Space Shuttle

Five-Segment Booster

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ATK Thiokol Propulsion
ROCKET MOTOR
OPERATIONAL SOLID WORLD'S LARGEST

Solid Rocket Motor (SRM)

Space Shuttle, Four-Segment Reusable

ATK Thiokol Propulsion
Return to Flight (STS-26)

- 220 flight motors
- 39 static tests
- Flown or tested
- 28 years: 259 total motors
- 85 RSRM flight: 1988 to 2002
- Return to Flight: September 29, 1988
- To-case joint, and nozzle ablative
- Improved field joints, igniter joints, nozzle-
- Redesign activity: 1985 to 1988
- Challenger disaster: January 28, 1986
- 25 flight: 1981 to 1986
- First flight: April 12, 1981
- First static test: 1977
- Program start: 1974

RSRM History

ATK Thiokol Propulsion
Heavy-Lift Vehicle
Potential boost propulsion for
Reduce main engine throttle settings
Safe upgrades
Shuttle system reliability and
Enable crew escape module and other
Increased to 40,000 lb
Orbiter space station Alpha payload
Single engine out of the pad
Achieve about 10-Orbit (ATO) with
about modes
Eliminate Return to Launch Site

Enhance Space Shuttle capability
Segment solid rocket booster
Segment to the current four-
Space Shuttle by adding a fifth
NASAs is considering upgrading the

Future Plans: Five-Segment Booster (FSB)

ATK Thiorol Propulsion
Four-Segmant VS. Five-Segmant Booster

ATK THIOLK PROPELLION
About Modes (one SSME out) Study Results

ARTRP

Adequate performance margins

Achive ATO from Pad at 109 - 112% SSME throttle with

ARTRP

Return to Launch Site

Trans-Atlantic Landing

Abort to Orbit

Proceed to Mission

SSME 109-112%

SSME 109%

SSME 106%
Changes noted in italics

Nozzle Exit Plane

Silliner Rings

Field Joint

Et Attach Ring

Field Joint

Field Joint

Field Joint

New Cylinder

Segments

Fwd Skirt

Field Joint

RSRM Igniter

Thrust Post

Forward SRB

ET/SRB Attach Point

Factory Joins

Same attach location

Larger Diameter Thrust

Larger Diameter Exit Cone

New Nozzle

Five-Segment Booster

ATK Thiokol Propulsion
FSE Grain Design

ATK Thiokol Propulsion
STATIC PRESSURE DROP

FSB REPRESENTS ~1.15 PSIA INCREASE IN RPM

Based on CFD Analysis

FSB Bore Pressure

Pressure Drop Down the Bore at Ignition

ATK THIOKOL PROPULSION
Centerline Mach Number

FSB Represents ~0.2 Increase in RSRM

Based on CFD Analyses

FSB Bore Mach Number

Mach Number Down the Bore at Ignition
Required for FSB
Accurate erosive burning predictions:

- Motors relative to FSB
- Current models are empirically derived, and based on small scale testing
- Erosive burning difficult to predict
- Certified maximum expected operating pressure (MEOP)
- Erosive burning compounds operating pressure possibly affecting combustion
- During ignition
- Shuttle pressure rise reaches maximum head-end pressure
- Head-end pressure levels
- Burn rate enhancement due to erosive burning increases
- Subsonic (susceptible to "erosive burning"
- Solid rocket motor with high cross-flow velocities (high Mach
- Concerns

FSB Design Issue: Erosive Burning
ATK Thiokol Propulsion
Enhanced Propellant Burn Rate

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Factors Influencing Enhanced Burn Rate

- Nozzle throat diameter
- Grain bore diameter
- L/D
- Motor geometry
- Mass flow rate
- Bulk fluid velocity

Drivers of Enhanced Propellant Burn Rate

ATK Thiokol Propulsion
AND VALIDATION
FIRST STEP IN MODEL DEVELOPMENT

- Full-scale 5-segment RSRM static test (ETM-3) in July 2003
- Plan to validate FSB erosive burning scale factors using a planar model to CASTOR® IVB and RSRM
- Anchored model to CASTOR® IVB and RSRM
- Developed scale factors to adjust for motor size
- Subscale motor
- Developed relationships between burn rate and Mach number in regression and pressure drop down the motor
- Test motors instrumented to measure propellant surface regression and pressure drop down the motor
- Subscale tandem, segmented 5-in. CP test article designed
- Hydraulic diameter for propellants with different burn rates
- Developed relationship between Mach number, pressure, and approach

FSB Erosive Burning Model Development
ATK THIROL PROPELLION
Modeling Approach

ATK Thiokol Propulsion

FIVE SEGMENT ROCKET

Provide an accurate midsize test motor burning model without a scalable erosion data

Enable development of existing motor data
Stock Interface

- Return signal synchronized with reflection of propellant gun
- Elimination of standing wave noise

Noise Reduction

Surface

- Acoustic lens to reduce signal scatter on curved propellant
- Materials

Ultrasonic signal enhanced through impedance matching of

Signal Transmission

Instrumentation/Signal Acquisition

- Number of segments controls motor chamber pressure
- Bore/throat diameter controls Mach number
- Six tandem 5-in. center-perforated (CP) motors
- Subscale test motor configuration

Subscale Motor Hardware Overview

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Hardware Configuration

ATK Thiokol Propulsion
Ultrasound Instrument Configuration

 ATK THIOLPRO PROPEL

• CASTOR® ETM-3 RSRM
• Propellants
  - Propellant without solids
  - Material intermediate acoustic impedance
  - Propellant gum stock
    - Minimizes signal scatter
    - Surface curvature on the VESSEL surface
      - The signal on the propellant bore about the motor centerline to focus
      - Curvature on the VESSEL surface

• Acoustic Lens
  - Supports motor operating pressure
  - The case wall
  - Provides an acoustic window through VESSEL
  - Acoustic stack
Propellant Surface Mapping

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Subscale Motor Design

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Erosive burning is a boundary layer phenomena

Modeling Assumptions

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Erosive Burning Characterization

A TKIOL Propulsion

Motor Performance

Burn Rate (In/sec)

Time (sec)

Motor Performance

Burn Rate (In/sec)

Erosive Burning Region

Burn Rate (In/sec)

Erosive Burning Characterization

A TKIOL Propulsion
Chamber Pressure (psia)  

- Segmented performance captures individual burn rates that measured burn.  
- Accurate match indicates burn rate.  
- Measured propellant.  
- Re-prediction using.  

Tandem Motor Performance  

No erosive burning.  
- Tiring data from single motor.  
- Original prediction using.  

Tandem Motor Predicted Performance  

ATK Thiokol Propulsion
and full-scale data
Scale factor is curve
in a 1-D analysis
surface environment
the propellant
e a means to capture
hydraulic diameter is
Scaling with

Hydraulic Diameter Influence

on Erosive Burning
Trace matches well
CASTOR® IVB Pressure

CASTOR® IVB

In RSRM
enhanced burn rate present
approximately 6 psi
Model indicates
model for the erosive burning
RSRM used as a threshold

FIVE SECOND BOOSTER
Att Thiorok Propulsion
Computational Fluid Dynamics
Structures
Instrumentation
Propellant Formulation
Erosive burning (validate analytical predictions and scale factors)
Risk reduction and technical skill enhancement
ETM-3 provides opportunities for FSB

Techniques (models, methods, etc.)
RSRM (margins)
People

an endeavor focused on learning & improvement
verification of a five-segment Engineering Test Motor (ETM-3) —
MSFC and Thiokol are well under way with design and manufacturing.

ETM-3: World's Largest Segmented SRM
ARX Thiokol Propulsion

Five Segments Booster
Burning than 30 psi due to erosive rate enhancement or less
F3B models predict a burn
about 8 psi due to erosive burn rate enhancement or a
ETM-3 models predict a

Provide data for potential FSB design update and loads refinement
Demonstration of reduced burn rate propellant ballistic performance
Improve ignition transient model
Increase understanding of internal gas dynamics

Methods

Five-segment ETM-3 provides early validation of analytical methods to be a non-issue for FSB (less than 30 psi)

Subscale testing and preliminary analysis show erosive burning and safety upgrades

Enable crew escape module and other Space Shuttle system reliability
Orbiter space station Alpha payload increased to 40,000 lb
Achieve ATO with single engine out of the pad
Eliminate RTLS or TAL abort modes
FSB shows great potential to enhance Space Shuttle capability

FSB Program Summary

ATK Thiokol Propulsion