The Shuttle Propulsion Systems: Mitigating Development Risk through Testing

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Mitigating Risk Through Testing

Facilities are a critical part of a robust and successful test program.
What is the Space Shuttle?

• World’s first reusable heavy-lift spacecraft

• It is the most complex machine ever built

• Launches vertically (a rocket), carries crew, logistics, experiments and maneuvers in Earth orbit (a spacecraft), lands like a airplane

• Each Space Shuttle has a design life of 100 missions

  – 133 total missions to date/ Flown 530,608,887 miles (March 2011)

• Space Shuttle is a unique national asset

It has more than 2.5 million parts
230 miles of wire
nearly 1,100 valves and connectors
almost 1,500 circuit breakers
and over 27K insulated tiles and thermal blankets
• Cargo/payload delivery and retrieval
  – Up to 26 tons of payload capacity to orbit
  – Up to 20 tons of payload capacity on re-entry
    • 1,693,500 lbs returned to earth*

• On-orbit assembly and service (ISS, HST)
  – 53,692,090 lbs of hardware delivered to space*
    • 936,090 lbs delivered to ISS*

• Total Crew Members - 845  (15 Countries Represented)

• Satellite retrieval and repair
• On-orbit, point-to-point maneuvering of people and cargo
• Science payloads/Space Lab/SpaceHab
• EVA capable

*Status as of STS–133 (March 2011)
Shuttle Propulsion Office

Solid Rocket Booster

Solid Rocket Motor

External Tank

Main Engine
Teamwork
Space Shuttle Main Engine (SSME)

- Low Pressure Oxygen Duct
- Low Pressure Fuel Turbopump
- High Pressure Oxygen Turbopump
- High Pressure Fuel Turbopump
- Main Combustion Chamber
- Controller
- Nozzle

Manufactured by:
Pratt & Whitney/Rocketdyne Power, Inc.
Canoga Park, CA

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>LENGTH</td>
<td>14 ft (4.3 meters)</td>
</tr>
<tr>
<td>DIAMETER</td>
<td>7.5 ft (2.3 meters)</td>
</tr>
<tr>
<td># PER FLIGHT</td>
<td>3</td>
</tr>
<tr>
<td>PROPELLANTS</td>
<td>liquid hydrogen and liquid oxygen from the External Tank</td>
</tr>
<tr>
<td>THRUST</td>
<td>418,000 lbs (189,600 kg) sea-level</td>
</tr>
<tr>
<td>Ignition to MECO</td>
<td>Approx. 8.6 mins</td>
</tr>
<tr>
<td>LIFETIME</td>
<td>7.5 hours, 55 starts</td>
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</table>
Space Shuttle Main Engine (SSME) Overview

- 3 main engines operate for 8 1/2 minutes during ascent
- Sole source of propulsion once the Solid Rocket Motors are separated at T+120 seconds
- Engines have performed safely for all 133 launches (as of STS-133)
  - One in-flight shutdown (STS-51F July 29, 1985)
- Total seconds of operation – 1,092,624

Testing is an integral part of SSME success and flight readiness
Space Shuttle Main Engine
Amazing Facts

- High Pressure Fuel Turbopump (HPFTP) alone delivers as much horsepower as 28 locomotives and can drain an average-size swimming pool in 28 seconds!

- Turbine blades are one of the most critical components on the Shuttle

- The turbine disk spins at 600 revolutions per second

- Each turbine blade produces 700 HP

- Three main engines operate for 8 minutes and 40 seconds for each flight, with a combined output of 37 million horsepower (HP).

- Engine operates at temperatures from -423° F (liquid hydrogen) to 6,000° F (hotter than the boiling point of iron!)

- Three engines produce equivalent power of 13 Hoover Dams

- World’s highest efficiency reusable LOX/Hydrogen engine
<table>
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<tr>
<th>Characteristics</th>
<th>Operational</th>
</tr>
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<tbody>
<tr>
<td><strong>Propellants</strong></td>
<td>Main Combustion Chamber Pressure</td>
</tr>
<tr>
<td>Oxygen/Hydrogen</td>
<td>2,871 psia</td>
</tr>
<tr>
<td><strong>Thrust @ Rated Power Level (RPL) 100%</strong></td>
<td>Main Combustion Chamber Temperature</td>
</tr>
<tr>
<td>469,448 lb</td>
<td><strong>Fuel Flow rate</strong></td>
</tr>
<tr>
<td><strong>Thrust @ Nominal Power Level (NPL) 104.5%</strong></td>
<td>155 lb/sec</td>
</tr>
<tr>
<td>490,847 lb</td>
<td><strong>HPFTP Turbine Discharge</strong></td>
</tr>
<tr>
<td><strong>Thrust @ Full power level (FPL) 109%</strong></td>
<td>Temperature</td>
</tr>
<tr>
<td>512,271 lb</td>
<td><strong>HPFTP Speed</strong></td>
</tr>
<tr>
<td><strong>Chamber pressure (109%)</strong></td>
<td>2,994 psia</td>
</tr>
<tr>
<td></td>
<td><strong>Oxidizer Flow rate</strong></td>
</tr>
<tr>
<td>452 sec</td>
<td>933 lb/sec</td>
</tr>
<tr>
<td><strong>Throttle range (%)</strong></td>
<td><strong>HPOTP Turbine Discharge</strong></td>
</tr>
<tr>
<td>67 to 109</td>
<td>Temperature</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td><strong>HPOTP Discharge Pressure</strong></td>
</tr>
<tr>
<td>7,748 lb</td>
<td>4,040 psia</td>
</tr>
<tr>
<td></td>
<td><strong>HPOTP Speed</strong></td>
</tr>
<tr>
<td></td>
<td>22,357 rpm</td>
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</table>
• Through March of 2011, SSME has been hot-fired 3,156 times
  – 1,092,624 seconds during flights and ground tests
• First SSME tests conducted on May 19, 1975 at the Mississippi Test Facility (now the Stennis Space Center)
  – Six years of development test prior to first launch in 1981
  – 37 tests required to reach minimum power level (50% RPL at the time) during initial start sequence development (12 turbopump replacements)
  – 95 tests required to reach 100% power level
  – Initial flight start sequence implemented in 1978
    • 10 engine failures incurred during this time period
    • Further modifications to start sequence required as engine upgrades implemented
  – 726 tests on 24 engines for 110, 252 seconds prior to STS–1
• Last SSME test occurred at Stennis Space Center (SSC) on July 29, 2009
63 consecutive launches have occurred without an SSME related delay

Three Test Phases...

- **SSME Development Testing:**
  - Prior to STS–1, SSME had 726 starts / 110,000 seconds
  - Certification Test demonstrated boundary of performance on ground before flight
  - Historically, 75% of total engine development cost are from “test failures” which identify key risks early
    - Reduces likelihood of failure and consequences of the failure in flight

- **Operational Testing:**
  - Acceptance test of approved hardware design
  - Resolve anomalies (cycle testing, production anomaly, tolerance stack up, environments and repairs (flight specific or fleet issue)
  - Performance envelope and increased life limits
  - Drives inspection techniques for continued safety of flight
  - Test of other components on vehicle impact to SSME (MPS interface, flight rule changes, etc.)

- **Off-nominal Testing:**
  - Extensive knowledge on engine operations
  - Determining margins against undesirable conditions
  - Increased launch capability
  - Future design configurations
  - Increased safety upgrades
Space Shuttle Main Engine (SSME) Design Improvements

First Manned Orbital Flight
- Baseline Engine
  - STS–1 1981
  - Powerhead
  - Ducts
  - HPFTP
  - LPOTP
  - Avionics
  - Nozzle

Full Power Level
- STS–6 1983
  - HPFTP
  - HPOTP
  - MCC
  - LPOTP

Phase II
- STS–26R 1988
  - HPFTP
  - HPOTP
  - MCC
  - LPOTP
  - Avionics/Valves

Block I
- STS–70 1995
  - Two Duct Powerhead
  - Single Tube HEX
  - HPOTP
  - HPFTP EDM Inlet
  - Thermocouples

Block IIA
- STS–89 1998
  - Large Throat MCC
  - Main Injector Modifications
  - Block II LPOTP
  - Block II LPFTP
  - A-Cal Software
  - Pressure Sensor

Block II
- STS–104 2001
  - HPFTP
  - Main Fuel Valve
  - Non-Integral Spark Igniter
- STS–117 2007–today
  - Advanced Health Management System (active)

Block Change Philosophy
External Tank Evolution / Weight


**Design Improvements through a Block Change Philosophy**
External Tank Overview

• **The External Tank**
  
  – Serves as the structural backbone of the shuttle during launch operations
  
  – Contains and delivers Liquid Hydrogen (LH$_2$) and Liquid Oxygen (LO$_2$) propellants for the Orbiters three main engines

• **Three structural elements**
  
  – The LO$_2$ tank and LH$_2$ tank pressure vessels are welded assembly of machined and formed panels, barrel sections, ring frames and dome sections
  
  – The Intertank is a cylindrical mechanically joined assembly with flanges at each end for joining the LO$_2$ and LH$_2$ tanks
**Space Shuttle External Tank (ET)**

**Amazing Facts**

- Only major expendable shuttle element
- Skin of the ET is less than 0.25 inches thick, yet holds more than 1.5 million pounds of propellant
  - Holds 380,000 gallons of liquid hydrogen (−423° F)
  - 140,000 gallons of liquid oxygen (−300° F)
  - 2,993 feet (~over ½ mile of critical welding per tank.
- ET covered with spray-on foam insulation that keeps the LH$_2$ at −423° F even in the hot sun ~ 1/3 acre of foam surface
- Weights 1.6 million pounds at liftoff: equal to 32,000 elementary school children

- The External Tank is manufactured at Michoud Assembly Facility in Louisiana. The building is 43 acres under one roof!

- The ET is taller than the Statue of Liberty and is the structural backbone of the Shuttle vehicle
ET Critical Developmental Testing

- Material testing
  - Foams/Ablative Materials
  - Adhesion Testing

- Component Testing
  - Structural
  - Functional Testing

Major Ground Testing:

1. Structural Test Article (STA) – over 1,100 strain gauges
   - LH2, LO2 and (2) inter tanks

2. Mated Ground Vibration Test
   - Design information for guidance and control systems
     - (ET, RSRM & SRB (loaded and inert) ,and orbiter)

3. Main Propulsion Test Article:
   - Simulated orbiter aft section, 3 engines, flight weight ET, flight weight fuselage
ET Testing is Critical throughout the life of the program.....

• **MPT ET Pre-Flight Testing**
  – Verified Subsystem Performance Requirements
  – Validated and Anchored Analytical Models
  – Developed Propellant Loading and De-tanking Procedures
  – Identified Problematic Hardware, Optimized Requirements and Procedures Prior to Flight

• **ET Production Test and Verification**
  – LH\textsubscript{2} and LO\textsubscript{2} Systems Proof and Leak Testing
  – Propulsion Systems Verification Testing
  – Electrical Systems Verification Testing

• **ET Flight/Development test have enabled Block upgrades resulting in over 18,000 pound weight reductions**
  – MPT – Development of Pre-Flight Data
  – SWT – Generated Developmental Flight Loads Data
  – LWT – Reduced ET Weight from SWT Flight Loads Data
  – SLWT – Optimized ET Weight from LWT Flight Loads Data

• **1.4 Factor of Safety to 1.25 weight but after extensive structural tests were completed**
  – Significant redesigns and processing improvements have been accomplished since STS–107
  – Our understanding of risk has improved
  • Understanding of failure mechanisms is based upon testing and flight observations

• **ET Successfully Evolved and Continues to Fly Based on Testing and Verification Approach**
  – Significant redesigns and processing improvements have been accomplished since STS–107
  – Our understanding of risk has improved

External Tank RTF Major Continuous Risk Reduction

Processing Improvements
- Low Spray Guns
- Human Factors
- Lead In – Lead Out
- Video Review Of Sprays
- Improved Mats
- NDE
- Producibility Enhancements
- GUCP Improvements
- Friction Stir Welding

Design Improvements
- Bipod Fitting
- Bellows Heater
- Feedline Camera
- PAL Removal
- LH IFRs
- LO2 Ti Brackets
- ECO Feed Through
- Sixth Buy Tanks

Post Flight Assessment
- Imagery
- Failure Mode Assessment
- CAD Modeling
- EPAT Process
- Historical Data Base
- Statistical Assessments

Baseline SLWT

2005

ET–121 RTF Modifications
Bipod Fitting and Feedline Bellows Heater

2006

ET–119 RTF II Modifications
PAL Ramp Removal

2007

ET–124 Hail Damaged Tank

ET–120 LH₂ IFR Redesign Demonstration

2008

ET–125 ECO System Resolution

ET–128, First In-line Tank LO₂ Feedline Brackets and LH₂ IFRs

2009

ET–129/127/130/131 TPS Producibility Enhancements

Al 2219 Complex Curvature Panels, and Friction Stir Welding fully implemented on ET–134

SLWT mass unchanged

2010
Reusable Solid Rocket Booster (RSRB)

SSP-10-1826

Forward Separation Motors
Frustum
Forward Skirt
Igniter/S&A
Forward Segment With Igniter
Systems Tunnel
Nose Cap (pilot and drogue parachutes)
Three Main Parachutes
Avionics

Forward-Center Segment
Aft-Center Segment
Avionics
Three Aft Attach Struts (ET attach ring)
Aft Exit Cone
Aft Skirt
Aft Separation Motor
Aft Segment With Nozzle

Length 149 ft
Diameter 12.2 ft
# Per Flight 2
Propellant 1.1 million lbs of ammonium perchlorate fuel and aluminum oxidizer
Burn Duration 123 seconds
Chamber Pressure 906.8 psia (Ignition)
Weight 1.3 million lbs each

Supplied by RSRM/ATK
Supplied by SRB/USA
Reusable Solid Rocket Booster (RSRB) Overview

- Twin RSRBs burn for 123 seconds during ascent
- Provide 80% of thrust required to achieve liftoff
- Recovered 120 to 160 miles downrange from KSC
- Case segments are returned to manufacturer in Utah for refurbishment
  - Four cast segments per motor
  - Designed for 20 flight reuse
  - Each segment filled with approx. 280,000 lbs of propellant
  - Shipped via rail to/from KSC
- Segment cases made from D6AC steel
- RSRM shelf life is six years
  - Flight specific age life extension to 5.5 yrs
- 260 motors launched (RSRM and SRM)
- 1 Ares I-X Motor (Test Flight)
- 54 full scale static tests
  - Development, Qualification, Engineering Test, Disposal
  - Includes one 5-segment Engineering Test Motor, and two 5-segment Development Motors for Cx/Ares Program (DM-1 and DM-2)
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<td>Transmit RSRM thrust to Shuttle</td>
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<td>Attach ET and SRB</td>
<td>Attach ET and SRB</td>
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<td>Shuttle steering through SRB Separation</td>
<td>Avionics and Flight Controls</td>
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<td>Range Safety System (RSS)</td>
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<td>RSS Safe and Arm Device</td>
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<td>Linear Shape Charge (LSC)</td>
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<td>Command Receiver Decoder</td>
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<td>RSS Antennae</td>
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<td>SRB Separation</td>
<td>Separation System</td>
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<td>Booster Separation Motors</td>
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<td>Forward Separation Bolt</td>
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<td>Aft Separation Bolts/Attach Struts</td>
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<td>SRB Descent and Recovery</td>
<td>Recovery System</td>
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<td>Altitude Switch Assemblies (ASA)</td>
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<td>Nose Cap Thrusters</td>
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<tr>
<td>Pilot and Drogue Parachutes</td>
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<tr>
<td>Ordnance Separation Ring and LSC</td>
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<tr>
<td>Main Parachutes</td>
<td></td>
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<tr>
<td>Salt Water Activated Release (SWAR) System</td>
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</table>
• **World’s largest solid rocket**

- 149.1 feet high and 12.2 feet wide (1/2 football field long only 2 feet shorter than the Statue of Liberty)

- Each RSRM equivalent output during flight is 15,400,000 hp or about 51,300 Corvettes.

- Two RSRMs produce more thrust than thirty-two 747 jets at takeoff power or 14,700 six-axle diesel locomotives.

- RSRM combustion gas temperature approaches 6,000° F, approximately two-thirds the temperature of the sun’s surface. At this temperature steel does not melt, it boils.

- Produces 2.6 million pounds of thrust at liftoff - more than 32 747s at take-off power

- Boosters go to full power in 2/10th of a second – the heat they produce in the first 2 minutes could heat 87,000 houses for one full day.

- After 2 minutes, boosters separate at 28 miles altitude at a speed of 3,100 mph. They coast upward for 13 miles before beginning their fall.

- Three 136-foot wide parachutes slow the SRBs to a safe splashdown in the Atlantic Ocean.

- Boosters are recovered, refurbished and reused.

- The boosters are the heaviest object ever to be parachuted safely back to the surface!
Reusable Solid Rocket Booster (RSRB)
RSRM Development & Qualification Program Philosophy

• **Solid Rocket Motor (SRM)** – Pre-51L Design
  – Full scale static tests before first flight
    • Four Development Motors (DM)
    • Three Qualification Motors (QM)

• **Reusable Solid Rocket Motor (RSRM)** – Post 51L Design
  – Full scale static tests before first flight
    • One Engineering Test Motor (ETM)
    • Two Development Motors (DM)
    • Two Qualification Motors (QM)
    • PVM-1: Flaw test (primary O-ring)

*Philosophy: “Test before you fly”*
Commitment to a Robust Motor Test Program

FSM (Flight Support Motor): Full-scale test motor (typically one per year) with focus on testing all finalized changes before first flight
- 16 FSMs (last motor fired 2/2010)

FVM (Flight Verification Motor): Special designation for two “Mid-Life and Full-Life” full-scale aged test motors built for flight (RSRM-89 de-stacked and returned to Utah)
- FVM-1 was 3.8 yrs old (based on segment cast)
- FVM-2 was 7.2 yrs old (based on segment cast)

PRM (Production Rate Motor): Full-scale test motor fired prior to post-Columbia return-to-flight that provided process validation during periods of reduce production rates
- 2 TEMs for RSRM (11 pre-RSRM)

TEM (Technical Evaluation Motor): Full-scale test motors with a variety of purposes including evaluation of extended exposure to Florida environment (returned to Utah due to age life)
- 3 ETMs (including one 5-segment motor)

ETM (Engineering Test Motor): Full-scale test motor focused on the “off-nominal” – flaw, margin, and “physics based” knowledge testing
- 3 ETMs (including one 5-segment motor)

MNASA (48”) and SRTM (24”): Subscale test motors – focus is evaluation and down-selection of material and design changes, analytical model anchoring, etc.
- 24 MNASA and 17 SRTM
• SRB Hardware Verification Description
  – SRB Primary Structures were analyzed and tested.
    • Mated Vehicle Ground Vibration Test (MVGVT)
    • Static Test Articles (STA)
  – Component Level/Integrated System test:
    • Electrical and Instrumentation (E&I) System was developed and Flight Certified at the component level and tested in integrated system level
  – Component Level developed and flight certified:
    • Recovery and Separation Pyrotechnics systems and Booster Separation Motors
    • Range Safety Destruct System
  – Thrust Vector Control (TVC) System was developed and Flight Certified at the component level and performance tested as a full TVC system at MSFC
  – Thermal Protection System (TPS) was developed, tested and verified at MSFC
  – DDT&E Flights
• Structural Tests
  – Structural tests were performed to determine the ability of SRB structure to withstand predicted static and dynamic forces which may be encountered in assembly, storage, transportation, handling, flight, and recovery. Structural tests were performed on the largest practical assemblies of structural hardware.

• Mated Vehicle Ground Vibration Test (MVGVT)
  – Full size Solid Rocket Booster structures, Solid Rocket Motor inert segments, External Tank and Orbiter Simulator were integrated and vibration tested at MSFC.

• Static Test Article (STA)
  – All major SRB structures were subjected to static loads equivalent to 140% of flight loads.
  – Aft Skirt – Forward Skirt – Frustum – Nose Cap – External Tank Attach Ring
“Test before you fly”
Back-up
**ET Developmental Testing**

- **MPT Test Hardware Description**
  - Full size SWT External Tank (ET), Space Shuttle Aft compartment complete with full Main Propulsion Systems (MPS) and three Space Shuttle Main Engines (SSME). Propellant Tanking and Full Duration MPS Static Firing tests on B2 Test Position at Stennis Space Center (1979).

- **ET MPT Test Objectives**
  - Verify Subsystem Performance Requirements
    - SSP Volume X Requirement Verification
    - Instrumentation and Electrical Performance Verification
    - Thermal Protection System performance Verification
    - Environmental Conditioning (Purges) and Compartment Venting Verification
  - Validate and Anchor Analytical Models
    - Thermal Models
    - Pressurization Models
    - Structural Load Models
    - Resonate (Vibration) Models
  - Develop Propellant Loading and De-tanking Procedures
    - Tanking Tables
    - Launch Commitment Criteria (LCC)
    - KSC Ground Operations – Maintenance and Requirement Specification Documents (OMRSD)
  - Identify Problematic Hardware, Optimize Requirements and Procedures Prior to Flight
**Verification Process**

- **Methodology**
  - Verification approach consistent thru Standard Weight Tank (SWT), Light Weight Tank (LWT) and Super Light Weight Tank (SLWT) verification programs

**Design Verification**
(Assure design meets required Factor of Safety)

**Acceptance Verification**
(Assure workmanship and absence of any flaw that will cause failure in use)

- Partial/Complementary
  - Existing Data Base (MPT, SWT, LWT, SLWT)
  - Component Tests
  - Independent Analysis

- Total Tank
  - Proof Tests
  - Protoflight Tests
  - Structural Test Articles (SWT, SLWT)

- Material Acceptance
  - Proof Tests
  - Protoflight Tests
  - Nondestructive Evaluations

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**Verified ET**

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31
• Safety
  – A Systems Approach to Safety Program Management

- New Technology
- Retained Experience
- Hazard Identification & Analysis
- Safety Program Planning

Safety Criteria, Requirements, Constraints

Preventive Actions to Eliminate or Control Risk

Design and Development
- Flight and Prototype
- Facilities & Tooling
- Physical, Functional and Environmental Interfaces
- Operational Readiness

Production Fabrication
- Work Document Controls
- Monitoring and Surveillance
- Training and Certification

Test and Checkout
- Proof & Leak Test
- Validation Procedures
- Acceptance Reviews
- Crew Certification

Delivery
- Transportation
- Environmental Monitoring

Recurrence Controls from Lessons Learned

• Failure Analysis  Accident/Incident Investigation  Performance Evaluation and Trends  Post Flight Analysis
STS–114, External Tank – 121
RTF Modifications “Bipod Ramps Removed”

- **Remove/Replace Longeron Closeouts**
- **Feedline bellows**: Without heater, With heater
- **Forward feedline bellows heater**
- **Intertank/LH_2 Tank Flange Closeout Enhancement**
- **Feedline fairing camera**
- **Bipod Fitting Closeout**
- **Increase Area of Vented Intertank TPS**

**RTF I: ET-121 modifications to reduce foam and ice debris. The bipod ramp was eliminated.**
RTF II: Following STS-114, additional foam debris risk mitigation included elimination of the PAL ramps.
Beginning with ET–128 risk mitigation was integrated into the original build. Additional risk mitigation included LH$_2$ IFRs and LOX feedline titanium brackets.
Reusable Solid Rocket Motor Process Flow
Reusuable Solid Rocket Booster Changes

- Larger Main Chutes
  STS–14  41D  1984

- 360 degree ETA Ring
  STS–26  1988

- Field Joint Redesign (Challenger)
  STS–26  1988

- Aft Skirt Structural Reinforcement
  STS–95  1998

- North American Rayon Corporation Nozzle Material
  STS–57  1993

- MCC-1 (External Insulation)
  STS–79  1996

- Vehicle Imagery Addition
  STS–121  2006

- BSM Redesign / Vendor Change
  STS–122  2008

- Command Receiver/Decoder (CRD)
  STS–118  2007

- Fwd Segment Propellant Grain Redesign
  STS–125  2008

Years:
- 1984
- 1986
- 1988
- 1990
- 1992
- 1994
- 1996
- 1998
- 2000
- 2002
- 2004
- 2006
- 2008
- 2009
Reusable Solid Rocket Booster (RSRB)

SRB Process Flow

- **Assembly and Test**
  - TPS application
  - Mechanical assembly
  - Electrical assembly
  - Test

- **Hydrolazing**

- **Retrieval Disassembly**
  - Component removal
  - Corrosion removal

- **Unique to Reusable Hardware**

**SRB Stack ET and Orbiter Integration Launch**
Scope:

The Main Propulsion Test Article will integrate the main propulsion subsystem with the clustered Space Shuttle Main Engines, the External Tank and associated GSE. The test program consists of cryogenic tanking tests and short- and long duration static firings including gimbaling and throttling. The test program will be conducted on the S1-C test stand (Position F-2) at the National Space Technology Laboratories (NSTL).

Configuration:

The main propulsion test article shall consist of the three space shuttle main engines, flight weight external tank, flight weight aft fuselage, interface section and a boilerplate mid/fwd fuselage truss structure.
MPTA Accomplishments

• Qualification of the Shuttle cross-feed system (ET along side the Orbiter)
• Integration of SSME into the Orbiter
• Qualification of liquid delivery system hardware
• Qualification of gaseous pressurization system hardware
• Validation of structural and POGO models
• Development of loading and draining procedures/software
Results:

3 tanking tests and 20 hot fire tests conducted between December 21, 1977 and December 17, 1980

MPTA Data

• Attempts to static fire 20
• Failure to get SSME ignition 2
• Tests planned for full duration (500+ secs) 14
• Tests full duration accomplished 6
• Tests planned duration accomplished 10
• Tests with high percentage of objectives met 12
• Engine Total Seconds 10,813