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Development of IM Brimstone Rocket Motor; An IM, Minimum Smoke, Air-Launched System

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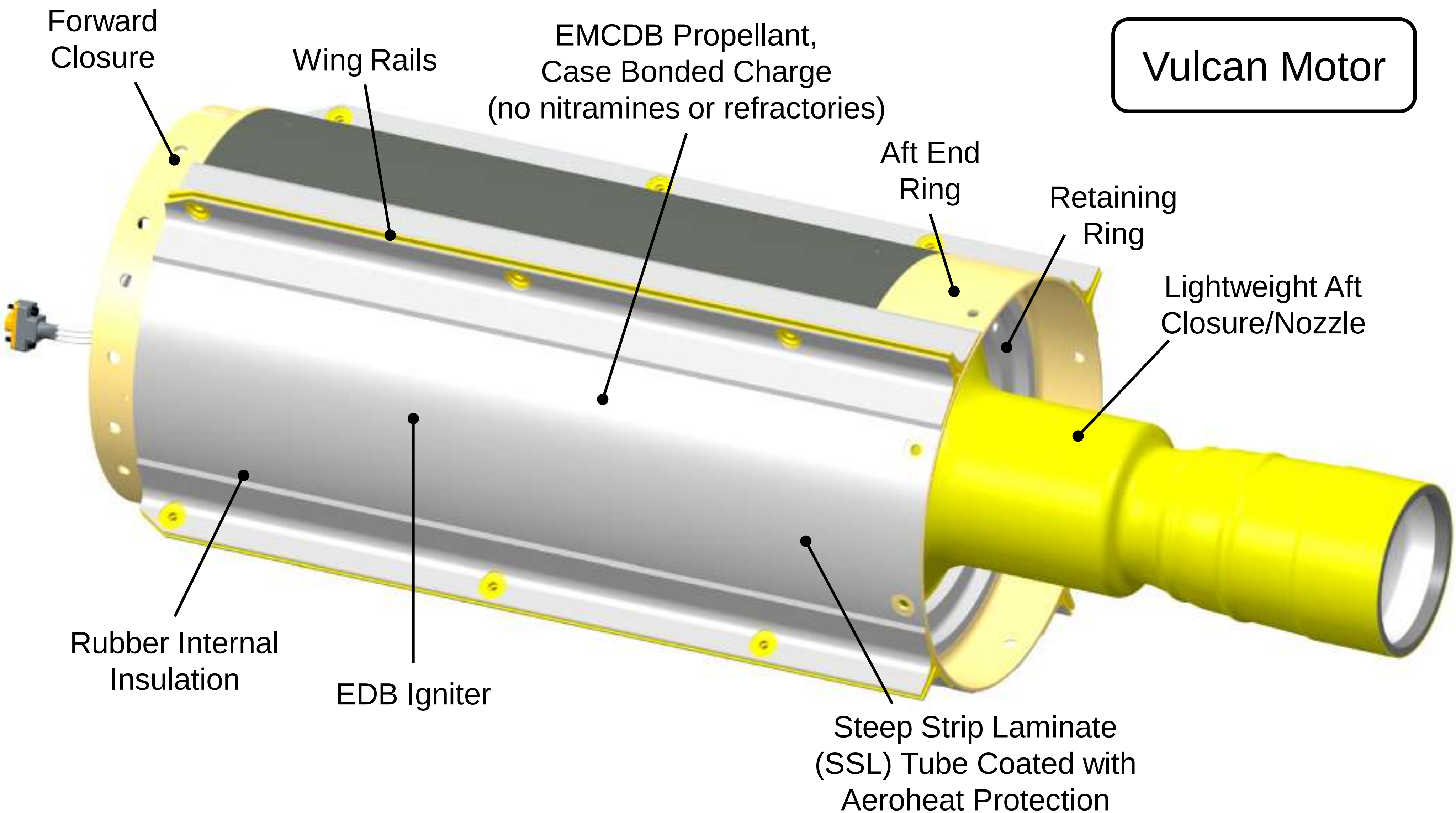
Introduction

- Roxel the motor supplier for MBDA's IM Brimstone Missile
  - Currently for UK MoD Tornado GR4
- Key objective to provide IM motor
  - Demonstrated excellent IM signature
- Roxel's first minimum smoke air-launched system
- Problems encountered during development
  - Since resolved and motors in series production
  - 100's of motors manufactured and delivered to MBDA
- Presentation will discuss….
  - Lessons learnt for development programmes
  - Results that demonstrate design robustness
  - IM signature and performance

Tornado GR4

IM Brimstone Rocket Motor

IM Brimstone Rocket Motor Design



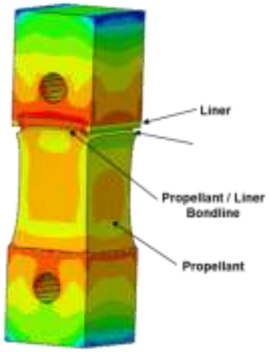
Development Issue & Improvement Plan

- Motor features observed during development
- Conduit crack
  - In cold stream motor
- Bondline features
  - In cold and hot stream motors
- Improvement programme conducted
  - Investigation led approach
  - Evidence based improvements
  - Improvements demonstrated through extensive trial programme
  - New design demonstrated to be robust
  - Qualification successfully completed

Centrifuge Firing (Normal Speed) and Air Carriage Aeroheat Static Firing (High Speed)

Improved Performance

- Series of motor trials were conducted to demonstrate and measure the charge and bondline design margin
- Over 20% improvement in bond strength after trials
  - Samples taken from motors post trial
- Some static firings after additional environmental trials
  - Demonstrates charge robustness
  - No conduit crack after 40 thermal shocks
  - Firings at -46°C after 40 thermal shocks
  - Firing at -46°C after 98 days arctic storage & 40 thermal shock cycles



Tensile Bond Test Sample Modelled (Von Mises Stress Presented)

Vulcan Rocket Motor -46°C Static Firing After Exposure To 98 days C2 Diurnal Cycling and 40 Thermal Shock Cycles

Firing At -46°C After 98 Days C2 & 40 Thermal Shocks

High Speed Video of Vulcan Rocket Motor -46°C Static Firing After Exposure To 98 days C2 Diurnal Cycling and 40 Thermal Shock Cycles

Development Lessons Learnt

1. Extensive Propellant Characterisation
   - Assess propellant response to damage effects
   - Thermal cycling
   - Low temperature strain endurance
   - Thermo-mechanical cycling damage

Increase In Damage Cycles

2. Advanced Non-Linear Viscoelastic Model
   - Calculate safety factors fresh and after cumulative environmental trials
   - Discussed further in J. Nota (Roxel) IMEMTS 2015 paper

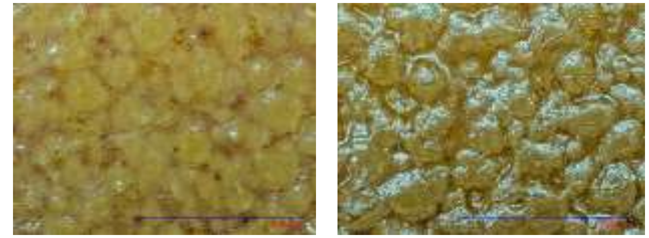
3. Charge Design Robustness
   - Techniques to reduce the stress and strains in critical areas of the charge
   - For example; conduit diameter, peripheral stress relief liner, improved propellant properties

Development Lessons Learnt

4. Bondline Process Improvements
   - Improved bonding surface finish
   - Moisture control throughout & after processes
   - Reduce liquid rich regions
   - Increase powder compaction & consolidation

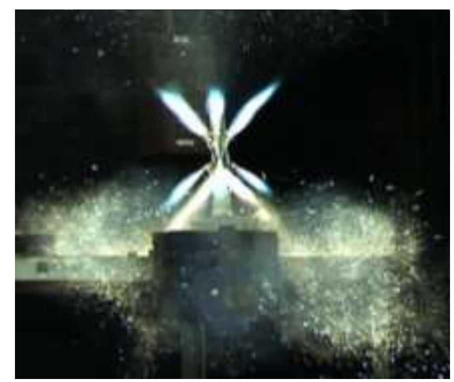
5. Motor Bondline Testing
   - Quantitatively characterise motor propellant bond
   - Metal-propellant machining for case bonded charges
   - Tensile bond strength measured after motor trials

6. Early Igniter Integration Trials
   - Complex interaction with initiator, gaine & pyrogen charge
   - Balance robust & fast cold ignition
   - With controlled peak pressure at hot



Bonding Surface Finish: (Left) Original, (Right) Improved

Motor Tensile Bond Test Sample



Igniter Firing

Development Lessons Learnt

7. Design Margin Trials – Explore failure modes and the design margin

a. Cooldown to Failure
   - Incrementally cooling motor until charge cracks
   - Charge measurements & cracking temperature validate modelling

b. Thermal Shock Cycling To Failure
   - X-ray inspection after each cycle
   - Demonstrate robustness of charge & bondline

c. High Temperature Trial
   - Storage of the motor at constant high temperature
   - Assess bondline robustness to chemical ageing

d. Cumulative Damage Pressurisation Firing
   - Cold firing at low operating temperature after rigorous environmental trials
   - Demonstrates model safety factor and charge robustness
   - Alternatives to consider; reduce firing temperature or nozzle throat area

IM Brimstone Rocket Motor IM Performance

- Excellent IM signature demonstrated by IM Brimstone rocket motor
- Will be one of the highest IM rated minimum smoke rocket motors in-service

Type V Burning Response in BI Trial

Fast Cook Off	Slow Cook Off	Bullet Impact	Fragment Impact		Sympathetic Reaction
			$1830ms^{-1}$	$2530ms^{-1}$	
V	IV*	V	IV	I	V*

* Demonstrated at missile level.

IM Performance

- Bullet Impact : Type V
  - SSL case delaminates upon impact
  - Large vent area created
  - Propellant burns at low pressure
- Fragment Impact – 1830ms^{-1} : Type IV
  - SSL case, EMCDB, velocity attenuation barriers
  - Detonation velocity threshold > 1830ms^{-1}
  - Level of pressure confinement dictates reaction
  - Fragment was stopped by igniter in trial
  - Distribution of large fragments at low pressure
- Fragment Impact – 2530ms^{-1} : Type I
  - Beyond detonation velocity threshold
  - Generally considered XDT response

Type V Burning Response in BI Trial

Type IV Response in FI Trial

IM Performance

- Fast Cook Off : Type V
  - High temperatures involved
  - SSL case adhesive strength degrades
  - Propellant ignites and burns
  - SSL case unravels and releases pressure

Vulcan Rocket Motor Type V IM Response to FCO; (Left) During The Fire, (Right) After Trial Condition

- Slow Cook Off : Type IV
  - Tested at missile level in missile packaging
  - Propellant / igniter ignites at 120°C to 130°C
  - Aft closure designed to eject under high & rapid pressurisation

- Sympathetic Reaction : Type V
  - Tested at missile level in missile packaging
  - Munitions stacked in 2 x 2 arrangement
  - IM mitigation to impact threats leads to burning reaction of acceptor motors

Type IV Response in SCO Trial – Ejected Aft Closure (Images Courtesy of MBDA UK)

Roxel

Conclusions

- Previous development problems have since been resolved
  - Development lessons learnt identified
  - High level of technical competency and understanding
- IM Brimstone rocket motor improved and demonstrated to be robust
  - No cracks after 40 thermal shock cycles
  - Subsequent successful static firings at -46°C
- Motor in full scale production and successfully delivered 100's to MBDA
- Demonstrated excellent IM performance
  - One of the highest IM rated minimum smoke rocket motor in-service
- Provides the UK MoD with a robust, minimum smoke rocket motor with a very good IM signature for use on IM Brimstone missile on Tornado GR4
  - Future opportunities for other platforms

Roxel
Propulsion systems

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