SPACE SHUTTLE CORROSION PROTECTION PERFORMANCE

Session: Corrosion – Space Applications

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Abstract

The reusable Manned Space Shuttle has been flying into Space and returning to earth for more than 25 years. The launch pad environment can be corrosive to metallic substrates and the Space Shuttles are exposed to this environment when preparing for launch. The Orbiter has been in service well past its design life of 10 years or 100 missions. As part of the aging vehicle assessment one question under evaluation is how the thermal protection system and aging protective coatings are performing to insure structural integrity. The assessment of this cost resources and time. The information is invaluable when minimizing risk to the safety of Astronauts and Vehicle. This paper will outline a strategic sampling plan and some operational improvements made by the Orbiter Structures team and Corrosion Control Review Board.

Introduction

The Orbiter Structures and Corrosion Control Review Board (CCRB) manages the Orbiter's corrosion to insure that the Space Shuttle Program (SSP) continues successful manned space flight missions past the Orbiter's original design life requirement of 10 years or 100 missions. One of the many concerns that the CCRB identified was degradation of primary structure due to degraded properties of the protective coatings. The integrity of the primary structure is not easily assessed because all inner mold line (IML) surfaces are covered with thermal protection materials. The primary structure consists of 2XXX series aluminum alloys and has protective coatings applied. If these coatings are breached then the aluminum primary structure will degrade. The non-metallic thermal protection system (TPS) insures that during earth's re-entry the primary structure integrity is maintained. Over the Space Shuttle's history during turnaround maintenance between flights the TPS is replaced for various reasons. This localized remove and replace process has allowed inspection of the primary structure. In April 2004, the criticality of corrosion enabled certification of corrosion inspectors to inspect substrates and not overlook potential corrosion characteristics that could become covered up and go unnoticed until next unplanned TPS removal. The responsibility of the aluminum integrity belongs to the structures discipline and the integrity of the TPS and bond strength to aluminum belongs to the TPS discipline. Over the years, the aluminum substrate surface preparation for bonding allowed the aluminum's protective coatings to be reduced or even removed. The CCRB recognized this and implemented procedures to insure that protective coatings return to an improved condition. The repair of protective coatings and not disturbing adjacent pre-existing coatings or TPS bonds is a specialized process. At the microscopic level protective coatings can have

micro-cracks due to configurations and stresses which could allow corrosion to initiate. The Space Shuttle's protective coating contains chromate to aid in corrosion protection and can degrade over time. Based on materials/processes capabilities, no qualified and certified Non-Destructive Inspection (NDI) equipment or method existed and to insure margin of safety. The Orbiter Project implemented a time based sampling plan that targeted specific locations. The sampling requirements were the following;

A. Sampling must be directed at areas of highest concern.
B. Sample size must be statistically significant based on population.
C. Structure not susceptible to corrosion shall be exempt from inspection.
D. Time limited.
E. (97) tile cavities on fuselage, heat shields, vertical tail, body flaps, wings and elevons spaced greater than 18 inches from each other.
F. (94) one square foot areas of fibrous reusable insulation locations on fuselage, heat shields, vertical tail, body flaps, wings and elevons spaced greater than 18 inches from each other.
G. (12) two linear feet of heatsink perimeter under tile cavities.

Next, development of how to implement the sampling plan required operations, information systems, engineering, quality, logistics and safety personnel to coordinate the implementation plan with no additional resources or available schedule time. The goal was to optimize and take advantage of pre-existing systems making this nearly invisible to all organizations. The tractability of corrosion difficulty was increased because TPS performs inspection of aluminum substrate during problem report repair of TPS. If suspect corrosion identified then a structures problem report is identified and reworked to an acceptable condition. The photo documentation may be captured during both repairs of TPS and structures. There has been primary stainless steel structure corrosion problems in the past where through holes that had fasteners installed have had cracks migrating from holes initiated with corrosion pitting. Since this configuration exist (fasteners through panels on the Orbiter's IML) under TPS draws focus if this existed in the lowest margin of safety location then risk would be high and unacceptable.

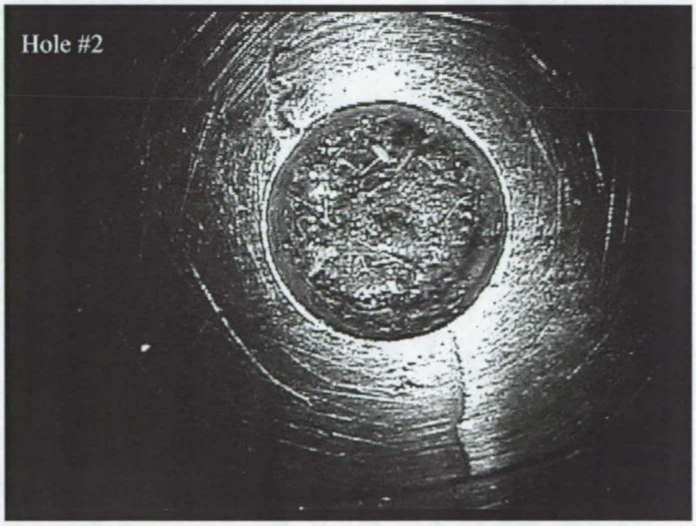

Figure 1: Cracks migrating after corrosion rework of aft heat shield

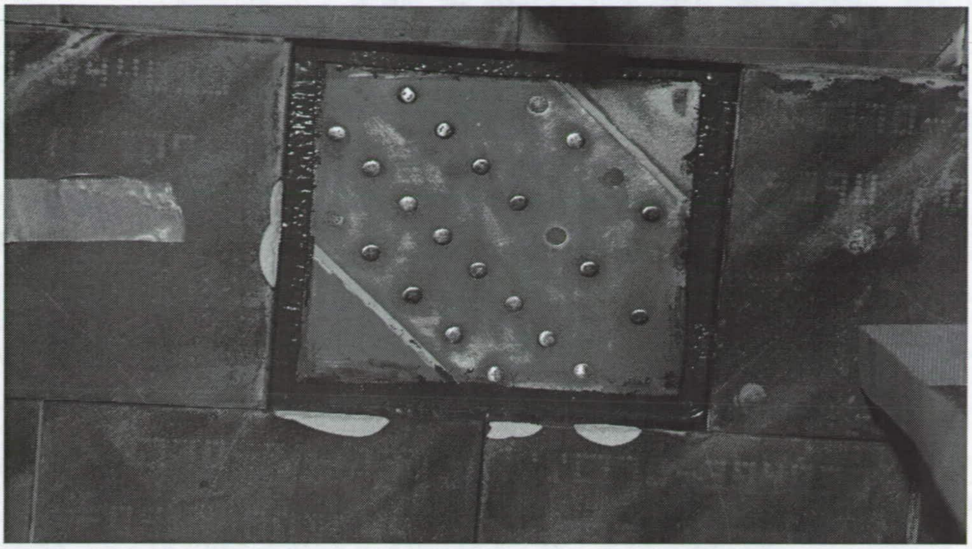

Figure 2: IML panel fasteners with TPS removed

Results

Not having the capability to assess the primary structure's integrity without destructively removing and replacing TPS facilitated the development of NDI methods which are now underway to have capability to detect corrosion. Confidence was quickly gained with all decision making and operations personnel by

A. Using certified corrosion inspectors insured that some historical minor credit may be obtained for recent TPS repairs.
B. The utilization of capturing pre/during/post digital images real time of every eventful location and uploading these to the Shuttle Image Management System (SIMS) for timely assessment.
C. Modifying TPS databases to capture Structures part numbers allowing graphical images of where on the Orbiter the problems are occurring to be formulated in a timely manner.
D. Pre-approved acceptance repair procedures eliminating long evaluation times and increasing though put.
E. Developing decision flow charts with roles and responsibilities.
F. Coordination and status of progress to date for Flight Readiness Reviews insuring Risk is understood.
G. Test results on 30 year old aged Super Koropon protective coating from Orbiter "Enterprise" mid-deck hardware located in Smithstonian Institute.
H. The Space Shuttle's worst case corrosion may not be applicable to the remainder of primary structure.
I. Substrate corrosion locations were on the outer edges not in center of repair areas.

The certification of technicians, inspectors and engineers is accomplished with training and hands on work. The majority of the workforce has received this training and certification. Prior to April 2004 inspection of substrates was performed but not with certified employees. The certification allows recognition of the various types of corrosion characteristics that could be observed on hardware. The photo documentation of corrosion anomalies allows discrete assessment by all disciplines. The SIMS has

attributes that links image to respective locations. It's a web based system that allows viewing with approved access and historical storage.

The TPS maintenance is time consuming during turnaround operations at Kennedy Space Center. The numbers can range in the hundreds depending on damage received post launch/landing, scheduled maintenances, or planned modifications. This mature information database system allows configuration and planning to control activities in an organized fashion. It was an opportunity to coordinate with owners of this system and see if modifications could be made to support the corrosion assessment. Requirements were identified and partnered with all responsible personnel. Modifications were implemented and the system generated timely graphical and documented reports.

The corrosion repair procedures eliminate process creep to insure all anomalies are handled with consistency. Engineering time is saved with not having to create this when the need arises. The procedures control dozens of materials, equipment, requirements and operations.

A. Flight and support
B. Tools and test
C. Personal protective
D. Non inventory items
E. Planning
F. Critical Skills
G. Safety
H. Cleaning
I. Inspection
J. Coating removal
K. Re-inspection
L. Disposition
M. Mechanical corrosion removal
N. Measurement of depths and thicknesses
O. Coating repair

The decision flow chart aided in identifying the communications, roles and responsibilities. This system allowed any person to view an Orbiter anomaly and immediately know what's going on, who is involved and at what level. Figure 3 is decision flow chart that supported personnel in corrosion assessment and repairs. When an anomaly could not be returned to drawing and required material reviews by additional resources this process was pre-existing. Documenting the activities allowed the team to assess where disconnects might interfere with accomplishing the mission.

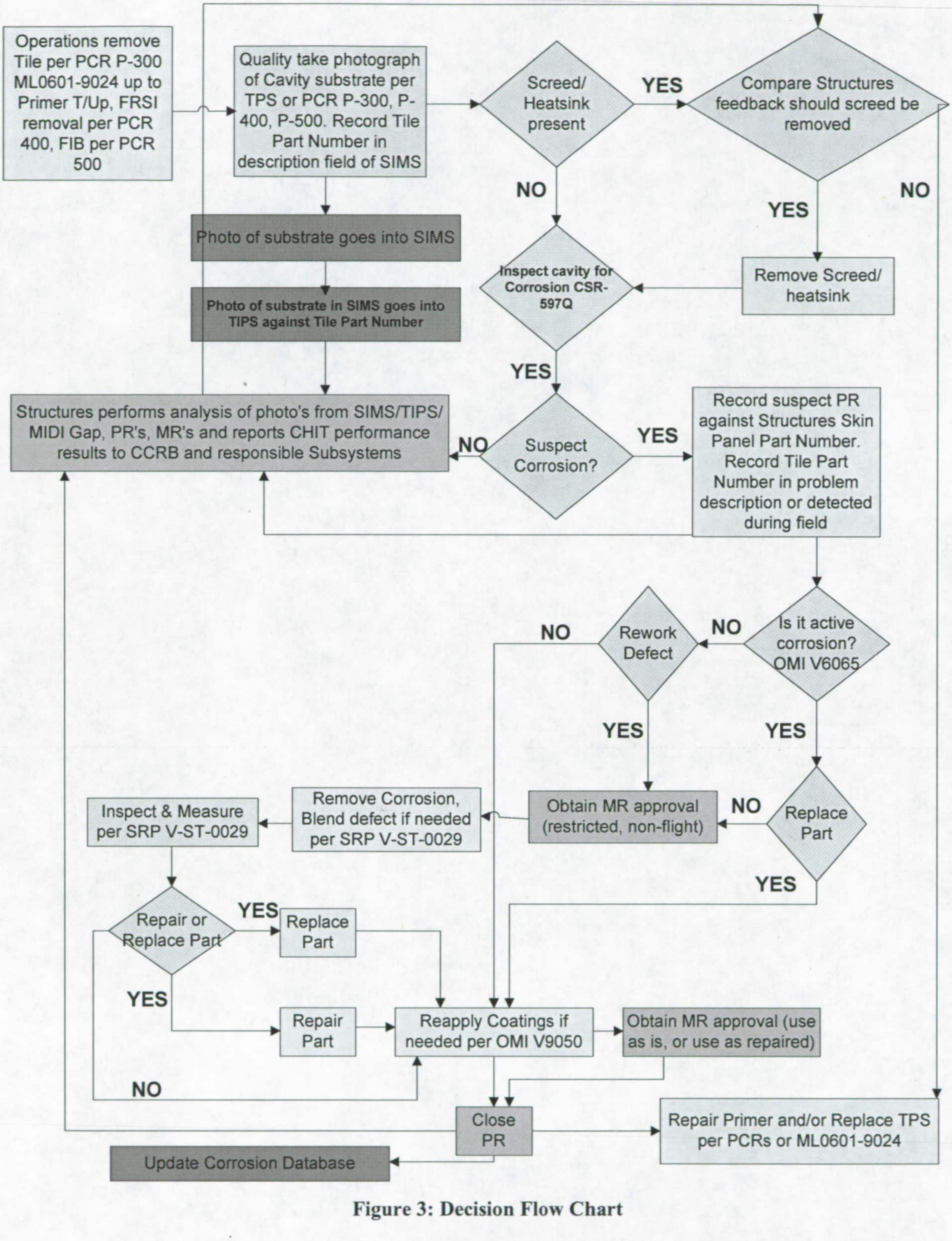

Figure 3: Decision Flow Chart

The risk was communicated to management personnel in a stop light format. This graphical and spreadsheet format worked together to insure no discrete locations escape. The locations under "Tile" that were sampled (which changes on a daily) on a directed or non-interference basis equals 2,494 locations on all the Orbiter's over the last 18 months. The surface locations sampled were

A. Forward lower fuselage
B. Forward sides and upper fuselage
C. Mid fuselage
D. Aft lower fuselage
E. Sides of aft fuselage
F. Aft base and dome heat shields
G. Aft vertical tail and rudder speed brake
H. Aft lower surface of body flap
I. Sides and upper surfaces of aft body flap
J. Left and right wings
K. Left inboard and outboard elevons
L. Right inboard and outboard elevons

Of the sampled >2,500 locations, corrosion was found on 37 separate cavities and 20 of these had material loss after rework. The sampling requirement of edge to edge distance was not fully satisfied.

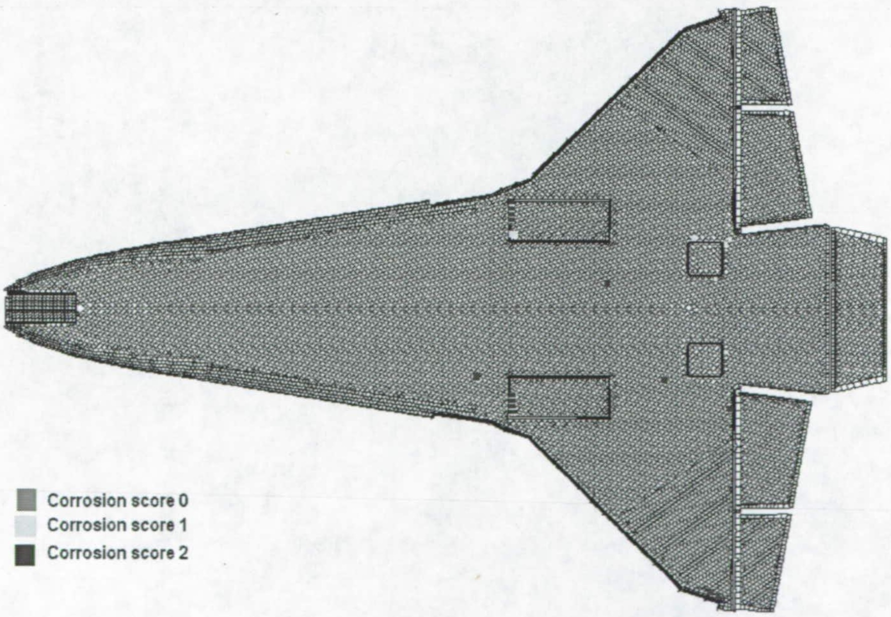

Figure 4: Corrosion Map Lower Surface

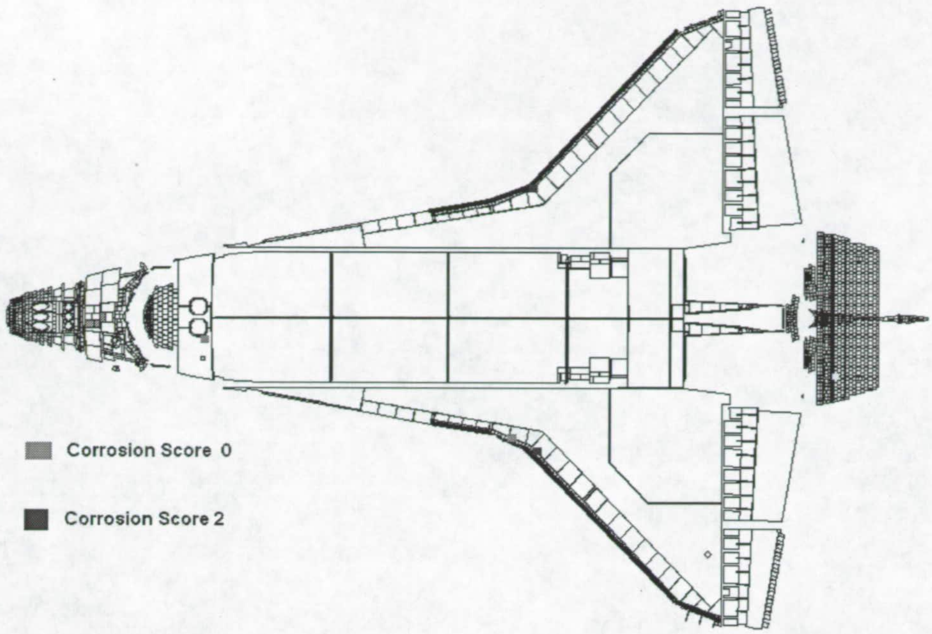

Figure 5: Corrosion Map Upper Surface

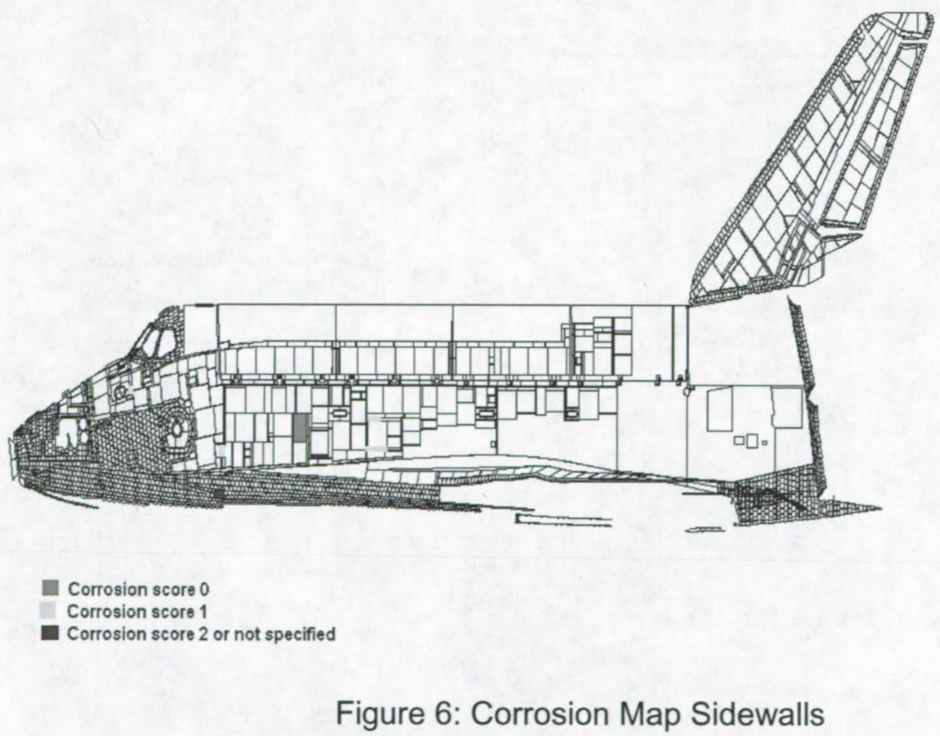

Figure 6: Corrosion Map Sidewalls

The other TPS sampling activity of concern is under Fibrous Insulation Blankets (FIB) and Felt Reusable Surface Insulation (FRSI). There have been several hundred removals to date and several locations with material loss from corrosion. Planning has recently been implemented to direct removals to satisfy requirements in the coming months. The surface locations sampled were

A. Forward sides and upper fuselage
B. Mid fuselage sides
C. Aft vertical tail and rudder speed brake

The surface locations that still need to be sampled are

D. Left and right wings
E. Left inboard and outboard elevons
F. Right inboard and outboard elevons

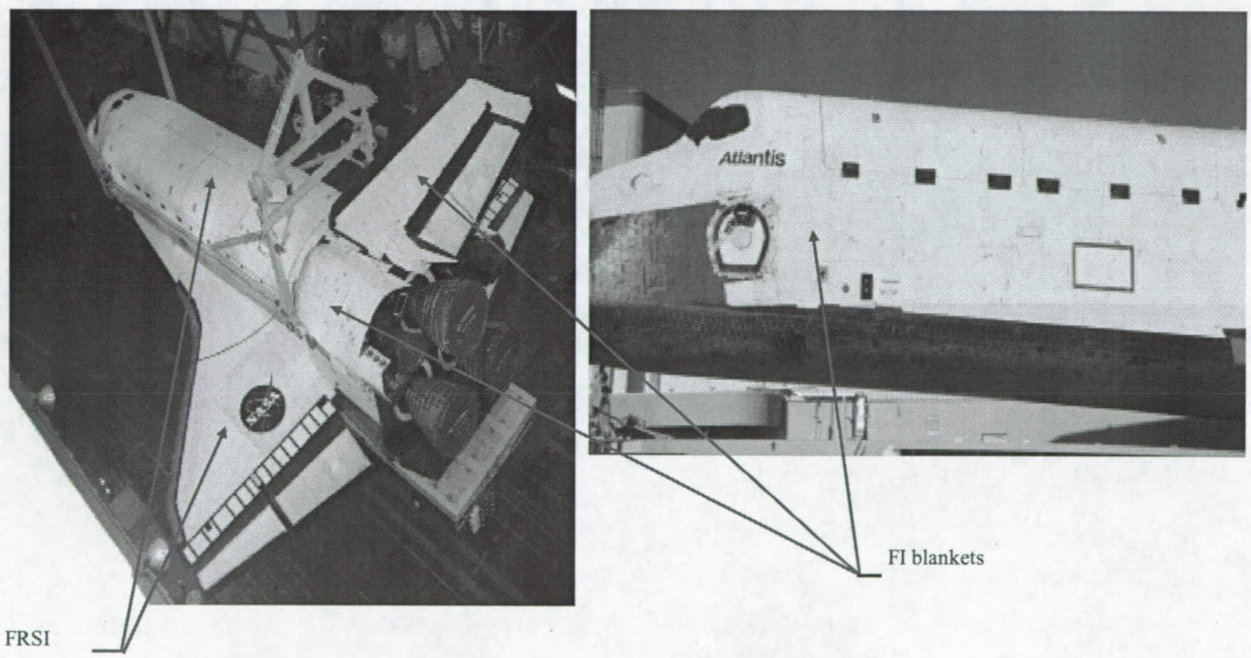

Figure 7: FRSI/FIB Locations

The sampling of heatsink perimeters for two foot linear at each location under tile cavities is the other remaining TPS concerns that still need to be sampled are

A. Bodyflap
B. Fwd fuselage
C. Left hand inboard/outboard elevons
D. Right hand inboard/outboard elevons

Even though hundreds of samples for TPS locations under Tile, FIB/FRSI, and heatsink the requirement for having a minimum distance of 18 inches from sample to sample has been difficult to satisfy.

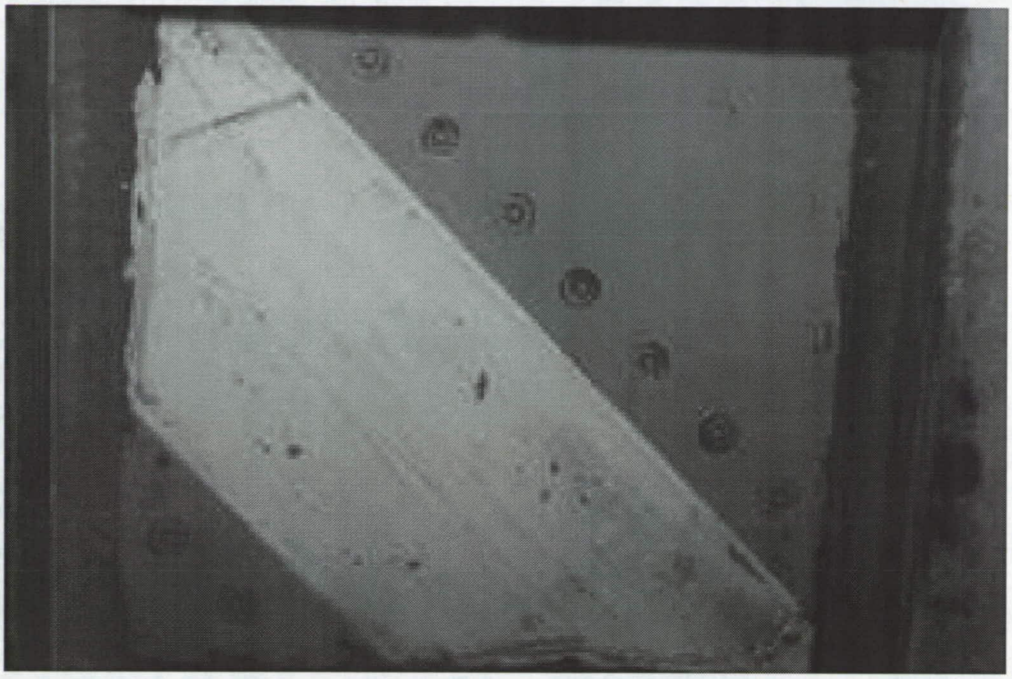

Figure 8: Heat sink, Screed on IML

Conclusion

Corrosion under TPS does exist and the sampling activity provided some knowledge of where the problems are and their magnitude. The majority of corrosion has been found near edges of hardware or interface openings, around fasteners and not in the central surface areas when an individual location is accessed. When safety margins are thin the repairs will replace with new hardware and or add additional materials to strengthen areas of concern. The aged protective coatings are still providing corrosion protection and the TPS has been protecting the underlying protective coatings from heat, moisture and other aging effects. There are still TPS areas that need to be assessed especially FRSI, FIB and heatsink locations.

References

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2. MA0608-301 Specification, Corrosion Control and Finish Requirements-Space Shuttle Orbiter
3. CHIT J5390C dated 4-10-2006, Orbiter Structure Inner Mold Line Surface Corrosion Sampling Inspection, Mike McCarley
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5. Website; http://usaflwas06.usa-spaceops.ksc.nasa.gov/EDCSI:/SIMS/sims.html
6. Eric Eichenger, Lab report no. M&PE-3-1661, "Comparison of new super koropon primer to 30 year old super koropon", August 29, 2005
7. John Patterson, Lab report no. M&PE-3-1822, "Determining the effects of age and exposure on super koropon", February 15, 2007

SPACE SHUTTLE
CORROSION PROTECTION PERFORMANCE

10th Joint DoD/NASA/FAA Conference on Aging Aircraft

Session: Corrosion - Space Applications

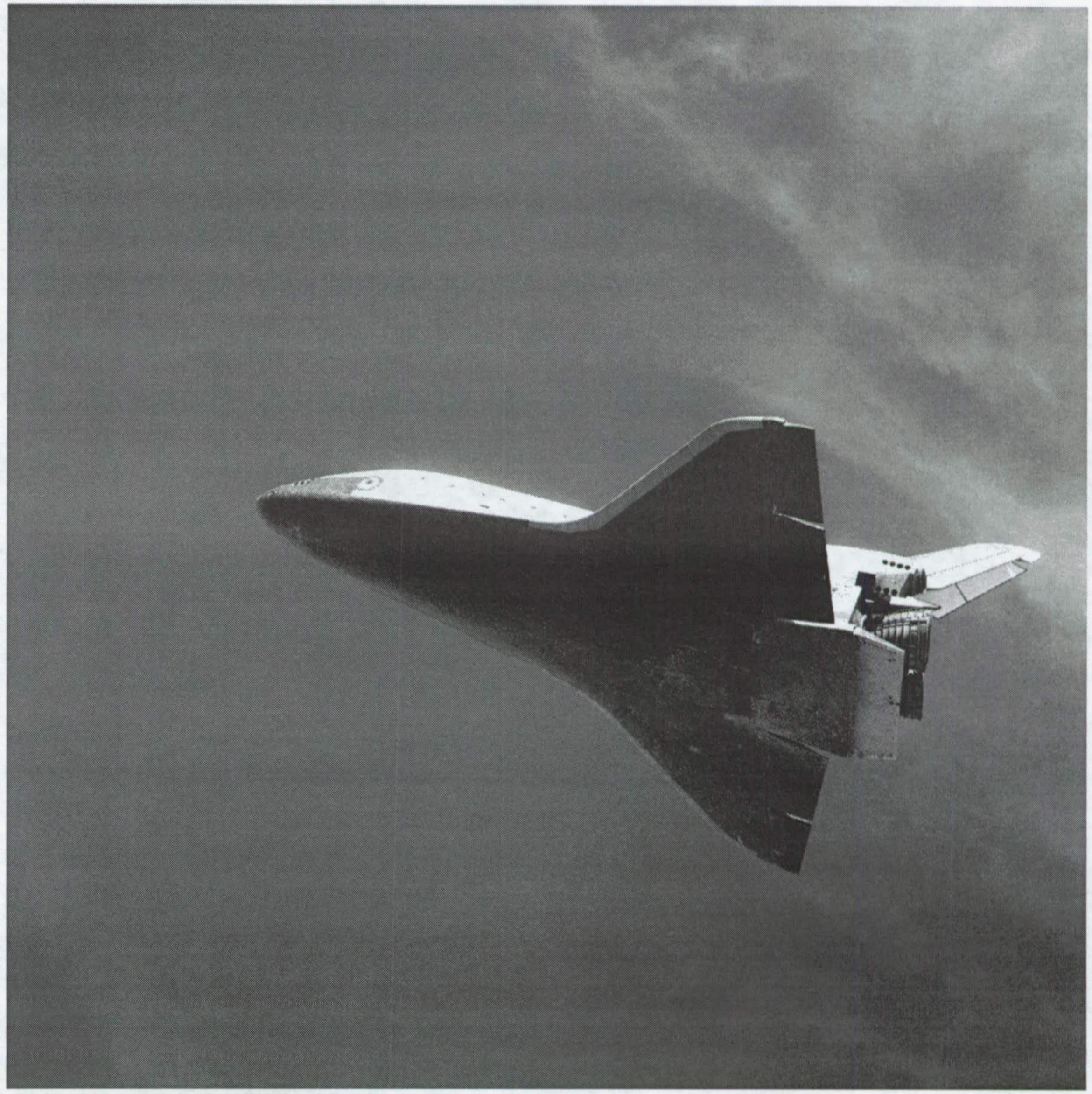
Cris Curtis

April 16-19, 2007

United Space Alliance

Agenda

- Purpose
- Procedure
- Results
- Conclusions



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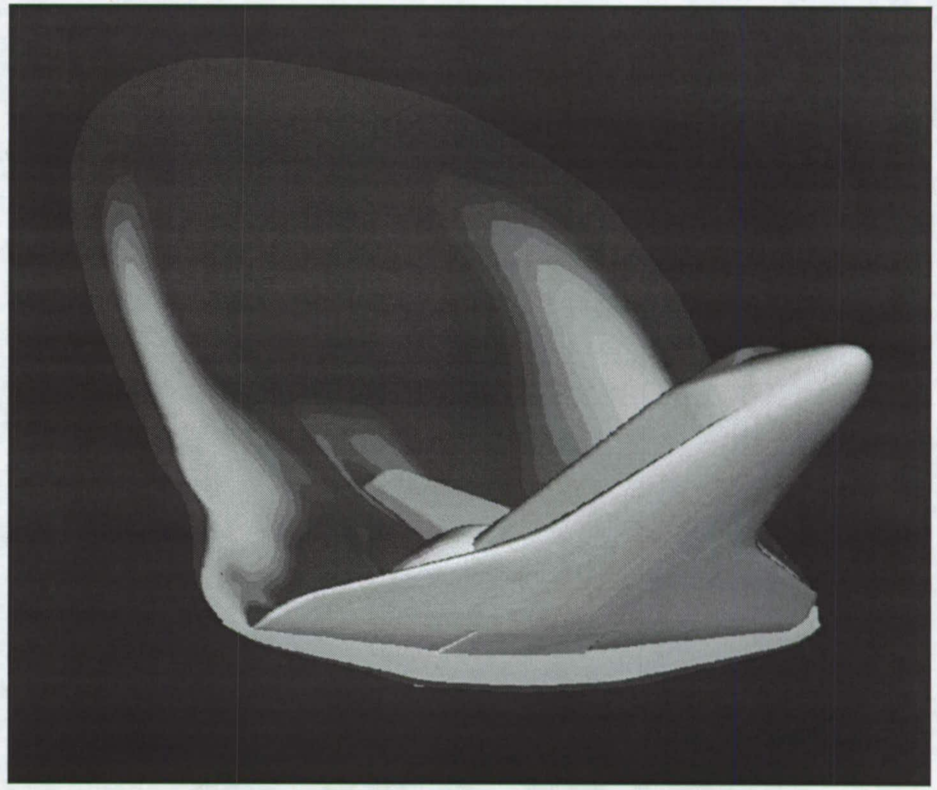
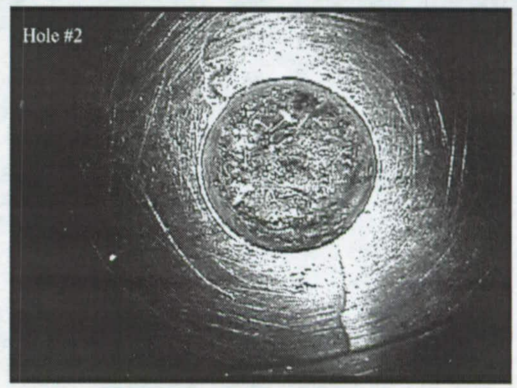
Purpose

- Design life 10 years or 100 missions
- How is thermal protection and protective coatings performing
- Structural integrity
- Certification
  - Inspectors
  - Historical processes
- Corrosion magnitude
- Sampling Plan assessing areas under
  - Tile (97 cavities)
  - FRSI/FIB (94 @ 1 sq. ft.)
  - Heatsink (13 @ 2 linear ft.)





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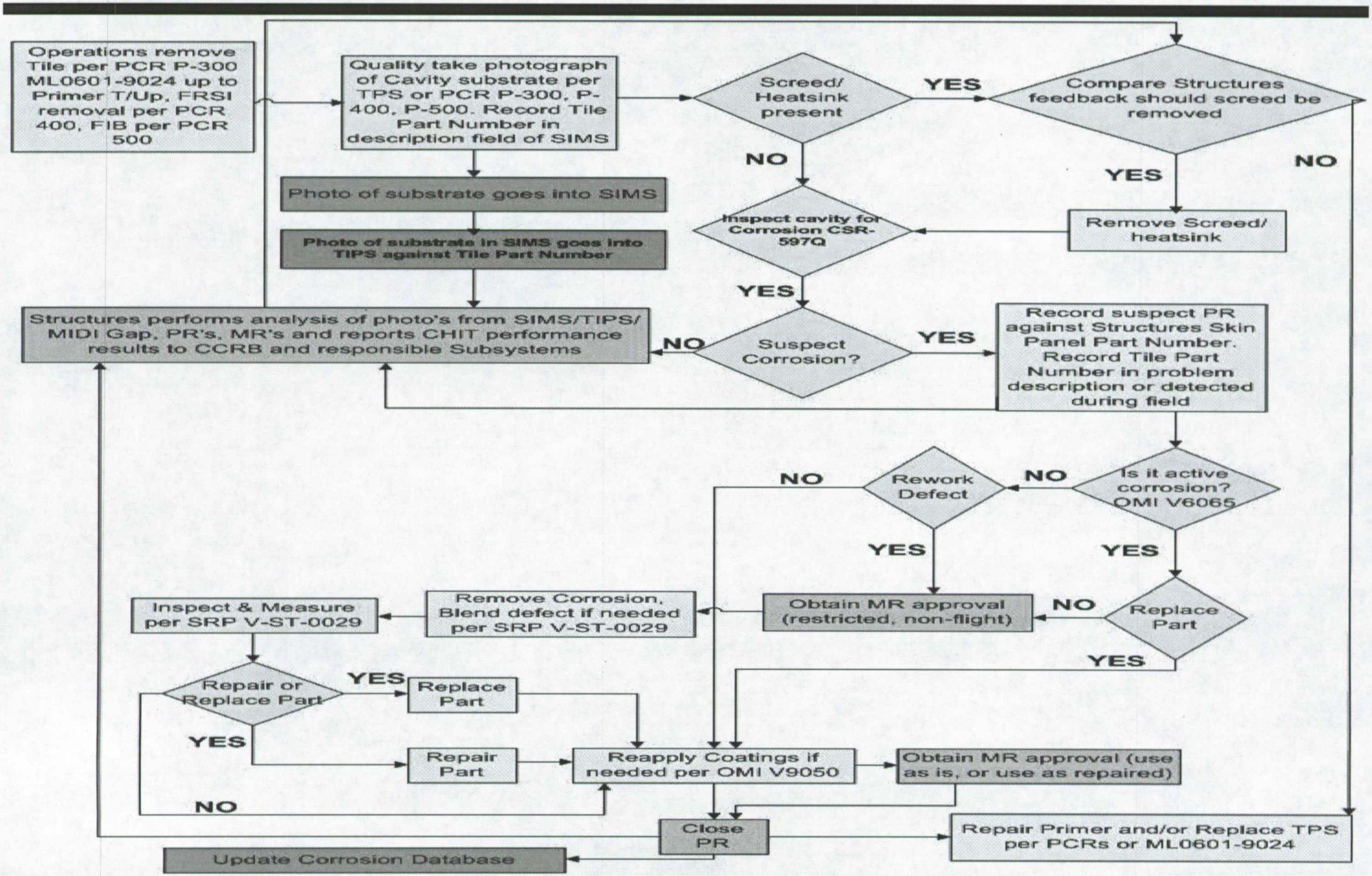
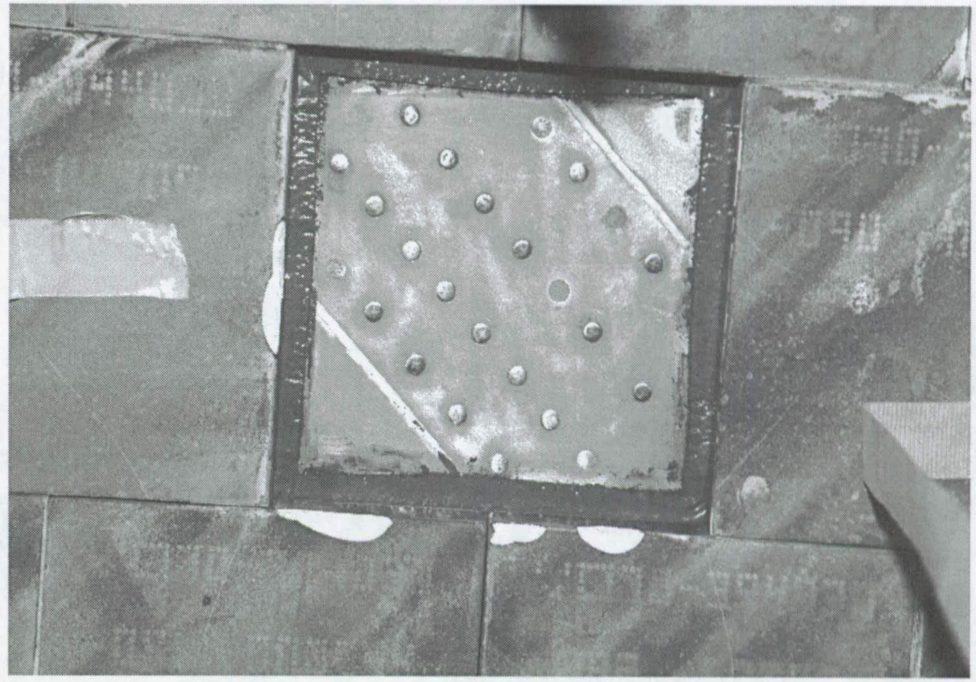
Procedure


Operations remove Tile per PCR P-300 ML0601-9024 up to Primer T/Up, FRSI removal per PCR 400, FIB per PCR 500
Quality take photograph of Cavity substrate per TPS or PCR P-300, P-400, P-500. Record Tile Part Number in description field of SIMS
Screed/ Heatsink present
YES
Compare Structures feedback should screed be removed
NO
YES
NO
Photo of substrate goes into SIMS
Inspect cavity for Corrosion CSR-597Q
Remove Screed/ heatsink
Photo of substrate in SIMS goes into TIPS against Tile Part Number
YES
Structures performs analysis of photo's from SIMS/TIPS/ MIDI Gap, PR's, MR's and reports CHIT performance results to CCRB and responsible Subsystems
NO
Suspect Corrosion?
YES
Record suspect PR against Structures Skin Panel Part Number. Record Tile Part Number in problem description or detected during field
NO
Rework Defect
NO
Is it active corrosion? OMI V6065
YES
YES
Inspect & Measure per SRP V-ST-0029
Remove Corrosion, Blend defect if needed per SRP V-ST-0029
Obtain MR approval (restricted, non-flight)
NO
Replace Part
YES
Repair or Replace Part
YES
Replace Part
YES
Repair Part
Reapply Coatings if needed per OMI V9050
Obtain MR approval (use as is, or use as repaired)
NO
Close PR
Repair Primer and/or Replace TPS per PCRs or ML0601-9024
Update Corrosion Database

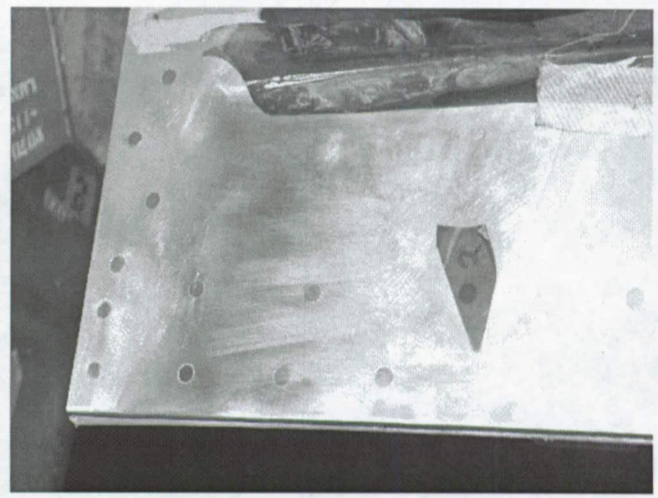
Results

- No Non-Destructive methods exist
  - Destructive evaluation required
    - Schedule impact
- Super Koropon (primer) Age
  - Test
  - Protecting aluminum structure
- Streamlined repair procedures
- Integration of multiple subsystems and disciplines
- Capturing digital images for evaluation



Results for under "TILE"

Type	Location			Sample Size	% Complete	Total	Wiped Clean	Active, No Material Loss	[redacted]
Tile	Forward	Fuselage	Lower	6	100	424	0	0	0
			Sides and Upper Surfaces	7	100	401	3	2	1
	MID		Lower	21	100	212	1	1	11
	AFT		Lower	7	100	124	1	6	2
			Sides	2	[redacted]	2	0	0	0
			Base and Dome Heat Shields	6	100	697	0	0	1
		RSB		4	100	122	0	0	0
		Bodyflap	Lower Surface	3	100	39	1	0	0
			Sides and Upper Surface	3	100	59	0	1	0
	Left	Hand	Wing	14	100	202	0	1	2
			In Board Elevon	3	100	15	0	0	0
			Out Board Elevon	2	50	20	0	0	0
	Right	Hand	Wing	14	86	154	0	0	3
			In Board Elevon	3	100	15	0	0	0
			Out Board Elevon	2	50	8	0	0	0
TOTAL				97		2494	6	11	20



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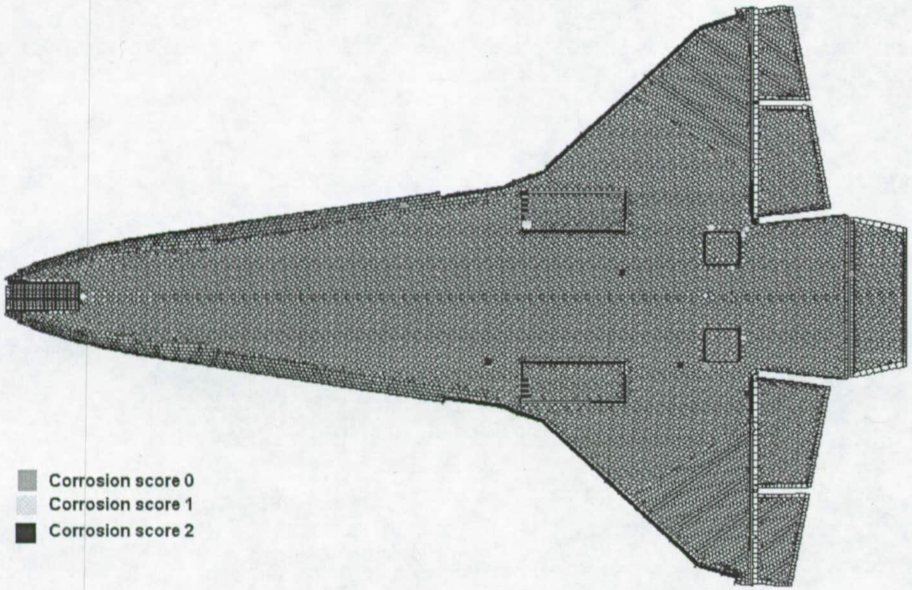
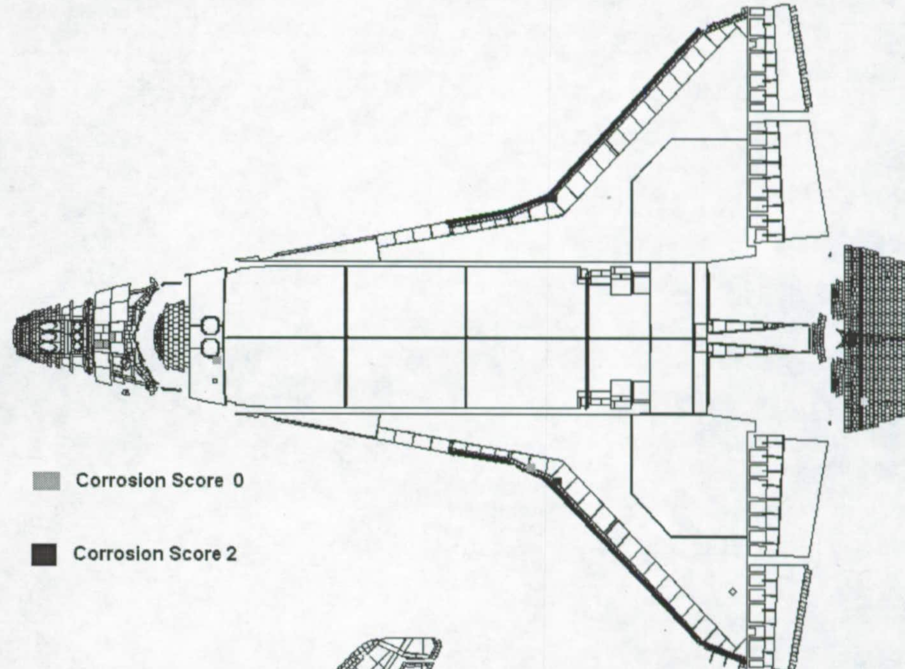
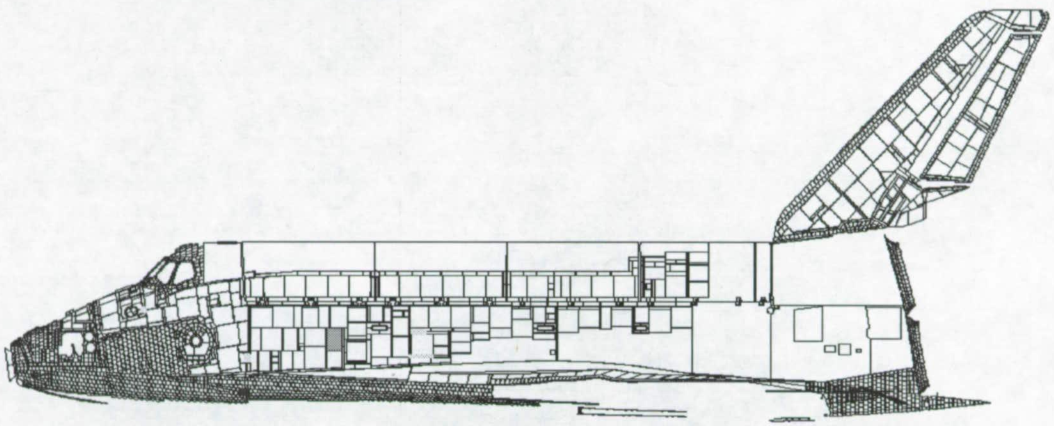
Results for under "TILE"



Corrosion score 0
Corrosion score 1
Corrosion score 2

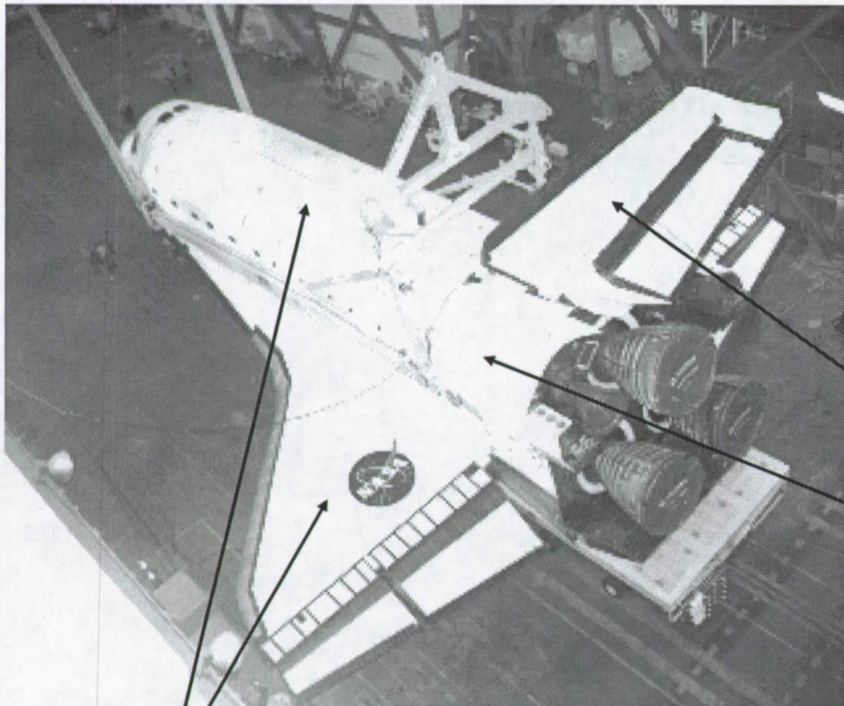


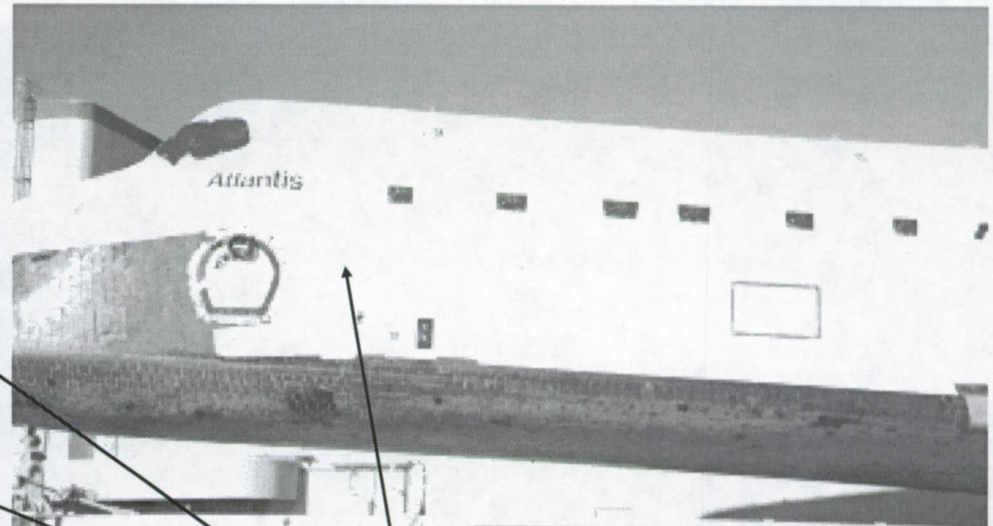
Corrosion Score 0
Corrosion Score 2



Corrosion score 0
Corrosion score 1
Corrosion score 2 or not specified

Results for under "FRSI/FIB"



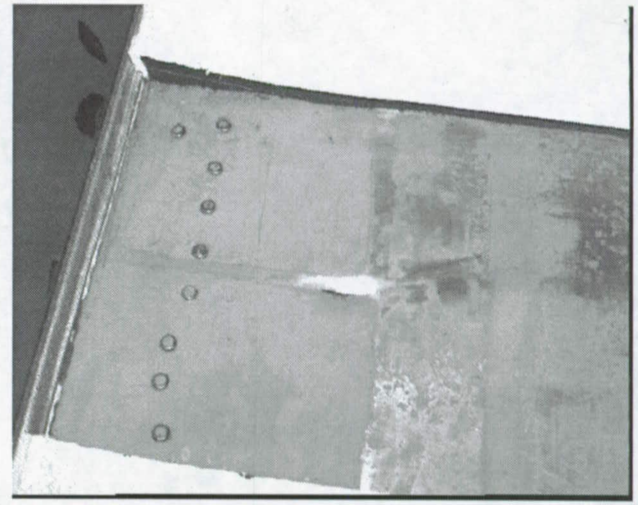


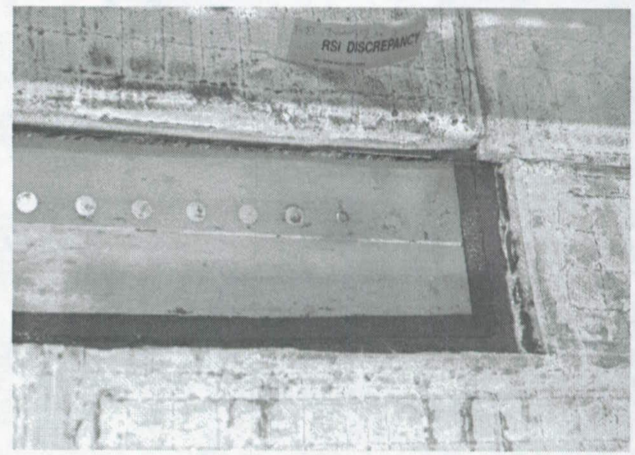
FI blankets

FRSI

Results for under “FRSI/FIB”

Type	Location			Sample Size	% Complete	Total	Wiped Clean	Active, No Material Loss	[illegible]
FRSI - FIB	FWD	Fuselage	Sides and Upper Surfaces	9	100	123	1	0	0
	MID	Fuselage	Mid Fuselage Sides	15	100	112	1	2	2
	AFT	Fuselage	Base BHS and DHS	3	33	2	0	0	0
	RSB			11	100	167	0	0	0
	Left	Hand	Wing	23	[illegible]	1	0	0	0
	Left	Hand	In Board Elevon	3	[illegible]	0	0	0	0
	Left	Hand	Out Board Elevon	2	[illegible]	0	0	0	0
	Right	Hand	Wing	23	[illegible]	0	0	0	0
	Right	Hand	In Board Elevon	3	[illegible]	0	0	0	0
	Right	Hand	Out Board Elevon	2	[illegible]	0	0	0	0
TOTAL				94		405	2	2	2





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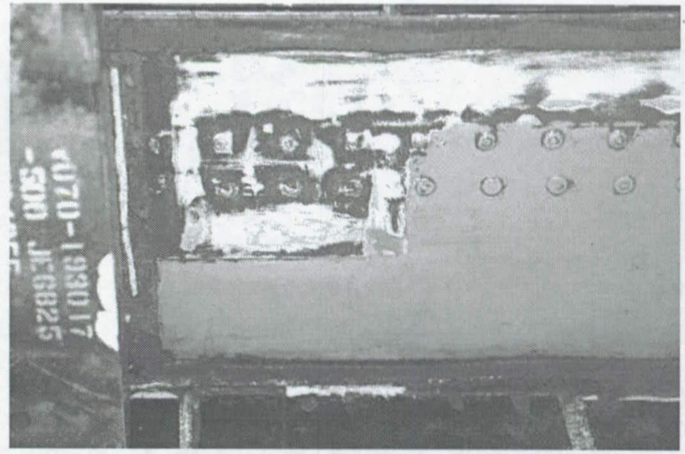
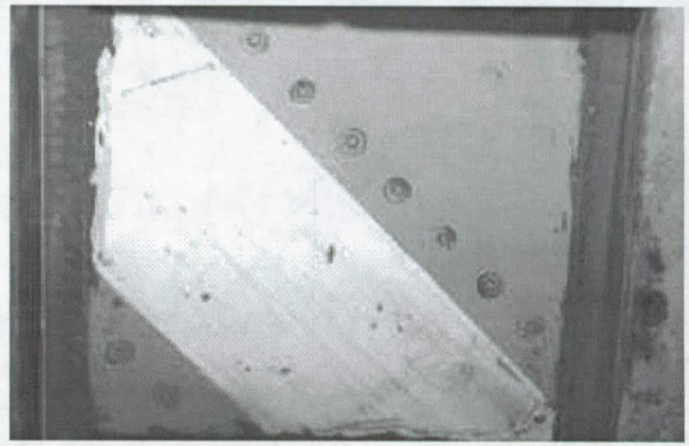
Results for under "Heatsink"

Type	Location		Sample Size	% Complete	Total	Wiped Clean	Active, No Material Loss	[redacted]
HEATSINK	FWD Fuselage	Sides and Upper Surfaces	3	[redacted]	0	0	0	0
	AFT	Bodyflap	3	[redacted]	0	0	0	0
	Left Hand	In Board Elevon	2	[redacted]	0	0	0	0
		Out Board Elevon	1	[redacted]	0	0	0	0
	Right Hand	In Board Elevon	2	[redacted]	0	0	0	0
		Out Board Elevon	1	[redacted]	0	0	0	0
TOTAL			12		0	0	0	0





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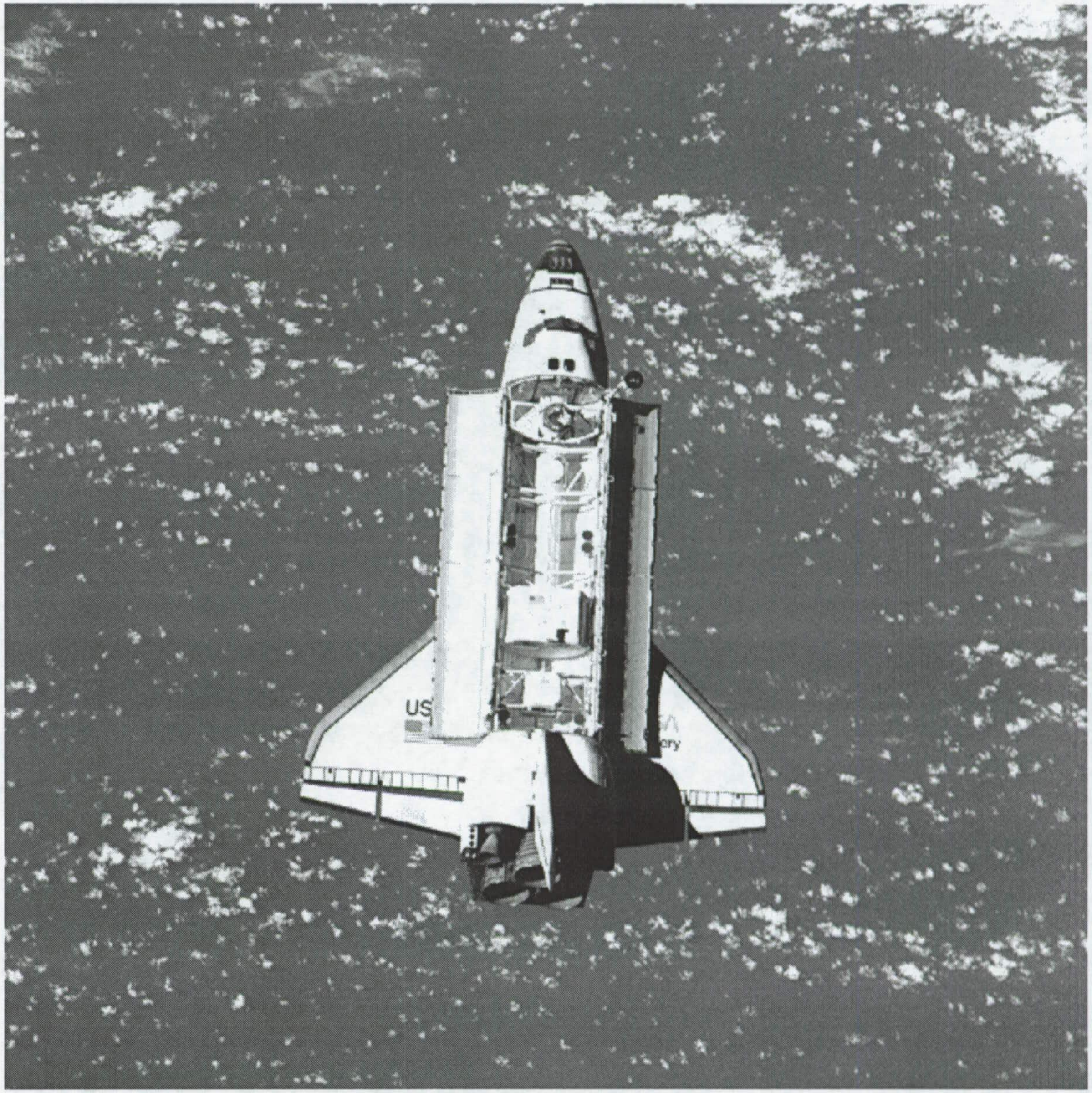
Conclusions

- Certified Inspections
- Primer performance - excellent
- Corrosion under Tile minimal
  - We know where problems are
  - Material loss on several locations
- More work required for FRSI, FIB and Heatsink
- NDE would eliminate major impact to operations and resources
- Progress and concerns addressed during Launch Readiness Reviews



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14. ABSTRACT

Provides assessment of how the orbiter's Thermal Protection System and protective coatings are performing to insure structural integrity of Inner mold Line.

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