Improved IM Response for Future 2.75” APKWS with Composite Case Technology

Tom Farabaugh, and Mike Kessinger
Alliant Techsystems Inc.

Christina Davis
AMRDEC, Redstone Arsenal, Alabama

ABSTRACT

The next generation 2.75-inch rocket motor for the Advanced Precision Kill Weapon System (APKWS) may require an improved insensitive munitions (IM) response for both guided and unguided rounds. Although the existing 2.75” MK-66 Rocket motor already utilizes a low vulnerability propellant (Class 1.3), the employed aluminum rocket motor case degrades the system’s IM response. An improved IM response may be achieved on the MK-66 rocket by replacing the metal aluminum rocket motor case with a composite material case. The composite rocket motor case should minimize hazardous metal fragments and vent at a low pressure when exposed to various external stimuli.

A previous composite case study was completed several years ago on the 2.75” rocket motor on the Non-Development Item (NDI) program. This program utilized a non-detonable propellant with a composite case. Although this program was discontinued, it did show improvements in IM could be achieved. The improvements were seen for bullet impact, fragment impact, fast cook-off and slow cook-off testing. Therefore, the goal of this study was to utilize the valuable composite case work and determine if these same improvements in IM response could be achieved by utilizing a composite case with the current MK-66 propellant.

Working together, ATK and AMRDEC utilized state-of-the-art technology to develop a drop-in composite case replacement for the MK-66 rocket motor. Different designs configurations were investigated, along with different composite fibers and fiber orientations in order to achieve optimal strength and maximize packaging volume. Hydro-burst data indicates promising burst pressure margins could be achieved that exceeds the current aluminum case design. Static testing of rocket motors at three different temperatures were proven to be successful and within performance specifications. Both nonstandard and standardized IM testing was completed on the composite and aluminum case motors. The unofficial IM test results showed significant improvements for the composite case over the current MK-66 aluminum case rocket motor utilizing the same propellant. These improvements suggest that a simple composite case replacement may provide improvement to the IM response of the HYDRA-70 rocket system.

BACKGROUND AND OBJECTIVES

Metal cases, either aluminum or steel, are utilized on almost every tactical rocket motor in the US arsenal. Although these metal cases have shown to be very reliable and cost effective, they typically perform poorly in IM testing. Unless the propellant is extremely insensitive, the confinement of the propellant plays a very important role in the IM response. New propellant technologies are starting to develop less sensitive minimum smoke propellants but more work needs to be done before they can be insensitive enough to put into a metal case. Therefore, a composite case is needed to improve the IM response of the 2.75” rocket system.

Several years ago, a composite case was designed and tested for the 2.75” MK-66 rocket motor. This was done under the Army’s 2.75” Non-Developmental Item (NDI) Rocket Motor Program. In this program, Thiokol Propulsion Inc. utilized a non-detonable, reduced smoke, Class 1.3 composite propellant. Although this program did not go forward, the IM results from this program were very favorable and showed that a composite case with the right propellant can be utilized to improve the IM response of the MK-66 rocket motor.

The objective of this study was to utilize the valuable information and work completed on the NDI motor program to develop a composite case replacement for the aluminum case in the 2.75” MK-66 rocket motor utilizing the current MK-66 cartridge loaded propellant grain. This modified configuration with the composite case is expected to exhibit improved IM characteristics. A Cooperative Research and Development Agreement (CRADA) between ATK Inc. and the Army’s Aviation & Missiles Research, Development and Engineering Center (AMRDEC) was setup to complete this work.

The propellant used in the current MK-66 rocket motor, NOSIH-AA2, is a minimum smoke propellant that has a hazards type classification of Class 1.3. It is a low cost, extruded double base (EDB) propellant formulation. It has enough energy to complete the mission and still have low vulnerability characteristics. Some propellant ratings systems suggest that a propellant is low vulnerability if it has an NOL Card gap test result of 70 cards or less. NOSIH-AA2 propellant and other similar minimum smoke EDB’s have been shown to have a NOL Card Gap test results of 40 cards or less. Additional propellant hazards assessment data for NOSIH-AA2 propellant show it to have:

- No. 8 blasting cap test ……………………………….No Detonation
- Impact Sensitivity with No Fire (Sheet form) ……….2 kg weight, 88 cm
- Friction (sheet)…………………………………………623 Mpa, 1.8 m/s

Although this propellant has low vulnerability characteristics, the confinement material/technique does play an important role for several types of external stimuli or threat hazards and does not respond well when utilized with a metal case.

A Threat Hazard Assessment (THA) has been completed on the Hydra 70 rocket system that incorporates the MK-66 rocket motor (Ref 1.) to characterize all of external stimuli to which the system might be exposed. Based on the THA and the IM response to external stimuli as defined by AOP39 (Guidance On The Development, Assessment And Testing Of Insensitive Munitions), a reaction no worse than a TYPE V (burning, See Table 1.) response is needed on the Slow Cook-off (SCO), Fast Cook-off (FCO), Fragment Impact (FI), and Bullet Impact (BI) testing. These IM tests and procedures are defined by Hazards Assessment Tests For Non-nuclear Munitions, MIL-STD-2105C.

TABLE 1. IM Response Types Defined By AOP-39 (Ref. 2)

- **Type I -** Supersonic decomposition reaction (**detonation**), **all energetic materials consumed**. Producing intense shock to surrounding medium. Plastic deformation of metallic cases followed by **extensive fragmentation**. Effects include ground craters, perforation/plastic deformation and/or fragmentation of adjacent metal plates. Blast overpressure damage to nearby structures.
- **Type II - Same as Type I** (**detonation**), but **not all energetic material consumed** in detonation.
- **Type III -** Ignition and **burning** of some or all energetic material leading to **violent pressure rupture** of confining structure. **Metal cases are fragmented** into large pieces and **thrown large distances**. Unreacted or burning material is scattered about. Air shocks are produced that can cause damage to nearby structures. The blast and **high velocity fragments** can cause minor ground craters and damage to adjacent metal plates. Blast pressures are lower than Type I or Type II responses.

- **Type IV -** Ignition and **burning** of some or all energetic material leading to nonviolent pressure release. The **case may rupture but does not fragment**. **Orifice covers may be expelled** and unburned and burning energetic material may be scattered about. Pressure releases **may propel an unsecured test item** causing an additional hazard. No blast effect or significant fragmentation damage to surroundings, only heat and smoke damage from burning energetic material.
- **Type V -** Energetic material ignites and **burns non-propulsively**. The case may split open, melt or weaken sufficiently to allow slow release of combustion gases. Case covers may be dislodged by internal pressure. Debris stays in the area of the fire although **covers may be thrown up to 15 meters**. The debris is unlikely to cause fatal wounds to personnel.

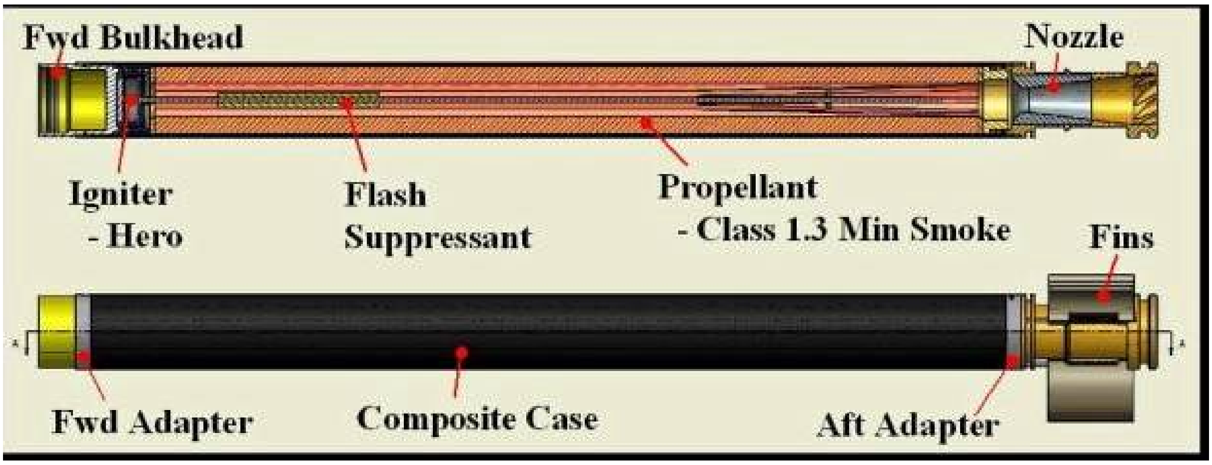
REQUIREMENTS & SUCCESS CRITERIA

In order to complete the task of developing a composite case replacement, with improved IM characteristics, of the current MK-66 aluminum case, AMRDEC and ATK established some basic requirements and success criteria. The overall system requirements were such that no changes were permitted to the launcher and the performance had to be within the specification limits of the current MK-66 rocket motor (Ref 2). Success criteria were established based on achieving measured improvements (Type V Response) for Bullet Impact (BI), Fragment Impact (FI), and Fast Cook-off (FCO). Although the composite case should improve the IM response to the Slow Cook-off (SCO) stimuli, the team agreed that passing this requirement was most likely not achievable without additional investment.

COMPOSITE CASE DESIGN

The NDI composite case was selected as the baseline composite case design. Various adapter configurations were considered and tested to attach the composite material to the other components. A switch was also made in the composite fiber from very high modulus and high cost fiber to a lower cost fiber with acceptable mechanical properties. The resin system used in the NDI program was tested for compatibility with NOSIH-AA2 propellant and was determined to be fully compatible with the propellant in the cured state. Therefore the resin system was unchanged from the NDI motor. Changes to the internal rocket motor components were minimal. Only very small OD changes were necessary to the propellant grain and nozzle interface. Figure 1 shows the composite case with the overall MK-66 motor configuration.

FIGURE 1. MK-66 Composite Case Motor Configuration



COMPOSITE CASE MANUFACTURING AND TESTING

Several composite cases were manufactured using different adapter configurations. These cases were manufactured and assembled with special closures and were then Hydro-burst tested. The cases all ruptured above 4800psi and had identical failure points in the metal adapters. This exceeds the 4000psi nominal aluminum case failure by 20% and validated the design to proceed with IM testing. Upon successful completion of Hydro Burst testing, 10 cases were manufactured and assembled into live motors for preliminary IM screening and analysis. In this test, both Slow and Fast cook-off tests were conducted on bare (no warheads) composite case rocket motors utilizing the current MK-66 propellant grain and different adapter configurations. Standard aluminum case MK-66 motors were also tested as a baseline. These preliminary IM tests were conducted at ATK-Thiokol utilizing a non-standard test arrangement. These tests were completed for screening purposes only and the modified test arrangement was necessary to ensure the event would be non-propulsive.

Preliminary Fast Cook-off (FCO) Screening Tests at ATK-Thiokol

Figures 2 & 3 show the test setup for the preliminary FCO test. The motor was suspended 3 ft above an 8' x 8' x 2' pit partially filled with diesel fuel. Diesel fuel is also nonstandard because it does not produce as much heat as JP fuel; however, it was used due to availability. The other nonstandard setup was that the motor was clamped on both ends using "C" type brackets and chained to a steel support structure. This was necessary to ensure a non-propulsive event due to test range constraints. Four thermal couples were placed near the motor, one fwd and aft, and two at mid motor locations.

Table 2 shows the results from this test. Although diesel fuel was used, the temperatures all exceeded 1600°F as required by STANAG 4240. The motors all ignited, popped open at low pressures, and fell into the pit and burned only. There was no detonation, deflagration, or high-pressure reaction. This was primarily due to the high heat causing significant weakening of both the metal and composite cases. In all tests, no metal case or composite case material was found outside the pit. On one test, we did find some small pieces of propellant outside the pit at about 60' from the pit. This may have been a testing issue associated with the grain falling into the pit and being completely submerged in diesel fuel prior to being partially reignited after the fuel level burned below the grain. Therefore, the fuel level was reduced on the next two tests.

The tests were deemed "No test" due to the nonstandard set up and allowance of the test articles to fall into the pit. For screening purposes only, the results did not show any significant differences between aluminum or composite case material nor adapter configuration. In addition, the tests did show that all of these designs might have a good chance of passing standardized FCO testing.

FIGURE 2. Non-Standard FCO Test Setup

FIGURE 3. Test Specimen Engulfed In Flames

TABLE 2. Preliminary Fast Cook-off Results

Test Article Configuration	Time from pit ignition to bare motor venting	Maximum Temperature (deg F)	Remarks
Composite Case Adapter Config 1	87 sec	1903 °F	Motor unzipped and fell into pit. Submerged propellant extinguished and reignited after fuel level burned bellow propellant. Propellant pieces were then thrown outside pit
Composite Case Adapter Config 2	90 sec	1640 °F	Motor unzipped & fell into pit. Propellant burned inside pit. Heat shields and igniter closure found outside pit
MK-66 w/Aluminum Case	42 sec	1764 °F	Vented faster and fell into pit. Propellant burned inside pit. Heat shields and igniter closure found outside pit

Preliminary Slow Cook-off (SCO) Screening Tests at ATK-Thiokol

Figures 4 & 5 show the test setup for the preliminary SCO test. The motor/test specimen was encapsulated in an insulated 55gal steel drum with heating coils and suspended approximately 5 ft in the air. Again, nonstandard test setup and temperature increase rates were used due to availability of time and test site constraints. The motors were clamped on both ends using "C" type brackets and chained to a steel support structure similar to the previous test. This was necessary to ensure a non-propulsive event. Two thermal couples were placed on the motor, one at a forward location and the other at an aft location. The applied temperature, inside the test chamber, was quickly brought up to 180°F and held for approximately 6 hrs then the temperature was ramped up at approximately 40deg/hr until the motor ignited.

Table 3 shows the results from this test. The motors all ignited at approximately 285°F. The aluminum case motor fragmented and sent metal fragments through the steel 55 gal drum indicating a possible Type III response. The composite case motors ruptured but did not fragment. However, they did throw the forward closure beyond 50 ft, indicating a Type IV response. This response may possibly be reduced when a 10 lbm warhead is attached to the forward closure as is during an All-Up-Round system test. The added warhead weight more than triples the mass being propelled, therefore, the projected fragment distance should be reduced by about a factor of three.

FIGURE 4. Non-Standard SCO Test Setup

FIGURE 5. Specimen Prior to Test Start

TABLE 3. Preliminary Slow Cook-off Results

Test Article Configuration	SCO Ignition Temperature (deg F)	Estimated Preliminary Non-standard SCO Rating	Remarks
Composite Case Adapter Config 1	~ 285 °F	Type IV	Case ruptured & threw bulkhead approximately 50 ft. No metal fragments, non-secured ends on 55gal drum blown out, 55 gal drum still intact with no damage.
Composite Case Adapter Config 2	~ 290 °F	Type IV	Case ruptured & clamps held onto bulkheads. No metal fragments, non-secured ends on 55gal drum blown out, 55 gal drum still intact with no damage, milder reaction than first test
MK-66 w/Aluminum Case	~ 283 °F	Type III	More intense reaction than composite case SCO test. Case ruptured and fragmented. Fragments were thrown through 55 gal drum. Non-secured ends were blown out.

Fragment Impact at Redstone Technical Test Center (RTTC)

The fragment impact test was completed at RTTC on 26 May 2005. The test was setup such that a single 18.6gm conical shaped fragment would hit a single bare rocket motor at a velocity of 6100 ft/s (Army fragment test). MK-66 rocket motors were used for this test, two of the motors utilized a composite motor casing with a Mod 4 configuration, and the remaining two motors were baseline MK-66 Mod 2 rocket motors with the standard aluminum motor case. For this test, the fragment was aimed at the mid point of the rocket motor case along the centerline. Fragment velocities were measured using electronic velocity screens. Blast overpressures were measured at 10' and 20' from the test article. High-speed motion photography was also used to record the event and analyze the response. Figure 6 shows the test setup for the fragment impact test. The test article is very loosely confined with banded straps and foam blocks. Once the bare rocket motor is hit with the fragment, the rocket is quickly dislodged and essentially free to move.

FIGURE 6. Fragment Impact Test Setup

Preliminary results from this test showed significant differences in the response between the rocket motors with the aluminum case versus the composite motor case. In all tests, the fragment impacted the center of the rocket motor, igniting the propellant and splitting the motor case in half. The aft end of the motor traveled approximately 20ft for the aluminum cases and 12 ft for the composite case motors. The forward half end of the aluminum case motors traveled 210ft and 300 ft. The fwd half end of the composite case motors traveled 80ft and 155 ft. The measured blast over pressures were low for each test with lower pressures measured for the composite case motors compared to the aluminum case (see Table 4). The major differences between the composite case motors and aluminum case motors, besides producing a lower pressure event, was that the aluminum cases fragmented with several metal fragments, in addition to the projected forward end, traveling over 50ft, with some exceeding 200ft. The composite case motors did not produce any of these dangerous metal fragments. Figure 7 & 8 show the debris that was found from the composite and aluminum case fragment impact test. Unofficially, these results indicate a Type III - IV reaction for the aluminum case and a Type IV reaction for the composite case motors. The only part of the test that keeps the composite case motor from being a Type V reaction is that the forward end traveled outside the 15M requirement. It should be noted that these motors did not contain a 10lb warhead that is typically attached to the forward end in the tactical configuration. Again, based on simple trajectory estimations, the 10 lbm added weight should more than triple the weight of the projected forward end, thus reducing the distance by a factor of three to approximately 50 ft. The fwd end of the aluminum case motor would also travel less distance, however, the aluminum case motors would still produce dangerous metal fragments regardless of weight attachments or any venting devices. Official results will be made available after further analysis and the final report is released by RTTC.

TABLE 4. Preliminary Fragment Impact Test Results (Army Frag)

Test Article Configuration	18.6gm Fragment Velocity (ft/s)	Propellant Reaction	Overpressure @ 10ft & 20 ft (psi)	Approx. Number of Projections Exceeding 50ft	Remarks
MK-66 w/Aluminum Case	6049	Burn	1.0, 0.5	> 9	Fwd End went 300’
MK-66 w/Aluminum Case	6143	Burn	No Data	> 12	Fwd End went 210’
MK-66 w/Composite Case	6124	Burn	0.75, 0.33	1	fwd end went 155’
MK-66 w/Composite Case	6121	Burn	0.70, 0.4	1	fwd end went 80’

FIGURE 7. Aluminum Case Debris

FIGURE 8. Composite Case Debris

Additional IM testing was performed at RTTC on both the aluminum case and composite case motors. These tests include Fast Cook-off and 50 cal bullet impact. Bullet Impact testing, using a 20mm bullet, was also scheduled to be performed. However, testing difficulties prevented achieving proper aimpoint and/or velocities; therefore, 20mm bullet impact testing was postponed until equipment could be fixed. Only preliminary data for FCO and 50 cal BI were available at the time of this report. This data showed that both aluminum and composite case motors had good IM response (unofficial Type V) to the 50 cal bullet impact test. The RTTC FCO test showed a marginal response for the aluminum case (unofficial Type IV) and an improved IM response for the composite case (unofficial Type V). We are currently waiting on the official analyzed data and report from RTTC on the FCO and 20mm BI test. All data will be presented to the safety review board and made public as needed when it becomes available from RTTC.

CONCLUSION / RECOMMENDATIONS

A total of 8 MK-66 aluminum case motors and 10 MK-66 composite case motors were subjected to standard and non-standard FCO, SCO, FI, and BI tests to date. Results show an improved IM response with the composite case versus the aluminum case. Table 5 shows the unofficial estimated rating for each test at the bare motor only level. These reported results are for a small sample size for this project only and are not to be confused with prior official government testing of the MK-66 rocket motor. Official results and scoring, of this, and future testing will be made public as needed and when available.

Due to the favorable results, it is recommended to continue the composite case development and to further extend the testing to include Navy Fragment Impact, 20mm BI and the fully assembled system configuration to include warheads, launchers, and shipping containers.

TABLE 5. Unofficial IM Test Results For Bare MK-66 Rocket Motor w/Aluminum & Composite Case

IM Test w/MK-66	Aluminum Case	Composite Case
Frag Impact (Army)	III – IV	IV**
Bullet Impact (.50 cal)	V	V
Fast Cook-Off	IV	V
Slow Cook-Off	III	IV**

** May improve to Type V reaction when tested with 10 lb IM warhead added to fwd end

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