



Particle Analysis Pitfalls

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Introduction

- HST Servicing Mission 4 will include an EVA repair of the STIS instrument
 - Remove astronaut handrail
 - Remove radiator and cover on Main Electronics Box (MEB)
 - Removal of the old LVPS-2 board
 - Installation of the new LVPS-2R board
 - Installation of the new cover and radiator
- No EVA design interfaces
 - Fasteners as small as #4 screws
 - Gasket materials that may shred
 - Standard electronics card guide slots and connectors
- Required contamination analysis to verify
 - Tool design is adequate to capture contamination
 - Released contaminants will not degrade the telescope

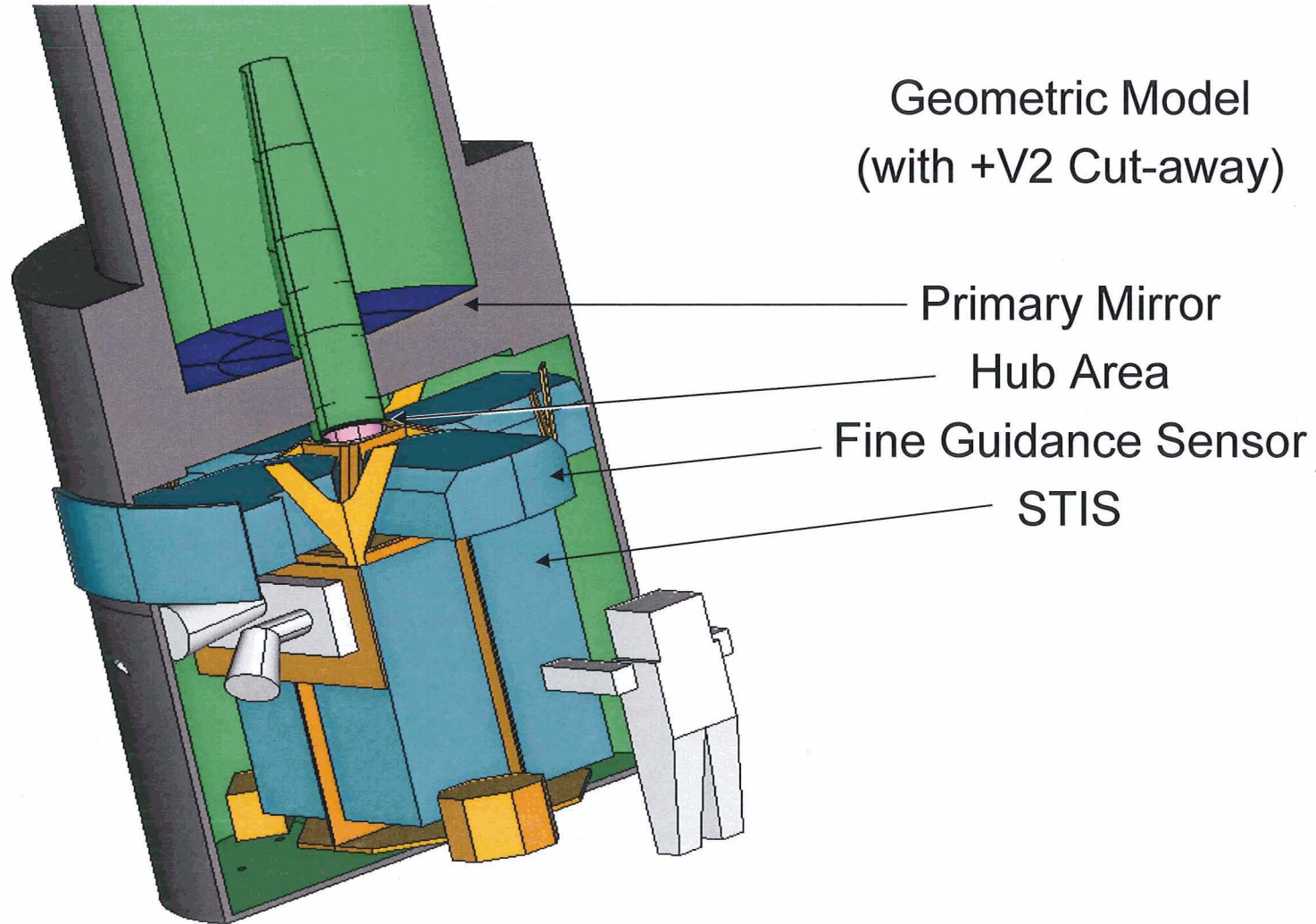


Particle Analysis Method

- Finite element mesh created in I-DEAS
 - Currently, only internal surfaces
 - Individual components modeled with coarse, medium, and fine meshes
- Black-body viewfactors generated using I-DEAS TMG Thermal Analysis
- Grey-body viewfactors calculated using Markov method
- Particle distribution modeled using an iterative Monte Carlo process (time-consuming); in house software called MASTRAM
- Differential analysis performed in Excel
- Visualization provided by Tecplot and I-DEAS

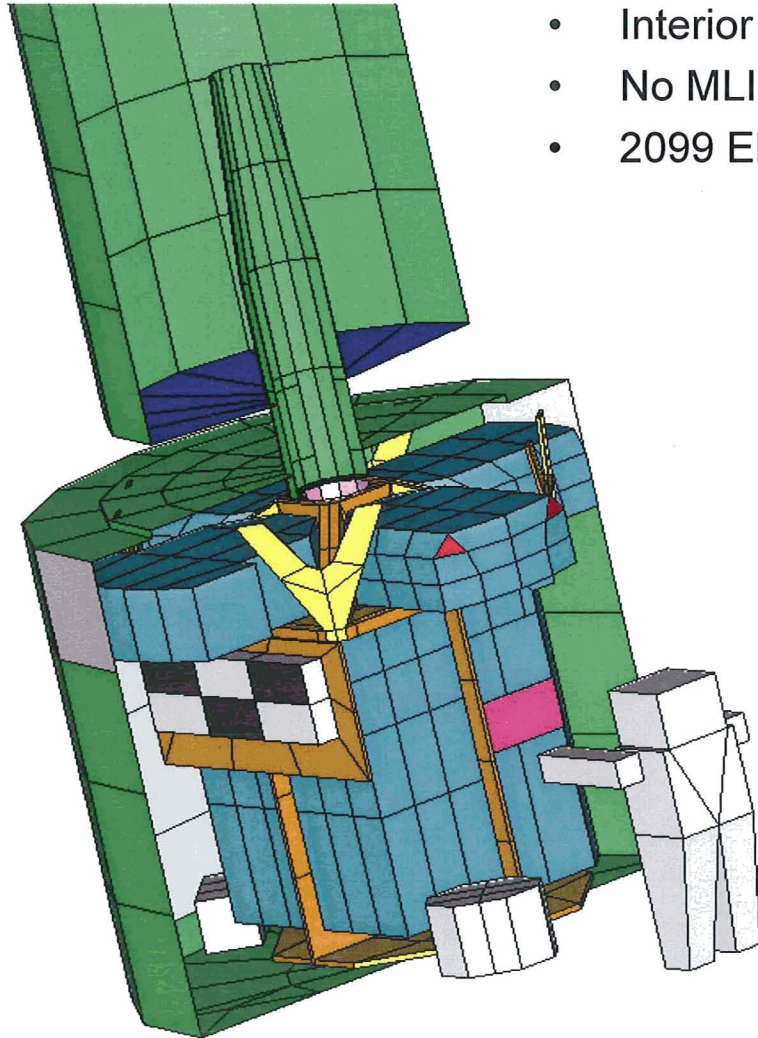


Model: Physical

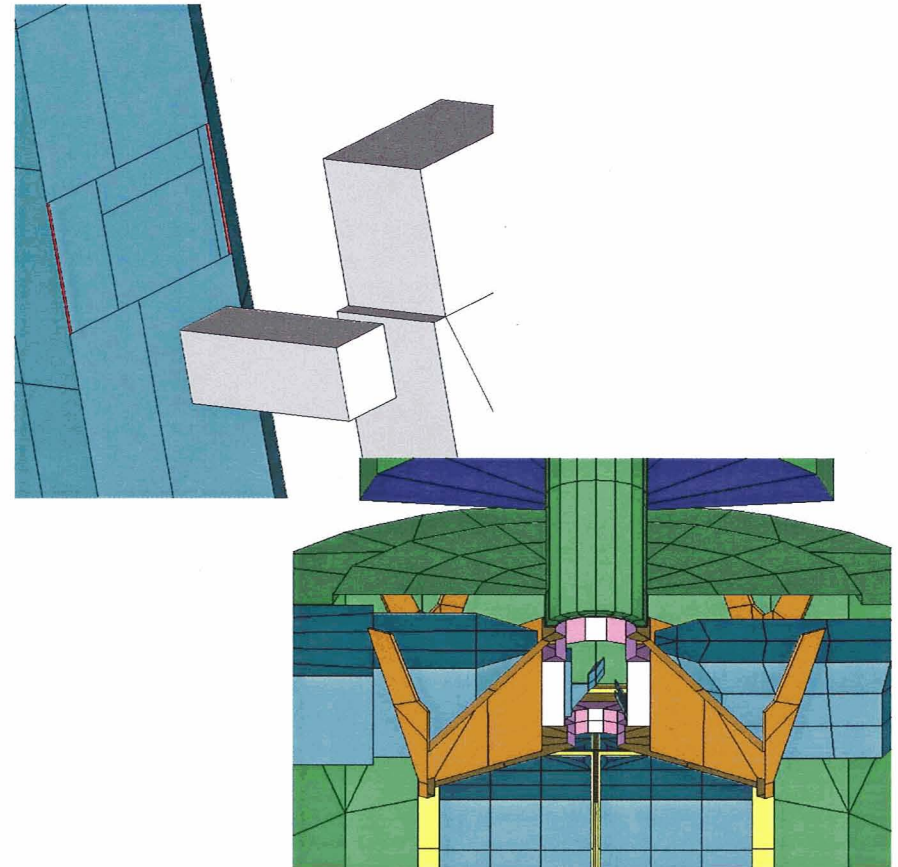




STIS Repair: Finite Element Mesh



- Interior of HST + 1 Astronaut
- No MLI / Harnesses, No Orbiter
- 2099 Elements





STIS Repair: Inputs to Analysis

- Particle generation data needed
 - Bolt removal on handrails, etc.
 - Fastener removal within FCP
 - EMI gasket separation
 - Card extraction
 - Card Insertion
- Tests performed
 - Conformal Coat Particle Study (May '06) HST-MEMO-010008
 - Card Extraction Study (July '06) HST-MEMO-010019
 - Cover Fastener Removal Particle Generation Study (July '06) SAI-TM-3067
 - EVA Handle Fastener Study (April '06) HST-MEMO-010006
 - E-Graf Vibration Particulate Study (Feb. '07)



Conformal Coating Particle Study

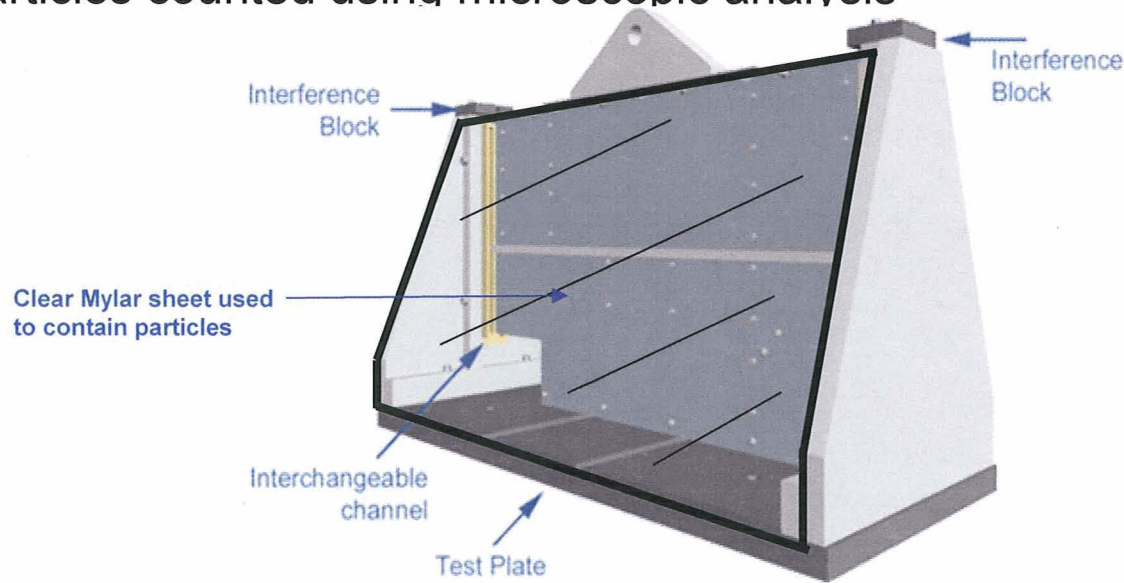
- STIS boards may have been coated during a period when there were process irregularities at the vendor
- Microscopic inspection of several improperly coated boards
 - Counts of particles (flakes) tabulated
 - Assume properties of polyurethane, flat disk shape
 - Expected shedding per 6x8" board

Microns	127	254	508	1270	3175
Count	3.63	3.63	14.52	14.157	0.363



Card Extraction Study

- This study determined the debris generated during the card removal in a series of different card-lok configurations
 - Card-loks fully locked
 - Interference blocks used
 - Card-loks locked and then unlocked
- Particles vacuumed onto gridded filter paper after test run
 - Particles counted using microscopic analysis



Test Configuration



Card Extraction Study

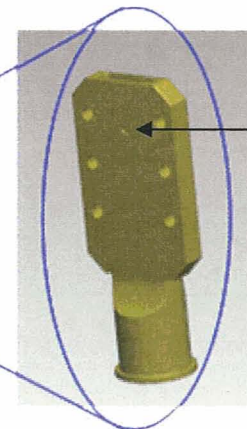
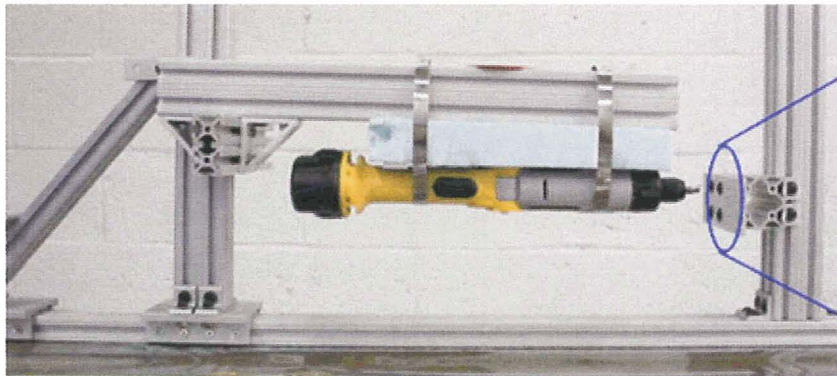
- Caveats
 - Nominal case produced more particles than Card-Locked case
 - Used the Nominal case for conservatism
 - Test boards were warped, so may have generated more particles during insertion than the flight boards will

Blank				
	<i>Metallic</i>	<i>Non-metallic</i>	<i>Total Count</i>	<i>% of Total Particles</i>
<= 50 microns	28	13	41	85.4
<=100 microns	33	13	46	95.8
<= 500 microns	34	15	48	100.0
> 500 microns	0	0	0	0.0
Aluminum Interface Bracket		246 lbs.		6" grips
	<i>Metallic</i>	<i>Non-metallic</i>	<i>Total Count</i>	<i>% of Total Particles</i>
<= 50 microns	2223	547	2770	94.8
<=100 microns	2360	557	2917	99.8
<= 500 microns	2364	557	2921	100.0
> 500 microns	1	0	1	0.0
Straight Pull/2 Lock (a)			549 lbs.	
	<i>Metallic</i>	<i>Non-metallic</i>	<i>Total Count</i>	<i>% of Total Particles</i>
< 50 microns	202	176	378	73.1
<100 microns	239	180	419	81.0
<= 500 microns	331	180	511	98.8
> 500 microns	5	0	6	1.2



Cover Fastener Removal Particle Generation Study

- Determined contamination generated as it correlated to driver speed, force applied to fastener, and stuck/unstuck fastener
- Utilized the CATs team's Head Deformation Test configuration
 - Particle Capture Vacuum Attachment (PCVA) was designed to capture particles for contamination study
- PCVA mounted to fastener mounting plate
 - Bottom of PCVA was attached to filter holder, then the filter holder to a vacuum
- Fastener was extracted through through-hole or left bound for three seconds as determined by test plan
- Filter caught particles as fastener was extracted, and tapelifts were performed on fastener head and driver bit
 - Particles counted using microscopic analysis



Fastener through-hole



Cover Fastener Removal Particle Generation Study

- Caveats
 - Only tested #4 torque set fasteners
 - Fastener #4 torque set – 39 count present
 - Fastener #4 SHC – 56 count present
 - Fastener #8 SHC – 16 count present
 - Metallic particles, only
 - In use, tool shaft might chip Lexan cover, but test setup prevented this
 - Locking compound did not shed an appreciable number of particles

Run #	1	2	3	4	5	6	7	8	9	10	11	12	13
15-50 μm	5	139	21	27	20	36	57	4	90	42	56	4	102
51-100 μm	0	27	4	0	6	3	7	0	4	4	43	0	20
101-500 μm	0	1	2	1	0	0	1	0	1	0	0	0	10
>500 μm	0	0	0	0	0	0	0	0	0	0	0	0	0



EMI Gasket Study I and II

- The EMI gasket on the inside of the MEB cover will have unknown properties when the astronaut removes the MEB cover
 - Cover removal on the ground has lead to the gasket ripping and tearing
- EMI Gasket Study I
 - Performed materials testing on new gasket material to determine gasket failure modes and the force needed to break material
 - Materials testing included flatwise tension, lengthwise tension, and shear
 - Variables included pre-load, one or two sided adhesive, and pull speed
- EMI Gasket Study II
 - Gasket was oven baked following the original MEB verification temperature profile
 - Same materials tests performed
 - Variables were the same other than 1-sided adhesive eliminated
 - High speed photography was used to determine the gasket tip velocity as it broke
 - This was used as a model input for particle initial velocities



Flatwise Tension and Shear Testing

Flatwise Tension:



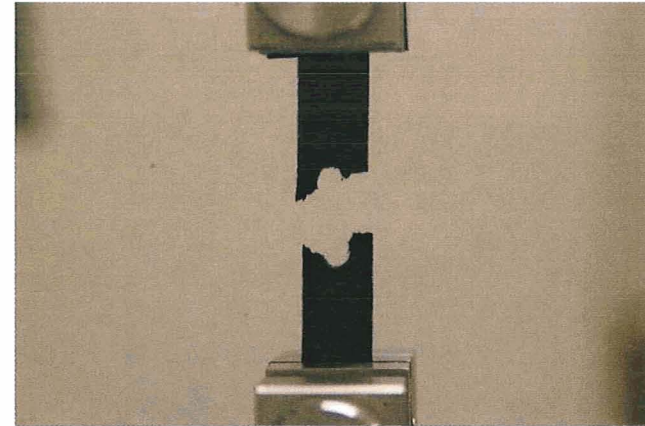
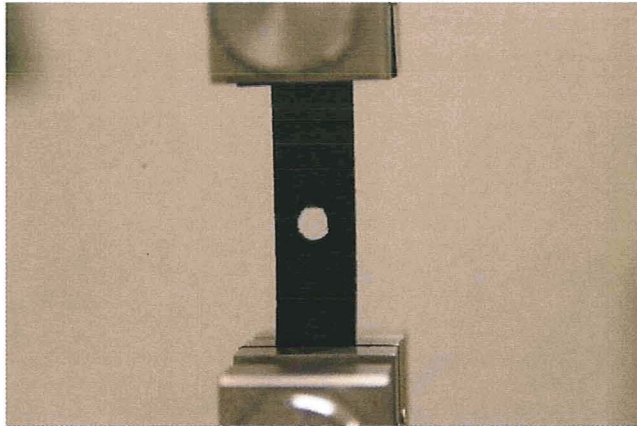
Shear:



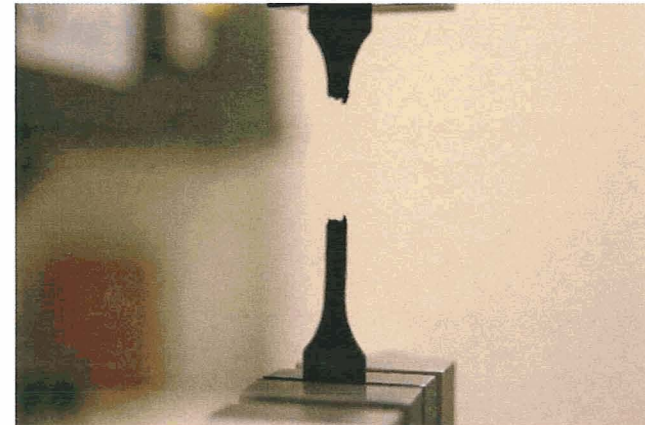
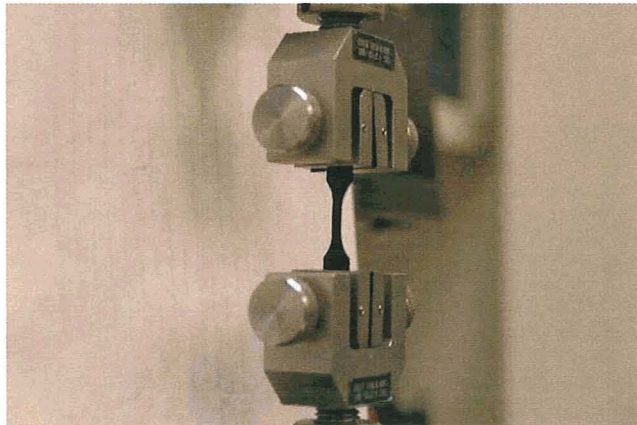


Lengthwise Tensile Testing

Hole:



Dogbone:





EMI Gasket Study I and II

- **Caveats**

- Did not count or size particles during lengthwise tensile pull tests, but did see them on high-speed video
- Could not test combined failure modes

		Temp. Cycled		Temp. Cycled		Temp. Cycled
	1.5"/MIN	1.5"/MIN	4.5"/MIN	4.5"/MIN	90"/MIN	90"/MIN
15u	4	28	6	8	16	231
25u	2	9	4	11	8	57
35u		4	1	16	5	23
50u		3	2	2	3	8
75u						1
100u				1		

- **EMI Gasket Study III**

- Gasket material followed the original STIS Ball specifications to remove factory-installed adhesive, and apply their own
- Samples oven baked in as in Round II testing, followed by thermal cycling in vacuum
- All samples be pre-loaded during curing
- Similar results to Round II testing



STIS Repair: Gasket Separation

- Teflon impregnated with carbon
 - Large particles ($> 100 \mu\text{m}$) assume Teflon fiber properties
 - Small particles assume average between Teflon and carbon properties, ball shape
- If gasket adheres, expect flatwise tensile mode failure
 - Results are per 1" length

Diameter	Flatwise Tension (0.5"/min)	Flatwise Tension (20"/min)	Shear (0.5"/min)	Shear (20"/min)	Model
5-15		4			4
15-25		3		4	4
25-35		1		1	1
50			1		1
120					1
200			1		1



EVA Handle Fastener Study

- Closeout photos indicate spots of staking around fasteners, but amount of staking used is unknown
 - End caps were filled with different amounts of staking to determine differences in fastener breakaway and running torques (CATs team's test)
 - Spots, 1/3 full, 2/3 full, and full (worst-case)
- Solvent rinses and tapelifts were taken of the removed fasteners and test configuration
 - Microscopic analysis was performed to characterize (metallic verses staking) and count particles
- Clamp Removal Study
 - The removal of the clamp and the EVA Handle is so similar that the clamp removal debris was input into the model at the same contamination levels as that of the EVA Handle removal (per fastener)



STIS Repair: Bolt Removal

- Bolt heads staked with epoxy
 - Raab aspect ratio distribution
 - Table shows statistics per bolt

Diameter	D/L
<70 um	$L^{-0.1068}$
70 - 180	$26.53L^{-0.8804}$
180 - 320	$1.815 \times 10^5 L^{-2.589}$
>320 um	$9.138L^{-0.8964}$

	Full		2/3		1/3		Spots		Model (Average)	
	Epoxy	Metallic	Epoxy	Metallic	Epoxy	Metallic	Epoxy	Metallic	Epoxy	Metallic
5-15 µm	33	22	0	2	0	0	6	43	9.8	16.8
15-25 µm	22	12	0	1.5	0	1	8	18.5	7.5	8.3
25-35 µm	15	4.5	0	2	32.5	0.5	0	14.5	11.9	5.4
35-50 µm	16.5	5.5	14.5	0	50	0	2.5	6	20.9	2.9
50-75 µm	21	2.5	16	0	0	0	0	0	9.3	0.6
75-100 µm	63	7	16	0	29	0	0.5	0	27.1	1.8
100-150 µm	8	0	0	0	0	0	1	0	2.3	0.0
150-200 µm	0	0	0	0	0	0	0	0	0.0	0.0
200-300 µm	0	0	2	0	0.5	0	0	0	0.6	0.0
300-500 µm	0	0	0.5	0	2	0	0	0	0.6	0.0
500-700 µm	0	0	0.5	0	0	0	0	0	0.1	0.0
700-900 µm	0	0	0.5	0	0	0	0	0	0.1	0.0
> 1000 µm (1800)	0	0	0.5	0	0	0	0	0	0.1	0.0



Pitfalls

Feeling overwhelmed yet?



Conditions Tested

- Card Extraction: *No flight like conditions*
 - Insertion of warped board
 - One or two card locks engaged
 - Card physically restrained (pull to failure)
- Cover Fasteners: *Missing flight like conditions*
 - #4 torque set fasteners
- EMI Gasket: *Too many non-flight like conditions*
 - New and old gasket material, with and without BASD adhesive process
 - Combinations of load, thermal cycles, and vacuum
 - Pull speeds from 1.5 to 90 inches/min
- Bolt removal: *Unknown flight like conditions*
 - Spots, 1/3 full, 2/3 full, and full



Data Gathering Anomalies

- Card Extraction
 - Warped boards scraped on insertion
- Fastener Removal
 - Dropped fasteners on vacuum filter accidentally
- EMI Gasket
 - Encapsulation method probably not reliable
 - Hand pulled for high speed – actual speed value unknown
- Bolt Removal
 - Attempted separate rinse of heads and threads
 - Dropped a bolt into the beaker



Lessons Learned

- Analyst should prepare particle bin size template
 - Certain sizes may be of importance to the analysis
 - Combining dissimilar bins results in bigger ranges – less information
- Make sure flight like conditions are tested or bracketed
 - Extrapolation beyond test conditions increases risk
- Minimize effort – don't collect data on extreme conditions that won't occur in flight
 - Extra data may confuse the issue or raise questions that aren't relevant
- Collect a statistically significant amount of data
 - Scaling data accentuates the noise



Analysis Results

- Obscuration within Hub area
 - Several timeline scenarios evaluated, none was significantly better than others
 - If all Hub Area particles are applied to WFC3 POM, only 1/3rd of PAC budget used:

Factor	7.19E-04	7.19E-04	4.60E-04	7.19E-04				
Source	Bolt	Fastener	EMI	Card		Reach Hub	Particles	
	Removal	Removal	Gasket	Removal	Install		Unit Area (cm ²)	Total Area
50µm	3511	105717	8876	3327	41	85.00	1.96E-05	1.67E-03
100µm	686	1677	56	342	5	1.97	7.85E-05	1.55E-04
500µm	76	256	0	14	3	0.25	1.96E-03	4.91E-04
							Total Area (cm ²)	2.31E-03
							POM Area (cm ²)	7.54E+01
							PAC	0.0031%
							PAC Budget	0.0100%