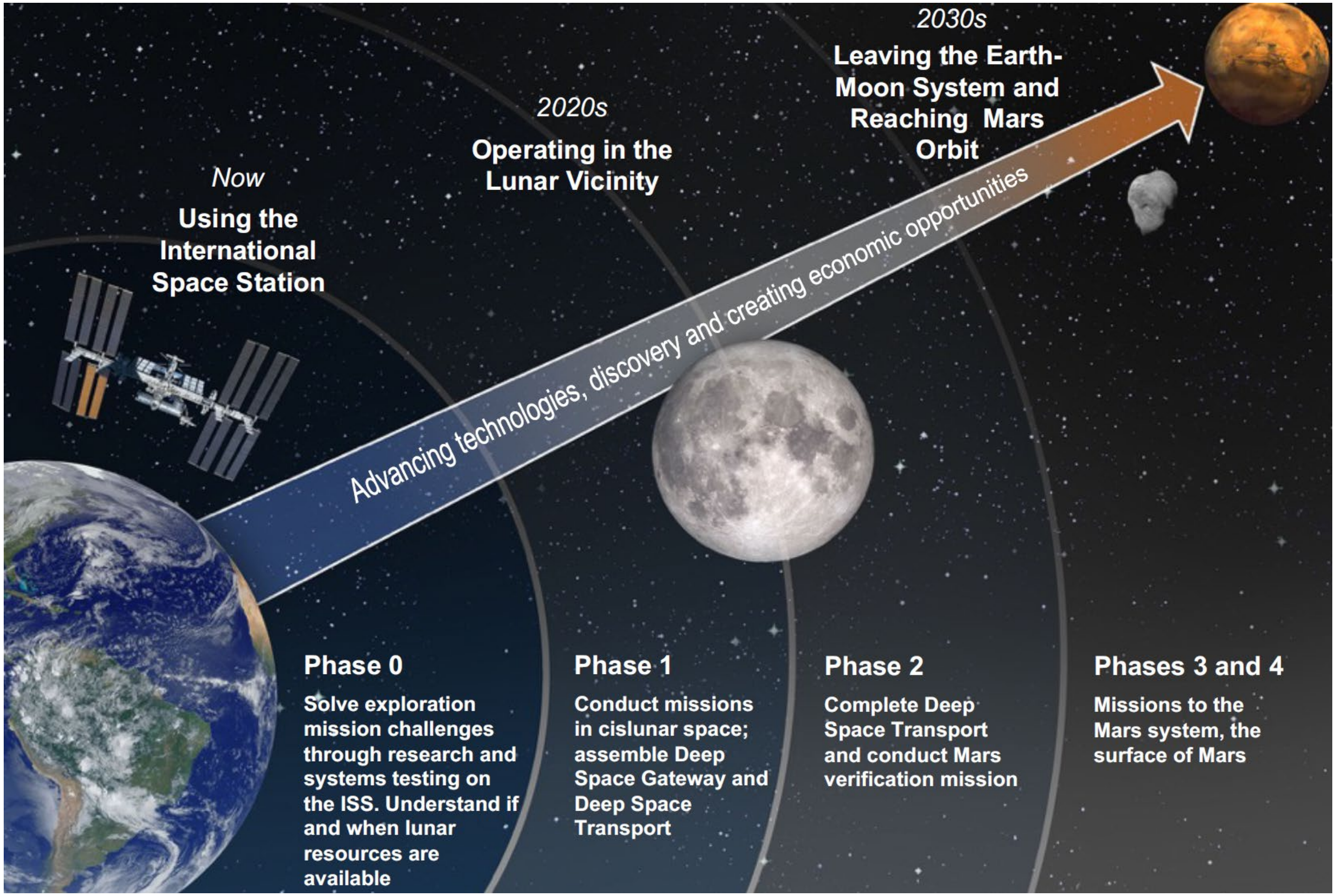
Composite Hard Upper Torso (CHUT) for xEMU Space Suit

ICES – 2023

Shridhar Yarlagadda

University of Delaware

Design Reference Missions – Exploration



xEMU Background

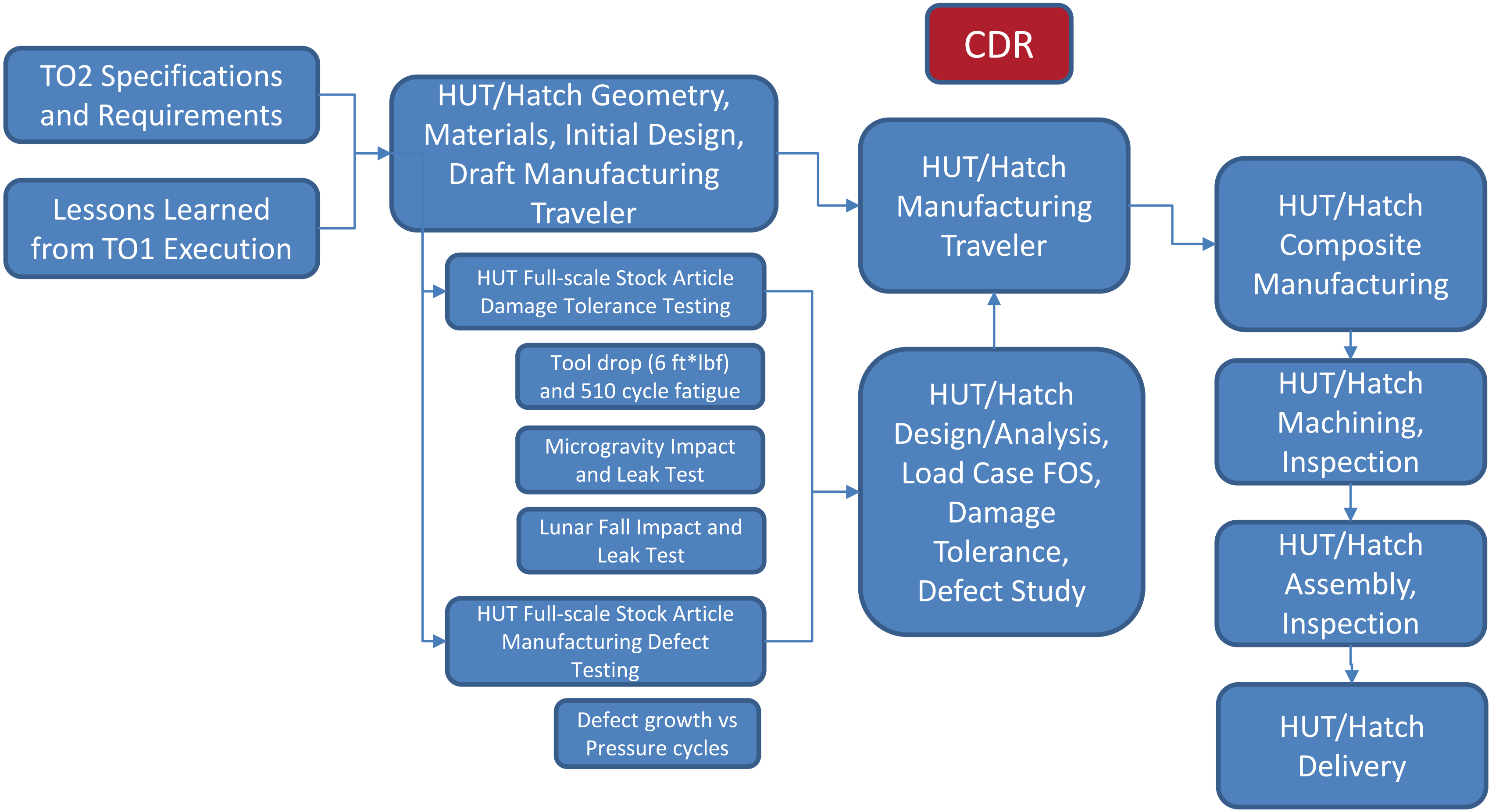
- The xEMU is the government reference design for an Exploration space suit, designed for microgravity (cislunar and low earth orbit (LEO)) and lunar surface operations.
- This suit allows crewmembers to perform extravehicular exploration, science, construction, maintenance, and contingency operations while unattached to a vehicle for life support in pressure and thermal environments that exceed human capability.
- The xEMU provides life support, environmental protection, and communications capabilities to the EVA crewmember while allowing sufficient mobility and visibility to perform dexterous EVA tasks.

A key risk that the pressure garment team has been working is to have **lightweight and highly robust structures**.

xEMU Lightweight and Robust Composite Structures Development

- Three potential hard composite components in the xEMU
  - HUT (Hard Upper Torso) – focus of this talk
  - Hatch
  - Brief
- The Z2 spacesuit development program developed hard composite prototypes for all three components
  - UD-CCM manufactured composite prototypes
- NASA established Composite Hard Upper Torso (CHUT) Task Order contract with UD-CCM to design, analyze, manufacture and test composite HUT prototypes
  - Primary focus on manufacturability for flight-quality hardware
  - TO1: CHUT prototyping and lessons learned
  - **<u>TO2: Small CHUT</u>**
  - TO3: Impact model development for xEMU with CHUT
  - TO4: Large CHUT

TO2 CHUT Development Strategy

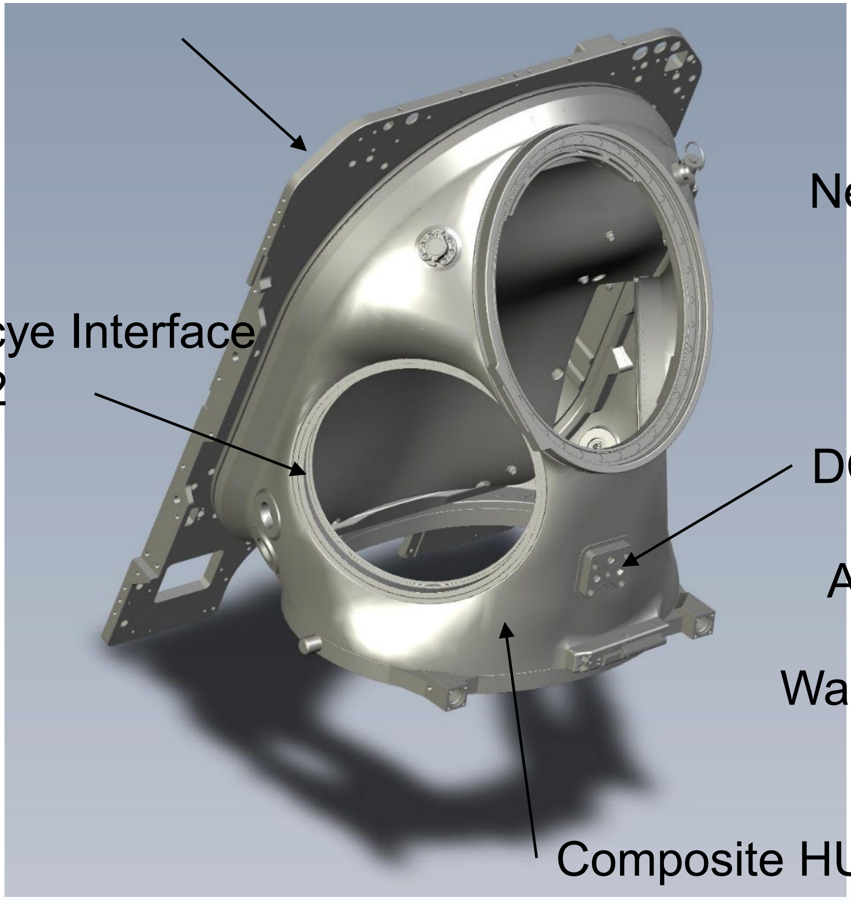


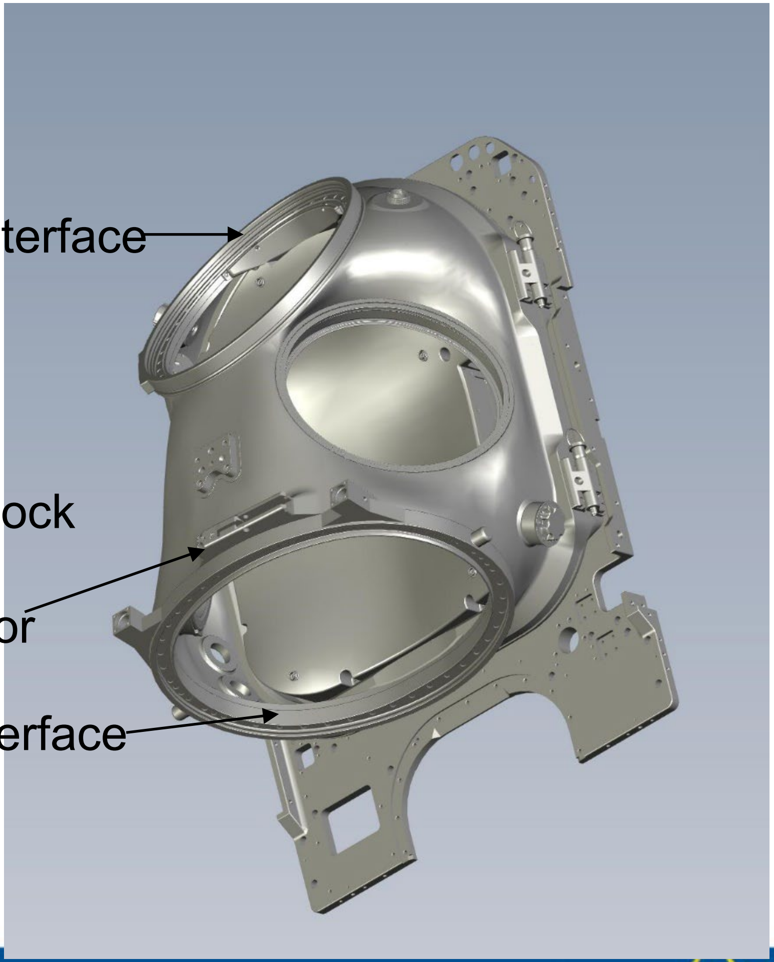
CHUT Overview: Key Requirements

- HUT key requirements
  - Pressure rated structure with leak seal requirement
    - Nominal Operating Pressure: 8.2 $\pm$ 0.2 psid
    - Maximum Design Pressure: 10.6 psid
    - Proof Pressure: 15.9 psid
    - Ultimate: 21.2 psid
  - Impact damage tolerance (suit fall or collision)
    - LVI to ~300 J impacts
    - Maximum leak rate specification post-impact damage
  - Fatigue (pressure cycling)
    - 2040 cycles at 10.1 psid (estimated lifetime use)
  - Many other load requirements related to Don/Doff of suit, Operational Loads, Suit Handling and Testing, Suit Transport (launch g and vibration)
  - Other systems/assembly related requirements (corrosion etc)
  - Temperature: -170.7 F to 168 F

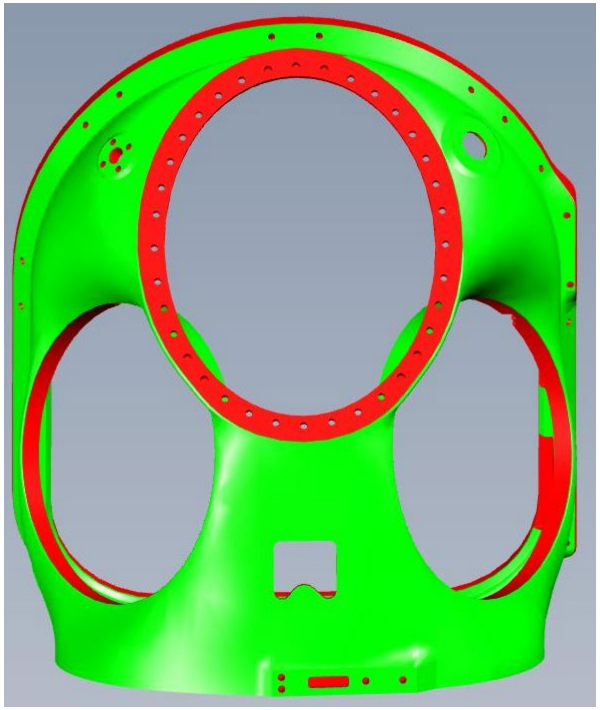
Astronaut Safety drives Everything!

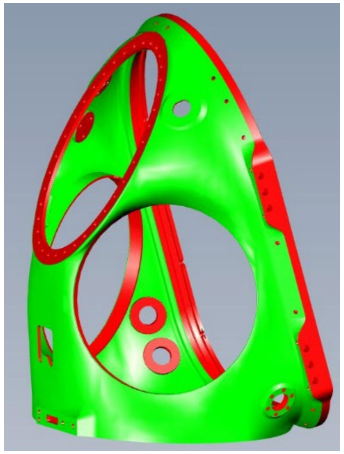
CHUT Overview: HUT/Hatch Assembly

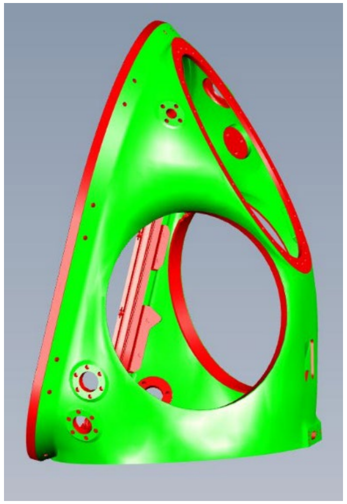


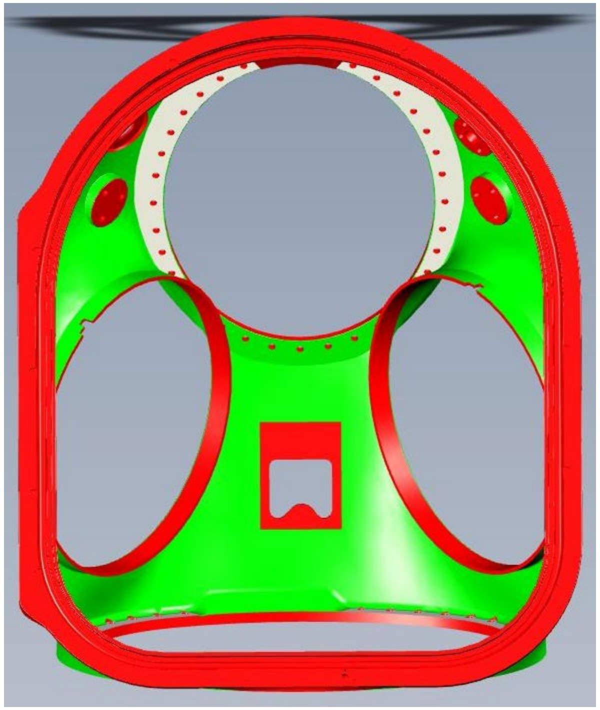


Composite Hard Upper Torso (CHUT)









Red reflects machined surfaces

CHUT: Materials/Properties

- S2-glass/Epoxy prepreg from Patz Materials, Inc
  - S2 6781HT/PMT-F4A toughened epoxy, 295 gsm FAW, 35% RC
    - 350 F epoxy curable at 250 F, >30 day out life
    - Carbon and other hybrids considered in the past
      - S-glass based system selected based on structure, impact, assembly, corrosion, NDI, cost etc.
- B-basis used in TO2 Small HUT work

Measured B-Basis Properties						
Property	**ASTM Test Method**	**Properties**	**Modulus (msi)**	**Strength (ksi)**	**Poissons**	**Failure Strain (%)**
0 Tension	D 3039	E11, X1T, Nu12, e1T	3.79	106.73	0.12	3.44
90 Tension	D 3039	E22, X2T, Nu21, e2T	3.53	81.53	0.11	2.68
0 Compression	D 3410	X1C		63.55		
90 Compression	D 3410	X2C		49.22		
In-plane Shear	D 3518	G12, X12, e12	0.46	8.91		5
Out of plane Shear	D 5379	G23, X23, e23	0.41	10.76		5
Short beam shear	D 2344	ILSS		9.95		
Short beam shear (30 day outlife)	D 2344	ILSS		9.45		
Z tension*	D 7291	E33, X3T	0.19	3.79		

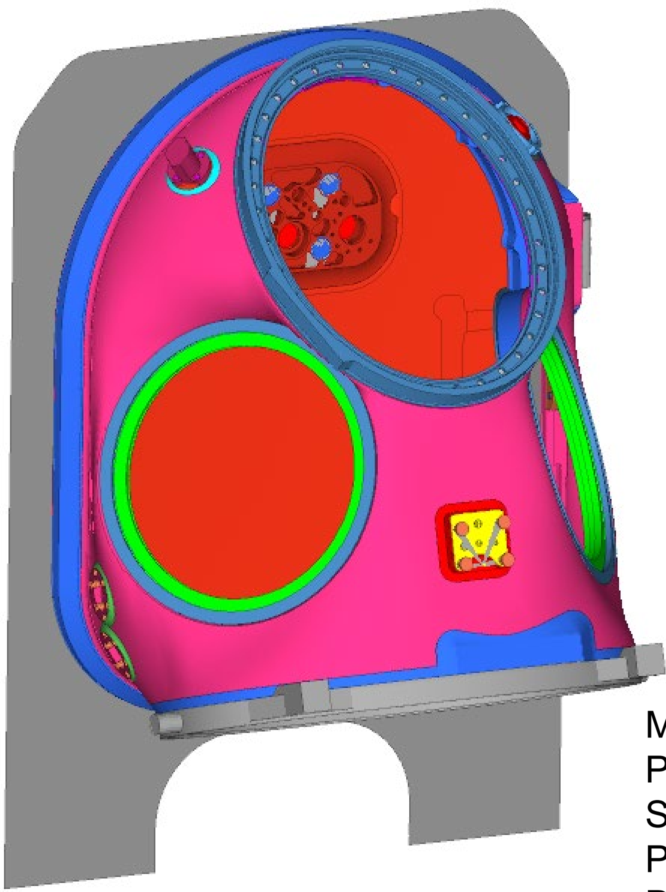
CHUT ANALYSIS

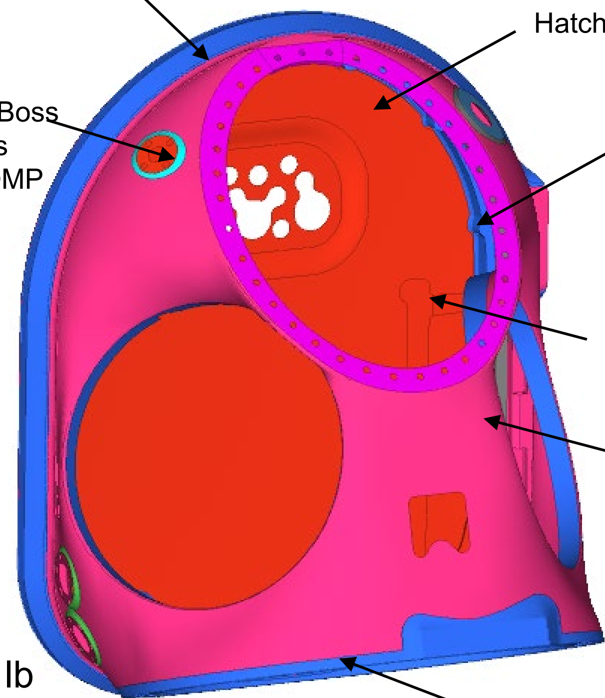
In collaboration with Altair Services Group (Mohan Parthasarathy, Eric Nelson)

CHUT Analysis Background

- TO2 CHUT analysis conducted with a system assembly comprised of
  - Composite Hatch and HUT
    - Presenting HUT results only today
  - All metal interface components (waist, neck and Scye)
  - PLSS back plate on Hatch
- Nine (9) static load case families were identified for analysis
  - Impact load cases is carried out in TO3 (HUT impact modeling task order)
- Analysis goals are to:
  - Establish Composite performance margins
  - Predict fastener loads for fastener sizing and analysis
  - Hinge loads and composite margins at Hinges
  - Composite teeth (Hatch), locking slot (HUT) performance
  - Adhesive performance assessment
  - Fail-safe analyses for fasteners and adhesive joints

HUT/Hatch Assembly Model



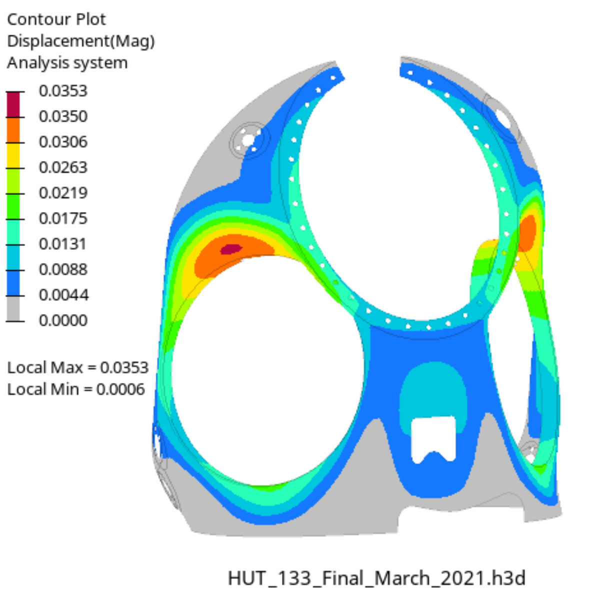


~1.4M elements

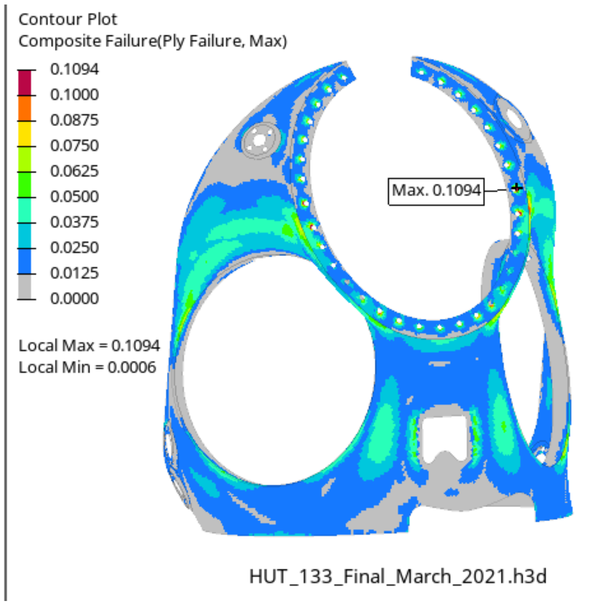
Masses:
Person: 243 lb
Suit: 150 lb
PLSS: 220 lb
DCU: 30 lb

Proof Pressure Load Case (Worst Case) Displacement, Failure Indices

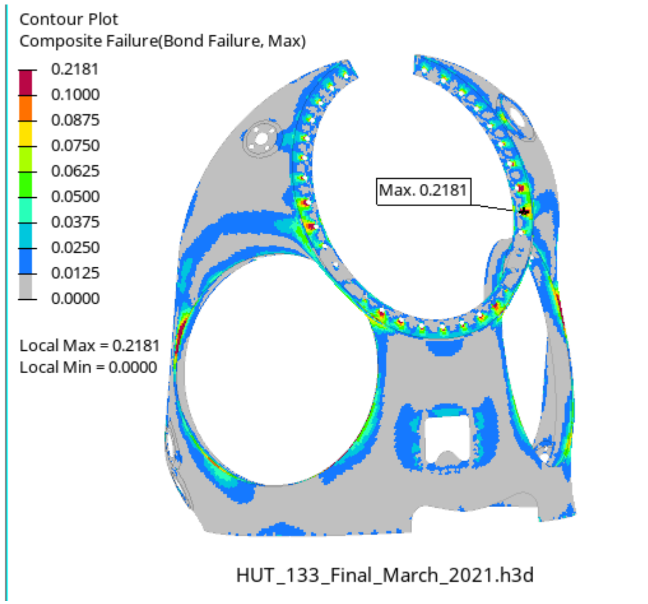
HUT Shells
Displacement (inch)



HUT Shells
Ply Failure (In-Plane)



HUT Shells
Bond Failure (Transverse Shear)



Analysis Methodology Validated with Sta
Pressure Testing of Stock HUT

- Composite stock HUT (not machined) tested under static pressure
  - Triax rosettes for principal strain comparison
- Comparison with FEA model of stock HUT
  - ~5% error compared to measured valued at pressure range of interest

Rosette 3			FEA		
Pressure	Pmax	Pmin	Pressure	Pmax	Pmin
5.04	550	203	5.04	493	168
6.22	645	238	6.22	608	207
8.41	814	306	8.41	823	279
9.69	913	344	9.69	948	322
10.59	981	371	10.59	1036	351

CHUT MANUFACTURING

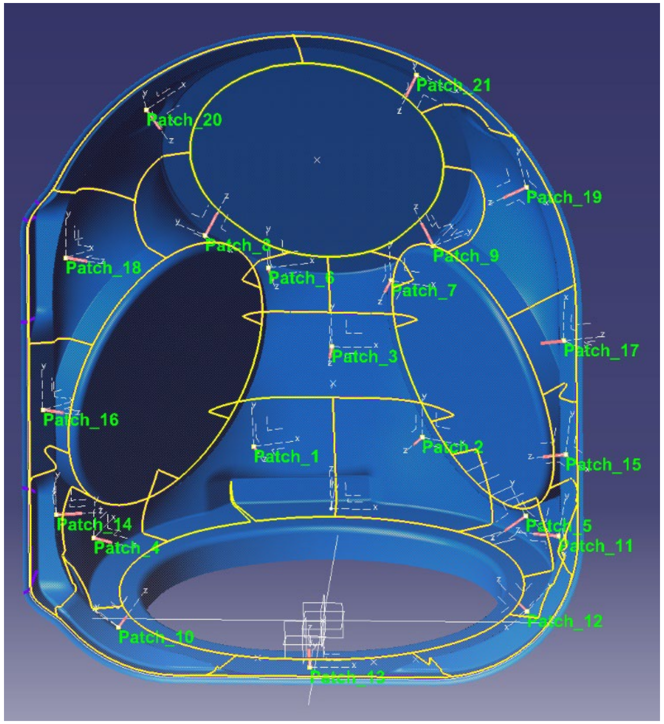
CHUT Ply Design and Example Pattern

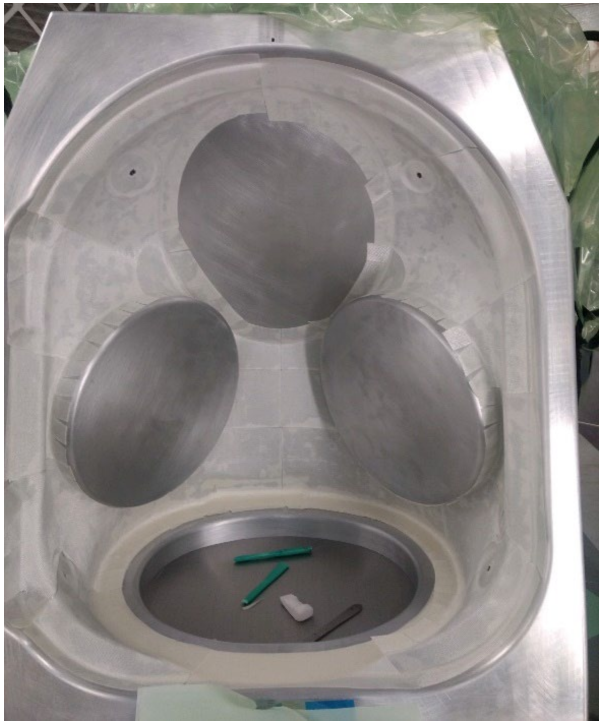
HUT Ply Build Strategy
~14 patches per Ply for full coverage

8 plies under cores
8 plies above cores with offset surfaces

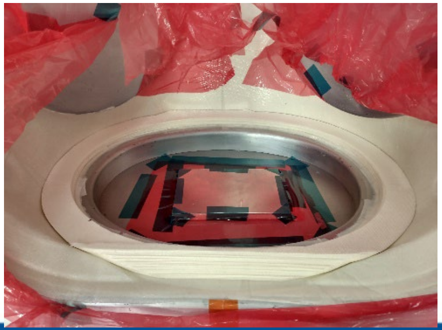
Example ply boundaries (yellow)

Adding filler plies to base for machining.
Adding noodle plies at base for rounding
Every patch (14) manually darted and checked for producability

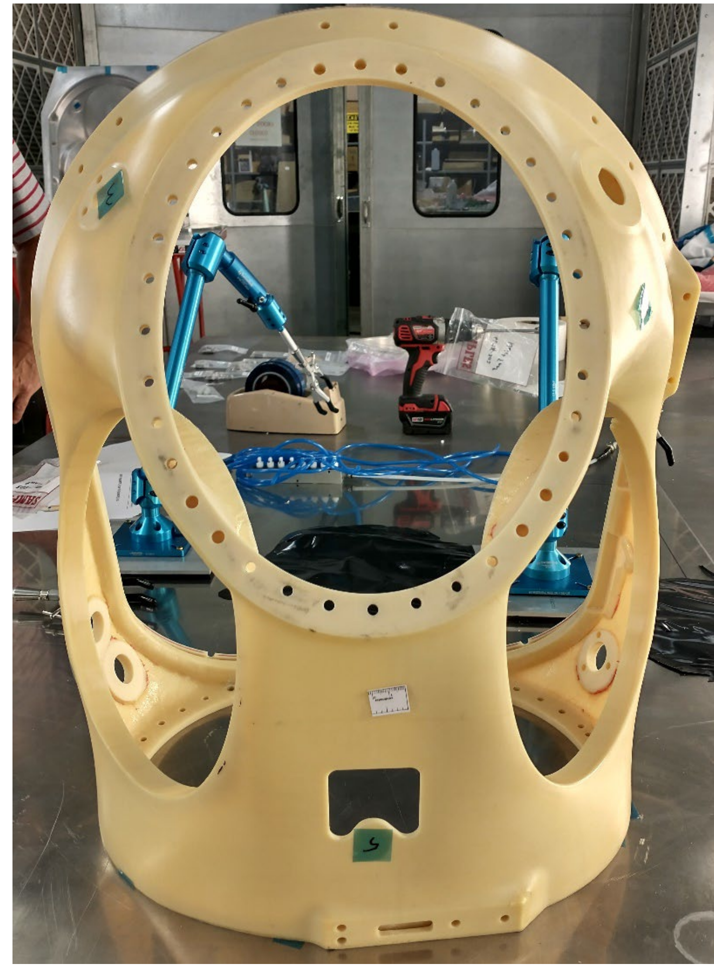




CHUT Layup Sequence Examples



Autoclaved, Post-Cured and Machined CHUT



Bechdon Inc

~400 hrs of programming and machine time

CHUT TESTING

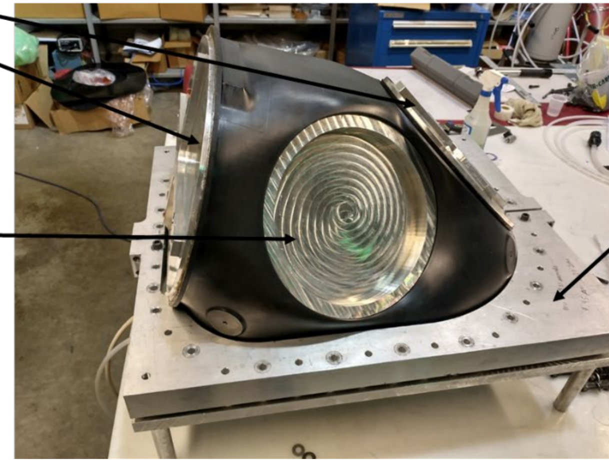
Full-size Stock Composite HUT

- Static and Fatigue pressure cycling
- Impact (LVI) testing
- Effect of Defects

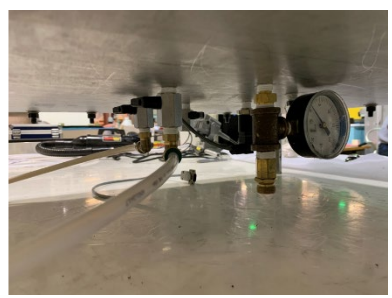
CHUT Testing Methodology

- Full-scale article Composite HUT (#1 and #2) fabricated for testing and validation of analysis results
  - 16-ply Quasi-isotropic shell, no boss features, no machining
  - Same layup procedure and autoclave cycle
- Composite HUT tested as-manufactured
  - HUT edges trimmed as well as frame surfaced for pressure seal
  - Neck and Waist composite flange sealed with doubler plates
  - Scye openings sealed with close-outs
    - Scye flange trimmed to nominal CAD flange height
    - Close-out geometry selected to match Scye bearing assembly stiffness
  - Hatch opening sealed with back plate
  - Back plate also has all pressure ports
- Testing Goals
  - Stock Composite HUT #1
    - Validate analysis results for static internal pressure
      - Up to MDP (10.6 psid)
    - Perform fatigue test to validate performance and quality
      - 2040 cycles at 10.1 psid
    - LVI impact (10J for tool drop, 20J for microgravity) assessment
      - NDI, Leak and Fatigue performance post-impact
    - Proof (15.9 psid), 2x MDP (21.2 psid) and possible burst
  - Stock Composite HUT #2
    - Effect of defects (0.375” and 0.5”) on fatigue performance

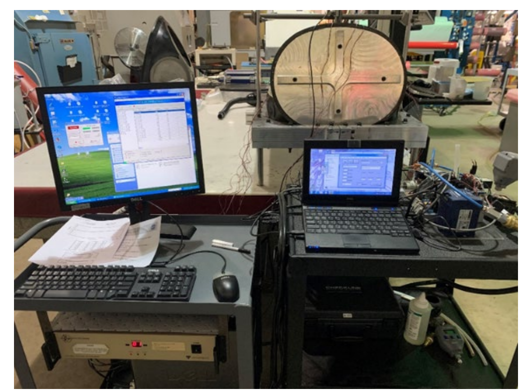
Stock HUT #1 Test Article



HUT #1 in Pressurization setup with Neck/Waist doubler sealing plates, bonded Scye plugs and Back plate for pressure ports/seal



- Inlet with control valve
- Outlet with control valve
- Transducer
- Safety release valve
- Additional if needed



DAQ (Strain, LVDT, Pressure)

Note: HUT #1 is black due to <0.05" carbon black loading in resin for UV resistance. Switched to no carbon black for later builds. No effect on mechanical performance.

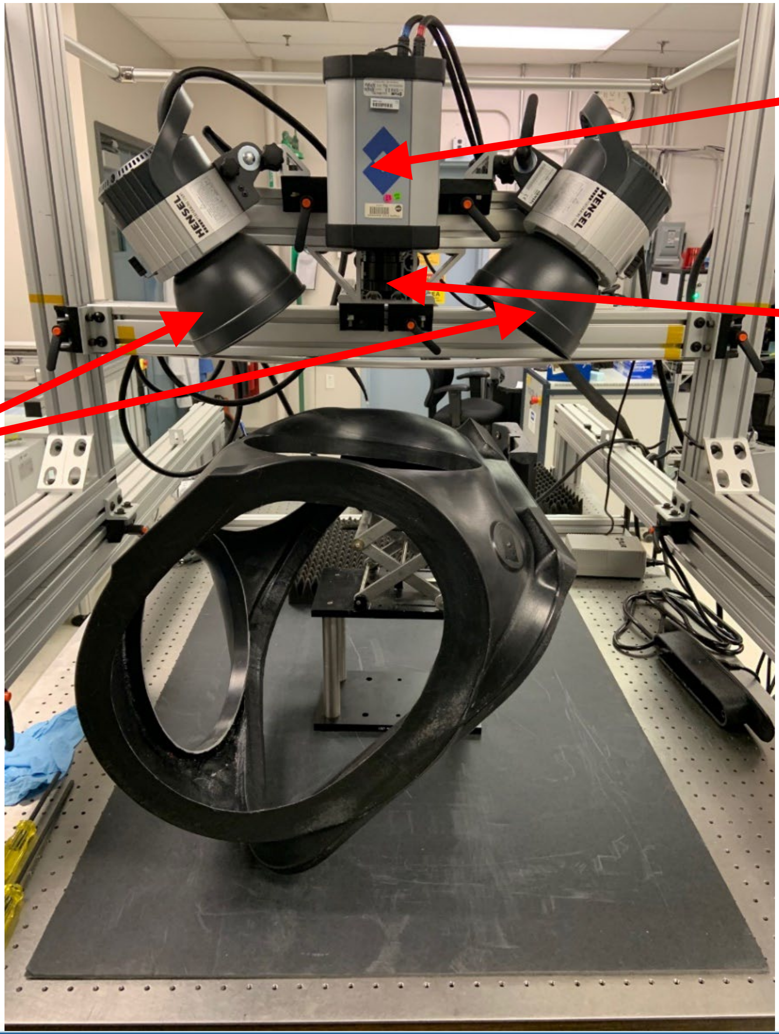
Flash-IR Thermography for HUT#1 NDI

Performed at:
Goddard Space Center
Justin Jones
William Mulhearn

IR Camera

Image working distance, field of view adjustable by placing lens spacer

Flash lamps

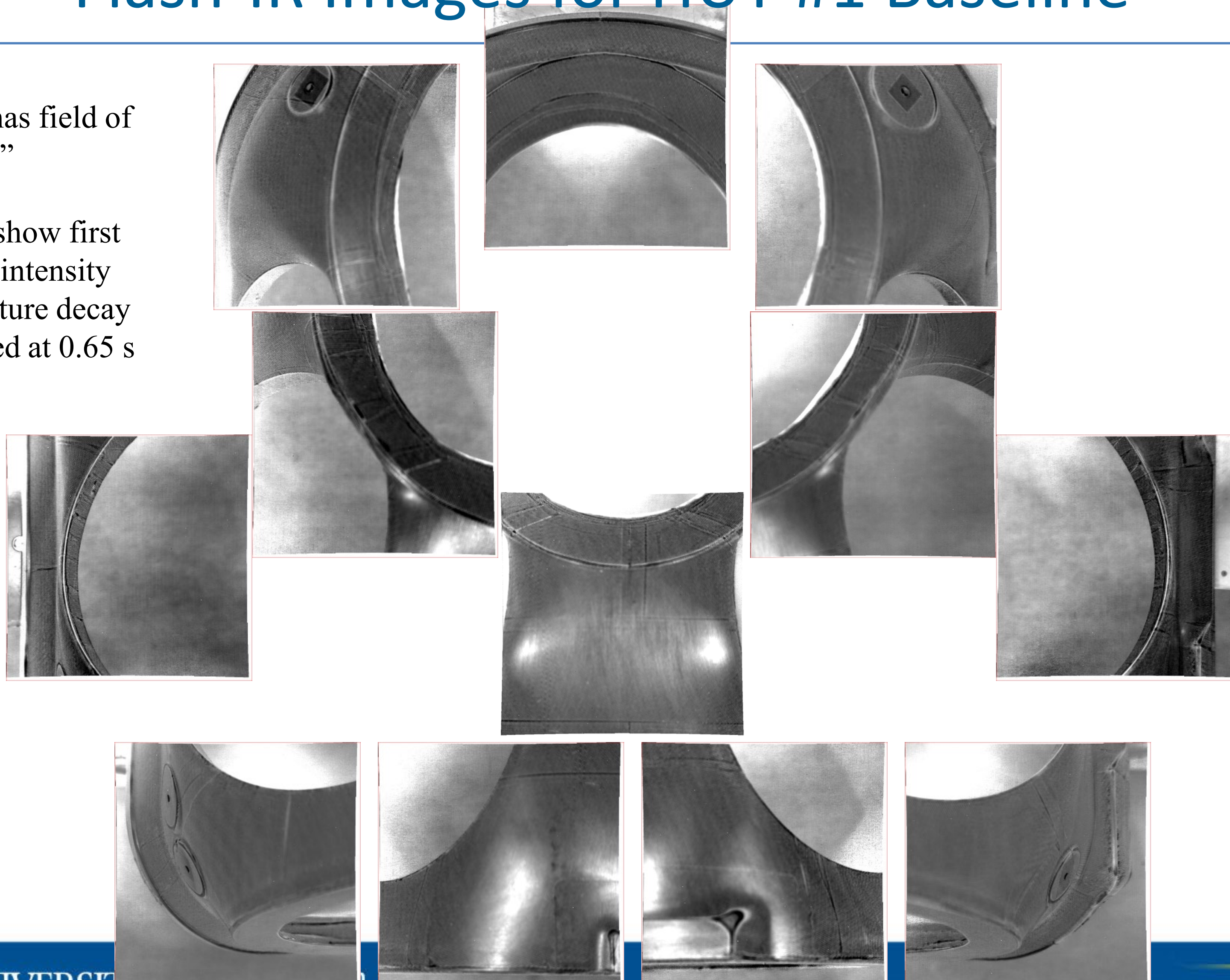


- Two lamps deliver 6000 J flash each to object surface
- IR camera records surface intensity at 60 fps following flash exposure

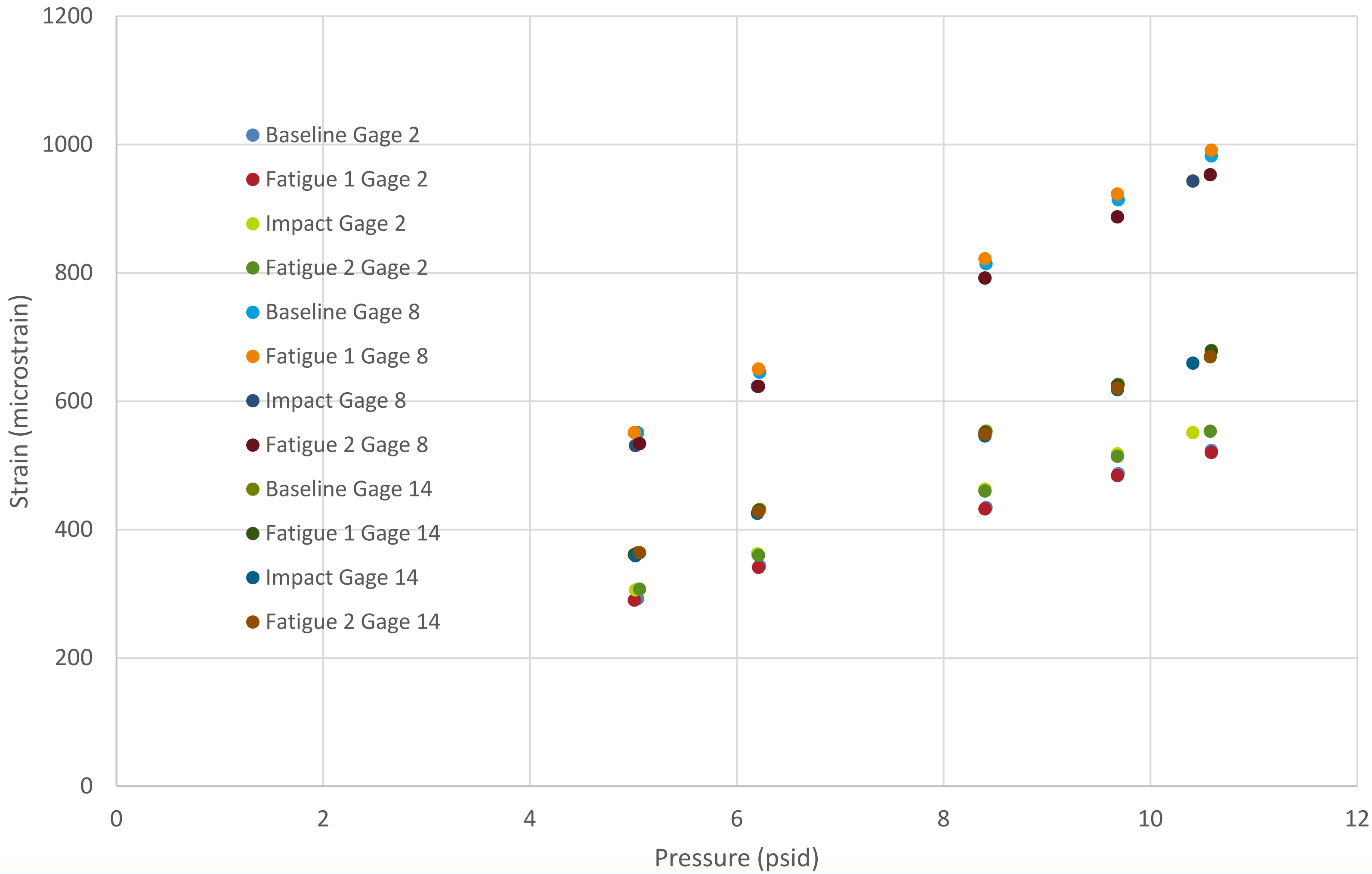
Flash-IR Images for HUT #1 Baseline

Each image has field of view 8”-by-8”

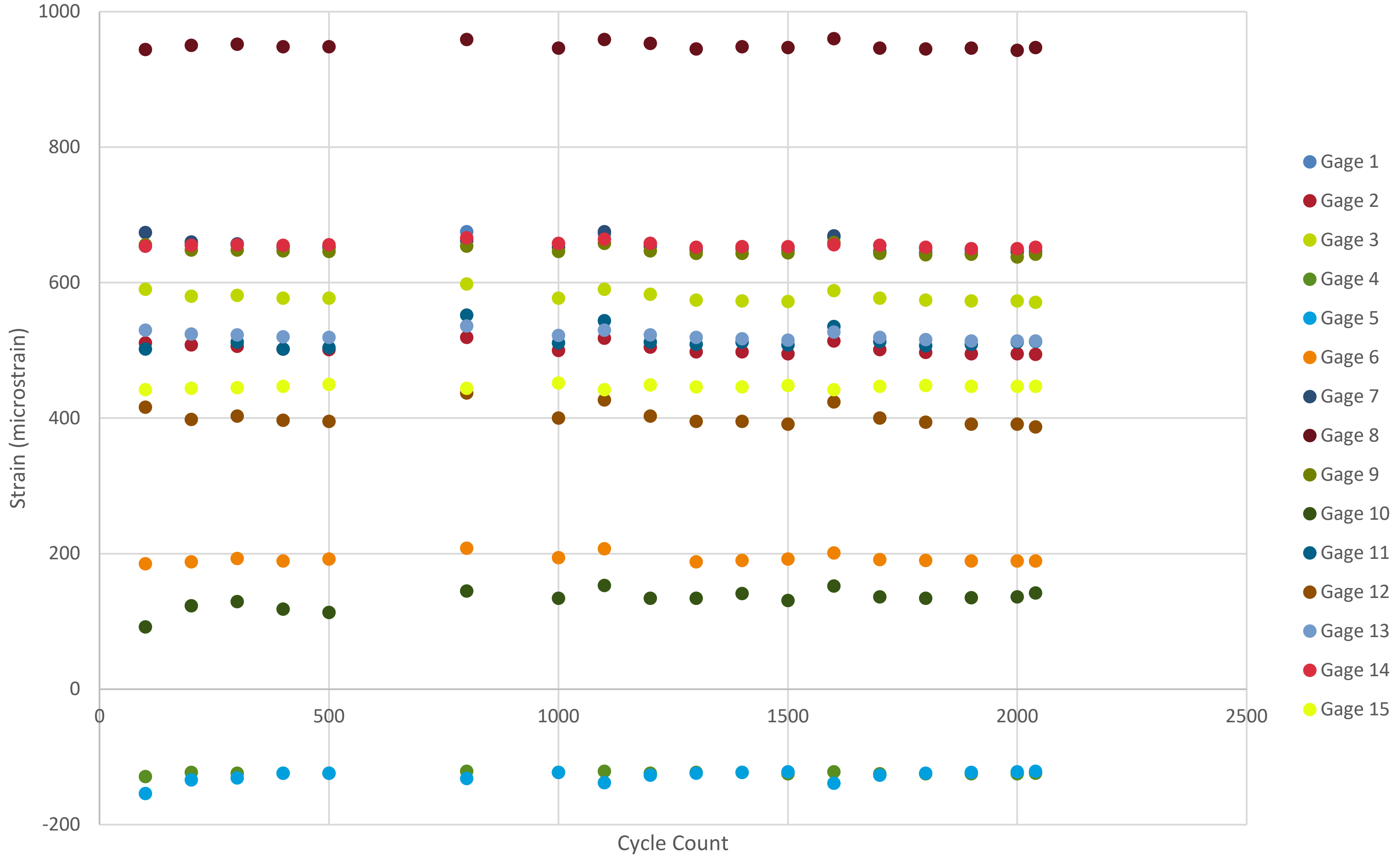
Images here show first derivative of intensity (*i.e.*, temperature decay rate), collected at 0.65 s after flash



HUT Response Linear across all Tests



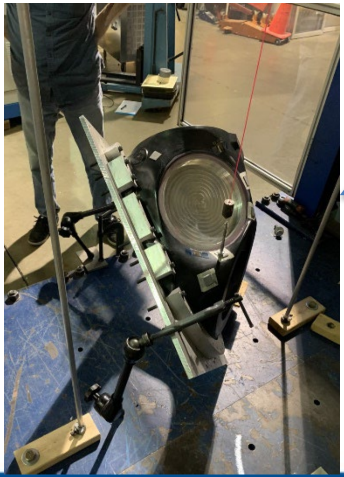
Measured Maximum Strains vs Cycles for 2040 cycle 10.1 psid Fatigue Pressure Test

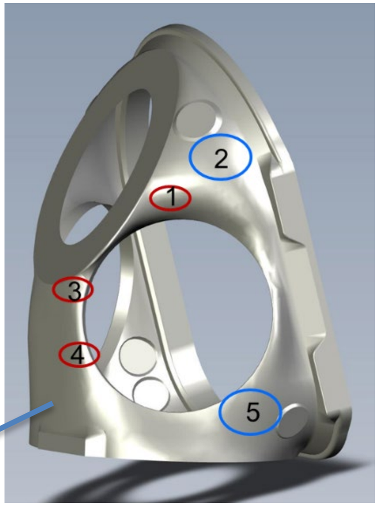


Impact Testing of CHUT
(10 impacts at selected locations)

Energy	Impactor	Mass	Height	Velocity
8.1 J for Tool Drop Based on 1 lb drop at 6 ft	0.5” hemi steel tup	1 lb total mass including cross-beam	1.8 m (6 ft)	6 m/s nominal
12.2 J drop simulating microgravity impact (295 lb empty suit mass at 1.4 fps)	2.0” hemi steel tup	5.4 lb total mass including cross-beam	0.5 m (20 in)	3.15 m/s nominal

- Tool drop requirement: 6ft/1lb drop and meet fatigue life
- Microgravity requirement: 2” impactor on empty suit mass (295 lbs) at 1.4 fps, no catastrophic failure

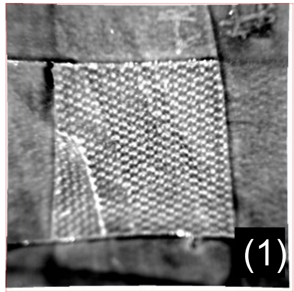


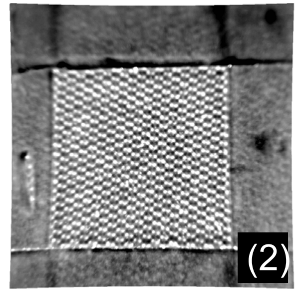


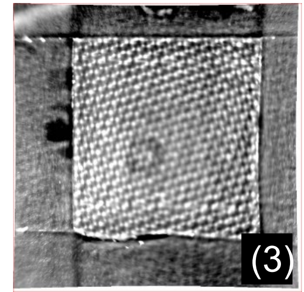
5 more impacts mirrored on other side

Impact Location Flash-IR Close Ups (5 was hard to view)

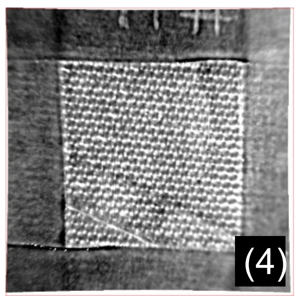
Third Round – Impact Location Closeups
WD = 6”
1D, 0.8 s







Surface dents seen in a few locations, no delaminations or other damage types detected



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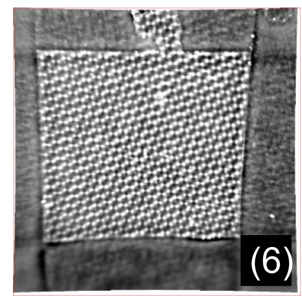
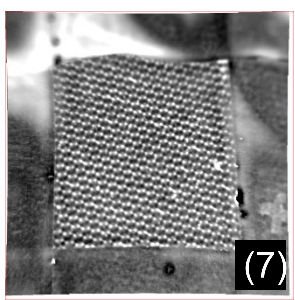
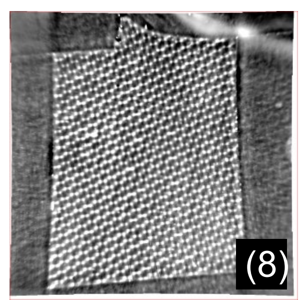
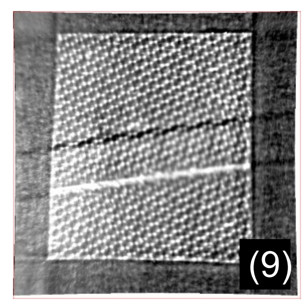




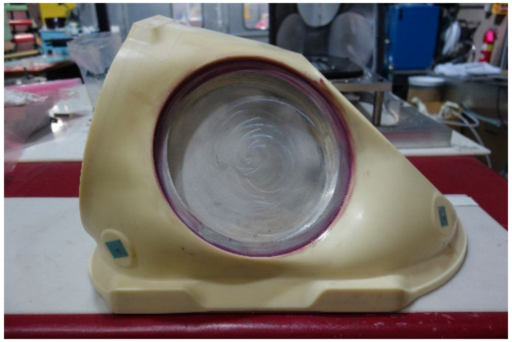


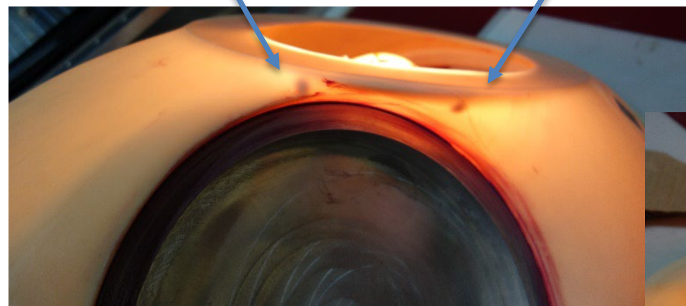


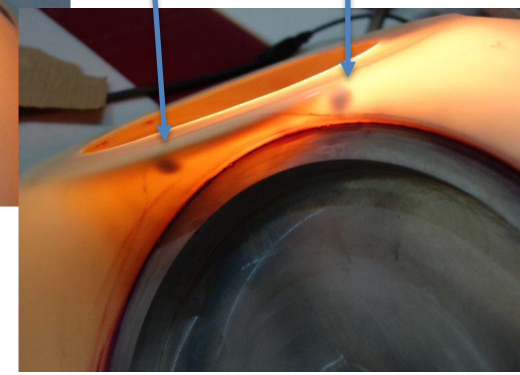
(10)

Effect of Defects with Stock HUT #2

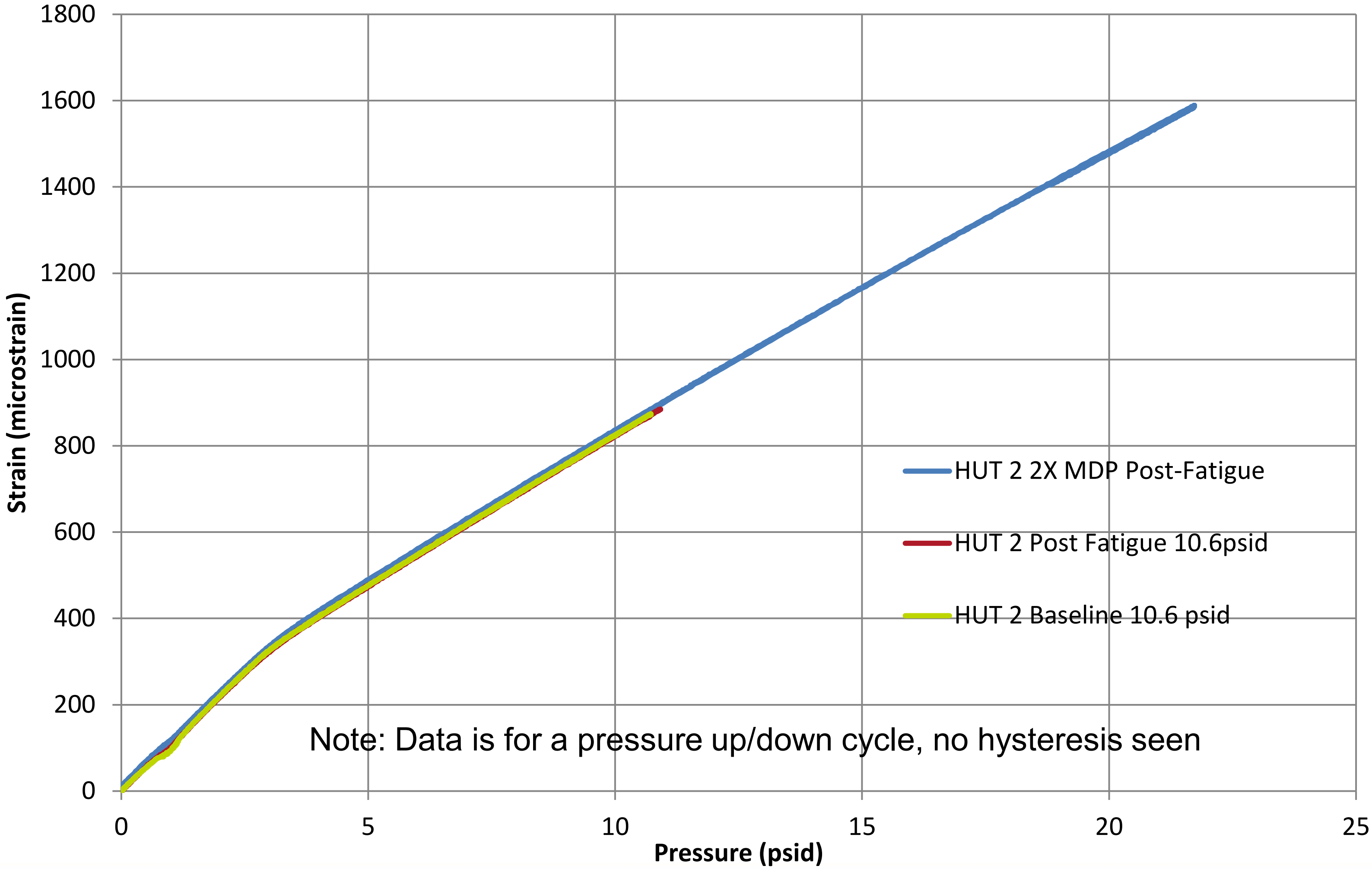
6 defects (3 @ 0.375” and 3 @0.5” at mid-plane in locations shown







Static Pressure Comparison for Stock HUT #2
No measurable effect from Defects



Summary

- Small Composite HUT has successfully developed
  - Analysis models for CHUT with experimental validation
    - Provided sizing loads for fasteners/inserts, adhesive bondlines and fail-safe operational scenarios
  - Manufacturing procedures (Traveler) for small CHUT
    - Validated with TO1, stock HUT #1 and #2
  - Validated through full-scale stock article testing
    - Fatigue performance for lifetime pressure cycling
    - Robust performance under LVI scenarios with no loss of fatigue performance
    - Linear response to Ultimate with no hysteresis post-fatigue
    - No effect of defects (up to 0.5”) on fatigue lifetime performance
  - DVT CHUT assemblies being delivered to NASA for full-suit testing
- Large Composite HUT is in manufacturing

xEMU CHUT Team

- NASA
  - Johnson Space Center
    - Richard Rhodes (PM), Daniel Kim, Jeremy Jacobs, Mykale-jamal Holland, Mark McElroy, Justin Smith
  - Glenn Space Center
    - Justin Jones, William Mulhearn
- UD-CCM
  - Shridhar Yarlagadda (PM), Jack Gillespie, David Roseman, John Tierney, Nick Shevchenko, Alex Vanarelli, Edward Lake, Joseph Cipriani
- Altair (modeling/analysis)
  - Mohan Parthasarathy, Eric Nelson
- Bechdon and HUB Corporation (all machining work)
- ARL (autoclave access and use)
  - Brendan Patterson