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Conceptual Design of a Multi-utility Aeroelastic Demonstrator

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I. Abstract

This paper presents the conceptual design of a flight vehicle to demonstrate active aeroelastic control technologies for suppressing flutter and aeroelastic instabilities. The technologies are directed at a class of high aspect ratio, flying wing ISR vehicles being pursued by the Air Force Research Laboratory as part of their SensorCraft program. This class of vehicles are susceptible to an unstable coupling of 1st wing bending and short period mode, known as body freedom flutter (BFF). The constraints on the flight demonstrator vehicle were that the vehicle have a size large enough to replicate the structure and flutter characteristics of a full scale SensorCraft but small enough to fit within AFRL program funding and not present a large debris field in the case of an in-flight break-up. Trade study results revealed that a 15% scale met the study constraints. The structural analysis approach for designing a subscale vehicle to have a specific body freedom flutter speed and frequency while meeting structural strength criteria is discussed. The design of a flight control system to control the combined rigid and flexible dynamics of a vehicle that exhibits BFF is discussed. Flight test considerations of this unique demonstrator vehicle are presented.

II. Introduction

Throughout the past several years Lockheed Martin Aeronautics (LM Aero) Company has participated in the Air Force Research Laboratory (AFRL) studies of a new high altitude, subsonic, long endurance autonomous aircraft for intelligence, surveillance, and reconnaissance (ISR) missions known as SensorCraft. Performance needs to meet the mission requirements of this new ISR platform place new challenges in sensor integration, aerodynamics, and structure. One outcome of these vehicle performance demands is a high aspect ratio highly flexible wing.

Configuration development studies conducted by LM Aero under contract to AFRL produced the swept-wing tailless configuration designated SC006A, shown in Figure 1. The SC006A is a flying wing configuration with structurally integrated multi-functional antennas in combination with aggressive structural sizing to achieve very

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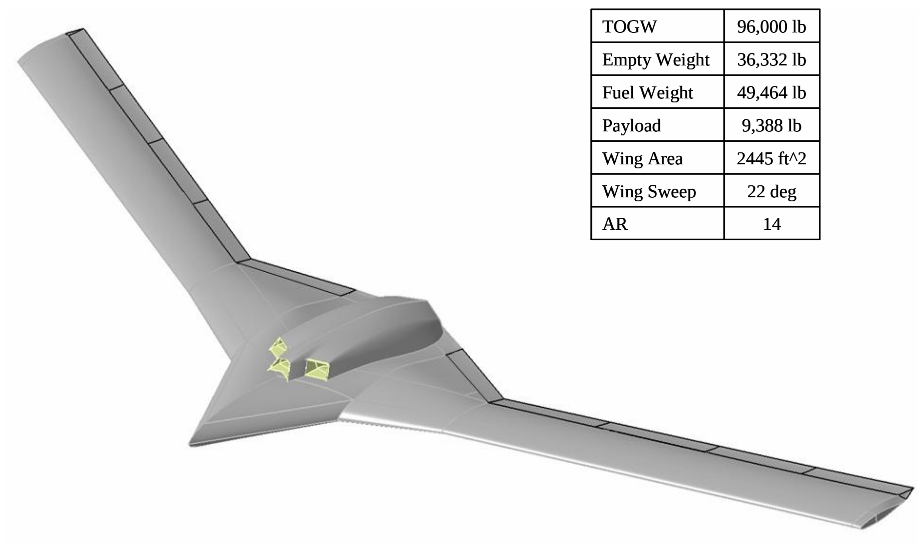
light weight structure. This very light weight structure in combination with the payload and fuel demands to meet mission requirements lead to significant aeroelastic challenges in flutter and gust load alleviation. Traditional methods of resolving many aeroelastic issues utilize increased structural stiffness to achieve the desired flight envelope but at great penalty to vehicle weight. Ultimately system performance is penalized due to this weight or through a reduced flight envelope. SensorCraft performance goals require an effective means of obtaining highly efficient structure while avoiding aeroelastic penalties of past vehicle development programs. Many active aeroelastic control designs have been developed and proven analytically and in wind tunnel testing. Maturation of this technology requires demonstration on a flying platform. Development and demonstration of active aeroelastic control is inherently risky and must be conducted in a cost effective method while achieving the desired technology payoff. Development of an aeroelastic demonstration vehicle is a case of trade-offs between cost, performance, technology demonstration, vehicle operations, and safety.

LM Aero participated in a contract with AFRL to conduct trade studies for the development of a multi-utility aeroelastic flight demonstrator, referred to as MUTT (Multi Utility Technology Testbed). The primary goal of such a vehicle was to mature critical technologies, such as active aeroelastic control, to allow for the development of performance aggressive vehicles such as the SensorCraft. Development of a low cost small scale vehicle concept for conducting high risk demonstrations was the primary focus of the effort. Vehicle modularity to allow for potential testing of multiple configurations such as a flying wing or a joined wing design (as shown in Figure 2) was a principal goal. The focus of this paper is the trade study that was conducted for a MUTT vehicle that is sufficiently modular to allow testing of different air vehicle configurations yet achieves the goal of active aeroelastic control technology maturation.



TOGW	96,000 lb
Empty Weight	36,332 lb
Fuel Weight	49,464 lb
Payload	9,388 lb
Wing Area	2445 ft^2
Wing Sweep	22 deg
AR	14

Figure 1. SC006A Configuration

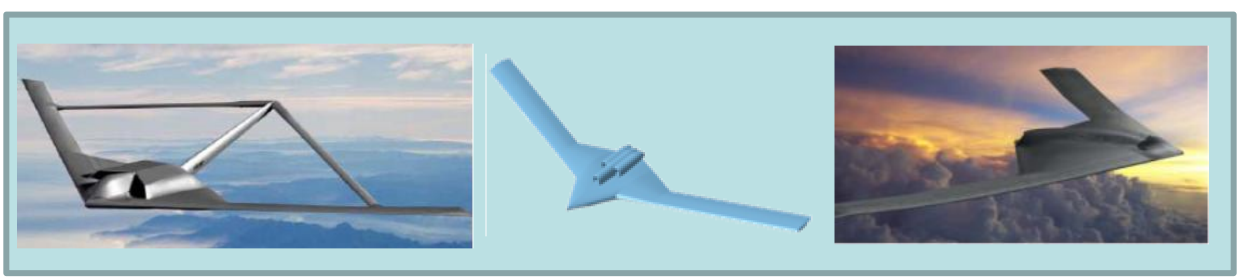


Figure 2. Potential Configurations for MUTT Vehicle Demonstration

III. Design Considerations

The MUTT flight vehicle has been configured to provide a low-cost platform capable of: multiple configurations; and demonstrating active flutter suppression and gust load alleviation (GLA) in flight. Several trade studies were conducted to determine the best vehicle configuration, construction method, launch and recovery method that allow the program to demonstrate the critical technologies with moderate risk and cost.

The size of the vehicle (scale factor) is a very important parameter determining the success of the program. The size drives the cost and the fidelity of the demonstration. A 25%scale factor was felt to provide the demonstration fidelity to achieve TRL 6-7. Using the square-cube law the span would be 46 feet and the empty weight ~ 750 lb. At this size the wing structural arrangement could replicate that of SC006A. Our experience with building and flying this size class of UAVs is that the unit cost of the vehicle is approximately $2300/lb which would make the unit cost of the aircraft almost $2M each. At this cost the idea of flying them to destruction needs careful consideration. Using the cost data for demonstrator programs as shown on Figure 3, the 750 lb empty weight was outside of the $12M program cost target. Another consideration was the weight change from start of mission to end of mission. SC006A had a 52% fuel fraction which meant that the TOGW would be ~ 1686 lb, start of climb weight ~ 1600 lb and end of mission weight ~ 875 lb. Finding engines, landing gear, parachute and actuators would be a major endeavor.

A 15% scale factor was examined which gave a wing span of 28 feet and an empty weight estimate of 160 lb using the square-cube law. This size and weight appeared to be acceptable assuming a unit cost of $2300/lb which would result in three vehicles at $368K each and a total program cost of $12M. This assessment appeared realistic based on historical data (Figure 3).

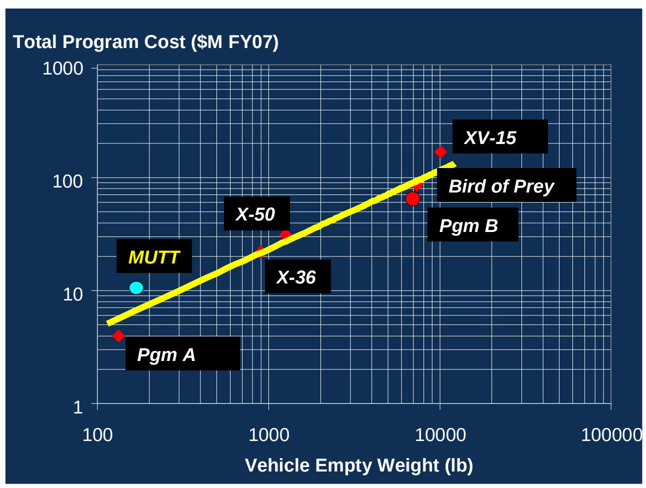


Figure 3 Demonstrator Historical Cost Trends

The 15% scale factor was further substantiated by assessment of overall vehicle performance needs to achieve the desired demonstrations. This includes both normal flight considerations and the probable event of an in flight breakup due to flutter. Assuming 60 lb of fuel (about one hour flight time) the vehicle would need about 180 lb of ballast to replicate the start and end of mission weight conditions. Most of this ballast would be distributed along the span to replicate the fuel load. The remaining ballast would be in the center body for CG control. The concept could be two sets of wings, one set without the ballast (end of mission condition) and one set with the ballast (start of mission condition). Or, the concept could be water ballast in the wings which would drain out during the flight and replicate a more realistic variable weight for flutter suppression. The use of water lets the weight vary faster than burning fuel and the weight change to be examined in one flight.

With a TOGW = 400 lb there are RC model components (engines, wheels/brakes, actuators, etc) available off-the-shelf (OTS). Two Jet Cat P-240 turbine engines at 50 lb SLS thrust each would integrate well into the design. Assuming drooped ailerons a max CL = 1.1 is realistic which would give a ground run of about 620 feet at a take-off W/S = 7.3 lb/ft^2 (stall speed = 46 KEAS). Consideration of kinetic energy of the vehicle is required due to the potential for in flight breakup due to flutter. Shown in Figure 4 is a plot of kinetic energy versus scale factor. The trade here is between the minimum scale to achieve realistic structure, acceptable amount of kinetic energy to minimize debris field, cost, and parts availability. Again, the 15% scale factor leads to the best scaling to achieve program goals.

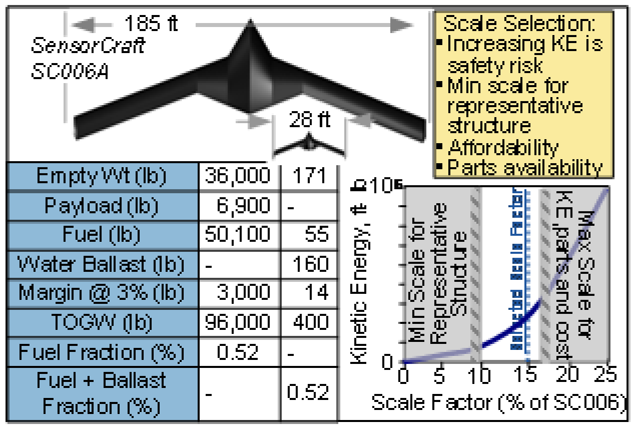


Figure 4 Demonstrator Scaling and Kinetic Energy

Finally, the need to be modular to allow for flight test of other wing configurations needed to be considered. Based on data from Boeing of their 410F-4 joined wing configuration, a scale factor of 13.3% would match our 15% scale factor control points at the edge of the center body as shown on Figure 5. The center body would have the capability of moving the cg and main gear over a 6 inch distance to accommodate both the SC006A wing and the Boeing joined wing cg and neutral point locations.

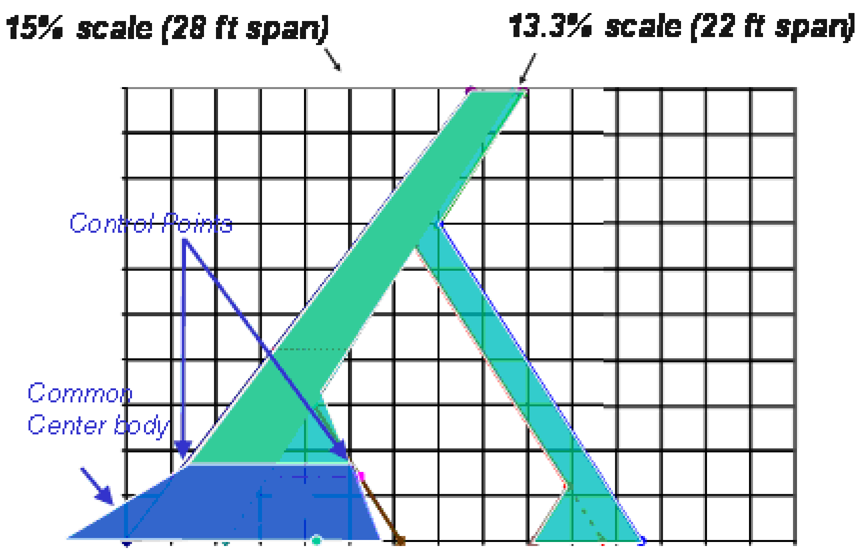


Figure 5 SC006A and Boeing 410F4 Comparison

The overall configuration of the MUTT is a scaled version of the SC006A SensorCraft configuration, as shown in Figure 6. Although there are some differences between the full scale and sub scale configurations, including externally mounted engines and winglets, these do not materially affect the flutter characteristics under consideration.

- **Scale Factor: 15%**
- **Span: 27.8 ft**
- **Sweep: 22 °**
- **Aspect Ratio: 14**
- **Max C_L ~ 1.1**
- **Wing Area: 55 ft ^{2}**
- **EW ~ 190 lb**
- **TOGW ~ 200 lb, 300 lb, 400 lb**
- **Propulsion: 2 Jet Cat P -240 turbine engines @ 50 lb each**
- **TO Grnd Run ~ 150, 350, 620 ft**
- **Fuel: 55 lb Max**

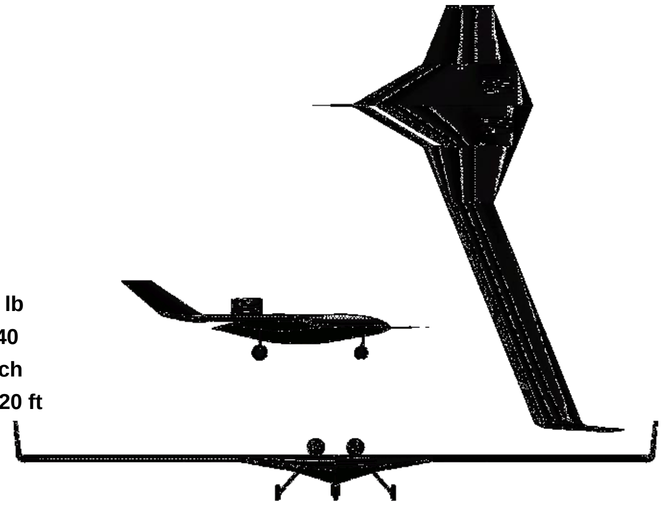


Figure 6 15% Scale Baseline Configuration Demonstrator

The center section of the air vehicle is fabricated of carbon fiber composite materials and houses the majority of the vehicle's flight systems, including flight controls, air data, flight termination, propulsion, batteries and fuel system as shown in Figure 7. The large center payload bay contains a ballistic recovery parachute that is used for flight termination and recovery from in-flight demonstrations that may lead to wing failure. The rugged construction of the center section allows it to protect the most expensive components in the event of a flutter occurrence, and does not significantly affect the flutter characteristics of the airplane.

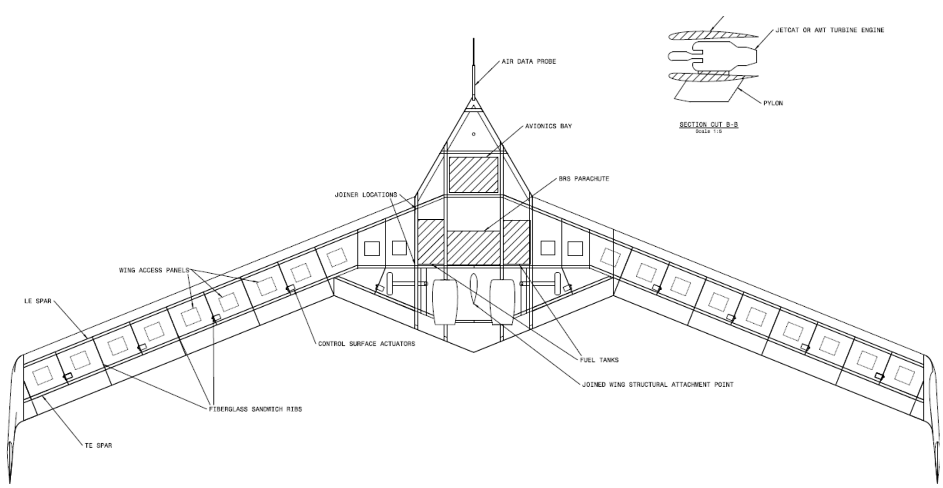


Figure 7 MUTT General Arrangement

The center section has provisions for attachment of the joined wing "boom" on the upper side of the aft end as shown on Figure 8. Additionally, wing attachment fittings are present on both the left and right sides to accommodate different wing configurations.

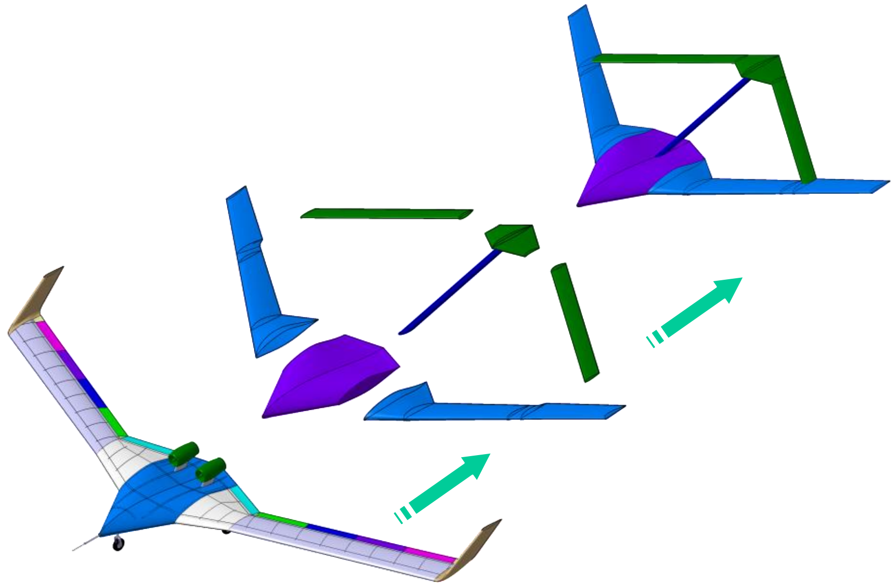


Figure 8 MUTT Alternative Planform Accommodation

The wing structure is similar in concept to a full-scale SensorCraft configuration, with fiberglass skins and a two-spar design. In addition to the desire for structural similarity to the full scale configuration, fiberglass is a superior material for wing construction because of the requirement to have low wing stiffness with adequate strength, ensuring that flutter occurs at the appropriate frequencies and within the flight test envelope. One of the goals of the MUTT demonstrator is to allow for testing at different representative vehicle weights, and originally it was envisioned that the demonstrator wing would contain provisions for addition of up to 200 lb of ballast in the wings. The results of a trade study indicated a lower cost approach is to build one wing set with integral water ballast tanks rather than two wing sets per ship set, with one "light" wing (no ballast) and one "heavy" (with ballast). This approach simplifies the structure and reduces ground handling and flight test time at the test site.

One early configuration decision on the demonstrator was to use two engines, as shown in Figure 6. This was done primarily to allow for installation of the joined-wing centerline boom. Based on prior experience, the engines are installed in pods rather than buried to simplify installation and improve vehicle packaging. Propeller-driven propulsion options were considered for the MUTT demonstrator, but it was found there was a lack of good candidate engines that would be easy to integrate and allow for flight test speeds up to 150 knots. On the other hand, several Jet Cat and AMT Turbines are available in the 50 lb thrust class and have performed well on previous demonstrator applications. The Jet Cat P-240 is used in the baseline demonstrator vehicle. A total of 100 lb uninstalled thrust with two engines will enable the vehicle to perform well on takeoff and climb out, as well as reach 150 knots, even with fixed landing gear.

Launch and recovery are traditionally some of the most hazardous portions of a flight test program, and careful consideration was given to the best method for the MUTT demonstrator. The weight and size of the baseline configuration precludes any type of hand launch or auto-based launch as used for the LM Aero BFF (Body Freedom Flutter) IRAD project. Rail launching was considered to be extremely risky because of the flexibility of the demonstrator's wing. The best option selected for the configuration is conventional takeoff and landing (CTOL) with the pilot flying heads-down via video downlink. This decision was made based on prior small UAV flight test experience and the difficulties associated with flying this large of a configuration "heads up". Performance analysis indicated that a retractable landing gear is not required to achieve the flight test objectives, and therefore a fixed gear is used on the MUTT demonstrator. This also avoided the complexity and increased weight of a retractable landing gear. One complication associated with accommodating the joined wing plan form is the different CG placement required for that configuration. In order to deal with this, the main landing gear is repositionable along the longitudinal axis up to a maximum of 6 inches.

IV. Flutter and GLA Considerations

The MUTT program is to demonstrate at least two major technologies; flutter suppression and gust load alleviation (GLA). This demonstration must be carried out on a vehicle that is representative of full scale vehicle characteristics such as realistic aircraft structure, multiple weight conditions, and varying degrees of vehicle rigid body stability. The SensorCraft SC006A was chosen as the basis for full scale vehicle characteristics. In this section, the flutter characteristics of the full scale SensorCraft will be discussed. The relationship of the full scale vehicle behavior to the demonstrator is then described. This will be followed with discussion of how the gust environment will be characterized and GLA demonstrated.

Demonstration on MUTT of full scale vehicle flutter first requires evaluation of the full scale vehicle flutter characteristics. The SensorCraft SC006A configuration has aggressive application of high strain allowables and reduced margin of safety to obtain minimum structural weight. Due to this effort to reduce structural weight, the vehicle exhibits a significant degree of flexibility leading to multiple flutter mechanisms.

Flutter is the coupling of vehicle flexible dynamics due to interaction with the airstream which can result in the extraction of energy from the airstream. Flutter occurs when the extracted energy from the airstream exceeds that which can be dissipated via structural damping. This phenomenon is commonly modeled via a structural dynamic model of the stiffness and mass distribution of the vehicle as well as the frequency dependent unsteady aerodynamics that interact with the structure. This results in a second order model of the system. The solution produces frequency, damping, and eigenvectors (vibration mode shapes) for each of the modes. The modal frequencies change as a function of airspeed (dynamic pressure) because of the unsteady aerodynamics and their inherent lag behavior. The aerodynamics actually act as additional mass, damping and stiffness terms to the dynamic equation. Some modes will increase in frequency while others may decrease in frequency as the speed increases. Not only do the frequencies change, but also the mode shapes themselves change. It is these modal changes that can result in the coupling of modes and lead to flutter. Results of flutter analyses are presented in terms of modal frequency versus velocity and modal damping versus velocity.

Flutter analyses were done of the SC006A in both the empty fuel and full fuel configurations across the full scale vehicle Mach range. Shown in Figure 9 is a velocity-frequency-damping (VFG) plot of the empty fuel SC006A vehicle at Mach 0.65. Coupling of the rigid body short period and symmetric wing 1st bending resulting in body freedom flutter (BFF) occurs at approximately 125 KEAS. This type of coupling is rather unique to low tail volume vehicles such as the SensorCraft due to the mode shape of the wing 1st bending mode. The mode shape of the wing results in the fuselage exhibiting a pitching motion which tends to aerodynamically couple the wing bending mode to the rigid body short period. The VFG plot also shows coupling of the symmetric wing 1st bending mode and the symmetric wing 1st torsion mode leading to symmetric wing bending/torsion flutter (SWBT) at approximately 235 KEAS. Note that anti-symmetric wing bending/torsion (AWBT) occurs at approximately 240 KEAS.

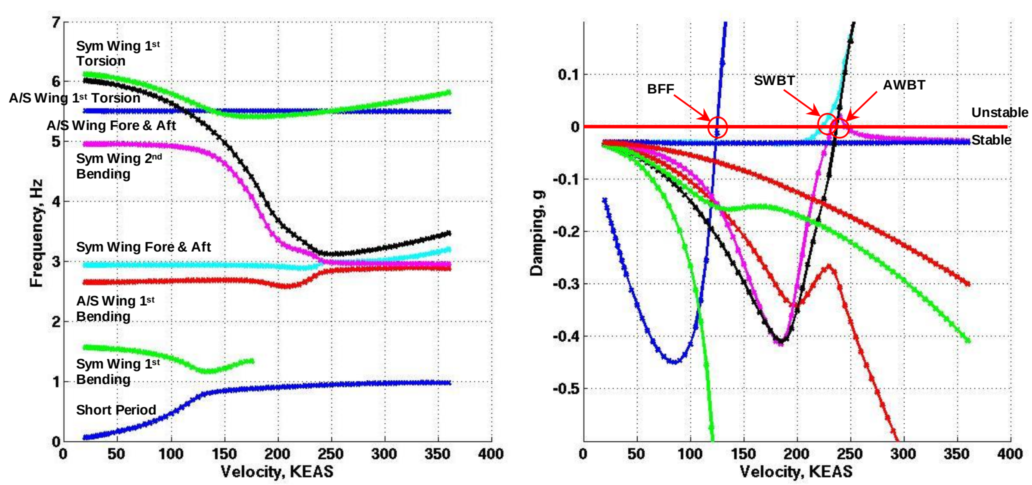


Figure 9 Full Scale SC006A Empty Fuel Flutter Results at 0.65Mach

Shown in Figure 10 is the VFG plot for the full fuel SC006A vehicle. BFF occurs at about 125 KEAS, SWBT occurs at about 245 KEAS, and AWBT flutter at approximately 190 KEAS due to the added fuel mass. This variable flutter characteristic is an important element to be demonstrated by the MUTT vehicle. This will challenge the development of a controller since it must not only produce desirable vehicle flying qualities but also stabilize rigid body and flexible vehicle dynamic coupling of BFF, decouple symmetric wing bending/torsion, and then decouple anti-symmetric wing bending/torsion at varying degrees of fuel state which involves different distributions of flexible vehicle modal frequencies. The change in fuel state and simultaneous suppression demonstration are key to increasing the Technology Readiness Level (TRL) of this control system.

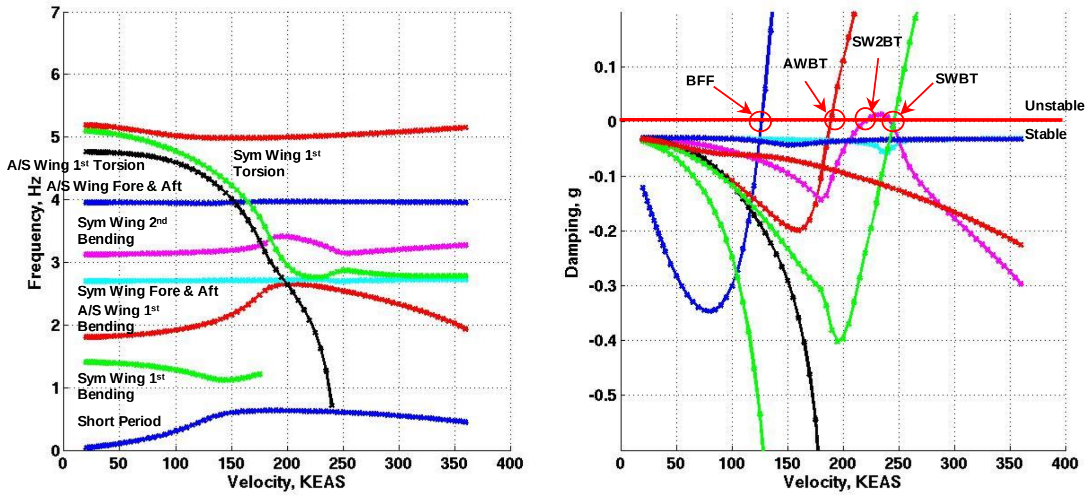


Figure 10 Full Scale SC006A Full Fuel Flutter Results at 0.65Mach

A key design element of the MUTT vehicle is to demonstrate full vehicle aeroelastic behavior as described above. The first consideration was to aeroelastically scale the SC006A based on flutter laws of similitude. An aeroelastically scaled vehicle lead to a nearly 1500 pound, 31 foot span vehicle flying at greater than 20,000 feet. Because of this excessively heavy model, high wing loading, and large flight envelope, it was determined that the vehicle should be sized using traditional scaling and to determine the feasibility of obtaining the desired aeroelastic behavior. Since the full scale vehicle flies at a maximum Mach of 0.65, compressibility effects are not very significant to the aeroelastic behavior of the vehicle. As long as the modal behavior of the demonstrator and the coupling mechanisms are similar to the full scale vehicle within the desired envelope, then the demonstrator will be capable of demonstrating full scale vehicle flutter.

Accommodating the ability to have a modular center body is a key driver to the MUTT demonstrator. The center body will be of a robust design in consideration of its multiple vehicle design role and the ability to survive following a potential in-flight aeroelastic instability. The stiffness characteristics of this center body portion will most likely be proportionately much higher than the full scale vehicle to meet these requirements. An early design decision for the demonstrator was the determination of what portion of the SC006A to make as the modular center body. As discussed earlier, symmetric wing bending is a primary participant in both BFF and symmetric wing/bending torsion flutter for the SC006A configuration. Wing bending shape and frequency are primarily affected by the bending stiffness of the inner third of the wing. Therefore, span-wise stiffness of the fuselage is a primary consideration in defining the width of the fuselage and ultimately its affect on wing 1st bending. As shown in Figure 11, the reinforced modular center section of the vehicle could either consist of the center body only or of the center body and inner wing section. A stiffness study of these two options was performed to understand their effect on flutter characteristics. Figure 11 shows plots of flutter speed and flutter frequency for the baseline configuration, a stiffened center body, and a stiffened center body and inner wing. These results are displayed for empty and full fuel; BFF, symmetric wing bending/torsion, and anti-symmetric wing bending/torsion flutter mechanisms. The plots indicate that the stiff center body configuration exhibits flutter characteristics similar to the baseline configuration; however the stiff center body and inner wing configuration show more significant changes to the flutter behavior relative to the baseline. In particular, the BFF mechanism increases from the baseline of 125

KEAS to 175 KEAS whereas it only changes from 125 to 140 KEAS for the stiff center body case. Based on these results, utilizing the stiffened center body for the fuselage module on the demonstrator will deliver aeroelastic results that are representative of the full scale vehicle.

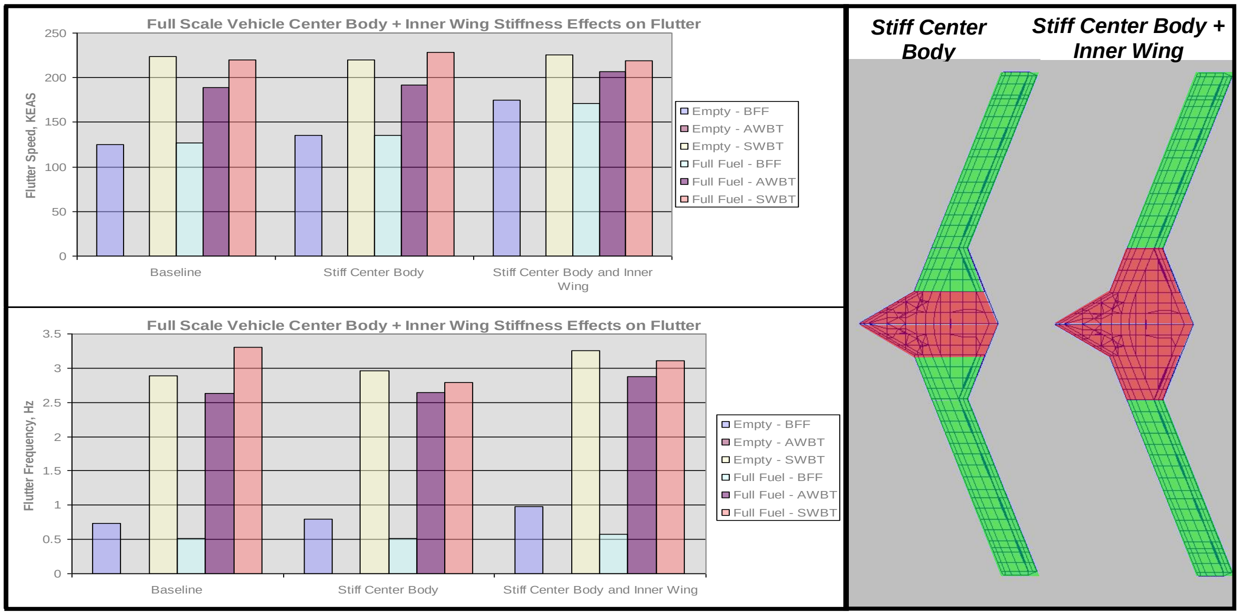


Figure 11 Center Body and Inner Wing Stiffness Effects on Flutter

Another driver of the MUTT study was feasibility of achieving adequate structural strength while retaining the flutter characteristics in terms of flutter speed and frequency within the desired flight envelope. Flutter speed requirements were driven by the desired flight envelope to minimize kinetic energy in the event of an in-flight breakup. Normally, flutter speed is placed such that flutter occurs outside of the design envelope including a margin of 15 percent in flutter speed. In the case of this aeroelastic demonstrator, it is required that flutter occurs within the design envelope. In consideration of kinetic energy and simplicity of flight for the flight test program, the design envelope was set to be a maximum speed of 150 KEAS and maximum altitude of 1000 feet AGL. Based on this, it was decided that the open loop flutter characteristics of the demonstrator should exhibit BFF at approximately 65 KEAS and wing bending/torsion flutter at approximately 90 KEAS. Closed loop flutter could then be demonstrated to a minimum of 120 KEAS. This minimum closed loop speed allows for the potential for further demonstration beyond 120 KEAS if so desired. Therefore, the flutter speed requirement for the demonstrator is between 65 and 100 KEAS. Another driving requirement for the aeroelastic demonstrator is actuator frequency bandwidth. The flutter suppression and GLA system of the demonstrator must be capable of controlling rigid body dynamics but also symmetric wing bending and torsion, and anti-symmetric wing bending and torsion. Current off the shelf actuators sized for this demonstrator are generally capable of sufficient frequency response up to approximately 10 Hz. Therefore, the actuator bandwidth requirement was set to be 10 Hz. This results in a frequency requirement for the demonstrator aeroelastic behavior to be no more than 10 Hz.

To determine the feasibility of the demonstrator to meet these speed and frequency requirements, a study was done of overall vehicle stiffness. A scaled finite element analysis model of the full scale SC006A was generated for doing this study. This model has a scaled SC006A mass distribution with an empty weight of 200 pounds and full weight of 400 pounds. The element sizing and material properties were like that of the full scale vehicle. An overall stiffness scale factor was then applied to the model to evaluate the feasibility of achieving the desired speed and frequency characteristics. Shown in Figure 12 are plots of flutter speed and flutter frequency as a function of a factor on overall vehicle stiffness. Results are shown for empty and full weight; BFF, symmetric wing bending/torsion, and anti-symmetric wing bending/torsion flutter of the demonstrator vehicle. The trends indicate that a factor between 0.02 and 0.025 produces flutter speeds in the range required for the demonstrator; between 65 and 100 KEAS. This same stiffness factor range results in frequencies that are generally less than approximately 10 Hz, which satisfies the actuator frequency bandwidth requirements. This is shown as the cross-hatched region of the flutter speed and frequency plots in Figure 12. Note that body freedom flutter and symmetric wing bending/torsion flutter occur in the 70 to 80 KEAS range and the 90 to 110 KEAS range respectively while anti-symmetric wing bending/torsion occurs between 60 and 70 KEAS.

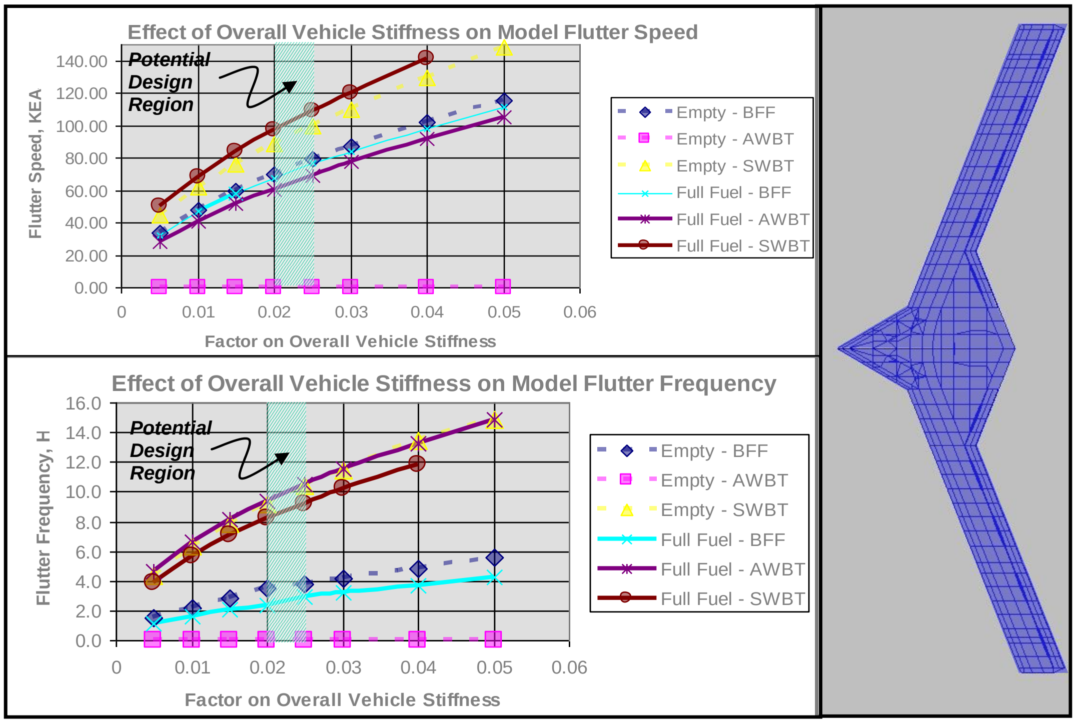


Figure 12 Overall Vehicle Stiffness Scaling Effects on Flutter

The full scale SC006A has four spars while the demonstrator has two. This in combination with material changes from the full scale carbon fiber composite and fiberglass to the demonstrator all fiberglass design leads to a structural design space that can deliver the stiffness requirements for the demonstrator vehicle. Preliminary studies have indicated that the demonstrator stiffness and strength requirements are compatible.

Adequacy of the demonstrator for modeling full scale vehicle flutter was evaluated by comparing the flutter behavior of the demonstrator to the full scale vehicle. Shown in Figure 13 and 14 are VFG plots for the demonstrator in the “empty” and “full fuel” states of 200 and 400 pounds respectively. These results are for the 0.02 scaled stiffness vehicle. Figure 13 shows BFF and SWBT flutter similar to that of the full scale vehicle. Figure 14 again shows BFF and SWBT flutter similar to that of the full scale vehicle. Also shown in this figure is AWBT flutter occurring below the BFF speed. This is not similar to the full scale vehicle. Detailed design of the demonstrator will improve the correlation of the anti-symmetric wing bending/torsion mechanism.

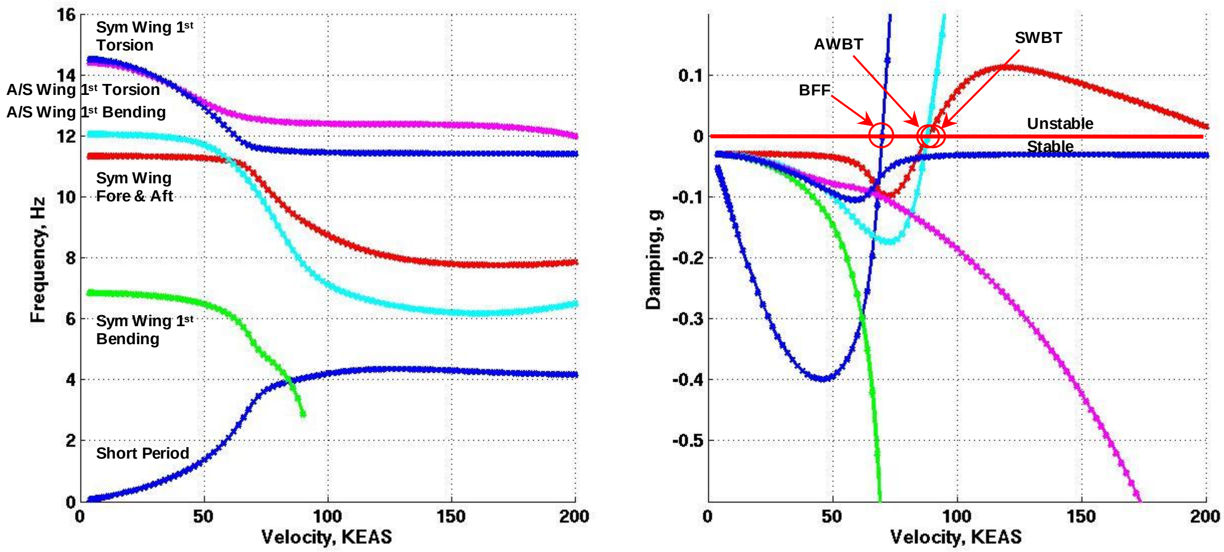


Figure 13 "Empty Fuel" Demonstrator Conceptual Flutter Results

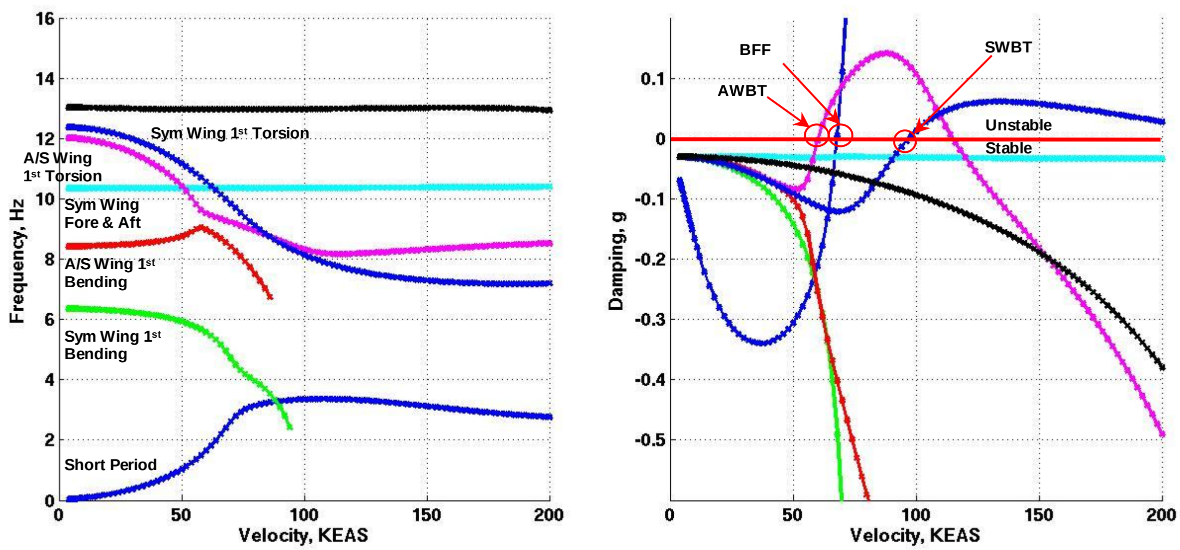


Figure 14 "Full Fuel" Demonstrator Conceptual Flutter Results

The other aeroelastic demonstration of the MUTT vehicle is gust load alleviation. Demonstration of GLA on the MUTT demonstrator will be done via evaluation of vehicle gust response per input measured in flight. The difficulty in conducting the GLA demonstration is quantification of the input. A combination of air data and angle of attack measurements taken via the flight test boom, rigid body rates and accelerations taken from the INS, and wing accelerometer data will be used to derive a gust angle of attack. A number of gust calibration flights will be done in relatively still air using pitch, roll, and yaw maneuvers to establish 0 gust alpha during maneuvers assuming no gust input. Actual gust flights will be done during increased turbulence days during the middle of summer at NASA Dryden.

V. Flight Control Considerations

The flight control system onboard the vehicle will be designed to demonstrate integrated flutter and vehicle control technology. Aircraft exhibit two types of dynamic behavior: rigid and flexible modes. Figure 15 shows graphically how rigid and flexible modes interact for different classes of aircraft. For example, on traditional fighter aircraft, the aircraft configuration and the structural design result in characteristics that permit the flexible modes to be analyzed separately from the rigid control of the vehicle. Aeroservoelastic issues that can result from structural mode feedback into the flight control system are typically resolved via notch filters to remove the structural mode response. As described in the previous section, the SensorCraft configuration leads to inherent coupling of the rigid and flexible modes as shown by the overlapping regions shown in Figure 15. The flight control system must be designed to control the combined rigid and flexible dynamics of the vehicle exhibited by BFF. Also, the flight control system will also need to actively stabilize flutter mechanisms such as SWBT and AWBT in certain parts of the flight envelope. The purpose of this vehicle is to demonstrate a critically coupled flight control system for a statically unstable aircraft with multiple unstable flutter modes.

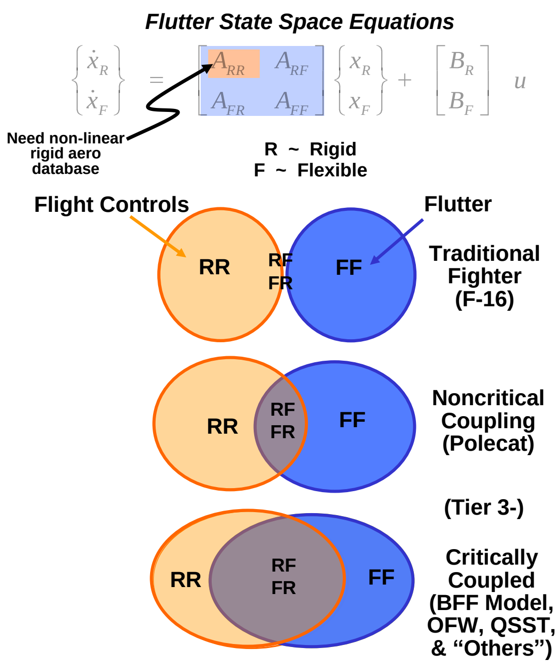


Figure 15 Rigid and Flexible Mode Coupling

To address the need for simultaneous control of rigid body and flexible vehicle dynamics a number of effectors are required. Control surface distribution on the demonstrator was chosen based on previous experience and knowledge of the character of the flexible modes. This analysis leads to a total of 10 control surfaces; four surfaces on each wing and two surfaces on the body as shown in Figure 8. This configuration offers control of the rigid body while giving a distribution of control for the symmetric and anti-symmetric flexible modes.

A block diagram of the basic flight control layout is shown in Figure 16. The flight control system will have two main tasks, although these tasks must be integrated due to the critical coupling of the rigid and flexible modes. The first task is to stabilize the rigid flight characteristics of the vehicle so that it can be piloted remotely from a ground station. The flight control system will receive high level commands, such as flight path angle, bank angle, and airspeed, from the pilot in the ground station, and it will use feedback sensor signals that correspond to the rigid states of the vehicle to achieve these commands. The second task performed by the flight control system is to stabilize the flutter modes of the aircraft. This will be achieved by feeding back sensor signals that correspond to the flexible states of the vehicle to achieve the desired stability margins for the flutter modes. The flight control laws will initially be optimized for maximum damping to stabilize flutter modes. After data is gathered from the sensors on the aircraft the control laws will be re-tuned to minimize the gust loads on the vehicle and demonstrate an active GLA system in flight.

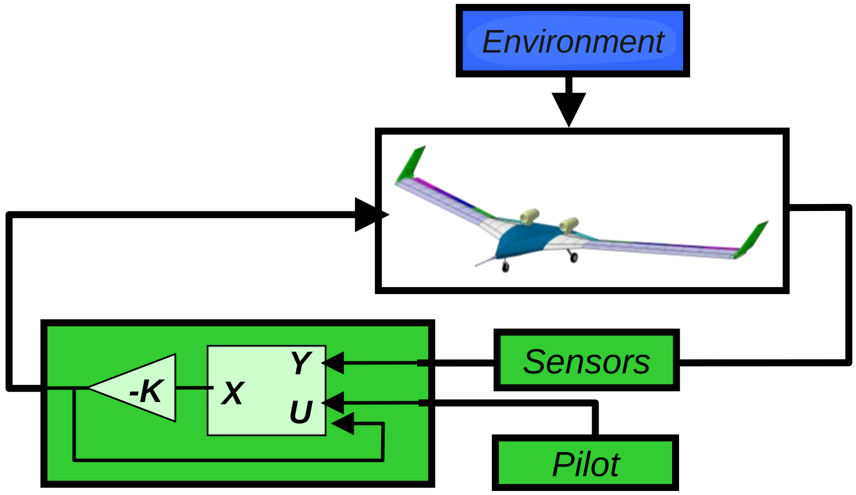


Figure 16 Flight Control Block Diagram

Because the rigid and flexible modes of the vehicle are critically coupled, all the sensor signals will measure a combination of rigid and flexible states. The flight control system will use state estimation algorithms to separate the rigid and flexible states. The control surfaces will also affect both the rigid and flexible modes of the vehicle. The flight control system will use distributed control allocation algorithms to affect the rigid and flexible modes separately. Because the dynamics of the vehicle change depending on weight, stability, and flight condition, it will likely be necessary to use an on-board model of the vehicle dynamics as part of the state estimation and control allocation algorithms.

To characterize the flexible nature of the SensorCraft to implement aeroelastic control, the flight control system will use 10 to 15 accelerometers, in combination with air data sensors and a GPS/INS package to estimate the rigid and flexible vehicle states. The flight computer will be a PC-104 system, which includes a single board computer, power supply, and multiple input/output (IO) boards. The computer IO will include analog input channels for accelerometer and air data signals, pulse-width-modulation (PWM) output signals to command the flight control servos and engine throttles, and serial communication ports for GPS/INS input and flight test data recording. Industrial servos will be used to actuate the control surfaces. The Volz Series 20-XX-41XX Actuators were chosen for their frequency response and load capability. A line-of-sight Ethernet radio transmitter and receiver will be used for the command and control of the vehicle from the ground station.

VI. Flight Test Considerations

As described above, safety of flight test was a major driver for the selection of the physical and stiffness scale of the vehicle. The maximum energy of the vehicle played an important role in the design trades. Consideration for flight operations was also given to achieve demonstrator performance goals and determine the ideal location for conducting flight test. Some of these considerations are:

- Vehicle piloting method
- Max speed acceptable for the vehicle piloting method
- Small test area
- No need for a chase plane
- Low momentum in case of in-flight breakup and small potential debris field
- Flexibility of the test site in take off and landing operations
- Proximity of gust inducing features such as mountains
- Ability to terminate flight
- Proximity of the test location to LM Aero facilities to minimize travel and logistics cost

Although the MUTT vehicle was designed to minimize energy for safety, the vehicle is of a size that conventional radio control hand held flight box is impractical. For this reason the MUTT aircraft will use a heads down control station augmented with video downlink. The control station will be a self contained trailer with redundant controls and flight test stations. Flight test observers would be positioned to provide radio feedback of the flight as well as the telemetry data and tracking systems.

Potential test sites were considered to be Camp Roberts in central California and NASA Dryden at Edwards Air Force Base in southern California. NASA Dryden was chosen due to its proximity to the LM Aero facility in Palmdale California, the immense dry lake bed for take off and landing, and local mountains for gust operations. Shown in Figure 17 is the NASA Dryden test area. The ground station would be positioned on the paved taxiway near the North Edwards hanger complex. This provides approximately a half mile of distance between the flight test area and personnel. A figure eight test profile would allow for good separation to personnel and provide good radio communications with the vehicle.

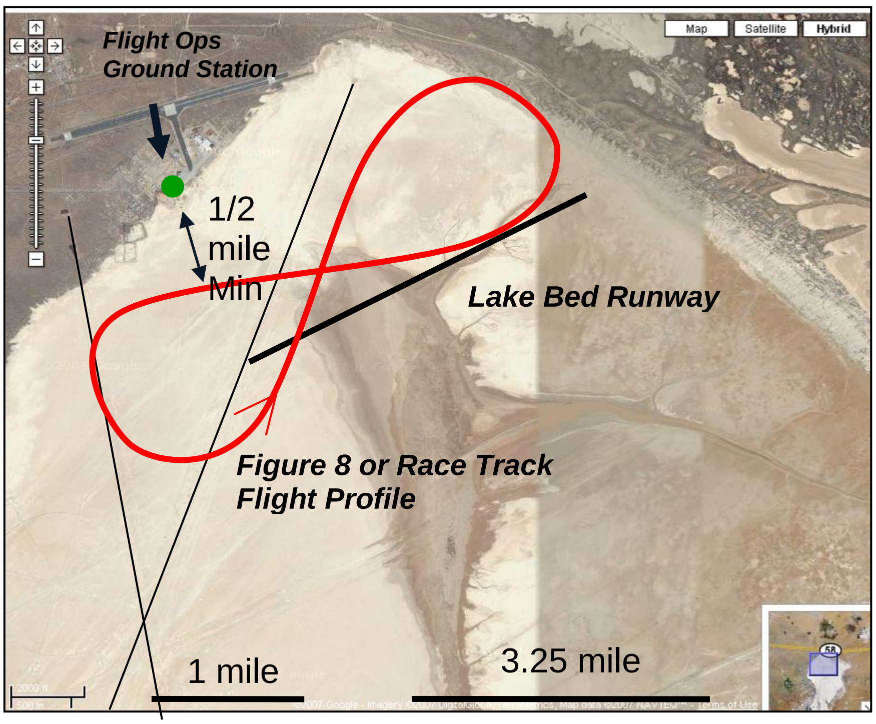


Figure 17 Flight Test Range Photo

The vehicle will use the Dryden Flight Termination System with an on board Flight Termination Receiver (Herley HFTR60-1). The FTS will initiate an engine fuel cut-off a pitch up command to reduce the kinetic energy of the aircraft and deploy a ballistic recovery parachute.

The final element to flight test was type and number of flights to achieve the program goal of demonstrating both flutter suppression and GLA. The plan starts by building up the MUTT demonstrator flight envelope in a stable, light weight configuration. The vehicle would be characterized in flight by performing a series of frequency sweeps. Next the GLA system would be tested for stability. The aircraft would then be tested to determine the BFF speed prior to the first test of the closed loop suppression system. The suppression system would then be tested with the GLA system active. This procedure would then be repeated with the aircraft loaded to be statically unstable. A final series of tests would be conducted with the vehicle ballasted to the heavy weight condition. A total of 24 flights are scheduled over the four month flight test program.

VII. Conclusion

Trade studies conducted by LM Aero to determine the feasibility of a MUTT aeroelastic demonstrator show a 15 percent scaled SensorCraft demonstrator will meet the AFRL goals at a program cost of $12.5M. This demonstrator consists of a modular center body that can be re-used in the event of an in-flight aeroelastic failure and is re-configurable to a joined wing design like that of the Boeing 410F4 configuration. Aeroelastic characteristics of the scaled vehicle model have been shown to be similar to that of the full scale vehicle. A flight test program has been outlined that will include flutter suppression demonstration as well as demonstration of gust load alleviation. Consideration has been given to ease and safety of flight test to maintain program cost goals as well as obtain valid demonstration data. These demonstrations include a range of mass distributions and cg locations on a vehicle with representative structure that will increase the readiness level of flutter suppression and GLA to a TRL of 6-7. This technological improvement is not only valid for the SC006A vehicle but also greatly increases the readiness level for vehicles that involve rigid body and flexible vehicle coupling.

VIII. Acknowledgement

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