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

- Will discuss that while it is straight forward to view the suit as a mobility system, it is a life support system
  - Interesting challenge to perform the life support function so well, that the mobility system comes to the forefront

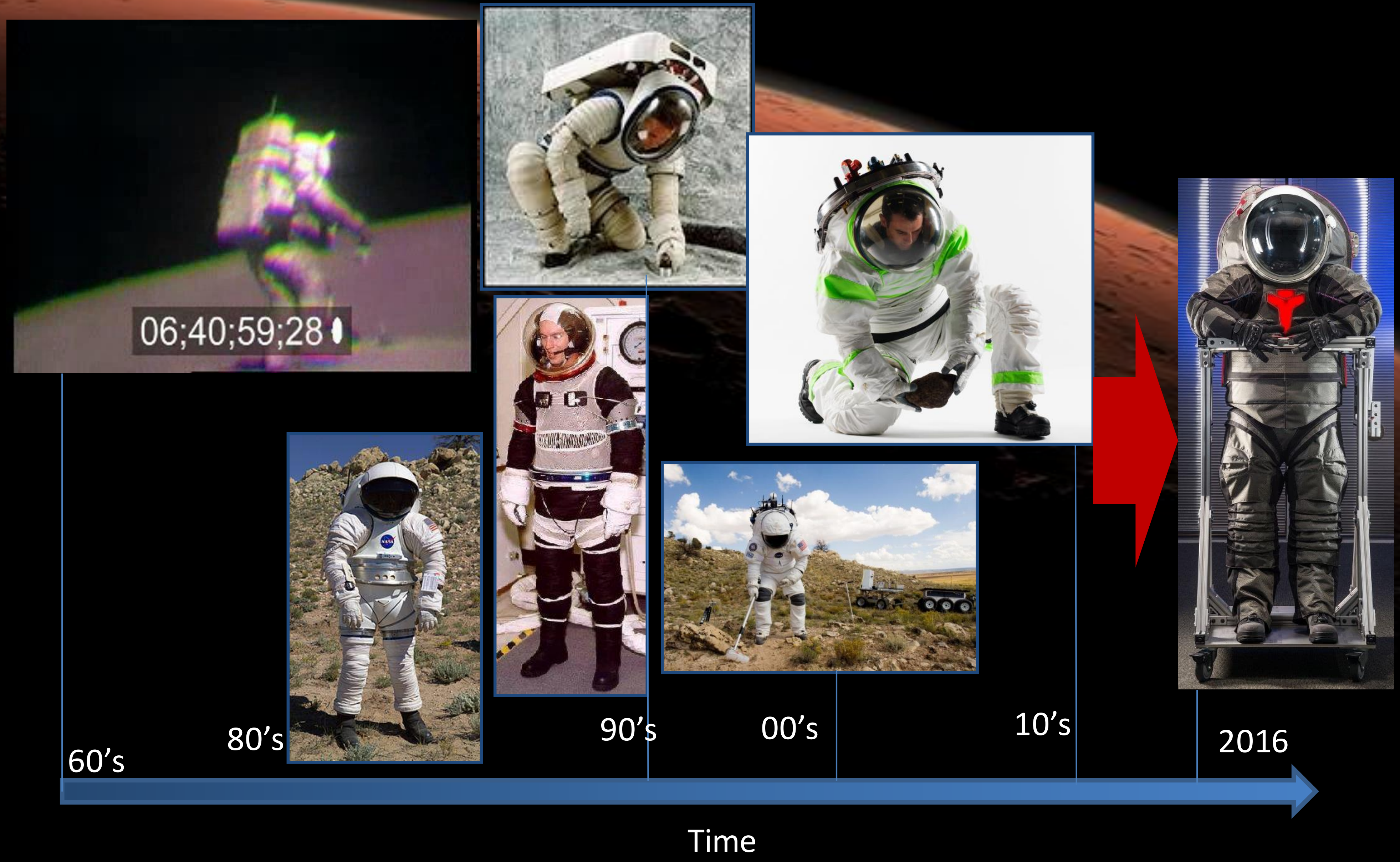
PG Development History cont.

- 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 ILC IR&D funds
  - *D-Suit* [1997]
  - *Demonstrator Suit* [2010]
  - Z-1 [2011]
  - Z-2 [2016]

- Will discuss the 2 standard of success against which we are measured
  - 1. Objectives requirements
  - 2. Customer acceptance of our product

- In the end, 1. is the easier criteria. 2. is the true go/no go
- Drives human-centered design

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

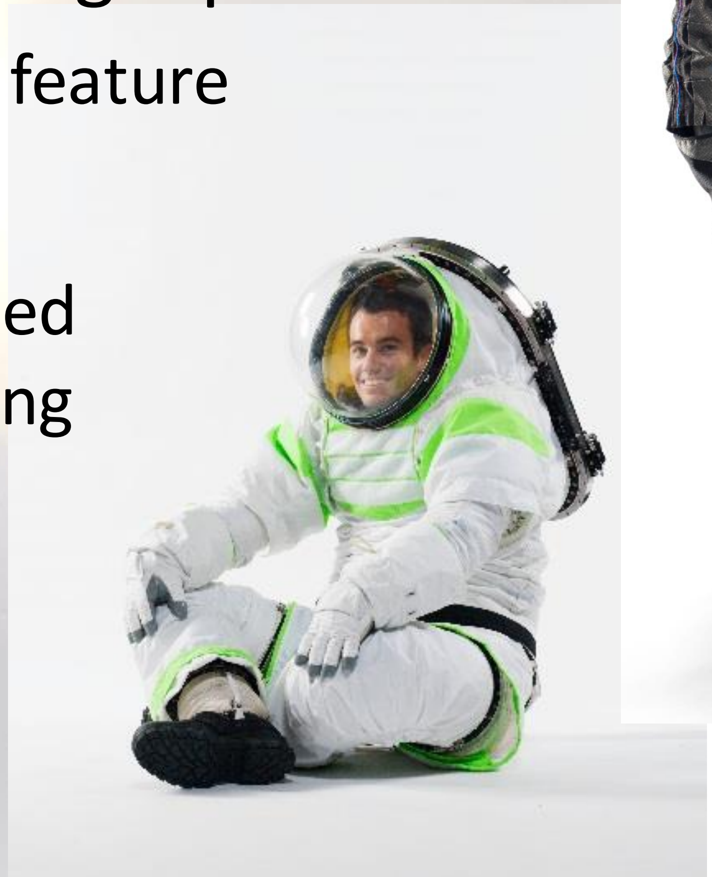
REI-Suit

Z-1

Z-2

Design variables evaluated

- Softgoods versus hard goods 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)

- Will discuss personal experience as a test subject, as well as a suit test engineer
  - Will discuss how the two roles are complementary

‘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

- Will discuss what objective data was collected vs. subjective data and how it was and is used.

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

Partial gravity translation and mobility

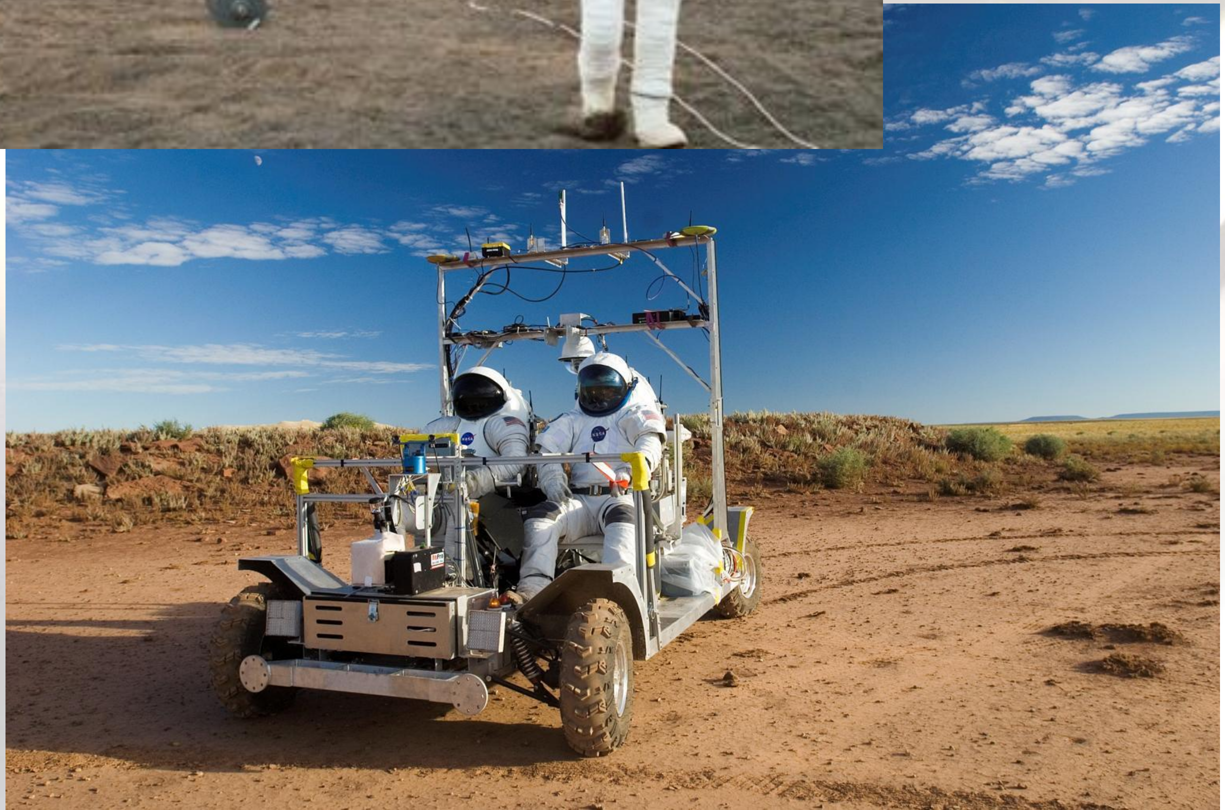

NASA

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.

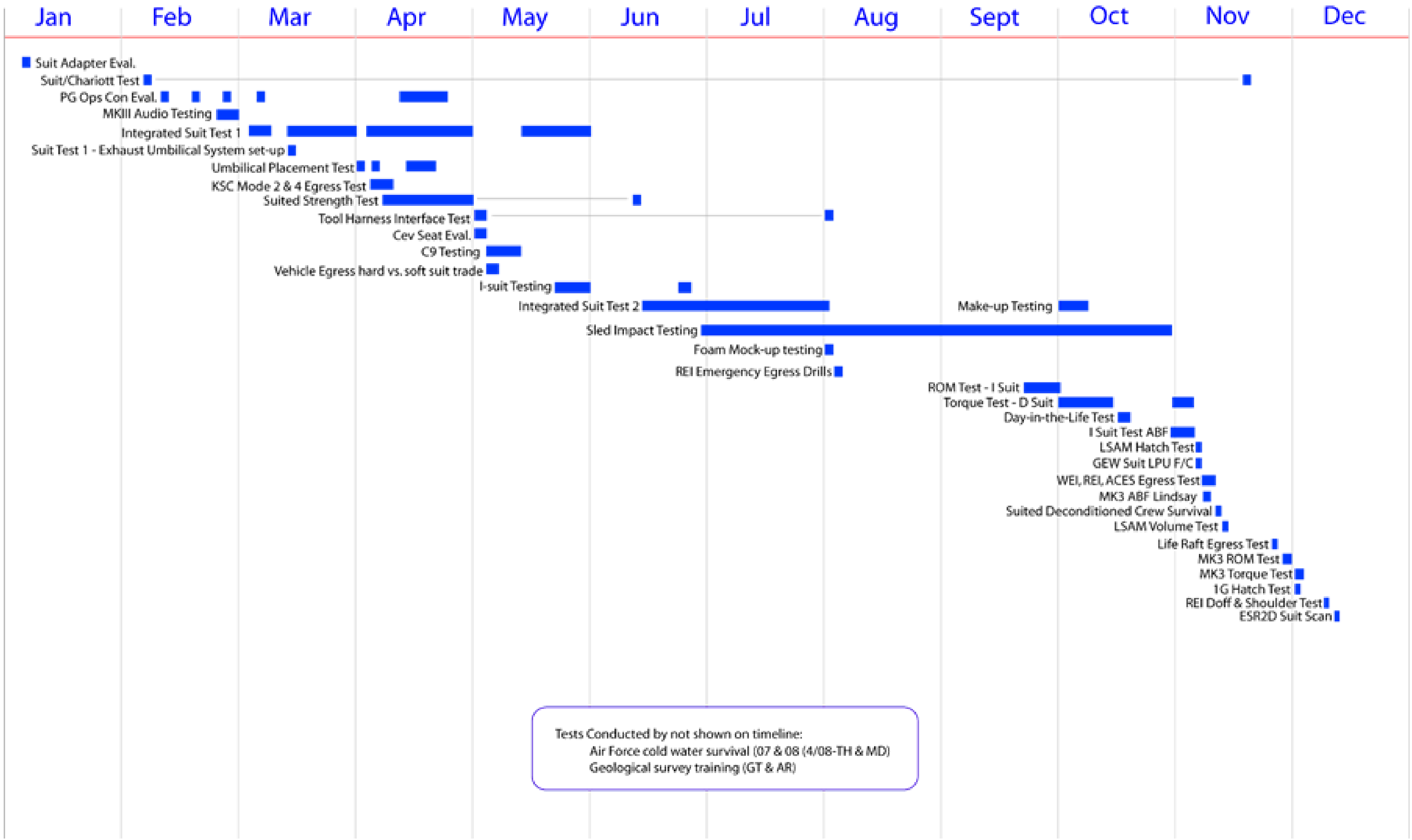
Provided schedule and fidelity goals for technology development, as well as a structure for collaborations.

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 additional tests included:
  - RGO
  - Day-in-the-Life launch and scrub tests
    - Included capsule ingress and egress, in-capsule donning, and operation of controls
  - Sled impact testing

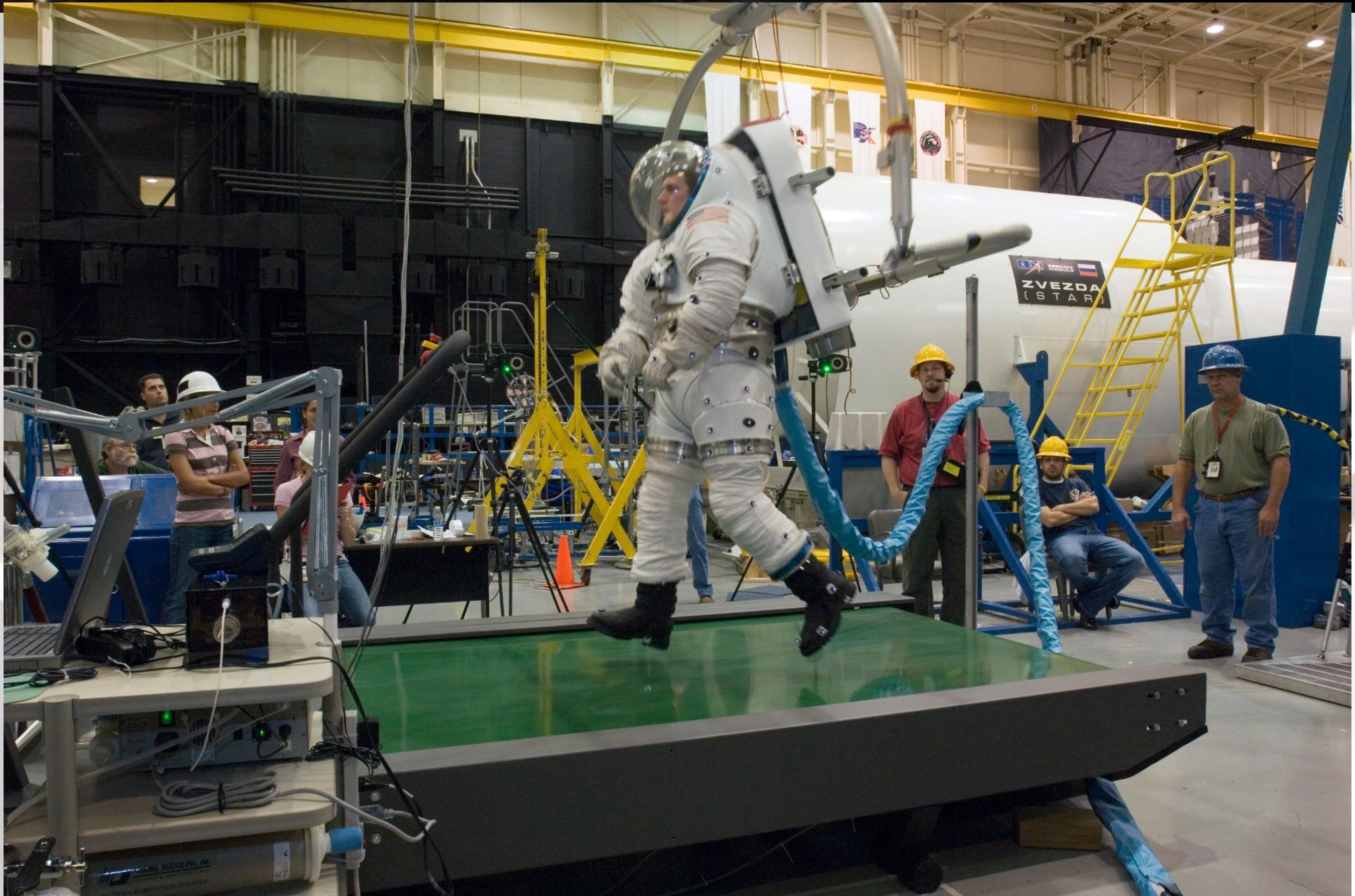
2007 Test Timeline



Constellation

Constellation

Translation



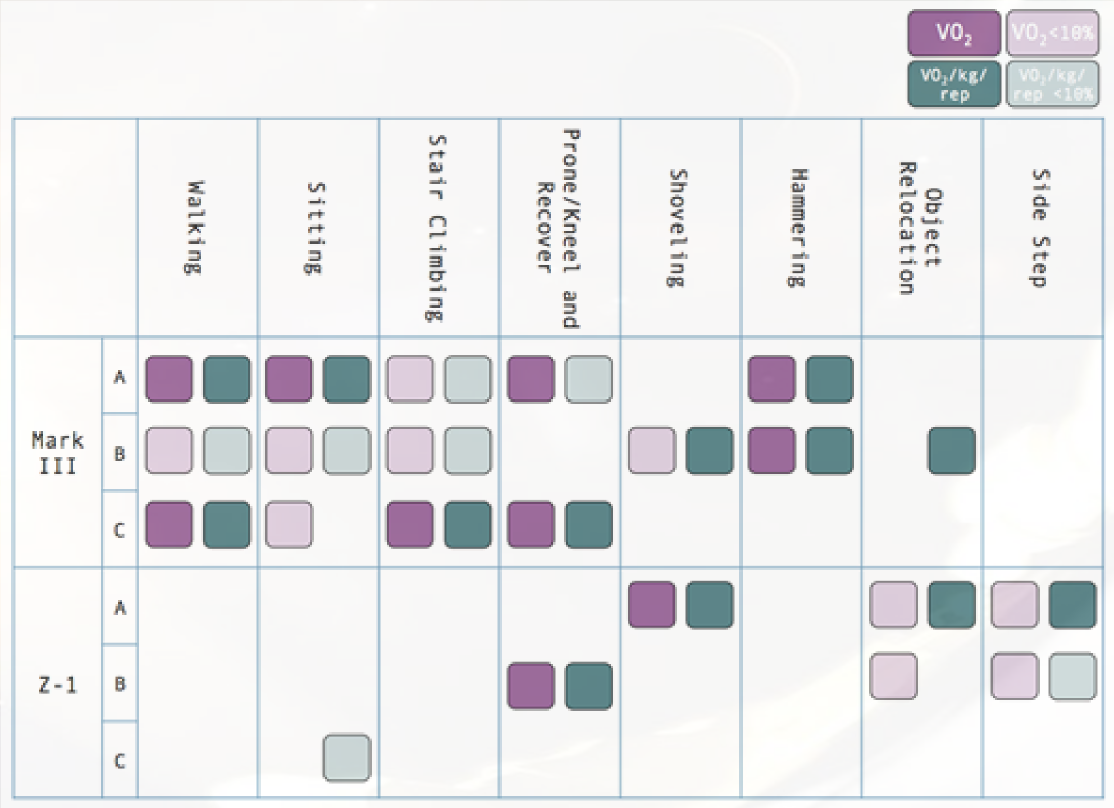
Translation

- 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

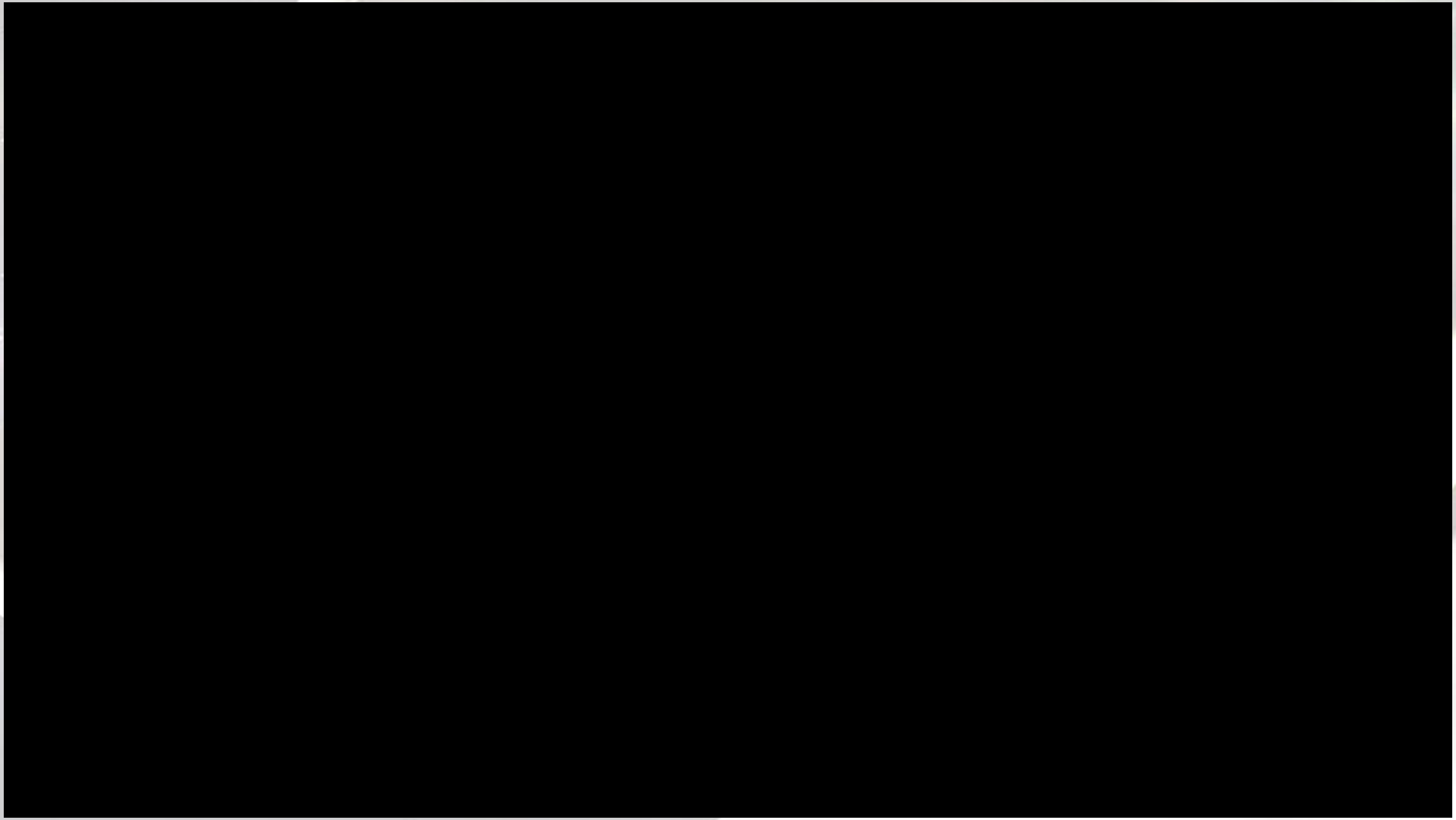
Energy Mobility

- A study to determine the feasibility of assessing suited mobility and requirements using functional tasks
  - Measured metabolic costs
- 5 tasks
  - Pilot test down selected 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



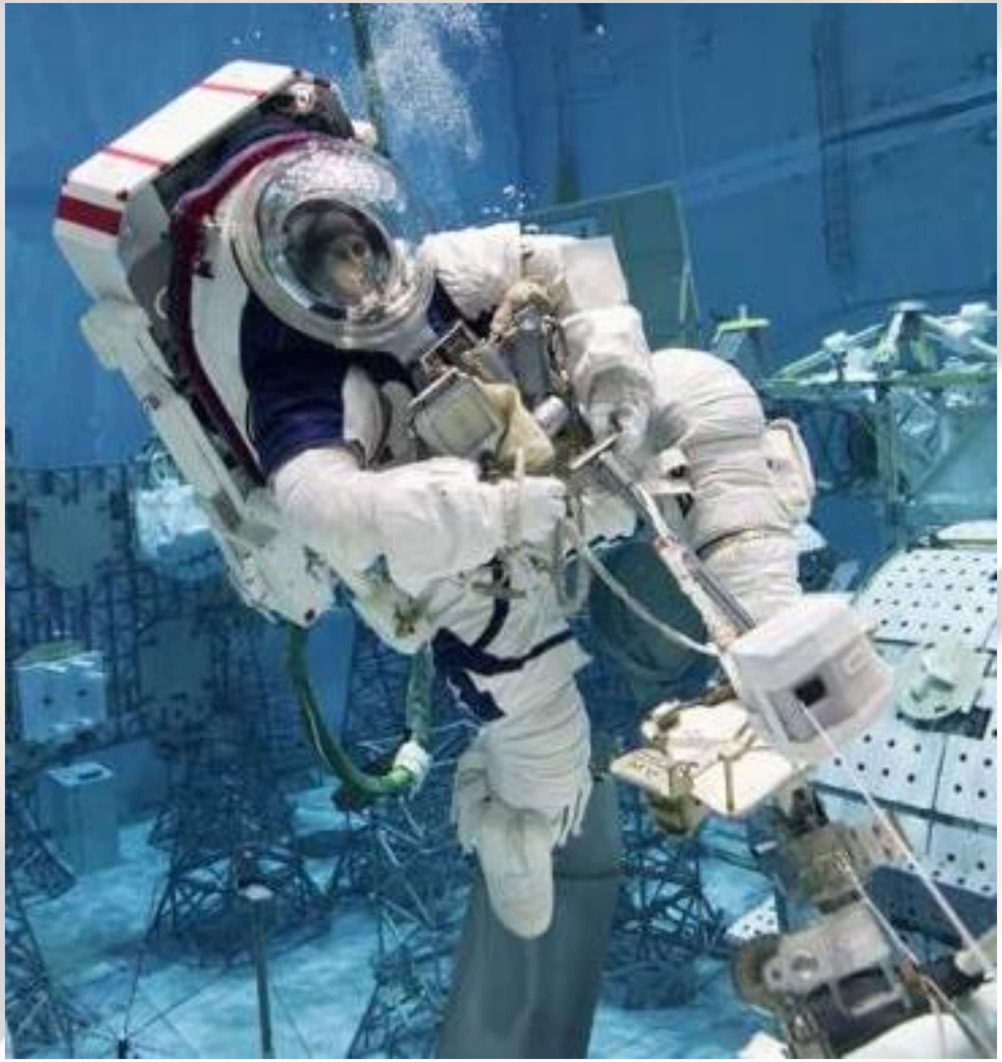
Sample of test results from pilot study

Task video



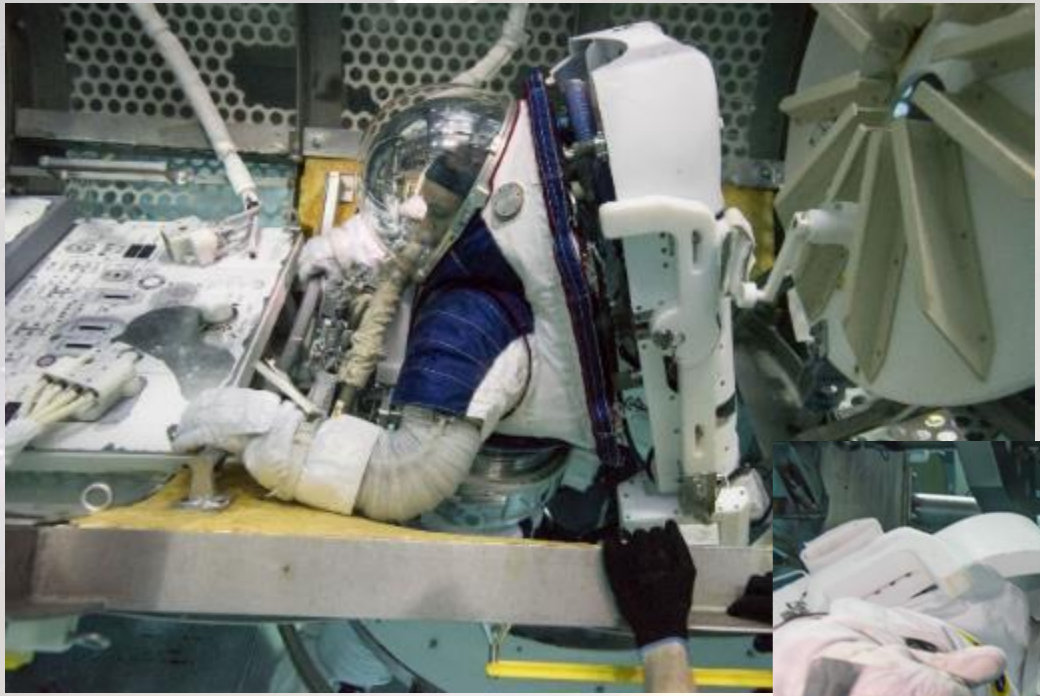
Z-2 NBL Runs

- 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



- Will discuss what and how the data was collected
  - Including the scales that were used
  - Lessons learned regarding subjective data collection
- Will discuss how the results of the NBL test are being incorporated now into the next hardware iteration

Z-2 NBL Runs



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

- From our conversation, I could image the following core topics would fit well:
- Comfort
- Human centered design
- User experience testing
- Learning from feedback in the testing process
- Testing for user acceptance
- UX Testing Methods & Scales