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Installed Thrust Measurements of Small Quadrotor Propellers

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The performance difference between isolated and installed propellers was investigated for various quadcopter platforms. Using a static testing rig and in-flight RPM measurements from a handheld tachometer, thrust losses during hover were quantified for six different quadrotor platforms using different propellers and loading conditions. Results indicate that installed propellers produce less thrust at a given RPM compared to isolated propellers. Increases in propeller power were estimated based on the C_T losses measures. Increases of at least 10% in power per propeller were seen with thrust losses as low as 0.006 in C_T.

I. Introduction

The rapid expansion of small unmanned aircraft systems (sUAS) for commercial, recreational, and research purposes has increased the demand for precise performance modeling. Advanced aerodynamic data allows for enhanced propeller efficiency, which is essential for optimizing flight endurance and capability. Historically, propeller performance data has been gathered through wind tunnel testing, primarily focusing on static or direct advancing flow. While these are effective for fixed-wing aircraft, they often fail to capture the operational realities of multirotor systems. While in flight, multirotor aircraft encounter a complex aerodynamic environment, characterized by varying flow angles and interference from both the aircraft body and neighboring rotors.

Previous quadrotor propeller performance testing done by Anantha et al.[1] focused on measuring installed thrust of two different propellers for the DJI Mavic Air 2 while in hover. Isolated testing was performed on the same propellers using a static propulsion testing apparatus. The hover and static results were then compared to analyze installed propeller performance. Post-testing analyses found that installed propellers produced less thrust than isolated propellers. There was a maximum loss of approximately 0.1 in C_T for both propellers. Successful testing on the Mavic Air 2 called for expanding test platforms. This paper follows the same method from previous work by measuring the flight C_T on six additional quadrotor platforms.

II. Aircraft and Propellers

Six quadrotors were used for testing for this paper and are listed in Table 1. The quadrotors ranged in baseline weight from 2.4 oz (63 g) to 4 lb (1.8 kg) and used propellers ranging from 2.25 in. (57 mm) to 13.1 in. (333 mm). The

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Table 1: Quadrotors Tested

Aircraft	Weight	Propeller Diameter	Location
Parrot Mambo	2.4 oz (68.3 g)	2.6 in. (66 mm)	Colorado
Dromida Hovershot	2.5 oz (72 g)	2.25 in. (57 mm)	Colorado
DJI Phantom 3	2.9 lb (1300 g)	9.45 in. (240 mm)	Colorado
3DR Solo	3.5 lb (1600 g)	10.0 in. (254 mm)	Colorado
Yuneec Typhoon 4K	4.0 lb (1800 g)	13.1 in. (333 mm)	Colorado
Hawk's Work F450	2.4 lb (1100 g)	9–10 in. (229–254 mm)	Maryland

Figure 1: Dromida Hovershot.

Figure 2: Parrot Mambo.

testing location is also provided in the table as the difference in elevation does have an effect on the results. Figures 1–6 provide photos of the six quadrotors.

The 11 propellers tested with the quadrotors are shown in Figs. 7–10. The Dromida Hovershot, Parrot Mambo, and Yuneec Typhoon were only tested with their original propellers. The 3DR Solo was tested with three different propellers, while the DJI Phantom 3 was tested with five propellers. The Hawk's Work F450 was tested with the two Master Airscrew propellers designed for the 3DR Solo and the Master Airscrew propeller designed for the DJI Phantom 3.

The chord and twist distribution for each propeller was measured using the PropellerScanner software created by Hepperle.[2] With this software, pictures of the front and side of the propeller are used to determine the chord and twist distributions. Figures 11–21 provide the chord and twist distributions for the 11 propellers. Only the geometry for right-handed variations of each propeller was measured, and based on the similar static results between the right- and

Figure 3: 3DR Solo.

Figure 4: DJI Phantom 3.

Figure 5: Yuneec Typhoon 4K.

Figure 6: Hawk's Work F450.

Figure 7: Dromida Hovershot (top) and Parrot Mambo (bottom) propellers.

Figure 8: 3DR Solo (top left), Master Airscrew Solo 10×5 (bottom left), and Master Airscrew Solo 3-Blade 9×4.5 (right) propellers.

left-handed propellers, it is assumed that the geometry between the two is nearly identical. The three propellers designed for the 3DR Solo are compared in Fig. 22, and the five propellers designed for the DJI Phantom 3 are compared in Fig. 23. There is a variation in the chord and twist for these propellers, but the twist for the APC and Master Airscrew propellers follows the trend expected in constant-pitch designs.

Figure 9: DJI P3 plastic (top left), DJI P3 carbon (bottom left), APC P3 9.5×5 (top right), Master Airscrew P3 9.4×5 (center right), and Ultimaxx (bottom right) propellers.

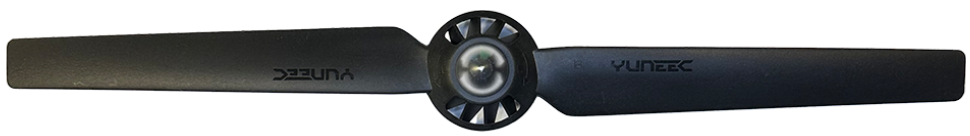


Figure 10: Propeller for the Yuneec Typhoon 4K.

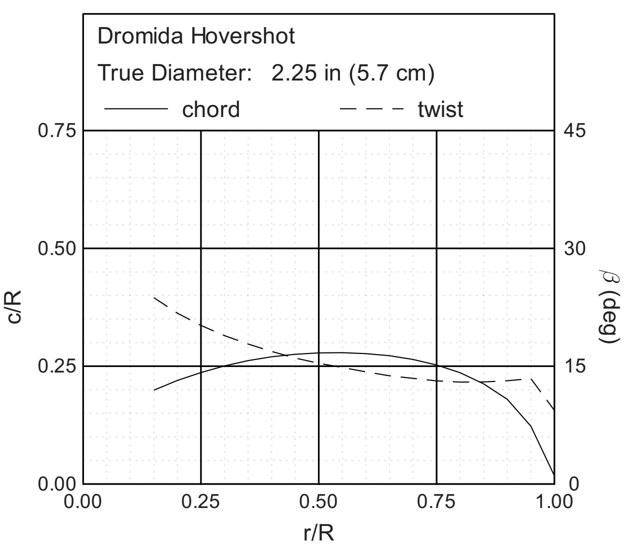


Figure 11: Dromida Hovershot propeller geometry.

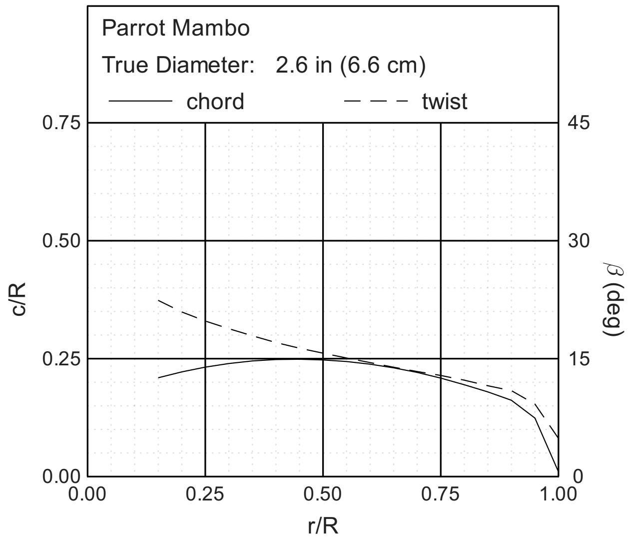


Figure 12: Parrot Mambo propeller geometry.

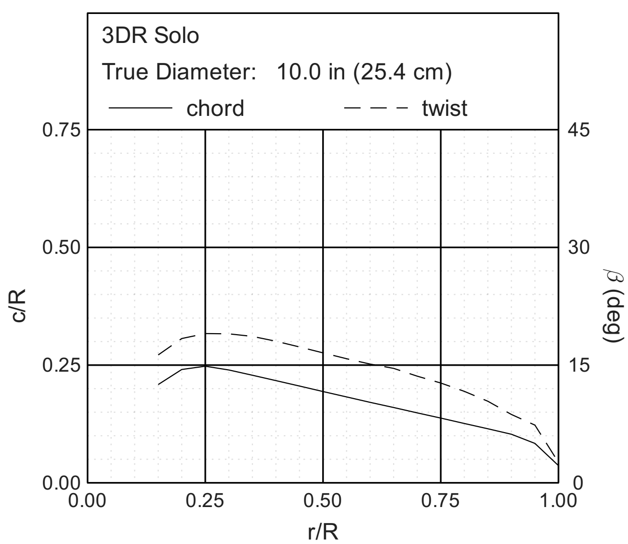


Figure 13: 3DR Solo propeller geometry.

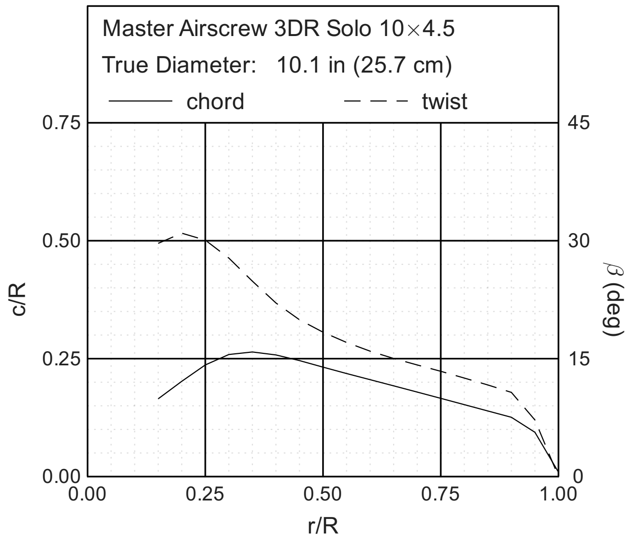


Figure 14: Master Airscrew 3DR Solo 10×5 propeller geometry.

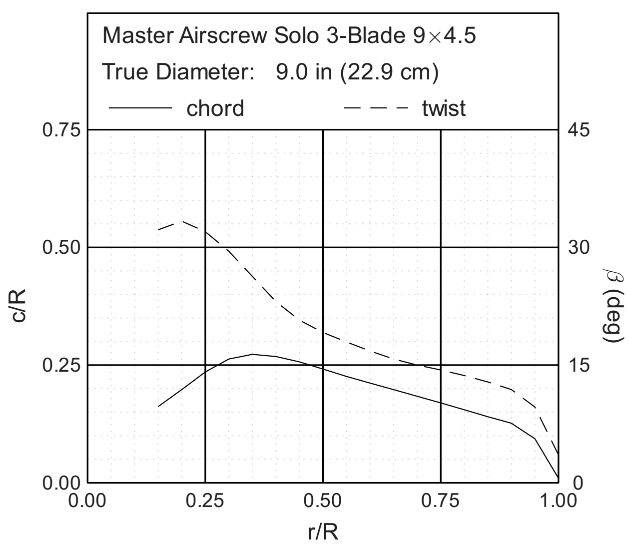


Figure 15: Master Airscrew 3DR Solo 3-Blade 90×4.5 propeller geometry.

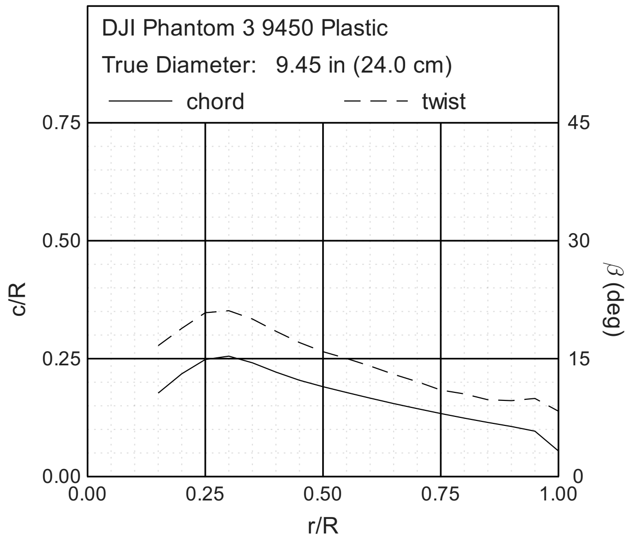


Figure 16: DJI Phantom 3 9.4×5 plastic propeller geometry.

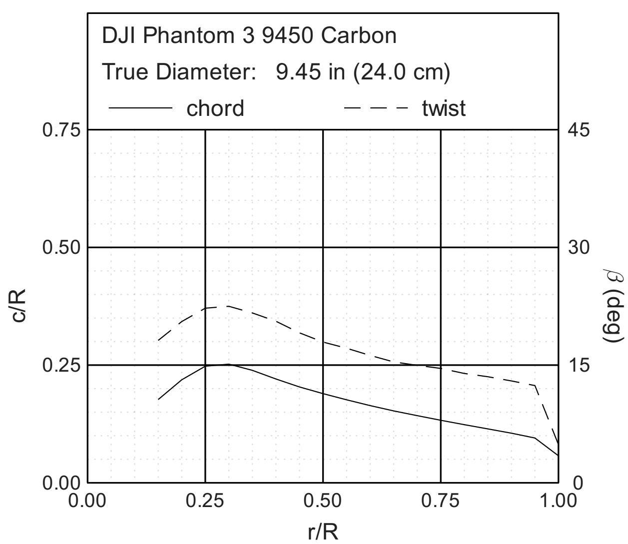


Figure 17: DJI Phantom 3 9.4×5 carbon propeller geometry.

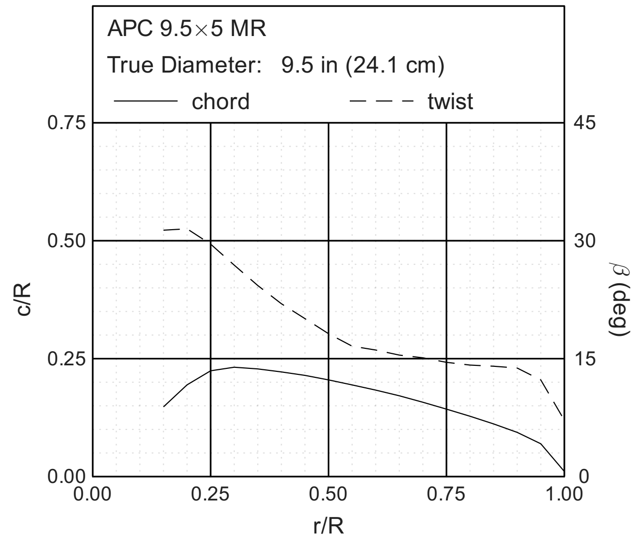


Figure 18: APC DJI P3 9.5×5 propeller geometry.

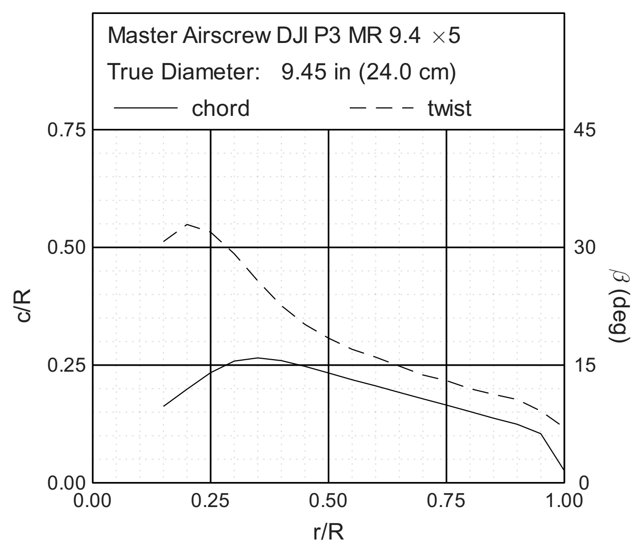


Figure 19: Master Airscrew DJI P3 9.4×5 propeller geometry.

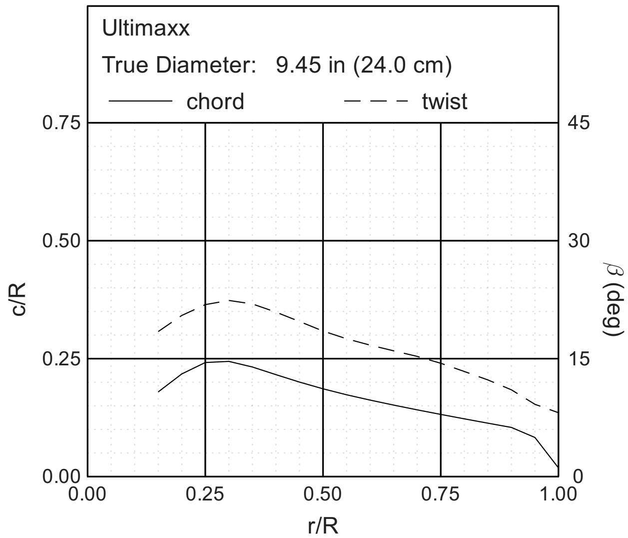


Figure 20: Ultimaxx propeller geometry.

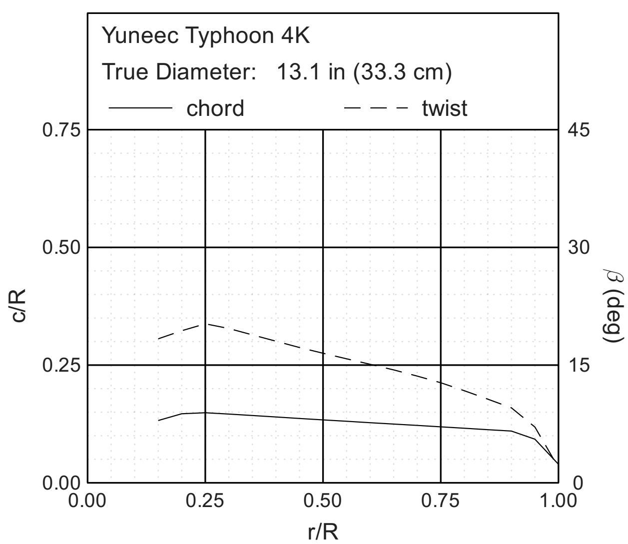


Figure 21: Yuneec Typhoon 4K propeller geometry.

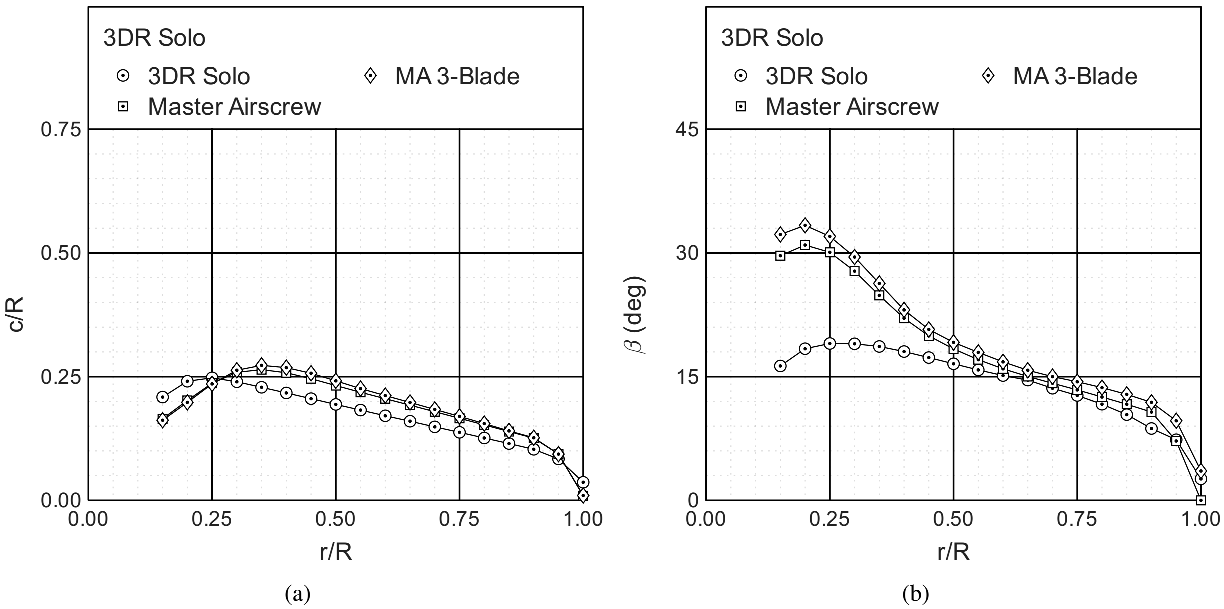


Figure 22: Comparison between propellers used for the 3DR Solo: (a) chord distribution and (b) twist distribution.

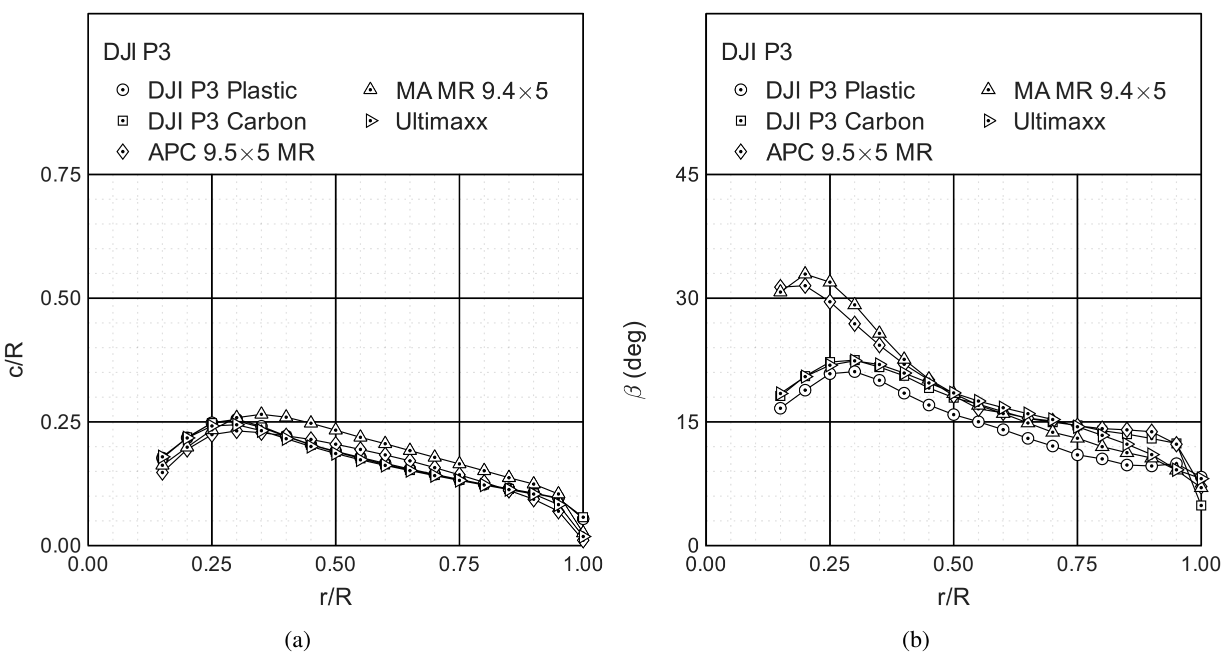


Figure 23: Comparison between propellers used for the DJI Phantom 3: (a) chord distribution and (b) twist distribution.

III. Isolated Propeller Tests

A. Testing Rig

Isolated propeller testing was performed at Indiana University using a propulsion system testing apparatus, which was previously developed[3] to measure the performance and efficiency parameters of electric propulsion system components (propellers, motors, and ESC) in a static environment. The testing rig (Fig. 24) was slightly modified for the current work and was validated by testing a similarly-sized propeller, an APC 8×3.8 SF Slow Flyer propeller with existing data available on the UIUC Propeller Database.[4]

Thrust is measured from the load cell while torque is measured using a reaction torque sensor. A computer was used to interface with a wheatstone bridge ADC to intake raw voltage measurements from the torque cell and load cell during testing. Propellers are tested through a range of RPMs with the resulting thrust and torque being measured. Propeller RPM is measured using an optical RPM meter. Ambient pressure and temperature are measured using an external pressure and temperature sensor. The component specifications for the propulsion system testing apparatus instrumentation are provided in Table 2.

Density is calculated from the equation of state

$$p = \rho R T \tag{1}$$

where R is the universal gas constant. The standard value of 1716 $\mathrm{ft}^2/\mathrm{s}^2/^\circ\mathrm{R}$ (287.0 $\mathrm{m}^2/\mathrm{s}^2/\mathrm{K}$) for air was used.

Propeller power is calculated from the measured propeller torque by

$$P = 2\pi n Q \tag{2}$$

Propeller coefficients are calculated using the standard definitions.

$$C_T = \frac{T}{\rho n^2 D^4} \tag{3}$$

$$C_P = \frac{P}{\rho n^3 D^5} \tag{4}$$

where nD can be considered the reference velocity and D^2 can be considered the reference area.

The propeller Reynolds number is calculated based on the rotational speed and chord at the 75% blade station. The Reynolds number is defined as

$$Re = \frac{\rho V c}{\mu} \tag{5}$$

where the viscosity μ is calculated from Sutherland's formula.

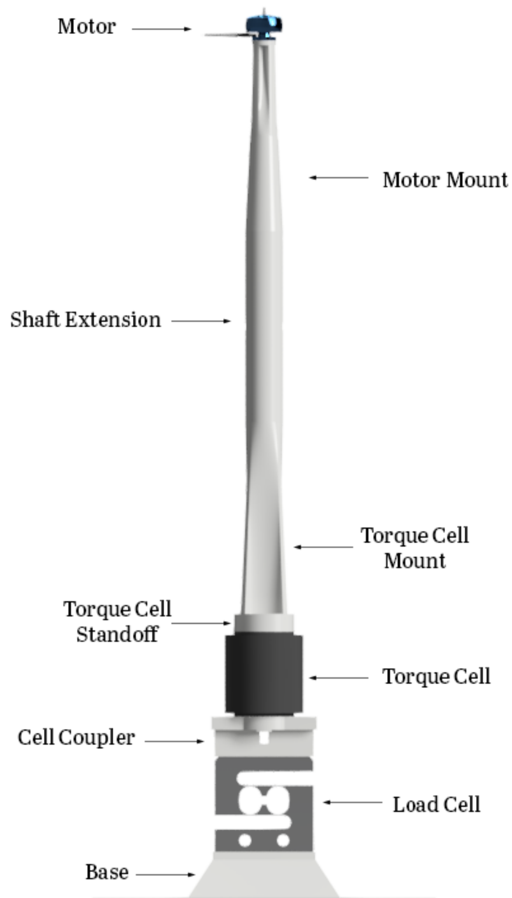


Figure 24: Static testing rig.

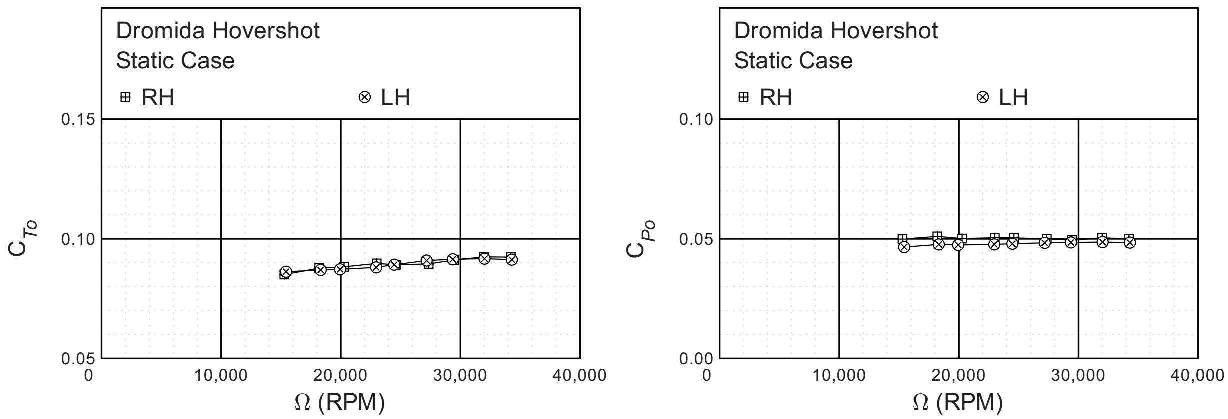
Table 2: Specifications of the Propulsion Testing Apparatus

Data acquisition system	Arduino Giga R1 WiFi
Sensors	
Thrust Cell	Phidgets S-Type Load Cell - 2kg
Torque Cell	Transducer Techniques 50 oz-in RTS reaction torque sensors
Wheatstone Bridge	Phidget Bridge 4-Input
RPM	Futaba Optical RPM Sensor
Pressure & Temperature	Adafruit Bosch BMP390
Drivers	
Motor	Yuneec Typhoon 4K OEM Motor, 3DR Solo OEM Motor, DJI Phantom 3 OEM Motor, iFlight XING2 1404 4600Kv
Speed Controller	Castle Phoenix Edge Lite 50, Castle Phoenix Edge HV 40
Power Supply	BK Precision
PWM Generator	Digital Pin on Arduino

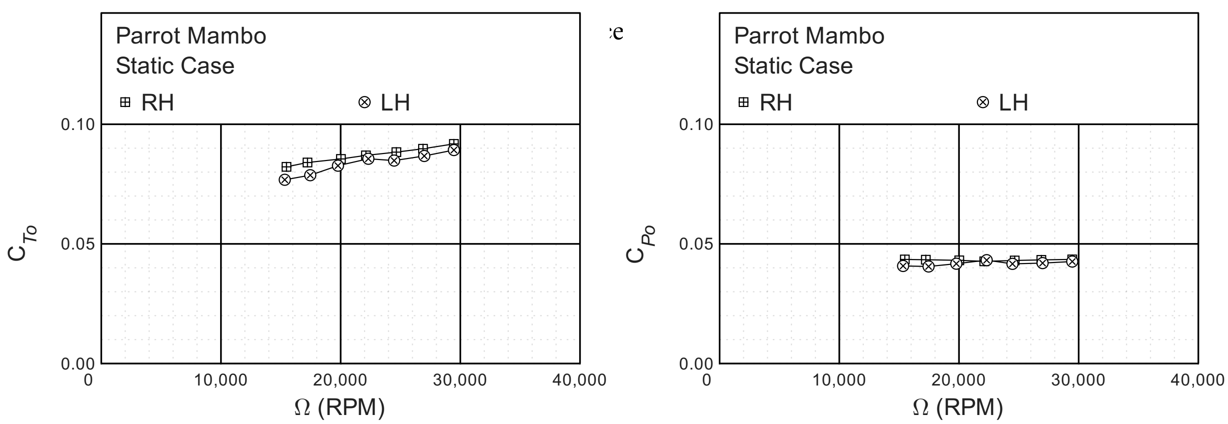
B. Propeller Performance

Static performance results for 9 of the propellers are provided in Figs. 25–33. These figures compare the right- and left-handed variation of each propeller. For most of the propellers, the difference in performance between the right- and left-handed is minimal, especially in the operating RPM range. Propellers such as the 3DR Solo (Fig. 27) diverge at lower RPMs, but these are smaller than those needed to fly. Two propellers (DJI Plastic and Ultimaxx) had a larger variation in their performance. These propellers are more flexible than most of the other propellers, so the discrepancy may be due to differences in manufacturing quality between specimens.

The Master Airscrew 9.4×5 (Fig. 34) and APC 9.5×5 (Fig. 35) could not be tested in time for this paper using the testing rig at Indiana. These propellers have been tested before,[5] so these previous results were used instead for the flight test comparisons.

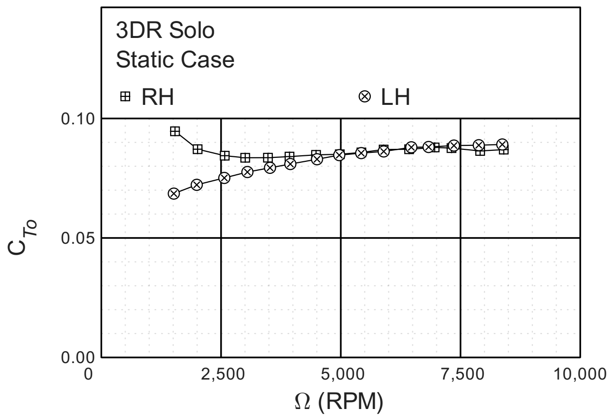


(a) (b)



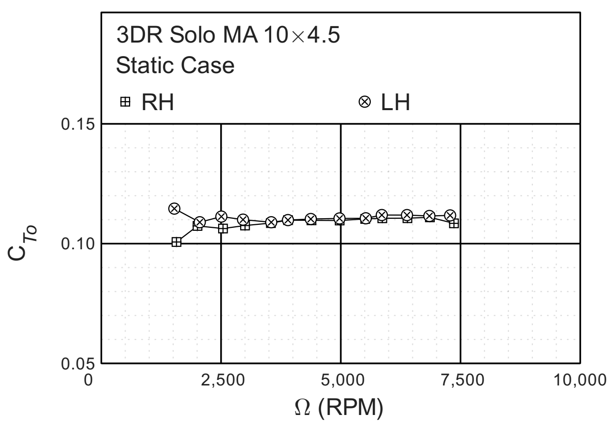
(a) (b)

Figure 26: Parrot Mambo static performance: (a) thrust coefficient and (b) power coefficient.



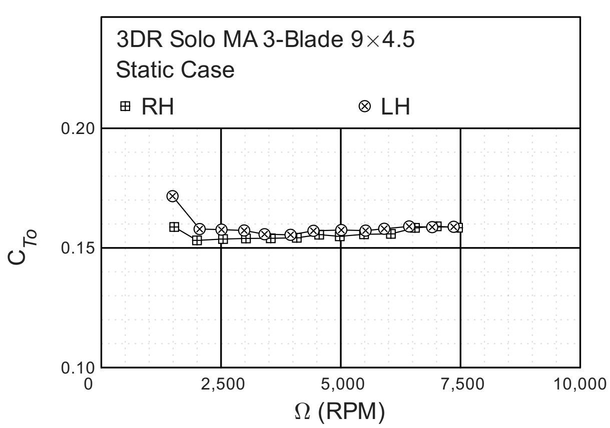
(a) (b)

Figure 27: 3DR Solo original propeller static performance: (a) thrust coefficient and (b) power coefficient.



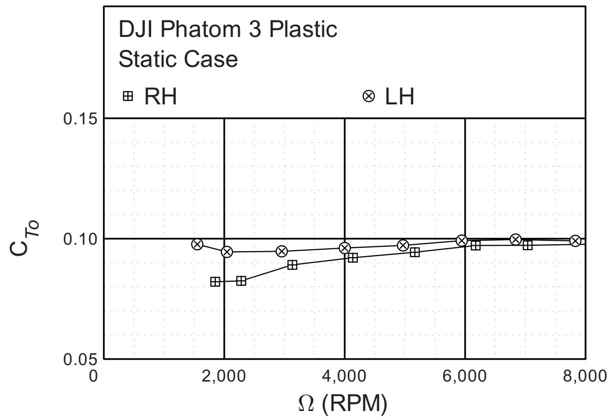
(a) (b)

Figure 28: Master Airscrew Solo 10×4.5 static performance: (a) thrust coefficient and (b) power coefficient.

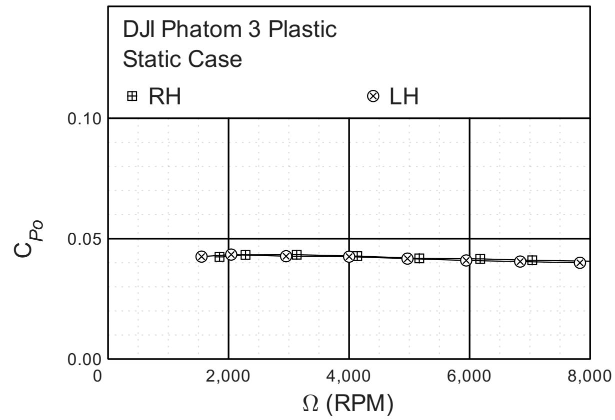


(a) (b)

Figure 29: Master Airscrew Solo 3-Blade 9×4.5 static performance: (a) thrust coefficient and (b) power coefficient.

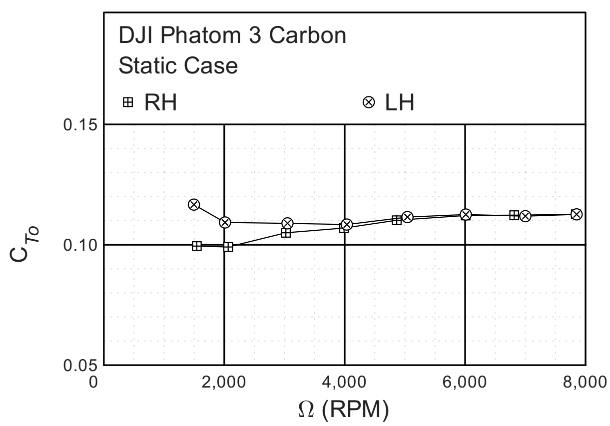


(a)

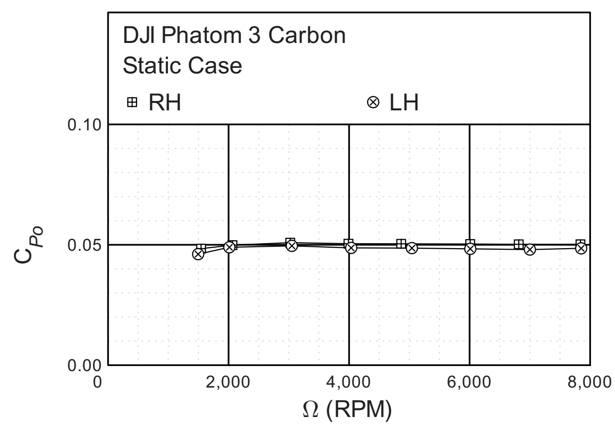


(b)

Figure 30: DJI Phantom 3 9.4×5 Plastic static performance: (a) thrust coefficient and (b) power coefficient.

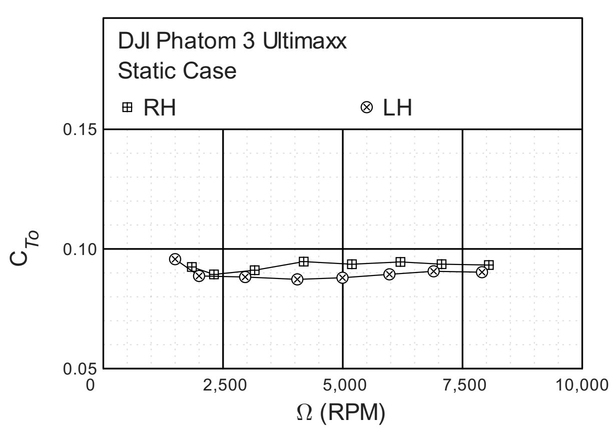


(a)

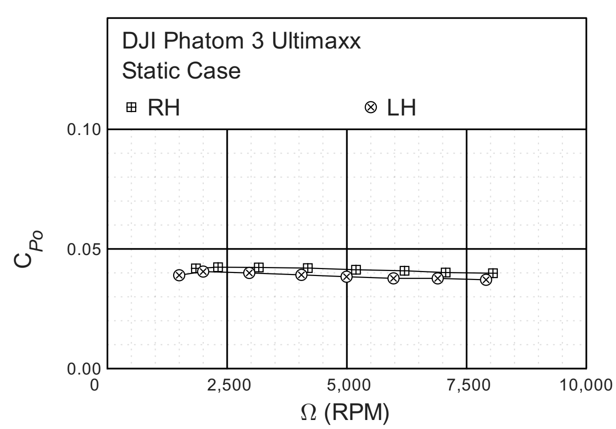


(b)

Figure 31: DJI Phantom 3 9.4×5 Carbon static performance: (a) thrust coefficient and (b) power coefficient.

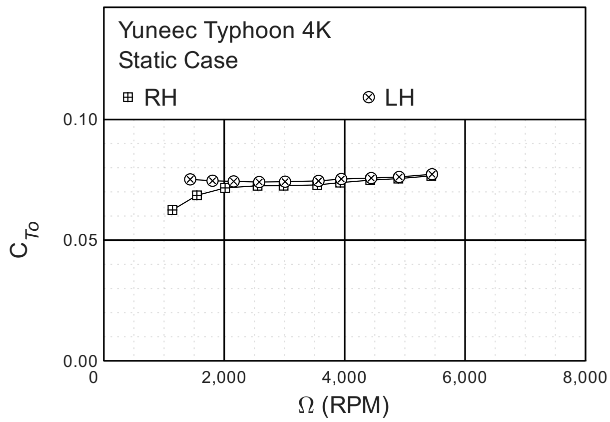


(a)

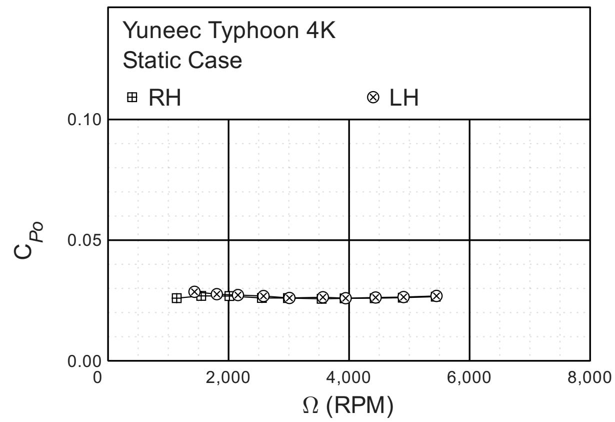


(b)

Figure 32: DJI Phantom 3 Ultimaxx static performance: (a) thrust coefficient and (b) power coefficient.



(a)



(b)

Figure 33: Yuneec Typhoon 4K original propeller static performance: (a) thrust coefficient and (b) power coefficient.

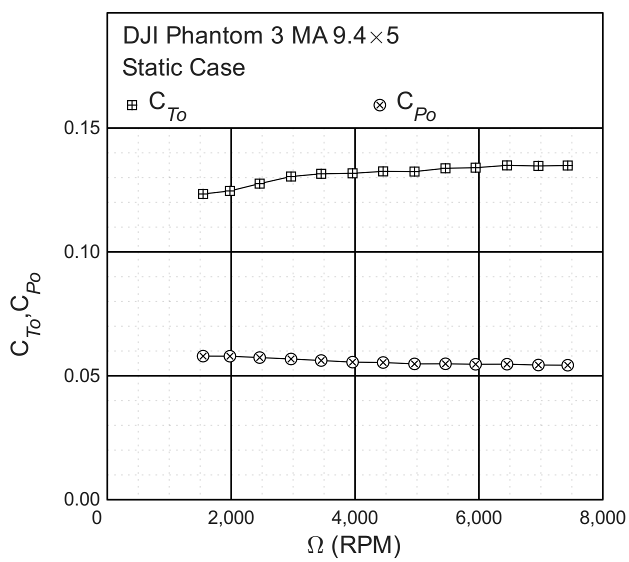


Figure 34: Parrot Mambo.

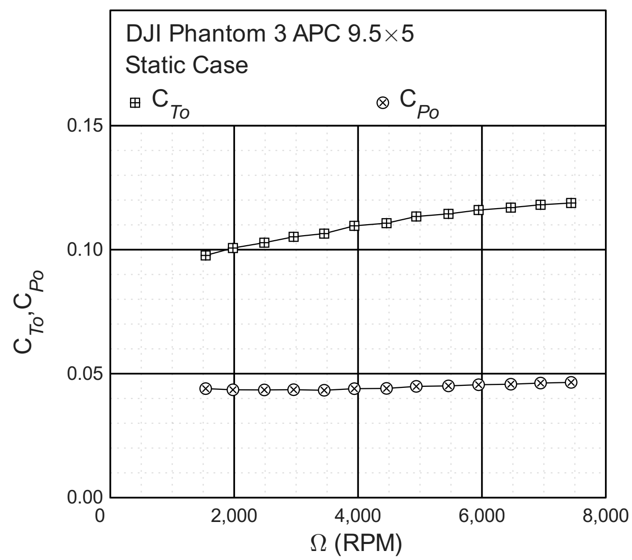


Figure 35: Parrot Mambo.

IV. Flight Tests and Comparison

Flight tests were performed on the six quadrotors. The Hawk's Work F450 was tested in Maryland while the other five were testing in Colorado. Table 3 lists the tests performed on each of the quadrotors. As mentioned earlier, the Dromida Hovershot, Parrot Mambo, and Yuneec Typhoon 4K were only tested with their own propellers, but each of these drones were tested under different loading conditions. The other quadrotors were tested using different propellers, and the Phantom 3 was also tested under different loading conditions while using the Master Airscrew 9.4×5 propeller. In-flight RPMs for each testing condition were measured using a handheld tachometer while the aircraft was in hover (Fig. 36). Figure 37 provides an example of how different loading conditions were achieved by adding weights to the aircraft. Due to their size, all but the Dromida and Parrot had to be tested outdoors. These aircraft (except for the Parrot) also did not have an automatic hovering setting, so the pilot had to make constant adjustments while another person took tachometer readings.

Figure 36: Measurement of propeller RPM while in flight using a handheld tachometer.

Figure 37: Example loading of additional weight on the Parrot Mambo.

Table 3: Flight Tests Performed

Dromida Hovershot	3DR Solo	DJI Phantom 3	Hawk's Work F450
Baseline	Original Solo	Plastic 9.4×5	MA 9.4×5
+10 g	MA 10×4.5	Carbon 9.4×5	MA 10×4.5
	MA 3-blade 9×4.5	APC 9.5×5	MA 3-blade 9×4.5
Parrot Mambo		Ultimaxx	
Baseline	**Yuneec Typhoon 4K**	MA 9.4×5	
+10 g	Baseline	MA 9.4×5 +140 g	
+14 g	+200 g	MA 9.4×5 +140 g	

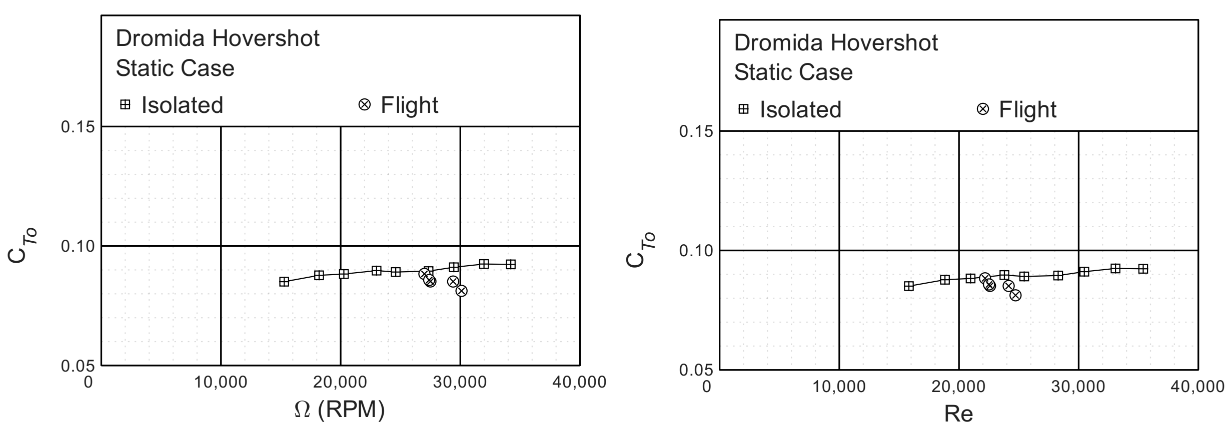
From the measured RPMs and aircraft weight, the thrust coefficient of each propeller was calculated using Eq. 3. Air density was calculated from the ambient temperature and pressure using the equation of state (Eq. 1). Results from the flight measurements were plotted with the isolated propeller C_T results that were provided earlier. The C_T results were plotted against both the RPM and the Reynolds number based on the 75% blade station. Results for all the tests are provided in Figs. 38–54.

Flight results for the Hawk's Work F450 showed little difference between the RPM and Reynolds number plots. The testing conditions for the isolated propeller tests from Indiana were not significantly different from those experienced for the flight tests in Maryland. For the tests performed in Colorado, there is a significant difference between the RPM and Reynolds number plots. The much higher elevation in Colorado led to a significantly lower air pressure and, therefore, lower air density. The Reynolds number effect was equivalent to the propeller operating at a lower RPM when compared with the isolated propeller results. For the smaller aircraft (Dromida and Parrot), the change in Reynolds number was equivalent to an approximate change of 4,000 in RPM. For the larger aircraft (Yuneec), the Reynolds number change was equivalent to a change of 500 in RPM.

The results provided from these tests showed a similar loss in C_T performance from the tests on the DJI Mavic Air 2 previously done by the authors.[1] A flight test thrust coefficient that is less than the isolated thrust coefficient means that the installed propeller is producing less thrust at a given RPM. An installed propeller must rotate faster in order to make up for the losses. There are a few results that did not show a loss, but testing conditions, such as wind and not having an automatic hovering setting, made gathering some measurements difficult. There is the possibility of some human error while gathering and reading the RPM measurements.

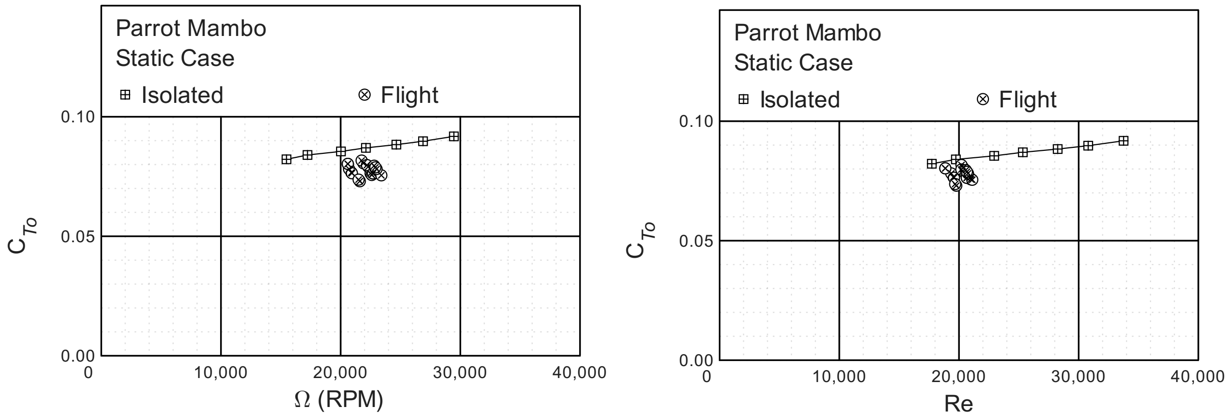
For all of the tested quadrotors, it was assumed the the thrust was evenly distributed between all four propellers. As seen in the photos of the quadrotors, these aircraft look to be symmetric about their longitudinal and lateral axes. The measured RPMs did not show a clear distinction between front and rear propellers as was seen with the DIJ Mavic Air 2 in the previous study.[1] However, RPM measurements from the F450 show a pattern of thrust distribution. This may be due to having some components mounted on the propellers arms. Further testing will include determining the CG location to better determine the thrust distribution.

Three of the propellers were tested on two different quadrotors (Figs. 52, 53, and 54). Because of the possible uneven thrust distribution with the F450, no conclusions can be made at this time about the effect of the drone frame on thrust loss, but further testing is planned.



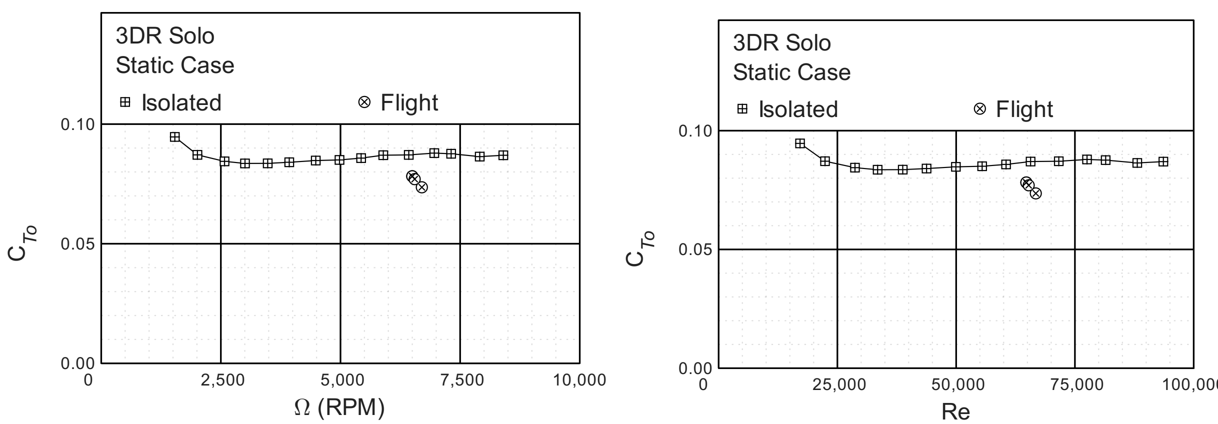
(a) (b)

Figure 38: Isolated and flight C_T for the Dromida Hovershot: (a) plotted against RPM and (b) plotted against Re.



(a) (b)

Figure 39: Isolated and flight C_T for the Parrot Mambo: (a) plotted against RPM and (b) plotted against Re.



(a) (b)

Figure 40: Isolated and flight C_T for the 3DR Solo propeller on the 3DR Solo: (a) plotted against RPM and (b) plotted against Re.

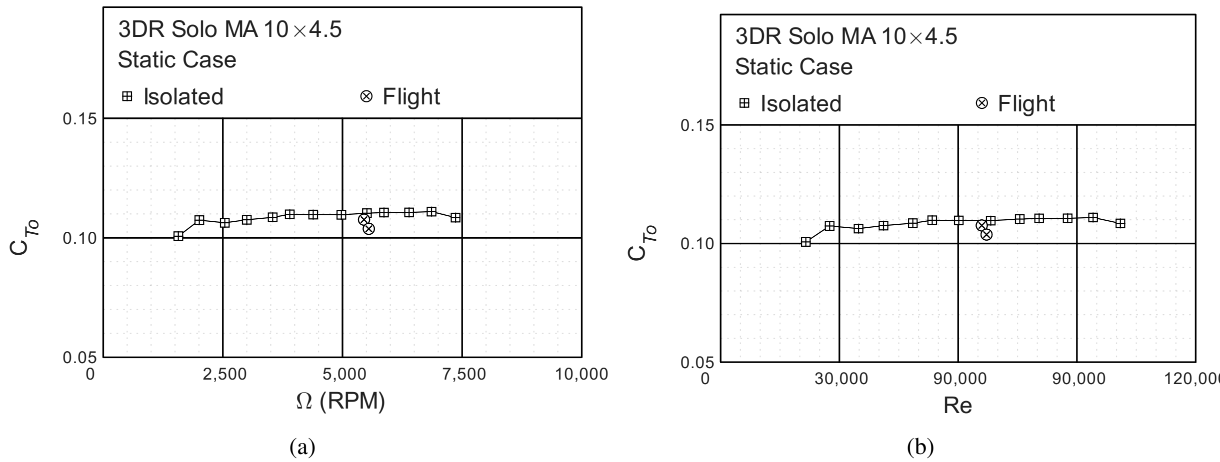


Figure 41: Isolated and flight C_T for the Master Airscrew 10×4.5 on the 3DR Solo: (a) plotted against RPM and (b) plotted against Re.

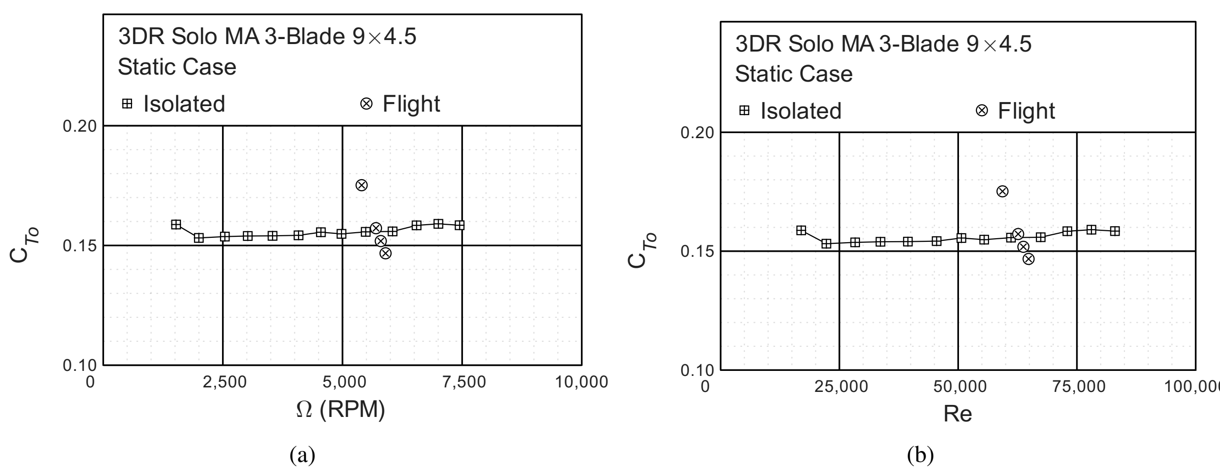


Figure 42: Isolated and flight C_T for the Master Airscrew 3-Blade 9×4.5 on the 3DR Solo: (a) plotted against RPM and (b) plotted against Re.

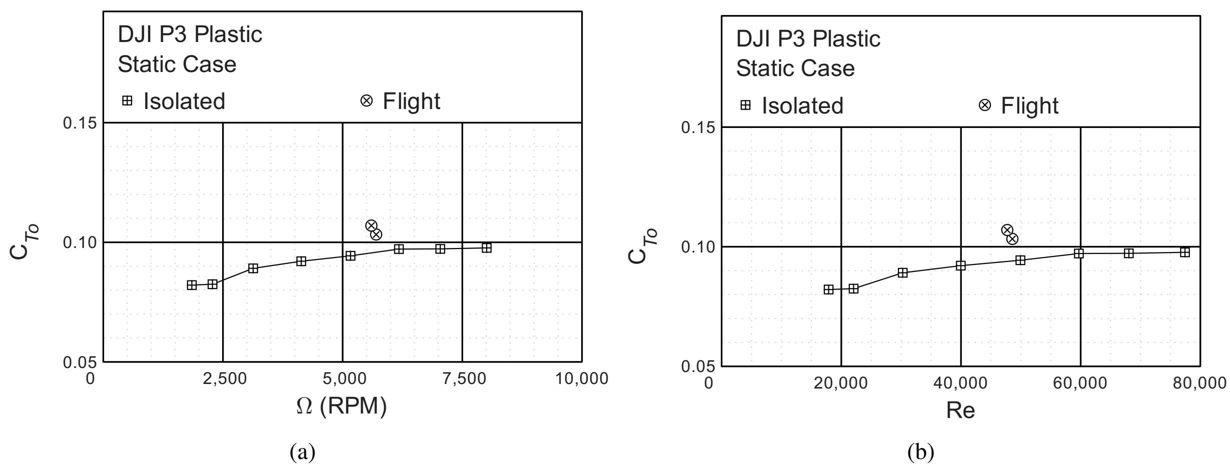


Figure 43: Isolated and flight C_T for the plastic DJI 9.4×5 propeller on the DJI Phantom 3: (a) plotted against RPM and (b) plotted against Re.

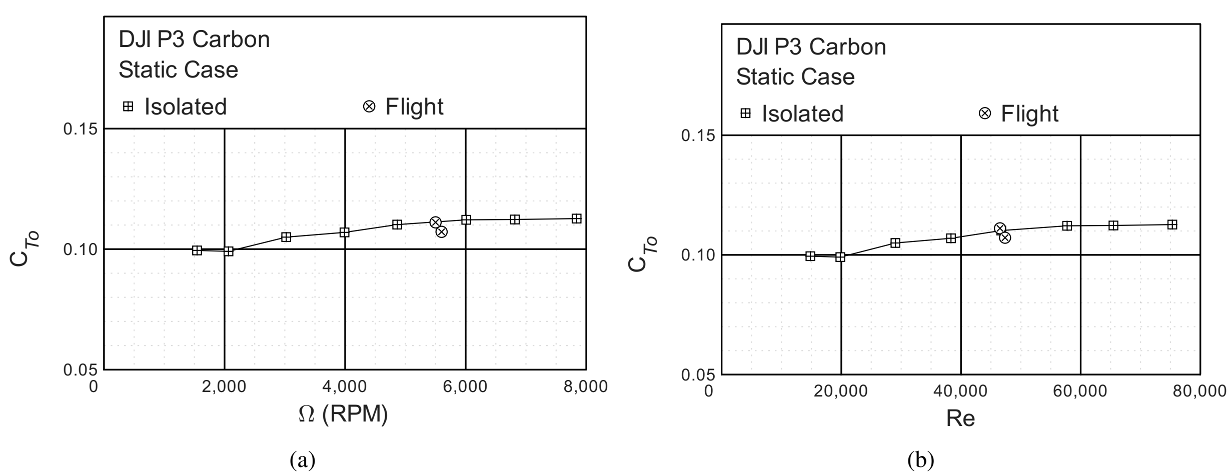
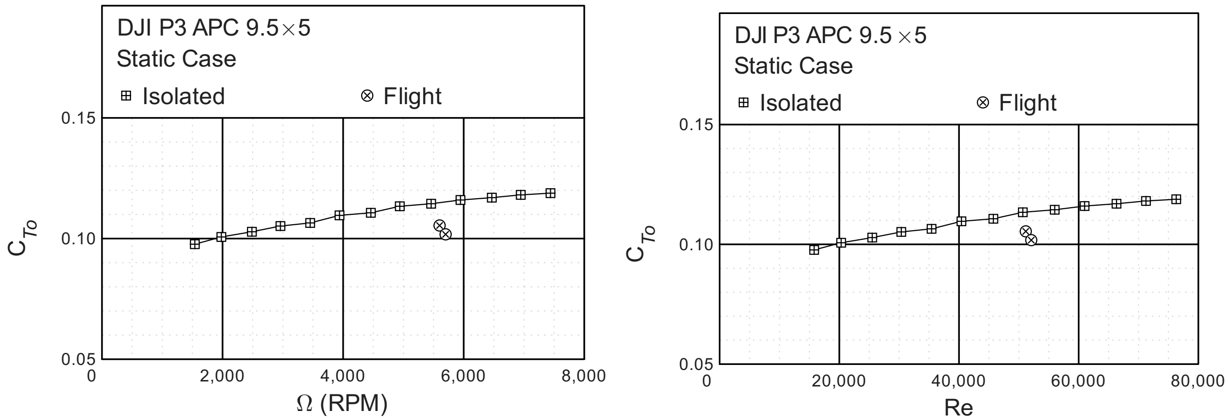
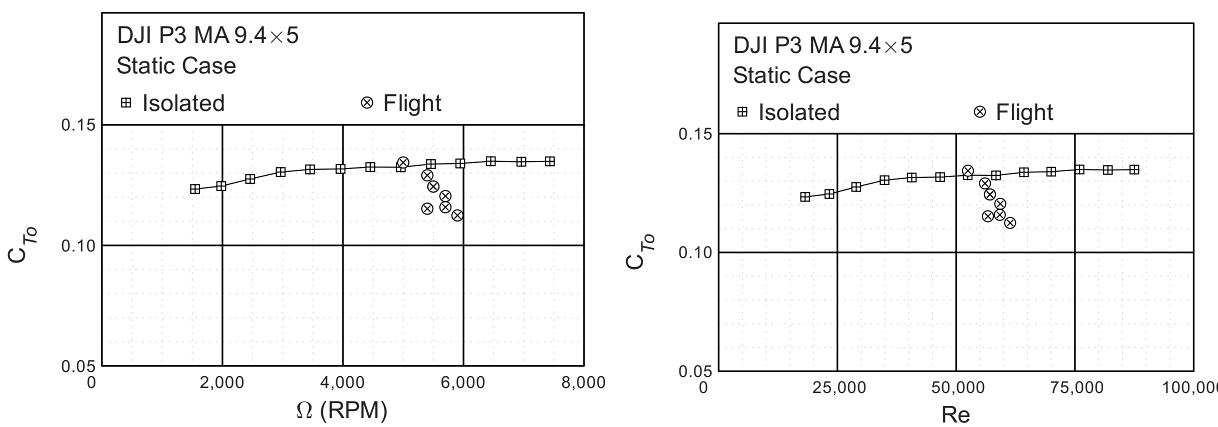


Figure 44: Isolated and flight C_T for the carbon DJI 9.4×5 propeller on the DJI Phantom 3: (a) plotted against RPM and (b) plotted against Re.



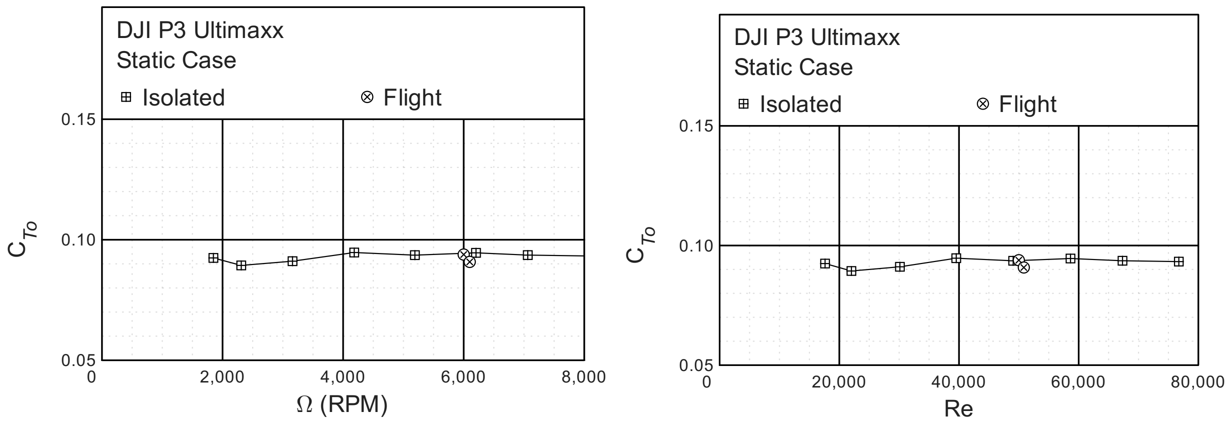
(a) (b)

Figure 45: Isolated and flight C_T for the APC 9.5×5 propeller on the DJI Phantom 3: (a) plotted against RPM and (b) plotted against Re.



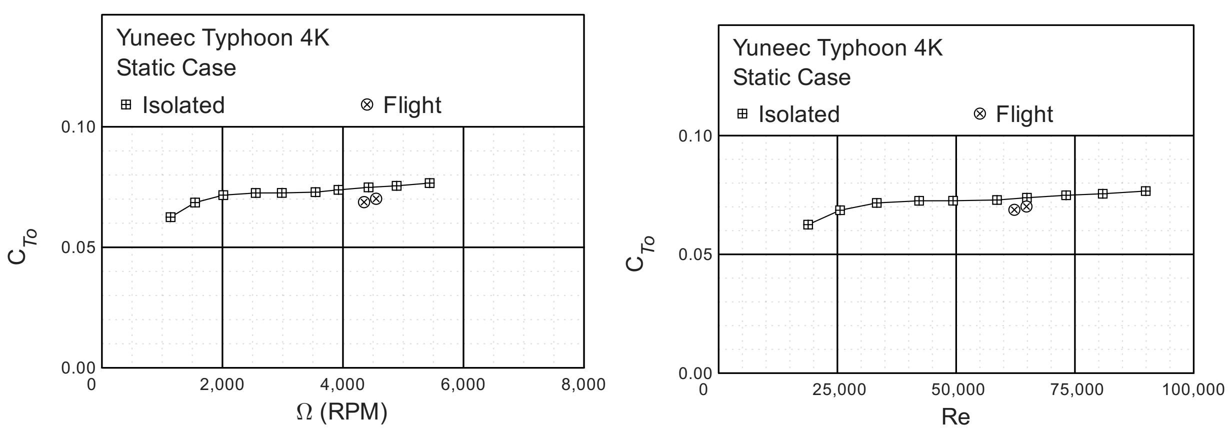
(a) (b)

Figure 46: Isolated and flight C_T for the Master Airscrew 9.4×5 propeller on the DJI Phantom 3: (a) plotted against RPM and (b) plotted against Re.



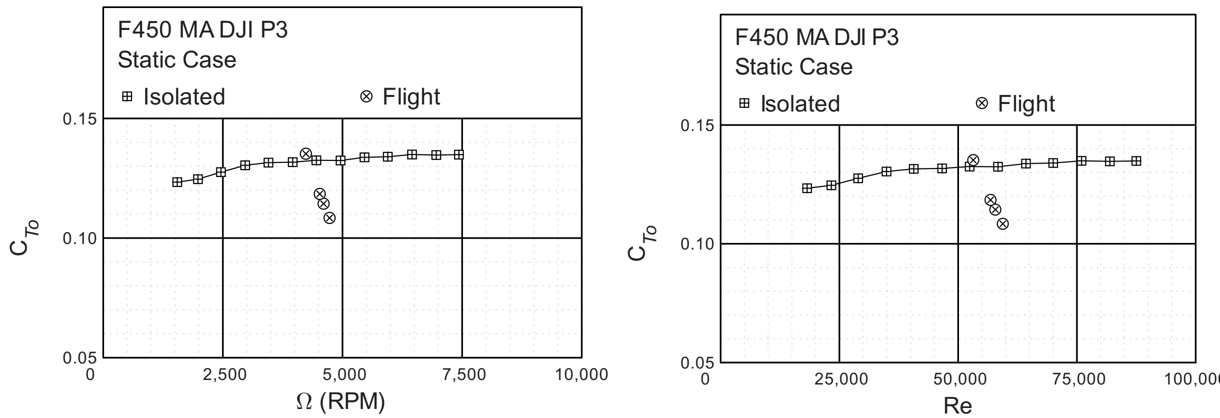
(a) (b)

Figure 47: Isolated and flight C_T for the Ultimaxx propeller on the DJI Phantom 3: (a) plotted against RPM and (b) plotted against Re.



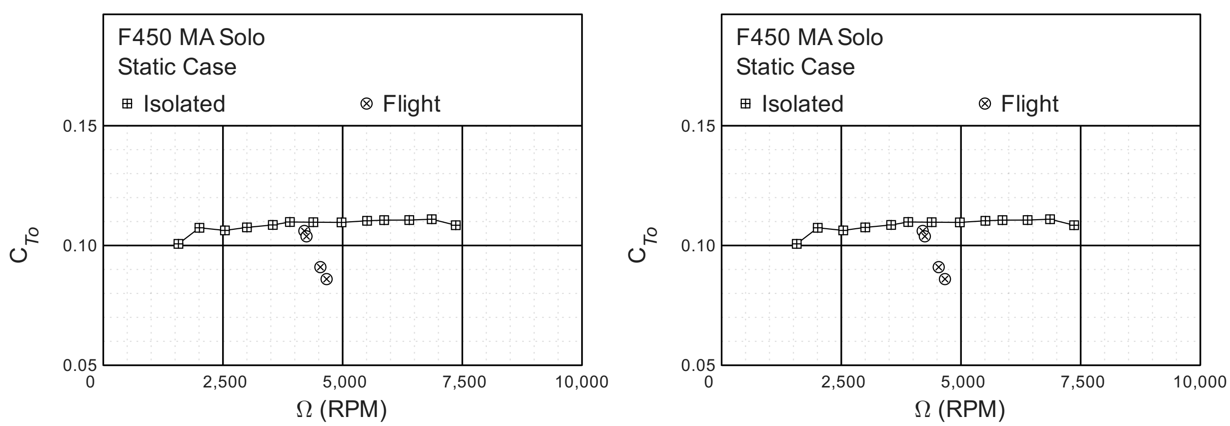
(a) (b)

Figure 48: Isolated and flight C_T for the Yuneec Typhoon 4K: (a) plotted against RPM and (b) plotted against Re.



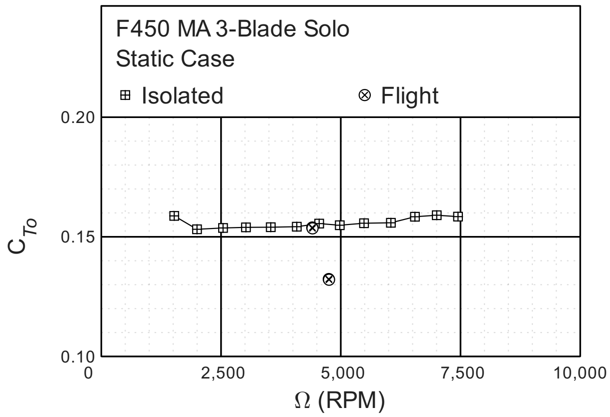
(a) (b)

Figure 49: Isolated and flight C_T for the Master Airscrew 9.4×5 propeller on the Hawk's Work F450: (a) plotted against RPM and (b) plotted against Re.

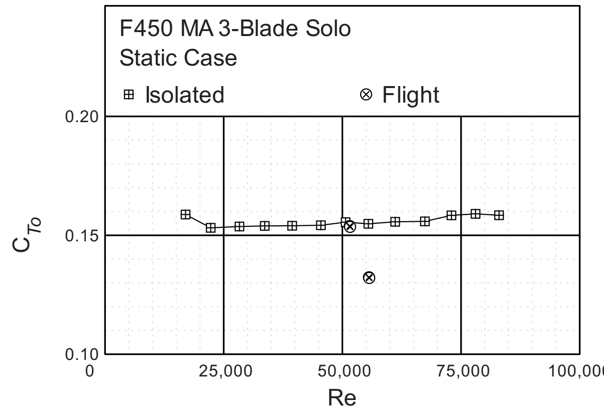


(a) (b)

Figure 50: Isolated and flight C_T for the Master Airscrew 10×4.5 propeller on the Hawk's Work F450: (a) plotted against RPM and (b) plotted against Re.

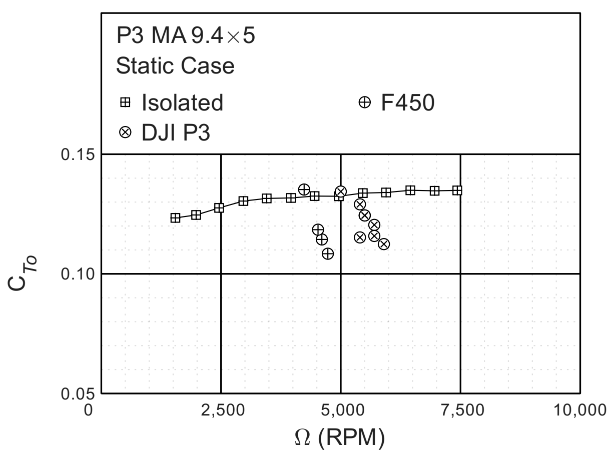


(a)

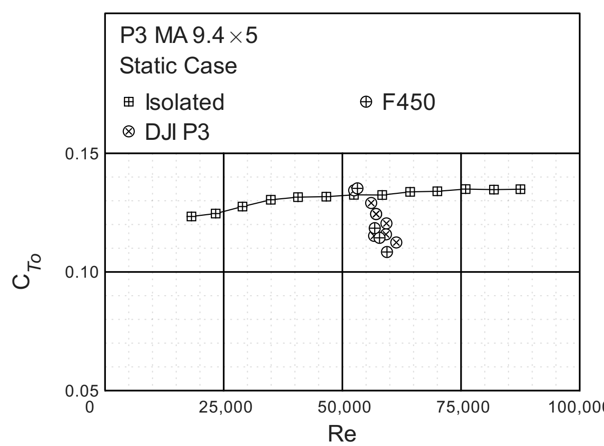


(b)

Figure 51: Isolated and flight C_T for the Master Airscrew 3-Blade 9×4.5 propeller on the Hawk's Work F450: (a) plotted against RPM and (b) plotted against Re.

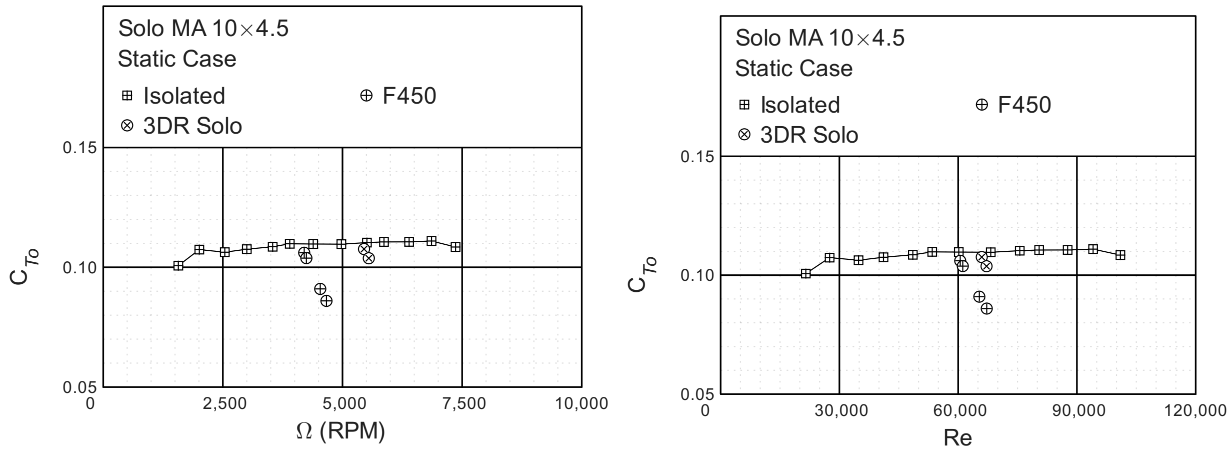


(a)



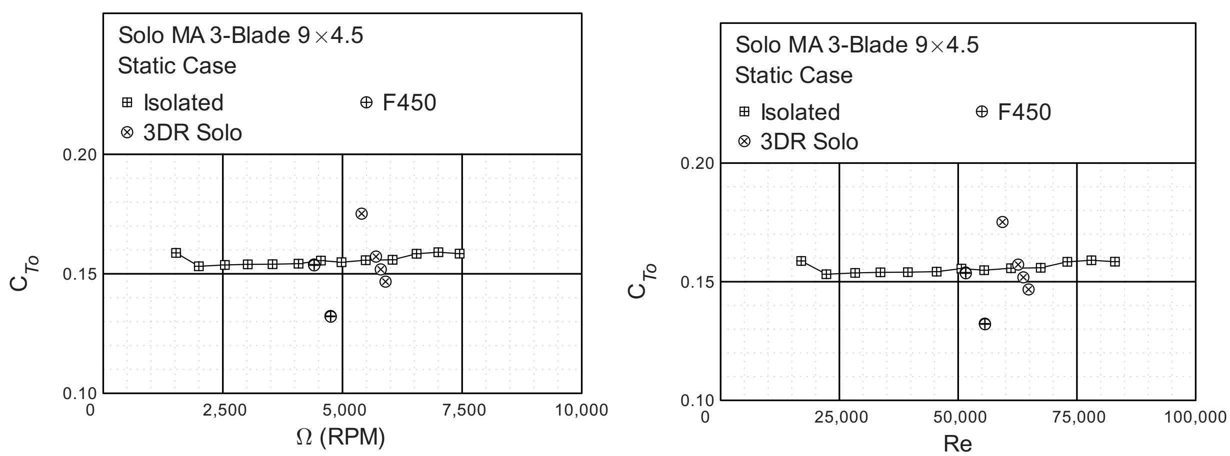
(b)

Figure 52: Isolated and flight C_T for the Master Airscrew 9.4×5 propeller on the DJI Phantom 3 and Hawk's Work F450: (a) plotted against RPM and (b) plotted against Re.



(a) (b)

Figure 53: Isolated and flight C_T for the Master Airscrew 10×4.5 propeller on the 3DR Solo and Hawk's Work F450: (a) plotted against RPM and (b) plotted against Re.



(a) (b)

Figure 54: Isolated and flight C_T for the Master Airscrew 3-Blade 9×4.5 propeller on the 3DR Solo and Hawk's Work F450: (a) plotted against RPM and (b) plotted against Re.

V. Estimate of Losses

Estimated C_T losses were used to assist in estimating the power increase of propellers to maintain hover. Estimated C_T losses were determined using two MATLAB scripts; the first as a C_T comparator to develop quantitative estimated results for C_T loss between isolated and installed propellers, and the second to estimate the power increase per propeller to maintain hover. To develop the scripts, functions were first tested in MATLAB that could be plugged into any script to calculate the desired output. These functions included loading data, Sutherland's Law, Reynolds number, air density using equation of state, and thrust/power/C_T/C_P functions to calculate thrust, power, thrust coefficient, and power coefficient, respectively.

Three quadrotors were selected to demonstrate the effect of C_T loss on the increase in power needed by the propellers. The Parrot Mambo was selected for a representative small quadrotor, the DJI Mavic Air 2 (tested previously[1]) was selected for a medium quadrotor, and the Yuneec Typhoon 4K was selected for a large quadrotor. The DJI Mavic Air 2 has a clear thrust distribution between the front and back propellers (approximately 56% and 44%, respectively). It was assumed that the thrust was evently distributed between all four propellers for the other two quadrotors.

Estimating percent power-increase for the installed propellers was achieved by using the C_T comparator to interpolate using isolated propeller data and installed propeller data to find the difference between isolated and installed propellers, providing the loss in C_T. These losses provided the foundation for the expected C_T loss used for estimating the percent power-increase for installed propellers in the second script. Table 4 displays a C_T-loss range and corresponding power increase for the front and back propellers of the DJI Mavic Air 2 at two weight classes and with two different propellers, yielding four sets of percent power-increase results.

As mentioned earlier,the thrust distribution of the Mavic Air 2 is approximately 56% on the front propellers and 44% on the rear propellers. With increasing C_T losses from 0.002 to 0.014, percent power-increase also increases. At 0.57 kg using the DJI Air 2S Low-Noise propellers, the front and back percent power-increase has a range of 2.82% to 24.15% and 2.97% to 24.56%, respectively. At 0.73 kg using the DJI Air 2S Low-Noise propellers, the front and back percent power-increase has a range of 2.83% to 24.26% and 2.83% to 24.16%, respectively. At 0.57 kg using the Master Airscrew Stealth propellers, the front and back percent power-increase has a range of 2.82% to 24.92% and 3.01% to 24.81%, respectively. At 0.73 kg using the Master Airscrew Stealth propellers, the front and back percent power-increase has a range of 2.98% to 24.79% and 2.81% to 24.91%.

The thrust distribution for the Parrot Mambo is approximately evenly distributed on all propellers. With increasing C_T losses from 0.002 to 0.014, Table 5 displays the percent power-increase for two weight classes. At 0.068 kg, the percent power-increase has a range of 3.39% to 31.01%. At 0.078 kg, the percent power-increase has a range of 3.06% to 30.35%.

The thrust distribution of the Yuneec Typhoon 4K is also approximately evenly distributed on all propellers. With increasing C_T losses from 0.002 to 0.014, Table 6 displays the percent power-increase for two weight classes. At 1.8 kg, the percent power-increase has a range of 3.93% to 36.89%. At 2.2 kg, the percent power-increase has a range of 3.73% to 36.15%.

Determining expected C_T losses assisted in predicting percent power-increase across three different quadrotor airframes. The potential for predicting power draws could lead to the development of engineering tools capable of estimating quadrotor performance, assisting with the purposive design of quadrotors.

Table 4: DJI Mavic Air 2 Percent Power Increase per Propeller

DJI Air 2S Low-Noise, W = 0.57 kg							
CT Loss	0.002	0.004	0.006	0.008	0.01	0.012	0.014
P Inc Front	2.82	5.93	9.20	12.65	16.28	20.11	24.15
P Inc Back	2.97	6.12	9.43	12.91	16.59	20.46	24.56
DJI Air 2S Low-Noise, W = 0.73 kg							
CT Loss	0.002	0.004	0.006	0.008	0.01	0.012	0.014
P Inc Front	2.83	5.95	9.24	12.70	16.35	20.19	24.26
P Inc Back	2.83	5.94	9.21	12.66	16.29	20.12	24.16
Master Airscrew Stealth, W = 0.57 kg							
CT Loss	0.002	0.004	0.006	0.008	0.01	0.012	0.014
P Inc Front	2.82	6.03	9.41	12.97	16.74	20.71	24.92
P Inc Back	3.01	6.18	9.52	13.04	16.75	20.66	24.81
Master Airscrew Stealth, W = 0.73 kg							
CT Loss	0.002	0.004	0.006	0.008	0.01	0.012	0.014
P Inc Front	2.98	6.15	9.49	13.01	16.72	20.64	24.79
P Inc Back	2.81	6.02	9.40	12.97	16.73	20.70	24.91

Table 5: Parrot Mambo Percent Power Increase per Propeller

W = 0.068 kg							
CT Loss	0.002	0.004	0.006	0.008	0.01	0.012	0.014
P Inc	3.39	7.28	11.42	15.84	20.56	25.61	31.01
W = 0.078 kg							
CT Loss	0.002	0.004	0.006	0.008	0.01	0.012	0.014
P Inc	3.06	6.91	11.01	15.38	20.04	25.02	30.35

Table 6: Yuneec Typhoon 4K Percent Power Increase per Propeller

W = 1.8 kg							
CT Loss	0.002	0.004	0.006	0.008	0.01	0.012	0.014
P Inc	3.93	8.44	13.30	18.52	24.16	30.27	36.89
W = 2.2 kg							
CT Loss	0.002	0.004	0.006	0.008	0.01	0.012	0.014
P Inc	3.73	8.18	12.97	18.11	23.66	29.66	36.15

VI. Summary and Future Work

In-flight RPMs were collected successfully for varying quadcopter platforms. From the weight of the aircraft, ambient conditions, and RPM measurements, the installed thrust coefficient of the propeller was calculated. Most measurements showed a loss in the thrust coefficient when compared with the isolated propeller data. Due to the high elevation difference between the isolated propeller tests and flight tests in Colorado, Reynolds number effects were seen in the installed thrust values. When accounting for the Reynolds number, the equivalent RPM when compared to the isolated propeller performance is smaller. This reduction is significant and ranges from approximately 500 RPM for the largest propeller (Yuneec) to 4,000 RPM for the smaller propellers (Dromida and Parrot).

To better understand the impact of the measured thrust loss, an estimation method was developed to determine the expected percent increase in propeller power. For the three representative quadrotors selected, an increase in propeller power of approximately 10% was estimated with a thrust loss of 0.006 in C_T. This method assumed that the power coefficient for the propeller did not change between the isolated case and the installed case. Future flight testing that measures the power draw from the motors will better quantify the power use increase.

Most of the quadrotors used in this research did not have autohover capabilities. Those with an autohover mode allowed for aircraft stability to collect RPM measurements using a handheld tachometer. Aircraft without autohover capabilities make the use of the tachometer challenging while posing a risk to the person collecting data. Due to uncontrollable environmental factors, such as wind, and quadcopter actions, such as drift, participants need to be attentive while using the device. Measurements need be taken within the range of the tachometer and there must be adequate ambient light. To address limitations and mitigate safety risks, an on-board system is being developed for use on multirotor platforms to record RPMs in flight and provide live aerodynamic data.

The on-board flight data recorder will use commercial off-the-shelf components, with the Arduino UNO as the core. Accelerations will be measured by an Arduino Modulino Movement, and ambient conditions (pressure, temperature, and humidity) will be measured by an Adafruit BME680. Two to four TT Electronics OPB732WZ infrared reflective switches will be installed to measure RPMs. This system will be capable of measuring the accelerations and RPMs of quadcopters in both hover and various flight conditions.

Acknowledgments

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[3]Cox, B., Dantsker, O.D., and Deters, R.W., “Propulsion System Testing Instrumentation for Multi-Rotor and Lighter-than-Air UAVs,” AIAA Paper 2025-0252, AIAA SciTech Forum, Orlando, Florida, January, 2025.

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