Final Report

for the

Uvionix Propeller Performance Measurement – Static Thrust

Rotorcraft Systems Engineering and Simulation Center

Contract Number: Uvionix 2017-001

Proposal Number: 2017-006

PoP: 10/15/2016 to 10/31/2016

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UAH Contract Title: C/Uvionix/Uvionix Aerospace UAV Propeller Characterization

UAH Org: 675427/2A149

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1. Scope

Uvionix Sky Revolution requested support from the University of Alabama in Huntsville's (UAH) Rotorcraft Systems Engineering and Simulation Center (RSESC) to execute static thrust testing on six small Unmanned Aerial Vehicle (UAV) propeller designs to verify propeller performance. This was a short-term research effort that used RSESC's in-house propeller testing and characterization equipment. This project focused on recording data per the test matrix which is shown in Table 1.

2. Testing Summary

2.1. Test Matrix

A total of 12 propeller and motor configurations were tested to collect data on static thrust, torque, non-dimensional coefficients, voltage, current, motor temperature at the end of each test, and the ambient conditions associated with each test iteration (Table 1). For the 900kV motors, planned test points for RPM ran from 6,000-10,000 RPM and included the maximum attainable RPM at 100% Pulse Width Modulation (PWM) signal. For the 1100kV motors, planned test points for RPM ran from 9,000-13,000 RPM and included the maximum attainable RPM at 100% PWM signal. Required thrust values from the customer ran from 400g to 1,000g. Some motor and rotor combinations were not able to attain the full range of RPM or thrust values. These combinations are annotated in the results section. All tests were conducted at 16V of motor input voltage. Each configuration was tested three times to verify the repeatability of the tests. Dynamometer calibration was verified prior to testing. All plotted data in the main body of this report and tabular data in the appendices shows the average value across the three iterations for each combination.

Table 1 - Static Thrust Testing Summary

ESC	Motor	Propeller	Measured Parameters										Test Points
Hobby Wing 40A ESC (minimum rating)	T-Motor MT 2216 V2.0 KV900	MAS MR 9x4.5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	**RPM:** 6,000-10,000, MAX RPM at 1,000 RPM Intervals; **Thrust:** 400g-1000g at 200g intervals
		MAS MR 8x4.5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
		APC MR 9x4.5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
		APC MR 8x4.5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
		Graupner 9x4	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
		Graupner 9x5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
	T-MOTOR MT 2216 V2.0 KV1100	MAS MR 9x4.5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	**RPM:** 9,000-13,000, MAX RPM at 1,000 RPM Intervals; **Thrust:** 400g-1000g at 200g intervals
		MAS MR 8x4.5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
		APC MR 9x4.5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
		APC MR 8x4.5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
		Graupner 9x4	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	
		Graupner 9x5	Static Thrust (g)	Torque (Nm)	Cp	Ct	Cq	Voltage	Current	End of Test Motor Temp	Ambient Temperature	Ambient Air Density	

3. Test Setup

The static thrust testing in this study used the following items to execute the test iterations:

1) RC Benchmark Series 1580 Dynamometer and RC Benchmark Google Application for test automation and data collection[1]
2) Extech Digital Psychrometer to measure dry bulb temperature and relative humidity
3) Volteq HY3080EX DC Power Supply (Outputs: 0-30V and 0-80A)
4) ASHREA Psychrometric Chart No. 1[2] for determining air density based on ambient conditions
5) FLIR i50 IR Thermometer for motor temperature measurements

The RC Benchmark Series 1580 Dynamometer directly measures torque, thrust, voltage, current, RPM, motor winding resistance, and accelerations due to vibrations. Derived parameters like coefficients of power, torque, and thrust are calculated by the automated test script based on propeller area, ambient conditions, and directly measured parameters. The design specifications of the RC Benchmark Series 1580 Dynamometer are shown in Table 2. The test script was configured for SI units, per customer input.

[1] https://www.rcbenchmark.com/product/rcbenchmark_dynamometer/
[2] ASHREA *2005 ASHREA Handbook Fundamentals,* SI Edition, Chapter 6, 2005. © American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

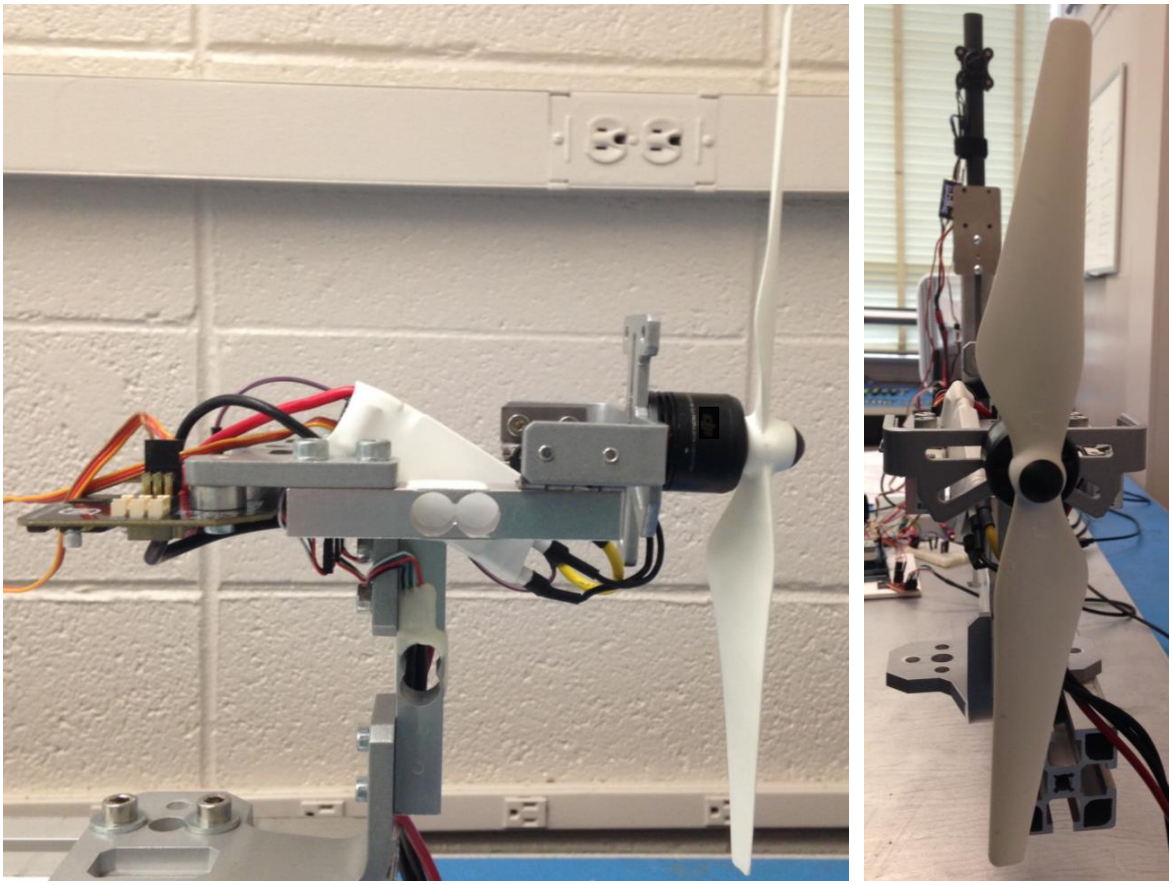

Figure 1 - RC Benchmark Series 1580 Dynamometer in Test Configuration

Table 2 - RC Benchmark Series 1580 Dynamometer Design Specifications[1]

Specification	Min.	Max.	Tolerance	Unit
Thrust	-5	5	0.5%	kgf
Torque	-1.5	1.5	0.5%	Nm
Voltage	0	35	0.5%	V
Current	0	40	1%	A
Angular speed*	0	190k	-	eRPM
Coil resistance	0.003	240	0.5%	Ohm
Digital scale	0	3	0.5%	kgf

*Electrical RPM, divide by the number of motor poles to obtain true mechanical RPM.

4. Test Report

The test results are broken out into four sections. First, the average test conditions are outlined. Two sections provide propeller performance plots based on data collected using the T-Motor MT2216 V2.0 KV900 motor, and then propeller performance plots based on data collected using the T-Motor MT2216 V2.0 KV1100 motor. Tabular data pertaining to the motor temperature, based on time of run at 100% test RPM is in the final section. Tabular data used to generate plots of the 900kv motor performance is in Appendix A: Tabular Results for 900kv Motor Tests, and tabular data used to generate plots of the 1100kv motor performance is in Appendix B: Tabular Results for 1100kv Motor Tests.

4.1. Test Conditions

Tests were conducted with ambient temperatures ranging from 25.5ºC – 26.8°C and air densities ranging from 1.16454 kg/m^3 - 1.1677 kg/m^3. Test iterations for any given rotor and propeller pair were conducted in rapid succession (less than 2 minutes' total time), and there were no observed fluctuations in ambient conditions during any single configuration. The exact ambient conditions for each test are shown in the tabular data in Appendix A: Tabular Results for 900kv Motor Tests and Appendix B: Tabular Results for 1100kv Motor Tests.

4.2. 900kv Motor Testing Results

None of the 900kv motor tests reached 14,000 RPM. Maximum RPM values reached during 900kv motor testing are shown in Table 3. The figures in this section contain all required test output data as per Table 1. All data points come from RPM values within ± 50 RPM of the target RPM values. RPM deviations are due to the lower precision of hobby-grade ESCs at high RPM where the rotor is spinning at rotational rates in excess of 166 rev/sec. All 900kv motor tests exceeded 10,000 RPM, per the customer requirements.

Table 3 - Maximum RPM Attained During 900kv Motor Testing

Propeller	Maximum Test RPM
MAS 9x4.5MR	10,151
MAS 8x4.5 MR	11,023
APC 9x4.5 MR	10,438
APC 8x4.5 MR	11,259
Graupner 9x4 C	11,161
Graupner 9x5 E	10,760

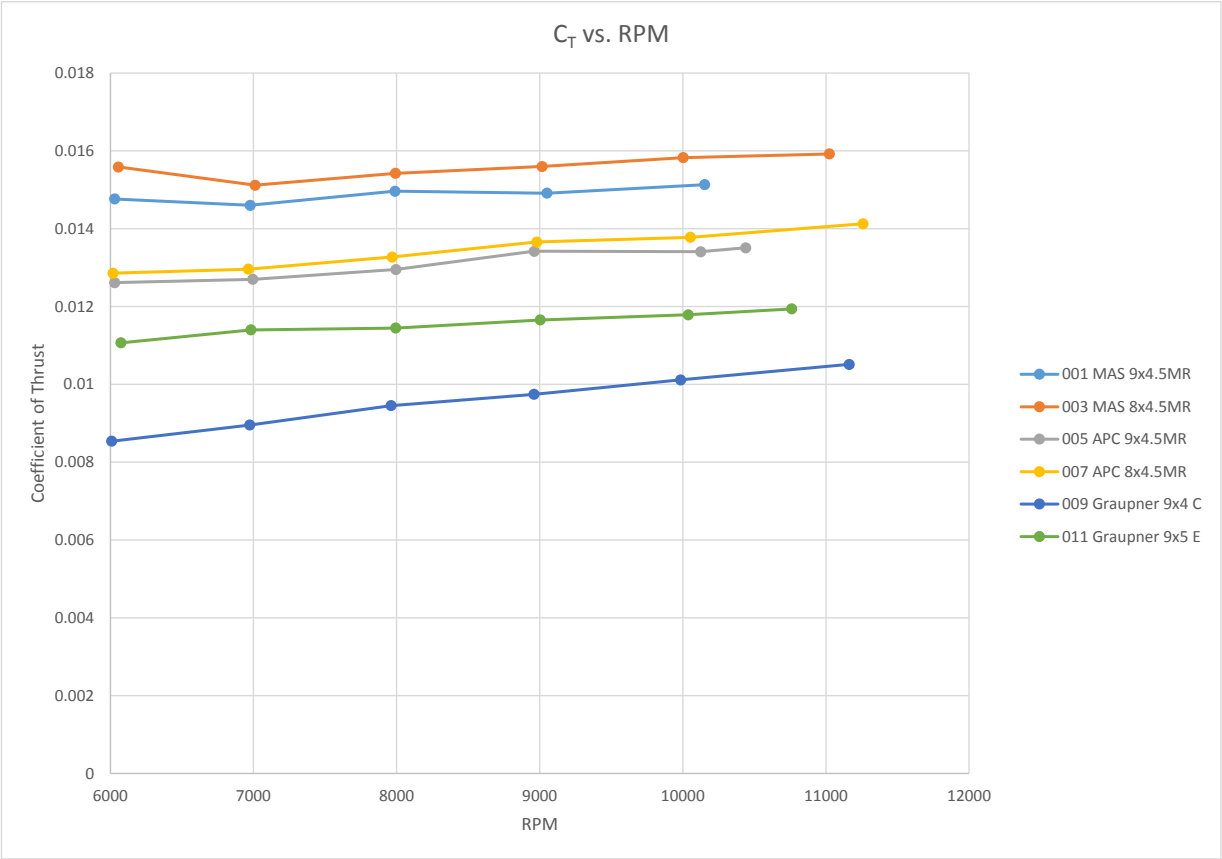

Figure 2 – C_T vs. RPM with 900kv Motor

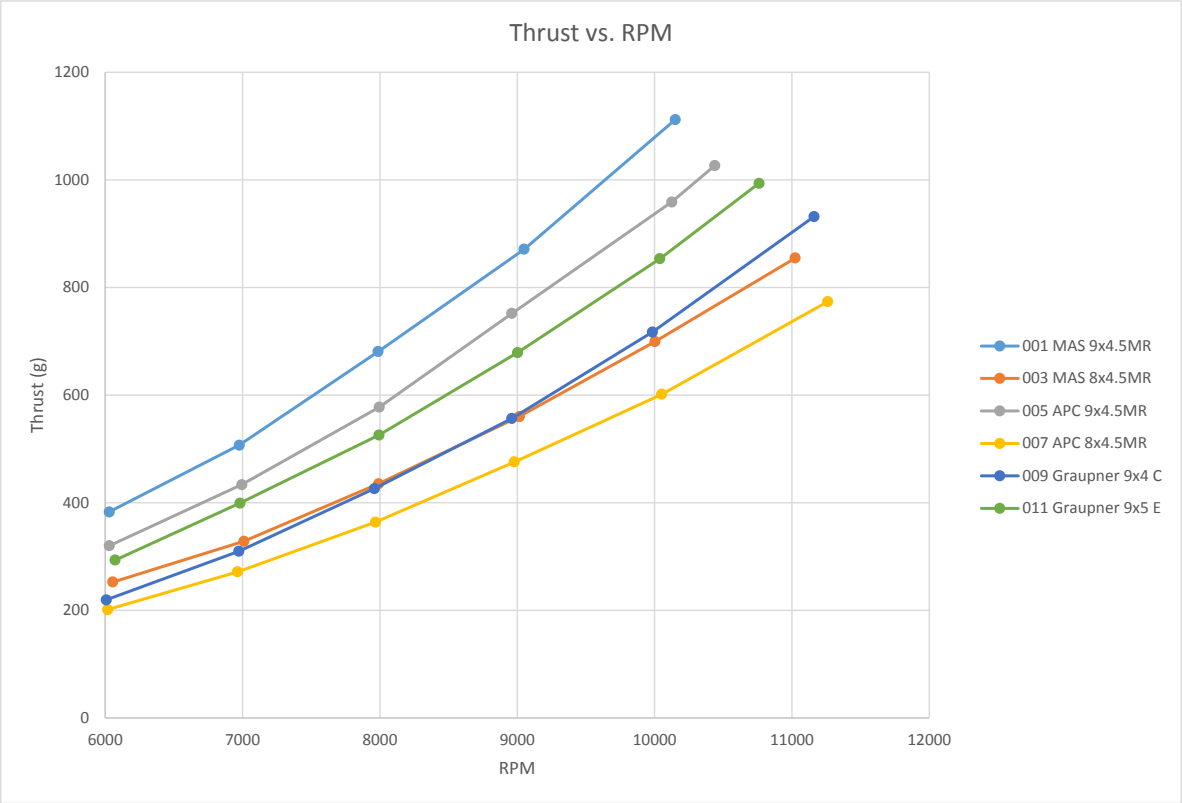

Figure 3 - Thrust vs. RPM with 900kv Motor

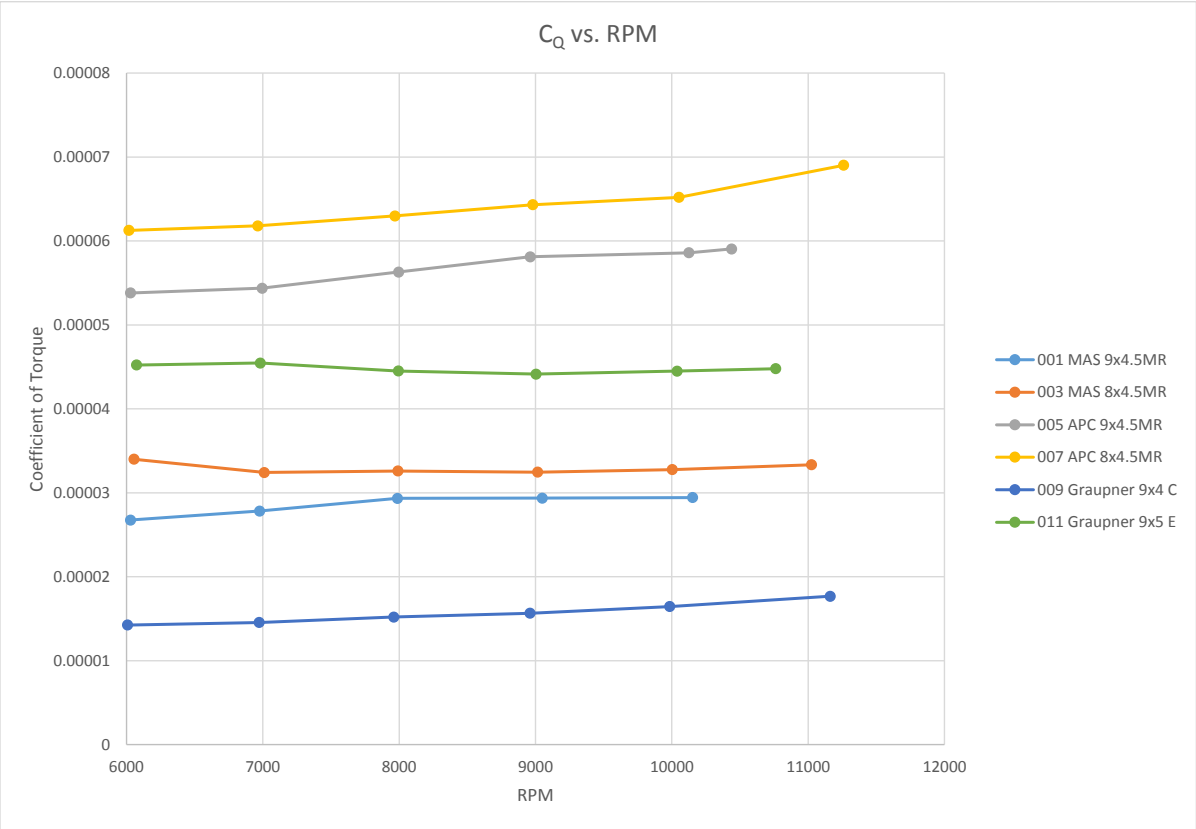

Figure 4- C_Q vs. RPM with 900kv Motor

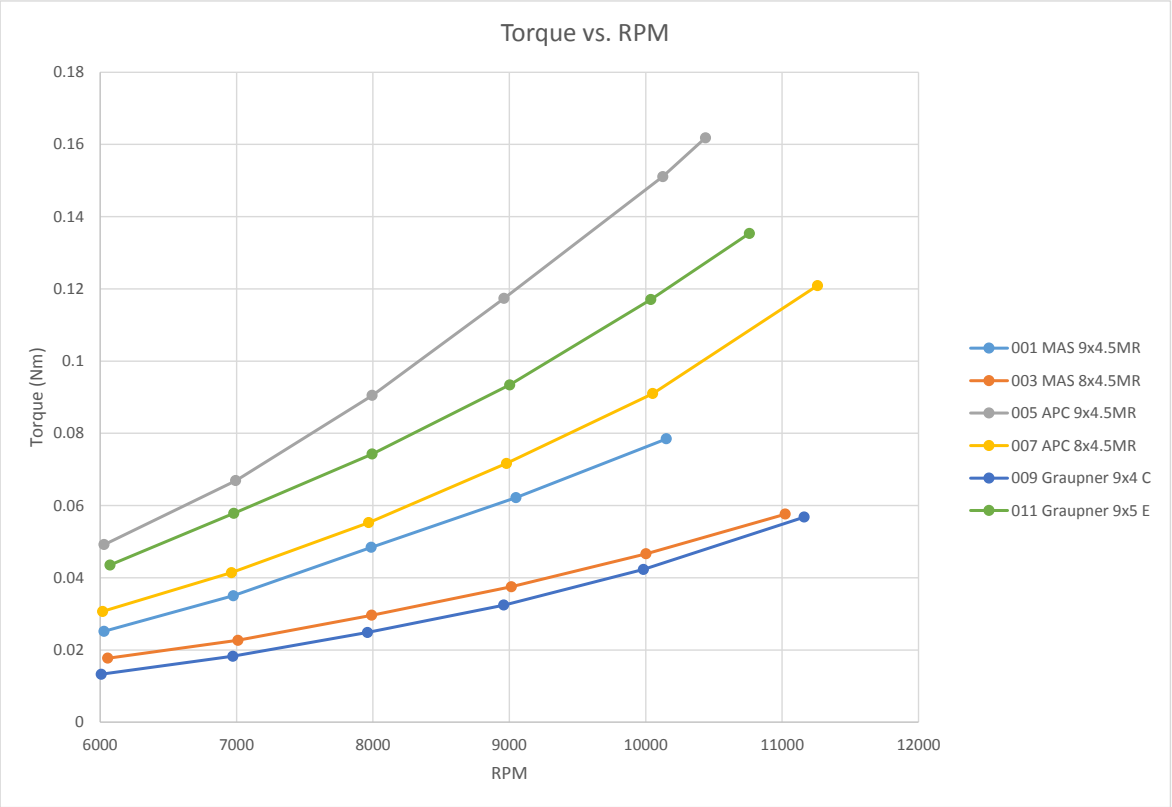

Figure 5 - Torque vs. RPM with 900kv Motor

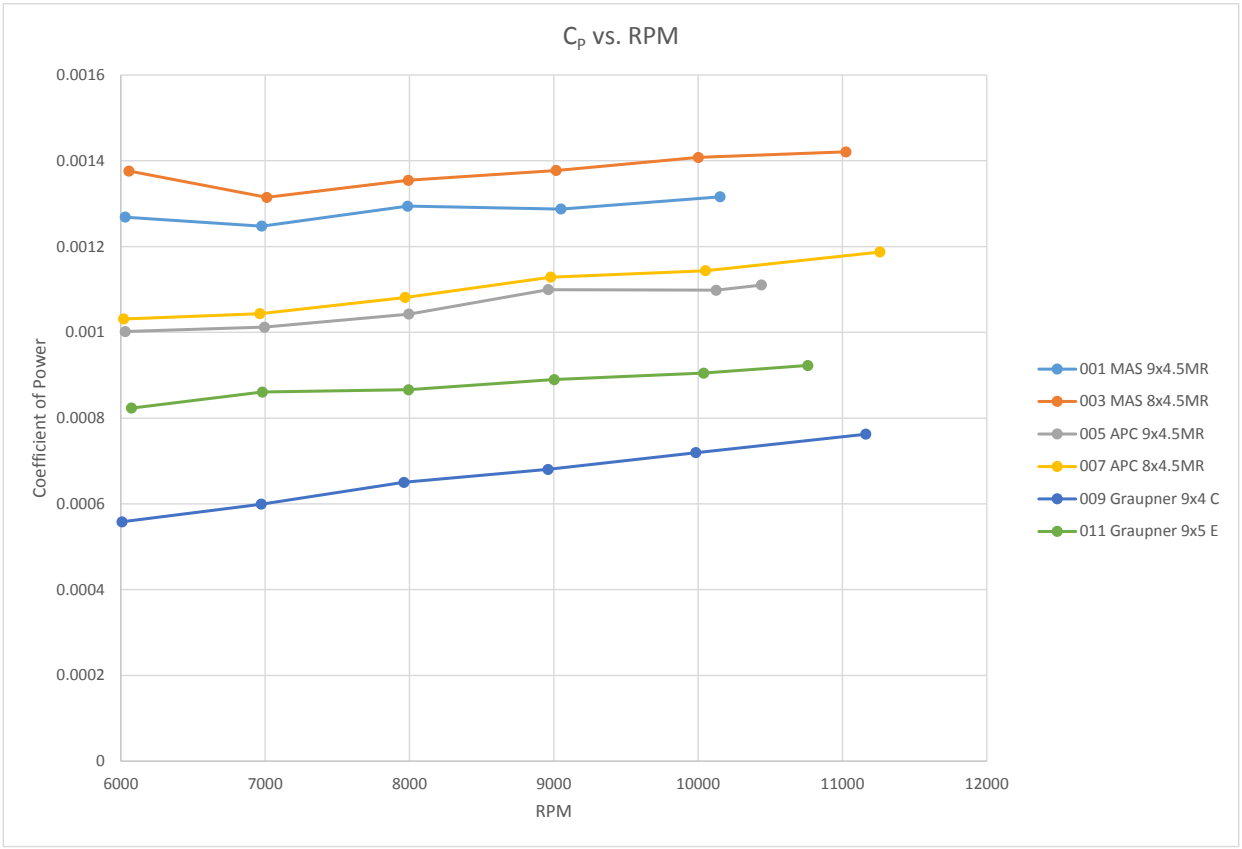

Figure 6 – C_P vs. RPM with 900kv Motor

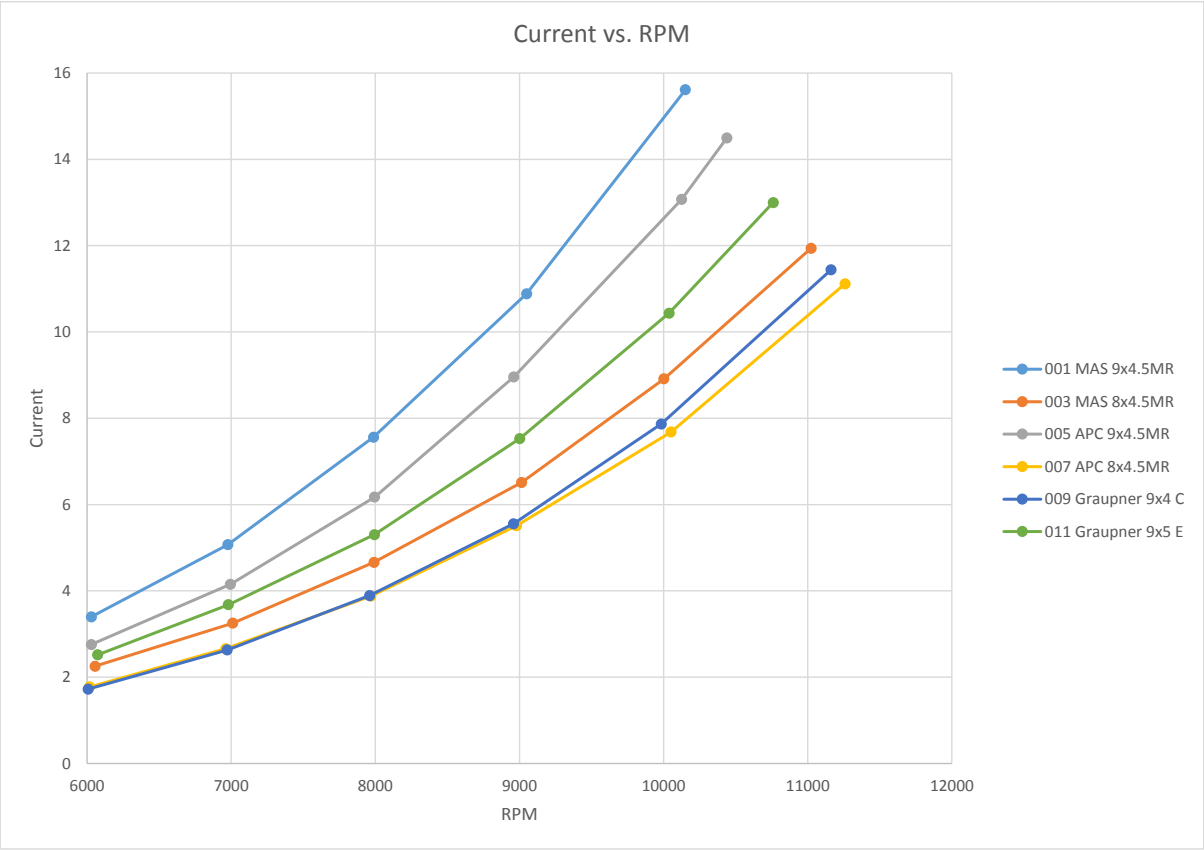

Figure 7- Current vs. RPM with 900kv Motor at 16.0V Input Voltage to the ESC

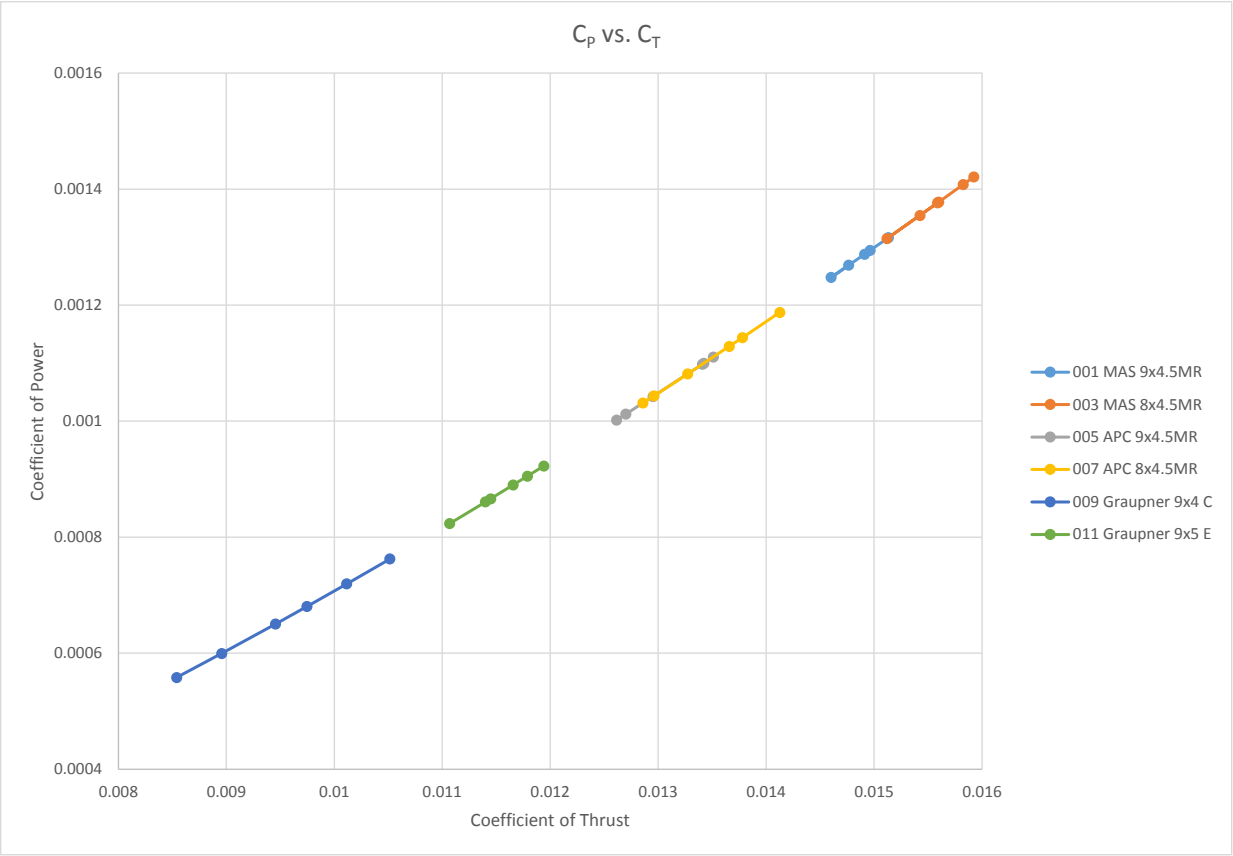

Figure 8 - C_P vs. C_T with 900kv Motor

4.3. 1100kv Motor Testing Results

None of the 1100kv motor tests reached 13,000 RPM. Maximum RPM values reached during 900kv motor testing are shown in Table 4. The figures in this section contain all required test output data as per Table 1. All data points come from RPM values within ± 50 RPM of the target RPM values. RPM deviations are due to the lower precision of hobby-grade ESCs at high RPM where the rotor is spinning at rotational rates in excess of 166 rev/sec. The RPM values in Table 4 are the highest values that the motor is able to attain with these propellers based on the tested 16.0V voltage supply. To achieve higher rates of rotation with these motor and propeller combinations, the supplied voltage must be higher.

Table 4 - Maximum RPM Attained During 1100kv Motor Testing

Propeller	Maximum Test RPM
MAS 9x4.5MR	11,383
MAS 8x4.5 MR	12,614
APC 9x4.5 MR	11,758
APC 8x4.5 MR	12,836
Graupner 9x4 C	12,680
Graupner 9x5 E	12,236

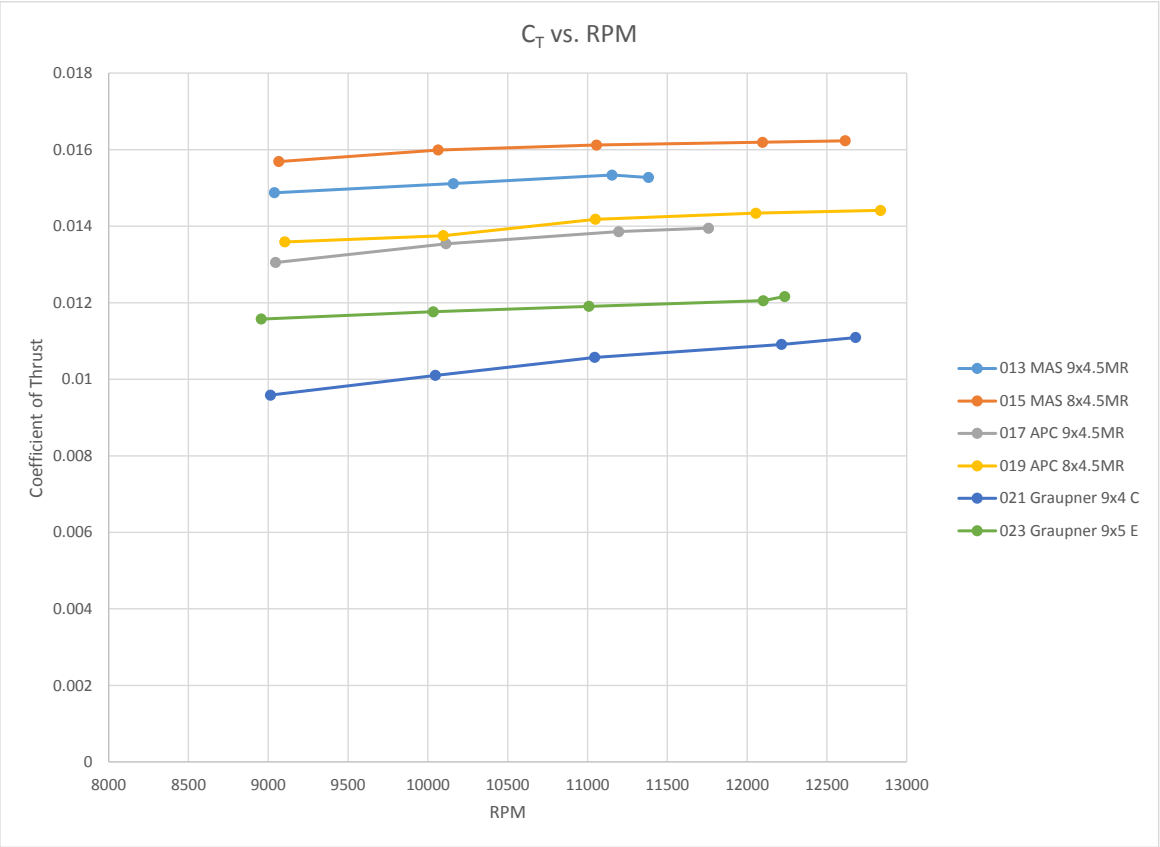

Figure 9 - C_T vs. RPM with 1100kv Motor

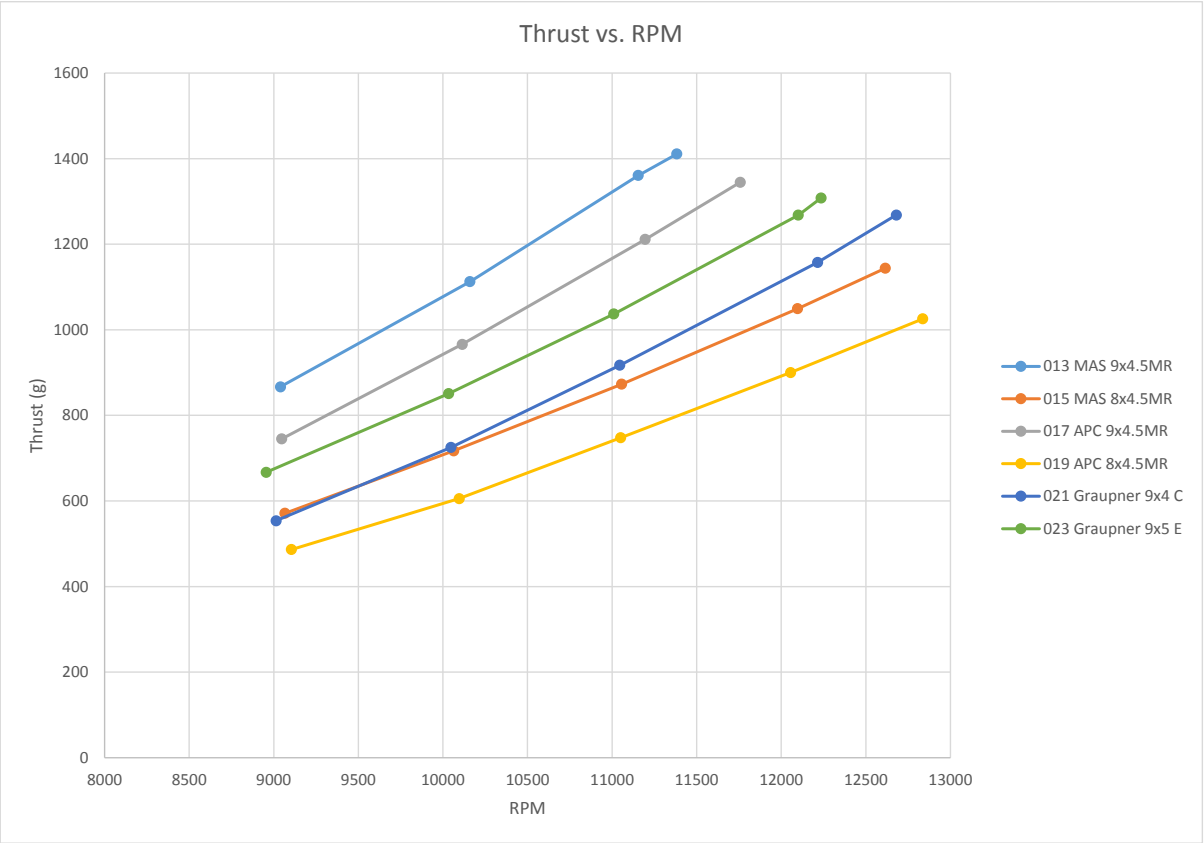

Figure 10 - Thrust vs. RPM with 1100kv Motor

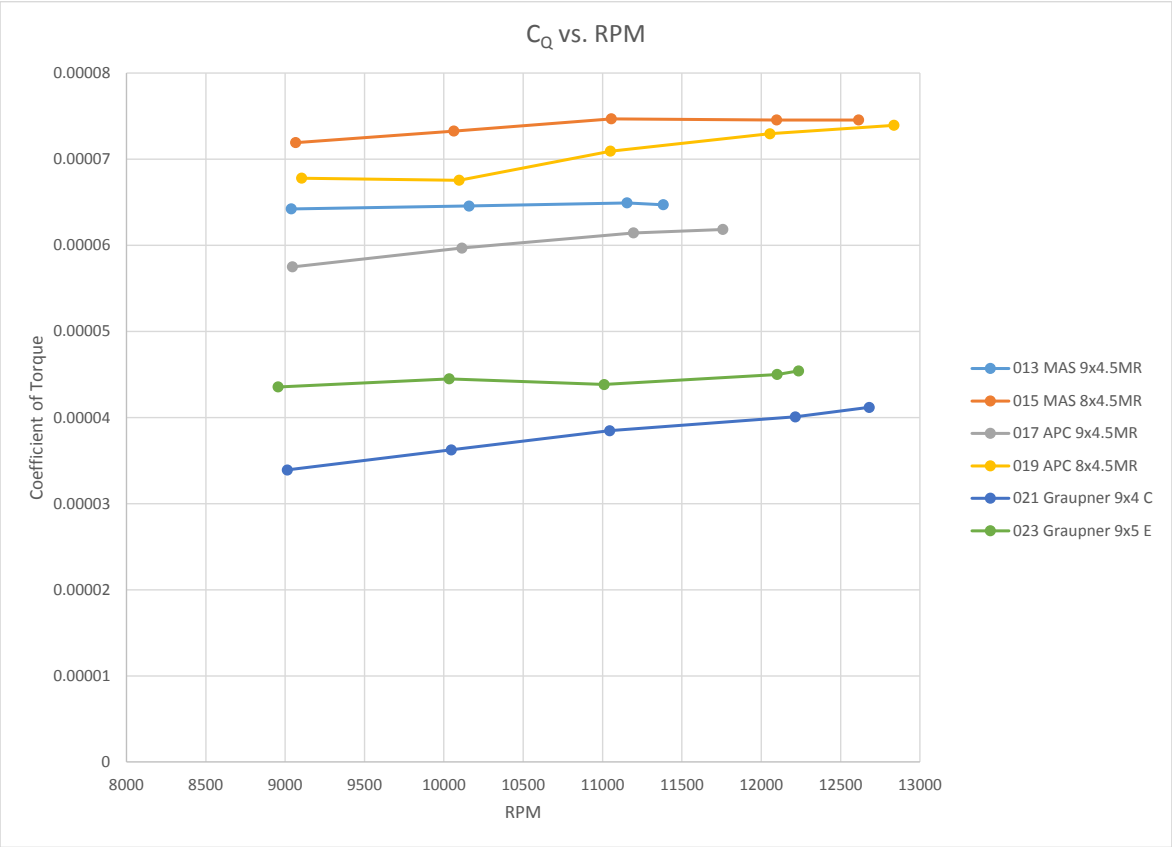

Figure 11 - C_Q vs. RPM with 1100kv Motor

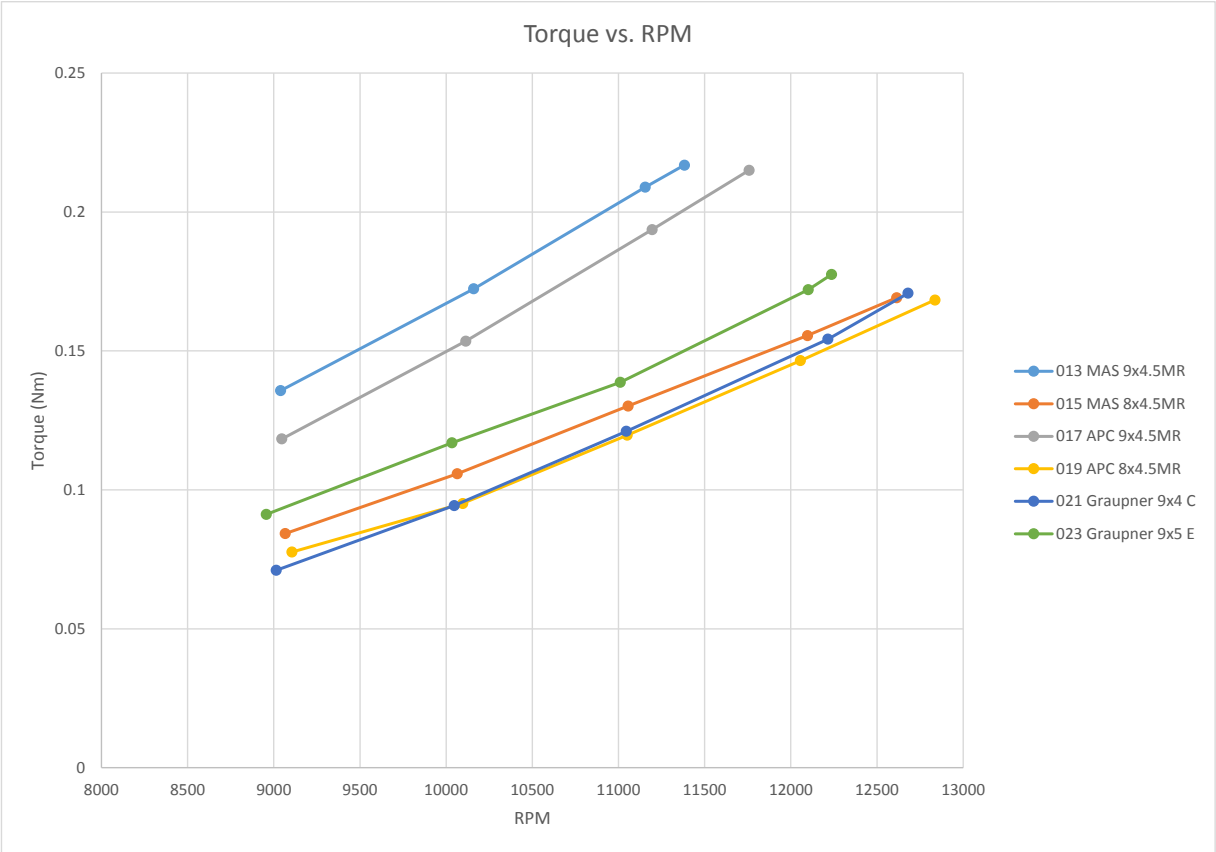

Figure 12 - Torque vs. RPM with 1100kv Motor

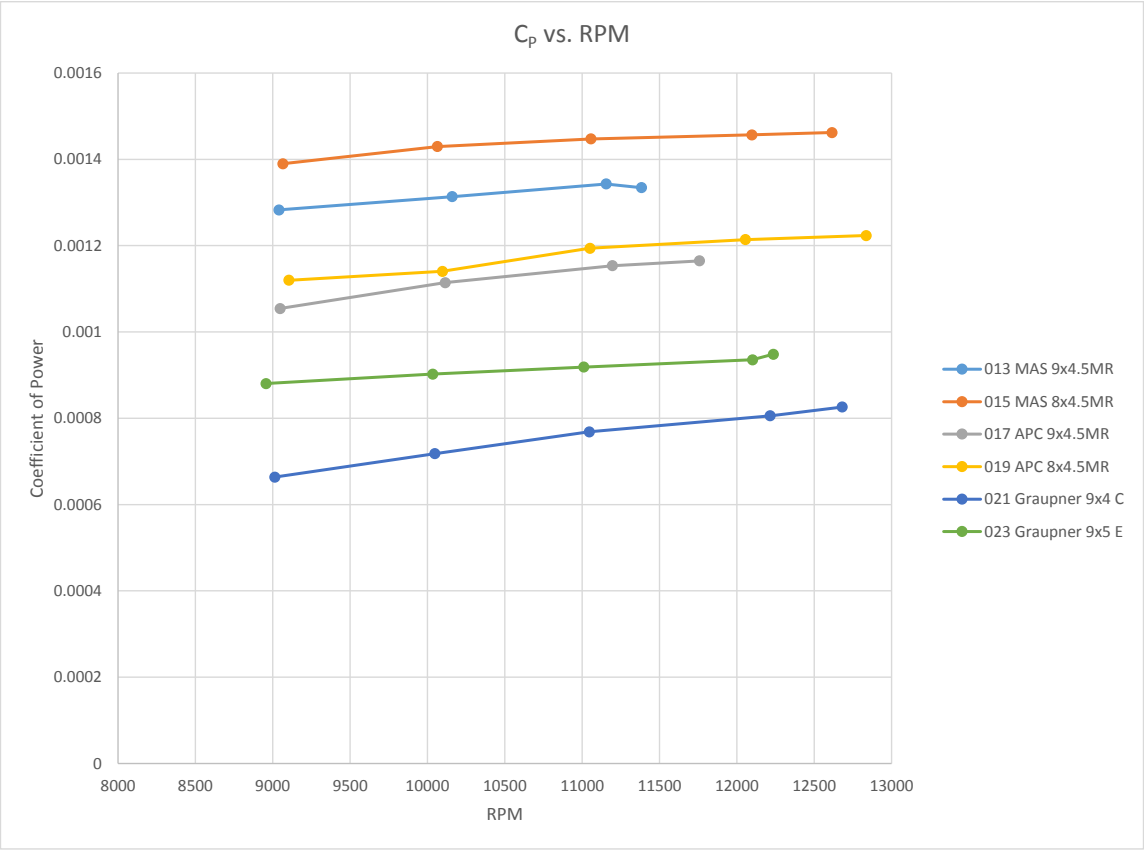

Figure 13 – C_P vs. RPM with 1100kv Motor

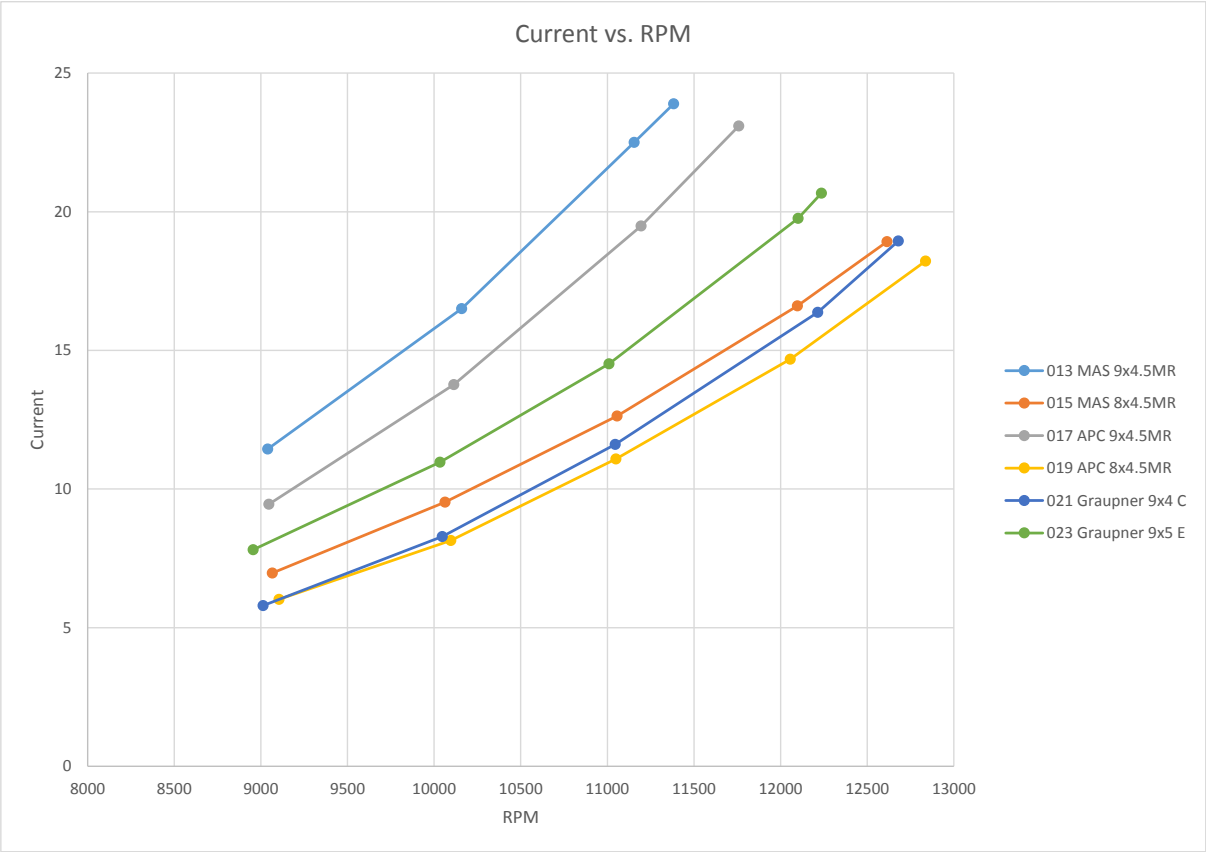

Figure 14 - Current vs. RPM with 1100kv Motor at 16.0V Input Voltage to the ESC

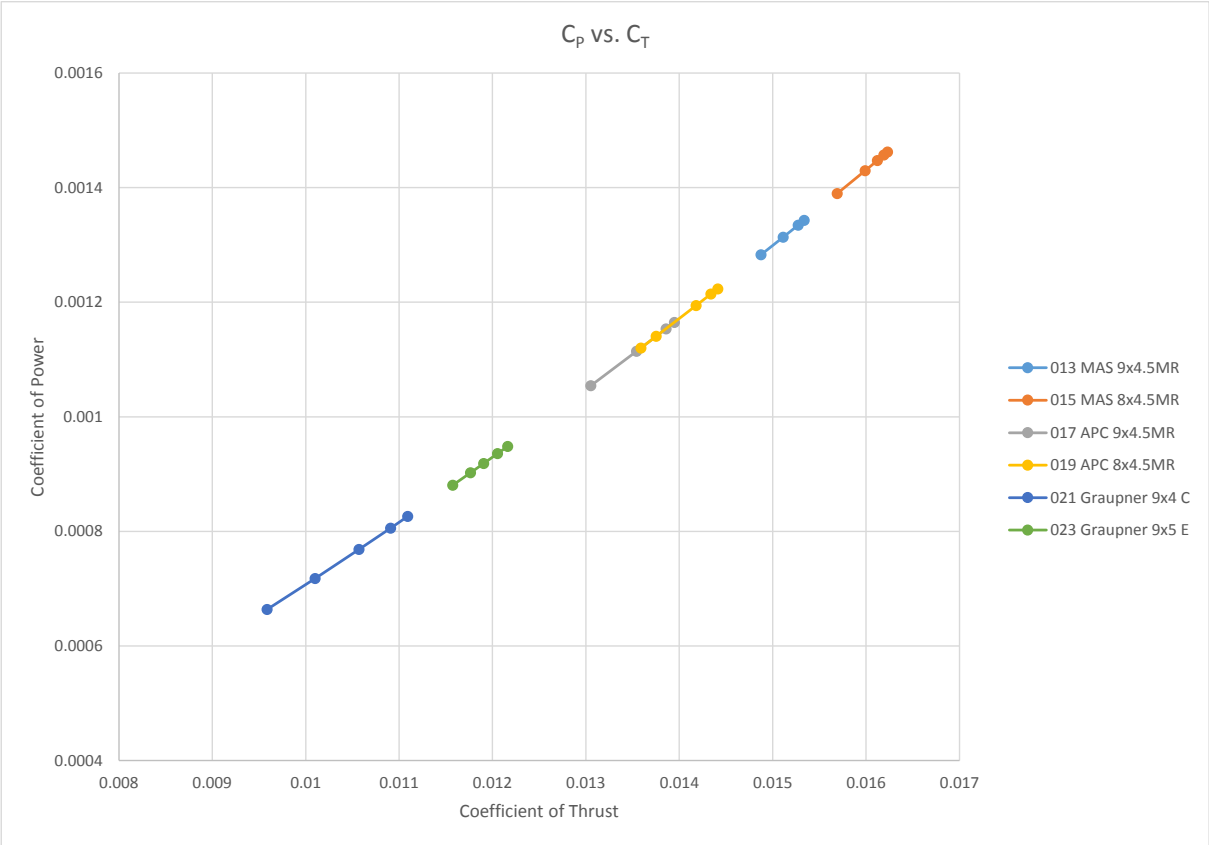

Figure 15 - C_P vs. C_T with 1100kv Motor