Performance Model Validation For Long-Endurance Unmanned Aircraft Using Mach VS. CL Test Method

Charity Ayre & Benjamin Brierty
47245 Tate Road
Patuxent River, MD 20670
UNITED STATES OF AMERICA

charity.r.ayre.civ@us.navy.mil & benjamin.j.brierty.civ@us.navy.mil

ABSTRACT

The standard method for fixed-wing aircraft performance testing uses a weight/delta method, however most wind-tunnel derived performance models are based on the relationship between Mach and CL. In order to better correlate with established performance models, test points can be flown at Mach and CL intervals by adjusting altitude and airspeed profiles based on real-time aircraft weight. This method is well-suited for long endurance unmanned aircraft since they can be setup on condition using inputs from the test crew and then execute pre-programmed commands that hold the aircraft steady on condition.

1.0 ACRONYMS AND ABBREVIATIONS

C_L – Coefficient of Lift
FTE – Flight Test Engineers
ITT- Integrated Test Team
NGC – Northrop Grumman Corporation
TC – Test Conductor
TLA – Throttle Lever Angle, Throttle Setting
TM - Telemetry
USNTPS – United States Naval Test Pilot School

2.0 INTRODUCTION

In planning the Triton (MQ-4C) performance testing, it was the team's goal to use the most efficient method possible within the aircraft's pre-programmed test commands and limited flight envelope. With the basis of the wind-tunnel model data being Mach and C¬¬L, an idea was hatched to disassociate the test points from pre-planned airspeeds and altitudes. Instead, the test matrix focused on the Mach and CL values required for model validation.

2.1 Triton Performance Testing Background

Triton is a derivative of the Northrop Grumman (NGC) Global Hawk (RQ-4B) block 20 platform, and has been modified to fit the US Navy's mission requirements. Aircraft test data from the Global Hawk program was initially leveraged to reduce the amount of air vehicle testing the Triton platform would require. The Triton air vehicle testing was intended to verify that the modifications from the Global Hawk design did not adversely affect the air vehicle response.

For Triton to meet performance requirements, the team needed to validate the performance model drag polar with flight test derived drag data. This method of flight test validation results in a robust and creditable performance model that can better serve the aircraft throughout its life cycle. In order to implement this method of flight testing, an inflight thrust measurement system needed to be established.

2.1 Initial Test Design

A requirement of an inflight thrust measurement system is a thermally static engine; In order to achieve this, the engine throttle needs to be constant during the data collection maneuver. Since the throttle is continuously active within the MQ-4C control system, a fixed Throttle Lever Angle (TLA) flight test command ("Fixed TLA" command) had to be developed in order to successfully implement this type of flight testing.

Once the "Fixed TLA" command is initiated, the aircraft would begin a 30 second altitude hold to determine an average throttle setting. Once the 30 second average is complete, the "Fixed TLA" command then transitioned the aircraft to the Climb setting. The aircraft nominal Climb logic would set the throttle to its maximum setting and the speed would then be controlled with the ruddervators. However, when operating under the "Fixed TLA" command, as the aircraft goes into the Climb setting the throttle would be fixed to the average TLA that was calculated during the first 30 seconds. The "Fixed TLA" command still requires going into the Climb setting to have the ruddervators control airspeed and let altitude vary.

Since the method of data capture had already been predetermined, the main item left to decide was how many test points would be required to validate the wind tunnel model, and at what flight conditions they needed to be captured. The initial test matrix started with the USNTPS test method recommendation of test points every 5,000 ft of pressure altitude (Gallagher et al, 1992), but given the large altitude span of the Triton test envelope, shown in Figure 1 below, the altitude bands were adjusted to every 10,000 ft of pressure altitude. Multiple test points were required at each altitude to cover the different weight/airspeed values.

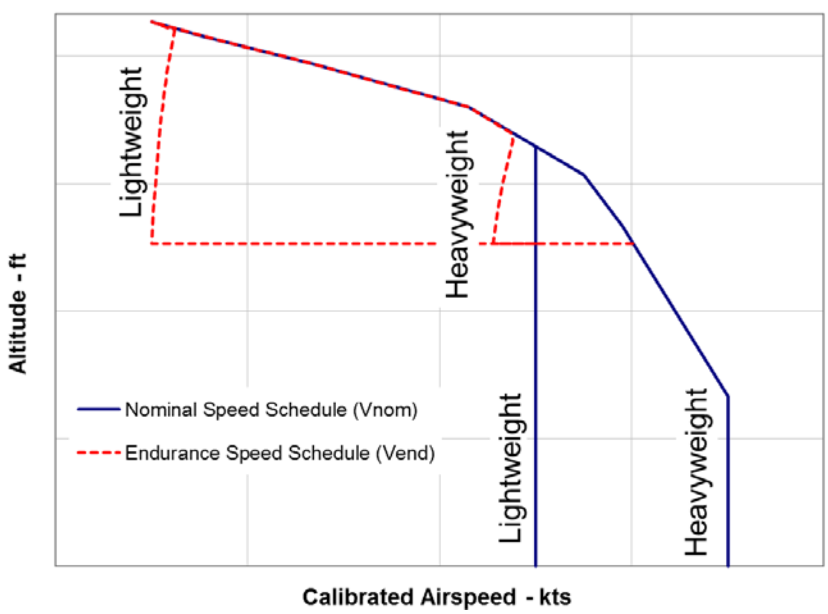

Figure 2-1: Triton Airspeed and Altitude Envelope.

2.3 Shift to Mach and CL Method

After determining how many test points would be required at each 10,000 ft condition to band the Mach and CL conditions of the wind-tunnel model, the discussion went to other possible ways to capture the required data with fewer test points. Since the performance flight test goal was to validate the performance model drag polar, it was decided to treat the development of the flight test matrix as a wind tunnel test. In wind tunnel testing, Mach and angle of attack are targeted, which in turn form the basis of the performance model. For the flight test validation of the performance model, it was decided to target the same Mach numbers and CL ranges that were tested in the wind tunnel.

By switching the flight test matrix from altitude-based to Mach and CL based, the number of test points required for model validation of the clean aircraft configuration was reduced by 14%. This reduction was possible because the test points now lined up with the data they were trying to validate, rather than bracketing that data on both sides.

Initially the new Mach/CL test points were still being tied to specific airspeeds, as shown in Figure 2. However, since the Triton airspeed schedule was related to the real-time weight of the aircraft, test points would only be possible for a limited weight band during each flight. This posed a major threat to test efficiency, and would have required significantly more flights to complete.

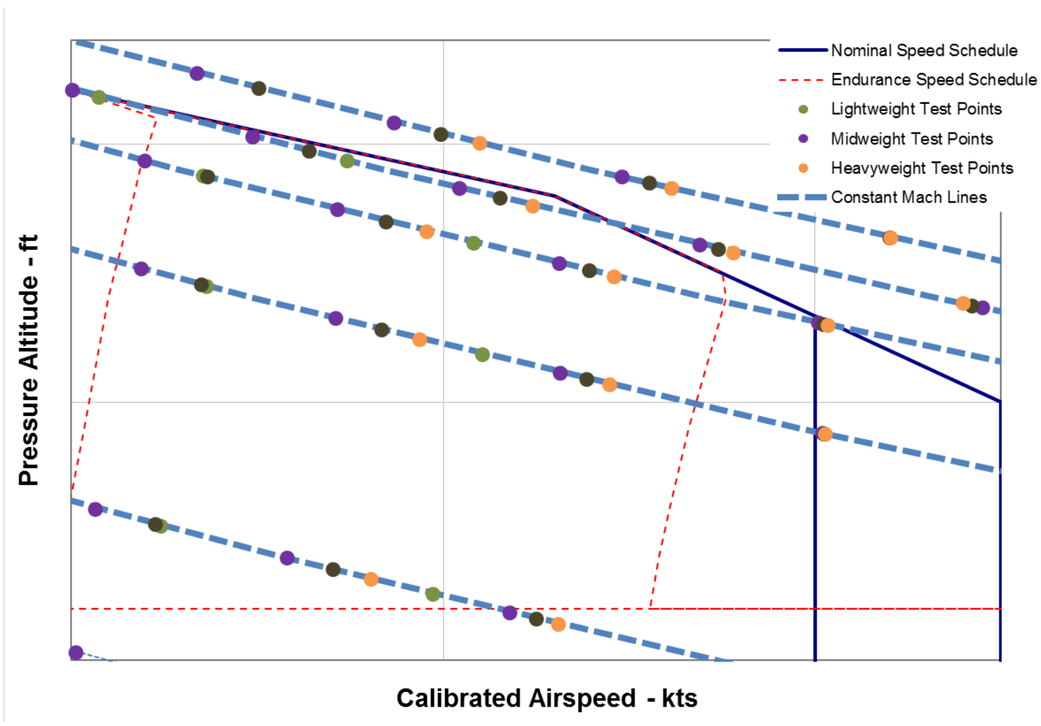

Figure 2-2: Subset of Test Envelope with Mach and CL Points Tied to Weight Bands

After further discussion it was determined that, since a specific Mach and CL point can be accomplished at any gross weight, the test matrix should be completely disassociated from altitude and airspeed, and a new test method was developed. For the given weight at the time of the test point collection, the altitude and airspeed is adjusted to achieve the desired Mach and CL.

2.4 Initial Test Event Planning

The disassociation from preplanned altitudes and airspeeds meant that those flight conditions needed to be calculated and provided to the aircrew real-time. The first step in getting this process approved was to demonstrate to the test plan review chain that we had a notional plan for how to move from one test point to the next. This led to the formation of the initially planned test point progression, shown in Figure 3, moving along the Mach lines to obtain each planned C_L point.

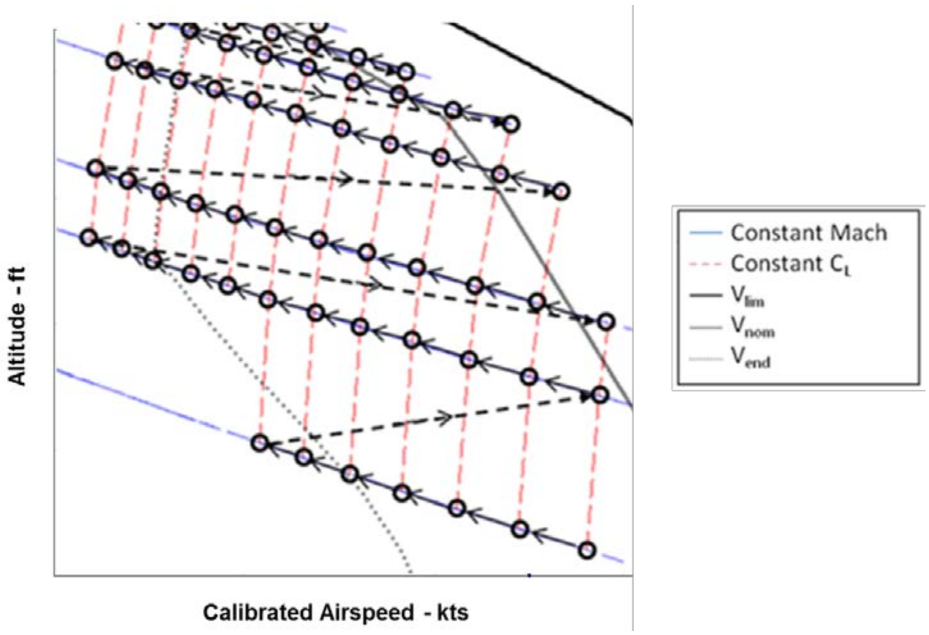

Figure 2-3: Sample Test Point Progression

The test plan review chain requested that we provide them with more information on how we would accurately choose the correct airspeeds and altitudes. A table was created to represent each Mach number with possible altitudes and airspeeds depending on the weight of the aircraft and targeted C_L. Figure 4 is an example of that type of table.

(Mach 0.50) ***CL/Weight***	16000	17000	18000	19000	20000	21000	22000	23000	24000	25000
0.55 (KCAS)	0	0	0	106	108	111	113	116	1108	120
(ft Hp)	0	0	0	47921	46849	45830	44858	43929	43040	42187
0.56	0	0	103	105	108	110	113	115	117	119
	0	0	49277	48147	47075	46056	45083	44155	43265	42413
0.57	0	100	102	105	107	110	112	114	117	119
	0	50696	49501	48371	47299	46279	45307	44378	43489	42636
0.58	97	99	102	104	107	109	112	114	116	118
	52185	50917	49722	48592	47520	46500	45528	44599	43710	42857
0.59	96	99	101	104	106	109	111	113	116	118
	52404	51136	49941	48811	47739	46719	45747	44818	43929	43076
0.60	96	98	101	103	106	108	111	113	115	117
	52620	51353	50158	49028	47955	46936	45963	45035	44145	43292
0.61	95	98	101	103	105	108	110	112	114	117
	52835	51567	50372	49242	48170	47150	46178	45249	44360	43507

Figure 2-4: Example Airspeed and Altitude Lookup Table

Each Mach line that was proposed for testing had an individual table. Every planned C_L test point was represented by a row in the table, and possible weight bands were represented by columns. The cells with zeroes indicate that the altitude and airspeed required to achieve the condition were not possible given the planned test envelope.

An automated version of the table was created as part of the Telemetry (TM) monitoring screens. The automated version takes into account the real-time weight of the aircraft and predicted future weight based on current fuel flow. This allows the Flight Test Engineers (FTEs) to calculate upcoming test points during the flight event. An example of this type of prediction tool can be seen in Figure 5. Values for the targeted Mach and C_L, desired C_L increments, and time until test point execution (Delta Time) would be input into the green boxes. From those inputs, the tool would calculate the altitude and airspeed for each C_L increment. Having the incremental C_L values provided potential test conditions and associated Mach Error. The upcoming test point would then be determined based on the lowest Mach error available for the desired Mach & C_L combination (selected row highlighted in blue). The FTE would ensure that the Test Speed was within the aircraft envelope, as indicated by the Min Speed and Max Speed columns. The FTE would then provide the value in the Rounded Altitude box and Test Speed box to the Test Conductor (TC) for the next test point.

C_L Increment:	0.002	Mach #:	0.5	Delta Time (min):	5	Future Weight at Delta Time (lbs) :	18289

	C_L	Altitude (ft)	Airspeed (KCAS)	Rounded Altitude (ft)	Min Speed (KCAS)	Test Speed (KCAS)	Max Speed (KCAS)	Mach Error
Predicted	0.576	49559	113.9	49600	92	114	139	-.00160
	0.578	49625	113.8	49600	92	114	139	.00078
	0.580	49674	113.7	49700	92	114	139	-.00089
	0.582	49720	113.5	49700	92	114	138	.00007
	0.584	49768	113.4	49800	92	113	138	-.00017

Green boxes need to be filled in based on planned test point

Blue boxes indicate row that would be selected based on Mach Error

Figure 2-5: Example Test Point Prediction Tool

2.5 Test Hazard Mitigation

The main risk associated with this test method was that an airspeed and altitude combination might be chosen that would be outside of the approved test envelope. The main mitigation for this hazard was the table shown in Figure 4 with the unachievable point showing 0/0, and an automated version of the table, shown in Figure 5, used within the test control room to setup for test points. The “Fixed TLA” test points were all planned within the envelope that was to be tested by the air vehicle team. The initial intent was that the detailed performance testing would not occur until the full envelope had been cleared by air vehicle testing to ensure proper stall and aeroelastic margins.

To allow for more performance test time within the program schedule, some “Fixed TLA” test points would be completed before the entire airspeed envelope had been cleared for testing. To accommodate this earlier performance testing, the performance FTE would verify the allowable speed schedule and flight envelope with the cognizant subject matter expert prior to each test event. The risk was further mitigated by planning out which test points would be achievable ahead of time based on allowable speeds, and noting areas that may be of concern if the aircraft weight was lower/heavier than anticipated. In the control room, while determining the exact airspeed for the next test point, the TM monitoring screens had calculations which showed how much the required speed would differ from the normal speed schedule. These measures helped ensure data was gathered in a safe operating envelope.

3.0 LESSONS LEARNED

Initial test execution attempts led to some adjustments in the test point progression. Instead of moving upward in altitude, the decision was made to descend between test points to better use the aircraft energy. Also, it was found that the aircraft was often quicker to change airspeed than altitude, so some points were easier to get by jumping between Mach lines rather than following a full Mach line sweep.

With the unique method of this testing, the task of planning out the flight profile shifted from the TC to a performance FTE. For standard test points that have specific altitude and airspeed, a TC can easily take a test plan and determine the logical progression of test points. For these points a rough estimate of altitude and airspeed could be determined, however it required more time to work through than is typically available for a TC during flight. Since the performance FTEs had predictive planning tools, they worked through each profile and determined the order that would best match the available airspace for each specific test event. As the flight profiles moved toward including test points from different Mach lines the complexity and vast options for test point completion required someone familiar with the test point requirements to select which points to attempt.

Thorough briefings and test crew coordination were considered key to having a successful flight. With the complexity of the aircraft speed schedule logic, pilots were briefed that for each test point they would be provided with specific instructions on how to command the required airspeed. For test efficiency, testers had to be informed of when the pilot was planning to make a turn. As test points were completed, predictive tools were used to determine what the next altitude and airspeed would be; therefore it was crucial to know when a turn for airspace would occur.

Once a few “Fixed TLA” flights had been completed, the team evaluated how the test point matrix could be improved if this method was to be used again. Consideration would be given to performing cruise points in tandem with the “Fixed TLA” points. Also, in the test matrix, points at each Mach number had a C_L range and spacing specified. The clean aircraft configuration and various aircraft drag configurations did not have the same spacing, which meant the points were offset from one another. Aligning to the same test conditions (Mach and C_L values), for each of the different test configurations, would make it easier to transition between test points. An example is provided in Figure 6.

Table 3-1: Test Point Spacing Alignment Example.

Mismatched Spacing		Aligned Spacing	
Clean Configuration	*Gear Down*	*Clean Configuration*	*Gear Down*
Mach 0.5 / C_L 1.00	Mach 0.5 / C_L 0.92	Mach 0.5 / C_L 1.00	Mach 0.5 / C_L 1.00
Mach 0.5 / C_L 0.95		Mach 0.5 / C_L 0.95	
Mach 0.5 / C_L 0.90	Mach 0.5 / C_L 0.86	Mach 0.5 / C_L 0.90	Mach 0.5 / C_L 0.90
Mach 0.5 / C_L 0.85		Mach 0.5 / C_L 0.85	
Mach 0.5 / C_L 0.80	Mach 0.5 / C_L 0.78	Mach 0.5 / C_L 0.80	Mach 0.5 / C_L 0.80
Mach 0.5 / C_L 0.75		Mach 0.5 / C_L 0.75	
Mach 0.5 / C_L 0.70	Mach 0.5 / C_L 0.70	Mach 0.5 / C_L 0.70	Mach 0.5 / C_L 0.70

After initial testing it was determined that the 30 second average period may have been too short of a time slice to get the actual TLA average at those conditions. For the 30 second time period the throttle seemed to average either too high or too low, which caused the aircraft to climb or descend outside of the given altitude tolerance.

For future implementation, it would be beneficial to be able to either set a specific throttle value within a safe range, or have the capability to adjust the duration of the averaging period, if more time is needed.

4.0 APPLICABILITY TO OTHER AIRCRAFT

With proper planning this methodology may be applied to any platform. The main requirement for using this method is to have the ability to monitor or predict the CL for a given flight condition. It is also recommended to have at least two performance engineers involved with the execution of the test event; this allows one person to be checking that the test point in progress stays within data tolerances, while the other person calculates the airspeed and altitude conditions for the next test point.

A manned aircraft platform would have the benefit of the pilot knowing sooner if the aircraft was leaving a steady cruise to climb or descend. This would allow the pilot to make minor adjustments to the setup, without needing to completely reset the test point. Other issues that would need to be considered are accounting for larger flight envelopes (in comparison to the basic speed schedule of the Triton aircraft), and whether this method could be done efficiently with aircraft that burn fuel at a higher rate (in comparison to the long endurance capability of Triton).

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5.0 REFERENCES

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