5-2005

Long Range Interdiction: Effects Based Justification of the B-1B Lancer Aircraft

Stanley Clay Jones
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Stanley Clay Jones entitled "Long Range Interdiction: Effects Based Justification of the B-1B Lancer Aircraft." 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.

Robert B. Richards, Major Professor

We have read this thesis and recommend its acceptance:

Frank G. Collins, Charles T. N. Paludan

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Anne Mayhew
Vice Chancellor and
Dean of Graduate Studies

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LONG RANGE INTERDICTION:
EFFECTS BASED JUSTIFICATION OF THE B-1B LANCER AIRCRAFT

A Thesis
Presented for the Master of Science Degree
The University of Tennessee, Knoxville

Stanley Clay Jones
May 2005

Dedication

This thesis is dedicated to my father, James Clarence Jones, for giving me every opportunity to succeed, for never questioning my ability, and supporting me in every endeavor that I've ever undertaken. It is also dedicated to my wife Gina, and my daughters Kennedy, Morgan, and Sydney for always having faith in me and for never wavering during my extended deployments in defense of our nation.

Acknowledgements

I wish to thank all those who have helped me complete my Master of Science in Aviation Systems. I would especially like to thank the staff of the U.S. Naval Test Pilot School and the University of Tennessee Space Institute, both for providing superb instruction and guidance during my studies. I would like to add a special thanks to Dr. Bob Richards for his personal time and expert advice, which allowed me to complete this degree.

Abstract

The purpose of this study was to evaluate the B-1B aircraft for the land-based, long-range, ground attack mission and to use that evaluation to support my belief that the B-1B aircraft provides a better platform than U.S. Naval fighter aircraft for the same, based on the effects that each aircraft delivers.

One flight totaling 6.5 hours was flown by the author in the B-1B aircraft during daylight visual meteorological conditions (VMC) and included low level flight, aerial refueling, low altitude weapons delivery, threat simulation at an Electronic warfare range, and terminal area operations. This flight was used to evaluate the B-1B aircraft in a test environment and concentrated mainly on aircraft flying qualities. Additionally, thirty-three F/A-18 flights were flown by the author during actual combat operations from the flight deck of the USS John C. Stennis, in support of actual combat operations in Afghanistan during Operation Enduring Freedom. The contrast in effects based capabilities between the F/A-18 and the B-1B form the basis of this thesis.

While the U.S. Navy's approach to long range interdiction was revolutionary, compared to how the U.S. Navy traditionally conducts flight operations, it was lacking in the effectiveness afforded through the use of the B-1B aircraft, primarily due to the B-1B's superior range, endurance, and payload. Quantitative and qualitative findings regarding the flying qualities, weapons systems, and overall aircraft performance of the B-1B support the continued

development of the B-1B aircraft and its inclusion as a critical weapons platform in future conflict planning and execution.

Preface

A portion of the data contained within this thesis was obtained during an academic exercise by the author when he was a student at the United States Naval Test Pilot School. The results, conclusions, and recommendations are the opinion of the author and are not the official position of the United States Navy, the United States Department of Defense, the Naval Air Systems Command, Naval Air Warfare Center, or the Boeing Company. The use of trade names within this thesis does not constitute an official endorsement.

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1 Operation Enduring Freedom and the F/A-18

1.1 Background

Following the events of September 11, 2001, United States naval forces were rapidly deployed to conduct combat carrier operations in Afghanistan. Over the past decade, the F/A-18 Hornet (Figure 1-1) had become the workhorse of the naval aviation fleet and had performed admirably. However, the impending missions in Operation Enduring Freedom would prove to stretch the multi-mission aircraft to its limits, for the months to follow would present challenges never faced before by the Hornet, or any other naval strike aircraft for that matter. The urgency in this matter dictated that the United States needed a rapid, overwhelming response to demonstrate our resolve and to send a message to the terrorist attackers that the United States would not stand idly by when thousands of Americans are killed. Due to the urgency, the United States Navy was called upon to get to the area and get to work. Aircraft carriers could be in the region in the shortest time and commence operations.

Positioned in the North Arabian Sea, interdiction missions would prove challenging, not because of a robust air defense system or a formidable air-to-air threat (neither existed), but because of the geographical distance between the carrier positions and Afghanistan itself. Additionally, there were political deals to be made with Pakistan so that U.S. naval aircraft could transit through their airspace to get to Afghanistan. These proved to be much less difficult than the task of getting those aircraft to Afghanistan target areas, some of which were as

Figure 1-1. F/A-18 with JDAM

Source: Boeing. http://www.boeing.com.

much as a thousand miles away, with sufficient fuel to remain on station long enough to prosecute targets, provide close air support for ground troops, conduct surveillance operations, and safely return to the carrier. In wars past, U.S. carriers typically operated directly off shore from the area of operations. In Vietnam, conducting missions over a range of only one hundred miles was considered difficult.

1.2 The Typical F/A-18 Flight

It was determined early on that in order to carry out such missions, there would be a heavy reliance of tanker aircraft for in-flight refueling. These aircraft were provided by the United States Air Force. The KC-10 Extender and KC-135 Stratotanker aircraft could carry sufficient fuel and possessed the range and endurance required to provide continuous tanking for the Navy while operating from various bases throughout the region, bases that were too far away for fighter aircraft to operate from.

The typical Hornet mission, from the deck of a U.S. carrier, would differ from any missions of the past. Navy pilots and planners, in coordination with the Joint Forces Air Component Commander, were forced to change their mindset in determining how to plan and carry out missions that would take them over a thousand miles during missions lasting typically between six and eight hours. This was in stark contrast to the traditional two to three hour missions flown during Operation Desert Storm, which then were thought to be stretching the envelope of capability.

Typically, the Navy employed the Hornet in sections (flights of two aircraft), one of which was dedicated the flight lead and had overall responsibility for the flight and the other the wingman. After launching from the carrier, these aircraft met at a predetermined rendezvous point somewhere near the carrier, and proceeded together north into Afghanistan. The first hurdle was locating the organic (carrier based) Navy tanker, usually a S-3 Viking, and taking on enough fuel to top off, usually approximately three thousand pounds each. With a full tank of gas, the section then proceed further north, passing into Pakistan in search of the next required tanker, this time a U.S. Air Force KC-10 or KC-135. It wasn't unusual for Hornets to arrive at the predetermine tanking location, only to find that clouds would force them to conduct aerial refueling at much higher altitudes than desired or while in the clouds, a feat not practiced in typical training missions. If forced to higher altitudes, this made the task of tanking even that much more difficult due to the thinner air, reduced thrust response of the Hornet engines, and increased angle of attack encountered when adhering to tanking indicated airspeed limits. Once complete, with yet another full tank of gas, the section of Hornets proceeded even further north to conduct their mission, often times conducting aerial refueling two or three more times before heading south to return to the carrier. All in all, the typical aerial refueling evolution would result in each aircraft taking on six to eight thousand pounds of fuel, ensuring that each had enough for the aircraft to at least get out of Afghanistan and to land in a remote, isolated, barely suitable airfield in Pakistan, in the event of an emergency that would preclude them from returning to the carrier. When all was said and done, on an average flight, the Hornets received approximately 35,000 pounds of fuel from airborne tankers and were able to dedicate only 30-40 minutes to the actual mission of putting bombs on target.

Making the missions even more difficult, half were flown at night while wearing night vision devices (NVDs). The insidious effects of wearing NVDs, which can include spatial disorientation, degraded depth perception, and fatigue to both the neck muscles and eyes of the aviator added to the complexity of the already daunting task of flying an extended mission, over hostile territory, while carrying out high risk, stressful evolutions such as night aerial refueling and delivering ordnance. Lastly, once back at the carrier, the pilots of these aircraft still had to land their aircraft, perhaps the most difficult, routinely conducted task in all of aviation. Though the opportunities for a mishap were abundant, not a single Hornet was lost.

1.3 F/A-18 Effects

Due to fuel requirements, the F/A-18s were forced to carry two additional drop tanks, leaving only two wing stations on which to carry air-to-ground ordnance. In the early stages of the conflict, multiple bomb types were carried, to include laser guided munitions, “dumb” bombs, and Global Positioning System (GPS) guided smart weapons such as Joint Direct Attack Munitions (JDAM). While all of these proved effective in destroying most of, if not all of, the easy to locate command and control (C2), radar sites, buildings and runways, it was soon realized that in order to maximize the effects of the Hornets, precision weapons were required to strike the most difficult of targets. This was primarily due to inclement weather, which served to obscure the target area. The JDAM became the weapon of choice due to its GPS guidance, ease of delivery, which did not require visual acquisition of targets, and reliability such that it could be expended in and through the weather due to its superior accuracy. JDAM is truly a drop and leave weapon. Additionally, the JDAM did not require the aircraft to descend to lower altitude and expend greater amounts of fuel or put themselves closer to the threat. Given the proper interface for programming the weapons (target coordinates, etc), the accuracy of JDAM munitions is not dependent on the platform by which they are dropped. This capability negates the possible negative effects of inertial drift, over extended flights that could otherwise affect the accuracy of ordnance delivery. The JDAM contains its own guidance system so that once properly programmed, it need only be released at the proper parameters to achieve the desired affects. Listing specific information on those parameters would classify this report, but it can be said that there is little difficulty in achieving them. The JDAM weapons met all expectations for accuracy and desired effects. With that said, the Hornet interdiction missions were as successful as they could possibly be.

While overcoming major obstacles to success, the net result was that in conducting six to eight hour missions, while working through all of the inherent difficulties already discussed, each aircraft could drop only two bombs and with the limited number of aircraft aboard an aircraft carrier, the use of overwhelming force would be conducted in the manner of a marathon rather than a sprint. This proved to be decisive, but not rapid. In all, U.S. Navy aircraft flew 75% of the sorties flown in support of Operation Enduring Freedom between 7 October 2001 and 23 December 2001, delivering less than 30% of the total weapons.

2 The B-1B Bomber

2.1 History

The first B-1A, produced by Rockwell International, now Boeing Defense And Space Group, was developed in 1974. Its prime mission was to replace the aging B-52 Stratofortress, though the initial conception was that of a nuclear bomber. However, prior to going into production, the program was cancelled, though flight testing continued. The B-1B, an improved variant, was approved in 1981. This variant included a vastly increased payload over the B-1A variant, as well as a significant reduction in radar cross section and improved avionics.

The B-1B was first used in combat in 1988 during Operation Desert Fox and has subsequently seen action in Operation Allied Force, Operation Enduring Freedom, and Operation Iraqi Freedom.

2.2 Aircraft Description

The B1-B, depicted in Figure 2-1, is a long range, supersonic bomber manufactured by Rockwell International and designed for supersonic speed at altitude and high subsonic speeds at low levels. The aircraft has accommodations for a pilot, copilot, Offensive Systems Officer (OSO), and Defensive Systems Officer (DSO) with provisions for an instructor Pilot (IP) and

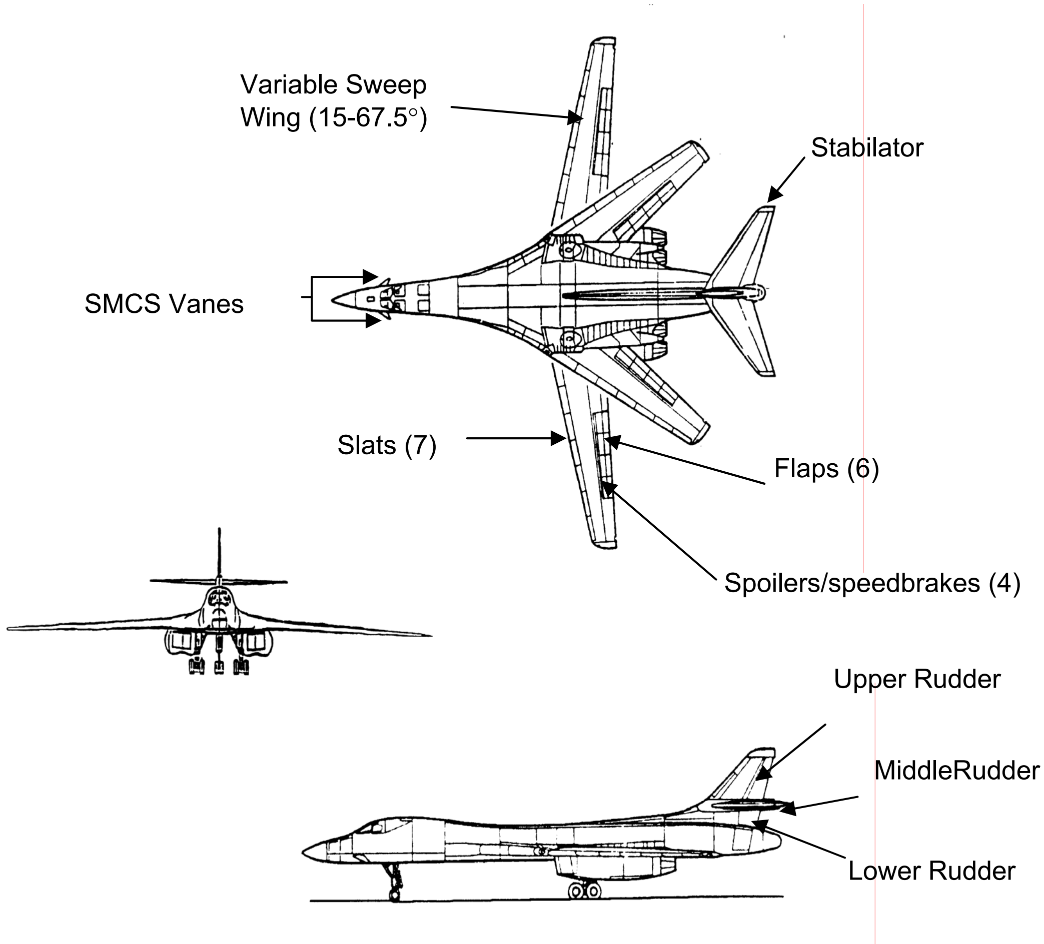

Figure 2-1. B-1B Three View

Source: Flight Manual, USAF Series B-1B Aircraft, TO 1B-1B-1-1, 15 July 1996 (modified by the author).

Avionics Instructor (AI). The B-1B aircraft was designed to penetrate highly defended airspace, attacking targets with conventional weapons and has been upgraded for precision guided munitions. The aircraft is powered by four General Electric F101-GE-102 dual rotor, afterburning turbofan engines designed to produce 15,000 lb of non-afterburning thrust and up to 30,000 lb of thrust with afterburner. The aircraft design incorporates a blended wing body with variable sweep wings.

The primary control surfaces consist of a three-section rudder, four spoiler panels on the upper surface of each wing, and horizontal stabilators. The pitch attitude of the aircraft is controlled by symmetrical deflection of the horizontal stabilators. Roll attitude is controlled by asymmetrical deflection of the horizontal stabilators and by deflection of the spoilers. The aircraft is equipped with a variable sweep wing which can stopped at any angle between 15 and 67.5 degrees. However, the only wing sweep positions currently cleared for use are 15, 20, 25, 55, and 67.5°.

The secondary flight control system consists of the wing sweep system, an overwing fairing system designed to accommodate wing sweep and to provide smooth aerodynamic surfaces at the wing root, leading edge slats, trailing edge flaps, and lateral control spoilers which also function as speedbrakes. Structural mode control vanes, designed to reduce structural bending oscillations in the longitudinal and lateral axes as part of the Structural Mode Control System (SMCS), are mounted on each side of the forward fuselage. Conventional control sticks and rudder pedals, mechanically connected between the pilot and copilot seats, provide control inputs to the respective control surface actuators. Artificial feel is provided in the lateral and longitudinal axes through pitch and roll bungees. Longitudinal and lateral trim control, through a five-position switch on each control stick, consists of actuators to position the horizontal stabilators through the pitch roll mixer. The pitch roll mixer also receives signals from the Stability Control and Augmentation System (SCAS), which was designed to provide stability about all axes by transforming signals from pilot inputs and aircraft motion into flight control surface displacements to produce the desired damping, maneuver control, and trim. The Automatic Flight Control System (AFCS) operates through the SCAS and provides several modes of operation, including Automatic Terrain Following (ATF). The aircraft is equipped with an electrically controlled and hydraulically operated tricycle landing gear system. The landing gear system includes nose wheel steering, a damping system, and a brake control and antiskid system. The aircraft is capable of carrying a wide assortment of air-to-ground munitions and fuel tanks in three configurable weapons bays.

The aircraft is equipped with a large avionics suite, including the APQ-164 Offensive Radar System (ORS) multi-mode radar, a SKN-2440 High Accuracy Inertial Navigation System (HAINS), the ALQ-161 Radio Frequency Surveillance/Electronic Counter-Measures System (RFS/ECMS), and other subsystems supporting the Offensive/Defensive Avionics System.

2.3 B-1B Handling Qualities

2.3.1 Overview

In evaluating the B-1B, flying qualities that were most important to completing the long range, interdiction mission and could be completed during the single flight were evaluated. Due to the limited scope of the actual test flight (only 6.5 hours), not all areas were looked at, however, enough areas were evaluated to make a determination as to the suitability of the aircraft.

The specific areas evaluated fall into one or more of the following categories: Longitudinal Flying Qualities (pitch), Lateral Directional Flying Qualities (roll and yaw), and Ground Handling. Quantitative testing consisted of classical longitudinal and lateral-directional test techniques routinely used in flight testing and taught at the US Naval Test Pilot School. Flight test techniques, described in the Fixed Wing Stability and Control Theory and Flight Test Techniques Manual and the Fixed Wing Performance Manual, references 1 and 2, were used throughout.

2.3.2 Ground Handling Qualities

2.3.2.1 Nose Wheel Steering

The effectiveness of the nose wheel steering system was evaluated while taxiing to and from the runway. The purpose was to ensure that the aircraft would maintain a constant track without over-tasking the pilot. To do so, the system must not have free play and must be predictably responsive to control inputs. Starting into and rolling out of turns, while maintaining the aircraft position on the taxiway centerline was easily accomplished through smooth rudder pedal inputs to steer the aircraft. There was no need for great anticipation, nor was there any lag or noticeable free play.

2.3.3 Flying Qualities and Performance

2.3.3.1 Takeoff

A consideration in the design of many aircraft is the distance that it takes to get airborne and the ease at which the pilot can safely achieve a desired pitch attitude while conducting a takeoff. The typical concern is not to over-rotate, or put the aircraft in a higher nose up attitude than is desired. This is to preclude stalling the aircraft or to prevent dragging the rear of the empennage, which would result in aircraft damage and potentially dangerous flying qualities as a result of damage. In the case of the B-1B, with its long airframe, this is a valid concern.

The ability to capture a desired attitude on takeoff was evaluated during a single takeoff from a dry runway with a 6 knot headwind component and 10 knot crosswind component. The aircraft weight was 355,000 pounds and was not loaded with ordnance. It is assumed that similar results would have been obtained as long as flight manual restrictions for center of gravity and gross weight were adhered to. The desired pitch attitude on takeoff for the B-1B is 7° nose up. Using this as a target and selecting full afterburner at the beginning of the takeoff roll, the aircraft responded smoothly and predictably to an aft stick deflection of approximately 1 ½ inches, requiring approximately 15 pounds of force. Capturing a 7° nose up attitude was relatively effortless and did not require any special skill from the pilot.

In addition to being able to capture a desired pitch attitude, it is desirable that the forces encountered when changing the aircraft configuration (raising the gear and flaps) be kept at a minimum, as well as the stick deflections required to maintain the flight conditions. These forces and deflections were measured and the results are shown in Table 2-1. In summary, the forces and deflections were very manageable and did not significantly increase pilot workload.

The takeoff distance was an impressive 4950 feet. The short distance allows the B-1B to easily takeoff from a wide range of military and civilian airfields.

Following takeoff, climb performance was evaluated by performing a climb from 5,000 feet mean sea level to 20,000 feet mean sea level using military power, following the contractor recommended climb schedule of 360 knots/0.76 mach. The time to climb was 7 minutes and 53 seconds while the fuel burned was 5400 pounds over a distance of 59 nautical miles.

Table 2-1. B-1B Takeoff Configuration Changes

Airspeed (KIAS)	Configuration Change	Maximum Stick Force (lb)	Maximum Stick Displacement (in)
175	Takeoff to Gear up	2 lb pull	1/8
200	Flaps full to 50%	3 lb push	3/8
225	Flaps 50% to full up	5 lb push	1/2

2.3.3.2 Airways Navigation

Once airborne, the B-1B flew nicely. Aircraft control was responsive and smooth in all axis. For an aircraft to conduct a long range mission, it is desirable for the pilot to fly with relative ease, that is, to not have to struggle to maintain a specific parameter such as altitude or airspeed. Over the course of a long flight, this could result in pilot fatigue or a flight violation from the Federal Aviation Administration (FAA). In order to determine the ease at which a pilot could expect to maintain a precise altitude, the aircraft was trimmed for level flight at an airspeed of 320 knots indicated airspeed. It was difficult to maintain deviations in altitude of less than 50 feet without paying close attention to the instruments. Though deviations of 50 feet are certainly acceptable, whether during airways navigation or expending JDAM ordnance, it was a bit annoying. This minor problem lead to further investigation of the long period mode (phugoid) of the B-1B and the documenting of the trim speed band.

The phugoid is the long term motion of an aircraft after a disturbance and is a significant factor in trimmed, cruise flight. It is a second order, oscillatory response and is described by frequency and damping ratio. A representative range of periods at cruise speeds is 30 seconds to 2 minutes, with damping ratios of 0.05 to 0.1 [7]. To document the phugoid, an aft longitudinal stick input is made to the trimmed aircraft to approximately 10 degrees nose up until the airspeed decreases approximately 20 knots, at which the time the controls are re-centered. Due to decreased lift at a given angle of attack, the aircraft’s flight patch will begin to go down, assuming that the aircraft has positive static stability.

The aircraft will then accelerate to a speed beyond the speed at which the maneuver was started until sufficient lift, as a result of the increase in airspeed, will cause the flight path to go up. Eventually, the aircraft will return to the original trimmed conditions after a number of iterations. For the B-1, the long period response was easily excited and lightly damped, the characteristics of which are shown in Table 2-2 and Figure 2-2. By being easily excited, it doesn't take much to get it going, and by being lightly damped, it takes a long time to settle out.

The trim speed band shows the range of airspeed that an aircraft will maintain for a given trim setting. Many factors can affect this, including freeplay in the flight control system and poor flight control centering. The trim speed band for the B-1B was fairly small in that it was only 5 knots. However, during the phugoid, the aircraft is trying to return to its original trimmed condition, which in this case could be plus or minus 5 knots of the original speed, depending on where that speed lies within the band. If it returns to a speed that is faster than the start speed of the maneuver, then the aircraft will descend, and if that speed is slower, it will climb.

The combination of the phugoid characteristics and the trim speed band are most likely what made it difficult to maintain altitude within 50 feet. However, the B-1B is equipped with an auto pilot function, which proved to be of great use and maintained selected flight parameters with great precision. Accordingly, the minor difficulties in maintaining altitude were nothing more than annoying and have no effect on mission success.

Table 2-2. B-1B Long Period Characteristics

Configuration	Period	Damping Ratio	Natural Frequency
CR	109 secs	0.06	.06 rad/sec

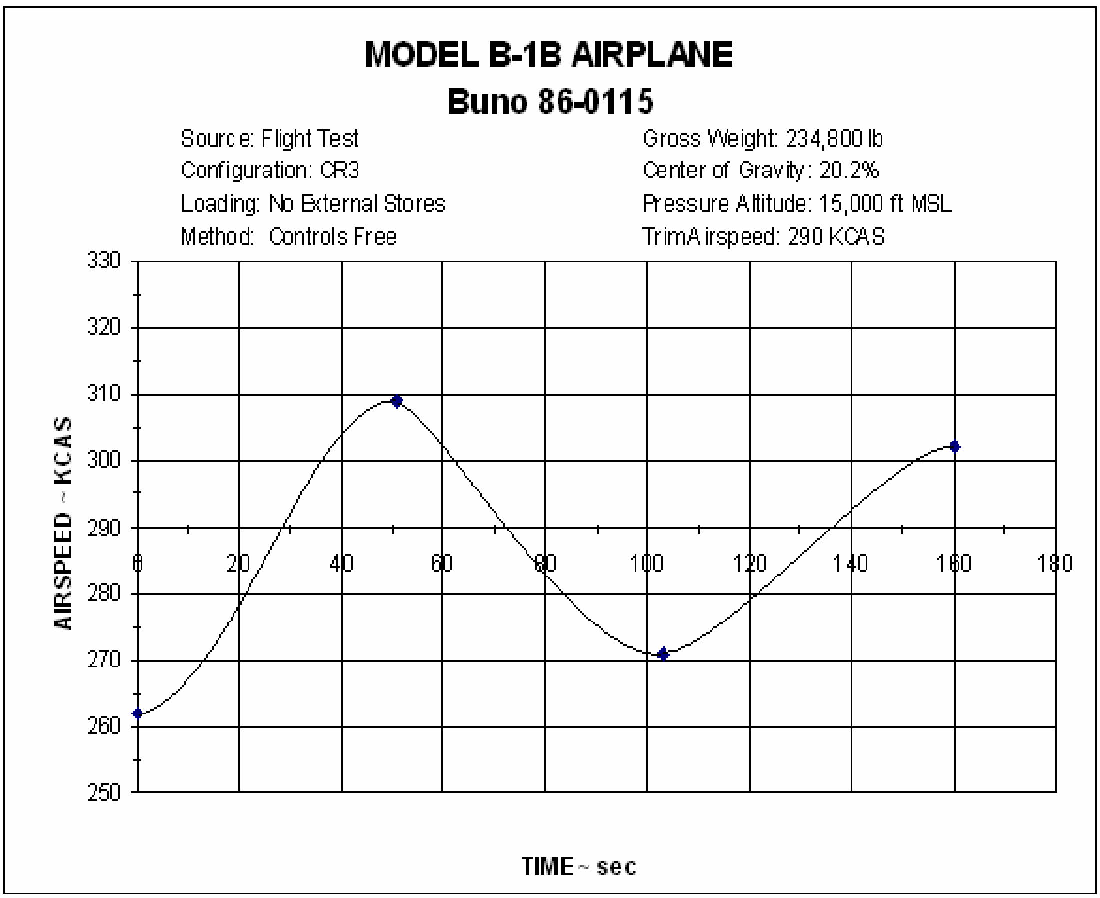

Figure 2-2. B-1B Phugoid

2.3.3.3 Combat Range

Fuel flow requirements from test day conditions were documented and used to construct a typical B-1B mission profile. The results are presented in Table 2-3. These results show the specific range, or plainly put, the gas mileage for the B-1B for different phases of flight. Based on actual fuel usage, the B-1B can start the engines with 204,575 pounds of fuel (full internal fuel), climb to an altitude of 20,000 feet mean sea level, and land at another NATO airfield with approximately 25,000 pounds of fuel while traveling a total distance of 3,579 nautical miles. Certainly there are many factors that determine the actual fuel mileage that an aircraft may achieve, such as wind, the speed at which the route is flown, and the weight of the aircraft. Regardless, these numbers support the

Table 2-3. B-1B Mission Profile

Flight Phase	Required Fuel (pounds)	Specific Range (nautical miles/pound)	Range	Total Fuel
Start/taxi/takoff	10,000	N/A		10,000
Climb 500-20,000 ft	7200	.0078	59	7,200
20,000 ft Max Range(.72 mach)	N/A	.022	3440	156,375
Idle Descent/Approach 20,000-500	1000	.032	80	6,000
Total			3579	179,575 (25,000 remaining)

claim that the B-1B has the capability to fly intercontinental ranges without ever conducting aerial refueling. Weapons payload is a critical factor in the design of attack aircraft, but if the aircraft can't get to the fight, then it is not of use. The requirement to be able to reach out to locations not necessarily easily accessible has made itself clear both in Iraq and Afghanistan. It will be increasingly pointless to design limited-range aircraft. Range is arguably the key criterion now for any combat aircraft – it could be argued that range should take priority over such factors as stealth [13].

2.3.3.4 Combat Endurance

There was no specific fuel flow data collection to document the endurance (how long it can stay airborne) of the B-1B during the single flight, however, during that single flight, the author flew for a total of 6.5 hours, un-refueled, while conducting over an hour of low altitude flight at transonic speeds, without the use of afterburner. In general, the B-1B can stay airborne for a long time, which begs the question, "Why dedicate tankers to refuel Hornet aircraft, who's effects do not measure up to that of the B-1B, when that fuel can be used to keep the most effective aircraft around longer?"

2.3.3.5 Aerial Refueling

Even with the B-1B's impressive un-refueled range, it is imperative that the aircraft demonstrate satisfactory flying qualities in the performance of aerial refueling. If the B-1B where to receive 45,000 pounds of fuel from an airborne tanker (well within the capabilities of today's tankers), its range could be extended approximately another 1,000 nautical miles, or that fuel could be used to loiter in the target area while providing support for troops on the ground, which was the case in Afghanistan, in which the B-1B aircraft remained in support of ground troops for several hours.

In an effort to document any potential problems areas, approximately 15 minutes of the flight was dedicated to investigating the B-1B flying qualities while in close proximity to a KC-10 tanker. From 50 ft to as close as 5 ft from the refueling boom, intentional deviations in formation position were established to document the aircraft response to control inputs, intended to correct those deviations. The rate and magnitude of the corrections were varied so that the optimum response could be achieved. To investigate the aircraft response to longitudinal inputs, several corrections were made from stepped-down positions up to the desired altitude. Plainly stated, the aircraft was flown to a position that was too low for the tanker aircraft to engage the boom, and then longitudinal control stick inputs were made to get back to position. The aircraft response was predictable, though slightly sluggish to small inputs. Avoiding the temptation to overdrive the response with larger inputs, it was fairly easy to correct back to the proper position and maintain that position. The slightly sluggish response was ideal in this situation because it is usually when the pilot makes corrections that are not smooth that pilot induced oscillations can occur. In a nutshell, it made things smoother. This proved to be the case when the boom was connected as well, which made longitudinal corrections prior to and during aerial refueling an easily accomplished task.

Much like determining longitudinal qualities during aerial refueling, lateral directional qualities were evaluated as well. Rather than positioning the aircraft in such a position that required a longitudinal correction, the aircraft was displaced horizontally from the desired position and lateral stick deflections were made to correct. Established approximately 10 feet right of the boom, a left lateral stick displacement of approximately ½ inch was applied and held for approximately 1 second until the aircraft began to slowly track horizontally toward the boom. The aircraft response was sluggish and seemed to lag the lateral input. This resulted in the need for close attention and great anticipation in order to make a timely input to stop the aircraft motion in front of the boom. Capturing lateral position was difficult, requiring 2-3 well timed, lateral stick deflections of up to ½ inch to drive the desired response and stop the aircraft drift. Though lateral corrections were much more intensive than longitudinal corrections, they are certainly manageable by a well trained aviator.

2.3.3.6 Level Turns

The B-1B cockpit is configured much like that of a fighter in that it has a stick rather than a yoke at both the pilot and copilot stations. It has the capability to be maneuvered aggressively, like the smaller, fighter aircraft of the U.S. military arsenal. However, due to its large size and potential heavy payloads, limits on how many g's (load factor) the aircraft is allowed to pull have been established. These were put into place, primarily, to extend the life of the aircraft and to prevent aircraft damage. Accordingly, it is important that the pilot be able to target and capture a desired load factor without exceeding the imposed limitations. Several level turns were performed to determine just how difficult it was to capture a desired load factor. In the course of performing these turns, observations were made with regard to the aircraft handling qualities. It is important to understand that these turns were performed, not to evaluate roll performance, but to evaluate load factor capture once established in a turn. In order to pull g's in a turn, and maintain level flight, longitudinal stick deflections must be accomplished while in an angle of bank. Much like during aerial refueling, the response was apparently sluggish, though predictable. This made it possible to pull to a certain load factor without exceeding the target, which could result in an aircraft overstress. The stick forces generally felt heavy, which, over time could lead to fatigue. Classical quantitative flight test techniques were used to document the stick force gradient, which plots the amount of force required for a given amount of stick deflection as well as for load factor. Because the B-1B provides artificial feel to the pilot through the use of bungees, stick forces versus deflections were measured on the ground with a hand held force gauge. The results are shown in Figure 2-3. Airborne, the amount of force per g level was measured and it was found that this gradient was moderately high, though constant, at 16 pounds per g (Figure 2-4). A stick force per g gradient of this magnitude will generally result in the aircraft feeling like a transport aircraft with a sense that it is very stable, with the high forces preventing quick response. Regardless, the qualities exhibited by the B-1B will aid the pilot in not exceeding prescribed g limits.

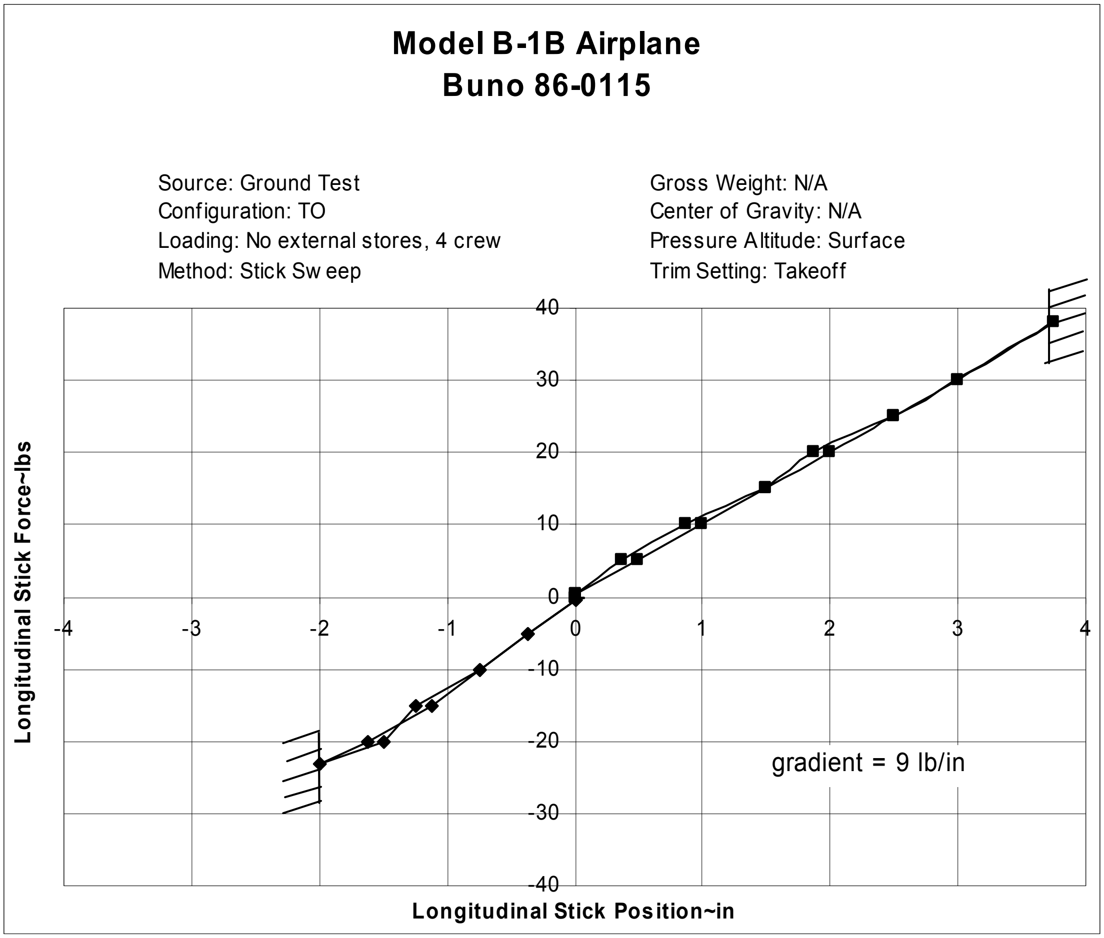

Figure 2-3. B-1B Longitudinal Stick Force Gradient for Deflection

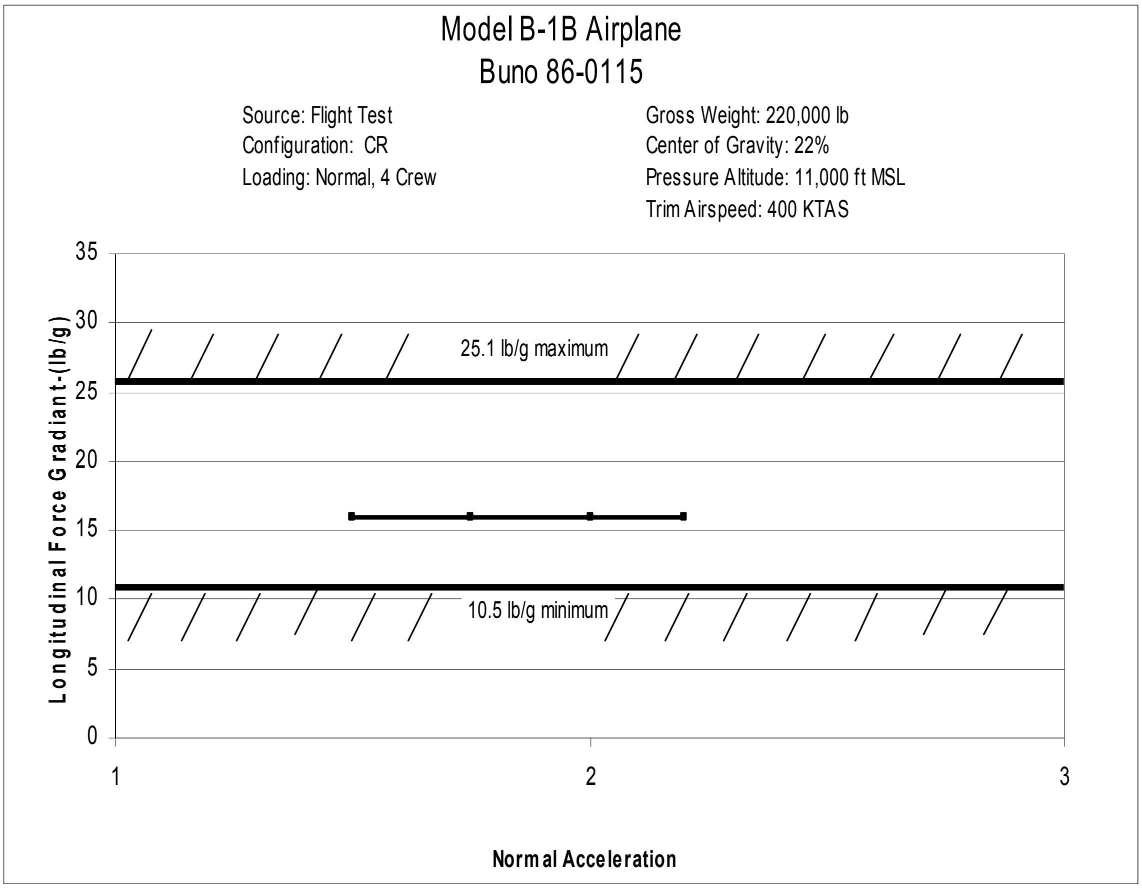

Figure 2-4. B-1B Stick Force Gradient for Normal Acceleration

A series of aggressive turns was attempted utilizing lateral stick deflection of approximately 1 ½ inches. The goal was to roll the aircraft as precisely as possible to 60 degrees angle of bank. The maneuvers were conducted at 540 knots ground speed during a low level bombing run at 1000 feet above ground level. Using smooth but deliberate lateral stick inputs, the aircraft response was unpredictable in that the initially slow roll rate increased rapidly passing approximately ½ inch lateral stick deflection, resulting in an overshoot of 5°. To compensate, a well timed lateral input in the opposite direction was required of approximately ½ inch past neutral and then back to neutral, leading the desired angle of bank by approximately 5°. This allowed the pilot to consistently get within 5° of the desired bank angle. The imprecise ability to roll the aircraft to a specific angle of bank will make this task intensive; however, there is no effect on the delivery of JDAM ordnance. Generally speaking, the delivery of JDAM ordnance is conducted from a more or less wings-level attitude, whether in a dive, a climb, or level flight.

As stated in the aircraft description, the B-1B aircraft is designed with spoilers to aid in roll performance. The spoilers work automatically when the stick is deflected greater than ½ inch laterally. The defection of the spoilers results in non-linear roll sensitivity, as indicated in Figure 2-5, which means that the aircraft achieves an increase in roll rate with stick deflections greater than ½ inch. Roll mode damping was estimated by measuring the time to reach zero roll

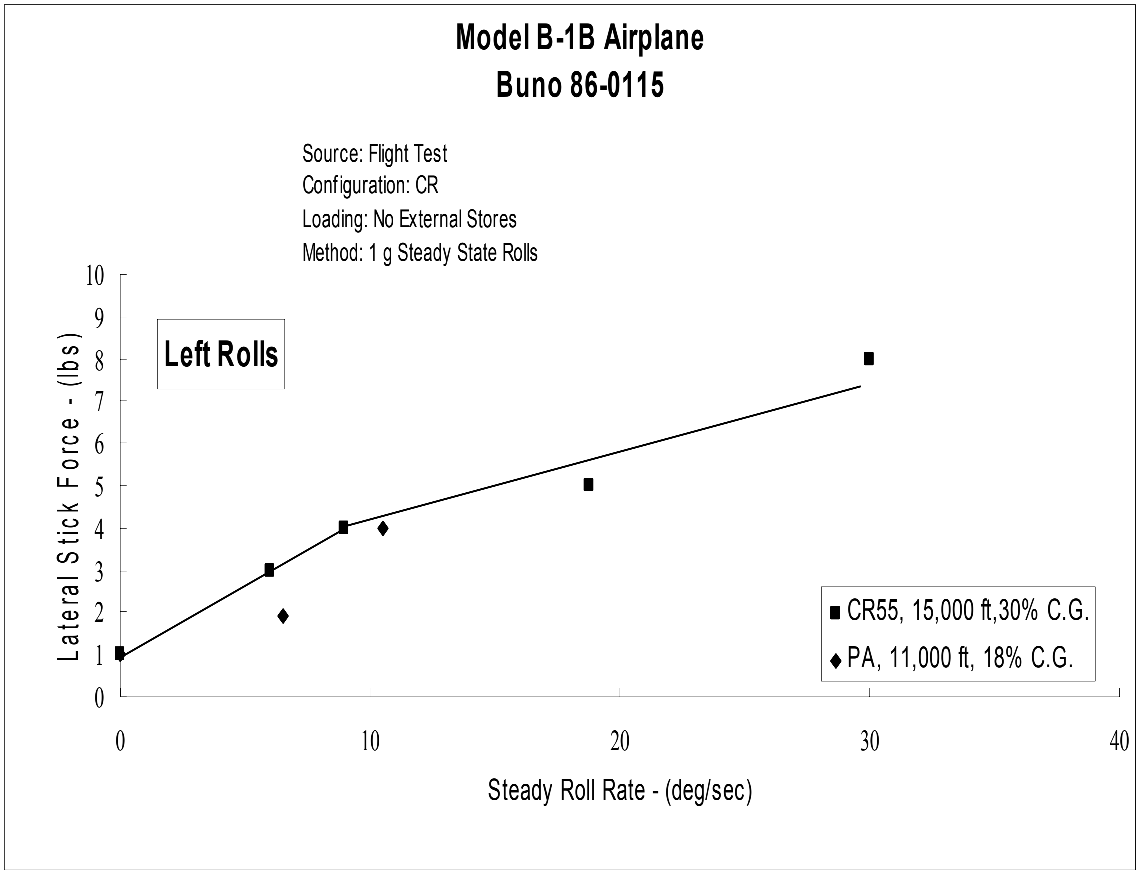

Figure 2-5. B-1B Roll Sensitivity

rate from a steady roll rate, following the re-centering of the stick. From this, the roll mode time constants were estimated 0.3 seconds in configuration PA (landing configuration) and 0.5 seconds in CR (gear and flaps up with the wing sweep set at 25 degrees) by dividing the time by 3. The roll mode time constant gives an indication of just how long the aircraft will continue to roll once the input is removed and is a function of roll damping and rolling moments of inertia (how much momentum the aircraft has once it gets going and how long it will take it to stop without control inputs). The non-linear roll sensitivity combined with the long roll mode time constant are the likely cause of the imprecise bank angle capture.

2.3.3.7 Landing

Regardless of the massive payload that an aircraft may have, it is of little use if landing that aircraft is hazardous. The landing characteristics of the B-1B aircraft were evaluated for this very reason. Many of the hazards associated with flying occur during takeoff and landing. It is at this time that the aircraft is close to the ground, at slower airspeeds, and in the midst of changing aircraft configurations (lowering or raising the gear and flaps). The B-1B exhibited excellent qualities with regard to configuration changes, as depicted in Table 2-4. The small forces and stick displacements allow the pilot to make smooth transitions while changing configurations.

Table 2-4. B-1B Landing Configuration Changes

Airspeed (knots)	Configuration Change	Maximum Stick Force (pounds)	Maximum Stick Displacement (inches)
275	CR25 to Gear down	4 lb push	3/8
240	Flaps down to 50%	4 lb pull	3/8
210	Flaps 50% to full	3 lb pull	3/8

Once configured for final approach and landing, maintaining a constant angle of attack, through maintaining a constant pitch attitude while modulating the power to control the rate of descent, was nearly effortless. The B-1B was quite stable in the landing configuration, which is gear down and flaps set to full. Small longitudinal inputs were required from time to time and once again, the aircraft was responsive and predictable. The pilot was able to make minor adjustments with precise results to pitch attitude in order to counter wind gusts and other causes of deviation. This evaluation can be directly related to the instance when an aircraft, making an approach to land in inclement weather, breaks out beneath the weather and has little time to get on centerline prior to touchdown. If poor qualities exist, that aircraft may be forced to execute a missed approach and try again, thereby increasing fuel requirements.

Lateral corrections to establish the aircraft on centerline were made during three touch and go landings with 10 knots of crosswind in the landing configuration during daytime, VMC conditions. This evaluation was set up much the same as for aerial refueling, by purposely lining up with the left edge of the runway and then making a correction to fly back to and establish the aircraft on centerline. The maneuver was conducted at 1000 feet above ground level. With lineup established on the left edge of the runway (approximately 150 feet lateral offset), a right lateral stick displacement of approximately 2 inches was applied to correct to centerline with a small power addition. Approaching centerline, a lateral stick deflection of approximately 1 inch in the opposite direction, in conjunction with a small power reduction was made. The aircraft response was crisp and predictable, with no yawing tendencies noted. Capturing centerline was simple and non-objectionable, requiring two small lateral stick inputs over a three second period.

Once established on centerline, it was desirous to maintain that position all the way to touchdown. Established on final approach at 800 ft AGL, the aircraft began to slowly drift left due to the 10 knot crosswind. A lateral stick deflection opposite the direction of drift of approximately 1 inch was applied to establish a crab into the wind. Once established on the desired heading, the stick was returned to neutral and a constant heading crab was flown to approximately 150 ft AGL. The aircraft was very stable both laterally and directionally, making it easy to maintain centerline with 1/8 inch stick deflections every 3-5 seconds. At 150 ft AGL, approximately ¼ inch of left rudder was applied to align the aircraft with the runway heading, which required approximately ½ inch of right stick and a small power addition to maintain a constant heading and rate of descent. There were no adverse characteristics or lightening of forces, which made maintaining centerline all the way to touchdown easy to accomplish.

For the full stop landing, aircraft gross weight was 208,000 pounds and the center of gravity was 17% mean aerodynamic chord. The ground roll distance to a speed of 10 knots was impressive in that it was only 3,700 feet with moderate braking. The short landing distance allows for flexibility in mission planning in that the B-1B is able to land at a multitude of military and civilian airfields.

2.4 B-1B JDAM Capabilities

The B-1B's initial design as a nuclear bomber would have kept its lethality from being utilized in most conflicts of our times. Using nuclear weapons would have political ramifications from which the United States would have great difficulty in recovering. In 1993, the Air Force began a transition program in which the B-1B was converted to a conventional Bomber. The program was called the Conventional Mission Upgrade Program (CMUP). The initial program included the means to carry 84 Mk-82 500-pound bombs. However, dumb bombs in a political environment requiring precision weapons would not suffice, due to the potential for collateral damage. Upgrades continued to include cluster weapons, improvements to offensive and defensive systems, and communication systems upgrades to include the addition of GPS, the critical link for precision munitions. The first JDAM ever dropped from a B-1B occurred on Feb 11, 1998 at the China Lake test range Figure 2-6. The weapon impacted 22 feet from its

Figure 2-6. B-1B JDAM Delivery at China Lake Test Range

Source: Boeing. http://www.boeing.com.

intended point of impact after being released from 22,000 feet mean sea level. In April 1998, the first of the B-1B GPS upgrade kits arrived at Tinker Air Force Base and so began the upgrade to fleet B-1Bs. The effectiveness of JDAM became apparent in Kosovo when, used for the first time in combat, the weapons destroyed a number of bridges that had survived numerous attacks with laser guided bombs.

Given the success in Kosovo and later conflicts, the current weapon of choice is the JDAM GBU-31, which consists of a kit mounted to the body of a conventional 2,000 pound free fall bomb. The tail portion of the kit provides guidance to the weapon as it free falls toward the intended target through variable position fins, while the strakes along the bomb body provide stability through its time of fall (see Figure 2-7). The simplicity of the kits and the gains that were achieved by modifying Vietnam era bomb bodies into the most precise bombs in the U.S. arsenal is impressive. This was indeed revolutionary in regard to weapons development. Several variants have been or are currently being developed to accommodate bomb bodies of various sizes (500 and 1000 pounds), however, at the onset of Operation Enduring Freedom, only the 2,000 pound GBU-31 was available. During Operation Enduring Freedom, the B-1Bs carried 24 GBU-31 weapons internally, twelve times as many as were carried on F/A-18s. The conclusion to be drawn from this fact is that it would take twelve Hornets to achieve the same effect as one B-1B, with 50 or so tanking evolutions and twelve carrier takeoffs and landings.

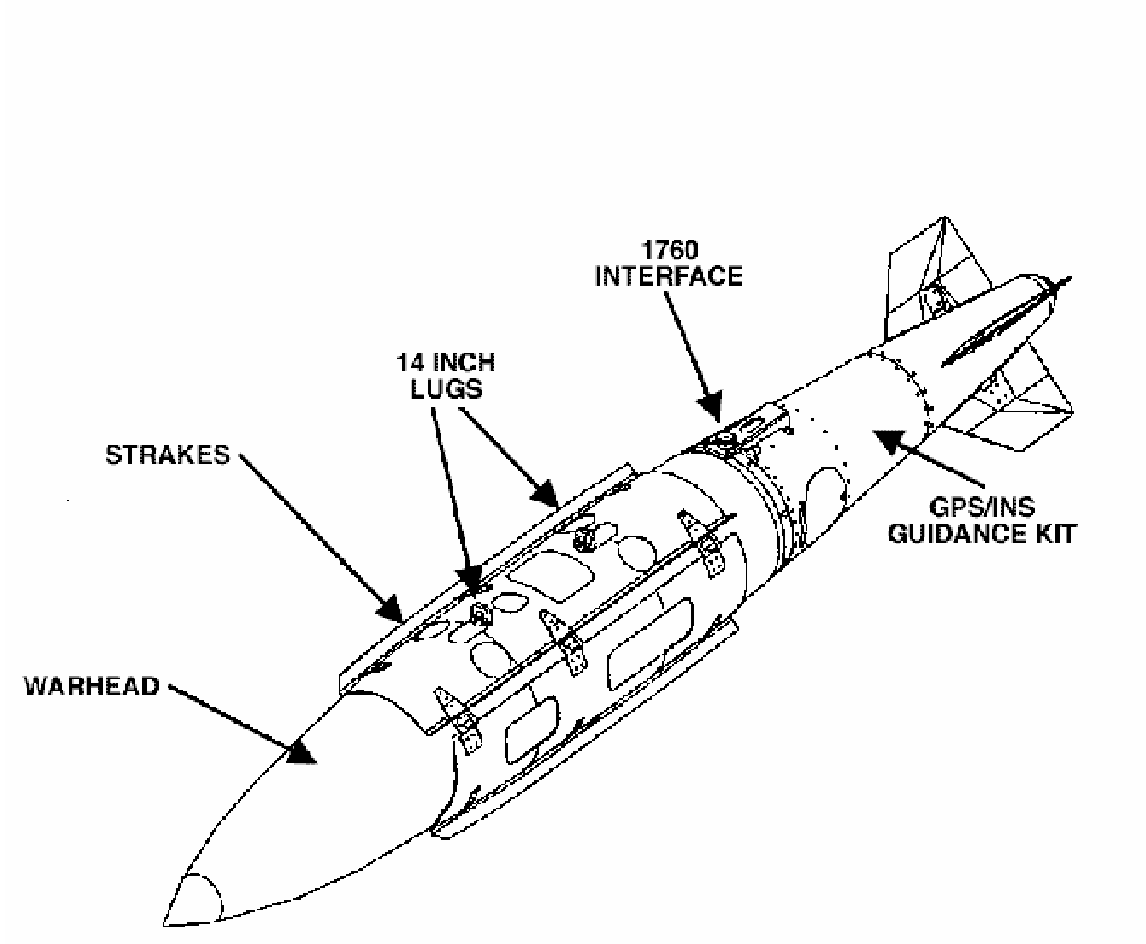

Figure 2-7. JDAM Schematic

Source: http://www.fas.org, modified by the author.

3 Operation Enduring Freedom and the B-1B

The B-1B was used extensively during Operation Enduring Freedom, primarily operating from Diego Garcia, a small island located in the Indian Ocean nearly 3,000 miles away. Only eight B-1Bs were deployed, yet the accomplishments of the B-1B speak for themselves. Flying less than 10% of the interdiction sorties, B-1Bs delivered over 40 percent of the total bombs during the first six months of Operation Enduring Freedom. Of that, they dropped a reported 3,900 JDAMs, 67% of the total JDAMs dropped by all U.S. forces. All in all, the B-1B dropped more ordnance than any other aircraft type in the U.S. inventory. Afghanistan showed that the bomber was still "king" – the reliable… B-1s… will show that they are still vital items in the US arsenal [Defense Systems Daily, 2002]. Only one B-1B was lost during the conflict, not due to battle damage but to a system malfunction. The aircrew ejected near Diego Garcia and were rescued.

4 Summary

The B-1B has excellent overall flying qualities with some minor issues that do not greatly affect mission success. Taking off and landing the aircraft is easy to do, and the distance required to do both allow it to operate from a variety of airfields and provides flexibility in planning. Airborne, the aircraft flies nicely, with only minor problems in the lateral and longitudinal axis. If required, it can refuel while airborne and further increase its impressive range and endurance. Capable of safely getting to the fight and being able to stay at the fight for extended periods of time, the B-1B need only the proper weaponry to be the complete package. With the advent of JDAM munitions and future smart weapons capabilities, its utility cannot be matched.

5 Conclusions and Recommendations

The B-1B demonstrates excellent overall flying qualities, particularly in mission critical areas, and possesses a robust payload and intercontinental range that make it a formidable weapons platform. Though carrier aviation has its advantage of being able to effectively position a U.S. airfield in many remote locations, often times more quickly than the logistics involved in establishing a U.S. Air Force operation allow, the lethality of the B-1B cannot be overlooked. The F/A-18 performs several missions well, but since its inception in the early 1980s, critics have expressed concern over its limited range and endurance.

To perform the long range interdiction mission, the aircraft must have the capability to travel large distances prior to accurately putting bombs on target. The nature of our conflicts dictates such, particularly in land locked locations such as Afghanistan. The U.S. has demonstrated that through a complex scheme of aerial refueling, made possible by complicated logistical plans, the Hornet can get there, but at the expense of the U.S. Air Force tankers. In the course of a mission, the Hornet must take on approximately 35,000 pounds of fuel while airborne. Due to its small size, this was accomplished during multiple refueling evolutions, at night, or in inclement weather. It has been shown that the B-1B possesses an unrefueled range of over 3,500 nautical miles, which eliminates the need for multiple refueling events. During the course of the missions, Hornet pilots grew more and more fatigued due to sitting in a confined cockpit and wearing NVDs for several hours. Depending on whether the mission was preplanned, in which the aircrew took off with designated targets, or they received tasking once airborne, B-1B aircrew could expect no more than one or two tanking evolutions (none for preplanned targets), had the luxury of a large crew station with enough room for the crew to at least stand up and stretch from time to time, and because of single aircraft operations, were not required to wear NVDs for formation keeping.

And, once on the scene, the F/A-18s couldn't stay nearly as long and were no more capable of delivering JDAM than the B-1B. Even when there was enough airborne fuel, the Hornets repeatedly had to leave the target area and return to the tanker, which proved to limit their effectiveness due to the constant breaks in communication with the ground forces for which they were providing support. On several occasions, Hornets received requests for immediate support, relayed through the tanker aircraft, while they were receiving fuel. They would be forced to terminate the fueling evolution to return to the target area, arrive late and miss a time sensitive opportunity, or deny the support, which was the sole reason for their being there in the first place. The B-1Bs remained on station for hours, while maintaining constant communication with ground forces, and were rarely forced to break the lines of communication or leave the target area in order to refuel.

Most importantly, the effects obtained from the B-1B's twenty-four JDAMs dwarf that of a section of Hornets, for it would take twelve F/A-18s to generate the same effects. Military planners have learned over the years that effects-based warfare is the most effective way to win battles. Rather than the random destruction of enemy assets, targets are selected and destroyed to achieve a desired effect, to bring us toward a strategic goal which has been determined as necessary for a desired outcome of the conflict.

Hornet pilots routinely fought to stay awake during the long transit back to the carrier, eating sugar filled protein bars or drinking caffeine. Sometimes, the only thing that could alleviate the drowsiness was the sun rising on the horizon after a long flight that started in total darkness. Lastly, they had to perform the carrier landing in an unforgiving environment, while fighting the effects of fatigue. In contrast, the B-1B had a crew of four, two of which were pilots so that the duties of flying the aircraft were shared. Landing on a 12,000 foot, stationary, well lit runway was dangerous only in that its simplicity could cause the crew to become complacent.

Not to say that the smaller interdiction aircraft such as the F/A-18 do not play a vital role in strike warfare, particularly when a quick response is required or when the potential for an air-to-air engagement exists, but when the bombing campaign begins and air supremacy has been established, there is no better platform than the B-1B. The B-1B is undergoing many upgrades to avionics, offensive and defensive systems, and to smart weapons capabilities. These efforts should be continued. The B-1B has not reached its full potential, yet already has staked its place in history as one of the best ever. With the advent of GPS guided munitions, whose accuracy is second to none and is not dependant upon the platform, the B-1B must be considered the weapons platform of choice for long range interdiction missions due to its flying qualities, superior range and endurance, and its unmatched payload capability.

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Vita

Stanley Jones was born in West Germany in 1965, is the son of an Army Officer, and grew up in various locations around the world before moving to Memphis, TN in 1979. He graduated from Sheffield High School in 1983 and enrolled at the University of Tennessee, Knoxville. He was a member of the 1985 Southeastern Conference Championship football team and in 1988, he graduated with a B.S. in Industrial Engineering. In 1991, he joined the United States Navy and became an F/A-18 fighter pilot. In 1997 he was selected to attend the United States Naval Test Pilot School and graduated with Class 115 in June 1999. Throughout his naval career, he has made four extended deployments in support of many U.S. operations. Most recently, he flew combat missions in support of Operation Enduring Freedom in Afghanistan and earned two strike flight air medals.

He currently resides in Virginia Beach, VA with his lovely wife Gina, his beautiful daughters Kennedy, Morgan, and Sydney, and his two rambunctious labs Rocky and Duke.