Raptor Supersonic JDAM: Faster, Further, Longer

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Abstract—The F-22A Raptor’s characteristics of stealth, supercruise, and integrated avionics make it an ideal self-escort or stealth package escort platform, capable of air-to-air operations and destroying heavily defended ground targets in high threat regions1 2. Once the subsonic air-to-ground Joint Direct Attack Munition (JDAM) capability became available in late 2004, the warfighter immediately recognized the need for an expanded release envelope into supersonic regions to improve the pilot’s tactical options and substantially increase the JDAM release range to a distance much greater than any other aircraft. The testing for supersonic JDAM was accelerated to significantly increase the Raptor’s air-to-ground combat lethality prior to Initial Operational Capability (IOC) in December 2005. This paper will detail the unique test effort, challenges, and lessons learned from the Raptor supersonic JDAM integration testing.

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1. OBJECTIVES

In 2005, the F-22 CTF conducted supersonic GBU-32 JDAM testing with the Raptor. This testing consisted of seven airborne separations, one captive carry flight, and one guided release flight. The testing was performed in the R2508 complex and W-532, utilizing Edwards, China Lake, and Vandenberg Ranges. The primary test objective was to clear an interim supersonic envelope for JDAM release in time to meet IOC in December 2005. A follow-on effort to clear the remainder of the supersonic JDAM envelope will be tested in 2006.

2. TEST ITEM

Figure 1 – F-22A Raptor

The test aircraft for airborne separation testing was F-22A S/N 91-4006. The test aircraft for JDAM captive carry and guided releases was F-22A S/N 91-4007 containing 3.1.3 software (the initial software load with air-to-ground functionality). The F-22A (Figure 1) is a two-engine, single-seat, all-weather low observable tactical fighter. The fuselage is characterized by a large bubble canopy and side-
mounted engine air inlets. The wing has automatic leading edge flaps, trailing edge flaperons and trailing edge ailerons that enhance performance over a wide speed range. The empennage consists of two vertical tails with rudders and two moveable horizontal stabilizers. All flight control surfaces are actuated hydraulically and are directed by signals through a fly-by-wire system. Basic armament includes a fuselage-mounted multi-barrel 20 mm gun and a mix of internally carried air-to-air and air-to-ground weapons. Four underwing hard points are provided to carry external weapons and fuel tanks.

MAIN WEAPONS BAYS

Two main weapons bays (MWB) account for a substantial portion of the belly of the aircraft. The MWB doors are hydraulically powered and provide access to the main weapons bays for maintenance, weapons loading, and weapons employment. Each main weapons bay can hold a mix of air-to-air and air-to-ground weapons. The main weapons bays hold Advanced Medium Range Air-to-Air Missiles (AMRAAMs) attached to AMRAAM Vertical Ejection Launchers (VELs), which deploy the missiles out of the weapons bays into the air stream. A single 1000-pound JDAM and a BRU-46 bomb rack can replace 2 AMRAAM/VEL pairs in each weapons bay (Figure 2). Subsequent Raptor upgrades will include the small diameter bomb to further enhance its air-to-ground role.

![Figure 2 – Left Main Weapon Bay](image)

The JDAM is attached to the aircraft with a BRU-46 bomb rack. The JDAM is ejected from the bomb rack via a forward and aft ejector. The distribution of ejector force from these two ejectors gives the JDAM the proper bomb attitude and ensures safe weapon-aircraft separation under a variety of conditions. The pitch valve settings that control these ejectors are not cockpit selectable and are set prior to flight for the particular weapon type and planned release conditions.

GBU-32

The GBU-32 is a 1000-pound JDAM variant that provides an all-weather launch and leave air-to-ground capability. JDAMs are employed by over fourteen different aircraft and were first dropped in combat in 1999 during Operation Allied Force. Multiple JDAMs can be dropped on multiple targets on a single run and can be programmed to hit at pilot-selected impact angles and azimuths. The release aircraft does not have to point directly at the target to release the JDAM and therefore targets can be destroyed using significant off-axis deliveries. JDAM target coordinates, impact conditions, and fuze settings can be programmed and changed in flight.

The GBU-32 is comprised of a Mk-83 bomb body and a JDAM kit that allows the weapon to glide to a programmed set of target coordinates using a GPS-aided inertial guidance system. The JDAM kit includes strakes that provide lift and enhance the maneuverability of the bomb. The electronics are contained in a tail kit that consists of a tail actuator subsystem, GPS antenna and receiver electronics, control fins, thermal battery, wire harness, and a guidance control unit. The GBU-32 can use the FMU-139 fuze or the Joint Programmable Fuze. The GBU-32 uses the navigation solution of the aircraft to initialize its INS. The aircraft also passes the weapon GPS keys, GPS satellite information and target data, including coordinates and desired impact conditions.

3. TEST SCHEDULE

Subsonic JDAM testing on the Raptor ended in October 2004 and was initially the only air-to-ground requirement for the aircraft prior to IOC. However, immediately after this capability became available, the warfighter recognized the need for faster JDAM releases in order to maximize JDAM range. In order to provide a portion of the supersonic envelope prior to IOC, the ultimate final envelope was divided into two sections identified as Step 1 and Step 2. The Step 1 envelope was a subset of the entire supersonic envelope, and required seven separation flights and one guided release to clear. The Step 2 envelope represents the entire supersonic envelope and will require additional separations and guided releases. It will be cleared and made available to the operational Raptor fleet in 2006.

The F-22A supersonic JDAM flight test program began with environmental testing which proved that the aircraft, the BRU-46, and the JDAM could withstand the loads, vibration, acoustics and temperatures encountered during JDAM carriage. This testing cleared the entire envelope (subsonic and supersonic) for JDAM carriage in 2003 before any releases were attempted. The airborne separation phase of the flight test program ensured the JDAM would safely separate from the aircraft and analyzed JDAM
performance in the first few seconds after leaving the weapons bay. The captive carry flight acted as a practice for the guided release flight, and analyzed the accuracy of the Launch Acceptability Region (LAR) at a variety of flight conditions and weapon impact parameters. The final phase of the test program included one JDAM guided release at the outer edge of the Step 1 supersonic envelope.

4. SEPARATION TESTS

The JDAM test assets used during the airborne separation flights were Separation Test Vehicles (STV). These items exhibit the same mass properties as actual JDAMs, but do not contain any of the actual electronics or movable fins. The STVs contain six degree-of-freedom (6DOF) telemetry kits to capture attitude and acceleration data during the separations. Additionally, the test aircraft visually recorded weapon separations via internally and externally mounted cameras.

5. CAPTIVE CARRY FLIGHT TEST

One captive carry JDAM flight was planned in order to practice the guided release test setup, and to analyze the LAR accuracy at a variety of release conditions and impact constraints. The captive carry flight originated from Nellis AFB, was executed over the Vandenberg AFB sea range, and was controlled by test engineers located at Edwards AFB. This presented a unique set of challenges for the entire test team.

The complication of launching the test aircraft from Nellis AFB instead of it’s assigned home of Edwards AFB introduced several challenges. At the time of supersonic JDAM testing, the aircraft was in the midst of supporting Final Operational Test and Evaluation (FOT&E) at Nellis AFB, which required the ground crews and instrumentation engineers assigned to the aircraft to deploy to support flight operations. Given this scenario, the test team decided that the most efficient course of action was to send the pilot to Nellis AFB and fly the sortie from there instead of returning the aircraft and all test support personnel back to Edwards AFB for this single test.

Testing from a different launch location necessitated running the normal mission brief on the day prior to the mission to allow travel time for the pilot and to maintain adequate crew rest. This also impacted the test engineers, removing their ability to support other missions the day prior to the test. It also required the test engineers from other locations (contractors and System Program Office personnel) to travel a day earlier than planned. However, the benefit of having a face-to-face briefing was critical to performing an efficient and effective test.

Another factor associated with this test scenario was the 30 minutes of additional flight time required to fly to the test range from Nellis AFB as compared with flight from Edwards AFB. This resulted in a shortened test period due to test sortie time limitations in accordance with Air Force regulations. To compensate for the shortened test period, extensive pre-mission planning was accomplished in an effort to lay out the LAR test points in such a way that the entire test could be accomplished on a single pass. Accomplishing this test over the sea range provided more flexibility in allowing supersonic conditions than over land. Prior to attempting this test flow, the entire profile was flown in the Raptor Software Integration Lab (SIL) in order to verify it could be successfully accomplished. The SIL also demonstrated that the Raptor would be near minimum fuel at the end of the run. This allowed the test team to preposition an air refueling tanker near the endpoint of the test profile during the actual test to meet fuel requirements. The simulator proved invaluable in providing efficient and safe testing. (Lesson Learned (LL) 1) A Software Integration Lab used for mission planning can drastically improve test efficiency and safety.

Additionally, the control room at Edwards AFB was not able to directly speak to the pilot during ground operations, nor could the control room receive the aircraft and JDAM telemetry signals. The communication issue was partly resolved by having the control room and the ground operations engineer talk via standard phone lines during ground operations. This allowed the mission control room to keep updated on the aircraft status and to resolve JDAM problems using the control room experts. To mitigate any potential telemetry issues, there was a ground operations instrumentation van at Nellis AFB to verify that aircraft and JDAM telemetry were being transmitted properly. However, during the flight the control room was unable to read the telemetry because a different set of cryptographic keys were used at Nellis AFB than were used in the control room at Edwards AFB. In order to correct the telemetry problem, the test aircraft landed at Edwards AFB and was rekeyed with the engines running at the end of the runway. This same contingency was used during subsonic JDAM testing in 2004 due to another issue. While the test was successful because of a good contingency plan, poor communication and configuration control almost cancelled the mission. (LL2) Cryptographic keys control several items in modern aircraft and proper keys must be coordinated and loaded for proper operations, test or otherwise. Configuration control of all types is critical.

During flight test, a key member of the control room is the Test Director (TD). While the Test Conductor (TC) typically coordinates with the pilot during a test, the TD oversees all test operations and coordinates airspace, outside agencies, and other personnel. In the midst of the quick reaction necessary to execute the above-mentioned contingency, the TD was called away from the test for a family emergency. Fortunately, the TC was dual qualified as a TC and TD and was able to take over both
responsibilities until a replacement TD could be located. (LL3) Dual qualified TCs/TDs and other redundant positions within the test team can provide flexibility during test missions. After a 40-minute delay on the ground at Edwards AFB to rekey the aircraft and verify all telemetry streams, the mission continued. This contingency plan, along with responsive maintenance personnel, allowed the test to be salvaged and the compressed test time line to be maintained. (LL4) This experience highlighted the importance of well-planned test contingencies in order to maintain a demanding test schedule. Thinking through various contingencies is critical to maintaining test efficiency and safety.

An additional hurdle was the result of an aircraft problem after the takeoff from Edwards AFB. A circuit breaker that supplied power to the Heads Up Display (HUD) and Integrated Control Panel (ICP) was tripped. The ICP enables the pilot to enter data into the aircraft computers during flight. After careful investigation, the pilot determined that he could safely continue the mission using a small backup HUD and a backup ICP. The only impact was to the post mission data requirements because video data recording was now unavailable. However, other methods were available to analyze all mission data and the mission was continued with a higher workload for the pilot than was typical. The pilot used for this mission had been involved in test planning from the early stages, and was the most experienced JDAM pilot. This enabled him to successfully execute the test, in spite of the increased workload. (LL5) The use of project pilots, involved with the engineers from early test planning, provides increased experience to overcome problems during testing.

The Launch Acceptability Region (LAR) investigation was accomplished as planned during the test. The LAR is displayed to the pilot to advise him when the aircraft is in range to release a JDAM against the selected target for the current aircraft airspeed and altitude. The ability to complete the LAR test points in a single run was especially crucial to the success of the mission due to the time lost in resolving the telemetry issue.

Following completion of the LAR investigation, simulated runs were accomplished against a target to gather data for planning of the guided release mission. The information gathered during this practice run helped determine the airspace required to accelerate to the test conditions from subsonic speeds. This helped provide a strong argument for an expanded supersonic corridor for the actual JDAM release as described in the Guided Release Section below. (LL6) Practice runs uncover critical unexpected items that can then be resolved prior to the actual testing.

6. GUIDED RELEASE FLIGHT TEST

The flight test scenario, which involved releasing a fully functional JDAM from a supersonic airspeed, was designated JDAM-04. The release was on-axis with an impact angle constraint on a single ground target. The target coordinates were loaded into the aircraft via a mission-planning computer and were confirmed by the pilot in the cockpit. This mission included two passes on the range: a practice pass and a hot pass. Both passes required the aircraft to be supersonic prior to entering the China Lake airspace. The guided release mission introduced several first time events for a JDAM release. These firsts included the longest downrange distance from which a JDAM had ever been released, the fastest airspeed for a JDAM release and the longest JDAM time of flight for an actual guided release.

The practice pass was executed as predicted and indicated that the timeline for the release was indeed compressed. This compressed timeline was due to the very fast release conditions for the relatively small area of available airspace. The relatively long downrange distance and supersonic release conditions presented unique challenges for the test team. In order to accomplish the test, the F-22A was authorized to fly supersonic outside of normal supersonic airspace. Extensive prior coordination was required with Edwards and China Lake Range Control Officers to provide this increased supersonic corridor. This expanded supersonic corridor allowed the pilot to ingress on-axis with the release point and focus his attention on the test rather than concentrating on airspace restrictions. (LL7) Proper prior coordination with range assets can streamline test planning and increase the likelihood of a successful test.

The combination of releasing a JDAM from a high supersonic airspeed and a relatively high altitude also resulted in a very large weapon footprint, the area a weapon could potentially reach from a given release point. Normally a large footprint weapon contains a flight termination system (FTS), which gives the range safety officer the option of destroying the weapon in-flight if anything unexpected occurs. The JDAM does not contain a FTS and therefore the entire JDAM footprint had to be cleared for safety reasons. The Cleared-to-Arm and Cleared-to-Release calls from the range controller were made relatively close to the release point due to the footprint and further compressed the timeline.

An additional factor that needed to be addressed for the guided release was the JDAM battery life versus weapon time of flight (TOF) from the planned release conditions. Since this release had a much greater TOF than any other JDAM ever released, it was necessary to ensure the weapon battery life exceeded the TOF. For this mission, the test team calculated the predicted JDAM time of flight based on various inputs such as release conditions, air data and impact conditions. The result of this study was that battery
life was not a concern. However, detailed planning and consideration of this factor eliminated unknown variables that could have caused a problem for the test.

The limiting factor for maximizing the downrange release distance for this test was the winds experienced during the release. The range at which a JDAM can be released is heavily dependent on the winds. Prior to the guided release flight, the test team created a table that gave release distances for several different wind conditions including combinations of head, tail and cross winds up to 130 knots. This successfully maximized the downrange release distance during the test, in order to stress the weapons system. (LL8) Detailed test planning uncovers and eliminates potential test hurdles.

7. TEST RESULTS AND CONCLUSIONS

The results of F-22A Raptor supersonic JDAM testing were impressive in spite of all of the challenges that the test team faced. Separation testing showed the JDAM could be safely released from the Raptor at a variety of supersonic speeds. Miss distance and impact parameters of the JDAM guided release met the JDAM accuracy requirements. Overall the testing proved that the Raptor met updated Initial Operational Requirements and will be very capable of delivering supersonic JDAMs when called upon to do so.

8. LESSONS LEARNED

1. A Software Integration Lab used for mission planning can drastically improve test efficiency and safety.

2. Cryptographic keys control several items in modern aircraft and proper keys must be coordinated and loaded for proper operations, test or otherwise. Configuration control of all types is critical.

3. Dual qualified TCs/TDs and other redundant positions within the test team can provide flexibility during test missions.

4. Well-planned test contingencies can help maintain a demanding test schedule. Thinking through various contingencies is critical to maintaining test efficiency and safety.

5. The use of project pilots, involved with the engineers from early test planning, provides increased experience to overcome problems during testing.

6. Practice runs uncover critical unexpected items that can then be resolved prior to the actual testing.

7. Proper prior coordination with range assets can streamline test planning and increase the likelihood of a successful test.

8. Detailed test planning uncovers and eliminates potential test hurdles.

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BIOGRAPHY

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