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Volume I

Manual on Testing of Radio Navigation Aids

Volume I — Testing of Ground-based Radio Navigation Systems

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AMENDMENTS

Amendments are announced in the supplements to the *Catalogue of ICAO Publications;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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Foreword

The need for uniform navigational guidance signals and consistent system performance for radio navigation aids used in the international aeronautical services has been recognized as an important adjunct to safety and regularity in civil aviation. ICAO continuing air navigation policies, and associated practices of the Organization in their part concerning ground and flight testing of radio navigation aids, call attention to this need and encourage improvements in radio navigation ground equipment, including associated testing and monitoring facilities, with the view to minimizing, to the extent practicable, the more demanding requirements of flight testing. Annex 10, Volume I, 2.2, provides an international Standard on the ground and flight testing of radio navigation aids.

This new edition of Doc 8071 comprises three Volumes as follows:

Volume I (fourth edition) — *Testing of Ground-based Radio Navigation Systems*

Volume II (fourth edition) — *Testing of Satellite-based Radio Navigation Systems* (update ongoing)

Volume III (first edition) — *Testing of Surveillance Radar Systems* (see Note)

The purpose of this document is to provide general guidance on the extent of testing and inspection normally carried out to ensure that radio navigation systems meet the Standards and Recommended Practices (SARPs) in Annex 10. The guidance is representative of practices existing in a number of States with considerable experience in the operation and maintenance of these systems.

This document describes the ground and flight testing to be accomplished for a specific radio navigation aid, and provides relevant information about special equipment required to carry out certain major tests. It is not intended to recommend certain models of equipment, but rather to provide general details relative to the systems under consideration.

Guidance on ground and flight validation of instrument flight procedures is published in Doc 9906, *Quality Assurance Manual for Flight Procedure Design*, Volume 5 — *Validation of Instrument Flight Procedures*.

Throughout this document, measurements have been given in SI units and non-SI approximate equivalents, the accuracy of conversion depends upon the general requirements of each specific stage.

Comments on this volume would be appreciated from States and other parties outside ICAO concerned with radio navigation systems development and provision of services. Comments, if any, should be addressed to:

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Note.— A minor update of Volume III to remove some obsolete material is ongoing; however it will remain applicable mainly to older radar systems. For testing of modern surveillance systems, see Doc 9924, Aeronautical Surveillance Manual.

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List of Acronyms

ADF	Automatic direction finder
AFC	Automatic frequency control
AGC	Automatic gain control
AIP	Aeronautical Information Publication
AM	Amplitude modulation
ANSP	Air navigation service provider
ATC	Air traffic control
ATIS	Automatic terminal information service
CATV	Cable television
CVOR	Conventional VOR
CMS	Control motion noise
CW	Continuous wave
DDM	Difference in depth of modulation
DGNSS	Differential global navigation satellite system
DME	Distance measuring equipment
DVOR	Doppler VOR
EIRP	Equivalent isotropic radiated power
EMI/EMC	Electromagnetic interference/compatibility
FM	Frequency modulation
FMS	Flight management system
GNSS	Global navigation satellite system
GP	Glide path
IAP	Instrument approach procedure
IF	Intermediate frequency
IFR	Instrument flight rules
ILS	Instrument landing system
IM/MM/OM	Inner/middle/outer marker
INS	Inertial navigation system
ISM	Industrial scientific medical
ITE	Information technology equipment
LF/MF/HF	Low/medium/high frequency
LOC	Localizer
MDS	Minimum discernible signal
MHA	Minimum holding altitude
MLS	Microwave landing system
MRA	Minimum reception altitude
MSL	Mean sea level
MTBF	Mean time between failures
MTBO	Mean time between outages
NDB	Non directional beacon
NOTAM	Notice to Airmen
PAR	Precision approach radar
PBN	Performance-based navigation
PFE	Path following error
PFN	Path following noise
PLC	Power line carrier
PM	Phase modulation

POP	Proof of performance
pp/s	Pulse pairs per second
PRF	Pulse repetition frequency
RDH	Reference datum height
RF	Radio frequency
RMS	Root mean square
RNAV	Area Navigation
RPAS	Remotely piloted aircraft systems
SARPs	Standards and recommended practices
SDM	Sum of depths of modulation
SID	Standard instrument departure
SRE	Surveillance radar element
STAR	Standard arrival route
UAV	Unmanned aerial vehicle
VFR	Visual flight rules
VMC	Visual meteorological conditions
VOR	VHF omnidirectional radio range
VSWR	Voltage standing wave ratio

Chapter 1

GENERAL

1.1 INTRODUCTION

1.1.1 Annex 10, Volume I, Chapter 2, 2.2 states, "Radio navigation aids of the types covered by the specifications in Chapter 3 and available for use by aircraft engaged in international air navigation shall be the subject of periodic ground and flight tests".

1.1.2 Volume I of the *Manual on Testing of Radio Navigation Aids* (Doc 8071, Fifth Edition) addresses ground-based radio navigation systems. This document contains "guidance material" only. The texts and procedures outlined do not have the status of Standards and Recommended Practices (SARPs) except for identified quotations from Annex 10.

1.1.3 Guidance on ground and flight validation of instrument flight procedures is described in the *Quality Assurance Manual for Flight Procedure Design*, Volume 5 — *Validation of Instrument Flight Procedures* (Doc 9906).

1.2 PURPOSE OF THE DOCUMENT

This document is intended to provide general guidance on the extent of testing and inspection normally carried out to ensure that radio navigation systems meet the SARPs in Annex 10. The guidance is representative of practices existing in a number of States with considerable experience in the operation and maintenance of these systems.

1.3 SCOPE OF THE DOCUMENT

1.3.1 This document describes the ground and flight testing to be accomplished for a specific radio navigation aid, and provides relevant information about special equipment required to carry out certain major tests. It is not intended to recommend certain models of equipment, but rather to provide general details relative to the systems under consideration.

1.3.2 System testing is addressed in this document in general terms. System testing is normally done as part of design and development activities, prior to volume production and individual site installations. System testing includes design qualification testing, operational testing and evaluation, and "shakedown" tests.

1.3.3 In this document, the terms "testing" and "inspection" have the following meanings:

— *Testing:* A specific measurement or check of facility performance that may form a part of an inspection when integrated with other tests.

— *Inspection:* A series of tests carried out by a State authority or an organization as authorized by the State to establish the operational classification of the radio navigation aid.

1.4 GROUND VERSUS FLIGHT TESTING/INSPECTION

1.4.1 Ground tests are carried out by a trained specialist using appropriate test equipment at the facility or at a point on the ground remote from the site. Flight tests are those carried out in the air by a trained flight inspection crew using a suitably equipped platform. Serious consideration should be given to the relative merits of these two methods taking into account both technical and economic factors.

1.4.2 Ground tests are usually more appropriate and less costly for accurate and quick evaluation of the facility performance. Flight tests are required to examine the signals-in-space as received at the aircraft after being influenced by external factors such as site conditions, ground conductivity, terrain irregularities, metallic structures, propagation effects, etc. Certain tests that may initially appear to be ground-based may be more appropriate as flight tests or vice versa.

1.4.3 Ground tests are normally carried out more frequently and can be used as indicators to determine when a flight test is required. It is often worthwhile to expend considerable effort in developing accurate and meaningful ground tests to minimize the costs and disruption of normal operations associated with flight tests. The demonstration of correlation between ground and flight test measurements will allow intelligent decisions to be made based on experience.

1.4.4 Flight testing will continue to be important in the proof of facility performance because it represents in-flight evaluation and provides a sampling of the radiated signals in the operating environment.

1.4.5 Where the small number of radio navigation aids in a State, or other reasons, make the establishment of a flight inspection unit uneconomical or impractical, it may be possible to obtain services through other States or a commercial company. Information regarding flight inspection service providers can usually be obtained from the appropriate ICAO Regional Office or online from the International Committee for Airspace Standards and Calibration (ICASC) at http://www.icasc.co.

1.5 CATEGORIES AND PRIORITIES OF TESTS AND INSPECTIONS

1.5.1 The establishment of appropriate intervals between various types of testing/inspections must take into account many associated factors specific to different States. Factors such as stability of equipment, extent of monitoring, weather, experience of maintenance crews, availability of standby equipment, etc., are all relevant. The intervals between tests/inspections of a new facility or type of facility may be shorter during early operation and may be extended as satisfactory experience is gained.

1.5.2 This document contains suggested schedules for each radio navigation aid, which should be considered (and modified, if necessary), based on the conditions relevant to each State and each site. The manufacturer’s equipment manual may contain recommendations that are useful in this regard. Facility testing can be considered in the following general categories.

Ground testing/inspection

1.5.3 *Site proving:* Tests carried out at proposed sites for the ground element of radio navigation aids to prove suitability in cases where site surveys and simulations do not provide sufficient confidence. Portable ground installations are used for this purpose.

1.5.4 *Initial proof of performance:* A complete inspection of the facility after installation and prior to commissioning to determine whether the equipment meets the Standards and specifications.

1.5.5 *Periodic:* Regular or routine inspections carried out on a facility to determine whether the equipment continues to meet the Standards and specifications.

1.5.6 *Special:* Tests after a failure of the facility or other circumstances that indicate special testing is required. The results of special tests will often identify corrective maintenance work necessary to restore the facility. (In some cases, a special flight inspection is also required.)

Flight testing/inspection

1.5.7 *Site proving:* In the case where a portable ground installation is used, a flight test is conducted at the proposed site at the option of the responsible authority to determine the effects of the environment on the performance of the planned radio navigation aid.

1.5.8 *Commissioning:* An extensive flight inspection following ground proof-of-performance inspection to establish the validity of the signals-in-space. The results of this inspection should be correlated with the results of the ground inspection. Together they form the basis for certification of the facility.

1.5.9 *Periodic:* Flight inspections to confirm the validity of the signals-in-space on a regular basis or after major scheduled facility maintenance.

1.5.10 *Special:* Flight inspections required as a result of certain corrective maintenance activities, reported or suspected degradation of signal-in-space performance, aircraft accidents, etc. Typically, it is necessary to test only those parameters which have or might have an effect on facility performance. However, it may be economically advantageous in many cases to complete the requirements for a periodic inspection.

Priority of inspections

1.5.11 Flight inspections should be scheduled and conducted using a priority system. The following is a suggested grouping:

a) *Priority 1:* accident investigation, restoration of established facilities after unscheduled outages that require a flight inspection and investigation of reported corruption of the signal-in-space;

b) *Priority 2:* periodic inspections, commissioning of newly installed facilities; and

c) *Priority 3*: evaluations of proposed sites for new installations and other investigations.

1.6 OPERATIONAL STATUS

Facility status can be identified as follows:

a) *Usable:* Available for operational use.

   i) *Unrestricted:* Providing safe, accurate signals-in-space conforming to established Standards within the coverage area of the facility.

   ii) *Limited or restricted:* Providing signals-in-space not conforming to established Standards in all respects or in all sectors of the coverage area, but safe for use within the restrictions defined.

b) *Unusable:* Not available for operational use as providing (potentially) unsafe or erroneous signals, or providing signals of an unknown quality.

1.7 AUTHORITY FOR FACILITY STATUS DETERMINATION

The responsibility for determining facility status rests with the appropriate State authority or the organization authorized by the State. The status determination should include all factors involved. This includes judgement (by the pilot) of the flyability of the signal-in-space, analysis of airborne measurements of the facility (by the flight inspection technician/engineer), and a statement of readiness (by ground maintenance personnel). The flyability of the instrument procedures is assessed as part of the validation activity conducted in accordance with ICAO Doc 9906, *Quality Assurance Manual for Flight Procedure Design*, *Volume 5 — Validation of Instrument Flight Procedures*.

1.8 NOTIFICATION OF CHANGE OF STATUS

1.8.1 Notification of a permanent change of the facility status is to be done through the appropriate Aeronautical Information Publication (AIP); differences from Standards are to be notified to ICAO and in the AIP.

1.8.2 Notification of temporary changes in the status of facilities are to be promptly and efficiently advertised. A change in the status of a commissioned facility as a direct result of ground or flight inspection procedures, and resulting in a change of operational status (“unrestricted/restricted/unusable”) or “unusable” designation, should be advertised immediately by air traffic control (ATC) personnel, and promptly by a Notice to Airmen (NOTAM).

1.8.3 A facility having an “unusable” status is normally removed from service and can operate only for test or troubleshooting purposes.

1.8.4 Particular attention should be given to periodic or corrective maintenance procedures that involve false guidance signals being temporarily radiated. These conditions should be coordinated with ATC and promulgated to users by NOTAM, before the procedures commence. Additional guidance on special measures preventing the operational use of ILS-radiated test signals is given in Chapter 4, 4.1.

1.9 AIRBORNE AND GROUND TEST EQUIPMENT CALIBRATION

The selection and utilization of ground and flight inspection equipment used to determine the validity of navigation information should minimize the uncertainty of the measurement being performed. This equipment should be periodically calibrated to ensure traceability of measurements to appropriate standards.

1.10 COORDINATION BETWEEN GROUND AND FLIGHT TESTING/INSPECTION

1.10.1 Comparison of the results, obtained during successive tests on the ground and in the air, can determine the extent of degradation in the performance of the installation as monitored on the ground. These results can also be used to determine the choice of the periodicity of the flight test/inspection.

1.10.2 Flight test/inspection may involve a coordinated effort with ground specialists who may make adjustments or participate in the flight test/inspection. Efficient two-way communications should be established between ground and air. An additional communication means is often installed in the flight inspection aircraft and a portable unit is employed at the facility to provide these communications without interfering with the air traffic control communications.

1.11 FLIGHT INSPECTION UNIT

1.11.1 This document considers the flight inspection unit to be comprised of three parts: the flight inspection crew, the flight inspection aircraft and the position-fixing system.

Flight inspection organization

1.11.2 The organization has a clearly defined management structure and is capable of showing the reporting lines up to the accountable manager, or board, as appropriate. Where the flight inspection operation is part of a larger organization, it is important to ensure that all contributing departments, divisions or other organizations (e.g., subcontractors) involved directly or indirectly with the flight inspection operation comply with the flight inspection organizations exposition or quality management system as appropriate.

1.11.3 The organization ensures that all changes to the area of operation are assessed and recorded through a change management process. Changes would normally include, but are not limited to, organizational, system and procedural changes. Significant equipment modifications and renewal might need approval by the accountable entity within the organization or by the civil aviation authority before implementation.

1.11.4 The organization ensures that all personnel concerned with the flight inspection are competent to conduct their job functions. The organization establishes a written procedure for determining required job competencies and continued competence checking of all personnel through regular assessment. Competence should be recognized through certification or qualification as detailed within the organization’s procedures.

1.11.5 The flight inspection crew normally consists of two pilots and one or two technicians or engineers. It is important that members of the flight inspection crew be experts in their individual fields, have sound knowledge and experience in flight testing/inspection procedures and requirements, and be capable of working as a team.

1.11.6 The State authority or flight inspection organization, as authorized by the State authority, should formally certify flight inspection personnel. The objectives are to:

a) grant authority to the flight crew member who ensures the satisfactory operation of air navigation facilities;

b) provide a uniform method for examining employee competence; and

c) issue credentials that authenticate inspection authority.

1.11.7 The organization should establish a written procedure for determining required job competencies and continued competence checking of all personnel through regular assessment. The procedure should consider all personnel directly engaged in the flight inspection operation, this includes, but is not limited to, the pilot (in terms of flying the correct flight inspection procedure), flight inspector, surveyor, documentation controller and auditor.

Flight inspection aircraft

1.11.8 The flight inspection aircraft shall be airworthy and approved by the airworthiness authorities for the intended operation in the area it operates.

1.11.9 More guidance on the flight inspection aircraft instrumentation, antennas and other aspects is provided in Attachment 1 to this chapter.

Position-reference systems

1.11.10 Appropriate aircraft position reference information for all types of flight testing/inspection is required when the accuracy of the navigation signal is being determined.

1.11.11 The position-reference system is independent from the facility under testing/inspection. The position-reference system and the flight testing/inspection receiver contribute to the error budget. The overall error budget should be five times better than the performance standard of the navigation signal.

1.11.12 The position-reference system generates position reference information using the same system parameters as the navigation system under testing, e.g. a reference distance for a DME, a reference localizer deviation, or a reference glide path signal. A great variety of technical solutions have been developed, either using position-reference equipment, which provide information already in the correct coordinate system, or using computer systems, which calculate the reference information from one or more sensors.

Position-reference systems for approach and landing aids

1.11.13 Theodolites with electric read-outs have traditionally been used as a position reference for ILS testing. If the output signal is transmitted to the flight inspection aircraft, this avoids the need for data to be recorded on the ground with later requirements for post-flight evaluation or transmitted to the flight inspection aircraft. ILS testing requires two different theodolite sites for azimuth and elevation data. The addition of ranging equipment allows ILS testing from a single site. The theodolite-based position referencing requires minimum visibility of 11 km (6 NM). A skilled theodolite operator is required to minimize manual tracking errors.

1.11.14 Manual theodolite tracking may result in significant contribution to the overall error budget of the flight inspection; therefore caution should be exercised when approach and landing aids, particularly Category III facilities, are evaluated using theodolite. Automatic tracking systems have been developed to optimize the error budget.

1.11.15 Alternative position-reference systems are based on inertial navigation systems (INSs) integrated with other sensors. Accuracy is aided by various sensor inputs such as global navigation satellite system (GNSS), laser trackers and on-board camera systems which provide independent reference update information. GNSS, augmented by differential corrections as required also serve as a position reference system. With these technologies, certain flight inspection operations can be conducted under limited visibility conditions.

1.11.16 Additional information on position-reference systems may be found in chapters specific to each navigation aid.

Position-reference systems for en-route navigation aids

1.11.17 The basic solution of a position-fixing system for flight inspection of en-route navigation aids is the use of charts. Aeronautical charts should be used if possible. Large scale charts that provide the greatest possible amount of detail are desirable so that ground position fixing points can be better defined. The charts are to be marked for preparation of the flight inspection mission. Typically, charts provide reference information only for some parts of the flight path. Information has to be evaluated manually by the flight crew.

1.11.18 The equipment described in 1.11.13 to 1.11.16 may be used for the inspection of en-route navigation aids if better accuracy or continuous reference data are required.

Position reference system integration

1.11.20 A more general approach is the use of a position reference system that provides information for all phases of the flight inspection. A state-of-the-art solution is the combination of different sensors for the testing, including INSs, barometric altimeters, tracking of several DME facilities, and GNSS augmented as necessary. A high degree of automation can be achieved for the flight inspection since continuous position reference information is available.

Human-machine interface aspects

1.11.21 The operator's console should be designed and located in such a way as to offer the proper interface between the flight inspection crew and test and data-processing equipment. The console location should be determined based on noise and vibration levels, lighting, outside visibility, proximity of the centre of gravity of the aircraft, air conditioning, and forward-facing orientation.

1.12 ORGANIZATION, SAFETY AND QUALITY

1.12.1 The management of organizational features that can cause a risk to safety should be conducted systematically. The effective management of safety should be achieved by the derivation of policy and application of principles and practices designed to prevent the occurrence of factors that could cause accidents or serious incidents.

1.12.2 The minimum requirements for the safety system should include written procedures that document all of the actions necessary to ensure the safe operation of the flight inspection aircraft and system.

1.12.3 The minimum requirements for the quality system should include written procedures that document all of the actions necessary to ensure the verification of the radio navigation aids. The ISO 9000 quality management model provides a useful framework, and particular note has to be made of the following features expected in the quality management system.

a) *Organizational and individual accountability.* Accountability and responsibility should be documented, traceable, and verifiable from the point of action through to the accountable manager (in most cases the Chief Executive).

b) *Management review.* The system for management review should be effective and should ensure that senior management is fully cognizant of the systems and features that affect quality.

c) *Exposition or company documentation.* An exposition or company documentation should be provided to clearly describe the organizational structure, personnel, accountabilities, responsibilities, resources, facilities, capabilities, policies, and purposes of the organization.

d) *Record keeping*. Records should be accurate, legible, and capable of independent analysis. The retention period for records should be defined. Commissioning records and those documenting system modifications (e.g. changes to ILS antenna configuration from sideband reference to capture effect) should be kept for the entire life cycle of the facility.

e) *Customer satisfaction*. The organization should establish a procedure to request feedback from their customer(s) of the service provided. This information should be utilized in a process to improve the service.

Personnel training and qualification

1.12.4 The organization should establish methods for determining required job competencies:

a) all personnel directly engaged in the flight inspection, maintenance, or installation of an aero-nautical navigation aid should be adequately qualified and trained, as well as experienced in their job functions;

b) the management system should include a written procedure for ensuring the continued competence of personnel through regular assessment; and

c) initial and recurrent training programmes for aeronautical navigation aid specialists should include a detailed explanation of maintenance procedures and their effect on the integrity of the radiated signal.

Documentation control

1.12.5 Under the quality system all test/inspection procedures should be controlled so that the correct version of any procedure can be easily identified and used.

1.12.6 Retention of data is required in order to permit trend analysis of the ground and airborne flight inspection equipment. Such analysis will assist in the identification of fault conditions or substandard performance before development of any safety hazard. Examples of items that might be identified in this way are: a decreasing mean time between outages (MTBO); a slow drift in one or more radiated parameters; or a specific component that may appear to have a high failure rate.

1.12.7 More guidance on documentation and data recording is provided in Attachment 2 to this chapter.

1.12.8 The organization shall ensure that all documents that support the flight inspection operation should be controlled so that the correct version of any document can be easily identified and used.

Design qualification of ground equipment

1.12.9 A new design of equipment is subject to design qualification tests. These tests ensure that the equipment meets its design requirements. These tests are normally made on the "first production equipment" or on the first batch of equipment. If no serious problems are encountered, those tests are not repeated for future installations of similar equipment. Items to be addressed during these tests include:

a) *Environmental performance.* These tests show that the equipment meets the tolerances under the range of environmental conditions specified by the manufacturer and purchaser. Environmental tests include all parts of the equipment, both internal and external.

b) *Mean time between failures (MTBF).* Before commencing such tests, it is essential to define the test conditions; for example, what constitutes a failure, what confidence level will be used during the demonstration, will modifications be permitted during the tests. See Annex 10, Volume I, Attachment A; Attachment C, 2.8 (Integrity and continuity of service – ILS ground equipment); Attachment F and Attachment G, 11 (Integrity and continuity of service – MLS ground equipment) for additional guidance on reliability aspects.

c) *Manufacturer's quality system.* The equipment is manufactured under an effective quality management system. There should be traceability from modules and components back through to system design requirements.

d) *Integrity.* The manufacturer should have made an in-depth study of system integrity. Safety critical components of the system are to be identified and all components used in these areas are to be traceable to their source. The integrity analysis should also define the maintenance and test intervals for the safety critical components of the system. Where a system is claimed to have automatic integrity checks, it is important to fully understand the depth of tests made by the automatic procedure. See Annex 10, Volume I, Attachment A; Attachment C, 2.8 (Integrity and continuity of service – ILS ground equipment); Attachment F and Attachment G, 11 (Integrity and continuity of service – MLS ground equipment) for additional guidance on integrity aspects.

e) *Monitor correlation tests.* Many systems use integral monitors or monitors in the near field area of the antenna array. Tests should show that simulated faults in the system produce the same response on monitors as in the far field. This investigation should concentrate mainly on simulated antenna faults, including individual elements and the signal distribution equipment.

f) *Safety assessment*: A system safety assessment should be conducted by the manufacturer of a navigation system element to provide evidence that the system meets the safety requirements as part of the overall design qualification requirements. The safety assessment process includes specific assessments conducted and updated during system design and development, and interacts with the system development supporting processes. The requirements for conducting safety assessments may vary on a national or regional basis.

g) *Hardware/software design assurance*: The roles of hardware and software in implementing the functional requirements of a system must be clearly specified and justified. The partitioning of functions between hardware and software should take into account safety criticality, testability, reliability, verification, validation, maintainability and life-cycle costs. A system development assurance level (as defined in RTCA and EUROCAE documents) will be based upon the contribution of hardware/software to potential failure conditions as determined by the system safety assessment process. The hardware/software level of development implies that the level of effort required to show compliance with the safety requirements varies with the failure condition category.

1.12.10 Quality maintenance measurements of the ground transmitting equipment can help ensure that the radiating signal generation has not changed since the last periodic correlation. Restricting the adjustment of the safety critical parameters without a flight inspection, and the establishment of ground maintenance methods to verify that the equipment is operating within clearly defined specifications, should be considered as part of a quality maintenance regime.

1.13 ELECTROMAGNETIC INTERFERENCE

1.13.1 Electromagnetic interference to a navigation aid is a rare occurrence, but the possibility of it happening should not be excluded. All reports of suspected interference should be investigated. During a flight inspection of a radio navigation aid following a report of suspected interference, the interference might affect the signals from the navigation aid being inspected or it might affect the signals used for some types of position-referencing, such as GNSS.

1.13.2 Attachment 3 to this chapter gives guidance on this subject, including types of interference, possible sources, methods of detection, and steps which can be taken to eliminate or mitigate the effects.

1.14 SIGNAL ANALYSIS

1.14.1 The use of a signal analyser (i.e., spectrum analyser or other capability which may be part of a multi-function device) on the flight inspection aircraft and on the ground at navigation aid sites can be an effective means of resolving problems with radio navigation aids. The following are some of the applications for signal analysis as it relates to testing of radio navigation systems.

1.14.2 Signal measurements at specific points in the service volume should be accomplished on a flight inspection aircraft. It is recommended that the signal analyser set-up information, aircraft antenna position, and measurement time be recorded with spectrum measurements. At remote sites, the signal analyser on a flight inspection aircraft may be used for verification of the radiated signal spectrum from the ground system when the required test equipment is not available at the site.

1.14.3 The signal analyser can be used to measure carrier frequency (Doppler shift should be taken into account), sideband modulation levels and spurious emission levels. Residual frequency or phase modulation components on ILS transmitters can be identified from the radiated spectrum components. If present, frequency or phase modulation may affect the AM sideband amplitudes as measured on the signal analyser. Care should be taken to account for the Doppler shift in signals as the aircraft moves at high speed toward or away from the transmitter. Computer-aided acquisition and set-up of the signal analyser will be of great advantage in the air.

1.14.4 The signal analyser can be used in the periodic flight inspection for dual frequency ILS to measure the power ratio between the course and clearance transmitters. The course and the clearance signal frequencies can be measured simultaneously and any error in frequency alignment of the ground facility can be detected. This technique greatly improves the effectiveness and accuracy of the measurement, eliminating the need to switch between the two transmitters on the ground and position the aircraft at exactly the same position in space for two sequential measurements. Course/clearance power ratio can be checked simultaneously with the normal clearance procedure using this technique.

1.14.5 The signal analyser can also be used to identify the frequency and relative power of the interfering source when interference has been detected through loss or erratic behaviour of the cross-pointer, audio or automatic gain control (AGC) signal. Information of the types of sources and testing techniques is provided in Attachment 3 to this chapter.

1.15 GROUND AND FLIGHT INSPECTION PERIODICITY

General

1.15.1 This document includes suggested periodicities for various ground and flight tests that should be considered in the light of conditions relevant to each State and each site.

1.15.2 The suggested periodicities are given as general guidance and may be modified based on the manufacturer's recommendation or operational experience. In some cases, it may be necessary to carry out more frequent inspections, e.g. following initial installation. It may also be reasonable to extend the inspection intervals in some circumstances, if the factors outlined in this section have been taken into account. It is recommended that States have a documented procedure for determining and changing the test/inspection interval.

1.15.3 The manufacturer's equipment manual usually contains recommendations which are also useful in this regard.

Determination of test/inspection intervals

1.15.4 Many factors influence the choice of appropriate intervals for both ground and flight tests. These include the reliability and stability of operation of the equipment, the extent of ground monitoring, the degree of correlation between ground and flight measurements, changes in the operating environment, manufacturer recommendations, and the quality of maintenance. The complete programme of ground and flight inspections should be considered when determining test intervals.

1.15.5 Reliability and stability of equipment is related to age, design technology, and the operational environment. Stability of operation may also be affected by excessive maintenance adjustments attributable to either human factors or variation in test equipment performance. This is particularly true with some older test equipment where the accuracy and stability of the test equipment is not significantly better than the equipment under test. A major contribution to the demonstration of stability of navigation aids in recent years is the design of modern flight inspection systems and ground facility test equipment, where the standard resolution and accuracy are very high.

1.15.6 Ground maintenance activity and its frequency is dependent upon the design, reliability and stability of a particular equipment and the quality of the ground test equipment employed as a transfer standard. It has been shown that equipment reliability may be adversely affected by frequently scheduled major maintenance activity. It is, therefore, desirable to limit such activity to essential testing only, particularly for tests that require the disconnection of cables. There is a requirement for additional supplementary flight inspection when some engineering activities, such as glide path antenna changes or adjustments are made. Further investigation may be initiated if the independent monitor calibration indicates any adjustments are required.

Example of criteria to be considered for the modification of ILS flight inspection intervals

1.15.7 The correlation of air and ground measurement records and historic demonstration of equipment stability have allowed some States to extend the intervals between flight inspections. This is supported by the use of routine monitor readings, strict environmental safeguarding and closer tolerances on flight inspection results to ensure operational stability is maintained. Example criteria for the extension of ILS flight inspection intervals are given in 1.15.8 and 1.15.9

1.15.8 This section gives an example of criteria applied to extend the nominal interval between flight inspections of selected facilities. The procedure requires:

a) an initial demonstration of stability over four consecutive periodic flight inspections with no transmitter adjustments;

b) good correlation between concurrent ground and airborne results;

c) a record of independent monitor test results;

d) a record of equipment monitor readings taken at regular intervals not to exceed 50 per cent of the extended flight inspection interval;

Note.— A shorter interval between monitor readings is suggested for ILS Facility Performance Categories II and III.

e) evidence that the quality of the maintenance is high and that the recorded test result and monitor readings of critical parameters indicates that the equipment consistently meets performance requirements;

f) that the facility is adequately safeguarded against changes in the operational environment, e.g. building development; and

g) a recommended decrease in tolerances applied to the flight inspection results for critical parameters to 75 per cent of the normal acceptance standards. Examples, of critical parameter(s) include:

   i) localizer alignment and displacement sensitivity;

   ii) glide path angle and displacement sensitivity; and

   iii) VOR approach radial alignment and structure.

1.15.9 Examples of cases in which the flight inspection interval should be decreased include:

   i) if the above criteria are no longer met; or

   ii) if a facility fails to meet the same performance requirement on successive inspections; or

   iii) if several requirements are not met on any one inspection.

Correlation as the basis for extending periodicity

1.15.10 A typical basis for extending the interval between required measurements without degrading ILS integrity is correlation. Any individual measurement is normally expected to be repeatable over time without adjustments to the equipment. Correlation between ILS measurements made both on the ground and in the air at the same or nearly the same time is also expected. This places equal responsibility on ground and airborne personnel and helps identify common-mode measurement errors. An additional requirement to extend flight inspection intervals is the influence of near- and far-field environments on the signals. These effects can be determined with a flight inspection aircraft. The following paragraphs give illustrations of the correlation technique.

1.15.11 *Preliminary requirements.* Certain fundamental requirements should be met prior to any measurement activity if correlation between ground and airborne measurements over time can be expected. Typical requirements include functionally similar training for personnel, appropriate calibrated test equipment, completion of all prescribed ground maintenance tasks, availability of commissioning reports and recent periodic inspection reports, and frequent use of measurement skills by both ground and airborne personnel.

1.15.12 *Techniques.* Achieving good correlation places the same or similar weight on both ground and airborne testing, and demands that both be conducted with great care. Initial or commissioning-type flight measurements should be made with special care, as the corresponding ground measurements will be used as references for ground maintenance personnel. The portable maintenance receiver is readily used in the far-field for localizer facilities, while glide path facilities may require measurements in the near- or mid-field with an auxiliary antenna placed near the transmitting antennas.

1.15.13 *Tolerances.* New tolerances may be developed to define acceptable correlation between measurements. A rigorous application of correlation principles might include the following types:

a) Setting tolerance — defines the exact value for a parameter, which should be achieved (within the measurement uncertainty) when adjustment is required.

b) Adjustment/maintenance tolerance — defines the limit within which a parameter may vary without requiring adjustment.

c) Operational tolerance — defines the ICAO Standard for a parameter.

d) Discrepancy tolerance — defines, for certain parameters only, the limits of divergence between various measurements:

   i) Ground/ground discrepancy — applies to a divergence over time, or between different methods of measuring the same parameter (e.g. alignment monitor, portable ILS receiver, and far-field monitor).

   ii) Ground/air discrepancy — applies to a divergence between measurements of the same parameter at the same or nearly the same time by ground and airborne testing personnel.

1.15.14 *Activities during flight inspection.* Typical correlation activities begin with a confirmation that airborne and ground test equipment is operating within tolerances. This may be achieved by comparing ground and flight test generators and receivers. (If the tolerances are not met, the flight inspection is delayed until the cause of the problem is eliminated.) If the ground or airborne results are out of discrepancy tolerances during the flight inspection and the cause cannot be determined, then the ground monitor alarm limits should be tightened, the facility declassified appropriately or removed from service. The successful completion of the flight inspection (all tolerances are met) establishes that the ground maintenance activities are effective and the interval between inspections may be maintained at the optimum periodicity.

Expiration of nominal intervals

1.15.15 To account for operational restrictions, States may permit the completion of a recurrent test/inspection within a certain time window following the nominal recommended interval. This extension is not to be intended as a means to systematically extend the test/inspection interval.

1.15.16 If a test/inspection is not conducted prior to the expiration of the appropriate time window, various actions may be considered:

a) extension of the expiration after engineering evaluation and/or ground maintenance reinforcement;

b) degrading of the category of ILS (Category III down to Category I) in cases where intervals vary according to the category of ILS; and

c) temporarily removing the navigation aid from service.

1.16 FLIGHT INSPECTION AT NIGHT

1.16.1 Certain areas have high densities of air traffic during daylight hours. Conducting flight inspections in these areas during daylight can cause delays to normal traffic if safety is not to be compromised. It is possible to make many of the flight inspections, described in this manual, during the night to avoid interfering with normal flight operations. Noise abatement may inhibit this.

1.16.2 Several additional factors need to be considered for night-time flight inspection. These are detailed in the following paragraphs.

1.16.3 *Effect of the environment on the radiated signal.* The signals radiated by some types of radio navigation aids are affected by propagation which differs between day and night. For example, the level of background radio noise over a city may be different.

1.16.4 *Effect of environment on the navigation aid.* The ground facility maintenance engineer should inform the flight inspector of any equipment variations, such as field monitor performance which may change at night. The effect of the local environment, such as changes in the position of reflecting obstacles should be considered.

1.16.5 *Position reference.* Flight inspection at night will normally use an independent reference system but the use of ground tracking equipment is not excluded.

1.16.6 *Evaluation of results.* The State authority or the organization authorized by the State should decide whether differences from measurements made during the daytime are due to night conditions, problems with the equipment or making the measurements at different positions.

1.16.7 *Flight inspection reports.* The flight inspection report should indicate whether the inspection was made at night.

1.16.8 *Types of flight.* The inspection flights should be made in accordance with the guidance given in this manual, with the exception of measurements that specifically need low-level flights. It is recommended that at specific intervals an inspection is made under the same conditions as prevailed at the time of commissioning.

1.16.9 *Safety of flight.* Flights should be conducted 300 m (1 000 ft) above the level normally used for daytime flight inspection in areas having obstructions. It will be necessary to change some horizontal distances in order to retain the same vertical angle from the navigation aid, where this is important to the measurements. Low-level below path (safety approach) glide path inspection flights should not be made during the night or when the level of natural light is low. Flights should normally be carried out in accordance with VFR. The probability of birdstrike during night flight should also be considered.

1.17 COMBINED FLIGHT INSPECTION OF COMPLEMENTARY FACILITIES

1.17.1 The combining of flight inspection activities for complementary or collocated facilities, where practical, may offer cost and schedule efficiencies for the flight inspection operation while reducing impacts to other air traffic operations.

1.17.2 Examples of opportunities for combined flight inspection activities include:

a) simultaneous measurements of flight inspection parameters for collocated VOR/DME or ILS/DME facilities;

b) inspection of associated position fixes based on other navigation aids during flight inspection of VOR facilities;

c) simultaneous measurements of selected flight inspection parameters for ILS localizer and glide path facilities;

and

d) assessment of visual approach aids during flight inspection of ILS facilities.

1.17.3 The realization of benefits from combined flight inspection activities will depend upon the incorporation of appropriate provisions in flight inspection procedures and equipment.

1.17.4 While guidance relating to flight validation is contained in Volume 5 of Doc 9906, in some cases it may also be possible to combine flight inspection and flight validation activities.

1.18 USE OF REMOTELY PILOTED AIRCRAFT SYSTEMS

1.18.1 A basic principle of flight inspection to assess compliance with Annex 10 Standards is to use representative avionics at normal aircraft speeds. While flight inspection aircraft and their avionics are not representative of all aircraft and avionics, they nonetheless facilitate making judgements on the operational relevance of signal anomalies. This principle does not prevent the use of more advanced measurement capabilities both in ground and flight testing; however, it requires that good correlation (impact of filtering, etc.) needs to be established.

1.18.2 Remotely piloted aircraft systems (RPAS) or unmanned aerial vehicles (UAV) should be assessed to determine that they provide the payload capability, speed and range necessary to conduct a flight inspection for navigation aids as recommended herein in a cost-effective manner. RPAS can and have been used for special and advanced measurement applications which are difficult to achieve with traditional ground and flight measurement capabilities. Nothing in this manual is intended to prevent the development of such capabilities. Some States are studying how the use of RPAS can help in making more regular measurement checks with the aim to reduce the periodicity of a full flight inspection with a typical flight inspection aircraft. These studies should take into account the guidance in section 1.15.

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ATTACHMENT 1 TO CHAPTER 1

FLIGHT INSPECTION AIRCRAFT

Aircraft type-preference should be given to multi-engine turbine aircraft for their reliability and performance. Pressurization and air conditioning should be available as a means to reduce crew workload, increase safety and keep the FIS equipment within the technical specification. Standard avionics must match the airspace requirements. Many factors should be considered when selecting an aircraft as a vehicle for flight inspection. The number of aircraft required will be determined by the qualities of the aircraft chosen and factors such as the number of facilities to be flight inspected, their relative geographical locations, periodicity of inspections, and other duties of the aircraft.

1. GENERAL CHARACTERISTICS

1.1 The following desirable characteristics should be found in a flight inspection aircraft:

a) reliable, efficient type equipped and certified for IFR operations;

b) sufficient carrying capacity for the flight crew, as well as all necessary electronic and recording equipment and spares. It may also be necessary to have additional capacity to transport ground personnel and equipment;

c) sufficient range and endurance to complete a normal mission without reservicing;

d) aerodynamically stable throughout its speed range, but particularly at speeds encountered during flight inspection;

e) low noise and vibration levels;

f) low electrical noise characteristics to minimize interference with received signals; e.g. propeller modulation of the received signal must be as low as possible;

g) stable electrical system of adequate capacity to operate the required electronic equipment in addition to the aircraft equipment;

h) reasonably wide-speed and altitude range to enable flight inspection to be conducted, where possible, under the conditions encountered by users. Good low-speed characteristics are essential where theodolite tracking by ground observers is carried out;

i) suitable for future modifications or expansion of equipment to allow for inspection of additional aids or to increase accuracy or processing speed on existing facilities;

j) aircraft cabin environmental control equipment that minimizes the adverse effects of temperature and humidity on the sensitive test equipment used in flight inspection systems and maintains a comfortable environment for the crew; and

k) equipped with an autopilot to reduce crew workload.

1.2 A variety of aircraft having the above characteristics have been successfully used for flight inspection work. Some States are using the smaller, more versatile jet aircraft, of the type usually referred to as “business jets”, for medium- and high-altitude inspection of radio navigation facilities.

2. AIRCRAFT INSTRUMENTATION

2.1 The flight inspection aircraft contains a full range of navigation equipment as required for instrument flying. Additional equipment must be provided for the monitoring and recording of the received navigation signals. The navigation receivers may be used for both navigation and flight inspection. Special flight inspection receivers installed in addition to those used for navigation are preferable because of their special accuracy requirements.

2.2 When navigation receivers are shared between the pilot and observer, the control of the receiver during flight inspection should be with the technician/engineer.

2.3 Inspection of PAR may require an on-board positioning system to record the azimuth, elevation and distance. The aircraft plays a passive role as a reflector of electromagnetic signals. Flight inspection procedures and Standards, particularly those relating to strength of signal return, are usually related to aircraft effective size as a reflector.

Flight Inspection System

Build state and modification control

2.4 The build state of all equipment, including test equipment, should be recorded and the records should be updated whenever modifications or changes are made. All modifications should be accurately documented and cross-referenced to modification strikes or numbers on the equipment. After making any modification, tests and analyses should ensure that the modification fulfils its intended purpose and that it has no undesired side effects.

Calibration of flight test equipment

2.5 All test equipment used for calibration, test or maintenance of an aeronautical navigation aid should be listed and subject to regular calibration checks. Each item of test equipment should have a documented calibration procedure and calibration records. Test equipment should be calibrated at the manufacturer's recommended intervals, unless otherwise indicated by objective evidence or operational conditions.

2.6 The conditions of use of individual items of test equipment should be fully considered and the manufacturer's recommended interval should be queried if the utilization profile may be outside of the specified environmental conditions.

2.7 Regular calibration of the flight inspection receivers and position-reference system is to be performed in order to ensure a back tracing of data to international or national standards. The calibration may be performed either on board the flight inspection aircraft or in a laboratory. In both cases, a test transmitter is connected to the radio frequency (RF) input of the receiver in order to input simulated signals. The receiver output is compared with the nominal signals; deviations are recorded either in a test protocol or in the memory of a computer. Calibration data are applied either on-line by the computer or during off-line data evaluation.

Control of spares

2.8 Equipment spares should be stored under suitable environmental conditions. Spares having a limited lifetime, or requiring regular maintenance or calibration should be suitably identified to that effect. Procedures should exist for the control, repair, and return-to-service of equipment or modules. The procedures should show which modules may be repaired on-site and which should be returned to the manufacturer or recognized repair facility.

System block diagram and description

2.9 The flight inspection equipment as shown in Figure I-1-1 comprises:

a) flight inspection receivers with associated antennas;

b) position-reference system;

c) equipment for data display and processing; and

d) equipment for data recording.

2.10 Flight inspection receivers provide both navigation information as in standard aircraft equipment and flight inspection information. Special care has to be taken concerning the location of antennas of the flight inspection receivers in order to avoid interference problems and to minimize the error contribution of the test equipment.

2.11 The position-reference system provides reference position (navigation) information in order to determine the navigation accuracy of the facility. Parts of the position-reference system may be shared with standard aircraft equipment.

2.12 Data generated from the flight inspection receivers and the position-reference system are to be displayed and processed. The processing may be performed either on-line or after completion of an inspection. One important element of data processing is the comparison of ground facility navigation and reference position (navigation) information.

2.13 A recording medium is required for documentation of raw data and inspection results.

2.14 Calibration equipment may be connected to the flight inspection equipment.

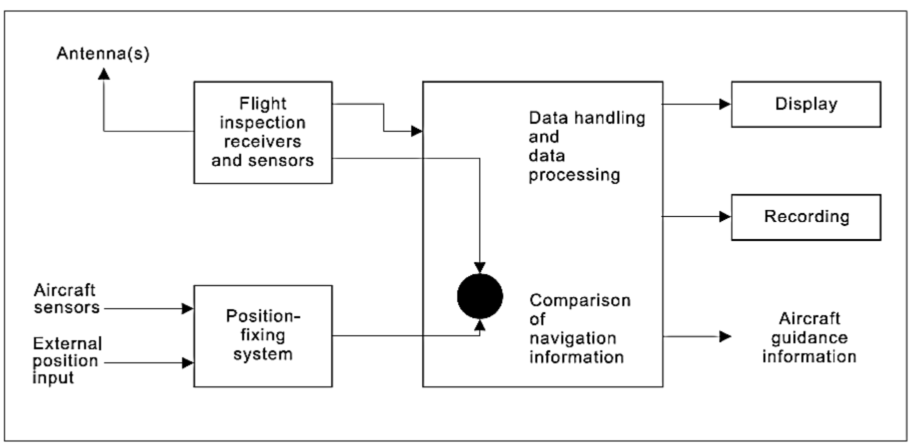

Figure I-1-1. Block diagram for flight inspection equipment

3. ANTENNAS

3.1 Calibration and extensive testing to verify performance are normally required for antennas used to inspect navigation aid coverage.

3.2 Calibration of the antenna system gain is required for antennas used to measure field strength and should be considered early in the installation planning stage. Antenna system gain characteristics (including all feed cables, switches and power splitters) must be determined in order to measure the field strength with reasonable accuracy. The characteristics must be measured over the range of frequencies to be used and at the aircraft orientations experienced during the measurement procedures. These antenna gain characteristics must then be applied either in real-time as data is input and displayed, or post-processed to generate the final report data.

3.3 The above methods may be used to correct absolute or relative field strength measurements, however, there are some flight inspection applications for which gain errors cannot be corrected. These place additional constraints on the achieved airborne antenna patterns. An example is course structure measurements for localizer, glide path, and VOR, for which the contributing multipath errors may propagate to the aircraft from a widely different azimuth than the desired direct signal. In this case, variations in gain from an omnidirectional pattern will affect the measured amplitude of the course structure, with or without aircraft attitude variations, and flight measurements, by differing aircraft types, will vary. Flight inspection organizations should make every reasonable effort to achieve antenna patterns that represent the antennas used by the fleet operating on the airport — this is particularly important for Category II and III measurements.

Antenna measurement techniques

3.4 Many techniques, including mathematical modeling, reduced-scale modeling, full-scale ground testing and flight testing, are available for optimizing the location of antennas and characterizing their gain in a given location on an aircraft. The complexity and cost are generally proportional to the number of azimuth and elevation angles to be measured as well as the accuracy required of the measurements. The overall cost is reduced if a combination of modeling and ground testing is used to establish expected performance; flight testing would then be used as the final confirmation stage.

3.5 Flight test techniques capable of full azimuth or lower hemisphere characterization with high accuracy are now available through many flight test ranges, these should be the preferred methods used to provide confirmation of antenna patterns. Procedures that provide ongoing confirmation of antenna performance are still required and some form of ramp-based check should be established.

3.6 Consideration should also be given to characterizing the localizer antenna pattern over the FM broadcast band (88–107.9 MHz), if the aircraft is to be used in resolving electromagnetic compatibility (EMC) problems from FM broadcast stations. A separate broadband antenna may be fitted if the aircraft is to be used for general interference investigation.

Installation considerations

3.7 Antenna installation can affect the flight inspection measurements and the operational use of the aircraft in many ways. The following are a few examples:

a) Propeller modulation effects can interfere with the received ILS localizer signal over a range of engine power settings. This can severely limit the use of the aircraft for flight inspection. Improving the antenna location is the best solution to this problem followed by the modification of the propeller frequency. The formula below shows the propeller modulation frequency.

Propeller Modulation Frequency (Hz) = Shaft Rotation Speed (RPM) x Number of Propeller Blades / 60

Examples:

3-blade propeller at 1800 RPM: 1800 x 3 / 60 = 90 Hz > BAD for ILS
4-blade propeller at 1800 RPM: 1800 x 4 / 60 = 120 Hz > OK for ILS

b) Physical movement of other antennas, such as the weather radar, may affect the signal received from a glide path antenna located nearby. The weather radar may have to be parked in a known orientation to obtain stable glide path signals.

c) Cross-coupling between aircraft transmitter antennas and receiving antennas can easily occur. Care must be taken to ensure adequate separation between potential interfering sources, such as VHF communications antennas and VOR/ILS localizer antennas.

d) Aircraft structures must be taken into account when selecting antenna locations. The mounting of antennas near discontinuities in material types should be avoided if a good ground plane is required. Metallic support rods stowed inside a composite material nose cone can act as re-radiators affecting the performance of a nearby antenna.

e) When one antenna is used to feed two or more receivers there is potential for receiver interaction resulting in an un-calibrated change to the antenna system gain. It is recommended that separate antennas be provided for the flight inspection receivers. Testing is recommended when a shared antenna must be used to ensure that tuning the second receiver over the band does not affect the signal level reaching the receiver used for coverage measurements.

f) Changes in aircraft attitude will affect the relative positions of the antenna and tracking reference point if the aircraft measuring antennas are not located at the same point as the reference for the tracking system as seen from the ground. Certain flight inspection systems correct this by using software and inputs from the aircraft navigation sensors.

g) The position of the phase centre for some types of antennas will vary according to the direction of arrival of the signals. Measurements have shown that the effective phase centre may move outside the physical area of the antenna. This change in position of the phase centre should be included in any correction algorithms which may be used.

4. FLIGHT INSPECTION RECEIVERS AND RADIO COMMUNICATION EQUIPMENT

4.1 Flight inspection receivers are to be of the highest quality in order to obtain the accuracy required for flight inspection purposes and should provide additional measurement outputs specific to flight inspection. A dual set of receivers is preferable to reduce statistical errors.

4.2 Flight inspection receivers include an AGC measurement. The AGC information allows the determination of the field strength if the receiver and antenna characteristic is taken into account. Further components have to be added like a temperature control for the receiver or a further dedicated receiver if the stability of the flight inspection receiver AGC output is not sufficient.

4.3 Flight inspection receivers used for the calibration of pulsed navigation facilities, such as DME and radars, provide the video signal of these facilities.

4.4 A radio is included in the flight inspection equipment in order to allow independent communication between the flight inspector and the ground crew, without affecting the pilot.

5. DATA PROCESSING, DISPLAY AND RECORDING

5.1 Modern flight inspection equipment includes a computer, which is used to read the data from the position-reference system and from the flight inspection receivers. The computer processes data in order to compare the facility navigation information and the position reference information. The computer has the capability of determining facility parameters, e.g. ILS localizer course width, alignment, etc.

5.2 The comparison of facility navigation information and position-reference point information may be performed with an analog solution, if the flight inspection system does not include a computer for calculating the results. The facility parameters have to be calculated manually in this case.

5.3 All relevant information like facility navigation information, reference information, facility error and additional receiver information, such as field strength, is displayed on board the flight inspection aircraft for the operator. Data may be displayed on analog or digital instruments as well as on computer screens.

5.4 Chart recorders or printers can be used for the documentation of flight inspection results. All data are annotated properly either by the operator or automatically by the data-processing system.

5.5 All raw data and computed data are recorded in electronic format on tapes or disks, if possible. This enables a later post-processing, if a specific investigation is required.

6. REGULATORY ASPECTS

6.1 Integration of the systems in the aircraft must not affect the Airworthiness Certificate of the aircraft. Every modification has to be recorded in the technical documentation of the aircraft, along with the approvals of the manufacturer and of the certification authority concerned.

6.2 Particular operating instructions should be registered in flight and exploitation manuals. If this integration entails any performance limitations or operational restrictions for the aircraft, they should appear clearly in the corresponding documents.

6.3 The integration of a flight inspection system results from the best compromise taking into account airworthiness constraints.

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ATTACHMENT 2 TO CHAPTER 1

DOCUMENTATION AND DATA RECORDING

1. FLIGHT INSPECTION REPORTS

1.1 The flight inspection report serves as the basic means of documentation and dissemination of the results of each flight inspection. The flight inspector in charge is responsible for initiating the report and ensuring that it clearly records the results of each parameter measured, along with an assessment of the conformance of the facility performance to the required standards. This assessment will normally involve an analysis of the data recordings and a review of the computer-aided analysis carried out on the data gathered during the inspection. Flight inspection reports should allow for “before” and “after” results to be entered into routine documentation of the adjustments made to the facilities.

1.2 Flight inspection reports typically include the following information:

a) station name and facility designation;

b) category of operation;

c) date(s) of inspection;

e) serial number of report / unique identifier;

f) type of inspection, e.g. routine or annual;

g) aircraft registration;

h) manufacturer and type of system being inspected;

i) wind conditions, to allow cross-wind to be established;

j) names and functions of all personnel involved in the inspection;

k) method of making each measurement (where alternatives are available); these may be referenced to the operating instructions;

l) details of associated attachments, e.g. recordings;

m) details of extra flights made necessary by system adjustments;

n) an assessment by the flight crew of the navigation facility performance;

o) comments by the flight inspector/equipment operator;

p) details of any immediately notifiable deficiencies;

q) results and tolerances;

r) statement of conformance/non-conformance; and

s) signatures of appropriate personnel.

1.3 A confirmation of the status of the inspection should be provided immediately after the inspection.

2. FLIGHT INSPECTION DATA RECORDINGS

The flight inspection data recordings serve as a record of the raw signal information used to assess ground facility performance. The recording medium may be a strip chart or electronic files of sampled data. Data recordings are normally archived and maintained on file with the flight inspection reports. This data should be made available to engineering and maintenance personnel for solving site problems and for assessing trends in facility or equipment performance.

3. FLIGHT INSPECTION SYSTEM CALIBRATION

Many of the components in a typical flight inspection system, as well as secondary or transfer standards, such as signal generators, must be calibrated on a periodic basis to ensure measurements are made with the required accuracy. Records of the calibration results (including the specific test equipment used) must be retained to ensure the calibration is traceable back to national measurement standards. The flight inspection organization shall ensure policies and procedures are in place to track the calibration status of equipment and recall equipment for calibration at the established intervals.

4. GROUND FACILITY DATA

Facility data sheets or computer files serve as a useful tool in providing the inspector and the flight inspection system with accurate information regarding facility survey data, facility and equipment types, frequencies, etc. Such information is normally prepared at the time of commissioning and revised as necessary to maintain current data. Its purpose is best served if the data are made part of a file to be carried in the aircraft or loaded into the flight inspection system.

5. RETENTION OF FLIGHT INSPECTION REPORTS AND DATA

Each flight inspection organization is responsible for ensuring that sufficient historical data are retained to establish the trends in facility performance over a reasonable interval of time. As a minimum, all commissioning inspection reports and data recordings should be retained in the facility file along with reports and data recordings from the last five periodic inspections. All special flight inspections carried out during this time period should be retained on file.

6. GROUND TEST REPORTS

It is recommended that the initial performance of a navigation aid facility be established through a formal proof of performance (POP) test and report. The facility is normally released for operational use once a satisfactory commissioning flight inspection is complete. It is normal practice that maintenance staff be certified to maintain the navigation aid in accordance with prescribed policies and procedures. These policies and procedures will normally specify what ground documentation and reports are required and the period for which they must be retained. It is recommended that the POP test report and reports on the implementation of modifications to the facility be retained throughout the life of the facility. Reports on routine maintenance actions should be maintained for a minimum of one year.

7. GROUND CALIBRATION REPORTS

Many of the components in a typical navigation aid system, as well as secondary or transfer standards, such as signal generators, must be calibrated on a periodic basis to ensure a facility is operating as intended. Reports of the calibration results (including the specific test equipment used) must be retained to ensure that measurements are traceable back to national calibration standards. The responsible maintenance organization shall ensure policies and procedures are in place to track the calibration status of equipment and recall equipment for calibration at the established intervals.

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ATTACHMENT 3 TO CHAPTER 1

INTERFERENCE ISSUES

1. INTERFERENCE EFFECTS

Interference to a navigation aid can manifest itself in many ways. A VOR receiver may appear to operate normally but indicate a solid bearing to an adjacent co-channel facility. A localizer deviation signal may become erratic while FM broadcast is heard on the receiver audio output. The glide path signal may be lost momentarily as an aircraft passes over an industrial facility. A GNSS receiver used for position fixing may lose track of satellites due to interference. Interference may be caused by not providing adequate separation between facilities on the same frequency. Ground-based non-aeronautical services such as FM broadcast stations may be the cause. Interference may originate on board the aircraft due to a poor avionics installation or from carry-on equipment. There are many possible sources and the probability of interference occurring is increasing as the frequency spectrum becomes more congested.

2. INTERFERENCE SOURCES

Note.— The following sources account for most of the problems affecting radio navigation or radio communications receivers.

Ground-based aeronautical sources

2.1 Aeronautical facilities are engineered, installed and maintained to avoid causing interference to users of other aeronautical facilities. The service volumes of aeronautical facilities are protected from co-channel and adjacent channel interference by using frequency coordination procedures based on minimum and maximum field strengths and protection criteria promulgated primarily in Annex 10. In-band interference is usually caused by malfunctioning transmitters, frequency coordination problems and receiver operation outside the protected service volume of the aeronautical facility. The use of signal generators on operational aeronautical frequencies during avionics testing can cause interference problems.

Ground-based non-aeronautical sources

2.2 These sources include broadcast transmitters and emitters such as industrial, scientific and medical (ISM) equipment and power lines. RF emitters are normally licensed and must comply with ITU Radio Regulations and domestic regulations. Malfunctioning transmitters and unintentional emitters are the cause of many interference problems.

FM broadcast transmitters

2.3 The FM broadcast services operating in the 88–107.9 MHz band can be a major source of interference in the adjacent VHF band 108–137 MHz, affecting ILS, VOR and VHF communications receivers. Two general types of interference can occur. The first is caused by FM broadcast emissions that fall inside the aeronautical band, such as intermodulation products generated when multiple FM transmitters feed one antenna or out-of-band emissions from stations operating at the upper edge of the FM band. The second type is generated within the navigation receiver in response to FM broadcast emissions that fall outside the aeronautical band. These are usually intermodulation or receiver desensitization effects caused by high-level signals outside the aeronautical band.

2.4 Annex 10, Volume I, Chapter 3, 3.1.4 and 3.3.8, and associated guidance material in Attachment C, contain FM immunity performance criteria for ILS and VOR receivers and additional related ITU references. The ICAO *Handbook for Evaluation of Electromagnetic Compatibility Between ILS and FM Broadcasting Stations Using Flight Test*[*] provides guidance on conducting flight tests of this kind of interference.

TV broadcast transmitters

2.5 Harmonics, intermodulation products and spurious emissions of TV video and audio carriers may cause interference to DME, VHF communications, VOR and ILS receivers, and GNSS.

Land mobile transmitters

2.6 In-band interference can be caused by spurious emissions from a single transmitter or by radiated inter-modulation products created at a co-sited facility. VHF communications frequencies are often affected because a fixed/mobile service band lies immediately above 137 MHz. The mobile satellite service operating in the band adjacent to the GNSS band or the fixed service operating in the GNSS band in some States can cause interference to GNSS receivers.

Cable television distribution systems

2.7 These CATV systems distribute TV broadcasting signals on ILS and VHF communications frequencies. Most CATV systems use coaxial cables, which can leak RF signals and cause in-band interference.

Industrial, scientific and medical (ISM) systems

2.8 Specific radio frequency bands (e.g. centred at 13.56, 27.12 and 40.98 MHz) are allocated for the operation of ISM equipment. In-band interference to VHF communications, VOR and ILS localizer receivers may be caused by the radiation of harmonics of the ISM frequencies from malfunctioning or inadequately shielded ISM equipment. The interfering signal sweeps repetitively through a portion of the VHF aeronautical band affecting several aeronautical frequencies. The most common ISM interference sources are industrial equipment such as plastic welders.

Power line distribution systems

2.9 Power line carrier (PLC) systems inject signals into power lines for monitoring and control purposes. ADF receivers can experience in-band interference because some PLC systems operate within the NDB band and PLC signals can radiate from power lines.

2.10 Corona noise and gap discharges from malfunctioning electrical equipment such as high-voltage bus-bars, switchgear, and insulators, can generate broadband impulsive-type noise, which can interfere with ILS localizer, VOR and VHF communications receivers in over-flying, low-altitude aircraft.

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* Available from the ICAO Air Navigation Bureau upon request (English only).

Other ground-based non-aeronautical sources

2.11 Low/medium/high frequency (LF/MF/HF) transmitters can cause co-channel and adjacent channel interference to ADF and HF communications receivers. High-power military radar may generate harmonic and spurious emission levels high enough to cause in-band and out-of-band interference to on-board pulse-type systems such as GNSS receivers. Radiated emissions from most information technology equipment (ITE) are regulated domestically. Malfunctioning ITE can cause in-band interference. Radiation of ITE clock frequency signals and their harmonics can interfere with VHF communications, ILS localizer, VOR and other receivers.

Airborne equipment sources

2.12 On-board aeronautical transmitters may cause in-band interference to aircraft receivers through harmonics of the intentional emissions or harmonics of local oscillator frequencies being conducted between units. Potential problems associated with portable electronic device installations on-board aircraft should normally be identified and resolved during airworthiness testing.

3. GENERAL METHODS FOR DETECTING AND RESOLVING INTERFERENCE PROBLEMS

3.1 There are many possible approaches to detecting and resolving interference problems. They all should be considered as tools to be applied when required.

EMC event-reporting system

3.2 An interference problem is often first observed by users of the navigation aid. Therefore, pilot and ATC reports are the first step in identifying the nature and approximate locations of where it occurs. The reporting system should be used to establish a point-of-contact between the users who observed the interference and the agency charged with resolving such occurrences.

Ground monitoring

3.3 The increasing pollution of the electromagnetic environment at or near airports is a major concern to many States. It can be a particular problem near major airports with a large number of aeronautical systems. The local electromagnetic environment tends to be more congested by the many ground-based non-aeronautical interference sources. Ground-based monitoring systems to detect interference events are being developed.

3.4 The protection of the integrity of the signal-in-space against degradation, which can arise from extraneous radio interference falling within the ILS frequency band, must be considered. This is particularly important where the ILS is used for Category II and III approach and landing operations. It is necessary, therefore, to periodically confirm that the radio environment at each Category II/III runway does not constitute a hazard.

Technical confirmation of the interference

3.5 Ground and/or airborne test equipment deployment to obtain technical measurements will depend on how and where the interference manifests itself.

3.6 Most flight inspection aircraft can readily record the effects of the interference on receiver AGC, cross-pointer, flag and audio signals, as well as determine the aircraft position and altitude when interference is observed. Confirmation of the interference characteristics and location by the flight inspection service is a second step toward solving the problem. More detailed information can be obtained about the relative signal levels and the frequencies being received at the aircraft antenna if the flight inspection aircraft is equipped with a spectrum analyser or field strength metre. Recording of the audio channel of the affected receiver, spectrum analyser or field strength meter is useful in identifying the interference source through its unique demodulated audio characteristics. A simple test such as inserting a suitable RF filter ahead of the receiver can often assist in identifying whether an interference source is in-band or out-of-band.

3.7 Confirmation of a suspected interference source can be achieved by switching the suspected source on and off several times and noting the resulting effects on the affected receiver.

3.8 It should be noted that there will be cases where the ground test equipment or the flight inspection aircraft may not be able to detect/confirm reported interference problems because:

a) the receiver systems used in the air or on the ground (i.e. receiver, antenna, and cable system) may have significantly different performance characteristics from those receiver systems reported to have experienced interference;

b) interference is intermittent and may not be occurring during the investigative flight test; or

c) it may be difficult to find a ground observation point which corresponds to the interference conditions seen in the air.

Specialized electromagnetic interference (EMI) troubleshooting methods

3.9 Specialized equipment and computer simulation will likely be required if a source of interference cannot be readily identified. Many States have invested considerable time and effort on hardware and software techniques to resolve EMI problems. These techniques include:

a) databases of potential interference sources;

b) EMC analysis software;

c) interference simulators;

d) special ground or airborne data acquisition systems;

e) interference direction-finding systems; and

f) antenna calibration techniques.

Interference investigation

3.10 It may be helpful, in resolving the more difficult interference problems, to form an investigative team consisting of personnel representing (as required) flight inspection services, the State spectrum regulatory agency, aeronautical spectrum management and aeronautical facility engineering/maintenance. This team could seek input from the affected users and the owner/operator of the potential interference source, develop and implement test plans, analyse results and make recommendations for resolving interference problems.

Chapter 2

VERY HIGH FREQUENCY OMNIDIRECTIONAL RADIO RANGE (VOR)

2.1 INTRODUCTION

General

2.1.1 This chapter provides guidance on the ground and flight inspection requirements applicable to both conventional (CVOR) and Doppler (DVOR) type VHF omnidirectional radio range (VOR), as specified in Annex 10, Volume I, 3.3.

System description

2.1.2 The VOR is a short-range radio navigation aid that produces an infinite number of bearings that may be visualized as lines radiating from the beacon. The number of bearings can be limited to 360, one degree apart, known as radials. A radial is identified by its magnetic bearing from the VOR.

2.1.3 The radials are generated in space by comparing the phase angle of two equal frequencies radiated from the beacon. One signal, called the reference, radiates omnidirectionally so that its phase is equal in all directions. The second signal, called the variable, radiates from a directional array. The phase of the variable signal received at the aircraft is dependent upon the radial on which the receiver lies with respect to magnetic north.

2.1.4 Both signals are in-phase at magnetic north. The phase of the variable signal lags that of the reference signal by an amount equal to the azimuth angle around the beacon.

2.1.5 Reserved.

2.1.6 Reserved.

Testing requirements

2.1.7 A summary of testing requirements is given in Table I-2-1.

2.2 GROUND TESTING

General

2.2.1 The following paragraphs contain information and guidance for establishment of an orderly maintenance programme for VOR facilities. A maintenance programme consists of standardized:

a) periodic performance tests to determine if the facility is operating in accordance with established criteria;

b) equipment adjustment procedures;

c) periodic formal facilities inspections;

d) logistic support procedures; and

e) equipment modification as required.

Note.— Since the means by which VOR signals are produced vary from one manufacturer to the other, it would be impracticable to include detailed procedures in this manual for the different equipment employed in the various States. For this reason, broad guidelines are provided and adaptation to specific equipment will be required.

Ground performance parameters

2.2.2 Ground test requirements are listed in Table I-2-2.

Ground test procedures

2.2.3 The VOR should be inspected in accordance with the manufacturer's recommended procedures. The following procedures provide guidance for testing of VOR specific parameters specified in Annex 10, Volume I. The manufacturer's procedures should include at least these tests.

Rotation

2.2.4 Correct rotation should be confirmed. This can be performed during the measurement of a ground error curve to determine antenna pattern accuracy.

Sensing

2.2.5 Correct sensing should be verified by checking a radial other than 0° or 180°.

Frequency

2.2.6 Using the frequency counter determines the transmitter carrier frequency in accordance with procedures in the equipment instruction book. If the frequency is out of tolerance, adjust it in accordance with the equipment instruction book.

Pattern accuracy

2.2.7 A ground check is a means for determining course alignment errors. The actual courses produced by the VOR are compared (using monitor circuits) with simulated courses produced by a VOR test generator. Data recorded during the ground check are used to prepare a ground check error curve. Establishment of a ground check capability will enable maintenance personnel to restore a VOR to normal operation, following most repairs to the facility without a flight inspection. It is desirable to maintain the ground check error curve (maximum positive error to maximum negative error) within approximately 2.0°. If the facility cannot provide this level of performance, a broader value should be considered. The stability of the error curve spread is considered more important to the facility performance analysis than the magnitude of the error spread.

Example of procedure for conducting a ground check for a conventional VOR:

a) Place a field detector into the 0° positioner bracket and feed signals to the monitor in the normal manner.

b) Rotate the azimuth selector of the monitor for an "on course" indication (reference and variable signals in phase).

c) Substitute signals from the test generator. This can be accomplished by temporarily switching the field detector and test generator cables.

d) Without changing monitor adjustments, rotate the test generator dial until an "on course" is again established. Read and record test generator dial reading. The difference between the dial reading of the test generator and the location of the field detector is the amount of course error at that location.

e) Repeat steps a) through d) for all bracket locations.

Plot a ground check error curve (amount of error versus azimuth) on rectangular co-ordinate graph paper.

Note 1.— Positioner brackets are installed on the edge of the counterpoise at every 22.5 ± 0.1° beginning at 0°. Alternatively, brackets could be mounted on poles appropriately spaced around the facility.

Note 2.— Course error is either plus or minus. Plus error means the course is clockwise from where it should be, minus error means the course is counterclockwise from where it should be.

Note 3.— An alternative method is to rotate the antenna through 360° and to plot the antenna characteristic from a single field monitor against the rotation angle.

2.2.8 Establishment of reference curve at commissioning. It is desirable to prepare a reference ground check error curve immediately following the commissioning flight inspection. This curve is no different from that described above except that it is an average of three separate ground checks conducted on the same day, if possible. The reference error curve serves as a standard for comparing subsequent ground checks. The reference error curve is updated whenever courses are realigned during a flight inspection.

Coverage

2.2.9 The coverage of the facility is established at the commissioning flight inspection. The standard operating condition of the facility should be established at this time including the carrier power level. Measure the RF power output using the wattmeter in accordance with the procedure in the equipment instruction book. Compare the level measured with the established standard operating condition at the periodic test.

Modulation

2.2.10 The preferred method is the use of a modulation meter. If a modulation meter is not available, an oscilloscope may be used instead.

9 960 Hz deviation

2.2.11 The deviation in a CVOR may be measured at the output of the FM modulation stage or by direct measurement of the radiated signal using a modulation analyser. The deviation is determined using an oscilloscope by displaying the 9 960 Hz signal and measuring the difference, Δt, in periods between the minimum frequency (9 960 Hz ! 480 Hz) and the maximum frequency (9 960 Hz + 480 Hz). The modulation index is determined by the following equation:

$$\text{Modulation Index} = \frac{\Delta t}{60T^2}$$

Where $T = 1/9\,960$

In a DVOR, the deviation of the 9 960 Hz subcarrier is determined by the rotation speed of the switched antennas and the physical characteristics of the array.

9 960 Hz modulation depth of the radio frequency carrier

2.2.12 The CVOR 9 960 Hz modulation depth of the carrier frequency can be measured by directly using a modulation meter, modulation analyser, or an oscilloscope. All other modulation should be inhibited unless the characteristics of the modulation analyser allow individual separation of the modulating signals.

2.2.13 In the oscilloscope method, a portion of the RF carrier (modulated by one frequency at a time) is coupled to the oscilloscope synchronized at the modulating frequency. An amplitude modulated waveform is produced from which the high (*Emax*) and low (*Emin*) points are measured. These values may be substituted in the following formula and the modulation percentage determined.

$$M = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100\%$$

2.2.14 The modulation of the carrier for a DVOR is achieved in space by the combination of the reference signal and the switched 9 960 Hz variable signal. The modulation depth should be checked using a signal derived from a field monitor. A tuned modulation analyser is required due to the lower signal strength available.

30 Hz modulation depth of the radio frequency carrier

2.2.15 The CVOR variable signal modulation level (space modulation) is a function of the ratio of sideband energy to carrier energy radiated. The procedure in the equipment instruction book should be followed for adjusting the variable signal modulation level because different means (i.e. antenna systems) are employed in producing the rotating figure-of-eight radiation pattern.

2.2.16 A procedure for adjusting the variable signal level that can be adapted to most VOR facilities is as follows:

a) Stop rotation of the figure-of-eight pattern.

b) Measure and record the relative field intensity (using monitor field intensity meter indications) at the two maximum field intensity points (180° apart) in the figure-of-eight radiation pattern. One of these points will be in-phase (Max) and the other out-of-phase (Min) with the carrier RF energy.

c) Compute the modulation percentage by substituting the Max and Min quantities obtained by applying b) above in the formula in 2.2.13.

d) Vary sideband power until the desired modulation level is attained.

2.2.17 Accuracy will require corrected field intensity readings obtained from a calibration curve (transmitter power output versus field detector meter indication) either furnished with the equipment or prepared by field maintenance personnel. The final setting of the 30 Hz variable signal level (course width) is determined by flight inspection.

2.2.18 DVOR carrier modulation depth by the 30 Hz can be measured directly using a modulation meter, modulation analyser, or an oscilloscope. All other modulation should be inhibited unless the characteristics of the modulation analyser allow individual separation of the modulating signals.

30 Hz modulation frequency

2.2.19 Measure the 30 Hz modulation frequency using the frequency counter.

9 960 Hz subcarrier frequency

2.2.20 Measure the 9 960 Hz subcarrier frequency using the frequency counter.

CVOR AM modulation of 9 960 Hz subcarrier

2.2.21 Observe the 9 960 Hz subcarrier using an oscilloscope at the output of the FM modulator or after detection from a field monitor. Use the method described above to determine the AM modulation of the subcarrier with all other modulation off.

DVOR AM modulation of 9 960 Hz subcarrier

2.2.22 Observe the composite signal with an oscilloscope connected to a test receiver or monitor and all other modulation off. Determine the percentage of amplitude modulation using the method described above.

Note.— The limit for AM on the subcarrier in the far field, further than 300 m (1 000 ft) away, is less than 40 per cent. This limit corresponds to a limit of 55 per cent when the signal from a monitor antenna at the 80 m (260 ft) distance is used. Refer to the manufacturer's equipment instruction book for additional guidance on particular equipment.

Sideband level of the harmonics of the 9 960 Hz component

2.2.23 The level of the 9 960 Hz harmonics can be determined by using a spectrum analyser and observing the radiated signal of the VOR from a field monitor probe. CVOR measurements can also be made at the antenna feed point of the reference signal.

Voice channel

2.2.24 *Peak modulation of voice channel.* Connect an audio generator set to the nominal line level to the audio input of the VOR. Measure the peak modulation using a modulation meter or the oscilloscope method described above.

2.2.25 *Audio frequency characteristics.* Select a frequency of 1 000 Hz using an audio generator and establish a reference modulation level. Maintain the same output level from the audio generator and vary the audio frequency between 300 Hz and 3 000 Hz noting the modulation characteristics over the range.

2.2.26 *Speech effect on normal navigation function.* Operate the VOR in normal mode with all navigation modulation present. Apply the normal audio programme and observe the station monitor for any effect on the navigation performance.

Identification

2.2.27 *Speed.* Observe the identification signal envelope using an oscilloscope. The code transmission speed can be established by measuring the period of a "dot".

2.2.28 *Repetition.* The repetition rate can be established by counting the repetition of the code cycle over a fixed period or by measuring the time required for the completion of several cycles.

2.2.29 *Tone.* The identification tone can be measured directly using a frequency counter.

2.2.30 *Modulation depth.* Measure the modulation depth using a modulation meter or the oscilloscope method with the identification tone continuously on and no other modulation present.

Monitoring

2.2.31 Two methods are available to test the monitor performance. The first method is the simulation of the monitor input signal by the use of test equipment; and the second method is the adjustment of the transmitter to provide the required test signals. The use of discrete test equipment is the preferred method. Additional monitors may be provided in different equipment types. The manufacturer's test procedures should be followed in such cases.

2.2.32 *Bearing.* Generate a VOR signal that equates to the monitored radial. Vary the phase of the variable signal relative to the reference signal to generate a positive and negative bearing alarm. Record the phase difference.

2.2.33 *Modulation.* Apply a standard monitor input signal and vary the modulation of the 9 960 Hz and the 30 Hz signals to cause alarm conditions for either or both of the navigation tones.

Polarization

2.2.34 This parameter is normally measured by flight inspection, but may be measured on the ground if suitable equipment is available.

Spurious modulation

2.2.35 Spurious (unwanted) modulation should be as low as possible (0.5 per cent or less) to prevent possible course errors. This modulation level may be determined by comparing AC voltage indications required to produce a known modulation level (only one modulation frequency applied) with the AC voltage indications, while audio input level controls (1 020 Hz, 10 kHz, and voice) are adjusted to zero. The modulation output meter may be used for these readings. Record the modulation value obtained.

Site infringement

2.2.36 The site surrounding the VOR should be inspected at each maintenance visit for infringements of the clear area surrounding the facility.

Maintenance activities that require flight inspection

2.2.37 Flight inspection is not required for all maintenance procedures or modifications to the transmitting and monitoring equipment if field measurement and monitoring indications can be restored to the conditions that existed at commissioning or during the last satisfactory flight test.

2.2.38 A flight test is required in the following situations before returning the VOR to service:

a) realignment of magnetic north reference;

b) replacement of the antenna;

c) repositioning the field monitor antenna;

d) replacement of transmission lines of critical length;

e) change of operating frequency; and

f) environmental changes.

Course error analysis

2.2.39 Improper equipment adjustments or faulty equipment can result in a ground check error curve having periodic variations. These variations approximate the shape of sine waves and depending upon the total number of positive and negative peaks above and below the zero course error line, are called duantal, quadrantal, or octantal error. These errors can appear singly or simultaneously in any combination. The Fourier analysis technique can be employed to determine the type and amount of error in an error curve if desired. The following examples apply for CVOR only.

2.2.40 Duantal error (two peaks, one positive and one negative) is caused by unwanted 30 Hz amplitude modulation of the RF carrier and/or improper RF phase relationship between sideband antenna currents of a pair. Possible causes of duantal error in a four-loop array are:

a) unequal electrical line lengths of paired transmission lines;

b) improper location of figure-of-eight radiation pattern Min points;

c) amplitude modulation of the 10 kHz signal at a 30 Hz rate; and/or

d) dissimilar antennas or antenna members elements.

2.2.41 Quadrantal error (four peaks, two positive and two negative) is caused by unwanted 60 Hz modulation of the RF carrier and/or antenna system faults. Possible causes of quadrantal error in a four-loop array are:

a) inequality of antenna pair currents;

b) misphasing of RF currents between antenna pairs;

c) unequal attenuation of sideband antenna feed lines; and/or

d) improper adjustment of the power amplifier stage of the transmitter.

2.2.42 Octantal error (eight peaks, four positives and four negatives) is found primarily in VOR facilities employing four (loop) antennas. This error results when they do not produce a true figure-of-eight radiation pattern. End-plates on loops should be adjusted to reduce octantal error.

2.2.43 Reserved.

Test equipment

2.2.44 The following is a suggested list of test equipment for use in maintaining VOR facilities:

a) oscilloscope — a bandwidth of 400 MHz is recommended;

b) audio oscillator;

c) VOR test generator;

d) frequency counter;

e) modulation analyser or modulation meter;

f) wattmeter, voltage standing wave ratio indicator or through-line wattmeter;

g) probe detector, VHF;

h) spectrum analyser.

2.3 FLIGHT TESTING

General

2.3.1 VORs should meet all requirements to be classified as unrestricted. The operating agency may, after proper coordination, prescribe the use of the facility on a restricted basis and issue a NOTAM accordingly when a facility does not meet these operating tolerances within a specific area.

Flight test performance parameters

2.3.2 Flight testing requirements are listed in Table I-2-3.

Flight test procedures

Sensing

2.3.3 This check is required at the beginning of the flight inspection and need not be repeated. The bearing of the aircraft from the station must be known. Select an appropriate radial and when the cross-pointer is centred, the indicator should indicate “FROM”.

Rotation

2.3.4 Begin an orbit. The radial bearing as indicated should continually decrease for a counterclockwise orbit, or increase for a clockwise orbit. Sensing should be checked before rotation. Incorrect sensing might cause the station rotation to appear reversed.

Polarization effect

2.3.5 The polarization effect results from vertically polarized RF energy being radiated from the antenna system. The presence of undesired “vertical polarization” should be checked by the “attitude effect” and may be further investigated by either the “360° turn method” or the “heading effect” method.

Attitude effect method

2.3.6 The vertical polarization effect should be checked when flying directly to, or from, the facility, at a distance of 18.5 to 37 km (10 to 20 NM). The aircraft should be rolled to a 30° bank, first to one side, then to the other, and returned to a straight level flight. Track and heading deviations should be kept to a minimum. Course deviation, as measured on the recording, is the indication of vertical polarization effect.

30° bank, 360° turn method

2.3.7 Vertical polarization may be checked by executing a 30° bank, 360° turn, 18.5 to 37 km (10 to 20 NM) from the antenna. The turn should begin from an “on-course” (toward the station) position over a measured ground checkpoint.

2.3.8 The recording should be marked at the start of the turn and at each 90° of heading change until the turn is completed. The turn should be completed over the starting point and the recording marked. The recording should show a smooth departure from and return to the “on-course” position, deviating only by the amount that the aircraft is displaced from the original starting point when the vertical polarization effect is not present. Other excursions of the cross-pointer may be attributed to the vertical polarization effect. The effect of the wing shadowing the aircraft antenna should be considered in evaluating the recording.

Pattern accuracy

Alignment

2.3.9 Alignment can be determined by flying an orbit or by flying a series of radials. The altitude selected for the flight should place the aircraft in the main lobe of the VOR.

2.3.10 The orbit should be flown at a height and range that allows the position reference system to accurately determine the position of the aircraft. This will require low, close-in orbits for theodolite-based position systems. Other automated systems will require the orbits to be conducted at a greater range to achieve the required accuracy. The orbit should have sufficient overlap to ensure that the measurement covers the complete 360°. The alignment of the VOR is determined by averaging the error throughout the orbit. Judgement may be exercised where the tracking of the orbit is interrupted to determine the effect of the lost information on the average alignment.

2.3.11 Alignment can also be determined by flying a series of radial approaches. These approaches should be conducted at equal angular displacements around the facility. A minimum of eight radials is considered necessary to determine the alignment of the VOR.

Bends

2.3.12 A bend is determined by flying a radial pattern and comparing the indicated course against a position reference system. The error is measured against the correct magnetic azimuth of the radial. The Annex 10 SARPs do not contain absolute accuracy standards for the VOR signal-in-space but only planning examples for procedure design. The following values are often used as default values for procedure design. If these values are exceeded at commissioning, it does not immediately result in a failure to meet the requirements, but an evaluation of the procedure design with the actual determined values should be conducted. Deviations of the course due to bends should not exceed 3.5° from the computed average course alignment and should remain within 3.5° of the correct azimuth.

Roughness and scalloping error

2.3.13 Scalloping is a cyclic deviation of the course line. The frequency is high enough so that the deviation is averaged out and will not cause aircraft displacement. Roughness is a ragged irregular series of deviations. Momentary deviations of the course due to roughness, scalloping or combinations thereof should not exceed 3.0° from the average course.

One way to systematically define and measure VOR accuracy is to consider that scalloping and roughness correspond to control motion noise (CMN) while bends and alignment errors are linked to path following error (PFE) and path following noise (PFN), where CMN, PFE and PFN are defined as the outputs of different filters. In order to filter short duration disturbances, a 40-second sliding window technique may be applied to the resulting filtered error components. The default tolerances are applied as:

Bias or Alignment:	± 2°
PFE and PFN:	± 3.5°
CMN:	± 3°

Flyability

2.3.14 Flyability is a subjective assessment by the pilot flying the inspection. Assessment of flyability should be performed on operational radials and during procedures based on the VOR, using the VOR as the track guidance source.

Coverage

2.3.15 Coverage of the VOR is the usable area within the operational service volume and is determined during the various checks of the VOR. Additional flight checks are required to determine the distance from the facility at which satisfactory coverage is obtained at the specified altitudes.

2.3.16 The coverage of a VOR can be affected by factors other than signal strength. Where out-of-tolerance roughness, scalloping, bends, alignment, and/or interference render the facility unusable in certain areas, a restriction should result which should be handled in the same manner as restricted coverage due to lack of signal strength.

Modulation

2.3.17 The modulation of the 30 Hz reference, 30 Hz variable and 9 960 Hz subcarrier should be measured during the flight inspection. Note that the roles of the FM and AM signals are reversed between the CVOR and the DVOR.

Voice channel

2.3.18 Voice communications on the VOR frequency should be checked for clarity, signal strength, and effect on the course structure in the same manner as described for identification checks. The audio level of voice communications is the same as the level of the voice identification feature. Flight inspection personnel should maintain surveillance of the quality and coverage of recorded voice transmissions (automatic terminal information service (ATIS) or other transcribed voice service) and ensure that there is no detrimental effect on the performance of the VOR. Comments and deficiencies should be included in the appropriate flight inspection reports.

2.3.19 *Speech effect on normal navigation functions.* Observe the indicated bearing information during a stable approach flight and determine if the bearing information is affected by the voice transmission.

Identification

2.3.20 The identification signal should be inspected for correctness, clarity, and possible detrimental effect on the course structure. This check should be performed while flying on-course and within radio line-of-sight of the station. Observe the course recording to determine if either code or voice identification affects the course structure. If course roughness is suspected, the identical track should be flown again with the identification turned off. Maintenance personnel should be advised immediately if it is determined that the course characteristics are affected by the identification signal.

2.3.21 The audible transmission of simultaneous voice/code identification signals should appear to be equal in volume to the user. The voice identification is not utilized during ground-to-air broadcasts on the VOR frequency, but the coded identification should be audible in the background.

Bearing monitor

2.3.22 The requirements for checking the monitor are as follows:

a) during commissioning inspections; and

b) during subsequent inspections, if the alignment at the reference checkpoint has changed more than one degree from the alignment last established and the monitor has not alarmed.

2.3.23 The check is made over the reference checkpoint at the same altitude as that used to establish the reference checkpoint. Position the aircraft inbound or outbound and activate the event mark exactly over the checkpoint while the following course conditions exist:

a) with the course in the normal operating condition;

b) with the course shifted to the alarm point;

c) with the course shifted to the alarm point to the opposite direction from b) above; or

d) with the course returned to the normal operating condition.

2.3.24 The course alignment should be compared, in each of these conditions, by reference to the recordings to determine the amplitude of shift to the alarm point and to verify the return to normal.

2.3.25 Where dual monitors are installed, follow the procedure for single monitor check above, except in steps b) and c) the course should be shifted in each direction until both monitors alarm. Determine the amplitude of course-shift required to alarm both monitors.

Reference checkpoint

2.3.26 A checkpoint should be selected during the commissioning inspection on or close to the monitor radial (usually 090 or 270 degrees) and located within 18.5 to 37 km (10 to 20 NM) of the antenna. This checkpoint should be used in establishing course alignment and should serve as a reference point for subsequent inspections of alignment, monitors, course sensitivity and modulation measurements. Course alignment and sensitivity should normally be adjusted with reference to this checkpoint. Adjustments made elsewhere will require a recheck of these parameters at this reference checkpoint.

2.3.27 The flight inspector should record a description of the reference checkpoint that includes the azimuth to the nearest tenth of a degree, the distance from the facility, and the mean sea level (MSL) altitude, which is usually 460 m (1 500 ft) above the antenna. This data should be revised any time the reference checkpoint is re-established. The final course alignment error, measured at the reference checkpoint, should be recorded on the facility data sheet for subsequent reference in order to determine the necessity for a complete monitor check as specified in 2.3.3.9.

Standby power

2.3.28 Standby power, when installed, should be checked during the commissioning inspection. This is not necessary for some types of standby power installations, e.g. float-charged battery supplies where there is no possibility of performance variation when operating on standby power. Subsequent inspections should not be required unless there is reported evidence of facility deterioration while this source of power is in use. The following items should be evaluated while operating on standby power:

a) course alignment (one radial);

b) course structure; and

c) modulations.

2.3.29 The inspections are to be performed when flying a portion of a radial with the station operating on normal power, and then repeating the check at the same altitude and over the same ground track with the station operating on standby power.

Standby equipment

2.3.30 Both transmitters should be checked against each required item of Table I-2-3. These checks may be performed using radial flights and a single alignment orbit.

2.3.31 Reserved.

Evaluation of operational procedures

Radials

2.3.32 Radials used, or proposed for use, for IFR should be inspected to determine their capability to support the procedure. On commissioning inspections, a selection of radials proposed for IFR use should be inspected. The selection should be based on the following criteria:

a) All radials supporting instrument approach procedures should be selected.

b) Radials should be selected from areas of poor performance indicated by the orbit inspection.

c) Any radials where the coverage may be affected by terrain should be selected.

d) At least one radial should be selected from each quadrant, if appropriate. In general, this should include the longest and lowest radials.

Routine inspection requirements are contained in the following paragraphs.

En-route radials (airways, off-airway routes, substitute routes)

2.3.33 En-route radials should be flown either inbound or outbound, along their entire length from the facility to the extremity of their intended use, at the minimum altitude for the associated airway or route as published. The minimum altitude for flying en-route radials, predicated on terminal facilities, is 300 m (1 000 ft) above the highest terrain or obstruction along the radial to a distance of 46.3 km (25 NM). The aircraft should be flown on the electronic radial and the position of the aircraft should be recorded using a position reference system.

2.3.34 Reference, variable and 9 960 Hz modulations and the vertical polarization effect should be checked at least once on each airway and direct-route radial. Signal strength, course deviation and aircraft position should be recorded throughout the radial flight.

2.3.35 Course structure and alignment should be determined by analysis of the recordings. The recordings should also be analysed for possible undesirable close-in or over-station characteristics to determine that use of the facility for approach, holding, etc., is not adversely affected.

Terminal radials (approach, missed approach, standard instrument departure (SID)

2.3.36 Approach radials should be evaluated at a distance that includes the procedure turn, holding pattern and missed approach on commissioning inspections. The approach radial should be flown 30 m (100 ft) below specified altitudes. Site and commissioning inspections require two additional radials 5° either side of the approach radial to be flown and analysed with the same criteria as the approach radial. This needs only to be performed if the approach radial shows performance near the set accuracy requirement. Radials used to support SID procedures should be evaluated to the extent to which they are used.

Intersections

2.3.37 Adjacent facilities that provide intersections should be inspected to determine their capability to support the intersection. Reliable facility performance and course guidance at the approved minimum holding altitude (MHA) should exist. Minimum signal strength should exist for the radial(s) forming the intersection within 7.4 km (4 NM) or

4.5°, whichever is greater, each side of the geographical location of the intersection fix.

2.3.38 Identification from each facility forming the intersection should be clear and distinct. The signal from each facility should be free from interference at all altitudes below the maximum authorized altitude for holding. A minimum reception altitude should be established for the intersection, which is normally determined by the facility providing the weakest signal.

Note.— All minimum en-route altitudes are to be corrected to and reported as true altitudes above mean sea level. All intersections prior to being published and authorized for use are to be flight inspected against the requirements stated above. Routine inspections of intersections can be accomplished adequately by recording an airway radial of one facility and the transition from other facilities forming the fix. Routine inspections can therefore be conducted concurrently with airway radials. Departure from the airway radial that is being inspected to evaluate another radial which is part of the fix is not required, unless detailed investigations become necessary.

Cross-check radials

2.3.39 Commissioning and routine flight inspections of cross-check radials are not required provided there is sufficient flight inspection data to support the publication of these radials. The radial(s) should be inspected prior to being authorized for use if cross-check radials are requested for use in areas outside of the operational service volume of the facility(ies) for which supporting flight inspection data is not available. Thereafter, flight inspections are not required.

2.3.40 Reserved.

Test equipment

2.3.41 The aircraft should be fitted with a typical VOR receiver and antenna system. The power level into the receiver is used as the normal reference parameter for the determination of field strength. The power level into the receiver can be converted to absolute field strength if the antenna factor and cable losses are known. Refer to Chapter 1, Attachment 1, for guidance on determining antenna performance.

2.3.42 Reserved.

Analysis

Course structure

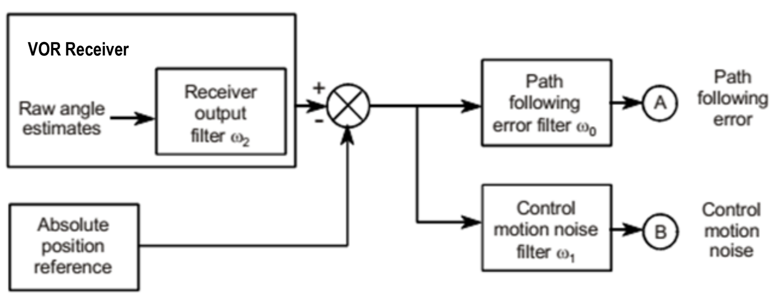
2.3.43 Roughness, scalloping, and bends are displayed as deviations of the cross-pointer. Roughness will show as a series of ragged irregular deviations; scalloping, as a series of smooth rhythmic deviations. The frequency of each is such that it is not flyable and must be averaged out to obtain a course. Modern flight inspection systems can automatically carry out the analysis of a course structure.

2.3.44 A manual method to measure the amplitude of roughness and scalloping, or combinations thereof, is to draw two lines on the recording which are tangential to and along each positive and negative peak of the course deviation. The number of degrees, or microamperes, between these lines will be the total magnitude of course deviations; one half of this magnitude will be the plus and minus deviation. A third line is drawn equidistant from these lines to obtain the average "on-course" from which alignment is measured. The alignment error may be computed from the course recordings at any point where an accurate checkpoint has been marked on the recording. An alignment error should be referred to the nearest tenth of a degree. Misalignment in the clockwise direction is considered positive. The error is positive when the magnetic azimuth of the measured (ground) checkpoint is greater than the electronic radial.

2.3.45 A bend is similar to scalloping except that its frequency is such that an aircraft can be manoeuvered throughout a bend to maintain a centered cross-pointer. A bend might be described as a brief misalignment of the course. It is therefore important to the analysis of a bend to consider aircraft heading and radial alignment deviations. Bends are sometimes difficult to discern, especially in those areas where good ground checkpoints or other means of aircraft positioning are not available. A smooth deviation of the course over a distance of 3.7 km (2 NM) two miles would manifest itself as a bend for a flight inspection aircraft at a ground speed of 140 knots. An aircraft of greater speed would not detect such smooth deviations of the course as a bend, unless it was over a much greater distance. The analysis of bends should further consider the flight levels and speeds of potential users.

2.3.46 These various course aberrations are usually caused by reflections of the RF signal from terrain, trees, power lines, hangars, fences, etc. The character of the deviation can indicate the type of reflecting objects, i.e. rough objects such as trees may cause roughness, smooth objects such as power lines and hangars may cause scalloping and bends. A study of flight inspection recordings and the surrounding terrain will often disclose the source of the course aberrations. These conditions (roughness, scalloping, bends) can occur alone or in any combination.

2.3.47 An alternate way to analysis VOR errors is to filter the VOR error using PFE and CMN filters as defined in Figure I-2-1. The VOR error is the result of the subtraction of the low-pass filtered output of the VOR receiver and the absolute position reference obtained by the tracking system. The characteristics of these filters are indicated in Figure I-2-2.



GUIDANCE FUNCTION	CORNER FREQUENCIES (RADIANS/SEC)		
	ω_0	ω_1	ω_2*
VOR	1.5	0.5	10

* This corner frequency may be less than 10 rad/sec for some applications.

RECEIVER OUTPUT FILTER $\frac{\omega_2}{S + \omega_2}$

PATH FOLLOWING FILTER $\frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}$ $\zeta = 1; \omega_0 = .64\,\omega_n$

CONTROL MOTION NOISE FILTER $\frac{S}{S + \omega_1}$

Figure I-2-1. Block diagram for alternative way to analyse VOR errors

Notes:

1. *Receiver output filter: First order low-pass filter with a corner frequency of 3 rad/s (ω2). This receiver filter is added when analysing the error if it is not included in the VOR receiver.*
2. *Alignment plus bend/bend only (PFE/PFN) filter: Second order low-pass filter with a corner frequency of ω0 = 0.125 * (Vground/140) rad/s, where Vground is the ground speed (in knots) of the flight inspection aircraft during the measurement.*

3. *Scalloping and roughness (CMN) filter: First order high-pass filter with a corner frequency of ω1= 0.125 * (Vground/140) rad/s, where Vground is the mean ground speed (in knots) of the flight inspection aircraft during the measurement.*
4. *The analysis is conducted in the direction of use of the VOR (inbound or outbound). If the flight inspection is not conducted in the published direction, a post analysis has to be done in order to analyse the accuracy performance in the right direction.*
5. *A 40-second sliding window technique is then used to apply the tolerances (Figure I-2-3).*
6. *The VOR PFE and CMN filter implementation need to be customized to the acquisition sampling rate of the flight inspection receiver. A typical value for the VOR signal-in-space sampling rate is 5 Hz. As the signal-in-space is sampled, the effects of the position reference output rate must also be taken into account.*

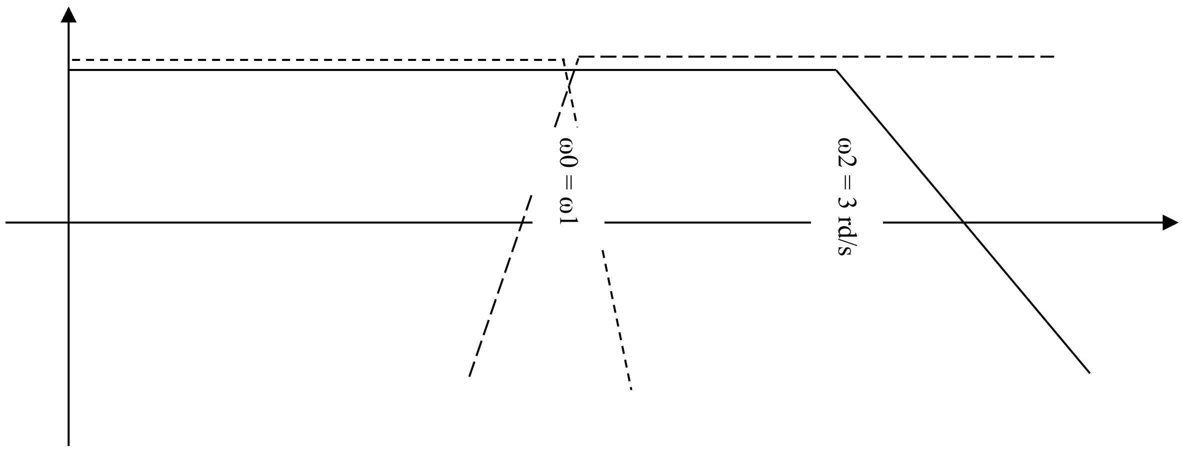


Figure I-2-2. Characteristics of analysis filters

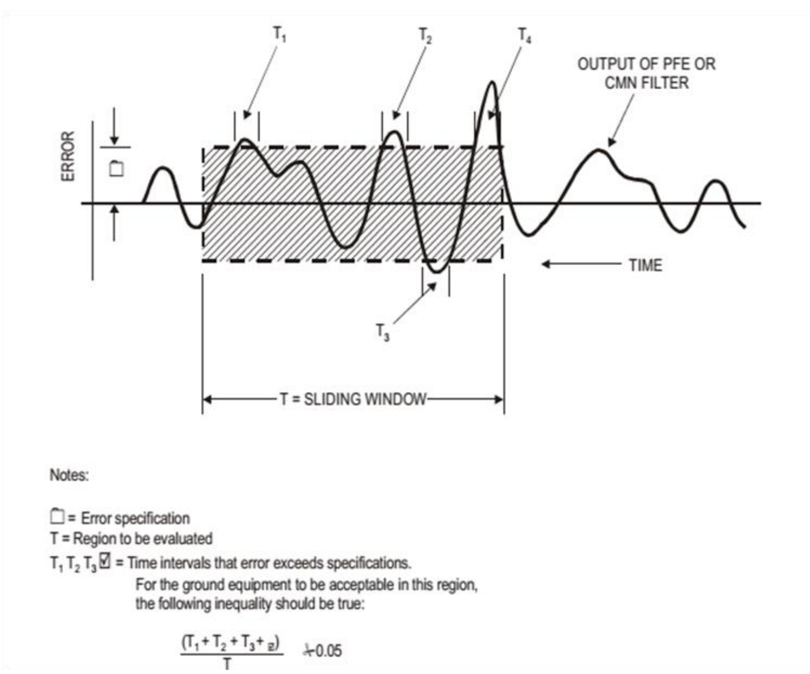


Figure I-2-3. Sliding window technique

Application of tolerances

2.3.48 The application of bend criteria should consider the navigation system accuracy, which is based partly on the typical maximum course displacement of 3.5° (bend tolerance) and the maximum distance an aircraft is expected to depart from an established course. The displacement of the course by a bend should not exceed 3.5° from either the correct magnetic azimuth or the on-course average, as provided by the facility, in order to satisfy these factors. The following two examples are offered for clarification:

a) A radial that has zero alignment error — the maximum bend tolerance of 3.5° is allowable on both sides of the "on-course" line whether the bend occurs singly or in series.

b) A radial that has an alignment error of +2.0° — further displacement of the course by a bend of +1.5° is allowable. This results in a +3.5° displacement from the correct magnetic azimuth. Since a bend displacement of the course of −3.5° from the "on-course" average is allowable; this results in a −1.5° displacement from the correct magnetic azimuth.

2.3.49 When roughness, or scalloping, or a combination is superimposed on the bend, the average "on-course" should be determined by averaging the total amplitude of such aberrations. This can result in a momentary displacement of the course of 6.5° where 3.0° of roughness is superimposed on a bend of 3.5°. Such a condition is highly unlikely; however, consideration should be given to the suitability of the facility in the areas of such occurrence.

2.3.50 The criteria for roughness and scalloping should not be applied strictly as a plus and minus factor, but as a maximum deviation from the course. Roughness and scalloping normally occur in a series. Where it is apparent that a rapid deviation occurs only on one side of the course, rather than in a series, the criteria should be applied as a plus factor, or a minus factor, as applicable. (See Figures I-2-4 and I-2-5.)

2.3.51 When using the PFE/PFN/CMN technique, the following defaults are applied:

Alignment error tolerance: 2°
PFE tolerance: ± 3.5°
PFN tolerance: ± 3.5°
CMN tolerance: ± 3°

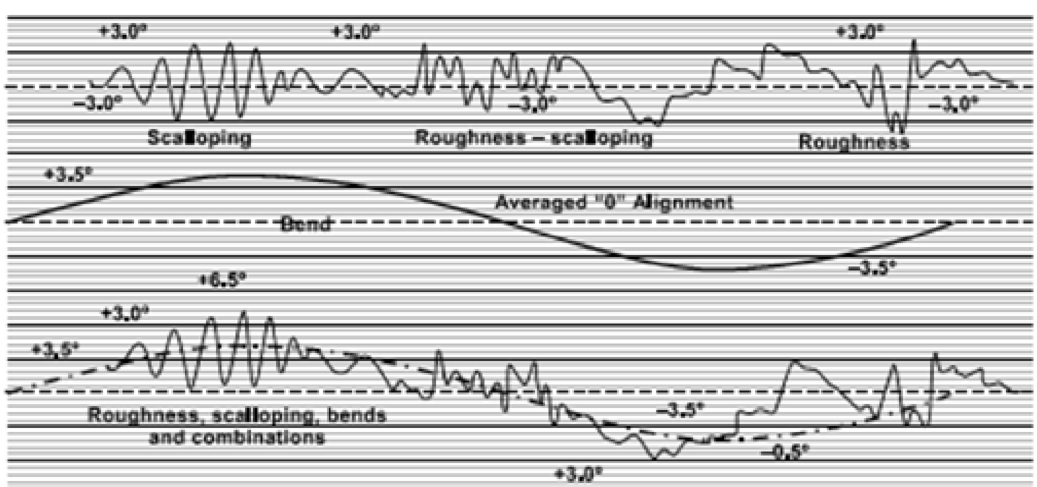


Figure I-2-4. Roughness, scalloping, bends and combinations

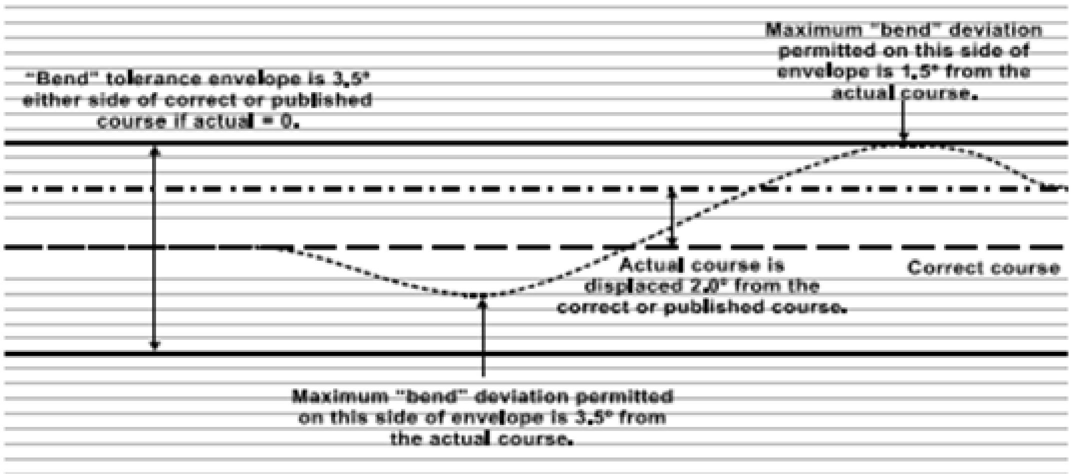


Figure I-2-5. Bend tolerance envelope

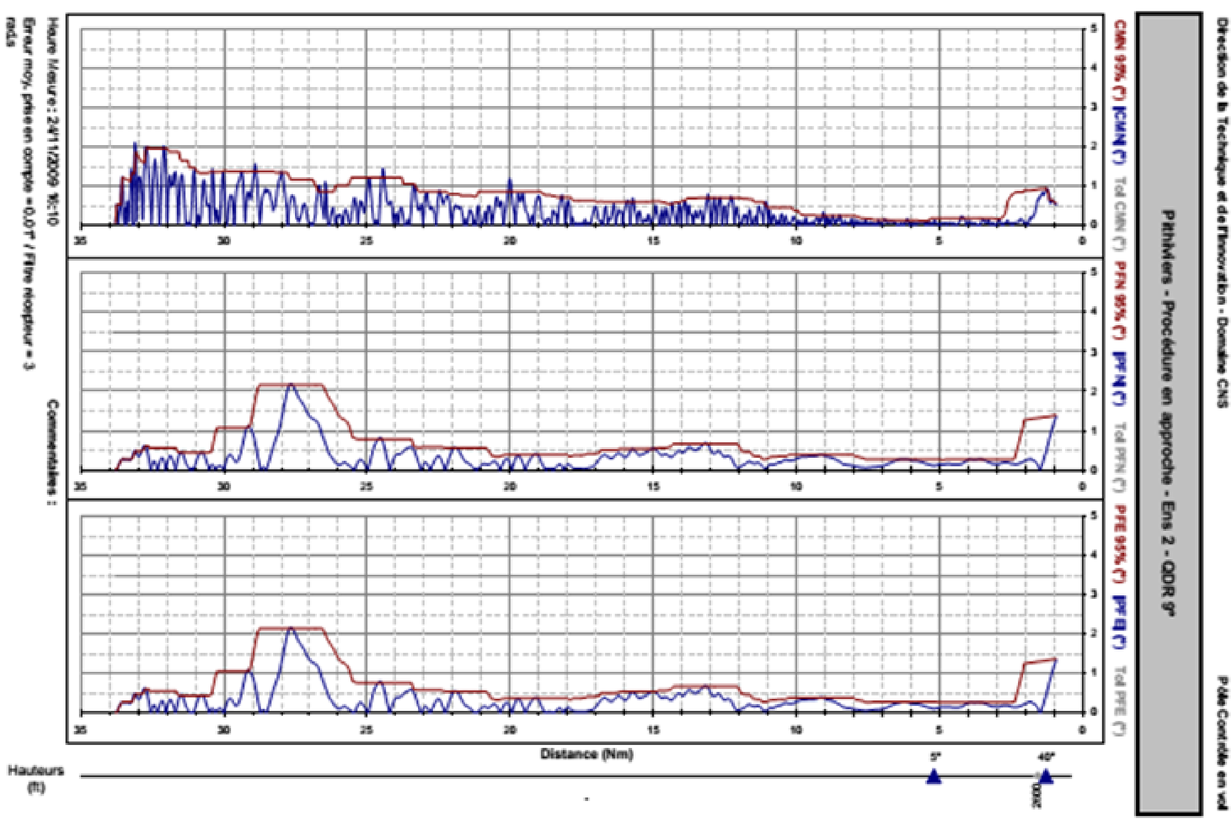


Figure I-2-6. Example of PFE/PFN/CMN analysis

Table I-2-1. Summary of testing requirements — VOR

Parameter	*Annex 10, Volume I, reference*	*Testing*
Rotation	3.3.1.1	F/G
Sensing	3.3.1.3	F/G
Frequency	3.3.2	G
Polarization	3.3.3.1	F/G
Pattern accuracy	3.3.3.2	F/G
Coverage	3.3.4	F/G
9 960 Hz deviation	3.3.5.1	F/G
9 960 Hz modulation depth	3.3.5.2	F/G
30 Hz modulation depth	3.3.5.3	F/G
30 Hz modulation frequency	3.3.5.4	G
9 960 Hz subcarrier frequency	3.3.5.5	G
CVOR AM modulation of 9 960 Hz subcarrier	3.3.5.6	F/G
DVOR AM modulation of 9 960 Hz subcarrier	3.3.5.6	F/G
Sideband level of the harmonics of the 9 960 Hz	3.3.5.7	G
Peak modulation of voice channel	3.3.6.2	G
Audio frequency characteristics	3.3.6.3	G
Identification speed	3.3.6.5	G
Identification repetition	3.3.6.5	G
Identification tone	3.3.6.5	G
Identification modulation depth	3.3.6.6	F/G
Speech effect on normal navigation function	3.3.6.7	F/G
Bearing monitor	3.3.7.1	F/G
Modulation monitor	3.3.7.1	G

Legend: *F = Flight test/inspection*
G = Ground test

Table I-2-2. Ground test requirements — VOR

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Periodicity*
Rotation	3.3.1.1	2.2.4	Clockwise	Correct		12 months
Sensing	3.3.1.3	2.2.5	Correctness	Correct		12 months
Carrier frequency	3.3.2	2.2.6	Frequency	±0.002%	0.0004%	12 months
Polarization	3.3.3.1	2.2.34	Deviation	±2.0	0.3	
Pattern accuracy	3.3.3.2	2.2.7 2.2.8	Alignment	±2.0	0.4	12 months
Coverage	3.3.4	2.2.9	Power density	-107 dBW/m^2 (90 µV/m) (recommendation)	3 dB	12 months
9 960 Hz deviation	3.3.5.1	2.2.11	Ratio	16 ±1		12 months
9 960 Hz modulation depth	3.3.5.2	2.2.12	Modulation depth	28 to 32%	1%	12 months
30 Hz modulation depth	3.3.5.3	2.2.15 to 2.2.18	Modulation depth	28 to 32%	1%	12 months
30 Hz modulation frequency	3.3.5.4	2.2.19	Frequency	30 Hz ±1%	0.06 Hz	12 months
9 960 Hz subcarrier frequency	3.3.5.5	2.2.20	Frequency	9 960 Hz ±1%	20 Hz	12 months
CVOR AM modulation of 9 960 Hz subcarrier	3.3.5.6	2.2.21	Modulation depth	≤5%	1%	12 months
DVOR AM modulation of 9 960 Hz subcarrier	3.3.5.6	2.2.22	Modulation depth	≤40%	1%	12 months
Sideband level of harmonics of 9 960 Hz	3.3.5.7	2.2.23	Modulation depth 2nd harmonic 3rd harmonic 4th and above	9 960 Hz = 0 dB ref. ≤-30 dB ≤-50 dB ≤-60 dB	1 dB	12 months
Peak modulation of voice channel	3.3.6.2	2.2.24	Modulation depth	≤30%	1%	12 months
Audio frequency characteristics	3.3.6.3	2.2.25	Power	±3 dB	1 dB	12 months
Identification speed	3.3.6.5	2.2.27	Time	7 words/minute		12 months
Identification repetition	3.3.6.5	2.2.28	Time	≥2 times/min		12 months
Identification tone frequency	3.3.6.5	2.2.29	Frequency	1 020 ±50 Hz	10 Hz	12 months
Identification modulation depth With communications channel No communications channel	3.3.6.6	2.2.30	Modulation depth	 ≤10% ≤20%	1%	12 months
Speech effect on navigation function Deviation Modulation	3.3.6.7	2.2.26	 Deviation Modulation		 0.3% 1%	12 months
Bearing monitor	3.3.7.1	2.2.32	Deviation	±1.0	0.3	12 months
Modulation monitor	3.3.7.1	2.2.33	Volts	15%	1%	12 months
Spurious modulation	None	2.2.35	Modulation depth	≤0.5%	0.1%	12 months
Site infringement	None	2.2.36				12 months

Table I-2-3. Flight test requirements — VOR

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type*
Rotation	3.3.1.1	2.3.4	Clockwise	Correct		C, P, S
Sensing	3.3.1.3	2.3.3	Correctness	Correct		C, P, S
Polarization	3.3.3.1	2.3.5	Deviation	±2.0	0.3	C, P, S
Pattern accuracy Alignment Bends (PFE/PFN) Roughness and scalloping (CMN) Flyability	3.3.3	 2.3.9 to 2.3.11 2.3.12 (2.3.47) 2.3.13 (2.3.47) 2.3.14	Deviation	 ±2.0 ±3.5 ±3.0 Flyable	 0.6 0.6 0.3 Subjective	C, P, S
Coverage Power density or field strength	3.3.4	2.3.15 2.3.16	Power density	-107 dBW/m^2 (90 µV/m)* At limits or operational requirements *(recommendation)	3 dB	C
Modulation 9 960 Hz modulation (VOR without voice modulation) 9 960 Hz modulation (VOR with voice modulation) 30 Hz modulation	3.3.5	2.3.17	Modulation depth up to 5º elevation	See Note. 20 to 55% 20 to 35% 25 to 35%	1%	C, P, S
Modulation 30 Hz FM deviation ratio CVOR DVOR (below 5º elevation) DVOR (5º to 40 º elevation)	3.3.5	2.3.17	Deviation ratio	 16 ±1 16 ±1 >11		C, P
Voice channel	3.3.6.2	2.3.18	Clarity	Clear		C, P
Identification	3.3.6.5	2.3.20 2.3.21	Clarity	Clear		C, P
Speech effect on navigation Bearing Modulation	3.3.6.7	2.3.19	 Deviation Modulation	No effect	 0.3 1%	C, P
Bearing monitor	3.3.7.1	2.3.22 to 2.3.25	Deviation	±1.0	0.3	C
Reference checkpoint		2.3.26 to 2.3.27	As required			C, P
Standby power		2.3.28 to 2.3.29	Normal operation			C, P
Standby equipment		2.3.30	As required			C, P
Complementary facilities		2.3.31	As required			C, P

Note: When modulation is measured during flight testing under strong dynamic multipath conditions, variations in the received modulation percentage are to be expected. Short-term variations beyond these values may be acceptable.

Legend: C = *Commissioning*
P = *Periodic. Nominal periodicity is 12 months. Some States have extended this interval, particularly for DVORs, based on the improved immunity of the Doppler equipment to multipath interference. Intervals of up to 5 years are applied by some States.*
S = *Site proving*

Chapter 3

DISTANCE MEASURING EQUIPMENT (DME)

3.1 INTRODUCTION

General

3.1.1 This chapter provides guidance on flight and ground testing requirements applicable to the standard distance measuring equipment (DME/N), as specified in Annex 10, Volume I, 3.5. The principles, upon which the DME functions are based, are such that the accuracy of the distance indications is essentially independent of the ground equipment-radiated field pattern. Consequently, the determination of correct ground equipment performance can generally be made with the ground monitoring and maintenance equipment in accordance with the procedures outlined in the individual DME manufacturer's documentation. Many of the Annex 10 parameters can also be tested in an aircraft with an appropriate airborne system.

System description

3.1.2 The DME system provides continuous distance information to an aircraft during execution of approach, departure, or en-route phases of flight in accordance with published procedures. The signals can be interpreted either by the pilot from the display or input directly into the flight management system (FMS).

Testing requirements

3.1.3 A summary of testing requirements is given is Table I-3-1.

3.2 GROUND TESTING

General

3.2.1 The parameters of the ground equipment that should be regularly checked are indicated in Table I-3-2. The suggested periodicities are given as general guidance and may require modification based on the manufacturer's recommendation or operational experience. The procedures and test equipment to be employed in ground testing a DME transponder vary according to the commercial product involved. Guidance may be available in the appropriate manufacturer's documentation.

Ground performance parameters

3.2.2 Ground test requirements are listed in Table I-3-2.

Ground test procedures

3.2.3 Recommended general instructions for testing of DME specific parameters are provided in the following paragraphs. The DME should be checked in accordance with the test procedures proposed in the manufacturer's documentation.

3.2.4 *Transmitter frequency stability.* Use the frequency counter to measure the transmitter frequency in accordance with the procedure in the manufacturer' s documentation. Adjust the frequency as required.

3.2.5 *Pulse spectrum.* Use the spectrum analyser to measure the spectrum of the output pulse according to the procedure in the equipment manufacterer's documentation. Check and correct the modulation level (pedestal and Gaussian pulse) and adjust the transmitter stages if provided. Note the output power and pulse shape during adjustments.

3.2.6 *Pulse shape.* Use the oscilloscope to measure the shape of the output pulse according to the procedure in the equipment manufacturer's documentation. If setting is necessary, refer to the adjustments of the output pulse spectrum in the paragraph above. After adjusting the pulse shape, it is very important to recheck the time decay. Check the pulse amplitude.

3.2.7 *Pulse spacing.* Use the oscilloscope to measure the spacing of the output pulse according to the procedure in the equipment manufacturer's documentation. Adjustments are generally not provided.

3.2.8 *Peak power output.* Use the peak power meter and the calibrated load, or the variable attenuator when available, to measure the peak power output of the transmitter according to the procedure in the equipment manufacturer's documentation. Refer to the adjustments of the Gaussian modulation pulse shape and transmitter stages in the previous paragraphs if adjustment is necessary. After adjustment, the time delay and pulse shape should be re-checked. Tolerances up to ±1dB of the power output are acceptable because these variations result in a change of the operational range by only 10 per cent. It is more important to obtain the output pulse spectrum and pulse shape within the requirements. Check the reflected power of the facility using the directional coupler.

3.2.9 *Peak variation.* Measure the power drop of the output pulse using the oscilloscope. The variation in power level at the peak of any pair should not deviate from the average peak power by more than ±1 dB.

3.2.10 *Pulse transmission rate.* The DME is set to a variable duty cycle or, if provided, to a constant duty cycle at commissioning. Measure the pulse transmission rate using the frequency counter, following the procedure of the equipment manufacturer's documentation. If the system is set to variable duty cycle, the measured pulse transmission rate depends on the manufacturer's design, which will be described in the detailed technical characteristics of the equipment. In any case, it should not be less than 700 pulse pairs per second (pp/s).

Note.— Operating DME transponders with quiescent transmission rates close to 700 pp/s will minimize the effects of pulse interference, particularly to other aviation services such as GNSS.

3.2.11 *Receiver frequency stability.* Use the frequency counter to measure the receiver frequency in accordance with the procedure in the equipment manufacturer's documentation. The accuracy of the receiver frequency depends on the accuracy of the transmitter frequency, and if provided with crystals, from their tolerances. Note that the transmitter frequency is always separated from the receiver frequency by ±63 MHz. The sign depends on operating channel mode.

3.2.12 *Receiver sensitivity.* Measure the on-channel sensitivity to 70 per cent reply efficiency at an interrogation rate of 30 to 40 pp/s. The receiver sensitivity can be set at commissioning to different values depending on the required output power. Use the procedures and settings of the calibrated test equipment as described in the manufacturer's documentation.

3.2.13 *Receiver sensitivity variation with load.* Measure the on-channel sensitivity to 70 per cent reply efficiency at an interrogation rate from 0 to 90 per cent of the maximum transponder transmission rate (depends on the requirements).

3.2.14 *Receiver bandwidth.* Measure the receiver sensitivity, as described in the paragraph "receiver sensitivity", except:

a) with an incoming frequency drift of ±100 kHz from the centre frequency. Check the loss in sensitivity; and/or

b) with an incoming frequency drift of ±900 kHz from the centre frequency and with a level of 80 dB above receiver threshold. Check the interrogation pulse rejection.

3.2.15 *Decoder.* Measure the receiver sensitivity as previously described, except:

a) with a shift of 0.4 μs in the pulse spacing of the interrogation signal. Check that there is no change in sensitivity;

b) with a shift between 0.5 μs and 2 μs in the pulse spacing of the interrogation signal. Check that the loss in sensitivity is less than 1 dB; and

c) with a shift of more than 2 μs in the pulse spacing of the interrogation signal. Check the interrogation pulse rejection.

3.2.16 *Time delay.* Measure the time between the first pulse of the interrogation to the first pulse of the reply using the 50 per cent point of the leading edge. Follow the manufacturer's recommended maintenance procedures and settings of the test equipment to make sure that the measurement is made precisely. The nominal transponder time delay is:

X-Mode: 50 μs
Y-Mode: 56 μs

Operational requirements at commissioning may justify setting the time delay to another value. It is recommended that the time delay variation be checked with different interrogation levels (from the receiver sensitivity threshold to 80 dB above the threshold) to verify that the slant distance accuracy is not dependent upon the level. Follow the procedure of the manufacturer's documentation.

Note.— The above figures are for first-pulse timing. If the transponder is set to second-pulse timing, the nominal time delay is 50 μs for both X-Mode and Y-Mode.

3.2.17 *Identification.* The identification signal consists of a series of paired pulses transmitted at a repetition rate of 1 350 pp/s. The identification keying is pre-settable for associated or independent facilities. Measure the time of the dots, the dashes, the spacing between dots and/or dashes and the spacing between consecutive letters or numerals. Check the total period of transmission of one identification code group. Check the repetition time between the code groups.

3.2.18 *The automatic monitor control.* Check and verify, using the milliwatt meter, the oscilloscope and the frequency counter that the monitor RF pulse peak output signal is correct (reference calibrated level: 0 dBm). Follow the test procedures of the manufacturer's documentation. Confirm the parameter alarm circuits operate within the tolerances. Check the indications and automatic functions for changing over to the standby transponder, or switching off the trans-ponder, if any alarm occurs.

3.2.19 The above is normally done for a conventional DME design. Modern DME designs have software controlled transmitters and receivers. The built-in test equipment uses sample signals at points in the DME circuits. A complete assessment of the performance of the DME is obtained from this built-in test equipment. Normally, further investigation with external test equipment is not necessary, provided that the principle of Chapter 1, 1.9 is respected according to the manufacturer's recommendations.

Test equipment

3.2.20 The following is a suggested list of test equipment, calibrated as appropriate, for use in maintaining DME facilities:

a) oscilloscope, with adequate time base;

b) UHF peak power meter;

c) UHF milliwatt meter;

d) UHF load, suitable for at least 1.3 GHz and 1.3 kW peak power;

e) UHF frequency counter;

f) UHF directional coupler with calibrated outputs;

g) calibrated attenuator, 10 dB, 20 W peak power;

h) calibrated attenuator, 20 dB, 20 W peak power;

i) UHF spectrum analyser;

j) built-in or external DME test equipment; and

k) recommended: variable UHF attenuator with calibration chart.

3.3 FLIGHT TESTING

General

3.3.1 The flight inspection aircraft should be equipped with a precision three-dimensional reference system, a high quality DME interrogator, an oscilloscope with storage and adequate timing capability, and a signal processing capability. The flight inspection of DME can be performed separately or in parallel with the more detailed check of the associated ILS, MLS, or VOR facility.

3.3.2 Important DME parameters will normally be checked on the ground. However, since DME is normally installed in association with an ILS, MLS, or VOR facility, it is good practice to check satisfactory DME operations when the collocated aid is being flight inspected. It is not necessary to establish a schedule of flight tests for DME, other than to specify that DME should be checked in accordance with the guidance material given in 3.3 whenever the associated aid is checked.

3.3.3 In many cases, a DME is installed at the site of a VOR or ILS facility that is already operational. The DME should not be brought into operational use until a commissioning flight inspection of the DME has been performed.

Flight test performance parameters

3.3.4 Flight test requirements are listed in Table I-3-3.

Flight test procedures

Coverage

3.3.5 The coverage is measured by recording the power density or field strength. When combined with the reference system, a horizontal and vertical pattern can be plotted. A high assurance of continuous coverage should be established for all flight procedures based on the use of DME.

Horizontal coverage

3.3.6 The aircraft is flown in a circular track with a radius depending on the service volume of the associated facility around the ground station antenna at an altitude corresponding to an angle of elevation of approximately 0.5° to 3.6° above the antenna site, or 300 m (1 000 ft) above intervening terrain, whichever is higher. If there is no associated facility, the orbit may be made at any radius greater than 18.5 km (10 NM). Since this flight is performed close to the radio horizon, it is possible to evaluate variations in the recorded power density or field strength values. Flight inspection of the coverage at maximum radius and minimum altitude, as prescribed by the operational requirements for the selected transponder, is usually necessary only on commissioning checks, when major modifications are made in the ground equipment, or if large structures are built in the vicinity of the antenna. The signal strength at the aircraft is generally adequate to maintain the interrogator in the tracking mode. Thus, the equipment itself can be used by the pilot for the desired orbit track guidance.

Note.— Checking of the associated VOR can be performed on the same flight.

Vertical coverage

3.3.7 The following flight inspection may be made to evaluate the lobing pattern of a DME transponder. The flight test aircraft is used to perform a horizontal flight at approximately 1 500 m (5 000 ft) following a radial. The flight inspector records power density from the flight inspection system. Airspace procedures based on the use of DME are evaluated at the minimum flight altitude. The flight inspector verifies that the distance information is properly available in the aircraft at ATC reporting points, along air routes.

3.3.8 It is possible to check that the interrogator-transponder system is operating properly at every point of the airspace under consideration by recording the power density. The measurements made in flight provide data for plotting a graph showing the range in relation to the altitude. This graph makes it possible to:

a) form a clear picture of the different lobes of the radiation pattern and thus evaluate the characteristics of the antenna and its environment;

b) show the cone as seen from directly overhead; and

c) determine limitations of the transponder coverage and their operational implications thereof.

Accuracy

3.3.9 The accuracy of the system can be evaluated by comparing the measured DME slant range with a three-dimensional reference. It is good practice to make the calculations in three-dimensional space to avoid errors based on differences between slant range and the range on the ground. The accuracy can be checked on both orbital and radial flights. The DME transponder’s contribution to the total error budget is principally the main delay. The most accurate calibration of this parameter is by ground measurement.

Pulse shape

3.3.10 It is not easy to measure the pulse shape of the DME transponder signal in orbital or radial flight, as the amplitude of the RF signal will vary along the flight path. One method is to store and examine a waveform of the pulse pair on a digital oscilloscope. Such specific flight test analysis is only recommended if reply efficiency and coverage (field strength) measurements indicate multipath or other propagation problems.

Pulse spacing

3.3.11 The same technique applies for the measurement of the pulse space as for the pulse shape.

Pulse transmission rate

3.3.12 The pulse transmission rate contains replies from interrogations, identification pulses and squitter. The pulse transmission rate can be counted with the oscilloscope to test that the values are those set at commissioning. The aircraft may be positioned in orbital or radial flight.

Identification

3.3.13 The identification signal should be checked for correctness and clarity, with the aircraft in orbital or radial flight. A DME associated with an ILS localizer or VOR should be checked for correct synchronization of the two identification signals.

Reply efficiency

3.3.14 Throughout the flight inspection, the reply efficiency should be monitored and recorded. This provides data on the service provided by the ground transponder to the aircraft within the service area. It can be used to indicate problem areas due to multipath and interference. Examination of received pulse shape using a digital oscilloscope may assist in identification of these effects.

Unlocks

3.3.15 Areas where persistent unlocks occur should be investigated by further flight inspection to determine whether engineering action or promulgation is necessary.

Standby equipment

3.3.16 The standby DME transponder should be spot-checked at the maximum orbit or radial distances in order to ensure that it meets the same tolerances and is comparable to the primary equipment. There should be no appreciable difference in the characteristics of the transponder (spectrum of pulses, energy radiated, etc.) between the primary and standby equipment.

Standby power

3.3.17 The standby power check can normally be performed satisfactorily on the ground. During commissioning and periodic inspections, this provision may be checked by observing operation and noting any appreciable differences in radiated signal characteristics that result from a changeover to standby power. The transponder characteristics (spectrum of pulses, energy radiated, etc.) should not be degraded when switched to standby power.

Charts and reports

3.3.18 The parameters from a DME inspection should be plotted on a graph relative to the distance or azimuth from the DME under test. When the DME is associated with ILS, MLS, or VOR, the DME details can be added to the report of the associated facility. In other cases, a separate report can be issued.

Test equipment

3.3.19 *Equipment.* In addition to the test equipment required to perform the VOR and ILS flight inspection, the following equipment is needed for a DME.

a) *A DME interrogator or, if possible, two.* Having a second interrogator in the aircraft provides standby equipment and makes it possible to compare the information given by the two interrogators in case of difficulties. It is desirable for the interrogators to have a certain number of outputs in order to:

   i) measure and record digital output with distance, and AGC voltage, from which the signal strength at the receiver input may be deduced. (Signal level errors of the order of 3 dB may be expected from the interrogator receiver and this should be taken into account when evaluating data from this source); and

   ii) make observations on an oscilloscope of the video signal before and after decoding; the suppression pulses, indicating that the transmitter is operating; and the coding signals of the interrogator, a particularly useful observation in case of anomalies during flight inspection.

b) *The corresponding antenna, the characteristics of which should be known, particularly its radiation pattern.* Accurate calibration of the antenna radiation pattern may be arduous, and determination of the antenna gain with an accuracy better than 3 to 5 dB may be difficult to achieve. However, it is recommended that this calibration is performed.

c) *An oscilloscope with good performance for time measurement.* Digital oscilloscopes have the capability to store waveforms and built-in functions for calculating the pulse shape parameters. Parameters and graphs should be recorded and documented.

d) *Spectrum analyser.* If it is desirable to measure the pulse spectrum with the flight inspection aircraft, a spectrum analyser should be carried on board. The increased pollution of the electromagnetic environment at or near our airports provides many good reasons for having an airborne spectrum analyser. Refer to Chapter 1 of this document for further information on this subject.

3.3.20 *Calibration.* The flight inspection DME interrogator should be maintained in accordance with the manufacturer's instructions and should conform to Annex 10 Standards and Recommended Practices. The following calibration instructions may be helpful:

a) *Interrogator pulse repetition rate.* The pulse transmission should be repeated at a rate of 30 pp/s, 5 per cent of the time spent in the SEARCH mode and 95 per cent in the TRACK mode. The variation in time between successive pairs should be sufficient to prevent false lock-on.

b) *Frequency stability.* The radio frequency of operation should not vary more than ±100 kHz from the assigned value.

c) *Peak power output.* The peak power output measured at the interrogator should be at least 100 watts. The constituent pulses of a pulse pair should have the same amplitude within 1dB. Special care should be taken when using GPS reference systems with phase measurements and, in particular, when using the GPS L_2 frequency. This frequency is close to the DME band and the maximum output power of the interrogator and the separation of the antennas should be kept in mind.

d) *Spurious radiation.* Spurious radiation between pulses on any DME interrogation or reply frequency measured in a receiver having the same characteristics of a DME transponder receiver should be more than 50 dB below the peak radiated power of the desired pulses. The spurious continuous wave (CW) power radiated from the interrogator on any DME interrogation or reply frequency should not exceed 20 micro-watts (–47 dBW).

e) *Sensitivity.* The signal level required at the input terminals to effect a successful end-of-search nine out of ten cycles should not exceed –82 dBm when the input signal is a DME test signal having a 70 per cent reply efficiency. The required signal level should not exceed –79 dBm when the test signal contains 6 000 random pulses 10 dB above the test signal level. The minimum signal levels are –85 and –82 dBm respectively to maintain tracking under the above conditions.

f) *Selectivity.* The level of the input signal required to produce a successful end-of-search nine out of ten cycles should not vary in excess of 6 dB over the band 120 kHz above and below the assigned reply frequency. This includes receiver frequency stability requirements. The level of the input signal required to produce an average of not more than one successful end-of-search out of ten cycles (and that one to track for not more than five seconds) should be at least 30 dB greater than the on-frequency signal described above, and nine out of ten successful end-of-search cycles when the off-frequency signal is displaced by 940 kHz either side of the assigned channel frequency. Over the frequency range of 960 MHz to 1 215 MHz, excluding frequencies within 1 MHz of the desired channel, the equipment should not respond to nor be adversely affected by an undesired frequency DME signal having a level 50 dB above the level of the signal on the desired channel.

Note 1.— In operational use, an adjacent channel transponder would provide at least 80 dB rejection of adjacent channel interrogations. Since the transponder effectively prevents replies to adjacent channel interrogations, no lock-on can occur.

Note 2.— Spurious responses. Over the frequency range of 90 kHz to 10 000 MHz, excluding frequencies within 3 MHz of the desired channel, a CW signal having a level of -30 dBm should not adversely affect the receiver sensitivity.

g) *Decoder selectivity.* The equipment should be calibrated to indicate distance satisfactorily when the spacing of the received pulses is varied from 11.5 to 12.5 microseconds for X-channel or from 29.5 to 30.5 microseconds for Y-channel, over the input signal level range from –48 dBm to the minimum tracking level. If the spacing between pulses is less than 10 microseconds or more than 14 microseconds for X-channel, or less than 28 microseconds or more than 32 microseconds for Y-channel, and the signal level is below –48 dBm, that signal should not be decoded.

h) *Search speed.* Search speed should be at least 10 NM per second.

i) *Memory.* To enable the detection of unlocks, the memory time of the equipment should be approximately 5 seconds upon the loss of the signal. The information displayed during this period should be that information which was being displayed at the time of the loss of the signal ±1.85 km (1 NM).

j) *Calibration.* The indication "Distance = 0 NM" should correspond to a time delay in responding to an interrogation of 50 μs ± 1 μs.

k) *Measuring accuracy.* Measuring accuracy including the distance reference system should be ≤± 0.025 NM (50 m).

l) *Identification signal.* The equipment should be capable of providing an intelligible and unambiguous aural identification signal at all usable receiver input levels.

m) *Airborne antenna.* The radiation pattern should be as omni-directional as possible in the horizontal plane. It should be sited in such a way as to be free from masking effects of the aircraft structure. The use of two antennas may be a good solution. The characteristics of the antenna and associated feeder line should be taken into account when interpreting the results of measurements.

Positioning

3.3.21 The increased accuracy requirements of the DME system require a reference system with accuracy better than 20 m (65 ft). A three-dimensional reference system suitable for calibration of the ILS will be adequate for DME calibration.

Table I-3-1. Summary of testing requirements — DME

Parameter	*Annex 10, Volume I, reference*	*Testing*
Coverage	3.5.3.1.2	F
Accuracy	3.5.3.1.3	F
Transmitter		
Frequency stability	3.5.4.1.2	G
Pulse spectrum	3.5.4.1.3	G
Pulse shape	3.5.4.1.3	F/G
Pulse spacing	3.5.4.1.4	F/G
Peak power output	3.5.4.1.5	G
Variation of peak power in any pair of pulses	3.5.4.1.5.4	G
Pulse transmission rate	3.5.4.1.5.6	G
Receiver		
Frequency stability	3.5.4.2.2	G
Sensitivity (reply efficiency)	3.5.4.2.3	G
Bandwidth	3.5.4.2.6	G
Decoder		
Decoder rejection	3.5.4.3.3	G
Time delay	3.5.4.4	G
Accuracy	3.5.4.5	F/G
Identification	3.5.3.6	F/G
Monitor	3.5.4.7.2	G

Legend: *F* = *Flight test/inspection*
G = *Ground test*

Table I-3-2. Ground test requirements — DME

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Periodicity*
Transmitter						
— Frequency stability	3.5.4.1.2	3.2.4	Frequency	Assigned channel frequency, ±0.002%	0.001%	12 months
— Pulse spectrum	3.5.4.1.3	3.2.5	Power	Output radiated within each 0.5 MHz band centred at ±0.8 MHz from the nominal frequency is not more than 200 mW; output radiated within each 0.5 MHz band centred at ±2 MHz from the nominal frequency is not more than 2 mW. Amplitude of successive lobes decreases in proportion to their frequency separation from the nominal frequency.	1 dB	6 months
— Pulse shape	3.5.4.1.3	3.2.6	Time, amplitude	Rise time ≤3 µs Duration 3.5 µs, ±0.5 µs Decay time ≤3.5 µs Amplitude, between 95% rise/fall amplitudes, ≥95%	0.1 µs 1%	6 months
— Pulse spacing	3.5.4.1.4	3.2.7	Time	X-channel: 12 ±0.25 µs Y-channel: 30 ±0.25 µs	0.1 s	6 months
— Peak power output (see Note 1)	3.5.4.1.5	3.2.8	Power	Peak EIRP such that field density ≥–89 dBW/m^2 at service volume limits	1 dB	6 months
— Peak variation	3.5.4.1.5.4	3.2.9	Power	Power difference between pulses of a pair ≤1 dB	0.2 dB	6 months
— Pulse transmission rate	3.5.4.1.5.6	3.2.10	Rate	≥700 pp/s	10 pulse pairs	6 months
Receiver						
— Frequency stability	3.5.4.2.2	3.2.11	Frequency	Assigned channel frequency, ±0.002%	0.001%	6 months
— Sensitivity (see Note 2)	3.5.4.2.3.1	3.2.12	Power	Such that power density at antenna ≥–103 dBW/m^2	1 dB	6 months
— Sensitivity variation with load	3.5.4.2.3.5	3.2.13	Power	<1 dB for loadings between 0 and 90% of maximum transmission rate	0.2 dB	6 months
— Bandwidth	3.5.4.2.6	3.2.14		Such that sensitivity degrades ≤3 dB for interrogation frequency drift of ±100 kHz.	0.5 dB	6 months
Decoder	3.5.4.3	3.2.15	Count	No response to interrogations with pulse spacing more than 2 µs from nominal	10 pulse pairs	6 months
Time delay	3.5.4.4	3.2.16	Time	X-channel: 50 µs Y-channel: 56 µs	1 µs	6 months
Identification	3.5.3.6	3.2.17	Identification	1 350 pulse pairs during key down periods proper Morse code sequence dot length = 0.1 to 0.16 s; dash = 0.3 to 0.48 s; spacing between dot and dash = dot length ±10%; spacing between letters ≥ 3 dots total length of one code sequence ≤10 seconds	10 pulse pairs 10 µs 0.5 s	12 months

Table I-3-2. Ground test requirements — DME

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Periodicity*
Monitor action	3.5.4.7.2.2	3.2.18	Time	Monitor alarms when: Reply delay varies by more than 1 µs (0.5 µs for DME associated with a landing aid)	0.2 µs	12 months
Monitor action delay	3.5.4.7.2.5		Time	Delay ≤10 seconds	0.5 s	12 months

Notes:
1. *Peak power output should be as set at commissioning.*
2. *Receiver sensitivity should be as set at commissioning.*

Table I-3-3. Flight test requirements — DME

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type (See Notes 1-3)*
Coverage Power density or field strength	3.5.3.1.2 3.5.4.1.5.2	3.3.5 to 3.3.8	Power density	Signal strength such that field density ≥-89 dBW/m^2 (690 µV/m) at limits or operational requirements	5 dB	S ,C
Accuracy	3.5.4.5	3.3.9	Distance	≤150 m ≤75 m for DME associated with landing aids	50 m	S, C, P
Pulse shape	3.5.4.1.3	3.3.10	Time, Amplitude	Rise time ≤3 µs Duration 3.5 µs, ±0.5 µs Decay time ≤3.5 µs Amplitude, between 95% rise/fall amplitudes, ≥95% of maximum amplitude	0.1 µs 1%	S, C, P
Pulse spacing	3.5.4.1.4	3.3.11	Time, Amplitude	X channel: 12 ±0.25 µsY channel: 30 ±0.25 µs	0.05 µs	S, C, P
Identification	3.5.3.6	3.3.13	Identification	Correct, clear, properly synchronized	N/A	S, C, P
Reply efficiency	3.5.4.6	3.3.14	Change in efficiency, position	Note areas where this changes significantly	N/A	S, C, P
Unlocks		3.3.15	Unlocking, position	Note where unlocking occurs	N/A	S, C, P
Standby equipment		3.3.16	Suitability	Same as primary transmitter	N/A	S, C, P
Standby power		3.3.17	Suitability	Should not affect transponder parameters	N/A	S, C, P

Notes:
1. *Site proving tests (S) are usually carried out to confirm facility performance prior to final construction of the site.*
2. *Commissioning checks (C) are to be carried out before the DME is initially placed in service. In addition, re-commissioning may be required whenever changes that may affect its performance (e.g. variations or repairs to the antenna system) are made.*
3. *Periodic checks (P) are typically made annually.*

Chapter 4

INSTRUMENT LANDING SYSTEM (ILS)

4.1 INTRODUCTION

General

4.1.1 The purpose of this chapter is to provide guidance on flight and ground inspection requirements applicable to the standard instrument landing system (ILS), as specified in Annex 10, Volume I, 2.7 and 3.1.

System description

4.1.2 The ILS provides precision guidance to an aircraft during the final stages of the approach. The signals can either be interpreted by the pilot from the instruments or be input directly into the autopilot and flight management system. ILS facility performance is divided into three categories depending on the reliability, integrity and quality of guidance, with facility performance Category III having the strictest requirements. An ILS comprises the following elements:

a) the localizer, operating in the frequency band from 108 to 112 MHz, providing azimuth guidance to a typical maximum range of 46.3 km (25 NM) from the runway threshold;

b) the glide path, operating in the frequency band from 328 to 336 MHz, providing elevation guidance to a typical maximum range of 18.5 km (10 NM) from the runway threshold; and

c) an appropriate means to enable glide path verification checks.

Distance to threshold information to enable glide path (altitude) verification checks is normally provided by:

- VHF marker beacons operating on the frequency of 75 MHz, providing position information at specific distances from the runway threshold; or

- distance measuring equipment (DME) operating in the frequency band from 960 to 1215 MHz on channels paired with the localizer, providing continuous distance to runway information.

Note.— If other standard radio navigation aids are used for this function, appropriate ground and flight test requirements must also be determined.

Ground and flight testing

4.1.3 Adequate monitoring, ground testing and maintenance on a routine and continuing basis should be the normal means of ensuring that the ILS signal-in-space performs within the specified tolerances and that the operational integrity and serviceability of the ILS facility is maintained. Flight testing is required to confirm the correctness of the setting of essential signal-in-space parameters, determine the operational safety and acceptability of the ILS installation, and periodically correlate signal patterns observed in flight and from the ground. Both types of testing provide awareness of long-term changes in the operational environment caused by effects such as multipath from on-airport construction activities. In practice, it has been found that certain ILS performance parameters can be determined more accurately and with greater reliability by ground measurements than through flight inspection. If the ground and flight measurements show different results, the reason for the divergence should be investigated.

4.1.4 Reserved.

Testing requirements

4.1.5 A summary of testing requirements for ILS localizer, glide path and markers is given in Tables I-4-1, I-4-2 and I-4-3. Where measurement uncertainties are given, they are the two-sigma or 95 per cent confidence level values.

Special measures preventing the operational use of test signals

4.1.6 Some ground and flight test procedures, as described in this chapter, involve misleading guidance signals being temporarily radiated by ILS or the executive monitoring function of the equipment being inhibited. Such signals, particularly those radiated for phasing and modulation balance testing, may be perceived on board the aircraft as "on-course" and/or "on-glide-path" indications regardless of the actual position of an aircraft within the ILS coverage and with no flag or alarm indication in the cockpit. The operational use of these signals for approach guidance can therefore result in misleading indications to the flight crew and has the potential to cause a controlled flight into terrain (CFIT) accident.

4.1.7 Accordingly, the appropriate State authority (or the organization authorized by the State) should develop measures to ensure that ILS test signals will not be used during normal flight operations when these signals are being radiated or the executive monitoring function of the facility is inhibited for testing/maintenance purposes. Coordination of testing procedures with ATC and the timely promulgation and distribution of relevant information by a NOTAM before the procedures commence are of paramount importance.

4.1.8 It is highly desirable to eliminate the possibility of any operational use to be made of the ILS guidance during the testing by administratively (e.g. by a NOTAM) removing the localizer and the glide path from service simultaneously. If this is not feasible for operational reasons, a deferral of testing should be considered. However, in case the localizer needs to remain in service while the glide path undergoes testing and the testing cannot be delayed, sufficient measures should be implemented to ensure that users are aware of the potential for false indications from the glide path facility.

4.1.9 In all circumstances, the basic protective measures should include as a minimum:

a) NOTAM phraseology that is specific about the possibility of false indications to the flight crew from the radiated test signals and clearly prohibits their use (suggested NOTAM wording — "RUNWAY XYZ ILS NOT AVBL DUE MAINTENANCE (or TESTING); DO NOT USE; FALSE INDICATIONS POSSIBLE");

b) confirmation by maintenance personnel that such a NOTAM has been issued by the Aeronautical Information Service before the testing procedures begin;

c) prior to beginning the tests, suspension or alteration to an unusual tone/sequence of the transmission of the unique Morse Code facility identification on the localizer, if the localizer should radiate solely for testing purposes; and

d) a requirement that ATC advise, by the automatic terminal information service (ATIS) and/or by a voice advisory, each pilot on an approach to the affected runway, emphasizing the possibility of false indications.

4.1.10 Additional protective measures may be appropriate, especially during phasing and modulation balance conditions for the localizer or the glide path (4.2.15, 4.2.37, 4.3.14, 4.3.39, 4.3.62 and 4.3.63 refer). Accordingly, when the phasing and modulation balance tests are being performed, the following options may be exercised:

a) when the tests are being performed on the localizer, remove the glide path from service by turning the signals off (to provide a glide path flag indication to the pilot);

b) when the tests are being performed on the glide path, remove the localizer from service by turning the signals off (to provide a localizer flag indication to the pilot); and/or

Note. — If option b) is exercised, the ATC advisories indicated in 4.1.9 d) above become redundant.

c) minimize the time radiating in a ground phasing condition by performing the testing with two or more technicians and radio communications.

4.1.11 In addition, it is essential to ensure that protective measures (in addition to the coordination and promulgation processes) are put in place to guard against single points of failure. One highly desirable measure is the installation of remote ILS status-indicating equipment such that it is visible to the air traffic controller issuing approach clearances.

Analysis concerning harmful interference caused by opposite runway localizer transmission

4.1.12 At those locations where two ILS facilities serve the opposite ends of a single runway without a means to avoid simultaneous transmission by both localizers (e.g. interlock), it is necessary to verify the absence of operationally harmful interference when both localizers are transmitting.

4.1.13 This verification may be done through flight test with both localizers transmitting or by geometry analysis. The second option consists in checking that the overflight of the opposite localizer (the area of harmful interference) is beyond the applicable limit at which the course structure requirements should be met.

4.2 GROUND TESTING

General

4.2.1 The primary purposes of ground testing are to ensure that the ILS radiates a signal meeting the requirements of Annex 10 and to confirm correct monitor operation. Since ILS equipment varies greatly, it is not possible to define detailed tests applicable to all types. Therefore, only a high-level description of the tests are provided below, and manufacturer’s recommendations should be used for additional tests and detailed procedures of specific equipment. The periodicity shown for ground tests may be extended based on appropriate considerations as discussed in Chapter 1, such as the use of continuous monitoring techniques or good correlation between ground and airborne measurements of the same parameters.

Ground performance parameters

4.2.2 Ground test requirements for localizers, glide paths, and ILS marker beacons are listed in Tables I-4-4, I-4-5, and I-4-6. Ground test requirements for DME associated with ILS are listed in Table I-3-2.

Ground test procedures

General

4.2.3 The procedures for conducting the ground testing of the parameters listed in Tables I-4-4, I-4-5 and I-4-6 are intended to provide basic guidance in the method of measuring the various parameters. These procedures should not be construed as the only means of accomplishing the intended purpose; particular air navigation service providers (ANSPs) might find modified or new methods which better suit their equipment or local situation.

Independence of ground measurements and monitor equipment

4.2.4 In most cases, these measurements will be made using equipment other than the monitors that are a part of the normal installation. This is because a primary value of ground tests is to confirm overall monitor performance, and it is therefore desirable to make corroborative checks on monitor indications using independent equipment. Significant differences in the correlation between the check measurements and monitor indications should always be investigated and resolved.

Correlation between field and monitor indications

4.2.5 When checks are made on the monitor indications by means of portable test equipment, the following effects should be taken into account:

a) *Aperture effect:* The extent of the near-field is a function of the aperture of the radiating antenna system.

   i) *Localizer:* For apertures up to 30 m (100 ft), negligible error due to the near-field effect will be introduced if measurements are made at points beyond a ten-aperture (twenty apertures preferred) distance from the localizer antenna. For larger aperture antennas, a minimum distance of twenty apertures is recommended to obtain readings that are more accurate.

   ii) *Glide path:* The equipment is normally adjusted so that the signal phase relationships existing on the runway centre line at threshold or beyond are correct. For this reason, the ILS reference datum represent a good position for glide path measurement. If possible, positions on the extended runway centre line should be used. However, any location is suitable if a good correlation between the measured and far-field conditions is obtained.

b) *Ground constants:* In the near-field region the measurement accuracy may be adversely affected by changes in ground constants. Satisfactory drainage and soil stabilization would help to achieve stability.

c) *Diffracted and reflected energy:* The alignment and displacement sensitivity of the localizer and the glide path may be affected by the presence of diffracted and reflected energy. This should be taken into account when such characteristics are determined for the first time.

Correlation between ground and flight tests

4.2.6 Whenever possible, the correlation between simultaneous or nearly simultaneous ground and airborne measurement results on the same or related parameters should be analysed. Good correlation will usually result in increased confidence in both measurements, and when rigorously applied, may be the basis for extending maintenance or test intervals, as discussed in Chapter 1.

4.2.7 Typically, the necessary conditions for correlation of measurement results include the availability of proper ground maintenance test equipment, traceable calibration programmes for ground and airborne test equipment, availability of commissioning and recent test reports, and similar level of understanding between ground and airborne personnel on the meaning and value of measurement correlation. If feasible, a meeting between ground maintenance and airborne test personnel before the measurements is desirable, particularly if dissimilar test generators and receivers are used. If measurements do not agree within pre-defined tolerances and cannot be resolved, actions such as tightening monitor alarm points, declassifying the facility, or removing it from service should be considered.

Localizer

Localizer course alignment

4.2.8 The measurement of localizer course alignment should be carried out in the far-field region of the localizer. There are several alternative methods that may be employed. One method, which is widely used, employs portable field test equipment which is located at pre-surveyed points on the runway centre line or on the extended centre line. The course structure at the position selected for these measurements should be stable and free of multipath distortions. By using this test equipment, the position of the course line relative to the runway centre line may be determined. This method enables single-point measurement of the course line to be obtained and is considered to be adequate for Category I and II facilities.

4.2.9 For Category III facilities, it may be desirable to employ a measurement procedure which is able to display the mean value of the course line over a significant portion of the runway. This test equipment may take the form of an ILS precision receiver, antenna and recorder mounted in a vehicle. An antenna height that approximates the height of an aircraft antenna on roll-out should be used, e.g. 3 to 8 m (10 to 26 ft). Typically, low-pass filtering of the raw cross-pointer signal is necessary to approximate the results obtained with an aircraft. The total time-constant of the receiver and recorder difference in depth of modulation (DDM) circuits for the vehicle measurements should be referenced to an aircraft speed of 195 km/hr (105 knt), for which the constant is approximately 0.5 second (refer to Attachment C to Annex 10, Volume I, 2.1.6 for specific filter guidance). The test vehicle is driven along the runway centre line and a recording of the course structure obtained over the region from the runway threshold to ILS Point E. From this recording the alignment for each zone for application of structure tolerances may be determined as the average course position between runway threshold and Point D, and separately between Point D and Point E. To analyse the post-filtering low frequency spectral components, the guidance found in Attachment C to Annex 10, Volume I, 2.1.3 and 2.1.5, should be used, with the structure tolerances referenced to the average course position in each zone. For alignment, it is preferable to use a directional antenna. For course structure, it is preferable to use an antenna with limited directivity, which is similar to the performance of an aircraft antenna.

Displacement sensitivity

4.2.10 Displacement sensitivity of the localizer is measured with test equipment located at surveyed positions in the far-field where the course structure is known and stable. These test positions are typically on opposite sides of the runway centre line as close as possible to the edge of the half-course sector and ideally at the same distance to the array. The test equipment reading obtained at each position is recorded, and the displacement sensitivity is calculated in units of DDM/metre as the sum of the absolute value of the two DDM values, divided by the distance between the two surveyed points. If the test positions are not located on a line perpendicular to the runway centre line at the ILS reference datum, then the measured displacement needs to be scaled as shown in Figure I-4-1.

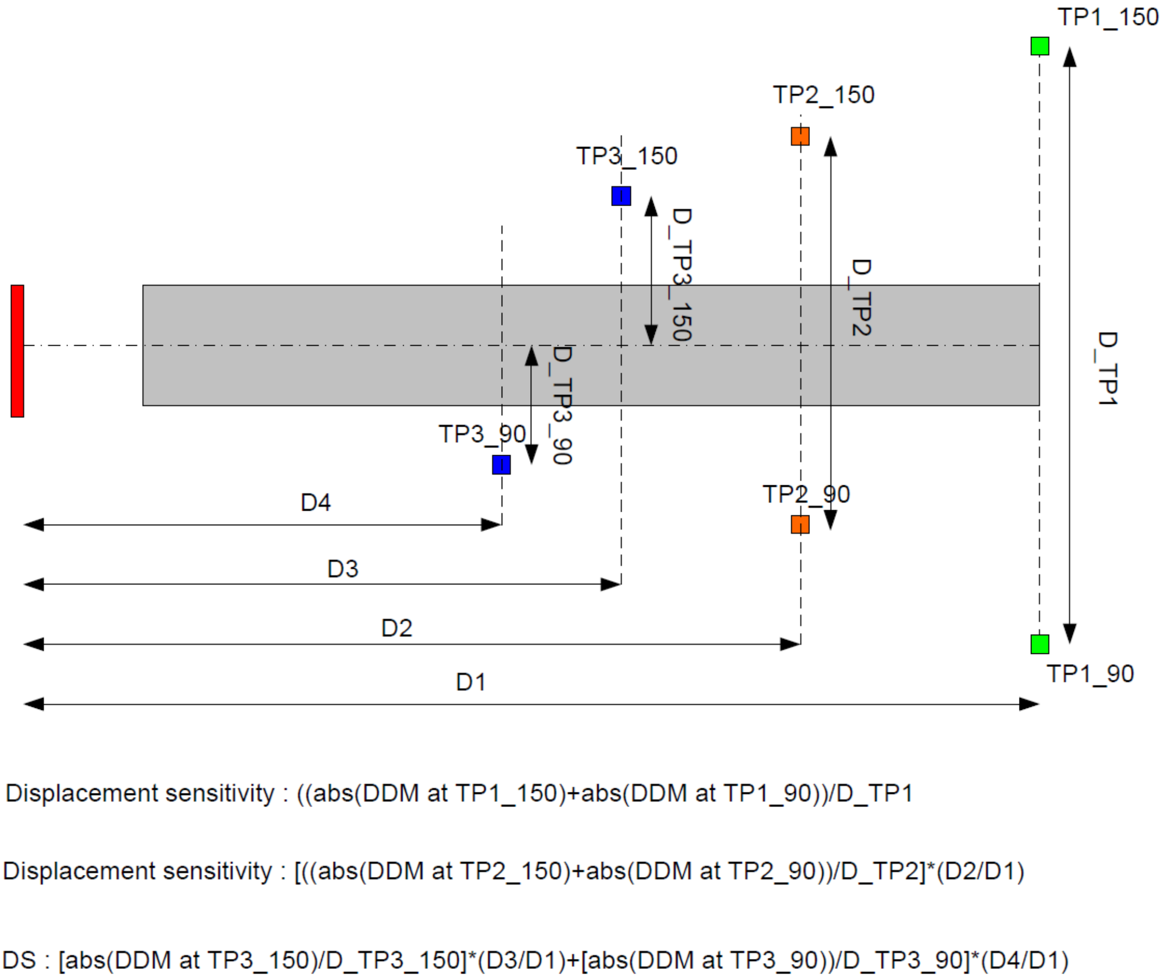


Figure I-4-1. Displacement sensitivity scaling

Off-course clearance

4.2.11 The procedure to be adopted for ground measurement of off-course clearance will vary from station to station depending upon the layout of the airfield. Typically, pre-surveyed points will be provided at intervals throughout the ±35-degree forward coverage area of the ILS localizer. In the case of localizers operating on the two-frequency principle, additional points may be provided at azimuths where the two patterns have equal signal strength on either side of the centre line. The portable test equipment is positioned at the pre-surveyed points and the off-course clearance signal conditions recorded. The results will be analysed to assess the stability and repeatability of the clearance parameters. For localizers providing clearance beyond the ±35-degree coverage sector, additional readings should be made. The spacing of the points may be greater here than the spacing employed within the coverage sector.

Carrier frequency

4.2.12 This is usually measured at the transmitter output using a dummy load tap or test point connected to a frequency counter or frequency meter. For a two-frequency system, the carriers are arranged symmetrically about the assigned frequency. Checks on those systems should be made of each frequency and of the difference between the two carriers.

Output power

4.2.13 The power into the antenna system may be measured using a wattmeter, preferably of the through-line type that is capable of indicating direct and reflected power. During installation, it may be convenient to relate this power measurement to field strength at the runway threshold. This can be done by measuring field strength on the course line at the threshold (at a height of 4 m (13 ft) for Category II and III) and at the same time recording the power into the antenna system. Subsequently, the power should be reduced by 3 dB and the resulting threshold field strength again recorded.

Tone frequency

4.2.14 Measurement of tone frequency is made by use of a frequency counter or other suitable type of basic test instrument. Instructions on the method to be employed can be found in the equipment handbook. In cases where signal tones are generated from very stable sources, this measurement of tone frequency may be performed less frequently.

Modulation depth (90/150 Hz)

4.2.15 Modulation depth is probably one of the most difficult quantities to measure to the required accuracy, and only high precision instruments should be used. The technique used to measure the modulation depths should preferably be one which analyses the waveform with both modulating tones present. If the measurement can only be made with one tone present, care should be taken to ensure that:

a) the individual tone amplitude is not affected by the removal or the addition of the other tone;

b) the modulator remains linear with both tones present; and

c) the harmonic content of the tone is as low as possible.

Modulation depth (1 020 Hz)

4.2.16 Measurement of the modulation depth of the 1 020 Hz identification tone can be carried out by wave analyser comparison between the modulation depth of the 90 Hz tone and the 1 020 Hz tone or by portable test equipment, which can measure it directly. The wave analyser is tuned to 90 Hz and the scale amplitude is noted. The wave analyser is then tuned to 1 020 Hz and the modulation depth of the 1 020 Hz is adjusted to the appropriate proportion of the 90 Hz reading.

Harmonic content of the 90 and 150 Hz tones

4.2.17 This is measured at the transmitter cabinet using a detector feeding a wave analyser from which a value is obtained on a root mean square (RMS) calculation basis. For future checks a distortion factor meter may be used, however, this can indicate a higher value of distortion than that contributed by the harmonics themselves.

90/150 Hz phasing

4.2.18 Measurement of the relative phase between the 90 and 150 Hz tones can most conveniently be made using one of the commercially available instruments specifically designed for this purpose. Where two frequency carrier systems are used, the relative phase of the 90/150 Hz tones should be checked separately for each system. An additional check of the relative phase of the two 90 Hz and two 150 Hz tones should then be carried out.

4.2.19 When such equipment is not available, a check that the 90/150 Hz phase is within the required tolerance can be made on the combined waveform using the following oscilloscope technique:

a) with the modulation balance adjusted for the zero DDM tone condition, adjust the oscilloscope time-base to give a locked display of the combined tones, such that four adjacent positive peaks of the waveform are simultaneously visible — two of a larger, equal or nearly equal amplitude, and two of a smaller, equal or nearly equal amplitude;

b) measure, as accurately as possible, the amplitudes of the two largest peaks; and

c) divide the lesser amplitude by the larger amplitude (for a ratio less than or equal to unity). The 90/150 Hz phasing is within tolerance if the ratio is greater than 0.903 for Category I and II localizers or greater than 0.951 for Category III localizers. (Note that any distortion of the tones will degrade the accuracy of the result.)

4.2.20 To measure the phase between the 90 Hz or 150 Hz tones of the two transmitters of a two-frequency system, connect the modulation signal from each transmitter to a separate oscilloscope channel. Configure the oscilloscope to display both channels simultaneously, such that the waveform for the transmitter that leads the other in time crosses the zero amplitude line at a convenient reference point on the horizontal axis. Measure the difference in time between the two waveforms at the point at which they each cross the zero amplitude line, and convert that time to degrees-of-phase for comparison with the tolerance.

ILS carrier frequency and phase modulation

4.2.21 In addition to the desired 90 Hz and 150 Hz AM modulation of the ILS RF carriers, undesired frequency modulation (FM) and/or phase modulation (PM) may exist. This undesired modulation may cause centring errors in ILS receivers due to slope detection by a ripple in the intermediate frequency (IF) filter pass-band.

4.2.22 One method of measuring this undesired FM and/or PM is to use a commercial modulation meter. The RF input to the modulation meter may be taken from any convenient RF carrier sampling point on the ILS transmitter. The modulation meter and its connecting cables should be well screened, since any unwanted pickup of sideband radiation may be interpreted as FM or PM. It is preferable to use a sampling point with a high signal level and place an attenuator directly on the input socket of the modulation meter.

4.2.23 The audio filters used in the modulation meter should have a bandwidth at least as wide as the tone filters used in ILS receivers. This is necessary to ensure that undesired FM and/or AM on frequencies other than 90 Hz and 150 Hz, which could affect an ILS receiver, will be measured by the modulation meter. For standardizing these measurements, the recommended filter characteristics are given in the table below.

Recommended filter characteristics for FM/PM measurement

Frequency (Hz)	*90 Hz band-pass filter attenuation dB*	*150 Hz band-pass filter attenuation dB*
45	10	16
85	0.5	(no spec.)
90	0	14
95	0.5	(no spec.)
142	(no spec.)	0.5
150	14	0
158	(no spec.)	0.5
300	16	!10

Monitoring system operation

4.2.24 This test is essentially a check on the overall executive operation of the monitor systems. The total time periods specified are never-to-be-exceeded limits and are intended to protect aircraft in the final stages of approach against prolonged or repeated periods of localizer guidance outside the monitor limits. For this reason they include not only the initial period of outside tolerance operation but also the total of any or all periods of out-of-tolerance radiation, which might occur during action-to-restore service, for example, in the course of consecutive monitor functioning and consequent change-over(s) to localizer equipment(s) or elements thereof. The intention is that no guidance outside the monitor limits be radiated after the time periods given, and that no further attempt be made to restore service until a period in the order of 20 seconds has elapsed.

Monitor course alignment alarm

4.2.25 The purpose of this check is to ensure that the monitor executive action occurs for a course alignment shift of the distances specified in Table I-4-4 (90 and 150 Hz side). One of the following methods may be used:

a) The alignment of the ILS localizer course line may be offset by the operation of a control in either the transmitter cabinet or antenna system, as may be appropriate to the particular installation under examination. At the point where the monitor system indicates that an alarm condition has been reached, measurement of the resulting far-field course alignment should be verified to be in accordance with Table I-4-4. This test should, where possible, be carried out at the time of the course alignment check.

b) The measurement of course alignment alarm may be carried out by the application of a precision ILS signal generator to the monitor input.

Monitor displacement sensitivity alarm

4.2.26 The purpose of this check is to ensure that the monitor displacement sensitivity alarm action occurs for changes in displacement sensitivity specified in Table I-4-4. One of the following methods may be used:

a) The ILS localizer course width may be adjusted by operating a suitable control (width control) until the monitor system indicates that a wide alarm condition has been reached. When an alarm is indicated, the displacement sensitivity in the far-field should be verified to be in accordance with Table I-4-4. Following this measurement, the width control setting needed to initiate the narrow alarm is selected and displacement sensitivity again measured using the ILS test method as described above.

b) The measurement of displacement sensitivity alarm may be carried out by the application of a precision ILS signal generator to the monitor input.

Monitor power reduction alarm

4.2.27 The purpose of this check is to ensure that the monitor power reduction alarm action occurs for the change in power specified in Table I-4-4. The ILS localizer output power is reduced by operation of a suitable control (transmitter output power) until the monitor system reaches an alarm condition. At this point, the output power should be measured. A calibrated signal generator input into the monitor can also be used for this measurement.

Far-field monitor

4.2.28 A far-field monitor usually consists of a number of antennas and receivers located at the middle marker-to-threshold region to provide continuous measurement of localizer parameters for ground inspection purposes. It may also function as a monitor of course position, and optionally, of course sensitivity. The far-field monitor indications are normally readily available to the ground maintenance staff to facilitate the assessment of localizer performance. A continuous logging or display of localizer parameters is preferred. In the interpretation of the results, it should be remembered that the indications will be disturbed by aircraft overflying the localizer and far-field monitor as well as other vehicle movements at the airport. Periodically, the correlation between the far-field monitor and the localizer signal-in-space should be established.

Glide path

Path angle

4.2.29 The recommended means of measurement of a glide path angle (θ) is by flight test. However, it may be measured on the ground either at the field monitoring location or at a distance of at least 400 m (1 200 ft) from the transmitting antenna, preferably on the extended centre line of the runway.

4.2.30 The measurement location used will depend on the type of glide path, its monitoring system and the local site conditions. Where there is no field monitoring, or where the signal at the monitor location may be affected by local conditions, e.g. accumulation of snow, change in ground characteristics, etc., then the angle measurements should be made at least 300 m (1 000 ft) in front of the glide path as suggested above. In any case, it is preferable at the time of commissioning to measure the glide path parameters at this location for future reference.

4.2.31 When measurements are made beyond the normal monitoring location, a portable ILS ground checking installation should be used comprising a vehicle or trailer suitably equipped for measuring glide path signals. The facilities should include lifting gear to enable the antenna of the test receiver to be raised to a height of at least 22 m (70 ft). Means should be provided for determining the height of the test antenna above ground level to an accuracy of ±5 cm (±2 inches). The figures obtained as a result of this test may differ from those derived from an in-flight measurement, by an amount which will depend on the siting of the test equipment relative to the transmitter antenna and the type of transmitting equipment used.

Displacement sensitivity

4.2.32 The recommended means of measurement of displacement sensitivity is by flight test. However, ground measurement of this parameter should be made using the method described for the glide path angle, but test antenna heights should be determined additionally at which 0.0875 DDM occurs below and above the glide path. The heights obtained will enable figures to be derived for the representative standard upper and lower half-sector displacement sensitivities at the position at which the checks are made.

Clearance below path

4.2.33 Ground measurement of below path clearance is not normally required for null reference systems. For other systems the measurement may be made as described for the glide path angle. Test antenna heights should be determined and DDM values recorded to enable a curve to be plotted showing DDM between 0.3θ and the lower half-sector. From the curve of DDM versus angle plotted, the representative standard clearance below path performance may be obtained. A value of 0.22 DDM should be achieved at an angle not less than 0.3θ above the horizontal. However, if it is achieved at an angle above 0.45θ, the DDM value should not be less than 0.22 at least down to 0.45θ.

Carrier frequency

4.2.34 This test is the same as for the localizer (4.2.12).

Output power

4.2.35 This test is the same as for the localizer (4.2.13), except that the threshold power measurements should be made at the zero DDM height.

Tone frequency (90/150 Hz)

4.2.36 This test is the same as for the localizer (4.2.14).

Modulation depth (90/150 Hz)

4.2.37 This test is the same as for the localizer (4.2.15).

Harmonic content of the 90 and 150 Hz tone

4.2.38 This test is the same as for the localizer (4.2.17).

90/150 Hz phasing

4.2.39 This test is the same as for the localizer (4.2.18).

ILS carrier frequency and phase modulation

4.2.40 This test is the same as for the localizer (4.2.21).

Monitor system operation

4.2.41 This test is the same as for the localizer (4.2.24).

Monitor angle alarms

4.2.42 The purpose of this check is to ensure that the monitor executive action occurs for a change in glide path angle specified in Table I-4-5 (90 and 150 Hz side). Some facilities may require monitor executive limits to be adjusted to closer limits than those specified in the table because of operational requirements. One of the following methods may be used:

a) The alignment of the ILS glide path may be offset by the operation of a control in either the transmitter cabinet or antenna system, as may be appropriate, to the particular installation under examination. At the point where the monitor system indicates that an alarm condition has been reached, measurement of the resulting far-field path alignment should be verified to be in accordance with Table I-4-5. This test should, where possible, be carried out at the time of the path alignment check.

b) The measurement of the path alignment alarm may be carried out by the application of a precision ILS signal generator to the monitor input.

Monitor displacement sensitivity alarm

4.2.43 The purpose of this check is to ensure that the monitor displacement sensitivity alarm action occurs for changes in displacement sensitivity specified in Table I-4-5. One of the following methods may be used:

a) The ILS glide path width is adjusted by operating a suitable control (width control) until the monitor system indicates that a wide or narrow alarm condition has been reached. When an alarm is indicated, the displacement sensitivity in the far-field should be measured. Following this measurement, the width control setting needed to initiate the alternate alarm is selected and displacement sensitivity again measured using the test method as described above.

b) The measurement of displacement sensitivity alarm may be carried out by the application of a precision ILS signal generator to the monitor input.

Monitor power reduction alarm

4.2.44 This test is the same as for the localizer (4.2.27).

Marker beacons

Carrier frequency

4.2.45 The carrier frequency should be checked using an accurate frequency counter to ensure that it is within tolerance. Reference should be made to the instructions supplied with the frequency counter which will give the detailed procedures for its use.

RF output power

4.2.46 Since the power output of the beacon transmitter directly affects the coverage obtained, it is important to keep the power output as close as possible to the value recorded at the time of commissioning. On most equipment, a meter is provided to read the reference output voltage (or some other measure of output power) of the transmitter. This indication may be checked by using an independent power output meter. The voltage standing wave radio (VSWR) should also be checked using the formula below based on measurements of forward and reflected powers. Any change in the output level or VSWR from its initial value at commissioning could be due to a change in the power delivered from the transmitter and/or a change in the characteristics of the antenna system. Changes should therefore be investigated, as the performance of the beacon will be affected.

$$\text{SWR} = \frac{1+p}{1-p} \text{ where } p = \sqrt{\frac{\text{Forward power}}{\text{Reflected power}}}$$

Modulation depth

4.2.47 The modulation depth can be measured using a modulation meter (it may be built into the equipment) or by an oscilloscope. Using an oscilloscope, the modulated signal from the beacon is displayed (usually by direct connection to the deflection plates), and the modulation percentage obtained by measuring the maximum and minimum of the modulation envelope. If *Amax* and *Amin* are the maximum and the minimum of the envelope respectively, then

$$\text{Modulation \%} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} \times 100\%$$

Modulation tone frequency

4.2.48 This test is the same as for the localizer (4.2.14).

Harmonic content of modulating tone

4.2.49 This test is the same as for the localizer (4.2.17).

Keying

4.2.50 An audible indication of keying will usually be available from a test point on the equipment or monitor. The keying can therefore be checked audibly for clear, correct identification. A more exact check can be made by using a suitable oscilloscope.

Monitor system

4.2.51 The monitor system should be checked to ensure it will detect erroneous transmissions from the marker beacon. Some monitors include switching functions that permit out-of-tolerance conditions to be simulated. Detailed procedures can be found in the manufacturer's instructions.

Charts and reports

General

4.2.52 The objective of the collection and analysis of data on the various ILS parameter measurements is to build up a record-of-performance of the equipment in order to determine whether its performance objectives are being achieved. In addition, these records can show performance trends and long-term drifts which, in some cases, will enable preventive maintenance to be carried out prior to an unscheduled service outage. Although the methods used by different authorities to carry out ground inspections and the analysis of results will vary, there are certain general principles to be observed and precautions to be taken.

Equipment failure analysis

4.2.53 It is important that records be kept and an analysis be made on equipment failures and outage times to determine if the reliability objectives appropriate to the category of operation are being achieved in service. Details of the type of data to be collected and the method of analysis can be found in Attachment F to Annex 10, Volume I.

Performance analysis

General

4.2.54 In order that the performance determined from measurements over a long period will be statistically valid, unnecessary adjustments should be minimized. The equipment settings should not be modified if the parameters listed in Tables I-4-4 through I-4-6 are within 50 per cent of the given tolerance.

Analysis of alignment and sensitivity measurement

4.2.55 The localizer and glide path alignment and displacement sensitivity measurements should be analysed to determine the mean and distribution of these parameters. Some States are installing “on-line” data processing systems, which will automatically collect and analyse these parameters and produce the performance statistics. The radiating equipment should then be adjusted so that, on a long-term basis, the mean of the parameter corresponds to the proper nominal value. The distribution should be analysed to determine whether 99.7 per cent of the measurements are contained within the “adjust and maintain” limits of Annex 10, Volume I, 3.1.3.6.1 and 3.1.3.7.3 for localizers, and 3.1.5.1.2.1 and 3.1.5.6.6 through 3.1.5.6.8 for glide paths. If this is not being achieved, then the cause needs to be investigated.

Test equipment

4.2.56 The test equipment inherent errors should be at least five times smaller than the tolerances specified in Tables I-4-4 to I-4-6.

4.2.57 *Test equipment list.* The following recommended list of test equipment, or equivalent, is necessary to make the measurements described in this chapter:

a) a frequency meter covering the 75, 108-112, and 328-336 MHz bands and having an accuracy of at least 0.001 per cent;

b) an audio frequency meter or standard frequency source having an accuracy of at least 0.5 per cent for the modulating frequency measurement;

c) a modulation meter or oscilloscope for modulation percentage measurement;

d) an audio wave analyser or a spectrum analyser for harmonic distortion measurements;

e) an RF power output meter, preferably of a directional type; and

f) a portable ILS receiver.

4.3 FLIGHT TESTING

General

4.3.1 The purpose of flight testing is to confirm the correctness of essential signal-in-space parameters, determine the operational safety and acceptability of the ILS installation, and periodically correlate signal patterns observed in flight and from the ground. Since flight testing instrumentation varies greatly, only a general description of the test methodology is given below.

4.3.2 Flight tests constitute in-flight evaluation and sampling of the radiated signals in the static operating environment. The signals-in-space are evaluated under the same conditions as they are presented to an aircraft receiving system and after being influenced by factors external to the installation, e.g. site conditions, ground conductivity, terrain irregularities, metallic structures, propagation effects, etc. Because dynamic conditions, such as multipath due to taxiing or overflying aircraft or moving ground vehicles, are continually changing, they cannot be realistically flight-tested. Instead, these effects on the signal-in-space are controlled by the establishment of critical and sensitive areas and by operational controls.

Flight test performance parameters

General

4.3.3 Flight test requirements for localizers, glide paths and ILS marker beacons are listed in Tables I-4-7, I-4-8 and I-4-9. Flight test requirements for DME associated with ILS are listed in Table I-3-3.

Schedules of flight inspection

4.3.4 *Site proving inspection.* This flight inspection is conducted at the option of the responsible authority, and its purpose is to determine the suitability of a proposed site for the permanent installation of an ILS facility. It is sometimes performed with portable localizer or glide path equipment. The inspection is sufficiently extensive to determine the effects that the ground environment will have on the facility performance. The site-proving inspection is not a recurring type inspection.

4.3.5 *Commissioning and categorization inspections.* The basic type of inspection, serving either of these purposes, is a comprehensive inspection designed to obtain complete detailed data relating to facility performance and to establish that the facility, as installed, will meet the operational requirements. This type of inspection is conducted under the following circumstances:

a) Commissioning:

   i) *Initial.* Prior to initial commissioning of an ILS;

   ii) *Recommissioning.* After relocation of an antenna or installation of a different type of antenna or of transmitting equipment;

b) *Categorization.* At the time when categorization of an ILS is required.

4.3.6 *Periodic inspections.* These are regularly scheduled flight inspections conducted to determine whether the facility performance continues to meet standards and satisfy its operational requirements. Typically, the transmitters are flown in both normal and alarm conditions, and path structure is evaluated.

4.3.7 *Special flight inspection.* This is a flight inspection required by special circumstances, e.g. major equipment modifications, reported or suspected malfunctions, etc. During special flight inspections it is usually necessary to inspect only those parameters that have or might have an effect on performance; however, in some cases it may be economically advantageous to complete the requirements for a routine or annual inspection. It is impractical to attempt to define all of the purposes for which special inspections will be conducted or the extent of inspection required for each. Special inspections may also be requested as a result of ground checks of the performance, or flight inspection, in which case the nature of the suspected malfunction will guide the inspection requirements.

4.3.8 *Flight inspections following ground maintenance activities.* Certain ground maintenance activities, as well as changes in the ground environment near radiating antenna systems, require a confirming flight inspection. This is because ground measurements cannot duplicate the operational use of the signals in some respects. Although engineering judgement should be used in individual cases to prevent unnecessary costly airborne testing, the following changes typically require a confirming inspection:

a) a change in the operating frequency;

b) significant changes in the multipath environment within the antenna pattern limits;

c) replacement of antenna arrays or antenna elements; and

d) replacement of radio frequency components, such as bridges, phasers, amplifiers, and cabling, when ground measurements prior to and after the changes are not available, or the results do not support restoration without a flight inspection.

Flight test procedures

General

4.3.9 The procedures for conducting the flight inspection of the parameters listed in Tables I-4-7, I-4-8 and I-4-9 are intended to provide basic instruction for positioning the aircraft for proper measurement, analysis of performance data and application of tolerances. These procedures should not be construed as the only means of accomplishing the intended purpose; particular air navigation service providers (ANSPs) might find modified or new methods which better suit their equipment or local situation.

4.3.10 Some requirements in the procedures can be fulfilled concurrently with others, thereby enhancing the efficiency of the flight inspection.

4.3.11 During inspections, certain parameters require the use of aircraft positioning or tracking devices to provide accurate aircraft position relative to the localizer course or glide path for adequate analysis of the performance. The position of the tracking device with respect to the facility being inspected is critical to obtaining good flight inspection results. Further guidance on tracker positioning and use is given in Chapter 1.

Localizer front course

Identification

4.3.12 The coded identification that is transmitted from the facility should be monitored during the various checks over all of the coverage area. The identification is satisfactory if the coded characters are correct, clear and properly spaced. The transmission of the identification signal should not interfere in any way with the basic localizer function. Monitoring the identification also serves the purpose of detecting frequency interference, which is primarily manifested by heterodyne, or noise which affects the identification.

Voice feature

4.3.13 Where the facility has the capability of ground-to-air voice transmission on the localizer frequency, it will be checked over all of the coverage area in generally the same way as the identification. It should be checked to ensure that it adequately serves its purpose as a ground-to-air communication channel and does not adversely affect the course.

Modulation

4.3.14 *Modulation balance.* Although the modulation balance is most easily measured on the ground, it may be measured from the air while radiating the carrier signal only. Position the aircraft close to the runway centre line and note the cross-pointer indication. Flight inspection of modulation balance should be conducted on specific engineering request only (see 4.1.6 – 4.1.11).

4.3.15 *Modulation depth.* The percentage of modulation should be determined only while flying in-bound and on course at a point where the receiver signal strength corresponds to the value at which the receiver modulation depth calibration was made; or on the ground during taxiing, backtracking or lining-up operations when the aircraft is close to the runway centre line. Therefore, this requirement should be fulfilled concurrently with the alignment check. If the receiver modulation depth indications are influenced significantly by the RF level, measure the modulation depth near Point A. (An adequate preliminary check of modulation can be made while the aircraft is crossing the course during the displacement sensitivity check.) Modulation percentage is determined by the use of calibration data furnished with the individual receiver. For LOC antenna systems with small apertures (e.g. a small number of elements) installed prior to January 2000 with narrow course widths, sum of depths of modulation (SDM) exceeding 60 per cent may occur due to design limitations. Over modulation can adversely influence the deviation value.

Displacement sensitivity

4.3.16 There are two basic methods of measuring the displacement sensitivity — approaches on the edges of the course sector, and crossovers or orbits through the course sector, at right angles to the extended runway centre line. For special and commissioning flight inspections, the approach method is recommended.

For all flight inspections the discrepancy between ground and air measurement should not exceed 10 per cent of the nominal displacement sensitivity; where this degree of correlation is not achieved, the reason for the discrepancy should be resolved. On initial categorization, the displacement sensitivity should be set to the nominal value for that installation.

4.3.17 To determine the half-sector width in degrees using the approach method, fly the aircraft on either side of the course line so that the average cross-pointer deflection is 75 (or 150) microamperes in each instance. The average angular position of the aircraft, measured by the tracking device on each side of the course line, will define the angular value of the half-sector width. The following formula must be used to compute an equivalent angular change that corresponds to a displacement sensitivity percentage change:

New sector width = current sector width / (1+ change %);

Example calculation:
Wide sector (-17% displacement sensitivity) = 6.0 /(1 + (-0.17)) = 6.0/(1 - 0.17) = 6.0/0.83 = 7.23;
Narrow sector (+17% displacement sensitivity) = 6.0 /(1 + (+0.17) = 6.0/(1 + 0.17) = 6.0/1.17 = 5.13;

Note.— Deviation of the aircraft toward the runway extended centre line will reduce the accuracy of the measurements — normally the average cross-pointer deflection should be within 15 (or 30) microamperes of the intended value.

4.3.18 The crossover or orbital method of displacement sensitivity measurement is typically used during periodic inspections. In case of structure perturbation, the approaches on the edges of the course sector are to be used during periodic inspections to minimize measurement errors.

4.3.19 When the crossover or orbital method is used, the measurement is made at a convenient known distance from the localizer antenna, taking into account ground speed and the sampling rate and delay of the navigation receiver and position reference system. To best calculate the displacement sensitivity, it is necessary to use several samples from the linear DDM area and find the slope of the straight line that fits the data. In order to provide an accurate reference for subsequent use, and to correlate the results with the half-sector width measurement, this abbreviated procedure should initially be carried out during the commissioning or major inspection. Experience has shown that the results of subsequent routine checks using the orbital method will show good correlation with the measurements obtained during the initial tests when the structure is not affected by perturbations. It may be possible to combine this abbreviated procedure with orbits flown for other measurement purposes.

4.3.20 The following is an example of measuring course displacement sensitivity by this method. Fly a track at right angles to the localizer course line so as to pass directly over the outer marker, or selected checkpoint, at a height of 460 m (1 500 ft) above the localizer antenna site elevation. The flight should begin sufficiently off course to assure stable airspeed prior to penetration of the course sector. Follow the aircraft position with the tracking device and measure the angles at which -150, -75, 0, 75 and 150 μA occur. The full sector from -150 to 150 μA should be flown so that linearity can be assessed by examining the recordings.

Off-course clearance

4.3.21 The localizer clearance is checked to determine that the transmitted signals will provide the user with the proper off-course indication and that there are no false courses. Conduct an orbital flight with a radius of 9 to 15 km (5 to 8 NM) from the facility and approximately 460 m (1 500 ft) above the antenna. Where terrain is a factor, the height will be adjusted to provide line-of-sight between the aircraft and the antenna.

4.3.22 Clearance should be checked within the promulgated angular limits of coverage provided on either side of the front course (typically 35 degrees), unless the back course is used for approaches. In such cases, clearances will also be checked to the angular coverage limits of the back course. Outside of the promulgated coverage, there may be false courses due to antenna pattern characteristics or environmental conditions.

High angle clearance

4.3.23 The combination of ground environment and antenna height can cause nulls, or false courses, which may not be apparent at all normal instrument approach altitudes. High altitude clearance should therefore be investigated upon:

a) initial commissioning;

b) a change in the location of an antenna;

c) a change in the height of an antenna; or

d) installation of a different type antenna.

4.3.24 Normally, high-angle clearance is investigated within the angular limit of coverage provided, in the same manner as for off-course clearance, at a height corresponding to an angle of 7 degrees above the horizontal through the antenna. If the minimum clearance at this height, in an orbit of 9 to 15 km (5 to 8 NM), exceeds 150 microamperes, and the clearance is satisfactory at 300 m (1 000 ft), the localizer will be assumed as satisfactory at all intermediate altitudes. Where the clearance is not satisfactory, additional checks will be made at lower heights to determine the highest level at and below that which the facility may be used. In such a case, procedural use of the localizer should be restricted.

4.3.25 If approach altitudes higher than the height of 1 800 m (6 000 ft) above the antenna elevation are required locally, investigation should also be made at higher heights to determine that adequate clearance is available and that no operationally significant false courses exist.

Course alignment accuracy

4.3.26 The measurement and analysis of localizer course alignment should take into account the course line bends. The alignment of the mean course line needs to be established in the following critical region before the appropriate decision height:

Category I — for at least 0.5 NM containing of ILS Point B
Category II — ILS Point B to ILS reference datum
Category III — ILS Point C to ILS Point D

4.3.27 A normal ILS approach should be flown, using the glide path, where available. The aircraft's position should be recorded using the tracking or position-reference system. By relating the aircraft average position to the average measured DDM, the alignment of the localizer may be determined.

4.3.28 Where there are course line bends in the area being evaluated, they should be analysed so that the average localizer alignment may be calculated.

Course structure

4.3.29 This is an accurate measurement of course bends and may be accomplished concurrently with the alignment and displacement sensitivity checks. Recordings of approaches made during the course alignment check and during the course sensitivity checks can be used for the calculation of course bends. The centre, or mean, of the total amplitude of bends represents the course line for bend evaluation purposes, and the tolerance for bends is applied to that as a reference. If the evaluation is made on airborne data, low pass filtering of the position-corrected cross-pointer signal is necessary to eliminate high-frequency structure components of no practical consequence. The total time-constant of the receiver and recorder DDM circuits for the measurements should be referenced to an aircraft speed of 105 knots, for which the constant is approximately 0.5 second (refer to Attachment C to Annex 10, Volume I, 2.1.6, for specific filter guidance). From the recording of airborne measurements, the alignment for each zone for application of structure tolerances may be determined as the average course position between the runway threshold and Point D, and separately between Point D and Point E. To analyse the post-filtering low frequency spectral components, the guidance found in Attachment C to Annex 10, Volume I, 2.1.3 and 2.1.5, should be used, with the structure tolerances referenced to the average course position in each zone.

4.3.30 For the evaluation of a course centre line structure, a normal approach should be flown, using the glide path, where available. For Category II and III localizers, the aircraft should cross the threshold at approximately the normal design height of the glide path and continue downward to the normal touchdown point. Continue a touchdown roll until at least Point E. Optionally, the touchdown roll may be conducted from touchdown to Point D, at which point a take-off may be executed, with an altitude not exceeding 15 m (50 ft) until Point E is reached. These procedures should be used to evaluate the localizer guidance in the user's environment. Accurate tracking or position reference should be provided from ILS Point A to the following points:

for Category I — ILS reference datum
for Category II — ILS reference datum
for Category III — ILS Point E

4.3.31 For Category III bend evaluation between the ILS reference datum and ILS Point E, ground measurements using a suitably equipped vehicle may be substituted for flight inspection measurements, as described in 4.2.8 and 4.2.9. This is the only area where a direct comparison between the ground and flight measurement results is possible. Therefore, it is useful to perform this measurement with the flight inspection aircraft to allow a comparison between the two measurement results.

4.3.32 If the localizer's course is used for take-off guidance, bend measurements along the runway should be made for any category of ILS.

4.3.33 Guidance material concerning course structure is provided in 2.1.3 to 2.1.6 of Attachment C to Annex 10, Volume I.

Note.— Course structure should be measured only while the course sector is in its normal operating width.

Coverage

4.3.34 This check is conducted to determine whether the facility provides the correct information to the user throughout the area of operational use. Coverage has been determined, to some extent, by various other checks; however, additional procedures are necessary to complete the check of the coverage at distances of 18.5, 31.5 and 46.3 km (10, 17 and 25 NM) from the antenna.

4.3.35 Flights at appropriate heights are required for routine and commissioning inspections to ensure the following coverage requirements are satisfied.

The localizer coverage sector is specified as follows (Annex 10, Volume I, 3.1.3.3.1), or as promulgated by the State:

> "3.1.3.3.1 […] The localizer coverage sector shall extend from the centre of the localizer antenna system to distances of:
>
> 46.3 km (25 NM) within plus or minus 10 degrees from the front course line;
> 31.5 km (17 NM) between 10 degrees and 35 degrees from the front course line; and
> 18.5 km (10 NM) outside of plus or minus 35 degrees from the front course line if coverage is provided;
>
> except that, where topographical features dictate or operational requirements permit, the limits may be reduced down to 33.3 km (18 NM) within the plus or minus 10-degree sector and 18.5 km (10 NM) within the remainder of the coverage when alternative navigational means provide satisfactory coverage within the intermediate approach area. The localizer signals shall be receivable at the distances specified at and above a height of 600 m (2 000 ft) above the elevation of the threshold, or 300 m (1 000 ft) above the elevation of the highest point within the intermediate and final approach areas, whichever is the higher; except that, where needed to protect ILS performance and if operational requirements permit, the lower limit of coverage at angles beyond 15 degrees from the front course line shall be raised linearly from its height at 15 degrees to as high as 1 350 m (4 500 ft) above the elevation of the threshold at 35 degrees from the front course line. Such signals shall be receivable, to the distances specified, up to a surface extending outward from the localizer antenna and inclined at 7 degrees above the horizontal.
>
> *Note. — Where intervening obstacles penetrate the lower surface, it is intended that guidance need not be provided at less than the line-of-sight height.*

In the specification above, all the localizer coverage requirements are based on the assumption that the aircraft is heading directly towards the facility. When power density measurements are gain compensated based on the aircraft antenna pattern polar diagram(s), arc profiles can also be performed for coverage checks.

The flight checks of such coverage may induce low altitude flights. In order to maintain safety during flight tests, it is important to never carry-out a run below minimum sector altitude or minimum radar vectoring altitude when operating in instrument meteorological conditions.

4.3.36 At periodic inspections, it is necessary to check coverage only at 31.5 km (17 NM) and 35 degrees either side of the course, unless use is made of the localizer outside of this area. Arc profiles may be flown at distances closer than this, provided an arc profile is flown at the same distance and altitude during the commissioning inspection to establish reference values.

Polarization

4.3.37 This check is conducted to determine the effects of undesired vertically polarized signal components. While maintaining the desired track (on the extended centre line), bank the aircraft around its longitudinal axis 20 degrees each way from level flight. The aircraft's position should be monitored using an accurate tracking or position fixing system. Analyse the cross-pointer recording to determine if there are any course deviations caused by the change in aircraft (antenna) orientation. The effects of vertically polarized signal components are acceptable when they are within specified tolerances. If this check is accomplished in the area of the outer marker, the possibility of errors due to position changes will be lessened. The amount of polarization effect measured also depends on polarization characteristics of the aircraft antenna, hence the vertical polarization effect of the aircraft antenna should be as low as possible.

Localizer monitors

4.3.38 Localizer course alignment and displacement sensitivity monitors may be checked by ground or flight inspection. A suggested method of flight inspection is given below:

a) *Alignment monitor.* Request the ground technician to adjust the localizer equipment to cause an alarm of the alignment monitor. Fly the aircraft on the extended centre line of the runway as indicated by the position reference system and note the precise displacement in microamperes from the recording in each condition of the alarm to the right and left of the centre line. After the course has been readjusted to a normal operating condition, its alignment should be confirmed.

b) *Displacement sensitivity monitor.* Request the maintenance technician to adjust the displacement sensitivity to the broad and narrow alarm limits and check the displacement sensitivity in each condition. This check should follow the normal displacement sensitivity check described in 4.3.16 to 4.3.20. The crossover or orbital flight method should be used only if good correlation with a more accurate approach method has been established. After the alarm limits have been verified or adjusted, it is also necessary to confirm the displacement sensitivity value in the normal operating condition.

   Note.— During commissioning inspection or after major modifications, clearance may be checked while the displacement sensitivity is adjusted to its broad alarm limit. The values of 175 microamperes and 150 microamperes specified for application during normal displacement sensitivity conditions will then be reduced to 160 microamperes and 135 microamperes, respectively.

c) *Power monitor.* For single-frequency systems, the field strength of the localizer signal should be measured on course at the greatest distance at which it is expected to be used, but not less than 33.3 km (18 NM), while operating at 50 per cent of normal power. For two-frequency carriers system, the field strength of the localizer signal should be measured on course at the greatest distance at which it is expected to be used, but not less than 33.3 km (18 NM), while operating at 80 per cent of normal power for the both carriers. Power monitor requirements for single-frequency and two-frequency systems are described in Annex 10, Volume I, 3.1.3.11.2 d) and e).

   In addition, if ground inspections do not allow control of the structure along the centre line, the structure performances have to be met on course while operating at 80 per cent of normal power for the carrier providing a radiation field pattern in the front course sector and 120 per cent for the carrier providing a radiation field pattern outside that sector. If the alarm thresholds are lower than these 1 dB values but not less than 3 dB, the structure performances have to be met at these lower values (less than 100 per cent for the front course sector carrier and more than 100 per cent for the other carrier).

The clearance areas have also to be checked with the carrier providing a radiation field pattern in the front course sector at 120 per cent of the nominal value or at the upper alarm limit while the carrier providing a radiation field pattern outside that sector at 80 per cent of the normal value or at the lower alarm limit.

Phasing

4.3.39 The following phasing procedure applies to typical localizer systems. Alternative phasing procedures in accordance with the manufacturer's recommendations should be followed for other types of localizers. To the extent possible, methods involving ground test procedures should be used, and airborne measurements made only upon request from ground maintenance personnel. If additional confirmation is desirable by means of a flight check, the following is a suitable example procedure:

Note.— Adjustments made during the phasing procedure may affect many of the radiated parameters. For this reason, it is advisable to confirm the localizer phasing as early as possible during the commissioning tests.

a) Measure the displacement sensitivity of the localizer if it is not already determined.

b) Feed the localizer antenna with the carrier equally modulated by 90 Hz and 150 Hz and load the sideband output with a dummy load. Note the cross-pointer deflection as X(90) or X(150) microamperes.

c) The aircraft should be flown at a suitable off-course angle (depending on the type of localizer antenna used) during the phasing adjustment and should not be closer than 5.6 km (3 NM) from the antenna.

d) Insert a 90-degree line in a series with the sideband input to the antenna and feed the antenna with sideband energy.

e) Adjust the phaser until the deviation indicator reading is the same as in b) above.

f) Remove the 90-degree line, used in step d) above.

4.3.40 This completes the process of phasing the carrier with the composite sidebands. As an additional check, displacement sensitivity should be rechecked, and compared with that obtained in step a) above. The value obtained after the phasing adjustment should never be greater than the value obtained before the phasing adjustment.

Localizer back course

4.3.41 The back course formed by some types of localizers can serve a useful purpose as an approach aid, provided that it meets specified requirements and that an associated aid is available to provide a final approach fix. Although a glide path is not to be used in conjunction with the back course, landing weather minima commensurate with those of other non-precision aids can be approved. The display in the aircraft cockpit will present a reverse sensing indication to the pilot; however, pilots are well aware of this and it is not considered significant.

4.3.42 Under no circumstances should localizer equipment be adjusted to enhance performance of the back course, if the adjustment would adversely affect the desired characteristics of the front course.

4.3.43 Where the localizer back course is to be used for approaches to landing, it should be evaluated for commissioning and at periodic intervals thereafter. Procedures used for checking the front course will normally be used for the back course, the principal difference being the application of certain different tolerances, which are given in Table I-4-7. As a minimum, alignment, sector width, structure, and modulation depth should be inspected.

Glide path

4.3.44 Most glide path parameters can be tested with two basic flight procedures — an approach along the course line, and a level run or orbit through the localizer course sector. Variations include approaches above, below, or abeam the course line, and level runs left and right of the extended runway centre line. By selecting suitable starting distances and angles, several measurements can be made during a single aircraft manoeuver.

Glide path angle (site, commissioning, categorization and periodic)

4.3.45 The glide path angle may be measured concurrently with the glide path structure during these inspections. To adequately check the glide path angle, an accurate tracking or positioning device should be employed. This is necessary in order to correct the recorded glide path for aircraft positioning errors in the vertical plane. The location of the tracking or positioning equipment with respect to the facility being inspected is critical for accurate measurement. Incorrect siting can lead to unusual characteristics being shown in the glide path structure measurements. The tracking device should initially be located using the results of an accurate ground survey. In certain cases, initial flight results may indicate a need to modify the location of the tracking device. The arithmetic mean of all deviations of this corrected glide path between ILS Point A and ILS Point B represented by a straight line will be the glide path angle, as well as the average path to which tolerances for glide path angle alignment and structure will be applied. Because of the normal hyperbolic characteristics of the glide path, the portion below ILS Point B is not used in the above calculation.

4.3.46 At commissioning, the glide path angle should be adjusted to be as near as possible to the desired nominal angle. During periodic inspections, the glide path angle must be within the figures given in Table I-4-8.

Displacement sensitivity (site, commissioning, categorization and periodic)

4.3.47 The mean displacement sensitivity is derived from measurements made between ILS Point A and Point B. Make approaches above and below the nominal glide path at angles where the nominal cross-pointer deflection is 75 μA and measure the aircraft's position using an accurate tracking device. During these measurements, the average cross-pointer deflection should be 75 ±15 μA. Note that any aircraft deviation toward the zero DDM course line will decrease the accuracy of the measurement. The displacement sensitivity can be calculated by relating the average cross-pointer deflection to the average measured angle.

Glide path angle and displacement sensitivity (routine periodic inspections)

4.3.48 During certain periodic inspections it may be possible to measure the glide path angle and displacement sensitivity by using a level run or "slice" method. This is only possible where the glide path is relatively free from bends so that there is a smooth transition from fly-up to fly-down on the level run. This method should not be used with systems that have asymmetrical displacement sensitivity above and below the glide path.

4.3.49 *Level run method.* Fly the aircraft towards the facility at a constant height (typically the intercept altitude), following the localizer centre line, starting at a point where the cross-pointer deflection is more than 75 μA fly-up (more than 190 μA recommended). This flight is usually made at 460 m (1 500 ft) above the facility unless terrain prevents a safe flight. If a different height is used, it should be noted on the flight inspection report and facility data sheet. During the flight, the aircraft's angular position should be constantly tracked. By relating the recorded cross-pointer current to the measured angles, the glide path angle and displacement sensitivity may be calculated. The exact method of correlating the angle and cross-pointer measurements is dependent on the particular flight inspection system.

Clearance

4.3.50 The clearance of the glide path sector is determined from a level run, or slice, through the complete sector during which the glide path transition through the sector is recorded. This measurement may be combined with the level flight method of measuring the glide path angle and displacement sensitivity.

4.3.51 This flight is made using the level run method, except that the run should commence at a distance corresponding to 0.3θ and should continue until a point equivalent to twice the glide path angle has been passed. The aircraft's position should be accurately measured throughout the approach. Cross-pointer current should be continuously recorded and the recording marked with all the necessary distances and angles to allow the figures required in Table I-4-8 to be evaluated. This recording should also permit linearity of the cross-pointer transition to be evaluated.

Glide path structure

4.3.52 Glide path structure is an accurate measurement of the bends and perturbations on the glide path. It is most important to employ an accurate tracking or positioning device for this measurement. This measurement may be made concurrently with the glide path angle measurement. Guidance material concerning course structure evaluation is provided in 2.1.4 of Attachment C to Annex 10, Volume I.

Modulation

4.3.53 *Modulation balance.* The modulation balance is measured while radiating the carrier signal only. Position the aircraft close to the glide path angle and note the cross-pointer indication. Flight inspection of modulation balance should be conducted on specific engineering request only (see 4.1.6 – 4.1.11).

4.3.54 *Modulation depth.* This check can be best accomplished accurately while the aircraft is "on-path"; therefore, final measurements are best obtained during angle checks. The measurements should be made at a point where the receiver input corresponds to the value at which the receiver modulation depth calibration was made. If the receiver modulation depth indications are influenced significantly by the RF level, measure the modulation depth near Point A. For measurement systems that do not provide separate modulation level outputs, preliminary indications of modulation can be obtained during level runs at the time the aircraft crosses the glide path. The depth of modulation (in per cent) can be obtained by comparing the glide path receiver- flag-alarm-current to the receiver-flag-current-calibration data.

Obstruction clearance

4.3.55 Checks may be made beneath the glide path sector to assure a safe flight path area between the bottom edge of the glide path and any obstructions. To accomplish this check, it is necessary to bias the pilot's indicator or use an expanded scale instrument. Position the aircraft on the localizer front course inbound at approximately five miles from the glide path antenna at an elevation to obtain at least 180 µA "fly-up" indication. Proceed inbound maintaining at least 180 µA clearance until the runway threshold is reached or it is necessary to alter the flight path to clear obstructions. This check will be conducted during monitor checks when the path width is adjusted to the wide alarm limits during which a minimum of 150 µA fly-up is used in lieu of 180 µA. When this check has been made during broad path width monitor limit checks, it need not be accomplished after the path is returned to the normal width of the normal approach envelope, except during the commissioning inspection.

Glide path coverage

4.3.56 This check may be combined with the clearance check using the same flight profile. If a separate flight is made, it is not necessary to continue the approach beyond the intercept with the glide path lower width angle. At site, commissioning, categorization and periodic checks this measurement should be made along the edges of a sector 8 degrees either side of the localizer centre line. Coverage will normally be checked to a distance of 18.5 km (10 NM) from the antenna. Coverage will be checked to a distance greater than 18.5 km (10 NM) to the extent required to safeguard the promulgated glide path intercept procedure.

Note.— Flight inspection alone is not sufficient to extend glide path coverage beyond 10 NM (e.g. frequency coordination).

Monitors

Note.— If checks are required, see Note 2 of Table I-4-8.

4.3.57 Where required, monitor checks may be made using identical measurement methods to those described for glide path angle, displacement sensitivity and clearance. The level flight method for angle and displacement sensitivity should not be used if there is non-linearity in the areas being evaluated.

4.3.58 *Power monitor (commissioning only).* The field strength of the glide path signal should be checked at the limits of its designated coverage volume, with the power reduced to the alarm level. Alternatively, if the monitor alarm limit has been accurately measured by ground inspection, the field strength may be measured under normal operating conditions and the field strength at the alarm limit may be calculated. This check may be made at the same time as clearance and coverage checks.

Phasing and associated engineering support tests

4.3.59 The glide path site test is made to determine whether the proposed site will provide satisfactory glide path performance at the required path angle. It is extremely important that the site tests be conducted accurately and completely to avoid resiting costs and unnecessary installation delays. Because this is functionally a site-proving test rather than an inspection of equipment performance, only one transmitter is required.

4.3.60 A preliminary glide path inspection is performed upon completion of the permanent transmitter and antenna installation, but prior to permanent installation of the monitor system. This inspection is conducted on one transmitter as a preliminary confirmation of airborne characteristics of the permanent installation. Additionally, it provides the installation engineer with data that enables the engineer to complete the facility adjustment to the optimum for the commissioning inspection. This requires the establishment of transmitter settings for monitor alarm limits. These settings may be utilized by ground personnel to determine that the field monitor is installed at its optimum location and that integral monitors recombining units are correctly adjusted to achieve the most satisfactory overall monitor response.

4.3.61 The procedures for conducting various glide path engineering support tests are described below. Normally, these checks will be performed by ground methods prior to the flight inspection, and airborne checks will be conducted at the option of the ground technician. It is not intended that they will supplant ground measurements, but that they will confirm and support ground tests. The details of these tests will be included in the flight inspection report.

4.3.62 *Modulation balance.* Although the modulation balance is most easily measured on the ground, it may be measured from the air while radiating the carrier signal only. Fly a simulated “on-path” approach recording the glide path indications. The average deviation of the glide path indication from “on-path” should be noted for use in the phasing check. Ground personnel should be advised of the result. The optimum condition is a perfect balance, i.e. zero on the precision microammeter. If the unbalance is 5 µA or more, corrective action should be taken by ground personnel before continuing this test.

Note.— Level runs are not satisfactory for this test since shifting of centring may occur in low-signal or null areas.

4.3.63 *Phasing — transmitting antennas.* The purpose of the phasing test is to determine that optimum phase exists between the radiating antennas. There are several different methods of achieving airborne phasing and these tests should normally be made using the manufacturer's recommended methods. Where difficulty is experienced in achieving airborne phasing to a definite reading by normal procedures, the flight inspector should coordinate with the ground engineer to determine the most advantageous area for conducting the phasing test. When this area and track are determined, it should be noted on the facility data record for use on future phasing tests of that facility.

4.3.64 *Phasing — monitor system.* Some types of glide path integral monitor need flight inspection checks to prove that they will accurately reproduce the far-field conditions when changes occur in transmitted signal phases. Procedures for making such checks should be developed in conjunction with the manufacturer's recommendations.

4.3.65 *Glide path antenna adjustment (null checks).* These checks are conducted to determine the vertical angles at which the RF nulls of the various glide path antennas may occur. The information is used by ground staff to assist them in determining the correct heights for the transmitting antennas. The test is made with carrier signals radiating only from each antenna in turn. The procedure for conducting this test is by level flight along the localizer course line. The angles of the nulls will be computed in the same manner as the glide path angle is computed. The nulls are characterized by a sharp fall in signal level.

Marker beacons

Keying

4.3.66 The keying is checked during an ILS approach over the beacons. The keying is assessed from both the aural and visual indication and is satisfactory when the coded characters are correct, clear and properly spaced. The frequency of the modulating tone can be checked by observing that visual indication is obtained on the correct lamp of a three lamp system, i.e. outer marker (OM) — blue, middle marker (MM) — orange and inner marker (IM) — white.

Coverage

4.3.67 Coverage is determined by flying over the marker beacons during a normal ILS approach on the localizer and glide path and measuring the total distance during which a visual indication is obtained from a calibrated marker receiver and antenna or during which a predetermined RF carrier signal level is obtained. The calibration of receiver/antenna and the determination of the required RF carrier signal level is discussed in Chapter 1.

4.3.68 At commissioning, the coverage should be determined by making a continuous recording of the RF signal strength from the calibrated aircraft antenna, since this allows a more detailed assessment of the ground beacon performance. The visual indication distance should be noted for comparison with subsequent routine checks. For routine checks, measuring the distance over which the visual indication is received will usually be sufficient, although the above procedure of recording signal strength is recommended.

4.3.69 The signal strength recording should be examined to ensure that there are no side-lobes of sufficient signal strength to cause false indications, and that there are no areas of weak signal strength within the main lobe.

4.3.70 At commissioning, a check should be made that the centre of the coverage area is in the correct position. This will usually be over the marker beacon but in some cases, due to siting difficulties, the polar axis of the marker beacon radiation pattern may have to be other than vertical. Reference should then be made to the operational procedures to determine the correct location of the centre-of-coverage, with respect to some recognizable point on the ground. The centre-of-coverage can be checked during the coverage flights described above, by marking the continuous recording when the aircraft is directly over the marker beacon (or other defined point). On a normal approach there should be a well-defined separation (in the order of 4.5 seconds at 180 km/hr (95 kt)) between the indications obtained from each marker.

4.3.71 At commissioning, categorization and annual inspections, a check should also be made to ensure that operationally acceptable marker beacon indications are obtained when an approach is made on the glide path but displaced ±75 µA from the localizer centre. The time at which the indication is obtained will usually be shorter than when on the localizer centre.

Monitor system

4.3.72 At commissioning, the coverage should be measured with the marker beacon operating at 50 per cent of normal power and with the modulation depth reduced to 50 per cent. An operationally usable indication should still be obtained; if not, the power should be increased to provide an indication and the monitor adjusted to alarm at this level.

4.3.73 Alternatively, the coverage under monitor alarm conditions can be determined by analysing the field strength recording as detailed in 4.3.67 to 4.3.71.

Standby equipment (if installed)

4.3.74 At commissioning, the standby equipment is checked in the same manner as the main equipment. It will usually not be necessary to check both the main and standby equipment at each routine check, if the equipment operation has been scheduled so that the routine checks are carried out on each equipment alternately.

Charts and reports

General

4.3.75 The ILS flight inspection report records the conformance of the facility performance to the Standards defined in Annex 10 as well as the equipment specific standards established by the authorized flight inspection organization and the responsible ground maintenance organization. Tables I-4-7 and I-4-8 list the parameters to be measured for localizer and glide path facilities, as well as localizer back course approaches. Table I-4-9 summarizes the parameters to be measured for ILS Marker Beacons. It is recommended that the flight inspection report include an assessment of the parameters listed in Tables I-4-7 through I-4-9, which are appropriate for the type of inspection. Flight inspection reports should allow for “As found” and “As left” results to be entered for routine documentation of the adjustments made to facilities.

Report contents

4.3.76 The ILS flight inspection report should contain the following minimum information:

a) basic identification items such as the aircraft tail number, facility name, facility identifier, category and type of inspection, date and time of inspection, names of the pilot and engineer or technician;

b) a summary listing of the run numbers, chart recordings or data files, which were analysed to produce the report;

c) a general comments section where pertinent information regarding the conduct of the inspection can be included;

d) a results section for each measured parameter indicating the value obtained, whether or not it conforms to requirements and the recording or data file from which the result was measured;

e) acceptability of performance is determined by measurements; however, flight inspection pilots should report any instances where flight manoeuvres and/or flight attitudes in instrument approaches resulting from course line/glide path irregularities are considered unacceptable;

f) a status section indicating the operational status of the facility; and

g) the type of flight inspection system used (AFIS, theodolite, manual, etc.).

Sample flight inspection report

4.3.77 Flight inspection reports can take several forms, varying from hand-filled paper forms to computer generated text files or database forms. The appendix to this chapter shows a sample flight inspection report for an ILS inspection which is further explained in the report introduction.

Analysis

4.3.78 *General.* This section provides brief material related to special topics involved with analysis of ground and flight testing of ILS facilities. In addition, considerable material on the analysis of ILS testing results is published in Attachment C to Annex 10, Volume I.

4.3.79 *Structure analysis.* Analysis of localizer course line and glide path angle structure is dependent upon aircraft speed, the time constant of receiver and recording equipment, and various other factors. Guidance on these topics can be found in Attachment C to Annex 10, Volume I, 2.1.3 and its preceding note, and 2.1.4 through 2.1.6.

4.3.80 *Computation of displacement sensitivity.* Displacement sensitivity is typically measured with orbital flights on localizers, and level inbound runs on glide slopes. Analogous measurements can be made for ground testing. In each case, the azimuth (localizer) or elevation (glide path) angles, at which nominal DDM values of 150 µA (75 µA) occur, are determined, and the sensitivity computed, taking into account the distance from the antenna system at which the measurements were taken. Particularly on glide path measurements, it is common for the DDM recording to be non-linear if significant multipath conditions exist. In these cases, the measurements may need to be taken at DDM values other than those stated above between which linearity is maintained, and the calculated sensitivity scaled to the nominal value.

4.3.81 *Reference datum height (RDH).* For commissioning and categorization flight tests, it may be necessary to determine the glide path RDH. This is done using a high-quality approach recording, from which the angle and structure measurements are made. Position-corrected DDM values for a selected portion of the approach (typically Point A to Point B for Category I facilities, and the last nautical mile of the approach for Category II and III facilities) are used in a linear regression to extend a best-fit line downward to a point above the threshold. The height of this line above the threshold is used as the RDH. If the tolerances are not met, an engineering analysis is necessary to determine whether the facility has been sited correctly. A different portion of the approach should be used for the regression analysis, or another type of analytical technique should be used.

Test equipment

General

4.3.82 As described in Chapter 1, a flight inspection system is composed of two distinct subsystems, one dedicated to the measurement and processing of the radio signals provided by the facilities to be inspected, and another dedicated to the determination of the positioning of the flight inspection aircraft.

4.3.83 The following paragraphs define minimal performances of the equipment constituting the radio signals in flight measurement subsystems and recommend calibration procedures to reach them. They highlight the level of equipment needed to verify compliance with the requirements specified in Annex 10, Volume I, for the different facility performance categories of ILS.

4.3.84 A flight-testing system may use equipment other than ILS receivers normally used for aircraft navigation (e.g. bench test equipment or portable ground maintenance receivers). Care should be used to ensure that this equipment performs the same as conventional, high-quality aircraft equipment.

4.3.85 For convenience reasons, the assessment of the accuracy of the reception and processing equipment of the radio subsystem will be made in units suitable to parameters to be measured — in microamperes. To ensure a simple equivalence between the different units in which tolerances are expressed, the following relations are used: 1µA = 0.01° for a distance of 4 000 m (13 000 ft) between the localizer antenna and the threshold, and 1µA = 0.005° for a glide path angle of 3 degrees.

Accuracy

4.3.86 *Uncertainty.* Whatever the measured parameter, the uncertainty on the measure has to be small by comparison with the tolerances applied to the measured parameter. A ratio of five is the minimum required.

4.3.87 *Treatment of error sources.* The evaluation of parameters such as course alignment and displacement sensitivity is performed by the radio electrical and positioning subsystems. These measurements are polluted by the specific errors of these two subsystems. By nature, these errors are independent, and it is allowable to consider that the global statistical error on the parameter to be measured is equal to the square root of the sum of the squares of the equally weighted errors of the two parts of the system.

Flight inspection equipment

4.3.88 *General.* To reach the fixed goal concerning accuracy, it is necessary to consider the performance of the reception and processing parts of the flight inspection.

4.3.89 *Aircraft ILS antennas.* To minimize the errors due to implementation, antennas should be installed according to the recommendations listed in Chapter 1. As an example of this importance, note that when the aircraft is over the runway threshold, a vertical displacement of 6 cm (2.5 inches) is equal to approximately 0.01° in elevation angle, observed from the glide path tracking site.

4.3.90 *The ILS flight inspection receivers.* The receivers used should measure, at a minimum, the DDM, SDM, signal input level and modulations depths. For integrity and technical comfort, the simultaneous use of two receivers is strongly recommended. This redundancy offers a protection against errors that might occur during the flight inspection because of unexpected short-term changes in a receiver's performance. A divergence of their output signals can therefore be noted immediately.

4.3.91 *Acquisition and processing equipment.* Equipment constituting the acquisition and processing subsystem should have such a performance that it does not degrade the acquired parameters. It is necessary that signal acquisition occurs synchronously with the positioning determination of the plane, to compare measurements that correspond in time. It will be possible to convert, by the use of calibration tables, the radio electrical signals into usual physical units with a convenient resolution, and to take into account the actual functioning of the receiver in its operational environment. The graphic display and record should be such that they will allow the flight inspector to evaluate fluctuations of signals against the required tolerances.

Calibration

General

4.3.92 The data provided by the reception and acquisition subsystem will vary with changes in working conditions, e.g. changes in the ambient temperature, the supply voltage, the input signal level, the frequency of modulating tones, the operating frequency, etc. Before using a given type receiver for flight inspection purposes, its comportment in the different working conditions should be known, and calibration procedures as complete as possible should be developed to establish a quantitative relationship between the outputs of the receiver and probable changes in the operational environment. It is also necessary to evaluate the stability of the receiver to determine the maximal time interval that separates two consecutive calibrations.

Integration of an ILS generator on board

4.3.93 To guarantee the accuracy required, the integration, in a permanent position, of an ILS signal generator is strongly recommended in any flight inspection system. The availability of the generator allows the flight inspector to:

a) perform receiver calibration in the plane rather than in the laboratory on the ground, allowing calibration of the complete subsystem in its environment;

b) resolve divergence of the two receivers during the flight;

c) update, if necessary during a mission, the calibration tables;

d) refine measurements on the actual ILS frequency to be inspected, since the provided calibration tables are usually established on two or three frequencies (middle and extremity of the band); and

e) compare, before the flight, the standard of measurements with that used by ILS ground maintenance people, avoiding decorrelation between ground and in-flight measurements, saving wasted flight hours.

Calibration standards

4.3.94 A signal generator having identical performance to those used by ground maintenance people should be used to calibrate the flight inspection measurement subsystem.

Calibration procedures

4.3.95 Calibration procedures of the reception and acquisition subsystem cannot be defined by a universal procedure. These procedures essentially depend on the chosen equipment that can behave differently in a given operational environment. In every case, it will be necessary to refer to the manufacturer’s recommendations.

4.3.96 In the case where receivers deliver electrical voltages characterizing signals to be measured, calibration tables are first necessary to provide changes of units. Some equipment delivers the flight inspection parameters directly in the desired units, and calibration tables converting the different voltages into suitable units are not required in this case. Nevertheless, it is necessary to correct some errors of the subsystem (for instance, receiver centring error), and limited calibration procedures have to be defined accordingly. It is necessary to establish enough calibration tables so that those established for a given frequency may be transposable to nearby ILS frequencies without significant error.

4.3.97 The tables to be developed are outlined below.

4.3.98 *Localizer:* For a given VHF frequency:

a) V_{agc} = f(input level),
input level varying from: –104 dBm to –18 dBm
I_{dev} = f(input level),
input level varying from: –90 dBm to –18 dBm
and for: DDM = 0
DDM = 0.155 in the 90 Hz
DDM = 0.155 in the 150 Hz

b) I_{flag} = f(input level),
input level varying from: –90 dBm to –18 dBm and for modulation depths varying from 17 per cent to 23 per cent.

c) V_{90Hz} and V_{150Hz} = f(modulation depth),
for different values of the modulation depths, their sum remaining constant, and at different values of input level.

4.3.99 *Glide path:* For a given UHF frequency:

a) V_{agc} = f(input level),
input level varying from: –104 dBm to –18 dBm
I_{dev} = f(input level),
input level varying from: –90 dBm to –18 dBm
and for: DDM = 0
DDM = 0.088 in the 90 Hz
DDM = 0.088 in the 150 Hz

b) I_{flag} = f(input level),
input level varying from: –90 dBm to –18 dBm and for modulation depths varying from 34 per cent to 46 per cent.

c) V_{90Hz} and V_{150Hz} = f(modulation depth),
for different values of the modulation depths, their sum remaining constant, and at different values of injection.

Note.— The different values to be chosen for localizer and glide path calibration tables depend on the receiver response and on the generator possibilities.

Positioning

General

4.3.100 The evaluation of some parameters includes a combination of errors coming from the radio electrical outputs and from the positioning subsystem. By nature these errors are independent, and it is acceptable to consider that the global statistical error on the parameter to be measured is equal to the square root of the sum of the squares of the equally weighted errors of the two parts of the system. Whatever the measured parameter is, the measurement uncertainty should be small compared with the tolerances for that parameter. A ratio of five is the minimum required.

Accuracy required

4.3.101 The required accuracies are calculated by converting tolerances on the different ILS parameters into degrees, using the following formulas:

Localizer alignment tolerance = ± (tolerance in µA × nominal sector width / 150) degrees

Glide path alignment tolerance = θ ± (tolerance in µA × nominal sector width / 150) degrees

Localizer or glide path sector tolerance = nominal sector × 150/(150 ± tolerance in µA) degrees

4.3.102 In Table I-4-10, the minimum accuracies of the positioning are calculated from adjust and maintain tolerances. The tables show that the accuracy of the aircraft positioning measurement has to be better than 1/100 of a degree for Category II and III localizers with narrow sector width.

For truth systems calculating linear cross track and vertical positions (e.g. differential global navigation satellite system (DGNSS) based systems), a set of cross track and vertical accuracy requirements is presented in Table I-4-11).

Error budget

4.3.103 The different components of the error budget relative to the positioning measurement of the plane are listed below:

a) the uncertainty on the database, describing geometrically, the field and the facility to be inspected (definition of every characteristic point in the runway reference coordinates system);

b) the uncertainty on the platform coordinates (x, y, z) on which the positioning system is set up (definition of some of them within one centimetre);

c) the care in setting up the positioning system on the ground;

d) the instrumental error within its operating limits defined by the manufacturer;

e) the error due to the atmospheric refraction if optical or infra-red tracker is used;

f) the parallax error due to the fact that the positioning system and the phase centre of the facility to be measured are not collocated;

g) the error in timestamping of flight check receivers' sampled data and truth system positioning data. Timing errors between components of a truth system, when using sensor fusion (e.g. DGNSS, attitude system, INS, laser range finder, auto tracking theodolite);

h) the error due to the fact that the reference aircraft positioning point and the localizer or glide path antenna are not collocated; and

i) the conical effect of the radiated pattern of the glide path in the final part of the approach and the fact that the ground reflection surface is not a perfect plane.

4.3.104 To reduce the three last components listed above, it is necessary to use high accuracy devices providing distance (to a few metres), heading and attitude (to about 0.1 degree each) information. If distance, heading, and attitude parameters are not available, a crosswind limit should be set allowing measurement accuracies to be within the limits required.

4.4 ILS-RELATED TOPICS

General

4.4.1 This section deals with technical issues that are not solely related to ground- or flight-testing.

Two-frequency system issues

Localizer receiver capture performance

4.4.2 When receiving signals from a two-frequency capture-effect localizer system, some receivers exhibit a strong capture performance. Where the signals differ in strength by more than 5 or 6 dB, the receiver will completely ignore the weaker signal. Other receivers require the signals to differ by more than 10 dB before the weaker signal is completely ignored.

4.4.3 This effect shows its presence when inspecting a localizer with a combination of clearance signal reflections onto the centre line and poor clearance carrier suppression on the centre line. If the receiver detector is not completely captured by the course signal on the centre line, it will respond to clearance signals. The result of this will be an increase in the measured amplitude of centre line bends.

4.4.4 The outcome of this effect is that on localizers with poor clearance suppression on the centre line, the measured bend amplitude is dependent on the receiver used for the measurement. Normally this effect is not noticed, but if an inspection of such a localizer is made using different types of receiver, the results can be confusing, unless this problem is understood.

Receiver passband ripple

4.4.5 Some flight inspection (and user) receivers have up to 6 dB of ripple in the IF passband. This can give rise to unusual results when inspecting a two-frequency capture-effect system. In regions where either the course or clearance signal predominates, a high passband ripple has little impact. Effects are only caused in the transition region where course and clearance signals are of equal signal strength.

4.4.6 As an example, some two-frequency systems are operated with the course and clearance frequencies interchanged between the main and standby transmitters. This can result, for example in the course signals of TX1 being received on a peak in the IF passband response, and the clearance signals being received in a trough of the passband response. The reverse is true when receiving TX2. The result is that in certain areas, TX1 and TX2 will have differing flight inspection results although ground measurements will show no difference between the two transmitters.

4.4.7 The largest discrepancies between the two transmitters for glide paths are normally seen when checking the azimuth coverage at ±8°, at 0.45θ and when examining the above-path signal near 1.75θ. This is not considered a serious problem, but awareness of it can save time by avoiding ground tests for discrepancies which in reality do not exist.

Receiver DDM processing

4.4.8 Several types of receivers that are in common use for flight inspection and navigation process the received DDM before providing an output to the recording or navigation equipment. This can affect measurements made on localizers where the modulation sum in the clearance region rises to values much higher than the nominal 40 per cent. These high values are common for many antenna systems with small apertures, e.g. a small number of elements installed on longer runways requiring smaller course widths. Paragraph 3.1.3.5.3.6.1 of Annex 10, Volume I, limits the SDM to a maximum value of 60 per cent for equipment installed after 1 January 2000. (This limit is not applied to arrays installed before that date.)

4.4.9 There are several different processing algorithms used by receiver manufacturers. One commonly used algorithm normalizes the DDM whenever the modulation sum exceeds 40 per cent. The process divides the absolute DDM by the modulation sum and then multiplies the result by 40. This means that if the modulation sum is 80 per cent, the absolute DDM figure will be halved.

4.4.10 This does not represent a problem for flight inspection use, but it is essential that the exact processing algorithm is known. This is particularly important where a flight inspection is being made to examine cases of false localizer capture. It is also important to know the processing algorithms in the navigation receivers fitted to the aircraft reporting the problem.

Localizer false capture

4.4.11 If a localizer with regions of high modulation depth outside the course sector is examined by a flight inspection system with no DDM processing, it will show a high value of DDM over the entire clearance region and would appear to conform to published specifications. However, an aircraft whose navigation receivers have the DDM processing described in 4.4.8 to 4.4.10 could incorrectly initiate capture of the localizer. As the aircraft enters the region of high modulation depth, the processed DDM from the receiver will fall rapidly and may be interpreted by the autopilot as entering the course sector and a capture manoeuvre will be instigated. There are other factors involved in this problem, such as the capture level setting of the autopilot, but the various DDM processing algorithms have a great influence.

4.4.12 With certain types of localizer antenna systems, it is difficult to eliminate the regions of high modulation depth without affecting the sector width. It is very important to know exactly what processing has been applied to the DDM being recorded. It is then possible to calculate whether the localizer could cause problems for any of the aircraft, which may use it for auto-coupled approaches.

Table I-4-1. Summary of testing requirements — localizer

Parameter	*Annex 10, Volume I, reference*	*Testing*
Voice feature	3.1.3.8	F
Modulation balance and depth	3.1.3.5	F/G
Displacement sensitivity	3.1.3.7	F/G
Off-course clearance	3.1.3.7.4	F
High-angle clearance	N/A	F
Course alignment accuracy	3.1.3.6	F/G
Course structure	3.1.3.4	F/G
Coverage (usable distance)	3.1.3.3	F/G
Polarization	3.1.3.2.2	F
Monitor system	3.1.3.11	F/G
Phasing	N/A	F/G
Orientation	3.1.3.1	G
Frequency	3.1.3.2	G
Spurious modulation	3.1.3.2.3	G
Carrier modulation frequency	3.1.3.5.3	G
Carrier modulation harmonic content 90 Hz	3.1.3.5.3 d)	G
Carrier modulation harmonic content 150 Hz	3.1.3.5.3 e)	G
Unwanted modulation	3.1.3.5.3.2	G
Phase of modulation tones	3.1.3.5.3.3	G
Phase of modulation tones dual frequency systems	3.1.3.5.3.4	G
Phasing of alternative systems	3.1.3.5.3.5	G
Sum of modulation depths	3.1.3.5.3.6.1	F/G
Sum of modulation depths when utilizing radiotelephony communications	3.1.3.5.3.7	F/G
Frequency and phase modulation	3.1.3.5.4	G
DDM increase linear	3.1.3.7.4	F
Voice no interference to basic function	3.1.3.8.2	
Phase to avoid null on dual frequency systems	3.1.3.8.3.1	F/G
Peak modulation depth	3.1.3.8.3.2	G
Audio frequency characteristic	3.1.3.8.3.3	G
Identification — no interference with guidance information	3.1.3.9.1	F
Identification tone frequency	3.1.3.9.2	G
Identification modulation depth	3.1.3.9.2	G
Identification speed	3.1.3.9.4	G
Identification repetition rate	3.1.3.9.4	G
Monitoring — total time of out-of-tolerance radiation	3.1.3.11.3	G
Back course sector width	N/A	F
Back course alignment	N/A	F
Back course structure	N/A	F
Back course modulation depth	N/A	F

Legend: *N/A* = *Not applicable*
F = *Flight inspection*
G = *Ground test*

Table I-4-2. Summary of testing requirements — glide path

Parameter	*Annex 10, Volume I, reference*	*Testing*
Angle		
Alignment	3.1.5.1.2.1, 3.1.5.1.3,	F/G
Height of reference datum	3.1.5.1.4, 3.1.5.1.5	
Displacement sensitivity	3.1.5.6	F/G
Clearance below and above path	3.1.5.3.1, 3.1.5.6.5	F/G
Glide path structure	3.1.5.4	F
Structure	N/A	F
Modulation balance and depth	3.1.5.5.1	F/G
Obstruction clearance	N/A	F
Coverage (usable distance)	3.1.5.3	F/G
Monitor system	3.1.5.7	F/G
Phasing	N/A	F/G
Orientation	3.1.5.1.1	G
Frequency	3.1.5.2.1	G
Polarization	3.1.5.2.2	F
Unwanted modulation	3.1.5.2.3	G
Carrier modulation frequency	3.1.5.5.2	
Carrier modulation harmonic content 90 Hz	3.1.5.5.2 d)	G
Carrier modulation harmonic content 150 Hz	3.1.5.5.2 e)	G
Unwanted amplitude modulation	3.1.5.5.2.2	
Phase of modulation tones	3.1.5.5.3	G
Phase of modulation tones, dual frequency systems	3.1.5.5.3.1	G
Phase of modulation tones, alternative systems	3.1.5.5.3.2	G
Monitoring — total time of out of tolerance radiation	3.1.5.7.3.1	G

Legend: *N/A* = *Not applicable*
F = *Flight inspection*
G = *Ground test*

Table I-4-3. Summary of testing requirements — markers

Parameter	*Annex 10, Volume I, reference*	*Testing*
Keying	3.1.7.4, 3.1.7.5	F/G
Coverage indications and field strength	3.1.7.3.1, 3.1.7.3.2	F
Monitor system	3.1.7.7	F
Standby equipment	N/A	F
Frequency	3.1.7.2.1	G
RF output power	N/A	G
Carrier modulation	3.1.7.4.2	G
Carrier modulation frequency	3.1.7.4.1	G
Carrier modulation harmonic content	N/A	G
Monitor system	3.1.7.7.1	F/G

Legend: *N/A* = *Not applicable*
F = *Flight inspection*
G = *Ground test*

Table I-4-4. Ground test requirements for ILS performance Categories I, II, and III localizers

Parameter	*Annex 10, Volume I, reference*	*Doc 8071 Volume I, reference*	*Measurand*	*Tolerance (See Note 1)*	*Uncertainty*	*Periodicity*
Orientation	3.1.3.1		Orientation	Correct		Annual
Frequency	3.1.3.2.1	4.2.12	Frequency	Frequency single: 0.005% Dual: 0.002% Separation: >5 kHz <14 kHz. Symmetry	0.001% 0.0005%	Annual
Spurious modulation	3.1.3.2.3		DDM, Deviation	<0.005 DDM peak-to-peak	0.001 DDM	Quarterly
Coverage (usable distance)	3.1.3.3.1	4.2.13	Power	As set at commissioning. See Note 2.	1 dB	Quarterly
Course structure (Category III only)	3.1.3.4	4.2.8, 4.2.9	DDM	As described in Annex 10.	0.001 DDM	Quarterly
Carrier modulation — Balance — Depth	3.1.3.5.1	4.2.15	DDM, Depth	Within 10 µA of the modulation balance value. 18-22%	0.001 DDM 0.2%	Quarterly
Carrier modulation frequency	3.1.3.5.3	4.2.14	Frequency	Cat I: ±2.5% Cat II: ±1.5% Cat III: ±1%	0.1%	Annual
Carrier modulation harmonic content (90 Hz)	3.1.3.5.3 d)	4.2.17	Total 2nd harmonic	<10% <5% (Cat III)	0.5%	Annual
Carrier modulation harmonic content (150 Hz)	3.1.3.5.3 e)	4.2.17	Total 2nd harmonic	<10% <5% (Cat III)	0.5%	Annual
Unwanted modulation	3.1.3.5.3.2		Ripple	Modulation depth <0.5%	0.1%	Semi-annual
Phase of modulation tones	3.1.3.5.3.3	4.2.18 to 4.2.20	LF phase	Cat I, II: <20° Cat III: <10°	4° 2°	Annual
Phase of modulation tones dual frequency systems (each carrier and between carriers)	3.1.3.5.3.4	4.2.18 to 4.2.20	LF phase	Cat I, II: <20° Cat III: <10°	4° 2°	Annual
Phasing of alternative systems	3.1.3.5.3.5	4.2.18 to 4.2.20	LF phase	Cat I, II, nominal: ±20° Cat III nominal: ±10°	4° 2°	Annual
Sum of modulation depths	3.1.3.5.3.6.1	4.2.15	Modulation depth	Modulation depth <95%	2%	Quarterly
Sum of modulation depths when using radiotelephony communications	3.1.3.5.3.7	4.2.15	Modulation depth	Modulation depth <65% ±10°, <78% beyond 10°	2%	Monthly

Parameter	*Annex 10, Volume I, reference*	*Doc 8071 Volume I, reference*	*Measurand*	*Tolerance (See Note 1)*	*Uncertainty*	*Periodicity*
Course alignment	3.1.3.6.1	4.2.8, 4.2.9	DDM, Distance	Cat I: <10.5 m. See Note 2. Cat II: <7.5 m Cat III: < 3 m	0.3 m	I — Quarterly II— Monthly III — Weekly
Displacement sensitivity	3.1.3.7	4.2.10	DDM/metre	0.00145 nominal. See Note 2. Cat I, II: ±17% Cat III: ±10%	±3% ±2%	I, II — Quarterly III — Monthly
Peak modulation depth	3.1.3.8.3.2		Modulation depth	<50%	2%	Quarterly
Audio frequency characteristic	3.1.3.8.3.3		Modulation depth	±3dB	0.5 dB	Annual
Identification tone frequency	3.1.3.9.2		Tone frequency	1 020 ±50 Hz	5 Hz	Annual
Identification modulation depth	3.1.3.9.2	4.2.16	Modulation depth	As commissioned.	1 %	Quarterly
Identification speed	3.1.3.9.4		Tone frequency	1 020 ±50 Hz	1 %	
Identification repetition rate	3.1.3.9.4		Time	As commissioned.		
Phase modulation	3.1.3.5.4	4.2.21 to 4.2.23	Peak deviation	Limits given in FM Hz/PM radians: see Note 5. 90 Hz / 150 Hz / (Difference Hz) Cat I: 135/1.5 / 135/0.9 / 45 Cat II: 60/0.66 / 60/0.4 / 20 Cat III: 45/0.5 / 45/0.3 / 15	10 Hz 5 Hz 5 Hz	3 years
Monitoring — Course shift	 3.1.3.11.2	 4.2.25	DDM, Distance	See Note 2. Monitor must alarm for a shift in the main course line from the runway centre line equivalent to or more than the following distances at the ILS reference datum. Cat I: 10.5 m (35 ft) Cat II: 7.5 m (25 ft) Cat III: 6.0 m (20 ft)	2 m 1 m 0.7 m	I — Quarterly II — Monthly III — Weekly See Notes 3 and 4
— Change in displacement sensitivity	3.1.3.11.2 f)	4.2.26	DDM, Distance	Monitor must alarm for a change in displacement sensitivity to a value differing from the nominal value by more than: Cat I: 17% Cat II: 17% Cat III: 17% Required only for certain types of localizer.	 ±3% ±3% ±3%	
— Clearance signal	3.1.3.11.2.1		DDM	Monitor must alarm when the off-course clearance cross-pointer deflection falls below 150 μA anywhere in the off-course coverage area.	±5 μA	

Parameter	*Annex 10, Volume I, reference*	*Doc 8071 Volume I, reference*	*Measurand*	*Tolerance (See Note 1)*	*Uncertainty*	*Periodicity*
— Reduction in power	3.1.3.11.2 d) and e)	4.2.27	Power field strength	Monitor must alarm either for a power reduction of 3 dB, or when the coverage falls below the requirement for the facility, whichever is the smaller change.	±1 dB relative	
— Total time, out-of-tolerance radiation	3.1.3.11.3	4.2.24	Time	For two-frequency localizers, the monitor must alarm for a change of ±1dB in either carrier, unless tests have proved that use of the wider limits above will not cause unacceptable signal degradation (>150 µa in clearance sector). Cat I: 10 s Cat II: 5 s Cat III: 2 s	±5 µA 0.2 s	

Notes:

1. *In general, the equipment settings should not be modified if the listed parameters are within 50 per cent of tolerance. See 4.2.54 and 4.2.55.*
2. *After the commissioning, flight check for the localizer, ground measurements of course alignment, displacement sensitivity, and power output should be made, both for normal and monitor alarm conditions. These measurements should be noted and used as reference in subsequent routine check measurements.*
3. *The periodicity for monitor tests may be increased if supported by an analysis of integrity and stability history.*
4. *These tests also apply to those parameters measured by the far-field monitor, if installed.*
5. *This measurement applies to the difference in peak frequency deviation between the separate measurements of the undesired 90 Hz FM (or equivalent PM) and the 150 Hz FM, using the filters specified in the table in 4.2.23.*

Table I-4-5. Ground test requirements for ILS performance Categories I, II and III glide paths

Parameter	*Annex 10, Volume I, reference*	*Doc 8071 Volume I, reference*	*Measurand*	*Tolerance (See Note 1)*	*Uncertainty*	*Periodicity*
Orientation	3.1.5.1.1		Orientation	Correct		Annual
Path angle	3.1.5.1.2.1	4.2.29 to 4.2.31	DDM, Angle	See Note 2. Cat I: Within 7.5% of nominal angle Cat II: Within 7.5% of nominal angle Cat III: Within 4% of nominal angle	 Cat I: 0.75% Cat II: 0.75% Cat III: 0.4%	Quarterly
Frequency	3.1.5.2.1	4.2.34	Frequency	Single 0.005% Dual 0.002% Separation >4 kHz, <32 kHz Symmetry	0.001% 0.0005% 0.0005%	Annual
Unwanted modulation	3.1.5.2.3		DDM	±0.02 DDM peak-to-peak	0.004 DDM	Semi-annual
Coverage (usable distance)	3.1.5.3	4.2.35	Power	As commissioned.	1 dB	Quarterly
Carrier modulation (See Note 3) — Balance — Depth	3.1.5.5.1	4.2.37	Modulation depth	0.002 DDM 37.5% to 42.5% for each tone	0.001 DDM 0.5%	Quarterly
Carrier modulation frequency	3.1.5.5.2 a), b), and c)	4.2.36	Frequency of modulation tones	Cat I: 2.5% Cat II: 1.5% Cat III: 1%	0.01%	Annual
Carrier modulation harmonic content (90 Hz)	3.1.5.5.2 d)	4.2.38	Total 2nd harmonic	<10% <5% (Cat III)	1%	Annual
Carrier modulation harmonic content (150 Hz)	3.1.5.5.2 e)	4.2.38	Total 2nd harmonic	<10% < 5% (Cat III)	1%	Annual
Unwanted amplitude modulation	3.1.5.5.2.2		Ripple	<1%		Annual
Phase of modulation tones	3.1.5.5.3	4.2.39	Phase	Cat I, II: <20° Cat III: <10°	4° 2°	Annual
Phase of modulation tones, dual frequency systems (each carrier and between carriers)	3.1.5.5.3.1	4.2.39	Phase	Cat I, II: <20° Cat III: <10°	4° 2°	Annual
Phase of modulation tones, alternative systems	3.1.5.5.3.2	4.2.39	Phase	Cat I, II: Nominal ± 20° Cat III: Nominal ± 10°	4° 2°	Annual
Displacement sensitivity	3.1.5.6	4.2.32	DDM, Angle	Refer to Annex 10, Volume I, 3.1.5.6 See Note 2.	Cat I: 2.5% Cat II: 2.0% Cat III: 1.5%	Quarterly Quarterly Monthly

Parameter	*Annex 10, Volume I, reference*	*Doc 8071 Volume I, reference*	*Measurand*	*Tolerance (See Note 1)*	*Uncertainty*	*Periodicity*
Phase modulation	3.1.5.5.4		Peak deviation	Limits given in FM Hz / PM radians: See Note 5. 90 Hz / 150 Hz / Difference (Hz) Cat I: 150/1.66 / 150/1.0 / 50 Cat II, III: 90/1.0 / 90/0.6 / 30	 10 Hz 10 Hz	3 years
Monitoring (See Note 4) — Path angle	 3.1.5.7.1 a), d)	 4.2.42	DDM, Angle	See Note 2. Monitor must alarm for a change in angle of 7.5% of the promulgated angle.	±4 µA	Cat I, II — Quarterly Cat III — Monthly
— Change in displacement sensitivity	3.1.5.7.1, e)	4.2.43	DDM, Angle	Cat I: Monitor must alarm for a change in the angle between the glide path and the line below the glide path at which 75 µA is obtained, by more than 3.75% of path angle. Cat II: Monitor must alarm for a change in displacement sensitivity by more than 25%. Cat III: Monitor must alarm for a change in displacement sensitivity by more than 25%.		
— Reduction in power	3.1.5.7.1 b), c)	4.2.44	Power	Monitor must alarm either for a power reduction of 3 dB, or when the coverage falls below the requirement for the facility, whichever is the smaller change. For two-frequency glide paths, the monitor must alarm for a change of ±1dB in either carrier, unless tests have proved that use of the wider limits above will not cause unacceptable signal degradation.	±1 dB ±0.5 dB	
— Clearance signal	3.1.5.7.1 g)		DDM, Angle	Monitor must alarm for DDM <0.175 below path clearance area		
— Total time of out-of-tolerance radiation	3.1.5.7.3.1	4.2.24	Time	Cat I: 6 s Cat II, III: 2 s		

Notes:

1. *In general, the equipment settings should not be modified if the listed parameters are within 50 per cent of the given tolerances. See 4.2.54 and 4.2.55.*

2a) *After the commissioning, flight check for the glide path, ground measurements of glide path angle, displacement sensitivity, and clearance below path, may be made, both for normal and monitor alarm conditions. These measurements may be used as reference in subsequent routine check measurements.*

2b) *After the commissioning, flight check for the glide path and ground measurements of the glide path power should be made, both for normal and monitor alarm conditions. These measurements may be used as reference in subsequent routine check measurements.*

3. *The tolerances given are for routine checks only. All parameters should be set to nominal values at the time of commissioning.*
4. *The periodicity for monitor tests may be increased if supported by an analysis of integrity and stability history.*
5. *This measurement applies to the difference in peak frequency deviation between the separate measurements of the undesired 90 Hz FM (or equivalent PM) and the 150 Hz FM, using the filters specified in the table in 4.2.23.*

Table I-4-6. Ground test requirements for ILS marker beacons

Parameter	*Annex 10, Volume I, reference*	*Doc 8071 Volume I, reference*	*Measurand*	*Tolerance (see Note 1)*	*Uncertainty*	*Periodicity*
Frequency	3.1.7.2.1	4.2.45	Frequency	±0.01% (0.005% recommended)	0.001%	Annual
RF output power		4.2.46	Power	±15%	5%	Quarterly
Carrier modulation	3.1.7.4.2	4.2.47	Modulation depth	91-99%	2%	Quarterly
Carrier modulation frequency	3.1.7.4.1	4.2.48	Frequency of tone	Nominal ±2.5%	0.01%	Semi-annual
Carrier modulation harmonic content		4.2.49	Modulation depth	Total <15%	1%	Annual
Keying	3.1.7.5.1	4.2.50	Keying	Proper keying, clearly audible OM:400 Hz, 2 dashes per second continuously. MM: 1 300 Hz, alternate dots and dashes continuously. The sequence being repeated once per second. IM: 3 000 Hz, 6 dots per second continuously.	 ±0.1 s ±0.1 s ±0.03 s	Quarterly
Monitor system — Carrier power — Modulation depth — Keying	3.1.7.7.1	4.2.51	 Power Percent Presence	Alarm at: –3 dB >50 % Loss or continuous	 1 dB 2%	Quarterly See Note 2.

Notes:

1. *The tolerances given are for routine checks only. All parameters should be set to nominal values at the time of commissioning.*
2. *The periodicity for monitor tests may be increased if supported by an analysis of integrity and stability history.*

Table I-4-7. Flight test requirements and tolerances for localizer Category (Cat) I, II and III

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type* *S*	*C, C*	*P*
Identification	3.1.3.9	4.3.12	Morse code	Proper keying, clearly audible to the limit of the range.	Subjective assessment		x	x
Voice feature	3.1.3.8	4.3.13	Audibility, DDM	Clear audio level similar to identification, no effect on course line.	Subjective assessment		x	x
Modulation — Balance — Depth — Sum	N/A 3.1.3.5 3.1.3.5.3.6.1	 4.3.14 4.3.15 4.4.8	DDM, Modulation, Depth SDM	See Note 1. 0.002 DDM 18% to 22% <60% SDM within ±35° azimuth or actual coverage sector for systems installed post January 2000	 0.001 DDM ±.5%	 x x	 (x) x x	 x x
Displacement sensitivity	3.1.3.7	4.3.16 to 4.3.20	DDM	Cat I: Within 17% of the nominal value Cat II: Within 17% of the nominal value Cat III: Within 10% of the nominal value See Note 2.	±3 µA ±3 µA ±2 µA For nominal 150 µA input	x	x	x
Off-course clearance	3.1.3.7.4	4.3.21, 4.3.22	DDM	On either side of course line, linear increase to 175 µA, then maintenance of 175 µA to 10°. Between 10° and 35°, minimum 150 µA. Where coverage required outside of ±35°, minimum of 150 µA except in back course sector.	±5 µA For nominal 150 µA input	x	x	x
High-angle clearance	N/A	4.3.23 to 4.3.25	DDM	Minimum of 150 µA.	±5 µA For nominal 150 µA input	x	x	
Course alignment accuracy	3.1.3.6	4.3.26 to 4.3.28	DDM, Distance, Angle	Equivalent to the following displacements at the ILS reference datum: Cat I: ±10.5 m (35 ft) Cat II: ±7.5 m (25 ft) [±4.5 m (15 ft) for those Cat II localizers which are adjusted and maintained within ±4.5 m] Cat III: ±3 m (10 ft)	 Cat I: ±2 m Cat II: ±1 m Cat III: ±0.7m	x	x	x
Phasing		4.3.39, 4.3.40	DDM	10 µA of the modulation balance value. See Note 3.	±1 µA	x	x	x
DDM increase linear	3.1.3.7.4		DDM	>180 µA (Linear increase from 0 to >180 µA)			x	x
Voice no interference to basic function	3.1.3.8		DDM, Speech	No interference.			x	x
Phase to avoid voice null on dual frequency systems	3.1.3.8.3.1		Speech	No nulls.			x	x

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type*		
						S	*C, C*	*P*
Course structure	3.1.3.4 See Annex 10, Volume I, Attachment C, Note to 2.1.3	4.3.29 to 4.3.33	DDM	Outer limit of coverage to Point A: 30 µA all categories Point A to Point B: Cat I: Linear decrease to 15 µA Cat II: Linear decrease to 5 µA Cat III: Linear decrease to 5 µA Beyond Point B: Cat I: 15 µA to Point C Cat II: 5 µA to Reference datum Cat III: 5 µA to Point D, then linear increase to 10 µA at Point E. See Note 4 for application of tolerances.	See Annex 10, Volume I, Att. C, 2.1.5. From Point A to B, 3 µA decreasing to 1 µA From Point B to E, 1 µA	x	x	x
Coverage (usable distance) — Power density	3.1.3.3 See Annex 10, Volume I, Attachment C, Figures C-7 and C-8	4.3.34 to 4.3.36	Flag status, DDM Power density	-114 dBW/m² (40 µV/m) in all parts of operational coverage volume from 25 NM, when within the LOC course sector and on GP: Cat I: -107 dBW/m² (90 µV/m) on ILS from 10 NM to 30 m height Cat II: -106 dBW/m² (100 µV/m) on ILS from 10 NM, increasing to -100 dBW/ m² (200 µV/m) at 15 m height above THR Cat III: -106 dBW/m² (100 µV/m) on ILS from 10 NM, increasing to -100 dBW/ m² (200 µV/m) at 6 m height above THR, -106 dBW/m² (100 µV/m) along the length of the runway *Note.— The conversion is stated in Annex 10, 3.1.3.3.2.*	±3 dB	x	x	x
Polarization	3.1.3.2.2	4.3.37	DDM	For a roll attitude of 20° from the horizontal: Cat I: 15 µA on the course line Cat II: 8 µA on the course line Cat III: 5 µA within a sector bounded by 20 µA either side of the course line.	± 1 µA	x	x	
Back course — Sector width	N/A	4.3.41 to 4.3.43	DDM, Angle	Not less than 3°.	0.1°		x	x
— Alignment	N/A		DDM, Distance	Within 60 m of the extended centre line at 1 NM.	±6 m		x	x
— Structure	N/A	4.3.79	DDM	Limit of coverage to final approach fix: ±40 µA FAF to 1.85 km (1 NM) from threshold: ±40 µA Decreasing at a linear rate to: ±20 µA	Annex 10, Volume I, Attachment C, 2.1.4		x	x

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type*		
						S	*C, C*	*P*
— Modulation depth	N/A		Modulation depth	18% to 22% approximately 9 km (5 NM) from the localizer. See Note 1.	±0.5%		x	x
Monitor system	3.1.3.11	4.3.38		See Note 2.				
— Alignment			DDM, Distance	Monitor must alarm for a shift in the main course line from the runway centre line equivalent to or more than the following distances at the ILS reference datum. Cat I: 10.5 m (35 ft) Cat II: 7.5 m (25 ft) Cat III: 6.0 m (20 ft)	 2 m 1 m 0.7 m		x	x
— Displacement sensitivity			DDM, Distance	Monitor must alarm for a change in displacement sensitivity to a value differing from the nominal value by more than: Cat I: 17% Cat II: 17% Cat III: 17%	 ±4% ±4% ±2%		x	x
— Off-course clearance			DDM	Required only for certain types of localizer. Monitor must alarm when the off-course clearance cross-pointer deflection falls below 150 µA anywhere in the off-course coverage area.	±5 µA ±1 dB relative		x	x
— Power			Power field strength	Monitor must alarm either for a power reduction of 3 dB, or when the coverage falls below the requirement for the facility, whichever is the smaller change. For two-frequency localizers, the monitor must alarm for a change of ±1 dB in either carrier, unless tests have proved that use of the wider limits above will not cause unacceptable signal degradation (>150 µA in clearance sector)	± 5 µA		x	

Notes:

1. *Recommended means of measurement is by ground check.*
2. *Recommended means of measurement is by ground check, provided that correlation has been established between ground and air measurements.*
3. *Optional, at the request of the ground technician, unless good correlation between airborne and ground phasing techniques has not been established.*
4. *Course structure along the runway may be measured by flight inspection or by ground vehicle. Refer to 4.3.79 for guidance on structure analysis.*

Legend: N/A = Not applicable
S = Site
C, C = Commissioning, Categorization
P = Periodic — Nominal periodicity 180 days

Table I-4-8. Flight test requirements and tolerances for glide path Categories (Cat) I, II and III

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type*		
						S	*C,C*	*P*
Angle — Alignment	 3.1.5.1.2.1	4.3.45, 4.3.46	DDM, Angle	Cat I: Within 7.5% of nominal angle Cat II: Within 7.5% of nominal angle Cat III: Within 4% of nominal angle	Cat I: 0.75% Cat II: 0.75% Cat III: 0.3% of nominal angle	x	x	x
— Height of reference datum	3.1.5.1.5 3.1.5.1.6 3.1.5.1.4	4.3.81	DDM	Cat I: 15 m (50 ft) + 3 m (10 ft) (See Note 3) Cat II: 15 m (50 ft) + 3 m (10 ft) (See Note 3) Cat III: 15 m (50 ft) + 3 m (10 ft) (See Note 3)	0.6 m		x	
Displacement sensitivity — Value — Symmetry	3.1.5.6	4.3.47 to 4.3.49	DDM, Angle	Symmetry: Cat I: Between 0.07θ and 0.14θ above and below path Cat I*: 0.12θ above and below path, within ±0.02θ Cat II: 0.12θ above path, within +0.02θ and -0.05θ Cat II: 0.12θ below path, within ±0.02θ Cat III: 0.12θ above and below path, within ±0.02θ * Recommendation Value: Cat I: Within ±25% of nominal displacement sensitivity Cat II: Within ±20% of nominal displacement sensitivity Cat III: Within ±15% of nominal displacement sensitivity	Cat I: 2.5% Cat II: 2.0% Cat III: 1.5%	x	x	x
Clearance — Below path	 3.1.5.6.5	4.3.50	DDM, Angle	Not less than 190 µA at an angle above the horizontal of not less than 0.3θ. If 190 µA is realized at an angle greater than 0.45θ, a minimum of 190 µA must be maintained at least down to 0.45θ.	±6 µA for a nominal 190 µA input	x	x	x
— Above path	3.1.5.3.1			Must attain at least 150 µA and not fall below 150 µA until 1.75θ is reached.				
Glide path structure	3.1.5.4	4.3.52 4.3.79	DDM	See Note 5. Cat I: From coverage limit to Point C: 30 µA. Cat II and III: From coverage limit to Point A: 30 µA From Point A to Point B: linear decrease from 30 µA to 20 µA. From Point B to reference datum: 20 µA.	 Cat I: 6 µA Cat II: 4 µA Cat III: 4 µA	x	x	x
Modulation — Balance — Depth	 3.1.5.5.1	 4.3.53 4.3.54	Modulation depth	See Note 1. 0.002 DDM 37.5% to 42.5% for each tone.	 0.001 DDM 0.5%	 x	 (x) x	 x
Obstruction — Clearance	N/A	 4.3.55	DDM	Safe clearance at 180 µA (Normal), or at 150 µA (wide alarm).	Subjective assessment	x	x	x

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type*		
						S	*C,C*	*P*
Coverage — Usable distance	3.1.5.3.1 Attachment C, Figure C-10	4.3.56	Flag status	Satisfactory receiver operation in sector 8° azimuth either side of the localizer centre line for at least 18.5 km (10 NM) up to 1.75θ and down to 0.45θ above the horizontal, or to a lower angle, down to 0.3θ as required to safeguard the glide path intercept procedure.		x	x	x
— Power density or field strength	3.1.5.3.2		Power density	-95 dBW/m² (400 µV/m)	±3 dB			
Monitor system — Angle	3.1.5.7	4.3.57, 4.3.58	DDM, Angle	See Note 2. Monitor must alarm for a change in angle of -7.5/+10% of the promulgated angle	±4 µA		x	x
— Displacement sensitivity			DDM, Angle	Cat I: Monitor must alarm for a change in the angle between the glide path and the line below the glide path at which 75 µA is obtained, by more than 0.037θ. Cat II: Monitor must alarm for a change in displacement sensitivity by more than 25%. Cat III: Monitor must alarm for a change in displacement sensitivity by more than 25%.	±4 µA ±1 dB		x	x
— Power		4.3.58	Power	Monitor must alarm either for a power reduction of 3 dB, or when the coverage falls below the requirement for the facility, whichever is the smaller change. For two-frequency glide paths, the monitor must alarm for a change of ±1 dB in either carrier, unless tests have proved that use of the wider limits above will not cause unacceptable signal degradation.	±0.5 dB		x	
Phasing	N/A	4.3.59 to 4.3.65		No fixed tolerance. To be optimized for the site and equipment. See Note 4.	N/A		x	x

Notes:

1. *Recommended means of measurement is by ground check.*
2. *Recommended means of measurement is by ground check, provided that correlation has been established between ground and air measurements.*
3. *This requirement only arises during commissioning and categorization checks. The method of calculating the height of the extended glide path at the threshold is described in 4.3.81, Analysis — Reference datum height (RDH). For Category I approaches on Code 1 and 2 runways, refer to 3.1.5.1.6 of Annex 10, Volume I.*
4. *Optional, at the request of the ground technician.*
5. *Tolerances are referenced to the mean course path between Points A and B, and relative to the mean curved path below Point B.*

Legend:
S = Site
C,C = Commissioning, Categorization
P = Periodic — Nominal periodicity is 180 days
N/A = Not applicable

Table I-4-9. Flight test requirements and tolerances for ILS marker beacons

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type*		
						S	*C,C*	*P*
Keying	3.1.7.4 3.1.7.5	4.3.66	Keying	Proper keying, clearly audible			x	x
Coverage — Indications	3.1.7.3	4.3.67 to 4.3.71	Signal level distance	Proper indication over the beacon or other defined point.		x	x	x
— Field strength	3.1.7.3.2		Field strength	When checked while flying on localizer and glide path, coverage should be: OM: 600 m ±200 m (2 000 ft ±650 ft) MM: 300 m ±100 m (1 000 ft ±325 ft) IM: 150 m ±50 m (500 ft ±160 ft) On a normal approach, there should be a well-defined separation between the indications from the middle and inner markers. Measurement should use the Low sensitivity setting on receiver. (Refer to Annex 10 for specific field strength requirements)	 ±40 m ±20 m ±10 m ±3 dB			
Monitor system	3.1.7.7	4.3.72, 4.3.73		An operationally usable indication should be obtained for a reduction in power output of 50%, or a higher power at which the equipment will be monitored. See Note.	±1 dB		x	x
Standby equipment		4.3.74		Same checks and tolerances as main equipment.			x	x

Note.— Alternatively, this can be checked by analysing the field strength recording.

Legend:
S = Site
C,C = Commissioning, Categorization
P = Periodic — Nominal periodicity is 180 days
N/A = Not applicable

Table I-4-10. Minimum positioning subsystem accuracies

	Category I		*Category II*		*Category III*	
Measurements	*Constraint point*	*Accuracy*	*Constraint point*	*Accuracy*	*Constraint point*	*Accuracy*
Angular						
— Localizer	C	0.02°, 0.06° (See Note)	T	0.0058°, 0.0173° (See Note)	D	0.0058°, 0.0173° (See Note)
— Glide path	C	0.0091 θ	T	0.0055 θ	T	0.0055 θ
Distance		0.19 km (0.1 NM)		0.19 km (0.1 NM)		0.19 km (0.1 NM)

Table I-4-11. Minimum positioning subsystem accuracies for linear truth systems

	Category I		*Category II*		*Category III*	
Measurements	*Constraint point*	*Accuracy*	*Constraint point*	*Accuracy*	*Constraint point*	*Accuracy*
Cross track — Localizer	C	2.17 m	T	0.61 m	D	0.33 m
Vertical — Glide path	C	0.27 m	T	0.083 m	T	0.083 m

Note.— Extreme localizer angular accuracy figures are calculated for localizer sector width of 2º and 6º, taking into account different runway lengths, as well as 0.5 µA airborne receiver uncertainty.

Extreme localizer cross track accuracy figures are calculated for localizer sector width of 2º for CAT I and 6º for CAT II and III, taking into account different runway lengths, as well as 0.5 µA airborne receiver uncertainty.

Extreme glide path angular tolerance figures are calculated for 286 metres of glide path setback distance and 2 µA airborne receiver uncertainty.

Extreme glide path vertical tolerance figures are calculated for 286 metres of glide path setback distance, 3º glide slope angle and 2 µA airborne receiver uncertainty.

Flight inspection systems with different receiver uncertainty values will require different positioning accuracy.

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APPENDIX TO CHAPTER 4

SAMPLE FLIGHT INSPECTION REPORT

On the next few pages, a typical ILS routine report, including inspection of monitors, is presented together with example graphs for each type of flight profile performed. Some flight inspection systems produce several graphs that may be collected during each profile to combine measurements and save flight hours. Some of the profiles may be repeated with different settings of ground equipment to achieve results from both Tx1 and Tx2 or for wide alarm and narrow alarm. An example set of profiles is given in Table A4-1-1 below.

General remarks:

a) To reduce transcription errors, the report should be computer-generated by the flight inspection system and include explanation of events, remarks and status of the equipment.

b) The report heading should contain a general section with basic report, crew and facility items.

c) An inspection identification key should be generated to keep track of all relevant data, graphs and records.

d) A system configuration key should identify actual hardware and software versions used by the flight inspection system.

e) From the inspection report it should be possible to trace back the utilized facility data-base settings, system calibration, antenna calibration diagrams, antenna lever arm corrections, cable loss and all relevant data involved in or related to the calculations used.

f) Selected receivers, antennas, reference source and other selectable parameters must be traceable for each profile.

g) Glide path (GP) aiming point offset calculations are terrain dependent and are normally calculated and compensated for during commissioning.

h) Recordings and results should be configurable for ILS ground maintenance personnel in their requested format, e.g. with DDM instead of µA, if so required.

Specific remarks:

a) A full set of applicable calculated data are presented in the result section of the enclosed report.

b) The results should be automatically checked against the tolerances specified and applied by ICAO regulations (or otherwise towards stated regulations), and any out of tolerance situations should be highlighted (i.e. * or red colour).

c) The course and glide path structure calculation should be based on a 95 per cent probability according to Annex 10, Figure C-2.

d) As found and as left results, with adjustments and repeated profiles should be properly noted and explained.

e) Width alarms are measured and shown on one transmitter for this sample, in practice this is as agreed in cooperation with ILS ground maintenance personnel.

f) If specific tests are requested by ILS ground maintenance personnel, the report should include results accordingly.

g) If any unforeseen events occur, this should be highlighted in the remarks section.

h) Current and any new restrictions applied should be properly referenced to in the remarks section.

i) Confirmation of status of the inspection as shown in the preliminary report below should be issued before leaving the site.

j) A final report as shown in the sample below should be issued as soon as possible after the completion of the inspection.

Table A4-1-1. Inspection Protocol - Inspection Id 2016-10-13 Airport ILS DME 18

Run	Recordings, flight profile, specifics and remarks
#1	GP-Tx1, LOC-Tx1, DME-Tx1, Approach 8 to -1 NM
#2	GP-Tx2, LOC-Tx2, DME-Tx2, Approach 8 to -1 NM
#3	LOC-Tx2, Arc ±40°, 7 NM, 1500 ft, CCW
#4	LOC-Tx1, Arc ±40°, 7NM, 1500 ft, CW
#5	LOC-Tx1, Wide Alarm, Arc ±10°, 7NM, 1500 ft, CCW
#6	LOC-Tx1, Narrow Alarm, Arc ±10°, 7NM, 1500 ft, CW
#7	GP-Tx2, 90Hz Alignment Alarm, LOC-Tx2, 90Hz Alignment Alarm, Approach 5 to 0 NM
#8	GP-Tx2, 150Hz Alignment Alarm, LOC-Tx2, 150Hz Alignment Alarm, Approach 5 to 0 NM
#9	GP-Tx1, 90Hz Alignment Alarm, LOC-Tx1, 90Hz Alignment Alarm, Approach 5 to 0 NM
#10	GP-Tx1, 150Hz Alignment Alarm, LOC-Tx1, 150Hz Alignment Alarm, Approach 5 to 0 NM
#11	GP-Tx1, Level 12 to 2 NM, CL Az 0°, 1500 ft
#12	GP-Tx1, Level 12 to 2 NM, CL Az 8°, 1500 ft
#13	GP-Tx1, Level 12 to 2 NM, CL Az -8°, 1500 ft
#14	GP-Tx2, Level 12 to 2 NM, CL Az 0°, 1500 ft
#15	GP-Tx1, Wide Alarm, Level 6 to 2 NM, 1500 ft, Width Adjustment
#16	GP-Tx1, Wide Alarm, Level 6 to 2 NM, 1500 ft
#17	GP-Tx1, Narrow Alarm, Level 6 to 2 NM, 1500 ft

Note 1.— Ranges and heights are site dependant and the information provided here is for example only.
Note 2.— Some States may perform more or less runs than this example protocol shows.

Preliminary Flight Inspection Report
ILS/DME 18 CCXX Airport, Country

Service Provider Name/Logo   Sys Config FIS-123-02 V8.44.1   Inspection Id 2016-10-13 Airport ILS DME 18

					GP	LOC
Ident	I-ILS	Cal. Aircraft	XX-ILS			
Frequency	110.1 MHz	Flight Inspector	Kilo	System	Type No	Type No
Category	I	Pilot	Alpha	Antenna	M, 2F	2F
Inspection Type	Periodic Monitor	1st Officer	Bravo	Nom Angle	3.00°	0.00°
Date of Inspection	13.10.2016	Ref Source	DGPS+INS	Nom XCS	0.72°	1.67°
Significant MET Cond.	None	Sel. Ref Point	Ref1	Nom CS	1.44°	3.33°

After flight inspection in accordance with ICAO Annex 10 and with reference to guidance material Doc 8071 the installation is temorary classified for:

X Unrestricted

Restricted

In accordance with published restrictions:

Aditional restrictions:

Unusable

Remarks:

After final evaluation of the flight inspection results, the installation will be classified in a detailed Flight Inspection Report.

Flight Inspector:	Oscar Kilo		OK
Phone:	+98 76 54 32 10 00	Signature, Date:	13.10.2016
Email:	post@amc.com	Distribution:	Airport Management Comp., Country

Flight Inspection Report
ILS/DME 18 CCXX Airport, Country

Service Provider Name/Logo **Sys Config** FIS-123-02 V8.44.1 **Inspection Id** 2016-10-13 Airport ILS DME 18

					GP	LOC
Ident	I-ILS	**Cal. Aircraft**	XX-ILS		**GP**	**LOC**
Frequency	110.1 MHz	**Flight Inspector**	Kilo	**System**	Type No	Type No
Category	I	**Pilot**	Alpha	**Antenna**	M, 2F	2F
Inspection Type	Periodic Monitor	**1st Officer**	Bravo	**Nom Angle**	3.00°	0.00°
Date of Inspection	13.10.2016	**Ref Source**	DGPS+INS	**Nom ½CS**	0.72°	1.67°
Significant MET Cond.	None	**Sel. Ref Point**	Ref1	**Nom CS**	1.44°	3.33°

Facility / Transmitter No / Requirements / Unit			GP 1	GP 2	LOC 1	LOC 2	Tolerance GP	Tolerance LOC
GP Angle / LOC Align.		GP (°) LOC (µA)	2.99	2.99	-1.5	-1.8	2.78/3.22	±13.5
Alignment	150Hz	GP (µA) LOC (µA)	-36.0	-37.0	-12.9	-13.4	-47	-14.5
Monitor	90Hz	GP (µA) LOC (µA)	34.2	33.8	12.6	12.7	62	14.5
Modulation Depth		SDM (%)	79.4	79.4	39.9	40.0	75/85	36/44
GP / Course Structure		(%)	100	100	100	100	95	95
Zone 1	- A	GP (µA) LOC (µA)	-4.6	-4.8	-1.5	-1.5	30	30
Zone 2	A - B	GP (µA) LOC (µA)	8.5	8.2	-2.0	-2.1	30	30-15
Zone 3	B - C/T	GP (µA) LOC (µA)	7.0	7.3	-1.5	-1.8	30	15
Zone 4	T - D	LOC (µA)			N/A	N/A		N/A
Zone 5	D - E	LOC (µA)			N/A	N/A		N/A
RDH / Polarization ±20° bank		GP (m) LOC (µA)	16.6	16.6	N/A	N/A	15-18	15
Aiming Point Offset		(m)	0.33	0.37				
Clearance		GP (µA/θ) LOC (µA/°)	-320/0.45	-316/0.45	-262/21°	-260/20°	< -190	< -150
		GP (µA/θ) LOC (µA/°)	370/1.75	380/1.75	278/-28°	276/-12°	> 150	> 150
LOC Course/Clearance Ratio		(dB)			-15	-15		-10
DS ¼ Sector 150Hz		GP (µA) LOC (µA)	72	75	74	72	56/94	62/88
DS ¼ Sector 90Hz		GP (µA) LOC (µA)	78	78	75	75	56/94	62/88
Wide	DS ¼ 150Hz	GP (µA)	58	N/A	63	N/A	> 52	> 62
Monitor	DS ¼ 90Hz	GP (µA)	63	N/A	64	N/A	N/A	> 62
Narrow	DS ¼ 150Hz	GP (µA)	90	N/A	85	N/A	< 98	< 88
Monitor	DS ¼ 90Hz	GP (µA)	98	N/A	85	N/A	N/A	< 88
Field Str	GP/LOC	min at 10 NM (dBW/m²)	-82	-80	-85	-84	-95	-107
Field Str	LOC/LOC	min 17 and 25 NM (dBW/m²)	N/A	N/A	N/A	N/A	-114	-114
Ident					ok	ok	Clearly audible	
Marker		OM (m) MM (m)	N/A	N/A	N/A	N/A	400-800	200-400
Beacon		IM (m)			N/A	N/A		100-200
Facility / Transmitter No / Requirements / Unit					DME 1	DME 2	Tolerance	
Range Error		(m)			17	18		75
Field Str		min at 25 NM (dBW/m²)			N/A	N/A		-89
Ident					ok	ok	Clearly audible	

Operational Status: Unrestricted

* Out of Tolerance
@ Adjustment

Remarks: @ GP Tx-1 Wide Monitor 150Hz adjusted from 51* µA to 58 µA.
GP Tx1 Coverage checked satisfactory ±8° centre line azimuth.

Flight Inspector:	Oscar Kilo		OK
Phone:	+98 76 54 32 10 00	**Signature, Date:**	14.10.2016
Email:	post@amc.com	**Distribution:**	Airport Management Comp., Country

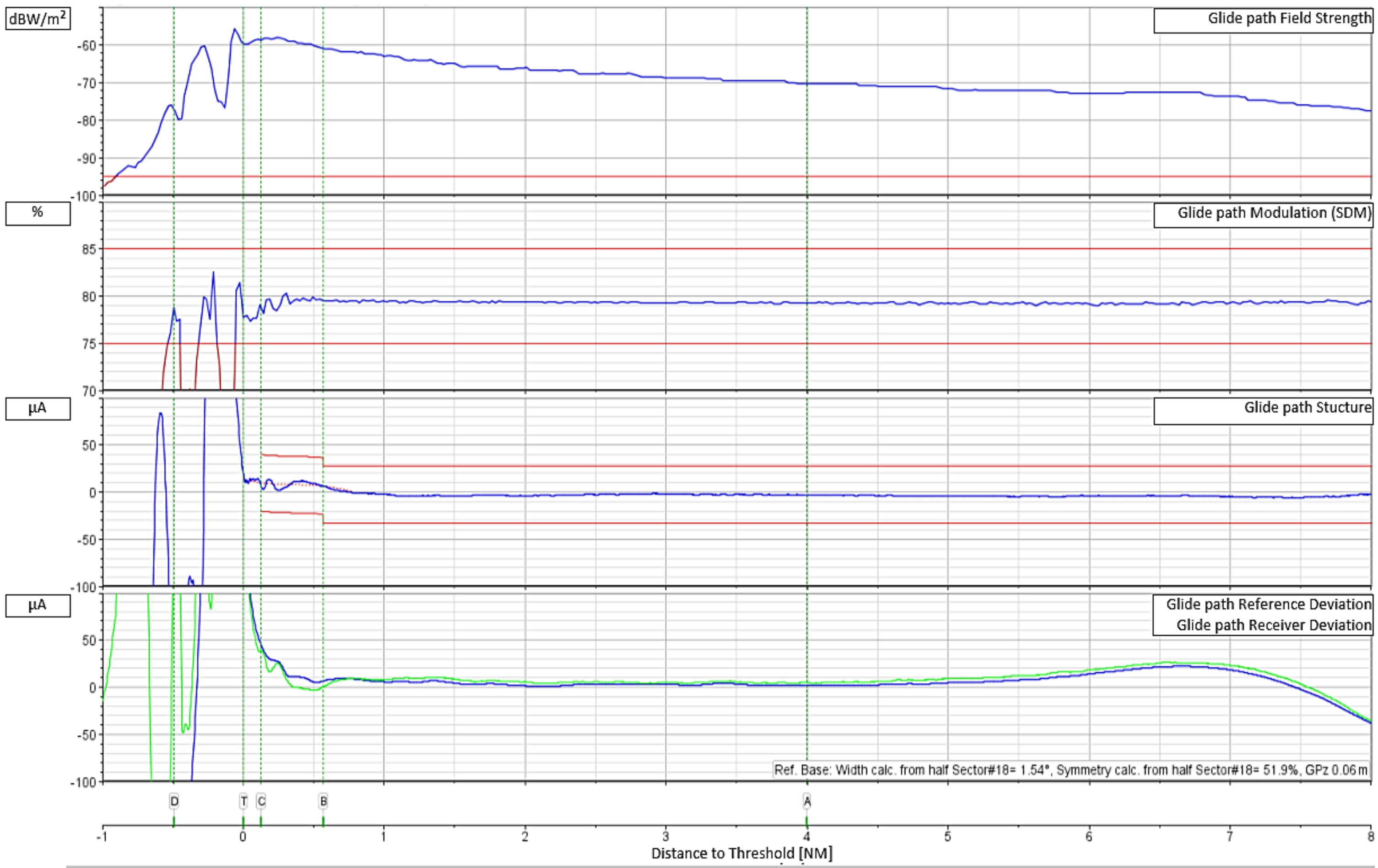

Figure I-4-1. Glide path approach

Note.— Data after point C is not relevant/evaluated for Category I evaluations, and point T for Category II-III evaluations.

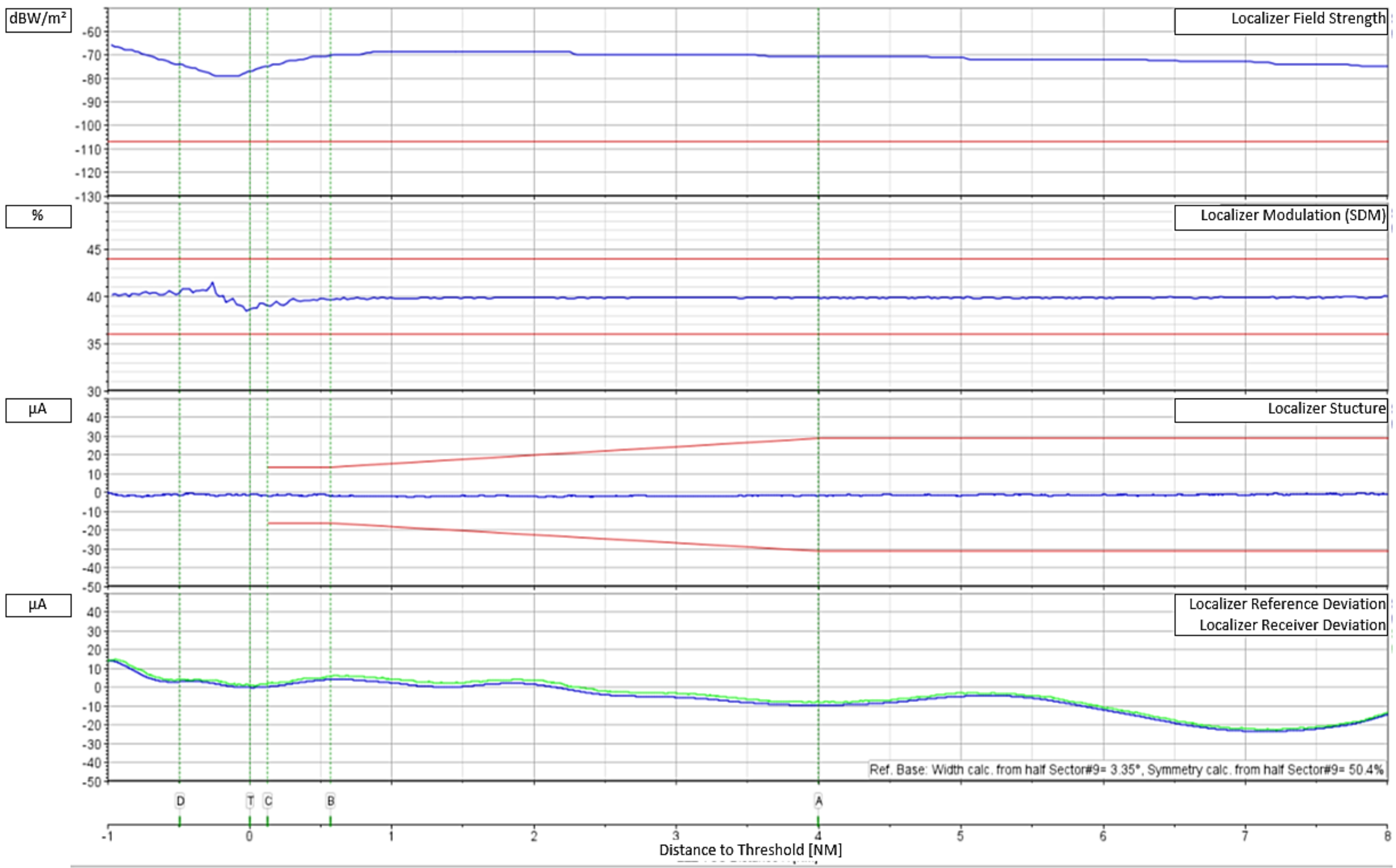

Figure I-4-2. Localizer approach

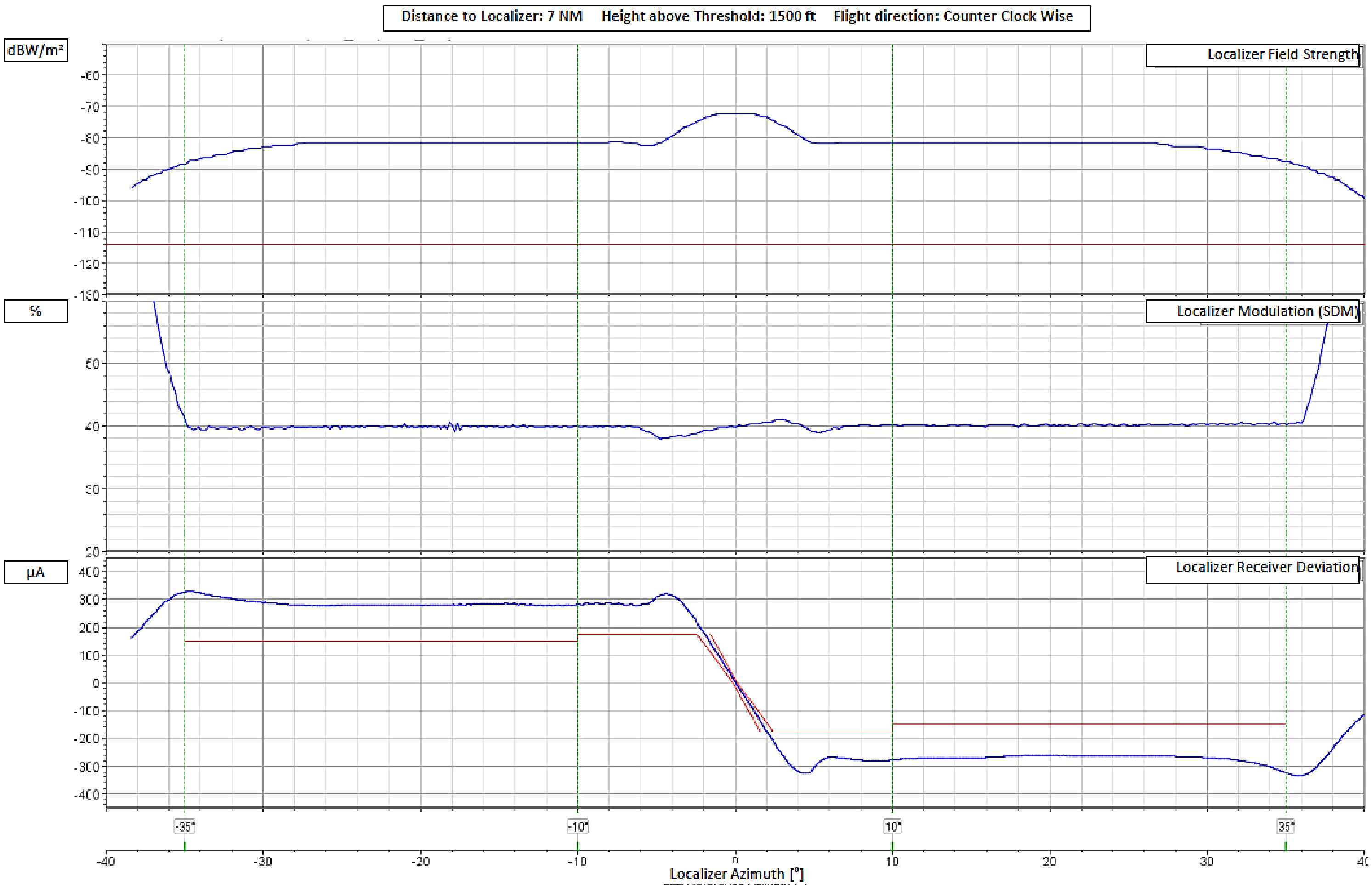

Figure I-4-3. Localizer arc

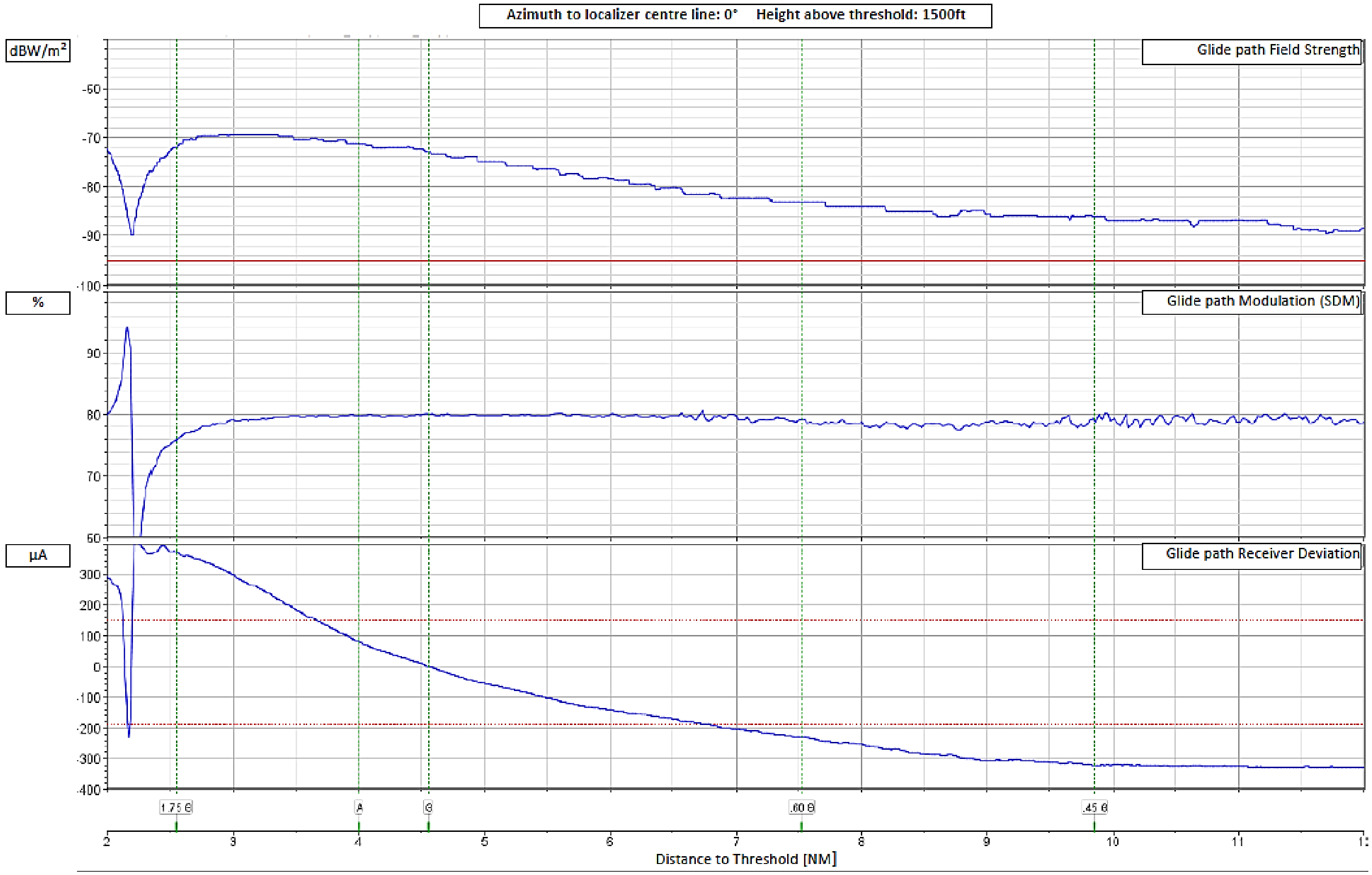

Figure I-4-4. Glide path level

Note.— Data after point C is not relevant/evaluated for Category I evaluations, and point T for Category II-III evaluations.

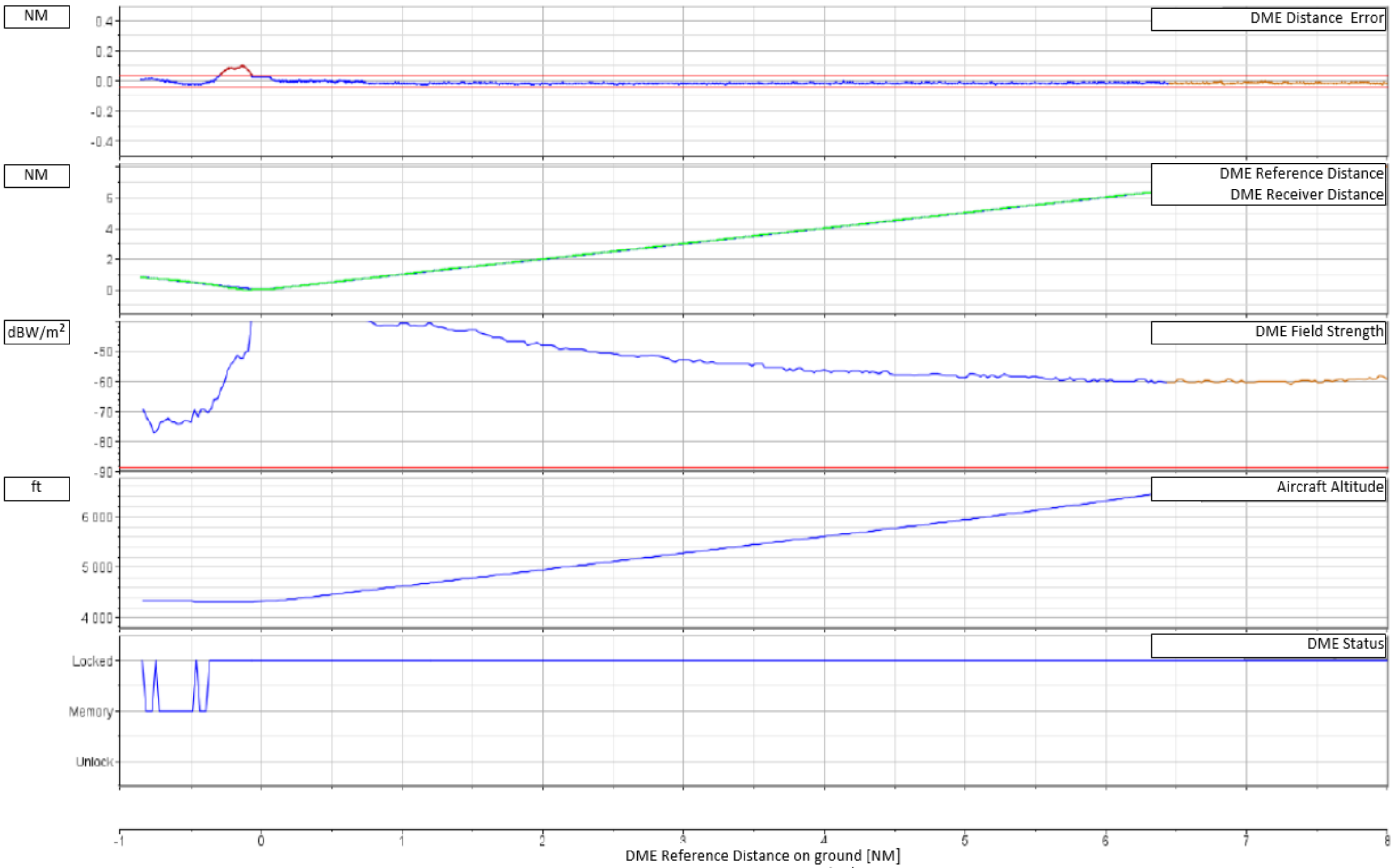

Figure I-4-5. ILS/DME approach

Chapter 5

NON-DIRECTIONAL BEACON (NDB)

5.1 INTRODUCTION

System description

5.1.1 A non-directional beacon (NDB) (also called a low- or medium-frequency homing beacon) transmits non-directional signals, primarily via ground wave propagation, whereby a pilot can determine the bearing to the ground beacon and “home-in” on it. These facilities operate on frequencies available in portions of the band between 190 and 1 750 kHz with keyed identification and optional voice modulation. The airborne receiver installation is usually called an Automatic Direction Finder (ADF).

Ground equipment

5.1.2 The ground equipment consists of a transmitter, antenna tuner and monitor, with optional standby transmitter, automatic changeover equipment and automatic antenna tuner. The monitor is not always collocated with the transmitter equipment. The transmitter normally transmits a continuous carrier modulated by either 1 020 Hz or 400 Hz keyed to provide identification. In some special cases of high interference or noise levels, the unmodulated carrier is keyed instead. The transmitter power is selected to provide the required minimum coverage, and varies from a few watts to several kilowatts. The antenna system is a vertical radiator, commonly with top loading, with an extensive earth system to improve efficiency and restrict high angle radiation.

Airborne user equipment

5.1.3 Airborne ADF equipment includes an omnidirectional sense antenna and a rotatable loop (or a fixed loop and a goniometer performing the same function). A continuous switched phase comparison process between loop and sense antenna inputs resolves the 180-degree ambiguity that normally exists in the loop input. As part of this process, a servo motor (or electronics) drives the loop (or goniometer) to a balanced position dependent upon the direction of the signal source, and a corresponding synchronous azimuth indication is provided on the aircraft ADF bearing indicator instrument. The performance of the equipment may be degraded if the signal from the NDB is modulated by an audio frequency equal or close to the loop switching frequency or its second harmonic. Loop switching frequencies are typically between 30 Hz and 120 Hz.

Factors affecting NDB performance

Rated coverage

5.1.4 The rated coverage of an NDB is an area in which a specified minimum signal strength of the ground wave is obtained. Provided that an adequate value of signal strength is chosen, there is a high probability of obtaining accurate bearings in this area. However, since other factors (some of which are discussed below) determine whether accurate bearings are obtained, it is necessary to measure the quality of the bearings from the ADF during a flight check to assess the effective coverage of the NDB.

Factors affecting signal strength of ground wave

5.1.5 *Antenna current.* The signal strength obtained at any point throughout the rated coverage area is directly proportional to the current in the vertical radiator of the antenna. Doubling the antenna current will double the strength at a fixed point or double the range for a fixed value of signal strength. The power radiated is dependent on the antenna and ground system efficiency, which varies typically from 2 to 10 per cent. The power dissipated by the NDB transmitter is the sum of the powers radiated and dissipated by the ground system and ohmic losses.

5.1.6 *Ground conductivity.* The transmitter power necessary to drive a given current through the antenna and ground system varies with the soil conductivity at the antenna site. The signal strength of the ground wave also depends on the conductivity of the soil between the transmitter and receiver. The conductivity of seawater is higher than soil, hence the range over seawater is usually greater than over land.

5.1.7 *Altitude.* An increase in signal strength can be expected as the aircraft height is increased, the effect being most marked over soil of poor conductivity, and almost negligible over seawater.

Factors affecting the quality and accuracy of ADF bearings (effective coverage)

5.1.8 *Noise.* The effective coverage is limited by the ratio of the strength of the steady (non-fading) signal received from the NDB to the total noise intercepted by the ADF receiver. The noise admitted to the receiver depends on the bandwidth of the receiver, the level and characteristics of atmospheric noise in the area together with noise sources in the aircraft and the level of the interference produced by other radio emissions. If the signal-to-noise ratio is less than the limiting value, useful bearings cannot be obtained. In some cases, the effective coverage may be limited to the range of a usable identification signal.

5.1.9 *Night effect.* The effective coverage of an NDB is also limited at night when a skywave, reflected from the ionosphere is present at the receiver in addition to the vertically polarized ground wave on which the system depends during the day. The interaction of these two signals from the NDB results in bearing errors in the ADF. The effect is independent of transmitter power.

5.1.10 *Terrain effects.* Errors in ADF bearings are often produced over rugged terrain or where abrupt discontinuities occur in the ground surface conductivity. The effect results in an oscillating bearing and usually diminishes with increasing aircraft altitude.

Testing requirements

5.1.11 A summary of testing requirements for NDB facilities is given in Table I-5-1.

5.2 GROUND TESTING

General

5.2.1 The purpose of ground testing is to ensure that the NDB radiates a signal, which meets the requirements of

Annex 10, Volume I, on a continuing basis. Since NDB equipment varies greatly, it is not possible to define detailed tests applicable to all types. Therefore, only a high-level description of the tests is provided. Refer to the manufacturer's recommendations for additional tests and detailed procedures for specific equipment.

Ground performance parameters

5.2.2 Ground test requirements are listed in Table I-5-2.

Ground test procedures

5.2.3 *Carrier frequency.* The carrier frequency should be checked against an accurate frequency standard or counter. Refer to the manufacturer's instructions for detailed procedures.

5.2.4 *Antenna current.* On most equipment, a meter is provided to read the current in the series-resonant antenna system. (If not provided, an RF thermocouple-type ammeter should be temporarily inserted at ground potential in the series resonant antenna tuner circuit.) Any change in this current from its initial value at commissioning could be due to a change in the power delivered from the transmitter and/or a change in the characteristics of the antenna system, including the transmission line and ground system. Changes should be investigated, as the coverage performance of the beacon will be affected.

5.2.5 *Modulation depth.* The modulation depth can be measured by a modulation meter (which may be built into the equipment) or by an oscilloscope. Refer to the manufacturer's instructions for detailed procedures for using a modulation meter. When using an oscilloscope, the modulated signal from the NDB (preferably obtained from a pick-up antenna) is displayed and the modulation depth obtained by measuring the maximum and minimum of the modulation envelope. (The radiated modulation percentage, as observed with a pick-up antenna, may be reduced due to the high Q factor of the antenna system.) If A_{max} and A_{min} are the maximum and minimum of the envelope respectively, then:

$$\text{Modulation \%} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} \times 100\%$$

5.2.6 *Modulation frequency.* The modulation frequency should be measured using a frequency meter or a counter, or by comparison of the modulation frequency with that generated by an accurate (1.0 per cent) audio generator. Refer to the manufacturer's instructions for the operation of these instruments.

5.2.7 *Modulation depth of power supply frequency components.* A monitor may be installed with some NDB equipment to provide a means of detecting excessive power supply modulation on the carrier. A metering position is usually provided to enable this modulation depth to be read for testing purposes. Alternatively, an oscilloscope can be used to display the NDB signal (with identification modulation removed). By using a suitable time base frequency, modulation at the power supply frequency can be identified.

5.2.8 *Spurious modulation components.* The measurement of the modulation depth of spurious components on the carrier requires the use of a modulation meter or the modulation measuring circuits, which may be incorporated in the monitor. With the identification modulation removed, the residual modulation depth of the carrier is measured.

5.2.9 *Carrier level during modulation.* A change in carrier level with modulation can be measured using a field intensity meter, modulation meter, carrier level meter on the monitor, or an oscilloscope. Using the first three methods, any change in the carrier level indication can be noted by comparing the level with and without identification modulation. (Depending on the detection and metering circuits used in these three methods, the bandwidth of the radio frequency circuits may need to be narrow enough to reject the modulation sidebands.) Using an oscilloscope, a pattern is displayed as described in 5.2.6 and the average carrier level with and without identification modulation is found. The carrier level without modulation can be read directly from the screen, while the average level with modulation is:

$$\frac{A_{max} + A_{min}}{2}$$

5.2.10 *Audio frequency distortion.* The design of the transmitting equipment will usually ensure that modulation distortion is acceptably small. However, if a distorted signal is reported, a measurement should be made of this parameter and appropriate action taken. The usual measuring equipment is a modulation monitor and distortion meter. Detailed procedures for the use of this equipment can be found in the manufacturer’s instructions.

5.2.11 *Monitor system.* The monitor system, when provided, should be checked to ensure it will detect erroneous transmissions from the NDB. Some monitors include switching functions that permit fault conditions to be simulated. In other cases, NDB fault conditions should be simulated as closely as possible to check that the monitor will alarm. Detailed procedures can be found in the manufacturer’s instructions.

5.2.12 Reserved.

Test equipment

5.2.13 *Test equipment list.* The following test equipment is recommended for NDB ground maintenance:

a) frequency meter, standard, or counter with an accuracy of at least 0.001 per cent (for carrier frequency);

b) RF thermocouple ammeter (if not part of the equipment), for measuring the antenna current;

c) distortion meter or wave analyser, for audio frequencies distortion;

d) frequency meter or standard frequency source with an accuracy of at least 0.5 per cent (for identification frequency measurement) — this instrument can typically be the same as used in a) above;

e) modulation meter or oscilloscope for modulation percentage measurements; and

f) field intensity meter where ground field strength measurements are to be made or where an airborne field strength installation is to be calibrated. The field intensity meter can also be used to check for the radiation of spurious harmonics from the NDB.

5.3 FLIGHT TESTING

General

5.3.1 The primary objectives of flight testing are to determine the coverage and quality of the guidance provided by the NDB system and to check for interference from other stations. These assessments are to be made in all areas where coverage is required and with all operational procedures designed for the NDB, in order to determine the usability of the facility and to ensure that it meets the operational requirements for which it was installed. However, this does not mean that the flight check aircraft must fly through the entire coverage area, but rather, from a consideration of all the factors affecting the coverage and usability of the particular NDB, significant areas can be chosen for flight measurements from which the overall performance can be assessed. Such significant areas are typically at extreme range, along airways, in holding patterns, over mountains, etc.

Flight test performance parameters

5.3.2 Flight test requirements are listed in Table I-5-3.

Flight test procedures

Identification

5.3.3 The coded identification on the NDB signal should be monitored during the flight inspection to the limit of coverage (in some cases, the range to which the identification can be received may determine the effective coverage of the NDB). The identification is satisfactory if the coded characters are correct, clear, and properly spaced. Monitoring of the identification during the flight also aids in identifying an interfering station.

Voice

5.3.4 When a facility provides voice transmissions such as weather broadcasts, the voice quality is checked. A voice transmission should be requested, if not available continuously, and a check made for quality, modulation and freedom from interference. If the voice transmission cannot be received at the maximum range from the beacon, the maximum range for satisfactory reception should be noted.

Coverage

5.3.5 An NDB coverage is determined by field strength measurements (rated coverage) or by a quality assessment (effective coverage) of factors such as signal strength, voice and identification, and cross-pointer activity. The use of either or both methods depends upon operational and engineering requirements.

5.3.6 *Co-channel interference.* In areas where the density of NDB facilities is high and interference amongst them is likely, a night-time check should be made to verify that the design field strength is obtained at the rated coverage limit. If not, the transmitter power output should be adjusted accordingly. This will optimize the power to minimize interference between NDBs.

5.3.7 *Rated coverage.* A representative orbit should be flown that demonstrates appropriate compliance to the rated coverage. If the terrain is considered sufficiently homogeneous or if no problem areas are found such that a complete orbit is unnecessary, the coverage can be probed via radial flight or measured in representative sectors by measuring the field strength along suitable airways, also at minimum altitude. Adjustments to the NDB antenna current may be required to obtain satisfactory results.

5.3.8 *Field strength measurements.* Field strength measurements are read from a meter or recorded along with DME distance or ground reference points. These reference points can then be plotted on a map together with the measured field strength in order to arrive at the rated coverage. The measurements should be made during daylight hours and in good weather conditions. If this is not possible, the measurement conditions should be described in detail in the report.

5.3.9 *Effective coverage.* Effective coverage is obtained from an assessment of the quality of the guidance signals provided by the NDB. The areas where the quality is measured will be largely determined by the operational usage to be made of the beacon and by a consideration of the factors affecting effective coverage described in 5.1.4 to 5.1.10. In most cases, it will be sufficient to fly the air routes served by the NDB together with a small radius orbit around the beacon. However, where the effective coverage is required in all sectors, and circumstances do not permit the coverage to be inferred from selected radials, an orbit commensurate with the required radius of coverage should be flown. Any unusual areas within the required coverage area where the quality of the signal may be affected, e.g. by mountains, should be flown. The flights should be conducted at minimum route or sector altitude and note made of excessive ADF needle oscillation, weak identification or interference, together with DME distance or ground reference points. These reference points can later be plotted on a map to obtain the effective coverage and the location of areas of poor quality. If suitable equipment is available, the ADF bearing from which the aircraft heading has been subtracted can be recorded. Where interference occurs from another facility, the interfering station should be identified.

Airways coverage

5.3.10 The facility coverage along the airways is obtained by flying the route at minimum altitude and checking for excessive ADF needle oscillation, identification quality and interference. Although all airways are checked at commissioning, it is usually not necessary to check all airways during routine tests. However, an airway in each quadrant should be checked annually.

Holding pattern and approach procedures

5.3.11 Where a holding pattern or approach procedure is based on an NDB, this procedure should be flown to check for flyability from a pilot’s viewpoint. A check is made for excessive needle oscillation, erroneous reversals giving a false impression of station passage, or any other unusual condition.

Station passage

5.3.12 This check confirms that a correct indication is given when passing over a station. The aircraft should be flown over the NDB, preferably from two radials 90 degrees apart, to ensure that an ADF reversal is obtained with an acceptably limited needle oscillation.

Standby equipment

5.3.13 The checks to be carried out on standby equipment (if installed) will depend on whether it is identical to the main equipment. If the main and standby equipments are interchangeable, the full commissioning checks are carried out on one equipment, and only the identification, voice, and a brief quality check on the other. Subsequent equipment operation can be scheduled so that routine checks are carried out on each equipment alternately. If the standby equipment is of lower power than the main, both equipments are checked during commissioning. This need not increase flight times if coordination between ground and air can be arranged to change the equipment when requested. Thus, on a flight outbound on an airway from the NDB, the lower power equipment is first checked, and when its coverage has been exceeded, the higher power equipment is brought on and the flight proceeds to the coverage limit of this equipment. If any change in the performance of the NDB is considered likely when connected to its source of standby power, then all the flight checks should be repeated with the NDB on standby power. Normally, facilities whose standby power source consists of float-charged batteries without switching equipment do not require this check.

5.3.14 Reserved.

Test equipment

5.3.15 The basic airborne equipment used for flight testing NDB facilities is a standard aircraft ADF receiver, calibrated to read field strength and bearing to the NDB. Continuous recording of the data derived from a flight check is highly desirable, and recordings of both field strength and the quality of the bearing information (needle swing) should be made, particularly at the time of commissioning. A voltage proportional to the received signal strength usually can be obtained from the receiver, or field strength readings may be taken from a separate field strength measuring equipment carried in the aircraft.

Positioning

5.3.16 The quality of guidance given is usually judged by observing the needle swing of the ADF. However, it should be noted that since the ADF indicates the angle between the aircraft and the ground beacon, any yawing motion of the aircraft will produce a swing in the ADF needle indication. Care should therefore be taken during a flight check to keep the aircraft heading as steady as possible. Alternatively, it has been found useful to record the difference between the ADF bearing and the aircraft heading by means of comparing the ADF and compass outputs. In this way, the yawing motion of the aircraft is removed from the record. A typical formula used for this purpose is:

$$\text{ADF error} = \text{ADF bearing} - (\text{azimuth to NDB} - \text{aircraft heading} \pm 180)\ \text{degrees.}$$

Table I-5-1. Summary of testing requirements for non-directional beacons

Parameter	*Annex 10, Volume I, reference*	*Testing*
Identification	3.4.5.1, 3.4.5.2, 3.4.5.3	F/G
Voice		F
Rated coverage	3.4.2	F
Airway coverage	3.4.2	F
Holding pattern, approach procedures (where applicable)		F
Station passage		F
Standby equipment		F/G
Carrier frequency	3.4.4.2	G
Antenna current		G
Field strength	3.4.2.1	F
Modulation depth	3.4.6.2	G
Modulation frequency	3.4.5.4	G
Modulation depth of power supply frequency components	3.4.6.5	G
Carrier level change during modulation	3.4.6.4	G
Audio distortion		G
Monitor system (see Note)		G
a) Antenna current or field strength	3.4.8.1 a)	
b) Failure of identification	3.4.8.1 b)	

Note.— When the monitor is remotely located, it measures the field strength rather than the antenna current.

Legend: *F* = *Flight test/inspection*
G = *Ground test*

Table I-5-2. Ground test requirements for non-directional beacons

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Periodicity*
Carrier frequency	3.4.4.2	5.2.3	Frequency	±0.01% (±0.005% for power >200 W at frequencies above 1 606.5 kHz)	0.001%	1 year
Antenna current		5.2.4	RF amperes	±30% of value set at commissioning	4%	6 months
Modulation depth	3.4.6.2	5.2.5	Depth, per cent	85% to 95%	2%	6 months
Modulation frequency	3.4.5.4	5.2.6	Audio frequency	1 020 ±50 Hz 400 ±25 Hz	5 Hz	6 months
Modulation depth of power supply frequency components	3.4.6.5	5.2.7	Modulation depth, per cent	Less than 5% modulation depth	1%	As required
Carrier level change during modulation	3.4.6.4	5.2.9	Signal strength	Less than 0.5 dB (1.5 dB) for beacons with less (greater) than 50-mile coverage	0.1 dB rel. resolution	6 months
Identification	3.4.5.2, 3.4.5.3		Keying	Clearly audible, proper keying, correct coding		
Audio distortion		5.2.10	Modulation depth	10% distortion maximum		As required
Monitor system a) Antenna current or field strength b) Failure of identification	 3.4.8.1 a) 3.4.8.1 b)	5.2.11	RF current or field strength keying	Alarm for 3 dB decrease (see Note) Alarm for loss of or continuous modulation	1 dB	6 months

Note.— Certain States have a monitor system which also alarms for a 2 dB increase in radiated power.

Table I-5-3. Flight test requirements for non-directional beacons

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance or purpose of flight check*	*Uncertainty*	*Inspection type*
Identification	3.4.5.1	5.3.3	Keying	Clearly audible, proper keying, correct coding to the limit of coverage.		C, P
Voice		5.3.4		Clearly audible and free from interference to the limit of coverage.		C, P
Rated coverage	3.4.2	5.3.7	Signal strength or bearing	The minimum signal strength as required for the particular geographical area ADF needle oscillations not to exceed 10 degrees throughout the specified coverage area. See Note 3.	3 dB 2 degrees	C
Airway coverage	3.4.2	5.3.9	Bearing	ADF needle oscillations not to exceed 10 degrees to the limit of coverage specified for the airway. See Note 3.	2 degrees	C, P
Holding pattern, approach procedures (where applicable)		5.3.11	Bearing	Adequate flyability, needle oscillations not to exceed ±5 degrees, with no erroneous reversals giving false impression of station passage. See Note 3.	2 degrees	C, P
Station passage		5.3.12		Absence of any tendency for false station passage or excessive ADF needle oscillation.		C, P
Standby equipment		5.3.13		Same tolerances as main equipment.		See 5.3.13

Notes:

1. *Commissioning checks (C) are to be carried out before the NDB is initially placed in service. In addition, special checks that include most or all of those required for commissioning may be required whenever changes that may affect its performance, such as a different antenna system, frequency change, etc., are made to the NDB.*

2. *Periodic checks (P) are typically made annually. In some cases, e.g. locator beacons used in a low approach procedure, more frequent checking may be found desirable. Locator beacons associated with an ILS facility can be checked coincident with the ILS routine check.*

3. *External and aircraft noise sources as well as terrain features routinely affect NDB cross-pointer accuracy. Although tolerances are shown for airways, approaches, and holding patterns, it is not necessary to restrict or remove from service an NDB solely because it provides momentary out-of-tolerance needle oscillations that are brief, relative to the intended procedural use. As long as bearing errors greater than the listed tolerances are generally oscillatory in nature rather than one-sided, and have durations less than 4 seconds for approaches and 8 seconds for airways and holding patterns, the NDB may be considered acceptable. (These time periods apply to each occurrence of oscillatory out-of-tolerance needle activity.)*

Chapter 6

EN-ROUTE VHF MARKER BEACONS (75 MHz)

6.1 INTRODUCTION

System description

6.1.1 En-route marker beacons identify a particular location along an airway and are generally associated with low frequency and VHF radio ranges. A 75 MHz signal modulated by 3 000 Hz is radiated from the ground equipment in a narrow beam directed upwards. This is received by aircraft flying overhead and an audible and visible indication is given to the pilot. On some beacons, the modulating tone is keyed to provide identification coding. Two types of en-route marker beacons are in general use. Fan or F markers are used to identify locations along airways, have an approximately elliptical coverage shape at a given altitude, and are generally located some distance from the navigation aid defining the airway. Station location or Z markers are used to identify the location of a navigation aid on an airway, have an approximately circular coverage at a given altitude, and are installed close to the station.

Ground equipment

6.1.2 The ground equipment consists of a 75 MHz transmitter, an antenna system usually consisting of a dipole or array of dipoles over an elevated counterpoise, and, in the usual case, a monitor to detect out-of-tolerance conditions. The transmitter generates a continuous carrier amplitude modulated approximately 95 per cent by a 3 000 Hz tone. The modulating tone may be keyed with dots and dashes to provide coded identification. Since the marker system depends on the measurement of a radio frequency signal level for its operation, the power output varies according to the marker's operational use.

Airborne user equipment

6.1.3 Airborne marker beacon systems consist of antenna, receiver, and indicator subsystems. The antenna may be a standard open wire or a flush mounted type, and is mounted on the underside of the aircraft. The receiver's detected modulation is monitored by headset or speaker, and is also passed through an appropriate filter (3 000 Hz for en-route markers) to operate a white lamp. This lamp is usually one of a three-lamp installation, the other two responding to ILS marker beacon signals. The sensitivity of the receiver and antenna combination is adjusted so that the indicator lamp illuminates when the signal level reaches a specified level.

6.1.4 Reserved.

Testing requirements

6.1.5 A summary of testing requirements for en-route marker beacons is given in Table I-6-1.

6.2 GROUND TESTING

General

6.2.1 The purpose of ground testing is to ensure that the marker beacon radiates a signal that meets the requirements of Annex 10, Volume I, on a continuous basis. Since marker equipment varies greatly, it is not possible to define detailed tests applicable to all types. Therefore, only a high-level description of the tests will be provided. Refer to a manufacturer's recommendation for additional tests and detailed procedures for specific equipment.

Ground performance parameters

6.2.2 Ground test requirements are listed Table I-6-2.

Ground test procedures

6.2.3 *Carrier frequency.* The carrier frequency should be checked using an accurate frequency standard to ensure that it is within tolerance. Refer to the instructions supplied with the frequency standard for detailed procedures.

6.2.4 *RF output power.* Since the power output of the transmitter directly affects the coverage, it is important to maintain the power as close as possible to the commissioning value. On most equipment a meter is provided and may be confirmed by using an independent power output meter.

6.2.5 *Modulation depth.* Modulation depth can be measured using a modulation meter (it may be built into the equipment) or by an oscilloscope. Using an oscilloscope, the modulated signal from the beacon is displayed (usually by direct connection to the deflection plates) and the modulation percentage obtained by measuring the maximum and minimum of the modulation envelope. If *Amax* and *Amin* are the maximum and minimum of the envelope respectively, then:

$$\text{Modulation \%} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} \times 100\%$$

Refer to the manufacturer's instructions for detailed procedures for using the modulation meter.

6.2.6 *Modulation frequency.* The modulation frequency can be measured using a frequency meter or by comparing the frequency with an accurate (0.5 per cent) audio generator.

Note.— Refer to the manufacturer's instructions for operation of these instruments.

6.2.7 *Harmonic content of modulation.* The design of the transmitting equipment will usually ensure that modulation distortion is acceptably small. However, if a distorted signal is reported, a measurement should be made of this parameter and appropriate action taken. The usual measuring equipment is a modulation monitor and distortion meter.

Note.— Refer to the manufacturer's instructions for use of this equipment.

6.2.8 *Identification keying.* If identification keying is used on the marker beacon, an audible indication is usually available from a test point on the equipment or monitor to audibly check for clear, correct keying.

6.2.9 *Monitor system.* The monitor system, when provided, should be checked to ensure that it will detect erroneous transmissions from the marker beacon. Some monitors include switching functions, which permit faulty conditions to be simulated. Detailed procedures will be found in the manufacturer's instructions. In other cases, marker beacon out-of-tolerance conditions should be simulated, as closely as possible, to check that the monitor will alarm.

6.2.10 Reserved.

Test equipment

6.2.11 *Test equipment list.* The following test equipment is recommended for marker beacon ground maintenance:

a) frequency meter covering the 75 MHz band with an accuracy of at least 0.004 per cent;

b) frequency meter or standard frequency source with an accuracy of at least 0.5 per cent (for modulation frequency measurement) — this instrument can typically be the same as that used in a) above;

c) modulation meter or oscilloscope for modulation percentage measurement;

d) wave analyser for harmonic distortion measurements; and

e) RF power meter.

6.3 FLIGHT TESTING

General

6.3.1 The purpose of flight testing is to determine whether the marker's coverage defined by the visual indication is within operational tolerances. This may be found by noting when the lamp is illuminated, by a calibrated marker receiver or by measuring the signal level from the marker beacon antenna.

Flight test performance parameters

6.3.2 Flight testing requirements are listed in Table I-6-3.

Flight test procedures

Identification coding

6.3.3 If identification coding is used on the marker beacon, it should be checked during a flight over the beacon. The identification is assessed from both the aural and visual indications and is satisfactory when the coded characters are correct, clear and properly spaced. The frequency of the modulating tone can be checked by observing that the visual indication is obtained on the correct (white) lamp of a three-lamp system.

Coverage

General

6.3.4 There is no international Standard for coverage of an en-route marker. It is determined by individual States' operational requirements. Coverage is measured by flying over the marker beacon at operationally used altitudes and by measuring the total time or distance during which a visual indication is obtained from a calibrated marker receiver and antenna, or during which a predetermined signal level is obtained. At commissioning, the coverage should be measured at a number of altitudes, while for routine checks it will usually be sufficient to make the check at a single altitude. Since the routine checks of the marker beacon will normally be carried out in conjunction with the associated navigation aid, it will be convenient to check both at the same altitude. At commissioning, it is preferable to determine the coverage by making a continuous recording of signal strength, since this allows a more detailed assessment of the ground beacon performance. For routine checks, measurement of light activation time or distance over which the visual indication is received will usually be sufficient.

Measuring procedure

6.3.5 The procedure used for coverage measurements is to fly over the beacon, noting the true air speed of the aircraft and the total time or distance over which the visual indication or predetermined signal level is obtained. A 180-degree turn is then made and the measurement repeated while flying over the beacon at the same air speed in the opposite direction. These two flights are required in order to average out the wind speed and other effects, such as receiver lag, tilt, or asymmetry in aircraft antenna pattern, etc. The time during which visual indication is obtained (light time) can be measured directly by a stopwatch. If a continuous recording of a signal level is being made, a knowledge of the chart speed will enable the time for which the predetermined value of the signal level is exceeded to be scaled directly from the chart. The coverage may be converted into time at a reference air speed or distance as follows:

If V_1 is the true air speed and T_1, T_2 are the coverage times obtained on the two flights in opposite directions, then the coverage time, T, at a reference air speed of V_2 and coverage distance, D, will be:

$$T = \frac{2(T_1 \times T_2)}{T_1 + T_2} \times \frac{V_1}{V_2} \qquad D = \frac{2(T_1 \times T_2)}{T_1 + T_2} \times V_1$$

6.3.6 Alternatively, coverage distance may be measured directly by flying over the beacon as described above; and noting the locations on the ground directly beneath the aircraft which coincide with the beginning and end of marker lights on. These points defining the coverage area are then plotted on a map of the locality and the coverage distance read off. If the flight check aircraft is fitted with a positioning system, it can be used to measure the coverage area. A DME, suitably located, could also be used.

6.3.7 At commissioning, a check should be made that the centre of the coverage area is in the correct position. This will usually be over the marker beacon but in some cases, due to siting difficulties, the polar axis of the marker beacon radiation pattern may have to be other than vertical. Reference should then be made to the operational procedures to determine the correct location of the centre of coverage, with respect to some recognizable point on the ground. The centre of coverage can be checked during the coverage flights described above, by marking the continuous recording when the aircraft is directly over the marker beacon (or other defined point). The average of the two recordings, taken with respect to the mark on the recording, will show whether the coverage pattern is centred over the beacon (or other defined point). The separate recordings taken in each direction will seldom be symmetrical about this reference mark on the recording due to such effects as asymmetry of ground beacon radiation pattern, tilt in aircraft antenna pattern, receiver lags, etc.

Standby equipment (if installed)

6.3.8 At commissioning, the standby equipment is checked in the same manner as the main equipment. For routine checks, it is usually not necessary to check both main and standby equipment, provided that the checks are carried out on each piece of equipment alternately. If any change in the performance of the marker beacon is considered likely when it is connected to its source of standby power, then all the flight checks should be repeated with the marker beacon on standby power.

6.3.9 Reserved.

Test equipment

Description of airborne flight inspection equipment

6.3.10 The airborne equipment used for the flight inspection of marker beacons is usually a standard aircraft marker receiver and antenna. It is highly desirable, particularly for commissioning, to have the receiver modified so that the field strength can be continuously recorded. Alternatively, a suitable general purpose field strength meter covering the 75 MHz band could be used. The signal level used for calibration of the airborne marker receiver or field strength meter depends on the type of aircraft antenna used.

6.3.11 The standard open-wire antenna referred to in this chapter is a half-wave dipole mounted 15 cm (6 inches) below the approximate centre line of the metallic fuselage with its axis parallel to the longitudinal axis of the aircraft and cleared from any other antennas or projections by at least one metre. The lead-in consists of a wire connecting the antenna 13 cm (5 inches) off-centre to a 70 ohm concentric transmission line. The lead-in connects to the transmission line within 5 cm (2 inches) of the fuselage skin inside the aircraft.

Calibration

6.3.12 When the marker beacon receiver is used with the standard open-wire antenna, the receiver sensitivity is adjusted so that the lamp is illuminated for an input signal level of 1 000 microvolts, 3 000 Hz modulated at 95 per cent. The lamp should be extinguished (50 per cent of lamp voltage or less) when the input signal is reduced to 800 microvolts. These signal levels are the open circuit voltages from a generator with a source impedance of 50 ohms. To ensure repeatable results, it is important that the input impedance of the marker receiver be resistive and between 50 and 100 ohms. If an antenna other than the above standard is used, a figure should be obtained from the manufacturer which relates its gain to that of the standard open-wire antenna. This same factor is then applied to the receiver sensitivity adjustment. For example, if the antenna gain is −3 dB relative to the standard open wire, then the receiver should be adjusted so that the lamp is illuminated for an input of 700 microvolts and extinguished for an input of 570 microvolts. The antenna should be adjusted in accordance with the manufacturer’s instructions to match the transmission line.

6.3.13 When the coverage is determined by measuring the signal level from the aircraft antenna, the coverage limits are defined by the 1 000 microvolt contour if the standard open wire antenna is employed. If another type of aircraft antenna is used, the equivalent signal level for coverage measurement is determined in the same manner described above for the receiver and lamp calibration.

6.3.14 Airborne test equipment uncertainty. The tolerance for the coverage performance of a marker beacon is ±5 s compared to a 20 s nominal value, or 25 per cent relative. When applied to the allowable variation of the signal, this tolerance corresponds to:

$$\frac{1}{4} \times (1\,000 - 800) = 50\ \mu \text{ volts}$$

Because the test equipment tolerances should be at least five times better than the parameter to be measured, the uncertainty on measuring the input signal level is 10 µV.

Positioning

6.3.15 *Minimum requirements.* Flight inspection of the signal characteristics of the 75 MHz en-route marker beacon does not require reference positioning of the aircraft. Tolerances are given in time units, requiring that the aircraft fly on a defined trajectory and at a constant ground speed. Nominal values are a ground speed of 220 km/hr (120 kt) or 60 m/s, and an altitude of 600 m (2 000 ft) or as determined from operational requirements.

6.3.16 *Advanced systems.* Flight inspection systems generally use a three-dimensional reference trajectory, providing real time values for the distance of the aircraft to the beacon within a few metres accuracy. In such a case, coverage measured in distance units is very accurate. Distance information also allows verification that the centre of the coverage area is in the correct position over the marker beacon or a well-defined point.

Table I-6-1. Summary of testing requirements for en-route markers

Parameter	*Annex 10, Volume I, reference*	*Testing*
Identification keying (if used)	3.6.1.2.4	F/G
Coverage	3.6.1.2.5	F
Standby equipment (if installed)		F/G
Carrier frequency	3.6.1.1	G
Coverage (RF output power)		G
Modulation depth	3.6.1.2.1	G
Modulation frequency	3.6.1.2.2	G
Harmonic content of modulation tone	3.6.1.2.1	G
Monitor system (where provided) a) Carrier power b) Modulation depth c) Keying (when used)	3.6.1.3	G

Legend: *F = Flight test/inspection*
G = Ground test

Table I-6-2. Summary of ground test requirements for en-route markers

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	Tolerance	*Uncertainty*	*Periodicity (See Note)*
Carrier frequency	3.6.1.1	6.2.3	Frequency	±0.005%	0.001%	12 months
Coverage (RF output power)	3.6.1.2.5	6.2.4	Power	±15% of value set at commissioning.	5%	6 months
Carrier modulation	3.6.1.2.1	6.2.5	Modulation depth	95-100%	2%	6 months
Carrier modulation frequency	3.6.1.2.2	6.2.6	Frequency of tone	±75 Hz	0.01%	6 months
Harmonic content of modulation tone	3.6.1.2.1	6.2.7	Modulation depth	Total less than 15%	1%	12 months
Keying (if used)	3.6.1.2.4	6.2.8	Keying	Proper, clearly audible		6 months
Monitor system (where provided)	3.6.1.3	6.2.9		Alarm at:		6 months
a) Carrier power			Power	-3 dB	1 dB	
b) Modulation depth			Per cent	70%	2%	
Keying (when used)			Presence	Loss		

Note.— These are typical intervals between tests. The actual periods adopted by one State may be vary in the light of experience with particular equipment and its reliability record. As many of the tests as necessary should be carried out when the marker beacon has been restored to service after the clearance of a fault.

Table I-6-3. Summary of flight test requirements for en-route markers

Parameter	*Annex 10, Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type (See Notes)*
Identification (if used)	3.6.1.2.4	6.3.3	Keying	Clearly audible, proper keying, correct coding and frequency.		C, P
Coverage	3.6.1.2.5, 3.6.1.2.6	6.3.4 to 6.3.7	Field strength	Proper indication given to aircraft of the particular location on the airway. The coverage pattern should be centered over the beacon (or other defined point).	1 second or 10 µV	
				Commissioning: Nominal (as determined by operational requirements), ±25%		C
				Periodic: Nominal (as determined by operational requirements), ±50%		P
Standby equipment (if installed)		6.3.8		Same checks and tolerances as main equipment.		C

Notes:

1. *Commissioning checks (C) are to be carried out before the marker beacon is initially placed in service. In addition, re-commissioning may be required whenever changes, which may affect its performance (e.g. variations or repairs to the antenna system), are made to the marker beacon.*

2. *Periodic checks (P) are typically made annually. However, it will usually be convenient to flight test the marker whenever the associated navigation aid is checked.*

Chapter 7

PRECISION APPROACH RADAR (PAR)

7.1 INTRODUCTION

System description

7.1.1 Precision approach radar (PAR) is the part of the precision approach radar system that provides the range, azimuth and elevation data when the aircraft is in the final stages of approach. The surveillance radar element (SRE), when installed, provides the orientation information required to direct the aircraft to the correct position and altitude so that the final approach can be instituted.

7.1.2 PAR is designed to provide an approach path for precise alignment and descent guidance to an aircraft on final approach to a specific runway, through the interpretation and oral instructions of a ground-based controller. PARs provide a very high degree of resolution in terms of range, azimuth and elevation by radiating a narrow pulse and beamwidth. Target information is displayed on an azimuth and elevation display. The displays must provide accurate information regarding an aircraft's range, azimuth, and elevation angle.

Equipment description

7.1.3 The PAR is a pulsed radar system employing two antennas that scan in a narrow sector, one in the azimuth plane and the other in the elevation plane. Systems can be analogue-based with single transmitter/receiver combinations feeding cathode ray tubes or more complex digital systems with phased array antennas and digital displays.

7.1.4 The transmitting equipment transmits pulsed RF energy at frequencies in the order of 9 000 MHz. The pulsed beams are radiated along the predetermined descent path by the azimuth and elevation antennas for an approximate range of 18.5 km (10 NM), and can cover sectors of up to 20 degrees (10 degrees nominally) in azimuth and 7 degrees (from −1 to 6 degrees) in elevation. Dual transmitter/receivers are provided at most PAR installations to increase the reliability of the system.

7.1.5 For older analogue systems the PAR shelter may be, designed specifically to house the two antennas and the electronic equipment, and is often mounted on a turntable located adjacent to intersecting runways to permit multiple coverage. Digital PARs may house the phased array antenna in one enclosure and the equipment in a separate one.

7.1.6 The display console of the PAR is generally located in a control tower or approach room. The video and control signals are transmitted between these two sites by the use of appropriate cables, either using analogue or digital techniques.

7.1.7 The PAR operator obtains the azimuth, elevation and distance information from the radar display and, through radiotelephone contact, provides guidance to the pilot so that a correct approach path can be followed. Guidance is provided on a "talk down" basis with the controller and pilot in continuous contact. Once the established minimum for the runway has been reached, the pilot completes the landing visually.

Airborne user equipment

7.1.8 There is no airborne equipment requirement for PAR to generate guidance information for the controller as the ground equipment relies on passive signals reflected from the aircraft skin. To use PAR, radio communication with air traffic control on the designated frequency at the airport is required.

Factors affecting PAR performance

7.1.9 The PAR employs directive scanning antenna systems, which do not rely on ground reflections in the formation of the radiation pattern. The condition of the terrain near the PAR can affect signal accuracy as with some other navigational facilities due to reflected multipath. The surrounding terrain is an important factor, as a ground reflection or a shadow effect can also create loss-of-aircraft-return in the ground clutter on the display or loss of line-of-sight to the aircraft.

7.1.10 The accuracy of the PAR depends significantly on the equipment design as it affects the read-out resolution of azimuth, elevation and distance. In addition, the ability of the radar to distinguish between two targets in close proximity is of prime importance. Similarly, the size of the displayed return on the display will affect the ability of the controller to resolve the aircraft's position. Accuracy can also be affected by the system settings chosen by the controller, such as rain/ground clutter filters and, for digital systems, the setting of the target size.

7.1.11 The flight testing and calibration of the PAR is of prime importance to the quality of the PAR. Great care should be taken during flight testing, and subsequent maintenance and adjustment on a regular basis should be such as to assure continued accurate operation.

Testing requirements

7.1.12 A summary of testing requirements is given in Table I-7-1.

7.2 GROUND TESTING

General

7.2.1 While this chapter outlines certain scheduled tests, which should form part of the maintenance routine, the need for non-scheduled maintenance due to failure or to suspected deterioration will periodically occur. Regular and conscientious scheduled maintenance will ensure the high level of availability required of the system and minimize non-scheduled maintenance.

7.2.2 Since the operation of the PAR involves an air traffic controller, it is important that this person be satisfied and confident in the operational validity of the equipment performance. Should conflict exist between the technical criteria and operational confidence, prompt action should always be taken to verify the system and resolve questionable factors.

Ground performance parameters

7.2.3 Ground testing of a PAR requires that certain tests be done periodically. The following text presents general performance tests that may be used. These should be modified to conform to the specific manufacturer's recommendations, tolerances, and experience with the specific equipment being maintained. Note the tests are specified for analogue systems. Manufacturer recommendations should be followed for modern digital PAR systems.

Ground test procedures

General

7.2.4 The ground test procedures described here are in general terms for analogue systems. Detailed test procedures should conform to the manufacturer's equipment manuals and will tend to vary considerably with the equipment being tested.

Procedures (analogue systems only)

7.2.5 *Panel meter readings.* The equipment is usually provided with front panel meters or computerized read-outs that allow regular checking of power supply and other voltages, as well as selected current figures for important circuits. These readings should be recorded and analysed to detect gradual changes in circuit performance and indications of possible future failures. Any out-of-tolerance readings obtained should be investigated and corrected.

7.2.6 *Transmitter power output.* Many PAR transmitters have included a power monitor unit that allows direct measurement of average RF power output. As the power is affected by the pulse width and pulse repetition frequency (PRF), these two tests should be carried out at the same time. If a power monitor unit is not part of the equipment, it will be necessary to have a power meter and associated thermistor mount, wave-guide coupler and variable attenuator to make this measurement.

7.2.7 *Transmitter pulse width.* The transmitter pulse width is measured using an oscilloscope triggered from the PAR trigger pulse with a calibrated time base of approximately 5 μs/cm. The detected pulse output from the transmitter is fed to the vertical input of the oscilloscope and a suitable vertical sensitivity position selected to produce near full vertical scale deflection. The pulse width is measured between the 50 per cent levels at the leading and trailing edge of the pulse.

7.2.8 *Transmitter PRF.* After measuring the pulse width, the oscilloscope time base is switched to a position suitable for measurement of the PRF. For instance, for a PRF of 3 850 pp/s, 260 μs between pulses, a time base of 50 μs/cm would be suitable. The PRF is measured between the 50 per cent levels of two successive pulses.

7.2.9 *Waveform measurements.* The waveforms at the various test points indicated on the equipment can be a valuable source of information regarding the equipment operation. These waveforms should be viewed on the oscilloscope and compared to the expected waveform. The correct setting for the oscilloscope will vary with the waveform and equipment. Normally, it will be necessary to trigger the oscilloscope from the PAR trigger pulse.

7.2.10 *Transmitter frequency.* A wave meter used in conjunction with a suitable indicating device, or a digital counter, may be used to measure transmitter frequency. A signal is obtained from the waveguide coupler, passed through the wave meter and after amplification (if necessary) is viewed on an oscilloscope. As the wave meter is tuned through its band, the display signal is viewed to detect minimum signal (some wave meters display maximum signal). As the minimum is reached, the transmitter frequency is read off the wave meter dial, applying any correction necessary. If the transmitter is off-frequency, it will be necessary to retune the magnetron.

7.2.11 *Receiver performance.* The operation of the receiver is usually characterized by two basic checks, noise figure and minimum discernible signal (MDS).

a) The noise figure is checked with the aid of a noise source and a noise meter. The noise source is inserted into the receiver at an appropriate point in the waveguide (through a waveguide switch) and the output of the IF amplifier applied to the noise meter. The noise source and meter must be compatible and the calibration of the noise meter carried out as per the manufacturer's instructions.

b) The MDS of the receiver system is measured by injecting a known signal level into the receiver through appropriate attenuators and measuring the point at which the IF output pulse disappears into the noise. The attenuation between the signal source and the receiver is increased until the signal at the output of the IF amplifier just disappears. The input signal level could be determined by use of a power meter and the attenuation can be read from the attenuator dial. The resulting input MDS level can then be determined.

7.2.12 *Local oscillator tuning.* The local oscillator (often a klystron oscillator) must be tuned to a frequency higher (in some cases lower) than the transmitter frequency by an amount equal to the centre frequency of the IF amplifier. For a typical IF of 60 MHz, the local oscillator tuning of 9 140 MHz would be required for a PAR operating frequency of 9 080 MHz.

a) The local oscillator tuning is checked using a test signal provided by a sweep frequency oscillator centred on the transmitter frequency. In some cases, the wave meter is used to centre the sweep generator.

b) Initially, the test signal is viewed on an oscilloscope and the swept pulse adjusted by use of a wave meter to be centred on the proper transmitter frequency. The centre frequency, as indicated by the wave meter, will appear as a dip in the wide pulse. When the dip is centred, the test signal is adjusted correctly.

c) The test signal is then injected into the receiver and the IF output viewed on the oscilloscope. The local oscillator is tuned from one end of its range to the other watching for two output responses, above and below transmitter frequency. The oscillator is then tuned for maximum output at the correct frequency above (or below, if so designed). Note that the notch in the pulse is still centred. When the output is maximum and the notch is centred, the local oscillator is correctly tuned.

d) After this procedure, the noise figure should be checked to ensure optimum performance.

7.2.13 *Automatic frequency control (AFC) tuning.* The AFC tuning ensures that the local oscillator will follow a change in transmitter frequency (within limits) so that the receiver will continue optimum operation. The AFC may be checked by viewing the IF output signal and slightly detuning the magnetron to each side of its optimum position. The AFC circuits should produce a corresponding shift in the local oscillator so that no effect is noted in the IF output. The extent of detuning that the AFC will follow depends on the equipment design and the criteria given in the manufacturer's instructions.

7.2.14 *Receiver noise level.* The voltage level of the noise ("grass") at the output of the IF amplifier is usually specified. This level is set by viewing the IF output on an oscilloscope and adjusting the appropriate controls. If sensitivity time control is provided on the equipment, its operation in eliminating the noise over the appropriate ranges may be checked at this time.

7.2.15 *Receiver bandwidth.* The receiver bandwidth may be checked using the same set-up as for the local oscillator tuning, provided suitable frequency markers are available on the sweep generator. When the local oscillator has been tuned to provide the correct pulse from the IF amplifier, the marker pulses are superimposed and adjusted until they coincide with the 3 dB points on the IF pulse. The difference in frequency between the marker pulses represents the bandwidth.

7.2.16 *Observing the PAR display.* The daily observation of the PAR display should include a check on the operation of all console controls, adequacy of the presented picture, accurate superimposition of the up and down scan frames, the presence of all range, elevation and azimuth marks and the condition of the cathode ray tube.

7.2.17 *Console high voltage check.* This check is carried out using a vacuum tube voltmeter (VTVM) and a high-voltage probe. Due to the high voltage present (approximately 15 kV), the check should be carefully done by switching off the high voltage before connecting the probe. If the reading of high voltage is not correct, it should be adjusted accordingly.

Inspection and modifications (applicable to both analogue and digital systems)

7.2.18 Periodic inspection of the PAR facility should be conducted to ensure that local maintenance staff are complying with directives and providing an adequate level of maintenance. This is also desirable from the point of view of keeping current with field experience with the equipment, so that problems can be investigated and corrected. The repeated requirement for adjustment or repair of some features of the PAR equipment may be an indication that modification is required. States should be prepared to approve standard modifications once they have been shown to improve operation or serviceability.

7.2.19 Reserved.

Test equipment

7.2.20 Usually the PAR equipment will have built-in test equipment for those tests peculiar to the equipment. In addition, the following will usually be required:

a) oscilloscope (wide band);

b) noise source;

c) noise meter;

d) spectrum analyser;

e) power meter, with associated thermistor mount;

f) waveguide coupler and attenuator;

g) wave meter;

h) test signal generator (swept);

i) voltmeter with HV probe; and

j) additional equipment as specified for digital systems by the PAR manufacturer.

7.3 FLIGHT TESTING

General

7.3.1 Although there are a number of flight test procedures used for PAR, the method described here will be the "visual flight testing procedure". This method requires a minimum of special equipment and can be carried out by personnel with a minimum of training when using methods other than a theodolite. Other methods include using modern flight inspection systems which do not require the need to have an additional person on the ground tracking the aircraft position.

7.3.2 *Ground personnel requirements.* The following personnel are required on the ground:

a) one controller to monitor the radar console; and

b) if theodolite is used, one technician to carry out the functions required from the theodolite. The technician, as the theodolite operator, is required to track the flight check aircraft with the crosshairs of the instrument to monitor the elevation or azimuth vernier scales and advise the pilot of the aircraft's position in relation to the glide path or the centre line of the runway and record the deviations. A series of "fixes" may be called out by the theodolite operator providing the readings to the on-aircraft system operator or dedicated PAR controller who can correlate the results with the PAR display.

Flight test performance parameters

7.3.3 Flight test requirements are listed in Table I-7-3.

Flight test procedures (using ground theodolite operator)

General

7.3.4 The general procedure is as follows:

1) The controller vectors the aircraft and provides initial guidance instructions to establish the aircraft on the runway centre line and the glide path, if possible, at a distance greater than 18.5 km (10 NM) from touchdown.

2) The controller continues using a talk-down procedure until the theodolite operator has made contact with the aircraft through theodolite.

3) Contact should be made before the aircraft reaches the distance of 11 km (6 NM) from touchdown. Under some conditions, it helps to have the aircraft approach lights turned on during the approach.

4) After the theodolite operator has contact, the pilot is provided with azimuth or elevation deviation in degrees every half-mile during the remainder of the approach.

5) The controller provides the indication as the aircraft passes each half-mile.

6) During the descent, the pilot uses the theodolite deviations to assist in maintaining the aircraft on path.

7) The controller and theodolite operator simultaneously record the aircraft's position on the console display and as seen by the theodolite.

8) After completion of the approach, the PAR errors may be calculated using this information.

Azimuth flight test

7.3.5 The procedures are as follows:

a) Locate the theodolite on the extended centre line of the runway, a safe distance off the approach end, carefully level and zero it accurately along the centre line.

b) Locate the radio unit near the theodolite to allow easy operation by the theodolite operator.

c) Incline the theodolite at the glide angle.

d) The controller at the console should now vector the aircraft at an appropriate altitude so that the aircraft will be positioned for a straight-in approach, if possible, at least 10 NM from touchdown.

e) The controller begins the talk-down so that the aircraft can establish the correct rate of descent and azimuth heading.

f) When the aircraft becomes visible to the theodolite operator, the operator begins tracking the nose of the aircraft and reading out the position of the aircraft every half-mile during the approach. The controller alerts the theodolite operator as each half-mile is crossed.

g) The aircraft deviations are read from the theodolite to an accuracy of 0.01 degree, if possible. For example, if the aircraft is on course, the operator will report 0.00 degree, if the aircraft is to the right of centre line the operator reports 0.02 degree and, if the aircraft is to the left, he reports 0.98 degree.

h) During the run, the pilot attempts to retain a suitable rate of descent so that the aircraft will remain within the field of vision of the theodolite. The pilot will also alter course in accordance with the indications from the theodolite so that the aircraft will remain as nearly as possible on course.

i) The approach is broken off when the aircraft is over the end of the runway and control reverts to the controller to position the aircraft for the next approach.

j) During the approach, the controller and the theodolite operator record, on a suitable form, the aircraft position with respect to the runway centre line every half-mile from the distance of 18.5 km (10 NM). This information is used later to calculate the PAR errors.

Glide path flight test

7.3.6 The procedures are as follows:

a) Locate the theodolite on the side of the runway towards the approach end, such that the optical plane of the instrument will pass through the touchdown point when inclined at the glide path angle. Since the instrument is higher than the touchdown point, it should be positioned in the direction of the approach end of the runway and the appropriate number of metres (feet) from the touchdown point. For a glide path angle of 2.5 degrees, the theodolite would be moved 7 m (23 ft) for every 0.3 m (1 ft) difference in height.

b) Locate the radio near the theodolite to allow easy operation by the theodolite operator.

c) Carefully level the theodolite, align it parallel to the runway centre line, and incline it at the desired glide angle.

d) The controller at the console should now vector the aircraft at an appropriate altitude so that the aircraft will be positioned for a normal approach, if possible, at least 18.5 km (10 NM) from touchdown.

e) The controller begins the talk-down so that the aircraft can establish the correct rate of descent and glide path heading.

f) When the aircraft becomes visible to the theodolite operator, the operator begins tracking the nose of the aircraft and reading out the position of the aircraft every half-mile during the approach. The controller alerts the theodolite operator as each half-mile is crossed.

g) The aircraft deviations are read from the theodolite to an accuracy of 0.01 degree, if possible. For example, for a glide angle of 2.5 degrees the operator will report 2.50 degrees when the aircraft is on path, 2.52 degrees when the aircraft is above path and 2.48 degrees when the aircraft is below path.

h) During the run, the pilot is required to remain in line with the extended runway centre line so that the aircraft will remain within the field of vision of the theodolite. The pilot will also alter the rate of descent in accordance with the indications from the theodolite so that the aircraft will remain as close as possible on the glide path.

i) The approach is broken off when the aircraft is over the end of the runway and control reverts to the controller to position the aircraft for the next approach.

j) During the approach, the controller and the theodolite operator record, on a suitable form, the aircraft position with respect to the runway centre line every half-mile, if possible, from 18.5 km (10 NM). This information is used later to calculate the PAR errors.

Coverage check

7.3.7 The coverage of the PAR facility can easily be confirmed during the azimuth and glide path flight tests. Coverage checks require solid returns from an aircraft with a reflection area of 15 m^2 (165 ft^2) and should be obtained from a distance of 16.7 km (9 NM) and an altitude of 300 m (1 000 ft) above intervening terrain. For aircraft having different surface reflection areas, the coverage requirements should be modified accordingly.

Resolution tests

7.3.8 The ability of the PAR to resolve two aircraft in close proximity cannot practically be flight-tested. This is a prime factor in the design of the equipment; it will normally be sufficient for the controller to evaluate the quality of successive returns from the aircraft during the flight test to ensure that the resolution in elevation, azimuth and distance is satisfactory. The factors that should be considered during this evaluation are size and clarity of displayed return, speed and direction of aircraft travel and distance between successive returns on the display.

Flight test analysis and report (theodolite method)

7.3.9 Data from the controller, pilot, and theodolite operator should be entered on a suitable form.

7.3.10 The inspector should record the following information during the flight test:

a) the altimeter reading each time the controller reports the aircraft's range;

b) the accuracy of the range information; and

c) the accuracy of the azimuth information provided by the PAR.

Note.— Both b) and c) above can be checked for gross errors by the inspector with the aid of visual references to geographical landmarks indicated on a specially prepared chart.

7.3.11 Following the flight test, the theodolite deviation should be converted to metres or feet so that the PAR error may be calculated. Each theodolite deviation for azimuth and glide path is converted and recorded in the appropriate column of the report form. The PAR error for both azimuth and glide path can then be calculated by combining the displayed deviations recorded by the controller and the theodolite operator.

7.3.12 After the above has been completed, the controller, inspector and theodolite operator review the results and jointly certify the facility, providing it is within tolerance. Copies of the report form are distributed in accordance with States' normal practices.

Charts and reports

7.3.13 *Report forms.* The regular maintenance visits to the PAR equipment should be suitably recorded using appropriate forms to record performance and deviations from normal. These reports should be reviewed periodically to determine stability and to anticipate problems that may be developing. These reports may also serve to indicate weaknesses in the equipment, which should be overcome through engineering changes.

7.3.14 The flight testing of a PAR facility should be documented using appropriate forms, which along with the above-mentioned maintenance form, represent a continuous record of the accuracy and performance of the PAR.

7.3.15 *Chart for flight testing.* The pilot of the test aircraft should have a chart of the approach area of the runway to be tested showing the runway, extended centre line, distances every 0.9 km (0.5 NM) from touchdown, and identifying landmarks along the flight path.

Test equipment

7.3.16 *Aircraft.* Although it is not necessary to utilize a special aircraft for the flight testing of PAR, it is highly desirable that the aircraft used be specially designated for this work and that it be piloted by a competent flight inspection pilot who is familiar with PAR talk-down procedures (i.e., ground controlled approach (GCA) procedure). The flight inspection aircraft may have automatic data recording systems that allow direct measurement of the aircraft position without the use of a theodolite placed on the ground. Such systems may be augmented by ground reference equipment that operate in an automatic mode (e.g. differential GPS ground stations).

7.3.17 *Special equipment.* A theodolite suitably modified to accurately read the displacement in azimuth and elevation of the flight test aircraft from the desired approach path may be required if automatic digital flight inspection systems are not employed. This can be provided by vertical and horizontal vernier read-outs on the theodolite to allow angular displacement to be determined to the nearest 0.01 degree. However, in keeping with the magnitude of PAR errors, an accuracy of 0.05 degrees is usually considered adequate.

7.3.18 *Communications.* Radio communications is required between the controller at the console and the aircraft pilot and between the theodolite operator and the pilot. The theodolite operator should also be capable of monitoring the controller's communications with the pilot.

Positioning

7.3.19 Positioning information may be achieved by several methods, including theodolite, radio telemetering theodolite, or an automatic airborne positioning system (automated flight inspection system). Any positioning system that is used but not described in this chapter will require specific instructions for use that may be obtained from the manufacturer of the equipment. An assessment of the measurement uncertainty of the system employed should be carried out to ensure it is commensurate with the requirements in Table I-7-3.

Table I-7-1. Summary of testing requirements for PAR

Parameter		*Annex 10, Volume I, reference*	*Testing*
Coverage		3.2.3.1	F
Accuracy		3.2.3.3	F
Azimuth		3.2.3.3.1	F
Elevation		3.2.3.3.2	F
Distance		3.2.3.3.3	F
Transmitter			
	Power output		
	Pulse width		G
	Pulse repetition frequency	N/A	G
	(PRF)		G
	Waveform		G
	Frequency		G
Receiver			
	Local oscillator		
	Automatic frequency control	N/A	G
	(AFC)		G
	Noise level		G
	Bandwidth		G
PAR display			G
	High voltage	N/A	G

Legend: F = Flight test/inspection
G = Ground tests

Table I-7-2. Reserved

Table I-7-3. Flight test requirements for PAR

Parameter	*Annex 10 Volume I, reference*	*Doc 8071, Volume I, reference*	*Measurand*	*Tolerance*	*Uncertainty*	*Inspection type*
Coverage	3.2.3.1	7.3.7	Distance	≥16.7 km (9 NM)	0.19 km (0.1 NM)	C, P
			Azimuth	20 º	1 º	
			Elevation	7 º	0.1 º	
Accuracy	3.2.3.3					C, P
Azimuth	3.2.3.3.1	7.3.5	Azimuth	0.6% of distance from PAR antenna + 10% of aircraft deviation, or 9 m (30 ft), whichever is greater (see Note).	3 m (10 ft)	
Elevation	3.2.3.3.2	7.3.6	Elevation	0.4% of distance from PAR antenna + 10% of aircraft deviation, or 6 m (20 ft), whichever is greater (see Note).	3 m (10 ft)	
Distance	3.2.3.3.3	7.3.5 7.3.6	Distance	30 m (100 ft) + 3% of distance to touchdown.	3 m (10 ft)	

Note.— In practice, it has been found that the following tolerances, although more stringent, are easily applied and attained:
Azimuth — 0.6 per cent of distance to PAR antenna;
Elevation — 0.4 per cent of distance to PAR antenna.

Legend: C = Commissioning;
P = Periodic (normally at least every 270 days)

Chapter 8

PERFORMANCE-BASED NAVIGATION (PBN)

8.1 INTRODUCTION

8.1.1 This chapter deals with the assessment and flight inspection of conventional navigation aids supporting instrument flight procedures which are not covered by the facility-specific chapters of this document. This concerns mainly the use of DME in supporting PBN. This chapter does not discuss flight validation because these are described in the *Quality Assurance Manual for Flight Procedure Design*, Volume 5 — *Validation of Instrument Flight Procedures* (Doc 9906). This does not preclude that the same organization which conducts flight inspection may also conduct flight validation. The use of global navigation satellite system (GNSS) to support PBN is addressed in Volume 2 — *Flight Procedure Designer Training (Development of a Flight Procedure Designer Training Programme)* of Doc 9906.

8.1.2 *Use of VOR for PBN*. The use of VOR in PBN is limited to VOR/DME supporting RNAV5. While multi-sensor avionics are normally capable of using VOR/DME for an RNAV solution, actual operational use is very limited.

8.1.3 *Use of DME for PBN*. Further guidance on the use of DME/DME to support RNAV is contained in Annex 10, Volume I, Attachment C, 7.2.3. The main role of DME in PBN is to support RNAV1 and RNAV5 as a complementary terrestrial infrastructure alongside GNSS.

8.2 GROUND ANALYSIS

8.2.1 *Infrastructure assessment for PBN*. VOR and DME are identified in the *Performance-based Navigation Manual* (Doc 9613) and in Annex 10, Volume I, Attachment H, as sensors which may support PBN operations and procedures. This may lead to VOR or DME signals being used in areas that are not normally flight inspected as part of the facility specific testing, since the link between PBN and its supporting infrastructure is less direct. If an air navigation service provider (ANSP) wishes to offer PBN procedures based on conventional facilities, an infrastructure assessment should be conducted to ensure that a minimum set of facilities is available which can be expected to support all equipped users.

Note.— Further guidance on navigation infrastructure assessment to support RNAV procedures is given in EUROCONTROL-GUID-0114 *(available at http://www.eurocontrol.int) and on the performance-based navigation (PBN) page of the ICAO website at http://www.icao.int/pbn*.

8.2.2 *Linking infrastructure assessment and flight inspection*. To support a particular PBN procedure using conventional radio navigation aids, the ANSP should perform an assessment to determine if sufficient facilities are available to support a given area or procedure with suitable geometry in accordance with the relevant PBN navigation specification. This may require reliance on facilities being used in areas where they are not normally flight inspected and where providing sufficient coverage (including accuracy) may be an issue. This assessment can be done with desktop software using a terrain and navigation facility database to determine coverage and resulting RNAV performance. If the assessment concludes that sufficient VOR or DME facilities are being relied on only in areas which are either part of facility-specific inspection or where performance can be expected to be good based on engineering judgement, no RNAV-specific flight inspection may be required. If the assessment concludes that there are areas where performance should be verified, the assessment should specify which facilities should be flight inspected in which areas. This normally concerns the use of facilities either at low altitudes (near line-of-sight taking into account terrain) or at extended ranges, where multipath and signal blockage are more prevalent. Because this may concern multiple facilities, the assessment should be used to plan the flight inspection in as efficient a manner as possible. Flight inspection results should be fed back into the infrastructure assessment. It may also be useful to note which DME facilities need to be operational to support a particular PBN procedure (when using conventional navigation aids).

8.3 FLIGHT TESTING

8.3.1 *Flight inspection parameters and procedures*. To evaluate if VOR or DME facilities are able to support PBN, both coverage (stable minimum field strength) and accuracy should be verified using the methods specified in Chapters 2 and 3. Additional parameters may be useful, such as reply efficiency in the case of DME. However, it must be noted that some of the parameter limits and associated measurement procedures have been defined only for radial or orbital flights. PBN specifications assume that the facility requirements in Annex 10 will be met, regardless of the orientation of the aircraft. If flight inspection of multiple facilities is needed (such as several DME), the use of multi-channel DME test sets is encouraged to reduce operational impact. When multi-channel DME measurement capabilities are used, it should be ensured that they provide sufficient information to indicate adequate signal coverage.

8.3.2 *Periodicity of PBN-specific flight inspection*. Once VOR and DME have been assessed and flight inspected where needed to show that they support a particular PBN procedure, there is normally no further need for periodic inspection in most environments. This assumes that safeguarding and/or appropriate facility-specific ground and/or flight testing is established to ensure the signals supporting the PBN procedure remain valid for use. If the navigation facilities supporting the procedure or the procedure itself changes, the need for renewed flight inspection should be assessed. However, if flight validation is performed with a flight inspection aircraft, it is good practice to also verify the signals of the associated navigation aids.

— END —