Multirotor Aerodynamics

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Intro:

Prior to my research there was hardly any data available on aerodynamic coefficients of multirotors. There was no good way to validate new designs or do proper powertrain sizing rather than by trial and error methods. There was also much speculation amongst the multirotor community about whether aerodynamics even really mattered in multirotors, since it was assumed that they always were always going to fly slow enough to where aerodynamic lift and drag would be negligible. Recently with the advent of mini quad racing and new high power lithium-polymer batteries, high current/small size electronic speed controllers, and high power mini brushless motors, mini quadcopters are now able to push speeds of up to 80 miles per hour and the racing aspect of the industry wants to push them even faster. Rather than design by heuristic methods, it would be best to be able to have solid concrete data on what configurations are more aerodynamic than others and being able to calculate how the vehicle should behave in flight rather than basing everything off of pilot feedback. This was the basis for the reasoning behind taking multiple multirotors of different sizes and configurations and then putting them into the low turbulence wind tunnel to measure their aerodynamic lift and drag coefficients.

Methods:

To measure the aerodynamic coefficients of each multirotor frame and configuration, a 3D printed adapter was created on SolidWorks and then printed in the aerospace engineering departments invention studio.The wind tunnel measurement device (called the sting) has limits of +30 to -30 degrees in pitch and +45 to -45 degrees in yaw. These constraints led to the design of the adapter having a 45 degree ramp built and hold the vehicle rotated 90 degrees in roll so pitch and yaw would be swapped, so going from -45 to +45 degrees in yaw on the sting would then be the same as going from 0 to -90 degrees in pitch in the vehicle’s frame of reference and data could be collected in one run from a hover state all the way to max possible pitch angle of 90 degrees forward. The sting measures side force, axial force, and normal forces in its frame of reference which I then had to do a coordinate rotation to then produce forces in the wind frame of reference. The sting and the vehicle are also offset by 45 degrees, so the measured angle of attack by the sting had to be shifted by 45 degrees to give the true angle of attack of the vehicle. The sting measured all of the forces in pounds and once it was rotated into the wind frame of reference, the forces were then divided by the dynamic pressure and the motor to motor distance of the vehicle (vehicle size) squared to normalize the data into lift and drag coeffecients.

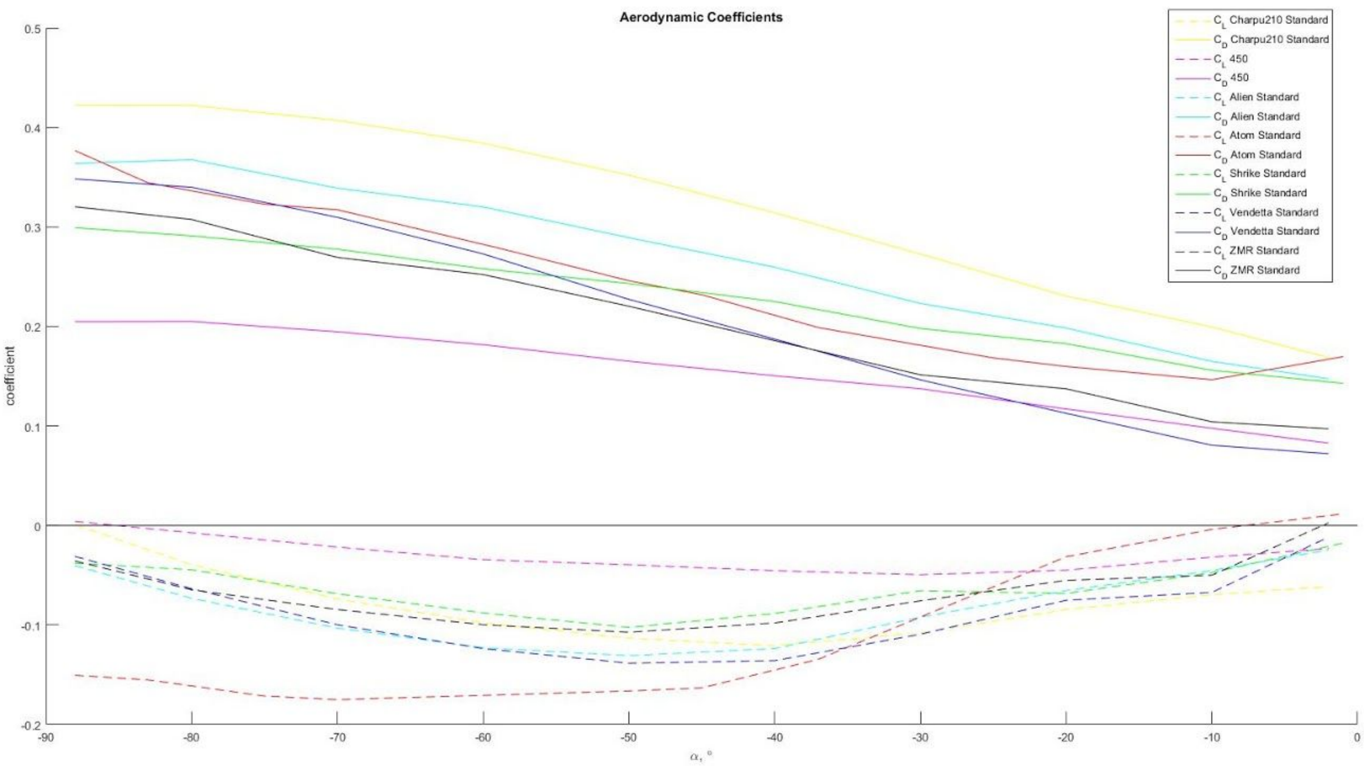
In total, 9 different frames and a total of 25 different configurations were tested in the wind tunnel. The frames ranged in size from 122mm from motor to motor up to 450mm motor to motor. Some of the configurations that were tested were:

- Bare frame vs. ready to fly frame
- 122mm to 450mm ready to fly frames
- Ready to fly frame props off vs. props on and free wheeling in the flow
- Frames using top plates vs. aerodynamic canopy
- GoPro on board vs. no HD recording camera onboard
- Small racing X frame vs. larger freestyle H frame
- Covered 5.8gHz video transmitter antenna vs. bare 5.8gHz antenna

These configurations were chosen based on multiple criteria. Firstly, I wanted to see if there was a correlation between frame size and aerodynamic coefficients so various sizes of ready to fly frames were tested. There has also been debate as to whether the props create a negligible amount of drag or not, so a small racing X frame and the most common larger freestyle H frame was tested with and without props to see what percentage of the drag was due to the props compared to the frame to get a baseline for what the minimum amount of drag and parasitic lift could be. Companies have also started making aerodynamic canopies to put on the vehicles to try and reduce drag and parasitic lift, so the canopies were tested against the frames with their standard construction of using 2 flat carbon fiber plates with 35mm spacers between them. Adding an HD camera such as a GoPro has also been speculated by the multirotor community to add lots of drag and therefore should be taken off in a racing situation where speed is required. The video transmitter antennas for the 5.8gHz video downlink also come in cylindrical plastic cases or as an uncased cloverleaf antenna and so they were both tested on an identical frame to see if they had any effect on aerodynamic coefficients.

<u>Results:</u>

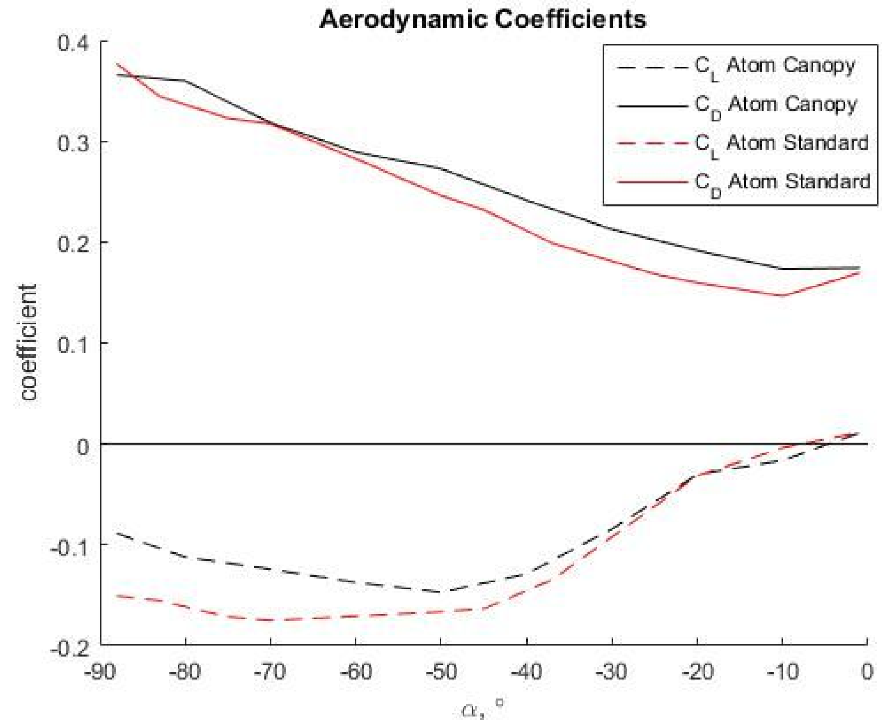
All Ready to Fly Frames



These are the lift and drag coefficients of each quadcopter frame tested in a standard RTF configuration with no props on.

Aerodynamic Canopy vs. Flat Top Plate Design

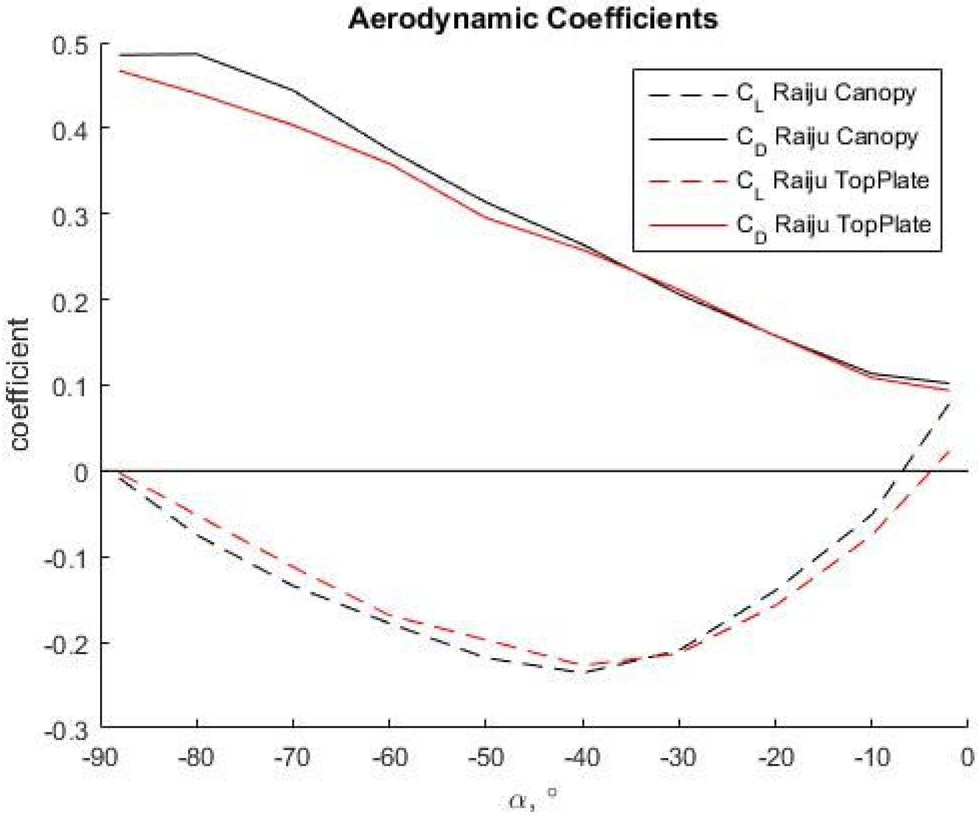
Adding an aerodynamic canopy on the 122 sized quadcopter increased drag by an average of 10% but reduced parasitic lift by an average of 24%.



122mm Quad with Flat Top Plate

122mm Quad with Canopy

On the 155 sized hexacopter, the aerodynamic canopy added an average of 1.5% to the drag coefficient and a negligible amount to the lift coefficient throughout, but it appears from the graph that the canopy helps reduce parasitic lift above -35 degrees angle of attack.



155mm Hex with Flat Top Plate

155mm Hex with Aero Canopy

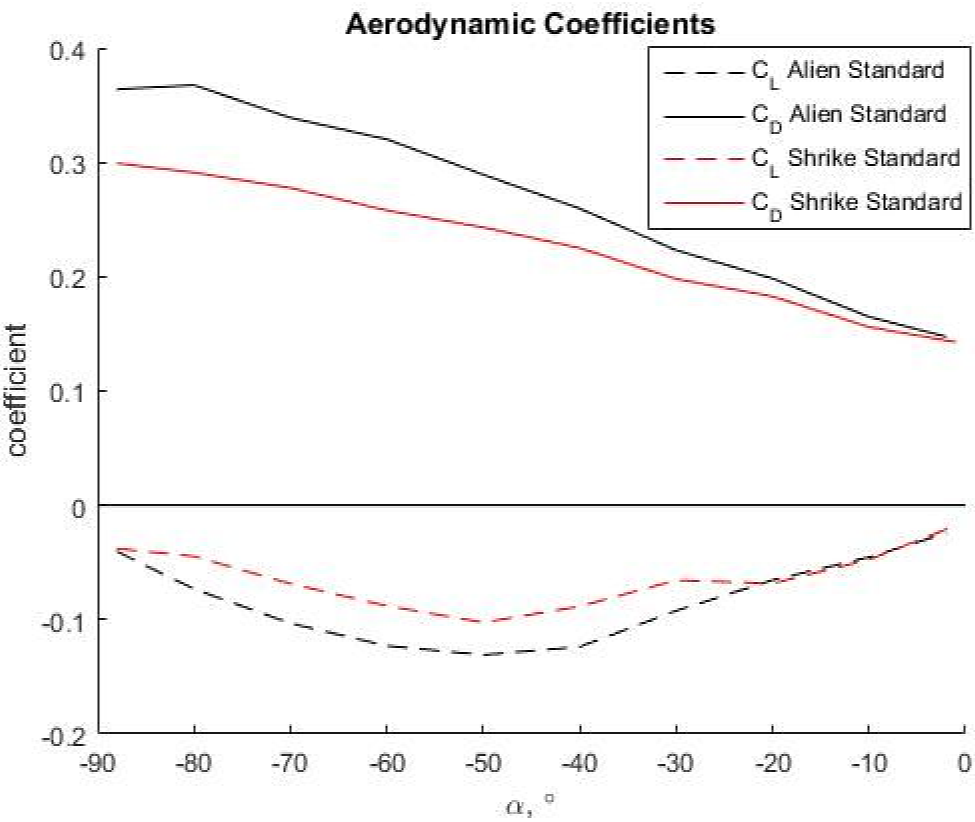
<u>Small Racing X Frame vs. Larger Freestyle H Frame</u>

It has been known for a while that current freestyle frames such as the 5" Alien that are larger and designed to be easier to build and have more room for components were less aerodynamic and heavier than the new minimalist frames designed for racing such as the Shrike, which is another 5” propeller quad that is designed for lightweight, high speed low drag racing.

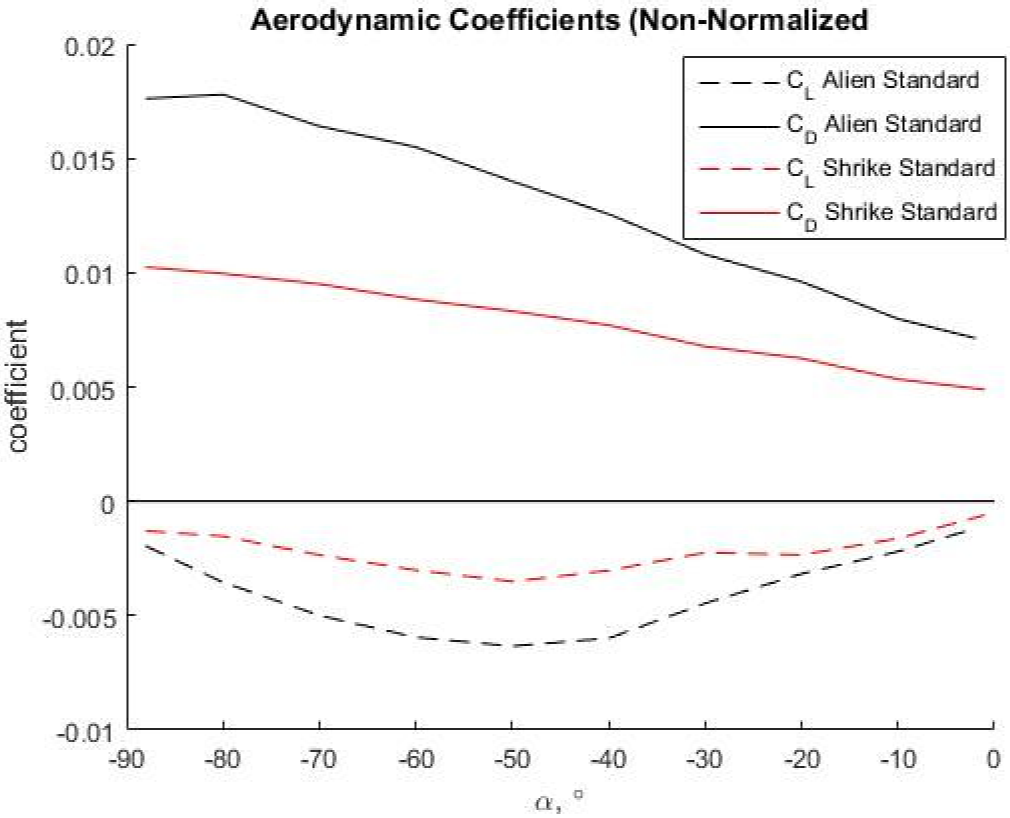
5” Alien

5” Shrike

The current data shows that the minimalist racing X frame (Shrike) has on average a 13% smaller drag coefficient and 20% smaller parasitic lift coefficient than the larger freestyle oriented H frame (Alien).



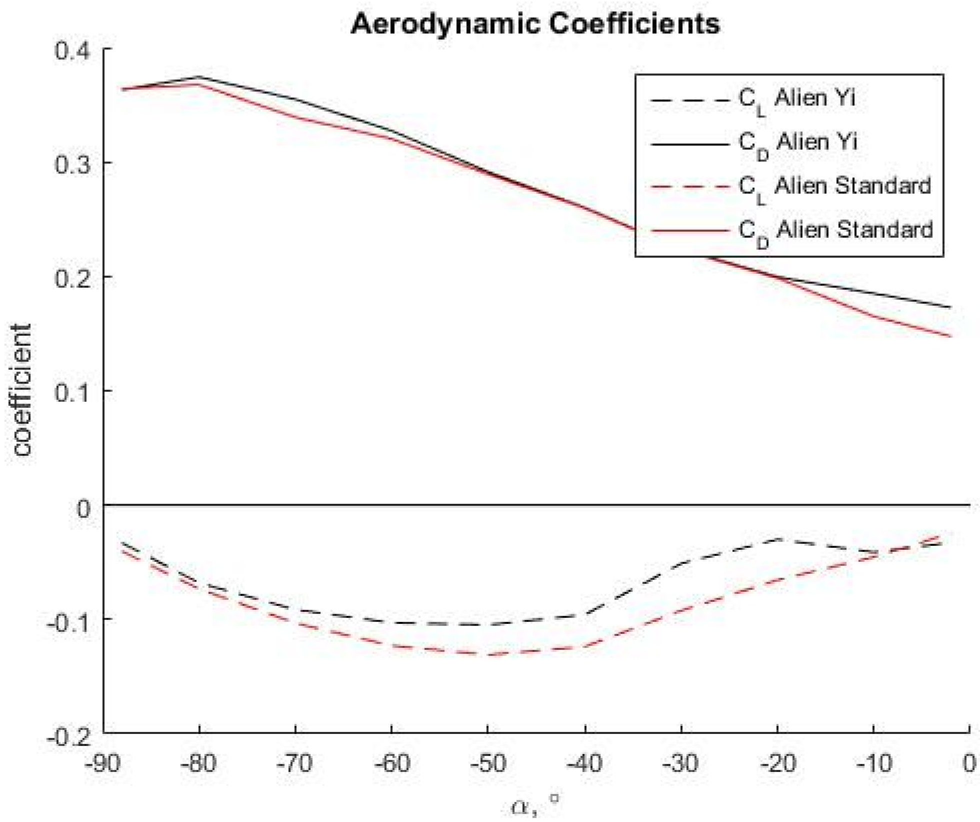
Since both the Alien and the Shrike use the same power system, it is more convenient to show the advantages of the smaller X style frame by comparing the non-normalized lift and drag coefficients.



Comparing the true lift and drag of each frame side by side, the Shrike shows an average 44% less parasitic and 39% less overall drag, which is a very large amount and makes a large difference in how the vehicle performs at higher speeds.

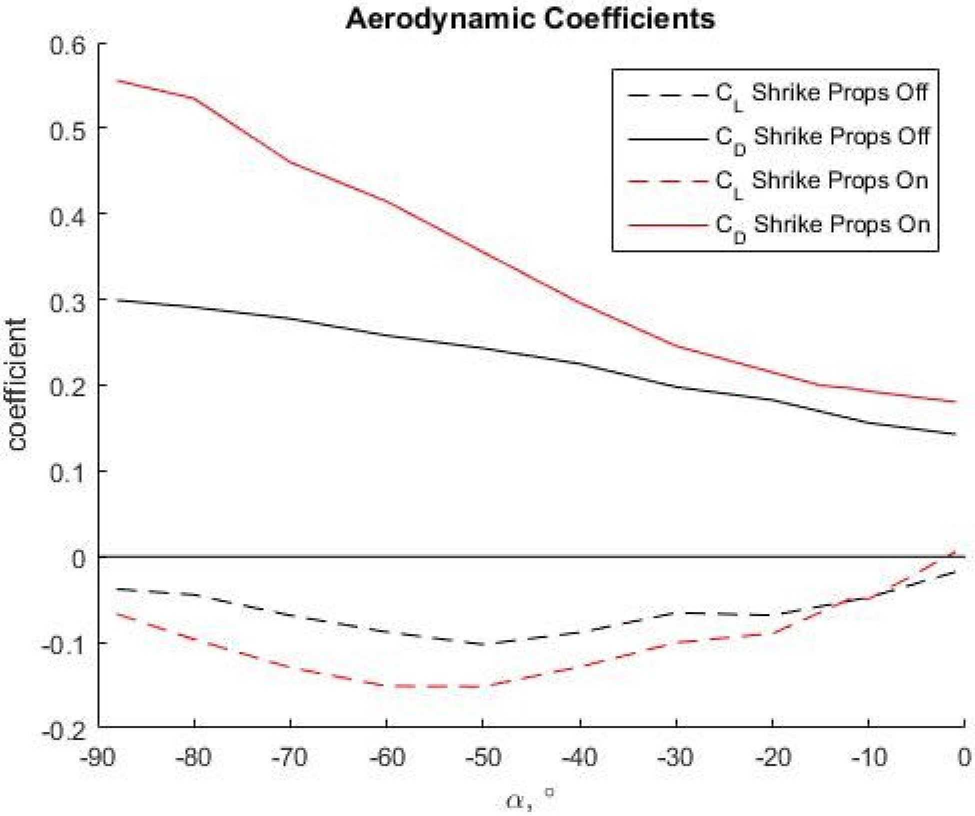
GoPro Onboard vs. No HD Recording Camera

When comparing a 5" Alien with and without a GoPro strapped to the top, it was assumed that the GoPro would add a decent amount more drag and parasitic lift, but upon testing it showed that adding a GoPro only adds about 3% more drag but actually reduces parasitic lift by 30%.

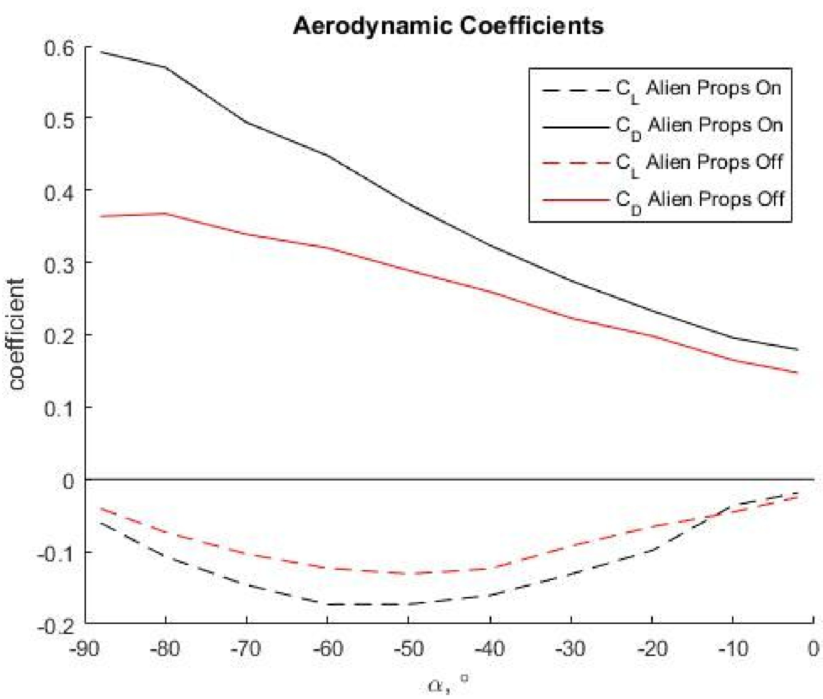


<u>RTF Vehicle Props On vs. Props Off</u>

In testing the small 5” prop racing X quad (Shrike) with and without props, adding props increased the drag by an average of 47% and increased parasitic lift by 40%.



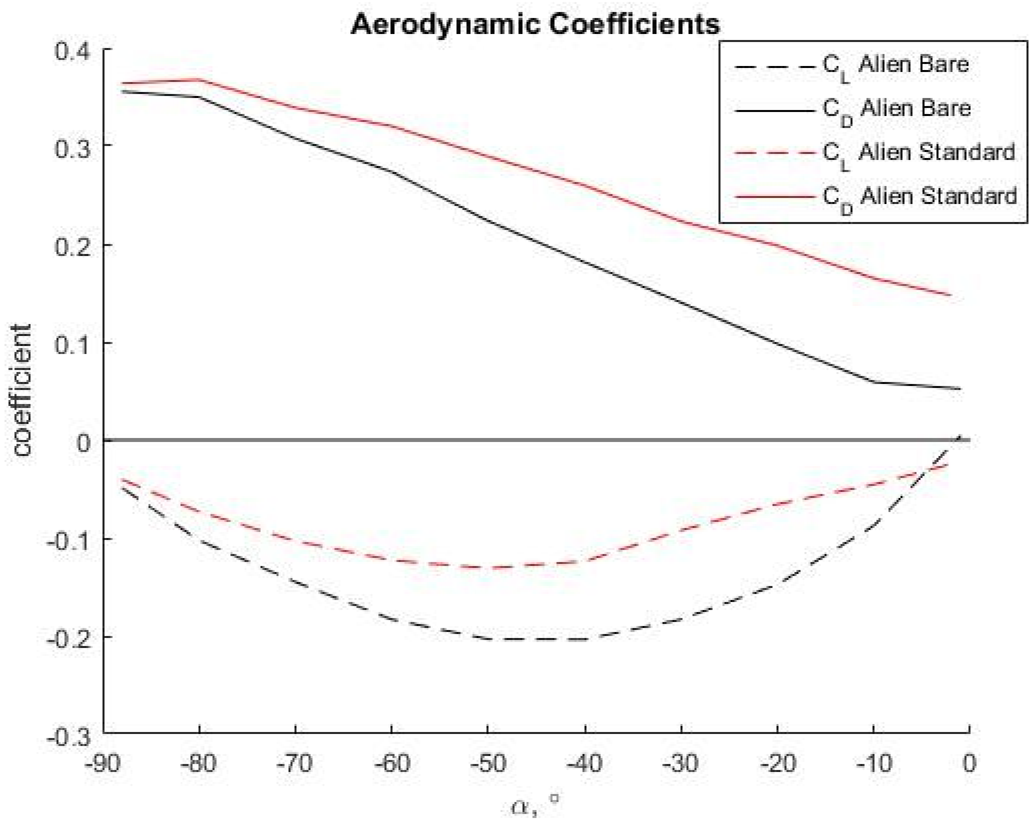
When testing the larger freestyle H frame (5” Alien), adding props only increased drag by an average of 25% and parasitic lift by 18%.



Bare Frame vs. RTF Frame

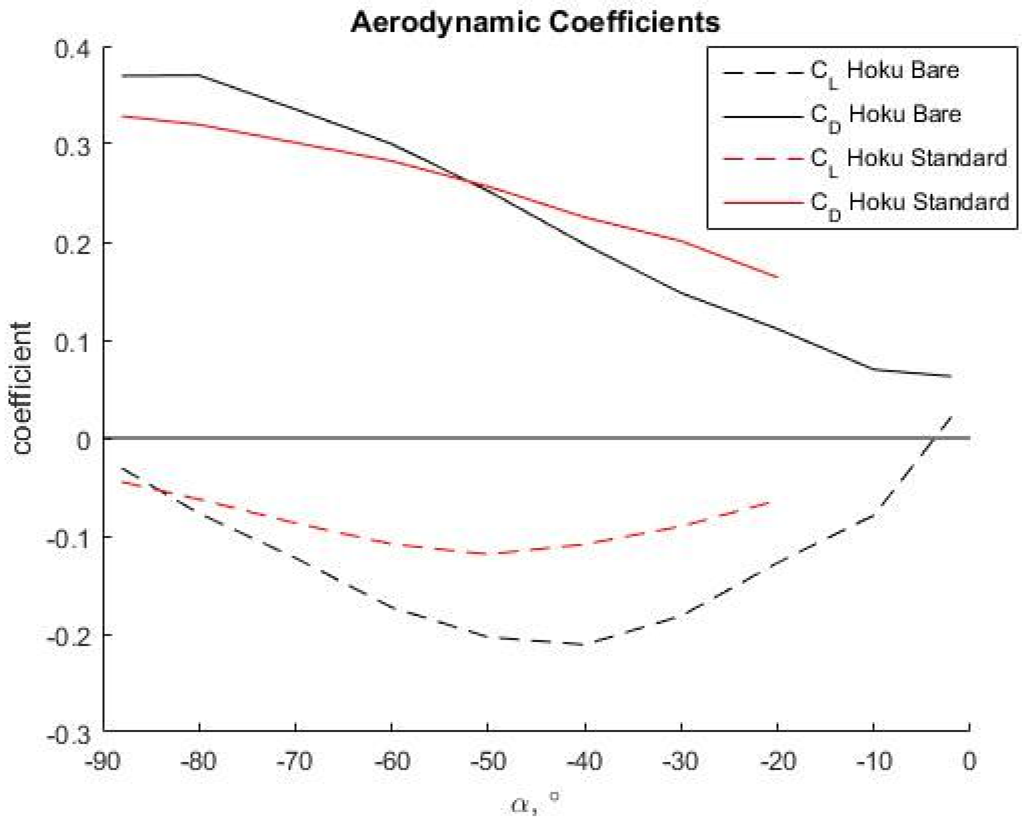
To see the effect that adding all of the electronic components, the 5” Alien frame, FlipModeQuads Hoku frame,Team BlackSheep Vendetta, and the ZMR250 were tested as bare frames and RTF vehicles.

5” Alien:
Adding all of the electronics to the bare 5” Alien frame increased its drag by an average of 60% but decreased parasitic lift by a whopping 98%.



FlipModeQuads Hoku:
The Hoku is designed as an X/H hybrid so it is smaller than the larger freestyle H frames such as the Alien, but larger than the small racing X frames such as the Shrike so building them is not as difficult.

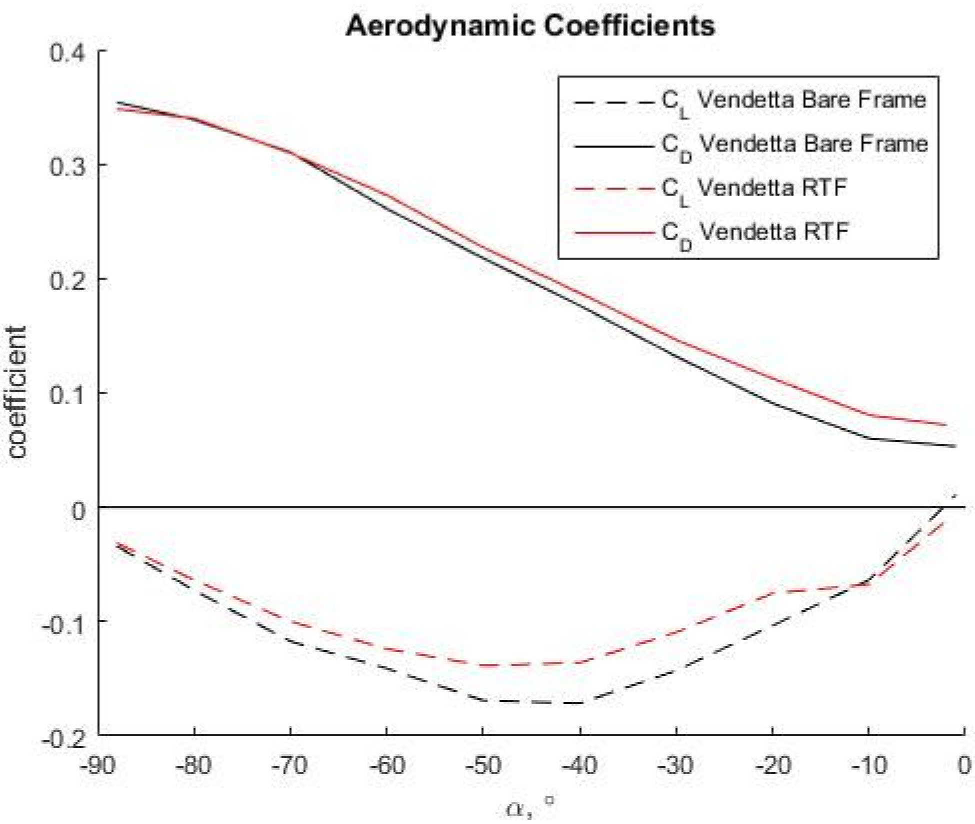
When adding all of the electronic components, drag only went up 8% on average and parasitic lift actually decreased by 29%. Drag seemed to be lower on the RTF frame below around -55 degrees angle of attack but higher at angles steeper than -55 degrees.



Team BlackSheep Vendetta:

The Team BlackSheep Vendetta is a new RTF racing quad that has a full carbon fiber molded monocoque center section and has all of the electronics housed internally except for the motors.

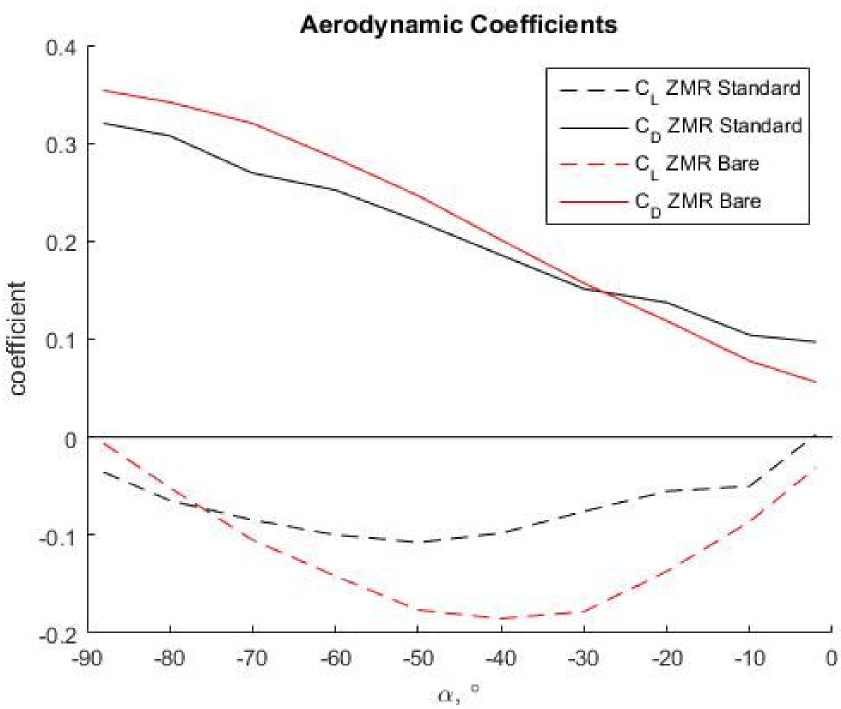
When comparing the bare frame to the RTF version with all of the electronics, the drag increase was only about 4% and parasitic lift was decreased by 12%.



ZMR250:

The ZMR250 is the most common starter quadcopter frame and is based off of the Blackout, which was the most popular and highest selling mini quad frame.

Drag was actually reduced on the RTF compared to the bare frame by a very small amount (~.5%) but parasitic lift was decreased by a whole 81% on the RTF frame versus the bare frame itself.



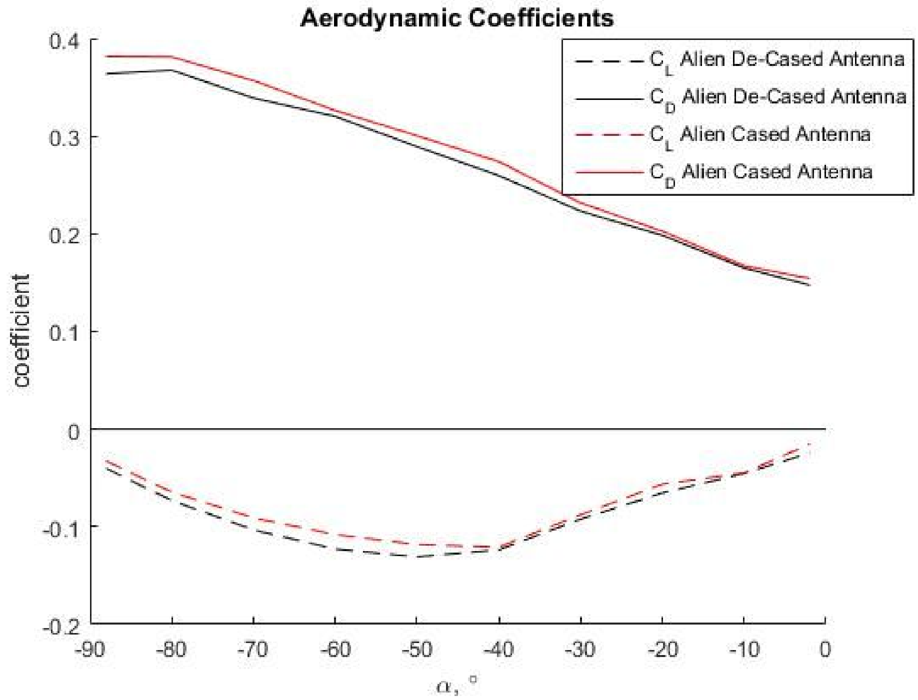
Cased Antenna vs. Non-Cased Antenna

3D Pilots have said that using 5.8gHz video transmitter antennas in a cylindrical case were more aerodynamic than running bare caseless antennas, but there was no data to prove that statement.

Cased 5.8gHz Antenna

De-cased Antenna

The data shows that the de-cased antenna actually yielded a 4% decrease in drag on the 5” Alien frame but a 12% increase in parasitic lift on average.



Concluding Remarks:

The data collected showed interesting trends that were not expected, such as adding an HD recording camera improves aerodynamics of the vehicle, the vast improvement of small racing X frames over the more common larger freestyle H frames, and the discovery that adding a canopy on top actually makes the aerodynamics of the frame generally worse.

There are many new and interesting frames being designed and released into the market and I plan on cont inuing this research and testing the new and improved frames and setups to see how they compare to our current vehicles. I would like to try and design an optimized racing X frame using my knowledge gained from this research and then test it in the wind tunnel and see if it is possible to build a better and faster quad than what is currently on the market now.