xPGS

EVA Technology Workshop 2017

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Agenda

- Overview of Architecture
  - xEMU and xEMU Lite
- Relevant Pressure Garment Development History
  - Mark III, I-Suits, D-Suit, CxP Demonstrator, Z-1, Z-2
  - Suit testing
- Component Details
  - Description and rationale
  - Development plan and schedule
- Technical Risks
  - xEMU Lite
  - xEMU

xEMU Lite vs xEMU

xEMU Lite
ISS Demonstration
and
Potential EMU Replacement

xEMU Lite	Feature	xEMU
4.3 psi	**Operating Pressure**	8.2 psi
LEO Microgravity	**Design Environment**	Deep Space Microgravity Surface
Upper Torso + Min. Lower Torso	**Mobility**	Upper Torso + Full Lower Torso
Scarred for future upgrade	**Crew Autonomy**	Graphical Display

xEMU
Deep Space EVA
For
Gateway and Mars Transit

Overview of xEMU PGS

Feature	xEMU
Operating Pressure	8.2 psi
Design Environment	Deep Space Microgravity Surface
Mobility	Upper Torso + Full Lower Torso

- Includes:
  - Cis-lunar and lunar surface (via lunar kit) mission and environment requirements
  - High durability/ cycle life
  - Dust tolerant EPG, bearings, and mechanisms

Overview of xEMU Lite PGS

Feature	xEMU Lite
Operating Pressure	4.3 psi*
Design Environment	LEO Microgravity
Mobility	Upper Torso + Min. Lower Torso

- Includes:
  - Integrated comm system (ICS)
  - Biomed
  - Mechanical extra-vehicular visor assembly (EVVA)
  - Liquid cooling and ventilation system (LCVG)
  - Environmental protection garment (EPG) interfaces (for dust tolerance)

*exploration PGS components will be designed for 8 psi

PG Development History

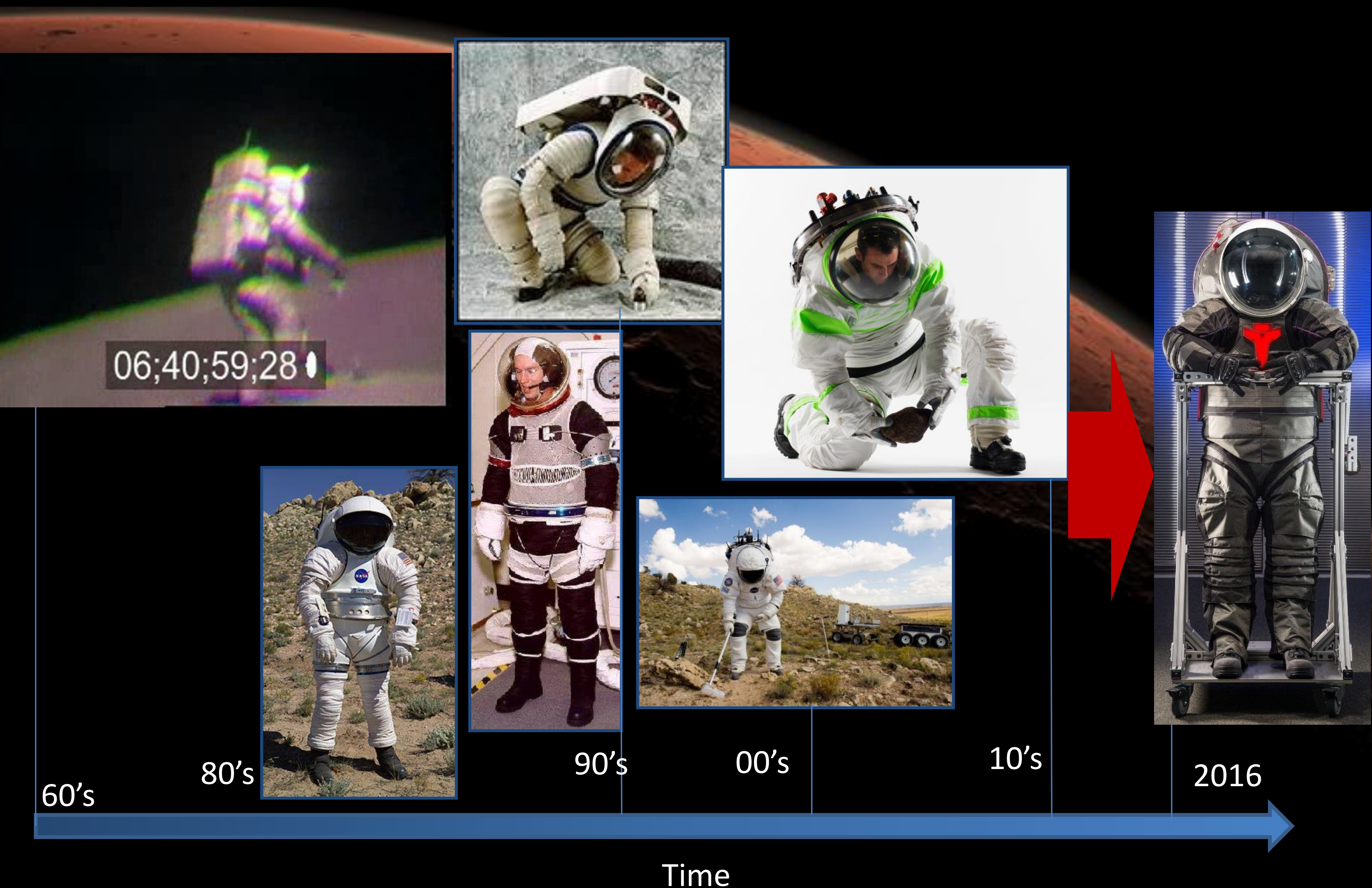
- From 1989 until present a series of pressure garments have been designed, fabricated, and tested by the Advanced Suit Lab (ASL).
- The testing performed over this 28-year period informed the architecture decisions reflected in the xPG
- The architecture is extensible to surface exploration missions
  - Detailed design changes will be required
    - Especially with regards to dust and durability/cycle life

PG Development History cont.

- Primary pressure garments tested to inform xPG architecture
  - Mark III [1989/1992]
  - Waist-entry and rear-entry I-Suits [1997, 2005*]

    *First use at Desert RATS field test, developed under
  - *D-Suit* [1997]
  - *Demonstrator Suit* [2010]
  - Z-1 [2011]
  - Z-2 [2016]

Mobility – Lessons Learned



Common Architecture

- Mark III, I-Suits and Z-Suit have common upper torso geometries
  - Rear-entry
    - Hatch size and angle
  - Shoulder angles
- Walking mobility lower torso

Mars Suit Prototypes

Mark III

WEI-Suit

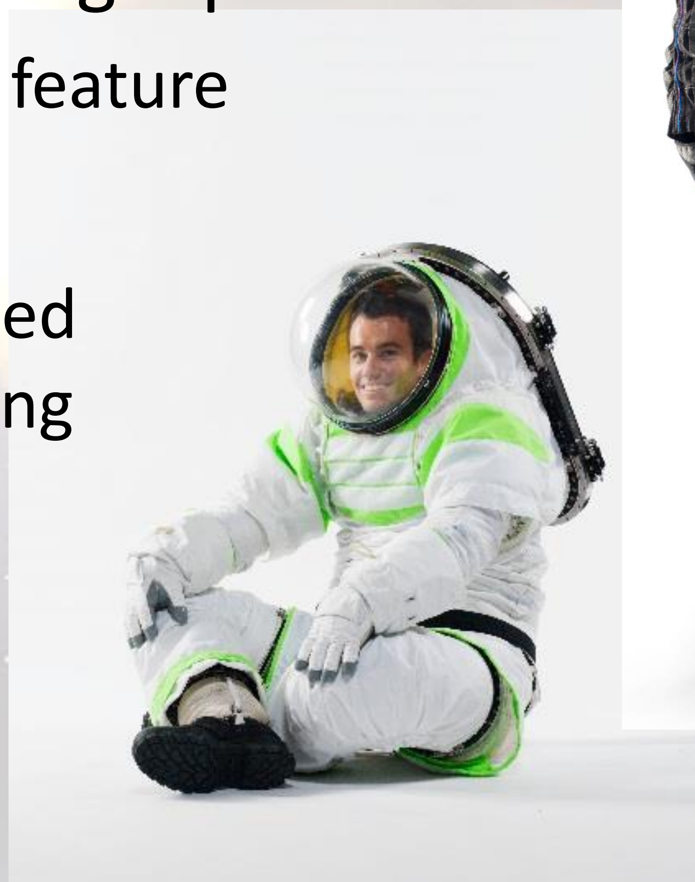
REI-Suit

Z-1

Z-2

Design variables evaluated

- Softgood versus hardgood upper torso construction
- 3-bearing vs 2-bearing hip
  - Hip ad/ab bearing feature
- Shoulder designs
  - 2-bearing, patterned convolute, 4-bearing



D- and Demonstrator Suits

- Represent more Apollo-like architectures
  - Softgoods construction
  - Cable-pulley shoulder
  - Cable-pulley hip
  - Bubble helmet at a flatter angle
- Demonstrator Suit also addresses crew survival design requirements
  - e.g. umbilical connector location

Extensive Testing

- Hundreds of hours of testing have been performed with these suit configurations in a variety of test scenarios and environment
  - A few significant examples are given
- As an overarching outcome, the tests have provided suit engineers with an understanding of the various benefits and issues associated with each joint system and architecture for various applications
  - This experience guided component selection for the xEMU architecture

Examples of Tests

- ‘Swim Off’ Test
- Planetary gravity translation and mobility tasks
- Mark III, I-Suit D-Suit photogrammetry
  - Isolated joint mobility
- Desert RATS
- Constellation
  - Vehicle ingress/egress
  - Seat ingress/dwell/egress
- Long duration/distance translation
  - Walk back, CO2 washout, PLSS Human-in-the-loop (HITL)
- Energy Mobility
- Z-2 Neutral Buoyancy Laboratory (NBL)

‘Swim Off’ Test

- Performed in 1990/1991
- Included Mark III, EMU, AX-5
  - AX-5 is an ‘all-hard’ suit architecture
- Was performed in the WETF
- Data collected:
  - Range of motion/photogrammetry
  - reach envelope
  - subjective comments and ratings
- Provided feedback on lower torso mobility and hard vs. soft elbow and knee components

Range of Motion Photogrammetry

- Upon delivery of the I-Suit and D-Suit, isolated joint range of motion testing was performed with those 2 suits and the Mark III

- This is one of several methods attempted to characterize suit performance.

- The method does not capture programming, functional ability, effort required, etc.

Partial gravity translation and mobility

- 2 '3-Suit' tests
  - Mark III, EMU, A7LB
  - Mark III, D-Suit, I-Suit
- Both $1/6^{th}$ and $1/3^{rd}$ g
- Utilized simulated rock surface
- Tasks include walk, run, lope, kneel, recover from a fall
- Allows observation of suit mobility in actual gravity environment

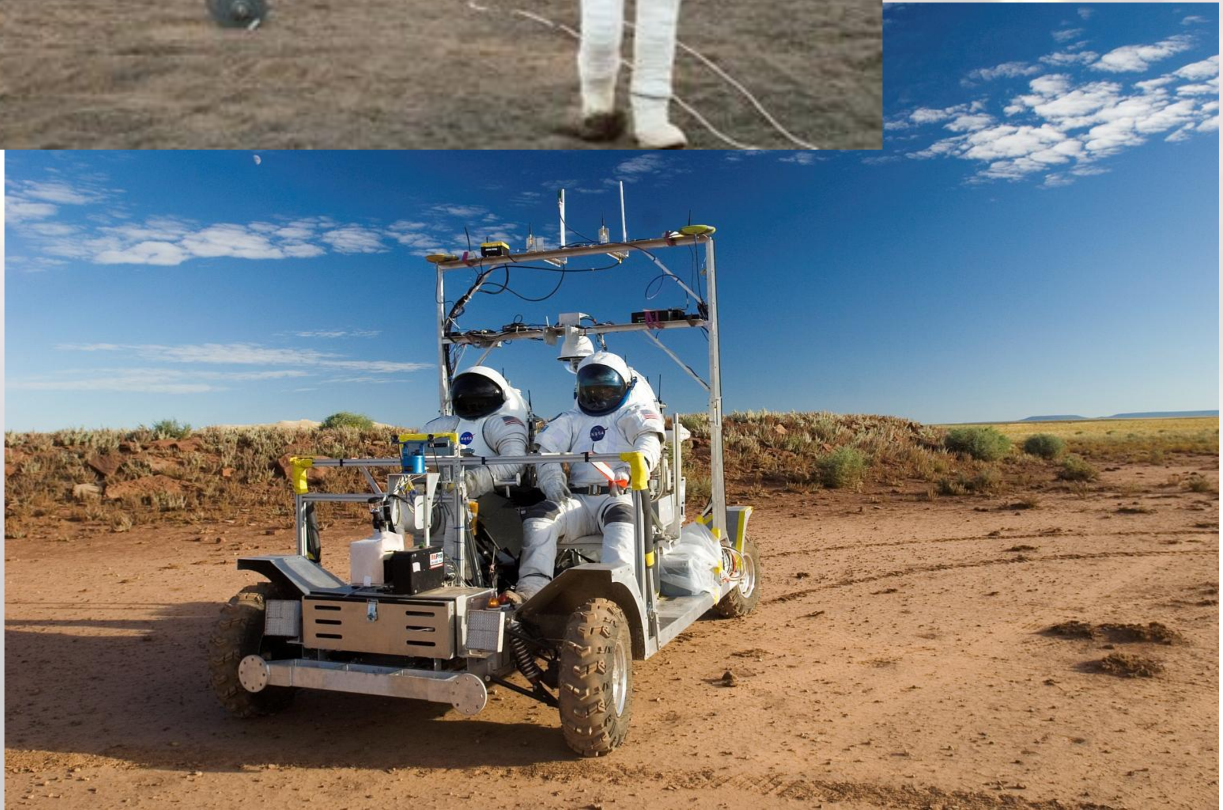
Partial gravity translation and mobility


NASA

Desert RATS

- Pressurized suited testing 1998-2007 [2008-2011 m/u suits or shirtsleeve simulations]
- Perform planetary surface tasks

Desert RATS



Desert RATS

Evaluated ability of suit configurations
to perform anticipated science and surface system set-up and maintenance.

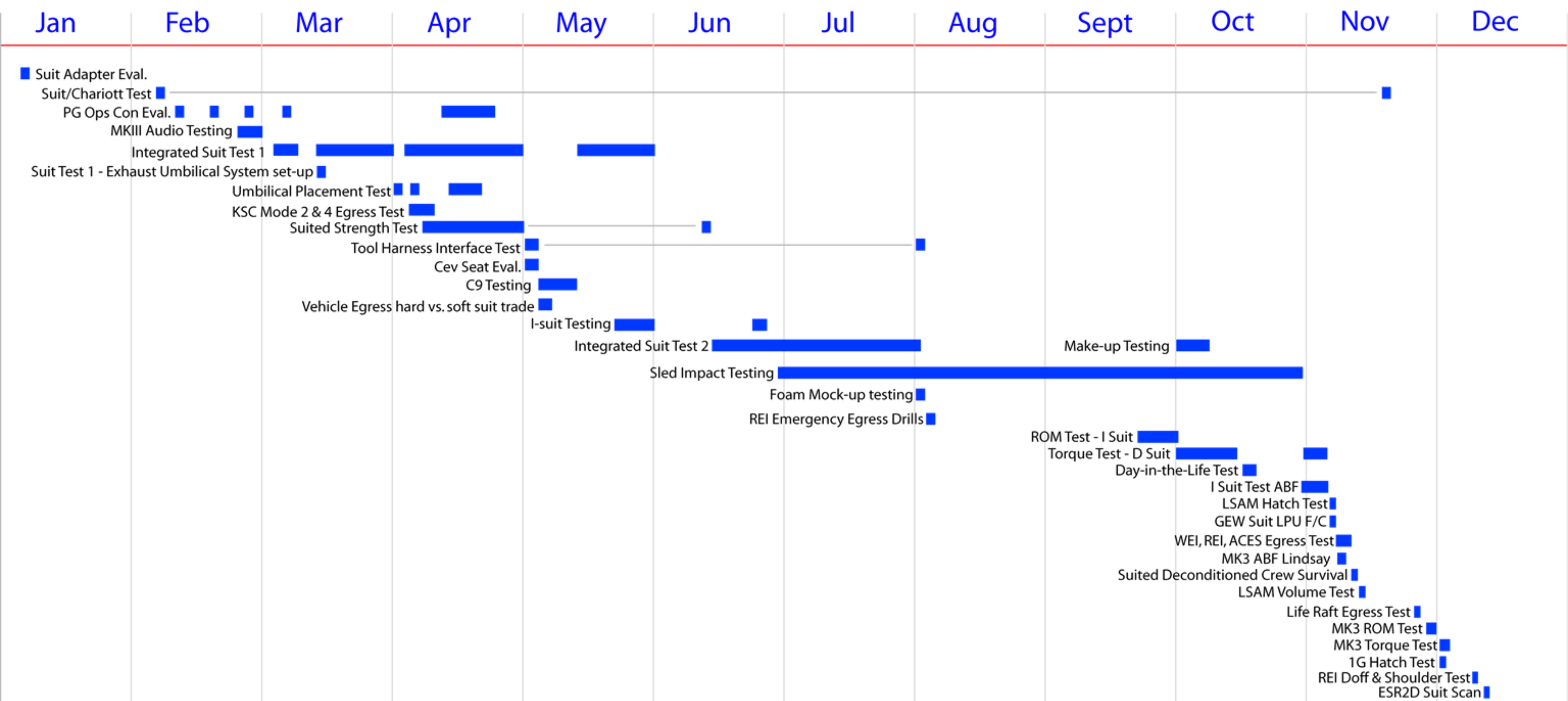
Provided schedule and fidelity goals for technology development, as well as a structure for collaborations.

Results informed technology gaps/ R&D investment and the validity of design requirement and operations concepts.

Constellation tests

- Looked at both EVA and crew survival activities and performance
- Provided the opportunity to understand unpressurized suit performance and issues
- Also provided the opportunity to revisit ‘soft’ designs such as in the Demonstrator
- Major dditional tests included:

2007 Test Timeline

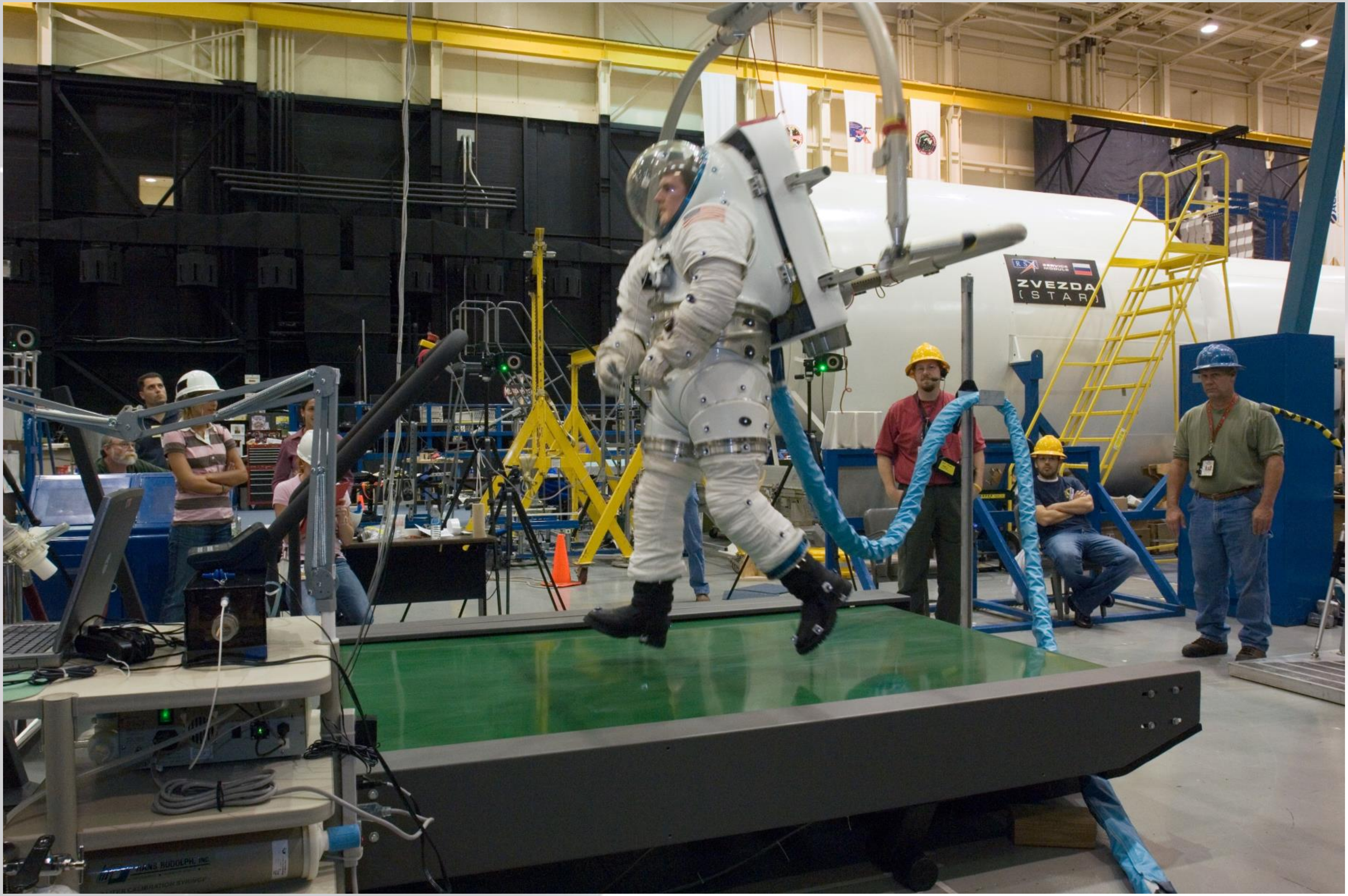


Tests Conducted by not shown on timeline:
Air Force cold water survival (07 & 08 (4/08-TH & MD)
Geological survey training (GT & AR)

Constellation

Constellation

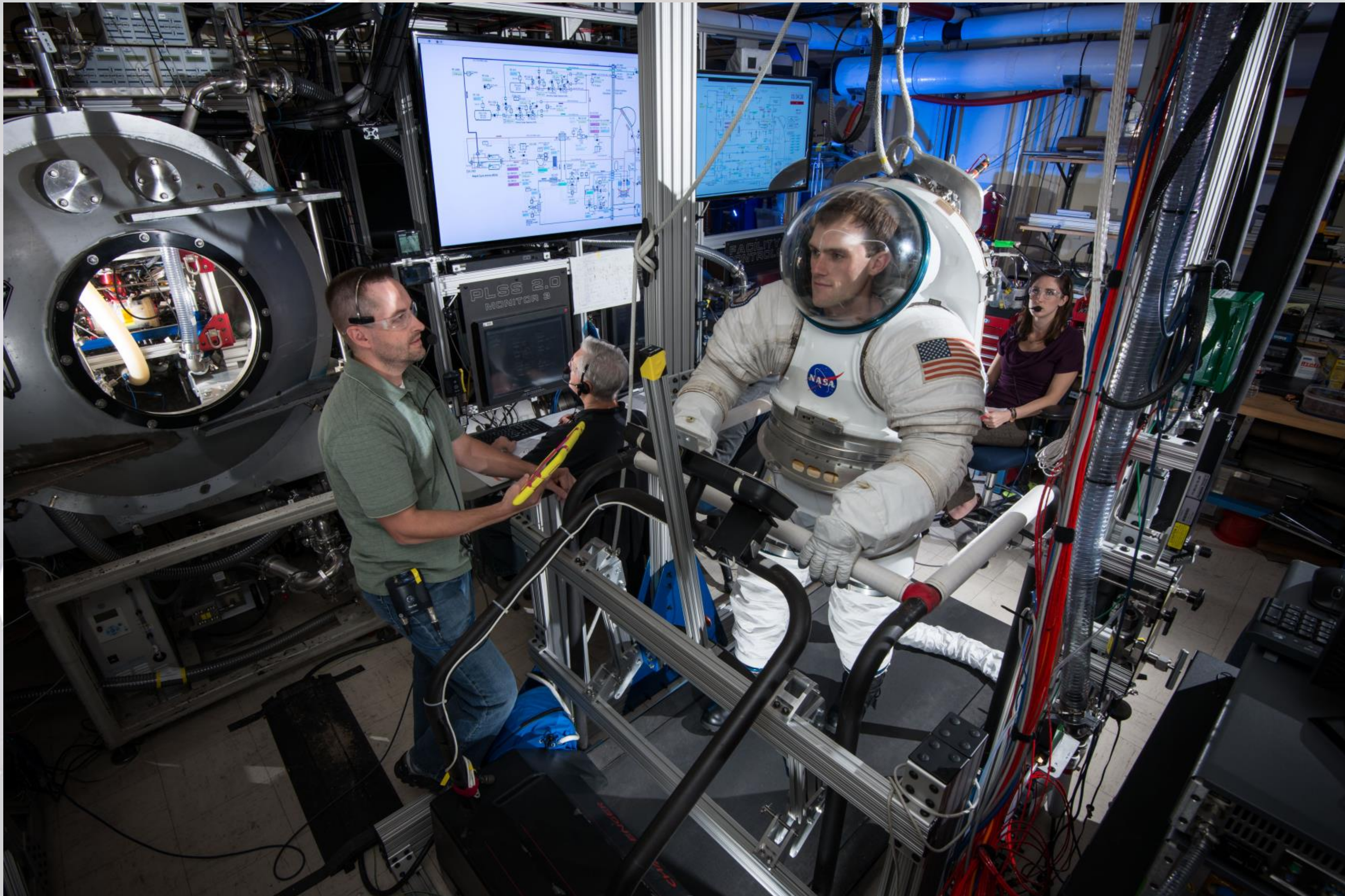
Translation



Translation

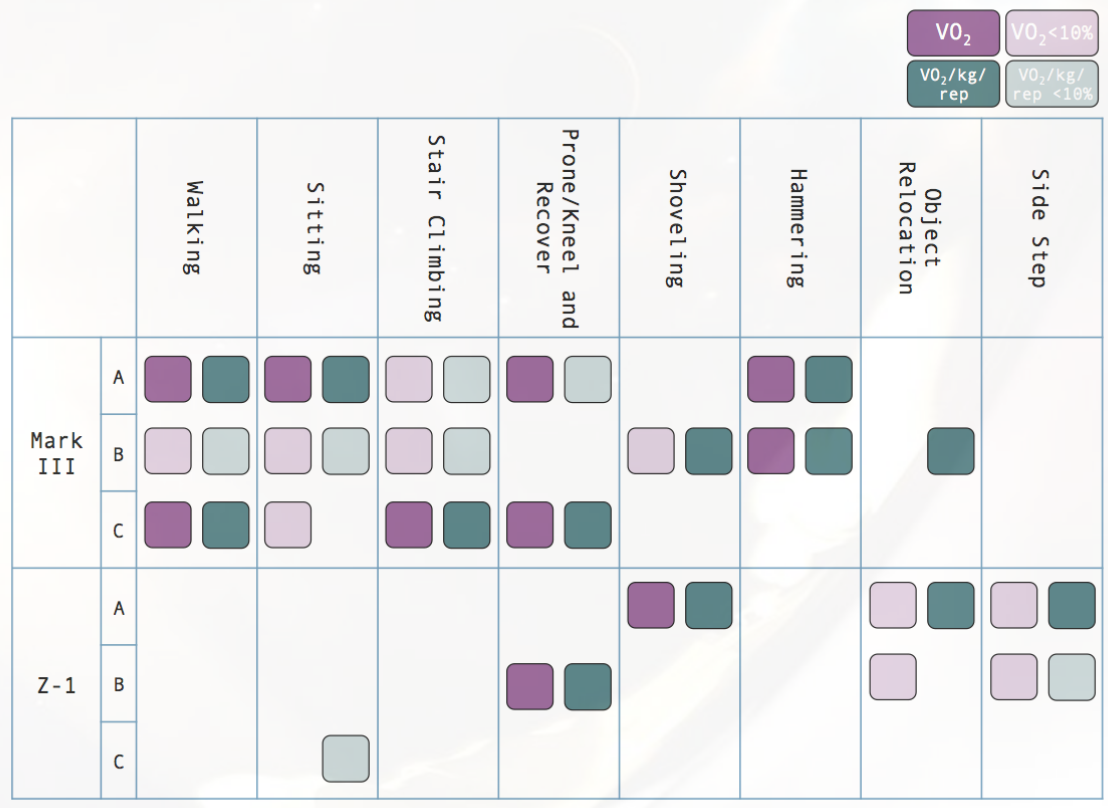
- Have supported translation tasks in 1-g, and both off-loaded and actual 1/6th-g, and 1/3rd-g
- Tests involving translation have included Desert RATS, boot testing, CO2 washout, PLSS HITL, and Walk back (10 km), and Energy Mobility
- Major observations:
  - Different gaits are utilized in different speed and gravity regimes
  - Leg lateral mobility is highly utilized during walking
  - A waist bearing enables a more natural walking gait
  - 2- and 3-bearing hip joint configurations provide good walking capability
  - Boot fit parallels glove fit in importance for walking

Translation-PLSS HITL



Energy Mobility

- A study to determine the feasibility of assessing suited mobility and requirements using functional tasks
  - Measured metabolic costs
- 5 tasks
  - Pilot test downselected to these tasks
  - 30 reps: walking, side step, stair climb,
  - 10 reps: upper body object relocation, full body object relocation
- While the method is promising, additional work is needed before application
  - Statistically relevant data
- Found that some subjects are relatively poor at rating Perceived Exertion so that it correlates to actual exertion

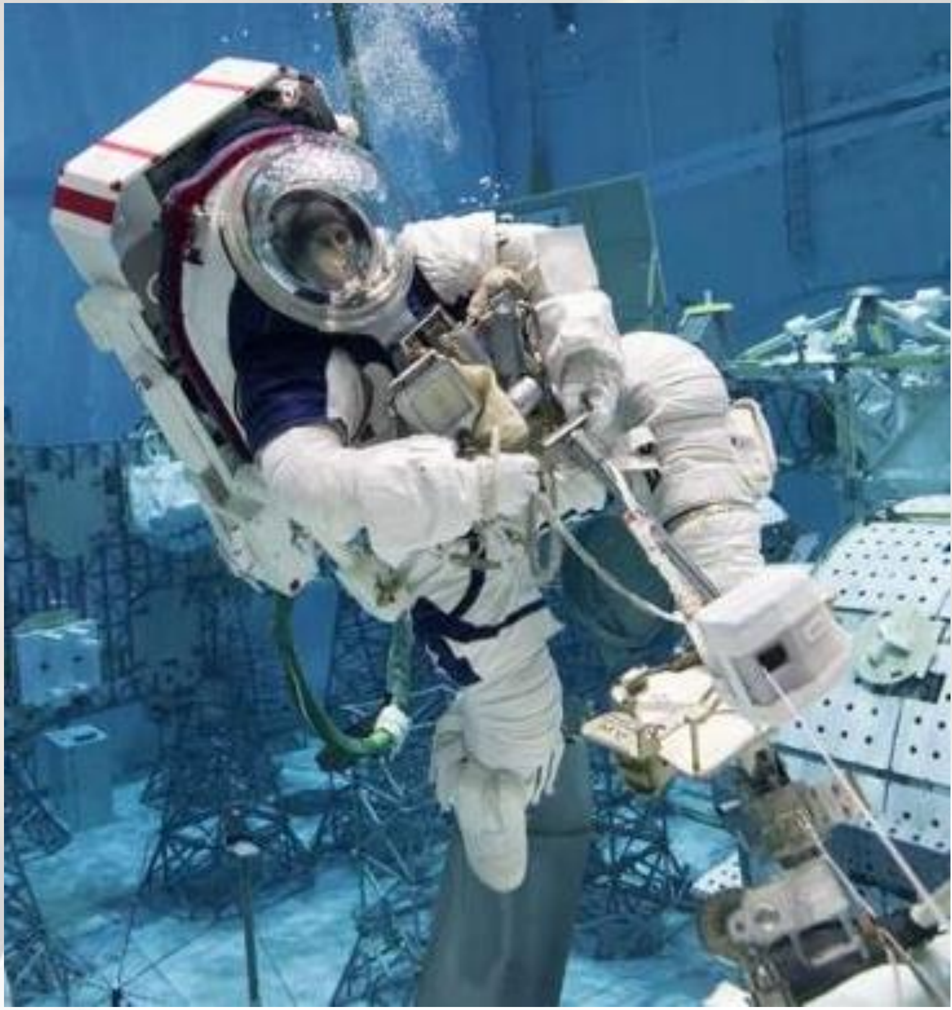


Sample of test results from pilot study

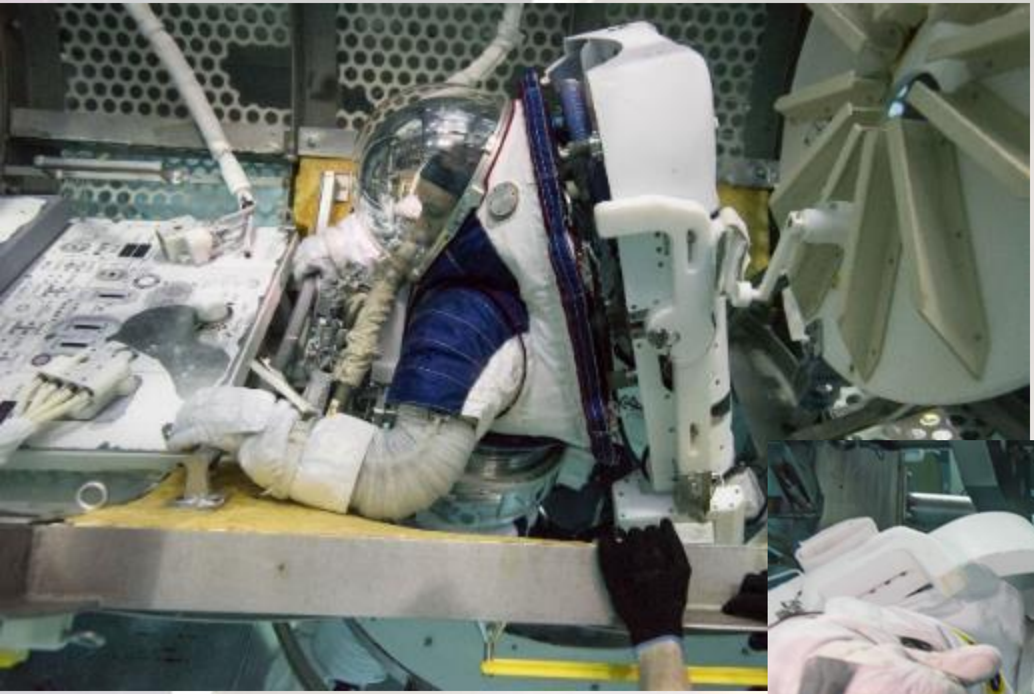
Task video

Z-2 NBL Runs

- Performed 16 runs + 2 test prep
- Assessed configurations using the EMU lower torso and Z-2 lower torso with the Z-2 upper torso
- Assessed complex tasks, volume constrained task sites, and airlock ingress/egress
- Last two runs investigated airlock ingress/egress with reduced front-to-back suit dimension
- Major findings:
    - Improved upper body mobility and visibility
    - Reduce helmet bubble depth
    - Airlock ingress/egress required increased control over that needed for EMU
        - However, subjects were successful in all configurations
    - Mobile lower torso provided improved capability in most cases



Z-2 NBL Runs



Anticipate utilizing a more realistic EVA timeline approach to Z-2.5 tesitng

Pressure Garment Components

- Upper Torso
- Shoulder
- Helmet
- Extravehicular visor assembly (EVVA)
- Integrated Communication System (ICS)
- Biomed
- EPG
- Liquid Cooling and Ventilation Garment
- Low-flow purge valve
- Ancillary

Development Plan

Component-level Development

- In general, each of the components follow the same basic development approach
  - Design and fabricate prototype unit (Z-2.5); FY18
    - Z-2.5 is fabricated from Al
  - Test prototype unit; FY18-19
    - Component level and in Z-2.5
  - Update design based on test results FY19

[System PDR: Late FY19]

  - Fabricate Design Verification Test (DVT)/Engineering Unit (EU) hardware; FY19-20
  - Perform acceptance testing on DVT/EU unit; FY20-21
  - Incorporate component into subsystem-level DVT/EU test; FY20-21

[System CDR: FY21]

Exceptions

- Dust mitigation efforts, including:
  - Environment Protection Garment (EPG) lay-up
    - Are attempting to include EPG interfaces into design
  - Dust tolerant mechanisms and connectors
    - Bearings, latches, locks, etc.
- LCVG development may span from now until DVT (no Z-2.5 unit)

Upper Torso

- Rear-entry
  - Provides improved placement of shoulder bearings to allow more natural shoulder movement and mobility
  - Limits stresses placed on shoulders during suit don/doff
  - Expect a reduction in incidence of shoulder injury

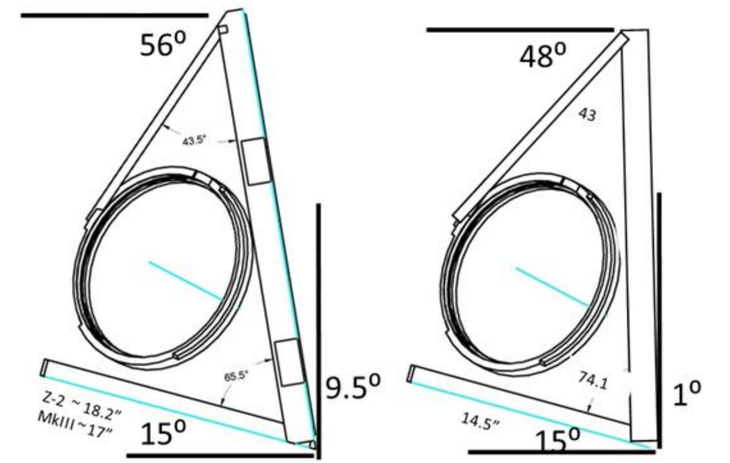
Waist Entry

Rear Entry

Rear Entry Donning

Upper Torso

- Composite structure
- Shoulder harness
- Self don/doff
  - Goal for DTO
- Implementing geometry changes to reduce front to back dimension
  - Maintaining scye angles
- Increasing design fidelity with interfaces
- Incorporating additional fault tolerance
  - e.g. Secondary hatch seal
- Z-2.5 NBL testing will assess geometry changes
  - Impact on surface activities unknown until able to evaluate

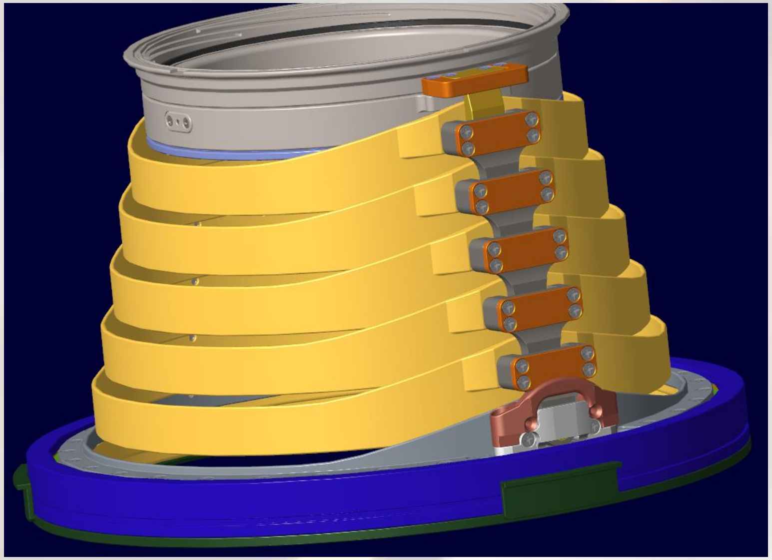


Z-2 & Mark III Heritage

xEMU HUT (hatch_study) Status

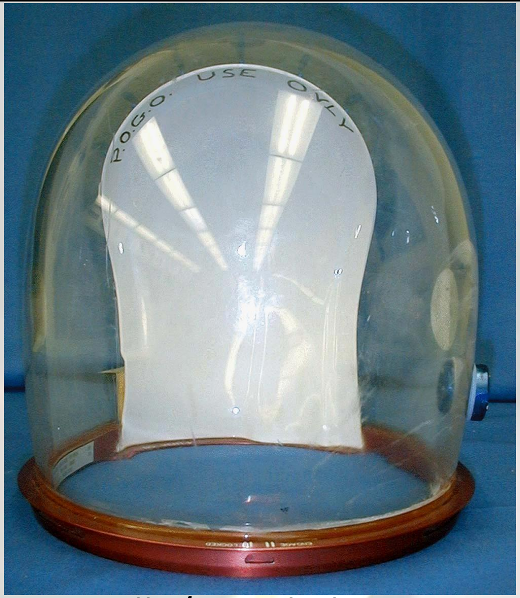
Shoulder

- Have tested more shoulders than any other joint
- Selected external link rolling convolute
  - Long history of performance
    - Mobility and durability
  - Will leverage recent design refinements
  - Performs well at 8 psi
- For Z-2.5 will re-use existing hardware
- FY18 scope includes kickload and impact analysis, but not test



Helmet

- Includes pressure bubble, protective visor, male side of helmet disconnect, EVVA attachment features
  - 10" x 13" inner dimension
    - Considering shorter long axis
    - Managing depth to less than 8.5"
      - Z-2 was too deep at 9.2"
  - Bayonet-style locking mechanism to provide more reliable engagement
    - Low profile



Apollo/EMU helmet

Z-2 helmet

Helmet

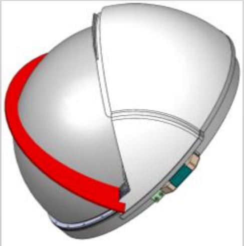
- Selected shape is a hemi-ellipsoid with constant longitudinal radius
  – Provides increased visibility, especially downward, for walking on planetary surfaces

– Testing to include kickloads and impact
  – FY18 scope is for analysis only

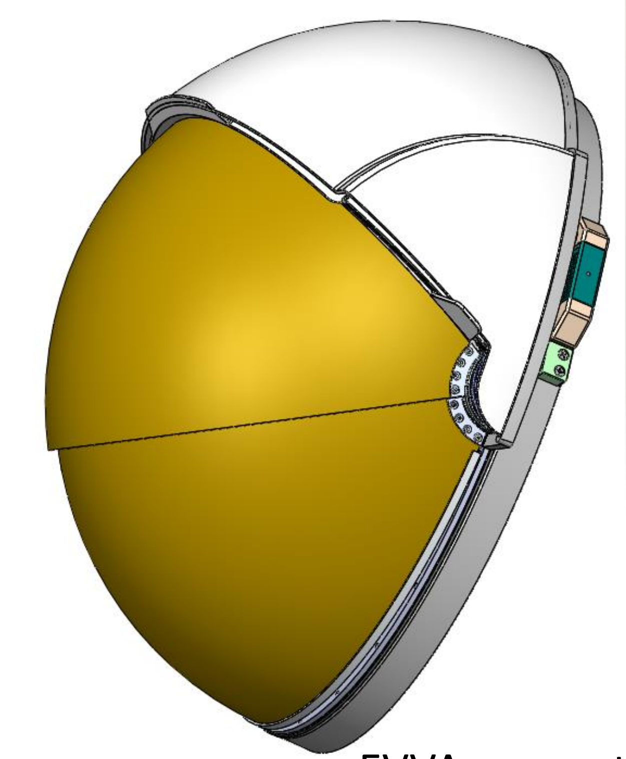
*How not to design a helmet for field of view

EVVA

- Includes outer shell, visor (tinted), shades (opaque), and coatings
  - Mechanical system can be realized in the DTO timeframe
- Visor
  - Sectioned
    - Evaluating acceptability
  - Provides 120° longitudinal field of view (FOV)
    - Determined during Z-2 NBL test
  - Provides 160° peripheral FOV
    - EMU requires 170°
    - Reduction is caused by interference at the hinge



  - Testing includes impact and kickloads



EVVA concept

Integrated Communication System

- ICS removes the communication carrier assembly (CCA) from the head of the astronaut and places it onto the suit
    - Addresses many comfort and interference issues associated with the CCA
        - ICS design must address performance with head movement and ambient noise
    - ICS prototypes have been tested in the previous advanced prototype suits
    - Mics on neck ring, speakers in hatch
- Most recent, highest-fidelity system was included in Z-2 testing
    - Mics and speakers on neck ring
- ICS architecture will return to the mics on neck ring and speakers in hatch configuration

Z-2 ICS

Biomed

- SOA
  - Circa 1975 signal conditioner + wired electrodes
- Measure heart rhythm
  - Sole physiological monitoring requirement for PGS
  - Required signal quality is an open issue
  - Goal of moving the signal conditioner outside of the PGS
- Testing will include:
  - EMI
  - Radiation

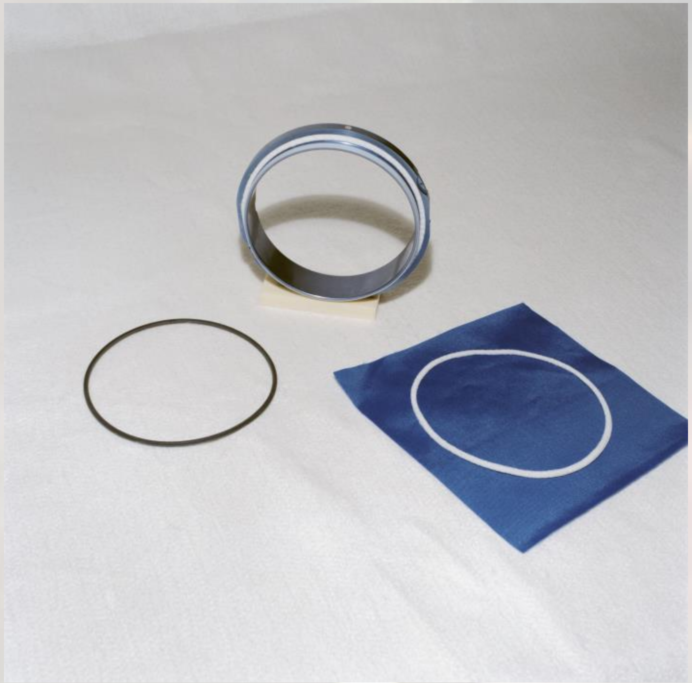
EMU Biomed Signal Conditioner

Environment Protection Garment

- Z-2.5 cover layer will be build in house
  - HUT and shoulders
- Development focus is on dust tolerant EPG interfaces
  - Both adherence and penetration/permeation
  - Developing test methology
- Current scope likely precludes new EPG material lay-up for DTO
  - Can use EMU TMG lay-up
  - Research and development will continue at a low level
    - SBIR/STTR on materials and coatings

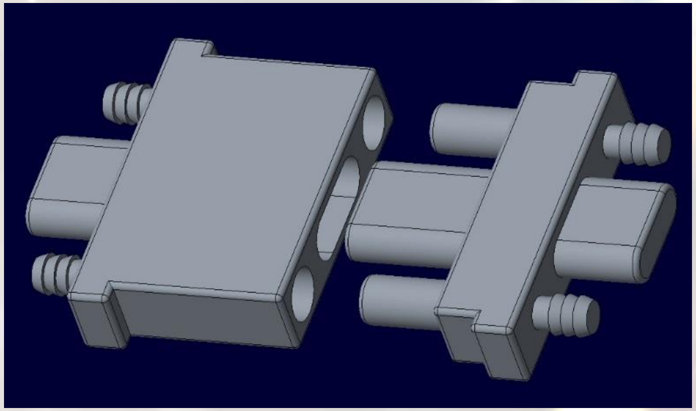
Dust Tolerant Mechanisms

- FY18 scope includes:
  - Refine bearing dust tolerance test method and testing hardware
    - Evaluate of current dust tolerant prototypes
  - Develop modular bearing dust mitigation concept test set-up
    - Commercial bearings in housings that incorporate dust mitigation features
  - Incorporate lessons learned



Liquid Cooling and Ventilation Garment

- FY18 scope is being determined
  - Test available prototypes
  - Design auxiliary multiple water connector
  - Determine if:
    - limited modifications (within budget and schedule) could create an acceptable Z-2.5 test article
    - Or if development for more involved design effort will be undertaken over FY18 and 19 to meet DVT testing



Low-flow Purge Valve

- FY18 scope is to define the interface
  - Location and physical interface
  - Model oral/nasal pickup if required

BACK UP