Orbiter Inspection and Repair Summary

JSC Mission Operations Directorate

Flight Director Office

DA8/Paul S. Hill

9 September 2003

Introduction

- **The Orbit Flight Techniques Panel has been investigating TPS inspection and repair since late February.**
  - OFTP has now had 15 meetings on inspection and repair.
  - Top options are apparent in all areas, and in many cases the single preferred option stands out.
  - Some return to flight solutions are not without issues and concerns.
  - There is still considerable developmental work in several areas.
  - As a solution to a specific facet of the problem is shown to be feasible, it is handed off to the normal processes for detailed development and implementation.

- **This presentation covers:**
  - Status in each technical area
  - Significant open work

Summary

- **Repair materials and tools are development items:**
  - Tile repair solutions are in detailed testing and appear understood.
  - RCC repair is still in an early investigation stage, but materials have been identified for testing.

- **Inspection:**
  - An inspection capability exists in most areas during ISS flights without depth measurement, but enhancement is required for the leading edges.
    - » Expect the Orbiter pitch maneuver at 600’ for tile photography.
  - A boom and laser are in development for use on the end of the SRMS to ensure all TPS surfaces can be inspected at the critical threshold, including depth.
  - Orbiter stand-alone inspection will be provided by the boom and laser.

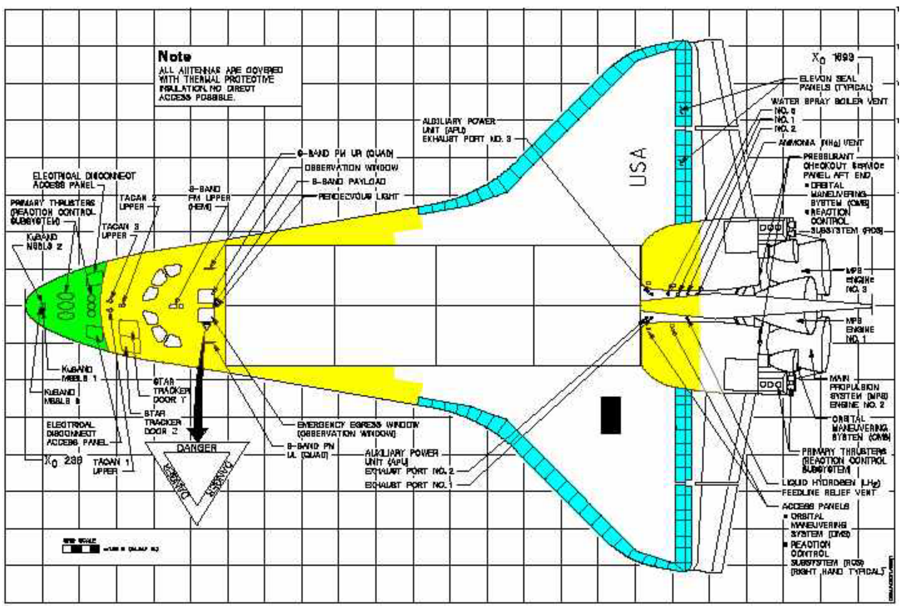
- **EVA access for repair:**
  - Feasible during docked ISS ops through 1J with current equipment.
  - Some form of a boom and worksite stabilization are in work to provide EVA access after 1J and during Orbiter stand-alone flight.

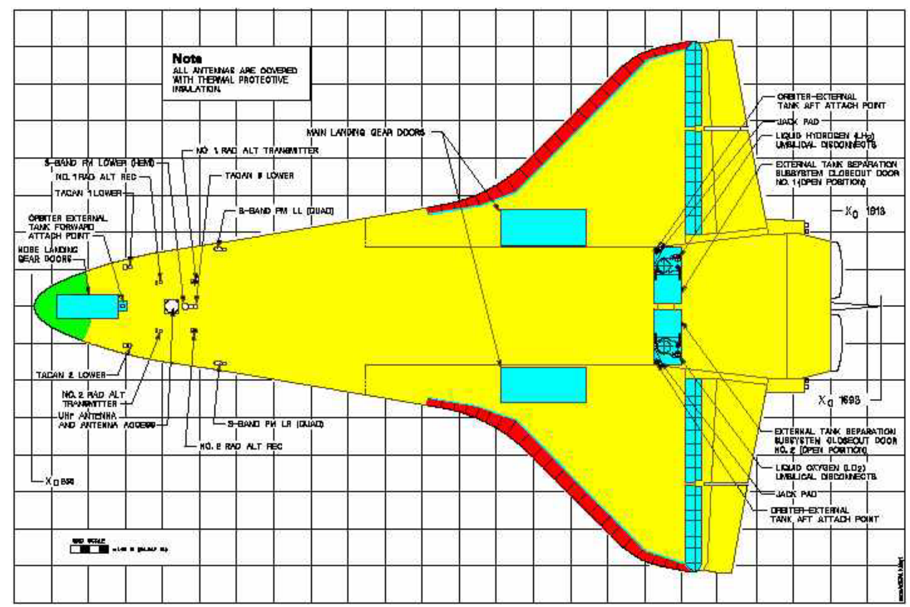
Damage Criteria

- **The following preliminary thresholds are based on entry heating:**
  - **0.25 inch for the wing leading edge lower surface**
  - **0.5 inch threshold for nose cap**
  - **1 inch major dimension around TPS seals and the wing leading edge upper surface**
  - **3 inch threshold for all other TPS surfaces**
  - **+/- 0.25 depth resolution required for damage determination.**

- **The goal of all TPS repairs is to return the TPS to near-specification capability.**

- **Engineering is working to relax some of the constraints through test and analysis.**





Minimum Crack Length Resolution

Red	- 0.25 inch
Green	- 0.5 inch
Cyan	- 1.0 inch
Yellow	- 3.0 inch

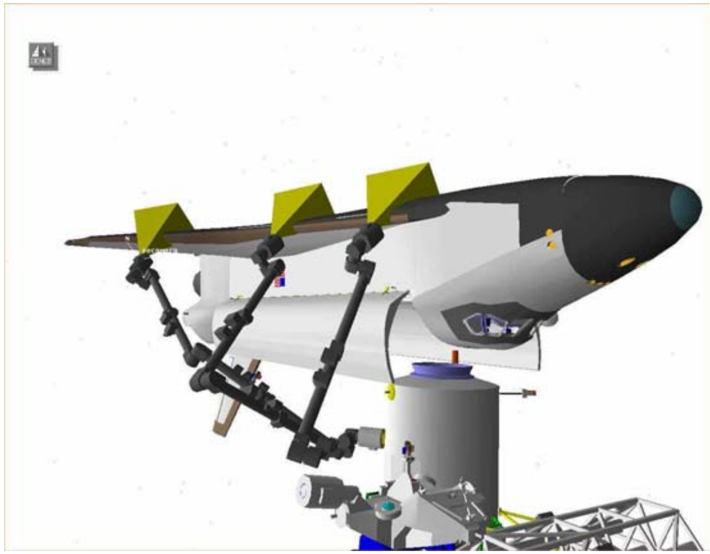
Inspection

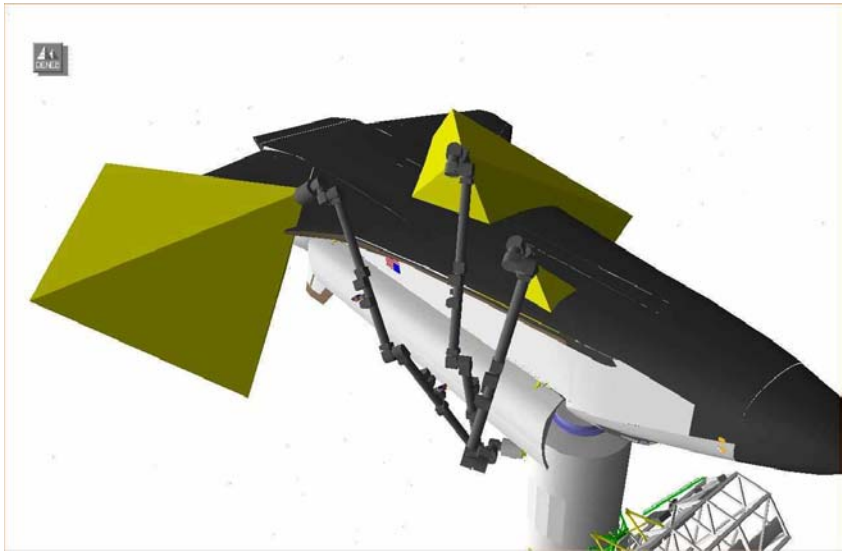
- **The goal is to inspect at critical damage level and minimize crew time using a combination of SRMS, SSRMS and digital still images.**
  - **Overall, high resolution video during ISS approach would be the minimum crew time impact, particularly for the leading edges – we don't have that camera yet.**
  - **Without a laser scanner, there will be some damage areas which will require EVA inspection to quantify depth, although the goal is to use a relatively benign technique for this like SAFER.**

- **Current imaging resolutions, with all on-board, downlink and processing losses:**
  - **Existing imaging capabilities are very close to detecting critical damage in all areas on ISS flights but not adequate in free flight.**

Camera	**Orbiter Surface**	**Detected Resolution** inches	**Analytical Resolution** inches
SRMS	Lower	<0.25 - 3	0.25-12
SRMS	Upper	<0.25 - 2	0.25 - 8
SSRMS, docked	Lower	<0.25 - >3	0.25 - >12
SSRMS, docked	Upper	<0.25 - 2	0.25 - 8
DCS-760, 400mm + 2x, at 600 ft	-	0.33	1.32
DCS-760, 400mm at 600 ft	-	0.34 < x < 0.67	1.36 < x <2.6
MSS camera at 600 ft	-	4.9	19.6
ETVCG at 600 ft	-	6.55	26.2
DCS-760, 180mm at 10', helmet & EE light		0.08	0.32
DCS-760, 180mm at 50', sun light		0.09	0.36
WVS, 12mm at 3 ft, sun light		0.09	0.36
WVS, 12mm at 10 ft, sun light	-	0.29	1.16
WVS, 12mm at 20 ft, helmet & EE light	-	0.6	2.4

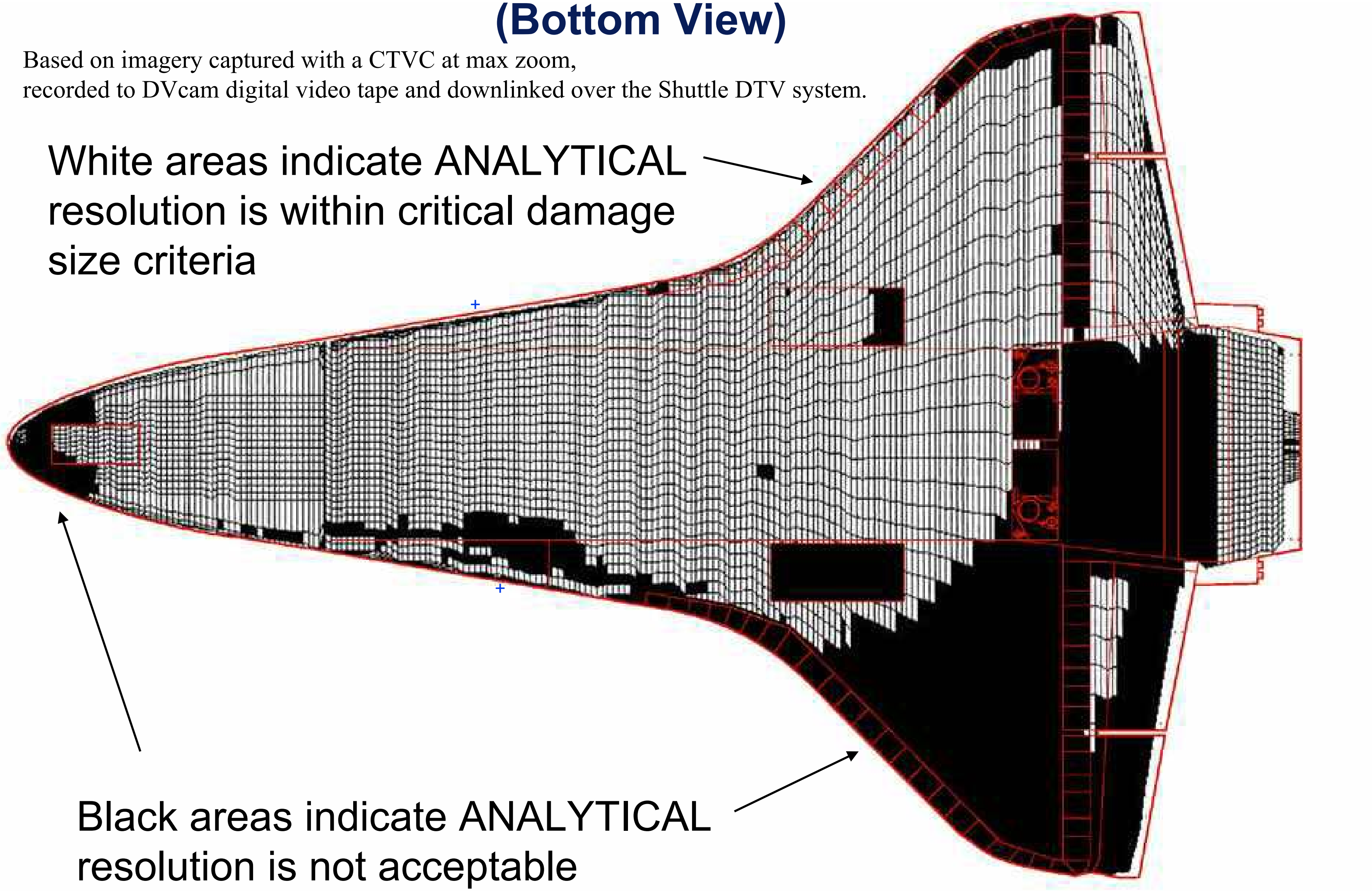
SRMS and SSRMS Inspection





Shuttle RMS Inspection Capability
(Bottom View)

Based on imagery captured with a CTVC at max zoom,
recorded to DVcam digital video tape and downlinked over the Shuttle DTV system.



Note: Black mesh gridlines in white areas are artifacts of mapping program and are within critical damage size criteria.

\+ Area where black mesh gridlines merge on curved surface appear black. Area resolvable within critical damage size criteria.

Shuttle RMS Inspection Capability
(Top View)

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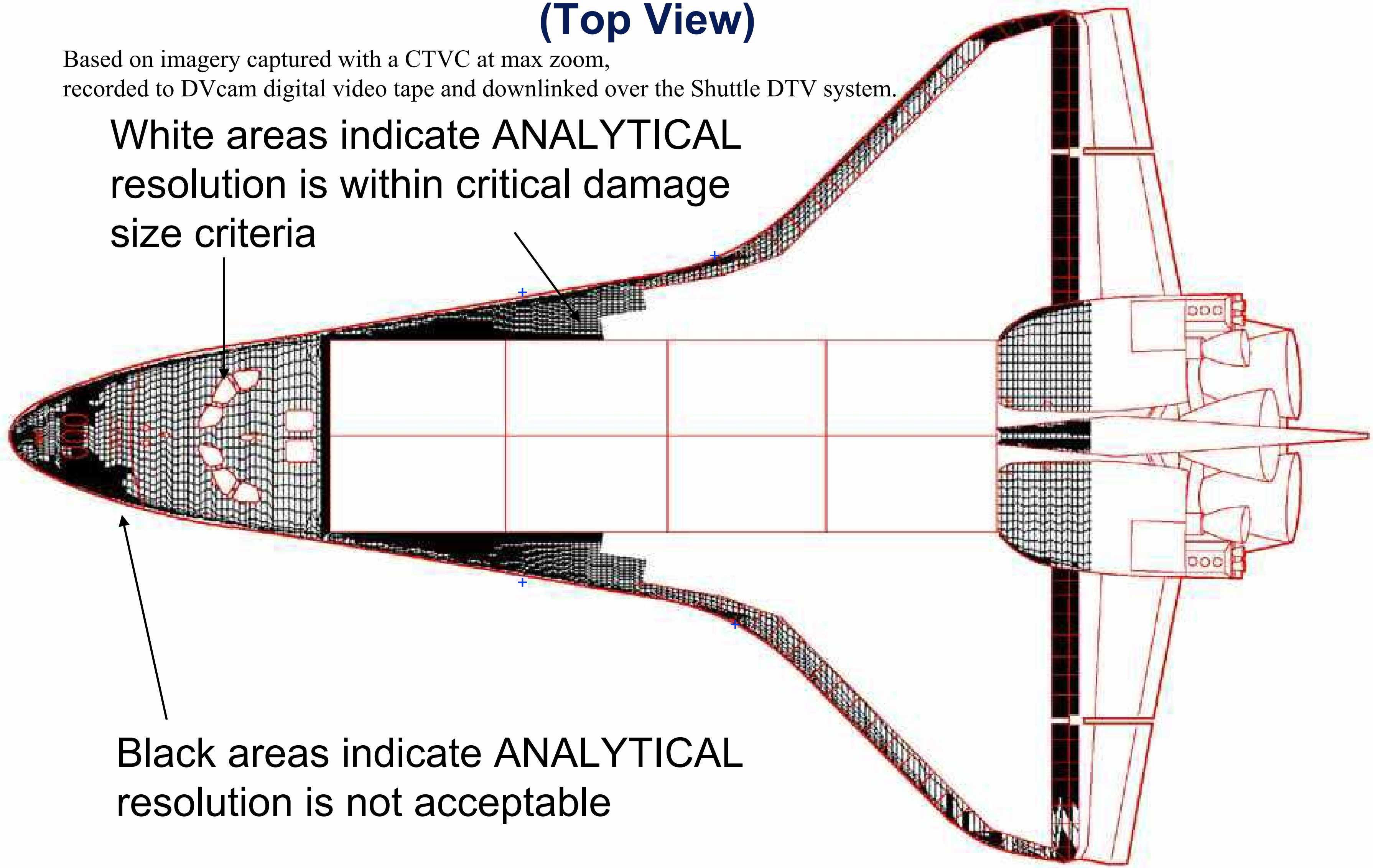

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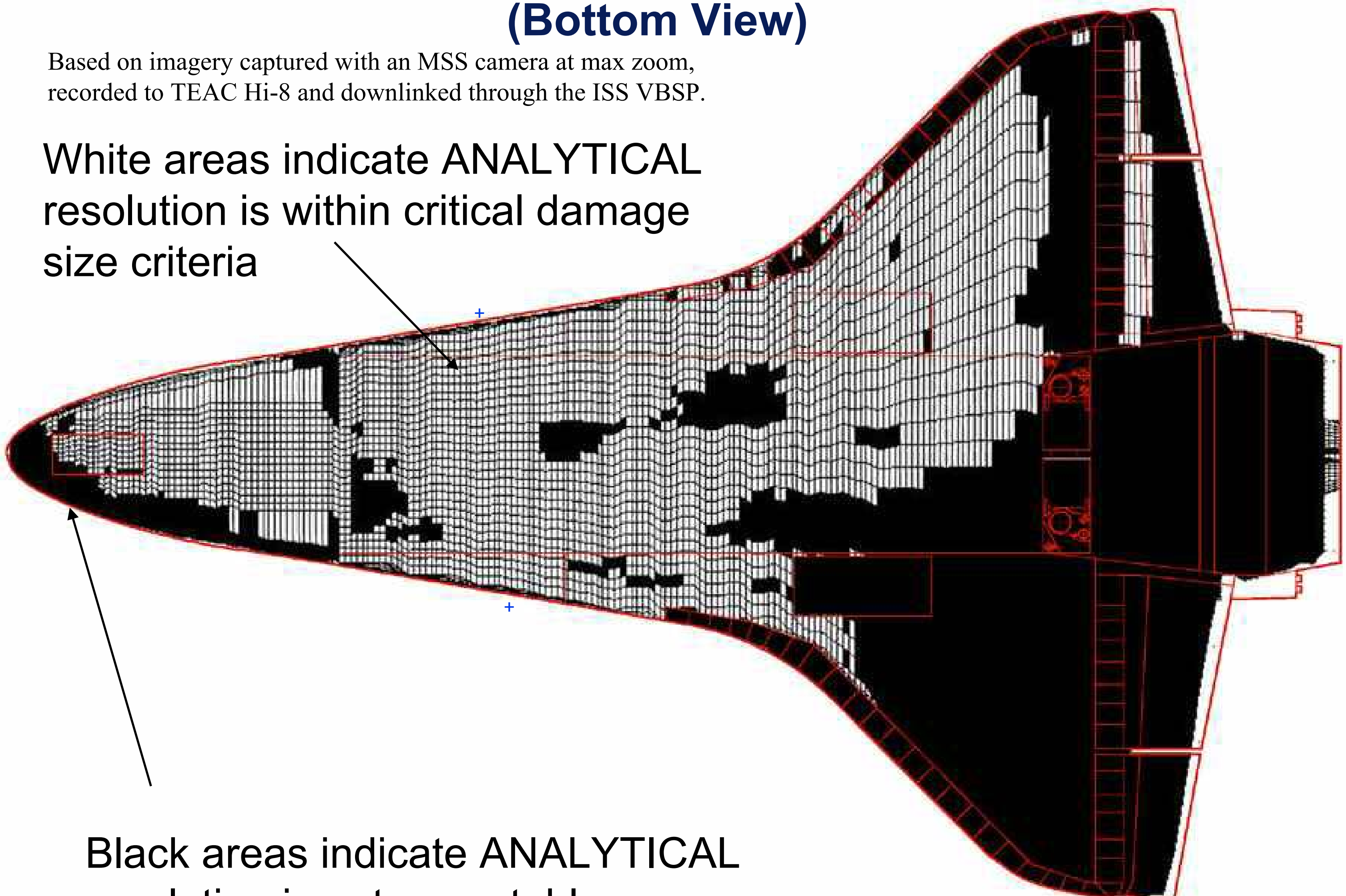
Station RMS, Lab Inspection Capability
(Bottom View)

Based on imagery captured with an MSS camera at max zoom, recorded to TEAC Hi-8 and downlinked through the ISS VBSP.

White areas indicate ANALYTICAL resolution is within critical damage size criteria



Black areas indicate ANALYTICAL resolution is not acceptable

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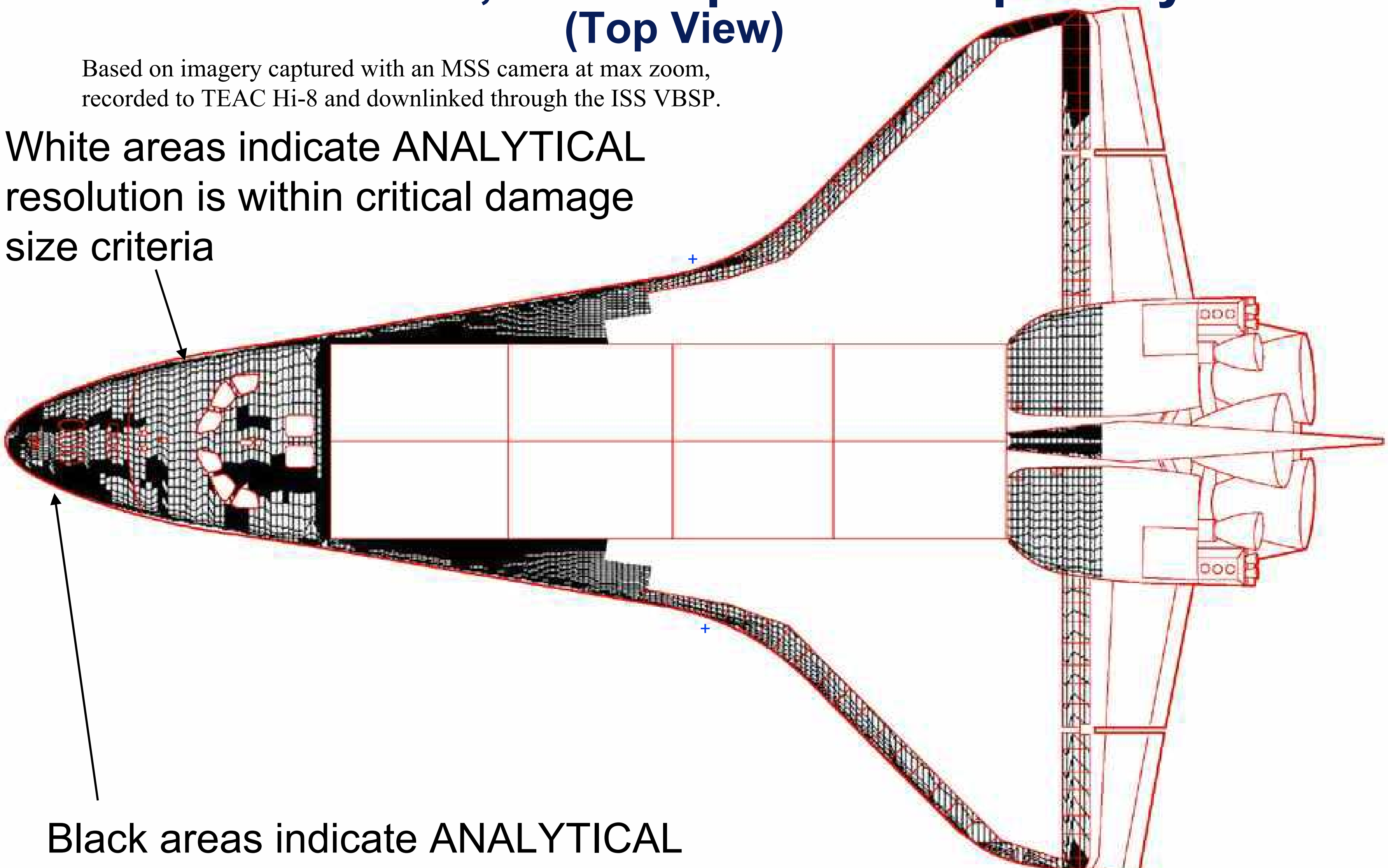

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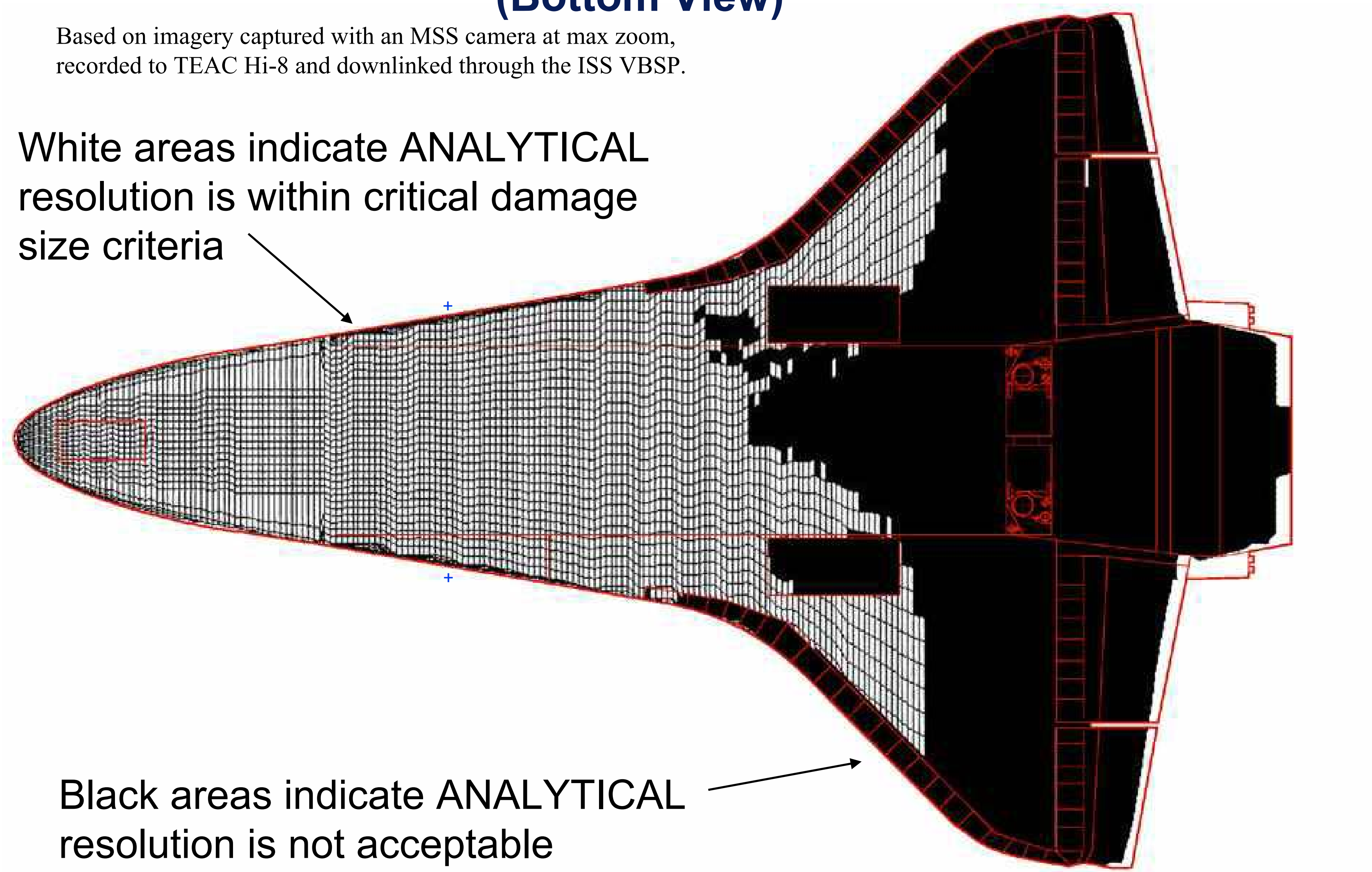
Station RMS, WS4/WS5 Inspection Capability
(Bottom View)



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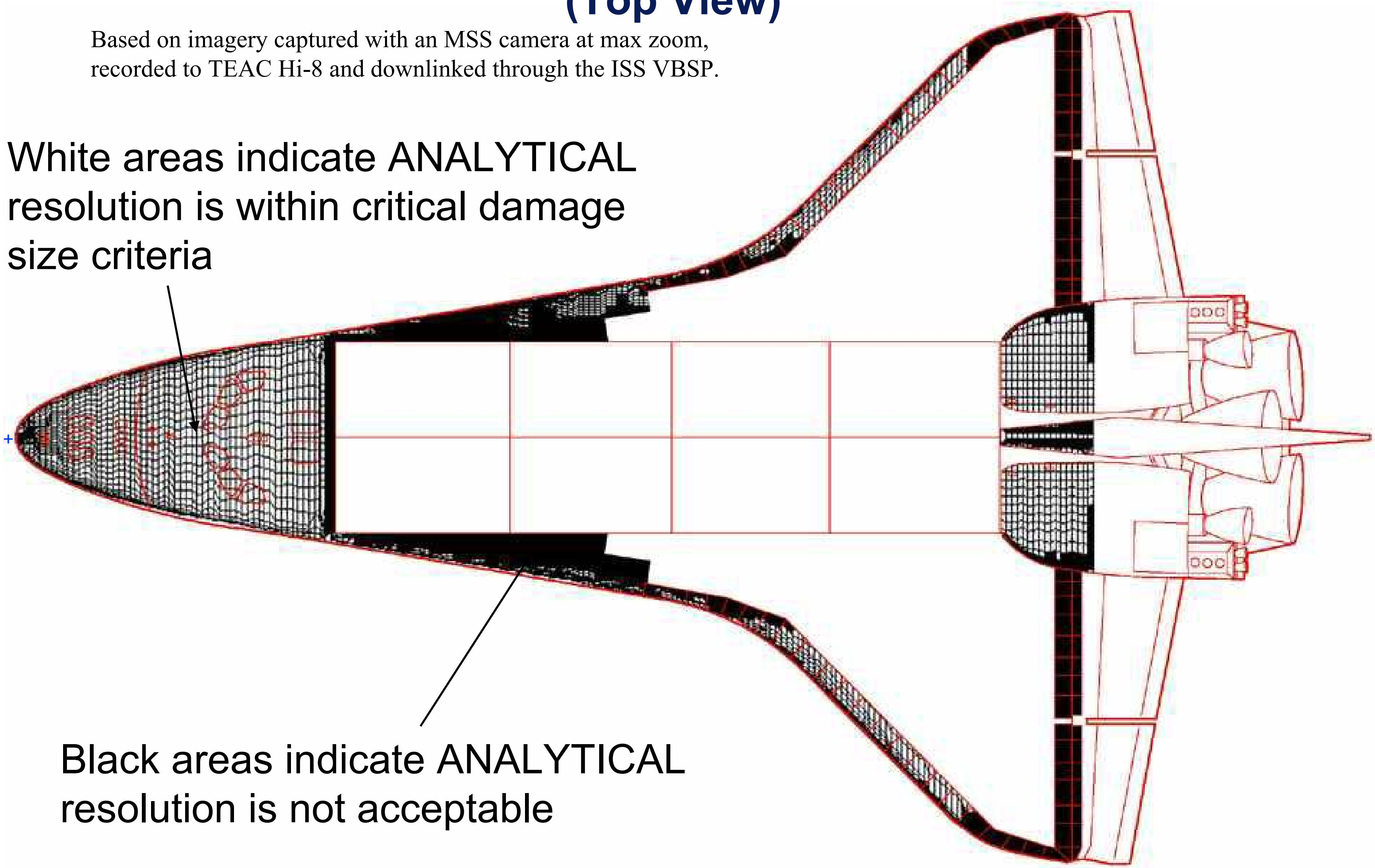

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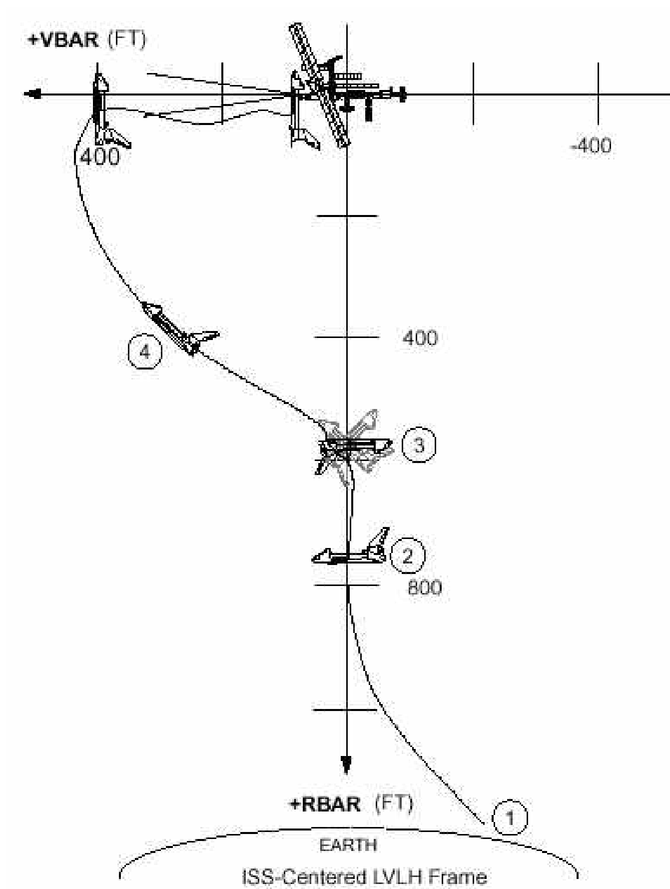
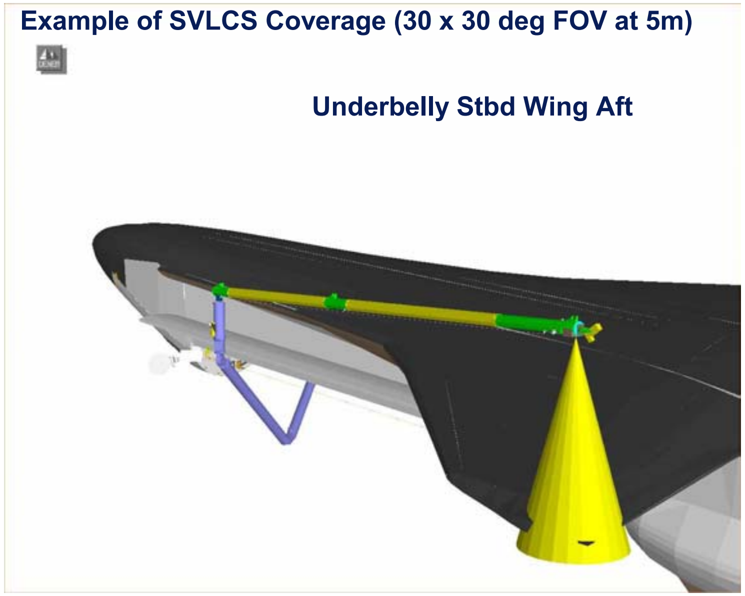
ISS approach, R-bar pitch-around at 600’

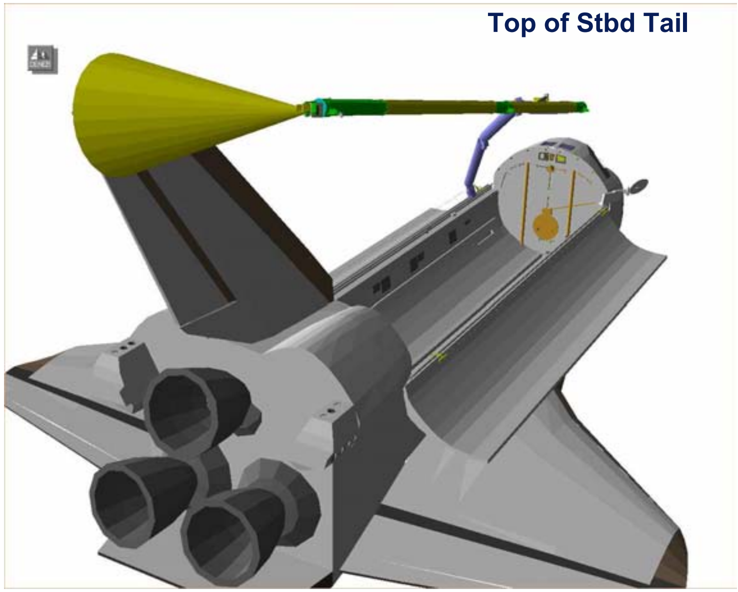
- **Provides adequate <u>tile</u> inspection resolution except for depth.**
- **Estimated to use ~75-100 lbm propellant.**
- **Relatively simple piloting task and inherently safe due to orbital mechanics.**
- **Employs normal rendezvous timing, with a possibility of up to 10 minutes R-bar station keeping to optimize lighting.**
- **Detailed procedure development complete and now being flown in generic, integrated simulations.**

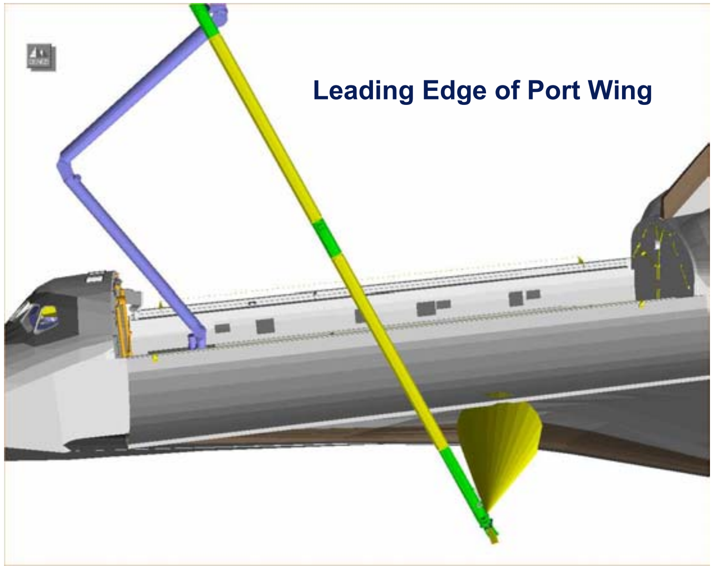


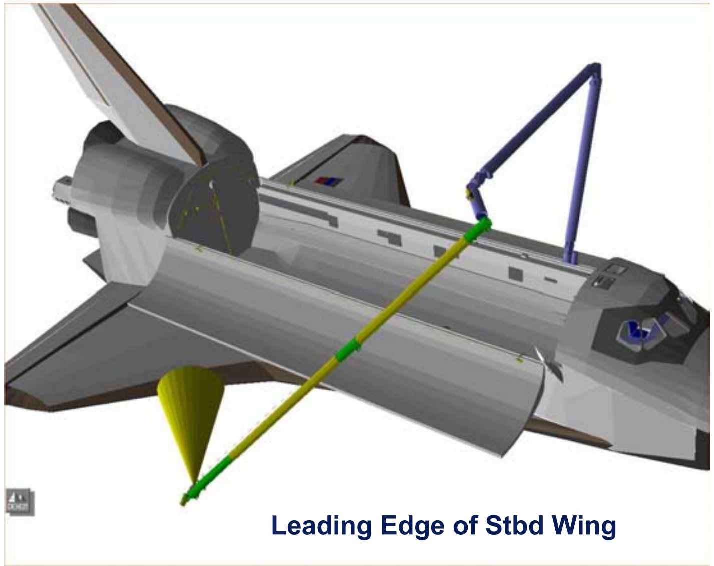
	EVENT
1	1000 FT RANGE RATE GATE (RDOT = -1.3 FPS) TRANSITION TO LOWZ
2	ORBITER ACQUIRES RBAR
3	600 FT (RDOT = -0.1 FPS) BEGIN 1 DEG/SEC POSITIVE PITCH AUTO MNVR; MODE TO FREE DRIFT TO PROTECT ISS FROM ORBITER PLUME LOADS AND CONTAMINATION
	ISS PHOTOGRAPHIC SURVEY OPPORTUNITY FROM U.S. LAB WINDOW
	RESUME ATTITUDE HOLD AS ORBITER RETURNS TO RBAR ATTITUDE AND PILOT BACK TO NOMINAL APPROACH PROFILE
4	TORVA (**T**WICE **O**RBITAL RATE **R**BAR TO **V**BAR **A**PPROACH)

Example Boom on the SRMS for TPS Viewing

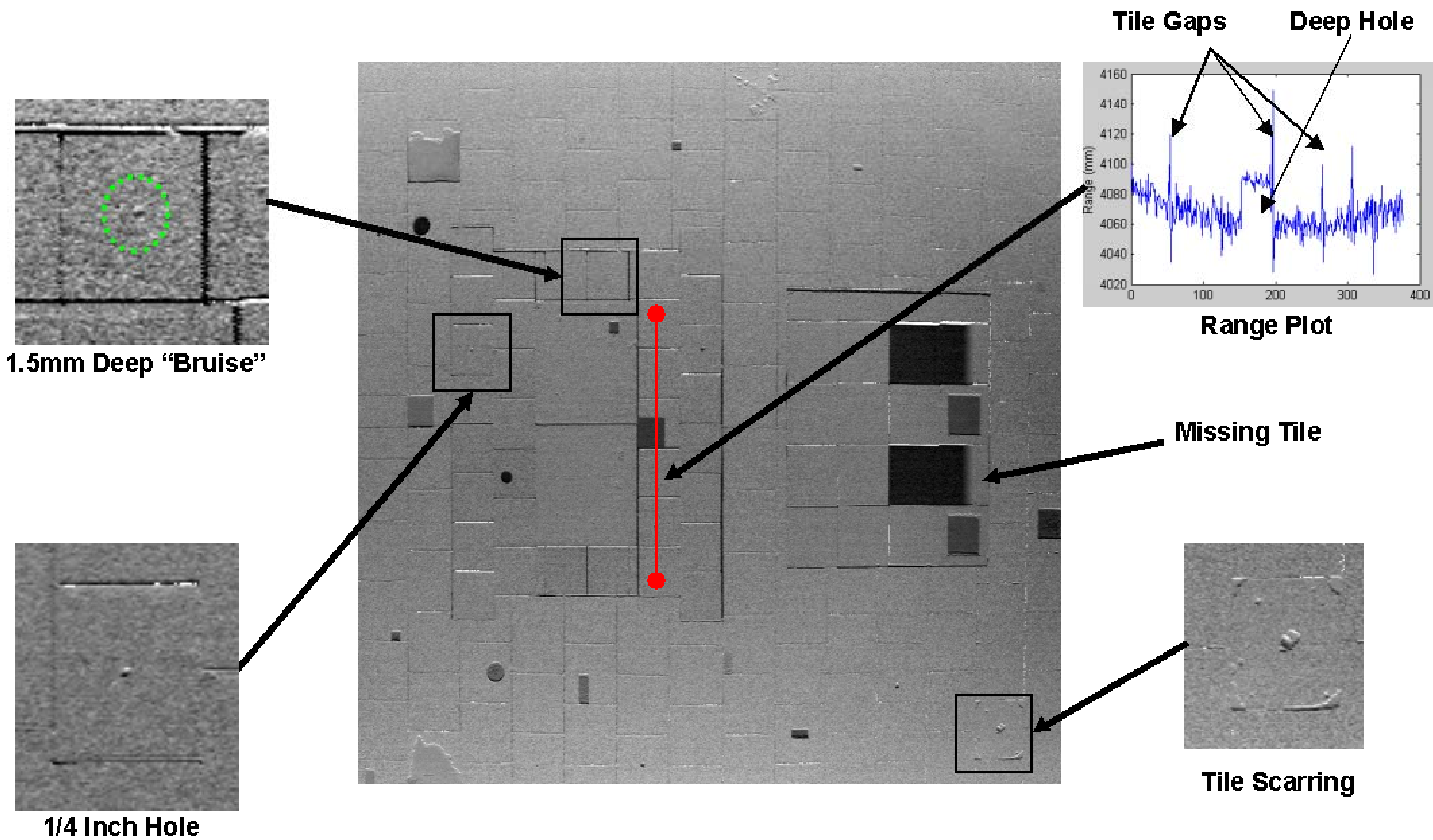








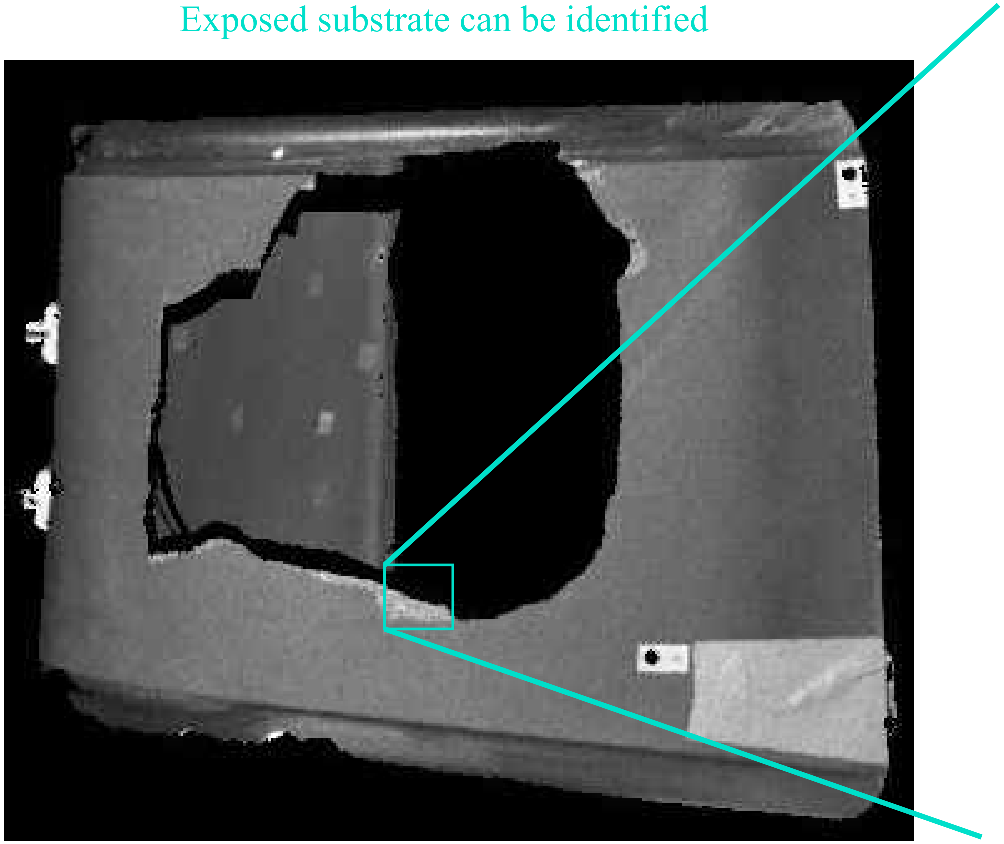
Laser Testing at JSC



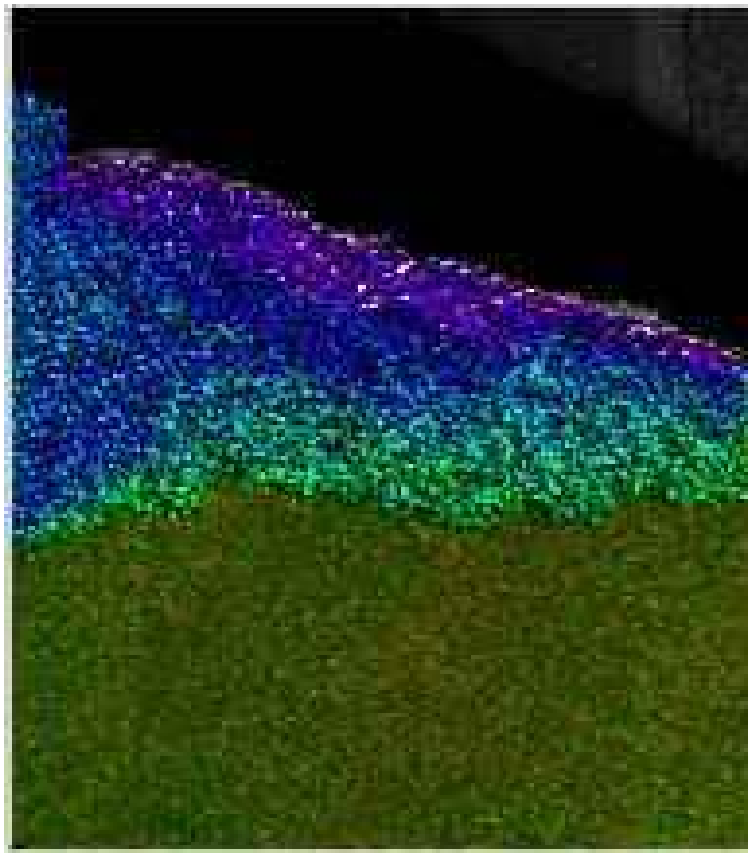
Scan from 4.5 meters at 0 degree incidence

Laser Testing at JSC

Intensity Image – from 2.5 m & 30deg FOV
Exposed substrate can be identified



Range Image – from 1.2 m & 5 deg FOV
Texture and RCC layers can be identified



Inspection, continued

- **Conclusions:**
  - Development was approved by the 31 July PRCB to resolve the inspection "gaps" and RCC inspection in particular:
    - » Goal is to fly a boom in active latches to support TPS inspection with no EVA.
    - » A laser scanner and camera will be attached to the boom tip.
    - » An EVA digital still camera is in development as a backup.
    - » This is being expedited with an intent to make STS-114.
    - » Final down-selection and integration impacts are in work now through the Vehicle Engineering Office.
    - » This boom is intended to evolve into EVA support on later flights.
  - Low contrast damage due to light level or material color (white tile, RCC) will be difficult to see, and we're pursuing optical filters to improve detection in these cases.
  - Tests are in work to confirm the oblique viewing angle image resolutions using real TPS materials.
  - External assets are not yet quantified and being worked outside the OFTP.

Inspection Sequence of Events

Flt Day	Inspection	Backup
2	SRMS: Crew compartment, OMS pods, vert stab	SSRMS
	SRMS + boom and laser scanner: Lower leading edges	EVA
	SRMS + boom and laser scanner: All remaining RCC	SSRMS
3	DCS-760, 400mm during approach: fwd and mid-body acreage tile	SRMS, SSRMS
	DCS-760, 400mm during approach: aft acreage tile	SRMS + boom
	DCS-760, 400mm+2X during approach: NLG, L-MLG door seals	SRMS, SSRMS
	DCS-760, 400mm+2X during approach: R-MLG, ET door seals, elevon cove	SRMS + boom

- Inspection data will be downlinked in real-time or during the same crew day by play-back.
- Detailed ground analysis process has not yet been developed, but assume for today:
  - 1 day to process imagery,
  - 1 day to evaluate data in MER,
  - MMT review on 3^{rd} day after each inspection.
- The timeline and imagery analysis process will be developed over the next several months.
  - Directly influenced by the decision on RCC scanning techniques.
  - The goal with laser scanning data is to use software to automate and speed the analysis.

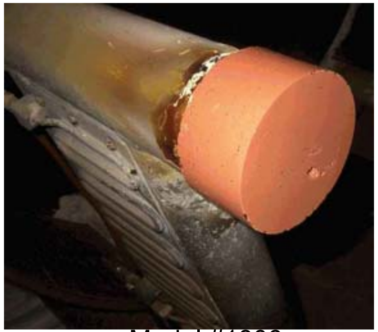
Tile Repair Material

- **An existing silicone based, cure in-place ablator (MA-25S) has shown promise in development testing at Boeing, Lockheed and JSC.**
  - **In feasibility testing, we have demonstrated controls for the problems in the 1979 and 1980 tests.**
  - **The material has been shown to bond to tile, tile-adhesive and aluminum and cures in vacuum.**
  - **Suited 1g tests and the first round of KC-135 are complete.**

- **Arc jet tests at JSC:**
  - **Good performance in near-normal entry heating conditions.**
  - **The highest heating condition tested yielded mix results, but the heat profile was more severe than actual.**
  - **Further testing in tile is in work.**

- **Forward work:**
  - **Follow-on stagnation and channel flow arc jet tests.**
  - **Various thermal-vac, air bearing floor and KC-135 tests through November.**
  - **Human thermal-vac RTV application and cure tests in October/November.**

- **Detailed MA-25S validation has been handed off to the Vehicle Engineering Office.**
  - **Formal material acceptance test plans are in work.**
  - **A tile repair DTO is in development for STS-114.**



Model #1806
BNA CIP

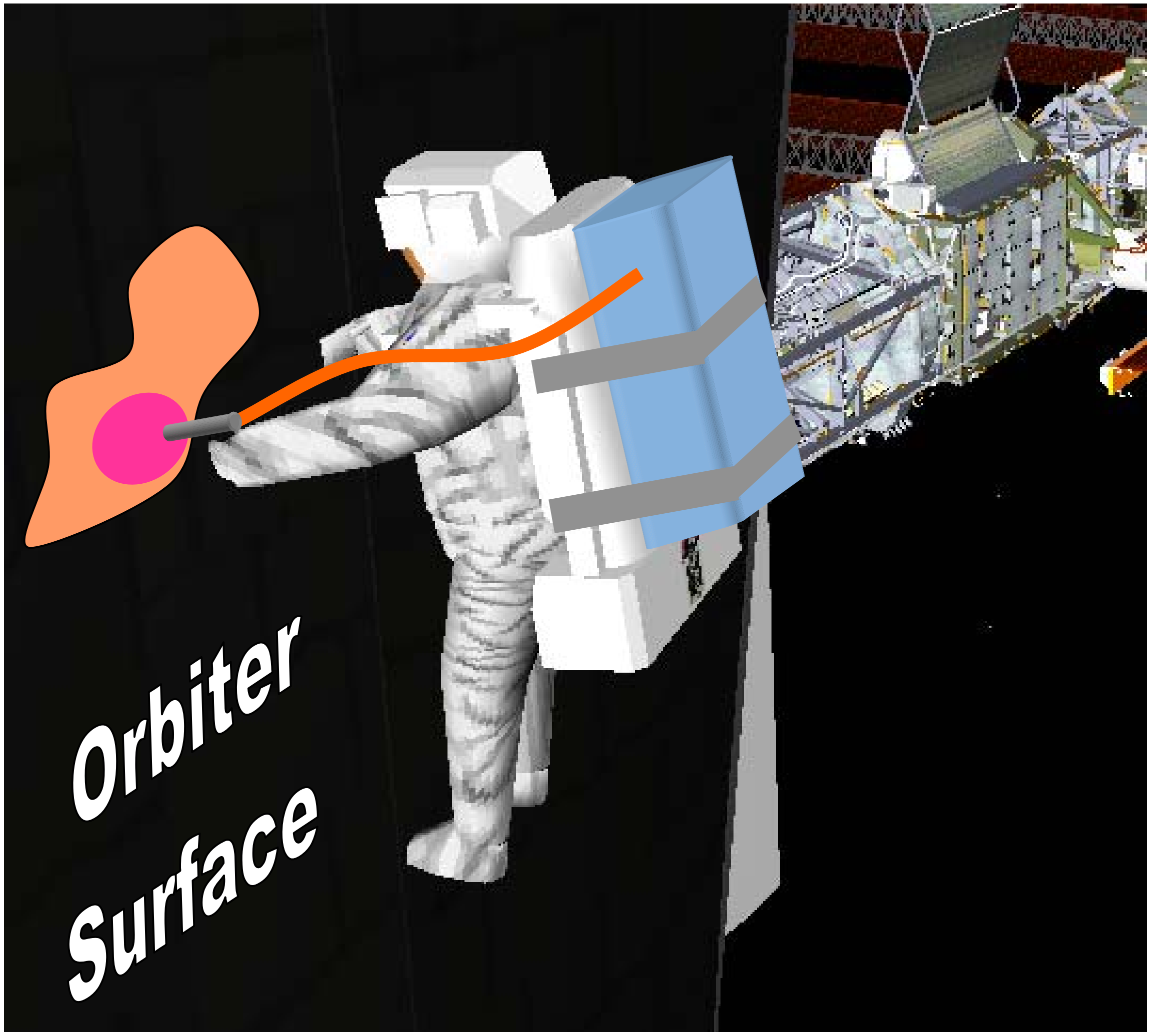
Porous
2300 deg F

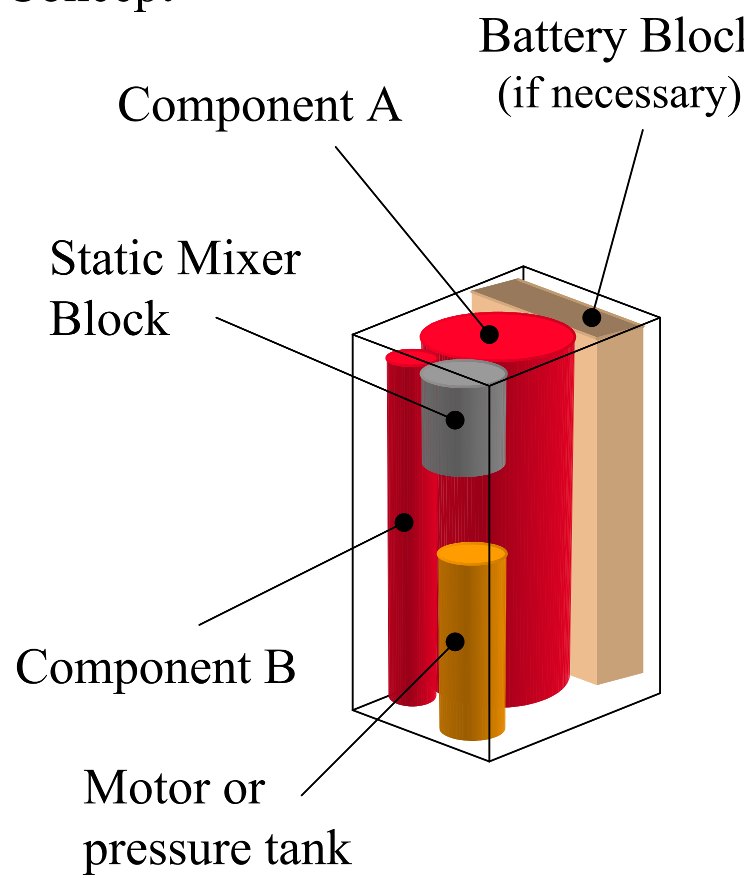
Dense
2700 deg F

Porous
2700 deg F

Tile Repair Tools and Technique

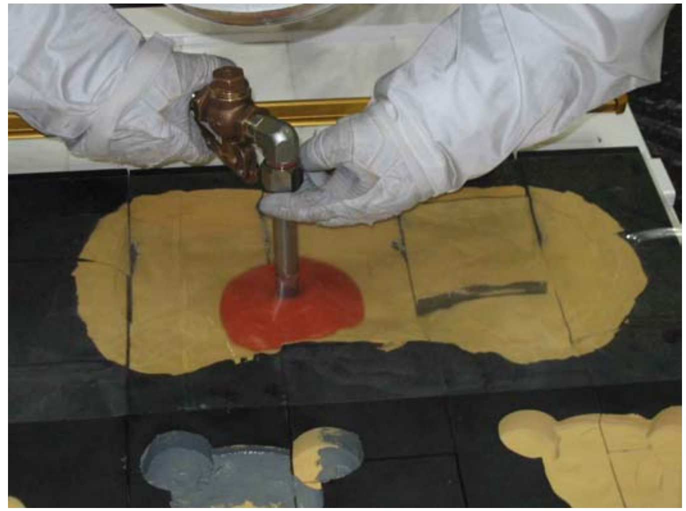
PLSS Mounted TPS Repair Kit Concept





Potential Packaging Concept

Tile Repair Tools and Technique, continued



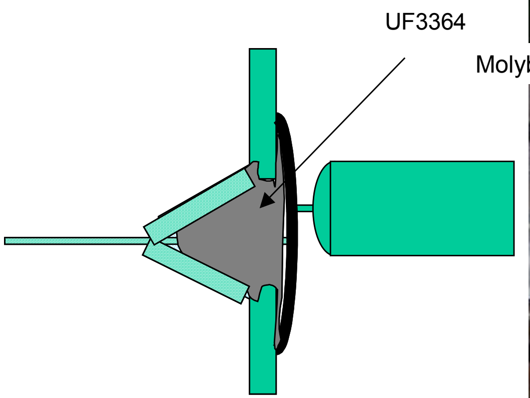
RCC Repair Materials and Tools

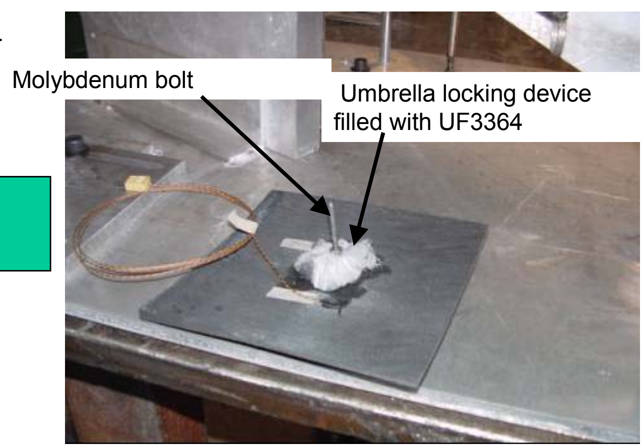
- **RCC repair material:**
  - Much less mature than tile repair material study in general, but evaluating concepts across 6 NASA centers and with 11 contractors.
  - The key challenges to repairing RCC are:
    - » Maintaining a bond to RCC coating during entry heating.
    - » Meeting step requirements.
    - » Ensuring the RCC damage will not propagate and fail outside of the repair during entry heating.
  - The options in work are:
    - » cure in place ablators similar to the tile repair material,
    - » variations of patches with some form of pre-preg, cure in-place resin and an epoxy-like ablator,
    - » Sleeves and over-wraps that fit over a damaged RCC panel or a series of panels,
    - » filled leading edge cavities.
  - Several facilities around the country will be used for initial screening, followed by more focused feasibility testing on the viable candidates.
    - » Carbon-carbon test samples have been coated to match RCC and are being distributed to repair concept developers for screening tests.
    - » As test samples become available, screening and concept feasibility tests will be performed in the JSC and ARC arc jet facilities, and in the JSC, LaRC and Lockheed-Martin radiant heat facilities .
    - » Have evaluated other arc jet, radiant heat, plasma and rocket exhaust exposure facilities at LaRC, MSFC, GRC, Lockheed-Martin, Boeing, AEDC, University of Texas and CIRA PWT in Italy which will be used if necessary to avoid test delays.
    - » Final validation testing will be performed in the JSC arc jet and radiant heat facilities.

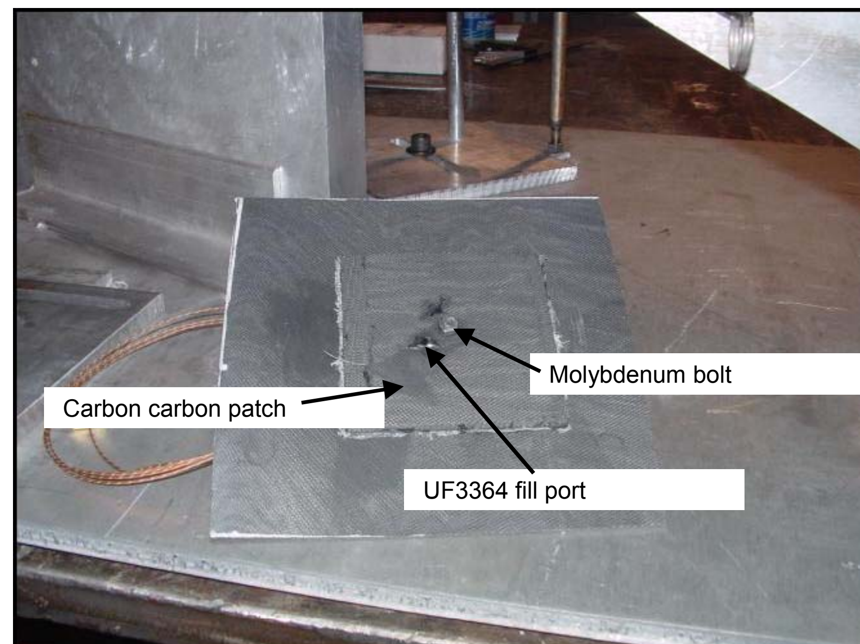
- **No predictions yet on material readiness to proceed with EVA tools, etc, and flight readiness.**

RCC Repair Materials and Tools, continued

- **Thiokol is testing an existing cure in-place ablator that has been used on carbon-carbon Delta IV engine nozzles.**
  - Targeted to repair 0.5 – 4.0 inch diameter through-holes.
  - Applies a coated, carbon-carbon patch with a molly-bolt-like fastener.
  - The backside is then filled with ablator as a redundant attachment and thermal patch.
  - This repair concept was tested using a propane-oxygen torch at 60 and 70 BTU/ft2/sec for over 600 sec with no flame penetration.
  - A test sample is expected in the JSC arc jet within a month.
  - EVA tool development is already in work.
  - Much test work is required to determine if this patch technique is viable on an RCC panel in entry conditions.

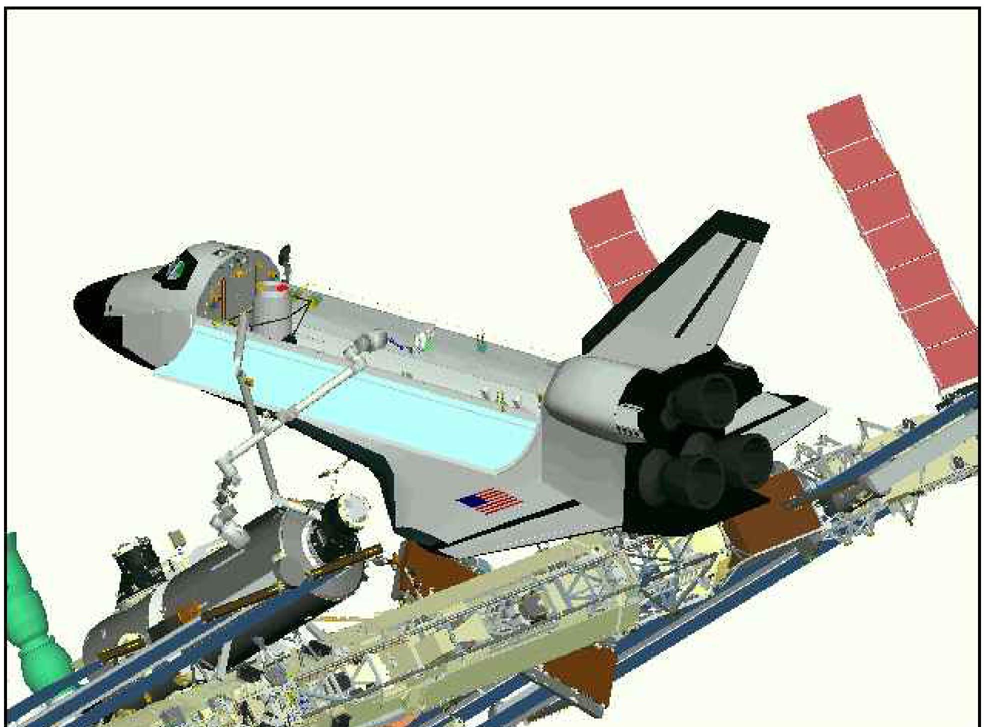




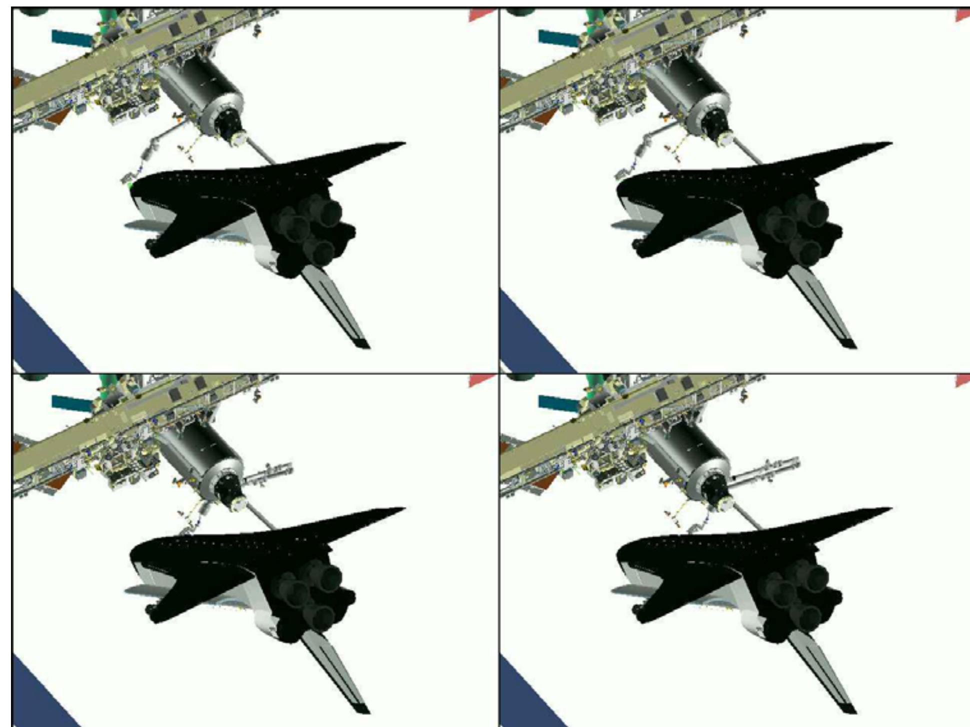


Repair Access

- **Baseline: Grappled Unberth/SRMS positions Orbiter for the SSRMS**
  - **Within the normal envelope in all ISS and SRMS analyses.**
  - **Final analysis is in work through Sep/Oct -- structure-controller interaction and attitude control during SRMS motion**
  - **~4 hr robotic operation to reach repair position, and another 4 hr to redock.**
  - **Expect this to be a long day, with all robotics and EVA on the same day.**
  - **Not required for inspection.**
  - **Orbiter stand-alone and post-1J solution is focusing on a boom and the SRMS.**
  - **DTO candidates: undock and dock while grappled; boom and SRMS flex under EVA loads.**



From MAGIK AI-1689 report – Orbiter Port-Aft view of EVA Access to PLB with SSRMS on the LAB PDGF



From MAGIK AI-1689 report – ISS Starboard-Zenith view of EVA Access to Orbiter with SSRMS on the LAB PDGF