Volume V
Appendix G.4

Group 1 Matrix Brief on Maintenance, Material, and Management

This Appendix contains a working matrix of slides on maintenance, material, and management. These slides were used by Group I in tasking NASA to respond to requests for information or specific issues. Each matrix subject addresses an action/issue, background/facts, findings, recommendations and source documentation. By using this tool, Group I was able to engage NASA on potential final report inclusions.

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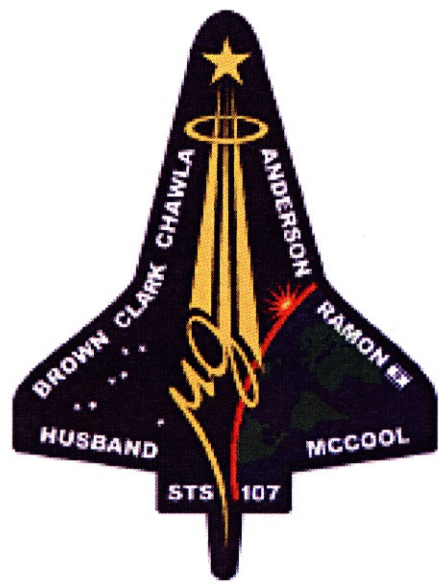
Group 1

INVESTIGATION MATRIX



Print Presentation

Group 1 Investigation Matrix

	E/T Foam	RCC	Tile	Orbiter	Other	Organization	Contract
Design / Certification	1 (3)	5 (3)	10 (1)	13 (1)	18 (1)		28 (1)
Production	2 (4)	6 (1)			19 (4)	24 (3)	29 (4)
Mission Life		7 (1)					
Fleet Experience / Aging		8 (4)	11 (5)	14 (7)	20 (2)	25 (3)	
Maintenance	3 (2)	9 (4)	12 (1)	15 (5)	21 (1)	26 (3)	30 (3)
Launch / Ascent	4 (5)			16 (3)	22 (7)		
Orbit					23 (1)	27 (3)	
Entry				17 (3)			

Reset Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	2 of 32

ET – Foam
Design – Certification

1-1 ET Bipod Ramp Redesign

1-2 Geometry of LH2-IT Flange

1-3 Super Lightweight Tank Design Change

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	3 of 32

ET – Foam
Design – Certification

- **Action / Issue:** Redesign of Bipod Fitting Enclosure
- **Background / Facts:**
  - Complex bipod attachment designed to be structurally optimal
    - TPS materials (incl. foam ramp) were incorporated into the design following structural optimization
  - Foam & SLA must be applied to a complex geometry
  - Combination of complex geometry and variable foam spraying techniques make current bipod foam ramp fabrication difficult
    - Only 6 spray operators are trained for foam application in this area
  - Bipod foam ramp has been redesigned twice in past
  - Foam from bipod ramp lost during ascent on at least 7 occasions:
    - STS-7 (ET-6), STS-32 (ET-32R), STS-50 (ET-50), STS-52 (ET-55), STS-62 (ET-62), STS-112 (ET-115), STS-107 (ET-93)

Presenter	M3/Material	Date	FINAL	Slide	1 of 12	Closed

ET – Foam
Design – Certification

- **Findings:**
  - Bipod fitting enclosure redesign efforts are already underway
    - Effort was initiated after loss bipod ramp foam on STS-112
  - Lessons learned indicate use of SLA is not necessary
  - Five designs proposed
    - All eliminate SLA
    - Two minimize size of sprayed-on foam ramp with metal (Ti) fitting
    - One uses a bare metal (Ti) fitting
    - Two use an Inconel housing to protect the metal fitting
  - Leading candidate (2a) is a bare metal fitting with no foam
  - Preliminary Design Review scheduled for 17-19 Jun 03
  - Critical Design Review planned for ~15 July 03

Presenter	M3/Material	Date	FINAL	Slide	2 of 12	Closed

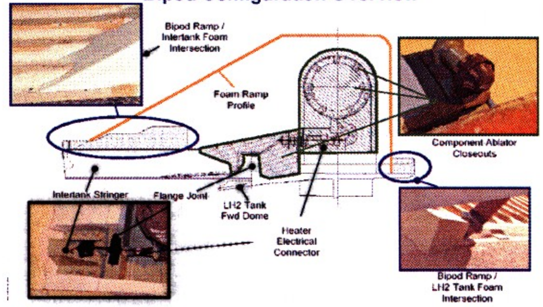
ET – Foam
Design – Certification

- **Recommendations:**
  - NASA efforts to redesign the bipod fitting enclosure must continue.
    - Redesign efforts must include testing and analyses that account for the complex combination of aerodynamic loads, structural loads, aerodynamic heating, cryogenic backface temperatures, and changes in atmospheric pressure.
  - Tests and analyses must be sufficient to ensure that the loss of foam or hardware from this region will not happen in the future.
  - The redesign of the bipod fitting enclosure will be a Return-To-Flight requirement.
  - If foam is still required on bipod fitting:
    - Tighten acceptable temperature & humidity spray envelope
    - Standardize operator techniques
    - Consider use of robotics to fabricate bipod ramp
    - Develop and validate NDE techniques to check for defects

Presenter	M3/Material	Date	FINAL	Slide	3 of 12	Closed

ET – Foam
Design – Certification

Bipod Configuration Overview

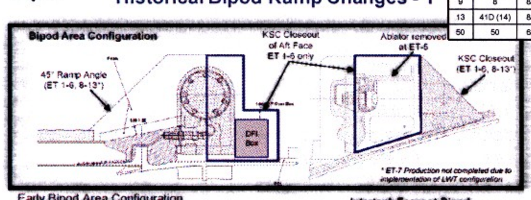


Presenter	M3/Material	Date	FINAL	Slide	4 of 12	Closed

ET – Foam
Design – Certification

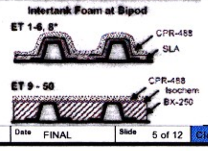
Historical Bipod Ramp Changes - 1

ET	STS	Launch Date
1	1	4/12/81
5	5	11/11/82
6	7	6/18/83
8	6	4/4/83
9	8	8/30/83
13	41D (14)	8/30/84
50	50	6/25/92



Early Bipod Area Configuration
- Forward face angle of 45 ± 5°
  - Edge straight into Intertank foam
- Development Flight Instrumentation (DFI) box and associated KSC closeout eliminated at ET-8
- SLA on bipod housing removed at ET-5
- Intertank foam configuration in area of bipod revised at ET-9
- Debris produced by -Y Bipod on ET-6 (STS-7)
  - Attributed to rework on forward ramp of closeout
    - Assessed repair criteria

Intertank Foam at Bipod

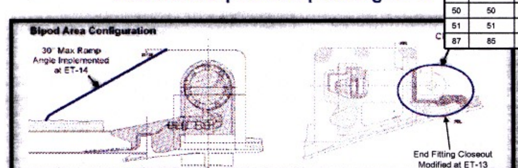


Presenter	M3/Material	Date	FINAL	Slide	5 of 12	Closed

ET – Foam
Design – Certification

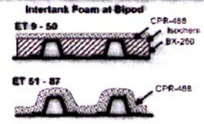
Historical Bipod Ramp Changes - 2

ET	STS	Launch Date
6	7	6/18/83
9	8	8/30/83
13	41D (14)	8/30/84
14	51C (20)	1/24/85
17	51B (24)	4/29/85
50	50	6/25/92
51	51	1/13/93
87	85	8/7/97



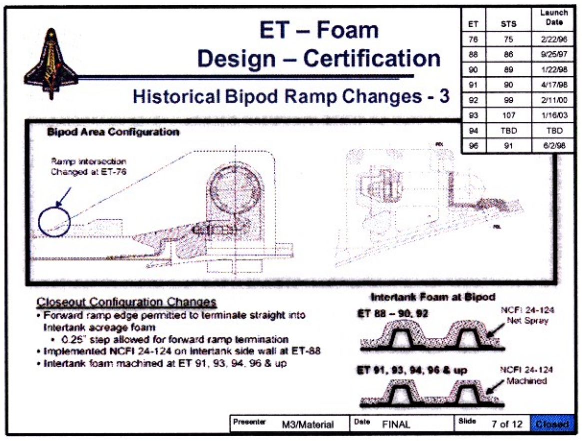
Closeout Configuration Changes
- PDL closeout under the clevis replaced the BX-250 closeout over the end fitting - KSC production flow enhancement
- Revised ramp impingement angle to 30° max with a 5.0 ± 1 inch radius at forward edge
  - Changed as a result of suspected foam debris on ET-6
  - ET 14-17 reworked at KSC
- Added restrictions to the allowable repair area
- Intertank foam configuration revised at ET-51 to eliminate the isochem / CPR-488 bond line
  - Foam loss during flight attributed to localized debonds

Intertank Foam at Bipod



Presenter	M3/Material	Date	FINAL	Slide	6 of 12	Closed

1


ET – Foam
Design – Certification
Historical Bipod Ramp Changes - 3
ET | STS | Launch Date
76 | 75 | 2/22/96
88 | 86 | 9/25/97
90 | 89 | 1/22/98
91 | 90 | 4/17/98
92 | 99 | 2/11/00
93 | 107 | 1/16/03
94 | TBD | TBD
96 | 91 | 6/2/98
Bipod Area Configuration
Ramp intersection Changed at ET-76
Closeout Configuration Changes
• Forward ramp edge permitted to terminate straight into Intertank acreage foam
• 0.25" step allowed for forward ramp termination
• Implemented NCFI 24-124 on Intertank side wall at ET-88
• Intertank foam machined at ET 91, 93, 94, 96 & up
Intertank Foam at Bipod
ET 88 – 90, 92
NCFI 24-124 Net Spray
ET 91, 93, 94, 96 & up
NCFI 24-124 Machined
Presenter M3/Material
Date FINAL
Slide 7 of 12
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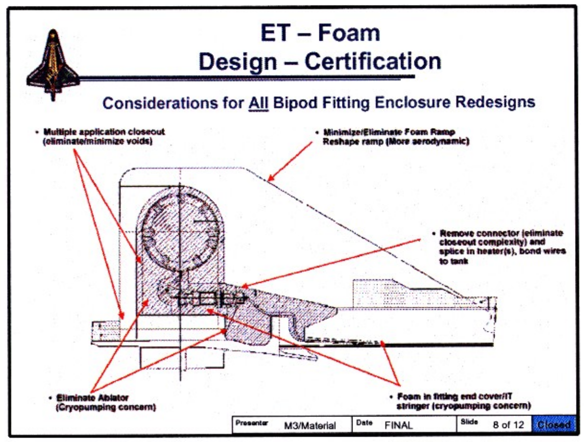
ET – Foam
Design – Certification
Considerations for All Bipod Fitting Enclosure Redesigns
• Multiple application closeout (eliminate/minimize voids)
• Minimize/Eliminate Foam Ramp Reshape ramp (More aerodynamic)
• Remove connector (eliminate closeout complexity) and splice in heater(s), bond wires to tank
• Eliminate Ablator (Cryopumping concern)
• Foam in fitting end cover/IT stringer (cryopumping concern)
Presenter M3/Material
Date FINAL
Slide 8 of 12
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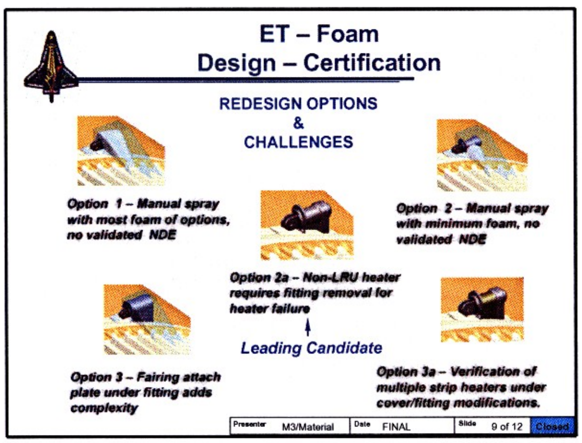
ET – Foam
Design – Certification
REDESIGN OPTIONS
&
CHALLENGES
Option 1 – Manual spray with most foam of options, no validated NDE
Option 2 – Manual spray with minimum foam, no validated NDE
Option 2a – Non-LRU heater requires fitting removal for heater failure
Leading Candidate
Option 3 – Fairing attach plate under fitting adds complexity
Option 3a – Verification of multiple strip heaters under cover/fitting modifications.
Presenter M3/Material
Date FINAL
Slide 9 of 12
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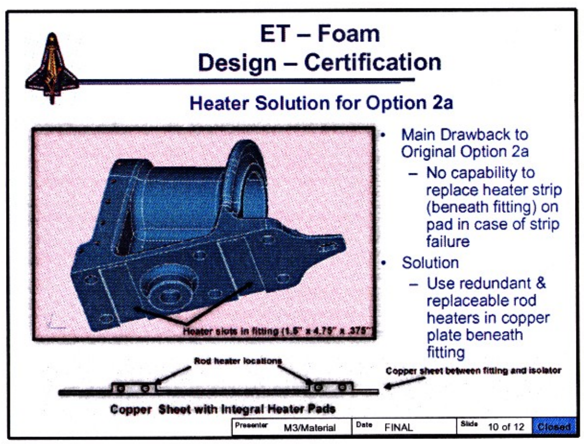
ET – Foam
Design – Certification
Heater Solution for Option 2a
• Main Drawback to Original Option 2a
– No capability to replace heater strip (beneath fitting) on pad in case of strip failure
• Solution
– Use redundant & replaceable rod heaters in copper plate beneath fitting
Heater slots in fitting (1.5" x 4.75" x .375")
Rod heater locations
Copper sheet between fitting and isolator
Copper Sheet with Integral Heater Pads
Presenter M3/Material
Date FINAL
Slide 10 of 12
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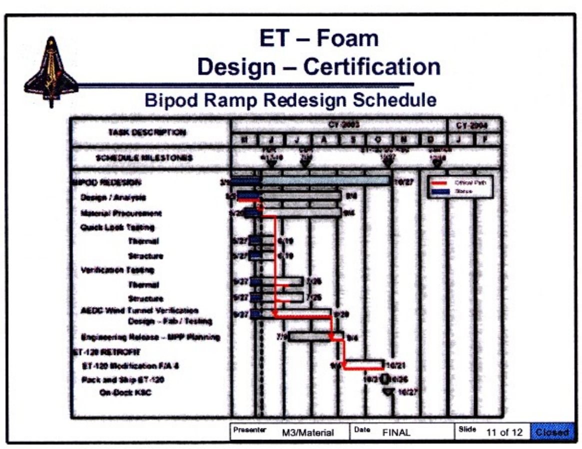
ET – Foam
Design – Certification
Bipod Ramp Redesign Schedule
TASK DESCRIPTION
SCHEDULE MILESTONES
Design / Analysis
Material Procurement
Quick Look Testing
Thermal
Structure
Verification Testing
Thermal
Structure
AEDC Wind Tunnel Verification
Design – Fab / Testing
Engineering Release – MPP Planning
ET-120 RETROFIT
ET-120 Modification F/A 4
Pack and Ship ET-120
On-Dock KSC
10/27
9/8
6/19
7/26
7/25
9/20
9/4
10/21
10/26
10/27
Presenter M3/Material
Date FINAL
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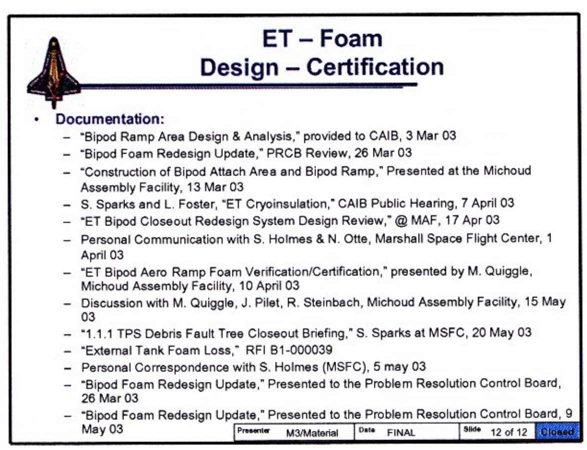

ET – Foam
Design – Certification
• Documentation:
– "Bipod Ramp Area Design & Analysis," provided to CAIB, 3 Mar 03
– "Bipod Foam Redesign Update," PRCB Review, 26 Mar 03
– "Construction of Bipod Attach Area and Bipod Ramp," Presented at the Michoud Assembly Facility, 13 Mar 03
– S. Sparks and L. Foster, "ET Cryoinsulation," CAIB Public Hearing, 7 April 03
– "ET Bipod Closeout Redesign System Design Review," @ MAF, 17 Apr 03
– Personal Communication with S. Holmes & N. Otte, Marshall Space Flight Center, 1 April 03
– "ET Bipod Aero Ramp Foam Verification/Certification," presented by M. Quiggle, Michoud Assembly Facility, 10 April 03
– Discussion with M. Quiggle, J. Pilet, R. Steinbach, Michoud Assembly Facility, 15 May 03
– "1.1.1 TPS Debris Fault Tree Closeout Briefing," S. Sparks at MSFC, 20 May 03
– "External Tank Foam Loss," RFI B1-000039
– Personal Correspondence with S. Holmes (MSFC), 5 may 03
– "Bipod Foam Redesign Update," Presented to the Problem Resolution Control Board, 26 Mar 03
– "Bipod Foam Redesign Update," Presented to the Problem Resolution Control Board, 9 May 03
Presenter M3/Material
Date FINAL
Slide 12 of 12
Closed

2

ET – Foam
Design – Certification

- **Action / Issue:** Geometry of the LH2-IT flange could contribute to foam loss
- **Background / Facts:**
  - LH2-IT geometry provides several paths where LN2 can possibly get into the flange area
  - Solid N2 to GN2 state transitions could possibly contribute to foam loss
  - A "Y" joint is formed where the LH2-IT connection is made provide a reservoir where LN2 can collect

Presenter M3/Material | Date FINAL | Slide 1 of 8 | Closed

ET – Foam
Design – Certification

- **Findings:**
  - Bolt holes, shim gaps and stringer venting could provide a path for LN2 to get behind the foam in the flange closeout area
  - During ascent, stresses in flange area change between tension and compression
    - LN2 path back to the IT could possibly be sealed leading to foam being "popped" off
  - Foam loss from the LH2-IT flange region has been observed on ~70% of missions where imagery was available

Presenter M3/Material | Date FINAL | Slide 2 of 8 | Closed

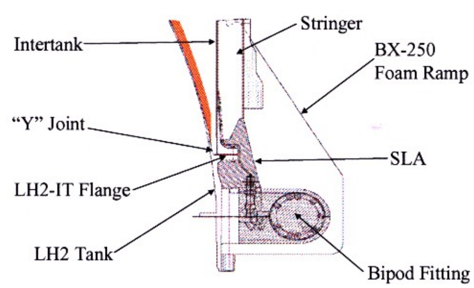
ET – Foam
Design – Certification

- **Recommendations:**
  - NASA must understand the relationship between the complex LH2-IT flange geometry and the high rate of foam loss from this region
    - Current testing efforts at MSFC and MAF should continue
  - NASA should use knowledge gained from testing and analysis of the current LH2-IT flange geometry to redesign this area
    - Redesign efforts should include, but not be limited to, considerations of:
      - minimizing the ability for nitrogen to come in contact with foam or SLA
      - replacing the existing intertank nitrogen purge with a helium purge
      - structural changes that eliminate or reduce all vent paths in the flange region

Presenter M3/Material | Date FINAL | Slide 3 of 8 | Closed

ET – Foam
Design – Certification

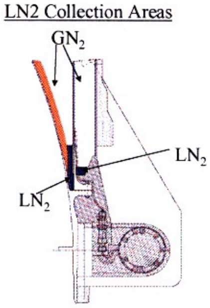
LH2-IT Geometry



Presenter M3/Material | Date FINAL | Slide 4 of 8 | Closed

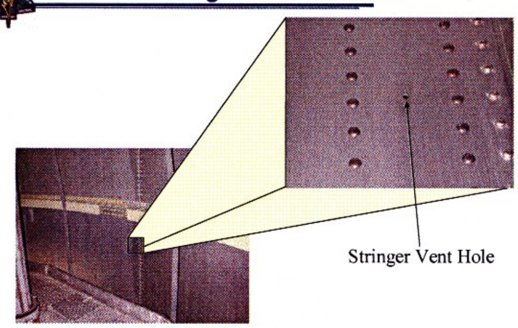
ET – Foam
Design – Certification

LN2 Collection Areas



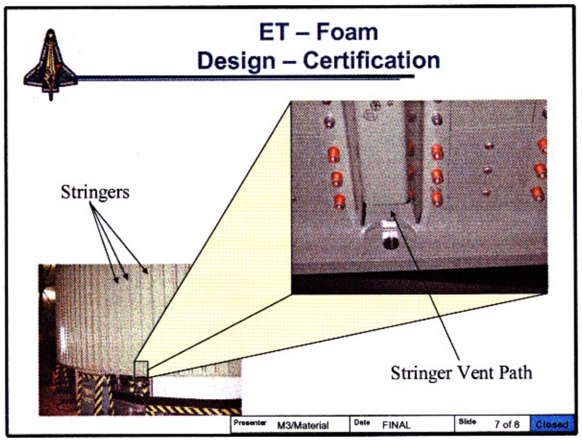
Presenter M3/Material | Date FINAL | Slide 5 of 8 | Closed

ET – Foam
Design – Certification



Presenter M3/Material | Date FINAL | Slide 6 of 8 | Closed

1



ET – Foam
Design – Certification

- **Documentation:**
  - http://www.lockheedmartin.com/michoud/et/description.htm
  - "Use of Shims in ET Flanges," presented at Michoud Assembly Facility, 10 Mar 03
  - History of External Tank Foam Loss," RFI B0-000026
  - Personal communication with Mike Javery, Lockheed Martin, Michoud Assembly Facility, 17 Apr 03
  - "ET Bipod Ramp and Flange Dissection Out Briefing," presented at Michoud Assembly Facility, 15 May 03

Presenter M3/Material | Date FINAL | Slide 8 of 8 | Closed

2

ET – Foam Design – Certification

- **Action / Issue:**
  - Stringer valley cracks have been documented as occurring on super lightweights more frequently than on other tanks
- **Background / Facts:**
  - Cracks in the valleys between stingers (external stiffening elements) on the intertank have been observed on several missions on all types of tanks
    - Standard weight [eg. ET-6]
    - Lightweight [eg. ET-29 & ET-35]
    - SLWT
  - However, the occurrence of these cracks have been identified more often beginning with the first SLWT, ET-96, launched with mission STS-91 in June 1998

Presenter M3/Material	Date FINAL	Slide 1 of 6	Closed

ET – Foam Design – Certification

- **Findings:**
  - Subsequent to the change to super lightweight tanks, final inspection teams started seeing cracks in the intertank stringer valleys more frequently than on lightweight or standard tanks
    - It is believed these cracks form during tanking as a form of stress relief as the aluminum ET cools and contracts
      - Hypothesis: thinner, machined foam in these areas (part of the super lightweight design) is more susceptible to cracking
    - Ice/Debris Team inspection & documentation procedures have not changed with respect to stringer valley cracks
    - Cracks are more difficult to spot in machined foam
    - Thus, so the sudden increase in the numbers of cracks observed with the advent of the SLWT appeas to be real.
  - A comprehensive review of historical records has not been performed
    - However a quick data search shows that these cracks were rarely recorded prior to the SLWT inception
  - These cracks, if underneath the bipod ramp, could provide a possible reservoir for LN2

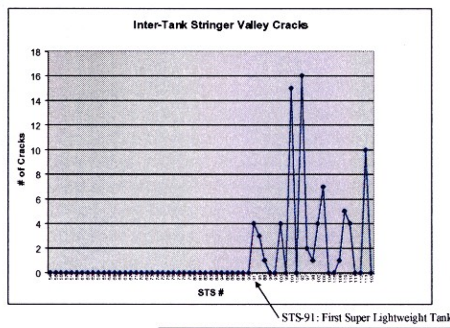
Presenter M3/Material	Date FINAL	Slide 2 of 6	Closed

ET – Foam Design – Certification

- **Recommendations:**
  - NASA should continue tests currently underway at MSFC and MAF to understand cryopumping and cryoingestion
    - The tests involving full-scale mock-ups of the LH2-IT should be monitored for the presence of stringer valley cracks
  - NASA should plan to continue additional analysis and testing on the SLWT configuration to understand the cause of these cracks, their effects, and ways to prevent them from occurring
    - If these cracks are found to be detrimental, NASA should take steps to prevent them

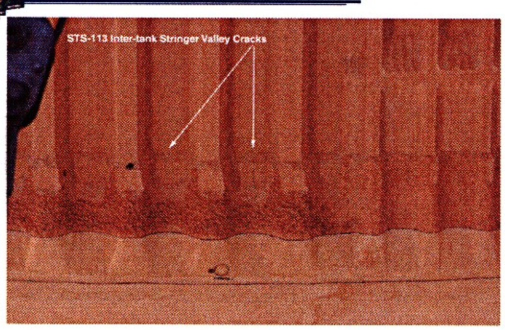
Presenter M3/Material	Date FINAL	Slide 3 of 6	Closed

ET – Foam Design – Certification



Presenter M3/Material	Date FINAL	Slide 4 of 6	Closed

ET – Foam Design – Certification



Presenter M3/Material	Date FINAL	Slide 5 of 6	Closed

ET – Foam Design – Certification

- **Documentation:**
  - "Lessons Learned: From Space Shuttle External Tank Development – A Technical History of the External Tank", October 30, 2002
  - Final Inspection Intertank Cracks Request for Information, RFI #B1-000134
  - Discussions with Armando Oliu, 24 March 2003
  - Discussions at Michoud Assembly Facility, 02 April 2003
  - Personal Communication, J. Feeley, Michoud Assembly Facility, 12 Jun 03.
  - E-mail, M. Quiggle, Michoud Assembly Facility, 19-23 Jun 03.

Presenter M3/Material	Date FINAL	Slide 6 of 6	Closed

1

ET – Foam Production

2-1	Blowing Agent Changes
2-2	Manual Spraying Operations
2-3	Processing Environment Controls for Foam Applications
2-4	NDE for ET During Production

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	4 of 32

ET – Foam Production

- **Action / Issue:**
  Concerns exist about changes to blowing agents used in ET foams and their influence on foam properties
- **Background / Facts:**
  - 1978: US bans CFCs in aerosol sprays
  - 1988: US Senate approves Montreal Protocol
  - 1988: Martin Marietta initiates activities to screen CFC alternates
  - 1990: Clean Air Act Amendment rules phase-out of CFCs by 2000
  - 1991: Martin Marietta selects best CFC alternative (HCFC 141b)
  - 1993: CFC 11 manufacture discontinued
    NASA chooses not to pursue "Essential Use Exemption" for production of CFC 11 after remaining stockpile exhausted
  - 1995: SS 1171 (HCFC 141b) chosen to replace BX 250 (CFC 11)
    CFC 11 stock secured by Martin Marietta to continue BX 250 production

Presenter M3/Material | Date FINAL | Slide 1 of 7 | Closed

ET – Foam Production

- **Background / Facts: (cont.)**
  - 1998: Problems with SS 1171 force continued use of BX 250
  - 2001: BX 265 (HCFC 141b) chosen to replace BX 250 (CFC 11)
  - 2002: BX 265 implemented on ET-117 (MAF) & ET-116 (KSC)
  - 2003: EPA phase-out of HCFC 141b production takes effect
    Waiver for continued HCFC 141b production approved for NASA

Findings:
- Thousands of tests conducted to develop & qualify each ET foam
- Change in blowing agents for acreage foam (from CPR 488 to NCFI 24-124) caused "popcorning" earlier in ascent profile
  - Popcorning = small pieces lost from thrust panels
    - Popcorning earlier in ascent results in debris with higher energy
  - Early popcorning first observed on STS-84/ET-85
  - Resulted in extensive tile damage on STS-87/ET-89

Presenter M3/Material | Date FINAL | Slide 2 of 7 | Closed

ET – Foam Production

- **Findings: (cont.)**
  - First attempt to change blowing agents for closeout foam (from BX 250 to SF-1171) failed due to production issues
    - Second change attempt (from BX 250 to BX 265)successful; first flown on STS-113 with ET-116
- **Recommendations:**
  - NASA should transition to a new blowing agent only if performance improvements in the foam can be achieved (e.g., greater stability – less shedding)
  - Foam blowing agent requirements should be reviewed to verify they are sufficient and specify the correct properties & attributes
  - NASA should continue complete and thorough testing of foam blowing agents to understand flight implications and minimize risks

Presenter M3/Material | Date FINAL | Slide 3 of 7 | Closed

ET – Foam Production

New foams (w/HCFC 141b) meet all requirements

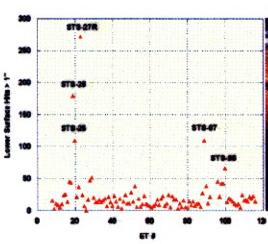
Foam / Property	(New) NCFI 24-124 (Old) CPR 488	(New) NCFI 24-57 (Old) NCFI 22-65	(New) PDL 1034 (Old) PDL 4034	(New) BX 265 (Old) BX 250
(% of total foam)	(77%)	(7%)	(1%)	(14%)
Application	LH2,LO2,I/T sidewall	LH2 aft dome	Closeouts and repairs	LH2 forward dome, LO2 aft dome, closeouts
Process	Spray	Spray	Pour/Mold	Spray
Description	Isocyanurate	Isocyanurate	Urethane	Urethane

Requirements	Spec Req	Typ Prop	Flt Req.	Spec Req	Typ Prop	Flt Req.	Spec Req	Typ Prop	Flt Req.	Spec Req	Typ Prop	Flt Req.
Density PCF	2.0-2.6 2.1-2.6	2.2[8] 2.4	Lighter[6]	2.6-3.1 2.6-3.1	2.97 2.90	Heavier[6]	2.3-3.1 2.3-3.1	2.6 2.6	same[6]	1.8-2.6 1.8-2.6	2.4 2.4	same[6]
Tensile RT (psi)	30min 35min	44 54	19	40min 40min	66 71	19	60 60	113 104	19	35min 35min	53 75	19
Tensile -423° F (psi)	N/A[1]	34 41	19	N/A	49 47	19	N/A	66 49	19	N/A	62 53	19
Tensile +300° F (psi)	N/A	32 37	19	N/A	38 46	19	N/A	71[2] 63	19	N/A	38[2] 47	19
Compression (psi)	25min 24min	33 40	20	35min 35min	49 61	20	30 30	61 42	20	24min 24min	36 42	20
Recession Rate @ 7 BTU/ft sq sec (in/sec)	N/A	0.0094 0.0168	lower[6]	N/A	0.0099[7] 0.0099[7]	same[6]	N/A	0.0363 0.0236	higher[6]	N/A	0.017[3] 0.024	lower[6]
Thermal Cond @ R/T BTU/hr ft °F)	0.026	0.017 0.017	same[6]	0.0226 0.0168	0.0186 0.0166	higher[6]	0.016 0.016	0.015 0.012	higher[6]	0.015 0.016	0.013 0.011	higher[6]
Cryostrain (ksi)	61@-423	66@-423 66@-423	pass	66@-423	66@-423 66@-423	pass	N/A	60@-320 60@-320	pass	N/A	66@-423 66@-423	pass

[1]N/A- Not Applicable [2]+200°F Values [3]@ 4 BTU/ft sq sec [4]Max density 3.0 in dome area allowed
[5]@ + 200°F [6]Means new vs. old [7]Radiant heating [8]2.4 – 2.8 PCF for thick/thin

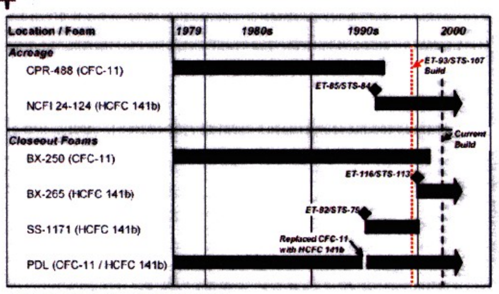
Presenter M3/Material | Date FINAL | Slide 4 of 7 | Closed

ET – Foam Production



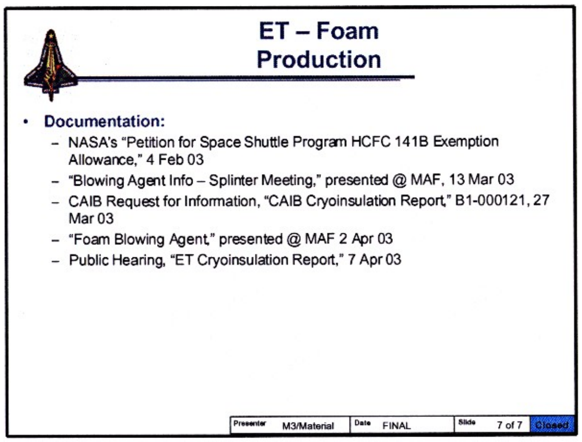
Presenter M3/Material | Date FINAL | Slide 5 of 7 | Closed

ET – Foam Production



(Blowing Agent shown in parentheses)

Presenter M3/Material | Date FINAL | Slide 6 of 7 | Closed


ET – Foam
Production
• Documentation:
– NASA's "Petition for Space Shuttle Program HCFC 141B Exemption Allowance," 4 Feb 03
– "Blowing Agent Info – Splinter Meeting," presented @ MAF, 13 Mar 03
– CAIB Request for Information, "CAIB Cryoinsulation Report," B1-000121, 27 Mar 03
– "Foam Blowing Agent," presented @ MAF 2 Apr 03
– Public Hearing, "ET Cryoinsulation Report," 7 Apr 03
M3/Material
FINAL
7 of 7
Closed

ET – Foam Production

- **Action / Issue:**
  - Manual spraying operations of complex and closeout areas are not sufficiently controlled
- **Background / Facts:**
  - Operators must be qualified to hand spray foam
  - Each spraying operation is unique and is operator dependent
  - Control of spraying variables has been limited except in the flange closeout area
    - Special techniques with limited qualified operators are now used due to prior problems in the flange closeout area
  - Spraying operations can be either one or two people depending on the operator's preference
  - Complex shapes and access to the area being sprayed makes these operations even more difficult to control

Presenter M3/Material | Date FINAL | Slide 1 of 6 | Closed

ET – Foam Production

- **Findings:**
  - Dissection of various bipod and flange closeout areas has revealed that defects are introduced during the spraying operation
  - Defects tend to occur in complex geometry regions or where there is limited access for operators during the spray evolution
  - Defects are random and unpredictable
  - There have been limited attempts to control spraying variables except in the flange closeout area
  - Summary: complexity of areas to be sprayed + variability in operator techniques = a unique product with insufficient/unknown foam quality

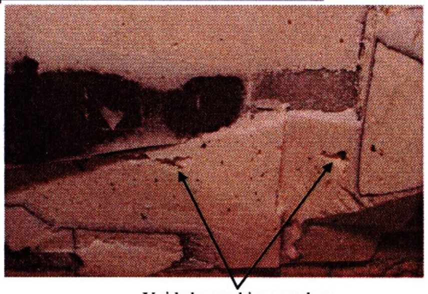
Presenter M3/Material | Date FINAL | Slide 2 of 6 | Closed

ET – Foam Production

- **Recommendations:**
  - Efforts should be made to try and standardize (control) the hand spraying process as much as possible
    - If automated processes can be put in place to spray these areas, such as is currently done on the acreage foam, every effort should be made to make that transition
    - In areas where hand spraying must continue, operators should be qualified to spray all complex geometries
  - There should be no foam application processes requiring less than two people

Presenter M3/Material | Date FINAL | Slide 3 of 6 | Closed

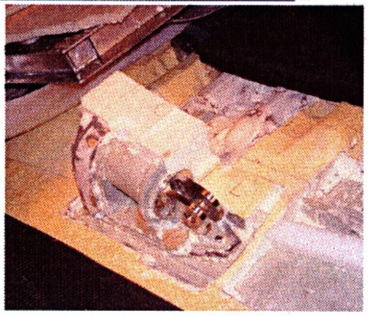
ET – Foam Production



Voids located in complex geometry areas

Presenter M3/Material | Date FINAL | Slide 4 of 6 | Closed

ET – Foam Production



Complex spray areas around bipod fixture

Presenter M3/Material | Date FINAL | Slide 5 of 6 | Closed

ET – Foam Production

- **Documentation:**
  - Personal observations at Michoud Assembly Facility (MAF), February – May 2003
  - Discussions with Lockheed Martin personnel, MAF, February to May 2003
  - Discussion with Marshall Space Flight Center/MAF personnel, 02 April 2003
  - ET Shedding – Composite Request for Information, RFI #B0-000026
  - ET-120 Dissection Outbrief, 10 April 2003

Presenter M3/Material | Date FINAL | Slide 6 of 6 | Closed

1

ET – Foam Production

- **Action / Issue:**
  - Process controls (especially those for temperature and humidity) may be insufficient to permit consistently high quality foam application.
- **Background / Facts:**
  - Spraying operations must be within required environmental conditions
  - Boundaries of the environmental conditions are considered to be conservative to guarantee proper foam performance
  - Plug pulls are performed subsequent to spraying operations to verify proper material bonding and strength

Presenter M3/Material | Date FINAL | Slide 1 of 6 | Closed

ET – Foam Production

- **Findings:**
  - Most spraying operations occur at or near the outer acceptable boundaries of the processing envelope
  - Large variability in the response of the foam based on inherent randomness of foam cell structure
  - Plug pulls, as a single indicator, might not be sufficient to verify the foam's bonding and strength properties

Presenter M3/Material | Date FINAL | Slide 2 of 6 | Closed

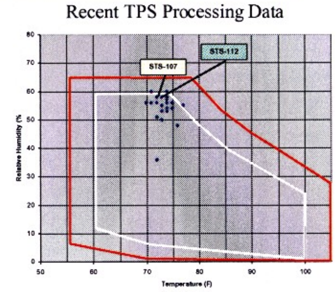
ET – Foam Production

- **Recommendations:**
  - Foam loss history should be looked at for correlation to processing environments and plug pull values
  - The processing envelope should be revalidated and attempts should be made to try and perform spraying operations more towards the center of the defined envelopes vice at the outer edges
  - Plug pull requirements should also be revalidated and the actual usefulness of these tests to determine overall foam application worthiness should be questioned
    - Localized plug values might not be telling the story for the whole tank

Presenter M3/Material | Date FINAL | Slide 3 of 6 | Closed

ET – Foam Production

Recent TPS Processing Data

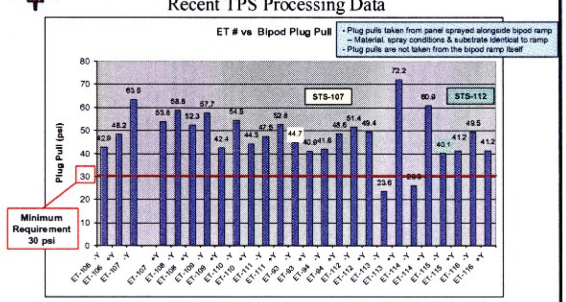


Absolute Limits in RED. Processing Envelope in WHITE.

Presenter M3/Material | Date FINAL | Slide 4 of 6 | Closed

ET – Foam Production

Recent TPS Processing Data



Significant scatter – is this a useful test?

Presenter M3/Material | Date FINAL | Slide 5 of 6 | Closed

ET – Foam Production

- **Documentation:**
  - CAIB Public Hearing – ET Cryoinsulation, Lee Foster and Scotty Sparks, 07 April 2003
  - Discussions with Michoud Assembly Facility personnel, February 2003

Presenter M3/Material | Date FINAL | Slide 6 of 6 | Closed

1

ET – Foam Production

- **Action / Issue:** No validated NDE techniques are available to identify subsurface damage within ET foam during or after production
- **Background / Facts:**
  - Extensive NDE is performed on welded aluminum sections of ET
  - No NDE performed on ET thermal protection system (TPS) except:
    - Visual checks during and after production
    - Eddy current checks for thickness
    - Preflight ice/debris inspections
    - Plug pulls & witness panels (*destructive* tests)
  - Previous efforts at MAF (1986-93) were unsuccessful in identifying NDE technologies that could be readily implemented
  - Boeing has had success using laser shearography on acreage foam of Delta-IV boosters, but
    - Geometry is much less complex than that of ET
    - Inspection requirement is for larger defects

Presenter M3/Material | Date FINAL | Slide 1 of 13 | Closed

ET – Foam Production

- **Findings:**
  - Previous tests of laser shearography on flat foam panels indicated the technique had promise as a potential NDE technique for foam
    - Some promise also seen on flat panels with intertank geometry
    - Additional work is required to develop technique for production
  - Production checks for foam quality are:
    - Visual -or-
    - Require destructive testing (plug pulls) -or-
    - Test representative foam sample rather than foam actually applied to tank ("witness panels")
  - Dissections of bipod foam ramps on ET-94, ET-120, and ET-124 revealed that production defects in foam are common
    - Laser Shearography and X-ray NDE indications provided minimal correlation with physical observations

Presenter M3/Material | Date FINAL | Slide 2 of 13 | Closed

ET – Foam Production

- **Findings:** (cont.)
  - MAF and MSFC are actively pursuing development of an NDE technique to use on hand-sprayed closeouts
    - Candidate techniques include: X-ray (radiography), backscatter X-ray, shearography, microwave, and terahertz
    - Experts in field among are in Working Group All post-build & KSC processing inspections of the ET are visual
    - No NDE is used to confirm or size regions needing repair
    - Visual examination relies on experienced personnel
      - Especially the Ice/Debris Team at KSC
  - LTI (John Newman) has estimated that 12-24 months is needed to develop shearography scanner hardware for the ET
    - Standards and procedures would also be required in addition to hardware

Presenter M3/Material | Date FINAL | Slide 3 of 13 | Closed

ET – Foam Production

- **Recommendations:**
  - Potential Return to Flight Recommendation: NASA should continue to pursue the development, validation, and implementation of NDE techniques that can be used to interrogate ET foam during production
  - NASA should continue to pursue the development, validation, and implementation of NDE techniques that can be used to interrogate ET foam following production (i.e. at KSC prior to launch)

Presenter M3/Material | Date FINAL | Slide 4 of 13 | Closed

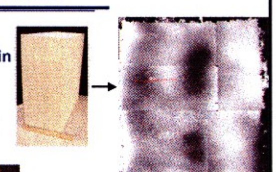
ET – Foam Production

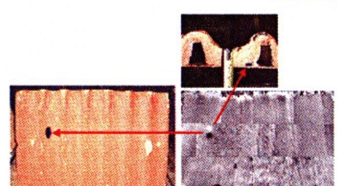
Laser shearography in use on Boeing Delta IV boosters

Presenter M3/Material | Date FINAL | Slide 5 of 13 | Closed

ET – Foam Production

NDE of 9" thick foam block revealed defects as small as 3" in diameter





NDE of flat panels with intertank geometry yielded promising results

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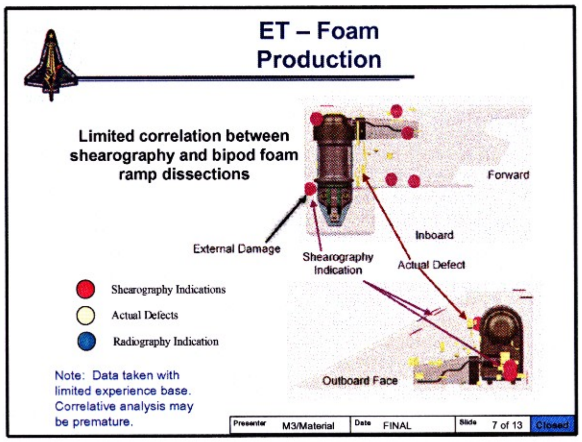

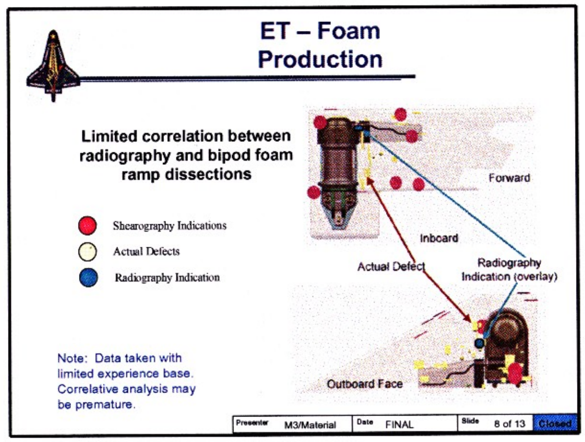

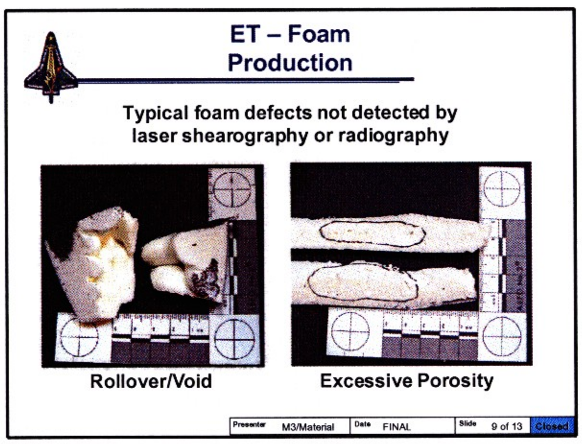

ET – Foam Production

Summary of MSCF/MAF NDE Efforts

Technology	Technology Partners	Contract	Progress: Flat Panel	LH2T Flange	PAL Ramp	Bipod
	(MAF)					
	Yxlon	None	√			
Backscatter Radiography	University of Florida	LM Subcontract	√			
	AS&E	None	√			
	GE Corp. Research Center	LM Subcontract	√			
	ARACOR	LM Subcontract				
Shearography	(KSC)					
	LTI	LM, KSC Subcontract	√	√		√
	Trillion	None	√			
Microwave	(MSFC, MAF)					
	University of Missouri	Grant	√			√
	Pacific NW Nat'l Labs	LM Subcontract	√			
	Ohio State	None	√			
Terahertz Imaging	(LaRC, MAF)					
	Picometrix	Purchase Order	√			
	Rensselaer	None	√			
Low Frequency UT	(MAF)					
	LM Advanced Technology Center	IWTA	√			
	Pacific NW Nat'l Labs	LM Subcontract	√			

√ = initial trials complete

Status as of 29 May 03

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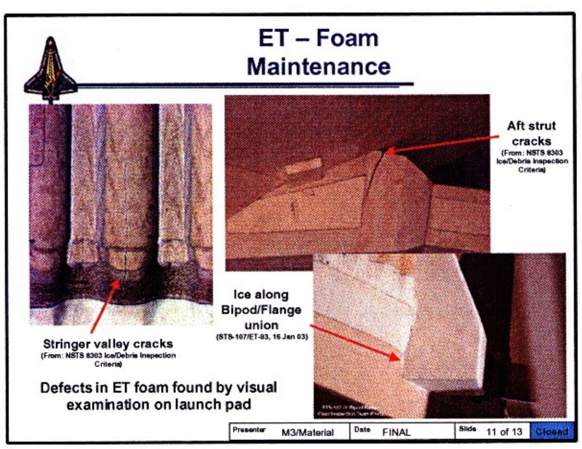
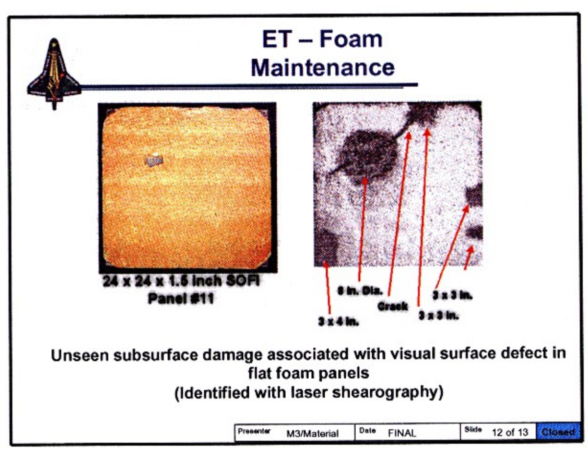
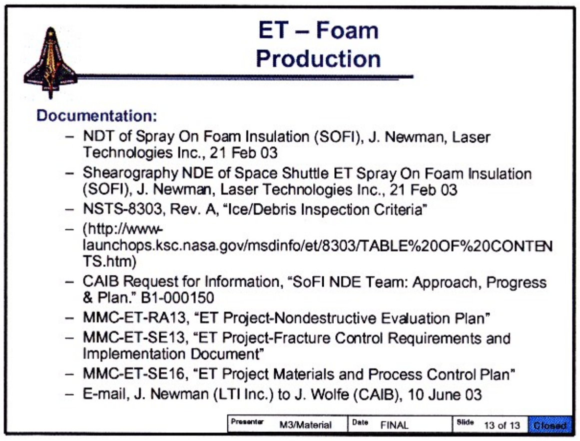





ET – Foam Production
Documentation:
– NDT of Spray On Foam Insulation (SOFI), J. Newman, Laser Technologies Inc., 21 Feb 03
– Shearography NDE of Space Shuttle ET Spray On Foam Insulation (SOFI), J. Newman, Laser Technologies Inc., 21 Feb 03
– NSTS-8303, Rev. A, "Ice/Debris Inspection Criteria"
– (http://www-launchops.ksc.nasa.gov/msdinfo/et/8303/TABLE%20OF%20CONTENTS.htm)
– CAIB Request for Information, "SoFI NDE Team: Approach, Progress & Plan." B1-000150
– MMC-ET-RA13, "ET Project-Nondestructive Evaluation Plan"
– MMC-ET-SE13, "ET Project-Fracture Control Requirements and Implementation Document"
– MMC-ET-SE16, "ET Project Materials and Process Control Plan"
– E-mail, J. Newman (LTI Inc.) to J. Wolfe (CAIB), 10 June 03
Presenter M3/Material
Date FINAL
Slide 13 of 13
Closed

3

ET – Foam Maintenance

3-2	ET Storage, Shipping, and Handling
3-4	Crushed Foam from Mate/De-Mate of ET-93

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	5 of 32

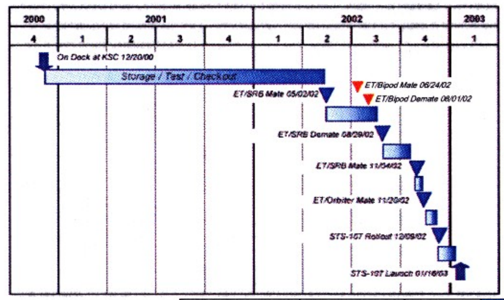
ET – Foam Maintenance

- **Action / Issue:** Foam crushed beneath the –Y (left side) bipod strut clevis during pre-launch mating & demating with the bipod strut may have contributed to the loss of the –Y bipod foam ramp from ET-93 during STS-107.
- **Background / Facts:**
  - ET-93 mated to SRBs on 8 May 02 in VAB; de-mated on 28 Aug 02
  - ET-93 mated to bipod on 24 Jun 02 in VAB; de-mated on 1 Aug 02
  - Operations carried out in accordance with standard procedures
  - Crushed foam seen after -Y strut removal (1.5" x 1.25" x 0.187")
    - Beneath –Y fitting-clevis joint after bipod struts removed
  - Thickness of foam in this area: 2.187"
  - Exposed crushed foam not permissible; Problem Report written
  - Testing was performed @ MAF and KSC (on ET-117) to determine:
    - If crushed foam on ET-93 could have caused loss of –Y bipod ramp
    - If limits specified in PR procedures were sufficient

Presenter M3/Material | Date FINAL | Slide 1 of 12 | Closed

ET – Foam Maintenance

ET-93 Processing Timeline at KSC



Presenter M3/Material | Date FINAL | Slide 2 of 12 | Closed

ET – Foam Maintenance

- **Findings:**
  - Crushed foam is always present at ET bipod attach points
    - Specifically designed to be an "interference fit"
  - KSC engineers decided to defer action on PR. Rationale:
    - Crushed foam was contained beneath bipod strut clevis after mating to a new set of bipod struts
    - Unexposed (i.e. contained) crushed foam is permissible
  - Inspection of region after installation of bipod struts showed that crushed foam did not extend further than 0.75" beyond bipod fitting-clevis joint
    - Within acceptable limits
  - STS-107 launched with crushed foam contained behind –Y bipod strut clevis

Presenter M3/Material | Date FINAL | Slide 3 of 12 | Closed

ET – Foam Maintenance

- **Findings: (cont.)**
  - Three other mate-de-mate instances occurred on shuttle program; unknown link between mating/de-mating & foam loss
    - ET-13 used on STS-14(41D)
      - No imagery to confirm/deny foam loss
    - ET-23 used on STS-27R
      - Handheld video imagery; bipod ramps not visible, no other loss noted
      - Mated & de-mated during checkout of Vandenberg AFB facilities
      - Extensive tile damage due to the loss of SRB ablator during launch
    - ET-80 used on STS-80
      - Lost 2 divots on flange under bipod
      - Lost one 10-inch diameter divot on intertank forward of –Y bipod ramp

Presenter M3/Material | Date FINAL | Slide 4 of 12 | Closed

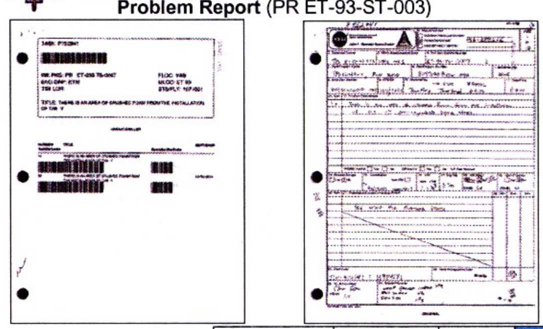
ET – Foam Maintenance

- **Findings: (cont.)**
  - Crushed foam testing conducted at MAF & KSC (on ET-117)
    - Red dye indicated extent of damage to be limited to a maximum of 0.5" beyond region visibly crushed with aid of dye
      - Within acceptable limit
      - Receives little/no airflow with bipod strut installed
    - Undamaged foam thickness was over 2" on ET-117
      - No ice/frost potential
    - Localized damage would have no impact on performance of ramp
    - Results indicate no contribution from crushed foam to the loss of the bipod foam ramp on ET-93
- **Recommendations:**
  - None

Presenter M3/Material | Date FINAL | Slide 5 of 12 | Closed

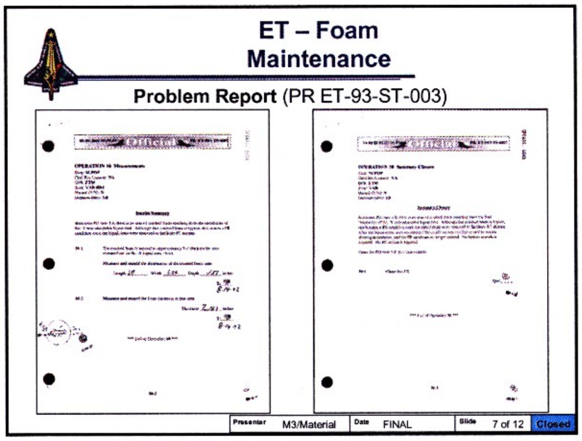
ET – Foam Maintenance

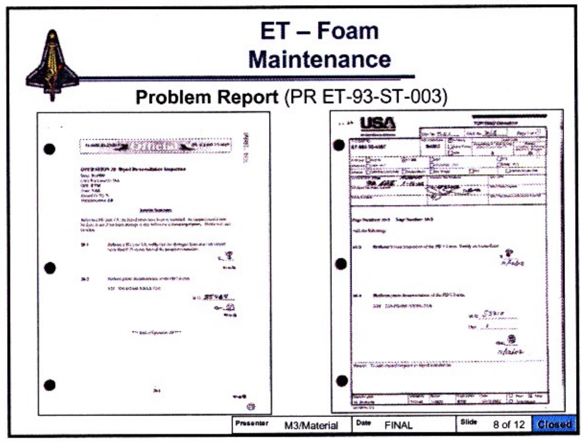
Problem Report (PR ET-93-ST-003)

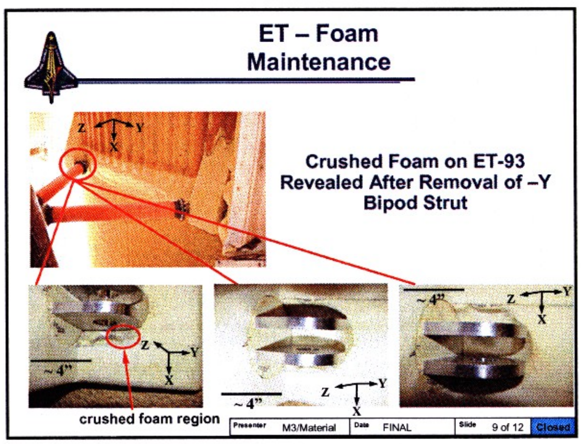


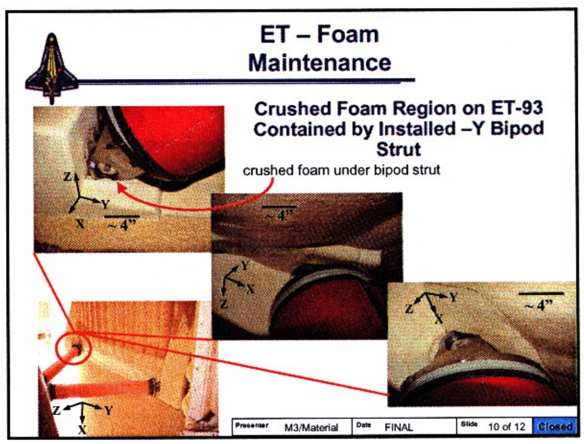
Presenter M3/Material | Date FINAL | Slide 6 of 12 | Closed

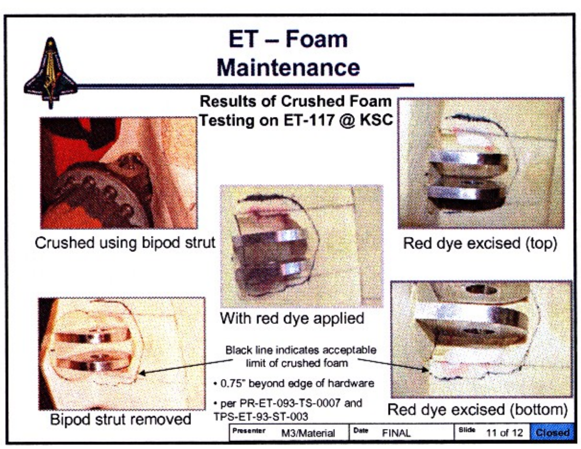
1

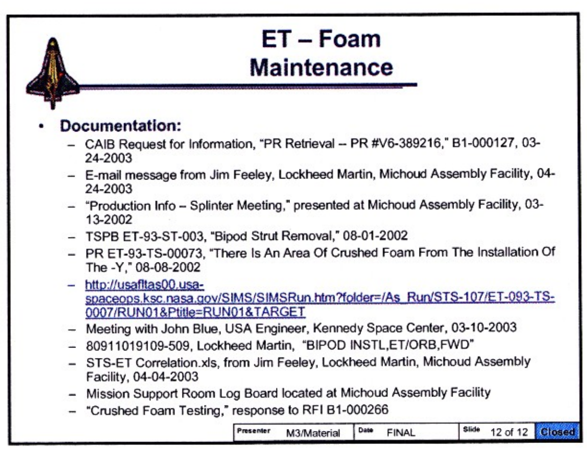

ET – Foam
Maintenance
Problem Report (PR ET-93-ST-003)
Presenter M3/Material
Date FINAL
Slide 7 of 12
Closed


ET – Foam
Maintenance
Problem Report (PR ET-93-ST-003)
USA
Presenter M3/Material
Date FINAL
Slide 8 of 12
Closed


ET – Foam
Maintenance
Crushed Foam on ET-93
Revealed After Removal of –Y
Bipod Strut
~4"
crushed foam region
Presenter M3/Material
Date FINAL
Slide 9 of 12
Closed


ET – Foam
Maintenance
Crushed Foam Region on ET-93
Contained by Installed –Y Bipod
Strut
crushed foam under bipod strut
~4"
Presenter M3/Material
Date FINAL
Slide 10 of 12
Closed


ET – Foam
Maintenance
Results of Crushed Foam
Testing on ET-117 @ KSC
Crushed using bipod strut
Red dye excised (top)
With red dye applied
Black line indicates acceptable
limit of crushed foam
• 0.75" beyond edge of hardware
• per PR-ET-093-TS-0007 and
TPS-ET-93-ST-003
Bipod strut removed
Red dye excised (bottom)
Presenter M3/Material
Date FINAL
Slide 11 of 12
Closed


ET – Foam
Maintenance
• Documentation:
– CAIB Request for Information, "PR Retrieval – PR #V6-389216," B1-000127, 03-24-2003
– E-mail message from Jim Feeley, Lockheed Martin, Michoud Assembly Facility, 04-24-2003
– "Production Info – Splinter Meeting," presented at Michoud Assembly Facility, 03-13-2002
– TSPB ET-93-ST-003, "Bipod Strut Removal," 08-01-2002
– PR ET-93-TS-00073, "There Is An Area Of Crushed Foam From The Installation Of The -Y," 08-08-2002
– http://usafltas00.usa-spaceops.ksc.nasa.gov/SIMS/SIMSRun.htm?folder=/As_Run/STS-107/ET-093-TS-0007/RUN01&Ptitle=RUN01&TARGET
– Meeting with John Blue, USA Engineer, Kennedy Space Center, 03-10-2003
– 80911019109-509, Lockheed Martin, "BIPOD INSTL,ET/ORB,FWD"
– STS-ET Correlation.xls, from Jim Feeley, Lockheed Martin, Michoud Assembly Facility, 04-04-2003
– Mission Support Room Log Board located at Michoud Assembly Facility
– "Crushed Foam Testing," response to RFI B1-000266
Presenter M3/Material
Date FINAL
Slide 12 of 12
Closed

ET – Foam Maintenance

- **Action / Issue:** A concern existed that improper storage and handling of the ET between its completion and launch may have damaged foam and contributed to foam loss during the ascent of STS-107.
- **Background / Facts:**
  - Post-build activities include storage at MAF, shipment to KSC, processing at KSC, and mating to SRBs and orbiter
- **Findings:**
  - Extensive documentation governs steps taken to care for ET
  - Storage takes place in locked, limited-access facilities
  - Tanks are pressured with nitrogen or helium to 6.0 +/- 0.5 psi
    - Pressure checked every 2 weeks at MAF, every week at KSC
  - Visual inspections performed every 90 days
  - ET is inspected 7 times between arrival at KSC and launch
    - This does not count daily inspections when stack exists

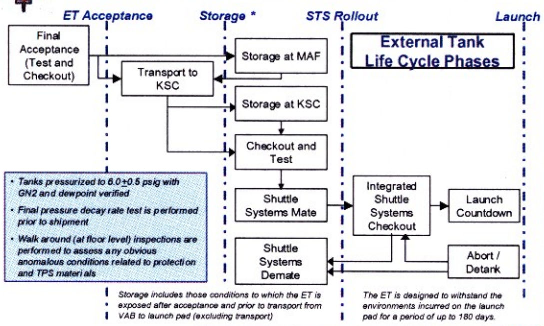
Presenter M3/Material | Date FINAL | Slide 1 of 9 | Closed

ET – Foam Maintenance

- **Findings (cont.):**
  - Protective covers are used for 14 areas with historically significant potential rates of damage due to collateral operations
  - Repairs performed by KSC with assistance from MAF if needed
    - Repaired areas inspected for "collateral" damage after repairs made
  - Post STS-107 paper review by KSC examined 56,000 pages of documentation
    - No contributing events identified
- **Recommendations:**
  - None
    - Processes appear to be in place and followed to ensure that shipping and handling is performed in a manner that minimizes damage to the ET

Presenter M3/Material | Date FINAL | Slide 2 of 9 | Closed

ET – Foam Maintenance

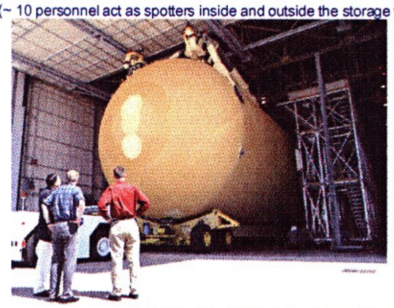


Presenter M3/Material | Date FINAL | Slide 3 of 9 | Closed

ET – Foam Maintenance

Maneuvering the ET at Michoud Assembly Facility

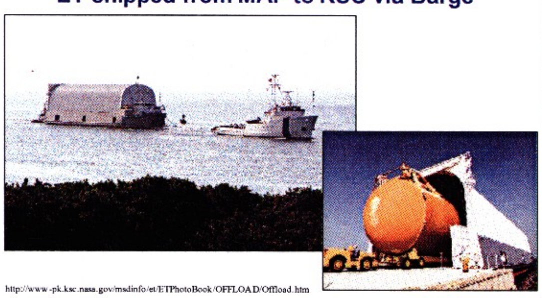
(~ 10 personnel act as spotters inside and outside the storage facility)



Presenter M3/Material | Date FINAL | Slide 4 of 9 | Closed

ET – Foam Maintenance

ET shipped from MAF to KSC via Barge

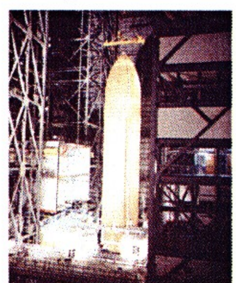


http://www-pk.ksc.nasa.gov/msdinfo/et/ETPhotoBook/OFFLOAD/Offload.htm

Presenter M3/Material | Date FINAL | Slide 5 of 9 | Closed

ET – Foam Maintenance

Raising the ET for Stacking in the Vehicle Assembly Building at KSC



Presenter M3/Material | Date FINAL | Slide 6 of 9 | Closed

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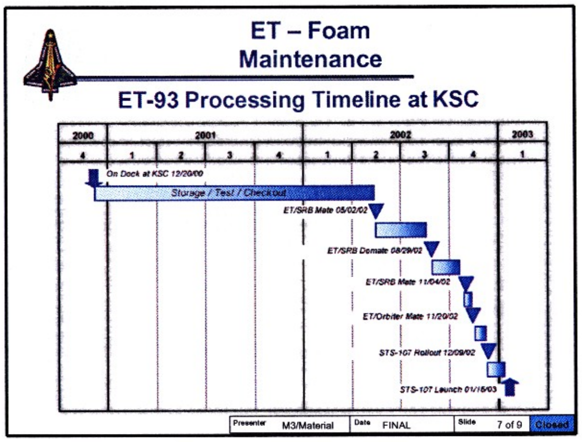
ET – Foam
Maintenance
ET-93 Processing Timeline at KSC
2000
2001
2002
2003
4
1
2
3
4
1
2
3
4
1
On Dock at KSC 12/20/00
Storage / Test / Checkout
ET/SRB Mate 05/02/02
ET/SRB Demate 08/29/02
ET/SRB Mate 11/04/02
ET/Orbiter Mate 11/20/02
STS-107 Rollout 12/09/02
STS-107 Launch 01/16/03
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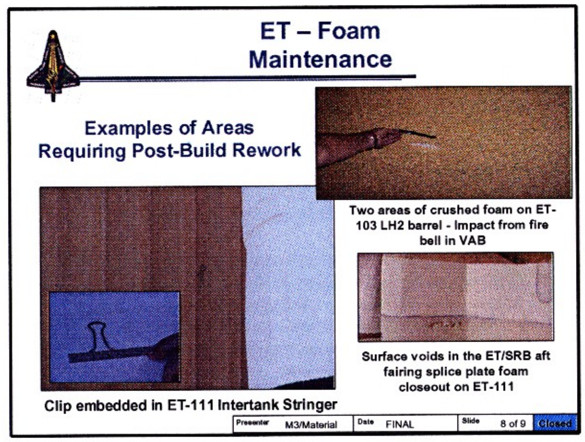
ET – Foam
Maintenance
Examples of Areas
Requiring Post-Build Rework
Two areas of crushed foam on ET-103 LH2 barrel - Impact from fire bell in VAB
Surface voids in the ET/SRB aft fairing splice plate foam closeout on ET-111
Clip embedded in ET-111 Intertank Stringer
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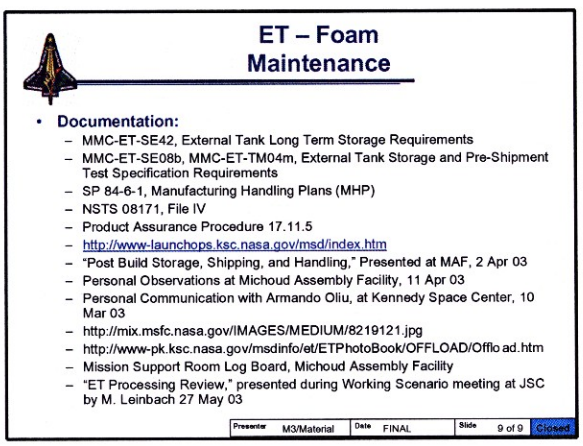
ET – Foam
Maintenance
• Documentation:
– MMC-ET-SE42, External Tank Long Term Storage Requirements
– MMC-ET-SE08b, MMC-ET-TM04m, External Tank Storage and Pre-Shipment Test Specification Requirements
– SP 84-6-1, Manufacturing Handling Plans (MHP)
– NSTS 08171, File IV
– Product Assurance Procedure 17.11.5
– http://www-launchops.ksc.nasa.gov/msd/index.htm
– "Post Build Storage, Shipping, and Handling," Presented at MAF, 2 Apr 03
– Personal Observations at Michoud Assembly Facility, 11 Apr 03
– Personal Communication with Armando Oliu, at Kennedy Space Center, 10 Mar 03
– http://mix.msfc.nasa.gov/IMAGES/MEDIUM/8219121.jpg
– http://www-pk.ksc.nasa.gov/msdinfo/et/ETPhotoBook/OFFLOAD/Offlo ad.htm
– Mission Support Room Log Board, Michoud Assembly Facility
– "ET Processing Review," presented during Working Scenario meeting at JSC by M. Leinbach 27 May 03
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ET – Foam
Launch – Ascent

4-1	Cryopumping
4-2	ET Foam Loss History
4-3	Aerodynamic Loads on the Bipod Ramp
4-4	Foam Loss Related to Weather
4-5	Water Absorption by ET Foam

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	6 of 32

ET – Foam
Launch – Ascent

- **Action / Issue:** Cryopumping & Cryoingestion
- **Background / Facts:**
  - Cryoingestion: escape of N2 from intertank into SLA or foam
    - Gaseous N2 used to purge inner tank condenses to liquid on upper surface of LH2 tank
    - LN2 can leak through LH2-intertank flange shims, panel joints, and vent holes under stringers
    - LN2 can then enter voids in foam or can be absorbed by SLA
  - Cryopumping: entry of ambient air through cracks in foam
    - Type (2) Ambient air condenses on surface of LO2 or LH2 tanks
    - Air can come into contact with tank surface through cracks in foam
    - Air can then enter voids or debonds at foam/substrate interface
  - Theory:
    - Trapped liquid N2 or liquid air vaporizes during ascent as temp rises
    - Lacking an escape path, vaporization causes a pressure build-up
    - Pressure can force foam to shed off the ET

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ET – Foam
Launch – Ascent

- **Findings:**
  - Recent dissections of bipod ramps and LH2-intertank flanges (ET-94, ET-120, ET-124) revealed flaws (voids, disbonds, FOD) - potential cryoingestion/cryopumping sites
  - Cracks in intertank stringer valleys & other areas may contribute to cryopumping
  - No evidence exists of SLA having spalled off along with foam
  - Test #6 at MSFC (cryoingestion) revealed:
    - When conditions were correct for cryoingestion and subsequent vaporization, foam failure mode was characterized by cracking
    - Cracking relieved pressure permitting N2 to escape from beneath foam
    - No spalling of foam was observed
    - Test #6 conditions do not simulate the operational environment

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ET – Foam
Launch – Ascent

- **Findings: (cont.)**
  - Test #2 at MSFC (combined thermo/cryo/vacuum environment) revealed:
    - Conditions during tanking favor the formation of liquid and/or solid N2 in "Y" joint at intertank flange
    - Conditions are not correct for vaporization of liquid/solid N2 during ascent
  - MSFC will continue to change parameters on Test #2 to determine if N2 vaporization can be artificially induced
  - Bottom Line: Vaporization following ingestion of N2 from the intertank may be a contributing mechanism for foam loss but does not appear to be the sole driver

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ET – Foam
Launch – Ascent

- **Findings: (cont.)**
  - Test #6 at MSFC (cryoingestion) revealed:
    - When conditions were correct for cryoingestion and subsequent vaporization, foam failure mode was characterized by cracking
    - Cracking relieved pressure permitting N2 to escape from beneath foam
    - No spalling of foam was observed
    - Test #6 conditions do not simulate the operational environment
      - Rapid warm up of the backface is not representative of flight environment
        - » Even with rapid warming, it takes approximately 3-5 minutes to build up enough pressure to crack foam, time far outside STS-107 bipod foam loss
  - **Bottom Line: Test #2 and Test #6 together show that vaporization following ingestion of N2 from the intertank is probably not a contributor to bipod ramp foam loss during ascent**

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ET – Foam
Launch – Ascent

- **Recommendations:**
  - NASA (MSFC) should continue with the series of tests planned to investigate the loss of the bipod foam ramp from ET-93 during STS-107
    - These tests will focus on understanding the cryopumping/ingestion issue and its effect on and relationship to other environmental conditions that the ET experiences during launch and ascent.
  - NASA should perform independent (non-MSFC) testing to understand cryo-effects and other foam properties/behavior
  - Lessons learned from these tests must be used in the redesign of the bipod fitting enclosure and also in the redesign of the LH2-intertank flange area
  - Cryopumping and cryoingestion must be eliminated as potential initiating events for foam loss from the ET.

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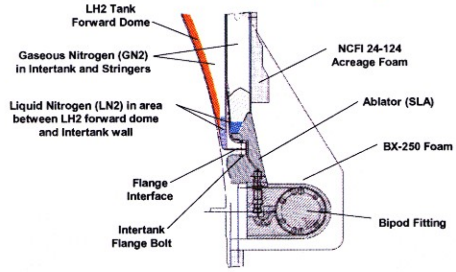
ET – Foam
Launch – Ascent

Cryoingestion of LN2 from Intertank through Intertank-LH2 Flange in Bipod Region



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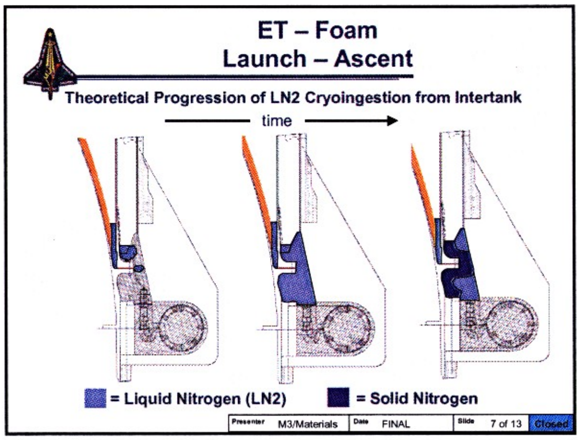
ET – Foam
Launch – Ascent
Theoretical Progression of LN2 Cryoingestion from Intertank
time
= Liquid Nitrogen (LN2)
= Solid Nitrogen
Presenter M3/Materials
Date FINAL
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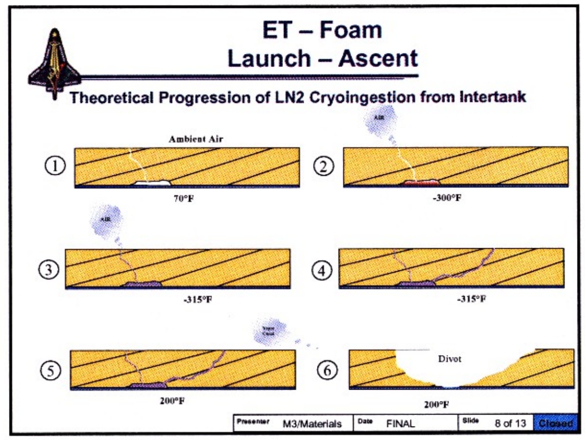
ET – Foam
Launch – Ascent
Theoretical Progression of LN2 Cryoingestion from Intertank
Ambient Air
70°F
-300°F
-315°F
-315°F
200°F
Divot
200°F
Presenter M3/Materials
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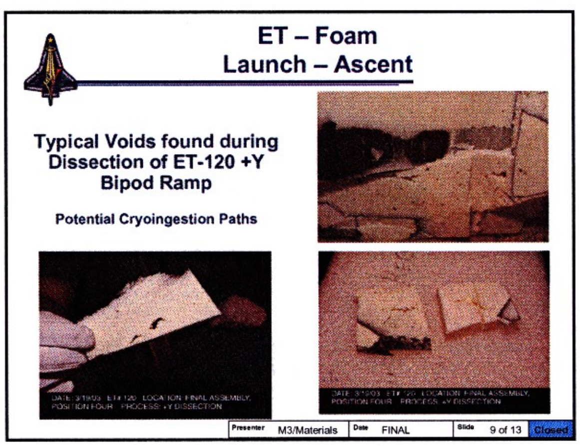
ET – Foam
Launch – Ascent
Typical Voids found during Dissection of ET-120 +Y Bipod Ramp
Potential Cryoingestion Paths
Presenter M3/Materials
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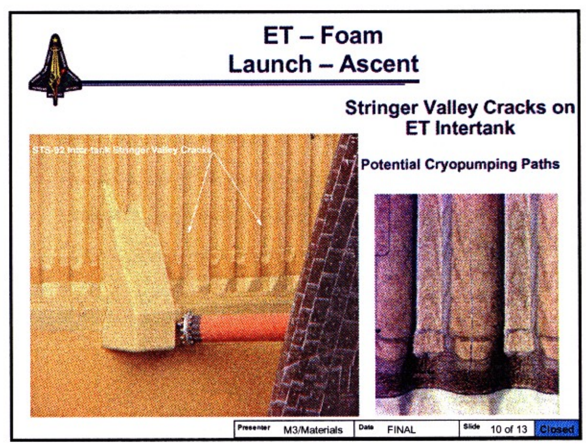
ET – Foam
Launch – Ascent
Stringer Valley Cracks on ET Intertank
Potential Cryopumping Paths
Presenter M3/Materials
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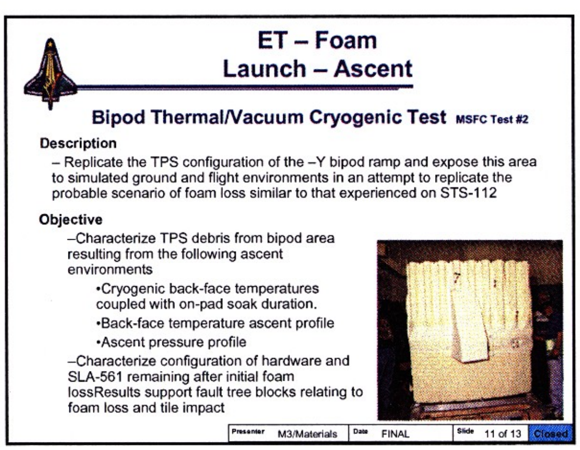
ET – Foam
Launch – Ascent
Bipod Thermal/Vacuum Cryogenic Test MSFC Test #2
Description
– Replicate the TPS configuration of the –Y bipod ramp and expose this area to simulated ground and flight environments in an attempt to replicate the probable scenario of foam loss similar to that experienced on STS-112
Objective
–Characterize TPS debris from bipod area resulting from the following ascent environments
•Cryogenic back-face temperatures coupled with on-pad soak duration.
•Back-face temperature ascent profile
•Ascent pressure profile
–Characterize configuration of hardware and SLA-561 remaining after initial foam lossResults support fault tree blocks relating to foam loss and tile impact
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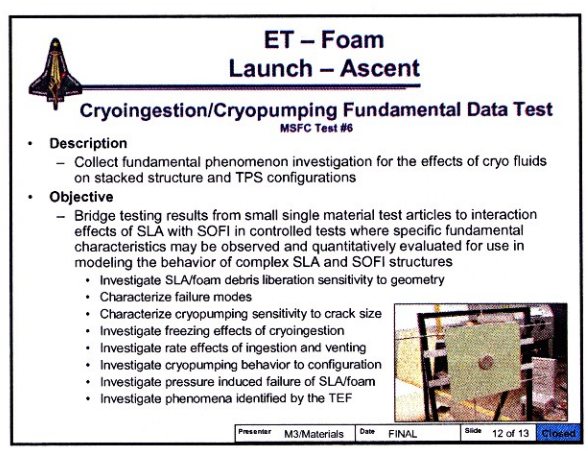
ET – Foam
Launch – Ascent
Cryoingestion/Cryopumping Fundamental Data Test
MSFC Test #6
• Description
– Collect fundamental phenomenon investigation for the effects of cryo fluids on stacked structure and TPS configurations
• Objective
– Bridge testing results from small single material test articles to interaction effects of SLA with SOFI in controlled tests where specific fundamental characteristics may be observed and quantitatively evaluated for use in modeling the behavior of complex SLA and SOFI structures
• Investigate SLA/foam debris liberation sensitivity to geometry
• Characterize failure modes
• Characterize cryopumping sensitivity to crack size
• Investigate freezing effects of cryoingestion
• Investigate rate effects of ingestion and venting
• Investigate cryopumping behavior to configuration
• Investigate pressure induced failure of SLA/foam
• Investigate phenomena identified by the TEF
Presenter M3/Materials
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ET – Foam
Launch – Ascent

- **Documentation:**
  - "External Tank Working Group Test Approval Request" presented to CAIB, 25 Feb 03
  - "Technical Exchange Forum on External Tank Nonmetallic Debris," MSFC, 3-4 Mar 03
  - "External Tank Working Group - Testing" presented at MAF, 14 Mar 03

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ET – Foam
Launch – Ascent

- **Action / Issue:** The ET has shed foam since STS-01. Major events, such as the loss of portions of bipod foam ramps, have occurred periodically.
- **Background / Facts:**
  - Although tile damage is often used as the indicator of foam loss, no conclusive evidence exists linking tile damage with foam loss
    - Chemical sampling of tile damage sites for foam has been inconclusive
    - Debris sources are not limited to the ET
    - Use of imagery from launch, ascent, and ET separation is necessary to confirm foam loss
  - All 113 STS missions have been reviewed to determine availability of launch/ascent imagery data
  - No imagery coverage available on 34 missions
    - 16 Night Launches & 18 Day Launches with no camera coverage
  - Bottom line: Presence or absence of foam loss can be visually confirmed on 79 of 113 missions at this time

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ET – Foam
Launch – Ascent

- **Findings:** *Recall, visual imagery available on 79 of 113 missions*
  - 65 missions experienced visually confirmed foam loss
    - Foam loss confirmed on **82%** of missions for which imagery was available
    - 55 experienced loss of foam from LH2-Intertank flange
    - 34 experienced loss of foam from Intertank acreage
    - At least 7 experienced loss of a portion of a bipod ramp (all –Y [left])
    - 12 experienced <u>confirmed</u> loss of foam from thrust panels ("popcorning")
    - 45 experienced loss of foam from other sites
    - Of the 57 without a bipod ramp loss, 39 experienced losses "near bipod"
  - Worst damage to orbiter tiles: STS-27R (OV-104)
    - Due to loss of SRB ablator material: **<u>not</u>** due to loss of ET foam
    - Hits to orbiter: 644 lower surface (272 >1") [707 total (298 > 1")]
  - Most damage to tiles from ET foam loss: STS-87 (OV-102)
    - Thrust panel popcorning
    - Hits to orbiter: 244 lower surface (109 >1") [308 total (132 > 1")]

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ET – Foam
Launch – Ascent

- **Findings (con't):**
  - MSFC has taken actions on numerous occasions to eliminate or reduce foam loss from the ET
- **Recommendations:**
  - NASA must continue testing currently underway at MSFC and MAF to identify the root cause(s) for the generation of debris from the ET.
  - NASA must minimize the generation of debris from the ET.
  - NASA must establish programs to understand the possible damage resulting from debris impacts on other Space Shuttle elements.
  - NASA must institute a policy to provide (visual) imagery on 100% of launches to check for ET foam loss and other launch debris.

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ET – Foam
Launch – Ascent

- **Recommendations (con't):**
  - NASA must harden each of the Space Shuttle elements (especially the orbiter) to maximize their impact damage tolerance.
  - NASA should take an integrated approach to address these recommendations
    - All future efforts that minimize the debris generated by each Space Shuttle element and maximize each element's impact damage tolerance must be mutually compatible.
  - NASA should consider eliminating a foam-covered ET from the Space Transportation System

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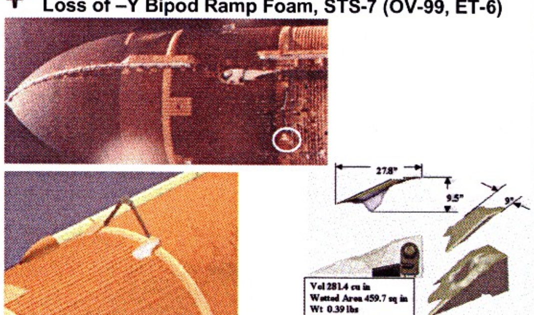
ET – Foam
Launch – Ascent

Loss of –Y Bipod Ramp Foam, STS-7 (OV-99, ET-6)



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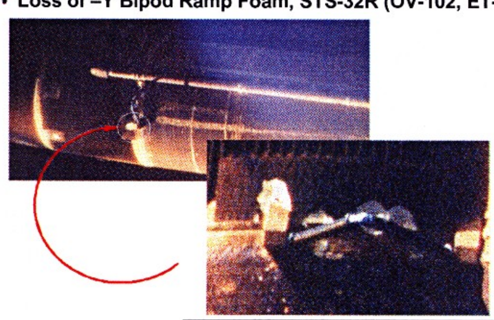
ET – Foam
Launch – Ascent

Loss of –Y Bipod Ramp Foam, STS-32R (OV-102, ET-32)



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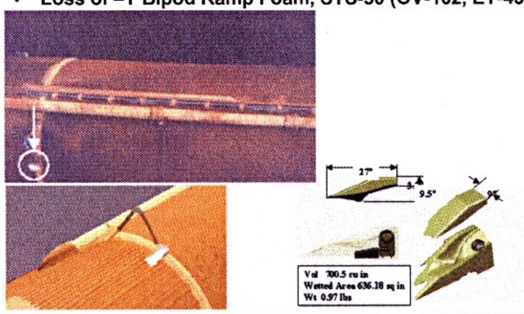
ET – Foam
Launch – Ascent

Loss of –Y Bipod Ramp Foam, STS-50 (OV-102, ET-43)



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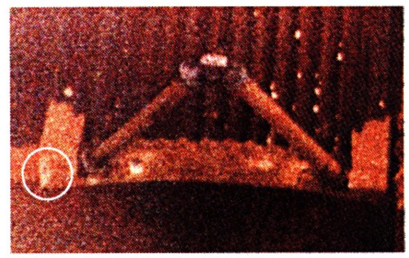
ET – Foam
Launch – Ascent

Loss of –Y Bipod Ramp Foam, STS-52 (OV-102, ET-55)



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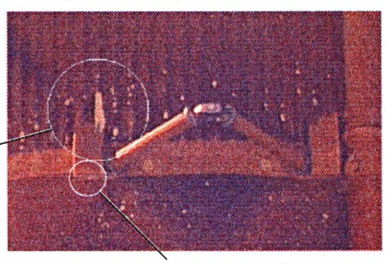
ET – Foam
Launch – Ascent

Loss of –Y Bipod Ramp Foam, STS-62 (OV-102, ET-62)

4" x 14" divot lost from stringer head on intertank



Shallow 1" x 3" divot lost from rear face of bipod foam ramp

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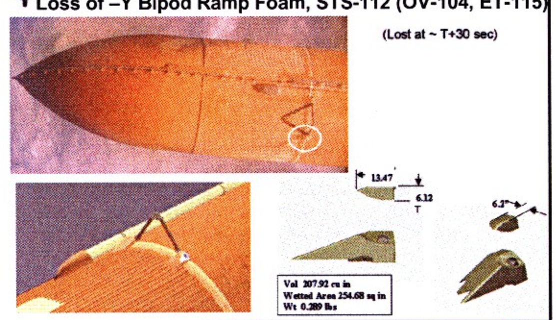
ET – Foam
Launch – Ascent

Loss of –Y Bipod Ramp Foam, STS-112 (OV-104, ET-115)

(Lost at ~ T+30 sec)



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ET – Foam
Launch – Ascent

Summary of Some ET Project Office Efforts to Reduce Debris Shed by External Tank

STS	ET	Launch Date	Precipitating Event / Concern	Efforts to Reduce Debris
1	1	4/12/1981	Ice may form on instrumentation islands and become debris	Removed instrumentation islands on LO2 Tank to insure no ice debris
6	8 (LWT 1	4/1/83	Block change to Lightweight Tank enabled design changes	Redesign of Bipod Ramp angle from 45° to 30° on LWT-7
				Incorporated maximum repairable defect limits on Bipod ramp
				Incorporated improved fabrication procedures for LH2 tank cable tray ice frost ramps (two-step single-pour application versus one-step multi-pour process)
				Reduced SLA areas
				Deleted anti-geyser line
				Incorporated "two-tone" foam configuration on areas of the Intertank
27	21	8/14/1985	Large intertank divots observed on STS-25 & STS-26	Corrective action (drilled holes) applied in two-tone areas to preclude debris due to Isochem bondlayer issues
32R	32	1/9/1990	Intertank / Bipod divot observed on STS-32R	Added inspection to verify vent hole depth in two-tone areas
35	35	12/2/1990	Ten flange area divots observed on STS-35	Incorporated process improvements to reduce potential for void formation around the flange bolts
50	50	6/25/1992	Jack-pad area divot observed on STS-50	Changed jack-pad closeout method
46	48	7/31/1992	Intertank / Bipod divot observed on STS-50	Added more vent holes around bipod ramps in two-tone areas
54	51	1/13/1993	Previous problems with two-tone Intertank foam	Incorporated two-gun spray foam application on intertank to replace two-tone foam
56	54	4/8/1993	Ten large, shallow divots on -Z Intertank Acreage	Enhancement of Process to reduce roll-over and crevicing
87	89	11/19/1997	Increased number of Orbiter tile hits	Reduced foam thickness
				Incorporated "vent" holes
112	115	10/7/2002	Bipod foam loss on STS-112	Proposed corrective action (to be presented 2/8/03): remove SLA from under the foam application

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ET – Foam
Launch – Ascent

- **Documentation:**
  - CAIB Request for Information, "External Tank Foam Loss,"B1-00039
  - MAF Mission Support Room Log Board, Michoud Assembly Facility
  - http://www-pao.ksc.nasa.gov/kscpao/factoids/shfacts.htm (night launches)
  - STS-ET Correlation.xls, from Jim Feeley, MAF
  - CAIB Request for Information, "Debris Info STS-32 -35 -42 - 58 Summary.xls." B0-000026
  - CAIB Request for Information, "CAIB Cryoinsulation Report," B1-000121
  - CAIB Request for Information, "Discussions at MSFC…" (w/ Scotty Sparks & Steve Holmes), B1-000132
  - "Tile Chemical Analysis," Discussion & E-mail with Jorge Rivera @ MAF, 10 Apr 03
  - "ET Cryoinsulation," presented at the CAIB Public Hearing, L. Foster & S. Sparks, 7 Apr 03.

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2

Ascent Debris Strike
Other (ET/Foam)

- **Action / Issue:** Complex aerodynamic loads on ET-93's bipod foam ramp may have caused it to fail during the ascent of STS-107
- **Background / Facts:**
  - Bipod foam ramp shed at 81 sec (Mach 2.46, $\alpha = 2.08^{o}$)
  - Ascent environment is very severe; flow field is complex
    - 3 intersecting shocks occur in bipod region
  - Airloads determined by numerous methods
    - Wind tunnel testing of 3% scale model
    - Computational Fluid Dynamics (CFD) analysis
    - Analytical (Hoerner) analysis

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Ascent Debris Strike
Other (ET/Foam)

- **Findings:**
  - Early wind tunnel tests on flat-faced and 20° angle ramps confirmed a 1.1 safety factor against failure caused by aerodynamic loads
    - Additional analysis calculated a safety factor of 2.35
    - Wind tunnel testing was not performed on the current bipod ramp geometry (22°-30°) nor on flight configuration articles (SLA, underlying bipod fitting, etc.)
  - Wind tunnel testing was also performed on 3% scale model of Space Shuttle
    - Correlation between this testing and CFD/analytical models was good
    - MADS data from the OEX recorded recovered from STS-107 confirmed that CFD and analytical models were conservative
  - No flight instrumentation was used on early ETs to investigate airloads on bipod ramps
    - Instrumentation on early flights collected only bipod strut strains

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Ascent Debris Strike
Other (ET/Foam)

- **Findings: (cont.)**
  - Aerodynamic loads predicted by CFD and analytical methods are significantly less than design requirements
    - Minimum safety factor is 1.4
  - Vibroacoustic analysis calculated a safety factor of 1.64 against the formation of divots
  - No finite element analysis was performed to determine the ability of the bipod foam ramps to withstand aerodynamic loads
    - Complexity of geometry and material makes such modeling difficult
    - Efforts are in place at MAF to develop a finite element modeling capability for foam protuberances
  - The complex combined aero/thermo/vibro/vacuum/acoustic is extremely difficult to simulate, thus, combined testing was never performed
    - "Worst case" conditions were solved and superimposed to determine the integrity of the bipod foam ramps under these conditions

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Ascent Debris Strike
Other (ET/Foam)

- **Findings: (cont.)**
  - No studies of the behavior of partially failed (i.e. cracked, etc.) bipod foam ramps was ever performed
  - No evidence that aerodynamic loads, alone, caused bipod ramp to fail on ET-93 during STS-107
    - In fact, precited aero loads have a large radial load component (300 lb) forcing ramp to remain on ET
- **Recommendations:**
  - NASA must continue to improve its capabilities to perform analytical and numerical simulations of the complex combined environments to which the the ET is exposed.
    - These capabilities must be validated with test and/or flight data

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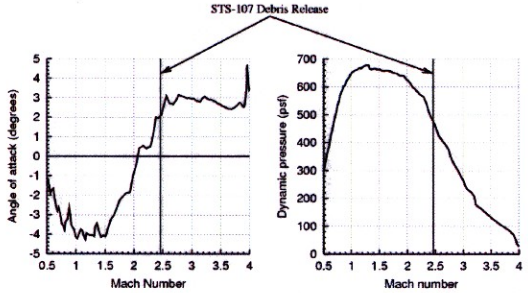
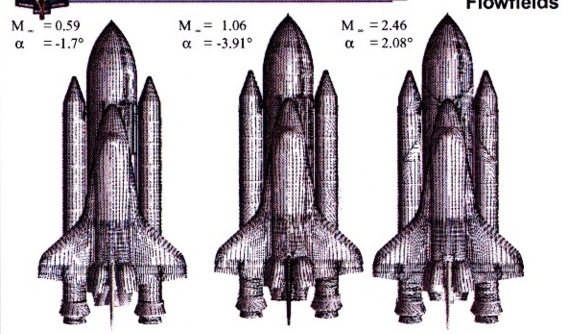
Ascent Debris Strike
Other (ET/Foam)



Presenter M3/Material | Date FINAL | Slide 5 of 15 | Closed

Ascent Debris Strike
Other (ET/Foam)

Flowfields



Presenter M3/Material | Date FINAL | Slide 6 of 15 | Closed

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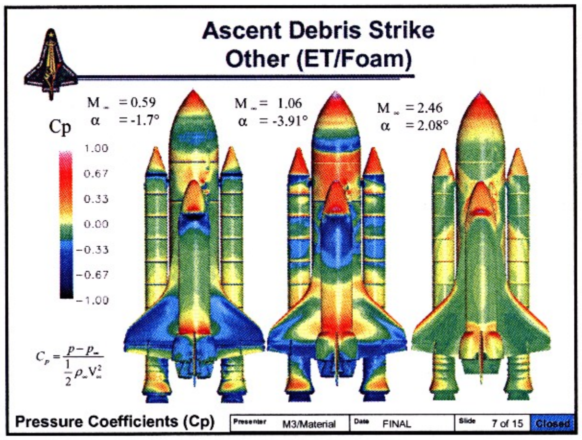
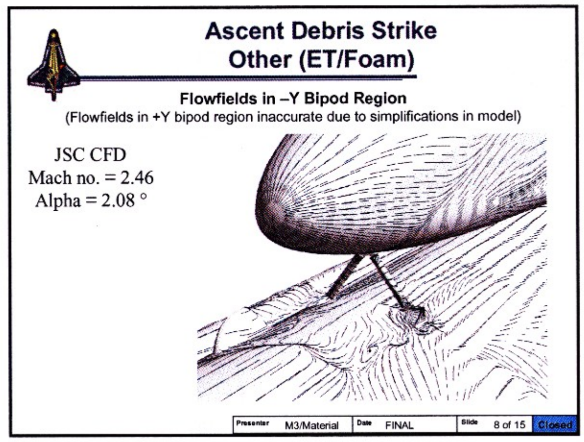
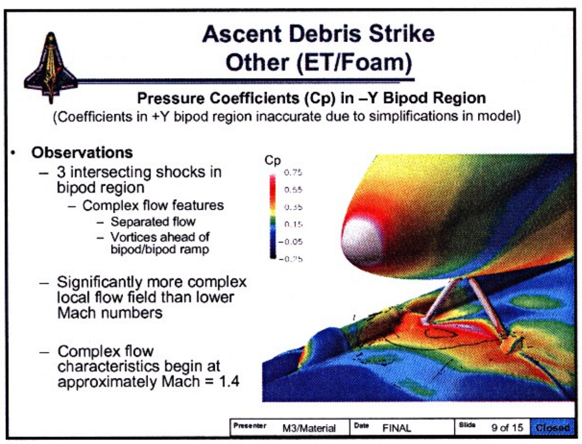
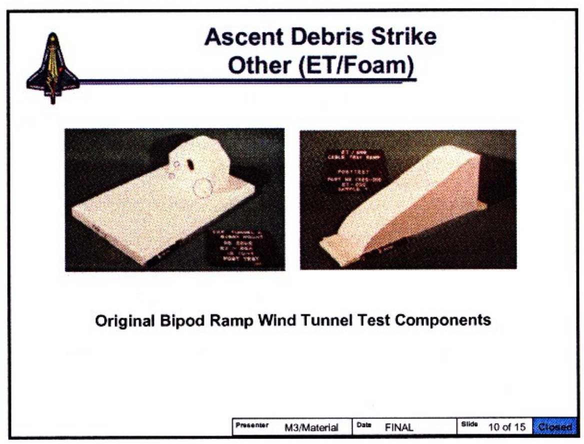
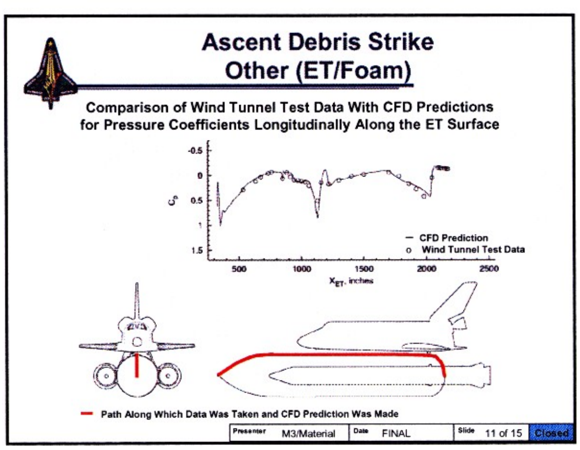
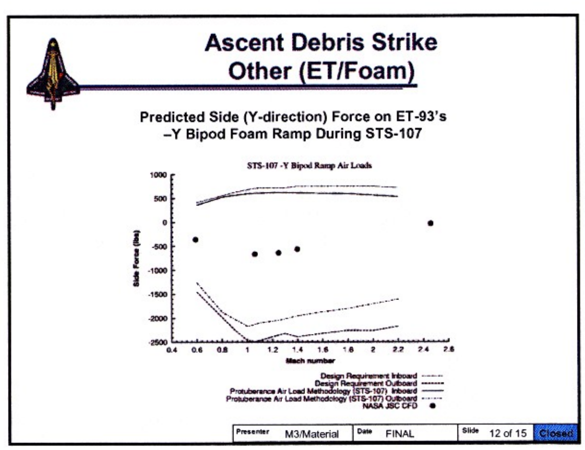

Ascent Debris Strike
Other (ET/Foam)
Cp
1.00
0.67
0.33
0.00
-0.33
-0.67
-1.00
M∞ = 0.59
α = -1.7°
M∞ = 1.06
α = -3.91°
M∞ = 2.46
α = 2.08°
Pressure Coefficients (Cp)
Presenter M3/Material Date FINAL Slide 7 of 15 Closed


Ascent Debris Strike
Other (ET/Foam)
Flowfields in –Y Bipod Region
(Flowfields in +Y bipod region inaccurate due to simplifications in model)
JSC CFD
Mach no. = 2.46
Alpha = 2.08 °
Presenter M3/Material Date FINAL Slide 8 of 15 Closed


Ascent Debris Strike
Other (ET/Foam)
Pressure Coefficients (Cp) in –Y Bipod Region
(Coefficients in +Y bipod region inaccurate due to simplifications in model)
• Observations
– 3 intersecting shocks in bipod region
– Complex flow features
– Separated flow
– Vortices ahead of bipod/bipod ramp
– Significantly more complex local flow field than lower Mach numbers
– Complex flow characteristics begin at approximately Mach = 1.4
Cp
Presenter M3/Material Date FINAL Slide 9 of 15 Closed


Ascent Debris Strike
Other (ET/Foam)
Original Bipod Ramp Wind Tunnel Test Components
Presenter M3/Material Date FINAL Slide 10 of 15 Closed


Ascent Debris Strike
Other (ET/Foam)
Comparison of Wind Tunnel Test Data With CFD Predictions
for Pressure Coefficients Longitudinally Along the ET Surface
— CFD Prediction
o Wind Tunnel Test Data
500
1000
1500
2000
2500
— Path Along Which Data Was Taken and CFD Prediction Was Made
Presenter M3/Material Date FINAL Slide 11 of 15 Closed


Ascent Debris Strike
Other (ET/Foam)
Predicted Side (Y-direction) Force on ET-93's
–Y Bipod Foam Ramp During STS-107
STS-107 -Y Bipod Ramp Air Loads
Mach number
Presenter M3/Material Date FINAL Slide 12 of 15 Closed

2

Ascent Debris Strike
Other (ET/Foam)

Predicted Bipod Foam Ramp Aerodynamic Loads

Axis	Design Requirements (lb) (Independent of Mach)	CFD predictions of Flight Loads		
		Mach 0.59	Mach 1.06	Mach 2.46
Max Axial Load (+aft)	899.4	254	637	48
Max Side Load (+/-) (+ inboard)	756.2/-2483.5	-359	-664	-24
Max Radial Load (+ inward)	1409.3	-332	-24	322

↑ Includes Safety Factor of 1.4

Predictions Indicate Aerodynamic Loads Are <u>Less Than</u> Design Limits

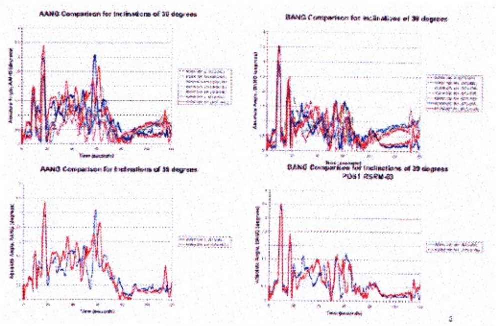
Presenter M3/Material | Date FINAL | Slide 13 of 15 | Closed

Ascent Debris Strike
Other (ET/Foam)

- **Documentation:**
  - "Bipod Airflow and Loads," presented by R. Gomez, RFI B1-000050, 23 Mar 03
  - "ET Bipod Aero Ramp Foam Verification / Certification," presented by M. Quiggle, at Michoud Assembly Facility, 10 Apr 03
  - "Ascent CFD Verification," RFI B1-000147, 22 Apr 03.
  - Personal Communication, M. Quiggle, at Michoud Assembly Facility, 15 May 03.
  - "1.1.1 TPS Debris Fault Tree Closeout Briefing," S. Sparks at MSFC, 20 May 03

Presenter M3/Material | Date FINAL | Slide 14 of 15 | Closed

Absolute Angle for Flights at 39° Inclination



Presenter M3/Material | Date FINAL | Slide 15 of 15 | Closed

ET – Foam
Launch – Ascent

- **Action / Issue:** Potential for Foam Loss to be Related to Weather
- **Background / Facts:**
  - Numerous suggestions (via PIAs and media) that foam loss is related to moisture absorption and/or ice formation
  - Weather office at KSC has provided the following historical info for the time during which the shuttle was outside for each mission: 1) daily rainfall, 2) min/max daily temps, 3) min/max daily rh, 4) min/max daily atm pressure, 5) max daily surface wind gusts & direction, 6) temp at start of tanking (fueling), 7) temp at launch
- **Findings:**
  - Average ET pre-launch exposure time for all missions is 38.5 days
    - ET-93 (used on STS-107) was on the pad for 39 days prior to launch
    - No apparent trend linking pre-launch exposure time to foam loss
  - No apparent trends linking foam loss with any weather variables analyzed

Presenter	M3/Material	Date	FINAL	Slide	1 of 3	Closed

ET – Foam
Launch – Ascent

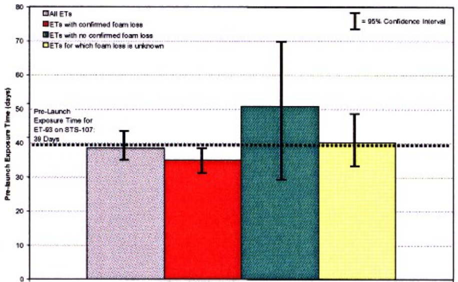
- **Recommendations:**
  - NASA should continue to investigate moisture absorption by foam and relate any results to pre-launch exposure of the ET to the atmosphere.
  - NASA should continue analyzing weather data in search of correlations between weather variables and foam loss. Particular attention should be given to identifying the importance of combinations of variables that might contribute to foam loss.
- **Documentation:**
  - RFI B1-00145 "Historical Weather Data," 27 Mar 03
  - John Madura, KSC Weather Office, 321-867-0814, john.t.madura@nasa.gov

Presenter	M3/Material	Date	FINAL	Slide	2 of 3	Closed

ET – Foam
Launch – Ascent

Relationship Between Foam Loss and ET Pre-Launch Exposure

(Overlapping confidence intervals indicate no significant difference among categories of data)



Presenter	M3/Material	Date	FINAL	Slide	3 of 3	Closed

ET – Foam
Launch – Ascent

- **Action / Issue:** Moisture absorption by the External tank (ET) foam may have caused or exacerbated the foam loss event by increasing the mass of the piece shed from ET-93 during the ascent of STS-107
- **Background / Facts:**
  - PIA #644 cited a "review of publications" indicating closed-cell foam can absorb water and increase in mass by a factor of 10
  - B. Peterson (formerly of Texaco Chemical) cited experience with polyurethane foams that could absorb water at near-freezing temperatures if chemical constituents of foam were correct
  - Prof. L. Glicksman (M.I.T.) performed preliminary calculations
    - Showed water vapor could be absorbed into foam at 68°F and 100% rh
    - 6-hour tanking would result in absorption of 0.001 lb/ft^2 of water
  - Moisture absorption by foam is a concern in the building industry
    - PIA # 671 identified two commercially available codes designed to predict moisture absorption in foam
  - Incorrect analyses by media led to public misunderstandings

Presenter M3/Material | Date FINAL | Slide 1 of 12 | Closed

ET – Foam
Launch – Ascent

- **Findings:**
  - ET foams do not have chemistry susceptible to moisture absorption
    - Peterson identified a specific EO/PO ratio (ethylene oxide / propylene oxide) that made foams absorptive near 32°F
    - EO is the hydrophyllic component (attractive to water)
    - EO/PO ratio of ET foams is <u>zero</u>
  - Regardless of chemistry, unlikely that <u>closed-cell</u> foam can absorb liquid water
    - Diffusional absorption of water vapor <u>may</u> be possible
  - Prof. Glicksman predicted ice and vaporization layers
    - Potential ice layer: thickness = 0.002 in, weight = 0.015 oz/ft^2
    - Vaporization layer: thickness = 0.2 in, weight = 0.06 oz/ft^2
  - Dr. Osheroff has performed simple experiments at Stanford
    - Immersion of foam in ice water suggests water permeates foam only to 0.004 in below surface
    - Consistent with depth of single layer of open cells at surface

Presenter M3/Material | Date FINAL | Slide 2 of 12 | Closed

ET – Foam
Launch – Ascent

- **Findings: (cont.)**
  - MSFC previously performed water absorption tests under accelerated conditions (7 days at 125°F and 95% rh)
    - NCFI 24-124 acreage foam: 0.12% weight gain
    - BX 250 closeout foam: 0.16% weight gain
    - SS 1171 feedline foam: 0.42% weight gain
    - PDL 1034 poured foam: 0.83% weight gain
    - Both foams had machined surfaces (i.e. surface cells were open)
  - Recent additional tests conducted at MSFC (with Prof. Leon Glicksman of M.I.T. retained as a consultant)
    - Immersion of BX 250 & NCFI 24-124 in distilled, de-aired water at 125°F for over 60 hours
      - Water absorption equivalent to thickness of exposed surface layer of open cells
      - Consistent with Dr. Glicksman's calculations and Dr. Osheroff's experiments

Presenter M3/Material | Date FINAL | Slide 3 of 12 | Closed

ET – Foam
Launch – Ascent

- **Findings: (cont.)**
  - Recent additional tests conducted at MSFC (cont.)
    - Vapor Phase Transmission through BX 250
      - Included thermal gradient of ~70°F to simulate tanking conditions
      - Level of transmission deemed insignificant (< 3 g/hr·m^2)
      - Especially in light of low moisture absorption & limited tanking times
  - Bottom Line from recent tests at MSFC
    - "Absorbed" water limited to open cells on surface
    - Any water absorbed deeper into foam does so through vapor transmission at a very low rate
    - Water ingress through voids/cracks open to surface and subsequent vaporization & crack formation or growth is a possibility
  - Role of long voids, wormholes, knitlines may merit further testing
  - Future research should integrate test results into a mechanistic, quantitative failure mode model

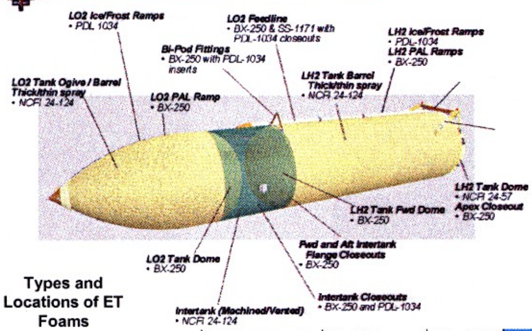
Presenter M3/Material | Date FINAL | Slide 4 of 12 | Closed

ET – Foam
Launch – Ascent

- **Group Recommendations:**
  - NASA should consider continued testing per Dr. Glicksman's suggestion
    - Investigating water ingress through unique features (long voids, etc.)
    - Developing failure mode model incorporating test results

Presenter M3/Material | Date FINAL | Slide 5 of 12 | Closed

ET – Foam
Launch – Ascent



Types and Locations of ET Foams

Presenter M3/Material | Date FINAL | Slide 6 of 12 | Closed

1

ET – Foam
Launch – Ascent

Types of ET Foams

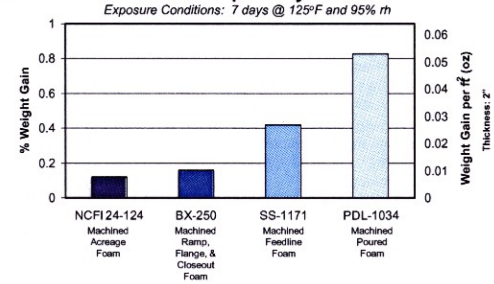
	NCFI 24-124	BX 250	NCFI 24-57	PDL 1034
% of Total Foam	(77%)	(14%)	(7%)	(1%)
Application Areas	LH2,L02,I/T sidewall	LH2 forward dome, L02 aft dome, closeouts	LH2 Aft Dome	Closeouts and repairs
Application Process	Automatic Spray	Manual Spray	Automatic Spray	Pour/Mold
Description	Isocyanurate	Urethane	Isocyanurate	Urethane

Presenter	M3/Material	Date	FINAL	Slide	7 of 12	Closed

ET – Foam
Launch – Ascent

Moisture Absorption by ET Foams

Exposure Conditions: 7 days @ 125°F and 95% rh



Presenter	M3/Material	Date	FINAL	Slide	8 of 12	Closed

ET – Foam
Launch – Ascent

ET Foam Moisture Absorption

Source: RFI B3-00060

- **NCFI 24-124**
  - Accelerated Exposure (7 days @ 125°F and 95% humidity)
    - 0.12% weight gain due to moisture absorption (machined foam)
  - Outdoor Exposure (28 day variable daily relative humidity)
    - 0.70% maximum weight gain due to moisture absorption (after 6 days)
    - 0.04% moisture loss after 28 days
- **Vented NCFI 24-124**
  - Concern: Holes in vented foam will wick moisture if ET is exposed to rain
  - Test performed: 5 repeated exposures of heavy rain and extreme freezing conditions caused no deterioration of the foam tensile properties

Presenter	M3/Material	Date	FINAL	Slide	9 of 12	Closed

ET – Foam
Launch – Ascent

ET Foam Moisture Absorption *(cont.)*

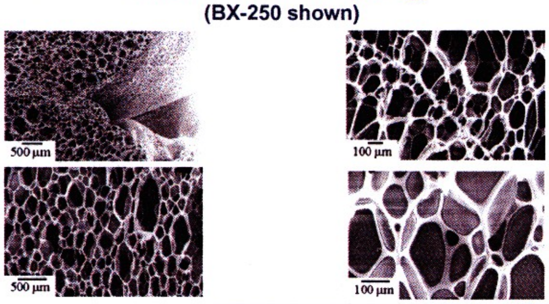
Source: RFI B3-00060

- **BX-250**
  - Accelerated Exposure (7 days @ 125°F and 95% humidity)
    - 0.16% weight gain due to moisture absorption (machined foam)
- **SS-1171**
  - Accelerated Exposure (7 days @ 125°F and 95% humidity)
    - 0.42% weight gain due to moisture absorption (machined foam)
- **PDL-1034**
  - Accelerated Exposure (7 days @ 125°F and 95% humidity)
    - 0.83% weight gain due to moisture absorption (machined foam)
- **Conclusion**
  - ET foam materials absorb insignificant amount of moisture under accelerated test conditions

Presenter	M3/Material	Date	FINAL	Slide	10 of 12	Closed

ET – Foam
Launch – Ascent

Closed-Cell Foam Morphology (BX-250 shown)



Presenter	M3/Material	Date	FINAL	Slide	11 of 12	Closed

ET – Foam
Launch – Ascent

- **Documentation:**
  - E-mail: Bruce Peterson to Johnny Wolfe, 27 Feb 03
  - E-mail: Leon Glicksman to MG Barry, 9 Mar 03
  - CAIB Request for Information, "External Tank Moisture Absorption," B3-00060
  - CAIB Request for Information, "ET Cryoinsulations," B1-000121
  - PIA 671 "Insulation & Moisture"
  - PIA 644 "Closed Cell Foam Can Absorb Water"
  - Discussion with Scotty Sparks (MSFC) at MAF, 16 Apr 03
  - Discussion with Dr. Osheroff (CAIB/Stanford) at MAF, 21 Apr 03
  - Response to RFI B1-000194 "ET Foam Moisture Absorption Testing," 1 Jun 03

Presenter	M3/Material	Date	FINAL	Slide	12 of 12	Closed

2

RCC
Design – Certification

5-1 WLE Subsystem Design Requirements and Certification

5-2 RCC Impact Energy Requirements and Certification

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	7 of 32

Wing Leading Edge Design & Certification

- **Action / Issue:** Determine adequacy of the WLE subsystem requirements, design and certification
- **Background / Facts:**
  - RCC is a critical component of the TPS (safety-of-flight)
  - Performance and design requirements documented in specification MJ070-0001-1E, 7 Nov 02
    - TPS impact energy design requirement is 0.006 foot-lbs (paragraph 3.3.1.8.11)
    - Orbiter not designed to withstand launch debris or ice (paragraph 3.3.1.8.16)

Presenter M3/Material | Date FINAL | Slide 1 of 26 | Closed

Wing Leading Edge Design & Certification

- **Background / Facts :**
  - Procurement specification MC621-0007, Rev E requirement more stringent than design requirement
    - Impact/ground handling damage resistance limits defined in figure 3.1
    - Impact energy limit ranges from 1 to 2.25 foot-pounds based on part thickness
  - TPS mission life requirement of 100 missions with scheduled maintenance and refurbishment (paragraph 3.4.3)

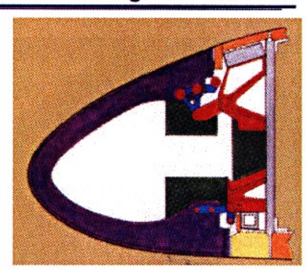
Presenter M3/Material | Date FINAL | Slide 2 of 26 | Closed

Wing Leading Edge Design & Certification

- **Background / Facts:**
  - RCC system is mounted to the wing front spar using attach fittings bolted to the front spar
  - Wing front spar attach fittings redesigned from a 2-piece design using A-286 steel (OV-102) to a 1-piece design using Ti-6Al-4V titanium (subsequent orbiters)
  - The insulators used to protect the metallic components of the WLE have been redesigned to increase survivability against MMOD
  - Moment constraint fittings (spanner beams) were retrofitted on several OV-102 RCC panels as a result of an increase in the predicted loads
    - OV-102 spanner beams installed on panels 5 through 19

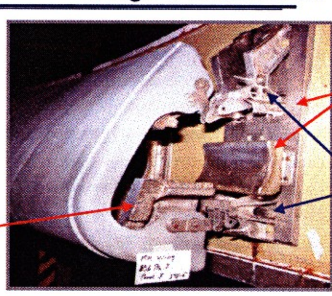
Presenter M3/Material | Date FINAL | Slide 3 of 26 | Closed

Wing Leading Edge Design & Certification



Presenter M3/Material | Date FINAL | Slide 4 of 26 | Closed

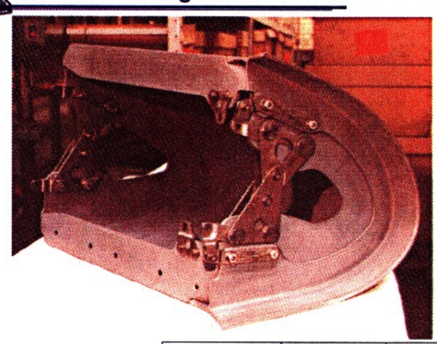
Wing Leading Edge Design & Certification



OV-102 RCC Panel 3 on Right Side

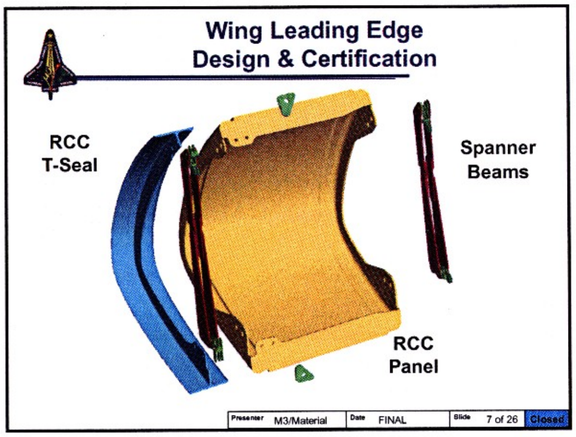
Presenter M3/Material | Date FINAL | Slide 5 of 26 | Closed

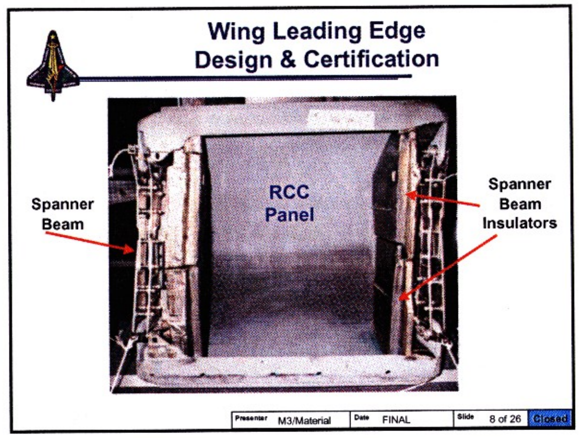
Wing Leading Edge Design & Certification

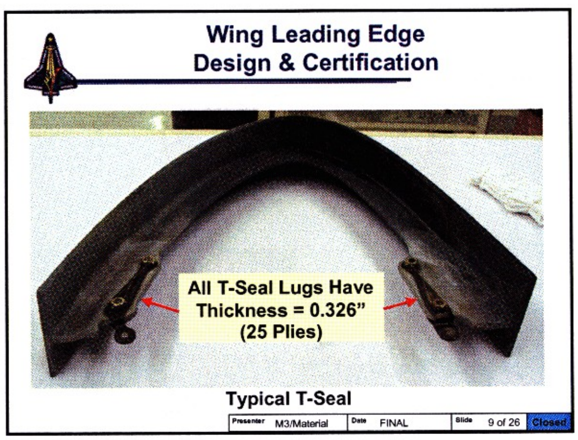


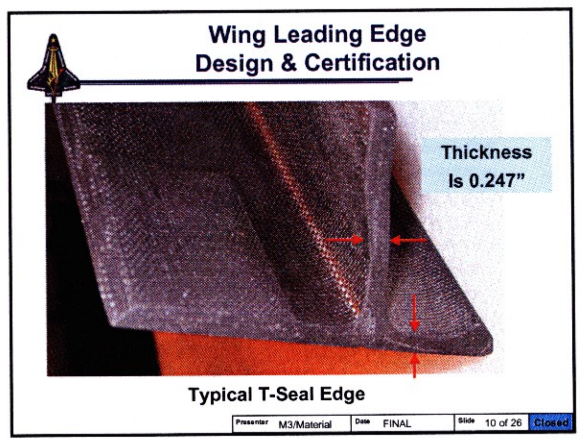
Presenter M3/Material | Date FINAL | Slide 6 of 26 | Closed

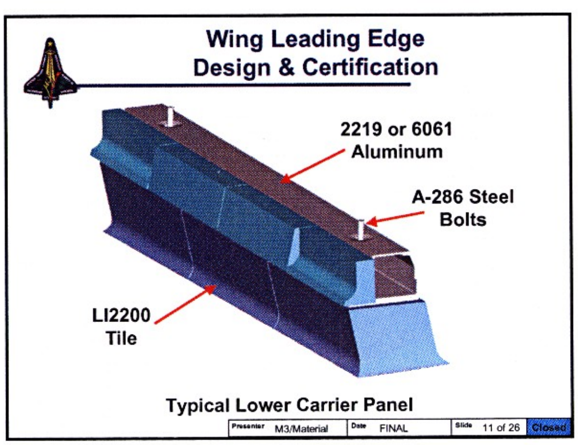
1

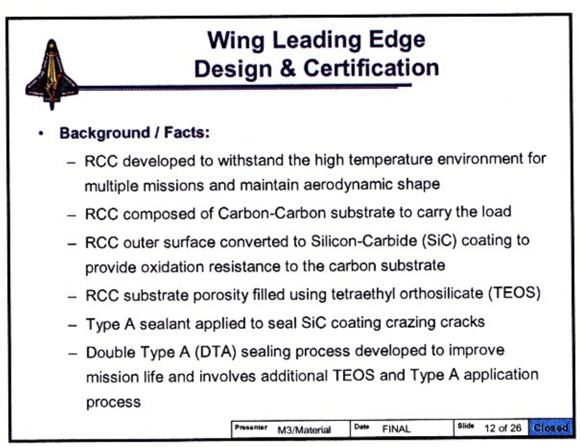

Wing Leading Edge
Design & Certification
RCC
T-Seal
Spanner
Beams
RCC
Panel
Presenter M3/Material
Date FINAL
Slide 7 of 26
Closed

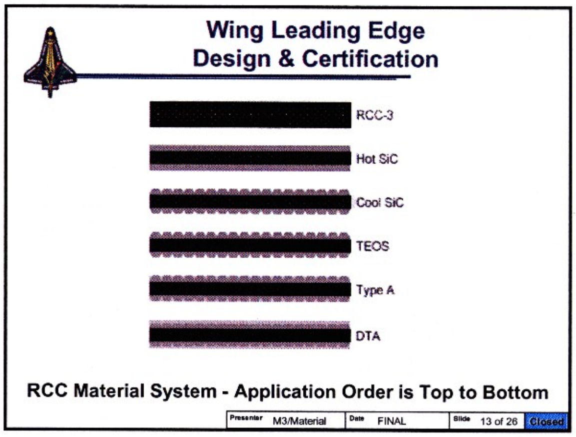

Wing Leading Edge
Design & Certification
Spanner
Beam
RCC
Panel
Spanner
Beam
Insulators
Presenter M3/Material
Date FINAL
Slide 8 of 26
Closed

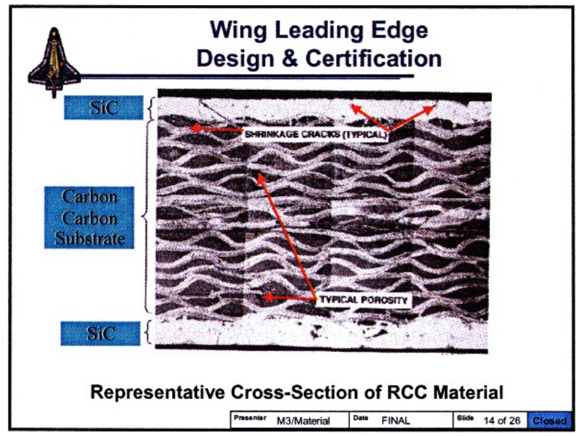

Wing Leading Edge
Design & Certification
All T-Seal Lugs Have
Thickness = 0.326"
(25 Plies)
Typical T-Seal
Presenter M3/Material
Date FINAL
Slide 9 of 26
Closed

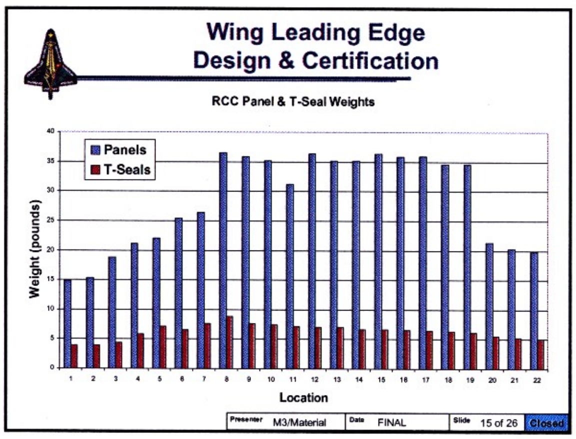

Wing Leading Edge
Design & Certification
Thickness
Is 0.247"
Typical T-Seal Edge
Presenter M3/Material
Date FINAL
Slide 10 of 26
Closed


Wing Leading Edge
Design & Certification
2219 or 6061
Aluminum
A-286 Steel
Bolts
LI2200
Tile
Typical Lower Carrier Panel
Presenter M3/Material
Date FINAL
Slide 11 of 26
Closed


Wing Leading Edge
Design & Certification
• Background / Facts:
– RCC developed to withstand the high temperature environment for multiple missions and maintain aerodynamic shape
– RCC composed of Carbon-Carbon substrate to carry the load
– RCC outer surface converted to Silicon-Carbide (SiC) coating to provide oxidation resistance to the carbon substrate
– RCC substrate porosity filled using tetraethyl orthosilicate (TEOS)
– Type A sealant applied to seal SiC coating crazing cracks
– Double Type A (DTA) sealing process developed to improve mission life and involves additional TEOS and Type A application process
Presenter M3/Material
Date FINAL
Slide 12 of 26
Closed







Wing Leading Edge Design & Certification

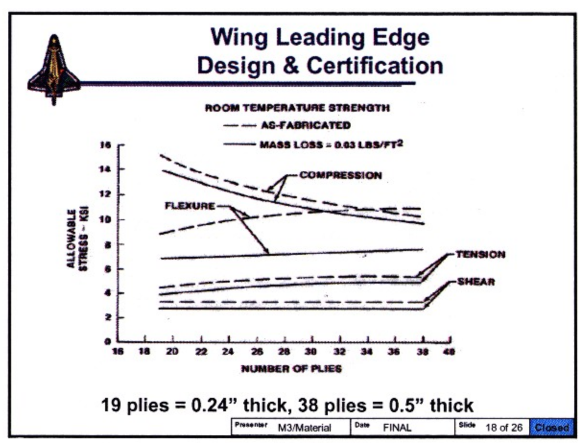
- **Background / Facts:**
  - Extensive analysis and testing was performed to certify the WLE subsystem to the performance requirements
  - Mechanical property (design allowables) documented in Vought Report 221RP00614, Rev A, 12 October 1994
    - Over 2,000 specimen tests were performed to characterize the RCC mechanical properties
  - Initial development tests did not reveal the susceptibility of RCC to subsurface oxidation

Presenter M3/Material | Date FINAL | Slide 16 of 26 | Closed

Wing Leading Edge Design & Certification

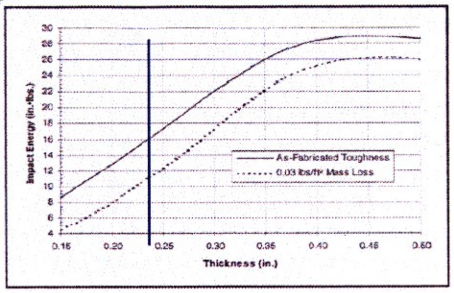
- **Background / Facts:**
  - Substrate mass loss significantly reduces flexure strength and impact energy resistance
  - Substrate mass loss has minimal affect on tension, compression and shear properties
  - Highest peak temperature occurs at Panel 9
  - Highest air loads occur at Panel 17

Presenter M3/Material | Date FINAL | Slide 17 of 26 | Closed



3

Wing Leading Edge Design & Certification



— Minimum WLE RCC Thickness

Presenter M3/Material | Date FINAL | Slide 19 of 26 | Closed

Wing Leading Edge Design & Certification

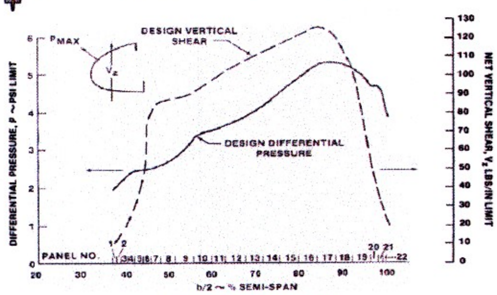


Figure 5 LESS Design Airloads

Presenter M3/Material | Date FINAL | Slide 20 of 26 | Closed

Wing Leading Edge Design & Certification

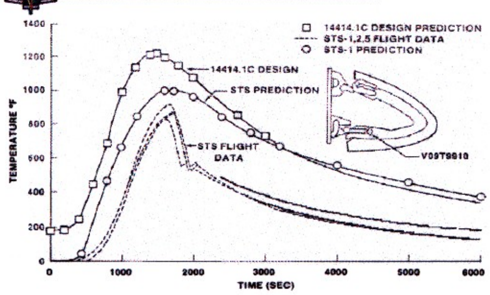


Figure 8 Wing LE Panel 9 Lower Attach Clevis Temperature

Presenter M3/Material | Date FINAL | Slide 21 of 26 | Closed

Wing Leading Edge Design & Certification

- **Findings (agreed to by Curry, Gordon, Grant):**
  - Impact of aging in terms of calendar time on corrosion, adhesive breakdown, etc. and impact to structural integrity must be determined
  - Safe-life design approach used for RCC mission life which is potentially an unsafe approach to ensure structural integrity
  - The residual strength of damaged RCC parts has not been demonstrated by testing with the exception of substrate oxidation, pinholes and craze cracks

Presenter M3/Material | Date FINAL | Slide 22 of 26 | Closed

Wing Leading Edge Design & Certification

- **Recommendations (agreed to by Curry, Gordon, Grant):**
  - Determine RCC component damage sources, frequency, and severity to include debris impact during ascent
  - Determine the damage tolerance capability for each damage type, location, and size ranges by calculating remaining service life and residual strength
  - Develop an NDE technique and capability to ensure damage limits have not been exceeded prior to each mission
  - Establish realistic service life duration expectation for remaining orbiters and revise operation and maintenance requirements accordingly

Presenter M3/Material | Date FINAL | Slide 23 of 26 | Closed

Wing Leading Edge Design & Certification

- **Documentation:**
  - Briefing by M. Gordon, "LESS/RCC Recovery and Reconstruction Data, OV-102 LESS/RCC Components Installed for STS-107", 1 March 2003
  - Boeing Specification MJ070-0001-1E, "Orbiter End Item Specification for the Space Shuttle Systems, Part 1, Performance and Design Requirements, 7 Nov 02
  - Briefing by D. Curry et al., "Orbiter RCC Design and Flight Experience", 28 July 1999

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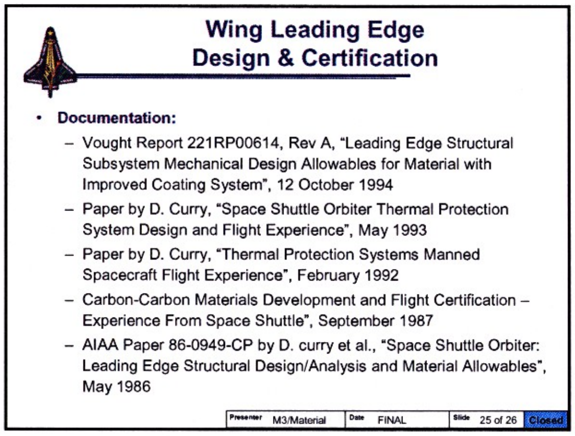
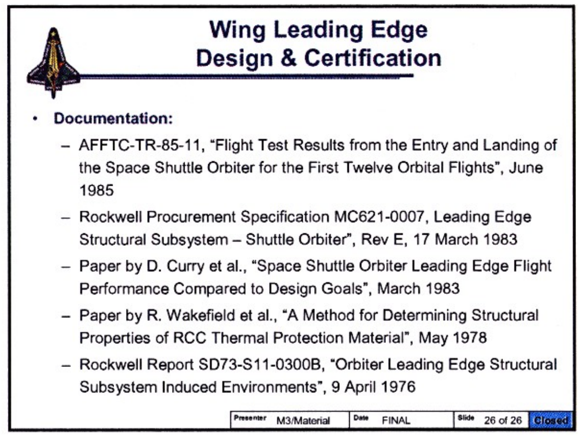
4


Wing Leading Edge
Design & Certification
• Documentation:
– Vought Report 221RP00614, Rev A, "Leading Edge Structural Subsystem Mechanical Design Allowables for Material with Improved Coating System", 12 October 1994
– Paper by D. Curry, "Space Shuttle Orbiter Thermal Protection System Design and Flight Experience", May 1993
– Paper by D. Curry, "Thermal Protection Systems Manned Spacecraft Flight Experience", February 1992
– Carbon-Carbon Materials Development and Flight Certification – Experience From Space Shuttle", September 1987
– AIAA Paper 86-0949-CP by D. curry et al., "Space Shuttle Orbiter: Leading Edge Structural Design/Analysis and Material Allowables", May 1986
Presenter M3/Material
Date FINAL
Slide 25 of 26
Closed


Wing Leading Edge
Design & Certification
• Documentation:
– AFFTC-TR-85-11, "Flight Test Results from the Entry and Landing of the Space Shuttle Orbiter for the First Twelve Orbital Flights", June 1985
– Rockwell Procurement Specification MC621-0007, Leading Edge Structural Subsystem – Shuttle Orbiter", Rev E, 17 March 1983
– Paper by D. Curry et al., "Space Shuttle Orbiter Leading Edge Flight Performance Compared to Design Goals", March 1983
– Paper by R. Wakefield et al., "A Method for Determining Structural Properties of RCC Thermal Protection Material", May 1978
– Rockwell Report SD73-S11-0300B, "Orbiter Leading Edge Structural Subsystem Induced Environments", 9 April 1976
Presenter M3/Material
Date FINAL
Slide 26 of 26
Closed

RCC Impact Energy Requirements

- **Action / Issue:** Determine adequacy of RCC impact requirements and certification
- **Background / Facts:**
  - Performance and design requirements documented in specification MJ070-0001-1E, 7 Nov 02
    - TPS impact energy design requirement is 0.006 foot-lbs (paragraph 3.3.1.8.11)
    - Orbiter not designed to withstand launch debris or ice (paragraph 3.3.1.8.16)
  - Procurement specification MC621-0007, Rev E requirement more stringent than design requirement
    - Impact energy limit ranges from 1 to 2.25 foot-pounds based on part thickness

Presenter M3/Material | Date FINAL | Slide 1 of 13 | Closed

Previous RCC Impact Testing

- **Background / Facts:**
  - Hypervelocity impact testing performed
    - Reference NASA-LARC Report TMX-74039, June 1977
    - Nylon projectile resulted in front face damage at 2.2 foot-pounds and both front and back face damage at 8.1 foot-pounds
    - Glass projectile resulted in front face damage at 0.2 foot-pounds
  - Hypervelocity impact testing performed in support of NRC MMOD study at JSC facility
    - 15 shots using 2017-T4 aluminum
    - Projectile energy ranged from 53 to 213 foot-pounds
    - Minimum damage: front face = 0.65" and back face = 0.87"

Presenter M3/Material | Date FINAL | Slide 2 of 13 | Closed

Previous RCC Impact Testing

- **Background / Facts :**
  - Low velocity ice impact testing performed
    - Reference Boeing report STS-82-0615
    - Specimen perforated at 132 foot-pounds normal to surface
  - Low velocity impact testing performed in an attempt to generate damage result seen on RCC panel 10R after STS-45 on OV-104-11
    - Aluminum projectile generated front face crater at 19.6 foot-pounds and front and rear face damage at 31.7 foot-pounds
    - Steel projectile generated front and rear face damage at 42.77 foot-pounds – best match of STS-45 damage
    - .22 short lead bullet did not damage specimen at 3.36 foot-pounds
    - Steel BB damaged front and rear face at 1.23 foot-pounds

Presenter M3/Material | Date FINAL | Slide 3 of 13 | Closed

WLE RCC Impact Fleet Experience Summary

Year	STS	OV	Flight #	Impact Location	Debris Type	Resulting Damage
1988	27R	104	3	T-Seal 7R	SRB Ablative	1 Dent, No SiC Loss
1992	45	104	11	Panel 10R	Man-Made Object	2 Dents with SiC Loss
1994	65	102	17	Panel 5L	MMOD	Small Crater
2003	107	102	28	Panel 5 to 10	ET Bi-Pod Foam	Under Evaluation

21 Flights Sampled, 43 Impacts Discovered due to Orbital Debris, Largest Damage = 0.2"

Presenter M3/Material | Date FINAL | Slide 4 of 13 | Closed

WLE RCC Impact Fleet Experience Foam/Ablative

- **Background / Facts:**
  - OV-104-03 impact damage to right wing discovered after STS-27R in 1988
    - Reference TPS post-flight report KL0-89-001
    - "Some of the RCC panels and tee seals had streaks on the OML"
    - "Rib station #7 had a dent near the upper trailing edge"
    - Most probable cause is the right SRB nose cap ablative insulating material
  - OV-102-28 ET bi-pod ramp foam impact to left wing during STS-107 in 2003

Presenter M3/Material | Date FINAL | Slide 5 of 13 | Closed

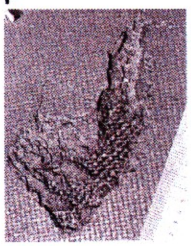
WLE RCC Impact Fleet Experience Man-Made Object

- **Background / Facts:**
  - OV-104-11 impact damage to panel 10R discovered after STS-45 in 1992
    - Reference S. Christensen briefing
    - Substrate was exposed and oxidized, panel scrapped
    - Failure analysis documented in LTR4088-2427
    - Impact was caused by a low velocity impact by a man-made object
    - Impact occurred before reentry heating
    - Ascent encounter determined to be possible
    - On-orbit encounter determined to be remote possibility

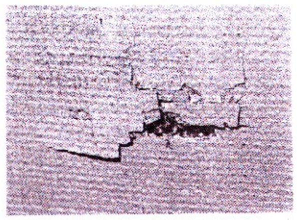
Presenter M3/Material | Date FINAL | Slide 6 of 13 | Closed

1

WLE RCC Impact Fleet Experience
Man-Made Object



OML



IML

OV-104-11, Panel 10R Impact Damage (1992)

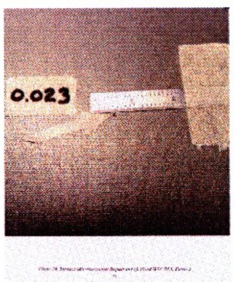
Presenter M3/Material | Date FINAL | Slide 7 of 13 | Closed

WLE RCC Impact Fleet Experience
MMOD

- **Background / Facts:**
  - OV-102-17 impact damage to panel 5L discovered after STS-65 in 1994
    - Most likely cause is a micro-meteorite (MMOD)
  - Hypervelocity impact to RCC components during flight is not unusual
    - 43 impacts occurred during the 21 flights sampled
    - Largest damage was 0.2"
    - No through-penetrations occurred

Presenter M3/Material | Date FINAL | Slide 8 of 13 | Closed

WLE RCC Impact Fleet Experience
MMOD



Crater Approximately 0.08" in Diameter

Depth Unknown but Reported not to be through-thickness

OV-102-17, Panel 5L Micro-meteorite (1994)

Presenter M3/Material | Date FINAL | Slide 9 of 13 | Closed

WLE RCC Impact
Category: Potential Contributor

- **Findings (agreed to by Curry, Gordon and Grant):**
  - Impact energy design requirement is minimal
  - Impact energy capability exceeds original design requirements
- **Recommendations (agreed to by Curry, Gordon and Grant):**
  - Utilize foam impact test results to evaluate impact energy resistance and adequacy of current requirements
  - Establish realistic launch/ascent debris types (foam, SLA, etc.) and evaluate capability of WLE system to withstand the impacts via testing and analysis

Presenter M3/Material | Date FINAL | Slide 10 of 13 | Closed

WLE RCC Impact

- **Documentation:**
  - Boeing report KL0-03-001, Mission STS-112 OV-104 Flight 26 Thermal Protection System Post-Flight Assessment", May 2003
  - JSC report, "STS-112 Launch Film Screening Report", 12 October 2002
  - MSFC report, "STS-112 JSC Launch Video Screening Report", 8 October 2002

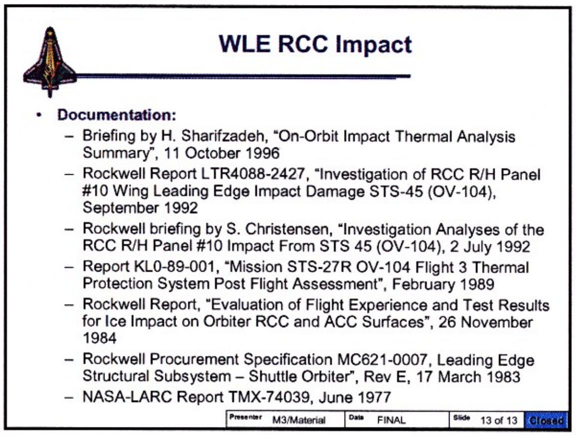
Presenter M3/Material | Date FINAL | Slide 11 of 13 | Closed

WLE RCC Impact

- **Documentation:**
  - Boeing Specification MJ070-0001-1E, "Orbiter End Item Specification for the Space Shuttle Systems, Part 1, Performance and Design Requirements, 7 Nov 02
  - Paper by D. Curry et.al., "Oxidation of Hypervelocity Impacted RCC", June 2000
  - NASA TP-2000-209760, "Oxidation of RCC Subjected to Hypervelocity Impact", March 2000
  - JSC Report 28768, "As-Flown Shuttle Orbiter Meteoroid/Orbital Debris Assessment", January 2000
  - JSC Report 28404, "STS-87 Orbiter Meteoroid/Orbital Debris Impact Damage Analysis", 7 August 1998
  - JSC Report 28398, "Hypervelocity Impact Testing of RCC", May 1998
  - Briefing by M. Hasselbeck, "Space Shuttle Orbiter On-Orbit Impact Critical Failure Criteria", 17 June 1997

Presenter M3/Material | Date FINAL | Slide 12 of 13 | Closed

2


WLE RCC Impact
• Documentation:
– Briefing by H. Sharifzadeh, "On-Orbit Impact Thermal Analysis Summary", 11 October 1996
– Rockwell Report LTR4088-2427, "Investigation of RCC R/H Panel #10 Wing Leading Edge Impact Damage STS-45 (OV-104), September 1992
– Rockwell briefing by S. Christensen, "Investigation Analyses of the RCC R/H Panel #10 Impact From STS 45 (OV-104), 2 July 1992
– Report KL0-89-001, "Mission STS-27R OV-104 Flight 3 Thermal Protection System Post Flight Assessment", February 1989
– Rockwell Report, "Evaluation of Flight Experience and Test Results for Ice Impact on Orbiter RCC and ACC Surfaces", 26 November 1984
– Rockwell Procurement Specification MC621-0007, Leading Edge Structural Subsystem – Shuttle Orbiter", Rev E, 17 March 1983
– NASA-LARC Report TMX-74039, June 1977
Presenter M3/Material
Date FINAL
Slide 13 of 13
Closed

3

RCC Production

6-1 RCC Production Processes

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	8 of 32

RCC Production

- **Action / Issue:** Determine adequacy of RCC production process
- **Background / Facts:**
  - Continuous production since 1973
  - RCC component manufacturing flow days = 6 months
  - Currently only limited production capacity exists due to low demand for parts
  - RCC part deliveries = 943 to date
  - Production of 7 T-Seals, 1 Chin Panel and 2 Panel/T-seal assemblies in work
  - NDI is performed after initial part cure and after the final pyrolysis cycle
  - Ultrasonic NDI is performed after the same processing steps and after the SiC coating process
  - Control panels are fabricated in parallel with RCC part production

Presenter M3/Material | Date FINAL | Slide 1 of 8 | Closed

RCC Production

RCC PAPER REVIEW

- **Paper review was conducted in Dallas from 4/25 – 5/1 with a five member team**
  - Team consisted of the following:
    - Brad Tipton - Boeing TPS M&P
    - Ali Nassori - LMMFC-D
    - Bob Brown - SAIC at NASA JSC
    - Tim Lawrence - NASA/MSFC/ED34
    - Larry Austin - USA
- **Review consisted of complete examination of all available documents related to left wing RCC panels 5-10 including metal hardware**
- **Each document was reviewed by at least two team members**

5/27/2003

Presenter M3/Material | Date FINAL | Slide 2 of 8 | Closed

RCC Production

RCC Paper Review Summary

- **Documents were reviewed and observations were noted according to the following categories**
  - A: MR rationale is not technically sound or does not address the discrepancy completely.
  - B: Drawing requirements incorrectly incorporated, incomplete, or missing (i.e. proper drawings and planning worked to during process)
  - C: Other specification incorrectly incorporated, incomplete, or missing (i.e. verification of latest version of specifications were used)
  - D: Retest incomplete, incorrect, or missing
  - E: Data recorded not within specified limits
  - F: Paper has open work steps
  - G: Wrong steps worked
  - H: MR rationale present but not complete (i.e. rationale sound, but not all signatures present)
  - I: Caution steps missing in work order planning
  - J: Other

5/27/2003

Presenter M3/Material | Date FINAL | Slide 3 of 8 | Closed

RCC Production

RCC Paper Review Summary (continued)

- **Total of 198 observations made during review**
  - A majority of the observations were documentation issues only
  - Many issues have been corrected through process improvements and would not occur today
  - None of the observations would have an adverse effect on the final RCC parts
- **The observations made by the review team break down as follows:**
  - Category A: 9 observations
    - Ex. Dispo. gives direction to check coating thickness and resubmit to MRB. Issue was never resubmitted to MRB.
  - Category B: 10 observations
    - Ex. E.O. requires adding steps to operations in planning. The steps were not added
  - Category C: 4 observations
    - Ex. Discrepancy sheet states to perform debulk operation without reference to proper specification to use.
  - Category D: 0 observations
  - Category E: 6 observations
    - Ex. Dimensions recorded in planning exceed requirements.

5/27/2003

Presenter M3/Material | Date FINAL | Slide 4 of 8 | Closed

RCC Production

RCC Paper Review Summary (continued)

- Category F: 41 observations
  - Ex. Various steps in planning not stamped.
- Category H: 7 observations
  - Ex. On material review action, the corrective action is inconclusive
- Category I: 1 observations
  - Ex. Missing caution steps
- Category J: 120 observations
  - Ex. No dates next to stamps
  - Ex. Deleted planning with out signature or stamp

5/27/2003

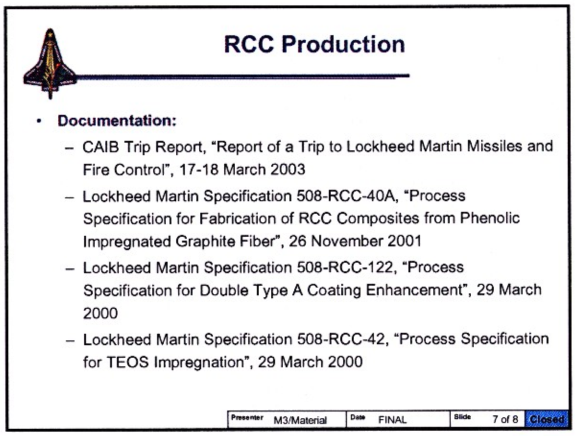
Presenter M3/Material | Date FINAL | Slide 5 of 8 | Closed

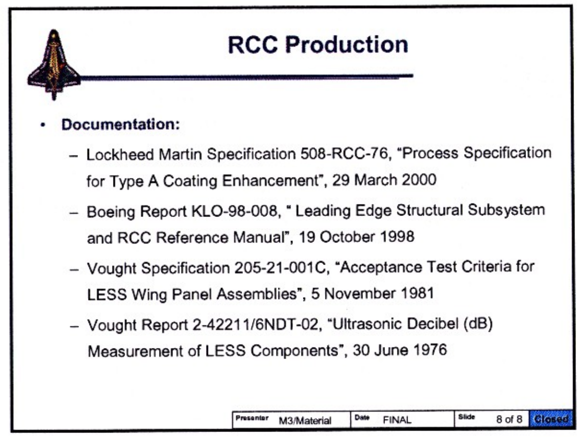
RCC Production

- **Findings (agreed to by Curry, Gordon and Grant):**
  - NDE technique and processes utilized at the supplier are out-dated
  - Low volume production work may result in poor quality
  - Senior personnel at LMM&FC have assessed the potential for NDE to inspect for substrate mass loss as improbable
- **Recommendations (agreed to by Curry, Gordon and Grant):**
  - Increase the fidelity and capability of NDE methods and equipment utilized during the production and refurbishment of RCC parts
  - Ensure NDE personnel training and skills

Presenter M3/Material | Date FINAL | Slide 6 of 8 | Closed

1


RCC Production
• Documentation:
– CAIB Trip Report, "Report of a Trip to Lockheed Martin Missiles and Fire Control", 17-18 March 2003
– Lockheed Martin Specification 508-RCC-40A, "Process Specification for Fabrication of RCC Composites from Phenolic Impregnated Graphite Fiber", 26 November 2001
– Lockheed Martin Specification 508-RCC-122, "Process Specification for Double Type A Coating Enhancement", 29 March 2000
– Lockheed Martin Specification 508-RCC-42, "Process Specification for TEOS Impregnation", 29 March 2000
Presenter M3/Material
Date FINAL
Slide 7 of 8
Closed


RCC Production
• Documentation:
– Lockheed Martin Specification 508-RCC-76, "Process Specification for Type A Coating Enhancement", 29 March 2000
– Boeing Report KLO-98-008, " Leading Edge Structural Subsystem and RCC Reference Manual", 19 October 1998
– Vought Specification 205-21-001C, "Acceptance Test Criteria for LESS Wing Panel Assemblies", 5 November 1981
– Vought Report 2-42211/6NDT-02, "Ultrasonic Decibel (dB) Measurement of LESS Components", 30 June 1976
Presenter M3/Material
Date FINAL
Slide 8 of 8
Closed

2

RCC
Mission Life

7-1 RCC Mission Life Capability

Matrix

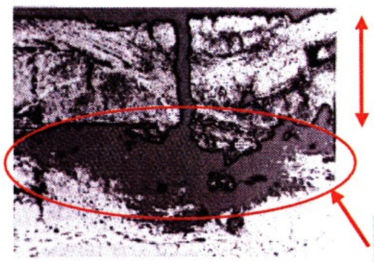
Presenter	CAIB/Group 1	Date	FINAL	Slide	9 of 32

RCC Mission Life

- **Action / Issue:** Determine adequacy of RCC mission life analysis methodology
- **Background / Facts:**
  - Oxidation rate is the most important parameter to determine mission life
    - Function of temperature, pressure and heating time
    - Resulting mass loss reduces part strength
  - Repeated exposure to the flight environment degrades the oxidation protection system and increases amount of mass loss
  - Mass loss rate characterized by laboratory testing

Presenter M3/Material | Date FINAL | Slide 1 of 23 | Closed

RCC Mission Life



Silicon Carbide Layer (0.02" to 0.04")

Oxidation at SiC / Substrate Interface

Presenter M3/Material | Date FINAL | Slide 2 of 23 | Closed

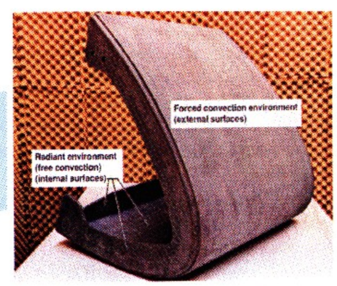
RCC Mission Life

- **Background / Facts:**
  - Arc jet test at Ames and JSC in 1973 first revealed mass loss with no apparent dimensional changes
  - Database generated for non-TEOS material
    - Arc jet and radiant exposure tests at JSC, ARC, LARC and Rockwell
    - Established strength reduction as a function of mass loss
    - Mass loss greater in plasma arc jet (convective) than radiant tests
    - Mass loss correlation (radiant/convective) developed from the test results (see charts 7 and 8 for convective heating results)
    - Established need for improved coating system

Presenter M3/Material | Date FINAL | Slide 3 of 23 | Closed

RCC Mission Life

Mass loss limit for internal surfaces is 0.10 psf



Mass loss limit for external surfaces is 0.03 psf

Presenter M3/Material | Date FINAL | Slide 4 of 23 | Closed

RCC Mission Life
Material System Evolution

- **Background / Facts:**
  - TEOS infiltration system baselined for OV-102 in March 1976
    - Mass loss correlation for radiant and convective heating developed in 1978
  - Surface porosity effects on mission life discovered in December 1978
  - Type A sealant developed in 1980 to seal surface porosity
    - Retrofitted onto OV-102 after 5th flight
    - Mass loss database developed in 1984
  - Double Type A (DTA) sealant developed to increase mission life
    - Baseline for OV-105 and all new parts
    - Mass loss database developed in 1994

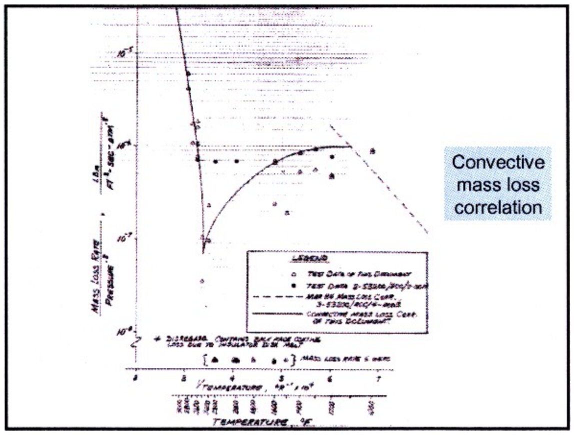
Presenter M3/Material | Date FINAL | Slide 5 of 23 | Closed

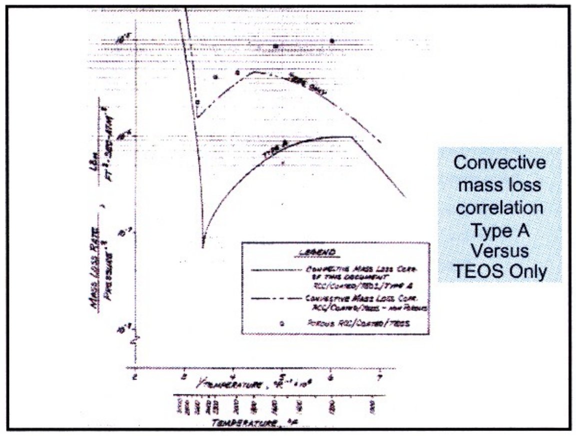
RCC Mission Life
Convective Mass Loss Correlation

- **Background / Facts:**
  - RCC/SiC/TEOS/Type A material system plasma arc jet tests for convective mass loss conducted at JSC in 1984
    - 40 total specimens, 2 each at 20 combinations of temperature and pressure
    - Temperature ranged from 1000 to 3000 F
    - Pressure ranged from 0.01 to 0.05 atmospheres
  - Test results summary
    - SiC erosion occurred at temperatures at 2800 F and above
    - Specimens exposed to temperatures at 2700 F and below did not indicate a thickness change
    - Mass loss rates increase rapidly above 2500 F
    - See next 2 charts for actual results

Presenter M3/Material | Date FINAL | Slide 6 of 23 | Closed

1





RCC Mission Life Determination

- **Background / Facts :**
  - Determination of mission lives due to operational aging includes both thermal and structural analysis results
    - Thermal analysis determines mass loss based on certification mission profiles (closest match to each actual mission)
    - Structural analysis determines strength based on air loads and thermal loads
  - Margin of safety is determined for longest possible mission life while preserving the required factor of safety = 1.4
  - Mission life limits are documented in NSTS 08171, Operations and Maintenance Requirements Specifications Document, File II, Volume 3

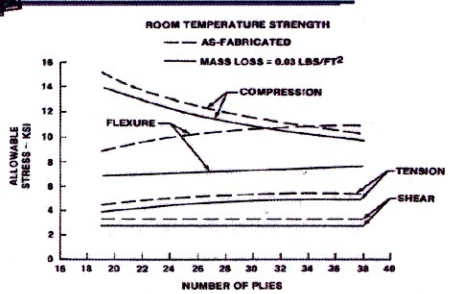
Presenter	M3/Material	Date	FINAL	Slide	9 of 23	Closed

RCC Mission Life Margin of Safety Versus Factor of Safety

- **Background / Facts :**
  - MS = (Allowable Stress / Applied Stress * FS) - 1
  - MS = Margin of Safety
    - Required to be 0 or positive
  - FS = Factor of Safety
    - Shuttle program uses 1.4
    - USAF, USN, commercial aircraft use 1.5
  - Allowable stress based on mechanical design allowables database generated from over 2000 RCC specimens (A-basis, 99% of material expected to exceed the value)
    - Allowable stress for material generated for material at mass loss cut-off limits
  - When we hear that a location has a reduced "factor of safety" – it really means a negative margin of safety (reduction of FS is typically not an option)
  - SRB ETA ring is an example of a liberal allowance of a FS reduction – issue only known for 24 hours prior to ET tanking meeting

Presenter	M3/Material	Date	FINAL	Slide	10 of 23	Closed

RCC Mission Life RCC Allowable Stress for Some Properties



19 plies = 0.24" thick, 38 plies = 0.5" thick

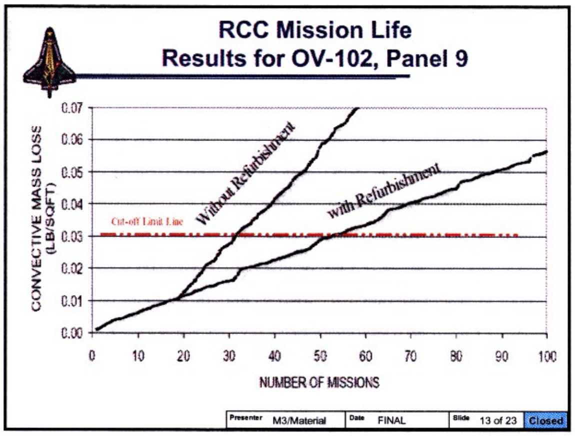
Presenter	M3/Material	Date	FINAL	Slide	11 of 23	Closed

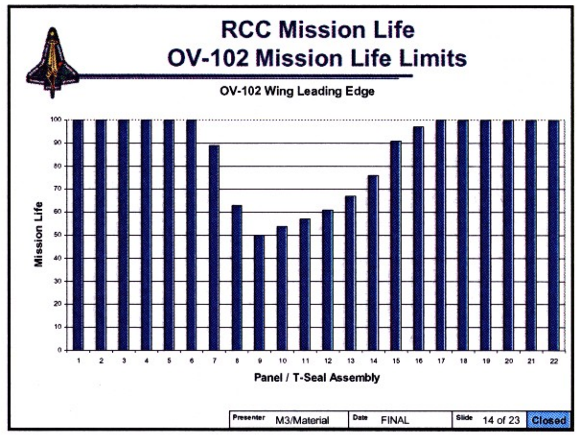
RCC Mission Life

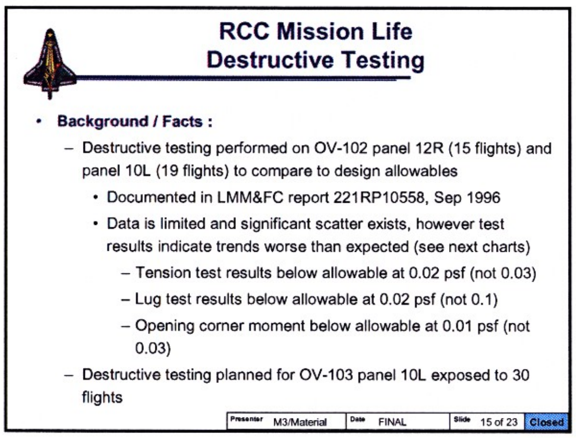
- **Background / Facts :**
  - OV-102 RCC components were not coated with Type A sealant for the first 5 missions – reduced mission lives from other orbiters
  - RCC Refurbishment intervals established to replenish Type A sealant to achieve desired mission life
  - Minor repair capability developed to allow for continued operation between scheduled OMM downtime
  - Minimum predicted life for WLE RCC component on OV-102 is 50 missions for panel/seal 9 assembly

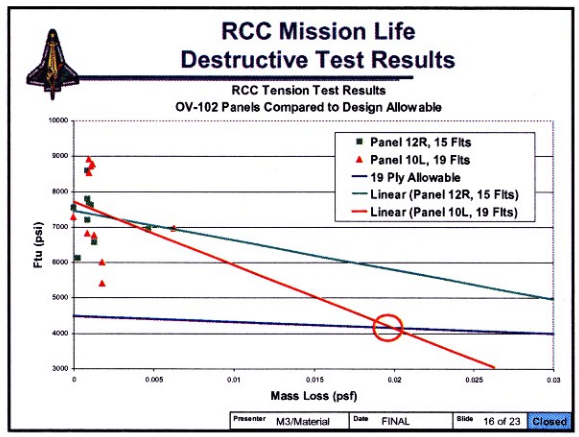
Presenter	M3/Material	Date	FINAL	Slide	12 of 23	Closed

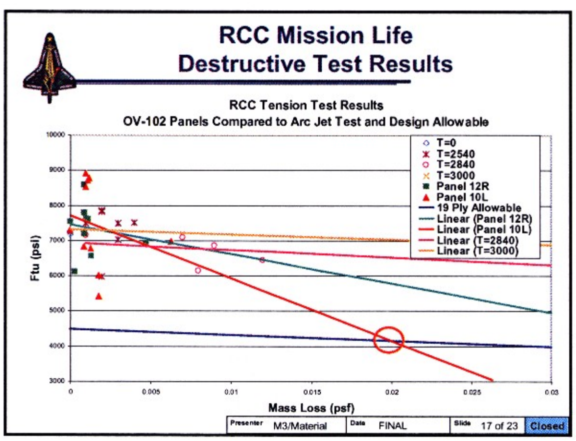
2

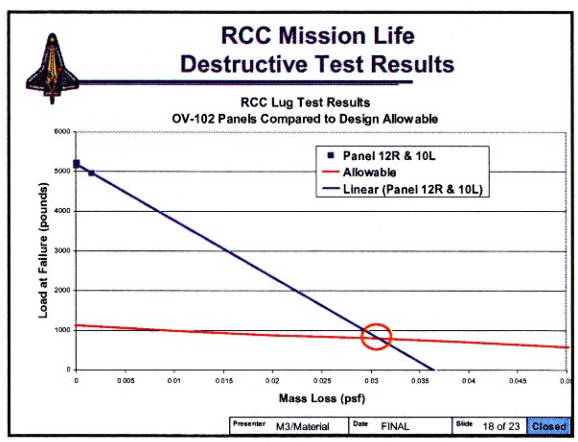

RCC Mission Life
Results for OV-102, Panel 9
CONVECTIVE MASS LOSS (LB/SQFT)
Cut-off Limit Line
Without Refurbishment
with Refurbishment
NUMBER OF MISSIONS
Presenter M3/Material
Date FINAL
Slide 13 of 23
Closed


RCC Mission Life
OV-102 Mission Life Limits
OV-102 Wing Leading Edge
Mission Life
Panel / T-Seal Assembly
Presenter M3/Material
Date FINAL
Slide 14 of 23
Closed


RCC Mission Life
Destructive Testing
• Background / Facts :
– Destructive testing performed on OV-102 panel 12R (15 flights) and panel 10L (19 flights) to compare to design allowables
• Documented in LMM&FC report 221RP10558, Sep 1996
• Data is limited and significant scatter exists, however test results indicate trends worse than expected (see next charts)
– Tension test results below allowable at 0.02 psf (not 0.03)
– Lug test results below allowable at 0.02 psf (not 0.1)
– Opening corner moment below allowable at 0.01 psf (not 0.03)
– Destructive testing planned for OV-103 panel 10L exposed to 30 flights
Presenter M3/Material
Date FINAL
Slide 15 of 23
Closed


RCC Mission Life
Destructive Test Results
RCC Tension Test Results
OV-102 Panels Compared to Design Allowable
Panel 12R, 15 Flts
Panel 10L, 19 Flts
19 Ply Allowable
Linear (Panel 12R, 15 Flts)
Linear (Panel 10L, 19 Flts)
Ftu (psi)
Mass Loss (psf)
Presenter M3/Material
Date FINAL
Slide 16 of 23
Closed


RCC Mission Life
Destructive Test Results
RCC Tension Test Results
OV-102 Panels Compared to Arc Jet Test and Design Allowable
T=0
T=2540
T=2840
T=3000
Panel 12R
Panel 10L
19 Ply Allowable
Linear (Panel 12R)
Linear (Panel 10L)
Linear (T=2840)
Linear (T=3000)
Ftu (psi)
Mass Loss (psf)
Presenter M3/Material
Date FINAL
Slide 17 of 23
Closed


RCC Mission Life
Destructive Test Results
RCC Lug Test Results
OV-102 Panels Compared to Design Allowable
Panel 12R & 10L
Allowable
Linear (Panel 12R & 10L)
Load at Failure (pounds)
Mass Loss (psf)
Presenter M3/Material
Date FINAL
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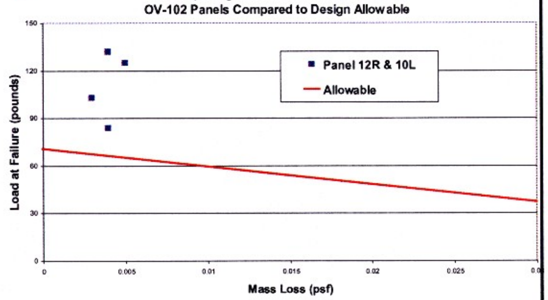
Closed

3

RCC Mission Life
Destructive Test Results

RCC Opening Corner Moment Test Results
OV-102 Panels Compared to Design Allowable



Presenter M3/Material	Date FINAL	Slide 19 of 23	Closed

RCC Mission Life
Category: Potential Contributor

- **Findings:**
  - Insufficient data exists to compare predicted mass loss and strength to actual mass loss and strength on flown hardware due to repeated exposure
  - However, results to date indicate need to accelerate additional destructive testing of flown hardware
  - Only 2 tests were performed to determine oxidation associated with craze cracks used to develop tactile evaluation method for coating adherence reduction due to oxidation along interface
  - Recent NASA GRC examination of OV-102 panel 12R has revealed coating and substrate anomalies that warrant further investigation

Presenter M3/Material	Date FINAL	Slide 20 of 23	Closed

RCC Mission Life
Category: Potential Contributor

- **Recommendations (Agreed to by Curry):**
  - Develop a plan to conduct destructive testing of flown RCC components that addresses:
    - Extensive NDE to select test specimen locations
    - Predicted mass loss rates and corresponding reduction in mechanical properties versus actual test results
    - Type A sealant loss on OML
    - Pinhole impact on coating adherence and mechanical property reductions
    - Oxidation associated with craze cracks
    - Substrate oxidation impact on mechanical properties
    - Impact energy resistance due to launch/ascent debris
  - Conduct testing of flown hardware ASAP per above plan

Presenter M3/Material	Date FINAL	Slide 21 of 23	Closed

RCC Mission Life

- **Documentation:**
  - NASA GRC Briefing by A. Calomino, "Microstructural Characterization of RCC Materials", 16 May 2003
  - NSTS 08171, Operations and Maintenance Requirements and Specifications Document, File II, Volume 3, "Limited Life/Time/Cycle Items", 1 May 2003
  - Lockheed Martin Report 221RP10558, "RCC Pinhole/Sealant Loss Investigation", September 1996
  - Lockheed Martin Report 221RP10551, "OV-102 Panel / Seal Set 10L Mechanical Properties Tests", August 1996
  - Lockheed Martin Report 221RP10539, "RCC Pin-Hole / Sealant Loss Coating Adherence", May 1996

Presenter M3/Material	Date FINAL	Slide 22 of 23	Closed

RCC Mission Life

- **Documentation:**
  - Paper by A. Eckel et.al, "Oxidation Kinetics of a Continuous Carbon Phase in a Nonreactive Matrix", 4 April 1995
  - NASA TM 106793, "Thermochemical Degradation Mechanisms for RCC Panels on the Space Shuttle, N. Jacobson, January 1995
  - NASA TM 104792, "Analysis of the Shuttle Orbiter RCC Oxidation Protection System", D. Curry et.al., June 1994
  - AIAA 94-2084, "Ablation Analysis of the Shuttle Orbiter Oxidation Protected RCC", June 1994
  - DIR NO. 3-53200/RCC/4-0006, "June 1984 Convective Mass Loss Correlation", 28 June 1984

Presenter M3/Material	Date FINAL	Slide 23 of 23	Closed

4

RCC
Fleet Experience – Aging

8-1 RCC Maintenance Actions

8-2 Pinholes in RCC Components

8-3 Deterioration of Type A Sealant

8-4 NDE of RCC Components

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	10 of 32

WLE Maintenance Actions

- **Action / Issue:** WLE maintenance actions evaluated for negative trends or damage experience not already incorporated into new OMRSD requirements
- **Background:**
  - 3 RCC panel/seals have been replaced on OV-102
    - Replaced panel/seal 12R after 15 flights for destructive testing
    - Replaced panel/seal 10L after 19 flights for destructive testing
    - Replaced panel/seal 11L after 19 flights due to fit-up issues with the new panel/seal 10L
      - Removed panel/seal 11L (P/N 10211LA001) is currently in the spares pool

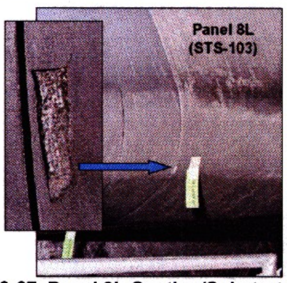
Presenter M3/Material | Date FINAL | Slide 1 of 20 | Closed

WLE Maintenance Actions

- **Background:**
  - 10 RCC panels and 8 seals have been repaired on OV-102
    - Repaired 7 panels and 6 seals on the left wing of OV-102
    - Repaired 3 panels and 2 seals on the right wing of OV-102
  - Refurbished 11 RCC panels and 12 seals on the left wing and 11 RCC panels and 11 seals on the right wing of OV-102

Presenter M3/Material | Date FINAL | Slide 2 of 20 | Closed

RCC Maintenance Actions



Suspected Oxidation At SiC and Substrate Interface

OV-103-27, Panel 8L Coating/Substrate Loss (Jan 00)
Panel Scrapped

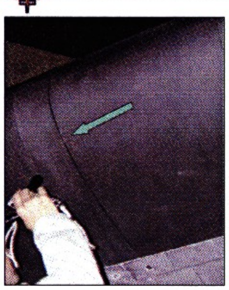
Presenter M3/Material | Date FINAL | Slide 3 of 20 | Closed

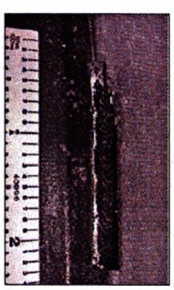
RCC Maintenance Actions

OV-102-26, T-Seal 11L Cavity (Dec 00)

Presenter M3/Material | Date FINAL | Slide 4 of 20 | Closed

RCC Maintenance Actions





Suspected Oxidation At SiC and Substrate Interface

(2"L x 0.3"W x 0.18"D)

OV-103-29, Panel 10L Coating/Substrate Loss (Apr 01)

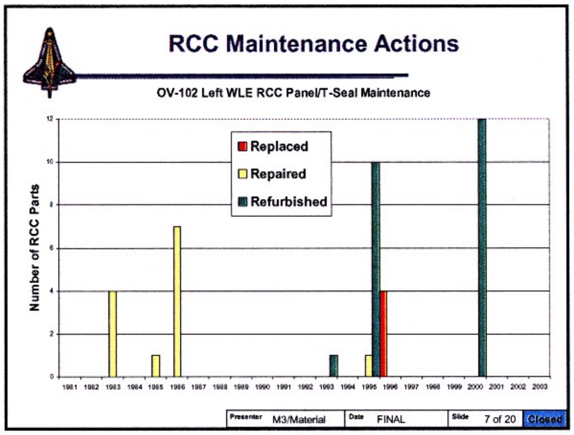
Presenter M3/Material | Date FINAL | Slide 5 of 20 | Closed

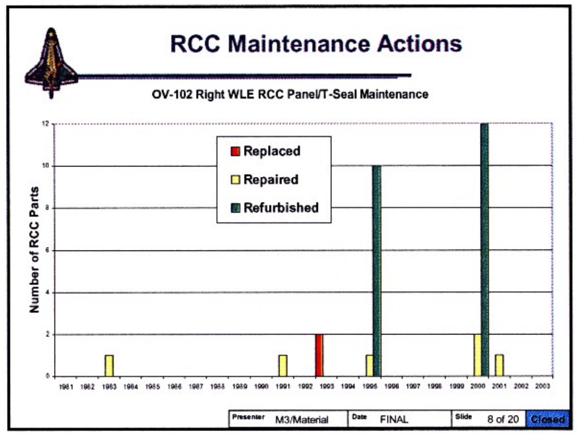
RCC Maintenance Actions

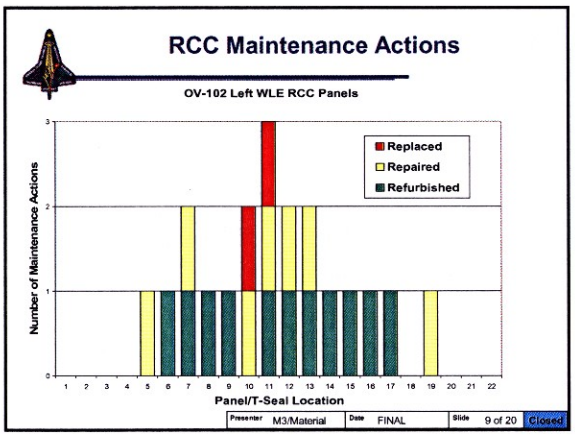
OV-103-30, Panel 10L Repair (Aug 01)
Damaged After 1 Flight, Panel Scrapped

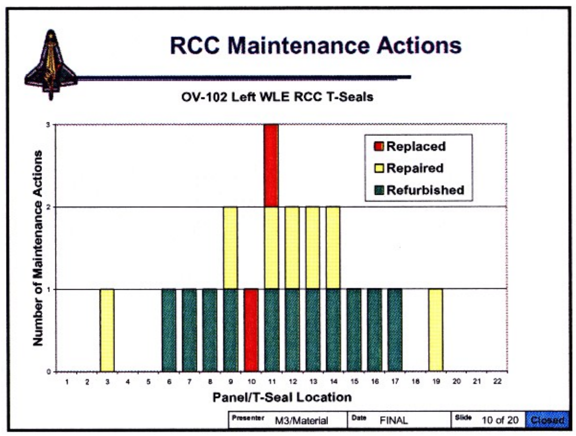
Presenter M3/Material | Date FINAL | Slide 6 of 20 | Closed

1





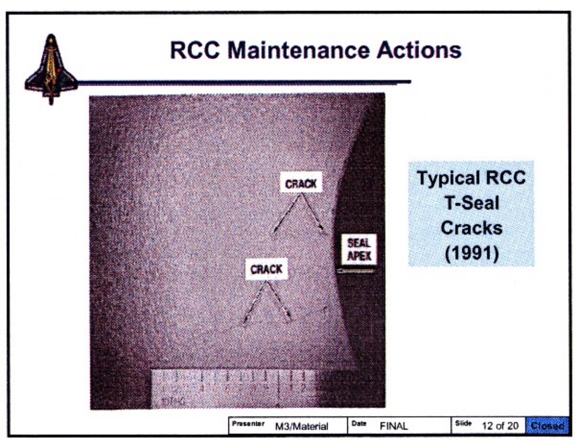




RCC Maintenance Actions

- **Background / Facts:**
  - WLE RCC T-Seals cracks discovered on OV-104, 17R during OMRSD turnaround inspection in 1991
    - All WLE RCC components inspected – no cracks discovered in RCC panels
  - 20 of 132 T-Seals were cracked, all within 0.5 inches of apex
    - OV-102: 11 cracked T-Seals, crack lengths less than 0.5 inches
      - Determined to be normal shrinkage cracks, not visible with unaided eye, all reinstalled in OV-102
    - OV-103: 1 cracked T-Seals, crack lengths up to 2 inches, replaced with new spare
    - OV-104: 8 cracked T-Seals, crack lengths up to 2 inches, replaced with new spares

Presenter M3/Material | Date FINAL | Slide 11 of 20 | Closed



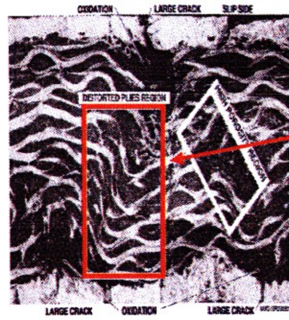
2

RCC Maintenance Actions

- **Background / Facts:**
  - RCC T-Seal Cracking investigation documented in Rockwell Report LTR 4088-2401, November 1991
  - Sectioned OV-104, 17R (worst cracking) and 18R (3rd worst case) for failure analysis
    - No substrate cracks
    - Laminates significantly distorted
    - OV-104 panel 17R had oxidation damage
  - Removed coating from several other T-seals – no substrate cracks found
  - Conclusions from failure analysis (metallurgical, fractography, etc.)
    - Cracks only in SiC layer
    - Cracks due to variations in fabrication lay up process resulting in different laminate distortions

Presenter M3/Material | Date FINAL | Slide 13 of 20 | Closed

RCC Maintenance Actions



Distorted Plies Region

Presenter M3/Material | Date FINAL | Slide 14 of 20 | Closed

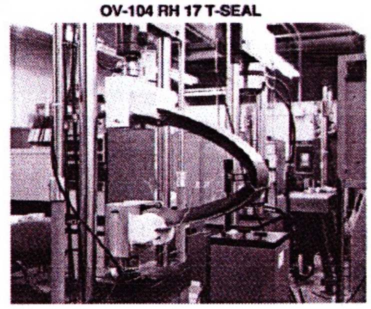
RCC Maintenance Actions

- **Background / Facts:**
  - Determined full length SiC layer crack does not affect static strength
  - Analyzed full-length substrate crack
    - Factor of safety > 1.4 for entry/landing
    - Factor of safety = 1.38 for ascent
  - Tested 2 T-seals for coating crack growth characteristics at a stress level of 80% of design limit in 1991
    - Tested OV-102 #9 left (between panels 9 and 10) for 400 cycles – determined via analysis and inspection negligible fatigue damage occurred and re-installed T-seal in OV-102
    - Tested OV-104 RH #18 for 100 cycles – no crack growth, part was scrapped for destructive testing

Presenter M3/Material | Date FINAL | Slide 15 of 20 | Closed

RCC Maintenance Actions

OV-104 RH 17 T-SEAL



RCC T-Seal Fatigue Test Setup

Presenter M3/Material | Date FINAL | Slide 16 of 20 | Closed

WLE Maintenance Actions

- **Background / Facts:**
  - OV-102 wing leading edge spars have a history of degradation due to corrosion
    - Design corrosion protection system was a single coat of MB0125-055 primer (Koropon)
    - MB0130-119 Type II RTV adhesive applied as a galvanic barrier on forward most plane of corrugated spar
    - Design change incorporated at J2 OMDP to apply 2 coats of Koropon and cover with RTV topcoat as moisture and galvanic barrier
  - Inspection process updated
    - Full inspection performed every 4 and ½ years (V30KG0.060 and V30LG0.060) which requires removal of all RCC panels and associated support fittings and insulators
    - Sampling inspection performed every 3 years (V30KG0.065 and V30LG0.065) for 6 panels per side

Presenter M3/Material | Date FINAL | Slide 17 of 20 | Closed

WLE Maintenance Actions

- **Background / Facts:**
  - OV-102 inspections performed in conjunction with WLE refurbishment per MCR18457 during J2 resulted in significant corrosion findings
    - 41 doublers required on the right side
    - Multiple doublers required on the left side
  - Exploratory holes were drilled for core inspection and no corrosion was detected
  - Inspections during J3 did not detect evidence of corrosion on the WLE spars

Presenter M3/Material | Date FINAL | Slide 18 of 20 | Closed

3

WLE Maintenance Actions

- **Findings (agreed to by Curry, Gordon and Grant):**
  - More unplanned maintenance actions on OV-102 left versus right wing RCC parts (varies with other vehicles)
  - A fatigue tested T-seal was installed in OV-102
    - Determined most likely not a contributor to the accident
    - However, the practice of utilizing fatigue tested components in a vehicle should be discontinued
- **Recommendations (agreed to by Curry, Gordon and Grant):**
  - Determine root cause for all exterior damage found and adjust maintenance requirements as needed

Presenter M3/Material	Date FINAL	Slide 19 of 20	Closed

WLE Maintenance Actions

- **Documentation:**
  - Briefing by M. Gordon, "Orbiter LESS/RCC Summary Major Events Since Last PRB", 29 March 2001
  - Boeing Report KLO-00-006, "Space Shuttle Orbiter Thermal Protection System Processing Assessment 2000", Appendix A and C, 17 October 2000
  - Vought Letter 3-47200/2L-146, "Failure/Problem, Analysis and Corrective Action Report (for Cracked T-Seals)", 3 March 1992
  - Rockwell Report LTR 4088-2401, "Shuttle Orbiter Leading Edge RCC T-Seal Cracking Investigation", November 1991

Presenter M3/Material	Date FINAL	Slide 20 of 20	Closed

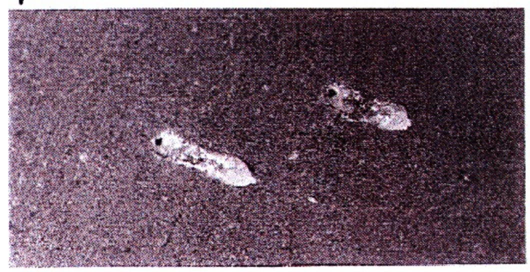
4

RCC Pinholes

- **Action / Issue:** Determine adequacy of pinhole corrective actions
- **Background / Facts:**
  - Pinholes first discovered on OV-102 after 12 flights in 1992
  - Pinholes subsequently found on all other orbiters
  - Pinhole size/quantity increased with flight exposure
  - Testing was performed to determine root cause of pinholes based on several theories
    - Zinc oxide contamination
    - Sea mist salt contamination
    - TEOS application

Presenter M3/Material | Date FINAL | Slide 1 of 16 | Closed

RCC Pinholes



Typical Pinholes (1992) First Discovered on OV-102-12

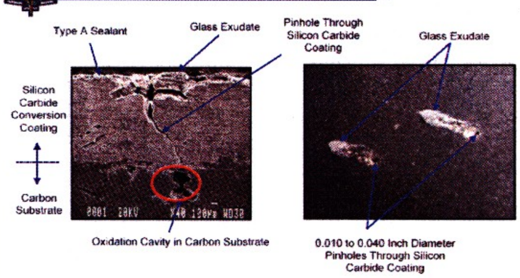
Presenter M3/Material | Date FINAL | Slide 2 of 16 | Closed

RCC Pinholes

- **Background / Facts:**
  - OV-102 RCC panel 12R removed after 15th flight for detailed destructive evaluation in October 1993
    - Reference Rockwell Report LTR 6322-4039, Dec 1994
  - Optical and SEM evaluation performed on 15 pinholes
    - Majority of pin holes occur along craze cracks in SiC layer
    - Typically in thick regions of SiC layer – indicative of porous substrate
  - Pinhole glass chemistry determined
    - Silicon, oxygen, aluminum and zinc
  - Zinc not a part of the RCC material system – suggested contamination from external source
  - 6 samples collected from the RSS of pad 39A in July 1994 and zinc was identified via chemical analysis

Presenter M3/Material | Date FINAL | Slide 3 of 16 | Closed

RCC Pinholes

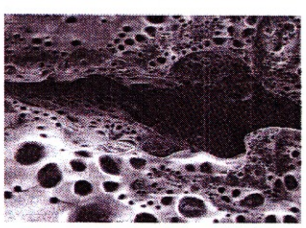


RCC Pinhole Cross-Section — RCC Pinhole Surface View

OV-102 Panel 12R After 15th Flight

Presenter M3/Material | Date FINAL | Slide 4 of 16 | Closed

RCC Pinholes



OV-102 Panel 12R After 15th Flight
Mouth of a Pinhole, Magnification Approximately 130X
Actual Pinhole Diameter = 0.01 Inches

Presenter M3/Material | Date FINAL | Slide 5 of 16 | Closed

RCC Pinholes

- **Background / Facts :**
  - Zinc oxide contamination determined to be root cause
    - Reference Boeing Report KL0-98-009, Launch Pad Zinc Fallout Determination, 22 December 1998
    - Launch pad service structure protected with a two-coat primer and topcoat system
    - Primer contains metallic zinc dust in a silica binder
    - Launch pad refurbishment process discontinued topcoat repairs
    - Weathering of exposed primer caused zinc oxide powdery residue
    - Rain washed the zinc oxide onto the orbiter
    - During reentry, zinc oxide reacts with the SiC layer resulting in pinholes and the zinc containing glass on the part surface

Presenter M3/Material | Date FINAL | Slide 6 of 16 | Closed

1

RCC Pinholes

- **Background / Facts:**
  - NASA review of old plasma arc jet test specimens indicated formation of small anomalies similar to pinholes but not typical of flight induced pinholes
  - Specimens with pinholes made from OV-102 panel 12R
    - Tested for 3.5 hours
    - Temperature ranged from 2400F to 3000F
    - Pressure ranged from 0.014 to 0.10 atmospheres
    - Testing did not significantly change pinhole dimensions nor substrate oxidation

Presenter M3/Material | Date FINAL | Slide 7 of 16 | Closed

RCC Pinholes

OV-102 Panel 12R Test Specimen Pinholes

Presenter M3/Material | Date FINAL | Slide 8 of 16 | Closed

RCC Pinholes

- **Background / Facts:**
  - Developed Type A sealant refurbishment process at Lockheed-Martin to repair pinholes
    - Process described in maintenance requirements portion of the briefing
    - Added step to fill pinholes with Type A sealant
    - Refurbishment does not prevent pinholes from reforming or restore carbon substrate integrity
  - Implemented refurbishment plan on all vehicles

Presenter M3/Material | Date FINAL | Slide 9 of 16 | Closed

RCC Pinholes

- **Background / Facts :**
  - Inspection accept/reject criteria established
    - Documented in ML0601-0002, RSI Acceptance Criteria for Operation Vehicles, 19 September 2002
    - All pinhole-related glass formations are acceptable regardless of the localized surface roughness associated with the formation (paragraph 4.12.9.1)
    - Pinholes are acceptable during routine processing flows (paragraph 4.12.9.2)
    - Pinholes greater than 0.04 inches are unacceptable during OMM (paragraph 4.12.9.3)

Presenter M3/Material | Date FINAL | Slide 10 of 16 | Closed

RCC Pinholes

- **Background / Facts :**
  - Launch pad sampling conducted in 1997 and 2003
  - Zinc fallout rate (mg/ft^2/day) comparisons:
    - Highest recorded value obtained in 2003 (8.69)
    - Other 9 locations in 2003 less than 1997 results
  - Zinc % content comparisons:
    - 2003 results consistently around 9% with one exception
    - 1997 results ranged from 10% to 25%
  - See next chart for results by locations

Presenter M3/Material | Date FINAL | Slide 11 of 16 | Closed

RCC Pinholes

Plate Location	Fallout Rate (mg/ft^2/day) 1997 Avg	Fallout Rate (mg/ft^2/day) 2003	2003/1997	Zinc % Content 1997 Avg	Zinc % Content 2003	2003/1997
LH5/Plate 9	4.8	0.66	0.14	14.2	9.55	0.67
LH10/Plate 1	6.25	4.02	0.64	13.2	8.58	0.65
LH22/Plate 5	6.08	5.33	0.88	15.9	8.82	0.55
RH7/Plate 2	5.29	8.69	1.64	19	9.31	0.49
RH13/Plate 4	4.33	1.21	0.28	15.6	5.64	0.36
RH21/Plate 3	7.05	4.04	0.57	21.4	9.48	0.44
NC/Plate 6	1.97	0.56	0.28	10.4	8.91	0.86
AH/Plate 7	2.16	0.49	0.23	11.5	8.75	0.76
RSS/Plate 8	4.39	0.44	0.10	18.8	9.07	0.48
MLP/None	6.63	N/A	N/A	24.5	N/A	N/A

Highest values shown in red

Presenter M3/Material | Date FINAL | Slide 12 of 16 | Closed

2

RCC Pinholes

- **Findings (agreed to by Curry):**
  - Refurbishment intervals and process established to repair pinholes, maintain sealant, and achieve maximum mission life
  - Accept/reject criteria allows for pinholes greater than 0.04 inches in service provided the underlying substrate is not exposed
  - 2003 launch pad zinc sampling indicates RSS is still a source for zinc contamination and potential pinhole formation

Presenter M3/Material | Date FINAL | Slide 13 of 16 | Closed

RCC Pinholes

- **Recommendations (agreed to by Curry):**
  - Consider taking action to minimize the potential of zinc contamination by judicious maintenance of the topcoat and/or protection of the RCC material system from rain water
  - Determine the number and size of pinholes expected based on the current maintenance requirements and impact on structural integrity

Presenter M3/Material | Date FINAL | Slide 14 of 16 | Closed

RCC Pinholes

- **Documentation:**
  - NASA report KSC-5600-6256, "Launch Pad Zinc Sampling at LC-39B", June 2003
  - NASA GRC Briefing by A. Calomino, "Microstructural Characterization of RCC Materials", 16 May 2003
  - ML0601-0002, "Reusable Surface Insulation Acceptance Criteria for Operation Vehicles", 19 September 2002
  - Boeing Specification ML0601-9026, "Thermal Protection System Material Review Maintenance Procedures"; TPS 365 "RCC Coating Repair", 25 July 2002
  - Boeing Report KL0-98-009, "Launch Pad Zinc Fallout Determination", 22 December 1998
  - NASA TM-1998-208659,"Space Shuttle Pinhole Formation Mechanism Studies", November 1998

Presenter M3/Material | Date FINAL | Slide 15 of 16 | Closed

RCC Pinholes

- **Documentation:**
  - Technical paper by Jacobsen et al., "Oxidative Attack of Carbon/Carbon Substrates Through Coating Pinholes", June 1998
  - Lockheed Martin Report 221RP10558, "RCC Pinhole/Sealant Loss Investigation", September 1996
  - Lockheed Martin Report 221RP10539, "RCC Pinhole/Sealant Loss Coating Adherence", August 1996
  - Rockwell briefing by M. Gordon, "RCC Pinhole & Sealant Loss Inspections at KSC", 11 September 1995
  - Rockwell Report LTR 6322-4039, "Examination of RCC Pinholes", December 1994
  - Rockwell briefing by G. Tiezzi, "Porosity of RCC Wing Edge Panels", 7 September 1993

Presenter M3/Material | Date FINAL | Slide 16 of 16 | Closed

RCC Type A Sealant

- **Action / Issue:** Deterioration of Type A sealant
- **Background / Facts:**
  - Discovered white residue on WLE RCC panels on OV-102, OV-104 and OV-105 in November 2001
  - Lab results determined deposits to be sodium carbonate
  - Root cause determined to be the Type A sealant converting to sodium carbonate when exposed to rain water

Presenter M3/Material | Date FINAL | Slide 1 of 5 | Closed

RCC Type A Sealant Locations With White Residue

OV-102 Left	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	A	A	A	A	A	A	A	A	A	DTA	DTA	A	A	A	A	A	A	A	A	A	A	A
Refurbished?	N	N	N	N	N	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y	N	N	N	N	N
White?	C	C	C	C	C	W	W	W	W	W	W	W	W	W	W	W	W	C	C	C	C	C
OV-102 Right	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	A	A	A	A	A	A	A	A	A	A	A	DTA	A	A	A	A	A	A	A	A	A	A
Refurbished?	N	N	N	N	N	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y	N	Y	N	N	N
White?	C	C	C	C	C	W	W	W	W	C	C	W	W	W	W	W	W	C	W	C	C	C

OV-104 Left	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	A	A	A	A	A	A	A	A	A	A	A	A	A	DTA	A	DTA	DTA	DTA	A	A	A	A
Refurbished?	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N
White?	W	W	C	C	C	W	W	W	W	W	W	W	W	W	W	W	W	C	C	C	C	C
OV-104 Right	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	A	A	A	A	A	A	A	A	A	DTA	A	A	A	A	DTA	DTA	DTA	DTA	A	A	A	A
Refurbished?	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N
White?	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	C	C	C	C

OV-105 Left	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA
Refurbished?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
White?	C	C	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	C	C	C	C	C
OV-105 Right	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA
Refurbished?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
White?	C	C	C	C	W	W	W	W	W	C	W	W	W	W	C	C	C	C	C	C	C	C

- DTA — Double Type A Sealant
- A — Single Type A Sealant
- N — No Recent Refurbishment and/or Recent Repairs (3 Years)
- Y — Recently Refurbished and/or Repaired
- C — Clean, No White Deposits
- W — White Deposits Found

TOTALS
OV-102 23
OV-104 32
OV-105 24

Presenter M3/Material | Date FINAL | Slide 2 of 5 | Closed

RCC Type A Sealant

- **Background / Facts:**
  - There are 3 possible outcomes for sodium carbonate deposits
    - Deposits are washed off and removed
      - Would decrease sealant effectiveness
    - Deposits remain on surface, melt on re-entry, and combine with glass
      - Favorable outcome, restores the composition of Type A sealant
    - Deposits remain on surface, melt on re-entry, and flow to other parts
      - Potentially damaging and needs to be monitored

Presenter M3/Material | Date FINAL | Slide 3 of 5 | Closed

RCC Type A Sealant

- **Findings (Agreed to by Curry):**
  - Root cause determined and found not to be detrimental to RCC
  - Deposits are potentially damaging to metallic hardware
- **Recommendations (Agreed to by Curry):**
  - Continue previous investigation of an improved sealant system
  - Continue monitoring for potential flow of deposits onto metallic hardware

Presenter M3/Material | Date FINAL | Slide 4 of 5 | Closed

1

RCC Type A Sealant

- **Action / Issue:** Deterioration of Type A sealant
- **Background / Facts:**
  - Discovered white residue on WLE RCC panels on OV-102, OV-104 and OV-105 in November 2001
  - Lab results determined deposits to be sodium carbonate
  - Root cause determined to be the Type A sealant converting to sodium carbonate when exposed to rain water

Presenter M3/Material | Date FINAL | Slide 1 of 5 | Closed

RCC Type A Sealant
Locations With White Residue

OV-102 Left	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	A	A	A	A	A	A	A	A	A	DTA	DTA	A	A	A	A	A	A	A	A	A	A	A
Refurbished?	N	N	N	N	N	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y	N	N	N	N	N
White?	C	C	C	C	C	W	W	W	W	W	W	W	W	W	W	W	W	C	C	C	C	C
OV-102 Right	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	A	A	A	A	A	A	A	A	A	A	A	DTA	A	A	A	A	A	A	A	A	A	A
Refurbished?	N	N	N	N	N	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y	N	Y	N	N	N
White?	C	C	C	C	C	W	W	W	W	C	C	W	W	W	W	W	W	C	W	C	C	C

OV-104 Left	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	A	A	A	A	A	A	A	A	A	A	A	A	A	DTA	A	DTA	DTA	DTA	A	A	A	A
Refurbished?	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N
White?	W	W	C	C	C	W	W	W	W	W	W	W	W	W	W	W	W	C	C	C	C	C
OV-104 Right	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	A	A	A	A	A	A	A	A	A	DTA	A	A	A	A	DTA	DTA	DTA	DTA	A	A	A	A
Refurbished?	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N
White?	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	C	C	C	C

OV-105 Left	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA
Refurbished?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
White?	C	C	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	C	C	C	C	C
OV-105 Right	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Sealant	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA	DTA
Refurbished?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
White?	C	C	C	C	W	W	W	W	W	C	W	W	W	W	C	C	C	C	C	C	C	C

DTA Double Type A Sealant
A Single Type A Sealant
N No Recent Refurbishment and/or Recent Repairs (3 Years)
Y Recently Refurbished and/or Repaired
C Clean, No White Deposits
W White Deposits Found

TOTALS	
OV-102	23
OV-104	32
OV-105	24

Presenter M3/Material | Date FINAL | Slide 2 of 5 | Closed

RCC Type A Sealant

- **Background / Facts:**
  - There are 3 possible outcomes for sodium carbonate deposits
    - Deposits are washed off and removed
      - Would decrease sealant effectiveness
    - Deposits remain on surface, melt on re-entry, and combine with glass
      - Favorable outcome, restores the composition of Type A sealant
    - Deposits remain on surface, melt on re-entry, and flow to other parts
      - Potentially damaging and needs to be monitored

Presenter M3/Material | Date FINAL | Slide 3 of 5 | Closed

RCC Type A Sealant

- **Findings (Agreed to by Curry):**
  - Root cause determined and found not to be detrimental to RCC
  - Deposits are potentially damaging to metallic hardware
- **Recommendations (Agreed to by Curry):**
  - Continue previous investigation of an improved sealant system
  - Continue monitoring for potential flow of deposits onto metallic hardware

Presenter M3/Material | Date FINAL | Slide 4 of 5 | Closed

RCC Type A Sealant

- **Documentation:**
  - NASA Labs at KSC letter KSC-MSL-0127-2001, "White Deposits Removed From OV-102, OV-104 and OV-105", 15 March 2001
  - Briefing by N. Jacobson et al., "Chemistry of Sodium Carbonate Deposits on the Orbiter Wing Leading Edge and Nose Cap"
  - Briefing by D. Curry et al., "Orbiter Reinforced Carbon/Carbon Advanced Sealant Systems Screening Tests", January 2000

Presenter M3/Material | Date FINAL | Slide 5 of 5 | Closed

1

RCC NDE

- **Action / Issue:** Determine NDE requirements for RCC components
- **Purposes of NDI:**
  1. Verify no carbon substrate defects exist of a quantify and size distribution that could result in structural failure
  2. Verify no SiC/substrate interface defects exist of a quantity and size distribution that could result in loss of the SiC layer and expose the carbon substrate
  3. Validate the mass loss analysis method/results and support determination of mission life capability for each RCC part

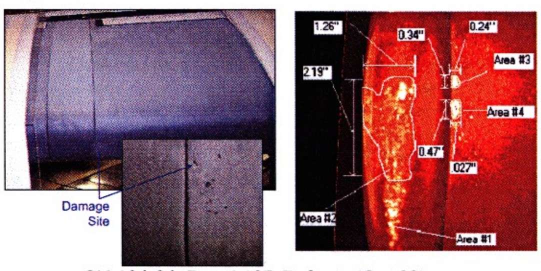
Presenter M3/Material | Date FINAL | Slide 1 of 25 | Closed

RCC NDE

- **Basis for Purpose 1 (Carbon Substrate):**
  - Visual and thermography NDE results of OV-104 panel 16R revealed surface and subsurface defect indications (see next chart)
  - X-Ray computed tomography NDI technique performed by Wyle Laboratories on same panel in Nov 02
    - Reference Wyle Laboratories Report, "CT Inspection of OV-104 RCC Panel", P. Engel, 22 November 2002
    - 75 CT slices were obtained
    - Subsurface defect indications were confirmed (see next 4 charts)

Presenter M3/Material | Date FINAL | Slide 2 of 25 | Closed

RCC NDE



OV-104-24, Panel 16R Defects (Oct 02)
Visual and Thermography Results

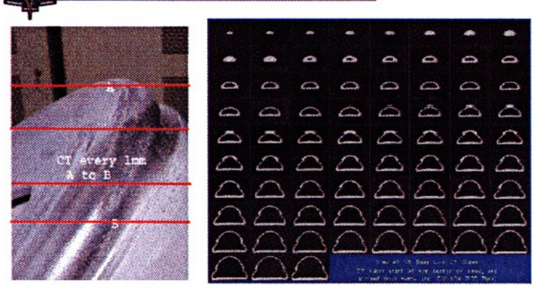
Presenter M3/Material | Date FINAL | Slide 3 of 25 | Closed

RCC NDE

OV-104-24, Panel 16R CT by Wyle Labs (Nov 02)

Presenter M3/Material | Date FINAL | Slide 4 of 25 | Closed

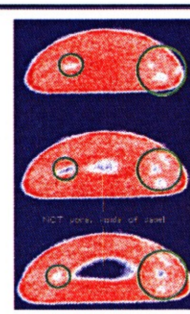
RCC NDE



75 CT Slices Were Obtained on OV-104-24, Panel 16R

Presenter M3/Material | Date FINAL | Slide 5 of 25 | Closed

RCC NDE



○ **Subsurface Indications**

OV-104-24, Panel 16R CT Results (Nov 02)

Presenter M3/Material | Date FINAL | Slide 6 of 25 | Closed

1

RCC NDE

Subsurface Indications — Surface Defects

OV-104-24, Panel 16R CT Results (Nov 02)

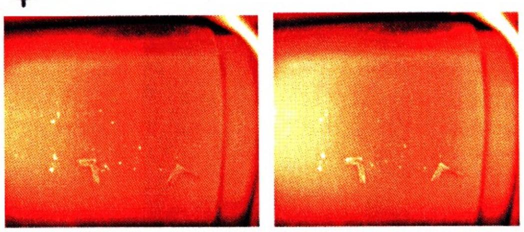
Presenter M3/Material | Date FINAL | Slide 7 of 25 | Closed

RCC NDE

- **Basis for Purpose 1 (Carbon Substrate) Continued:**
  - A study was performed on OV-103 and OV-105 RCC panels using thermography
    - Reference briefing by KSC personnel
    - Concentrated on panels 7 through 12, left and right
    - All 24 panels appeared to be in good condition
  - As an additional test, OV-103 panel 16R was inspected using thermography
    - Subsurface defect indications observed (see next chart)

Presenter M3/Material | Date FINAL | Slide 8 of 25 | Closed

RCC NDE



0.234-0.651 Seconds (Averaged) — 0.334-0.851 Seconds (Averaged)

OV-103-30, Panel 16R Thermography Results (Nov 02)

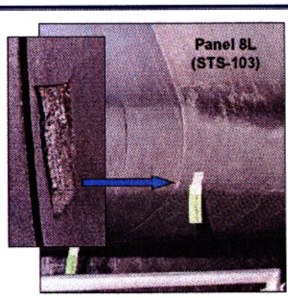
Presenter M3/Material | Date FINAL | Slide 9 of 25 | Closed

RCC NDE

- **Basis for Purpose 2 (SiC Layer):**
  - 6 occurrences of SiC layer loss or damage have been identified
    - November 1997, OV-102-24 (STS-87), 3 damaged parts
      - Reference Boeing Report KLO-98-002, March 1998 (no photos included in report)
      - Panel 19R, 0.04" diameter, 0.035" deep exposing carbon substrate
      - Panel 17R, 0.1" x 0.2" x 0.025" deep exposing carbon substrate
      - Arrowhead, 0.2" x 0.15" x 0.026" deep exposing carbon substrate
    - January 2000, OV-103-27 (STS-103), Panel 8L, panel scrapped
    - December 2000, OV-102-26 (STS-93), T-Seal 11L
    - April 2001, OV-103-29 (STS-102), Panel 10L

Presenter M3/Material | Date FINAL | Slide 10 of 25 | Closed

RCC NDE



Suspected Oxidation At SiC and Substrate Interface

OV-103-27, Panel 8L SiC Loss (Jan 00), Panel Scrapped

Presenter M3/Material | Date FINAL | Slide 11 of 25 | Closed

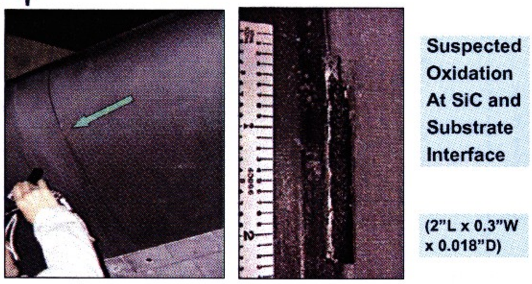
RCC NDE

OV-102-26, T-Seal 11L SiC Damage (Dec 00)

Presenter M3/Material | Date FINAL | Slide 12 of 25 | Closed

2

RCC NDE



OV-103-29, Panel 10L SiC Loss (Apr 01)

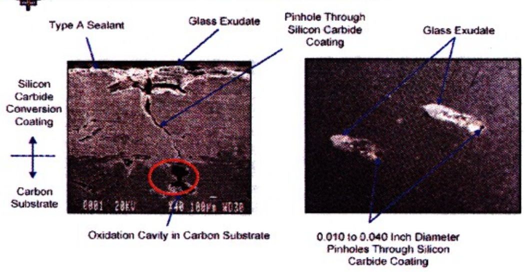
Presenter M3/Material | Date FINAL | Slide 13 of 25 | Closed

RCC NDE

- **Basis for Purpose 2 (SiC Layer) Continued:**
  - Pinholes in SiC layer have potential to result in oxidation of the carbon substrate and/or SiC/substrate interface
    - Majority of pinholes occur along craze cracks in SiC layer
    - Typically in thick regions of SiC layer – indicative of porous substrate
  - Oxidation below the SiC layer has been discovered associated with pinhole locations (see next charts)

Presenter M3/Material | Date FINAL | Slide 14 of 25 | Closed

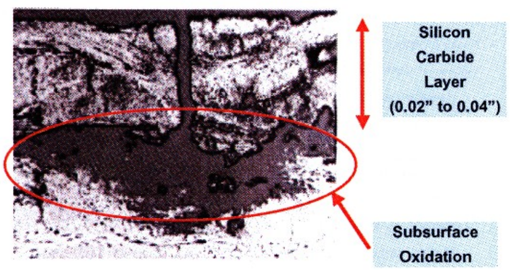
RCC NDE



OV-102 Panel 12R After 15th Flight

Presenter M3/Material | Date FINAL | Slide 15 of 25 | Closed

RCC NDE



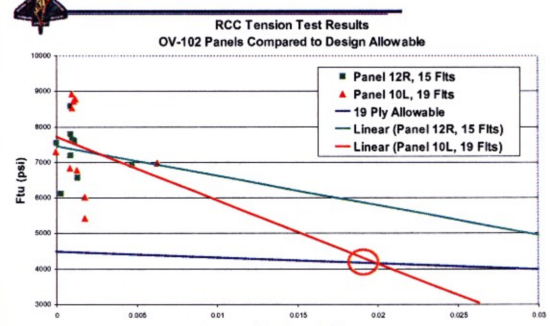
Presenter M3/Material | Date FINAL | Slide 16 of 25 | Closed

RCC NDE

- **Basis for Purpose 3 (Mission Life):**
  - Destructive testing performed on OV-102 panel 12R (15 flights) and panel 10L (19 flights) to compare to design allowables
    - Documented in LMM&FC report 221RP10558, Sep 1996
  - Data is limited and significant scatter exists, however test results indicate trends worse than expected (see next charts)
    - Tension test results below allowable at 0.02 psf (not 0.03)
    - Lug test results below allowable at 0.02 psf (not 0.1)
    - Opening corner moment below allowable at 0.01 psf (not 0.03)
  - Results indicate mass loss prediction method should be revalidated

Presenter M3/Material | Date FINAL | Slide 17 of 25 | Closed

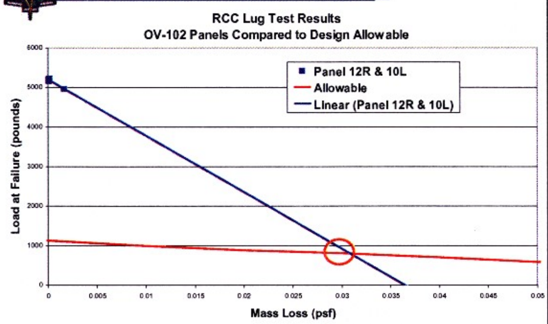
RCC NDE



Presenter M3/Material | Date FINAL | Slide 18 of 25 | Closed

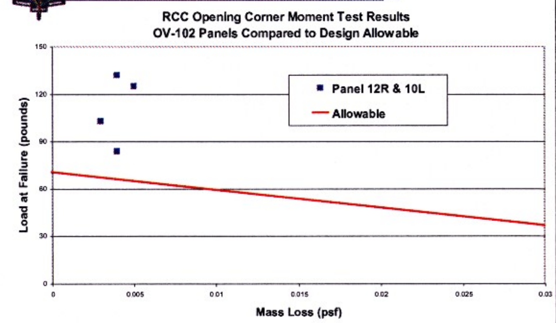
3

RCC NDE



Presenter M3/Material | Date FINAL | Slide 19 of 25 | Closed

RCC NDE



Presenter M3/Material | Date FINAL | Slide 20 of 25 | Closed

RCC NDE

- **Basis for Purpose 3 (Mission Life) Continued:**
  - X-ray Computed Tomography (CT) NDI technique demonstrated to be viable for determining variable RCC mass loss due to oxidation
    - Reference Rockwell Report MPR 6146-2000, "Evaluation of Carbon-Carbon Materials and Structures Using Computerized Tomography Techniques", March 1994
    - Rockwell Report LTR 5928-2442, "Prediction of RCC Flexural Strength Using CT Techniques", September 1992
    - Reference Rockwell Report MPR 5806-2020, "Determination of Mass Loss coated RCC Carbon-Carbon Orbiter Structures", May 1992

Presenter M3/Material | Date FINAL | Slide 21 of 25 | Closed

RCC NDE

- **Basis for Purpose 3 (Mission Life) Continued:**
  - MCR19643, "Develop a NDE Method for RCC Components", 11 March 2002 was presented to the ERB
  - Proposed a 3-year development program to develop a credible RCC NDE program
    - Fabricate and characterize NDE standards
    - Down-select NDE techniques
    - Fully characterize RCC flight hardware via destructive testing
    - Validate analysis predictions of mass loss and strength reduction using NDE results
  - Right approach!!! – schedule can be accelerated

Presenter M3/Material | Date FINAL | Slide 22 of 25 | Closed

RCC NDE

- **Findings (agreed to by Curry, Gordon and Grant):**
  - Damage and defects discovered on RCC components warrants development of NDI techniques to verify structural integrity
- **Recommendations (agreed to by Curry, Gordon and Grant):**
  - NDE all flown WLE RCC parts ASAP to support investigation
    - Determine defect quantity and size distribution
    - Use results to determine what parts should be included in the impact test program
  - Identify and implement NDE techniques for carbon substrate and SiC/substrate layer inspection as a **return to flight** criteria and for routine use
  - Develop and implement NDE techniques for carbon substrate mass loss to validate analysis methods and results (need date is TBD)

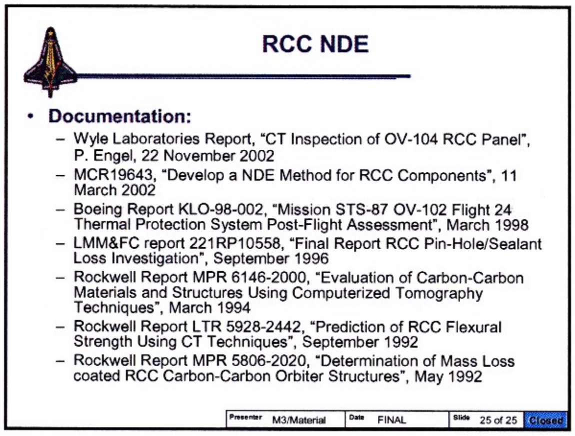
Presenter M3/Material | Date FINAL | Slide 23 of 25 | Closed

RCC NDE

- **Recommendations Continued (agreed to by Curry, Gordon and Grant):**
  - NDE technique development and application should address the following
    - NDE standards
    - Probability of detection
    - Inspector certification requirements
    - Basis for accept/reject criteria
    - Basis for inspection frequency
    - How NDE results will be used in the mission life analysis
    - If production NDE techniques and processes are used, demonstrate the adequacy to include detection capability, accept/reject criteria, and implications to structural integrity via mechanical testing as was performed originally

Presenter M3/Material | Date FINAL | Slide 24 of 25 | Closed

4


RCC NDE
• Documentation:
– Wyle Laboratories Report, "CT Inspection of OV-104 RCC Panel", P. Engel, 22 November 2002
– MCR19643, "Develop a NDE Method for RCC Components", 11 March 2002
– Boeing Report KLO-98-002, "Mission STS-87 OV-102 Flight 24 Thermal Protection System Post-Flight Assessment", March 1998
– LMM&FC report 221RP10558, "Final Report RCC Pin-Hole/Sealant Loss Investigation", September 1996
– Rockwell Report MPR 6146-2000, "Evaluation of Carbon-Carbon Materials and Structures Using Computerized Tomography Techniques", March 1994
– Rockwell Report LTR 5928-2442, "Prediction of RCC Flexural Strength Using CT Techniques", September 1992
– Rockwell Report MPR 5806-2020, "Determination of Mass Loss coated RCC Carbon-Carbon Orbiter Structures", May 1992
Presenter M3/Material
Date FINAL
Slide 25 of 25
Closed

5

RCC Maintenance

9-1	RCC Maintenance Requirements
9-2	RCC Maintenance Repair and Refurbishment Process
9-3	Left WLE Maintenance During OMM & Flows
9-4	LESS Hardware Use

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	11 of 32

RCC Maintenance Requirements

- **Action / Issue:** Determine adequacy of RCC maintenance requirements
- **Background / Facts:**
  - RCC inspection requirements are documented in NSTS 08171, OMRSD File III, Volume 9 and Volume 30
    - Inspection methods are primarily visual
    - Tactile pressure test of large craze cracks performed to identify excessive subsurface oxidation
    - Accept/reject criteria established for expected defect types and locations

Presenter M3/Material | Date FINAL | Slide 1 of 5 | Closed

RCC Maintenance Requirements

- **Background / Facts:**
  - RCC tactile pressure requirements are documented in NSTS 08171, OMRSD File III, Volume 9, Number V09AJ0.075
    - Use compressive gloved-finger technique only at the inboard and outboard regions adjacent to each T-seal of each panel
    - Region limited to within 12 inches of panel apex
    - Panels 6 through 17 are inspected as a minimum
    - Additional panels may require tactile inspection based on craze crack sizes

Presenter M3/Material | Date FINAL | Slide 2 of 5 | Closed

RCC Maintenance Requirements

- **Background / Facts:**
  - Inspection accept/reject criteria are documented in ML0601-0002, RSI Acceptance Criteria for Operation Vehicles, 19 September 2002
    - Craze cracks with gap width less than 0.003 inches are acceptable
    - Flaking of Type A sealant is acceptable when depth is less than 0.015 inches
    - SiC chips, scratches, or abrasions are acceptable when depth is less than 0.015 inches and the substrate is not exposed
    - Pinholes are covered in the aging portion of this briefing

Presenter M3/Material | Date FINAL | Slide 3 of 5 | Closed

RCC Maintenance Requirements

- **Findings (agreed to by Curry, Gordon and Grant):**
  - Established maintenance requirements are thoroughly documented
  - No NDE technique is routinely employed during maintenance of RCC
  - Inspection requirements and accept/reject criteria appear to be difficult to implement consistently
  - Protection of RCC during maintenance is inadequate against tool drops, impact from maintenance stands, etc.
- **Recommendations (agreed to by Curry, Gordon and Grant):**
  - Improve the protection of RCC components in the maintenance facilities
  - Reevaluate adequacy of maintenance requirements considering inspection burden and reliability of visual method

Presenter M3/Material | Date FINAL | Slide 4 of 5 | Closed

RCC Maintenance Requirements

- **Documentation:**
  - NSTS 08171, "Space Shuttle Operations and Maintenance Requirements and Specification Document"; File III, Volume 9, "Thermal Protection System", 21 November 2002
  - NSTS 08171, "Space Shuttle Operations and Maintenance Requirements and Specification Document"; File III, Volume 30, "Airframe Inspection", 1 May 2003
  - ML0601-0002, "Reusable Surface Insulation Acceptance Criteria for Operational Vehicles", 19 September 2002
  - Lockheed Martin Engineering Specification 508-RCC-43, "Process Specification for Split Bushing Removal and Installation", 29 March 2000

Presenter M3/Material | Date FINAL | Slide 5 of 5 | Closed

1

RCC Repair & Refurbishment

- **Action / Issue:** Determine adequacy of RCC repair and refurbishment requirements
- **Repair Process:**
  - Repairs are performed using Boeing Specification ML0601-9026, Procedure TPS-365, RCC Coating Repair
  - Repairs to RCC parts limited to minor damage to Silicon-Carbide coating
    - Repairs are performed at KSC
    - Not authorized for pinholes and substrate damage
  - RCC repair involves the following process steps:
    - Part cleaning
    - Type A sealant application
    - Sanding of repaired region to meet flushness requirements

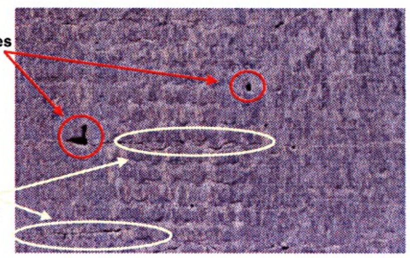
Presenter M3/Material | Date FINAL | Slide 1 of 9 | Closed

RCC Repair & Refurbishment

- **Refurbishment Process:**
  - Refurbishments are performed using Lockheed-Martin Specification 508-RCC-318, Refurbishment of Flown RCC Parts, 16 February 2000
  - Refurbishments to RCC parts performed to achieve the desired part mission life by replenishing the Type A sealant
  - Refurbishments performed by only Lockheed-Martin using the following process:
    - Type A sealant removed by sanding
    - Vacuum heat clean to bake-out contaminants
    - Pinholes repaired using Type A sealant forcefully wiped into the holes
    - TEOS impregnation and cure
    - Type A sealant application and cure
    - Reassembly of the metallic parts to the RCC panel

Presenter M3/Material | Date FINAL | Slide 2 of 9 | Closed

RCC Repair & Refurbishment



OV-102-17, T-Seal 9L After Sanding During Refurbishment, Magnification Approximately = 10X

Presenter M3/Material | Date FINAL | Slide 3 of 9 | Closed

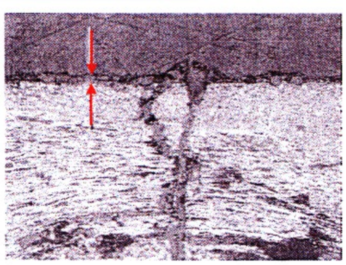
RCC Repair & Refurbishment

- **Background / Facts:**
  - Refurbishment interval established based on destructive evaluation of OV-102 panel 12R after 15th flight
    - Reference Rockwell Report LTR 6322-4039, "Examination of RCC Pinholes", December 1994
    - Evaluation performed to characterize pinholes
    - Discovered that OML is losing the Type A sealant layer
  - Type A sealant thickness measured near 5 pinholes
    - Minimum ranged from 0.0001 to 0.0002 inches
    - Maximum ranged from 0.006 to 0.0014 inches

Presenter M3/Material | Date FINAL | Slide 4 of 9 | Closed

RCC Repair & Refurbishment

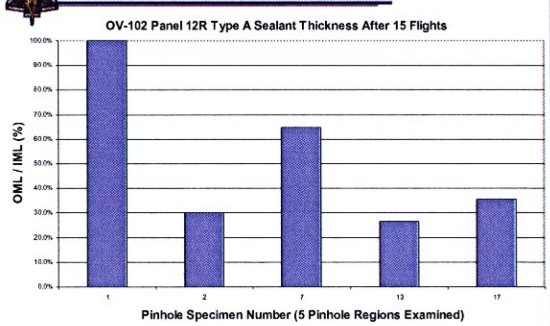
Type A Sealant Thickness Range 0.0002 to 0.0014 Inches



OV-102 Panel 12R After 15th Flight
Pinhole Cross-Section, Magnification Approximately 200X

Presenter M3/Material | Date FINAL | Slide 5 of 9 | Closed

RCC Repair & Refurbishment



Presenter M3/Material | Date FINAL | Slide 6 of 9 | Closed

1

RCC Repair & Refurbishment

- **Background / Facts :**
  - Since significant substrate oxidation was not found with panel 12R, established refurbishment interval to be every other OMM
  - Approach was supported by arc-jet testing in the mid-1990s
  - Refurbishment intervals are documented in OMRSD File II, Volume 3
    - 18 missions for panel/T-seal assemblies 6 through 17
    - 36 missions for panel/T-seal assemblies 18 and 19
    - Implies no refurbishment is required for panel/T-seals 1 through 5 and 20 through 22

Presenter M3/Material | Date FINAL | Slide 7 of 9 | Closed

RCC Repair & Refurbishment

- **Findings (agreed to by Curry):**
  - Refurbishment of panel/T-seal assemblies 1 through 5 and 20 through 22 are not required
- **Recommendations (agreed to by Curry, Gordon and Grant):**
  - Conduct evaluation of RCC panels to determine Type A sealant thickness loss rate at various locations as part of the planned destructive testing of RCC panels
  - Use above result to confirm or revise current refurbishment intervals

Presenter M3/Material | Date FINAL | Slide 8 of 9 | Closed

RCC Repair & Refurbishment

- **Documentation:**
  - Briefing by M. Gordon, "STS-107 Mishap Investigation Team Action Item OVE-195, RCC Specifics for CAIB Item B1-0036", 13 March 2003
  - Boeing Specification ML0601-9026, "Thermal Protection System Material Review Maintenance Procedures"; TPS 365 "RCC Coating Repair", 25 July 2002
  - Lockheed Martin Letter 3-47200/2L-129, "RCC Coating Repair History", 16 May 2002
  - Vought Letter 3-47200/5L-276, "Refurbishment of OV-102", 1 November 1995
  - Paper by S. Williams et al., "Ablation Analysis of the Shuttle Orbiter Oxidation Protected Reinforced Carbon-Carbon", September 1995
  - Rockwell Report, "Field Repair of RCC Coating Advanced TPS Flight Demonstration", August 1993

Presenter M3/Material | Date FINAL | Slide 9 of 9 | Closed

2

RCC Maintenance OMM in 2000

- **Action / Issue:** Determine potential for left WLE maintenance actions to be a contributing cause of the accident
- **Background / Facts:**
  - OV-102 inducted into OMM after STS-93, 26th flight for OV-102
  - OMM conducted at Palmdale October 1999 through February 2001
  - All WLE RCC components were removed to accomplish required inspections
  - RCC panel/T-seals 6, and 13-17 were refurbished
  - RCC parts were inspected for pinholes, etc.
    - Pinholes in Panel 8 and 19 originally reported > 0.04 inches in diameter (TES-2-J3-0412, 0416)
    - Quality evaluated pinholes using optical comparator and determined them to be within acceptable limits

Presenter M3/Material | Date FINAL | Slide 1 of 13 | Closed

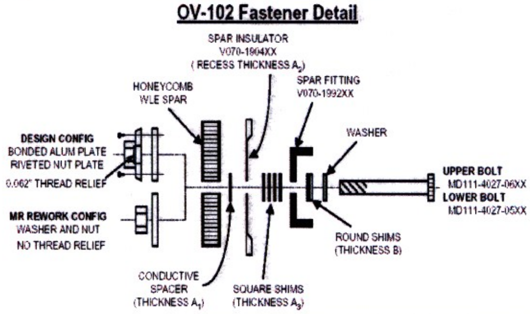
RCC Maintenance OMM in 2000

- **Background / Facts :**
  - After re-installation of the RCC components, step and gap measurements were found to be unacceptable (TES-2-J3-0495)
  - Complete removal of Left WLE subsystem was performed and the following issues were discovered
    - Spar fitting shims not per design (STR-2-J3-7033)
    - Lower access panel nutplate issues (STR-2-J3-6689)
    - Debonded nutplates, low running torque and damaged nuts (TES-2-J3-0439)
  - Evaluated 152 of the 176 fitting fasteners (24 were not evaluated since some fittings were already removed)
    - 104 of 152 (68%) were per drawing requirements
    - 48 of 152 (32%) had low torque values

Presenter M3/Material | Date FINAL | Slide 2 of 13 | Closed

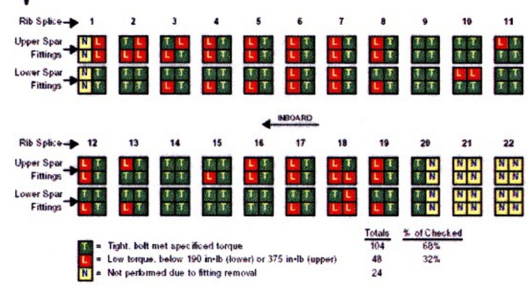
RCC Maintenance OMM in 2000

OV-102 Fastener Detail



Presenter M3/Material | Date FINAL | Slide 3 of 13 | Closed

RCC Maintenance OMM in 2000



OV-102 Left Wing Torque Check Results

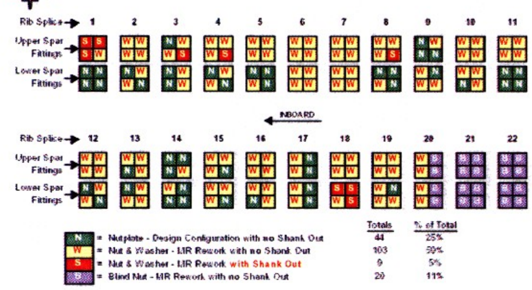
Presenter M3/Material | Date FINAL | Slide 4 of 13 | Closed

RCC Maintenance OMM in 2000

- **Background / Facts :**
  - Improper shims resulted in shank-out condition in some locations
    - Observed in MR nut and washer rework areas only
    - Shim stack returned to original build configuration
  - Bolt torque sequence standardized to reduce panel torsion and deformation
    - Sequence steps and torque increments defined
    - Torque checked after a minimum of 24 hours
  - Both OV-102 wings reworked to design configuration
  - Boeing Specification ML0301-0023 installation procedures revised

Presenter M3/Material | Date FINAL | Slide 5 of 13 | Closed

RCC Maintenance OMM in 2000



OV-102 Left Wing Fastener Shank-Out Check Results

Presenter M3/Material | Date FINAL | Slide 6 of 13 | Closed

1

RCC Maintenance

2. WLE Attach Fitting Bolt Torque

UA Closure Team

Related Fault Tree Block
- SFOML Wing 9-19 Loss of RCC Panel Due to Supporting Structure Failure

Finding
- Experience at the OV-102 OMM in Palmdale resulted in the program establishing a new baseline procedure for torquing the LESS attach fitting bolts to assure proper preload.
- Not all attachment fittings have been torqued per the new procedure.

OV-103: All RCC panels are currently off the vehicle and undergoing inspection per OMRSD. All fittings are off and will be torqued per the new procedure.

OV-104: Twelve panels (9-11 and 20-22) are now scheduled for removal and inspection this flow per existing OMRSD 3 year requirement.
8 fittings are scheduled for removal and torque per the new procedure.

OV-105: All fittings have been removed and will be torqued per the new procedure.

This material is PRELIMINARY information only. It is for limited distribution.
DO NOT FORWARD.

18

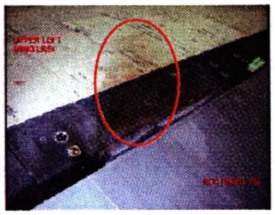
Presenter M3/Material | Date FINAL | Slide 7 of 13 | Closed

RCC Maintenance After STS-109

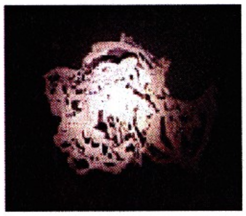
- **Background / Facts:**
  - STS-109, 27th flight for OV-102 launched 1 March 2002
  - Post-flight processing performed May 2001 through Jan 2002
  - Upper wing discoloration discovered near panel 15 left
  - Upper and lower access panels removed for inspection
  - Baseball size hard object found
    - Most likely glass-backed white masking tape
    - Tape used for paint masking may have fallen into RCC cavity during OMM
  - Area cleaned and accepted with MR concurrence

Presenter M3/Material | Date FINAL | Slide 8 of 13 | Closed

RCC Maintenance After STS-109



Discoloration Near Panel 15L



Ball of Masking Tape

OV-102-27, Post Flight Inspection

Presenter M3/Material | Date FINAL | Slide 9 of 13 | Closed

RCC Maintenance Before STS-107

- **Background / Facts:**
  - Pre-flight processing performed Mar 2002 through Aug 2002
  - STS-107, 28th flight for OV-102 launched 16 January 2003
  - OV-102 left wing horseshoe gap fillers were removed and replaced at panels 1, 19 and 20
    - Gap filler repaired during OMM J3 and found torn following STS-109

Presenter M3/Material | Date FINAL | Slide 10 of 13 | Closed

RCC Maintenance Before STS-107

- **Background / Facts :**
  - RCC angle seal 1L was removed to replace horseshoe gap filler
  - During bushing removal, the load applied was not calculated
    - Boeing specification MLO301-0023 states loads applied to RCC components should be kept below 30 pounds
    - PR disposition specified RCC loading should be kept below 20 pounds
  - Clevis fitting damaged during removal of the bushing
    - Replaced bolt and bushing
    - Damaged region was polished

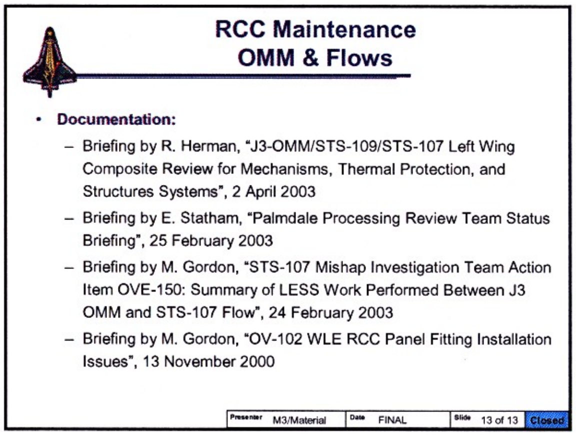
Presenter M3/Material | Date FINAL | Slide 11 of 13 | Closed

RCC Maintenance OMM & Flows

- **Findings (agreed to by Curry, Gordon and Grant):**
  - Significant WLE maintenance performed during OMM J3
  - Few maintenance actions after OMM J3 and prior to STS-107
  - Not all the fittings on OV-104 are scheduled for bolt torque prior to next flight
- **Recommendations (agreed to by Curry, Gordon and Grant):**
  - Perform torque of OV-104 attach fitting bolts prior to next flight

Presenter M3/Material | Date FINAL | Slide 12 of 13 | Closed

2


RCC Maintenance
OMM & Flows
• Documentation:
– Briefing by R. Herman, "J3-OMM/STS-109/STS-107 Left Wing Composite Review for Mechanisms, Thermal Protection, and Structures Systems", 2 April 2003
– Briefing by E. Statham, "Palmdale Processing Review Team Status Briefing", 25 February 2003
– Briefing by M. Gordon, "STS-107 Mishap Investigation Team Action Item OVE-150: Summary of LESS Work Performed Between J3 OMM and STS-107 Flow", 24 February 2003
– Briefing by M. Gordon, "OV-102 WLE RCC Panel Fitting Installation Issues", 13 November 2000
M3/Material
FINAL
13 of 13
Closed

3

RCC Maintenance

Maintenance Practices: LESS Hardware Use

- **Action / Issue:** Review/assess orbiter Leading Edge Structural Subsystem (LESS) maintenance practices regarding hardware use
- **Background:**
  - LESS consists of:
    - 22 Reinforced Carbon-Carbon (RCC) panels on each wing
    - 44 carrier panels: 22 upper, 22 lower on each wing
    - Numerous other components (spar insulators, clevis insulators, spanner beam insulators, attach fittings, brackets) and hardware (bolts, pins, sleeves, etc)
  - LESS subjected to thermal and aero stresses during reentry
    - Proper inspection/maintenance of components essential to system performing as designed/intended

Presenter	M3/Maintenance	Date	FINAL	Slide	1 of 5	Closed

RCC Maintenance

Maintenance Practices: LESS Hardware Use

- **Findings:**
  - Work Authorization Documents (WADs) very specific on most tasks
  - One exception: carrier panel (C/P) hardware (A286 bolt) reuse
    - 4 bolts per upper panel, 2 per lower panel
    - Engineers initially stated bolts are reused
    - Technicians stated hardware is discarded/replaced
    - Inspected multiple storage containers holding removed C/Ps
      - No bolts found
    - After further discussion, engineers restated bolts "can be reused" at technician's discretion, based on cleaning (using isopropyl alcohol) and visual inspection

Presenter	M3/Maintenance	Date	FINAL	Slide	2 of 5	Closed

RCC Maintenance

Maintenance Practices: LESS Hardware Use

- **Findings (cont'd):**
  - Unlike the predominance of WADs reviewed, the C/P WADs provide no clear guidance on hardware disposition
    - Both WADs (removal and installation of C/Ps) reviewed
    - No specific requirement to clean, inspect, or reuse (or replace)
  - By contrast, WADs covering removal of RCC panels clearly state "...identify, bag and retain hardware for future use" with respect to four separate component removals
    - Verified through physical inspection of removed components
  - Inconsistent/lacking guidance allows varying interpretations and creates the potential for process variation(s)

Presenter	M3/Maintenance	Date	FINAL	Slide	3 of 5	Closed

RCC Maintenance

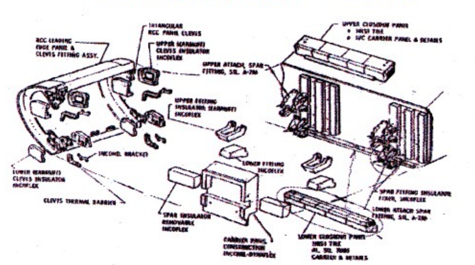
Maintenance Practices: LESS Hardware Use

- **Findings (cont'd):**
  - Results of investigation by metallurgist
    - "There was no evidence of stress corrosion cracking at pre-launch conditions. There was no evidence of cumulative failures that started on previous missions."
- **Recommendations:**
  - Eliminate the potential for varying interpretations of carrier panel bolt reuse by making the WADs more specific

Presenter	M3/Maintenance	Date	FINAL	Slide	4 of 5	Closed

RCC Maintenance

Maintenance Practices: LESS Hardware Use



February 24, 2003

Presenter	M3/Maintenance	Date	FINAL	Slide	5 of 5	Closed

1

Tile
Design – Certification

10-1 Design for Impact Resistance

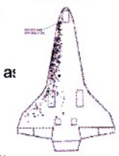
Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	12 of 32

Tile
Design – Certification

- **Action / Issue:**
  - Debris impact resistance of the tile TPS may be below safe levels.
- **Background / Facts:**
  - Current design requirements for impact damage as follows [17]:
    - The TPS shall not be designed to accommodate particle impact (such as from hail, rain, runway debris, meteoroids, etc.) whose kinetic energy levels exceed 0.006 ft-lb to the surface normal.
    - The Orbiter shall not be designed to withstand launch debris or ice.
  - Yet, tile damage occurs with every flight. In some cases localized structural heating due to the damage has been severe and could have caused loss of vehicle if located at another location [16]

STS-27



Presenter M3/Material | Date FINAL | Slide 1 of 11 | Closed

Tile
Design – Certification

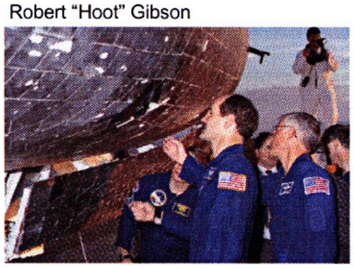
- **Background / Facts (cont'd):**
  - For the orbiter, TPS damage tolerance could be defined as the attribute that permits it to retain the required thermal protection for reentry after the structure has sustained described levels damage
  - Damage
    - Impact damage would include impact incurred during any phase of the mission
    - Other service induced damage could include undetected cracks along the densified layer in the tile
    - Maintenance induced damage would include undetected cracks incurred during maintenance (e.g. stepping on "piano key" tile)

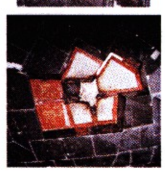
STS-27R

Presenter M3/Material | Date FINAL | Slide 2 of 11 | Closed

STS-27R, OV-104, Flight 3

Robert "Hoot" Gibson





Presenter M3/Material | Date FINAL | Slide 3 of 11 | Closed

Composite of Post-Flight Damage

STS
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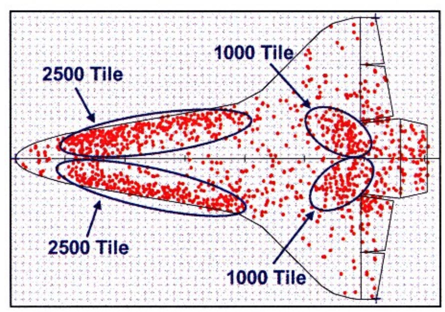
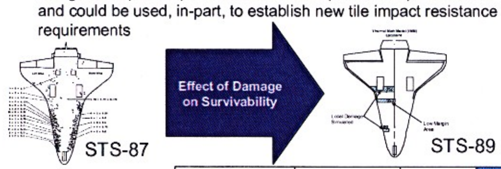


Presenter M3/Material | Date FINAL | Slide 4 of 11 | Closed

Tile
Design – Certification

- **Background / Facts (cont'd):**
  - A 1998 Boeing effort did assess the TPS damage to OV-102 during STS-87 and the potential damage to OV-105 during the next flight (STS-89) [18]; *this type of analysis is the lead-in for impact damage resistant design; helps define requirement for tile impact resistance*
  - Criteria required to establish magnitude of survivable damage is being developed as part of the on-orbit repair development effort and could be used, in-part, to establish new tile impact resistance requirements



Presenter M3/Material | Date FINAL | Slide 5 of 11 | Closed

Tile
Design – Certification

- **Background / Facts (cont'd):**
  - 1st generation tile (LI-900, LI-2200 and FRCI-12) have thin RCG coating that is not resistant to impact; cannot be coated with TUFI/RCG coating
  - 2nd generation tile (AETB-8) with TUFI/RCG coating has a factor of 6 increase in resistance to low-velocity impact damage [61] but can't be used over large areas on lower surface due to it higher thermal conductivity
  - 3rd generation tile (BRI-8) can be coated with TUFI/RCG and has conductivity similar to LI-900; design goal was also to have a strength similar to AETB-8
    - May be a one-for-one replacement for LI-900 lower surface acreage tile
    - Boeing IR&D funded BRI development prior to 2000
    - NASA upgrade program funded BRI development in 2000, 2001 and 2003
    - Additional development and testing required to fully ascertain its potential to replace lower surface LI-900 tile

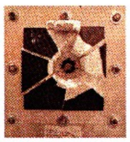
Presenter M3/Material | Date FINAL | Slide 6 of 11 | Closed

1

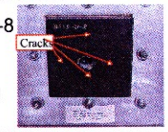
Tile
Design – Certification

- **Background / Facts (cont'd):**
  - Additional BRI development and testing required
    - Assess dimensional stability for complex shaped tile
    - Fully assess thermal characteristics (e.g. conductivity)
    - Material allowables
    - BRI at other densities
    - Evaluate impact resistance (various velocities and projectiles) based on damage tolerance requirements

LI-900



BRI-8



Hypervelocity Impact Testing

Presenter M3/Material | Date FINAL | Slide 7 of 11 | Closed

Tile
Design – Certification

- **Findings:**
  - The loss of a single tile before entry interface on the lower surface of the orbiter forward of location $X_0$1357 could result in the loss of the orbiter. The loss of two tiles before entry interface on the lower surface of the orbiter forward of location $X_0$1357 would most likely result in the loss of the orbiter [67].
  - Some tile possess more risk than others: some tile have a greater probability of being struck by debris, some locations are subject to greater heat load, and some locations have are adjacent to critical non-structural components [72]
  - The orbiter has been subjected to debris strikes since its first flight. Yet the requirements to tolerate or resist debris impact are exceedingly weak for general impact resistance and nonexistent for debris impact during launch [17].

Presenter M3/Material | Date FINAL | Slide 8 of 11 | Closed

Tile
Design – Certification

- **Findings (cont'd):**
  - Boeing has studied the consequence of impact damage resulting from debris impact under NASA sponsorship [74, 18]. The thermal and structural analysis performed as part of the study subsequent to the large debris impact damaged experienced during STS-87 [74, 18], demonstrated that plausible damage states could cause structural factors of safety to drop below 1.0 [46].
  - History has shown that the orbiters have suffered 10 tile loss events since Columbia first flew in April 1981. On average, that's one tile loss event every two years or 11 flights. One tile-loss event was directly attributable to debris impact from the SRB nose-cap.
  - A systematic approach to evaluate the effect of various tile damage scenarios on reentry survivability has not been performed.
  - As can be seen from the impact map, some areas of the orbiter are more likely to be damaged than others. Knowing the probability of where damage may occur is important, but the critical damage levels and consequences must also be ascertained.

Presenter M3/Material | Date FINAL | Slide 9 of 11 | Closed

Tile
Design – Certification

- **Recommendations:**
  - Compute/analyze the distribution of known damage sizes and locations
  - Establish the critical damage size for each critical location
  - Identify the consequences of sustaining critical damage in a critical location
  - Compute the probability of sustaining critical damage in a critical location based upon a predictive model that accounts for impacts of debris emanating from various sources
  - Develop a tile designed to withstand the critical damage computed for various locations and install it at those critical locations

Presenter M3/Material | Date FINAL | Slide 10 of 11 | Closed

References

Number	Filename	Reference
16	STS-27_Post Flight.pdf	Mission STS-27 OV-104 (Atlantis) Flight 3 TPS Post Flight Assessment (Hoot Gibson)
17	Orbiter Vehicle End Item Specification for The Space Shuttle.pdf	Orbiter Vehicle End Item Specification for the Space Shuttle System, Part 1, Performance and Design Requirement, Contract NAS9-20000, 7 Nov 02
18	OV-102 STS-87 TPS Damage.ppt	Gatto, "OV-102 (STS-87) TPS Damage," Boeing Presentation -Space Shuttle Vehicle Engineering Office, 6 January 1998
60	MIL-HDBK-1530.pdf	"Military Handbook - Aircraft Structural Integrity Program, " MIL-HDBK-1530, 4 November 1996
61	TPS Imp Post-PRT Basic2.pdf	Boeing, "TPS Enhancement Study Options," UCN 23273 (presentation), 28 March 2003

Presenter M3/Material | Date FINAL | Slide 11 of 11 | Closed

2

Tile
Fleet Experience – Aging

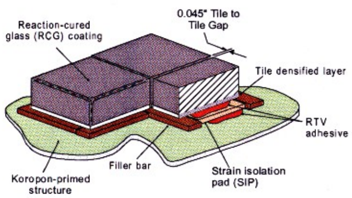
- 11-1 Tile System Integrity
- 11-2 Lost Tiles
- 11-3 Lack of NDI/E
- 11-4 Potential for Corrosion
- 11-6 Tile Shrinkage

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	13 of 32

Tile System Integrity

- **Action / Issue:**
  - Tile system components may degrade as a function of thermal/mechanical loads, chemical environment, and calendar time

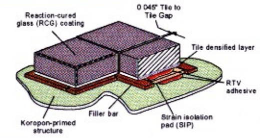


Tile System
- RCG Coating
- LI-900 / LI-2200 / FRCI-12 / AETB-8
- Densified Layer
- RTV Adhesive
- SIP
- RTV Adhesive
- Heatsink/Screed
- Koropon Primer

Presenter M3/Material | Date FINAL | Slide 1 of 18 | Closed

What will be the Weak Link In the Future?

Evaluate each tile component for aging effects



Material	Strength (psi) Material Allowable	Strength (psi) Average
LI-900	13	23
LI-2200	35	60
FRCI-12	50	75
AETB-8	29	45
BRI-8*	20	33
0.090-in Class 1, Grade A SIP	45	
0.115-in Class 2, Grade A SIP	45	
0.160-in Class 3, Grade A SIP	25	
RTV 560/566	280	480
Koropon Primer	?	
RTV 577		

The question:
Do these properties change as a function of thermal/mechanical loading, ground environment and/or time?

Presenter M3/Material | Date FINAL | Slide 2 of 18 | Closed

Coating/Tile/Densification Integrity

- **Background / Facts:**
  - Tile "poisoning" possible and inhibits efficacy of rewaterproofing; however, treatment of tile with multiple injection of DMES overcomes "poisoning"
  - Cooper test was used to evaluate mechanical strength under various loads
- **Findings:**
  - Evaluation of tile coating, substrate and densification to date indicates that tile should continue to be resistant to thermal/mechanical effects

Tile System
- ➡ RCG Coating
- ➡ LI-900 / LI-2200 / FRCI-12 / AETB-8
- ➡ Densified Layer
- RTV Adhesive
- SIP
- RTV Adhesive
- Heatsink/Screed
- Koropon Primer

Presenter M3/Material | Date FINAL | Slide 3 of 18 | Closed

RTV Integrity

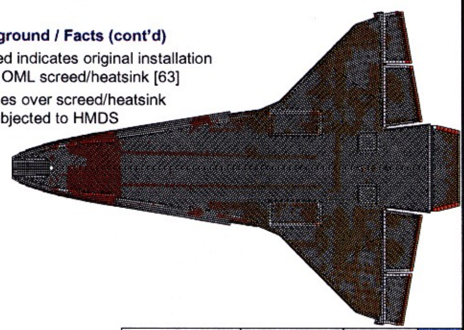
- **Background / Facts (cont'd):**
  - RTV Adhesive/Heatsink/Screed
    - Adhesive, heatsink and screed are all RTV silicone products supplied by General Electric
    - RTV known to degrade when exposed to certain environments
    - HMDS waterproofing used on OV-102 and OV-103; degrades RTV strength properties
    - A NASA/USA program is in place to sample and analyze RTV for degradation

Tile System
- RCG Coating
- LI-900 / LI-2200 / FRCI-12 / AETB-8
- Densified Layer
- ➡ RTV Adhesive
- SIP
- ➡ RTV Adhesive
- ➡ Heatsink/Screed
- Koropon Primer

Presenter M3/Material | Date FINAL | Slide 4 of 18 | Closed

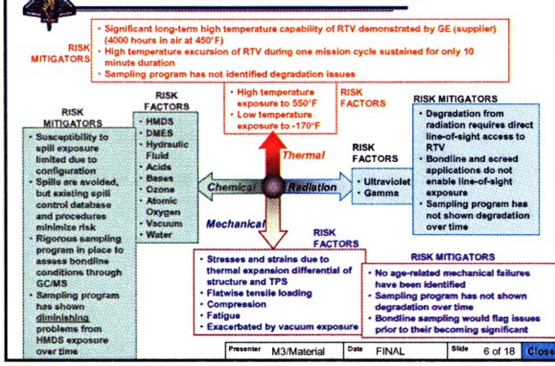
RTV Screed/Heatsink for OV-102

- **Background / Facts (cont'd)**
  - Red indicates original installation of OML screed/heatsink [63]
  - Tiles over screed/heatsink subjected to HMDS



Presenter M3/Material | Date FINAL | Slide 5 of 18 | Closed

Major Factors For RTV Degradation Have Been Identified



Presenter M3/Material | Date FINAL | Slide 6 of 18 | Closed

1

RTV Bondline Sampling Test Program (Since 1980s) [30]

Contractual Requirement Defines Key Locations → RTV Samples Removed During Ops & OMM → Assessment Made of RTV Bond During TPS Removal → RTV Specimens Tested and Analyzed at Boeing-HB → Analysis and Trends Presented to Customer Every 2 Years at TPS PRB

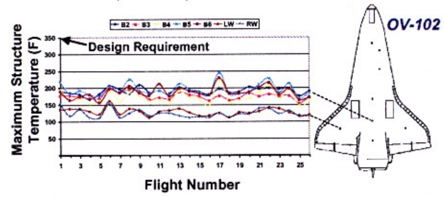
- **Samples are taken from key areas of Orbiter per OMRSD V09AW0**
  - Hydraulic Fluid Inspection - piano hinge/body flap
  - Screed/Heatsink Inspection - 7 locations (from 14 options)
  - Orbiter RTV Bondline Sampling - 10 locations
  - OMS RTV Bondline Sampling - 1 location per pod
- **Samples accompanied by Tile Removal PR**
  - Includes subjective evaluation of peel strength, tackiness
- **Samples sent to Boeing HB labs for analysis**
  - Derived Shore A Harness
  - Gas Chromatography/Mass Spectrometry (GC/MS)

Analysis Results Presented at TPS Process Review Boards Every 2 Years Do Not Show Degradation Trends

Presenter M3/Material | Date FINAL | Slide 7 of 18 | Closed

Thermal Effects on RTV

- **Background / Facts (cont'd):**
  - Maximum structural surface temperatures experienced by OV-102 [62]
  - At 250F, RTV/Koropon average strength drops to 220 psi; material allowable drops to 120 psi; at 350F, allowable drops to < 20 psi



Presenter M3/Material | Date FINAL | Slide 8 of 18 | Closed

RTV Integrity

- **Background / Facts (cont'd):**
  - Sampling program in place since 1980s to identify age/environment related changes in material properties [29, 30]
  - To date, the sampling program has not found any negative trends [30]
  - The loss of two tiles before entry interface on the lower surface of the orbiter forward of X01357 would most likely result in the loss of the orbiter [67]
- **Findings:**
  - Sub-nominal bonds probably exist
- **Recommendations:**
  - Ensure continuation of sampling program; statistical analysis?; enough samples?
  - Relate results of sampling program to reduction in risk
  - Investigate effect of combined environment (thermal/mechanical/chemical) and age on degradation
  - Qualify subjective peel-strength evaluation process
  - Investigate methods to detect subnominal bonds (long-term)

Presenter M3/Material | Date FINAL | Slide 9 of 18 | Closed

Strain Isolation Pad (SIP) Integrity

- **Background / Facts (cont'd):**
  - Strain Isolation Pad (SIP)
    - SIP is a Nomex felt comprised of polyamide fibers formed into a pad
    - The felt is heat set at 500F for 30 minutes to provide dimensional stability and then coated with RTV (0.006"-0.010")
    - Multiple thicknesses are used:
      - 0.090-in for high modulus applications (e.g. next to thermal barriers around doors)
      - 0.160-in for most applications (acreage tile)
    - Due to buy-out of SIP in the 1980's SIP no longer manufactured
    - There is no shelf-life requirement for SIP

Tile System
RCG Coating
LI-900 LI-2200 FRCI-12 AETB-8
Densified Layer
RTV Adhesive
➡ SIP
RTV Adhesive
Heatsink/Screed
Koropon Primer

Presenter M3/Material | Date FINAL | Slide 10 of 18 | Closed

SIP Integrity

- **Background / Facts (cont'd):**
  - Material allowables development [H77]
    - Permanent extension of SIP (flatwise) occurs after exposure to cyclic mechanical loads [H77]
    - Testing to develop modulus included exposure of SIP (flatwise) to cyclic mechanical loads
    - Tensile strength (flatwise) specimens exposed up to 25 hrs at test temperature prior to test to failure

Presenter M3/Material | Date FINAL | Slide 11 of 18 | Closed

SIP Integrity

- **Background / Facts (cont'd):**
  - SIP properties are tested indirectly:
  - Indirect testing provides information about "threshold" strength, but cannot be used to model degradation effects
    - "Time-aged" SIP tested indirectly during recertification of tile:
      - Tile densification qualification using a new coloring agent
      - AETB tile certification for used on base heat shield
    - "Thermal/mechanical" aging indirectly tested for 26 missions during certification of of DMES rewaterproofing
    - "Thermal/mechanical" aging indirectly tested during certification of tile system for 100 Orbiter missions

Presenter M3/Material | Date FINAL | Slide 12 of 18 | Closed

2

SIP Integrity

- **Findings:**
  - SIP currently thought to be robust
- **Recommendations:**
  - Direct testing and evaluation of SIP to assess aging effects is not necessary
  - Establish periodic testing of SIP stock to monitor potential aging effects due to time and, currently unknown, degradation effects

Presenter M3/Material | Date FINAL | Slide 13 of 18 | Closed

Koropon Primer Integrity

- **Background / Facts (cont'd):**
  - Super Koropon used as a primer on aluminum surfaces of orbiter
  - Over-spray of Koropon results in reduction in cohesion properties
    - Over-spray occurred during orbiter assembly and has occurred during insulation installation
  - Strength of RTV applied over bare aluminum greater versus application over Koropon
  - At 120F the flatwise strength ("A" allowable) of RTV over Koropon and RTV over bare aluminum begins to diverge; the allowable for RTV over Koropon drops to 13 psi at 350F

Tile System

Tile System
RCG Coating
LI-900 LI-2200 FRCI-12 AETB-8
Densified Layer
RTV Adhesive
SIP
RTV Adhesive
Heatsink/Screed
➡ Koropon Primer

Presenter M3/Material | Date FINAL | Slide 14 of 18 | Closed

Koropon Primer Integrity

- **Background / Facts (cont'd):**
  - Koropon develops microcracks which enhances adhesion
  - Koropon softens when used under thick applications of RTV 577 and RTV 560
    - Screed thickness: 0.2 and 0.4 inches
    - Screed not applied over Koropon
  - The loss of two tiles before entry interface on the lower surface of the orbiter forward of X01357 would most likely result in the loss of the orbiter [67]

Tile System
RCG Coating
LI-900 LI-2200 FRCI-12 AETB-8
Densified Layer
RTV Adhesive
SIP
RTV Adhesive
Heatsink/Screed
➡ Koropon Primer

Presenter M3/Material | Date FINAL | Slide 15 of 18 | Closed

Koropon Primer Integrity

- **Findings:**
  - No thermal/mechnical testing has been accomplished to evaluate the loss of cohesion due to Koropon over-spray
- **Recommendations**
  - Initiate a program to ascertain thermal/mechanical effects on over-spray adhesion
    - Identify areas of probable over-spray and sample

Presenter M3/Material | Date FINAL | Slide 16 of 18 | Closed

Overall Findings and Recommendations

- **Findings:**
  - Effect of age and operational exposure not completely understood
    - Subnominal tile component properties probably exist
      - Magnitude of degradation is unknown
  - The loss of two tiles before entry interface on the lower surface of the orbiter forward of X01357 would most likely result in the loss of the orbiter [67]
- **Recommendation:**
  - Implement a program to systematically characterize effect of aging on all tile system components relative to design conditions
    - Initial emphasis should be on Super Koropon and RTV

Presenter M3/Material | Date FINAL | Slide 17 of 18 | Closed

References

Number	Filename	Reference
29	RTV Scrap History and Age Life March 2001.ppt	Robert J. Perez, Tom Luce, Michael P. Gordon, "RTV Scrap History & Age Life," Material & Process Engineering, TPS PRB, March 2001
30	RTV aging.ppt	Mary Litwinski, "Integrity of RTV for TPS Applications," Boeing-HB M&P Engineering, 6 February 2003
62	ShuttleAeroheatingStatistics.xls	Gearld Kinder, Shuttle Aeroheating Statistics from Boeing, Huntington Beach Meeting 25 April 2003
63	OV-102 Screed_heatsink_recorded_prior_to_deliveryl.ppt	TiPs generated output depicting original installation of screed/heatsink

Presenter M3/Material | Date FINAL | Slide 18 of 18 | Closed

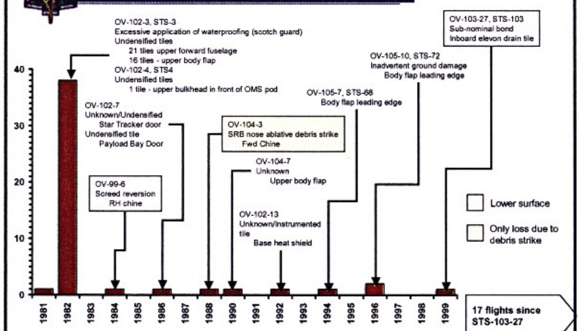
3

Tile Fleet Experience

- **Action / Issue:**
  - It is not possible to determine when the tile system has degraded to the point where there will be a loss of tile
- **Background / Facts:**
  - The loss of two tiles before entry interface on the lower surface of the orbiter forward of $X_0$1357 would most likely result in the loss of the orbiter [67]
  - Many tile losses resulted in a design modification or change in process
    - Did not know that something was wrong prior to flight
    - Development and certification testing/analysis did not predict failure
  - On average, tile is lost every 2 years (11 flights)
    - Last loss occurred 3 years ago (16 flights)

Presenter M3/Material | Date FINAL | Slide 1 of 9 | Closed

Lost Tiles – All Orbiters



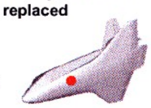
Presenter M3/Material | Date FINAL | Slide 2 of 9 | Closed

Right Wing Lost Tile

STS-41G
OV-99, Flight #6
5 October 1984

Screed remained in cavity; initiated "Soft Screed" hunt

Ultimately, 4011 tiles would be replaced



Cause: Sub-nominal bond due to RTV reversion after application of HMDS rewaterproofing

Presenter M3/Material | Date FINAL | Slide 3 of 9 | Closed

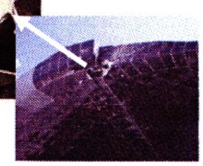
Left Elevon Burn Through

Not classified as a lost tile.

STS-51D
OV-103, Flight #4
12 April 1985

Severe TPS damage on left outboard elevon caused carrier panel burn-through and significant structural damage to the forward outboard corner of the elevon.

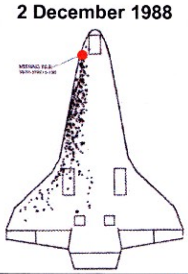
Tile found on ground after landing



Presenter M3/Material | Date FINAL | Slide 4 of 9 | Closed

Missing Chine Tile

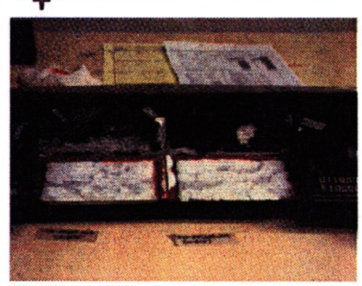
STS-27R
OV-104, Flight #3
2 December 1988



Cause: SRB Nose-cap Ablative Debris Strike

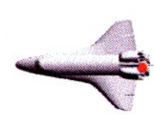
Presenter M3/Material | Date FINAL | Slide 5 of 9 | Closed

Lost Upper Body Flap Leading Edge Tile



STS-72
OV-105, Flight #10
11 January 1996

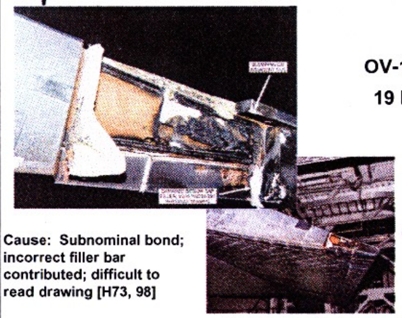
Bonded SIP and tile densification layer remained in cavity.



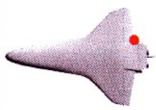
Cause: Inadvertent ground damage

Presenter M3/Material | Date FINAL | Slide 6 of 9 | Closed

Lost Inboard Elevon Drain Tile



STS-103
OV-103, Flight #27
19 December 1999



Cause: Subnominal bond; incorrect filler bar contributed; difficult to read drawing [H73, 98]

Presenter M3/Material | Date FINAL | Slide 7 of 9 | Closed

Design / Mods / Manufacturing TPS Under Wing

- **Findings:**
  - Cannot predict tile failure
    - Failure due to design, maintenance process changes and inadvertent ground damage
  - Effect of aging difficult to predict and may be a risk contributor in the future
- **Recommendations:**
  - The fact that a dominant or common cause does not exist underscores the need to address tile system integrity on several fronts: design and process change certification, training for maintenance personnel, clear process instructions, design of processes to reduce sensitivity and variance and NDI/E or "health monitoring" system to aid in determining when tiles are damaged.
  - Continue RTV sampling program to help assure ability to to detect potential, and currently unknown, aging effects on tile system integrity

Presenter M3/Material | Date FINAL | Slide 8 of 9 | Closed

References

Number	Filename	Reference
47	OV104 Lost Tile PP Version 4.ppt	Karrie Hinkle, "STS-99 Flight Readiness Review, OV-103 Lost Elevon Tile, Boeing/USA " 18 January 2000
67	RE Criticality of Tile.htm	Email from Boeing
68	STS-4 Thermal Protection System Postflight Analysis Part II Tile, SIP, and Gap Filler Analysis.pdf	Laboratory analysis of lost tile and tile damage
69	STS-72_Book.pdf	Mission STS-72 OV-105 Flight 10 TPS Post-Flight Assessment, SE-1617T9, KLO-96-003, April 1996
70	Significant TPS Event History 29Mar03.XLS	TPS event history from SSM website; modified by Clare Paul to include analysis data contained in workbook
98	OV103ElevonDrainHole.pdf	Boeing Corrective Action Request - Elevon Drain Tile, Problem 103RF02-010

Presenter M3/Material | Date FINAL | Slide 9 of 9 | Closed

2

Tile
Fleet Experience – Aging

- **Action / Issue:**
  - Bond-line integrity and/or strength is unknown
- **Background / Facts:**

  Bond-line Integrity
  - There are two techniques used to characterize bond-line integrity: a proof test (bond verification test) and the manual deflection test ("wiggle" test).
  - Bond verification (BV), for regular tile, is performed by attaching a specialized tensile test unit over the tile and utilizing a vacuum chuck tool. The maximum applied load is generally determined by using the known bond surface area multiplied by the stress levels given in table specification The load is held at the maximum value for at least one second. For a typical lower surface regular five-inch square SIP footprint, the test load required to achieve the required 10-psi would be 250-lbs.

Presenter M3/Material | Date FINAL | Slide 1 of 11 | Closed

Maintenance Turnaround Work
TPS Under Wing

- **Background / Facts (cont'd):**
  - A partial bond could exist and the BV test would not detect it
  - There are specialized test load procedures for modified regular tile, irregular tile, structurally limited tile, tile bonded to filler bar, carrier panel tile, closeout tile and TUFI-coated and TUFI-RCG-coated tile.
  - Structurally limited tiles will be tested using reduced loads due to the structural limitations of the underlying substrate.
  - The tile bond is characterized as acceptable if the required tension load is sustained for one second without the tile pull-off.
  - Another method used to evaluate the tile to substrate bond is through the manual deflection test, also known as the "wiggle" test. This test requires an experienced technician to "wiggle" the tile and sense when the tile to substrate bond is unacceptable.

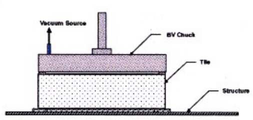
Presenter M3/Material | Date FINAL | Slide 2 of 11 | Closed

Current Method: Tile Bond Verification

Tile System Component Strength [H76]

Material	Strength (psi) Material Allowable	Average
LI-900	13	23
LI-2200	35	60
FRCI-12	50	75
AETB-8	29	45
BRI-8*	20	33
0.090-in Class 1, Grade A SIP	45	
0.115-in Class 2, Grade A SIP	45	
0.160-in Class 3, Grade A SIP	25	
RTV 560/566	280	480
Koropon Primer	?	
RTV 577		

Bond Verification



Bond Verification Stress [H24]

Type	Applied Stress (psi)
HRSI	10
LRSI	6-10
TUFI	10

Design Limit Stress (DLS)[65]

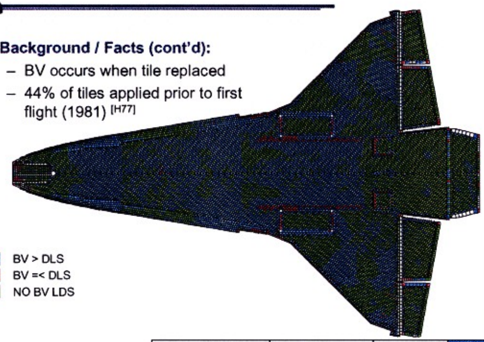
Total of 14,735 Lower Surface Tiles

DLS (psi)	Number of Tile	Percent of Total
0-4	4862	33.00%
4-6	4792	32.52%
6-8	3320	22.53%
8-10	1065	7.23%
10-12	204	1.38%
12-14	269	1.83%
14-16	143	0.97%
16-20	44	0.30%
20-30	36	0.24%

Presenter M3/Material | Date FINAL | Slide 3 of 11 | Closed

Tile BV Compared to DLS

- **Background / Facts (cont'd):**
  - BV occurs when tile replaced
  - 44% of tiles applied prior to first flight (1981) [H77]



BV > DLS
BV =< DLS
NO BV LDS

Presenter M3/Material | Date FINAL | Slide 4 of 11 | Closed

Heavy Reliance on Process Control and Sampling

- **Background / Facts (cont'd):**
  - There is a heavy reliance on process control to ensure tile system integrity
  - Sampling program removes tile and samples RTV [13]
    - Samples sent to Boeing HB labs for analysis
      - Derived Shore A Harness
      - Gas Chromatography/Mass Spectrometry (GC/MS)

Presenter M3/Material | Date FINAL | Slide 5 of 11 | Closed

Matrix of NDI/E Methods Evaluated Over the Years[10]

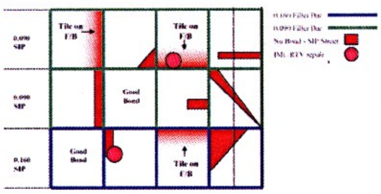
	Method	Year	Company	Used for	Flaw Size	Strength	Weakness	Tested on TPS
Off Orbiter	Film X-Ray	1980-2003	Lockheed & Boeing	Internal Voids	.025 inch x .025	Well established method	Requires standards	Yes Production Units
	CT	1996	EG&G	Internal Voids/ Density	No voids or inclusions Density shall be 8 +-1.0 pcf	Multi slices	Time consuming	Yes Production Units
On Orbiter	Acoustic Excitation	1986-1989	EG&G	Disbond	Target 10% disbond	Portable	No debonds were found	Yes
	Laser Vibrometry	1991	Navcon Engineering Network/Ometron	Disbond	Target 10% disbond	Portable	No debonds were found	Yes 1991 OV102 (43 Tiles)
	Shearography	1991 & 1997	Laser Technology	Disbond	Target 10% disbond	Portable	No debonds were found	Yes 1991 OV102 (43 Tiles) 1997 OV105 (470 Tiles)
	Reverse Geometry X-ray	1997	Digiray	Disbond	Target 10% disbond	Portable	No debonds were found	Yes OV105 (21 Tiles)

Presenter M3/Material | Date FINAL | Slide 6 of 11 | Closed

1

NDI/E Development and Evaluation

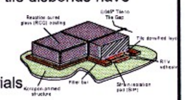
- **Background / Facts (cont'd)**
  - Boeing (Huntington Beach) is not in the business of developing tile bond-line NDI
    - Now allows NASA/vendors to test NDI/E on specially fabricated test panels [10]



Presenter M3/Material | Date FINAL | Slide 7 of 11 | Closed

Boeing Proposed New NDI/E Methods for Tiles

- **Background / Facts (cont'd):**
  - The following new NDE Methods for detecting tile disbonds have been proposed[10]
    - Microwave Technology
      - Proposed by University of Missouri
      - Never funded or tested on TPS materials
    - Nonlinear Structural Dynamic Response
      - Proposed by Georgia Tech
      - Never funded or tested on TPS materials
    - Laser Vibration
      - Proposed by University of Central Florida
        - » Funded by NASA KSC
        - » Has been tested on Tiles



Presenter M3/Material | Date FINAL | Slide 8 of 11 | Closed

General Results of NDE/I Methods[10]

- **Background / Facts (cont'd):**
  - Changes in material properties, Tile (Silica & Air), SIP (Nomex), RTV thickness, Gap fillers (Fabric) and Aluminum structure limit accuracy / repeatability of NDE to detect disbonds
  - None of the methods or combination of them could accurately detect disbonds
    - Suspect NDE disbond tiles were removed and evaluated as a good bond
    - NDE method would show promise when used on disbonded test panel but fail when tested on the Orbiter
  - New Tile disbond panel has been made and sent to NASA Marshall Space Flight Center for evaluation

Presenter M3/Material | Date FINAL | Slide 9 of 11 | Closed

Lack of Tile NDI/E

- **Findings:**
  - There are no widely accepted NDI/E methods that are used to detect disbonds. General methods to detect a disbonds are in development, and the time when they will be available is unknown. A even more useful NDI/E method would be one that can measure the bond strength. This is an even more challenging problem and will not likely be resolved in the near future.
  - The loss of two tiles before entry interface on the lower surface of the orbiter forward of X01357 would most likely result in the loss of the orbiter [67]
  - NASA and Boeing seem to have a sense for the need to develop a method to better quantify the bond-line integrity and have tested various methods on test panels and the orbiters
- **Recommendations:**
  - It is recommended that efforts to develop and evaluate NDI/E methods to assess bond integrity be given increased emphasis

Presenter M3/Material | Date FINAL | Slide 10 of 11 | Closed

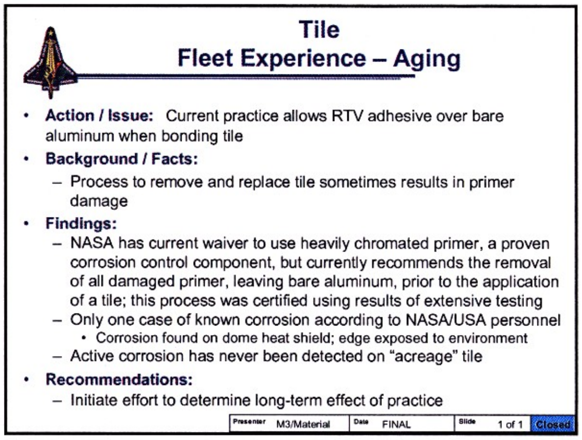
References

Number	Filename	Reference
10	Processes Used to Test Tile Bonds and Inspect RCC from SSM Website.ppt	
13	NSTS 08171 File 3 V09 Thermal Protection System.pdf	NSTS 08171- Space Shuttle Operations and Maintenance Requirements and Specifications document, File III , V09 - Thermal Protection System, 21 Nov 02
15	Tile NDE Boeing 28May97.pdf	A Boeing presentation that discusses the use of reverse geometry x-ray and shearography to NDI/E tile bond.
37	Tiles Replaced on OV-102.ppt	Tile Replaced on OV-102 from SSM Website
65	v102lower_paul.xls	TIPS generated Excel output from Jenny Tran, Boeing, Huntington Beach tabulating tile location, DLS, BV values and more
66	CAIBNDE TPS4-25-03.ppt	NDE Presentatin from Boeing, Huntington Beach 25 April 2003
67	RE Criticality of Tile.htm	Email from Boeing

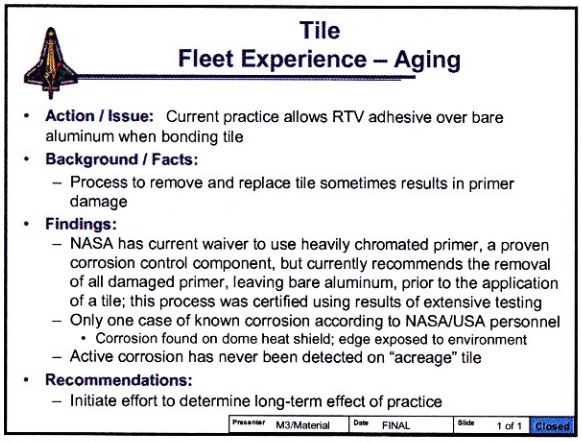
Ref	Content
H23	Bond Verification and Design Limit Stresses
H24	ML0601-9024, Process 315 - Bond Verification of RSI Tiles
H76	Materials Properties Manual, Volume 3, Thermal Protection System Materials Data prepared by Laboratories and Test D/284, Rockwell International, August 1988
H77	Original Tile History for OV-102, RFI: B1-0090194

Presenter M3/Material | Date FINAL | Slide 11 of 11 | Closed

2


Tile
Fleet Experience – Aging
• Action / Issue: Current practice allows RTV adhesive over bare aluminum when bonding tile
• Background / Facts:
– Process to remove and replace tile sometimes results in primer damage
• Findings:
– NASA has current waiver to use heavily chromated primer, a proven corrosion control component, but currently recommends the removal of all damaged primer, leaving bare aluminum, prior to the application of a tile; this process was certified using results of extensive testing
– Only one case of known corrosion according to NASA/USA personnel
• Corrosion found on dome heat shield; edge exposed to environment
– Active corrosion has never been detected on "acreage" tile
• Recommendations:
– Initiate effort to determine long-term effect of practice
Presenter M3/Material
Date FINAL
Slide 1 of 1
Closed

1


Tile
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Presenter M3/Material
Date FINAL
Slide 1 of 1
Closed

1

Tile Shrinkage

- **Action / Issue:** Investigate orbiter fleet problems related to tile shrinkage
- **Background / Facts:**
  - Tile shrinkage does occur during manufacturing
  - Localized Heating Results in Tile Repair and Replacement
    - Localized High Heating in Flight Causes Tile Lips to Shrink Back, Corners to Round Off, Overhangs to Slump, and Tile to Tile Gaps to Widen
    - STS-91 Resulted in 8 Tile Replacements Due to Slumping on Reentry
      - ISS Missions Have More Severe Reentry Heating

Replacement of Complex Shaped Tiles Is Expensive

Presenter M3/Material | Date 5 June, 2003 | Slide 1 of 6 | Closed

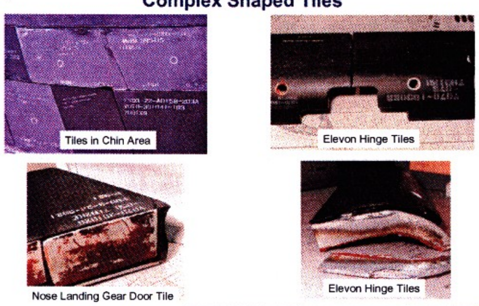
Tile Shrinkage

- **Findings:**
  - Tile shrinkage generally not a safety-of-flight issue; it is a maintenance issue
  - Tile certification tests indicate total gap sizes from 0.075-0.093 inches after a 100 mission simulation.
    - Allowable gaps are on the order of 0.025-0.065 inches; filled gaps range from approximately 0.066-0.085 inches
  - Tile shrinkage of BRI-8 much less than LI-900
- **Recommendations:**
  - Revisit tile shrinkage as a function of temperature for acreage installations and assess long-term impact. If the ultimate solution to tile shrinkage is tile replacement at some time in the orbiters life, it may provide further impetus to migrate to a tougher tile system

Presenter M3/Material | Date 5 June, 2003 | Slide 2 of 6 | Closed

Areas That Typically Experience Slumping (Localized Shrinkage)

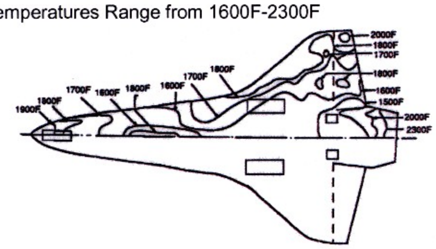
Complex Shaped Tiles



Presenter M3/Material | Date 5 June, 2003 | Slide 3 of 6 | Closed

Maximum Recorded OML Surface Temperatures

Temperatures Range from 1600F-2300F



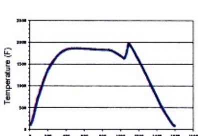
Presenter M3/Material | Date 5 June, 2003 | Slide 4 of 6 | Closed

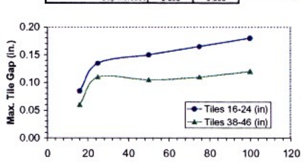
Tile Shrinkage

- **Background / Facts (cont'd):**

Tile certification test results and temperature exposure profile

Block	Thermal Cycles	Cum. Cycles	Individual Wide Gaps: Tiles 16-24 (in)	Individual Wide Gaps: Tiles 38-46 (in)	Mission (after rebond)
6	6	16	0.085	0.060	Pre-Block 7
7	9	25	0.135	0.110	Post-Block 7
8	25	50	0.150	0.105	Post-Block 8
9	25	75	0.165	0.110	Post-Block 9
10	25	100	0.180	0.120	Post-Block 10
		Gap Increase	0.095	0.060	

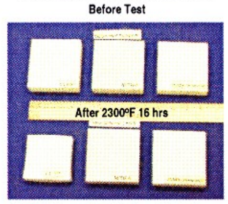


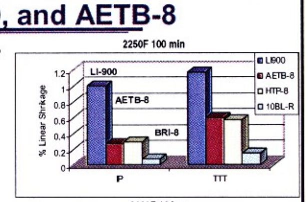


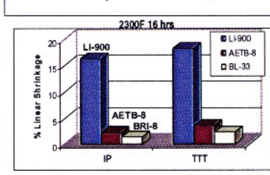
Presenter M3/Material | Date 5 June, 2003 | Slide 5 of 6 | Closed

Dimensional stability of BRI-8, LI-900, and AETB-8

- For these tests, entire tile exposed to high temperature
- Orbiter tile not exposed on all sides during mission
- These tests used to compare tile shrinkage of different tile materials







IP: In-Plane
TTT: Through the Thickness

Presenter M3/Material | Date 5 June, 2003 | Slide 6 of 6 | Closed

1

Tile Maintenance

12-1 <u>Tile Repair Discrepancies</u>

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	14 of 32

Tile Maintenance

- **Action / Issue:**
  - Some repairs performed on tile were not consistent with standard procedures.
- **Background / Facts:**
  - USA and NASA personnel reviewed 137 lower surface TPS WADs to determine in search of discrepancies that could have contributed to OV-102 failure
- **Findings:**
  - Four of five tile repairs on the orbiter chine and lower surface were found to exceed TPS-211 repair criteria for maximum volume/depth.
  - One repair around the LMLG door was found to be outside repair criteria found TPS-211 due to the failure to remove an existing repair prior to rework.
  - USA/NASA reported the discrepancies did not present a safety-of-flight issue

Presenter M3/Material | Date FINAL | Slide 1 of 5 | Closed

STS-107 LH Wing TPS Process Review "Findings of Concern" [H22]

- **Findings:**

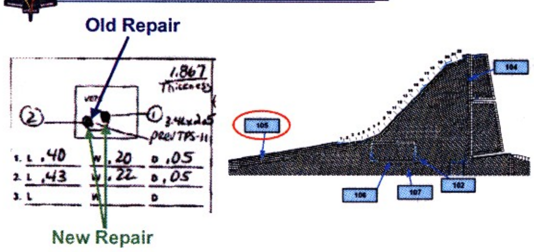
ID #	WAD	Wad Type	Area	Findings	Observations
105	MMID-2-28-6070	Finding	CHINE	Damage Volume exceeds TPS-211 Repair Criteria	Damage Volume exceeds TPS-211 Repair Criteria
102	MLWNG-2-28-7548	Finding	Gear	Damage was too deep for a TPS-211 Repair (Upper Surf Tile)	Damage Depth exceeds TPS-211 Repair Criteria (Investigation - Evaluation Indicated that TPS-311 is OK)
104	MLWNG-2-28-7576	Finding	Lower Wing Acreage	Damage was too deep for a TPS-211 Repair	Damage Depth exceeds TPS-211 Repair Criteria (Investigation - Evaluation Indicated that TPS-311 is OK)
107	MMID-2-28-6012	Finding	GEAR	Damage Volume exceeds TPS-211 Repair Criteria	Damage Volume exceeds TPS-211 Repair Criteria
106	MLWNG-2-28-7523	Finding	GEAR	Previous damage Not removed (Investigation - Evaluation Indicated that TPS-311 is ok)	Previous Damage Not removed (Investigation - Evaluation Indicated that TPS-311 is OK)

137 Total WADS reviewed for the LH Wing Lower Surface

71 Matrix DRs (Not TIPS Tracked) were reviewed but are not included on the maps (minor putty repairs TPS-211/311)

Presenter M3/Material | Date FINAL | Slide 2 of 5 | Closed

Example: Paper Study Find #105



Damage volume exceeds TPS-211 repair criteria. Volume exceeds limits. Previous repair should have been included in volume calculation [H22].

Presenter M3/Material | Date FINAL | Slide 3 of 5 | Closed

Tile Maintenance

- **Recommendations:**
  - Determine cause of process escapes
    - Training, process clarity, etc.
  - Establish and execute action plan to mitigate the cause of process escapes

See also: Orbiter Maintenance (14-3)

Presenter M3/Material | Date FINAL | Slide 4 of 5 | Closed

References

Ref	Tab Number	Content
H22	3	Kathy Laufenberg, USA, "OV-102 Flight 28-STS-107 Team A, TPS, CAIB Requests Repsponse," Tile Repair Procedures TPS-211 and -311, WADS for "high concern" TPS Damage; 7 March 2003

Number	Filename	Reference
64	WAD MMID-2-28-6070.tif	Paper Study Finding 105, Work Package MMID-2028-6070

Presenter M3/Material | Date FINAL | Slide 5 of 5 | Closed

1

Orbiter
Design / Certification

28-1 Orbiter Design Concerns

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	15 of 32

Orbiter Design Concerns

- **Action/Issue:**
  - Unexplained Anomaly (UA) team has uncovered additional orbiter design and maintenance concerns that should be addressed
- **Background:**
  - UA Team objective was to develop the effort required for safe Return to Flight utilizing UA logic and rationale should results of the investigation prove inconclusive
  - UA Team assessed possible causes from the Fault Tree and identified areas of concern that might warrant further action
  - UA Team also addressed the vulnerability of critical lower surface areas which, while not a contributor to the accident, had potential for a critical breach and warranted design review action before reflight
  - UA charts for issues not addressed in other locations of the Matrix follow

Presenter M3/Material | Date FINAL | Slide 1 of 14 | Closed

Orbiter Design Concerns

7. Door Seal Requirements

UA Closure Team

Related Fault Tree Block
- SFOML Wing 8-24

Findings

OVEI Specification states:

3.3.1.3.8 Access Doors – The primary structure shall be designed so that frequently-used doors including landing gear doors are not relied upon to carry primary body loads except local pressure loads. Sealing provisions shall be provided to preclude ingestion of adverse environments (i.e., hot gases, rain, dust, etc.)

- There is no specified requirement to assure environmental sealing of the NLG, MLG, and ET doors on a flight-by-flight basis
  - There are no seal compression verification requirements for MLG and NLG doors. A non-specified tactile check is performed after door closure which has initiated installation of gap fillers at the thermal barrier when purge leakage was considered excessive
  - Drawing requirement for ET door seal compression is 0.100 +/-0.050 inches with a recommended method for seal compression measurement after door re-rigging by ink imprint on tape. Not an every-flight activity

Presenter M3/Material | Date FINAL | Slide 2 of 14 | Closed

Orbiter Design Concerns

7. Door Seal Requirements (contd)

UA Closure Team

Findings (cont'd)
- Different materials are used for the door seals
  - ET = Teflon coated Silicon (very smooth surface)
  - NLG and MLG = Nomex coated Silicon (textured surface)
- The ET disconnect umbilical purge curtain ("baggie") which is destroyed during ascent consistently sandwiches unliberated remnants of the Kapton film baggie between door structure and environmental seal and/or thermal barrier. This potentially compromises seal integrity after door closure on orbit.

Concern
- Leakage bypassing the environmental seal on OV-104 (STS-51J and STS-61B) resulted in structural overtemp of the MLG wheel well frame edge and flow into the wheel well
- Leakage bypassing the environmental seal on OV-102 (STS-40) resulted in structural overtemp of ET door latch and flow into the aft fuselage compartment.

Presenter M3/Material | Date FINAL | Slide 3 of 14 | Closed

Orbiter Design Concerns

7. Door Seal Requirements (contd)

UA Closure Team

Recommendation
- Establish FMEAs for critical door seals and umbilical purge curtain
- Establish OMRSD requirement to verify sealing
- Review significance of seal coating differences
- Review ET door purge curtain design to eliminate compromising door sealing

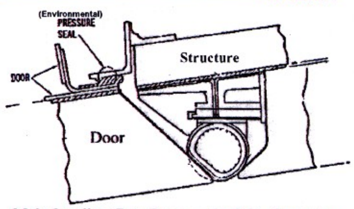
Effectivity
- All vehicles – Return to Flight

Presenter M3/Material | Date FINAL | Slide 4 of 14 | Closed

Orbiter Design Concerns

Main Landing Gear Pressure Seal Configuration Shown

UA Closure Team



Main Landing Gear Pressure Seal Configuration

Presenter M3/Material | Date FINAL | Slide 5 of 14 | Closed

Orbiter Design Concerns

8. Carrier Panel Bonded Studs

UA Closure Team

Related Fault Tree Block:	SFOML-WING-8-12, 20, 17, 24 SFOML-WING-7-20
Finding:	Bonded Studs are used for TPS Tile Carrier Panel Attachment
Concern:	Flight and ground processing history indicates an unacceptable risk associated with the use of Bonded Studs for tile carrier panel attachment.
Recommendation:	The UA Closure Team recommends the elimination of bonded studs for future design. In addition, the team recommends an analysis of applications (including those existing as a result of prior Material Review action) to ensure positive margins if studs are completely debonded. In the event positive margins are not maintained, the team recommends redesign to an alternative fastener.
Effectivity:	Return to Flight

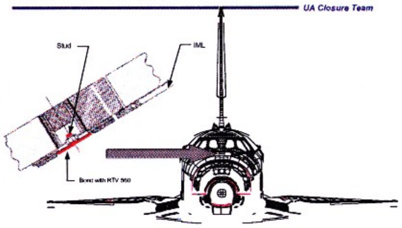
Presenter M3/Material | Date FINAL | Slide 6 of 14 | Closed

1

Orbiter Design Concerns

Bonded Stud Installation

UA Closure Team

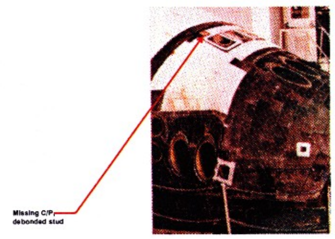


Presenter M3/Material | Date FINAL | Slide 7 of 14 | Closed

Orbiter Design Concerns

Lost Carrier Panel Caused by Debonded Stud

UA Closure Team



Presenter M3/Material | Date FINAL | Slide 8 of 14 | Closed

Orbiter Design Concerns

9. Elevon Cove Carrier Panel Fasteners

UA Closure Team

Related Fault Tree Block: SFOML-Wing-8-12, 20, 17, 24. SFOML-Wing-7-20

Finding: The elevon cove leading edge carrier panels are fastened to the seal panel with two #10 (0.188 in. dia.) fasteners engaging a self-locking thin wall insert. The carrier panels have been modified (per MCR 11656) since the original design, adding flow restrictors between the seal panel and carrier panel. The flow restrictors added preload to the fasteners, placing them in tension.

Concern: Failure of the insert or fastener would expose the primary seal panel to direct plasma flow during entry.

Recommendation: Perform a design study to re-evaluate the margins associated with the fastener/insert combination used in pre-loaded tension for this application.

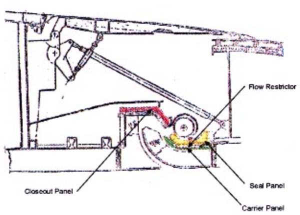
Effectivity: Return to Flight

Presenter M3/Material | Date FINAL | Slide 9 of 14 | Closed

Orbiter Design Concerns

Cross Section Through Elevon Cove Shows Key Details

UA Closure Team

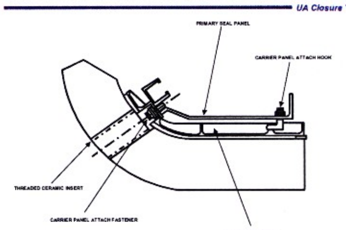


Presenter M3/Material | Date FINAL | Slide 10 of 14 | Closed

Orbiter Design Concerns

Elevon Cove Seal Carrier Panel Fastener Detail

UA Closure Team



Presenter M3/Material | Date FINAL | Slide 11 of 14 | Closed

Orbiter Design Concerns

10. Elevon Cove Seals

UA Closure Team

Finding
The elevon cove seal has numerous critical TPS features. It is unique in that it is designed with known hot gas leak paths. The design has no FMEA. Leakage is allowed to levels up to 65 scfm and 110 scfm. Although there have been significant flight damage events in the early flights, the maintenance experience and processing have matured such that current thermal damage is minimal

Concern
Failure of any one of several structural features could result in significant risk to the elevon structure, wing structure and to the control surface effectiveness. In particular, loss of the "ski slope" tile, loss of the wiper seal carrier panel or loss of the honeycomb seal closeout panel would result in a significant hot gas breach.

Recommendation
Perform FMEA. Include potential effect of hot gas breach on control surface effectiveness as well as propagation of structural damage. Identify and quantify significant hazards.

Effectivity
Return to Flight

Presenter M3/Material | Date FINAL | Slide 12 of 14 | Closed

2

Orbiter Design Concerns

- **Findings:**
  – UA team has uncovered additional orbiter design and maintenance concerns that should be addressed
  – Frank Buzzard note to Mike Kostelnik indicates concurrence with all 10 items included in UA briefing
    - First 6 items included in RCC and Tile portion of the Matrix
    - Remaining 4 items included in this briefing
- **Recommendations:**
  – Implement UA recommendations as described

Presenter M3/Material	Date FINAL	Slide 13 of 14	Closed

Orbiter Design Concerns

- **Documentation:**
  – Briefing by UA Closure Team, "Return-to-Flight Recommendations", 24 April 2003

Presenter M3/Material	Date FINAL	Slide 14 of 14	Closed

Orbiter
Fleet Experience – Aging

- 13-1 Orbiter Service Life
- 13-2 Aging and Corrosion of OV-102
- 13-3 Corrosion found on and near forward fuselage (X0 582)
- 13-4 Environmentally Assisted Cracking of Carrier Panel Bolts
- 13-5 Challenges Associated with Wire Inspection
- 13-6 OV-102 Exposure to the Elements
- 13-7 Service Life of the Shuttle Fleet

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	16 of 32

Orbiter Service Life

- **Action / Issue:** Determine knowledge of OV-102 service life capability
- **Background / Facts:**
  - Comparison of key parameters used to determine orbiter structure service life to the most current fatigue loads spectra (PE Cycle 6.0) is documented in RSS99D0510D, "Space Shuttle Life Tracking", March 2003
  - Includes all missions from 1981 through February 2003 spanning STS-1 through STS-107
    - OV-102, Columbia, 28 flights
    - OV-103, Discovery, 30 flights
    - OV-104, Atlantis, 26 flights
    - OV-105, Endeavor, 19 flights

Presenter M3/Material | Date FINAL | Slide 1 of 18 | Closed

Orbiter Service Life

- **Background / Facts:**
  - Space shuttle has been analyzed for 4 different changes in usage
  - Most current fatigue loads spectra is designated Performance Enhancement
    - PE did not change descent or ferry flight regimes and includes DOLILU II

Number of Missions

	Starts with	All	OV-102	OV-103	OV-104	OV-105
First Flight Date			STS-1 4/12/1981	STS-41D 8/30/1984	STS-51J 10/3/1985	STS-49 5/7/1992
All Flights	STS-1	113	28	30	26	19
DCR2 (RTF)	STS-26	88	21	24	24	19
DOLILU II	STS-70	44	11	10	12	11
PE	STS-88	21	3	5	6	7

Presenter M3/Material | Date FINAL | Slide 2 of 18 | Closed

Parameter Comparisons

	Number of Occurrences of Parameter in Life					
	All flts	OV-102	OV-103	OV-104	OV-105	Spectra
< 195,000						
195,000 - 205,000						
205,000 - 215,000						
215,000 - 225,000	1	1				4
225,000 - 235,000	2	1		1		7
235,000 - 245,000	12	2	5	1	1	12
245,000 - 255,000	32	4	9	7	7	38
255,000 - 265,000	51	17	13	12	8	21
265,000 - 275,000	8	2	1	1	3	18
275,000 - 285,000						
285,000 - 295,000						
Total	106	27	28	22	19	100

OV-102 orbiter liftoff weight is within fatigue spectra although rate of occurrences at 260K more than expected

Presenter M3/Material | Date FINAL | Slide 3 of 18 | Closed

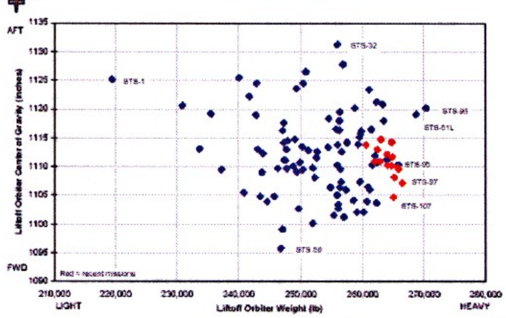
Parameter Comparisons

	Number of Occurrences of Parameter in Life					
	All flts	OV-102	OV-103	OV-104	OV-105	Spectra
< 1094						
1094 - 1098	1				1	
1098 - 1102	4	3			1	2
1102 - 1106	16	10	4		2	10
1106 - 1110	19	5	3	5	5	10
1110 - 1114	30	2	7	13	6	6
1114 - 1118	16	1	8	3	3	13
1118 - 1122	10	3	4		1	23
1122 - 1126	7	2	1	1		15
1126 - 1130	2		1			21
1130 - 1134	1	1				
Total	106	27	28	22	19	100

OV-102 C.G. location is within fatigue spectra although a more forward shift from expected usage

Presenter M3/Material | Date FINAL | Slide 4 of 18 | Closed

Parameter Comparisons



Presenter M3/Material | Date FINAL | Slide 5 of 18 | Closed

Parameter Comparisons

	Number of Occurrences of Parameter in Life					
	All flts	OV-102	OV-103	OV-104	OV-105	Spectra
< 600						
600 - 620	1	1				2
620 - 640	2	1				4
640 - 660	11	4	3	3	1	9
660 - 680	19	4	7	3	3	15
680 - 700	26	9	3	6	6	12
700 - 720	25	8	10	2	2	22
720 - 740	12	1	4	5	2	17
740 - 760	9		2	4	3	13
760 - 780	5			2	2	6
780 - 800						
Total	110	28	29	25	19	100

OV-102 max Q is well within the fatigue spectra

Presenter M3/Material | Date FINAL | Slide 6 of 18 | Closed

1

Parameter Comparisons

Value Range (psf-deg)	All flts	OV-102	OV-103	OV-104	OV-105	Spectra
	Number of Occurrences of Parameter in Life					
< -3000						
-3000 to -2500						1
-2500 to -2000						
-2000 to -1500	4	1	1	1	1	2
-1500 to -1000	25	8	4	2	7	3
-1000 to -500	74	17	22	19	11	49
-500 to 0	7	2	2	3		44
0 to 900						1
Total	110	28	29	25	19	100

OV-102 Q-beta is within fatigue spectra although rate of higher occurrences greater than expected - warrants re-evaluation

Presenter M3/Material | Date FINAL | Slide 7 of 18 | Closed

Parameter Comparisons

Vibro-Acoustic Limited Life Parts	OV102 NEW PRED LIFE	OV103 NEW PRED LIFE	OV104 NEW PRED LIFE	OV105 NEW PRED LIFE	Worst Case NEW PRED LIFE	Life as Reported Aug-96
LOWER FORWARD FUSELAGE						
V070-320739-003	95	94	91	90	90	90
PAYLOAD BAY DOORS						
Fwd Radiator Panel Index Hinge Doubler Panel 1, Hinge 2, Inbd, z=0	86	81	83	83	81	80
Aft Radiator Panel 4, Core 3.1 Around Studs Stud 6, Ribbon Direction W	90	89	86	85	85	85
Aft Latch 3 & 4, X-Load Tie	72	72	69	68	68	68
Aft Latch 4, X-Load Hook	72	72	70	69	69	68
Shear Hinge Fasteners, Net 13, Fastener 11	97	97	89	89	89	88
Shear Hinge Fasteners, Net 14, Fastener 18	88	73	71	70	70	70
Torque Box Upper and Lower Closeout Beam Net 11/12, Section 1, Element II	NA	100	97	96	96	96

Vibro-Acoustic life limited parts

Presenter M3/Material | Date FINAL | Slide 8 of 18 | Closed

Parameter Comparisons

	All flts	OV-102	OV-103	OV-104	OV-105	Spectra
	Number of Occurrences of Parameter in Life					
<5.0E+6						
5.0E+6 to 1.0E+7						1
1.0E+7 to 1.5E+7	2	2				2
1.5E+7 to 2.0E+7	51	11	13	13	14	85
2.0E+7 to 2.5E+7	5	2	2		1	4
2.5E+7 to 3.0E+7						8
3.0E+7 to 3.5E+7						
Total	58	15	15	13	15	100

OV-102 right wing root bending moment is indeterminate due to number of missing flights - warrants re-evaluation

Presenter M3/Material | Date FINAL | Slide 9 of 18 | Closed

Parameter Comparisons

	All flts	OV-102	OV-103	OV-104	OV-105	Spectra
	Number of Occurrences of Parameter in Life					
-3.5E+7 to -3.0E+7						
-3.0E+7 to -2.5E+7						8
-2.5E+7 to -2.0E+7	20	7	5	1	7	4
-2.0E+7 to -1.5E+7	36	6	10	12	8	85
-1.5E+7 to -1.0E+7	2	2				2
-1.0E+7 to -5.0E+6						1
-5.0E+6 to 0.0E+0						
0.0E+0 to 5.0E+6						
Total	58	15	15	13	15	100

OV-102 left wing root bending moment is indeterminate due to number of missing flights - warrants re-evaluation

Presenter M3/Material | Date FINAL | Slide 10 of 18 | Closed

Parameter Comparisons

	All flts	OV-102	OV-103	OV-104	OV-105	RCC102	RCC103
	# of Occurrences of Parameter in Life						
28 - 30	52	16	16	8	7	51	14
30 - 40	11	9		1	1		
40 - 50	2	1					
50 - 63	47	2	14	17	11	49	86
63 - 70							
Total	112	28	30	26	19	100	100

OV-102 inclination angle well within fatigue spectra

Presenter M3/Material | Date FINAL | Slide 11 of 18 | Closed

Parameter Comparisons

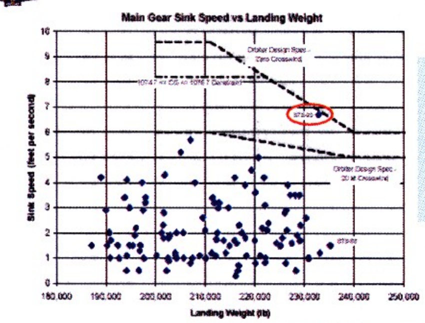
	All flts	OV-102	OV-103	OV-104	OV-105	Spectra
	Number of Occurrences of Parameter in Life					
<180,000						
180,000 - 190,000	2		1	1		
190,000 - 200,000	24	1	10	9	2	26
200,000 - 210,000	25	6	6	6	3	
210,000 - 220,000	26	2	8	8	5	48
220,000 - 230,000	29	13	5	2	9	
230,000 - 240,000	6	6				24
240,000 - 250,000						2
250,000 - 260,000						
260,000 - 270,000						
270,000 - 280,000						
Total	112	28	30	26	19	100

OV-102 orbiter landing weight within fatigue spectra

Presenter M3/Material | Date FINAL | Slide 12 of 18 | Closed

2

Parameter Comparisons



Hard landing data reviewed, well w/i structural limits

Presenter M3/Material | Date FINAL | Slide 13 of 18 | Closed

Wing Heating Load

- **Background / Facts:**
  - OV-102 had the highest predicted wing heating load for a location near the wing leading edge
    - Maximum heating load: OV-102 was 1.3 to 1.1 times higher than the other orbiters
    - Average heating load: OV-102 was 1.15 times higher than the other orbiters
  - OV-102 peak structural temperatures significantly less than certification peak temperatures
    - Wing bottom: 190 versus 326 F
    - Fuselage: 244 versus 326 F

Presenter M3/Material | Date FINAL | Slide 14 of 18 | Closed

Spectra Comparisons PE Versus 5.4

- **Background / Facts:**
  - At the request of the CAIB (reference RFI B1-120), 9 wing and vertical stabilizer control points crack growth life predictions were determined using the certification spectra (5.4) and compared to the current spectra (PE)
    - PE spectra 1.4 to 1.6 times more severe for wing bending moment
    - PE less severe for vertical stabilizer bending moment
  - Comprehensive analysis update performed for the airframe structure using the PE spectra (CAIB conducted spot check review)

Presenter M3/Material | Date FINAL | Slide 15 of 18 | Closed

Orbiter Actual Usage

- **Findings:**
  - Wing root bending moment results were not determined prior to STS-51
  - Parameters obtained and summarized in the Life Tracking report are not utilized to determine mission life capability (crack growth lives) for each orbiter based on actual usage
  - Fatigue testing of the wing structure has not been performed
  - Fatigue spectra appears to be adequate for near-term operations given the number of missions achieved (30 versus 100), however the spectra may need to be updated to safely achieve 100 missions

Presenter M3/Material | Date FINAL | Slide 16 of 18 | Closed

Orbiter Actual Usage

- **Recommendations:**
  - If possible, fill in the missing wing root bending moment data and re-evaluate adequacy of fatigue spectra
  - Carefully monitor the trends of the following parameters: liftoff weight, C.G. location, ascent Q-beta, ascent wing root bending moment
  - Develop the capability to determine mission life capability (crack growth lives) for each orbiter based on actual usage

Presenter M3/Material | Date FINAL | Slide 17 of 18 | Closed

Orbiter Actual Usage

- **Documentation:**
  - Responses to RFIs 120 and 195
  - Briefing by T. Kott, "Orbiter Life Cycle Analysis Process Overview", 3 April 2003
  - Boeing Report RSS99D0510D, "Space Shuttle Life Tracking", March 2003
  - Briefing by C. Modlin, "Orbiter Structural Life", 23 June 1992

Presenter M3/Material | Date FINAL | Slide 18 of 18 | Closed

3

Aging Structural Issues

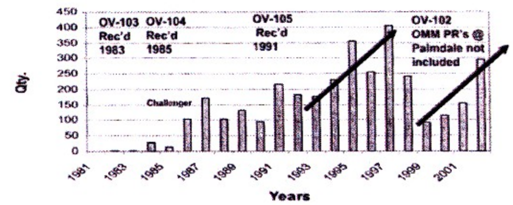
- **Action / Issue:**
  - Aging and Corrosion
- **Background / Facts:**
  - Orbiter designed as maintenance-free for 10 years—all are now older than 10 years
  - Spar is aluminum honeycomb (known to be corrosion prone) in service for 24 years—concerns about galvanic couple between spar and IN718 or A-286 that could lead to degradation
  - Crevice corrosion known to occur on other shuttle locations with 2024-T81
  - 200 doublers reported on OV-102 in response to corrosion damage
  - Anecdotal evidence indicates that chromates leach out of primer after 6-12 years

Presenter M3/Material | Date FINAL | Slide 1 of 5 | Closed

Orbiter OMRS Corrosion Anomalies at KSC

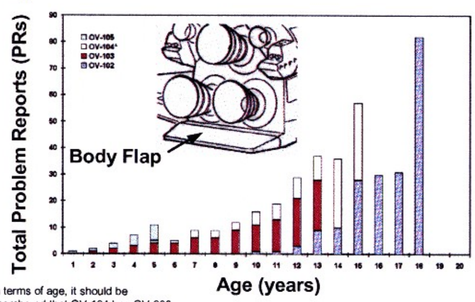
Background/Facts (cont'd):

- Corrosion Problems Reports (PRs) are on the Increase



Presenter M3/Material | Date FINAL | Slide 2 of 5 | Closed

Orbiter Body Flap Cumulative Corrosion Occurrence versus Age



* In terms of age, it should be remembered that OV-104 has OV-099s body flap assy. Circa 1982.

Presenter M3/Material | Date FINAL | Slide 3 of 5 | Closed

Orbiter Corrosion

- **Findings:**
  - Corrosion is on the rise
- **Recommendations:**
  - Ascertain parameters that contribute to the aging of corrosion protection materials and processes
    - Chromate leach rates
    - Effect of chemical/thermal/mechanical environments and age
  - Quantify CPC efficacy and limitations
    - e.g. Reapplication frequency and outgassing
    - Expand use if appropriate
  - Continue to trend corrosion problems and address problems as early as possible

Presenter M3/Material | Date FINAL | Slide 4 of 5 | Closed

Orbiter Corrosion

- **Recommendations (cont'd):**
  - In order to better establish inspection requirements for corrosion based on environmental exposure, it's important to establish corrosion rates via test for environments, materials and structural configuration specific to the orbiter.
  - USAF and Navy aircraft structure very similar in construction to the orbiter. It may be beneficial to review their corrosion prevention and control practices.
  - Recent USAF and Navy R&D efforts aimed at providing practical modeling techniques for corrosion may also provide insight into the corrosion problem.
  - A USAF Air Mobility Command sponsored program developed an approach to ascertain the Economic Service Life for the KC-135. Their, and similar efforts by others, may be applicable to the obiter.

Presenter M3/Material | Date FINAL | Slide 5 of 5 | Closed

1

Corrosion Near Aft End of Crew Module

- **Action / Issue:**
  - Corrosion found on and near forward fuselage ($X_0$582) and was left unrepaired
- **Background / Facts:**
  - $X_0$582 is a frame near the aft end of the crew module
  - Corrosion found and repaired on forward side of X0 582
  - Corrosion "monitored" but not repaired near X0 576 (slightly forward of X0 582)
  - While corrosion was not removed, CPC was applied to forward fuselage floor
    - Use of CPC not straightforward; specialized application process required because outgassing may occur and interfere with Star Tracker

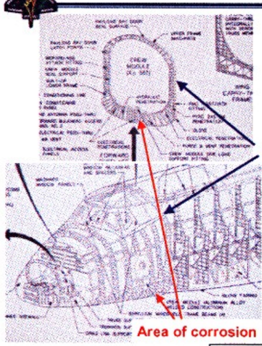
Presenter M3/Material | Date FINAL | Slide 1 of 7 | Closed

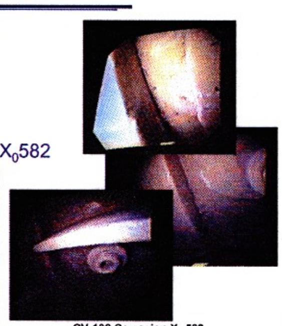
Corrosion Near Aft End of Crew Module

- **Background / Facts (cont'd):**
  - OV-102 had different construction to subsequent orbiters making it more susceptible
    - Goldized insulation blanket directly on aluminum stringers
    - Uncoated steel fasteners
  - However, construction used for other orbiters not "corrosion-proof"
    - Titanium fasteners (react with aluminum)
    - Aluminum not clad
    - No faying surface sealant
    - Susceptible materials

Presenter M3/Material | Date FINAL | Slide 2 of 7 | Closed

Location of $X_0$582 Corrosion





OV-102 Corrosion X_o 582 Bulkhead to floor

Presenter M3/Material | Date FINAL | Slide 3 of 7 | Closed

Location of $X_0$582 Corrosion

OV-102 Corrosion X_o 582 Bulkhead to floor

Borescope View of Typical "582" Corrosion

- **Using video borescope, corrosion found on lower forward fuselage skin panel and stringer areas. Extensive rework and corrosion protection of "582" bulkhead forward surface was accepted for unrestricted use.**

- **In addition to "582" frame, borescope inspection revealed suspect corrosion (X_o 576) on visible rivets and on the sides and feet of hat section stringers.**
- **This PR was deferred due to the inability to fully access the area in question to effect a repair. The condition is to be visually assessed on a recurrent basis.**

Source: OV-102 V30/31 Inspection Report September 1999 - February 2001

Presenter M3/Material | Date FINAL | Slide 4 of 7 | Closed

Corrosion Near Aft End of Crew Module

- **Findings:**
  - Access to area between crew module and outer hull difficult to access for inspection and repair
  - Concern that unmitigated corrosion could progress and degrade structure below minimum safe level
  - OV-102 lower fuselage construction in area forward of $X_0$582 was unique and caused it to be more susceptible to corrosion
  - Corrosion cannot be eliminated as a potential degradation mechanism on the other orbiters
- **Recommendations:**
  - To better understand potential impact, perform analysis of corrosion susceptibility, growth and damage consequences relative to factors influencing corrosion:
    - Material
      - Alloy, Temper, orientation, product form, anodized, clad/unclad

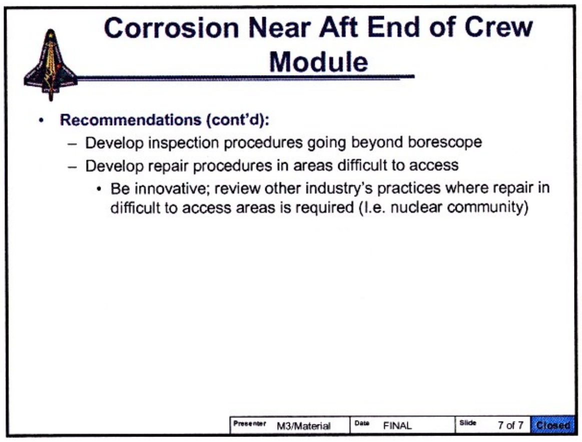
Presenter M3/Material | Date FINAL | Slide 5 of 7 | Closed

Corrosion Near Aft End of Crew Module

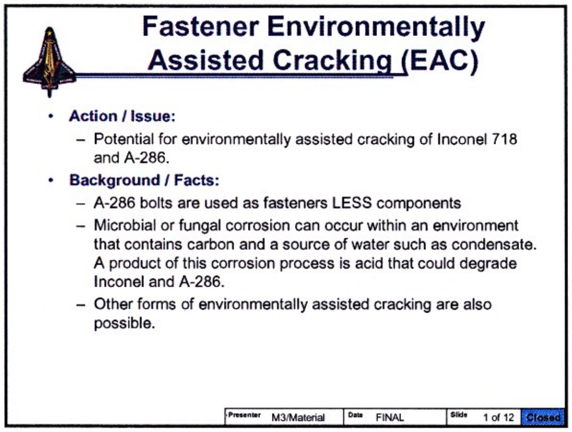
- **Recommendations (cont'd):**
  - Fasteners
    - Type, finish, AMS, wet/dry installed
  - Coating
    - Conversion coats, primer, CPC
  - Mechanical load orientation
  - Blanket insulation
    - Attachment material and method of attachment
    - Blanket material
  - Environment
    - Accidental fire suppression activation, OPF environment, rain exposure; pad exposure

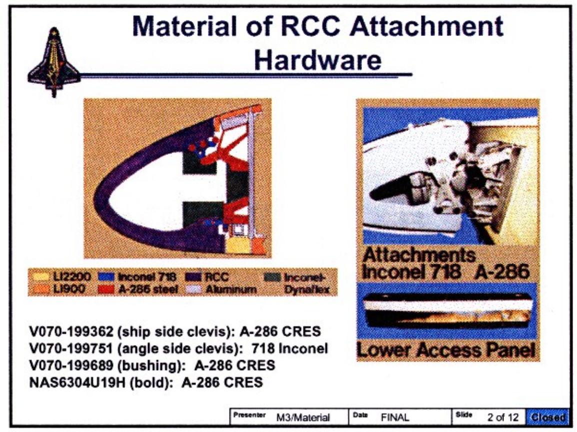
Presenter M3/Material | Date FINAL | Slide 6 of 7 | Closed

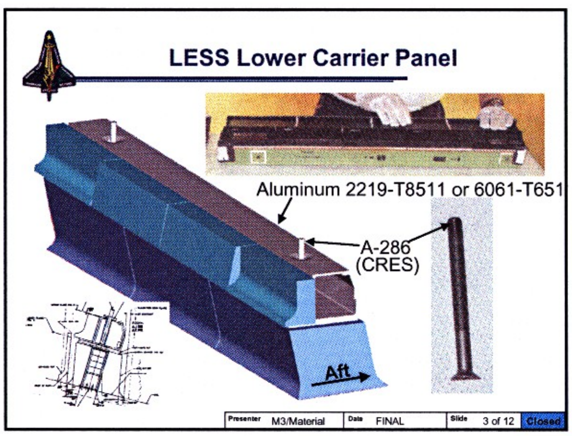
1

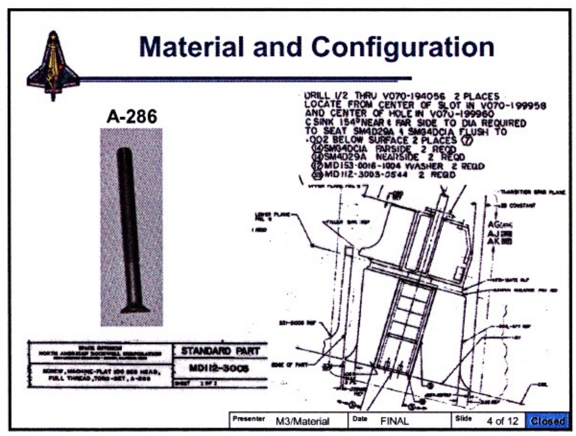

Corrosion Near Aft End of Crew Module
• Recommendations (cont'd):
– Develop inspection procedures going beyond borescope
– Develop repair procedures in areas difficult to access
• Be innovative; review other industry's practices where repair in difficult to access areas is required (I.e. nuclear community)
Presenter M3/Material
Date FINAL
Slide 7 of 7
Closed

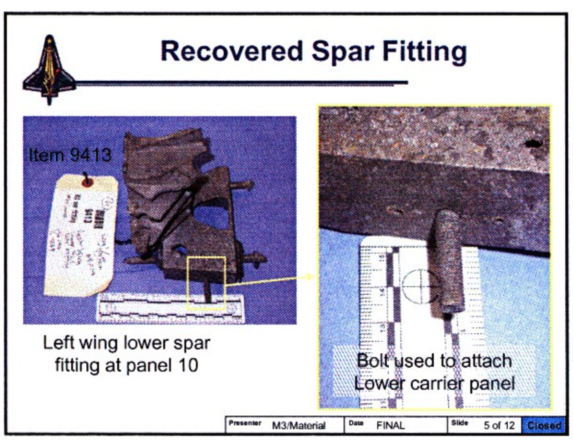
2

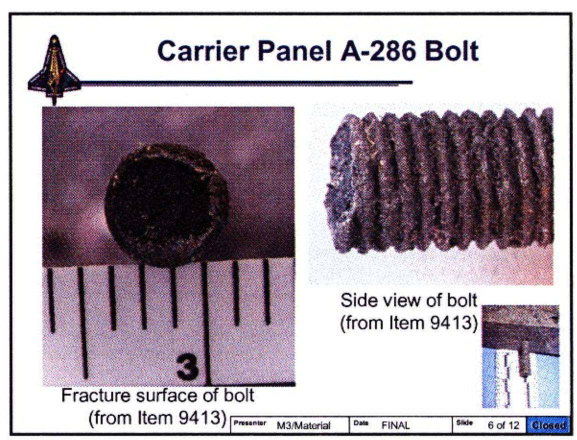

Fastener Environmentally Assisted Cracking (EAC)
• Action / Issue:
– Potential for environmentally assisted cracking of Inconel 718 and A-286.
• Background / Facts:
– A-286 bolts are used as fasteners LESS components
– Microbial or fungal corrosion can occur within an environment that contains carbon and a source of water such as condensate. A product of this corrosion process is acid that could degrade Inconel and A-286.
– Other forms of environmentally assisted cracking are also possible.
Presenter M3/Material Date FINAL Slide 1 of 12 Closed


Material of RCC Attachment Hardware
LI2200 Inconel 718 RCC Inconel-Dynaflex
LI900 A-286 steel Aluminum
Attachments Inconel 718 A-286
Lower Access Panel
V070-199362 (ship side clevis): A-286 CRES
V070-199751 (angle side clevis): 718 Inconel
V070-199689 (bushing): A-286 CRES
NAS6304U19H (bold): A-286 CRES
Presenter M3/Material Date FINAL Slide 2 of 12 Closed


LESS Lower Carrier Panel
Aluminum 2219-T8511 or 6061-T651
A-286 (CRES)
Aft
Presenter M3/Material Date FINAL Slide 3 of 12 Closed


Material and Configuration
A-286
STANDARD PART
MD112-3005
Presenter M3/Material Date FINAL Slide 4 of 12 Closed

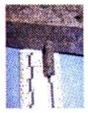

Recovered Spar Fitting
Item 9413
Left wing lower spar fitting at panel 10
Bolt used to attach Lower carrier panel
Presenter M3/Material Date FINAL Slide 5 of 12 Closed

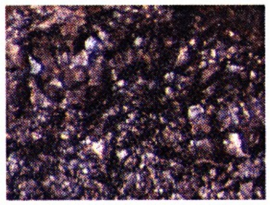

Carrier Panel A-286 Bolt
3
Fracture surface of bolt (from Item 9413)
Side view of bolt (from Item 9413)
Presenter M3/Material Date FINAL Slide 6 of 12 Closed

1

Carrier Panel A-286 Bolt

Higher magnification photos of fracture surface of bolt from Item 9413



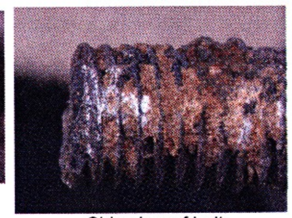


Presenter M3/Material | Date FINAL | Slide 7 of 12 | Closed

Fracture Surface

Similar features found on bolt from left wing lower spar fitting at panel 17

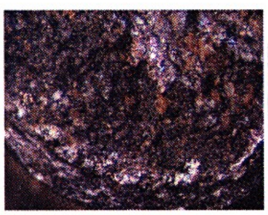
Fracture surface of bolt from Item 866

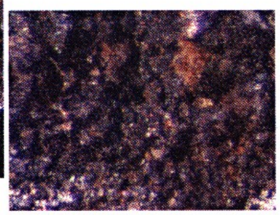


Side view of bolt

Presenter M3/Material | Date FINAL | Slide 8 of 12 | Closed

Higher magnification photos of fracture surface of bolt from Item 866





Presenter M3/Material | Date FINAL | Slide 9 of 12 | Closed

OV-102 Debris Sampled

Lower Spar Fittings Carrier Panel Bolts

Item	Inbrd/Outbrd	Panel	Intact	Bent	Fractured	Bushing	Length at Fracture	Lat.	Long.
717	Outboard	2	X	X				31.61275	-94.72366
431	Inboard	3	X					31.61903	-94.74134
708	Outboard	3	X	X				31.62673	-94.73083
823	Inboard	5			Yes		5/8" beyond threads		
823	Outboard	5	X	X					
64805	Inboard	6		X	Yes		3/4" from edge of fitting	31.53335	-94.52234
64805	Outboard	6		X	Yes		1" beyond threads		
9413	Inboard	10		X	Yes		7/8" from edge of fitting	31.69806	-94.9949
	Outboard	10							
12203	Inboard	14	X			Yes		31.68358	-94.99158
12203	Outboard	14	X	X		Yes			
68	Inboard	15	X			Yes		31.68404	-95.0005
68	Outboard	15	X			Yes			
12239	Inboard	16	X	X		Yes		31.68969	-95.01096
12239	Outboard	16	X	X					
866	Inboard	17			Yes		11/16" from edge of fitting		
866	Outboard	17							
67060	Inboard	20		X	Yes		1/8" from edge of fitting	31.63379	-94.92818
67060	Outboard	20	X	X					
36	Inboard	21	X					31.68369	-95.01647
36	Outboard	21	X						

Presenter M3/Material | Date FINAL | Slide 10 of 12 | Closed

Fastener Environmentally Assisted Cracking (EAC)

Findings:

- Failure mode of recovered carrier panel bolts is consistent with high-temperature failure; failure is not due to EAC
- Current design and maintenance practices leave components at greater risk for corrosion

Recommendations:

- Obvious galvanic couples between aluminum and steel alloys should be avoided or clearly mitigated
- The use of TFE and MoS_2 should be expressly forbidden in assembling components
- The use of primers and sealants such as RTV 560 and Korpon should be reviewed with respect to their possibly accelerating corrosion in real environments including in tight crevices.

Presenter M3/Material | Date FINAL | Slide 11 of 12 | Closed

Fastener Environmentally Assisted Cracking (EAC)

Recommendations (cont'd)

- The negligible and compressive stresses presently occurring in A286 bolts provide protection against failure; assuring the continued presence of such low to negative residual stresses should be part of acceptance and qualification procedures.
- The detailed general and impurity chemistry of all paints, adhesives, and sealants should be reviewed periodically at the ppb to ppm concentrations, and such results should be reviewed from a corrosion point of view.
- The procedures and criteria for qualifying materials and coatings from a corrosion point of view should be reviewed for their relevance and adequacy.
- A substantially higher level of understanding and appreciation of damaging effects of all relevant ambient and applied environments on critical materials should be incorporated into the design and maintenance of the orbiters

Presenter M3/Material | Date FINAL | Slide 12 of 12 | Closed

2

Maintenance Wiring Inspections

- **Action / Issue:** Kapton wiring, currently used in orbiters, poses inspection/maintenance challenges. Assess NASA actions to address these challenges.
- **Background:**
  - Each orbiter contains approximately 852,000 feet of wiring
    - Amounts vary depending on modifications/instrumentation
    - Most of the wiring is insulated with Kapton
- **Findings:**
  - Kapton (MIL-W-81381) refers to a type of insulation (technical name: aromatic polyimide) originally developed by DuPont in the 1960s

Presenter M3/Maintenance	Date FINAL	Slide 1 of 10	Open

Maintenance Wiring Inspections

- **Findings (cont'd):**
  - When the shuttle was built, Kapton was state-of-the-art, exhibiting many positive attributes
    - 50% less space, 25% less weight, tough, durable to a wide temperature range, will not melt/drip/propagate flame
    - Widely used in both military and civil aviation
    - Continues to be used today, though notable shortcomings have emerged over the years
  - Major concern is arc tracking
    - A phenomenon in which overheated wiring carbonizes
    - Overheating typically caused by broken insulation/arcing
    - Carbonized Kapton acts as a conductor; result: "soft shorts"
    - "Soft shorts" (as opposed to "hard shorts") continue to conduct below the tripping threshhold of circuit protection devices, thereby propagating further carbonization/damage

Presenter M3/Maintenance	Date FINAL	Slide 2 of 10	Open

Maintenance Wiring Inspections

- **Findings (cont'd):**
  - Major causes of insulation failure (splitting/cracking/flaking)
    - Improper installation during manufacture (unknown at the time), such as routing (tight bends), clamping (too tightly), or positioning wires against burred screw heads/rivet tails/sharp edges; causes insulation wear/failure due to vibration and/or maintenance
    - Wire stress during inspection/maintenance: repositioning by technicians for access and/or unintentional actions (stepping)
      - Determined to be the single largest cause on orbiters
    - Exposure to elements such as solvents/corrosives/moisture
    - Parallel, extensive AF study (1986) concludes most problems due to design, installation, and maintenance
  - OV-102/STS-93 (Jul 99) incident raised awareness: loss of power to two of six Main Engine Controller computers 5 sec after liftoff
    - Investigation identified root cause as damaged wire

Presenter M3/Maintenance	Date FINAL	Slide 3 of 10	Open

Maintenance Wiring Inspections

- **Findings (cont'd):**
  - NASA has taken numerous corrective actions since STS-93
    - Extensive inspections/corrective actions, starting with OV-102's J3 OMM (Sep 99); chit 1-month after roll-in complicated OMM
    - Other orbiters grounded for inspection (partial); full inspections to be completed during scheduled OMMs
    - Results of OV-102/J3 OMM used to refine inspection/ documentation methodologies (more comprehensive/specific tracking)
    - Improvements made in technician/inspector training and certification, maintenance procedures (e.g., calibrated crimpers)
    - Wiring inspection now required during any ground processing actions

Presenter M3/Maintenance	Date FINAL	Slide 4 of 10	Open

Maintenance Wiring Inspections

- **Findings (cont'd):**
  - OV-103 currently in OMM/undergoing remainder of wire inspection
    - Total discrepancies (stand down + OMM) nearing OV-102 proportions
  - Arc track testing using orbiter circuit protection/wiring displayed limited track lengths; worst case = 6.5 inches
    - Current mods include separating all critical wire paths from main bundles and individually protecting them
  - Numerous tests indicate Kapton is still the leading choice for orbiter environment despite development of hybrid insulators
  - Development of improved inspection equipment/techniques (to supplement visual) continues in the aviation community
  - Wholesale replacement, whether in military/commercial aviation, or the orbiter fleet, is costly
    - Hybrids used on new build B737/B757/F-15/F-22 (post-1995)

Presenter M3/Maintenance	Date FINAL	Slide 5 of 10	Open

Maintenance Wiring Inspections

- **Findings (cont'd):**
  - Modifications either complete, in progress, or scheduled show ongoing efforts to mitigate wiring problems
    - MCR 19448: Orbiter Wire Protection Enhancements addressed routing of redendant Crit 1 wires; 127 cases ID'd
    - MCR 19527: Orbiter Wire Redundancy Separation corrects all 127
    - MCR 19596: AC Bus Separation separates critical wires to C/B pnls
    - MCR 23167: Arc Track Protection continues efforts; Rev 1 for OV-102/Flt 29 (STS-107)
  - Approx 2,000 feet of orbiter wiring is inaccessible
    - Primarily below crew module
    - No plans to inspect over the life of the orbiter
    - No technician traffic/hands-on maintenance due to inaccessibility
    - NASA has confirmed, thru USA and Boeing, no Crit 1 wiring in inaccessible areas
    - Concern: installation-induced problems over 20+ yrs of service

Presenter M3/Maintenance	Date FINAL	Slide 6 of 10	Open

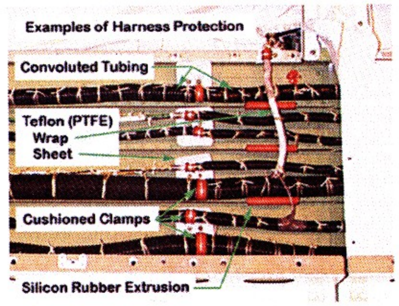
1

Maintenance
Wiring Inspections

- **Conclusions:**
  - NASA has taken extensive action to mitigate orbiter wiring-related problems
  - Kapton issues (especially age-related), are still not fully understood
- **Recommendations:**
  - Continue as expeditious as possible implementation of all wiring-related inspections/mods
  - Inspect/track/monitor wiring to determine aging effects
  - Develop plans to inspect inaccessible wiring as part of the Shuttle Service Life Extension Program
  - Assess the adequacy of Kapton wiring inspection/maintenance in non-orbiter areas, such as RSRM/ET and SRB/MLP separation bolts

Presenter M3/Maintenance | Date FINAL | Slide 7 of 10 | Open

Maintenance
Added Wiring Insulation/Separation Examples

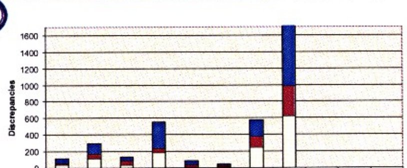


Presenter M3/Maintenance | Date FINAL | Slide 8 of 10 | Open

103 J3 Wire Discrepancies Summary

919 OEL PRs as of 4/4/03

Total Discrepancies 1793*



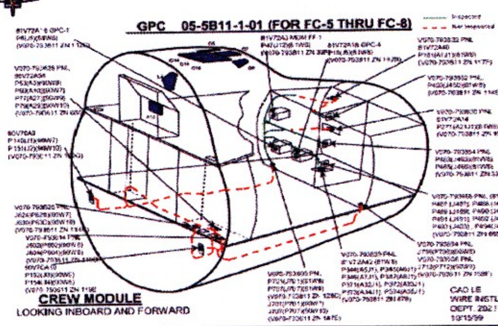
	Conductor Damage	Exposed Conductor	Shield Damage	Jacket Damage	Kapton Damage	Chafe Protection	Non-Wire	103 J3 Total	OV-103 Stnd Dwn	103 Grand Total	OV-102 J3
OV-102 J3	114	293	168	483	654	954	1301				3967
103 Grand Total	206	462	187	847	386	202	1180			3470	
OV-103 Stnd Dwn	95	168	53	298	300	161	602		1677		
103 J3 Total	111	294	134	549	86	41	578	1793			
FWD	57	124	48	315	48	15	200	807	223	1030	1289
MID	18	60	57	50	32	19	131	367	346	713	1388
AFT	36	110	29	184	6	7	247	619	1108	1727	1290

Damage by Type

•Multiple discrepancies may be documented on a single PR.
•Baseline assumption 2200 discrepancies.

Presenter M3/Maintenance | Date FINAL | Slide 9 of 10 | Open

Maintenance – Wiring Inspections
Red Dashed Lines Indicate Inaccessible Wiring



Presenter M3/Maintenance | Date FINAL | Slide 10 of 10 | Open

2

Orbiter Environmental Exposure

- **Action / Issue:** Review/assess orbiter exposure to elements
- **Background / Facts**
  - OV-102 cumulative launch pad weather exposure - 3.3 years
    - Longest single exposure: STS-35/164 days (Apr-Dec 90)
  - Exposure to elements (rain, dew, salt air) has a negative impact
    - Corrosion to structure, oxidation/damage to RCC (suspected), wiring, etc.
- **Findings:**
  - Orbiter total exposure time (less –102) varies from 2.1 to 2.9 years
    - OV-102 leads fleet in total exposure time, but not in total launches
    - OV-102: 28 launches; OV-103: 30 launches
  - Rollovers/rollouts/rollbacks due to launch scrubs, follow-on maintenance, & ops checks contribute to prolonged exposure

Presenter M3/Maintenance | Date FINAL | Slide 1 of 15 | Closed

Orbiter Environmental Exposure

- **Findings (cont'd)**
  - STS-35's 164-day exposure driven by scrubbed launch attempts
    - Rollout to pad (22 Apr) for initial launch attempt (30 May)
      - Freon system repair - 14 add'l days
      - Launch scrubbed – 30 May (MPS LH2 leak)
      - Rollback – 12 Jun (following troubleshooting/maintenance preps)
    - Rollout to pad (9 Aug) for second launch attempt (1 Sep)
      - Stand down for payload telemetry repair – 6 add'l days
      - Launch scrubbed – 5 Sep (Orbiter H2 leak, maintenance at pad)
    - Third launch attempt (18 Sep)
      - Launch scrubbed – 18 Sep (MPS LH2 leak)
      - Rollback – 9 Oct (following troubleshooting, maintenance preps)
    - Rollout to pad (14 Oct) for fourth launch attempt
      - Special LH2 tanking tests performed – 2 add'l days
      - APU water valve problems; maintenance/servicing – add'l 16 days
      - Launched 2 Dec
    - STS-35 was an outlier compared with other missions (see chart)

Presenter M3/Maintenance | Date FINAL | Slide 2 of 15 | Closed

Orbiter Environmental Exposure

- **Findings (cont'd):**
  - Besides pad exposure, most notable vulnerability is during mate/demate/ferry ops; three incidents noted
  - Sep 99: OV-102 caught in rain at KSC during mating
    - 128 lbs/16 gals removed after arrival at Palmdale
  - Feb 01: OV-102 caught in rain at Palmdale after mating
    - 747/shuttle could only be partially hangared (see picture)
    - 112 lbs/14 gals removed after arrival at KSC
  - Feb 01: OV-104 caught in rain during mating at Edwards AFB
    - 1,600 lbs/200 gals removed after arrival at KSC
      - "Aft fuselage under bay 6 full of standing water"
      - "Five inches deep along back of 1307 bulkhead"
  - Mate/demate ops highly vulnerable to inclement weather
    - Lengthy operation; no shelter at any location
    - No positive pressure inside shuttle, as at pad

Presenter M3/Maintenance | Date FINAL | Slide 3 of 15 | Closed

Orbiter Environmental Exposure

- **Findings (cont'd):**
  - Exposure is a major contributor to corrosion on all orbiters; trending upward 10% annually
    - 140+ PRs written due to corrosion damage in the body flap cove area alone (low point in vertical position)
      - 84 on OV-102 (51 in last flow)
      - 19 on OV-103
      - 29 on OV-104
      - 6 on OV-105
    - Frequency/quantity of PRs citing corrosion increasing
      - 91% of occurrences since '92
    - Impact on logistics (reparability/availability of spare parts)
      - Components (e.g., body flap actuators) being replaced due to corrosion
      - Repair taking longer: some piece parts beyond repair, must be manufactured, lead times as long as 1 year away
      - No serviceable spare actuators & 2 "holes"; first available – Jun 03

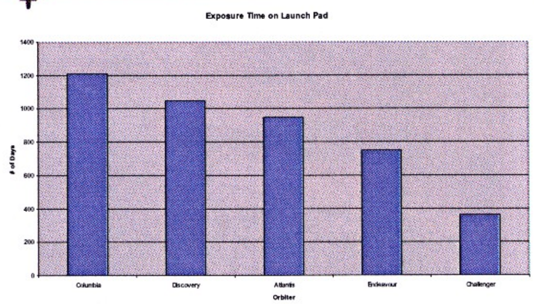
Presenter M3/Maintenance | Date FINAL | Slide 4 of 15 | Closed

Orbiter Environmental Exposure

- **Findings (cont'd):**
  - Environmental (specifically weather) exposure constraints clearly outlined in RTOMI S0018.100, Adverse Environmental and Lightning Monitoring at LC39
    - Includes guidance on actions to be taken to minimize exposure to rain/hail/winds/freezing temps/tornadoes, etc.
- **Recommendations:**
  - Emphasize strict adherence to existing guidance
  - Take every opportunity to avoid/minimize/reduce exposure
    - Review/analyze launches where exposure was significantly over or under the mean (e.g., >1 standard deviation) for lessons learned
  - As some amount of exposure is unavoidable, an intensive corrosion program (inspection, treatment, prevention) is a must
    - See related "Action/Issue" slides on Corrosion and Service Life Extension Program (SLEP)

Presenter M3/Maintenance | Date FINAL | Slide 5 of 15 | Closed

Orbiter Environmental Exposure
Total Launch Pad Exposure by Orbiter



Presenter M3/Maintenance | Date FINAL | Slide 6 of 15 | Closed

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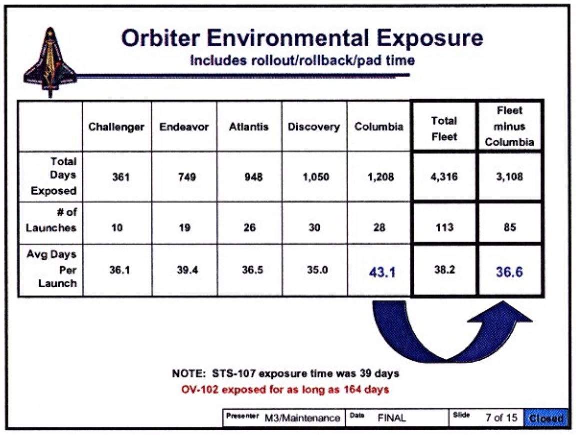


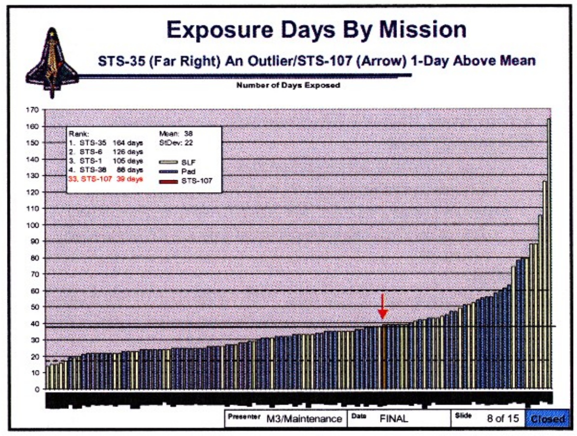
Orbiter Environmental Exposure

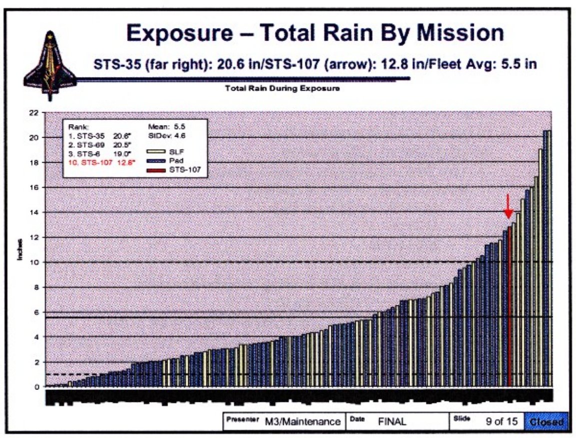
Includes rollout/rollback/pad time

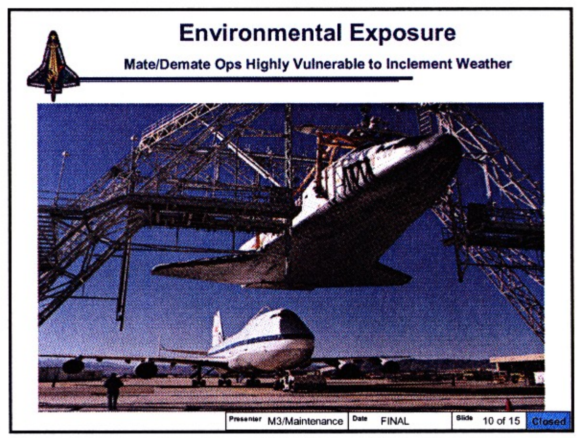
	Challenger	Endeavor	Atlantis	Discovery	Columbia	Total Fleet	Fleet minus Columbia
Total Days Exposed	361	749	948	1,050	1,208	4,316	3,108
# of Launches	10	19	26	30	28	113	85
Avg Days Per Launch	36.1	39.4	36.5	35.0	43.1	38.2	36.6

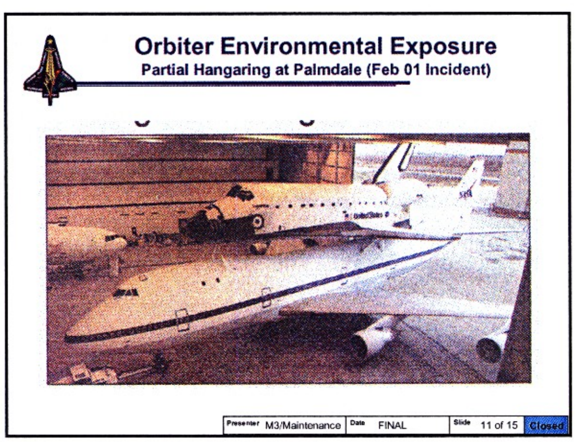
NOTE: STS-107 exposure time was 39 days
OV-102 exposed for as long as 164 days

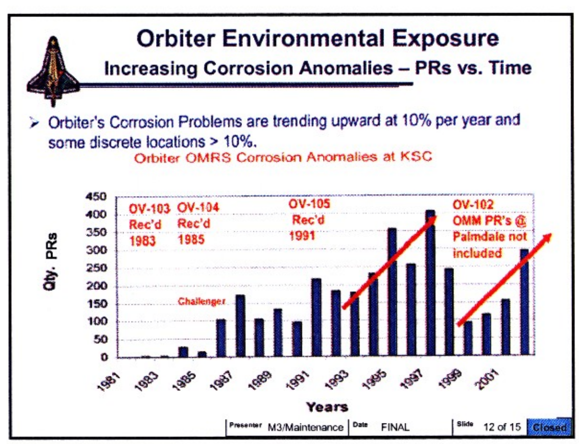
Presenter M3/Maintenance | Date FINAL | Slide 7 of 15 | Closed











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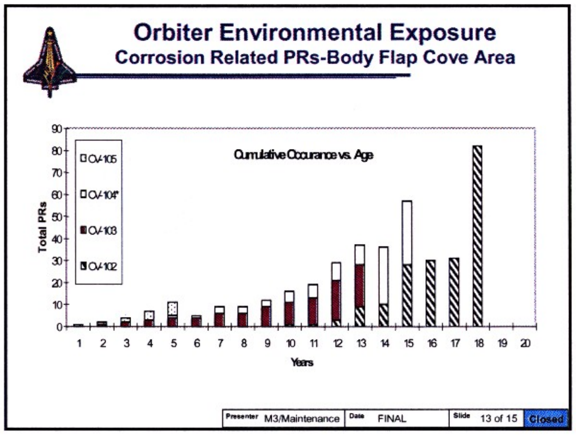
Orbiter Environmental Exposure
Corrosion Related PRs-Body Flap Cove Area
Cumulative Occurance vs. Age
OV-105
OV-104*
OV-103
OV-102
Total PRs
Years
Presenter M3/Maintenance
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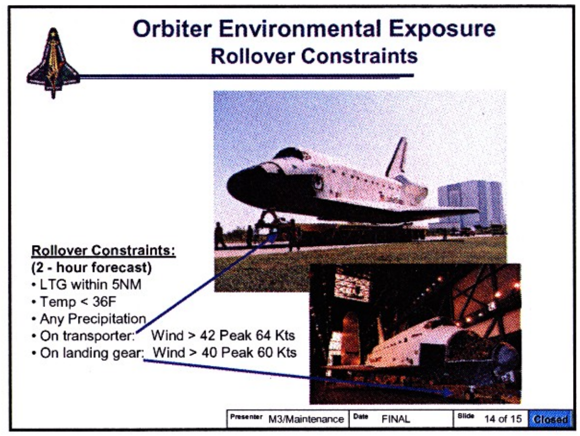
Slide 13 of 15
Closed


Orbiter Environmental Exposure
Rollover Constraints
Rollover Constraints:
(2 - hour forecast)
• LTG within 5NM
• Temp < 36F
• Any Precipitation
• On transporter: Wind > 42 Peak 64 Kts
• On landing gear: Wind > 40 Peak 60 Kts
Presenter M3/Maintenance
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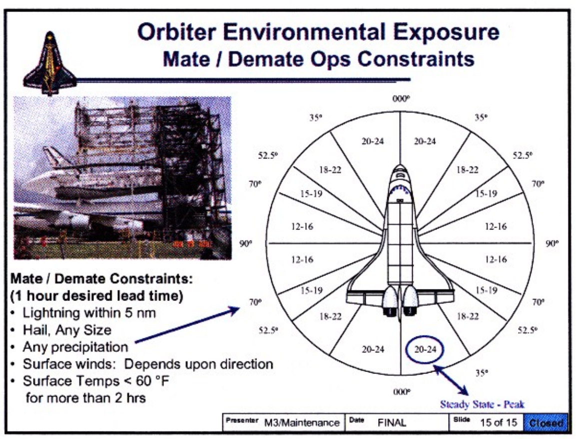
Slide 14 of 15
Closed


Orbiter Environmental Exposure
Mate / Demate Ops Constraints
Mate / Demate Constraints:
(1 hour desired lead time)
• Lightning within 5 nm
• Hail, Any Size
• Any precipitation
• Surface winds: Depends upon direction
• Surface Temps < 60 °F
for more than 2 hrs
Steady State - Peak
Presenter M3/Maintenance
Date FINAL
Slide 15 of 15
Closed

3

Maintenance
Aging Vehicle/SLEP

- **Action / Issue:** Service Life Extension of Shuttle Fleet
- **Background / Facts:**
  - Shuttle fleet has been in service since 1980s
  - Originally programmed for replacement by early 21st century
  - Basic subsystem life requirement is 100 missions in 10 years
    - Performance and Design Requirement (PDRD FE093)
- **Findings:**
  - SLEP objective very general: Integrated Space Trans. Plan says "middle of next decade", DAA - ISS/SSP uses "2020 and beyond."
  - Original certification for 10 years, recertified in 1991 for 10 years
  - Limited structural data available: destructive testing of partial/ subscale structures at beginning, follow-on tests at subsystem level
  - SLEP initiated by HQ Code M Dec 2002, delegated to SSP Development Office is responsible for SLEP
  - First act…provide candidate projects list for SLEP independent panel review and final recommendation to Space Flight Leadership Council on May 7, 2003…over 100 collected

Presenter M3/Maintenance | Date FINAL | Slide 1 of 8 | Closed

Maintenance
Aging Vehicle/SLEP

- **Findings:**
  - Used Analytical Hierarchy Process (AHP) tool to compare projects on impact to life extension, safety, urgency and cost.
  - 4 groups used to categorize the AHP priorities
    1. Must Do…imminent obsolescence or DMS concerns in 03; e.g. sustaining test equipment tasks for SSME and case hardware availability for RSRM.
    2. Current Commitments…e.g. CAU (glass cockpit), SSME Advanced Health Mgmt Sys (ph 1), Infrastructure (bldg, GSE), Industrial Engineering for Safety
    3. Foundational Activities…Aging vehicle studies, Mid-Life Certification, NDE upgrades, Project Feasibility Studies

    4a.b.c. Sustainability, Improvement, New Capabilities…e.g. obsolescence issues, vehicle health monitoring, Hydrazine Replacement, and crew survivability.
  - Used AHP to prioritize over 50 projects for first budget submission
  - Foundational Activities and Project Feasibility Studies may lead to increases in subsequent summit and budget cycles

Presenter M3/Maintenance | Date FINAL | Slide 2 of 8 | Closed

Maintenance
Aging Vehicle/SLEP

- **Findings:**
  - Funding request in May for initial studies to identify tasks in most crucial sustainment programs…Mid-Life Recertification (MLR), Fleet Leader, Corrosion Control and Risk Management.
    - MLR will define tasks to be completed to recertify the STS for continued used through foreseeable life span
    - Results expected to identify necessary upgrades to structures and subsystems to assure safe operation as well as recommendations for additive maintenance and inspection programs
    - MLR funding undefined
    - Significant effort to prioritize previously identified candidate programs and add to budget request
  - Higher headquarters supportive but concerned over financial impact of CAIB recommendations

Presenter M3/Maintenance | Date FINAL | Slide 3 of 8 | Closed

Maintenance
Aging Vehicle/SLEP

- **Recommendations:**
  - Sustainment program needs a clearly enunciated goal in terms consistently applied across NASA to focus efforts
  - Mid-Life Recertification is the foundation of SLEP. Accelerate funding to to ensure competitive consideration in budget request
  - NASA is charting new ground and seems to be accepting the financial reality that sustaining systems is a long-term commitment
    - Will require programmatic support (organizationally and financially) throughout the remainder of the system's operational life.
    - NASA should consider a sustainment-based reorganization and develop doctrine to guide them
  - Restrictively define the SLEP mission. Current construct establishes this program as the central repository for nearly any shuttle related project. This will leave SLEP vulnerable to budget cuts and dilution of NASA's ability to resolve sustainment issues.

Presenter M3/Maintenance | Date FINAL | Slide 4 of 8 | Closed

Maintenance
Aging Vehicle/SLEP

Cost by SLEP Prioritization Categories
Real Year Dollars in Millions - Not in Full Cost

		FY03	FY04	FY05	FY06	FY07	FY08	FY09	Total FY04-FY08
FY04 President's Budget Request		299	364	367	297	301	304	--	1,633
Delta to Presidents Budget		18	-52	-59	-50	54	71		-35
Total POP 03 SLEP Recommendation		281	416	426	347	246	233	214	1,668
1	Should Start In Fiscal Year 2004	0	15	16	14	9	13	13	66
2	Commitments	261	274	234	156	136	126	124	926
3	Foundational Activities	3	23	31	23	12	24	12	113
4a	Sustainability	2	40	62	73	47	38	40	259
4b	Improvements	16	45	62	62	23	12	5	204
4c	New Capabilities	0	0	0	0	0	0	0	0
	Reserves	0	20	20	20	20	20	20	100

Presenter M3/Maintenance | Date FINAL | Slide 5 of 8 | Closed

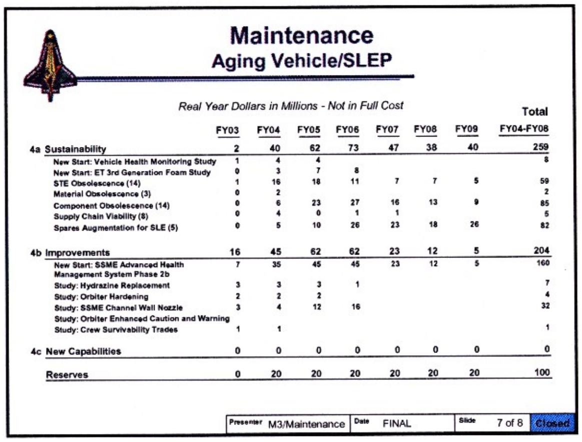
Maintenance
Aging Vehicle/SLEP

Real Year Dollars in Millions - Not in Full Cost

	FY03	FY04	FY05	FY06	FY07	FY08	FY09	Total FY04-FY08
Total POP 03 SLEP Recommendation	281	416	426	347	246	233	214	1,668
1 Should Start In Fiscal Year 2004	0	15	16	14	9	13	13	66
RSRM - Case Hardware Availability	0	5	5	5	5	5	5	25
Orbiter - Certify PRSD Tank Supplier & Procure Spares	0	4	8	8	4	8	8	31
SSME - Sustaining Test Equipment Tasks	0	6	3	1	0	0	0	10
2 Commitments	261	274	234	156	136	126	124	926
Vehicle Cockpit Avionics Upgrade (CAU)	89	91	77	14	0	0	0	182
Vehicle Main Landing Gear Tire & Wheel	3	3	0	0	0	0	0	3
SSME Advanced Health Management System (AHMS Phase 1)	8	4	3	2	1	0	0	10
Industrial Engineering for Safety	8	15	15	15	15	15	15	75
RSRM Obsolescence	12	18	19	20	20	21	21	98
Infrastructure	91	92	77	78	79	80	80	406
Others	50	51	43	27	21	10	8	152
3 Foundational Activities	3	23	31	23	12	24	12	113
Aging Vehicle Studies	2	10	14					24
Mid-Life Certification Assessment & Issue Mitigation								
Fleet Leader Program								
Corrosion Control								
STE Survey / Evaluation								
Non-Destructive Evaluation Upgrades								
Ground Test Program	0	4	10	20	9	21	9	64
Performance Trade Studies / Lift, Power	1	2	2					4
Improved Tools / Metrics	1	7	5	3	3	3	3	21
Probabilistic Risk Assessment								
Sustainability Health Metrics								
Analytical Hierarchy Tool System								

Presenter M3/Maintenance | Date FINAL | Slide 6 of 8 | Closed

1

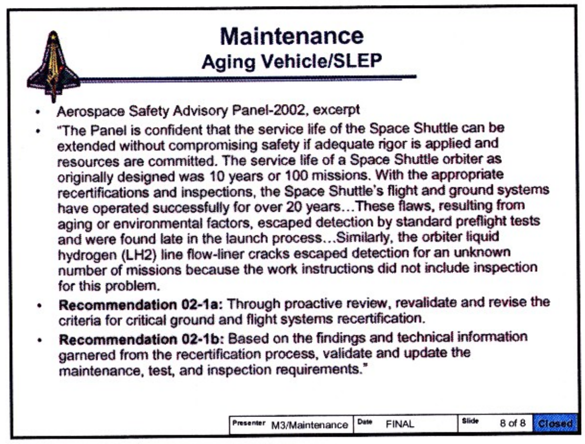


Maintenance
Aging Vehicle/SLEP

Real Year Dollars in Millions - Not in Full Cost

	FY03	FY04	FY05	FY06	FY07	FY08	FY09	Total FY04-FY08
4a Sustainability	2	40	62	73	47	38	40	259
New Start: Vehicle Health Monitoring Study	1	4	4					8
New Start: ET 3rd Generation Foam Study	0	3	7	8				
STE Obsolescence (14)	1	16	18	11	7	7	5	59
Material Obsolescence (3)	0	2						2
Component Obsolescence (14)	0	6	23	27	16	13	9	85
Supply Chain Viability (8)	0	4	0	1	1			5
Spares Augmentation for SLE (5)	0	5	10	26	23	18	26	82
4b Improvements	16	45	62	62	23	12	5	204
New Start: SSME Advanced Health Management System Phase 2b	7	35	45	45	23	12	5	160
Study: Hydrazine Replacement	3	3	3	1				7
Study: Orbiter Hardening	2	2	2					4
Study: SSME Channel Wall Nozzle	3	4	12	16				32
Study: Orbiter Enhanced Caution and Warning								
Study: Crew Survivability Trades	1	1						1
4c New Capabilities	0	0	0	0	0	0	0	0
Reserves	0	20	20	20	20	20	20	100

Presenter M3/Maintenance | Date FINAL | Slide 7 of 8 | Closed



Maintenance
Aging Vehicle/SLEP

- Aerospace Safety Advisory Panel-2002, excerpt
- "The Panel is confident that the service life of the Space Shuttle can be extended without compromising safety if adequate rigor is applied and resources are committed. The service life of a Space Shuttle orbiter as originally designed was 10 years or 100 missions. With the appropriate recertifications and inspections, the Space Shuttle's flight and ground systems have operated successfully for over 20 years…These flaws, resulting from aging or environmental factors, escaped detection by standard preflight tests and were found late in the launch process…Similarly, the orbiter liquid hydrogen (LH2) line flow-liner cracks escaped detection for an unknown number of missions because the work instructions did not include inspection for this problem.
- **Recommendation 02-1a:** Through proactive review, revalidate and revise the criteria for critical ground and flight systems recertification.
- **Recommendation 02-1b:** Based on the findings and technical information garnered from the recertification process, validate and update the maintenance, test, and inspection requirements."

Presenter M3/Maintenance | Date FINAL | Slide 8 of 8 | Closed

2

Orbiter Maintenance

14-1	Assessment of OV-102/STS-90 Hard Landing
14-2	Hypergolic Fuel Spill
14-3	WAD Accuracy
14-4	OV-102 Unique Wiring Configuration
14-5	OMDP – OMM

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	17 of 32

OV-102 Hard Landing

- **Action / Issue:** Review NASA assessment of OV-102/STS-90 hard landing (May 98)
- **Background / Facts:**
  - Main gear impact was highest sink rate in flight history
    - Estimated max of 6.7 fps through camera data
  - Crosswind: 4 – 11 kts range
    - Worst case (11) used in assessment
  - Landing weight: 233,000 lbs
  - Combined sink rate/x-wind/landing weight exceeded design criteria
    - Design criteria of 5.97 fps versus estimated 6.7 fps

Presenter	M3/Maintenance	Date	FINAL	Slide	1 of 2	Closed

OV-102 Hard Landing

- **Findings:**
  - Design criteria not equally critical at all landing weights
    - Possible to exceed design criteria and still remain within structural capability
  - Calculated MLG loads/reviewed & approved by Loads Panel/Load factors used in structural analysis
    - Reconstructed loads less than half of design load
    - Energy comparison explains why capability can be higher than design
  - MADS flight strain data confirmed accelerations/analytical conclusion
  - Reviewed/approved by Orbiter Structures Team 14 Jul 98
- **Group Recommendations:**
  - None. Eliminate as a causal factor.

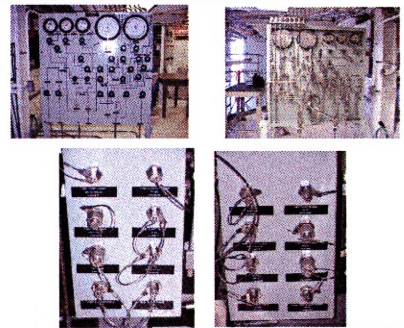
Presenter	M3/Maintenance	Date	FINAL	Slide	2 of 2	Closed

Maintenance
Structural Issues- Hypergolic Spill

- **Action / Issue:** Hypergolic Fuel Spill (McDonald-Gehman letter)
- **Background / Facts**
  - SIAT learned of hypergolic fuel spill 20 Aug 99 at KSC
  - Occurred during OV-102 prep for shipment to Palmdale
  - Issue briefed to Shuttle Operations Advisory Group 1 Nov 99
- **Findings**
  - 2.25 oz. dripped from GSE onto left wing inboard elevon trailing edge
  - Spill cleaned; 2 tiles removed for inspection; no damage found
  - USA employees at KSC received training; GSE improvements proposed to minimize risk of future spill
    - Quick disconnects now separated at vehicle/GSE interface only
  - Permanent panels now installed in each OPF, eliminates multiple QDs and flex lines on interface and test panel for each job
- **Group Recommendations**
  - None; spill was small/cleaned/assessed no effect on TPS or wiring

Presenter M3/Maintenance	Date FINAL	Slide 1 of 2	Closed

Maintenance
Structural Issues- Hypergolic Spill



Presenter M3/Maintenance	Date FINAL	Slide 2 of 2	Closed

1

Maintenance
Paper Work Review

- **Action / Issue:** NASA's review of STS 107/109 paperwork showed that current WAD accuracy may not be adequate to assure CoFR.
- **Background:** CAIB requested NASA explain the methodology and summarize their findings from the paper work audit with emphasis on how they will use them wrt trends/corrective actions/applicability
- **Findings:**
  – Review of subsystem WADs is ongoing. Early results reveal many "Findings" and "observations" in -107/-109 records
  – "Finding" = "discrepancies that impact the technical execution of the work" per KSC/Palmdale Processing Review Teams Guidelines and Criteria, Rev G.
    - Ex: incorrect guidance provided by the author/engineer and failure to document corrective action or initiate PR/MR

Presenter	M3/Maintenance	Date	FINAL	Slide	1 of 2	Closed

Maintenance
Paper Work Review

- **Findings:**
  – New WADs will be reviewed by one to three people (depending on the system) who will sign it or stamp before being issued
    - Monthly sampling of WADs called Technical Accuracy Measurement
  – Completed WAD steps may be reviewed by USA & NASA QA
  – Closed WADs undergo several review layers by supervisors, USA and NASA QA, engineers before passed to Quality Data Center
  – No apparent documentation of findings outside PRACA if relevant
- **Recommendations:**
  – SSP program management should consider review of STS 114/115 records prior to flight
  – NASA should institute a system to review and evaluate all CRIT 1 and 2 systems paperwork and sample the rest.
  – Build a documentation quality control process to sample and document errors to use in trend analysis and process feedback

Presenter	M3/Maintenance	Date	FINAL	Slide	2 of 2	Closed

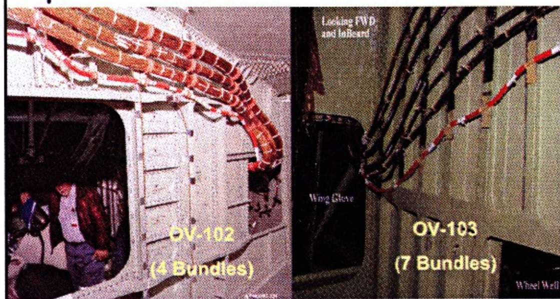
1

Fire (Pyro /Wiring / etc.)
OV-102 Unique Wiring Configuration

- **Action / Issue:** Determine reason for OV-102's unique wiring configuration (left wing) and its role in data loss leading up to LOS
- **Background / Facts:**
  - OV-102 wiring outboard of MLG wheel well routed in 4 large bundles; other orbiters have 7 small bundles
- **Findings:**
  - As the first operational orbiter, OV-102 had additional instrumentation; nearly 90% of wires routed through this area associated with OEX data gathering and/or disconnected systems
  - Bundle securing method changed from clamps to tape straps in later orbiters; tape less able to secure large bundles – additional smaller diameter bundles (0.5 in or less) required
- **Group Recommendations:**
  - Not causal, but inclusion in OEX data analysis/sequence of events leading up to LOS will enhance investigation
  - Role in data loss sequence TBD; NASA wire heating tests ongoing

Presenter M3/Maintenance	Date FINAL	Slide 1 of 2	Closed

Fire (Pyro /Wiring / etc.)
Internal Hazard



Presenter M3/Maintenance	Date FINAL	Slide 2 of 2	Closed

1

Orbiter Major Modification (OMM)

- **Action / Issue:** Review/assess past OMM performance, movement of OMMs from Palmdale (PD) to KSC, and OV-102's most recent OMM; identify significant issues/concerns.
- **Background / Facts**
  - NSTS 07700, Volume III, requires each orbiter to undergo an OMM every 8 flights or 3 years
    - Orbiters are removed from service for varying amounts of time, depending on work to be performed
      - Length of OMM driven more by mods than inspections
    - Work includes baseline rqmts (time/cycle changes), routine inspections (structural), special inspections (wiring), mods, deferred work, and correcting "stumble ons" (est'd at ≥40% of total work)
    - OMMs typically involve more intrusive inspections/maintenance/mods than during flows (down-/up-mission processing)
    - OMMs are a subset of OMDPs (Orbiter Maintenance Down Period), which also include down-/up-mission processing (DMP/UMP)

Presenter M1/Maintenance | Date FINAL | Slide 1 of 21 | Closed

Orbiter Major Modification (OMM)

- **Background / Facts (cont'd)**
  - 10 OMMs to date
    - 8 at PD (OEM), including OV–102 "AA" (demod from test/development to operational configuration)
    - 2 at KSC: OV-103/J1 (2-8/92) and OV-103/J3 (in progress)
    - Durations (as measured from landing to launch) have ranged from 5.7 months (OV-102/J1) to 19.5 months (OV-104/J1)
    - Wide variation in durations result from variations in OMM content
  - Historical challenges meeting 8 flight/3 year interval
    - OV-102: 9 flights/4 years between J2 and J3
    - OV-103: 9 flights/4.5 years between J2 and J3 (in progress)
    - OV-105: currently 8 flights/>5 years; next OMM: 11 flights/6+ years
    - OV-104: 12 flights/6 years based on manifest & Oct 05 OMM

Presenter M1/Maintenance | Date FINAL | Slide 2 of 21 | Closed

Orbiter Major Modification (OMM)

- **Background / Facts:**
  - Studies/analysis since 99 on how intervals might be extended to 12 flights/6.0 years
    - Major challenge: Calendar rqmts versus flight rqmts; e.g., clock continues to run during post-Columbia grounding
    - General rule in industry: Time-based inspections become more frequent as vehicles age
    - No decision to date
  - By numbers alone, more mods performed in DMP/UMP than OMM
    - 2,177 (36%) of 5,985 total mods (fleet) done in OMM
    - Remainder, or 3,808 (64%), accomplished during flow (DMP/UMP)
    - Reflects philosophy of getting mods done when possible (schedule permitting) vice deferring to OMM
    - Scheduling less complex mods during flows leaves OMMs with increased flexibility for more complex mods & unexpected problems

Presenter M1/Maintenance | Date FINAL | Slide 3 of 21 | Closed

Orbiter Major Modification (OMM)

- **Findings:**
  - OMM location weighed since early 90s: PD or KSC?
    - NASA IG (95): Cost savings at KSC, but due to complexity of scheduled work and launch schedule, leave next 2 at PD
    - NASA IG (98): PD costlier, but "risk…greatly reduced"; "risk [at KSC] outweighs potential cost savings"; "…reevaluate location when significant changes occur."
    - SSP conducted reviews, starting in May 01, to address most efficient use of resources (personnel, infrastructure)
    - JSC Sys Mgt Office concluded significant savings between worst case at KSC and best case at PD
    - Feb 02: NASA approved OV-103 OMM (Sep 02) at KSC
      - Short term factors cited: FY03 budget shortfalls, FY 02 impact
      - Long term: Life cycle cost reduction
      - Slightly decreased launch rate from '01 (7) to '02 (6) a 2ndary factor

Presenter M1/Maintenance | Date FINAL | Slide 4 of 21 | Closed

Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - Facilities: 3 bays at KSC, 2 at PD; KSC max'd after OMM move
    - Challenged to "juggle" 4 orbiters between 3 bays; increased workload/ disruption from movements; OV-103 moved 6 times in 9 months (prior to OMM start in 9/02)
    - PD OMMs historically a buffer; OV-102's loss alleviated situation
  - Logistics: Capabilities growth at NASA Shuttle Logistics Depot (NSLD) has reduced the need for West Coast duplication; even prior to OMM move, support increasingly from NSLD
    - OV-102/J3: 2,663 orders/76,894 pieces shipped from KSC; 50% hardware, 20% LRUs, 10% other (e.g., paints/chemicals)
    - OV-104/J2 (prior to OV-102): 1,538 orders/47,487 pieces
    - PD industrial shops have generally atrophied (TPS, avionics), with a few exceptions (17" disconnect, cold plates); others (machine shop) continue supporting other work & are called on for KSC backup capacity

Presenter M1/Maintenance | Date FINAL | Slide 5 of 21 | Closed

Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - Workforce/labor expenditures appear more efficient at KSC, but too early for any definitive conclusions
    - Last 4 PD OMMs: 324 to 448 (blue/white collar) equivalent personnel (EP); 383 average
      - Additional KSC augmentation: 30-40 techs/inspectors/engineers
    - Current KSC OMM (first 7 months): 235 EP projected, averaging 301
      - No other recent OMMs for comparison (last OMM 10 yrs prior)
    - Potential reasons for KSC efficiency compared w/PD
      - Larger workforce allows flexibility in shifting resources to match peaks/valleys
      - Steadier overall workload (not just OMMs) keeps worker proficiency at a higher level; workers not laid off/moved to other jobs as at PD
    - One concern voiced by several managers: ability of fluid workforce (especially engineers) to focus

Presenter M1/Maintenance | Date FINAL | Slide 6 of 21 | Closed

1

Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - Workforce experience levels more stable at KSC due to fewer workload fluctuations
    - 176 additional workers hired at KSC for OMM relocation; assimilated throughout entire workforce (1,900) to minimize training load/impact of inexperience
    - By contrast, 85% of PD workforce (342) during OV-102/J3 had prior OMM or orbiter manufacturing experience
      - Some experienced personnel strategically placed in other Boeing jobs to preserve expertise, then recalled for OMMs
      - Others laid off after OMMs, rehired prior to next OMM
      - As OV-102/J3 requirements/workload increased, the workforce grew to 500, experienced personnel were quickly "tapped out", and experience dropped to 58%; time spent training new/inexperienced workers increased, including on-the-job training

Presenter M1/Maintenance | Date FINAL | Slide 7 of 21 | Closed

Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - Support equipment capability comparable; slight advantage at PD WRT large component removal/reinstallation due to OEM
    - Ground Support Equipment readily moved between sites
  - Last PD OMM: OV-102 J3
    - Roll-in: 26 Sep 99; roll-out: 24 Feb 01
    - Initial duration: 293 days; actual: 517 days (76% growth)
    - Despite delay, roll-out achieved with 98% of work completed
    - Major mods included MEDS (glass cockpit), GPS, wireless video
    - Large growth in requirements/"stumble ons" (see chart)
    - HEDS IA KS-0003 (3/28/01) perspective
      - "Poor performance on NASA, USA, and Boeing" (schedule/cost)
      - "Work quality very good to excellent" (product)
    - Offers MANY important lessons learned applicable to the fleet

Presenter M1/Maintenance | Date FINAL | Slide 8 of 21 | Closed

Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - HEDS Independent Assessment (IA) of OV-102 OMM
    - Contractor estimated 331-day flow; SSP directed 293; contractor initially assessed schedule as "red", though management subsequently agreed based on anticipated efficiencies & revised schedule risk assessment
    - PD adequately staffed (initially) for the OV-102/J3 OMM, but unforeseen problems/add'l work quickly exceeded capabilities
    - OMM requirements increased by 103% over initial planning (MSRR), and by 82% after roll-in; high by comparison with other OMMs (see chart)
    - Wire inspection added 1-month after roll-in, 8-week extension based on expectation of 500-700 anomalies; actual - 4,600+ anomalies; SSP allowed a second 8-week extension; inspection chit revised 6 times
    - Other technical surprises (e.g., cold plate corrosion) and procedural problems (e.g., payload bay door rigging) exceeded scheduled time by more than double and slipped power-on testing

Presenter M1/Maintenance | Date FINAL | Slide 9 of 21 | Closed

Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - Additional HEDS IA determinations
    - OMM management suffered due to an inexperienced flow manager
      - Message to SSP was regularly optimistic re: key milestones
    - Flow manager used a new, unproven scheduling tool that proved inadequate; returned to previous tool after 12-months
    - The rapidly rising number of anomalies made integration of workload scheduling increasingly difficult
    - Integrated scheduling meetings were not held frequently enough to keep abreast of changes (weekly vice daily); daily mtgs 12-months into OMM
    - The large volume of PRs generated by nonconformances inundated the system and contributed to management difficulties
    - OMM problems were exacerbated by the Program Office turning the process over to USA without a structured insight function in place

Presenter M1/Maintenance | Date FINAL | Slide 10 of 21 | Closed

Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - Despite the large number of complications during OV-102/J3 OMM, Columbia was delivered with 98% of all scheduled work completed
  - "Traveled work" to KSC equaled 9,071 hours (0.66% of total)
    - OV-102 J2: 7,886 hours (0.89%)
    - OV-103 J2: 2,252 hours (0.38%)
    - Fully coordinated…no surprises
  - OV-102 J3 "lessons learned" being applied to OV-103 J3 at KSC
    - Efforts at better communication: scheduling meetings 3X/wk; Ground Ops reviews 2X/wk; program management reviews monthly
    - Healthy "give and take" observed at PMRs
    - Capabilities assessments for resource constrained areas (OPF tile technicians and tile backshop) presented at PMRs

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Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - OV-103 J3 OMM still a challenge
    - Requirements growth continues: 20 mods originally scheduled due to budget limitations and conservative approach (first KSC OMM); however, mods alone have increased to 84 (320%) by mid-April (67% thru OMM)
    - 24 additional mods being held to not overload capability
    - Despite growth, overall OMM flow well managed (compared to OV-102)
  - AF Depot Maintenance Team benchmarking visit to KSC in Jun
    - Invited by NASA Code M to assess OMDP/OMM processes
    - Benchmark areas: documentation, policy/procedure adherence, logistics (NSLD) support, "ship side" engineering support, safety, communication
    - Areas requiring review/increased attention:
      - Requirements definition plans (e.g., MVP, OMRSD, QPRD) lack a closed loop feedback to process to routinely/systematically adjust
      - Plans and scheduling can benefit from increased stability

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Orbiter Major Modification (OMM)

- **Findings (cont'd):**
  - AF Depot Maintenance Team/OMM areas requiring review (cont'd)
    - Orbiter sustainment roadmap must be tied into OMM requirements
    - Gov't/contractor relationships require review to ensure the right OMM "behavior" is being incentivized
- **Conclusions:**
  - While there are specific baseline elements, no two OMMs are alike; variations occur as orbiters age (wiring inspection, cold plate corrosion), as mission rqmts change (reconfiguration for MIR) and, in some cases, due to lack of funding; improving schedule and funding stability can help reduce process variation and aid in better planning/scheduling and less turmoil
  - Increasing OMM intervals as orbiters age is counter to industry norms; for high performance systems, it raises even greater questions

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Orbiter Major Modification (OMM)

- **Conclusions (cont'd):**
  - Relocation of OMMs to KSC provides many advantages over PD (e.g., a more stable, more fully/steadily employed workforce), but also creates new challenges
    - KSC advantages can still be overwhelmed if not carefully managed
    - Several NASA/USA/Boeing managers expressed concern over a fluid workforce's (especially engineers) ability to focus
  - The wire inspection chit and its timing (1-month after OV-102 roll-in) played a major role in OMM schedule slippage
    - A "must do", representative of technical surprises that will continue
  - OV-102 J3 OMM "lessons learned" have fleet implications because:
    - As orbiters age, workload will likely increase
    - The likelihood of technical surprises will also increase
    - A significant return-to-flight workload is highly probable
    - All of the above will generate new challenges, similar to those encountered during OV-102's OMM, for both managers/workforce

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Orbiter Major Modification (OMM)

- **Recommendations:**
  - The Program Office MUST work to achieve greater stability in OMM-scheduled work, particularly the number of mods (biggest driver of schedule/workload variation); a continually changing schedule (rqmts growth) creates unnecessary turmoil/stress and increases the potential for quality escapes
  - Managers (NASA/USA) MUST understand workforce/facilities capabilities, schedule to those capabilities, and take necessary actions to avoid exceeding them (ref. Capabilities Assessment briefing)
  - The SSP Office MUST determine how it will effectively meet the challenges of inspecting/maintaining an aging orbiter fleet prior to increasing the OMM interval
  - NASA/USAF benchmarking efforts should be continued using the same personnel as much as possible for continuity

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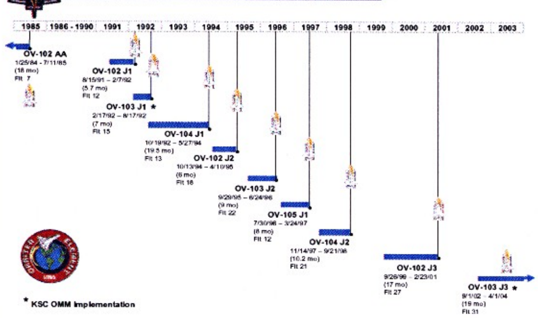
Orbiter Major Modification (OMM) Boeing/Palmdale

Presenter M1/Maintenance | Date FINAL | Slide 16 of 21 | Closed

Orbiter Major Modification (OMM) History



Presenter M1/Maintenance | Date FINAL | Slide 17 of 21 | Closed

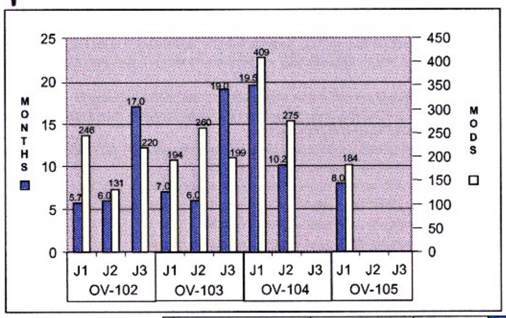
Orbiter Modifications OMM vs. Flow

ORBITER	MODS IN OMM	MODS IN FLOW	TOTAL MODS
OV-102	608	1,058	1,666
OV-103	675	936	1,611
OV-104	691	725	1,416
OV-105	203	1,089	1,292
TOTAL	2,177	3,808	5,985

Presenter M1/Maintenance | Date FINAL | Slide 18 of 21 | Closed

3

OMM History
Required Time vs. Mods Performed



Presenter M1/Maintenance | Date FINAL | Slide 19 of 21 | Closed

OV-102J3 OMM Workload Growth

Start: 9/26/99 Complete: 2/24/2001 Est/Act Time: 331/517 days

	Preplanning Baseline (11/6/98)	Initial Baseline (4/1/99)	Baseline Wire Insp (10/13/99)	CCB Baseline (10/25/00)	CCB Baseline (1/31/01)	Percent Growth (since 98)
MCRs	66	70	75	99	102	85%
Mod Kits	62	68	80	142	152	145%
Tech Orders	28	36	42	56	58	107%
TCTIs & NSW	55	58	68	100	110	100%
Deferred WADs	105	150	194	204	206	96%
Chits	14	17	20	37	43	207%
Total	330	399	479	638	671	103%

Presenter M1/Maintenance | Date FINAL | Slide 20 of 21 | Closed

OMM Requirements
Growth Comparison

ORBITER	INITIAL PLANNING	CCB BASELINE	PERCENT INCREASE
OV-103 J2 9/95 – 6/96	383	532	39%
OV-105 J1 7/96 – 3/97	278	405	46%
OV-104 J2 11/97 – 9/98	461	844	83%
OV-102 J3 9/99 – 2/01	330	671	103%
OV-102 J3 w/o WIRE INSP	330	591	79%

Presenter M1/Maintenance | Date FINAL | Slide 21 of 21 | Closed

4

Orbiter
Launch – Ascent

15-1 STS-107 Key Loads Parameters Versus Design and Experience

15-2 STS-107 Ascent Loads (DOLILU)

15-3 STS-107 OEX Ascent Data

Matrix

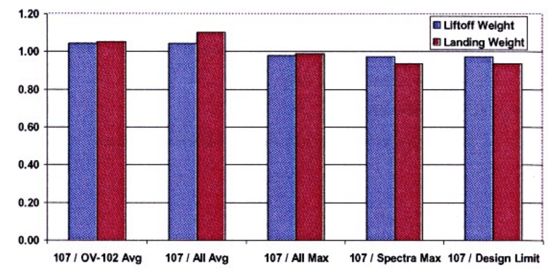
Presenter	CAIB/Group 1	Date	FINAL	Slide	18 of 32

STS-107 Vs Past Experience

- **Action / Issue:** Compare STS-107 key parameters to past experience and design limits
- **Background / Facts:**
  - STS-107 key parameters extracted from RSS99D0510D, "Space Shuttle Life Tracking", March 2003

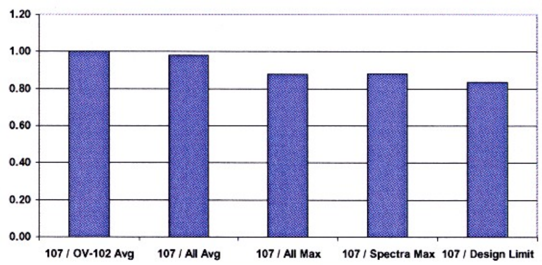
Presenter M3/Material | Date FINAL | Slide 1 of 7 | Closed

STS-107 Vs Past Experience



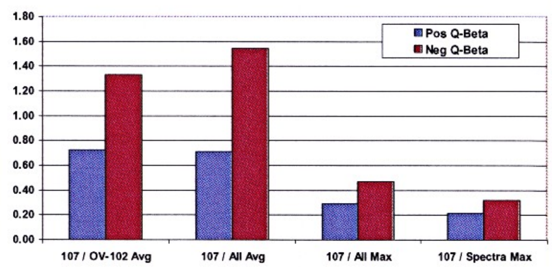
Presenter M3/Material | Date FINAL | Slide 2 of 7 | Closed

STS-107 Vs Past Experience



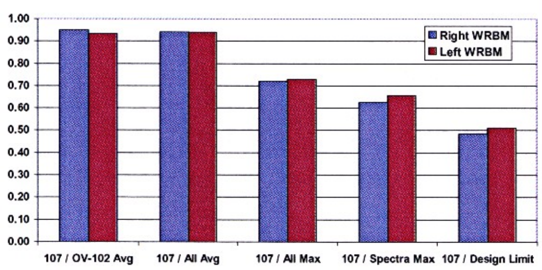
Presenter M3/Material | Date FINAL | Slide 3 of 7 | Closed

STS-107 Vs Past Experience



Presenter M3/Material | Date FINAL | Slide 4 of 7 | Closed

STS-107 Vs Past Experience



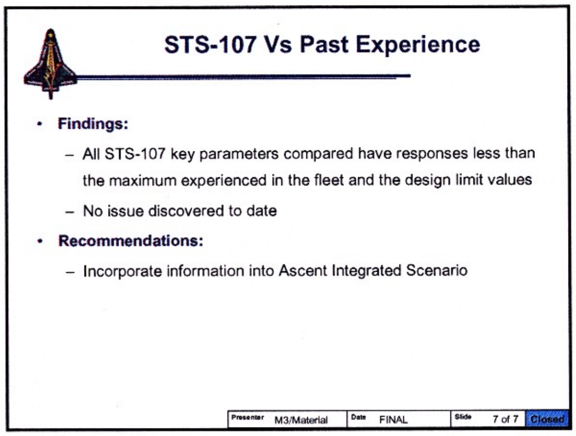
Presenter M3/Material | Date FINAL | Slide 5 of 7 | Closed

STS-107 Vs Past Experience

Parameter	Units	STS-107 Value	STS-109 Value	STS-93 Value	OV-102 Average	All Flights Average	All Flights Maximum	All Flights Minimum
Liftoff Orbiter Weight	lbs	265081	260665	270455	253760	254308	270455	219441
Liftoff Orbiter Center of Gravity	in	1104.7	1113.8	1129.2	1109.7	1112.2	1131.3	1095.8
Ascent Maximum Dynamic Pressure (Q)	psf	683.6	708.6	701.9	683.9	697.7	777.9	606.7
Ascent Q-Beta Positive Maximum	psf-deg	544.7	889.2	495.0	751.9	766.7	1686.2	
Ascent Q-Beta Negative Minimum	psf-deg	-1106.9	-878.5	-690.6	-881.4	-847.0		-1734.4
Ascent Beta Positive Maximum, M 0.9 to 1.6	deg	0.64	0.63	0.44	0.44	0.51	1.53	
Ascent Beta Negative Minimum, M 0.9 to 1.6	deg	-0.86	-0.39	-0.44	-0.66	-0.57		-1.66
Ascent Right Wing Root Bending Mx Positive	in-lb	1.714E+07	1.995E+07	1.806E+07	1.636E+07	1.622E+07	2.382E+07	
Ascent Left Wing Root Bending Mx Negative	in-lb	-1.801E+07	-1.951E+07	-1.866E+07	-1.928E+07	-1.820E+07		-2.471E+07
Landing Orbiter Weight	lbs	232648	222160	202721	220966	211117	235285	187200

Presenter M3/Material | Date FINAL | Slide 6 of 7 | Closed

1


STS-107 Vs Past Experience
Findings:
– All STS-107 key parameters compared have responses less than the maximum experienced in the fleet and the design limit values
– No issue discovered to date
Recommendations:
– Incorporate information into Ascent Integrated Scenario
Presenter M3/Material
Date FINAL
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Closed

2

STS-107 Launch/Ascent

- **Action / Issue:** Review STS-107 structural responses during ascent
- **Background / Facts:**
  - Structural response of Shuttle depends on a combination of:
    - Flight control commands
    - Shuttle responses (α and β changes, gimbal angles, LOX slosh, etc.)
    - Environment through which Shuttle ascends (winds, etc.)
  - Guidance commands in the Day of Launch I-Load Update (DOLILU) provide input to flight control software
    - Inputs to DOLILU: measured winds, atmospheric data, vehicle config.
    - What DOLILU targets: angle of attack (α), angle of sideslip (β), dynamic pressure (q) as function of Mach number
    - DOLILU Outputs: guidance commands to control
      - Vehicle pitch & yaw attitudes
      - SSME throttle
    - SSME & SRB gimbal angles controlled by flight control software
    - DOLILU is used to ensure vehicle is flown within an acceptable structural loads envelope

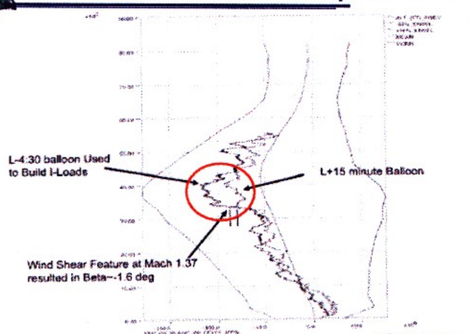
Presenter M3/Material | Date FINAL | Slide 1 of 34 | Closed

STS-107 Launch/Ascent

- **Background / Facts:** (cont.)
  - DOLILU inputs (winds)
    - Based on observation from Jimsphere balloon released at L-4:35
    - Verified using data from Jimspheres released at L-3:25, -2:15, & -1:10
    - STS-107 Data
      - L-4:35: Max wind shear of 41.0 fps at 34,300 feet = 74.0% of design limit
      - L-3:25: Max wind shear of 46.0 fps at 33,800 feet = 83.1% of design limit
      - L-2:15: Max wind shear of 43.6 fps at 33,400 feet = 78.6% of design limit
      - L-1:10: Max wind shear of 26.9 fps at 33,400 feet = 70.9% of design limit
      - No exceedances on any Jimsphere data
  - STS-107 Experience (wind shear) at MET = 57 sec and Mach 1.27
    - Not measured by vehicle – no capability to do so
  - Post-launch (L+15) Jimsphere confirmed wind shear was less than design limit
    - L+0:15: Max wind shear of 37.7 fps at 33,200 feet = 68.0% of design limit
    - Also ~40 ft/sec less than L-4:35 wind shear used for DOLILU
    - See next chart

Presenter M3/Material | Date FINAL | Slide 2 of 34 | Closed

STS-107 Launch/Ascent
L-04:30 and L+00:15 Jimsphere Data



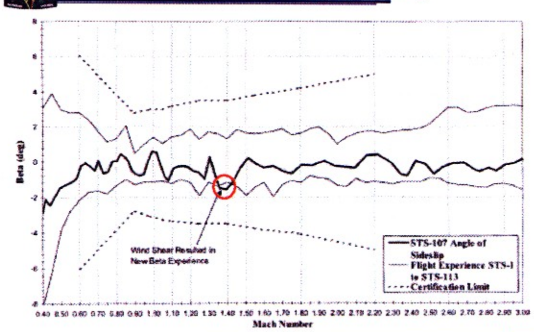
Presenter M3/Material | Date FINAL | Slide 3 of 34 | Closed

STS-107 Launch/Ascent

- **Background / Facts:** (cont.)
  - STS-107 Experience (wind shear) at MET = 57 sec (cont.)
    - Due to wind shear, the following Shuttle responses exceeded prior flight experience (See next 3 charts)
      - Orbiter β of 1.6 degrees
      - SRB gimbal angles
      - SSME #3 pitch gimbal angle

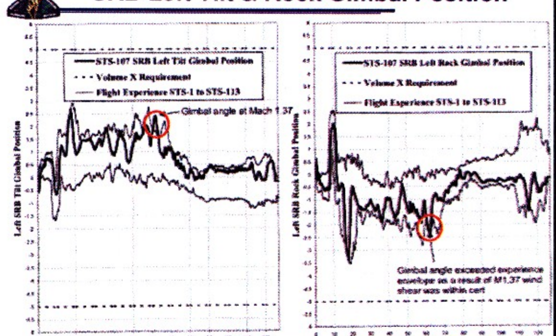
Presenter M3/Material | Date FINAL | Slide 4 of 34 | Closed

STS-107 Launch/Ascent
Angle of Sideslip (Beta)



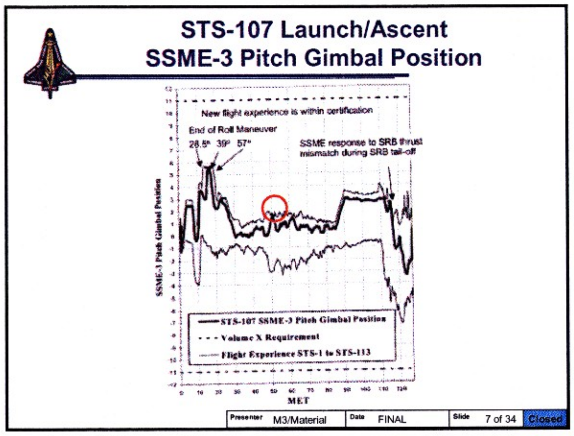
Presenter M3/Material | Date FINAL | Slide 5 of 34 | Closed

STS-107 Launch/Ascent
SRB Left Tilt & Rock Gimbal Position



Presenter M3/Material | Date FINAL | Slide 6 of 34 | Closed

1


STS-107 Launch/Ascent
SSME-3 Pitch Gimbal Position
New flight experience is within certification
End of Roll Maneuver
28.5s 39s 57s
SSME response to SRB thrust mismatch during SRB tail-off
SSME-3 Pitch Gimbal Position
STS-107 SSME-3 Pitch Gimbal Position
Volume X Requirement
Flight Experience STS-1 to STS-113
MET
Presenter M3/Material
Date FINAL
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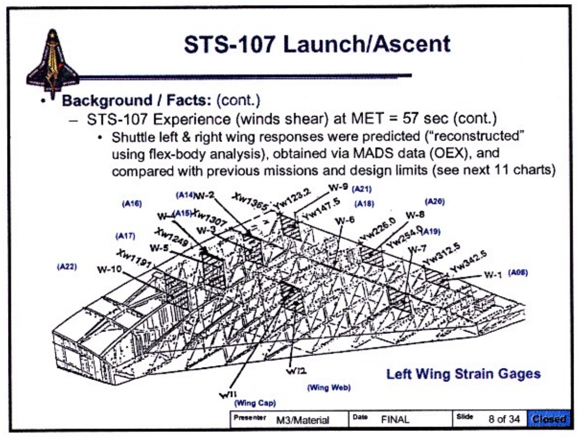
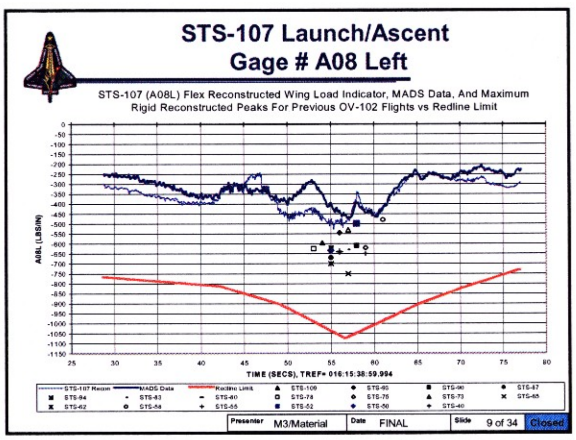
Closed


STS-107 Launch/Ascent
• Background / Facts: (cont.)
– STS-107 Experience (winds shear) at MET = 57 sec (cont.)
• Shuttle left & right wing responses were predicted ("reconstructed" using flex-body analysis), obtained via MADS data (OEX), and compared with previous missions and design limits (see next 11 charts)
Left Wing Strain Gages
(Wing Web)
(Wing Cap)
Presenter M3/Material
Date FINAL
Slide 8 of 34
Closed


STS-107 Launch/Ascent
Gage # A08 Left
STS-107 (A08L) Flex Reconstructed Wing Load Indicator, MADS Data, And Maximum Rigid Reconstructed Peaks For Previous OV-102 Flights vs Redline Limit
A08L (LBS/IN)
TIME (SECS), TREF= 016:15:38:59.994
Presenter M3/Material
Date FINAL
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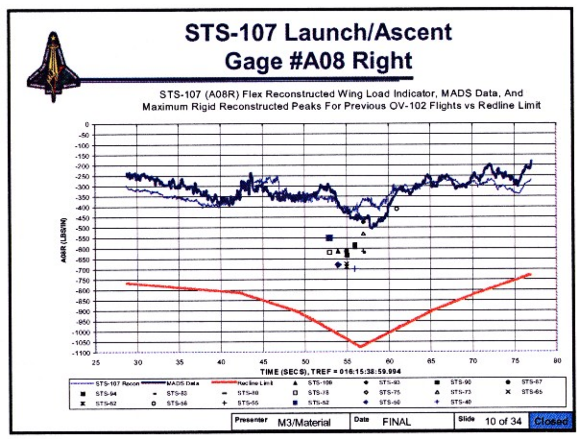
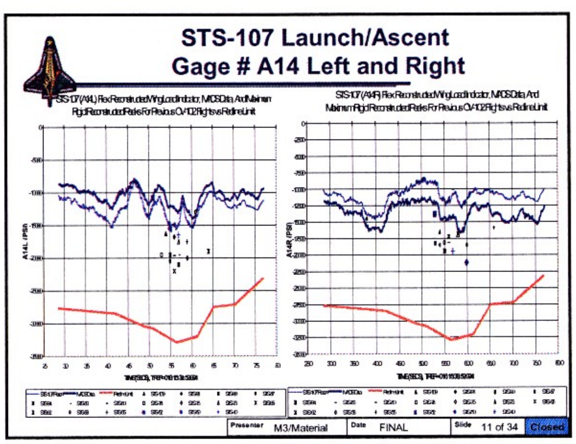
Closed


STS-107 Launch/Ascent
Gage #A08 Right
STS-107 (A08R) Flex Reconstructed Wing Load Indicator, MADS Data, And Maximum Rigid Reconstructed Peaks For Previous OV-102 Flights vs Redline Limit
A08R (LBS/IN)
TIME (SECS), TREF = 016:15:38:59.994
Presenter M3/Material
Date FINAL
Slide 10 of 34
Closed


STS-107 Launch/Ascent
Gage # A14 Left and Right
A14L (PSI)
A14R (PSI)
Presenter M3/Material
Date FINAL
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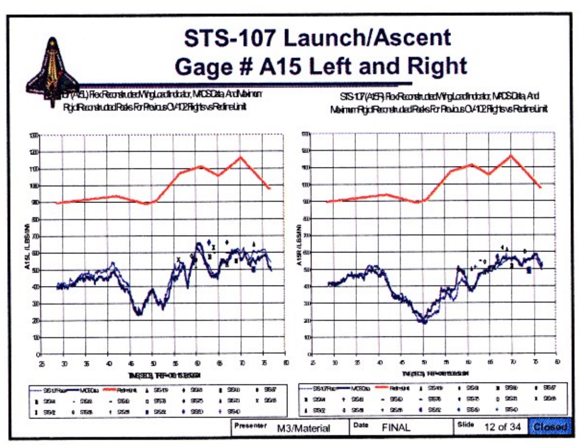
Closed


STS-107 Launch/Ascent
Gage # A15 Left and Right
Presenter M3/Material
Date FINAL
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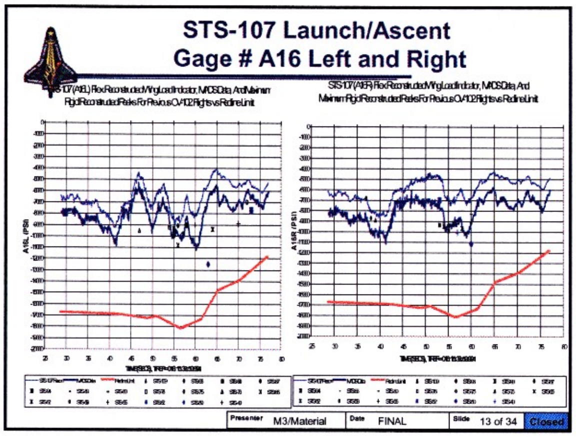
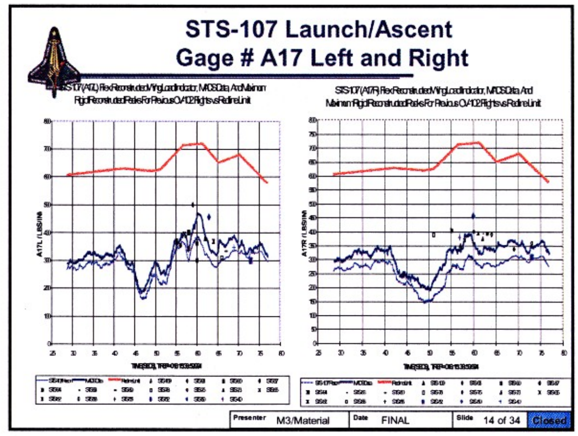
Closed

2


STS-107 Launch/Ascent
Gage # A16 Left and Right
Presenter M3/Material
Date FINAL
Slide 13 of 34
Closed


STS-107 Launch/Ascent
Gage # A17 Left and Right
Presenter M3/Material
Date FINAL
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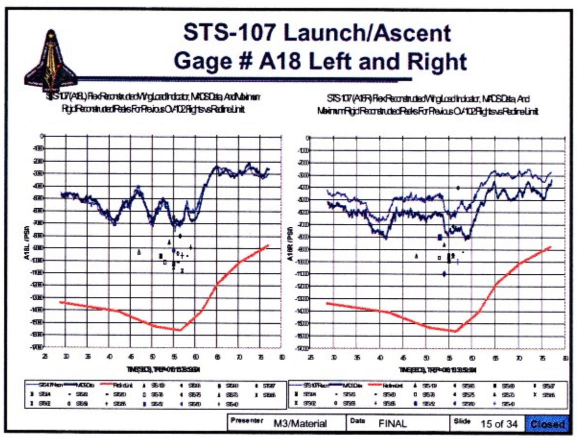
Closed


STS-107 Launch/Ascent
Gage # A18 Left and Right
Presenter M3/Material
Date FINAL
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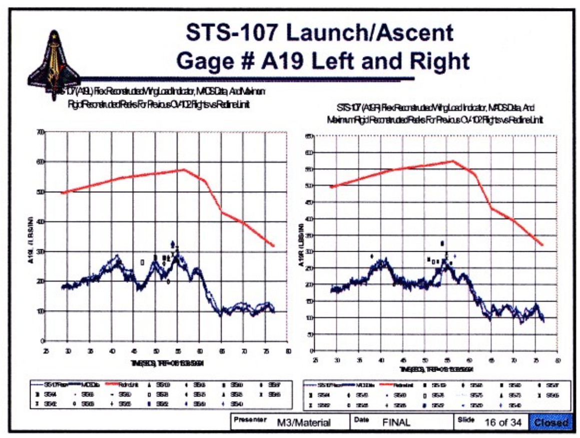
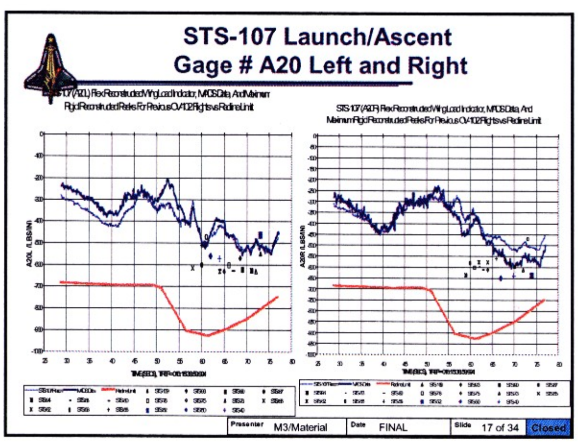
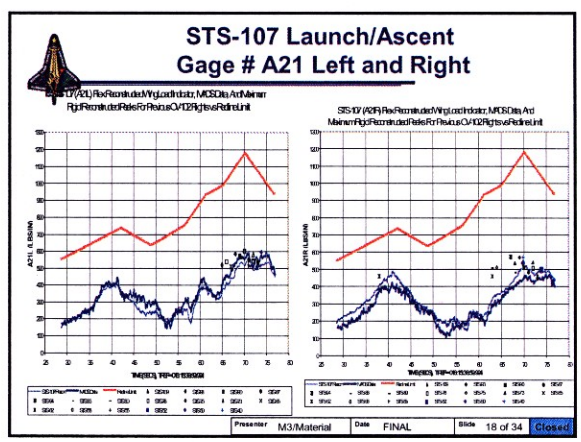
Closed


STS-107 Launch/Ascent
Gage # A19 Left and Right
Presenter M3/Material
Date FINAL
Slide 16 of 34
Closed


STS-107 Launch/Ascent
Gage # A20 Left and Right
Presenter M3/Material
Date FINAL
Slide 17 of 34
Closed


STS-107 Launch/Ascent
Gage # A21 Left and Right
Presenter M3/Material
Date FINAL
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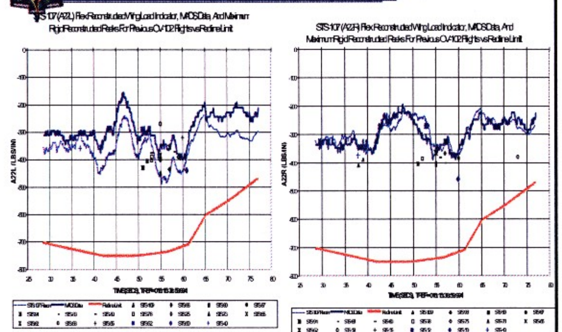
Closed

3

STS-107 Launch/Ascent
Gage # A22 Left and Right

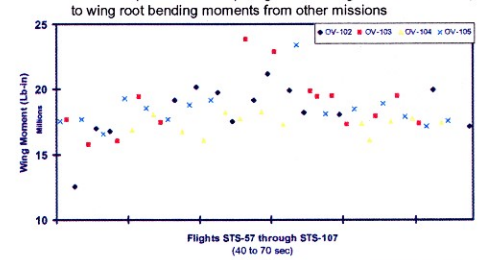


Presenter M3/Material | Date FINAL | Slide 19 of 34 | Closed

Reconstructed left wing root moment for previous flights

STS-107 Launch/Ascent

- **Background / Facts:** (cont.)
  - STS-107 Experience (winds shear) at MET = 57 sec (cont.)
    - Predicted ("reconstructed") wing root bending moment was compared to wing root bending moments from other missions



Presenter M3/Material | Date FINAL | Slide 20 of 34 | Closed

STS-107 Launch/Ascent

- **Background / Facts:** (cont.)
  - STS-107 Experience (ascent oads)
    - Max & min predicted ("reconstructed" using rigid body analysis) loads on ET-Orbiter attachments, struts, and orbiter body also measured and compared against design limit during ascent (see next 4 charts)
    - Highest % of limits indicated with red arrow ←

STS-107 Reconstructed Max/Min Attachment Loads

ET - Attachment Loads

Indicator	Upper Side				Lower Side			
Name	% of Limit	Mach	Load (kips)	Limit (kips)	% of Limit	Mach	Load (kips)	Limit (kips)
FTB1	16.96	0.78	37.42	220.60	9.37	1.54	-14.19	-151.50
FTB2	11.64	0.64	25.94	222.80	16.11	1.42	-23.67	-147.00
FTB3	48.38	2.20	93.76	193.80	*	*	36.81	-80.40
FTB4	*	*	-32.27	83.60	42.11	2.08	-84.77	-201.30
FTB5	*	*	-1025.36	168.80	81.43	2.20	-1368.24	-1680.30
FTB6	*	*	-1033.62	152.70	82.41 ←	2.20	-1384.23	-1679.60
FTB7	25.35	1.01	69.93	275.90	20.11	1.38	-39.21	-195.00
FTB8	40.39	1.40	121.13	299.90	9.99	0.84	-20.45	-204.70
FTB9	*	*	-21.21	269.90	39.43	1.40	-118.58	-300.70
FTB0	30.26	1.50	92.84	306.80	*	*	3.19	-296.00
MTB1	15.63	1.36	2731.63	17481.10	19.24	1.00	-4869.35	-25309.00
MTB2	31.86	1.37	8078.14	25352.90	5.45	0.83	-991.29	-18189.30

Presenter M3/Material | Date FINAL | Slide 21 of 34 | Closed

STS-107 Launch/Ascent

STS-107 Reconstructed Max/Min Attachment Loads

Strut Loads

Indicator	Upper Side				Lower Side			
Name	% of Limit	Mach	Load (kips)	Limit (kips)	% of Limit	Mach	Load (kips)	Limit (kips)
P1	19.25	0.84	14.47	75.20	34.56	1.41	-33.00	-95.50
P2	15.27	0.90	11.67	76.40	27.27	1.53	-27.27	-100.00
P3	44.78	0.71	188.75	421.50	4.81	1.07	-11.62	-241.70
P4	55.02	1.36	251.93	457.90	*	*	20.29	-231.00
P5	*	*	-180.72	181.10	53.29 ←	0.73	-426.74	-800.80
P6	*	*	-166.31	182.60	51.12	0.71	-412.50	-806.90
P7	15.02	0.99	18.80	125.10	22.32	1.26	-29.75	-133.30
P8	17.53	1.48	35.42	202.00	14.52	1.06	-27.16	-187.00
P9	39.06	1.37	103.50	265.00	*	*	6.83	-124.10
P10	9.99	0.84	21.35	213.70	40.39	1.40	-126.46	-313.10
P11	33.86	1.36	68.39	202.00	6.19	1.00	-11.58	-187.00
P12	27.01	1.48	71.57	265.00	0.08	0.88	-0.10	-127.20
P13	20.11	1.38	40.93	203.50	25.35	1.01	-73.00	-288.00

Presenter M3/Material | Date FINAL | Slide 22 of 34 | Closed

STS-107 Launch/Ascent

STS-107 Reconstructed Max/Min Attachment Loads

Orbiter - Attachment Loads

Indicator	Upper Side				Lower Side			
Name	% of Limit	Mach	Load (kips)	Limit (kips)	% of Limit	Mach	Load (kips)	Limit (kips)
FTO1	15.49	0.87	14.20	91.70	31.46	1.54	-39.89	-126.80
FTO2	26.80	1.39	18.07	67.40	20.10	0.82	-13.37	-66.50
FTO3	19.61	1.36	62.66	319.50	20.83	1.00	-67.83	-325.70
FTO4	13.47	0.83	37.14	275.70	36.90	1.38	-134.98	-365.80
FTO5	19.60	1.36	20.72	105.70	20.83	1.00	-22.43	-107.70
FTO6	29.67	1.42	29.23	98.50	6.43	0.87	-4.29	-66.60
FTO7	*	*	-145.41	159.60	51.11	0.71	-360.47	-705.30
FTO8	*	*	-157.97	158.20	53.30 ←	0.73	-372.97	-699.80
FTO9	24.50	1.54	2.67	10.90	11.59	0.87	-0.95	-8.20

Presenter M3/Material | Date FINAL | Slide 23 of 34 | Closed

STS-107 Launch/Ascent

Orbiter Unit Load Indicators - Left Side

Indicator	Upper Side				Lower Side			
Name	% of Limit	Mach	Nominal Load	Limit	% of Limit	Mach	Nominal Load	Limit
FWDL-F1	1.5	1.95	46.94	3103.00	62.5	0.86	-1938.01	-3103.00
FWDL-F2	*	*	*	0.00	39.1	1.30	-5562.40	-14225.00
FWDL-F4	*	*	-488.32	3448.00	65.6	0.92	-2260.92	-3448.00
FWDL-F5	59.6	1.00	404.41	679.00	*	*	*	0.00
FWDL-F6	73.6	0.86	348.74	474.00	*	*	*	0.00
MIDL-M1	*	*	*	0.00	32.2	1.10	-4761.89	-14806.00
MIDL-M2	50.4	1.10	7783.51	15444.00	*	*	*	0.00
MIDL-M3	*	*	*	0.00	40.9	1.36	-2695.55	-6584.00
MIDL-M4	*	*	*	0.00	27.1	1.38	-1851.70	-6835.00
MIDL-M5	*	*	*	0.00	46.6	1.10	-3535.50	-7586.00
MIDL-M6	*	*	*	0.00	34.0	1.55	-2423.70	-7130.00
MIDL-M7	69.4	1.55	17905.80	25806.00	*	*	*	0.00
MIDL-M8	70.0	1.25	14527.50	20766.00	*	*	*	0.00
MIDL-M10	*	*	*	0.00	56.2	1.14	-23742.60	-42228.00
MIDL-M18	*	*	*	0.00	39.5	1.09	-4738.97	-12000.00
MIDL-M19	*	*	*	0.00	40.5	1.08	-2729.22	-6731.00
MIDL-M21	*	*	*	0.00	71.6	1.55	-4347.18	-6074.00
MIDL-M22	64.6	1.55	14255.10	22050.00	*	*	*	0.00
PBDL-D1	*	*	-16.42	356.00	44.9	1.05	-159.89	-356.00
PBDL-D2	8.7	0.80	33.73	387.00	33.8	1.05	-130.83	-387.00
PBDL-D3	33.0	1.08	108.94	330.00	24.0	0.80	-79.07	-330.00
PBDL-D5	85.8 ←	1.10	15694.90	18296.00	*	*	*	0.00
WNGL-W11	*	*	*	0.00	49.9	1.25	-6473.27	-12978.00
WNGL-W12	*	*	-146.32	591.00	54.3	1.25	-320.67	-591.00
AFTL-A1	*	*	*	0.00	25.2	1.37	-958.00	-3798.00
AFTL-A2	*	*	*	0.00	60.4	1.54	-4037.63	-6689.00
AFTL-A4	61.0	1.25	11455.50	18783.00	*	*	*	0.00
AFTL-A7	*	*	*	0.00	29.3	1.51	-7960.54	-27136.00
AFTL-A8	*	*	*	0.00	*	*	179.42	-22134.00
VTLL-T3	22.7	1.37	37808.90	166550.00	*	*	374.08	-166550.00
VTLL-T4	33.3	1.37	4199.12	12604.00	11.6	1.00	-1457.09	-12604.00
VTLL-T8	12.6	1.00	1865.12	14790.00	28.6	1.37	-4232.73	-14790.00

Presenter M3/Material | Date FINAL | Slide 24 of 34 | Closed

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STS-107 Launch/Ascent

Orbiter Unit Load Indicators - Right Side

Indicator Name	Upper Side				Lower Side			
	% of Limit	Mach	Nominal Load	Limit	% of Limit	Mach	Nominal Load	Limit
FWDR-F1	4.3	1.93	134.68	3103.00	63.4	0.90	-1966.32	-3103.00
FWDR-F2	*	*	*	0.00	49.4	1.25	-7026.49	-14225.00
FWDR-F4	*	*	-442.48	3448.00	64.3	0.96	-2217.18	-3448.00
FWDR-F5	59.3	1.03	402.89	679.00	*	*	*	0.00
FWDR-F6	77.3	0.90	366.39	474.00	*	*	*	0.00
MIDR-M1	*	*	*	0.00	27.8	1.10	-4121.60	-14806.00
MIDR-M2	54.1	1.10	8348.37	15444.00	*	*	*	0.00
MIDR-M3	*	*	*	0.00	38.4	1.25	-2529.99	-6584.00
MIDR-M4	*	*	*	0.00	14.6	1.37	-999.14	-6835.00
MIDR-M5	*	*	*	0.00	46.8	1.10	-3548.93	-7586.00
MIDR-M6	*	*	*	0.00	32.3	1.54	-2299.55	-7130.00
MIDR-M7	67.3	1.55	17378.30	25806.00	*	*	*	0.00
MIDR-M8	58.4	1.58	12123.40	20766.00	*	*	*	0.00
MIDR-M10	*	*	*	0.00	61.0	1.15	-25745.00	-42228.00
MIDR-M18	*	*	*	0.00	41.5	1.10	-4984.86	-12000.00
MIDR-M19	*	*	*	0.00	41.7	1.09	-2804.78	-6731.00
MIDR-M21	*	*	*	0.00	68.1	1.54	-4134.30	-6074.00
MIDR-M22	63.4	1.54	13974.90	22050.00	*	*	*	0.00
PBDR-D1	5.4	0.80	19.12	356.00	48.1	1.06	-171.11	-356.00
PBDR-D2	15.8	0.80	61.29	387.00	42.7	1.08	-165.31	-387.00
PBDR-D3	18.9	1.11	62.42	330.00	11.2	0.90	-37.02	-330.00
PBDR-D5	85.8	1.10	15694.90	18296.00	*	*	*	0.00
WNGR-W11	*	*	*	0.00	46.9	0.86	-6086.19	-12978.00
WNGR-W12	*	*	-148.29	591.00	49.4	0.88	-291.98	-591.00
AFTR-A1	*	*	*	0.00	16.7	1.30	-634.12	-3798.00
AFTR-A2	*	*	*	0.00	59.9	1.53	-4008.70	-6689.00
AFTR-A4	49.0	1.31	9195.42	18783.00	*	*	*	0.00
AFTR-A7	*	*	*	0.00	30.9	1.41	-8378.90	-27136.00
AFTR-A8	*	*	*	0.00	1.2	1.41	-254.92	-22134.00
VTLR-T3	42.8	1.37	71219.80	166550.00	*	*	275.09	-166550.00
VTLR-T4	11.6	1.00	1456.76	12604.00	33.3	1.37	-4200.59	-12604.00
VTLR-T8	28.6	1.37	4230.32	14790.00	12.6	1.00	-1865.55	-14790.00

Presenter M3/Material | Date FINAL | Slide 25 of 34 | Closed

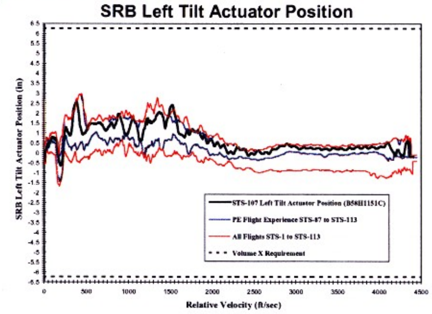
STS-107 Launch/Ascent
SRB Actuator Angular Deflections

- **Background / Facts:** (cont.)
  - STS-107 Experience (SRB gimbal oscillations)
    - STS-107 accelerometers & SRB actuators show 0.6 Hz oscillation
    - All missions experience a 0.6 Hz frequency content
      - 0.6 Hz frequency due to LOX slosh and winds
      - Missions 2, 51, 53, 84, 85, 90, 97, & 101 experienced similar oscillations
    - Left & right rock and tilt actuator positions were compared to program experience, Performance Enhancement (PE) mission experience, PE analysis database, and design limits (see next four charts)

Presenter M3/Material | Date FINAL | Slide 26 of 34 | Closed

STS-107 Launch/Ascent
SRB Actuator Angular Deflections

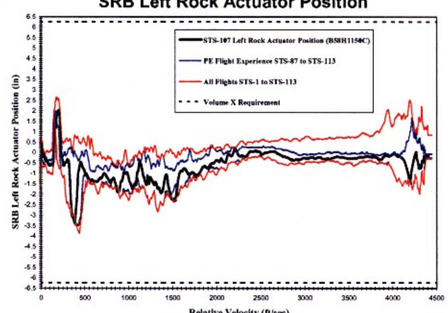
SRB Left Tilt Actuator Position



Presenter M3/Material | Date FINAL | Slide 27 of 34 | Closed

STS-107 Launch/Ascent
SRB Actuator Angular Deflections

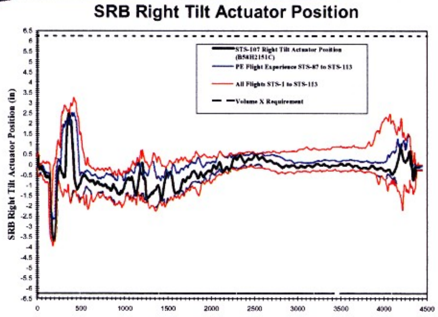
SRB Left Rock Actuator Position



Presenter M3/Material | Date FINAL | Slide 28 of 34 | Closed

STS-107 Launch/Ascent
SRB Actuator Angular Deflections

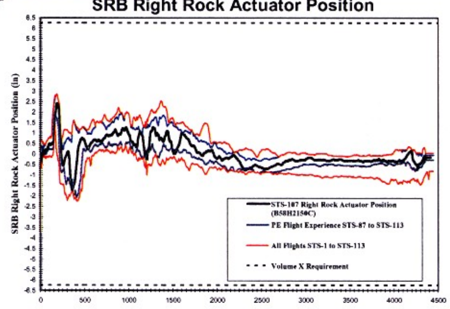
SRB Right Tilt Actuator Position



Presenter M3/Material | Date FINAL | Slide 29 of 34 | Closed

STS-107 Launch/Ascent
SRB Actuator Angular Deflections

SRB Right Rock Actuator Position



Presenter M3/Material | Date FINAL | Slide 30 of 34 | Closed

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STS-107 Launch/Ascent

- **Findings:**
  - Out-of-experience events were within certification limits
  - Flight Control System operated as designed
  - During the wind shear event at MET = 57 sec, wind shears, sideslip (β) angle, SRB gimbal angles, SSME #3 gimbal angle, and observed & predicted left & right wing loads were all below design limits
    - All wing loads were $\leq$ 50% of design limits
  - Maximum attachment and orbiter body loads during entire ascent were below design limits
  - Wing instrumentation indicates more cycles on left vs. right wing
  - Left & right SRB rock and tilt actuator positions were within design limits
- **Recommendations:** None

Presenter M3/Material	Date FINAL	Slide 31 of 34	Closed

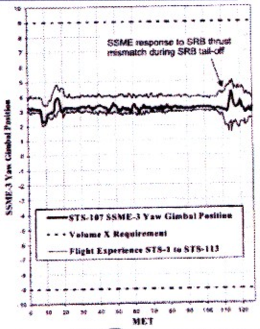
STS-107 Launch/Ascent

- **Documentation:**
  - "STS-107 Natural Environments Data," Marshall Space Flight Center, Engineering Directorate, Environments Group, (ED44), 10 Feb 03
  - "DOLILU & Structural Loads," response to RFI B1-000123, 4 April 03
  - "STS-107 Integrated Ascent Timeline," 8 May 03
  - "STS-107 Flex Reconstructed Left Wing Unit Load Indicators, MADS Data, And Maximum Rigid Body Reconstructed Peaks For Previous OV-102 Flights Versus Variable Redline Limit," E Dougherty, 17 May 03
  - "STS-107 Flex Reconstructed Right Wing Unit Load Indicators, MADS Data, And Maximum Rigid Body Reconstructed Peaks For Previous OV-102 Flights Versus Variable Redline Limit," E Dougherty, 17 May 03
  - "RSRM Actuator responses During STS Missions," response to RFI B1-000170, file:
  - E-Mail from Rod Wallace, 3 June 03.

Presenter M3/Material	Date FINAL	Slide 32 of 34	Closed

STS-107 Launch/Ascent

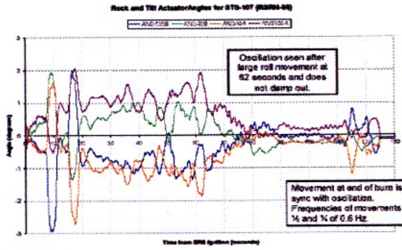
SSME-3 Pitch Gimbal Position @ SRB Tail-Off



Presenter M3/Material	Date FINAL	Slide 33 of 34	Closed

STS-107 Launch/Ascent

SRB Actuator Angular Deflections



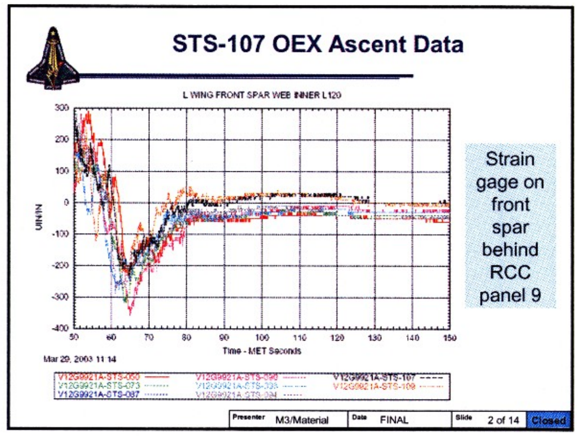
Presenter M3/Material	Date FINAL	Slide 34 of 34	Closed

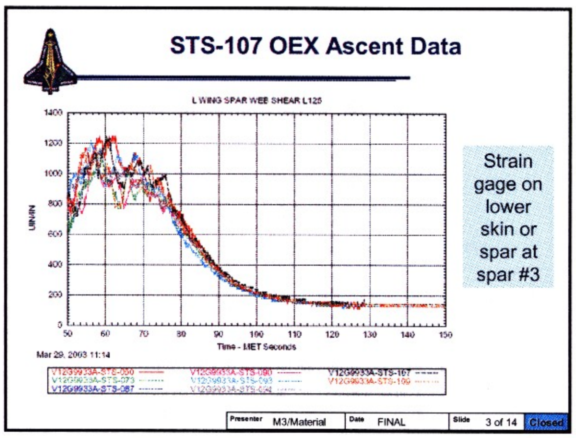
6

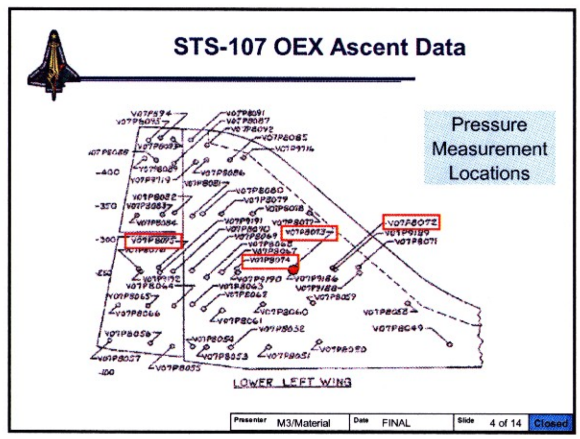
STS-107 OEX Ascent Data

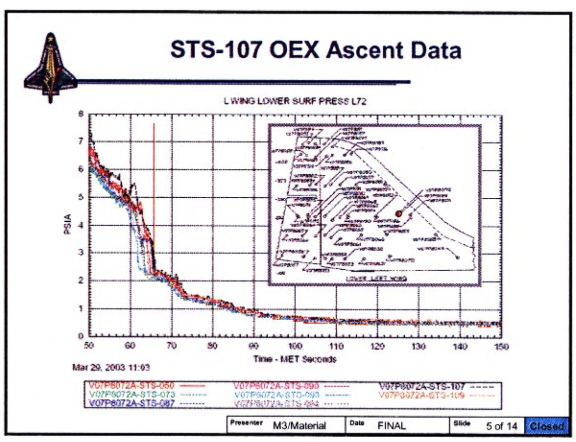
- **Action / Issue:** Review STS-107 OEX ascent data for anomalies
- **Background / Facts:**
  - Ascent significant events included:
    - 60 seconds – wind shear occurred at Mach 1.37 at an altitude of approximately 32,000 Feet
    - 82 seconds – foam impacted orbiter wing at Mach 2.46 at an altitude of approximately 60,000 feet

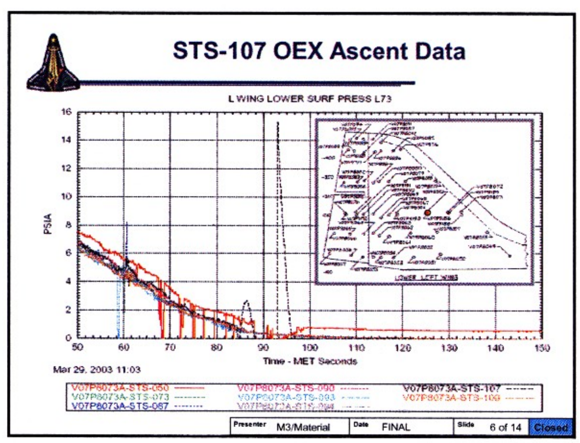
Presenter	M3/Material	Date	FINAL	Slide	1 of 14	Closed



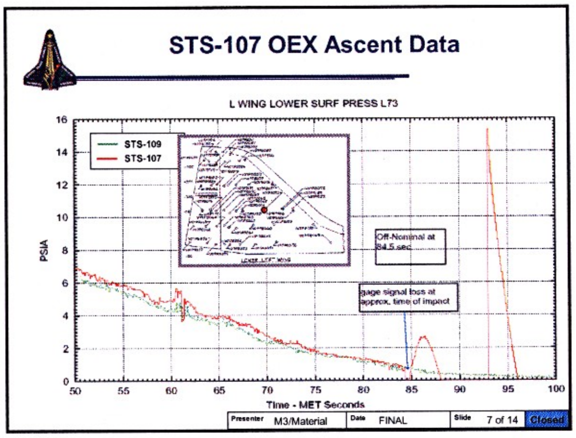


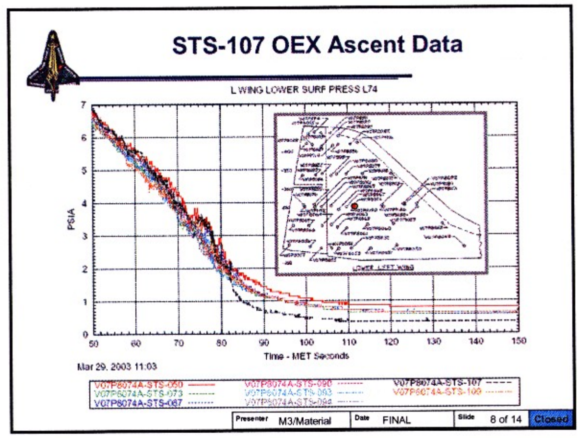


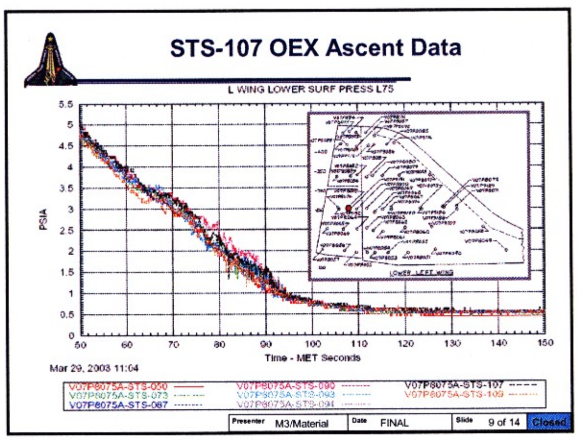


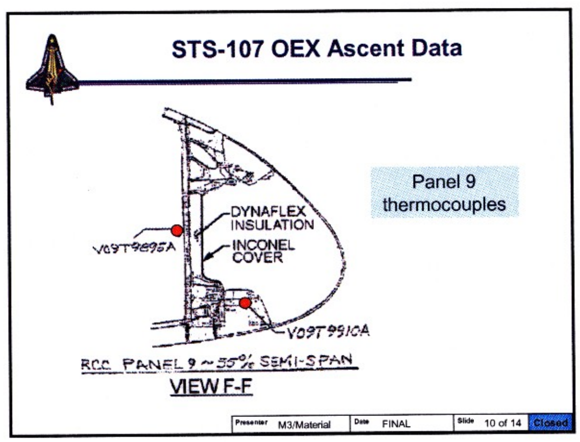


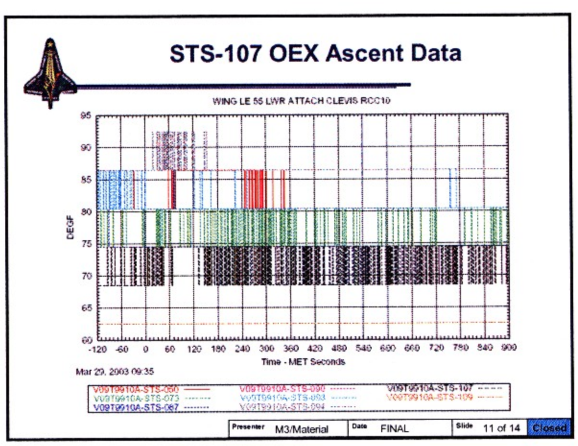
1

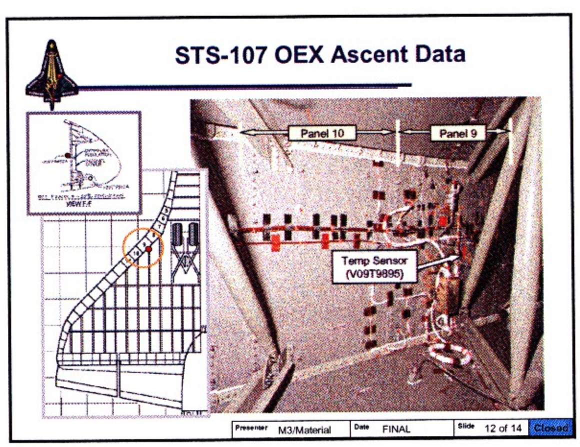

STS-107 OEX Ascent Data
L WING LOWER SURF PRESS L73
STS-109
STS-107
PSIA
Off-Nominal at 84.5 sec.
gage signal loss at approx. time of impact
Time - MET Seconds
Presenter M3/Material
Date FINAL
Slide 7 of 14
Closed


STS-107 OEX Ascent Data
L WING LOWER SURF PRESS L74
PSIA
Time - MET Seconds
Mar 29, 2003 11:03
Presenter M3/Material
Date FINAL
Slide 8 of 14
Closed

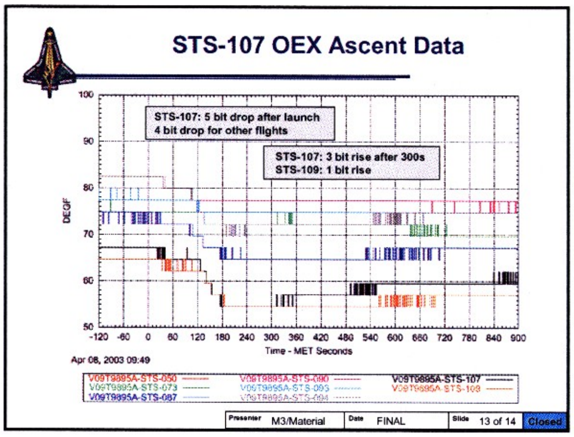

STS-107 OEX Ascent Data
L WING LOWER SURF PRESS L75
PSIA
Time - MET Seconds
Mar 29, 2003 11:04
Presenter M3/Material
Date FINAL
Slide 9 of 14
Closed

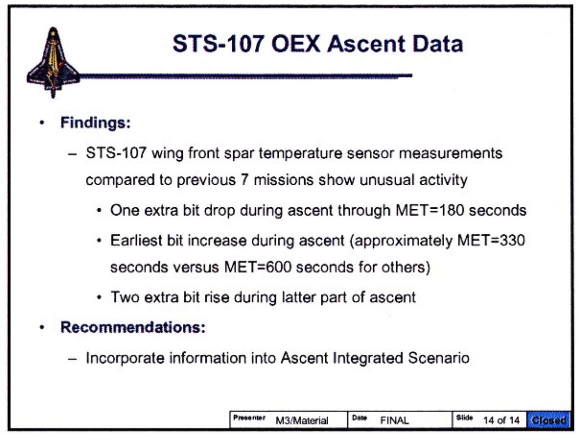

STS-107 OEX Ascent Data
Panel 9 thermocouples
DYNAFLEX INSULATION
INCONEL COVER
V09T9895A
V09T9910A
RCC PANEL 9 ~ 55% SEMI-SPAN
VIEW F-F
Presenter M3/Material
Date FINAL
Slide 10 of 14
Closed


STS-107 OEX Ascent Data
WING LE 55 LWR ATTACH CLEVIS RCC10
DEGF
Time - MET Seconds
Mar 29, 2003 09:35
Presenter M3/Material
Date FINAL
Slide 11 of 14
Closed


STS-107 OEX Ascent Data
Panel 10
Panel 9
Temp Sensor (V09T9895)
Presenter M3/Material
Date FINAL
Slide 12 of 14
Closed

2


STS-107 OEX Ascent Data
STS-107: 5 bit drop after launch
4 bit drop for other flights
STS-107: 3 bit rise after 300s
STS-109: 1 bit rise
DEGF
100
90
80
70
60
50
-120 -60 0 60 120 180 240 300 360 420 480 540 600 660 720 780 840 900
Time - MET Seconds
Apr 08, 2003 09:49
V09T9895A-STS-050
V09T9895A-STS-073
V09T9895A-STS-087
V09T9895A-STS-090
V09T9895A-STS-093
V09T9895A-STS-094
V09T9895A-STS-107
V09T9895A-STS-109
Presenter M3/Material
Date FINAL
Slide 13 of 14
Closed


STS-107 OEX Ascent Data
• Findings:
– STS-107 wing front spar temperature sensor measurements compared to previous 7 missions show unusual activity
• One extra bit drop during ascent through MET=180 seconds
• Earliest bit increase during ascent (approximately MET=330 seconds versus MET=600 seconds for others)
• Two extra bit rise during latter part of ascent
• Recommendations:
– Incorporate information into Ascent Integrated Scenario
Presenter M3/Material
Date FINAL
Slide 14 of 14
Closed

3

Orbiter Entry

16-1 Effect of Roughness (Keq) on Orbiter Heat Load

16-2 Kapton Wiring

16-3 Premature Firing of Pyrotechnic Devices

Matrix

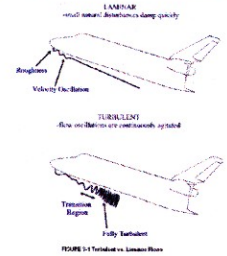
Presenter	CAIB/Group 1	Date	FINAL	Slide	19 of 32

Rough Wing Structural Issues

- **Action / Issue:**
  - Effect of Roughness (Keq) on Orbiter Heat Load
- **Background / Facts:**
  - Speculation that OV-102's wing was "rougher"—Keq nearly twice that of other orbiters
  - High Keq causes early transition to turbulent flow and greater heat load (hotter longer)
- **Findings:**
  - Found that OV-102 Keq similar to that of other orbiters
- **Recommendation:**
  - Continue to emphasize the importance of minimizing Keq

Presenter M3/Material | Date FINAL | Slide 1 of 7 | Closed

Boundary Layer Transition



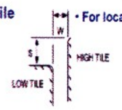
Presenter M3/Material | Date FINAL | Slide 2 of 7 | Closed

Step and Gap Measurement

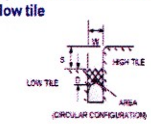
- For an unfilled gap:
  s= step measured from low tile
  w= gap width

$Keq=((step)^2+(gap-0.045)^2)^{1/2}$

- For locations where the gap is 0.045" or less Keq=step

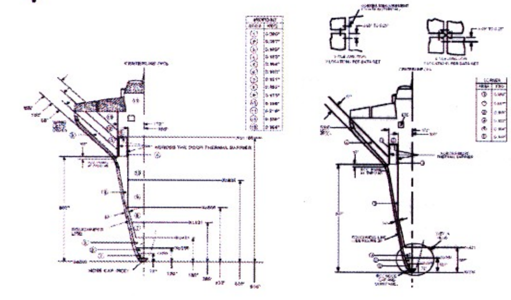


- For a gap filled with a gap filler or thermal barrier with a circular crown:
  s= step measured from low tile
  w= gap width
  d= recession from the low tile

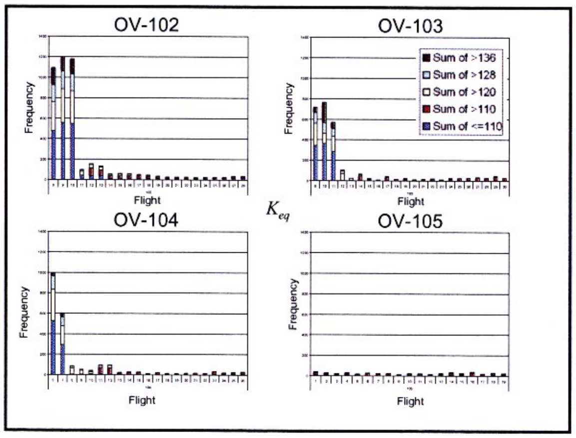


Presenter M3/Material | Date FINAL | Slide 3 of 7 | Closed

Measurement Locations



Presenter M3/Material | Date FINAL | Slide 4 of 7 | Closed



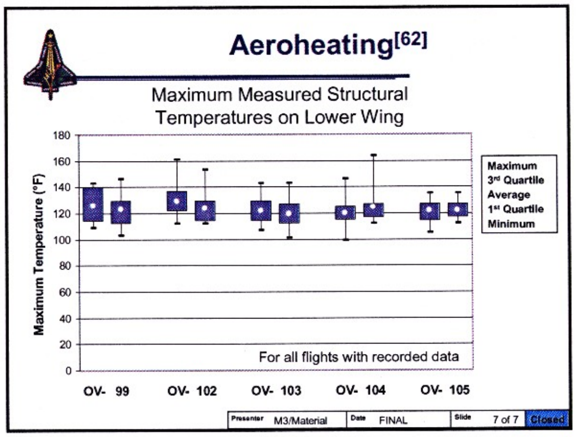
OV-102 Transition History

Flight	STS	X/l = 0.3	X/l = 0.6
8	28	1215	900
9	32	1210	1250
10	35	1225	1210
11	40	1200	1220
12	50	1300	1200
13	52	1230	1240
14	55	1068	1068
15	58	1260	1142
16	62	1214	1207
17	65		
18	73	1021	893
19	75	1260	1260
20	78		1261
21	80	1233	1233
22	83		
23	94	1040	1040
24	87	1281	1234
25	90	1186	1047
26	93	1328	1276
27	109		1199
28	107		
OV-102 Average		1204	1160
Fleet Average		1190	1173

Transition time from Entry Interface (sec.)

Presenter M3/Material | Date FINAL | Slide 6 of 7 | Closed

1


Aeroheating[62]
Maximum Measured Structural
Temperatures on Lower Wing
Maximum Temperature (°F)
180
160
140
120
100
80
60
40
20
0
Maximum
3rd Quartile
Average
1st Quartile
Minimum
For all flights with recorded data
OV- 99
OV- 102
OV- 103
OV- 104
OV- 105
Presenter M3/Material
Date FINAL
Slide 7 of 7
Closed

2

Fire (Pyro /Wiring / etc.)
Kapton Wiring as Causal

- **Action / Issue:** Assess Kapton wiring as a fire/explosion risk to OV-102/STS-107.
- **Background / Facts:**
  - Kapton insulation proven to degrade under certain conditions
  - Insulation degradation leads to risk of shorting between wires
    - "Arc tracking" along length of wire
    - Arcing can damage adjacent wires
- **Findings:**
  - In-depth inspection of OV-102 during J3 OMM (Sep 99 – Mar 01) identified/corrected numerous nonconformances (nearly 5,000)
    - Prompted by damaged insulation/shorted wire/loss of power to two of six main engine controller computers during STS-93 (Jul 99)
  - OV-102 inspection results formed a good baseline for subsequent studies/development of preventive measures
    - Most common cause: work-induced, either during inspection/maintenance
    - Other causes: improper installation (routing/securing) during manufacture; moisture intrusion, chemical spillage

Presenter M3/Maintenance	Date FINAL	Slide 1 of 4	Closed

Fire (Pyro /Wiring / etc.)
Internal Hazard

- **Findings (con't.):**
  - Despite numerous ongoing studies of alternate insulators, Kapton still viewed as a leading candidate
    - Various reasons: Kapton does not burn, but carbonizes at approx 650 degrees C; also lightweight, durable
  - Telemetry from OV-102's last minutes prior to breakup does not point to Kapton wiring as causal
    - Data from 14 left wing sensors analyzed: hydraulic line/wing skin/ wheel temperatures, tire pressure, & landing gear downlock position
    - Sensor failure signatures consistent with leading causal scenario of left wing thermal intrusion, NOT with Kapton-associated failure
  - Actual/extensive NASA testing immediately following Columbia tragedy verified failure signature analyses
    - Kapton wiring subjected to oven, blowtorch, and arc jet heating
  - Testing/analysis for years prior to STS-107 showed Kapton wiring w/low voltages & low currents associated with orbiter instrumentation (such as in the left wing) have a very low probability of arc tracking

Presenter M3/Maintenance	Date FINAL	Slide 2 of 4	Closed

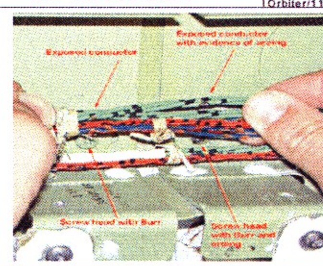
Fire (Pyro /Wiring / etc.)
Internal Hazard

- **Conclusions:**
  - Based on extensive wiring inspections/maintenance/modifications to OV-102 prior to STS-107, analysis of sensor/wiring failure signatures, physical verification of those signatures, and prior Kapton wiring studies, Kapton's role as causal to Columbia's loss is highly unlikely
- **Recommendations:**
  - Inspection of remainder of fleet planned/being executed
    - Partial inspection completed on all orbiters during initial grounding
    - Complete inspection to occur during respective OMMs
      -- OV-103 currently in progress with expected completion in Apr 04
      -- OV-105 to be completed in 04 (input date accelerated to summer 03)
    - OV-104 must be fully inspected as soon as possible

Presenter M3/Maintenance	Date FINAL	Slide 3 of 4	Closed

Fire (Pyro /Wiring / etc.)
Internal Hazard

FLEET WIRE INSPECTION & REPAIR SUMMARY	Presenter: Doug White Organization/Date: Orbiter/11-2-99



BOEING 3 USA

Presenter M3/Maintenance	Date FINAL	Slide 4 of 4	Closed

1

Fire (Pyro /Wiring / etc.) Internal Hazard

- **Action / Issue:** Determine conditions necessary for auto-ignition of pyrotechnic devices and their role in STS-107's loss
- **Background / Facts:**
  - 137 NASA Standard Initiators (NSI) used throughout shuttle
    - 102 units fired during nominal mission
    - 35 units for emergency applications (including landing gear extension)
- **Findings:**
  - Qualification requirement: No auto-ignition with thermal soaking of 425 deg F for 1 hr.
  - Individual component chemicals auto-ignite at 700-750 degrees F
  - Actual cartridge testing (1 Feb):
    - Assets removed from NASA stock; manufactured Feb 84
    - Auto-ignited at 598 deg F
- **Group Recommendations:**
  - While not likely to be causal, pyro cartridge auto-ignition due to wheel well heating must be included/accounted for in any failure scenario involving thermal intrusion into the LMLG well

Presenter	M3/Maintenance	Date	FINAL	Slide	1 of 1	Closed

Other
Design – Certification

17-1 SRB ET Attach Ring Structure Factor of Safety

Matrix

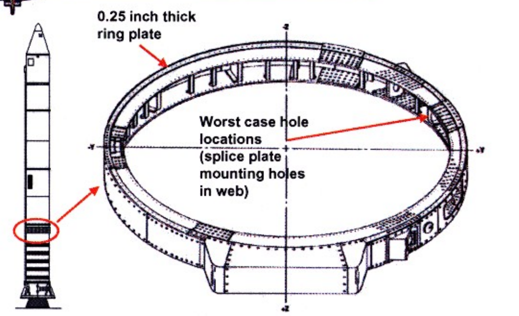
Presenter	CAIB/Group 1	Date	FINAL	Slide	20 of 32

SRB ETA Ring

- **Action / Issue:** SRB ET attach (ETA) ring has reduced properties
- **Background / Facts:**
  - Recent material testing discovered strength values less than the design requirement
    - Minimum requirement is 180 ksi
    - Lowest value from 2 S/Ns is 144 and 150 ksi
  - Issue presented during ET tanking meeting on 16 Jan 03
  - SSP CR S091496 approved on 16 Jan 03
    - Waived the factor of safety requirement of 1.4, accepted 1.25
    - No full technical review prior to launch of STS-107
  - ETA design life is 40 missions (inspection interval is 13 missions), STS-107 ETA rings:
    - Left: S/N 19, 9 flights prior to launch
    - Right: S/N 6, 12 flights prior to launch

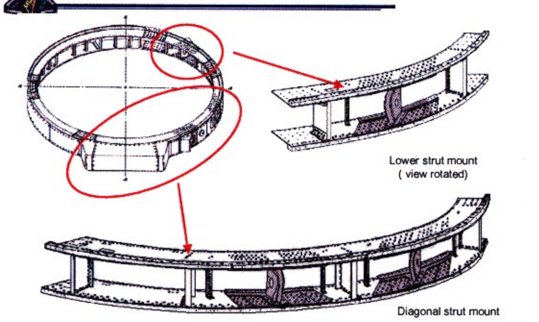
Presenter M3/Material | Date FINAL | Slide 1 of 12 | Closed

SRB ETA Ring



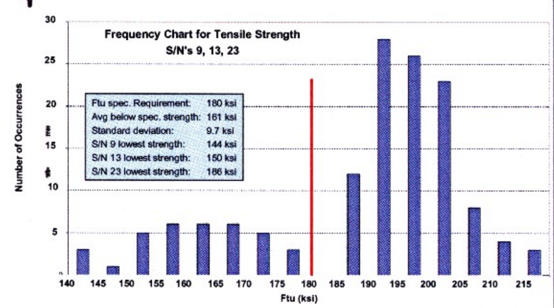
Presenter M3/Material | Date FINAL | Slide 2 of 12 | Closed

SRB ETA Ring



Presenter M3/Material | Date FINAL | Slide 3 of 12 | Closed

SRB ETA Ring



Presenter M3/Material | Date FINAL | Slide 4 of 12 | Closed

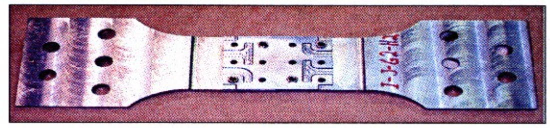
SRB ETA Ring

- **Background / Facts :**
  - STS-107 strength analysis performed using 147 ksi
    - Factor of safety reduced to 1.25 (ET tanking meeting value)
  - MSFC recommended using 136 ksi based on metallurgical assessment in March 2003
    - Factor of safety reduced to 1.16
  - Below design minimum thickness measured on 7 ETA rings in March 2003
  - Strength analysis being revised accounting for hardness test results correlated to strength and actual part thickness
    - Both the current analysis method (linear material properties) and non-linear analysis methods are being utilized

Presenter M3/Material | Date FINAL | Slide 5 of 12 | Closed

SRB ETA Ring

- **Background / Facts :**
  - Non-linear analysis method (takes advantage of entire material stress-strain response) to determine ultimate strength capability validated by test of specimen shown below
  - Good correlation between predicted and measured strains and failure load was obtained



Presenter M3/Material | Date FINAL | Slide 6 of 12 | Closed

1

SRB ETA Ring

#	ETA Ring Area (same areas apply on fwd & aft web plates)	Ftu = 147 ksi (STS-107 Waiver) Linear analysis with Modulus of Rupture	Ftu = 136 ksi Linear analysis with Modulus of Rupture	Ftu = 136 ksi Non-linear analysis using Material Stress-Strain Curve
		Factor of Safety	Factor of Safety	Factor of Safety
1	W-131-W132	1.38	1.27	
2	W239-W240	1.36	1.26	
3	W248-W250	1.27	1.16	1.65
4	W200	> 1.40	1.35	
5	W208		1.31	
6	W260		1.29	
7	W41		1.30 (D-Holes)	

Summary of Original, Revised and Current Strength Analysis

Presenter M3/Material | Date FINAL | Slide 7 of 12 | Closed

SRB ETA Ring

- **Background / Facts :**
  - Total quantify of SRB ETA rings is 17
  - 9 rings were readily available for hardness and thickness measurements (the others require some level of disassembly) and have been completed
    - S/Ns: 5, 6, 9, 15, 16, 19, 22, 24, and 27
  - Strength analysis performed using linear analysis (more conservative) and actual hardness and thickness results
    - S/N 16 has a region with a factor of safety less than 1.4 and a region with low hardness results
    - The other 8 S/Ns have a minimum factor of safety > 1.4
    - S/N 15 has a couple of regions with marginal hardness results
  - All rings have factor of safety > 1.4 using non-linear analysis method
  - 9 rings have completed NDE in the critical regions
  - All rings will undergo a complete re-baselining NDE, S/Ns 9 and 24 are in-work to support first return to flight

Presenter M3/Material | Date FINAL | Slide 8 of 12 | Closed

SRB ETA Ring

No.	ETA Ring Serial No.		Critical Zone 1 FOS	Critical Zone 2 FOS	Critical Zone 3 FOS	Critical Zone 4 FOS	Critical Zone 5 FOS	Critical Zone 6 FOS	Critical Zone 7 FOS
1	S/N 09	Fwd	1.53	1.63	1.55	1.68	1.68	1.84	1.83
		Aft	1.45	1.64	1.62	1.60	1.56	1.66	N/A
2	S/N 24	Fwd	1.65	1.67	1.63	1.65	1.70	1.66	1.67
		Aft	1.63	1.53	1.48	1.58	1.72	1.71	N/A
3	S/N 05	Fwd	1.56	1.61	1.57	1.61	1.65	1.66	1.68
		Aft	1.59	1.57	1.59	1.65	1.76	1.65	N/A
4	S/N 22	Fwd	1.59	1.62	1.61	1.70	1.62	1.66	1.67
		Aft	1.75	1.63	1.64	1.65	1.87	1.72	N/A
5	S/N 16	Fwd	TBD						
		Aft							
6	S/N 27	Fwd	1.69	1.67	1.61	1.64	1.67	1.53	N/A
		Aft	1.65	1.59	1.57	1.62	1.65	1.69	N/A
7	S/N 15	Fwd	1.55	1.76	1.68	1.41	1.50	1.70	1.65
		Aft	1.41	1.72	1.69	1.42	1.65	1.66	N/A
8	S/N 6	Fwd	1.63	1.65	1.62	1.68	1.62	1.72	1.78
		Aft	1.65	1.59	1.65	1.61	1.71	1.73	N/A
9	S/N 19	Fwd	1.72	1.65	1.62	1.66	1.69	1.47	1.75
		Aft	1.71	1.68	1.66	1.77	1.70	1.70	N/A

Presenter M3/Material | Date FINAL | Slide 9 of 12 | Closed

SRB ETA Ring

- **Background / Facts :**
  - NASA's short-term plan:
    - Complete NDE on 9 uninstalled rings
    - Uninstall the remaining 8 rings and perform hardness and thickness measurements and NDE
  - NASA's long-term plan:
    - Replace ring web plates with new material or material that meets specification and proper thickness
    - Implementation plans have not been approved by the program

Presenter M3/Material | Date FINAL | Slide 10 of 12 | Closed

SRB ETA Ring
Category: Other Significant Finding

- **Findings:**
  - Short-term plan to include hardness and thickness measurements and NDE of the 8 remaining rings is adequate
  - 7 of the 9 rings measured to date appear to be adequate for limited use
  - Long-term plan is the best approach, funding and implementation schedule has not been authorized by the program
- **Recommendations:**
  - Don't use S/N 16 and 15 in their present condition
  - Accelerate implementation of long-term plan

Presenter M3/Material | Date FINAL | Slide 11 of 12 | Closed

SRB ETA Ring

- **Documentation:**
  - PCRB briefing, "SRB External Tank Attach Ring Status", June 5, 2003
  - MSFC/ED33 document, "Strength and Safe-Life Parameters for 4130 ET Attach Ring", 28 May 2003
  - Briefing by D. Martin, "SRB External Tank Attach Ring"; Action CAIB-NAIT-00154, B1-00153, 14 April 2003
  - Briefing by P. Gutierrez, "SRB External Tank Attach Ring Program Requirements Control Board", 26 March 2003
  - SRB ETA Ring Factor of Safety Change Request, 28 Jan 03
  - Briefing by R. Elliott, "STS-107 (BI116) ET Tanking Meeting Program – Solid Rocket Booster", 16 January 2003

Presenter M3/Material | Date FINAL | Slide 12 of 12 | Closed

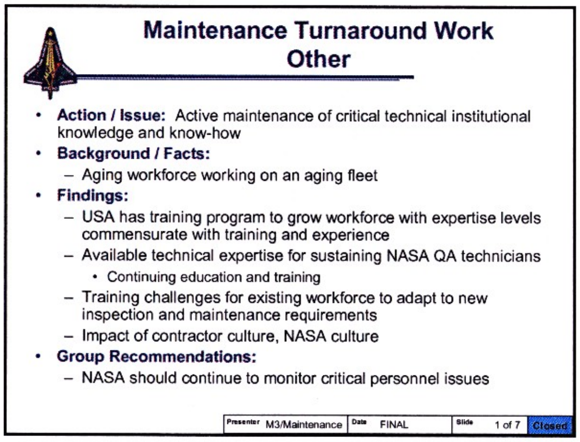
2

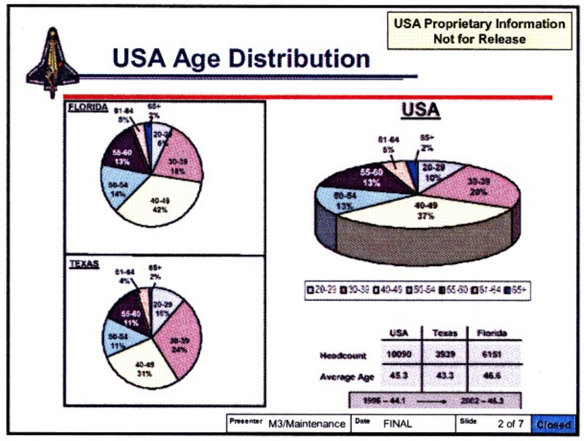
Other Production

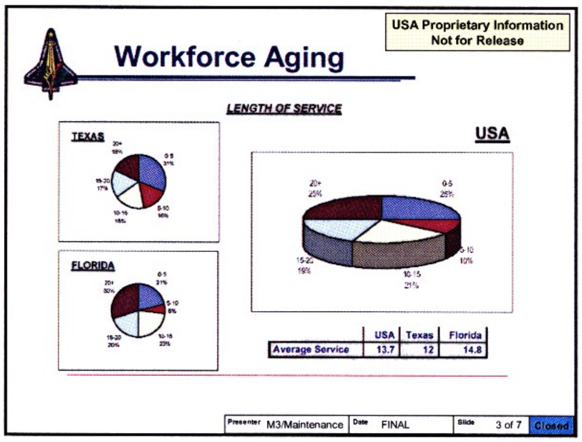
18-1	Maintaining Critical Technical Knowledge
18-2	S&MA Quality Assurance Organization
18-3	USA/NASA FOD Prevention Programs
18-5	Capabilities Analysis

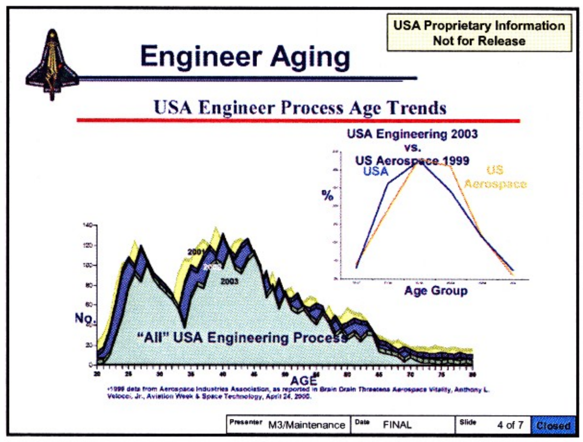
Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	21 of 32


Maintenance Turnaround Work
Other
Action / Issue: Active maintenance of critical technical institutional knowledge and know-how
Background / Facts:
– Aging workforce working on an aging fleet
Findings:
– USA has training program to grow workforce with expertise levels commensurate with training and experience
– Available technical expertise for sustaining NASA QA technicians
• Continuing education and training
– Training challenges for existing workforce to adapt to new inspection and maintenance requirements
– Impact of contractor culture, NASA culture
Group Recommendations:
– NASA should continue to monitor critical personnel issues
Presenter M3/Maintenance
Date FINAL
Slide 1 of 7
Closed


USA Proprietary Information
Not for Release
USA Age Distribution
FLORIDA
TEXAS
USA
61-64 5%
65+ 2%
20-29 10%
30-39 20%
40-49 37%
50-54 13%
55-60 13%
USA Texas Florida
Headcount 10090 3939 6151
Average Age 45.3 43.3 46.6
Presenter M3/Maintenance
Date FINAL
Slide 2 of 7
Closed


USA Proprietary Information
Not for Release
Workforce Aging
LENGTH OF SERVICE
TEXAS
FLORIDA
USA
USA Texas Florida
Average Service 13.7 12 14.8
Presenter M3/Maintenance
Date FINAL
Slide 3 of 7
Closed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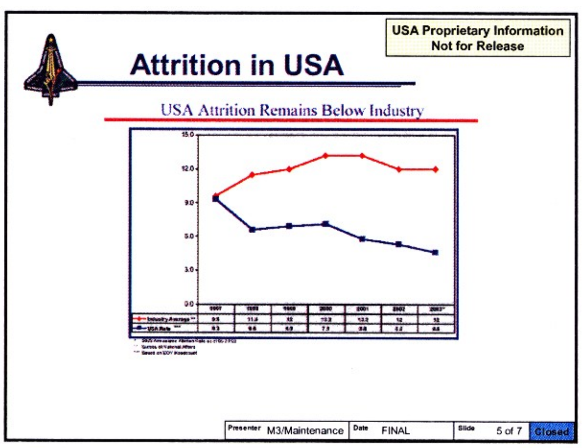
Not for Release
Engineer Aging
USA Engineer Process Age Trends
USA Engineering 2003
vs.
US Aerospace 1999
USA
US Aerospace
%
Age Group
No.
"All" USA Engineering Process
AGE
Presenter M3/Maintenance
Date FINAL
Slide 4 of 7
Closed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Attrition in USA
USA Attrition Remains Below Industry
Presenter M3/Maintenance
Date FINAL
Slide 5 of 7
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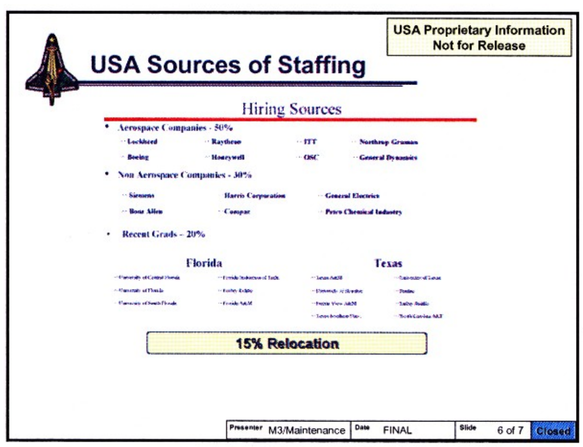
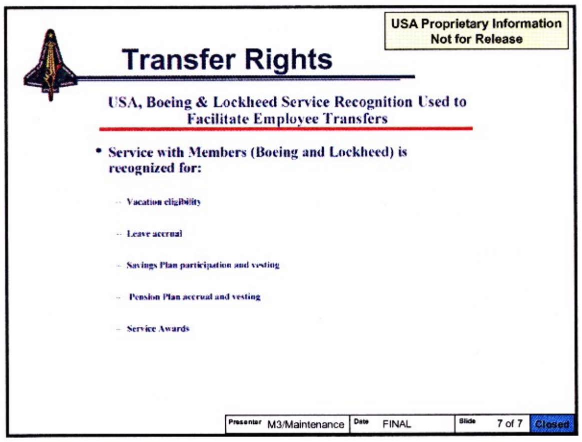

USA Proprietary Information
Not for Release
USA Sources of Staffing
Hiring Sources
Aerospace Companies - 50%
Lockheed
Raytheon
ITT
Northrop Grumman
Boeing
Honeywell
OSC
General Dynamics
Non Aerospace Companies - 30%
Siemens
Harris Corporation
General Electrics
Booz Allen
Compaq
Petro Chemical Industry
Recent Grads – 20%
Florida
Texas
15% Relocation
Presenter M3/Maintenance
Date FINAL
Slide 6 of 7
Closed

1


USA Proprietary Information
Not for Release
Transfer Rights
USA, Boeing & Lockheed Service Recognition Used to Facilitate Employee Transfers
• Service with Members (Boeing and Lockheed) is recognized for:
– Vacation eligibility
– Leave accrual
– Savings Plan participation and vesting
– Pension Plan accrual and vesting
– Service Awards
Presenter M3/Maintenance
Date FINAL
Slide 7 of 7
Closed

Maintenance
Safety & Mission Assurance

- **Action / Issue:** NASA/USA's Safety & Mission Assurance has had significant changes in workforce & inspection methodology
- **Background / Facts:**
  - Sufficiency of Government Mandated Inspection Points (GMIPs) was questionable by numerous testimonies
    - KSC GMIPs reduced from 44,000 in 89' to 22,500 in 96' to 8,500 now
- **Observations and interview information:**
  - Need thorough review of quality program requirements (doing non-value added looks but not some critical items – e.g., hydraulic pump installation, mating of SRBs)
  - Penny wise and pound foolish? (batteries, lights, inspection mirror tools)
  - Yielding to contractor (FOD definition, schedule, nonexistent unscheduled surveillance)
  - Unsupportive quality program management at KSC (instances of having to go to NASA HQ for resolution); dysfunctional organization of "camps"

Presenter M3/Maintenance | Date FINAL | Slide 1 of 6 | Closed

Maintenance
Safety & Mission Assurance

- **Observations and interview information**
  - Abundance of "fly as is" dispositions
  - Government inspector hiring eval needed (DCMA and NASA PDs)
  - Disgruntled employees at MAF
  - Safety and security consistently rated strong
  - Potentially too few government inspectors
- **Findings:**
  - Quality assurance done by S&MA, SQ&MA and some engineering
  - QA's role in process improvement through interpretative trend analysis of PRACA and the Integrated Quality Support database is inconsistent and not integrated between the players
  - NASA inspectors inconsistently use the Hex or reject stamp for jobs closed out by SQ&MA (testimony given to CAIB staff)
    - Consequently, NASA S&MA has no means of tracking/trending for use as evaluation tool for personnel training and assessment

Presenter M3/Maintenance | Date FINAL | Slide 2 of 6 | Closed

Maintenance
Safety & Mission Assurance

Government inspections …

Spread thin (even for few GMIPs)	Reduced GMIPs
Flow delays waiting for inspectors	Reduced coverage (3 in OPFs?)
Contractor Pressure to inspect	Nothing other than GMIPs
Contract incentives to meet dates	Zero surveillance
Adversarial conditions	Reliance on "diving catches"

Underscored by SIAT and other recommendations

Presenter M3/Maintenance | Date FINAL | Slide 3 of 6 | Closed

Maintenance
Safety & Mission Assurance

- **Findings:**
  - NASA involvement beyond GMIPs is very limited. Sampling of routine or non-critical tasks not formally done
  - GMIPs review process is ad hoc with no regular methodology for review of historic data to adjust QA emphasis
  - S&MA manning levels dropped due to retirements and moves to engineering posts without replacement
- **Interviews:**
  - KSC – with additional quality inspectors (several suggested by previous interviewees), and the head and deputy of the quality program
  - MAF -- with additional quality inspectors (several suggested by previous interviewees)

Presenter M3/Maintenance | Date FINAL | Slide 4 of 6 | Closed

Maintenance
Safety & Mission Assurance

- **Reviews**
  - Contract regarding items such as FOD, engaging NASA inspectors during the flow
  - Facility upkeep and needs
  - Quality Planning Requirements Document
  - Quality inspector PDs
  - Past reports observations & recommendations (e.g., SIAT, Rogers, ASAP, GAO)
- **Recommendations:**
  - Independently-led bottom-up review of QPRD at KSC and MAF with intent to validate adequacy of oversight in terms of # of GMIPs, scope of authority outside the enumerated GMIPs and manpower
  - Add tasks to GMIPs that evaluate hardware and housekeeping
  - Build a regular review process to evaluate assurance program to provide trend analysis data, for training and inspection targeting

Presenter M3/Maintenance | Date FINAL | Slide 5 of 6 | Closed

Maintenance
Safety & Mission Assurance

- **Recommendations:**
  - Broaden S&MA inspections to include statistically-driven sampling of all maintenance-related processes
    - Should go beyond GMIPs specific events to validate USA Quality inspection results and verify work quality before close out
    - Include a process to sample/validate documentation of maintenance for completion of the tasks and adequacy of the audit trail
  - Validate S&MA workforce is adequately sized and manned to accomplish it's mission to enforce quality and safety
  - Implement the NNBE "model for compliance verification"
  - Return to past closed loop discrepancy system
  - Return to true FOD definition, enforce "clean as you go" program
  - Ensure no closeout work can be done by a single person alone (e.g., foam spraying)
  - Allow employees to accomplish the duties in their PDs (!)
  - NASA Code Q examination of safety specialist manning and responsibilities at KSC (in relation to USA safety)

Presenter M3/Maintenance | Date FINAL | Slide 6 of 6 | Closed

1

Maintenance
FOD Policy

- **Action / Issue:** USA / NASA Foreign Object Damage (FOD) Prevention Programs Require Evaluation
- **Background / Facts:**
  - USA program consists of daily debris walk-downs by management, workers "clean as you go," and statistically-based process sampling
  - 23 separate checks of launch pad complex from pre- to post-launch accomplished in varying levels of detail by various organizations
  - USA FOD prevention metrics differentiate "FOD" and "process debris"
    - "FOD" -- After job is stamped
    - "Processing Debris" -- Before job signoff or end of shift
      - No other NASA contractor uses this category
- **Findings:**
  - FOD prevention is highly emphasized in USA/NASA daily operations
  - Assessment of responsibility is delineated: S&MA (NASA) responsible for FOD and SQ&MA (USA) primarily responsible for Process Debris

Presenter M3/Maintenance | Date FINAL | Slide 1 of 6 | Closed

Maintenance
FOD Policy

- NASA inspects and assesses FOD failures only after USA has closed a WAD
- "FOD" is an industry standard term – basis for prevention programs and immediately recognized as critical part of prevention
- Commonly expressed opinion: FOD was redefined to accommodate SFOC award fee determination
- FOD and Process Debris are "feeder" metrics that are rolled up into the TMR's scoring for inclusion in the SFOC award calculation.
  - First half FY 03 performance assessment: the "good" FOD rate canceled out the moderate Process Debris rate
  - Unique effect of splitting FOD into two metrics
  - Second half FY 02: 2nd straight poor performance in both categories, award fee impact minimal, received highest score ever in roll up
- FOD found on launch pad is a direct award fee impact

Presenter M3/Maintenance | Date FINAL | Slide 2 of 6 | Closed

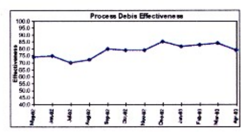
Maintenance
FOD Policy

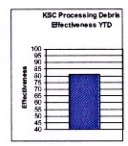
- **Recommendations:**
  - Greater NASA involvement in FOD program beyond GMIPs or occasional process sampling may improve program emphasis
  - NASA's role regarding the FOD program should be evaluated for expansion of inspector involvement, and expansion of inspections
  - Add random "Process Surveillance" of all processes, including FOD prevention
  - Eliminate alternative definitions of FOD
    - Could be interpreted as diminishing significance
    - Eliminate lines that separate NASA and USA quality assurance by authority over FOD prevention
  - Realign Award fee algorithm to increase FOD impact

Presenter M3/Maintenance | Date FINAL | Slide 3 of 6 | Closed

Maintenance
FOD Policy

Process Debris Statistics



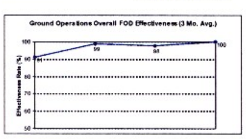


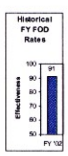
	[illegible]	[illegible]	Jul-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Jan-03	Feb-03	Mar-03	Apr-03
# of Reports	660	486	546	556	427	487	427	331	424	345	387	373
# Debris Free Reports	489	363	382	400	340	385	337	282	347	286	308	295
# of Debris Findings	171	123	164	156	87	102	90	49	77	59	59	78
% effectiveness	74	75	70	72	80	79	79	85	82	83	84	79
Process Debris Rate	25.9%	25.3%	30.0%	28.1%	20.4%	20.9%	21.1%	14.8%	18.2%	17.1%	16.1%	20.9%

Presenter M3/Maintenance | Date FINAL | Slide 4 of 6 | Closed

Maintenance
FOD Policy

FOD Statistics





		FY '02						FY '03					
		APR - JUN			JLY - SEP			OCT - DEC			JAN - MAR		
# of Closeout Inspections		205			172			83			60		
# FOD Free Closeouts		187			170			81			60		
		APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
STS 107	# INSPECTIONS	21	45	48	1	1	0	3	8	9	6	0	
	# FOD FREE	18	36	42	1	1	0	3	8	9	6	0	
STS 114	# INSPECTIONS	0	1	4	0	0	0	0	1	10	38	1	
	# FOD FREE	0	1	4	0	0	0	0	1	10	38	1	
OTHER	# INSPECTIONS	34	23	29	52	42	76	28	21	3	2	13	
	# FOD FREE	34	23	29	52	41	75	27	20	3	2	13	

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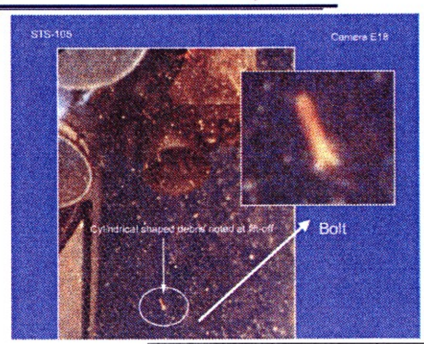
Maintenance
FOD Policy



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Maintenance Capabilities Analysis

- **Action / Issue:**
  - Do NASA/USA ground operations managers routinely assess their capability to support the launch schedule?
    - Do they have the tools to identify when they are approaching (or exceeding) the "ragged edge"?
    - At what point does a launch schedule become unsupportable from a ground processing viewpoint?
- **Background / Facts:**
  - Six launches originally planned for FY02/03; 4 more in FY04/1&2Q
    - Compare with 8 in FY 91/7 in FY 92
  - SSP combined workforce (NASA/USA) at KSC totals 4,400 today
    - Compare with 8,900 in FY 91/8,400 in FY 92
  - A professional, high-tech workforce (both white- and blue-collar) is typically not easily expanded to respond to fluctuating requirements

Presenter M3/Maintenance | Date FINAL | Slide 1 of 13 | Closed

Maintenance Capabilities Analysis

- **Findings:**
  - Workload variations driven by numerous factors
    - Vehicle age, modifications, mission requirements, etc.
  - One example: OV-103, currently 8 months into J3 OMM
    - 28 percent growth over original tile replacement projections
    - 11.5 percent tile growth over original projected man hours
    - Potential additional tile growth ranges from 7 to 24 percent
      - From original 82,522 to 111,892 man hours
  - Second example: TPSF ("tile backshop")
    - Currently supporting OV-103 OMM, OV-104 flow
    - Test tile production (CAIB support) increasing rqmt by 473%
      - Mar – May 03: 128 originally projected, 606 now required

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Maintenance Capabilities Analysis

- **Findings (cont'd):**
  - Both Orbiter Operations (OPF) and Integrated Logistics (TPSF) are assessing capabilities against requirements
    - Briefed at 1 May OV-103 OMDP Program Management Review
    - Presented various options to potential increases in requirements
      - Work employees longer, augment work force with additional manpower, slip delivery schedule
      - For TPSF, additional options included:
        - Reactivating Palmdale tile shop to produce test tiles
        - Augmenting KSC with Palmdale technicians
    - Both capability assessment efforts in a fledgling state
      - Represent efforts to communicate workforce constraints and mitigation options to higher management levels

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Maintenance Capabilities Analysis

- **Findings (cont'd):**
  - Ground Operations managers also "plowing new ground" with capability assessments using "equivalent flow" (EF) model
    - Based on OPF standard flow of 315,000 man hours
    - Total (OPF/ET/Booster/Integration) of 525,000 man hours
    - OMM baseline being developed using OV-103
      - 700,000 man hours estimated
    - Adjustments made based on OMM/flow content
    - EF capabilities being applied against launch schedule (manifest) to determine shortfalls
      - Original FY 03/04 manifest exceeded EF capability by as much as 64%
      - Managers envision being able to level "peaks" and fill in "valleys"
      - Managers using EF capabilities to develop mitigation plans
      - Key question: How flexible can/will the launch schedule be?

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Maintenance Capabilities Analysis

- **Findings (cont'd):**
  - What if the launch schedule is inflexible?
    - Work longer hours, increase workforce size, or adjust milestones internal to the processing flow
  - Longer hours bring well-recognized concerns
    - Potential for increased mistakes, injuries, higher costs
  - The workforce has been "leaned out" by 50 percent since 91
    - While more efficient than ever, surge capability is primarily thru overtime
    - Increasing the size of a professional, high-tech work force is not quick
    - Tile technician (OPF): approx 1 year necessary to work independently, longer until fully qualified
    - Tile technician (back shop): approx 3-months necessary to work independently, 3-5 years until fully qualified
  - Management must have the ability to routinely/accurately forecast capabilities, compare against requirements, and have sufficient lead time to take mitigating actions

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Maintenance Capabilities Analysis

- **Recommendations:**
  - Ground Operations managers have been developing a complement of tools in recent years to do capability assessment modeling
    - They should expedite efforts to refine these models (e.g., the equivalent flow model) and use the results to take proper action(s) when requirements exceed capabilities
  - Managers need to develop sufficient confidence in capability assessments to use them in manifest and resource planning

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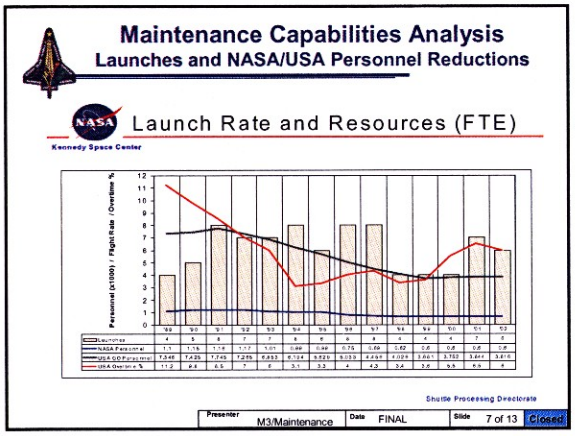
Maintenance Capabilities Analysis
Launches and NASA/USA Personnel Reductions
NASA
Launch Rate and Resources (FTE)
Kennedy Space Center
Personnel (x1000) / Flight Rate / Overtime %
Shuttle Processing Directorate
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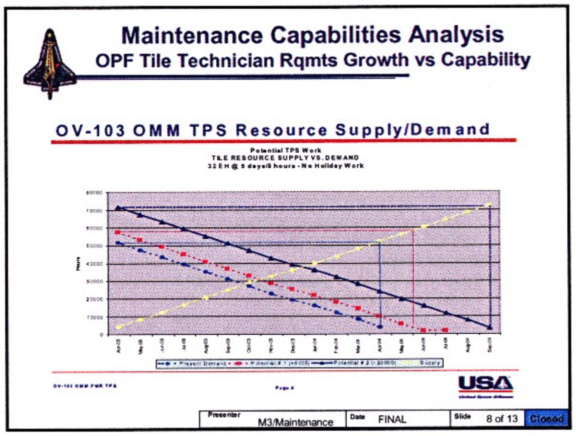
Maintenance Capabilities Analysis
OPF Tile Technician Rqmts Growth vs Capability
OV-103 OMM TPS Resource Supply/Demand
USA
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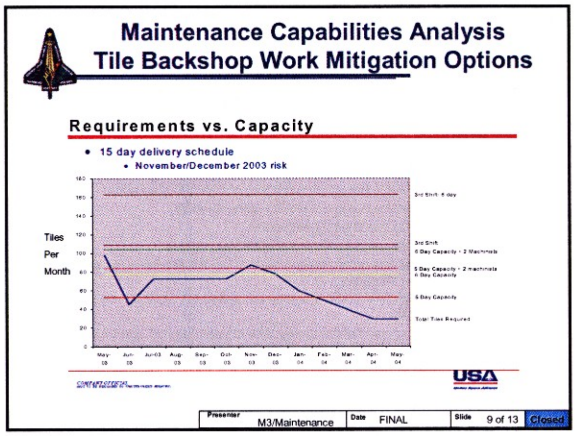
Maintenance Capabilities Analysis
Tile Backshop Work Mitigation Options
Requirements vs. Capacity
• 15 day delivery schedule
• November/December 2003 risk
Tiles Per Month
USA
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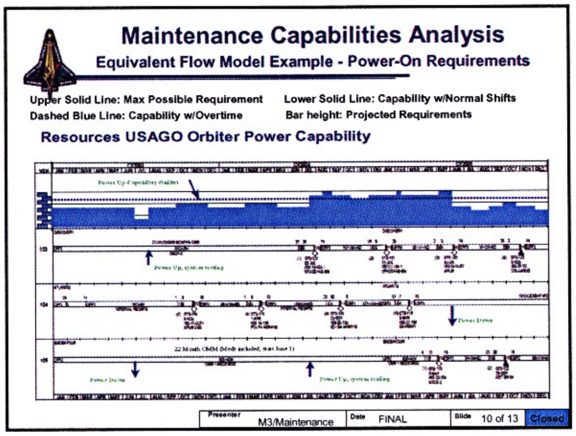
Maintenance Capabilities Analysis
Equivalent Flow Model Example - Power-On Requirements
Upper Solid Line: Max Possible Requirement
Lower Solid Line: Capability w/Normal Shifts
Dashed Blue Line: Capability w/Overtime
Bar height: Projected Requirements
Resources USAGO Orbiter Power Capability
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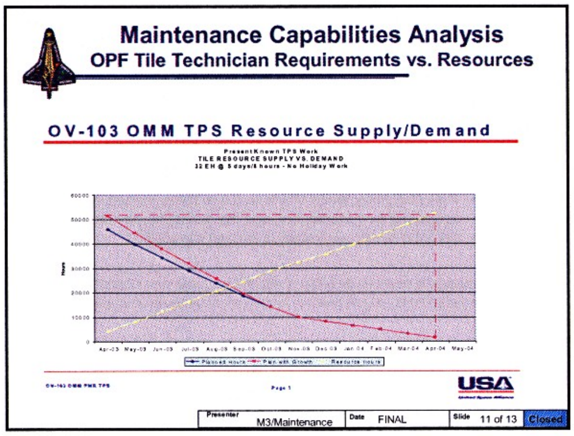
Maintenance Capabilities Analysis
OPF Tile Technician Requirements vs. Resources
OV-103 OMM TPS Resource Supply/Demand
USA
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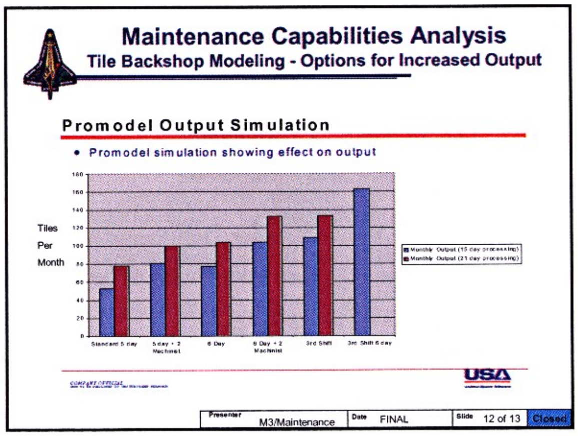
Maintenance Capabilities Analysis
Tile Backshop Modeling - Options for Increased Output
Promodel Output Simulation
• Promodel simulation showing effect on output
Tiles Per Month
USA
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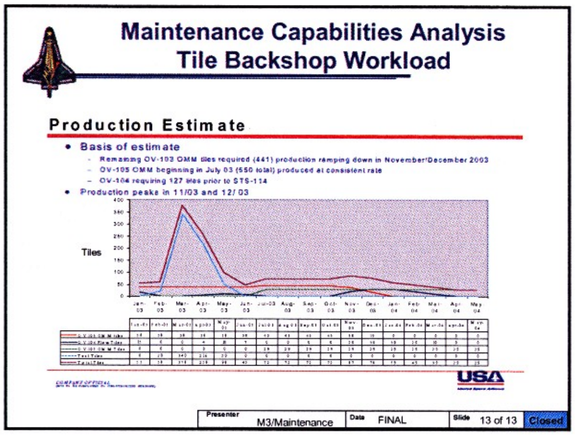
Maintenance Capabilities Analysis
Tile Backshop Workload
Production Estimate
• Basis of estimate
– Remaining OV-103 OMM tiles required (441) production ramping down in November/December 2003
– OV-105 OMM beginning in July 03 (550 total) produced at consistent rate
– OV-104 requiring 127 tiles prior to STS-114
• Production peaks in 11/03 and 12/ 03
Tiles
USA
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3

Other
Fleet Experience – Aging

19-1 Loose Carrier Panel Fasteners

19-2 Programming for Aging Infrastructure

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	22 of 32

Carrier Panels

- **Action / Issue:** Determine adequacy of maintenance requirements for carrier panel fasteners
- **Background / Facts:**
  - Upper and lower access/carrier panels closeout the WLE between the RCC panels and the wing front spar
  - OV-102 has 794 total carrier panels including the OMS pods
  - WLE lower carrier panel utilizes a gap filler referred to as a horsecollar
  - OV-102 left wing lower access panels had 27 horsecollars replaced, 9 HRSI tiles replaced, 9 fills in the gap filler material, 12 HRSI tile repairs and 7 MRs
  - OV-102 left wing upper access panels had 7 HRSI tiles replaced, 7 HRSI tile repairs and 7 MRs

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Carrier Panels

- **Background / Facts:**
  - Post-flight inspection after STS-87 (OV-102-24, 1997) revealed a large step in the number 4R lower access panel
    - Reference Boeing Report KLO-98-002, "Mission STS-87 OV-102 Flight 24 Thermal Protection System Post-Flight Assessment", March 1998
    - A 0.4" gap under the head of the bolt was discovered during panel removal
    - No signs of overheating were noted
    - The remaining fasteners were inspected and low torque values were found but none were unseated (report doesn't provide quantity)
    - "Bolts were retorqued and the problem was resolved"

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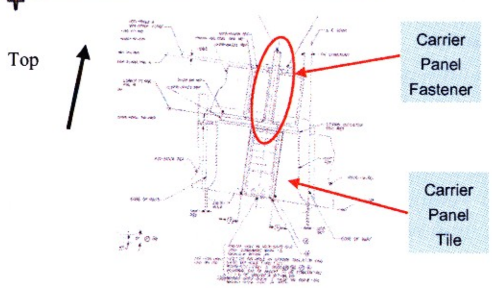
Carrier Panels



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Carrier Panels

- **Background / Facts:**
  - During OV-103-25, STS-95, 1998 a carrier panel on the OMS pod Y-web door peeled back and structure under the panel was damaged during entry
  - Torque check of all the fasteners on OV-103's and OV-105's OMS pod Y-web doors were performed
    - OV-103 had 4 loose washers found spinning under the fastener heads, and 13 out of 44 fasteners with low torque
    - OV-105 had 7 fasteners found with low torque
  - Concluded "no concern for loose TPS carrier panel fasteners"
  - Recommended monitoring plan for fastener torque
    - 2 lower LESS carrier panels (1 LH and 1 RH)
    - 2 star tracker carrier panels
    - 2 OMS pod stringer carrier panels

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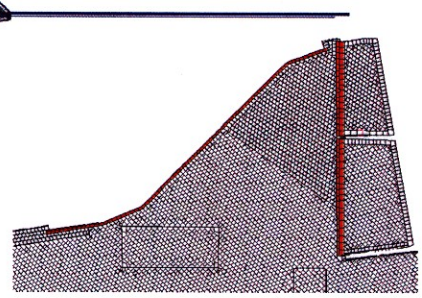
Carrier Panels



Wing Carrier Panel Locations Shown in Red

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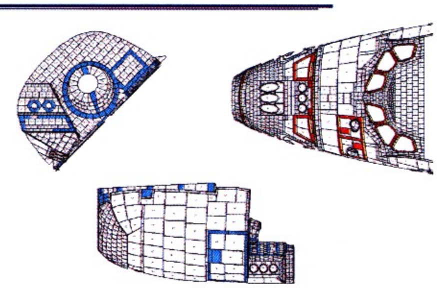
Carrier Panels



Other Carrier Panel Locations

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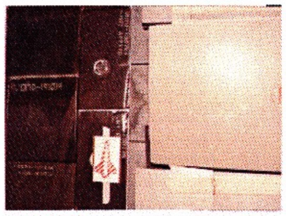
1

Carrier Panels

L/H LESS PNL #7 DAMAGE TO TILE



TILE SLUMPING ADJ TO RCC T-SEAL

OV-103-01, WLE Carrier Panel 7L Slumped Tile (1984)

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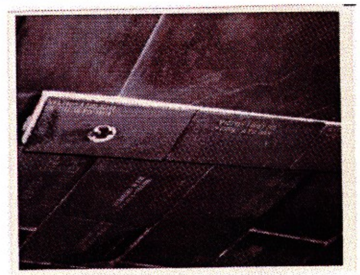
Carrier Panels



OV-103-04, WLE Loose Carrier Panel 16R (1985)

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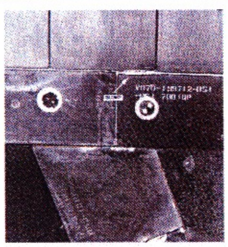
Carrier Panels



OV-104-21, WLE Carrier Panel 7L Slumped Tile (May 00)

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Carrier Panels
Category: Other Significant Finding

- **Findings:**
  - Carrier panels have a history of having loose fasteners
  - Recommended monitoring plan appears to be inadequate (if it was even implemented)
- **Recommendations:**
  - Revisit carrier panel loose fastener issue and revised planned maintenance actions

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Carrier Panels

- **Documentation:**
  - Briefing by A. Mirdamadi, "TPS Carrier Panel Fasteners Monitoring Plan", 30 March 1999
  - Meeting minutes by H. Ashkar, "8-27-98 Palmdale Visit Minutes", 27 August 1998
  - Briefing by S. Cavanaugh, "OV-102 Wing Leading Edge Carrier Panel", January 1998

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Aging Infrastructure Facilities/Equipment

- **Action / Issue:** Assess aging infrastructure, to include planning/programming of sustainment/replacement actions
- **Background / Facts:**
  - Much of NASA infrastructure (facilities/equipment), was built in the Apollo era ('60s); design life was 10 years
    - Rehabilitated/modified numerous times to remain "launch ready"
  - KSC further challenged by accelerated corrosion due to proximity to ocean; acidic SRM exhaust compounds pad-vicinity problems
  - Primary focus on infrastructure deemed critical to immediate mission; many other systems have received only basic attention (at best) and are well past their projected service life
  - Major budget cuts from 1994 led to NASA strategy to absorb most reductions from infrastructure
  - Facility maintenance strategy WRT SSP abruptly changed from "life support until imminent retirement" (1990s) to "sustain until 2020"

Presenter M3/Maintenance | Date FINAL | Slide 1 of 22 | Closed

Aging Infrastructure Facilities/Equipment

- **Findings:**
  - Example 1: Launch Pads
    - Extensive structural corrosion due to SRM propellant/proximity to ocean
    - Older designs trap corrosive elements despite post-launch washdown
    - Delaminating walls in RSS Payload Changeout Room (temp fixed)
    - Concrete deterioration problems at pad base & blast deflector area
    - Railroad boxcars (83 between LC 39A & B) serve as offices/work centers
      - Severely deteriorated, some with evidence of leaking ceilings
    - Efforts to reverse this deterioration evident in some areas
      - Pad wiring upgrades in Pad Terminal Control Room reflect continuous attention to sustainment; critical to launches
      - Later structural additions reflect designs less prone to trap corrosives
      - Boxcar replacement facilities funded, move-in this year (FY 03)

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Aging Infrastructure Facilities/Equipment

- **Findings:**
  - Example 1: Launch Pads – Zinc Fallout Issue
    - Reinforced carbon-carbon (RCC) pinholes initially ID'd in 1992
      - Subsequently found on all orbiters
      - Affects service life of RCC panels
    - Rain sampling (1994) linked pinholes to zinc oxide contamination; exposed inorganic zinc primer on launch pad washing onto RCC
    - Despite improved corrosion control management and execution since initial discovery, recent rain sampling (July 2003) confirmed problem still exists, though zinc levels were lower in all but one sample
    - Illustrates the direct impact infrastructure maintenance can have, not just on immediate shuttle operations, but also on service life

Presenter M3/Maintenance | Date FINAL | Slide 3 of 22 | Closed

Aging Infrastructure Facilities/Equipment

- **Findings (cont'd):**
  - Example 2: Crawler/Transporter
    - Designed/built for the Apollo program (circa 1965); only two in world
    - Currently have an average of 1,700 miles each
    - Critical for launches & during hurricane season (to "safe haven" shuttle)
    - Challenges: age, obsolescence, vanishing vendors, small fleet size, uniqueness, highly corrosive environment/outdoor storage, etc.
      - Despite these challenges, C/Ts are recognized for their critical role and are well supported (e.g., control room upgrades/laser docking)
      - One notable exception: outdoor storage accelerates corrosion and leads to continual weather disruptions (work stoppage for lightning)
    - Managers track resources expended (cost of mods/parts/labor) over time vice per unit of output (e.g., miles driven or operating hours)
      - In certain cases, analysis/trending of support costs based on unit of output can more clearly define cost/benefit tradeoffs

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Aging Infrastructure Facilities/Equipment

- **Findings (cont'd):**
  - USA in its 3rd yr using a web-based corrosion info/tracking system ("CorrPro/Basecoat"); adopted from offshore oil industry
    - "Light years" ahead of former paper system…file cabinets w/folders & paper reports…time consuming to prepare, review, & update
    - Using CorrPro, engineers annually assess infrastructure, using digital photo documentation; work prioritized based on corrosion severity
    - CorrPro also enables forecasting time/labor/mat'ls for corrective actions
    - Valuable tool in prioritizing rqmts w/add'l "drill downs" (e.g., for launch pads, rqmts categorized by level and further by component); helpful in sizing budget and scheduling work in increments if necessary
  - Ground Systems Working Team (GSWT) assesses/prioritizes infrastructure requirements
    - Considers risks associated with likelihood of failure and consequences
    - Factors in cost savings/avoidance
    - Uses Ground Systems Survivability Assessment (GSSA) database

Presenter M3/Maintenance | Date FINAL | Slide 5 of 22 | Closed

Aging Infrastructure Facilities/Equipment

- **Findings (cont'd):**
  - "The hardest part of our job is getting the funding, the resources, and the operations schedule window to line up"…senior NASA/USA mgrs
    - Effective scheduling of preventive/corrective maintenance of ground support systems essential to maximizing windows of opportunity
    - USA's Ground Systems Support (GSS) established a master planner position in late CY 02
      - Similar position established for horizontal operations in early CY03
      - These two new planners routinely interface w/a vertical operations master planner to better align/deconflict activities
    - Overtime hours and work time deviations/violations have been decreasing with this new focus
      - Another expectation: more infrastructure support will be accomplished based on lining up "windows" more efficiently

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Aging Infrastructure Facilities/Equipment

- **Findings (cont'd):**
  - MSFC/Michoud Assembly Facility (GOCO-govt owned contractor operated)
    - Some facilities date to 1940s; add-ons for Apollo (60s) and SSP (70s)
    - Advantages (over KSC): smaller operation, more single-mission focused, fewer "balls to juggle", much less corrosive environment
    - Kudo: 15-yr Strategic Plan prioritizes rqmts in "big picture" context
      - Developed in 97; ongoing updates; disciplined, systematic approach
      - Also have a comprehensive 15-yr Equipment Strategic Plan
    - Successes
      - CoF funding increased by 371% (97 vs 03), $7.9M to $37.2M
      - Repair of 43-acre roof on Main Mfg Bldg in 2nd/final yr of funding
      - 1940s-vintage 480V electrical system upgraded – 4 1-yr segments
    - Despite being challenged by old infrastructure, MAF's approach has typically secured needed funding

Presenter M3/Maintenance | Date FINAL | Slide 7 of 22 | Closed

Aging Infrastructure Facilities/Equipment

- **Findings (cont'd):**
  - Stennis Space Center (SSC)
    - Built as part of Apollo ramp-up (mid-60s)
    - Primary mission: liquid fueled rocket engine testing
      - Every shuttle engine tested after mod/overhaul
    - Three test stands – "national assets" – A1, A2, B1/2
      - Only A1 capable of testing gimbaling
      - A1 to be mothballed in FY 03 (infrastructure reduction)
      - Remaining test stands deemed adequate
      - Known rqmts do not include gimbal testing
  - Palmdale facilities (aka Plant 42) leased from AF
    - Facilities/equipment generally in good condition due to environment
    - Degradation (primarily equipment) due primarily to decreased activity/use

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Aging Infrastructure Facilities/Equipment

- **Findings (cont'd):**
  - The NASA "big picture"
    - >2,600 bldgs, >2,600 other major structures, avg age nearing 40 yrs
    - $21.9B Current Replacement Value (CRV); avg NASA CRV 40% > DoD
      - Reflects unique nature/small # of facilities (e.g., VAB, launch pads)
    - NASA-wide infrastructure assessment conducted in FY 02
      - Backlog of Maintenance and Repair (BMAR) not consistent/ auditable, subject to "spin", difficult to roll up
      - New uniform "yardstick" via Deferred Maintenance (DM)
    - >$2B DM NASA-wide
      - 100%>BMAR estimate, which did not consider all facilities
      - 10% of NASA CRV; industry rule of thumb: 2-4% annual funding
      - NASA playing catch up based on years of underfunding
      - Uniqueness/small #s of facilities also drive a "must fix" approach
      - Code JX working to apply DM database to planning/programming

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Aging Infrastructure Facilities/Equipment

- **Findings (cont'd):**
  - The "big picture" continued
    - A second uniform "yardstick": Facility Condition Index (FCI)
      - 5-pt scale: 5 is excellent, 1 is bad
      - Average ratings based on FY 02 NASA-wide assessment:
        - NASA: 3.6 - Code M: 3.5 - JSC: 3.6
        - KSC: 3.3 - MSFC: 3.9 - SSC: 3.1
      - KSC rating reflects large number of assets (>60%) dedicated to SSP
      - SSC rating skewed by high $ value/condition of test stands relative to overall center value; stands are 37% of SSC CRV w/FCI of 2.2; w/o stands, SSC is 3.6
      - Assessments "peel back" to individual areas: structure/roof/exterior/ interior/electric/HVAC/plumbing/equipment
      - NASA goal: improve average to 4.2 by FY 09; requires $312M/yr

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Aging Infrastructure Facilities/Equipment

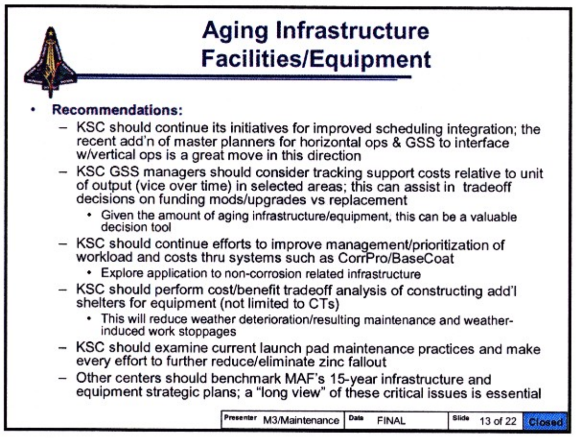
- **Findings (cont'd):**
  - NASA "big picture" continued
    - Code JX has adopted DoD's Facility Sustainment Model (FSM)
      - Refining model for NASA use
    - FSM requires $333M annual facility maintenance funding to arrest deterioration
      - FY 02: $224M (67% of actual)
      - FY 05: $273M (82% of planned)
    - Facility Revitalization Rate (FRR) measures how often a facility will be replaced/revitalized based on investment funding
      - OSD FRR target is 67 yrs; industry standard is 55 yrs; current NASA FRR >100 yrs (down from 200+ yrs)
      - Estimated cost for NASA to reach 67 yrs: $302M/yr
      - Improvement also possible by reducing infrastructure
    - GAO (1996): NASA problems identifying, assessing, implementing infrastructure cost reduction opportunities
      - NASA addressing this via DM/FCI assessments & tools such as FSM/FRR

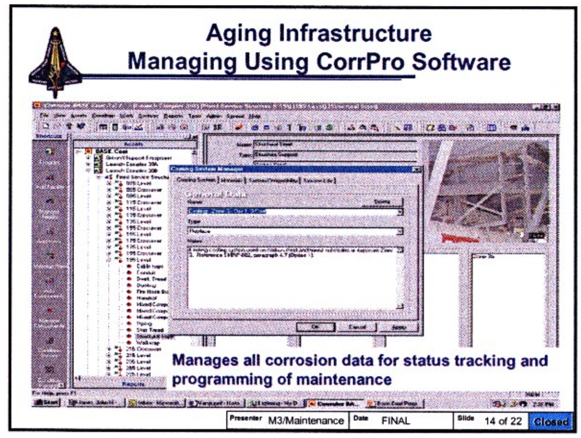
Presenter M3/Maintenance | Date FINAL | Slide 11 of 22 | Closed

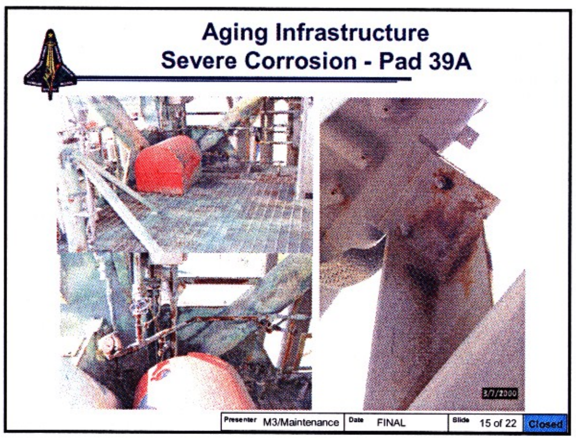
Aging Infrastructure Facilities/Equipment

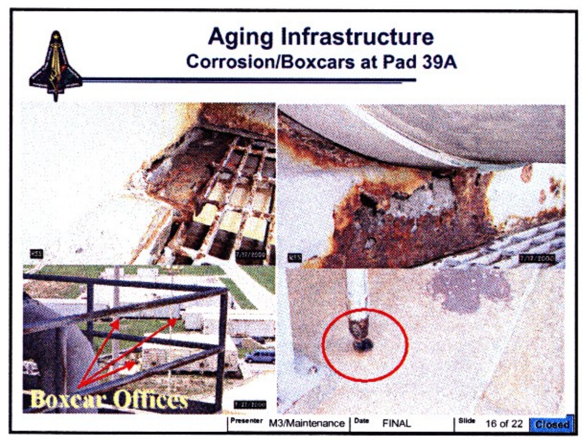
- **Findings (cont'd):**
  - NASA road ahead
    - Identify/dispose of excess infrastructure
    - Make better use of under-utilized facilities through consolidations
    - Sustain remaining infrastructure by:
      - Reducing backlog of maintenance and repair
      - Bringing revitalization rate down from 100+ yrs
      - Advocating for "repair by replacement" where smart
      - Successfully advocating/securing funding to support all of above
- **Conclusions / Recommendations:**
  - Strategic level assessment/planning by Code JX on the right track
    - Provides a structured approach to assess and prioritize requirements
    - Based on recognition that past assessments have not presented an accurate picture nor a NASA-wide requirements prioritization
    - 15-yr Strategic Plans at MAF are worthy of benchmarking across NASA
      - Allow a long range view (beyond 5-yr POP) for proper prioritization of both facilities and equipment

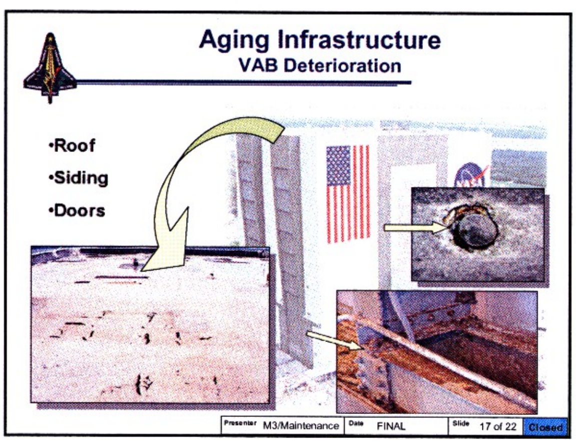
Presenter M3/Maintenance | Date FINAL | Slide 12 of 22 | Closed

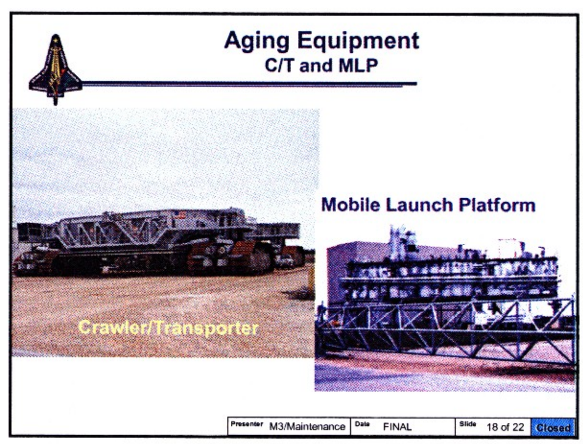

Aging Infrastructure
Facilities/Equipment
• Recommendations:
– KSC should continue its initiatives for improved scheduling integration; the recent add'n of master planners for horizontal ops & GSS to interface w/vertical ops is a great move in this direction
– KSC GSS managers should consider tracking support costs relative to unit of output (vice over time) in selected areas; this can assist in tradeoff decisions on funding mods/upgrades vs replacement
• Given the amount of aging infrastructure/equipment, this can be a valuable decision tool
– KSC should continue efforts to improve management/prioritization of workload and costs thru systems such as CorrPro/BaseCoat
• Explore application to non-corrosion related infrastructure
– KSC should perform cost/benefit tradeoff analysis of constructing add'l shelters for equipment (not limited to CTs)
• This will reduce weather deterioration/resulting maintenance and weather-induced work stoppages
– KSC should examine current launch pad maintenance practices and make every effort to further reduce/eliminate zinc fallout
– Other centers should benchmark MAF's 15-year infrastructure and equipment strategic plans; a "long view" of these critical issues is essential
Presenter M3/Maintenance Date FINAL Slide 13 of 22 Closed


Aging Infrastructure
Managing Using CorrPro Software
Manages all corrosion data for status tracking and programming of maintenance
Presenter M3/Maintenance Date FINAL Slide 14 of 22 Closed

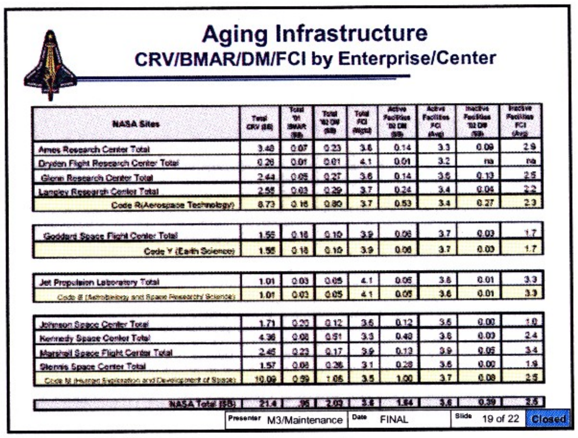

Aging Infrastructure
Severe Corrosion - Pad 39A
Presenter M3/Maintenance Date FINAL Slide 15 of 22 Closed


Aging Infrastructure
Corrosion/Boxcars at Pad 39A
Boxcar Offices
Presenter M3/Maintenance Date FINAL Slide 16 of 22 Closed

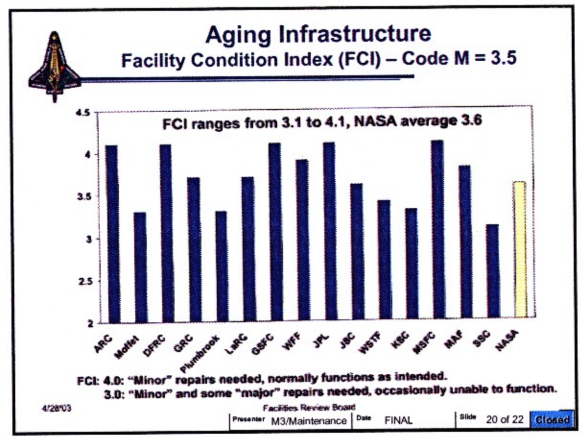

Aging Infrastructure
VAB Deterioration
•Roof
•Siding
•Doors
Presenter M3/Maintenance Date FINAL Slide 17 of 22 Closed

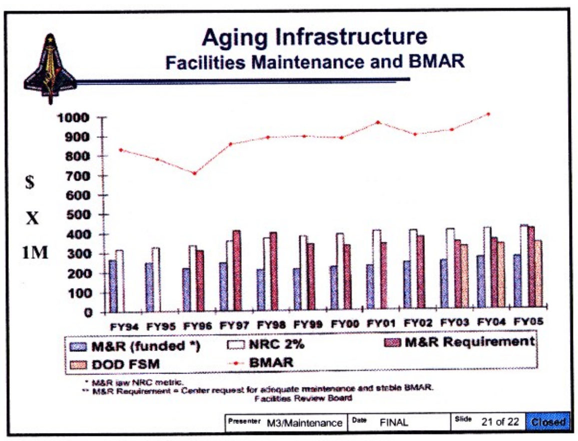

Aging Equipment
C/T and MLP
Mobile Launch Platform
Crawler/Transporter
Presenter M3/Maintenance Date FINAL Slide 18 of 22 Closed

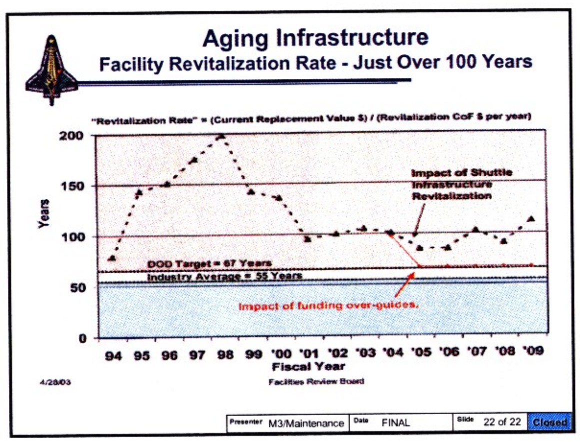
3



NASA Sites	Total CRV ($B)	Total '01 BMAR ($B)	Total '02 DM ($B)	Total FCI (Wgtd)	Active Facilities '02 DM ($B)	Active Facilities FCI (Avg)	Inactive Facilities '02 DM ($B)	Inactive Facilities FCI (Avg)
Ames Research Center Total	3.48	0.07	0.23	3.6	0.14	3.3	0.09	2.9
Dryden Flight Research Center Total	0.26	0.01	0.01	4.1	0.01	3.2	na	na
Glenn Research Center Total	2.44	0.05	0.27	3.6	0.14	3.6	0.13	2.5
Langley Research Center Total	2.55	0.03	0.29	3.7	0.24	3.4	0.04	2.2
Code R (Aerospace Technology)	8.73	0.16	0.80	3.7	0.53	3.4	0.27	2.3
Goddard Space Flight Center Total	1.55	0.18	0.10	3.9	0.06	3.7	0.03	1.7
Code Y (Earth Science)	1.55	0.18	0.10	3.9	0.06	3.7	0.03	1.7
Jet Propulsion Laboratory Total	1.01	0.03	0.05	4.1	0.05	3.6	0.01	3.3
Code S (Astrobiology and Space Research/ Science)	1.01	0.03	0.05	4.1	0.05	3.6	0.01	3.3
Johnson Space Center Total	1.71	0.20	0.12	3.6	0.12	3.6	0.00	1.0
Kennedy Space Center Total	4.36	0.08	0.51	3.3	0.48	3.6	0.03	2.4
Marshall Space Flight Center Total	2.45	0.23	0.17	3.9	0.13	3.9	0.05	3.4
Stennis Space Center Total	1.57	0.08	0.26	3.1	0.28	3.6	0.00	1.9
Code M (Human Exploration and Development of Space)	10.09	0.59	1.06	3.5	1.00	3.7	0.08	2.5
NASA Total ($B)	21.4	.95	2.03	3.6	1.64	3.6	0.39	2.5







4

Other Maintenance

20-1 Engineering Orders

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	23 of 32

Maintenance
Engineering Orders

- **Action/Issue:** Backlog of unincorporated Engineering Orders (UEO) is significant and may impact the quality and timeliness of maintenance
- **Background:**
  - Last 5 ASAP reports document a large and growing number of UEOs (over 1600 with > 10 changes ea; now 1400 with removed from schedule)
  - NNBE referenced using Navy's zero level as a baseline
- **Facts:**
  - Observed examples of UEOs in shop and OPF
    - Observed the impact and difficulties of navigating EO with multiple unincorporated changes and potential for human error
    - NASA built a noteworthy plan to incorporate the most important changes to drawings for orbiter on basis of highest use and complexity (2002-2004)
- **Recommendations:**
  - Draft a plan to finish incorporating the >10 UEOs

Presenter M3/Maintenance	Date FINAL	Slide 1 of 4	Closed

Maintenance
Engineering Orders

Aerospace Safety Advisory Panel, 2002... report excerpt:

"Previously, the Panel has been concerned with the large number of orbiter drawings that are out of date. Many EO changes have not been incorporated into the drawings. Although they are noted on the drawings,engineers must refer to additional paperwork to understand the state of the hardware systems. Over 1,600 drawings have more than 10 unincorporated EOs. The orbiter program will update and incorporate all EOs on 59 of the most frequently used drawings by the end of 2003. Also during the year,an effort to address the 589 drawings referenced most frequently after those 59 will begin. The remaining drawings will be updated as opportunity permits. Orbiter program management has committed to maintaining the upgraded drawings at no more than 10 unincorporated EOs. The orbiter program is now reviewing the possibility of identifying the safety-critical drawings that should always be kept current.

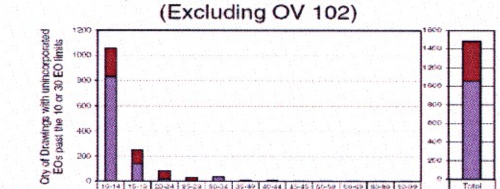
Recommendation 02-8:

Identify drawings that are critical to flight safety, update them to include all EOs, and keep them current."

Presenter M3/Maintenance	Date FINAL	Slide 2 of 4	Closed

Maintenance
Engineering Orders

Drawings with unincorporated EOs past the 10 or 30 EO limits (Excluding OV 102)



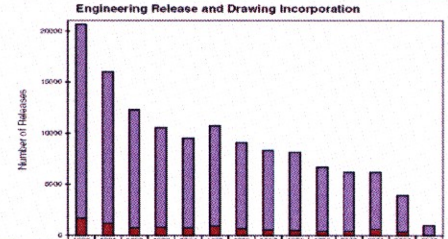
	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-59	60-69	80-89	90-99	Total
Exempt to 99	1	1	0	0	0	0	0	0	0	2	1	3	8
Exempt to 30	228	111	60	24	0	0	0	0	0	0	5	0	423
Incorporation Required	829	139	22	5	33	9	6	4	3	2	3	1	1058

Unincorporated EO range for the drawings

Presenter M3/Maintenance	Date FINAL	Slide 3 of 4	Closed

Maintenance
Engineering Orders

Engineering Release and Drawing Incorporation



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total Releases	20632	15926	12344	10557	9474	10770	9037	8325	8162	6710	6179	6159	3645	927
Incorporation Releases	1675	1192	752	793	725	896	656	509	512	447	442	636	347	90
10 EOs & Over Incorp	922	236	121	117	42	84	85	42	49	41	59	125	46	10

Presenter M3/Maintenance	Date FINAL	Slide 4 of 4	Closed

1

Other
Launch – Ascent

21-1 Day of Launch Assets, Hardware Security, and Scenarios
21-2 SRB Bolt Catchers
21-3 Separation Bolt Certification
21-4 RSRM Flex Boot Tear
21-5 STS-107 Impact Analysis
21-6 STS-107 Ascent Debris (Radar & Imaging)
21-7 Hold-Down Cable Anomaly

Matrix

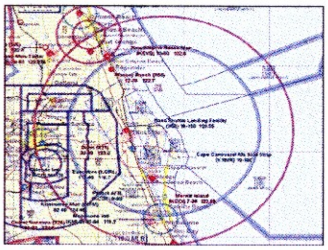
Presenter	CAIB/Group 1	Date	FINAL	Slide	24 of 32

Willful Damage All Areas

- **Action/Issue:** Potential for willful damage
- **Background/Facts:**

Day-of-Launch Assets included:
- Fighters
- Helicopters
- Sea surveillance
- Ground security
- Sensors

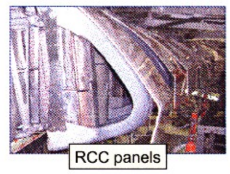
"Tightest security ever … briefed to NSC"

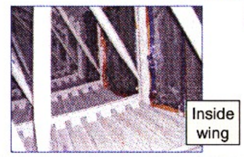


Presenter M3 | Date FINAL | Slide 1 of 3 | Closed

Hardware Security

- **Background/Facts:**
  - Panel and door close-outs
    - Multiple technicians
    - Multiple contract quality inspectors
    - Multiple government inspectors





Presenter M3 | Date FINAL | Slide 2 of 3 | Closed

"Willful damage" scenarios

- **Background/Facts:**
  - Examining via testing (outside agencies involved)
  - HOWEVER … to be credible, each must still pass "tests"
    - Telemetry (digital, voice)
    - Imagery (still, video, telescopic)
    - Thermodynamics
    - Aerodynamics
    - Debris shedding, ground evidence
    - Documentation
    - And -- grounded in shuttle systems facts
- **Findings:**
  - Thus far, none meets the tests to be credible
  - FBI testing and chemical/metallurgical evidence do not support willful damage
- **Recommendations:**
  - Continue high level of diligence to prevent willful damage

Presenter M3 | Date FINAL | Slide 3 of 3 | Closed

1

Maintenance
Bolt Catcher

- **Action / Issue:** Did a malfunction of the SRB forward Bolt Catcher contribute to the accident chain of events?
- **Background / Facts:**
  – Function: Catch fired separation bolts attaching SRBs to ET
    - Upper catcher attached to ET, lower attached to SRB, different design
    - Good example of SIAT (99) documented concern with "fly what you test, test what you fly"
  – SUMMA and Harris manufacture, subKtr, USA serial #
    - Pulled from supply to install on ET, coated with (SLA) ablative which requires # removal-- MAF assigns new serial #
    - Serial # discrepancy between USA and MAF serial #s on STS --107

Presenter M3/Maintenance | Date FINAL | Slide 1 of 9 | Closed

Maintenance
Bolt Catcher

- **Background/Facts:**
  – Bolt Catcher never qualified as flown…79/80 tests
    - Attachment to ET qualified with through-bolts (vice inserts)
    - SLA 561 not applied on test articles
    - Reduced resistance aluminum honeycomb not tested
  – System changes certified by "analysis and similarity"
  – In-flight photograph of STS 107 Bolt Catcher black and unusable
  – Radar images at 126 seconds point originally considered normal
- **Findings**:
  – Tests run 27 May – 8 July of representative articles to evaluate/determine as-flown environment and safety margin
  – Test profiles designed to verify engineering profile of system performance as certified including as-flown configuration
    - 18 tests completed …4 bolts fired into instrumented catcher,seven stress tests of catcher to failure

Presenter M3/Maintenance | Date FINAL | Slide 2 of 9 | Closed

Maintenance
Bolt Catcher

Findings:
  – Dynamic test #2 measured 46KIPs in Summa serial #50 dome
  – Stress test #3 of catcher failed at weld at 44KIPs…engineering analysis expected bolt failure at 68,000lb
    - Same failure point as 1979 certification test
    - Implies 0.956 safety margin
    - Additional tests requested
  – X-Ray film of #50 showed poor quality film and strong evidence of substandard welding…would not have been certified today
  – STS-107, Summa catcher #1 installed on left SRB/ET
    - X-Ray film failed in quality as well as substandard weld

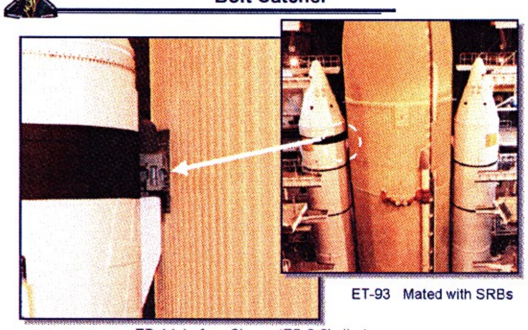
Presenter M3/Maintenance | Date FINAL | Slide 3 of 9 | Closed

Maintenance
Bolt Catcher

- **Findings**
- STS-107 launch radar data comparison with bolt catcher radar cross section (RCS) complete
  – Event #33 at 128 second similar in size to bolt catcher RCS
  – Lack of photographic evidence means event #33 cannot be ruled out as a possible bolt catcher or fragment.
- **Group Recommendations**
  – Certification by "analysis and similarity" flawed…how many other bolt catchers on SSP?
  – Remove all Bolt Catchers from service
  – Redesign system to assure 1.4 safety margin at a minimum

Presenter M3/Maintenance | Date FINAL | Slide 4 of 9 | Closed

Maintenance
Bolt Catcher

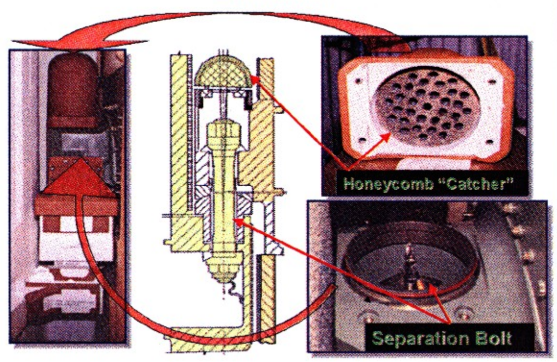


ET-93 Mated with SRBs

EB-1 Interface Shown (EB-2 Similar)

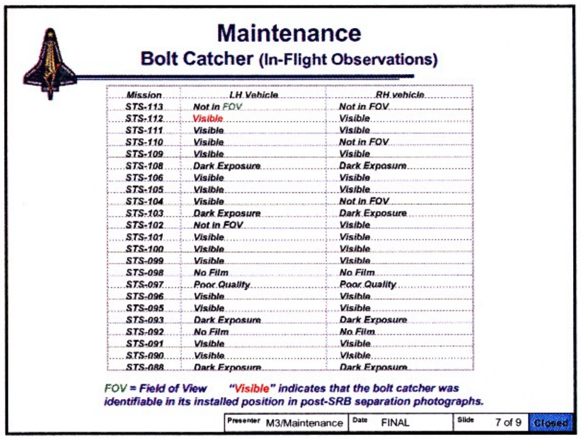
Presenter M3/Maintenance | Date FINAL | Slide 5 of 9 | Closed

Bolt Catcher

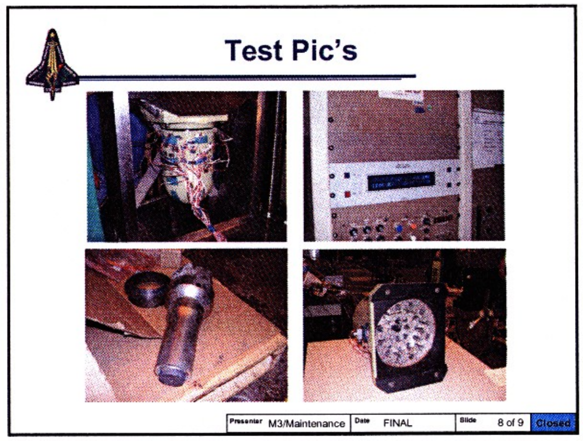


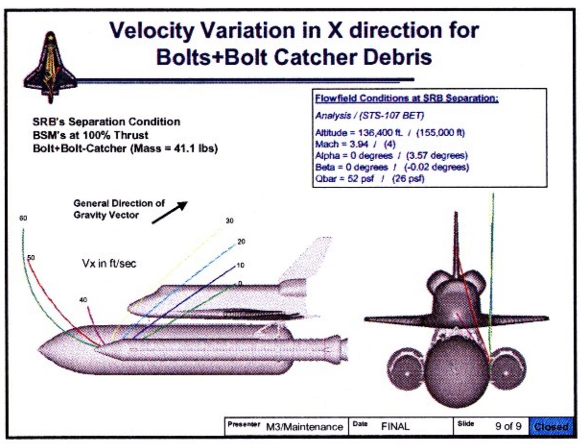
Presenter M3/Maintenance | Date FINAL | Slide 6 of 9 | Closed

1



Mission	LH Vehicle	RH vehicle
STS-113	Not in FOV	Not in FOV
STS-112	Visible	Visible
STS-111	Visible	Visible
STS-110	Visible	Not in FOV
STS-109	Visible	Visible
STS-108	Dark Exposure	Dark Exposure
STS-106	Visible	Visible
STS-105	Visible	Visible
STS-104	Visible	Not in FOV
STS-103	Dark Exposure	Dark Exposure
STS-102	Not in FOV	Visible
STS-101	Visible	Visible
STS-100	Visible	Visible
STS-099	Visible	Visible
STS-098	No Film	No Film
STS-097	Poor Quality	Poor Quality
STS-096	Visible	Visible
STS-095	Visible	Visible
STS-093	Dark Exposure	Dark Exposure
STS-092	No Film	No Film
STS-091	Visible	Visible
STS-090	Visible	Visible
STS-088	Dark Exposure	Dark Exposure





Maintenance
Separation Bolt Certification

- **Action / Issue:** Separation bolts manufactured by Pacific-Scientific were not adequately NDI'd before flight on STS 107
- **Background / Facts:**
  - USA replaced Hi-Shear as the prime contractor for separation bolts in May 2000. Certification of new bolts may have been done without adequate NDI (magnetic particle) of the internal bore
- **Findings:**
  - P-S used Pacific Magnetic and Penetrant for NDI verification
  - PS/PMP used same NDI specifications as Hi-Shear
  - First lot (Lot AAN) used on STS 107 and installed on STS 114
    - All NDI results were approved and certified by PS, USA, and DCMA
  - 2nd lot (AAP) magnetic particle inspection eval'ed by DCMA NDI expert
    - Determined process inadequate WRT analysis of Magnetic Part. Insp.
    - ASTM E 1444-01, par. 5.7.3 stipulates use of a borescope

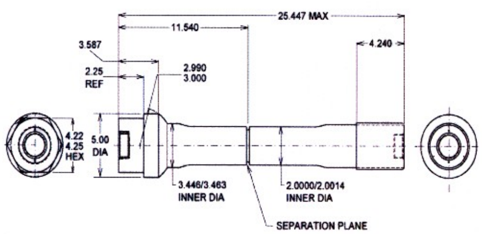
Presenter	Date	Slide	
M3/Maintenance	FINAL	1 of 4	Closed

Maintenance
Separation Bolt Certification

- **Findings (con't):**
  - USA had verbally authorized PMP to deviate from the purchase order specification since borescope was not available
  - USA and DCMA NDI experts disagree over test sufficiency
  - USA built a Defect Standard Bolt with known flaws to evaluate process
    - "Initial assessment of PMP's inspection procedure by USA NDE confirms procedure meets engineering requirement imposed but could be improved"…USA briefing to CAIB
  - USA impounded existing supply of 1st lot: dedicated to test only
  - This situation is not a contributor to the STS-107 mishap
- **Recommendations:**
  - Use more stringent inspection criteria IAW ASTM E 1444, par. 5.7.3, Restricted Area Examination **with** borescope or new method that can adequately identify flaws in the ID

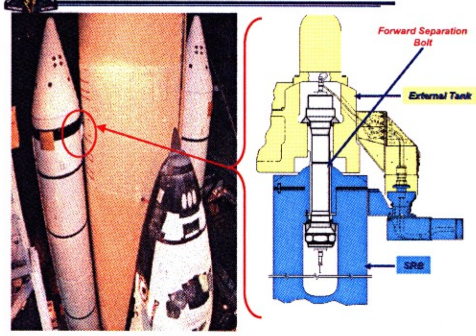
Presenter	Date	Slide	
M3/Maintenance	FINAL	2 of 4	Closed

Maintenance
Separation Bolt Certification



Presenter	Date	Slide	
M3/Maintenance	FINAL	3 of 4	Closed

Maintenance
Separation Bolt Certification



Presenter	Date	Slide	
M3/Maintenance	FINAL	4 of 4	Closed

1

Ascent Debris Strike
Other

- **Action / Issue:** 57-inch tear in the flex boot on the right RSRM adjacent to the inner boot ring—first time observation
- **Background / Facts:**
  - Flex boot is key to allowing reuse of the RSRM
  - Separation did not result in violation of flex boot thermal protection—not sure of the cause—might have been water impact
- **Findings:**
  - None at this time
- **Group Recommendations:**
  - Issue closed per RSRM Fault Tree closeout on 9 Apr 03

Presenter	M3/Material	Date	FINAL	Slide	1 of 1	Closed

Ascent Impact Analysis
(includes Crater)

- **Action / Issue:**
  - The impact damage analysis process did not accurately predict the damage sustained by OV-102 during the ascent of STS-107
- **Background / Facts** (Impact Analysis Process):
  - Crater is a tool used in impact analysis
  - "Impact Analysis" includes Crater, thermal, & stress analyses
    - For STS-107, the impact analysis was performed using the image analysis team's assessment of debris size and location
    - Crater program predicted severe damage to several tiles
    - Thermal and stress analyses predicted localized heating but safe return of orbiter
  - Boeing's Debris Assessment Team recently experienced a transition from Huntington Beach to Houston

Presenter M3/Material | Date FINAL | Slide 1 of 17 | Closed

Ascent Impact Analysis
(includes Crater)

- **Background / Facts** (Crater):
  - Crater is a semi-empirical/semi-theoretical set of equations that results in a tile damage prediction for LI-900 tiles
    - Crater is only model used by NASA to predict impact damage to tiles
    - Crater is conservative and predicts worst case damage
  - Crater originally designed for "in family" (small < 3 in^3) hits
    - Crater is appropriately named; accounts for only for cratering (no other damage mechanisms considered)
    - Never intended to be used for large projectiles (STS-107 analysis)
      - Extrapolation to higher energy debris never validated through testing
    - Crater predicted severe damage to several tiles for STS-107
  - Crater's capabilities are limited by test data used to verify the model
  - Most probable cause of Columbia accident has been identified as impact damage to RCC panels
    - Revised photo analysis
    - Analysis of onboard instrumentation
    - Forensics

Presenter M3/Material | Date FINAL | Slide 2 of 17 | Closed

Ascent Impact Analysis
(includes Crater)

- **Findings** (Impact Analysis Process):
  - Basic types of analyses performed at Boeing-Huntington Beach (pre-transition) and Boeing-Houston (for STS-107) appear to have been the same
  - Boeing-HB and Boeing Houston differ in their assessment of the effectiveness of the training program
    - One key engineering analyst, as reported by HB had only several hours of training on Crater but not by the HB personnel
    - Boeing-Houston team believes training quality & quantity sufficient
      - Boeing Houston team states OJT occurred in Houston, independent of HB training to understand:
        - » Supporting documentation
        - » Crater equation development
        - » V* threshold development
      - Sensitivity studies reported to have been conducted prior to STS-107 final analysis release

Presenter M3/Material | Date FINAL | Slide 3 of 17 | Closed

Ascent Impact Analysis
(includes Crater)

- **Findings** (Impact Analysis Process):
  - Impact analysis uses an iterative, multidisciplinary (transport, impact, Crater, thermal, stress) team-based process
    - STS-107 analysis appears to have been done in the same manner however, without enough feedback between analysis components
      - Thermal analysis may have had minor errors due to communications issues with the Crater analysis hand-off

Presenter M3/Material | Date FINAL | Slide 4 of 17 | Closed

Ascent Impact Analysis
(includes Crater)

- **Findings** (Impact Analysis Process):
  - Photo analysis during the mission identified the most probable location of foam impact on wing acreage tile, not RCC
    - Also indicated no debris over top of wing – impact below WLE apex
  - The Orbiter RCC design requirements did not include debris impact tolerance
    - Some impact testing was performed, but was limited to small projectiles that resulted in localized "cratering" or penetration
      - Mostly ice tests, no foam tests
    - No impacts of the size and mass that occurred on STS-107 were previously predicted, analyzed, or tested.
  - The tools and models available to the analysis team during the flight did not account for the bending failure mode that is currently believed to be the failure cause on STS-107.
    - Data from preliminary detailed analyses and initial fiberglass impact test support this failure mode

Presenter M3/Material | Date FINAL | Slide 5 of 17 | Closed

Ascent Impact Analysis
(includes Crater)

- **Findings** (Crater):
  - Crater's use on STS-107 was far outside it's verified limits of applicability
  - Crater limitations:
    - Only for LI-900 tiles
    - Does not account for special geometry present on some tiles
    - Valid for ascent impact velocities only
      - Hypervelocity impacts not part of this methodology
    - Valid for a limited set of impactor materials
    - Impactor shapes limited to cylinder, rectangular block, or sphere
      - For rectangular block impactors, predicts damage for "edge" orientation only
    - Does not include effects of crossing tile boundaries in large impacts
    - Need to define more stringent limits to Crater's useage when tile depth reaches a defined % of total tile thickness

Presenter M3/Material | Date FINAL | Slide 6 of 17 | Closed

1

Ascent Impact Analysis
(includes Crater)

- **Findings** (Crater):
  - Crater works well within its established limits
    - In the experimental space in which Crater was developed (foam projectiles up to 3 in^3), it provides a reasonable solution
  - Extrapolating beyond the limits of Crater may be performed with:
    - Interpretation based on experience
    - An understanding that the accuracy of predictions will be reduced
  - Crater does not capture "non-cratering" effects on tile or substructural response
  - Crater is not a "turn-key" code
    - Effective use of Crater assumes users have knowledge of model's development and experience in interpreting results
  - Crater has been underutilized in developing acceptable debris/ice criteria for "In Family" hits

Presenter M3/Material	Date FINAL	Slide 7 of 17	Closed

Ascent Impact Analysis
(includes Crater)

- **Findings** (Crater):
  - For STS-107, the Crater model predicted severe damage to several tiles
  - Crater results were interpreted using potentially un-conservative assumptions based upon inherent conservatism of model
    - Extent of tile damage assumed to stop at tile's densified layer

Presenter M3/Material	Date FINAL	Slide 8 of 17	Closed

Ascent Impact Analysis
(includes Crater)

- **Recommendations** (Impact Analysis Process):
  - Boeing should not view the process for knowledge capture as "complete," despite the completion of the transition period
    - They should build on previous efforts to develop a systematic and comprehensive training process to ensure ongoing proficiency in critical tasks
    - Boeing/NASA should conduct an in-depth training curriculum for Boeing-Houston to assure proper understanding and interpretation of impact damage analysis models and procedures
    - Free & open communication between Boeing-Houston and Boeing-HB should be encouraged and financially supported until it is agreed that a full and proper transition is complete

Presenter M3/Material	Date FINAL	Slide 9 of 17	Closed

Ascent Impact Analysis
(includes Crater)

- **Recommendations** (Impact Analysis Process):
  - Boeing, under NASA supervision, should review training matrices for transitioned personnel to verify individuals meet established requirements
    - Upon completing the review, action plans should be developed to remediate those not meeting set job criteria.
      - Boeing should risk manage the remediation process, not only on a group/technology area level, but also on an individual employee level.
        - » Particular attention should be given to new hires with low shuttle experience and areas with several inexperienced personnel.
      - Boeing should employ HB incumbents to remediate new/transitioned personnel failing to meet established job criteria
        - » Affected employee's time should be dedicated to the programmed remediation

Presenter M3/Material	Date FINAL	Slide 10 of 17	Closed

Ascent Impact Analysis
(includes Crater)

- **Recommendations** (Impact Analysis Process):
  - Boeing should facilitate team building within their Houston-based Debris Assessment Team to achieve a greater degree of cohesion and more effective (i.e., "closed-loop") communication flows.
    - This could be accomplished through close monitoring by SSMs, holding regular staff meetings, group training sessions, and routine feedback sessions.
    - The desired outcomes of such efforts would be improved overall decision-making practices and calculation usage methodology. Upon completing the review, action plans should be developed to remediate those not meeting set job criteria.
  - When a decision is to be made by upper management, the engineering solutions given to management should include a quantifiable uncertainty analysis and risk analysis.

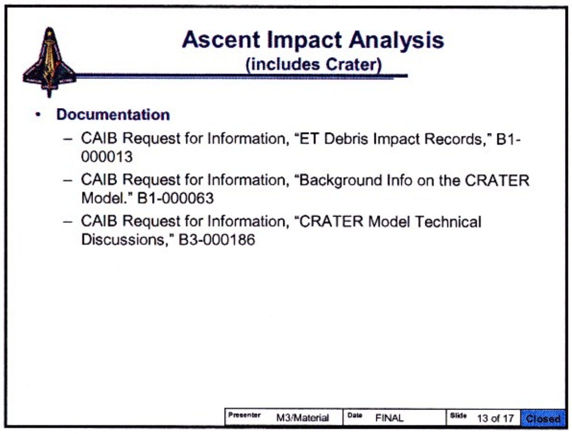
Presenter M3/Material	Date FINAL	Slide 11 of 17	Closed

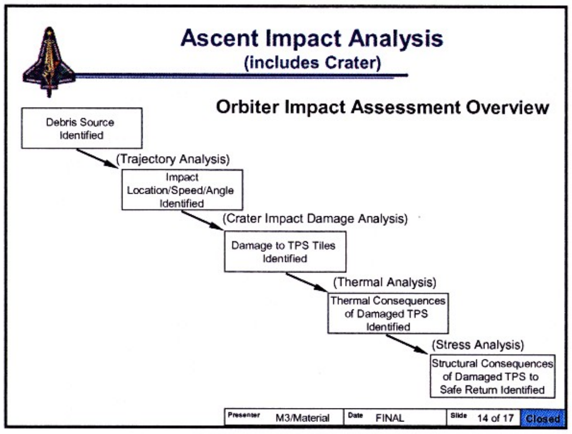
Ascent Impact Analysis
(includes Crater)

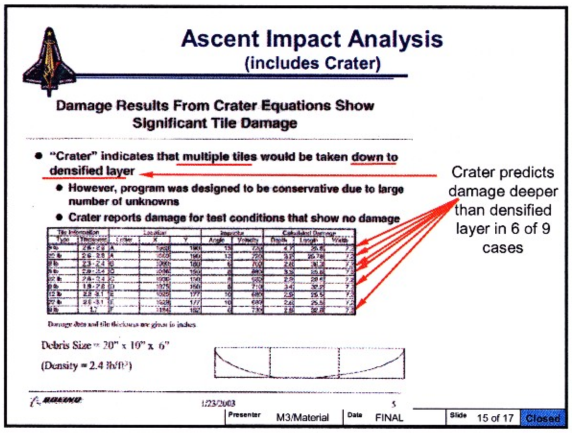
- **Recommendations** (Crater):
  - NASA/USA/Boeing should continue to develop a more robust, physics-based model to analyze impact damage to tile and RCC
    - Development should take advantage of expertise from all available resources
  - Boeing should work to develop a user's manual for thermal and stress analysis associated with impacts
  - Boeing should continue to encourage communication between Houston and Huntington Beach technical communities in the future

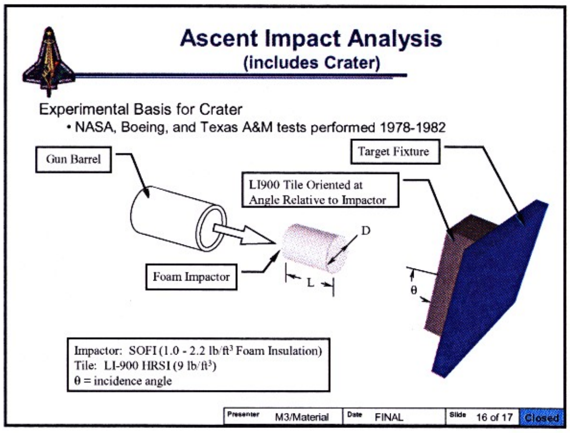
Presenter M3/Material	Date FINAL	Slide 12 of 17	Closed

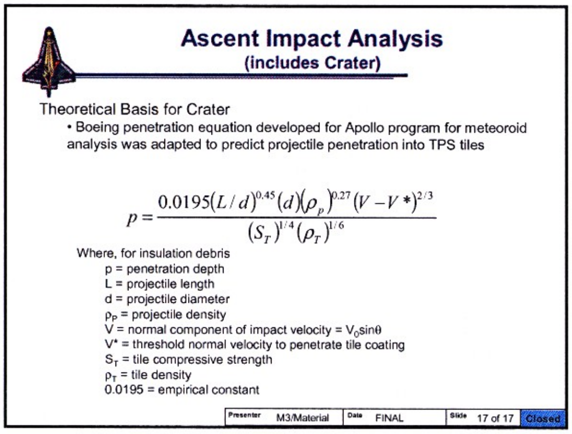
2


Ascent Impact Analysis
(includes Crater)
• Documentation
– CAIB Request for Information, "ET Debris Impact Records," B1-000013
– CAIB Request for Information, "Background Info on the CRATER Model." B1-000063
– CAIB Request for Information, "CRATER Model Technical Discussions," B3-000186
Presenter M3/Material Date FINAL Slide 13 of 17 Closed


Ascent Impact Analysis
(includes Crater)
Orbiter Impact Assessment Overview
Debris Source Identified
(Trajectory Analysis)
Impact Location/Speed/Angle Identified
(Crater Impact Damage Analysis)
Damage to TPS Tiles Identified
(Thermal Analysis)
Thermal Consequences of Damaged TPS Identified
(Stress Analysis)
Structural Consequences of Damaged TPS to Safe Return Identified
Presenter M3/Material Date FINAL Slide 14 of 17 Closed


Ascent Impact Analysis
(includes Crater)
Damage Results From Crater Equations Show Significant Tile Damage
• "Crater" indicates that multiple tiles would be taken down to densified layer
• However, program was designed to be conservative due to large number of unknowns
• Crater reports damage for test conditions that show no damage
Crater predicts damage deeper than densified layer in 6 of 9 cases
Debris Size = 20" x 10" x 6"
(Density = 2.4 lb/ft³)
1/23/2003
5
Presenter M3/Material Date FINAL Slide 15 of 17 Closed


Ascent Impact Analysis
(includes Crater)
Experimental Basis for Crater
• NASA, Boeing, and Texas A&M tests performed 1978-1982
Gun Barrel
Target Fixture
LI900 Tile Oriented at Angle Relative to Impactor
D
Foam Impactor
L
θ
Impactor: SOFI (1.0 - 2.2 lb/ft³ Foam Insulation)
Tile: LI-900 HRSI (9 lb/ft³)
θ = incidence angle
Presenter M3/Material Date FINAL Slide 16 of 17 Closed


Ascent Impact Analysis
(includes Crater)
Theoretical Basis for Crater
• Boeing penetration equation developed for Apollo program for meteoroid analysis was adapted to predict projectile penetration into TPS tiles
$p = \frac{0.0195(L/d)^{0.45}(d)(\rho_p)^{0.27}(V - V^*)^{2/3}}{(S_T)^{1/4}(\rho_T)^{1/6}}$
Where, for insulation debris
p = penetration depth
L = projectile length
d = projectile diameter
ρ_P = projectile density
V = normal component of impact velocity = $V_0 \sin\theta$
V* = threshold normal velocity to penetrate tile coating
S_T = tile compressive strength
ρ_T = tile density
0.0195 = empirical constant
Presenter M3/Material Date FINAL Slide 17 of 17 Closed

3

Ascent Debris

- **Action / Issue:** Review radar and optics results for evidence of debris during ascent
- **Background / Facts:**
  - STS-107 was tracked during ascent by Eastern Range land-based C-band radar and metric optics
  - Data was examined to identify any previously undetected debris
  - No radars detected debris prior to SRB separation
  - Only the Cocoa Beach Distant Object Attitude Measurement System (CB DOAMS) optical telescope observed debris around 81 seconds
    - 81.66 sec: single object between Orbiter nose cone and ET 1st detected, appeared white
    - 81.82 sec: struck under Orbiter's left wing, disintegrates into a cloud of orange-colored debris

Presenter M3/Material | Date FINAL | Slide 1 of 7 | Closed

Ascent Debris

- **Background / Facts:**
  - Debris detected by radar following SRB separation from T+150 to T+230 seconds
    - One radar (radar 0.14) detected 21 items
    - Another radar (radar 28.14) detected 6 items
    - Radar Cross-Section (RCS) ranged from –26 to –15 dBsm
    - Radar return signal was not of sufficient strength to determine approximate shape, size or rigidity of the debris
    - Radar analysis results are consistent with the debris analyses from previous STS missions

Presenter M3/Material | Date FINAL | Slide 2 of 7 | Closed

Ascent Debris
Radar 0.14 Results

CATALOG #	PIECE NUMBER	FIRST APPEARANCE	LAST APPEARANCE	MAX RCS (dBsm)	RANGE SEPARATION RATE (m/s)
1	**	80.4	87	5	14
2	1	152.5	156	*	*
3	2	152.5	162.5	-24	326
4	3	153	160	-23	229
5	4	156	170	-20	217
6	5	158.5	171	-21	309
7	6	164	170	-21	312
8	7	166.5	173	-21	357
9	8	167	184.5	-19	260
10	9	170	184.5	-19	265
11	10	174.5	180	-20	290
12	11	173	180	-21	206
13	12	174	175.1	-19	244
14	13	175.5	180	-18	180
15	14	178	180	-18	296
16	15	184	190	-20	236

Presenter M3/Material | Date FINAL | Slide 3 of 7 | Closed

Ascent Debris
Radar 0.14 Results (Continued)

CATALOG #	PIECE NUMBER	FIRST APPEARANCE	LAST APPEARANCE	MAX RCS (dBsm)	RANGE SEPARATION RATE (m/s)
17	16	187	192.5	-20	649
18	17	204.5	210	*	*
19	18	204.5	214	-26	326
20	19	204.5	212	-24	166
21	20	206	212	-24	225
22	21	211.5	228	-22	219

* The RCS and range separation rate of these pieces cannot be determined due to the low level of signal returns. RCS is estimated to be within 0 to 3 dB of the Minimum Detectable RCS.

** These events have been determined to be due to plume effects.

Presenter M3/Material | Date FINAL | Slide 4 of 7 | Closed

Ascent Debris
Radar 28.14 Results

CATALOG #	PIECE NUMBER	FIRST APPEARANCE	LAST APPEARANCE	MAX RCS (dBsm)	RANGE SEPARATION RATE (m/s)
23	2	152	158.5	*	*
24	4	154.5	162	-17	400
25	8 or 9	167	176.5	-20	221
26	14	179	187.5	-15	884
27	16	201	207	*	*
28	17 or 18	205	208.5	*	*

* The RCS and range separation rate of these pieces cannot be determined due to the low level of signal returns. RCS is estimated to be within 0 to 3 dB of the Minimum Detectable RCS.

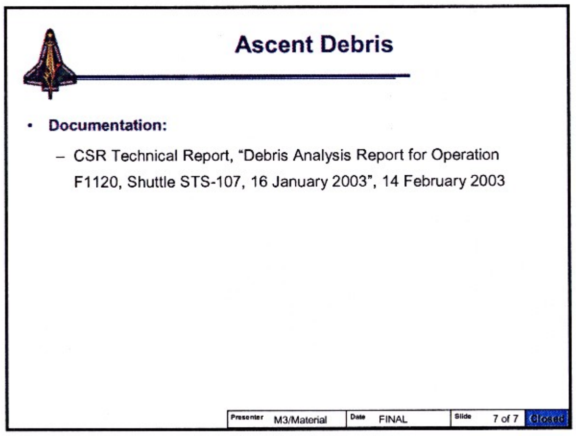
Presenter M3/Material | Date FINAL | Slide 5 of 7 | Closed

Ascent Debris

- **Findings:**
  - Radar detected debris after T=150 seconds
    - Debris could not be identified
    - Radar returns similar to past STS missions
  - CB DOAMS observed debris between orbiter and ET at 81.66 seconds
- **Recommendations:**
  - Issue should be closed

Presenter M3/Material | Date FINAL | Slide 6 of 7 | Closed

1


Ascent Debris
• Documentation:
– CSR Technical Report, "Debris Analysis Report for Operation F1120, Shuttle STS-107, 16 January 2003", 14 February 2003
Presenter M3/Material
Date FINAL
Slide 7 of 7
Closed

2

Maintenance
Hold Down Cable Anomaly

- **Action / Issue:** Could orbiter MECs/cabling failure to the hold down post (HDP) pyrotechnics and ET vent arm system (ETVAS) be catastrophic?
- **Background / Facts:**
  - PIA #3007 stated that STS 112 had a failure in the system that controls firing of the initiators in each SRB restraint nut
  - Redundancy in each Master Events Controller (MEC)
    - MEC#1 feeds A system, MEC#2 feeds B system
  - Each nut has two initiators, one on A system, one on B
  - Signal sent by MECs to nut to fire and ETVAS to retract
  - Either MEC will operate system in event of failure in the other
  - During STS-112 the Ground Launch Sequencer (GLS) issued "Cut Off" at T+ 3 Seconds
    - Post launch review indicated that system A HDP and ETVAS Pyrotechnic Initiator Controllers (PICs) did not discharge

Presenter M3/Maintenance | Date FINAL | Slide 1 of 7 | Closed

Maintenance
Hold Down Cable Anomaly

- **Findings:**
  - Pyro systems A and B are independent and redundant
  - The HDP and ETVAS systems receive Fire commands at T-0
    - Fire 1 and Fire 2 commands are sent as a nearly simultaneous event
  - Each redundant pyro device is initiated by a dedicated PIC
    - 16 separate PICs for "A" and "B" HDP devices and four separate PICs for "A" and "B" ETVAS devices
  - The PIC design requires 3 separate commands to detonate its NASA Standard Initiator (NSI)
    - ARM—Activates the PIC's power supply and charges capacitor bank
    - Fire1—Activates a switching transistor controlling the PIC output return and enables the Fire2
    - Fire2—Activates a switching transistor controlling the PIC output
  - ETVAS pyro Fire commands are branched from the HDP Fire commands
  - HDP "A" PIC and ETVAS "A" PIC failed to discharge

Presenter M3/Maintenance | Date FINAL | Slide 2 of 7 | Closed

Maintenance
Hold Down Cable Anomaly

- **Findings:**
  - Extensive analysis and study was initiated immediately
  - Approx. 25 different potential fault chains were considered as source of A system failure
  - Definite cause never determined, considered intermittent
  - Most probable cause: the fire 1 command wasn't transmitted properly from MEC 1 to PIC Rack 6743 in the MLP
  - Focus of command path anomaly is on T-0 electrical interface
    - Not cleared during investigation since normal function (T-0 separation) destroyed evidence
  - Inspection has detected wear and contamination at interface

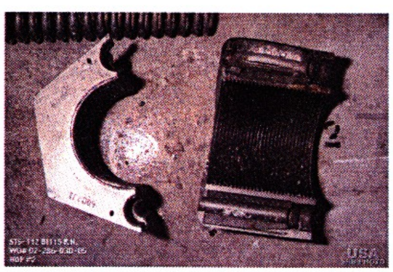
Presenter M3/Maintenance | Date FINAL | Slide 3 of 7 | Closed

Maintenance
Hold Down Cable Anomaly

- **Findings:**
  - STS-112 investigation recommendations implemented:
    - All T-0 Ground Cables have been replaced after every flight
    - T-0 interface to PIC rack cable in redesign, ETIC July 03
      - Old T-0 Ground cable and this Kapton
    - All Orbiter T-0 Connector Savers have been replaced
      - Pyro connectors prescreened with pin retention test
    - Connector saver mate will be verified using Videoscope
- **Recommendations:**
  - Inquiry released for failure potential on this CRIT IR system
  - Specifically, what is chance of a concurrent failure of a MEC/cable and one or more initiators? What would result? Can NASA redesign system to add cable from each system to every initiator so a signal system failure would not disable half of the initiators?

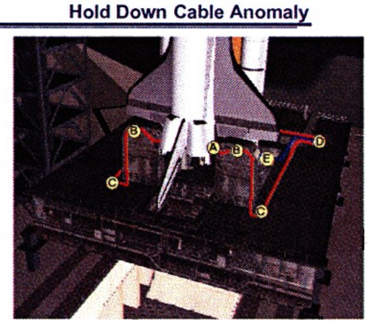
Presenter M3/Maintenance | Date FINAL | Slide 4 of 7 | Closed

Maintenance
Hold Down Cable Anomaly



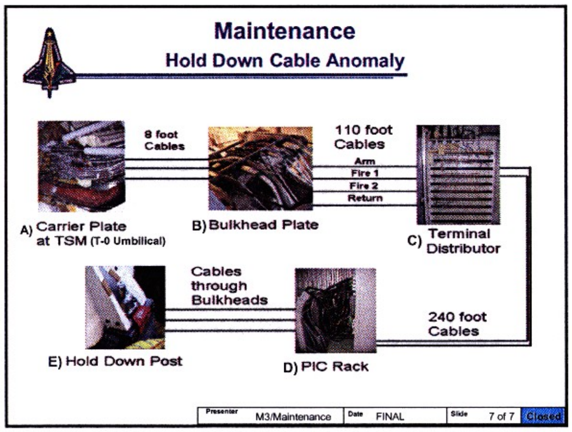
Presenter M3/Maintenance | Date FINAL | Slide 5 of 7 | Closed

Maintenance
Hold Down Cable Anomaly



Presenter M3/Maintenance | Date FINAL | Slide 6 of 7 | Closed

1


Maintenance
Hold Down Cable Anomaly
8 foot Cables
110 foot Cables
Arm
Fire 1
Fire 2
Return
A) Carrier Plate at TSM (T-0 Umbilical)
B) Bulkhead Plate
C) Terminal Distributor
Cables through Bulkheads
240 foot Cables
E) Hold Down Post
D) PIC Rack
Presenter M3/Maintenance
Date FINAL
Slide 7 of 7
Closed

2

Other Orbit

22-1 FD2 On-Orbit Object

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	25 of 32

FD2 – On-Orbit Object

- **Action / Issue:** Determine on-orbit object detected by ground radar during post-flight data review
- **Background / Facts:**
  - While on orbit, 3,180 separate radar or optical observations of Columbia were collected
  - Collection sites includes: Eglin AFB, Beale AFB, Navy Space Surveillance, Cape Cod, Maui, and Kirtland AFB
  - Each observation was individually examined **after** the accident
  - 1st Space Control Squadron and AFSPC Space Analysis Center personnel conducted detailed analysis
  - Post-flight processing discovered a small object in shuttle orbit
    - Object referred to by International Designator 2003-003B

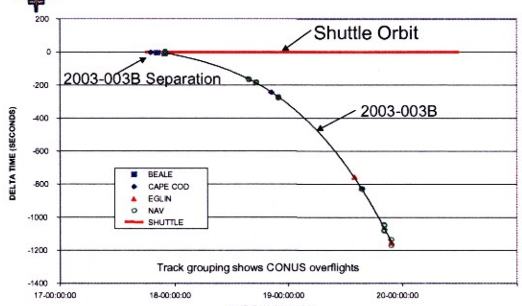
Presenter M3/Material | Date FINAL | Slide 1 of 25 | Closed

FD2 – On-Orbit Object

- **Event Timeline:**
  - Jan 17, 1442Z: Shuttle reoriented
    - Moved from tail-first to right wing-first orientation
  - Jan 17, 1517Z: Shuttle reoriented
    - Returned to tail-first orientation
  - Jan 17, 1500-1615Z: Object 2003-003B separates
  - Jan 17, 1857Z: First confirmed sensor track
  - Jan 19, 2146Z: Last confirmed sensor track
  - Jan 20, 0145-0445Z: Object 2003-003B decays

Presenter M3/Material | Date FINAL | Slide 2 of 25 | Closed

FD2 – On-Orbit Object



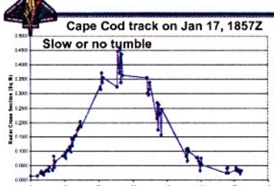
Presenter M3/Material | Date FINAL | Slide 3 of 25 | Closed

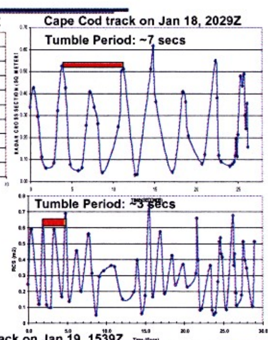
FD2 – On-Orbit Object

- **Background / Facts:**
  - On-orbit object 2003-003B detected by Cape Cod PAVE PAWS radar during passes on 3 days before de-orbiting
    - Day 1 Track: -18 to - 4 dBsm
    - Day 2 Track: -15 to - 2 dBsm
    - Day 3 Track: -13 to -1.75 dBsm
  - Object tumble rate increased with time
  - RCS varies from ~0.1 to ~0.7 m^2

Presenter M3/Material | Date FINAL | Slide 4 of 25 | Closed

FD2 – On-Orbit Object





- 2003-003B started to rapidly tumble between Jan 17 and 18, rate increased on Jan 19

Presenter M3/Material | Date FINAL | Slide 5 of 25 | Closed

FD2 – On-Orbit Object

- **Background / Facts :**
  - Radar Cross-Section (RCS) combined with ballistics results used to determine potential FD2 object
    - Potential candidate orbiter parts must match both RCS and ballistics as a minimum
  - AFRL conducted RCS measurements of 26 orbiter parts to compare to on-orbit signature and 4 RCC pieces from STS-107 RH debris
  - US Space Command determined ballistics coefficient of on-orbit object and all parts measured for RCS signature
    - Ballistics coefficient = (Drag Coefficient * Area) / Mass
    - Area/Mass ratio for on-orbit object determined to be 0.1 $meters^2$ / kg

Presenter M3/Material | Date FINAL | Slide 6 of 25 | Closed

1

FD2 – On-Orbit Object

- **Background / Facts:**
  - Obtained RCS measurements for the following RH parts from OV-102 debris:
    - Part 51311, 8" x 13" RCC fragment with lip
    - Part 37736, curved RCC fragment with no lip
    - Part 2018, 8" x 11" RCC flat acreage
    - Part 51313, T-seal fragment at panel 8/9

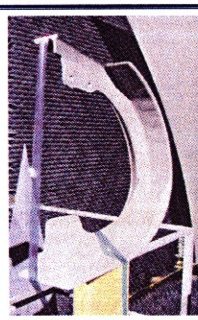
Presenter M3/Material | Date FINAL | Slide 7 of 25 | Closed

FD2 – On-Orbit Object

- **Background / Facts:**
  - Parts that matched both RCS signature and ballistics:
    - RCC panel acreage piece if approximately 100 to 150 inch^2
  - Parts rejected due to RCS signature, ballistics or both include:
    - 14 blanket-type insulators or cloth-like material
    - 5 lower carrier panels with and without horsecollars
    - 4 RSI tiles
    - 1 RCC panel with all metallic hardware
    - 1 upper carrier panel

Presenter M3/Material | Date FINAL | Slide 8 of 25 | Closed

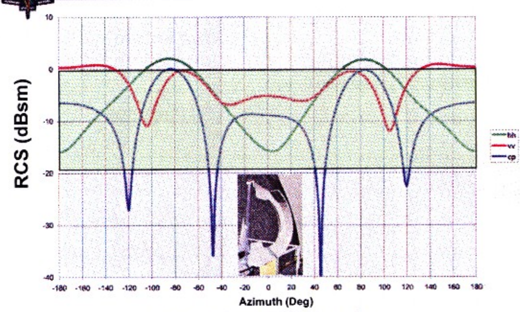
FD2 – On-Orbit Object



RCC T-Seal Measured for RCS Signature

Presenter M3/Material | Date FINAL | Slide 9 of 25 | Closed

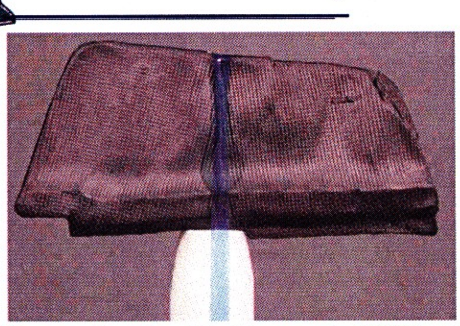
FD2 – On-Orbit Object



RCC T-Seal RCS Results

Presenter M3/Material | Date FINAL | Slide 10 of 25 | Closed

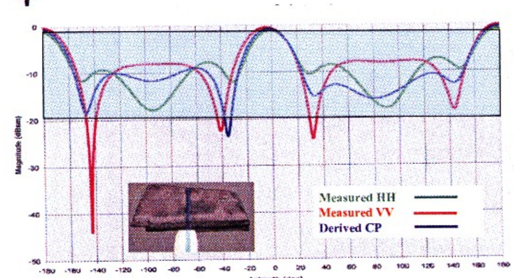
FD2 – On-Orbit Object



WLE Spanner Beam Insulator Measured for RCS Signature

Presenter M3/Material | Date FINAL | Slide 11 of 25 | Closed

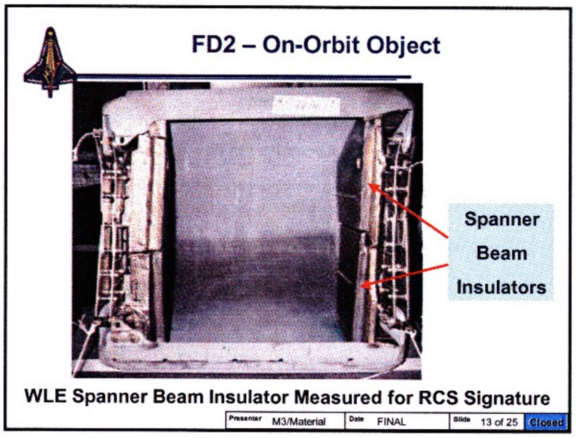
FD2 – On-Orbit Object

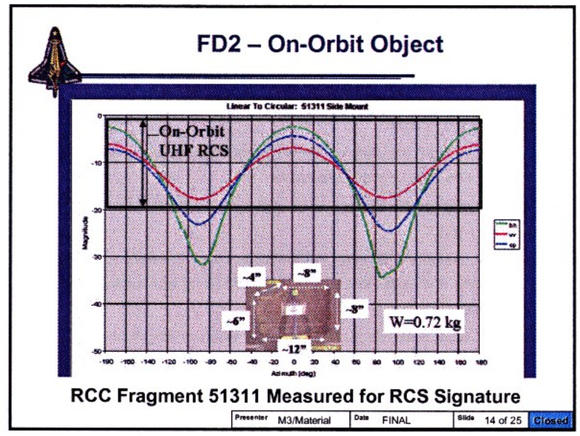


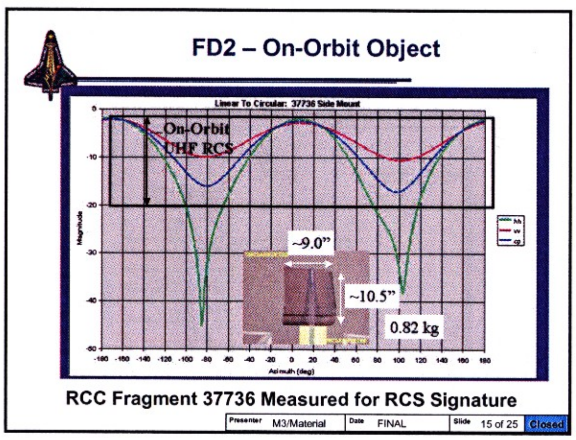
WLE Spanner Beam Insulator RCS Results

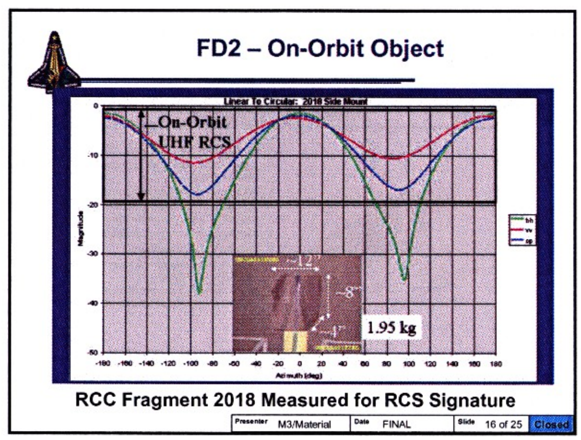
Presenter M3/Material | Date FINAL | Slide 12 of 25 | Closed

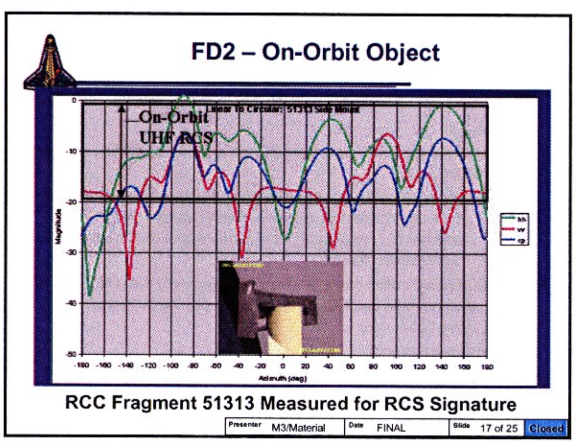
2

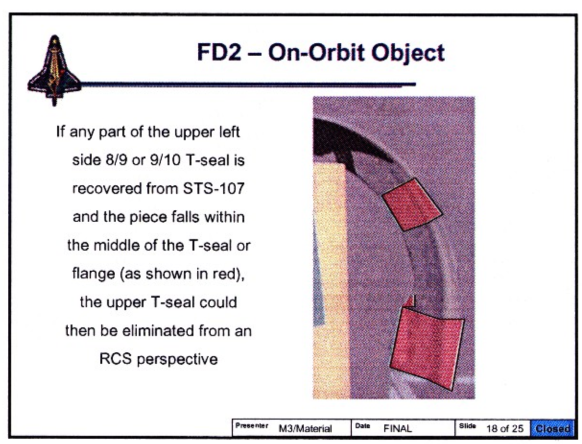

FD2 – On-Orbit Object
Spanner
Beam
Insulators
WLE Spanner Beam Insulator Measured for RCS Signature
Presenter M3/Material
Date FINAL
Slide 13 of 25
Closed


FD2 – On-Orbit Object
On-Orbit
UHF RCS
~4"
~8"
~8"
~6"
~12"
W=0.72 kg
RCC Fragment 51311 Measured for RCS Signature
Presenter M3/Material
Date FINAL
Slide 14 of 25
Closed


FD2 – On-Orbit Object
On-Orbit
UHF RCS
~9.0"
~10.5"
0.82 kg
RCC Fragment 37736 Measured for RCS Signature
Presenter M3/Material
Date FINAL
Slide 15 of 25
Closed


FD2 – On-Orbit Object
On-Orbit
UHF RCS
1.95 kg
RCC Fragment 2018 Measured for RCS Signature
Presenter M3/Material
Date FINAL
Slide 16 of 25
Closed


FD2 – On-Orbit Object
On-Orbit
UHF RCS
RCC Fragment 51313 Measured for RCS Signature
Presenter M3/Material
Date FINAL
Slide 17 of 25
Closed


FD2 – On-Orbit Object
If any part of the upper left side 8/9 or 9/10 T-seal is recovered from STS-107 and the piece falls within the middle of the T-seal or flange (as shown in red), the upper T-seal could then be eliminated from an RCS perspective
Presenter M3/Material
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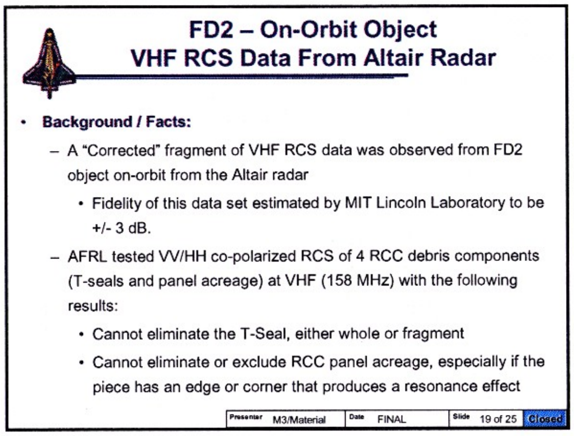
3


FD2 – On-Orbit Object
VHF RCS Data From Altair Radar
• Background / Facts:
– A "Corrected" fragment of VHF RCS data was observed from FD2 object on-orbit from the Altair radar
• Fidelity of this data set estimated by MIT Lincoln Laboratory to be +/- 3 dB.
– AFRL tested VV/HH co-polarized RCS of 4 RCC debris components (T-seals and panel acreage) at VHF (158 MHz) with the following results:
• Cannot eliminate the T-Seal, either whole or fragment
• Cannot eliminate or exclude RCC panel acreage, especially if the piece has an edge or corner that produces a resonance effect
Presenter M3/Material
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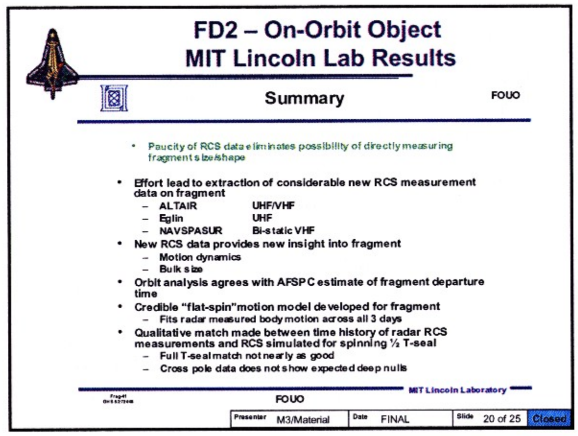
FD2 – On-Orbit Object
MIT Lincoln Lab Results
Summary
FOUO
• Paucity of RCS data eliminates possibility of directly measuring fragment size/shape
• Effort lead to extraction of considerable new RCS measurement data on fragment
– ALTAIR UHF/VHF
– Eglin UHF
– NAVSPASUR Bi-static VHF
• New RCS data provides new insight into fragment
– Motion dynamics
– Bulk size
• Orbit analysis agrees with AFSPC estimate of fragment departure time
• Credible "flat-spin" motion model developed for fragment
– Fits radar measured body motion across all 3 days
• Qualitative match made between time history of radar RCS measurements and RCS simulated for spinning ½ T-seal
– Full T-seal match not nearly as good
– Cross pole data does not show expected deep nulls
MIT Lincoln Laboratory
FOUO
Presenter M3/Material
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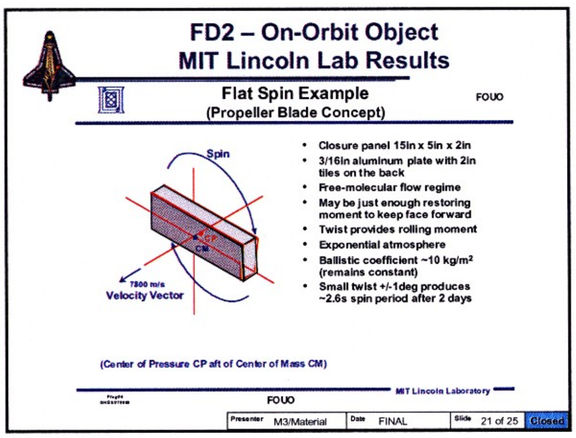
FD2 – On-Orbit Object
MIT Lincoln Lab Results
Flat Spin Example
(Propeller Blade Concept)
FOUO
Spin
CP
CM
7800 m/s
Velocity Vector
• Closure panel 15in x 5in x 2in
• 3/16in aluminum plate with 2in tiles on the back
• Free-molecular flow regime
• May be just enough restoring moment to keep face forward
• Twist provides rolling moment
• Exponential atmosphere
• Ballistic coefficient ~10 kg/m²
(remains constant)
• Small twist +/-1deg produces ~2.6s spin period after 2 days
(Center of Pressure CP aft of Center of Mass CM)
MIT Lincoln Laboratory
FOUO
Presenter M3/Material
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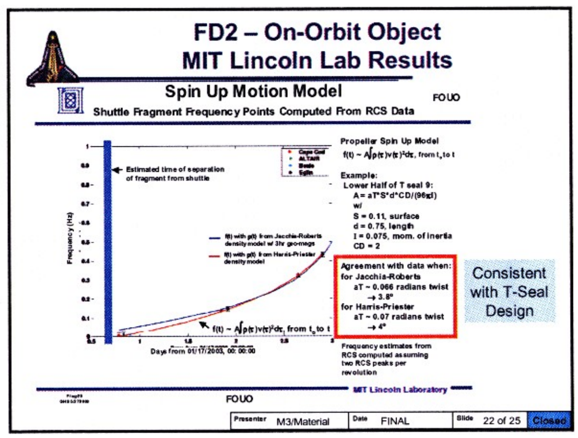
FD2 – On-Orbit Object
MIT Lincoln Lab Results
Spin Up Motion Model
Shuttle Fragment Frequency Points Computed From RCS Data
FOUO
Estimated time of separation of fragment from shuttle
Frequency (Hz)
Days from 01/17/2003, 00:00:00
Propeller Spin Up Model
Example:
Lower Half of T seal 9:
S = 0.11, surface
d = 0.75, length
I = 0.075, mom. of inertia
CD = 2
Agreement with data when:
for Jacchia-Roberts
aT ~ 0.066 radians twist
→ 3.8°
for Harris-Priester
aT ~ 0.07 radians twist
→ 4°
Consistent with T-Seal Design
Frequency estimates from RCS computed assuming two RCS peaks per revolution
MIT Lincoln Laboratory
FOUO
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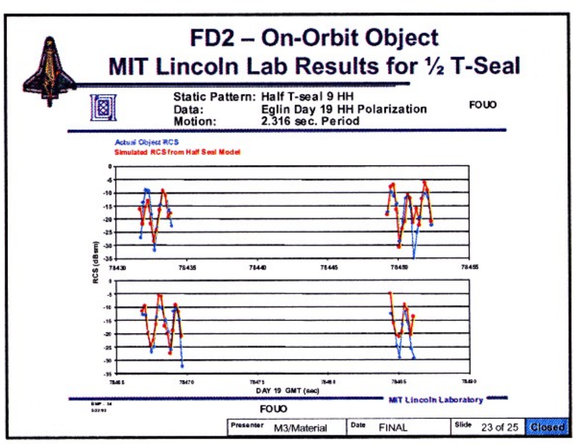
FD2 – On-Orbit Object
MIT Lincoln Lab Results for ½ T-Seal
Static Pattern: Half T-seal 9 HH
Data: Eglin Day 19 HH Polarization
Motion: 2.316 sec. Period
FOUO
Actual Object RCS
Simulated RCS from Half Seal Model
RCS (dBsm)
DAY 19 GMT (sec)
MIT Lincoln Laboratory
FOUO
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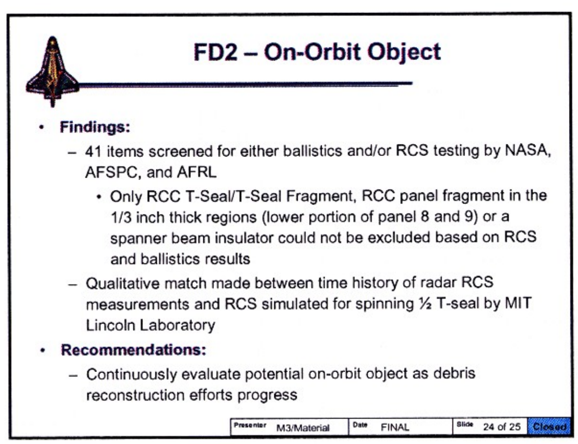
FD2 – On-Orbit Object
• Findings:
– 41 items screened for either ballistics and/or RCS testing by NASA, AFSPC, and AFRL
• Only RCC T-Seal/T-Seal Fragment, RCC panel fragment in the 1/3 inch thick regions (lower portion of panel 8 and 9) or a spanner beam insulator could not be excluded based on RCS and ballistics results
– Qualitative match made between time history of radar RCS measurements and RCS simulated for spinning ½ T-seal by MIT Lincoln Laboratory
• Recommendations:
– Continuously evaluate potential on-orbit object as debris reconstruction efforts progress
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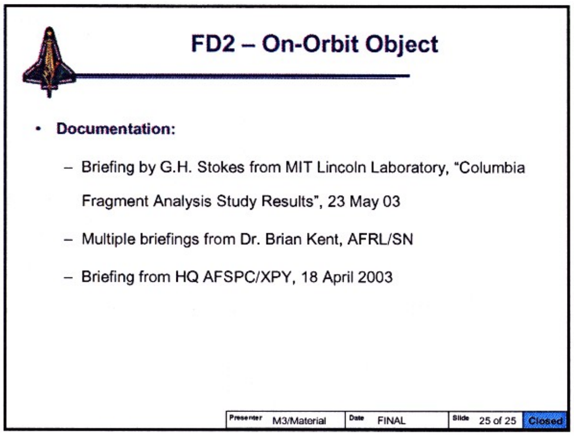
FD2 – On-Orbit Object
• Documentation:
– Briefing by G.H. Stokes from MIT Lincoln Laboratory, "Columbia Fragment Analysis Study Results", 23 May 03
– Multiple briefings from Dr. Brian Kent, AFRL/SN
– Briefing from HQ AFSPC/XPY, 18 April 2003
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5

Organization
Production

23-1 SSP Centralization/Decentralization

23-5 Contract Management Culture

23-6 CoFR Process Integrity

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	26 of 32

Production-Organization
Centralization/Decentralization in SSP

- **Action / Issue:** Organizational Characteristics, Policies, & Practices
- **Background / Facts:**
  - Centralized and formal communications, decision-making, and risk management to cope with "tight coupling" linked to the numerous events associated with "normal operations" to provide for immediate responses (e.g., FRR, COFR, etc.).
  - Decentralized and more informal communications, decision-making, and risk management to provide for deliberate analysis to handle unplanned "interactive complexity" of failures by those closest to subsystems (e.g., MMT, MER, etc.).
  - Scheduling demands, workload, staffing shortages/inexperience, performance incentives , etc. increase the opportunity for tighter coupling and additional interactive complexity for both normal and emergency operations.

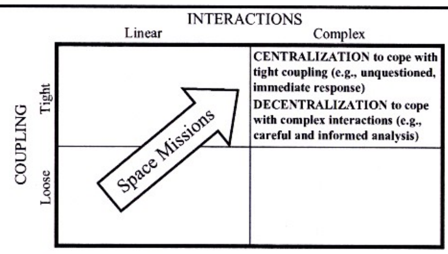
Presenter M3/Human Factors | Date FINAL | Slide 1 of 4 | Closed

Production-Organization
Centralization/Decentralization in SSP

- **Findings:** Demands associated with centralized and decentralized processes are incompatible, while the former presses for inputs to address scheduled events, the latter presses for time to thoroughly make assessments. Centralization leads to more prescribed meetings, documentation, etc., whereas decentralization tends to be more informal and have varied patterns of interactions, level of documentation, etc.

- **Recommendations:** SSP should be viewed as a flight test environment, therefore the post-launch management should be more formal and systematic, similar to that for the Pre-Launch COFR

Presenter M3/Human Factors | Date FINAL | Slide 2 of 4 | Closed



"For the interactively complex and tightly coupled system the demands are inconsistent. Because of the complexity, they are best decentralized; because of tight coupling, they are best centralized. While some mix might be possible, and is sometimes tried, this appears to be difficult for systems that are reasonably complex and tightly coupled, and impossible for those that are highly complex and tightly coupled. We saw the space missions move from a highly centralized mode in the first missions to a more decentralized one in the moon shots, and the somewhat less complex and tightly coupled space shuttle may allow for more decentralization. But I predict that the tensions between the two modes will remain, and consume a good deal of organizational energy."

(Source: Perrow *Normal Accidents*)

Centralization/Decentralization in SSP: Pre- vs. Post- Launch Comparison

- Pre-Launch:
  - Centralized Decision Making w/Defined CoC Roles/Actions
  - Formalized Mission Planning, Problem Resolution, & SOF Determination

  Theme:
  "Prove There Is Not A SOF Problem"
  - NASA Space Centers Visibly Interacting
  - Interactive Complexity Due To Geographic Dislocation & Component Integration Process
  - Tight Coupling Due to Mission Schedule & Stovepipe Operations; # CRIT 1 Hazards & Lack of Redundant Systems
- Post-Launch:
  - Centralized Decision Making w/Delegated Responsibilities
  - Less Formal Mission Monitoring, Anomaly Review, & SOF Determination

  Theme:
  "Prove There Is A SOF Problem"
  - JSC Primary w/Minimal Outside Center Input
  - Greater Interactive Complexity Due To Orbiter Technologies & Space Environment
  - Increased Tight Coupling Due to Real-time OPS & Little On-Orbit Flexibility; # CRIT 1 Hazards & Lack of Redundant Systems

Presenter M3/Human Factors | Date FINAL | Slide 4 of 4 | Closed

1

Organization-Production: SSP Contracting Culture

- **Action / Issue:** Evolution of NASA SSP culture from engineering to one dominated by contract management
- **Background / Facts:** Transition to SFOC & Primary Contractors has altered the balance of SSP engineering efforts from NASA to contractors
- **Findings:**
  - SSP engineering personnel shortages have led to reduced oversight of contractor activities, and increased use of "insight" within them.
  - Planned SLEP extension and an aging shuttle require added attention to analyze operational stress effects, identify new hazards, etc.
  - Potential exits for reduced engineering awareness to identify problem areas as well as engineering capability to effectively address them.
  - NASA SSP engineering and scientific oversight is necessary to ensure aging aircraft issues are monitored, studied, and acted on.

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Automation-Contracting Analogy

- Reasons for Implementation of Automation in Aircraft
  - Reduce Pilot Workload to Cope w/Advanced Technology
  - Shift Pilot Primary Focus to Mission vs. A/C Operation
  - Decrease Potential for Pilot Errors
- Actual Outcomes
  - Shift from Psychomotor to Primarily Cognitive Workload
  - Causes Similar Errors; Generated New Types
- Reasons for Instituting SFOC & Other Contracts
  - Reduce NASA SSP Workload to Cope w/Budget Constraints
  - Shift SSP Primary Focus to Operations vs. R & D effort
  - Increase Efficiency; Maintain Safety
- Actual Outcomes
  - Shift from Engineer Oversight to Contract Manager Insight
  - Some Efficiencies; May have Impacted Safety

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Automation-Contracting Analogy

- Effects of Automation
  - Increased Systems Monitoring
  - Automation Complacency
  - Loss/Erosion of Situational Awareness
  - Selective Signal Display Filtering
  - Eroded Pilot Skills
- Effects of Contracting
  - Increased Contract Monitoring
  - Contract Complacency
  - Loss/Erosion of Program Awareness
  - Selective Signal Display Filtering
  - Eroded Engineer Skills

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Organization-Production: SSP Contracting Culture

- **Recommendations:**
  - NASA must develop a capacity to provide oversight, not only for S&MA, but also oversight on the engineering level for each critical technology area.
  - NASA must acquire and develop an engineering staff and provide for requisite training to support both oversight roles

Presenter	M3/Human Factors	Date	FINAL	Slide	4 of 4	Closed

1

Organization- Fleet Experience: Potential COFR Process Defense Breaches

- **Action/Issue:**
  Pre-Launch Factors May Impact COFR Process Effectiveness
- **Background/Facts:** Reason's "Swiss Cheese" Model is used to categorize/organize latent conditions of failed or absent defenses that "set the stage" for active failures which lead to incidents; it can also be used for examining those factors affecting decision-making
- **Findings:** SSP COFR is considered a rigorous, systematic process leading to accurate SOF launch decisions. It is perceived as being shielded from outside factors, yet if an organization, supervisor, or member is influenced by external factors, it can be contended the process can miss signals of absent/failed defenses, accept perceived minor deviations, or permit margin of safety reductions.

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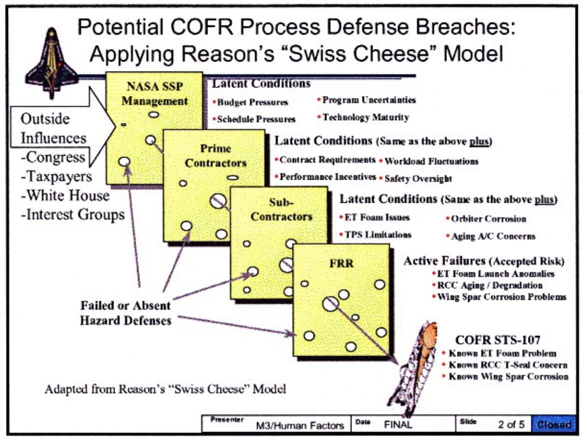

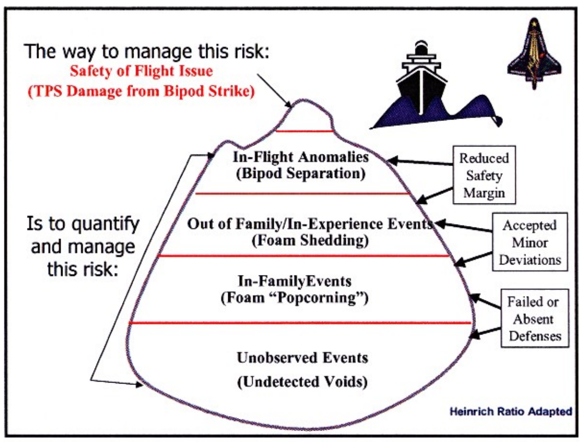

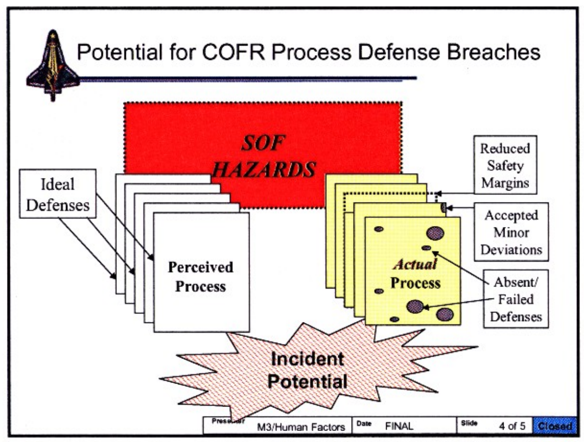

Organization-Fleet Experience: Potential COFR Process Defense Breaches

- **Recommendations:**
  - NASA should examine potential pre-launch factors that can influence FRRs and the subsequent COFR process to ensure external factors do not weigh-in on SOF decisions
  - NASA should ensure potential SOF information is actively sought and acted upon, not filtered and ignored due to pressure, complacency, or norms.

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Organization
Fleet Experience – Aging

23-2 High Reliability Organizations

23-3 Risk Acceptance in the SSP

23-9 Role of Space Shuttle Systems Integration Office

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	27 of 32

Organization-Fleet Experience: SSP as a High Reliability Organization

- **Action / Issue:** The SSP needs to more closely align itself as an HRO
- **Background / Facts:** Organizations that have less than their "fair share" of failures (e.g., nuclear submarines, petrochemical plants, etc. despite:
  - managing complex & demanding technologies
  - meeting peak requirements & time pressures
  - routinely handling significant risks & hazards
  - executing dynamic/intensely interactive tasks

  are termed High Reliability Organizations (HROs). They exhibit "mindfulness", an ability to identify an maintain awareness of potentially hazardous situations and to act quickly to contain or mitigate them

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Organization-Fleet Experience: SSP as a High Reliability Organization

- **Background / Facts (con't):**
  - ✓ Preoccupation with failures- treating any performance lapses as a symptom of a system based problem
  - ✓ Reluctance to simplify interpretations- deliberately taking steps to create more complete/nuanced pictures
  - ✓ Sensitivity to operations- attending to front-line conditions for well-developed situational awareness
  - ✓ Commitment to resilience- develop capabilities to detect, contain, and recover from inevitable errors
  - ✓ Deference to expertise- encouragement of a fluid decision-making system using appropriate personnel

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Organization-Fleet Experience: SSP as a High Reliability Organization

- **Findings:** Pre-launch events as well as historical factors indicate the SSP is not fully aligned as an HRO. Some examples that the SSP does not fully exhibit the characteristics of a HRO, include :
  - ➢ *Preoccupation with Success:*
    - ET foam shedding accepted as in-family event
  - ➢ *Tendency to Simplify Interpretations:*
    - Shuttle is operational and its technology is mature
  - ➢ *Insensitivity to Operations:*
    - Effect of consolidation moves on experience and skill level
  - ➢ *Non-Commitment to Resilience:*
    - Predisposition for post-landing vs. on-orbit damage assessment
  - ➢ *Lack of Deference to Expertise:*
    - Limited post-launch JSC interactions w/centers (OPS vs. R&D)

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Table 1: Reasons for Spacecraft Failures

Reasons for Failure	Major Program Reviews: Broad Area Review	Lockheed Martin Independent Assessment Team	Faster, Better, Cheaper Task Force	Major Mishap Reviews: WIRE[a]	Mars Climate Orbiter	Mars Polar Lander	Lewis	SOHO[b]	Mars Observer	DC-X[c]	Challenger
Cost and Schedule Constraints	•			•			•		•		•
Insufficient Risk Assessment and Planning		•	•		•	•	•	•	•	•	•
Underestimation of Complexity and Technology Maturity	•		•				•	•	•		
Insufficient Testing			•	•	•		•		•	•	•
Poor Team Communication	•	•	•	•	•	•	•	•			•
Inattention to Quality and Safety	•	•	•		•						•
Inadequate Review Process	•	•	•	•	•	•	•	•		•	•
Design Errors	•			•	•	•			•	•	•
Inadequate System Engineering	•	•	•	•	•	•	•	•	•		
Inadequate or Under Trained Staff		•			•	•		•	•	•	•

Identified Reasons for Failure

Source: RAND, used with permission.

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Reason for Failure (Taken from Rand report)	STS-107 Pre-Launch Issues
Cost & Schedule Constraints	OMM Overrun, #Mission Slips, & ISS Schedule
Insufficient Risk Assessment & Planning	Previous Foam, Tile, & RCC Events & Potential Interaction
Underestimation of Complexity & (Overestimation of) Technology Maturity	TPS- Tile/RCC & Foam (e.g., MFG, Install, Aging, & Repairs)
Insufficient Testing (e.g., Testing, Analysis, NDE, etc.)	TPS- Tile/RCC & Foam (e.g., MFG, Install, Aging, & Repairs)
Poor Team Communication	Stove-Piping of Component Operations & Horizontal Integration in Technology Areas
Inattention to Quality & Safety	SFOC Transition: NASA Insight vs. Oversight
Inadequate Review Process	TPS- Tile/RCC & Foam (e.g., MFG, Install, Aging, & Repairs)
Design Errors (e.g. Inadequate Specs, Criteria, etc.)	TPS- Tile/ RCC & Foam (e.g., Anomalies, Specifications, BiPOD, etc.)
Inadequate System Engineering	Component Integration Concerns (e.g., ET Foam Mating Damage)
Inadequate or Under Trained Staff	ENG: Staffing Levels, Size, & Experience* OMM: QA Insp., Aging Workers, & Workload*

*Not a factor in STS-107

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Organization-Fleet Experience: SSP as a High Reliability Organization

- **Recommendations:**
  - Re-examine treatment/resolution of past, present & future anomalies
  - Provide for greater hands-on presence & involvement of NASA personnel in all aspects of the SSP
  - Reform pre-/ post- launch reviews, add a pre-landing review, & retool on-orbit mission monitoring/support
  - Provide for improved post-launch & on-orbit vehicle assessment as well as on-orbit repair & escape
  - Establish a matrix of Subject Matter Experts to be enlisted for respective technology areas impacted by anomalies

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Organization-Fleet Experience:
Risk Acceptance in the SSP

- **Action / Issue:**
  Risk Acceptance in the SSP
- **Background / Facts:**
  Scholars studying NASA & SSP have raised the issue of **risk acceptance,** overlooking/failing to recognize the severity of possible problems (e.g.,Vaughan, Feynman, etc.)

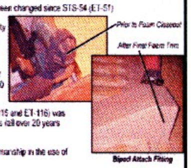
"Experience Rationalization"

SPACE SHUTTLE PROGRAM
Space Shuttle Projects Office (MSFC)

STS-112/ET-115 Bipod Ramp Foam Loss

Date October 31, 2002 Page 4

- **Rationale for Flight**
  - Current bipod ramp closeout has not been changed since STS-54 (ET-51)
  - The Orbiter has not experienced "Safety of Flight" damage from loss of foam in 112 flights (including 3 known flights with bipod ramp foam loss)
  - There have been no design / process / equipment changes over the the last 60 ETs (flights)
  - All ramp closeout work (including ET-115 and ET-116) was performed by experienced practitioners (all over 20 years experience each)
  - Ramp foam application involves craftsmanship in the use of validated application processes
  - No change in inspection / Process control / Post application handling, etc.
  - Probability of loss of ramp TPS is no higher/no lower than previous flights
  - ***The ET is safe to fly with no new concerns (and no added risk)***



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Organization-Fleet Experience:
Risk Acceptance in the SSP

How do We Know What to Fix?

There are things we know that we know,

There are things we do know that we don't know,

There are things we don't know that we don't know.

Honorable Donald Rumsfeld
U. S. Secretary of Defense
NATO HQ Press Conference, June '02

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Organization-Fleet Experience:
Risk Acceptance in the SSP

- **Findings:**
  - Risk acceptance may be a continuing phenomenon in the SSP.
    - Increase in waivers and "work arounds"
  - There seems to be repeated failure to identify and attend to weak signals occurring over time.
    - "foam loss never has been a SOF issue"
  - Bryan O'Connor (NASA HQ S&MA Officer) discusses 3 levels of the Risk Iceberg to describe Risk Acceptance in NASA:
    1. Known Knowns: Repeated or routine events and established facts.
    2. Known Unknowns: Known possible events, but unknown when or how they will happen. Also, recognizing the limits of one's knowledge.
    3. Unknown Unknowns: Rare (or have yet to occur) events. There is insufficient vigilance in the process to look for their possibility.
    4. *A possible fourth category:* Unknown Knowns: Situations where an abundance of data exists (known knowns), but it's too much information to filter through & select out the relevant data for a given situation in a timely manner. High signal to noise ratio (Thompson 2003). Especially relevant during crisis or unusual conditions, like mishaps.

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The Risk Iceberg

- Mishap recommendations
- Problem solutions
- IFA fixes

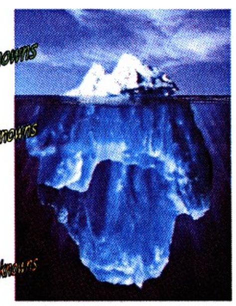
Known Knowns

- FMEA/Hazard controls
- Close call recommendations

Known Unknowns

- Ignored close calls?
- Old cert, new environment?
- Inadvertent excursions out of cert/family?
- Hardware talking…nobody listening?

Unknown Unknowns



Taken from a briefing by Bryan O'Connor on 19 March 03

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Organization-Fleet Experience:
Risk Acceptance in the SSP

Collaborative Product Between NASA and CAIB

LEVELS OF RISK ICEBURG	SKILLS	ANALYTICAL TOOLS
• Known Known –Repeated / routine events –Established facts –Verifiable	• Classical surveillance techniques • Mentoring of engineering science • Structured analytical approaches	• Statistical Process Control • Test / checkout procedures • Trending analysis
• Known Unknowns –Known possible events –Unknown when or how –Limits of knowledge known	• Inquisitive surveillance • Predictive / imaginative hypothesis • Measurements of knowledge	• Predictive analyses / documentation • Controlled experimentation • Test – to – failure approaches • Fleet leader approaches
• Unknown Known –Data exist –Too much information to filter –"High signal to noise"	• Data management skills • Interpretation skills • "Art" form of surveillance	• Automated data search technology • Trending / Analytical techniques • Intelligent applications
• Unknown Unknown –Rare / yet to occur events –Unable to recognize possibility –Beyond limits of knowledge	• Out-of-box thinking / inquisitive • Exploratory surveillance • High experience / technical knowledge • Imaginative / Intuitive –Naïve Objectivity "fresh look" perspective	• Integrity programs • Fleet leader approaches • Test – analyze – fix approaches • Design for test

- All levels require skill development and maintenance (structured training, simulation, case studies, etc.)
- Great discipline and care must prevent one category from "sliding" into lower category
- Proper selection and execution of analytical tools will draw out and nurture (exercise) the desired skill

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Organization-Fleet Experience:
Risk Acceptance in the SSP

- **Recommendations:**
  SSP should increase its vigilance regarding Risk Acceptance by incorporating various preventative measures. For example:
  - A Personnel-focused Mentoring Program:
    - The SSP should establish ongoing relationships between experienced and less experienced personnel.
    - Senior personnel have knowledge stores, problem resolution experience, troubleshooting, and ability to detect nuances with complex systems.
    - Such attributes allow for practicing "art" vs. science of Shuttle engineering when confronted with situations where existing models and processes may not fit perfectly.
  - A Process-focused Program:
    - The SSP should consider incorporating a structured paradigm providing a disciplined approach to technical analyses & other critical processes.
      - The KNOT model (Known, Need to Know, Opinion, Thought to be Know) is used by some USAF analysts in cases of unexpected or unexplained failures. It can be used in combination with a "fishbone" model of fault-tree analysis.

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1

The KNOT Model

Known	Thought to be Known	Need to Know	Opinions
✓ **Known** through Established Facts Ex. SOF determination is required for CoFR ✓ **Known** through Direct Information Ex. TPS Burn through temperatures	✓ Understood by extrapolation on what is **Known** Ex. Damage assessment software accuracy ✓ Understood via experience with similar events Ex. "Foam loss never has been a SOF issue"	✓ Unknown due to inexperience, lack of information, etc. Ex. Tile SOF concerns from large foam strikes ✓ Unknown due to not recognizing its importance or need Ex. Potential capability of satellite imagery	✓ Judgments based on what is "**Known** Ex. Current NDE techniques are sufficient for inspections or "**Thought to be Known**" Ex. No need for DoD imaging given damage not deemed SOF ✓ Hypotheses based on what is "**Known**" Ex. Burn through will occur given a compromised RCC or "**Thought to be Known**" Ex. On-orbit tile repair will cause more damage than good

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Organization-Fleet Experience:
Risk Acceptance in the SSP

- **Recommendations (continued):**

  An Empirically-Based Program
  - **The SSP should continue its development/implementation of a Probability Risk Assessment (PRA)**
  - PRA is currently being developed by SSP S&MA Office, it integrates all models into a complete Shuttle PRA
  - The Shuttle Project Offices build project-unique failure logic models and perform corresponding data analysis
  - The PRA applies a linked fault tree approach to develop failure probabilities (functional, common cause, human error, & phenomenological); Bayesian updating is used when insufficient Shuttle-specific data exists to help to identify <u>Unknown Unknowns</u>

Taken from a briefing by J. Railsback/R. Boyer 14 April 03

Presenter M3/Human Factors | Date FINAL | Slide 8 of 8 | Closed

2

Space Shuttle Systems Integration Office

- **Action / Issue:**
  - Space Shuttle Systems Integration Office (MS) stovepiped and not organized to enhance horizontal integration of the various STS elements and projects.
- **Background / Facts:**
  - Space Shuttle Systems Integration Office (MS*) supposedly* conducts integration responsibilities across all STS elements and projects
  - Tasks involving the Orbiter are worked by MV
  - MS, MV equal on organizational charts; both at JSC
  - Integration relationship between MS and the MSFC projects (ET, SSME, SRB, RSRM) better defined
  - Rank for the respective managers in MS is GS-15 and MV is an SES

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Space Shuttle Systems Integration Office

- MV does not send representative to Integration Control Board (ICB) run by MS
- MS representation not required participant at MV Vehicle Engineering Control Board
- Not every bipod shedding resulted in IFA.
- Sometimes the Orbiter office had responsibility, sometime the ET office at MSFC
- No contingency plan for using fault trees.
  - MV started an Orbiter fault tree
  - MSFC started a fault tree for each of its projects (ET, SSME, SRB, RSRM) independent of JSC

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Space Shuttle Systems Integration Office

- **Findings (to date):**
  - MS does not integrate the STS.
  - office works closely with MSFC projects, MS does not integrate the Orbiter under MV
  - MS is an interaction office stovepiped to the Shuttle projects at MSFC and works with the Orbiter office.
  - If MS office properly used, could have focused away from day-to-day brush fires and worked proactively to prevent problems
  - MS has limited integration responsibility with the SFOC (SRB is under the SFOC) contract and contracts for the ET, RSRM and SSME.
  - If all contractor elements of the STS were integrated from MS, tracking the bipod shedding might have been centrally monitored and worked.

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Space Shuttle Systems Integration Office

- **Recommendations (to date):**
  - SSP needs to reorganize the Space Shuttle Integration Office to make it organization for all the elements of the STS, not just the ones at MSFC and separate from the Orbiter.
  - Any integration needs to include the STS contracts: SFOC (KSC and SRB), LM (ET), Thiokol (RSRM) and Boeing/Rocketdyne (SSME)
  - Integration will be particularly important in all the Return to Flight actions.
  - Setting up a more efficient integration office will allow the SSP to focus on the strategic planning and program development for the STS and not just on operations.

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Organization
Maintenance

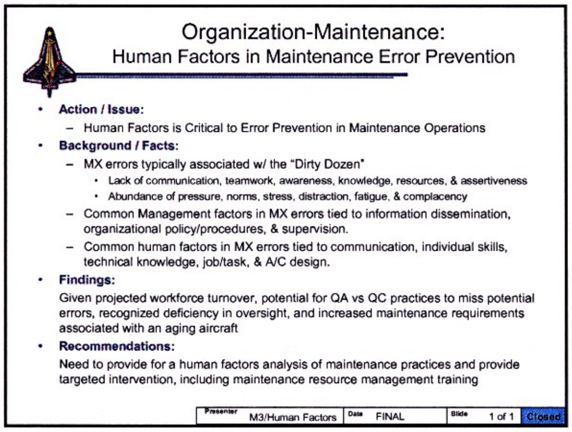
24-2 Human Factors and Maintenance Operations

24-3 Human Factors in NDE, QA, and Inspection

24-4 Human Factors in FOD Prevention

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	28 of 32


Organization-Maintenance:
Human Factors in Maintenance Error Prevention
• Action / Issue:
– Human Factors is Critical to Error Prevention in Maintenance Operations
• Background / Facts:
– MX errors typically associated w/ the "Dirty Dozen"
• Lack of communication, teamwork, awareness, knowledge, resources, & assertiveness
• Abundance of pressure, norms, stress, distraction, fatigue, & complacency
– Common Management factors in MX errors tied to information dissemination, organizational policy/procedures, & supervision.
– Common human factors in MX errors tied to communication, individual skills, technical knowledge, job/task, & A/C design.
• Findings:
Given projected workforce turnover, potential for QA vs QC practices to miss potential errors, recognized deficiency in oversight, and increased maintenance requirements associated with an aging aircraft
• Recommendations:
Need to provide for a human factors analysis of maintenance practices and provide targeted intervention, including maintenance resource management training
Presenter M3/Human Factors
Date FINAL
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1

Organization- Maintenance:
Human Factors in Inspection

- **Action / Issue:**
  - Human Factors is Critical in NDE, QA, & Inspection Activities
- **Background / Facts:**
  - Primary human factors associated with inspection process effectiveness are training, OJT, co-worker information, understanding of fault modes, & expectations of faults
  - Job factors include documentation, standards, SPECs, lighting, and visual/physical access
- **Findings:**
  - Numerous inspection activities related to ET foam installation, TPS integrity/repair, & aging orbiter are critical to safety of flight
  - Numerous inspection activities related to orbiter and component construction, overhaul, and repair are critical to safety of flight
- **Recommendations:**
  - Conduct human factors analysis of present/future inspection procedures and conditions to provide for optimized Human Systems Integration
  - Observe the impact of workforce norms, complacency, etc. on the inspection process and provide proper oversight

Presenter	Date	Slide	
M3/Human Factors	FINAL	1 of 1	Closed

1

Organization-Maintenance:
Human Factors in FOD Prevention

- **Action / Issue:**
  - Human Factors Is an Essential Component in FOD Prevention
- **Background / Facts:**
  - Human factors in FOD prevention includes preventative practices, training, & personnel awareness.
  - Management factors in prevention include specialized assignments, awards programs, housekeeping guidelines, tool control, material handling, & reporting.
- **Findings:**

  FOD concerns should not be compromised by renaming to facilitate contract award and operations; potential for FOD to create a Safety of Flight issue is great
- **Recommendations:**
  - Provide for a human factors analysis of FOD practices, handling, and disposition to to provide for optimized Human Systems Integration
  - Need to observe the impact of workforce norms, complacency, etc. on the FOD prevention and provide proper oversight

Presenter	M3/Human Factors	Date	FINAL	Slide	1 of 1	Closed

Organization
Orbit

23-4 Langley and JSC E-Mail Exchange

23-7 Engineer Simulation Training

23-8 Boeing Transition of Orbiter Support from CA to TX

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	29 of 32

Decentralization & Resilience in Handling Anomalies:
LaRC-JSC Exchanges on MLG Concerns

- **Action / Issue:**
  - Decentralization is critical in detecting anomalies and providing for resilience
- **Background / Facts:**
  - Jan 27th JSC & LaRC engineers had phone/e-mail exchanges on the foam debris assessment (included charts indicating that the left MLG area could be involved).
  - JSC engineer stated there was concern the MLG door was "vulnerable", perhaps leading to a two flat tire landing (or compromising MLG). Discussed simulating landings to evaluate outcomes, but no formal request was pending; Explored doing "after hours" piggy-backing on astronaut training underway at NASA ARC.
  - LaRC engineer expressed concerns to JSC counterpart to be prepared in case a problem arose on landing; contacted management on JAN 28th an about concerns
  - Reviewed previous related data runs; JAN 30th provided scenarios tied to potential MLG problem (most had severe outcomes). Simulation results for a two flat tire landing provided on JAN 31st showed it was survivable/controllable condition.
  - Based on established working relationships, the negative scenario observations (with caveats) were passed to select JSC personnel for consideration, whereas favorable simulation results were given to a wider JSC audience for review.

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Decentralization & Resilience in Handling Anomalies:
LaRC-JSC Exchanges on MLG Concerns

- **Findings:**
  - Formal dissemination of foam debris assessment did not make it directly (or in a timely manner) to all potentially affected parties, especially those who may have the expertise for the proper diagnosis of associated problems and /or the development of mitigation/containment procedures.
  - Ineffective dissemination leads to informal channeling that can not be relied upon to get information expeditiously to affected system/technology experts and provide them an adequate chances to make inputs for decision-making.
  - E-mail/Powerpoint are tools for asynchronous communication (often to a select audience), however they can not be relied upon to ensure understanding, influence decision-making, or elicit action (especially from non-targeted recipients/respondents).
  - Note. The actions these working level engineers took to overcome limited horizontal integration between OPS and R&D (& NASA Centers) so as to network, marshal resources, and prepare for a potential contingency is an example of the resilient spirit that led to the successful return of Apollo 13.

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Decentralization & Resilience in Handling Anomalies:
LaRC-JSC Exchanges on MLG Concerns

- **Recommendations:**
  - Guidelines regarding communication of safety issues/concerns should be established to ensure early/full dissemination of information to recognized government and contractor system and technology experts who work OPS, R&D, etc. at all NASA Centers.
  - All channels of communication (e-mail, phone, etc.) should be open and encouraged to discuss/disseminate safety concerns, but assurance must be made that information is raised to appropriate management and safety oversight personnel.
  - Disseminate information prior to decision-making sessions (if possible) for preliminary review and potential comment to increase early feedback, participation from attendees, as well as comments from interested parties unable to attend.

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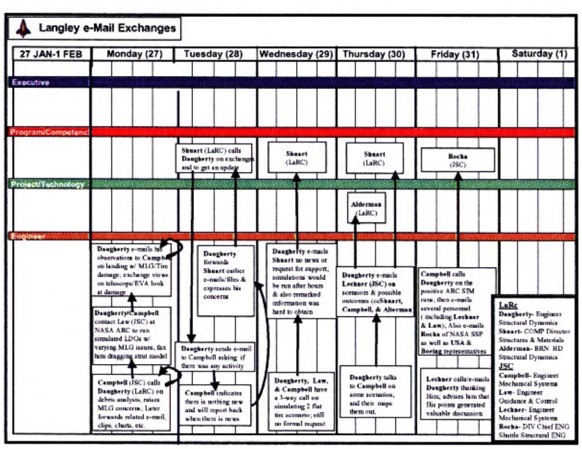
Decentralization & Resilience in Handling Anomalies:
LaRC-JSC Exchanges on MLG Concerns

- **References:**

  - E-mail exchanges on foam damage and LaRC and JSC interactions regarding the initial damage assessment. Complete set of email beginning on Jan. 23. (http://www.nasa.gov/pdf/2207main_COL_email_030226.pdf)
  - E-mail exchange on Jan. 28-31, 2003, on assessment of potential for a breach in the landing gear door or wheel well during re-entry into Earth's atmosphere (http://www.nasa.gov/pdf/2205main_COL_debris_email.pdf)
  - E-mail exchange within LaRC regarding main gear breach concerns on Jan. 31. (http://www.nasa.gov/pdf/2208main_COL_email_larc.pdf)
  - Daugherty, R. & Shuart, M. (10 MAR 03) NASA Langley Press Conference (http://www.spaceref.com/news/viewsr.html?pid=8270)
  - NASA HQ Records Management Bulletin 97.01 (http://www.hq.nasa.gov/office/codea/codeao/recn9701.html)
  - NASA Information Systems Directorate e-mail Guidelines (http://isd.jsc.nasa.gov/GA/computer/email/EmailDosDonts.html)
  - Palme, J. (23 MAY 99). Support for Decisions by E-mail. TERENA Conference (http://www.dsv.su.se/~jpalme/ietf/JPMADS.html)

Presenter M3/Human Factors | Date FINAL | Slide 4 of 5 | Closed



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Organization-Orbit: Engineer Simulation Training

- **Action / Issue:**
  - Lack of Ongoing Formal Event Simulation Training for Shuttle Engineers involved in the MMT/MER
- **Background/Facts:**
  - Comparisons with SSP and DoD safety performance should consider differences in training levels
  - DoD trains at all levels, across nearly all operations, with all affected personnel: An established and accepted organizational norm.
- **Findings:**
  - In SSP, only the Astronaut crew and Flight Control team receive on-going formal training; the MMT conducts a simulation exercise once/18 months
  - The MER and other principle engineering support teams receive no on-going formal training beyond initial orientation

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Organization-Orbit: Engineer Simulation Training

- **Recommendations:**
  - A formal training program should be developed to meet 2 major goals:
    1. Strengthen basic & advanced skills and processes during routine and unusual conditions
    2. Strengthen team integration & communication processes within & among technical & management elements, specifically the MER & MMT
  - Training should include practice problems, simulations, realistic scenario play, performance evaluation, & feedback (strengths, weaknesses, & lessons learned).
  - Seasoned engineers (i.e., mentors) should be incorporated into training exercises to continue the knowledge transfer effort (Note. Particularly important to develop trouble shooting skills and situations requiring subjective judgment calls.).

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Action / Issue:**
  - Boeing transition (12/01-03/03) of Shuttle operations (OPS) support function from Huntington Beach, CA (HB) to Houston,TX (HOU) precipitated a large turnover in personnel with significant program experience and technical expertise.
  - To minimize effects from a potential loss of experience/expertise, Boeing planned a risk managed knowledge transition process, with an emphasis on key positions.
  - Process was not uniformly implemented, potentially impacting support capabilities.
- **Background:**
  - In Dittemore's March 6th testimony to the CAIB, he indicated the transition was a contractor-based initiative to get "engineering closer to the customer" and achieve ". . .efficiencies that would lower the overall cost".
  - Pre-transition Boeing had ~1,300 jobs: ~1,000 (76%) in HB & ~150 (12%) in HOU; Post-transition Boeing had ~500 jobs in HB (38%) & ~580 jobs (45%) in HOU.
  - Only 97 HB Boeing incumbents transferred to HOU, requiring over 330 jobs to be filled (This included both critical SSM and various engineering positions).

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

Boeing Proprietary Information Not for Release

- **Background (con't):**
  - By March 31, 2003 there were 531 total jobs that transferred from Huntington Beach to Houston and Florida
  - Of the 531 jobs that transferred, 140 people relocated from Huntington Beach. The remaining 391 positions were filled by replacements

Job Distribution by Category (March 31, 2003)

	Engineer	Management	Others	Totals
Total Jobs Transferred (est)	424	55	52	**531**
Relocations (est)	89	33	18	**140**
Replacements (est)	335	22	34	**391**

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

Overall, their plan appeared to be both systematic and comprehensive, encompassing:

- Knowledge capture process (KCP), to catalog incumbent KSAs through questionnaires, video interviews, and toolboxes
- Critical skill checklists, based on inputs from each incumbent performing a task comprising a given "job"
- HB competency managers and HOU Integrated Team Managers review of KCPs w/ corresponding checklists,
- Risk management of the task transition process, to effectively identify, assess, and address hazards; "Red-flagging" areas for additional oversight based risk
- 15-month transition timeline that covered two shuttle missions (STS 112 & 113), providing "real time" OJT
- Set 3-month period for individual job transition, to include face-to-face training
- Certification process for key positions (e.g.,Sub-System Manager) & Integrated Team Manager sign-off for others
- Established guidelines for identifying and selecting critical personnel and engineering replacement candidates
- Pairing a job candidate with respective incumbents for formal task training and mentoring whenever possible

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Background (continued):**
  - Boeing transition review (11/02) accomplishments listed hired 95% of replacements, completed 85% of programmed training (70% completed all of the training), and replaced 98% of critical skills
  - Boeing HB site director indicated that a further endorsement of the transition's success was USA's consideration to use this KCP model in their organization.
  - Boeing performance and safety award fee scores were higher than pre-transition
- **Findings:**

<u>Witness Impressions of the Overall Transition Process</u>
  - Despite the official reports' positive tone and the site director's comments, witnesses questioned the actual success of the transition process (including knowledge capture, individual training, and exit evaluation).
  - Witnesses characterized the process as compressed (and consequently rushed); lacking standardization, clear job-based criteria, and post transition group/ individual risk re-assessment.
  - Further, former analysts (aero, stress, thermo, & structures) had additional concerns that the transition could impact the on-orbit reported damage assessment process/findings.

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Findings (continued):**

  Knowledge Capture Process (KCP)
  - <u>Witnesses' General Observations</u>:
    - The KCP was seen as "too little, too late."
    - Parts of the KCP were not as useful as others; whereas some felt the entire KCP was not useful at all.
    - The KCP was not as specific on analyses functions as it was in hardware areas; but lead analysts reported they did effectively document troubleshooting, problem-solving, lessons learned, etc.
    - Overall, there was a cumulative loss of experience across all technology areas. This concern was expressed to management in both formal and informal settings, including all-hands, staff, and hallway meetings.
    - HOU witnesses reported that while KCP was lacking, actual knowledge transfer process was sufficient
  - <u>Questionnaires</u>:
    - The job questionnaire documented inputs, processes, and products of a position.
    - Some witnesses indicated it was adequate, but it could not capture decades of experience.
    - It was perceived as too brief and inadequate, as it gathered only top-level, generic information about positions.

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Findings (continued):**

  Knowledge Capture Process (KCP)
  - <u>Video Interviews</u>:
    - The video-taped interviews were intended as a "how-to" demonstration of procedures lending themselves to hands-on or hardware processes.
    - Many incumbents were not asked to participate in videotape interview.
    - Most felt they were useful for technical, hands-on tasks, but not useful for other activities, like procedures and analysis.
    - One analyst thought this was the only useful KCP component.
  - <u>Toolboxes</u>:
    - Incumbents were asked to make a complete listing of all files, references, locations of guiding documents, policies, analytical tools, software, etc. that would be relevant for a particular position.
    - While this compilation was not required of some lower-level engineers, most agreed that this was the most useful part of the KCP.
    - HOU engineers acknowledged there is continuing work being done on the toolboxes

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1

Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Findings (continued):**

  Knowledge Capture Process (KCP)

  – Management Review:
    - Review of the KCP products after the incumbent compiled them was sporadic at best.
    - They generally indicated that their manager received it and in some cases reviewed it, and asked for clarification. In other cases they merely took it, with no revision or refinement.
    - The witnesses collectively stated there was no training on how to do the KCP, no standardization of the product produced, and it was not systematically/uniformly implemented.
    - The process was more difficult for senior personnel and for management types, e.g., to produce an effective video interview as stated above.
    - Overall, the KCP did not consistently follow the transition plan in many cases, especially for non-critical positions.

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Findings (continued):**

  Selection, Training, & Certification

  – HOU mgmt. oversaw most new personnel hiring. Except for a few senior positions and transfers from HB, the HB supervisors were not involved in the selection process.

  – KCP end products were collected from the incumbents and then provided to the Integrated Team Managers (ITMs) who oversaw the transition training for new hires and transfers. ITMs were either senior SSP people who transferred or experienced SSP people recruited from NASA or USA. There were some instances where the ITM themselves were new hires.

  – Training utilized the HB incumbent when they were available. The incumbent conducted 2-3 weeks of training with the trainee at HB, while the ITMs oversaw the remainder of the training process at HOU.

  – Training plans or checklists were to be covered over a 3-month period (approx.) for each job; all jobs were to be transitioned over an 18-month period. When incumbents and management were satisfied with trainee's performance, the incumbent was given a 60-day notice. Incumbent remained available to the trainee during this time period.

  – New SSMs required a controlled, multi-step training and certification process. Certifications requirements and processes were approved by USA/NASA. Each SSM was evaluated by Boeing/Customer Boards foe final certification.

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Findings (continued):**

  Selection, Training, & Certification

  – The transition's beginning phases appeared rushed. Thus some positions and any process perturbations (e.g., a candidate or incumbent leaving) compromised process integrity.

  – Toward the transition's end, some witnesses stated there was pressure to finish training to complete the transition. Though incumbents were available for training candidates, they were not given 3 dedicated months to train: either the incumbent attended to other duties or the candidate was not on site.

  – During the 3-month training period, the incumbent charged a special transition job order number, while the candidate charged to SSP.
    - There was some pressure not to exceed the allotted transition time, despite the trainee's proficiency status and/or checklist completion.
    - HOU management stated the training budget was under-run by $2M

  – In contrast to HB incumbent experience, the replacement HOU based employees reported the training to be sufficient in quantity and quality.

  – Most candidates were deemed proficient for normal tasks and conditions. However, incumbents indicated that training was conducted with an understanding that in unusual cases (out of family, etc.), the incumbent and trainee would work together.

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Findings (continued):**

  Selection, Training, & Certification

  – Exit criteria for the training process was unclear to incumbents, other than completing the checklist/training plan. In some instances, the list was not completed or the candidate was not proficient to the task(s) by the time the transition ended. *Some witnesses expressed significant frustration and concern about this.*

  – Most SSM training and certification processes were coordinated by managers. They indicated the process was rigorous and included USA/NASA participation. Most SSMs held significant seniority with the SSP. Although some portions of the certification process was not highly structured, most witnesses said this process went very well. Records indicated that the training and certification process for SSMs was well documented.

  – The incumbent and candidate worked together for STS 112 & STS 113, two missions flown during the transition process. STS-107 was the first mission flown after transition completion, with HOU holding primary responsibility.

  – After the transition was complete, incumbents provided further assistance ***only as requested by the new employee.***

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Findings (continued):**
- Risk Management and Over-Site

  – Risk mitigation plans for each task/task group were incorporated into official Task Transition Plans. This process included assessment of probability,severity, and risk mitigation for each risk item. Tasks were identified and tasked on team schedules; monitoring of the knowledge capture, transition training, and certification/completion processes were employed. However, Witnesses observed the process as non-systematic in overall implementation.

  – Baseline risk assessments were not adjusted on an individual basis to consider experience level, "out of family" selection, etc.

  – A 02/02 NASA SSP S&MA risk mgmt. report indicated "yellow" (5- "high" likelihood & 2- "med-low" consequences) through FY 02 for supportability and safety due to the Boeing relocation; A 10/02 NASA SSP S&MA risk mgmt. report indicated "yellow" (4- high-med likelihood & 2- med-low consequences) for supportability and safety through FY 03 (est. Resolution 01/03) due to the Boeing relocation.

  – Listed as a "Top Issue", the impacts listed were "Low percentage of incumbent personnel willing to relocate" and "Could impact COFR process integrity." It also indicated various concerns: loss of existing skills and experience, challenges to replace personnel, incumbent retention to support contracted tasks and train replacements, and quality of NASA/USA available for out-of-family support.

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Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX

- **Findings (continued):**

  Risk Management and Over-Site

  – STS-107 & STS-114 were listed as yellow due to some Orbiter replacement personnel generating flight products with approved work around plan and some System Integration personnel having no certified back-up. The action plan to mitigate risk was listed as "Transition plan has been developed and partnered with NASA" and "NASA and USA in oversight mode until transition completed".

  – Once the transition process was complete, no re-assessment of individual risk was done.

  – Boeing contracted Independent Risk Assessments (IRA) for the transition.
    - The goal was to complete staff training by the end of 12/02. "Victory Criteria" included: completing 90% of the hiring, 90% of the training, 90% of the critical skill replacement, 90% of the redeployment, and 100% SSMs trained and certified.
    - Their analysis indicated a 95% chance that criteria would **not** be met by the end DEC 02, a 50% chance by 02/02, and a chance it may extend until 03/03 (and until 05/04 without careful management).
    - Given the situation, they recommended a "supercharged" interview and pre-screening process; acceleration of making offers, hire decisions, reporting dates, and training start-up; carefully control/manage training time and work on scheduling (especially if incumbent is leaving).

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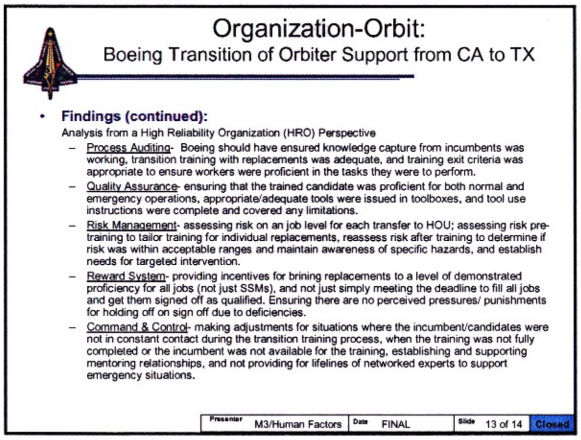
Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX
• Findings (continued):
Analysis from a High Reliability Organization (HRO) Perspective
– Process Auditing- Boeing should have ensured knowledge capture from incumbents was working, transition training with replacements was adequate, and training exit criteria was appropriate to ensure workers were proficient in the tasks they were to perform.
– Quality Assurance- ensuring that the trained candidate was proficient for both normal and emergency operations, appropriate/adequate tools were issued in toolboxes, and tool use instructions were complete and covered any limitations.
– Risk Management- assessing risk on an job level for each transfer to HOU; assessing risk pre-training to tailor training for individual replacements, reassess risk after training to determine if risk was within acceptable ranges and maintain awareness of specific hazards, and establish needs for targeted intervention.
– Reward System- providing incentives for brining replacements to a level of demonstrated proficiency for all jobs (not just SSMs), and not just simply meeting the deadline to fill all jobs and get them signed off as qualified. Ensuring there are no perceived pressures/ punishments for holding off on sign off due to deficiencies.
– Command & Control- making adjustments for situations where the incumbent/candidates were not in constant contact during the transition training process, when the training was not fully completed or the incumbent was not available for the training, establishing and supporting mentoring relationships, and not providing for lifelines of networked experts to support emergency situations.
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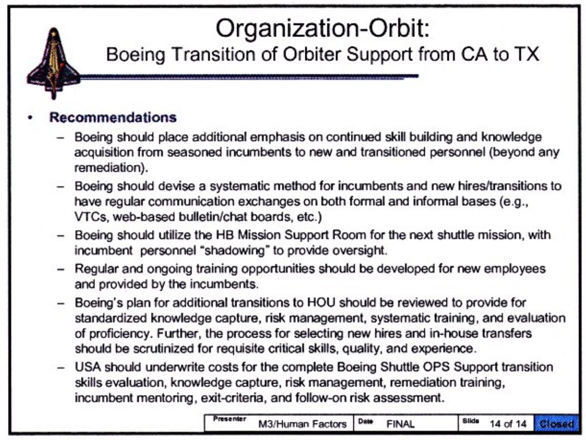
Organization-Orbit:
Boeing Transition of Orbiter Support from CA to TX
• Recommendations
– Boeing should place additional emphasis on continued skill building and knowledge acquisition from seasoned incumbents to new and transitioned personnel (beyond any remediation).
– Boeing should devise a systematic method for incumbents and new hires/transitions to have regular communication exchanges on both formal and informal bases (e.g., VTCs, web-based bulletin/chat boards, etc.)
– Boeing should utilize the HB Mission Support Room for the next shuttle mission, with incumbent personnel "shadowing" to provide oversight.
– Regular and ongoing training opportunities should be developed for new employees and provided by the incumbents.
– Boeing's plan for additional transitions to HOU should be reviewed to provide for standardized knowledge capture, risk management, systematic training, and evaluation of proficiency. Further, the process for selecting new hires and in-house transfers should be scrutinized for requisite critical skills, quality, and experience.
– USA should underwrite costs for the complete Boeing Shuttle OPS Support transition skills evaluation, knowledge capture, risk management, remediation training, incumbent mentoring, exit-criteria, and follow-on risk assessment.
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3

Contract
Design – Certification

25-1 Contracting & Financial Considerations

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	30 of 32

Budget and Finance Considerations

- **Action / Issue:** Budget and Finance Considerations Influence Shuttle Program Performance
- **Background / Facts:**
  - Cost pressure may adversely influence mission success at USA and sub-contractors as ISS cost overruns take greater share of NASA budget
  - Reduction at NASA funded level would be distributed to program based on NASA priorities. Cost growth in other priority programs could negatively affect funding on the SFOC and other SSP contracts.
- **Findings:**
  - Committee reports, new media, etc. indicate extensive cost growth on ISS

Presenter M3/Contracting | Date FINAL | Slide 1 of 6 | Closed

Budget and Finance Considerations

- **Group Recommendation:**
  - NASA should accelerate move to full cost accounting of the Space Shuttle Program in order to provide the adequate future funding in NASA and Centers' budget

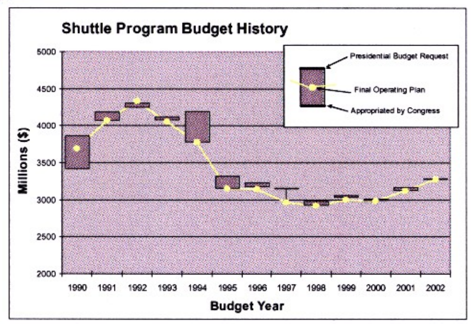
Presenter M3/Contracting | Date FINAL | Slide 2 of 6 | Closed

SSP Budget

- Human Space Flight is approx 40% of NASA budget
- Space Shuttle is half of human space flight Budget
- No recent large congressional cuts
- FY2001 necessary to redirect advanced areas to address cost and program management needs of the ISS

Presenter M3/Contracting | Date FINAL | Slide 3 of 6 | Closed

Shuttle Budget History



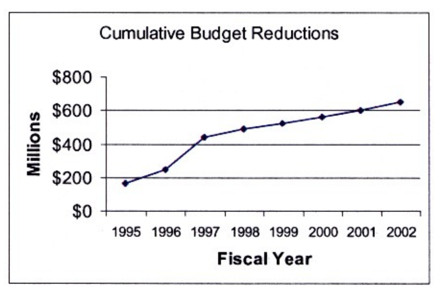
Presenter M3/Contracting | Date FINAL | Slide 4 of 6 | Closed

Shuttle Budget History

- 2002 reduced $50mil
- 2001 reduced $40mil for Mars initiative
- 2000 earmark of $40mil transfer to ISS
- 1999 reduced $31mil
- 1998 transferred $50mil to ISS
- 1997 transferred $190mil to ISS
- 1996 reduced $53mil; transferred $30mil to ISS
- 1995 general reduction $168 to Human Space Flight

Presenter M3/Contracting | Date FINAL | Slide 5 of 6 | Closed

SSP Budget



Presenter M3/Contracting | Date FINAL | Slide 6 of 6 | Closed

Contract
Production

26-1	Non-SFOC Contracts
26-2	Foam Application Process not Specified as Contractual Requirement
26-3	ET Not Subject to Catastrophic Loss Penalty Clause
26-4	Pressure to Decrease Costs on SRB

Matrix

Presenter	CAIB/Group 1	Date	FINAL	Slide	31 of 32

Contracting Issues
Non-SFOC Contracts

- **Action / Issue:** Non-SFOC Contracts "evolve" to shift emphasis away from cost savings
- **Background / Facts:**
  - MSFC has contract cognizance over Space Shuttle element contracts that are not part of the SFOC
- **Findings:**
  - MSFC evaluates whether contractor headcount had been reduced to minimum safe level and whether continued personnel reductions would have a negative rather than a positive effect
  - ATK Thiokol Propulsion has been Reusable Solid Rocket Booster (RSRM) supplier since 1974
  - Contracts from Buy 1 to Buy 4 included cost savings share line, allowing Thiokol to share in any savings below target cost
  - Current buy, while including a 1% incentive fee at target cost, contains no incentive for underrun

Presenter M3/Contracting | Date FINAL | Slide 1 of 18 | Closed

Contracting Issues
Non-SFOC Contracts

- **Group Recommendation:**
  - NASA JSC should examine removing cost savings incentives from SFOC

Presenter M3/Contracting | Date FINAL | Slide 2 of 18 | Closed

Fee Structures of Non-SFOC

- Issue: SFOC was planned to include other "element" contracts as Phase 2
- Only SRB added (1998)
- Elements not included in SFOC
  - External Tank (ET)
  - Space Shuttle Main Engine (SSME)
  - Reusable Solid Rocket Motor (RSRM)

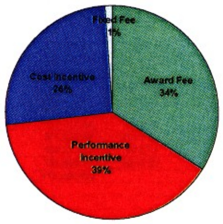
Presenter M3/Contracting | Date FINAL | Slide 3 of 18 | Closed

Non-SFOC:External Tank

- Michoud Assembly Facility (GOCO) operated by Lockheed Martin
- Estimated Cost (ET Production): $2.06 B
- Estimated Fees: $134.4 M (Incentive, Employee Motivation, Award)

Presenter M3/Contracting | Date FINAL | Slide 4 of 18 | Closed

ET



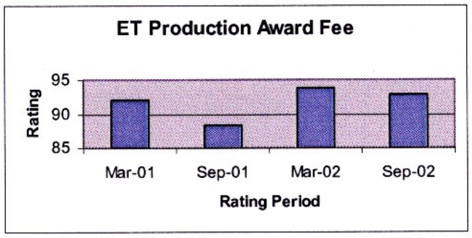
Presenter M3/Contracting | Date FINAL | Slide 5 of 18 | Closed

ET Production Award Fee

- Quality Performance 70%
  - Subcriteria: Quality of hardware; problem reporting/resolution; hardware performance; safety performance
- Management Performance 30%
  - Subcriteria: Project management; flight support; contract management

Presenter M3/Contracting | Date FINAL | Slide 6 of 18 | Closed

ET Award Fee



Presenter M3/Contracting | Date FINAL | Slide 7 of 18 | Closed

ET

Production Award Fee Pools

Period	Amount Available		Earned Amount	Earned Percent
October 1, 2000 - March 31, 2001	$1,499,664		$1,370,693	91.40%
April 1, 2001 - September 30, 2001	$2,493,361		$2,202,136	88.32%
October 1, 2001 - March 31, 2002	$3,273,186		$3,070,903	93.82%
April 1, 2002 - September 30, 2002	$2,498,684		$2,296,290	91.90%
Total	$9,764,895		$8,940,022	91.55%

MAF Operations & Maintenance Award Fee Pools

Period	Amount Available		Earned Amount	Earned Percent
October 1, 2000 - March 31, 2001	$345,327		$334,622	96.90%
April 1, 2001 - September 30, 2001	$485,448		$461,661	95.10%
October 1, 2001 - March 31, 2002	$658,718		$645,544	98.00%
April 1, 2002 - September 30, 2002	$761,736		$717,555	94.20%
Total	$2,251,229		$2,159,382	95.92%

B02063 – "Implementation of Friction Stir Welding" Award Fee Pools

Period	Amount Available		Earned Amount	Earned Percent
May 1, 2000 - March 31, 2001	$ 343,218-		$314,044	91.50%
April 1, 2001 - September 30, 2001	$297,000		$268,785	90.50%
October 1, 2001 - March 31, 2002	$128,000		$114,278	89.28%
April 1, 2002 - September 30, 2002	$84,687		$83,840	99.00%
Total	$852,905		$780,947	91.56%

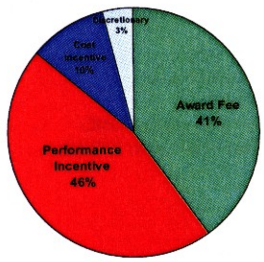
Presenter M3/Contracting | Date FINAL | Slide 8 of 18 | Closed

Non-SFOC: Space Shuttle Main Engine

- Contractor: Boeing (formerly Rockwell/Rocketdyne)
- Current Contract Thru December 2003
- Estimated Total Cost: $1.04 B
- Estimated Fees: $123.6M (fixed, incentive,award)
  - 12% of cost

Presenter M3/Contracting | Date FINAL | Slide 9 of 18 | Closed

SSME



Presenter M3/Contracting | Date FINAL | Slide 10 of 18 | Closed

SSME Award Fee

- Management performance : 30%
- Flight support: 40%
- Safety, Reliability, QA: 30%
- Current Rating:
  - June 2002: 81.2
  - December 2002: 91.4

Presenter M3/Contracting | Date FINAL | Slide 11 of 18 | Closed

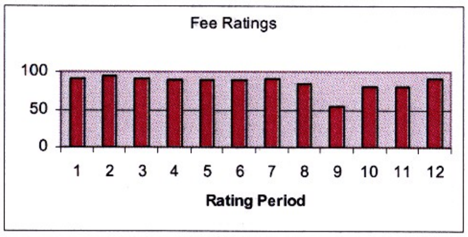
SSME Award Fee History

Evaluation Period	Start Date	End Date	Avail. Award Fee Dollars	Dollars Earned	Dollars Not Earned	Overall Score
1	1/1/02	6/30/02	$4,823,679	$3,916,827	$906,852	81.20%
2	7/1/02	12/31/02	$5,222,203	$4,773,094	$449,109	91.40%
3	1/1/03	6/30/03	$5,370,488			
4	7/1/03	12/31/03	$5,261,730			
5	1/1/04	6/30/04	$5,111,443			
6	7/1/04	12/31/04	$5,051,295			
7	1/1/05	6/30/05	$5,118,927			
8	7/1/05	12/31/05	$4,950,116			
9	1/1/06	6/30/06	$5,182,323			
10	7/1/06	12/31/06	$4,906,367			
			$50,998,571			

Presenter M3/Contracting | Date FINAL | Slide 12 of 18 | Closed

2

SSME Award Fee (prior)



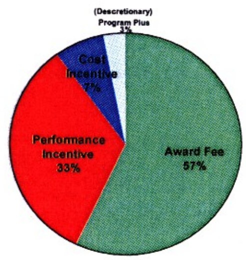
Presenter M3/Contracting | Date FINAL | Slide 13 of 18 | Closed

Reusable Solid Rocket Motor (RSRM)

- ATK THIOKOL PROPULSION HAS BEEN RSRM SUPPLIER SINCE 1974
- Current Contract value: $2.34 B
- Fee: 15%

Presenter M3/Contracting | Date FINAL | Slide 14 of 18 | Closed

RSRM



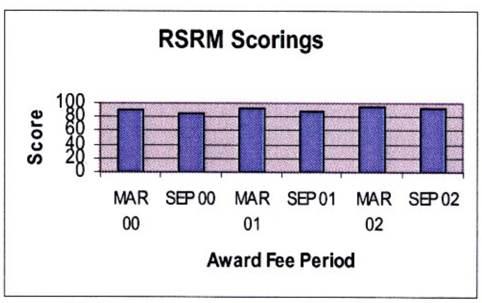
Presenter M3/Contracting | Date FINAL | Slide 15 of 18 | Closed

RSRM Award Fee

- Performance Management 50%
  - Subcriteria: Flight Support; Budget Management; Contract Management
- Safety, Reliability and QA 50%

Presenter M3/Contracting | Date FINAL | Slide 16 of 18 | Closed

RSRM Award Fee History



Presenter M3/Contracting | Date FINAL | Slide 17 of 18 | Closed

RSRM Award Fee History

Evaluation Period	Start Date	End Date	Avail. Award Fee Dollars	Dollars Earned	Dollars Not Earned	Overall Score
1	10/01/98	03/31/00	$21,013,756	$18,912,380	$2,101,376	90.0%
2	04/01/00	09/30/00	$9,711,956	$8,381,418	$1,330,538	86.3%
3	10/01/00	03/31/01	$15,142,213	$13,779,414	$1,362,799	91.0%
4	04/01/01	09/30/01	$16,690,226	$14,236,763	$2,453,463	85.3%
5	10/01/01	03/31/02	$14,234,638	$13,594,079	$640,559	95.5%
6	04/01/02	09/30/02	$14,032,556	$12,909,952	$1,122,604	92.0%
7	10/01/02	03/31/03	$16,905,169			
8	04/01/03	09/30/03	$17,204,304			
9	10/01/03	03/31/04	$13,381,973			
10	04/01/04	09/30/04	$11,838,699			
11	10/01/04	03/31/05	$10,169,653			
12	04/01/05	09/30/05	$6,914,057			
13	10/01/05	03/31/06	$2,237,675			
14	04/01/06	09/30/06	$1,001,715			
15	10/04/06	05/31/07	$750,576			

Presenter M3/Contracting | Date FINAL | Slide 18 of 18 | Closed

3

Contracting Issues
External Tank

- **Action / Issue:** Foam Application Process not specified as contractual requirement
- **Background / Facts:**
  - External Tank Contract NAS8-00016 does not specify the application process to be used by Lockheed Martin Michoud Assembly Facility for the External Tank
- **Findings:**
  - ET Statement of Work (SOW) as included in the contract imposes the ET end Item Specification, CM02 and materials Process Control Plan as Type 1 documents.
  - Items below SE 16 level include engineering drawings, product processes and manufacturing plan (MPP)
  - NASA and DCMA are to review any changes the contractor that affect form, fit or function

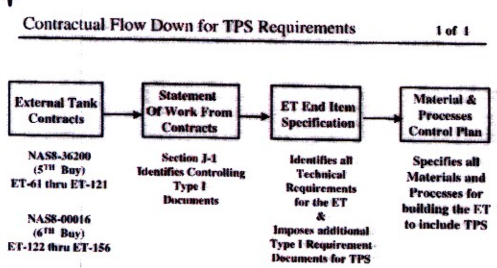
Presenter M3/Contracting | Date FINAL | Slide 1 of 7 | Closed

Contracting Issues
External Tank

- **Group Recommendation:**
  - NASA MSFC should consider specifying the ET Foam application process in the contract End Item Specification to maintain consistent control of the process

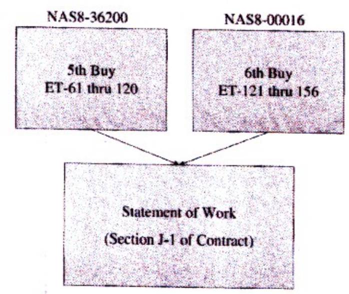
Presenter M3/Contracting | Date FINAL | Slide 2 of 7 | Closed

Contracting Issues
External Tank



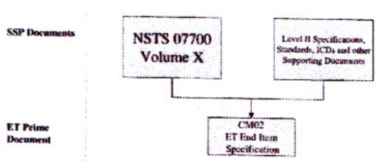
Presenter M3/Contracting | Date FINAL | Slide 3 of 7 | Closed

Contracting Issues
External Tank



Presenter M3/Contracting | Date FINAL | Slide 4 of 7 | Closed

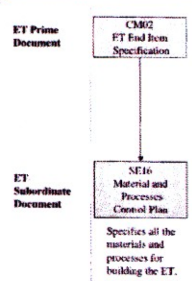
Contracting Issues
External Tank



CM02 identifies all the technical requirements that are pertinent to the ET. This document contains a cross reference matrix to identify the NSTS 07700 Volume X requirement and it's applicable EIS paragraph.

Presenter M3/Contracting | Date FINAL | Slide 5 of 7 | Closed

Contracting Issues
External Tank

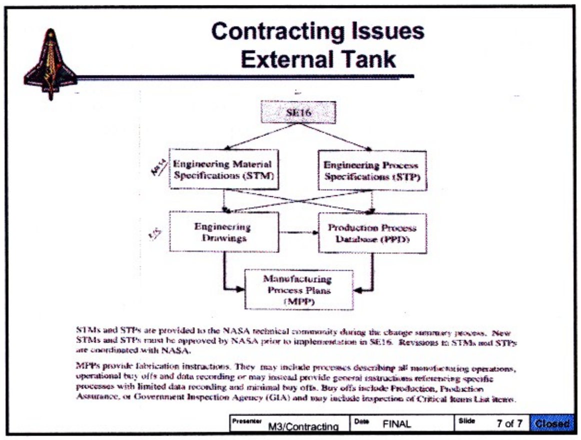


CM02 is a Type 1 Document. All changes must be approved by the ET Project Manager and the Contracting Officer prior to implementation. A Preliminary Specification Change Notice (PSCN) is drafted and submitted to NASA as part of a Change Summary. "Clean Up" PSCNs are submitted occasionally to correct typographical and other minutae errors, as well as eliminate outdated and irrelevant information.

MMC-ET-SE16 is also a Type 1 Document. All changes to this document must also be processed through the NASA ET Project Office. A Preliminary Drawing Change Notice (PDCN) is drafted and submitted as part of a Change Summary.

Presenter M3/Contracting | Date FINAL | Slide 6 of 7 | Closed

1


Contracting Issues
External Tank
SE16
Engineering Material Specifications (STM)
Engineering Process Specifications (STP)
Engineering Drawings
Production Process Database (PPD)
Manufacturing Process Plans (MPP)
STMs and STPs are provided to the NASA technical community during the change summary process. New STMs and STPs must be approved by NASA prior to implementation in SE16. Revisions to STMs and STPs are coordinated with NASA.
MPPs provide fabrication instructions. They may include processes describing all manufacturing operations, operational buy offs and data recording or may instead provide general instructions referencing specific processes with limited data recording and minimal buy offs. Buy offs include Production, Production Assurance, or Government Inspection Agency (GIA) and may include inspection of Critical Items List items.
Presenter M3/Contracting
Date FINAL
Slide 7 of 7
Closed

Contracting Issues
External Tank

- **Action / Issue:** External Tank used on STS-107 not subject to Catastrophic Loss Penalty Clause
- **Background / Facts:**
  - External Tank 93 was delivered in 2000 under MSFC contract. Tank was held by the Government until needed
- **Findings:**
  - Current buy for Tanks ET-122 through ET-156 contains a catastrophic loss penalty clause
  - Category 1 Failure, death of crew or loss of orbiter: $10M
  - Category 2 Failure, mission failure: $5M
  - Contract NAS 8-00016 was awarded September , 1999 for production of 35 tanks

Presenter M3/Contracting | Date FINAL | Slide 1 of 4 | Closed

Contracting Issues
External Tank

- **Findings (con't):**
  - In negotiation, Lockheed Martin wanted fee raised considerably before accepting a catastrophic loss penalty
  - MSFC decided benefit of including the clause did not support the cost of the additional
- **Group Recommendation:**
  - Should NASA determine ET contractor culpability, complete contract review should be accomplished to identify whether other provisions exist in prior contracts to assign penalties or fee forfeitures

Presenter M3/Contracting | Date FINAL | Slide 2 of 4 | Closed

RSRM Loss Provisions

- Fee reduction for loss of crew, vehicle or mission
- Category I failure
  - Incident directly attributable to an RSRM
  - Results in loss of life or vehicle
  - Forfeiture of $10M plus all fee earned or available during award fee period in which loss occurs
- Category II failure
  - Incident directly attributable to an RSRM
  - Results in loss of mission
  - Forfeiture of $5M plus all fee earned or available during award fee period in which loss occurs

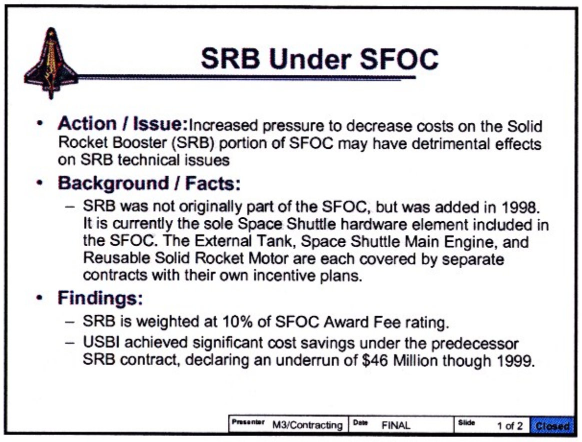
Presenter M3/Contracting | Date FINAL | Slide 3 of 4 | Closed

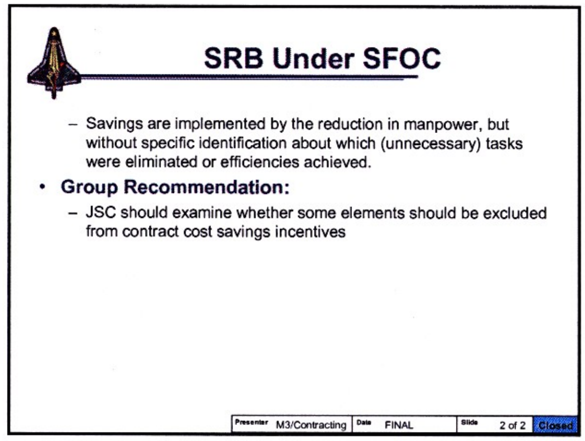
SSME Loss Provisions

- Fee reduction for loss of crew, vehicle or mission
  - Category I failure
  - Incident directly attributable to an SSME
  - Results in loss of life or vehicle
  - Forfeiture of $10M plus all fee earned or available during award fee period in which loss occurs
  - Category II failure
  - Incident directly attributable to an SSME
  - Results in loss of mission
  - Forfeiture of $5M
  - Category I and II failures to be determined by a failure investigation board per NMI 8621.1
  - If failure determined to be both category I and II, only category I penalties shall be applied

Presenter M3/Contracting | Date FINAL | Slide 4 of 4 | Closed

1


SRB Under SFOC
• Action / Issue: Increased pressure to decrease costs on the Solid Rocket Booster (SRB) portion of SFOC may have detrimental effects on SRB technical issues
• Background / Facts:
– SRB was not originally part of the SFOC, but was added in 1998. It is currently the sole Space Shuttle hardware element included in the SFOC. The External Tank, Space Shuttle Main Engine, and Reusable Solid Rocket Motor are each covered by separate contracts with their own incentive plans.
• Findings:
– SRB is weighted at 10% of SFOC Award Fee rating.
– USBI achieved significant cost savings under the predecessor SRB contract, declaring an underrun of $46 Million though 1999.
Presenter M3/Contracting
Date FINAL
Slide 1 of 2
Closed


SRB Under SFOC
– Savings are implemented by the reduction in manpower, but without specific identification about which (unnecessary) tasks were eliminated or efficiencies achieved.
• Group Recommendation:
– JSC should examine whether some elements should be excluded from contract cost savings incentives
Presenter M3/Contracting
Date FINAL
Slide 2 of 2
Closed

1

Contract Maintenance

- 27-1 SFOC Fees and Cost Limitations
- 27-2 TMR Weights
- 27-3 USA Benefits

Matrix

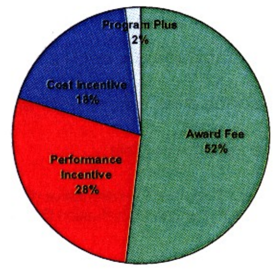
Presenter	CAIB/Group 1	Date	FINAL	Slide	32 of 32

Space Shuttle Operations Contract

- **Action / Issue:** SFOC award fees, incentive fees, performance fees, and cost limitations may affect the profitability of the contract
- **Background / Facts:**
  - SFOC is susceptible to funding limitations
  - Reduction at NASA funded level would be distributed to program based on NASA priorities. Cost growth in other priority programs could negatively affect funding on the SFOC and other SSP contracts.
  - Using commercial business practices can reduce cost and provide increase profit incentives for cost reduction and performance
- **Findings:**
  - Fee Structure (see following slides)
- **Group Recommendation:**
  - NASA should review contract history to evaluate whether fee plan is rewarding cost savings at expense of performance

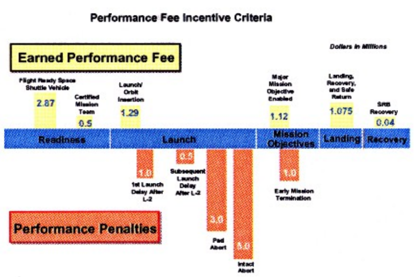
Presenter M3/Contracting | Date FINAL | Slide 1 of 14 | Closed

Space Shuttle Operations Contract Fee Structure



Presenter M3/Contracting | Date FINAL | Slide 2 of 14 | Closed

SFOC Performance Fee Plan



Presenter M3/Contracting | Date FINAL | Slide 3 of 14 | Closed

SFOC Performance Fees

- Available fee: $6Million (STS 80 – STS 91); $6.8Million (STS 95 STS 110)
- Total earned over 31 flights: $190 million
- Fees forfeited:
  - $1M STS 80 (OV-102), January 1997 (challenged by USA,resolved September 1997)
    - In Flight anomaly (IFA), inability to accomplish major mission objectives
  - $1M STS 92 (OV-103) September, 2000
    - 24-hour launch delay

Presenter M3/Contracting | Date FINAL | Slide 4 of 14 | Closed

SFOC Performance Fees

- Fee Not Earned (cont)
  - $2.87M STS 103 (OV-103): January 2000
    - Missed manifest launch date by more than 7 days - due to workmanship damage to wiring
  - $2,87M STS 99 (OV-105): March 2000
    - Workmanship damage to wiring
  - $2.879 STS 101 (OV-104): June 2000
    - Workmanship damage to wiring
  - $1.435M STS 109 (OV-102) May 2002
    - Missed manifest date, ready for launch criteria not met

Presenter M3/Contracting | Date FINAL | Slide 5 of 14 | Closed

Performance Fees Earned

SHUTTLE MISSION	AVAILABLE PERFORMANCE	DOLLARS EARNED	DOLLARS NOT EARNED
STS 80	$6,000,000	$5,000,000	$1,000,000
STS 81	$6,000,000	$6,000,000	$0
STS 82	$6,000,000	$6,000,000	$0
STS 83	$6,000,000	$6,000,000	$0
STS 84	$6,000,000	$6,000,000	$0
STS 85	$6,000,000	$6,000,000	$0
STS 94	$6,000,000	$6,000,000	$0
STS 86	$6,000,000	$6,000,000	$0
STS 87	$6,000,000	$6,000,000	$0
STS 89	$6,000,000	$6,000,000	$0
STS 90	$6,000,000	$6,000,000	$0
STS 91	$6,000,000	$6,000,000	$0
STS 95	$6,895,000	$6,895,000	$0
STS 88	$6,895,000	$6,895,000	$0
STS 96	$6,895,000	$6,895,000	$0
STS 93	$6,895,000	$6,895,000	$0
STS-103	$6,895,000	$4,025,000	$2,870,000
STS-99	$6,895,000	$4,025,000	$2,870,000
STS-101	$6,895,000	$4,025,000	$2,870,000
STS-106	$6,895,000	$6,895,000	$0
STS-92	$6,895,000	$5,895,000	$1,000,000
STS-97	$6,895,000	$6,895,000	$0
STS-98	$6,895,000	$6,895,000	$0
STS-102	$6,895,000	$6,895,000	$0
STS-100	$6,895,000	$6,895,000	$0
STS-104	$6,895,000	$6,895,000	$0
STS-105	$6,895,000	$6,895,000	$0
STS-108	$6,895,000	$6,895,000	$0
STS-109	$6,895,000	$5,460,000	$1,435,000
STS-110	$6,895,000	$6,895,000	$0
STS-111	$6,895,000	$6,895,000	$0
STS-112	$6,895,000	$6,895,000	$0

Presenter M3/Contracting | Date FINAL | Slide 6 of 14 | Closed

1

Award Fee

- Six-month periods
- Scores range from 0-100, reflect per cent of available fee
- Fee Determining Official (FDO) signs the performance determination
- Safety Score and Performance Score
- Contracting Officer's Technical Representative (COTR) recommends based on input from Performance Evaluation Board

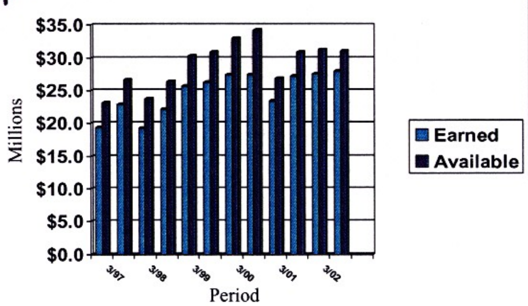
Presenter M3/Contracting | Date FINAL | Slide 7 of 14 | Closed

Award Fee

- Performance Evaluation Team (PET) rates USA on 13 functional areas.
- Technical Management Representatives (TMR) provide numerical evaluations on areas of emphasis
- Identify Strengths and Weaknesses

Presenter M3/Contracting | Date FINAL | Slide 8 of 14 | Closed

SFOC Award Fee



Presenter M3/Contracting | Date FINAL | Slide 9 of 14 | Closed

SFOC Award Fee History

EVALUATION PERIOD	START DATE	END DATE	AVAILABLE AWARD FEE	DOLLARS EARNED	DOLLARS NOT EARNED
1	10/1/1996	3/31/1997	$23,200,000	$19,488,000	$3,712,000
2	4/1/1997	9/30/1997	$26,661,483	$22,928,875	$3,732,608
3	10/1/1997	3/31/1998	$23,788,065	$19,268,333	$4,519,732
4	4/1/1998	9/30/1998	$26,425,761	$22,197,639	$4,228,122
5	10/1/1998	3/31/1999	$30,303,402	$25,757,894	$4,545,508
6	4/1/1999	9/30/1999	$30,971,263	$26,325,576	$4,645,687
7	10/1/1999	3/31/2000	$33,052,574	$27,433,636	$5,618,938
8	4/1/2000	9/30/2000	$34,327,255	$27,461,804	$6,865,451
9	10/1/2000	3/31/2001	$26,917,106	$23,415,781	$3,498,910
10	4/1/2001	9/30/2001	$30,915,116	$27,205,302	$3,709,814
11	10/1/2001	3/30/2002	$31,366,792	$27,602,777	$3,764,015
12	4/1/2002	9/30/2002	$31,073,024	$28,274,949	$2,796,423
13	10/1/2002	3/31/2003	**$41,218,518**		
14	4/1/2003	9/30/2003	**$41,906,566**		
15	10/1/2003	3/30/2004	**$42,102,291**		
16	4/1/2004	9/30/2004	**$49,178,918**		
17	10/1/2004	3/30/2005	**$484,163**		
18	4/1/2005	9/30/2005	**$436,857**		
19	10/1/2005	3/30/2006	**$387,583**		
20	4/1/2006	9/30/2006	**$368,279**		
21	10/1/2006	3/30/2007	**$348,238**		
22	4/1/2007	9/30/2007	**$343,043**		
23			**7,967**		
24					
25					
26					
27					
28					
TOTAL			**$525,784,264**	$297,360,566	$51,637,208

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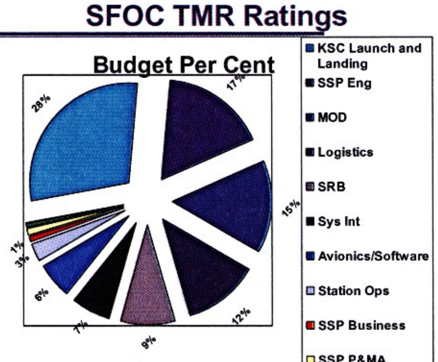
SFOC TMR Ratings



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Boeing Subcontract to SFOC

- Boeing subcontract makes up largest share of SFOC
- Subcontract value is $2.3 B
  - Cost of $2.1B
  - Fees total $197.4M
- Award fee plan mirrors SFOC
- Award fees scores track to within 5% of SFOC score by agreement

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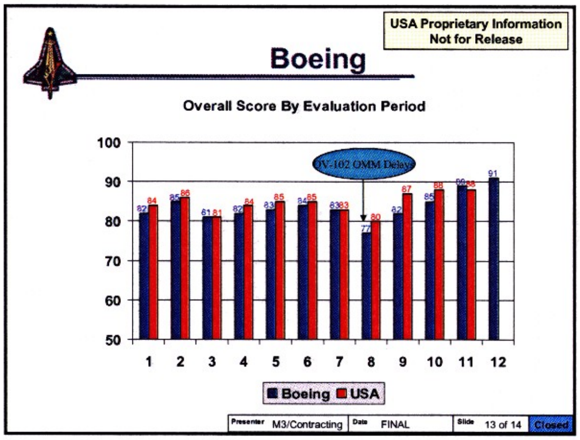
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Not for Release
Boeing
Overall Score By Evaluation Period
100
90
80
70
60
50
OV-102 OMM Delays
1 2 3 4 5 6 7 8 9 10 11 12
Boeing USA
Presenter M3/Contracting
Date FINAL
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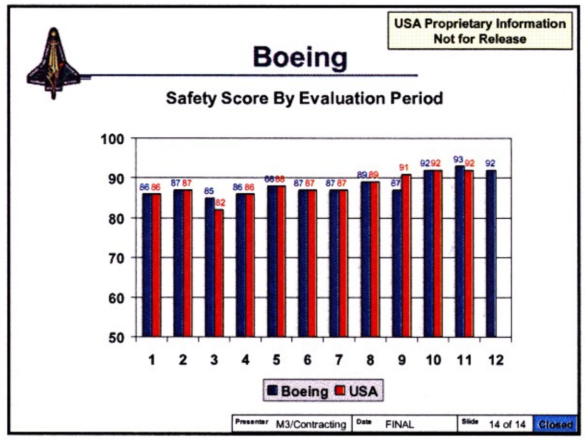
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Not for Release
Boeing
Safety Score By Evaluation Period
100
90
80
70
60
50
1 2 3 4 5 6 7 8 9 10 11 12
Boeing USA
Presenter M3/Contracting
Date FINAL
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Closed

3

Contracting Issues SFOC

- **Action / Issue:** Technical Management Representatives score weightings may hide substandard performance on contract requirements
- **Background / Facts:**
  - Each Technical Management Representative (TMR) assigns USA a performance grade in each of 6 areas. TMR Scores are weighted based on an individual share of the budget
  - Weighted scores are totaled to provide recommended score
- **Findings:**
  - 13 TMRs rate contractor performance every 6 months
  - Weighted scores become the recommendation to the PEB
  - Weights of TMRs on small share elements "disappear" when summary number produced

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SFOC TMR Weighted Ratings

- **Group Recommendation:**
  - NASA should review low ratings regardless of budget weights; consider assigning award fee pools to each TMR to reward performance in each area rather than aggregate.

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TMR Weighted scoring

KSC Launch and landing:	27.96%
SSP vehicle engineering:	17.67%
MOD:	14.47%
Integrated Logistics:	12.03%
Solid Rocket Booster:	9.26%
SSP SYS INT	6.99%
Avionics and Software	5.48%
Station Ops and Util	2.69%
SP Business	.89%
SSP S&MA	1.09%
Management Int	0.39%
FCOD	0.27%

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SFOC TMR Weighted Ratings

- KSC Launch and Landing weighted at 30%
- Vehicle Engineering weighted at 17%
- System Integration weighted at 6.5%
- Safety and Mission Assurance weighted at 1.1%
- Reinforces commitment to meeting manifest

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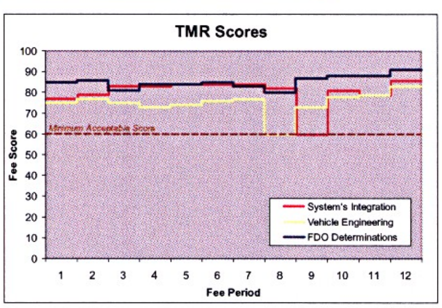
TMR Scores



Presenter M3/Contracting | Date FINAL | Slide 5 of 5 | Closed

1

USA Employee Benefits

- **Action / Issue:**
  Potential "Substandard" United Space Alliance (USA) Benefits package May Impact Workforce Retention, Quality, and Morale
- **Background / Facts:**
  - USA's employee benefit package is viewed by some as as being below aerospace industry average.
  - Defense Contract Audit Agency (DCAA) conducted audits of several areas of compensation including:
    - Compensation System Internal Controls
    - Fringe Benefits
    - Health Care Cost

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USA Benefits

- Compared to Chamber of Commerce Study of companies with over 5,000 employees, USA is excessively generous
- Industry-wide healthcare company contribution 83%; employee contribution 17%
- Watson Wyatt survey of comparable companies: company contribution 86%; employee contribution 14%
- USA pays 92% of employee healthcare costs
- Also, excessive Paid Time Off (PTO) not charged as leave
- At least one more paid Holiday than average
- DCAA suggested that USA could save $12 million annually by REDUCING benefits to comparable average

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USA Benefits

- Federal Acquisition Regulations (FAR) directs that compensation be considered sum of ALL pay and benefits, rather than Pay OR Benefits separately
- **Group Recommendation:**
  - Perception of poor benefits may be in comparison with heritage aircraft industries (Lockheed; Boeing) where large hourly labor force historically drives generous benefits packages. There is no support to the suspected issue and it should be disposed of.

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