# Performance Evaluation and Parameter Identification on DROID III

Julianna J. Plumb[1]
*USRP intern, Dryden Flight Research Center, Edwards, CA, 93523*

**The DROID III project consisted of two main parts. The former, performance evaluation, focused on the performance characteristics of the aircraft such as lift to drag ratio, thrust required for level flight, and rate of climb. The latter, parameter identification, focused on finding the aerodynamic coefficients for the aircraft using a system that creates a mathematical model to match the flight data of doublet maneuvers and the aircraft's response. Both portions of the project called for flight testing and that data is now available on account of this project. The conclusion of the project is that the performance evaluation data is well-within desired standards but could be improved with a thrust model, and that parameter identification is still in need of more data processing but seems to produce reasonable results thus far.**

## I. Introduction

DROID III, one of the four DROID (Dryden Remotely Operated Integrated Drone) aircraft, has been tasked to the INSPIRE students for a second summer of research with the aircraft. Previously, only performance evaluation and moments of inertia testing were conducted. This summer, not only did the INSPIRE team improve upon the methods of the previous team, but the INSPIRE team also worked towards accomplishing parameter identification for the aircraft. The goal is to provide enough aero data for a simulation of the DROID aircraft, as a reliable simulation does not exist at this time. This simulation would not only assist the regularly operating DROID team, but would also contribute towards the demonstration of ACAT (Automated Collision Avoidance Technology) on one of the DROID aircraft.

Performance evaluation consists of pre-flight estimates of characteristics of flight, a preparation for flight testing, flight testing itself, and post-flight data analysis to compare the estimates and flight data. The characteristics focused on were the ratio of lift to drag, thrust required for level flight, and rate of climb. Parameter identification consists of doublet maneuvers during flight and a significant amount of post-flight data analysis using pEst (a parameter estimation tool) in Matlab. The use of pEst is how the different aerodynamic coefficients can be determined. These two sets of data combined can be used to create the desired simulation.

## II. Aircraft Characteristics

The DROID III has a wingspan of 116 inches, a fuselage length of 81 inches, and an empty weight of approximately 50 pounds. This project flew with a 26x10 propeller. The airfoil of this aircraft resembles that of a NACA 2412 which has a 2% camber and therefore continues to produce lift until an angle of attack of -2.0°.

The aircraft was modified in order to better suit this project. Modifications included the addition of string potentiometers on the rudder, elevator, and both ailerons as well as the installation and rewiring of the Piccolo instrumentation system to support the autopilot function.

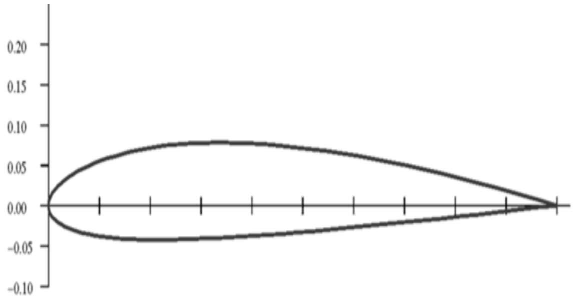

**Figure 1. NACA 2412**. *Camber: 2.0%, Max $C_L$: 1.6,*

### A. Center of Gravity

The initial calculations were performed with only an x-cg location from a slightly different DROID aircraft. These calculations were later updated to

---

[1] INSPIRE Technical Lead, Research and Controls Branch, DFRC, Biola University.

provide better comparisons with the flight data. The actual DROID III center of gravity analysis is included below. The procedures for finding the x and y center of gravity consisted of placing a scale under each wheel (nose gear and the two wheels on the main landing gear) and recording the weights. Then, using the moment arm for each weight position, the center of gravity could be calculated.

$$CG = \frac{Total\ Moment}{Total\ Weight} \tag{1}$$

The z axis center of gravity was determined using a tilt method. In this method either the nose or the tail was displaced several degrees from its original position, the new weights recorded, and the new moments used to find the z-cg. In the end, the y-cg was determined to be located along the centerline of the aircraft due to the symmetrical composition of the DROID III.

| AXIS | POSITION |
|---|---|
| X | 7.45 inches behind leading edge |
| Y | Centerline |
| Z | 6.5 inches above the bottom of the fuselage |

**Table 1. Center of Gravity Locations.** *Relative to the aircraft*

### B. Moments of Inertia

The moments of inertia (MOI) of the DROID III were found through both analytical and testing methods with a smaller team of INSPIRE students. The entirety of this project could be a paper on its own. However, this paper will simply address the highlights and results of the project.

The MOI team performed a thorough analysis of the geometry-based moments of inertia of the DROID III. The previous year had used a simple model of only four shapes. However, this team used a model composed of 18 shapes in order to best estimate the moments of inertia of the aircraft. Using this model and basic inertia equations as well as the parallel axis theorem, the team derived analytical moments of inertia for the aircraft.

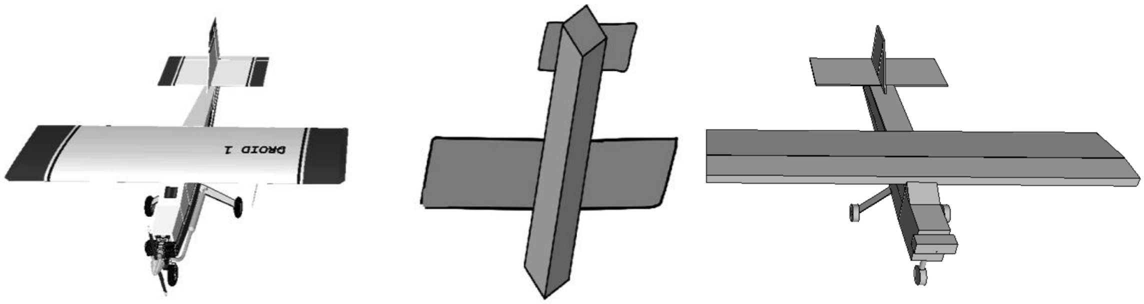

**Figure 2. MOI Models.** *Actual Aircraft, Previous Model, New Model*

The team also found experimental moments of inertia using two test methods: a compound pendulum and a bifilar pendulum test. The compound pendulum test is designed to test the moments of inertia in the roll and pitch (x and y axes) moments. The aircraft is first attached to a secure attachment plate. This plate is made level with respect to the x axis of the aircraft. This detail is extremely important in order to collect valid data. The actual pendulum rod needs to be rigid enough to avoid coupling. That is why the MOI team this summer developed 3’ long square tubing to be used in place of the previous flat rectangular metal rod used. In testing, the method is to swing the aircraft at a small angle in order to excite the moments but not induce coupling.

The bifilar pendulum test consists of two 5’ long cables attached in parallel and equidistant from the center of gravity of the aircraft. This is designed to test the yaw (z axis) moment. The method is to twist the aircraft at a small angle in order to excite the yawing moment but not induce coupling.

| AXIS | ANALYTICAL | EXPERIMENTAL | PERCENT ERROR |
|---|---|---|---|
| Roll – $I_{XX}$ | 3.22 slugs $ft^2$ | 4.97 slugs $ft^2$ | 35% |
| Pitch - $I_{YY}$ | 10.37 slugs $ft^2$ | 4.73 slugs $ft^2$ | 119% |
| Yaw - $I_{ZZ}$ | 11.51 slugs $ft^2$ | 7.74 slugs $ft^2$ | 49% |

**Table 2. Moments of Inertia**

In the end, the experimental moments of inertia proved to be relatively reliable as the data was reasonably clear in watching the damping of the moments. However, these values made for a poor comparison to the analytical moments on account of a few calculation errors that were unable to be remedied prior to the completion of the project. These experimental moments of inertia, all with respect to the previously found center of gravity of the aircraft, were used in the parameter identification analysis.

## III. Performance Evaluation

Pre-flight estimates are performed using basic aerodynamics equations as described in more detail below. This portion of data analysis focuses on specific performance aspects of the aircraft, namely, the ratio of lift to drag, thrust required for level flight, and rate of climb. All of these describe certain aspects of the aircraft that can be easily compared to other aircraft in order to determine how well the aircraft performs overall. What is also necessary for these calculations is an airspeed calibration in order to compensate for installation error in the alpha/beta vane. The following sections will describe the math behind the estimates, the in-flight maneuvers performed, and the final results for each.

### A. Assumptions

In order to perform the pre-flight calculations, a few assumptions needed to be made. The first is that the flying conditions were performed at 85°F at 2600 ft elevation with no wind. The actual flying conditions were relatively close to this assumption with the exception of the lack of wind interference. The second assumption is that the transition from laminar to turbulent flow occurs at a Reynold’s number of 10,000,000. After much research this proved to be a valid assumption. The third assumption is that weight remains constant. This assumption had to be made because the ability to truly monitor the weight change during flight due to fuel usage was quite difficult. Also, the weight varied no more than 2.5 lbs per each thirty minute flight. The fourth assumption made is that the maximum thrust available is constant. Although this is known to be false, it was unable to be truly corrected. In order to correct for propeller efficiency the team would have needed this data. However, this data does not currently exist for the 26x10 propeller for this aircraft. Therefore, using the static thrust data from the previous year of research, the 45 lbs of maximum thrust was used as the standard thrust available. The fifth and final assumption was the equations for large aircraft are the same for small scale aircraft. After comparisons of the data this proved to be a reasonable assumption.

### B. Airspeed Calibration

Pre-flight there are no estimations to be done for this calculation, this can only be discovered in flight with a particular maneuver.

In-flight, the maneuver consists of flying in a circle and repeating at different airspeeds in order to get the best calibration. A circle maneuver is important because at one point the aircraft will have a headwind and on the opposite side of the circle it will encounter a tail wind, therefore it will cover the entire spectrum. During flight, these test points were conducted with the autopilot onboard. The most significant issue was that of the aircraft’s inability to maintain a tight turn at higher speeds resulting in partial circles. However, enough good data was collected to perform the analysis.

$$
\begin{gathered}
Wind\ speed = \frac{Max - Min}{2} \\
True\ airspeed = Min\ + wind\ speed \\
Calibration = True\ airspeed - Pitot\ tube\ speed
\end{gathered}
\tag{2}
$$

Post-flight, Eqs.(2) are used to calculate the necessary calibration. This calibration factor is then integrated into all the data in order to use correct values for the pre-flight estimates.

## C. Lift to Drag Ratio

Pre-flight calculations were performed using basic aerodynamics calculations. Using the fact that the DROID III has an airfoil like that of a NACA 2412, the data from this airfoil provided the two-dimensional $C_{l\alpha}$ (coefficient of lift with respect to angle of attack) that was used to calculate the three-dimensional $C_{L\alpha}$. Both equations take into account the dynamic pressure, surface area, and the respective coefficient.

$$\begin{gathered} L = qSC_L \\ D = qSC_D \end{gathered} \tag{3}$$

In-flight this data was gathered using a series of glides. The pilot would climb to 1000 ft above ground level, trim the aircraft, shut off the engine and attempt to maintain a glide around a certain velocity without affecting the flight too much with movement of the control surfaces. This was then repeated at different velocities.

Post-flight the team looked at the glide lateral distance to the loss of altitude. The final data did seem to follow the correct trend from the pre-flight estimate. This portion of the research was considered successful but could be improved if needed.

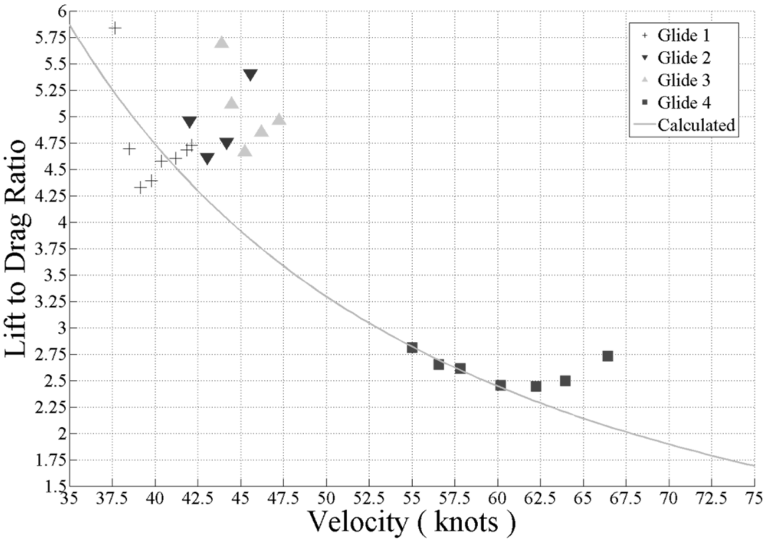

**Figure 3. L/D.** *Pre-flight estimates as compared to the flight data*

## D. Thrust Required for Level Flight

Pre-flight calculations were performed under the idea that the aircraft would be flying at a constant speed and a constant altitude. These provide for a few assumptions to be made. Those assumptions are the fact that when an aircraft is flying at a constant speed then thrust equals drag. When the aircraft is at a constant altitude then lift is equal to weight. When both conditions are satisfied then both assumptions can be made and result in the thrust required for level flight to be equal to the amount of drag at varying velocities.

In-flight the autopilot was used to maintain steady level flight at a constant velocity. This test point was repeated for varying velocities. Small difficulties were encountered because the path for the aircraft was too short to support higher speeds as the aircraft would need to begin its turn for the next leg of its track sooner than at lower speeds.

Post-flight, using the previously mentioned value of 45 lbs of static thrust as the maximum thrust available, the flight data was compared to the pre-flight estimate and matched up rather well.

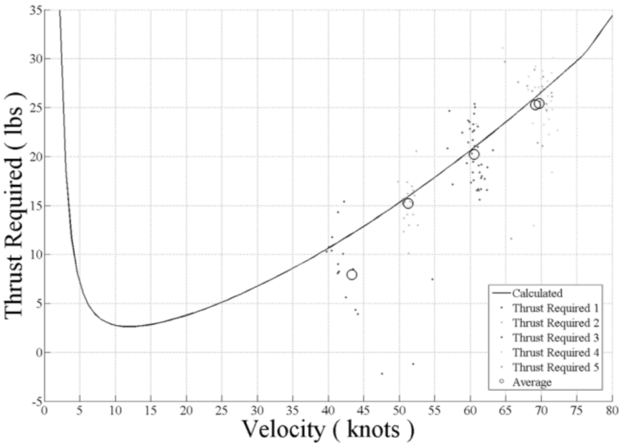

**Figure 4. Thrust Required for Level Flight.** *Flight data as compared to pre-flight estimates*

### E. Rate of Climb

Pre-flight estimates were performed using the value of 45 lbs of static thrust available as well as the constant 50 lb weight of the aircraft and velocities varying from 0-85 knots.

$$ROC = \frac{V \times T_{ex}}{W} \tag{4}$$

In-flight the procedure called for the pilot to achieve steady level flight at a low altitude and then to put the throttle to full and attempt to maintain a specific constant velocity during the climb. This was repeated for varying velocities. Despite the difficulties, the standard deviation of the speed throughout these maneuvers was only 2 or 3 knots.

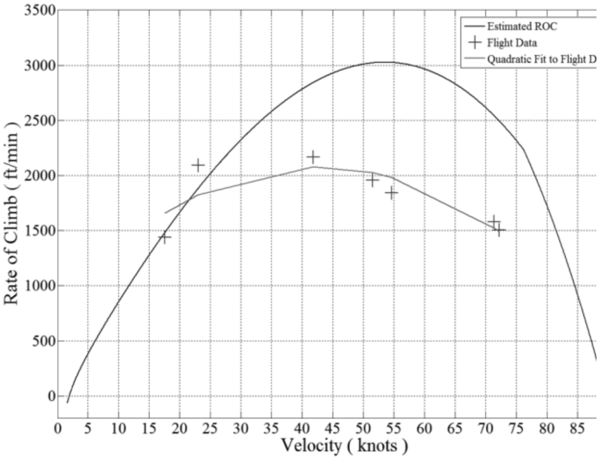

**Figure 5. Rate of Climb.** *Flight data as compared to pre-flight estimates*

Post-flight the team found the amount of altitude achieved in a certain amount of time and used that to calculate the respective rate of climb at the velocity. The comparison of the pre-flight estimates with the flight data was rather reasonable. Although, there is a shift in the peak to peak at a much lower rate of climb, this can be accounted for by the fact of the usage of the 45 lbs of static thrust instead of a true thrust model. However, this was unavailable and the results are quite acceptable.

### F. Partial Conclusions

Overall, the performance evaluation characteristics were within the desired standard of error. The flight data was significantly better than in the previous year of testing. The comparison between the pre-flight estimates and the in-flight calculations is a rather good one with the exception of the need for a better thrust model.

## IV. Parameter Identification

Parameter Identification is, in general, a process involving building a mathematical model that represents a dynamic system using input and output data. Specifically for this project, it was used to find the aerodynamic coefficients of the DROID III. In order to do so, the dynamics of the aircraft must be excited enough to excite a visual damping response from the aircraft. Then these inputs and outputs are used to create a model to represent the DROID III in flight in order to calculate the needed parameters (aerodynamic coefficients).

### A. In-flight

Doublet maneuvers are used to excite the dynamics of the aircraft. A doublet maneuver is when the pilot excites one control surface and either repeats this several times or waits for a response before performing another doublet. The team performed doublets with the ailerons, elevator, and rudder. These, respectively, give you roll, pitch, and yaw doublets. This in turn excites the dynamics in all three axes. Now there is a wide enough spectrum of data to accurately model the aircraft.

### B. Data Analysis in pEst

pEst is a parameter estimation tool that the team used within Matlab. This tool uses all the flight data and looks at control surface deflections, angle of attack, angle of sideslip, velocity, roll rate, yaw rate, pitch rate, all the accelerations, and much more as inputs to its math model system. It then produces an estimated output, compares the estimated output with the actual response of the aircraft, and then uses the difference to keep adjusting the model until it reaches the best fit possible. The numbers that pEst adjusts in order to get a better fit are all the parameters that it is estimating. The parameters are all the aerodynamic coefficients and pEst continues adjusting the numbers until a proper fit is found. The final parameter values are the needed output from pEst. Hopefully, if all has been done correctly, these parameter values will be relatively the same for all the different data sets.

In order to obtain better fits or more reasonable values the user can adjust certain values. However, these are only the ability to either turn a parameter on or off or set its value or to change the weight of the responses to which pEst gives a time history fit. These responses are what pEst looks at to see how close it is to best modeling the aircraft. Changing the weight simply makes it more or less ‘significant’ to pEst when it is trying to find the best fit. The basic usage of pEst consists of this process: input all constants and flight data, run several iterations until it converges in order to find initial values, adjust parameters and responses in order to get a better time history fit on the responses, use the parameter values and compare with other doublet maneuvers at similar flight conditions in order to gauge the accuracy of the values. The final analysis of the parameters relies solely on the comparison with other doublet maneuvers.

The most significant issue with pEst is that the user can achieve good time history fits on the responses and yet have incorrect parameter values. This is the reason for testing different data sets because there is a possibility that the data itself is no good. In the end, the only certainty provided for the values is the repeatability factor for the values for each parameter. pEst also gives Cramer-Rao bounds in order to account for the certainty for each individual parameter value, and hopefully all the parameters are contained within the largest error bound.

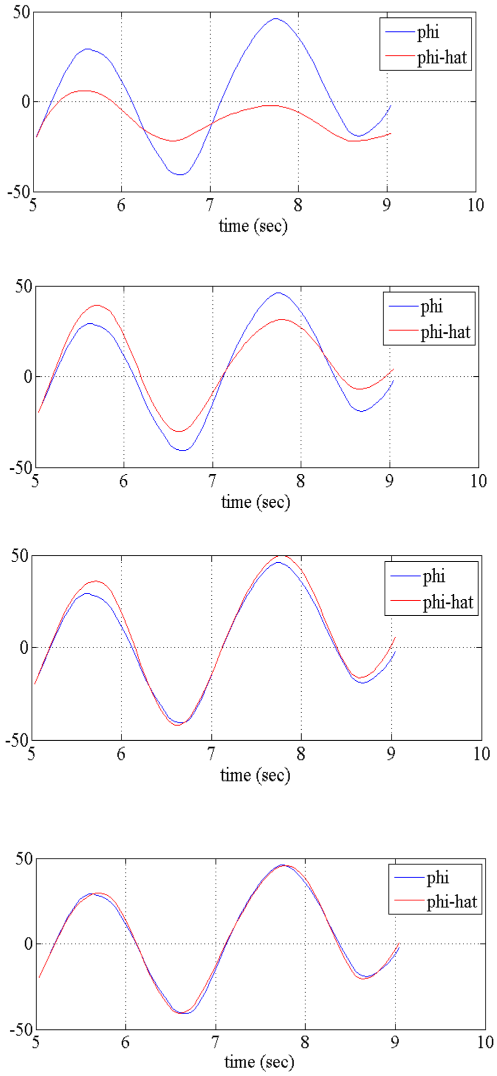

**Figure 6. Response Time History Fit.** *Example of how pEst changes parameters until it achieves the best fit. Red is the pEst estimate.*

### C. Results

The beginning of reasonable results was reached on 8/15/11. However, there is still a significant amount of analysis to be done with all the flight data. The data and processes will be handed off to be finished. At the moment the method is relatively smoothed out and it is simply the labor-intensive portion that needs to be dealt with. Figure (7) gives an example of the end result, a comparison of all the values of a particular parameter at the average alpha for that particular maneuver.

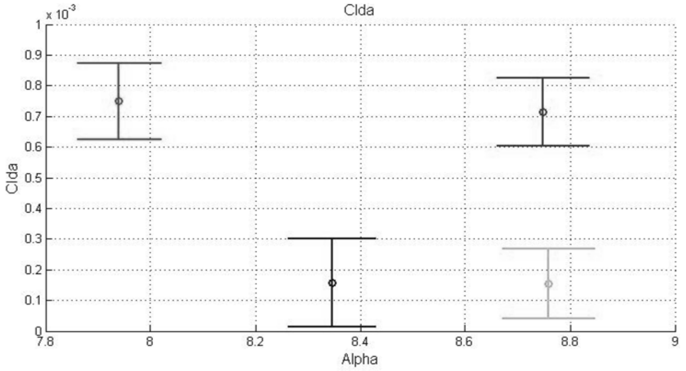

**Figure 7. $C_{lda}$ Values.** *Reasonable values and a small amount of deviation makes for reasonable results.*

### D. Partial Conclusion

Parameter identification proved to be a trying process but just might have provided some decent results in the end. Those results are yet to be run through and compared, but at the moment, the numbers look good. Hopefully the analysis will be completed shortly and the results will make for a usable data set to create a simulation for the DROID III.

## V. Conclusion

This project is considered successful even though the parameter identification is not yet complete. The necessary flight data has been obtained and now only needs to be processed. This rather significant, labor-intensive part of the project, flight-testing, is now complete and should save time and money in the future. The team was careful with all of its procedures and therefore the data quality should be at its maximum quality ability. Once the data is processed it will be used to make a simulation for the DROID aircraft and hopefully will be integrated into a test program.

## Acknowledgments

The author thanks Jinu Idicula and Oscur Murillo for their mentorship, Leslie Monforton and Gary Cosentino for their piloting abilities and other help, Mark Smith for significant Matlab assistance, Amy Scott-Williams for assisting with the coordination of the program, and all Dryden staff and students for supporting the project.