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To the Graduate Council:

I am submitting herewith a thesis written by Christopher David Dotson entitled "Ground and Flight Vibration Environment at Fuselage Station 505 in the C-2A Airplane." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Stephen Corda, Major Professor

We have read this thesis and recommend its acceptance:

U. Peter Solies, John Muratore

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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GROUND AND FLIGHT VIBRATION ENVIRONMENT AT FUSELAGE STATION 505 IN THE C-2A AIRPLANE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee Space Institute

Christopher David Dotson
August 2008

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ABSTRACT

The purpose of this test was to collect ground and flight vibration data at Fuselage Station (FS) 505 in the C-2A airplane. Collection of this data was necessary to determine operational and structural compatibility of certain navigation equipment with this vibratory environment. Vibration data were collected using triaxial accelerometers mounted to the FS 505 overhead equipment shelf and to an H-764 Embedded Global Positioning System/Inertial Navigation System (EGI) mounted on the shelf. A total of 0.8 hr of ground testing and 3.6 hr of flight testing was conducted at Naval Air Warfare Center Aircraft Division Patuxent River, Maryland. Testing included mission-representative ground and flight maneuvers under normal operating conditions. Power Spectral Density (PSD) plots constructed from ground and flight events were the primary means of quantifying the vibration data from 0 to 1,000 Hz. Generally, on both the equipment shelf and the EGI box, vibration levels were highest in the vertical axis. Neither dynamic pressure nor Mach number had a significant effect on vibration levels. Instead, engine power, as determined by power lever position for a given set of flight conditions, was the most influential factor. The largest PSD peak responses occurred at the 4P frequency (four times the rotational speed of the propeller), approximately 73 Hz. The largest peak, recorded during a maximum power ground turn, had a magnitude of 0.25 g^2/Hz in the vertical axis, and corresponded to a G_{rms} value from 0 to 1,000 Hz of 1.42 g. This peak exceeded the published functional envelope to which the H-764 EGI had been qualified. Throughout the rest of the frequency spectrum for all ground and flight conditions tested, response peaks were within the existing H-764 functional envelope. From the data collected, functional and endurance profiles were constructed and forwarded to the EGI manufacturer, Honeywell, Inc. Honeywell conducted random vibration bench testing of the H-764 EGI, and subsequently determined it is operationally and structurally compatible with the vibratory environment at FS 505 in the C-2A airplane.

PREFACE

Previous to the test results discussed in this dissertation, empirical vibratory data at FS 505 in the C-2A airplane did not exist. Various engineering attempts to extrapolate vibration data to FS 505 resulted in significantly different profiles, including a profile that led to failures of multiple components internal to the H-764 EGI during bench-level qualification testing. Due to the major differences in the theoretical vibration profiles at FS 505 in the airplane, a conclusion could not be reached as to the compatibility of the H-764 EGI with the C-2A vibratory environment until empirical ground and flight data was collected.

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NOMENCLATURE

ADC	Analog-to-Digital Converter
CAINS	Carrier Aircraft Inertial Navigation System
CNS/ATM	Communication Navigation Surveillance/Air Traffic Management
COD	Carrier Onboard Delivery
dB	decibel
DSA	Dynamic Signal Acquisition
EGI	Embedded Global Positioning System/Inertial Navigation System
EMC	Electromagnetic Compatibility
FMS	Flight Management System
FS	Fuselage Station
f_s	sample frequency
gm	gram
hr	hour
Hz	Hertz
IAW	In Accordance With
in	inch
ISHP	Indicated Shaft Horsepower
g	gravitational acceleration constant, 32.174 ft/sec^2
KIAS	Knots Indicated Airspeed
mV	millivolt
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIRSYSCOM	Naval Air Systems Command
NAWCAD	Naval Air Warfare Center Aircraft Division
PC	Personal Computer
PFD	Primary Flight Display
PMA	Program Management Activity
PSD	Power Spectral Density
Rms	root mean square
Sec	second
SOFT	Safety of Flight Test
TECT	Test and Experimentation Coordination Team
USB	Universal Serial Bus

CHAPTER I
INTRODUCTION

Test Background

The C-2A Communication Navigation Surveillance (CNS)/Air Traffic Management (ATM) Program is a cockpit, avionics, and navigation upgrade to the current airplane configuration. Part of this upgrade includes removal of two AN/ASN-139 Carrier Aircraft Inertial Navigation Systems (CAINS II), and replacement with two Honeywell H-764 Embedded Global Positioning System /Inertial Navigation System (EGI) systems. The H-764 EGI is designed to provide attitude, heading, and navigation solutions to the Flight Management System (FMS) and cockpit primary flight displays, and will be mounted on the overhead equipment shelf at Fuselage Station (FS) 505 in the cabin of the C-2A airplane.

Laboratory vibration testing was necessary to ensure compatibility of the H-764 EGI with the C-2A vibratory environment. However, empirical vibratory data did not exist for that section of the airframe, and engineering attempts to extrapolate an accurate vibration profile to FS 505 were unsuccessful. As a result, the E-2/C-2 Flight Test Team at Navy Test and Evaluation Squadron TWO ZERO (VX-20) conducted ground and flight tests in November 2006 to collect mission-representative empirical vibration data. Ground and flight tests were funded by Naval Air Systems Command (NAVAIRSYSCOM), Program Management Activity (PMA) 209.

Test Purpose and Objectives

The purpose of this test was to conduct a vibration survey of FS 505 in the C-2A airplane during mission representative maneuvers for the following objectives:

(1) Documentation of an empirical vibration profile at FS 505.

(2) Development of functional and endurance vibration envelopes to be delivered to Honeywell, Inc. for H-764 EGI qualification testing.

(3) To assist in determining if the H-764 EGI is compatible in its current configuration with the C-2A vibration environment, and is satisfactory for the CNS/ATM system design.

Scope of Test

Because data from this test were critical in determining the design of the CNS/ATM integration into the C-2A airplane, a limited scope effort was perform in an attempt to preserve the existing install and test schedule. No data were collected during actual operational missions or maneuvers. Instead, mission-representative maneuvers were chosen to emulate flight conditions encountered in the C-2A during both shore-based and carrier-based operations. Test events and conditions were selected IAW the normal operating limits of the C-2A airplane, as delineated in the Naval Air Training and Operating Procedures Standardization (NATOPS)

Manual, reference 1. The ground and flight test events were documented and approved via Naval Air Warfare Center Aircraft Division (NAWCAD) test plans, references 2 and 3. Specific limitations to the scope of this test event are listed below:

(1) All flight regimes within the C-2A operating envelope were not tested. Emphasis on testing was placed on common operational profiles expected to produce the highest magnitude vibration levels on the airframe, including high-speed, high-q, and high-mach effect flight regimes.
(2) Vibration data was collected at FS 505, on the overhead equipment shelf and on the H-764 EGI box. A full aircraft vibration analysis was not conducted.

In total, 0.8 hr of ground tests and 3.6 hr of flight tests were conducted in the NAS Patuxent River operating areas under day/visual meteorological conditions. Appendix A contains the detailed list of all test configurations and test events performed. The test envelope is provided below in table 1.

Table 1: Test Envelope

Parameter	Actual Test Limit Reached	Test Plan Limit	Aircraft Limit
Airspeed	300 KIAS @ 5,000 ft MSL 270 KIAS @ 15,000 ft MSL 250 KIAS @ 20,000 ft MSL	0 to 310 KIAS	(1)
Altitude	21,000 ft Mean Sea Level (MSL)	0 to 21,000 ft MSL	None
Angle-of-Attack (AOA)	20 units AOA	23.5 units	(2)
Load Factor	2 g	+0.5 to +2.3 g	(3)
Horsepower	4,600 ISHP	4,600 ISHP (4)	4,600 ISHP (4)
Turbine Inlet Temp (TIT)	1,070° C	1,083° C (5)	1,083° C (5)

NOTES:

(1) Maximum (max) permissible airspeed is dependent on altitude, from approximately 206 KIAS at 30,000 ft MSL to approximately 343 KIAS at sea level (standard day conditions).
(2) Max allowable AOA is stall AOA.
(3) Max load factor is dependent on aircraft gross weight. Max positive load factor ranges from +2.7 g at aircraft gross weight of 38,000 lbs to +2.4 g at aircraft gross weight of 57,500 lbs. Max negative load factor is –1.0 g for all aircraft gross weights.
(4) 4,600 ISHP NATOPS time limit is 30 min. An overshoot of 4,800 ISHP is permitted for 3 sec.
(5) 1,049 °C NATOPS time limit is 30 min and 1,083 °C TIT NATOPS time limit is 5 min. An overshoot of 1,083 to 1,175 °C TIT is permitted for 5 sec.

CHAPTER II
EXPERIMENTAL SET-UP

Test Airplane

The C-2A Greyhound, shown in figure 1, is a dual-piloted, high-wing, all-weather twin-engine turboprop airplane manufactured by Northrop Grumman Corporation. The test airplane was BuNo 162177; the first C-2A selected for the CNS/ATM system upgrade. The primary mission of the C-2A is Carrier Onboard Delivery (COD), capable of delivering 10,000 pounds of combined payload over 1,000 nautical miles to air groups deployed on aircraft carriers. The C-2A has a minimum crew of three, consisting of a pilot, copilot, and carrier transport crew chief. A complete description of the airplane is provided in the NATOPS Flight Manual Navy Model C-2A, reference 1. The test airplane was considered production representative for the purposes of this test.

Modifications to the airplane for the purposes of this test included replacement of the No. 1 AN/ASN-139 CAINS II box with an H-764 EGI. The EGI was mounted on the overhead equipment shelf at FS 505; the exact location of the removed CAINS II box, where the EGI will be mounted for the CNS/ATM integration. The location of FS 505 in the C-2A airplane is shown in figure 2, and the overhead equipment shelf at FS 505 is shown in figure 3.

Test Items

H-764 Embedded GPS/INS

The H-764 EGI was designed by Honeywell, Inc. to meet evolving military requirements, including CNS/ATM upgrade programs that cover multiple platforms. Through the use of Digital Laser Gyro's, the EGI was designed to provide attitude, heading, turn rate, flight path vector, and slip/skid information. In the C-2A integration, this information is designed to be displayed on 6 in. (w) x 8 in. (h) primary flight displays (PFDs). Additionally, the H-764 EGI included functionality to calculate a triple navigation solution, including both GPS position-aided as well as pure inertial solutions. The EGI unit had the following dimensions: 7 in. (h) x 7 in. (w) x 9.8 in. (d). The approximate weight of the box was 18.5 lb. A complete description of the H-764 EGI is contained in reference 4, and the unit is shown in figure 4.

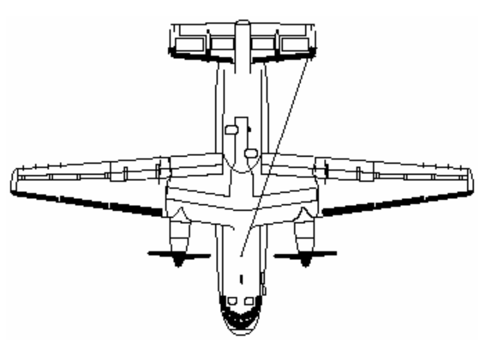

Figure 1: C-2A Airplane Plan View

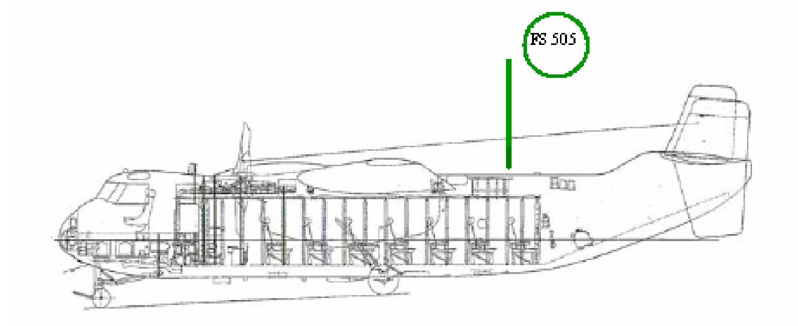

Figure 2: C-2A FS 505 Location

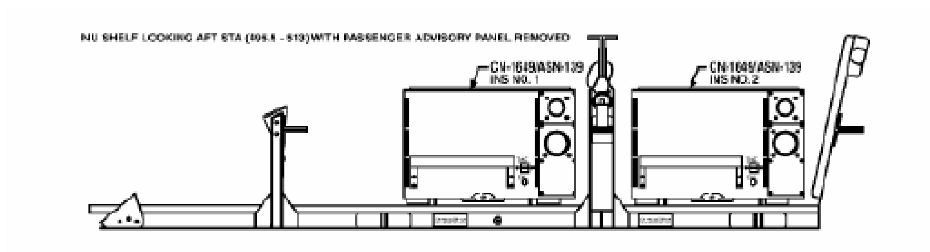

Figure 3: FS 505 Overhead Equipment Shelf

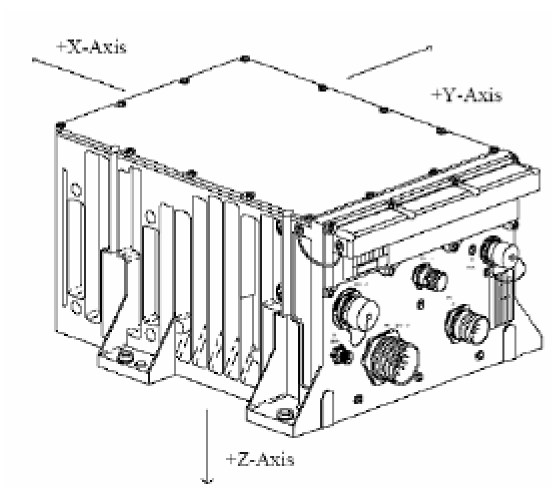

Figure 4: H-764 EGI

The objectives of this test did not require the H-764 EGI box to be functional. As such, the EGI was not powered, and was connected to the airplane only by the mounting hardware on the overhead equipment shelf described below.

Fuselage Station 505 Overhead Equipment Shelf

The H-764 EGI was mounted on the overhead equipment shelf at FS 505 in the cabin of the airplane, in the exact location as the removed No. 1 CAINS II box. An aluminum adapter plate was used to enable mounting of the EGI to the existing hardware on the equipment shelf. This adapter plate was designed specifically to enable mounting of the EGI to the existing CAINS II mount, and was identical to the plate that will be utilized for the CNS/ATM system modification. All cables that were normally plugged into the No. 1 CAINS box were unplugged, capped, and secured to the airplane.

Instrumentation Hardware

All instrumentation hardware was bought or leased through the Modal Shop, Inc. (Cincinnati, Ohio), and consisted of accelerometers, Dynamic Signal Acquisition (DSA) modules, a laptop personal computer (PC), and associated cables.

Triaxial Accelerometers

Two triaxial accelerometers were used to obtain acceleration data. The accelerometers were PCB model No. 356A15, high-sensitivity ceramic shear accels, housed in titanium and hermetically sealed. Laboratory calibration summaries for the test accelerometers are included in reference 5, and the accelerometer specifications are summarized in table 2.

Accelerometer ID No. 28367 was attached to the top of the EGI box as shown in figure 5. Accelerometer ID No. 28365 was attached to the underside of the FS 505 overhead equipment shelf, as shown in figure 6, and was attached closely to the supporting brackets and mounting bolts to reduce any affects of shelf modal responses that may have occurred.

Table 2: PCB Model No. 356A15 Accelerometer Specifications

Characteristic	Specification
Sensitivity (± 10%)	100 mV/G
Measurement Range	± 50 g pk
Frequency Range (± 5%)	2 to 5,000 Hz
Resonant Frequency	≥ 25 kHz
Broadband Resolution (up to 10 kHz)	0.0002 g rms
Size (H x L x W)	0.55 in x 0.80 in x 0.55 in
Weight	0.37 gm

Figure 5: Test Accelerometer ID No. 28367 Mounted to EGI Box

Figure 6: Test Accelerometer ID No. 28365 Mounted to Equipment Shelf

Dynamic Signal Acquisition Modules

Two National Instruments DSA modules, model No. NI Universal Serial Bus (USB)-9233, were used as the Analog-to-Digital Converter (ADC) interfaces between the accelerometers and the laptop PC. Four-conductor shielded cables, model No. 010G10, were used to connect the triaxial accels to the DSA modules, while the DSA modules were connected to the PC via a standard USB cable. Specifications of the DSA modules are listed in table 3.

Laptop Personal Computer

The laptop PC was a Sony VAIO PCG-GRT390Z, powered by a Li-ion rechargeable battery module also manufactured by Sony. Extra batteries were carried onboard during testing as power supply backups.

Instrumentation Software

The PC used SmartOffice DSA and Analysis Software, also supplied by the Modal Shop, Inc., to record and analyze DSA module data. The software was version V3.1 B2682 CD4.10.

Test Methods

Test Planning

Ground and flight test planning took place during October and November 2006, prior to conducting any ground or flight tests. The E-2/C-2 Flight Test Team of Navy Test and Evaluation Squadron TWO ZERO planned all test events to cover the majority of the operational envelope of the C-2A airplane. All planned events were reviewed and approved by the NAVAIR Loads and Dynamics Competency (AIR-4.3.3.3). Final authority for execution of all test events was granted by the VX-20 Test and Experimentation Coordination Team (TECT) in the form of NAWCAD Ground and Flight Test Plans, references 2 and 3, respectively. Approval to fly the C-2A in the test configuration was granted by a NAVAIR Interim Flight Clearance, reference 6.

Table 3: DSA Module Model No. NI USB-9233 Specifications

Characteristic	Specification
Number of Channels	4 analog input channels
ADC Resolution	24 bits
ADC Type	Delta-sigma (with analog pre-filtering)
Input Coupling	AC
Passband ($\leq$ 25kS/s)	0.45 x f_s
Stopband ($\leq$ 25kS/s)	0.58 x f_s (95 dB Attenuation)
Bus Interface	USB 2.0 high speed
Size (H x L x W)	5.55 in x 3.37 in x 0.99 in
Weight	275 gm (approximate)

Ground Test Techniques

Ground tests were conducted in accordance with reference 2, and consisted of data recording with the airplane parked and engines turning, under multiple power and flap configurations. Prior to testing, instrumentation checks were conducted to ensure proper operation, and the instrumentation PC time was synced with aircraft GPS time. In each flap configuration, test data were recorded for approximately 41 sec at each stabilized power setting. All ground tests and the conditions under which they were conducted are listed in table A-2. To conserve PC battery and to assist in identifying files for post-test analysis, data recording was stopped between events. The onboard Crew Chief manually controlled the recording operation of the instrumentation PC software. The beginning of each recorded time history file was time-tagged by the software, allowing for post-test identification.

Flight Test Techniques

Flight tests were conducted in accordance with reference 3, and consisted of both stabilized-point and maneuvering test events. Stabilized-point events included level flight and steady-g turns, during which airspeed, altitude, and power were held constant. Maneuvering test events included level accelerations, climbs, descents, turn reversals, and mission representative terminal operations. Prior to flight, in addition to the instrumentation checks and time-sync preparations mentioned above, an Electromagnetic Compatibility (EMC) Safety of Flight Test (SOFT) was performed to ensure the instrumentation set-up did not interfere with any on-board aircraft systems. For stabilized flight points, approximately 41 sec of test data were recorded. For the maneuvering test events, time history data was recorded for the entire length of the maneuver. All flight tests and the conditions under which they were conducted are listed in table A-3. Data recording was stopped between events by the Crew Chief in the same manner described above for the ground test events.

CHAPTER III
TEST THEORY AND METHODS

Data Collection

The primary data collection objective was to record three-axis time history acceleration data on both the FS 505 equipment shelf and on the H-764 EGI box. Ultimately, the frequency responses of the shelf and the EGI box from 1 to 1,000 Hz during ground and flight operations were desired to enable bench-level qualification testing of the EGI. To achieve this objective, the PCB accelerometers were mounted to both the equipment shelf and the EGI box, as described above.

During testing, analog vibration data sensed by the accelerometers were transmitted to two DSA modules via 10 ft. four-conductor shielded cables. The DSA modules provided the analog-to-digital conversion of the acceleration signals as well as the USB interface required for the laptop PC. The sample rate of the DSA modules was set to 5,000 samples/sec via the SmartOffice DSA and Analysis Software on the PC. This relatively high sample rate (5X the highest desired frequency response data of 1,000 Hz) was well within the specifications of the DSA, and ensured negligible distortion of the original signal.

The DSAs were connected to the laptop PC via standard USB cables. These cables enabled data transfer to the PC, as well as a means to provide power to the DSAs from the PC. The sampled time histories were stored on the laptop hard drive as .sot extension (SOT), time-tagged data files. Between test events, the recording operation of the software was turned on/off by the onboard crew chief.

Data Reduction

All data reduction was conducted post-test on the instrumentation PC laptop utilizing the SmartOffice Software. Vibration time history files were identified by their time-tags, and then labeled according to the test event title. Each recorded test event resulted in six separate time history plots: longitudinal, lateral, and vertical acceleration traces for the equipment shelf, and longitudinal, lateral, and vertical acceleration traces for the EGI box. For stabilized point events, defined as tests that resulted in relatively constant vibration levels throughout, the entire time histories were used for spectral analysis. However, for events that resulted in continuously changing vibration levels (level accelerations, climbs, descents, turn reversals, field landing patterns, and waveoffs), the time histories were segmented in order to perform accurate spectral analysis. An example of the steps followed for this technique is provided for the 5,000 ft MSL max power level acceleration:

(1) The point on the time history plot corresponding to 150 KIAS was identified.

(2) A 10-sec (approximately) window around that point was extracted as its own time history data file.

(3) Spectral analysis was done on this 10-sec time history.

(4) The resulting Power Spectral Density (PSD) plot represented the spectral composition at FS 505 at 5,000 ft MSL, 150 KIAS, maximum Indicated Shaft Horsepower (ISHP).

(5) Steps (1) through (4) were repeated in 25 kt intervals for the level acceleration event, out to 300 KIAS, resulting in PSD plots at airspeeds of 150 KIAS, 175 KIAS, 200 KIAS, 225 KIAS, 250 KIAS, 275 KIAS, and 300 KIAS.

For climbs and descents, the same data reduction technique was used, except vibration time histories were segmented in intervals of altitude instead of indicated airspeed.

To determine the spectral composition in all three axes from each test event time history file, PSD plots were generated from the recorded data. The same SmartOffice Software was used to generate the PSD plots using the Hanning Window technique with linear averaging and a 50% block overlap. The PSD plots were also saved in SOT format. Finally, the SmartOffice Software was used to calculate G_{rms} values from 0 to 1,000 Hz for every PSD plot that was generated.

Data Analysis

Six separate time history plots were constructed for each event: X-, Y-, and Z-axis vibration time histories recorded from the accelerometer mounted to the EGI box, and X-, Y-, and Z-axis vibration time histories recorded from the accelerometer mounted on the overhead equipment shelf at FS 505. Figure 1 of appendix D presents the airplane and accelerometer reference axes used throughout this thesis. The PSD plots generated from these time histories include six separate traces on each plot, representing the PSDs calculated in all three axes on both the EGI box and the equipment shelf. Sample time histories and PSD plots are provided in figures B-1 and B-2, respectively. The PSD plots also include calculated G_{rms} values from 0 to 1,000 Hz, although these values were used as reference only, and were not for any test result or conclusion determination. In total, 127 plots (50 time history and 77 PSD) were generated, and are included in reference 5. A list of all plots is included in appendix C.

The PSD plots were analyzed to determine the highest magnitude response peaks from 0 to 1,000 Hz. Each resulting response peak had a bandwidth of approximately 15 to 20 Hz. Table 4 summarizes the events which resulted in the highest magnitude response peaks.

Using the maximum response peak values listed in table 4, a recommended functional qualification envelope was constructed. This functional qualification envelope was multiplied by a factor of 4.6 across the frequency spectrum to produce a recommended endurance qualification envelope. Figure 7 presents the maximum response peaks in graphical format, with the recommended functional and recommended endurance qualification envelopes included.

Table 4: Summary of Highest Magnitude Response Peaks at FS 505

Frequency		Peak Magnitude Response (g^2/Hz)	Event Description
Primary Multiple	Hz		
1P	18.3	5.0E-04	GR(0) Ground Turn, 3,000 ISHP
2P	36.6	6.0E-03	MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 150 KIAS
4P	73.2	2.5E-01	GR(0) Ground Turn, 4,000 ISHP
6P	109.8	1.4E-03	MAX Power Level Acceleration, 15,000 ft MSL, CR(0) – 150 KIAS
8P	146.4	8.0E-03	MAX TIT Level Acceleration, 20,000 ft MSL, CR(0) – 175 KIAS
10P	183	6.0E-04	Max Power Bingo Climb, 5,000 ft MSL, CR(0) – 160 KIAS
12P	219.6	2.0E-03	Level Flight, 5,000 ft MSL, CR(0) – 300 KIAS
16P	292.8	1.2E-03	MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 250 KIAS
20P	366	7.0E-04	GR(20) Ground Turn, 3,000 ISHP
24P	439.2	7.0E-04	GR(0) Ground Turn, 4,000 ISHP
28P	512.4	1.0E-03	MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 300 KIAS
30P	549	2.0E-03	Lat Yoke ½ Step L Turn Rev, 15,000 ft MSL, CR(0) – 220 KIAS
32P	585.6	1.5E-03	MAX TIT Level Acceleration, 20,000 ft MSL, CR(0) – 225 KIAS
36P	658.8	1.0E-03	Level Flight, 15,000 ft MSL, CR(0) – 270 KIAS
40P	732	5.5E-04	2 g Sustained Right Turn, 5,000 ft MSL, CR(0) – 260 KIAS
44P	805.2	7.0E-04	MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 300 KIAS
48P	878.4	6.0E-04	MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 300 KIAS
50P	915	4.6E-04	Level Flight, 5,000 ft MSL, CR(0) – 300 KIAS

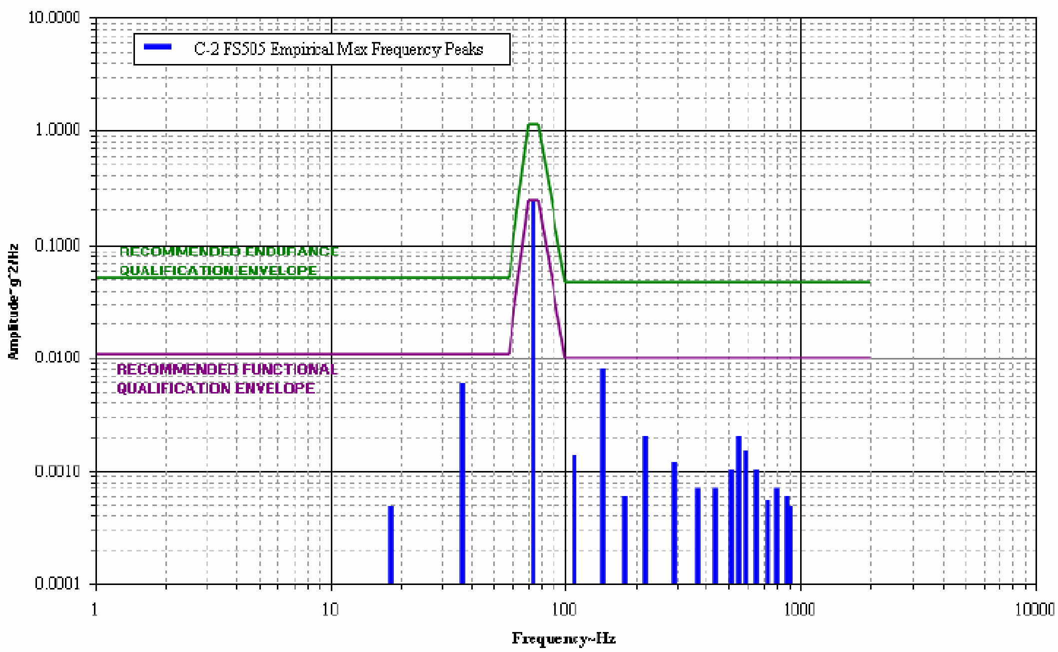

Figure 7: Recommended Functional and Endurance Qualification Envelopes with Maximum Response Peaks Measured at FS 505 in the C-2A Airplane

CHAPTER IV
TEST RESULTS AND DISCUSSION

Ground and Flight Test Results

Within the scope of this test, the effects of q and Mach number on measured vibration levels at FS 505 were negligible. Additionally, changes in aircraft landing gear and flap configuration did not show any noticeable affects. The primary influence on vibration levels was engine power, set by power lever position for a given set of flight conditions. As expected, the highest magnitude peak responses were observed at the 4P frequency of approximately 73 Hz. This 4P frequency is defined as four times the primary frequency, or four times the rotational speed of the propeller. The largest 4P response observed had a magnitude of 0.25 g^2/Hz, and occurred during a ground turn in configuration GR(0) with 4,000 ISHP set per engine. This maximum peak, recorded in the Z-axis by the accelerometer mounted to the overhead equipment shelf, had a G_{rms} value of 1.42 g from 0 to 1,000 Hz. Multiple other ground and flight conditions experienced during various test events produced 4P peak response magnitudes around 0.1 g^2/Hz. Other than at the 4P frequency, response peak magnitudes throughout the rest of the frequency spectrum were within the functional envelope to which the H-764 EGI had already been qualified.

As a general trend for both the equipment shelf and EGI box, measured acceleration levels in the Z-axis were higher than the levels measured in the X- and Y-axis. In the Z-axis for a given test event, vibration levels were nearly equal when comparing EGI box accelerometer measurements to equipment shelf accelerometer measurements. However, X- and Y-axis vibration levels were generally higher on the EGI box in comparison to the equipment shelf. This was likely due to the mounting placement of the accelerometer on the EGI box. It was mounted on the upper corner of the box, where the moment arm measured from the EGI mounting bolts was longest. This placement was chosen purposely to product worst-case vibration measurements on the box.

Up to 1,000 Hz, peak vibration levels fell within the vibration envelope to which the H-764 EGI had already been qualified, with the exception of the frequency response peak at 73 Hz (4P). At the 4P frequency of 73 Hz, the largest empirical peak recorded had a vibration level of 0.25 g^2/Hz, exceeding the functional envelope of the H-764 EGI by 0.20 g^2/Hz (500%). Figure 8 summarizes these results in graphical format.

Figure 7 above presented the recommended functional and endurance envelopes to which the H-764 box should be qualified for use in the C-2A airplane. Figure 9 below shows these recommended envelopes in comparison to the existing envelopes for the box. At 73 Hz, the recommended functional envelope exceeds the current EGI functional envelope by 0.20 g^2/Hz, (500%), and the recommended endurance profile exceeds the current EGI endurance envelope by 1.1 g^2/Hz (2,750%).

Test Results Comparison to Predicted Results

Prior to this research, empirical vibratory data did not exist near the FS 505 overhead equipment shelf, the planned mounting location for the EGIs. As such, NAVAIRSYCOM attempted to use engineering techniques to extrapolate and characterize the spectral

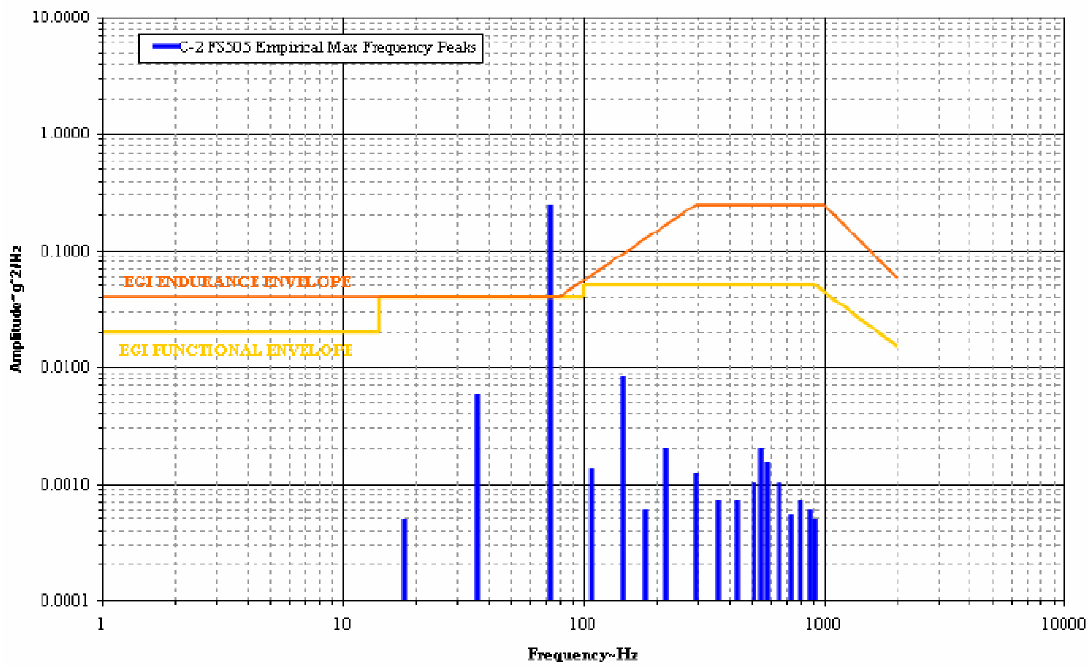

Figure 8: Existing Functional and Endurance Qualification Envelopes with Maximum Response Peaks Measured at FS 505 in the C-2A Airplane

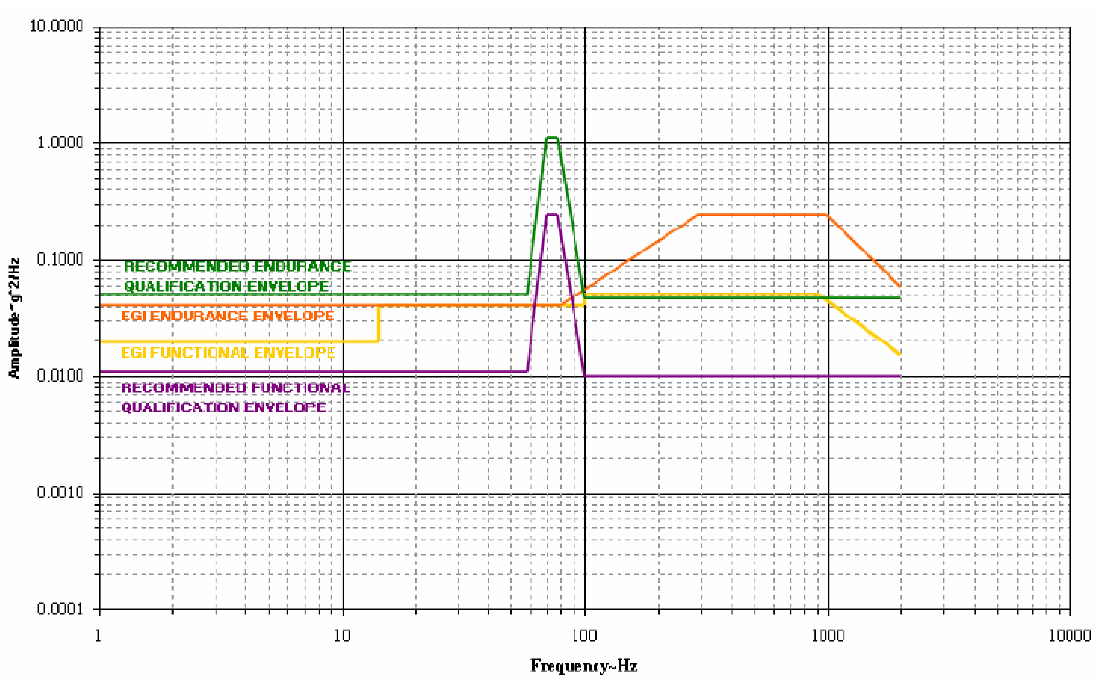

Figure 9: Comparison of Recommended and Existing Functional and Endurance Qualification Envelopes for the H-764 EGI Box

composition and vibratory environment in this section of the airplane. Their predictions are presented in figure 10. These profiles were forwarded to Honeywell, Inc. and were used for random vibration bench testing of the H-764 EGI, resulting in multiple internal component failures of the EGI. In comparison to the empirical results shown above in figure 8, the engineering estimates included large response peaks between 100 Hz and 600 Hz that were not observed during any actual ground or flight events.

H-764 Embedded GPS/INS Lab Qualification Results

In April 2007, Honeywell again conducted random vibration bench testing on all three axes of the EGI, this time using the data presented in this thesis. With the EGI in navigation mode, the system was subjected to thirty minutes at the functional vibration level, followed by sixty minutes of vibration at the endurance level. After one hour of system performance navigation functional tests, the system was subjected to another thirty minutes of vibration at the functional level. Finally, the test sequence concluded with one hour of static navigation performance tests to verify health of the unit, in addition to a visual inspection of EGI components to verify no external or internal structural failures. A complete summary of the random vibration lab qualification test sequence and test results is contained in reference 7.

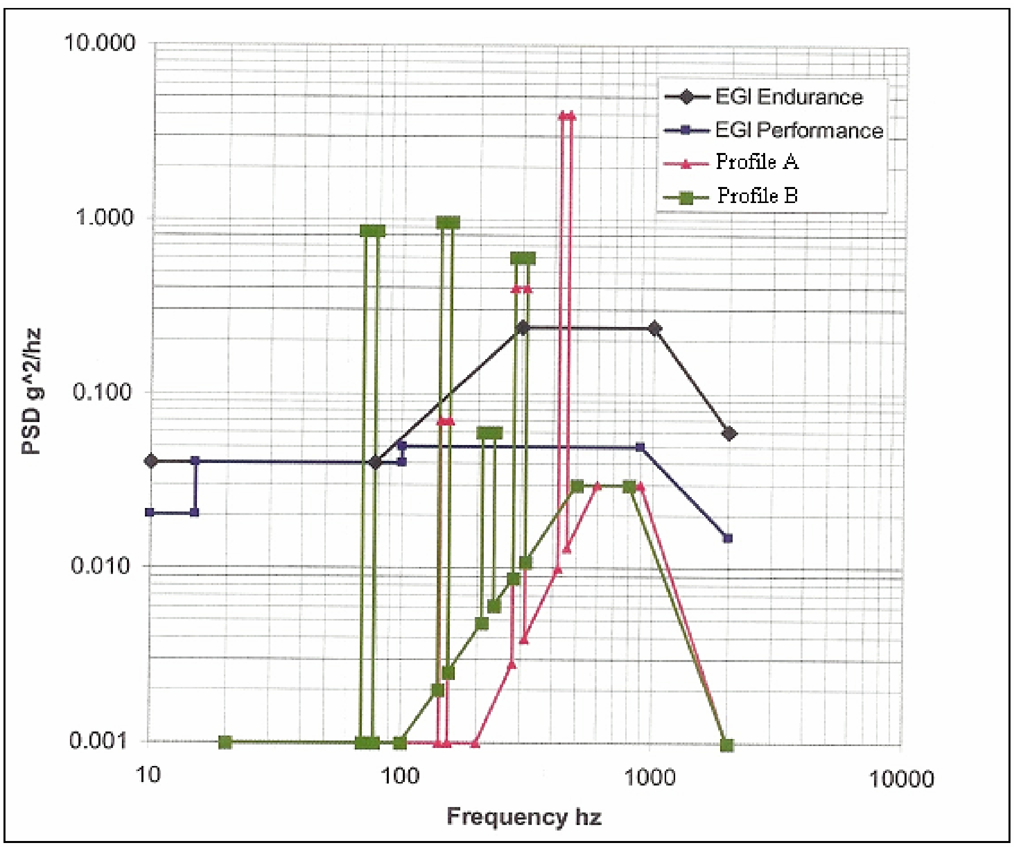

Figure 10: NAVAIR Predicted Response Peaks at FS 505 in the C-2A Airplane

CHAPTER V
CONCLUSIONS

All planned ground and flight testing was conducted in accordance with the events outlined in the approved test plans. The tests encompassed the flight conditions under which the C-2A normally operates during both carrier- and shore-based operations. The random vibration environment at FS 505 in the C-2A airplane, as collected by the accelerometers mounted to the H-764 EGI and to the overhead equipment shelf, was quantified using spectral analysis. The resulting PSD plots showed that the dominant factor affecting vibration levels in this section of the airplane was engine power setting, both on the ground and airborne. Aircraft configuration, q-effect, and Mach-effect had negligible impact on the vibration levels. In general, the largest accelerations were recorded in the vertical axis of the airplane.

The spectral analysis showed that the highest magnitude response peaks occurred at the 4P frequency of 73 Hz, and at this frequency, the highest recorded peak exceeded the existing functional envelope of the H-764 EGI by 0.20 g^2/Hz (500%). Throughout the rest of the frequency spectrum up to 1,000 Hz, response peaks were within the functional envelope of the EGI box.

From the empirical data, recommended functional and endurance envelopes were generated and forwarded to Honeywell, Inc. as the proposed criteria for qualification of the H-764 EGI for use in the C-2A airplane. Random vibration bench testing determined that the H-764 EGI is operationally and structurally compatible with the vibratory environment at FS 505 in the C-2A airplane.

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APPENDICES

APPENDIX A
TEST CONFIGURATIONS AND DETAILED TEST EVENTS

Table A-1: Test Configurations

Configuration	Trailing Edge Flap Position (deg)	Landing Gear Position	Power
Cruise – CR(0)	0	UP	PLF or PAR(1)
CR(10)	10	UP	PLF or PAR
CR(20)	20	UP	PLF or PAR
CR(30)	30	UP	PLF or PAR
Power Approach – PA(0)	0	DOWN	PLF or PGS(2)
PA(10)	10	DOWN	PLF or PGS
PA(20)	20	DOWN	PLF or PGS
PA(30)	30	DOWN	PLF or PGS
Takeoff – TO(0)	0	DOWN	MAX(3)
TO(10)	10	DOWN	MAX
TO(20)	20	DOWN	MAX
Waveoff – WO(20)	20	DOWN	MAX
WO(30)	30	DOWN	MAX

NOTES:

(1) PLF – Power for Level Flight; PAR – Power as Required

(2) PGS – Power for Glide Slope

(3) MAX – NATOPS Maximum Rated Power is defined as 4,600 ISHP or 1083° C TIT, whichever is reached first.

Table A-2: Detailed Ground Test Events

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft AGL)	Engine Power Setting (ISHP) left/right	Data[1]	Remarks/Limits
1	Instrumentation Checks	GR(0)	N/A	On Deck	GRD IDLE/ GRD IDLE	Ensured connectivity and data recording functionality of instrumentation	Test File was recorded and verified by onboard Carrier Transport Crew Chief
1.A	Data Recording Synchronization	GR(0)	N/A	On Deck	GRD IDLE/ GRD IDLE	Laptop time synched with GPS time on aircraft Control Display Navigation Unit (CDNU)	Time synchronization was verified periodically throughout testing
2.A	Vibration Analysis	GR(0)	N/A	On Deck	GRD IDLE/ GRD IDLE	HP: 450 / 450 ISHP TIT: 590 / 605° C	Note 3. Figure 1
2.B	Vibration Analysis	GR(0)	N/A	On Deck	FLT IDLE/ FLT IDLE	HP: 850 / 975 ISHP TIT: 620 / 650° C	Note 3. Figure 3
2.C	Vibration Analysis	GR(0)	N/A	On Deck	2,000/2,000	HP: 2,000 / 2,000 ISHP TIT: 750 / 775° C	Note 3. Figure 5
2.D	Vibration Analysis	GR(0)	N/A	On Deck	3,000/3,000	HP: 3,000 / 3,000 ISHP TIT: 860 / 870° C	Note 3. Figure 7
2.E	Vibration Analysis	GR(0)	N/A	On Deck	4,000/4,000	HP: 4,000 / 4,000 ISHP TIT: 960 / 990° C	Note 3. Figure 9
2.F	Vibration Analysis	GR(0)	N/A	On Deck	MAX/MAX	HP: 4,500 / 4,500 ISHP TIT: 1015 / 1035° C	Note 3. Figure 11
3.A	Vibration Analysis	GR(20)	N/A	On Deck	GRD IDLE/ GRD IDLE	HP: 500 / 450 ISHP TIT: 600 / 610° C	Note 3. Figure 13
3.B	Vibration Analysis	GR(20)	N/A	On Deck	FLT IDLE/ FLT IDLE	HP: 850 / 950 ISHP TIT: 620 / 650° C	Note 3. Figure 15
3.C	Vibration Analysis	GR(20)	N/A	On Deck	2,000/2,000	HP: 2,000 / 2,000 ISHP TIT: 755 / 775° C	Note 3. Figure 17
3.D	Vibration Analysis	GR(20)	N/A	On Deck	3,000/3,000	HP: 3,000 / 3,000 ISHP TIT: 855 / 885° C	Note 3. Figure 19
3.E	Vibration Analysis	GR(20)	N/A	On Deck	4,000/4,000	HP: 4,000 / 4,000 ISHP TIT: 965 / 995° C	Note 3. Figure 21
3.F	Vibration Analysis	GR(20)	N/A	On Deck	MAX/MAX	HP: 4,500 / 4,500 ISHP TIT: 1010 / 1040° C	Note 3. Figure 23

Table A-2: Detailed Ground Test Events, Continued

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft AGL)	Engine Power Setting (ISHP) left/right	Data[1]	Remarks/Limits
4.A	Vibration Analysis	GR(30)	N/A	On Deck	GRD IDLE/ GRD IDLE	HP: 475 / 450 ISHP TIT: 600 / 610° C	Note 3. Figure 25
4.B	Vibration Analysis	GR(30)	N/A	On Deck	FLT IDLE/ FLT IDLE	HP: 850 / 950 ISHP TIT: 620 / 650° C	Note 3. Figure 27
4.C	Vibration Analysis	GR(30)	N/A	On Deck	2,000/2,000	HP: 2,000 / 2,000 ISHP TIT: 755 / 775° C	Note 3. Figure 29
4.D	Vibration Analysis	GR(30)	N/A	On Deck	3,000/3,000	HP: 3,000 / 3,000 ISHP TIT: 860 / 885° C	Note 3. Figure 31
4.E	Vibration Analysis	GR(30)	N/A	On Deck	4,000/4,000	HP: 4,000 / 4,000 ISHP TIT: 965 / 990° C	Note 3. Figure 33
4.F	Vibration Analysis	GR(30)	N/A	On Deck	MAX/MAX	HP: 4,500 / 4,500 ISHP TIT: 1020 / 1045° C	Note 3. Figure 35

Notes: (1) All ground events were recorded under the following conditions:
Outside Air Temperature (OAT): 55° F
Power Approach (PA): -75 ft
Winds: 350° @ 5 to 10 kts
Aircraft Heading: 359°
(2) Figure numbers refer to table C-1.
(3) Approximately 41 seconds of data was recorded once power on each engine was stabilized at the desired power setting.

Table A-3: Detailed Flight Test Events

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft MSL)	Engine Power Setting (ISHP) left/right	Data	Remarks/Limits
1.1	Electromagnetic Capability (EMC) Safety of Flight Test (SOFT)	GR(0)	N/A	On Deck	GI	IAW EMC SOFT Checklist	All aircraft systems functioned properly with instrumentation PC powered and recording.
1.2	Instrumentation Checks	GR(0)	N/A	On Deck	GI	Ensure connectivity and data recording functionality of instrumentation	Verified a vibration data file was recorded and saved.
1.3	Data Recording Synchronization	GR(0)	N/A	On Deck	GI	PC laptop time synced to CDNU GPS time	None
2.1	MAX Power Takeoff	TO(10) to CR(0)	0 to 250	0 to 500	MAX/MAX	OAT: 54F TIT: 1010/1015 ISHP: 4400/4450 Data start time: 20:24:03 Brake release: 20:24:30 250 KIAS time: 20:25:32 Runway (RWY) 06, winds calm Fuel: 6.0/6.15	None
2.2	MAX Power Level Acceleration	CR(0)	150 to 300	5,000	MAX/MAX	OAT: 10 C @ 150 KIAS, 16 C @ 300 KIAS TIT: 1040/1040 ISHP: 4300/4350 @ 150 KIAS 4500/4500 @ 300 KIAS Data start time: 20:30:33 Data stop time: 20:32:55 Fuel: 5.8/5.9	GPS time was noted at 150, 175, 200, 225, 250, 275, and 300 KIAS for post-flight data analysis. At 300 KIAS, 41 sec of stabilized flight data was recorded to satisfy event #2.8a, 300 KIAS level flight point.

Table A-3: Detailed Flight Test Events, Continued

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft MSL)	Engine Power Setting (ISHP) left/right	Data	Remarks/Limits
2.3	Engine Sulfidation Power Climb	CR(0)	160 ± 5	5,000 to 15,000	950 deg C TIT	OAT: 10 C @ 160 KIAS, 5,000 ft 1 C @ 160 KIAS, 15,000 ft TIT: 950/950 Data start time: 19:00:41 Data stop time: 19:07:10 Fuel: 5.7/5.7	GPS time was noted at 5,000, 7,000, 9,000, 11,000, 13,000, and 15,000 ft MSL for post-flight data analysis.
2.4	MAX Power Level Acceleration	CR(0)	150 to 270	15,000	MAX/MAX	OAT: 0 C @ 150 KIAS, 4 C @ 270 KIAS TIT: 1080/1070 Data start time: 19:11:37 Data stop time: 19:17:10 Fuel: 5.3/5.4	GPS time was noted at 150, 175, 200, 225, 250, and 270 KIAS for post-flight data analysis. At 270 KIAS, 41 sec of stabilized flight data was recorded to satisfy event #2.5a, 270 KIAS level flight point.
2.5a	Level Flight	CR(0)	180 220 270	15,000	PLF/PLF	OAT: 1 C @ 180 KIAS, 4 C @ 270 KIAS 180 KIAS TIT: 760/780 HP: 1650/1650 220 KIAS TIT: 875/890 HP: 2400/2400 270 KIAS TIT: 1075/1075 HP: 4000/3850 Fuel: 5.3/5.4	Approx 41 sec of data recorded with airplane stabilized in level flight at 180, 220, and 270 KIAS

Table A-3: Detailed Flight Test Events, Continued

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft MSL)	Engine Power Setting (ISHP) left/right	Data	Remarks/Limits
2.5b	Level Flight	CR(10)	150 180	15,000	PLF/PLF	OAT: -1 C @ 150 KIAS, 0 C @ 180 KIAS 150 KIAS TIT: 675/685 HP: 1000/1000 180 KIAS TIT: 810/825 HP: 1900/1900 Fuel: 4.85/5.1	Approx 41 sec of data recorded with airplane stabilized in level flight at 150 and 180 KIAS
2.5c	Level Flight	PA(20)	110 150	15,000	PLF/PLF	OAT: -1 C @ 110 KIAS, -1 C @ 150 KIAS 110 KIAS TIT: 755/785 HP: 1550/1550 150 KIAS TIT: 910/930 HP: 2500/2500 Fuel: 4.8/4.8	Approx 41 sec of data recorded with airplane stabilized in level flight at 110 and 150 KIAS
2.6	Turn Reversals	CR(0)	225 ±5	15,000	PLF	OAT: 3 C TIT: 940/950 Fuel: 4.7/4.8	For 30 deg bank to bank event, GPS time was noted at left yoke input, 30 deg left AOB, right yoke input, and 30 deg right AOB. For reversal series, 6 turn reversals were recorded in approx 55 sec.

Table A-3: Detailed Flight Test Events, Continued

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft MSL)	Engine Power Setting (ISHP) left/right	Data	Remarks/Limits
2.7	Power Descent	CR(0)	250	15,000 to 7,000	As Req'd	OAT: 5 C @ 15,000 ft MSL, 11 C @ 7,000 ft MSL TIT: 755/775 ISHP: 1750/1750 Data start time: 20:00:11 Data stop time: 20:07:05 Fuel: 4.6/4.7	GPS time was noted at 15,000, 13,000, 11,000, 9,000, and 7,000 ft MSL for post-flight data analysis.
2.8a	Level Flight	CR(0)	180 220 270 300	5,000	PLF/PLF	OAT: 10 C @ 180 KIAS, 15 C @ 300 KIAS 180 KIAS TIT: 715/720 HP: 1550/1500 220 KIAS TIT: 770/780 HP: 2100/2100 270 KIAS TIT: 955/965 HP: 3850/3850 300 KIAS TIT: 1030/1030 HP: 4500/4500 Fuel: 5.75/5.85	Approx 41 sec of data recorded with airplane stabilized in level flight at 180, 220, 270, and 300 KIAS

Table A-3: Detailed Flight Test Events, Continued

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft MSL)	Engine Power Setting (ISHP) left/right	Data	Remarks/Limits
2.8b	Level Flight	CR(10)	150 170 180	5,000	PLF/PLF	OAT: 10 C @ 150 KIAS, 11 C @ 180 KIAS 150 KIAS TIT: 660/685 HP: 1100/1100 170 KIAS TIT: 700/720 HP: 1400/1400 180 KIAS TIT: 740/755 HP: 1700/1700 Fuel: 5.55/5.65	Approx 41 sec of data recorded with airplane stabilized in level flight at 150, 170, and 180 KIAS
2.8c	Level Flight	PA(20)	108 150	5,000	PLF/PLF	OAT: 10 C @ 108 and 150 KIAS 108 KIAS TIT: 715/730 HP: 1500/1450 150 KIAS TIT: 770/790 HP: 2000/2000 Fuel: 5.3/5.45	Approx 41 sec of data recorded with airplane stabilized in level flight at 108, and 150 KIAS

Table A-3: Detailed Flight Test Events, Continued

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft MSL)	Engine Power Setting (ISHP) left/right	Data	Remarks/Limits
2.9	MAX Power Climb	CR(0)	Bingo Profile[1]	5,000 to 20,000	MAX/MAX	OAT: 11C @ 5,000ft and 150 KIAS -11C @ 20,000ft and 145 KIAS 150 KIAS @ 5,000 ft TIT: 1060/1075 HP: 4450/4350 145 KIAS @ 20,000 ft TIT: 1065/1065 HP: 3100/3000 Fuel Start: 4.4/4.5 Fuel Stop: 4.2/4.2	GPS time was noted at 5,000, 7,000, 9,000, 11,000, 13,000, 15,000, 17,000, 19,000, and 20,000 ft MSL for post-flight data analysis.
2.10	MAX Power Level Acceleration	CR(0)	140 to 250	20,000	MAX/MAX	OAT: -10 C @ 140 KIAS, -5 C @ 250 KIAS TIT: 1075/1070 Data start time: 20:25:53 Data stop time: 20:29:04 Fuel: 4.15/4.25	GPS time was noted at 140, 160, 175, 200, 225, and 250 KIAS for post-flight data analysis. At 250 KIAS, 41 sec of stabilized flight data was recorded to satisfy even.
2.11	FLT IDLE Descent	CR(0)	245 to 255	20,000 to 8,000	FLT IDLE/ FLT IDLE	OAT: -5C @ 20,000ft and 250 KIAS 11C @ 8,000ft and 250 KIAS 250 KIAS @ 20,000 ft TIT: 525/525 HP: 300/300 250 KIAS @ 8,000 ft TIT: 530/540 HP: 180/180 Fuel: 3.9/3.75	GPS time was noted at 20,000, 18,000, 16,000, 14,000, 12,000, 10,000, and 8,000 ft MSL for post-flight data analysis. The descent was planned from 20,000 ft to 5,000 ft. However, the descent was knocked off at 8,000 ft for a cloud deck.

Table A-3: Detailed Flight Test Events, Continued

Evt	Description	A/C Config	Airspeed (KIAS)	Alt (ft MSL)	Engine Power Setting (ISHP) left/right	Data	Remarks/Limits
2.12	2 g Level Turns	CR(0)	245 to 260	5,000	MAX/MAX	TIT: 1050/1050 C ISHP: 4500/4500 OAT: 15C Fuel: 5.25/5.3	None
2.13	Normal Field Entry	CR(0)	~250	3,500 to 1,000	As Req'd	RWY: 06 (KNHK) Winds: Calm Fuel: 4.8/4.9	None
2.14	Overhead VFR Break	CR(0) to PA(20)	250 to 20 units	1,000	FLT IDLE/ FLT IDLE	Data start time: 21:17:08 Break: 21:17:25 Data off: 21:18:00 Fuel: 4.8/4.9	Left Break performed at 1,000 ft, KNHK
2.15	Normal VFR Landing Patterns	PA(10), PA(20) PA (30)	As Req'd	1,000 to on deck	As Req'd	RWY 06 (KNHK) Winds Calm	For all flap configurations, data was recorded from downwind until after the touch-and-go on upwind.
2.16	VFR Pattern Waveoff	PA(10), PA(20) PA (30)	20 units to 170	10 to 1,000	MAX/MAX	RWY 06 (KNHK) Winds Calm	For all flap configurations, data was recorded from final until after the waveoff on upwind.
2.17	Full Stop Landing	PA(20)	As Req'd	1,000 to on deck	As Req'd	RWY 06 (KNHK) Fuel: 4.25/4.4 Winds 310@04	Data was recorded from final until clear of runway following full stop.

Notes: (1) Bingo profile climb schedule: 165 KCAS at sea level minus 1 kt per 1,000 ft above sea level.

APPENDIX B
SAMPLE TIME HISTORY AND POWER SPECTRAL DENSITY (PSD) PLOTS

C-2A EGI FLIGHT VIBRATION ANALYSIS
5,000 ft Level Flight, 220 KIAS, PLF
BuNo: 162177

Source: Flight Test
Configuration: CR(0)
Method: Stabilized Point

Fuel Load: 5,750 lbs Left / 5,850 lbs Right
Power Setting: 2100/2100 ISHP
Gross Weight: 48,900 lbs

OAT: 10°C
Hp: 5,000 ft

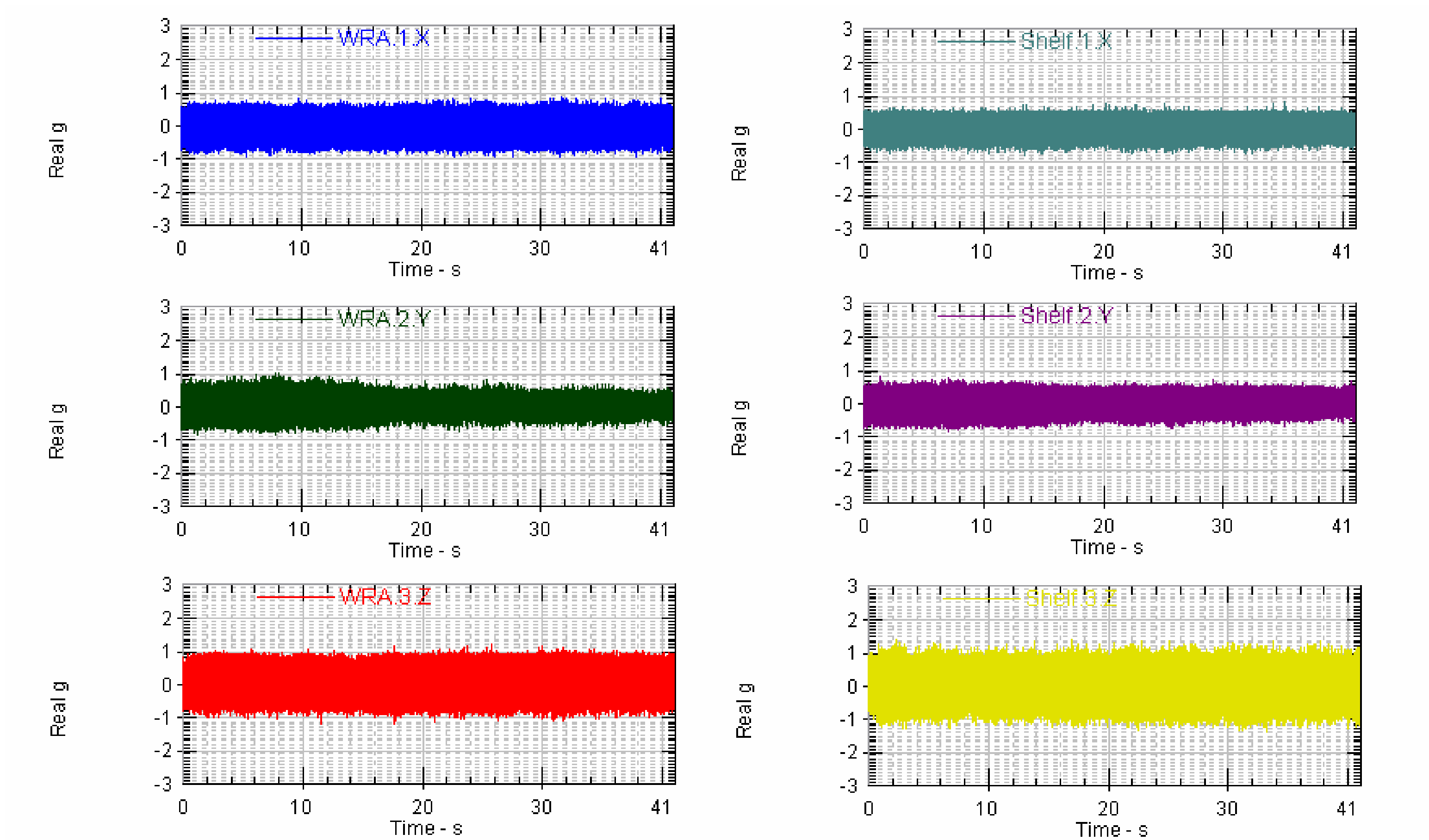

Figure B-1: Sample EGI and Equipment Shelf Vibration Time History Plots

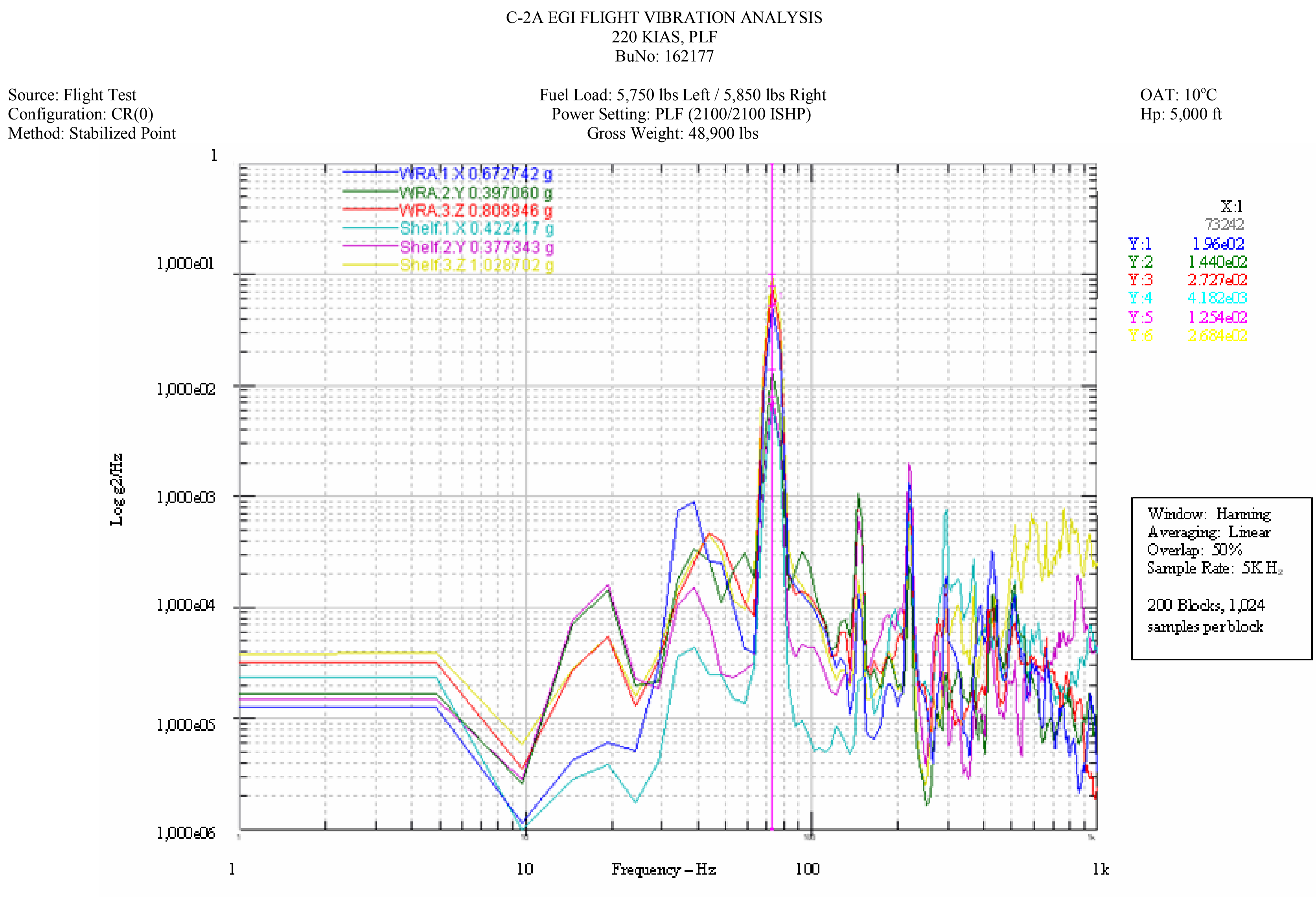

Figure B-2: Sample EGI and Equipment Shelf Vibration PSD Plots

APPENDIX C
LIST OF FIGURES FOR TEST TIME HISTORY AND PSD PLOTS

Table C-1: Time History and PSD List of Figures

Figure	Test Point Description
1	Time History, GR(0) Ground Turn, Ground Idle
2	PSD, GR(0) Ground Turn, Ground Idle
3	Time History, GR(0) Ground Turn, Flight Idle
4	PSD, GR(0) Ground Turn, Flight Idle
5	Time History, GR(0) Ground Turn, 2,000 ISHP
6	PSD, GR(0) Ground Turn, 2,000 ISHP
7	Time History, GR(0) Ground Turn, 3,000 ISHP
8	PSD, GR(0) Ground Turn, 3,000 ISHP
9	Time History, GR(0) Ground Turn, 4,000 ISHP
10	PSD, GR(0) Ground Turn, 4,000 ISHP
11	Time History, GR(0) Ground Turn, 4,500 ISHP (MAX)
12	PSD, GR(0) Ground Turn, 4,500 ISHP (MAX)
13	Time History, GR(20) Ground Turn, Ground Idle
14	PSD, GR(20) Ground Turn, Ground Idle
15	Time History, GR(20) Ground Turn, Flight Idle
16	PSD, GR(20) Ground Turn, Flight Idle
17	Time History, GR(20) Ground Turn, 2,000 ISHP
18	PSD, GR(20) Ground Turn, 2,000 ISHP
19	Time History, GR(20) Ground Turn, 3,000 ISHP
20	PSD, GR(20) Ground Turn, 3,000 ISHP
21	Time History, GR(20) Ground Turn, 4,000 ISHP
22	PSD, GR(20) Ground Turn, 4,000 ISHP
23	Time History, GR(20) Ground Turn, 4,500 ISHP (MAX)
24	PSD, GR(20) Ground Turn, 4,500 ISHP (MAX)
25	Time History, GR(30) Ground Turn, Ground Idle
26	PSD, GR(30) Ground Turn, Ground Idle
27	Time History, GR(30) Ground Turn, Flight Idle
28	PSD, GR(30) Ground Turn, Flight Idle
29	Time History, GR(30) Ground Turn, 2,000 ISHP
30	PSD, GR(30) Ground Turn, 2,000 ISHP
31	Time History, GR(30) Ground Turn, 3,000 ISHP
32	PSD, GR(30) Ground Turn, 3,000 ISHP
33	Time History, GR(30) Ground Turn, 4,000 ISHP
34	PSD, GR(30) Ground Turn, 4,000 ISHP
35	Time History, GR(30) Ground Turn, 4,500 ISHP (MAX)
36	PSD, GR(30) Ground Turn, 4,500 ISHP (MAX)
37	Time History, MAX Power Level Acceleration, 5,000 ft MSL, CR(0)
38	PSD, MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 150 KIAS
39	PSD, MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 175 KIAS
40	PSD, MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 200 KIAS
41	PSD, MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 225 KIAS
42	PSD, MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 250 KIAS
43	PSD, MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 275 KIAS
44	PSD, MAX Power Level Acceleration, 5,000 ft MSL, CR(0) – 300 KIAS
45	Time History, MAX Power Level Acceleration, 15,000 ft MSL, CR(0)
46	PSD, MAX Power Level Acceleration, 15,000 ft MSL, CR(0) – 150 KIAS
47	PSD, MAX Power Level Acceleration, 15,000 ft MSL, CR(0) – 175 KIAS

Table C-1: Time History and PSD List of Figures, Continued

Figure	Test Point Description
48	PSD, MAX Power Level Acceleration, 15,000 ft MSL, CR(0) – 225 KIAS
49	PSD, MAX Power Level Acceleration, 15,000 ft MSL, CR(0) – 250 KIAS
50	PSD, MAX Power Level Acceleration, 15,000 ft MSL, CR(0) – 270 KIAS
51	Time History, MAX TIT Level Acceleration, 20,000 ft MSL, CR(0)
52	PSD, MAX TIT Level Acceleration, 20,000 ft MSL, CR(0) – 160 KIAS
53	PSD, MAX TIT Level Acceleration, 20,000 ft MSL, CR(0) – 175 KIAS
54	PSD, MAX TIT Level Acceleration, 20,000 ft MSL, CR(0) – 200 KIAS
55	PSD, MAX TIT Level Acceleration, 20,000 ft MSL, CR(0) – 225 KIAS
56	PSD, MAX TIT Level Acceleration, 20,000 ft MSL, CR(0) – 250 KIAS
57	Time History, Level Flight, 5,000 ft MSL, CR(0) – 180 KIAS
58	PSD, Level Flight, 5,000 ft MSL, CR(0) – 180 KIAS
59	Time History, Level Flight, 5,000 ft MSL, CR(0) – 220 KIAS
60	PSD, Level Flight, 5,000 ft MSL, CR(0) – 220 KIAS
61	Time History, Level Flight, 5,000 ft MSL, CR(0) – 270 KIAS
62	PSD, Level Flight, 5,000 ft MSL, CR(0) – 270 KIAS
63	Time History, Level Flight, 5,000 ft MSL, CR(0) – 300 KIAS
64	PSD, Level Flight, 5,000 ft MSL, CR(0) – 300 KIAS
65	Time History, Level Flight, 5,000 ft MSL, CR(10) – 150 KIAS
66	PSD, Level Flight, 5,000 ft MSL, CR(10) – 150 KIAS
67	Time History, Level Flight, 5,000 ft MSL, CR(10) – 180 KIAS
68	PSD, Level Flight, 5,000 ft MSL, CR(10) – 180 KIAS
69	Time History, Level Flight, 5,000 ft MSL, PA(20) – 108 KIAS
70	PSD, Level Flight, 5,000 ft MSL, PA(20) – 108 KIAS
71	Time History, Level Flight, 5,000 ft MSL, PA(20) – 150 KIAS
72	PSD, Level Flight, 5,000 ft MSL, PA(20) – 150 KIAS
73	Time History, Level Flight, 15,000 ft MSL, CR(0) – 180 KIAS
74	PSD, Level Flight, 15,000 ft MSL, CR(0) – 180 KIAS
75	Time History, Level Flight, 15,000 ft MSL, CR(0) – 220 KIAS
76	PSD, Level Flight, 15,000 ft MSL, CR(0) – 220 KIAS
77	Time History, Level Flight, 15,000 ft MSL, CR(0) – 270 KIAS
78	PSD, Level Flight, 15,000 ft MSL, CR(0) – 270 KIAS
79	Time History, Level Flight, 15,000 ft MSL, CR(10) – 150 KIAS
80	PSD, Level Flight, 15,000 ft MSL, CR(10) – 150 KIAS
81	Time History, Level Flight, 15,000 ft MSL, CR(10) – 180 KIAS
82	PSD, Level Flight, 15,000 ft MSL, CR(10) – 180 KIAS
83	Time History, Level Flight, 15,000 ft MSL, PA(20) – 110 KIAS
84	PSD, Level Flight, 15,000 ft MSL, PA(20) – 110 KIAS
85	Time History, Level Flight, 15,000 ft MSL, PA(20) – 150 KIAS
86	PSD, Level Flight, 15,000 ft MSL, PA(20) – 150 KIAS
87	Time History, Level Flight, 19,000 ft MSL, CR(0) – 140 KIAS
88	PSD, Level Flight, 19,000 ft MSL, CR(0) – 140 KIAS
89	Time History, Level Flight, 20,000 ft MSL, CR(0) – 250 KIAS
90	PSD, Level Flight, 20,000 ft MSL, CR(0) – 250 KIAS
91	Time History, 2 g Sustained Left Turn, 5,000 ft MSL, CR(0) – 250 KIAS
92	PSD, 2 g Sustained Left Turn, 5,000 ft MSL, CR(0) – 250 KIAS
93	Time History, 2 g Sustained Right Turn, 5,000 ft MSL, CR(0) – 260 KIAS
94	PSD, 2 g Sustained Right Turn, 5,000 ft MSL, CR(0) – 260 KIAS

Table C-1: Time History and PSD List of Figures, Continued

Figure	Test Point Description
95	Time History, ~2 g Field Overhead Break, 600 ft MSL, CR(0) – 275 KIAS
96	PSD, ~2 g Field Overhead Break, 600 ft MSL, CR(0) – 275 KIAS
97	Time History, Lateral Yoke ½ Step Turn Reversals, 15,000 ft MSL, CR(0) – 220 KIAS
98	PSD, Lateral Yoke ½ Step Left Turn Reversal, 15,000 ft MSL, CR(0) – 220 KIAS
99	PSD, Lateral Yoke ½ Step Right Turn Reversal, 15,000 ft MSL, CR(0) – 220 KIAS
100	Time History, Turn Reversal Series, 15,000 ft MSL, CR(0) – 230 KIAS
101	PSD, Turn Reversal Series, 15,000 ft MSL, CR(0) – 230 KIAS
102	Time History, Pattern Waveoff, PA(10) – 125 KIAS
103	PSD, Pattern Waveoff, PA(10) – 125 KIAS
104	Time History, Pattern Waveoff, PA(20) – 110 KIAS
105	PSD, Pattern Waveoff, PA(20) – 110 KIAS
106	Time History, Pattern Waveoff, PA(30) – 105 KIAS
107	PSD, Pattern Waveoff, PA(30) – 105 KIAS
108	Time History, Engine Sulfidation Climb, 5K to 15K ft MSL, CR(0) – 160 KIAS
109	PSD, Engine Sulfidation Climb, 5,000 ft MSL, CR(0) – 160 KIAS
110	PSD, Engine Sulfidation Climb, 9,000 ft MSL, CR(0) – 160 KIAS
111	PSD, Engine Sulfidation Climb, 13,000 ft MSL, CR(0) – 160 KIAS
112	Time History, Max Power Bingo Climb, 5K to 20K ft MSL, CR(0)
113	PSD, Max Power Bingo Climb, 5,000 ft MSL, CR(0) – 160 KIAS
114	PSD, Max Power Bingo Climb, 13,000 ft MSL, CR(0) – 152 KIAS
115	PSD, Max Power Bingo Climb, 17,000 ft MSL, CR(0) – 148 KIAS
116	PSD, Max Power Bingo Climb, 20,000 ft MSL, CR(0) – 145 KIAS
117	Time History, Power-On Descent, 15K to 7K ft MSL, CR(0) – 250 KIAS
118	PSD, Power-On Descent, 15,000 ft MSL, CR(0) – 250 KIAS
119	PSD, Power-On Descent, 13,000 ft MSL, CR(0) – 250 KIAS
120	PSD, Power-On Descent, 11,000 ft MSL, CR(0) – 250 KIAS
121	PSD, Power-On Descent, 9,000 ft MSL, CR(0) – 250 KIAS
122	PSD, Power-On Descent, 7,000 ft MSL, CR(0) – 250 KIAS
123	Time History, Flt Idle Descent, 20K to 8K ft MSL, CR(0) – 250 KIAS
124	PSD, Flt Idle Descent, 20,000 ft MSL, CR(0) – 250 KIAS
125	PSD, Flt Idle Descent, 16,000 ft MSL, CR(0) – 250 KIAS
126	PSD, Flt Idle Descent, 12,000 ft MSL, CR(0) – 250 KIAS
127	PSD, Flt Idle Descent, 8,000 ft MSL, CR(0) – 250 KIAS

APPENDIX D
AIRPLANE AND ACCELEROMETER REFERENCE AXES

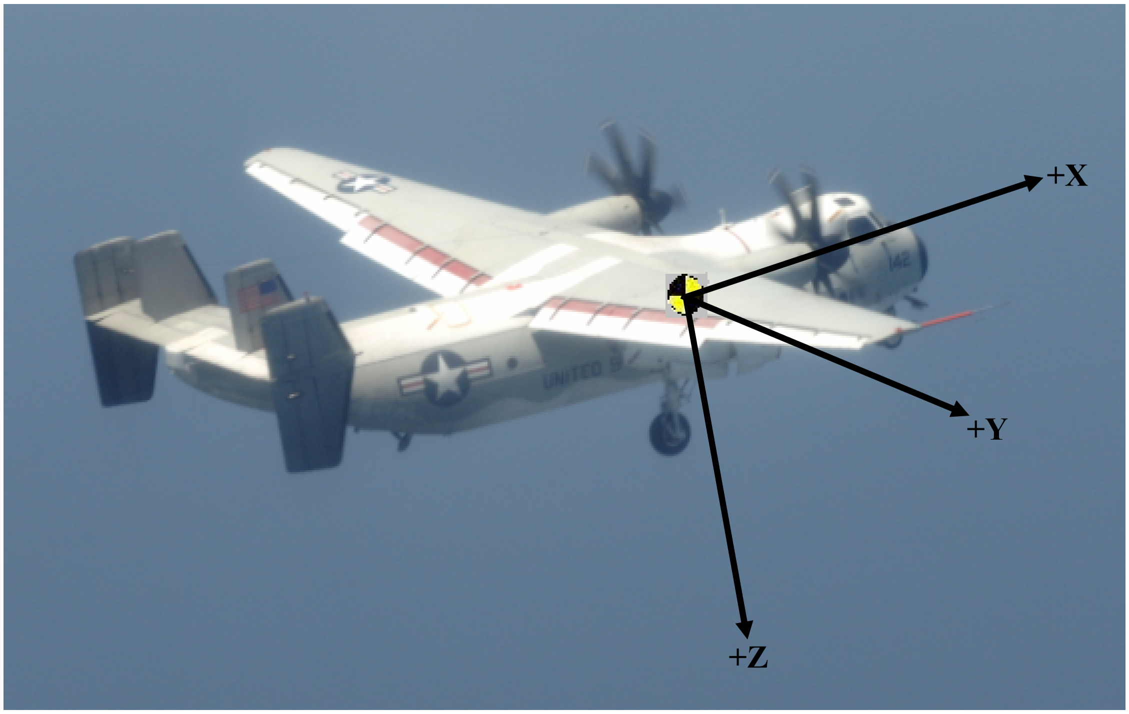

Figure D-1: Airplane and Accelerometer Reference Axes

VITA

Christopher David Dotson was born in Indianapolis, IN on August 8, 1976. He was raised in New Castle, PA, where he graduated as Valedictorian from Neshannock High School in 1994. From there he attended the University of Notre Dame and received a Bachelor of Science Degree in Electrical Engineering in May, 1998. Christopher was commissioned in the United States Navy that same year, and shortly thereafter began flight school at Vance AFB in Enid, OK. He was designated a Naval Aviator in August, 2000, and continues to serve as a U.S. Naval Test Pilot at NAS Patuxent River, MD. Christopher is currently pursuing his Master of Science Degree in Aviation Systems at the University of Tennessee Space Institute, Tullahoma, TN.