AH-1Z Stores Compatibility Testing Lessons Learned

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Abstract—The AH-1Z Cobra was a major upgrade of the AH-1W performed under the United States Marine Corps (USMC) H-1 Upgrades Program. Upgrades significant to weapons employment included a new rotor system, new stub-wing weapons stations, countermeasure dispensing system, and upgraded drive-train. These upgrades required testing to evaluate the AH-1Z’s ability to safely employ weapon systems. The objectives of this test were to evaluate the separation characteristics of weapons and stores fired, launched or dispensed from the AH-1Z; measure aircraft structural loads, strains, and vibrations during weapons firing; and use measured flight data to evaluate the effects of weapon firings on engines and drive systems in order to recommend safe store employment envelopes. During the test program, stores compatibility results were encountered which were not expected during test planning, including rocket gas ingestion and unsatisfactory 20-mm ammunition link separation. The AH-1Z stores compatibility test program was originally planned with limited scope since the aircraft was merely an “upgrade” of the AH-1W (figure 1), which had no known stores compatibility issues with the systems to be tested. While the original test planning had allowed the discovery of these unforeseen issues, it did not provide the ability to fully evaluate them or define the flight envelope where these phenomena occur. As a result, not only did the scope of testing need to increase, but the test methodology with which the tests were performed required revision as well.

This paper will present the results of rocket gas ingestion and 20-mm ammunition link separation, examine how the AH-1Z Cobra stores compatibility test team refined its test methodology as aircraft/stores compatibility issues arose, and present lessons learned from the test program.

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1. INTRODUCTION

The AH-1Z Cobra was a major upgrade of the AH-1W performed under the United States Marine Corps (USMC) H-1 Upgrades Program. Upgrades significant to weapons employment included a new rotor system, new stub-wing weapons stations, countermeasure dispensing system, and upgraded drive-train. These upgrades required testing to evaluate the AH-1Z’s ability to safely employ weapon systems. The objectives of this test were to evaluate the separation characteristics of weapons and stores fired, launched or dispensed from the AH-1Z; measure aircraft structural loads, strains, and vibrations during weapons firing; and use measured flight data to evaluate the effects of weapon firings on engines and drive systems in order to recommend safe store employment envelopes. AH-1Z weapons and stores tested during this flight evaluation included AGM-114 Hellfire missiles, AIM-9 Sidewinder missiles, 2.75-inch rockets, aircraft parachute flares, 20-millimeter (mm) cannon, and dispensed countermeasures.

During the test program, stores compatibility results were encountered which were not expected during test planning, including rocket gas ingestion and unsatisfactory 20-mm ammunition link separation. The AH-1Z stores compatibility test program was originally planned with limited scope since the aircraft was merely an “upgrade” of the AH-1W (figure 1), which had no known stores compatibility issues with the systems to be tested. While the original test planning had allowed the discovery of these unforeseen issues, it did not provide the ability to fully evaluate them or define the flight envelope where these phenomena occur. As a result, not only did the scope of testing need to increase, but the test methodology with which the tests were performed required revision as well.

This paper will present the results of rocket gas ingestion and 20-mm ammunition link separation, examine how the AH-1Z Cobra stores compatibility test team refined its test methodology as aircraft/stores compatibility issues arose, and present lessons learned from the test program.

2. TEST ARTICLE DESCRIPTION

AH-1Z Cobra

The AH-1Z is a two-seat, four-bladed main rotor attack helicopter powered by two T700-GE-401 engines, manufactured by Bell Helicopter Textron, Inc. (BHTI). The primary missions of the AH-1Z are close air support, anti-armor and escort. The AH-1Z has six external weapon stations. The stations are supported by the weapons pylon installation (“stub wings”), which is a primarily aluminum structure shaped as an aerodynamically neutral airfoil. Each wing contains the Store Station Electronics boxes as well as a 50-gal. fuel cell (between spars). BRU-59 bomb racks provide 14-inch suspension lugs for stores and launchers on the four universal weapon stations (2 through 5). The two outboard stations (1 and 6) incorporate LAU-7 series missile launchers for rail-launched stores and are non-jettisonable. AH-1Z Aircraft #2 (Z2), BuNo 166478 (BHTI S/N 59002) was used for this test. For the purpose of this
test, the test aircraft was representative of the production AH-1Z. The AH-1Z is shown in figure 2.

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Figure 1: AH-1W Cobra

Figure 2: AH-1Z Cobra

2.75-Inch Rockets

Mk 66 Mod 2 and Mod 4 rocket motors with WTU-1/B warheads were used for this test. Rocket motors include the following components: an igniter, propellant grain with a stabilizing rod, nozzle, fin assembly, and firing contact disk/band. The motor is ignited by 28-VDC aircraft power distributed by the launcher intervalometer to each tube’s firing contact. Gas pressure resulting from the burning igniter charge ruptures the igniter case and ignites the propellant grain. The propellant burns from front to rear to minimize center of gravity shifts. Propellant gases rupture the nozzle seal and exert forward pressure (motor movement) that overcomes the launcher tube locking detent. The salt-coated stabilizing rod, located in the center of the propellant grain, prevents unstable burning of the grain and reduces flash and afterburning that contribute to compressor stalls and flameout of jet engines. The wrap-around fins on the Mk 66 2.75-inch motors are spring actuated to open and seat in the nozzle body fin slots as the motor exits the launcher tube.

The LAU-61C/A rocket launcher was used for this test. The LAU-61 rocket launcher is capable of carrying 19 2.75-inch. rockets, is 59.9-in. long (86.2-in. with fairings) and 16-in. in diameter. When fully loaded (Mk 66 motors and WTU-1/B inert warheads), the LAU-61 weighs 591-lbs. For the purposes of this test, the LAU-61 was also representative of the LAU-68 rocket launcher.

Figure 3 shows the LAU-61 launching 2.75-inch rockets from the AH-1Z.

Figure 3: 2.75-Inch Rocket Launched from AH-1Z

M197 20-mm Gun System

The A/A49E-7 (V4) turret system is chin-mounted on the helicopter and provides the capability to position, feed, and fire the M197 20-millimeter (mm) automatic gun. Major components of the turret system include the turret assembly, M197 gun, torque box assembly, recoil compensation system, M89/M89E1 feeder/delinker, gun drive assembly, gun control system, and the 20-mm feed system. The azimuth drive system rotates the turret through a range of $110^\circ$. The gun can be lowered to $-50^\circ$, while the positive elevation limit varies between $6.0^\circ$ and $14.6^\circ$ to provide adequate rotor clearance for safe firing conditions. The gun control assembly controls operation of the gun and operation of the ammunition system. The production ammunition feed system contains 750 rounds of belted 20-mm ammunition. The ammunition feed system of the test aircraft was modified and contained only 80 rounds to accommodate test instrumentation located in the ammunition bay. The gun drive assembly rotates the gun barrels at a rate of approximately 650 rounds per minute. The turret system is electrically operated and requires 28VDC and 115VAC at 400Hz from the helicopter electrical system. Expended ammunition casings and links are expended from the bottom of the turret and into the air.
stream. For the purpose of this test, the M197 gun system was production representative. A link ejection system (P/N 11830861) was utilized during a portion of the test program and is shown in figure 4. The link ejection system attaches to the bottom of the M89 delinker. The link ejection system rotates the ammunition links as they are dispensed from the delinker, breaking up the expended link chain.

![Figure 4: Link Ejection System Attached to M89 Delinker](image)

**Photographic Instrumentation**

The test aircraft was equipped with six external digital video cameras used for documentation of store separation characteristics. On board cameras and mounting locations are shown in figures 5 and 6. Store separation characteristics were also documented with chase aircraft video. All recorded video was viewed for qualitative analysis of store separation characteristics. Onboard external camera video and chase video was monitored via telemetry for real-time store separation evaluation and verification of proper aircraft, store, and camera system operation.

![Figure 5: Port Camera Locations](image)

![Figure 6: Starboard Camera Locations](image)

**Aircraft Instrumentation Package**

The test aircraft was fully instrumented for basic aircraft parameters, loads, vibrations, ingestion testing. The data acquisition system consisted of an airborne data system, a telemetry receiving ground station, and a flight test data network. The Airborne Data Acquisition System (ADAS) was primarily installed in the test aircraft’s ammunition bay, with data sources that included flight test instrumentation measurement transducers, the aircraft flight control system and the avionics system data buses. The ADAS recorded all of the required parameters for each test onto an onboard recording system, and telemetered a selected data stream to the ground receiving station. BHTI’s Computer Aided Flight Test Analysis (CAFTA) system was used for data processing, automatic limit checking, and post-test engineering analysis. The CAFTA system contains a database of all measured data parameters for each flight.

3. **TEST PLANNING PROCESS**

During the initial planning for AH-1Z stores compatibility testing, assumptions were made to aid in defining the scope and method of the flight test program. As this is a “lessons learned” paper, the author will focus on what went wrong, rather than what went right.

**General Planning**

The philosophy regarding AH-1Z stores compatibility testing was “test to qualify” vice “test to learn.” The objective of testing was to qualify each store type on the AH-1Z. As a result, the scope of testing was planned to safely gather the necessary data for store qualification in the minimum number of test points. No effort was planned to gather additional data to investigate and better understand any issues that might come up during the test program.

**2.75-Inch Rocket Planning**

The AH-1Z is a major upgrade of the AH-1W. As such, previous reports documenting results of rocket system testing including “AH-1W Super Cobra Armament Flight Tests” (reference 1), which documented initial stores compatibility testing on the AH-1W, were reviewed by the test team. Although rocket gas ingestion issues with 5-inch
(Zuni) rockets were noted, reference 1 reported that the employment of 2.75-inch rockets from the AH-1W was satisfactory within the complete flight envelope of the aircraft with no firing restrictions.

Although the AH-1Z included many upgraded systems compared to the AH-1W, it retained the same engine type, engine inlets, fuselage mold line, rocket motor type, and rocket launcher type. As a result, the test team did not anticipate any major difference in rocket gas ingestion characteristics from the AH-1W.

The test team made one other poor assumption during rocket test planning. The test team assumed that rocket gas ingestion test points resulted in repeatable data, meaning that a particular test condition would only produce one particular result.

These two poor assumptions combined (similar characteristics as the AH-1W and repeatable data) led the test team to develop a rocket system test matrix progressing quickly from high to low speed, outboard to inboard store stations, and single fire to ripple fire, while only executing one sample at each test condition.

M197 20-mm Gun System Planning

The M197 20-mm gun system on the AH-1Z is retained unchanged from the AH-1W. In fact, the design goes back to previous versions of the AH-1, dating back more than 30 years. The test team was not aware of any ammunition link separation issues or deficiencies. As a result, planned test points focused on gathering structural loads and vibration data as a result of gun firing. Although the onboard external cameras would be used to record ammunition link separation, no concern existed and consequently no dedicated testing was developed for link separation.

4. TEST RESULTS

2.75-Inch Rocket Results

Initial AH-1Z 2.75-inch rocket compatibility testing was conducted during the summer of 2004 at Yuma Proving Ground, Arizona. During initial testing, 49 rocket firing test points were conducted totaling 342 rockets. Out of the 49 test events, 14 events resulted in minor ingestion, 3 events resulted in significant ingestion, and 1 event resulted in severe ingestion. A minor ingestion event is defined as ingestion of rocket motor exhaust into the engine, leading to an inlet temperature rise but not resulting in drive system fluctuations. A significant ingestion event is one where ingestion of rocket motor exhaust leads to excessive inlet temperature rise and pressure surges, which result in engine discharge and torque fluctuations in the aircraft drive system. A severe ingestion event results in torque fluctuations of a magnitude that require replacement of drive system components. Significant rocket exhaust ingestion was observed during: left and right sideward flight above 15 knots, rearward flight above 15 knots, and low speed forward flight between 30 and 60 knots. Due to the limited scope of our test, insufficient data was available to determine the envelope limits where ingestion becomes an issue.

Rocket accuracy testing was also conducted during the summer of 2004 at Yuma Proving Ground. Rocket accuracy testing required that each test condition be repeated at least eight times in order to gather a statistically significant sample of accuracy data. This led to an unforeseen discovery regarding rocket gas ingestion. Although not a primary objective of accuracy testing, all engine and drive system instrumentation was monitored to gather additional data. This led to the discovery that the rocket exhaust effects on the engine and drive system could vary significantly from shot to shot at the same test condition. The test team’s assumption of repeatable data was a gross error.

Fortunately, the test method and scope had allowed the discovery of a serious issue in a safe manner in the test environment. Unfortunately, the test scope and method did not allow the ability to adequately evaluate this serious issue. Consequently, our test scope and methodology required major revision.

A Tiger Team was formed in August 2004 to support the H-1 Upgrades flight test team in resolving AH-1Z rocket exhaust ingestion issues. The Tiger Team was comprised of eight members from outside the test team from Bell Helicopter and Naval Aviation Systems Command. The Tiger Team’s charter was to review the AH-1Z rocket firing requirements, review the AH-1Z rocket firing test plan, examine the AH-1Z design with respect to rocket exhaust gas ingestion, establish criteria for acceptable/unacceptable levels of exhaust gas ingestion to be used in future firing tests, examine the rocket firing data collected to date, and formulate a proposal for future testing.

The Tiger Team included a former U.S. Army test pilot who had experience with U.S. Army AH-1 rocket gas ingestion testing and directed the test team to review U.S. Army results (reference 2). These results had not been previously reviewed by the test team, who had focused their research on previous USMC AH-1 weapons system testing. The Army testing concluded what the test team had learned the hard way, that the occurrence and severity of an engine surge was not predictable and a severe engine surge could occur at a given flight condition and no surge may occur when the flight condition was repeated.

The Tiger Team review concluded that insufficient data was available to determine a safe rocket employment envelope and recommended that additional testing be conducted. This has resulted in additional testing, which continues at the
time of this writing in fall 2005, many times the magnitude of the original scope, incorporating the lessons learned during our initial rocket gas ingestion testing.

20-mm Ammunition Link Separation Results

Initial AH-1Z 20-mm gun system testing was conducted during the summer of 2004. No ammunition link separation envelope expansion was conducted as is normally done in a stores compatibility test program, since no separation issues were foreseen. While firing during a 200 knot dive, a link was observed impacting the helicopter’s port elevator. This event occurred during a structural loads and vibrations data gathering test point. Following this event, all 20-mm testing at high speed (200 knots) was terminated and a safe separation envelope expansion plan was developed to investigate the issue.

The safe separation envelope expansion plan consisted of firing 80 round bursts starting at 150 knots and working up in 10 knot increments to 200 knots (aircraft’s top speed). The safe separation envelope expansion plan was completed with the aircraft proceeding to 200 knots without another incident of unsatisfactory separation. Again, the test team found that their assumption of repeatable data was incorrect as the unsatisfactory separation previously encountered at 200 knots was not repeated.

However, unsatisfactory link separation was again encountered. During real-time monitoring of the onboard video cameras, a link was observed in the vicinity of the tail rotor while firing during a 2G symmetric pull-up from a 200 knot dive. Post-flight analysis of the video showed that a clump of 5-6 links impacted the starboard aft skid cross-tube after separating from the turret. After impacting the skid cross-tube, the clump dispersed into single links, traveling upward. Multiple links from the clump impacted the starboard elevator. One link crossed the aircraft centerline in front of the vertical stabilizer and passed between the vertical stabilizer and the tail-rotor as shown in figure 7.

A review of available test data indicated that links striking the landing skid, particularly the aft cross-tube was common during high-speed flight. This was due to the random flight path followed by the links after separating from the bottom of the turret. This random path was most likely due to turbulent airflow underneath the turret interacting with the low weight, high drag links. This random flight path accounted for the non-repeatability of the test data. After striking the skid, the links took an unpredictable flight path. This unpredictable flight path had the potential of sending the links into the tail or tail rotor. Skid strikes were observed with airspeed as low as 140 knots, in straight and level flight. The occurrence of skid strikes and the randomness of the resultant flight path increased with airspeed and dynamic maneuvering.

In an effort to improve 20-mm separation characteristics, a link ejector system was installed, as shown in figure 4. The link ejector was evaluated on every subsequent flight. The link ejector system significantly improved separation characteristics. The addition of the link ejector caused the links to separate in individual links rather than clumps. From qualitative analysis, it appeared the link ejector also caused the links to separate in a more uniform (less random) path. Although the addition of the link ejector significantly improved separation, it did not eliminate the occurrence of landing-skid strikes and the resultant potential of tail or tail rotor strikes. Figure 8 shows another event of unsatisfactory link separation that occurred after the installation of the link ejector system.
Again, the good news was that our test method and scope had allowed the discovery of a serious issue in a safe manner in the test environment. The bad news was that our test scope and method did not allow the ability to adequately evaluate this serious issue.

5. CONCLUSIONS

The unexpected results encountered during the AH-1Z Cobra stores compatibility flight test program offered the opportunity for many lessons to be learned:

**Do Not Assume Data is Repeatable**

Going into testing, the test team did not sufficiently understand the complex phenomena involved in rocket gas ingestion testing. As a result, the test was planned assuming repeatable data, as is common in other types of stores compatibility testing. However, the flight testing demonstrated that the data was not repeatable. Repeated test points at the same test condition often resulted in drastically different results. In this case, thorough understanding of the subject matter was replaced with an assumption.

Assumptions should only be made regarding areas of subject matter expertise. Lacking expertise regarding repeatability, it should not be assumed.

**“No Known Deficiencies” is No Guarantee a Deficiency Does Not Exist**

As the AH-1Z was an upgrade of the AH-1W, the test team thoroughly researched previous AH-1W test results regarding stores compatibility. The test team found that there were no known deficiencies regarding 2.75-inch rocket firing or 20-mm link separation. This caused the test team to limit the scope of testing on the AH-1Z, as no significant changes in characteristics were expected.

Do not rely on previous testing to have discovered all the deficiencies in a system. Just because a sub-system is already in service or is unchanged from a previous version there is no guarantee there are not issues or deficiencies in hiding.

**Minor Modifications Are Rarely Minor**

Although the AH-1Z included many upgraded systems compared to the AH-1W, it retained the same engine type, engine inlets, fuselage mold line, rocket motor type, and rocket launcher type. As a result, the test team did not anticipate any major difference in rocket gas ingestion characteristics from the AH-1W.

However, the flight testing proved that even a minor change to a system can result in major changes to the system’s performance or operating characteristics.

**Plan as Much Flexibility Into Test Plans as Possible**

Too often, our testing came to a grinding halt because we ran into a result that our test plan didn’t allow us the ability to sufficiently evaluate. This resulted in a significant amount of lost time as we stopped the testing, revised the test plan, and waited for approval.

Plan for the unexpected. Define ahead of time all the possible results of testing. Plan ahead of time what the appropriate course of action would be for each set of results. Plan flexibility into your plan so its course can change depending on the results. This can be accomplished by early and frequent communication with the testing leadership and test plan approving authorities.

**Invest in the Planning Stage**

Too often, we incurred delays during the “testing phase” of our test program in order to perform additional planning. This resulted in not only schedule delays, but significant additional expense.

Time invested during the planning stage is very well spent. Once all the testing logistics pieces are in place and you are on-range, delays for additional planning are very expensive. Invest the time up-front during planning to get it right the first time.

**Perform Pre-Test Research from a Wide Range of Sources**

During the test planning process, the AH-1Z stores compatibility flight test team extensively researched previous flight test results. However, we made the mistake of only researching results from previous USMC stores-
compatibility testing. We later found that valuable information was available in reports from other types of flight testing and testing from other services.

Following the discovery of rocket gas ingestion issues, the test team found that previous rocket gas ingestion data was presented in an AH-1W hydromechanical unit (HMU) report. This report had not been reviewed by the test team during planning since it was not a “stores compatibility” report. The test team learned that research must also be done in all potentially associated fields and not focused on one subject.

The test team also learned that valuable data was available in reports from other services. Gathering data from other service branches and agencies is often difficult. Due to different administrative processes, bureaucratic infrastructure and protectiveness of one’s own data, seeking help from other agencies is a challenge. However, it is an investment with the potential for great dividends. The time spent and pain endured gathering that data and learning their lessons may be nothing compared to the time and pain involved learning those lessons on your own.

Summary

The lessons learned during the AH-1Z stores compatibility flight test program were often related to testing an “upgrade” of a previous system. As defense budgets are further tightened and the lead-time to develop a new major weapon system continues to lengthen, the desire to upgrade systems rather than develop new systems will surely increase. The AH-1Z stores compatibility test team made a few poor assumptions while planning the scope of testing for a system that was “only an upgrade.” It is the author’s hope that the lessons learned during this test program may assist a future test planner in not repeating them.

REFERENCES


BIOGRAPHY

Chris joined the Naval Air Warfare Center Aircraft Division (NAWCAD) at NAS Patuxent River, Maryland in July 2002 after graduation from Virginia Tech with a B.S. in Aerospace Engineering. Prior to coming to NAWCAD, he was an intern at the Naval Research Laboratory. He is an air vehicle / stores compatibility flight test engineer in the Manned and Unmanned Air Vehicle Evaluation Division. His flight test projects have included testing 7.62-mm and .50-caliber crew-served gun systems on U.S. Marine Corps, U.S. Coast Guard, and U.S. Navy helicopters. He is currently a flight test engineer for the USMC H-1 Upgrades program testing missile, rocket, countermeasure, and gun system compatibility on the AH-1Z Cobra and UH-1Y Huey. Chris is an avid pilot and is currently working on his Certified Flight Instructor Certificate.