T Reeves, H Jones, N White, P Cheese, H Pennington

UK MOD
Fir 3a Abbey Wood
Bristol BS34 8JH
United Kingdom

The Brimstone 2 Missile: IM technology insertion and the benefits for UK MOD

Summary

1. The Brimstone missile is a valuable component of UK's inventory, providing a precision low-collateral damage capability against static and moving targets. The original RF seeker version, and the dual-mode combined RF and SAL variant, have proved their effectiveness in operations in Afghanistan, Libya and Iraq. Both types use the same motor and warhead, developed in the 1990s. Brimstone 2 is being developed to improve the capability offered still further and in particular to introduce an IM warhead and rocket motor.

2. The IM characteristics of the original Brimstone were due in the main to the energetic materials employed. The Brimstone 2 programme introduces a warhead and motor incorporating modern IM technologies:

   a. TDW selected a cast-cured PBX explosive for the tandem shaped charge warhead, balancing low charge-scale explosiveness and sensitiveness with the performance requirement.

   b. Roxel UK's "Vulcan" motor uses a low explosiveness propellant coupled with Steel Strip Laminate case, in a minimum-smoke motor suitable for both fast jet and rotary wing applications, as demonstrated previously by their Smokeless Large Insensitive Motor (SLIM) project.

3. This systems approach to reducing vulnerability has resulted in very good IM responses in full scale testing of Brimstone 2 with many reactions reduced to burning. UK MOD's IM Assessment Panel (IMAP) is satisfied that Brimstone 2 represents the state of the art for Insensitivity of tactical missiles.

4. UK MOD will benefit greatly from the low vulnerability and hazard that Brimstone 2 will bring. This will lead to cost savings in manufacture, storage and transport, and provide the RAF with more flexibility in operational usage.

Introduction

5. Attempts to develop an IM version of Brimstone stretch back many years, with work on the motor predating the introduction of the original Legacy Brimstone into UK service. During this period numerous IM tests and trials were conducted and reported on; this document provides an overview of the testing, trials and results of the final production standard missile.

6. Legacy Brimstone encompasses: Brimstone 1; DMB (Dual Mode Brimstone); and DMSB+ (Dual Mode Seeker Brimstone Plus). The original IM requirement for Brimstone 2 was that it would demonstrate no worse than: a burning hazard when subjected to the IM fast heating, slow heating, bullet impact and fragment impact threats; and no worse than an explosion hazard for sympathetic reaction and shape charge jet IM tests.

Assessment Methodology

7. The UK IMAP applies a whole body of evidence approach to IM assessment as described in AOP-39[1] and JSP520 Volume 11. For Legacy Brimstone and Brimstone 2 the assessments were based on the characterisation of the explosiveness and sensitiveness of the energetic materials by suitable charge scale explosiveness tests (EMTAP); component level testing on the warhead and rocket motor; and full scale testing in the form of the IM tests according to STANAG 4439.

8. This evidence was drawn together to produce assessments of the worst case reaction that could be obtained from the components in isolation, and the complete missile in its packaged and un-packaged configurations.

Selection of Brimstone 2 Energetics

9. The primary reason for the IM characteristics of the Legacy Brimstone was the choice of energetics in the Rocket Motor and Warheads, so to meet the key user requirement for IM compliance new energetics were selected for the Brimstone 2 system. Those materials, KS33[2] and Vulcan propellant[3], were subjected to small scale testing confirm their explosiveness hazard properties.

Vulcan Motor Propellant Small Scale

10. Small scale tests of the Vulcan motor main charge propellant SRS 142/F65(D3) of specific interest for its likely IM characteristics were EMTAP 36 Fragment Attack[4] EMTAP 41 Fast Heating[4]; and EMTAP 42 Electrical Heating[4].

11. EMTAP 36 Fragment Attack test finds the Shock to Detonation Transition (SDT) threshold for an energetic when subjected to an impact from a cylindrical steel projectile of diameter 13.15mm and length 25.4mm. The small scale testing demonstrated that the threshold for SDT for the Vulcan Motor is between 1848 ms^{-1} and 1911 ms^{-1}. Although the EMTAP 36 Fragment Impact test provides an indication of the potential detonation hazard of the Vulcan motor from the Standard 2560 ms^{-1} IM Fragment threat; Alternative 1830ms^{-1} IM fragment threat; and IM Bullet Attack, when integrated in to the full system, it does not provide a definitive answer and needed to be confirmed through large scale testing.

[1] AOP-39 Guidance on the assessment and development of Insensitive Munitions (IM)

[2] Hazard testing of the PBX KS33, QinetiQ, QinetiQ/04/00579

[3] Tube Tests on Brimstone Propellant, Radnor, RT03/10

[4] EMTAP Manual of Tests Volume 1 Issue 4, Energetic Materials Testing Assessment Policy Committee , November 2007

Figure 1 & 2: Response of SRS 142/F65(D3) to Fragment Impact 1848 m/s


Figure 3 & 4: Response of SRS 142/F65(D3) to Fragment Impact 1911 m/s

12. EMTAP 41 Fast Heating tests the response of the energetic in a fuel fire environment when heavy confinement is applied. 10 tests were conducted for the Vulcan rocket motor propellant and in all the tests a pressure burst/decomposition response occurred. A typical response is shown in figure 5. Similar to the EMTAP 36 Fragment Impact test, the response demonstrated in the small scale testing is an indicator for the response that should be expected when the IM fuel fire testing is conducted on the final system, but it is not definitive.

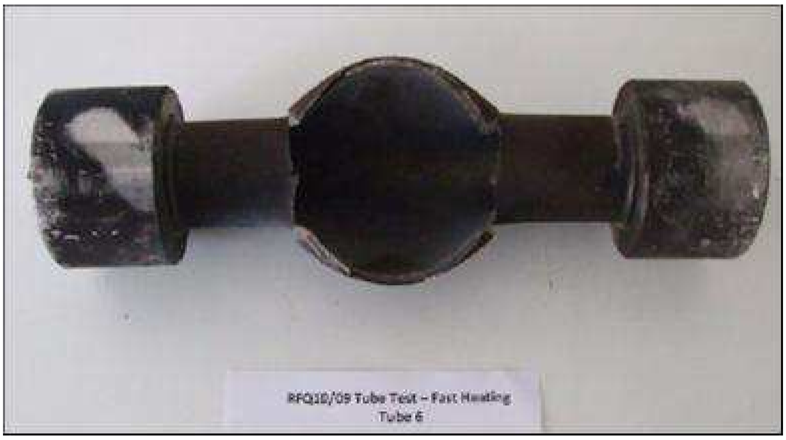

Figure 5: Response of SRS 142/F65(D3) to EMTAP 41 Fast Heating test.

13. EMTAP 42 Electrical Heating tests the response of the energetic to heating rates of 10° C/hour, 1, 5, 10 and 100 °C/minute when under high confinement. 5 tests were conducted, 1 per heating rate and no worse than a pressure burst was witnessed. Examples of the responses are shown in Figure 6 and 7. This test provides an indication

of the expected response, of a full system, to the Slow Heating IM threat and Fast Heating IM threat.

Figure 6 & 7: Response of SRS 142/F65(D3) to EMTAP 42 at 10°C/hour and 100°C/minute.

14. The small scale testing indicated that the Vulcan Rocket propellant has low explosiveness, and that when it was integrated into the full system the risk of not meeting the IM requirements would be low for all tests except for Fragment Impact standard velocity. The testing showed that the threshold for SDT is significantly lower than the IM Fragment Impact at standard velocity. This was accepted due to the performance requirements of the system.

KS33 Small Scale

15. Small scale testing of KS33 demonstrated it was a low explosiveness material, with minimal variability, indicating that system level results would be acceptable.

Assessment of Brimstone 2: Fast Heating

16. The Brimstone 2 system was subjected to the IM Fast Heating trial unpackaged at QinetiQ Shoeburyness UK. The trial setup is shown in Figure 8.

Figure 8: Brimstone 2 system prior to the IM Fast Heating trial.

17. The Fast Heating trial was conducted as per STANAG 4240[5], the hearth contained 4400 litres of ACTUR A1 aviation fuel. The mean temperature recorded by the thermocouples reached 550 °C after 22 seconds and all thermocouples recorded a temperature of at least 800 °C after 28 seconds.

[5] STANAG 4240 Edition 2: Liquid Fuel/External Fire, Munition Test Procedures

18. Intense burning from the rear of the missile after 43 seconds which lasted for approximately 20 seconds. A second site of lower intensity burning was witness at the front of the system at 59 seconds for approximately 15 seconds. Limited fragmentation was found in the surrounding area and no significant over pressure was recorded. When the system was inspected post trial the majority of the components were found in their original location.


Figure 9: Image of Brimstone 2 system post IM Fast Heating trial

19. Component level testing supported Type V burning as the system level response for Brimstone 2. The test and the system were scored as a Type V burning response by IMAP.

Assessment of Brimstone 2: Slow Heating

20. The system was contained within an insulated purpose built oven as shown in figure 10. Hot air was pumped in and out via the ducts shown in the image, with a temperature delta no greater than 5 °C, to increase the temperature at a rate of 3.3 °C/hour. Prior to commencement of the test the oven was held at 50 °C for 8 hours. Figure 11 shows the temperature measured by the various probes during the final hours of the test.


Figure 10: Packaged Brimstone 2 within Slow Heating oven

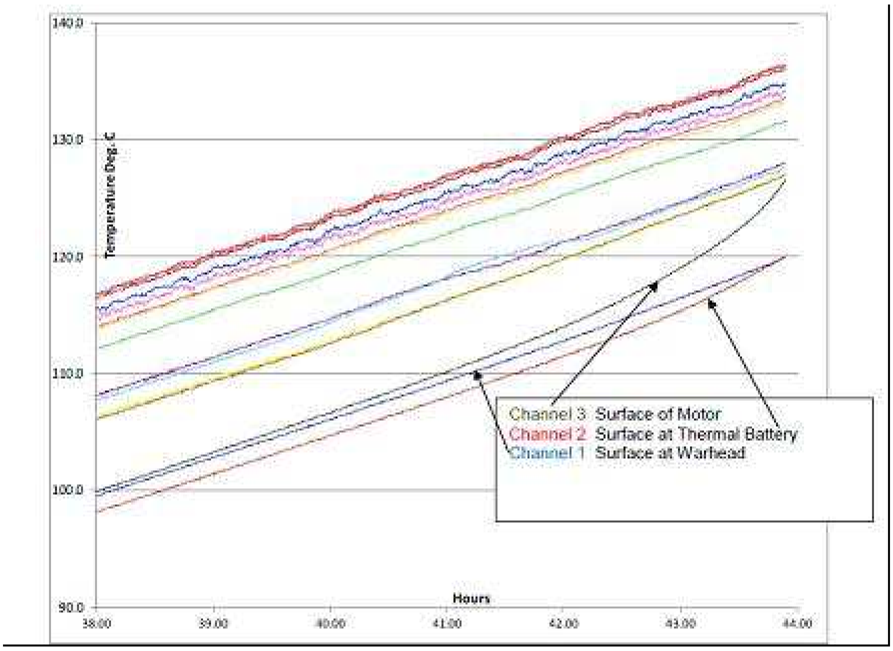

Figure 11: Temperature Vs Time for temperature probes during Slow Heating trial

21. At approximately 39 hours an increase in the temperature at the surface of the motor, greater than 3.3 °C/hour, was recorded. It is assessed that an exothermic reaction occurred from the rocket motor, which is typical of this material when subjected to this environment. At 42 hours a smaller exotherm was recorded by the probe located adjacent to the thermal battery. At 44 hours an energetic reaction occurred; a fireball was witnessed in addition to burning and non-burning debris being ejected from the test site. Minimal overpressure was recorded (see figure 12).

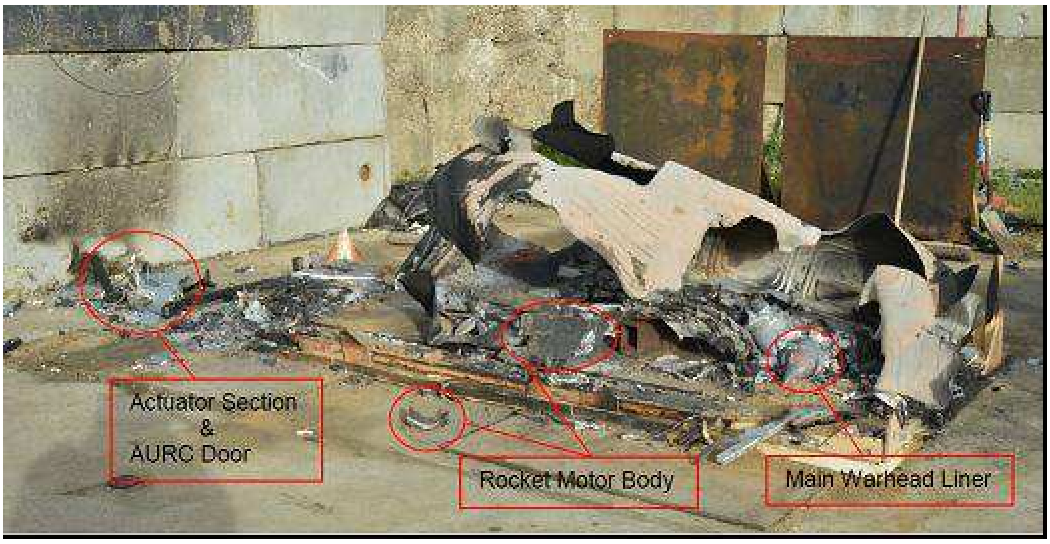

Figure 12: Post trial image of the Brimstone 2 Slow Heating trial.

22. IMAP scored the trials as Type IV deflagration. Component level testing had also been conducted on the Rocket Motor and Warhead; the Rocket Motor produced a Type III response during this test. Due to the component level response, and the inability to rule out a Type III response in future tests, IMAP assessed the system response as Type III for Slow Heating in both the packaged and unpackaged configuration.

Assessment of Brimstone 2: Bullet Impact

23. Component level testing was conducted on the Rocket Motor and the Warheads for Bullet Impact; full scale testing was not required due to the configuration of the tests and the responses witnessed. Bullet Impact testing on the Warheads[6] gave a Type V response, where only a small amount of burning was observed. Bullet impact testing on the Rocket Motor[7] caused a burning response to occur after 1 second (figure 13). This continued for approximately 25 seconds; no significant over pressure response was recorded. As no reaction greater than a Type V was seen in the component testing, and low explosiveness was demonstrated through small scale testing, IMAP assessed the Bullet Impact response as a Type V.

Figure 13: Vulcan Rocket Motor 1 second after Bullet Attack

Assessment of Brimstone 2: Fragment Impact (1830 m/s)

24. Component level testing was conducted on the Rocket Motor and the Warheads for Fragment Impact (alternative velocity). Full scale testing was not required due to the configuration of the tests and the responses witnessed. Firings were conducted against the cone of the shape charge warhead and against the longest distance of explosive in the second warhead. The Fragment Impact (alternative velocity) testing on the Warheads[8] demonstrated Type V responses, where only a small amount of burning was witnessed. The Fragment Impact Alternative velocity testing on the Rocket Motor[9] caused a deflagration response to occur. No significant over pressure response was recorded but debris, including unburnt propellant, was projected greater than 15 metres and the reaction was calculated to be sufficient to propel the All Up Round (AUR).

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[6] WHS Design Safety Assessment REP-BIM-112510-087

[7] Bullet Attack Trial on the E640 Vulcan Rocket Motor, RADNOR, RTR 08/10

[8] WHS Design Safety Assessment REP-BIM-112510-087

[9] Fragment Attack Trial on the E640 Vulcan Rocket Motor, RADNOR, RTR 09/10

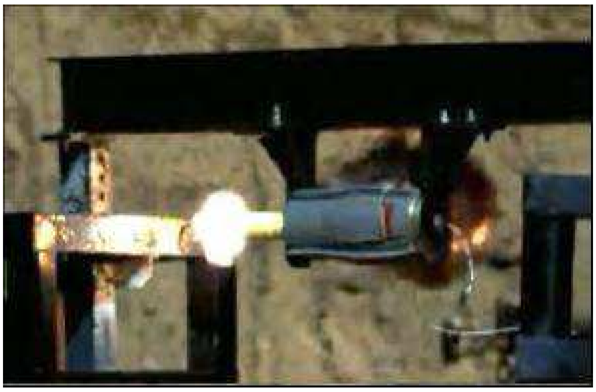


Figure 14 & 15: Rocket Motor Fragment Impact alternative velocity.
Left image 3 ms after impact Right image 500 ms after impact

25. As no reaction greater than a Type IV response was seen during the component testing, and low explosiveness was demonstrated through small scale testing, the UK IMAP evaluated the Fragment Impact alternative velocity response as a Type IV deflagration.

Assessment of Brimstone 2: Fragment Impact (2560 ms^{-1})

26. Component level testing was conducted on the Rocket Motor and the Warheads for Fragment Impact standard velocity and it was deemed that full scale testing was not required due to the configuration of the tests and the responses witnessed. Firings were conducted to determine the SDT threshold of bare energetic material using the IM standard fragment[8]. The threshold was found to be between 1950 ms^{-1} and 2200 ms^{-1}; therefore it was assed as unlikely that the warhead would do anything other than detonate under this IM threat.

27. The Fragment Impact (standard velocity) testing on the Rocket Motor[10] caused detonation. A significant over pressure was recorded and the HSV was unambiguous (See Figure 16 for images). It was not clear whether an SDT or XDT response occurred. This response was consistent with the small scale testing that had been conducted.

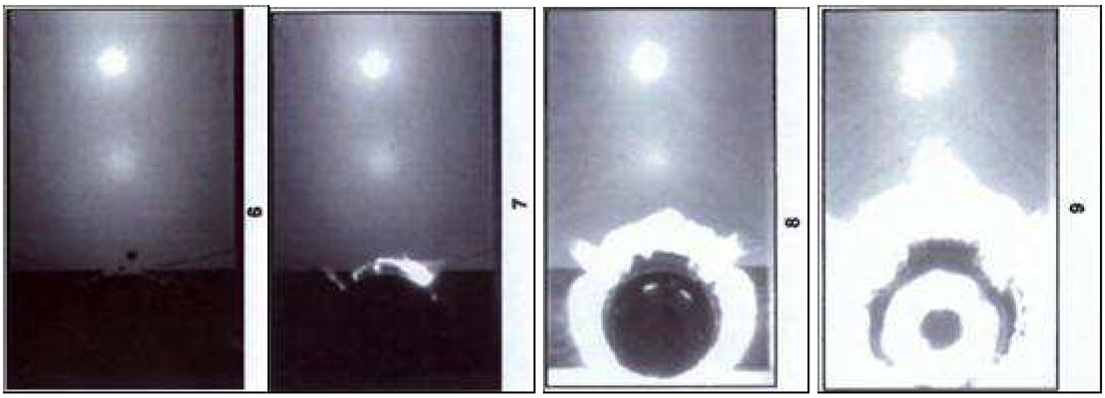

Figure 16: Excerpts from HSV of Fragment Impact Standard Velocity on Rocket Motor

28. Due to the response of the Rocket Motor to Fragment Impact and the small scale testing the IMAP assessed the response of Brimstone 2 in packaged and unpackaged configurations as Type I detonations.

[10] Roxel Vulcan Rocket Motor Fragment Attack, QinetiQ/TEG/WES/CR1000435/2.0

Assessment of Brimstone 2: Sympathetic Reaction

29. A full scale trial was conducted as per STANAG 4396[11]. The Rocket Motor was initiated by a small SCJ (Shape Charge Jet). The shape charge was aimed at 45 degrees off the axis of the missile and at 45 degrees to the horizontal to ensure the jet impacted on the donor Rocket Motor only.

Figure 17: Sympathetic Reaction trial setup. Red live donor; Blue and White live acceptors; Green mass representative inert.

30. Post firing, the donor missile warhead was recovered along with most of the energetic materials from the live acceptors. Over pressure readings were recorded which were indicative of an initiation of the Rocket Motor, and HSV showed that a detonation occurred. The acceptors were recovered structurally intact; an example is shown in figure 18. Due to the lack of propagation IMAP assessed the sympathetic reaction response as Type V in the packaged configuration.

Figure 18: Sympathetic Reaction post trial. Live acceptor.

[11] STANAG 4396 Edition 2: Sympathetic Reaction, Munition Test Procedures

Assessment of Brimstone 2 Shape Charge Jet

31. As the shaped charge used to initiate the Rocket motor for the sympathetic reaction was smaller than the IM SCJ threat, IMAP assessed the system as a Type I detonation hazard for SCJ.

Conclusions

32. Testing has demonstrated that Brimstone 2's IM signature is as good as current technology allows. The UK will soon have an in-service fixed wing Air to Ground Anti-Armour capability with world leading IM characteristics.

33. UK will benefit greatly from the low vulnerability of Brimstone 2, which will bring cost savings in manufacture, storage and transport, and provide the RAF with more flexibility in operational usage.

34. Due to the success of the Brimstone 2 program other potential applications of the system are currently being investigated. Work is ongoing to look at the potential for integrating the system into Unmanned Air Systems, rotary wing and naval environments.