Marshall Space Flight Center

Space Shuttle Knowledge Sharing Forum

Solid Rocket Booster
Lesson on Unintended Consequences

January 27, 2011

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Agenda

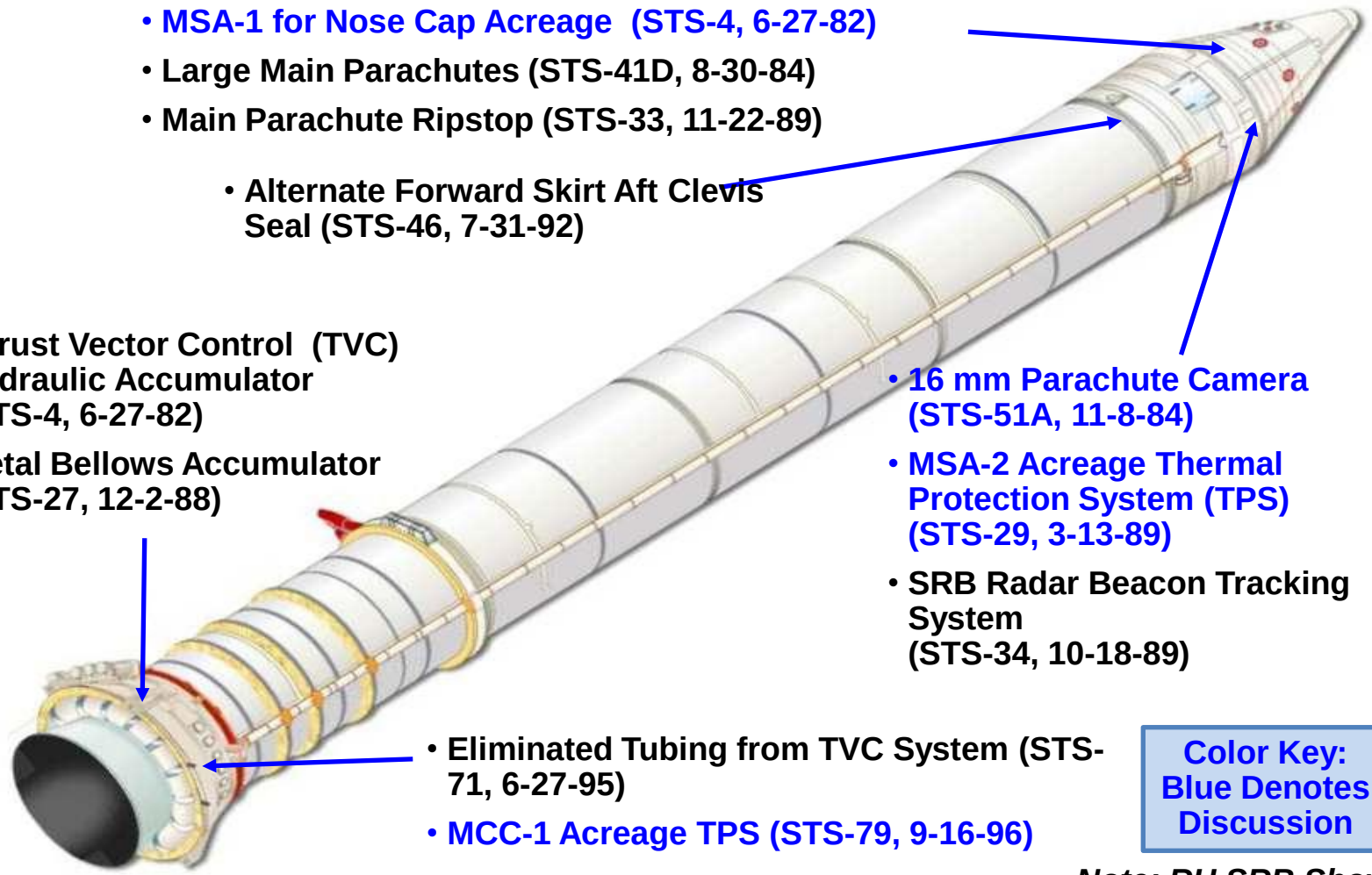
- SRB Full Flight Video
- Overview of Booster Evolution
- Lesson on Unintended Consequences
  - External Tank Attach (ETA) Ring Material Issue
  - Gas Generator Injector Stem O-ring X-ray Test
  - Evolution of Holddown Post (HDP) System
  - Evolution of Fuel Isolation Valve (FIV)
  - SRB Camera Systems

  …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

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)



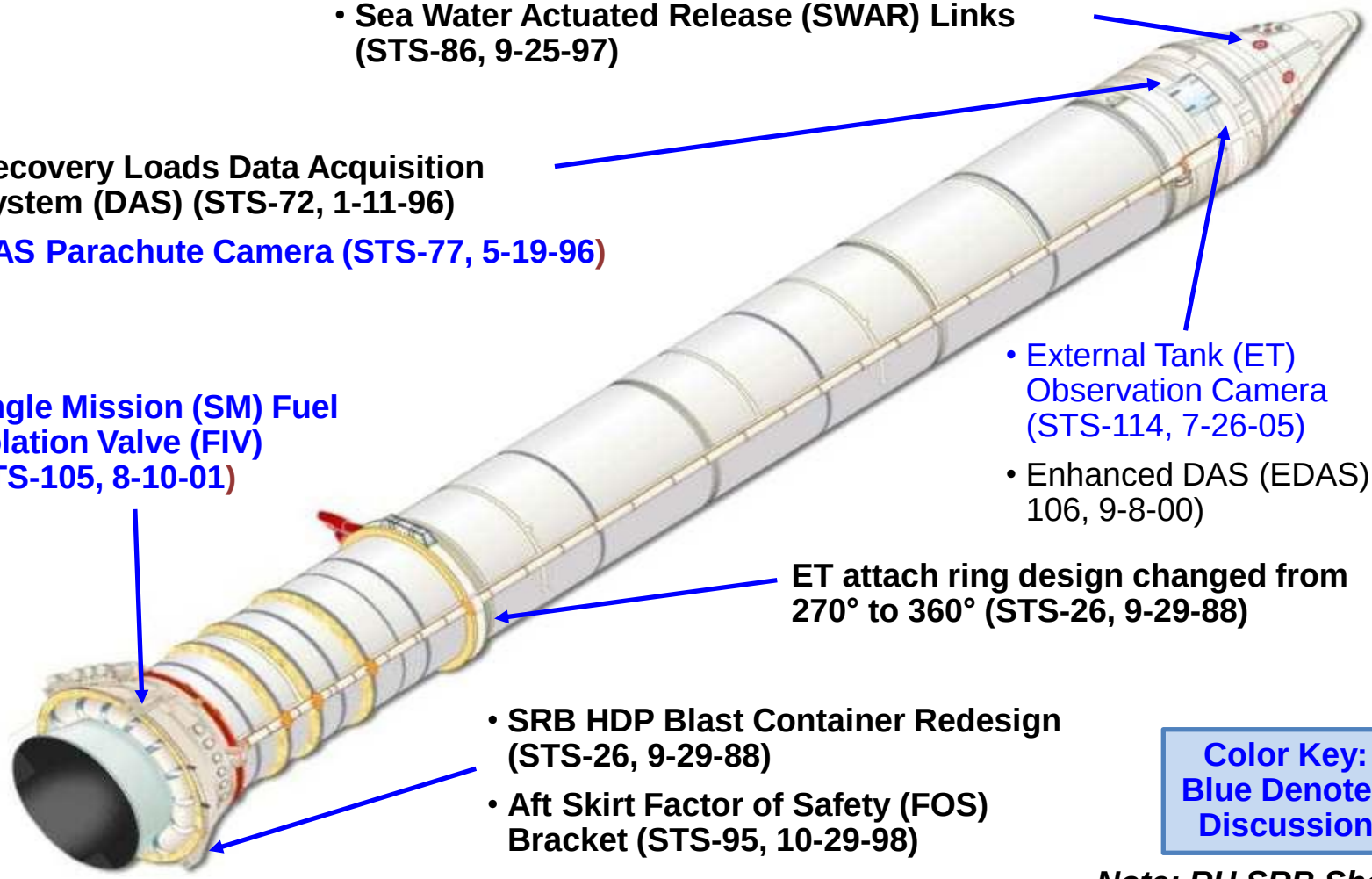
- Thrust Vector Control (TVC) Hydraulic Accumulator (STS-4, 6-27-82)
- Metal Bellows Accumulator (STS-27, 12-2-88)
- 16 mm Parachute Camera (STS-51A, 11-8-84)
- MSA-2 Acreage Thermal Protection System (TPS) (STS-29, 3-13-89)
- SRB Radar Beacon Tracking System (STS-34, 10-18-89)
- Eliminated Tubing from TVC System (STS-71, 6-27-95)
- MCC-1 Acreage TPS (STS-79, 9-16-96)

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)**
- External Tank (ET) Observation Camera (STS-114, 7-26-05)
- Enhanced DAS (EDAS) (STS-106, 9-8-00)
- **ET attach ring design changed from 270° to 360° (STS-26, 9-29-88)**
- **SRB HDP Blast Container Redesign (STS-26, 9-29-88)**
- **Aft Skirt Factor of Safety (FOS) Bracket (STS-95, 10-29-98)**



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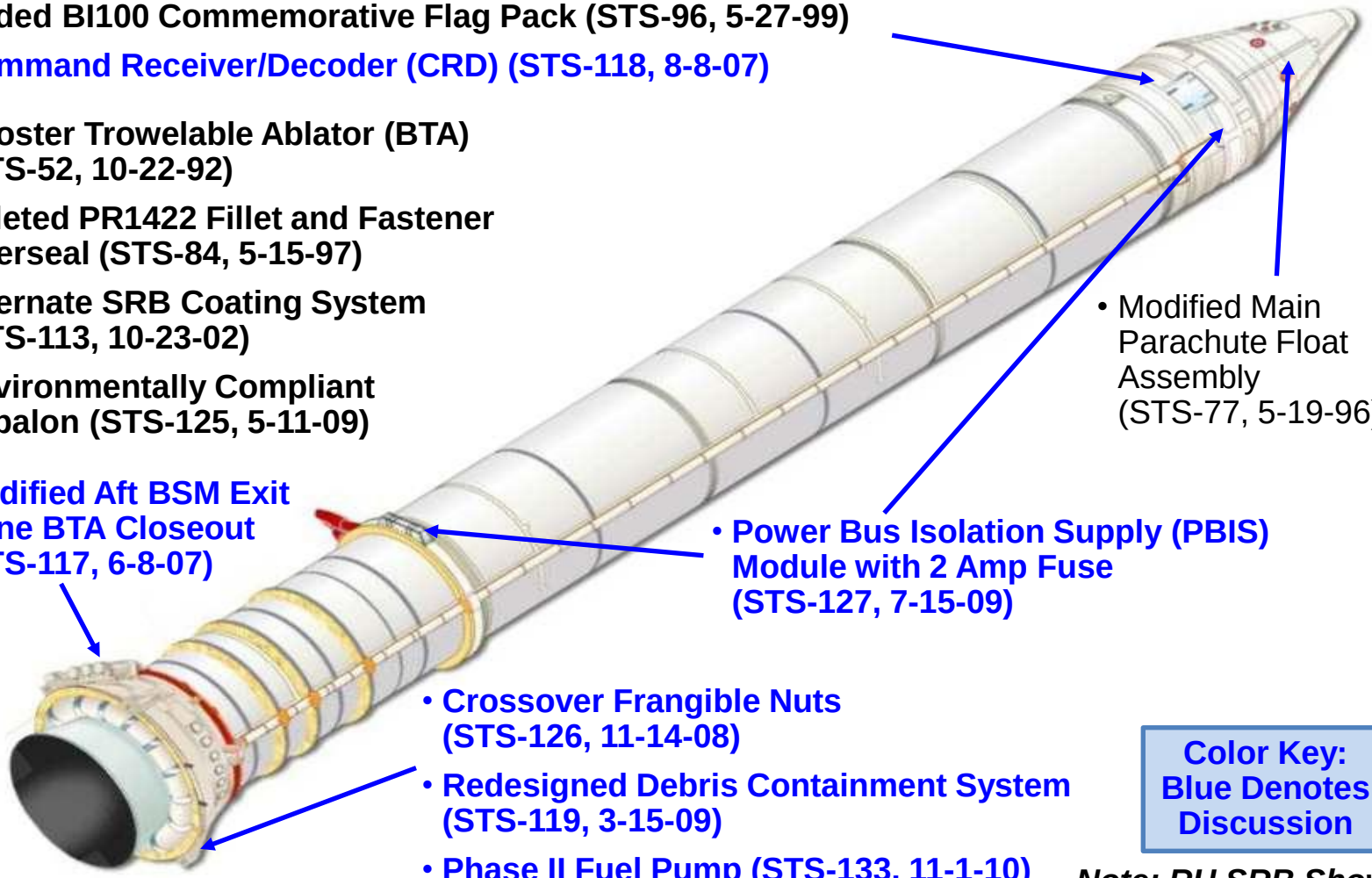
Note: RH SRB Shown

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)



- Modified Main Parachute Float Assembly (STS-77, 5-19-96)
- Power Bus Isolation Supply (PBIS) Module with 2 Amp Fuse (STS-127, 7-15-09)
- 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)

Color Key: Blue Denotes Discussion

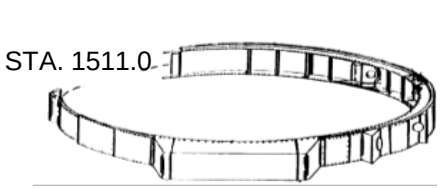
Note: RH SRB Shown

Lesson on Unintended Consequences

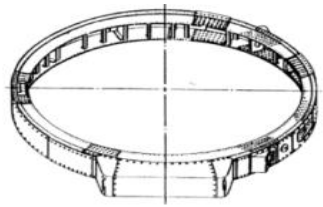
- Topic
  - External Tank Attach (ETA) ring material issue
- Story
  - Initial 4130 steel ETA ring spanned 270°
  - Redesigned ETA ring to 360° for STS-26
    - Modified existing hardware
    - Eliminated negative margins of safety during thrust build-up

ETA Ring Location

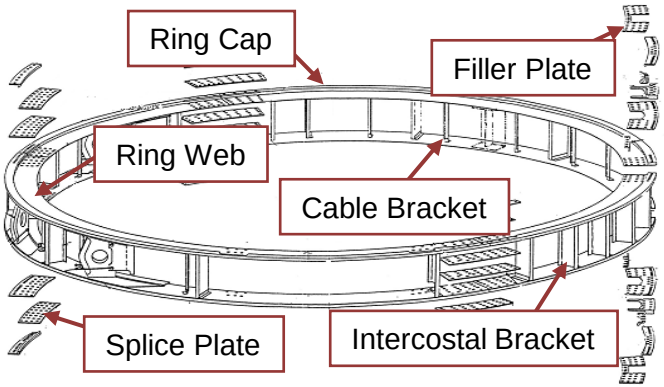
ETA Ring Buildup



270° ETA Ring



360° ETA Ring



360° ETA Ring Components

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

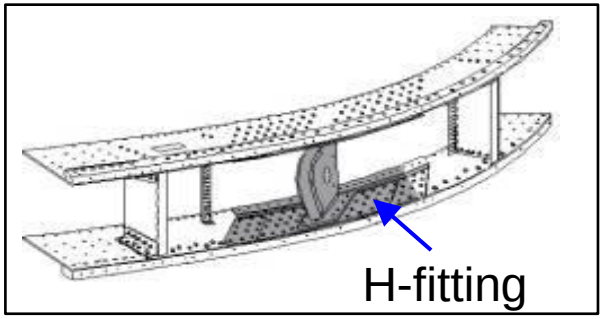
	ETA Ring Tensile Strength (ksi)	
	Yield	Ultimate
Test *	130-189	152-202
Requirement	163	180
* Performed on ETA Ring S/N 13		

  - 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

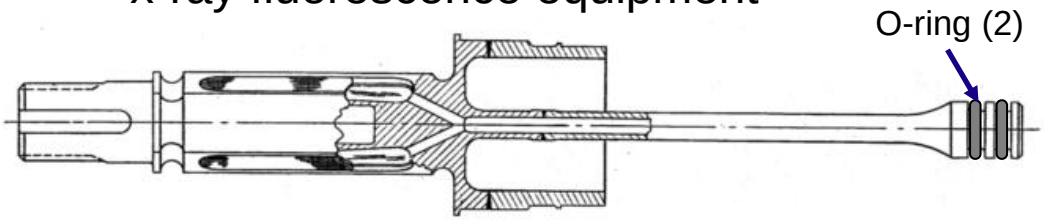
ETA Ring
Hardness Testing



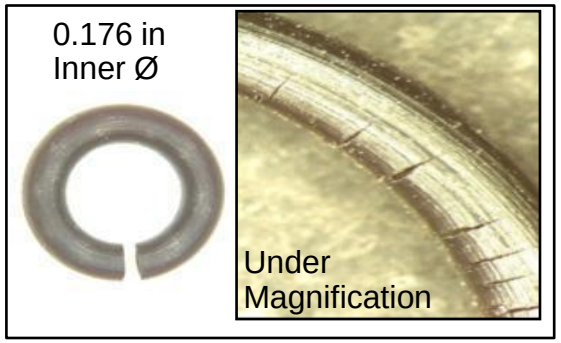
Ring Segment

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



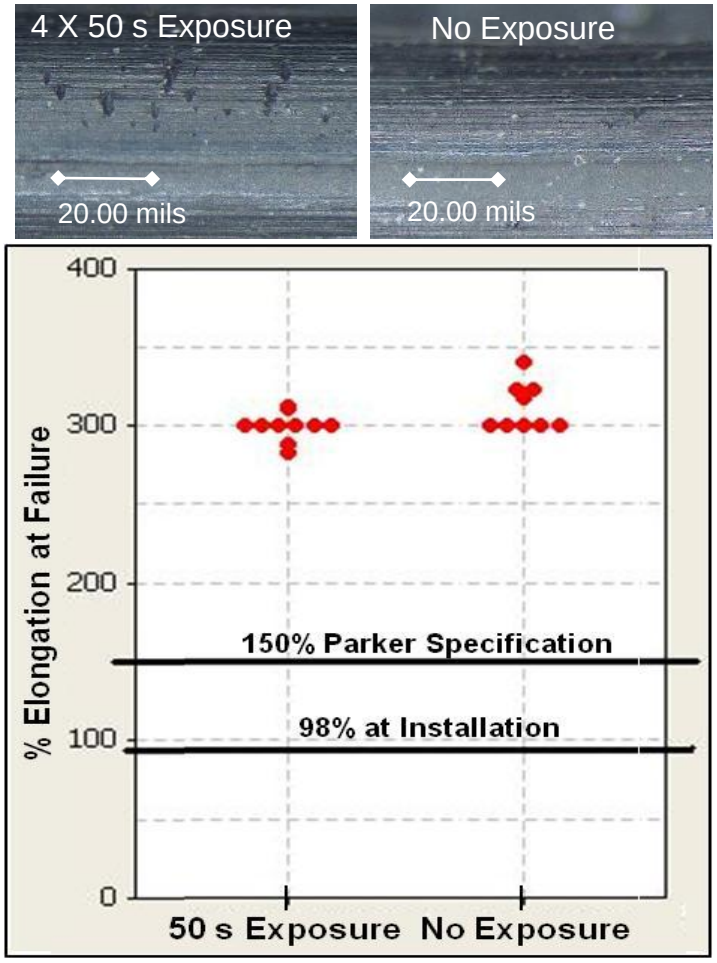
Gas Generator Injector Stem with O-Ring



Failed GG Stem O-ring

Lesson on Unintended Consequences

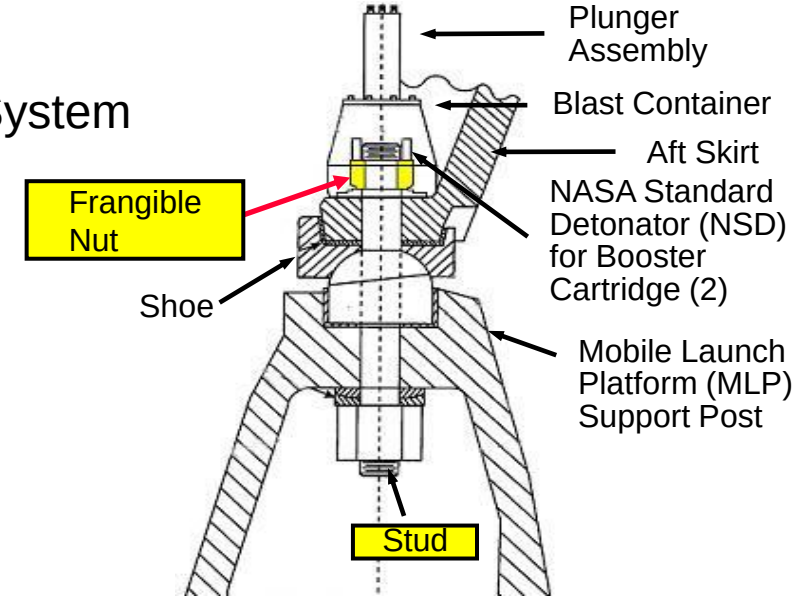
- Outcome
  - New equipment programmed to prevent o-ring degradation
    - Testing demonstrated proper material identification without unacceptable degradation
    - Analysis indicates new process exposure less than from original equipment
  - All suspect o-rings scrapped
  - Replacements tested with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



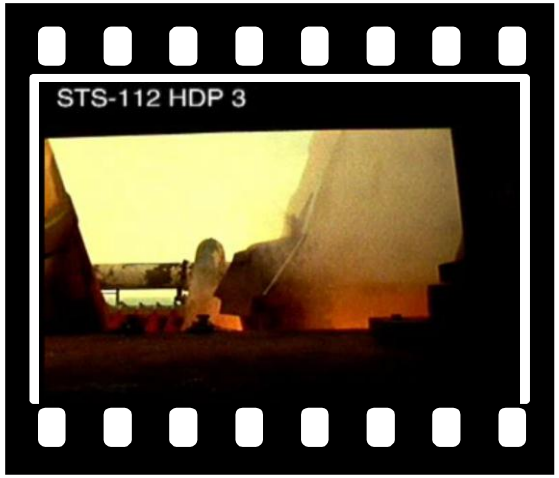
New X-ray Settings Evaluation

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

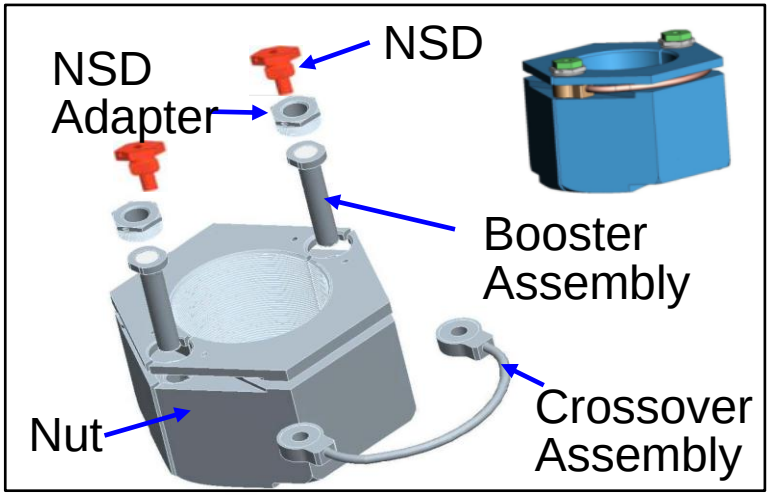


SRB Holddown Post Assembly



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

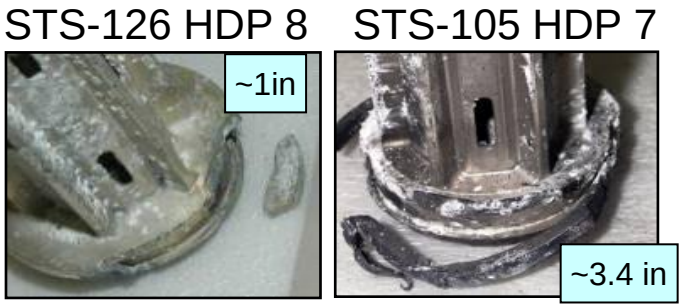


New Frangible Nut Design

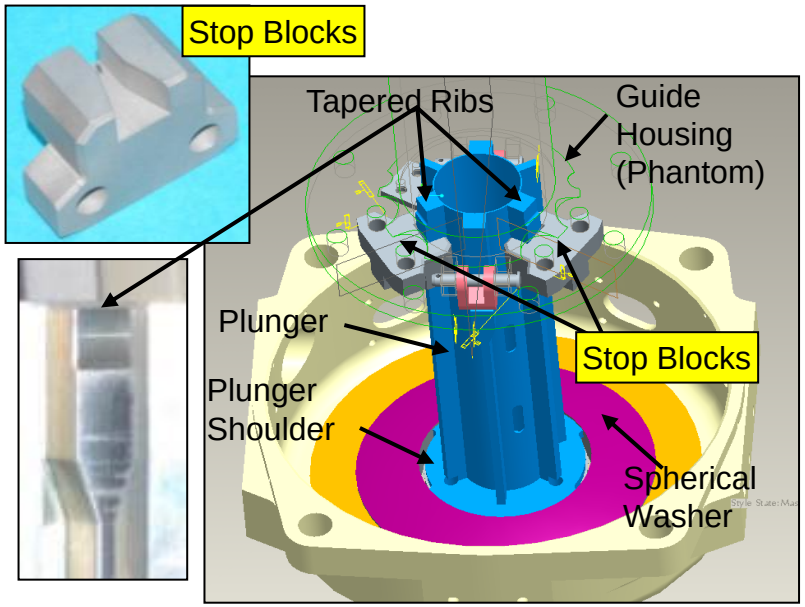
STS-126 Launch Video

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



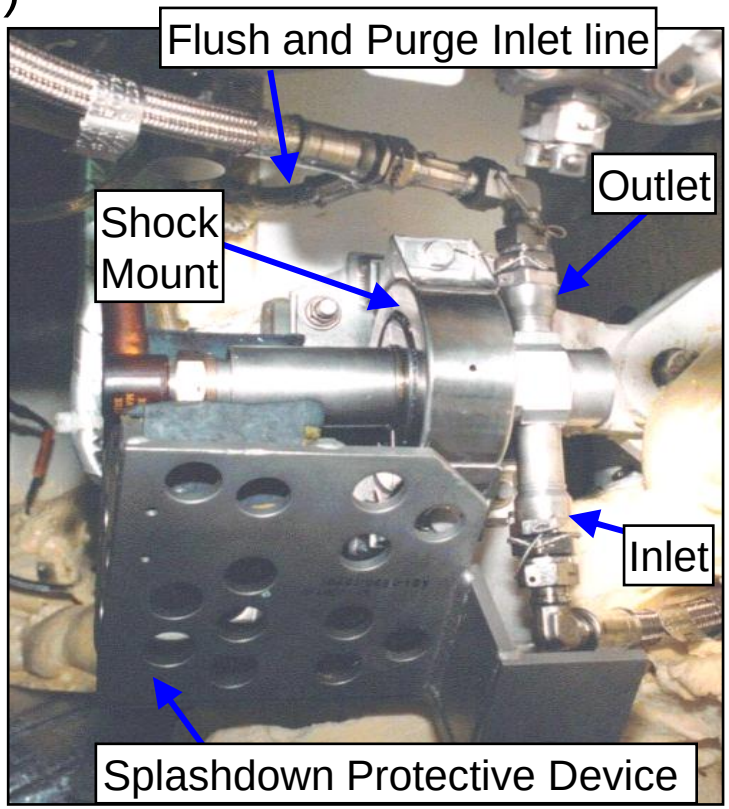
Example Plunger Damage



Modified DCS Configuration

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



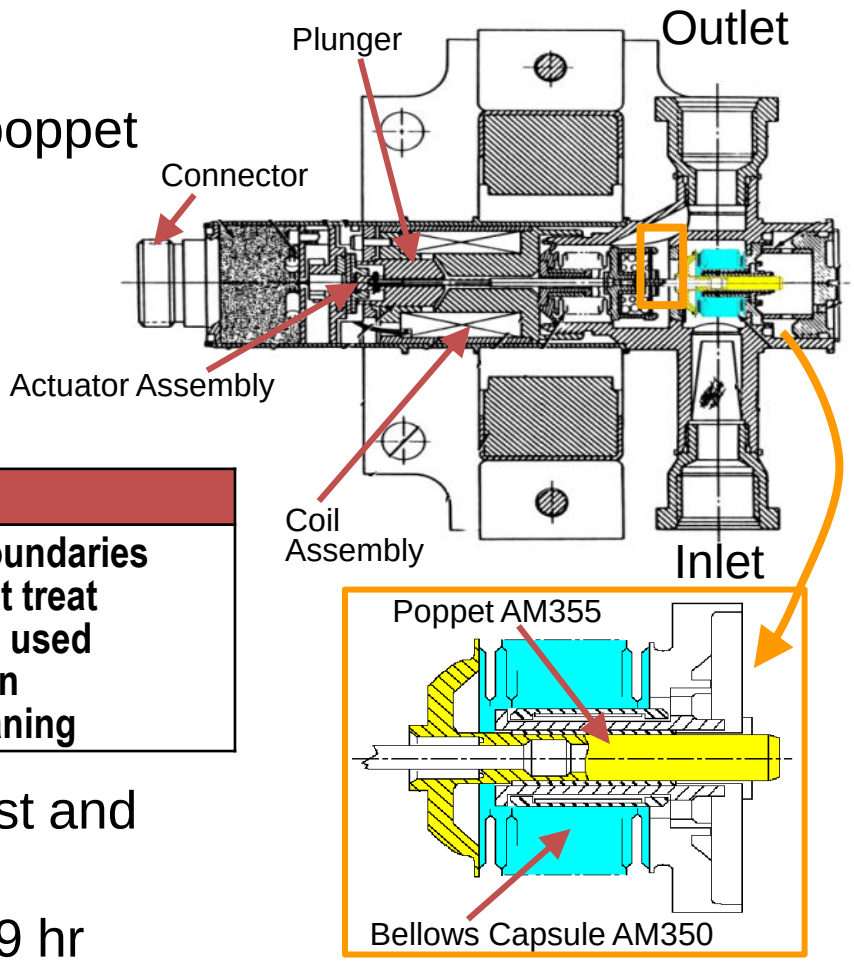
Multi-mission FIV

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

Root Cause	Notes
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

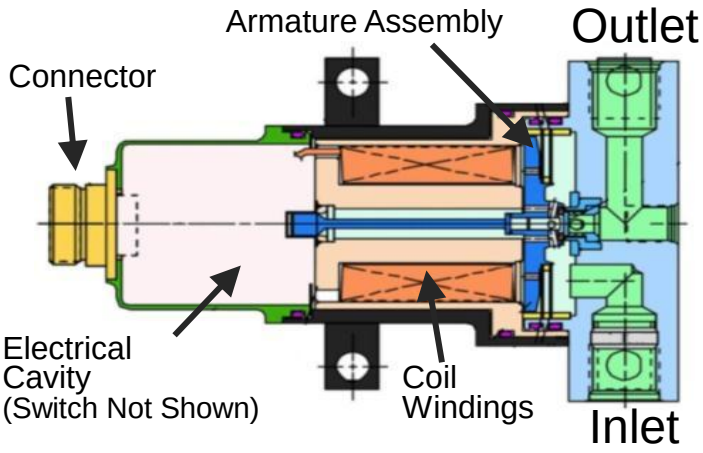
  - Incorporated additional leak test and Built-in Test Equipment (BITE) resistance tests at T-24 and T-9 hr to verify FIV integrity for flight
  - Endcap test port added for FIV leak check

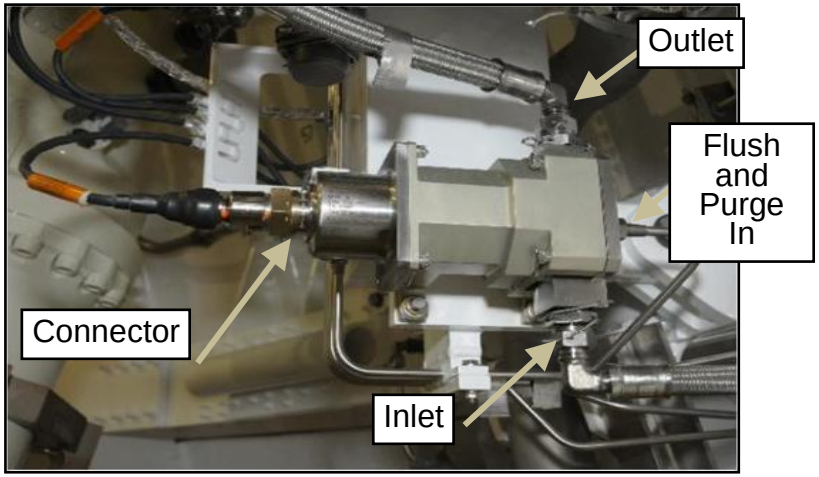


Multi-mission FIV

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

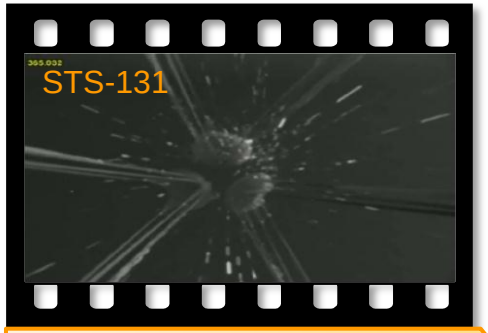




Single Mission FIV

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



STS-36
2-28-90

Lesson on Unintended Consequences

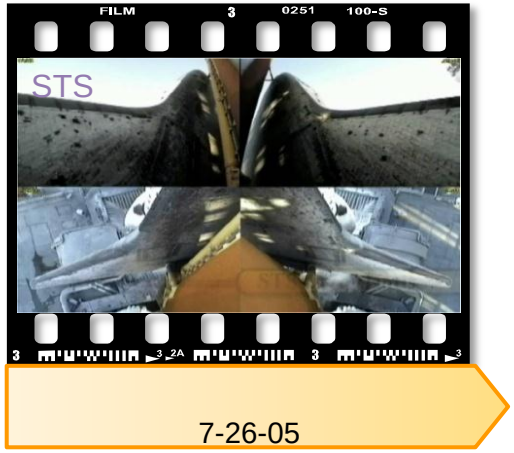
- Story (cont.)
  - Postflight photographs of off-nominal items taken since STS-26 (9-29-88)
    - Used for comparisons to build-up and previous missions photographs
    - Minimal photographic requirements established and controlled by engineering (10REQ-0033)
  - Additional photography during recovery 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

Aft Skirt Bluing
12-85-01

Recovery

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

Parachute Failure

Hypalon Off Gassing

Hardwater impact

BTA from Aft BSM Hits Orbiter

Dive Operations

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
  - Path to SRB Phase II Fuel Pumps