Doc 10126, CAEP/11

ELEVENTH MEETING

Montréal, 4–15 February 2019

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION

REPORT

Approved by the Committee on Aviation Environmental Protection and published by decision of the Council.

The views expressed in this report should be taken as advice of a body of experts to the Council but not as representing the views of the Organization.

The Supplement to the report indicates the action taken on the report by the Council.

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INTERNATIONAL CIVIL AVIATION ORGANIZATION

ELEVENTH MEETING OF THE
COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

Montréal, 4 to 15 February 2019

SUPPLEMENT NO. 1

1. The Council, at the ninth meeting of its 217th Session on 7 June 2019, took action on the recommendations of the eleventh meeting of the Committee on Aviation Environmental Protection (CAEP/11), as set forth hereunder.

2. RECOMMENDATIONS FOR AMENDMENT OF STANDARDS AND RECOMMENDED PRACTICES AND PROCEDURES (RSPP)

2.1 Recommendation 3/1, page 3-9
Recommendation 3/4, page 3-10
Recommendation 4/1, page 4-2

2.2 The Council noted that the Air Navigation Commission reviewed the above recommendations and agreed that they should be referred to Member States and international organizations. Following receipt of comments, the Commission will conduct a detailed review and will then present its recommendations for action to the Council.

3. RECOMMENDATIONS OTHER THAN FOR STANDARDS AND RECOMMENDED PRACTICES AND PROCEDURES

3.1 The Secretary General will arrange for any follow-up action in respect of all approved recommendations as indicated in the action taken hereunder.

Report Reference		Action by Council (C) / Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
1/1	iii-5	C	**ICAO Doc 9988, *Guidance on the Development of States Action Plans on CO_2 Emissions Reduction Activities*** Approved the recommendation and requested the Secretary General to take the necessary action.
1/2	iii-6	C	**Submission of State Action Plans** Approved the recommendation and requested the Secretary General to take the necessary action.
1/3	iii-6	C	**State Action Plan Buddy Partnerships** Approved the recommendation and requested the Secretary General to take the necessary action.
2/1	1-9	ANC	**Endorsement of the global environmental trends assessments** Approved the recommendation and requested the Secretary General to take the necessary action.
2/2	1-9	ANC	**Publication of the Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft** Approved the recommendation and requested the Secretary General to take the necessary action.
2/3	1-9	ANC	**Acceptance of the CAEP/11 integrated noise and emissions technology goals for engines and aircraft** Approved the recommendation and requested the Secretary General to take the necessary action.
3/2	3-10	C	**Use of the nvPM Standard** Approved the recommendation and requested the Secretary General to take the necessary action.

Report Reference		Action by Council (C) / Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
3/3	3-10	C	**Amendments to the *Environmental Technical Manual*, Volume II — *Procedures for the Emissions Certification of Aircraft Engines*** Approved the recommendation and requested the Secretary General to take the necessary action.
3/5	3-11	C	**Amendments to the *Environmental Technical Manual*, Volume III — *Procedures for the CO_2 Emissions Certification of Aeroplanes*** Approved the recommendation and requested the Secretary General to take the necessary action.
3/6	3-11	C	**Amendments to ICAO Doc 9889 — *Airport Air Quality Manual*** Approved the recommendation and requested the Secretary General to take the necessary action.
4/2	4-2	C	**Amendments to the *Environmental Technical Manual*, Volume I — *Procedures for the Noise Certification of Aircraft*** Approved the recommendation and requested the Secretary General to take the necessary action.
5/1	5-1	ANC	**ASBU Block 1 environmental analysis** Approved the recommendation and requested the Secretary General to take the necessary action.
5/2	5-2	ANC	**Global air traffic management efficiency and the environmental impact of uncompensated traffic growth** Approved the recommendation and requested the Secretary General to take the necessary action.

Report Reference		Action by Council (C) / Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
5/3	5-4	C	**Environmental community engagement for performance-based navigation** Approved the recommendation and requested the Secretary General to take the necessary action.
5/4	5-5	C	**Climate adaptation synthesis** Approved the recommendation and requested the Secretary General to take the necessary action.
5/5	5-6	C	**Eco-airport toolkit e-collection** Approved the recommendation and requested the Secretary General to take the necessary action.
5/6	5-7	C	**Aircraft end-of-life and recycling** Approved the recommendation and requested the Secretary General to take the necessary action.
8/1	6-7	C	**Amendments to the *Environmental Technical Manual*, Volume IV** Approved the recommendation and requested the Secretary General to take the necessary action.
8/2	6-8	C	**Rules of Procedure of the Technical Advisory Body (TAB)** Approved the recommendation and requested the Secretary General to take the necessary action.
9/1	9-2	C	**ICAO document "CORSIA Sustainability Criteria for CORSIA Eligible Fuels" referenced in Annex 16, Volume IV** Approved the recommendation and requested the Secretary General to take the necessary action.

Report Reference		Action by Council (C) / Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
9/2	9-5	C	**ICAO document "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes" referenced in Annex 16, Volume IV** Approved the recommendation and requested the Secretary General to take the necessary action.
9/3	9-7	C	**ICAO document "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels," referenced in Annex 16, Volume IV** Approved the recommendation and requested the Secretary General to take the necessary action.
9/4	9-7	C	**ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values," referenced in Annex 16, Volume IV** Approved the recommendation and requested the Secretary General to take the necessary action.
9/5	9-7	C	**CORSIA Supporting Document "CORSIA Eligible Fuels – LCA Methodology"** Approved the recommendation and requested the Secretary General to take the necessary action.
10/1	10-2	C	**Aviation noise impacts white paper** Approved the recommendation and requested the Secretary General to take the necessary action.
12/1	12-4	C	**CAEP/12 work programme** Approved the revised work programme.

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ELEVENTH MEETING OF THE COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP) (2019)

LETTER OF TRANSMITTAL

To: President of the Council

From: Chairperson, Committee on Aviation Environmental Protection (CAEP) (2019)

I have the honour to submit the report of the eleventh meeting of the Committee on Aviation Environmental Protection (CAEP) which was held in Montréal, Canada, from 4 to 15 February 2019.

Mr. Tan Kah Han
Chairperson

Montréal, 15 February 2019

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COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

ELEVENTH MEETING

Montréal, 4 to 15 February 2019

HISTORY OF THE MEETING

1. DURATION

1.1 The eleventh meeting of the Committee on Aviation Environmental Protection (CAEP) was opened by the President of the Council in Montréal, Canada, at 1400 hours on 4 February 2019. The meeting ended on 15 February 2019.

2. ATTENDANCE

2.1 The meeting was attended by Members and Observers nominated by 30 Member States and 10 international organizations, as well as by advisers and others as shown in the list below:

Member	Advisor	Nominated by
Carlos Ruben Fernandez	Maria Fabiana Loguzzo	Argentina
Lachlan Phillips (Alternate)		Australia
Ricardo Antonio Binotto Dupont	Bruno Franciscone Daniel Ramos Longo Dario Taufner Guilherme Lima Renato Godinho	Brazil
Gilles Bourgeois	Alissa Boardley David Bilcock David Branton-Brown Jon Albert Obnamia Kerri Henry Prem Lobo Ted McDonald Wendy Bailey Yves Cousineau	Canada
Xiaojie Liu Xiaojun Yang (Alternate from 4 to 6 February 2019)	Henry Chiu Xiaojun Yang Xiaoning Ma	China
Abdelghafar Elsayed Abdelhalim (Alternate)		Egypt
Robert Mauri	Anouck Barreaux	France

Member	Advisor	Nominated by
	Bruno Hamon Claire Rais Assa Jonathan Gilad Pierre Primard	
Frauke Pleines-Schmidt	Georg Naumann Petra Bollich Stefan Bickert	Germany
Rohit Thakur (Alternate)	Rajasekar Ganesan	India
Fransiscus Budi Prayitno (Alternate)	Avirianto Suratno Budi Djatmiko Chandra Apriyatno Kusmini Kusmini Margaretta Rozetta Nurdini Tambunan Pintanugra Persanta Putu Eka Cahyadhi Sayuta Senobua Sigit Hani Adiyanto Wendy Aritenang	Indonesia
Silvia Egoli Giovanni Barraco (Alternate from 4 to 8 February 2019)	Alberto Anglade Giovanni Barraco	Italy
Koichi Minato	Kotaro Yamamoto Masato Takehisa Naoya Takahashi Shion Kanamori Shoji Kawamori Shomei Tanamachi Takahiro Nakashima Takashi Hongo Yoshikazu Makino	Japan
Michael Lunter	Beatrice Adolehoume	Netherlands
Tadeusz Reklewski	— — — — —	Poland
Artur Mirzoyan	Agrafena Kotova Aleksei Sipatov Galina Kirichenko Iurii Khaletskii Ivan Belyaev Liudmila Rostovtseva Victor Kopiev	Russian Federation

Member	Advisor	Nominated by
Mohammed Habib	Adnan Alotaibi Danh Alkurdi Mohammed Alsalama	Saudi Arabia
Tan Kah Han	Qing Ming Go (Alternate)	Singapore
Gabriel Bestbier	Chinga Mazhetese	South Africa
Alfredo Iglesias Sastre	Arturo Benito César Velarde Catolfi-Salvoni Juan Hermira	Spain
Eva Marie Hankanen	Carola Lindberg Emma Jeppsson Henrik Ekstrand Therése Sjöberg	Sweden
Urs Ziegler	Catherine Marthe Theodor Rindlisbacher	Switzerland
Oleksandr Zaporozhets	Ivan Iatsenko Svitlana Marunych	Ukraine
Maryam Al Balooshi	Rebekah Marshall	United Arab Emirates
Jennifer Raynor	Alexandra Chittenden Bethan Owen Darren Rhodes David Lee David Moroz Ian Jopson Nicholas Cumpsty	United Kingdom
Kevin Welsh	Bryan Manning Charlie Ashley Cullen Leggett Dimitri Mavris Donald Scata Gregg Fleming James Hileman John Mueller Molly Peters-Stanley Peter Coen Philippe Bonnefoy Ralph Iovinelli Rebecca Cointin Roger Schaufele Victor Sparrow	United States

Observer	Advisor	Nominated by
Cesar Mac-Namara Alberto Mena (Alternate from 4 to 8 February 2019)	Alberto Mena Patricio Arancibia Jose E. Sanhueza Flores	Chile
Konstantina Chrysikopoulou Georgia Lykou (Alternate from 4 to 8 February 2019)	Georgia Lykou	Greece
Hilde Hoiem	Jyrki Laitila	Norway
— — — — —		Malaysia
— — — — —		Peru
Artur Sousa	Ana Barbosa	Portugal
Deniz Kaymak	Ibrahim Sahinkaya	Turkey
Juliana Scavuzzi	Glynys Jones Guillaume Rodier Jeeyoon Jung Kathleen Henderson Mary Eagan Melinda Pagliarello Philippe Villard	ACI
Adil Bouloutar		ACAO
— — — — —		CANSO
Isabelle Besson	Andrei Mungiu Andrew Watt David Brain Grégoire Le Comte Illimar Bilas Ivan de Lépinay Marco Paviotti Rachel Burbidge Richard Clarkson Stephen Arrowsmith	EU
Michel Adam	Aaron Robinson Thomas Roetger Tim Pohle Ray Brown Nancy Young	IATA
Bruce M Parry	Alexandra Grose Eli Cotti Kahina Oudjehani Leo Knaapen	IBAC

Daniel Carnelly (4 to 5 February 2019) Arnaud Bonnet (Alternate from 6 to 15 February 2019)	Amr Ali Arnaud Bonnet Brian Kim Bruno Pasturel Carlos Grandi Charles Etter Dale Smith Daniel Allyn Daniel Bassani Danielle Patton David Hyde David Lye Dominique Collin Eli Dourado Eric Jacobs Eric Upton Eugene Kors Hideki Moriai Jan Pie Jason Matisheck Jeffrey Peters John Morgenstern Jose Alonso Joseph Zelina Julien Dezombre Kevin Morris Kian Mccaldon Larry Gray Maria Chiara Detragiache Michel Wachenheim Miguel F. García Claro Minoru Hanakata Muni Majjigi Olivier Husse Olivier Penanhoat Paul Madden Peter Iosifidis Pierre Lempereur Raymond Russell Robby Lapointe Robert Cowart Rudy Dudebout Scott Piercy Sean Newsum Simone Rauer Thierry Percheron Tsutomu Oishi Vincent De Vroey Yoshiharu Sasaki	ICCAIA

Tim Johnson	Amy Malaki Andrew Murphy Bill Hemmings Brad Schallert Dan Rutherford Hongming Liu John Holler Kristin Qui Pedro Piris-Cabezas	ICSA
Robert Brons	— — — — —	IFALPA
Gabriel Labbate	— — — — —	UNEP
Katia Simeonova	Perumal Arumugam	UNFCCC
Jane Hupe	Bruno Silva Chrystelle Damar Demi Tighe Joonas Laukia Manuel Caballero Alarcon Mathias Grossmann Neil Dickson Sean Donovan Stelios Pesmajouglou Tetsuya Tanaka Yury Medvedev	Secretariat

3. OFFICERS AND SECRETARIAT

3.1 Mr. Tan Kah Han was elected Chairperson of the meeting and Ms. Frauke Pleines-Schmidt was elected Vice-Chairperson of the meeting. The Secretary of the meeting was Ms. J. Hupe, assisted by Dr. N. Dickson, Chief, Environmental Standards and Mr. T. Tanaka, Chief, Climate Change, and supported by Mr. B. Silva, Mr. M. Caballero, Ms. C. Damar, Mr. S. Donovan, Mr. J. Laukia, and Mr. Y. Medvedev. Also participating in the meeting were Mr. Boubacar Djibo, Director, Air Transport Bureau, Mr. Stephen Creamer, Director, Air Navigation Bureau, and Mr. Andrew Opolot of the Legal Bureau.

4. AGENDA OF THE MEETING

4.1 The agenda for the meeting shown hereunder was approved by the Council of ICAO on 9 March 2018[2].

Agenda Item 1: Assessments of the present and future impact of aircraft noise and emissions

Agenda Item 2: Environmental models and databases

Agenda Item 3: Aircraft engine emissions

Agenda Item 4: Aircraft noise

Agenda Item 5: Airports and operations

Agenda Item 6: CORSIA – Monitoring, reporting and verification (MRV)

Agenda Item 7: CORSIA – Emissions unit

Agenda Item 8: CORSIA – Registries

Agenda Item 9: Sustainable aviation fuels

Agenda Item 10: Current science related to aircraft noise and emissions

Agenda Item 11: Decisions of the Council on the CAEP's terms of reference (TOR), structure, membership and working methods, and election of Chairperson and Vice-Chairpersons

Agenda Item 12: Future work

5. WORKING ARRANGEMENTS

5.1 The technical committee met as a single body, with ad hoc drafting groups as required. Discussions in the main meeting were conducted in Arabic, Chinese, English, French, Russian and Spanish. Some working papers were presented in English only. The draft report was issued in English only.

6. TERMS OF REFERENCE OF CAEP FOR CAEP/11

6.1 To undertake specific studies, as approved by the Council, related to control of aircraft noise and gaseous emissions from aircraft engines.

6.2 In its work the Committee shall take into account the following:

[2] The agenda was further amended and agreed by the Council on 14 August 2018 and 1 February 2019.

a) effectiveness and reliability of certification schemes from the viewpoint of technical feasibility, economic reasonableness and environmental benefit to be achieved;

b) developments in other associated fields, e.g. land use planning, noise abatement operating procedures, emission control through operational practices, etc.;

c) international and national programmes of research into control of aircraft noise and control of gaseous emissions from aircraft engines; and

d) the potential interdependence of measures taken to control noise and to control engine emissions.

6.3 New Terms of Reference for the work of CAEP were approved on 1 February 2019 and are available on the ICAO public website.[3]

7. RULES GOVERNING CAEP

7.1 Specific directives for CAEP were developed as CAEP Directives, which were approved by the Council in June 2011. The Council subsequently reviewed these Directives in November 2018 and issued them in their final form on 4 February 2019.

8. CAEP/11 WORK PROGRAMME

8.1 The Committee's work programme for this cycle was agreed during the CAEP/10 meeting and adjusted during the subsequent Steering Group meetings to accommodate the requests of the 39th Session of the ICAO Assembly. The following tables (English only) reflect the updated work programme:

CAEP/11 Working Group 1 – Noise Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
N.01	Coordination	Coordinate with other working group Rapporteurs on + interdependencies related to technology, operational issues, and goals as well as harmonizing the goal setting process. + interdependencies related to management and update of noise and emissions databases + interdependencies related to environmental impacts, including stringency + programmes for development of both noise and emissions SARPs for future supersonic aeroplanes	Coordination	Ongoing

[3] https://www.icao.int/Pages/default.aspx

CAEP/11 Working Group 1 – Noise Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
N.02	Annex and ETM maintenance	Maintain and update Annex 16, Vol. I and ETM, Vol. I.	Updates to ETM	SG2018
			Updates to Annex 16	CAEP/11
N.03	NoisedB	Ensure process integrity and data currency of the ICAO noise certification database.	Up-to-date ICAO NoisedB	Ongoing
N.04.01	Monitor research and development	Monitor and report on the various national and international research programme goals and milestones. Review data on emerging technologies as it becomes available.	Report	CAEP/11
N.05.01	Monitoring Sonic Boom research	Monitor and report on research to characterize, quantify and measure (including metric) climb and en route noise from supersonic flight, including Mach cut-off conditions, and its acceptability while also assisting in promoting and defining such research.	Report	CAEP/11
N.05.02	SST standards development (subsonic and supersonic regime)	Continue to work on noise certification standards for supersonic aircraft: 1) based on subsonic noise standards for local airport noise that may include the use of Variable Noise Reduction System (VNRS) technology as "acceptable means of compliance." and 2) a new scheme for supersonic flight, as informed by developments under N.5.01.	Progress report	CAEP/11
N.05.03	SST coordination	Update Air Navigation Commission with SSTG Report on progress of SST noise activities.	Briefing to ANC	May/June 2016
N.05.04	Monitoring SST projects	Monitor, and report on, status of SST projects and expectations of supersonic development.	Report	CAEP/11
N.06.01	Support: Understanding the effects of standards on the evolution of the global fleet	Support MDG in an analysis to allow for a better understanding of whether standards are driving the desired behaviours and what are the potential influences from other factors; e.g., fuel price changes, global economic downturn, etc.	Support	
N.06.02	Support: Global Aviation Environmental Plan (GAEP)	Support the Secretariat in developing a Global Aviation Environmental Plan (GAEP). Similar to the Global Air Navigation Plan (GANP), this would allow for a schedule of planned Annex 16 amendments to be developed	Support	Ongoing

CAEP/11 Working Group 1 – Noise Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
		in a coordinated manner. It is recommended that the proposed noise and emissions technology reviews serve as the basis for the development of the GAEP.		
N.07.01	UA noise monitoring	Monitor developments around UA noise and where appropriate suggest specific work items to SG.	Report	
N.07.02	UA noise certification	Develop proposals for a non-zero lower weight for applicability of noise requirements in Annex 16.	Proposal for Change	
N.08.01	Helicopter Noise Correlation	Investigate the feasibility of correlating certification noise levels with operational noise levels to better assess the helicopter noise certification scheme and its relevance to day-to-day operations, similar to the studies done for jets.	Report	SG2017
N.08.02	Helicopter Hover Noise	Review any past evaluations of a noise certification scheme for the hover condition, and assess whether the current helicopter noise certification scheme is applicable for assessing hover noise including the sufficiency of a correlation with one or more of the existing reference conditions.	WP to SG2017	SG2017
N.09	Integrated IE Technology Goals Assessment and Review for Engines and Aircraft	In coordination with WG3, conduct an Independent Expert (IE) Technology Assessment and Review. *Engine Level*: Provide assessment of combustion technology including both NOx and nvPM, and consider within the context of existing CAEP Standards and CAEP NOx goals. *Aircraft Level*: Provide assessment of aircraft subsonic technologies including both fuel efficiency and noise. Consider these in the context of the existing CAEP Standards and CAEP goals.	Proposed way forward to SG2016 Report	CAEP/11
N.10	Applicability for derived versions of recertified aeroplanes	Review of the applicability language in Chapter 4 and Chapter 14 regarding the required Standards for derived versions of recertified aeroplanes.	Report to SG2016 on result of the review and implications of amendments being considered	CAEP/11

CAEP/11 Working Group 1 – Noise Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
			Proposed Amendments to Annex 16, Vol. I and ETM pending decision by SG2016	

CAEP/11 Working Group 2 – Airports and Operations – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
O.01	Environmental Community Engagement for PBN	To gather information on PBN implementation challenges, needs and potential solutions, including methods for cross-industry collaboration and structured community engagement, leading to the creation of a report to SG2.	1. Compilation of a body of information on issues with PBN implementation; 2. Identification of any gaps/needs and recommended next steps to supplement the recently published WG2 Community Engagement Circular and the appropriate format; 3. Development of proposals on how to disseminate the deliverables	CAEP/11
O.02	Operational Opportunities to Reduce Aircraft Noise	Developing a document, similar to ICAO Document 10013 “Operational Opportunities to Reduce Fuel Burn and Emissions”, but for noise emissions. The task will be aimed at identifying and highlighting good practices and the operational opportunities to minimise aircraft noise from aircraft operations where practicable and operationally safe to do so.	1. Framework of topic chapters; 2. Reference material; 3. Report to CAEP on further work that may be required	Draft report to CAEP/11 Final report to CAEP/12
O.03	Operational Interdependencies	Operational Interdependencies - Assessment - Continuation of	Report to SG	SG2017

CAEP/11 Working Group 2 – Airports and Operations – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
	- Assessment of Interrelationships Information	CAEP/10 Task O.02 to perform an assessment of the interrelationships information found in the ICAO documents, in order to identify any inconsistencies and/or gaps and make recommendations for improvement where appropriate.		
O.04	Aviation System Block Upgrade (ASBU) Block 1 Analysis	ASBU Block 1 - Continue the ASBU Analysis task thread into CAEP/11 with the intent of analysing the potential environmental benefits of the current and planned implementation of ASBU Block 1 modules.	At CAEP/11, report on environmental assessment of the benefits that may be generated following planned implementation of the Block 1 modules	CAEP/11
O.05	Improved Static ATM and Aircraft Technology scenario	Improved Static ATM and Aircraft Technology scenario - Carry out a top-down analysis to identify the levels of ATM inefficiency that need to be bridged and where the ASBU module implementations should be targeted. This analysis will carry on from the work undertaken during the CAEP/8 cycle.	At SG1, feasibility study based on a literature review to determine what data and methodologies are available. If feasibility is demonstrated, then the following deliverables are envisaged potentially for CAEP/11: a) New figures for estimated global (in)efficiency, preferably broken down to the regional level and b) A new estimate of the static ATM do-nothing case	SG2016 CAEP/11
O.06	New APM Part II appendices	APM Part II appendices - Continuation of CAEP/10 Task O.06 to complete: a) updates to remaining chapters based on CAEP/10 review, and b) new Chapters on Heritage Considerations and Climate Change Resilience and Adaptation, and 3 new appendices for the APM Part 2. Appendix 1 will include	Three new appendices for the APM Part II	SG2018

CAEP/11 Working Group 2 – Airports and Operations – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
		case studies of airport infrastructure for environmental management, Appendix 4 will include case studies of heritage management and Appendix 5 will include case studies of climate adaptation.		
O.07	Climate Adaptation Synthesis	To synthesise existing information on the range of projected climate impacts for the aviation sector to better understand risks to airport and ANSP planning, infrastructure and operations, ***including bringing to the attention of the relevant ICAO bodies*** how they relate to safety, capacity and efficiency.	CAEP Report with synthesis and recommended next steps	CAEP/11
O.08	"Green Your Airport" e-collection	A set of practical and ready-to-use information, to support the planning and implementation of airport infrastructure projects. Each publication will focus on a specific aspect of environmental planning at airports.	A series of short publications accessible from ICAO Environment website, forming an e-collection.	Ongoing
O.09	Aircraft end of life and recycling	Assess and collate the current best practices on aircraft end of life management techniques and recommend guidance material.	Report and Guidance material	CAEP/11
O.10	Aviation and Global Atmosphere update	Contribute to an update to the information.	Ongoing support	Ongoing
O.11	Update to Doc 9889	Support WG3 in an update of ICAO Doc 9889 to replace emissions technical information that is now out-of-dated)	Input to WG3 on operations-related aspects of Doc 9889	As required, final updated document by CAEP/11
O.12	Support to ICAO Secretariat	Continue support ICAO Secretariat in communicating the results of tasks from WG2, including ASBU analysis and update to APM.	ASBU analysis results. Comments on APM.	As required

CAEP/11 Working Group 3 – Emissions Technical – Work Programme				
Task Number	**Short Title**	**Task Description**	**Deliverables**	**Deliverable Date**
E.01	Interdependencies	Coordinate with other working group Rapporteurs on interdependencies related to (a) technology, operational issues and goals (b) management and update of noise and emissions databases (c) environmental impacts (d) SARPs for future SST aircraft.	Coordination report for each SG	Ongoing
E.02	Fuel composition and emissions	Monitor trends in 1) petroleum-based aviation kerosene fuel supply composition, 2) aviation alternative fuel based kerosene fuel supply, and 3) blended fuel types. Assess consequences for emissions and emissions certification. Including a global survey of fuel sulphur content to support the estimation of global and regional SOx emissions.	Report	During CAEP/11
E.03	Emissions Certification requirements – new aeroplane applications and concepts	Monitor developments in aeroplane and engine applications and concepts, such as freighter applications or technology developments e.g. blended wing body, or non-classical tube and wing configurations and open-rotor engines etc., and develop methodologies for emissions certification.	Report	CAEP/11
E.04	Annex 16 maintenance for emissions	Maintain Annex 16 on emissions.	Proposed Annex changes	CAEP/11
E.05	Emissions ETM maintenance	Maintain Emission Environmental Technical Manual.	Proposed ETM changes	CAEP/11
E.06	Emissions Databank maintenance	Maintain emissions certification databank.	up-to-date databank	CAEP/11
E.07	G&R database maintenance	Review and update a "Growth & Replacement" database in order to support development of models used to populate future fleets and the replacement of retired aircraft. Coordinate with PMTG, WG1 and support groups to ensure consistency in assumptions.	up-to-date G&R databank	During CAEP/11

CAEP/11 Working Group 3 – Emissions Technical – Work Programme				
Task Number	**Short Title**	**Task Description**	**Deliverables**	**Deliverable Date**
E.08	NOx cruise - Climb relationship	Review the LTO NOx - cruise climb NOx relationship for staged combustion and future engine technologies, to quantify control of mission emissions of NOx, and identify any methodology issues with respect to the correlation between LTO and climb/cruise and to quantify interdependencies with other emissions.	Report	CAEP/11
E.09	Certification Requirements - SST	Monitor trends in supersonic technology and assess consequences for engine based emissions and certification standards.	Proposed change to Annex 16	CAEP/11
E.10	Modelling emissions at low power	Provide guidance to MDG on the modelling of emissions at low power settings.		
E.11.01	PM - Non-volatile	Provide representative engine data for assessing the nvPM emissions standard for mass and number regarding turbofan/turbojet engines ≥26.7kN by February 2017. Provide recommendations on technology responses, stringency options and applicability [new types and in-production] to SG2017.	Report	By Feb 2017
E.11.02	PM - Non-volatile	Develop an aircraft engine based LTO nvPM mass and number standard for turbofan/turbojet engines ≥26.7kN.	Annex 16, Vol. II	During CAEP/11
E.11.03	PM - Non-volatile	Investigation the possible replacement of the smoke number standard for engine categories ≥26.7kN and other engine categories <26.7kN.	Annex 16, Vol. II	During CAEP/11
E.11.04	PM - Non-volatile	Develop improved nvPM model inputs to both local air quality models and, as required, global climate models per advice from ISG. Including the investigation into the apportionment of PM emissions for engines <26.7kN, ≥26.7kN, helicopter engines and Auxiliary Power Units (APUs) etc. Continue collaborative work	WG3 Report	During CAEP/11

CAEP/11 Working Group 3 – Emissions Technical – Work Programme				
Task Number	**Short Title**	**Task Description**	**Deliverables**	**Deliverable Date**
		with MDG. Note input from ISG on nvPM impacts.		
E.12	Update and Review Doc 9889	Update Doc 9889 to reflect industry best practices, new emissions data for modern aircraft and airport emission sources, airport operational information that affect aviation emissions, and emissions modelling methodologies.	Updated Doc 9889	CAEP/11
E.13	Properties of Engine Black Carbon Emissions	Measurements to support ISG in answering questions regarding the size and size distribution, density, morphology and internal structure of nvPM and Black Carbon emissions from aircraft engines.	Report	SG2016
E.14	Integrated IE Technology Goals Assessment and Review for Engines and Aircraft	In coordination with WG1, conduct an Independent Expert (IE) Technology Assessment and Review. *Engine Level*: Provide assessment of combustion technology including both NOx and nvPM, and consider within the context of existing CAEP Standards and CAEP NOx goals. *Aircraft Level*: Provide assessment of aircraft subsonic technologies including both fuel efficiency and noise. Consider these in the context of the existing CAEP Standards and CAEP goals.	Report	CAEP/11
E.15	Aviation and Global Atmosphere update	Contribute to an update to the information.	Plan for SG2016 Report to CAEP/11	Ongoing
E.16	Understanding the effects of standards on the evolution of the global fleet	Support MDG in an analysis to allow for a better understanding of whether standards are driving the desired behaviours and what are the potential influences from other factors; e.g., fuel price changes, global economic downturn, etc.	Comprehensive Fleet Evolution Study Report, Interim Analyses and Final Report	SG1 – Comprehensive Fleet Evolution Study Report, SG2- Fleet Database, SG-3 Preliminary analyses, CAEP/11 – Final Report

CAEP/11 Working Group 3 – Emissions Technical – Work Programme				
Task Number	**Short Title**	**Task Description**	**Deliverables**	**Deliverable Date**
E.17	Global Aviation Environmental Plan (GAEP)	Support the Secretariat in developing a Global Aviation Environmental Plan (GAEP). Similar to the Global Air Navigation Plan (GANP), this would allow for a schedule of planned Annex 16 amendments to be developed in a coordinated manner. It is recommended that the proposed noise and emissions technology reviews serve as the basis for the development of the GAEP.	Report	CAEP/11
E.18	Follow-On CO_2 Standard Remits	Complete the work related to the implementation of CO_2 Standards; Finalisation of CO_2 standard exemption process and ETM Vol. III text by CAEP SG2016. Finalisation of CO_2 Certification Database structure providing views on potentially incorporating information of exempted aeroplanes by CAEP SG2017.	Revised ETM, Vol. III; CO_2 Certification Database	SG2016; SG2017

CAEP/11 Aviation Carbon Calculator Support Group (ACCS) Work Programme				
Resources offered by: Brazil, ICSA				
Task Number	**Short Title**	**Task Description**	**Deliverables**	**Deliverable Date**
C.01	Obtain Aviation Offset Data	Assist ICAO in collecting data on offsets used for aviation including mandatory MBMs, large offset providers, and voluntary airline schemes.	List of available sources	SG2016: Initial list SG2017: Updated list SG2018 Updated list
C.02	Enhancements to Passenger Carbon Calculator	Review publicly-available data sources and the current passenger methodology to identify areas of improvement.	Recommendations for enhancements to the Calculator to be implemented by the Secretariat	SG2017
C.03	Enhancement to Cargo Carbon Calculator	Based on experiences from implementing the cargo calculator methodology developed during the CAEP/10 cycle, identify areas of improvement.	Recommendations for enhancements to the cargo calculator methodology	SG2017

CAEP/11 Forecasting and Economic Analysis Support Group (FESG) Work Programme				
Note: Meetings of FESG and MDG are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
F.01	Review of Economic Models	Review of economic models as needed for the CAEP/11 analyses. A review of the underlying economic cost assumptions used in the fleet evolution modelling tools is needed. These include crew, route, capital, and landing costs, all of which will need to be re-estimated and updated in concert with the development of a new fleet forecast.	Report	SG2018 CAEP/11
F.02	New CAEP Forecast consistent with the long-term traffic forecasts developed by the ADAP MDWG-LTF	Develop a new CAEP forecast in support to the CAEP/11 analyses (e.g. passenger aircraft and freighter fleet forecasts, forecast for aircraft with less than 20 seats, retirement curves) using as an input the long-term (passenger and cargo) traffic forecasts developed by the ADAP MDWG-LTF.	Forecast and Report	SG2017
F.03	Analysis lessons learned	Conduct a review of lessons to be learned from prior analyses, with a view toward improving the process for future economic assessment of stringency options.	Report	SG2016
F.04	Cost-effectiveness analysis of potential PM policy options	Conduct the cost-effectiveness analysis of the potential particulate matter (PM) policy options under consideration for CAEP/11.	Draft Report Final Report	SG2018 CAEP/11
F.05	ADAP Participation	FESG/MDG to ensure coordination with the ICAO Aviation Data and Analysis Panel (ADAP) Multi-Disciplinary Working Group on Long-Term Traffic Forecasts (MDWG-LTF).	Status report	Per ADAP MDWG-LTF schedule
F.06	Aviation and Global Atmosphere update	Contribute to an update to the information.	Plan for SG2016 Report to CAEP/11	Ongoing
F.07	Evaluation of CBA	Evaluation of how cost-benefit assessment might support decision-making in CAEP.	Report	CAEP/11

CAEP/11 Modelling and Databases Group (MDG) Work Programme				
Note: Meetings of FESG and MDG are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.01	Interdependencies	Coordinate with other working group Rapporteurs on interdependencies related to technology, operational issues, goals, environmental impacts and management and update of noise and emissions databases.	Coordinated WP	Each SG meeting and final report to CAEP/11
M.02	Analysis lessons learned	Conduct a review of lessons to be learned from prior analyses, with a view toward improving the process for future analyses. This should include an identification of gaps in analysis assumptions, databases and tools.	Report	SG2016
M.03	ICAO Environmental Trends Projection	Conduct an updated trends projection, for the 201x baseline case and forecasts, for various cases which consider technology, operational improvements (both infrastructure and operator-initiated improvements) and alternative fuels life cycle, for noise, NOx, PM, fuel burn, and CO_2. The trends projection will support the display of the following information, as appropriate: 1. A static ATM (informed by WG2) and static aircraft technology scenario 2. Progress being achieved toward the ICAO global aspirational environmental goals (i.e. 2% annual fuel efficiency improvement and carbon neutral growth from 2020) 3. Anticipated progress toward the goals based on the information communicated by States in their voluntary Action Plans 4. Additional efforts that would be required to meet those goals (i.e. feasibility analysis results) 5. The effects of ASBU Block 0 and 1 implementation The MDG fuel trends results will be published in a Structured Query Language (SQL) database that could be easily accessed by experts from other CAEP groups.	Report that include graphical depiction of the trends and database	CAEP/11
M.04	Identification of Assessment Tools	MDG in concert with ISG identify and evaluate tools for including noise, LAQ and GHG impacts (including monetization) tools for use as part of future CAEP assessments.		CAEP/11
M.05	Existing Model and Database Management	Maintain version control of models and databases to be used in support of specific CAEP analyses. Determine if updates to models or databases require a re-evaluation,	Updated models and databases	Each SG meeting and final report to CAEP/11

CAEP/11 Modelling and Databases Group (MDG) Work Programme				
Note: Meetings of FESG and MDG are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
		including providing feedback to the ICAO Secretariat regarding databases to be used in CAEP that they maintain. In support of the CAEP/11 work programme, the following specific enhancements to air quality and or greenhouse gas models have been identified: 1. Ability to model nvPM over the full flight regime (in conjunction with WG3) 2. Enhancement and standardization of low-power setting emissions modelling 3. Emissions dispersion modelling In support of the CAEP/11 work programme, the following specific enhancements to the fleet database have been identified: 1. a more complete set of smaller aircraft (e.g. business jets, turbo-props and helicopters), 2. payload and seat information harmonization – which often propagates to the related growth and replacement database; and 3. the better tracking and monitoring of business jet tail numbers which are included in the COD as flight IDs would all add significant value.	Progress report	
M.06	New Model Evaluation	If new models are introduced to support CAEP/11, continue the candidate model evaluation process, which calls for sensitivity tests, comparisons with "gold standard data, and sample problems. Refine the process as appropriate on the basis of relevant criteria, to better inform CAEP which tools are sufficiently robust, rigorous and transparent, and appropriate for which analysis, and why there might be differences in modelling results.	Report	As model evaluations are complete Final report to CAEP/11

CAEP/11 Modelling and Databases Group (MDG) Work Programme				
Note: Meetings of FESG and MDG are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.07	Doc 9911 Update	Update ICAO Doc 9911 as required. Potential areas for update that should be scoped out and considered (in coordination with WG1 and ISG) include: 1. full ICAO Doc. 9911 harmonization and implementation across all models, including implementation of the extended level line segment, the latest start-of-take-off roll directivity, and speed-varying effects on noise-power-distance (NPD) curves; 2. standard approaches for modelling of helicopter noise; 3. modelling of reduced thrust departures; 4.sonic boom modelling; 5. noise modelling for commercial space vehicles and unmanned aerial vehicles(UAV) ; and 6. improved noise propagation modelling, possibly including terrain effects	Updated Doc 9911	CAEP/11
M.08	New Emissions Database	In cooperation with WG3, develop a comprehensive database of aircraft emissions indices by operating mode within the LTO cycle for CO, HC, NOx, PM, Fuel Flow, and CO_2 for all aircraft types observed in the COD. The database would augment the ICAO Engine Exhaust Emissions Databank and would support CAEP analyses and external model developers.	Database	SG2017
M.09	ICAO Support	Provide support to ICAO Secretariat in dissemination of MDG results.	As requested	As requested
M.10	PM Standard	Conduct sample problem and policy option analyses of the environmental benefits and interdependencies of a potential PM standard as directed by CAEP and SG. In cooperation with other CAEP WG's.	Report	CAEP/11
M.11	ASBU Analysis	Estimate the benefits from the implementation of ASBU Block 1 for display on the updated trends assessment charts (with an emphasis on fuel burn and CO_2, and consideration for noise and LAQ, if feasible based on the analysis). Note: WG2 has the lead on this task and the success of this task is dependent on receiving sufficient and timely input from States.	Report	SG2018

CAEP/11 Modelling and Databases Group (MDG) Work Programme				
Note: Meetings of FESG and MDG are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.12	COD Improve-ment(s)	Develop and maintain a 201x Common Operations Database (COD) (preferably including a full 52-weeks of operations) and manage the acquisition and treatment of additional State data. Two versions of the COD will be maintained: 1. A version that can be used by the ICAO Secretariat and those States who contribute data to the COD, with sensitive data removed or deidentified; and 2. A version that is limited to those organizations who have signed an appropriate agreement This task will also include a comparison of the COD and WISDOM, e.g. using 2012 traffic, and identify areas of improvements in the process applied to generate the databases. Further work could be undertaken to refine and harmonise the description of aircraft in the base year operations (airframe, engine, age, seat / freight capacity), which would help improve the fidelity of the future fleet and operations forecast.	Database	SG2017
M.13	Feasibility of ICAO climate change goals	(If requested by A39) Analysis of the feasibility of achieving ICAO goals for international aviation and climate change, based on the updated trends generated in Task M.03.	Draft Report Final Report	SG2017 CAEP/11
M.14	ADAP Participation	FESG/MDG to ensure coordination with the ICAO Aviation Data and Analysis Panel (ADAP) Multi-Disciplinary Working Group on Long-Term Traffic Forecasts (MDWG-LTF).	As requested	As requested
M.15	Airports Database	Augment the data included in ICAO Doc 7910 (Location Identifiers) to add information required to support CAEP analyses, in cooperation with the ICAO Secretariat and relevant panels.	Airports database	Prior to the start of analyses requiring the data
M.16	GMBM Support	Provide technical support in the development of a global market-based measure for international aviation, as requested.	As requested	As requested

CAEP/11 Modelling and Databases Group (MDG) Work Programme				
Note: Meetings of FESG and MDG are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.17	CO_2 Goals Assessment	Conduct a scoping exercise to assess the contribution of CO_2 Standard to ICAO global aspirational goals in CAEP/11 cycle.		CAEP/11
M.18	Understanding the effects of standards on the evolution of the global fleet	Conduct an analysis to allow for a better understanding of whether standards are driving the desired behaviours and what are the potential influences from other factors; e.g. fuel price changes, global economic downturn, etc.	Compre-hensive Fleet Evolution Study Report, Interim Analyses and Final Report	SG1 – Compre-hensive Fleet Evolution Study Report, SG2- Fleet Database, SG-3 Preliminary analyses, CAEP/11 – Final Report
M.19	Aviation and Global Atmosphere update	Contribute to an update to the information.	Plan for SG2016 Report to CAEP/11	Ongoing
M.20	Feasibility of ICAO climate change goals	ISG, AFTF, MDG to scope work for putting international aviation emissions into the context of a 1,000 Gt budget (1.5/2°C scenario).	Scope of work	SG2016

CAEP/11 Impacts and Science Group (ISG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
I.01.01	Coordination (internal group)	Coordination on activities.	Coordination	Ongoing
I.01.02	Coordination (internal ICAO)	Coordination with other WGs, TFs, RFPs, etc. Rapporteurs and ICAO Secretariat on activities.	Coordination	Ongoing
I.01.03	ISG membership	As per the ISG Terms of Reference, the ISG co-rapporteurs, in conjunction with the ICAO Secretariat, will identify suitable scientific experts. This will involve requesting that CAEP Members and observers nominate experts who are appropriately qualified and who conduct research in a subject area relevant to the CAEP/11 work programme.	Membership	SG2016

CAEP/11 Impacts and Science Group (ISG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
I.02	Aviation Noise	ISG to conduct a 'Noise Impacts Workshop' and provide an update to the current White Paper under development for CAEP/10 on aviation noise (in conjunction with WG1 & WG2).	WP to CAEP	Draft to SG2018 Final to CAEP/11
I.03	Adaptation	Assist WG2 in the assessment of the current understanding of the risks to aviation from climate change and develop guidance material on the best practices on adaptation.	Report and Guidance material	Draft to SG2018 Final to CAEP/11
I.04	Properties of Engine Black Carbon Emissions	**[Led by WG3, ref. Task E.13]** As a climate-related activity, ISG will Support WG3 in the provision of estimations for the size and size distribution, density, morphology and internal structure of nvPM and Black Carbon emissions from aircraft engines. Assist WG3 in providing details on the scientific uncertainties associated with the estimates. And support any IE review (e.g. NOx/PM) as appropriate drawing in external expertise.	Report	SG2017
I.05	Aviation and Global Atmosphere update	Contribute to an update to the information.	Plan for SG2016 Report to CAEP/11	Ongoing
I.06	Update to Doc 9889	To provide ad hoc support and advice to WG3 as required in an update of ICAO Doc 9889 to replace emissions technical information that is now out-of-date.	Report	Ongoing
I.07	CBA Scoping	MDG in concert with ISG identify and evaluate tools for including noise, LAQ and GHG impacts (including monetization tools for use as future CAEP assessments).	Report	CAEP/11
I.08	Feasibility of ICAO climate change goals	ISG, AFTF, MDG to scope work for putting international aviation emissions into the context of a 1,000 Gt budget (1.5/2°C scenario).	Scope of work	SG2016

CAEP/11 Alternative Fuels Task Force (AFTF) Work Programme				
Note: Meetings of AFTF and GMTF are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
S.01	Computation of alternative fuels land use change emissions for use in the GMBM MRV	Over CAEP/11, a follow-on of the AFTF would carry out the computations of induced land use change emissions from alternative fuels for all world regions, for use to report alternative fuels emissions in the GMBM MRV.	List of default values	CAEP/11
S.02	Computation of default values for alternative jet fuel life cycle emissions for use in the GMBM MRV	Over CAEP/11, a follow-on of the AFTF would carry out the computations of "core" LCA default values that could be used by operators to report their emissions from the use alternative fuels. "Core" life cycle emissions designate the emissions from the feedstock production to the tank of the aircraft, land use change emissions being excluded.	List of default values	CAEP/11
S.03	Aviation and Global Atmosphere update	Contribute to an update to the information.	Ongoing support	Ongoing
S.04	Guidance on Potential Policies and Coordinated Approaches for the Deployment of Sustainable Alternative Fuels for Aviation	Outline existing policy instruments incentivizing deployment of sustainable alternative fuels, as well as barriers or disincentive mechanisms grouped in different types or categories with similar characteristics and nature. As a second step, the work provided to the Steering Group should identify "potential policies" which have been demonstrated to be feasible, effective, and practical. Such identification should be done through CAEP assessment based on best practices, lesson learned, and proven positive results from the implementation of those policy instruments, which might include policies developed for other sectors, applicable to air transport. Report on common elements and general recommendations, based on the above assessments and analyses from already implemented policies, to facilitate the implementation of those policies and incentive mechanisms by Member States or regions, using	Step 1: SG 2016 Step 2: SG 2017 Step 3: SG 2018 Final Report: CAEP/11	CAEP/11

CAEP/11 Alternative Fuels Task Force (AFTF) Work Programme				
Note: Meetings of AFTF and GMTF are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
		effective policy approaches when considered beneficial.		
S.05	Sustainability criteria	The goal is to develop recommendations on sustainability criteria for alternative fuels in the context of the recognition under the Global Market-Based Mechanism (GMBM). The work will be prioritized by developing environmental criteria first, followed by social and economic criteria at a later stage. It is planned to build as much as possible upon existing sustainability standards and frameworks, which will be analysed and compared in order to develop recommendations for CAEP.	Report: SG 2016 Report: SG 2017 Report: SG 2018 Final Report: CAEP/11	CAEP/11
S.06	Roundtable	Secretariat organize a series of roundtable discussion or workshops that would bring the appropriate experts together to further discuss on specific scientific/technical discussions that co-rapporteurs might consider necessary to develop outside the main work stream.	As required	As required
S.07	Feasibility of ICAO climate change goals	ISG, AFTF, MDG to scope work for putting international aviation emissions into the context of a 1,000 Gt budget (1.5/2°C scenario).	Scope of work	SG2016

CAEP/11 Global Market-Based Measure Technical Task Force (GMTF) Work Programme				
Note: Meetings of AFTF and GMTF are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
G.01	MRV: Accountable Entities	Develop recommendations on how to apply accountable entity declaration process, how to pool accountable entities and how to attribute accountable entities to States.	Additional recommendations on accountable entities declaration process and identification /allocation	SG2016

CAEP/11 Global Market-Based Measure Technical Task Force (GMTF) Work Programme				
Note: Meetings of AFTF and GMTF are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
G.02	MRV: Monitoring Plans	Further assess elements and procedures for implementing emissions monitoring plans and prepare initial guidance.	Additional recommendations on procedures for implementing monitoring plans and initial guidance on procedures and monitoring plan elements	SG2016
G.03	MRV: Monitoring of Fuel Use	Establish uncertainty thresholds for monitoring methods. Analyse thresholds for eligibility to apply Tier 2 monitoring, create steps for implementation of different monitoring methods and analyse block hour fuel methodology.	Recommendations on eligibility thresholds and implementation procedures	SG2016
G.04	MRV: Reporting	Identify and make recommendations on which entities should develop, maintain and update the online tools, the common reporting language and the reporting template. Revise and update of the minimum data set to be reported.	Recommendations for emissions reporting	SG2016
G.05	MRV: Transparency and Confidentiality	Continue work on which data could be made available to different stakeholders, take into account the need for States exchange information as required on MRV related matters.	Recommendations on data transparency	SG2016
G.06	MRV: Verification	Continue the development of specific recommendations and guidance for each step of the pathway, basing these on the relevant ISO standards as appropriate.	Recommendations on verification	SG2016
G.07	MRV: Simplified Compliance Procedures	Create simplified MRV procedures for small emitters. Further analyse eligibility thresholds and simplified emissions estimation methods.	Recommendations for simplified procedures	SG2016
G.08	MRV: Alternative Fuels	Finalize technical recommendations on monitoring, reporting and verifying emissions from alternative fuels.	Recommendations on MRV procedures for alternative fuels	SG2016
G.09	MRV: Administration	Support the continuation of MRV work on other open issues including those related to administration, for example, the compliance cycle, and roles and responsibilities.	Recommendations for other MRV open issues.	Ongoing

CAEP/11 Global Market-Based Measure Technical Task Force (GMTF) Work Programme				
Note: Meetings of AFTF and GMTF are to be held back-to-back during CAEP/11				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
G.10	MRV: Implementation	Develop "MRV Implementation Guidance".	Guidance document	SG2016
G.11	EUC: Eligibility Criteria	Review need to revise recommendations in view of outcome of COP-21 in Paris.	Recommendations for eligibility criteria	For GMTF/8 review and SG2016 approval
G.12	EUC: Supply, Demand and Price of Units	Review need to revise assessment in view of outcome of COP-21 in Paris and latest developments in markets. Analyse the feasibility of ICAO's regular monitoring of emissions unit prices that could inform price safeguards (should such measures be included in the design of a global MBM).	Assessment of supply, demand and price of units	For GMTF/8 review and SG2016 approval
G.13	EUC: Work on Early Action	Develop recommendations to support early decision of programmes and potentially project types that meet eligibility criteria. Analyse and recommend options for the duration of applicability of any early decisions on emissions unit programmes and potentially project types eligibility.	Summary report with a list of programmes and potential project types that meet eligibility criteria, and their duration of applicability	SG2016
G.14	Registry: Design Elements	Continuation of the work on registries. Contact registry developers and experts to understand and develop design elements and timing of a registry for the global MBM.	Plan for the practical implementation of the global MBM registry system	SG2016
G.15	Registry: Registry Development	Assess cost and develop technical specifications of the global MBM registry system.	Recommendations for the global MBM registry system	CAEP/11
G.16	MBM Implementation Support	Support Council requests for implementing the global MBM.	Information papers	As required
G.17	Technical Analysis Support	Support Council requests for addition technical analysis relating to the distribution of obligations. Summarize all analytical work undertaken during the CAEP/10 cycle in a report.	Information papers	As required
G.18	GMTF Glossary	Further refine the GMTF glossary.	Glossary	As required

9. OPENING REMARKS BY THE PRESIDENT OF THE COUNCIL

9.1 Good morning ladies and gentlemen. It's my honour to welcome you to this Eleventh Meeting of ICAO's Committee on Aviation Environmental Protection (CAEP).

9.2 The global importance of environmental protection has grown immensely over recent decades, and with it the significance and relevance of the work of ICAO in minimizing the effects of global civil aviation on the environment.

9.3 Improving the environmental performance of aviation is a challenge that ICAO and all relevant stakeholders take very seriously. In fulfilling its responsibilities, ICAO has three major environmental goals aimed at limiting or reducing:

1) the number of people affected by significant aircraft noise;

2) the impact of aviation emissions on local air quality; and

3) the impact of aviation greenhouse gas emissions on the global climate.

9.4 A more recent challenge we've begun to face together concerns the monitoring and mitigation of climate change effects on aviation activities, and I'm encouraged that you have already begun some important work on extreme climate event risk identification and adaptation.

9.5 Our main challenge during this CAEP cycle has been to reduce the impact of aviation greenhouse gas emissions on the global climate.

9.6 As you are aware, ICAO has developed a Basket of Measures which includes activities and solutions focused on new airframe and engine technologies, more streamlined operations, sustainable aviation fuels, and of course the global Carbon Offsetting and Reduction Scheme for International Aviation, or 'CORSIA'.

9.7 Each category of measures contributes to our overall efforts to reduce CO_2 emissions from the air transport system, and to achieve ICAO's global aspirational goals. Having been pleased to see the progress achieved in each of them, in particular, I wish to make special reference to the Committee's work that has led to the adoption of the new Annex 16, Volume IV on CORSIA, in June 2018.

9.8 Congratulations on this major achievement, and I wish to thank you as well for accommodating such a difficult and challenging timeline. It's my expectation that this meeting will be making further progress on key CORSIA Implementation Elements.

9.9 Another topic of importance here at CAEP/11 concerns the options for the new nvPM emissions Standards, which supplements the scope of applicability for Annex 16, Volume II. This expands on the work stemming from CAEP/10, and since then we've sought to further develop the Standard and analyse how cost-effective it would be across a wide range of applicability and stringency options. This technical effort has required the CAEP to overcome important modelling and measurement challenges.

9.10 With respect to CORSIA, I'm sure we've all been encouraged by the progress achieved during the first phase of its implementation, as well as the very successful results of the ICAO ACT-CORSIA capacity-building programme.

9.11 The Council and I will look forward to the outcome of your discussions on the CORSIA emission units, the Council's Technical Advisory Body (TAB), as well as on sustainable aviation fuels. CAEP/11 will also be considering important issues on the sustainability criteria for CORSIA eligible fuels, and its sustainability certification schemes.

9.12 Regarding sustainable aviation fuels, it is important to recall that they are a key element of the ICAO Basket of Measures to reduce CO_2 emissions from international aviation. A recent major step in this area was the 2050 ICAO Vision adopted at the second ICAO Conference on Aviation and Alternative Fuels, in October of 2017, and we continue to expect these to make a very meaningful contribution to international aviation's environmental goals.

9.13 I would like to take a moment at this time to congratulate you on the golden anniversary of the adoption of the first volume of Annex 16, Volume I.

9.14 Significant progress has been made over the past 50 years, with aircraft today being 75 per cent quieter than in the 1960s, however aircraft noise still remains an important subject for ICAO.

9.15 During this CAEP cycle, you will also continue to advance your work on a supersonic aeroplane noise and emissions Standard. Please rest assured that this work will only become more important over the coming years as new supersonic aircraft are developed and begin to enter into service.

9.16 Our expectation is that CAEP/11 will maintain the momentum in this area, advancing efforts to address several gaps in the current ICAO emissions and noise Standards while setting a firm basis for further progress during the CAEP/12 cycle.

9.17 We should take note, however, that CAEP will not only need to look at supersonics, but also other emerging technologies and innovations that are arising in response to environmental challenges, such as hybrid and electric aircraft. Understanding their environmental impacts and benefits, and defining the groundwork for their certification, will be an important challenge for CAEP in its next cycle.

9.18 I understand that the new trends assessment update on greenhouse gas emissions, noise, and local air quality will be discussed during this meeting, and the Council looks forward to these results. The trends are a vital pillar for related Assembly discussions, providing the information needed to place ICAO's environmental work into proper context with respect to both current and future challenges. I wish to express my appreciation to those States which have so generously made their important tools and databases available for the work of the CAEP, and ultimately so that ICAO Member States can make well-informed decisions and take meaningful actions to address the environmental impact of their aviation activities. Ensuring that both the ICAO trends and the ICAO tools remain up-to-date, with timely and high quality information and data, is invaluable to achieving ICAO's goals under the No Country Left Behind initiative.

9.19 Ladies and Gentlemen, throughout its existence, ICAO's Committee on Aviation Environmental Protection has provided the Council with technical advice that has proven essential in facilitating political decisions. As a world leading expert forum, the CAEP continues to deliver, and ICAO, its Member States and aviation stakeholders have come to expect only the best technical outputs in your consideration of technical feasibilities, environmental benefits, economic reasonableness, and, of course, the interrelationships and trade-offs are among the various measures.

9.20 The CAEP has initiated the important analytical work to support the conceptualization and development of a Global Aviation Environment Plan (GAEP), and I appreciate the recommendations from the wide ranging aviation, economics, airport and industry experts. The GAEP would be a crucial new component in the global aviation environment framework.

9.21 Before concluding now, I would like to take this opportunity to comment on the recent decision taken by the Council last November to revise certain aspects of the CAEP's Directives and Terms of Reference (TORs). I wish to reaffirm that these changes were made to help enhance the visibility and significance of the CAEP to all ICAO Member States, and to encourage greater regional engagement on behalf of our 192 Member States in this Committee. Moreover, these revisions seek to improve transparency and communication at all levels, including with the Council, in order to facilitate related decisions. Accordingly, you are required to take action now to ensure the effective implementation of the Council's Decisions.

9.22 In the 35 years since the CAEP was established, the scope of your work and the technical areas which it covers have widened. And yet despite the monumental challenges set before it, the CAEP remains a tremendous example of international cooperation and has solidified a reputation for delivering quality work on time.

9.23 Your work here over the coming two weeks will have a lasting impact for many years to come, and on that note let me thank you once again for your dedication, support and technical excellence. I wish you all a very cooperative and productive meeting as I await the outcomes. Thank you.

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GENERAL

1. MEMBERSHIP AND PARTICIPATION IN CAEP ACTIVITIES

1.1 The Committee currently consists of 25 Members and 18 Observers, from States and international organizations. Since the last Steering Group Meeting in June 2018, there have been four changes in representatives for CAEP Member States, namely Brazil, Egypt, the Russian Federation and the United Kingdom. Moreover, Saudi Arabia has obtained CAEP Member status. There have been two changes in the Observer representatives, namely: the Arab Civil Aviation Organization (ACAO[1]) and Greece. Malaysia and the United Nations Environment Programme (UNEP) also obtained CAEP Observer status.

2. DEVELOPMENTS IN OTHER UNITED NATIONS BODIES

2.1 The CAEP Secretary updated the meeting on cooperation with United Nations (UN) bodies and other international organizations, and latest developments with relevance to the environmental work of ICAO.

2.2 United Nations Framework Convention on Climate Change (UNFCCC)

2.2.1 In particular, the need for ICAO to closely monitor and participate at the United Nations Framework Convention on Climate Change (UNFCCC) meetings was recognized by the last ICAO Assembly and reinforced by the ICAO Council, and the meeting received information on the UNFCCC 24th Conference of Parties (COP24) held in Katowice, Poland in December 2018. The conference discussed a number of issues with a focus on the implementation of the Paris Agreement, from which of most interest to ICAO was the development of guidance on cooperative approaches and the establishment of a new market mechanism referred to in Article 6 of the Paris Agreement.

2.2.2 ICAO participated in the relevant discussions at COP24 to understand the implications for ICAO's work on CORSIA, in particular the issue of double-counting of emissions units, and to showcase ICAO's recent developments related to international aviation and climate change, with a view to gaining full recognition thereof and ensuring that international aviation would not be considered as a potential source for the mobilization of revenue for climate financing to the other sectors, in a disproportional manner. As the Paris Rulebook was not finalized at COP24, there is not yet clarity on a number of features of its implementation that could have implications for CORSIA.

2.2.3 ICAO informed the meeting that it had observed with concern, that many studies presented at different COP24 side events were misleading to the audience on the impact and future share of international aviation emissions. More than ever, a clear message from ICAO and the parties involved in this process, providing a solid, technically-based and politically unbiased approach using the good work done by CAEP, was needed. The ICAO Secretariat noted that this issue would need to be further considered in the context of the CAEP/11 meeting deliberations on Agenda Items 1, 10 and 12, and in terms of the discussions regarding outreach.

[1] The Arab Civil Aviation Commission (ACAC) changed its name to the Arab Civil Aviation Organization (ACAO) in 2018.

2.2.4 The good cooperation between the ICAO and UNFCCC Secretariats was highlighted. The Observer of the UNFCCC provided a statement to update the CAEP/11 meeting of the results of COP24 and the outlook for COP25. This statement was made available together with the CAEP/11 meeting documentation on the CAEP/11 secure portal.

2.3 **World Health Organization (WHO)**

2.3.1 ICAO has tried to coordinate with WHO-Europe with regard to the development of the "WHO Environmental Noise Guidelines for the European Region". Participation in the study has been requested by ICAO since 2016. WHO shared a draft guideline document in February 2018 to a wide range of stakeholders, including ICAO, for comment and as this draft document contained recommendations related to aircraft noise and transportation policy, ICAO provided an extensive list of comments for the consideration of WHO. These included comments to address the misinterpretation of scientific evidence that associates noise with health that were used to develop the recommendations in the report. Furthermore, despite the significant impacts they attributed to the aviation sector, no cost-effectiveness analysis was done to support these recommendations.

2.3.2 ICAO formally requested WHO to establish a proper coordination and consideration of such comments before the guidelines were published. Despite that, the final WHO guidelines were published by WHO in October 2018, without specific feedback on the ICAO comments. By means of a letter replying to the ICAO Secretary General's concerns, the WHO Director General recently expressed the intention for improved collaboration with ICAO on the practical aspects of implementation of the guidelines.

2.4 **Intergovernmental Panel on Climate Change (IPCC)**

2.4.1 The *Special Report on Global Warming of 1.5°C* was approved by the IPCC during its 48th Session, held in Incheon, Republic of Korea on 6 October 2018. The Summary for Policy Makers (SPM) presents the key findings of the Special Report, and is available online through the IPCC website at: http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf.

2.5 **UN Environment Management Group (EMG)**

2.5.1 ICAO attended the 24th Senior Officials Meeting (SOM) of the UN Environment Management Group (EMG) in New York on 24 September 2018. ICAO highlighted the initiative being undertaken by the Organization in the field of aviation environmental protection, as well as its efforts related to the Climate Neutral UN initiative, such as the use of the ICAO Carbon Calculator. The CAEP Secretary informed the meeting of the 2019 UN Climate Summit that will precede the UN General Assembly in September 2019.

2.6 **Sustainable Mobility for All (Sum4All)**

2.6.1 In January 2017, the Sum4All global partnership was established by over 50 multilateral development banks, UN agencies, bilateral donor organizations, non-governmental organizations, civil society, and academic institutions. The partnership aims at engaging countries and the private sector in a discussion on possible actions to achieve sustainable mobility through the development of a document entitled "Global Roadmap of Action Toward Sustainable Mobility" (GRA), and through six companion papers to the GRA. These documents define policy goals and identify measures for universal access, efficiency, safety, and environment that will guide countries moving the transport sector toward sustainable mobility.

2.6.2 ICAO provided input to these documents based on the developments by ICAO Member States. It should be noted that while positive synergies for environmental actions could be explored between different transport modes (e.g. automobile, railways, shipping, aviation) through the development of these documents under SuM4All, ICAO has consistently emphasized the importance of accurately reflecting specific ICAO policies, agreements, Standards and measures, in particular the ICAO aspirational goals, as already agreed by ICAO Member States, in any documentation produced by SuM4All, which is a paramount condition for ICAO to be associated with this report.

Discussions and Conclusions

2.6.3 The meeting thanked the ICAO Secretariat for the good work in cooperating with other UN bodies and for keeping CAEP informed of the relevant ongoing discussions.

2.6.4 The meeting was appreciative of the coordination by ICAO and noted the information provided on the WHO guidelines, the possible implications for international aviation and the need to avoid such policy recommendations being promoted without proper coordination with ICAO and its Member States. The meeting agreed to discuss the WHO guidelines under Agenda Items 4 and 12.

2.6.5 The meeting encouraged CAEP Members and Observers to take action in terms of outreach on all the work being carried out by ICAO and its Member States on noise, local air quality and climate change.

3. DEVELOPMENTS IN ICAO

3.1 States' Action Plans

3.1.1 ICAO continues to work directly with Member States in order to support the development of States' Action Plans. The State Action Plan initiative is a key element of the Organization's comprehensive capacity-building and assistance strategy to support Member States in the implementation of CO_2 emissions mitigation measures selected from the ICAO Basket of Measures. By 2 November 2018, 110 Member States, representing 91.8 per cent of international aviation revenue tonne kilometres (RTK)[2] had voluntarily submitted action plans to ICAO. It was noted that one additional State had recently submitted an Action Plan to ICAO, bringing the total number of 111 Action Plans submitted to date. These successful results demonstrate the high level of interest and engagement of ICAO Member States in this initiative, as well as the impact of ICAO's assistance and capacity-building activities.

3.2 ICAO State Action Plans "Buddy" Programme

3.2.1 With respect to the ICAO State Action Plan Buddy Programme, Assembly Resolution A39-2 further encouraged States that have already submitted action plans to share information contained in the action plans and build partnerships with other Member States in order to support those States that had not prepared action plans. To date, six partnerships have been established under the ICAO State Action Plan Programme[3].

[2] Based on RTK for 2015.
[3] https://www.icao.int/environmental-protection/Pages/ActionPlan-Questions.aspx

3.3 **Update of ICAO Doc 9988**

3.3.1 ICAO has also been engaged in the update of ICAO Doc 9988, *Guidance on the Development of States Action Plans on CO_2 Emissions Reduction Activities*. This document was first published in 2013 and updated in 2016, and provides ICAO Member States with a step-by-step description of the actions to be taken when developing an Action Plan on CO_2 emissions reduction activities from international aviation. The ongoing update is aimed at reflecting the key decisions that have been made in the area of environmental protection since the 39th Session of the ICAO Assembly on the implementation of the ICAO Basket of Measures. Ultimately, the update of Doc 9988 will also integrate the lessons learned from the capacity-building and assistance projects implemented by ICAO.

3.3.2 The meeting was provided with a synthesis report presenting the initial assessment of submitted States' Action Plans, which is expected to be updated in time for the 40th Assembly.

3.4 **ICAO-EU capacity-building and assistance project**

3.4.1 Under the framework of the ICAO-European Union (EU) capacity-building and assistance project, ICAO continued to support the 14 selected States in the implementation of the mitigation measures in their Action Plans. Two solar-at-gate pilot projects, consisting of a solar photovoltaic system and gate electrification equipment, were implemented in Cameroon and Kenya, as part of the mitigation measures to reduce CO_2 emissions from international aviation. Inauguration ceremonies for the solar projects were held on 12 December 2018 in Mombasa, Kenya, and on 10 January 2019, in Douala, Cameroon.

3.5 **ICAO-UNDP/GEF capacity-building project**

3.5.1 The ICAO – United Nations Development Programme (UNDP) capacity-building project, with financing from the Global Environment Facility (GEF), has reached its concluding phase, across all deliverables, including the implementation of solar-at-gate pilot projects at two international airports in Jamaica and the publication of four unique publications to assist ICAO Member States in developing environmental policy and decision-making, and an online platform to enable knowledge-sharing. Building upon the strong interest expressed by SIDS in the Asia and Pacific region, options are being explored to pursue further cooperation with the UNDP and the GEF and other potential sources to scale-up the "solar-at-gate" approach in SIDS and other African States, as a key component of their international aviation CO_2 emissions reduction activities.

Discussions and Conclusions

3.5.2 The meeting noted the latest developments related to the States' Action Plan initiative and the benefits linked to the development of a long-term strategy for CO_2 emissions from international aviation, involving all aviation stakeholders at the national level. The meeting also noted that fully quantified States' Action Plans are essential to assess the collective progress of the international aviation sector towards the ICAO global aspirational goals. The States of the European Civil Aviation Conference (ECAC) expressed their disappointment that the robust data which they provided in their action plans was disregarded by ICAO on the grounds that it was aggregated throughout 44 ECAC States. They highlighted the fact that this results in a severe underestimation of the contribution of Europe to achieve the ICAO goals, and overall, an underestimation of the level of achievement of the ICAO goals. They asked Secretariat to correct that.

3.5.3 While recognizing the good work and efforts undertaken in the European region in terms of quantification of emissions at the regional level, the CAEP Secretary clarified that Assembly Resolution A39-2 and all related guidance focusses on a State-level approach and that this approach has led to substantial benefits, mainly to developing States in terms of capacity-building and readiness. In addition, only by separating the benefits under the various elements of the Basket of Measures, will ICAO be able to respond to Assembly Resolution A39-3, paragraphs 6 and 7. It was also noted that States with extensive experience in implementing environmental measures, by publishing their individual Action Plans are also providing current, tangible examples of best practices that can be used by other States.

3.5.4 The meeting recognized the value of individual Action Plans and encouraged ICAO to consider how to also recognize and integrate data aggregated at a regional level into the overall assessment of Action Plans by ICAO. The meeting agreed that the updated version (Third Edition) of ICAO Doc 9988 should be published as soon as possible, with the inclusion of wording to highlight that ways on how aggregated data can be integrated are under development and could be included in future revisions of this document.

3.5.5 The meeting welcomed the efforts deployed by ICAO in implementing the State Action Plans initiative that led to 111 States submitting plans to date, and on the development and update of guidance and tools, noting that these efforts have been complemented by ICAO capacity building and assistance projects and the State Action Plan Buddy Programme. While the update to ICAO Doc 9988 had been conducted with ICAO Member States only, one Observer reiterated the willingness of their organization to contribute to the update of ICAO Doc 9988 and emphasized the importance of engaging with industry in the development and implementation of State Action Plans.

3.5.6 The meeting encouraged further actions by ICAO and its Member States to increase the number of States submitting fully quantified action plans.

3.5.7 **Recommendations**

3.5.7.1 In light of the foregoing discussion, the meeting developed the following recommendations:

> **Recommendation 1/1 — ICAO Doc 9988, *Guidance on the Development of States Action Plans on CO_2 Emissions Reduction Activities***
>
> That the updated version (Third Edition) of ICAO Doc 9988 be published as soon as possible.

Recommendation 1/2 — Submission of State Action Plans

That States be invited to submit fully quantified State Action Plans on CO_2 emissions reductions from international aviation to ICAO, in line with the guidance contained in the updated ICAO Doc 9988 (Third Edition), and to update their State Action Plans every three years thereafter.

Recommendation 1/3 — State Action Plan Buddy Partnerships

That States which have expertise in the development of State Action Plans be encouraged to support other States, through the establishment of a Buddy Partnership.

4. DEVELOPMENTS IN CORSIA

4.1 Adoption of Annex 16, Volume IV

4.1.1 The ICAO Council, at its 214th Session in June 2018, adopted the First Edition of Annex 16 — *Environmental Protection,* Volume IV — *Carbon Offsetting and Reduction Scheme for International Aviation* (CORSIA), which became effective as of 22 October 2018, and subsequently became applicable from 1 January 2019. In addition, the First Edition of the ICAO *Environmental Technical Manual* (ETM), Volume IV — *Procedures for Demonstrating Compliance with the CORSIA* (Doc 9501) was published in July 2018.

4.2 CORSIA Implementation Elements

4.2.1 Following the adoption of the First Edition of Annex 16, Volume IV, the Council approved the 2018 version of the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT) and its technical methodologies, which were made available on the ICAO CORSIA public website in early August 2018, and that CAEP work is ongoing on the development of the 2019 version of the ICAO CORSIA CERT, which will provide necessary output data to be incorporated into the aeroplane operators' annual Emissions Report from 2019. The meeting was also informed of the approval by the Council of the functional requirements of the CORSIA Central Registry (CCR), for which development and testing will be undertaken until the end of 2019 by a vendor selected under an ICAO procurement process, prior to the operationalization of the CCR in early 2020.

4.2.2 Regarding progress made on the CORSIA eligible emissions units, the 215th Session of the Council in November 2018 had noted the results of the work of CAEP on the informal testing of emissions unit programmes against the emissions units criteria (EUC) and agreed that, when the Technical Advisory Body (TAB) is established, the outcome of the work of the CAEP's Programme Testing Group (PTG) should be used as a starting point for the TAB to undertake its work. The meeting was also informed of the Council's approval of the basic Terms of Reference (ToR) for the TAB, based on the CAEP recommendations, with amendments proposed by the Council's Advisory Group on CORSIA (AGC).

4.2.3 As requested by the Council, ICAO issued State letter ENV 6/1 – 18/110, inviting the nomination of experts from States to the TAB, as well as to inform States of developments related to the EUC and inviting them to provide comments thereon. Both nominations to the TAB and comments on the EUC will be presented for the Council's consideration during its 216th Session (March 2019). The meeting was informed of the Council's request to CAEP to provide, for Council's consideration and approval during the 216th Session, further advice regarding additional rules of procedure for the TAB, which would complement the approved basic TOR. The Council also requested CAEP to consider, as part of CAEP's work programme, guidance on how to monitor and review the continued eligibility of emissions unit programmes that the Council had determined to be eligible under CORSIA, and to report thereon to the Council in due course.

4.3 **CORSIA outreach and capacity building**

4.3.1 During its 214th Session the Council endorsed the ICAO ACT-CORSIA (Assistance, Capacity-building and Training for CORSIA) Programme, emphasizing the importance of a coordinated approach under ICAO to harmonize and bring together all relevant actions and promote coherence in capacity-building efforts. The meeting was reminded that the Council also requested that any bilateral or multilateral partnerships among States should be coordinated with ICAO, so that the global progress of such coordinated efforts would be monitored and recognized under ACT-CORSIA. The meeting was updated on the status of the CORSIA Buddy Partnerships established within the framework of the ACT-CORSIA Programme, whereby a donor State provides assistance, in close coordination with the ICAO Secretariat, to a recipient State to build its national capacity to implement CORSIA; CORSIA Buddy Partnerships currently established involve 15 donor States providing support to 96 recipient States, of which 71 had received on-site training.

4.3.2 The meeting was informed that the ICAO Secretariat, through its Global Aviation Training (GAT) office, is in the last stage of developing the ICAO CORSIA Verification Course aimed at helping verification bodies increase their knowledge of CORSIA and related verification requirements. The CAEP Secretary highlighted that the course had completed its validation delivery session right before the start of the CAEP/11 meeting, with the contribution of representatives from States and verification bodies, and that delivery of the course is expected to take place from April 2019.

4.3.3 In response to the request by the Council to enhance the communication efforts of the Secretariat to the public, the Secretariat has restructured and updated the ICAO CORSIA public website (www.icao.int/corsia), with updated materials on subjects such as the ACT-CORSIA Programme and related CORSIA Buddy Partnerships; seminars and workshops; and outreach materials including Frequently Asked Questions (FAQs) on CORSIA, brochures, videos, and leaflets. The meeting was also informed of the upcoming five CORSIA regional workshops to be held in five venues from 21 March to 12 April 2019, for which the continued contributions by experts from CAEP would be essential.

Discussions and Conclusions

4.3.4 In response to a question from a Member, the Secretariat reminded the meeting that States and operators who, as a result of the use of the 2018 version of the ICAO CORSIA CERT, identified any issues, were invited to report them to the Secretariat via a designated e-mail address, as reflected on the ICAO CORSIA public website.

4.3.5 The meeting recognized the significant efforts and contributions of CAEP Member and Observer States and international organizations to the successful adoption of the First Edition of Annex 16, Volume IV in June 2018, as well as to the establishment of the ICAO ACT-CORSIA Programme and associated Buddy Partnerships across various regions in a short timeframe, in support of the implementation of CORSIA. The meeting thanked the Secretariat for the tremendous support provided to States in preparing for CORSIA implementation, and acknowledged the importance of information-sharing among States in the context of the CORSIA Buddy Partnerships.

4.3.6 The meeting encouraged more CAEP Member and Observer States to participate in the ICAO ACT-CORSIA Programme and to consider establishing Buddy Partnerships with other States to support the implementation of CORSIA, recognizing the importance of a coordinated approach under ICAO. The meeting encouraged CAEP Member and Observer States that have not yet nominated CORSIA focal points to do so as soon as possible, as per State letter ENV 6/6 – 18/1.

4.3.7 The meeting also recognized the importance of the continued contribution by experts from CAEP to future ICAO Secretariat outreach and capacity building activities for CORSIA implementation, including at the upcoming 2019 CORSIA regional workshops, as well as in the next stages of the ACT-CORSIA Programme and related CORSIA Buddy Partnerships .

4.3.8 Regarding the Council's request to CAEP related to TAB, the meeting noted that, upon agreement by CAEP Members, a small group of CAEP Members had been established to make progress in developing the draft Rules of Procedure for TAB. The meeting thanked Mr. Alfredo Iglesias, CAEP Member from Spain, for agreeing to lead this discussion of the small group during the CAEP/11 meeting, and noted that the small group would be composed of the CAEP Members from Argentina, Australia, Brazil, Canada, China, Egypt, France, Japan, the Russian Federation, Singapore, Spain, Switzerland, United Arab Emirates, the United Kingdom and the United States. The meeting also noted that the outcome of the work of the small group would be presented at a later stage of the meeting, for its consideration.

4.3.9 The meeting noted another request by the Council to consider, as part of CAEP's work progamme, guidance on how to monitor and review the continued eligibility of emissions unit programmes that the Council had determined to be eligible under CORSIA, and to report thereon to the Council in due course. The meeting agreed to consider this request when considering proposals for future work on CORSIA during the CAEP/12 cycle under Agenda Item 12 of the meeting.

5. GLOBAL AVIATION ENVIRONMENT PLAN (GAEP)

5.1 During the 2018 CAEP Steering Group Meeting (SG2018), CAEP discussed the concept of the Global Aviation Environment Plan (GAEP). This led to a broad and cautious support for the development of the GAEP, and the need to reflect on the best process for the consultation and approval of such a plan, which would go beyond the CAEP to involve all States and various stakeholders. It had been agreed that it should be clear that what was expected by the 40th Session of the Assembly was the concept of the GAEP, rather than the GAEP itself. During its 214th Session, the Council noted that CAEP had undertaken a preliminary discussion on the possible development of the ICAO GAEP and that a detailed concept and development approach would be considered by the CAEP/11 meeting in February 2019. In this regard, the Council requested that it be closely involved in any development approach on a potential ICAO GAEP. Based on this, the GAEP Concept Paper was presented to the CAEP/11 meeting, which provided background information on the possible structure, content and adoption process for the ICAO GAEP. It was complemented with a non-exhaustive resource list that contributed to further establishing the foundation for the themes proposed for the GAEP and further information on a Circular Economy in International Aviation.

5.2 The GAEP Concept Paper was structured around four main sections: 1) introduction to ICAO's Global Aviation Environmental Plan (GAEP); 2) a vision for an environmentally sustainable international aviation sector; 3) the Implementation Strategy; and 4) the proposed process for the development and approval of the ICAO GAEP.

5.3 Several Members and Observers commented that the proposed objective of the GAEP was currently too broad and vague, and expressed concerns regarding the proposed GAEP mandate and the implications for ICAO Member States. Further, the Members and Observers noted that there has not been a demonstrated need for the GAEP. They also raised issues on resource requirements for ICAO Member States to develop the GAEP, and commented that this process should be led by States with the support of the ICAO Secretariat. The Members and Observers stated that a decision to develop a GAEP must be member-driven, provide a net-benefit to ICAO States, and not result in a drain on limited resources, in light of competing priorities. The Members and Observers stated that they do not believe these factors are satisfied and do not support further development of the GAEP.

5.4 Based on the successful implementation of the ICAO Global Aviation Safety Plan (GASP) and Global Air Navigation Plan (GANP), the Secretariat clarified that the GAEP could result in a document that would report on the current state of ICAO's work on environmental protection to assist Member States in implementing ICAO policies, SARPs and guidance materials. The meeting agreed that the GAEP Concept Paper would be discussed further during the CAEP/11 meeting under Agenda Item 12 in order to decide its need and scope.

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Agenda Item 1: Assessments of the present and future impact of aircraft noise and emissions

1.1 GLOBAL ENVIRONMENTAL TRENDS

1.1.1 The MDG co-Rapporteurs presented the result of the future trends assessments for aircraft noise, aircraft engine emissions that affect local air quality, and aircraft engine emissions that affect the global climate.

1.1.2 Aircraft Engine Emissions Trends That Affect Local Air Quality (LAQ)

1.1.2.1 The LAQ trends assessment included oxides of nitrogen (NOx) and PM emissions results. Figure 1 presents aircraft NOx emissions below 3 000 feet above ground level from international aviation. Depending upon the scenario, technology improvements could provide additional 0.35 Mt and 0.46 Mt reductions in NOx emissions in 2050 for international and global (international plus domestic) aviation, respectively. Operational improvements are smaller than those that could be realized by technology, namely additional reductions of up to 0.15 and 0.23 Mt in 2050 for international and global aviation, respectively.

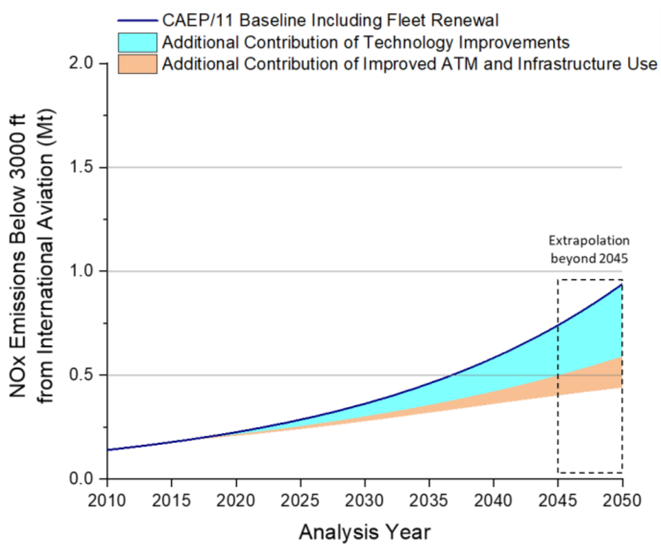


Figure 1. NOx emissions below 3 000 ft from international aviation, 2010 to 2050

1.1.2.2 Figure 2 presents total (volatile and non-volatile) PM emissions below 3 000 ft from international aviation. Operational improvements could provide additional reductions of up to 1 160 tonnes and 3 100 tonnes in PM emissions in 2050 for international and global aviation, respectively. No PM technology scenario was assessed.

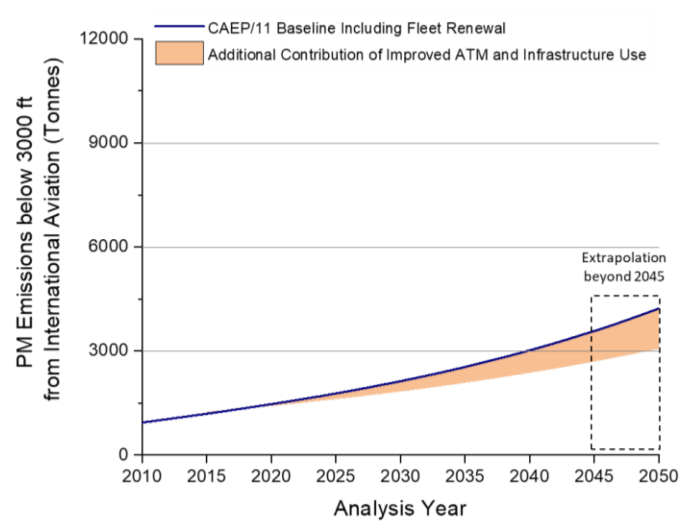


Figure 2. PM emissions below 3 000 ft from international aviation, 2010 to 2050

1.1.3 Aircraft Engine Emissions Trends That Affect Global Climate

1.1.3.1 The greenhouse gas (GHG) portion of the trends assessment evaluated potential contributions of operational and technology improvements to reducing projected fuel demand and associated future emissions. The results included conventional fuel consumption, net CO_2 emissions (i.e., the CO_2 emitted during the flight only), and NOx emissions.

1.1.3.2 Conventional fuel consumption and net CO_2 emissions from international aviation are shown in Figures 3 and 4, respectively. Depending upon the scenario, technology improvements could provide an additional 157 Mt reduction in fuel consumption (Figure 1) and 497 Mt reduction in CO_2 emissions (Figure 2) in 2050. Operational improvements are smaller than those that could be realized by technology, namely up to an additional 57 Mt reduction in fuel consumption and 183 Mt reduction in CO_2 emissions in 2050. Under the current most optimistic technology and operational scenarios, fuel efficiency is expected to improve at an average rate of 1.37 per cent per annum, i.e. the 2 per cent per annum fuel efficiency goal is unlikely to be met.

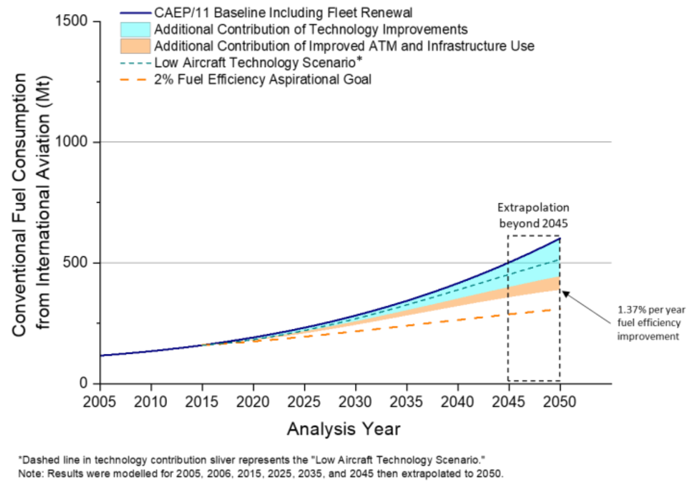


Figure 3. Conventional fuel consumption from international aviation, 2005 to 2050

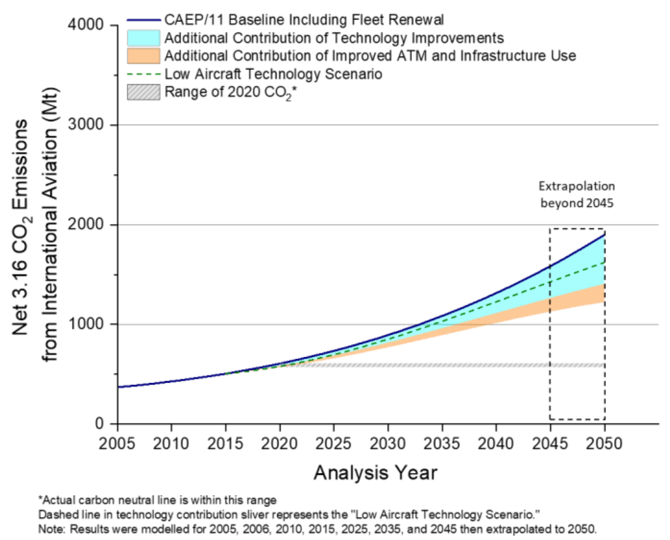
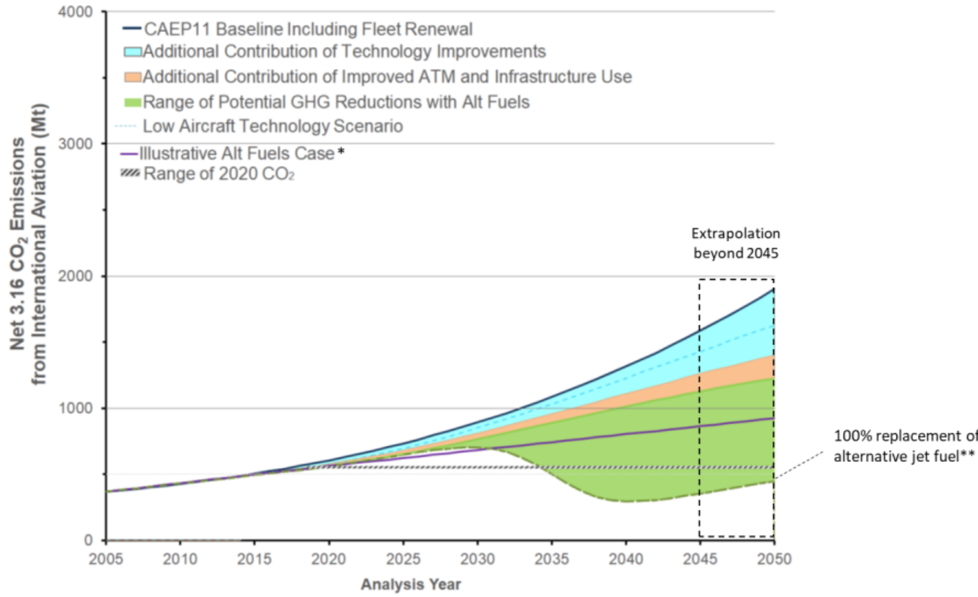


Figure 4. Net 3.16 CO_2 emissions from international aviation, 2005 to 2050

1.1.3.3 The CAEP Alternative Fuels Task Force (AFTF) conducted analyses to provide estimates of potential alternative fuels production and associated life cycle GHG emissions change for 2020 and 2050. For 2020, there were six production estimates and two GHG LCA estimates (low and high), resulting in 12 possible GHG emissions scenarios. The 2020 scenarios provide up to 2 per cent petroleum-based fuel replacement and up to 1.2 per cent GHG emissions reductions. For 2050, AFTF calculated 60 production achievement scenarios and 2 GHG emissions scenarios resulting in 120 scenarios. Certain global conditions, economic investments, and policy decisions are assumed as part of each scenario definition and would be necessary to reach the associated outcome of alternative fuel production and GHG reductions. The amount of alternative fuel and the associated GHG emissions reductions were allocated proportionally between international and domestic use based on projected fuel demand (roughly 60/40, respectively). Figure 5 provides the associated GHG emissions results.



*Illustrative case would require high availability of bioenergy feedstocks, the production of which is significantly incentivized by price or other policy mechanisms. **100% replacement of alternative jet fuel would require a complete shift in aviation from petroleum refining to biofuel production and a substantial expansion of the agricultural sector, both of which would require substantial policy support; Note: alternative fuel increase appears curved due to subtraction of the ramp up from Scenario 9 growth curve.

Figure 5. Net 3.16 CO_2 emissions from international aviation, 2005 to 2050, including alternative fuels life cycle emissions reductions

1.1.4 Aircraft Noise Trends

1.1.4.1 The noise portion of the trends includes contour area and total population exposed to noise above a day-night average sound level in dB (DNL) of 55, 60, and 65 at 315 airports representing around 80 per cent of global flight operations. The noise trends assessment included coordination with WG1 on technology improvement assumptions and WG2 on operational improvement assumptions. Operational improvements were applied to total population exposed, but not to contour area. Four modelling scenarios were undertaken and each was modelled for the 2015 datum and for each of three future years, 2025, 2035, 2045. Total global graphical results are presented for base year 2015 and future years 2025, 2035, and 2045, with an extrapolation out to 2050. Historical data modelled in the CAEP/10 work cycle is also provided for 2010.

1.1.4.2 Figure 6 provides results for the total global contour area (i.e. for 315 airports) from aircraft noise above 55 DNL. These results include noise from all aircraft, regardless of whether the operation is an international or a domestic flight. The 2015 baseline value is 14 378 km^2. In 2050, total global contour area decreases to 14 261 km^2 with advanced technology improvements and increases to 26 483 km^2 with low technology improvements.

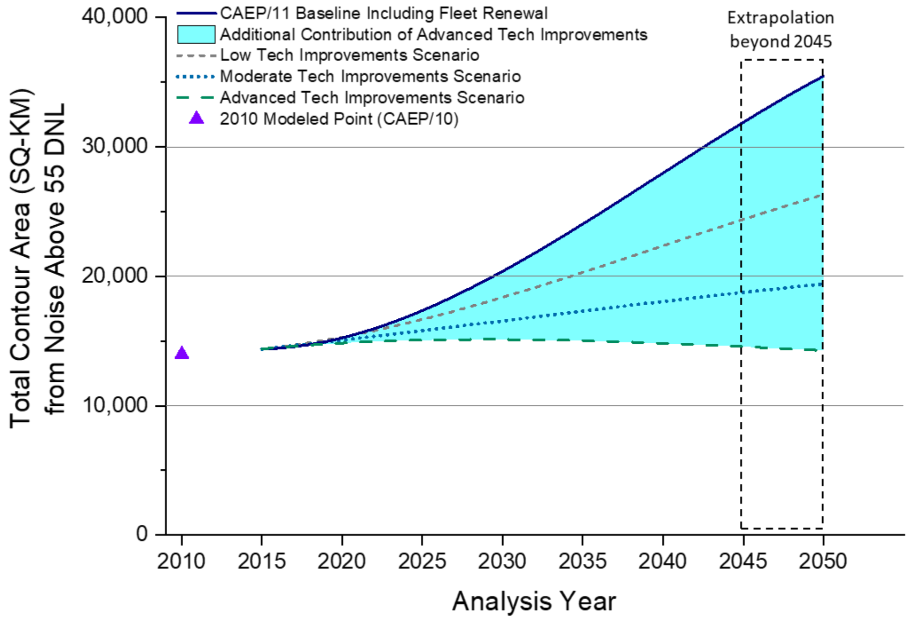


Figure 6. Total Contour Area from Aircraft Noise above 55 DNL

1.1.4.3 Figure 7 provides results for the total global population (i.e. for 315 airports) exposed to aircraft noise above 55 DNL. WG2 recommended that operational improvements be applied to total population exposed, but not to contour area. Historical data modelled during the CAEP/10 work cycle is also shown for 2010, with a range in population values since multiple population databases were used at the time. The 2015 baseline value is 30.5 million people. In 2050, total population exposed increases to 34.2 million people with the advanced technology and operational improvement scenario, and to 66.9 million people with low technology and operational improvement scenario.

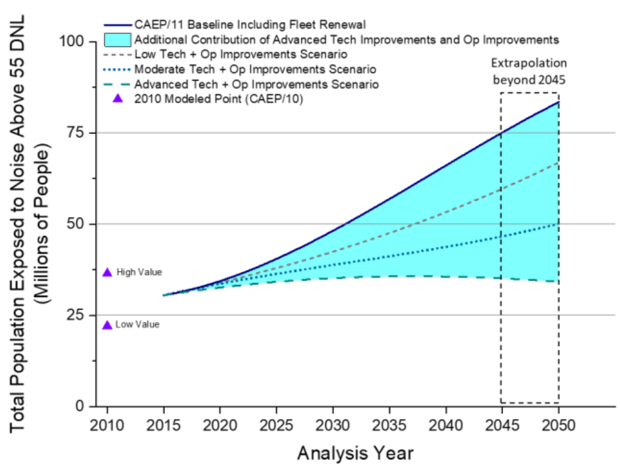


Figure 7. Total population exposed to aircraft noise above 55 DNL

Discussions and Conclusions

1.1.5 The meeting thanked MDG for the tremendous amount of work and the improvements in LAQ modelling. One Member asked how MDG considers the differences in results between the various models used in the analysis, and it was clarified that the noise models show nearly identical agreement on the results since they follow the detailed methodology from ICAO Doc 9911, while the LAQ and GHG modelling use different tools that are complementary to each other. The co-Rapporteurs highlighted that, since these differences are fully understood, they bring benefits to the process by facilitating the identification of errors and possible improvements to the models. Specifically regarding LAQ dispersion modelling, it was explained that prior model evaluation shows very different approaches, which MDG proposed to further investigate in the CAEP/12 cycle.

1.1.6 Regarding the dissemination of results, it was noted by the meeting that as is customary, after the CAEP, more work on the communication of the trends can be undertaken before the trends results are published in the ICAO Environmental Report.

1.1.7 Responding to a question by a Member, an MDG co-Rapporteur clarified that the baselines used in the analysis are based on a static growth and replacement database, which is used to replace the fleet up to 2050. The technology and operational improvement scenarios are added on top of that, representing the adoption of new technology that may occur as part of the fleet renewal. The co-Rapporteur acknowledged that this point would be better clarified in the trends paper to the ICAO Assembly, and would work with the ICAO Secretariat to capture this point.

1.1.8 A Member noted that all the different CO_2 emission scenarios used in the GHG trends are based on the assumption of a static technology level for conventional fuels, and recommended that CAEP consider possible benefits from improved low carbon fuels technologies in this area, which can be supported by a wealth of research studies that can be provided. Also, the Member expressed his State's willingness to participate in the future work by providing information and expertise in this regard. In addition, the Member stated that CAEP needs to involve stakeholders that are in the conventional fuel industry who have not been involved thus far. The meeting noted that this would be considered in the future work item associated with the update of the trends assumptions. The meeting also noted that the trends update is heavily dependent on information provided by CAEP Member States and Observers, and welcomed data on new technologies for consideration under the next trends assessment.

1.1.9 Responding to a question by a Member regarding the differences between the CAEP/10 and CAEP/11 baselines, the MDG co-Rapporteurs confirmed that the CAEP/11 trends used a new forecast which resulted in baselines with a lower trend on all results, as a result of the reduced demand forecasted and new technologies entering the fleet. They highlighted that both factors contributed to the lower trend, and indicated that it was difficult to separately quantify the contribution of each.

1.1.10 Regarding noise trends, one Member was of the opinion that information from the Independent Expert Integrated Review (IEIR), historical noise mitigation aspects, research on noise annoyance, noise metrics and non-acoustical factors should also be submitted to the Council when they discuss noise. Specifically on annoyance and sleep disturbance, the meeting was reminded that the ICAO environmental goals refer to limiting the number of people affected by noise, but the current trends provide noise exposure numbers. In replying to a question on encroachment, one MDG co-Rapporteur highlighted that the population modelling is based on static census data; that is, the modelling does not consider possible population growth with time.

1.1.11 The MDG co-Rapporteurs highlighted that MDG, FESG and ISG evaluated several tools potentially available for including noise, LAQ and GHG impacts (including monetization) in future CAEP assessments, and this analysis could be useful for CAEP to define a proper way forward to consider these topics in the future.

1.1.12 The CAEP Secretary welcomed the work on the trends, while highlighting the importance of the trends for the work of the Organization and as a basis for the setting of policies at the Assembly, and as such, the need for a process to fine-tune the message. In addition, she highlighted that due to its relevance, more substantial efforts should be reflected in the future work programme for all working groups involved in undertaking this task.

1.1.13 One Member welcomed further work to properly communicate the results of the trends analysis, but noted that such communication should be kept as simple as possible and maintain the high-level messaging supported by these results.

1.1.14 The meeting agreed that the messaging from the trends analysis should be further refined, including consideration of any new information available prior to the 40th Assembly. The results will accompany the CAEP recommendation on the trends as the basis for ICAO decision-making on noise and emissions. This messaging should include proper qualitative and quantitative interpretation of the results, with clear caveats and assumptions, as needed. The meeting also agreed to consider which other assumptions may need to be reviewed for the CAEP/12 trends assessment, under future work.

1.1.15 **Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft**

1.1.15.1 The Independent Expert (IE) Panel co-Chairs provided a summary of the outcomes on the Independent Experts Integrated Technology Goals Assessment and Review for Engines and Aircraft (IEIR) process. The interdependency between fuel burn and noise was assessed using design space modelling, but it was not possible to consider interdependency of emissions using modelling. Nevertheless, this review was far more taxing than previous reviews, which looked separately at noise, emissions and fuel burn.

1.1.15.2 The goals for fuel burn and noise were taken together, both following from the combined optimization process. For the single-aisle aircraft, the IEs assumed that a completely new airframe would be available in 2037. The fuel burn goals, expressed in terms of the CO_2 certification metric system as percentage margins relative to the CAEP/10 New Type Regulatory Level are:

EIS Date	BJ	RJ	SA	TA
2027	-15	-16	-14	-12
2037	-23	-26	-24	-21

1.1.15.3 The complementary noise goals expressed as EPNdB cumulative below Chapter 14 Noise Limit are:

EIS Date	BJ	RJ	SA	TA
2027	10.0	14.5	15.5	19.5
2037	15.0	17.0	24.0	26.5

1.1.15.4 The IEs recommended, based on the evidence provided, that a new 2027 MT LTO NOx Goal should be set at 54 per cent below CAEP/8 at OPR=30, covering the entire OPR range, using the equation:

$$Dp/F_{00} = 5.75 + 0.577*OPR.$$

Discussion and Conclusions

1.1.16 The meeting expressed its gratitude to the IEIR panel for its efforts, dedication and hard work.

1.1.17 An Observer expressed support for the technology goals proposed by the IEIR report. Additionally, the Observer highlighted that, during the IEIR process, concerns were voiced regarding the large (7 per cent) additional aerodynamic efficiency increase assigned by the IEs to the Single-Aisle Technology Reference Aircraft. The Observer noted a fundamental difference in achievable L/D between single-aisle and twin-aisle aircraft, and that it was unclear which technologies beyond the categories used in the IEIR report could account for the assumed large aerodynamic efficiency increase for the single-aisle 2037 aircraft. While agreeing with the IEIR report, the Observer suggested that the IEs could have assumed a small aerodynamic efficiency increase (no more than 2 per cent) relative to current Single-Aisle Technology Reference Aircraft to account for a “clean-sheet” single-aisle aeroplane (that satisfies existing ICAO Code-D airport operational constraints).

1.1.18 An Observer expressed appreciation for the work done by the IEs and the inclusion of a business jet aircraft reference in the review process, and welcomed the outcomes provided in the comprehensive final IEIR report.

1.1.19 A Member and an Observer noted that the report raised important issues that will shape the future work of CAEP, and therefore supported that it should be made publicly available by ICAO, preferably free of charge. The ICAO Secretariat clarified that the report will be published as an ICAO publication as soon as possible, following its approval by CAEP and the ICAO Council.

1.1.20 A Member noted that the report mentioned interdependencies between the different environmental parameters, and questioned if any interdependencies between nvPM, NOx and fuel-burn exist for some of the technologies considered. The IE co-Chair clarified that the IE panel did not have access to nvPM measurements, which prevented a proper assessment of these interdependencies. The IE co-Chair confirmed there was a trade-off between NOx and nvPM, and stated that there is evidence that two combustor technologies may reach low values for both NOx and nvPM, and that others may not.

1.1.21 One Member noted the importance of the IE reports for the CAEP processes due to their independent nature and technical quality of the work. The Member supported the continuation of the IE reviews in the future, and noted that CAEP should properly consider the IE recommendations in terms of possible improvements in the IE review process.

1.1.22 **Recommendations**

1.1.22.1 In light of the foregoing discussion, the meeting developed the following recommendations:

Recommendation 2/1 — Endorsement of the global environmental trends assessments

That the ICAO/CAEP global environmental trends should be used as the basis for decision-making on noise and emissions discussions by the 40th Session of the ICAO Assembly, and be continually reviewed by CAEP.

Recommendation 2/2 — Publication of the Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft

That the final report on the Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft should be published by ICAO as soon as possible.

Recommendation 2/3 — Acceptance of the CAEP/11 integrated noise and emissions technology goals for engines and aircraft

That the CAEP/11 integrated noise and emissions technology goals are endorsed by CAEP and should be used to inform ICAO noise and emissions activities.

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Agenda Item 2: Environmental models and databases

2.1 COORDINATION BETWEEN WORKING GROUPS

2.1.1 Due to the substantial resource demands and complexity of the CAEP/11 work programme and the numerous cross-cutting issues between the various CAEP working groups, the groups took deliberate action to ensure sufficient coordination. This included frequent reviews of activities that required coordination and jointly reporting on those activities to each of the Steering Group meetings.

Discussion and Conclusions

2.1.2 The meeting thanked the MDG co-Rapporteurs for their effective, necessary coordination throughout the CAEP/11 work programme. The meeting agreed to discuss the coordination aspects related to supersonics SARPs development, as well as the updates on the input assumptions for the ICAO environmental trends assessment, under future work.

2.2 MDG PROGRESS REPORT

2.2.1 The MDG co-Rapporteurs presented an overview of MDG activities during CAEP/11. The work that related to policy option analyses of the environmental benefits and interdependencies of a potential ICAO non-volatile particulate matter (nvPM) mass and number Emissions Standard is described under Agenda Item 3. Related work, which summarizes the models and databases used to support the nvPM analysis, is described under Agenda Item 3. In addition, MDG provided updated trends assessments on noise, NOx, PM, fuel burn, and CO_2 as described under Agenda Item 1 of this report.

2.2.2 Following the establishment of the CORSIA CERT Group (CCG) to develop and maintain the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT), MDG reviewed and evaluated the CO_2 Estimation Models (CEMs) underlying the CERT and concluded that the 2018 version of the CERT was fit for purpose.

2.2.3 MDG has continued to work with WG2 to conduct an analysis of the benefits of the Aviation System Block Upgrades (ASBU) Block 1. The results of this task are presented under Agenda Item 5 of this report.

2.2.4 MDG provided maintenance on the models and databases used in support of CAEP analyses. The nvPM computation modules were updated in the CAEP-approved tools, and the MDG consensus tool for calculating LTO nvPM using ICAO Times in Mode was developed for the nvPM Standard analysis. The CAEP-approved GHG models (AEDT, IMPACT, FAST) were updated to include the latest cruise nvPM algorithms. In addition, updates were completed to the airports database, the Campbell Hill fleet database and the Common Operations Database (COD). A 2012 baseline COD was developed and used by FESG to develop a related forecast for the nvPM stringency assessment. A 2015 baseline COD was also developed and used with a related updated forecast within the ICAO environmental trends assessment.

2.2.5 MDG and FESG coordinated with the ICAO Aviation Data and Analysis Panel (ADAP) by providing the 2012 and 2015 COD to support preparation of the ICAO traffic demand forecasts.

2.2.6 In coordination with FESG, MDG conducted a review of historic fleet data, environmental standards and other potential fleet influences (e.g. fuel price changes, global economic activity) to provide a better understanding of the evolution of global fleet trends in relation to environmental standards. It concluded that it is possible that environmental standards both reflect and influence market forces. Environmental standards may also encourage a positive environmental trend by preventing back-sliding to older technologies.

2.2.7 MDG and FESG also reviewed lessons learned from prior analyses, with a view to improving the process for future analyses. This task included an identification of gaps in analysis assumptions, databases and tools.

2.2.8 Together with FESG and ISG, MDG reviewed existing definitions of cost-benefit analyses (CBAs), the results of the identification of tools and methodologies, and an initial comprehensive documentation of these tools and methodologies. Initial discussion on the pros and cons of the use of CBAs for CAEP purposes was also provided.

Discussions and Conclusions

2.2.9 The meeting congratulated MDG for the significant amount of high quality work. The meeting agreed that the scoping exercise to assess the contribution of the ICAO CO_2 Standard to ICAO global aspirational goals should be carried over to the CAEP/12 cycle, and agreed that MDG had completed all the other tasks from its CAEP/11 work programme.

2.3 REPORT OF THE FESG

2.3.1 The Rapporteur of FESG presented an overview of FESG activities during CAEP/11. Besides the tasks developed jointly with MDG, FESG reviewed and updated the input cost assumptions related to fleet evolution and cost effectiveness. Work was also accomplished to define, develop and agree upon additional economic cost elements. A CAEP/11 version of the FESG cost model was also developed, tested and approved. All these developments were used in the nvPM Standard analysis.

2.3.2 Following final review and approval by ADAP, an updated ICAO long-term traffic forecast (LTF), with a 2015 base year, was delivered to FESG at the end of March 2018. It was used by FESG to develop new CAEP passenger and freighter fleet forecasts. FESG also developed a business jet forecast from a 2015-based forecast provided by the International Business Aviation Council (IBAC).

Discussion and Conclusions

2.3.3 The meeting thanked the FESG for its work, in particular for the significant efforts in supporting the nvPM mass and number Standard-related analyses, and their coordination with ADAP.

2.3.4 Responding to a question by the Chairperson, the FESG Rapporteur confirmed that CAEP could benefit from an updated forecast for the work during the CAEP/12 cycle. Such an updated forecast should be made available by mid-2020 in order to be considered for the CAEP/12 trends assessment and eventual stringency analyses. It was highlighted that the eventual inclusion of supersonics in the forecast could impact this timeline and should be properly coordinated with the ICAO Secretariat. A Member emphasized that the coordination with ADAP should be taken very seriously and this timeline defined properly.

2.3.5 Responding to a question by a Member, the FESG Rapporteur clarified that the passenger and freighter forecasts developed by ADAP are available on the ICAO website as the official ICAO Long-Term Forecast, and can be freely referenced. It was also clarified that the CAEP passenger and freighter fleet forecasts could also be published, in principle, subject to proper approval from CAEP.

2.3.6 The meeting approved the 2015 base year CAEP/11 fleet forecast and agreed that FESG had completed its tasks as per the CAEP/11 work programme.

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Agenda Item 3: Aircraft engine emissions

3.1 REPORT OF WG3

3.1.1 The co-Rapporteurs of WG3 provided an overview of the work carried out by WG3 during the CAEP/11 cycle. The majority of the work items were dealt with by three Task Groups (Particulate Matter (PMTG); Certification (CTG); and Technology and Goals (TGTG)). The work on the non-volatile Particulate Matter (nvPM) mass and number SARPs, and the associated Annex 16, Volume II and ETM, Volume II amendments, were provided in a separate report under this agenda item.

3.1.2 The meeting thanked WG3 for its dedication, efforts and high quality work during this CAEP cycle.

3.2 PARTICULATE MATTER STANDARD DEVELOPMENT

3.2.1 Prior to the presentation of the work of WG3 and MDG on the nvPM stringency assessment, a Member presented information that outlined a proposal to shift the nvPM mass regulatory limit line for in-production engines to accommodate the Russian engine PS-90A, which is planned to be in-production after 2023. The Member commented that, due to scheduling issues, the nvPM certification-like measurements for these engines were conducted after the final CAEP/11 WG3 meeting and therefore, the data were submitted to the CAEP/11 meeting for consideration during the nvPM Standard-setting process.

3.2.2 The meeting noted the nvPM mass metric value of the PS-90A engine, relative to the WG3 proposed in-production regulatory limit, and agreed to shift the proposed nvPM mass regulatory limit for in-production engines to accommodate the Russian engine PS-90A.

3.2.3 The WG3 co-Rapporteurs reported on the completion of the CAEP/11 tasks pertaining to nvPM emissions, including on the proposed Landing and Take-Off (LTO)-based nvPM mass and number SARPs and associated guidance material.

3.2.4 The WG3 co-Rapporteurs noted that additional work is required to finalize ambient conditions corrections during the CAEP/12 cycle. Additional new data from combustor rig tests and multiple engine tests could be used to validate and improve the cruise nvPM methodology. The WG3 co-Rapporteurs highlighted that more work would also be needed to address nvPM losses in the measurement system and proposed to include the above mentioned work items in the CAEP/12 work programme.

3.2.5 The WG3 co-Rapporteurs proposed to end the Smoke Number (SN) Standard applicability for engines of rated thrust >26.7 kN from 1 January 2023, given that the agreed CAEP/10 limit line will give the visibility constraint provided by the SN Standard.

3.2.6 The MDG co-Rapporteurs provided an overview of the work on the nvPM stringency analysis carried out under the CAEP/11 work programme including caveats, limitations and the context of the information; summaries of key tools, methods, data and assumptions; and environmental costs and cost-effectiveness results.

3.2.7 The meeting accepted the results presented and acknowledged the corresponding caveats related to modelling, business jet market uncertainties and nvPM measurement uncertainties.

3.2.8 The WG3 co-Rapporteurs provided material to support the public rulemaking processes of a number of ICAO Member States and to assist in the development of States' nvPM Regulatory Impact Assessments (RIAs) for the implementation of the proposed CAEP/11 nvPM LTO mass and number emissions SARPs. Additionally, since WG3 had recommended ending the applicability of the SN Standard for engines of rated thrust >26.7 kN on 1 January 2023, the material provided the background technical information that was used to develop this recommendation.

3.2.9 A Member acknowledged the importance of supporting the public rulemaking processes of ICAO Member States and assisting the development of States' nvPM RIAs for implementation of the proposed CAEP/11 nvPM LTO mass and number emissions Standard. The meeting agreed that the RIA would be updated based on the CAEP/11 decisions and included in Appendix C to the report on this agenda item.

3.2.10 Several Members and Observers supported setting the new aircraft engine LTO-based nvPM mass and number SARPs for turbofan and turbojet engines >26.7 kN, but also acknowledged specific technology issues associated with nvPM mass and number emissions control, and that different manufacturers are at different stages of the development cycle of potential technological solutions for in-production and new type engine designs. The Members and an Observer supported only stringency options 1-3 for consideration in setting the new technology nvPM SARPs.

3.2.11 Referring to the statements made by several Members and Observers, a Member asked about additional information on the rationale for the applicability date proposals and which stringency options these Members and Observers would consider appropriate. The Members and Observers clarified that the decision should be data-driven and from this standpoint, the new Standards should be sufficiently challenging, but not extreme for the stakeholders.

3.2.12 The meeting acknowledged the specific technology issues associated with nvPM mass and number emissions control, and noted that different manufacturers have in-production engines which are at very different positions relative to the new technology stringency options. The meeting further recognized that different manufacturers are at different stages of the development cycle of potential technological solutions for new technology designs.

3.2.13 A Member supported the work on the nvPM mass and number Standards, expressing the view that stringency options (SOs) 6, 9, 10-12 should not be considered for a new type Standard. The Member also shared concerns that scaling challenges for small engines require consideration of their particular issues in the selection of the stringencies, to ensure technical feasibility. The Member proposed that selecting a stringency level for the new type nvPM mass and number Standard should take into account interdependencies, and should be technologically feasible, economically reasonable and environmentally beneficial across a full range of engine rated thrusts. The meeting acknowledged the concerns raised by the Member regarding scaling challenges for small engines.

3.2.14 A Member suggested that for new type engines the limit lines should be selected in accordance with the CAEP Terms of Reference based on the results of the analysis. The Member supported the anti-backsliding in-production limit lines for nvPM mass and number with an applicability date of 1 January 2023. The Member noted that the preferable stringencies for mass would be 3 and 4, and the number stringencies would be 1 and 2. The Member supported ending the applicability of the SN

SARPs for engines with rated thrust > 26.7 kN to reflect the new in-production nvPM emissions Standard.

3.2.15 An Observer commented that the stringency options 4 and beyond were not cost effective and were highly likely to result in additional costs of USD 5 to 10 billion to the industry.

3.2.16 An Observer supported the adoption of LTO-based nvPM mass and number emissions SARPs for in-production and new type aircraft engines. The Observer supported the proposed limit lines for nvPM mass and number for in-production engines, with an applicability date of 1 January 2023, and supported ending the applicability of the existing SN SARPs from 1 January 2023.

3.2.17 A Member and an Observer underlined the proposed new nvPM emissions SARPs should not be used as a basis to restrict the growth of civil aviation, such as imposing operating restrictions or levying emission charges. The Observer also noted that the most challenging stringency options, 10 to 12 for the new technology aircraft, do not meet the technological feasibility requirement.

3.2.18 Another Observer objected and clarified that although the observer agrees that in principle the objective of developing SARPs is not to impose operation restrictions or levy charges, the observer's view is that both charges and operation restrictions may be necessary to address constraints from airports in terms of their ability to continue operating and meeting the required demand of air transport, in accordance with policies established by ICAO Doc 9082, particularly regarding Section II, paragraph 9.

3.2.19 Two Observers shared their views on the nvPM mass and number stringencies, underlining that for the SOs 10 to 12 analysis results, market forces overwhelm the technology responses, thus giving unreliable results. The Observers expressed concerns on technological feasibility of NI3 and that as a result, selection of a limit line beyond SO3 would represent high risks for manufacturers.

3.2.20 Following the comments from the two Observers, one Member asked why other stringency options were considered as not technologically feasible or economically reasonable, given that they had been agreed by WG3 to be part of the stringency analysis. The Observers clarified that due to variability and uncertainty in the analysis, initially they had requested to exclude several stringency options during the WG3 process, while commenting that the manufacturers require time to reach the higher stringency options from a technical perspective. The WG3 co-Rapporteurs clarified that additional uncertainty had been added to the analysis lines to preserve variability. The Observers noted that the cost-effectiveness results should not be reviewed in isolation – cumulative costs and trade-offs with other emissions and fuel burn/CO_2 must also be considered and this would be the challenge for the industry.

3.2.21 An Observer acknowledged and appreciated the work completed by all stakeholders in support of a CAEP/11 decision, and supported the development of ICAO's nvPM Standard and the "anti-backsliding" limit line for in-production aircraft as proposed by WG3 with an applicability date of 1 January 2023. The Observer proposed that SO12 should be selected for the CAEP/11 new type nvPM Standard with an applicability date of 1 January 2023.

Discussion and Conclusions

3.2.22 Several Members and Observers highlighted their support of the approval of the LTO-based nvPM mass and number SARPs and associated guidance material.

3.2.23 Several Members and an Observer noted that, according to the previous experience with the NOx Standard, industry requires a reasonable time in order to meet the new requirements. A Member and an Observer acknowledged that even minimal SOs would have a positive effect, while giving industry time for adaptation. One Member supported SOs 1 to 9, proposing that it would initially be reasonable to accept a lower option with a possibility to switch to a higher option at a later date.

3.2.24 The meeting agreed on 1 January 2023 as the end date for the applicability of the SN SARPs for engines of a rated thrust > 26.7 kN, as proposed by WG3. The meeting also agreed to the WG3 proposal for an anti-backsliding in-production nvPM emissions Standard, which included recently submitted measurement data.

3.2.25 An Observer noted that the process of inclusion of the late data from the Russian Federation and subsequent revision of the in-production limit line endorsed by the CAEP 2017 Steering Group meeting, was inconsistent with the procedure used to analyse all other submitted nvPM data. It was clarified that following the data submission to CAEP, the CAEP Members were consulted, WG3 performed an analysis and agreed on a revision to the proposed in-production limit line. The purpose was to preserve consistency and transparency in CAEP, and the meeting noted that while this practice was unusual, the process was adapted due to time constraints.

3.2.26 An Observer urged CAEP to exercise caution in the evaluation of stringency options for new type engines and expressed concerns related to potential trade-offs with fuel efficiency and NOx emissions, as well as the importance of not undermining the adaptability and flexibility in fleet choices. Several Observers also expressed concerns on trade-offs risks with NOx, CO and HC as well as CO_2, when setting the nvPM mass and number Standards, and noted the lack of ambient condition corrections and the differences in nvPM number measurement equipment when setting the nvPM number Standards.

3.2.27 The meeting agreed to exercise caution in the selection of the stringency option for the new type nvPM SARPs, and further agreed that new type nvPM SARPs should be based on a stringency level which takes into account interdependencies, is technologically feasible, economically reasonable and environmentally beneficial across a full range of engine rated thrusts. The meeting also agreed to consider the risk of trade-offs with NOx, CO and HC, as well as CO_2, the lack of ambient condition corrections and the differences in nvPM number measurement equipment, in evaluating stringency options as part of the nvPM mass and number Standard-setting process.

3.2.28 Following a discussion on the possible use of the new nvPM SARPs for operating restrictions, an Observer proposed that CAEP reiterate the principle that ICAO's environmental Standards are not intended to introduce or serve as the basis for operating restrictions or levies, but have been adopted for certification purposes only. One Observer reiterated their objection as described in section 3.2.18. The Observer also urged consistency between ICAO policies and highlighted that previous recommendations from CAEP/10 on the intention of the CO_2 Standard was not based on a local air quality emissions Standard. The Observer replied that the wording was not intended to contradict or question the policies in Doc 9082 and explained that the recognition of the principle would ensure continued support for the adoption of ICAO certification Standards. The meeting agreed that the operating restrictions and charges would be discussed further at a later point during the meeting.

3.2.29 The meeting acknowledged the large body of work carried out by WG3 in the development of nvPM SARPs, and noted the technical contributions of SAE E-31 in this work.

3.3 AGREEMENT ON NEW nvPM MASS AND NUMBER SARPs

3.3.1 The Members and Observers shared their views on the acceptable stringency options (SOs) related to the new type nvPM mass and number SARPs.

3.3.2 Several Members and Observers stated that in their papers they had suggested the exclusion of SOs from consideration and not necessarily the preferred SOs. The meeting then discussed and agreed to eliminate SOs 10 to 12 from consideration. A Member commented that only SOs 2 to 9 should be considered.

3.3.3 A Member stated a preference for some alleviation for small engines with less than 50 kN thrust and that SO2 would represent an appropriate level.

3.3.4 Several Members considered as the optimum nvPM number stringency 2 and nvPM mass stringencies 2 to 3 that would yield a result between SO3 and SO5, highlighting that should a lower stringency option be chosen, then an earlier applicability of 2023 would be appropriate. This would give a result close to SO5, with costs only slightly higher than those of SO3. Should these options be chosen, then the Members supported an earlier review of the new type Standard in 2025. Another Member suggested that if lower SOs were selected, then CAEP should commit to reviewing the nvPM SARPs no later than 2028 for substantially higher mass and number SOs.

3.3.5 Several Members commented that engines with thrust below 150kN should be granted some alleviation due to scaling constraints that affect the implementation of the low emission technologies for these sizes of engines.

3.3.6 Several Members asked to remove from consideration SOs associated with the number stringency 3 (i.e. SO6 and SO9). One Member supported SO8, which would remain the most stringent of the options left, noting that some alleviation in stringency may be possible for engines with rated thrust less than 150 kN. Another Member commented that, in his opinion, SO8 and SO9 did not fulfil the CAEP Terms of Reference.

3.3.7 Several Members shared concerns on whether an earlier applicability date would be feasible (i.e. 2023 instead of 2025), since sufficient time would still be required for inclusion of the new nvPM SARPs into the legislative frameworks of ICAO Member States.

3.3.8 A Member further commented that the nvPM limit line should be set at an SO beyond SO3, and preferably SO5. Another Member added their preference to consider only SOs 1 to 5 in the standard-setting process.

3.3.9 One Member proposed SO3, with an applicability date of 2025.

Discussion and Conclusions

3.3.10 The meeting discussed the available options for a new type nvPM mass and number Standard and following consideration of all the various viewpoints on SOs and applicability dates, the meeting agreed on new type nvPM mass and number SARPs. This included limit lines for nvPM mass and number[1], that would be applied to new engine types from 1 January 2023, providing some alleviation for engines with rated thrusts below 150 kN. As agreed earlier in the meeting, these new type SARPs would be accompanied by an in-production Standard for nvPM mass and number, with an applicability date of 1 January 2023. The meeting agreed to the amendments to Annex 16, Volume II as presented in Appendix A to this agenda item. The meeting also agreed to amendments to the ETM, Volume II, as contained in the report from the working group, in order to include elements that would facilitate the implementation of the new nvPM mass and number SARPs. The recommendations on the new nvPM mass and number SARPs for Annex 16, Volume II and associated guidance in the ETM, Volume II, along with the collation of all other Annex 16, Volume II and ETM, Volume II amendments agreed at CAEP/11, are contained in section 3.5 of this report.

3.3.11 This agreement on a new nvPM mass and number Standard was accompanied with the agreement for an early review of the regulatory levels. The meeting agreed that this will involve the collation and analysis of the certified and certification-like nvPM mass and number emissions data that becomes available for all in-production engines during the period 2019 to 2022. The meeting also agreed to review the margins to the agreed CAEP/11 new type nvPM mass and number Standards and to assess possible technological advancements to reduce nvPM emissions. It was agreed that a recommendation will be provided from WG3 to CAEP/12 to inform the need to update nvPM engine emissions Standards. If agreed at CAEP/12, a Standard-setting process will be performed during CAEP/13 to consider revised nvPM mass and number SARPs.

3.3.12 While agreeing to the new nvPM mass and number SARPs, two Members expressed reservations regarding the early applicability date (of 2023) as this would require significant efforts to update the States' regulatory frameworks in a timely manner.

3.3.13 A Member, reflecting the sentiment of the meeting, congratulated CAEP Members on successfully agreeing these new nvPM mass and number SARPs. In commending these new SARPs and ground breaking achievement, the Member highlighted that this now meant that the final component of aircraft environmental certification had been agreed, closing the full circle on noise, local air quality and CO_2 Standards for subsonic aeroplanes. This new Standard would lead to nvPM emissions reductions from international aviation in the coming years.

3.4 SUPERSONIC ENGINE EMISSIONS STANDARD

3.4.1 The co-Rapporteurs of WG3 presented an overview of the work on supersonic transport (SST) engine emissions SARPs. As a result of this work, WG3 concluded that there was insufficient technical information currently available to recommend changes to Annex 16, Volume II, Chapter 3. In addition, there was also no consensus in WG3 to repeal the current applicability requirements. However, WG3 did conclude that the subsonic LTO cycle as currently defined in Chapters 2 and 4 was considered a reasonable starting point for future work. WG3 recognized that additional SST engine emissions data would be useful to guide potential updates to the SARPs in the near-term and WG3 proposed amendments to the ETM, Volume II in order to highlight that engine manufacturers may voluntarily collect a broader set of emissions data spanning Chapters 2, 3, and 4, which could be made available to ICAO/CAEP WG3 to inform potential updates to SST engine emissions SARPs. It was highlighted that data on gaseous, nvPM, and smoke emissions, for SST engines without afterburners, would only be collected.

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[1] For information only, in the context of the proposed SOs, the agreed limit lines are equivalent to nvPM mass stringency 2.8 and nvPM number stringency 2 for engines with rated thrust greater than 150kN.

3.4.2 Several Members thanked WG3 and supported the important progress made towards the update of the SST emission SARPs. A Member and an Observer asked which data would be required to further progress the work, and when this data was expected to be received. The WG3 co-Rapporteurs clarified that WG3 requires manufacturers' data from mature SST engine projects, based on real measurements, as early as possible. One Member expressed support for the report of WG3 and shared the view that further assessment on data correction is needed to develop SST emission SARPs, taking into account technology advancements.

3.4.3 Several Members and an Observer shared their views on SST emission Standards supporting the approach proposed by WG3, noting their view on the need for a CO_2 Standard for new SST aeroplane types, and proposed that this item be included in the work programme for the next CAEP cycle. The Members and the Observer proposed approaching the SST Standards under consideration as a package, and to add a Note to Annex 16, Volume II, Chapter 3, to clarify that the chapter is considered outdated.

3.4.4 An Observer supported the views expressed by the Members and the Observer. Another Observer inquired whether there was an interim process to start gathering data, given that the proposal on the CO_2 Standard for new SST aeroplane types would require sufficient time. The Member replied that more time is needed, as well as the manufacturer data, and that there was no approved schedule for the work. Another Observer noted that due to lack of data, it was premature to make a decision on a CO_2 Standard for new SST aeroplane types.

3.4.5 Several Members objected to considering SST SARPs as a package, as such an approach would not facilitate the process of Standard development.

3.4.6 A Member expressed a concern regarding the proposal to include an additional Note in Annex 16, Volume II, Chapter 3, due to inconsistency with the State's legislation. Several Members supported this view, sharing their concerns that an additional Note would neither provide clarity to the aviation authorities, nor would it have any regulatory effect.

3.4.7 The meeting recognized that new SST aeroplane engine projects were not yet sufficiently mature to yield the necessary data to inform amendments of Annex 16, Volume II, Chapter 3 at CAEP/11. However, the meeting noted the need to continue to work on updating the SST engine emissions requirements in Annex 16, Volume II by CAEP/12.

3.4.8 A Member shared views on supersonic engine emissions and emphasized the need for technical data from sufficiently mature civil supersonic engine programmes in order to update supersonic engine emissions SARPs, with the highest confidence. The Member also noted that the work to create the existing Annex 16, Volume II, Chapter 3, specifically in regard to afterburning engine applicability, should not be discarded as WG3 endeavours to revise the Standards for the anticipated non-afterburning supersonic engines. Another Member supported these views on supersonic engine emissions.

3.4.9 Responding to a question regarding the differences between the noise and emissions SARPs development, a Member clarified that, differently for engine emissions certification, there is not currently a noise certification Standard applicable to new supersonic aircraft in his State.

3.4.10 An Observer shared views on the introduction of supersonic aircraft into the global fleet, and proposed that this must not lead to a net increase in total noise, air pollution, or CO_2 emissions from aviation, compared to a baseline of subsonic aircraft only. The Observer proposed that CAEP should develop new SARPs for supersonic aircraft and engines in a deliberate, data-driven manner, and that until sufficient data was available, the latest subsonic Standards should apply to new supersonic designs.

3.4.11 One Member noted that the concept of "no net increase" in environmental parameters was never used in CAEP processes, and asked how this would be applied in other CAEP Standard-setting processes. The Observer acknowledged that, even if supersonics were to comply with current subsonic aircraft Standards, there remained a possibility of a net increase of environmental parameters at a global level. Over and above the Standard-setting process the Observer argued that ICAO's environmental activities should aim to avoid the possibility of such a net increase.

3.4.12 One Observer noted that given the fundamental technical differences between supersonics and subsonic aeroplanes, applying the same Standards for subsonic and supersonic engines would not be in line with the CAEP Terms of Reference. The Observer supported further work to assess the noise and emission impact of supersonics, but cautioned that this assessment could differ from traditional CAEP cost-effectiveness analyses, due to the specificities of the supersonic aircraft market.

3.4.13 The CAEP Secretary noted that the traditional CAEP Standard-setting processes were typically supported by measured data, gathered from real operating fleets, and questioned whether this approach should be adjusted for future SARP-development processes to consider other types of data, keeping in mind the new aircraft designs under development, such as hybrid and electric aircraft. The Observer noted that CAEP should consider possible ways to develop Standards for these new designs in a manner that is not selective with respect to aircraft type or pollutants, so that the same principles in terms of technological feasibility are applied uniformly.

Discussion and conclusions

3.4.14 The meeting agreed to retain and revise Annex 16, Volume II, Chapter 3 as part of the CAEP/12 work programme. The meeting also noted the concerns raised on the consideration of the existing Annex 16, Volume II, Chapter 3, with respect to afterburning engine applicability.

3.4.15 In order to highlight that engine manufacturers may voluntarily collect a broader set of emissions data spanning Chapters 2, 3, and 4, which could be made available to ICAO/CAEP WG3 to inform potential updates to SST engine emissions SARPs, the meeting agreed to amend the ETM, Volume II to include the following text: "*Based on work in ICAO, it is recognized that additional supersonic engine emissions data would be helpful to inform potential updates to the supersonic engine emissions Standards in Annex 16, Volume II, Part III, Chapter 3. It is highlighted that engine manufacturers may voluntarily measure and report engine emissions according to the Chapters 2 and 4 subsonic LTO cycle. The engine manufacturer is encouraged to offer the broader set of emissions data spanning Chapters 2, 3 and 4 to support discussions in ICAO/CAEP for the purpose of updating the supersonic engine emissions Standards in Annex 16, Volume II, Part III, Chapter 3.*"

3.4.16 The meeting noted an Observer's position that the introduction of supersonic aircraft into the global fleet must not lead to a net increase in total noise, air pollution, or CO_2 emissions from aviation, compared to a baseline for subsonic aircraft only.

3.4.17 The meeting agreed that the development of SST environmental Standards should be pursued in parallel by CAEP, but did not agree that SST environmental Standards should be considered as a package.

3.4.18 Responding to a question, the WG3 co-Rapporteurs clarified that the WG3 proposal for further work on supersonic engine Standards is generic, as it is unclear what data would be available. The meeting agreed to discuss this further under Agenda Item 12 on future work.

3.4.19 Regarding a question for clarification that the CAEP Terms of Reference did not contain any specific reference to a type of aircraft, the CAEP Secretary replied that at present, although there were no mature supersonic projects with full data available, as new aircraft types with novel technologies on-board came to fruition, work on an appropriate and applicable process for Standard-setting could be developed for them, highlighting that CAEP may need to be flexible in the future to deal with the high pace of technology development.

3.4.20 Several Members and an Observer noted that SST operating modes were expected to be significantly different from their subsonic counterparts. The meeting considered whether it would be reasonable to apply current subsonic SARPs to new SST engine types.

3.4.21 One Member raised a proposal for future work on CO_2-related subsonic aeroplane SARPs and the meeting agreed that this would be considered under Agenda Item 12 on future work.

3.5 PROPOSED AMENDMENTS TO ANNEX 16, VOLUME II AND ETM (DOC 9501), VOLUME II

3.5.1 The WG3 co-Rapporteurs presented the report on the proposed amendment to Annex 16, Volume II and the proposed amendment to ICAO Doc 9501, *Environmental Technical Manual*, Volume II – *Procedures for Emissions Certification of Aircraft Engines*. These changes include, amongst others, applicability date language for new engines, flow rate specifications and conditions, and exemptions for production engines.

3.5.2 The meeting thanked WG3 for the hard work in keeping the ICAO SARPs on engine emissions up to date and approved the amendments as contained in Appendix A to this agenda item.

3.5.3 The meeting also approved the amendments to the ETM, Volume II as contained in the reports of the Working Group.

3.5.4 The meeting developed the following recommendation to reflect the agreed amendments for Annex 16, Volume II in sections 3.3.10 (the new nvPM mass and number emissions SARPs) and 3.5.2 (other amendments) of the meeting report:

RSPP **Recommendation 3/1 — Amendments to Annex 16 — *Environmental Protection*, Volume II — *Aircraft Engine Emissions***

That Annex 16, Volume II be amended as indicated in Appendix A to the report on this agenda item.

Recommendation 3/2 — Use of the nvPM Standard

Recognize that the nvPM emissions certification Standards are a technical comparison of aviation technologies designed for use in nvPM emissions certification processes, and are not designed to serve as a basis for operating restrictions or emissions levies.

3.5.5 The meeting also developed the following recommendation to reflect the agreed amendments for the ETM, Volume II in sections 3.3.10 (the new nvPM mass and number emissions SARPs), 3.4.15 (supersonics) and 3.5.3 (other amendments):

Recommendation 3/3 — Amendments to the *Environmental Technical Manual*, Volume II — *Procedures for the Emissions Certification of Aircraft Engines*

That the Environmental Technical Manual, Volume II be amended and published, and that revised versions approved by subsequent CAEP Steering Groups be made available, free of charge, on the CAEP website.

3.6 PROPOSED AMENDMENTS TO ANNEX 16, VOLUME III AND ETM (DOC 9501), VOLUME III

3.6.1 The co-Rapporteurs of WG3 presented the report on the proposed amendments to Annex 16, Volume III and the corresponding amendments to ICAO Doc 9501, *Environmental Technical Manual*, Volume III – *Procedures for the CO_2 Emissions Certification of Aeroplanes*. These changes include, amongst others, improvements for definitions, reference condition specification, clarifications for exemption issuing authority and applicability for CO_2-certified derived versions.

3.6.2 The meeting agreed with the WG3 proposed amendments to Annex 16, Volume III as shown in Appendix B to the report on this agenda item and the corresponding ETM, Volume III, as shown in the report of the working group.

3.6.3 Recommendations

3.6.3.1 In light of the foregoing discussion, the meeting developed the following recommendations:

RSPP **Recommendation 3/4 — Amendments to Annex 16 — *Environmental Protection*, Volume III — *Aeroplane CO_2 Emissions***

That Annex 16, Volume III be amended as indicated in Appendix B to the report on this agenda item.

Recommendation 3/5 — Amendments to the *Environmental Technical Manual*, Volume III — *Procedures for the CO_2 Emissions Certification of Aeroplanes*

That the Environmental Technical Manual, Volume III be amended and published, and that revised versions approved by subsequent CAEP Steering Groups be made available, free of charge, on the CAEP website.

3.7 PROPOSED AMENDMENTS TO DOC 9889

3.7.1 The co-Rapporteurs of WG3 presented the report on the proposed amendments to ICAO Doc 9889, *Airport Air Quality Manual*. The amendments relate to the update of information related to aircraft PM emissions (mass and number), both with actual sample engine data, and with a recommended calculation methodology. Information was provided for both aircraft main engines, as well as for auxiliary power units (APU). Doc 9889 was also reviewed for consistency regarding particle mass and number considerations.

3.7.2 A Member and an Observer expressed appreciation to WG3 for a remarkable achievement and noted that this update to Doc 9889 would be required by the sector to be published as soon as possible and preferably free of charge. The meeting agreed to the proposed WG3 updates to Doc 9889.

3.7.3 Recommendations

3.7.3.1 In light of the foregoing discussion, the meeting developed the following recommendations:

Recommendation 3/6 — Amendments to ICAO Doc 9889 - *Airport Air Quality Manual*

That the updated ICAO Doc 9889, *Airport Air Quality Manual* be published as soon as possible.

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APPENDIX A

PROPOSED AMENDMENTS TO ANNEX 16, VOLUME II

The text of the amendment is arranged to show deleted text with a line through it and new text highlighted with grey shading, as shown below:

1. ~~Text to be deleted is shown with a line through it.~~	text to be deleted
2. New text to be inserted is highlighted with grey shading	new text to be inserted
3. ~~Text to be deleted is shown with a line through it~~ followed by the replacement text which is highlighted with grey shading.	new text to replace existing text

TEXT OF PROPOSED AMENDMENTS TO THE

INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES

ENVIRONMENTAL PROTECTION

ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME II
AIRCRAFT ENGINE EMISSIONS

…

PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. DEFINITIONS

…

Smoke Number. The dimensionless term quantifying smoke emissions (*see* 3 of Appendix 2).

State of Design. The State having jurisdiction over the organization responsible for the type design.

Take-off phase. The operating phase defined by the time during which the engine is operated at the rated thrust.

Taxi/ground idle. The operating phases involving taxi and idle between the initial starting of the ***propulsion*** engine(s) and the initiation of the take-off roll and between the time of runway turn-off and final shutdown of all propulsion engine(s).

Type Certificate. A document issued by a Contracting State to define the design of an aircraft, engine or propeller type and to certify that this design meets the appropriate airworthiness requirements of that State.

Note 1.— In some Contracting States a document equivalent to a Type Certificate may be issued for an engine or propeller type.

Note 2.— In some Contracting States the Type Certificate may also certify that the design meets the appropriate aircraft engine emissions requirements of that State.

Unburned hydrocarbons. The ***total*** of hydrocarbon compounds of all classes and molecular weights contained in a gas sample, calculated as if they were in the form of methane.

…

PART III. EMISSIONS CERTIFICATION

CHAPTER 1. ADMINISTRATION

...

1.3 The document attesting emissions certification for each individual engine shall include at least the following information which is applicable to the engine type:

a) name of certificating authority;

b) manufacturers type and model designation;

c) statement of any additional modifications incorporated for the purpose of compliance with the applicable emissions certification requirements;

d) rated thrust;

e) reference pressure ratio;

f) a statement indicating compliance with Smoke Number requirements;

g) a statement indicating compliance with gaseous pollutant requirements~~.~~ ;

h) a statement indicating compliance with particulate matter requirements.

1.4 Contracting States shall recognize as valid emissions certification granted by the certificating authority of another Contracting State provided that the requirements under which such certification was granted are not less stringent than the provisions of Volume II of this Annex.

…

1.5 Contracting States shall recognize as valid engine exemptions ~~for an engine production cut-off requirement~~ granted by ~~a certificating~~ the competent authority of another Contracting State which is responsible for the production organisation of the engine provided that ~~the exemptions are granted in accordance with the process and criteria defined in the *Environmental Technical Manual* (Doc 9501),Volume II — *Procedures for the Emissions Certification of Aircraft Engines*~~an acceptable process was used.

Note. – Guidance on acceptable processes and criteria for granting exemptions is provided in the Environmental Technical Manual (Doc 9501), Volume II — Procedures for the Emissions Certification of Aircraft Engines.

1.6 Unless otherwise specified in this volume of the Annex, the date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date when the application for a Type Certificate for engines of a type or model was submitted to the State of Design, or the date of submission under an equivalent application procedure prescribed by the certificating authority of the State of Design.

1.7 An application for a Type Certificate for engines of a type or model shall be effective for the period specified in the designation of the airworthiness regulations appropriate to the engine of a type or model, except in special cases where the certificating authority accepts an extension of this period. When this period of effectivity is exceeded and an extension is approved, the date to be used in determining the applicability of the Standards in this Annex shall be the date of issue of the Type Certificate or approval of the change in the type design, or the date of issue of approval under an equivalent procedure prescribed by the State of Design, less the period of effectivity.

CHAPTER 2. TURBOJET AND TURBOFAN ENGINES INTENDED FOR PROPULSION ONLY AT SUBSONIC SPEEDS

2.1 General

2.1.1 Applicability

2.1.1.1 The provisions of this chapter shall apply to all turbojet and turbofan engines, as further specified in 2.2 and 2.3, intended for propulsion only at subsonic speeds, except when the certificating ~~authorities~~ authority or the competent authority responsible for the production organisation of the engines ~~make~~ grants exemptions for:

a) specific engine types and derivative versions of such engines for which the type certificate of the first basic type was issued or other equivalent prescribed procedure was carried out before 1 January 1965; ~~and~~

b) a limited number of engines over a specific period of time beyond the dates of applicability specified in 2.2 and 2.3 for the manufacture of the individual engine.

2.1.1.2 In such cases, an exemption document shall be issued by the certificating authority or the competent authority responsible for the production organisation of the engine, the identification plates on the engines shall be marked "EXEMPT ~~NEW" or "EXEMPT SPARE~~" and the grant of exemption shall be noted in the permanent engine record. The certificating authority or the competent authority responsible for the production organisation of the engines shall take into account the numbers of exempted engines that will be produced and their impact on the environment. Exemptions shall be reported by engine serial number and made available via an official public register.

Recommendation.- *When such an exemption is granted, the certificating authority or the competent authorities responsible for the production organisation of the engines should consider imposing a time limit on the production of such engines.*

~~2.1.1.3 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines.~~

Note.— ~~In considering exemptions, certificating authorities should take into account the probable numbers of such engines that will be produced and their impact on the environment. When such an exemption is granted, the certificating authority should consider imposing a time limit on the production of such engines for installation on new aircraft.~~ Further guidance on issuing exemptions is provided in *the* Environmental Technical Manual *(Doc 9501), Volume II* — Procedures for the Emissions Certification of Aircraft Engines.

2.1.1.3 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines and which are designed as an integrated propulsive power plant and certified with a rated thrust.

Note.— Guidance material is provided in the Environmental Technical Manual (Doc 9501), Volume II — Procedures for the Emissions Certification of Aircraft Engines

…

2.1.4 Reference conditions

2.1.4.1 *Atmospheric conditions*

The reference atmospheric conditions shall be ISA at sea level except that the reference ~~absolute~~ humidity shall be 0.00634 kg water/kg dry air.

2.1.4.2 *Thrust settings*

…

2.2 Smoke

2.2.1 Applicability

The provisions of 2.2.2 shall apply:

a) to engines whose date of manufacture is on or after 1 January 1983 and before 1 January 2023; and

b) to engines with a maximum rated thrust of less than or equal to 26.7kN whose date of manufacture is on or after 1 January 2023.

2.2.2 Regulatory Smoke Number

The Smoke Number at any of the four LTO operating mode thrust settings when measured and computed in accordance with the procedures of Appendix 2, or equivalent procedures as agreed by the certificating authority, and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the level determined from the following formula:

Regulatory Smoke Number = $83.6\ (F_{oo})^{-0.274}$
or a value of 50, whichever is lower

Note.— Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual *(Doc 9501), Volume II* — Procedures for the Emissions Certification of Aircraft Engines.

2.3 Gaseous emissions

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2.3.2 Regulatory levels

…

e) for engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 2014 and for which an application for a Type Certificate was submitted before 1 January 2023:

1) for engines with a pressure ratio of 30 or less:

i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = 7.88 + 1.4080\pi_{oo}$$

ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\pi_{oo}F_{oo}$$

2) for engines with a pressure ratio of more than 30 but less than 104.7:

i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = -9.88 + 2.0\pi_{oo}$$

ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo}F_{oo}$$

3) for engines with a pressure ratio of 104.7 or more:

$$D_p/F_{oo} = 32 + 1.6\pi_{oo}$$

f) for engines of a type or model for which an application for a Type Certificate was submitted on or after 1 January 2023:

1) for engines with a pressure ratio of 30 or less:

i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = 7.88 + 1.4080\pi_{oo}$$

ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\pi_{oo}F_{oo}$$

2) for engines with a pressure ratio of more than 30 but less than 104.7:

i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p / F_{oo} = -9.88 + 2.0\pi_{oo}$$

ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p / F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} F_{oo}$$

3) for engines with a pressure ratio of 104.7 or more:

$$D_p / F_{oo} = 32 + 1.6\pi_{oo}$$

Note.— Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual *(Doc 9501), Volume II* — Procedures for the Emissions Certification of Aircraft Engines.

2.4 Information required

…

CHAPTER 4. PARTICULATE MATTER EMISSIONS

4.1 General

4.1.1 Applicability

4.1.1.1 The provisions of this chapter shall apply to all aircraft engines, as further specified in 4.2, intended for propulsion only at subsonic speeds~~, for which an application for type certification is submitted to the certificating authority~~.

4.1.1.2 Specific provisions for the relevant engine categories shall apply as detailed in section 4.2 except when the certificating authority or the competent authority responsible for the production organisation of the engines grants exemptions for a limited number of engines over a specific period of time beyond the dates of applicability specified in 4.2 for the manufacture of the individual engine.

4.1.1.3 In such cases, an exemption document shall be issued by the certificating authority or the competent authority responsible for the production organisation of the engine, the identification plates on the engines shall be marked “EXEMPT” and the grant of exemption shall be noted in the permanent engine record. The certificating authority or the competent authority responsible for the production organisation of the engines shall take into account the number of exempted engines that will be produced and their impact on the environment. Exemptions shall be reported by engine serial number and made available via an official public register.

Recommendation.— *When such an exemption is granted, the certificating authority or the competent authorities responsible for the production organisation of the engines should consider imposing a time limit on the production of such engines.*

Note.— Further guidance on issuing exemptions is provided in the Environmental Technical Manual (Doc 9501), Volume II — Procedures for the Emissions Certification of Aircraft Engines.

4.1.2 Emissions involved

The purpose of this section is to control non-volatile particulate matter (nvPM) emissions.

4.1.3 Units of measurement

4.1.3.1 The concentration of nvPM mass ~~($nvPM_{mass}$)~~ shall be measured and reported in ~~μg~~micrograms/m^3.

4.1.3.2 The nvPM mass emitted during the reference emissions landing and take-off (LTO) cycle, defined in 4.1.4.2 (LTO_{mass}), shall be measured and reported in milligrams.

4.1.3.3 The nvPM number emitted during the reference emissions landing and take-off (LTO) cycle, defined in 4.1.4.2 (LTO_{num}), shall be measured and reported in number of particles.

4.1.4 Reference conditions

4.1.4.1 *Atmospheric conditions*

The reference atmospheric conditions for the reference standard engine shall be ISA at sea level except that the reference ~~absolute~~ humidity shall be 0.00634 kg water/kg dry air.

4.1.4.2 *Reference emissions landing and take-off (LTO) cycle*

The engine shall be tested at sufficient thrust settings to define the nvPM emissions of the engine so that nvPM mass emission indices (EI_{mass}) and nvPM number emission indices (EI_{num}) can be determined at ~~the following specific percentages of rated thrust~~ the reference emissions LTO cycle thrust settings and at thrusts producing maximum nvPM~~$_{mass}$~~ mass concentration, maximum EI_{mass} and maximum EI_{num} as agreed by the certificating authority~~:~~.

For the calculation and reporting of nvPM emissions the reference emissions LTO cycle shall be represented by the following thrust setting and time in each following operating mode:

LTO operating mode	*Thrust setting Per cent F_{oo}*	*Time in operating mode Minutes*
Take-off	100 ~~per cent Foo~~	0.7
Climb	85 ~~per cent Foo~~	2.2
Approach	30 ~~per cent Foo~~	4.0
	7 ~~per cent Foo~~	26.0

4.1.4.3 *Fuel specifications*

The fuel used during tests shall meet the specifications of Appendix 4.

4.1.5 Test conditions

4.1.5.1 The tests shall be made with the engine on its test bed.

4.1.5.2 The engine shall be representative of the certificated configuration (see Appendix 6); off-take bleeds and accessory loads other than those necessary for the engine's basic operation shall not be simulated.

4.1.5.3 When test conditions differ from the reference atmospheric conditions in 4.1.4.1, EI_{mass} and EI_{num} shall be corrected to the engine combustor inlet temperature under the reference atmospheric conditions in accordance with the procedures of Appendix 7.

4.1.5.4 The maximum nvPM~~$_{mass}$~~ mass concentration shall be corrected for dilution and thermophoretic losses in the Collection Part of the sampling system in accordance with the procedures of Appendix 7. The~~and~~ EI_{mass} and EI_{num} shall be corrected for thermophoretic losses in the ~~collection part~~Collection Part of the sampling system and fuel composition in accordance with the procedures of Appendix 7.

4.2 Non-Volatile Particulate Matter Emissions

4.2.1 Applicability

4.2.1.1 The provisions further specified in 4.2.2 and 4.2.3 shall apply to all turbofan and turbojet engines of a type or model~~, and their derivative versions,~~ with a rated thrust greater than 26.7 kN ~~and whose date of manufacture of the individual engine is on or after 1 January 2020~~.

4.2.1.2 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines and which are designed as an integrated propulsive power plant and certified with a rated thrust.

4.2.2 Regulatory levels

4.2.2.1 *Maximum nvPM mass concentration*

For an engine whose date of manufacture of the individual engine is on or after 1 January 2020, t~~T~~he maximum nvPM~~$_{mass}$~~ mass concentration ~~[$\mu g/m^3$]~~ obtained from measurement at sufficient thrust settings, in such a way that the emission maximum can be determined, and computed in accordance with the procedures of Appendix 7 and converted to characteristic levels by the procedures of Appendix 6, or equivalent procedures as agreed by the certificating authority, shall not exceed the regulatory level determined from the following formula:

$$\text{Regulatory limit } \sout{\text{concentration}} \text{ of nvPM}_{\sout{mass}} \text{mass concentration} = 10^{(3 + 2.9 F_{oo}^{-0.274})}$$

Note.— Since there is a correlation between nvPM mass concentration and Smoke Number, the regulatory level in §4.2.2.1 was derived from the Smoke Number regulatory level. Further information is provided in the Environmental Technical Manual (Doc 9501), Volume II – Procedure for the Emissions Certification of Aircraft Engines.

4.2.2.2 *nvPM mass and nvPM number emitted during the reference LTO cycle*

The nvPM mass and nvPM number emission levels when measured and computed in accordance with the procedures of Appendix 7 and converted to characteristic levels by the procedures of Appendix 6, or equivalent procedures as agreed by the certificating authority, shall not exceed the regulatory levels determined from the following formulas:

a) LTO_{mass}:

1) for engines of a type or model for which the date of manufacture of the individual engine was on or after 1 January 2023:

i) for engines with a maximum rated thrust of more than 200kN:

$$LTO_{mass}/F_{oo} = 347.5$$

ii) for engines with a maximum rated thrust of more than 26.7kN but not more than 200kN

$$LTO_{mass}/F_{oo} = 4646.9 – 21.497F_{oo}$$

2) for engines of a type or model for which an application for a type certificate was submitted on or after 1 January 2023:

i) for engines with a maximum rated thrust of more than 150kN:

$$LTO_{mass}/F_{oo} = 214.0$$

ii) for engines with a maximum rated thrust of more than 26.7kN but not more than 150kN

$$LTO_{mass}/F_{oo} = 1251.1 – 6.914F_{oo}$$

b) LTO_{num}:

1) for engines of a type or model for which the date of manufacture of the individual engine was on or after 1 January 2023:

i) for engines with a maximum rated thrust of more than 200kN:

$$LTO_{number}/F_{oo} = 4.170 \times 10^{15}$$

ii) for engines with a maximum rated thrust of more than 26.7kN but not more than than 200kN

$$LTO_{number}/F_{oo} = 2.669 \times 10^{16} – 1.126 \times 10^{14} Foo$$

2) for engines of a type or model for which an application for a type certificate was submitted on or after 1 January 2023:

i) for engines with a maximum rated thrust of more than 150kN:

$$LTO_{number}/F_{oo} = 2.780 \times 10^{15}$$

ii) for engines with a maximum rated thrust of more than 26.7kN but not more than 150kN

$$LTO_{number}/F_{oo} = 1.490 \times 10^{16} – 8.080 \times 10^{13} F_{oo}$$

4.2.3 Reporting requirement

The manufacturer shall report the following values of nvPM emissions measured and computed in accordance with the procedures of Appendix 7, or any equivalent procedures as agreed by the certificating authority:

~~a) characteristic level for the maximum $nvPM_{mass}$ concentration (μg/m^3);~~

~~b) fuel flow (kg/s) at each thrust setting of the LTO cycle;~~

~~c) EI_{mass} (mg/kg of fuel) at each thrust setting of the LTO cycle;~~

~~d) EI_{num} (particles/kg of fuel) at each thrust setting of the LTO cycle;~~

~~e~~a) maximum EI_{mass} (~~mg~~milligrams/kg of fuel); and

~~f~~b) maximum EI_{num} (particles/kg of fuel).

4.3 Information required

Note.— The information required is divided into ~~two~~ three groups: 1) general information to identify the engine characteristics, the fuel used and the method of data analysis; ~~and~~ 2) the data obtained from the engine test(s); and 3) derived information.

4.3.1 General information

The following information shall be provided for each engine type for which emissions certification is sought:

a) engine identification;

b) rated thrust (kN);

c) reference pressure ratio;

d) fuel specification reference;

e) fuel hydrogen/carbon ratio;

f) the methods of data acquisition; and

~~g) the method of making corrections for thermophoretic losses in the collection part of the sampling system; and~~

~~h)~~g) the method of data analysis.

4.3.2 Test information

4.3.2.1 The following information shall be provided for each engine tested for certification purposes~~For each test the following information shall be reported~~:

a) fuel net heat of combustion (MJ/kg);

b) fuel hydrogen content (mass %);

c) fuel total aromatics content (volume %);

d) fuel naphthalenes content (volume %); and

e) fuel sulphur content (ppm by mass ~~%~~).

4.3.2.2 The following information as measured and computed in accordance with the procedures of Appendix 7, or any equivalent procedures as agreed by the certificating authority, shall be provided for each engine tested for certification purposes:

a) fuel flow (kg/s) at each thrust setting of the LTO cycle;

b) EI_{mass} (milligrams/kg of fuel) at each thrust setting of the LTO cycle;

c) EI_{num} (particles/kg of fuel) at each thrust setting of the LTO cycle;

4.3.3 Derived Information

4.3.3.1 The following derived information shall be provided for each engine tested for certification purposes:

a) emission rate, i.e. emission index × fuel flow, (milligrams/s) for nvPM mass;

b) emissions rate, i.e. emission index × fuel flow, (particles/s) for nvPM number;

c) total gross emission of nvPM mass measured over the LTO cycle (milligrams);

d) total gross emission of nvPM number measured over the LTO cycle (particles);

e) values of LTO_{mass} / F_{oo} (milligrams/kN);

f) values of LTO_{num} / F_{oo} (particles/kN); and

g) maximum nvPM mass concentration (micrograms/m^3)

4.3.3.2 The characteristic levels shall be provided for the maximum nvPM mass concentration, the LTO_{mass}/F_{oo} and the LTO_{num}/F_{oo} for each engine type for which emissions certification is sought.

PART IV. NON-VOLATILE PARTICULATE MATTER ASSESSMENT FOR INVENTORY AND MODELLING PURPOSES

Note 1.— The purpose of this part is to provide recommendations on how to calculate the nvPM mass and number correction factors for the nvPM system losses other than the collection partCollection Part thermophoretic losses. The nvPM sampling and measurement system, the collection partCollection Part and the thermophoretic losses calculation are described in Appendix 7.

Note 2.— The nvPM mass and number system loss correction factors permit an estimation of the nvPM mass and number emissions at the exhaust of the aircraft engine from the nvPM mass and number concentration obtained in accordance with the procedures of Appendix 7.

For engines of a type or model subject to Part III Chapter 4, and for which the date of manufacture of the individual engine was on or after 1 January 2023, the nvPM mass and nvPM number system loss correction factors (k_{SL_mass} and k_{SL_number}), and EI_{mass} and EI_{number} corrected for system losses shall be reported to the certificating authority in accordance with the procedures of Appendix 8, or equivalent procedures as agreed by the certificating authority.

Recommendation 1.— *For inventory and modelling purposes, the aircraft turbine engine manufacturers should determine the nvPM mass and nvPM number system loss correction factors (k_{SL_mass} and k_{SL_num}) using the methodology described by Appendix 8 Band should report these factors to the appropriate authority.*

Recommendation 2.— *For inventory and modelling purposes, the nvPM mass and nvPM number concentrationemissions obtained in accordance with the procedures of Appendix 7 should be corrected for system losses using the methodology described in Appendix 8.*

…

APPENDIX 2. SMOKE EMISSION EVALUATION

…

2. MEASUREMENT OF SMOKE EMISSIONS

2.1 Sampling probe for smoke emissions

The sampling probe shall meet the following requirements:

a) The probe material with which the exhaust emission sample is in contact shall be stainless steel or any other non-reactive material.

b) If a sampling probe with multiple sampling orifices is used,:

1) all sampling orifices shall be of equal diameter. ; and

2) Tthe sampling probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices.

c) The number of locations sampled shall not be less than 12.

…

2.3 Smoke analysis system

Note.— The method prescribed herein is based upon the measurement of the reduction in reflectance of a filter when stained by a given mass flow of exhaust sample.

The arrangement of the various components of the system for acquiring the necessary stained filter samples shall be as shown schematically in Figure A2-1. An optional bypass around the volume meter may be installed to facilitate meter reading. The major elements of the system shall meet the following requirements:

…

e) *vacuum pump:* this pump shall have a no-flow vacuum capability of –75 kPa with respect to atmospheric pressure; its full-flow rate shall not be less than ~~28~~26 L/min at ~~normal~~standard temperature and pressure;

…

i) *leak performance:* the subsystem shall meet the requirements of the following test:

1) clamp clean filter material into holder,

2) shut off valve A, fully open valves B, C and D.

3) run vacuum pump for one minute to reach equilibrium conditions;

4) continue to pump and measure the ~~volume~~ flow rate through the meter over a period of five minutes. This ~~volume~~flow rate shall not exceed ~~5~~1 L/min (referred to ~~normal~~standard temperature and pressure) and the system shall not be used until this standard has been achieved.

…

2.5 Smoke measurement procedures

…

2.5.2 Leakage and cleanliness checks

No measurements shall be made until all sample transfer lines and valves are warmed up and stable. Prior to a series of tests the system shall be checked for leakage and cleanliness as follows:

a) *leakage check:* isolate probe and close off end of sample line, perform leakage test as specified in 2.3 h) with the exceptions that valve A is opened and set to “bypass”, valve D is closed and that the leakage limit is ~~2~~0.4 L/min at standard temperature and pressure. Restore probe and line interconnection;

…

APPENDIX 3. INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS

…

5.1 Sampling system

5.1.1 Sampling probe

The sampling probe shall meet the following requirements:

a) The probe material with which the exhaust emission sample is in contact shall be stainless steel or any other non-reactive material.

b) If a sampling probe with multiple sampling orifices is used,:

1) all sampling orifices shall be of equal diameter. ; and

2) Tthe sampling probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices.

c) The number of locations sampled shall not be less than 12.

…

6.3 Operation

6.3.1 No measurements shall be made until all instruments and sample transfer lines are warmed up and stable and the following checks have been carried out:

a) leakage check: prior to a series of tests the system shall be checked for leakage by isolating the probe and the analysers, connecting and operating a vacuum pump of equivalent performance to that used in the smoke measurement system to verify that the system leakage flow rate is less than 0.4 L/min referred to normal standard temperature and pressure. The vacuum pump shall have a no-flow vacuum capability of –75 kPa with respect to atmospheric pressure; its full-flow rate shall not be less than 26 L/min at normal temperature and pressure;

b) cleanliness check: isolate the gas sampling system from the probe and connect the end of the sampling line to a source of zero gas. Warm the system up to the operational temperature needed to perform hydrocarbon measurements. Operate the sample flow pump and set the flow rate to that used during engine emission testing. Record the hydrocarbon analyser reading. The reading shall not exceed 1 per cent of the engine idle emission level or 1 ppm (both expressed as methane), whichever is the greater.

…

APPENDIX 4. SPECIFICATION FOR FUEL TO BE USED IN AIRCRAFT TURBINE ENGINE EMISSION TESTING

The fuel shall meet the specifications of this appendix, unless a deviation and any necessary corrections have been agreed upon by the certificating authority. Additives used for the purpose of smoke suppression (such as organometallic compounds) shall not be present.

Property	*Allowable range of values*
Density kg/m^3 at 15°C	780 – 820
Distillation temperature, °C	
10% boiling point	155 – 201
Final boiling point	235 – 285
Net heat of combustion, MJ/kg	42.86 – 43.50
Aromatics, volume %	15 – 23
Naphthalenes, volume %	0.0 – 3.0
Smoke point, mm	20 – 28
Hydrogen, mass %	13.4 – 14.3
Sulphur, ppm by mass ~~%~~	less than ~~0.~~3000
Kinematic viscosity at –20°C, mm^2/s	2.5 – 6.5

…

APPENDIX 6. COMPLIANCE PROCEDURE FOR GASEOUS EMISSIONS, SMOKE AND PARTICULATE MATTER EMISSIONS

1. GENERAL

…

2. COMPLIANCE PROCEDURES

2.1 Gaseous emissions and Smoke Number

The certificating authority shall award a certificate of compliance if the mean of the values measured and corrected (to the reference standard engine and reference atmospheric conditions) for all the engines tested, when converted to a characteristic level using the appropriate factor which is determined by the number of engines tested (i) as shown in Table A6-1, does not exceed the regulatory level.

Note.— The characteristic level of the Smoke Number or gaseous emissions is the mean of the values of all the engines tested, and, for gaseous emissions only, appropriately corrected to the reference standard engine and reference atmospheric conditions, divided by the coefficient corresponding to the number of engines tested, as shown in Table A6-1.

Table A6-1. Coefficients to determine characteristic levels

Number of engines tested (i)	*CO*	*HC*	*NOx*	*SN*	*nvPM mass concentration*	*nvPM LTO mass*	*nvPM LTO number*
1	0.814 7	0.649 3	0.862 7	0.776 9	0.776 9	0.719 4	0.719 4
2	0.877 7	0.768 5	0.909 4	0.852 7	0.852 7	0.814 8	0.814 8
3	0.924 6	0.857 2	0.944 1	0.909 1	0.909 1	0.885 8	0.885 8
4	0.934 7	0.876 4	0.951 6	0.921 3	0.921 3	0.901 1	0.901 1
5	0.941 6	0.889 4	0.956 7	0.929 6	0.929 6	0.911 6	0.911 6
6	0.946 7	0.899 0	0.960 5	0.935 8	0.935 8	0.919 3	0.919 3
7	0.950 6	0.906 5	0.963 4	0.940 5	0.940 5	0.925 2	0.925 2
8	0.953 8	0.912 6	0.965 8	0.944 4	0.944 4	0.930 1	0.930 1
9	0.956 5	0.917 6	0.967 7	0.947 6	0.947 6	0.934 1	0.934 1
10	0.958 7	0.921 8	0.969 4	0.950 2	0.950 2	0.937 5	0.937 5
more than 10	$1-\frac{0.130\,59}{\sqrt{i}}$	$1-\frac{0.247\,24}{\sqrt{i}}$	$1-\frac{0.096\,78}{\sqrt{i}}$	$1-\frac{0.157\,36}{\sqrt{i}}$	$1-\frac{0.157\,36}{\sqrt{i}}$	$1-\frac{0.197\,78}{\sqrt{i}}$	$1-\frac{0.197\,78}{\sqrt{i}}$

2.2 Particulate matter emissions

2.2.1 The certificating authority shall award a certificate of compliance if the mean of the values of the maximum nvPM mass concentration measured and corrected for thermophoretic losses in the ~~collection part~~Collection Part of the sampling system for all the engines tested, when converted to a characteristic level using the appropriate factor which is determined by the number of engines tested (i) as shown in Table A6-1, does not exceed the regulatory level.

Note.— The characteristic level of the maximum nvPM mass concentration is the mean of the maximum values of all the engines tested, and appropriately corrected for the thermophoretic losses in the ~~collection part~~Collection Part *of the sampling system, divided by the coefficient corresponding to the number of engines tested, as shown in Table A6-1.*

2.2.2 The certificating authority shall award a certificate of compliance if the mean of the values of the nvPM mass and the mean of the values of the nvPM number emissions measured and corrected for thermophoretic losses in the Collection Part of the sampling system and for fuel composition for all the engines tested, when converted to a characteristic level using the appropriate factor which is determined by the number of engines tested (i) as shown in Table A6-1, does not exceed the regulatory level.

Note.— The characteristic level of the nvPM mass and nvPM number emissions is the mean of the values of all the engines tested, and appropriately corrected for the thermophoretic losses in the Collection Part of the sampling system *and for fuel composition, divided by the coefficient corresponding to the number of engines tested, as shown in Table A6-1.*

2.3 Characteristic level

The coefficients needed to determine the characteristic levels of engine emissions are given in Table A6-1.

3. PROCEDURE IN THE CASE OF FAILURE

Note.— When a certification test fails, it does not necessarily mean that the engine type does not comply with the requirements, but it may mean that the confidence given to the certificating authority in compliance is not sufficiently high, i.e. less than 90 per cent. Consequently, the manufacturer should be allowed to present additional evidence of engine type compliance.

…

APPENDIX 7. INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR NON-VOLATILE PARTICULATE MATTER EMISSIONS

1. INTRODUCTION

…

2.3 Symbols

…

EI_{mass} nvPM mass emission index corrected for thermophoretic losses and for fuel composition, in mg/kg fuel

EI_{num} nvPM number emission index corrected for thermophoretic losses and for fuel composition, in number/kg fuel

F thrust for the given operating mode

H fuel hydrogen content (mass percentage)

[HC] Mean gas concentration of hydrocarbons in exhaust sample, vol/vol, wet, expressed as carbon

$\eta_{VPR}(D_m)$ Particle penetration fraction of VPR for particles of D_m

k_{fuel_M} fuel composition correction factor for nvPM mass emissions index

k_{fuel_N} fuel composition correction factor for nvPM number emissions index

k_{thermo} Collection ~~part~~Part thermophoretic loss correction factor

…

4. GENERAL ARRANGEMENT OF THE nvPM SAMPLING AND MEASUREMENT SYSTEM

4.1 nvPM sampling and measurement system

…

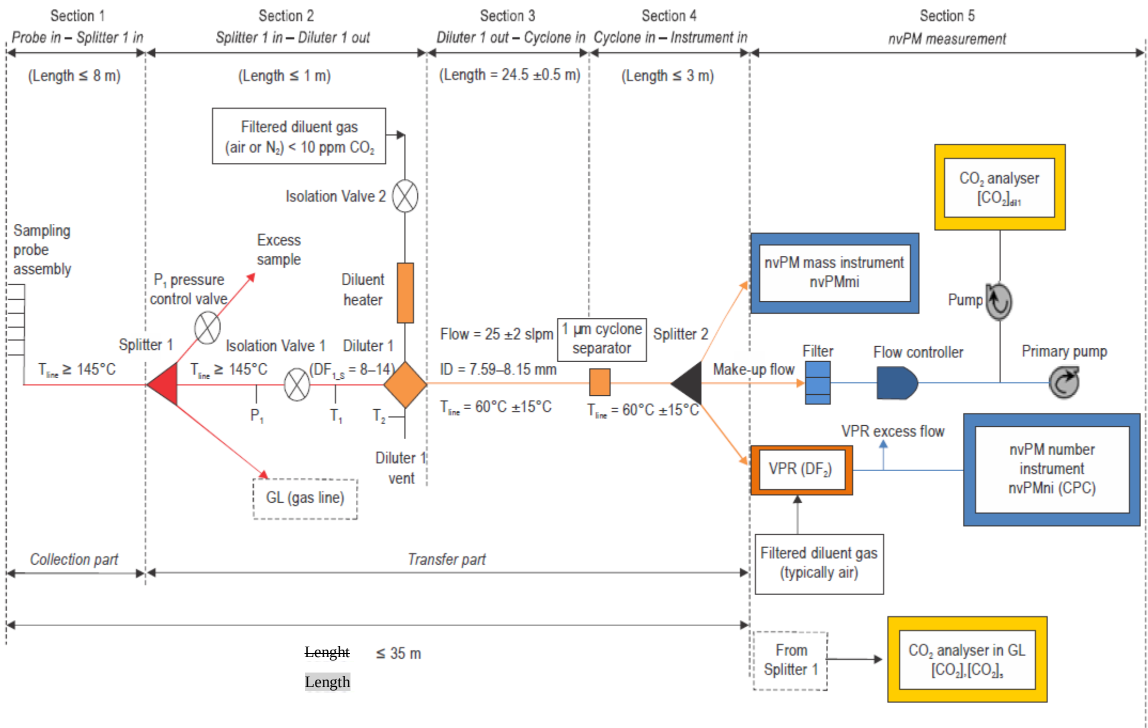

Figure A7-1. Overview schematic of an nvPM sampling and measurement system

…

4.2 Collection part

4.2.1 Section 1 is comprised of the probe/rake hardware and the connection line. It shall meet the following requirements:

a) The sampling probe material shall be stainless steel or any other non-reactive high temperature material.

b) If a sampling probe with multiple sample orifices is used~~,~~:

1) all sampling orifices shall be of equal diameter~~.~~; and

2) ~~T~~the sampling probe design shall be such that at least 80 per cent of the pressure drop through the sampling probe assembly is taken at the orifices.

c) The number of locations sampled shall not be less than 12.

…

6. CALCULATIONS

6.1 nvPM mass concentration and nvPM mass and number emission indices equations

…

6.1.1 nvPM mass concentration

The nvPM mass concentration ($nvPM_{mass}$) represents the mass of particles per unit volume of engine exhaust sample corrected for the first stage dilution factor (DF_1) and the Collection Part thermophoretic particle losses. It is calculated using the following equation:

$$nvPM_{mass} = DF_1 \times nvPM_{mass\_STP} \times k_{thermo}$$

6.1.2 nvPM mass and number emission indices

The nvPM mass and nvPM number emission indices (EI_{mass} and EI_{num}) represent the mass (in milligrams) and number of engine exhaust particles per mass of fuel burned (in kilograms) corrected for their respective dilution factors ~~and~~, the Collection Part thermophoretic particle losses and their respective fuel composition correction factors. They are calculated using the following equations:

$$EI_{mass} = \frac{22.4 \times nvPM_{mass\_STP} \times 10^{-3}}{\left([CO_2]_{dil1} + \frac{1}{DF_1}([CO] - [CO_2]_b + [HC])\right)(M_C + \alpha M_H)} \times k_{thermo} \times k_{fuel\_M}$$

$$EI_{num} = \frac{22.4 \times DF_2 \times nvPM_{num\_STP} \times 10^{6}}{\left([CO_2]_{dil1} + \frac{1}{DF_1}([CO] - [CO_2]_b + [HC])\right)(M_C + \alpha M_H)} \times k_{thermo} \times k_{fuel\_N}$$

$[CO_2]$, $[CO]$ and $[HC]$ shall be calculated as shown in Attachment E to Appendix 3.

…

6.2 Correction factors for nvPM emissions

6.2.1 Correction for nvPM thermophoretic losses in the Collection Part

…

6.2.2 Correction for fuel composition

The correction for fuel composition shall be determined using:

$$k_{fuel\_M} = exp\left\{\left(1.08\frac{F}{F_{00}} - 1.31\right)(13.8 - H)\right\}$$

$$k_{fuel\_N} = exp\left\{\left(0.99\frac{F}{F_{00}} - 1.05\right)(13.8 - H)\right\}$$

…

ATTACHMENT A TO APPENDIX 7. REQUIREMENTS AND RECOMMENDATIONS FOR NVPM SAMPLING SYSTEM

…

4.2 Splitter2

The Splitter2 shall meet the following requirements:

a) The Splitter2 body material shall be stainless steel

b) The Splitter2 shall be heated to 60°C ±15°C.

c) The Splitter2 shall separate the sample into three flow paths to deliver the diluted nvPM sample to:

1) nvPMmi

2) VPR

3) make-up flow

d) The split angles relative to the incoming flow shall be as acute as practical not exceeding 35°.

e) All nvPM flow paths shall be as ~~straight-through and~~ short as practical.

…

ATTACHMENT E TO APPENDIX 7 PROCEDURES FOR SYSTEM OPERATION

1. COLLECTION PART AND GAS LINE LEAKAGE CHECK

1.1 Leakage check procedure

Prior to an engine test series, the Collection Part and the GL shall be checked for leakage using the following procedure:

a) isolate the GL from the nvPM Measurement Part using the Isolation Valve 1, the P1 Pressure Control Valve and, if installed, the optional shut-off valve;

b) isolate the probe and the analysers;

c) connect and operate a vacuum pump to verify the leakage flow rate.

d) The vacuum pump shall have a no-flow vacuum capability of –75 kPa with respect to atmospheric pressure; its full-flow rate shall not be less than ~~28~~26 L/min at ~~normal~~standard temperature and pressure.

1.2 Leakage check requirement

…

2. COLLECTION PART AND GAS LINE CLEANLINESS CHECK

This check is only performed if using the full gaseous nvPM EI calculation method.

2.1 Cleanliness check procedure

The ~~collection part~~Collection Part and GL shall be checked for cleanliness using the following procedure:

a) Isolate the GL from the nvPM measurement part using Isolation Valve 1 and the P1 pressure control valve.

b) Isolate the GL from the probe and connect that end of the sampling line to a source of zero gas.

c) Warm the system up to the operational temperature needed to perform HC measurements.

d) Operate the sample flow pump and set the flow rate to that used during engine emission testing.

e) Record the HC analyser reading.

2.2 Cleanliness check requirement

2.2.1 The HC reading shall not exceed 1 per cent of the engine idle emission level or 1 ppm (both expressed as C), whichever is the greater.

2.2.2 **Recommendation.—** *It is recommended to monitor the inlet air quality at the start and end of an engine test and at least once per hour during a test. If HC levels are considered significant, then they should be taken into account.*

3. TRANSFER PART CLEANLINESS/LEAKAGE CHECK

…

APPENDIX 8. PROCEDURES FOR ESTIMATING NON-VOLATILE PARTICULATE MATTER SYSTEM LOSS CORRECTIONS

Note 1.— The procedures specified in this ~~appendix~~Appendix are concerned with the determination of non-volatile particulate matter (nvPM) sampling and measurement system loss correction factors, excluding the ~~collection part~~Collection Part thermophoretic losses which are included in Appendix 7 data reporting.

Note 2.— Implementation of the nvPM sampling and measurement system requires a long sample line of up to 35 m and includes several sampling and measurement system components, which can result in significant particle loss on the order of 50 per cent for nvPM mass and 90 per cent for nvPM number. The particle losses are size dependent and hence are dependent on engine operating condition, combustor technology and possibly other factors. The procedures specified in this ~~appendix~~Appendix allow for an estimation of the particle losses.

~~Note 3.— The system loss correction factors are estimated based on the following assumptions: engine exhaust exit plane nvPM have a lognormal distribution, a constant value of nvPM effective density, a fixed value of geometric standard deviation, limiting the nvPM mass concentration to limit of detection, a minimum particle size cut-off of 0.01μm and no coagulation.~~

Note ~~4~~3.— The method proposed in this ~~appendix~~Appendix uses data and measurements as specified in Appendix 7 and ~~its attachments~~Attachments to Appendix 7. Symbols and definitions not defined in this ~~appendix~~Appendix are defined in Appendix 7 and ~~its attachments~~Attachments.

1. GENERAL

1.1 Within the nvPM sampling and measurement system, particles are lost to the sampling system walls by deposition mechanisms. These losses are both size dependent and independent. The size independent ~~collection part~~Collection Part thermophoretic loss is specified in Appendix 7, 6.2.1.

1.2 The overall nvPM sampling and measurement system particle loss excluding the ~~collection part~~Collection Part thermophoretic loss is referred to as system loss.

1.3 The nvPM size distribution needs to be taken into consideration because the particle loss mechanisms are particle size dependent. These particle size dependent losses are quantified in terms of the fraction of particles of a given size that penetrate through the sampling and measurement system.

2. DEFINITIONS, ACRONYMS, AND SYMBOLS

2.1 Definitions

Where the following expressions are used in this appendix, they have the meanings ascribed to them below:

Aerodynamic diameter of a particle. The diameter of an equivalent sphere of unit density (1g/cm^3) with the same ~~terminal~~ settling velocity as the particle in question, also referred to as "~~classical~~ aerodynamic diameter".

Competent laboratory. A testing and calibration laboratory which establishes, implements and maintains a quality system appropriate to the scope of its activities, in compliance with the International Organization for Standardization standard ISO/IEC 17025:2005, as amended from time to time, or equivalent standard and for which the programme for calibration of equipment is designed and operated so as to ensure that calibrations and measurements made by the laboratory are traceable to the International System of Units (SI). Formal accreditation of the laboratory to ISO/IEC 17025:2005 is not required.

Cyclone separator. Separation of particles larger than a prescribed aerodynamic diameter via rotational and gravitational means. The specified cut-point aerodynamic diameter is associated with the percent of particles ~~of a particular size~~ that penetrate through the cyclone separator.

Electrical mobility diameter of a particle. The diameter of a sphere that moves with exactly the same mobility in an electrical field as the particle in question.

Non-volatile particulate matter (nvPM). Emitted particles that exist at a gas turbine engine exhaust nozzle exit plane that do not volatilize when heated to a temperature of 350°C.

Particle loss. The loss of particles during transport through a sampling or measurement system component or due to instrument performance. ~~This~~ Sampling and measurement system loss is due to various deposition mechanisms, some of which are particle size dependent.

Particle mass concentration. The mass of particles per unit volume of sample.

Particle mass emission index. The mass of particles emitted per unit of fuel mass used.

Particle number concentration. The number of particles per unit volume of sample.

Particle number emission index. The number of particles emitted per unit of fuel mass used.

Particle size distribution. A list of values or a mathematical function that represents particle number concentration according to size.

Penetration fraction. The ratio of particle concentration downstream and upstream of a sampling system element.

2.2 Acronyms

CPC	Condensation particle counter
EENEP	Engine Exhaust Nozzle Exit Plane
nvPMmi	Non-volatile particulate matter mass instrument
nvPMni	Non-volatile particulate matter number instrument

nvPM	Non-volatile particulate matter (*see* definition)
slpm	Standard litres per minute (~~litres~~Litres per minute at STP)
STP	Instrument condition at standard temperature 0°C and pressure 101.325 kPa
VPR	Volatile ~~particle remover~~Particle Remover

2.3 Symbols

C_c	$1+\frac{2\lambda}{D_m}\times\left(1.165+0.483\times e^{-\frac{0.997D_m}{2\lambda}}\right)$, ~~the~~ dimensionless Cunningham slip correction factor
D	$\frac{k_B\times(273.15+T_i)\times C_c}{3\times\pi\times\mu\times D_m}\times 10^7$, the particle diffusion coefficient, cm^2/s
DF_1	First stage dilution factor
DF_2	Second stage (VPR) dilution factor as per calibration
D_m	nvPM ~~electrical mobility~~particle diameter, refers to the electrical mobility diameter except for the cyclone separator where the particle diameter is the aerodynamic diameter, ~~μm~~nm
D_{mg}	Geometric mean diameter of nvPM size distribution, ~~μm~~nm
δ	~~The sum~~Sum of the square of relative differences between measured and calculated dilution corrected nvPM mass and number concentrations
EI_{mass}	nvPM mass emission index corrected for Collection Part thermophoretic losses, in mg/kg fuel
EI_{num}	nvPM number emission index corrected for Collection Part thermophoretic losses, in number/kg fuel
~~ε~~	~~Convergence criterion (1×10^{-9})~~
$f_{lgn}(D_m)$	~~The lognormal~~Lognormal distribution function with parameters of geometric standard deviation, σ_g, and geometric mean diameter, D_{mg}
$f_N(D_m)$	The ~~engine exhaust nozzle exit plane~~EENEP particle number lognormal distribution function
ID_{ti}	Inner diameter of the i^{th} segment of the sampling line, mm
k_B	1.3806×10^{-16}, Boltzmann constant, $(g\cdot cm^2)/(s^2\cdot K)$

k_{SL_mass} ~~EImass~~EI_{mass} correction factor for system loss~~es~~ without Collection Part thermophoretic loss correction~~, μg/m^3~~

k_{SL_num} ~~EInum~~EI_{num} correction factor for system loss~~es~~ without Collection Part thermophoretic loss correction~~, number/cm^3~~

k_{thermo} Collection part thermophoretic loss correction factor, specified in Appendix 7, 6.2.1

λ 67.3~~$\times 10^{-3}$~~ $\times \left(\frac{273.15+T_i}{296.15}\right)^2 \times \left(\frac{101.325}{P_i}\right) \times \left(\frac{406.55}{T_i+383.55}\right)$, the carrier gas mean free path, ~~μm~~nm

μ Carrier gas viscosity, g/cm·s

~~$nvPM_{mass\_EST}$ Estimated undiluted (i.e., corrected for dilution) instrument mass concentration, μg/m^3~~

~~$nvPM_{num\_EST}$ Estimated undiluted (i.e., corrected for dilution) instrument number concentration, number/cm^3~~.

~~$nvPM_{mass\_EP}$ Estimated engine exhaust nozzle exit plane nvPM mass concentration, specified in section 4 of this appendix, not corrected for collection part thermophoretic losses.~~

~~$nvPM_{num\_EP}$ Estimated engine exhaust nozzle exit plane nvPM number concentration, specified in section 4 to this appendix, not corrected for collection part thermophoretic losses~~

$nvPM_{mass\_STP}$ Diluted nvPM mass concentration at instrument STP condition, μg/m^3

$nvPM_{num\_STP}$ Diluted nvPM number concentration at instrument STP condition, number/cm^3

$\eta_{mass}(D_m)$ ~~The overall~~Overall sampling and measurement system penetration fraction for the nvPMmi without ~~collection part~~Collection Part thermophoretic losses at electrical mobility particle size Dm

$\eta_{num}(D_m)$ ~~The overall~~Overall sampling and measurement system penetration fraction for the nvPMni without ~~collection part~~Collection Part thermophoretic losses at electrical mobility particle size Dm

$\eta i(D_m)$ Penetration fraction for the ith component of the sampling and measurement system at electrical mobility particle size D_m

$\eta bi(D_m)$ Penetration fraction for the sampling line bend for ith component of the sampling and measurement system at electrical mobility particle size D_m

P_i Carrier gas pressure in the ith segment of the sampling line, kPa

ρ ~~The assumed~~Assumed nvPM effective density, g/cm^3

σ_g ~~The assumed~~Assumed geometric standard deviation of lognormal distribution

Q_i ~~The carrier~~Carrier gas flow in the ith segment of the sampling line, slpm

Re $\frac{2\times\rho_{gas}\times Q_i}{3\times\pi\times\mu\times ID_{ti}}$, the carrier gas Reynolds number

$R_{MN}(D_m)$ Calculated ratio of the estimated nvPM mass concentration to the estimated nvPM number concentration

T_i ~~The carrier~~Carrier gas temperature in the i[th] segment of the sampling line, °C

~~3. CORRECTION FACTORS FOR nvPM MASS AND NUMBER EIs~~

~~3.1 **Recommendation.** — *The EI_{mass} correction factor for system losses is the ratio between estimated engine exhaust nozzle exit plane mass concentration without collection part thermophoretic loss correction and measured mass concentration, and should be calculated as follows:*~~

$$k_{SL\_mass} = \frac{nvPM_{mass\_EP}}{DF_1 \times nvPM_{mass\_STP}}$$

~~3.2 **Recommendation.** — *The EI_{num} correction factor for system losses is the ratio between estimated engine exhaust nozzle exit plane number concentration without collection part thermophoretic loss correction and measured number concentration, and should be calculated as follows:*~~

$$k_{SL\_num} = \frac{nvPM_{num\_EP}}{DF_1 \times DF_2 \times nvPM_{num\_STP}}$$

~~4. PROCEDURE TO ESTIMATE ENGINE EXHAUST NOZZLE EXIT PLANE MASS AND NUMBER CONCENTRATIONS CORRECTED FOR SYSTEM LOSSES~~

~~4.1 **Recommendation.** — *The engine exhaust nozzle exit plane mass ($nvPM_{mass\_EP}$) and number ($nvPM_{num\_EP}$) should be determined using the following procedure:*~~

~~*a) For a measured $nvPM_{num\_STP}$, begin with an initial value of $nvPM_{num\_EP} = 3 \times DF_1 \times DF_2 \times nvPM_{num\_STP}$.*~~

~~*b) An initial value of 0.02 µm should be assumed for the geometric mean diameter, D_{mg}, of the lognormal particle size distribution.*~~

~~*c) Starting with initial assumed values of $nvPM_{num\_EP}$ and D_{mg} from a) and b), estimate the nvPM mass ($nvPM_{mass\_EST}$) and number ($nvPM_{num\_EST}$) concentrations using the following equations:*~~

$$nvPM_{mass\_EST} = \sum_{D_m=0.01\mu m}^{1\mu m} \eta_{mass}(D_m) \times \frac{\rho\pi D_m^3}{6} \times nvPM_{num\_EP} \times f_{lgn}(D_m) \times \Delta\, ln(D_m)$$

$$nvPM_{num\_EST} = \sum_{D_m=0.01\mu m}^{1\mu m} \eta_{num}(D_m) \times nvPM_{num\_EP} \times f_{lgn}(D_m) \times \Delta ln(D_m)$$

~~*where*~~

$$f_{lgn}(D_m) = \frac{1}{\sqrt{2\pi}\ ln(\sigma_g)} \times e^{-\frac{1}{2}\left\{\frac{ln(D_m)-ln(D_{mg})}{ln(\sigma_g)}\right\}^2}$$

$\Delta ln(D_m) = \frac{1}{n} \times \frac{1}{log_{10}(e)}$ *is the width of a size bin in base natural logarithm; e is the Euler's number, and n is the number of particle size bins per decade.*

d) Determine the difference, δ, between $nvPM_{num\_STP}$, $nvPM_{mass\_STP}$ *and the estimates of the nvPM number concentration (*$nvPM_{num\_EST}$*) and the nvPM mass concentration (*$nvPM_{mass\_EST}$*) from the initial engine exhaust nozzle exit plane values using the equation:*

$$\delta = \left(\frac{DF_1 \times DF_2 \times nvPM_{num\_STP} - nvPM_{num\_EST}}{DF_1 \times DF_2 \times nvPM_{num\_STP}}\right)^2 + \left(\frac{DF_1 \times nvPM_{mass\_STP} - nvPM_{mass\_EST}}{DF_1 \times nvPM_{mass\_STP}}\right)^2$$

e) Repeat steps c) through d) varying $nvPM_{num\_EP}$ *and* D_{mg} *until δ reduces to less than* 1×10^{-9}.

f) Once δ is reduced to less than 1×10^{-9}*, the final values of* $nvPM_{num\_EP}$ *and* D_{mg} *are those associated with this minimized value of δ.*

g) Using $nvPM_{num\_EP}$ *and* D_{mg} *from step f),* $nvPM_{mass\_EP}$ *should be determined using the following expression:*

$$nvPM_{mass\_EP} = \sum_{D_m=0.01\mu m}^{1\mu m} \frac{\rho\pi D_m^3}{6} \times nvPM_{num\_EP} \times f_{lgn}(D_m) \times \Delta\, ln(D_m)$$

4.2 **Recommendation.** — *A total of 80 discrete sizes in the particle size range from 0.003 µm to 1 µm should be used in this calculation. In this case, the number of size bins per decade, n, is 32 (see the definition for* $\Delta ln(D_m)$ *above). The sums in the above equations start at 0.01 µm.*

4.3 **Recommendation.** — *The nvPM effective density should be a constant and equal to 1 g/cm*^{3} *across all particle sizes.*

4.4 **Recommendation.** — *The geometric standard deviation of the lognormal particle number distribution should be equal to 1.8.*

Note 1.— The flow chart shown in figure A8-1 describes this procedure pictorially.

Note 2.— If $nvPM_{mass\_STP}$ is less than 1 µg/m³, a minimum value of 1 µg/m³ should be used for the procedure to converge.

Note 3.— The procedure outlined in section 3 is solvable using commercially available software programs.

Note 4.— The units for D_m are in µm which is different from tabulated values given in Appendix 7.

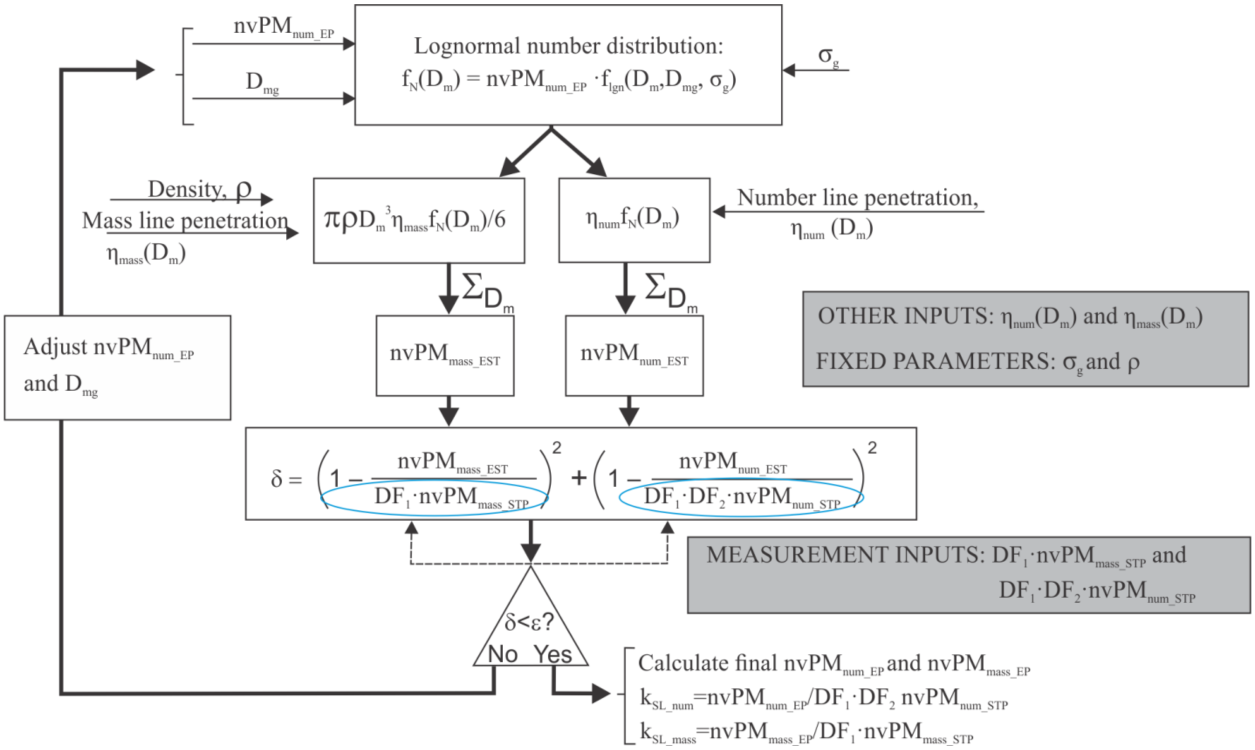

Figure A8-1.— Iterative method for calculation of nvPM mass and number corrected for losses other than collection part thermophoresis

5. OVERALL SYSTEM PENETRATION FRACTIONS

Note 1.— The particle penetration fractions are different between the nvPM mass concentration measurement and nvPM number concentration measurement because of the difference in sample flow paths after Splitter 2.

Note 2.— Penetration fractions may change between different engine condition measurement points because of changing particle size distribution.

Note 3.— Where continuous functions are calculated to estimate penetration fractions or CPC counting efficiency, care should be taken such that they do not go below zero.

Table A8-1. Required nvPM sampling and measurement system component penetration fractions

Parameter symbol	*Description*
$\eta_1(D_m)$	Section 1 — Probe inlet to Splitter 1
$\eta_{b1}(D_m)$	Section 1 — Probe inlet to Splitter 1 for bends
$\eta_2(D_m)$	Section 2 — Splitter 1 to Diluter 1 inlet
$\eta_{b2}(D_m)$	Section 2 — Splitter 1 to Diluter 1 inlet for sampling line bends
$\eta_{dil}(D_m)$	Section 2 — Diluter 1
$\eta_3(D_m)$	Section 3 — Diluter 1 outlet to cyclone separator inlet
$\eta_{b3}(D_m)$	Section 3 — Diluter 1 outlet to cyclone separator inlet for sampling line bends
$\eta_{cyc}(D_m)$	Cyclone separator
$\eta_4(D_m)$	Section 4 — Cyclone separator outlet to Splitter 2
$\eta_{b4}(D_m)$	Section 4 — Cyclone separator outlet to Splitter 2 for sampling line bends
$\eta_5(D_m)$	Section 4 — Splitter 2 to nvPMmi
$\eta_{b5}(D_m)$	Section 4 — Splitter 2 to nvPMmi for sampling line bends
η_{th_m}	Section 5 — Due to thermophoretic loss at the nvPMmi inlet
$\eta_6(D_m)$	Section 4 — Splitter 2 to VPR
$\eta_{b6}(D_m)$	Section 4 — Splitter 2 to VPR for sampling line bends
$\eta_{VPR}(D_m)$	Section 5 — VPR
$\eta_{CPC}(D_m)$	Section 5 — nvPMni (CPC) counting efficiency
η_{th_n}	Section 5 — Due to thermophoretic loss at the nvPMni inlet

5.1 System penetration fraction for nvPM mass

Recommendation. — *The overall penetration fraction for the nvPM mass, for 80 discrete particle sizes (D_m) from 0.003 μm to 1 μm, should be calculated by combining system component penetration fractions:*

$$\eta_{mass}(D_m) = \eta_1 \times \eta_{b1} \times \eta_2 \times \eta_{b2} \times \eta_3 \times \eta_{b3} \times \eta_{cyc} \times \eta_4 \times \eta_{b4} \times \eta_5 \times \eta_{b5} \times \eta_{th\_m}$$

where η with subscripts refer to penetration fractions of individual components of the nvPM sampling and measurement system defined in Table A8-1. Procedures to estimate the individual component penetration fractions are defined in section 6 of this appendix.

Note. — Depending on the precise geometry of the nvPM sampling system, there can be more individually described components of the nvPM sampling and measurement system than described in Table A8-1.

5.2 System penetration fraction for nvPM number

Recommendation.— *The overall penetration fraction for the nvPM number, for 80 discrete particle sizes (D_m) from 0.003 µm to 1 µm, should be calculated by combining system component penetration fractions:*

$$\eta_{num}(D_m) = \eta_1 \times \eta_{b1} \times \eta_2 \times \eta_{b2} \times \eta_3 \times \eta_{b3} \times \eta_{cyc} \times \eta_4 \times \eta_{b4} \times \eta_6 \times \eta_{b6} \times \eta_{VPR} \times \eta_{CPC} \times \eta_{th\_n}$$

where η with subscripts refer to penetration fractions of individual components of the nvPM sampling and measurement system defined in Table A8-1. Procedures to estimate the individual component penetration fractions are defined in section 6 of this appendix.

Note.— Depending on the precise geometry of the nvPM sampling system, there can be more individually described components of the nvPM sampling and measurement system than described in Table A8-1.

6. PROCEDURE TO DETERMINE PENETRATION FRACTIONS OF INDIVIDUAL COMPONENTS OF THE nvPM SAMPLING AND MEASUREMENT SYSTEM

6.1 Data required

To calculate transport efficiency for particles over a range of sizes, the characteristics of the flow, transport line and ambient conditions are required. These parameters, defined for each line section, are listed in Table A8-2.

Table A8-2. Input parameters

Parameter symbol	*Description*	*Unit*
T_i	Temperature of the carrier gas at the entrance of i[th] segment of the sampling line, except for the collection part. Assumed to be equal to the temperature of the wall of each section of the transport line and constant throughout the i[th] segment of the sampling line	°C
P_i	Pressure of the carrier gas in the i[th] segment of the sampling line, assumed constant throughout the i[th] section and equal to 101.325 kPa	kPa
Q_i	Flow rate of the carrier gas through the i[th] segment of the sampling line	slpm
ID_{ti}	Inside diameter of the i[th] segment of the sampling line	mm
L_i	Length of of the i[th] segment of the sampling line	m
θ_{bi}	Total angle of bends in the i[th] segment of the sampling line	degrees
η_{VPR}(15),	VPR penetration fractions at four particle diameters	dimensionless

$\eta_{VPR}(30)$, $\eta_{VPR}(50)$, $\eta_{VPR}(100)$		
$\eta_{CPC}(10)$, $\eta_{CPC}(15)$	CPC counting efficiency at two particle diameters	dimensionless

6.2 Diffusional penetration fractions

6.2.1 Diffusion of particles onto the surface of the sampling system tube walls results in loss of particles entering a segment of the sampling line or a component. Penetration fractions, $\eta_i(D_m)$, for diffusional losses in sections up to the instrument inlets, $\eta_i(D_m)$, i = 1, 2, 3, 4, 5 and 6 are calculated using the expression:

$$\eta_i(D_m) = e^{\frac{-0.6 \times \pi \times ID_{ti} \times L_i \times V_{diff}}{Q_i}}$$

where

L_i = length of the i[th] segment of the sampling line, m

V_{diff} = $1.18 \times Re^{0.875} \times Sc^{0.333} \times \frac{D}{ID_{ti}}$, the deposition speed, cm/s

Sc = $\frac{\mu}{\rho_{gas} D} \times 10^3$, the carrier gas Schmidt number

m_{gas} = 29.0 kg/mol , the molecular mass of the carrier gas

P_i = the carrier gas pressure, kPa (assumed to be 101.325 kPa)

6.2.2 **Recommendation.**— *Penetration fractions at 80 discrete particle sizes (D_m) from 0.003 µm to 1 µm should be calculated for diffusional losses for each applicable line section.*

6.3 Thermophoresis

Recommendation.— *A constant instrument inlet thermophoretic penetration, $\eta_{th\_m}(D_m)$ = 1 should be used for nvPMmi and $\eta_{th\_n}(D_m)$ = 1 should be used for nvPMni for all particle sizes.*

6.4 Particle loss in bends

6.4.1 **Recommendation.**— *The penetration faction due to losses in bends $\eta_{bi}(D_m)$, i = 1, 2, 3, 4, 5 and 6 is distinguished for turbulent flow, Re greater than 5 000, and laminar flow, Re less than or equal to 5 000 where Re is the Reynolds number. For laminar flow when Re less than or equal to 5 000, the penetration due to bends in the transport lines should be calculated as:*

$$\eta_{bi} = 1 - 0.01745 \times Stk \times \theta_{bi}$$

For turbulent flow when Re greater than 5 000, the penetration due to bends in the transport lines should be calculated as:

$$\eta_{bi} = e^{-0.04927 \times Stk \times \theta_{bi}}$$

where

Stk = $\frac{Q_i \times C_c \times \rho \times D_m^2 \times 10^{-3}}{27 \times \pi \times \mu \times ID_{ti}^3}$, *the dimensionless Stokes number*

θ_{bi} = *total angle of bends in the of the i*th *segment of the sampling line, degrees.*

6.4.2 **Recommendation.** — *Penetration fractions at 80 discrete particle sizes (D_m) from 0.003 µm to 1 µm should be calculated for bend losses as applicable for each section of the sampling and measurement system.*

6.5 Cyclone separator penetration function

6.5.1 **Recommendation.** — *The penetration function of the cyclone separator should be estimated using the following expression:*

$$\eta_{cyc}(D_m) = 1 - \int_{x>0}^{D_m} \frac{e^{-\frac{(\ln x - \mu_{cyc})^2}{2\sigma_{cyc}^2}}}{x\sigma_{cyc}\sqrt{2\pi}} dx$$

where

μ_{cyc} = *ln*(D_{50}), *and*

σ_{cyc} = *ln*$(D_{16}/D_{84})^{0.5}$

6.5.2 **Recommendation.** — *Penetration fractions at 80 discrete particle sizes (D_m) from 0.003 µm to 1 µm should be calculated from the cyclone penetration function. The cyclone separator in the nvPM sampling and analysis system has the following specifications:*

a) cut-point: D_{50} = 1.0 µm ±0.1 µm; and

b) sharpness: $(D_{16}/D_{84})^{0.5}$ less than or equal to 1.25.

Note 1.— Modern computer spreadsheet applications have the cumulative lognormal distribution built into the function library that can be used to generate the penetration function of the cyclone separator.

Note 2.— For most gas turbine engine applications D_m will be less than 0.3 µm. In such cases the cyclone penetration function will be effectively equal to 1.0.

6.6 VPR penetration function

Note.— A smooth function provided by the calibration laboratory that has goodness of fit results (R^2 greater than 0.95) for the four VPR calibration penetration points (Table A8-3) may be used in place of the function determined from the calculation procedure outlined below. Particle losses in the VPR are due to both diffusion and thermophoresis. The thermophoretic factor, η_{VPRth}, is a constant. The diffusion factor, η_{VPRdi}, is determined from standard particle losses due to diffusion in a laminar flow.

6.6.1 **Recommendation.**— *The total VPR penetration function should be estimated using the expression:*

$$\eta_{VPR} = \eta_{VPRth} \times \begin{cases} 1 - 5.5 \times \psi^{\frac{2}{3}} + 3.77 \times \psi & \psi < 0.007 \\ 0.819 \times e^{-11.5\psi} + 0.0975 \times e^{-70.1\psi} + 0.0325 \times e^{-179\psi} & \psi > 0.007 \end{cases}$$

where

Ψ = $\frac{6 \times D \times L_{VPR}}{Q_{VPR}}$, *the deposition parameter*

L_{VPR} = *the effective length of the VPR, m*

Q_{VPR} = *the carrier gas flow in the VPR, slpm*

T_{VPR} = *the VPR temperature, °C*

η_{VPRth} = *VPR thermophoretic loss*

6.6.2 **Recommendation.**— *The VPR penetration function (η_{VPR}) should be fitted to the four measured penetration points by varying the VPR effective length (L_{VPR}) and the thermophoretic loss factor (η_{VPRth}). The R^2 value should be greater than 0.95 to ensure a good fit to the measured penetrations.*

6.6.3 **Recommendation.**— *Penetration fractions at 80 discrete particle sizes (D_m) from 0.003 µm to 1 µm should be calculated from the VPR continuous function.*

Table A8-3. Minimum allowed penetration fractions of the VPR at four particle diameters

Electrical mobility particle diameter, D_m	0.015 µm	0.03 µm	0.05 µm	0.1 µm
Minimum penetration fraction, $\eta_{VPR}(D_m)$	0.30	0.55	0.65	0.70

6.7 Diluter 1 penetration fraction

6.7.1 **Recommendation.**— *A constant Diluter 1 penetration, $\eta_{di1}(D_m) = 1$ should be used for all particle sizes.*

6.7.2 **Recommendation.**— *Penetration fractions at 80 discrete particle sizes (D_m) from 0.003 µm to 1 µm should be used for the diluter penetration function.*

6.8 CPC counting efficiency

6.8.1 **Recommendation.** — *A continuous function for the CPC counting efficiency should be determined using the two CPC counting efficiencies specified with a two parameter sigmoid function using the expression:*

$$\eta_{CPC} = 1 - e^{-ln(2)\cdot\left[\frac{D_m - D_0}{D_{50} - D_0}\right]}$$

where

$$D_0 = \frac{\alpha_{10}D_{15} - \alpha_{15}D_{10}}{\alpha_{10} - \alpha_{15}}$$

$$D_{50} = \frac{(\alpha_{15}+1)D_{10} + (\alpha_{10}+1)D_{15}}{\alpha_{15} - \alpha_{10}}$$

$$\alpha_i = \frac{ln(1 - \eta_{CPC,i})}{ln(2)}, i = 0.01\ \mu m\ \ or\ 0.015\ \mu m$$

D_{10} = *0.01 μm*

D_{15} = *0.015 μm*

$\eta_{CPC,10}$ = *the counting efficiency at 0.01 μm*

$\eta_{CPC,15}$ = *the counting efficiency at 0.015 μm.*

6.8.2 **Recommendation.** — *Penetration fractions at 80 discrete particle sizes (D_m) from 0.003 μm to 1 μm should be calculated from the CPC continuous function.*

3. DATA REQUIRED

3.1 nvPM Emissions

In order to calculate the system loss correction factors, the following concentrations as specified in Appendix 7 are needed:

a) nvPM mass concentration: $nvPM_{mass\_STP}$;

b) nvPM number concentration: $nvPM_{num\_STP}$.

3.2 Other Information

Additional information listed in Attachment D to Appendix 7 is required to perform the calculation procedure.

4. nvPM SYSTEM LOSS CORRECTION METHODOLOGY AND CALCULATION PROCEDURE

4.1 Overview

Note.— An overview diagram of the methodology for estimating the system loss correction factors is shown Figure A8-1.

4.1.1 The system loss correction factors shall be estimated based on the following assumptions: EENEP nvPM is represented by a constant value of nvPM effective density, a lognormal distribution, a fixed value of geometric standard deviation, no coagulation, limiting the nvPM mass and number concentrations as described in the calculation method limitations section, and a minimum summation particle size cut-off of 10 nm.

4.1.1.1 The system loss correction methodology shall use a particle effective density of 1 g/cm^3

4.1.1.2 A mono-modal lognormal distribution with a geometric standard deviation of 1.8 shall be used in the system loss correction methodology.

4.1.1.3 The system loss correction methodology does not consider reduction in nvPM number concentration due to coagulation.

4.1.1.4 The EENEP nvPM number concentration calculated using:

$$k_{SL\_num} \times k_{thermo} \times DF_1 \times DF_2 \times nvPM_{num\_STP}$$

is greater 10^8 particles/cm^3, coagulation may occur and shall be reported to the certificating authority.

Note 1.— The system loss correction methodology does not consider penetration drift. This is not considered significant for Appendix 7 compliant nvPM measurement systems.

Note 2.— An illustration of the iterative calculation procedure is shown in Figure A8-2.

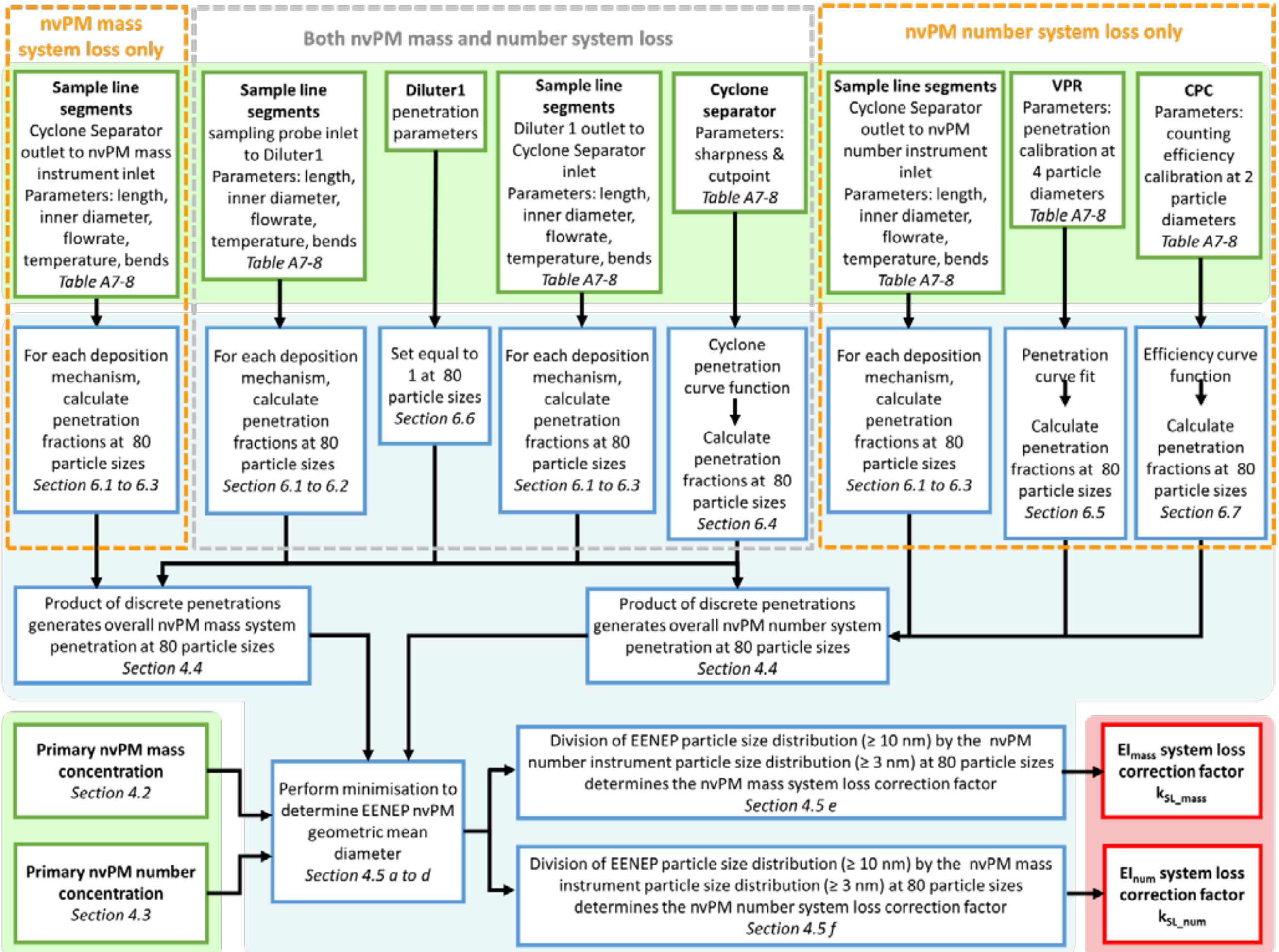

Figure A8-1: Flow block diagram of the nvPM system loss correction methodology. Green blocks show model input parameters, the blue blocks shows model calculations and the red outline blocks shows calculation output system loss correction factors.

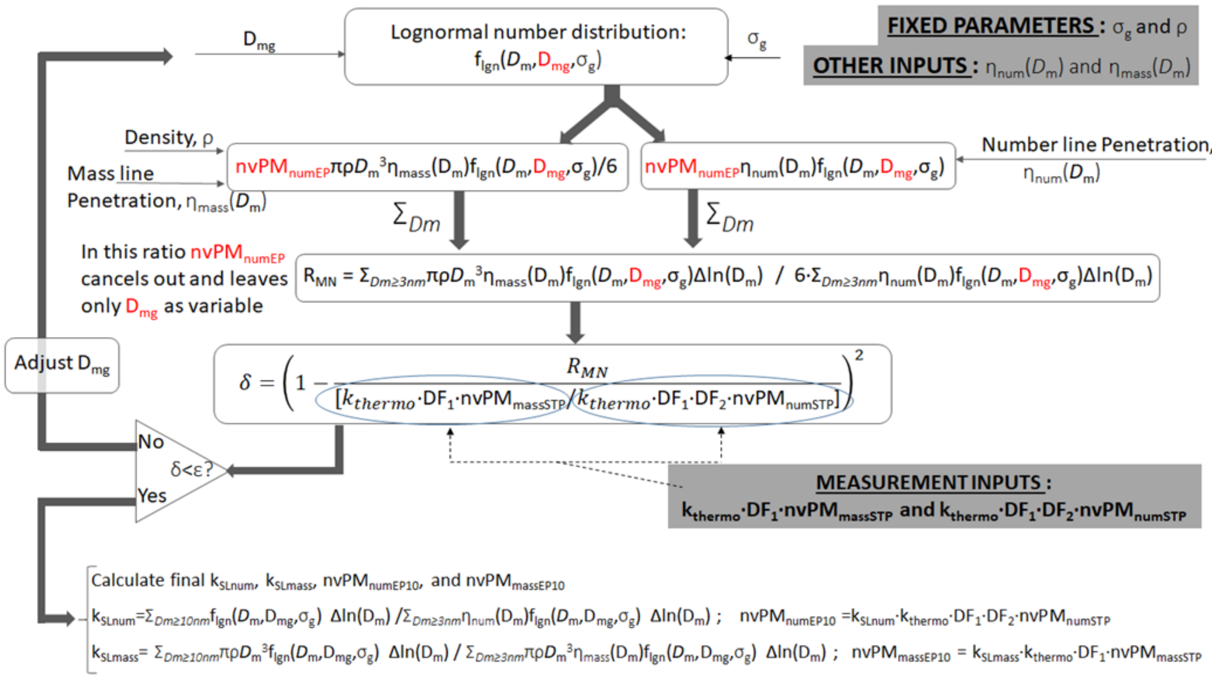

Figure A8-2: Iterative calculation procedure diagram for determination of system loss correction factors

4.2 Primary nvPM Mass Concentration

The primary nvPM mass concentration ($nvPM_{mass}$) is calculated using the following equation as defined in Appendix 7:

$$\mathbf{nvPM_{mass} = k_{thermo} \times DF_1 \times nvPM_{mass\_STP}}$$

4.3 Primary nvPM Number Concentration

The primary nvPM number concentration (nvPMnum) represents the number of particles per unit volume of engine exhaust sample corrected for the first stage dilution factor (DF1) and second stage dilution factor (DF2) and the Collection Part thermophoretic particle loss. It is calculated using the following equation:

$$\mathbf{nvPM_{num} = k_{thermo} \times DF_1 \times DF_2 \times nvPM_{num\_STP}}$$

4.4 nvPM Penetration Functions

4.4.1 The sampling system penetration fraction is a product of the individual penetration and counting efficiency functions. Table A8-1 provides the required nvPM penetration and counting efficiency functions and shall be calculated using the procedures described in Section 6.

4.4.2 The sampling system penetration for nvPMmi for a particle of diameter D_m is:

$$\eta_{mass}(D_m) = \eta_1 \times \eta_{b1} \times \eta_2 \times \eta_{b2} \times \eta_3 \times \eta_{b3} \times \ldots \times \eta_{dil} \times \eta_{cyc}$$

4.4.3 The sampling system penetration for nvPMni for a particle of diameter D_m is:

$$\eta_{num}(D_m) = \eta_1 \times \eta_{b1} \times \eta_2 \times \eta_{b2} \times \eta_3 \times \eta_{b3} \times \ldots \times \eta_{dil} \times \eta_{cyc} \times \eta_{VPR} \times \eta_{CPC}$$

4.4.4 The size independent nvPM mass and number sampling system thermophoretic penetration is:

$$\eta_{thermo} = \eta_{th1} \times \eta_{th2} \times \eta_{th3} \times \ldots$$

Note.— The Collection Part thermophoretic loss, k_{thermo}, is specified in Appendix 7, paragraph 6.2.1 and shall not be included in this calculation.

Table A8-1. Required nvPM Sampling and Measurement system component penetration fractions

Symbol	Description of nvPM Sampling and Measurement system particle transport functions
$\eta_i(D_m)$	Diffusional penetration fraction of ith segment of sampling system
$\eta_{bi}(\Theta_i)$	Penetration fraction due to bends in ith segment of sampling system
η_{thi}	Penetration fraction due to thermophoresis in ith segment of sampling system
$\eta_{dil}(D_m)$	Diluter1 penetration fraction
$\eta_{cyc}(D_m)$	Cyclone separator penetration fraction
$\eta_{VPR}(D_m)$	VPR penetration fraction
$\eta_{CPC}(D_m)$	CPC counting efficiency

4.5 Calculation of System Loss Correction Factors

System loss correction factors for nvPM mass (k_{SL_mass}) and nvPM number (k_{SL_num}) shall be calculated using the iterative procedure:

a) Estimate an initial value of the geometric mean diameter using the equation:

$$\mathbf{D_{mg}} = \sqrt[3]{\frac{\mathbf{6 \times DF_1 \times nvPM_{mass\_STP}}}{\boldsymbol{\pi} \times \boldsymbol{\rho} \times \mathbf{DF_1 \times DF_2 \times nvPM_{num\_STP}}}} \times \mathbf{10^3}$$

Note.— Using the units defined for the inputs, the calculated particle diameter will be in nm.

b) Using the value of D_{mg} from step a), calculate the estimated nvPM mass to nvPM number ratio, $R_{MN}(D_{mg})$, using the equation:

$$\mathbf{R_{MN}(D_{mg})} = \frac{\sum_{D_m>3nm}^{1000nm} \boldsymbol{\eta}_{\mathbf{mass}}(\mathbf{D_m}) \times \frac{\boldsymbol{\pi\rho}\mathbf{D_m^3}}{\mathbf{6}} \times \mathbf{e}^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\mathbf{ln}(\mathbf{D_m})}{\sum_{D_m>3nm}^{1000nm} \boldsymbol{\eta}_{\mathbf{num}}(\mathbf{D_m}) \times \mathbf{e}^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\mathbf{ln}(\mathbf{D_m})}$$

where the exponential functions come from the lognormal distribution function,

$$f_{lgn}(D_m) = \frac{1}{\sqrt{2\pi}\ \ln(\sigma_g)} \times e^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2}$$

$\Delta\ln(D_m) = \frac{1}{n} \times \frac{1}{log_{10}(e)}$, is the width of a size bin in base natural logarithm; *e* is the Euler's number, and n is the number of particle size bins per decade.

c) Determine the squared relative difference, δ, between the measured and estimated nvPM mass to number ratio using:

$$\boldsymbol{\delta} = \left\{\mathbf{1} - \frac{\mathbf{R_{MN}(D_{mg})} \times \mathbf{10^{-9}}}{\left[\left(\mathbf{k_{thermo}} \times \mathbf{DF_1} \times \mathbf{nvPM_{mass\_STP}}\right)/\left(\mathbf{k_{thermo}} \times \mathbf{DF_1} \times \mathbf{DF_2} \times \mathbf{nvPM_{num\_STP}}\right)\right]}\right\}^2$$

d) Repeat steps b) and c) until δ reduces to less than 1×10^{-9}. The D_{mg} associated with this minimised value of δ shall be used to calculate the system loss correction factors.

e) Calculate the nvPM mass system loss correction factor using the equation:

$$\mathbf{k_{SL\_mass}} = \frac{\sum_{D_m>10nm}^{1000nm} \mathbf{D_m^3} \times \mathbf{e}^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\mathbf{ln}(\mathbf{D_m})}{\sum_{D_m>3nm}^{1000nm} \boldsymbol{\eta}_{\mathbf{mass}}(\mathbf{D_m}) \times \mathbf{D_m^3} \times \mathbf{e}^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\mathbf{ln}(\mathbf{D_m})}$$

f) Calculate the nvPM number system loss correction factor using the equation:

$$\mathbf{k_{SL\_num}} = \frac{\sum_{D_m>10nm}^{1000nm} \mathbf{e}^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\mathbf{ln}(\mathbf{D_m})}{\sum_{D_m>3nm}^{1000nm} \boldsymbol{\eta}_{\mathbf{num}}(\mathbf{D_m}) \times \mathbf{e}^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\mathbf{ln}(\mathbf{D_m})}$$

g) A minimum of 80 discrete sizes in the particle size range from 3 nm to 1000 nm or a minimum number of bins that will produce equivalent results as agreed by the certificating authority shall be used in this calculation.

Note 1.— For 80 discrete sizes, the number of size bins per decade, n, is 32 (see the definition for $\Delta\ln(D_m)$ *above).*

Note 2.– The summations to compute the system loss correction factors start at 10 nm in the numerator and 3 nm in the denominator.

Note 3.– The calculation procedure can be implemented using commercially available software programmes.

5. REPORTING AND LIMITATIONS

Note 1.— The system loss correction factor calculation method described in Appendix 8 Section 4 has been shown to give acceptable results over a wide range of nvPM mass and number concentrations observed in aircraft turbine engine nvPM emissions. There are, however, ranges of mass and number concentrations that have been identified where the inputs to the analysis may lack the fidelity for the calculation method to yield quality results.

Note 2.— Any variations from the assumptions used by the calculation method as required in section 4.1.1 can lead to variation in the system loss correction factors. Similarly, variations in the data supplied to the calculation method will result in variation in system loss correction factors. The variation in the data could be due to particle size distributions, sampling system, or instruments. In addition, sampling and measurement system artifacts such as possible shedding from the walls when concentrations are low may provide invalid system loss correction factor. Method limitations are due to variation within the input data rather than the calculation method.

5.1 Applicable Mass Concentration Ranges

Note.— When raw nvPM mass concentrations at the nvPMmi (not dilution corrected) are below 3 μg/m³, use of this method to estimate system loss correction factors is cautioned because of the possible uncertainties with the nvPM mass concentration determination at such low values.

If the nvPMmi raw mass concentrations are below 3 μg/m^3, the applicant shall confirm that the predicted EENEP D_{mg} falls within the applicable range in section 5.3.

Recommendation.— *For cases where calculations from this Appendix or other equivalent methods do not provide reasonable values as noted in section 5.3 (e.g. when the system loss methodology calculates EENEP geometric mean diameters less than 7nm or greater than 100nm), or when the system loss methodology does not converge, alternate means of estimating system loss correction factors for the LTO operating modes may be used, subject to the approval of the certificating authority.*

Note.— There are no currently known limitations regarding high nvPM mass concentrations as long as it is verified that the nvPM mass concentration readings are within the range of the nvPMmi used.

5.2 Applicable Number Concentration Ranges

If the nvPM number concentration measured at the nvPMni, corrected for dilution (both DF1 and DF2) and Collection Part thermophoretic loss, is found to be less than or equal to the measured ambient number concentration[2], the applicant shall confirm that the predicted EENEP D_{mg} falls within the applicable range in section 5.3.

Recommendation.— *For cases where calculations from this Appendix or other equivalent methods do not provide reasonable values as noted in section 5.3 (e.g. when the system loss methodology calculates EENEP geometric mean diameters less than 7nm or greater than 100nm), or when the system loss methodology does not converge, alternate means of estimating system loss correction factors for the LTO operating modes may be used, subject to the approval of the certificating authority.*

Note.— For the nvPMni, there are no currently known limitations on low nvPM number concentrations. CPC manufacturers report the CPC LOD to be about 1 particle/cm^3. High number concentration measurements are limited by the requirement for the CPC to stay in the single count mode. If EENEP nvPM number concentrations are above 10^8 particles /cm^3, particle coagulation may be occurring. Coagulation is not considered in the system loss calculation method.

5.3 Applicable Predicted Geometric Mean Diameters

Note.— The geometric mean diameter of nvPM at EENEP from aircraft gas turbines is anticipated to be in the range of 7 to 100nm.

If the system loss calculation method predicts an EENEP geometric mean diameter that is smaller than 7nm or larger than 100nm, and/or if the system loss calculation method predicts an EENEP geometric mean diameter whereby the convergence criterion is not met (δ is greater than 1×10^{-9}), results for k_{SL_mass} and k_{SL_num} shall be reviewed with the certificating authority to determine if the recommendation below applies.

Recommendation.— *For cases where calculations from this Appendix or other equivalent methods do not provide reasonable values (e.g. when the system loss methodology calculates EENEP geometric mean diameters less than 7nm or greater than 100nm), or when the system loss methodology does not converge, alternate means of estimating system loss correction factors for the LTO operating modes may be used, subject to the approval of the certificating authority.*

Note.— Calculated EENEP geometric mean diameters <20 nm will result in underestimation of system loss factors due to the minimum summation particle size cut-off. The underestimation can be significant for k_{SL_num} when EENEP D_{mg} ≤10 nm.

6. PROCEDURE TO DETERMINE PENETRATION FRACTIONS OF INDIVIDUAL COMPONENTS OF THE nvPM SAMPLING AND MEASUREMENT SYSTEM

To estimate the nvPM transport efficiency for particles over a range of sizes, penetration fractions shall be calculated for each component of the nvPM sampling and measurement system, for a minimum of 80 discrete particle sizes or a minimum number of discrete particle sizes that will produce equivalent result as agreed by the certificating authority in the range from 3 nm to 1000 nm.

---

[2] See Appendix 7, Attachment E

Note 1.— Where continuous functions are calculated to estimate penetration fractions, care should be taken such that they do not go below zero.

Note 2.— The nvPM measurement and sampling system parameters required to perform the penetration fraction calculations in this Attachment are contained in Appendix 7 Attachment D.

6.1 Segment Diffusional Penetration Fractions

Penetration values, $\eta_i(D_m)$, for diffusional losses in sampling system segments at electrical mobility particle size D_m are calculated with the expression:

$$\eta_i(D_m) = e^{\frac{-\pi \times ID_{ti} \times L_i \times V_{d,diff}}{Q_i}}$$

where:

L_i	length of the i[th] segment of the sampling line, m
$V_{d,diff}$	$0.0118 \times Re^{\frac{7}{8}} \times Sc^{\frac{1}{3}} \times D/ID_{ti}$, the deposition speed, cm/s
Sc	$\frac{\mu}{\rho_{gas} D} \times 10^3$, the carrier gas Schmidt number
ID_{ti}	Inner diameter of the i[th] segment of the sampling line, mm
Q_i	the carrier gas flow in the i[th] segment of the sampling line, slpm

6.2 Segment Bend Penetration Fractions

The bend penetration fractions are distinguished for turbulent flow, Re is greater than 5000, and laminar flow, Re is less than or equal to 5000 where Re is the Reynolds number. For laminar flow (including the transition regime) the penetration due to bends in the sample transport lines for each segment at electrical mobility particle size D_m is calculated as:

$$\eta_{bi}(D_m) = 1 - 0.01745 \times Stk \times \theta_{bi}$$

For turbulent flow the penetration due to bends in the sample transport lines shall be calculated as

$$\eta_{bi}(D_m) = e^{-0.04927 \times Stk \times \theta_{bi}}$$

where

Stk	$\frac{Q_i \times C_c \times \rho \times D_m^2 \times 10^{-3}}{27 \times \pi \times \mu \times ID_{ti}^3}$, the dimensionless Stokes number
θ_{bi}	Total angle of bends in the of the i[th] segment of the sampling line, degrees

6.3 Segment Thermophoretic Losses

Thermal gradients ocurring because sample line wall temperatures are lower than gas temperatures cause additional particle deposition, thermophoretic losses, onto the sampling line surfaces. The thermophoretic losses, except for those in the Collection Part, are calculated using:

$$\eta_{thi} = \left[\frac{T_{linei} + 273.15}{T_{gasi} + 273.15}\right]^{Pr\times K_{th}} \times \left[1 + \left(\frac{T_{gasi} + 273.15}{T_{linei} + 273.15} - 1\right) \times e^{-\frac{\pi\times ID_i\times h_{gas}\times L_i}{\rho_{gas}\times Q_i\times C_p}}\right]^{Pr\times K_{th}}$$

where

T_{gasi}	sample gas temperature in °C
T_{linei}	line wall temperature in °C
h_{gas}	carrier gas convective heat transfer coefficient (W/(m^2 K))
C_p	constant pressure carrier gas specific heat (J/(kg K))
Pr	Prandtl number
K_{th}	$\frac{2\times C_s\times C_c}{1+3\times C_m\times K_n}\left[2 + \frac{1}{\left(k_{gas}/k_p\right)+C_t\times K_n}\right]^{-1}$, the thermophoretic coefficient
C_s	1.17, slip coefficient
C_m	1.14, soot momentum
C_t	2.18, thermal coefficient
k_{gas}	thermal conductivity of the carrier gas (Wm^{-1}K^{-1})
K_n	$2\lambda/D_m$,Knudsen number
k_p	0.2 Wm^{-1}K^{-1}, particle thermal conductivity.

Note.— The Collection Part and VPR thermophoretic losses are taken in to account as specified in Appendix 7, paragraph 6.2.1 and paragraph 1.5 of this Attachment. A system compliant with specifications in Appendix 7 uses instruments and segments that currently don't need to be corrected for thermophoretic losses and therefore η_{thi} *will effectively be equal to 1.0.*

6.4 Cyclone Separator Penetration Function

The penetration function of the cyclone separator shall be estimated using the following expression:

$$\eta_{cyc}(D_m) = 1 - \int_{x>0}^{D_m} \frac{e^{-\frac{(\ln x - \mu_{cyc})^2}{2\sigma_{cyc}^2}}}{x\sigma_{cyc}\sqrt{2\pi}}\,dx$$

where

μ_{cyc} ln(D_{50}), and

σ_{cyc} $\ln(D_{16}/D_{84})^{0.5}$

Note 1.— Modern computer spreadsheet applications have the cumulative lognormal distribution built into the function library that can be used to generate the penetration function of the cyclone separator.

Note 2.— For most gas turbine engine applications D_m will be less than 300 nm. *In such cases the Cyclone separator penetration function will be effectively equal to 1.0.*

6.5 VPR Penetration Function

Note.— A smooth function provided by the calibration laboratory that has goodness of fit results (R^2 greater than 0.95) for the four VPR calibration penetration points may be used in place of the function determined from the calculation procedure outlined below.

Particle losses in the VPR are due to both diffusion and thermophoresis. The thermophoretic factor, η_{VPRth}, is a constant. The diffusion factor, η_{VPRdi}, is determined from standard particle losses due to diffusion in a laminar flow. The total VPR penetration function should be estimated using the expression:

$$\eta_{VPR} = \eta_{VPRth} \times \begin{cases} 1 - 5.5 \times \psi^{\frac{2}{3}} + 3.77 \times \psi & \psi < 0.007 \\ 0.819 \times e^{-11.5\psi} + 0.0975 \times e^{-70.1\psi} + 0.0325 \times e^{-179\psi} & \psi > 0.007 \end{cases}$$

where

Ψ $\frac{D \times L_{VPR} \times 100}{Q_{VPR}}$, deposition parameter
L_{VPR} effective length of the VPR, m
Q_{VPR} carrier gas flow in the VPR, slpm
T_{VPR} VPR temperature, °C
η_{VPRth} VPR thermophoretic loss

The VPR penetration function (η_{VPR}) shall be fitted to the four measured penetration points by varying the VPR effective length (L_{VPR}) and the thermophoretic loss factor (η_{VPRth}). The fit shall be calculated by minimising δ_{VPR}, the relative sum of squares difference between the measured VPR penetration, $\eta_{VPRmeas}$, and the calculated penetration function.

$$\delta_{VPR} = \sqrt{\sum_{D_m} \left(\frac{\eta_{VPRmeas}(D_m) - \eta_{VPR}(D_m)}{\eta_{VPRmeas}(D_m)} \right)^2}$$

A value of δ_{VPR} less than 0.08 has been shown to provide a good fit to the measured penetrations.

6.6 Diluter1 Penetration Function

A constant diluter1 penetration, $\eta_{dil}(D_m) = 1$ shall be used for all particle sizes.

6.7 CPC Counting Efficiency

A continuous function for the CPC counting efficiency shall be determined using the two CPC counting efficiencies specified with a two-parameter sigmoid function using the expression:

$$\eta_{CPC} = 1 - e^{-\ln(2)\times\left[\frac{D_m - D_0}{D_{50} - D_0}\right]}$$

where

$$D_0 = \frac{\alpha_{10}D_{15} - \alpha_{15}D_{10}}{\alpha_{10} - \alpha_{15}}$$

$$D_{50} = \frac{(\alpha_{15}+1)D_{10} - (\alpha_{10}+1)D_{15}}{\alpha_{15} - \alpha_{10}}$$

$$\alpha_i = \frac{\ln(1 - \eta_{CPC,i})}{\ln(2)}, i = 10\ nm\ \ or\ 15\ nm$$

D_{10}10 nm,
D_{15}15 nm,
$\eta_{CPC,10}$ the counting efficiency at 10 nm, and
$\eta_{CPC,15}$ the counting efficiency at 15 nm.

— — — — — — — —

APPENDIX B

PROPOSED AMENDMENTS TO ANNEX 16, VOLUME III

The text of the amendment is arranged to show deleted text with a line through it and new text highlighted with grey shading, as shown below:

1. ~~Text to be deleted is shown with a line through it.~~	text to be deleted
2. New text to be inserted is highlighted with grey shading	new text to be inserted
3. ~~Text to be deleted is shown with a line through it~~ followed by the replacement text which is highlighted with grey shading.	new text to replace existing text

TEXT OF THE PROPOSED AMENDMENTS TO THE INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES

ENVIRONMENTAL PROTECTION
ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME III
AEROPLANE CO_2 EMISSIONS

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APPENDICES

…

INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES

PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. DEFINITIONS

…

Derived version of a CO_2-certified aeroplane. An aeroplane which incorporates ~~changes~~ a change in the type design that either ~~increase~~ increases its maximum take-off mass, or that ~~increase~~ increases its CO_2 emissions evaluation metric value by more than:

a) 1.35 per cent at a maximum take-off mass of 5 700 kg, decreasing linearly to;

b) 0.75 per cent at a maximum take-off mass of 60 000 kg, decreasing linearly to;

c) 0.70 per cent at a maximum take-off mass of 600 000 kg; and

d) a constant 0.70 per cent at maximum take-off masses greater than 600 000 kg.

Note.— In some States, ~~Where~~ where the certificating authority finds that the proposed change in design, configuration, power or mass is so extensive that a substantially ~~new~~ complete investigation of compliance with the applicable airworthiness regulations is required, the aeroplane ~~will be considered to be a new type design rather than a derived version~~ requires a new Type Certificate.

Derived version of a non-CO_2-certified aeroplane. An individual aeroplane that conforms to an existing Type Certificate, but which is not certified to Annex 16, Volume III, and to which changes a change in the type design are is made prior to the issuance of the aeroplane's first certificate of airworthiness that increase increases its CO_2 emissions evaluation metric value by more than 1.5 per cent or are is considered to be a significant CO_2 changes change.

…

Type design. The set of data and information necessary to define an aircraft, engine or propeller type for airworthiness determination.

CHAPTER 2. SYMBOLS

Where the following symbols are used in Volume III of this Annex, they have the meanings, and where applicable the units, ascribed to them below:

AVG	Average
CG	Centre of gravity
CO_2	Carbon dioxide
g_0	Standard acceleration due to gravity at sea level and a geodetic latitude of 45.5 degrees, 9.80665 (m/s^2)
Hz	Hertz (cycle per second)
MTOM	Maximum take-off mass (kg)
OML	Outer mould line
RGF	Reference geometric factor
RSS	Root sum of squares
SAR	Specific air range (km/kg)
TAS	True airspeed (km/h)
W_f	Total aeroplane fuel flow (kg/h)
~~δ~~	~~Ratio of atmospheric pressure at a given altitude to the atmospheric pressure at sea level~~

…

PART II. CERTIFICATION STANDARD FOR AEROPLANE CO_2 EMISSIONS BASED ON THE CONSUMPTION OF FUEL

CHAPTER 1. ADMINISTRATION

…

1.11 Contracting States shall recognize valid aeroplane exemptions granted by ~~an~~ the competent authority of another Contracting State which is responsible for the production organisation of the aeroplane provided that an acceptable process was used.

…

CHAPTER 2.

1.— SUBSONIC JET AEROPLANES OVER 5 700 kg

2.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg

2.1 Applicability

Note.— See also Chapter 1, 1.4, 1.5, 1.6, 1.7, 1.8 and 1.11.

2.1.1 The Standards of this chapter shall, with the exception of amphibious aeroplanes, aeroplanes initially designed or modified and used for specialized operational requirements, aeroplanes designed with zero reference geometric factor (RGF), and those aeroplanes specifically designed or modified and used for fire-fighting purposes, be applicable to:

…

d) derived versions of non-CO_2-certified subsonic jet aeroplanes, including their subsequent CO_2-certified derived versions, of greater than 5 700 kg maximum certificated take-off mass, for which the application for certification of the change in type design was submitted on or after 1 January 2023;

e) derived versions of non-CO_2 certified propeller-driven aeroplanes, including their subsequent CO_2-certified derived versions, of greater than 8 618 kg maximum certificated take-off mass, for which the application for certification of the change in type design was submitted on or after 1 January 2023;

...

Note.— Aeroplanes initially designed or modified and used for specialized operational requirements refer to aeroplane type ~~configurations~~ designs which, in the view of the certificating authority, have different design characteristics to meet specific operational needs compared to typical civil aeroplane types covered by the scope of this volume of Annex 16, and which may result in a very different CO_2 emissions evaluation metric value.

…

2.1.3 ~~The granting of an exemption for an aeroplane against applicability requirements specified in 2.1.1 shall be noted on the aeroplane statement of conformity issued by the certificating authority~~ The certificating authority or the competent authority responsible for the production organisation of the aeroplane may grant exemptions from the applicability specified in §2.1.1. In such cases, the authority shall issue an exemption document. The grant of exemption shall be noted in the permanent aeroplane record. ~~Certificating authorities~~ The authority shall take into account the ~~numbers~~ number of exempted aeroplanes that will be produced and their impact on the environment. Exemptions shall be reported by aeroplane serial number and made available via an official public register.

…

2.5 Reference conditions for determining aeroplane specific air range

2.5.1 The reference conditions shall consist of the following conditions within the approved normal operating envelope of the aeroplane:

a) the aeroplane gross masses defined in 2.3;

b) a combination of altitude and airspeed selected by the applicant ~~for each of the specified reference aeroplane gross masses~~;

…

2.6 Test procedures

2.6.1 The SAR values that form the basis of the CO_2 emissions evaluation metric value shall be established either directly from flight tests or from a performance model validated by flight tests.

2.6.2 The test aeroplane shall be representative of the ~~configuration~~ type design for which certification is requested.

…

APPENDIX 1. DETERMINATION OF THE AEROPLANE CO_2 EMISSIONS EVALUATION METRIC VALUE

1.— SUBSONIC JET AEROPLANES OVER 5 700 kg

2.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg

…

3. SPECIFIC AIR RANGE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

3.1 General

This section prescribes the conditions under which SAR certification tests shall be conducted and the measurement procedures that shall be used.

Note.— ~~Many applications~~ An application for certification of a CO_2 emissions metric value may involve only a minor ~~changes~~ change to the aeroplane type design. The resultant ~~changes~~ change in the CO_2 emissions metric value can often be established reliably by way of an equivalent ~~procedures~~ procedure without the necessity of resorting to a complete test.

3.2 Flight test procedure

3.2.1 Pre-flight

The pre-flight procedure shall be approved by the certificating authority and shall include the following elements:

a) ***Aeroplane conformity***. The test aeroplane shall be confirmed to be in conformance with the type design ~~configuration~~ for which certification is sought.

…

5. CALCULATION OF REFERENCE SPECIFIC AIR RANGE FROM MEASURED DATA

…

5.2 Corrections from test to reference conditions

5.2.1 Corrections shall be applied to the measured SAR values to correct to the reference conditions specified in 2.5 of Part II, Chapter 2. Corrections shall be applied for each of the following measured parameters that are not at the reference conditions:

…

~~***Mass/δ.*** The lift coefficient of the aeroplane is a function of mass/δ and Mach number, where δ is the ratio of the atmospheric pressure at a given altitude to the atmospheric pressure at sea level. The lift coefficient for the test condition affects the drag of the aeroplane. The reference mass/δ is derived from the combination of the reference mass, reference altitude and atmospheric pressures determined from the ICAO standard atmosphere.~~

Reynolds number. The Reynolds number affects aeroplane drag. For a given test condition the Reynolds number is a function of the density and viscosity of air at the test altitude and temperature. The reference Reynolds number is derived from the density and viscosity of air from the ICAO standard atmosphere at the reference altitude ~~and temperature~~.

…

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APPENDIX C
(English only)

REGULATORY IMPACT ASSESSMENT

INFORMATION TO SUPPORT THE RULEMAKING PROCESSES OF ICAO MEMBER STATES

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1. **INTRODUCTION**

1.1 The International Civil Aviation Organization (ICAO) is a United Nations (UN) specialized agency, established by States in 1944 to manage the administration and governance of the *Convention on International Civil Aviation* (referred to as the Chicago Convention). ICAO works with the Convention's 192 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs) and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. Presently, there are over 10,000 such Standards and provisions contained in ICAO Annexes to the Chicago Convention. ICAO's ongoing mission is to support a global air transport network that meets or surpasses the social and economic development and broader connectivity needs of global businesses and passengers. While acknowledging the clear need to anticipate and manage the projected doubling of global air transport capacity by 2030 without unnecessary adverse impacts on system safety, efficiency, convenience or environmental performance, ICAO has established five comprehensive Strategic Objectives, namely: Safety, Air Navigation Capacity and Efficiency, Security and Facilitation, Economic Development of Air Transport, and Environmental Protection.

1.2 Improving the environmental performance of aviation is a challenge ICAO takes very seriously. In fulfilling its responsibilities, ICAO has three major environmental goals, which are to limit or reduce: 1) the number of people affected by significant aircraft noise, 2) the impact of aviation emissions on local air quality, and 3) the impact of aviation greenhouse gas emissions on the global climate. To limit or reduce the impact of aviation emissions on local air quality, ICAO takes actions on revising current and adopting new emission standards for international aviation. Following the development of a visibility based non-volatile Particulate Matter (nvPM) Standard, aircraft engine landing and take-off (LTO) nvPM mass and number emissions Standard is being adopted. The non-volatile particulate matter is defined as emitted particles that do not volatilize when heated to a temperature of 350° C. These particles are also known as "ultrafine soot" or "black carbon" particles. The new Standards regulate the mass and the number of such particles emitted during the landing and take-off cycle.

1.3 The ICAO Committee on Aviation Environmental Protection (CAEP) is a technical committee of the ICAO Council established in 1983. CAEP assists the Council in formulating new policies and adopting new SARPs related to aircraft noise and emissions, and more generally to aviation environmental impacts. CAEP undertakes specific studies, as requested by the Council. Its scope of activities encompasses noise, air quality and the Basket of Measures considered for reducing international aviation CO_2 emissions. CAEP is structured into Working Groups in order to progress tasks under the various environmental areas (noise, emissions, modelling, etc.).

1.4 Since 2013, CAEP has been developing Engine nvPM mass and number Emissions Certification Standards, following the plan approved by the ICAO Council and the request from the 38th Session of the Assembly (ResolutionA38-17[3]). These new Standards will be added to Chapter 4 (Volume II) to Annex 16 to the *Convention on International Civil Aviation*, where Annex 16, Volume I covers aircraft noise and Volume III addresses aircraft CO_2 emissions.

1.5 The nvPM mass and number Standards have been developed considering the four core CAEP tenets, which are technical feasibility, environmental effectiveness, economic reasonableness, and

[3] Doc 10022, Assembly Resolutions in Force (as of 4 October 2013), ISBN 978-92-9249-419-3, ICAO, 2014

the consideration of interdependencies (e.g. with noise and local air quality emissions). This has involved two phases of work, which have focussed on the development of a certification requirement and options for a regulatory limit line. Figure 1.1 shows a representative framework of an ICAO Environmental Standard.

Figure 1.1: The basic framework of an ICAO Environmental Standard

1.6 Phase 1 involved tasks associated with the forming of a certification requirement for the nvPM mass and number Standards, including the development of nvPM emissions evaluation metric systems (i.e. metric/correlating parameter/test points), certification procedures, measurement methodologies, applicability to new engine types, and initial inputs to the cost effectiveness assessment. Phase 2 included the following. (1) Development of the regulatory limit stringency options for in-production and new engine types; (2) considering various combinations of mass and number limits; (3) technology responses from the manufacturers when engines do not meet the nvPM mass and number stringency option combinations (SO); and, (4) the cost effectiveness analyses. The subsequent material is a summary of the nvPM mass and number Standard development work that was conducted through a period of six years (i.e., two CAEP work cycles).

2. CAVEATS, LIMITATIONS AND CONTEXT

2.1 Context: The framework for this analysis does not necessarily represent what would occur in the real world. Specifically, (a) the real world does not ensure that all products of a similar capacity get used equally regardless of price or performance; and (b) the real world does not require in production aircraft or engines to go out of production if they do not perform to a level required of newly certificated types. This analysis uses aircraft and engines that are assumed to be in production at the implementation date to assess the technical feasibility, benefits and costs of the proposed stringency option combinations. When a product no longer responds, results are influenced by the fleet evolution analysis assumptions; and coincidently the remaining fleet tends to be more fuel-efficient.

2.2 Technological Feasibility: For the purposes of the nvPM Standard setting process, CAEP relied upon representative, certificated engines to measure nvPM performance as a basis for technological feasibility and economic reasonableness. In the larger context of technology for improved engine, emissions environmental performance to be used as part of the basis for ICAO certification Standard setting, technological feasibility refers to any technology demonstrated to be safe and airworthy proven to Technical Readiness Level (TRL) 8 and available for application over a sufficient range of newly certificated aircraft.

2.3 Limitations: The information used in the analysis included a mixture of public and non-public data that is subject to change. The data was informed by assumptions unique to this analysis, which limits the applicability of the data to only this work.

2.4 The data and information provided in this document were provided to support the selection of nvPM mass and number Standards by ICAO CAEP in the context of the current ICAO Standard setting process. The in-production fleet and known products scheduled for entry into the fleet by 2023 were used for growth and replacement throughout the full analysis period (i.e., 2012-2042). The analysis did not speculate on potential future technology developments.

2.5 Fleet evolution is an element of CAEP modelling that defines the future fleet and its' deployment on routes and schedules, under different policy options and assumptions regarding the future state of the air transport system. Many of the input assumptions for this modelling are forward-looking and cannot be proven in advance. Thus, there is no certainty that any one baseline predicts what will actually happen in the future.

2.6 Assumptions of engine technology responses to regulatory levels were based on input from both manufacturers and other expert sources. These responses were meant for nvPM cost effectiveness modelling purposes, and do not imply a commitment from manufacturers to develop actual individual products.

2.7 Consequently, the environmental benefits and the costs are comparable relatively between analysis cases but cannot be represented as absolute benefits and costs. Hence, the data and information are not suitable for application to any other purpose of any kind, and any attempt at such application would be in error.

2.8 Recognizing the potential trade-offs between nvPM emissions and fuel efficiency and NOx, a range of trade-offs were modelled with the analysis submitted to CAEP. It should be noted however, regarding the proposed nvPM mass and number Standards for new engine type certificates, engines obtaining new type certificates are required to pass standards for all regulated pollutants. The anti-backsliding nvPM mass stringency proposed for in-production (INP) engines was not assessed.

2.9 Business Jets: Fleet evolution modelling for business jets (BJ) uses all types within a competition bin (CBin) equally without considering capacity, capital or operating costs, with the goal that CBins contain equivalent products in terms of costs and capabilities. However, after the analysis was run it was discovered that two BJ CBins had types with noticeably different capital costs. When some BJ types no longer respond, they were replaced by much less expensive types. This BJ CBin modelling is sufficiently influential that the combined market results are presented with and without the BJ market.

2.10 Two Paths: The analysis for the potential CAEP/11 nvPM mass and number Standards included a portion of the growth and replacement fleet modelled in two ways. Small and medium wide-bodied passenger aircraft were originally defined from the fleet forecast as CBin-9 (211 to 300 seats) and CBin-10 (301 to 400 seats). That fleet forecast-based approach was modelled as "**Path-B**" with CBin-9 and CBin-10 separated. An alternative "**Path-A**" approach modelled CBin-9/10 together. These different paths along with the equal product market share assumption resulted in a noticeable difference in the distribution of baseline operations. The original fleet forecast (Path-B) has an 82% to 18% distribution for the small and medium WB-PAX types; but 47% to 53% in the alternative (Path-A) modelling. The two paths have no noticeable consequence for the analysis until SO10 (mass5 #1) when some WB-PAX types no longer respond. Under Path-A, some small WB-PAX baseline operations are replaced by medium WB-PAX types at SO10 resulting in a noticeable capital cost increase. Results for the analysis are presented for all SO using the original fleet forecast (Path-B), as well as the alternative (Path-A) approach for SO10-12a.

3. ANNEX 16, VOLUME II AND THE ENVIRONMENTAL TECHNICAL MANUAL, VOLUME II

3.1 Overview of the nvPM Mass and Number Emissions Evaluation Metric

3.1.1 The provisions contained in the draft update to Part 3 Chapter 4 of Annex 16, Vol. II represent the SARPs for the certification of engine nvPM mass and number emissions for the standard ICAO LTO cycle: 1. The LTO nvPM mass emissions from the measured engines normalized by the given engine's rated thrust and plotted against the rated thrust; 2. The LTO nvPM number emissions from the measured engines normalized by the given engine's rated thrust and plotted against the rated thrust as follows:

3.1.1.1 nvPM Mass Metric Value:

$$\frac{LTO_{nvpm\_mass}}{F_{\infty}} = \frac{\sum_{LTO} t_m \times W_f \times EI_{nvpm\_mass}}{F_{\infty}}$$

3.1.1.2 nvPM number Metric Value:

$$\frac{LTO_{nvpm\_num}}{F_{\infty}} = \frac{\sum_{LTO} t_m \times W_f \times EI_{nvpm\_num}}{F_{\infty}}$$

Where: t_m time in mode [seconds s], W_f is the fuel flow [kg/s] and EI_{nvpm_mass} is the nvPM mass emissions index [mg/kg of fuel], EI_{nvpm_num} is nvPM number emissions index [particles/kg of fuel] and F_{∞} is the rated thrust [kN].

3.2 The Environmental Technical Manual (ETM), Volume II

3.3 An update to Part 3, Chapter 4 of the Environmental Technical Manual, Volume II (ETM, Vol. II) has also been developed to promote implementation uniformity of the technical procedures of Annex 16, Volume II by providing the following: (1) Guidance to certificating authorities, applicants and other interested parties regarding the intended meaning and stringency of the Standards in the current edition of the Annex; (2) Guidance on specific methods that are deemed acceptable in demonstrating compliance with those Standards and (3) equivalent procedures resulting in effectively the same nvPM emissions evaluation metric that may be used in lieu of the procedures specified in those Standards.

4. STRINGENCY OPTIONS

4.1 An important part of the Standard-setting process was the definition of the nvPM mass and number stringency options, which could be chosen to represent the eventual limit lines for the nvPM mass and number standards. Each stringency option for nvPM mass and number aimed to maintain the intended behaviour of the nvPM emissions metric; i.e., to equitably reward advances in engine technologies that contribute to reductions in engine nvPM emissions, and to differentiate between engines of different size and with different generations of technologies.

4.2 The development of the nvPM mass and number stringency options was based on the nvPM metric value database (nvPMVdb). The nvPMVdb contained engine test data provided directly from manufacturers and certification authorities on in-production engine types. Most of the measurements were targeted to comply with the CAEP/10 nvPM Standard (applicable from 1 January 2020), which contains the nvPM measurement system requirements, procedure and evaluation of LTO points and as such, the confidential nvPMVdb contained "certification-like" data. Overall, data from 23 engine types was used to develop the metric values and stringency options.

4.3 To correct nvPM emissions to standard day conditions, two proposed ambient conditions correction methodologies for nvPM mass and one for nvPM number were evaluated. Based on the results of the evaluation, it was concluded that additional tests may be needed and further analysis will be pursued in order to be able to propose satisfactory ambient corrections for nvPM mass and number emission indices (EIs), robust enough for inclusion into ICAO Annex 16, Volume II. For stringency options development, the nvPM emission EIs were not corrected for ambient conditions effects. The uncertainty on metric values for not correcting for ambient conditions have been taken into account, with an order of ± 10% for nvPM mass and ± 30% for nvPM number.

4.4 Application of fuel corrections was recommended and used the following functions to correct measured nvPM mass and number EIs to a fuel hydrogen content reference of 13.8% mass, hence normalising the nvPM emission values to the reference fuel for the stringency options development:

$$\boldsymbol{k_{FUEL\_M}} = exp\left\{\left(0.95\frac{F}{F_{00}} - 1.12\right)(13.8 - H)\right\}$$

$$\boldsymbol{k_{FUEL\_N}} = exp\left\{\left(0.99\frac{F}{F_{00}} - 1.05\right)(13.8 - H)\right\}$$

where $\boldsymbol{k_{FUEL\_M}}$ is the fuel correction factor for the nvPM mass emission index, $\boldsymbol{k_{FUEL\_N}}$ fuel correction factor for the nvPM number emission index, exp the exponential function, F the thrust in mode [*kN*], F_{00} the rated thrust [*kN*] and H the fuel hydrogen content measured in %mass.

4.5 In contrast to gaseous emissions not being lost in a leak-tight system, any particle measurement system will have losses for particles in the sampling system resulting in nvPM values at instrument level that will always be lower than the values at engine exit plane. The dominant particle loss mechanisms are particle size dependent and are higher for nvPM number than for nvPM mass. Relatively bigger particles penetrate better compared to smaller particles; however, larger particles contribute more to nvPM mass. For example, an engine emitting generally larger particles than a competitor engine would report higher nvPM number levels at the instrument, although it may have similar nvPM number levels at the engine exit plane.

4.6 Based on the state of science informed by data analysis, it was concluded that the metric values could not be corrected for system losses with confidence while noting that not correcting for system losses may lead to some bias between engine metric values especially for number emissions, despite the use of standardised measurement systems. This potential bias was not taken into consideration in the stringency options development for the following additional reasons. (1) The certified metric value of an engine depends on its own performance, not on the relative performance of another engine; and (2) the unintended consequence of not addressing the potential bias could be an incentive to design engines to emit even smaller particles. However, the proposed CAEP/11 Standard makes use of two metric systems, for nvPM mass and nvPM number, which work together. If particle sizes are reduced and e.g. the particle number does increase, the particle mass is reduced but the particle number will be higher. The measurement system is less responsive to the smallest particles but it does not cut them off and is still measuring them. The metric values for nvPM mass and number in the nvPMVdb show that in general, engines with a lower number emit less mass.

4.7 **nvPM Mass Stringency Options**

4.7.1 A specific nvPM mass regulatory limit for in-production (INP) engines with a proposed applicability date of 1 January 2023 was derived based on the measured data. The INP regulatory limit is designed to be an anti-backsliding Standard. Given the fact that a number of small engine technologies had relatively higher metric values, the INP regulatory limit has a decreasing metric value as thrust increases until the 200 kN kink point. For engines with rated thrusts greater than 200 kN, the data indicates no trend in metric values and therefore a constant metric value is chosen to provide the INP regulatory limit.

4.7.2 The five New Type (NT) nvPM mass stringency options are chosen with a 150 kN kink point. The 150 kN is chosen because: a) it is the best mathematical fit to the clusters of data from different technologies; and b) this allows for reduction in severity of stringency for engines of rated thrust below 89 kN without being very lenient. Above a rated thrust of 150 kN, the five stringency options have been prescribed as per cent reductions from NT-1 (0%, 16%, 44%, 72% and 82%) for which the metric value is set at 250 mg/kN. Below a rated thrust of 150 kN, these five options provide increasing margin to smaller engines due to associated technical challenges (200 per cent alleviation for NT-1 through NT-4 and 30 per cent for NT-5). Table 4.1 are the equations for the nvPM mass stringency lines are shown in Figure 4.1.

Table 4.1: nvPM Mass Stringency Equations for In-Production (INP) and New Type (NT) Engines

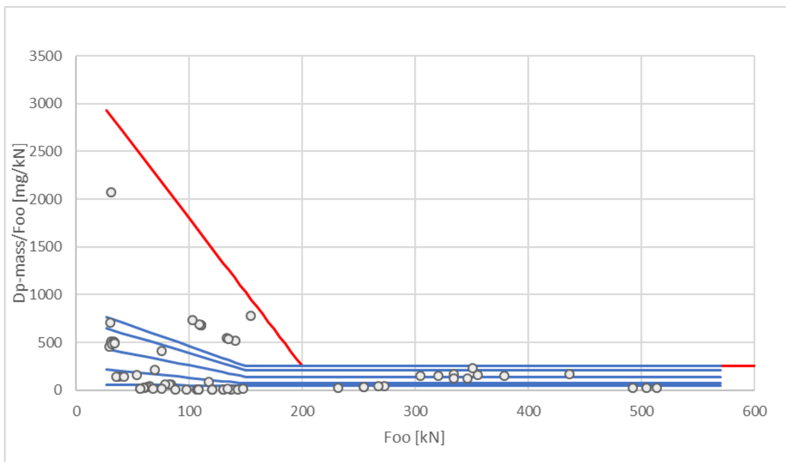
nvPM Mass Stringencies	Equations	Rated Output Range
INP	3343 – 15.465 F_{00}	26.7kN < F_{00} < 200 kN
	250	$F_{00} \geq 200$ kN
NT-1	879.1 – 4.19 F_{00}	26.7kN < F_{00} < 150 kN
	250	$F_{00} \geq 150$ kN
NT-2	738.4 – 3.52 F_{00}	26.7kN < F_{00} < 150 kN
	210	$F_{00} \geq 150$ kN
NT-3	492.3 – 2.35 F_{00}	26.7kN < F_{00} < 150 kN
	140	$F_{00} \geq 150$ kN
NT-4	246.1 – 1.17 F_{00}	26.7kN < F_{00} < 150 kN
	70	$F_{00} \geq 150$ kN
NT-5	61.5 – 0.11 F_{00}	26.7kN < F_{00} < 150 kN
	45	$F_{00} \geq 150$ kN

Figure 4.1: Proposed nvPM Mass Stringency Options.

The red line is the In-Production Regulatory Limit.

The blue lines represent the five proposed New Type nvPM Mass Stringency Options.

The circles are metric values obtained from the list of representative in-production engines in the nvPMVdb.



4.8 **nvPM Number Stringency Options**

4.8.1 One nvPM number stringency level for in-production engines with a proposed applicability date of 1 January 2023 was derived based on the cluster of data points across the thrust range. This necessitates a kink point at 200 kN. Given the trend of nvPM number metric values across the thrust range, use of one kink point is justified to represent this anti-backsliding stringency line.

4.8.2 The NT nvPM number stringency options are derived to be consistent with the mass stringency levels with a 150 kN kink point. The number of stringency options is limited to three, based on the analysis that reduction in nvPM mass does not translate to similar reductions in nvPM number metric values. Above a rated thrust of 150 kN, three stringency levels have been prescribed as per cent reductions from NT-1 (0%, 33% and 66%) for which the metric value is set at 3×1015 #/kN. The strictest stringency level for nvPM number has more margin to the best performing engines than for nvPM mass. Below a rated thrust of 150 kN, these three levels provide increasing margin to smaller engines due to associated technical challenges (200 percent alleviation for NT-1 through NT-3). The nvPM number stringency levels are shown in Figure 4.2. The equations for these lines are shown in Table 4.2.

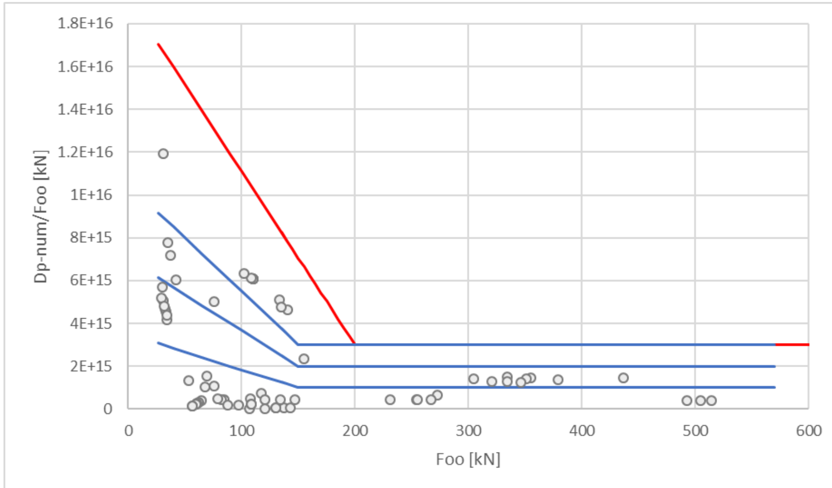


Figure 4.2: Proposed nvPM Number Stringency Options.

The red line is the In-Production Regulatory Limit.

The blue lines represent the three proposed New Type Stringency Options.

The circles are metric values obtained from the list of representative in-production engines in the nvPMVdb.

There are two additional stringencies for nvPM mass as reducing mass emissions is better understood at this point of time.

Table 4.2: nvPM Number Stringency Equations for In-Production (INP) and New Type (NT) Engines

nvPM Number Stringencies	Equations	Rated Output Range
INP	$1.92\times10^{16} - 8.1\times10^{13}\ F_{00}$	$26.7kN < F_{00} < 200$ kN
	3.0×10^{15}	$F_{00} \geq 200$ kN
NT-1	$1.05\times10^{16} - 5.0\times10^{13}\ F_{00}$	$26.7kN < F_{00} < 150$ kN
	3.0×10^{15}	$F_{00} \geq 150$ kN
NT-2	$7.03\times10^{15} - 3.36\times10^{13}\ F_{00}$	$26.7kN < F_{00} < 150$ kN
	2.0×10^{15}	$F_{00} \geq 150$ kN
NT-3	$3.52\times10^{15} - 1.68\times10^{13}\ F_{00}$	$26.7kN < F_{00} < 150$ kN
	1.0×10^{15}	$F_{00} \geq 150$ kN

4.9 nvPM Mass and Number Stringency Option Combinations (SO)

4.9.1 For the NT engines cost effectiveness analysis, the five nvPM mass and three nvPM number stringencies were combined to form the twelve stringency option combinations (SO) shown in Table 4.3. The colour differentiation is to indicate that the nvPM mass levels drive the responses for SO2, SO4, SO5 and SO7 to SO12, while the nvPM number levels drive the responses for SO1, SO3 and SO6.

Table 4.3: nvPM Mass and Number Stringencies Modelled for New Types

	nvPM number Stringency 1	**nvPM number Stringency 2**	**nvPM number Stringency 3**
nvPM mass Stringency 1	SO-1		
nvPM mass Stringency 2	SO-2	SO-3	
nvPM mass Stringency 3	SO-4	SO-5	SO-6
nvPM mass Stringency 4	SO-7	SO-8	SO-9
nvPM mass Stringency 5	SO-10	SO-11	SO-12

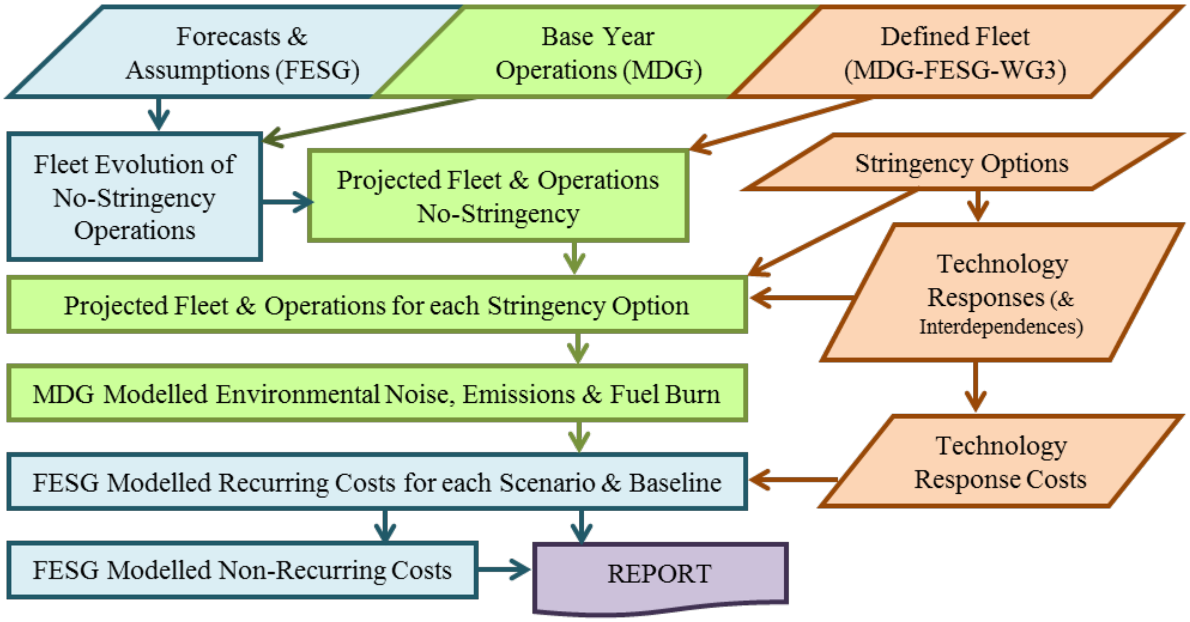
5. COST EFFECTIVENESS ANALYSIS APPROACH

5.1 In order to address the CAEP tenets of environmental effectiveness and economic reasonableness, CAEP has conducted a full cost effectiveness analysis. This involved the definition of an analysis framework and analytical tools, including fleet evolution modelling, environmental modelling, recurring costs, non-recurring costs, and costs per nvPM mass and number emissions avoided. The analysis was conducted with the aim of providing a reasonable assessment of the economic costs and environmental benefits for a potential nvPM mass and number emissions Standard in comparison with a "No ICAO action" baseline. The models that contributed to the analysis are listed in Table 5.1 and a high-level overview of the modelling process is provided in Figure 5.1.

Table 5.1: Contributing Models

	Model	Area	Sponsor
AAT	Aircraft Assignment Tool	Fleet Evolution	EUROCONTROL, EC and EASA
APMT-E	Aviation Portfolio Management Tool for Economics	Fleet Evolution & Costs	US
FCM	FESG Cost Model for nvPM	Cost-Effectiveness	FESG
FAST	Future Civil Aviation Scenario Software Tool	GHG	UK
IMPACT		GHG	EUROCONTROL
AEDT	Aviation Environmental Design Tool	GHG and Noise	US
ANCON	Aircraft Noise Contour Model	Noise	UK
STAPES	SysTem for AirPort noise Exposure Studies	Noise	EUROCONTROL, EC and EASA
MDG Landing and Take-Off cycle (LTO) Consensus Model		LTO Emissions	MDG

Figure 5.2: Analysis Process Overview



5.2 Defining the Global Fleet

5.2.1 The analysis process requires defining aeroplane and engine types that enter into the global fleet during the forecast years up to 2042, for both the baseline and each SO. This information is collated into the Growth and Replacement database (GRdb). This database documents all of the information required by the modelling community regarding each aeroplane and engine type in the analysis, both in their base configuration and as defined for each SO. The GRdb also includes references to other data sources such as the ICAO Aircraft Engine Emissions Databank and the ICAO noise certification database (NoisedB).

5.2.2 The GRdb was defined with aeroplane and engine types that are both in-production (InP) and scheduled for entry into the fleet before 2023. For products that remain to be certified, the information required for modelling (project data) were provided by manufacturers. (The analysis did not speculate on potential future technology developments.) The baseline analysis scenario included some InP types going out of production and replaced by types entering the fleet prior to the 2023-implementation year. The transition between these paired types was immediate; i.e., there was no over-lapping “ramp up/ramp down” of production between transition pairs for this analysis. Because the transitioning process ended before the 2023 stringency applicability year, it had no effect on the results.

5.2.3 Another element defined in the GRdb are competition bins (CBins), which align to the fleet forecast seat classes. There can be a one-to-one relationship between the fleet forecast seat classes and CBins (as was the case for business jets); however, CBins have also been used to separate regional jets and turboprops[4] (which are not separated in the fleet forecast). While CBins are required for the modelling process, results are primarily reported with all markets combined or at a market-specific level. Table 5.2 shows the market shares of all baseline aviation markets combined versus only those subject to the proposed CAEP/11 nvPM mass and number Standards.

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[4] Turboprops are not subject to the proposed nvPM mass and number standards

Table 5.2: Comparison of All Baseline Path-B (2025-2042) **Operations vs. Those Subject to nvPM**

Market	All Operations Market Share	Operations Subject to nvPM Market Share	Operations Not Subject to nvPM Market Share
Narrow Body Passenger (NB-PAX)	55.6%	63.6%	0%
Wide Body Passenger (WB-PAX)	24.8%	28.4%	0%
Turboprops	9.2%	0.0%	73%
Business Jets (BJ)	7.6%	6.1%	18%
WB-Freighters	1.7%	1.5%	3%
NB-Freighters	1.1%	0.4%	6%
Total	100%	100%	100%

5.3 **Two Paths**

5.3.1 The analysis for the potential CAEP/11 nvPM mass and number Standards included a portion of the GRdb fleet modelled in two ways. Small and medium wide-bodied passenger aircraft were originally defined from the fleet forecast as CBin-9 (211 to 300 seats) and CBin-10 (301 to 400 seats). That fleet forecast-based approach was modelled as "**Path-B**" with CBin-9 and CBin-10 separated. An alternative "**Path-A**" approach modelled CBin-9/10 together. These different paths along with the equal product market share fleet evolution modelling assumption resulted in operations being distributed differently between the small and medium WB-PAX aircraft, as shown in Table 5.3.

Table 5.3: Operations distribution between CBin-9 and CBin-10 for Path-A and Path-B.

	Alternate Path-A BSL CBin-9/10 Combined	Path-A SO10 CBin-9/10 Combined	Forecasted Path-B BSL CBin-9 vs CBin-10 Separated	Path-B SO10 CBin-9 vs CBin-10 Separated
CBin-9 %	47%	46%	**82%**	**82%**
CBin-10 %	**53%**	**54%**	18%	18%

5.3.2 The "all-market" level results, presented later in the document, indicate whether the small and medium WB-PAX aircraft component is from Path-A or Path-B by the letter after the SO number; e.g., SO10a and SO10b. In most figures, all Path-B SO results are shown along with the Path-A SO10-12a on the right since SO10 through SO12 are where the two paths have the most notable differences in results, and because Path-B represents the original fleet forecast.

5.4 **Fleet Evolution Modelling**

5.4.1 Fleet evolution models use forecasted fleet and traffic demand as targets to project a scenario-compliant future fleet-specific schedule of operations and generate required inputs for the environmental models. The fleet evolution modelling process requires the following. (1) Base-year data, including a fleet-specific schedule of operations and the age profile for the base-year fleet. (2) The GRdb defined for the baseline (no stringency) and for each SO, and including seat/capacity assumptions for each aircraft/engine. (3) Fleet and traffic forecast targets along with compatible (4) aircraft retirement curves.

5.4.2 Depending on the "fleet choice" assumption used for particular analysis, costs can also be required for fleet evolution modelling. However, the fleet choice assumption for the CAEP/11 nvPM mass and number Standard analysis was "Equal Product Market Share" in which each available (scenario compliant) aircraft/engine within a competition bin is used equally (without considering operating costs).

5.4.3 The fleet-specific schedule of operations varies from the baseline when a GRdb entry does not respond to an SO, and is assumed to go out of production at the implementation date. The technology response nvPM Improvement (NI) levels do not impact fleet selection. Therefore, the fleet evolution modellers only needed to model four scenarios to represent the twelve SO defined for the cost-effectiveness analysis. This point is highlighted in Table 5.4; namely, a run where all engine families remain in the analysis; a run where one drops out of the analysis; a run where two drop out of the analysis; and a run where eleven drop out of the analysis.

Table 5.4: Summary of Engine Family nvPM Technology Responses

	BSL	SO1 m1n1	SO2 m2n1	SO3 m2n2	SO4 m3n1	SO5 m3n2	SO6 m3n3	SO7 m4n1	SO8 m4n2	SO9 m4n3	SO10 m5n1	SO11 m5n2	SO12 m5n3
Pass	33	31	28	26	23	22	21	18	18	18	13	13	13
NI1	0	0	1	1	1	1	0	1	1	1	0	0	0
NI2#	0	1	1	3	2	2	1	0	0	0	0	0	0
NI2M	0	0	2	1	2	2	0	2	2	2	1	1	1
NI3	0	1	1	1	5	5	9	10	10	10	8	8	8
No Response	0	0	0	1	0	1	2	2	2	2	11	11	11

5.4.4 When a growth and replacement fleet option (GRdb type) does not respond to an SO, the consequence varies by how much the remaining CBin growth and replacement options differ from the GRdb type(s) that do not respond. Apart from emissions improvements, the change from baseline stringency-results become more pronounced the more a stringency scenario fleet otherwise differs from the baseline fleet. Fuel burn and cost elements for individual GRdb types are part of the change; however, capacity differences magnify the change from the baseline because the levels of operations and deliveries change, which results in more (positive or negative) fuel burn, capital and direct operating cost changes.

5.5 **nvPM Mass and Number Emissions Modelling**

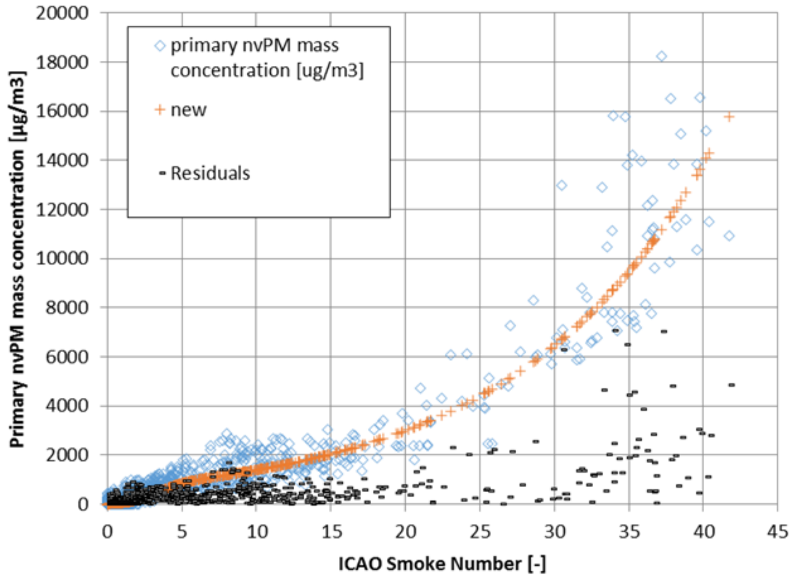
5.5.1 As much as possible, the 2012 base year and GRdb fleets were mapped to measured emission indices (EIs) from the nvPM metric value database (nvPMVdb) and provided directly from manufacturers. However, there were no measured nvPM emissions available for eleven of the thirty-three GRdb engine families represented in the analysis; so, the nvPM mass and number metric values for those engines had to be estimated. Those estimations were based on certified ICAO Smoke Numbers and correlation to nvPM derived-from-measurement comparisons between Smoke Numbers and nvPM.

5.5.2 A large set of nvPM mass concentration to Smoke Number pairs was available as more engines were tested and a correlation database (Cdb) was updated using these measurements. With this larger set of data pairs, the Cdb correlation of nvPM mass concentration to SN could be more reliably determined. An improved correlation and the corresponding equations have been derived, based on this more extensive data set. The updated correlation can be expressed as:

$$nvPM\ mass\ concentration\ [\mu g/m3] = \frac{648.4\, e^{(0.0766\, SN)}}{1 + e^{-1.098(SN - 3.064)}}$$

5.5.3 This correlation was recommended for use in estimating nvPM mass concentrations when measured nvPM mass data is not available and SN data is available. In particular, this correlation was used to calculate the nvPM mass Emission Index (EI) in conjunction with the Fuel to Air Ratio (FAR) estimation procedure previously developed for the published, so called FOA3 method used before, to estimate PM LTO mass emissions from aircraft engines.

Figure 5.2:
Updated smoke number to mass concentration correlation



5.5.4 The new Smoke Number to nvPM mass correlation was named SCOPE11 and provides estimations of nvPM mass EIs corresponding to measured values at instrument level of an nvPM standard measurement system required for aircraft engine nvPM emission certification. An additional step was the estimation of nvPM number EIs, which is based on the nvPM mass EIs estimated from smoke number with SCOPE11 as provided by the equation below:

$$nvPM_{EI_{number,i}} = \frac{nvPM_{EI_{mass,i}}}{\left(\frac{\pi}{6}\right) \cdot GMD_i^{\ 3} \cdot \rho_i \cdot e^{(4.5\ (ln\ \sigma_i)^2)}}$$

Where $nvPM_{EI_{number,i}}$ is the nvPM number EI of LTO mode i (idle, approach, climb-out, take-off). $nvPM_{EI_{mass,i}}$ is the nvPM mass EI of LTO mode i. GMD_i is the geometric mean diameter of the particles in mode i (recommended values used in modelling provided in paragraphs below). ρ_i is the assumed particle effective density (proposed value for all modes 1 g/cm^3). σ_i is the dimensionless geometric standard deviation of an assumed one-mode lognormal distribution (proposed value for all modes 1.8).[5]

5.5.5 Two approaches were used in modelling nvPM number emissions from the mass EIs estimated from Smoke Number.

5.5.5.1 Approach 1: Use of a mode-specific set of GMDs with fixed values for the four LTO modes (GMD = 20 nm at idle and approach, 38 nm at climb-out and 41 nm at take-off thrust conditions).

5.5.5.2 Approach 2: Use a mass concentration-GMD relationship, which was given with the following formula:

$$GMD = 12.5 \cdot C^{0.15}$$

5 Note that unit conversion factors may be needed depending on the units used in the formula

Where C is the nvPM mass concentration in μg/m^3 in the engine core, estimated using the SCOPE11 correlation and the GMD is the geometric mean diameter in nm.

5.5.6 The modellers estimated the nvPM number emissions using both approaches. While nvPM number metric values and emissions estimated using the two approaches were different, this did not adversely affect the technology response. This is because the engines for which the nvPM emissions had to be estimated using Smoke Number were driven by the mass components of the combined stringency options.

5.6 **Environmental Modelling**

5.6.1 Landing and Take-Off cycle (LTO) Modelling – Time in mode-based LTO modelling was used with the ICAO/CAEP Modelling and Database Group (MDG) LTO Consensus Model for this analysis.

5.6.2 Project Data – The information required for modelling products that remain to be certified were provided by manufacturers. Modellers applied adjustments to fuel burn and emissions for all project types entering the fleet in the future years. A separate adjustment was also applied to the NOx results when specified. These results were applied as a scalar multiplier to each operation in the LTO dataset.

5.6.3 Trajectory Assumptions – Traditionally, CAEP full-flight greenhouse gas (GHG) emissions and fuel burn modelling has involved the use of great circle trajectory for the underlying origin-destination (OD) pairs as defined in the COD. For this analysis, however, all possible aircraft/engine types were modelled flying 18 representative tracks for the maximum possible range. In addition, each aircraft/engine type was modelled flying the type-specific minimum and maximum OD pair from the 2012 Common Operations Database (COD). Operations from each analysis year were then mapped to one of these tracks and all the parameters were interpolated (except for the minimum and maximum distance in which case the values were directly used) based on the actual and representative OD distances. In addition, AEDT modellers also processed base year 2012 using the traditional modelling method and compared the results with the representative tracks approach. Distance and fuel burn were within 0.5% and all other parameters were within 1% between the two approaches.

5.6.4 Other Environmental Modelling – Trade-off response modelling is the assessment of potential environmental disbenefits that may occur when technology improvements are focused on a single pollutant. While a range from zero to “full” noise and emissions trade-offs were modelled with the analysis submitted to CAEP, engines obtaining new type certificates are required to pass standards for all regulated pollutants; so, that data is not relevant for this document.

5.7 **Cost Modelling**

5.7.1 Recurring – Direct operating costs (DOC) include fuel costs, capital costs (depreciation and finance) and other-DOCs (crew, maintenance, landing and route costs).

5.7.2 Non-Recurring – Because there are no limiting nvPM mass and number standards, there is no historic data on fleet valuation impacts on owner/operators or on how manufacturers will determine the technology response given changes in market demand associated with potential regulatory levels. Consistent with standard principles of economic analysis, all relevant recurring and non-recurring cost (NRC) items should be accounted for in the cost analysis for a potential Standard. Among these cost items, non-recurring (N-R) aircraft owner/operator (AO/O) costs may include a loss in fleet value that could be incurred by aircraft owners and operators for fleet assets that would not meet the stringency options; referred to as asset value loss (AVL). This is based on the premise that the introduction of a new Standard would reduce the market value of existing fleets that do not meet the Standard, even if the Standard does not apply to the in-service aircraft. However, it should be noted that CAEP has not definitively stated whether AVL costs should be included and therefore the results of the analysis were considered with and without AVL.

5.7.3 NRC was used to represent technology response (TR) costs. It is understood, however, that while NRC capture the fixed cost associated with developing TR to pass a standard level, they do not reflect additional production cost of implementing these responses, i.e., material, labour and other recurring costs. The analysis assumes that the cost of manufacturing remains unchanged before and after TR, whereas the additional technology contained in a TR may cost more to manufacture.

5.7.4 Further details on the NRC assumptions are provided in Section 6.

6. TECHNOLOGY RESPONSE ASSUMPTIONS

6.1 Non-Recurring Manufacturer Technology Response Cost (NRC)

6.1.1 The need for considering the inclusion of manufacturer non-recurring cost (NRC) into the analysis arises from the stringency option combinations where one or more engine-family does not meet a stringency and receives a technology response (TR) to remain in the market. NRC captures the fixed costs associated with developing the TR applied to engine-families so that they pass the standard, but not any additional production costs associated with implementing TR. Thus, NRC does not include material, labour or other recurring costs. WG3 developed the technology responses and defined the non-recurring manufacturer costs. The agreed TR framework, as applied to the GRdb engine-families, is summarized in Table 6.1. The agreed TR framework included single, low and high NRC values. Table 6.2 shows the single NRC values applied for the respective NI levels by SO in the second through fourth columns; the last three columns show the total NRC by SO for the single, low and high NRC values respectively.

Table 6.1: Summary of Engine Family nvPM Technology Responses

	Pass	NI1	NI2#	NI2M	NI3	No Response
Baseline	33	0	0	0	0	**0**
SO-1: NT SO mass1 #1	31	0	1	0	1	**0**
SO-2: NT SO mass2 #1	28	1	1	2	1	**0**
SO-3: NT SO mass2 #2	26	1	3	1	1	1
SO-4: NT SO mass3 #1	23	1	2	2	5	**0**
SO-5: NT SO mass3 #2	22	1	2	2	5	1
SO-6: NT SO mass3 #3	21	0	1	0	9	2
SO-7: NT SO mass4 #1	18	1	0	2	10	2
SO-8: NT SO mass4 #2	18	1	0	2	10	2
SO-9: NT SO mass4 #3	18	1	0	2	10	2
SO-10: NT SO mass5 #1	13	0	0	1	8	11
SO-11: NT SO mass5 #2	13	0	0	1	8	11
SO-12: NT SO mass5 #3	13	0	0	1	8	11

Table 6.2: Manufacturer Non-Recurring Costs for Engine Family Responses

Single Value NRC ($M)	$15	$250	$150	$500	Single Value	Low NRC	High NRC
	NI1	NI2#	NI2M	NI3	NRC TOTAL	TOTAL	TOTAL
SO-1: NT SO mass1 #1	$-	$250	$-	$500	$750	$450	$1,050
SO-2: NT SO mass2 #1	$30	$250	$150	$500	$930	$560	$1,350
SO-3: NT SO mass2 #2	$15	$750	$150	$500	$1,415	$955	$1,900
SO-4: NT SO mass3 #1	$15	$250	$450	$2,500	$3,215	$1,755	$4,700
SO-5: NT SO mass3 #2	$15	$500	$300	$2,500	$3,315	$1,855	$4,800
SO-6: NT SO mass3 #3	$-	$250	$-	$4,500	$4,750	$2,450	$7,050
SO-7: NT SO mass4 #1	$-	$-	$150	$5,000	$5,150	$2,600	$7,700
SO-8: NT SO mass4 #2	$-	$-	$150	$5,000	$5,150	$2,600	$7,700
SO-9: NT SO mass4 #3	$-	$-	$150	$5,000	$5,150	$2,600	$7,700
SO-10: NT SO mass5 #1	$-	$-	$150	$3,500	$3,650	$1,850	$5,450
SO-11: NT SO mass5 #2	$-	$-	$150	$3,500	$3,650	$1,850	$5,450
SO-12: NT SO mass5 #3	$-	$-	$150	$3,500	$3,650	$1,850	$5,450

6.2 Non-recurring aircraft owner/operator Asset Value Loss (AVL)

6.2.1 Consistent with prior FESG practice and standard principles of economic analysis, all relevant recurring and non-recurring cost items should be accounted for in the cost analysis of the stringency option combinations. Among these, non-recurring (N-R) owner/operator (O/O) costs may include a loss in fleet value that could be incurred by owners and operators for fleet assets that would not meet a new standard (represented in the analysis by the stringency option combinations). This Asset Value Loss (AVL) is based on the following premises. (1) The introduction of a new Standard would reduce the market value of existing fleets that do not meet the Standard, even if the standard does not apply to the in-service fleet. (2) The introduction of a new Standard would cause a loss of fleet commonality between pre-Standard assets and new compliant-fleet assets.

6.2.2 The method used in this analysis uses much of the methodology developed for the CO_2 main analysis (CO2ma) that informed the CAEP/10 Standard.[6] As with the CO2ma, fleet assets subject to AVL are all those in the growth and replacement database that do not pass the nvPM stringency option combinations and enter the fleet between the announcement and implementation dates. For example, if the Standard is announced in 2019 and implemented in 2025, AVL would be assessed for aircraft that entered the fleet in 2020, 2021, 2022, 2023 and 2024.

6.2.2.1 <u>How to recognize AVL</u>: It is acknowledged that accounting practices allow for asset value losses and that they are recorded as impairment charges. When there is a change in the operating environment, such as the implementation of a new regulation, negative impacts on an asset's value are recorded in financial statements as an impairment loss.

6.2.2.2 <u>When to recognize AVL</u>: For the purposes of the modelling, an impairment charge is being used as a proxy for the actual realized market value loss, which would be recognized when an aircraft being assessed an AVL is sold. The idea is to consider the loss an operator would incur by selling an aircraft before the end of its economic life at a lower cost than initially estimated when the aircraft was purchased. For this purpose, it is assumed that asset values as projected through depreciation schedules are sensible proxies for resale prices.

[6] CAEP/10-IP/06 Appendix E, and to FESG-MDG in CAEP/11-FESG-MDG/6-WP/15, January 2018

6.2.2.3 It is also assumed that the impairment charge calculated at the implementation date will be equal to the loss in value when aircraft are sold when they near the end of the first third of their 25-year economic useful lives, that is, 8 years after their entry into service. This is due to the fact that, under the assumption of parallel depreciation curves, the impairment charge calculated at the Standard implementation date will be the same as the loss in market value observed when an aircraft is sold.

6.2.2.4 Estimating the AVL connected to the nvPM stringency analysis: Similar to the CAEP/8 NOx Standard analysis (NOx/8), the loss of asset value is tied to reduction in value to the engines that do not pass the Standard, whereas engines delivered from the Standard effective date will have technologies that allow them to pass the Standard. The magnitude of the value of the AVL or impairment charge for the current analysis was developed from the NOx/8 work.

6.2.2.5 One method for calculating lost value in engine fleets delivered before the stringency effective date that would not pass the Standard is to estimate the "upgrade" retrofit cost required to allow those same engines to pass the new Standard through engine improvements. For the NOx/8, the engine manufacturer experts had scaled the costs of existing emissions kits to develop cost estimates for hypothetical engine modification packages.

6.2.2.6 Table 6.3 shows the AVL values used for NOx/8 along with the values to use for the nvPM stringency analysis. The values for CAEP/8 were in 2009 US Dollars. The cost analysis for nvPM is in 2012 US Dollars. The agreed approach is to use the CAEP/8 values by Modification Status (MS) level and escalate them to 2012 US Dollars. That requires a 1.07 escalation factor.

Table 6.3 – CAEP/8 AVL

CAEP/8 Technology Response	**AVL per Engine**
MS1: Minor Changes	0
MS2: Scaled Proven Technology	$250,000
MS3: New Technology	$500,000

Table 6.4 – CAEP/11 AVL

Technology Response	**AVL per Engine**
NI1	0
NI2	$268,000
NI3	$535,000
No Response	$535,000

6.2.3 Table 6.4 presents the escalated values to use for the CAEP/11 nvPM stringency analysis. For CAEP/11, there are significantly more “no technical” responses at the higher stringency option combinations which wasn’t the case for the CAEP/8 NOX Standard analysis. Therefore, an additional impairment charge value is needed for the “no responses” in the CAEP/11 analysis. It has been agreed to use the highest technical response, NI3, value as a proxy. However, it should be acknowledged that with a “no response”, the aircraft goes out of production and the loss of asset value may be underestimated.

6.3 Spare Engine Costs

6.3.1 Spare engines are required by operators to cover scheduled maintenance visits and unscheduled engine removals. By exchanging a ready-to-fly spare engine for an on-wing engine that requires repair, operators can keep their aircraft flying with minimum lost time on the ground while the removed engine is sent to a maintenance provider for servicing.

6.3.2 The introduction of a new Standard would cause a loss of fleet commonality between pre-Standard assets and new compliant-fleet assets. This would incur additional owner/ operator costs to maintain spare engines for the portion of the fleet acquired before the Standard effectiveness date and a separate set of spare engines for the subsequently acquired fleet.

6.3.3 A review and survey were conducted regarding the spare engine assumptions used for the CAEP/6 and CAEP/8 NOx stringency analyses because those were based on 15-year old data that did not consider the business jet market. In addition, there were concerns that assets may be managed differently with the rise of engine leasing.[7]

6.3.4 IATA 2018 inputs were assessed against the CAEP/6 and CAEP/8 assumptions with the conclusion that the requirement for spare engines has trended lower for the commercial passenger and freighter markets than previously calculated.[8]

6.3.5 The business jet segment's investment in spare engines is somewhat similar to the commercial segment, however the business jet operators rely ever more greatly on the engine manufacturers and maintenance repair organizations (MROs) to invest in a pool of engines and make them available to the operator on a rental basis to support scheduled and unscheduled maintenance and inspections. With input from two IBAC member companies, the conclusion was to use the agreed upon commercial fleet spare engine curve to also represent the business jet market. From a global perspective, a similar relationship of spare engines required, measured in terms of percent of in-service fleet, should hold for business jet and commercial operators. The engine manufacturers and MRO providers act effectively in bringing efficiencies to the market by bringing small fleets together to act like a large fleet in terms of spare asset management.

6.3.6 An investigation was made into the relationship between aircraft and engine prices; and the linear regression that is a function of airplane price was used to estimate spare engine prices for the families that require a NI3 technical response to meet certain stringency option combinations. Average engine price was calculated for the engines grouped by aircraft retirement code and the results are presented in Table 6.5.

[7] CAEP/6-IP/13, Economic Assessment of the NOx Stringency Options, and CAEP/8-IP/14, Economic Assessment of the NOx Stringency Scenarios

[8] CAEP/11-FESG-MDG/7-WP/08

Table 6.5: Spare Engine Price Assumptions

Aircraft Retirement Code	Spare Engine Price (US2012$ Millions)
B_WB_PAX	$11.3
G_NB_FRT	$6.5
H_WB_FRT	$5.3
A_NB_PAX	$5.1
F_BJ	$3.4

6.3.7 Commonality Factor – The CAEP/8 NOx stringency analysis assumed that the requirements for extra spare engines would apply to 50% of the engines receiving a modification status level 3 (MS3) technology response. It was assumed that the other 50% of engines (receiving a MS3 technology response) could be mixed with the engines that they replaced and so did not require additional spare engines to be acquired. Lacking information to contradict the CAEP/8 assumption, the 50% commonality factor for engines receiving a NI3 response (equivalent to the CAEP/8 MS3 response) for the present analysis.

6.4 Lost Revenue Assessment

6.4.1 The cost impact for lost revenue is directly linked to engines receiving a NI3 tech response, where there is a 0% to 0.5% fuel burn penalty trade-off from technology to improve nvPM mass and number. The population of flights (operations) for which this cost impact is assessed is limited to those flights that are operated at long-range distances where the aircraft is operated at its maximum take-off mass (MTOM). For previous CAEP analyses, the percentage of an aircraft's total operations has been on the order of 0% to 2% for narrow body aircraft and 5% for wide body aircraft.

6.4.2 For the current CAEP/11 nvPM stringency analysis, forecast operations have been allocated into separate Competition Bins (CBins) that are organized by aircraft operating up to their MTOW and where the distance bands being operated on exceed the aircrafts' MTOW at full passengers; thus, the operations for these aircraft are at lower payloads to meet the long-range requirements.[9] It is this last set of CBins with long-range missions that would be impacted by an incremental fuel penalty from the NI3 tech response. An amount of payload has to be "off-loaded" so that additional fuel can be loaded to cover the incremental fuel penalty and still operate at a take-off mass that doesn't exceed the MTOM of the aircraft. Cargo is restricted first before blocking off seats to restrict revenue passengers. The reduction in payload to offset the incremental NI3 fuel penalty is approximated by a reduction in revenue belly cargo at a distance where aircraft is operated at MTOM.

6.4.3 To assess the cost impact for lost revenue the first step is to identify the aircraft models that would be impacted. For the CAEP/11 nvPM stringency analysis, the impacted aircraft are models belonging to the wide body segment that at a given level of stringency receive a NI3 tech response. The aircraft impacted for the nvPM stringency analysis are 787, A330neo, A350 and A380.

[9] Reduced capacity wide-bodied aircraft were used for operations above 999nmi in CBin-33 (85 seats); above 2499nmi in CBin-34 (100 seats) and CBin-35 (125 seats); above 3499nmi in CBin-36 (150 seats), CBin-37 (175 seats) and CBin-38 (210 seats); and above 6499nmi in CBin-39 (300 seats).

6.4.4 To simplify the analysis and to protect proprietary data, a single blended value was computed for the payload "off-loaded" at the long-range distances where the aircraft is operated at their respective MTOM.

Average cargo impact from off-loaded payload = 0.17 tonnes

6.4.5 The next step is to choose a representative cargo revenue yield. For the CAEP/8 NOx stringency analysis, cargo yields were determined from comparing IATA 2007 system average yields, yield data collected by a manufacturer from the 2008 Association of European Airlines (AEA) Star Report and data obtained from public sources used as inputs in the APMT-Economics model. The values were reasonably close. The system wide values were adjusted to the 5000 NM distance using the yield - distance adjustment curve. The cargo revenue yield value for CAEP/8 was $$0.26/RTK, in 2009 US Dollars. This cargo revenue yield was inflated to 2012 US dollars using the US Consumer Price Index (CPI) and the resulting value was $0.28/RTK.

6.4.6 The final step is to perform a set of calculations to estimate the lost revenue for each impacted aircraft for the forecast years 2032 and 2042, then interpolate the intermediate years and calculate the cumulative and present value of the lost revenue. The following equation illustrates the approach.

Lost Revenue per year =
Off-loaded payload * C-Bin Distance * Cargo Yield ($0.28 / RTK) * number of operations at MTOM

6.4.7 The lost revenue for each impacted aircraft is then aggregated to report a global cost impact for each stringency option combination.

6.5 **Other Costs**

6.5.1 In subsequent sections, the label "Other Costs" represents the lost revenue, spare engine, maintenance and incremental build costs.

7. COST EFFECTIVENESS ANALYSIS RESULTS

7.1.1 As shown in Table 5.4, the nvPM technology responses are slightly different for stringency option combinations SO1 to SO6; but they are the same for SO7 to SO9 and for SO10 to SO12. With these inputs, the cost and benefit consequences will be slightly different for the SO1 to SO6 stringency option combinations. Stringency option combinations SO7 to SO9 are defined by mass stringency 4 and number stringencies 1, 2, and 3, respectively. The same engine family technology responses were provided for SO7 to SO9 because mass stringency 4 is determined to be the driving force for these technology responses. Likewise, SO10 to SO12 are defined by mass stringency 5 and number stringencies 1, 2, and 3, respectively. The same engine family technology responses were provided for SO10 to SO12 because mass stringency 5 is determined to be the driving force for these technology responses. It is therefore understandable that there are identical cost and benefit results for SO7 to SO9, and for SO10 to SO12

7.2 The LTO nvPM mass and number emissions results are shown in Figures 7.1 and 7.2. Note that responding engines get their maximum nvPM Improvement (NI) level as soon as they respond. Thus, when an engine is defined to have an NI3 mass response to pass SO3 through SO9, the NI3 benefits are those achieved at SO9 for all NI3 responses. This response approach results in identical costs and benefits for combined SO7 to SO9, as well as combined SO10 to SO12.

Figure 7.1: LTO nvPM Mass (t) Change from Baseline, Cumulative 2025-2042

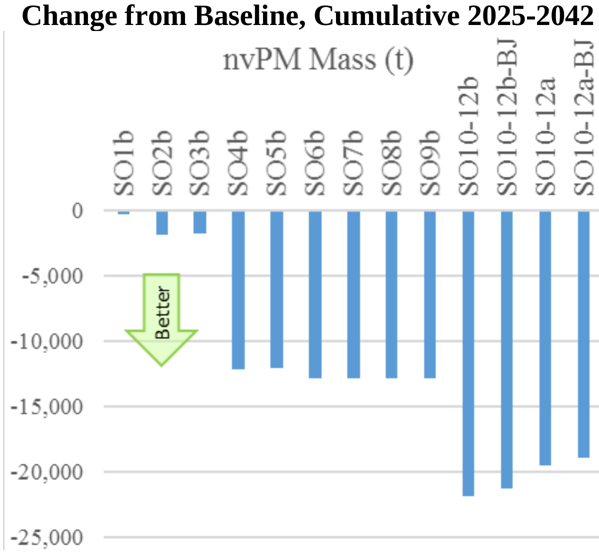
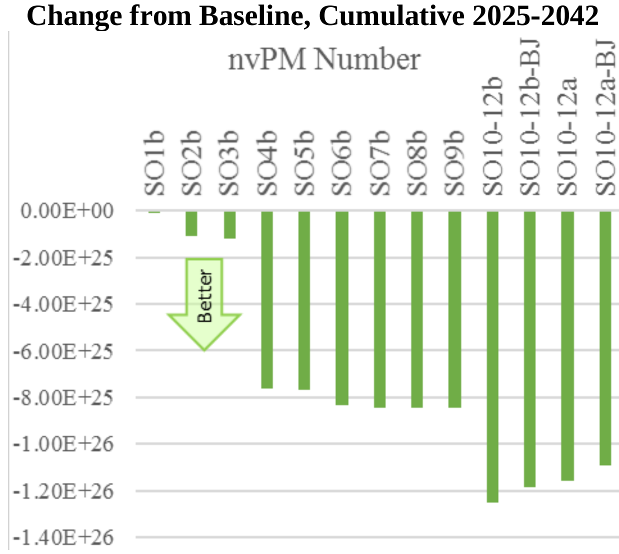


Figure 7.2: LTO nvPM Number Change from Baseline, Cumulative 2025-2042



7.3 The costs calculated included: fuel[10] costs, capital costs (depreciation and finance), other direct operating costs (crew, maintenance, landing and route costs), non-recurring aircraft owner/operator asset value loss (AVL), non-recurring manufacturer technology response cost (NRC), spare engine costs, incremental build costs, maintenance costs and lost revenue for long-range flights that are impacted by the fuel trade-off penalty. In subsequent figures, the label 'Other Costs' represents the lost revenue, spare engine, maintenance and incremental build costs.

[10] Figures reflect the full fuel-burn trade-off penalty, which applied .25% to all operations performed by NI3 responding types.

7.4 Undiscounted change in cumulative (2025-2042) costs (Billions US2012$) is presented in Figure 7.3a for all markets combined. From left to right results are first shown using the original fleet forecast (Path-B), with SO10 to SO12 shown together (SO10-12b); followed by the Path-B SO10 to SO12 combined results minus the business jet market (SO10-12b-BJ). The last two columns on the right are the alternative (Path A) approach for SO10-12a, and those minus the business jet market (SO10-12a-BJ). Figure 7.3b is also provided to zoom in on the SO1 through SO9 results.

Figure 7.3a: Change in Cumulative Costs (2025-2042, 2012$ Billions)

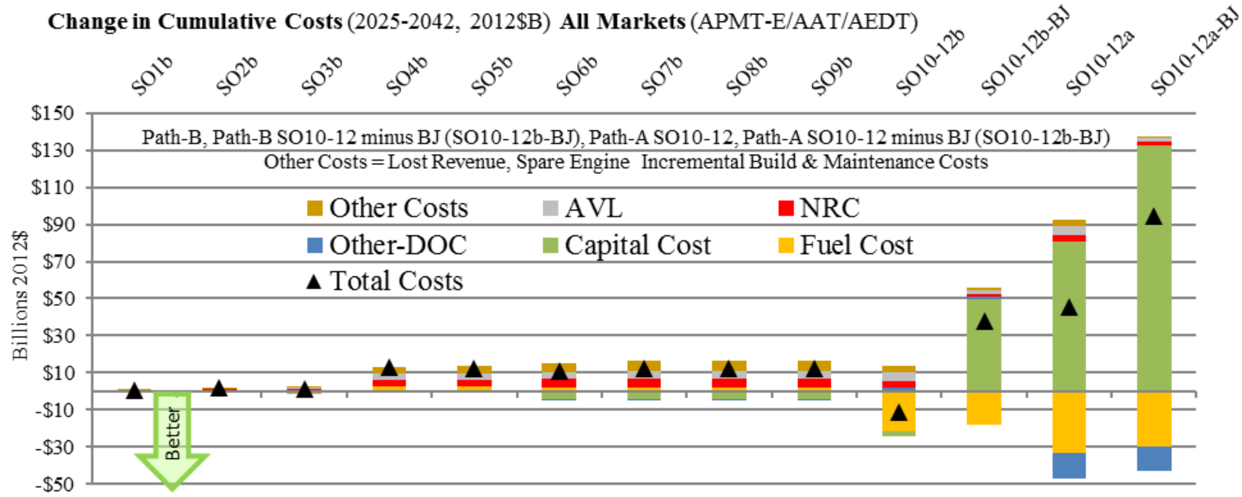
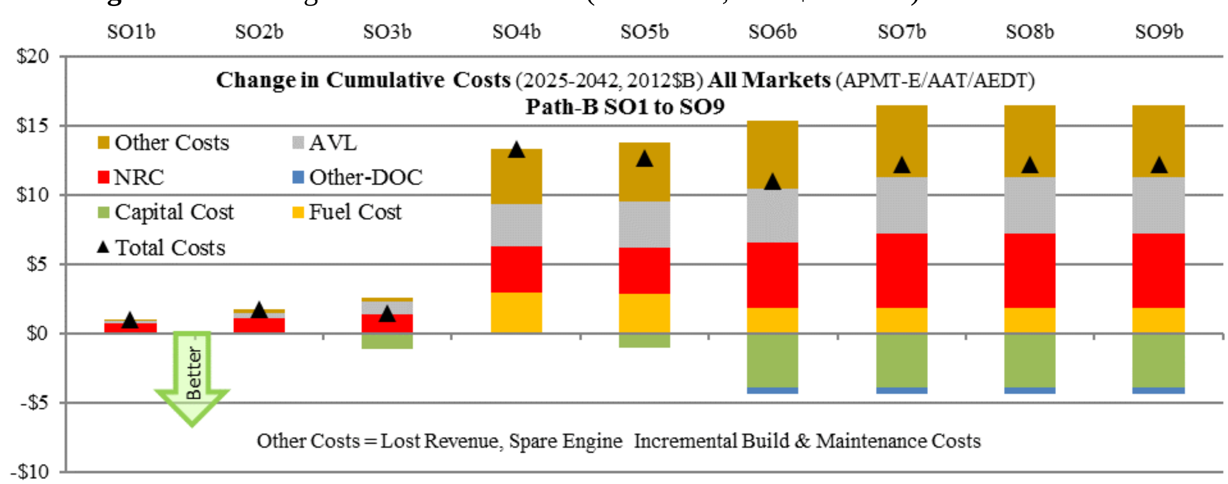


Figure 7.3b: Change in Cumulative Costs (2025-2042, 2012$ Billions) Path-B SO1 to SO9



7.5 Undiscounted change in cumulative costs per nvPM Mass avoided is presented for all markets combined in Figure 7.4. Results for nvPM Number avoided is presented Figure 7.5. The trend of the cost effectiveness ratios for both nvPM Mass and Number show the highest cost for emissions benefit at SO1, where only 7 of 119 GRdb types need to respond. The trend in total cost per emissions benefit is also relatively flat from SO2 through SO9 because the analysis framework required that responding engines meet the maximum stringency option combination defined for an nvPM Improvement (NI) level. Thus, when an engine is defined to have an NI3 mass response to pass SO3 through SO9, the NI3 benefits would be those achieved at SO9 for all NI3 responses.

Figure 7.4: Change in Cumulative Costs per nvPM Mass (Gram) Avoided

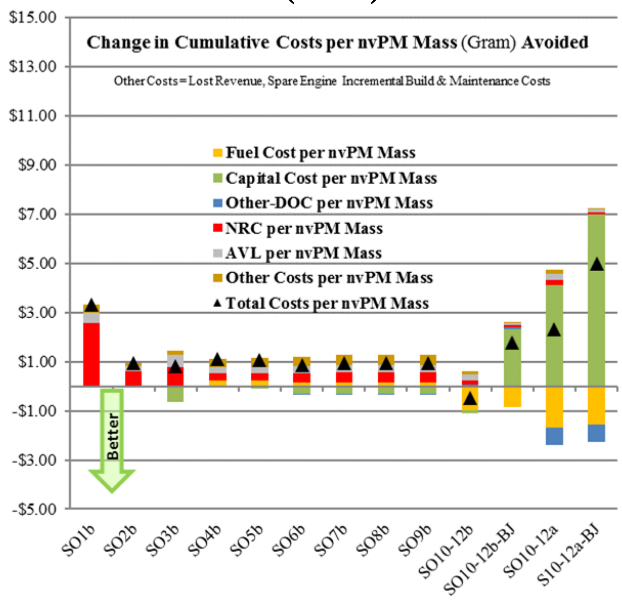


Figure 7.5: Change in Cumulative Costs per nvPM Number (10^{16}) Avoided

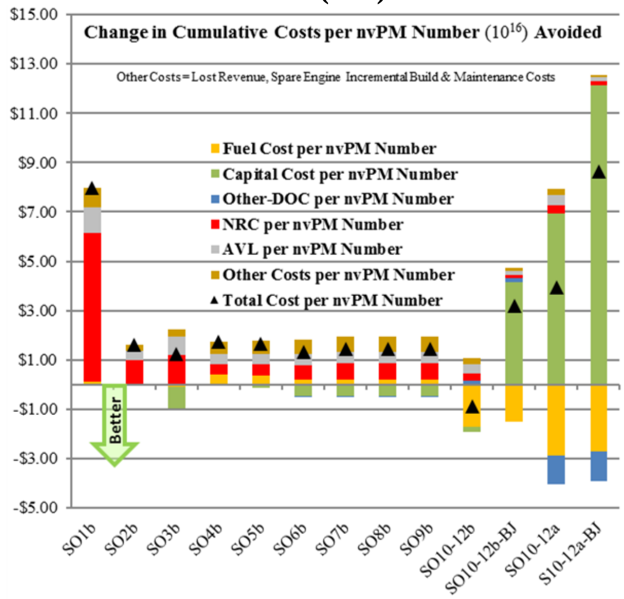
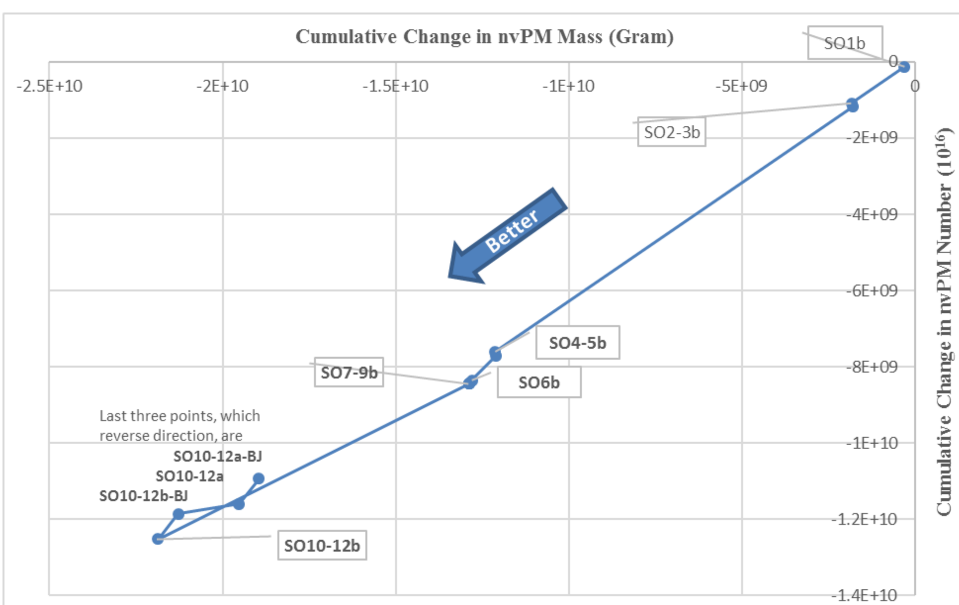


Table 8.1 Total Costs per	SO1b	SO2b	SO3b	SO4b	SO5b	SO6b	SO7b SO8b SO9b	SO10b SO11b SO12b	SO10/11/12b Minus BJ	SO10a SO11a SO12a	SO10/11/12a Minus BJ
nvPM Mass	$3.31	$0.96	$0.82	$1.10	$1.05	$0.86	$0.95	-$0.49	$1.79	$2.33	$4.98
nvPM Number	$7.96	$1.62	$1.25	$1.76	$1.65	$1.32	$1.44	-$0.86	$3.21	$3.93	$8.64

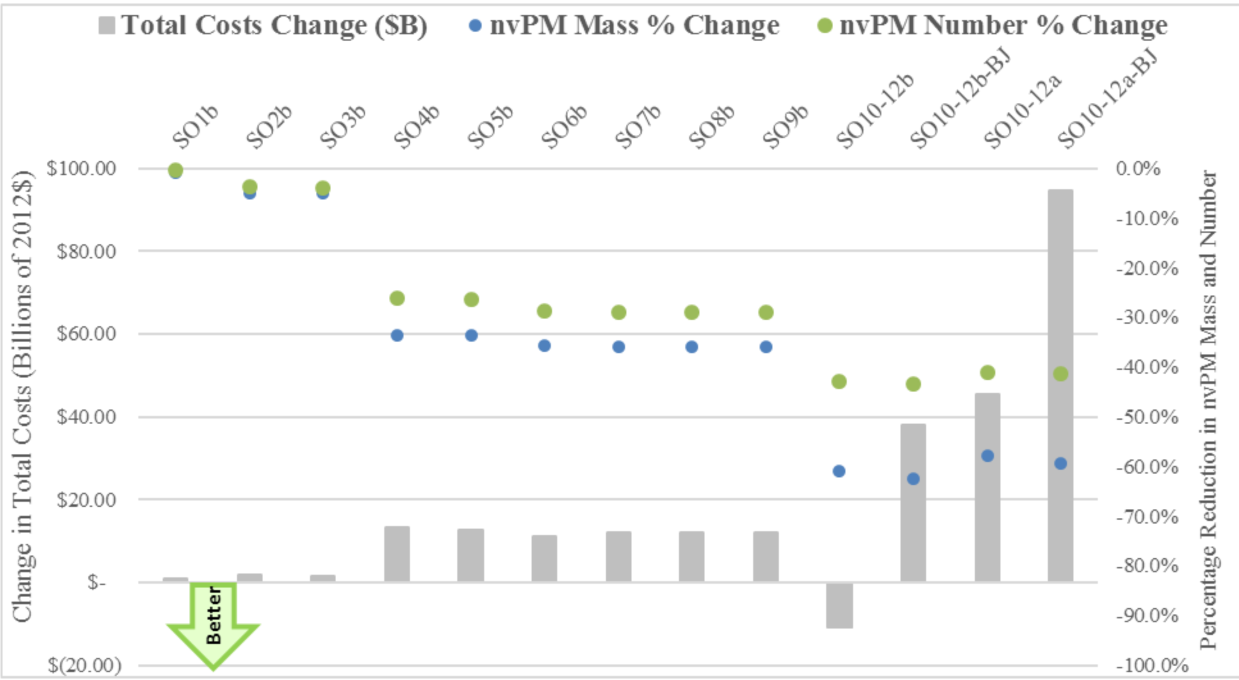
7.6 Figure 7.6 plots change in LTO nvPM mass versus nvPM number for all Path-B markets combined, with SO10 to SO12 shown together (SO10-12b); followed by the Path-B SO10 to SO12 combined results minus the business jet market (SO10-12b-BJ). The last points are the Path-A all markets combined for SO10 to SO12 (SO10-12b); and those minus the business jet market (SO10-12a-BJ).

Figure 7.6: Change in nvPM mass and number



7.7 Figure 7.7 shows the same scenarios with per cent change in nvPM mass (blue dots) and nvPM number (green dots) against change in total cumulative costs (DOC + AVL + NRC + Other) from the 2025 implementation year to 2042.

Figure 7.7: Per cent nvPM Emissions Change and Change in Total Cumulative Costs

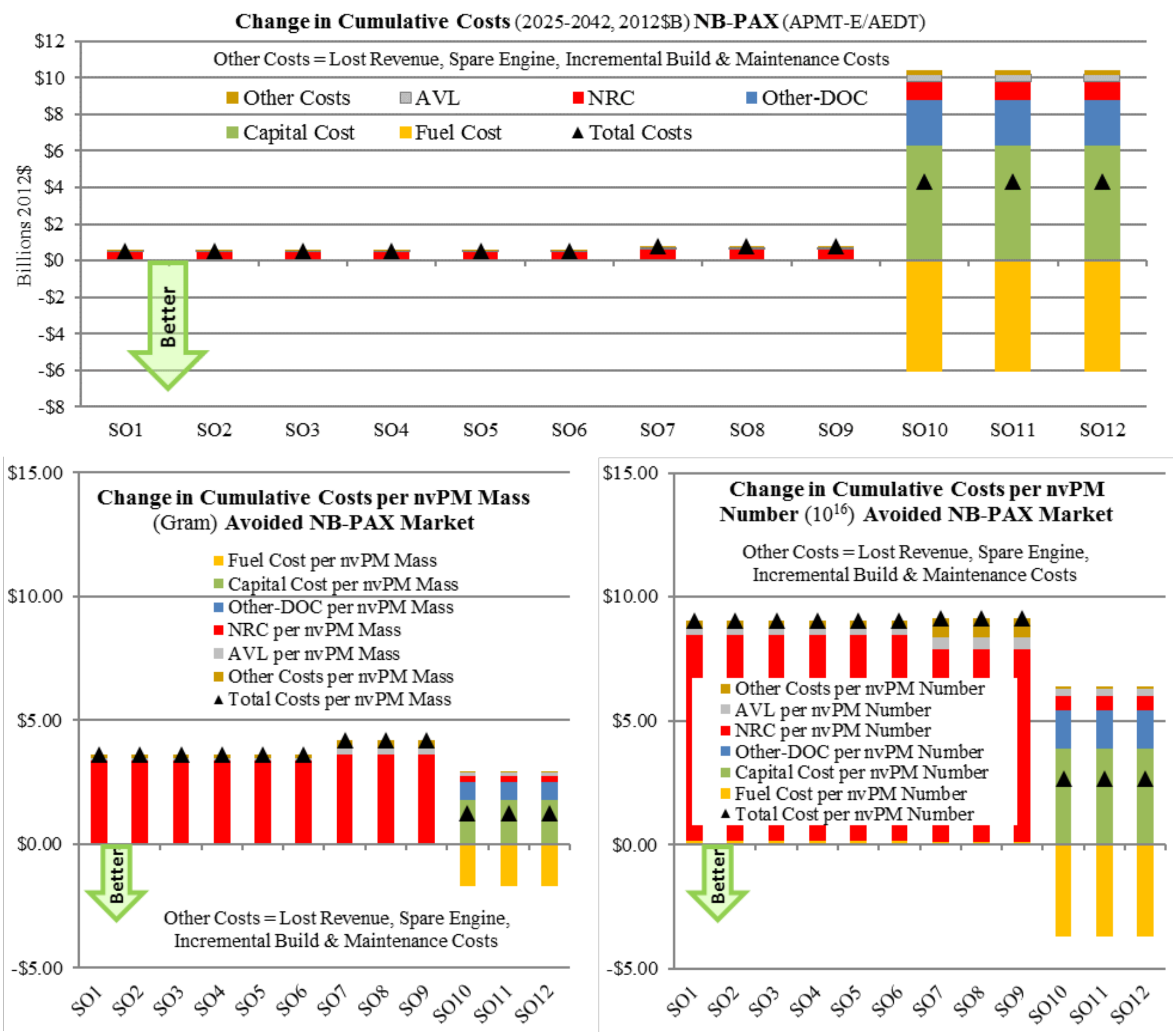


8. OTHER RESULT VIEWS

8.1 **Specific Markets:** In this section, undiscounted stringency change from the baseline results are presented for each market. Note that the scale used in the figures varies by market.

8.1.1 **Narrow Body Passenger Market**[11] (NB-PAX): All types remain available in this market through SO9; and for CBin-5 (101-125 seats) and CBin-7 (151-175 seats) all types remain available for all SO. For SO10-SO12 two engine families do not respond, which results in CBin-04 (86-100 seats) and CBin-06 (126-150 seats) capacities decreasing by 1%; operations, flight kilometres and aircraft deliveries increase to meet the forecasted demand. The other NB-PAX CBins maintain their average capacities.

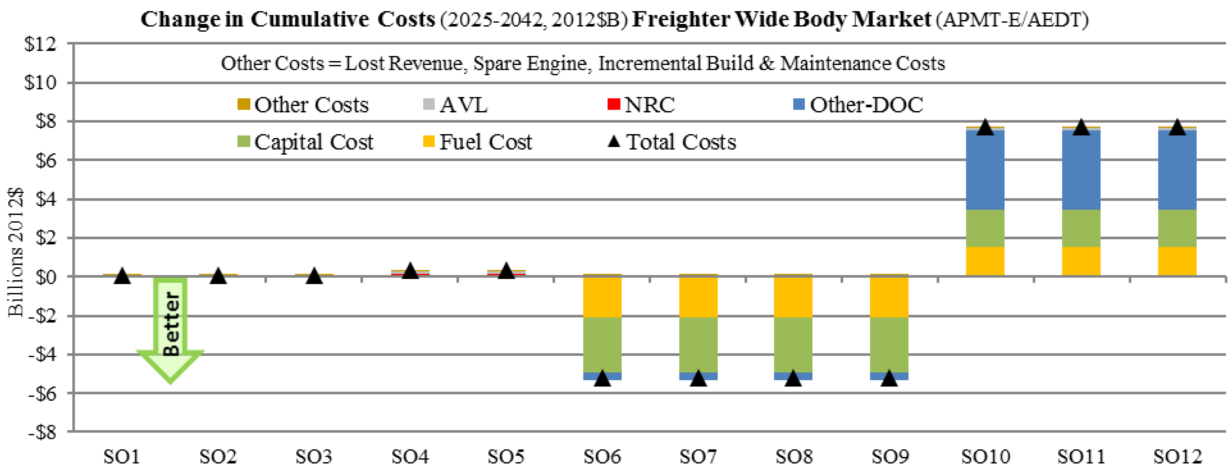
Figures 8.1a-c: Narrow Body Passenger Results



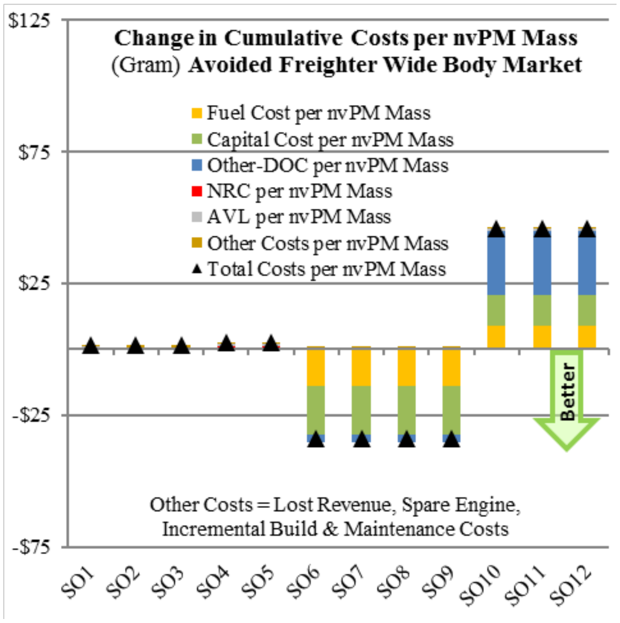
[11] For this analysis regional jets are included in the NB-PAX market.

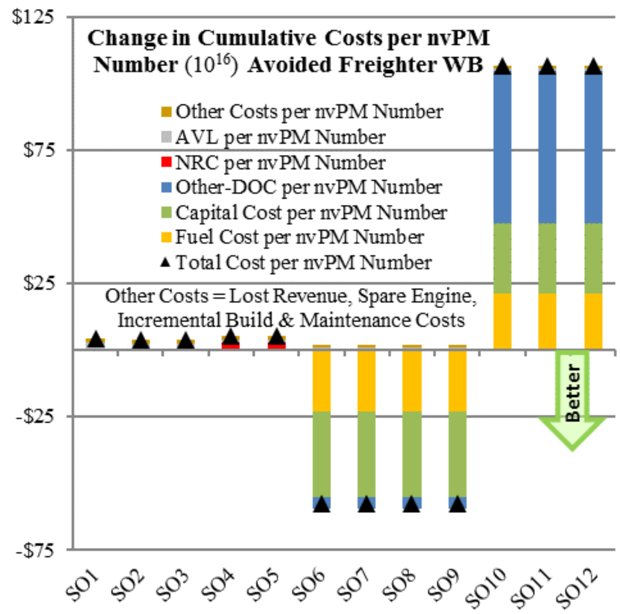
8.1.2 **Freighter Markets:** The FESG fleet forecast for narrow-bodied freighters (NB-FR) defines all demand as being for passenger-to-freighter converted aircraft, which are not subject to the Standard. Russian and Ukrainian manufacturers are of a different opinion; so there are two NB-FR entries that are included in the modelling. Both of these remain available for all SO. All wide-bodied freighter (WB-FR) types subject to the Standard either pass or respond. Medium wide-bodied freighters (CBin-19) are impacted by engine families not responding at SO6, when average capacity increases by 1%, and at SO10, when average capacity decreases by 14%. For SO6-SO9 when average capacity increases it results in a decrease in operations, flight kilometres and fleet deliveries. For SO10-SO12 when average capacity decreases it leads to an increase in operations, flight kilometres and fleet deliveries.[12]

Figures 8.2a-c: Freighter Results



[12] The two fleet evolution models use different capacity metrics; AAT uses ATKs and APMT-E seats. To improve alignment between the two models, the freighter equivalent seat counts in APMT-E were adjusted to more closely reflect the change in payload capacity observed in AAT for the stringencies. The results presented in the Compendium files now show closer operational and fleet alignment between the two models.





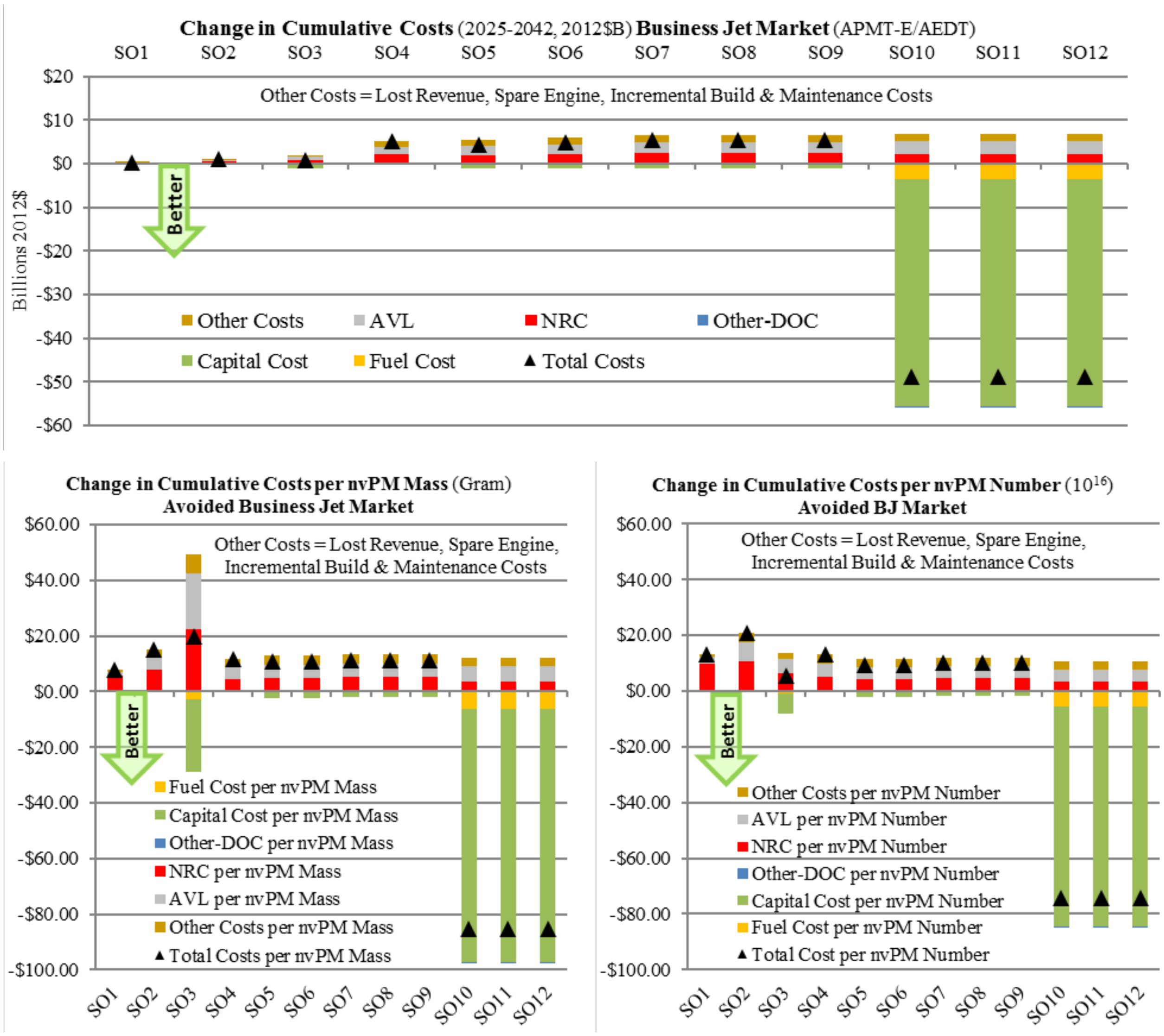
8.1.3 **Business Jet Market:** Since business jets are assumed to have equivalent capacity within a CBin, there are no capacity consequences such as operational changes or fleet deliveries. There are, however, cost consequences.

8.1.3.1 Light-medium business jets (CBins 27&28) are impacted at SO3 and SO5 and above when one engine family does not respond. Average capital cost decreases 13% in CBin-27 and 3% in CBin-28.

8.1.3.2 Large business jets (CBins 29-31) are impacted at SO10 when 3 of 6 engine families do not respond. Average capital cost decreases 1% in CBin-29, 8% in CBin-30, and 3% in CBin-31.

8.1.3.3 Corporate business jets (CBin-32) are impacted at SO10 when two engine families do not respond. Unfortunately, given the wide range of aircraft prices in this CBin, it should have been subdivided between types above (3) and below (6) the $100M price. However, because they were modelled together the average capital cost drops by 26% when two types priced above $200M do not respond.

Figures 8.3a-c: Business Jet Market Results



8.1.3.4 Concerns: Some feel that it is counterintuitive to see less-expensive BJs replacing more expensive types, which no longer respond at SO10 through SO12. There is also concern that the business jet responses are producing a disproportionate impact on the overall fleet analysis, particularly in terms of capital costs. Figure 5.3b shows the sensitivity results where the corporate business jet market goes from a $29B capital cost saving to a $4B savings when the highest priced variants are no longer available and are replaced with only a similar type priced above $200M.

8.1.4 **Passenger Wide Body Market** (WB-PAX): This market has nine engine families; and all GRdb types remain available through SO9. For CBin-11 (≥401 seats) when one engine family does not respond at SO10, the average remaining capacity is 3% lower. Two engine families are used for CBin-9 (211-300 seats), when one does not respond at SO10 average capacity increases by 1% when CBin-9 is modelled alone (Path-B). Six engine families are used for CBin-10 (301-400 seats), when three do not respond at SO10 average capacity increases by 3% when CBin-10 is modelled alone (Path-B). These capacity increases reduce fleet deliveries, operations and the associated costs.

8.1.4.1 The reason this analysis had a Path-A and Path-B was covered in Section 1.3. The details regarding the Path-A and Path-B fleet evolution modelling results was covered in Section 3.2.6. The impact for capital costs is discussed in Section 5.4.6.

8.1.4.2 Per Table 3.1, the proportion of total baseline operations forecasted for CBin-9 (211-300 seats) is 14.5% and 3.5% for CBin-10 (301-400 seats). So, the assumptions for CBin-9 and how it is modelled have more influence on the analysis than those for CBin-10. Table 8.1 lists technology responses, seats and price assumptions for the wide-bodied passenger GRdb types up to 400 seats; and it shows a smaller price range for CBin-9 versus CBin-10.[13] So, when some GRdb types are no longer available at SO10, the similarity of prices within CBin-9 means the change from the baseline is small if demand is met with only CBin-9 types (Path-B). To break from the forecast and mix CBin-9/10 (Path-A) causes the wider range of CBin-10 prices to significantly influence capital costs.

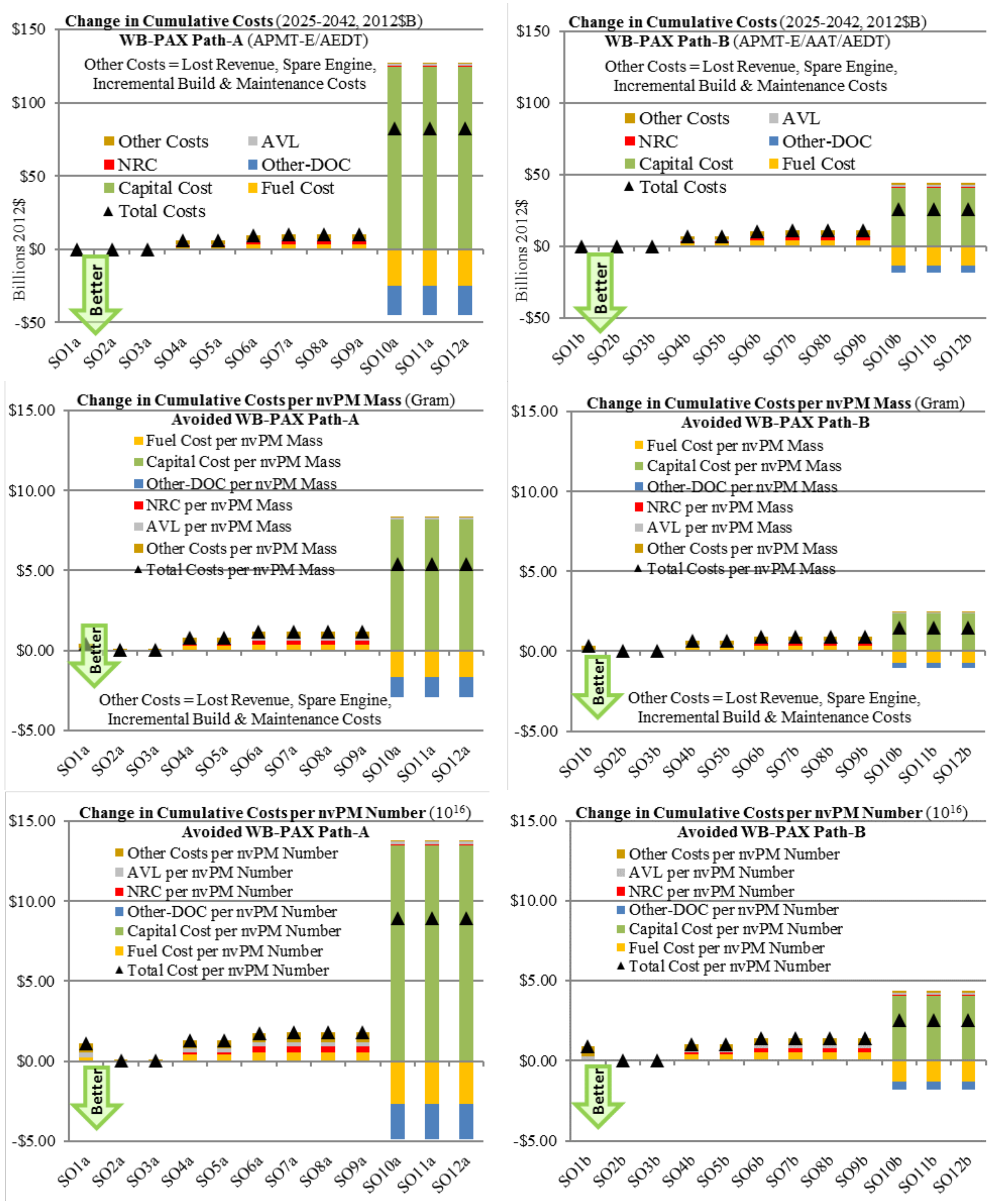
Table 8.1: GRdb wide-bodied passenger technology responses

CBin	SO-1	SO-2/3	SO-4/5	SO-6	SO7/8/9	SO10/11/12	Engine	Seats	Price
CBin-09	Pass	NI1@ SO3	NI3@ SO9	NI3@ SO9	NI3@ SO9	No Response	25	256	$119,435,310
CBin-09	Pass	NI1@ SO3	NI3@ SO9	NI3@ SO9	NI3@ SO9	No Response	25	257	$126,808,000
CBin-09	Pass	NI1@ SO3	NI3@ SO9	NI3@ SO9	NI3@ SO9	No Response	25	277	$132,388,990
CBin-09	Pass	Pass	Pass	Pass	Pass	Pass	07	256	$119,435,310
CBin-09	Pass	Pass	Pass	Pass	Pass	Pass	07	277	$132,388,990
CBin-10	NI3@ SO12	NI3@ SO12	NI3@ SO12	NI3@ SO12	NI3@ SO12	NI3@ SO12	32	350	$141,480,000
CBin-10	Pass	NI1@ SO3	NI3@ SO9	NI3@ SO9	NI3@ SO9	No Response	25	315	$132,388,990
CBin-10	Pass	NI1@ SO3	NI3@ SO9	NI3@ SO9	NI3@ SO9	No Response	25	318	$126,808,000
CBin-10	Pass	Pass	NI1@ SO5	NI3@ SO9	NI3@ SO9	No Response	22	305	$144,100,000
CBin-10	Pass	Pass	NI2M@ SO5	NI3@ SO9	NI3@ SO9	No Response	26	369	$161,392,000
CBin-10	Pass	Pass	Pass	Pass	Pass	Pass	07	315	$132,388,990
CBin-10	Pass	Pass	Pass	Pass	Pass	Pass	08	345	$201,238,972
CBin-10	Pass	Pass	Pass	Pass	Pass	Pass	08	365	$217,338,090

8.1.4.3 The undiscounted change in cumulative costs (2025-2042, 2012$B) and cost effectiveness results for the Path A and Path B WB-PAX market are shown in Figures 8.4a to 9.4f.

[13] Stringencies are clustered when there is no difference between the technology responses.

Figures 8.4a to 8.4f: Wide Body Passenger Market Results for Path-A and Path-B



8.2 Outcome of Path-A and Path-B for All-Markets

8.2.1 Table 8.2 shows the all-market[14] level cost results for Path-A and Path-B for SO4 through SO12.[15] The only difference between the paths is for the 211-400 seat wide-bodied passenger market; i.e., forecast-based Path-B and alternate Path-A for WB-PAX aircraft. For SO10 through SO12, there is an $83.4B capital cost difference between the paths, which is the primary reason total costs shift from being less than the baseline for Path-B to significantly more than the baseline for Path-A.

Table 8.2: Path-A and Path-B Change in Cumulative Costs (2025-2042, 2012$B; All Market Level)

	Path-A	Path-B	Path-A	Path-B	Path-A	Path-B	Path-A	Path-B	Path-A	Path-B
	SO4	**SO4**	**SO5**	**SO5**	**SO6**	**SO6**	**SO7/8/9**	**SO7/8/9**	**SO10/11/12**	**SO10/11/12**
Total Costs	**$11.92**	**$13.37**	**$11.25**	**$12.70**	**$10.01**	**$11.02**	**$11.17**	**$12.18**	**$45.58**	**-$10.79**
Fuel Cost	$1.97	$3.00	$1.87	$2.90	$0.97	$1.84	$0.99	$1.86	-$33.12	-$21.39
Capital Cost	$0.00	$0.00	-$1.05	-$1.05	-$3.92	-$3.92	-$3.92	-$3.92	$80.59	-$2.83
Other-DOC	$0.00	$0.00	$0.00	$0.00	-$0.40	-$0.40	-$0.40	-$0.40	-$13.48	$1.74
NRC	$3.32	$3.32	$3.32	$3.32	$4.75	$4.75	$5.32	$5.32	$3.65	$3.65
AVL	$2.84	$2.98	$3.17	$3.32	$3.74	$3.82	$4.00	$4.08	$5.06	$5.14
Other Costs	$3.80	$4.07	$3.96	$4.22	$4.86	$4.93	$5.19	$5.25	$2.89	$2.90

"Other Costs" = lost revenue, spare engine, incremental build and maintenance costs.

8.2.2 Table 8.3 shows the Path-A and Path-B change in cumulative (2025-2042) total costs (2012$B) for all markets combined, effectiveness (total costs per emissions benefit), and the difference between the paths (last three rows) by stringency option combination (SO).

Table 8.3: Path-A and Path-B Total Cost (2012$B) **Results for All Markets Combined**

2012$ Billions	**SO1**	**SO2**	**SO3**	**SO4**	**SO5**	**SO6**	**SO7/8/9**	**SO10/11/12**
Path-A Total Costs	$0.99	$1.75	$1.47	$11.92	$11.25	$10.01	$11.17	$45.58
Path-B Total Costs	$0.99	$1.75	$1.47	$13.37	$12.70	$11.02	$12.18	-$10.79
Path-A Total Costs per nvPM Mass	$3.33	$1.41	$1.21	$1.51	$1.43	$1.10	$1.22	$2.33
Path-B Total Costs per nvPM Mass	$3.31	$0.96	$0.82	$1.10	$1.05	$0.86	$0.95	-$0.49
Path-A Total Cost per nvPM Number	$7.99	$2.43	$1.81	$2.37	$2.20	$1.61	$1.78	$3.93
Path-B Total Cost per nvPM Number	$7.96	$1.62	$1.25	$1.76	$1.65	$1.32	$1.44	-$0.86
Total Costs Difference	$0.00	$0.00	$0.00	-$1.44	-$1.44	-$1.02	-$1.01	$56.36
Total Costs per nvPM Mass Difference	$0.01	$0.45	$0.39	$0.41	$0.38	$0.24	$0.28	$2.83
Total Cost per nvPM Number Difference	$0.03	$0.81	$0.56	$0.61	$0.55	$0.29	$0.33	$4.79

[14] All-markets is the sum of the freighter, business jet, and the narrow and wide body passenger markets subject to the Standard.

[15] Results for SO7 through SO9 and SO10 through SO12 are clustered because they are identical. Results for SO1 through SO3 are in the Compendium files and are within $0.004B for the two paths.

9. **CAEP/11 DECISION**

9.1 During the CAEP/11 meeting the new nvPM mass and number SARPs were agreed. This included limit lines for nvPM mass and number, that would be applied to in-production and new engine types from 1 January 2023, providing some alleviation for smaller engines. These limit lines were adjusted according to the one engine characteristic level factor, and can be found in the proposed amendments to Annex 16, Volume II contained in Appendix A to Agenda Item 3 of the CAEP/11 Report.

9.2 The CAEP/11 decision amends Annex 16, Volume II, Part IV to include mandatory reporting of nvPM system losses to the certificating authority. The mandatory reporting of system losses allows for proper calculation of nvPM emissions for inventory purposes, is expected to be a minor burden on the competent authority, and is not part of the pass/fail compliance determination of an engine type during the certification process.

Figure 9.1 – nvPM Mass In-Production and New Type Regulatory Limits

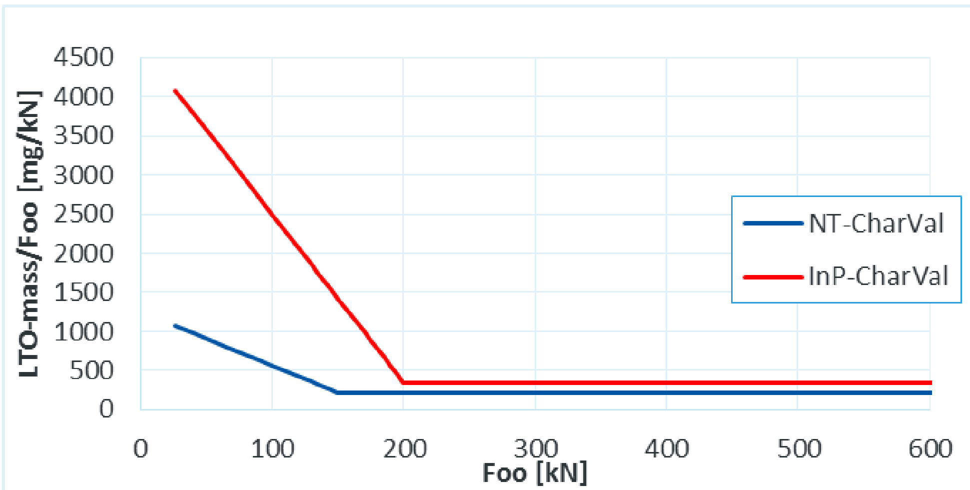
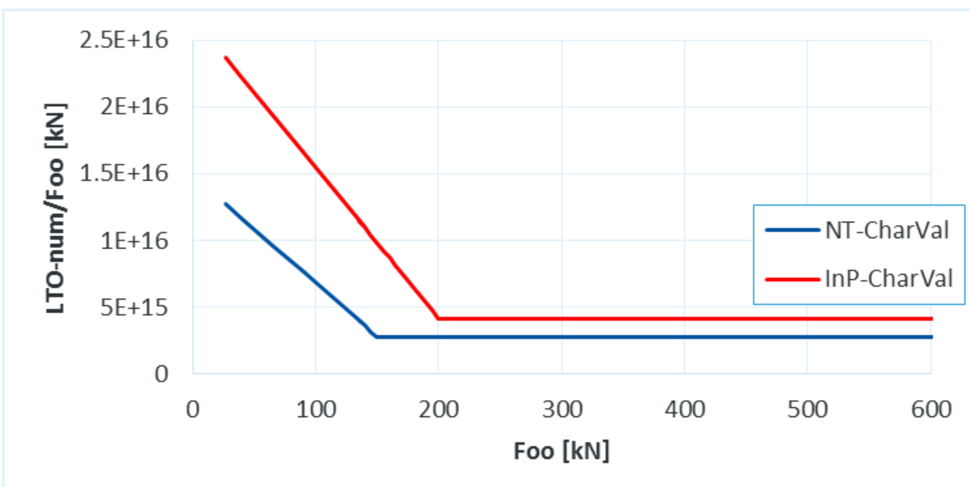


Figure 9.2 – nvPM Number In-Production and New Type Regulatory Limits



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ON THE VISIBILITY OF THE EXHAUST PLUMES OF AIRCRAFT ENGINES

1. INTRODUCTION

1.1 During CAEP/10, a mass concentration limit line was developed with the aim to "transition" towards a regulation "that is equivalent to the existing SN [Smoke Number] Standard" [CAEP10-WG3-PMTG10-WP6]. This transitional mass concentration Standard was developed by correlating SN with mass concentration, shifting this best fit line upwards by ~2 standard deviations and substituting the $SN = f(F_{00})$ limit line relationship into this. The goal of the transition was to allow for the collection of mass concentration data to create the framework for the regulation and thus it was developed to ensure all engines that pass the SN limit line would also pass the mass concentration limit line.

1.2 A corollary of this ~2 standard deviation shift is that statistically we expect approximately 97.5% of engines that lie on the CAEP/10 limit line to be above the SN limit line. A schematic portrayal of this was provided in CAEP11-WG3-PMTG08-Flimsy06. These conclusions suggest that the method used to convert the SN limit line to an equivalent mass concentration limit line does not provide the clarity required for regulatory purposes to assess whether the CAEP/10 limit prevents the visibility of smoke plumes.

1.3 Aerosol optical theory and a visibility criterion can be used to identify the mass concentration at which the smoke plume may become visible, which formed the basis for developing the SN limit line. An introduction to this theory was provided in CAEP11-WG3-PMTG09-Flimsy03, which included a preliminary method to estimate the core nozzle diameter of unmixed turbofan engines. In this paper, we improve upon and extend the analysis presented during PMTG/09 with a validated, iterative gas turbine model used to estimate the exhaust nozzle diameter, a modern update to the optics theory equations and constants, and a model for estimating the transmissivity of exhaust plumes for mixed and unmixed turbofan engines.

1.4 During CAEP/11 meeting it was agreed that 1 January 2023 would be the end date for the applicability of the SN SARPs for engines of a rated thrust > 26.7kN.

2. VISIBILITY OF THE SMOKE NUMBER LIMIT LINE FOR TURBOJETS

2.1 A derivation of the smoke number (SN) that has a transmission of 98% is covered in Munt (1979), which finds that the limit line has a transmission slightly greater than this. This means that, according to the method developed by Munt, the SN limit line conservatively prevents the visibility of an exhaust plume at the 98% transmission level.

2.2 The derivation requires three pieces of information. First, optics theory and associated absorption coefficients gives a relationship to estimate the transmission as a function of concentration and path length. The optics theory is based on a method described in Champagne (1971) and the absorption coefficient is derived analytically in Stockham and Betz (1970) for graphite rather than soot from a kerosene flame. Second, a relationship between mass concentration and smoke number is required, which is also described in Champagne (1971). Finally, a relationship between rated thrust and path length is derived based on measurements made by Munt.

2.3 These three parts can be combined together to produce an estimate of the SN with a transmission of 98% as a function of rated thrust. Munt finds this line to lie slightly above the EPA NPRM (equivalent to the SN limit line) as shown in the diagram below.

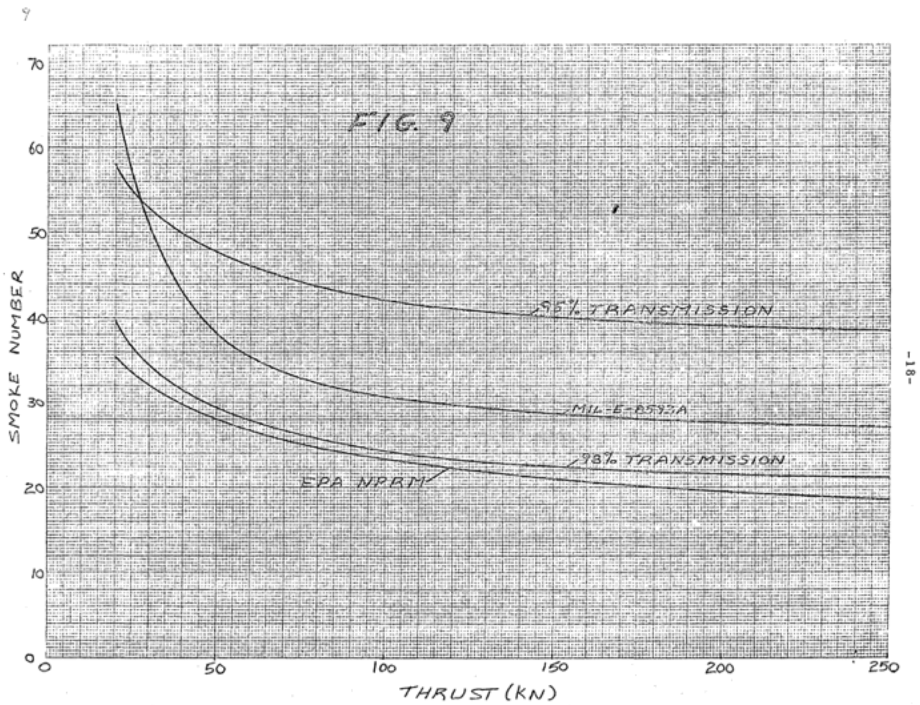

FIGURE B3: RELATIONSHIP BETWEEN SN AND RATED THRUST ADAPTED FROM MUNT (1979). THE EPA NPRM IS IDENTICAL TO THE SN LIMIT LINE, THE MIL-E-8593A IS THE CORRESPONDING MILITARY LIMIT LINE AND THE 98% AND 95% TRANSMISSION LINES ARE DERIVED BY MUNT.

2.4 The analysis by Munt can be reproduced on a mass concentration versus rated thrust basis. This is useful to help identify the mass concentration at 98% transmission according to the method developed by Munt. Unfortunately, the path length versus rated thrust relationship was not provided by Munt, so we use his data points to estimate the best fit line. The relationship is shown in Figure B4 and Eq 1 shows the coefficients and form of the equation.

$$L = 1.23 - 0.95 \cdot e^{-0.011 \cdot F_{00}} \qquad \text{Eq 1}$$

where L is the path length in meters and F_{00} is the rated thrust in kN.

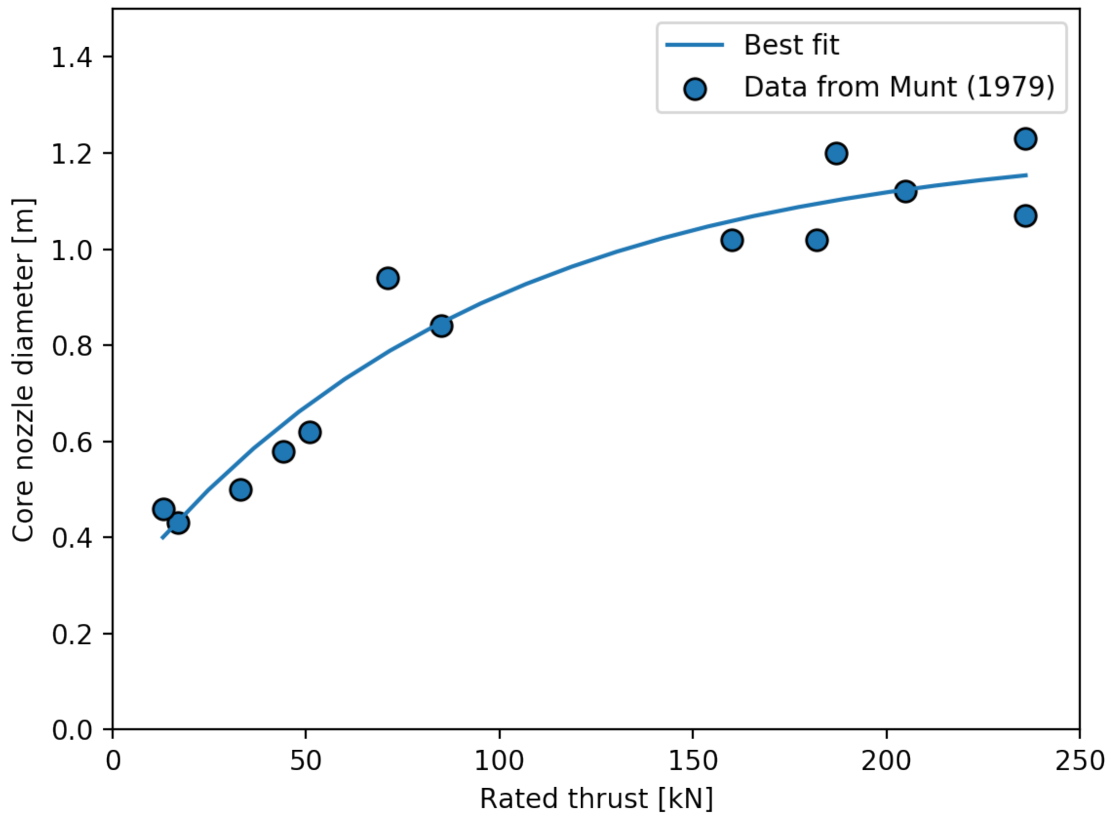

FIGURE B4: BEST FIT LINE BETWEEN RATED THRUST AND CORE NOZZLE DIAMETER USING DATA TABULATED IN MUNT (1979).

2.5 With this relationship, we can apply the optics theory from Champagne (1971) to estimate the mass concentration at a transmission of 98% and 95%, which is shown in Figure B5. These results suggest that the SN limit line in mass concentration space is at a transmission of ~98% according to this particular optics theory. It is also noticeable that the shape of the 98% transmission points differ from the SN limit line, particularly at low rated thrust. This is an artefact of the relationship between rated thrust and path length, where our best fit line is slightly higher than that derived by Munt at a rated thrust below ~50 kN.

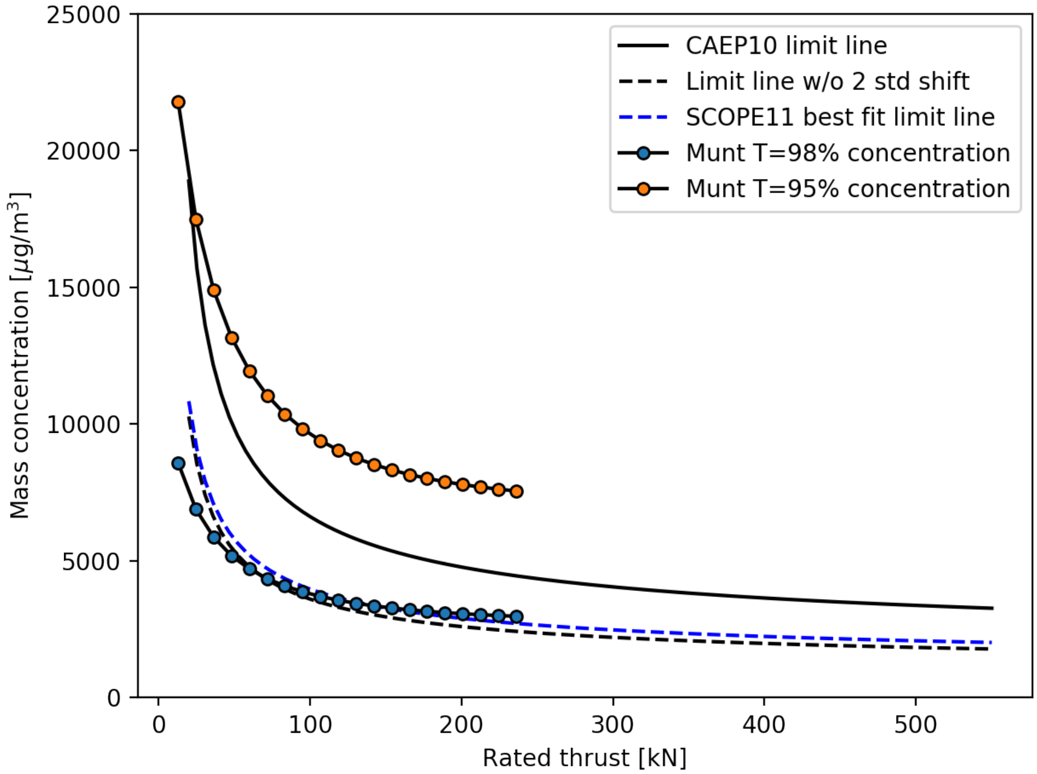

FIGURE B5: MASS CONCENTRATION AT A TRANSMISSION OF 98% (BLUE) AND 95% (ORANGE) AS A FUNCTION OF RATED THRUST DERIVED USING THE SAME METHOD AS IN MUNT (1979). THE SOLID BLACK LINE SHOWS THE CAEP/10 LIMIT LINE, THE DASHED BLACK LINE IS THE LIMIT LINE WITHOUT THE 2 STANDARD DEVIATION SHIFT IN THE SN – MASS CONCENTRATION RELATIONSHIP AND THE DASHED BLUE LINE IS THAT BUT USING THE SCOPE11 RELATIONSHIP.

3. IMPROVEMENTS TO MUNT'S ANALYSIS

3.1 There are three caveats to Munt's analysis which we address.

3.1.1 First, the optics theory that Munt used is now outdated and the modern version of it is shown in Eq 2. In addition, the absorption coefficient was based on theoretical estimates starting from the refractive index of black carbon. Recent literature finds that experimentally measured mass-normalized absorption coefficients are 7.5±1.2 m^2/g at a light wavelength of 550 nm (Bond and Bergstrom (2006)), ~50% higher than the equivalent value in Munt (1979) (~5.76 m^2/g at a wavelength of 490 nm).

$$C_{m,e} = \frac{\rho_{soot}\,\lambda \log(1/T)}{K_e\, L} \qquad \text{Eq 2}$$

3.1.2 Second, the exhaust nozzle diameters tabulated in Munt (1979) were measured from photographs and include the size of the exhaust cone. This means that the nozzle diameters represent the physical outer diameter of the core nozzle, while the area-equivalent diameter would be smaller than this.

Instead of using measured values, we have developed a simple turbojet cycle model that is able to estimate the area-equivalent nozzle diameter. The model only requires the overall pressure ratio (OPR) and rated thrust, and assumes values for the air-fuel ratio (AFR) of 55 at rated thrust and that the exhaust nozzle is choked. The full method is described in Appendix J.1 and the final equation to estimate the nozzle diameter is shown in Eq 3.

$$\mathrm{L} = \sqrt{\frac{4F_{00}}{\pi\gamma_c P_9}} \qquad \text{Eq 3}$$

where F_{00} is the rated thrust in N, $\gamma_c = 1.4$ is the heat capacity ratio in the compressor and P_9 is the static pressure at the exit plane found using the method described in Appendix J.1.

3.1.3 Third, the measurement system upon which the mass concentration limit line was developed corrects all measurements to standard temperature and pressure (STP) conditions and leads to the loss of particles as the flow passes through it. This information was not available to Munt and so we correct to STP conditions by scaling the mass concentration from Eq 2 by the ratio of density at STP (1.2 kg/m^3) to the density at the exhaust of the engine. The latter density can be found using the turbojet cycle model. System losses can be accounted for using the correlation found in the SCOPE11 method that relates losses to mass concentration in reverse.

3.2 Using a subset of engines in the Engine Emissions Data Bank (EEDB), we have used the method introduced by Munt to predict the mass concentration at a transmission of 98%. The results are shown in Figure B6 in the blue circles. We then apply each of the 3 changes discussed earlier to show the effect of the changes.

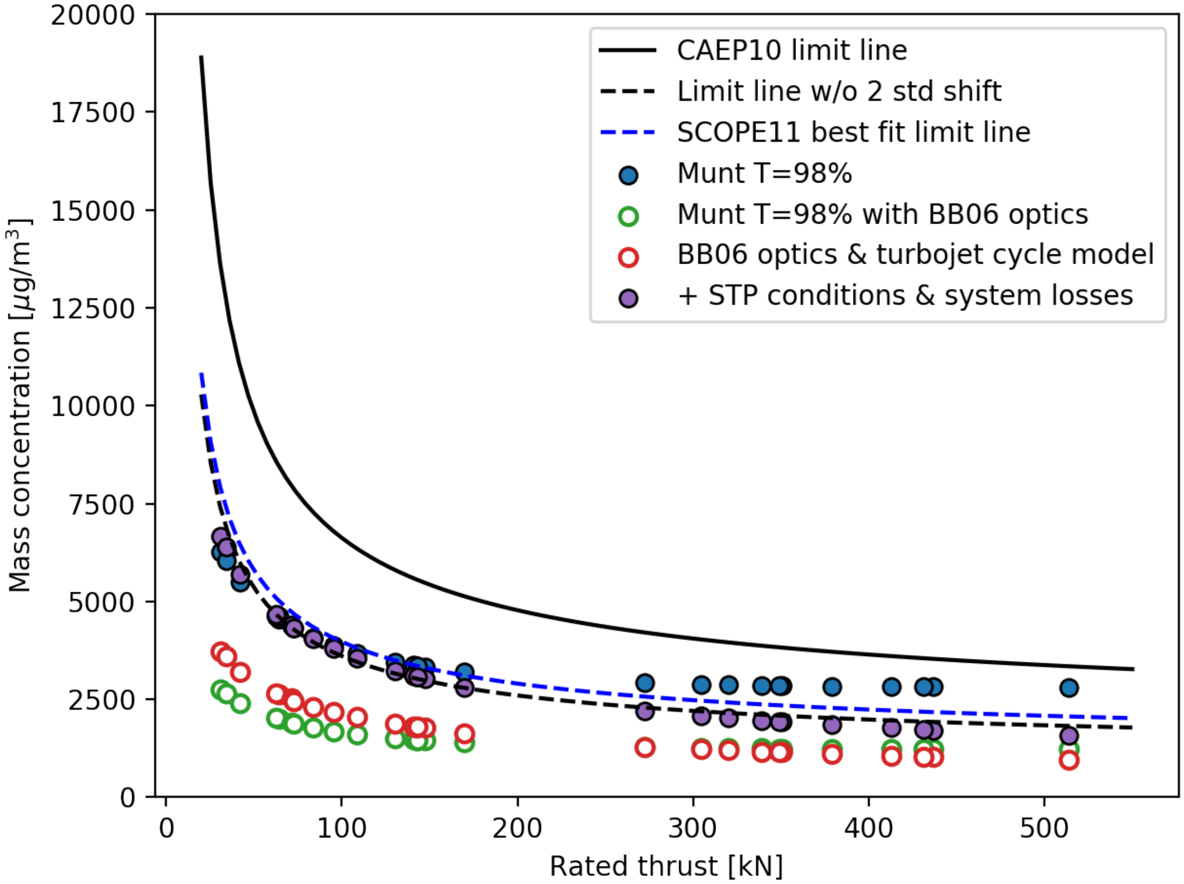

FIGURE B6: THE MASS CONCENTRATION AT 98% VISIBILITY AGAINST RATED THRUST. BLUE FILLED CIRCLES SHOW THE RESULTS USING THE METHOD IN MUNT (1979). THE GREEN OPEN CIRCLES APPLY THE UPDATED OPTICS THEORY BUT USE THE RATED THRUST TO PATH LENGTH RELATIONSHIP FROM MUNT. THE RED OPEN CIRCLES THEN USE OUR TURBOJET CYCLE MODEL TO PREDICT PATH LENGTH FOR A GIVEN RATED THRUST. FINALLY, THE PURPLE FILLED CIRCLES CORRECT THE RESULTS TO STP CONDITIONS AND INCLUDE THE EFFECT OF SYSTEM LOSSES.

3.3 The green circles use the rated thrust to path length relationship derived by Munt, but use the optics theory and coefficients from Bond and Bergstrom (2006). Relative to the blue circles, we find that the mass concentration at 98% transmission reduces by 44%. This is an expected change since the dimensionless absorption coefficient in Bond and Bergstrom (2006) is ~50% larger than that used by Munt (1979).

3.4 The red circles then include the effect of using our turbojet cycle model to predict the nozzle diameter. In this case, we find the effect on the mass concentration depends on the thrust. On average, the nozzle diameter decreases by 10% compared with Munt (1979) leading to an increase in mass concentration of 13%. At rated thrust above ~300 kN, where the Munt (1979) correlation is extrapolated, the nozzle diameter is 13% larger and the mass concentration is 11% lower.

3.5 Finally, the correction to STP conditions and including system losses has the largest effect on the mass concentration. On average, the mass concentration at 98% transmission increases by 78%. The other noticeable feature is that the purple circles more closely follow the shape of the dashed line.

3.6 The three updates to the method show that we can reproduce the SN limit line in mass concentration space, finding this to have a transmission of approximately 98% for turbojet engines. The modern optics theory reduces the allowable mass concentration and this is offset mainly by the correction to STP conditions.

4. VISIBILITY FOR UNMIXED TURBOFAN ENGINES

4.1 The previous section showed the ability to reproduce the SN limit line in mass concentration space for turbojet engines. In this case, there was a single nozzle that contained all of the emissions and it was this nozzle diameter that we were interested in. For an unmixed turbofan engine, the nozzle is split into a core and bypass stream. The emissions are all contained within the core stream and thus the relationship between the rated thrust and core nozzle diameter is now of interest. Compared to turbojet engines, this relationship is more complicated, so we must develop a new gas turbine cycle model that is capable of modelling unmixed turbofan engines. The optics theory, required correction to STP conditions and artificially including system losses, are all applied in the same way as in Section 3.

4.2 The gas turbine model we have developed extracts the rated thrust, overall pressure ratio, bypass ratio and fuel flow rate at rated thrust from the EEDB and assumes the bypass to jet velocity ratio is fixed at 0.9. The calculation method requires iterating over the fan pressure ratio to begin until we obtain the desired jet velocity ratio. The implementation is conducted in Python and leads to the rapid estimation of the conditions within the engine and thus the core nozzle diameter and exhaust density. This model is described in Appendix J.2.

4.3 To validate the results of iterative model, we have estimated the fan diameter and compared with publicly available values for a range of engines as shown in Figure B7. The engines chosen include mixed and unmixed engines, however every engine has been modelled as unmixed. Estimating fan diameter requires knowledge of the air mass flow rate through the engine, which is estimated in the iterative model, but also the hub-to-tip ratio of the fan blade. Although this value varies between engines, we assume it to be 0.33 to create Figure B7.

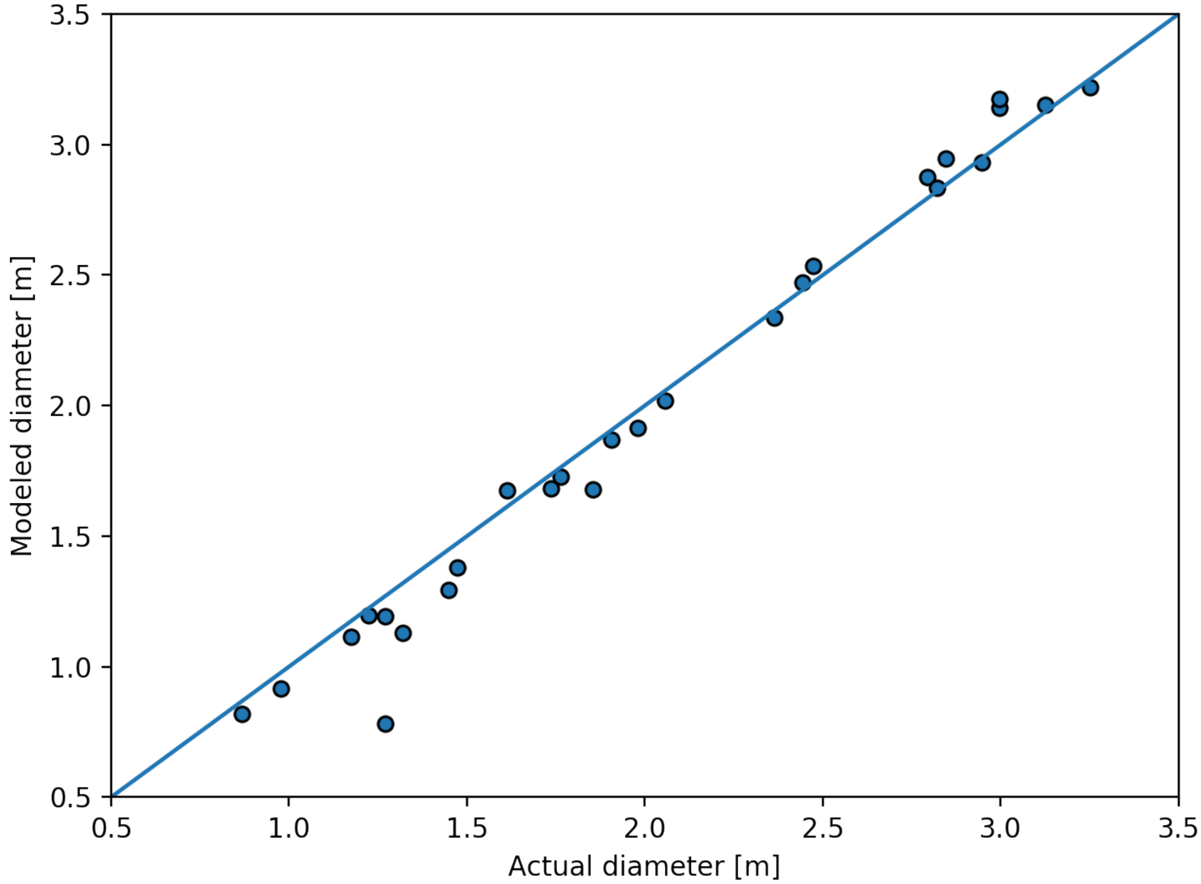

FIGURE B7: ACTUAL VERSUS MODELED FAN DIAMETER [IN]. BOTH MIXED AND UNMIXED ARE INCLUDED, BUT ALL ENGINES ARE MODELED AS UNMIXED.

4.4 We find the error in predicting fan diameter to be 3% on average. There is a skew of -1.56[16] in the residuals and we find too small a diameter at low rated thrust and too large a diameter at high rated thrust. We expect that this is driven by the variation in hub-to-tip ratio as a function of rated thrust. The largest error is 38%, however we expect this is an incorrect measured diameter that includes the size of the nacelle, rather than just the fan blade diameter.

4.5 To further validate the results, we have run simulations in GasTurb, a detailed gas turbine cycle programme, which is capable of modelling a variety of aircraft engine configurations. For unmixed engines, the OPR and BPR were fixed as per the EEDB. Three iteration variables were then set: (1) the turbine inlet temperature until the required fuel flow rate was attained; (2) the fan pressure ratio (FPR) for a fixed jet velocity ratio; and the air mass flow rate for a fixed fan diameter.

4.6 Upon convergence of the GasTurb simulations, we compared the core nozzle diameter with that found using the turbojet cycle discussed above. A comparison of the results is shown in Figure B8. The error for all engines was found to be less than 5%, except for one engine with an error of 15%.

[16] A skew between ±2 are considered acceptable to prove normally distributed residual

This particular engine was modelled as unmixed, however is actually a mixed-flow engine leading to a larger error in predicting the core nozzle diameter.

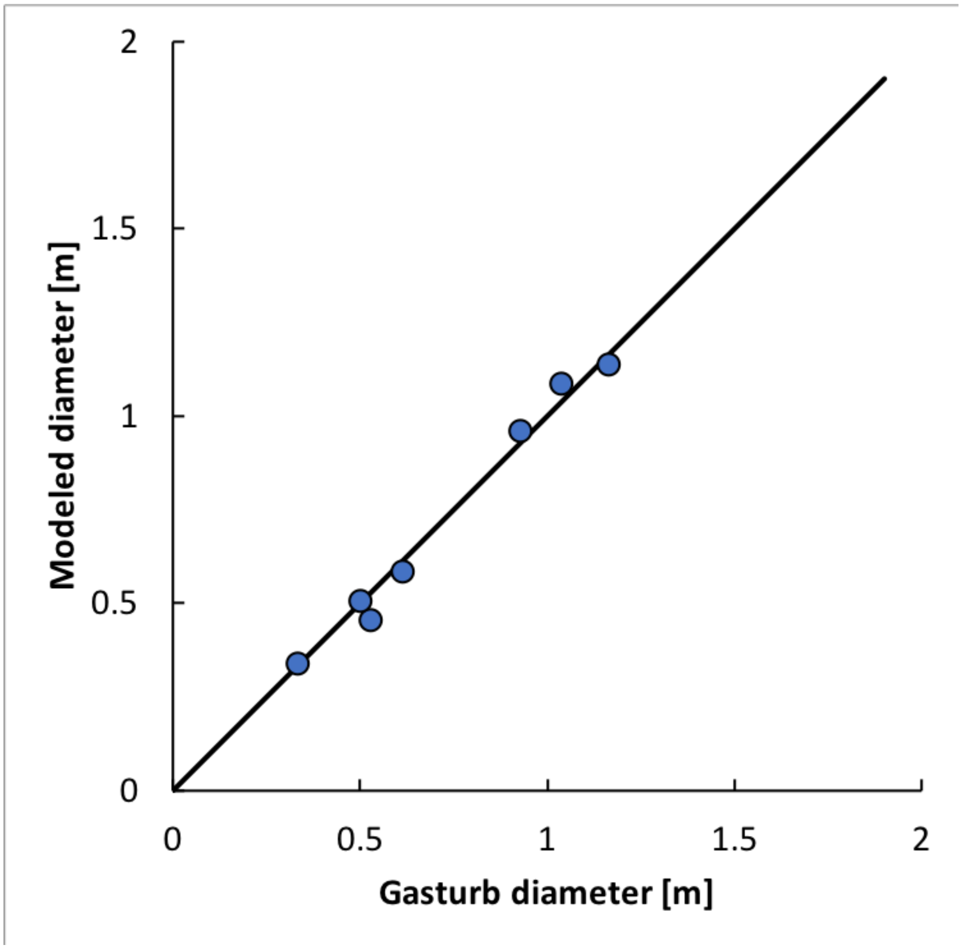

FIGURE B8: COMPARISON BETWEEN CORE NOZZLE DIAMETER FROM GASTURB AND THE MODELED, ITERATIVE GAS TURBINE CYCLE FOR UNMIXED ENGINES.

4.7 We can now apply the diameter estimated using our gas turbine cycle model with the optics theory described in Section 3 to estimate the mass concentration at 98% transmission of unmixed turbofan engines at the exit plane. These results are shown by the orange circles in Figure B9 and include the correction to STP conditions and system losses. We also include the results for turbojets (blue circles).

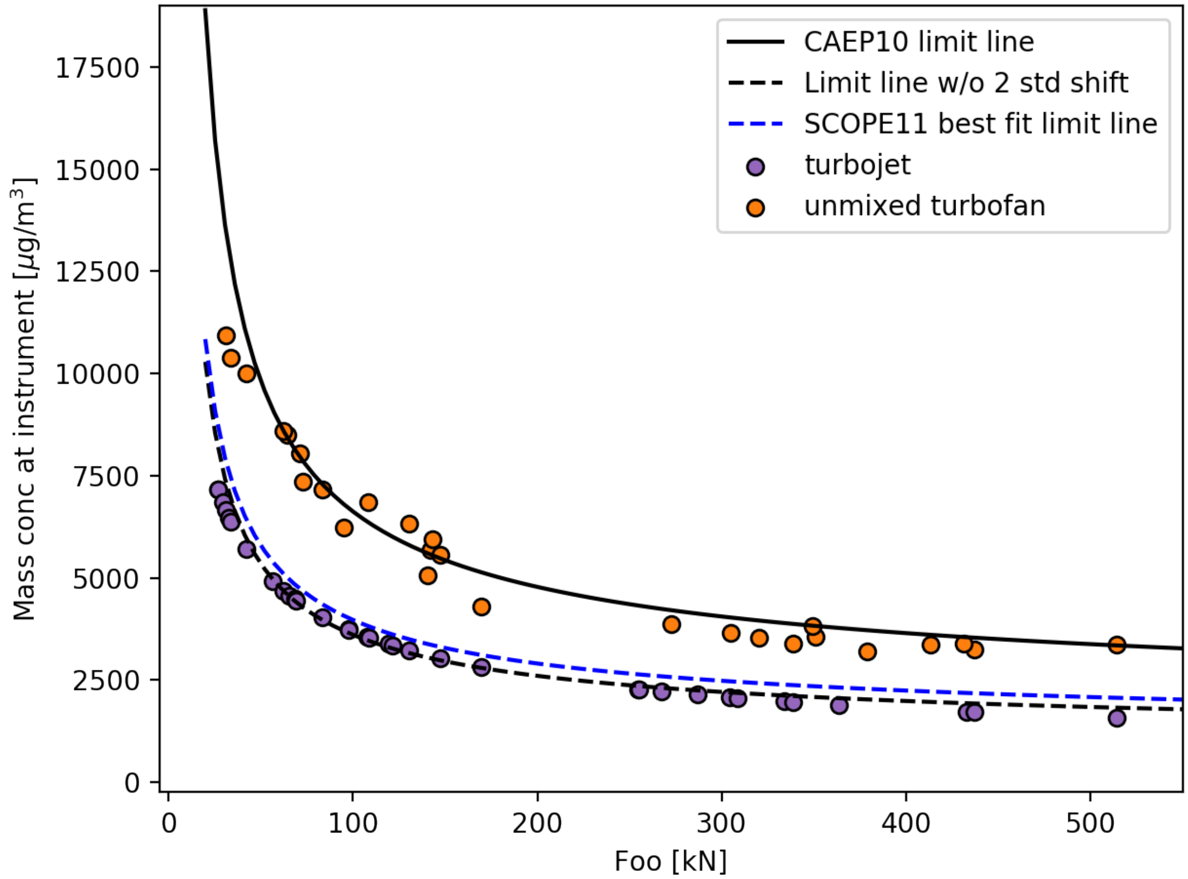

FIGURE B9: THE MASS CONCENTRATION AT 98% VISIBILITY AGAINST RATED THRUST FOR TURBOJETS AS FOUND IN FIGURE B5 IN PURPLE AND FOR UNMIXED TURBOFANS IN ORANGE.

4.8 These results show that the CAEP/10 limit line is at a transmission of around 98% for unmixed turbofan engines. The variation in the results around the limit line is driven by differences in the bypass ratio. Modern engines have gas generators with a higher specific power, driven by improvements in component efficiency and higher turbine inlet temperatures. Furthermore, the trends also have reduced fan pressure ratio for increased propulsive efficiency. These trends result in a smaller core nozzle diameter and larger bypass ratio. Thus, modern turbofan engines have a higher allowable mass concentration to prevent a visibility of 98%.

5. VISIBILITY FOR MIXED-FLOW ENGINES

5.1 The mixing between the core and bypass streams of mixed-flow engines changes the visibility of the plume at the exit plane. Firstly, the relevant nozzle diameter changes. For unmixed changes, we were interested in the core nozzle diameter, but for mixed-flow engines, there is only one exhaust diameter to measure. Secondly, the mixing process leads to a lower density at the exit plane and accordingly a smaller correction to STP conditions. Combining these two effects together, we expect that the mass concentration at a 98% transmission to be lower for mixed-flow engines compared with unmixed engines. At the same time, for a given core nvPM mass concentration, the mixing process reduces the mass concentration at the exit plane by the factor $(1 + \text{BPR})$. This gives mixed-flow engines an advantage under the current CAEP/10 limit line.

5.2 To study the visibility of mixed-flow engines, we must adapt our iterative gas turbine model to account for the mixing process. In the engine, the static pressure at the location of mixing should be equal. This condition requires knowledge of the internal velocities or areas, which is difficult to estimate in our simple model. Instead, we impose that the stagnation pressure must be equal at this stage. Although this is technically incorrect, it may be reasonable if we assume the velocities are low and similar in the core and bypass streams prior to mixing. This model is described in Appendix J.3.

5.3 As with the unmixed engines, we have attempted to predict fan diameter using our predicted mass flow rate and a hub-to-tip ratio of 0.33. The results are shown in Figure B10, which shows engines that are actually unmixed in blue and engines that are actually mixed-flow in yellow. It should be noted that all the engines were modelled as mixed-flow whether they are actually mixed or unmixed.

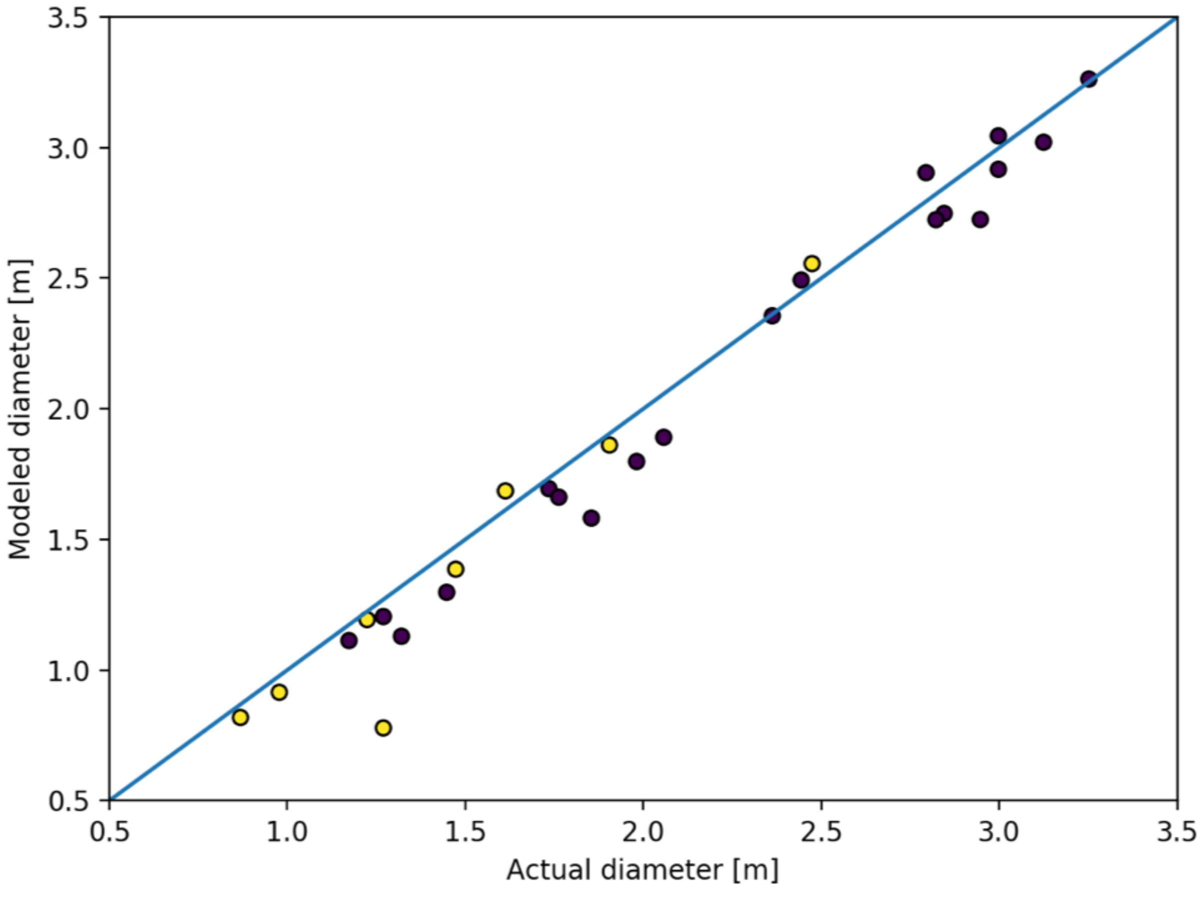

FIGURE B10: ACTUAL VERSUS PREDICTED DIAMETER USING THE SIMPLE GAS TURBINE MODEL. ALL ENGINES WERE MODELED AS IF THEY WERE MIXED-FLOW. ENGINES THAT ARE ACTUALLY MIXED-FLOW ARE SHOWN IN YELLOW AND THOSE THAT ARE UNMIXED ARE SHOWN IN BLUE.

5.4 For all the mixed-flow engines, the error in predicting fan diameter is under 10%, except for 1 engine where the actual fan diameter includes the nacelle size. We also run a subset of mixed-flow engines in GasTurb and the ability to predict exhaust nozzle diameter is shown in Figure B11. These results suggest that we consistently under-predict the exhaust nozzle diameter and we expect this to be caused by the stagnation pressure condition that was enforced at the mixing plane.

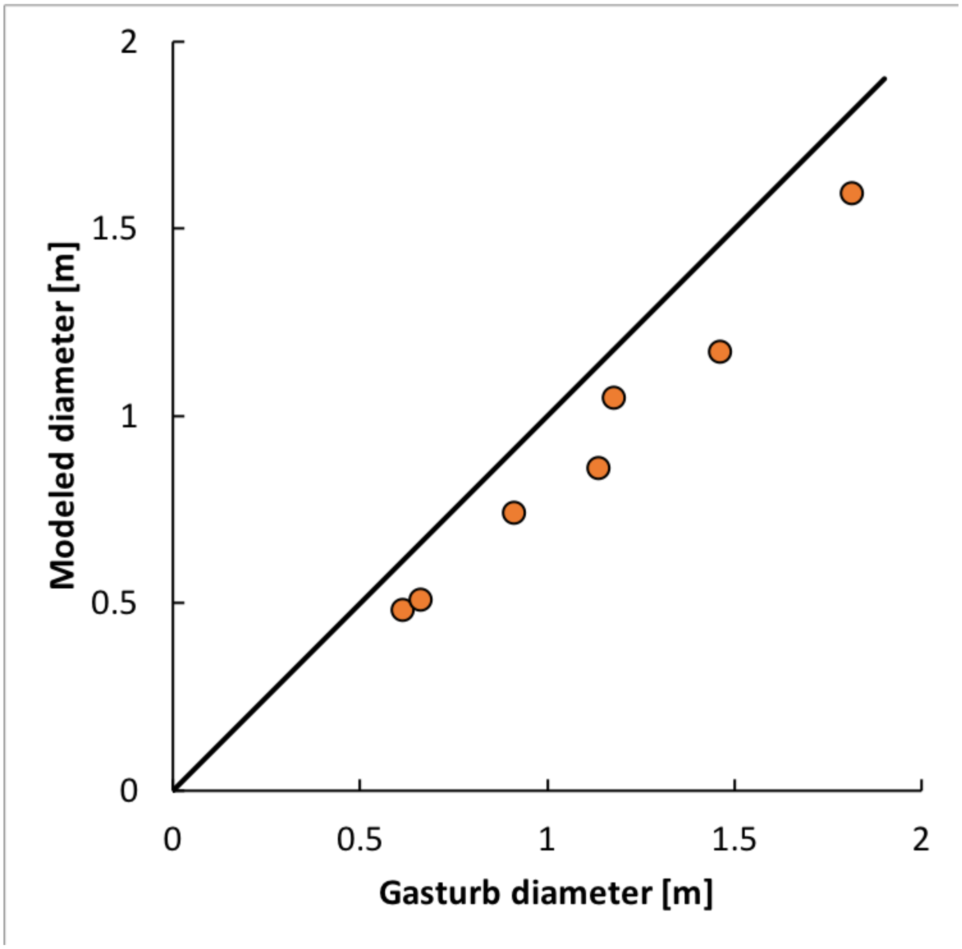

FIGURE B11: COMPARISON BETWEEN NOZZLE DIAMETER FROM GASTURB AND THE MODELED, ITERATIVE GAS TURBINE CYCLE FOR MIXED-FLOW ENGINES.

5.5 Despite this consistent under-prediction of nozzle diameter, the results from our iterative model can still be used to provide a mass concentration at 98% transmission. The absolute value of this mass concentration would be slightly higher than using the GasTurb diameter, however would provide an upper bound on the results. These results, as well as those for the turbojet and unmixed turbofan, are shown in Figure B12.

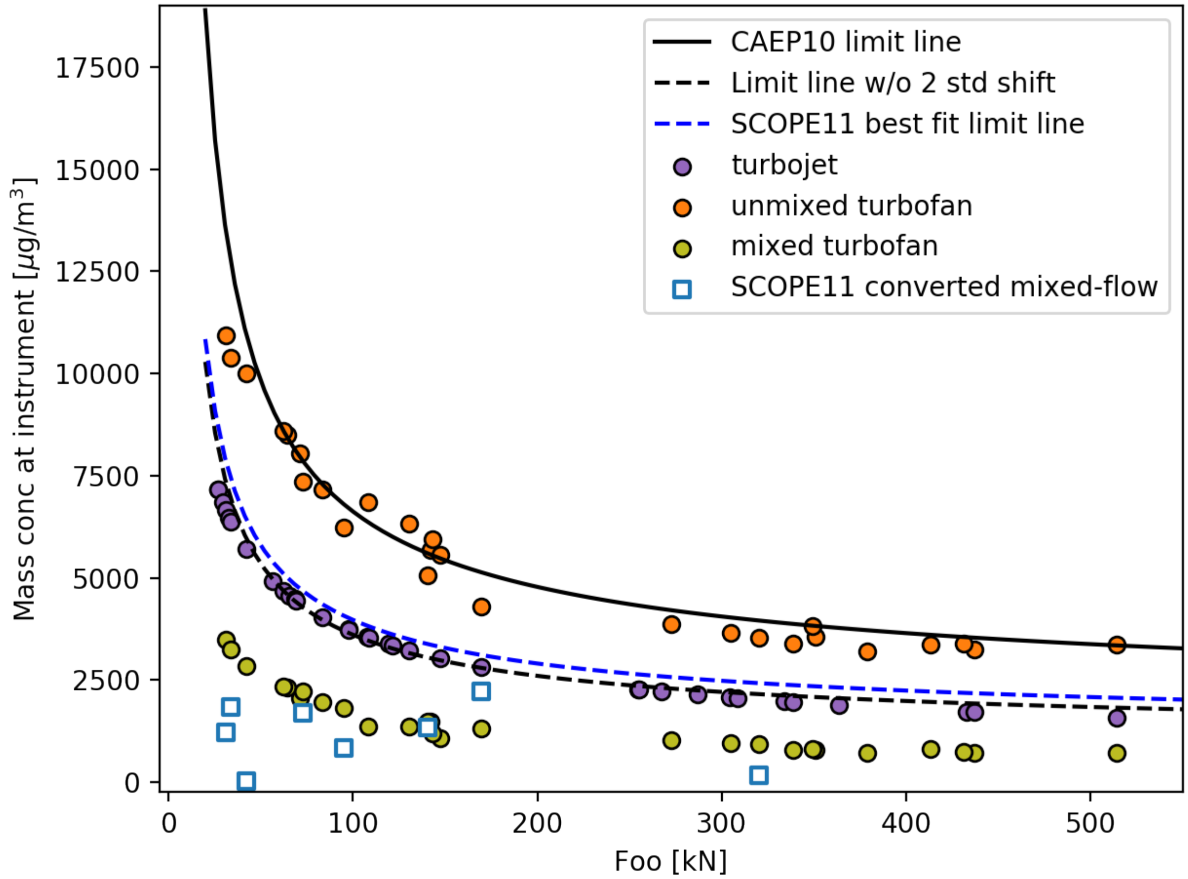

FIGURE B12: THE MASS CONCENTRATION AT 98% VISIBILITY AGAINST RATED THRUST FOR TURBOJETS IN PURPLE, UNMIXED TURBOFANS IN ORANGE AND MIXED-FLOW ENGINES IN GREEN. THE UNFILLED BLUE SQUARES REPRESENT THE MASS CONCENTRATION OF MIXED-FLOW ENGINES ESTIMATED BY CONVERTING THE MAXIMUM SN FROM THE EDB USING THE SCOPE11 METHOD.

5.6 On average, the mass concentration at 98% transmission for mixed-flow engines is 25% that for unmixed engines. The mixed-flow results lie below the SN limit line in mass concentration space and the mass concentration at 98% transmission of turbojet engines. This trend occurs in spite of the under-estimate in the nozzle diameter and so we expect the mass concentration at 98% transmission of mixed flow engines to be even lower. These results suggest that the SN and CAEP/10 limit lines would not prevent the visibility of plumes from mixed-flow engines at the 98% transmission level.

5.7 Figure B12 also includes the mass concentration of mixed flow engines estimated by converting the maximum SN from the EDB using the SCOPE11 method in the unfilled blue squares. These results show that all but one of the selected engines lie below our estimated mass concentration at 98% transmission for mixed-flow engines. Only one other engine lies within 10% of the estimated mass concentration at 98% transmission. These results suggest that mixed flow engines with a mass concentration at the CAEP/10 limit line or a smoke number at the SN limit line would have a transmission below 98% and thus may be visible.

6. CONCLUSIONS

6.1 The SN limit line is reproducible if we consider turbojet engines and apply appropriate corrections to STP conditions and system losses. Our results suggest that the SN limit line is at a transmission of 98% for these engines.

6.2 First-order cycle models can be used to estimate the nozzle diameter of unmixed and mixed-flow engines using data from the EEDB, which is needed to determine the mass concentration at 98% transmission. Validation using publicly available fan diameters and GasTurb simulations showed that the unmixed turbofan model is accurate within 3%, while the mixed-flow turbofan model underestimates nozzle diameter by ~20%.

6.3 For unmixed turbofan engines, the mass concentration at 98% transmission was found to be close to the CAEP/10 limit line, however there was variability around this line driven by the differences in bypass ratio.

6.4 For mixed-flow engines, the mass concentration at 98% transmission was found to be below both the CAEP/10 and SN limit lines. This means that both these limit lines would not prevent the visibility of plumes from mixed-flow engines.

6.5 Comparing the mass concentration at a 98% transmission with mass concentration estimated using the SCOPE11 method for in-production mixed-flow engines, we found that all mixed-flow engines, except 1, lay below the mass concentration at 98% transmission, suggesting that these mixed-flow engines would not have a visible plume.

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8. APPENDIX J.1 – TURBOJET CYCLE MODEL

8.1 Eq 4 shows how the engine nozzle diameter is found

$$\mathrm{L} = \sqrt{\frac{4\mathrm{F}_{00}}{\pi \gamma_c P_9}} \qquad \text{Eq 4}$$

where F_{00} is the engine rated thrust, γ_c is the heat capacity ratio in the compressor and P_9 is the static pressure at the exit plane. To estimate P_9, we have developed a turbojet cycle model. This also lets us estimate the density at the exit plane in order to correct the mass concentration to STP conditions.

8.2 The model requires the input of two variables: the overall pressure ratio (OPR) and the air-fuel ratio (AFR). The OPR is found from the EEDB, where we use rated thrust and OPR pairs in order to sample the domain space. The AFR is assumed to be 55 for all turbojets and we assume overall compressor and turbine polytropic efficiencies to be 0.78 and 0.83 respectively. Gas properties are also assumed to change after combustion with the heat capacity ratio reducing from 1.4 to 1.3 and the heat capacity at constant pressure increasing from $c_{pc} = 1{,}005$ to $c_{pt} = 1{,}250$ J/kg/K. The fuel is assumed to have a lower calorific value (LCV) of 43.2 MJ/kg.

8.3 Conditions at the combustor exit are calculated using Eq 5.

$$\mathrm{P}_{t3} = \mathrm{OPR} \cdot \mathrm{P}_{t2}$$
$$T_{t3} = T_{t2}\mathrm{OPR}^{\frac{\gamma_c - 1}{\gamma_c \eta_c}} \qquad \text{Eq 5}$$

where subscript t2 refers to conditions at the engine inlet and t3 to conditions downstream of the compressor, and η_c is the polytropic efficiency of the compressor assumed to 0.78.

8.4 We assume no stagnation pressure loss in the combustor such that $\mathrm{P}_{t4} = \mathrm{P}_{t3}$ and then apply an energy balance across the combustor to estimate the turbine inlet conditions (subscript t4).

$$T_{t4} = \frac{\mathrm{AFR} c_{pc} T_{t3} + \mathrm{LCV}}{c_{pt}(1 + \mathrm{AFR})} \qquad \text{Eq 6}$$

8.5 The turbine is used to drive the compressor and thus we use a power balance to estimate conditions downstream of the turbine (subscript t5). The pressure is calculated using a similar version of the second equation in Eq 5.

$$T_{t5} = T_{t4} - (T_{t3} - T_{t2})\frac{c_{pc}}{c_{pt}}$$
$$P_{t5} = P_{t4}\left(\frac{T_{t5}}{T_{t4}}\right)^{\frac{\gamma_t}{(\gamma_t - 1)\eta_t}} \qquad \text{Eq 7}$$

8.6 To calculate conditions at the engine exit plane (subscript 9), we assume that the nozzle is choked. Isentropic relations can thus be used to estimate the static temperature and pressure:

$$T_9 = \frac{\mathrm{T_{t5}}}{1 + \frac{\gamma_t - 1}{2}}$$
$$P_9 = P_{t5}\left(\frac{T_9}{T_{t5}}\right)^{\frac{\gamma_t}{\gamma_t - 1}} \qquad \text{Eq 8}$$

We then use the ideal gas equation to estimate the exit plane density.

$$\rho_9 = \frac{P_9}{R_{air} T_9} \qquad \text{Eq 9}$$

where R_{air} is the specific gas constant for air.

9. APPENDIX J.2 – UNMIXED TURBOFAN CYCLE MODEL

9.1 For unmixed turbofans, the typical method to estimate conditions within the engine are to specify a rated thrust, OPR, BPR and turbine inlet temperature (T_{t4}), while setting the jet velocity ratio to be ~0.9. The EEDB does not provide T_{t4} at take-off conditions, instead supplying the fuel flow rate. This requires us to use an iterative process to converge on a solution for this engine.

9.2 We use a least-squares solver in Python in order to identify the value of fan pressure ratio (FPR) that leads to a converged solution. The first step therefore involves guessing a FPR. With this value, we can estimate the conditions downstream of the fan as well as the bypass jet velocity.

$$\mathrm{P_{t13}} = \mathrm{FPR} \cdot \mathrm{P_{t2}} \qquad \text{Eq 10}$$
$$T_{t13} = T_{t2}\mathrm{FPR}^{\frac{\gamma_c - 1}{\gamma_c \eta_f}}$$

where subscript 13 refers to conditions downstream of the fan in the bypass stream and η_f is the fan polytropic efficiency assumed to be 0.9. The bypass jet velocity (V_{19}) is then found using Eq 11.

$$V_{19} = \sqrt{2 c_{pc} T_{t13}\left(1 - \left(\frac{P_{amb}}{P_{t13}}\right)^{\frac{\gamma_c - 1}{\gamma_c}}\right)} \qquad \text{Eq 11}$$

where subscript 19 refers to the bypass nozzle exit plane and P_{amb} is the ambient pressure. This method assumes that the bypass nozzle is perfectly expanded. This may not be reasonable particularly for smaller engines with a higher FPR. Thus, we check the exit Mach number to see if it is subsonic. If it is supersonic, we force the Mach number to be 1 and back out the exit plane pressure accordingly.

9.3 The conditions in the gas generator can then be estimated following a similar method to that for turbojet engines. We apply Eq 5 to estimate conditions downstream of the compressor assuming

$\eta_c = 0.9$. Before we apply the combustor energy balance in Eq 6, we must identify the AFR. This is found using the jet velocity ratio of 0.9 to estimate the core jet velocity (V_9) from the bypass jet velocity found in Eq 11 and then applying a momentum balance around the whole engine.

$$V_9 = \frac{V_{19}}{\alpha}$$
$$\dot{m}_c = \frac{F_{00}}{V_9(1 + \mathrm{BPR} \cdot \alpha)} \qquad \text{Eq 12}$$

Knowing the core mass flow rate, $\dot{m}_c$, we can the calculate the AFR $= \frac{\dot{m}_c}{\dot{m}_f}$ and subsequently apply Eq 6 to estimate conditions at the combustor exit/turbine inlet location.

9.4 We then conduct a power balance similar to that for turbojet engines but extending to include the power drawn by the fan to estimate conditions downstream of the turbine.

$$T_{t5} = T_{t4} - (T_{t3} - T_{t2})\frac{c_{pc}}{c_{pt}} - (T_{t13} - T_{t2})\frac{c_{pc}}{c_{pt}}\ \mathrm{BPR}$$
$$P_{t5} = P_{t4}\left(\frac{T_{t5}}{T_{t4}}\right)^{\frac{\gamma_t}{(\gamma_t - 1)\eta_t}} \qquad \text{Eq 13}$$

where $\eta_t = 0.95$ is the polytropic efficiency of the turbine.

9.5 We can now use the turbine exit conditions to estimate the core jet velocity following Eq 14.

$$V_9 = \sqrt{2c_{pt}T_{t5}\left(1 - \left(\frac{P_{amb}}{P_{t5}}\right)^{\frac{\gamma_t - 1}{\gamma_t}}\right)} \qquad \text{Eq 14}$$

9.6 V_9 was also estimated in Eq 12 using the jet velocity ratio. To ensure that the original FPR used is correct, we compare the two V_9 values in order to check if they are equal. If they are equal, then the calculation procedure is complete, otherwise we loop round again with a different value of the FPR.

9.7 Upon completing the cycle calculations, the core exit nozzle diameter can be found using the core mass flow rate.

$$d_9 = \sqrt{\frac{4\dot{m}_c}{\pi\rho_9 V_9}} \qquad \text{Eq 15}$$

where ρ_9 is found using Eq 9.

10. APPENDIX J.3 – MIXED-FLOW TURBOFAN CYCLE MODEL

10.1 For mixed-flow engines, the jet velocity ratio cannot be fixed since there is a single stream exiting the engine. Instead, the static pressure in the core and bypass stream must be equal at the mixer. To force this condition, we require information on the velocities at the mixer, which in turn requires details of the areas at these locations. An alternative, less accurate option is to enforce that the stagnation pressures at the mixer match. This is expected to give reasonable results since the velocity tends to be subsonic and thus leads to stagnation pressures being close to matching.

10.2 The method begins in a similar fashion to unmixed turbofan engines. We guess a FPR and apply Eq 10 to estimate conditions downstream of the fan in the bypass stream.

10.3 We then need a method to estimate the core mass flow rate that leads to the stagnation pressure downstream of the turbine being equal to that downstream of the fan in the bypass. This requires a second, embedded iteration loop where we cycle over the core mass flow rate, solving Eq 6 across the combustor and Eq 13 across the turbine until the stagnation pressure condition is found. This gives us the stagnation conditions at the turbine exit.

10.4 The final step involves modelling the mixing process between the core and bypass streams. We assume that the flow perfectly mixes with no stagnation pressure loss and calculate the mixed out conditions by mass-averaging between the core and bypass conditions.

$$T_{tm} = \frac{T_{t13}\mathrm{BPR} + T_{t5}}{1 + \mathrm{BPR}}$$
$$c_{pm} = \frac{c_{pc}\mathrm{BPR} + c_{pt}}{1 + \mathrm{BPR}}$$
Eq 16

where subscript m refers to the mixed out conditions.

10.5 Finally, these mixed out conditions can be used to find the jet velocity and thus the gross thrust of the engine. This is compared with the rated thrust input to the solver and if the error is low enough then the solver completes. If not then, the iteration loops over a different FPR.

11. APPENDIX J.4 – GASTURB SIMULATIONS

11.1 To validate both the unmixed and mixed flow solvers, we have used the GasTurb software to model a subset of engines.

11.2 GasTurb is a fast and accurate solver that allows us to iterate over certain variables to model engines. The OPR and BPR are provided in the EEDB and set as fixed variables in the solver.

11.2.1 For unmixed engines, we set three variables that we iterate over: (1) T_{t4} until the desired fuel flow rate from the EEDB is found; (2) FPR until the jet velocity ratio, set as 0.9, is found; and (3) air mass flow rate until the fan diameter is found. The fan diameter is publicly available and we believe is better for estimating the nozzle dimensions than rated thrust.

11.2.2 For mixed flow engines, a very similar set of variables are selected to iterate over, however the jet velocity ratio is no longer available to us.

12. APPENDIX J.5 – SN LIMIT LINE CONVERTED USING THE SCOPE11 CORRELATION

12.1 The SCOPE11 method provides a correlation to convert smoke number to mass concentration and so we can use this to convert the smoke number limit line to a mass concentration basis. This is found to be

$$\text{SCOPE11 best fit limit}\left[\frac{\mu\text{g}}{\text{m}^3}\right] = \frac{648.4\, e^{6.4F_{00}^{-0.274}}}{1 + e^{-1.098\cdot(83.6F_{00}^{-0.274}-3.064)}} \qquad \text{Eq 17}$$

12.2 The SCOPE11 best fit limit line is between 5% and 12% greater than the limit line without a 2 standard deviation shift.

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Agenda Item 4: Aircraft noise

4.1 REPORT OF WORKING GROUP 1 – NOISE TECHNICAL

4.1.1 The co-Rapporteurs of Working Group 1 (WG1 – Noise Technical) presented the group's work since CAEP/10. The main aim of WG1 is to keep ICAO aircraft noise SARPs up to date and effective, whilst ensuring that the certification procedures are as simple and inexpensive as possible. The report provided an overview of progress on each of the work items as related to these objectives.

4.1.2 WG1 presented proposals (under N.02) to revise Annex 16, Volume I and ICAO Doc 9501, *Environmental Technical Manual* (ETM), Volume I – *Procedures for the Noise Certification of Aircraft*, which had previously been endorsed by the 2018 CAEP Steering Group meeting. These amendments include the caretaking of the Annex and ETM, monitoring the progress and status of IEC Standards referenced within the Annex and ETM, and the development of guidance material for flight path measurement.

4.1.3 During CAEP/11, the ICAO NoisedB was updated and extended several times. In September 2018, WG1 agreed to publish Version 2.26 of the ICAO NoisedB. Compared to the previous version (v2.25), changes were incorporated for 272 aeroplanes and Version 2.26 of the NoisedB was published on 4 October 2018.

4.1.4 WG1 has also continued to monitor the various national and international research programme goals and milestones (Task N.04.01) and a report on this activity was given, which provided a perspective on the strong government and industry commitment to address the technology aspects of the Balanced Approach.

4.1.5 WG1 reviewed the progress on the four supersonic aeroplane noise-related work items (Tasks N.05.01 to N.05.04). A presentation on the current status of supersonic aeroplane Standards and Recommended Practices (SARPs) development, industry projects, and the latest research was provided to the Air Navigation Commission (ANC) on 9 June 2016.

4.1.6 Concerning helicopter noise, WG1 reported on the feasibility of correlating certification noise levels with operational noise levels. This report is provided in Appendix B to the report on this agenda item. WG1 also assessed whether the current helicopter noise certification scheme is applicable for assessing hover noise, including the sufficiency of a correlation with one or more of the existing reference conditions. This report is provided in Appendix C to the report on this agenda item.

Discussion and Conclusions

4.1.7 The meeting thanked WG1 for keeping Annex 16, Volume I up to date and relevant and the meeting approved the amendments as presented in Appendix A to the report on this agenda item. The meeting also approved the amendments to the ETM, Volume I as previously endorsed by the 2018 CAEP Steering Group meeting, as contained in the report from the working group.

4.1.8 The meeting approved the report on the feasibility of correlating helicopter certification noise levels with operational noise levels, and the report on helicopter hover noise. An Observer expressed appreciation for WG1's work on the CAEP/11 N.08 helicopter tasks, and underlined that helicopter noise is a major noise issue in her country. The Observer stressed the need for WG1 to continue these tasks when new data is available.

4.1.9 **Recommendations**

4.1.9.1 In light of the foregoing discussion, the meeting developed the following recommendations:

RSPP **Recommendation 4/1 — Amendments to Annex 16 — *Environmental Protection*, Volume I — *Aircraft Noise***

That Annex 16, Volume I be amended as indicated in Appendix A to the report on this agenda item.

Recommendation 4/2 — Amendments to the *Environmental Technical Manual*, Volume I — *Procedures for the Noise Certification of Aircraft*

That the *Environmental Technical Manual*, Volume I be amended, and that revised versions approved by subsequent CAEP Steering Group Meetings be made available, free of charge on the ICAO website.

4.2 PROGRESS ON THE DEVELOPMENT OF A SUPERSONIC EN ROUTE (SONIC BOOM) NOISE STANDARD

4.2.1 The co-Rapporteurs of WG1 reported on progress in the development of an en route (sonic boom) noise certification Standard for supersonic aeroplanes. This effort has focused on: the identification of viable sonic boom data processing scheme options; candidate reference atmosphere and humidity standards; updated sonic boom metric(s) analyses; and sonic boom reference flight conditions. An overview of recent supersonic noise technology research was also presented.

4.2.2 The WG1 Supersonic Research Focal Points (RFPs) presented an update on the state-of-the-art in sonic boom technology, with an overview of many of the developments in supersonic technology made by various organizations from the United States, Japan, Europe and industry. Each organization devoted a portion of their resources to efforts to develop understanding of, and models for, the effects of atmospheric turbulence on the propagated acoustic signature from a supersonic aircraft, and significant progress has been made in this important area of research. Atmospheric turbulence can distort the propagating waveform and result in a ground signature that is louder or quieter than the predicted level in a quiescent atmosphere. These new models will play a vital role in understanding the potential variation in the noise levels from quiet supersonic aircraft in daily operations. An additional conclusion was that there remain many unknowns related to overland supersonic flight, and continued careful monitoring of the developments in supersonics would be in the best interest of CAEP.

4.2.3 Several Members and Observers considered that perception of sonic boom over land would constitute a new form of nuisance, therefore any supersonic civil aeroplanes should be subject to en route noise certification in order to establish its sonic boom noise level.

4.2.4 An Observer, on behalf of WG1, presented the industry efforts in the area of supersonics, including aeroplane development projects related to supersonic flight over water only, and enabling technologies to support low boom aeroplanes capable of supersonic operation over land. During the CAEP/11 cycle, six major developments had occurred, making it clear that sustained investments are being made by various international industry members and national research agencies.

Discussion And Conclusions

4.2.5 A Member congratulated WG1 on the work on the sonic boom noise Standard, and noted the challenging timeline proposed by WG1, which foresees the conclusion of this work at CAEP/13. The Member encouraged further research on the effects of sonic boom, especially on rattle, vibration and sleep disturbance.

4.2.6 Responding to a question by a Member, a WG1 RFP informed that, based on currently available results from NASA community testing, a level of 75 PLdB was identified as the threshold where sonic boom noise is potentially indistinguishable from background noise. On a related subject, the WG1 co-Rapporteurs clarified that WG1 had not yet investigated the data needed to support a future stringency definition on sonic boom levels.

4.2.7 A Member welcomed the initiatives of NASA on sonic boom community testing, and expressed the view that an eventual sonic boom certification scheme should only be applicable to designs interested in a “low boom” certification. An Observer highlighted how the present research constitutes only the beginning of the understanding of the issue as other factors should be considered such as culture, type of boom and location. The meeting encouraged the continuation of State supported supersonic noise research. The CAEP Secretary thanked WG1 RFPs for their presentation and highlighted the importance of the information provided in support of the work of CAEP.

4.2.8 The meeting acknowledged the supersonic standards work to date, and noted the logical staging of the basic technical activities timed by data availability, as outlined by WG1.

4.2.9 The meeting endorsed the six finalist sonic boom metrics (Stevens Mark VII Perceived Level (PL); Indoor sonic boom annoyance predictor (ISBAP); A-weighted Sound Exposure Level (ASEL); B-weighted Sound Exposure Level (BSEL); E-weighted Sound Exposure Level (ESEL); and D-weighted Sound Exposure Level (DSEL)), following the reassessment to include new laboratory subjective data pertaining to low-boom response.

4.2.10 The meeting agreed that WG1 should address the sonic boom data processing scheme, reference atmosphere-humidity standards, en route reference flight conditions and measurement locations, low boom SARPs applicability for non-low boom designs, continue to explore the management of Mach cut-off operations, and continue to gather data on which “other factors” need to be considered for SARP development. These may include boom at “off design” Mach numbers, boom from accelerations and turns, secondary sonic booms, restricting N-wave booms over water, sleep and booms at night, effects on animals, and avalanches.

4.3 PROGRESS ON THE DEVELOPMENT OF A LANDING AND TAKE-OFF LTO NOISE STANDARD FOR SUPERSONIC AEROPLANES

4.3.1 The co-Rapporteurs of WG1 reported on progress in the development of a landing and take-off noise certification Standard for supersonic aeroplanes. WG1 started by gaining a common understanding of the current relevant regulations, reviewing historical data on civil supersonic aircraft, reviewing the details of programme lapse rate (PLR), and reviewing design differences between subsonic and supersonic aeroplanes. Additionally, take-off and landing differences were highlighted in terms of speeds and configurations.

4.3.2 In the absence of manufacturers' data, WG1 started working with a 55-tonne Supersonic Technology Concept Aeroplane (STCA) developed by NASA with manufacturers' oversight and cross-checking. JAXA and TsAGI also contributed by independently predicting noise levels of this STCA with the same publicly available input.

4.3.3 With a non-disclosure agreement finalized, manufacturers' data from three project aeroplanes was presented to WG1 members, including noise level estimates, weight information, range, balance field length, Mach number, engine information, operating procedures, etc.

4.3.4 At the 2017 CAEP Steering Group meeting, CAEP acknowledged that the basic design characteristics T/W (Thrust-to-weight-ratio), W/S (Wing loading) and CLMax (Maximum Usable Lift Coefficient) are, in general terms, fundamentally different between supersonic and subsonic aircraft, and that the evaluation of these differences in more precise terms will only be possible with a specific design in hand. The project aeroplanes data provided to WG1 supported some of the key differences between subsonic and supersonic aeroplanes. Data from the 55-tonne STCA also supported these differences.

4.3.5 WG1 assessed the suitability of the current LTO noise certification Standards and the ETM, developed for subsonic aeroplanes, for aircraft designed to fly at supersonic speeds. Based on this assessment, WG1 identified some categories that need, or may need, further investigation to determine their suitability. All the subsonic Standards that do not fit into these categories will require minor wording changes, or no changes at all, to become suitable for supersonic aircraft.

4.3.6 The metric Effective Perceived Noise Level (EPNL) was adopted as the single noise metric and agreed to during the 2017 CAEP Steering Group meeting, and is expected to be used without modification. While applicability definitions are needed, these will be completed at a later stage. A majority of WG1 members agreed that the Chapter 14 noise limit for each individual reference point should be used, but some felt that it was premature to make this decision before additional discussions on procedures took place. WG1 had not reached any agreement on whether the cumulative noise level would be an item for further review. The group had also not reached any consensus on whether a correlating parameter was an item for further review with the current knowledge in WG1. However, WG1 agreed to consider the use of an additional correlating parameter, to accommodate a range of design Mach numbers, provided that OEMs data and computational analysis data are made available to the group. Concerning procedures, WG1 agreed that test and reference day speeds for take-off needed further review. VNRS is already allowed for subsonics in the ETM, but some additional guidance may be needed for supersonics in the SARPs. PLR is expected to be a feature of supersonic products, and this is considered to be incorporated under VNRS provisions. At this point, there is insufficient data to decide whether a change is needed in Chapter 14 (being used as a starting point) in several other sections, including approach procedures.

4.3.7 One Observer supported that a supersonic fleet forecast is needed rapidly, including how and where this fleet will operate, which would allow fruitful discussions about regulatory impacts. The Observer offered resources to this effort, and supported the creation of a coordination group for SST SARPs development.

4.3.8 Responding to a question, the WG1 co-Rapporteurs clarified that Chapter 14 presents noise limits in terms of each of the three measurement points, but also presents a limit in terms of the cumulative margin to these points. This makes it possible for a design to comply with the three individual limits, but not comply with the cumulative noise limit, thus not meeting Chapter 14.

4.3.9 A Member highlighted, and the WG1 co-Rapporteurs concurred, that the current WG1 analyses regarding supersonics compliance with Chapter 14 requirements were not yet conclusive, as they were supported by data from only two project aircraft, not including data from the third project aircraft with a higher design cruise Mach number.

4.3.10 Several Members and Observers presented their views related to the development of supersonic aeroplane LTO noise Standards. They reiterated their view that the development of noise SARPs for supersonic aeroplanes (both LTO and sonic boom) must be based on ICAO Assembly Resolution A39-1, ensuring no unacceptable situation is created for the public. Regarding LTO noise, they considered that civil supersonic aeroplanes should not be noisier than current and future subsonic aeroplanes in LTO operations. Also, they considered that civil supersonic aeroplanes should be certified according to Chapter 14 with some technical adaptations if need be, therefore they did not see the need to consider a set of new stringency options or to conduct a relative cost-effectiveness analysis of candidate options.

4.3.11 A Member proposed a CAEP future work item covering a scoping study for updating the Chapter 14 noise requirements for subsonic aeroplanes. This will be considered under Agenda Item 12 on future work.

4.3.12 A Member expressed the view that the unacceptable situations referred to in Resolution A39-1 can be interpreted in different ways by each State, and supported that the language could be clarified by including the word “inhabited land” when referring to sonic boom impact. A Member noted that this aspect could be addressed by proper operational rules.

4.3.13 Some Members and Observers supported the view that supersonic aircraft should comply with the current and future noise Standards for subsonics, while others supported gathering more data and analysis, as recommended by WG1, before reaching any decision.

4.3.14 A Member presented views on the supersonic noise work within CAEP. The Member recommended that CAEP develop a SARP and conduct an associated stringency assessment for civil supersonic aircraft landing and take-off noise for consideration at CAEP/12, in 2022. The Member recognized that there are fundamental technological differences between subsonic and supersonic aircraft types, which may lead to different approaches to Standard-setting, and at the very least, warrant a technical review and analysis prior to drawing policy conclusions. The Member reminded that Assembly Resolution A39-1, paragraph 1.1 “reaffirms the importance” that the Assembly attaches “to ensuring that no unacceptable situation for the public is created by sonic boom.” The Member interprets this language as specific to the issue of sonic boom and ensuring that sonic boom does not result in “unacceptable situations.” The Member did not support creating a new concept of “public acceptability” based on Resolution A39-1, as he considered this term to be subjective, imprecise, and inconsistent with the longstanding CAEP Terms of Reference that are premised on technological feasibility, environmental benefit and cost effectiveness.

4.3.15 Responding to a question, the Member affirmed that it would be possible to consider noise limits for supersonics more stringent than Chapter 14 limits, after the proper technical analysis was completed. The Member was also of the view that CAEP will have to adapt its Standard-setting process to address the unique situation caused by the lack of certified noise data for supersonics, and noted that such adaptations should not set a precedent for future analyses, due to their exceptional characteristics.

4.3.16 One Member supported innovations in air transport, provided they do not come with unacceptable environmental impacts, and expressed the view that supersonics have potentially serious environmental impacts, which could be avoided only by applying existing subsonic Standards in their certification. The Member also noted that supersonics and subsonics will compete in the same markets, and therefore different noise limits for supersonics would incur a competitive advantage for them.

4.3.17 An Observer shared concerns regarding the development of supersonics LTO SARPs, and expressed that in order to be acceptable to communities around airports, supersonic aircraft cannot be noisier than their subsonic counterparts (same level of MTOM) under subsonic operations and must also comply with current and future noise and emissions subsonic SARPs. The Observer proposed work on further analysis of community noise impact of supersonic operations around airports using other noise indicators, in addition to the EPNL, and expressed views on the application of the ICAO Assembly Resolution A39-1 to the SST LTO noise.

4.3.18 Members and Observers questioned how the results of the proposed analysis of community noise would be used by CAEP. The Observer clarified that such results would be used to support policy decisions on supersonics but would not question the choice of EPNL as the metric for noise certification. The meeting agreed to discuss the proposal under the future work agenda item.

4.3.19 Two Observers summarized the significant technical progress on the development of LTO noise Standards for supersonics, as well as the contributions provided by the industry. They highlighted that OEMs are working hard to bring supersonic aeroplanes into service by the mid-2020s, and therefore OEMs need definitive LTO noise requirements in order to finalize project designs. The Observers supported the initiation of elements of SARPs development and identification of resources to meet the proposed CAEP/12 date for supersonic LTO noise SARPs.

4.3.20 An Observer questioned the consistency between the traditional SARPs development approach of CAEP, namely the setting of SARPs based on measurement and certification data, and the new approach suggested by industry to solely rely on project aircraft and modelling data of lower TRL. He then asked if the TRL of the project aeroplanes could be clearly identified. Another Observer replied that this was not possible due to the variety of technologies involved.

4.3.21 An Observer presented the view that future certification of supersonic aeroplanes must be handled carefully to ensure no net increase in airport noise and community disturbance. The Observer proposed that, until a robust data set of SST noise performance is available to develop supersonic noise Standards, new SST aircraft should comply with the current subsonic Chapter 14 noise Standards.

4.3.22 The meeting noted the information provided by a Member regarding the potential noise reduction for supersonics from using take-off thrust management, as well as on the interdependencies of noise, emissions and flight range for supersonics. According to the information, taking into account main engine noise sources, the noise level predictions show that SST would fail Chapter 14 even with the use of take-off thrust control.

Discussion And Conclusions

4.3.23 The meeting considered the interpretation that CAEP work is aimed at maintaining at least the existing level of environmental protection, referred to as "environmental benefit" in the CAEP Terms of Reference. Responding to a question regarding the term "existing level of environmental protection", a Member expressed the opinion that this term means to not deteriorate the existing noise levels around airports. An Observer questioned whether CAEP work should aim at a specific element of the Terms of Reference, or on a balance amongst the four elements, to which a Member responded that the industry efforts on technology development may still allow this balance to be achieved. An Observer was of the opinion that the term "anti-backsliding" should be a non-controversial interpretation of the environmental benefit aspect under CAEP Standard-setting. A Member expressed concerns that the "environmental benefit" aspect of the CAEP Terms of Reference is being interpreted by some Members and Observers as a "net environmental benefit to the overall system", which is not in line with past CAEP practices. The meeting noted the different interpretations on this element of the CAEP Terms of Reference.

4.3.24 Some Members supported the view that the language in Resolution A39-1 is specific to the issue of sonic boom and ensuring that sonic boom does not result in "unacceptable situations". Other Members noted that Resolution A39-1 refers to the "problems which the operation of supersonic aircraft may create for the public", and supported that these problems include LTO noise and its public acceptability. A Member commented that the concept of public acceptability is not new to CAEP, since the CAEP/10 meeting noted that the CAEP 2015 Steering Group meeting "acknowledged public acceptability of booms is a pre-requisite of a standard for supersonic aircraft", while another Member supported that CAEP should refrain from referencing Steering Group decisions instead of the Assembly resolution language, which refers to "unacceptable situations for the public due to sonic boom".

4.3.25 Given the different views expressed, the meeting noted the view of a Member that the language of Resolution A39-1 is specific to the issue of sonic boom and ensuring that sonic boom does not result in "unacceptable situations".

4.3.26 The meeting agreed that both subsonic and supersonic civil aeroplanes are jet aeroplanes with fixed wings intended for passenger transport and that certain basic design characteristics are fundamentally different between supersonic and subsonic aeroplanes.

4.3.27 Several Members and Observers objected to performing a noise stringency assessment for supersonics under the CAEP/12 work programme, as there was no clarity on how such a stringency assessment would be performed and which data would be used. These Members and Observers supported the adoption of Chapter 14 as the LTO noise Standard, with some technical adaptations if needed. A Member noted that the use of current subsonic Standards as a reference for supersonics would provide regulatory certainty to the industry, which is also important, besides the environmental benefit aspects.

4.3.28 A Member stated that in the absence of certification data, the current data can be used to carry out a stringency analysis. Other Members and Observers supported that there is still insufficient data and analysis available to decide on Chapter 14 adoption for supersonics, and requested further work from WG1 during the CAEP/12 cycle. A Member highlighted the fundamental design differences between supersonic and subsonic aeroplanes, and considered it simplistic to equate subsonics and supersonic aeroplanes. Another Member reminded that Chapter 14 currently covers both turbojets and turboprops, which are also fundamentally different.

4.3.29 From the ensuing discussion, the meeting agreed with the elements of an exploratory study for supersonic aircraft during the CAEP/12 work programme, detailed as follows:

4.3.30 Recognizing that there is no consensus on the necessity to conduct a stringency option analysis on LTO noise for supersonic aircraft, CAEP recommended that an exploratory study using currently available data be undertaken during the CAEP/12 cycle. The results of the study are intended to provide CAEP with a better understanding of airport noise impacts resulting from the introduction of supersonic aircraft, and do not prejudge the need to conduct a stringency options analysis. This work consists of a fleet and operations forecast and an LTO noise impact assessment for a selection of airports based on the noise performance information currently available. It will also include an assessment of the project aircraft used, with regards to Annex 16, Volume I, Chapter 14 noise levels and margin requirements.

4.3.31 The study is to contain the various elements below:

1) **Procedures**

— Working Group 1 to make recommendations by the 2019 CAEP Steering Group (SG2019) meeting on procedures for LTO noise certification, taking into account the need for additional data from industry.

2) **Forecast Scenarios**

— FESG to develop multiple demand scenarios for supersonic transport markets, based on data provided by the industry and by Working Groups of CAEP.

3) **Aircraft Data**

— CAEP expressly recognizes the uncertainty associated with the available aircraft data.

— WG1 to use STCA and OEM data to develop an environmental and performance modelling data, which would represent a range of concept and project aircraft, as a proxy for future supersonic aircraft types.

— WG1 to develop noise-power-distance and spectral data based on certification procedures, subject to a feasibility assessment. As appropriate, new aircraft data is to be considered for inclusion as it becomes available.

— WG3 to provide corresponding estimates on LTO engine emissions as well as aeroplane fuel burn and CO_2 emissions data (cruise and full-flight) for the purposes of an exploratory analysis, subject to feasibility assessment.

— ISG, with input from WG1 and WG3 if needed, to provide information regarding environmental impacts originating from SST noise and emissions.

— WG1 and WG3 to provide information regarding trades among noise, emissions, fuel burn, and Mach number.

4) **Study**

— MDG to develop environmental modelling scenarios, acknowledging that this will require additional resources to update existing models and databases, and run the exploratory study.

— Include regional representation of business jet and mixed-use large airports, and consider the feasibility of taking into account airport capacity constraints, as needed, to ensure a realistic representation of subsonic operations. As part of the regionally based airport selection for LTO noise analysis, sample origin-destination pairs will also be included so that full-flight fuel burn and emissions can be computed.

— Noise metric would be DNL, and single event metrics (LA max, SEL).

— Considering the uncertainty of the project aircraft data used in the study, an assessment of the corresponding uncertainty of the output results will be conducted.

— Consider trades such as noise and full-flight fuel burn.

5) **Results**

— Results of the analysis to be presented for initial consideration by the 2021 CAEP Steering Group (SG2021) meeting, and final results to CAEP/12.

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APPENDIX A

PROPOSED AMENDMENTS TO ANNEX 16, VOLUME I

The text of the amendment is arranged to show deleted text with a line through it and new text highlighted with grey shading, as shown below:

1. ~~Text to be deleted is shown with a line through it.~~	text to be deleted
2. New text to be inserted is highlighted with grey shading	new text to be inserted
3. ~~Text to be deleted is shown with a line through it~~ followed by the replacement text which is highlighted with grey shading.	new text to replace existing text

TEXT OF PROPOSED AMENDMENT TO THE

INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES

ENVIRONMENTAL PROTECTION

ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME I
AIRCRAFT NOISE

…

NOMENCLATURE: SYMBOLS AND UNITS

Note.— Many of the following definitions and symbols are specific to aircraft noise certification. Some of the definitions and symbols may also apply to purposes beyond aircraft noise certification.

1.1 Velocity

Symbol	*Unit*	*Meaning*
c_R	m/s	*Reference speed of sound*. Speed of sound at reference conditions.
c_{HR}	m/s	*Reference speed of sound*. The reference speed of sound corresponding to the ambient temperature – assuming a lapse rate of 0.65°C per 100 m – for a standard day at the aeroplane reference height above mean sea level.
M_{ATR}	—	*Helicopter rotor reference advancing blade tip Mach number*. The sum of the reference rotor rotational tip speed and the reference speed of the helicopter, divided by the reference speed of sound.
M_H	—	*Propeller helical tip Mach number*. The square root of the sum of the square of the propeller test rotational tip speed and the square of the test airspeed of the aeroplane, divided by the test speed of sound.
M_{HR}	—	*Propeller reference helical tip Mach number*. The square root of the sum of the square of the propeller reference rotational tip speed and the square of the reference speed of the aeroplane, divided by the reference speed of sound.
Best R/C	m/s	*Best rate of climb*. The certificated maximum take-off rate of climb at the maximum power setting and engine speed.
V_{AR}	~~km/h~~ m/s	*Adjusted reference speed*. On a non-standard test day, the helicopter reference speed adjusted to achieve the same advancing tip Mach number as the reference speed at reference conditions.

V_{CON}	~~km/h~~ m/s	*Maximum airspeed in conversion mode*. The never-exceed airspeed of a tilt-rotor when in conversion mode.
V_G	~~km/h~~ m/s	*Ground speed*. The aircraft velocity relative to the ground.
V_{GR}	~~km/h~~ m/s	*Reference ground speed*. The aircraft true velocity relative to the ground in the direction of the ground track under reference conditions. V_{GR} is the horizontal component of the reference aircraft speed V_R.
V_H	~~km/h~~ m/s	*Maximum airspeed in level flight*. The maximum airspeed of a helicopter in level flight when operating at maximum continuous power.
V_{MCP}	~~km/h~~ m/s	*Maximum airspeed in level flight*. The maximum airspeed of a tilt-rotor in level flight when operating in aeroplane mode at maximum continuous power.
V_{MO}	~~km/h~~ m/s	*Maximum operating airspeed*. The maximum operating limit airspeed of a tilt-rotor that may not be deliberately exceeded.
V_{NE}	~~km/h~~ m/s	*Never-exceed airspeed*. The maximum operating limit airspeed that may not be deliberately exceeded.
V_R	~~km/h~~ m/s	*Reference speed*. The aircraft true velocity at reference conditions in the direction of the reference flight path. *Note.— This symbol should not be confused with the symbol commonly used for aeroplane take-off rotation speed.*
V_{REF}	~~km/h~~ m/s	*Reference landing airspeed*. The speed of the aeroplane, in a specific landing configuration, at the point where it descends through the landing screen height, in the determination of the landing distance for manual landings.
V_S	~~km/h~~ m/s	*Stalling airspeed*. The minimum steady airspeed in the landing configuration.
V_{tip}	m/s	*Tip speed*. The rotational speed of a rotor or propeller tip at test conditions, excluding the aircraft velocity component.
V_{tipR}	m/s	*Reference tip speed.* The rotational speed of a rotor or propeller tip at reference conditions, excluding the aircraft velocity component.
V_Y	~~km/h~~ m/s	*Speed for best rate of climb*. The test airspeed for best take-off rate of climb.
V_2	~~km/h~~ m/s	*Take-off safety speed*. The minimum airspeed for a safe take-off.

…

1.4 Noise metrics

Symbol	*Unit*	*Meaning*
…		
L_{AE}	dB ~~SEL~~(A)	*Sound exposure level (SEL)*. A single event noise level for an aircraft pass-by, consisting of an integration over the noise duration of the A-weighted sound level (dB(A)), normalized to a reference duration of 1 second. (See Appendix 4, Section 3 for specifications.)
Δ_1	TPNdB	*PNLTM adjustment* for Appendix 2 or Attachment F. In the simplified adjustment method, the adjustment to be added to the measured EPNL to account for noise level changes due to differences in atmospheric absorption and noise path length, between test and reference conditions at PNLTM.
	dB(A)	Under Appendix 4. The adjustments to be added to the measured L_{AE} to account for noise level changes for spherical spreading and duration due to the difference between test and reference helicopter height.
	dB(A)	Under Appendix 6. For propeller-driven aeroplanes not exceeding 8 618 kg, the adjustment to be added to the measured L_{ASmax} to account for noise level changes due to the difference between test and reference aeroplane heights.
Δ_2	TPNdB	*Duration adjustment* for Appendix 2 or Attachment F. In the simplified adjustment method, the adjustment to be added to the measured EPNL to account for noise level changes due to the change in noise duration, caused by differences between test and reference aircraft speed and position relative to the microphone.
	dB(A)	Under Appendix 4. The adjustments to be added to the measured L_{AE} to account for noise level changes due to difference between reference and adjusted airspeed.
	dB(A)	Under Appendix 6. For propeller-driven aeroplanes not exceeding 8 618 kg, the adjustment to be added to the measured L_{ASmax} to account for the noise level changes due to the difference between test and reference propeller helical tip Mach number.

Symbol	*Unit*	*Meaning*
Δ_3	TPNdB	*Source noise adjustment* for Appendix 2. In the simplified or integrated adjustment method, the adjustment to be added to the measured EPNL to account for noise level changes due to differences in source noise generating mechanisms, between test and reference conditions.
	dB(A)	Under Appendix 6. For propeller-driven aeroplanes not exceeding 8 618 kg, the adjustment to be added to the measured L_{ASmax} to account for noise level changes due to the difference between test and reference engine power.
Δ_4	dB(A)	*Atmospheric absorption adjustment* for Appendix 6. For propeller-driven aeroplanes not exceeding 8 618 kg, the adjustment to be added to the measured L_{ASmax} for noise level changes due to the change in atmospheric absorption, caused by the difference between test and reference aeroplane heights.

…

1.6 Flight path geometry

Symbol	*Unit*	*Meaning*
H	m	*Height*. The aircraft height ~~when overhead or abeam of the centre microphone~~ at the point where the flight path intercepts the vertical geometrical plane perpendicular to the reference ground track at the centre microphone.
H_R	m	*Reference height*. The reference aircraft height ~~when overhead or abeam of the centre microphone~~ at the point where the reference flight path intercepts the vertical geometrical plane perpendicular to the reference ground track at the centre microphone.

…

CHAPTER 11. HELICOPTERS NOT EXCEEDING 3 175 kg MAXIMUM CERTIFICATED TAKE-OFF MASS

…

11.2 Noise evaluation measure

The noise evaluation measure shall be the sound exposure level ~~(SEL)~~L_{AE} as described in Appendix 4.

…

11.4 Maximum noise level

11.4.1 For helicopters specified in 11.1.2 and 11.1.3, the maximum noise levels, when determined in accordance with the noise evaluation method of Appendix 4, shall not exceed 82 ~~decibels~~ dB(A) ~~SEL~~ for helicopters with maximum certificated take-off mass, at which the noise certification is requested, of up to 788 kg and increasing linearly with the logarithm of the helicopter mass at a rate of 3 decibels per doubling of mass thereafter.

11.4.2 For helicopters specified in 11.1.4, the maximum noise levels, when determined in accordance with the noise evaluation method of Appendix 4, shall not exceed 82 ~~decibels~~ dB(A) ~~SEL~~ for helicopters with maximum certificated take-off mass, at which the noise certification is requested, of up to 1 417 kg and increasing linearly with the logarithm of the helicopter mass at a rate of 3 decibels per doubling of mass thereafter.

Note.— See Attachment A for equations for the calculation of maximum permitted noise levels as a function of take-off mass.

…

11.6 Test procedures

11.6.1 The test procedures shall be acceptable to the airworthiness and noise certificating authorities of the State issuing the certificate.

11.6.2 The test procedure and noise measurements shall be conducted and processed in an approved manner to yield the noise evaluation measure designated as sound exposure level (~~SEL~~L_{AE}), in A-weighted decibels integrated over the duration time, as described in Appendix 4.

11.6.3 Test conditions and procedures shall be closely similar to reference conditions and procedures or the acoustic data shall be adjusted, by the methods outlined in Appendix 4, to the reference conditions and procedures specified in this chapter.

11.6.4 During the test, flights shall be made in equal numbers with tailwind and headwind components.

11.6.5 Adjustments for differences between test and reference flight procedures shall not exceed 2.0 dB(A).

11.6.6 During the test, the average rotor rpm shall not vary from the normal maximum operating rpm by more than ±1.0 per cent during the 10 dB-down period.

11.6.7 The helicopter airspeed shall not vary from the reference airspeed appropriate to the flight demonstration as described in Appendix 4 by more than ±5.5 km/h (±3 kt) throughout the 10 dB-down period.

11.6.8 The helicopter shall fly within ±10° from the vertical above the reference track through the reference noise measurement position.

11.6.9 Tests shall be conducted at a helicopter mass not less than 90 per cent of the relevant maximum certificated mass and may be conducted at a mass not exceeding 105 per cent of the relevant maximum certificated mass.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual *(Doc 9501), Volume I —* Procedures for the Noise Certification of Aircraft.

…

CHAPTER 13. TILT-ROTORS

…

13.2 Noise evaluation measure

The noise evaluation measure shall be the effective perceived noise level in EPNdB as described in Appendix 2 of this Annex. The correction for spectral irregularities shall start at 50 Hz (see 4.3.1 of Appendix 2).

Note.— Additional data in ~~SEL~~L_{AE} and L_{ASmax} as defined in Appendix 4, and one-third octave SPLs as defined in Appendix 2 corresponding to L_{ASmax} should be made available to the certificating authority for land-use planning purposes.

…

APPENDIX 2. EVALUATION METHOD FOR NOISE CERTIFICATION OF:

1.— SUBSONIC JET AEROPLANES — Application for Type Certificate submitted on or after 6 October 1977

2.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg — Application for Type Certificate submitted on or after 1 January 1985

3.— HELICOPTERS

4.— TILT-ROTORS

…

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

…

2.2 Test environment

…

2.2.2 Atmospheric conditions

2.2.2.1 *Definitions and specifications*

For the purposes of noise certification in this section the following specifications apply:

Average crosswind component shall be determined from the series of individual values of the "cross-track" (v) component of the wind samples obtained during the aircraft test run, using a linear averaging process over 30 seconds or an averaging process that has a time constant of no more than 30 seconds, the result of which is read out at a moment approximately 15 seconds after the time at which the aircraft ~~passes either over or abeam the microphone~~ flight path intercepts the vertical geometrical plane perpendicular to the reference ground track at the centre microphone.

Note.— The reference ground track is defined in 8.1.3.5.

Average wind speed shall be determined from the series of individual wind speed samples obtained during the aircraft test run, using a linear averaging process over 30 seconds, or an averaging process that has a time constant of no more than 30 seconds, the result of which is read out at a moment approximately 15 seconds after the time at which the aircraft passes either over or abeam the microphone. Alternatively, each wind vector shall be broken down into its "along-track" (u) and "cross-track" (v) components. The u and v components of the series of individual wind samples obtained during the aircraft test run shall be separately averaged using a linear averaging process over

30 seconds, or an averaging process that has a time constant of no more than 30 seconds, the result of which is read out at a moment approximately 15 seconds after the time at which the aircraft passes either over or abeam the microphone flight path intercepts the vertical geometrical plane perpendicular to the reference ground track at the centre microphone. The average wind speed and direction (with respect to the track) shall then be calculated from the averaged u and v components according to Pythagorean Theorem and "arctan(v/u)".

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3. MEASUREMENT OF AIRCRAFT NOISE RECEIVED ON THE GROUND

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3.7 Analysis systems

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3.7.3 The one-third octave band analysis system shall conform to the class 1 electrical performance requirements of IEC 61260-1[2] as amended, over the range of one-third octave filters having nominal midband frequencies from 50 Hz to 10 kHz inclusive.

Note 1.— The certificating authority may allow the substitution of an analysis system that complies with class 2 as an alternative to class 1 electrical performance requirements of IEC 61260-1[2] or with class 1 or class 2 of an earlier version of IEC 61260.

Note 2.—Tests of the one-third octave band analysis system should be made according to the methods described in IEC 61260-3[x1] or by an equivalent procedure approved by the certificating authority, for relative attenuation, anti-aliasing filters, real-time operation, level linearity, and filter integrated response (effective bandwidth).

3.7.4 When SLOW-time-averaging is performed in the analyser, the response of the one-third octave band analysis system to a sudden onset or interruption of a constant sinusoidal signal at the respective one-third octave nominal midband frequency shall be measured at sampling instants 0.5, 1, 1.5 and 2 seconds after both the onset and 0.5 and 1 seconds after the interruption. The rising response shall be –4 ± 1 dB at 0.5 seconds, –1.75 ± 0.75 dB at 1 second, –1 ± 0.5 dB at 1.5 seconds and –0.5 ± 0.5 dB at 2 seconds relative to the steady-state level. The falling response shall be such that the sum of the output signal levels, relative to the initial steady-state level, and the corresponding rising response reading is The sum of the rising and corresponding falling response shall be –6.5 ± 1 dB, at both 0.5 and 1 seconds. At subsequent times the The sum of the rising and falling responses shall be –7.5 –6.5 dB or less at 1.5 seconds and –7.5 dB or less at 2 seconds and subsequent times relative to the steady-state levels. This equates to an exponential averaging process (SLOW weighting) with a nominal 1-second time constant (i.e. 2 seconds averaging time).

…

4. CALCULATION OF EFFECTIVE PERCEIVED NOISE LEVEL FROM MEASURED NOISE DATA

…

1. IEC 61260-1:19952014 entitled "Electroacoustics — Octave-band and fractional-octave-band filters - Part 1: Specifications". This IEC publication may be obtained from the Central Office of the International Electrotechnical Commission, 3 rue de Varembé, Geneva, Switzerland.

x2. IEC 61260-3:2016 entitled "Electroacoustics — Octave-band and fractional-octave-band filters - Part 3: Periodic tests". This IEC publication may be obtained from the Central Office of the International Electrotechnical Commission, 3 rue de Varembé, Geneva, Switzerland

4.7 Mathematical formulation of noy tables

4.7.1 The relationship between sound pressure level (SPL) and the logarithm of perceived noisiness is illustrated in Table A2-3 and Figure A2-3.

…

Table A2-3. Constants for mathematically formulated noy values

BAND (*i*)	ISO BAND	*f* Hz	SPL(*a*)	SPL(*b*)	SPL(*c*)	SPL(*d*)	SPL(*e*)	*M*(*b*)	*M*(*c*)	*M*(*d*)	*M*(*e*)
1	17	50	91.0	64	52	49	55	0.043478	0.030103	0.079520	0.058098
2	18	63	85.9	60	51	44	51	0.040570	0.030103	0.068160	0.058098
3	19	80	87.3	56	49	39	46	0.036831	0.030103	0.068160	0.052288
4	20	100	79.~~0~~9	53	47	34	42	0.036831	0.030103	0.059640	0.047534
5	21	125	79.8	51	46	30	39	0.035336	0.030103	0.053013	0.043573
6	22	160	76.0	48	45	27	36	0.033333	0.030103	0.053013	0.043573
7	23	200	74.0	46	43	24	33	0.033333	0.030103	0.053013	0.040221
8	24	250	74.9	44	42	21	30	0.032051	0.030103	0.053013	0.037349
9	25	315	94.6	42	41	18	27	0.030675	0.030103	0.053013	0.034859
10	26	400	∞	40	40	16	25	0.030103	NOT APPLICABLE	0.053013	0.034859
11	27	500	∞	40	40	16	25	0.030103		0.053013	0.034859
12	28	630	∞	40	40	16	25	0.030103		0.053013	0.034859
13	29	800	∞	40	40	16	25	0.030103		0.053013	0.034859
14	30	1 000	∞	40	40	16	25	0.030103		0.053013	0.034859
15	31	1 250	∞	38	38	15	23	0.030103		0.059640	0.034859
16	32	1 600	∞	34	34	12	21	0.029960		0.053013	0.040221
17	33	2 000	∞	32	32	9	18	0.029960		0.053013	0.037349
18	34	2 500	∞	30	30	5	15	0.029960		0.047712	0.034859
19	35	3 150	∞	29	29	4	14	0.029960		0.047712	0.034859
20	36	4 000	∞	29	29	5	14	0.029960		0.053013	0.034859
21	37	5 000	∞	30	30	6	15	0.029960		0.053013	0.034859
22	38	6 300	∞	31	31	10	17	0.029960	0.029960	0.068160	0.037349
23	39	8 000	44.3	37	34	17	23	0.042285	0.029960	0.079520	0.037349
24	40	10 000	50.7	41	37	21	29	0.042285	0.029960	0.059640	0.043573

…

8. ADJUSTMENT OF AIRCRAFT FLIGHT TEST RESULTS

8.1 Flight profiles and noise geometry

…

8.1.1 Aeroplane flight profiles

8.1.1.1 *Reference lateral full-power profile characteristics*

Figure A2-4 illustrates the profile characteristics for the aeroplane take-off procedure for noise measurements made at the lateral full-power noise measurement points:

a) the aeroplane begins the take-off roll at point A and lifts off at point B at full take-off power. The climb angle increases between points B and C. From point C the climb angle is constant up to point F, the end of the noise flight path; and

b) positions K_{2L} and K_{2R} are the left and right lateral noise measurement points for jet aeroplanes, located on a line parallel to and at the specified distance ~~abeam~~ from the runway centre line, where the noise level during take-off is greatest. Position K_4 is the "lateral" full-power noise measurement point for propeller-driven aeroplanes located on the extended centre line of the runway vertically below the point on the climb-out flight path where the aeroplane is at the specified height.

…

8.1.3 Adjustment of measured noise levels from measured to reference profile in the calculation of EPNL

…

8.1.3.5 The reference ground track is defined as the vertical projection of the reference flight path onto the ground.

…

APPENDIX 4. EVALUATION METHOD FOR NOISE CERTIFICATION OF HELICOPTERS NOT EXCEEDING 3 175 kg MAXIMUM CERTIFICATED TAKE-OFF MASS

…

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

…

2.4 Flight test conditions

…

2.4.3 The reference advancing blade tip Mach number, M_{ATR}, is defined as the ratio of the arithmetic sum of the reference blade tip rotational speed, V_{tipR}, and the reference helicopter true airspeed, V_R, divided by the reference speed of sound, c_R at 25°C such that:

$$M_{ATR} = \frac{(V_{tipR} + V_R)}{c_R}$$

3. NOISE UNIT DEFINITION

…

3.4 The integration time ($t_2 - t_1$) in practice shall not be less than the 10 dB-down period during which $L_{AS}(t)$ first rises to 10 dB(A) below its maximum value and last falls below 10 dB(A) of its maximum value.

…

4. MEASUREMENT OF HELICOPTER NOISE RECEIVED ON THE GROUND

…

4.3 Sensing, recording and reproducing equipment

…

4.3.2 The ~~SEL~~ L_{AE} may be directly determined from an integrating sound level meter. Alternatively, with the approval of the certificating authority the sound pressure signal produced by the helicopter may be stored on an analogue magnetic tape recorder or a digital audio recorder for later evaluation using an integrating sound level meter. The ~~SEL~~ L_{AE} may also be calculated from one-third octave band data obtained from measurements made in conformity with Section 3 of Appendix 2 and using the equation given in 3.3. In this case each one-third octave band sound pressure level shall be weighted in accordance with the A-weighting values given in IEC Publication 61672-1.[2]

4.3.3 The characteristics of the complete system with regard to directional response, frequency weighting A, time weighting S (slow), level linearity, and response to short-duration signals shall comply with the class 1 specifications given in IEC 61672-1.[1] The complete system may include tape recorders or digital audio recorders according to IEC 61672-1.[1]

Note.— The certificating authority may approve the use of equipment compliant with class 2 of the current IEC standard, or the use of equipment compliant with class 1 or Type 1 specifications of an earlier standard, if the applicant can show that the equipment had previously been approved for noise certification use by a certificating authority. This includes the use of a sound level meter and graphic level recorder to approximate ~~SEL~~ L_{AE} using the equation given in 3.3. The certificating authority may also approve the use of magnetic tape recorders that comply with the specifications of the older IEC 561 standard if the applicant can show that such use had previously been approved for noise certification use by a certificating authority.

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2. IEC 61672-1: 2002 entitled "Electroacoustics — Sound level meters — Part I: Specifications". This IEC publication may be obtained from the Bureau central de la Commission électrotechnique internationale, 3 rue de Varembé, Geneva, Switzerland.

...

4.3.5 When the sound pressure signals from the helicopter are recorded, the ~~SEL~~ L_{AE} may be determined by playback of the recorded signals into the electrical input facility of an approved sound level meter that conforms to the class 1 performance requirements of IEC 61672-1.[3] The acoustical sensitivity of the sound level meter shall be established from playback of the associated recording of the signal from the sound calibrator and knowledge of the sound pressure level produced in the coupler of the sound calibrator under the environmental conditions prevailing at the time of the recording of the sound from the helicopter.

4.3.6 A windscreen should be employed with the microphone during all measurements of helicopter sound levels. Its characteristics should be such that when it is used, the complete system including the windscreen will meet the specifications in 4.3.3.

…

5. ADJUSTMENT TO TEST RESULTS

…

5.2 Corrections and adjustments

…

5.2.2 The adjustments for spherical spreading and duration may be approximated from:

$$\Delta_1 = 12.5 \log (H/150\ \underline{m})$$

where H is the height, in metres, of the test helicopter when directly over the noise measurement point.

5.2.3 The adjustment for the difference between reference airspeed and adjusted reference airspeed is calculated from:

$$\Delta_2 = 10 \log\left(\frac{V_{AR}}{V_R}\right)$$

where Δ_2 is the quantity in decibels that must be algebraically added to the measured ~~SEL~~ L_{AE} noise level to correct for the influence of the adjustment of the reference airspeed on the duration of the measured flyover event as perceived at the noise measurement station. V_R is the reference airspeed as prescribed under Part II, Chapter 11, 11.5.2, and V_{AR} is the adjusted reference airspeed as prescribed in 2.4.2 of this appendix.

6. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY AND VALIDITY OF RESULTS

6.3 Validity of results

6.3.1 The measuring point shall be overflown at least six times. The test results shall produce an average ~~SEL~~ L_{AE} and its 90 per cent confidence limits, the noise level being the arithmetic average of the

3. IEC 61672-1: 2002 entitled “Electroacoustics — Sound level meters — Part I: Specifications”. This IEC publication may be obtained from the Bureau central de la Commission électrotechnique internationale, 3 rue de Varembé, Geneva, Switzerland.

corrected acoustical measurements for all valid test runs over the measuring point for the reference procedure.

6.3.2 The sample shall be large enough to establish statistically a 90 per cent confidence limit not exceeding ±1.5 dB(A). No test results shall be omitted from the averaging process unless approved by the certificating authority.

Note.— Methods for calculating the 90 per cent confidence interval are given in the section of the Environmental Technical Manual *(Doc 9501), Volume I —* Procedures for the Noise Certification of Aircraft *concerning the calculation of confidence intervals.*

…

APPENDIX 6. EVALUATION METHOD FOR NOISE CERTIFICATION OF PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — Application for Type Certificate or Certification of Derived Version submitted on or after 17 November 1988

…

5. ADJUSTMENT TO TEST RESULTS

…

5.2 Corrections and adjustments

…

5.2.2 The noise level under reference conditions,L_{ASmaxR} REF is obtained by adding increments for each of the above effects to the test day noise level, $L_{ASmax,}$ TEST.

$$L_{ASmaxR} = L_{ASmax} + \Delta_1 + \Delta_2 + \Delta_3 + \Delta_4$$

where

Δ_1 is the adjustment for sound propagation path lengths;
Δ_2 is the adjustment for helical tip Mach number;
Δ_3 is the adjustment for engine power; and
Δ_4 is the adjustment for the change in atmospheric absorption between test and reference conditions.

….

d) Measured sound levels shall be adjusted for engine power by algebraically adding an increment equal to:

$$\Delta_3 = k_3 \log (P_{\theta R}/P)$$

where $P_{\theta R}$ and P are the test and reference engine powers respectively obtained from the manifold pressure/torque gauges and engine rpm. The value of k_3 shall be determined from approved data from the test aeroplane. In the absence of flight test data and at the discretion of the certificating authority a value of $k_3 = 17$ may be used. The reference power $P_{\theta R}$ shall be that obtained at the reference height temperature and pressure assuming temperature and pressure lapse rates with height defined by the ICAO Standard Atmosphere.

…

ATTACHMENTS TO ANNEX 16, VOLUME I

ATTACHMENT A. EQUATIONS FOR THE CALCULATION OF MAXIMUM PERMITTED NOISE LEVELS AS A FUNCTION OF TAKE-OFF MASS

…

10. CONDITIONS DESCRIBED IN CHAPTER 11, 11.4.1

M = Maximum take-off mass in 1 000 kg	0	0.788	3.175
Noise level in dB(A) ~~SEL~~	82	83.03 + 9.97 log M	

11. CONDITIONS DESCRIBED IN CHAPTER 11, 11.4.2

M = Maximum take-off mass in 1 000 kg	0	1.417	3.175
Noise level in dB(A) ~~SEL~~	82	80.49 + 9.97 log M	

…

ATTACHMENT F. GUIDELINES FOR NOISE CERTIFICATION OF TILT-ROTORS

…

2. NOISE EVALUATION MEASURE

The noise evaluation measure should be the effective perceived noise level in EPNdB as described in Appendix 2 of this Annex.

Note.— Additional data in ~~SEL~~ L_{AE} and L_{ASmax} as defined in Appendix 4, and one-third octave SPLs as defined in Appendix 2 corresponding to L_{ASmax} should be made available to the certificating authority for land-use planning purposes.

…

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APPENDIX B
(English only)

HELICOPTER NOISE CORRELATION TASK REPORT

1. INTRODUCTION

1.1 The task N.08.01, decided at the CAEP/10, asked to "Investigate the feasibility of correlating certification noise levels with operational noise levels to better assess the helicopter noise certification scheme and its relevance to day- to-day operations, similar to the studies done for jets."

1.2 WG1 reviewed the mentioned study done for jets to facilitate the analysis. In addition, the task description "similar to the studies done for jets" was refined and the task description accordingly reformulated to: "Investigate the feasibility of correlating the ranking of helicopters based on noise certification levels with the ranking based on operational noise data to better assess the helicopter noise certification scheme and its relevance to day-to-day operations". Finally, WG1 discussed basic considerations on typical flight phases during helicopter missions and their possible applicability for the correlation task along with possible sources of operational data.

1.3 WG1 then worked to secure operational noise measurements data. A sample of helicopter noise measurement performed in Sweden was presented during WG1_1. Norway provided helicopter noise measurements performed for two offshore helicopters for development of Noise Power Distance (NPD) data typically used for land-use planning purposes. In order to acquire available measurements to support the analysis, the group agreed to prepare a State Letter to request helicopter noise data from ICAO contracting states. Additionally, measurement information on eight different helicopters in various flight conditions came from the Public European Environmental Model Suite for Aviation. Finally, WG1 decided to review data from a 1984 operational noise test conducted by the FAA at Dulles Airport near Washington, DC where eight helicopters models were measured.

2. DATA REVIEW AND PRELIMINARY RESULTS

2.1 Methodology Review: WG1 reviewed a correlation analyses between noise certification EPNL and operational SEL for the eight helicopter models included in operational noise testing conducted by the FAA at Dulles Airport near Washington DC in 1984. The correlations give preliminary indications that noise certification data can provide adequate rank ordering of operational noise emissions for helicopters.

2.2 Data Review: As feedback to the state letter, data from four members (Latvia, Australia, Japan, Russia) involving operational data was provided. WG1 reviewed available information received in response to the state letter and determined that only the Australian noise data sets were considered to be sufficient for the correlation task. Either the other data sets represented certification data only or the number of different helicopter models contained was too small to allow a meaningful statistical analysis. For example, the Latvian data is of similar nature to the Australian data but heavily dominated by only one helicopter model and thus not appropriate for a statistically relevant analysis.

2.3 Among the data sets supplied by Australia, the operational data obtained around Sydney Airport was identified as most promising for the correlation task due to the large number of different helicopter models combined with a significant number of recorded movements. Based on the location of the operational measurements relative to the Sydney Airport, however, correlations were limited to Flyover only.

2.4 Data Analysis: Substantial effort was needed to utilize the Sydney Airport data for the correlation task, since the helicopters in the Australian data set are only characterized by their ICAO type designation. In order to assign the respective noise certification level to each database entry, the unique helicopter model identifier needed to be established. WG1 requested this information from Australia but unfortunately, the information is not available in their database. Therefore, the identification of models has been conducted manually by the OEMs by correlating the noise data base with Australian CAA registration data and in-house information from the respective sales departments. Using this methodology, an identification of helicopter models operated in the Sydney area has been achieved for many models.

2.5 Based on the operational noise dataset around Sidney Airport, a statistical analysis was establish to compare the rankings of helicopter models based on operational and certification noise data. This statistical analysis concludes that "there is a good correlation between the certified noise level in EPNdB on Flyover and the noise levels measured in operational conditions in SEL. The sample is composed of very different helicopter types (twin-engine and single engine, different power, different MTOM, different manufacturer)." WG1 also suggests that to confirm this trend, a larger dataset should be investigated.

2.6 Aside from the operational data received in response to the ICAO state letter, two large scale test campaigns in Europe and the US have been conducted in 2017/2018. However, the data is not yet available.

3. CONCLUSIONS

3.1 Considerable effort has been put in the search for adequate data and the pre-processing of this data to render it accessible for a noise ranking correlation analyses.

3.2 Analysis of a 1984 FAA measurement campaign at Dulles Airport with eight helicopters indicates a preliminary feasibility of correlating the ranking of helicopters based on certification noise levels with a ranking based on operational noise levels.

3.3 Analysis of operational noise measurement data acquired around Sydney Airport for five different helicopter models showed a good correlation between the ranking of helicopters based on flyover noise certification with the ranking of helicopters based on operational data.

3.4 Results of the analyses of the earlier FAA noise data and the more recent operational noise data support further extending the correlation analysis when the additional European and U.S. noise test data becomes available.

3.5 The achievability of the task is limited particularly by the lack of adequate operational data. Even with the lack of data, the feasibility analyses of the information available to date indicate a potential for correlation between the ranking of helicopters based on certification noise levels and a ranking based on operational noise levels, while noting that a low number of aircraft models were represented on the current analysis.

3.6 WG1 agreed that the information available to date suggests that the helicopter noise certification scheme has relevancy to day-to-day operations especially for flyover.

3.7 WG1 discussed the need for additional data to support further investigations on this topic, and it was agreed that additional data should ideally contain helicopter model and tail number associated with the noise measurements.

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APPENDIX C
(English only)

HELICOPTER HOVER TASK REPORT

1. INTRODUCTION

1.1 Working Group 1 was tasked to review any past evaluations of a noise certification scheme for the hover condition, and assess whether the current helicopter noise certification scheme is applicable for assessing hover noise including the sufficiency of a correlation with one or more of the existing reference conditions.

1.2 Including a hover reference point for helicopter noise certification was examined as part of the original development of Chapter 8 of the Annex during CAN/5 and CAN/6. During this development period for the Annex, it was concluded that the hover condition did not provide the repeatability and accuracy needed for a noise certification reference point. This conclusion was primarily based on the results of measurement programs carried out by Member States.

1.3 WG1 conducted a more detailed review of the hover work done during and subsequent to CAN/5 and CAN/6. To facilitate this review, WG1 collected the relevant documentation produced during CAN/5 – CAN/6 and identified additional relevant WG1 documentation from CAEP/6.

1.4 WG1 identified a 2016 European test campaign where hover data was measured. An evaluation of hover noise data acquired during the 2016 European test campaign indicated that measurement of hover noise lacks adequate repeatability for noise certification purposes. In addition, the U.S. conducted a test campaign in 2017, which also had a goal of collecting hover data.

1.5 In summary, WG1 found no new information to alter the conclusion reached by CAN/5 and CAN/6 during development of Chapter 8 of the Annex to exclude the hover condition or to change the recommendation to exclude hover from Land Use Planning guidelines developed during CAEP/6, which stated "The hover flight configuration should not be included in any noise measurement programme (noise certification or Land Use Planning)."

2. DATA ANALYSIS

2.1 Considering that final data from the European and US test campaigns have not yet been analysed, WG1 examined In-Ground Effect (IGE) and Out-of-Ground Effect (OGE) hover noise data for several helicopter models acquired by the FAA during 1983 and 1984. While a preliminary rank order analysis of three of the helicopter models was completed, it illustrated some of the issues in defining a hover noise measurement/metric for correlation with the noise certification test points such as hard vs. soft surface and average vs. maximum azimuthal level. WG1 also conducted a correlation analyses between noise certification EPNL and hover noise data for nine of the helicopter models tested by the FAA in 1983 and 1984. Three correlation methods were examined including comparisons of noise level correlations with gross weight, direct correlations of hover noise levels with noise certification levels and rank order comparisons of hover noise and noise certification levels. In general, no or inconclusive statistical correlations between hover and certification noise levels were observed. More specifically, only a correlation of Out-of-Ground Effect (OGE) hover noise levels vs. gross weight provided any indication of comparative results to noise certification levels, albeit with insufficient correlation strength/data points to be considered conclusive. OGE hover noise data for more helicopter models over a broader gross weight range could potentially provide a more conclusive result. The prospect for additional data would be enhanced with the establishment of guidelines for acquisition of hover noise data to ensure more consistent testing procedures.

3. CONCLUSIONS

3.1 The review of past evaluations of a noise certification scheme for the hover conditions (In-Ground Effect - IGE and Out-of-Ground Effect - OGE) is complete and further data is not available at the time being. Based on the information available to date, it does not appear feasible to define a measurement method for the hover condition with the accuracy and repeatability needed for a reference noise certification point in Annex 16, Chapters 8 and 11.

3.2 The limited IGE and OGE hover noise data acquired during FAA noise testing in 1983-84 do not support, or indicate the feasibility of, correlating hover noise levels with the current helicopter noise certification test scheme. While the possibility of having a trend between OGE hover noise and helicopter gross weight was discussed, it was recognized that the current trend identified is supported by a single point in the low-weight helicopter range. Therefore, this investigation could benefit from additional data from helicopters with gross weights in that weight range. On that note, WG1 agreed that further work is needed to substantiate if there is a trend between OGE hover noise and gross weight comparable to that of noise certification test conditions.

3.3 WG1 recommends that if new data becomes available, the feasibility of correlating hover noise with the current helicopter noise certification scheme should be further examined.

3.4 WG1 recommends that the CAEP/12 work programme include the development of measurement guidelines for hover noise data in support of future hover noise work. Members of ICCAIA will consider sharing OEM hover measurement procedures and hover data.

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Agenda Item 5: Airports and operations

5.1 AVIATION SYSTEM BLOCK UPGRADES (ASBU) BLOCK 1 ANALYSIS

5.1.1 Building upon the work carried out during the CAEP/10 cycle, WG2, in cooperation with MDG, performed a combined Block 0 (B0) and Block 1 (B1) analysis of the fuel burn and CO_2 emissions reductions attributable to the implementation of the relevant ASBU B0 and B1 modules by 2025. Current and planned implementation of the B0/B1 ASBU elements detailed within the ASBU framework are estimated to provide a total annual global fuel saving in 2025 of between 167 to 307 kg per flight, which corresponds to a reduction of 26.2 Mt of CO_2 to 48.2 Mt of CO_2, or savings of USD 5 billion to USD 9.2 billion.

Discussion and Conclusions

5.1.2 The meeting welcomed the results of the combined ASBU B0/B1 analysis and recognized the intensive data analysis undertaken by WG2 and MDG.

5.1.3 The ICAO Director, Air Navigation Bureau (D/ANB) addressed the meeting and while providing an overview of the Global Air Navigation Plan (GANP) and the ASBU Blocks, he highlighted the need to support the implementation of ATM improvements with concrete data on the benefits to be expected from these improvements in the area of safety, capacity, efficiency and environmental protection and to be able to quantify the actual value of the implementation to the industry. He highlighted the important work carried out by WG2 in support of the development of methodologies and providing the assessment of the environmental benefits of the implementation of the operational measures. D/ANB added that improvements in the ATM system would have to pay for themselves and investments made should generate benefits that include CO_2 emissions reductions.

5.1.4 The CAEP Secretary highlighted that operational improvements are one element in the ICAO Basket of Measures on CO_2 emissions and that the work done by ICAO contributes to quantifying the impacts of each element. To this end, tools have been developed, such as the ICAO Fuel Savings Estimation Tool (IFSET), to assist States to estimate fuel savings in a manner consistent with the models approved by CAEP and aligned with the GANP.

5.1.5 Further reflecting upon the application of the results of the combined B0/B1 analysis, the meeting considered that these results could be integrated in the ICAO trends, using 2025 as a wedge.

5.1.6 Recommendations

5.1.6.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 5/1 — ASBU Block 1 environmental analysis**
>
> That States be invited to use the results of the ASBU combined Block 0/Block 1 environmental analysis by CAEP to support the implementation of Block 0 and Block 1 and to communicate the environmental benefits from operational improvements within their State.

5.2 GLOBAL AIR TRAFFIC MANAGEMENT EFFICIENCY AND THE ENVIRONMENTAL IMPACT OF UNCOMPENSATED TRAFFIC GROWTH

5.2.1 WG2 performed the first global Horizontal Flight Efficiency (HFE) analysis using a new global data source (ADS-B surveillance data) together with a single parameter to estimate different traffic flow efficiencies. The results were broken down by ICAO region for 2017 data and showed that efficiency levels vary between 94 and 98 per cent. The conclusions identified limitations, such as the possible confusion between this HFE analysis and an ATM efficiency analysis, and the fact that ADS-B surveillance data, while becoming increasingly available, are estimated to cover only 68 per cent of all global movements, with regional disparities. WG2 considered that further steps for assessing global flight efficiency would need to address vertical flight efficiency (VFE), the relationship between HFE and VFE, efficiency in terminal airspaces and on airport surfaces, as well as trying to fill the data gap identified in the analysis.

Discussion and Conclusions

5.2.2 The meeting commended WG2 for this global HFE analysis and expressed a clear interest in undertaking a follow-on global VFE analysis which would be considered under Agenda Item 12 on Future Work. This would contribute to estimating the percentage of inefficiency needed in the ATM system to ensure its optimal level of performance. Indeed, an Observer informed the meeting that the flight plan provided may not be the optimal route to fly and that the actual route flown would not match the flight plan under certain operational circumstances, such as weather.

5.2.3 Responding to a question raised by a Member, WG2 co-Rapporteurs indicated that the analysis was based on a range of assumptions but that no uncertainty range was provided.

5.2.4 The meeting agreed that the results of the HFE analysis should be disseminated in conjunction with the contextual elements supporting the accurate interpretation of the results, both at a global level and to ICAO Regional Offices.

5.2.5 Recommendations

5.2.5.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 5/2 — Global air traffic management efficiency and the environmental impact of uncompensated traffic growth**
>
> That the results of the Horizontal Flight Efficiency (HFE) analysis and associated conclusions be published on the ICAO website, free of charge, under a dedicated webpage.

5.3 STATUS OF WG2 ACTIVITIES

5.3.1 The co-Rapporteurs of WG2 presented an overview of the group's activities during CAEP/11. As follow-on to a CAEP/10 task on interdependencies, WG2 improved the user-friendliness of the dedicated ICAO website and shared a report on the assessment of the interrelationships information found in ICAO documents. WG2 also completed the update of ICAO Doc 9184, *Airport Planning*

Manual, Part 2 – *Land Use and Environmental Management*, and with the collection of case studies forming the document's new appendices. Comments were provided on the Aviation and Global Atmosphere update (Task O.10) and WG2 closely followed-up the update of ICAO Doc 9889, *Airport Air Quality Manual*. In addition, the *ad hoc* support to ICAO ANB included an assessment of possible suitable environmental performance indicators, in coordination with WG1 (Noise) and WG3 (Emissions). Analytical tasks were once again an important element of the WG2 work programme, with a global HFE analysis and a combined analysis of the CO_2 emissions benefits of the ASBU B0 and B1. New reports were developed on environmental community engagement for performance-based navigation (PBN), climate change adaptation, and aircraft end-of-life and recycling. WG2 had also initiated work on new guidance material on operational opportunities to reduce aircraft noise, and delivered three issues of the Eco-Airport Toolkit e-collection.

Discussions and conclusions

5.3.2 The meeting expressed its support for the work carried out by WG2 and supported the dissemination of information emanating from WG2 as a general rule, as the role of WG2 is to collect best practices and develop guidance material. The meeting highlighted that the primary beneficiaries of this work are States that do not usually participate in WG2 meetings; however a Member affirmed the importance of this work for all States including his State, as access to global best practices can lead to further improvement of environmental management policies.

5.3.3 Accessibility to the WG2-related documentation was considered and the ICAO Secretariat was invited to reflect upon outreach activities other than dissemination on the ICAO website.

5.3.4 The CAEP Secretary highlighted that the work of WG2 is global in reach and an important vehicle for capacity-building for all ICAO Member States, in line with the ICAO *No Country Left Behind* initiative. The CAEP Secretary also referred to the Eco-Airport Toolkit e-collection, which has been an innovative way to collect and disseminate best practises and guidance on environmental management at airports, noting that it had been very well received.

5.4 ENVIRONMENTAL COMMUNITY ENGAGEMENT FOR PERFORMANCE-BASED NAVIGATION

5.4.1 WG2 prepared a report to CAEP/11 focusing on the community engagement aspects of PBN implementation and related challenges. The report was drafted on the basis of information gathered through a questionnaire to CAEP Members and Observers, a literature review and analysis of the ICAO State PBN implementation plans. Conclusions and dissemination options were presented to the CAEP/11 meeting.

Discussions and conclusions

5.4.2 A Member acknowledged that community engagement is a significant part of PBN implementation activities and that a balance had been achieved by WG2 between the development of global community engagement principles, and the necessity to tailor community engagement practices to local circumstances. The Member recommended not engaging in a full dissemination strategy of the Task O.01 report but to make it available on the ICAO website. One Member highlighted that the lack of dedicated capacity-building activities on this matter could prevent certain States from responding to the questionnaires circulated by ICAO in the context of this work. The meeting highlighted the benefits of raising awareness on the information included in the CAEP Report.

5.4.3 A Member considered that the report included very useful material but that community engagement is a fast-evolving topic and that there should be an opportunity to post additional information on an ICAO webpage. Other Members welcomed the report and the work done and recommended that it be published to assist States and training organizations.

5.4.4 **Recommendations**

5.4.4.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 5/3 — Environmental Community Engagement for Performance-Based Navigation**
>
> That the information included in the CAEP report be tailored for dissemination and outreach on the ICAO public website.

5.5 OPERATIONAL OPPORTUNITIES TO REDUCE AIRCRAFT NOISE

5.5.1 WG2 started the development of new guidance material to provide ICAO Member States and international aviation stakeholders with detailed and concrete information on the implementation of measures to reduce aircraft noise at, and in the vicinity, of airports. This includes noise-abatement operational procedures, one of the pillars of the Balanced Approach to aircraft noise. This guidance document is expected to be finalized over the course of the CAEP/12 cycle.

Discussion and Conclusions

5.5.2 An Observer highlighted the necessity for each of the operational procedures included in this future ICAO guidance document to be safe and should in principle be based on ICAO Standards or current practices. It was clarified that the noise abatement procedures examined in the context of this task are not aimed at replacing current standardized procedures, but provide a non-prescriptive set of options to be considered, first and foremost, from a safety perspective. The guidance document to be presented to the CAEP/12 meeting will include carefully drafted language to this effect. The meeting discussed the opportunity to organize a workshop prior to the completion of the task in order to gather additional practices that could inform the guidance document; or after the adoption of the future guidance document in order to disseminate its content. A Member indicated that due to the expected workload of WG2 during the next cycle, it would be preferable to not organize such workshops. The CAEP Secretary considered that synergies with other ICAO events could be identified in order to best inform the task in a cost-effective manner.

5.6 CLIMATE ADAPTATION SYNTHESIS

5.6.1 WG2 presented a climate adaptation synthesis, stemming from the CAEP/10 update of ICAO Doc 9184, *Airport Planning Manual,* Part 2. Further information was collected through a literature review and a questionnaire was circulated under cover of a CAEP Memo and a State letter. Coordination with ISG was ensured throughout the process. As a result, the synthesis report included information on the range of projected climate impacts on the aviation sector and views from international aviation stakeholders on how these might impact their operations, their level of preparedness and expectations.

Discussion and Conclusions

5.6.2 The meeting commended WG2 for the climate adaptation synthesis and encouraged the dissemination of the information included therein, as well as requesting consideration of regular updates.

5.6.3 Several Members encouraged the dissemination of the information included in the climate adaptation synthesis and the possibility to update this work regularly. Several Members and Observers stressed the importance of this work for Small Island Developing States (SIDS) and archipelago States, as these are particularly vulnerable to the effects of climate change. One Member committed to support the work of WG2 continually, given its broad spectrum and benefits.

5.6.4 An Observer supported the task and future work proposal, and shared that a survey will be conducted for its membership on resilience and adaptation to climate change, which will incorporate other aspects beyond environmental protection. The Observer shared its intention to update the Committee of the progress.

5.6.5 The CAEP Secretary provided background information on the work carried out by ICAO in the area of disaster risk and climate adaptation, and informed the meeting that this work is twofold, with the disaster recovery component, and the climate change risk assessment and climate resilience component. She indicated that airports are already starting to integrate climate change adaptation and resilience in their design phase, such as the new Istanbul Airport in Turkey. Support was expressed by the meeting for continuing activities on climate change risk assessment.

5.6.6 **Recommendation**

5.6.6.1 In light of the foregoing discussion, the meeting developed the following recommendation:

Recommendation 5/4 — Climate Adaptation Synthesis

That the information included in the CAEP report be tailored for dissemination and outreach and, in addition, be subject to an Eco-Airport e-collection publication.

5.7 ECO-AIRPORT TOOLKIT E-COLLECTION

5.7.1 WG2 developed a range of practical and ready-to-use e-publications aimed at supporting the implementation of environmental management measures at airports. Three publications were approved by the 2018 CAEP Steering Group meeting on renewable energy at airports, waste management and environmental management systems for airports, respectively, and are available free of charge on the ICAO website.

5.7.2 WG2 presented the latest issue on eco-design of airport buildings to CAEP and a series of thematic proposals to carry forward during the CAEP/12 cycle.

Discussion and Conclusions

5.7.3 The meeting expressed its support for this task. The meeting appreciated the relevance of the themes subject to the Eco-Airport Toolkit e-collection and the ability to deliver practical, ready-to-use information to the international aviation community in a proactive manner. An Observer asked if environmental guidance existed for engineers involved in the design of airports. ICAO Doc 9184, *Airport Planning Manual*, Part 2 – *Land Use and Environmental Management* was identified as being the most relevant document in this context.

5.7.4 The meeting recalled that the Eco-Airport Toolkit e-collection aims to provide general information on technical topics and that a list of available resources is provided with each e-publication, for ease of reference. The necessity to publish case studies was also highlighted, as they complement the information included in the Eco-Airport Toolkit e-collections and illustrate these with practical examples from which other airports may draw inspiration.

5.7.5 **Recommendations**

5.7.5.1 In light of the foregoing discussion, the meeting developed the following recommendation:

Recommendation 5/5 — Eco-Airport Toolkit e-collection

That the edition of the Eco-Airport Toolkit e-collection on the Eco-Design of Airport Buildings be published on the ICAO website, free of charge, under the Eco-Airport Toolkit dedicated webpage.

5.8 AIRCRAFT END-OF-LIFE AND RECYCLING

5.8.1 WG2 presented a state-of-play report on aircraft end-of-life and recycling, which provided an overview of the relevant international policies and industry guidance pertaining to the environmental management of aircraft end-of-life procedures. Recognizing the very good work undertaken by WG2, it was reminded that the scope of the task had been adjusted in light of the absence of the required expertise in CAEP.

Discussion and Conclusions

5.8.2 The meeting welcomed the information included in the report and acknowledged that the state-of-play report was the most comprehensive piece of information that WG2 would be able to provide, in light of the available expertise on the subject matter. The WG2 co-Rapporteurs reminded that the 2018 Steering Group meeting had considered that additional work could be undertaken by ICAO, through the establishment of a multidisciplinary group covering the legal, safety, airworthiness and environmental aspects of aircraft end-of-life and recycling.

5.8.3 The WG2 co-Rapporteurs brought to the attention of the meeting that one of the publications examined in the report had been released after the submission of CAEP/11-WP/35. It was agreed to include the link to this publication in the state-of-play report.

5.8.4 **Recommendations**

5.8.4.1 In light of the foregoing discussion, the meeting developed the following recommendation:

Recommendation 5/6 — Aircraft end-of-life and recycling

That the information included in the CAEP report be tailored to communications and outreach activities and be published on the ICAO website, free of charge, under a dedicated webpage.

5.9 FUTURE WORK OF WG2

5.9.1 Several Members and Observers provided their views on the WG2 work programme. Some key deliverables of the CAEP/11 work programme were highlighted and it was requested to make the deliverables of Task O.01, Task O.07 and Task O.09 available, as these would benefit the efforts being undertaken by the aviation community to enhance the environmental sustainability of international operations at airports. In addition, they identified key areas of work for the CAEP/12 cycle, including the continuation of the work on global flight efficiency, the assessment of new material related to the GANP update, and work on a concept of “community acceptance” for supersonic transport.

5.9.2 Diverse views were expressed on the opportunity to create tasks on operational issues related to supersonic aircraft for the CAEP/12 cycle.

5.9.3 A Member supported the ICAO initiative to setup a multidisciplinary group to progress the topic of aircraft end-of-life and recycling, as the number of aircraft to be retired from the fleet worldwide will continuously increase.

5.9.4 The meeting agreed with the request to make the deliverables of Task O.01, Task O.07 and Task O.09 available and deferred further actions on future work to Agenda Item 12.

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Agenda Item 6: CORSIA – Monitoring, reporting and verification (MRV)
7: CORSIA – Emissions unit
8: CORSIA – Registries

6.1.1 The GMTF co-Rapporteurs presented the work undertaken by the Global Market-Based Measure Technical Task Force (GMTF) during the CAEP/11 cycle. The GMTF co-Rapporteurs provided an overview of the group's structure, leadership and membership, as well as dates of the seven meetings the group has held during the CAEP/11 cycle. The GMTF co-Rapporteurs pointed out that, in response to the request of the 39th Session of the ICAO Assembly, GMTF prioritized work on the drafting of a CORSIA Package consisting of the draft Annex 16, Volume IV (i.e. CORSIA-related SARPs), the *Environmental Technical Manual* (Doc 9501), Volume IV and CORSIA Implementation Elements. As a result of this prioritization, GMTF delivered the CORSIA Package in time for consideration by the 2017 Meeting of CAEP's Steering Group, which in turn allowed for the adoption of Annex 16, Volume IV by the ICAO Council at its 214th Session (June 2018). The meeting was also reminded that GMTF work led to the delivery of: the 2018 version of ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT) and related technical methodologies; and the functional requirements of the CORSIA Central Registry (CCR), both of which were approved by the ICAO Council at its 214th Session. In addition to this, the GMTF co-Rapporteurs reflected on additional deliverables stemming from the work undertaken under the 23 Tasks included in the GMTF work programme for the CAEP/11 cycle, noting that GMTF had satisfactorily fulfilled its tasks, with GMTF having identified future work to be undertaken during the CAEP/12 cycle.

6.1.2 The co-Lead of GMTF's Emissions Units Criteria Task Group (GMTF-EUC) presented GMTF's work on supply, demand and price of emissions units. This work served as an update to the initial analysis from 2016 and outlined the relationships between supply, demand, and price and how they had responded to a range of external factors, taking into consideration the results of a literature review and additional reports. In total, 31 reports informed this analysis. A detailed quantitative analysis was not provided at this time in light of the various economic, political and technical factors. Analysis results provided confidence, based on the given experience with historical data and future estimates and projections, that the market will be able to respond to an increase in offset demand from the airline industry provided that the boundary conditions are set properly, will not meaningfully constrain supply. It concluded that results presented to CAEP/10, namely "the market will be capable to react on clear signals of future demand from the international aviation global MBM" still held. Additional work may have to be done according to specific requests from CAEP.

6.1.3 Upon a request for clarification by a Member, the GMTF-EUC co-Lead confirmed that the inclusion or exclusion of any type of programme or activity generating emissions units in the scope of the analysis would have an impact on the analysis results regarding the level of supply of emissions units available in the market, and consequently on their price.

6.1.4 The co-Lead of GMTF's Programme Testing Group (GMTF-PTG) presented the work undertaken by PTG during the CAEP/11 cycle. PTG was established by CAEP in response to a request by the ICAO Council, at its 211th Session (5 – 23 June 2017), to further progress work on the application of the emissions units criteria (EUC), including the informal testing of some programmes against the criteria. The meeting was presented the PTG Full Report and its Executive Summary, as accepted by CAEP and as shared with the Council during its 215th Session (29 October – 16 November 2018). The meeting was informed of PTG's key findings and recommendations, with clarification on what constitutes the CAEP-recommended procedures and guidelines applied by PTG.

6.1.5 Upon a request for clarification from a Member regarding the eligibility of a specific type of activity for CORSIA purposes, the meeting was reminded that the main objective of the work of CAEP-PTG was to test the applicability of emissions units criteria, not the eligibility of the emissions units programmes that participated in the informal testing. In line with an Observer's remark on the nuances regarding the application of some of the criteria (namely, double counting and additionality), the meeting was reminded that GMTF-PTG's report reflects on the recommendations of the group regarding these issues, based on the group's experience during the informal testing exercise.

6.1.6 The co-Lead of GMTF's CORSIA CERT Group (GMTF-CCG) reported on the development of the 2018 version of the ICAO CORSIA CERT, and the planned activities for the development of the 2019 version of the tool. The presentation recalled that the 2018 version of the ICAO CORSIA CERT was approved by the ICAO Council, at its 214th Session (11 – 29 June 2018), together with CERT's technical methodologies. Regarding the CO_2 Estimation Models (CEMs), the meeting was reminded that the CEMs could be requested through the ICAO CORSIA website. The meeting was informed that GMTF-CCG had started the development of a more detailed architecture of the 2019 version of the ICAO CORSIA CERT, and in order to meet the growing requirements for the tool, additional functionalities would be added in the 2019 version, including: improvements of the CEMs based on Great Circle Distance, and the development of new CEMs based on Block Time Input. The meeting was informed of GMTF-CCG's expectation to continue work during the CAEP/12 cycle by being transferred in its entirety under a new CAEP working group on CORSIA, and that a mechanism would be created for submitting the ICAO CORSIA CERT and its underlying features to CAEP Members on a fixed annual basis to allow timely submission for the consideration of the Council.

6.1.7 Upon a request for clarification from a Member regarding the secure use of the ICAO CORSIA CERT by aeroplane operators, the meeting was reminded that the 2018 version of the ICAO CORSIA CERT is available for download on the ICAO CORSIA website, and that operators who download the tool would be able to use it with a level of security determined by the characteristics of the hardware in which they downloaded the tool.

6.1.8 The meeting was provided with an update to the supplemental GMTF Analysis on the Estimation of the Costs and CO_2 Reductions Expected to Result from CORSIA (based on the Assembly Resolution A39-3), including the assessment of the potential costs from the implementation of the CORSIA Monitoring, Reporting and Verification (MRV) System and Registries. The status update resulted from updated assumptions and recent GMTF recommendations regarding States that announced their decision to voluntarily participate in CORSIA from its outset, estimates of verification costs for operators eligible to use simplified procedures, and updates of the sensitivity analysis based on recently released 2017 RTK statistics. Based on estimations of CO_2 reductions and costs expected to result from CORSIA to aeroplane operators, States and ICAO, the analysis included the following observations: the total offsetting requirements are estimated to be approximately 2.5 billion tonnes of CO_2 from 2021 to 2035; the vast majority of the total cost resulting from CORSIA is comprised of costs from offsetting requirements (i.e., 98%), with these costs representing a small fraction of total operating costs or revenue from international aviation; MRV and Registry costs are borne by aeroplane operators, Member States and ICAO at 1.4%, 0.5%, and 0.02% of total cost from CORSIA, respectively; and comparison of costs from offsetting requirements versus costs from MRV and registry show non-uniform distribution of costs across categories of States. The meeting was informed that this analysis could be updated during the CAEP/12 cycle, if requested by CAEP Members.

6.1.9 The meeting welcomed the analysis, with one Observer highlighting the benefit of its publication. Clarification was provided to confirm that the analysis undertaken by GMTF took as a reference CAEP/10 CO_2 emissions trends, and that a future update could take into consideration CAEP/11

CO_2 emissions trends. The meeting was informed that the analysis could be updated to provide information on the extent to which implementation of CORSIA is expected to have an impact on aeroplane operators' total revenue as well as on cost impact on a per flight basis and on a per passenger basis. The meeting also received clarification on the analysis' distinction between small operators and mid- and large-size ones, that distinction being made on the basis of the applicable threshold (in terms of annual CO_2 emissions) to determine whether an operator can use the ICAO CORSIA CERT for the estimation of its CO_2 emissions, as determined in Annex 16, Volume IV. Upon a request for clarification from a Member, the meeting was informed that the percentages of total cost of CORSIA implementation for aeroplane operators and States are always subject to a certain degree of variability based on differences either among operators or among States.

6.1.10 The GMTF co-Rapporteurs presented the results of the work of the GMTF's Registries Task Group focusing on two specific aspects: publication of information and data to be made public by ICAO and States, and through eligible emissions unit registries; and definition of requirements for registries to facilitate application of the SARPs. Regarding the publication of information, the GMTF co-Rapporteurs outlined the main recommendations in relation to the publication by ICAO of the documents listed in Annex 16, Volume IV, Part II, Chapter 1, Note 2, and the publication by States of data on cancelled emission units as per the recommendations in Annex 16, Volume IV, Part II, Chapter 4, 4.3.3. These recommendations apply to both how the public information should be presented as well as the timing of publications for documents where there is no specific deadline in Annex 16, Volume IV. In relation to requirements for programme registries, the GMTF co-Rapporteurs elaborated on the possible need for programme registry requirements that are additional or complementary to those contained in the EUC and guidelines, which experts have recommended as necessary to ensure that programme registries can enable aeroplane operators' implementation of relevant requirements in CORSIA. The GMTF co-Rapporteurs also informed CAEP of the recommendation to continue the discussion on this subject in order to identify and evaluate possible approaches to implementing these requirements taking into account the results of the work thus far.

6.1.11 A Member reflected on the plausibility of defining common rules for programme registries taking into account that emissions units programmes and their registries can widely differ in their characteristics.

6.1.12 The meeting recognized that further work is needed during the CAEP/12 cycle in order to identify and recommend an approach for applying the programme registry requirements, and that a discussion has to take place regarding the organization of work for tackling this task in the CAEP/12 cycle, as there are linkages with other areas of work on CORSIA.

6.1.13 The GMTF co-Rapporteurs presented an overview of the continued work performed by the GMTF CORSIA SARPs Drafting Group (SDG) on the CORSIA Package. The GMTF co-Rapporteurs presented a proposed revision of the ETM, Volume IV, resulting from GMTF and AFTF having identified further guidance that is considered useful to support CORSIA implementation. This included guidance on the process for cancelling of CORSIA Eligible Emissions Units by an aeroplane operator and related verification activities. The GMTF co-Rapporteurs also provided details on the rationale for the recommended amendments to the ETM, Volume IV.

6.1.14 Two Members emphasized that the materials included in ETM, Volume IV are guidance vis-à-vis the Standards included in Annex 16, Volume IV. A Member expressed his appreciation for the work undertaken by GMTF on this matter, and suggested an edit to the proposed revision of the ETM, Volume IV (to re-name the Pacific Accreditation Cooperation (PAC) Asian-Pacific Accreditation Cooperation (APAC)).

6.1.15 The GMTF co-Rapporteurs presented information on six tasks proposed by GMTF for CAEP work on CORSIA during the CAEP/12 cycle, namely: maintenance of Annex 16, Volume IV and related guidance material; development of the 2019 and subsequent versions of the ICAO CORSIA CO_2 CERT; development of further guidance on MRV in CORSIA; further assessment of supply, demand and price of emissions units for CORSIA implementation; development of recommendations on technical approaches to the management of EUC; and identification of an approach for the application of programme registry requirements to facilitate application of the SARPS. For each of the proposed tasks, GMTF detailed its main characteristics including, *inter alia*: rationale and benefits; timeline; approach for undertaking the task; and deliverables.

6.1.16 Upon a request for clarification from a Member, the GMTF co-Rapporteurs explained that, similar to what has been done by GMTF during the CAEP/11 cycle, a task has been proposed for the maintenance of Annex 16, Volume IV and related guidance material, with a separate task on the development of further guidance on MRV in CORSIA whose deliverables may include, among others, proposals for amendments of Annex 16, Volume IV and the related ETM, Volume IV.

6.1.17 A group of Members and Observers presented their views on CORSIA work. The presenters praised the results achieved over the CAEP/11 cycle and reaffirmed the need to carry forward the work on the CORSIA package as proposed by the GMTF co-Rapporteurs. In this regard, the presenters supported the establishment of a dedicated working group on CORSIA. The presenters also noted the importance of avoiding the double counting of emissions units, requested the adoption of a mandatory set of requirements for programme registries, stated the need for an evidence-based eligibility review of emissions units, and proposed work on the consequences of non-compliance by aeroplane operators under CORSIA.

6.1.18 Some Members and Observers provided comments and requested clarification on some of the views on future work on CORSIA presented by a group of Members and Observers. With regard to the proposal for an evidence-based eligibility review of emissions units and underlying programmes and possibly projects, two Members expressed reservations on this proposal due to lack of clarity and to the fact that this may be undertaken in the context of CORSIA's periodic review. With regard to the proposed work on the consequences of non-compliance by aeroplane operators under CORSIA, the CAEP Secretary clarified that paragraph 20 j) of Assembly Resolution A39-3 requests Member States to take necessary action to ensure that the necessary national policies and regulatory framework be established for the compliance and enforcement of the scheme; some Members and an Observer stated that it is not up to ICAO to impose rules on States and their operators on non-compliance. Regarding the establishment of a group to identify actual and potential future ways of manifestation of double counting and to elaborate mechanisms which prevent this phenomenon, some Members and an Observer did not support the establishment of such a group, on account of the fact that double counting is already included in the EUC, and will be considered by the Technical Advisory Body (TAB). Some Members expressed their preference to consider this as part of the task on EUC management for future work, with ICAO continuing to monitor and take into account the ongoing discussion on double counting under the UNFCCC process.

6.1.19 A Member presented views on GMTF and CORSIA, voicing support for providing more guidance in the ETM, specifically regarding the Emissions Unit Cancellation Report (EUCR). The Member noted that further work on the supply and price of eligible emissions units would only be productive after a decision on CORSIA-eligible emissions unit programmes. The Member supported continued work on EUC management as well as CERT. The Member supported the GMTF recommendations regarding the publication of CORSIA-related data, noting the importance of system transparency. Additionally, the Member supported the "attestation" approach for programme registries requirements, as outlined by the GMTF co-Rapporteurs when presenting GMTF's work on Registries. The Member recommended the establishment of a permanent working group to continue work on CORSIA during the CAEP/12 cycle. The Member also supported that CAEP work to support the ICAO Council in undertaking the 2022 CORSIA periodic review be undertaken by this new working group.

6.1.20 An Observer presented views on CAEP's work related to CORSIA MRV. The Observer supported incorporating the additional guidance developed by the GMTF, including the additional guidance developed on verification, in a revised edition of the ETM, Volume IV. The Observer also supported to review the CORSIA MRV requirements in the future, based on the experiences gained from implementing the CORSIA, and to include an item on the future work programme to maintain the CORSIA package. The Observer supported the work of the CCG, and highlighted his constituency's commitment to continue contributing to the development of the ICAO CORSIA CERT, as well as reiterated his constituency's view of the importance to allow aeroplane operators, authorities and verifiers to implement CEMs in their IT systems to facilitate compliance with CORSIA. The Observer also supported considering ways of sharing the updated analysis of the costs and CO_2 reductions expected to result from CORSIA, reiterating the request formulated at the 2017 CAEP Steering Group meeting.

6.1.21 The Observer expressed concern that some States had filed differences against the MRV provisions of Annex 16, Volume IV. Another Observer explained that his State had filed a difference, consisting of the State requesting its operators to report CO_2 emissions on a flight-by-flight basis. The Observer who expressed the concern clarified that such a difference was not the source of his concern, but rather the type of differences that may have an impact on the way the calculation of annual CO_2 emissions is done by operators, and thus on the operators' offsetting requirements.

6.1.22 An Observer presented views on CAEP's work related to eligible emissions units. The Observer noted that current supply, demand, and price forecasts do not take into account potential new demand from other sectors and States, and thus such analysis should note that limitation if included in the CAEP/11 Report or presented to the Council. The Observer highlighted that providing certainty to offset project investors and compliance entities should be achieved as soon as possible by approving EUC, programmes, and project types. The Observer considered that a decision on criteria and eligible units should not intend to limit the supply of emissions units, but rather to guarantee their environmental integrity. The Observer supported the current approach to double-counting, which is through the EUCR and the criterion that programmes have in place measures to avoid double-counting. The Observer pointed out that the UNFCCC process would be a critical part of ensuring that emissions units are not counted twice. Additionally, the Observer welcomed the work which the GMTF had done on EUC management, and highlighted the need for market certainty and buyer confidence.

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6.1.23 The meeting noted the information provided by GMTF on the overview of the group's work during the CAEP/11 cycle.

6.1.24 The meeting agreed to the recommended updates to the ETM, Volume IV and asked for the revised document to be published on the ICAO website as soon as possible.

6.1.25 The meeting agreed on the recommendations to the Secretariat on the publication of information by ICAO related to the ICAO CORSIA Implementation Elements, as provided in Appendix A to the report on these agenda items. The meeting requested that such recommendations be compiled in a document containing such CAEP recommendations to the Secretariat for ease of reference by both CAEP and the Secretariat.

6.1.26 The meeting agreed on the recommended programme registry-related requirements to facilitate application of the SARPs, as provided in Appendix B to the report on these agenda items, and agreed that further work will be required during the CAEP/12 cycle, taking into account the need to address governance issues in order to identify and recommend an approach for applying these requirements.

6.1.27 The meeting agreed that the Secretariat find the best way to include the GMTF's updated analysis of the costs and CO_2 reductions expected to result from CORSIA, among the materials already available on the ICAO CORSIA public website.

6.1.28 The meeting recognized the limitations of GMTF's updated analysis on supply, demand and price and agreed that caution is required when sharing the results of this analysis outside CAEP, taking into account that further work is needed to refine the analysis, as acknowledged by GMTF.

6.1.29 The meeting agreed that the GMTF had satisfactorily fulfilled the GMTF work programme for the CAEP/11 cycle, with completion of deliverables, noting the broad support from CAEP Members and Observers on the results achieved by the GMTF.

6.1.30 The meeting noted the proposals for future work presented by GMTF, and agreed to consider these proposals as the basis for the discussion on future work under Agenda Item 12 of the meeting, noting the views from a number of CAEP Members and Observers supporting GMTF's proposals and advocating for the creation of a working group on CORSIA to undertake the work on CORSIA during the CAEP/12 cycle, integrating work on specific aspects such as the work on the ICAO CORSIA CERT, or specific aspects related to emissions units criteria and eligibility of emissions units, into the new working group on CORSIA, and also in the wider context of CAEP work during the CAEP/12 cycle.

6.1.31 The meeting recognized the importance of the Council's approval of the EUC and highlighted the importance of initiating the review and approval of emissions unit programmes and project types as soon as possible.

6.1.32 The meeting was presented with draft Rules of Procedure of the TAB, and agreed with the text, with the exception of the last section that read as follows:

> *[**12. COMMUNICATION OF TAB'S RECOMMENDATIONS***
>
> *12.1 The Council's decisions on the list of eligible emissions unit programmes (and potentially project types), based on TAB's recommendations, will be made publicly available on the ICAO CORSIA website.]*

6.1.33 While recognizing that previous decisions by the ICAO Council already addressed the need to have the CORSIA Implementation Elements, including the CORSIA eligible emissions units, made available on the ICAO CORSIA website once they are approved by the Council, the meeting reemphasized the need to ensure the transparency of the process, including on whether the TAB's recommendations should be made public, and requested that this aspect be brought to the attention of the ICAO Council while presenting CAEP's recommendations on the Rules of Procedure of the TAB. Nevertheless, the meeting agreed to delete the text as written in paragraph 6.1.32 above, as it refers to an action which is not within the remit of the TAB itself, and therefore it should not be part of the Rules of Procedure of the TAB.

6.1.34 An Observer expressed the need for the TAB, once established, to clarify a specific duration of the public information period. A Member highlighted the importance for the TAB to define a detailed work programme and timeline to undertake its tasks. A Member clarified that the Rules of Procedure of the TAB should not be too restrictive, but rather provide overarching guidance on the basis of which TAB could elaborate on mode detailed procedures, based on the recommendations of the GMTF - PTG. With regard to the decision process of the TAB, as reflected in paragraph 8.7 of the TAB Rules of Procedure, a Member expressed the view that, in the absence of consensus in any of the TAB's recommendations, the result of the voting ratio should be included in the information presented by TAB to support that recommendation.

6.1.35 The meeting agreed on the Rules of Procedure of the TAB, as provided in Part B of Appendix C to the report on these agenda items, and that they be submitted for consideration by the Council.

6.1.36 The meeting recognized the importance and supported the objective of consistency among ICAO emissions tools, such as the ICAO CORSIA CERT and the ICAO Carbon Emissions Calculator.

6.1.37 There was also a question on whether the ICAO CORSIA CERT, as a publicly available tool, could be used for purposes beyond CORSIA.

6.1.38 The meeting recognized that further work had to be undertaken following the CAEP/11 meeting, in order to investigate the feasibility of using the ICAO CORSIA CERT and the underlying CEMs, to be utilized in the ICAO Carbon Emissions Calculator. This would include ensuring that the ICAO CORSIA CERT is fit for purpose and that the use of the ICAO CORSIA CERT in this manner is supported by appropriate use agreements to support non-CORSIA uses, which may mean amending the existing agreements. The evaluation could be carried out by the CCG and the Secretariat would work with data providing States and organizations to update the use agreements, in order to find a suitable solution by the end of May 2019.

6.1.39 The meeting agreed that the CCG consider the issue of non-ICAO uses of the ICAO CORSIA CERT, and make appropriate recommendations in a timely manner.

6.1.40 **Recommendation**

6.1.40.1 In light of the discussions, the following recommendations were developed:

Recommendation 8/1 — Amendments to the *Environmental Technical Manual*, Volume IV

That the *Environmental Technical Manual*, Volume IV be amended and published as indicated in the report of GMTF.

Recommendation 8/2 — Rules of Procedure of the Technical Advisory Body (TAB)

That the Rules of Procedure of the Technical Advisory Body (TAB) be submitted for consideration by the Council, during its 216th Session.

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APPENDIX A
(English only)

RECOMMENDATIONS ON OPERATIONALIZATION OF THE PUBLICATION OF DATA BY ICAO

1.1 The recommendations in this section apply to ICAO, and are relevant to the documents listed in Note 2 of Part II, Chapter 1 of Annex 16, Volume IV. The Registries Task Group acknowledges the standard practice of the ICAO Secretariat is that the documents listed in Table 1 should follow the harmonized format rules and be presented in a downloadable .pdf.

1.2 Table 1 presents a list of documents referred to in paragraph 1.1, including information on SARPs data submission and publication deadlines, as well as any additional relevant information. Specific recommendations for the documents in Table 1 are:

1.2.1 Table 1, Document 2 '*ICAO CORSIA* CO_2 *Estimation and Reporting Tool*' should be published as soon as practicable for each year of CORSIA.

1.2.2 Table 1, Document 8 '*CORSIA Eligible Emissions Units*' should present information in a format which shows the eligibility parameters of eligible units.

1.2.3 Table 1, Document 14, part containing '*List of verification bodies accredited in each State*', should be published as soon as practicable, but no later than 31 May 2019. Further updates to this list should be published as soon as practicable on an ongoing basis, subject to the provision of updated information from States as per Annex 16, Volume IV, Part II, Chapter 1, 1.3.7.

1.2.4 Table 1, Document 14, part containing '*Total average* CO_2 *emissions for 2019 and 2020 aggregated for all Aeroplane Operators on each State pair route*', should be published as soon as practicable, but no later than 30 November 2021.

1.2.5 Table 1, Document 14, part containing '*CCR State reported emissions*', should be published in accordance with Note 2, of Table A5-8, in Appendix 5 of Annex 16, Volume IV, as soon as practicable, but no later than 31 October 2022 (for 2021 emissions). The same day and month should apply to subsequent years.

1.2.6 Table 1, Document 14, part containing '*CCR State reported emissions unit cancellations*', should be published in accordance with Note 2, of Table A5-8, in Appendix 5 of Annex 16, Volume IV, as soon as practicable, but for the Pilot Phase no later than 31 October 2025. The same day and month should apply to subsequent compliance periods.

1.3 ICAO public information relating to identification of States, aeroplane operators, verification bodies, or other entities will be as notified to ICAO by the States. This is to ensure a high level of consistency of data published by ICAO and States.

1.4 Public information should be available free of charge. The web pages containing this information should be available to the general public, with no credentials required, and with no prior authorization necessary to access them.

1.5 When there is an update to the information, a change log should be published alongside the new version of the document. The change log should include the modifications occurring since the previous version, as well as the date when the modifications occurred. For data for which this is relevant, the change log should include the beginning of the validity of the modifications. Previous versions of the implementation elements may be required for various purposes and should be archived (but downloadable) for State and public use. The exception is where there are two (or more) versions of the same document could be simultaneously valid and should remain clearly visible and available for download. In this case, it should be clearly specified under which circumstances each version is applicable.

1.6 Where a State or ICAO identifies a discrepancy of data already published, it is recommended that ICAO and States coordinate in order to publish the correction with a minimum of delay between each other, to reduce the time interval when the data is discrepant between the two web pages. To ensure transparency, previous versions (editions) of documents which have been modified should be retained and made available on the web page, while making clear they have been subsequently updated.

1.7 The CORSIA public web pages should have contact information for further enquiries by the general public. It is recommended that there is a dedicated online form or electronic mailbox for CORSIA enquiries.

1.8 In addition to any web-based presentation / summary information, and any presentation of information in a downloadable document, where large quantities of information are to be published, the recommendation is for the information to be published in a machine-readable, downloadable format, e.g. xlsx.

1.9 Where large quantities of information are to be presented by ICAO on a publicly accessible website, it is recommended that all such available information can be searched on the website by each relevant data field, subject to the availability of financial resources.

Table 1: Documents referenced in Note 2 of Part II, Chapter 1 of Annex 16, Volume IV

#	Information	Data availability date	SARPs Publication Deadline	Update frequency
1	**CORSIA States for Chapter 3 State Pairs**	30.06.2020	01.08.2020	Annually
Note: This ICAO document will only show participating States from 2021 for the purpose of determining Chapter 3 State pairs and not the State pairs themselves.				
2	**ICAO CORSIA CO_2 Estimation and Reporting Tool**	31.07.2018	See 1.2.1	Annually
Note: Approved recommendations relating to this document are as per GMTF/11-WP/03 pages D-5 and D-16 and CAEPSG.20172.ICAO CORSIA Package, Draft Supporting Information and Supporting Documents, pages 8 and p29.				
3	**CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes**	Following approval by the ICAO Council	Following approval by the ICAO Council	Ongoing
Note: This document was approved at SG2018 (ref WP11 https://portal.icao.int/CAEP/2018%20Singapore%20Meeting/CAEPSG.20183.WP.011.4.en.pdf).				
4	**CORSIA Approved Sustainability Certification Schemes**	Following approval by the ICAO Council	Following approval by the ICAO Council	Ongoing
Note: The format for this table was approved at SG2018 (ref WP11 https://portal.icao.int/CAEP/2018%20Singapore%20Meeting/CAEPSG.20183.WP.011.4.en.pdf). It is a single table with three columns.				
5	**CORSIA Sustainability Criteria for CORSIA Eligible Fuels**	Following approval by the ICAO Council	Following approval by the ICAO Council	Ongoing
Note: The criteria will be presented in a table format and followed / accompanied by Guidance.				
6	**CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels**	Following approval by the ICAO Council	Following approval by the ICAO Council	Ongoing
Note: There is no official expiry date for the values, but they are subject to the regular review process of the Annex. In case of changes, it is not clear if it will affect previously certified fuels; therefore, this would need further discussion and agreement within the CAEP/AFTF. In any case, this should not have an impact on the fact that the values are published together with the validity date.				
7	**CORSIA Methodology for Calculating Actual Life Cycle Emissions Values**	Following approval by the ICAO Council	Following approval by the ICAO Council	Ongoing
8	**CORSIA Eligible Emissions Units**	Following approval by the ICAO Council	Following approval by the ICAO Council	Ongoing
Recommendation: The information should be presented in a format which shows the eligibility parameters of eligible units.				
9	**CORSIA Emissions Units Eligibility Criteria**	Following approval by the ICAO Council	Following approval by the ICAO Council	Ongoing
10	**CORSIA Central Registry (CCR):**	See rows 11 - 13		

	Information and Data for the Implementation of CORSIA			
11	**CORSIA Aeroplane Operator to States Attributions**	30.11.2018	31.12.2018	Annually
12	**CORSIA 2020 Emissions**	31.08.2021	Following approval by the ICAO Council	Once
Note: This will be just one number.				
13	**CORSIA Annual Sector's Growth Factor (SGF)**	31.07.2022	31.10.2022	Annually
Note: This will be a list showing a numerical value for each year.				
14	**CORSIA Central Registry (CCR): Information and Data for Transparency**	See rows 14.1 – 14.4		
14.1	List of verification bodies accredited in each State	30.04.2019	See 1.2.3	Ongoing
14.2	Total average CO_2 emissions for 2019 and 2020 aggregated for all Aeroplane Operators on each State pair route	30.09.2021	See 1.2.4	Once
14.3	CCR State reported emissions	31.07.2022	See 1.2.5	Annually
Recommendation: Publish in accordance with Note 2, of Table A5-8, in Appendix 5 of Annex 16, Volume IV.				
14.4	CCR State reported emissions unit cancellations	31.07.2025	See 1.2.6	Once per period
Recommendation: Publish in accordance with Note 2, of Table A5-8, in Appendix 5 of Annex 16, Volume IV.				

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APPENDIX B
(English only)

PROPOSED PROGRAM REGISTRY-RELATED CONSIDERATIONS AND REQUIREMENTS

1.1. The following proposed registry-related considerations and requirements follow from the contents of the proposed draft Emissions Unit Program Registry Attestation (Section 4).

1.1.1. *Recommended definition of Emissions Unit Program Registry*: An Emissions Unit Program Registry is a registry that the program designates to provide its registry services; and is described in the information that the program submits to ICAO.

1.1.2. *Recommended definition of the emissions unit program – registry relationship*: The application of the EUC to determine program eligibility includes an assessment of the program's provisions and procedures governing the program registry, as represented by the program in the information that the program submits to ICAO. ICAO does not separately or independently evaluate the program registry. The program registry's provision of registry services relevant to the CORSIA shall be subject to the terms and conditions of the program's eligibility. Such terms include, *inter alia*, the program's commitment to administer any and all provisions and procedures governing the program registry in the manner represented by the program in the information that the program submits to ICAO.

1.1.3. *Recommendation on timing of applicability of registry requirements*: The program registry can provide registry services to Aeroplane Operators prior to the program's and program registry's demonstration of the registry's consistency with these registry requirements. However, the program registry can only claim to support and can only provide for Airplane Operators to fulfill CORSIA SARPs involving emissions unit cancellation-, reporting-, and verification-related actions after its consistency with these requirements is demonstrated, and published on the CORSIA website along with the list of CORSIA Eligible Emissions Units.

1.1.4. *Recommendation on registry affirmation of program information*: The program registry shall / should affirm that the program's representation of its provisions and procedures governing the program registry, and of program registry functionality, as contained in the most recent information that the program submits to ICAO, is true, accurate, and complete, to the best of the registry representative's knowledge;

1.1.5. *Recommendation on notification of material changes to registry*: The program registry shall / should notify the program of any material changes[1] to the program registry, such that the program can maintain consistency with relevant criteria and guidelines.

1.1.6. *Recommendation on registry non-discrimination based solely on account applicant location*: The program registry shall / should not deny a CORSIA participant's request for a registry account solely on the basis of the country in which the requestor is headquartered or based.

[1] As referred to in CAEP-11/SG20161/WP-015, "Material" change is defined as "…updates that would alter the program's response(s) to questions in application form." In the context of an emissions unit program registry, the same applies to any changes to the registry procedures or functions that are addressed in the EUC, Guidelines, or the requirements in Section 2 of this Appendix that would alter the program's response(s) to questions in application form or contradict the confirmation of the registry's adherence to the requirements contained in Section 2 of this Appendix.

1.1.7. *Recommendation on functionality for designating purpose of cancellation*: The program registry shall / should have the capability to designate the participant's cancellation of units for the purpose of reconciling offsetting requirements under the CORSIA, including by compliance cycle.

1.1.8. *Recommendation on publishing the cancellation information*: The program registry shall / should, within 1 – 3 business days[2] of receipt of formal instruction from a duly authorized representative of the owner of an account capable of holding and cancelling CORSIA Eligible Emission Units within the registry, and barring system downtime that is scheduled in advance or beyond the control of the registry administrator, make visible on the program registry's public website the account owners cancellations of CORSIA Eligible Emission Units as instructed. Such cancellation information shall / should include all fields that are specified for this purpose in the CORSIA SARPs

1.1.9. *Recommendation on public accessibility of cancelation information*: The program registry shall / should ensure that all cancellation information on its website is presented in a user-friendly format; is available at no cost and with no credentials required; is capable of being searched based on data fields; and can be downloaded in a machine-readable format, e.g., .xlsx.

1.1.10. *Recommendation on generation of reports, upon request*: The program registry shall / should, upon request of the CORSIA participant account holder or participant's designee, generate report(s) containing the information specified for this purpose in the CORSIA SARPs.

1.1.11. *Recommendation on verifier registry access*: The program registry shall / should, upon request of an account owner, provide a verification body with "viewing-privileges-only" access to the relevant account(s) and/or cancelled emissions units.

1.1.12. *Recommendation on document and data retention*: The program registry shall / should retain documents and data relevant to CORSIA Eligible Emissions Units and cancellations on an ongoing basis and for at least three years beyond the end date of the latest compliance period in which the emissions unit program is determined to be eligible; and consistent with the program's long-term planning, including plans for possible dissolution.

1.1.13. *Recommendation on registry security provisions*: The program registry shall / should maintain security practices that ensure the integrity of, and authenticated and secure access to, the registry data of CORSIA participant account holders or participants' designees, and transaction events carried out by a user; and disclose documentation of such practices upon request. The program registry shall / should utilize appropriate method(s) to authenticate the identity of each user accessing an account; grant each user access only to the information and functions that a user is entitled to; and ensure each event initiated by a user (i.e. transfer of units between accounts; cancellation / retirement of a unit, update of data, etc.) is an intentional transaction event confirmed by the user. Such security features should meet and be periodically updated in accordance with industry best practice.

1.1.14. *Recommendation on notification of breach of data security or integrity*: The program registry shall / should, upon identifying any breach of program registry data security or integrity that affects a CORSIA participant account holder or participant's designee, notify the CORSIA participant account holder or their designee, and inform the program, which will notify and engage with ICAO on the matter in the same manner as conducted for any material changes to program procedures.

[2] Business days as defined by the registry administrator.

1.1.15. *Recommendation on irreversibility of emissions units cancellation*: The program registry shall / should ensure the irreversibility of emissions unit cancellations and the designation of the purpose of emissions units cancellations as per the requirements contained in paragraphs 2.1.7 and 2.1.8, and as defined and required in Annex 16 Volume IV, Chapter 4: Standard and Recommend Practices (SARPs) for the CORSIA[3]. Without prejudice to the aforementioned, such requirement would not prevent a program registry from utilizing secure, time-bound and auditable methods for correcting unintentional user-entry errors.

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[3] From Annex 16, Volume IV, Chapter 4: Standards and Recommend Practices (SARPs) for the CORSIA: "'*Cancel' means the permanent removal and single use of an CORSIA Eligible Emissions Unit within a CORSIA Eligible Emissions Unit Program designated Registry such that the same emissions unit may not be used more than once. This is sometimes also referred to as 'retirement', 'cancelled', 'cancelling' or 'cancellation'*."

APPENDIX C
(English only)

BASIC TOR AND PROPOSED ADDITIONAL RULES OF PROCEDURE FOR THE TECHNICAL ADVISORY BODY (TAB)

Part A: Basic TOR for the TAB (as approved by the Council as C-DEC 215/7, Appendix)

Secretariat note: Upon approval of Part B by the Council, Part A and Part B will be integrated as the TOR for TAB.

1. MANDATE OF TAB

1.1 In line with the Assembly request, the mandate of the TAB is to make recommendations to the Council on the eligible emissions units for use by the CORSIA.

2. TASKS OF TAB

2.1 In fulfilling this mandate, the TAB is tasked to:

1) undertake the assessment of emissions unit programmes (and potentially project types) against the emissions units criteria, applying as a starting point the CAEP Programme Testing Group's procedures and guidelines for applying the emissions units criteria;

2) ensure that emissions unit programmes around the world can receive advance notice of, and are given ample time to apply for, the assessment by TAB; ensure outreach and ample notice and opportunity for input from stakeholders, with the support of the ICAO Secretariat;

3) develop, in a transparent manner, recommendations on the list of eligible emissions unit programmes (and potentially project types) whose emissions units would be eligible based on the emissions units criteria, for the compliance use under the CORSIA, for presentation to the Council;

4) adjust its work, if needed, in light of any developments of work by the ICAO Council, with technical contribution of CAEP, in any reviews of the emissions unit criteria, which are set out in the ICAO CORSIA Implementation Elements; and

5) undertake any other tasks as instructed by the Council.

3. EXPERTISE AND EXPERIENCE REQUIREMENTS

3.1 In order for the TAB to undertake the tasks as outlined in paragraph 2 above, TAB members are required to have relevant expertise and experience such as in carbon markets, carbon offset project development, carbon offset programmes and methodologies, and climate policy and related subjects. TAB members are required to meet at least two of the following five technical expertise requirements, which have to be substantiated at the time of nomination:

a) experience in the design, development, operation or evaluation of market-based measures for the reduction of greenhouse gas emissions (e.g. emissions trading systems, offsetting standards or programmes, the international carbon market);

b) experience in the quantification or forecasting of greenhouse gas emissions;

c) experience in the creation or use of emissions units (offset credits or allowances);

d) experience in developing, operating or using emissions units registries/carbon trading registries and emissions inventories;

e) experience in ensuring the transparency and accountability of carbon market programmes and carbon market operations.

3.2 In addition, it would be desirable (though not essential) that TAB members have experience with ICAO processes, in particular those related to CORSIA.

4. AVOIDANCE OF CONFLICTS OF INTEREST

4.1 Thorough evaluation is undertaken to avoid conflicts of interest of TAB members. In particular, TAB members should not be holding a financial and/or commercial interest in any organization, project, and/or programme that would benefit from the member’s appointment. This has to be substantiated at the time of nomination, through a personal declaration.

5. DURATION OF SERVICE

5.1 Regarding the duration of service by TAB members and to ensure consistency in the work of TAB, TAB membership is aligned with the compliance cycles of the CORSIA (potentially with a short term for work undertaken prior to 2021), and a statement of commitment to the work of TAB for at least one full compliance cycle of CORSIA is provided at the time of nomination.

6. MEMBERSHIP SIZE

6.1 In principle, the size of the TAB should be in the order of 14 to 16 experts, nominated by States, taking into account the need for balanced geographical representation.

Part B: Proposed Additional Rules of Procedure for the TAB

Secretariat note: The Council, in November 2018, requested CAEP to provide further advice regarding additional rules of procedure for the TAB, which would complement the approved basic TOR, for the Council consideration and approval by its 216th Session in March 2019 (C-DEC 215/7, paragraph 32 e)).

Secretariat note: Upon approval of Part B by the Council, Part A and Part B will be integrated as the TOR for TAB.

7. MEMBERSHIP

Selection of Co-Chairpersons for TAB

7.1 The TAB selects two Co-Chairpersons from among its members at the first TAB meeting.

7.2 The Co-Chairpersons should not be from the same geographical region.

Conduct of TAB members:

7.3 TAB members are to conduct themselves in accordance with the TAB's TOR.

7.4 The TAB Co-Chairpersons may bring to the Council's attention any serious concerns regarding a member's consistency with the TOR, which may become apparent in the course of the TAB's work, in particular concerns related to the participation of TAB members and conflicts of interest should be informed to the Council.

Replacement of TAB Members during a CORSIA compliance cycle

7.5 The replacement of an existing TAB Member during a compliance cycle of the CORSIA is approved by the Council.

7.6 The replacement must meet the same criteria as outlined in the TOR for the TAB.

7.7 The outgoing member's nominating State should first be allowed to nominate a replacement.

7.7.1 If a replacement is not nominated by that State or should the Council reject the nominated replacement, ICAO would then seek nominations from the outgoing member's geographic region.

7.7.2 If a replacement is not nominated by a State from that geographical region or should the Council reject the nominated replacement(s), ICAO would then seek nominations from all States.

7.7.3 Where possible, the replacement of TAB members should be staggered over CORSIA compliance cycles to ensure continuity of knowledge and expertise.

8. WORKING METHODS

Modality and frequency of TAB meetings

8.1 Face-to-face meetings of the TAB are the primary means of organizing the TAB's work, making significant decisions in particular TAB's recommendations to the Council, and resolving substantive issues.

8.2 The TAB is also expected to conduct business via teleconferences and emails between the face-to-face meetings to progress the work.

8.3 TAB discusses and agrees on a schedule of meetings, which can be reviewed later as necessary. The number of TAB meetings should be sufficient to achieve the deliverables for the TAB as set by the Council.

8.4 If changes to the meeting schedule or additional meetings are required, the Co-Chairpersons will, after consultations with TAB members, give notice of any changes in the meeting schedule and/or additional meetings.

Note. The Co-Chairpersons are encouraged to give approximately 8 weeks' notice of any changes in the face-to-face meeting schedule and/or additional face-to-face meetings.

Quorum for TAB recommendations

8.5 A majority of TAB Members, at least from three geographical regions, must be present at a TAB meeting in order to constitute a quorum to make TAB recommendations. This rule would not apply to the meetings of a sub-group or other structural arrangements by TAB, to make progress on specific work.

Working language for TAB meetings

8.6 The working language of the TAB is English. The recommendations of TAB are translated in all six languages, for consideration by the Council.

Decision process

8.7 TAB's final recommendations to the Council, including the underlining decisions by the TAB, are taken by consensus. If there is no consensus, then the prevailing and alternative conclusions will be described and substantiated, and presented to the Council for decision.

Openness of TAB meetings

8.8 As a general rule, TAB meetings will only be open to TAB Members, with support provided by the ICAO Secretariat.

8.9 Other participants may, upon request by the TAB, be invited by the ICAO Secretariat to participate in TAB meetings relating to matters under consideration by the TAB.

Secretariat

8.10 The ICAO Secretariat will:

a) publish general information related to TAB on the ICAO CORSIA website, including the membership, TOR, and the latest timeline of work;

b) provide administrative and logistical support for TAB meetings and business conducted by TAB

c) facilitate all communications between emissions unit programmes and the TAB; and

d) support the preparation of necessary documentation and reports related to TAB.

9. TAB WORK PROGRAMME

9.1 Based on the TOR, TAB will initiate its work by defining its work programme and timeline, and use as a starting point the CAEP Programme Testing Group's procedures and guidelines for applying the emissions unit criteria, including as a source of guidance on any specific procedures or issues not addressed in the TOR.

10. PROGRAMME APPLICATION AND ADMINISTRATIVE PROCESS

10.1 The TAB, with the support of the ICAO Secretariat, will issue an open invitation on the ICAO CORSIA public website, by which emissions unit programmes that wish to be considered for eligibility in CORSIA can apply. To facilitate the applications by emissions unit programmes, the website will include an application form and other information that need to be prepared and submitted electronically to ICAO.

10.2 Once the application process is initiated, the status of applications submitted by emissions units programmes will be made available on the ICAO CORSIA public website.

11. PUBLIC INFORMATION AND TRANSPARENCY

11.1 Applications and other information submitted by emissions unit programmes will be publicly available on the ICAO CORSIA website, except for materials which the applicants designate as business confidential.

11.2 The public will be invited to submit comments on the programmes applications including regarding their consistency with the emissions units criteria (EUC), through the ICAO CORSIA website, for consideration by the TAB following its initial assessment of programmes applications.

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Agenda Item 9: Sustainable aviation fuels

9.1 REPORT OF THE AFTF

9.1.1 The AFTF co-Rapporteurs presented a summary of the group's progress since CAEP/10. The AFTF had focused on seven tasks throughout the CAEP/11 cycle and had delivered proposals to complete all missing sections of the CORSIA Implementation Elements related to CORSIA Eligible Fuels. The work of AFTF had only considered sustainable aviation fuels (SAF), as the definition of "CORSIA Lower Carbon Aviation Fuels" (LCAF) was only adopted by the ICAO Council during its 214th Session (June 2018), and thus "Lower Carbon Aviation Fuels" had not been included on the AFTF work programme for CAEP/11.

9.1.2 Several Members and Observers expressed their view that the work on the TAB and Fuel Advisory Body (FAB) should be completed in parallel. They reiterated their support for the full set of criteria recommended by CAEP to ensure both socio-economic and environmental sustainability of fuels eligible under CORSIA. They noted the importance of the work accomplished on both induced land use change (ILUC) and low ILUC risk practices, while noting that more work is needed during the CAEP/12 cycle. These Members also expressed the view that the negative life cycle emission value of a fuel (LSf) should not be allowed, as a precautionary interim measure, while trying to address concerns such as double counting. The Members and Observers recommended future work items on both SAF and LCAF be carried out by CAEP.

9.1.3 A Member provided views on specific outstanding topics and supported the methodology proposed for landfill emission credits (LEC) and recycling emission credits (REC) by AFTF as reasonable, providing that emissions credits could not be used to obtain a negative value for LSf, noting that this would mitigate the risk of double claiming of emissions reductions. The Member also recommended that no further credits be considered for any fuels to be used in CORSIA due to the potential risk of unintended consequences.

9.1.4 An Observer presented their view that the approach recommended by AFTF for the accounting of SAF under CORSIA was rigorous and appropriate. They noted their view that the core sustainability requirements need to be complemented by a broader set of sustainability criteria. The Observer supported the AFTF recommendations on life-cycle assessment (LCA) methodology and stressed the importance of recognizing LEC and REC from Municipal Solid Waste (MSW) feedstock.

9.2 SUSTAINABILITY CRITERIA (TASK S.05)

9.2.1 Over the CAEP/11 cycle, the AFTF worked to develop recommendations on sustainability criteria for SAF in the context of CORSIA, building as much as possible on existing sustainability standards and frameworks. Although this task was completed, as an outcome of the 212th Session of the ICAO Council, further work was expected from CAEP concerning those sustainability themes and criteria for SAF not approved at the 212th Council Session (those previously recommended by CAEP as 'Themes 3-12'). The AFTF co-Rapporteurs presented a "Report on Additional Sustainability Themes, Principles and Criteria for Sustainable Aviation Fuels", developed jointly with the ICAO Secretariat as an initial step to address the work on sustainability criteria, as requested by the Council.

Discussion and conclusions

9.2.2 The meeting noted the support of several CAEP Members and Observers on the deployment of SAF.

9.2.3 Several Members and Observers expressed their support for the “Report on Additional Sustainability Themes, Principles and Criteria for Sustainable Aviation Fuels” and recommended that it be presented to Council as soon as possible, while some Members requested that proper caveats be included to inform that the current work only considered SAF, and that CAEP will develop further work to properly consider LCAF in the context of sustainability. The CAEP Secretary informed that the Report will be provided to Council as part of the CAEP/11 Report. A Member noted the point made by the AFTF co-Rapporteurs that the report does not preclude any considerations of LCAF, and as such supported continued work, but in such a manner that the developments on SAF are not slowed down.

9.2.4 The meeting agreed to accept the “Report on Additional Sustainability Themes, Principles and Criteria for Sustainable Aviation Fuels”, as provided in Appendix A to the report on this agenda item, as an initial step to inform the Council of the progress of work by CAEP to address the ICAO Council’s requests for further work on additional sustainability criteria for SAF, made during its 212th Session (November 2017), and for strengthened sustainability criteria for CORSIA Eligible Fuels, made during its 214th Session (June 2018), recognizing that further CAEP work would be needed to develop CAEP recommendations on this subject.

9.2.5 The meeting noted that the two sustainability criteria to be applied during the pilot phase of CORSIA, which were considered by the Council as part of its decision during the 212th Session, should be reflected in the ICAO Document “CORSIA Sustainability Criteria for CORSIA Eligible Fuels” as provided in Appendix B, for publication as part of the complete CORSIA Implementation Elements related to “CORSIA Eligible Fuels”.

Recommendation 9/1 – ICAO Document “CORSIA Sustainability Criteria for CORSIA Eligible Fuels” referenced in Annex 16, Volume IV

That the material in Appendix B to the report of on this agenda item, be included as the ICAO Document “CORSIA Sustainability Criteria for CORSIA Eligible Fuels”, for publication.

9.3 ASSESSMENT OF SUSTAINABILITY CERTIFICATION SCHEMES

9.3.1 The AFTF co-Rapporteurs presented initial thoughts on (1) the role, (2) membership, (3) function, and (4) governance of a specialized technical body, referred to as the FAB, to be responsible for providing advice on the eligibility of Sustainability Certification Schemes (SCS) under CORSIA.

Discussions and Conclusions

9.3.2 Several Members supported the composition of FAB with nominees from CAEP Members, provided that diverse geographic representation within the group is ensured.

9.3.3 Regarding a comment made comparing the possible FAB and the TAB, the AFTF co-Rapporteurs explained that the scope and volume of work associated with the FAB is expected to be very different than from TAB. Considering this, the AFTF co-Rapporteurs expressed the view that such a group could be established directly as a CAEP group. The CAEP Secretary also supported this view, reiterating that there is no real similarity between the FAB and the TAB. The CAEP Secretary also commented that the CORSIA Implementation Elements, including a list of eligible SCS, must be approved by the Council, so any recommendations made by the FAB related to the eligible SCS will be subject to final scrutiny and approval by Council, regardless where this group is established. One Member pointed out that eventual requirements for the FAB components should also include competencies related to LCAF, in addition to SAF.

9.3.4 From the ensuing discussions, the meeting noted that the name "Fuels Advisory Body" did not appropriately reflect the specific role of this group, and agreed with the name "SCS Evaluation Group (SCSEG)". The meeting agreed to create the SCSEG as a subgroup of CAEP mandated with developing technical recommendations to the Council on the eligibility of SCS.

9.3.5 The meeting agreed that the SCSEG should be composed of independent experts nominated by CAEP Members. The membership should reflect a balanced geographical representation. The meeting agreed on the Terms of Reference for the SCSEG, as included in Appendix C to the report of this agenda item.

9.3.6 The meeting agreed on the following timeline and deliverables for the SCSEG work:

a) by June 2019: with the Council approval of the work programme for the CAEP/12 cycle, including the TOR for CAEP SCSEG, CAEP will invite nominations for membership from CAEP Members;

b) by August 2019: CAEP Members will appoint members to the SCSEG;

c) by September 2019: the CAEP SCSEG, with the support of the ICAO Secretariat, will issue an open invitation on the ICAO CORSIA public website, by which SCS that wish to be considered for eligibility in CORSIA can apply. A template of the application form will include requirements set up in the tables in the section "Eligibility Requirements of the ICAO documents CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes"; and

d) by CAEP-SG2019: the CAEP SCSEG will evaluate the applications from SCS, and develop technical recommendations on the list of eligible SCS, for comments by CAEP, prior to submission to the Council at the earliest in March 2020.

9.4 COMPUTATION OF DEFAULT VALUES FOR ALTERNATIVE JET FUEL LIFE CYCLE EMISSIONS FOR USE IN THE GMBM MRV (TASK S.02)

9.4.1 Over the CAEP/11 cycle, AFTF carried out computations of "core" LCA default values that could be used by operators to report emissions reductions from the use of SAF. Per agreement, AFTF have used a team of researchers from Brazil, Canada, Europe and the United States to perform the calculations. Based on this work, the AFTF co-Rapporteurs presented a proposal for additional core LCA values to be added to the table in the ICAO document entitled, "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels".

9.4.2 To accompany this work, the AFTF co-Rapporteurs presented text for the "Feedstock Categories" and "Technical Report Requirements" sections of the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values", as well as a proposal for the supporting document "LCA Methodology – Core LCA Calculations", which also included technical information on the LCA models and on how the results were created.

9.4.3 An Observer proposed that the agreement on default core LCA values for "closed pond palm oil" pathway be put on hold until further analysis has been carried out to avoid double counting of emissions reductions and inappropriate default value designation. The Observer presented proposals to ensure proper designations to default core LCA values, which would avoid granting LSf values to pathways with substantially greater carbon intensities.

Discussions and Conclusions

9.4.4 The meeting agreed that it was premature to exclude the "closed pond palm oil" pathway.

9.4.5 The meeting acknowledged the work performed by AFTF and agreed to include the core LCA values provided in the ICAO document entitled, "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels".

9.4.6 The meeting agreed to the text proposed for the sections "Technical Report Requirements" and "Feedstock Categories" of the ICAO document entitled "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values," with the inclusion of editorial corrections pointed out by the AFTF co-Rapporteurs.

9.5 **EMISSIONS CREDITS**

9.5.1 The AFTF co-Rapporteurs presented methodologies for the calculation of avoided LEC and REC associated with MSW derived SAF in order to allow for the inclusion of emission credits in the calculation of LSf, to be included in the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values."

9.5.2 A Member presented their view that emission credits should not be included in the CORSIA Package at present, due to concerns that the proposed LEC and REC credits will not result in credits of a similar quality as CORSIA emission units. As an alternative and interim solution, several Members supported that LSf of fuels subject to emission credits should be limited to zero.

9.5.3 An Observer presented the view that LSf values should not be limited to zero, as it would limit the magnitude of emissions reduction claims and treat MSW-based CEF producers asymmetrically. The Observer proposed a different way of addressing double claiming of CEF by performing corresponding adjustments in the accounting balance of the country where the CEF was produced. To do so, the Observer proposed provisions for the ICAO document "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes," that would avoid CEF double claiming from the onset of CORSIA. The Observer considered that the emission credits methodologies proposed by AFTF did not limit unintended incentives for poor landfill management, nor did they address the risk of double counting, and that the LEC methodology represents an unprecedented approach inconsistent with UNFCCC accounting and crediting rules applying elsewhere. As a result, the Observer presented proposals to address these issues on the LEC and REC methodologies.

Discussions and Conclusions

9.5.4 Some Members noted that while limiting LSf to zero is an imperfect approach, it could be useful as an interim measure. Several Members also supported that emissions credits should only be considered within the context of MSW; however some Members and Observers expressed that such an approach was too radical, as there should be an opportunity to consider additional types of emissions credits in the future. One Member also reminded the meeting of previous agreements from CAEP regarding the need for the definition of general rules that would be applicable to emission credits. Some Members highlighted the need to limit unintended incentives for poor landfill management and to address the risk of double counting associated with these emission credits.

9.5.5 After considering the conflicting views on limiting LSf to zero and on the limitation of types of emissions credits, the meeting agreed that emission credits may be generated from the production of SAF from wastes and residues, as defined in the section "Feedstock Categories" of the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values". The meeting also agreed that CAEP should pursue further work to refine the methodologies associated with emission credits. The meeting agreed to include consequential changes agreement in the relevant section of the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values". The meeting agreed that during the pilot phase of CORSIA, and until additional requirements and guidance have been developed to (a) ensure that emission credits for SAF generated under CORSIA are of an equivalent quality to emission units and (b) resolve concerns regarding double counting, after the subtraction of the LEC and/or REC applicable to a SAF, the total LSf value cannot be smaller than 0 gCO2e/MJ.

9.5.6 From the ensuing discussion, the meeting agreed with the recommendation for the ICAO document "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes".

Recommendation 9/2 – ICAO Document "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes" referenced in Annex 16, Volume IV

That the material in Appendix D to the report of this agenda item, be included as the ICAO document "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes", for publication.

9.6 COMPUTATION OF ALTERNATIVE FUELS LAND USE CHANGE EMISSIONS FOR USE IN THE GMBM MRV (TASK S.01)

9.6.1 The AFTF co-Rapporteurs presented the results of ILUC emissions calculated from SAF produced in varied world regions. The ILUC modelling relies on economic models that are structurally based on a consequential approach to life cycle assessment. The two global models used by AFTF are GTAP-BIO, a publicly available computable general equilibrium model from Purdue University, and GLOBIOM, a constrained optimization partial equilibrium model from the International Institute for Applied System Analysis (IIASA). ILUC analysis was performed for feedstocks and pathways from four regions: US, Brazil, EU, and Malaysia/Indonesia. AFTF recommended the use of regional values because the characteristics underlying ILUC values vary significantly by region. The AFTF co-Rapporteurs recommended language to describe how interested parties could seek the development of ILUC values by CAEP.

9.6.2 The AFTF co-Rapporteurs also presented an approach for SCS to determine if a feedstock can be classified as "low LUC risk", but noted that this approach should be provisional and used only during the pilot phase of CORSIA, such that SCS have sufficient time to test it.

9.6.3 A Member expressed the preference to the use of GTAP-BIO as the single model for ILUC calculations under CORSIA, while agreeing with the compromise proposal brought forward by AFTF. The Member also considered that regional ILUC values should be used, since they lead to more accurate estimation of the ILUC emissions for a SAF pathway in a region. This Member also supported the process for adding new default life cycle values under CORSIA, but highlighted that additional information should be provided to define the process and what constitutes the criterion on data adequacy from a region.

9.6.4 An Observer commented that the low LUC risk methodology presented by AFTF requires substantial improvements to ensure that it generates real and measurable net improvements in biomass production, and proposed changes to address that. The Observer presented views on ILUC values and suggested averaging the two separate ILUC emission factors estimated using each model to avoid dropping valuable information and prevent uncertain GHG emissions reduction claims. The Observer also recommended not changing the risk-based ILUC approach to grant modelled negative ILUC values to feedstocks.

Discussions and Conclusions

9.6.5 In regard to ILUC values and methodologies, and specifically the development of regional ILUC values, some Members questioned the definition of "regional" and pointed out that a single "region" as currently included in the work of AFTF can include diverse land types. The AFTF co-Rapporteurs noted that a more precise definition of "region" can be considered as future work.

9.6.6 The Advanced Biofuels Association (ABFA) expressed their concerns about using more than one model to develop one default ILUC value, considering that such a process could delay agreement on a value. A Member replied that they support the use of two models, as it ensures quality of the approach, the data and the results.

9.6.7 Responding to a question, the AFTF co-Rapporteurs clarified that the risk associated with grandfathering of low LUC practices during the pilot phase of CORSIA is very small, considering that current SAF production volumes are small. ABFA supported grandfathering, stating that there are some projects under development that are anticipating future benefits.

9.6.8 Regarding the provisional approach for low LUC methodologies, the meeting agreed to the criteria and methodology provided for the purpose of determining which practices and land uses would qualify for the yield increase and unused land approaches, as a provisional approach for the pilot phase of CORSIA, during which time the SCS would have time to test the approaches.

9.6.9 After considering the conflicting views of the meeting on the timeframe for low ILUC designation and other outstanding issues, the meeting agreed on the section "Low LUC Risk Practices", including the sections "Yield Increase Approach" and "Unused Land Approach", as included in Appendix F to the report of this agenda item.

9.6.10 Noting the concerns of some Members about double counting and permanence, the meeting agreed that negative ILUC values represent modelled benefits of carbon storage that would occur with certain feedstocks. The meeting agreed that, during the pilot phase of CORSIA, negative ILUC values will be provisionally allowed to obtain a negative LSf. A decision on whether to continue allowing negative LSf values, due to reductions from negative ILUC, will be made by the end of the pilot phase. The meeting agreed to include this wording in the ICAO document "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels."

9.6.11 The meeting agreed that a recommendation to Council on allowing negative LSf, which result from negative ILUC values, will be based on the results of the work on accounting for double counting and on permanence of the carbon reductions associated with the life cycle emissions reductions associated with negative ILUC values. This recommendation will be provided by CAEP/12. There will not be grandfathering of negative LSf values due to reductions from negative ILUC.

9.6.12 The meeting noted a Member's preference for GTAP-BIO as the single model, more openly/widely used, and less costly option for determining ILUC values for inclusion in CORSIA. The meeting endorsed the agreement on the default ILUC emission intensity calculation based on results from both GTAP-BIO and GLOBIOM. As a result, the meeting agreed to include the ILUC values proposed by AFTF in the ICAO document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels". The meeting noted the methodology used by AFTF to model default ILUC LCA values for SAF in CORSIA and agreed to include the details of the methodology as a section of the "LCA Methodology" CORSIA supporting document.

9.6.13 From the ensuing discussion, the meeting agreed with the recommendation for the ICAO document "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels"

Recommendation 9/3 –ICAO Document "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels," referenced in Annex 16, Volume IV

That the material in Appendix E to the report on this Agenda Item be included as the ICAO Document "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels," for publication.

9.6.14 From the ensuing discussion, the meeting agreed with the recommendation for the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values".

Recommendation 9/4 – ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values," referenced in Annex 16, Volume IV

That the material in Appendix F to the report of this Agenda Item, be included as the ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values", for publication.

9.6.15 Regarding the process for adding new default life cycle values, the meeting agreed with the proposed text for the section "Adding New Default Life Cycle Values," in the "LCA Methodology" supporting document, with the inclusion of a correction pointed out by a Member that AFTF (or its successor body) will agree on the model simulation results.

9.6.16 From the ensuing discussion, the meeting agreed with the recommendation for the CORSIA supporting document "CORSIA Eligible Fuels – LCA Methodology ".

Recommendation 9/5 – CORSIA Supporting Document "CORSIA Eligible Fuels – LCA Methodology"

That the CORSIA supporting document entitled "CORSIA Eligible Fuels – LCA Methodology," be published as indicated in the Report of AFTF.

9.7 GUIDANCE ON POTENTIAL POLICIES (TASK S.04)

9.7.1 The AFTF co-Rapporteurs presented the results of the AFTF's work on examining existing policy instruments that are intended to incentivize deployment of SAF, as well as barriers, disincentive mechanisms, or policy externalities, to help identify "potential policies" which have been demonstrated to be feasible, effective, and practical. As a part of this work, AFTF performed a stochastic techno-economic analysis (TEA) of a number of SAF pathways. The AFTF co-Rapporteurs presented the purpose and methods of this analysis, described the limitations of the analysis, and presented the preliminary results. Feedback was requested on whether a policy analysis task should be kept in the CAEP future work programme to provide further guidance material as result of the analysis.

9.7.2 A Member welcomed this work and proposed that the results be presented in a format that could be made available to all ICAO Member States, including those outside CAEP, as a supporting tool for policy makers. One Member expressed his support for the TEA and his desire for this analysis to be of a larger scope in the future and to encompass all the types of fuel under CORSIA, and expressed the desire of his country to support this study in the future.

9.7.3 Two Members presented an overview of their shared desire to set national sustainable fuel targets to achieve a balanced compromise through dialogue between States and industry, which promotes the deployment of SAF without detriment to the air transport industry's competitiveness, with a target of incorporating 2 per cent SAF in 2025.

9.7.4 CAEP noted the initiatives taken by these Members, and many additional Members and Observers provided overviews of their own initiatives and policy considerations. The CAEP Secretary reminded the meeting of the upcoming first ICAO Stocktaking Seminar toward the 2050 Vision for Sustainable Aviation Fuels, to be held in Montreal, Canada from 30 April to 1 May 2019, as this event will provide Members and Observers the opportunity to provide further information about their SAF projects.

9.7.5 Several Members and Observers commented on the challenging nature of achieving 2 per cent SAF use in 2025, and the lack of feasibility studies to support this achievement, while others highlighted the importance of developing a global policy in order to provide more certainty to SAF producers. The meeting acknowledged the concept of regulator-industry "balanced compromise" as a means to establish national SAF supply objectives. The meeting noted the views of the two Members that presented the paper that achieving a 2 per cent use of SAF in 2025, according to each national circumstance, can be a reasonable policy objective to promote SAF in line with the 2050 ICAO Vision for Sustainable Aviation Fuels endorsed by CAAF/2. An Observer expressed the view that while regulator-industry dialogue is critical to establish policies that support the development of SAF, more discussion would be needed in CAEP before the concept of "balanced compromise" can be acknowledged.

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APPENDIX A
(English only)

REPORT ON SUSTAINABILITY THEMES, PRINCIPLES AND CRITERIA FOR SUSTAINABLE AVIATION FUELS

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EXECUTIVE SUMMARY

The ICAO Council's adoption of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Standards and Recommended Practices (SARPs) in 2018 established the requirement that both sustainable aviation fuels and lower carbon aviation fuels need to comply with a set of Sustainability Criteria to be eligible to reduce offsetting obligations under the Scheme.

The First ICAO International Conference on Aviation and Alternative Fuels (CAAF, Rio de Janeiro 2009) recognized the need for a common definition of sustainability requirements at the international level.

The ICAO Assembly, at its 38th session (2013), acknowledged the need for sustainable aviation fuels to be developed and deployed in an economically feasible, socially and environmentally acceptable manner and the need for increased harmonization of the approaches to sustainability.

The 39th Assembly requested States to recognize existing approaches to assess sustainability, which should achieve net GHG emissions reduction, contribute to local social and economic development; competition with food and water should be avoided.

In addition, the Second ICAO International Conference on Aviation and Alternative Fuels (CAAF/2, Mexico City, 2017) recognized that the sustainability of alternative aviation fuels is of essential importance to the efforts of international civil aviation to reduce its CO_2 emissions, and that this is ensured by application of sustainability criteria to aviation fuels.

Considering these agreements from the Assembly, the Committee on Aviation Environmental Protection (CAEP) developed a list of 12 Sustainability Principles and Themes with 17 associated Criteria that should be met for a sustainable aviation fuel to generate carbon offset reductions under CORSIA. This list was agreed by CAEP on its 2017 Steering Group meeting (Montreal, Canada, 11 to 15 September 2017), and covers the three aspects of sustainability acknowledged by the ICAO Assembly (environmental, social and economic). CAEP also agreed to the inclusion of specific guidance for assessing compliance with the socio-economic themes (8 to 12), aiming to address concerns of national sovereignty, as well as to address aspects that are beyond the fuel producer control.

This report provides the rationale underlying the CAEP recommendation. For that, a detailed comparison is done with the main approaches in place worldwide to assess sustainability. This analysis supports the conclusion that the list of Sustainability Themes, Principles and Criteria recommended by CAEP builds on existing approaches or combination of approaches to sustainability, including work developed by other UN bodies, fulfilling the ICAO Assembly directive of ensuring the sustainability of aviation fuels.

Consideration of Sustainability Criteria in different approaches

	EXISTING APPROACHES TO SUSTAINABILITY									
	FAO SAFA	GBEP	ISO	EU RED	ISPO	RFS2	Bonsucro	ISCC	RSB	RSPO
3.1 Water Quality	x	x	x	x	x	x	x	x	x	x
3.2 Water Use	x	x	x	x	x	x	x	x	x	x
4.1 Soil Health	x	x	x	x	x	x	x	x	x	x
5.1 Air Pollution	x	x	x	x	x	x	x	x	x	x
6.1 Conservation – Use of Protected Areas	x	x	x	x	x	x	x	x	x	x
6.2 Conservation – Invasive Feedstocks	x	x		x		x		x	x	
6.3 Conservation – Effects on Protected Areas	x	x	x	x	x	x	x	x	x	x
7.1 Waste and Chemicals - Use and Disposal	x	x	x	x	x		x	x	x	x
7.2 Waste and Chemicals – Pesticide Use	x				x	x	x	x	x	x
8.1 Human and Labour Rights	x	x	x	x	x		x	x	x	x
9.1 Land use rights and land use	x	x	x	x	x		x	x	x	x
10.1 Water use rights	x		x				x	x	x	x
11.1 Local and social development	x	x		x	x	x	x	x	x	x
12.1 Food security	x	x	x	x		x		x	x	
total criteria covered	**14**	**12**	**11**	**12**	**11**	**10**	**12**	**14**	**14**	**12**

CHAPTER 1. HISTORY OF ICAO WORK ON SUSTAINABILITY OF AVIATION FUELS

1.1 ICAO ASSEMBLY RESOLUTIONS AND CONFERENCES

The first reference to alternative fuels in ICAO Assembly Resolutions was registered in its 36th Session (2007), when the Assembly recognized the importance of research and development in fuel efficiency and alternative fuels for aviation that will enable international air transport operations with a lower environmental impact, and encouraged the Council to promote improved understanding of the potential use, and the related emissions impacts, of alternative aviation fuels.

In 2009, ICAO organized the first Conference on Aviation and Alternative Fuels (CAAF), which endorsed the use of sustainable alternative fuels for aviation, particularly the use of drop-in fuels in the short- to mid-term, as an important means of reducing aviation emissions. The Conference also recognized the need for a common definition of sustainability requirements at the international level, and declared that Member States and stakeholders “work together through ICAO and other relevant international bodies, to exchange information and best practices, and in particular to reach a common definition of sustainability requirements for alternative fuels”. It also acknowledged that the technology exists to produce substitute, sustainable fuels for aviation that take into consideration the world´s food security, energy and sustainable development needs.

These outcomes were reflected in the ICAO Assembly Resolution A37-18 (2010), which requested the Council to encourage Member States and invite industry to actively participate in further work on sustainable alternative fuels for aviation.

Building on the successful outcomes of the ICAO SUSTAF Workshop (Montréal, 18 - 20 October 2011) and on the discussions in the third meeting of the 194th Session of the ICAO Council, ICAO created the SUSTAF Expert Group in June 2012 to develop recommendations to further facilitate the global development and deployment of sustainable alternative fuels for aviation, leading up to the 38th Session of the ICAO Assembly. One of the conclusions of this expert group was that States should focus on developing and deploying sustainable alternative fuels for aviation and acknowledge the environmental, social and economic dimensions of sustainability. Similar conclusions were later included in the ICAO Assembly Resolution A38-18 (2013), as follows:

> *A38-18: Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change*
>
> *(…)*
>
> *Acknowledging the need for such fuels to be developed and deployed in an economically feasible, socially and environmentally acceptable manner and the need for increased harmonization of the approaches to sustainability;*
>
> *(…)*
>
> *The Assembly:*
>
> *(…)*

32. Requests States to:

j) recognize existing approaches to assess the sustainability of all alternative fuels in general, including those for use in aviation which should:

i. achieve net GHG emissions reduction on a life cycle basis;

ii. respect the areas of high importance for biodiversity, conservation and benefits for people from ecosystems, in accordance with international and national regulations; and

iii. contribute to local social and economic development, and competition with food and water should be avoided;

k) adopt measures to ensure the sustainability of alternative fuels for aviation, building on existing approaches or combination of approaches, and monitor, at a national level, the sustainability of the production of alternative fuels for aviation.

Similar requests related to sustainability of aviation fuels were made by the ICAO Assembly during its 39th Session (2016).

A39-2 Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change

Recognizing that the technological feasibility of drop-in sustainable alternative fuels for aviation is proven and that the introduction of appropriate policies and incentives to create a long-term market perspective is required;

Acknowledging the need for such fuels to be developed and deployed in an economically feasible, socially and environmentally acceptable manner and the progress achieved in the harmonization of the approaches to sustainability;

The Assembly

32. Requests States to:

i) recognize existing approaches to assess the sustainability of all alternative fuels in general, including those for use in aviation which should achieve net GHG emissions reduction on a life cycle basis, contribute to local social and economic development; competition with food and water should be avoided; and

j) adopt measures to ensure the sustainability of alternative fuels for aviation, building on existing approaches or combination of approaches, monitor, at a national level, the sustainability of the production of alternative fuels for aviation, and work together through ICAO and other relevant international bodies, to exchange information and best practices, including for the harmonization on the sustainability criteria of aviation alternative fuels;

In 2017, ICAO organized the second Conference on Aviation and Alternative Fuels (CAAF/2), which recognized that the sustainability of alternative aviation fuels is of essential importance to the efforts of international civil aviation to reduce its CO_2 emissions, and that this is ensured by application of sustainability criteria to aviation fuels. The Conference also noted that the introduction of sustainable aviation fuels (SAF) may realize economic, social, and environmental advantages that contribute to the vision set out in 13 out of 17 of the United Nations Sustainable

Development Goals (SDGs). Details on the potential contribution of SAFs to the SDGs are available at CAAF/2-WP-12.

1.2 CAEP AND AFTF

In response to the ICAO Assembly Resolution requests, the ICAO Committee on Aviation Environmental Protection (CAEP) established the Alternative Fuels Task Force (AFTF) in 2013 to provide technical support to all aspects of ICAO work on aviation fuels, including sustainability.

During the CAEP/10 cycle (from 2013 to 2016), the CAEP-AFTF developed a scoping exercise for future work on sustainability criteria for aviation fuels[1].

Based on this scoping exercise, in the CAEP/11 cycle (2016-2019) CAEP tasked AFTF to develop recommendations on sustainability criteria for alternative fuels in the context of the recognition under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) . CAEP instructed AFTF to prioritize the development of environmental criteria first, followed by social and economic criteria at a later stage, and planned the work to build as much as possible upon existing sustainability standards and frameworks, which would be analysed and compared in order to develop recommendations for CAEP.

To develop such a task, AFTF set up the "Sustainability Task Group", composed of 72 experts[2] nominated by 11 CAEP Member States and seven international organizations.

1.3 THE CAEP APPROACH

In the development of the CAEP approach, the AFTF recommended that ICAO should rely on existing sustainability standards, whether regulatory or voluntary, for the actual sustainability demonstration of alternative fuels as long as: (1) their scope matches with the sustainability criteria agreed upon within ICAO, and (2) their effectiveness has been demonstrated, including how the standards are implemented, verified and monitored.

Certification and conformity of a product, service or system to meet certain requirements is a common approach applied to assess sustainability and recommended by the International Organization for Standardization (ISO) to promote sustainable growth.

The AFTF refers to this approach as the development of an "umbrella standard" in which a set of sustainability criteria is defined and existing regulatory or voluntary Sustainability Certification Schemes (SCS) can be recognized as a means of compliance if they cover all criteria of the "umbrella standard." Existing SCS covering only part of the "umbrella standard" criteria will require additional certification to comply with the CORSIA sustainability requirements.

Under the current CORSIA framework, SCSs interested in being recognized under CORSIA will need to be approved by the ICAO Council, after being evaluated by a "Fuels Advisory Body" to be created under the auspices of ICAO.

This "umbrella standard" approach is similar to the approach adopted by some regulatory sustainability approaches (e.g. the European Union's Renewable Energy Directive), which

[1] CAEP/10-WP/42
[2] As of 11/Jun/2018

defines sustainability criteria without specific indicators, which should be developed by the SCS. CAEP agreed to this approach at its 2016 Steering Group meeting and all of the sustainability criteria subsequently agreed to by CAEP and presented to the Council followed this approach.

1.4 CAEP RECOMMENDATION OF SUSTAINABILITY THEMES, PRINCIPLES, CRITERIA AND GUIDANCE

In the course of four meetings and 12 conference calls, AFTF developed a recommended set of 12 Sustainability Themes, Principles and Criteria to be adopted as part of CORSIA requirements for sustainable aviation fuels. To ensure that the proposed sustainably criteria are based on current best practices of sustainability certification, AFTF compared 10 existing approaches to sustainability, with various scopes and formats.

These Sustainability Themes, Principles and Criteria were adjusted by CAEP during its 2017 Steering Group meeting, which also agreed on specific guidance to the application of the socio-economic criteria. With regards to Themes 8, 9 and 10, the guidance aims to address concerns of national sovereignty related to the compliance with these themes. Additionally, the agreed guidance recognizes that Themes 11 and 12 are largely beyond the economic operator’s control, and ensures that compliance with them is granted exclusively on the basis of requiring the economic operator to report actions being taken to meet the related criteria, without further judgement of those actions by the SCS.

These recommendations were presented to the ICAO Council during its 212th Session (November, 2017) for consideration, as provided in **Table 1**. The detailed list of documents presented in CAEP to develop these recommendations is provided in Appendix C.

It is important to note that these recommendations from CAEP did not consider the concept of “CORSIA lower carbon aviation fuels” adopted by the ICAO Council during its 214th Session (June 2018). Further work will be conducted by CAEP to assess the suitability of these sustainability Themes, Principles and Criteria for the “CORSIA eligible fuels” (including “CORSIA lower carbon aviation fuels”), in line with the Council request for CAEP to develop further proposals, at the latest by the end of the pilot phase, on strengthened Sustainability Criteria, including Themes 1 and 2, specifically applicable to CORSIA eligible fuels (C-DEC214/10, 2 i).

Table 1 - Sustainability Themes, Principles, Criteria and Guidance recommended by CAEP during its 2017 Steering Group Meeting

Theme	Principle	Criteria
1. Greenhouse Gases (GHG)	Principle: Sustainable alternative jet fuel should generate lower carbon emissions than conventional kerosene on a life cycle basis.	Criterion 1: Sustainable alternative jet fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to fossil jet fuel on a life cycle basis.
2 Carbon stock	Principle: Sustainable alternative jet fuel should not be made from biomass obtained from land with high carbon stock.	Criterion 1: Sustainable alternative jet fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest~~s~~, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.
		Criterion 2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.
3. Water	Principle: Production of sustainable alternative jet fuel should maintain or enhance water quality and availability.	Criterion 1: Operational practices shall be implemented to maintain or enhance water quality.
		Criterion 2: Operational practices shall be implemented to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities.
4. Soil	Principle: Production of sustainable alternative jet fuels should maintain or enhance soil health.	Criterion 1: Agricultural and forestry best management practices for feedstock production or residue collection shall be implemented to maintain or enhance soil health, such as physical, chemical and biological conditions.
5. Air	Principle: Production of sustainable alternative jet fuel should minimize negative effects on air quality.	Criterion 1: Air pollution emissions shall be limited.
6. Conservation	Principle: Production of sustainable alternative jet fuel should maintain or enhance biodiversity, conservation and ecosystem services.	Criterion 1: Sustainable alternative jet fuel shall not be made from biomass obtained from areas that are protected for their biodiversity, conservation value, or ecosystem services unless evidence is provided that shows the activity does not interfere with the protection purposes.
		Criterion 2: Low invasive-risk feedstock shall be selected for cultivation and appropriate controls shall be adopted with the intention of preventing the uncontrolled spread of cultivated non-native species and modified microorganisms
		Criterion 3: Operational practices shall be implemented to avoid adverse effects on areas that are protected for their biodiversity, conservation value, or ecosystem services.
7. Waste and Chemicals	Principle: Production of sustainable alternative jet fuel should promote responsible management of waste and use of chemicals.	Criterion 1: Operational practices shall be implemented to ensure that waste arising from production processes as well as chemicals used are stored, handled and disposed of responsibly.
		Criterion 2: Operational practices shall be implemented to limit or reduce pesticide use.
8. Human and labour rights	Principle: Production of sustainable alternative jet fuel should respect human and labour rights.	Criterion 1: Sustainable alternative jet fuel production shall respect human and labour rights.
9. Land use rights and land use	Principle: Production of sustainable alternative jet fuel should respect land rights and land use rights including indigenous and/or customary rights.	Criterion 1: Sustainable alternative jet fuel production shall respect existing land rights and land use rights including indigenous peoples' rights, both formal and informal.
10. Water use rights	Principle: Production of sustainable alternative jet fuel should respect prior formal or customary water use rights.	Criterion 1: Sustainable alternative jet fuel production shall respect the existing water use rights of local and indigenous communities.
11. Local and social development	Principle: Production of sustainable alternative jet fuel should contribute to social and economic development in regions of poverty.	Criterion 1: Sustainable alternative jet fuel production shall strive to, in regions of poverty, improve the socioeconomic conditions of the communities affected by the operation.
12. Food security	Principle: Production of sustainable alternative jet fuel should promote food security in food insecure regions.	Criterion 1: Sustainable alternative jet fuel production shall, in food insecure regions, strive to enhance the local food security of directly affected stakeholders.

Guidance on the application of sustainability criteria

Compliance with Themes 11 and 12 is granted exclusively on the basis of requiring the economic operator to report actions being taken to meet the related criteria, without further judgement of those actions by the Sustainability Certification Scheme (SCS).

A national attestation of compliance with Themes 8, 9 and 10, and the related criteria, is considered sufficient, and precludes any assessment of those criteria by the SCS.

CHAPTER 2. EXISTING APPROACHES TO SUSTAINABILITY

2.1 TYPES OF APPROACHES

Ten approaches to sustainability were considered for the development of the 12 CAEP Sustainability Themes and Criteria. They can be grouped as follows:

- **Internationally agreed sustainability approaches**

This category encompasses approaches that were agreed by international forums. However, differently from CORSIA, these approaches do not include a framework for enforcing compliance with their criteria. They include.

- Food and Agriculture Organization Sustainability Assessment Of Food And Agriculture Systems) (FAO SAFA) (2013) – This approach was developed by the FAO to be an international reference for assessing trade-offs and synergies between all dimensions of sustainability. The target audience of a SAFA assessment is economic operators and stakeholders that participate in crop, livestock, forestry, aquaculture and fishery value chains. However, SAFA is also relevant to governments' strategies, policy and planning.
- Global Bioenergy Partnership (GBEP) (2011) - developed by 23 countries and 15 international organizations and institutions including nine UN agencies, the GBEP indicators are intended to provide policy-makers and other stakeholders a set of analytical tools that can inform on the development of national bioenergy policies and programmes and monitor the impact of these policies and programmes. That is, GBEP assessments are meant to be applied at a State or regional level, not at the economic-operator-level required by CORSIA.
- ISO 13065 - Sustainability criteria for bioenergy (2015). The purpose of this International Standard is to provide a framework for considering environmental, social and economic aspects that can be used to facilitate the evaluation and comparability of bioenergy production and products, supply chains and applications. It does not provide threshold values, which can be defined by economic operators and/or other organizations (e.g. governments). Other standards, certification initiatives and government agencies can use this International Standard as a reference for how to provide information regarding sustainability.

- **Regulatory sustainability approaches**

Sustainability approaches adopted at a national level for the sustainability assessment of economic operators. In the case of the EU RED and United States RFS, these regulatory approaches include requirements not only for the economic operators, but also reporting requirements by the responsible governmental agencies. The compliance verification is either done directly by the respective governments (e.g. ISPO) or by third-parties duly recognized to perform such verification (EU RED and US RFS). These approaches are:

- European Union's Renewable Energy Directive (RED) (2009)
- Indonesian Sustainable Palm Oil (ISPO) (2015)

- United States' Renewable Fuel Standard (RFS) Program (2017)

- **Voluntary global sustainability certification schemes**

Certification schemes that are voluntarily adopted by economic operators to certify the sustainability of their products. They include frameworks for verification of compliance, as well as indicators and, in some instances, thresholds.

- Bonsucro (2016)
- International Sustainability and Carbon Certification (ISCC) (2016)
- Roundtable on Sustainable Biomaterials (RSB) (2016)
- Roundtable on Sustainable Palm Oil (RSPO) (2013)

2.2 STRUCTURE OF SUSTAINABILITY APPROACHES

Most of the sustainability approaches considered by CAEP are formatted with three layers of information: Principles, Criteria, and Indicators. These terms are defined by the ISO 13065 as follows:

> ***Principle*** *— aspirational goal that governs decisions or behavior*
>
> ***Criterion*** *— requirement that describes what is to be assessed.*
>
> > *Note 1: A criterion adds meaning and operability to a principle without itself being a direct measure of performance.*
> >
> > *Note 2: A criterion is characterized by a set of related indicators.*
>
> ***Indicator*** *— quantitative, qualitative or binary variable that can be measured or described, in response to a defined criterion.*

Some of the sustainability approaches also include specific guidance on the application of the indicators.

Table 2 provides a summary of these elements in the different sustainability approaches.

Table 2 - Summary of Sustainability Themes, Principles and Indicators in different approaches

Sustainability Approach	Reference document date	Principles	Criteria	Indicators	Guidance provided?	Target audience
CAEP	2017	12	17	0	YES	Economic Operators
FAO SAFA	2013	16	44	116	YES	Economic Operators, States
GBEP	2011	24**	0	46***	YES	States and Regional Organizations
ISO	2015	12	18	62	YES	Government, other standard-setting organizations
EU RED	2009	0*	23	8	NO	Economic operators, government agencies
ISPO	2015	7	45	131	YES	Economic operators
RFS2	2017	0*	15	0	NO	Economic operators, government agencies
BONSUCRO	2016	6	19	55	YES	Economic operators
ISCC	2016	6	96	255	YES	Economic operators
RSB	2016	12	39	156	YES	Economic operators
RSPO	2013	8	46	140	YES	Economic operators

*The EU RED and RFS2 do not explicitly reference sustainability principles or indicators.

**GBEP is based on 24 Indicators that are expressed similarly to the CAEP principles

*** As defined in the GBEP "Indicator Descriptions"

It should be noted that, while being informative, the number of principles, criteria and indicators does not necessarily represent the comprehensiveness of a specific sustainability approach, since the same topic may be covered differently by the different sustainability approaches. For example, CAEP Principle 3 (Water) covers two GBEP Principles (5 – Water use and Efficiency, and 6 – Water Quality).

More details on each of these sustainability approaches are provided in Appendix A.

CHAPTER 3. COMPARATIVE ASSESSMENT OF SUSTAINABILITY APPROACHES

3.1 METHODOLOGY USED

Sustainability aspects are considered in different ways by the existing sustainability approaches, due to their different scopes, objectives, and structures. To overcome those differences, the adherence of the Sustainability Approaches to the Sustainability Themes, Principles and Criteria recommended by CAEP was done in a qualitative manner. This qualitative assessment was performed by identifying which elements of the existing Sustainability Approaches are associated with the Themes, Principles and Criteria recommended by CAEP. In some cases, this methodology required the comparison of elements with different scopes and objectives, for example where there are elements that are included as part of the approach as responsibilities of the implementing organization (e.g., government agency), but are not explicit criteria for economic operator qualification. .

The main objective of such a qualitative assessment is to demonstrate that the list of Sustainability Themes, Principles and Criteria recommended by CAEP builds on existing approaches or combination of approaches to sustainability, including work developed by other UN bodies, fulfilling the ICAO Assembly directive of ensuring the sustainability of aviation fuels. It should not be interpreted as a recommendation or endorsement of any particular sustainability approach for the purposes of CORSIA: the current CORSIA framework includes an approval process by the ICAO Council for SCSs to be recognized under CORSIA. This process will include a detailed assessment of the SCSs by a dedicated ICAO body.

The results of this qualitative assessment are provided in this chapter. More detailed background underlying the assessment is provided in Appendix B.

3.2 ASSESSMENT OF SUSTAINABILITY PRINCIPLES

Table 3 provides an overall assessment of the inclusion of the Principles from the analyzed sustainability approaches, and the 12 Principles recommended by CAEP.

Table 3 - Comparison of Sustainability Principles coverage

	EXISTING APPROACHES TO SUSTAINABILITY									
CAEP-proposed principles	FAO SAFA	GBEP	ISO	EU RED	ISPO	RFS2	Bonsucro	ISCC	RSB	RSPO
3. Water	X	X	X	X	X	X	X	X	X	X
4. Soil	X	X	X	X	X	X	X	X	X	X
5. Air	X	X	X	X	X	X	X	X	X	X
6. Conservation	X	X	X	X	X	X	X	X	X	X
7. Waste and Chemicals	X	X	X	X	X	X	X	X	X	X
8. Human and labour rights	X	X	X	X	X		X	X	X	X
9. Land use rights and land us	X	X	X	X	X		X	X	X	X
10. Water use rights	X		X				X	X	X	X
11. Local and social developm	X	X		X	X	X	X	X	X	X
12. Food security	X	X	X	X		X		X	X	
total principles covered	**10**	**9**	**9**	**9**	**8**	**7**	**9**	**10**	**10**	**9**

3.3 ASSESSMENT OF SUSTAINABILITY CRITERIA

Table 4 provides an overall assessment of the Criteria from the analyzed sustainability approaches, and the 17 Criteria recommended by CAEP.

A detailed assessment of the wording of the different Criteria and detailed references are provided in Appendix B.

Table 4 - Comparison of Sustainability Criteria coverage

	EXISTING APPROACHES TO SUSTAINABILITY									
	FAO SAFA	GBEP	ISO	EU RED	ISPO	RFS2	Bonsucro	ISCC	RSB	RSPO
3.1 Water Quality	x	x	x	x	x	x	x	x	x	x
3.2 Water Use	x	x	x	x	x	x	x	x	x	x
4.1 Soil Health	x	x	x	x	x	x	x	x	x	x
5.1 Air Pollution	x	x	x	x	x	x	x	x	x	x
6.1 Conservation – Use of Protected Areas	x	x	x	x	x	x	x	x	x	x
6.2 Conservation – Invasive Feedstocks	x	x		x		x		x	x	
6.3 Conservation – Effects on Protected Areas	x	x	x	x	x	x	x	x	x	x
7.1 Waste and Chemicals - Use and Disposal	x	x	x	x	x		x	x	x	x
7.2 Waste and Chemicals – Pesticide Use	x				x	x	x	x	x	x
8.1 Human and Labour Rights	x	x	x	x	x		x	x	x	x
9.1 Land use rights and land use	x	x	x	x	x		x	x	x	x
10.1 Water use rights	x		x				x	x	x	x
11.1 Local and social development	x	x		x	x	x	x	x	x	x
12.1 Food security	x	x	x	x		x		x	x	
total criteria covered	**14**	**12**	**11**	**12**	**11**	**10**	**12**	**14**	**14**	**12**

CHAPTER 4. CONCLUSIONS

The need for a common definition of sustainability requirements at the international level applicable to alternative fuels has been an ICAO concern and request since the potential of those fuels to reduce international aviation effects on climate change was identified.

ICAO Assembly resolutions have called to ensure the sustainability of alternative fuels for aviation, and for the harmonization of approaches to sustainability building up on existing approaches or combination of approaches,

In addition to achieving net GHG emissions reductions, the 38th and 39th Assemblies agreed that to be sustainable, aviation alternative fuels should also contribute to local social and economic development, and that competition with food and water should be avoided.

The adoption of ICAO CORSIA SARPs in 2018 established the need to define Sustainability Criteria for the specific purpose of CORSIA compliance for certain fuels to be eligible under the Scheme to reduce offsetting obligations.

Considering these agreements from the Assembly and ICAO Conferences, the Committee on Aviation Environmental Protection (CAEP) developed a list of 12 Sustainability Themes and Principles, and 17 associated Criteria that should be met for an aviation fuel to generate carbon offset reductions under CORSIA. This list was agreed by CAEP during its 2017 Steering Group meeting (Montreal, Canada, 11 to 15 September 2017), and only considered sustainable aviation fuels.

The analysis presented in this report supports the conclusion that the list of 12 Sustainability Themes and Principles, and the 17 associated Criteria recommended by CAEP builds on existing global approaches or combination of approaches to Sustainability, including work developed by other UN bodies, which comprises:

- ✓ Internationally-agreed sustainability approaches developed by: the UN FAO, the Global Bioenergy Partnership (which comprises 52 countries and 28 international organizations including 9 UN bodies) and the International Organization for Standardization (ISO).
- ✓ Regulatory sustainability approaches developed by the EU, Indonesia, and the United States.
- ✓ Voluntary global sustainability certification schemes currently widely used in bioenergy production.

A comparative analysis of the sustainability themes, principles and criteria included on those global approaches show that the recommended list of 12 Sustainability Themes and Principles, and the 17 associated Criteria, for the purpose of its application in CORSIA, fulfil the ICAO Assembly directive of ensuring the sustainability of aviation fuels while building upon a combination of existing global approaches to sustainability. As part of the CORSIA framework, an approval of the ICAO Council is required for the recognition of any sustainability approach under CORSIA.

APPENDIX A – SUSTAINABILITY APPROACHES CONSIDERED BY CAEP

A.1 FAO SAFA

SAFA is a holistic global framework developed by the FAO (Food and Agriculture Organization of the United Nations) for the assessment of sustainability along food and agriculture value chains. SAFA establishes an international reference for assessing trade-offs and synergies between all dimensions of sustainability. It has been prepared so that enterprises, whether companies or small-scale producers, involved with the production, processing, distribution and marketing of goods have a clear understanding of the constituent components of sustainability and how strength, weakness and progress could be tackled. By providing a transparent and aggregated framework for assessing sustainability, SAFA seeks to harmonize sustainability approaches within the food value chain, as well as furthering good practices.

The SAFA provide the protocol for assessing sustainability along 21 themes and 58 sub-themes, and 118 default indicators, which are applicable at the macro level – meaning to all enterprise sizes and types, and in all contexts. Specific guidelines are also provided, together with a computational tool and mobile app that assist users in their implementation.

Reference: http://www.fao.org/nr/sustainability/sustainability-assessments-safa/en/

A.2 GBEP (FAO)

The Global Bioenergy Partnership (GBEP) was created in 2006 with the mission to promote the wider production and use of modern bioenergy, particularly in the developing world where traditional use of biomass is prevalent. GBEP includes 23 Partner countries and 15 Partner international organizations and institutions (9 UN bodies among them), along with 29 countries and 13 international organizations that participate as Observers. It is supported by the GBEP Secretariat, hosted at FAO Headquarters in Rome.

In 2011, GBEP published the first edition of "The Global Bioenergy Partnership Sustainability Indicators for Bioenergy". This report includes 24 sustainability indicators for bioenergy and their methodology sheets, which were intended to provide policy-makers and other stakeholders with a tool that can inform on the development of national bioenergy policies and programmes, monitor the impact of these policies and programmes, as well as interpret and respond to the environmental, social and economic impacts of their bioenergy production and use.

It should be highlighted that GBEP indicators are value-neutral, do not feature directions, thresholds or limits and do not constitute a standard, nor are they legally binding. The "GBEP indicators" can be correlated with the "Principles" and "Indicators" from other sustainability approaches. These indicators are intended to inform on policy-making and facilitate the sustainable development of bioenergy.

Although being considered by CAEP, especially for the identification of themes, it should be noted that the GBEP approach is not in line with the CAEP needs for sustainability certification, since its scope is just to evaluate State´s bioenergy policies, and not specific project-scale performance.

References: http://www.fao.org/docrep/016/i2668e/i2668e.pdf

http://www.globalbioenergy.org/programmeofwork/task-force-on-sustainability/gbep-report-on-sustainability-indicators-for-bioenergy/pt/

A.3 ISO 13065

The International Organization for Standardization (ISO) was officially established in 1947 in order to "facilitate the international coordination and unification of industrial standards". The 22,236 International Standards published by ISO to date cover various aspects of technology and manufacturing. As of 2018, ISO includes 783 technical committees and subcommittees, made up of members from 160 States. The organization is supported by the ISO Central Secretariat, based in Geneva, Switzerland.

In 2015, ISO published the first edition of "ISO 13065: Sustainability criteria for bioenergy". This standard includes general requirements and recommendations, 12 sustainability Principles with associated Criteria and Indicators, and informative guidance related to several of the indicators. This Standard provides a framework for considering environmental, social and economic factors, and can be used to evaluate bioenergy production and products, supply chains, and applications. The Standard indicates that it was developed with due consideration to existing relevant sustainability initiatives and International Standards.

Reference: https://www.iso.org/standard/52528.html

A.4 EU RED

The European Union's Renewable Energy Directive (RED) was established by the European Parliament and the Council of the European Union in 2009. This Directive established a policy for the production and promotion of renewable energy throughout the EU. The EU RED mandated that 20% of the EU's total energy needs are to be met with renewables by 2020, and established individual targets for each EU member state. It also mandated that 10% of each EU member state's transport fuels must come from renewable sources by 2020.

The EU RED includes requirements related to 8 of the CAEP-proposed sustainability criteria. These requirements can be found in Article 17, "Sustainability criteria for biofuels and bioliquids" and Article 18, "Verification of compliance with the sustainability criteria for biofuels and bioliquids".

References: https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

A.5 ISPO

The Indonesian Sustainable Palm Oil (ISPO) policy was established by the Government of Indonesia in the interest of improving the competitiveness of Indonesian palm oil in the global market, while reducing greenhouse gas emissions. The most recent version of the policy was published in 2015. It includes five separate annexes that detail the regulations relevant for various types of producers and manufacturers. The Annexes used for comparison within this document were Annex II, III and IV which apply to plantation companies and mills, while annexes V and VI apply to smallholders. As the regulation is published in the Indonesian language, for the purpose of this work a courtesy translated version provided by the Government was used.

References: http://www.ispo-org.or.id/index.php?lang=en

A.6 US RFS2

The United States' Renewable Fuel Standard (RFS) Program was created by the U.S. Congress in an effort to reduce greenhouse gas emissions while encouraging the development of renewable fuels. The RFS was first created under the Energy Policy Act of 2005. It was largely amended by the Energy Independence and Security Act of 2007 (RFS2). The RFS is implemented by the Environmental Protection Agency (US EPA) in cooperation with the Department of Agriculture and the Department of Energy. The RFS mandates a "volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil or jet fuel". Fuel pathways (based on feedstock, production process, and fuel type) are approved for RFS inclusion based on GHG intensity, as well as other sustainability criteria. The applicable regulations are found at 40 CFR Part 80, Subpart M.

References: https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard

A.7 BONSUCRO

Bonsucro is a global multi-stakeholder non-for-profit initiative that provides voluntary sustainability certification for the sugarcane industry. The Bonsucro Production Standard can be applied worldwide to any sugarcane mill and their suppliers. It was first established in 2005 and has since grown to include over 480 members, representing 25% of land used for sugarcane production. The organization is supported by the Bonsucro Secretariat, based in London, England.

The most recent version of the Bonsucro Production Standard is Version 4.2, published in 2016. This version included updates that align Bonsucro with the requirements of EU RED, and covers three pillars of sustainability: economic, social and environmental viability. The document defines "a set of principles, criteria and indicators, along with explanatory notes, for the assessment of the performance of operators against the three pillars of sustainability". It was developed alongside a document titled "Guidance for the Bonsucro Production Standard" which provides further support for compliance with the Bonsucro Production Standard.

References: https://www.bonsucro.com/what-is-bonsucro/

http://www.bonsucro.com/wp-content/uploads/2017/04/Bonsucro-PS-STD-English-2.pdf

A.8 ISCC

The International Sustainability and Carbon Certification (ISCC) is an independent multi-stakeholder organisation providing sustainability certification for various raw materials and products around the world. The ISCC certification system is applicable to entire supply chains, including all feedstock types. The ISCC Association (ISCC e.V.), the governing body of the ISCC, is based in Cologne, Germany.

The ISCC requirements used for comparison with the CAEP-proposed sustainability criteria are those within ISCC Plus. ISCC Plus includes sets of sustainability add-ons, which can be implemented on top of the requirements set in the standard. The latest version of ISCC Plus is ISCC202, "Sustainability Requirements for the Production of Biomass," published in 2016. These requirements include 6 overarching sustainability principles and corresponding detailed criteria for the production of sustainable biomass.

References: https://www.iscc-system.org/about/governance-and-transparency/

https://www.iscc-system.org/process/audit-and-certification-process/iscc-system-documents/

A.9 RSB

The Roundtable on Sustainable Biomaterials (RSB) is an independent multi-stakeholder coalition providing sustainability certification around the world. The RSB has members from 60 organizations, including businesses, NGOs, academics, government and UN organisations. The RSB is supported by its Secretariat, based in Geneva, Switzerland.

The most recent version of the RSB's Principles and Criteria (Version 3.0) was published in 2016. The document includes the RSB's 12 overarching principles for sustainability, which are further elaborated into specific criteria and minimum requirements (e.g. indicators). The RSB has also published a series of standards, procedures and guidance documents, to complement the Principles & Criteria. Together, these documents represent the RSB Standard.

References: https://rsb.org/about/what-we-do/the-rsb-principles/

http://rsb.org/wp-content/uploads/2017/04/RSB-STD-01-001_Principles_and_Criteria-DIGITAL.pdf

A.10 RSPO

The Roundtable on Sustainable Palm Oil (RSPO) is a not-for-profit organization that includes stakeholders from the entire palm oil supply chain. It was formally established in 2004, and has since grown to include over 3,000 members worldwide. RSPO aims to promote the production and use of sustainably derived palm oil. As of 2017, over 19% of the world's palm oil production was certified by the RSPO. The RSPO is supported by the RSPO Secretariat, headquartered in Kuala Lumpur, Malaysia.

The RSPO requirements used for comparison with the CAEP-proposed sustainability criteria are those within RSPO P&C 2013, "Audit Checklist for assessing compliance". This standard includes 8 overarching sustainability principles, which are further elaborated into a series of criteria and indicators. Each indicator has a set of questions included as a checklist, and some indicators include additional guidance information.

References: https://rspo.org/about

https://rspo.org/about/who-we-are

https://www.rspo.org/key-documents/certification/rspo-principles-and-criteria#

APPENDIX B – QUALITATIVE ASSESSMENT OF SUSTAINABILITY CRITERIA

Note. The material contained in Appendix B, "Qualitative Assessment of Sustainability Criteria", of Appendix A, "Report on Sustainability Themes, Principles and Criteria for Sustainable Aviation Fuels," to the CAEP/11 Report on Agenda Item 9, is available at the following link:

http://www.icao.int/environmental-protection/Documents/CAEP11_assessment_of_sustainability_criteria.pdf

APPENDIX C – CAEP REFERENCES

CAEP-AFTF References	
Reference	**Title**
CAEP/11-AFTF/1-WP/03	Task S.5: Sustainability Criteria
CAEP/11-AFTF/1-IP/05	CAEP/10 Scoping Study for Future Work on Sustainability Criteria for Alternative Fuels
CAEP/11-AFTF/1-IP/10	Alternative Jet Fuel Environmental Sustainability Overview
CAEP/11-AFTF/1-IP/15	Supply and Sustainability of Carbon Credits and Alternative Fuels for International Aviation (2020-2035)
CAEP/11-AFTF/1-IP/16	ICSA'S Views on the Work of the Alternative Fuels Task Force
CAEP/11-AFTF/1-IP/18	Extract from CAEP/10 Report
CAEP/10-AFTF/04-FL/08	Sustainability criteria for alternative aviation fuels under the GMBM Scoping study
CAEP/11-AFTF/1-Report	Report of the First Meeting
CAEP/11-AFTF/2-WP/04	Report of the Sustainability Task Group
CAEP/11-AFTF/2-IP/02	Process for Confirming LCA and Sustainability of Alternative Fuels
CAEP/11-AFTF/2-FL/11	AFTF Task S5 Sustainability
CAEP/11-AFTF/2-Report	Report of the Second Meeting
CAEP/11-AFTF/3-WP/06 - Presentation	AFTF Sustainability Task Group WP/6 - Presentation
CAEP/11-AFTF/3-WP/06	Report of the Sustainability Task Group
CAEP/11-AFTF/3-WP/06 – Appendix B	Sustainability Criteria for Alternative Aviation Fuels
CAEP/11-AFTF/3-WP/07 - Presentation	Sustainability Criteria Tracking
CAEP/11-AFTF/3-WP/07	Sustainability Criteria Tracking
CAEP/11-AFTF/3-FL/01	Environmental Themes Principles and Criteria
CAEP/11-AFTF/3-FL/06	Sustainability Criteria for Alternative Aviation Fuels
CAEP/11-AFTF/3-FL/08	Framework for Treating Sustainability Under CORSIA
CAEP/11-AFTF/3-Report	Report of the third Meeting
CAEP/11-AFTF/4-WP/07 - Presentation	Report of the Sustainability Task Group - Presentation
CAEP/11-AFTF/4-WP/07	Report of the Sustainability Task Group
CAEP/11-AFTF/4-WP/08 -	ICAO Sustainability Standard Eligibility Process - Presentation

Presentation	
CAEP/11-AFTF/4-WP/08 rev1	ICAO Sustainability Standard Eligibility Process
CAEP/11-AFTF/4-IP/08 - Presentation	Risk Based Verification of the Protection of No Go Areas for the Production of Sustainable Alternative Jet-Fuels - Presentation
CAEP/11-AFTF/4-IP/08	Risk Based Verification of the Protection of No Go Areas for the Production of Sustainable Alternative Jet-Fuels
CAEP/11-AFTF/04-FL07	Sustainability Criteria Status after AFTF04
CAEP-SG/20153-WP/28	Methodology for the Assessment of Life Cycle Emissions from Alternative Jet Fuels for use in the Global Market Based Measure System
CAEP-SG/20153-WP/48	Further Assessment of Alternative Fuels in a Global Market-Based Measure (MBM)
CAEP-SG/20153-SD/4	Summary of Discussions and Decisions of the Fourth Meeting of the Steering Group
CAEP-SG/20161-WP/21	Report of the Sustainability Task Group
CAEP-SG/20161-SD/3	Summary of Discussions and Decisions of the Third Meeting of the Steering Group
CAEP-SG/20172-WP/6	ICAO CORSIA Package
CAEP-SG/20172-WP/13	Sustainability Themes, Principles and Criteria for Alternative Fuels Under CORSIA
CAEP-SG/20172-SD/2	CAEPSG.20172.SD.2 Agenda Item 4 SD sections (AFTF)
CAEP/9-IP/6	Sustainable Alternative Fuels for Aviation
CAEP/10-WP/42	Scoping Study for Future Work on Sustainability Criteria for Alternative Fuels

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APPENDIX B
(English only)

ICAO DOCUMENT

CORSIA SUSTAINABILITY CRITERIA FOR CORSIA ELIGIBLE FUELS

Theme	Principle	Criteria
1. Greenhouse Gases (GHG)	Principle: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis.	Criterion 1: CORSIA eligible fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2. Carbon stock	Principle: CORSIA eligible fuel should not be made from biomass obtained from land with high carbon stock.	Criterion 1: CORSIA eligible fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.
		Criterion 2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.

2.1 Guidance on the application of sustainability criteria

a) *Compliance with Themes 1 and 2 is granted on the basis of independent attestation by CORSIA approved Sustainability Certification Schemes;*
b) *Work on other themes such as Water; Soil; Air; Conservation; Waste and Chemicals; Human and labour rights; Land use rights and land use; Water use rights; Local and social development; and Food security, and related criteria, and on the application of these criteria, is ongoing under the Committee on Aviation Environmental Protection (CAEP) and will be subject to approval by the Council by the end of the pilot phase;*
c) *CORSIA Sustainability Criteria for CORSIA Eligible Fuels does not set a precedent for, or prejudge the outcome of negotiations in other fora.*

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APPENDIX C

(English only)

PROPOSED TERMS OF REFERENCE FOR THE CAEP SCS EVALUATION GROUP (SCSEG)

1. MANDATE

1.1 The SCSEG is a subgroup of CAEP mandated with developing technical recommendations to the Council on the eligibility of Sustainability Certification Schemes (SCS).

2. TASKS

2.1 In fulfilling this mandate, the CAEP SCSEG is tasked to:

1) undertake the evaluation of Sustainability Certification Schemes (SCS) against the eligibility requirements listed in the ICAO document "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes";

2) develop technical recommendations based on the above evaluation of SCS applicants for submission to the Council;

3) ensure that SCS around the world can receive advance notice of, and are given ample time to apply for, the evaluation by CAEP SCSEG, and conduct outreach as necessary, with the support of the ICAO Secretariat;

4) collect additional information from SCS and/or economic operators and issue guidance to the SCSs, as required;

5) monitor the compliance of the SCS contained in the ICAO document "CORSIA Approved Sustainability Certification Schemes" with the "CORSIA Eligibility Framework and Requirements for SCSs", and make technical recommendations to Council to decide on the continuity of the SCSs being on the list of eligible SCS;

6) ensure SCS eligibility is re-assessed at least every five years; and

7) raise any technical issues to CAEP for consideration, including issues related to the ICAO document "CORSIA Eligibility Framework and Requirements for SCS".

3. GOVERNANCE STRUCTURE

3.1 The SCSEG subject administrative to guidance from CAEP and members are nominated by CAEP Members.

3.2 SCSEG Members are invited to observe the deliberations of CAEP and the CAEP Fuels Task Group (CAEP FTG) but the SCSEG technical work is independent of these bodies.

3.3 The SCSEG's technical recommendations on the eligibility of SCS are contained in a report that is sent to CAEP Members and CAEP Observers who will have 30 days to provide comments on the report prior to the report being forwarded to the Council by CAEP. These comments from CAEP Members and CAEP Observers are reported by CAEP to the Council alongside the report of the CAEP SCSEG.

3.4 Evaluations and reports from the SCSEG following the procedure described above and subsequent reporting to the Council could occur at any time during the CAEP cycle without the need of a formal CAEP meeting.

4. EXPERTISE AND EXPERIENCE REQUIREMENTS

4.1 In order for the CAEP SCSEG to undertake the tasks as outlined in paragraph 2 above, SCSEG members are required to meet at least two of the following five technical expertise and experience requirements, which have to be substantiated at the time of nomination:

a) experience in the development or deployment of fuels for aviation which could fall under the definition of sustainable fuels or lower carbon fuels;

b) experience in the design, development, operation or evaluation of SCS;

c) experience in the development, assessment, or implementation of international standards relevant to aviation fuel, sustainability certification, or sustainable development;

d) experience in fossil-based fuels, biomass, biofuel and/or agriculture value chain sustainability assessments and requirements; and

e) experience in the development, assessment, or oversight of climate change policies and/or sustainable development policies.

4.2 In addition, it would be desirable (though not essential) that CAEP SCSEG members have experience with ICAO processes, in particular those related to CORSIA.

4.3 The collective membership of the CAEP SCSEG should cover all of the areas of expertise provided in Section 4.1.

5. MEMBERSHIP

Nomination of CAEP SCSEG members

5.1 In principle, the size of the SCSEG should be in the order of 14 to 16 experts, nominated by CAEP Members, taking into account the need for balanced geographical representation.

5.2 Nomination is to be made through the submission of a letter (or an email) to the CAEP Secretary, highlighting the areas of expertise and experience of the proposed expert, including a personal conflict of interest declaration and a statement of commitment by the proposed expert to the work of CAEP SCSEG for at least one full CORSIA compliance cycle (i.e., 3 years). Nominations would be considered for approval by CAEP.

Selection of Co-Chairpersons for CAEP SCSEG

5.3 The CAEP SCSEG selects two co-Chairpersons from among its members at its first meeting.

5.4 The co-Chairpersons should not be from the same geographical region.

Replacement of CAEP SCSEG Members during a CORSIA compliance cycle

5.5 The replacement of an existing CAEP SCSEG Member during a compliance cycle of the CORSIA is allowed, if the replacement member is approved by CAEP (through correspondence).

5.6 The replacement must meet the same criteria as outlined in the TOR.

5.7 The outgoing member's nominating CAEP Member should first be allowed to nominate a replacement.

5.7.1 If a replacement is not nominated by that CAEP Member or should CAEP reject the nominated replacement, the CAEP Secretary would then seek nominations from CAEP Members of the outgoing member's geographic region.

5.7.2 If a replacement is not nominated by CAEP Members from that geographical region or should CAEP reject the nominated replacement(s), the CAEP Secretary would then seek nominations from all CAEP Members.

5.7.3 Where possible, the replacement of CAEP SCSEG Members should be staggered over CORSIA compliance cycles to ensure continuity of knowledge and expertise.

6. AVOIDANCE OF CONFLICTS OF INTEREST

6.1 As a part of the nomination process, SCSEG nominees will have to present a personal declaration about potential conflicts of interest assessed/validated by the proposing CAEP Member. SCSEG Members should not benefit materially from decisions made by the SCSEG. This could include employment by or having financial and/or commercial interest in any SCS or an economic actor along the fuel supply chain that would benefit from the expert's appointment. This has to be substantiated at the time of nomination, through a personal declaration.

7. WORKING METHODS

Modality and frequency of SCSEG meetings

7.1 Face-to-face meetings of the CAEP SCSEG are the primary means of organizing its work, making significant decisions and resolving substantive issues.

7.2 The CAEP SCSEG is also expected to conduct business via teleconferences and emails between the face-to-face meetings to progress the work.

7.3 The CAEP SCSEG will discuss and agree on a schedule of meetings, which can be reviewed later as necessary. The number of meetings should be sufficient to achieve its deliverables.

7.4 If changes to the meeting schedule or additional meetings are required, the co-Chairpersons will, after consultations with CAEP SCSEG Members, give notice of any changes in the meeting schedule and/or additional meetings.

Quorum for CAEP SCSEG recommendations

7.5 A majority of CAEP SCSEG Members from at least three geographical regions must be present at its meeting in order to constitute a quorum to make technical recommendations.

Working language for CAEP SCSEG meetings

7.6 The working language of the CAEP SCSEG is English. The recommendations of CAEP SCSEG are translated in all six languages, for consideration by the Council.

Decision process of CAEP SCSEG

7.7 The SCSEG's technical recommendations, including the underlining decisions by the SCSEG, are taken by consensus. If there is no consensus, then the prevailing and alternative conclusions will be described and substantiated, and presented to the Council for decision.

8. PUBLIC INFORMATION, TRANSPARENCY AND COMMUNICATION

8.1 Applications and other information submitted by SCSs will be publicly available on the ICAO CORSIA website, except for materials, which the applicants designate as business confidential.

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APPENDIX D
(English only)

ICAO DOCUMENT

CORSIA ELIGIBILITY FRAMEWORK AND REQUIREMENTS FOR SUSTAINABILITY CERTIFICATION SCHEMES

1. Definitions:

Accreditation bodies: authoritative bodies that perform accreditation (ISO 17011).

Accreditation: a third-party attestation related to a certification body conveying formal demonstration of its competence to carry out specific conformity assessment tasks (adapted from ISO 17011).

Auditors: Auditors plan, conduct and complete audits on behalf of the certification body. Responsibilities include designing risk-based audit and evidence-gathering plans, designing sampling procedures, evaluating the adequacy and sufficiency of evidence of compliance, identifying nonconformities, issuing a recommendation for or against certification and preparing an audit report.

Audits: systematic, independent and documented processes for obtaining audit evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled (adapted from ISO 19011:2011).

Certification bodies: third-party conformity assessment bodies (ISO 17065:2012) making certification decisions and issuing certificates.

Economic operator: Economic operators include feedstock producers, processing facilities, and traders.

Stakeholder: individual or group that has an interest in any decision or activity of an organization (adapted from ISO 26000).

Sustainability Certification Schemes (SCS): organizations that certify economic operators against the sustainability criteria, and ensure that economic operators calculate actual life cycle emissions values (if default values are not applied) using the agreed methodology. SCS define sustainability certification requirements, set requirements for certification bodies, auditors and accreditation bodies, and monitor effectiveness of the assurance mechanism.

2. Eligibility requirements.

SCS meets the requirements specified in Table 1.

Table 1: Requirements for SCS

#	THEME	REQUIREMENT
1)	Documentation management	• SCS has a documentation management system that addresses each of the following elements: o General management system documentation for the SCS CORSIA certification programme (e.g. policies, roles/responsibilities within SCS, etc.). o Control of documents. o Control of records. o Management review of management system. • SCS keeps records for a minimum of 10 years.
2)	Audit competencies	• The SCS documentation describes in sufficient detail the specific audit competencies requirements and how it is ensured that the requirements concerning auditors' competencies (see Table 5, Requirement 6) are met.
3)	SCS Group auditing requirements (where applicable)	• Where the SCS permits group auditing, SCS establishes requirements and provides guidance to certification bodies on: o Risk-based sampling of units within a group audit, including minimum sample size (see Table 5, Requirement 5) and the threshold for non-compliance. o Group management. o Process and conditions to join a group.
4)	Non-compliance with certification requirements	• SCS has documented procedures for addressing when a certified economic operator is found to not comply with the certification requirements. This includes: o Procedures for withdrawing or suspending certificates and the circumstances under which this occurs. o Procedures to ensure that any non-conformities that do not lead to immediate withdrawal or suspension of the certificate are corrected. • SCS makes these procedures available to economic operators.
5)	Monitoring and system review	• SCS has procedures and timelines for reviewing its CORSIA certification programme, including compliance of economic operators, certification bodies and accreditation bodies with the provisions of the programme, to ensure its continuing integrity, adequacy, and effectiveness. • Review of the CORSIA certification programme occurs at planned intervals and after significant changes to the CORSIA requirements as specified by ICAO, as well as in response to complaints received, where necessary. • SCS uses the results of the review to improve its assurance programme where indicated and maintains records of any corrective actions taken.

6)	Transparency	• SCS ensures that the following information is made publicly available on a website: ○ The list of economic operators that are certified under its CORSIA certification programme, including the start and expiry dates of each certificate, and those who no longer participate. Information on the withdrawal or suspension of certificates must be published without delay after the decision has been made. ○ The latest version of SCS CORSIA certification programme requirements. ○ The list of certification bodies that are permitted to conduct audits within the CORSIA certification programme, as well as any certification bodies that are no longer permitted to conduct audits within the programme and those that are temporarily suspended. ○ Publication of contact details for the SCS CORSIA certification programme e.g. telephone number, email address and correspondence address. ○ The names of any other eligible SCS that the subject SCS recognizes within its CORSIA certification programme.
7)	Annual reports	• Recognized SCS submits annually a report to ICAO that includes relevant information • SCS has a procedure in place to collect the information required to fulfil this reporting obligation. • SCS records detailed information about the calculation of actual values within their system and provide this information to ICAO on request, in line with the ICAO document entitled, “CORSIA Methodology for Calculating Actual Life Cycle Emissions Values”.
8)	Risk Management Plan	• SCS has a documented plan for addressing the risks to the integrity of the assurance system.
9)	Accreditation of certification bodies	• SCS uses an accreditation body complying with ISO 17011 to ensure that certification body requirements listed herein are implemented by the certification bodies. • SCS periodically assesses the effectiveness of the accreditation mechanism as part of their system review. • SCS has procedures in place that ensure that the accreditation body has the following competencies: o Knowledge of the 5 ICAO documents that compose the CORSIA Implementation Elements related to CORSIA eligible fuels and the SCS CORSIA certification programme requirements. o Competence to review sampling protocols and practice, where this is undertaken by the Certification Body. o Competence to review assessment of groups under group auditing procedures, where this is permitted by the SCS and undertaken by the Certification Body.
10)	Stakeholder Engagement	• SCS has a process for incorporating stakeholder input relevant to the CORSIA sustainability criteria and adequate to the scope and scale of the operation.
11)	Complaint procedure	• SCS has a documented complaints procedure to respond to complaints received from clients, the public and other stakeholders about its CORSIA certification programme and fraud or potential fraud. • SCS has procedures in place for: o Investigating and responding to relevant complaints, including reporting relevant information, to the oversight body or certification body, as appropriate and in a timely manner. o Reviewing the assurance system and taking corrective actions where necessary (see

		Table 1, Requirement 5). o Documenting all complaints received and actions taken for consideration in the system review. • SCS has procedures in place for responding to requests for information from the ICAO Fuels Advisory Body.
12)	Transparency on GHG reporting and accounting	• SCS will provide any information required by the relevant national authority related to GHG reporting.

SCS ensures that economic operators meet the general requirements specified in Table 2.

Table 2: General requirements set by SCS on Economic Operators

	THEME	REQUIREMENTS
1)	Documentation management	• SCS requires that economic operators: i) have an auditable documentation management system for the evidence related to the claims they make or rely on for certification; ii) keep records for a minimum of 5 years; and iii) accept responsibility for preparing any information related to the auditing of such evidence.
2)	Transparency on other SCS participation by economic operators	• SCS requires all economic operators to declare the names of all SCS under which they are and/or were certified and make available to the auditors all information relevant to those certifications.

3)	CORSIA certification requirements	• SCS requires the economic operator to demonstrate and document that it satisfies all CORSIA requirements specific to the economic operator stated herein, including the following which form the basis for audit objectives:
		o The fuel under review satisfies the CORSIA sustainability criteria specified [ICAO Document "CORSIA Sustainability Criteria for CORSIA Eligible Fuels"].
		o (where applicable) The default GHG LCA value applied by the economic operator matches the value and associated feedstock and conversion process (pathway) specified by ICAO in the ICAO Document "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels".
		o (where applicable) The system of the economic operator to calculate GHG emissions for an actual LCA value ensures that:
		  o The CORSIA LCA methodology specified in the ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values" is accurately followed to calculate its actual LCA value.
		  o The LCA value calculation is complete, accurate and transparent.
		o (where applicable) The actual LCA value calculated by the economic operator is accurate and has been calculated in accordance with the CORSIA LCA methodology specified in the ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values" using the most recent data available.
		o (where applicable) The emissions credits used to calculate the actual LCA value by the economic operator are accurate, have been calculated in accordance with the relevant CORSIA emissions credit methodology or methodologies, and satisfy all other requirements for emissions crediting, as specified in the ICAO document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values",

		Section 6. o In the case of waste or residue feedstocks, the material meets the definition for waste or residues specified by ICAO for CORSIA and can be traced back to the first gathering point [ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values", Section 4]. o In the case of by-products, the material meets the definition for by-products specified by ICAO for CORSIA and can be traced back to the point of origin [ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values" , Section 4]. o In the case of low LUC risk feedstocks, the feedstocks and / or land use practices meet the criteria specified by ICAO for CORSIA [ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values", Section 5].

SCS ensures that economic operators meet the traceability requirements specified in Table 3.

Table 3: Traceability requirements set by SCS on Economic Operators

	THEME	REQUIREMENTS
1)	Traceability: Mass balance	• SCS requires economic operators to use a mass balance system that: a) Allows batches of sustainable materials with differing sustainability characteristics to be mixed. b) Requires information about the sustainability characteristics and sizes of the physical quantity (batches) referred to in point (a) to remain assigned to the mixture. c) Provides for the sum of all consignments withdrawn from the mixture to be described as having the same sustainability characteristics, in the same quantities, as the sum of all consignments added to the mixture. d) Demonstrates that the product claims are linked correctly to the feedstock quantities claimed.
2)	Traceability: Mass balance system documentation	• SCS requires each economic operator to include, as part of its documentation management system (see Table 2, Requirement 1), a system for documenting the mass balance. • SCS requires the economic operator to assign a unique reference/identification number to each batch of certified product sold (also known as batch number).
3)	Traceability: Mass balance level of operation	• SCS requires economic operators to operate the mass balance system at a site level. • SCS requires that if more than one legal entity operates on a site then each legal entity that is an economic operator is required to operate its own mass balance.
4)	Traceability: Mass balance timeframe	• SCS requires the economic operator to monitor the balance of material withdrawn from and added to the mass balance system. • SCS requires economic operators to specify a timeframe over which they will ensure that the mass balance is respected. o The operator ensures that the balance is achieved over an appropriate period of time no longer than three months. A deficit is not allowed at the end of the period. • At the end of the reporting period, a positive balance can be forwarded to the next reporting period as long as an equivalent physical stock is available.

SCS ensures that economic operators meet the information transmission requirements specified in Table 4.

Table 4: Information Transmission requirements set by SCS on Economic Operators

	THEME	REQUIREMENT
1)	Transmission of information in the supply chain	• SCS requires the economic operator to transmit relevant information necessary to demonstrate compliance with the CORSIA sustainability criteria throughout the supply chain. The information transmitted includes all of the relevant reporting elements listed in Annex 16. Volume IV, Appendix 5, Table A5-2 for which the economic operator has information. The information is related to a specific physical quantity of material.

SCS ensures that certification bodies meet the requirements specified in Table 5.

Table 5: Requirements set by SCS on Certification Bodies

	THEME	REQUIREMENTS
1)	Accreditation and Auditing Standards	• SCS requires certification bodies to be accredited to ISO standard 17065 by an accreditation body operating in compliance with ISO 17011. • SCS requires that certification bodies are accredited in accordance with Table 1, Requirement 9. • SCS requires certification bodies to inform the SCS immediately if the accreditation is suspended, withdrawn or terminated by the accreditation body. • SCS requires that certification bodies conduct assessments of GHG LCA values in line with ISO 14064-3. • SCS requires that certification bodies conduct audits in line with ISO 19011.
2)	Audits	• The SCS requires that certification bodies being recognized within its CORSIA certification programme, apply the audit objectives to meet CORSIA certification requirements (Table 2, Requirement 3) . • Initial audits should be performed on-site. • SCS may permit remote audits by the certification body under the following conditions: ○ The audit risk as assessed by the certification body is low. ○ The same level of assurance can be achieved with remote audits as with on-site audits. ○ Sufficient traceability (mass balance) records, greenhouse gas data and other forms of appropriate evidence are available. ○ The systems in place for collecting and processing traceability and greenhouse gas data and ensuring data quality are reliable. • It is the responsibility of the certification body to define the size of the sample of mass balance or GHG data to audit in consideration of the audit risk and the required level of assurance (see Table 5, Requirement 7).
3)	Transfer from one SCS to another	• Prior to re-certification of an economic operator that was previously found to be in major non-conformity with any other SCS, the certification body will be required to bring this to the attention of the SCS.

4)	Certificate Issuance	• The SCS requires that certification bodies issue a certificate to an economic operator only after a positive certification decision is reached confirming that the requirements of the SCS CORSIA certification programme have been satisfied.
5)	Group auditing (where applicable)	• Group auditing of economic operators by the certification body is permitted under the following conditions: ○ For the following economic operators: producers of raw material, points of origin in the case of waste and residue supply chains, and warehouses or storage facilities under common management. ○ When confirming compliance with the CORSIA sustainability criteria when the areas concerned are near each other and have similar characteristics. ○ For the purpose of assessing the accuracy of the claimed LCA value when the units have similar production systems and products. ○ A sample of at least the square root of the number of group members is audited individually annually or, for wastes and residues, using a risk-based sampling approach providing the same level of assurance. ○ Self-declarations from economic operators are not accepted by the certification body as sufficient evidence to replace audits supporting a group claim. • A group value for actual GHG LCA would be permitted as long as the SCS sets the guidelines for how this should be determined. • If the conditions for group auditing are not fulfilled, economic operators are audited individually.
6)	Auditor competencies	• SCS requires that certification bodies appoint competent auditor(s), in accordance with the process set out in ISO 19011. • The auditor(s) as a whole, and the independent reviewer, demonstrates knowledge and appropriate necessary skills to conduct audits under the CORSIA eligible fuels framework, in accordance with the audit scope, including: ○ Knowledge of the requirements of the SCS CORSIA certification programme and the ICAO CORSIA Implementation Elements related to CORSIA eligible fuels. ○ Knowledge of and experience with CORSIA or similar sustainability criteria, mass balance systems, traceability, GHG LCA calculations, and data collection and handling. ○ Knowledge of and experience with appropriate sectors (e.g., agriculture, engineering, etc.).
7)	Establishment of a level of assurance	• SCS requires the certification body to conduct all audits to a “reasonable assurance level.” • SCS requires the certification body to apply a materiality threshold of 5% for traceability (volume of sustainable material sold as compliant) and actual GHG LCA value calculations.

Referenced ISO standards

ISO/IEC 17065 Conformity assessment — Requirements for bodies certifying products, processes and services
ISO 19011 Guidelines for auditing management systems
ISO 14064-3 Specification with guidance for the validation and verification of greenhouse gas assertions
ISO/IEC 17011 Conformity assessment — Requirements for accreditation bodies accrediting conformity assessment bodies
NOTE: The most recent version of the standards apply.

3. Eligibility framework.

The approval of SCS will be exclusively carried out centrally by the ICAO Council with the technical assistance of CAEP, which will assess the compliance of the SCS with the eligibility requirements listed in this ICAO Document. Only the SCS that meet all the eligibility requirements will be included in the list of approved SCS.

In case the scope of the certification scheme is limited to part of the CEF supply chain (or specific feedstocks or conversion processes), the assessment mechanism and potential recognition will only apply to the scope of the certification scheme.

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APPENDIX E
(English only)

ICAO DOCUMENT

CORSIA DEFAULT LIFE CYCLE EMISSIONS VALUES FOR CORSIA ELIGIBLE FUELS

1. Acronyms

ATJ = Alcohol-to-jet
CO_2e = Carbon dioxide equivalent
FT = Fischer-Tropsch
HEFA = Hydroprocessed esters and fatty acids
ILUC = Induced land use change
LCA = Life cycle assessment
LS_f = Life cycle emissions factor for a CORSIA Eligible fuel in gCO_2/MJ
MSW = Municipal Solid Waste
NBC = Non-biogenic carbon
SIP = Synthetic iso-paraffin

2. CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels

Fuel Conversion Process	Region	Fuel Feedstock	Core LCA Value	ILUC LCA Value	LS_f (gCO_2e/MJ)
Fischer-Tropsch (FT)	Global	Agricultural residues	7.7	0.0	7.7
	Global	Forestry residues	8.3		8.3
	Global	Municipal solid waste (MSW), 0% non-biogenic carbon (NBC)	5.2		5.2
	Global	Municipal solid waste (MSW) (NBC given as a percentage of the non-biogenic carbon content)	NBC*170.5 + 5.2		NBC*170.5 + 5.2
	USA	Poplar (short-rotation woody crops)	12.2	-5.2	7.0
	USA	Miscanthus (herbaceous energy crops)	10.4	-32.9	-22.5
	EU	Miscanthus (herbaceous energy crops)	10.4	-22.0	-11.6
	USA	Switchgrass (herbaceous energy crops)	10.4	-3.8	6.6
Hydroprocessed esters and fatty acids (HEFA)	Global	Tallow	22.5	0.0	22.5
	Global	Used cooking oil	13.9		13.9
	Global	Palm fatty acid distillate	20.7		20.7
	Global	Corn oil (from dry mill ethanol plant)	17.2		17.2
	USA	Soybean oil	40.4	24.5	64.9
	Brazil	Soybean oil	40.4	27.0	67.4
	EU	Rapeseed oil	47.4	24.1	71.5
	Malaysia & Indonesia	Palm oil – closed pond	37.4	39.1	76.5
	Malaysia & Indonesia	Palm oil – open pond	60.0	39.1	99.1
Alcohol (isobutanol) to jet (ATJ)	Global	Agricultural residues	29.3	0.0	29.3
	Global	Forestry residues	23.8		23.8
	Brazil	Sugarcane	24.0	7.3	31.3
	USA	Corn grain	55.8	22.1	77.9
	USA	Miscanthus (herbaceous energy crops)	43.4	-54.1	-10.7
	EU	Miscanthus (herbaceous energy crops)	43.4	-31.0	12.4
	USA	Switchgrass (herbaceous energy crops)	43.4	-14.5	28.9
Alcohol (ethanol) to jet (ATJ)	Brazil	Sugarcane	24.1	8.7	32.8
	USA	Corn grain	65.7	25.1	90.8
Synthesized iso-paraffins (SIP)	Brazil	Sugarcane	32.8	11.3	44.1
	EU	Sugar beet	32.4	20.2	52.6

NOTE: The "LCA Methodology Supporting Document" describes the methodologies used by ICAO to calculate these Default Life Cycle Emissions Values, as well as the process for requesting the inclusion of a new conversion process, feedstock, and/or region on this table.

During the pilot phase, negative ILUC values, as shown above, will be provisionally allowed to obtain a negative LS_f. A decision on whether to continue allowing negative LS_f values, due to reductions from negative ILUC, will be made by the end of the pilot phase.

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APPENDIX F
(English only)

ICAO DOCUMENT

CORSIA METHODOLOGY FOR CALCULATING ACTUAL LIFE CYCLE EMISSIONS VALUES

1. Acronyms

CO_2 = Carbon dioxide
CO_2e = Carbon dioxide equivalent
CEF = CORSIA eligible fuel. A CORSIA sustainable aviation fuel or a CORSIA lower carbon aviation fuel, which an operator may use to reduce their offsetting requirements
CH_4 = Methane
GHG = Greenhouse gas
ILUC = Induced land use change
LCA = Life cycle assessment
LEC = Landfill Emissions Credit
LS_f = Life cycle emissions factor for a CORSIA Eligible fuel in gCO_2/MJ
MSW = Municipal Solid Waste
N_2O = Nitrous oxide
REC = Recycling Emissions Credit
SCS = Sustainability Certification Scheme

2. **CORSIA Methodology for Calculating Actual Life Cycle Emissions Values**

An Aeroplane Operator seeking benefits from the use of CEF in terms of reductions in CORSIA CO_2 offsetting requirements will have to provide documentation to their State on the life cycle emissions values (LS_f) and sustainability. An Aeroplane Operator will need to work with an CEF supplier to obtain this information.

1. An Aeroplane Operator may use an actual core life cycle value – described in paragraphs 3 and 6 – as part of an accepted fuel sustainability certification process if a fuel producer can demonstrate lower core life cycle emissions compared to the default core life cycle values provided in the ICAO Document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels", or if a fuel producer has defined a new pathway that does not have a default core life cycle value. If the Aeroplane Operator chooses to use an actual core life cycle value, then the Aeroplane Operator shall select an eligible Sustainability Certification Scheme from the ICAO Document entitled "CORSIA Approved Sustainability Certification Schemes" to ensure the analysis is in accordance to the LCA methodology defined below. The results of the actual core life cycle value analysis shall be added to the appropriate ILUC value from the ICAO Document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels" to calculate the total Life Cycle Emissions Value (LS_f). The SCS shall ensure that the methodology has been applied correctly and that relevant information on GHG emissions is transmitted through the chain of custody. SCS shall record detailed information about the calculation of actual values within their system and provide this information to ICAO on request.

2. If a fuel was produced from a feedstock that is defined as a waste, residue, or by-product according to Section 4, then the actual core LCA value shall be the total LS_f. If the feedstock is not a waste, residue, or by-product, then a default core LCA value and an ILUC value will need to be added to the ICAO Document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels" before the fuel can be included in CORSIA.

   NOTE: Information on how fuels can be added to the ICAO Document entitled "CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels can be found in the "LCA Methodology Supporting Document".

3. The system boundary of the core LCA value calculation shall include the full supply chain of CEF production and use. As such, emissions associated with the following life cycle stages of the CEF supply chain must be accounted for: (1) production at source (e.g., feedstock cultivation); (2) conditioning at source (e.g., feedstock harvesting, collection, and recovery); (3) feedstock processing and extraction; (4) feedstock transportation to processing and fuel production facilities; (5) feedstock-to-fuel conversion processes; (6) fuel transportation and distribution to the blend point; and (7) fuel combustion in an aircraft engine.

4. For life cycle stages 1-6 described in Paragraph 3, carbon dioxide equivalent (CO_2e) emissions of CH_4, N_2O and non-biogenic CO_2 from these activities shall be calculated on the basis of 100-year global warming potential (GWP). CO_2e values for CH_4 and N_2O shall be based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (28 and 265, respectively). Only non-biogenic CO_2 emissions from fuel combustion shall be included in the calculation of CO_2e emissions.

5. The functional unit for final LS_f results shall be grams of CO_2e per megajoule of fuel produced and combusted in an aircraft engine, in terms of lower heating value (gCO_2e/MJ).

6. The calculated LS_f values shall include emissions generated during on-going operational

activities (e.g., operation of a fuel production facility, feedstock cultivation), as well as emissions associated with the material and utility inputs to operational activities, such as processing chemicals, electricity, and natural gas. Emissions generated during one-time construction or manufacturing activities (e.g., fuel production facility construction, equipment manufacturing) shall not be included.

7. In many cases, the CEF supply chain of interest will result in the co-production of multiple commodities. These co-products may include non-CEF liquid fuels, chemicals, electricity, steam, hydrogen, and/or animal feed. Energy allocation shall be used to assign emissions burdens to all co-products in proportion to their contribution to the total energy content (measured as lower heating value) of the products and co-products. CO_2e emissions shall not be allocated to waste, residues and by-products that result from the CEF supply chain of interest.

8. CEF feedstocks can be broadly categorized into three groups - primary or co-products, by-products, and wastes and residues. Further information on how feedstocks are categorized into these group for the purposes of CORSIA can be found in Section 4.

9. Feedstocks that are “low risk” for land use change have been identified and assigned as having zero emissions from land use change. The low land use change risk feedstock list includes: (1) feedstocks that do not result in expansion of global agricultural land use for their production; (2) wastes, residues, and by-products (see Section 4); and (3) feedstocks that have yields per surface unit significantly higher than terrestrial crops (~ one order of magnitude higher) such as some algal feedstocks. The feedstocks in these three categories shall all receive an ILUC value of zero in the fourth column of the table in the ICAO Document “CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels”.

10. Aeroplane Operators may choose to capture the benefits of utilizing land use change-risk mitigation practices, (e.g., land management practices) to avoid ILUC emissions as part of an accepted fuel sustainability certification process (see the ICAO Document “CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes”). Mitigation practices that avoid ILUC emissions and the requirements that shall be met to obtain these reductions can be found in Section 5. The ILUC value of zero shall be used in place of the default ILUC value to calculate total LSf. If the Aeroplane Operator chooses to claim emissions reductions from the implementation of land use change-risk mitigation practices, then the Aeroplane Operator shall select an eligible Sustainability Certification Scheme from the ICAO document “CORSIA Approved Sustainability Certification Schemes” to provide documentation that the fuel was produced using land use change-risk mitigation practices according to Section 5.

11. Waste, residue, and by-product feedstocks are assumed to incur zero emissions during the feedstock production step of the lifecycle. Emissions generated during the collection, recovery, extraction, and processing of these wastes, residues, and by-products, however, shall be included (life cycle stages 2-7 described in paragraph 3).

12. The production of SAF from wastes and residues, as defined in Section 4 (Feedstock Categories section of the CORSIA Methodology for Calculating Actual Life Cycle Emissions Values), may generate emission credits that can be subtracted from the actual LCA values to calculate total LS_f. If the Aeroplane Operator chooses to use a SAF that would generate such an emission credit, then the Aeroplane Operator shall select an eligible Sustainability Certification Scheme from the CORSIA ICAO Document “CORSIA Approved Sustainability Certification Schemes” to ensure the calculation of emission credits is in accordance with the specific methodologies

defined in this document, as follows.

- Avoided Landfill Emissions Credit (LEC) for SAF derived from Municipal Solid Waste (MSW) – Section 6.1
- Recycling Emissions Credit (REC) for SAF derived from Municipal Solid Waste (MSW) – Section 6.2

The analysis to calculate these emission credits values shall be documented in a technical report citing fully the data sources, such that the results are replicable and use the most recent data available. The technical report must also demonstrate that the emission credits claimed are permanent; directly attributable to the SAF production; exceed any emissions reductions required by law, regulation or legally binding mandate; avoid double counting (including double issuance[3] or double claiming[4]) of such credits; and exceed emissions reductions that would otherwise occur in a business-as-usual scenario.

During the pilot phase of CORSIA, and until additional requirements and guidance have been developed to (a) ensure that emission credits for SAF generated under CORSIA are of an equivalent quality and quantity to emission units and (b) resolve concerns regarding double counting, after the subtraction of the LEC and/or REC applicable to a SAF, the total LS_f value cannot be smaller than 0 gCO_{2e}/MJ.

3. Technical Report Requirements

3.1 Reporting Requirements

The SCS will require economic operators to document all relevant data appropriately in a Technical Report, which is verified by an accredited certification body. Upon request, the economic operator will submit the technical report to the SCS and on request, the SCS will submit the report to ICAO.

Relevant data include:

a) GHG emissions by life cycle step within the scope of certification, broken out by GHG emission species and aggregated in CO_2e (100 year GWP). With regard to the life cycle steps, Section 2, Paragraph 3 of the ICAO Document "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values" states: "The system boundary of the core LCA value calculation shall include the full supply chain of SAF production and use. As such, emissions associated with the following life cycle stages of the SAF supply chain must be accounted for: (1) production at source (e.g., feedstock cultivation); (2) conditioning at source (e.g., feedstock harvesting, collection, and recovery); (3) feedstock processing and extraction; (4) feedstock transportation to processing and fuel production facilities; (5) feedstock-to-fuel conversion processes; (6) fuel transportation and distribution to the blend point; and (7) fuel combustion in an aircraft engine."

b) The LCA inventory data by life cycle step within the scope of certification, including all energy and material inputs. For life cycle steps 1-4, the inventory data are to be

[3] In this instance, double issuance occurs when two or more credits or units are being issued for the same reduction.
[4] In this instance, double claiming occurs when the same unit was used by multiple entities

provided per mass of feedstock, for the other steps per total fuel energy yield (MJ of fuel).

c) Emission factors used for calculating GHG emissions associated with energy and material inputs, including information about the source for the emission factors.

d) All relevant feedstock characteristics within the scope of certification, such as, for example, agricultural yield, lower heating value, moisture content, the content of sugar, starch, cellulose, hemicellulose, lignin, vegetable oil, or any other energy carrier (as applicable to feedstock of interest).

e) Quantities for all final and intermediate products, per total energy yield.

f) If Municipal Solid Waste is being used as a feedstock, then all relevant data required for the calculation of landfill emissions credits and recycling emissions credit will be disclosed according to the MSW crediting methodology in Section 6 on "Emissions Credits."

g) In case a low LUC risk practice is being used, all relevant data required for the calculation and certification will be disclosed according to the Low LUC Risk Practices methodology.

The SCS will report evidence that the certification body has verified that the economic operator has accurately followed the methodology specified in the ICAO Document “CORSIA Methodology for Calculating Actual Life Cycle Emissions Values” to calculate its actual LCA value using the most recent and scientifically rigorous data available, and that the LCA value calculation is complete, accurate and transparent.

The SCS will report information on chain of custody system employed.

Data will be recorded and reported to ICAO upon request in a format conducive to re-calculation and verification, for example as a spreadsheet in .csv or .txt file format.

3.2 **Flow Of Information Along The Supply Chain For Actual LCA Values**

Each economic operator along the supply chain will implement a robust and transparent system to track the flow of data outlined in Section 2, Paragraph 3 of the ICAO Document “CORSIA Methodology for Calculating Actual Life Cycle Emissions Values” along the supply chain (“chain of custody system”).

Tracking will occur each time the feedstock or fuel passes through an internal processing step or changes ownership along the supply chain.

The SCS will implement procedures that allow verification that the economic operator has used an appropriate chain of custody system.

4. **Feedstock Categories**

Primary and co- products are the main products of a production process. These products have significant economic value and elastic supply, (i.e., there is evidence that there is a causal link between feedstock prices and the quantity of feedstock being produced).

By-products are secondary products with inelastic supply and economic value.

Wastes are materials with inelastic supply and no economic value. A waste is any substance or object which the holder discards or intends or is required to discard. Raw materials or substances that have been intentionally modified or contaminated to meet this definition are not covered by this definition.

Residues are secondary materials with inelastic supply and little economic value. Residues include:

a) Agricultural, aquaculture, fisheries and forestry residues: Residues directly deriving from or generated by agriculture, aquaculture, fisheries and forestry.

b) Processing residues: A substance that is not the end product that a production process directly seeks to produce; the production of the residue or substance is not the primary aim of the production process and the process has not been deliberately modified to produce it.

The positive list provided in Table 1 includes feedstocks that have been classified as by-product, wastes and residues. It has been arrived at considering a broad range of publicly-available regulatory and voluntary approaches.

The positive list is non-exhaustive. It includes materials currently in use or in discussion to be used for sustainable aviation fuel.

The classification of specific feedstocks as by-products is subject to later revisions as part of the regular CORSIA review process in case there is strong scientific evidence showing that significant indirect effects could be associated to these feedstocks.

Residues
Agricultural residues:
- Bagasse
- Cobs
- Stover
- Husks
- Manure
- Nut shells
- Stalks
- Straw
Forestry residues:
- Bark
- Branches
- Cutter shavings
- Leaves
- Needles
- Pre- commercial thinnings
- Slash
- Tree tops
Processing residues:
- Crude glycerine

-	Forestry processing residues
-	Empty palm fruit bunches
-	Palm oil mill effluent
-	Sewage sludge
-	Crude Tall Oil
-	Tall oil pitch
Wastes	
-	Municipal solid waste
-	Used cooking oil
By-products	
-	Palm Fatty Acid Distillate
-	Tallow
-	Technical corn oil

Table 1: Positive lists of materials classified as residues, wastes or by-products

The positive list is an open list. The ICAO Council can add materials to it, according to the definitions of feedstocks above and using the process shown in Figure 1 as a guide:

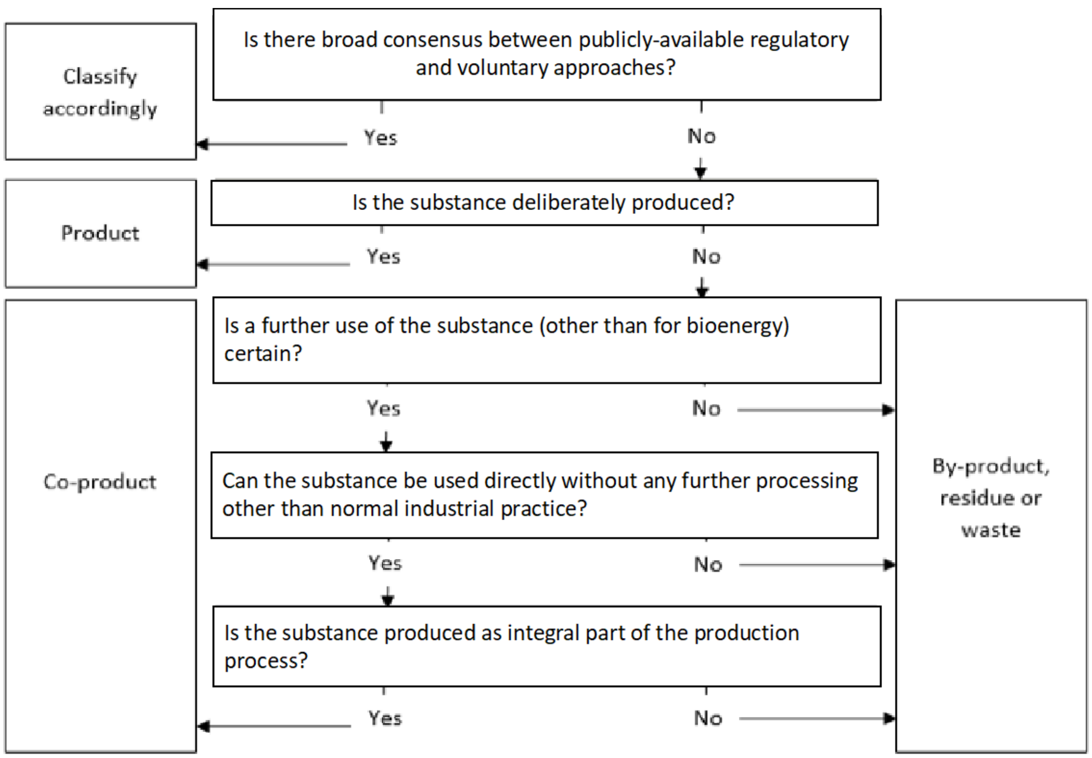

Figure 1: Guidance for inclusion of additional materials in positive list

5. **Low LUC Risk Practices**

For the purposes of CORSIA, using certain types of land, land management practices (LMP), and the incorporation of innovative agricultural practices could all be considered as contributing to low risk for land use change and therefore receive a value of zero for ILUC. The implementation of these low LUC risk practices for a project should avoid market mediated responses that lead to changes in land use, and lead to additional SAF feedstock available relative to a baseline, without increasing land requirements.

SCS with a methodology consistent with the principles and criteria listed below could be authorized by the ICAO Council to assess the implementation of low LUC risk practices and certify their low LUC risk status on a case-by-case, project-specific basis. The methodology must be open, documented, and publicly communicated. Feedstocks designated under the Low LUC Risk Practices approach during the CORSIA pilot phase are designated as such until 2030, subject to periodic audits to ensure ongoing compliance with the original requirements when the feedstocks were certified by the SCS.

In all cases, this methodology should consider that, for a specific project to be eligible for recognition as a low LUC risk practice, the practice must be verified as a net enhancement in SAF feedstock available per unit of land.

There are two approaches for low LUC risk SAF feedstock production:

a) Yield Increase Approach.

b) Unused Land Approach.

Low LUC risk practices implemented on or after 1 January 2016 could be eligible. The feedstock producer needs to provide credible and verifiable evidence of the nature of the new land management practice, timing of its implementation and level of additional feedstock production. Exceptionally, practices implemented between 1 January 2013 to 31 December 2015 may be accepted where it can be demonstrated that low LUC risk practices were implemented primarily as a result of demand for biofuels. This would have to be demonstrated on a project-specific basis.

This methodology is applicable during the pilot phase of CORSIA only.

5.1 **Yield Increase Approach**

Eligible land management practices for the yield increase approach could include, among others, sequential cropping where more than one crop is planted per year, cover crops, the use of fallow land in a prescribed crop rotation, significant post-harvest loss reduction, and significant project level productivity increases due to the introduction of good practices and technology.

The Yield Increase approach applies to any situation where feedstock producers are able to increase the amount of available feedstock out of a fixed area of land (i.e. without expanding the surface of the land). An increase in the harvested feedstock may be the result of:

a) An improvement in agricultural practices, (practices that increase yields through means such as increased organic matter content, reduced soil compaction/erosion, decreased pests, post-harvest loss reduction, etc.);

b) Intercropping, (i.e. the combination of two or more crops that grow simultaneously, for example as hedges or through an agroforestry system);

c) Sequential cropping, (i.e. the combination of two or more crops that grow at different periods of the year); and/or

d) Improvements in post-harvest losses, (i.e. losses that occur at cultivation and transport up to but not including the first conversion unit in the supply chain).

If there is a decrease of the available feedstock for the food or feed market at the project level resulting from the LMP (e.g., reduced yield from the main crop) this should be accounted for in calculating the volume of low LUC risk SAF feedstock (i.e., the volume of low LUC risk SAF feedstock represents the net increase in feedstock after accounting for any reduction in production of the primary food/feed crop that had been grown historically).

Measurements of yield increases and post-harvest loss reduction relative to a baseline are calculated based on historical practices using the annual yield per unit of land based on data from the preceding 5 years before the LMP measure takes effect from similar producers within the same region for the duration of the LMP measure. The low LUC risk feedstock thus represents additional feedstock obtained as a consequence of the improvement relative to the baseline.

The amount of additional feedstock available and considered eligible for low LUC risk feedstock is calculated as follows:

1) The average amount of feedstock available historically, from similar producers within the same region, is calculated based on actual net feedstock production (i.e., amount harvested less post- harvest losses) in the five years before the LMP measure takes effect. Similar producers can be defined as producers growing the same (or equivalent) crops and using a similar management model (e.g., smallholder, small or large scale plantation).

2) The amount of feedstock available as a consequence of the LMP is calculated based on the current/new net feedstock production (amount harvested less post-harvest losses) that is attributable to the adoption of the new LMP measure.

3) The additional low LUC risk feedstock represents the difference between the values calculated via the two previous steps.

5.2 **Unused Land Approach:**

Eligible lands for the unused land approach could include, among others, marginal lands, underused lands, unused lands, degraded pasture lands, and lands in need of remediation.

For a land to be eligible for the unused land approach, it needs to meet one of the following criteria:

a) Land was not considered to be arable land or used for crop production during the five years preceding the reference date.

b) Land is identified as severely degraded land or undergoing a severe degradation process for at least three years, according to criteria proposed by a Sustainability Certification Scheme recognized under CORSIA, where the criteria are based on scientific literature.

For a land to be eligible for the unused land approach, it also needs to have little risk for displacement of services from that land onto different and equivalent amounts of land elsewhere. *Note: services refer to products obtained from ecosystems such as food, animal feed, or bioenergy feedstocks.*

The amount of feedstock considered eligible for low LUC risk feedstock is equal to the amount of feedstock harvested for SAF production.

6. **Emissions Credits**

6.1 **Methodology for Calculation of Landfill Emissions Credits**

SAF produced from Municipal Solid Waste (MSW) feedstocks may generate an avoided Landfill Emissions Credit (LEC). The value of the LEC shall be calculated as follows:

Step 1 – Estimate the proportional shares of each of the following four waste categories (*j*) that make up the MSW diverted from landfilling: paper/textiles; wood/straw; other (non-food) organic putrescible/garden and park waste; and food waste/sewage sludge. These shares should be expressed in terms of the dry mass of each waste category (*j*) per dry mass of MSW diverted from landfilling (before additional sorting and recycling, if applicable) (eg. $W_{paper/textiles}$ = 0.4 dry tonne per dry tonne of MSW).

Step 2 – Select the degradable organic carbon content (DOC) and the fraction of carbon dissimilated (DOC_F) values from Table 2 that best represent each waste category (*j*) in the MSW. Use weighted averages to generate DOC and DOC_F values that accurately represent each of the four waste categories of the MSW feedstock of interest.

Table 2: DOC and DOC_F

Material	DOC[5] (% of dry matter)	DOC_F (%)
Corrugated containers	47%	45%
Newspaper	49%	16%
Office paper	32%	88%
Coated paper	34%	26%
Food waste	50%	84%
Grass	45%	46%
Leaves	46%	15%
Branches	49%	23%
Gypsum board	5%	45%
Dimensional lumber	49%	12%
Medium-density fiberboard	44%	16%
Wood flooring	46%	5%

Step 3 – Select the methane correction factor (MCF) from Table 3 that most accurately represents the conditions of the landfill in question.

[5] EPA, "Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM). Management Practices Chapters." 2016. EPA Office of Resource Conservation and Recovery (ORCR). https://www.epa.gov/sites/production/files/2016-03/documents/warm_v14_management_practices.pdf

Table 3: Methane correction factor (MCF)[6]

Landfill conditions	MCF
Anaerobic managed solid waste disposal site	1.0
Unmanaged solid waste disposal site – deep	0.8
Semi-aerobic managed solid waste disposal site	0.5
Unmanaged solid waste disposal site - shallow	0.4

Step 4 – Use Equation 1 to calculate total CH_4 generation, Q, from each waste category, j, per dry tonne of diverted MSW.

Equation 1: Total CH_4 generation from waste category *j*, per dry tonne of diverted MSW [g CH_4 / t dry diverted MSW]

$$Q_j = W_j \times DOC_j \times DOC_{F\_j} \times F \times MCF \times (16/12) \times 10^6$$

where:

Q_j	= total CH_4 generation over a 100-year period from waste category *j*
W_j	= dry mass of waste category *j* per dry mass of MSW diverted from landfilling [%]
DOC	= degradable organic carbon content from Table 2 [%]
DOC_F	= fraction of degradable organic carbon dissimilated from Table 2 [%]
F	= CH_4 concentration in LFG, 50%
MCF	= Methane correction factor from Table 3
16/12	= CH_4 to carbon ratio
10^6	= grams per tonne conversion [g / t]

Step 5 – Select the lifetime LFG collection efficiency (*LFGCE*) that most accurately represents the landfill-specific conditions in Table 4, for each waste category of the organic MSW diverted from the landfill. If the landfill in question is not managed, and LFG is not collected, use a value of 0%. Note that in this case, it would be inappropriate to also select a MCF value of 1.0 which corresponds to an anaerobic managed solid waste disposal site.

[6] Intergovernmental Panel on Climate Change (IPCC). 2006 IPCC guidelines for national greenhouse gas inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html

Table 4: Landfill gas collection efficiency (LFGCE)[7]

Climate zone		Boreal and temperate (MAT ≤ 20°C)						Tropical (MAT > 20°C)					
		Dry (MAP/PET < 1)			Wet (MAP/PET >1)			Dry (MAP < 1000 mm)			Moist and wet (MAP >1000 mm)		
Waste category, *j* \ LFG collection		Active[a]	Moderate[b]	Minimal[c]	Active[a]	Moderate[b]	Minimal[c]	Active[a]	Moderate[b]	Minimal[c]	Active[a]	Moderate[b]	Minimal[c]
Slowly degrading waste	Paper/textiles waste	78%	70%	56%	82%	71%	56%	79%	70%	56%	83%	71%	56%
	Wood/straw waste	68%	63%	51%	74%	67%	54%	71%	65%	53%	76%	68%	55%
Moderately degrading waste	Other (non-food) organic putrescible/garden and park waste	80%	71%	56%	83%	69%	54%	83%	71%	56%	80%	61%	55%
Rapidly degrading waste	Food waste/Sewage sludge	82%	71%	56%	79%	59%	49%	84%	70%	55%	72%	46%	43%

MAT – Mean annual temperature; MAP – Mean annual precipitation; PET – Potential evapotranspiration.
[a] Active: Typically, the landfill operator is using horizontal LFG collectors from the early stage of cell development while still accepting MSW (less than a year after cells' first waste disposal), and vertical collectors once cells are capped.
[b] Moderate: Horizontal collectors are installed to capture LFG 1-3 years after cells' first waste disposal, and vertical collectors are used once cells are capped.
[c] Minimal: LFG is not collected during waste acceptance, but vertical collectors are used once cells are capped.

Step 6 – Select the oxidation rate that best represents the landfill conditions: 10% should be used for modern, sanitary, and well-managed landfills; 0% should be used in all other cases.[2]

Step 7 – Calculate non-captured CH_4 emissions, CH_4^n, per dry tonne of diverted MSW using Equation 2. Note that Q_j and $LFGCE_j$ are defined for each waste category, *j*.

Equation 2: Non-captured CH_4 emissions (CH_4^n) [g CH_4 / t dry MSW]

$$CH_4^n = \sum_j \left[Q_j \times \left(1 - LFGCE_j\right) \times (1 - \text{oxidation rate}) \right]$$

[7] Nine landfills were interviewed, and three landfills that represent active, moderate, and minimal LFG collection were selected and simulated based on the method provided in Lee et al. (2018) with phased collection efficiency specified in Barlaz et al. (2009).

Lee, U., Han, J. and Wang, M., 2017. Evaluation of landfill gas emissions from municipal solid waste landfills for the life-cycle analysis of waste-to-energy pathways. Journal of Cleaner Production, 166, pp.335-342.

Barlaz, M.A., Chanton, J.P., Green, R.B., 2009. Controls on landfill gas collection efficiency: instantaneous and lifetime performance. J. Air Waste Manag. Assoc. 59, 1399–1404.

Step 8 – Calculate biogenic CO_2 in non-captured CH_4 emissions, CO_2^n, and biogenic CO_2 that remains as carbon in the landfill, CO_2^s, using Equation 3.

Equation 3: CO_2^n and CO_2^s [g CO_2e / t dry MSW]

$$CO_2^n = CH_4^n \times 44/16$$

$$CO_2^s = \sum_j \left[W_j \times DOC \times (1 - DOC_F) \times (44/12) \times 10^6 \right]$$

Step 9 – In the case that the project of interest diverts MSW from a landfill where collected CH_4 is used for electricity generation instead of flaring, calculate the avoided electricity credit using Equation 4.

Equation 4: Avoided electricity credit [g CO_2e / t dry MSW]

$$Avoided\ electricity\ credit\ = LHV_{CH4} \times \boldsymbol{\eta} \times CF \times [\Sigma_j (Q_j \times LFGCE_j)] \times CI_{elec} \times 10^{-3}$$

where:

LHV_{CH4}	= lower heating value of CH_4, 0.0139 MWh / kg
η	= net electricity generation efficiency (eg. 30%, dependent on landfill of interest)
CF	= capacity factor including downtime (eg. 85%, dependent on landfill of interest)
Q_j	= total CH_4 generation from waste category j from Equation 1[g CO2e / t dry MSW]
$LFGCE_n$	= landfill gas collection efficiency selected from Table 3 [%]
CI_{elec}	= average carbon intensity of grid electricity in the region where the landfill generating electricity is located (use the highest spatial resolution regional-level CI published by a relevant national entity) [gCO_2e / MWh]
10^{-3}	= kilogram per gram conversion [kg / g]

Step 10 – Calculate the final LEC of the SAF production process, as shown in Equation 5. This landfill- and waste-specific LEC value is to be subtracted from the core LCA value (g CO_2e/MJ) of MSW-derived SAF.

Equation 5: Final LEC calculation [g CO_2e/MJ]

$$LEC = \frac{CH_4^n \times (GWP_{CH4}) - CO_2^n - CO_2^s - [avoided\ electricity\ credit]}{Y}$$

where:

CH_4^n	= non-captured CH_4 emission [g CH_4 / t dry MSW]
GWP_{CH4}	= 100-year global warming potential of CH_4, 28 g CO_2e / g CH_4
CO_2^n	= Biogenic CO_2 in non-captured CH_4 emissions [g CO_2e / t dry MSW]
CO_2^s	= Biogenic CO_2 that remains as carbon in the landfill [g CO_2e / t dry MSW]
[avoided electricity credit]	= Emissions offset by replacing grid electricity with electricity from captured CH_4 [g CO_2e / t dry MSW]
Y	= Total energy yield (liquid fuels, other fuel and energy co-products and non-energy co-products) from MSW [MJ/ t dry MSW]. Note that this is calculated on the basis of MSW diverted from the landfill, before any additional sorting or recycling takes place.

6.2 **Methodology for Calculation of Recycling Emissions Credits**

SAF produced from Municipal Solid Waste (MSW) feedstocks may generate a Recycling Emissions Credit (REC), due to additional recyclable material being recovered and sorted during feedstock preparation. The emissions avoided for additional recycling of plastics and metals, calculated separately, are summed to generate a total REC value. REC shall be calculated as follows:

1. Plastics

Step 1a. – Select the energy consumption factors for virgin plastic production and recycling from Table 5, for the plastic types recovered from the MSW feedstock in question.

Table 5: Energy factors for virgin plastic production and recycling[8]

Material	Specific electricity consumption for virgin plastic production (SEC_{bl})	Specific fossil fuel consumption for the production of virgin plastic (SFC)	Specific electricity consumption for plastic recycling (SEC_{rec})
	[MWh / t]	*[GJ / t]*	*[MWh / t]*
PET	1.11	15.0	0.83
HDPE	0.83	15.0	0.83
LDPE	1.67	15.0	0.83
PP	0.56	11.6	0.83

Step 1b. – Select appropriate emission factors for electricity, and direct fossil fuels use, for virgin plastic production, that accurately represent the specific project in question.

CI_{elec}	*= average carbon intensity of grid electricity in the region where the virgin plastic production is being offset (use the highest spatial resolution regional-level CI published by a relevant national entity) [gCO$_2$e / MWh]*
CI_{ff}	*= carbon intensity of fossil fuel used in the virgin plastic production process [g CO_{2e} / GJ]. The life cycle CIs of coal, natural gas, fuel oil, and diesel, used as stationary fuels in US industrial processes, are 100.7, 69.4, 95.6, and 93.4 g CO_2e/MJ, respectively. Note that more regionally or context appropriate data should be substituted for the values given here, if available.*

Step 1c. – Estimate the emissions avoided by using recycled plastics to reduce virgin plastic production, per tonne of diverted MSW feedstock. This calculation should be carried out for each plastic type, and summed up, as shown in Equation 6.

Equation 6: REC associated with additional recycled plastic [g CO2e / t dry MSW]

$$REC_{plastic} = \sum_{i} q_i \times \left[L_i \times \left(SEC_{bl,i} \times CI_{elec} + SFC_i \times CI_{ff}\right) - \left(SEC_{rec,i} \times CI_{elec}\right)\right]$$

where:

q_i	*= quantity of plastic i recycled [t / dry t MSW]. This is on the basis of per tonne of dry MSW diverted from the landfill, before additional recycling takes place.*
i	*= type of plastic recycled (eg. PET, HDPE, LDPE, or PP)*
L_i	*= adjustment factor for degradation in material quality and loss when using the recycled material, 0.75*
$SEC_{bl,i}$	*= specific electricity consumption for virgin material production for plastic i [MWh / t plastic]*
$SEC_{rec,i}$	*= specific electricity consumption for recycling of plastic i [MWh / t plastic]*
SFC_i	*= specific fossil fuel consumption for virgin material production of plastic i [GJ / t plastic]*

[8] United Nations Framework Convention on Climate Change (UNFCCC). 2018. *AMS-III.AJ.: Recovery and recycling of materials from solid wastes --- Version 7.0. Clean Development Mechanism.* Valid from August 2018.

2. Metals

Step 2a. – Select the energy consumption factors for virgin metal production and recycling from Table 6, for the metal types recovered from the MSW feedstock in question.

Table 6: Emissions and energy factors for virgin metal production recycling[9]

Material	Emission factor for virgin metal production (*CI*)	Specific electricity consumption for metal recycling (SEC_{rec})
	[g $CO_{2e}e$ / t]	*[GJ / t]*
Aluminium	8.40×10^6	0.66
Steel	1.27×10^6	0.9

Step 2b. – Select an appropriate emission factor for electricity use in virgin metal production that accurately represents the specific project in question.

CI_{elec} = *average carbon intensity of grid electricity in the region where virgin metal production is being offset (use the highest spatial resolution regional-level CI published by a relevant national entity) [gCO_2e / MWh]*

Step 2c. – Estimate the emissions avoided by using recycled metals to reduce virgin metal production, per tonne of diverted MSW feedstock. This calculation should be carried out for each metal type, and summed up, as shown in Equation 7.

Equation 7: REC associated with additional recycled metal [g CO2e / t dry MSW]

$$REC_{metal} = \sum_i q_i \times [L_i \times (CI_i) - (SEC_{rec,i} \times CI_{elec})]$$

where:

q_i = *quantity of metal i recycled [t / dry t MSW]. This is on the basis of per tonne of dry MSW diverted from the landfill, before additional recycling takes place.*
i = *type of metal recycled (eg. steel, or aluminum)*
CI_i = *emission factor for virgin production of metal i [g CO_2e / t metal]*
L_i = *adjustment factor for degradation in material quality and loss when using the recycled material, 0.75*
$SEC_{rec,i}$ = *specific electricity consumption for recycling of metal i [MWh / t plastic]*

Step 3 – Sum up emissions credits from plastics and metals, and convert to a basis of per MJ of fuel, as shown in Equation 8.

Equation 8: Final REC calculation [g CO2e / MJ]

$$REC = \frac{REC_{plastic} + REC_{metal}}{Y}$$

where:

Y = *Total energy yield (liquid fuels, other fuel and energy co-products and non-energy co-products) from MSW [MJ/ t dry MSW]. Note that this is calculated on the basis of MSW diverted from the landfill, before any additional sorting or recycling takes place.*

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[9] United Nations Framework Convention on Climate Change (UNFCCC). 2018. *AMS-III.AJ.: Recovery and recycling of materials from solid wastes --- Version 7.0. Clean Development Mechanism.* Valid from August 2018.

Agenda Item 10: Current science related to aircraft noise and emissions

10.1 UPDATING THE 1999 *SPECIAL REPORT BY THE IPCC ON AVIATION AND THE GLOBAL ATMOSPHERE*

10.1.1 The ICAO Secretariat presented the work done to update the information contained within the Intergovernmental Panel on Climate Change (IPCC) 1999 *Special Report on Aviation and the Global Atmosphere*. Eight topic areas were defined for the update of the information contained in the IPCC 1999 Report: 1) Aircraft emissions and the environment, 2) Emissions scenarios, 3) Aviation impacts on climate, 4) Potential climate change from aviation, 5) Aircraft technology, 6) Air transport operations, 7) Mitigation pathways and regulatory measures, and 8) Future scenarios. Specifically on item 4, a self-assembled group of scientists has been working on an assessment of the potential climate change impacts from aviation and this should include a revised estimate of the radiative forcing climate effects. The Secretariat highlighted that it has not been possible to identify further resources and funding for any other work to provide a thorough update of the majority of the remaining information contained within IPCC 1999 Report. Consequently, the ICAO Secretariat has focussed on deriving an update from the work conducted by ICAO through CAEP and other bodies, and making this information available on the ICAO website.

Discussion and Conclusions

10.1.2 Following a question from a Member on the relationship between the work carried out by the Secretariat and any future update by the IPCC, it was clarified that the work presented did not intend to replace any formal IPCC update, and would only supplement the IPCC 1999 Report with available information, noting that any future IPCC update is a significant undertaking, following the formal procedures of IPCC and would represent a complete update of the IPCC work carried out in 1999.

10.1.3 The meeting agreed to use the materials as suggested by the Secretariat to supplement the IPCC 1999 Report, and agreed to make these materials available on the ICAO Website.

10.2 REPORT OF THE IMPACTS AND SCIENCE GROUP

10.2.1 The ISG co-Rapporteurs presented an overview of the activities of the ISG over the CAEP/11 cycle. ISG developed and held an ISG Aviation Noise Impacts Workshop in close coordination with WG1 and WG2, with the purpose of gathering the latest consensus scientific information on aviation noise impacts in preparation for ISG's production of an "Aviation Noise Impacts White Paper". This white paper covers many different aircraft noise impacts, including community noise annoyance, sleep disturbance, health impacts, children's learning, helicopter noise, en-route noise from supersonic aircraft, Urban Air Mobility and Unmanned Aerial Systems noise and economic cost of aviation noise.

Discussion and Conclusions

10.2.2 The meeting agreed that ISG had completed its tasks for the CAEP/11 cycle and that the "Aviation Noise Impacts White Paper" provided by ISG should be published by ICAO, with appropriate caveats and associated authorship. It was acknowledged that an appropriate method of publishing it could be through the ICAO Environmental Report.

10.2.3 A Member commented that a significant amount of technical terminology had been used in the "Aviation Noise Impacts White Paper" and as such offered to work with the Secretariat to develop a glossary of terms prior to the papers publication.

10.2.4 Commenting on the conclusion of the "Aviation Noise Impacts White Paper" that for light civilian aircraft there was not a pronounced difference between responses to fixed wing and rotary wing aircraft, an Observer highlighted that this was contrary to some local guidance in some ICAO Member States.

10.2.5 The meeting discussed how the "Aviation Noise Impacts White Paper" related to the recently published WHO guidelines on noise (as discussed at the beginning of the meeting) and it was clarified that while the two pieces of work had relied on the latest scientific evidence, the "Aviation Noise Impacts White Paper" had not made policy recommendations. Commenting specifically on the scientific validity of the WHO guidelines and recommendations, an Observer stated that the WHO recommendations had been made without the due technical and scientific expertise, cost benefit and impact analysis and as such had made unjustified policy recommendations. Another Observer commented that the WHO Guidelines affect primarily European States and therefore it is up to these States to consider how and if these recommendations should be implemented, rather than ICAO.

10.2.6 **Recommendations**

10.2.6.1 From the ensuing discussion, the meeting agreed with the recommendation to publish the ISG "Aviation Noise Impacts White Paper", as follows:

> **Recommendation 10/1** – Aviation Noise Impacts White Paper
>
> The Aviation Noise Impacts White Paper be published by ICAO as contained in the appendix to the report on this agenda item.

10.3 DEVELOPMENT OF A LONG TERM ASPIRATIONAL GOAL FOR INTERNATIONAL AVIATION EMISSIONS

10.3.1 The ISG co-Rapporteurs presented the work on a long-term goal (LTG) for international aviation emissions in the light of the recently published IPCC *Special Report on Global Warming of 1.5 °C*. The Summary for Policy Makers (SPM) presents the key findings of the Special Report, based on the assessment of the available scientific, technical and socio-economic literature relevant to global warming of 1.5°C and for the comparison between global warming of 1.5°C and 2°C above preindustrial levels. The data from the IPCC report, along with the ICAO environmental trends data, could be used to build a basis for an analysis that could underpin the rationale for a long-term aspirational goal.

10.3.2 One Observer presented the view that ICAO should set a long-term goal as a matter of urgency, demonstrating how the sector will make a fair contribution to the overall effort necessary to deliver net-zero emissions and the 1.5°C temperature goal. The Observer recommended CAEP to develop a draft LTG analysis using a simplified carbon budget approach for presentation at the 40th ICAO Assembly.

Discussion and Conclusions

10.3.3 Several Members recognized the importance of the work on understanding long-term projections and strategy for aviation, urging caution in setting a LTG. The Members commented that any work should highlight the efforts being undertaken by ICAO and its Member States to reduce the impact of aviation on the global climate, including the aspirational goal of carbon neutral growth and the Basket of Measures. The Members urged caution in setting this work directly in the context of the Paris Agreement and suggested that if the IPCC 1.5°C scenarios were to be used, then great care should be taken.

10.3.4 Several other Members and Observers stated how important it is to progress work on a LTG, stating that this work should not only consider the contribution aviation can make to the 1.5°C temperature goal, but also what contribution aviation should make. The Members reflected on the request from the ICAO Assembly and how the ICAO Council had been requested to continue to explore the feasibility of a long term global aspirational goal for international aviation, through conducting detailed studies assessing the attainability and impacts of any goals proposed, including the impact on growth, as well as costs in all countries, especially developing countries, for the progress of the work to be presented to the 40th Session of the ICAO Assembly. Assessment of long-term goals should include information from Member States on their experiences working towards the medium-term goal (Resolution A39-2 refers).

10.3.5 The meeting agreed that the work tasked to ISG in support of the request contained in A39-2, paragraph 9, would first focus on a bottom-up approach to analysis of the aviation sector's efforts to address climate change, including implementation of the ICAO Basket of Measures, and would be conducted through a staged approach that focuses first on CO_2, acknowledging that further expansion to integrate short-lived climate pollutants would require more detailed climate modelling, and noting that the task should not be to define a share of a global carbon budget; and report progress to the 2019 CAEP Steering Group meeting.

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APPENDIX

AVIATION NOISE IMPACTS WHITE PAPER

STATE OF THE SCIENCE 2019: AVIATION NOISE IMPACTS

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SUMMARY

This paper provides an overview of the state of the science regarding aviation noise impacts as of early 2019. It contains information on impacts including community noise annoyance, sleep disturbance, health impacts, children's learning, helicopter noise, supersonic aircraft, urban air mobility and unmanned aerial systems. The paper also considers the economic costs of aviation noise. This information was collected during an ICAO/CAEP Aviation Noise Impacts Workshop in November 2017 and in subsequent follow-on discussions.

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CHAPTER 1. INTRODUCTION

The purpose of this document is to provide an overview of the state of the science in the area of aviation noise impacts. As part of its work programme CAEP's Impacts and Science Group (ISG) was tasked with providing an updated white paper on the topic of aviation noise impacts. A white paper on aviation noise impacts was provided at the CAEP/10 meeting as WP/54-Appendix G, and was later published in 2017 as an open access journal article[1], but it did not address some emerging areas in aviation. So instead of merely providing an update, the course taken was to extend the review to the above mentioned topics. An Aviation Noise Impacts Workshop was held for invited scientists and other observers and guests in Montreal, Canada November 1-3, 2017. The purpose of this workshop was to lay the foundation for this white paper, and over 50 attendees participated. One specific topic requested by the CAEP Steering Group (CAEP SG.20161.SD.4) was for ISG to address the non-technical environmental aspects of the public acceptability for supersonic aircraft noise, and ISG began to explore this topic. In addition, the authors found much material on supersonics that had not previously been summarized for CAEP, and these details are provided in an appendix. Subsequent follow-up discussions led to additions to this white paper beyond those discussed at the workshop, and this includes urban air mobility (UAM) and unmanned aerial systems (UAS) noise. The basic of metrics for aircraft noise were defined in an appendix to WP/54-Appendix G and the open access journal article[1], and those will not be repeated here.

CHAPTER 2. COMMUNITY NOISE ANNOYANCE

2.1 Definition

Community noise annoyance refers to the average evaluation of the annoying aspects of a noise situation by a "community" or group of people. Annoyance, in this context, comprises a response that reflects negative experiences or feelings such as dissatisfaction, anger, disappointment, etc. due to interference with activities (e.g., communication or sleep) or simply an expression of being bothered by the noise.
To facilitate inter-study comparisons standardized annoyance questions and response scales have been introduced by the International Commission on Biological Effects of Noise, ICBEN.[2] These recommendations have been adopted by the International Standards Organization[3], ISO TS 15666, and translated into a number of new languages, following a standard protocol.[4]

2.2 Exposure-response relationships

Over the years, many attempts have been made to relate the percentage of respondents highly annoyed by a specific noise source to the day-night average noise exposure level, L_{dn}, or a similar indicator, e.g. day-evening-night average noise exposure level, L_{den}.[5,6] The standard ISO 1996: 2016 has tables with % HA as a function of L_{dn} and L_{den} for various transportation noise sources.[7] A review by Gelderblom et al.[8] confirms these data for aircraft noise. Another review suggests different relationships, particularly for aircraft noise annoyance.[9]

2.3 Generalized versus local exposure-response relationships

While exposure-response relationships have been recommended for assessing the expected annoyance response in a certain noise situation, they are not applicable to assess the effects of a change in the noise climate. Existing survey results reveal a higher annoyance response in situations with a high rate of change, for instance, where a new runway is opened.[10,11,12] Such heightened annoyance response seems to prevail.

Since airports and communities may differ greatly with respect to acoustic and non-acoustic variables, local exposure–response relationships, if available, may be preferred for predicting annoyance and describing the noise situation with desired accuracy. Still, generalized exposure–response relationships are desirable to allow assessment across communities and to establish recommended limit values for levels of aircraft noise.

2.4 Moderating variables

Analyses show that the common noise exposure variables *per se* explain about one third of the variance of individual annoyance responses. The annoyance response is moderated by a series of other factors, both acoustic and non-acoustic. Acoustic factors can be maximum levels, number of flights, fleet composition, and their respective distribution over time. Non-acoustic factors are for instance, personal noise sensitivity and attitude towards the noise source. In the aviation industry all "non- L_{dn} factors" are commonly referred to as "non-acoustic".

Two old meta-analyses on the influence of non-acoustic factors on annoyance[13,14] showed the factors of fear of danger of aircraft operations, followed by noise sensitivity and age, had the largest effects. More recent results indicate that fear is no longer a dominating modifying factor. Other important modifying factors may be distrust in authorities and expectations of property devaluation.[15] Guski et al. suggested[9] that the rate of change at an airport with respect to noise and operational procedures could be an important moderating factor. They defined two types: LRC and HRC, low/high rate of change airport. Gelderblom et al. have shown that the average difference in the annoyance response between these two types of airports, LRC and HRC, corresponds to a 9-dB-difference (9 dB ± 4 dB) in the noise exposure.[17] Guski et al. reported a similar, but smaller difference, about 6 dB.[9] The difference between the two studies is likely due to different selections and weighting of survey samples.

An important non-acoustic factor seems to be the attitude towards the noise source and/or its owner. Contrary to common beliefs, people that benefit from the air traffic are not more tolerant to aircraft noise.[18] A lack of trust in the authorities, misfeasance, and a feeling of not being fairly treated will increase the annoyance.[15] People may adapt different coping strategies, i.e. to master, minimize or tolerate the noise situation. Noise sensitive people have more difficulties coping with noise than others.[19]
If the respondents in a survey are selected according to proper random procedures, and the number of respondents is large enough to be an accurate representation of the population, individual factors will have the same effect in all surveys. However, other factors are location specific, for instance number of aircraft movements, prevalence of night time operations, LRC/HRC categorization, etc. The survey results from different airports will therefore vary unless these location specific factors are the same, or that they are accounted for statistically. Hence the search for a common exposure-response function, a "one curve fits all" solution, may not be applicable for all purposes.

2.5 Temporal trends in aircraft noise annoyance

Systematic surveys on aircraft noise annoyance have been conducted regularly over a good half century. Analyses by some researchers indicate that there has been an increase in aircraft noise annoyance over the past decades.[20,21] These authors state that at equal noise exposure levels, people today seem to be more annoyed by aircraft noise than they were 30-40 years ago.

Other researchers, however, claim that they can observe no change provided that the comparisons comprise similar and comparable noise situations.[17] Gelderblom et al. point out that the trend observations made by others can be explained by variations in non-acoustic factors, such as the fact that the prevalence of HRC airports are higher among recent surveys than among older ones. When LRC and HRC airports are analyzed separately they claim that there has been no change in the annoyance response over the past 50 years. Guski et al. on the other hand, claim that even at LRC airports the prevalence of highly annoyed people is higher for all exposure levels compared to older studies.[9]

Survey results from different airports show a large variation in the annoyance response. The result of a trend analysis based on a limited sample of surveys is therefore highly dependent on the selection criteria.

2.6 Noise mitigation strategies

Annoyance due to aircraft noise has been recognized by authorities and policy makers as a harmful effect that should be reduced or prevented. Priority is given to noise reduction at the source (e.g., engine noise, aerodynamic noise) and reducing noise impact by adjusting operational procedures and take-off and landing trajectories. Attempts to modify the noise spectrum to produce a more agreeable "sound" were made in the EU-funded COSMA project.[22] Such changes gave little or no effect. Sound insulation of dwellings is often applied, but such measures have no consequences for the outdoor experience of aircraft noise. The observed influence on annoyance of personal non-acoustic factors such as perceived control, and trust in authorities suggests that communication strategies addressing these issues could contribute to the reduction of annoyance, alongside or even in the absence of a noise reduction.

2.7 Conclusions

There is substantial evidence that there is an increase in annoyance as a function of noise level, e.g. L_{dn} or L_{den}. The noise level alone, however, accounts for only a part of the annoyance. Location and/or situation specific acoustic and non-acoustic factors play a significant role and must be taken into account.

There is conflicting evidence that there has been a change in the annoyance response in recent years. Under equal conditions, people today are not more annoyed at a given noise level than they were 30-40 years ago. However, due to changes in both acoustic and non-acoustic factors (more HRC airports, higher number of aircraft movements, etc.), the average prevalence of highly annoyed people at a given noise level (L_{dn} or L_{den}) seems to be increasing. Existing exposure-response functions should be updated and diversified to account for various acoustic and non-acoustic factors. The difference between a high rate change and a low rate change situation seems to be particularly important.

CHAPTER 3. SLEEP DISTURBANCE

3.1 Sleep And Its Importance For Health

Sleep is a biological imperative and a very active process that serves several vital functions. Undisturbed sleep of sufficient length is essential for daytime alertness and performance, quality of life, and health.23,24 The epidemiologic evidence that chronically disturbed or curtailed sleep is associated with negative health outcomes (like obesity, diabetes, and high blood pressure) is overwhelming. For these reasons, noise-induced sleep disturbance is considered one of the most important non-auditory effects of environmental noise exposure.

3.2 Aircraft noise effects on sleep

The auditory system has a watchman function and constantly scans the environment for potential threats. Humans perceive, evaluate and react to environmental sounds while asleep.[25] At the same sound pressure level (SPL), meaningful or potentially harmful noise events are more likely to cause arousals from sleep than less meaningful events. As aircraft noise is intermittent noise, its effects on sleep are primarily determined by the number and acoustical properties (e.g., maximum SPL, spectral composition) of single noise events. However, whether or not noise will disturb sleep also depends on situational (e.g., sleep depth[26]) and individual (e.g., noise sensitivity) moderators.[25]

Sensitivity to nocturnal noise exposure varies considerably between individuals. The elderly, children, shift-workers, and those in ill health are considered at risk for noise-induced sleep disturbance.[24] Children are in a sensitive developmental stage and often sleep during the shoulder hours of the day with high air traffic volumes. Likewise, shift-workers often sleep during the day when their circadian rhythm is promoting wakefulness and when traffic volume is high. Sleep depth decreases with age, which is why the elderly are often more easily aroused from sleep by noise than younger subjects.

Repeated noise-induced arousals impair sleep quality through changes in sleep structure including delayed sleep onset and early awakenings, less deep (slow wave) and rapid eye movement (REM) sleep, and more time spent awake and in superficial sleep stages.[26,27] Deep and REM sleep have been shown to be important for sleep recuperation in general and memory consolidation specifically. Non-acoustic factors (e.g., high temperature, nightmares) can also disturb sleep and complicate the unequivocal attribution of arousals to noise.28 Field studies in the vicinity of airports have shown that most arousals cannot be attributed to aircraft noise, and noise-induced sleep-disturbance is in general less severe than that observed in clinical sleep disorders like obstructive sleep apnea.[29,30] However, noise-induced arousals are not part of the physiologic sleep process, and may therefore be more consequential for sleep recuperation.132 Short-term effects of noise-induced sleep disturbance include impaired mood, subjectively and objectively increased daytime sleepiness, and impaired cognitive performance.[31,32] It is hypothesized that noise-induced sleep disturbance contributes to the increased risk of cardiovascular disease if individuals are exposed to relevant noise levels over years. Recent epidemiologic studies indicate that nocturnal noise exposure may be more relevant for long-term health consequences than daytime noise exposure, probably also because people are at home more consistently during the night.[16,33]

3.3 Noise effects assessment

Exposure-response functions relating a noise indicator (e.g., maximum SPL) to a sleep outcome (e.g. awakening probability) can be used for health impact assessments and inform political decision making. Subjects exposed to noise typically habituate, and exposure-response functions derived in the field (where subjects have often been exposed to the noise for many years) are much shallower than those derived in unfamiliar laboratory settings.[34,35] Unfortunately, sample sizes and response rates of the studies that are the basis for exposure-response relationships were usually low, which restricts generalizability.

Exposure-response functions are typically sigmoidal (s-shaped) and show monotonically increasing effects. Maximum SPLs as low as 33 dB(A) induce physiological reactions during sleep, i.e., once the organism is able to differentiate a noise event from the background, physiologic reactions can be expected (albeit with a low probability at low noise levels).[34] This reaction threshold should not be confused with limit values used in legislative and policy settings, which are usually considerably higher. At the same maximum SPL, aircraft noise has been shown to be less likely to disturb sleep compared to road and rail traffic noise, which was partly explained by the frequency distribution, duration, and rise time of the noise events.[27,36] At the same time, the percent highly sleep disturbed assessed via self-reports is typically higher for aircraft noise compared to road and rail traffic noise at the same L_{night} level.[37]

Although equivalent noise levels are correlated with sleep disturbance, there is general agreement that the number and acoustical properties of noise events better reflect the degree of sleep disturbance (especially for intermittent aircraft noise). As exposure-response functions are typically without a clearly discernible sudden increase in sleep disturbance at a specific noise level, defining limit values is not straight forward and remains a political decision weighing the negative consequences of aircraft noise on sleep with the economic and societal benefits of air traffic. Accordingly, night-time noise legislation differs between Contracting States.

3.4 Noise mitigation

Mitigating the effects of aircraft noise on sleep is a three-tiered approach. Noise reduction at the source has highest priority. However, as it will take years for new aircraft with reduced noise emissions to penetrate the market (and will thus not solve the problem in the near future), additional immediate measures are needed. For example, noise-reducing take-off and landing procedures can often be more easily implemented during the low-traffic night-time. Land-use planning can be used to reduce the number of relevantly exposed subjects. Passive sound insulation (including ventilation) represent mitigation measures that can be effective in reducing sleep disturbance, as subjects usually spend their nights indoors. At some airports, nocturnal traffic curfews have been imposed by regulation. It is important to line up the curfew period with the (internationally varying) sleep patterns of the population.

3.5 Recent evidence review

For sleep disturbance, a systematic evidence review based on studies published in or after the year 2000 was recently published.[37] According to GRADE[38] criteria, the quality of the evidence was found to be moderate for cortical awakenings and self-reported sleep disturbance (for questions that referred to noise) induced by aircraft noise, low for motility measures of aircraft noise induced sleep disturbance, and very low for all other investigated sleep outcomes. Significant exposure-response functions were found for aircraft noise for (a) sleep stage changes to wake or superficial stage S1 (unadjusted OR 1.35, 95% CI 1.22-1.50 per 10 dB increase in $L_{AS,max}$; based on N=61 subjects of a single study) and (b) percent highly sleep disturbed for questions mentioning the noise source (OR 1.94, 95% CI 1.61-2.33 for a 10 dBA increase in L_{night}; based on N=6 studies including > 6,000 respondents). For percent highly sleep disturbed, heterogeneity between studies was found to be high (I^2=84%).

CHAPTER 4. HEALTH IMPACTS

4.1 Introduction

There is good biological plausibility for health impacts of environmental noise, with potential mechanisms involving sleep disturbance, 'fight and flight' physiological response and annoyance.[39,40] The number of epidemiological studies investigating impacts of environmental noise on disease risk and risk factors has increased greatly since the previous ICAO white paper[1] and these have been used to define exposure-response relationships. Some variability is expected between epidemiological studies due to differences in populations, methodology, exposures and study design. Therefore, a combined estimate from a meta-analysis of studies with a low risk of bias is used to provide a state of the art estimate of the exposure-response relationship.

This section highlights main findings from the systematic literature reviews and meta-analyses published in 2017-2018. These reviews reference the noise and health literature up to August 2015 for cardiovascular outcomes[41] and December 2016 for birth outcomes.[42] This section also considers new publications up to end July 2018, including from the NORAH (http://www.laermstudie.de/en/norah-study/) and SIRENE (http://www.sirene-studie.ch/) studies in Germany and Switzerland respectively. Almost all studies available were conducted in European and North American populations.

4.2 Aircraft noise and cardiovascular impacts

The systematic review on cardiovascular and metabolic effects of environmental noise was performed by van Kempen et al.[41] and described in detail in an RIVM (Dutch National Institute for Public Health and the Environment) report.[46] The authors reviewed studies on the association between environmental noise (different source types) and hypertension in adults (none were identified focusing on children), ischaemic heart disease, stroke and obesity published up to August 2015. Findings for aircraft noise were reported to be consistent with findings for road traffic noise, where there are more studies available.

For hypertension: the van Kempen et al.[41] meta-analysis included nine cross-sectional studies and provided an estimated increased risk of 5% (95% confidence intervals -5% to +17%) per 10 dB (L_{den}) aircraft noise (comprising 60,121 residents, including 9487 cases of hypertension). The one cohort study identified[50] (4721 residents and 1346 cases in Sweden published in 2010) did not show an overall association with hypertension incidence, but there were significant associations in subgroup analyses of males and of those annoyed by aircraft noise. The authors of the review ranked the quality of the evidence for noise from air traffic as "low" using the GRADE ranking system, meaning that further research is considered very likely to have both an important impact on confidence in the estimate of effect and to change the size of the estimate. Subsequent to the systematic review, a large case-control study (137,577 cases and 355,591 controls) from the NORAH study[51] found no associations overall for aircraft noise with hypertension, but an increased risk for the subgroup of those who went on to develop hypertension-related heart disease, i.e. more severe cases. A subsequent publication from a small cohort (N=420) with up to 9 years follow-up in Athens who formed part of the original HYENA (Hypertension and Exposure to Noise

Near Airports) study found a 2.6-fold increased risk of hypertension in association with a 10 dB increase in night-time aircraft noise.[52]

Hypertension shows a positive but non-statistically significant association overall reflecting inconsistency between studies. This can be a difficult outcome to define precisely – the PURE multi-country study published in 2013 found nearly half of all cases of hypertension were unrecognised.[198] There are various issues about defining hypertension by medication use, and recognised issues about measuring blood pressure in individuals. Also, hypertension may not be the only or most important mechanism contributing to potential impacts of noise on the heart – inflammation, small blood vessel function and sleep disturbance also need to be considered.[196,197]

For ischaemic heart disease (IHD) and heart failure, findings were more consistent than for hypertension: the van Kempen et al. systematic review[41] reported a statistically significant increased risk of new cases of ischaemic heart disease of +9% (95% confidence intervals +4% to +15%) per 10 dB L_{den}, derived from a meta-analysis of two very large registry-based studies of 9.6 million participants and 158,977 cases. Taking into account evidence relating to existing as well as new cases and to mortality, the authors of the systematic review concluded "Overall, we rate the quality of the evidence supporting an association between air traffic noise and IHD as 'low'" [using the GRADE ranking system] "indicating that further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate". Subsequent published analyses from the SIRENE project using data from the Swiss National Cohort covering 4.4 million people[53], reported associations between aircraft noise and myocardial infarction mortality with increased risk of +2.6% (95% confidence intervals +0.4% to +4.8%) per 10 dB L_{den}. Highest associations between noise and IHD were seen with intermittent night-time exposures.[54] A large case-control study in Germany (19,632 cases and 834,734 controls) forming part of the NORAH study found associations of aircraft noise with diagnosis of myocardial infarction at higher noise levels (>55 dB) in the early morning hours, although not for 24 hour average noise levels. A further large NORAH study analysis[55] found a statistically significant linear exposure-response relationship with aircraft noise for heart failure or hypertensive heart disease of +1.6% per 10 dB increase in 24 hour continuous noise level (analysis based on 104,145 cases and 654,172 controls).

For stroke: the van Kempen et al. systematic review[41] considered seven studies of different designs including one cohort study (the Swiss National Cohort). Findings were mixed but the meta-analysis did not show statistically significant associations of aircraft noise with stroke outcomes. This result is consistent with subsequently published SIRENE study findings on stroke mortality also using the Swiss National Cohort but with improved noise exposure estimates.[53]

Comparisons with findings for road traffic noise: findings for aircraft noise and the cardiovascular disease outcomes presented above are consistent with those for road traffic noise as reported in the van Kempen et al systematic review.[41] In particular, for ischaemic heart disease, the systematic review rated the quality of the evidence supporting an association between road traffic noise and new cases of ischaemic heart disease to be high, providing an increased risk of +8% (+1% to +15%) per 10 dB L_{den} road traffic noise (as compared with findings for aircraft noise for this outcome of +9% (+4% to +15%) as noted above). Analogy with road traffic noise is meaningful, because, as well as impacts on annoyance, noise also functions as a non-specific stressor with non-auditory impacts on the autonomic nervous system and endocrine system. These stressor effects are seen with noise from different sources and result in adverse effects on oxidative stress and vascular function in experimental studies.[196,197]

4.3 Aircraft noise and metabolic effects (diabetes, obesity, waist circumference, metabolic biomarkers)

The van Kempen et al. systematic review[41] identified one Swedish cohort study considering aircraft noise,[56] which found a significant association between aircraft noise exposure and increased waist circumference over 8-10 years follow-up, but not for Body Mass Index (BMI) or type 2 diabetes. The authors of the systematic review concluded that further research would be likely to have an important impact on both size and statistical confidence in the estimate of effect. Three more recent publications also report some associations of aircraft noise with metabolic disturbance.[57-59] A 2017 Swiss cohort study analysis forming part of the SIRENE project suggested an approximate doubling of diabetes incidence per 12 dB L_{den} increase in aircraft noise exposure[57] and positive although non-significant associations of aircraft noise exposure with glycosylated haemoglobin, a measure of glucose control over the past three months and a predictor of diabetes.[58] A 2017 study in Korea of 18,165 pregnant women identified through health insurance records,[59] found an association between night-time but not daytime aircraft noise exposure during the first trimester of pregnancy and risk of gestational diabetes mellitus.

Findings are consistent with a hypothesis that noise exposure is related to stress-hormone-mediated deposition of fat centrally and other impacts on metabolic functioning and/or adverse effects of disturbed sleep on metabolic and endocrine function, also with results from a small number of studies considering road traffic noise that also found associations with diabetes, but more studies are needed to strengthen the evidence base for this outcome.

4.4 Aircraft noise and birth outcomes

A systematic review by Nieuwenhuijsen, et al.[42] published in 2017 considered literature published up to December 2016. Six aircraft noise studies were included, but there were too few studies to conduct a meta-analysis. Four studies (published 1973-2001) considered birth weight and all studies found associations with aircraft noise exposure, but noise exposure levels in these studies were high (> 75 dB, various metrics). A further two studies conducted in the 1970s considered birth defects, of which one found significant associations – again, noise levels considered were high. Evidence was considered such that any estimate of effect is very uncertain. The authors commented that “there may be some suggestive evidence for an association between environmental noise exposure and birth outcomes” with some support for this from studies of occupational noise exposure (which were higher than most current environmental aircraft noise exposures), but that further and high quality studies were needed. No further studies relating birth outcomes to aircraft noise have been published to date.

4.5 Aircraft noise and mental health

There remain very few studies of aircraft noise exposure in relation to wellbeing, quality of life, and psychological ill-health. Since the previous ICAO paper and publication[1] in 2017, there has been one major German analysis[60] published from the NORAH study, which found a significant association with depression as recorded in health insurance claims. Risk estimates increased with increasing noise levels to a maximum Odds Ratio (OR) of 1.23 (95% CI=1.19-1.28) at 50-55 dB (24 hour average), but decreased at higher exposure categories. The reason for this is unclear but it may potentially be due to uncertainties related to very small numbers of exposed and cases at higher noise levels. A cohort study following 1185 German school children[61] from age 5-6 to 9-10 years did not find associations of aircraft noise exposure with mental health problems (such as emotional symptoms, hyperactivity and conduct problems), but as the study used parental noise annoyance at place of residence as the measure of exposure as opposed to objectively assessed (modelled or measured) quantitative exposure levels, it is difficult to draw firm conclusions.

4.6 Conclusions

There has been a large increase in studies in recent years examining associations of noise exposure with health outcomes. The best epidemiological evidence relates to cardiovascular disease, which includes analyses from population-based studies covering millions of individuals, in particular for new cases of ischaemic heart disease. Findings for aircraft noise are consistent with those for road traffic noise (for which more studies have been conducted and where the quality of evidence is rated as high). Results from epidemiological studies are also supported by evidence from human and animal field and laboratory experimental studie[45-49] showing biological effects of noise on mechanistic pathways relating to risk factors for cardiovascular disease. This experimental evidence, together with consistency with findings for road traffic noise, supports the likelihood that associations for aircraft noise with heart disease observed in epidemiological studies are causal. However, the exact magnitude of the exposure-response estimate for heart disease varies between studies and best estimates (obtained by combining results from good quality studies in a systematic review) are likely to change as further studies add to the evidence base.

There are important gaps in the evidence base for other outcomes. Perhaps surprisingly, few studies have been conducted in relation to impact of aircraft noise on mental health. There are also few studies relating to maternal health and birth outcomes including birth weight.

Generally, health studies to date have used L_{den}, L_{day} and L_{night} metrics, most likely as these were available and had been extensively validated in annoyance studies. There is a need to examine other noise metrics that may be more relevant to health endpoints – some of the more recent studies are starting to include other metrics, including intermittency ratio,[43] maximum noise level and to examine specific time periods,[44] especially for night-time exposures. These new metrics should be additional, but not replace the standard equivalent metrics (L_{Aeq}, L_{den}) to allow for comparability of results, at least at present while the evidence base is being compiled.

CHAPTER 5. CHILDREN'S LEARNING

5.1 Chronic aircraft noise exposure and children's learning

Several studies have found effects of aircraft noise exposure at school or at home on children's reading comprehension or memory skills[62] or standardized test scores.[63,64] The RANCH study (Road traffic and Aircraft Noise and children's Cognition & Health) of 2844 9-10 year old children from 89 schools around London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports found exposure-response associations between aircraft noise and poorer reading comprehension and poorer recognition memory, after taking social position and road traffic noise exposure, into account.[65] A 5 dB increase in aircraft noise exposure was associated with a two month delay in reading age in the UK, and a one month delay in the Netherlands.[66] These associations were not explained by co-occurring air pollution.[67] Night-time aircraft noise at the child's home was also associated with impaired reading comprehension and recognition memory, but night-noise did not have an additional effect to that of daytime noise exposure on reading comprehension or recognition memory.[68] The recent NORAH study of 1242 children aged 8 years from 29 primary schools around Frankfurt airport in Germany found that a 10 dB (L_{Aeq} 08.00am-14.00pm) increase in aircraft noise was associated with a one-month delay in terms of reading age. The RANCH and NORAH studies examine the effect of aircraft noise on children's reading comprehension starting from a very low level of exposure. This enables the studies to adequately assess where effects of aircraft begin (i.e. identify thresholds): we should not be concerned by the inclusion of the examination of such low levels of aircraft noise exposure as both the RANCH and the NORAH study adjust the results for other noise exposures (e.g. road noise in RANCH and road and rail noise in NORAH) making the assessment meaningful in terms of considering other noise exposures and ambient noise exposure per se. Effects of aircraft noise on children's learning have been demonstrated across a range of aircraft noise metrics including L_{Aeq}, L_{max}, number of events above a threshold, and time above a threshold. [64]

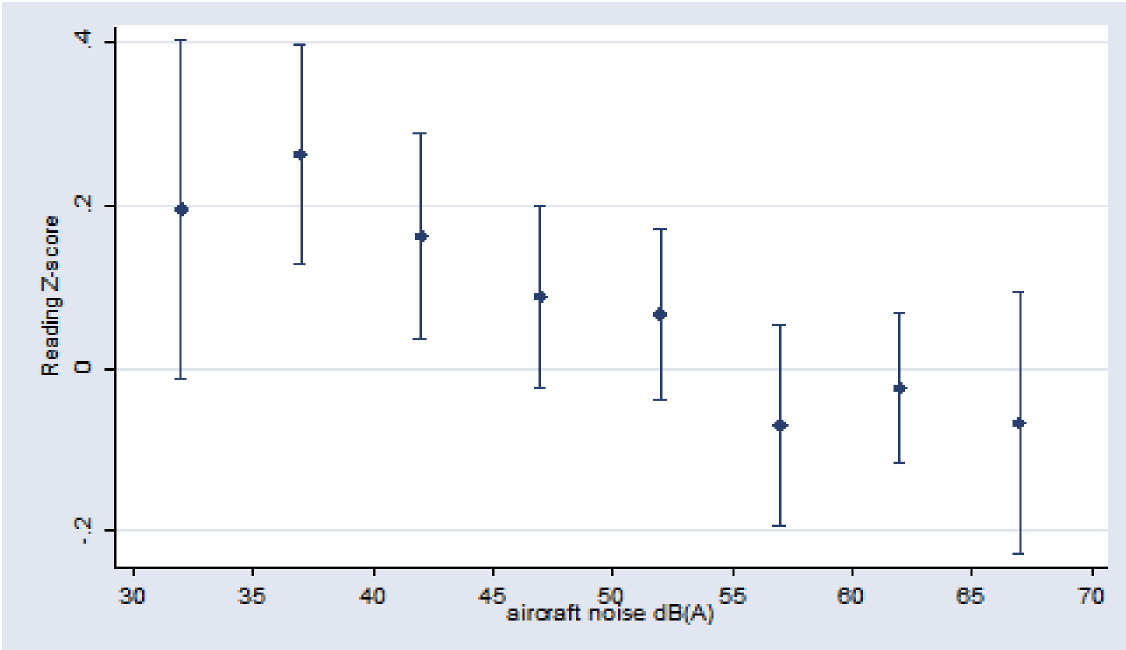

Figure 1. Exposure-effect relationship between aircraft noise exposure at school and reading comprehension in the RANCH study. The vertical axis shows the adjusted mean reading z scores and 95% confidence intervals for 5-dB(A) bands of aircraft noise at school (adjusted for age, gender, and country).[66]

Data from the RANCH study and the NORAH study enable the exposure-effect association between aircraft noise exposure and children's reading comprehension to be estimated[69,70] (see Figures 1 and 2). Both studies suggest that the relationship between aircraft noise and reading comprehension is linear, so reducing exposure at any level should lead to improvements in reading comprehension. In the RANCH study, reading comprehension began to fall below average at exposures greater than 55 dB L_{Aeq} 16 hour at school.

It is possible that children may be exposed to aircraft noise for many of their childhood years, but few studies have assessed the consequences of long-term noise exposure at school on learning or cognitive outcomes. Whilst it is plausible that aircraft noise exposure across a child's education may be detrimental for learning, evidence to support this position is lacking. A six-year follow-up of the UK sample of the RANCH study, when the children were aged 15-16 years of age, failed to find a statistically significant association but did suggest a trend between higher aircraft noise exposure at primary school and poorer reading comprehension at follow-up,[71] as well as a trend between higher aircraft noise exposure at secondary school and poorer reading comprehension at secondary school. This study was limited by its small sample size, which may be why it detects trends rather than significant associations. There remains an urgent need to evaluate the impact of aircraft noise exposure throughout a child's education on cognitive skills, academic outcomes and life chances.

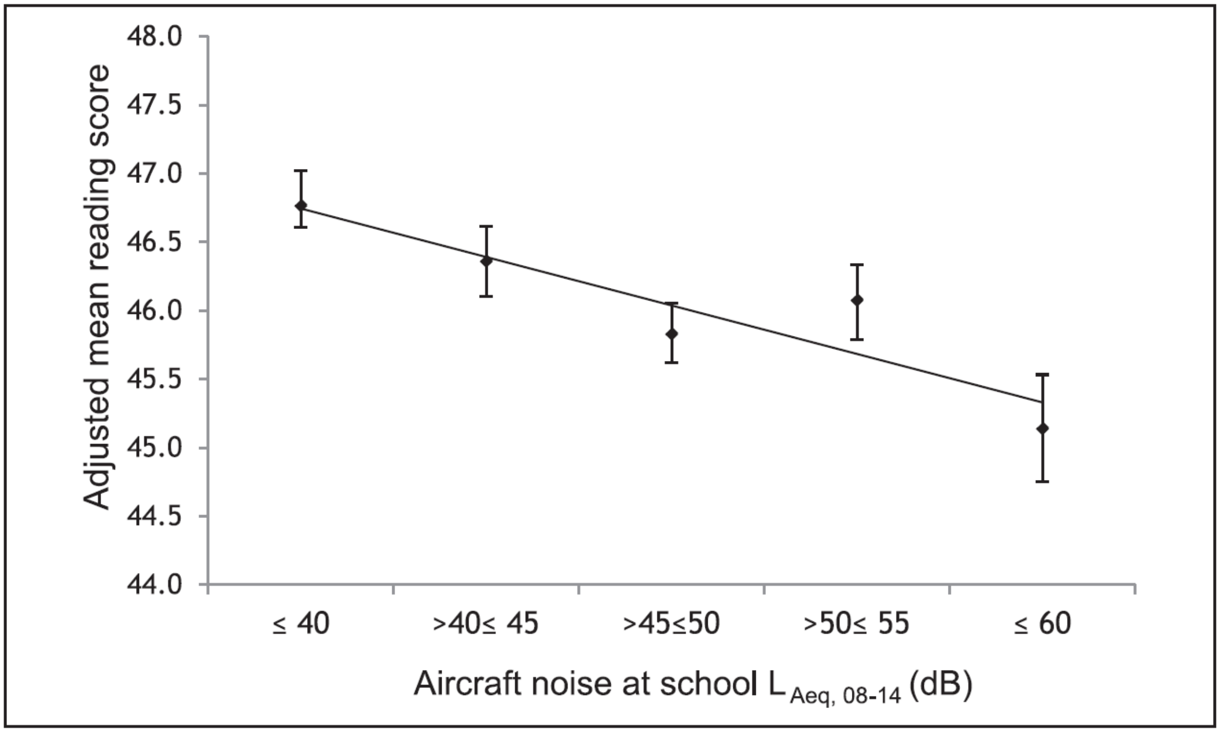

Figure 2. Exposure-response function between aircraft noise exposure at school and reading comprehension in the NORAH study.[70]

5.2 How might chronic aircraft noise exposure cause learning deficits?

Aircraft noise may directly affect the development of cognitive skills relevant for learning such as reading and memory. A range of other plausible pathways and mechanisms for the effects have also been proposed. Communication difficulties might also account for the effects: teacher behavior is influenced by fluctuations in external noise, with a recent observational study finding associations between aircraft noise events and teacher voice-masking (when the teacher's voice is distorted or drowned out by noise) and teacher's raising their voice).[72] Effects might also be accounted for by teacher and pupil frustration, reduced morale, impaired attention, increased arousal – which influences task performance, and sleep disturbance from home exposure which might cause performance effects the next day.[73,74] Noise causes annoyance, particularly if an individual feels their activities are being disturbed or if it causes difficulties with communication. In some individuals, annoyance responses may result in physiological and psychological stress responses, which might explain poorer learning outcomes.

5.3 Interventions to reduce aircraft noise exposure at school

Studies have shown that interventions to reduce aircraft noise exposure at school do improve children's learning outcomes. The longitudinal Munich Airport study[75] found that prior to the relocation of the airport in Munich, high noise exposure was associated with poorer long-term memory and reading comprehension in children aged 10 years. Two years after the airport closed these cognitive impairments were no longer present, suggesting that the effects of aircraft noise on cognitive performance may be reversible if the noise stops. In the cohort of children living near the newly opened Munich airport impairments in memory and reading developed over the first two-year period following the opening of the new airport. A recent study of 6,000 schools exposed between the years 2000-2009 at the top 46 United States airports (exposed to Day-Night-Average Sound Level of 55 dB or higher) found significant associations between aircraft noise and standardized tests of mathematics and reading, after taking demographic and school factors into account.[64] In a sub-sample of 119 schools, they found that the effect of aircraft noise on children's learning disappeared once the school had sound insulation installed. These studies evidence the effectiveness of the insulation of schools that may be exposed to high levels of aircraft noise.

Sound-field systems, which ensure even distributions of sound from the teacher across the classroom, could provide a solution to improving children's learning in situations of aircraft noise. However, an evaluation of these systems in schools in the UK, which were not exposed to aircraft noise, found that whilst the systems improved children's performance on tests of understanding of spoken language they did not influence academic attainment in terms of test of numeracy, reading or spelling.[76] Whether such systems may be an effective intervention for children attending schools with high levels of aircraft noise exposure remains to be evaluated.

5.4 Conclusions

There is robust evidence for an effect of aircraft noise exposure on children's cognitive skills such as reading and memory, as well as on standardized academic test scores. Evidence is also emerging to support the insulation of schools that may be exposed to high levels of aircraft noise. Whilst a range of plausible mechanisms have been proposed to account for aircraft noise effects on children's learning, future research needs to test these pathways, to further inform decision-making concerning the design of physical, educational and psychological interventions for children exposed to high levels of aircraft noise. Further knowledge about exposure-effect relationships in different contexts, using either individually collected cognitive performance data or standardized school test data, would also further inform decision-making. It would also be productive to derive relationships for a range of additional noise exposure metrics, such as the number of noise events. To date, few studies have evaluated the effects of persistent aircraft noise exposure throughout the child's education and there remains a need for longitudinal lifecourse studies of aircraft noise exposure at school and cognitive skills, educational outcomes and life chances.

CHAPTER 6. HELICOPTER NOISE

6.1 Exposure-response relationships

Exposure-response relationships derived for annoyance by aircraft noise were viewed as not necessarily valid for specific sources such as helicopters, low-flying military aircraft or aircraft ground noise.[6] Although relatively little is known on annoyance induced by helicopter noise, some surveys performed in the past have shown that helicopter noise is more often reported as annoying than fixed-wing aircraft noise, at similar or even lower A-weighted outdoor noise levels.[78-82] This was found for heavy military helicopters as well as for lighter civilian helicopters. A more recent survey[83] was done in three residential areas under or adjacent to helicopter corridors that were used by light civilian helicopters. The study was limited to only three surveys, but it was clear that for light civilian aircraft there was not a pronounced difference between response to fixed wing and rotary wing aircraft. The study did show that there was a residual annoyance associated with helicopter operations that was not associated with noise exposure level.

6.2 Role of non-acoustic factors

Some field studies[81,84] have shown that helicopter noise annoyance is heightened by certain non-acoustic factors, in particular fear of a crash, lack of information on the reason of the flights, and low perceived necessity of the helicopter flights themselves (such as when the helicopter is viewed as 'rich person's toy') or of the noise that is produced by them (for instance when it is felt that the pilot or operator could reduce the disturbance by choosing a different flight pattern).

A more recent study[83] also found that for three surveys completed under or near light civil helicopter routes there was 'residual annoyance,' not a function of noise exposure level, an annoyance that was constant for all noise exposures with no evident tendency to approach zero at even very low noise levels. This lack of correlation between noise exposure level; and annoyance was associated with the strong influence of non-acoustic factors. These and earlier findings suggest that observed differences in annoyance between helicopters and fixed-wing aircraft may heavily depend on non-acoustic factors.

6.3 Role of impulse noise

Several laboratory studies have explored whether the degree of impulsiveness of the helicopter noise may contribute to annoyance.[85-89] No consistent differences in annoyance were found between helicopter and aircraft noise, again suggesting that observed differences in the field were partly due to non-acoustic factors, nor did annoyance depend on the degree of impulsiveness. Therefore, the overall consensus is that there is no evidence to justify the application of an impulse correction to the noise level of helicopters with impulsive characteristics.[90-91]

6.4 Role of rattle noise and vibrations

There is evidence that helicopter noise characterized by large low frequency components may impact the building and produce rattle (i.e. sounds of rattling objects or windows within the dwelling) or vibration (the perception of vibrating building elements or furniture), which in turn may lead to increased annoyance by the helicopter noise.[92] While rattle noise and vibration may also be induced by the low-frequency components of ground noise during aircraft landing and take-off,[93,94] it is only sporadically induced by overflying fixed-wing aircraft.[95] In a large field study in the United States[96] it was found that noise from helicopters flying over was rated by subjects (seated in a wooden frame building) as more annoying than a control stimulus, but only when the helicopter induced rattle noise or vibration within the building. The results suggest a decibel offset of at least 10 dB to account for the extra annoyance when rattle or vibration were induced by the helicopter noise (i.e. the control stimulus had to be at least 10 dB higher to induce equal annoyance). An extension of this study suggested similar offset values of 10 and 8 dB for two helicopter types inducing rattle and vibration.[80] A recent study in the Netherlands suggests a lower offset, around 5-6 dB, for helicopter noise in combination with rattle noise induced within the building.[97] This conclusion is not supported for light civil helicopter surveys[83] where survey respondents did not report vibration or rattle as a source of annoyance. The relatively small degree of low frequency energy associated with light civil helicopters as compared to heavy lift helicopters is not expected to produce rattle noise, which is the most plausible explanation for the difference.

CHAPTER 7. EN-ROUTE NOISE FROM SUPERSONIC AIRCRAFT

7.1 Introduction

Sonic booms are the unique sounds produced by supersonic aircraft. This section summarizes many of the properties and impacts of sonic booms, as we know them today. Additional detail about sonic boom noise impacts is provided in an Appendix to this white paper, for readers interested in those specifics. Detailed references are given in that Appendix.[98-164]

Conventional sonic booms are widely considered to be loud, and this forms the basis of current regulations in many countries that prohibit supersonic overland flight. However, new research has enabled aeronautical engineers the tools to develop quiet “low-boom” aircraft designs that may be available in 5 to 10 years. Hence, sonic boom research needs to clearly distinguish whether the sonic booms are the conventional N-wave sounds, so called because of their letter N pressure versus time shape, or the new low-booms which are considerably smoothed. The low-booms, or “sonic thumps”, can be as much as 35 dB quieter than conventional booms.

7.2 Human response studies

Studies have shown that sonic booms can be reproduced quite accurately in the laboratory, and this makes it possible to perform subjective experiments under controlled conditions. Although no supersonic aircraft has produced a low-boom signature yet, a similar surrogate sound can be created using a special aircraft dive manoeuver. This makes it possible to conduct tests with real aircraft outdoors for either N-waves or low-booms, complementing the laboratory tests.

A number of subjective tests have been conducted. One trend seen in studies from both the U.S. and Japan is that annoyance to sonic boom noise is greater indoors compared to outdoors. The findings show that indoor annoyance can be estimated based on the outdoor sonic boom exposure. There has been recent work to establish that both rattle and vibration contribute to indoor annoyance of sonic booms. One interesting point is that although conventional N-waves can be accompanied by a startle response, it turns out that low-booms are of low enough amplitude that they don’t induce a consistent physiological startle response.

There has been substantial work in recent years to establish metrics to assess sonic boom noise. Out of a list of 70 possible metrics, a group of 6 metrics has been identified for the purposes of use in certification standards and in developing dose-response curves for future community response studies. Clearly the low-booms are much quieter than the conventional N-wave booms, but additional community studies with a low-boom aircraft need to be conducted to assess public response.

7.3 Non-technical aspects of public acceptability for sonic boom

An additional aspect that should be considered for sonic booms includes the non-technical aspects of acceptability. The CAEP Steering Group specifically requested that ISG look into this topic. A preliminary discussion has revealed a strong resemblance to the non-acoustical factors of subsonic aircraft noise, previously mentioned in Section 2 “Community Noise Annoyance” of this white paper. There are currently no peer-reviewed studies on the topic of non-acoustical factors for sonic boom noise, but it seems plausible that the knowledge of subsonic aircraft non-acoustical factors could be extended for application to sonic boom noise non-technical aspects.

7.4 Impacts of sonic boom on animals

Recently there has been renewed interest regarding the impacts of sonic boom noise on animals. Fortunately there is an extensive literature extending from before the days of Concorde to recent years, mostly for conventional N-wave aircraft. The details of the many studies are available in the Appendix to this white paper.

There have been substantial studies for both livestock and other domesticated animals, and detailed studies of some wildlife species. For conventional sonic booms the animals usually show no reactions or minimal reactions, although occasionally they may startle just as humans do. There are no reported problems of developing fish eggs or of avian eggs due to sonic boom exposures. NASA conducted a number of studies in the late 1990s and early 2000s to assess the impact of overwater sonic booms on marine mammals. There is a good bit of knowledge as to how much sonic boom noise transitions from air into water, and fortunately, very little of the sound gets into the water. For the California sea lion, elephant seals, and harbor seals, careful lab experiments showed no temporary hearing shifts in those species.

In 1997 and 1998 a study of a colony of seals exposed to Concorde booms on a regular basis showed that the booms didn’t substantially affect the breeding behavior of gray or harbor seals. It instead seems that these animals substantially habituated to hearing these N-wave sonic booms on a routine basis.

Most of what is known about noise impacts on animals comes from the literature of the effects of subsonic aircraft and other anthropogenic noise sources, not sonic booms, on animals. It is well known that human activities can interfere with animal communication, for example.

There have not been many specific studies on the effects of sonic boom noise on animals in recent years. Some species with good low-frequency hearing, such as elephants, have never been evaluated regarding sonic boom noise. But it makes sense that if the already tested animals were not negatively affected by sonic boom noise from conventional N-waves, that they will likely not be affected by the proposed low-booms of the future. Long-term effects of sonic boom exposure on animals seem unlikely.

7.5 Conclusions

Much progress has been made to model and mitigate the effect of sonic booms from supersonic flight. Ongoing research to assess the impact on the public indicate that new supersonic aircraft designs will create quieter sonic thumps that are much less annoying than conventional sonic booms. Upcoming community tests with a low-boom demonstrator aircraft will collect the data needed on noise exposure and resulting public reactions.

CHAPTER 8. UAM/UAS noise

8.1 Current status

New aircraft technologies for increased mobility are likely to lead to new sources of community noise. Urban Air Mobility (UAM) refers to a range of vehicle concepts and missions operating in a community, from small Unmanned Aerial Systems (sUAS) to vehicles large enough for several passengers. The sUAS are envisioned for package delivery, surveillance, agriculture, surveying, and other similar applications that can benefit from use of a small and agile autonomous system, while the larger vehicles are envisioned for on-demand urban passenger transportation.[165] Electric propulsion is seen as a key technology that could enable these kinds of systems, across the range of vehicle types and sizes.[165]

UAM vehicles have the potential to alter the community soundscape due to their noise characteristics that are qualitatively different from traditional aircraft.[166-168] In addition, similar to sonic booms from supersonic aircraft en route, the noise may not be concentrated around traditional airports. There is very little scientific research on the human impacts of noise from UAM aircraft, although there have been increased efforts to measure and model the noise generated by them and their components.[167,169-172] Two psychoacoustic studies are briefly described here.

A study[166] was conducted by NASA to evaluate human annoyance to sUAS noise, including the effect of variation in operational factors and a comparison of annoyance to noise from road vehicles. The noise from four commercially available sUAS and four road vehicles, ranging in size from a passenger car to a step van, were recorded and presented to test subjects in a specialized simulation facility. For this limited set of noise sources, a systematic offset was found that indicates the noise of sUAS is more annoying than noise from road vehicles when presented at the same loudness.

Another NASA psychoacoustic study[168] concentrated on annoyance to noise from a simulated distributed electric propulsion (DEP) aircraft. Using auralizations from noise predictions of spatially-distributed, isolated propeller noise sources, the subjective study in a specialized psychoacoustic facility found that the number of propellers and inclusion of time-varying effects were significant factors in annoyance, while variation of the relative revolutions-per-minute (RPM) between propellers was not significant. The study also developed an annoyance model based on loudness, roughness, and tonality for predicting annoyance to these DEP sounds. Despite the limitations in prediction methods and simplifications, the study identified the relevant parameters and metrics that should be studied further.

8.2 Conclusions

Growing interest in UAM aircraft has been observed from different sectors, such as hobbyists, commercial entities, the military, government agencies, and scientists.[165] There is preliminary evidence that the public may be concerned with these new noise sources intended for transportation and package delivery.[173] Although there is only a very limited amount of research on subjective reaction to noise from these new aircraft types, indications that the noise characteristics differ from traditional aircraft warrant further research to understand and predict human perception of these sounds.

CHAPTER 9. ECONOMIC COST OF AVIATION NOISE / MONETIZATION

9.1 Introduction

Sleep disturbance, myocardial infarction, annoyance, stroke, dementia, and other health effects are increasingly recognized as economic costs of noise.[174] Recent studies estimating annual noise costs around specific major world airports are useful in considering the scale of the challenge and include: Taipei Songshan Airport €33 million[175] and Heathrow £80.3 million.[176] An unpublished student thesis by Kish (2008) suggests annual costs for aviation noise at 181 airports worldwide in excess of $1 billion, which is not out of line with the individual airport estimates.[177] It is clear that noise can be a key factor when airport expansion is considered. Values of disturbance from aircraft noise are used in analysis and planning decisions affecting airport development and operations. Their main application is in estimating the costs or benefits arising from changes in noise levels and/or exposure. It is therefore important to look at the evidence that underpins these value estimates. There are three main approaches for monetizing noise costs, two of which value the nuisance according to individual preferences: revealed preference, usually hedonic pricing, and stated preference methods, which include contingent valuation and stated choice. The third type of approach, the impact pathway, links health effects of noise nuisance to monetary values from reducing morbidity risks that are typically derived from elsewhere. These are discussed in turn below.

9.2 Hedonic Pricing (HP)

The main method using revealed preference is hedonic pricing whereby the market for an existing good or service, in this case housing, is used to derive the value for components of that good, in this case the noise environment. House price in HP is modelled as a function of property characteristics that should include all social, spatial, and environmental factors. HP then provides the percentage change in house prices resulting from a 1 dB change in noise levels.[178,179] The method has been extensively applied to the problem of aircraft noise, especially in North America. Individual studies yield a wide range of price changes from 0% to 2.3% per dB.[180] Thus a key challenge is to derive values that are applicable or transferable in different contexts.

Meta-analyses have sought to estimate consensus values based on pooled evidence from individual studies.[181-183] These meta-analyses are based on a reasonably small number of, US dominated studies, observations of 30, 29 and 53 respectively. Nelson (2004) and Wadud (2013) converge on 0.5 to 0.6% house price fall in response to a 1 dB increase in aviation noise, with caveats concerning the broad range of estimates and a dearth of studies in less developed countries. Using data on income, Kish (2008) carried out a meta-analysis on US based HP evidence, estimating a model with a low but reasonable fit, which he found did not transfer well to UK data. He et al. (2014) built on this work[184] but their model fit was poor. The evidence from these studies also suggests that values in Canada are higher[182,183] or more generically that values outside the US are higher.[184] Interestingly, Kopsch (2016) reports a meta-analysis including air and road noise, finding that aviation noise increases the NDI by 0.4 to 0.6% relative to road.[185] To conclude, the best available evidence from the HP is that house prices fall by 0.5 to 0.6%, on average, per 1 dBA increase in aircraft noise, and there is also some support for country specific effects.[182,183]

9.3 Stated Preference (SP)

Stated preference approaches have been increasingly applied to value noise nuisance especially in Europe. These involve either direct questioning on value, contingent valuation, or trade-off approaches, stated choice or ranking. As with HP, individual studies exhibit a wide range in values per unit of noise. A data set of 258 values of transportation noise derived from SP studies, adjusted to 2009 prices, yielded an average value per decibel change per household per annum of $141.59, 95% Confidence Interval (CI) +/- $30.24 with a range from $0 to $3,407.67. However the aviation noise values within this data, 69, exhibit less variation with a mean of $292.24 and a CI of +/- $23.10 and smaller range of $15.05 to $1097.83. Such variation in values may reflect genuine variations in preferences, the impact of contextual variables, variations in approach, systematic study or country effects, and changing preferences over time or some combination of these effects.[186] Again, meta-analysis can assist in explaining some of this variation. Only one meta-analysis has been conducted on studies of transportation noise, utilising 258 values derived from 49 studies across 23 countries conducted over a 40-year period.[186] As might be expected, the value of noise reduction or the cost of noise increases were found to be dependent on level of annoyance and income. The income elasticity was close to one, suggesting that the value placed on reduced noise increases broadly in line with income; this is higher than estimates from cross sectional studies. There were no country effects found in this meta-analysis, suggesting that the model and values derived from it are transferable. Additionally, aviation noise was found to have a higher cost per dBA than road and rail noise. A result that is consistent both with studies of annoyance,[6] and HP meta-analysis.[185] Furthermore, comparison with the then HP-based approach applied by the UK Department for Transport at the time (2014) indicated that the values from the SP meta-analysis and the HP-based approach were broadly comparable. [186] This is also supported by the primary research of Thanos *et al.* (2015), applying SP and HP in the same context.[195]

9.4 Impact pathway

The third approach is rather different by exploring the impact pathway (IP) for noise effects on human health, and expressing those endpoints in terms of Disability Adjusted Life Years (DALYs) or Quality Adjusted Life Years QALYs) to quantify healthy life years lost. The World Health Organization adopted this approach[174] and identified disability weights (DW) for cardiovascular disease, sleep disturbance, tinnitus and annoyance resulting from environmental noise. The evidence on the health impacts in all areas has been growing over the years. However, the evidence base underpinning the DWs for sleep disturbance and annoyance is extremely sparse, with a high degree of uncertainty.[180] This is reflected in the WHO (2011, p: 93) weight on annoyance where “a tentative DW of 0.02 is proposed with a relatively large uncertainty interval (0.01-0.12)”. This DW is only applicable those who are “highly annoyed”, so any individuals experiencing annoyance who are not highly annoyed are assigned a value of zero.

There is uncertainty around the value of a healthy life year lost, which is combined with the DW weights to derive monetary values. In practice, value of life has been derived from stated preference studies of traffic fatalities in the UK,[188] or reduced mortality risk based on stated preference studies in Europe.[189] As these values do not stem from analysing the health risks of noise nuisance, there is an added element of uncertainty regarding transferability of values from diverse contexts. Furthermore, the impact pathway approach has many steps each with potential to add error and uncertainty to the value/cost estimates. As Freeman et al., (2014, p: 441) put it, “significant work is needed to improve and update the values of reducing risks that lead to morbidity and/or mortality.”[190] Nevertheless, the method has been adopted into policy analysis by the UK Department of Transport[191] in assessing transport schemes and by the European Commission in evaluating the environmental noise directive.[192]

9.5 The abatement and mitigation costs of dealing with noise

The costs imposed by noise lead to efforts to measure, manage and mitigate. Airports can bear substantial costs, for example at the high end of the scale, Amsterdam Schiphol spent approximately €644.6m largely on insulation between 1984 and 2005.[193] Nevertheless this only amounted to €0.58 per passenger. Whilst manufacturers have produced quieter aircraft, there is a trade-off between achieving energy efficiency and quieter design and operation. The benefits of any mitigation activity should outweigh the costs. The costs of mitigation are relatively straightforward to estimate, as they have a market price of implementation and maintenance, in the case of noise insulation or barriers, or of estimating forgone benefits, for instance, of noise curfews. It is also rational to compare the costs of different routes to achieving a noise reduction target, for example through regulation or market incentives. Once both the costs of noise and any additional costs of mitigation are established; cost benefit analysis (CBA) can be used to guide towards solutions with the highest net benefits.

9.6 Conclusions

Economic valuation of noise nuisance and health effects is necessary and robust values are available. Most importantly, these values are applied and used in decision making. Meta-analysis of both hedonic pricing and stated preference studies suggests that these approaches, when properly applied, deliver robust values of noise nuisance. These preference-based approaches do not capture the health effects of noise that are not perceived by the exposed population. The impact pathway approach provides non-market values for these health effects. However, IP does not value annoyance at levels less than “highly annoyed”, has a less well developed evidence base than HP and SP, and requires more steps that have the potential to introduce more error. Furthermore, HP and SP meta-analyses have improved the transferability of values providing confidence intervals for their variation, whereas there is no robust evidence on value transferability for the IP approach. This approach should be viewed with caution in the absence of a well-developed evidence base, and especially in the case of annoyance effects perceived by the exposed populations, for which robust values of noise nuisance can be delivered by tested methods.

CHAPTER 10. OVERALL CONCLUSIONS AND FUTURE WORK

This paper has provided an overview of the many different aircraft noise impacts. There is substantial evidence that increases in noise levels lead to increases in community annoyance, but there are other non-acoustical contributors to annoyance. In future work, existing exposure-response functions should be updated and diversified to account for various acoustic and non-acoustic factors. The difference between a high rate change and a low rate change situation seems to be particularly important.

Undisturbed sleep is a prerequisite for high daytime performance, well-being and health. Aircraft noise can disturb sleep and impair sleep recuperation. Further research is needed to (a) derive reliable exposure-response relationships between aircraft noise exposure and sleep disturbance, (b) explore the link between noise-induced sleep disturbance and long-term health consequences, (c) investigate vulnerable populations, and (d) demonstrate the effectiveness of noise mitigation strategies. This research will inform political decision making and help mitigate the effects of aircraft noise on sleep.

Epidemiological evidence from a systematic review published in 2018 covering studies up to 2016 and subsequent published studies involving several million participants show associations of aircraft noise with ischaemic heart disease. This is consistent with the evidence for road traffic noise, with larger numbers of studies. There is biological plausibility for impacts of noise on health and experimental evidence of effects of noise on the mechanistic pathways relating to cardiovascular disease, supporting the likelihood that associations are causal. Associations between aircraft noise and hypertension or stroke are less consistent across epidemiological studies, but other biological mechanisms than hypertension are available to explain associations with heart disease. However, the evidence base for aircraft noise remains limited and further research may result in changes to exposure-response relationships with cardiovascular disease, such as those derived from the systematic review of studies published in 2018. The evidence base is limited for non-cardiovascular outcomes; further research is particularly needed on diabetes and obesity, mental health, and pregnancy and birth outcomes. Further research is also needed using additional noise metrics, including those that better characterise air traffic events than average sound level (e.g. number of events above a certain noise threshold) and that consider time period (e.g. late evening and early morning).

There is robust evidence for an effect of aircraft noise exposure on children's cognitive skills such as reading and memory, as well as on standardized academic test scores. Future research needs to test the different mechanisms and to inform key individuals who can intervene on the behalf of exposed children. Longitudinal studies over the lifecourse need to be conducted.

While some surveys suggest a higher response to helicopter noise than to noise from fixed-wing aircraft, any observed differences in annoyance seem to heavily depend on non-acoustic factors. Overall, there is no evidence for a pronounced difference between response to fixed-wing and to rotary wing aircraft at equal noise levels that would justify a stricter evaluation of helicopter noise. Only when the helicopter noise is characterized by a large degree of low-frequency energy, which may produce rattle noise or vibration in buildings, there is evidence that annoyance is markedly increased. Further research should consider the consequences of rattle noise to the evaluation of helicopter noise, as well as the important role of non-acoustic factors.

Using laboratory simulators and testing in the field with special aircraft manoeuvers, progress has been made on understanding and predicting human response to sonic boom noise from overflight of new proposed quiet supersonic aircraft. To confirm these results and extend the applicability of derived models, a new low boom flight demonstrator aircraft is being built to conduct sonic boom community response studies. Plans are underway for designing these experiments to develop exposure-response models for this new kind of quiet supersonic aircraft. Several aspects of human response to low-boom supersonic flight still remain to be researched. Subjective studies have not fully investigated perception of focus booms, booms from other parts of the trajectory outside the cruise portion, noise in the shadow zone beyond lateral cut-off, Mach cut-off booms, and secondary booms. In addition, sleep disturbance relating to low-boom supersonic cruise flight or any of these other conditions has not been studied. Finally, community studies are needed using quiet supersonic aircraft in areas where people are not accustomed to hearing sonic booms, in order to develop a dose-response relationship for this new sector of commercial transportation. Regarding the non-technical aspects of public acceptability for supersonic aircraft noise, there is nothing in the literature that directly applies. However, it may be possible in the future to draw from the existing literature on the topic of non-acoustical factors for subsonic aircraft noise. We are fortunate that there already have been many studies on how animals react to conventional sonic booms, and current thinking is that the new low-boom aircraft would even have less of an impact. It is still unknown if large animals with good low-frequency hearing such as elephants will respond any differently compared to the medium and small sized animals that have already been studied.

There is preliminary evidence that the public may be concerned with the new UAM noise sources intended for transportation and package delivery. Although there is only a very limited amount of research on subjective reaction to noise from these new aircraft types, indications that the noise characteristics differ from traditional aircraft warrant further research to understand and predict human perception of these sounds.

Evidence from hedonic pricing and stated preference studies suggests that these approaches, when properly applied, deliver robust monetary values of noise nuisance. Although the impact pathway approach additionally provides non-market values for health effects, it should be viewed with caution especially in the absence of a well-developed evidence base and evidence on value transferability. There remains a need for further research to improve the robustness of the impact pathway approach and comparisons with other approaches. A further issue is that of evidence for lower income countries which is very sparse.

Comparisons between aircraft noise impacts and other noise source impacts, such as rail, road, and industrial noise, are beyond the scope of this current white paper. Others have already pointed out some of the similarities and differences in impacts between different types of noise sources, so much of that information is currently available.[194]

CHAPTER 11. ACKNOWLEDGMENTS

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APPENDIX A - Sonic Boom Noise Impact, Additional Detail And References

A1. Sonic boom impacts on humans

A.1.1 Unique qualities of sonic booms

There are several unique aspects of sonic booms that require different treatment from subsonic aircraft noise. The transient nature of the sonic boom and large amount of low-frequency energy in the signal result in a sound character that is perceived much differently than conventional aircraft. While subsonic aircraft noise is a concern near airports, the sonic booms from supersonic aircraft are created along the entire supersonic route and could potentially affect large segments of the population. Thus the existing methods and noise metrics for measuring and regulating aviation noise impacts cannot be used for supersonic aircraft.

With advances in aircraft shaping techniques, modern supersonic aircraft designs are predicted to create shaped, low-amplitude sonic booms heard on the ground that are much quieter than conventional sonic booms from military aircraft or the Concorde. The significant reduction in waveform amplitude and increase in rise time lead to a reduction in sound pressure level spectra, particularly at higher frequencies where the reduction can reach 60 dB. Accordingly, the loudness spectra are also reduced, by over a factor of 10 in sones over most of the frequency range critical to human hearing.

Historically, the maximum overpressure of the front shock of the waveform was used to describe the level of conventional N-wave sonic booms. Years of research using outdoor sonic boom simulators, however, resulted in identification of Perceived Level (PL) as a noise metric[98,99] that works best for a variety of signature shapes.[100] Annoyance to sonic booms as experienced indoors presents additional factors to consider that are related to the building environment.

A.1.2 Sonic boom noise generation for subjective studies

Laboratory simulators have been used effectively to study human annoyance to a broad range of sonic boom signals under controlled conditions.[101] Simulators can reproduce measured booms as well as booms predicted for aircraft designs. They can also be used to study other boom-like waveforms to study human response to different parameters and interactions. The majority of simulators reproduce sonic booms as they would be experienced outdoors, although filtered outdoor waveforms or recordings of indoor waveforms have also been presented to estimate the indoor environment. These simulators, however, lack indoor realism because there is an absence of space and reverberation, secondary rattle and vibration, and overall aesthetic composition.

Most outdoor sonic boom simulators in existence today consist of an airtight, small rigid-walled booth. The cavity is driven with subwoofer loudspeakers to reproduce the low frequencies characteristic of sonic booms, while mid-range loudspeakers fill in the rest of the pertinent spectrum. Another simulator design consists of a mobile trailer that creates a traveling wave using an array of loudspeakers, a folded horn, and an anechoic termination.[102]

High-quality headphones or earphones are also used to reproduce the audible content of sonic booms and secondary rattle noises typically encountered in indoor environments. Binaural signals have been used to approximate the auditory experience of sonic boom and rattle exposure in different-sized rooms, through the use of models and filtering.[103,104] Some limitations of this playback equipment are the absence of experiencing the sounds in a real space with natural reverberation, the absence of tactile vibration, and decreased realism due to limited very low-frequency reproduction. High-quality systems of amplifiers and headphones have mitigated this last point somewhat, but the systems are still more limited than subwoofer systems for reproducing the full frequency content of the sonic booms.

Lastly, newer simulators allow for more realistic indoor soundscapes for investigating causes of elevated annoyance to sonic booms experienced indoors. One configuration[105] consists of a small booth that can be configured for indoor listening using a partition with a window. Another installation[106] called the Interior Effects Room (IER) at NASA Langley Research Center consists of a small room configured as a living room with loudspeaker playback over arrays adjacent to two exterior walls of the simulator. The realistic indoor soundscape and environment, augmented with the ability to control secondary rattle noises and vibration, have enabled systematic studies of the factors contributing to human annoyance to sonic booms.

Sonic boom subjective studies have also been conducted with real supersonic overflight of an aircraft. In the past, these studies were limited to assessing response to very loud booms, usually produced with military aircraft. However, a special flight manoeuver called a low-boom dive has been developed[107] to mimic the lower amplitudes at the ground that would be expected from supersonic overflight of future aircraft. By adjusting the location of the dive, the ground sonic boom can be varied in level over a small geographic area. This manoeuver has been used successfully in several field studies to create a variety of boom loudness levels that would otherwise not be possible with today's aircraft in steady, level flight.

A.1.3 Human response studies

Human response to outdoor booms

Many human response tests were performed in NASA's outdoor sonic boom simulator[100] in the 1990s. These laboratory studies were designed to investigate a wide range of shaped sonic boom signatures and to gather human perception of loudness and annoyance to these sounds. Several noise metrics were evaluated for their ability to predict the subjective response. Shaped booms were rated less loud than symmetric N-waves, and PL was found to be the best noise metric for describing subjective effects both outdoors and indoors. The metric PL has hence been used widely to design and assess sonic boom characteristics of supersonic aircraft. Conclusions on the indoor environment are limited because the waveforms were created by pre-filtering booms based on frequency-dependent noise reduction for transmission of sound into a typical house.

An evaluation of the realism of outdoor boom simulation was conducted between three simulators and real booms from overflight of a supersonic aircraft.[108] PL values were found to be highly correlated between field recordings and simulator reproduction, and results increased confidence in the use of simulators for human response testing. It was noted that very low frequency energy (less than 7 Hz) was not found to be significant for assessing realism to booms experienced in an outdoor environment.

Outdoor vs. indoor response

Some studies have been conducted to compare perception of sonic booms heard in indoor and outdoor environments. A field study conducted by NASA compared ratings from test subjects seated inside and outside a house overflown by a supersonic airplane, using the low-boom dive maneuver.[109] Although the annoyance ratings showed that indoor and outdoor annoyance were the same for the same noise exposure, a post-test questionnaire highlighted an increase in annoyance indoors. This inconsistency could possibly be attributed to the methodology chosen or to the presence of a rattle indoors.

A series of subjective tests with playback of measured low-amplitude sonic booms was conducted[110,111] to further explore the inconsistency discovered by Sullivan et al.[109] Three different listening environments were explored, including headphones indoors, headphones outdoors, and an outdoor simulator,[102] and the same set of signatures were used in each case. Indoor signatures were found to be more annoying than outdoor signatures regardless of listening environment, and signatures experienced indoors were considered more annoying.

A series of tests was also conducted by JAXA[105] to evaluate both loudness and annoyance ratings of N-waves with different amplitudes and rise times, using both indoor and outdoor configurations of their simulator. Different Japanese adjectives were evaluated for correspondence with the English words of loudness and annoyance. Most of the noise metrics investigated exhibited a high correlation with response, with indoor response being higher than outdoor response for the same loudness.

Given the evidence from older community studies[101,112] and these more recent studies, it is expected that indoor annoyance will be higher than outdoor annoyance, due to several factors discussed in the following section.

Human response to indoor booms

In recent years, sonic boom subjective research has shifted to exploring perception of booms experienced indoors.[104, 113-126] Initial studies in NASA's IER simulator found that boom amplitude and rise time persist as important factors for indoor response.[113,114] Overall, the longer rise times of low booms result in decreased annoyance.

A later study evaluated indoor annoyance to sonic booms predicted for sub-scale and full-scale supersonic aircraft, which have different low-frequency energy, even for the same overall loudness value.[115,116] The test was conducted using shaped, low-amplitude booms for four classes of aircraft size from sub-scale demonstrator to full-sized airliner. For a given exterior PL, the annoyance to sub-scale aircraft booms was not significantly different than that for full-scale aircraft booms. This finding confirmed that exterior PL can be used to evaluate supersonic aircraft designs, regardless of size. These results help justify plans for use of a sub-scale demonstrator for community studies. However, results were limited to isolated booms with no rattle.

In order to address the concern from community studies that rattle is important to perception of sonic booms indoors, a series of tests was conducted to investigate human response to rattle and to combined boom and rattle.[104] Using binaural recordings of rattle played back over headphones, the study found differences in annoyance between rattle sounds of the same PL. Rattle sounds from structural elements such as windows, walls, and doors were judged more annoying than rattle from smaller objects. Most combinations of boom and rattle were more annoying than the boom alone at equal PL, giving a rattle penalty of 3-9 dB, depending on the rattle type. This result confirms the elevated annoyance indoors when rattle is present. Lastly, standard loudness and sound quality metrics were found to be poor predictors of annoyance to rattle sounds and boom/rattle combinations, but hybrid models incorporating multiple metrics resulted in higher correlations with subjective data.

Rattle studies conducted in NASA's IER facility using a more realistic sonic boom playback and indoor environment[117-119] found that rattle increased indoor annoyance. Window rattle sounds reproduced for a variety of window types demonstrated that the average increase in annoyance due to rattle was equivalent to an increase in exterior boom PL of 4 dB, confirming the headphone test rattle penalty of 3-9 dB.

Two vibration studies were also conducted in the IER to investigate the effect of vibration on annoyance to sonic booms.[120-123] The vibration condition was varied using vibration isolators on the test chair legs and in the second study, shakers attached to the seat bottom. The shaker signals were determined through structural modeling for an ensemble of approximately 6000 houses with varied physical properties, and the levels from the 84^{th} and 99^{th} percentile of the predicted peak acceleration distribution were chosen.[124] Between the two studies, vibration penalties up to 10 dB were observed, indicating that vibration also plays a role in indoor perception of sonic booms.

Another possible factor in human response to sonic booms is the startle experienced due to the transient nature of the boom. Earphone studies examined annoyance, startle, and loudness ratings for impulsive sounds including sonic booms.[125,126] The startle ratings were strongly correlated with annoyance, and the importance of the abruptness of the initial shock and resulting high-frequency energy were highlighted. Subjective judgments of startle were then compared to physiological responses using measured skin conductance, heart rate, and electrical activity of three neck muscles. Subject-to-subject and day-to-day variability in the physiological responses were observed, and their association with startle were rare. It was concluded that low booms are below the threshold of consistent physiological startle responses using the current measurement techniques.

Community studies

A community study was conducted of the response of 100 Edwards Air Force Base (EAFB, USA) residents to sonic booms, ranging from low amplitude using the low-boom dive manoeuver to higher amplitude from conventional overflight.[127,128] Although the study was primarily a methodological test in preparation for future studies with a low-boom demonstration aircraft, the daily annoyance results are remarkably similar to those from the 1960s Oklahoma City test.[129] Lessons learned from this test are being used to develop follow-on risk reduction studies in preparation for community testing with a low-boom flight demonstrator aircraft.

A.1.4 Sonic boom metrics evaluation

Since no international standard exists for defining a sonic boom metric, there is a need to identify noise metrics to quantify the noise exposure dose in dose-response curves of community test data. A study was conducted to combine results from several years of laboratory testing into a meta-analysis to evaluate candidate noise metrics, with the objective of identifying the best subset of metrics.[130] A meta-analysis was chosen because there was no clear preferred metric. Some metrics performed relatively better than other metrics in some studies, while the metrics ranking was very different for other studies. Some studies showed low or high correlations of metrics with human response in general for all metrics, compared to other studies.

An exhaustive list of approximately 70 metrics was compiled from standards and literature; expert judgment, including consideration of non-acoustic factors, resulted in 25 metrics being chosen for quantitative analysis. Different metrics treat lower frequencies differently, which is critical for describing sonic boom noise. The candidates were grouped into three categories: engineering metrics that describe aspects of the sound, loudness metrics that attempt to account for human perception of sound, and "hybrid" metrics that combine several metrics. Using three laboratory studies of human response to isolated outdoor and indoor booms, eight metrics were retained.[130] Additional analysis with two more laboratory studies on rattle and vibration effects reduced the number to six metrics: ASEL, BSEL, DSEL, ESEL (A-, B-, D-, and E-weighted sound exposure levels, respectively), PL, and ISBAP (indoor sonic boom annoyance predictor).[131] This set of six metrics will be used by NASA in development of dose-response curves from future studies of community response to sonic booms.

A.1.5 Conclusions

Sonic boom simulators and special aircraft manoeuvers have been used to investigate human annoyance to sonic booms in outdoor and indoor environments. The most important factors have been studied separately to shed light on the role they each play in human perception. Studies have confirmed the viability of using an outdoor metric to predict human response indoors, despite differences in noise dose indoors. Results indicate that low-amplitude shaped sonic booms are much less annoying than conventional sonic booms, although annoyance levels need to be confirmed with community testing.

Laboratory test results have been used in meta-analyses to evaluate candidate noise metrics, and six metrics are recommended for further study. This subset of metrics will be used by NASA in future dose-response curve analyses of community field studies using a purpose-built low-boom flight demonstrator.

Other factors not considered in the subjective studies to date include: focus boom, booms from other parts of the trajectory outside the cruise design point, secondary booms, noise in the shadow zone beyond lateral cut-off, Mach cut-off booms, and sleep disturbance relating to any of these conditions.

A2. Non-technical aspects of public acceptability for sonic boom

As most people are not yet familiar with the concept of quiet supersonic civilian flight that may be developed in the future, it is likely that some individuals will assume future supersonic flights will be very much like those of Concorde or today's military aircraft, each creating loud sounds both on take-off and approach to landing as well as during supersonic cruise. In contrast, some members of the population could very well not be aware of noise concerns regarding supersonic flight from years ago, and hence, would be more open to this new transportation option. Therefore, it seems likely that, from the start, the public will have mixed reactions to future supersonic aircraft, without even having heard them.

The CAEP Steering Group requested that its Impacts and Science Group (ISG) investigate the "non-technical aspects of public acceptability" for the noise of future supersonic civilian aircraft. There is no peer-reviewed literature available to easily address this topic. At the Aviation Noise Impacts Workshop held in Montreal, forming the basis of the present white paper, an open discussion was held on the topic by the attending scientific experts. It became clear during the discussion that there were some parallels between the "non-technical aspects of public acceptability" and the area known as "non-acoustical factors" of noise annoyance research, previously described in this paper for subsonic aircraft.

Currently there are no studies available to compare attitudes and/or reactions of the public between subsonic and supersonic aircraft noise. Referring back to the section of this white paper on community annoyance briefly, the population usually does not think of the benefits of air travel when assessing their tolerance to aircraft-generated noise, and there is no reason to think there will be differences in these tolerances between subsonic and supersonic aircraft. There is also no reason to believe that a lack of trust in and/or sensitivity to fair treatment by politicians, airports, airlines, and manufacturers would be any different between subsonic and supersonic travel. So much of the knowledge regarding "non-acoustical factors" of annoyance may well also apply to the "non-technical aspects of public acceptability." Hence, the applicability of our knowledge of "non-acoustical factors" to the issues of "non-technical aspects of public acceptability" should be explored in the future. ISG will continue to study this issue, but it is unlikely that our knowledge, based in science, will change in the next few years regarding public acceptability to new supersonic noise sources.

A3. Impacts of sonic booms on animals

Animals can be affected by aviation operations, and the impact of supersonic aircraft noise (sonic boom) has been a topic of discussion since the 1960s when the Concorde and the U.S. SST programs were initiated. There is a sizable existing literature regarding effects of sonic boom noise on animals, both wild and domesticated. It should be noted that all past studies were primarily concerned with N-wave sonic booms with amplitudes determined by civilian and military supersonic aircraft. No studies have been conducted thus far examining the effects of low-boom supersonic aircraft, now on the drawing board, on animals.

During the 1960s and 1970s the emphasis was on farm animals and potential adverse effects of sonic booms and their economic consequences. The concern was that operators of supersonic aircraft might have to pay damages via court orders. For either low-altitude flights or accidental incidents of high-amplitude focused sonic booms, military supersonic aircraft can cause breaking of windows or cracking of plaster in buildings, resulting in damages that must be compensated. Clearly, the developers of supersonic passenger aircraft and the regulatory authorities wanted to avoid such situations. Some of the primary references for the studies of the time are (Runyan & Kane, 1973; Bell, 1972; Cottereau, 1972; and Bond, 1971).[133-136]

Bell notes that during the period 1961 to 1970, the U.S. Air Force received claims of almost 900,000 USD but paid out about 128,000 USD in awards. Over 100,000 USD of those awards were for mink, a type of animal used to make warm coats. Because of their monetary value, there were several controlled experiments conducted in which mink were exposed to real and simulated sonic booms. It was noted that female kits may be alerted, pause in activity, and look around for sources of the sound. Sleeping females may awaken and mating pairs may show momentary alertness, but the mating ritual is not disturbed. No wounding, killing, carrying or burying of kits in the nests of females were observed. One study observed that the reactions of mink to barking dogs, truck noises, or mine blasting were similar to their reactions to sonic booms. Bell noted that domestic or pet animals may react to sonic booms, and simple startle is the most common response. Occasionally reactions such as trampling, moving, raising the head, stampeding, jumping, or running may be observed due to sonic boom. Avian species occasionally will run, fly, or crowd. It was noted that these reactions are similar to those due to subsonic airplane or helicopter flights, barking dogs, or other sudden noises. Regarding studies of wild animals and to animals in zoos, it was reported that observations of deer, reindeer, and some zoo animals showed no reaction or only minimal and momentary reactions such as raising the head, pricking the ears, or scenting the air. The Federal Aviation Administration funded a study on the effects of sonic boom on fish.[137] The conclusion of the study was that sonic booms have no effects on developing fish eggs or fish. It was suggested that the pressure of a sonic boom was akin to the pressure of a pebble, stone, or boulder being dropped into water, and that this should be investigated in future studies. No follow-up studies are in the literature.

Later in the 1980s and early 1990s the emphasis switched to the studies on the hatchability of eggs and to studies conducted by the United States Air Force. The Air Force program with interest in this topic was NSBIT ADPO, the Noise and Sonic Boom Impact Technology Aerospace-Medical Division Program Office. The program director during 1989-1994 was Robert Kull, and he at the time chaired the “Noise and Animals” team of ICBEN. That team no longer exists. The two large detailed literature reviews of the time were (Kull and Fisher, 1987; and Manci, *et al.*, 1988).[138-139] In one of his unpublished overview presentations of the time Kull noted that it was difficult to observe animals in their natural environment, it's difficult to measure the noise exposure at the animal's position, the species of concern are usually low in population size and laws and/or regulations restrict access to those animals, there are thousands of species, the animals cannot be interviewed, the animals seem to habituate quickly, and terrestrial animals are usually not exposed for long periods or high levels. Each of these points make it a challenge to get the same types of impacts data for animals that we can get for the human population.

There were a number of studies examining the possibility that chicken or other avian eggs might not hatch or might be cracked by sonic booms. In 1972 Bell reported on a number of studies in the 1960s where egg hatchability was not affected by sonic booms. A later study in 1994 by Bowles et al. showed similar results.[140] However, there was one report from 1970 that a mass hatching failure of Sooty Tern eggs might have been caused by sonic booms.[141] This prompted additional research, and subsequent detailed studies[142,143] that showed this mass hatching failure was very likely not caused by sonic booms. It was suggested that it was much more likely that a predator, weather, lack of food, or insects caused the incident. Another study from this period noted that nesting peregrine falcons and other raptors were often minimally affected by mid to high- altitude sonic booms, showing no effects on their production of offspring. Overall, it was reported that adult birds would sometimes be alerted or would flee their nests in response to a loud boom, but no productivity-limiting responses were detected.[144]

Another species studied in the 1990s was the Desert Tortoise (Gopherus Agassizii). Bowles et al. reported in 1999 that simulated carpet sonic booms "did not stimulate any significant changes in behavior other than brief bouts of looking." Overall, it was concluded that the Desert Tortoise does not have an acoustic startle response.[145] It should be noted that this was a very complete study where the animals' hearing, metabolic rate, heart rate, oxygen consumption, etc. were very carefully monitored throughout the testing. During the 1990s and early 2000s NASA undertook a number of studies to assess the impact of overwater N-wave sonic booms on marine mammals, including both pinnipeds and whales. NASA's aim was to ensure that N-wave booms would be compliant with existing U.S. regulations such as the Marine Mammal Protection Act (MMPA). Physics tells us that when a sonic boom traveling through air impinges on the water that the pressure just above the air/water interface must be the same as the pressure just below the air/water interface, i.e. the boundary condition is matched. This is true for any aircraft traveling at a speed of Mach 3 or less. Also there is a large density change, a factor of about 800, between air and water. This and the sound speed difference between air and water means that almost zero acoustic energy is transferred between the air and water. Thus although there is a pressure created in the water due to sonic booms in air, there is no propagating wave into the water. So the pressure disturbance in the water hugs the surface, and the sound pressure decays exponentially with depth. High frequencies (hundreds of hertz or higher) die off very fast with depth, but some very low frequencies penetrate to distances of about 50 m. Hence whales, which come up to breath air at the surface, would likely hear sounds created by sonic booms when they are very near the surface. They will hear nothing if they are diving to deep depths. In 2001 Rochat and Sparrow conducted a computational study to see if swell on the ocean surface could focus this sound energy and create acoustic hot spots, but this focusing was very small and had little effect.[146]

The theory to predict N-wave sonic boom penetration into the ocean was developed in the 1960s, and this theory was updated by Sparrow and Ferguson in 1997 to handle arbitrary sonic boom signatures.[147] The theory was tested in the field with hydrophones (underwater microphones) deployed by boats with a supersonic aircraft overhead by Sohn *et al.* in 2000.[148] The acquired field data closely matched the simulation predictions, and these theories and results were summarized in a review paper by Sparrow in 2002.[149] It should be noted that the sonic boom sounds that might be heard underwater are at levels much less than if a sound source is making sound IN the water. In that case, there is no mismatch between the density and speed of sound as in the case of sonic booms, and the sound will propagate very effectively. This has been seen for other types of anthropogenic underwater noise such as active sonar from military operations, underwater explosions, and pile driving. Such high amplitude underwater noises are known to create problems for underwater marine life and their habitats. So there are good physical reasons why sonic booms are not in the same category and will not cause similar problems for marine life.

For the case of pinnipeds such as walrus, sea lions, seals, etc., NASA sponsored studies to measure the hearing thresholds of animals such as harbour seals, elephant seals, and the California sea lion. The results in the lab showed that after exposure to N-wave booms, that there was no evidence of temporary hearing loss for these animals.[150,151] An additional field study of a colony of seals regularly exposed to Concorde sonic booms sheds additional light.[152] Gray and harbour seals located on Sable Island, 163 km off the coast of Nova Scotia, Canada, were regularly exposed to sonic booms from Concorde flights during the 1990s. A team from the National Zoo of the United States travelled to the island and observed the seals during 3 weeks in January 1997 and during 3 additional weeks in June 1998. The team and the seals heard Concorde booms about 3 times per day during these periods. It was noted[152] that "No significant differences in the behaviour or beach counts following sonic booms, regardless of the season" and that the booms "do not substantially affect the breeding behaviour of gray or harbour seals." The takeaway from this study is that over time the animals very likely habituated to the N-wave Concorde booms, and the animals showed no adverse effects whatsoever due to regular exposure to the N-wave booms.

During the later 2000s and in the last few years there has been little new research on supersonic aircraft noise effects on animals, but a number of studies have been conducted on subsonic aviation and other transportation noise and their effects on wildlife. Some of this research has been funded by the United States National Park Service. A short overview of some of this recent research is now provided, and some review articles are now summarized.

Hanson in 2008 noted that high speed train noise with high levels can cause effects on wildlife and livestock.[153] Barber, Crooks, and Fristrup in their extensive 2010 review on chronic noise exposure for terrestrial organisms stated that there is a "preponderance" of "suggestive but inconclusive evidence" that noise "masking is substantially altering ecosystems."[154] A further extensive review by Shannon *et al.* in 2016 noted that anthropogenic "noise is detrimental."[155]

A number of recent papers found no adverse effects on animals from aircraft noise.[156-159] Other papers found that high levels of noise could cause effects. Barber *et al.* in 2011 cited studies of clear negative relationships between traffic noise on roads and birds nesting near the roads.[160] Bunkley *et al.* in 2017 showed that high levels of compressor noise could be impactful.[161] In a laboratory study in 2014 Schmidt *et al.* described that male cricket calls were not heard by females when noise was present.[162]

In 2017 Damsky and Gall noted that anthropogenic noise can affect the behaviour of songbirds.[163] In cases where the noises under study were relatively continuous there is a distinct possibility of interference with communication between members of a species and disruption of auditory cues that are part of predator/prey relationships.

In summary an extensive literature is available for N-wave sonic booms and their effects on a range of animals. Some animals such as the Desert Tortoise do not startle at all, but many animals react to sudden noises the same way that humans do. It is likely that hearing an isolated N-wave sonic boom would cause momentary startle in some animals. As there are many species of animals, there are many that have not been studied. These include large animals such as elephants and rhinoceroses that have good low-frequency hearing. Such animals can communicate over many kilometres of distance because of this low-frequency hearing capability.[164] For other sound sources, there is a body of literature showing that louder and continuous sources have effects on animal communication. And it is well established that underwater sound sources with high sound levels such as active sonar, pile driving, etc. can have detrimental effects on marine life.

The issue of startle and habituation due to sonic boom is still an open research question. However, the Perry *et al.* 2002 study clearly points to the likelihood that some animals will habituate to hearing N-wave sonic booms on a regular basis.[152] Based on the known hearing characteristics of many animal species, there is little reason to expect hearing damage from exposure to infrequent sonic booms from aircraft at cruise altitudes. Other adverse long-term effects due to sonic boom exposure also seem unlikely, but such long-term studies have not been conducted.

For overall conclusions regarding en-route supersonic aircraft noise, see Sections 7 and 10 of this white paper.

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Agenda Item 11: Decisions of the Council on the CAEP's terms of reference (TOR), structure, membership and working methods, and election of Chairperson and Vice-Chairpersons

11.1 The Chairperson presented the revised CAEP Terms of Reference and revised CAEP Directives. Consistent with the CAEP Directives, paragraph 8.1.2, the Chairperson invited CAEP to elect a Chairperson and two Vice-Chairpersons from among its Members.

11.2 In electing the Chairperson, the Member of Argentina motioned, and the Member of Saudi Arabia seconded the motion, to nominate Mr. Gilles Bourgeois, the CAEP Member of Canada, as the CAEP Chairperson, and the Chairperson was unanimously elected by the meeting.

11.3 With respect to the election of the two Vice-Chairpersons, the Member of the United States motioned, and Egypt seconded the motion, to nominate Mr. Tan Kah Han, the CAEP Member of Singapore, as one of the CAEP Vice-Chairpersons, while the CAEP Member of Australia motioned, seconded by the CAEP Member of Brazil, to nominate Mr. Urs Ziegler, the CAEP Member of Switzerland as the other Vice-Chairperson, and the two Vice-Chairpersons were unanimously elected by the meeting.

11.4 The meeting discussed the revised CAEP Directives, paragraphs 6.6 and 7.5, which state that the CAEP, CAEP Steering Groups, and CAEP subgroups should be held in Montréal, Canada to the extent possible, and that this does not rule out holding some meetings in the regions in order to facilitate regional participation. Several Members and Observers expressed concerns that convening all CAEP meetings in Montréal would disproportionally impact CAEP participants from some regions and that such a procedure was not in line with the intent of having more participation from developing States. It was highlighted that holding meetings in States from regions that are underrepresented in CAEP could encourage more participation and facilitate information flow in the region. One Member and an Observer highlighted that meetings held outside Montréal also facilitate technical visits, which are important to contextualizing the work of CAEP. Some Members noted that the prioritization of Montréal meetings facilitates the participation of States with resident delegations at ICAO.

11.5 The meeting agreed that there was wide support for holding some meetings outside of Montréal, and noted that a balance should be sought, bearing in mind the budgets of States and the Secretariat. The meeting agreed that the working group meetings which are already planned outside Montréal should remain as currently planned, as it would be too late to make the proper adjustments. The meeting agreed that CAEP should strive to define a long-term plan for meetings so that Members and Observers can secure the appropriate budgets. The Chairperson informed the meeting that he would bring these concerns to the Council.

11.6 One Member raised a question on the status of the User Agreement to obtain access to the CAEP secure portal in light of access given to Resident National Delegations to ICAO and other Member States. The CAEP Secretary informed that the updated CAEP Directives did not change the administrative process required for CAEP Members and Observers to access the ICAO Secure Portals.

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Agenda Item 12: Future work

12.1 CAEP STRUCTURE AND CAEP/12 WORK PROGRAMME

12.1.1 The Secretariat presented a compilation of potential CAEP/12 work items proposed by the current working groups and task forces. This information had been modified by the 2018 CAEP Steering Group meeting and was subsequently revised by the final set of CAEP/11 working group and task force meetings. The ICAO Secretariat also proposed additional work items for CAEP consideration.

12.1.2 A Member presented views on the organization of future work relating to CORSIA and communications. The Member supported the establishment of a working group to provide ongoing support to CORSIA, including the maintenance of Annex 16, Volume IV and of the ETM, Volume IV, as well as of the majority of the Implementation Elements (such as the continued development of the CERT). The Member also supported the view that AFTF should be maintained with a revised remit, with some of the future work on CORSIA Eligible Fuels to be undertaken by the new working group on CORSIA. The Member recommended establishing a communications sub-group in CAEP that would bring together relevant CAEP information in order to provide the what, why and how of CAEP tasks so that Council Members and aviation authorities can keep abreast of the present and upcoming work of CAEP.

12.1.3 A Member proposed conducting a stringency analysis and developing LTO noise SARPs for supersonic aeroplanes; supported the ongoing maintenance of Annex 16, Volumes I to IV and their associated ETMs; supported work on updating and improving existing models and databases; and supported the review of new modelling capabilities to better position CAEP to support future assessments. Regarding the structure of CAEP leading up to CAEP/12, the Member supported that GMTF and AFTF should evolve into two permanent CAEP groups.

Discussion and Conclusions

12.1.4 The meeting discussed the proposal for a communications sub-group and while the meeting acknowledged the need to properly communicate CAEP results, it noted that CAEP results do not completely represent the full breadth of ICAO's environmental work, which was under the purview of the ICAO Secretariat. A Member highlighted that there is an ICAO structure dedicated to communications, including regional offices, and it was unclear how a CAEP communications sub-group would interact with this structure. The meeting recognized the importance of further contributions from CAEP experts to the ICAO Secretariat work on outreach and capacity building.

12.1.5 The meeting discussed the CAEP structure to handle future work on CORSIA. A Member noted that, now that the First edition of Annex 16, Volume IV had been adopted, its maintenance could be done with a governance structure similar to WG1 and WG3, without the need of a "chaperone group" of CAEP Members. The meeting agreed that the "chaperone group" previously used in GMTF would not be needed for WG4.The meeting agreed to evolve GMTF and AFTF into permanent CAEP groups, WG4 and FTG (Fuels Task Group), respectively. The meeting agreed that the operational, policy and oversight activities related to fuels should be part of the FTG work programme, since bringing these activities to WG4 would result in a loss of expertise to perform them. The meeting agreed to the CAEP structure leading up to the CAEP/11 meeting, along with the co-Rapporteurs for each group. This information is provided in Appendix A to the report on this agenda item.

WG1 work programme

12.1.6 With regard to the WG1 work programme, a new task was included to reflect the agreement on the "Exploratory Study For Supersonic Aircraft", described in detail in 4.3.29 to 4.3.31 of the report of Agenda Item 4. This task replaced the one originally proposed by WG1 for the SST Standard development (subsonic regime). Similar tasks were included in the work programme of MDG, FESG, WG3, and ISG. Previous agreements under Agenda Item 4 were also reflected in the task related to the SST Standard development (supersonic regime), and a task related to GAEP was removed from the WG1 work programme to reflect the meeting conclusions.

12.1.7 The meeting discussed the WG1 task that proposed an investigation on possible indicators for encroachment, in cooperation with WG2. The WG2 co-Rapporteur highlighted that encroachment is a global problem and supported work to investigate the level of encroachment that has happened historically and could potentially happen in the future. One Observer was of the opinion that encroachment can only be meaningfully evaluated and understood at a local level and highlighted that there are various other factors beyond policies and legislations on land use planning that influence the population change near airports, and it was unclear how this would be considered and reflected in the study. Finally, the Observer noted that States use different metrics for noise contours, and expressed concerns that this discrepancy would mean incorrect conclusions were drawn at a global level. The meeting agreed to task WG2 with a scoping study on this proposal, to be presented at the 2019 CAEP Steering Group meeting.

12.1.8 After discussing a proposal from several Members and Observers, the meeting agreed to include an additional task requesting WG1 to review and analyse certification noise levels for subsonic jet and heavy propeller-driven aeroplanes.

WG2 work programme

12.1.9 An Observer proposed performing a scoping study to assess the potential for the creation of a global database containing details of methods used to manage environmental impacts from worldwide airport operations, as part of the WG2 work programme for CAEP/12.

12.1.10 The meeting agreed to task WG2 to develop a feasibility report to assess the potential for an airport database on noise and emissions management initiatives, despite an Observer expressing concerns about the amount of resources required to create and maintain such a database.

12.1.11 The meeting considered additional WG2 tasks proposed by the ICAO Secretariat, Members and Observers. Amongst the proposals, the meeting expressed interest in a scoping report on the environmental impact of the integration of unmanned aircraft in the ATM system. Regarding the proposed task on Circular Economy, while the meeting did not approve this task, it expressed interest in receiving regular updates from the ICAO Secretariat on the topic.

12.1.12 Several CAEP Members and Observers proposed a study on the environmental impacts of supersonic flight operations and impacts of their integration into the ATM system and airports. A Member commented that this proposed task would not question the previous agreement to carry out an exploratory study on supersonics. The Member considered that making an early assessment of any environmental impacts of supersonic flight operations would give the opportunity for environmental objectives to be integrated in the ATM design phase, rather than retrospectively when the aircraft is in service. Commenting on this proposal, a Member noted that the existing compromise on the exploratory study on supersonics aircraft should be protected and the meeting agreed that this issue should not be re-opened and as such this proposed task was not included in the CAEP/12 work programme.

WG3 work programme

12.1.13 Three Observers supported future work to update WG3 emissions modelling guidance materials, including updates to NOx, nvPM and volatile PM modelling methodologies that would result in updates to ICAO Doc 9889. The WG3 co-Rapporteurs noted that the future work item E.16 “Update and Review Doc 9889” already reflected these recommendations from the Observers.

12.1.14 The meeting discussed the future work of WG3 on engine emissions and agreed on a series of new tasks that reflect the outcomes of Agenda Item 3, including continued work on nvPM-related items.

12.1.15 Several Members and Observers proposed a new future work item on the monitoring and review of CO_2 certification and project aeroplane data with further analysis to anticipate more information on new technologies, and based on the study outcomes, provide information for a decision on whether to review the current Annex 16, Volume III regulatory levels during CAEP/13. A Member, while supporting the principle of monitoring CO_2 information, commented that it is likely too soon to review the CO_2 Standard. The meeting agreed that the task would be to monitor CO_2 information, noting that this topic may require additional input during the 2019 CAEP Steering Group meeting.

MDG and FESG work programme

12.1.16 Two Members and an Observer proposed adjusting the MDG and FESG future work items to cover new type stringency modelling, costs of standards, harmonization of analyses, uncertainties and local air quality modelling.

12.1.17 One Observer expressed concerns on the future work item F.04 “Influence of airport capacity constraints on global air traffic” due to issues related to international comparability of airport capacity data. The Observer highlighted that, at the international level, the Organisation for Economic Cooperation and Development (OECD) had invested time to develop models for the world’s 100 busiest airports, and recommended that CAEP consider this work, in coordination with ADAP, before progressing with the analysis. Concerns were also expressed on the sharing of airport-level data, which is sensitive and confidential, and therefore it was recommended to aggregate the data at a regional level.

12.1.18 In response to a request from a MDG co-Rapporteur, the meeting supported the formation of a coordination group involving WG1, WG3, MDG, FESG and ISG, in support of the exploratory study on supersonic aeroplanes. Following the suggestion from a Member, the meeting agreed that Terms of Reference for this group should be developed, having as a basis the ToR adopted for the WMF coordination group which supported the CO_2 Standard development.

ISG work programme

12.1.19 An Observer proposed that ISG develop a white paper on non-acoustic factors, which are accounted to be responsible for about 70 per cent of community annoyance related to aircraft. The meeting discussed the proposal and agreed with the task, which will be focused on a literature review on non-acoustic factors. It was highlighted that possibly most of this review was already done by ISG as part of the development of the “Aviation Noise Impacts White Paper”, and thus, ISG should verify if any additions should be made to this work.

12.1.20 The meeting agreed with the work programme proposed by ISG, with proper adjustments to consider the meeting outcomes on supersonics and the long-term goal discussions.

WG4 work programme

12.1.21 The GMTF co-Rapporteurs presented proposed tasks for future work on CORSIA to be undertaken by WG4. In line with the discussion under Agenda Items 6, 7 and 8, it was highlighted that the proposals for future work submitted by GMTF to the meeting would be the basis for work on CORSIA during the CAEP/12 cycle. The meeting noted that proposals for future work presented by some Members and Observers were already included in proposals made by GMTF, with the addition of two additional items (support to Council in preparation for the CORSIA periodic review, and continuation of the work on technical analysis relating to the implementation of CORSIA), and the need to amend GMTF's proposal on the task "EUC Management" to incorporate future work on double counting. For the latter, a Member presented a specific wording proposal which was agreed by the meeting. One Observer presented a proposal to include a stocktaking of the implementation of Annex 16, Volume IV across all States, with a focus on Part II, Chapters 1 and 2, in the task to provide support to Council in preparation for the CORSIA periodic review; the proposal was noted by the meeting, which agreed that the specific way to perform the stocktaking exercise would be determined by the new WG4.

FTG and SCSEG work programme

12.1.22 A FTG co-Rapporteur described the proposed work programme for FTG, based on the initial proposal developed by AFTF with the inclusion of amendments to reflect the meeting conclusions. The work programme for the SCSEG was also provided to the meeting, and CAEP agreed to the proposed programmes.

Aviation Carbon Calculator Support Group (ACCS) work programme

12.1.23 The ACCS Rapporteur presented the proposed work programme for ACCS, which was agreed by the meeting.

Final work programme for CAEP/12

12.1.24 As a result of the meeting discussions, the approved work programmes for all CAEP sub-groups are provided in Appendix B to the report on this agenda Item.

12.1.25 **Recommendation**

12.1.25.1 In light of the discussions the following recommendation was developed:

Recommendation 12/1 – CAEP/12 work programme

That the Council approve the revised work programme of CAEP contained in Appendix B to the report on this agenda item.

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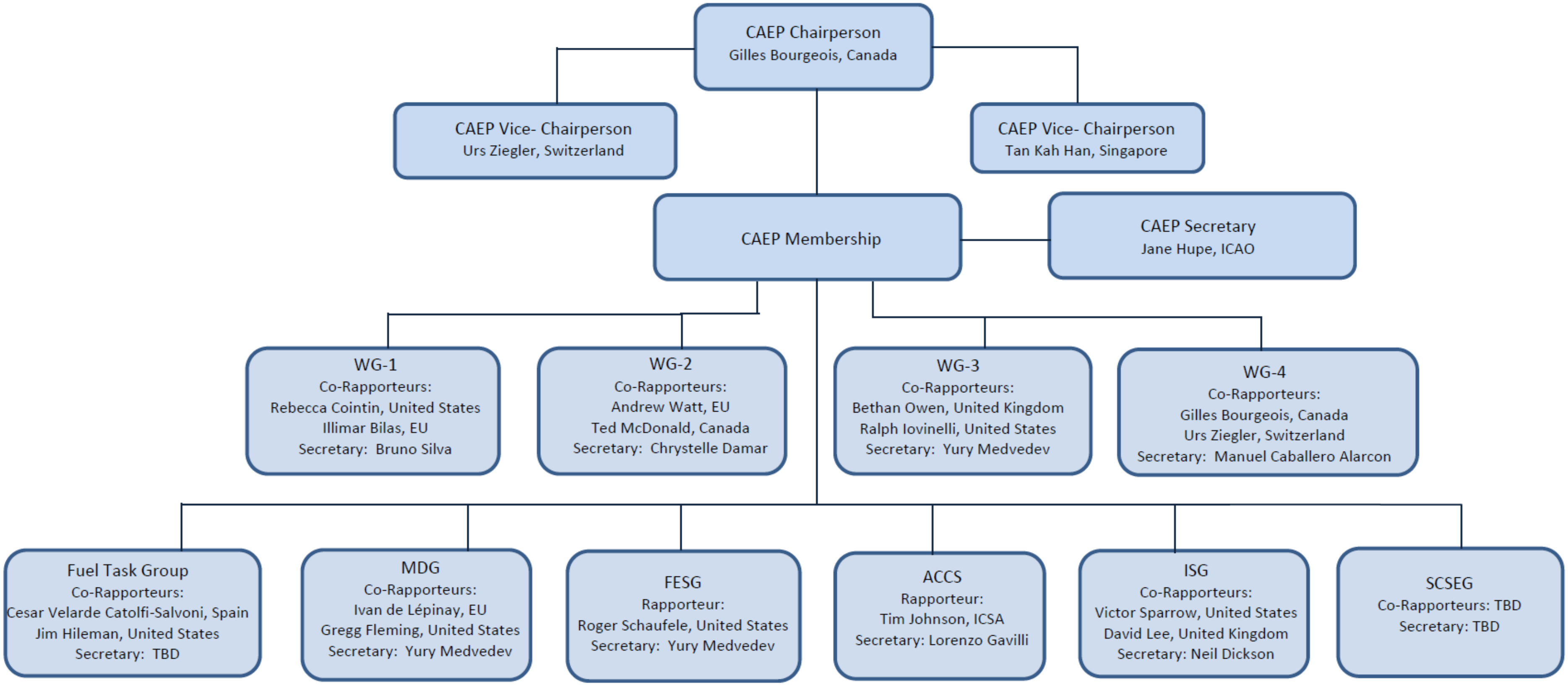
APPENDIX A
(English only)

CAEP STRUCTURE LEADING UP TO CAEP/12



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APPENDIX B
(English only)

CAEP/12 WORK PROGRAMME

CAEP/12 Working Group 1 – Noise Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
N.01	Coordination	Coordinate with other working group Rapporteurs on + interdependencies related to technology, operational issues, and goals as well as harmonizing the goal setting process. + interdependencies related to management and update of noise and emissions databases + interdependencies related to environmental impacts, including stringency + programmes for development of both noise and emissions SARPs for future supersonic aeroplanes	Coordination	Ongoing
N.02	Annex and ETM maintenance	Maintain and update Annex 16, Vol. I and ETM, Vol. I.	Updates to ETM Updates to Annex 16	SG2021 CAEP/12
N.03	NoisedB	Ensure process integrity and data currency of the ICAO noise certification database.	Up-to-date ICAO NoisedB	Ongoing
N.04	Monitor research and development	Monitor and report on the various national and international research programme goals and milestones. Review data on emerging technologies as it becomes available.	Report	CAEP/12
N.05.01	Monitoring SST research	Monitor and report on research to characterize, quantify and measure (including metric) climb and en route noise from supersonic flight, including Mach cut-off conditions, and its acceptability while also assisting in promoting and defining such research.	Report	CAEP/12

CAEP/12 Working Group 1 – Noise Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
N.05.02	SST Standard development (supersonic regime)	Continue to work on a new scheme for en route noise/sonic boom certification for supersonic flight, as informed by developments under N.05.01. Continue to gather data on which “other factors” need to be considered for SARPs development. These may include boom at “off design” Mach numbers, boom from accelerations and turns, secondary sonic booms, restricting N-wave booms over water, sleep and booms at night, effects on animals, and avalanches.	Progress report	CAEP/12
N.05.03	SST coordination	Update Air Navigation Commission with SSTG Report on progress of SST noise activities.	Briefing to ANC	May/June 2019
N.05.04	Monitoring SST projects	Monitor, and report on, status of SST projects and expectations of supersonic development.	Report	CAEP/12
N.06	New entrants noise monitoring	Monitor developments around new entrants noise (e.g. RPAS/UAS, electric aircraft, air taxis) and where appropriate suggest specific work items to SG.	Report	CAEP/12
N.07.01	Helicopter Noise Correlation	Monitor the availability of appropriate operational helicopter noise datasets, and use them to: - augment the investigation on correlating the ranking of helicopters based on certification and operational noise levels, - assess the helicopter noise certification scheme and its relevance to day-to-day operations.	Report	CAEP/12
N.07.02	Helicopter Hover Noise	Monitor the availability of appropriate helicopter hover noise datasets, and use them to assess whether the current helicopter noise certification scheme is suitable for assessing hover noise.	Report	CAEP/12

CAEP/12 Working Group 1 – Noise Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
N.08	Environmental Trends	WG1, WG2, WG3 and AFTF to update their respective input assumptions to the ICAO Environmental Trends Assessment, in coordination with MDG.	Status Report: SG2019 Final inputs: SG2020	SG2020
N.09	Review of Annex 16, Vol. I, Chapter 14	Review and analyse certification noise levels for subsonic jet and heavy propeller-driven aeroplanes. Based on the analysis, assess cumulative margin relative to Chapter 14 and the margins at each of the 3 certification points.	Report on the findings	CAEP/12
N.10	Exploratory Study For Supersonic Aircraft	Conduct the exploratory study for supersonic aircraft as detailed in Sections 4.3.29 to 4.3.31 of the CAEP/11 report.	Recommendations on procedures for LTO noise certification	SG2019
			Preliminary Results	SG2021
			Final Results	CAEP/12

CAEP/12 Working Group 2 –Airports and Operations – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
O.01	Understanding Aviation Stakeholder Community Engagement Needs in the Context of Delivering ATM Change	Having completed the report on PBN and community engagement, discussions at WG2 focused on the desire to continue working on this subject and to understand the needs of States and other stakeholders in the area of community engagement relating to deploying change in the ATM system. This task seeks views from States regarding their needs on community engagement practices and lessons learned.	Report	CAEP/12
O.02	Operational Opportunities to Reduce Aircraft Noise	Continue with CAEP/11, task O.02, to develop an ICAO document "Operational Opportunities to Reduce Aircraft Noise", to completion. The task will be aimed at identifying and highlighting good practices and the operational opportunities to minimize aircraft noise from aircraft operations where practicable and operationally safe to do so.	Report	CAEP/12
O.03	Environmental Metrics of relevance to the Global Aviation System	During the CAEP/11 cycle, WG2 was requested to consider the possibility to develop environmental KPIs for use in an ATM context. The work conducted during the CAEP/10 cycle by CAEP WG2 (Task O.12) in coordination with WG1 and WG3, demonstrated that the current level of understanding of the environmental impacts of the current GANP KPIs would not allow to satisfactorily address the definition of environmental indicator. Task O.12 led to the conclusion that further work would be necessary to understand better current environmental metrics used by States and operational stakeholders beyond an ATM environment, to assess the performance of all players within the global aviation system.	Report	SG3 (state-of-play) and CAEP/12 (recommendations if deemed necessary by SG3)

CAEP/12 Working Group 2 –Airports and Operations – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
O.04	Review of the 2019 update to the Global Air Navigation Plan	ICAO will undertake a major update of the GANP in 2019 including the ASBU documentation. In this update, a new structure is expected including updated blocks, modules and elements. The future task proposal is to undertake a review of the 2019 GANP (to be proposed for adoption at the 40th Session of the ICAO Assembly) with a view of understanding whether the new structure/content modules would result in the need for further ASBU analysis.	Oral report (initially)	SG2019
O.05	Flight efficiency	Based on the conclusions presented to CAEP/11, the global HFE analysis was considered as a first step towards analyzing global flight efficiency. The task proposed for the CAEP/12 cycle would consist of performing a global VFE analysis.	Report	CAEP/12
O.06	Climate Change Adaptation Synthesis Dissemination	1) Assist Secretariat in making relevant information from the climate adaptation synthesis adopted by CAEP/11 available on the ICAO website. Review and assess the synthesis information for suitability and relevance for dissemination, and determine the best format to make it available. 2) Determine a methodology and timeline for ensuring the information in the synthesis stays current and incorporates the latest scientific information. If significant and relevant information is published in the next CAEP cycle the update process may be initiated. 3) Assess whether an update of the survey sent for the CAEP/11 Synthesis Report would provide useful information and, if so, what would be an appropriate timeframe e.g. for CAEP/13.	Public dissemination of the CAEP/11 Climate Adaptation Synthesis, and report to CAEP on process for regular updates to the Synthesis.	CAEP/12

CAEP/12 Working Group 2 –Airports and Operations – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
O.07	Climate Change Risk Assessment, Adaptation, and Resilience	Building on the CAEP/11 Task O.07 Climate Adaptation Synthesis adopted by CAEP/11, this task will produce and distribute a report on identified steps to develop climate change risk assessments and adaptation and resilience measures, so as to provide a “menu” of options for aviation stakeholders to consider in their own planning. Aircraft operations will be included in the scope of the study (Climate Change risk assessment, adaptation and resilience for ANSP and airport infrastructure and operations). The document will be broadly-applicable and non-prescriptive.	Guidance Document	CAEP/12
O.08	Eco-Airport Toolkit e-collection	It is proposed to deliver four e-publications to be made freely available on the ICAO website and covering the following topics: • Water management at airports (including glycol management); • Air Quality Management; • Green airport surface access; • Climate resilient airports; These topics were identified by WG2 during the CAEP/11 cycle.	e-collection series	SG2019, SG2020, SG2021 and CAEP/12
O.09	Monitor Developments and Maintenance of Publications	The work of WG2 includes monitoring and reporting of national and international advancements in support of improved environmental procedures and operations. WG2 reviews these advancements in order to maintain the ongoing relevance of existing publications and to make recommendations for updates or additional information, as required.	WPs submitted to Steering Groups	on-going
O.10	Environmental Trends	WG1, WG2, WG3 and AFTF to update their respective input assumptions to the ICAO Environmental Trends Assessment, in coordination with MDG.	Status Report: SG2019 Final inputs: SG2020	SG2020

CAEP/12 Working Group 2 –Airports and Operations – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
O.11	Environmental Impact of Unmanned Aircraft Operations at and around airports	As Unmanned Aircraft (UA) operations are increasing and their applications diversifying (wildfire mapping, disaster management, weather/environment monitoring, package delivery/freight transport), Remotely Piloted Aircraft (RPA) are expected to be ultimately integrated into airspace for international, instrument flight rules (IFR) operations. ICAO has developed a work programme to review the relevant Annexes to the Chicago Convention and integrate RPAs-related element. The 13th Air Navigation Conference requested ICAO to "provide an update on a fully integrated approach for ICAO's RPAS related work programme to the 40th Session of the Assembly in 2019" (ANC/13). While CAEP WG1 (noise) is responsible for assessing the noise certification impacts of RPAs, it is proposed that CAEP gains understanding on the impact of RPAS operations at and around airports and communicates this information to Council. The objective would be to get a snapshot of the current situation at international airports throughout the world and to collect the views from aviation stakeholders on their assessment of the impact of RPAS operations on their own activities. This would allow responding to very concrete questions, such as the potential need for dedicated infrastructure at airports, the ability of operational stakeholders to pursue the implementation of ATM-related changes delivering environmental benefits.	Scoping report	SG2020 and CAEP/12 for recommendations, if deemed necessary by SG2020
O.12	Investigation on possible indicators for encroachment	Investigation of possible means to evaluate encroachment levels at a global scale.	Scoping Report	CAEP/12

CAEP/12 Working Group 2 –Airports and Operations – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
O.13	Assessment of the potential for an airport database on noise and emissions management initiatives	The task is to complete a scoping study to assess the potential, feasibility and resource necessary to create a centralized database of existing initiatives related to the environmental impact of aircraft operations at airports, globally. If it was found to be feasible and desirable, then a follow-on task could be to support the creation of a database containing a reliable, consolidated source for initiatives used to manage environmental impacts at worldwide airport operations, for use by airport operators, aircraft operators, policy makers, and others involved and interested with the management of noise and emissions at airports	Report	SG 2021

CAEP/12 Working Group 3 –Emissions Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
E.01	Interdependencies	Coordinate with other working group Rapporteurs on interdependencies related to (a) technology, operational issues and goals (b) management and update of noise and emissions databases (c) environmental impacts (d) SARPs for future SST aircraft.	Coordination report for each SG	CAEP/12
E.02	Fuel composition and emissions	Monitor trends in 1) petroleum-based aviation kerosene fuel supply composition, 2) aviation alternative fuel based kerosene fuel supply, and 3) blended fuel types. Consider the impacts of fuel composition on nvPM or precursors of vPM at the engine exit and the corresponding emission indices. This would permit to assess, for example, the potential benefit of fossil fuel desulfurization on emission indices. Coordinate with ISG (I.04) when necessary.	Report	CAEP/12
E.03	Emissions Certification requirements - new subsonic aeroplane applications and concepts	Monitor developments in aeroplane and engine applications and concepts, such as freighter applications or technology developments e.g. blended wing body, or non-classical tube and wing configurations and open-rotor engines etc., and develop methodologies for emissions certification.	Report	CAEP/12
E.04	Annex 16, Volume II maintenance	Maintain Annex 16, Volume II on aircraft engine emissions.	Proposed Annex changes	CAEP/12
E.05	ETM, Volume II maintenance	Maintain Environmental Technical Manual, Volume II on aircraft engine emissions.	Proposed ETM changes	CAEP/12
E.06	Annex 16, Volume III maintenance	Maintain Annex 16, Volume III on aeroplane CO_2 emissions.	Proposed Annex changes	CAEP/12
E.07	ETM, Volume III maintenance	Maintain Environmental Technical Manual, Volume III on aeroplane CO_2 emissions.	Proposed ETM changes	CAEP/12

CAEP/12 Working Group 3 –Emissions Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
E.08	Emissions Engine Databank maintenance	Maintain engine emissions certification databank.	up-to-date databank	CAEP/12
E.09	CO_2 Certification Database maintenance	Maintain aeroplane CO_2 certification database.	up-to-date database	CAEP/12
E.10	G&R database maintenance	Review and update a "Growth & Replacement" database in order to support development of models used to populate future fleets and the replacement of retired aircraft. Coordinate with MDG/FESG, WG1 and support groups to ensure consistency in assumptions.	up-to-date G&R database	CAEP/12
E.11	NOx + nvPM Cruise - Climb relationship	Review the LTO nvPM and NOx - cruise climb relationship for staged combustion and future engine technologies, to quantify control of mission emissions of nvPM/NOx, and identify any methodology issues with respect to the correlation between LTO and climb/cruise and to quantify interdependencies with other emissions, in coordination with ISG (item I.03) when necessary.	Report	CAEP/12
E.12	Certification Requirements - SST	Monitor trends in supersonic technology and assess consequences for engine based emissions and certification Standards.	Proposed changes to Annex 16, Volume II and ETM, Volume II	CAEP/12
E.13	SST CO_2	Monitor trends in supersonic technology and assess consequences for aeroplane emissions and certification Standards.	Report	CAEP/12
E.14	Modelling emissions at low power	Provide guidance on the modelling of emissions at low power settings.	Report	CAEP/12

CAEP/12 Working Group 3 –Emissions Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
E.15	nvPM model inputs and emissions inventories	Develop improved nvPM model inputs to both local air quality models and, as required, global climate models per advice from ISG. Note input from ISG on nvPM impacts.	WG3 Report	CAEP/12
E.16	Update and review Doc 9889	Update Doc 9889 to reflect industry best practices, new emissions data for modern aircraft and airport emission sources, airport operational information that affect aviation emissions, and emissions modelling methodologies.	Updated Doc 9889	CAEP/12
E.17	NOx scoping study	Conduct NOx scoping study cut-off for in-production engines and present the analysis results to SG2019.	Report	SG2019
E.18	Environmental Trends	WG1, WG2, WG3 and AFTF to update their respective input assumptions to the ICAO Environmental Trends Assessment, in coordination with MDG.	Status Report: SG2019 Final inputs: SG2020	SG2020
E.19	Exploratory Study For Supersonic Aircraft	Conduct the exploratory study for supersonic aircraft as detailed in Sections 4.3.29 to 4.3.31 of the CAEP/11 report.	Report	Each SG and CAEP/12
E.20	nvPM Emissions	Following proposals in CAEP/11-WP/17 for WG3 further to investigate ambient conditions corrections for nvPM. Additional work is also needed to address nvPM losses in the measurement system.	Report	CAEP/12
E.21	Review CO_2 information	Monitor, review and analyze latest CO_2 information for subsonic aeroplanes and any available certification data. Based on the analysis, assess margin relative to the CO_2 subsonic Standard. The analysis should anticipate more information on new technologies, including project aircraft.	Report	CAEP/12

CAEP/12 Working Group 3 –Emissions Technical – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
E.22	Review of nvPM regulatory levels	Following CAEP/11 decisions on the new nvPM Standard, WG3 to review the nvPM regulatory levels. This will involve the collation and analysis of the certified and certification-like nvPM mass and number emissions data that becomes available for all in-production engines. This will include a review of margins to the new type nvPM mass and number Standards and an assessment of possible technological advancements to reduce nvPM emissions.	Report to inform the need to update the nvPM emissions Standards	CAEP/12

CAEP/12 Working Group 4 – CORSIA – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
C.01	Maintenance of Annex 16, Volume IV and related guidance material	Maintenance of Annex 16, Volume IV and related guidance material in line with similar work undertaken for other Volumes of Annex 16	If required, revised Annex 16, Volume IV	CAEP/12
			If required, revised Doc 9501 (ETM, Volume IV)	
			Continuous support to the ICAO Secretariat in the production of materials aimed at facilitating implementation of Annex 16, Volume IV	
C.02	Work on the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT)	Development of the 2019 and subsequent versions of the ICAO CORSIA CERT	2019 version of the ICAO CORSIA CERT and related technical documentation	June 2019
			2020 version of the ICAO CORSIA CERT and related technical documentation	June 2020
			2021 version of the ICAO CORSIA CERT and related technical documentation	June 2021
C.03	Development of further guidance on monitoring, reporting and verification (MRV) in CORSIA	Development of further guidance on monitoring, reporting and verification (MRV) in CORSIA	Guidance material to be incorporated in subsequent revisions of Doc 9501 (ETM, Volume IV)	CAEP/12
C.04	Supply, Demand and Price of Units	Further assessment of supply, demand and price of emissions units for CORSIA implementation	If requested, update of the work undertaken by GMTF on this topic in the CAEP/11 cycle, as reported in CAEP/11-IP/14	CAEP/12

CAEP/12 Working Group 4 – CORSIA – Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
C.05	EUC Management	Development of recommendations on technical approaches to the management of Emissions Units Criteria (EUC)	Recommendations on technical approaches to the management of EUC	CAEP/12-SG2019 for recommendation s for items in CAEP/12-IP/18 Section 2 CAEP/12 for further items
C.06	Programme registry requirements to facilitate application of the SARPS	Identification of an approach for the application of programme registry requirements to facilitate application of the SARPs	Identified approach for applying programme registry requirements	To be determined
C.07	Support Council in preparation for the CORSIA periodic review	Development of methodologies and procedures for the CORSIA periodic review, including stocktaking of the implementation of Annex 16, Volume IV across all States, with a focus on Part II, Chapters 1 and 2, which will be used to inform the review	Report to CAEP for approval and submission to the Council, when requested	For CAEP consideration: as soon as practicable in advance of the first review in 2022. For Council consideration: upon Council's request.
C.08	Technical Analysis Support	Support Council requests and needs from other Working Group on CORSIA tasks (e.g., C.04) on technical analysis relating to the implementation of CORSIA. Support updates to technical analyses to (1) reflect the evolution of assumptions underlying the implementation of CORSIA and (2) ensure consistency with other CAEP analyses e.g., updates of GHG trends at CAEP/11.	Report on analyses (as needed and appropriate) during CAEP/12 and summary report at CAEP/12.	CAEP/12 (with interim reports as needed).

CAEP/12 Fuels Task Group (FTG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
S.01.01	Computation of induced land use change emissions for SAF for use in CORSIA	Over CAEP/12, continue to carry out the computations of induced land use change (ILUC) emissions associated with SAF production for requested world regions, for use in CORSIA.	List of ILUC values	SG2019 SG2020 SG2021 CAEP12
S.01.02	Low ILUC risk practices	Develop an approach for low ILUC risk practices for adoption beyond the CORSIA Pilot phase, in light of the experience gathered in real projects.	Proposal to amend the CEF Implementation Element	CAEP12
S.01.03	Feedstocks classification	Continuously update the positive list of feedstocks in the CORSIA Implementation Elements	Proposal to amend the CEF Implementation Element	CAEP12
S.02	Computation of default core LCA emission values for SAF for use in CORSIA	Over CAEP/12, continue to carry out the computations of default core LCA emission values for SAF, for use in CORSIA, with an emphasis on aligning the LCA values available for Alcohol (isobutanol) to jet (ATJ) and Alcohol ethanol to jet (ATJ).	List of default Core LCA values	SG2019 SG2020 SG2021 CAEP12
S.03	Co-processing of esters and fatty acids in petroleum refineries	Develop default LCA and ILUC values for co-processed fuels, including an approach for use in the CORSIA MRV system to quantify the CORSIA-eligible fuel present in co-processed products.	default LCA values, ILUC values, and approach for fuels produced using co-processing	SG2019
S.04.01	Methodology refinements – core LCA	Analyze the applicability of the core LCA methodology, reporting rules under CORSIA to Lower Carbon Aviation Fuels, and other considerations, and identify possible required adjustments to enable eligibility under CORSIA.	Report on the applicability of the LCA methodology and reporting rules under CORSIA to Lower Carbon Aviation Fuels.	SG2019

CAEP/12 Fuels Task Group (FTG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
			Proposed changes to the CEF Implementation Elements	SG2020 SG2021 CAEP12
S.04.02	Methodology refinements – ILUC	Reviewing the approach to ILUC in light of emerging scientific evidence and data. Develop definition of the ILUC regions.	Report on the need for amendments in the CEF Implementation Elements	CAEP12
S.04.03	Methodology refinements – Emission Credits	Define robust and specific criteria for determining when an exception to the LCA energy allocation approach is acceptable for generating emission credits. Develop additional requirements and guidance to ensure that emission credits for SAF generated under CORSIA are of an equivalent quality and quantity to emission units, with specific reference to the concepts described in paragraph 12 As requested, consider and approve new emissions credits for applicable pathways, based on the above-mentioned criteria, requirements and guidance. Develop further requirements for LEC and REC calculation to limit unintended incentives for poor landfill management.	Report on the need for amendments in the CEF Implementation elements	SG2019 SG2020 SG2021 CAEP12
S.05	CORSIA Package Updates	Maintain the components of the CORSIA SARP Package (e.g., Vol. 4, Implementation Elements, Supporting Documents, etc.) that relate to CORSIA Eligible Fuels, including on providing definitions for the terms included in the implementation elements.	Report on changes to the CORSIA SARP Package that pertains to CORSIA Eligible Fuels	SG2019 SG2020 SG2021 CAEP12

CAEP/12 Fuels Task Group (FTG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
S.06	Sustainability criteria	Develop further proposals, at the latest by the end of the pilot phase, on additional and/or strengthened Sustainability Criteria, including on Themes 1 and 2, specifically applicable to CORSIA Eligible Fuels and other sustainability themes, as requested.	Report: SG2019 Report: SG2020 Report: SG2021 Final report : CAEP12	CAEP/12
S.07	SCS Requirements	As needed, update information contained in the ICAO document, "CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes (SCS)" such that the SCSEG can evaluate SCS	As needed	As needed
S.08	Technology evaluation	Assess emerging and future technologies and processes that could lead to the production of CORSIA eligible fuels	Report: SG2019 Report: SG2020 Report: SG2021 Final report : CAEP12	CAEP/12
S.09	Fuel Production Evaluation	Using data on current offtake of CEFs and the TEA methods developed under S.10 and information from CAEP/10 AFTF Fuel Production Assessment, assess CORSIA Eligible Fuel availability through 2035 based on the range of estimated offset prices that have been developed by the GMTF.	Report: SG2019 Report: SG2020 Report: SG2021 Final report : CAEP12	CAEP/12

CAEP/12 Fuels Task Group (FTG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
S.10	Guidance on Potential Policies and Coordinated Approaches for the Deployment of SAF	Continue to develop the techno-economic analysis (TEA) of policy options available to foster the deployment of Sustainable Aviation Fuels (SAF) and Lower Carbon Aviation Fuels (LCAF), and produce guidance material that identifies policies, or combination of policies, that are particularly interesting as result of the analysis. The material developed could be made available as a “toolbox” to support Member States activities on SAF and LCAF.	Report containing the guidance to be shared with ICAO Member States	CAEP/12
S.11	Double counting	Develop approach(es) to minimize the risk of double counting related to LSf values within CORSIA including those that use either emissions credits or negative ILUC values. This could include a true-up mechanism in line with paragraph 1.2 of CAEP/11-WP/80.	Report	SG2020
S.12	ILUC Permanence	Examine permanence of the carbon reductions associated with the life cycle emissions reductions associated with negative ILUC values and develop approaches to minimize associated risks.	Report	SG2020

CAEP/12 Modelling and Databases Group (MDG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.01	Interdependencies	Coordinate with other working group Rapporteurs on interdependencies related to technology, operational issues, goals, environmental impacts and management and update of noise and emissions databases.	Coordinated WP	Each SG meeting and final report to CAEP/12
M.02	ICAO Environmental Trends Projection	Conduct an updated trends projection, for the 20xx baseline case and forecasts, for various cases which consider technology, operational improvements (both infrastructure and operator-initiated improvements) and alternative fuels life cycle, for noise, NOx, PM, fuel burn, and CO2. In doing so, consider potential input from WG3 Task E.11. The trends projection will support the display of the following information, as appropriate: 1. A static ATM (informed by WG2) and static aircraft technology scenario; 2. Progress being achieved toward the ICAO global aspirational environmental goals (i.e. 2% annual fuel efficiency improvement and carbon neutral growth from 2020); 3. Anticipated progress toward the goals based on the information communicated by States in their voluntary Action Plans; 4. Additional efforts that would be required to meet those goals (i.e. feasibility analysis results); and 5. The effects of ASBU Block 0, 1 and 2 implementation The MDG fuel trends results will be published in a Structured Query Language (SQL) database that could be easily accessed by experts from other CAEP groups. To the extent possible, the trends will use the same forecast, models and data as the other MDG analyses in the cycle.	Report that includes graphical depiction of the trends and database	CAEP/12

CAEP/12 Modelling and Databases Group (MDG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.03	Existing Model and Database Management	Maintain version control of models and databases to be used in support of specific CAEP analyses. Determine if updates to models or databases require a re-evaluation, including providing feedback to the ICAO Secretariat regarding databases to be used in CAEP that they maintain. In support of the CAEP/12 work programme, the following specific enhancements to air quality and or greenhouse gas models have been identified: 1. Advance modelling of nvPM mass and number (in conjunction with WG3) 2. Enhancement and standardization of low-power setting emissions modelling 3. Define a methodology to assess pollutant concentrations around airports in the trends and stringency analyses 4. Analyse and reconcile HC and CO computation across models as needed (in conjunction with WG3) 5. Update the tools as appropriate to support new policy analyses (e.g. supersonics) 6. To the extent possible, provide quantified uncertainties for data and models.	Updated models and databases	Each SG meeting and final report to CAEP/12

CAEP/12 Modelling and Databases Group (MDG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.04	New Model Evaluation	If new models are introduced to support CAEP/12, continue the candidate model evaluation process, which calls for sensitivity tests, comparisons with "gold standard data, and sample problems. Refine the process as appropriate on the basis of relevant criteria, to better inform CAEP which tools are sufficiently robust, rigorous and transparent, and appropriate for which analysis, and why there might be differences in modelling results.	Report	As model evaluations are complete Final report to CAEP/12
M.05	Doc 9911 Update	Update ICAO Doc 9911 as required. Potential areas for update that should be scoped out and considered (in coordination with WG1 and ISG) include: 1. full ICAO Doc 9911 harmonization and implementation across all models, including implementation of the extended level line segment, the latest start-of-take-off roll directivity, and speed-varying effects on noise-power-distance (NPD) curves; 2. standard approaches for modelling of helicopter noise; 3. modelling of reduced thrust departures; 4.sonic boom modelling; 5. noise modelling for commercial space vehicles and unmanned aerial vehicles(UAV) ; and 6. improved noise propagation modelling, possibly including terrain effects	Updated Doc 9911	CAEP/12
M.06	ICAO Support	Provide support to ICAO Secretariat in dissemination of MDG results.	As requested	As requested

CAEP/12 Modelling and Databases Group (MDG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.07	Analysis lessons learned	Conduct a review of lessons learned from CAEP/11 analyses since the development of the most recent MDG/FESG lessons learned document. This should include: 1) An identification of gaps in analysis assumptions, databases and tools. 2) Reviewing/discussing potential methodologies to assess the costs, benefits and interdependencies of a "new type" Standard with a view to potential application to future stringency analysis. 3) A methodology to quantify and report uncertainties in the noise and emissions trends projections. The objective is to present the benefits and interdependencies of Standards in relative terms (per cent change) compared to the total noise and emissions of aviation, thereby improving the assessment of trade-offs.	Report	CAEP/12

CAEP/12 Modelling and Databases Group (MDG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.08	COD Improvement(s)	Develop and maintain a 20xx Common Operations Database (COD) (preferably including a full 52-weeks of operations) and manage the acquisition and treatment of additional State data. Two versions of the COD will be maintained: 1. A version that can be used by the ICAO Secretariat and those States who contribute data to the COD, with sensitive data removed or de-identified; and 2. A version that is limited to those organizations who have signed an appropriate agreement This task will also include a comparison of the COD and WISDOM, e.g. using 20xx traffic, and identify areas of improvements in the process applied to generate the databases. Further work could be undertaken to refine and harmonize the description of aircraft in the base year operations (airframe, engine, age, seat / freight capacity), which would help improve the fidelity of the future fleet and operations forecast.	Database	SG2020
M.09	ADAP Participation	FESG/MDG to ensure coordination with the ICAO Aviation Data and Analysis Panel (ADAP) Multi-Disciplinary Working Group on Long-Term Traffic Forecasts (MDWG-LTF).	As requested	As requested
M.10	Airports Database	Augment the data included in ICAO Doc 7910 (Location Identifiers) to add information required to support CAEP analyses, in cooperation with the ICAO Secretariat and relevant panels.	Airports database	Prior to the start of analyses requiring the data
M.11	CORSIA Support	Provide technical support to CORSIA, as requested.	As requested	As requested

CAEP/12 Modelling and Databases Group (MDG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
M.12	CO2 Goals Assessment	Conduct a scoping exercise to assess the contribution of CO2 Standard to ICAO global aspirational goals in CAEP/12 cycle.		CAEP/12
M.13	Exploratory Study For Supersonic Aircraft	Conduct the exploratory study for supersonic aircraft as detailed in Sections 4.3.29 to 4.3.31 of the CAEP/11 report.	Report	Each SG and CAEP/12

CAEP/12 Forecasting and Economic Analysis (FESG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
F.01	New CAEP Forecast consistent with the long-term traffic forecasts developed by the ADAP MDWG-LTF	Develop a new CAEP forecast in support to the CAEP/12 analyses (e.g. passenger aircraft and freighter fleet forecasts, forecast for aircraft with less than 20 seats, retirement curves, and supersonics) using as an input the long-term (passenger and cargo) traffic forecasts developed by the ADAP MDWG-LTF. Agree with ADAP on a regular schedule for new forecast development, including base year, which would allow CAEP to use the same forecast for all their analyses in a given CAEP cycle	Forecast and Report	SG2020
F.02	Review of Economic Models	Review of economic models as needed for the future analyses. A review of the underlying economic cost assumptions used in the fleet evolution modelling tools is needed. These include crew, route, capital, and landing costs, all of which will need to be re-estimated and updated in concert with the development of a new fleet forecast. A review of the data and methodologies used to assess manufacturer and airline costs in stringency analyses should also be performed, in coordination with WG1 and WG3.	Report	SG2020 CAEP/12
F.03	ADAP Participation	FESG/MDG to ensure coordination with the ICAO Aviation Data and Analysis Panel (ADAP) Multi-Disciplinary Working Group on Long-Term Traffic Forecasts (MDWG-LTF).	Status report	Per ADAP MDWG-LTF schedule

CAEP/12 Forecasting and Economic Analysis (FESG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
F.04	Influence of airport capacity constraints on global air traffic	1. Assessing the methodology and results of a modelling tool suite developed at the German Aerospace Center (DLR) with a focus on airport capacity constraints and its effects on global air traffic, fleets and emissions 2. Assessing the potential and identifying options to improve the ICAO forecast	Methodology and results on traffic forecast to consider current & future Airport Capacity Constraints	CAEP/12
F.05	Exploratory Study For Supersonic Aircraft	Conduct the exploratory study for supersonic aircraft as detailed in Sections 4.3.29 to 4.3.31 of the CAEP/11 Report.	Report	Each SG and CAEP/12
F.06	Interdependencies	Coordinate with other working group Rapporteurs on interdependencies within the integrated approach to CAEP work items.	Coordinated WP	Each SG meeting and final report to CAEP/12

CAEP/12 Aviation Carbon Calculator Support Group (ACCS) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
A.01	Support updates to the ICAO Carbon Calculator	Assist the Secretariat in updating the current methodology used in the Carbon Calculator, identifying areas of improvement and potential changes to improve functionality.	Recommendations for enhancements to the Calculator to be implemented by the Secretariat	Report to SG meetings CAEP/12

CAEP/12 Sustainability Certification Schemes Evaluation Group (SCSEG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
G.01	SCS evaluation	Evaluate whether Sustainability Certification Schemes (SCS) comply with the SCS requirements defined in the CORSIA SARPs	SCS evaluation reports	Ongoing

CAEP/12 Impacts and Science Group (ISG) Work Programme				
Task Number	**Task Title**	**Task Description**	**Deliverables**	**Deliverable Date**
I.01.01	Coordination (internal group)	Coordination on activities.	Coordination	Ongoing
I.01.02	Coordination (internal ICAO)	Coordination with other WGs, TFs, RFPs, etc. Rapporteurs and ICAO Secretariat on activities.	Coordination	Ongoing
I.01.03	ISG membership	As per the ISG Terms of Reference, the ISG co-rapporteurs, in conjunction with the ICAO Secretariat, will identify suitable scientific experts. This will involve requesting that CAEP Members and observers nominate experts who are appropriately qualified and who conduct research in a subject area relevant to the CAEP/11 work programme.	Membership	SG2019
I.02	Aviation Emissions in context	ISG to focus on a bottom-up approach to analysis of the aviation sector's efforts to address climate change including implementation of the "basket" of technical solutions and market-based measures, and would be conducted through a staged approach that focuses first on carbon dioxide (CO2), acknowledging that further expansion to integrate short-lived climate pollutants would require more detailed climate modelling, and noting that the task should not be to define a share of a global carbon budget.	Report	Progress Report: SG2019
I.03	NOx Impacts	Assessment of: the impact of airport emissions on local levels of NOx and human health, impacts of cruise emissions of NOx on human health; impacts of cruise NOx on climate.	Report	Status Report: SG2019 Status Report: SG2020 Status Report: SG2021 Final report: CAEP/12

I.04	nvPM and fuel composition	Assessment of the role of fuel composition in nvPM emission characteristics and eventual trade-offs associated	Report	Status Report: SG2019 Status Report: SG2020 Status Report: SG2021 Final report: CAEP/12
I.05	Exploratory Study For Supersonic Aircraft	Conduct the exploratory study for supersonic aircraft as detailed in Sections 4.3.29 to 4.3.31 of the CAEP/11 Report.	Report	Status Report: SG2019 Status Report: SG2020 Status Report: SG2021 Final report: CAEP/12
I.06	White Paper on non-acoustic factors	ISG to develop a white paper on non-acoustic factors accounted to be responsible for about 70% of community annoyance related to aircraft noise.	White paper	CAEP/12

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