Marshall Space Flight Center
Space Shuttle Knowledge Sharing Forum

Solid Rocket Booster
Lesson on Unintended Consequences

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Agenda

• SRB Full Flight Video
• Overview of Booster Evolution
• Lesson on Unintended Consequences
  – External Tank Attach (ETA) Ring Material Issue
  – Gas Generator Injector Stem O-ring X-ray Test
  – Evolution of Holddown Post (HDP) System
  – Evolution of Fuel Isolation Valve (FIV)
  – SRB Camera Systems
  …And Wait, There’s Still More!
    – Evolution of Marshall Sprayable Ablative (MSA) to Marshall Convergent Coating (MCC)
    – Implementation of Command Receiver Decoder (CRD)
    – Frustum Linear Shaped Charge (LSC) Rotation
    – Integrated Electronics Assembly (IEA) Power Bus Isolation Supply (PBIS) Module Design Enhancement
    – Path to SRB Phase II Fuel Pumps
SRB Flight Video

STS-117
Overview Of Booster Evolution

- MSA-1 for Nose Cap Acreage (STS-4, 6-27-82)
- Large Main Parachutes (STS-41D, 8-30-84)
- Main Parachute Ripstop (STS-33, 11-22-89)
  - Alternate Forward Skirt Aft Clevis Seal (STS-46, 7-31-92)
- Thrust Vector Control (TVC) Hydraulic Accumulator (STS-4, 6-27-82)
- Metal Bellows Accumulator (STS-27, 12-2-88)
- Eliminated Tubing from TVC System (STS-71, 6-27-95)
  - MCC-1 Acreage TPS (STS-79, 9-16-96)
- 16 mm Parachute Camera (STS-51A, 11-8-84)
- MSA-2 Acreage Thermal Protection System (TPS) (STS-29, 3-13-89)
- SRB Radar Beacon Tracking System (STS-34, 10-18-89)

Color Key: Blue Denotes Discussion

Note: RH SRB Shown
Overview Of Booster Evolution

- Sea Water Actuated Release (SWAR) Links (STS-86, 9-25-97)
- Recovery Loads Data Acquisition System (DAS) (STS-72, 1-11-96)
  - DAS Parachute Camera (STS-77, 5-19-96)
- Single Mission (SM) Fuel Isolation Valve (FIV) (STS-105, 8-10-01)
- SRB HDP Blast Container Redesign (STS-26, 9-29-88)
- Aft Skirt Factor of Safety (FOS) Bracket (STS-95, 10-29-98)
- ET attach ring design changed from 270° to 360° (STS-26, 9-29-88)
- External Tank (ET) Observation Camera (STS-114, 7-26-05)
- Enhanced DAS (EDAS) (STS-106, 9-8-00)

Note: RH SRB Shown

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Overview Of Booster Evolution

- Added BI100 Commemorative Flag Pack (STS-96, 5-27-99)
- Command Receiver/Decoder (CRD) (STS-118, 8-8-07)
- Booster Trowelable Ablator (BTA) (STS-52, 10-22-92)
- Deleted PR1422 Fillet and Fastener Overseal (STS-84, 5-15-97)
- Alternate SRB Coating System (STS-113, 10-23-02)
- Environmentally Compliant Hypalon (STS-125, 5-11-09)
- Modified Aft BSM Exit Cone BTA Closeout (STS-117, 6-8-07)
- Crossover Frangible Nuts (STS-126, 11-14-08)
- Redesigned Debris Containment System (STS-119, 3-15-09)
- Phase II Fuel Pump (STS-133, 11-1-10)
- Power Bus Isolation Supply (PBIS) Module with 2 Amp Fuse (STS-127, 7-15-09)

Color Key: Blue Denotes Discussion

Note: RH SRB Shown
Lesson on Unintended Consequences

• Topic
  – External Tank Attach (ETA) ring material issue

• Story
  – Initial 4130 steel ETA ring spanned 270°
  – Redesigned ETA ring to 360° for STS-26

• Modified existing hardware
• Eliminated negative margins of safety during thrust build-up
Lesson on Unintended Consequences

• Story (cont.)
  – MSFC found suspect strength properties during early 2003 testing for ETA ring fracture properties
  – Historically used generic properties for all alloy steels
  – Design load case analysis using worst case material properties resulted in minimum Factor Of Safety (FOS) of 1.25
    • Violated FOS requirement of 1.4
    • Analysis completed day before STS-107 launch
    • STS-107 flight specific loads analysis supported FOS of 1.3
  – SRB presented issue and waiver rationale at STS-107 ET Tanking Meeting 1-16-03
    • Tanking meeting not Mission Management Team (MMT) meeting
    • Waiver CR S091496 approved
    • STS-107 ETA rings performed successfully as expected
Lesson on Unintended Consequences

- **Outcome**
  - Extensive testing and evaluation performed to certify 1.4 FOS requirement for STS-114 and STS-126
  - Procured 4340 steel ETA rings for STS-115
- New components manufactured under fracture critical and critical process control requirements
  - Web plates, splice plates, filler plates, ring caps, intercostal brackets, and cable brackets
  - Only Inconel 718 H-fittings common
- Lessons Learned
  - Significant safety concerns require discussion at appropriate level to ensure full awareness of associated risks
  - Reason for safety margins
Lesson on Unintended Consequences

• Topic
  – Gas Generator (GG) injector stem o-ring x-ray test
  – Story
  – 100% x-ray fluorescence implemented for all o-rings in 1998
    • Vendor self imposed to verify Ethylene Propylene Rubber (EPR)
      – Too small for material identification coding
      – Many handling opportunities
  – Equipment replaced at vendor on 2-19-09 (more powerful)
  – Reported o-ring failed during installation onto GG stem 5-1-09
    • O-ring brittle and cracked
    • Found degradation due to new x-ray fluorescence equipment
Lesson on Unintended Consequences

• Outcome
  – New equipment programmed to prevent o-ring degradation
  • Testing demonstrated proper material identification without unacceptable degradation
  • Analysis indicates new process exposure less than from original equipment
  – All suspect o-rings scrapped
  – Replacements tested with new equipment and settings
  – Lessons Learned
  – Verification required to ensure good intentions do not result in unintended consequences
Lesson on Unintended Consequences

- **Topic**
  - Evolution of Holddown Post (HDP) System

- **Story**
  - 25 aft skirt stud hang-ups at launch randomly occurred on 23 Shuttle launches over program
  - Experienced two stud hang-ups on one aft skirt on STS-2 and STS-92
  - Efforts to understand and minimize stud hang-ups performed numerous times in course of program
  - Most recently NASA Engineering Safety Council (NESC) tasked to determine root cause during post Columbia return to flight efforts
    - Tests and computer model showed obtaining close to zero skew significantly reduces probability of stud hang-ups
    - Skew: time delta between booster cartridge detonations
Lesson on Unintended Consequences

• Story (cont.)
  – SRB redesigned frangible nut to incorporate pyrotechnic crossover assembly for STS-126
  • Qualification included significant test program with nine flight like configurations
  – During crossover’s first flight video showed HDP 3 spring and plunger extended during liftoff
    • Within Debris Containment System (DCS)
    • Only portion of spring found post launch
      – No evidence of HDP 3 stud hang-up
    • Similar failure on STS-56 HDP 5
      – Plunger and spring remained attached to stud

New Frangible Nut Design

STS-126 Launch Video
Lesson on Unintended Consequences

• Story (cont.)
  – Investigation found nut halves damaged plunger shoulder
  • Historical assessment revealed frequent plunger shoulder damage and missing material
  – Outcome
  – Modified DCS prior to next flight
    • Added retention feature to limit plunger travel if shoulder fails
  – Lessons Learned
  – Review postflight and PRACA records prior to changes to identify any adverse trends
  – Follow through with corrective actions
Lesson on Unintended Consequences

• Topic
  – Evolution of Fuel Isolation Valve (FIV)

• Story
  – Initial FIV design multi-mission
    • Isolates fuel from Auxiliary Power Unit (APU) in normal deenergized position
    • Fuel allowed to pass via poppet assembly
  – Prior to STS-53 (12-2-92) uninstalled FIV failed Acceptance Test Procedure (ATP) at vendor
    • Valve failed Dielectric Withstanding Voltage (DWV)
    • Subsequent teardown found fluid in electrical cavity
Lesson on Unintended Consequences

- Story (cont.)
  - Found intergranular attack of poppet and bellows capsule
  - Provided hydrazine leakage path
  - Root cause identified through M&P evaluation and testing

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<th>Root Cause</th>
<th>Notes</th>
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| Sensitized material susceptible to attack by long term exposure to postflight processing fluids | • Sensitized grain boundaries from post weld heat treat  
• Hydroxyacetic acid used for decontamination  
• Turco used for cleaning |

- Incorporated additional leak test and Built-in Test Equipment (BITE) resistance tests at T-24 and T-9 hr to verify FIV integrity for flight
- Endcap test port added for FIV leak check
Lesson on Unintended Consequences

• **Outcome**
  - Ultimately implemented single mission FIV on STS-105 (8-10-01)
  - Magnetically actuated switch
  - Non-flexing weldment separation of fluid and electrical cavities
  - Maintained key multi-mission FIV requirements
    - Envelope and interfaces
    - Power, transient suppression, and dual position switch feedback

• **Lessons Learned**
  - Full life cycle, including processing, needs consideration during design
Lesson on Unintended Consequences

• Topic
  – Role of SRB Photography and Imagery
  – Story
  – Photographic coverage of SRB descent and parachute deployment important at beginning of Shuttle Program
  • Provided by ship and aircraft
    – Redstone/Vandenberg ships and Starcast/Castglance aircraft
  • Discontinued after STS-35 (12-2-90)
  – STS-51A (11-8-84) first installed 16 mm camera into forward skirt dome to capture parachute deployment
  • Implemented permanently STS-36 (2-28-90)
  • Upgraded to Data Acquisition System (DAS) with video camera STS-72 (1-11-96)
    – Included recording accelerometers data
Lesson on Unintended Consequences

• Story (cont.)
  – Postflight photographs of off-nominal items taken since STS-26 (9-29-88)
    • Used for comparisons to build-up and previous missions photographs
    • Minimal photographic requirements established and controlled by engineering (10REQ-0033)
  – Additional photography during recovery from on-board observer initiated after STS-26 (9-29-88)
    • Enhancements throughout follow-on missions including
      – Both stills and video and improved equipment
      – Detailed guidelines and recommendations
      – Underwater observations during dives
Lesson on Unintended Consequences

• Story (cont.)
  – Second camera installed in forward skirt on STS-95 (10-29-98) to observe ET foam popcorning from intertank
    • Utilized for five flights
    • Permanently implemented on STS-114 (7-26-05)
  – STS-121 implemented two additional standard SRB cameras to evaluate ascent debris conditions
    • Forward skirt aft looking and ETA ring forward looking cameras
    • Refinements incorporated to improve camera settings and modify field of view
Lesson on Unintended Consequences

- Outcome
  - Learned capability of hardware
  - Expanded understanding of environments and associated variability from flight to flight
  - Allows flight specific evaluations to assess time of occurrence and debris hazards
  - Ultimately supports taking advantage of fact SRB recovered to improve designs and processing

- Lessons Learned
  - Picture = thousand words
  - Some Criticality 3 systems are really important
Lesson on Unintended Consequences

- It Doesn’t End There…
  - Evolution of Marshall Sprayable Ablative (MSA) to Marshall Convergent Coating (MCC)
  - Implementation of Command Receiver Decoder (CRD)
  - Frustum Linear Shaped Charge (LSC) Rotation
  - Integrated Electronics Assembly (IEA) Power Bus Isolation Supply (PBIS) Module Design Enhancement
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