

AEROELASTIC SCALED FLIGHT TEST OF A SCALED JOINED WING SENSORCRAFT CONFIGURATION

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The design, construction and flight testing of a 1/9th scale, aeroelastically scaled model of the Joined Wing SensorCraft is the subject of an ongoing international collaboration aimed at experimentally demonstrating the nonlinear aeroelastic response associated with the configuration. To measure and characterize the desired response, the aircraft must exhibit equivalent aeroelastic properties while also being designed for flight worthiness. Additionally, the aircraft must be instrumented to record the required structural response data. Flight testing of the 1/9th scale Joined Wing SensorCraft will begin with a rigid prototype. Current work at Virginia Tech includes instrumentation system design and testing, flight testing of reduced complexity models and flight test planning. A parallel effort at Quaternion Engineering in Victoria, BC includes the structural design and fabrication of the test article as well as simulation of flight test maneuvers. Final preparations are underway for the first flight test, scheduled to go wheels up in May 2011.

Introduction

The Boeing Joined Wing SensorCraft (JWSC) is a concept proposed to serve as a next-generation, high altitude, long endurance (HALE) reconnaissance unmanned aircraft. The aeroelastic responses, specifically aft wing buckling and gust load response, associated with the JWSC have been investigated in numerous computational and wind tunnel studies¹⁻³; however, these phenomena have never been successfully demonstrated and measured in a flight test program (FTP). The design, fabrication and flight testing of a reduced scale, aeroelastically scaled JWSC remotely piloted vehicle (RPV) is the subject of an ongoing international collaboration between The Air Force Research Laboratory (AFRL), Virginia Tech, The AFRL/Virginia Tech/Wright State/University of Maryland Collaborative Center for Multidisciplinary Sciences (CCMS), University of Victoria, Quaternion Engineering and the Portuguese Air Force Academy⁴. By experimentally demonstrating, investigating and measuring the aft wing buckling response in flight, future flight test programs will be able to design active aeroelastic control and gust load alleviation systems to reduce the structural and aerodynamic effects of the nonlinear responses.

Background

The SensorCraft is a concept initiated by AFRL to serve as a next-generation, HALE reconnaissance system. The SensorCraft, when equipped with an advanced sensor package, will provide intelligence, surveillance and reconnaissance (ISR) capabilities to contribute to persistent battlespace awareness in the 2015 time frame.⁵ The Boeing Joined Wing SensorCraft Concept is shown in Figure 1.



Figure 1. Joined wing SensorCraft Concept

The primary driver behind the JWSC's unique configuration is the ability to incorporate conformal foliage penetrating radar antennas in the fore and aft wings to provide persistent 360 degree radar coverage. This ability is of great benefit to the ISR mission; however, it does come with a price. Previous computational studies of joined-wing aircraft

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configurations have shown the importance of geometric nonlinearity due to large deflections and follower forces that may lead to buckling of the aft wing^{1,6}. The nonlinear behavior could be removed by strengthening the wing; however, this would result in large penalties in aspect ratio and structural weight, greatly reducing the performance of the aircraft. To avoid these penalties, nonlinear aeroelastic design, analysis and testing are required to ensure that the JWSC is able to sustain the nonlinear responses required to complete the proposed ISR mission.

The full scale flight point of interest corresponds to a fully fueled take off condition at sea level. This “worst case” flight condition represents the most hazardous portion of the mission due to high wing loading and low thrust-to-weight ratio due to the high volume of onboard fuel. The Air Force requests that a 1/9th scale RPV be built with equivalent scaled physics. Table 1 summarizes both the full scale and the corresponding reduced scale test configuration.

Table 1. Summary of full scale and RPV test configurations

	Full Scale	RPV
Span (ft)	150	16.4
Speed (kt)	168	56
Maximum Weight (lb)	155,337	204.5
Wing Loading (psf)	124.4	13.6
Altitude (ft)	Sea Level	Sea Level

Program Overview

The design, construction and flight testing of the 1/9th scale JWSC RPV is an international collaboration between six entities: AFRL, Virginia Tech, CCMS, University of Victoria, Quaternion Engineering and the Portuguese Air Force Academy. Figure 2 presents a flowchart of the project organizational hierarchy.

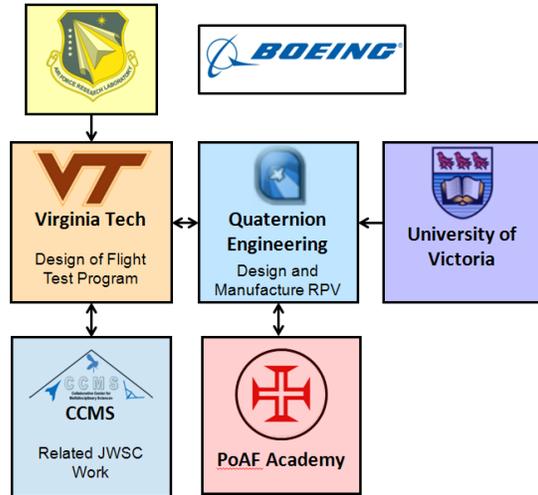


Figure 2. Project Organizational Hierarchy

JWSC is a Boeing concept, and accordingly Boeing is at the top of the organizational hierarchy. The funding organization is the AFRL, who has contracted Virginia Tech for the design, development and implementation of the flight test plan for the RPV. CCMS is a collaborative center with research groups at both Virginia Tech and Wright State aimed at multidisciplinary design and development of air vehicles. A large component of the CCMS research taking place at Virginia Tech is focused on the JWSC concept. Several research projects, including the JWSC Flight Test Program, are aimed at the development and understanding of the JWSC and its associated aeroelastic phenomena. Virginia Tech has contracted Quaternion Engineering, a SME based in Victoria, BC, Canada for the design and fabrication of the RPVs. Quaternion Engineering is working in conjunction with the University of Victoria. Quaternion Engineering has also secured flight test facilities at the Portuguese Air Force Academy (PoAFA) in Portugal.

Approach

Due to the unique JWSC geometry, the relative large scale of the RPV and the challenge of fabricating aeroelastically scaled, flight worthy components, the JWSC FTP is divided into three distinct phases: the Configuration Evaluation Program, the Flight Demonstration Program and the Aeroelastic Response Program. Each of these phases is described in detail below.

Configuration Evaluation Program

The Configuration Evaluation Program involves the use of simulators and reduced complexity flight models to better understand the flying qualities and trim

requirements of the JWSC configuration. Three independent simulators are used. The first is a custom six degree-of-freedom (DoF) flight simulator developed for this project. The second is a commercially available R/C flight simulator used for pilot training. The final is a simulator developed by the autopilot manufacturer that includes “hardware in the loop” capability to test proposed autopilot and instrumentation packages.

The reduced complexity flight models are a series of three sub-scale (approximately 6 ft wingspan), non-aeroelastically scaled aircraft that designed to investigate stability and control, to train pilots and ground crew and to determine mass and space reservations for supporting systems required for the final aircraft. Ranging from flat plate foam models to full composite aircraft, these models support the overall test effort by providing experimental insight into the flight characteristics of the JWSC before the 1/9th scale models ever reach the flight line.

Flight Demonstration Program

The Flight Demonstration Program involves the design, fabrication and flight testing of a Rigid RPV. The Rigid RPV is a full 1/9th scale (16.4 ft wingspan) flight vehicle with equivalent rigid body dynamics (preserved aerodynamics, overall mass and moments of inertia), but no aeroelastic tailoring. This program includes the design of the RPV including construction methods, flight test instrumentation selection and integration, control system tuning and flight test program development. This stage of the project has the objective of evaluating the flight worthiness and dynamic characteristics of the joined-wing configuration, and to determine design constraints such as component masses and space reservations. This information will be used during the future aeroelastic scaling process. The first stage of the project includes the evaluation of composite manufacturing methods, flight test instrumentation and flight test procedures on a Rigid RPV where the complexities of aeroelastic scaling are not present.

Aeroelastic Response Program

The Aeroelastic Response program builds upon the success of the Flight Demonstration Program and expands it to include the design, fabrication and flight testing of a linearly scaled RPV. This program begins with linear aeroelastic scaling of the 1/9th scale RPV designed to have the identical modal response (mode shapes and scaled frequencies) as the full scale JWSC. Upon completion of the computational aeroelastic scaling process, the flight vehicle will be equipped with the flexible wings and flight test instrumentation while a flight test program is being developed.

The final stage of the project will include an experimental evaluation and characterization of the nonlinear aeroelastic response of the flight demonstrator vehicle. During the execution of the flight test program the Aeroelastically Scaled RPV will be subjected to a series of tests designed to load the aft wing to a point where the desired nonlinear response can be achieved, observed and measured.

Context of this Paper

The remainder of this paper serves to document and present the work completed at Virginia Tech between August 2010 and March 2011 in preparation for the Rigid RPV flight test. The complimentary effort at Quaternion Engineering, including the design and fabrication of the RPV and simulation work will be introduced and referenced at the end of this paper.

Instrumentation System Design

This section outlines the instrumentation system that was designed for the Rigid RPV. The Rigid RPV instrumentation package serves as a low cost, low complexity means of testing several methods of wing deflection measurement, and it also allows flight test data logging and post processing operations to be designed and debugged with a smaller volume of data than will be required for the Aeroelastically Scaled RPV flights. Lessons learned from this instrumentation package will be used to optimize a more complex instrumentation package for the future Aeroelastically Scaled RPV flights.

The following sub-sections outline the components of the instrumentation package: the flight control system, (Piccolo II autopilot and the Acroname Robotics Receiver Multiplexer), the JetCat P200-SX In-Flight Health Monitoring System, the Air Data Boom, two analog wing deflection measurement systems (accelerometers and strain gages) and cameras, including stereoscopic wing deflection measurement.

Flight Control System

Control of the Rigid RPV is accomplished via the onboard Cloud Cap Technology Piccolo II Autopilot coupled with an Acroname Robotics Receiver Multiplexer (RxMUX). The Rigid RPV will be under manual control at all times during flight test operations; however, the use of the autopilot allows for the incorporation of stability augmentation, as well as a centralized data acquisition system on board the aircraft. The Piccolo II is shown in Figure 3.

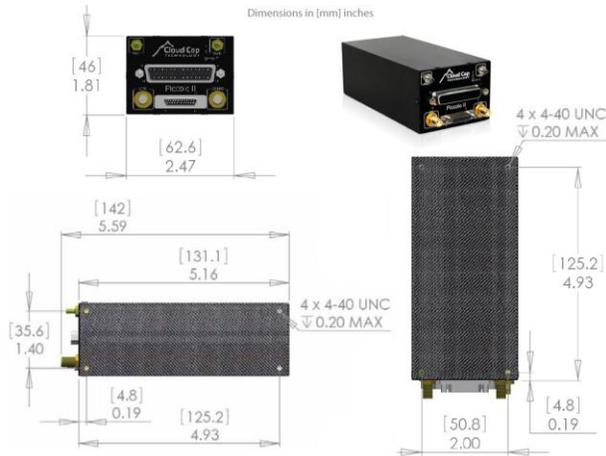


Figure 3. Mechanical Drawings of the Piccolo II Autopilot (modified from Refs. 7,8)

The Piccolo II is capable measuring and transmitting real-time aircraft altitude (barometric and GPS), aircraft attitude, airspeed, groundspeed and servo commands to the ground station during flight operations. The Piccolo II also features four, 0-5 volt, 10 bit conversion analog input channels which will be used to read and transmit data from the two potentiometers inside the onboard air data boom. The Acroname Robotics RxMUX, shown in Figure 4, provides the ability to incorporate a backup, redundant receiver for use in the event that primary control is lost.

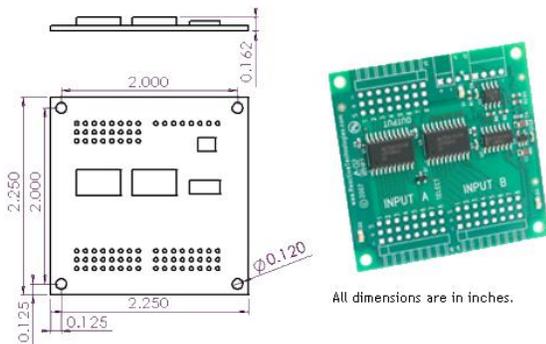


Figure 4. Acroname Robotics RxMUX (modified from Ref. 9)

The RxMUX is a specialized multiplexer that allows for control of eight servo channels. The RxMUX features two, eight-channel inputs and a single eight-channel output. Connecting one of the inputs to the autopilot and the second to a backup receiver easily incorporates an independent, backup receiver system for the RPV. Switching between the two input groups is easily accomplished via a switch on either the primary or backup transmitter.

To actuate the various surfaces requires a total of 28 servos. This exceeds the limit of signal outputs provided by the autopilot, so two servo control boxes are employed. The PowerBox Systems PowerBox Royal supplies dual redundant isolated voltage regulation to servos and allows distributing control from one input channel to multiple servos. Due to the large number of servos, two PowerBox Royals are used, one for each half of the aircraft.

The Piccolo II, the dual PowerBox Royals and the RxMUX combine to form the complete control system for the Rigid RPV. A schematic of the complete system is shown in Figure 5.

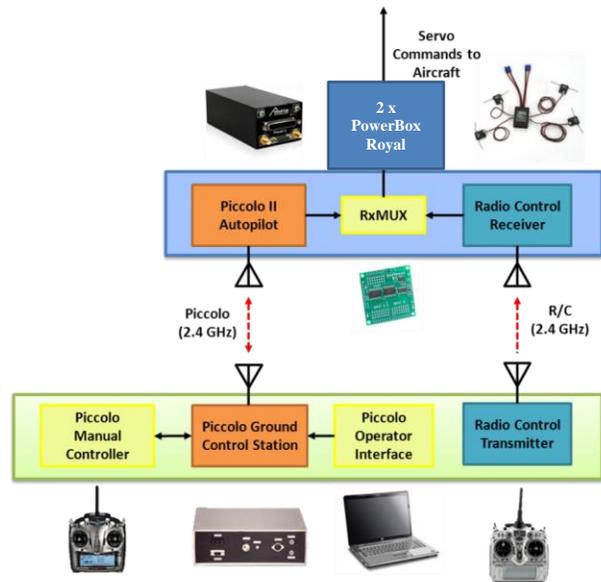


Figure 5. Piccolo II/ RxMUX System Concept (modified from Ref. 7)

Primary control of the RPV is provided through a JR 11X 2.4 GHz transmitter, labeled above as the Piccolo Manual Controller, connected to the Piccolo Ground Control Station. Control signals are then sent to the RPV via the 2.4 GHz Frequency Hopping Spread Spectrum (FHSS) RF link. A backup transmitter, a JR 12X (labeled above as the Radio Control Transmitter), provides an entirely independent 2.4 GHz Direct Sequencing Spread Spectrum (DSSS) backup RF system. The use of several 2.4 GHz RF links will not cause interference because of the “binding” process between the transmitter and the receiver. The JR 12X provides a link to a separate remote control (R/C) receiver on board of the RPV, connected through the RxMUX, and this backup link can be activated at any time during the flight by simply flipping a switch on the backup transmitter. Flipping this switch changes the

active input on the RxMUX, changing the source of the servo commands to the aircraft. The system is designed such that the backup controller can take control of the aircraft at any time, especially in the event of signal loss with the primary controller.

JetCat P200-SX In-Flight Health Monitoring System

The JetCat P200-SX turbines contain built in sensors for engine RPM, exhaust gas temperature and fuel pump voltage. This data is continuously monitored by the JetCat Engine Control Unit (ECU), and this data can be viewed in real time by using the Ground Support Unit (GSU) while the aircraft is on the ground. Current work is aimed at incorporating real-time transmission of these parameters to the ground station during flight operations by reading them using the ECU’s RS232 serial connection.

Air Data Boom

An air data boom will be used to provide accurate angle of attack and sideslip angle measurements during all flight test operations. Commercial air data booms are too expensive to fit within the instrumentation budget of this project, so a custom air data boom was designed and fabricated. This boom consists of a 40 in long, 0.75 in inner diameter aluminum rod and two custom, laser cut acrylic vanes. Counterweight to balance the vanes at the hinge line is provided by 0.70 in long, 0.3125 inch diameter zinc steel inserts. The angular measurements are provided by two Spectrum Sensors 6909-1003-030 low friction rotational potentiometers mounted on custom machined aluminum inserts. The wipers for the potentiometers are mounted on the rotational shaft of each vane. Figure 6 presents an exploded view of the vane assembly.

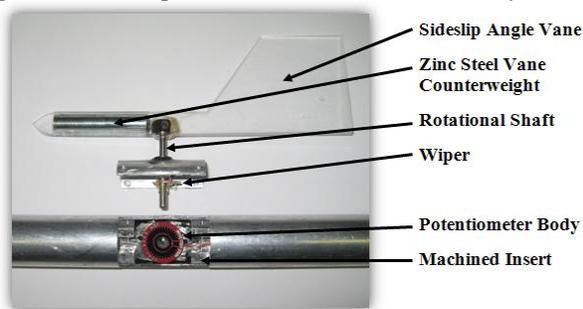


Figure 6. Exploded View of Air Data Boom Vane Assembly

Future work includes the calibration of this air data boom in Virginia Tech’s Open Jet Wind Tunnel using a Space Age Control 100400 Mini Air Data Boom. The angle of attack and sideslip angle measurements from the Mini Air Data Boom will be used to calibrate the analog output from the rotational potentiometers.

Wing Deflection

Wing deflection measurement will be an integral part of the future flight test of the Aeroelastically Scaled RPV, and as such, the Rigid RPV will serve as a testing platform for wing deflection measurement systems. The overall wing deflections of the Rigid RPV will be small (nowhere near the non-linear range desired for the Aeroelastically Scaled RPV); however, testing the instrumentation in flight on the Rigid RPV will promote the success of the Aeroelastic Response Program.

There are three methods of measuring wing deflection that will be tested on the Aeroelastically Scaled RPV: strain gauges, accelerometers and stereoscopic imagery. Figure 7 shows the location of the strain gauges and accelerometers on the rigid RPV.

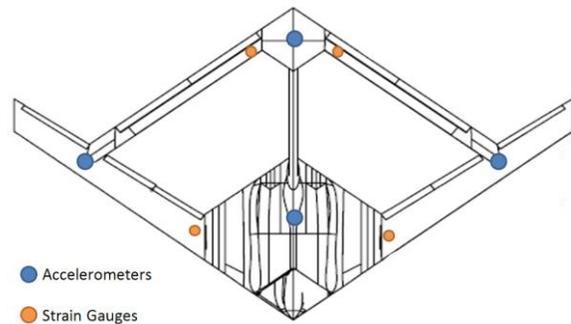


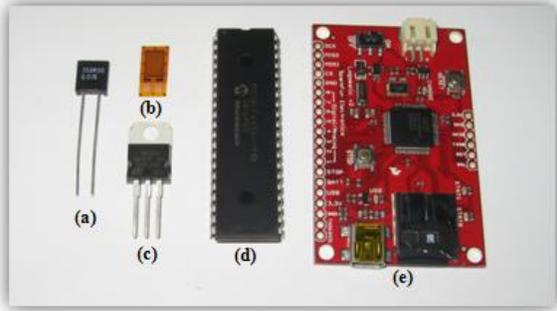
Figure 7. Accelerometer and Strain Gauge Locations

The use of all three deflection measurement methods allows for redundant measurement of critical flight test data, and also allow for the comparison of the quality of the data. These three measurement methods are presented in detail next.

1. Strain gages

Quarter-bridge strain gauge arrays are located at root of both the forward and aft wings. By measuring the strain on each gauge, and integrating these strains, wing deflection can be computed and recorded. The strain gauges used are Micro-Measurements CEA-06-250UW-350 General Purpose Strain Gages. These strain gauges were selected based on the maximum expected strain at each strain gauge location, computed using FEA. Three Micro-Measurements S-350-01 350 Ohm Bridge Completion Precision Resistors were used to complete each strain gauge array. The analog output from each quarter bridge is connected to one of the 12-bit analog to digital conversion (ADC) channels on a MicroChip PIC18LF4553 microcontroller. The PIC18LF4553 is programmed to take the analog input

from each of the four strain gauge arrays and convert them into a single digital output. This digital signal is then sent to a Sparkfun Logomatic v2 Serial SD Datalogger, which stores the data onboard on a 1GB micro-SD memory card. The entire system is powered by a 2.7V Lithium Polymer (LiPo) battery pack fed through a Sparkfun LM7805 5V voltage regulator. Figure 8 shows each of the components used to complete this strain gauge system.



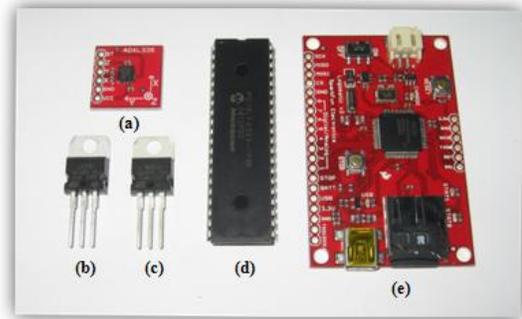
(a) 350Ω Bridge Completion Precision Resistors
 (b) Strain Gauge
 (c) 5V Voltage Regulator
 (d) PIC18F4553 Microcontroller
 (e) Logomatic v2 Datalogger

Figure 8. Strain Gauge System Components

2. Accelerometers

Tri-axial accelerometers are located at the CG, the top of the vertical tail boom and at each wing joint. By integrating the accelerations at these locations twice with respect to time, the displacement of these locations can be calculated. Aircraft attitude information from the Piccolo II autopilot can then be used to rotate the accelerometer displacements into the inertial reference frame. Finally, the rotated displacements can be compared to the baseline un-deflected aircraft geometry to compute wing deflections. Level turn wing loading calculations show that the maximum planned load factor during the Rigid RPV flights is 2.1 g's. To account for all planned flight maneuvers, the accelerometers selected are Analog Devices ADXL335 3-axis, $\pm 3g$ accelerometers. The accelerometers are mounted on Sparkfun breakout boards providing 0.1 μ F capacitors on each analog output (x,y and z-axes) giving the ADXL335 a functional bandwidth of 50Hz on each axis. The three analog outputs from each accelerometer were connected to one of the 12-bit ADC channels on a MicroChip PIC18LF4553 microcontroller, and just as in the strain gauge system, the PIC18LF4553 converts the 12 analog inputs into a single, digital output. This output is then sent to a second onboard Logomatic v2 Serial SD datalogger. The system is powered by a 2.7V LiPo battery pack fed through a Sparkfun LM7850 5V voltage regulator to

power the Logomatic v2 and a Sparkfun LD1117V33 3.3V voltage regulator to power the accelerometers. Figure 9 shows each of the components used to complete this accelerometer system.



(a) ADXL335 Accelerometer
 (b) 3.3V Voltage Regulator
 (c) 5V Voltage Regulator
 (d) PIC18F4553 Microcontroller
 (e) Logomatic v2 Datalogger

Figure 9. Accelerometer System Components

3. Stereoscopic imagery

Stereoscopic imagery involves the use of two cameras placed at a known distance and angle from one another, each focused on the same object (in this case a wing). By combining these images through post processing software, a single, composite, three-dimensional image can be created. Fixed points of reference on the wings can then be used to back out wing deflections. Current work is aimed at developing a stereoscopic measurement system for the Rigid RPV.

A stereoscopic system is advantageous because it allows for the deflected shape of the entire wing to be determined from two cameras. With strain gauges and accelerometers, each instrument only gives information about a single point on the wing, and thus many accelerometers and/or strain gauges are required in each wing to determine the deflected shape of the entire wing. Installing and calibrating a large number of instruments in each wing is not only time consuming, but it also requires the modification of the aircraft structure and skin. For the future planned flight tests of the Aeroelastically Scaled RPV, the dynamically scaled lifting surfaces will be designed with specific mass and stiffness distributions to achieve the required aeroelastic response. Incorporating strain gauges and accelerometers without changing the required mass and stiffness distribution will be difficult, so stereoscopic imagery is being investigated as a less structurally invasive measurement system.

Navigation & Structural Health Monitoring Cameras

In addition to the cameras that will be used for stereoscopic measurement, the Rigid RPV will also be equipped with several cameras to monitor the structure of the aircraft during flight, as well as to provide emergency first person view (FPV) navigation in the event that the RPV inadvertently travels out of visual range. Initial design of camera locations has cameras for navigation placed in the nose and at the top of the boom, both pointing forward. Cameras will also be placed at the root of the forward wing and at the top of the boom pointing spanwise out the front and aft wing, respectively. These locations are also the locations that will be used for the placement of the stereoscopic imagery cameras. It may be possible for a single camera to function as both a real-time emergency navigation and/or structural monitoring camera and also to function as a stereoscopic imagery camera.

Current Work

Current work includes installing the strain gauge system, accelerometer system and the air data boom on a Sig Rascal 110 airframe to test in flight data acquisition and post flight data processing techniques prior to installing the instrumentation package on the Rigid RPV. A Sig Rascal 110, a 110 in span, high wing, trainer style R/C aircraft.

Flight Testing

This section summarizes the methodology and design of the rigorous flight test plan document that has been created for the Rigid RPV and is currently in the final stages of AFRL approval.

Program Goals

The overall program goals of the Rigid RPV flight test are to validate the scaling of the overall mass and moments of inertia and subsequently demonstrate the airworthiness of the vehicle through safe, controlled flight. Successful completion of the Rigid RPV flight test will pave the way for the future planned flight test of the more complex Aeroelastically Scaled RPV and the measurement of geometrically nonlinear aeroelastic responses in flight.

Program Objectives

Guided by the aforementioned goals, a series of primary, secondary and tertiary objectives are listed below. The test (or series of tests) that corresponds to each objective is shown after that objective in parentheses. In order for the flight test program to be considered a success, all primary objectives must be

met, along with a majority of the secondary objectives. Tertiary objectives have no bearing on whether or not the test is declared a success, but successful completion of these objectives will promote the success of the Aeroelastically Scaled RPV flight test program. The successful completion of the tests associated with each objective will be used to quantify the meeting of that objective.

1. Primary Objectives

- Validate scaled overall mass and center of gravity (CG) location (*Center of Gravity Test*)
- Validate scaled rigid body mass moments of inertia (*Bifilar Pendulum Test*)
- Demonstrate airworthiness and successful control of the Rigid RPV (*Phasing Flight Test*)

2. Secondary Objectives

- Demonstrate successful data acquisition and logging of flight test data (*Ground Tests, Phasing Flight Test*)
- Experimentally determine key turbine parameters, including static thrust, installed static thrust and fuel consumption (*Turbine Tests*)
- Validate control surface deflections and mixing (*Servo Response Test, Control Surface Scheduling Test*)
- Validate structural design (*Static Structural Loading Test*)
- Investigate feasibility of safely reaching 204 lb weight test point (*Incremental Weight Increase Test*)

3. Tertiary Objectives

- Obtain dynamic model parameters (*Dynamic Mode Flight Tests*)
- Investigate flight maneuvers to achieve required loading for nonlinear aeroelastic response (*Aeroelastic Response Preparation Test*)

Test Methodology and Breakdown

The Rigid RPV flight test is divided into three distinct phases, with the complexity and scope of the tests increasing within each phase. The goals of each phase are presented next, along with a brief description of the tests that comprise that phase.

Phase 1 - System Tests

Phase 1, System Tests, includes the integration and testing of all onboard systems. The successful completion of these tests will ensure that all onboard systems, including instrumentation, are functioning

properly prior to traveling to the flight test site. The tests included in this phase include a servo response test, control surface scheduling test, backup control test, instrumentation system tests and propulsion tests.

For the servo response test, a servo tester and a control surface deflection meter are used to establish an experimental correlation between commanded servo pulse width and control surface deflection for each surface. These correlations can then be used to monitor control surface deflection during flight as the Piccolo II logs servo commands. The control surface scheduling test verifies that control surface schedule that has been developed for the Rigid RPV is successfully implemented. In other words, all 28 servos and control surfaces move as expected given a particular flight command. This procedure tests all control mixing implemented in both the transmitter and onboard via the PowerBox Royals. The instrumentation system tests check the data logging, storage and transmission capability of all onboard instrumentation systems. This test will also check for interference between the instrumentation and flight control systems. Finally, the propulsion tests will bench test the JetCat P200-SX turbines to verify that the manufacturer's specified performance is achieved. This includes both the bench testing of an individual turbine as well as a static installed thrust test of the full Rigid RPV.

Phase 2 - Flight Readiness Tests

Once the Rigid RPV has successfully completed Phase 1 testing, which tests the individual components that make up the Rigid RPV, Phase 2 testing will begin. Phase 2, Flight Readiness Tests, includes ground testing of the complete RPV system. This phase includes a center of gravity test, a bifilar pendulum test and a static structural loading test.

For the center of gravity test, two electronic scales are used to calculate overall mass and CG of the aircraft. With the aircraft at zero degrees angle of attack, summing the readings on the two scales gives the overall mass and the weight distribution on each scale can be used to compute the longitudinal CG. Placing the aircraft at an angle of attack allows the vertical CG to be calculated, once the longitudinal CG is known. The bifilar pendulum test is used to experimentally determine the overall moments of inertia. This test involves hanging the aircraft from a bifilar (two parallel support chords) pendulum system in three separate orientations. In each orientation, the CG of the aircraft must be between the chords and one axis (roll, pitch or yaw) must be parallel to the chords. The period of the rotational oscillations of the system can be used to compute the moment of inertia about each axis. Finally, for the static structural loading test, the aircraft is inverted on a custom support structure

and sand bags are used to simulate all expected in-flight wing loadings. This test will validate the structural design of the RPV.

Phase 3 - Flight Tests

Once the Rigid RPV has successfully complete Phases 1 and 2, the aircraft will be ready for flight test operations. Phase 3, Flight Tests, includes all flight test operations of the RPV. To mitigate risk, a low-speed handling test and a high-speed taxi test open this phase. This is followed by the most important test in the entire program, the phasing flight test. If time and resources allow, the dynamic mode flight test, incremental weight increase test and aeroelastic response preparation test close the flight test.

The low speed handling test involves taxiing the aircraft and testing its handling qualities at speeds up to 10 knots. The high-speed taxi test consists of straight line, mock takeoff runs down the runway with a gradual increase in speed up to a maximum of 85% of the takeoff speed. The phasing flight test is the first wheels up flight test and involves takeoff, climb and trimming the aircraft, followed by two maneuvers: a level racetrack pattern and a level figure 8 pattern. These maneuvers are used to evaluate the flying qualities of the aircraft. The phasing flight test is closed with a landing configuration handling evaluation and finally landing. For the landing configuration handling evaluation, the flaps are deployed at altitude and the handling qualities are evaluated. This test mitigates risk during approach and landing.

The dynamic mode flight test investigates the dynamic stability of the aircraft with the primary focus on the Phugoid mode and the Dutch roll mode. Preliminary vortex lattice analysis has shown that both the Phugoid mode and the Dutch roll mode are marginally stable, and this test will serve to verify these results. The incremental weight increase test directly mirrors the phasing flight test with the exception that trimming weights are added to the aircraft to gradually increase its weight to the test point. Finally, the aeroelastic response preparation test determines the flight test maneuver that achieves the required loading on the aft wing to excite the non-linear aeroelastic response while minimizing risk. This test allows the pilot to try three maneuvers that can generate the required loading: an upwind turn, a push-over/pull-up, and a windup turn.

Reduced Complexity Flight Test Program

In order to reduce overall program risk, a series of reduced scale, reduced complexity aircraft have been developed and flown both at Virginia Tech and at Quaternion Engineering. These aircraft have been used

to investigate the Joined Wing's flying qualities, test various control surface scheduling schemes, determine landing gear location and layout and test avionics and instrumentation.

Trainer Aircraft

Two “trainer” style aircraft, both shown in Figure 10, have been used during the lead up work to flying the Rigid RPV. These platforms were chosen since they are stable, conventional airframes that provide a low risk platform for practicing flight operations, familiarizing pilot/ground crew with local airspace and as a platform for testing and tuning of autopilots and instrumentation before integration into the JWSC Rigid RPV.



Figure 10. UVic’s Senior Telemaster and QT1 Trainer Aircraft Used for Lead-Up Operations

Reduced Scale Joined Wing Models

A series of reduced scale aircraft have been developed to test various aspects of the JWSC Rigid RPV design including landing gear configurations, control surface scheduling and stability augmentation. Table 2 below summarizes the various reduced complexity aircraft which have been or are being flown at present. A detailed description of these aircraft is available in the Appendix of Reference 4.

Table 2. Reduced Complexity Aircraft Used to Mitigate Overall Project Risk

Flat Plate Foamie	TC EDF Foamie	Mini SensorCraft
- 66 in span	-66 in span	- 66 in span
- 2.2lb TOW	-2.6-6lb TOW	- 5.5-6.5lb TOW
- Electric Prop propulsion	- corrected wing twist	- Exact scaled outer mold line
	- 2x EDF provide scaled thrust	- 2x EDF provide scaled thrust

A simple flat plate foam model (Flat Plate Foamie) was flown for initial investigation into flight stability and controllability of the joined wing configuration. A

second set of foam aircraft (TC EDF Foamie) improved on the initial model with accurate twist distribution along the span, more accurate geometry and electric ducted fan propulsion systems. Later models used dual ducted fans to achieve accurate scaled thrust. A series of four TC EDF Foamies were used to test control surface scheduling schemes, investigate landing gear configurations and locations and to train pilots.

The final iteration of these reduced complexity aircraft is the Mini SensorCraft. The Mini SensorCraft has the exact same outer mold line as the Rigid RPV to ensure similar aerodynamics. The mass can also be trimmed to duplicate the scaled take off weights and moments of inertia for various flight conditions to be flown on the 1/9th scale aircraft. This ensures realistic predictions of stability characteristics that will be seen in the full scale. Early manual flights indicated a severe wing rock tendency caused by a marginally stable dutch roll mode. This has led to the development of a stability augmentation system using an autopilot system and was a driving factor in the choice to include an autopilot for initial Rigid RPV flights.

These aircraft have been subjected to over 20 hours of flight time in Victoria, BC using fully manual control, pilot assist mode and finally fully autonomous flights with auto land and waypoint navigation. These aircraft are to be used during flight testing of the Rigid RPV to dry run flight tests, train pilots and ground crew and demonstrate flightworthiness of the Joined Wing configuration. Examples of these reduced complexity aircraft are pictured below in Figure 11.



Figure 11. Reduced Complexity JWSC Flight Models used for Testing and Validation Purposes

Complimentary Work

In order to make this flight test effort a success, a complimentary effort is underway at Quaternion Engineering in Victoria, BC which includes the design and fabrication of the Rigid RPV, advanced simulation of flight test maneuvers and flight testing of the above mentioned reduced complexity models. The success of this flight test effort is hinging on the cooperation of Virginia Tech and Quaternion Engineering, and this section serves to acknowledge the impressive work and tireless dedication of Jenner Richards, the author’s primary collaborator at Quaternion Engineering. For a detailed description of this work, please see Reference

4 and Reference 10. Figure 12 shows Jenner with the Rigid RPV during the assembly process.



Figure 12 - Rigid RPV in the Assembly Jig

Future Work

The Rigid RPV flight test plan is currently in the final stages of approval by AFRL, and the program is on schedule to begin Phase 1 flight testing in May 2011. At the conclusion of testing of the Rigid RPV, linear aeroelastic scaling will resume and flight test planning for the Aeroelastically Scaled RPV flight test program will commence. The goal is to begin the testing of the Aeroelastically Scaled RPV by summer, 2012.

Conclusion

The design, fabrication and flight testing of a reduced scale, aeroelastically scaled JWSC remotely piloted vehicle is the subject of an ongoing international collaboration tasked with investigating non-linear aeroelastic response of the Joined Wing Sensorcraft. Current work includes the structural design and fabrication of the Rigid RPV, instrumentation system design and integration, simulation, flight testing of reduced complexity models and flight test planning. Final preparations are underway for the first flight test, scheduled to go wheels up in May 2011. Successful completion of this flight test program will validate the flightworthiness of the Joined Wing configuration and lay groundwork for future aeroelastically scaled aircraft.

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