NASA Advanced Space Suit xEMU Development Report - Waist Brief Hip Assembly

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Agenda

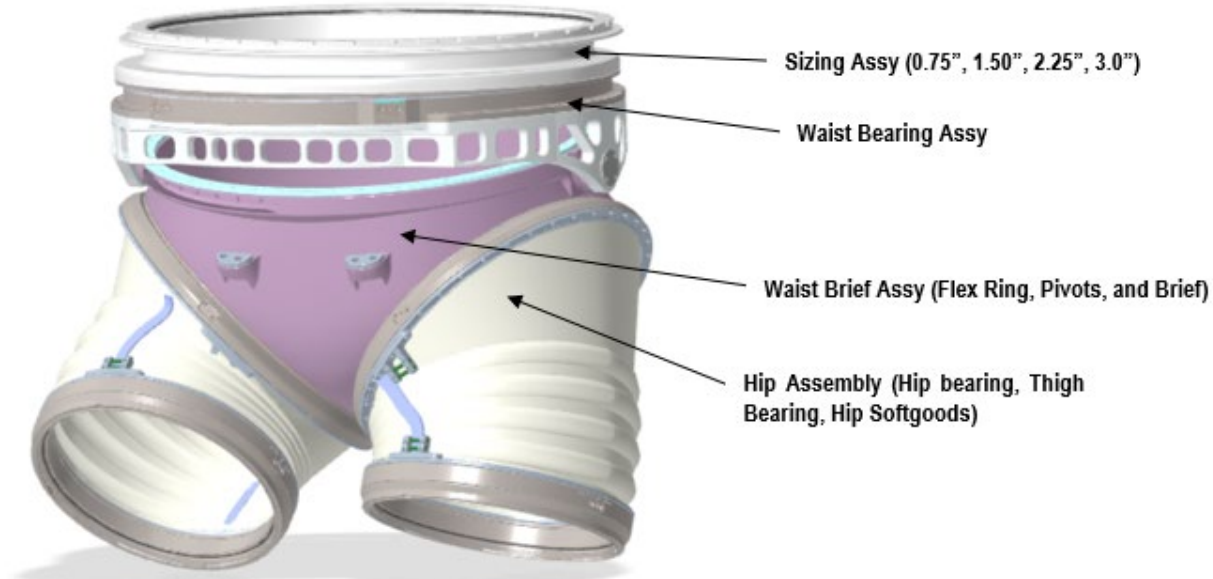
- Waist Brief Hip (WBH) Introduction
- WBH Design History
- Driving Requirements
- Design Overview
- DVT Testing
- Forward Work

xEMU Introduction

- The Exploration Extra-Vehicular Mobility Unit (xEMU) space suit is NASA's latest space suit development effort
  - Designed to support ISS and Artemis lunar missions
- xEMU incorporated lessons learned from previous spacesuit and prototype iterations
  - Apollo, EMU, Mark III, I-Suit, Z-1, Z-2, Z-2.5
- This presentation focuses on the Waist Brief Hip (WBH) assembly for xEMU

Waist Brief Hip (WBH) Introduction

- xEMU WBH is the integral piece of the lower torso assembly (LTA) to enable natural movements for planetary mobility
- Consists of:
  - Waist Bearing Assembly
  - Flexion/Extension Joint
    - Allows for 40 deg flex/ex for short and 50 deg flex/ex for long
  - Brief
    - Two sizes: Short and Long
  - Hip Assemblies
    - Allows for 40 deg abduction and adduction
    - Consists of hip bearings, leg bearings, and hip softgoods
  - Sizing rings (4 sizes)
    - Placed between Hard Upper Torso (HUT) Body Seal Closure (BSC) depending on subject's vertical trunk diameter (VTD)



WBH Assembly (Flexion/Extension Bladder not represented)

WBH Design History

- Multiple tests have been performed from 1980's-present that provide data regarding the contributions to mobility of lower torso mobility joints
- High level results indicate:
  - The set of mobility joint systems baselined for the xEMU architecture provide improved center of gravity control and more avenues to accomplish tasks, which results in greater efficiency due to reduced programming
  - Removal of joint mobility systems, does not prohibit all motions, but increases their difficulty due to increased instability and programming
    - Reduced stability:
      - Reduced the ability to recover from stumbles, increasing the likelihood of a fall
      - Increased the difficulty of fall recovery
      - Decreasing effectiveness to complete geology tasks, more repositioning required
      - Required more physical and mental effort to perform tasks
  - The impacts of each mobility joint will be discussed in the following slides.
    - KC-135 flight where Mark III joints were individually "locked out" contributes to this data set

WBH Design History (cont)

- Waist Bearing
  - Achieving natural (unsuited) motions requires the suited subject to control the Center of Gravity (CG)
    - While subjects walk, the upper torso motion is primarily manifested in the rotation of the waist bearing
      - The upper body will shift to compensate for the movement of the lower torso
    - When kneeling while suited to retrieve objects from the ground, the motion includes rotation at the waist to bring the arm closer to the ground to shift the CG
  - When locking out the waist bearing, the CG control and consequently stability is removed.
    - Subjects would develop new techniques to compensate
    - Subjects would obtain rotation from the hip assembly, the Flex/Ex softgoods becoming more active, and the shoulder swing increasing
    - The gait tended to be wider, stiffer, and required more concentration to maintain stability
    - All test motions could still be performed while the waist bearing was locked out without excessive effort

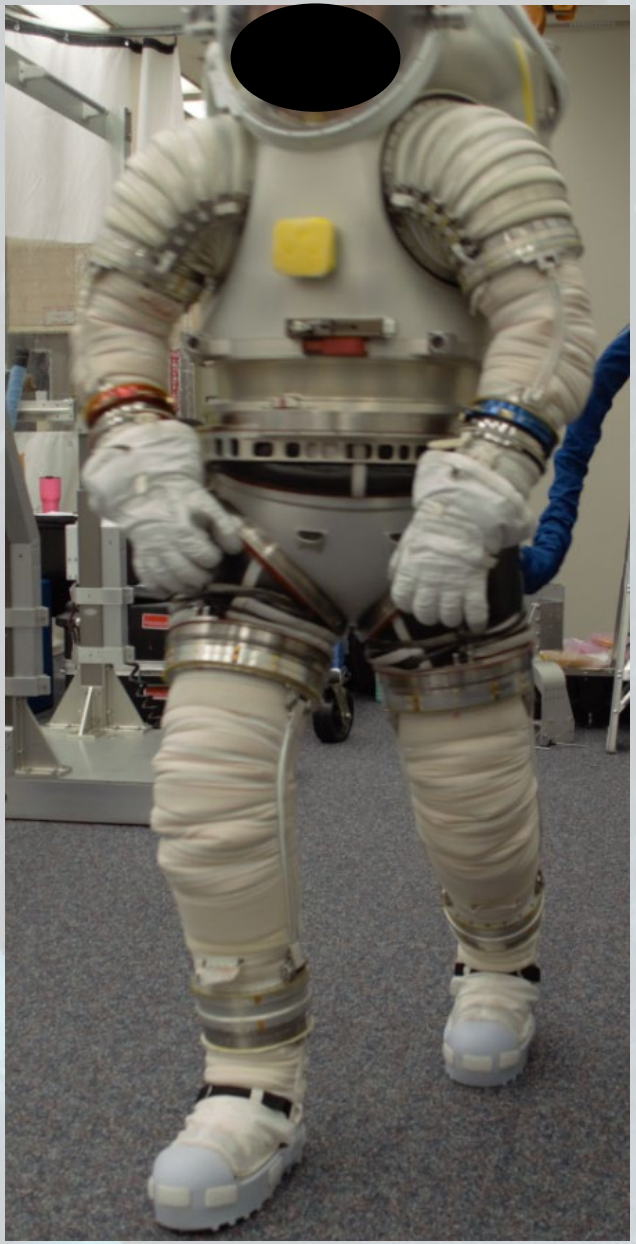
WBH Design History (cont)

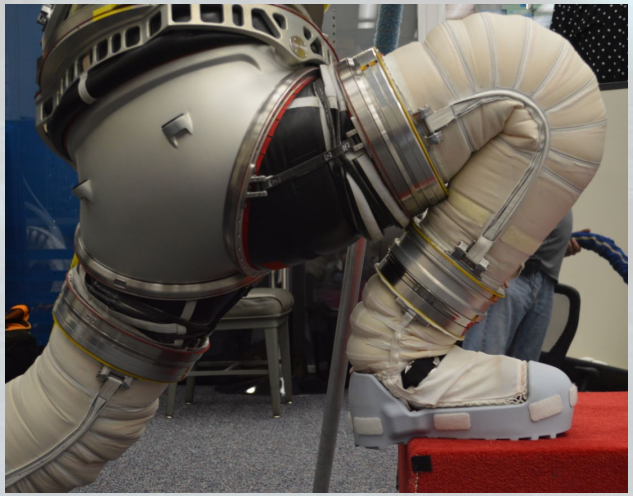
- Flexion/Extension (Flex/Ex) Joint
  - During activities that require leaning forward (seat ingress/egress, supine recovery, and kneel/recover), the full range of the Flex/Ex softgoods are used
    - When completing a lunge and recover, the Flex/Ex softgoods allow the subjects to get closer to the floor to retrieve an object more easily
    - The Flex/Ex softgoods contribute to recovery from supine position as the subjects move from supine to prone and then get their feet under them to stand up.
  - Flex/Ex softgoods had the most contribution during ingress/egress of a representative rover vehicle seat.
    - The softgoods provide forward waist flexion for the subjects to shift their weight forward as they sat down and stood up.
    - Locking out the Flex/Ex softgoods, the subject tended to have a more upright position in the spacesuit.
      - The hip assembly than tended to provide flexion.

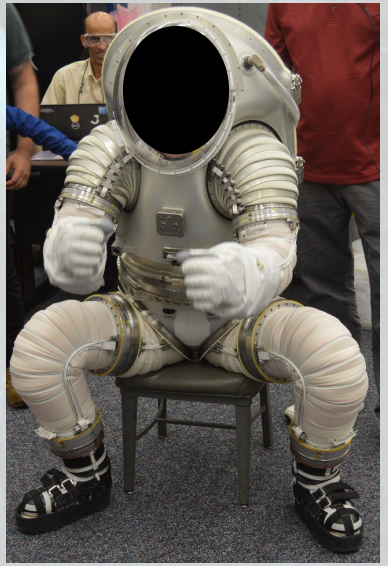
WBH Design History (cont)

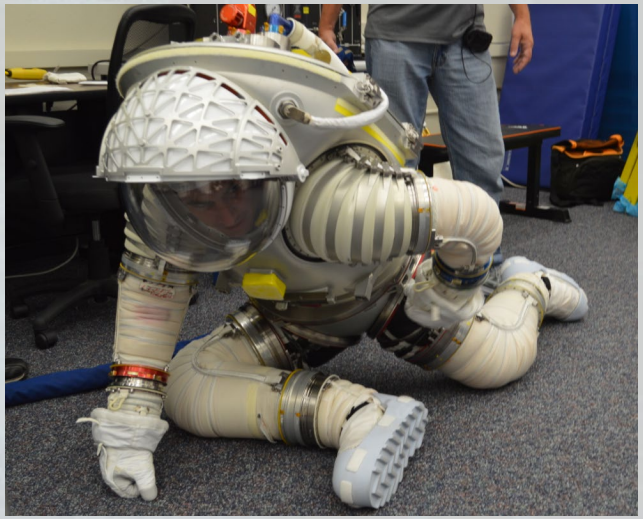
- Hip Assembly
  - The hip assembly is an integral component used most frequently to perform activities such as walking, kneeling, recovery from prone, controlled fall recovery, stepping up, etc.
  - Tested with a 3-bearings functional, locking one bearing (i.e. 2 bearing hip), and locking out all three bearings.
    - The 2 bearing hip results can be assumed to be like the PGS hip/leg bearing design, chosen for reduction in weight while maintaining capability
    - The three-bearing hip allowed for the subject to have a very natural walk and lope gait.
      - Kneel and recover was easily performed.
    - The two-bearing hip (one bearing locked out) was workable, but the subject did note mobility reduction.
      - The walking and loping gait were also affected.
      - It made the foot rotate outboard when stepping forward.
    - When locking out all three bearings, the result was crippling to the subjects' mobility.

Task Mobility



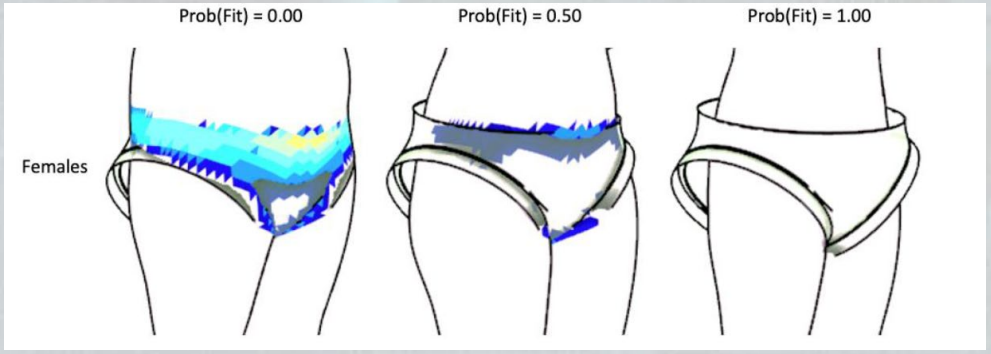


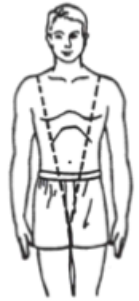




Driving Requirements

- Anthropometric range
  - By using two sizes of briefs and four sizing rings, WBH covers 1st percentile to 99th percentile population (i.e., 90% in total) for the pictured anthropometric measurements
  - Two studies focusing on fleet sizing were performed with NASA Anthropometric and Biomechanics Facility (ABF)
    - First study optimized the internal geometry of the brief to better fit population
    - Second study focused on stack-up of HUT with LTA to accommodate different VTDs
      - Identified the need for two brief sizes (short and long)



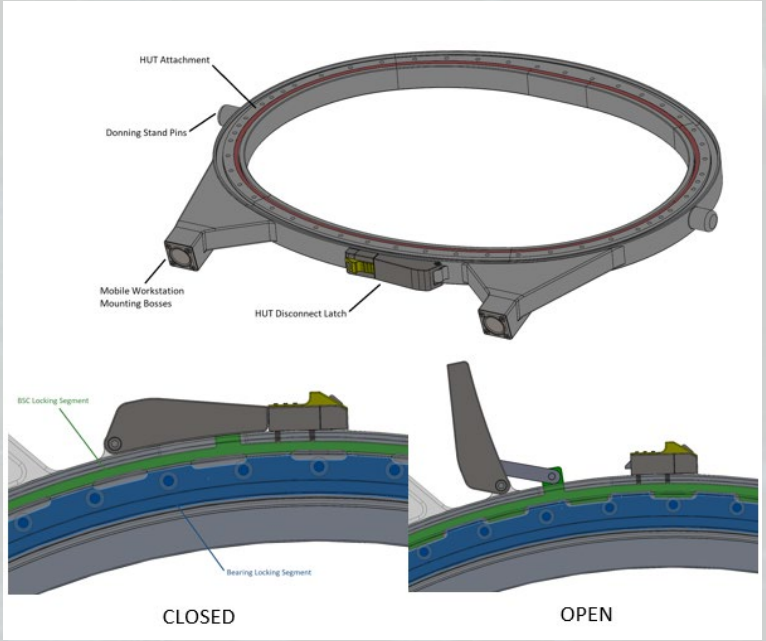
Measurement	Figures
Hip Breadth	
Thigh Circumference	
Vertical Trunk Diameter (VTD)	
Crotch Height	

Driving Requirements cont.

- Mass
  - Self-imposed requirement, based on masses of previous prototype suits
  - Drives the selection of softgoods and number of bearings in assembly
- Mobility Tasks
  - Focuses on tasks which the WBH will directly impact the comfort of the user while completing such as: walking, kneeling, squatting, laddering climbing, stepping onto and off a ledge, and recovery from prone
- Pressure schedule
  - Operate at a nominal pressure of 8.2 or 4.3 psid depending on use case

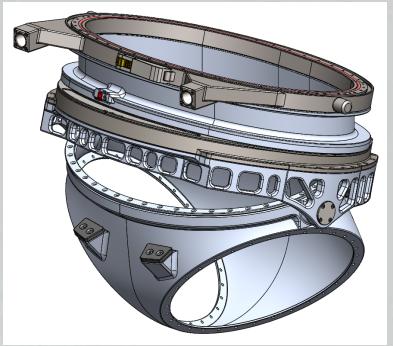
Driving Requirements cont.

- Range of Motion
  - Flex/Ex Joint: 40 degrees for short, 50 degrees for long
  - Hip Joint: 40 degrees abduction/adduction
- Interfaces
  - Waist Bearing to HUT BSC
  - Leg Bearing to EMU Lower Leg Fabric Attachment Ring
  - Safety tether and crew restraint system
- Dust
  - By utilizing dust seals, the bearings will prevent lunar regolith from contaminating the primary pressure seal

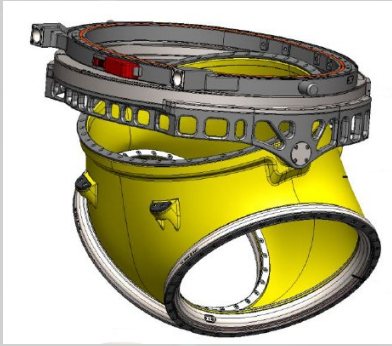


Design Breakdown: Hardgoods

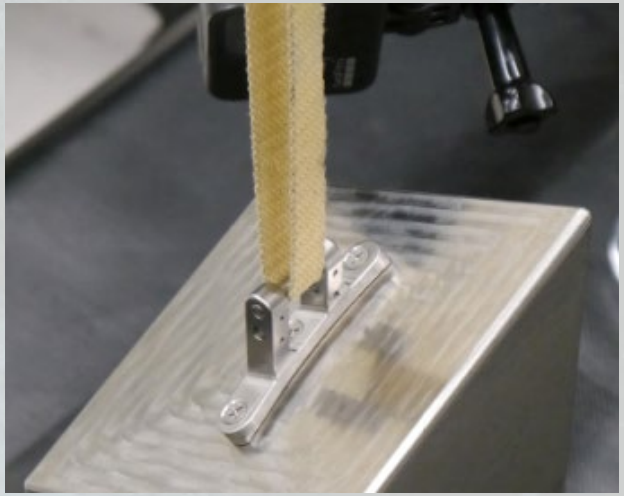
- Hardgoods designed and manufactured by Air-Lock, Incorporated
  - Waist bearing, waist brief assembly, hip bearings, and leg bearings, sizing rings
  - Material:
    - Aluminum: Waist brief assembly and sizing rings
    - Titanium: Waist bearing, hip bearings, and leg bearings
- Upper and lower axial restraint brackets for hip assemblies
  - Manufactured by external vendors
  - Attachment points for primary and secondary restraint lines
  - Pull tested to failure (> 2000 lbf)



Short Brief Assembly



Long Brief Assembly

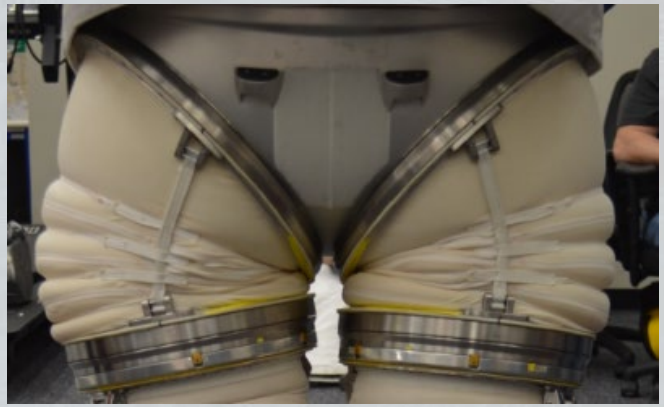


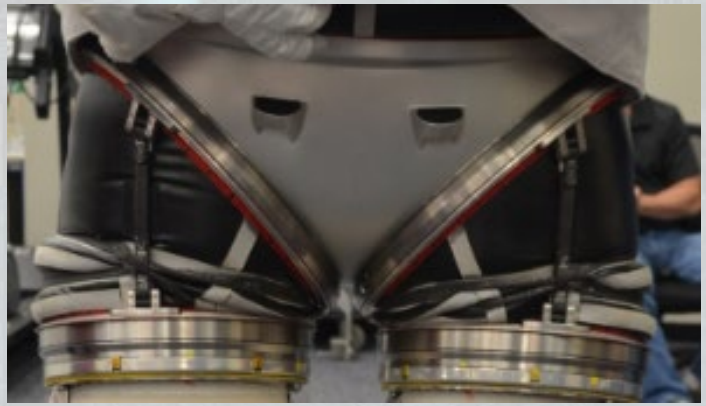
Design Breakdown: Softgoods

- To accelerate WBH softgoods development and mitigate risk, xEMU funded development and fabrication of two different vendors:
  - Final Frontier Design (now Paragon SDC)
  - David Clark Company Inc. (DCCI)
- Vendors anonymized to Vendor 1/Vendor 2
- Two types of softgoods manufactured
  - Hips (left/right)
  - Flex/Ex joint

Design Breakdown: Hip Softgoods

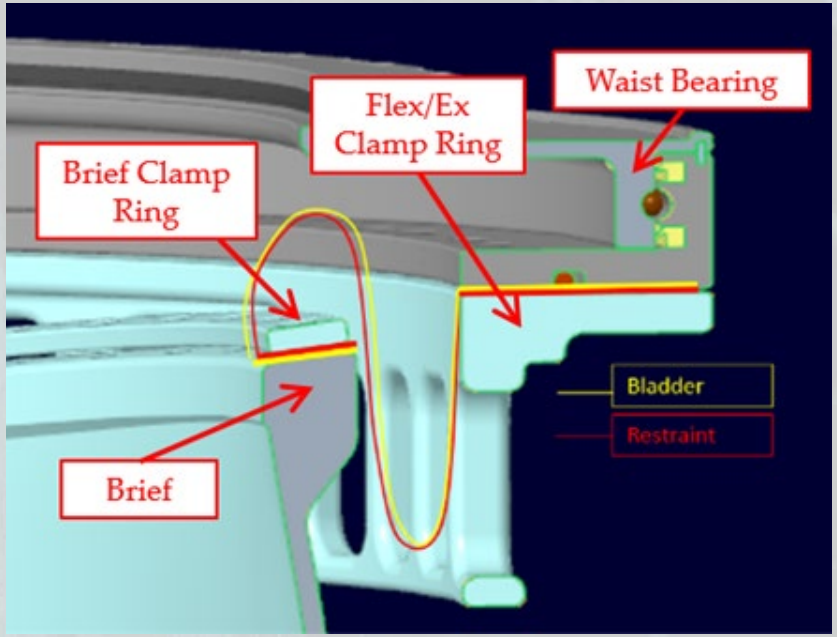
- Vendor 1:
  - Gore style pattern comparable to an EMU knee or elbow
    - Uses four Polyurethane Nylon fabric patterned gores to allow abduction and adduction
  - Dacron cloth restraint layer tabbed to the bladder by tie-ins to stiffen the fabric to create convolutes.
  - Spectra webbing restraint lines for axial loading.
- Vendor 2:
  - Orlan-style orifice system
    - Urethane coated nylon restraint and bladder double layer
    - Equalized flow from bladder to restraint for an effectively two fault tolerant bladder
    - Restraint layer acts as the nominal pressure tight layer
  - Two-convolute, asymmetric joint patterning
  - Transversal restraints and axial restraints made of Ultra-high-molecular-weight polyethylene(UHMWP).





Design Breakdown: Flex/Ex Softgoods

- The Flex/Ex joint is clamped between the brief clamp ring/brief, and the Flex/Ex Clamp Ring/waist bearing
- Design follows a similar architecture and materials from each vendor as described in the prior section
  - Vendor 1: gore style pattern with radio frequency sealed seam tape and is indexed by tie-ins with the restraint layer
  - Vendor 2: two patterned pieces that vary in height to allow range of motion while utilizing the orifice system to equalize pressure
    - Additional gasket used between the brief/brief clamp ring is used to reduce leakage

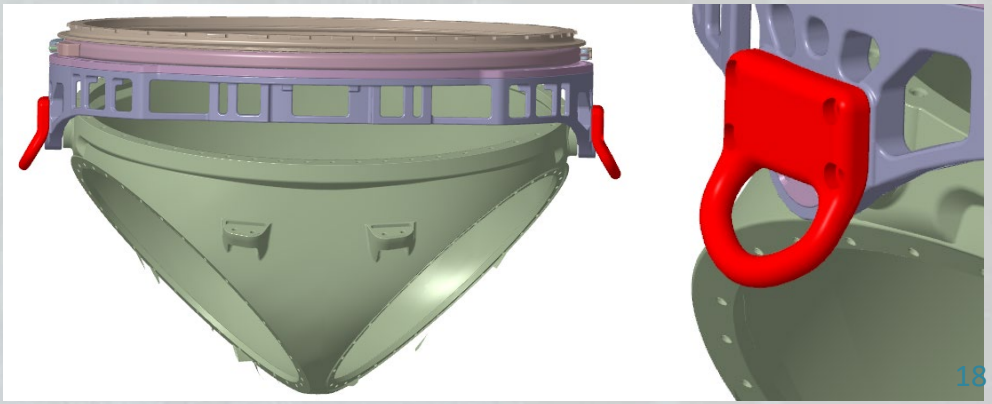


DVT Testing

- Pre-Delivery Acceptance and Pre-Installation Acceptance (PDA/PIA) to accept hardware
  - Results: All WBHs assembled passed
- Mobility Test Series
  - Environments:
    - 1-g lab testing
      - Testing in the lab environment without any subject offload
    - Active Response Gravity Offload System (ARGOS) using 1/6th-G offload
  - Tasks:
    - Walking, Squat, Lunge, Stepping onto/off ledge, Tool use, etc.
  - Results: WBH was able to enable acceptable performance of the test subjects throughout all tasks.
- Cycle Testing
  - WBH cycle testing activities focused on abduction/adduction of hips softgoods and flexion/extension of Flex Ex softgoods
  - Manned cycle testing is still ongoing so no results to report

Forward Work

- Widen brief to 16”
  - To meet hip breadth anthropometric requirement.
- ISS safety tether hook attachments.
  - Incorporating D-Ring Extender due to interference with PLSS during waist rotation.
- Environmental and dust seals added to bearings.
  - Environmental seal prevents debris from inside the suit from entering bearing.
  - Dust seals will be the secondary method of dust protection.
- Support transition to xEVAs partners



Questions?

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