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This paper describes a number of technology advantages currently under development for tactical rocket motors which have direct application to land-based long-range rocket systems. Materials advances that enable superior inert mass fractions, along with innovative optimization design techniques have the potential to allow for increased rocket payload capacity, improved rocket range or increased rocket loadout from the volumetrically constrained environment of a land-based launcher.

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# ADVANCED TACTICAL BOOSTER TECHNOLOGIES

## Applications for Long-Range Rocket Systems

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***Abstract*—This paper describes a number of technology advantages currently under development for tactical rocket motors which have direct application to land-based long-range rocket systems. Materials advances that enable superior inert mass fractions, along with innovative optimization design techniques have the potential to allow for increased rocket payload capacity, improved rocket range or increased rocket loadout from the volumetrically constrained environment of a land-based launcher.**

***Keywords—solid rocket; optimisation; artillery***

## I. INTRODUCTION

The Australian 2016 Defence White Paper has highlighted the desire for a new long-range rocket system for the future land force [1] capable of providing fire support out to 300 km. Several such systems exist, for example the M270 Multiple Launch Rocket System (MLRS) [2] and M142 High Mobility Artillery System HIMARS [3] which can employ the MGM-140 Army Tactical Missile System (ATacMS) solid propellant missile [4] to achieve the required range. Improvements in tactical solid rocket motor technologies and performance have the potential to directly expand the capabilities of such land-based rocket systems, including increasing their per-shot capacity, through new motor design. The *Advanced Tactical Booster Technologies* Program (ATBT) — a collaboration between the Australian Defence Science and Technology (DST) Group and the United States Air Force Research Laboratory (AFRL) — is currently developing and demonstrating key solid rocket motor technologies to enable new high performance applications. This paper will highlight two key results from ATBT that offer analogous improvements for land based rocket systems: reduction in inert mass fraction, and system level design optimisation.

## II. ADVANCED TACTICAL BOOSTER TECHNOLOGIES

Coupled with an experimental effort, the ATBT Program has developed a unique design tool based on evolutionary optimisation methods, to explore the impact and effect of a range of materials technology improvements on the system performance for a notional air-launched high speed system. The reference design employed was a generic ATacMS-sized solid motor. Design optimisations were undertaken across a range of objective scenarios; the two primary being optimising for maximum payload mass carriage to a specified insertion speed, and optimisation for maximum insertion speed with a given payload mass, both from a highly volumetrically constrained platform.

### A. Inert Mass Fraction

Reduction of the inert mass, or dead mass, of a rocket motor leads to an increase in the velocity increment the motor can theoretically achieve [5] and is represented in Tsiolkovsky's equation (1) through a reduction in the final mass parameter.

$$\Delta v = I_{sp} g_0 \times \ln({}^{m_0}/_{m_1}) \qquad (1)$$

$\Delta v$ = velocity increment (m/s)
$m_0$ = initial system mass (kg)
$m_1$ = final system mass (kg)
$I_{sp}$ = motor specific impulse (s)
$g_0$ = gravitational acceleration (m/s$^2$)

This gain in performance has been realised in space-launch solid rocket motors through the use of carbon fibre case materials, as in the Vega solid rocket motors [6], replacing more conventional heavy metallic cases. ATBT has explored where such benefits might also be realised on smaller-diameter tactical systems. Point design optimisations were undertaken to directly assess the maximum payload capacity and maximum insertion velocity for a notional air-launched metallic case motor, and an equivalent design using a carbon fibre case (T800S, epoxy resin). The results shown in Table I highlight the influence of case material on the inert mass fraction and maximum payload capacity to a fixed insertion velocity. By using carbon fibre, case mass was reduced by 47% and this is reflected in the improved inert mass fraction; the subsequent optimised payload mass is 8% higher than the metallic counterpart. Based on these results, every 1kg reduction in inert mass improved the mission payload capacity by 1.14kg.

TABLE I. MAXIMUM PAYLOAD MASS DESIGNS

| **Case Material** | **Optimised Design** | | |
|---|---|---|---|
| | ***Case Mass*** | ***Maximum payload*** | ***Inert mass fraction*** |
| D6AC Metallic | 109 kg | 727 kg | 0.146 |
| T800S Carbon-Epoxy | 58 kg | 785 kg | 0.116 |

Similar optimisation trade studies were conducted across a range of motor physical constraints (length, diameter, payload mass) using a suite of advanced technology options in order to understand their individual effect on inert mass. Using this data a correlation was established highlighting the impact of inert mass fraction on the ‘lifting capacity’ of the system, shown in Fig. 1, with lifting capacity defined as the payload mass (kg) multiplied by the delivered Mach number, divided by 100. The positive influence of inert mass fraction can clearly be seen, with small changes effecting large improvements in the lifting capacity.

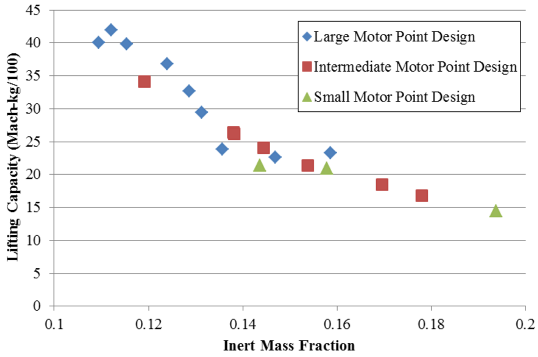

Fig. 1. Effect of inert mass fraction on lifting capacity

In summary, inert mass fraction is a key measure of system performance capability, and technologies which reduce inert mass contribute to better mission performance. While the presented data is anchored in air-launched mission concepts, the same trends apply for a land-based system where improving the inert mass fraction can allow:

- Larger payload masses for a given mission
- Smaller and lighter systems for a given mission
- Increased mission range for a given payload

### B. *System Optimisation*

To assess the relative impact of various technologies on mission performance, a system level optimisation tool was developed for ATBT that included the vehicle trajectory. A global evolutionary optimiser [7] controlled the overall motor design through specification of the propellant grain geometry; each candidate configuration used a nested pseudo-spectral optimisation routine to then determine the most efficient trajectory and subsequent optimal system level design. This approach was able to exploit the multiplicative effect of several technologies, as shown in Fig. 2. Combined, several technology sets reinforce one another for a cumulative benefit greater than the sum of the individual technologies. For example, higher strength carbon fibres not only reduce the system inert mass, they enable use of high energy propellants at higher operating pressures relative to a metal case, which combine to further improve rocket motor total and specific impulse.

When applied to land based systems, this type of mission-based holistic optimisation affords the ability to rapidly and rigorously explore the design space for improved capability by including the rocket motor, desired payload, actual trajectory and the platform volumetric constraints in the analysis.

## III. SUMMARY

Tactical solid rocket motors are employed in both land-based and air-launched tactical systems, with many common technology sets. Current research programs for the air-launched scenario are yielding benefits that directly translate to a long-range land-based rocket system. Innovative system design optimisation techniques afford the possibility to fully explore potential capability improvements for a land-based system operating from a physically restrictive environment; optimising for maximum range, payload mass, or number of rounds from a given constrained volume. Underpinning these advantages are the materials technologies such as carbon fibre cases that are allowing far superior inert mass fractions and vastly more efficient rocket motor designs.

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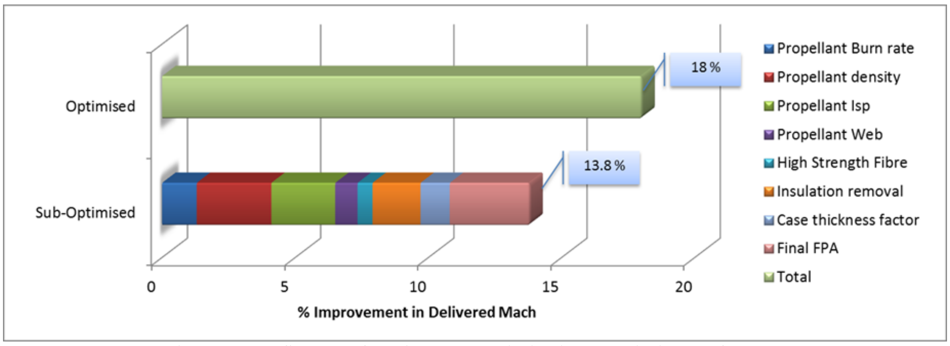

Fig. 2. Influence of total system optimisation on mission performance