The application of bi-propellant systems to tactical missiles

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1) Introduction

Bi-propellants offer the opportunity of achieving IM compliance in response to all stimuli, including shaped charges and high velocity fragment impact. They also have a number of other advantages for military use, such as thrust control, but due to their often toxic nature they are perceived as being unsuitable. Two key areas of advancement may now make bi-propellants viable for tactical use, namely gelled propellants and greater missile 'intelligence'.

Gelling is Important to propellant toxicity as it significantly reduces the dispersion of spilled propellant and reduces vaporisation. Hence, although a propellant may be toxic, its effect will be localised and pose reduced risk. Advances in, and miniaturisation of, computing and sensing equipment now means that a future tactical missile can effectively make use of controllable thrust in real time, for example in response to a manoeuvring target.

The balance between the advantages and disadvantages of bi-propellants and solid motors now needs re-examining. This poster aims to provide an overview of the relevant issues and a brief outline of some recent QinetiQ research in this area.

Figure 1: Gelling effectively controls propellant spills.

2) Advantages of bi-propellants

Thrust control
- Range extension, end game manoeuvre and variable time of flight
- Future tactical missiles can take full advantage due to sensor, communication and processing developments – NEC IW

Well proven concept
- Many successful examples of non gelled systems
- Controllable developmental risks

IM compliance
- Type V response to <u>**all test stimuli**</u> **– not propulsive**
- Fire fighting can proceed without the threat of explosion.

WLC implications
- Not classified as an explosive during storage
- Low disposal costs
- Life extension easier

Adaptable propellant storage
- Ideal for non-circular airframes
- Distributed tanks help maintain C of G

Figure 2: Control of a simulated motor accident

3) Disadvantages of bi-propellants

More complex than solid motors
- But not compared to typical missile systems as a whole

Involve toxic and corrosive materials
- Not exposed during normal operation
- Gelling significantly reduces contamination and vaporisation
- Clean-up easily performed, usually with water

Combustion can occur if fuel and oxidiser meet
- Not explosive
- Can be extinguished with water, which also dilutes the oxidiser down to an unreactive state

Figure 3: Tests to show the spillage of a hypergolic fuel and oxidiser.

4) QinetiQ research

Recent research has attempted to make full use of prior work, whilst also targeting research in key areas that were expected to lead to innovation or where missing data prevented useful conclusions being made. Although propellant selection and development is an important criterion in a successful system, attention was particularly paid to the mechanics of producing a viable system within the tight volumetric constraints of such missiles. The estimated performance of bi-propellant powered missiles in comparison to solid propellant powered ones was also assessed by use of a multi-disciplinary missile performance model to cover a range of missile specifications. The study hoped to draw useful conclusions for future development work.

5) IM characteristics

New IM tests were not performed during this study, but instead previous UK and international research was examined. The various images on this poster illustrate some of the testing performed at PERME (Propellants, Explosives and Rocket Motor Establishment) Westcott pre 1990. The tests were not to current STANAG standards, but they still illustrate the effect of various stimuli. Testing included bullet impact and cook off, and in all cases showed that combustion was the worst response seen, ie Type V. Research was also performed on extinguishing propellant fires and the treatment of spilled propellants. Their propellants of choice at the time were Inhibited Red Fuming Nitric Acid oxidiser and Mixed Amine Fuel, which are hypergolic and prone to vaporisation.

The very good IM responses are due to the two propellant components effectively separating the oxidiser and fuel functions, hence stimuli directed to either one cannot cause an explosive reaction. Some oxidisers, such as HAN or hydrogen peroxide, are monopropellants in their own right, ie can react without a fuel. The IM response of such oxidisers is potentially different to that stated here and requires further examination.

The anticipated responses to the IM tests are as follows for gelled hypergolic propellants;-

Stimuli: Shaped charge, all fragments and bullets.

Response: Propellant spillage. If two tanks holed, then combustion at interface of the spilled propellants.

Control: Leave to burn itself out or extinguish fire with water. Treat any spillage with water to dilute and remove damaged tanks for disposal (eg burning off of the fuel and controlled aqueous based reaction of the oxidiser). Personnel in vicinity of the spilled oxidiser would require suitable breathing apparatus.

Stimuli: Cook off tests

Response: The main failure mode would be rupture of the tanks due to pressure build up, but this would occur after significant heating duration. The effect of such rupture could be limited by controlled venting at a pressure below that which would cause tank failure. The vented propellant would increase the intensity of the surrounding fire.

Control: Normal fire extinguishing techniques, although vented oxidiser may cause some complication. Treatment as above.

Figure 4: Response to bullet attack – puddle of propellant (liquid)

6) Motor firing

Early in the programme it was identified that the firing of a test motor would benefit the research by providing a source of test data and by allowing some operational aspects of motor use to be tested. Firing a motor representative of the propellants and thrusts of a proposed tactical system was outside of the budgetary constraints and would have pre-empted the required assessment and development processes. A low thrust system was constructed that used low risk propellants (hydrogen peroxide and kerosene) to provide an initial test bed that could be extended to a range of propellants in the future (with suitable combustion chamber modification).

The control of the motor was automated via a computer system so that thrust requirements representative of operational usage could be tested. These basically consisted of two variants; the first being a pre-programmed thrust profile stored as a data file on the computer. This allowed reproducible tests, for example establishing the maximum duration of thrusting that could be used for range extension. The second mode of operation made use of the computer to control the initial burn period and ensure safe operation, but after a preset thrust time it passed control over to the operator. The thrust could then be controlled via a push button to give a real time response. Although this admirably demonstrated how a missile could respond to operational requirements during flight, it also provided a range of random thrust profiles that fully tested the motors response. A total of 32 bi-propellant and 2 monopropellant firings were performed.

Figure 5: Typical firing of the test motor

7) Expulsion system research

A tactical missile is highly constrained by volume and weight. The simplicity of a solid propellant motor means that a high level of bi-propellant system development is required to reach similar levels. One major factor is the efficient expulsion of propellant from the tanks. This can be done either by pumping or displacement (ie by a high pressure gas or piston etc). Although innovative pumping mechanisms were identified that may meet the requirements, developments of displacement type tank expulsion was favoured due to its greater application and simplicity, especially for smaller sizes.

A QinetiQ design has been developed and tested at pressures, volumes and flow rates representative of a 'Hellfire' sized system, although under laboratory conditions. The tests showed that gel could efficiently be expelled from a non cylindrical tank (the cylinder shown in Figure 6 had a feature attached to the inside of the side wall). The design requires further development and testing, but appears to provide a route to achieving an adaptable and volumetrically efficient expulsion technique.

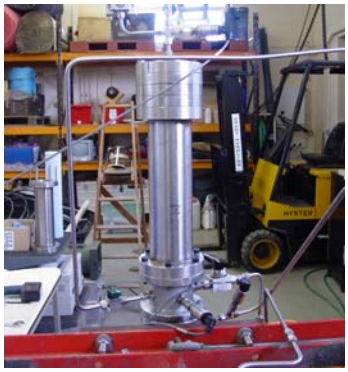

Figure 6: Gel expulsion test rig

8) Conclusions

Gelled bi-propellants offer the opportunity of achieving full IM compliance combined with the operational advantages of thrust control. There is a wealth of previous research, but development is required to produce viable tactical systems that are acceptable for service. QinetiQ's research has provided a UK perspective to MOD on this area of technology that will help ensure a balanced view of future propulsion alternatives and also provided advancement towards future realisation.

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