IM warheads and rocket motors for tactical missiles: progress to date, future opportunities and challenges

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Abstract

In general, there has been more progress on IM solutions for artillery/ammunition than for missiles. However, several IM rocket motors and warheads have successfully entered service on missile systems, including ASRAAM, GMLRS and Brimstone. The sub-systems are described with regards to the technical solutions adopted, timescales and required manufacturing facilities/infrastructure.

There have been several projects, e.g. JCM/JAGM, where IM progress was achieved but deployment to service was not – in some cases for reasons unrelated to the IM solution. The most important of these unsuccessful efforts are also described.

Carbon fibre motor cases have been used widely with interceptors and space launchers but have seen limited in-service application for tactical missile propulsion (exceptions being VT1 and NSM); however, GMLRS has now been successfully qualified for a such an application whilst carbon fibre has recently also been employed on the SDB and BLU-129 bomb warheads (with the main objective being to reduce collateral damage). The reasons for the slow take up of carbon fibre composites are discussed and comparisons are made with other IM case alternatives (e.g. Steel Strip Laminate, active/passive venting on montholic steel cases, Aluminium, etc).

Design for IM clearly requires a system approach and not just energetics with suitable properties; although if the energetic is fundamentally sensitive it is difficult-to-impossible to achieve a good IM response to the recognised threats. A considerable number of new energetic molecules have been explored in the last 30 years but very few have shown an ability to perform successfully, either with regard to IM or due to other constraints, e.g. burn rate; such energetics are described together with their issues.

MSIAC's IM State of the Art report is referenced (as the baseline for IM's) whilst considering why IM adoption has often been protracted. Examples are also cited of fielded IM solutions that provide equal or better performance than the legacy non-IM variants.

Keywords:

Tactical missile, Insensitive Munitions (IM) performance, evolution, solid rocket motor, warheads, implementation, progress

1. Introduction

The separate presentation covers the scope of the abstract, but this paper addresses one particular area: the method used to establish the evolution of IM performance for US, French & UK tactical missiles with significant production since 1980. It should be noted that missiles that do not employ at least one Solid Rocket Motor, or SRM, (e.g. Stormshadow) are not included. This is because it is generally easier to achieve a high IM performance with such systems – in any case there are relatively few such missiles. Additionally, not all missiles are included, but the sample is judged to be representative of those with significant production since 1980.

US, French & UK missiles were selected since it is easier to obtain data on these systems from the open literature & since these countries represent the vast majority of the free world's missiles. Table 1 lists the 39 missiles studied, that comprise 45 entries (since there are several variants of some missiles, e.g. Super 530F & D). The relevant IM standard & quantities of these missiles are assessed, e.g. there have been approximately 630,000 TOW missiles produced but, for this study, only those corresponding to TOW 2A, 2B & Bunker Buster (representing an estimated total of 105,000) are included.

Sector	Missiles included in Spreadsheet
Air to Air	R550 Magic, Skyflash, Super 530F, AIM-7M/P Sparrow, Super 530D, ASRAAM, AIM-120C/D, AMRAAM, Mica, Sidewinder AIM9X, IRIS-T, Meteor
Air to Ground	AGM-65H&K Maverick, AGM-65G Maverick, APKWS, JAGM, Brimstone (non-IM), IM Brimstone (Brimstone2), Hellfire
Anti-Ship	Exocet MM40 Block 1 & 2, Sea Skua
Anti Tank	Eryx, MMP, TOW2A, TOW2B, Javelin (US not UK)
Ground to Air	Sea Dart, Crotale R460, Rapier, RIM-7, Sea Sparrow, Stinger, PAC-3, HARM (AGM 88), Mistral, VT1 (Crotale NG), RAM, Starstreak (HVM), Aster 15, ESSM, Seawolf Block 2, CAMM (SeaCeptor), LMM
Ground to Ground	TOW Bunker Buster, GMLRS, GMLRS IM

Table 1. Missiles assessed for IM signature

The IM Performance Indicator (PI) rating was advocated by the UK MoD's DOSG in the early 2000's. It has been modified here to include a separate & equal weighting for both slow (1834 m/s) & fast (2030 m/s) fragments, but with double the weighting for the other main stimuli (Bullet Impact, FH, SH & Sympathetic Reaction). Thus, a warhead or motor that give a type V response to all of these stimuli scores 100% & one that has Type I responses scores 0%.

In this paper more than 90% of the IM response data considers the "stand alone" sub-system rather than that of an All Up Round (AUR), that may also be in a missile pod or shipping container. In general, the overall IM response of a missile in a pod or shipping container or missile pod is better than that of the "stand alone" sub-system; whilst for some systems (e.g. Hellfire, JAGM) when the missile is deployed the sub-systems are "stand alone".

Other methods (coloured charts) have been used to show the IM response of various munition types at the start of the IM initiative & the State of the Art at a particular point in time; Figure 1 refers. However, whilst such a method highlights what is possible it does not show how IM is generally being implemented in the inventory. The objective of this paper is to predict how the inventory's IM performance is evolving, using a weighted IM performance figure, to also take account of both the number of missiles in service & the Net Explosive Quantity (NEQ) of the missile's warhead & motor.

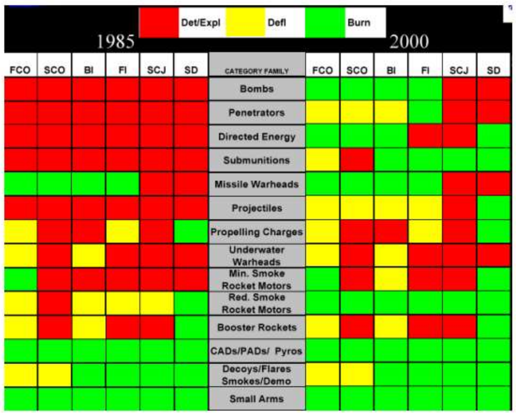

Figure 1. ***Reduction of IM responses following selected IM implementation***

2. IM performance for individual sub-systems: methodology

IM signature data is only openly published for a relatively small number of missiles & even in such cases this does not generally include test data for all stimuli. Thus, in order to predict a missile's IM signature, for both sub-systems (W/h's & SRM's), the IM responses have been assessed based on a consideration of the type of explosive/propellant (Card Gap/sensitiveness), containment, venting/pre-ignition & the mass of energetic (as larger rocket motors & warheads are generally found to give a poorer IM response). The IM predicted for some individual stimuli, or the total rating for a particular missile, may be inaccurate but the overall IM trend of the inventory with time is expected to be sound.

There are a large number of open sources that contain information on the types of propellants & explosives used in missiles, for example Roxel Group's listing.

2.1 SRM's

Based on the judgment & experience of the authors, together with cross references to a number of IM signatures for known SRM's, the different types of SRM's & the resulting IM signatures have been calculated as shown in Figure 2.

17 of the 45 entries represent missiles with both boost & sustain/DACS rocket motors. For these missiles a consideration is made as to whether the FH &/or SH response of the smaller NEQ motor requires the overall SRM FH/SH response to be

reduced, where the first propellant to initiate is predicted to give a detonation reaction & the other propellant is susceptible to sympathetic detonation.

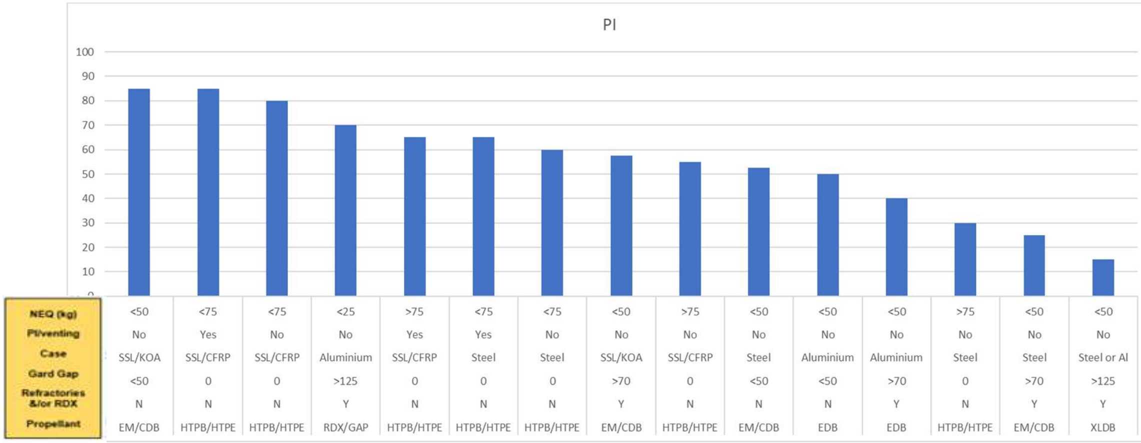

Figure 2. IM rating for different types of SRM's

2.2 Warheads

Like SRM's the IM response of warheads is [sometimes seen to be worse at higher NEQ](). However, since the NEQ of the warheads varies by less than SRM's (0.9 – 49 kg & 1.4 to 295 kg, respectively) there has not been at attempt to apply a different PI rating for higher warhead NEQ's. The different types of IM ratings for warheads are shown in Figure 3.

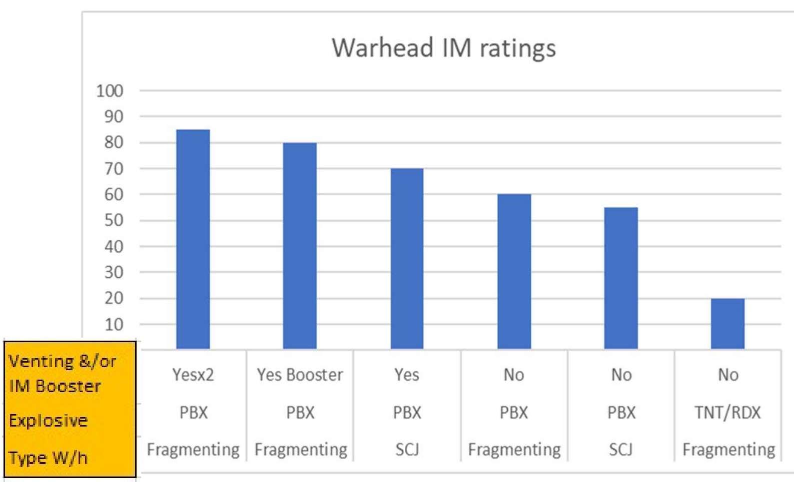

Figure 3. IM rating for different types of SRM's

2.3 Comments that apply to both sub-systems

Where an IM signature is known for a warhead or SRM then the responses to one or more stimuli have been adjusted to that value in the spreadsheet so as to calculate a more accurate PI rating.

This paper does not include the individual IM signatures assigned to each stimuli although this is listed for the warheads (w/h's) & SRM's in the spreadsheet, for each missile. The PI rating is then calculated using the method described in section 1.

3. Results of IM Performance for SRM's & warheads

As would be expected there are a wide range of IM signatures, as shown in Figures 4 through 7.

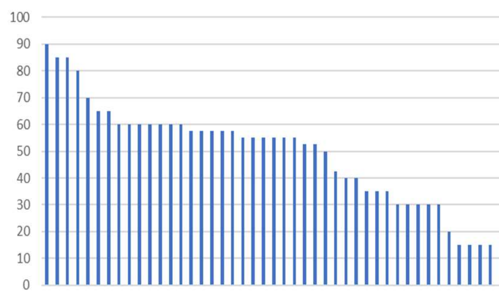

Figure 4. Distribution of SRM PI ratings

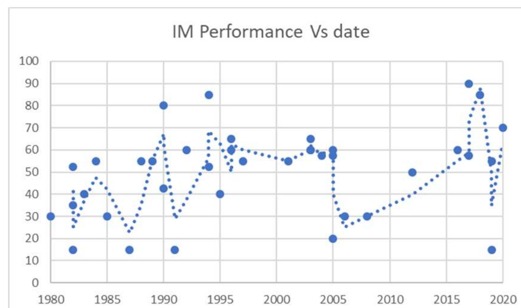

Figure 5. SRM PI ratings

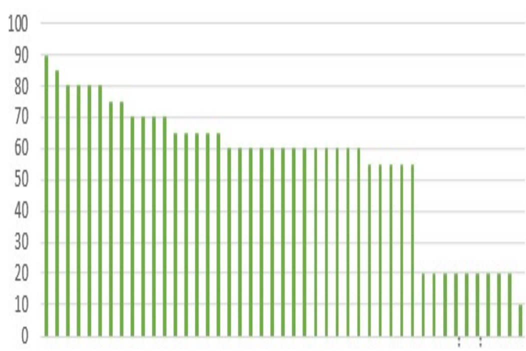

Figure 6. Distribution of w/h PI ratings

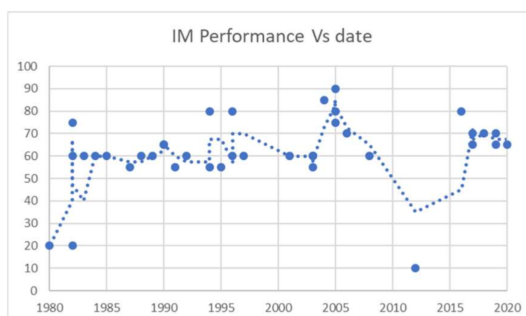

Figure 7. Warhead PI ratings

4. Weighted IM Performance: methodology

The w/h & SRM NEQ's are published for some missiles. Where this data is not available algorithms have been used to estimate both the w/h & SRM NEQ. Further details are included in the spreadsheet.

The quantity (Q) of missiles has been adjusted to take account of the relatively high usage (in conflicts) of a small number of missiles; thus, only 30% of Hellfire & 50% of the legacy GMLRS missiles manufactured contribute to IM_w.

After sorting the missiles into ISD (In Service Date) order, the weighted IM Performance Indicator (PI_w) is calculated for both sub-systems

$$PI_{w\,n} = (PI_{w\,(n-1)} \times Sum[Q*NEQ]_{n-1} + [Q*NEQ]_n * PI_n) / Sum(Q*NEQ)_n$$

It should be noted that eight missiles are included that had ISD's from 1973 to 1980, e.g. RIM7 Sparrow (1976), Skyflash (1978); thus, PI_w commences in 1980 with the aggregate resulting from these eight missiles.

PI_w is influenced mainly by ~30% of the missile population that have relatively high Q & NEQ with these missiles listed in Table 2.

GMLRS, PAC-3, HARM (AGM 88), AIM-7M/P Sparrow, Exocet MM40 Block 1 & 2, RIM-7 Sea Sparrow (retired in 2007), ESSM, AIM-120C/D, AMRAAM, Aster 15, R550 Magic, AGM-65H&K Maverick, Hellfire

Table 2. Missiles with largest Q*NEQ (representing ~80% total) for SRM's

Until the current date, IM_w has not increased as a result of missiles retiring from service since of the high NEQ*Q missiles (as listed in Table 2), that also have relatively low PI's, only RIM-7 Sea Sparrow's OSD (2007) was retired before 2019.

5. Results of weighted IM Performance for SRM's & warheads

The results for SRM's & warheads are given in Figures 8 & 9, respectively.

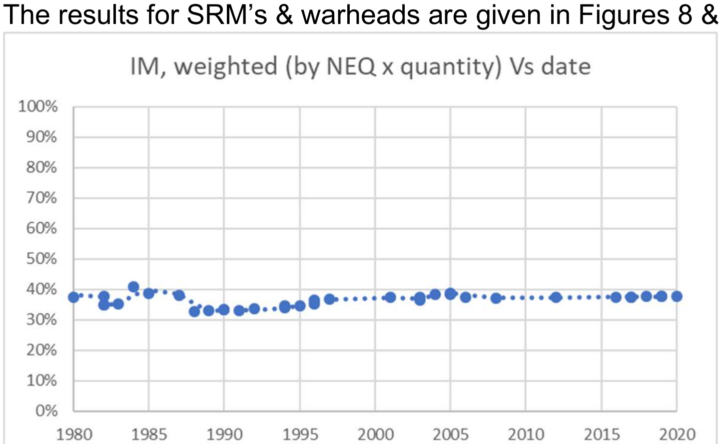

Figure 8. IMw for Solid Rocket Motors

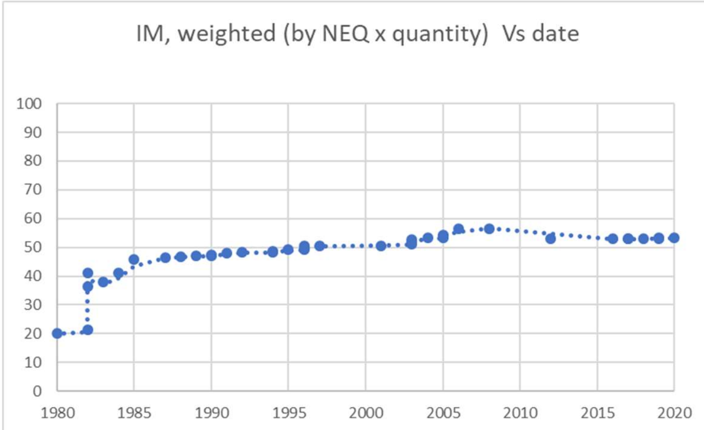

Figure 9. IMw for warheads

6. Spreadsheet

For each missile data for the following characteristics are included in a spreadsheet: missile name & variant, missile prime, AUR mass, sector (Air to Air, etc), ISD, OSD, total quantity manufactured & the quantity employed for use in weighting (to take account of usage &/or disposal), if the missile continues in production, selected comments & hyperlinked references to selected information sources.

For both sub-systems: Design Authority, type of energetic (e.g. Min Smoke, Shaped Charge Jet, etc), energetic material (e.g. PBXN-9), total mass (where available), NEQ, venting/pre-ignition, type of case construction plus responses to BI, FH @ 1834 & 2530 m/s, FH, SH & SR with the resulting % IM PI rating for each sub-system including the factored rating (IM_w) .

Filters allow sorting for each of the characteristics described above.

The spreadsheet itself does not form part of presentation for the IMEMTS. However, any enquiries about access can be made to the authors: Charles Jones for the USA & Jim Fleming for the rest of the world.

7. Conclusions

Based on a significant sample of missiles manufactured in the last 40 years by the US, FR & UK, this paper has presented the results associated with the change in SRM & warhead IM performance together with the methodology employed to estimate the weighted IM rating (based on the estimated total NEQ in service).

For both sub-systems, the IM signature for most recent designs is very good whilst a few recent missiles have w/h's &/or SRM's with relatively poor IM performance. Considering the overall inventory, there has only been a modest improvement in IM since 1980 since approximately a third of the missiles with high [NEQ x quantities manufactured] have poor to modest IM ratings whilst almost all of these missiles are yet to retire from service.

As IM is implemented on future new missiles &/or insertion opportunities are found, plus legacy systems with modest IM rating retire from service, the average IM for the inventory will gradually improve.