8-2006

A Study To Enhance The B-1B Targeting Pod Integration Developmental Processes

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Recommended Citation

Lane, Joshua Aaron, "A Study To Enhance The B-1B Targeting Pod Integration Developmental Processes. " Master's Thesis, University of Tennessee, 2006.
https://trace.tennessee.edu/utk_gradthes/1723

To the Graduate Council:

I am submitting herewith a thesis written by Joshua Aaron Lane entitled "A Study To Enhance The B-1B Targeting Pod Integration Developmental Processes." 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.

Richard Ranaudo, Major Professor

We have read this thesis and recommend its acceptance:

U. Peter Solies, Basil Antar

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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Dr. Anne Mayhew

Vice Chancellor and Dean of
Graduate Studies

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

A STUDY TO ENHANCE THE B-1B TARGETING POD INTEGRATION DEVELOPMENTAL PROCESSES

A Thesis Presented for the Master of Science Degree

The University of Tennessee, Knoxville

Joshua Aaron Lane
August, 2006

Acknowledgments

I wish to thank all those who helped me complete my Master of Science degree in Aviation Systems. I would like to thank Professor Richard Ranaudo for his technical guidance and his tireless efforts in helping me prepare this thesis. I would like to thank Dr. Ka'iliwai III, Mr. Dan Roth, Mr. John Haire, Lt Col Moss, and Mrs. Lynnell Parker for their support and effort in validating and approving this military technical paper for public release. I would like to thank Betsy Harbin for providing coordination with the distance learning process.

Lastly, I would like to thank my wife, Christine, three children, and family whose support and encouragement made this work possible and complete.

ABSTRACT

Recent United States combat operations required weapon systems to incorporate enhanced targeting capabilities to improve their effectiveness in weapons employment. The United States Air Force B-1B heavy bomber played a key role in releasing GPS guided munitions in Operation Enduring Freedom and Operation Iraqi Freedom without enhanced targeting capabilities. Future conflicts are expected to continue to address this requirement as the battlefield evolves. These operations highlighted the need for the B-1B to incorporate an advanced targeting pod (TGP) to provide positive identification of targets and allow for more precisely planned weapon releases without the aid of additional off-board resources. During 2004-2006 a concept demonstration electro-optical and infrared TGP program was developed and tested on the B-1B to address targeting limitations. The goal of the test program was to demonstrate a limited operational capability of the TGP using minimal testing resources.

The concept demonstration highlighted areas for improvement in the final TGP implementation design. The improved alternatives were submitted as future design candidates and test procedures for the TGP development effort. The purpose of this thesis was to examine the concept demonstration test plan and planned test process and recommend improved testing processes and design enhancements for the fully integrated pod design. The planned testing included modeling and simulation of aerodynamics and structures, laboratory system functional testing, hardware development testing, ground vibration testing (GVT), electromagnetic interference compatibility testing (EMIC), crew operability testing, and flight envelope testing. Many of these elements were not planned to be thoroughly tested due to the limited demonstration constraints.

The findings of this study indicate that a further evaluation of handling qualities are required, and pod related weapon separation testing should be expanded to include more release configurations and conditions. The Man Machine Interface (MMI) for the TGP future cockpit upgrade requires improvement while EMIC tests and related crew training should be increased during the final TGP System Developmental Design (SDD). No further increases in testing efforts relative to flight test instrumentation, GVT, logistics support, or aerodynamics are required.

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GLOSSARY

1553	Data Bus Type
1760	Weapon Data Bus Type
ACM	Advanced Cruise Missile
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AFS	Avionics Flight Software
AFSEO	Air Force Seek Eagle Office
AGL	Above Ground Level
ALCM	Air Launched Cruise Missile
AoA/α	Angle of Attack/alpha
β	Angle of Side-slip
BLOS	Beyond Line of Sight
CAT	Computer Aided Axial Tomography
CBM	Conventional Bomb Module
CCD	Charge Coupled Device
CFD	Computation Fluid Dynamics
CITS	Central Integrated Test System
CMNS	Combat Mission Needs Statement
COTS	Commercial Off The Shelf
CRL	Conventional Rotary Launcher
CT II	Combat Track Two
DEV	Design Eye View
DMPI	Desired Mean Point of Impact
DOE	Design Of Experiments
EMIC	Electromagnetic Interference Compatibility
EMUX	Electrical Multiplexing System
EO	Electro-Optical
ERS	Engineering Research Simulator
FIDL	Fully Integrated Data Link
FLIR	Forward Looking Infra-red
FLTS	Flight Test Squadron
FOR	Field Of Regard
FQ	Flying Qualities
GAINR	GPS Aided Inertial Navigation Reference
GBU	Guided Bomb Unit
GPS	Global Positioning System
GUI	Graphical User Interface
GVT	Ground Vibration Testing
HIL	Hardware Integration Laboratory
HOTAS	Hands On Throttle And Stick
HQ	Handling Qualities
Hz	Hertz
ICD	Interface Control Document
IFAST	Integrated Facility Avionics& Systems Test
INU	Inertial Navigation Unit

IR	Infrared
JASSM	Joint Air to Surface Stand-off Missile
JDAM	Joint Direct Attack Munitions
JSOW	Joint Stand Off Weapon
Kts	Knots
M	Mach
MAU	Munitions Adapter Unit
MIL-STD	Military Standard
MK	Mark
MMI	Man Machine Interface
MOTS	Military Off The Shelf
MPRL	Multi-Purpose Rotary Launcher
MSC	MacNeil-Schwindler Corp
MSL	Mean Sea Level
NDI	Non-Developmental Item
OKC	Oklahoma City
ONS	Operation Needs Statements
OSO	Offensive Systems Officer
PEP	Program Execution Plan
PID	Positive Target Identification
PID	Program Introduction Document
POPU	Push-Over Pull-Up
PSD	Power Spectral Density
PTC	Parametric Technology Corporation
q	Dynamic Pressure
SALT	Strategic Arms Limitations Talks
SCAS	Stability Control Augmentation System
SDD	System Developmental Design
SECBM	1760 Conventional Bomb Module
SI	Special Instrumentation
SIL	Software/System Integration Laboratory
SOC	Statement of Capability
START	Strategic Arms Reduction Talks
T.O.	Technical Order
T-1/T-2	Type One and Type Two Modification
TGP	Targeting Pod
TIM	Technical Interchange Meeting
TIS	Test Information Sheet
TM	Telemetry
TV	Television
US	United States
USAF	United States Air Force
USN	United States Navy
WCMD	Wind Corrected Munitions Dispenser
WUT	Wind-Up Turn

1. INTRODUCTION

B-1B involvement in Operations ENDURING FREEDOM and IRAQI FREEDOM identified limitations in bomber employment capabilities. During many missions the B-1B crew force participated in time sensitive targeting and close air support operations. Although effective, these types of operations highlighted the need for on-board positive target identification (PID) without the support of other combat platforms. The employment rules of engagement along with the nature of the targets being attacked required such fundamental capabilities.

By incorporating an onboard capability to find, fix, target, track, engage, and assess potential targets, essential combat asset requirements were reduced while United States (US) battlefield synergy was enhanced through increased independent target strike capability [1].

Two independent sources recommended this needed capability for the B-1B. A combat mission needs statement (CMNS) was submitted and approved by the Air Force in early September 2003 [2]. The United States Army submitted an Operation Need Statement (ONS) shortly thereafter in March 2004. Both documents emphasized the requirement for the B-1B to have PID capability in a dynamic battlefield environment [2]. This thesis presents recommendations obtained from an analysis of the test plan developed for the targeting pod (TGP) implementation. These recommendations were made to enhance the test process associated with a final targeting pod implementation effort known as System Developmental Design (SDD). Other recommendations relate to system integration of the TGP into the current and future B-1B cockpit design.

BACKGROUND

Beginning in 2003, a study was completed to determine the feasibility of providing a TGP solution for the B-1B. During the summer of 2004, two different TGPs were mounted but not flown on the B-1B as a form-fit check and as an initial statement of pursuit. In Sept 2004, the 419th Flight Test Squadron (FLTS) flew an operationally representative sortie on an F-16 to assess the chosen TGP capabilities and to help provide planning inputs for the upcoming B-1B pod concept demonstration test. Initial planning for this test began in October 2004 with the primary contractors, the B-1B Systems Group, and Air Combat Command B-1B Requirements (ACC/A3A1) [1].

A Statement of Capability (SOC) providing inputs on requirements and support capability used to test a B-1B TGP concept demonstration was generated in April with the final revision completed in September 2005. The goal of the concept demonstration flight test was to provide the feedback required to achieve a fully funded fully implemented TGP program [3].

Developmental ground test planning began within the bomber test community from July through November 2005 with all functional areas providing inputs and design requirements for the TGP concept demonstration flight. Structural design requirements were developed for mounting the pod on the aircraft in a flight worthy configuration, instrumentation planning was developed, laboratory and ground test requirements were established, and nuclear proliferation treaty requirements were satisfied.

A ground vibration test was completed by mid January 2006 while concurrent ground tests were being performed on the pod and aircraft interface development. The hard-point welding processes allowing the mounting of a Munitions Adaptor Unit (MAU-12) modified pylon to the aircraft were being tested and refined through the fall of 2005 and spring of 2006.

Flight test planning began in December of 2005 and continued through the spring of 2006. Additionally, several Technical Interchange Meetings (TIMS) were accomplished to analyze the detailed approach of every aspect of the test while also refining test requirements and processes.

Aircraft modifications for instrumentation and TGP hardware were planned for four months starting in March 2006. Instrumentation modifications had to be completed before an EMIC test could be performed to certify the aircraft for flight test. Finally, a series of flight tests were scheduled from July through September 2006 and test reporting and aircraft de-modification would follow shortly after final demonstration [3].

SYSTEM DESCRIPTION

The TGP chosen for the concept demonstration flight test was a generation three capable Advanced TGP. The major components of this pod are an electro-optical system, an infrared system, laser capabilities, and a self contained navigation unit.

The advanced TGP provides greatly enhanced ranges over earlier models and the pod allows for detection and identification from ranges outside counter-threat detection in the auditory spectrum. These ranges are consistent with employment ranges for Joint (J) series weapons, and provided accuracy consistent with Joint Direct Attack Munitions (JDAM) employment [www.globalsecurity.org].

The advanced TGP incorporates a third generation high-resolution Forward Looking Infrared (FLIR), a Charge Coupled Device Television (CCD-TV), and a multi-mode laser. This pod offers several advances in all aspects of image processing and improved tracking stability. Furthermore, the pod's fundamental body design allows for supersonic employment, a low observable design, and improved maintenance features. It includes all features of the earlier models with newer enhancements such as passive air-to-air detection and tracking [www.Lockheedmartin.com/mfc].

OBJECTIVES

The objective of this study was to analyze the test planning and test process of the concept demonstration pod testing, assess the adequacy of the systems under test, and make recommendations which support a final TGP integration during System Design and Development (SDD) Fiscal Year (FY) 2009.

2. CREW SYSTEMS EVALUATION AND ASSESSMENT

The following section addresses hardware systems development and planning for the TGP concept flight demonstration planned in 2006. Instrumentation, TGP mounting, and aircrew interface were addressed for SDD suitability.

FLIGHT TEST INSTRUMENTATION

The instrumentation package for the concept demonstration flight test is a Type Two (T-2) modification. A T-2 modification is a temporary modification consisting of Commercial off the Shelf (COTS), Non Developmental Items (NDI), or existing stock items [4]. The instrumentation includes power supplies for the TGP, and a communication connection between the pod and aircraft in the form of an Ethernet cable and video line. A communication link provides the operator interface to the pod and includes the hand controller and laptop functionality. Additionally, the instrumentation requirement provides telemetry (TM) which allows for real time monitoring and post flight analysis of onboard sensors via physical media storage.

The largest and most time consuming portion of the modification is the addition of approximately 180 onboard sensors. These sensors are located across the aircraft lower fuselage and weapon bay areas near and around the TGP mounting location, the bomb bay doors downstream of this position and the engine nacelle. A few cockpit sensors are also used to measure load factor on the aircrew. These sensors shown in Figure 1 are

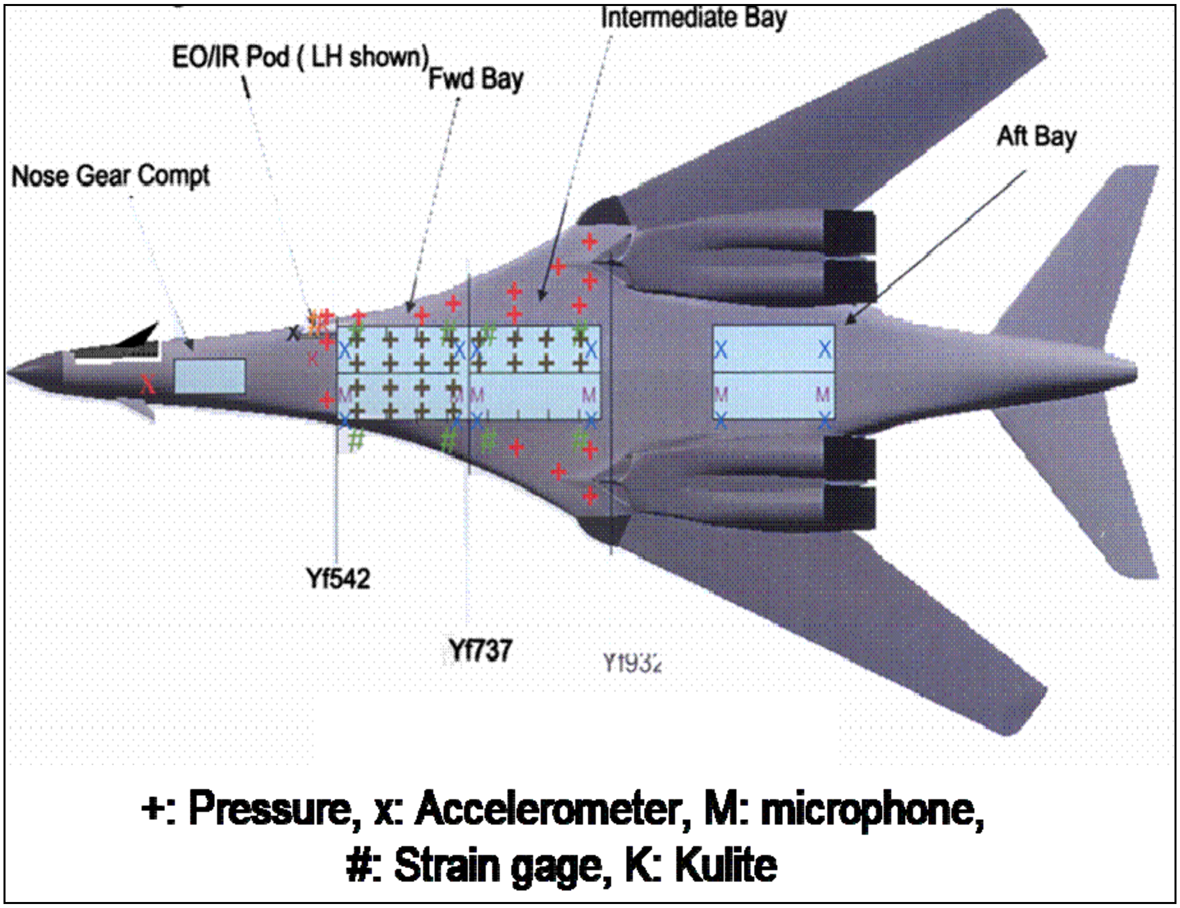

Figure 1. Sensor Placement for Aerodynamic Investigation [5]

installed to measure pressure, structural accelerations, stress and strain, and weapon bay acoustic levels. [5]. One of the primary sensors used, the Kulite, is a solid state transducer that measures free air pressure and system pressure [www.kulite.com]. Similar acoustic and pressure sensors are also used to complete to collection grid.

The vast grid of data collection from these 180 sensors provides real-time and post flight data measurements and will allow the test team to validate the structures, aerodynamic, and Computational Fluid Dynamics (CFD) model predictions throughout the flight envelope. Weapon bay sensors will provide data on door movements and loads, and internal and external disturbed airflow to each weapon bay caused by the TGP installation. The side of the weapon bay and aircraft shared with the TGP are of greatest interest, therefore analyzing the effects of the disturbed airflow in that area is important.

From the data recorded using these sensors, TGP airflow disturbances will be determined for all aircraft, pod, weapon bay, and engine interactions. An area of key study is the left hand side of the lower fuselage. One of the concerns from the modeling and simulation of the installed TGP is vortex shedding and its affect on airflow around the intermediate weapon bay and the inboard left hand engine. Data from the flight test instrumentation will be used to verify these analyses.

Sensor data is recorded at a rate of 2000 Hertz (Hz). This high sample rate was required to show any structural modes predicted on the aircraft without aliasing concerns. The highest predicted TGP and aircraft structural mode frequencies of interest are less than 100 Hz, Figure 2.

TARGETING POD HARDWARE INSTALLATION

The criterion for mounting the TGP to the aircraft was to use existing external nuclear Air Launched Cruise Missile (ALCM) pylon fittings. The Strategic Arms Reduction Talks (START) and the Strategic Arms Limitations Talks (SALT), barred the B-1B from carrying nuclear cruise missiles, but the external hard-points were only covered with a material and plate to achieve treaty compliance.

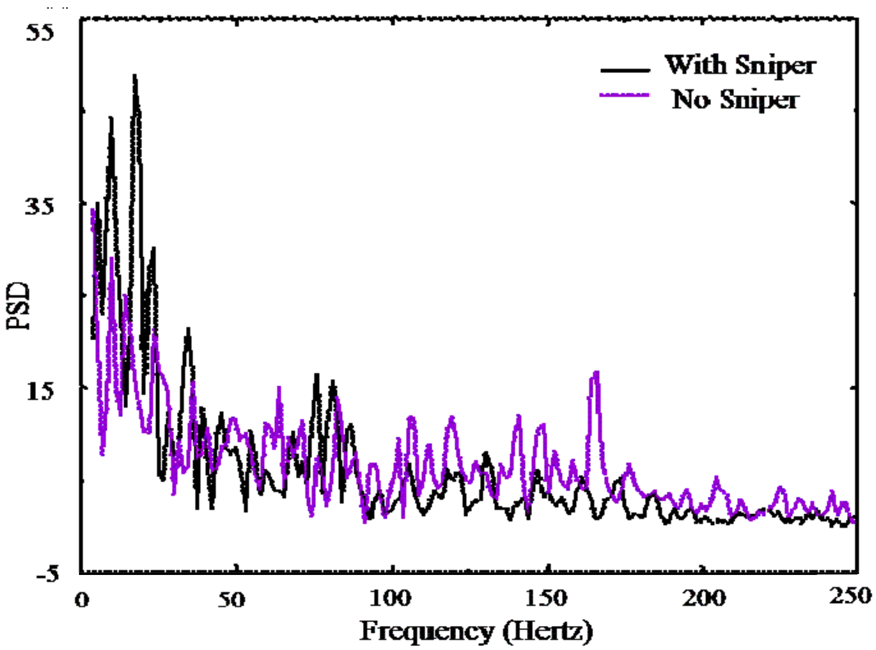

Figure 2. GVT Resolved Pod Modal Frequencies [6]

The conduit to these 10 hard-points however, including wiring interfaces, was never removed and was readily available for this effort. [http://www.fas.org/nuke/control/start1/, http://dosfan.lib.uic.edu/acda/treaties/salt2].

The ALCM hard-points provided the most feasible method to attach the TGP. The covering was removed from the hard-point of interest and a welded sleeve mount was inserted into the point connection. The welded sleeve provided the mounting option for the TGP pylon while rendering the attachment area non-operational for ALCMs due to the reduced size of the mounting port. The conduit was used with new military standard (MIL-STD) 1553 wiring to interface the pod to the aircraft. As can be seen in figure 3,

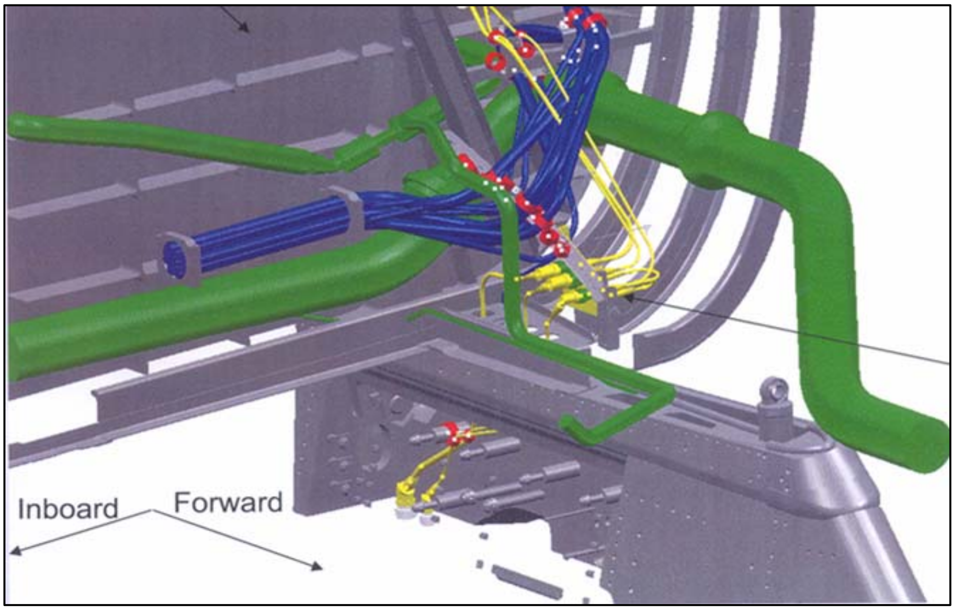

Figure 3. Cutaway Revealing Existing Aircraft Conduit & Wiring Interface [5]

plumbing provided easy access to enable connectivity to the pod. In this figure, the yellow represents new wiring adapted to the existing green and blue conduit and wiring harnesses.

When planning the initial concept demonstration flights both chin mounts closest to the nose of the aircraft were considered optimum, and the left hand mount shown colored in blue in figure 4 was selected for the test case. The right hand chin mount was symmetrically located but was not tested. Figure 4 shows six other possible mounting options for the targeting pod.

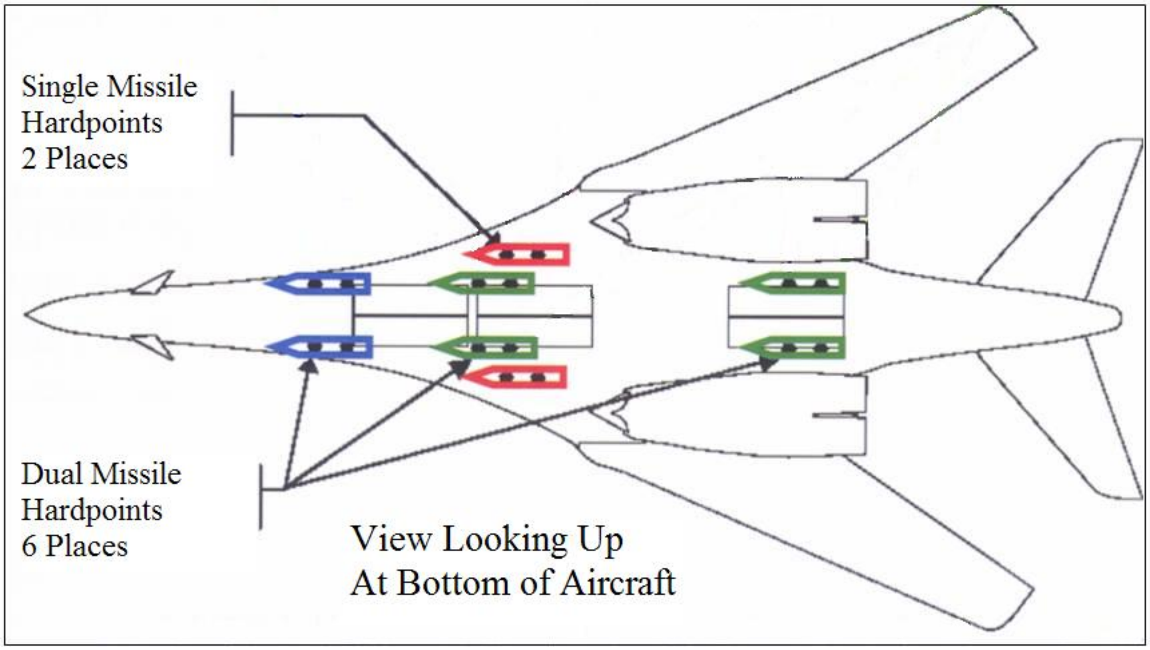

Figure 4. External Pylon Hard-points [5]

Mounting the pod in the chin area allows the best TGP field of regard (FOR). This location is also the furthest from weapon bays and engine nacelles. As shown in figures 4 & 5, the other hard-point locations are farther aft under the aircraft fuselage. The middle mounting options shown in red and green in figure 4 are closer to the under-slung engine nacelles. In the mid-line location, airflow distortions around the weapon bays may be a concern due to proximity to engines and weapon bay doors. These intermediate location FOR were masked by an additional 10-15 percent in the lateral-to-aft sector as compared to the chin option. Finally, the aft mounting option shown in green in figure 4 was not chosen due to its proximity to the aft weapon bay and the location between the nacelles. During ALCM flight testing, these stations had received unfavorable aerodynamic loads due to a moving pressure gradient that exists at employment airspeeds

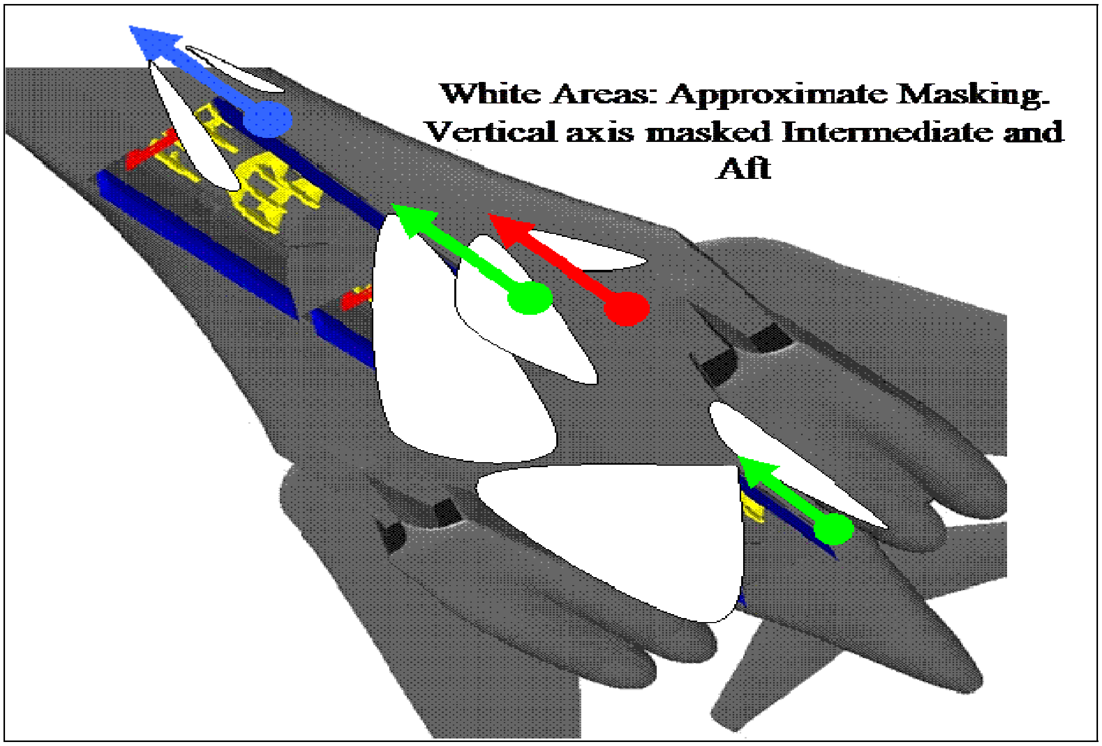

Figure 5. Generic TGP Field of Regard (FOR) [8]

between the nacelles [9]. Structural integrity of the pylon eliminated this loading option. Additionally, as shown in figure 5, the FOR at this station was the least capable of all the mounting options because of masking which adversely affects tactical employment.

In summary, the chin mounting location was deemed optimum and provided the best opportunity for successful integration. The intermediate and aft locations would require more extensive structural analysis. ALCM testing, for example, experienced some severe bending and twisting modes on the weapon and mount that were unfavorable around and aft of the nacelles. The same structural modes were expected to be produced on the TGP at these aft locations as well [9].

DISPLAYS AND CONTROLS

The TGP concept demonstration focuses on implementation of a basic pod interface with the bomber without assessing future cockpit upgrades. Planning was performed to maximize testing on flight characteristics and system capability vice focusing on the Man Machine Interface (MMI). This section includes a discussion of identified MMI problems and the related recommendations that will improve the operator interface prior to the final TGP implementation.

In order to provide a visual interface for the concept demonstration, a temporary design incorporated a post production laptop modification that had been used on the aircraft since August 2001. The laptop modification began as a temporary modification (T-2) and was subsequently converted to a permanent Type one (T-1) modification with full modification support being achieved by 2003 [10]. The original purpose of the laptop and communication modification, known as the Beyond Line of Sight (BLOS) configuration, was to provide a moving map capability to aircrew and to provide an interface to a Combat Track II (CT II) communication link used to provide limited network capability for combat operations.

For the concept demonstration test, a Panasonic CF-73 will be used as the visual interface to the TGP. It has a 13.3 inch daylight readable anti-reflective active matrix viewing area [www.rugged-systems.com/p/Portables/0029.htm]. The laptop is mounted below the

Figure 6. B-1B Aft Station

Central Integrated Test System (CITS) control panel in the aft station between the two rear crew members using a pull-out tray [11]. Since a laptop addition was not part of the original cockpit design, its placement suffered from lack of cockpit real-estate. Figure 6 shows the original aft station cockpit panel before the BLOS installation.

As shown in the figure, there was very little available space to place a new display. To accommodate the limited space, the BLOS computer tray was designed as a pull-out drawer for a laptop below the CITS panel. When the laptop was raised, the CITS panel was covered preventing access to system messages that are used for aircraft diagnostics.

Display Interface

The display interface was a Military off the Shelf (MOTS) design. It used proven systems that allowed for limited development of interface software and hardware. The interface chosen for the test was the F-15 TGP display design group. Without performing a trade study of bomber cockpit integration, this interface was chosen. For this demonstration, it was purposely decided to use the MOTS display interface to perform the test due to maturity and availability.

In 2004 an F-16 was used to assess TGP and bomber interface compatibility. This interface was similar to the F-15 interface chosen for the B-1B concept demonstration. During the F-16 test flight interface problems were identified with target orientation references and target dimensions assessment. Scale markers used on the pod were fixed and could not be changed by the operator. This implementation was inconsistent with the B-1B interface. The bomber scale markers on the radar display are adjustable allowing the operator to measure target sizes. Another compatibility problem was the reference to North. The bomber radar display has the ability to show a synthetic map as either North-Up or Track-Up for a reference. The TGP display evaluated in the F-16 flight test implemented a North arrow that was constantly moving based on the position of the line of sight from the pod to the target. Determining orientation of a target set where multiple targets were present proved difficult [12]. These types of implementations will be used during the concept demonstration and the incompatibilities identified will likely decrease mission effectiveness due to increased workload. Therefore, the display interface needs to be redesigned to a compatible B-1B standard for weapon employment (R1).

Since the future cockpit upgrade of the B-1B is migrating to glass design with bezel control, bezel functionality should be incorporated in the pod interface. For example, the order and labeling of bezels should be consistent with the Fully Integrated Data Link (FIDL) design that will be implemented by TGP SDD. If different bezel controllers are implemented with dissimilar templates, the operator will be forced to memorize multiple layouts. Consequently, cockpit efficiency will be reduced. For the final pod integration, the symbology and formats must not only be consistent with all other weapon system formats but should allow for future upgrades that incorporate new displays (R2).

The operator interface chosen for the concept demonstration was the BLOS laptop and F-15 hand controller. This set-up incorporated a Graphical User Interface (GUI), to the operator. Since the CF-73 had a touch-screen feature, the designers opted to provide two methods to operate many of the control functions of the pod either by the hand controller or via the laptop touch-screen. The touch-screen option proved less than optimum for control functions due to the location of the laptop in the aft station.

As was shown in the FIDL cockpit layout study [13], the primary viewing envelope for an optimum workstation environment to include screen contrasts, cockpit lighting, glare, and eye strain is ± 20° vertically and ± 50° horizontally. The installed viewing angle of the laptop in the bomber is greater than -50° horizontally and -8° vertically from the Design Eye View (DEV) of the primary TGP operator [13]. This FIDL study showed that at the primary viewing location the characters require a 16 percent larger font to compensate for the off angle viewing to avoid operator difficulty reading the screen. In order to effectively test the TGP during the concept demonstration, the TGP display should also incorporate increased font size. During the concept demonstration test, screen reading difficulty will likely lead to missed information affecting the test results.

Precise aiming at targets is expected to be difficult due to parallax error from off angle viewing combined with the two-thirds screen display on the laptop. Therefore, the laptop should be mounted on a swivel during the concept demonstration testing such that it is within the operator's DEV, and ultimately, the final TGP display interface must be within the operator's DEV (R3).

Lastly, a related display interface problem was identified during the F-16 TGP assessment flight in September 2004. The existing slew functionality for the TGP uses the pod body orientation as the reference frame. The flight revealed that the TGP cueing interface could be improved by using the earth inertial reference frame to slew the controller. In a case where the aircraft was in a steep bank or maneuvering, the operator had difficulty slewing the cursor because it was oriented to a pod frame of reference. In other than level flight conditions, cursor axes were transposed due to bank angle causing cursor placement difficulty [12]. The TGP slewing must use inertial references to eliminate slewing errors associated with attitude interpretation (R4).

Control Interface

The hand controller planned for the concept demonstration TGP interface is an existing F-15 Hands on Throttle and Stick (HOTAS) controller, figure 7. This installation is not

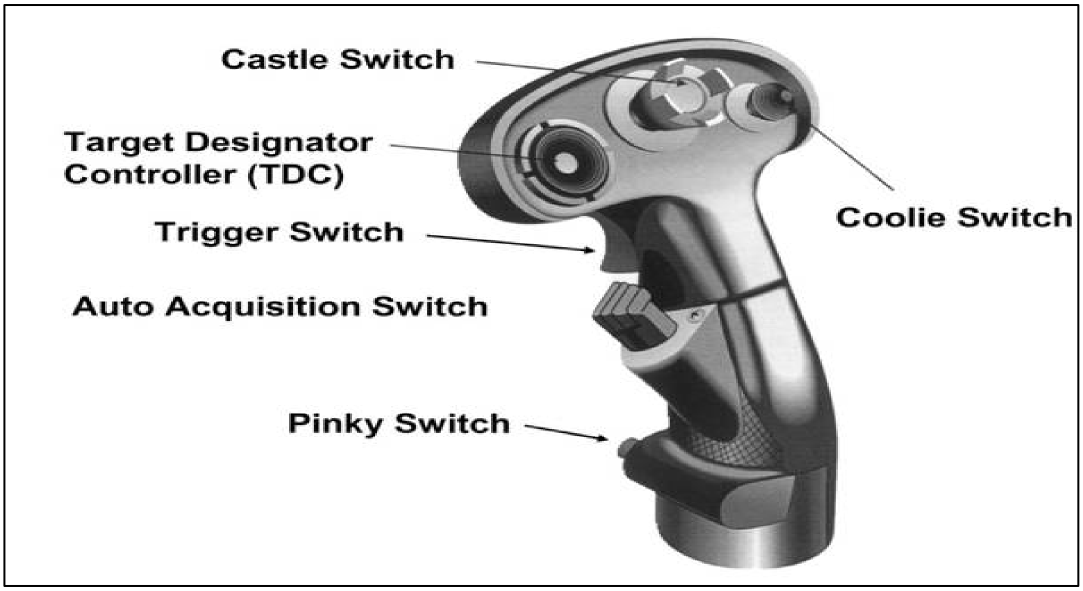

Figure 7. F-15 Type Hand Controller [5]

intended for the final TGP implementation. The F-15 controller will be mounted at the aft station on the Offensive Systems Officer (OSO) track handle pedestal via a mounting bracket. The hand controllers will be separated by approximately four inches. In order to use both controllers the TGP controller will be mounted slightly lower and rotated to the outside of the existing controller. Figure 8 shows a side view of this TGP controller mounting.

The B-1B final pod implementation is intended to be controlled from both the front and aft station. During the concept demonstration, only the aft station controller will be evaluated since the front station controller was not installed. Pilots will not be able to determine crew performance and workload while flying the aircraft and using the TGP.

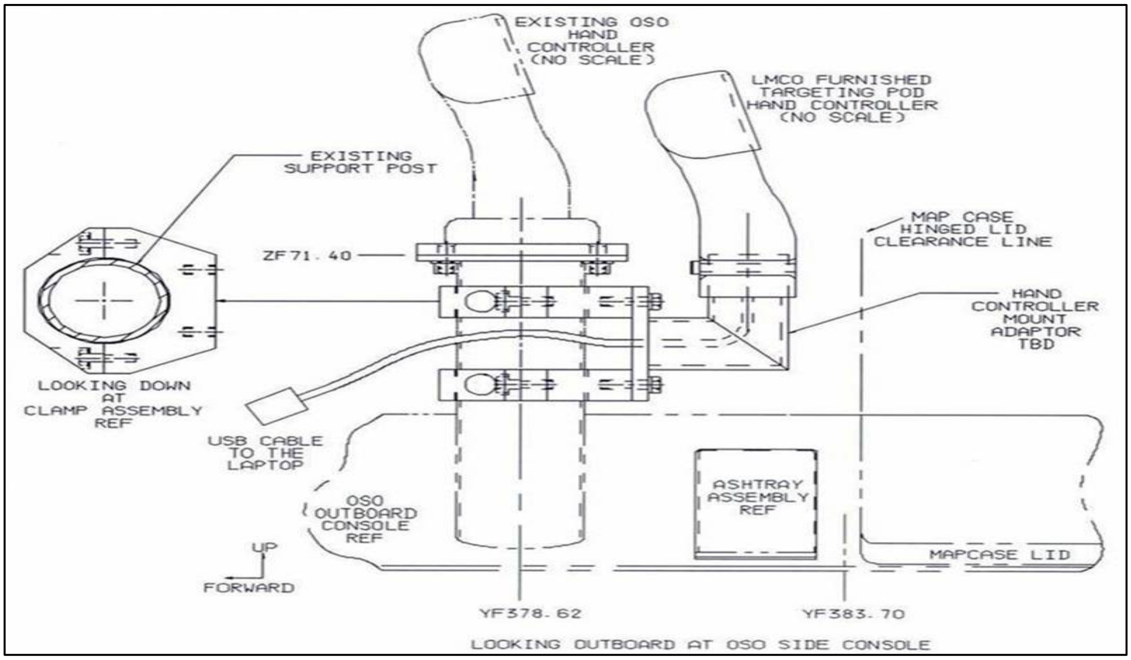

Figure 8. TGP Hand Controller Mounting [15]

Additionally, crew coordination between the pilots and Weapon Systems Officers (WSO) will not be assessed during the concept demonstration flights. A controller must be placed in the front station to assess cockpit design requirements (R5).

Hand controller integration is critical to proper employment of the weapon system. The HH-60 final controller shown in figure 9 is the controller that is planned for the FIDL design and will not be evaluated during the planned concept demonstration testing. A risk is incurred since potential ergonomic deficiencies associated with this controller may not be discovered until after FIDL. This could result in program delays, increased costs, and re-design of the interface. An evaluation of the FIDL controller must be done before final TGP implementation (R6).

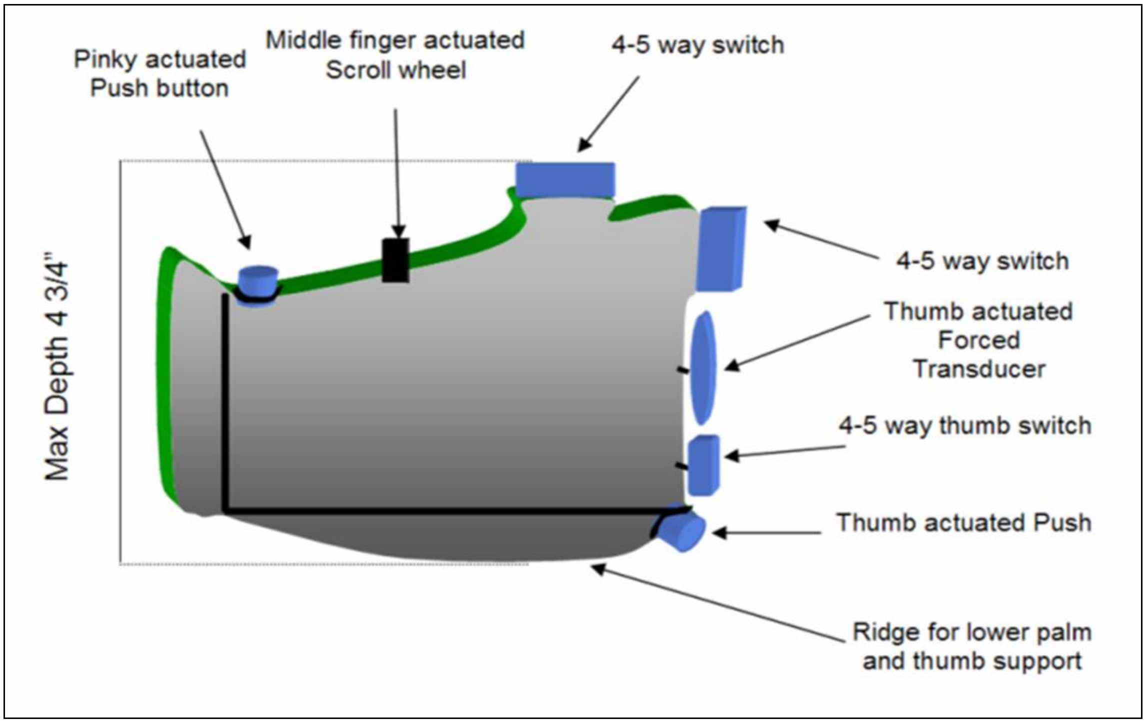

Figure 9. Top View Left-Handed FIDL Hand Controller [13]

As shown in figure 10, the current controller design is vastly different from the FIDL controller, figure 9, and the concept demonstration TGP controller, figure 7. Each of these controllers has unique system interface requirements resulting in varied controller response. For example, the current B-1B track handle used to operate the radar, figure 10, has a known response delay deficiency. The result is difficulty with precise target capture tasks due to overshoots. In an aircrew study using the Cooper-Harper rating scale as a means of evaluation, Appendix A, aircrew rated their workload and ability to perform a simple precise target capture task from various locations on the display. Appendix B shows a sample from this study conducted on this deficiency. Because the FIDL hand controller is not ready for testing there is a risk that similar track handle

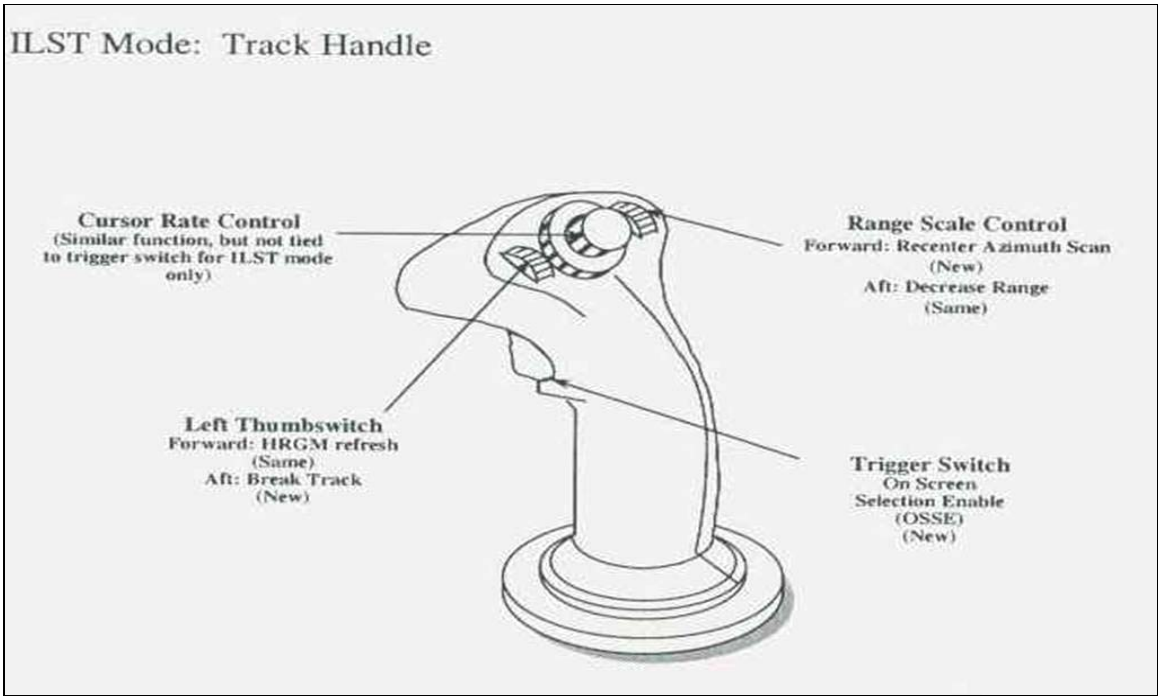

Figure 10. Legacy Aircraft Track Handle

problems could occur when FIDL is implemented with the TGP. The hand controller functionality and response characteristics are critical to effective weapon employment. The concept demonstration process should provide a capability to evaluate a fully integrated system before final TGP system integration during SDD.

Lastly, the location of the controller and the associated TGP panel interface violates standard workspace design principles. Since control and aiming were achieved from the touch screen and hand controller, the operator was required to perform two tasks simultaneously. Figure 11 shows the region of reach for a workspace design using a sitting requirement. In this figure, the black area represents an overhead view of a sitting person. A single task performance without handgrip requirements in the figure is

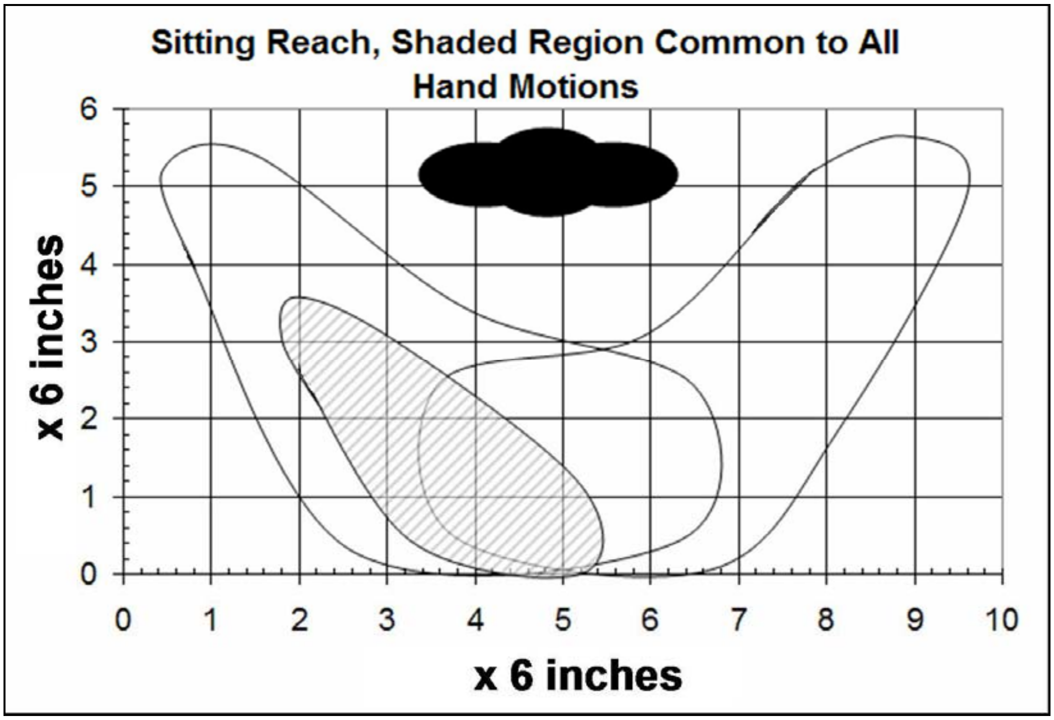

Figure 11. Sitting Workspace Reach [14]

represented by the open areas while a task requirement of varying handgrips is represented by the reduced shaded areas. The single outline is the maximum range for various hand positions without specific grip requirements. In the shaded region, an operator could be expected to perform common tasks with various types of hand grips using the corresponding hand. The task requiring complex handgrips reduces this region and severely impedes the operator's ability to perform tasks across body with opposing hands. If using both hands to perform two independent tasks requiring different hand movements, the figure reveals how an operator can be limited in task performance.

Figure 12 shows that performing multiple reach tasks on opposing sides is a poor

Figure 12. Two Simultaneous Tasks Reach Requirement

ergonomic design [14]. The distance between the hand controller and the laptop made simultaneous viewing and cursor control very difficult. To depress the depicted buttons on the laptop, the operator had to extend his reach or in many cases lean toward the laptop. When leaning occurred and the operator was attempting to operate the hand controller, the operator became displaced. The hand controller was on the operator's right hand side while the lean occurred to the left hand side. While strapped into an ejection seat that reduces mobility, this configuration placed the operator in an awkward position. Performing both tasks lead to operating errors, extended task time, and fatigue related to the unnatural body positions.

These issues highlight the need for expanded development of the TGP crew interface. Prior to SDD, an evaluation of cursor tracking tasks in a standardized cockpit environment must be performed to address TGP cockpit interoperability (R7).

3. LABORATORY PROCESSES

An evaluation of the laboratory processes involved with demonstrating TGP capability on the B-1B during the concept demonstration testing is discussed in the following section.

LABORATORY AND SOFTWARE VERIFICATION TESTING

Flight dynamic laboratory testing was conducted at Oklahoma City, OK (OKC) facility approximately eight months before the actual flight test. The purpose of the laboratory test was to assess integration of pod navigation systems with aircraft navigation systems through the measurement of parameters such as direction cosines, system altitudes, moment arm comparisons, and angular measurement references [5]. Before the pod could be flown on the aircraft, these navigation systems had to be integrated and any known system errors had to be addressed.

In order for the TGP to correctly align its navigation reference, moment arm and attitude messages had to be validated. These messages provided the operator with alignment status of the pod and in-flight navigation solution referencing. Software and hardware performance were assessed and some coding changes had to be made to ensure that the primary navigation models worked together correctly. The results of the laboratory testing provided information that would be used to modify Kalman filters prior to flight test [www.cs.unc edu/~welch/media/pdf/Kalman_intro.pdf].

Laboratory testing also verified that correct transfer alignment information was being passed to the TGP. Additional laboratory testing included simulated flights with both the pod and aircraft navigation systems interfaced. Navigation testing proved more difficult since it was not possible to provide actual dynamic flight information to the navigation systems simulated in the laboratory. It was important to verify that the aircraft passed its navigation solution to the pod. This ensured that both systems had the same pointing reference and the targeting pod computed the correct desired mean point of impact (DMPI).

A simple taxi test that varied aircraft direction will be performed before the concept demonstration flight tests to provide the information needed to improve the navigation model predictions and Kalman tuning. This testing will fill the data gap that was not achievable in the laboratory.

The B-1B Avionics Flight Software (AFS) to pod interface required that new software had to translate MIL-STD 1553 data to message traffic understood by the TGP. All the command and control capability passed to the TGP had to be tested for validity. These included many of the different track command modes, laser controllers, system bits, and operation modes. To correctly write TGP software, the B-1B Interface Control Document (ICD) was referenced side by side with the Lockheed Martin design interface for the TGP. The ICD thoroughly explains required design parameters and implementation of coding to achieve system integration [8]. This allowed the conversion of C++ TGP coding to adapt to the B-1B programming format. The B-1B avionics flight software coding was modified to meet existing ICD requirements while providing the correct control interface to the TGP. Command and control testing was completed using a TGP simulator while MIL-STD 1553 bus traffic was verified to assure messages were passed to the pod in the correct format such as bit size, content, expected frequency, etc. From a laboratory integration standpoint, thorough testing of the system was completed. The laboratory methodology applied to this program should also be pursued during SDD (R8).

MODELING AND SIMULATION

Modeling and simulation were key elements used to analyze the bomber and TGP aerodynamic effects including any structural interactions between them. The results of these analyses were used to support the flight test program.

A NASTRAN finite element model as shown in figure 13 was used to perform structural mode analysis of the aircraft and pod mounting system. The study provided a flutter prediction for flight test. [www.mscsoftware.com, 17]. The results of the flutter analysis study were later used to develop the test plan for the Ground Vibration Testing (GVT) and finally flight aerodynamic testing. The model helped predict modes, behaviors, and frequencies of interest for the pod and aircraft interaction under varying structural conditions. Associated flight dynamics that drove these structural modes could not be determined with this model.

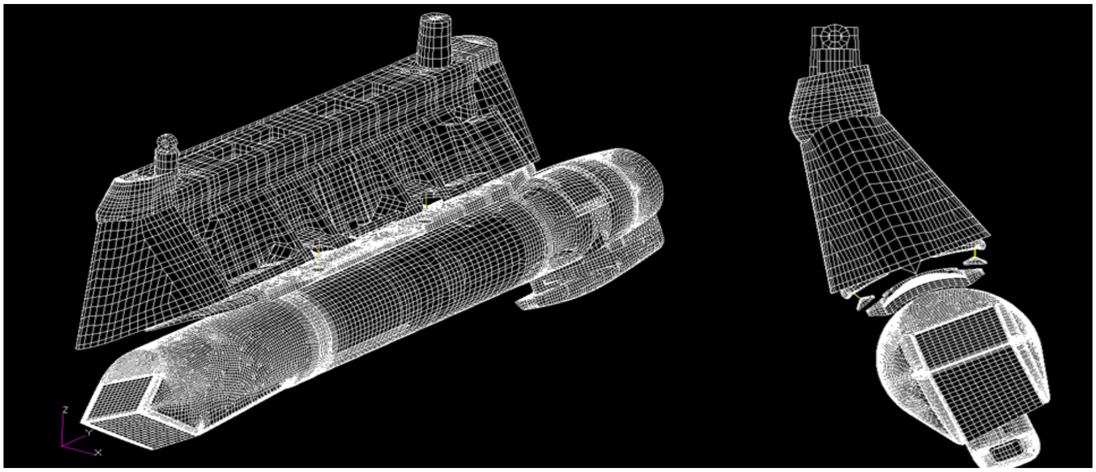

Figure 13. Nastran Model (Flutter Analysis) [5, 15]

A MECHANICA Model using a coarse grid structure was used to represent the complex surfaces of the TGP with varying shape. A model of the pylon was developed by Boeing, and the pod was simulated by a load that represented the pod's weight [17]. The purpose of this model was to determine structural integrity of the pylon pod mounting design. A detailed stress analysis was performed with a capable model of this configuration [www.ptc.com/products/]. This model allowed variations in conditions such as applying forces in all axes to simulate dynamic loaded flight conditions. The results of the analysis indicated that the loads on the pylon were negligible and that the design could handle forces well beyond those that would be achieved in the B-1B flying envelope. This pylon design could also carry external weights far greater than the TGP. Figure 14 depicts the MECHANICA model with a sample color loads scale used to perform visual cross-checks of data. In the left figure blue represents a no-load condition and other colors such as red represent increasing changes in loads under a given condition.

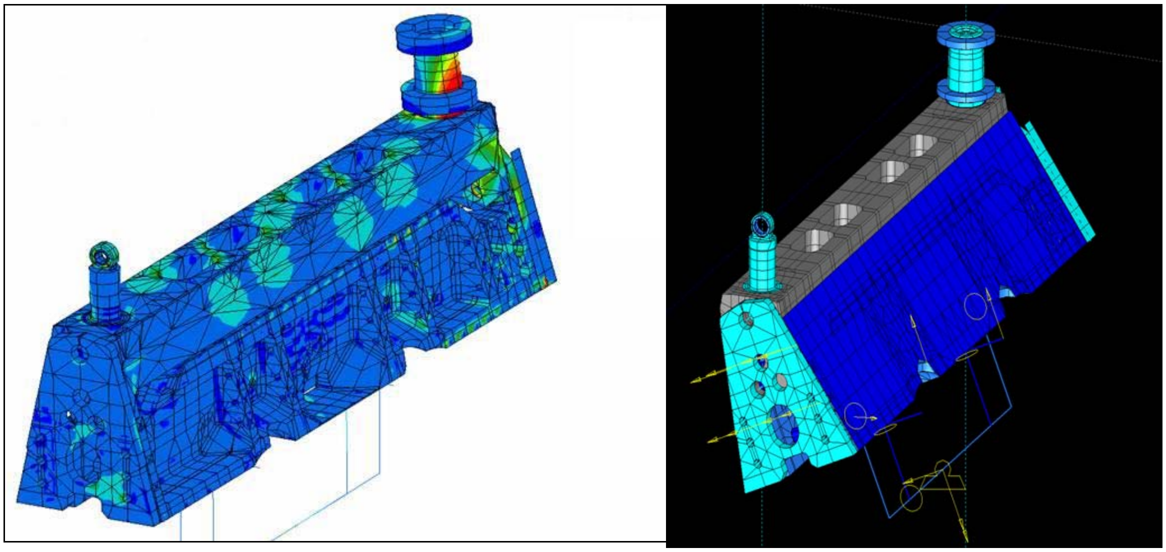

Figure 14. Mechanica Model (Stress Analysis) [5, 15]

COMPUTATIONAL FLUID DYNAMICS (CFD)

Completing the modeling and simulation effort, CFD was used extensively to provide aerodynamic analysis effects of the pod/pylon on the aircraft structure and weapon bays. CFD also provided weapon separation characteristics based on aerodynamic flow [18]. Figure 15 is an example of a CFD grid used in the analysis. This figure represents a developed grid about the TGP at a fixed distance from its leading edge. By combining multiple grid layers such as the one depicted, a complete 3D analysis can be performed.

The CFD analysis was completed by the Air Force Seek Eagle Office (AFSEO). They provided an investigation of the aerodynamic effects from the TGP on the B-1B, an analysis of the disturbed airflow effects on engine nacelle and weapon bay doors, and an analysis of weapon separation effects from the TGP.

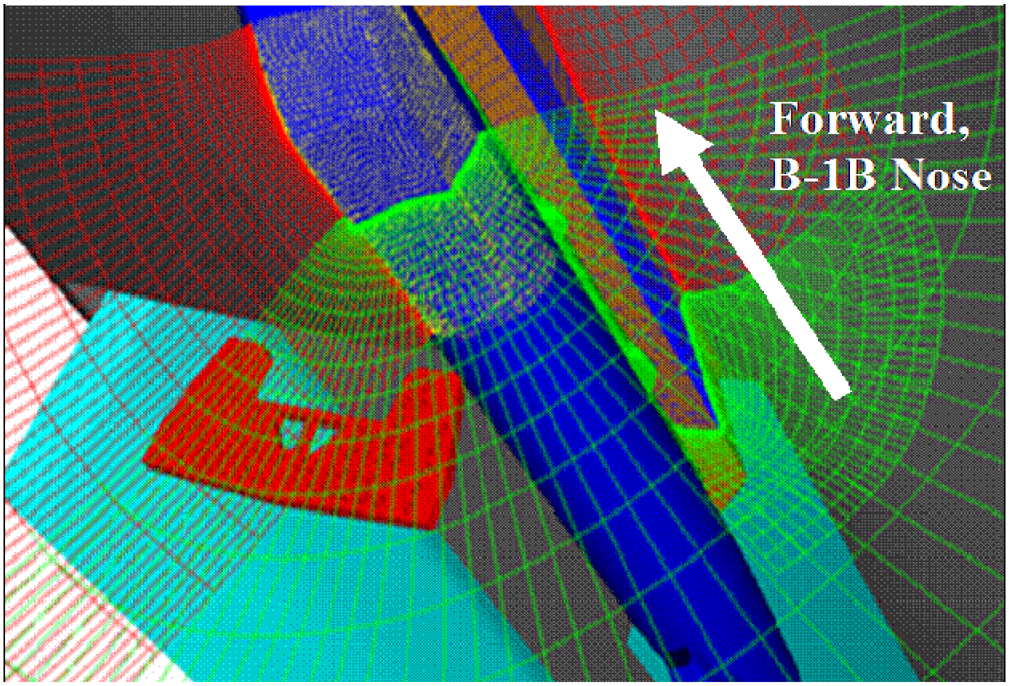

Figure 15. Sample CFD Grid Development (Pod, Pylon & Fuselage)

AFSEO used a "Delta" approach in their analysis. In the Delta method, CFD was run in a clean configuration, without a pod or pylon. This analysis was then repeated with a pod, a pylon, and with both as the final configuration. The results were imposed on a Cartesian grid and subtracted from each other, yielding a “Delta” to show the effects of the additional hardware.

The solution allowed for a visual presentation of results for quick interpretation along with the analytical results or the composite grid [18]. Figure 16 represents a two-dimensional time step solution to one of these runs. Very similar to a Computed Axial Tomography (CAT) scan, these individual layers were combined to provide a full 3-D model.

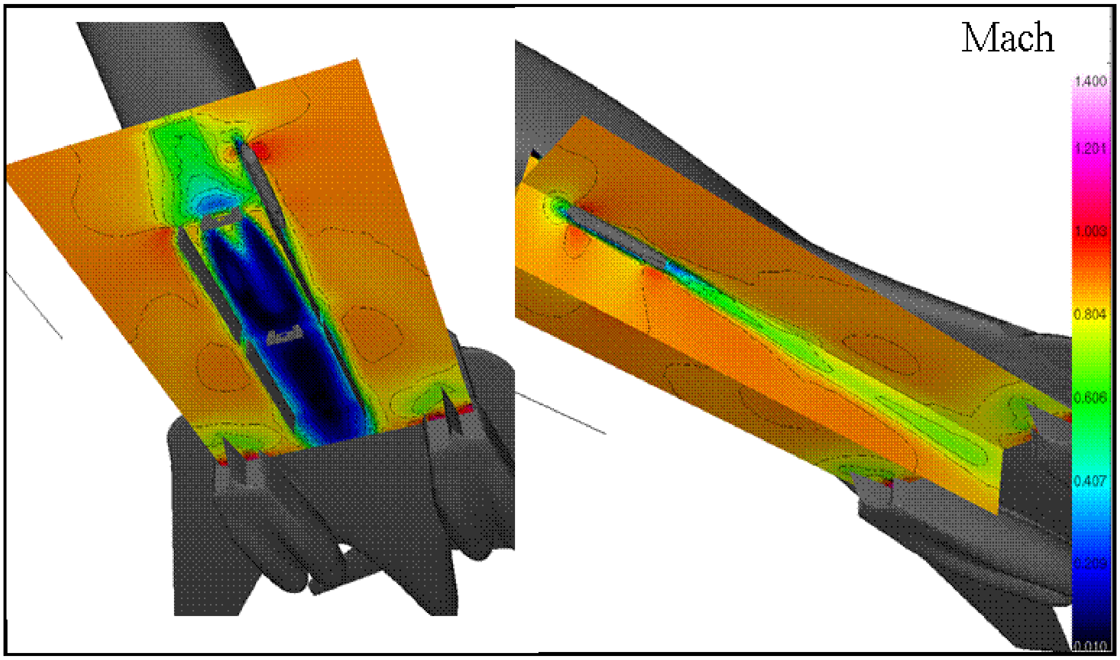

Figure 16. Discrete CFD Time-slice (Horizontal Plane)

CFD analyses were very intensive and required up to 14,000 processing hours to analyze 66 million grid points [18]. Figure 17 shows these solved CFD layers propagated from fore to aft of the aircraft and left to right. Here the colors indicate varying Mach numbers caused by flow characteristics of the different aircraft components to include the TGP. As can be seen in the right side of the figure, the TGP causes flow distortion downstream at the given Mach number. By using such discrete samples, a particular location of interest can be isolated for further investigation.

CFD in conjunction with the other modeling and simulation was used to recommend the concept demonstration flight test profile.

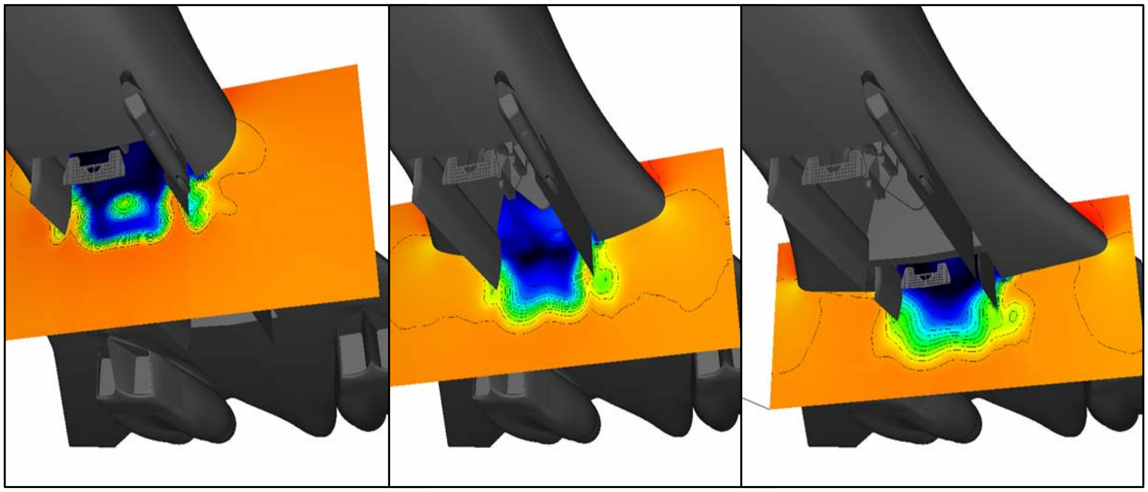

Figure 17. Discrete CFD Steps; Forward to Aft Longitudinal Axis

For example, it was suggested that flight testing begin by following lower dynamic pressure (q) contours with increasing altitude and then repeating with higher q contours. By following these contours, the test team could focus specifically on the aft portion of the forward bay and the intermediate weapon bay approaching the high subsonic region. For optimum weapon employment, the high subsonic region is of greatest interest. CFD results indicated that for weapon release scenarios, the intermediate weapon bay would pose the most concern from a flow distortion perspective. An expected vortex shedding was expected to occur in this regime that could affect the intermediate weapon bay and the inboard left engine nacelle. Figure 16 shows a 0.9 M high q condition with vortex shedding from the TGP installation [6].

This analysis indicated that following the contours of q when approaching higher Mach numbers would require caution. Another test condition of interest was with the nose landing gear extended and the aircraft flying at approach speeds. In this case, disturbed airflow shed from the nose gear was expected to excite TGP structural modes by impinging on it. CFD provided the critical analysis to correctly determine a conservative approach for initial flight tests.

Many different configurations were available for CFD analysis. The aircraft employs three types of weapon suspension systems referred to as modules or launchers. The modules consist of the two different Conventional Bomb Modules (CBM) and a Conventional Rotary Launcher (CRL). Each of these modules can carry different types of weapons and in some cases mix these weapons on a module. Additionally, each module has unique locations inside the weapon bay where the weapons are released. Each launcher also has unique weapon release characteristics, dependent on the weapon, module, location, and dynamic flight environment.

Since the planned testing was limited in scope, the CFD analysis was performed for a few weapon configurations and over a relatively small portion of the aircraft envelope. Table 1 summarizes the flight conditions and configurations that were analyzed. In this table, the aircraft was modeled with and without the TGP. The scenarios were completed with different weapon carriage systems such as CBM and the CRL. These modules allow different types of weapons to be carried at varying positions inside the weapon bay.

Table 1. CFD Test Points Initial Demonstration [6]

Weapon Bay Door Position FWD/INT/AFT	Pressure Altitude X1000 ft	Weapon Suspension System	TGP Mounting
FFF	15	CBM	On/Off
FFC	15	CBM	On/Off
CFC	15	CBM	On/Off
FFC	15	CBM	On/Off
FFC	3	CBM	On/Off
FFC	3	CBM	On/Off
PPC	3	CRL	On/Off
CPC	3	CRL	On/Off
Conditions Analyzed With Stores at Varied Altitudes			
FFC	GBU-38	CBM	On/Off
FFC	Mk-82	CBM	On/Off
FFC	CBU-105	CBM	On/Off
PPC	GBU-31	CRL	On/Off
Note: F=Full Open, P=Part Open, C=Closed Note: CBM= Conventional Bomb Module CRL= Conventional Rotary Launcher			

Therefore, the analysis considered each of these modules, door positions, and various employment altitudes. CFD was vital in helping to determine critical weapon configurations and flight conditions to reduce flight test risk while improving test safety. During SDD a much more comprehensive analysis of critical configurations should be completed to assess weapon separation characteristics not tested during the demonstration effort (R9). This analysis should include all variables related to the critical configurations and flight conditions affecting safe weapon separation [http://www.eglin.af.mil/afseo/].

Another tool used concurrently with CFD, but not in this effort, is Design of Experiment (DOE). DOE uses tables that statistically quantify interactions between measured factors and indeterminate measurements of factors [www.isixsigma.com/dictionary/Design of Experiments]. By applying DOE, the required amount of modeling and testing can be reduced. The solution would allow planning to limit the number of flights while maximizing weapon envelope testing. DOE would provide the optimum combinations of weapons on each flight to start the process. Establishing a priority scheme would allow for timely releases of weapon flight clearances to the field for the weapons that are expected to be used the most. For example, Guided Bomb Unit (GBU-31/38), JASSM, and Wind Corrected Munitions Dispenser (WCMD), would take priority over the Joint Stand-Off Weapon (JSOW), MK-84, MK-65, and MK-82s based on employment needs. DOE planning and CFD analysis should be used for the final TGP integration to prioritize weapon testing and optimize test resources (R10).

4. GROUND DEVELOPMENTAL PROCESSES

GROUND VIBRATION TESTING (GVT)

Ground vibration testing was conducted to determine structural responses exhibited by the TGP and pylon. The aircraft was configured for the test by placing shakers on the TGP and pylon in multiple axes and angles to attempt to stimulate anticipated modal responses observed during flight under different loading conditions. The shakers used a direct impulse method to apply a range of frequencies to the test object. Frequency applications were controlled via a computer and frequency amplitudes were monitored and adjusted to keep the modal responses bounded.

In order to obtain the feedback of the modal responses, small tri-axial accelerometers were attached to over 100 locations on the pod and pylon mounting [21]. These accelerometers were accurately mapped into a computer program that generated a wire diagram model of the system response. Post test responses could be analyzed visually via a video playback of the model. Additionally, GVT information was digitally stored to provide engineering analysis throughout an entire frequency spectrum. Since the accelerometers were very small, their measurements were recorded in inch pounds (in/lbs) and converted to foot pounds (ft/lbs) for modeling and analysis. The aircraft was not raised from the floor, and air was left in the tires. It was assessed that the pneumatic damping potentially provided by the tires would not affect any modal responses of the pod to aircraft interaction.

The results of the GVT indicated that several low frequency responses provided up to 39 structural modes on the pod below 100 Hz while frequencies above 100 Hz were attenuated similar to the aircraft response without the pod. When comparing the lower frequencies to those of the aircraft and weapon bays, it was determined that between four Hz and 50 Hz, shared harmonics of the TGP and aircraft are present [15]. Table 2 shows some of the TGP structural frequencies that are the most apt to cause a coupled structural response between the aircraft and TGP.

Figure 18 details an overlay of TGP discrete frequencies that are at or near the peak pressure responses of the forward and intermediate bays, and the weapon bay door power spectral density. These bay and bay door aerodynamic loads were determined from flight tests of the original bomber design to refine spoiler configurations that would suppress the dynamic cavity noise of the weapon bays.

Table 2. Sample TGP Structural Frequency Modes Exhibited During GVT [1]

Mode	Frequency Hertz	Type of TGP and Pylon Motion
1	2.6	Aircraft forebody vertical, Pod Lateral Rock
2	4	Pylon/Pod rigid body roll
3	14.6	Pod Lateral Rock
4	28.7	Pod Lateral Rock
5	34.4	Pylon rigid Body Pitching Coupled with Pod Pitch and Yaw
6	39.7	Pylon and Pod Yawing out of Phase

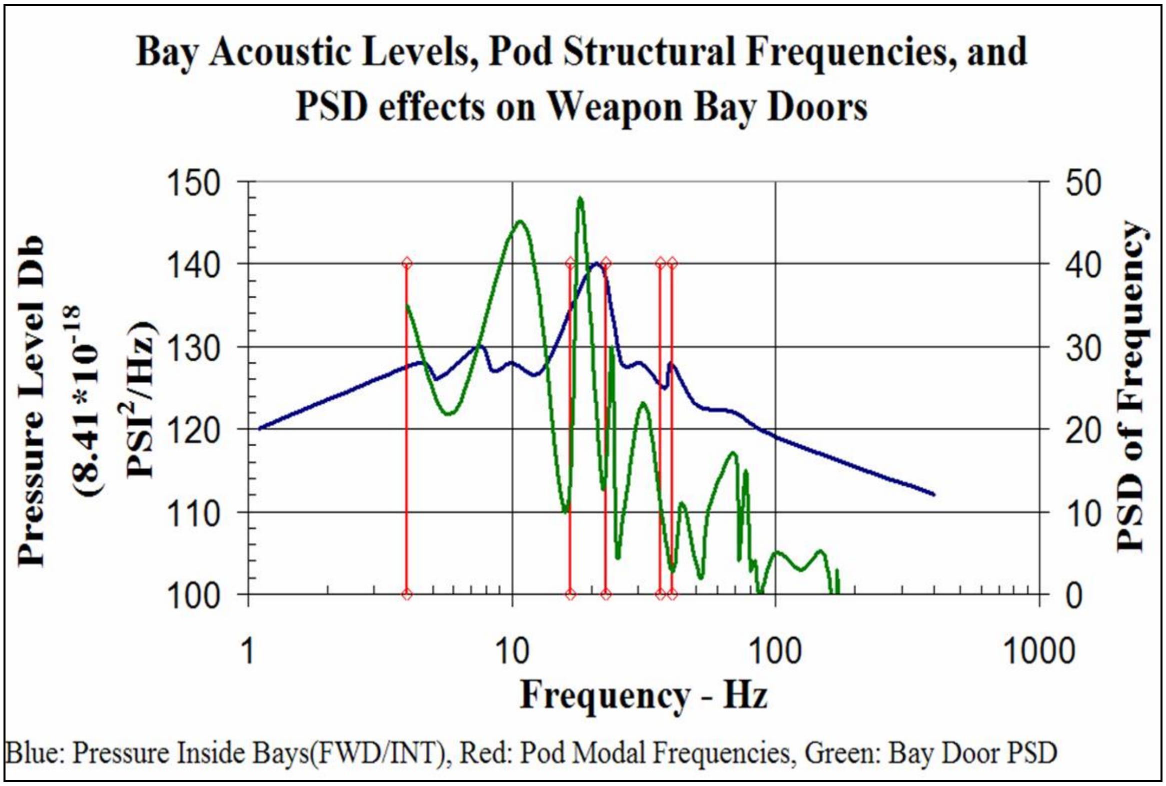

Figure 18. Comparative Response of Weapon Bay Dynamics to TGP Modes [6, 15, 20]

Initial studies also revealed that the weapon bay doors have four natural frequencies of approximately 16, 32, 42, and 62 Hz respectively [20]. These frequencies were very close to four TGP response modes determined in the GVT that associate with pod bending, pitching, and yawing. An excited response from the TGP can be present at the same time a weapon bay is being excited causing a coupled response leading to structural fatigue.

Even though these aircraft modes were all bounded, a concern was raised that the interaction of these two independent structures could cause stresses or loads that are incompatible in certain flight regimes. Additionally, other observed TGP structural frequencies common to aircraft structural modes including the nose gear assembly may cause undesirable aerodynamic loads on the downstream TGP.

The GVT was completed with the pod and pylon combination and the pylon only mounting to provide data supporting the aerodynamic and structures testing of both aircraft configurations. After the GVT was completed the results were used to update the structural model. The updated model was used to define the conditions for flutter testing.

Since the modes of the basic aircraft are now well understood, and a data base exists from thoroughly testing the aircraft during development, there is no need to perform further GVT unless structural issues not currently anticipated are discovered during the concept demonstration flight test program.

ELECTROMAGNETIC INTERFERENCE COMPATABILITY (EMIC)

Following any major change of special instrumentation (SI) or the addition of new flight systems or hardware on the aircraft, a safety of flight electromagnetic interference test must be performed. During the TGP modification the major items of interest for the EMIC were the operating pod system, the use of new MIL-STD 1553 data transmission lines from the pod to the aircraft interface, and the onboard instrumentation. This instrumentation included data acquisition units mounted on a specially modified weapon launcher. Other SI included sensors wiring, power supplies to support the SI interface, and the alteration of pre-existing nuclear wiring.

EMIC testing was scheduled for early July 2006. The EMIC followed historical procedures that tested aircraft and TGP systems each as a source of interference, and as a victim of interference. An EMIC procedure is extensive and attempts to isolate and correct any interference that would preclude normal flight operations.

Since flight test on the pod was considered limited in scope, an EMIC was only performed with weapons in the intermediate bay to support a weapon release from that bay in flight. However, for this program, modifications of pre-existing nuclear wiring were completed in all three weapon bays. Since the TGP modification was a direct alteration of weapon control interfacing in each bay, these components should require a complete EMIC test that exercises the AFS weapon interface to all three bays.

B-1B systems specifications require a complete EMIC of all associated aircraft and weapon systems when a new component is introduced or altered on the aircraft. This more complete weapon analysis required during the EMIC would include using MIL-STD 1760 guided weapons, and the associated weapon carriage components to determine any potential data bus communication anomalies [27]. For the fully developed pod effort, a full scale EMIC should be performed using an aircraft that is representative of all flight test conditions including defensive systems checks, and weapon bay interference checks for all three bays (R11).

LOGISTICS SUPPORT

During the demonstration effort, many logistical areas were addressed that could be carried through SDD. The maintenance and support chain was addressed and planned from the start with a systematic approach. The analysis focused on resources required to maintain and operate the TGP including materiel and personnel, and the reliability of the TGP. Equipment used to support the TGP was determined, and the level and type of maintenance required to support this equipment and the TGP were identified. The planning phase addressed manpower requirements for maintenance as well as how to provide tools for system training.

Several draft Technical Orders (T.O.s) were completed to support the pod effort. The T.O.s provided the necessary requirements for loading, maintaining, and operating the TGP. During reviews, draft T.O. changes were developed that would alter current aircraft publications, and the plan was to use these changes during the TGP concept demonstration. These efforts would not lead to a certification of the new publications, but would be updated during the program as required, and archived for use when the final TGP SDD effort takes place [5]. By analyzing the logistics effort involved in the preliminary pod investigation, it was apparent that bomber and TGP logistic support were very mature and the process could adapt to requirements generated from a program.

Since the test effort was only a demonstration, logistics support did not perform or evaluate maintenance areas that are addressed with human factors studies. For example, maintenance and weapon load crews were not assessed on performing normal support requirements with other than normal environmental conditions [5]. Before SDD begins, a logistics support human factors focus should be performed that addresses environmental adversities such as cold weather or chemical defense posture handling and support (R12).

Overall logistical support and assessment were at the level required for the TGP demonstration, and would be able to provide increased support during a more in-depth test and development effort.

CREW TRAINING

To achieve better results before flight testing began, aircrews required pod operation training, ideally in a dynamic range environment. There were several facilities that could support limited aircrew training and would be required since the AFFTC did not have a complete training facility and environment. These facilities each offered unique training capabilities, but were either limited to controls and displays or not co-located with the flight test center.

One such facility was United States Navy (USN) at China Lake, California. China Lake facilities provide a dynamic range environment where targets are presented in actual field conditions that include target clutter, different classes of targets, and an equivalent electro-optical signature such as heating a vehicle. Additionally, the China Lake facility included the user interface controls and displays, a cockpit mockup, and a dynamic range environment. Aircrews planned to utilize the China Lake facility to enhance training before flight test.

Another facility that supported aircrew training was the Engineering Research System (ERS) at Wright Patterson AFB, OH. The ERS laboratory incorporated a system mockup which was to be used before a working TGP was integrated into the Integrated Facility for Avionics and Systems Test (IFAST) located at Edwards Air Force Base (AFB), California. The ERS provided a simulated dynamic flight environment that emphasized the functionality and operation of the pod.

IFAST was the most accessible ground training facility used by the test team. Before flight testing, a working TGP was incorporated into the existing B-1B system trainer which consists of a Software and Hardware Integration Laboratory (SIL/HIL). This hardware included operational radar components. Crews were trained on basic operation of the pod and the hand controller and laptop. IFAST did not incorporate a dynamic range environment.

Testing can be greatly improved by exposing aircrew to aircraft and the support facilities that provide training on these systems. By taking this approach, aircrew can learn and develop tactics, gain understanding of TGP system operation, and become proficient with the operator interface. Aircrew can also develop target study and assessment skills by having a dedicated target range. A dynamic range would reduce the need for more expensive flight test by providing realistic ground training. Lessons learned and techniques from this training could be applied by aircrews testing the system. It would be essential to this and other test programs to evaluate the need for a dynamic range environment at the AFFTC to support TGP test requirements (R13).

5. PLANNED FLIGHT TESTING

The last section of this thesis addresses the flight test planning processes associated with TGP testing. Four major areas that were planned for the demonstration flight were aerodynamics, flying and handling qualities, system integration, and weapon separation testing. Aircraft performance with the TGP installed was not planned because the TGP would not significantly reduce performance [15]. Handling qualities and weapon separation testing was also very limited in effort.

AERODYNAMICS

Aerodynamic flight testing was targeted at clearing the normal operational flight envelope for the B-1B. Table 3 indicates the maneuvers planned to assess aerodynamic effects and structural loads. These maneuvers are often associated with determining aircraft performance, but are equally reliable for extracting aerodynamic and loads data. From the different maneuvers, dynamic pressures, and airspeeds planned, table 3 represents over 150 test points when all conditions in the chart are accomplished. Aerodynamic flight tests were planned with the pod mounted to the pylon and pylon only configurations. The purpose for testing the pylon only was to assess aerodynamic effects of an operational configuration where a TGP may not be available or required, but retaining the pylon was viable.

Table 3. Planned Aerodynamic Maneuvers [22]

Aerodynamic Test Maneuver	Mach/Airspeed (Kts)	Altitude Mean Sea Level (MSL)X1000 ft	Wing Sweep (degrees)
Take Off & Landing (Yaw)	240Kts-0.2M	Field Elevation-5	15-20
Yaw investigation	0.70-1.15	5-30	>65
Bank to Bank Roll	0.70-1.15	5-30	>65
Wind Up Turn	0.70-1.15	5-30	>65
Push Over Pull Up	0.70-1.15	5-30	>65
Pitch Doublet	0.70-1.15	5-30	>65
Yaw Doublet	0.70-1.15	5-30	>65
Spiral Stability	0.70-1.15	5-30	>65
Notes:			
1) Points flown at approximately every 0.05 Mach 2) Points flown to obtain data at dynamic pressures of 300,450,600,800, &1000 pounds per square foot (psf) respectively 3) Wing Sweep at lower Mach may be adjusted to 45,55, or as required			

The aerodynamic test plan included landing gear extended test points. The gear extended conditions were intended to test the landing configuration characteristics of the aircraft while investigating the disturbed airflow effects of the nose gear assembly on TGP structural modes. Figure 19 shows the extended nose gear and close proximity to the TGP. As can be seen with the TGP at the chin pylon station, the nose gear assembly and the TGP are closely aligned. With this close proximity, the airflow disturbance and vortex shedding associated with the nose gear assembly was expected to impinge on the TGP. Under certain flight conditions, this disturbed airflow could excite structural modes of the TGP [9].

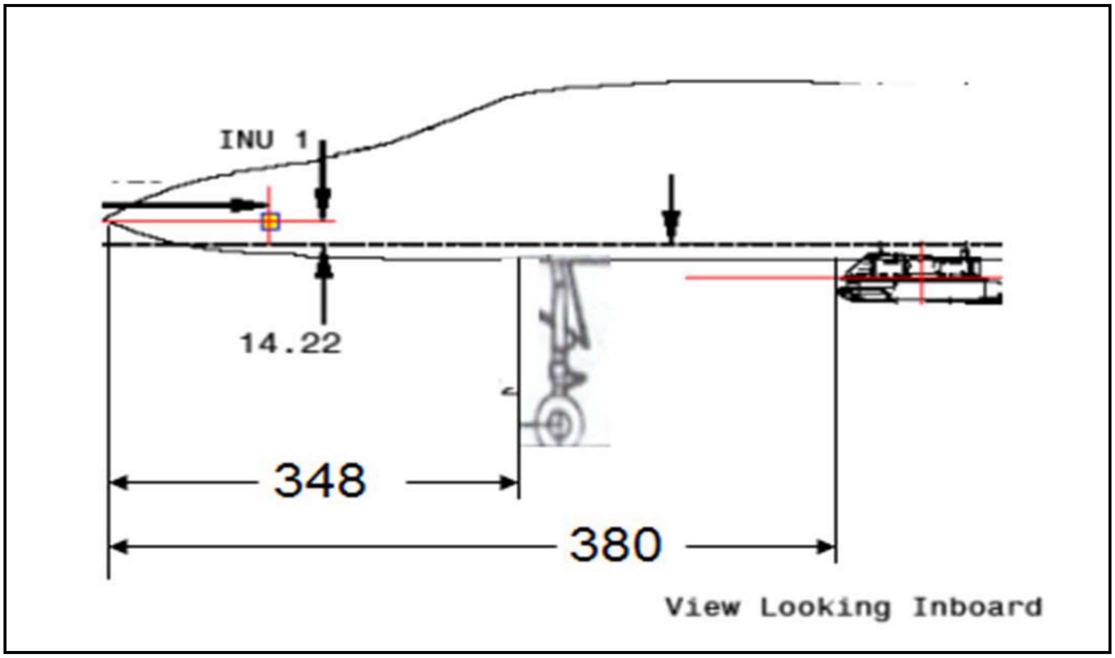

Figure 19. Longitudinal Position in Inches from Datum of TGP and Nose Gear

The landing gear extended test points were planned to be flown up and away greater than 7,000 ft above ground level (AGL) using a build-up approach in dynamic pressure (q). This flight condition allowed for altitude to recover the aircraft if adverse flight conditions are experienced that cause controllability problems. These test points will begin at the higher indicated airspeeds and then decreased in 10 Knot (Kts) intervals. Controllability checks are planned at each airspeed before proceeding to lower airspeeds that approach stall.

The approach used for aerodynamic testing is shown in Figure 20. In this approach, the q lines will be tested at specified airspeeds, and then the process will be repeated at higher q with increasing Mach. The final portion of the testing requires a climb to a higher

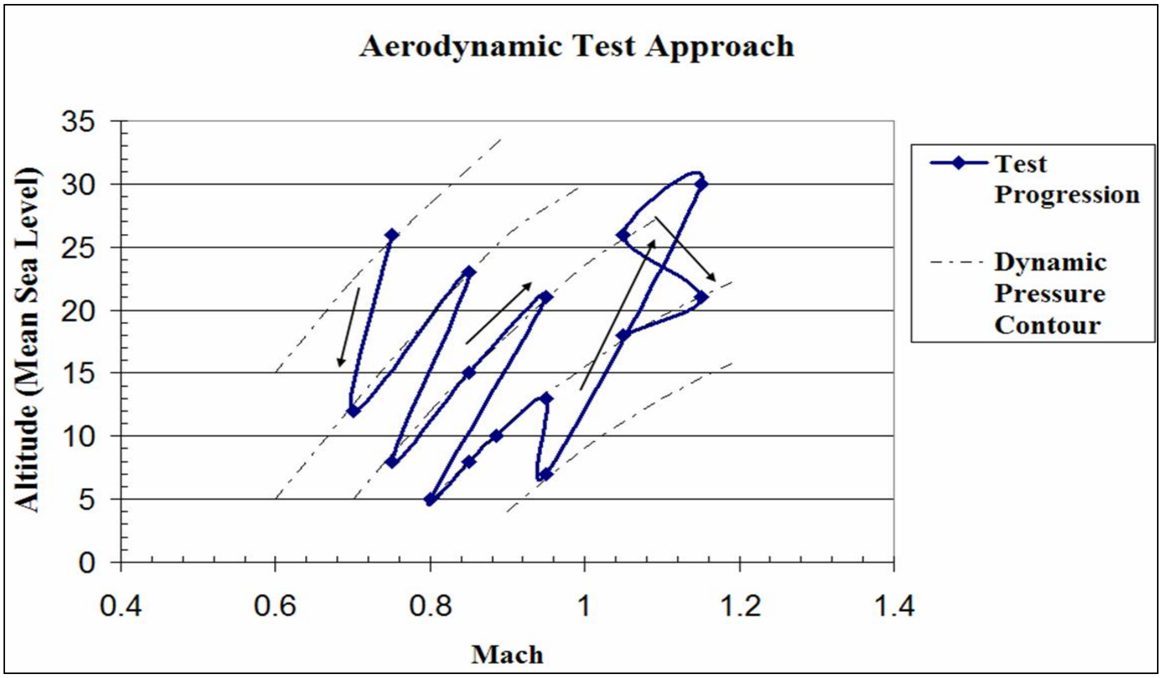

Figure 20. Planned Aerodynamic Test Profile [22]

altitude with decreasing q to assess the envelope around and beyond the transonic region (0.95-1.05M). Aircraft performance and fuel efficiency warrants the deviation from pursuing lines of constant q beyond the transonic region as shown by the serpentine line in Figure 20.

Clean configuration testing was planned in two phases for the concept demonstration. The first phase addressed flight points where no weapon bays were opened. The second and more important test called for the weapon bay doors to be opened. The test team selected test conditions based on GVT results and modeling and simulation analysis. GVT results provided the TGP structural frequencies and loads, but did not identify what flight conditions would excite these modes. CFD predicted some loads at discrete flight conditions, but was not capable of assessing modal responses between the aircraft and TGP. The CFD analysis provided a set of flight conditions where vortex shedding from the pod could occur [6]. This prediction was used to plan testing so as to approach questionable regions with caution. Together GVT and CFD analysis provided an understanding of flight conditions where the TGP and aircraft interact adversely or exhibit undesirable characteristics. ALCM testing data was also used to help construct the flight test. During the ALCM testing, inlet distortion was observed at supersonic airspeeds requiring aircraft flight restrictions [15]. By comparing the TGP to ALCM, emphasis was placed on the approach to the supersonic region. Testing was therefore planned to build-up to the critical flight conditions and to clear the B-1B flight envelope for TGP carriage. This plan provided the flexibility for the test team, which allowed them to make real time alterations to the test profile. The planned flight maneuvers included: yaw investigations, bank to bank rolls, wind up turns (WUT), and push over pull ups (POPU) [22].

Yawing maneuvers will be performed by applying a steady rate rudder input while maintaining a constant heading. These steady heading sideslips will occur in both directions to assess the effects of vortex shedding on flight characteristics, engine performance, and structural loads. Bank to bank rolls will be flown by applying a half lateral stick deflection step input from an initial 45 degree bank to the opposite direction of the bank. These maneuvers will help assess aircraft rolling effects on vortex shedding and any interactions of these disturbances on structures, nacelles, and engine performance.

As with the yaw investigation, engine operations will be assessed qualitatively by the aircrew as instrumentation was not established specifically for engine performance. The Central Integrated Test System (CITS) computer can be used post flight to analyze engine parameters if an anomaly is suspected, but will not provide detailed information on factors responsible for that anomaly. Bank to bank rolls will also be used to provide aircraft handling data on any incurred proverse or adverse yaw due to the asymmetrical mounting of the TGP.

The WUTs will be executed by increasing bank angle and angle of attack at constant Mach during a descent. These maneuvers were planned at aft wing sweep to allow for maximum aircraft g loading. WUTs allow for collection of pod vortex shedding interactions, boundary layer investigations, and overall effects of aero-loading over a range of AoA and Mach numbers. Pilots will also be able to assess handling qualities during these maneuvers. The POPU or roller coaster maneuver allows for aerodynamic testing of the different configurations at low AoA. This consists of a series of wings level pull-ups and push-overs at planned Mach numbers [23, 24].

Open-loop test points were planned concurrently with the aerodynamic testing to assess aircraft responses with the addition of the mounted TGP. These points will be initiated by applying step inputs in each axis and observing aircraft response. Overshoots in pitch, yaw, and roll will be measured over a time period to make an assessment of damping ratios. These maneuvers will be flown first without a pod mounting to gather current baseline data on the test aircraft.

At the completion of the aerodynamic testing the flight envelope for the pylon only, and TGP and pylon configuration will be defined. Any restrictions or limitations from the analysis of this testing are expected to be applied to the final TGP implementation. These aerodynamic tests will qualify the TGP for flight, and negate the need for further aerodynamic testing barring the discovery of any unforeseen problems

POD EFFECTS ON AIRCRAFT PERFORMANCE

The drag assessment of the mounted pod was determined to be less than 40 percent of an ALCM and Advanced Cruise Missile (ACM) configuration [15]. Based on this analysis, performance testing will not be accomplished in the concept demonstration testing.

FLYING AND HANDLING QUALITIES

During the concept demonstration test, a limited flying quality assessment was planned. The planned tasks that will be flown concurrent or in addition to the aerodynamic points are in table 3 and will provide pilots insight to aircraft characteristics before progressing to a closed-loop evaluation [23]. Pilots will generally evaluate flying qualities during and between aerodynamic test points. A more specific closed loop handling evaluation is planned to evaluate an air refueling task using a Cooper-Harper rating scale. The data will be collected and presented in a histogram format with associated comments. The air refueling task will be flown first in a clean configuration to provide a comparison point for pilots before performing the Cooper-Harper assessment with the TGP and pylon.

The concept demonstration testing limits handling qualities testing and should be expanded to assess several unique B-1B handling qualities concerns. During the prototype bomber testing several flight characteristics were identified that made flying the aircraft less than optimum under varying flight conditions. These included pitch sensitivity at high Mach number, and light lateral axis damping in almost all flight regimes. For example, the pitch axis is sensitive to input as compared to the lateral axis leading to poor control harmony, and the aircraft exhibits Dutch Roll characteristics during landing tasks without stability augmentation [7]. Other characteristics leading to flight coordination concerns include pitch excursions when performing high load factor turns and very high roll rates as compared to turn rate.

The addition of the TGP warrants a more in-depth study of HQ to determine whether HQ characteristics have been further degraded in the areas mentioned above. Table 4 lists a set of tasks where aircraft damping ratios, control harmony, and general aircraft characteristics observed during prior prototype bomber testing may pose a challenge when flown with the TGP. Aircrew should determine whether the addition of the TGP alters handling qualities adversely by performing the suggested handling evaluations (R14).

Table 4. Author's Suggested Handling Evaluation Tasks

Handling Evaluation	Mach/Airspeed (Kts)	Altitude Mean Sea Level (MSL)x1000 ft	Wing Sweep degrees	Target Parameters
Visual Contour Bomb Run	0.7-0.9	2 MSL-500 ft AGL	>65	Pitch, Hdg, Airspeed
High Altitude Bomb Run	0.75-1.2	>25K	As Rqd	Pitch, Hdg, Airspeed
Precision Approach (ILS)	240Kts-0.2M	Glideslope Intercept to Decision Height	<20 or As Rqd	Course Guidance, Glide slope, Airspeed
Defensive Reaction (Level Notch > 90 deg of turn)	>1.1M-Corner Velocity	>25 down to >500 AGL	As Rqd	Altitude, Airspeed, Heading, g
Defensive Reaction (Descending Notch)	>1.1M-Corner Velocity	>25	As Rqd	Altitude, Airspeed, Heading, g
Manual Letdown to Low Level	~0.9	>20	As Rqd	Recovery Angle, Airspeed, g

SYSTEMS INTEGRATION

The system integration phase of testing is planned to address the compatibility of the TGP with the aircraft navigation, radar, and targeting systems. To validate navigation compatibility, the test plan includes measuring and analyzing data from initial ground alignment, and in-flight alignments. Additionally Inertial Navigation Unit (INU) data from both the aircraft and pod will be collected on each flight profile and compared for accuracy. After completing these first few flights, the TGP navigation model filter will be tuned if required to more closely track aircraft performance.

Pod slaving to the radar will be systematically measured during test flights by sampling TGP generated target coordinates at different ranges, angles, and altitudes. The aircraft radar will be used to track the target and the pod will then be slewed to the radar or slewed from the initial track. The TGP generated coordinates will be compared to the mensurated coordinates and the accuracy errors recorded to provide a statistical sampling of the performance.

During the final TGP implementation on the B-1B, another important capability in complete system integration should be addressed. The final TGP design should apply bi-directional system integration such that the aircraft or TGP can pass and receive target information from any available source on the aircraft. The concept demonstration only allows for the pod to receive aircraft targeting and alignment information and does not consider the aircraft receiving any targeting or navigation data from the TGP. In this case, target coordinates generated by the TGP will have to be typed into the aircraft weapon system by the aircrew. Also, the aircraft radar will not slew to the TGP during this testing. Such integration shortfalls limit targeting capability and increase aircrew workload.

The flight testing which is planned is adequate to determine the level of integration established for a demonstration test, but as functionality is expanded in the final TGP implementation, system integration flight testing will require more focus on implementation of integrated AFS to TGP capability. A fully integrated system must allow the TGP and aircraft to send and receive targeting and alignment data bi-directionally (R15).

WEAPON TESTING

Planned weapon testing during the TGP demonstration is limited to two weapon separation conditions. To complete this preliminary sampling of store separations, AFSEO analyzed GBU-31 and GBU-38 releases from the intermediate bay. Table 5 shows the planned test points to validate the analysis. The goal of these releases is to make an initial assessment of the CFD results and validate this model while taking a cursory look at the effects of the TGP on weapons separation.

Because the CFD analysis indicated that the intermediate weapon bay was the most critical location with the TGP configuration for weapon separation, this bay was chosen for the limited weapon releases.

Table 5. Concept Demonstration Planned Weapon Separation Testing

Release Store	Weapon Bay Door Position (FWD/INT/AFT)	Carriage Module	Bay(s)	Module Stations	TGP & Pylon Configuration
GBU-31 2000 lbs	F/F/C	CRL	INT	NA	On
GBU-38 500 lbs	F/C/C	SECBM	FWD	C21 or D22	On

Note: F=Full, C=closed. C21, D22=individual positions in forward bank and aft bank of SECBM respectively.
Note: SECBM= Conventional Bomb Module equipped for 1760 weapons.
CRL= Conventional Rotary Launcher, weapon release always from down station.

Therefore, if these releases are nominal, further testing can proceed with confidence that the results will be good since other configurations are expected to have better separation characteristics.

These two planned releases will provide data points for future weapon configurations testing and will not clear the entire bomber release envelope. In order to clear multiple weapon release envelopes, results of previous separation testing should be considered. As an example, prior to the TGP effort, Joint Air to Surface Stand-Off Missile (JASSM) had required no less than six releases to clear the employment envelope.

The JASSM plan required more effort to clear the intermediate weapon bay due to weapon and aerodynamic characteristics in the high dynamic pressure regime. The results were intermediate bay JASSM release restrictions [19]. Similarly, the TGP is expected to influence weapon separations in the intermediate bay, and the JASSM plan shown in Table 6, would be comparable to the TGP effort.

Using available weapon integration plans such as JASSM for planning purposes, a thorough approach to TGP integration with weapon delivery can be achieved. Such previous testing had focused on known conditions where weapon separations were abnormal. The JASSM testing focused on the intermediate bay while other tests focused on anomalies in the aft bay and flow distortions in the bays caused by the engine nacelles. From these combined tests, multiple release restrictions based on airspeed, weapon

Table 6. Previous JASSM Weapon Separation Testing [26]

Sortie	Fwd Bay	Intermediate Bay	Aft Bay
A	Empty/MPRL	JASSM	Empty/MPRL
B	JSOW	JSOW	JSOW
C	JSOW	JSOW	JSOW
D	JASSM, JSOW, JDAM	JASSM, JSOW, JDAM	JASSM, JSOW,JDAM
E	JASSM, JDAM	JASSM	JASSM
F	JASSM	JASSM	JASSM
G	JASSM	JSOW	JDAM
H	Empty	PAR/MK-82,JASSM	Empty

Note: Totals released during flight test: 6 JASSM vehicles, 10 JSOW vehicles.
Only type of weapon listed in bay, and number of weapons carried and released vary.
PAR=Pneumatic assisted rack prototype

configuration, weapon door configuration, and weapon position in the bays were derived [19]. Some of these conditions are relevant to the expected effects of the TGP on the intermediate weapon bay and provide a baseline for future TGP testing. Since CFD analysis has shown that the TGP is expected to disturb airflow in critical regions around the weapon bays, separation testing is warranted with an attached pod [6]. Table 7 shows a listing of testing and analysis that should be considered for the final TGP qualification effort and represents several conditions where release restrictions already exist and could be expected with the TGP. For example, in the table, a GBU-38 may be limited to a specific station in the aft bay and require an upstream bay door to be open to affect a clean release, or similarly a CBU may have these limits in the intermediate bay. Overall, varying the weapon type and location, type of launcher, door configuration, and flight condition leads to these restrictions that must be assessed with the TGP.

Table 7. Weapon Separation Analysis Configurations

Store	Door Position (P, F, C)	Carriage Module	Bay(s)	Stations	Sniper &Pylon Mounting
GBU-31 class	All	CRL	Fwd/Int/Aft	NA	On
JASSM JSOW	All	CRL	Fwd/Int/Aft	NA	On
Mk-84	All	CRL	Fwd/Int/Aft	NA	On
GBU-38	F/C	SECBM	Fwd/Int/Aft	TBD	On
Mk-82 class	F/C	CBM/SECBM	Fwd/Int/Aft	TBD	On
CBU class	F/C	SECBM	Fwd/Int/Aft	TBD	On
WCMD class	F/C	SECBM	Fwd/Int/Aft	TBD	On
Quickstrike class	All	CRL or CBM/SECBM	Fwd/Int/Aft	TBD & NA	On
Future Weapon	TBD	TBD	Fwd/Int/Aft	TBD	Off/On

Note: P=Part, F=Full, C= Closed. CRL=Conventional Rotary Launcher. (SE)CBM= Conventional Bomb Module Variants. TBD=To Be Determined

Some insight will be gained from the two planned weapon separations during the concept demonstration. However, a much larger test effort is required to have TGP and aircraft compatibility for weapon releases due to multiple pre-existing release restrictions that may propagate into the TGP configurations. Such dynamic weapon separation testing requires multiple contingency plans to overcome unpredicted results while still allowing for testing that clears a weapon envelope. The SDD TGP test effort must expand weapon separation flight testing to provide flight clearances for weapon envelopes while addressing existing release restrictions (R16).

6. CONCLUSIONS

The crew systems evaluation and assessment provided important insight to the level of development required for a successful TGP final qualification flight test. It revealed that the instrumentation plan was very thorough and was expected to help complete a one time aerodynamic evaluation of the pod. Very little emphasis was placed on an operationally suitable MMI solution that would be implemented in the B-1B cockpit when the pod was fully developed. The existing COTS laptop used to provide BLOS capabilities was configured to provide display and control interface to the TGP without consideration for good ergonomic design and human factors. A MOTS hand controller was affixed to the existing aircraft hand controller on the OSO side to provide additional TGP control capability and was cumbersome. It was a significant finding that the planned concept demonstration testing did not provide for an assessment of the integrated controls and displays with the existing aircraft architecture, or the architecture planned for FIDL, the future cockpit modification. Failure to perform this assessment is potentially the largest oversight of the program. The results of these planning oversights may increase program risk for the SDD TGP effort. Controls and displays implementation with respect to the aircraft cockpit modernization and TGP integration was also not in the current plan leaving in question the future suitability of this system

Laboratory processes were determined to be both mature and suitable for this test effort. All modeling and simulation capabilities were very advanced and had supported the B-1B test community in previous testing. The major modeling and simulation limitations highlighted from this section were evidenced by the scope of testing performed. This limited testing would achieve the test objectives for TGP demonstration, but would require bolstering during SDD.

A study of ground developmental testing revealed support areas that were sufficient for the planned concept demonstration test. The study also showed several areas where improvements could be made prior to SDD, the final TGP implementation. The GVT testing was very thorough and was expected to provide ample data to support the aerodynamic flight testing. Areas that required a more detailed study included EMIC testing. EMIC testing was limited to the operation of the pod with aircraft systems and instrumentation to exclude weapon interface, bay configurations, and defensive systems that would not be used for the test. Additionally, the AFS was developed without a full weapon interface to expedite the testing. Therefore, a combat ready bomber configuration was not tested in the laboratory, on the ground, or in-flight. For full TGP employment capabilities, a fully configured bomber will need an EMIC performed.

Logistic support for the test was complete and the process could be carried to SDD. Crew training for the demonstration was limited to mostly controls and displays. Further development of crew training facilities such as IFAST may be required to support realistic crew training scenarios. These facilities could include realistic target environments. B-1B crewmembers at large were unfamiliar with TGP concepts of operations.

Finally the planned flight test and conduct was strong in some areas but required modifications for SDD. The areas that were thorough included the planned aerodynamic testing, and systems integration. From this demonstration testing, the aerodynamic testing was expected to clear the carriage of the TGP for the B-1B flight envelope and refine any points of concern as required. The systems integration testing would clearly demonstrate the capabilities of the TGP on the bomber. The process for systems integration will also lay the foundation for systematic testing should SDD require an additional analysis.

The plan for assessing handling qualities testing was very limited and only considered one closed-loop task. Several other key tracking tasks that are common to bomber operation should be performed during this test.

The weapon testing plan was intended to provide a snapshot evaluation of one point in the weapon release envelope for two weapons. This point was determined by the modeling and simulation results. This one point will provide insight into the broader weapon separation testing requirement, and help determine if interaction of the TGP and aircraft is suitable for weapon employment. Other separation tests such as JASSM that share similar weapon bay airflow separation concerns should be used as models for the TGP SDD effort.

Overall, the planned demonstration effort is considered to be adequate for moving forward with mounting and integrating the TGP on the aircraft. However, additional testing will be required to make this system a more viable asset to the B-1B. An initial answer concerning feasibility will be achieved during the concept demonstration flight test. Suitability and capability will have to be determined when the TGP goes into SDD.

7. RECOMMENDATIONS

Several recommendations were generated from this study. These recommendations are intended to improve the SDD for the TGP. These recommendations are extracted from the text in the order in which they appeared in this study and slightly modified for clarity in this section.

1. The TGP display interface needs to be redesigned to a compatible B-1B standard for weapon employment.

2. For the final pod integration, the symbology and formats must not only be consistent with all other weapon system formats but should allow for future upgrades that incorporate new displays.

3. The TGP laptop interface should be mounted on a swivel during the concept demonstration testing such that it is within the operator's DEV, and ultimately, the final TGP display interface must be within the operator's DEV.

4. The TGP slewing must use inertial references to eliminate slewing errors associated with attitude interpretation.

5. A controller must be placed in the front station to assess cockpit design requirements.

6. An evaluation of the FIDL controller must be done before final TGP implementation.

7. Prior to SDD, an evaluation of cursor tracking tasks in a standardized cockpit environment must be performed to address TGP cockpit interoperability.

8. The laboratory methodology applied to this program should be pursued during SDD.

9. During SDD a much more comprehensive analysis of critical configurations should be completed to assess weapon separation characteristics not tested during the demonstration effort.

10. DOE planning and CFD analysis should be used for the final TGP integration to prioritize weapon testing and optimize test resources.

11. For the fully developed pod effort, a full scale EMIC should be performed using an aircraft that is representative of all flight test conditions including defensive systems checks, and weapon bay interference checks for all three bays.

12. Before SDD begins, a logistics support human factors focus should be performed that addresses environmental adversities such as cold weather or chemical defense posture handling and support.

13. It would be advantageous to this and other test programs to evaluate the need for a dynamic range environment at the AFFTC to support TGP test requirements.

14. Aircrew should determine whether the addition of the TGP alters handling qualities adversely by performing the suggested handling evaluations.

15. A fully integrated system must allow the TGP and aircraft to send and receive targeting and alignment data bi-directionally.

16. The SDD TGP test effort must expand weapon separation flight testing to provide flight clearances for weapon envelopes while addressing existing release restrictions.

REFERENCES

1. Program Execution Plan (PEP), *B-1B TGP Pre-SDD*. B-1B Systems Group, Wright-Patterson AFB, OH, November 2004.
2. Program Introduction (PI), *Demonstration of Electro-optical Infrared (EO/IR) Targeting Pod on the B-1B Bomber*. B-1B Systems Group, Wright-Patterson AFB, OH, June 2005.
3. Air Force Flight Test Center (AFFTC) Statement of Capability (SOC), *B-1B Electro-Optical Infrared (EO/IR) Targeting Pod Demonstration, Revision 1*. 412 TW/DR, Edwards AFB, CA, September 2005.
4. Air Force Instruction 63-1101, *Air Mobility Command Supplement 1 23 May 2005 Acquisition Modification Management*. Scott AFB, IL, May 2005.
5. Technical Interchange Meeting (TIM) #1, *Pylon/Targeting Pod Program*. Dayton, OH, July 2005.
6. *Capability via Compatibility AFSEO CFD support of B-1B/SNIPER Flight Tests*. B-1B WWGM, AFSEO, Eglin AFB, FL, November 2005.
7. Air Force Flight Test Center Test Report (AFFTC-TR-79-2), *Flying Qualities and Flight control System Evaluation of the B-1B Strategic Bomber*. Air Force Flight Test Center, Edwards AFB, CA. 1979.
8. Interface Control Document (ICD), *B-1B Avionics Flight Software (AFS) to SNIPER XR TGP Interface*. Boeing Military Integrated Defense Systems B-1B Bomber Program, Oklahoma City, OK, July 2005.
9. Tyler, R. Targeting Pod Test Plan Working Group (TPWG). Long Beach, CA, February 2006.
10. Program Execution Plan (PEP), *B-1B Digital Communication Improvement Program (Draft)*. B-1B Systems Group, Wright-Patterson AFB, OH, February 2006.
11. Flight Manual, USAF Series Aircraft B-1B, *Technical Order 1B-1B-1*, Department of Defense, October 2005.
12. Lane, J. Sniper XR Flight Evaluation. Edwards AFB, CA, September 2004.
13. Human Engineering Design Approach Document-Operator (HEDAD-O), *B-1B Fully Integrated Data Link (FIDL) Man/Machine Interface*. The Boeing Company, Long Beach, CA, November 2005.

14. Sanders, M. & McCormick, E. *Human Factors In Engineering and Design*. McGraw-Hill, Inc., 1993.

15. Technical Interchange Meeting (TIM) #2, *Pylon/Targeting Pod Program, Sniper Structural Analysis*. Oklahoma City, OK, October 2005.

16. Lane, J. & Sabo, D. *ILST Evaluation of Human Inputs for a Fixed Gain*. 419FLTS & United States Air Force Test Pilot School, Edwards AFB, CA, November 2004.

17. Binder, R. Modeling and Simulation Email Discussion. Team Lead, B-1 Structure Analysis, Long Beach, CA, January 2006.

18. Westmoreland, William S. CFD discussion Email. Controller 46 SK/SKI, Eglin AFB, FL, February 2006.

19. Flight Manual, USAF Series Aircraft B-1B, *Technical Order 1B-1B-34-2-1*, Department of Defense, February 2003.

20. Tipton, A. & Hodson, C. *Status Of Cavity Noise Phenomena Measurement And Suppression On The B-1B Aircraft*. Rockwell International Los Angeles Division, CA, 1978.

21. *Targeting Pod Ground Vibration Test Plan And Procedures*. The Boeing Company Integrated Defense Systems, Long Beach, CA, November 2005.

22. Test Information Sheet (TIS), *B-1B Electro-Optical/Infra-Red (EO/IR) Pod and Pylon/Pylon Alone Aerodynamic, Vibration & Acoustics Flight Test Evaluation*. The Boeing Company, Long Beach, CA, 2006.

23. *Flying Qualities Phase Planning Guide*, USAF Test Pilot School, Edwards Air Force Base, CA, August 2003.

24. *Performance Phase Planning Guide*, USAF Test Pilot School, Edwards Air Force Base, CA, 2002.

25. Test Information Sheet (TIS), *B-1B Electro-Optical/Infra-Red (EO/IR) Pod and Pylon/Pylon Alone Aerodynamic, System Integration*. The Boeing Company, Long Beach, CA, 2006.

26. *JJI Weapon Plan*, 419th Flight Test Squadron, Edwards Air Force Base, CA, October 2003.

27. B-1B Electromagnetic Effects (EME), Safety-Of-Flight (SOF) Test Plan/Procedure, JASSM-ER, The Boeing Integrated Defense Systems, Long Beach, CA, 2005.

BIBLIOGRAPHY

Wiener, E.L., and Nagel D.C. (1988). *Information processing. Human Factors in Aviation*. Academic Press, 1988.

Tetreault, S.D. IFAST B-1B Flight Test. Boeing HDAIT program briefing. Edwards AFB, CA, 2004.

MIL-STD-1797A, *Flying Qualities of Piloted Aircraft*, Department of Defense Handbook, December 1997.

Cooper, G. E. and Harper, R. P., Jr., *The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities*, NASA-TN-D-5153, NASA Ames Research Center, Moffet Field, CA, April 1969.

APPENDIX A

COOPER-HARPER RATING SCALE

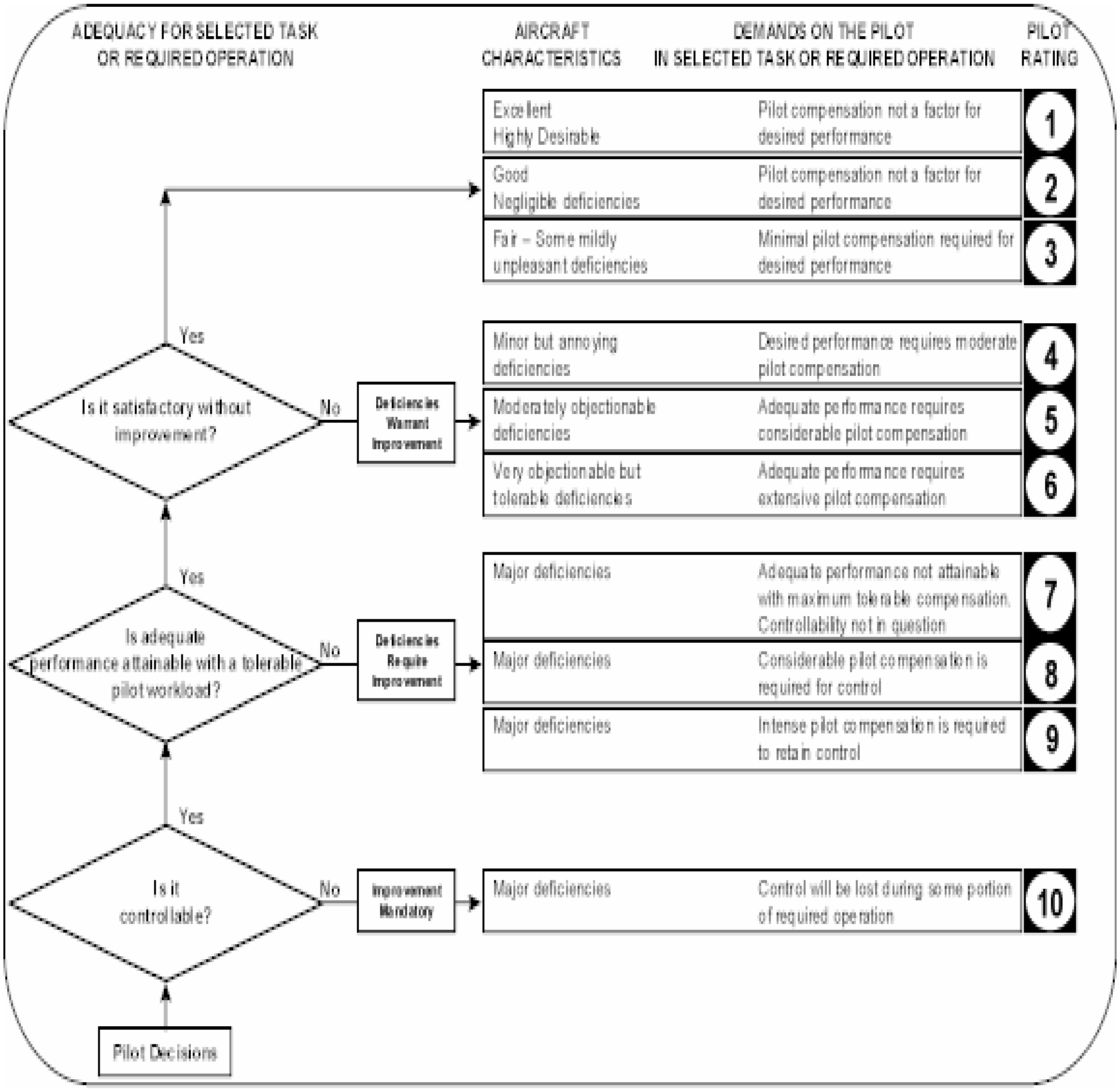

Figure A1. Cooper-Harper Scale

APPENDIX B

Sample Results (Track Handle Study), [16]

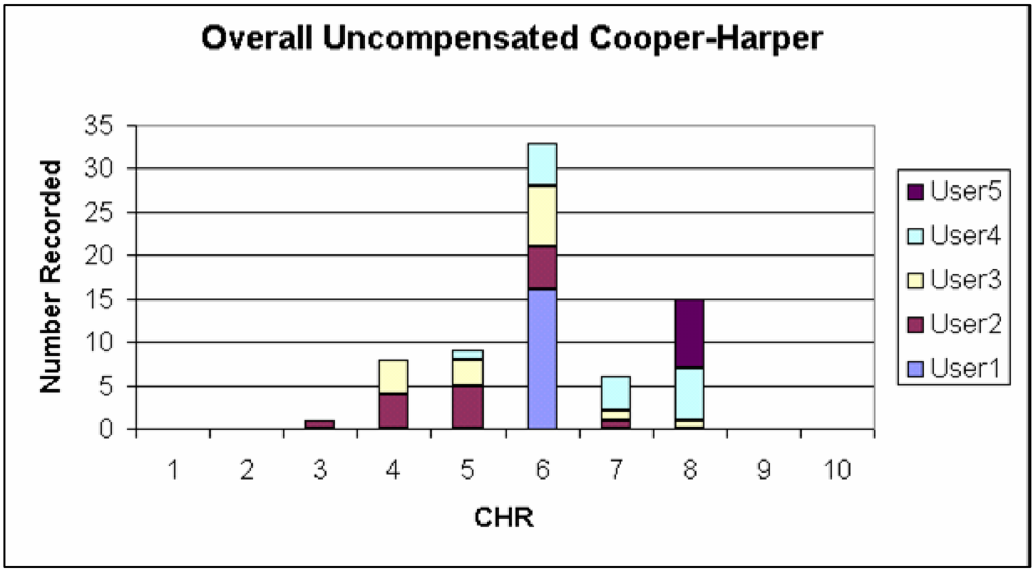

Figure B1. Cooper-Harper Histogram (Overshoots)

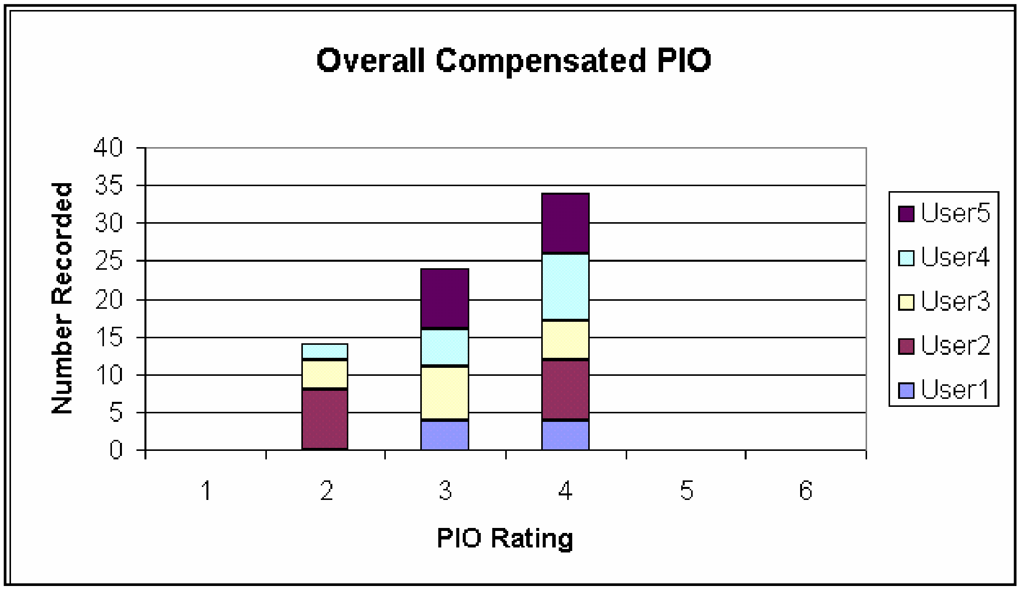

Figure B2. Cooper-Harper Histogram (PIO)

VITA

Joshua Aaron Lane was born in Winston Salem, NC on April 18, 1974. He was raised in Shoals, NC until 10 years of age, when he moved to Crestview FL and attended Bob Sikes Elementary. He attended Richburg Middle School, and graduated Crestview High School in 1992. From there he went to the University of Florida, Gainesville and received a B.S. in Electrical Engineering in 1996. Upon graduation he was recognized as a ROTC Distinguished Graduate and received a commission in the United States Air Force. He attended undergraduate Navigator Training and Electronic Warfare Training from 1997-1998 before selecting the B-1B bomber as his primary aircraft. He was a Distinguished Graduate from Initial B-1B Formal Training and assigned to the 34th Bomb Squadron. Josh upgraded to B-1B Instructor Weapon System Officer in 2001 and became an Evaluator Weapon System Officer prior to serving in Operation Enduring Freedom 2001-2002. After a short tour as an Instructor at the 28th Bomb Squadron Formal Training Unit, he attended the United States Air Force Test Pilot School (TPS) in the summer of 2003. After TPS graduation he was assigned to the 419th Flight Test Squadron as an Experimental Test Weapon System Officer and Evaluator. He received his M.S. in Aviation Systems at the University of Tennessee Space Institute, Tullahoma, TN in 2006.