PLANNING, EXECUTION, AND ANALYSIS OF THE MERIDIAN UAS FLIGHT TEST PROGRAM INCLUDING SYSTEM AND PARAMETER IDENTIFICATION

BY

Jonathan Tom

Submitted to the graduate degree program in Aerospace Engineering and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Science.

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Dr. Shahriar Keshmiri, Chairperson

Committee members:

____
Dr. David Downing

____
Dr. Richard Hale

____
Dr. Mark Ewing

Date defended: April 21, 2010

The Thesis Committee for Jonathan Tom certifies
that this is the approved Version of the following thesis:

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Committee:

____
Dr. Shahriar Keshmiri, Chairperson

Committee members: _______________________________
Dr. David Downing

____
Dr. Richard Hale

____
Dr. Mark Ewing

Date approved: April 27, 2010

Abstract

The purpose of this Master Thesis is to present the flight test procedures, planning, and analysis including system identification, parameter identification, and drag calculations of the Meridian UAS. The system identification is performed using traditional techniques including Modified Transient Peak Ratio method and Time Ratio method. A drag reduction effort on the aircraft is also analyzed and the drag coefficient is calculated during specific flight conditions. The parameter identification is performed using a 6-DOF non-linear model of the Meridian UAS.

The 6-DOF non-linear model was adapted from a previous model made for the 1/3 scale Yak-54 UAV. The model was adapted to the Meridian UAS by changing the input stability and control derivatives developed in AAA and integrating an enhanced engine model. The resulting AAA generated model is then compared to flight test telemetry demonstrating that it effectively predicts the dynamics of the Meridian.

The input stability and control derivatives are then tuned to the flight test telemetry to improve the fidelity of the model. The tuning identifies error in the derivatives and demonstrates the dominant stability and control derivative for a specific dynamic mode. The performance of the tuned Meridian 6-DOF non-linear model is comparable to a high fidelity model and can be used for Meridian simulation and crew training.

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First I must thank Dr. Shah Keshmiri for his advice and guidance over the last two years. Without your support, this work would not be possible. Thanks to Dave Royer and Bill Donovan for being diligent co-workers and fellow Antarctic explorers!

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Finally, I want to thank my family for supporting and believing in me when I told them that I, a country bumpkin raised on a South Texas cattle ranch, wanted to become an Aerospace Engineer.

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Nomenclature

Symbol	***Description***	***Units***
C_{D_1}	Drag coefficient	-
C_{D_0}	Drag coefficient for zero angle of attack	-
C_{D_1}	Drag coefficient for trim condition	-
C_{D_α}	Change in drag coefficient w.r.t. angle of attack	1/rad
$C_{D_{\delta e}}$	Change in drag coefficient w.r.t. elevator deflection	1/rad
C_{D_u}	Change in drag coefficient w.r.t. airspeed	-
C_{L_0}	Lift coefficient for zero angle of attack	-
C_{L_1}	Lift coefficient for trim condition	-
C_{L_α}	Change in lift coefficient w.r.t. angle of attack	1/rad
$C_{L_{\dot{\alpha}}}$	Change in lift coefficient w.r.t. change in angle of attack	1/rad
C_{l_β}	Change in rolling moment coefficient w.r.t. sideslip angle	1/rad
$C_{l_{\delta a}}$	Change in rolling moment coefficient w.r.t. aileron deflection	1/rad
$C_{L_{\delta e}}$	Change in lift coefficient w.r.t. elevator deflection	1/rad

Symbol	***Description***	***Units***
$C_{l_{\delta r}}$	Change in rolling moment coefficient w.r.t. rudder deflection	1/rad
C_{l_p}	Change in rolling moment coefficient w.r.t. roll rate	1/rad
C_{L_q}	Change in lift coefficient w.r.t. pitch rate	1/rad
C_{l_r}	Change in rolling moment coefficient w.r.t. yaw rate	1/rad
C_{L_u}	Change in lift coefficient w.r.t. airspeed	-
C_{m_0}	Pitching moment coefficient for zero angle of attack	-
C_{m_1}	Pitching moment coefficient for trim condition	-
C_{m_α}	Change in pitching moment coefficient w.r.t. angle of attack	1/rad
$C_{m_{\dot{\alpha}}}$	Change in pitching moment coefficient w.r.t. change in angle of attack	1/rad
$C_{m_{\delta e}}$	Change in pitching moment coefficient w.r.t. elevator deflection	1/rad
C_{m_q}	Change in pitching moment coefficient w.r.t. pitch rate	1/rad
$C_{m_{T1}}$	Trim pitching moment coefficient due to thrust	-
$C_{m_{T\alpha}}$	Change in trim pitching moment coefficient due to thrust w.r.t. angle of attack	1/rad

Symbol	***Description***	***Units***
$C_{m_{Tu}}$	Change in trim pitching moment coefficient due to thrust w.r.t. airspeed	-
C_{m_u}	Change in pitching moment coefficient w.r.t. airspeed	-
C_{n_β}	Change in yawing moment coefficient w.r.t. sideslip angle	1/rad
$C_{n_{\delta a}}$	Change in yawing moment coefficient w.r.t. aileron deflection	1/rad
$C_{n_{\delta r}}$	Change in yawing moment coefficient w.r.t. rudder deflection	1/rad
C_{n_p}	Change in yawing moment coefficient w.r.t. roll rate	1/rad
C_{n_r}	Change in yawing moment coefficient w.r.t. yaw rate	1/rad
$C_{n_{T\beta}}$	Change in yawing moment coefficient due to thrust w.r.t. sideslip angle	1/rad
$C_{T_{x1}}$	Thrust coefficient for trim condition in X-direction	-
$C_{T_{xu}}$	Change in thrust coefficient in X-direction w.r.t. airspeed	-
C_{y_β}	Change in side force coefficient w.r.t. sideslip angle	1/rad
$C_{y_{\delta a}}$	Change in side force coefficient w.r.t. aileron deflection	1/rad
$C_{y_{\delta r}}$	Change in side force coefficient w.r.t. rudder deflection	1/rad

Symbol	***Description***	***Units***
C_{y_p}	Change in side force coefficient w.r.t. roll rate	1/rad
C_{y_r}	Change in side force coefficient w.r.t. yaw rate	1/rad
δ_T	Throttle setting	%
g	gravity	ft/sec^2
m	mass of aircraft	slugs
P	Aircraft engine power	HP
Q	Pitch Rate	deg/sec
R	Yaw rate	deg/sec
S	Wing surface area	ft2
T	Thrust	lbs
$\dot{U}$	Change in X-direction airspeed	ft/sec^2
V	Y-direction airspeed	ft/sec
V_a	Total true airspeed	ft/sec
W	Z-direction airspeed	ft/sec

Greek	***Description***	***Units***
α	Angle of attack	deg
β	Sideslip angle	deg
δ	Control surface deflection angle	deg
θ	Pitch attitude angle	deg

List of Abbreviations

Abbreviation	***Description***
6-DOF	6 Degrees of Freedom
A&P	Airframe and Powerplant
AAA	Advanced Aircraft Analysis
AGL	Above Ground Level
CG	Center of Gravity
CReSIS	Center for Remote Sensing of Ice Sheets
CST	Central Standard Time
FADEC	Full Authority Digital Engine Control
FTE	Flight Test Engineer
GPS	Global Positioning System
GUI	Graphic User Interface
HP	Horse Power
KUAE	University of Kansas Department of Aerospace Engineering
LOS	Line-of-Sight

Abbreviation	***Description***
MAAS	Meridian Auxiliary Avionics System
MFD	Multi-Functional Display
MSL	Mean Sea Level
MT	Mountain Time
NSF	National Science Foundation
NZ	New Zealand Time
PFD	Primary Flight Display
PIC	Pilot in Command
RC	Radio Control
TAF	Terminal Aerodrome Forecast
TPR	Transient Peak Ratio Method
UAS	Uninhabited Aerial System
UAV	Unmanned Aerial Vehicle
VHF	Very High Frequency

1 Introduction

The University of Kansas Department of Aerospace Engineering (KUAE) [1] is a leader in the development and research of Unmanned Aerial Vehicles (UAV) including an extensive flight test program. KUAE operates a fleet of 1/3 scale Yak-54 UAVs and is currently manufacturing and testing the Meridian Uninhabited Aerial System (UAS). The Meridian UAS is a semi-autonomous aircraft designed and developed for the Center for Remote Sensing of Ice Sheets (CReSIS) [2]. The CReSIS is a National Science Foundation (NSF) funded research center based at the University of Kansas with the mission to develop the technology and equipment necessary for measuring the melting rate of polar ice sheets.

The Meridian UAS is a CReSIS funded project designed to carry the ice penetrating radar for the polar research missions. The Meridian UAS is a V-tail configuration with a 26 foot wing span and a gross takeoff weight of 1,100 pounds [3]. The Meridian UAS has a 135 horsepower Thielert diesel engine [4,5] that is monitored using the Meridian Auxiliary Avionics System (MAAS) [6]. The Meridian UAS is designed and manufactured by faculty and students in the KUAE department and is currently in the testing phase of development. An image of the Meridian UAS is presented in Figure 1.1.

Figure 1.1: Meridian Uninhabited Aerial System [7]

The testing phase of the Meridian UAS involves the evaluation of the hardware and software installed on the aircraft via ground and flight testing. Before the flight test program initiated, the aircraft underwent an extensive ground test program beginning 6 months prior to the first flight. During the flight test program, ground testing continued in support of the flight test missions.

The primary focus of this thesis is the system identification and parameter identification performed using the flight test telemetry. The maneuvers required for the analysis must be planned and integrated into the flight test mission and safe procedures must be developed to minimize the risk for each flight. Because the quality of the analysis is dependent on the quality of the flight test telemetry, the flight test procedures and planning are presented in this document.

The flight test procedure discusses the method developed to ensure that each flight test mission is efficiently executed in a safe manner. The flight test planning discusses the flight test missions designed to bring the Meridian UAS to a fully operational status and gather adequate data for this analysis. The execution of the flight test missions presents a summary of each mission completed and the specific maneuvers performed for system and parameter identification. In an effort to improve the efficiency and effectiveness of the flight test operations, a list of recommended changes to the flight test program are presented. The flight test plans presented in this document are updated to reflect the lessons learned from the actual flight test missions.

During the flight test program, the Dutch Roll and Short Period modes of the Meridian UAS are perturbed. The Dutch Roll and Short Period are the only dynamic modes analyzed because the Meridian UAS is a prototype aircraft and these two modes are the easiest and safest to perturb. These maneuvers are analyzed using traditional techniques including Time Ratio Method and Modified Transient Peak Ratio Method [8] and then further investigated using a 6-DOF non-linear model of the Meridian UAS. The non-dimensional aerodynamic derivatives for the Meridian UAS are calculated using the Advanced Aircraft Analysis (AAA) software [9] and input into a 6-DOF non-linear aircraft model developed in Simulink [10,11]. To further increase the fidelity of the 6-DOF model, an advanced engine model was integrated into the Meridian 6-DOF model [12].

To validate the 6-DOF non-linear model, the initial conditions and control inputs downloaded from the flight test telemetry are entered into the model and the output is compared with the flight telemetry. The non-dimensional derivatives developed in AAA are then tuned to minimize the normalized root mean squared error between the relevant outputs of the 6-DOF non-linear model and the flight test telemetry.

After the first flight of the Meridian UAS, it was determined that the drag was unacceptably high. Since that discovery, a drag reduction effort commenced. To evaluate the effectiveness of the drag reduction techniques, the drag coefficient is calculated for different missions of the flight test program.

2 Flight Test Procedures

The purpose of this chapter is to describe the procedures required to carry out a Meridian UAS flight test mission. The flight test procedures described in this chapter must be followed before every flight test to minimize risk and maximize success in the completion of mission objectives.

Before any flight test the A&P mechanic assigned to the Meridian must update and sign off on the Maintenance and Alterations Log. Unless there is an applicable weight and balance document already on record, the Meridian must be fully assembled and weighed using scales beneath the landing gear to determine the location of the center of gravity with the aircraft in the flight configuration. The flight plan document is then completed using the location of the center of gravity, amount of fuel onboard, weather, and other mission specifics. The flight plan document is presented in the pre-flight briefing along with the mission objectives and procedure so that the entire flight test team can comment and make suggestions as a group. The pre-flight checklist and startup procedure must be followed every time a test requires an engine start.

2.1 Weight and Balance Procedure

A completed copy of the weight and balance document is a required for every flight test mission. A previous weight and balance document may be used for the flight test mission if the only change in aircraft configuration and weight is the amount of fuel onboard. The weight and balance must be completed with the Meridian in the flight configuration. A blank copy of the weight and balance document along with the center of gravity shift due to fuel added and a figure of the aircraft in the flight configuration are presented in Appendix A.

2.2 Flight Plan Document

A flight plan document must be completed for every flight test mission. A blank copy of the flight plan document is shown in Appendix B. The flight plan document includes the date, aircraft, and flight number for identification. Flights are numbered by the date flown followed by a dash and the flight for that date (YYYYMMDD-#). The flight number for the first flight on January 1^{st}, 2010 would be 20100101-1. A second flight on the same date would be 20100101-2.

The flight test team members are listed by name next to their respective titles. The team includes a safety officer, flight test director, pilot, pilot assistant, multiple flight test engineer positions, and an observer.

The aircraft section provides space to list the aircraft configuration including the center of gravity location, gross takeoff weight, fuel onboard, estimated mission flight time, reserve flight time, and any maintenance items that have been worked on since the last flight. The mission flight plan is listed in the procedure.

The mission section of the flight plan document lists the primary objective of the flight test mission and the medium on which the data is recorded. The safety section lists any go/no-go items, abort criteria with regards to the environment, weather, or aircraft, and any unusual emergency procedures for the mission.

The weather section provides space to list the current weather observation and forecast from the local TAF. The post-flight comments box provides space for the flight test engineer to note the performance of the mission.

2.3 Flight Briefings

Before every flight test mission, the flight test director leads a pre-flight briefing. The pre-flight briefing must include all members of the flight test team and representatives of the flight test range depending on availability. During the briefing, the flight test engineers present the weight and balance and flight test plan. The flight test team also discusses the mission procedures and emergency procedures. The briefing provides all those involved with the mission a chance to make comments or suggestions to improve the efficiency or effectiveness in the effort of completing mission objectives while increasing the margin of safety.

A post-flight briefing should also be conducted so that the team members can discuss the efficiency and effectiveness of the flight test procedure and the completion of objectives. Safety concerns that may have arisen during the flight test are also discussed and any appropriate changes to the flight test procedures to alleviate those concerns. The post-flight briefing also provides a moment for the team members to note down what they observed during the flight test.

2.4 Pre-Flight Checklist and Engine Startup Procedure

Any time the engine is ran on the Meridian, a pre-flight check must be performed following the checklist. The Meridian pre-flight checklist is presented in Appendix C. The first step of the pre-flight checklist is a visual inspection of the airframe including the following components.

- Fuselage
- Left Wing
- Firewall Forward
- Right Wing
- Empennage

The engine startup battery and wePilot backup battery must be checked for appropriate charge. The engine oil, gearbox oil, and engine coolant levels must be checked.

The current weather observation must be checked within 30 minutes of takeoff. The weather conditions to be checked include:

- Wind Speed
- Wind Direction
- Visibility
- Cloud Ceiling
- Temperature
- Dew Point
- Pressure Altitude
- Density Altitude

Critical weather information required for accurate data analysis includes the temperature and pressure altitude.

Before takeoff, a field safety briefing is conducted to ensure everyone involved is aware of the mission and safety procedures during the flight test. Following the safety briefing, the engine startup procedure may begin. The engine startup must follow the procedure detailed in the pre-flight checklist to ensure that all systems are activated in the correct order and prevent a FADEC error. The checklist also details when team members should be notified of specific events during the procedure.

The wePilot ground station must be checked before the engine start according to the checklist provided by Viking Aerospace and the pilot must conduct an actuator control sweep, throttle test, kill switch test, and range check.

After the engine is turned on and warmed, the pilot will perform a brakes check and brief taxi test while MAAS is checked for functionality. At this point the radio operator calls the local air traffic control for clearance to takeoff and performs the final go/no-go for take-off.

The preflight checklist must be considered a “living document” that must change and evolve with the aircraft. If the aircraft is modified, the preflight checklist should be adjusted to reflect that modification.

3 Meridian Flight Test Planning

The initial field trials and flight tests are carried out in two phases. Phase I includes the pilot-in-the-loop flight test operations of the Meridian conducted under radio control within close line-of-sight. Phase II includes Meridian autonomous flight test operations similar to Yak-54 autonomous flights, except on a larger scale and within line-of-sight of the ground station. All Phase I and II flight test plans are tested using the Yak-54 testbed UAV before the Meridian flight test is conducted.

The wePilot control system operates in three modes:

- Pilot-in-the-Loop Radio Control Mode
- Pilot-in-the-Loop Assisted Mode
- Automatic Mode

In the radio control mode, the pilot directly controls the Meridian's throttle and control surface positions using the RC transmitter. The radio control mode is used during the Phase I flight test plan. The wePilot assisted mode allows the pilot to control the wePilot's outer control loops including airspeed, climb and descent rate, and bank limited turning. The wePilot automatic mode removes control of the aircraft from the pilot and cedes it to the wePilot ground station operator. From the wePilot ground station, the operator can command the wePilot to track to preprogrammed way points at a predetermined speed and altitude. The wePilot assisted and automatic modes are tested in Phase II of the flight test program.

Before any of the flight test plans described in this section can be attempted, the procedures detailed in Chapter 2 must be completed.

3.1 Phase I: Pilot-in-the-Loop Flight Tests

This section provides a detailed explanation of the phase I flight test plan for the CReSIS Meridian unmanned aerial system. The purpose of the Phase I flight tests is to verify the integrity of the Meridian's airframe and systems in flight. The first flight operation will take place on the scaled mortar firing range located at Fort Riley, Kansas. The flight test procedure calls for a runway taxi test before take-off to validate that the grass strip runway at Fort Riley is suitable for a large uninhabited aircraft. The flight plan calls for the aircraft to take-off, trim, practice approaches, and land. The desired flight path is designed to keep the UAS in visual range and under radio control.

3.1.1 Flight Test Objectives

The Phase I flight test objectives include:

1. Demonstrate the airworthiness of the Meridian's airframe and avionics systems in flight

2. Evaluate the handling qualities of the Meridian using the Cooper-Harper Pilot Rating Scale
3. Examine flight control history for saturated control surface inputs
4. Examine the engine performance and overall drag of the Meridian
5. Validate the wePilot sensors in flight
6. Validate the communication systems in flight

At the conclusion of a Phase I flight, the flight telemetry is examined to find if any of the control surfaces are being saturated during flight. The pilot evaluates the handling qualities of the aircraft using the Cooper-Harper pilot rating scale shown in Appendix D. Though the Phase I flight plan is not specifically a system identification flight, control surface doublets may be performed in flight and the flight telemetry analyzed to harvest aircraft flight characteristics that can be compared with the mathematical model of the Meridian. This comparison can be used to evaluate if the aircraft dynamics are within the expected uncertainty of the mathematical model used to design the wePilot flight control system.

The pilot must verify that the aircraft has adequate handling qualities that require no alterations, and the aircraft controls are not being saturated in flight, before the flight test program can enter Phase II, autonomous flight test. If the aircraft does not have adequate handling qualities or controllability, then the aircraft controls must be reconfigured and the Phase I flight plan repeated. The flight telemetry can be analyzed to confirm the handling qualities using the MIL-F-8785C standards. If the handling qualities cannot be confirmed during Phase I due to a bad elevator input, then the objective will be completed during the Phase II dynamic analysis flight test, and is not a primary objective of Phase I.

The engine load and flight telemetry is used to determine the overall drag of the aircraft and determine if it meets the design requirements. The flight telemetry is examined closely to determine if the wePilot sensors are providing the correct information to the autopilot. The wePilot sensors telemetry can be compared with that of the NAV-420 installed in the avionics box. The communication systems must be confirmed to be working in flight with no drop outs. All of the communication systems must be thoroughly tested on the ground before the tested in flight.

3.1.2 Flight Test Limits

The Phase I flight test limits for the Meridian are as follows:

1. Manual Flight Time Limit: 30 minutes
2. Maximum Crosswinds: 5 knots
3. Maximum Constant Winds: 10 knots Head / 0 knots Tail
4. Maximum Wind Gusts: 5 knots
5. Maximum Ambient Temperature: 85° F
6. Maximum Test Altitude: 1500 feet AGL

7. Minimum Maneuvering Airspeed: 70 knots
8. Maximum Test Airspeed: 90 knots
9. Maximum Bank Angle: 30 degrees
10. Load Factor Min: -0.5
11. Load Factor Max: 1.5

The manual flight time limit was determined by having a discussion with the pilot and regarding his physical limits. The winds limits were determined after discussing safety concerns during the flight safety review board. The maximum ambient temperature was suggested by the structural designers and avionics box temperature limits. The maximum test altitude was set 500 feet above a standard flight pattern. The minimum airspeed limit was determined using the estimated stall speed of the aircraft, and the maximum airspeed was limited to keep the aircraft inside the flight test area. The bank angle and load limits were set by the structural designers to limit the loads on the aircraft during the first flight.

If at any time during the flight test the aircraft approaches a predefined limit, the flight test engineer monitoring the ground station calls out to the pilot assistant with a warning, whom then directs the pilot with a course of action. The flight time has a never exceed limit of 30 minutes, and the fuel bladder will carry a minimum of 5 gallons of fuel for every flight test. The Phase I flight test has a planned flight time no longer than 15 minutes to reduce pilot workload.

The desired cruise airspeed is 80 knots and has a safety factor of 1.5 over the estimated stall airspeed at 54 knots [3]. The desired approach airspeed is 70 knots, selected with a safety factor of 1.3 over the estimated stall airspeed. The pilot is warned if the aircraft reaches an airspeed below 70 knots or above 90 knots. The lower bound is to prevent the aircraft from stalling, and the upper bound is to prevent the aircraft from flying out of line-of-sight.

The maximum crosswinds are limited to 5 knots to ease the difficulty of landing the aircraft. The maximum constant winds are limited to 10 knots of head wind with 5 knots of gust to limit in flight turbulence. Having the wind out of the north in the direction of the Fort Riley runway will lower the ground speed of the aircraft during take-off and landing. Tail wind is bound to 0 knots to limit the ground speed of the aircraft on take-off and landing. On the day of the flight the wind must be at calm or prevailing out of the North. The maximum ambient temperature is limited to 85° F to limit the temperature on the composite structure and inside the avionics box.

3.1.3 Fort Riley Flight Test Area

The flight test will be conducted at Fort Riley, KS. For initial RC flight tests, the vehicle will be kept within close line of sight using the flight test area defined in Figure 3.1. The flight test area has dimensions of approximately 1.15 by 1.2 miles and contains a grass strip runway approximately 1,800 feet long and 100 feet wide. The ground station will be set up on the southeast corner of the runway while all flying will be conducted west of the runway. The runway is located at an elevation of 1,250 feet above sea level. The runway has an average gradient of 2% sloping upwards at a heading of 350°, making 350° the only direction the aircraft can land. The map shows an outline for the flight test area that the vehicle must remain in for this flight.

There is a densely populated area composed of parking lots and office buildings approximately 0.9 miles southwest of the southern flight test boundary. The northern boundary of the flight test area is immediately adjacent to an occasionally populated live firing range. The designated runway is 0.25 miles south of the live firing range. If the aircraft is lost in the live firing range, a large coordination effort with Fort Riley will be required to recover it.

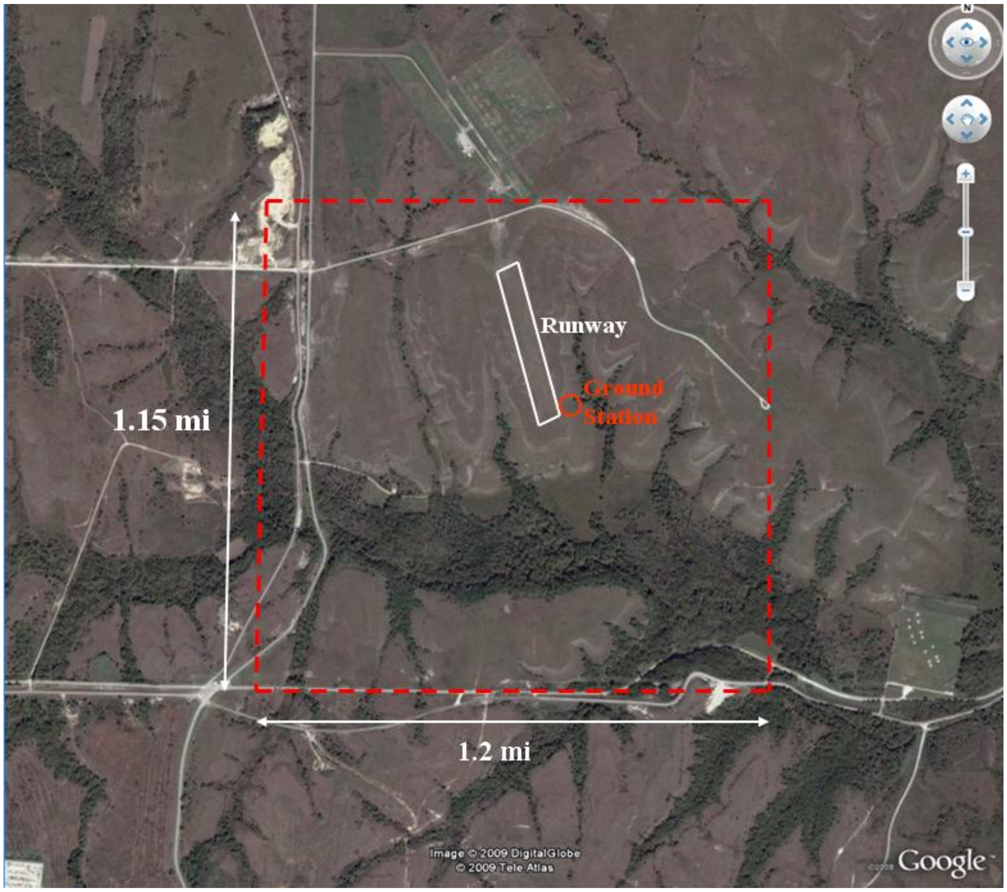

Figure 3.1: Fort Riley Flight Test Area

For future autonomous flight test missions at Fort Riley, it should be noted that the flight test area can be expanded to the Northwest. However, keeping the aircraft within visual contact in the expanded flight test area may be difficult due to terrain.

3.1.4 Flight Test Plan

After the engine, wePilot sensors, and MAAS have been confirmed to be working within operational limits and the taxi test completed, the Phase I flight test may take place. The aircraft remains under radio control throughout the entire flight test. The Phase I flight plan includes:

- Take-off
- Figure-8 Pattern
  - Trim to 80 knots
  - Perform Rudder and Elevator Doublets
- Racetrack Pattern
  - Practice Approach for Landing
  - 70 knots Approach Airspeed
- Land

With the flaps deflected 20°, the aircraft will takeoff uphill on the runway at a heading of 350. After takeoff, the pilot will trim the aircraft at 80 knots and enter a figure-8 pattern at an altitude where the pilot feels comfortable, but no higher than 1,500 feet AGL. Flying the aircraft in a figure eight pattern ensures that the aircraft will always be turning away from the ground team and observers.

After the aircraft has been trimmed and the pilot feels comfortable to begin practice approaches, the pilot will transition the aircraft from a figure-8 pattern to a racetrack pattern, with the east leg of the racetrack over the runway. At an airspeed of 80 knots (no wind) and a bank angle of 30°, the aircraft has a turning radius of 1,085 feet. This turning radius results in a flight pattern that is approximately 0.4

miles wide with a maximum distance from the ground station of 0.6 miles. Using the Yak-54 UAV, both the 900 MHz and 72 MHz wireless connections have been verified to work in this range and beyond. Each figure-8 or racetrack is expected to take 90 seconds to complete with the aircraft at the desired cruise speed of 80 knots. If possible, the pilot will conduct a brief control surface doublet for additional flight characteristic data. An elevator doublet is used to perturb the Short Period mode and a rudder doublet is used to perturb the Dutch Roll mode. If the aircraft is flying near or above the maneuvering speed, the amplitude of the doublet must be small to prevent structural damage. It is recommended that the amplitude of the doublets never exceed 5 degrees. A diagram of the Phase I flight test plan is shown in Figure 3.2.

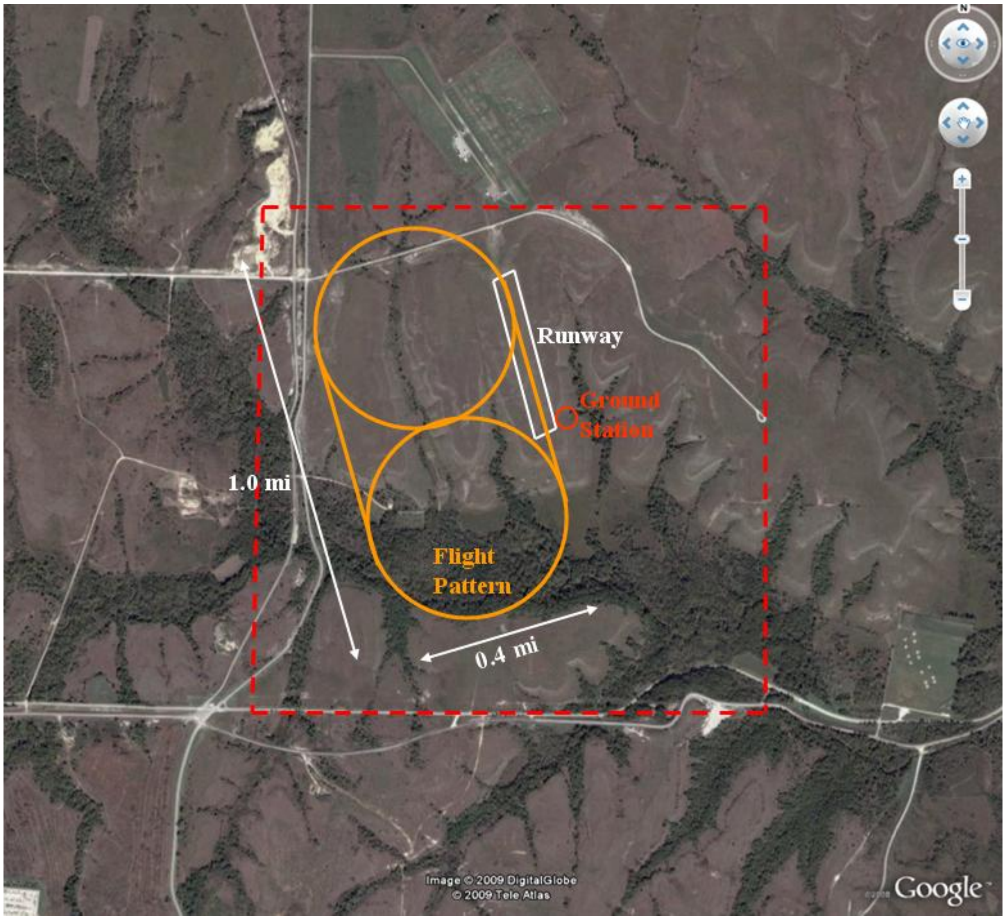

Figure 3.2: Phase I Flight Diagram

The desired practice approach airspeed is 70 knots at an altitude of 100 feet over the runway. When the aircraft is directly over the runway, the pilot will call for the airspeed to gain an orientation of the elevator input with respect to the landing airspeed. After passing over the runway, the pilot will increase speed to 80 knots and gain altitude for the go-around in the racetrack pattern. After the pilot completes enough approaches to feel comfortable landing the aircraft, a landing will be attempted. Once the main gear touches the ground, the pilot will kill the engine power and allow the aircraft to come to a rolling stop without using the brakes. From take-off to landing, the entire flight test is expected to last no longer than 15 minutes.

3.1.5 Emergency Procedures

In the event of a fire emergency, a fire extinguisher is kept with the ground team and the local fire department will be notified when the flight test is being conducted.

The Meridian's systems are monitored by an onboard health monitoring system. In the event of a UAV system failure, a series of preliminary contingency plans have been developed. Table 3.1Table 3.2 lists some of the possible failures the UAV may experience and their respective contingency plans.

Table 3.1: Phase I Emergency Contingency Planning [7]

Aircraft Failure Mode	Contingency Plan
Airframe	In the event of a structural failure, the pilot will immediately conduct a controlled emergency landing on the designated runway or flight termination over an unpopulated area.
Control Actuation System	In the event of an actuator failure, the pilot will immediately conduct a controlled emergency landing on the designated runway or flight termination over an unpopulated area.
Engine	In the event of an engine failure, the pilot will conduct a controlled emergency landing on the designated runway or unpopulated area.
Internal Environmental Control System	If the avionics temperature rises above normal, the pilot will immediately land the aircraft on the designated runway.
Avionics Failure Mode	**Contingency Plan**
wePilot System	In the event of a wePilot failure, the pilot immediately conducts a flight termination in an unpopulated area.
wePilot Autopilot	The autopilot is not utilized during Phase I flights.
GPS	Not a flight critical system since the autopilot is not being utilized during Phase I flights.
Vehicle Sensors	Not a flight critical system since the autopilot is not being utilized during Phase I flights.
Communication Failure Mode	**Contingency Plan**
72 MHz Pilot Control	In the event of a 72 MHz failure, the pilot immediately conducts and emergency flight termination over an unpopulated area.
900 MHz wePilot Communication	The wePilot 900 MHz link is only utilized for real-time flight telemetry during Phase I flights. In the event of a wePilot communication failure, the pilot conducts an immediate landing on the designated runway.
900 Mhz MAAS Telemetry	The MAAS 900 MHz link is only utilized for real-time engine monitoring during Phase I flights. In the event of a MAAS communication failure, the pilot conducts an immediate landing on the designated runway.
Iridium Satellite Link	The iridium satellite link is not utilized for Phase I flights.

Weather Failure Mode	Contingency Plan
Wing Speeds	The mission is delayed until the wind speeds are within the appropriate limits.
Storm Systems	The UAV only operates in Visual Flight Rules conditions. Flights are delayed until such conditions are present.

3.2 Phase II: Line-of-Sight Autonomous Flight Test

The second Phase of flight test operations is the first set of Meridian autonomous flights. All Phase II autonomous mission plans for the Meridian are previously flown and tested using the 1/3 scale Yak-54. The Phase II autonomous flights are conducted at Dugway Proving Ground, Utah and Pegasus Airfield, Antarctica.

3.2.1 Flight Test Objectives

The Phase II flight test objectives include:

1. Evaluate the performance of the wePilot flight control system in flight
2. Verify functionality of the satellite communication with the aircraft in flight
3. Conduct dynamic analysis and system identification flight test operations
4. Conduct lateral-directional dynamic analysis and system identification flight test operations with mounted radar antennas

Objectives 1 and 2 are completed using similar flight test plans with the only difference being the use of the Iridium satellite communication system during the objective 2 flight test operation. The objective 3 flight test plan utilizes carefully planned flight test maneuvers designed to perturb the longitudinal and lateral-directional dynamic modes of the Meridian. The flight telemetry from the objective 3 flight test is analyzed to determine the characteristics of these dynamic modes which are then compared with the mathematical model of the Meridian. To complete objective 4, the lateral-directional portion of the objective 3 flight test plan is repeated with the aircraft in different radar antenna configurations. The objective 4 flight test does not require the radar to be active during the test nor the radar payload to be onboard the aircraft. The objective 4 flight test only requires that structurally identical antennas are attached to their designated hard points on the bottom of the wing.

3.2.2 Flight Test Limits

The Phase II flight test limits for the airplane are as follows:

1. Flight Time Limit: 120 minutes
2. Maximum Crosswinds: 5 knots
3. Maximum Constant Winds: 10 knots Head / 0 knots Tail
4. Maximum Wind Gusts: 5 knots
5. Maximum Ambient Temperature: 85° F

6. Maximum Test Altitude: 1,500 feet AGL
7. Minimum Maneuvering Airspeed: 70 knots
8. Maximum Test Airspeed: 120 knots
9. Maximum Bank Angle: 60 degrees
10. Load Factor Min: -0.5
11. Load Factor Max: 2.0

The maximum test airspeed has been increased from the Phase I flight test limit of 90 knots to the maximum airspeed setting configured on the wePilot of 120 knots.

3.2.3 Dugway Proving Ground Flight Test Area

During the Dugway Proving Ground field campaign, the Meridian UAS will operate from the center Michael Army Airfield 10,000 foot runway. The flight test area is 16 square miles in size and neighboring flight test areas will have UAV traffic. The runway is located in the southern most corner of the provided flight test area and the ground station will be located mid-field off the southwest side of the runway. South of the designated flight test area is a populated area for base operations. The runway is also used as an emergency airfield for military aircraft performing training mission. If there is an aircraft requiring an emergency landing, the airspace and runway must be cleared immediately.

The airfield is located at an elevation of 4,350 feet above sea level and has a wide range of temperatures throughout the day. If the given test day has high temperatures, combined with the high altitude will create a high density altitude reducing the aerodynamic and engine performance of the Meridian UAS. The reduced performance means that the UAS will have faster takeoff and landing speeds with longer ground rolls and a higher throttle setting will be required for cruise.

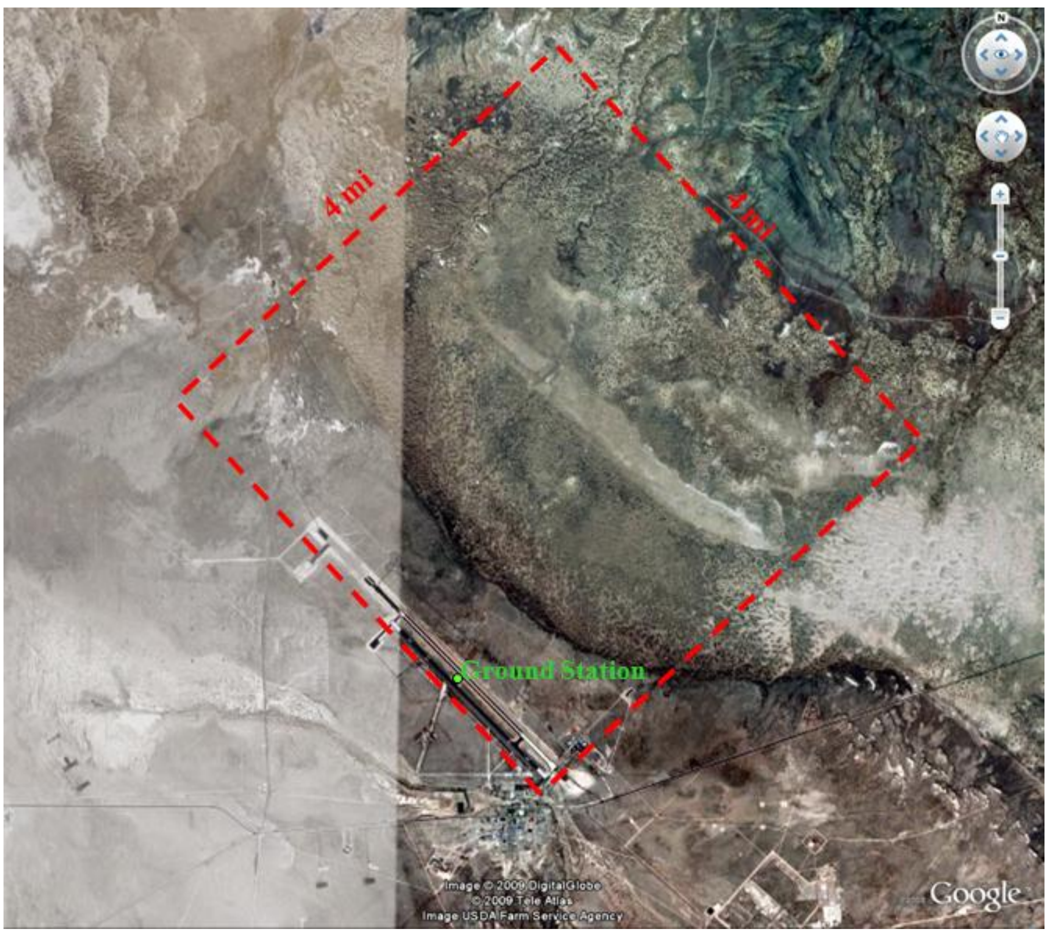

Figure 3.3: Dugway Proving Ground Flight Test Area

3.2.4 Pegasus Airfield Flight Test Area

During the Antarctic field campaign, the Meridian UAS will be operated off of the southern 5,000 feet of the 10,000 foot Pegasus ice runway during the hours that the airfield is least active. The proposed flight test area is approximately 2 miles in length and 1.5 miles in width. The Meridian will take off and land into the wind requiring 2,500 feet of the Pegasus ice runway. The UAS ground station and team will be located on the west side of the allocated runway. Most of the flight test maneuvers will be performed on the East side of the allocated runway keeping the UAS within line-of-sight. The UAS will conduct flight test maneuvers at a pattern altitude of 1,000 feet AGL. If notified that an aircraft is on approach or about to take-off on the nearby Pegasus skiway, the flight test team will be given a 30 minute warning and the UAS will immediately land and be secured while the separate runway is active.

The Pegasus ice runway is located at sea level and the summer temperature remains below freezing. These conditions create a very low density altitude giving the UAS excellent engine and aerodynamic performance.

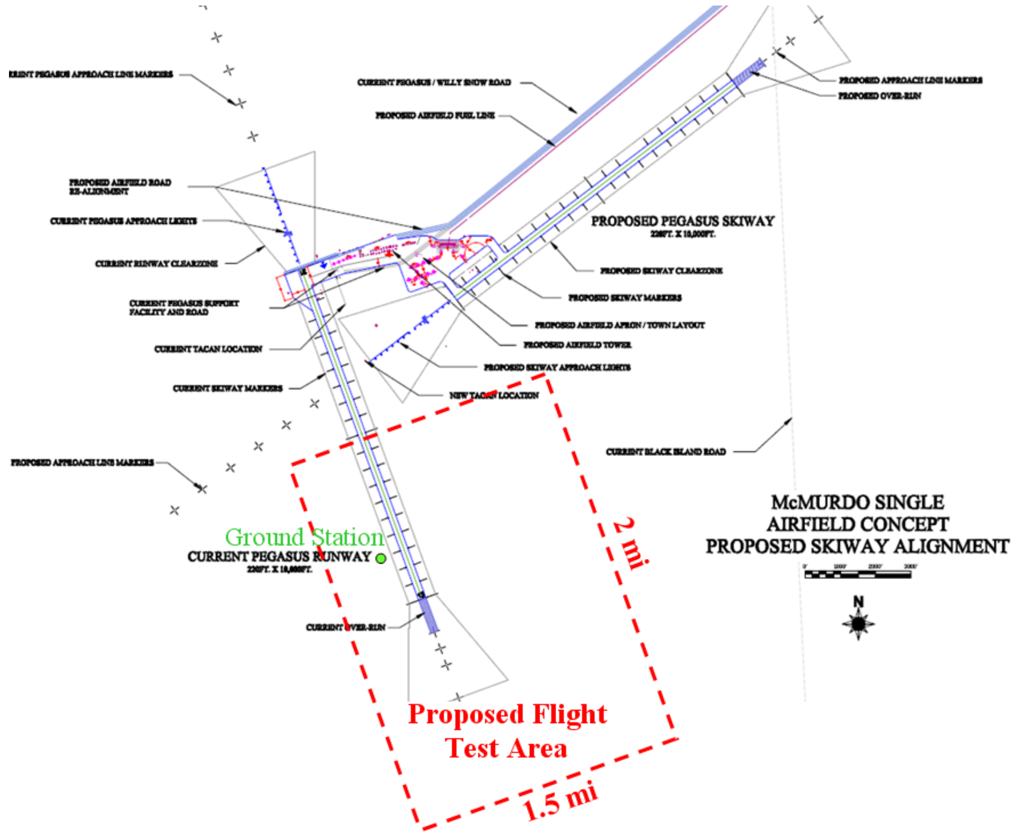

Figure 3.4: Proposed Line-of-Sight Flight Test Area

3.2.5 wePilot Performance Flight Test Plan

The purpose of this flight test plan is to complete objective 1 of Phase II, evaluate the performance of the wePilot control system in flight. The objective 1 flight plan includes:

- Take-off
- Enter Autonomous Orbit
- Land

After completing the pre-flight procedures, the aircraft will takeoff under pilot control from the designed runway and enter a racetrack pattern. From the racetrack pattern the pilot will trim the aircraft for cruise. At this point, the pilot assistant will confirm that the wePilot ground station operator is ready. When the wePilot operator is ready, the pilot will switch the wePilot into assisted mode and the pilot assistant will say aloud or over the radio “Autopilot ON”. The wePilot ground station operator will then direct the wePilot to the first waypoint. The flight path for the first autonomous flight is shown in Figure 3.5.

When initially switched to autonomous mode, the aircraft will enter the orbit flight pattern with a minimum turning radius of 1,250 feet, airspeed of 80 knots, and altitude of 1,000 feet AGL. From the autonomous orbit, the pilot can easily switch the aircraft back to radio control and transition the flight pattern into an approach for landing.

This flight test plan may be modified and repeated until the wePilot autopilot is tuned to the desired performance.

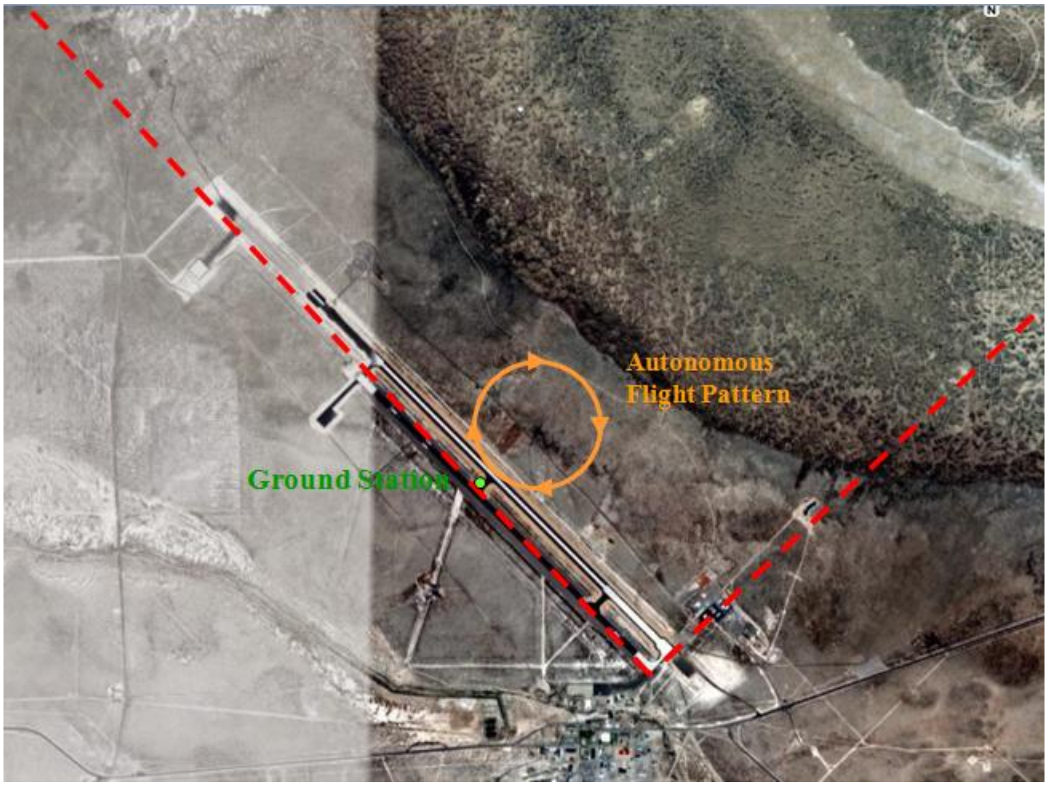

Figure 3.5: wePilot Performance Flight Diagram

3.2.6 Satellite Communication Flight Test Plan

In order to complete objective 2 of Phase II, verify satellite communication with the aircraft in flight, the objective 1 flight test plan is repeated, except the command to transition from the home orbit to the waypoint pattern is sent over the Iridium satellite network. The objective 2 flight also tests the capability of uploading a new mission to the wePilot by means of satellite communication. The 900 MHz transmitter located at the ground station may need to be disconnected during the time that the aircraft is commanded via satellite communication. This flight plan must be tested multiple times in the wePilot simulation before it is attempted in a flight test. This flight test objective must be completed before an over-the-horizon mission is attempted that requires control of the wePilot via iridium satellite.

3.2.7 Dynamic Analysis and System ID Flight Test Plan

In order to complete objective 3 of Phase II, the pilot perturbs the longitudinal and lateral-directional dynamic modes while flying the aircraft at the wePilot preset airspeeds, 80 knots, 100 knots, and 120 knots. Control surface inputs should not exceed an amplitude of 5 degrees to minimize risk of structural damage. The maneuvers used to perturb the dynamic modes are commanded by the pilot via radio control. The maneuvers include:

- Control Surface Frequency Sweeps
- Longitudinal Modes
    - Phugoid Mode
        - Maneuver: Elevator Singlet
    - Short Period Mode
        - Maneuver: Elevator Doublet
- Lateral-Directional modes
    - Roll Mode
        - Maneuver: Aileron Singlet
    - Dutch Roll mode

        - Maneuver: Rudder Doublet
    - Spiral Mode
        - Maneuver: Bank (Time to Double)

The pilot carefully trims the aircraft on the racetrack straight-aways until the aircraft can fly straight and level for 10 seconds without input from the pilot. Straight and level requires the aircraft to remain within 20 feet of its trimmed altitude and 2 knots of its trimmed airspeed during the 10 second period without pilot input.

The control surface frequency sweeps are conducted by sweeping a control surface at a gradually increasing frequency while oscillating about the trim point. The starting frequency for the sweep will begin at 0.1 Hz and increase to 2 Hz.

To perturb the Phugoid mode after confirming the aircraft is properly trimmed on the near straight-away, on the far straight-away the pilot conducts an elevator singlet that decreases the airspeed of the aircraft by 5 knots. After the airspeed reaches 75 knots, the pilot releases controls of the vehicle and the flight test engineer examining the real-time data plotter confirms if the vehicle is successfully perturbed. If the aircraft is successfully perturbed, one full cycle of the Phugoid mode is completed after 19 seconds or approximately 0.5 miles of flight. The pilot uses the near straight-away to confirm or reset trim condition of the aircraft. The Phugoid is the most difficult mode to test due to the long response time.

To perturb the Short Period mode, Roll mode, and Dutch Roll mode, the pilot conducts an elevator doublet, aileron singlet, and rudder doublet respectively. Because the Meridian has an unstable Spiral mode, the Spiral mode is verified by putting the aircraft in a 10° bank and counting the time to double to a 20° bank. The expected time to double the bank amplitude is 19 seconds.

The pilot is restricted to a 20 minute radio controlled flight time limit during Phase II flight test operations. After 15 minutes into the dynamic analysis flight, the pilot will begin the approach for landing or switch to autonomous mode to either loiter the aircraft, or complete autonomous flight test objectives. During the dynamic analysis flight test, the pilot will attempt to complete as many maneuvers as possible, but the maneuvers that are not completed due to the time restriction are accomplished in a later flight test. It is expected that the pilot will only be able to complete a maximum of 8 maneuvers during the 15 minute time frame.

If the functionality is available, the wePilot should be used to input the maneuvers with the autopilot control loops disabled. The wePilot can better trim the aircraft at the desired condition and input a precise maneuver. The pilot in command must remain within line-of-sight during the wePilot maneuvers to recover the aircraft if necessary.

3.2.8 Radar Antennas Dynamic Analysis and System ID Flight Test Plan

In order to complete objective 4 of Phase II, the lateral-directional dynamic analysis portion of the objective 3 flight test plan must be repeated with the aircraft in 4 different radar antenna configurations shown in Figure 3.6.

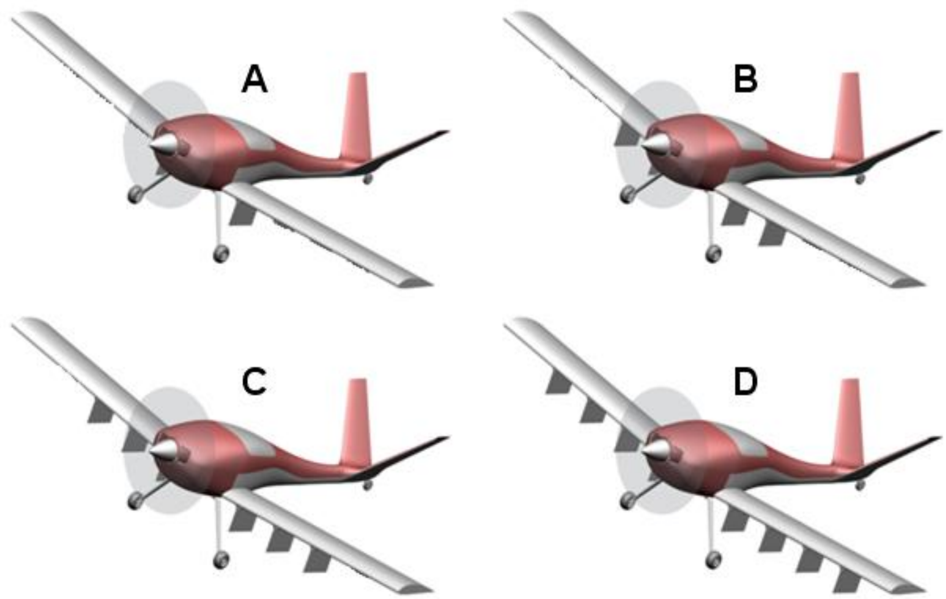

Figure 3.6: Meridian RADAR Antenna Configurations

Configuration A in Figure 3.6 shows the Meridian with 2 radar antennas installed in the most inboard hard points. With the aircraft in configuration A, the lateral directional portion of the dynamic analysis flight test plan is repeated in addition to the pilot evaluating the handling quality of the aircraft. At the completion of the configuration A flight test, the radar antennas are then arranged in configuration B and the previous flight test plan is repeated. This procedure is continued until the completion of the configuration D flight test. The flight telemetry is then analyzed using dynamic analysis and system identification techniques to determine if the antennas adversely affect the dynamics of the aircraft.

3.2.9 Emergency Procedures

Fire extinguishers must be kept with the ground station and near the UAS during the startup procedure. The local fire department should be aware of when the flight test is taking place. The flight cannot take place until there is no longer any traffic that will be in or entering the designated flight test area. If an aircraft is approaching the flight test area, the Meridian must be cleared from the active runway and secured or put into a holding pattern in an area designated by the local air traffic control if the wePilot autopilot has reached operational status.

Table 3.2: Phase II Emergency Contingency Planning [7]

Aircraft Failure Mode	Contingency Plan
Airframe	In the event of a structural failure, the pilot will immediately conduct a controlled emergency landing on the designated runway or flight termination over an unpopulated area.
Control Actuation System	In the event of an actuator failure, the pilot will immediately conduct a controlled emergency landing on the designated runway or flight termination over an unpopulated area.
Engine	In the event of an engine failure, the pilot will conduct a controlled emergency landing on the designated runway or unpopulated area.

Internal Environmental Control System	If the avionics temperature rises above normal, the pilot will immediately land the aircraft on the designated runway.
Avionics Failure Mode	**Contingency Plan**
wePilot System	In the event of a wePilot failure, the pilot immediately conducts a flight termination in an unpopulated area.
wePilot Autopilot	If the autopilot function of the wePilot is not functional, the pilot will land on the designated runway for trouble shooting.
GPS	If the GPS function of the wePilot is not functional, the pilot will land on the designated runway for trouble shooting.
Vehicle Sensors	If the vehicle sensors are not functional, the pilot will land on the designated runway for trouble shooting.
Communication Failure Mode	**Contingency Plan**
72 MHz Pilot Control	In the event of a 72 MHz failure, the wePilot will take control of the aircraft and enter a holding pattern.
900 MHz wePilot Communication	In the event of a wePilot communication failure, the pilot conducts an immediate landing on the designated runway.
900 MHz MAAS Telemetry	In the event of a MAAS communication failure, the pilot conducts an immediate landing on the designated runway.
Iridium Satellite Link	The iridium satellite link is not a critical path of communication during Phase II flights.
Weather Failure Mode	**Contingency Plan**
Wing Speeds	The mission is delayed until the wind speeds are within the appropriate limits.
Storm Systems	The UAV only operates in Visual Flight Rules conditions. Flights are delayed until such conditions are present.

4 Flight Test Missions

The Meridian UAS has completed 5 flight test missions. During the 5 completed flight test missions, the objectives completed include the following:

- Phase I
  - Validate the Meridian's airframe and system in flight
  - Evaluate the handling qualities of the Meridian
  - Examine the flight control inputs for saturated controls
  - Evaluate the engine performance and vehicle drag
- Phase II
  - Validate the wePilot sensors in flight
  - Evaluate the performance of the wePilot in flight

The first flight of the Meridian took place late August at Fort Riley, Kansas on the scaled mortar firing range. The next three flights were executed mid-September at Dugway Proving Ground, Utah. The final flight for this campaign of testing took place on the last day of 2009 at Pegasus Airfield, Antarctica. Weight and balance documents for each flight are shown in Appendix E and flight plan documents are shown in Appendix F.

4.1 Fort Riley Flight 20090828-1

On August 28th, 2009 at 1430 CST, the first flight of the Meridian UAS took place at Fort Riley, Kansas after 7 months of ground testing. The objectives of the first flight were validate the airworthiness of the airframe and systems installed on the Meridian, evaluate the handling qualities using the Cooper-Harper Pilot Rating Scale, and examine flight control history for saturated control surface inputs. The mission procedure was:

1. Takeoff
2. Trim at 80 knots
3. Optional: perform control surface doublets
4. Practice approach for landing
5. Land

The gross takeoff weight of the aircraft was 1,064 pounds and the center of gravity was located 6.8 inches aft of the leading edge. An image of the Meridian before the first flight is shown in Figure 4.1.

Figure 4.1: Meridian UAS before Flight 20090828-1 [7]

4.1.1 Weather Conditions

The weather observation during the time of flight was as follows:

1. Wind Speed: 7 knots
2. Wind Direction: 330°
3. Visibility: 10 miles
4. Ceiling: Clear
5. Temperature: 82° F
6. Dew Point: 59° F
7. Altimeter Setting: 30.03 inHg
8. Density Altitude: 3,000 feet

4.1.2 Mission Results

The Meridian had a ground roll of approximately 670 feet and a takeoff ground speed of 58 knots. After takeoff, pilot Lance Holly entered a left racetrack pattern and attempted to trim the aircraft. Flying an aircraft this large at speeds near 100 knots in a small pattern to keep the vehicle within line-of-sight produces a large pilot work load. Due to this high work load, it was very difficult for the pilot to hold a consistent altitude or airspeed. Because the vehicle was never in a steady level flight condition, the pilot never input a control surface doublet. The flight path is shown in Figure 4.2.

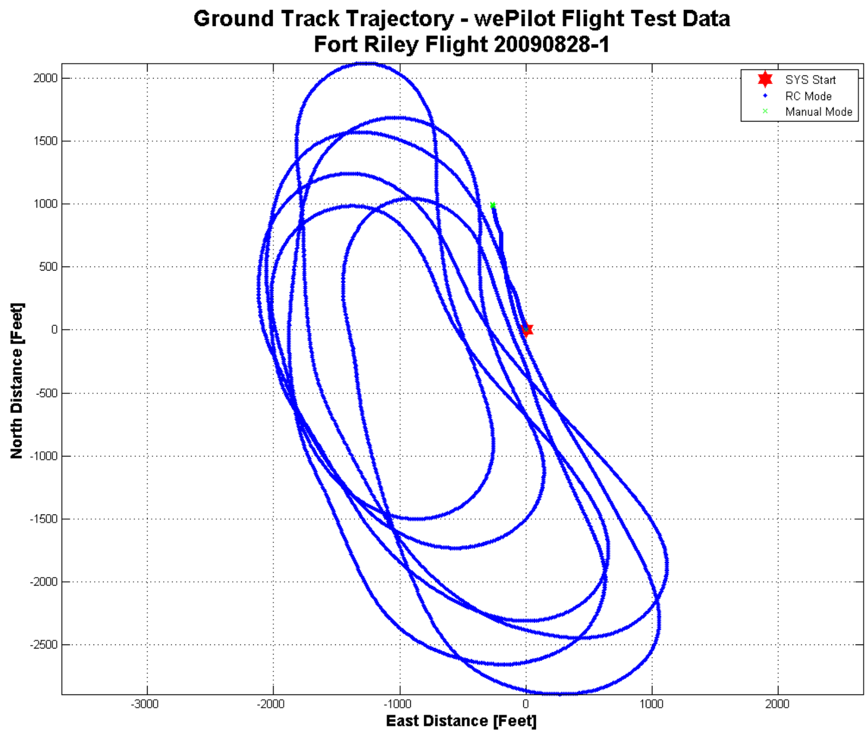

Figure 4.2: Fort Riley Flight 20090828-1 Flight Path

After flying four complete racetrack patterns reaching a peak altitude of 2,100 feet MSL or 850 feet AGL, the pilot then made a practice approach for landing. The practice approach came in short on the runway, so the pilot went around the pattern for a second attempt. On the second approach the Meridian had a landing ground speed of 55 knots and a ground roll of 900 feet. The total flight time for the first flight of the Meridian was 7 minutes and 12 seconds.

The wePilot flight telemetry was analyzed after the flight, and it was discovered that the wePilot was producing the wrong compass heading. The heading angle error is shown in Figure 4.3.

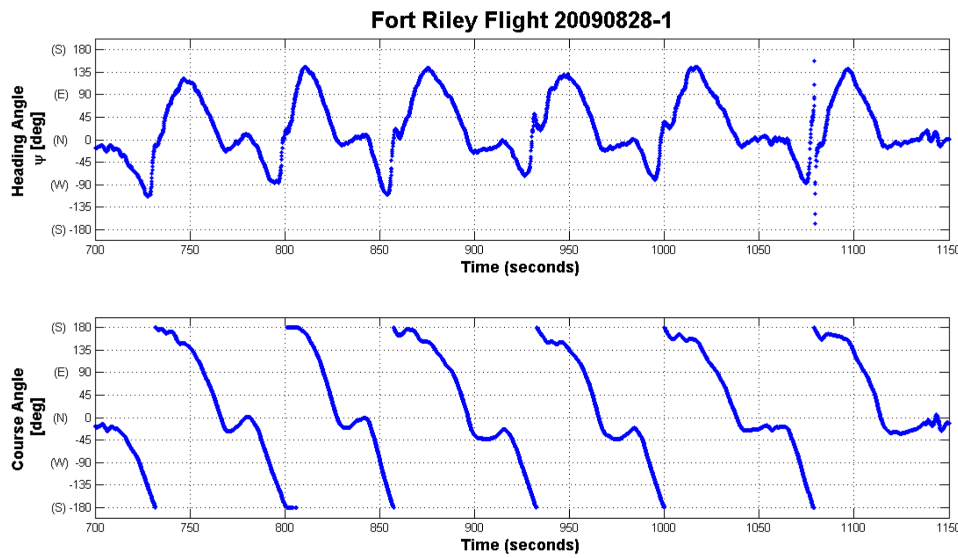

Figure 4.3: Fort Riley Flight 20090828-1 Heading Angle Error

The course angle is calculated from GPS and shows that the aircraft was flying in a racetrack pattern. The heading angle from the flight telemetry would suggest that the aircraft was flying in a figure-8 pattern, which it was not. The problem was originally thought to have been caused by a wiring error on the magnetometer pin-outs or a calibration error, because when the magnetometer was calibrated, the aircraft was in the ground configuration with the tail wheel on the ground rather than the flight configuration with the aircraft leveled.

4.1.3 Post Flight

Because the pilot had difficulty trimming the aircraft, it was decided that the pilot could not ask for airspeed when he wanted, but the airspeed should be announced in real time as it changes in flight. The airspeed is read aloud by the wePilot ground station operator.

After the first flight at Fort Riley, it was determined that the runway and airspace leave little room for error, so a larger runway with more airspace is required for future flights. A 10,000 foot runway was located at Dugway Proving Ground, Utah where they provided the flight test program with 16 square miles of airspace.

4.2 Dugway Flight 20090910-1

In September, flight test operations of the Meridian took place at Dugway Proving Ground, Utah. Ten days were spent at the flight test range and three flight test missions were completed. The objective of the first Dugway mission was to test the wePilot sensors in flight. The mission procedure to complete this objective was:

1. Takeoff
2. Trim at 80 knots
3. Perform control surface doublets
4. Practice approach for landing

5. Land

Before the flight, the ailerons were trimmed to help reduce the pilot work load. Speed tape was used to seal the gaps around the engine cowling in an effort to reduce drag. The pin-outs on the magnetometer were altered to see if it had an effect on the compass heading error found in the first flight. The magnetometer was then calibrated with the aircraft in the flight configuration. The gross takeoff weight was 1,048 pounds and the center of gravity was located 7.0 inches aft of the leading edge.

4.2.1 Weather Conditions

The weather observation during the time of the flight was as follows:

1. Wind Speed: 2 knots
2. Wind Direction: 250°
3. Visibility: 50 miles
4. Ceiling: Clear
5. Temperature: 75° C
6. Humidity: 28%
7. Altimeter Setting: 30.24 inHg
8. Density Altitude: 6,145 feet

Due to high temperatures at Dugway Proving Ground, all flights must be completed before noon; otherwise the ambient temperature will exceed the safety limits for the structural components and avionics.

4.2.2 Mission Results

At 1034 MT the Meridian took off with a ground roll of 740 feet and was airborne at 61 knots. After takeoff, pilot Nick Brown entered a right racetrack pattern and trimmed the aircraft. The flight path for this mission is shown in Figure 4.4.

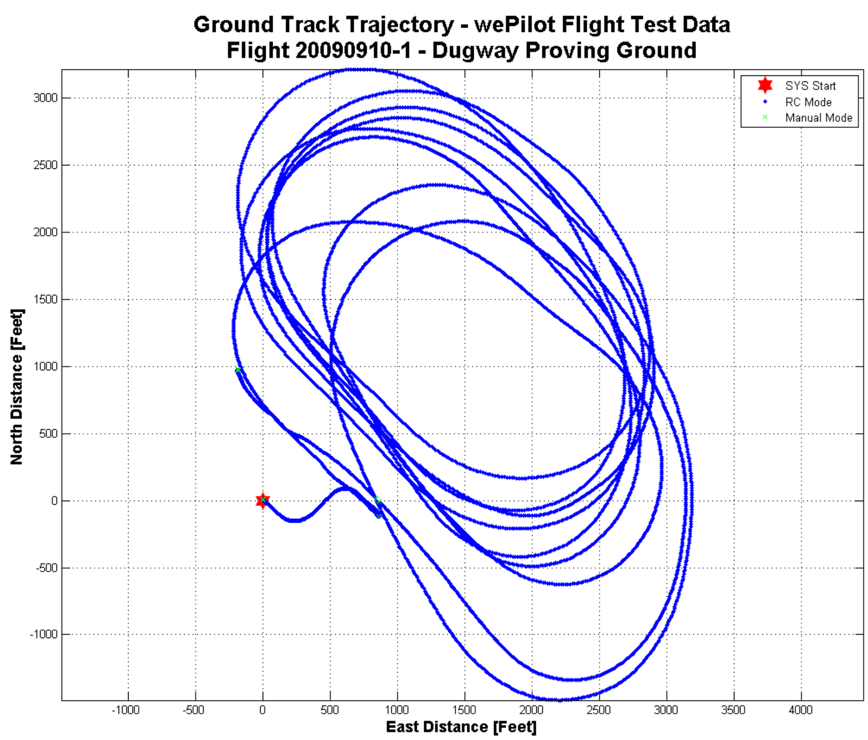

Figure 4.4: Dugway Flight 20090910-1 Flight Path

Before takeoff, the 72 MHz receiver momentarily lost communication with the transmitter twice, causing the wePilot assisted mode to activate for 0.3 seconds and the second time for 0.7 seconds. The pilot completed nine racetrack patterns before landing. During one of the upwind passes, the pilot input a rudder doublet to perturb the Dutch Roll mode for analysis. Figure 4.5 shows the flight telemetry gathered from the Dutch Roll maneuver.

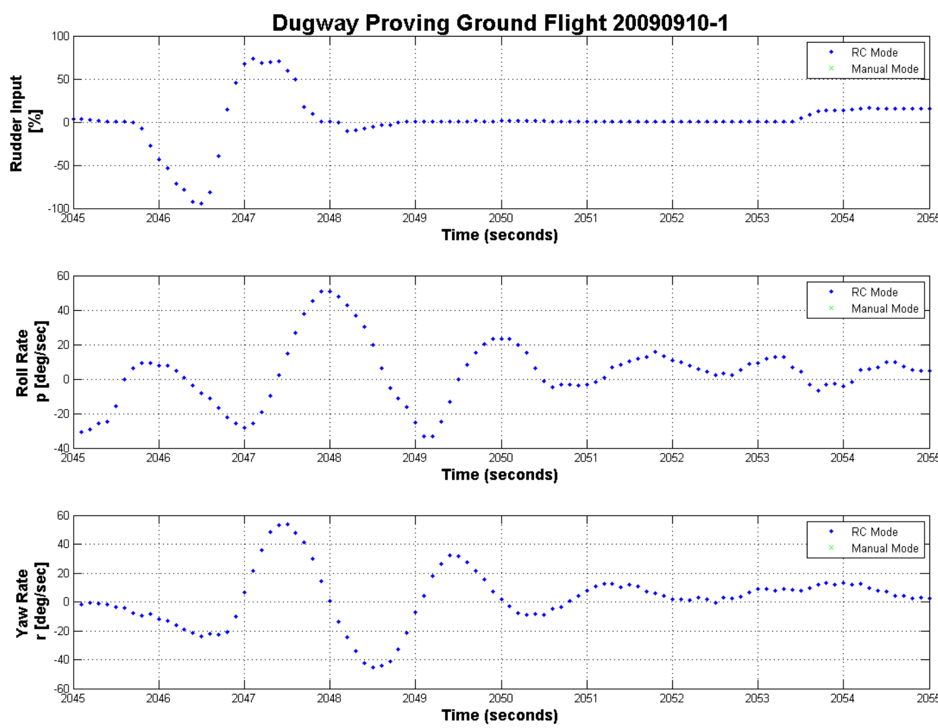

Figure 4.5: Dugway Flight 20090910-1 Dutch Roll

While the Meridian was airborne, a warning on MAAS indicated that the engine coolant temperature was nearing the maximum limit. The pilot was then instructed to land the vehicle. On the final approach for landing, the 72 MHz receiver again lost communication with the transmitter causing the wePilot assisted mode to activate and the engine to throttle up for 0.4 seconds. The communication glitches were so brief that they did not affect the pilot's ability to control the aircraft. The aircraft landed at an airspeed of 67 knots and had a ground roll of 1,030 feet.

When the wePilot flight telemetry was analyzed after the flight, there was no heading angle error unlike the previous flight at Fort Riley.

4.2.3 Post Flight

During the first two flights of the Meridian, the airspeed data probe was non-functional. After considerable trouble shooting between the second and third flights, it was determined that the bad data from the airspeed probe was due to an electrical ground loop. After the ground loop was corrected, the airspeed data probe was calibrated for the next flight.

4.3 Dugway Flight 20090912-1

The objective of the second flight at Dugway Proving Ground was to test the wePilot sensors and autopilot in flight. The procedure to complete the objective of this mission was:

1. Takeoff

2. Trim at 80-90 knots
3. Activate wePilot assisted mode
    a. Perform assisted turns, climbs, and accelerations
4. Activate wePilot automatic mode and enter home orbit
5. Perform control surface doublets
6. Land

Before the flight, the airspeed data probe was calibrated and tested on the ground. The wePilot box was opened and the wiring was inspected. The engine was serviced by adding coolant and gearbox oil. The surface of the wing leading edge and the V-tails were filled and wet sanded in an effort to reduce drag. After the first two flights, both pilots complained that the aircraft did not feel very responsive in the longitudinal axis. To make the aircraft more responsive, 10 pounds of ballast was secured to the tail bracket moving the center of gravity to 7.9 inches aft of the wing leading edge, a change of 0.9 inches aft from the previous flight. The gross takeoff weight was 1,045 pounds.

4.3.1 Weather Conditions

The weather observation during the time of the flight was as follows:

1. Wind: Calm
2. Visibility: 50 miles
3. Ceiling: Clear
4. Temperature: 66° F
5. Humidity: 28%
6. Altimeter Setting: 30.05 inHg
7. Density Altitude: 5,749 feet

4.3.2 Mission Results

At 0758 MT the Meridian took off with a ground roll of 890 feet and was airborne at 69 knots. After takeoff, pilot Nick Brown entered a right racetrack pattern and trimmed the aircraft. The flight path for this mission is shown in Figure 4.6.

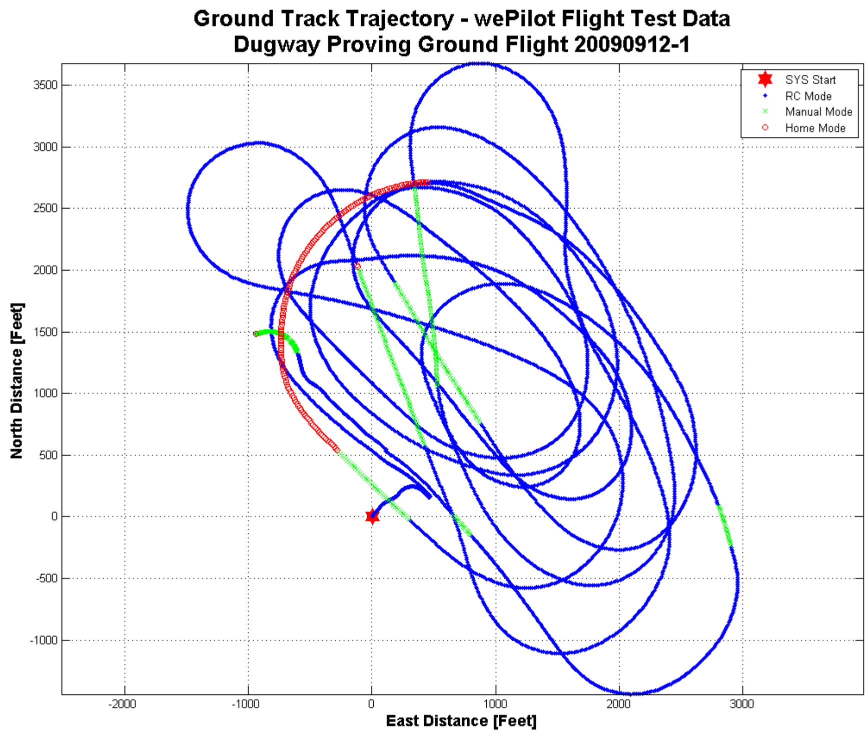

Figure 4.6: Dugway Flight 20090912-1 Flight Path

During this flight test mission, the wePilot assisted mode was tested on three upwind passes and the wePilot automatic mode was activated on one upwind pass where it was then commanded to enter the home orbit. Each assisted mode test lasted no longer than 9 seconds, which was not a long enough time span to determine if the wePilot was properly controlling the aircraft. During the automatic mode test, the wePilot was actively controlling the aircraft for 20 seconds. During this time frame, it was noticeable that the aircraft was losing both altitude and airspeed, so the pilot retook control of the aircraft. The altitude and indicated airspeed during the automatic mode test is shown in Figure 4.7.

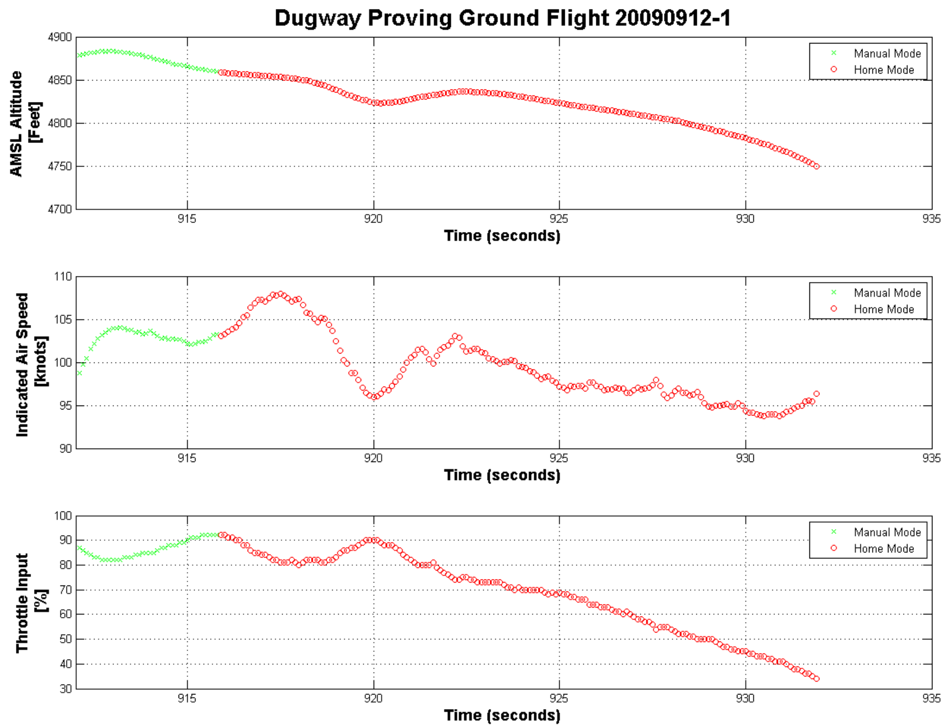

Figure 4.7: Dugway Flight 20090912-1 Automatic Mode Test

When the wePilot flight telemetry was analyzed, it showed that when the aircraft was switched into automatic mode, the heading angle error reoccurred, shown in Figure 4.8.

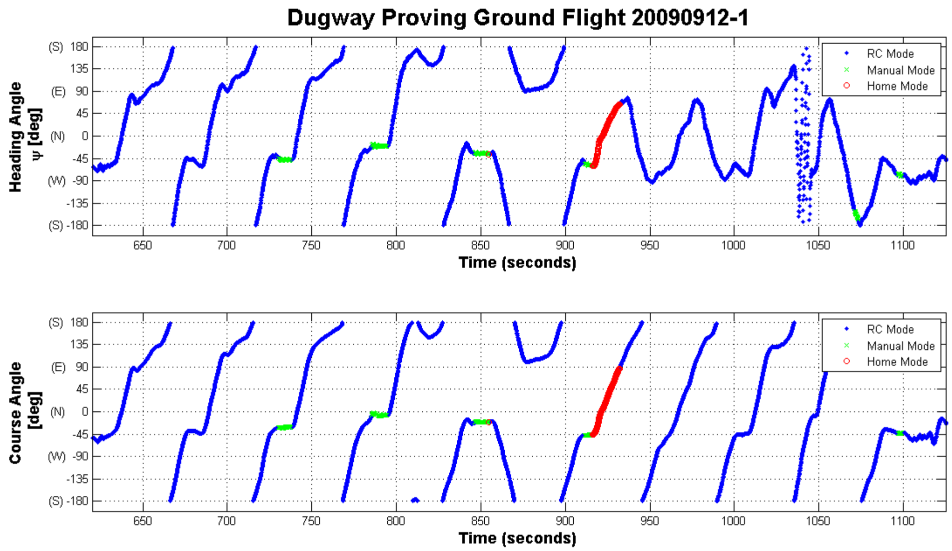

Figure 4.8: Dugway Flight 20090912-1 Heading Angle Error

The heading angle correctly followed the course angle until the wePilot was switched into the automatic mode, shortly after 900 seconds into the recording. At that point the course angle continued to correctly follow the movement of the aircraft, while the heading angle favored a heading of North.

Near the end of the flight, the pilot input two elevator doublets to perturb the Short Period mode for analysis. The flight telemetry gathered from the elevator doublets is shown in Figure 4.9.

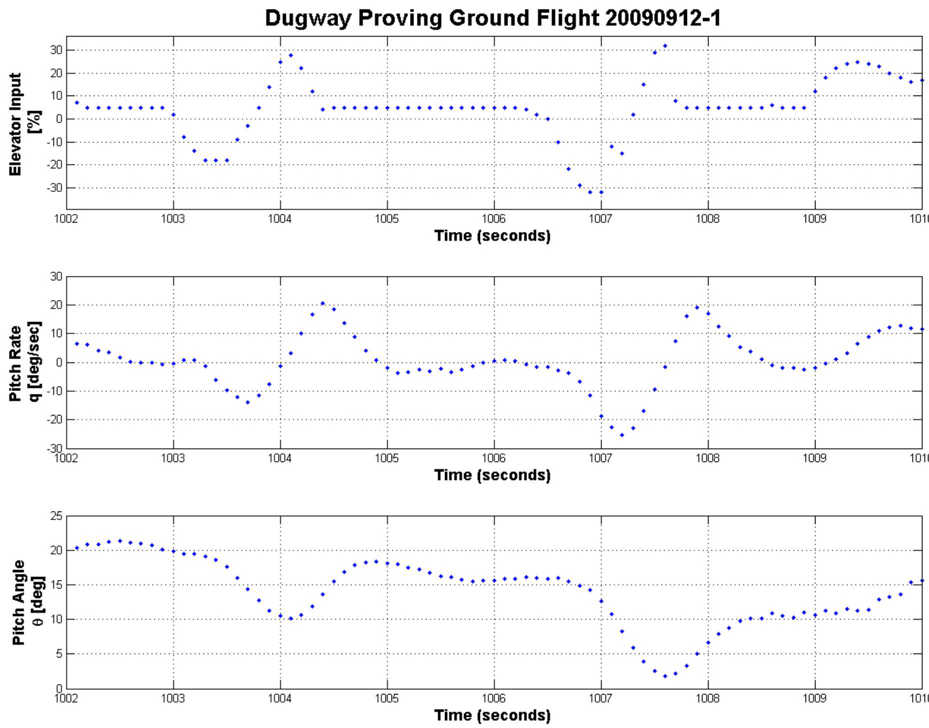

Figure 4.9: Dugway Flight 20090912-1 Short Period

On the downwind leg immediately before landing, the 72 MHz receiver lost communication for 2 seconds. The 72 MHz receiver lost communication again for 2 seconds while the aircraft was on short final for landing. When the main gear touched the ground, the receiver lost communication causing the wePilot assisted mode to activate and the aircraft to throttle up for 2 seconds. The communication drop out is shown in Figure 4.10.

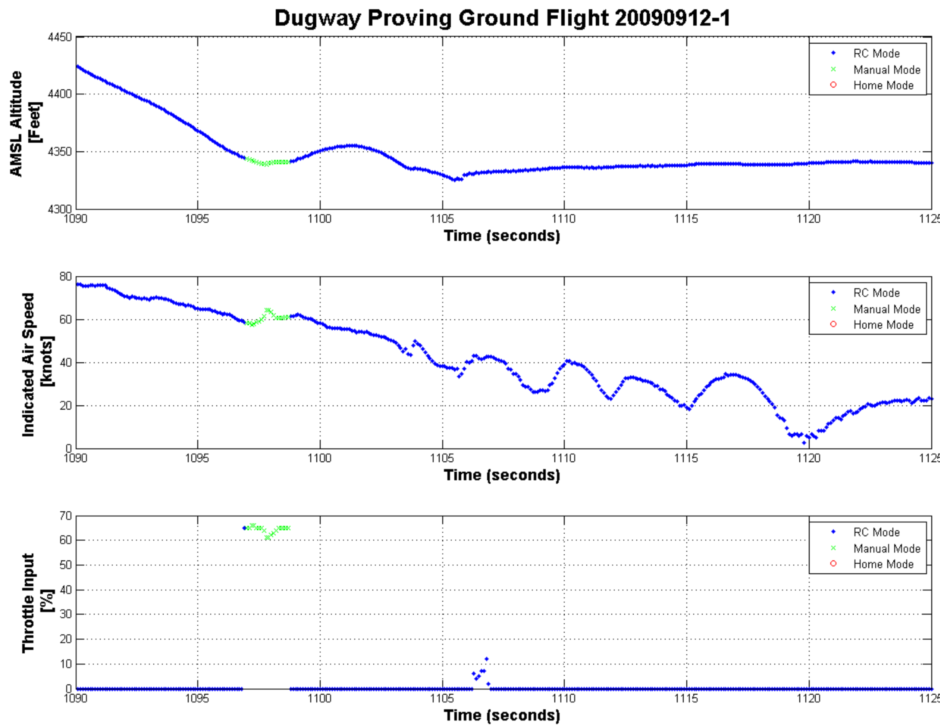

Figure 4.10: Dugway Flight 20090912-1 72MHz Drop Out

The increase in throttle sent the aircraft airborne again after touchdown, shown in the altitude plot. When the lapse in communication ended, the throttle dropped and the aircraft sustained a hard landing. The aircraft landed at an airspeed of 76 knots and had a ground roll of 1420 feet.

4.3.3 Post Flight

The hard landing did not inflict damage to the aircraft, but the loss of 72 MHz communication was a far more serious problem than originally anticipated. The origin of the drop outs is thought to be a result of either 'dirty' power coming from the aircraft electrical system, or interference from an auxiliary 72 MHz receiver installed next to the primary receiver. To fix the drop outs, the 72 MHz receiver on board the aircraft was removed from aircraft power and put on redundant battery power and the auxiliary 72 MHz receiver installed next to the primary receiver was removed. Since this fix, the 72 MHz drop out has not reoccurred.

To confirm the solution to the 72 MHz drop outs, it is recommended that the aircraft power cable running to the receiver is checked for proper voltage and current with the engine running. Also, two test receivers should be tested side by side to see if they can interfere with one another. Electrical noise should then be introduced to the test receiver to find the threshold that will cause a communication loss.

4.4 Dugway Flight 20090915-1

The third flight at Dugway Proving Ground was a repeat of the previous flight with the objective of testing the wePilot sensors and autopilot in flight. The procedure for this mission is the same as the previous mission. The only change on the aircraft for this flight was that the 72 MHz receiver was put on battery power to eliminate the communication drop outs and the magnetometer was moved from the belly of the fuselage of the aircraft to the avionics box. The aircraft had a gross takeoff weight of 1,037 pounds and the center of gravity was located 7.8 inches behind the leading edge.

4.4.1 Weather Conditions

The weather observation during the flight was as follows:

1. Wind: Light and Variable
2. Visibility: 50 miles
3. Ceiling: Clear
4. Temperature: 59° F
5. Dew Point: 50° F
6. Altimeter Setting: 30.19 inHg
7. Density Altitude: 5,265 feet

4.4.2 Mission Results

At 1023 MT the Meridian took off with a ground roll of 630 feet and was airborne at 62 knots. After takeoff, pilot Nick Brown entered a right racetrack pattern and trimmed the aircraft. The flight path for this mission is shown in Figure 4.11.

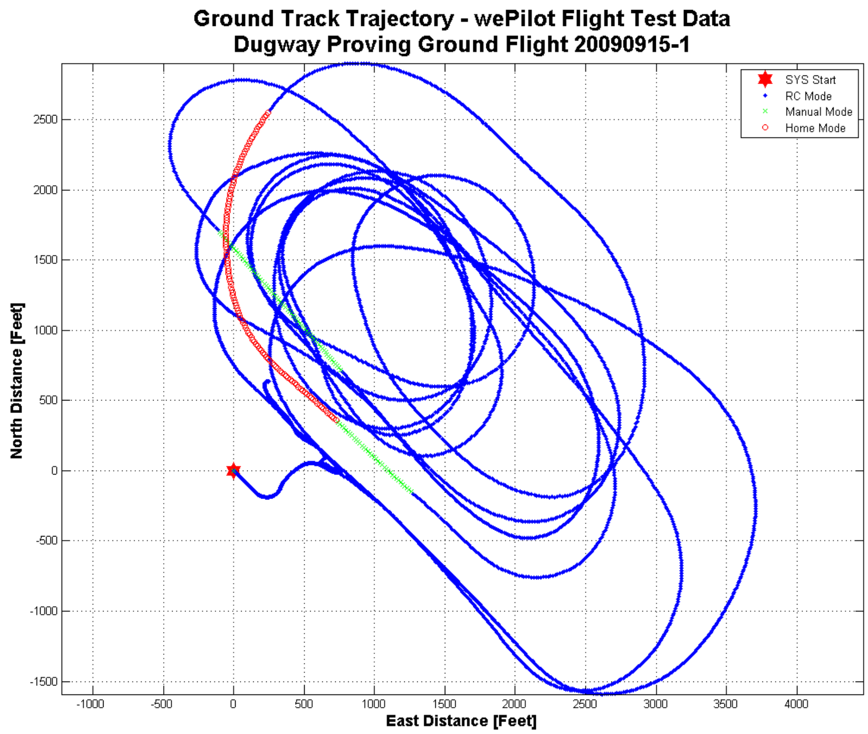

Figure 4.11: Dugway Flight 20090915-1 Flight Path

During this flight test mission the wePilot assisted mode was tested once, and then the wePilot automatic mode was tested, shown in Figure 4.12.

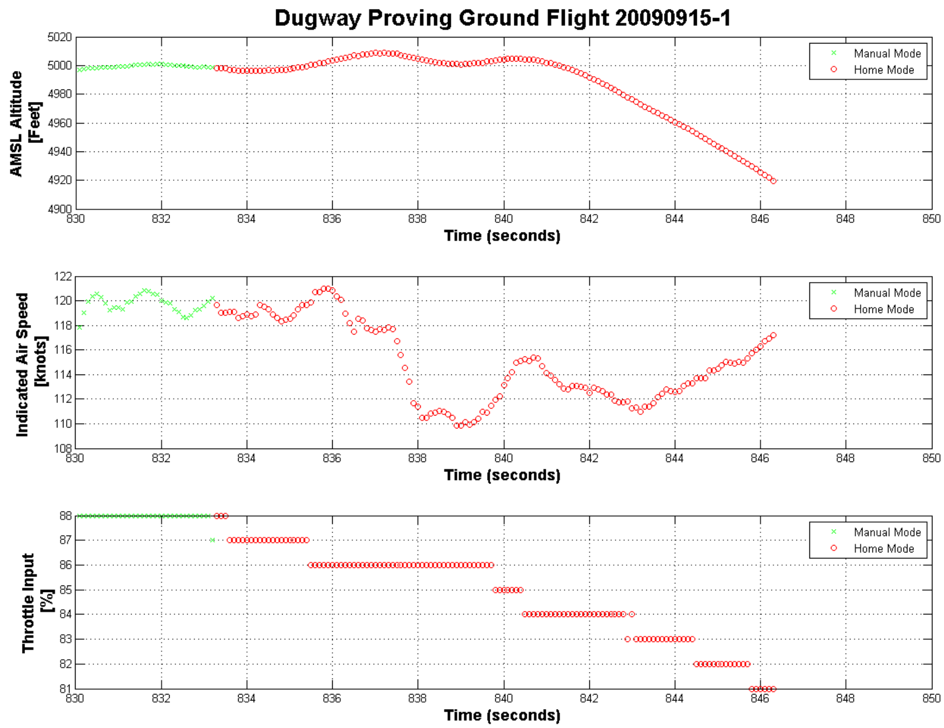

Figure 4.12: Dugway Flight 20090915-1 Automatic Mode Test

During the automatic mode test, altitude once again began to drop off along with the throttle, and the vehicle was not able to maintain an airspeed. After 15 seconds of automatic mode, the pilot retook control of the vehicle and landed. When the pilot flared just before touch down, he applied the elevator too quickly causing the aircraft to “balloon” followed by a stall just above the ground, causing a hard landing. The hard landing did not inflict any damage to the aircraft.

4.4.3 Post Flight

A fourth flight was attempted at Dugway Proving Ground, but on takeoff, the aircraft over rotated forward causing a propeller strike. The airframe and engine were not damaged during this incident, but the propeller was a total loss. The exact cause of the incident remains unclear. To prevent it from reoccurring, the pilot will always perform a 3-point takeoff with the tail wheel never leaving the ground throughout the entire takeoff ground roll. For further deterrence during the Antarctic campaign, two L-beams were attached protruding forward of the main gear to prevent the aircraft from landing on the propeller during a nose over.

Between the Dugway and Antarctica flights, significant ground testing went into determining the source of the heading angle error. The source of the error was due to vibrational noise entering the Kalman filter through the accelerometers. This problem was fixed by decreasing the stiffness of the shock dampers that mount the wePilot to the avionics box.

4.5 Antarctica Flight 20091231-1

The Meridian UAS performed its first successful autonomous orbit at Pegasus Airfield, Antarctica on December 31st, 2009. Before the flight, a number of changes were made to the Meridian. The wings, engine cowl, and payload hatch were professionally painted, reducing the skin friction over those surfaces. Fairings were installed at the wing root to reduce interference drag. The engine cowl had a new air intake for the engine and the tail wheel leaf spring was replaced. The new propeller sits flush with the engine which will reduce the drag. An image of the Meridian UAS before the Antarctica flight is shown in Figure 4.13.

Figure 4.13: Meridian UAS before Flight 20091231-1 [7]

The changes to the airframe shifted the center of gravity from 7.8 inches aft of the wing leading edge at Dugway to 8.9 inches aft in Antarctica. The gross weight of the aircraft at takeoff was 1,100 pounds.

The objective for this mission is to test the wePilot sensors and autopilot in the Antarctic environment. The procedure to complete the objective of this mission was:

1. 3-Point takeoff

2. Trim at 80-90 knots
3. Activate wePilot automatic mode and enter waypoint orbit
4. Land

Ground testing in Antarctica demonstrated that the magnetometer was unreliable in the polar environment due to the proximity to the magnetic South Pole. The magnetometer was removed as a navigational sensor leaving only the GPS for directional navigation.

4.5.1 Weather Conditions

The weather observation during the flight was as follows:

1. Wind Speed: 6 knots
2. Wind Direction: GRID 160°
3. Visibility: 10 miles
4. Ceiling: Clear
5. Temperature: 30° F
6. Altimeter Setting: 29.39 inHg

Pegasus ice runway is located at sea level and when combined with the low temperatures in Antarctica results in a very low density altitude that gives the Meridian UAS improved engine and aerodynamic performance.

4.5.2 Mission Results

At 2203 NZ, the Meridian UAS took off from Pegasus ice runway at an airspeed of 62 knots with a ground roll of 490 feet. The takeoff ground roll in Antarctica was significantly shorter than previous takeoffs due to the low density altitude. The flaps were half deployed on all previous flights, but for this flight, the takeoff was performed with the flaps fully retracted. The flight path for this mission is shown in Figure 4.14.

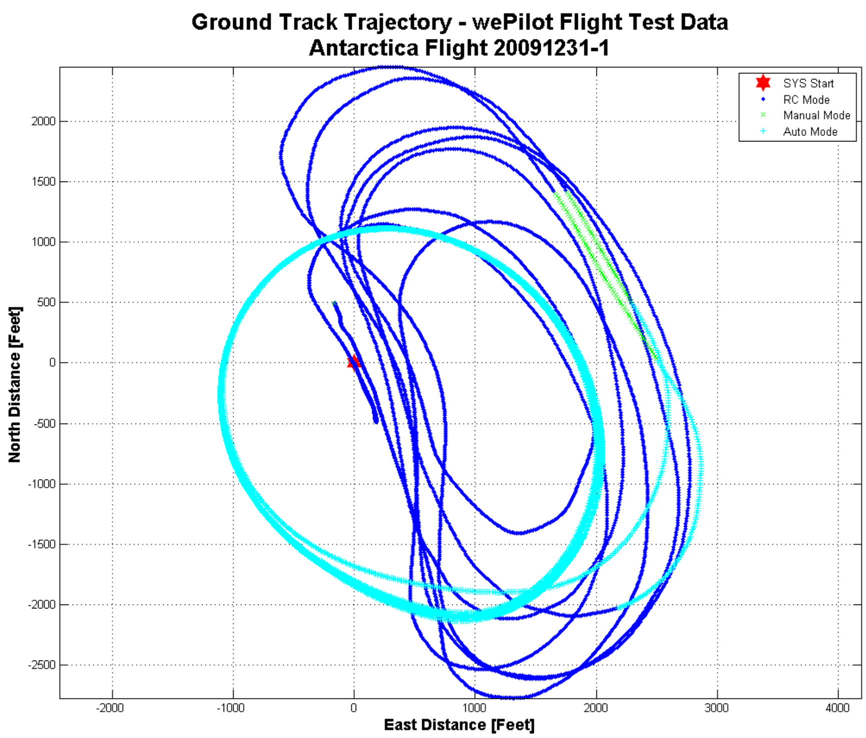

Figure 4.14: Antarctica Flight 20091231-1 Flight Path

After takeoff, pilot Nick Brown entered a right racetrack pattern where he began to trim the aircraft. When entering the downwind leg of the racetrack pattern, the pilot switched the autopilot on, and the wePilot ground station operator commanded to the wePilot to enter a 120 knot orbit at an altitude of 800 feet. While in the orbit, the wePilot was able to hold the airspeed ±10 knots and altitude ±150 feet. Flight telemetry from the autopilot guided orbit is shown in Figure 4.15.

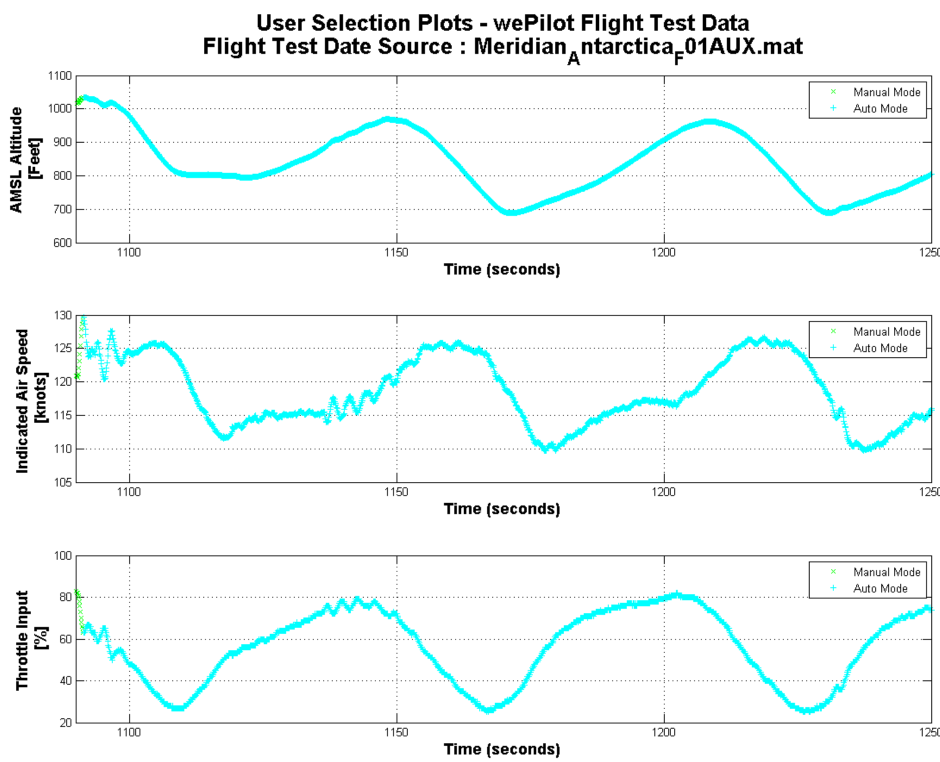

Figure 4.15: Antarctica Flight 20091231-1 Automatic Mode

After flying autonomously in the orbit for 15 minutes, the pilot retook control of the aircraft and landed. The landing was mistakenly performed with the flaps fully retracted and the landing speed was 70 knots with a ground roll of 1,040 feet. During the 10 minute preflight taxi and 19 minute flight, the aircraft burned 12 pounds of fuel.

4.5.3 Post Flight

During the Antarctic mission, the pilot's transmitter is encased in a mitten in order to keep the pilot's hands warm while flying the aircraft. On previous flights, the pilot assistant was able to help the pilot add trim to the aircraft as he asked for it, but the transmitter mitten eliminated this capability. Due to the significant center of gravity shift and possible change in the aerodynamic center due to painting the wings since the previous flight, the pilot had to add several degrees of nose down trim to the elevator without the help of the pilot assistant. In order to add the trim, the pilot had to momentarily release control of the aircraft, dial in some trim, retake control of the aircraft, and assess the handling of the aircraft. The pilot workload vastly increases when focused on flying the aircraft in the racetrack pattern, while simultaneously trimming the elevator. During the trimming process, the engine throttle was neglected, and the aircraft reached a top airspeed of 160 knots. The aircraft hit the top airspeed while in a shallow dive during one of the attempts to trim the aircraft. When the pilot was recovering from the dive, 5 G's of load was inflicted on the wing. The high loading caused a crack on the inboard section of the wing spar, closest to the aircraft centerline. The aircraft had to be grounded until the crack was repaired.

This entire incident could have been avoided if the flight test team realized how the transmitter mitten would affect our flight procedures. In future cold climate missions that require a transmitter mitten, the aircraft must be trimmed on the ground according to the trim diagram before every flight. To ensure this new procedure is followed, an elevator trim diagram is appended to the weight and balance document.

5 Recommendations for Flight Test Improvements

The purpose of this chapter is to discuss various methods of improving the safety and efficiency of Meridian UAS flight test operations using the experience gained during the flight test missions completed.

5.1 Flight Test Team

The purpose of this section is to discuss how the flight test team can be reduced from the 8 members used in previous Meridian flight test missions to 6 members for future missions. The reduction in team members is only possible if it does not affect the capability of the flight test team. To help the organization of the team, the team members are provided with specific roles and the responsibilities they must be capable of fulfilling in those roles. The flight test team is broken up into two sub-teams that operate in different locations.

- Ground Station Sub-Team
  - Flight Test Director
  - Flight Safety Officer
  - Flight Test Engineer
- Flight Line Sub-Team
  - Pilot in Command
  - Pilot Assistant

- Radio Officer

One of the team members must also be a skilled A&P mechanic that has the ability to fulfill one of the roles listed above. The ground station sub-team is located in a climate controlled environment with an uninterrupted supply of electrical power. The purpose of the ground station sub-team is to operate the wePilot and MAAS ground station hardware and monitor the performance and health of the aircraft from the live flight telemetry. The ground station sub-team must remain in radio communication with the flight line sub-team at all times. Both sub-teams must be in radio contact with the local air traffic control.

The flight line sub-team is located on the designated runway with the Meridian. The flight line sub-team must be capable of setting up the aircraft, going through the pre-flight checklist, starting the engine, and performing the takeoff without any physical help from the ground station sub-team. The organization chart for the flight test team is shown in Figure 5.1.

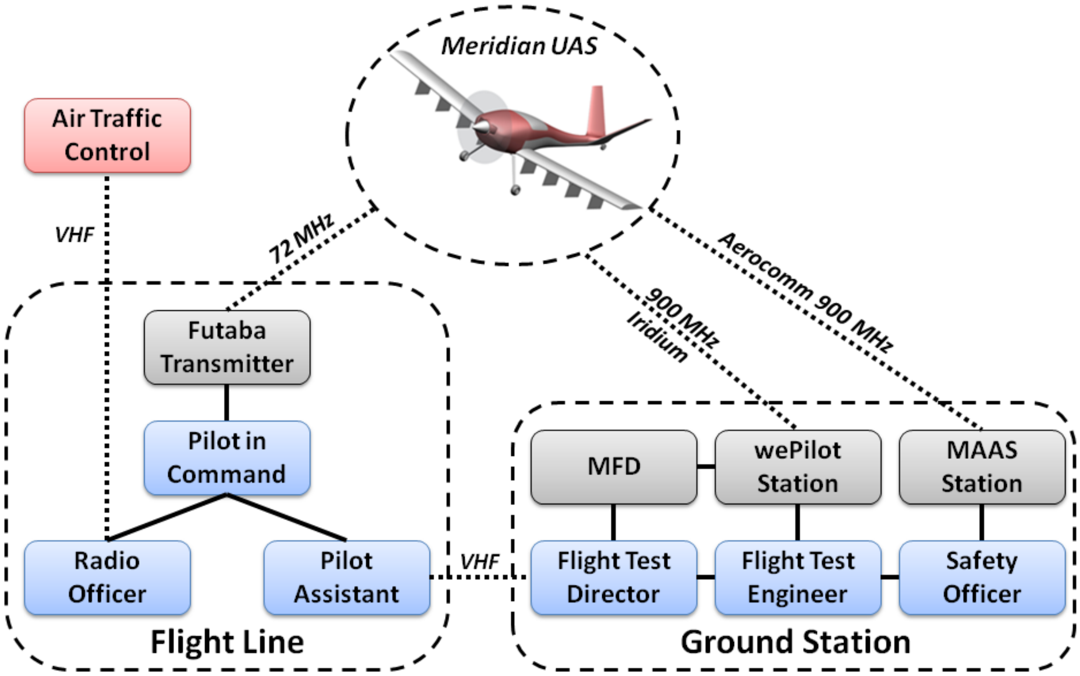

Figure 5.1: Flight Test Team Organizational Chart

The organizational chart shows that each member of a sub-team is in direct communication with the other members of their sub-team. Communication between the sub-teams is performed between the Flight Test Director and the Pilot Assistant over a VHF radio. All other team members must monitor this communication between the two sub-teams for full situational awareness of the mission. The Radio Officer is in VHF radio communication with the local air traffic control and relays pertinent information to the pilot in command. The Safety Officer must monitor the air traffic control frequency for the ground station sub-team.

The purpose of the Pilot Assistant and the Radio Officer is to filter the communication from the other team members and air traffic control to provide only pertinent information to the pilot. Pertinent information is defined as information that the Pilot in Command wants or needs to know regarding the giving flight test mission. Pertinent information includes:

- Pertinent Information from the Ground Station Sub-Team
  - Present Airspeed and Altitude
  - Autopilot Status
  - Dance Card Points
  - Exceeding Flight Safety Limits
- Pertinent Information from Air Traffic Control
  - Clearance for Takeoff/Landing
  - Clearance for Flight Path
  - Incoming Traffic
  - Wind Speed and Direction

The following sections describe the duties and skills required for each member of the flight test team.

5.1.1 Flight Test Director

The flight test director manages the flight test operation and directs the flight test team on what procedures to follow to complete the mission objectives. The FTD oversees the appropriate communication and discipline of the flight test team during flight test operations. The FTD ensures that comprehensive, written flight test procedures are developed, followed, and constructively modified throughout the flight test program [8]. The FTD has the following responsibilities:

1. Coordinates flight test missions with the local airspace authority
2. Conduct preflight and post flight briefings
3. Ensure all team members are aware of the flight test limits and objectives
4. Adheres to the flight test safety procedures
5. Manages communication between the pilot assistant and ground station sub-team
6. Instructs the pilot assistant on which flight test point to follow

The flight test director must be a strong team leader with excellent communication skills. The director must be able to complete mission objectives efficiently and without violating flight safety procedures. During a flight test mission, the flight test director communicates with the pilot assistant relaying relevant flight telemetry to the pilot and coordinating dance card points.

5.1.2 Flight Safety Officer

The safety officer's primary responsibility is the safety and well being of the flight test team. The safety officer must advise safe practices and reprimand any team member not following a specific safety procedure. The safety officer has the following responsibilities:

1. Ensure documented safety procedures are followed
2. Has final go/no-go authority with regards to mission safety
3. Observes that safe practices are followed
4. Monitors engine on, flight, and autonomous time
5. Monitors MAAS for warnings or violations of flight test limits

During a flight test mission, the safety officer monitors MAAS and communicates any relevant information to the flight test director including violations of the flight test limits and warning indicators. While monitoring MAAS, the safety officer keeps track of the mission time. It is the job of the safety officer to improve specific safety procedures if they are judged inadequate. The safety officer also monitors to the communication between the radio officer and the air traffic control.

5.1.3 Flight Test Engineer

The flight test engineer operates the wePilot ground station and programs the waypoints for the autonomous portion of the flight test mission. The flight test engineer must test the autonomous mission using the simulation mode of the wePilot prior to the flight test. The flight test engineer is responsible for the following:

1. Has go/no-go authority on the wePilot system
2. Manages the wePilot ground station and programs autonomous missions
3. Simulates wePilot autonomous missions prior to the flight test
4. Performs the wePilot ground station preflight checks
5. Responsible for all autonomous flight commands to the autopilot

When planning the autonomous portion of the mission, the flight test engineer must work closely with the rest of the flight test team. The flight test director must review the planned mission to ensure that it completes the appropriate mission objectives. During the simulation of the autonomous mission, the flight test team must be present in order to have an awareness of how the Meridian is supposed to perform while in autonomous mode. During a flight test mission, the flight test engineer monitors the wePilot ground station and commands the wePilot during the autonomous portion of the flight.

5.1.4 Pilot in Command

The pilot in command (PIC) has the final authority with regards to pilot-in-the-loop activities including takeoff, landing, and any piloted maneuvers. The pilot in command's primary concern is operating the aircraft safely in the effort to complete mission objectives. The pilot in command has the following responsibilities:

1. Safety of the aircraft is the PIC's highest responsibility
2. Makes independent pre-flight checks
3. Performs all assisted and radio controlled flight activities
4. Activates/Deactivates autopilot
5. Deactivates the autopilot and recovers the aircraft if the PIC judges it to be entering an unsafe flight condition

The pilot in command must be a skilled radio control pilot that can instinctively handle an in flight emergency situation. The pilot in command must maintain a situational awareness of the aircraft at all times during the mission. The pilot in command must apply his flight experiences to the mission planning and discuss any flight test maneuvers that may not be appropriate. The pilot in command should be capable of setting up the Meridian for flight and completing the preflight checklist with the help of the radio officer and pilot assistant.

5.1.5 Pilot Assistant

It is the duty of the pilot assistant is to support the pilot in command in the operation of the aircraft. The pilot assistant may help the pilot in command trim the aircraft and operate the landing flaps. The pilot assistant guides the pilot in command through the flight test procedure and communicates with the flight test director over the radio for real-time flight telemetry including airspeed and altitude. The pilot assistant has the following responsibilities:

1. Go through the preflight checklist with the pilot in command and radio officer
2. Support and advise the pilot
3. Recite the flight test dance card for the pilot
4. Communicate with the ground station sub-team for the pilot
5. Take control of the aircraft should the pilot become incapacitated

The pilot assistant develops the flight test dance card for each mission. To develop the dance card, the pilot assistant must coordinate with the pilot in command, flight test director, and flight test engineer. When the flight test dance card is finalized, the pilot assistant must present it in the preflight briefing, and ensure that the flight test director has a copy for the flight. The pilot assistant should be a skilled radio control pilot that is capable of landing the Meridian in an emergency situation should the pilot in command become incapacitated. The pilot assistant provides the pilot in command only with information that he wants or needs to know from the ground station sub-team. The pilot assistant should be capable of setting up the Meridian for flight and completing the preflight checklist with the help of the radio officer and pilot in command.

5.1.6 Radio Officer

It is the duty of the radio officer to communicate to the local air traffic control during the flight test mission. The radio officer keeps the air traffic control advised on the status and location of the Meridian. The radio officer relays any important information from air traffic control to the pilot in command. The radio officer has the following responsibilities:

1. Communicates with the local air traffic control during a flight test mission
2. Relays critical information from air traffic control to the pilot in command
3. Observes local airspace for incoming traffic

During the mission, the radio officer acts at the mission observer and looks out for incoming traffic. It is recommended that the radio officer is trained to speak to the air traffic control authority as a pilot would. The radio officer should be capable of setting up the Meridian for flight and completing the preflight checklist with the help of the pilot in command and pilot assistant.

5.2 Flight Test Procedures

A trim diagram should be kept with the weight and balance document for each flight. Before the flight, the flight test engineer and pilot in command can use the measured center of gravity and estimated aerodynamic center to determine and adjust the elevator trim. This procedure will reduce the amount of trim the pilot must add after takeoff, therefore reducing the pilot workload.

During the 2009 Meridian flight test campaign, the some of the preflight briefings were substituted for on the field safety briefings. Though the safety briefings are important and must be conducted, it is recommended that the preflight briefing be conducted more formally. A preflight briefing must be performed before every flight test mission. The preflight briefing is led by the flight test director and all members of the flight test team must be present. It is also recommended that a representative of the local airspace authority is present for the briefing.

During the preflight briefing, the flight test director discusses the flight test objectives for the mission. The flight test engineer presents the mission plan designed for the wePilot and the simulation of the mission. The pilot assistant presents the flight test dance card for the mission. The safety officer addresses any safety concerns that may affect the mission. All other team members can offer suggestions and commentary on the planned flight test mission.

At the conclusion of each mission, a formal post flight briefing must be performed. During the briefing the flight test director discusses the mission objectives complete or incomplete. The flight test engineer presents any relevant flight test telemetry downloaded from the wePilot. The pilot discusses the handling characteristics of the Meridian and any changes in procedure that may reduce the pilot work load. The safety officer addresses any safety concerns that may have came up during the flight.

5.3 Maximum Airspeed Limiter

The current control system configuration allows the pilot full authority over the all of the controls of the aircraft during RC mode. If the pilot does not have a complete situation awareness of the aircraft, for example airspeed, this can allow the aircraft to enter an unsafe flight condition. What must be avoided is over loading the airframe of the aircraft which is caused by a combination of over speeding the aircraft and performing a drastic maneuver. To prevent this situation from occurring, either the airspeed or control surface inputs must be limited during RC mode.

It is recommended that a feature is added to the wePilot software so that the ground station operator can impose a maximum airspeed limit for all operational conditions. It is recommended that the maximum airspeed limit is placed at 120 knots and controlled using the throttle. Limiting the maximum airspeed to 120 knots will greatly reduce pilot work load by eliminating the pilot’s ability to over speed the aircraft. During the flight, the pilot can reduce his workload by maxing out the airspeed at 120 knots, and then no longer be concerned with the throttle and focus on the yaw, pitch, and roll of the aircraft. 120 knots is selected for the maximum airspeed limit because it is the maximum airspeed setting for the wePilot autonomous control, but this airspeed can be debated and limited to a lower airspeed.

5.4 Ground Station

It is recommended that the wePilot GUI, shown in Figure 5.2, is redesigned to make it more user friendly during flight test missions.

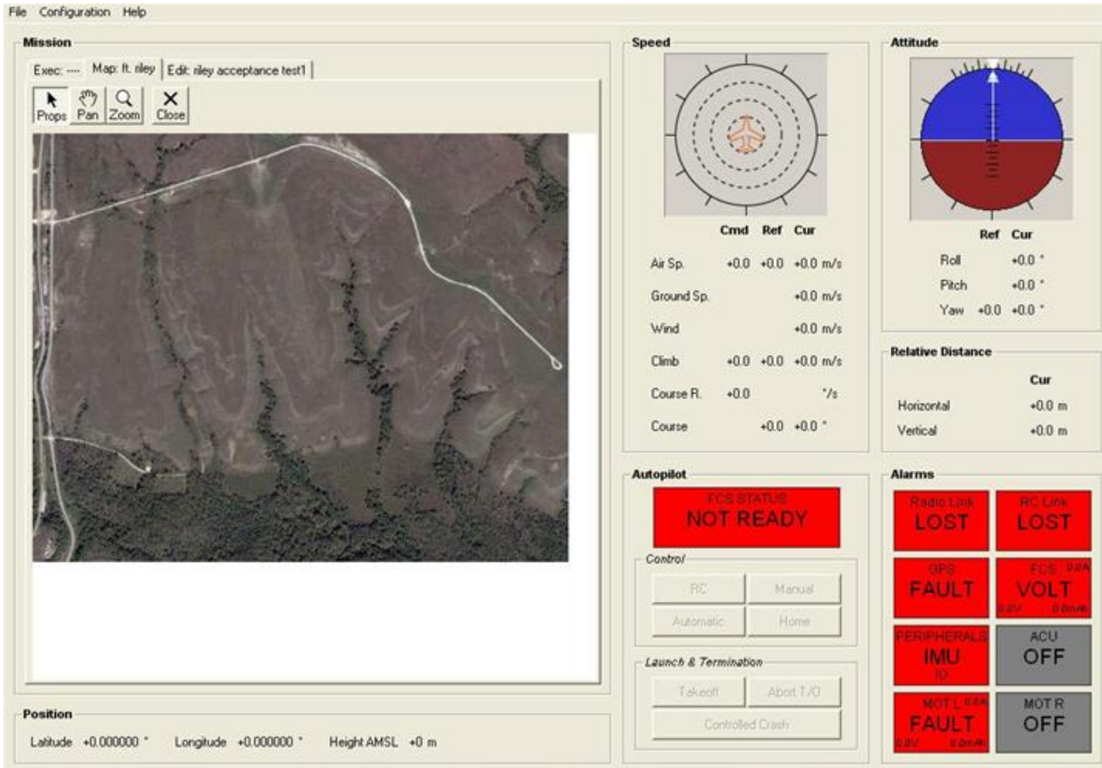

Figure 5.2: Existing wePilot GUI

Currently, the wePilot provides airspeed and ground speed in meters per second, but the pilot better understands the airspeed in knots. A primary flight display (PFD) should be designed to provide information to the flight test engineer and flight test director more efficiently. The primary flight display must provide the following information:

- wePilot's current mode of flight
    - Radio control
    - Manual mode

    - Automatic mode
- Aircraft attitude in degrees
- Heading in degrees
    - Commanded heading
- Airspeed in knots
    - Commanded airspeed
- Altitude MSL in feet
    - Commanded altitude
    - Reference starting point altitude

The PFD can be displayed beside the GPS calibrated wePilot map and provide the flight test engineer and flight test director a better situational awareness of the Meridian. A representation of the recommended wePilot interface is shown in Figure 5.3.

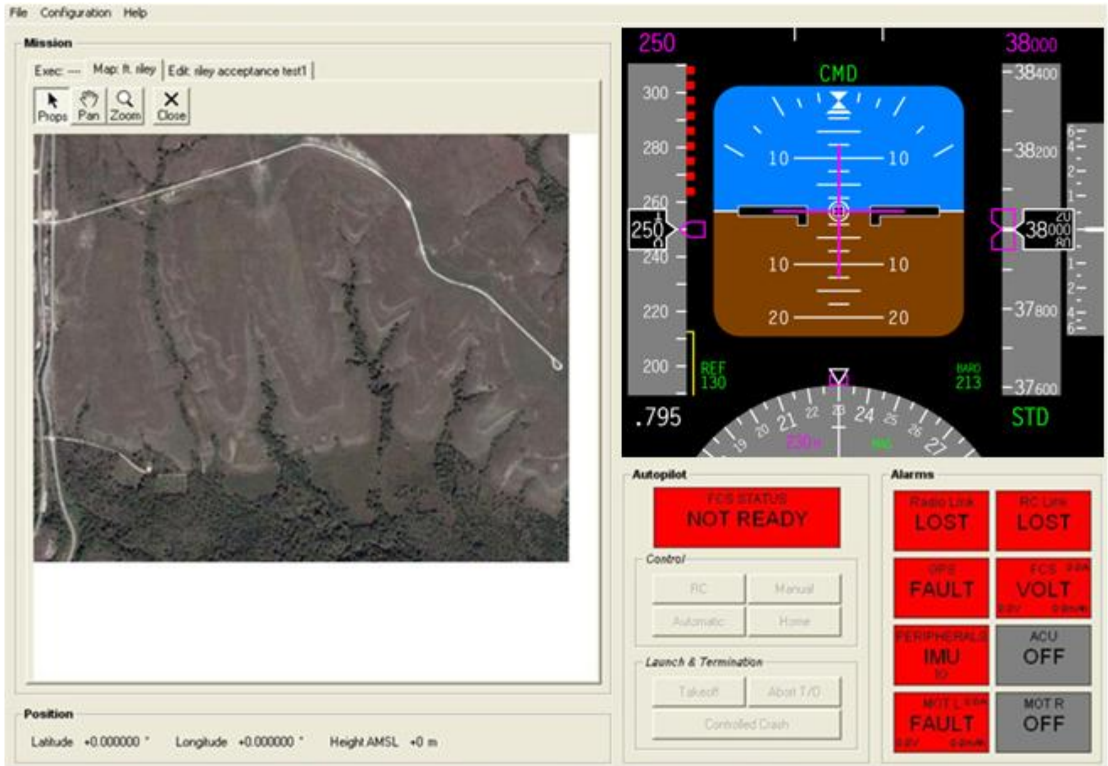

Figure 5.3: Representation of Recommended wePilot GUI

For system identification flight tests, it is recommended that the maneuvers be programmed into the wePilot's automatic mode. The wePilot can trim the Meridian better than the pilot and input preprogrammed maneuvers designed by the flight test engineer. The flight test engineer should be able to control when the maneuver is executed from the wePilot ground station and when to tell the autopilot to recover from the dynamics of the maneuver. During any system identification flight test, the flight line crew must be within line-of-sight of the aircraft when the maneuvers are performed. Maneuvers that should be programmed in the wePilot's automatic mode for system identification include:

- Control Surface Frequency Sweeps
- Longitudinal Modes
  - Phugoid Mode
    - Maneuver: Elevator Singlet
  - Short Period Mode
    - Maneuver: Elevator Doublet
- Lateral-Directional modes
  - Roll Mode
    - Maneuver: Aileron Singlet
  - Dutch Roll mode
    - Maneuver: Rudder Doublet
  - Spiral Mode
- Maneuver: Bank (Time to Double)

A prevalent problem with the ground station is that the computers and battery power are susceptible to performance reduction due to extreme temperatures. The ground station computers loose performance and can even fail in high temperatures and the battery life of the computers and ground station components is greatly reduced in low temperatures. It is recommended that the ground station is located in a climate controlled facility during future flight tests. The facility should have a reliable source of electricity to eliminate batteries as a point of failure and located within VHF radio and 900 MHz range of the flight line.

At the beginning of every flight test mission, MAAS has failed during the initial engine start up. For MAAS to be operational during the flight, the engine must be shut down and the avionics rebooted. This problem is a nuisance and must be solved before the next flight test campaign.

6 Flight Test Telemetry Analysis and Parameter Identification

The modal analysis is performed in two parts. First the dynamic response to the pilot's input is analyzed using a traditional technique. For the Dutch Roll mode, the technique used is the Modified Transient Peak Ratio method [8]. For the Short Period mode, the technique used for analysis is the Time Ratio method [8].

The second part of the modal analysis involves inputting the initial conditions and control commands into a 6-DOF non-linear model of the Meridian UAS and comparing the output of the model to the flight test telemetry. The non-dimensional derivatives that govern the dynamics of the model can then be tuned to minimize the error between the model and the flight test telemetry. This method was previously used to identify the non-dimensional derivatives of the 1/3 scale Yak-54 UAV [10,11].

A drag analysis of the Meridian UAS is performed at the end of this chapter to determine the effectiveness of the drag reduction efforts.

The wePilot attitude determination is unreliable during the first four flights of the Meridian. Since the wePilot attitude is unreliable, the NAV-420 attitude is used to determine the pitch angle for the drag calculations. The angular rates and accelerations recorded by the wePilot are correct, but the acceleration data must be filtered to reduce the amplitude of the noise. The commanded deflections of the control surfaces are recorded by the wePilot.

6.1 Dynamic Analysis of the Dutch Roll Mode

The Dutch Roll mode is best perturbed using a rudder doublet at the frequency of the estimated Dutch Roll natural frequency. The Meridian's Dutch Roll natural frequency is estimated to be near 3.5 rad/sec, or just over 0.5 Hz, using AAA. Therefore, the rudder doublet to perturb the Dutch Roll mode of the Meridian was input at a frequency of 0.5 Hz, which is an easy maneuver for the pilot. The Dutch Roll is excited when an oscillation is recorded in the yaw rate and roll rate of the aircraft. This oscillation can also be seen in the heading and bank angle.

The Dutch Roll mode of the Meridian, shown in Figure 6.1, is analyzed using Modified Transient Peak Ratio (MTPR) method. MTPR method works well with oscillations that have a damping ratio between -0.5 and 0.5 [8]. The Dutch Roll mode was intentionally perturbed once in the five Meridian flight test missions giving only the one data point for analysis. The instance being analyzed for the Dutch Roll mode is wePilot time stamp 2045 – 2055 of flight 20090910-1.

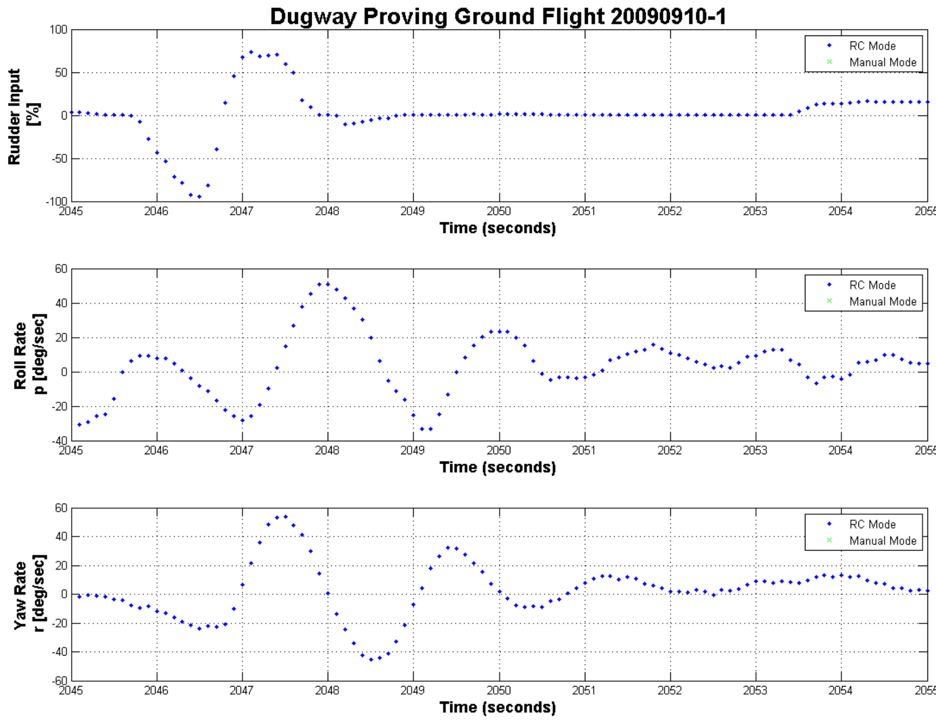

Figure 6.1: Dugway Flight 20090910-1 Dutch Roll Perturbation

During the perturbation, the aircraft had an airspeed of 109 knots and a dynamic pressure of 34 pounds per square foot. To account for the difference in altitude between the AAA model and the test point, the model with the closest dynamic pressure is used for comparison. The results from the MTPR method of analysis are shown in

Table 6.1.

Table 6.1: Dutch Roll Mode Results

Damping Ratio	Natural Frequency [rad/sec]	Dynamic Pressure [lbs/ft^2]	Source
0.19	3.36	34	MTPR Method
0.14	3.52	33.86	AAA Model

The results show that the predictions from the AAA model and the MTPR method used on the flight test telemetry are very similar. The normalized error in the damping ratio of the AAA model with respect to the MTPR method is 26% and the normalized error of the Natural Frequency is 5%. When this same analysis was used on the 1/3 scale Yak-54 UAV, the normalized error in the Dutch Roll damping ratio and natural frequency were 30% and 21% respectively [10].

6.2 Dynamic Analysis of the Short Period Mode

The Short Period mode is best perturbed using an elevator doublet at the frequency of the estimated Short Period natural frequency. The Meridian's Short Period natural frequency is estimated to be near 3.81 rad/sec, or just over 0.5 Hz, using AAA. Therefore, the elevator doublet to perturb the Short Period mode of the Meridian was input at a frequency of 0.5 Hz. The Short Period is excited when an oscillation is recorded in the pitch rate of the aircraft. This oscillation can also be seen in the pitch angle.

The Short Period mode of the Meridian, shown in Figure 6.2, is analyzed using the Time Ratio (TR) method. The Time Ratio method is applicable to oscillations with a damping ratio between 0.5 and 1.2 [8]. The Short Period mode was intentionally perturbed twice during the second Dugway flight. The perturbations were performed consecutively during one pass, the first perturbation being the better of the two. The instance being analyzed for the Short Period mode is wePilot time stamp 1002 – 1010 of flight 20090912-1.

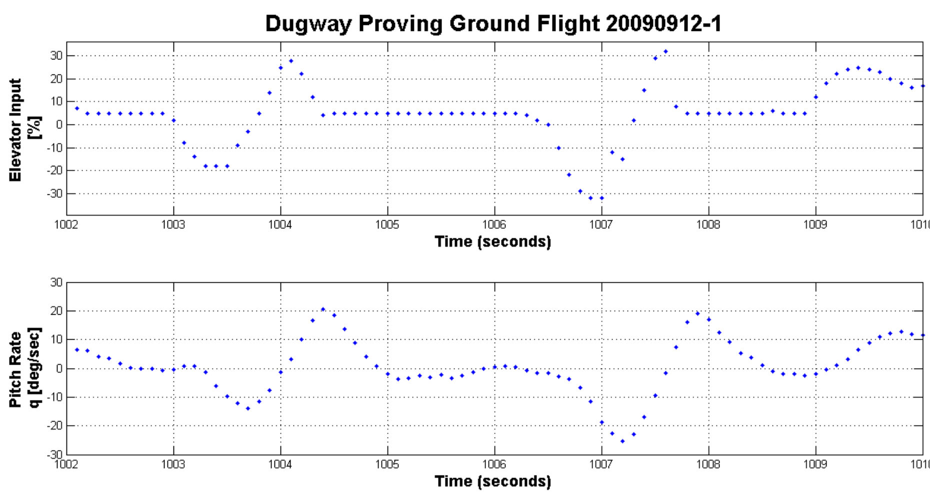

Figure 6.2: Dugway Flight 20090912-1 Short Period Perturbation

During the perturbation, the aircraft had an airspeed of 92 knots and a dynamic pressure of 20.9 pounds per square foot and is compared to the AAA model with the nearest dynamic pressure. The results from the time ratio method of analysis are shown in Table 6.2.

Table 6.2: Short Period Mode Results

Damping Ratio	**Natural Frequency [rad/sec]**	**Dynamic Pressure [lbs/ft^2]**	**Source**
0.60	5.14	20.9	TR Method
0.45	4.40	21.67	AAA Model

The results show that the damping ratio predicted from the AAA model is close to ratio calculated from the flight test telemetry using the Time Ratio method. However, there is a fairly large error in the natural frequency results. The normalized error of the AAA predicted damping ratio with respect to the ratio calculated from the flight test telemetry is 14%. The normalized error of the natural frequency is 26%. The Time Ratio method was used on the 1/3 scale Yak-54 UAV and resulted in normalized errors of 10% for the Short Period damping ratio and 43% for the natural frequency. The large error in the Yak-54 UAV natural frequency was attributed to the highly damped response making the natural frequency calculation difficult and unreliable [10].

6.3 6-DOF Model of the Dutch Roll Mode

The purpose of this exercise is the compare the non-dimensional derivatives generated by AAA with the flight test telemetry using a 6-DOF non-linear model of the Meridian. The 6-DOF non-linear model was originally developed for the 1/3 scale Yak-54 UAV and validated using Yak-54 flight test data [10,11]. The 6-DOF non-linear model was adapted to the Meridian by developing a more advanced engine model [12] that better predicts the performance of the engine in a wide range of atmospheric conditions. The Simulink diagrams of the 6-DOF non-linear model developed for the Meridian are shown in Appendix G.

The 6-DOF non-linear model is stepped through time using the equations of motion, where the forces in the equations of motion are calculated using the non-dimensional derivatives calculated using the AAA software [9]. The non-dimensional derivatives used in the 6-DOF model are selected by matching the closest dynamic pressure at the time of the test point. The model is initialized using the initial conditions at the beginning of the test point being analyzed. The model is then tuned by modifying the non-dimensional derivatives until the normalized root mean squared error between the model and the flight test telemetry is minimized.

The AAA model [9] used in the 6-DOF analysis of the Dutch Roll perturbation is shown in Appendix H.

6.3.1 6-DOF Model Using AAA Non-Dimensional Derivatives

Figure 6.3 shows the AAA generated 6-DOF model of the Meridian compared with the flight test telemetry of the Dutch Roll mode.

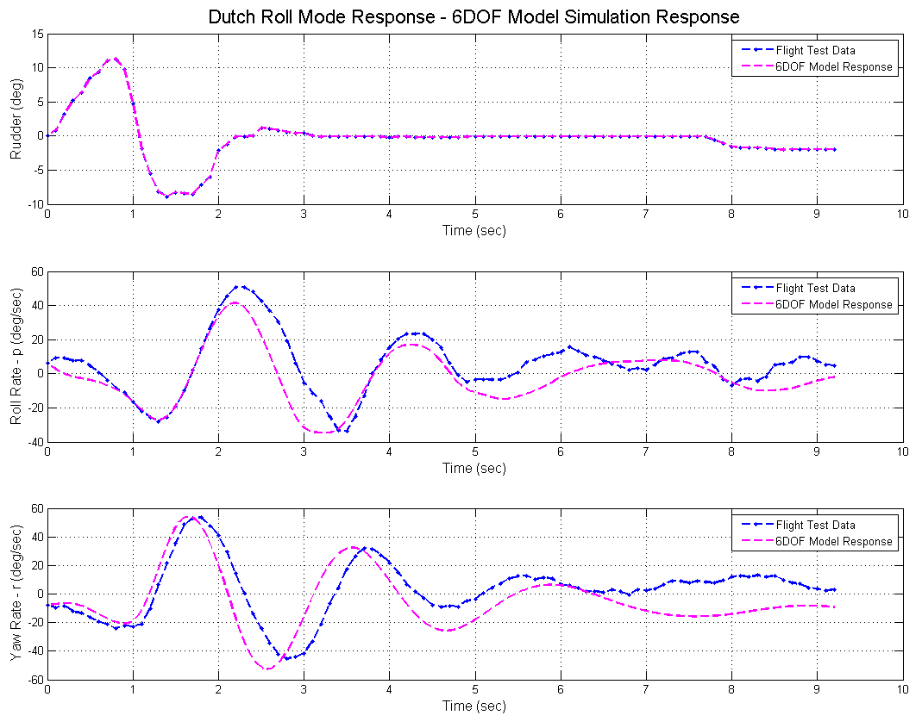

Figure 6.3: 6-DOF Model of Dutch Roll Mode – Angular Rates

The side-by-side comparison shows that the AAA generated 6-DOF model slightly overestimates the natural frequency but predicts the damping ratio of the Dutch Roll mode very accurately.

If the accelerations calculated by the 6-DOF model can match up with the flight test telemetry disregarding the recorded noise, then that demonstrates that the non-dimensional derivatives used for calculating aerodynamic forces on the Meridian are accurate. Figure 6.4 shows that the accelerations generated by 6-DOF model are not able to accurately follow the accelerations recorded in the flight test telemetry.

All of the flight test acceleration data in this chapter is filtered to reduce the amplitude of the vibration noise. The filter used is an averaging filter that averages two consecutive data points. Any further filtering would distort the flight test telemetry making comparison difficult. An averaging filter was selected over a band pass filter because the data is being recorded at 10 Hz and filtering would reduce the Nyquist frequency which is already at 5 Hz.

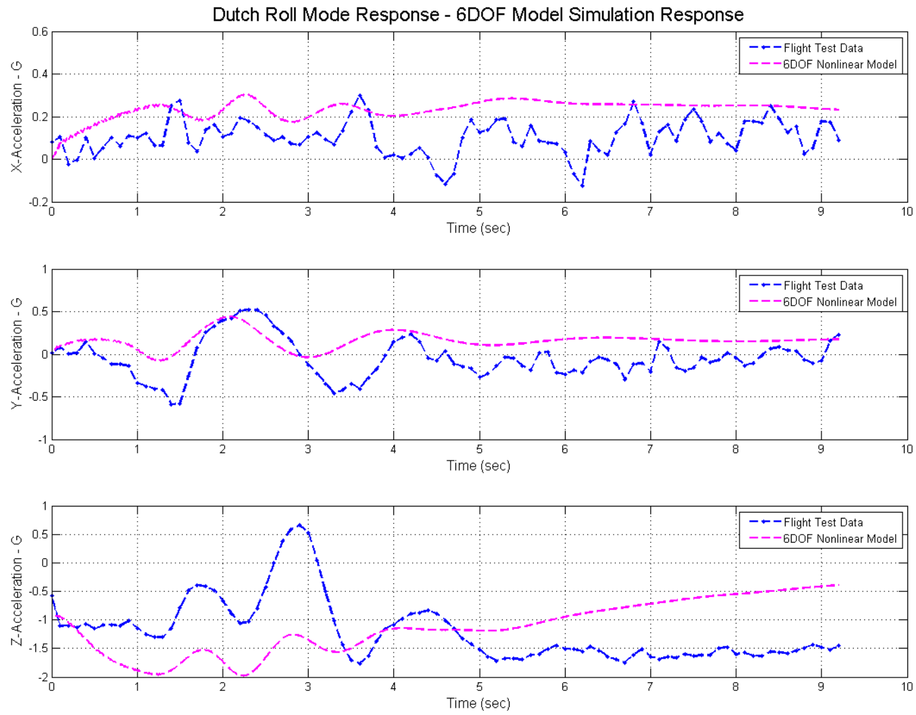

Figure 6.4: 6-DOF Model of Dutch Roll Mode – Body Axis Accelerations

For the Dutch Roll mode, the Y-axis is the primary concern for accuracy. Figure 6.4 shows that the magnitude of the perturbation in the model generated Y-axis acceleration is less than the flight test data. It should also be noted that there is a large discrepancy in the Z-axis acceleration due to cross coupling that is not predicted by the AAA generated model. This cross coupling is noticeable in the pitch rate response to the Dutch Roll maneuver shown in Figure 6.5.

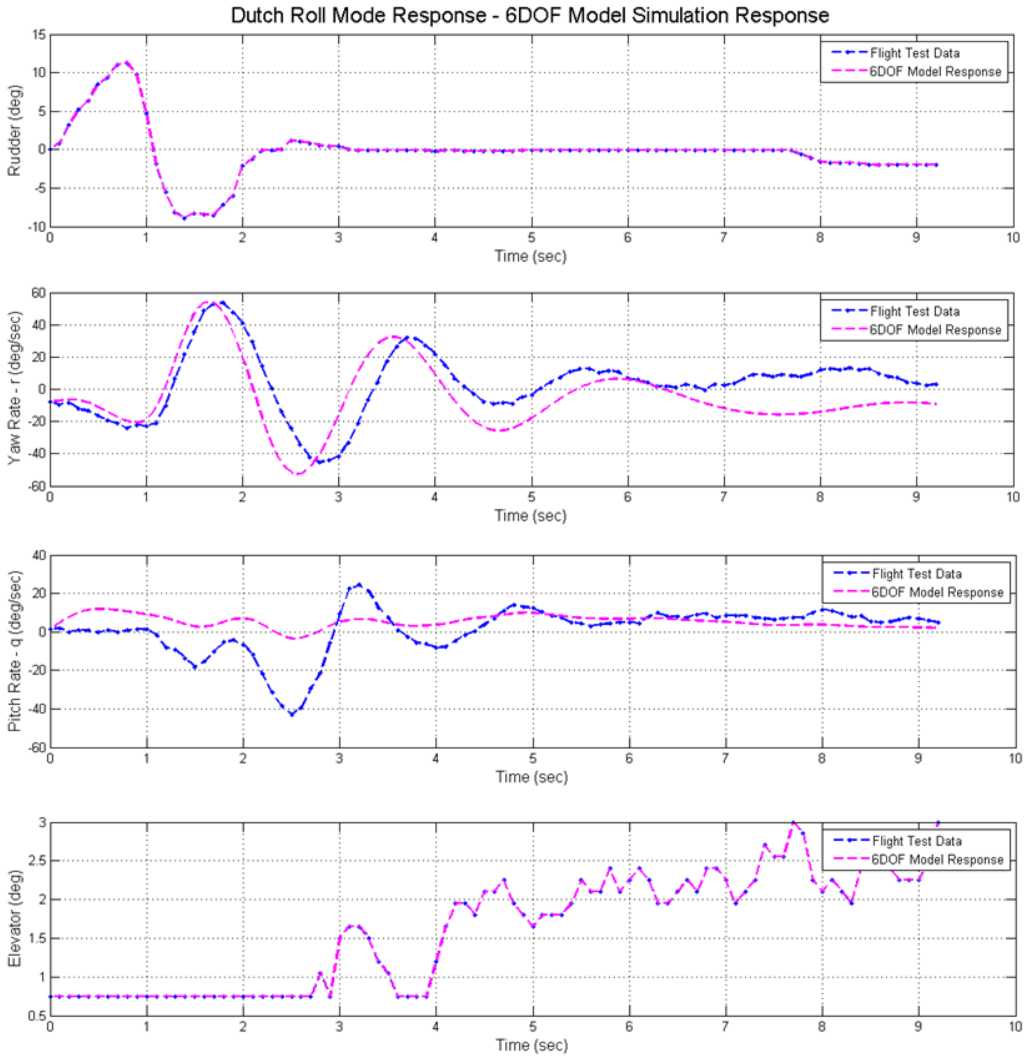

Figure 6.5: Dutch Roll Pitch Rate Coupling

The pitch rate is coupled to the yaw rate. As the aircraft yaws left and right, the side force induced on the V-tail generates a nose down pitching moment due to the dihedral of the tail. As the aircraft noses over, the longitudinal stability of the aircraft causes a nose up pitching moment returning the aircraft to the trim condition.

The 6-DOF can not predict the cross coupling because it specifically assumes that there is no cross coupling between the lateral-directional and longitudinal motion. Therefore, there are no non-dimensional derivatives that reflect cross coupling.

To quantify the performance of the 6-DOF non-linear model of the Meridian, the mean squared error between the model and the flight test telemetry is measured. The normalized root mean squared error of the roll rate and yaw rate is 14.4% and 16.6% respectively.

6.3.2 6-DOF Model Using Modified AAA Non-Dimensional Derivatives

To improve the performance of the 6-DOF model, the AAA non-dimensional derivatives are modified until the normalized mean squared error is minimized. This process is performed by adjusting one derivative by 10% and checking the affect on the normalized mean squared error. The derivative is tuned until the error is minimized, and then the next derivative is tuned in 10% increments. The Dutch Roll approximation suggests that C_{n_β} is the most effective derivative for tuning the 6-DOF model [13]. The more advanced Dutch Roll approximation suggests that the C_{n_r} term is usually negligible relative to C_{n_β} [14].

To tune the Dutch Roll mode, C_{n_β} was reduced by 20% and C_{y_β} was increased by 100%. The tuning reduced the normalized root mean squared error of the roll rate and yaw rate to 11.9% and 5.9% respectively. 75% of the error reduction is a result of tuning C_{n_β}, while tuning C_{y_β} only accounted by 25% of the error reduction. Tuning all other non-dimensional derivatives had little effect on reducing the error. A summary of the tuning is shown in

Table 6.3.

Table 6.3: Tuning Lateral-Directional Derivatives

Derivative	Original Value [1/rad]	Tuned Value [1/rad]	Change in Value [%]	Reduced Error in Model [deg/sec]
C_{n_β}	0.14	0.112	-20	16
$C_{n_{\delta r}}$	0.148	0.148	0	0
C_{n_r}	-0.137	-0.137	0	0
C_{y_β}	-0.478	-0.956	100	5.3

Tuning C_{n_r} had no effect on reducing the error in the model. This result confirms that C_{n_r} is negligible compared to C_{n_β} according to the Dutch Roll approximation [14]. For every 1% change in the value of C_{n_β}, the normalized root mean square error was reduced by 0.50%. C_{y_β} only reduced the error by 0.03% for every 1% change in the value of the derivative. This result demonstrates that tuning C_{n_β} was 16 times more effective than tuning C_{y_β} with respect to reducing error in the model. This result confirms that C_{n_β} is by far the dominant non-dimensional derivative with regards to the Dutch Roll dynamics as suggested by the Dutch Roll approximations [13,14].

Tuning the 1/3 scale Yak-54 UAV 6-DOF model required increasing C_{n_r} by 150% and $C_{n_{\delta r}}$ by 40% [10]. Since C_{n_r} is a negligible term in the Dutch Roll approximation, tuning the model using C_{n_r} must require drastic changes similar to tuning C_{y_β} for the Meridian 6-DOF model. $C_{n_{\delta r}}$ must be tuned when there is a discrepancy in the initial magnitude of the response as a direct result of the rudder deflection. The Meridian model did not have this discrepancy suggesting that $C_{n_{\delta r}}$ was correctly predicted by AAA.

The tuned 6-DOF simulation is shown with the flight test telemetry from the Dutch Roll perturbation in Figure 6.6. When comparing a model to flight test telemetry, results after 5 seconds into the simulation can become unreliable as the simulation inevitably diverges [15,16].

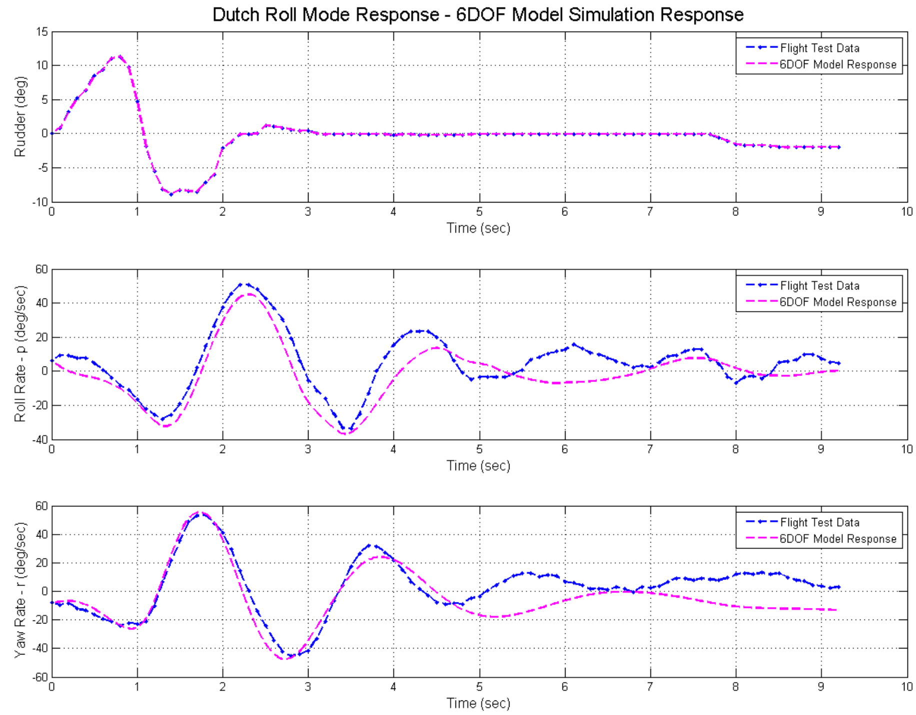

Figure 6.6: Tuned 6-DOF Model of Dutch Roll Mode – Angular Rates

Figure 6.6 shows that the modified non-dimensional derivatives improved the performance of the 6-DOF model. The frequency and damping of the 6-DOF model Dutch Roll response better matches the response recorded in the flight test telemetry. The accelerations from the tuned 6-DOF are shown in Figure 6.7.

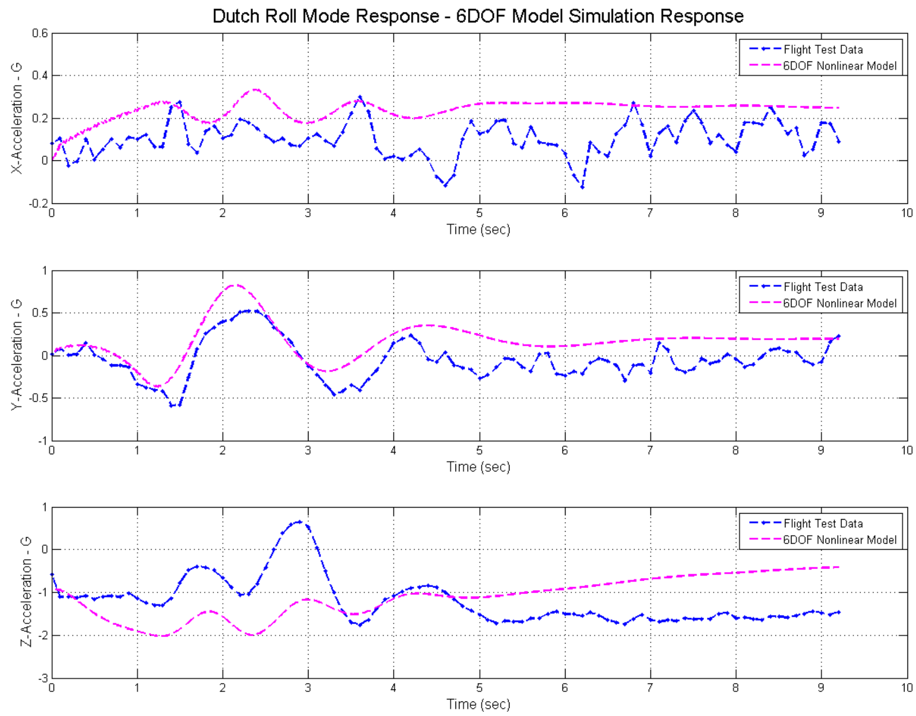

Figure 6.7: Tuned 6-DOF Model of Dutch Roll Mode – Body Axis Accelerations

Looking at the accelerations shows that the Y-acceleration generated by the 6-DOF model follows the flight test telemetry more accurately than the original model. The X and Z accelerations are largely unchanged because the longitudinal non-dimensional derivatives were not modified in this exercise. Error in the X-axis acceleration can be attributed to residual error in the engine model and error in the Z-axis is attributed to the cross coupling in the Dutch Roll mode that is not predicted by the 6-DOF model.

Using the tuned stability and control derivatives for the Dutch Roll mode, a lateral-directional state space model was generated. The Eigen values from this state space model were used to determine the natural frequency and damping ratio of the Dutch Roll mode for the tuned model. Table 6.4 shows the damping ratio and natural frequency of the tuned 6-DOF non-linear model compared with the original AAA model and the dynamics calculated using the MTPR method.

Table 6.4: Dutch Roll Dynamics Comparison

Damping Ratio	Natural Frequency [rad/sec]	Dynamic Pressure [lbs/ft^2]	Source
0.19	3.36	34	MTPR Method
0.14	3.52	33.86	AAA Model
0.19	3.21	33.86	Tuned Model

The tuned model eliminated the error with respect to the MTPR method in the damping ratio and reduced the normalized error in the natural frequency from 5% in the original AAA model to 4% in the tuned model.

6.3.3 6-DOF Model of the Short Period Mode

For this analysis to be accurate, the AAA model must be altered to account for the center of gravity location during the flight test mission. The location of the center of gravity affects the static margin of the aircraft which directly influences the value of C_{m_α}. To account for this, C_{m_α} is recalculated using the estimated static margin during the flight test mission. The AAA model assumes the static margin is at 12%, but during the flight test mission, the static margin was estimated to be closer to 20%.

The AAA model used in the 6-DOF analysis of the short period perturbation is shown in Appendix I [9].

6.3.4 6-DOF Model Using AAA Non-Dimensional Derivatives

Figure 6.8 shows the AAA generated 6-DOF model of the Meridian compared with the flight test telemetry of the short period mode.

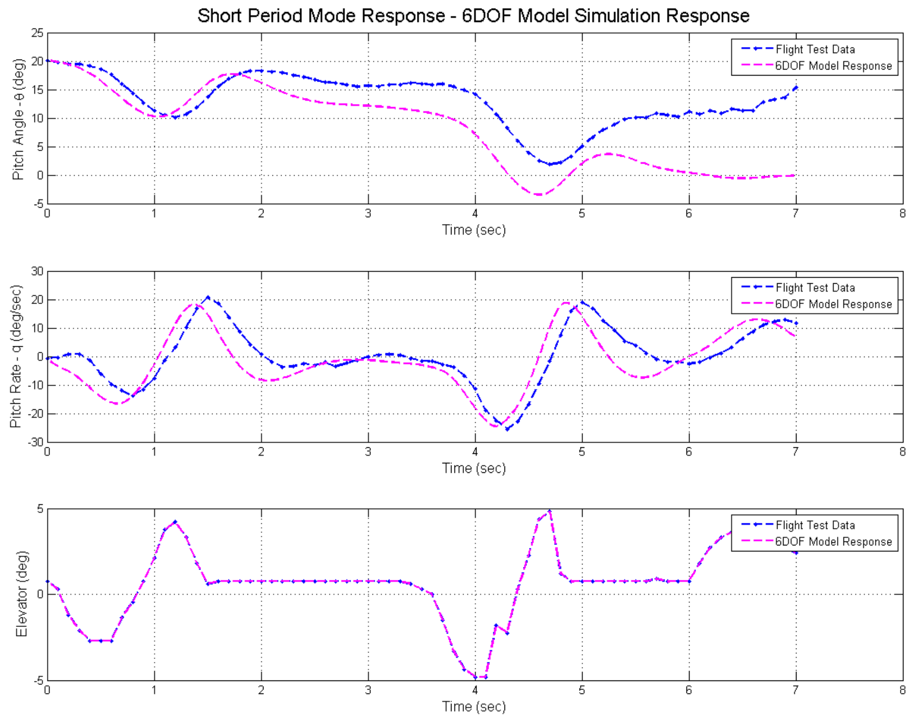

Figure 6.8: 6-DOF Model of Short Period Mode – Longitudinal Response

Comparing the roll rate between the 6-DOF model and the flight test telemetry shows that the model is slightly under estimating the damping of the short period mode. This finding agrees with the dynamic analysis of the short period performed previously. The normalized root mean squared error of the pitch rate between the flight test telemetry and the 6-DOF model response is 13.4%, which is very impressive considering the model has not been tuned.

The accelerations from flight test telemetry and 6-DOF model of the short period mode are shown in Figure 6.9.

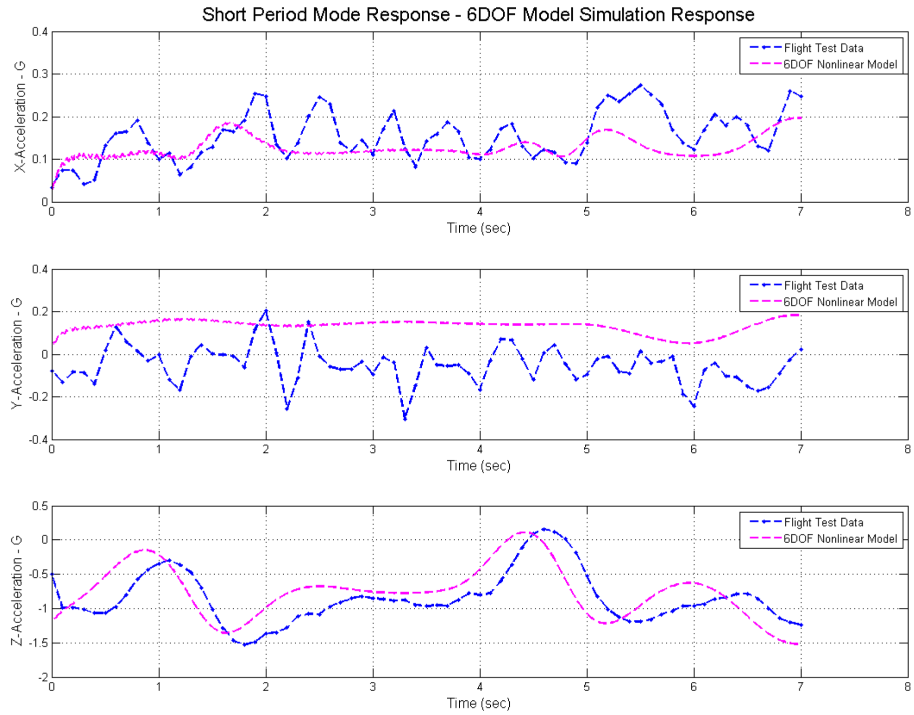

Figure 6.9: 6-DOF Model of Short Period Mode – Body Axis Accelerations

6.3.5 6-DOF Model Using Modified AAA Non-Dimensional Derivatives

To improve the 6-DOF non-linear model, the non-dimensional derivatives are tuned in 10% increments until the mean squared error of the pitch rate between the flight test telemetry and the 6-DOF model is minimized. The Short Period approximation suggests that C_{m_α} is the most effect derivative for tuning the 6-DOF model [13]. A more advanced short period approximation [14] states that if C_{m_q} is small, the term can be completely neglected. Since the value of the Meridian's C_{m_q} is -14.088, this term is not neglected being that it is much larger relative to the other derivatives.

The model is tuned after decreasing C_{m_α} by 50%, which reduced the normalized root mean square error of the pitch rate to 5.1%. Adjusting any of the other non-dimensional derivatives had little effect on reducing the mean squared error. A summary of the changes made to the model are shown in Table 6.5.

Table 6.5: Tuning Longitudinal Derivatives

S&C Derivative	Original Value [1/rad]	Tuned Value [1/rad]	Change in Value [%]	Reduced Error in Model [deg/sec]
C_{L_α}	5.151	5.151	0	0
C_{m_α}	-1.030	-0.515	-50	5.7
$C_{m_{\dot{\alpha}}}$	-3.172	-3.172	0	0
$C_{m_{\delta e}}$	-1.662	-1.495	-10	0.14
C_{m_q}	-14.088	-12.679	-10	0.17

For every 1% change in C_{m_α}, there was a 0.16% reduction in the normalized root mean squared error. For $C_{m_{\delta e}}$ and C_{m_q} there was only a 0.02% reduction in normalized error for every 1% change in the derivative. This demonstrates that C_{m_α} is 8 times more effective at tuning the Short Period mode than the other derivatives. This result also confirms that C_{m_α} is the dominant non-dimensional derivative of the Short Period mode as suggested by the Short Period approximations [13,14].

It should also be noted that the 50% change in C_{m_α} suggests 2 possible errors in the calculation of the value. Either the aerodynamic center is located further forward than originally estimated, or the value of C_{L_α} is less than what was originally calculated using AAA.

When this method was used to tune the non-dimensional derivatives of the 1/3 scale Yak-54 UAV, C_{m_q} was increased by 100% and $C_{m_{\delta e}}$ was increased by 40% [10]. Since C_{m_q} is a negligible term according to the Short Period approximation, it must be adjusted drastically to have a meaningful effect. $C_{m_{\delta e}}$ must be tuned if there is a discrepancy in the magnitude of the response as a direct result of the elevator input. The Meridian model did not have a very large discrepancy and $C_{m_{\delta e}}$ was only adjusted by 10%.

The longitudinal response of the tuned 6-DOF model is shown in Figure 6.10.

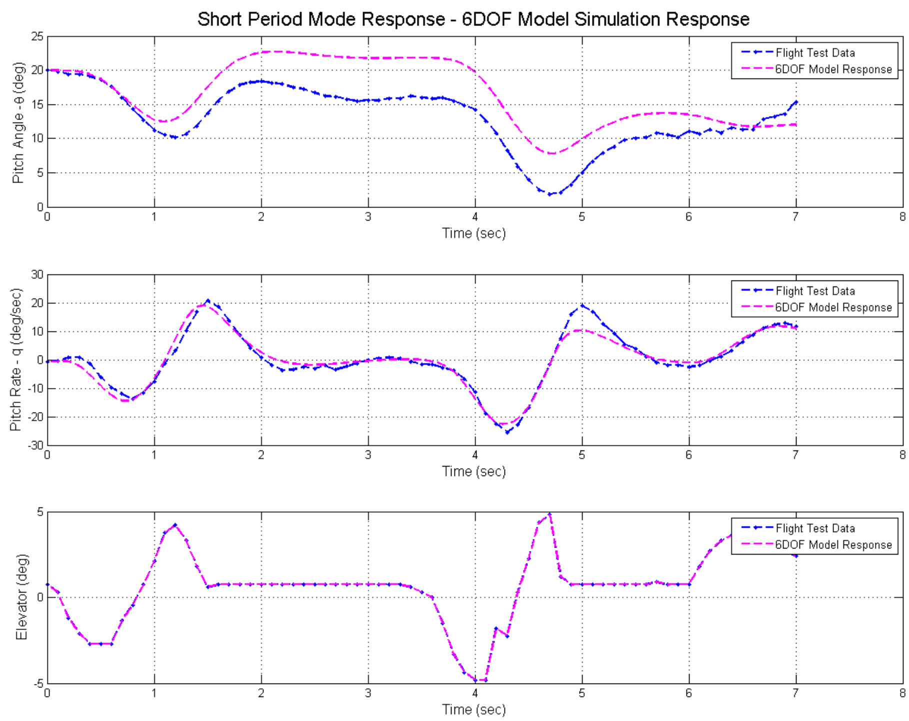

Figure 6.10: Tuned 6-DOF Model of Short Period Mode – Longitudinal Response

The improved model follows the pitch rate recorded by the flight test telemetry. Since the pitch rate of the model and flight test are nearly matched, the pitch angle of the model and flight test should be matched. This result confirms the attitude error recorded in the flight test telemetry. The error in the Pitch angle can be attributed to the noise entering the Kalman filter through the poorly damped accelerometers. The accelerations for the improved model are shown in Figure 6.11.

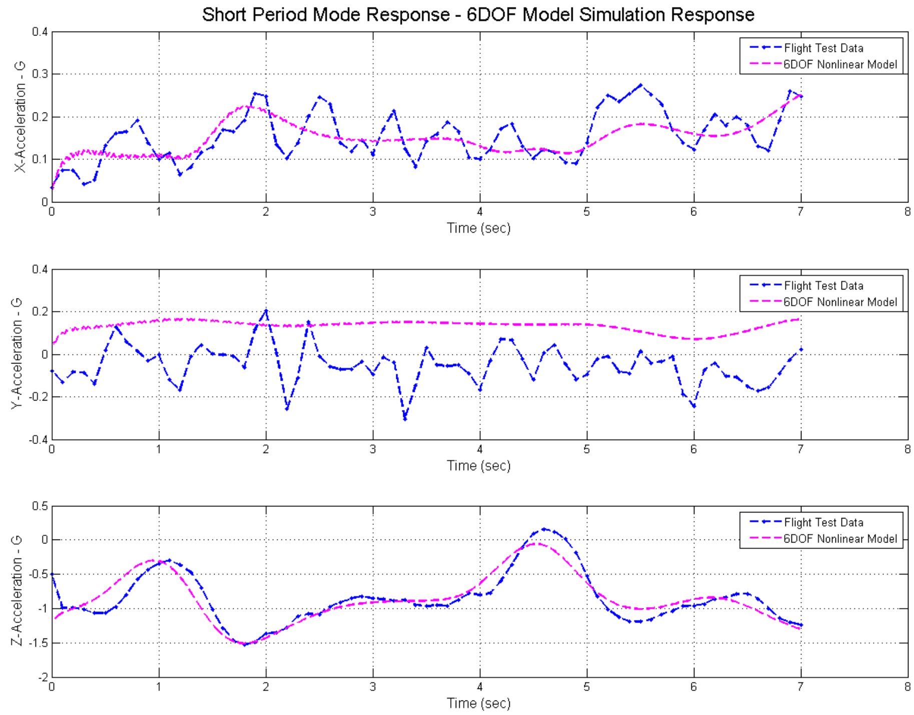

Figure 6.11: Tuned 6-DOF Model of Short Period Mode – Body Axis Accelerations

When comparing the accelerations of the tuned model to the original model, an improvement is noticeable. The X and Z-axis accelerations more closely match up. The lateral-directional derivatives were not altered during the Short Period tuning, so the Y-axis accelerations were unchanged.

Using the tuned stability and control derivatives, a state space model is generated for the longitudinal dynamics. Table 6.6 shows the dynamics of the tuned state space model compared with the original AAA model and the calculations from the Time Ratio method.

Table 6.6: Short Period Dynamics Comparison

Damping Ratio	Natural Frequency [rad/sec]	Dynamic Pressure [lbs/ft^2]	Source
0.60	5.14	20.9	TR Method
0.45	4.40	21.67	AAA Model
0.53	3.55	21.67	Tuned Model

The comparison shows that the tuned model reduced the error in the damping ratio with respect to the Time Ratio method, but the error in the natural frequency increased. Some of this error may be attributed to inaccuracy that may exist in the Time Ratio method calculations.

6.4 Summary of Meridian UAS 6-DOF Non-Linear Model

Figure 6.12 shows a CH-47F helicopter high fidelity model generated using CIFER compared with flight test results [17].

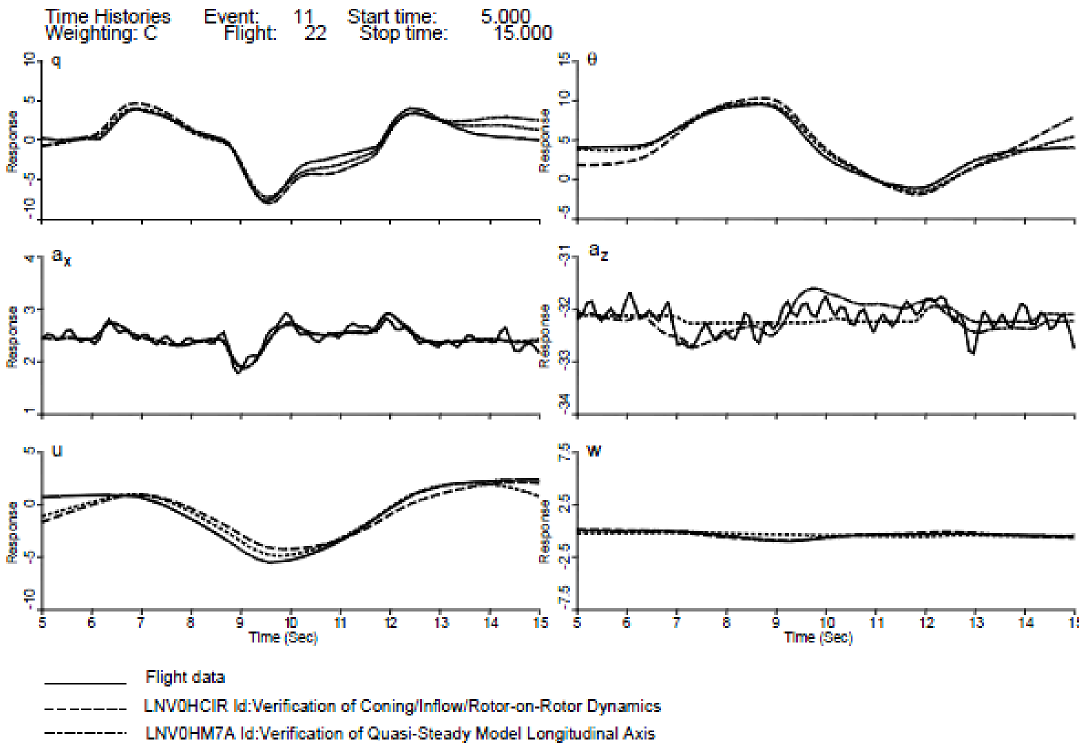

Figure 6.12: High Fidelity Simulation Model Time Domain Response Compared to Flight Test Results [17]

Comparing the results of the high fidelity model generated using CIFER to the results of the tuned low fidelity AAA model demonstrates that the tuned 6-DOF non-linear model of the Meridian effectively has the same accuracy as a high fidelity model.

The tuning of the AAA model to minimize the normalized root mean squared error from the flight test telemetry can be summarized in the following table.

Table 6.7: Summary of Tuned AAA Non-Dimensional Derivatives

Derivative	Original Value [1/rad]	Tuned Value [1/rad]	Change in Value [%]	Reduced Error in Model [deg/sec]
C_{m_α}	-1.030	-0.515	-50	5.70
$C_{m_{\delta e}}$	-1.662	-1.495	-10	0.14
C_{m_q}	-14.088	-12.679	-10	0.17
C_{n_β}	0.140	0.112	-20	16.0
C_{y_β}	-0.478	-0.956	100	5.30

When comparing the tuning of the Meridian model to the tuning the 1/3 scale Yak-54 UAV model, it is evident that the Meridian model required less tuning to minimize the normalized error. In the case of the Dutch Roll mode, the Meridian model only required 37% less tuning than the Yak-54 and 50% less for the Short Period mode. These results suggest that AAA was more accurate at predicting the non-dimensional derivatives of the Meridian when compared with the Yak-54 UAV. This is likely because the Meridian is a much larger vehicle than the Yak-54, and therefore has a higher Reynolds number. The AAA software is most effective at a Reynolds number greater than 3 million.

The following summarizes the results of the Meridian UAS 6-DOF model using non-dimensional derivatives generated using the AAA software.

- Showing the AAA Meridian model and the flight test telemetry side-by-side shows that the AAA generated 6-DOF non-linear model effectively predicts the dynamics of the modes despite being a low fidelity model.
- The Meridian AAA model required less tuning than the scaled Yak-54 AAA model.
- Tuning the AAA model to minimize normalized root mean squared error proves to be a very useful tool for parameter identification.
- Tuning the AAA model using flight test telemetry increases the accuracy of the model so that it can be adapted into a high fidelity simulator for the Meridian UAS.
- The 6-DOF non-linear model can be used to identify the dominant non-dimensional derivative of a specific dynamic mode.
- C_{n_β} is the most effective parameter to be tuned for the Dutch Roll response, as predicted by the Dutch Roll approximation.
- C_{m_α} is the most effective parameter to be tuned for the Short Period response, as predicted by the Short Period approximation.

The Meridian is tasked with flying long missions in diverse environments and possibly extreme weather conditions. It is highly recommended that the dynamics of the aircraft are fully analyzed using traditional system identification techniques such as inputting doublets, but also frequency sweeps should be used [15,16,17].

Performing doublets help to understand the dynamic modes of the aircraft, but control frequency sweeps will provide a more complete picture.

6.5 Drag Analysis

The drag of the Meridian is calculated using the steady state equation of motion in the body coordinate X-axis.

$$m\left(\dot{U} - V \cdot R + W \cdot Q\right) = -m \cdot g \cdot \sin(\theta) - C_D \cdot \bar{q} \cdot S + T$$

To calculate the drag, the left side of the equation of motion must be equal to zero, which assumes that the aircraft is in steady state rectilinear flight, or the aircraft is not accelerating and the angular rates are equal to zero. There are a few brief moments in the flight test telemetry where the aircraft is trimmed and this condition exists. When the aircraft is trimmed in steady state rectilinear flight, the equation of motion can be re-written as:

$$C_D \cdot \bar{q} \cdot S = T - m \cdot g \cdot \sin(\theta)$$

Where surface area (S) is known from the Meridians geometry, the weight of the aircraft ($m\,.\,g$) is known from the weight and balance, and the dynamic pressure ($\bar{q}$) and pitch angle (θ) are known from the flight telemetry. The thrust can be calculated using the following equation:

$$T = \frac{\delta_T \cdot P}{V_a}$$

Where the power of the engine (P) is known (135 HP), and the engine load, or throttle, (δ_T) and velocity (V) are found in the flight telemetry. The power of the engine is affected by the density altitude. To correct for the density altitude, the DIN 70020 standard was used to calculate the correction factor [18].

The drag analysis is performed on the first, third, and fifth flights of the Meridian because the change in drag between those flights is most noticeable. During the first flight of the Meridian, the skin surface was rough and unfinished. Before the third flight, the entire aircraft was wet sanded and a filler was applied on the leading edge of the wing and V-tails then sanded smooth. Before the fifth flight of the Meridian that took place in Antarctica, the wings were professionally painted, the engine cowl was modified to reduce drag, and fairings were installed over the wing roots. The results from the drag analysis are shown in Table 6.8.

Table 6.8: Drag Analysis Results

Flight Number	**Location**	**Throttle**	**Airspeed**	**Altitude**	**Pitch Angle**	**Drag Coefficient**
		[%]	**[knots]**	**[feet]**	**[deg]**	**[-]**
1	Fort Riley, KS	69	102.0*	1685	-10	0.1994
3	Dugway, UT	92	100.3	5171	5	0.1041
5	Antarctica	49	111.5	705	5	0.0326
5	Antarctica	51	110.9	708	4	0.0427

** Estimated from Ground Speed and Wind Conditions*

Since the air data probe was not operational during the first flight, the air density and airspeed had to be estimated. The airspeed is estimated using the GPS ground and wind conditions during the flight. The air density at the time of the flight is estimated from the altitude using the Standard Atmospheric Tables [19]. It should also be noted that the flaps were half deployed during the first flight, which added to the overall drag. AAA predicts that a full deflection of flaps would increase the drag by 535 counts, which does not account for the 950 count deficit between the first flight and the third flight.

Wet sanding the surface of the aircraft to reduce the skin friction and filling in the leading edge and v-tails reduced the drag by 900 counts. Painting the wings, installing fairings, and modifying the engine cowl reduced the drag by another 600 counts. AAA predicts that the steady state drag coefficient for the Meridian in the fifth flight trim condition should be 0.0247. This means that the Meridian still needs some more drag reduction efforts to reach the AAA predicted value. Professionally painting the fuselage and V-tails and installing fairings over the wheels will likely complete the drag reduction efforts.

6.6 Future Flight Test Analysis Recommendations

For the best quality data, the aircraft must be trimmed during these system identification maneuvers and the maneuvers must be repeated several times at the same trim point so that a large sample size can be analyzed. It is recommended that the wePilot is used to trim the aircraft and preprogrammed to input the maneuvers. Using the wePilot to perturb the dynamic modes with the inner loops disabled would create more consistent data for analysis. Also, with the wePilot trimming the aircraft, better flight telemetry can be gathered and examined for the drag analysis.

When frequency sweep maneuvers are performed, it is recommended that the wePilot sample rate is increased so that the Nyquist frequency is equal to that of the highest frequency being tested.

Test maneuvers should be performed at the wePilot trim speeds of 80 knots, 100 knots, and 120 knots. All of the system identification flight test data should be applied to the Meridian 6-DOF non-linear model to increase the fidelity of the model.

7 Conclusions and Recommendations

7.1 Conclusions

By critically examining the Meridian UAS Flight Test Program and resulting flight test telemetry, the following conclusions can be made:

1. To prove the Meridian as fully operational, all of the flight test objectives described in this document must be completed.
2. Flight test planning is an ongoing process that requires constant tweaking as experience gained on completed flight test missions.
3. The most significant hold up in getting the autopilot to function correctly was vibration noise entering the Kalman filter through the accelerometers due to inadequate dampening.
4. Comparing the Meridian model developed in AAA to the flight test telemetry clearly demonstrates that the AAA software is an effective tool for predicting the aerodynamic characteristics of a non-conventional unmanned aerial vehicle and the parameter tuning is only necessary for increasing the fidelity of the model.
5. The 6-DOF non-linear model is a useful tool for parameter identification when provided with properly gathered flight test telemetry.

6. The normalized root mean squared error is the best tool for tuning the non-dimensional derivatives of the 6-DOF non-linear model and identifying the dominant derivative for a dynamic mode.
7. The performance of the 6-DOF non-linear model tuned using flight test telemetry is on par with a high fidelity model.
8. The tuned 6-DOF non-linear model can be used as a Meridian simulator for training a new pilot and crew on the dynamics and performance of the Meridian UAS.
9. From the first flight of the Meridian at Fort Riley, KS to the fifth flight at Pegasus Airfield, Antarctica, it is estimated that the drag on the aircraft was reduced by 80% or nearly 1600 counts.
10. Finishing the fuselage and tail of the aircraft with a professional coat of paint and installing wheel fairings is likely to reduce the drag of the Meridian to the AAA predicted value.

7.2 Recommendations

Based on the results of this thesis, the following recommendations for the Meridian UAS Flight Test Program are advised:

1. Every takeoff must be conducted as a 3-point takeoff.
2. Before every flight test, check the vehicle trim after completing the weight and balance document.

3. Develop and implement a maximum airspeed limiter for the wePilot that can override the pilot's control of the throttle.
4. Redesign the wePilot GUI so that it is provides flight information in a more efficient manner for the ground station operators.
5. Patch MAAS so that it will not fail during the engine startup procedure.
6. To truly determine the performance of the wePilot, the automatic mode must be tested in steady state rectilinear flight.
7. Use the wePilot to trim the Meridian UAS and input the appropriate system and parameter identification maneuvers with the inner loops disabled to improve the quality of the flight test data.
8. Repeat the dynamic analysis and system identification maneuvers multiple times so that an adequate data set is available for analysis.
9. All system and parameter identification flight test data should be applied to the Meridian 6-DOF non-linear model to improve the fidelity as a Meridian simulator.
10. Caution should still be exercised when using the AAA software to predict aerodynamic characteristics of a non-conventional aircraft due its assumption that there is no cross coupling between longitudinal and lateral-directional motion.

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Appendix A. Weight and Balance Document

Weight and Balance Document

DATE:	MM/DD/YYYY	AIRCRAFT:	Meridian UAS

AIRCRAFT CONFIGURATION:

DISTANCE MEASUREMENTS:

MG to LE (x):		in	RM to LM (y):		in
MG to TW (x):		in			

WEIGHT MEASUREMENTS:

Right Main Gear:		lbs
Left Main Gear:		lbs
Tail Wheel:		lbs

CG CALCULATIONS:

Gross Weight:	0	lbs
RM X-Moment Arm:	0	in-lbs
LM X-Moment Arm:	0	in-lbs
TW X-Moment Arm:	0	in-lbs
CG X-Location:		inches (Aft of Wing Leading Edge)
CG w.r.t. MGC:		
Static Margin:		(Aerodynamic Center located at 45% MGC)
RM Y-Moment Arm:	0	in-lbs
LM Y-Moment Arm:	0	in-lbs
CG Y-Location:		inches (With Respect to Center-Line)

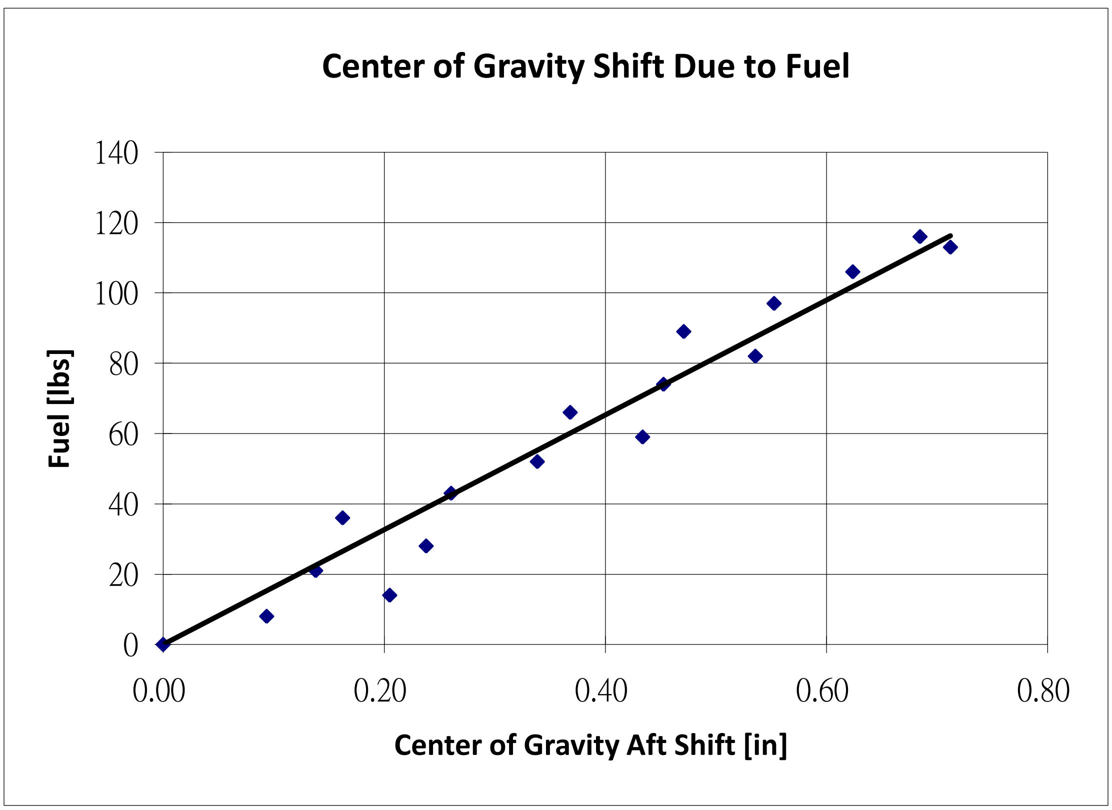
NOMENCLATURE:

MG:	Main Gear	RM:	Right Main Gear
TW:	Tail Wheel	LM:	Left Main Gear
LE:	Leading Edge	MGC:	Mean Geometric Cord

REFERENCE DATUM:

The reference datum is located at the wing leading edge. Positive distance is measured aft of the datum and to the right of the center line. Negative distance is measured forward of the datum.

Flight Configuration



C.G. Shift Due to Fuel Added

Appendix B. Flight Plan Document

DATE: MM/DD/YY	**FLIGHT NO.:**		**AIRCRAFT:** Meridian UAS

FLIGHT TEST CREW:

Saftey Officer:		**FTE 1:**	
Flight Director:		**FTE 2:**	
Pilot:		**FTE 3:**	
Pilot Assistant:		**Observer:**	

AIRCRAFT:

Configuration:		
CG:		(8.0-11.1 in limit)
Weight:		(1200 lbs limit)
Fuel:		(5-25 gal limit)
Flight Time:		
Reserve:		
Maintenance Items:		

Procedure:

MISSION:

Objectives:	
Test Data:	

SAFETY:

Go/No-Go Items:	
Abort Criteria:	
Emergency:	

WEATHER:

Local:	
Forecast:	

Post-Flight Comments:

Appendix C. Pre-Flight Checklist and Engine Startup Procedure

Airframe Checklist

Fuselage

All Avionics Switches OFF		___
Avionics Box Secure		___
Avionics Wiring Secure and Correct		___
Fuel Tank Secure		___
Appropriate Fuel Onboard	________ gal	___
Fuel Lines Secure with No Leaks		___
Lower Fuselage Hatch Secure		___
Lower Antennas Secure		___

Left Wing

Left Flap Secure	___
Left Flap Actuator Secure	___
Left Aileron Secure	___
Left Aileron Actuator Secure	___
Left Wing Hatches Secure	___
Left Wingtip Secure	___
Left Leading Edge	___
Pitot Tube Secure and Clear	___
Left Wing Pin Secure	___

Firewall Forward

Left Wheel Secure	___
Left Brake Secure with No Leaks	___
Left Gear Mount Secure	___
Cowling Secure	___
Propeller Secure	___
Propeller Spinner Secure	___
Right Gear Mount Secure	___
Right Brake Secure with No Leaks	___
Right Wheel Secure	___

Right Wing

Right Wing Pin Secure	___
Right Leading Edge	___
Right Wingtip Secure	___
Right Aileron Secure	___
Right Aileron Actuator Secure	___
Right Flap Secure	___
Right Flap Actuator Secure	___
Right Wing Hatches Secure	___

Empennage

Right V-Tail Secure	___
Tail Cone Secure	___
Tail Antennas Secure	___

Tail Wheel Secure ___
Tail Wheel Actuator Secure ___
Left V-Tail Secure ___

Batteries Charged

Engine Startup Battery (12v + 12v) ________ v ___
Avionics Battery (24v) ________ v ___

Powerplant Checklist

Engine Oil Level CHECKED ___
Gearbox Oil Level CHECKED ___
Engine Coolant Level CHECKED ___
Check Fuel Tank for Water and Debris

Weather Conditions

Wind Speed	____________________	KTS	___
Wind Direction	____________________		___
Visibility	____________________	mi	___
Ceiling	____________________	ft	___
Temperature	____________________	°F / °C	___
Dew Point	____________________	°F / °C	___
Pressure Altitude	____________________	inHg	___
Density Altitude	____________________	ft	___

Safety

ABC Fire Extinguisher 1 (Designate Personnel) _________
ABC Fire Extinguisher 2 (Designate Personnel) _________
Emergency Response Officer 1 (Calls 911 in Emergency) _________
Emergency Response Officer 2 (Calls 911 in Emergency) _________
Radio Controller _________
Pre-Flight Briefing COMPLETE ___
Cell Phones OFF ___
Propeller Hazard Zone CLEAR of debri ___
Wheels Chocked ___

wePilot Ground Station

Power Supply READY ___
Ground Station Antennas CONNECTED ___
wePilot Software RUNNING ___

Futaba Transmitter

Futaba Transmitter ON ___
Transmitter Battery Charged (S/B > 10v) ________ % ___
Correct Flight Profile Selected (Meridian One) ___

Avionics Box

Receiver Switches ON ___
Hatch Antennas SECURE and CORRECT ___
Engine Ground Station Control Cable SECURE ___
Engine Power Switch ON ___
Engine Ground Station Startup Battery SECURE ___
Avionics Mode Set to GROUND ___
Ground Box Master Buss ON ___
Ground Box Battery Master ON ___
wePilot Backup Battery SECURE ___
Master Switch ON ___
Avionics Master Switch ON (Wait to Boot Up) ___
Servo Switch ON ___
Engine Switch ON ___
Avionics Mode Set to FLIGHT ___
Ground Box Master Buss OFF ___
Ground Box Battery Master OFF ___

wePilot Ground Station

900 MHz Link GREEN ___
72 MHz Link GREEN ___
Iridium Satellite Link GREEN
GPS Link GREEN ___
FCS Voltage GREEN (>12V) ___
Autopilot FCS Status GREEN ___
GPS Telemetry CHECK (Correct Position on Map) ___
Altitude CHECK (MSL) ___
Attitude Angles CHECK ___
Speeds Check (Air, Ground, and Winds Speed) ___
Verify Relative Distance (Horizontal and Vertical) ___
Map Page CONFIGURED ___
Home Waypoint SET ___
Flight Mission Plans UPLOADED ___
Kill Switch TEST ___

Pre-Engine Startup Checks

Actuator Control Sweep COMPLETE ___
Throttle TEST ___
Kill Switch TEST ___
Range Check ___

Go/No-Go for Engine Startup

Pilot ___

Flight Controls ___
MAAS ___
Real-Time Telemetry
Powerplant ___
Video ___
Safety ___

Engine Startup Checklist

Wheel Chocks SET ___
Brakes ON ___
Load Selector (Throttle) SET 0% ___
Lights Switch ON
Transponder Switch ON
Fuselage Hatch SECURE ___
Propeller Hazard Zone CLEAR ___
Engine Start ___
Engine Startup Time NOTE ________ ___
FADEC A/B TEST
Engine Oil Pressure GREEN ___
Engine Oil Temperature GREEN ___
Engine Coolant Temperature GREEN ___
Engine Gearbox Temperature GREEN ___
Disconnect Engine Ground Box ___
Engine Run-up (Hold the Tail Down) ___
Remove Chocks ___

Pre-Flight Checks

Brakes CHECK ___
Taxi Test ___
Airspace CLEAR for Take-off ___

Go/No-Go for Take-off

Pilot ___
Flight Controls ___
MAAS ___
Real-Time Telemetry ___
Safety ___

Take-off

Take-off Time NOTE ________ ___

Landing Checklist

Approach Airspeed 70 KTS ___
Brakes OFF ___

Flaps DOWN FULL ___

Landing Time NOTE ________ ___

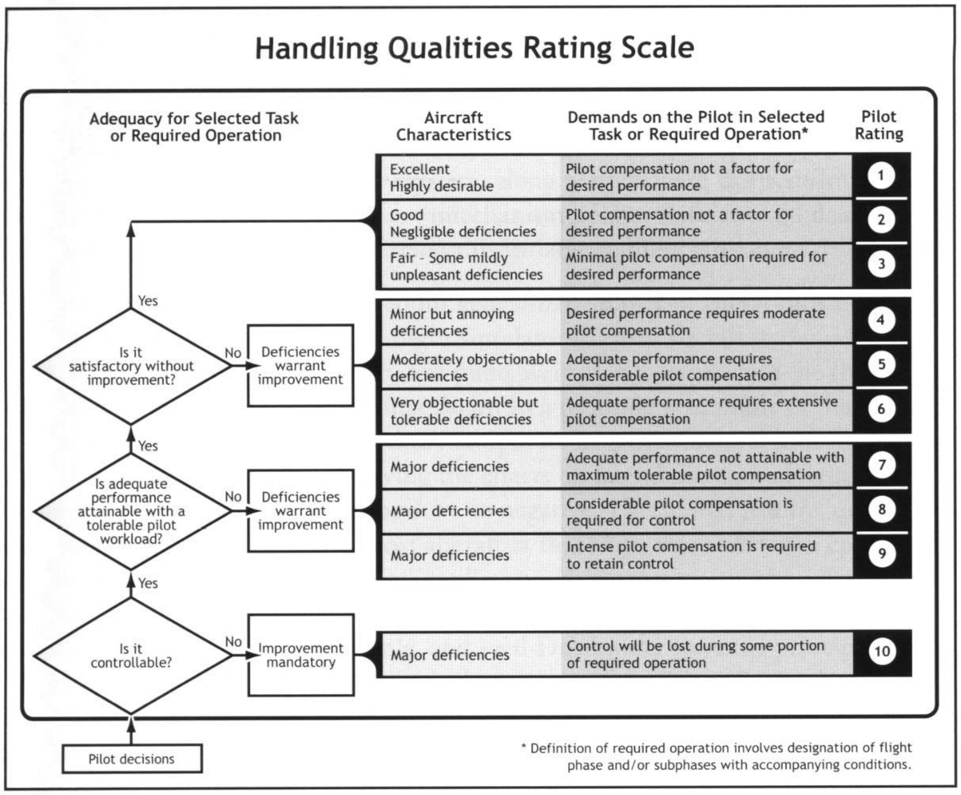
Engine Shutdown Checklist

Engine KILL ___

Engine Off Time NOTE ________ ___

Brakes OFF ___

Appendix D. Cooper-Harper Pilot Rating Scale



Cooper-Harper Pilot Rating Scale

Appendix E. Weight and Balance Documents

Weight and Balance Document

DATE:	8/27/2009		**AIRCRAFT:**	Meridian UAS
AIRCRAFT CONFIGURATION:	First flight configuration with new avionics box, full tank of fuel			
DISTANCE MEASUREMENTS:				
MG to LE (x):	-0.4	in	**RM to LM (y):**	74.5 in
MG to TW (x):	157.125	in		
WEIGHT MEASUREMENTS:				
Right Main Gear:	498	lbs		
Left Main Gear:	517	lbs		
Tail Wheel:	49	lbs		
CG CALCULATIONS:				
Gross Weight:	1064	lbs		
RM X-Moment Arm:	-199	in-lbs		
LM X-Moment Arm:	-207	in-lbs		
TW X-Moment Arm:	7680	in-lbs		
CG X-Location:	6.836	inches (Aft of Wing Leading Edge)		
CG w.r.t. MGC:	21.58%			
Static Margin:	23.42%	(Aerodynamic Center located at 45% MGC)		
RM Y-Moment Arm:	18550.5	in-lbs		
LM Y-Moment Arm:	-19258.25	in-lbs		
CG Y-Location:	-0.665	inches (With Respect to Center-Line)		
NOMENCLATURE:				
MG:	Main Gear		**RM:**	Right Main Gear
TW:	Tail Wheel		**LM:**	Left Main Gear
LE:	Leading Edge		**MGC:**	Mean Geometric Cord

REFERENCE DATUM:

The reference datum is located at the wing leading edge. Positive distance is measured aft of the datum and to the right of the center line. Negative distance is measured forward of the datum.

Weight and Balance Document

DATE: 9/9/2009 **AIRCRAFT:** Meridian UAS

AIRCRAFT CONFIGURATION: DPG Flight Configuration.

DISTANCE MEASUREMENTS:

MG to LE (x):	-0.4	in	**RM to LM (y):**	74.5	in
MG to TW (x):	157.125	in			

WEIGHT MEASUREMENTS:

Right Main Gear:	482	lbs
Left Main Gear:	517	lbs
Tail Wheel:	49	lbs

CG CALCULATIONS:

Gross Weight:	1048	lbs
RM X-Moment Arm:	-193	in-lbs
LM X-Moment Arm:	-207	in-lbs
TW X-Moment Arm:	7680	in-lbs
CG X-Location:	6.946	inches (Aft of Wing Leading Edge)
CG w.r.t. MGC:	21.93%	
Static Margin:	23.07%	(Aerodynamic Center located at 36% MGC)
RM Y-Moment Arm:	17954.5	in-lbs
LM Y-Moment Arm:	-19258.25	in-lbs
CG Y-Location:	-1.244	inches (With Respect to Center-Line)

NOMENCLATURE:

MG:	Main Gear	**RM:**	Right Main Gear
TW:	Tail Wheel	**LM:**	Left Main Gear
LE:	Leading Edge	**MGC:**	Mean Geometric Cord

REFERENCE DATUM:

The reference datum is located at the wing leading edge. Positive distance is measured aft of the datum and to the right of the center line. Negative distance is measured forward of the datum.

Weight and Balance Document

DATE:	9/11/2009	**AIRCRAFT:**	Meridian UAS

AIRCRAFT CONFIGURATION: DPG Flight Configuration. 10 lbs added to tail bracket.

DISTANCE MEASUREMENTS:

MG to LE (x):	-0.4	in	**RM to LM (y):**	74.5	in
MG to TW (x):	157.125	in			

WEIGHT MEASUREMENTS:

Right Main Gear:	477	lbs
Left Main Gear:	513	lbs
Tail Wheel:	55	lbs

CG CALCULATIONS:

Gross Weight:	1045	lbs
RM X-Moment Arm:	-191	in-lbs
LM X-Moment Arm:	-205	in-lbs
TW X-Moment Arm:	8620	in-lbs
CG X-Location:	7.870	inches (Aft of Wing Leading Edge)
CG w.r.t. MGC:	24.84%	
Static Margin:	20.16%	(Aerodynamic Center located at 36% MGC)
RM Y-Moment Arm:	17768.25	in-lbs
LM Y-Moment Arm:	-19109.25	in-lbs
CG Y-Location:	-1.283	inches (With Respect to Center-Line)

NOMENCLATURE:

MG:	Main Gear	**RM:**	Right Main Gear
TW:	Tail Wheel	**LM:**	Left Main Gear
LE:	Leading Edge	**MGC:**	Mean Geometric Cord

REFERENCE DATUM:

The reference datum is located at the wing leading edge. Positive distance is measured aft of the datum and to the right of the center line. Negative distance is measured forward of the datum.

Weight and Balance Document

DATE:	9/12/2009					**AIRCRAFT:** Meridian UAS		
AIRCRAFT CONFIGURATION:			DPG Flight Configuration. 10 lbs added to tail bracket.					
DISTANCE MEASUREMENTS:								
	MG to LE (x):	-0.4	in			**RM to LM (y):**	74.5	in
	MG to TW (x):	157.125	in					
WEIGHT MEASUREMENTS:								
	Right Main Gear:	474	lbs					
	Left Main Gear:	509	lbs					
	Tail Wheel:	54	lbs					
CG CALCULATIONS:								
	Gross Weight:	1037	lbs					
	RM X-Moment Arm:	-190	in-lbs					
	LM X-Moment Arm:	-204	in-lbs					
	TW X-Moment Arm:	8463	in-lbs					
	CG X-Location:	7.782	inches (Aft of Wing Leading Edge)					
	CG w.r.t. MGC:	24.56%						
	Static Margin:	20.44%	(Aerodynamic Center located at 45% MGC)					
	RM Y-Moment Arm:	17656.5	in-lbs					
	LM Y-Moment Arm:	-18960.25	in-lbs					
	CG Y-Location:	-1.257	inches (With Respect to Center-Line)					
NOMENCLATURE:								
	MG:	Main Gear			**RM:**	Right Main Gear		
	TW:	Tail Wheel			**LM:**	Left Main Gear		
	LE:	Leading Edge			**MGC:**	Mean Geometric Cord		
REFERENCE DATUM:								

The reference datum is located at the wing leading edge. Positive distance is measured aft of the datum and to the right of the center line. Negative distance is measured forward of the datum.

Weight and Balance Document

DATE:	12/30/2009	**AIRCRAFT:**	Meridian UAS

AIRCRAFT CONFIGURATION: No Wings

DISTANCE MEASUREMENTS:

MG to LE (x):	-0.4	in	**RM to LM (y):**	74.5	in
MG to TW (x):	154.5	in			

WEIGHT MEASUREMENTS:			No Wing	Wing
Right Main Gear:	502	lbs	424	78
Left Main Gear:	532	lbs	449	83
Tail Wheel:	66	lbs	47	19

CG CALCULATIONS:

Gross Weight:	1100	lbs
RM X-Moment Arm:	-201	in-lbs
LM X-Moment Arm:	-213	in-lbs
TW X-Moment Arm:	10171	in-lbs
CG X-Location:	8.870	inches (Aft of Wing Leading Edge)
CG w.r.t. MGC:	28.00%	
Static Margin:	17.00%	(Aerodynamic Center located at 45% MGC)
RM Y-Moment Arm:	18699.5	in-lbs
LM Y-Moment Arm:	-19817	in-lbs
CG Y-Location:	-1.016	inches (With Respect to Center-Line)

NOMENCLATURE:

MG:	Main Gear	**RM:**	Right Main Gear
TW:	Tail Wheel	**LM:**	Left Main Gear
LE:	Leading Edge	**MGC:**	Mean Geometric Cord

REFERENCE DATUM:

The reference datum is located at the wing leading edge. Positive distance is measured aft of the datum and to the right of the center line. Negative distance is measured forward of the datum.

Appendix F. Flight Plan Documents

Flight Plan Document

DATE:	8/28/2009	**FLIGHT NO.:**	20090828-1	**AIRCRAFT:** Meridian UAS

FLIGHT TEST CREW:

Saftey Officer:	Shahriar Keshmiri	**FTE 1:**	Dave Royer
Flight Director:	Rick Hale	**FTE 2:**	Jonathan Tom
Pilot:	Lance Holly	**FTE 3:**	
Pilot Assistant:	Bill Donovan	**Observer:**	Kelly Gulker

AIRCRAFT:

Configuration:	Flight critical systems only.	
CG:	6.836	(6.65-8.25 in limit)
Weight:	1064	(1200 lbs limit)
Fuel:	20	(5-25 gal limit)
Flight Time:	30 min	
Reserve:	4 hrs	
Maintenance Items:	New avionics battery installed	

Procedure:

Take-off, Trim at 80 KTS (±5 KTS), Perform control surface doublets, Practice approach for landing, Land

MISSION:

Objectives: First Flight Demonstration

Test Data: wePilot Flight Log, MAAS Flight Log
Video and still photography.

SAFETY:

Go/No-Go Items: Runway Condition

Abort Criteria: Weather Conditions (85 F, wind 10 KTS)

Emergency: Loss of 72 MHz, the aircraft is controlled under wePilot manual control,
Re-establish 72 MHz link and immediately land the aircraft, If 72 MHz can not be established, attempt landing in manual mode.

WEATHER:

Local: 1849Z 33007KTS 28/15 3003
DA3000

Forecast:
KFRI 2811/2911 VRB05KT 4800 BR SKC QNH3005INS
TEMPO 2811/2813 1600 BR
BECMG 2813/2814 01008KT 9999 NSW SKC
QNH2999INS
BECMG 2900/2901 VRB05KT 9999 SKC QNH3000INS
T27/2821Z T13/2811Z

Post-Flight Comments:

DATE:	9/10/2009	FLIGHT NO.:	20090910-1	AIRCRAFT: Meridian UAS

FLIGHT TEST CREW:

Saftey Officer:	Shahriar Keshmiri	**FTE 1:**	Dave Royer
Flight Director:	Rick Hale	**FTE 2:**	Jonathan Tom
Pilot:	Lance Holly / Nick Brown	**FTE 3:**	
Pilot Assistant:	Bill Donovan	**Observer:**	Andy Pritchard

AIRCRAFT:

Configuration:	Speed tape over gaps, ailerons trimmed for flight	
CG:	6.95	(6.65-8.25 in limit)
Weight:	1048	(1200 lbs limit)
Fuel:	17	(5-25 gal limit)
Flight Time:	30 min	
Reserve:	4 hr	
Maintenance Items:	Changed pins on magnetometer	

Procedure:

Take-off, Trim at 80 KTS (±5 KTS), Perform control surface doublets, Practice approach for landing, Land

MISSION:

Objectives: First Flight Demonstration

Test Data: wePilot Flight Log, MAAS Flight Log

Video and still photography.

SAFETY:

Go/No-Go Items:

Abort Criteria: Weather Conditions (85 F, wind 10 KTS)

Emergency: Aircraft on emergency approach; clear the runway if the vehicle is on the ground, land and clear the runway if the aircraft is in the air, or loiter west of the runway.

WEATHER:

Local: 1034MT 25002KTS 50 CLR 24C 28% Humidity 3024 DA6145

Forecast:

Post-Flight Comments:

Perturbed the dutch roll at 1885 secs into wepilot data. Air data probe was non-functional during flight. The engine coolant temperature went red-line high mid-flight. The wePilot autopilot activated sitting on the ground before take-off and during the middle of landing.

DATE: 9/12/2009 **FLIGHT NO.:** 20090912-1 **AIRCRAFT:** Meridian UAS

FLIGHT TEST CREW:

Saftey Officer:	Shahriar Keshmiri	**FTE 1:**	Dave Royer
Flight Director:	Rick Hale	**FTE 2:**	Jonathan Tom
Pilot:	Lance Holly / Nick Brown	**FTE 3:**	
Pilot Assistant:	Bill Donovan	**Observer:**	Andy Pritchard

AIRCRAFT:

Configuration:	10 lbs ballast added to tail bracket	
CG:	7.87	(6.65-8.25 in limit)
Weight:	1045	(1200 lbs limit)
Fuel:	17	(5-25 gal limit)
Flight Time:	30 min	
Reserve:	3 hr	

Maintenance Items: Pitot-tube calibrated and tested, wePilot opened and wiring inspected, coolant and gearbox oil added, wing leading edge filled and sanded.

Procedure:

Take-off, Trim at 80-90 KTS, Activate wePilot manual mode, Perform manual turns, climbs, and accellerations, Activate wePilot and enter home waypoint, Perform control surface doublets, Land

MISSION:

Objectives: wePilot Manual Mode Test

Test Data: wePilot Flight Log, MAAS Flight Log Video and still photography.

SAFETY:

Go/No-Go Items:

Abort Criteria: Weather Conditions (85 F, wind 10 KTS)

Emergency: Aircraft on emergency approach; clear the runway if the vehicle is on the ground, land and clear the runway if the aircraft is in the air, or loiter west of the runway.

WEATHER:

Local: CALM 50 CLR 66F 28% Humidity 30.05inHg DA 5749

Forecast:

Post-Flight Comments:

Magnetometer failure mid-flight, wePilot activated unintentionally on landing and mid-flight, hard landing, wePilot unintended descent in home waypoint, takeoff 0758, land 0808.

DATE:	9/15/2009	**FLIGHT NO.:**	20090915-1	**AIRCRAFT:** Meridian UAS

FLIGHT TEST CREW:

Saftey Officer:	Shahriar Keshmiri	**FTE 1:**	Dave Royer
Flight Director:	Rick Hale	**FTE 2:**	Jonathan Tom
Pilot:	Lance Holly / Nick Brown	**FTE 3:**	
Pilot Assistant:	Bill Donovan	**Observer:**	Andy Pritchard

AIRCRAFT:

Configuration:	10 lbs ballast added to tail bracket	
CG:	7.8	(6.65-8.25 in limit)
Weight:	1037	(1200 lbs limit)
Fuel:	17	(5-25 gal limit)
Flight Time:	30 min	
Reserve:	3 hr	

Maintenance Items: Pitot-tube calibrated and tested, receiver put on battery power

Procedure:

Take-off, Trim at 80-90 KTS, Activate wePilot manual mode, Perform manual turns, climbs, and accellerations, Activate wePilot and enter home waypoint, Perform control surface doublets, Land

MISSION:

Objectives: wePilot Manual Mode Test

Test Data: wePilot Flight Log, MAAS Flight Log Video and still photography.

SAFETY:

Go/No-Go Items:

Abort Criteria: Weather Conditions (85 F, wind 10 KTS)

Emergency: Aircraft on emergency approach; clear the runway if the vehicle is on the ground, land and clear the runway if the aircraft is in the air, or loiter west of the runway.

WEATHER:

Local: VRB 30.19inHg 15C/50F 5265DA

Forecast:

Post-Flight Comments:

No 72MHz drop outs during flight, wePilot could not hold altitude, engine on 1016, takeoff 1023, land 1031.

DATE:	12/31/2009	FLIGHT NO.:	20091231-1	AIRCRAFT: Meridian UAS

FLIGHT TEST CREW:

Saftey Officer:	Shahriar Keshmiri	**FTE 1:**	Dave Royer
Flight Director:	Rick Hale	**FTE 2:**	Jonathan Tom
Pilot:	Lance Holly / Nick Brown	**FTE 3:**	
Pilot Assistant:	Bill Donovan	**Observer:**	Andy Pritchard

AIRCRAFT:

Configuration:	10 lbs ballast added to tail bracket	
CG:	8.87	(8.0-11.1 in limit)
Weight:	1100	(1200 lbs limit)
Fuel:	17	(5-25 gal limit)
Flight Time:	30 min	
Reserve:	3 hr	

Maintenance Items: Tail wheel spring changed out, New GPS antenna installed, wing farings installed, new air intake, new propeller, painted wings, pitot heat on, nose over prevention devices installed

Procedure:

Shortfield Take-off, Trim at 90-110 KTS, Activate wePilot manual mode on upwind, Activate wePilot and enter circular waypoint, Loiter in at waypoint for 15 minutes, Land full flaps

MISSION:

Objectives: wePilot Automatic Mode Test

Test Data: wePilot Flight Log, MAAS Flight Log Video and still photography.

SAFETY:

Go/No-Go Items:

Abort Criteria: Weather Conditions (icing, crosswind 5 KTS)

Emergency: 30 minute warning for aircraft approach; clear the runway if the vehicle is on the ground, land and clear the runway if the aircraft is in the air.

WEATHER:

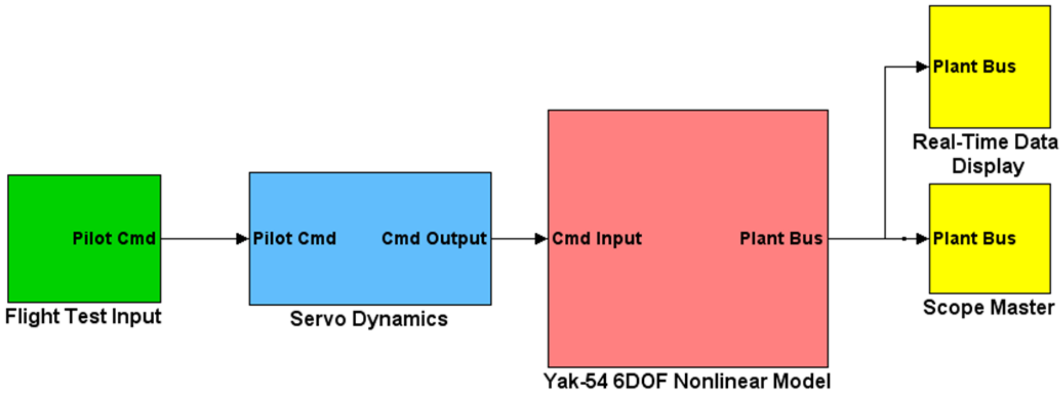
Local: GRID16006KT CLR 30F 29.39alt

Forecast:

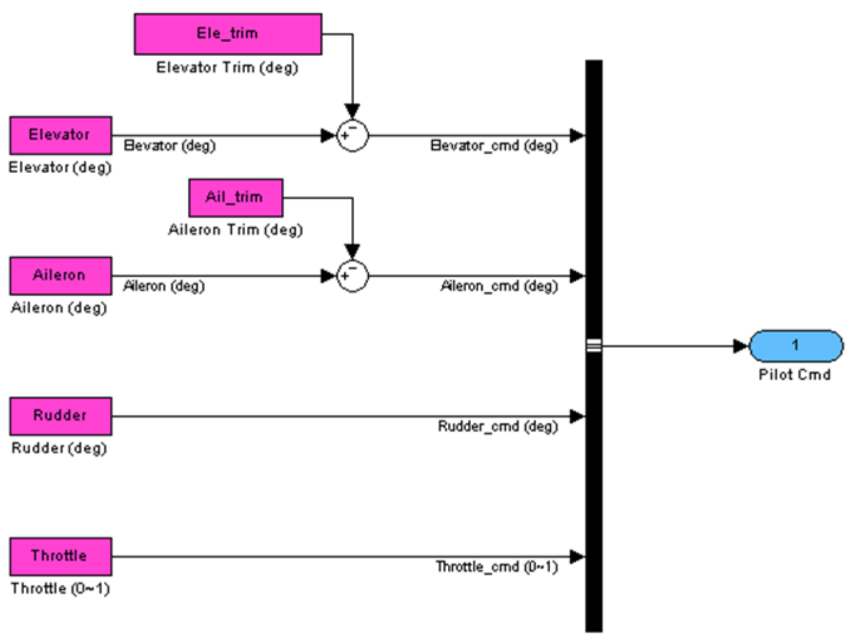
Post-Flight Comments:

MAAS Failed on initial start-up, Did NOT re-trim the vehicle for new CG location, Burned 12 pounds of fuel in flight, wePilot held airspeed 120KTS, held altitude +-40 meters, engine on 2153, takeoff 2203, landing 2222 with no flaps, 19 minute flight, 5g pull up in flight, inboard wing spar cracked.

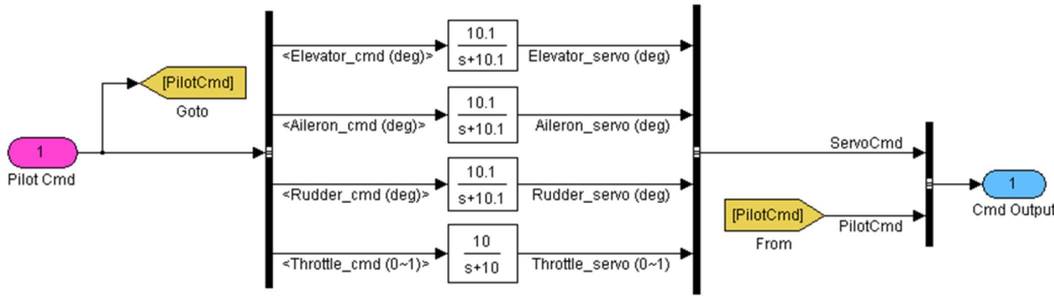
Appendix G. Meridian 6-DOF Non-Linear Model



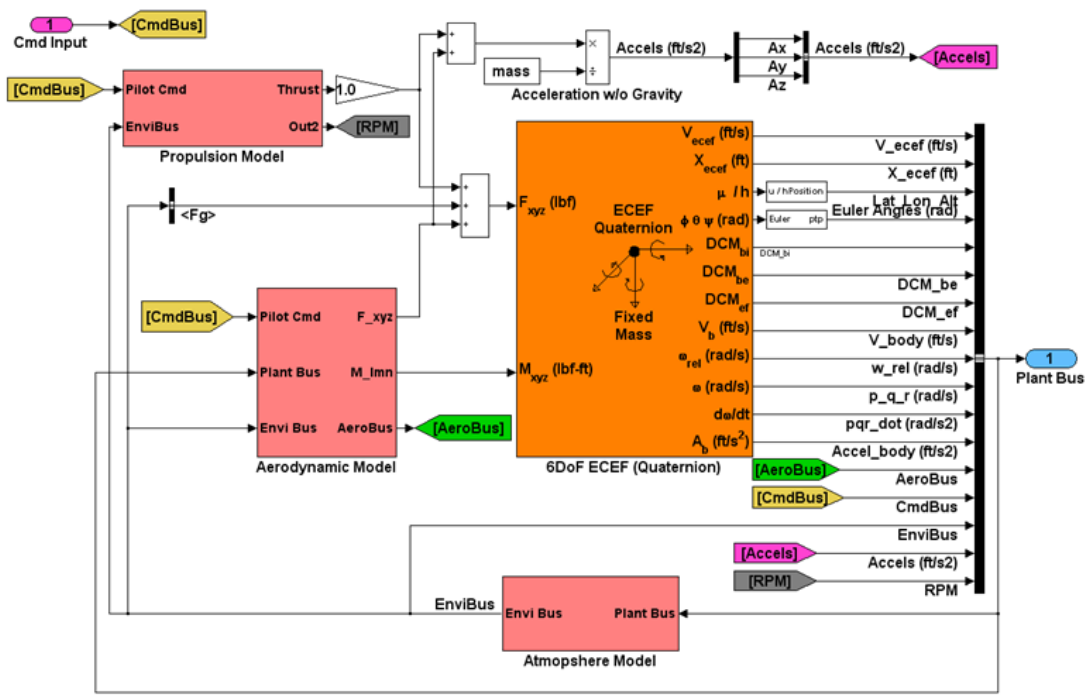
Meridian 6-DOF Non-Linear Model Structure



Flight Test Input

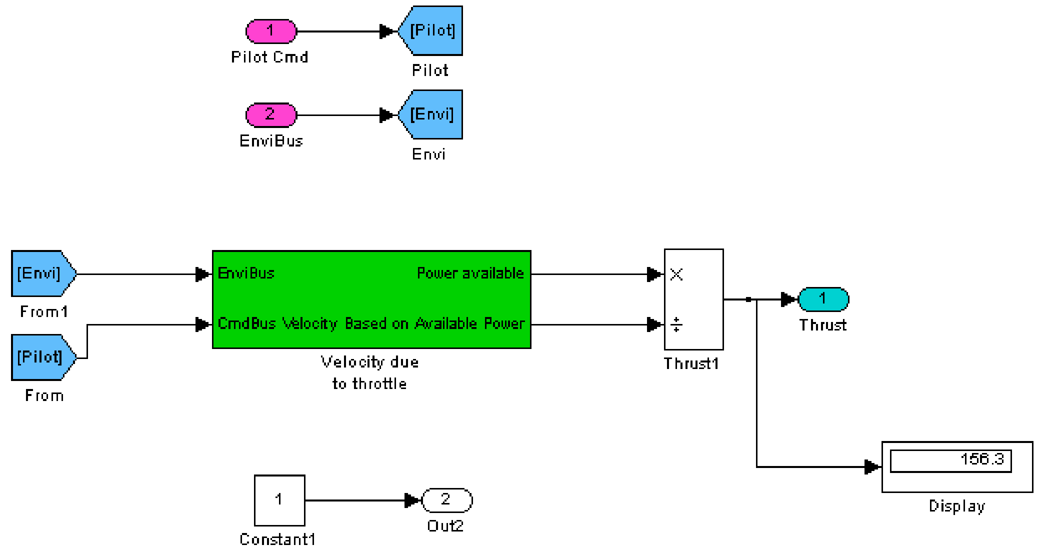


Servo Dynamics

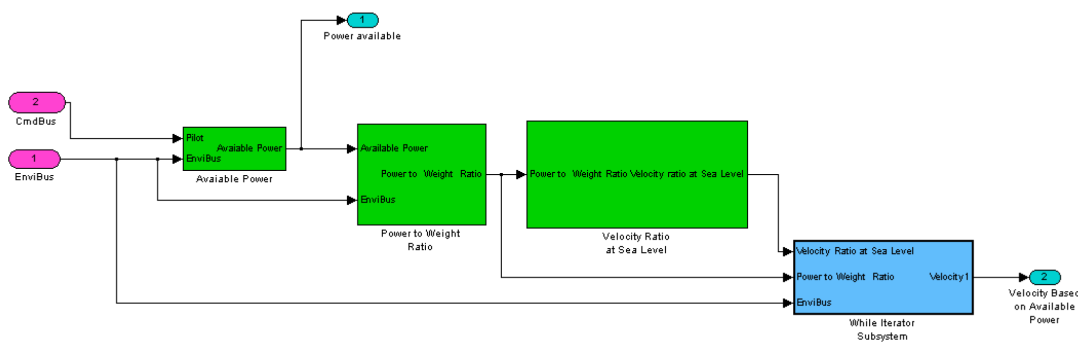


6-DOF Non-Linear Model

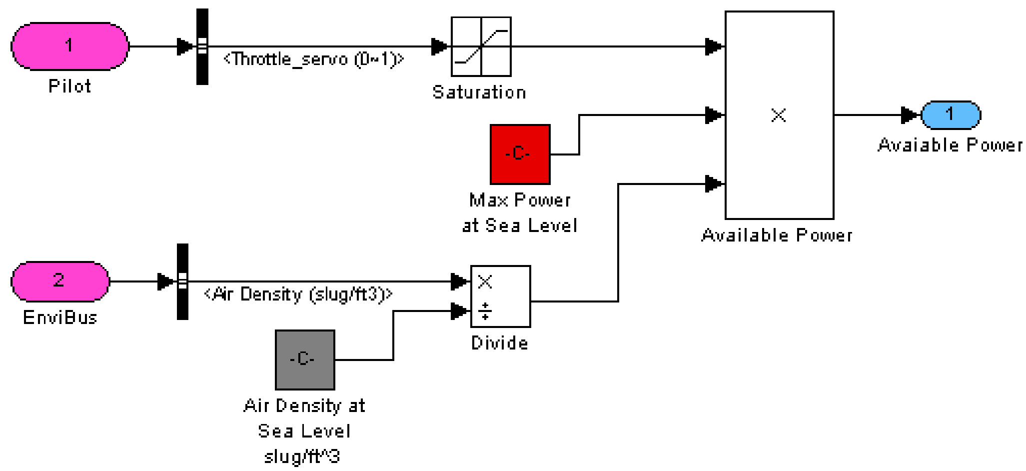
NOTE: Consult reference [10] for aerodynamic and atmospheric models.



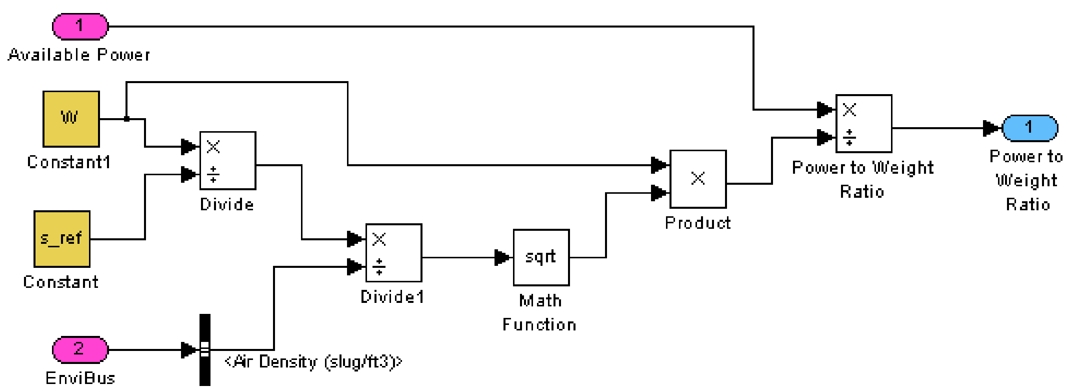
Engine Model [12]



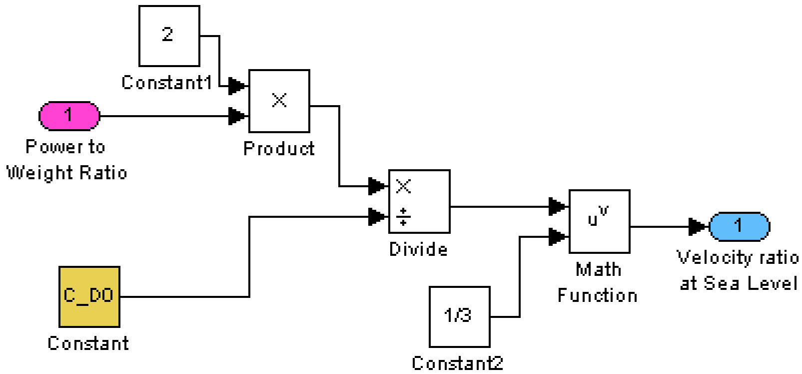
Velocity due to Throttle



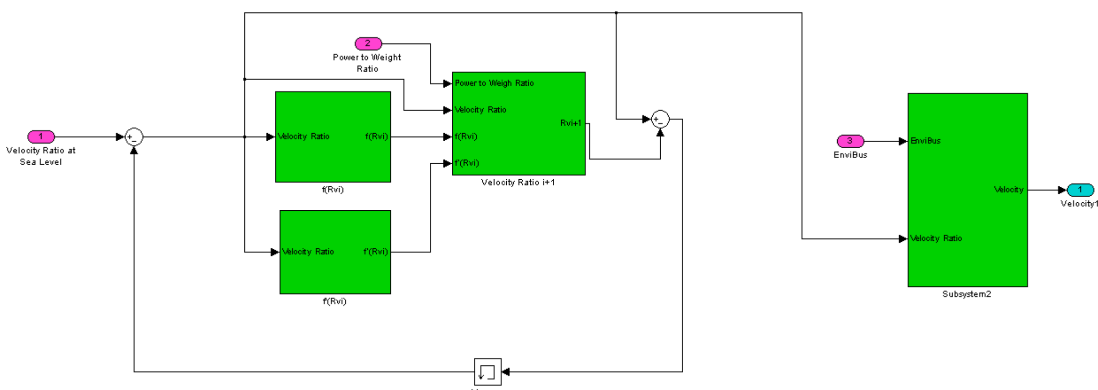
Available Power



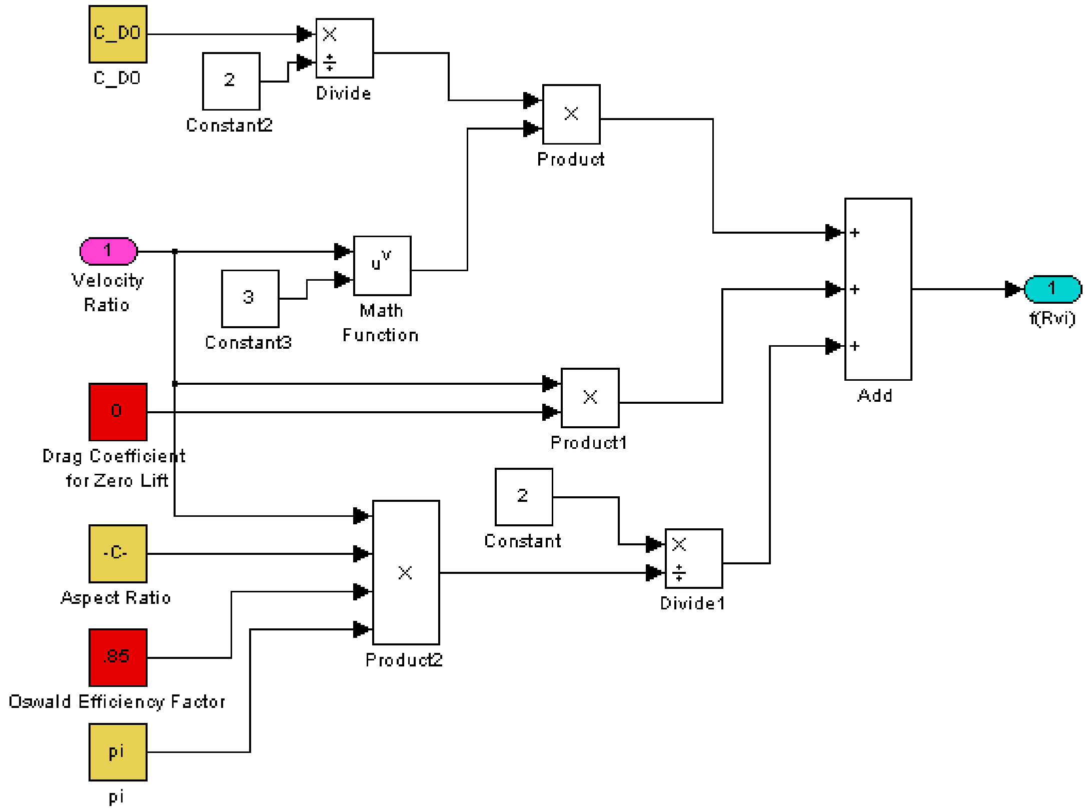
Power to Weight Ratio



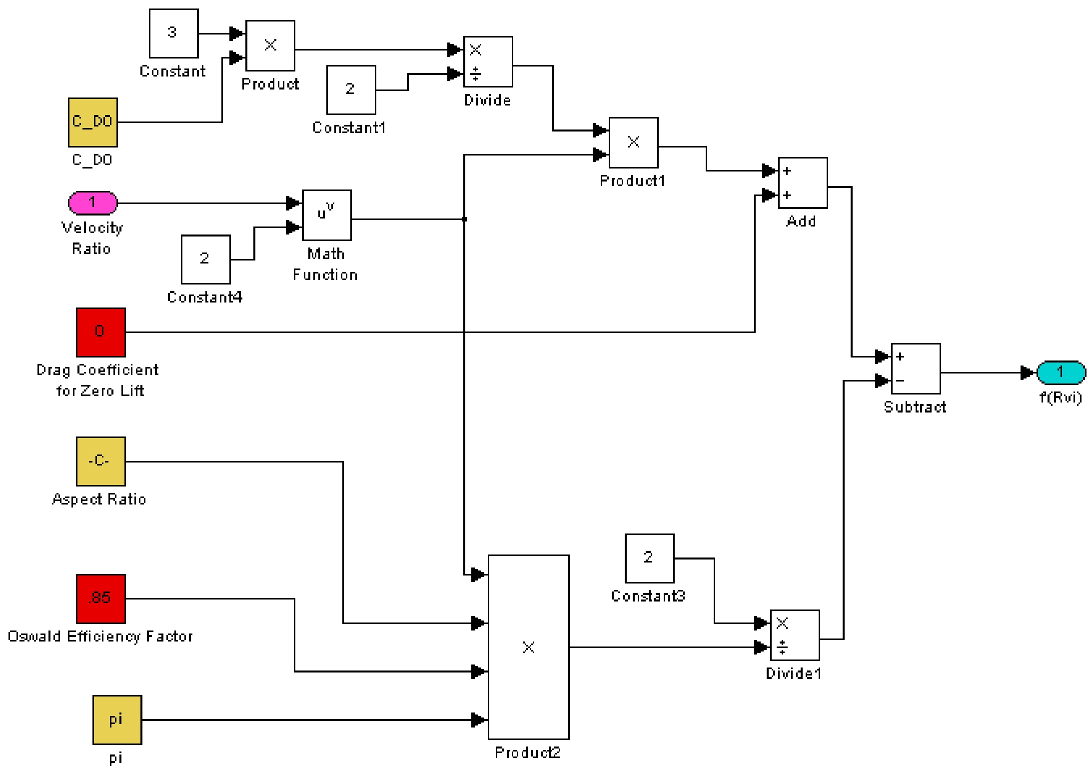
Velocity Ratio at Sea Level



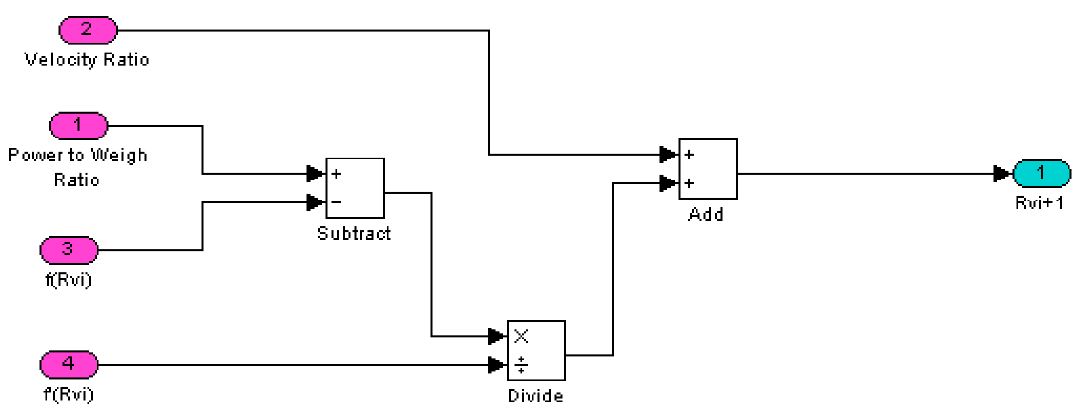
While Iteration Subsystem


C_D0
C_D0
2
Constant2
Divide
Product
1
Velocity Ratio
3
Constant3
u^v
Math Function
+
+
+
Add
1
f(Rvi)
0
Drag Coefficient for Zero Lift
Product1
2
Constant
Divide1
-C-
Aspect Ratio
Product2
.85
Oswald Efficiency Factor
pi
pi

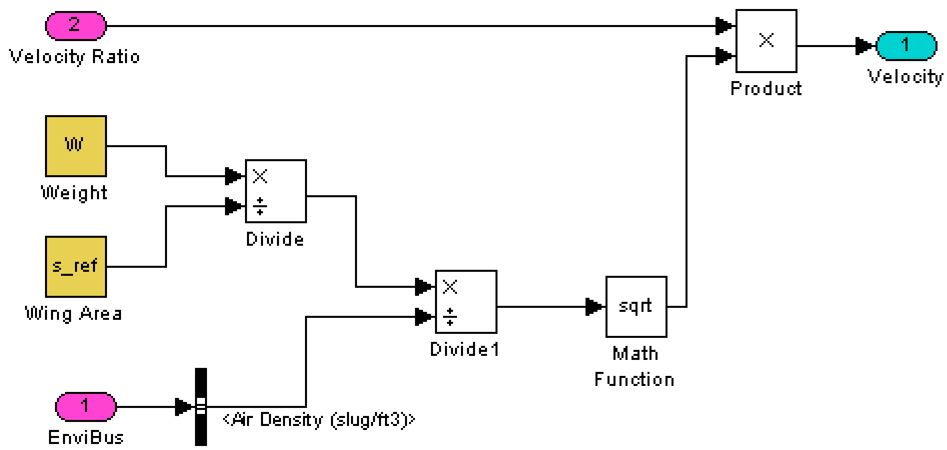
F(Rvi)



f'(Rvi)



Velocity Ratio (i+1)


2
Velocity Ratio
W
Weight
s_ref
Wing Area
Divide
Divide1
1
EnviBus
<Air Density (slug/ft3)>
sqrt
Math
Function
Product
1
Velocity

Subsystem 2

Appendix H. AAA 6-DOF Non-Linear Model for Dutch Roll

AAA Model Input for Dutch Roll Analysis			
Steady State Coefficients		**Lateral-Directional Coefficients**	
C_{L_1}	0.462	C_{l_β}	-0.084
C_{D_1}	0.027	C_{l_p}	-0.554
$C_{T_{x1}}$	0.028	C_{l_r}	0.144
C_{m_1}	0.012	C_{y_β}	-0.478
$C_{m_{T1}}$	-0.011	C_{y_p}	-0.137
		C_{y_r}	0.323
Longitudinal Coefficients		C_{n_β}	0.140
C_{D_0}	0.020	$C_{n_{T\beta}}$	-0.001
C_{D_u}	0.000	C_{n_p}	-0.055
C_{D_α}	0.202	C_{n_r}	-0.137
$C_{T_{xu}}$	-0.084		
C_{L_0}	0.331	**Lateral-Directional Control and Hinge**	
C_{L_u}	0.011	$C_{l_{\delta a}}$	0.229
C_{L_α}	5.151	$C_{l_{\delta r}}$	-0.021
$C_{L_{\dot\alpha}}$	0.735	$C_{y_{\delta a}}$	0.000
C_{L_q}	4.604	$C_{y_{\delta r}}$	-0.368
C_{m_q}	0.023	$C_{n_{\delta a}}$	-0.019
C_{m_u}	0.003	$C_{n_{\delta r}}$	0.148
C_{m_α}	-0.620		
$C_{m_{\dot\alpha}}$	-2.961	**Longitudinal Control and Hinge**	
C_{m_q}	-13.930	$C_{D_{\delta e}}$	0.012
$C_{m_{Tu}}$	0.035	$C_{L_{\delta e}}$	0.414
$C_{m_{T\alpha}}$	-0.277	$C_{m_{\delta e}}$	-1.666

Appendix I. AAA 6-DOF Non-Linear Model for Short Period

AAA Model Input for Short Period Analysis			
Steady State Coefficients		**Lateral-Directional Coefficients**	
C_{L_1}	0.720	C_{l_β}	-0.095
C_{D_1}	0.038	C_{l_p}	-0.554
$C_{T_{x1}}$	0.040	C_{l_r}	0.206
C_{m_1}	0.017	C_{y_β}	-0.477
$C_{m_{T1}}$	-0.016	C_{y_p}	-0.120
		C_{y_r}	0.324
Longitudinal Coefficients		C_{n_β}	0.141
C_{D_0}	0.020	$C_{n_{T\beta}}$	-0.001
C_{D_u}	0.000	C_{n_p}	-0.090
C_{D_α}	0.314	C_{n_r}	-0.143
$C_{T_{xu}}$	-0.120		
C_{L_0}	0.333	**Lateral-Directional Control and Hinge**	
C_{L_u}	0.011	$C_{l_{\delta a}}$	0.227
C_{L_α}	5.151	$C_{l_{\delta r}}$	-0.014
$C_{L_{\dot{\alpha}}}$	0.788	$C_{y_{\delta a}}$	0.000
C_{L_q}	4.644	$C_{y_{\delta r}}$	-0.371
C_{m_q}	0.023	$C_{n_{\delta a}}$	-0.029
C_{m_u}	0.003	$C_{n_{\delta r}}$	0.151
C_{m_α}	-1.030		
$C_{m_{\dot{\alpha}}}$	-3.172	**Longitudinal Control and Hinge**	
C_{m_q}	-14.088	$C_{D_{\delta e}}$	0.012
$C_{m_{Tu}}$	0.050	$C_{L_{\delta e}}$	0.413
$C_{m_{T\alpha}}$	-0.253	$C_{m_{\delta e}}$	-1.662