TR13030
CR00014200

SPACE SHUTTLE PROGRAM
Space Shuttle Propulsion Office (MSFC)
NASA Marshall Space Flight Center, Huntsville, Alabama

Reusable Solid Rocket Motor

STS-114 Flight Readiness Review/CoFR

Motor Set RSRM-92

29-30 June 2005

Presented by Terry Boardman

ATK THIOKOL

092-FRRK

Agenda

Flight Readiness Review/CoFR

1.0	Previous Flight/Test Assessment	To Be Presented
2.0	Configuration Inspection	
2.1	As-Built Versus As-Designed, Hardware and Closeout Photo Review Status	No Issues
2.2	Hardware Changes Since ET/SRB Mate Review	No Issues
3.0	Motor Set Summary	To Be Presented
4.0	Changes Since Previous Flight	To Be Presented
5.0	SMRB Nonconformances	No Issues
6.0	Technical Issues	To Be Presented
7.0	Special Topics	To Be Presented
8.0	Certification Status	To Be Presented
9.0	Readiness Assessment	To Be Presented
Backup	LCC and Contingency Temperatures for STS-114	

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Previous Flight/Test Assessment

1.0

Disassembly Evaluation Summary—Status of Disassembly Activity

Motor/Test	Completion Status	Remarks
STS-107 (RSRM-88)	August 2003	Nozzle flex boot separation (IFA STS-107-M-01)
FSM-10	December 2003	No issues
ETM-3 (Five segment)	May 2004	Margin test motor—no issues
FSM-11	December 2004	No issues
Aged Igniter Tests (2)	January 2005	20 year old igniter—20-year-old initiator—no issues
Aged Igniter Test	April 2005	15 year old igniter—20-year-old initiator—no issues
FVM-1 (RSRM-89 RH)	May 2005	No issues
Aged Igniter Test	June 2005	20 year old igniter—2-year-old initiator—no issues

* No constraints to STS-114 flight

Motor Set Summary

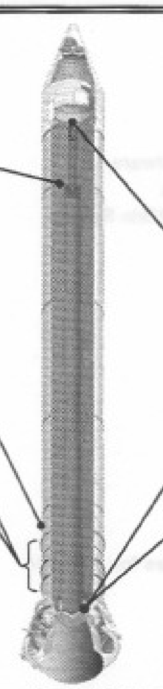
3.0

Items Previously Presented at STS-114 DCRs/DVR*

- Forward Segment Horizontal Storage and Transportation Negative Margin of Safety (Ref. RWW0551)
- Inactive Stiffener Stub TPS Redesign Due to Corrosion (Ref. ECP SRM-3760)
- Stiffener Ring Froth Pak/PDL Foam Verification (Ref. ECP SRM-3789)
- Stiffener Stub T-Ring Splice Plate RT455 Unbond (Ref. RWW0553)
- Debris Liberation/Impact Tolerance Verification

Project DCR:	26 Oct 2004
Systems DCR:	22 Feb 2005
Program DCR:	19 Apr 2005
Project Pre-FRR:	15 Jun 2005
Debris DVR:	24 Jun 2005

* Details not presented in this FRR. Detailed presentations provided in the DCR and RSRM Project CoFR process



Both Motors

Items to be Presented

Hardware Aging
Special Topic

STS-300 LON Readiness
Special Topic

Implement New Stellar OPT
(Ref. ECP SRM-3553R1)
Change

Corrosion on Nozzle Joint No. 5 Socket Head Cap Screws (Ref. PR SB-BI124-0020, PR AB-BI125-0002)
Technical Issue

Nozzle Flex Boot Separation
(Ref. IFA STS-107-M-01, PRACA DRD4-5/338)
Technical Issue

Changes Since Previous Flight

4.0

ECP SRM-3553R1, New Stellar Technologies, Inc. (STI) Operational Pressure Transducer (OPT) Installation
Criticality: 1
Status: Approved per CCBD 5693 on 30 May 2002

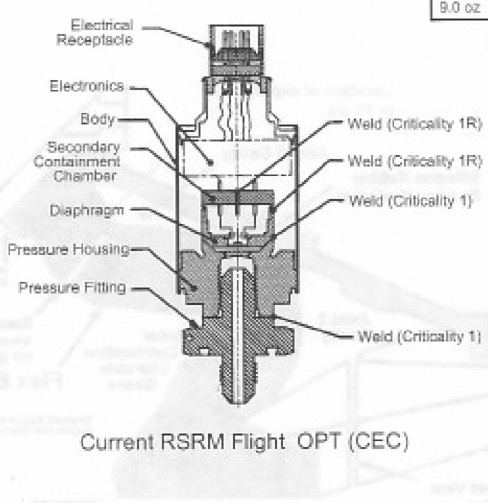
Change Description	Reason for Change	Basis of Verification
Implement new STI OPT in 180-deg location of the igniter Two Consolidated Electronic Control (CEC) OPTs will continue to be used at 40-deg and 270-deg locations Note: OPTs provide cue for booster separation and collect data for ballistics reconstruction	Obsolescence issue CEC OPTs have not been available since 1989. The STI OPT has been developed to replace the CEC OPT Eliminates Criticality 1 welds	Test: CTP and ETP testing* successfully completed for vibration and electrical testing, over-pressure testing, electromagnetic compatibility testing, ballistics evaluation, and KSC on-motor demonstration Qualification: STI OPT successfully qualified on FSM-8 Demonstration: STI OPT successfully demonstrated on FSM-9, ETM-2, FSM-10, ETM-3, and FSM-11 STS-114 and subsequent are safe to fly

Changes Since Previous Flight

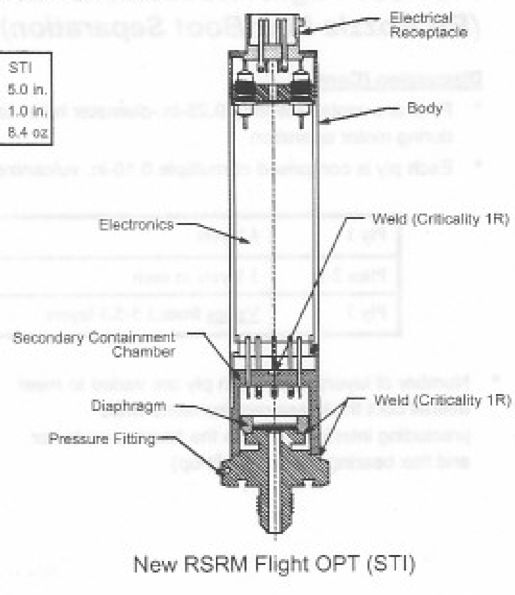
4.0

ECP SRM-3553R1, New Stellar Technologies, Inc. (STI) OPT Installation (Cont)

CEC		STI
3.75 in.	Length	5.0 in.
1.37 in.	Diameter	1.0 in.
9.0 oz	Weight	8.4 oz



Current RSRM Flight OPT (CEC)



New RSRM Flight OPT (STI)

Technical Issues

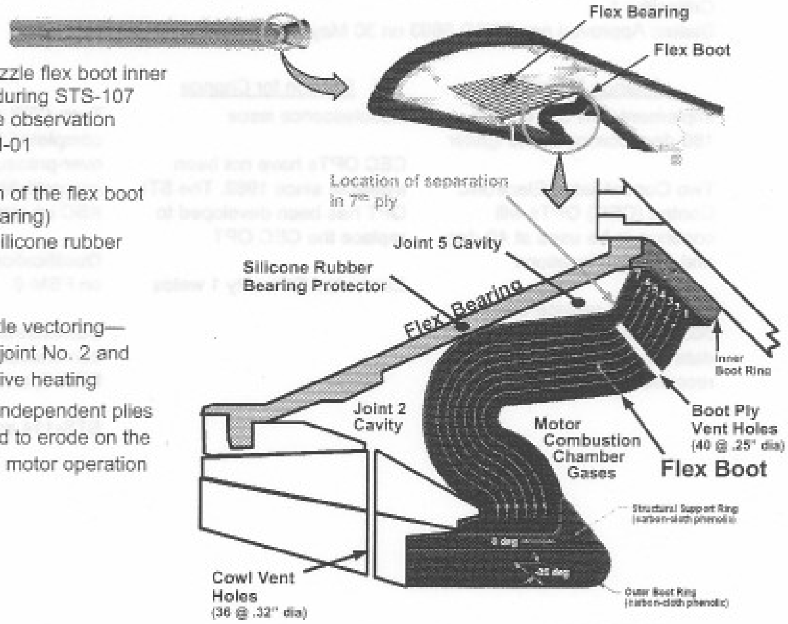
In-Flight Anomaly (IFA) STS-107-M-01 (RH Nozzle Flex Boot Separation)

Observation

- A 57-in. separation of the RH nozzle flex boot inner (seventh) rubber ply was noted during STS-107 postflight disassembly—first-time observation
  - Elevated to IFA STS-107-M-01 (20 Feb 2004 PRCB)
- Separation did not affect function of the flex boot (thermal protection of the flex bearing)
  - No heat affect to adjacent silicone rubber bearing protector

Discussion

- Rubber boot "flexes" during nozzle vectoring—protects flex bearing and nozzle joint No. 2 and No. 5 from convective and radiative heating
- The boot is comprised of seven independent plies of rubber—the rubber is designed to erode on the combustion chamber side during motor operation



Technical Issues

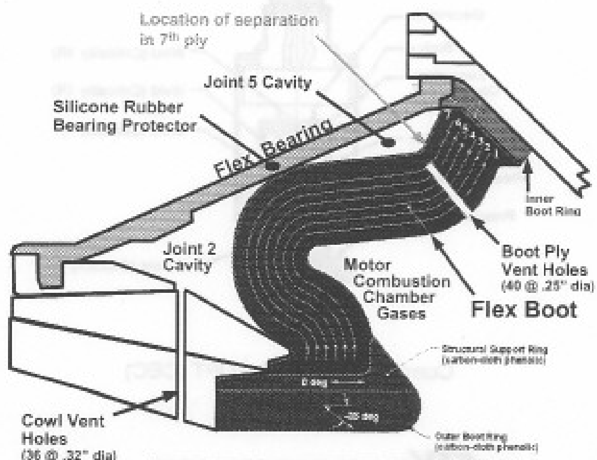
Previous Flight Assessment—In-Flight Anomaly (IFA) STS-107-M-01 *(RH Nozzle Flex Boot Separation)*

Discussion (Cont)

- Plies are vented via forty 0.25-in.-diameter holes to reduce stiffness of boot during motor operation
- Each ply is comprised of multiple 0.10-in. vulcanized layers

Ply 1	4 layers
Plies 2-6	3 layers in each
Ply 7	Varies from 3.5-5.5 layers

- Number of layers in seventh ply are varied to meet overall boot thickness requirements while precluding interference with the bearing protector and flex bearing (assembly fit-up)



Technical Issues

6.0

Previous Flight Assessment—In-Flight Anomaly (IFA) STS-107-M-01 *(RH Nozzle Flex Boot Separation)*

Discussion (Cont)

- Fault tree approach used to guide investigation
- Cause understood—localized thermal degradation of seventh ply during motor operation *coupled* with end-of-motor operation depressurization strain loading (strain loading also occurs at splashdown) *and* a thinner than normal seventh ply
- Special cause factor associated with STS-107 RH boot—seventh ply was thinner than normal (one of only two 3.5-layer seventh ply boots flown—STS-113 seventh ply did not separate)
- All remaining boots in inventory have four or more layers in the seventh ply
  - No four-layer boots have exhibited a seventh ply separation *(includes eight flown and two static tested)—static testing includes recent ETM-3 margin test*
  - RSRM-89 RH boot with four layers in seventh ply did not exhibit separation in FVM-1 static test
  - STS-114 RH (RSRM-92B) has the only remaining four layer seventh ply boot that will fly

Technical Issues

6.0

Previous Flight Assessment—In-Flight Anomaly (IFA) STS-107-M-01 *(RH Nozzle Flex Boot Separation)*

Flight Rationale

- Cause of STS-107 RH flex boot separation is understood
  - Thinner than normal seventh ply (3.5 layers) was locally degraded by slag heating
  - Thermal degradation increases with time—failure not possible early in burn
  - Mechanical loading conditions for separation can occur only at motor depressurization or splashdown
- No separations have been noted in boots with four or more layers in seventh ply—all remaining flight inventory boots have four or more layers in seventh ply
  - STS-114 RH (RSRM-92B) has the only remaining four layer seventh ply boot that will fly
- Bounding thermal analyses with slag heating inside boot cavity for entire burn duration show positive thermal margins at joint No. 2 and No. 5 primary seals
- Separation of the inner boot ply in STS-114 and subsequent is not expected
  - If a separation did occur, it would happen during motor depressurization, or at splashdown—flight safety would not be compromised
- STS-114 and subsequent are safe to fly

Review/Concurrence

- IRT, ITA, CAIB, NESC, Chief Engineers Council, SSRP, PRCB (closed 03/18/04), Project DCR, Systems DCR

Technical Issues

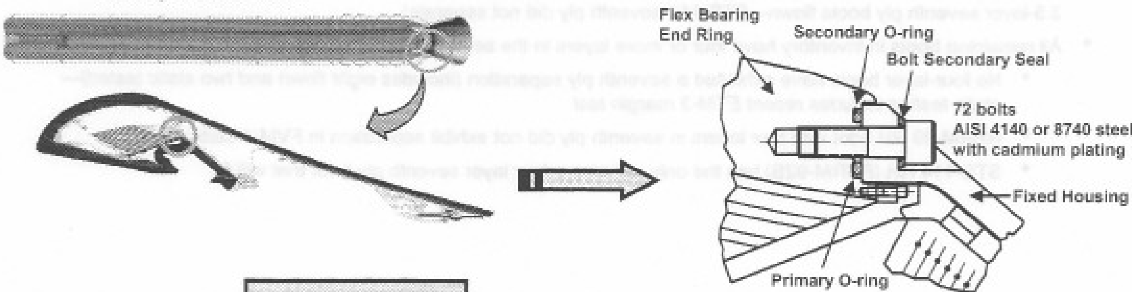
Nozzle Joint No. 5 Bolt Corrosion

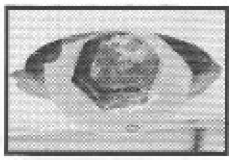
Observation

- PRs AB-BI125-0002 [STS-114 (RSRM-92)] and SB-BI124-0020 [STS-121 (RSRM-90)] have been written against four RSRM nozzles for corrosion on the nozzle joint No. 5 bolts. Corrosion is in the head-wrenching element

Concern

- Corrosion of high-strength steel raises a concern for degradation of bolt capability due to net section loss and/or environmentally-assisted cracking (stress corrosion cracking or hydrogen embrittlement) and subsequent bolt failure





Example of heavy corrosion in Joint No.5 bolt head wrenching element

Technical Issues

Nozzle Joint No. 5 Bolt Corrosion (Cont)

Background

- Mapping of STS-114 (RSRM-92) and STS-121 (RSRM-90) joint No. 5 bolt corrosion over visible 180-deg arc showed 20-to-80 percent of bolts corroded
- Approximately half of corroded bolts characterized as having medium corrosion with approximately equal numbers characterized as having heavy or light corrosion

Discussion

- Bolt corrosion investigation evaluated all potential corrosion-induced failure modes:

  Failure due to reduction of bolt cross-section resulting from general corrosion — No Concern
  - NASA corrosion study (MTB 099-74) conducted wherein AISI 4130 steel panels were placed at various distances from beach for one year and weight loss assessed
    - 100 feet from beach = lost 17 grams 2500 feet from beach = lost 6.6 grams
    - Using conservative coupon weight loss of 7 grams/year based on RSRM hardware location/environment equates to a surface loss of 1.1 mils/year
  - Beach testing loss rate indicates bolts will not fail due to cross-section reduction over a 5-year period at KSC in RPSF or VAB environments

  Failure due to hydrogen embrittlement (HE) — No Concern
  - Testing exposed notched bolt specimens to saltwater at pH of 4.0 while loaded to 100 percent of yield followed by incremental step loading to failure (ASTM F1624)
    - Normal pH environment for bolts is approximately 6
    - pH of 4.0 represents a bounding case for HE mechanism
  - No reduction of notched tensile strength noted relative to baseline—no evidence of HE

Technical Issues

6.0

Nozzle Joint No. 5 Bolt Corrosion (Cont)

<u>Discussion (Cont)</u>

<u>Failure due to stress corrosion cracking (SCC)</u> — **No Concern**

- NASA testing of various steel alloys in severe seacoast environment showed no SCC failures below 100 percent of yield stress for loading direction parallel to grain flow
  - Out of 34 specimens tested, only one failed with 14 months of exposure at 100 percent of yield loading
- Bolts have low stress at corner of wrenching elements (20-to-40 percent of yield)—principle stress is aligned with grain flow direction
- Vendors report no corrosion related failures in bolt-wrenching elements
- Metallurgical testing and evaluation of 15 FVM-1 bolts exposed to two years of KSC environment found no SCC or forging cracks (same vendor lots)

<u>Interaction of failure modes assessed</u> — **No Concern**

- No plausible interactions were identified

- No bolt failures have ever been observed postflight
  - Postflight environment puts bolts through a severe environment (alternate wet dry in seawater) with the bolt under preload
- Vendor process controls minimize potential for grain flaws due to bolt manufacturing process
  - Visual examination of dissected bolt with macro etch is performed to minimize occurrence of flaws
  - Stress durability test performed to verify no effects from HE during plating
  - 100-percent magnetic particle inspection for flaws

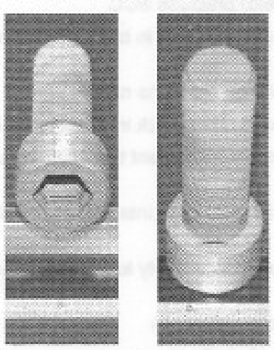
Technical Issues

6.0

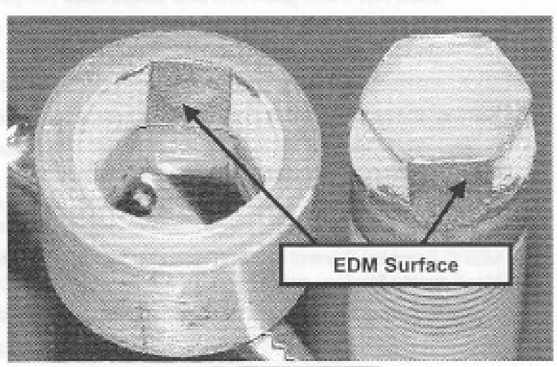
Nozzle Joint No. 5 Bolt Corrosion (Cont)

<u>Discussion (Cont)</u>

- Residual capability test, simulating a crack completely through one of six bolt-wrenching element plains, showed bolt heads to be fault tolerant
  - Electron discharge machined (EDM) flaw at the bottom of the socket head to the head/shank radius—approximately 0.35 in. wide by 0.3 in. deep
  - Four bolts pulled to failure and all bolts broke in the head at loads greater than 70 kips—minimum specification limit is 63 kips, maximum preload is 54 kips



EDM Notched Bolt



Failed Bolt

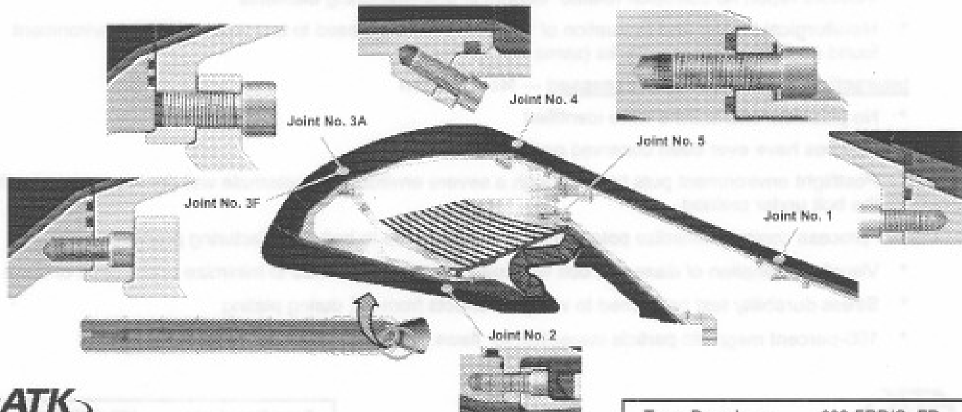
Technical Issues

6.0

Nozzle Joint No. 5 Bolt Corrosion (Cont)

Discussion (Cont)

- All nozzle joints are fault tolerant with respect to bolt failure
  - Compressive operational loads are carried across nozzle joints
  - Joint No. 5 seal tracking ability assured with a pattern of three bolts out—one bolt in
- Joint No. 5 represents bounding case for nozzle joint Nos. 1, 3F, 3A, and 4 which use bolts of the same material
  - Joint No. 5 is the only opening joint
  - Only joint in which bolt stress increases during motor operation
  - Only joint with a secondary seal provided by packing-with-retainer



Technical Issues

6.0

Nozzle Joint No. 5 Bolt Corrosion (Cont)

Flight Rationale

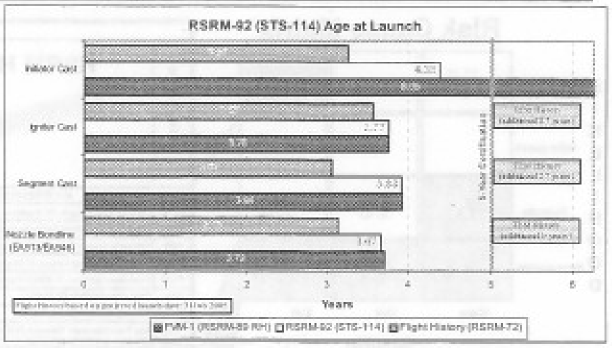
- Corrosion condition evident on joint No. 5 bolts is bounded by both beach test data and exposure to laboratory induced low pH environments
  - No evidence of SCC in severe beach environment specimens with similar grain orientation and loading levels set near 100 percent of yield strength
  - No evidence of SCC in laboratory bolt specimens at pH levels as low as 4.0—step loaded to failure
  - Joint No. 5 bolt grain flow and stress state (40 percent of yield) preclude SCC
  - Worst-case loss rate of bolt cross-section due to corrosion will not result in bolt failure over 5-year period in KSC storage/assembly environment
  - Interaction of potential failure modes has been assessed with no concerns noted
- Testing shows bolt minimum strength requirement met with simulated large crack in wrenching element
- Vendor production set-up testing, subsequent in-process testing, and 100-percent bolt NDE ensure low probability of bolts escaping with pre-existing flaws
- If multiple bolts were flawed and exhibited SCC, joint No. 5 will retain structural integrity and seal tracking capability—all other nozzle joints are bounded by this behavior
- MSFC Fracture Control Board (FCB) concurs that joint No. 5 corrosion is unlikely to cause SCC and that joint No. 5 meets fracture control criteria due to fault tolerance
- There are no adverse interactions with MRB, changes, or other technical issues
- STS-114 (RSRM-92), STS-121 (RSRM-90), and subsequent are safe to fly

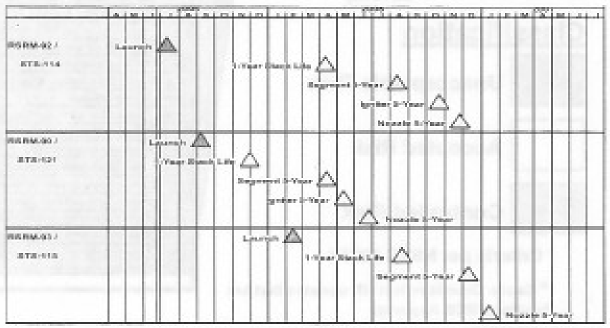
Special Topics

7.0

Hardware Aging

- The age of the STS-114 (RSRM-92) hardware exceeds previous flight history by roughly one year—*hardware remains within 5-year age life certification*
  - Hardware certification basis reviewed/scrubbed—no issues, *certification includes static test of up to 8-year-old SRM motors*
  - Archived RSRM-92 witness panels and material samples tested with no issues
  - Sister RSRM of similar age static tested 17 Feb 2005 (FVM-1)—hardware in excellent condition, performance as expected
- STS-114 (RSRM-92) RSRMs are ready for flight
- STS-121/300 (RSRM-90) RSRMs ready to support
- Review/concurrence: MSFC Hardware Aging TIM (03/04), Project DCR, Systems DCR





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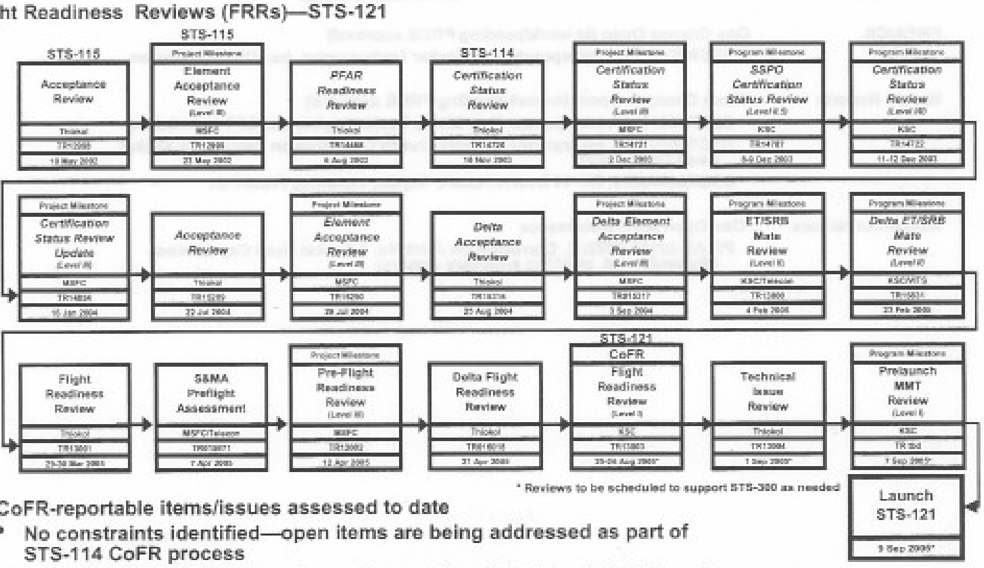
Special Topics

7.0

STS-300 Launch on Need (LON) Crew Rescue Mission Readiness

- Flight Readiness Reviews (FRRs)—STS-121



- All CoFR-reportable items/issues assessed to date
  - No constraints identified—open items are being addressed as part of STS-114 CoFR process
- Pending satisfactory completion of normal operations flow (per OMRSD) and any open items identified, the RSRM-90 hardware is ready to support flight of STS-300 if required

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RSRM Hazard Report Risk Summary

7.0

Risk Cause Matrix*

LIKELIHOOD	Marg.	Crit.	Cat.
Probable	**5		
Infrequent			
Remote	6	10	**24
Improbable	**14	17	**959

Severity

Classification

- Unacceptable Risk
- Accepted Risk
- Controlled Risk

* Criteria per NSTS 22254

** Cause Counts reflect HR updates that are Pending PRCB Approval

RSRM Hazard Reports

Hazard Report #		Controlled: Remote-Marginal	Controlled: Improbable-Marginal	Controlled: Improbable-Critical	Controlled: Improbable-Catastrophic	Accepted Risk: Probable-Marginal	Accepted Risk: Infrequent-Marginal	Accepted Risk: Remote-Critical	Accepted Risk: Remote-Catastrophic	Accepted Risk: Probable-Critical	Accepted Risk: Infrequent-Critical	Accepted Risk: Infrequent-Catastrophic
ACCEPTED RISK HAZARD REPORTS (10)												
BC04	Loss Of Seal Integrity Of Nozzle-to-Case Joint	3	6	0	57	0	0	10	0	0	0	0
BC07	Failure Of Propellant To Ignite Or Excessive Ignition Delay	0	6	0	7	0	0	0	1	0	0	0
BI02	Failure Of Igniter To Ignite Or Ignition Delay	0	0	0	85	0	0	0	1	0	0	0
BN04	Structural/thermal Failure Of Nozzle/AEC Metal/Phenolic Components	0	0	0	62	0	0	0	2	0	0	0
FC01	Premature Ignition Of RSRM Propellant	0	0	0	7	0	0	0	5	0	0	0
FI01	Premature Ignition Of Igniter	0	3	0	31	0	0	0	4	0	0	0
**BC11	Primary and Secondary Debris	0	2	0	22	5	0	0	7	0	0	0
**BN02	Gas Path Develops Through AEC-to-Forward Exit Cone Joint	0	2	0	61	0	0	0	1	0	0	0
**BN03	Gas Path Develops Through Internal Joint	0	3	0	96	0	0	0	2	0	0	0
**BN05	Compliance Ring Assembly, Actuator Bracket Assy, AEC Shell Failure	0	0	0	11	0	0	0	1	0	0	0
CONTROLLED HAZARD REPORTS (14)												
BC01	Failure of Field Joints	2	5	16	80	0	0	0	0	0	0	0
BC02	Failure of Factory Joints	6	3	0	27	0	0	0	0	0	0	0
BC03	Loss of Seal Integrity of Igniter-to-Case Joint	6	3	0	25	0	0	0	0	0	0	0
BC06	Propellant Failures	5	3	0	14	0	0	0	0	0	0	0
BC09	Failure of Case Membrane To Contain Internal Motor Pressure	2	3	0	26	0	0	0	0	0	0	0
BC10	Failure of RSRM Internal Insulation	6	3	0	45	0	0	0	0	0	0	0
**BI01	Structural Failure of Igniter	1	3	0	76	0	0	0	0	0	0	0
BI02	Loss of Igniter Sealing Function	0	3	0	105	0	0	0	0	0	0	0
BI03	Thermal Failure of Igniter Components	0	0	0	34	0	0	0	0	0	0	0
BN01	Premature Separation of the Nozzle Aft Exit Cone	2	3	0	8	0	0	0	0	0	0	0
BN06	Structural/Thermal Failure of Flex Bearing and Bearing Protector	5	0	0	26	0	0	0	0	0	0	0
FC02	Structural Failure of RSRM as Load Bearing Member	0	0	0	7	0	0	0	0	0	0	0
[illegible]	Failure of [illegible] To Protect Propellant Grain From An Ext. Ign Source	0	0	0	11	0	0	0	0	0	0	0
**SE01	Premature Separation of SRMs	0	0	0	0	0	0	0	0	0	0	0
		TOTAL = 996				TOTAL = 39						

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Certification Status

8.0

Category	Description/(Status)	Constraint to Launch
FMEA/CIL	One Change Open (in-work/pending PRCB approval)	
	SSCR00017648, Incorporate New Stellar Technologies, Inc. OPT Installation	Yes
Hazard Reports	Three Changes Open (in-work/pending PRCB approval)	
	SSCR00017717, Incorporate New Stellar Technologies, Inc. OPT Installation	Yes
	SSCR00040017, Incorporate Updates Due to Corrosion on Joint No. 5 Socket Head Cap Screws	Yes
	SSCR00040002, BC-11 Debris Hazard Report, Including Froth-Pak	Yes
Nonconformances	One Open Nonconformance	
	PR AB-BI125-0002(1), Corrosion on Joint No. 5 Socket Head Cap Screws (dispositioned, awaiting summary closure)	Yes

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Space Shuttle Program

<u>STS-114 Readiness Assessment</u>

Pending satisfactory completion of normal operations flow (per OMRSD) and any open items identified for this review, the RSRM hardware is ready to support flight for mission STS-114

29-30 June 2005

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