JSC/EC5 U.S. Spacesuit Knowledge Capture (KC) Series Synopsis

All KC events will be approved for public using NASA Form 1676.

This synopsis provides information about the Knowledge Capture event below.

Topic: EVA Development and Verification Testing at NASA's Neutral Buoyancy Laboratory

Date: August 14, 2012 **Time:** 11:30-12:30 pm **Location:** JSC/B5S/R3102

DAA 1676 Form #: 29347

A PDF of the presentation is also attached to the DAA 1676 and this is a link to all lecture material and video: \\js-ea-fs-01\pd01\EC\Knowledge-Capture\FY12 Knowledge Capture\20120814 Jairala-Durkin_EVA Testing-NBL\For 1676 Review and Public Release

*A copy of the video will be provided to NASA Center for AeroSpace Information (CASI) via the Agency's Large File Transfer (LFT), or by DVD using the USPS when the DAA 1676 review is complete.

Assessment of Export Control Applicability:

This Knowledge Capture event has been reviewed by the EC5 Spacesuit Knowledge Capture Manager in collaboration with the author and is assessed to not contain any technical content that is export controlled. It is requested to be publicly released to the JSC Engineering Academy, as well as to CASI for distribution through NTRS or NA&SD (public or non-public) and with video through DVD request or YouTube viewing with download of any presentation material.

Presenters: Juniper Jairala and Robert Durkin

* Personal contact information has been removed in the final PDF of the original PowerPoint presentation, which is attached to this 1676, and will be used for distribution.

Synopsis: As an early step in preparing for future EVAs, astronauts perform neutral buoyancy testing to develop and verify EVA hardware and operations. To date, neutral buoyancy demonstrations at NASA JSC's Sonny Carter Training Facility have primarily evaluated assembly and maintenance tasks associated with several elements of the ISS. With the retirement of the Space Shuttle, completion of ISS assembly, and introduction of commercial participants for human transportation into space, evaluations at the NBL will take on a new focus. In this session, Juniper Jairala briefly discussed the design of the NBL and, in more detail, described the requirements and process for performing a neutral buoyancy test, including typical hardware and support equipment requirements, personnel and administrative resource requirements, examples of ISS systems and operations that are evaluated, and typical operational objectives that are evaluated. Robert Durkin discussed the new and potential types of uses for the NBL, including those by non-NASA external customers.

Biographies: Juniper Jairala was born in Chicago, Illinois and was raised there, in San Diego, California, and in Quito, Ecuador. After receiving a bachelor of science in mechanical engineering from Cornell University in 1997, Jairala worked as a ride-and-show engineer building Universal Studios and Warner Brothers theme parks in Los Angeles, Japan, and Spain until 2001. Afterward, she worked at NASA

Dryden in Flight Operations before earning a master of science in aerospace engineering sciences, with an emphasis in bioastronautics, at the University of Colorado Boulder in 2004. From 2005 to 2008, Jairala worked as a NASA graduate cooperative education student at JSC, continued graduate education with an emphasis in integrated physiology at UCLA, and worked as an employee of several commercial spaceflight companies (Blue Origin, X Prize, SpaceX, Andrews Space, and Zero Gravity Corporation). In 2008, she returned to JSC with Jacobs Technology, working for the CTSD as a project and test engineer on the EVA Development and Verification Test Team, where she continues to work today.

Robert Durkin was born and raised in Herington, Kansas. He received a bachelor of science in aerospace engineering in 1993 from Wichita State University. He started his civil servant career at NASA in 1993 at the Weightless Environment Training Facility (WETF). He transitioned to the NBL in 1997 and was responsible for the Breathing Gas System and was the flight lead for STS-88, the first NASA mission trained in the NBL. In 1998, he moved to EA and was the EM division lead for Mockup Design and Fabrication. In 2001, he became the assistant to the subsystem manager for Shuttle Landing Systems. In 2002, he returned to the NBL as the facility manager and has continued to take jobs of higher responsibility in the facility. He became the chief of the NBL in August 2010.

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EVA
Development and Verification Testing
at NASA's
Neutral Buoyancy Laboratory

Juniper Jairala

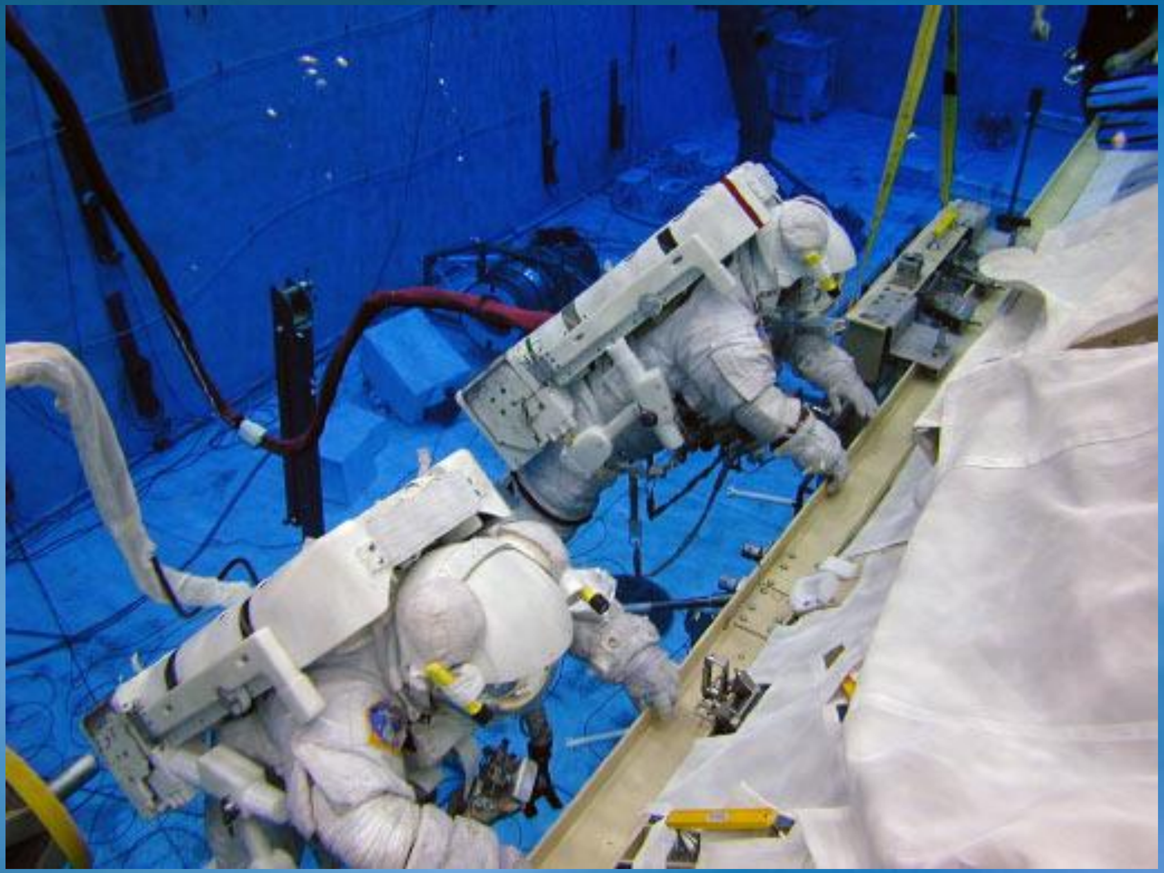
Contributors: Robert Durkin, Ralph Marak, Angela Prince, Stephanie Sipila, Zane Ney, Dr. Scott Parazynski, and Arthur Thomason

Purpose

- Increase the larger community's awareness about the Neutral Buoyancy Laboratory (NBL)

- Share why & how EVA development & verification testing is conducted at the NBL

- Share ideas on use of the NBL for future NASA & commercial human spaceflight programs



Agenda

Background

Test Philosophy

Facility & Test Setup

Test Planning (Roles & Responsibilities)

Test Hardware & Mockups

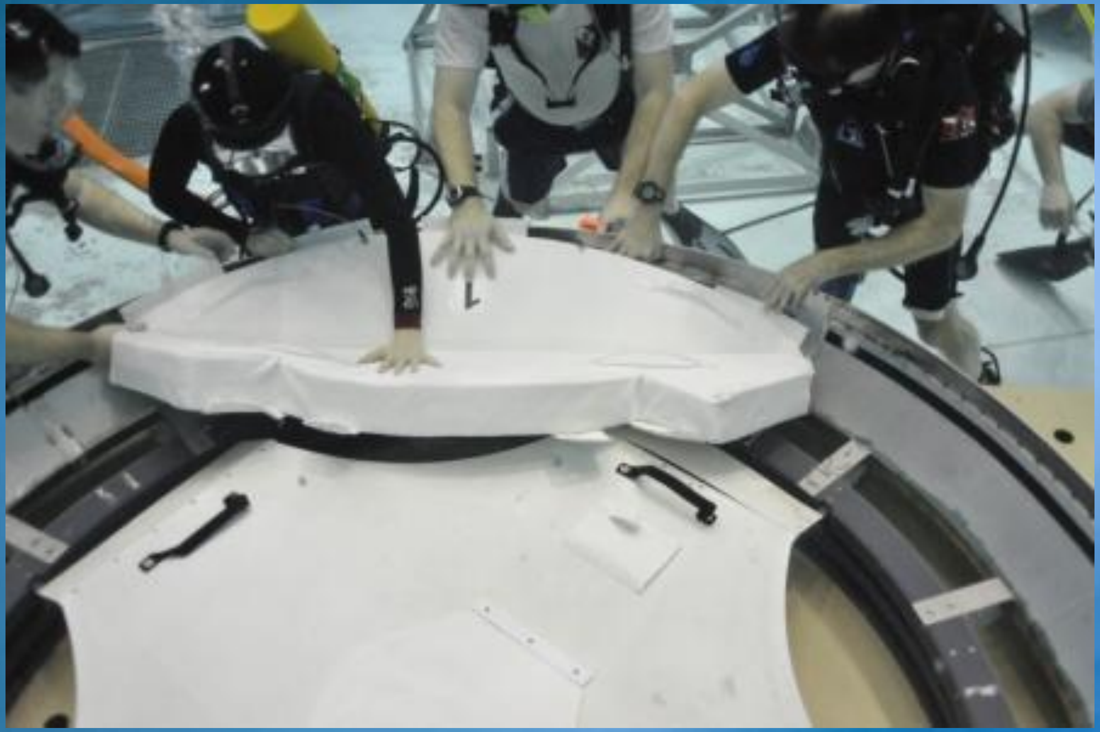
Daily Operations

NBL Successes & Challenges

Other (non-ISS) NBL Testing

NBL External Customers & Future Uses

References & Acknowledgements



EVA TEST TEAM

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Background

• Large Indoor pool (202' x 102' x 40') for EVA training at JSC

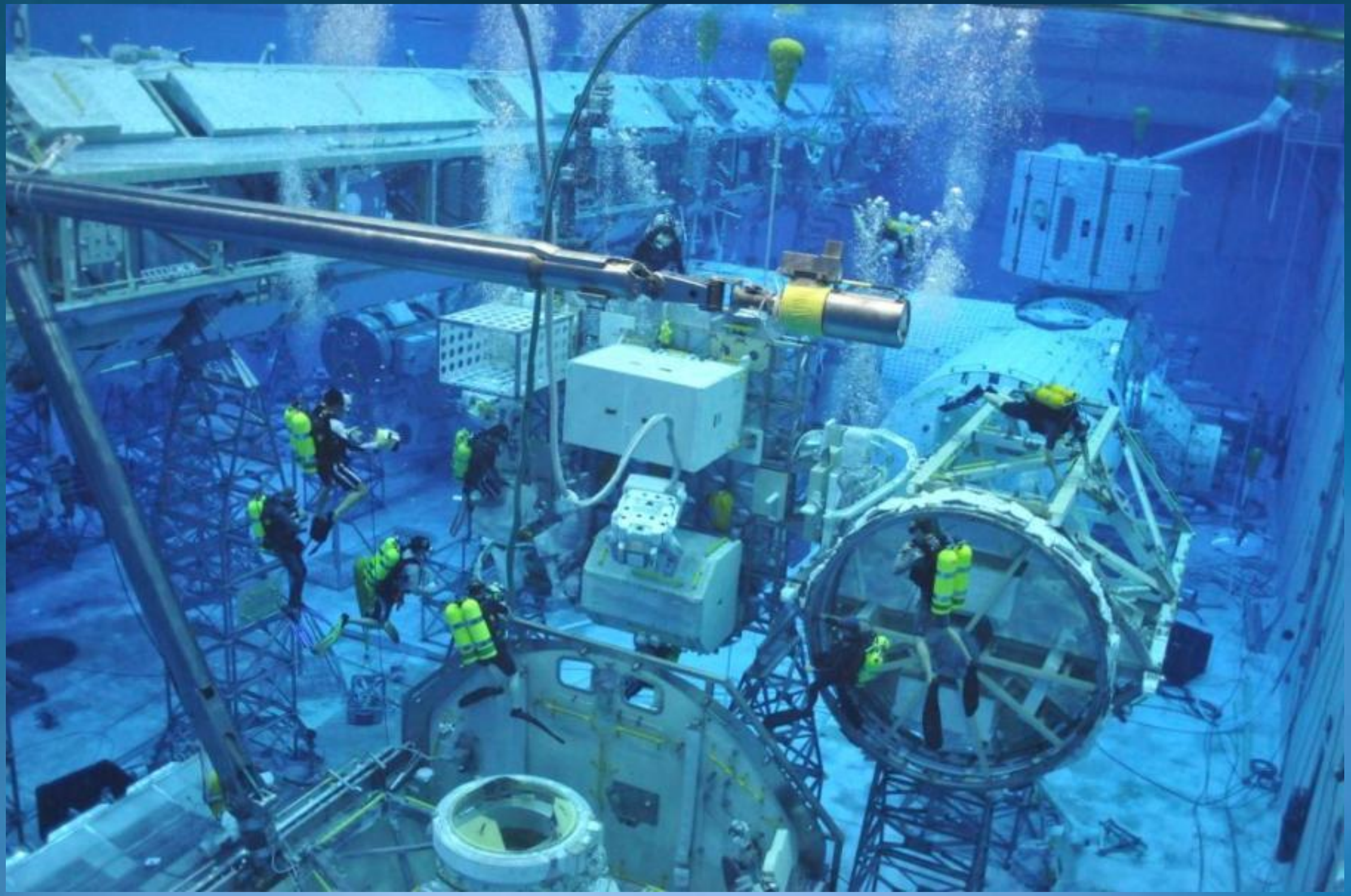
• Built in 1996 to help us assemble the ISS (126 EVAs, 840 sortie hours)

• Accommodates full-scale replicas of the ISS truss complement, US ISS elements, International segments, airlock, pallets, robotic arms, HTV4, shuttle payload bay

• Two simultaneous activities, up to five suited subjects

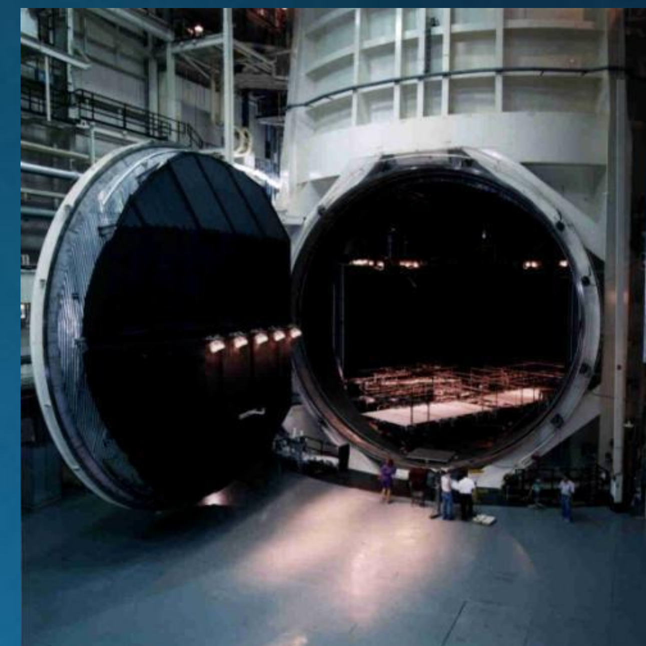
• 46% oxygen gives suited subjects 400 minutes (~6.7 hrs)

• Essential tool for the design, testing, & development of the ISS & future NASA programs:
  - >1,000 issues identified & resolved through NBL testing
  - >1700 underwater hours



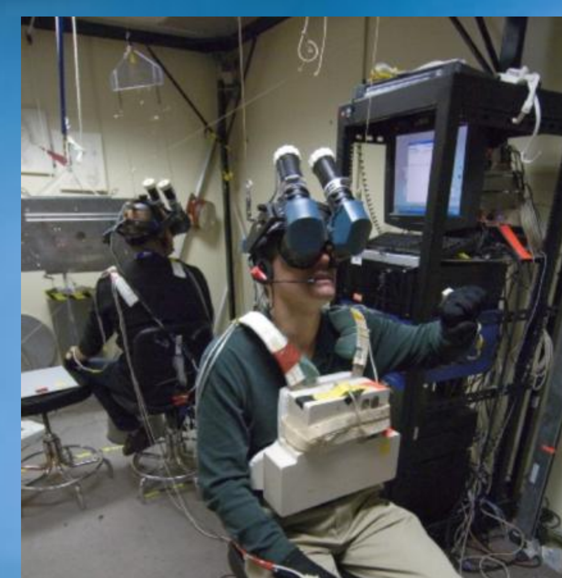
Test Philosophy: Alternatives

Parabolic Flights: most realistic zero/reduced gravity simulation (no drag); however short, complex, expensive



Thermal/Vacuum Chambers: environment external to spacecraft, great for extremely high-fidelity hardware or flight hardware evaluations

Gravity Offload Systems: data on reaction forces, body positioning & strength requirements for tasks; however, encumbering attachment devices

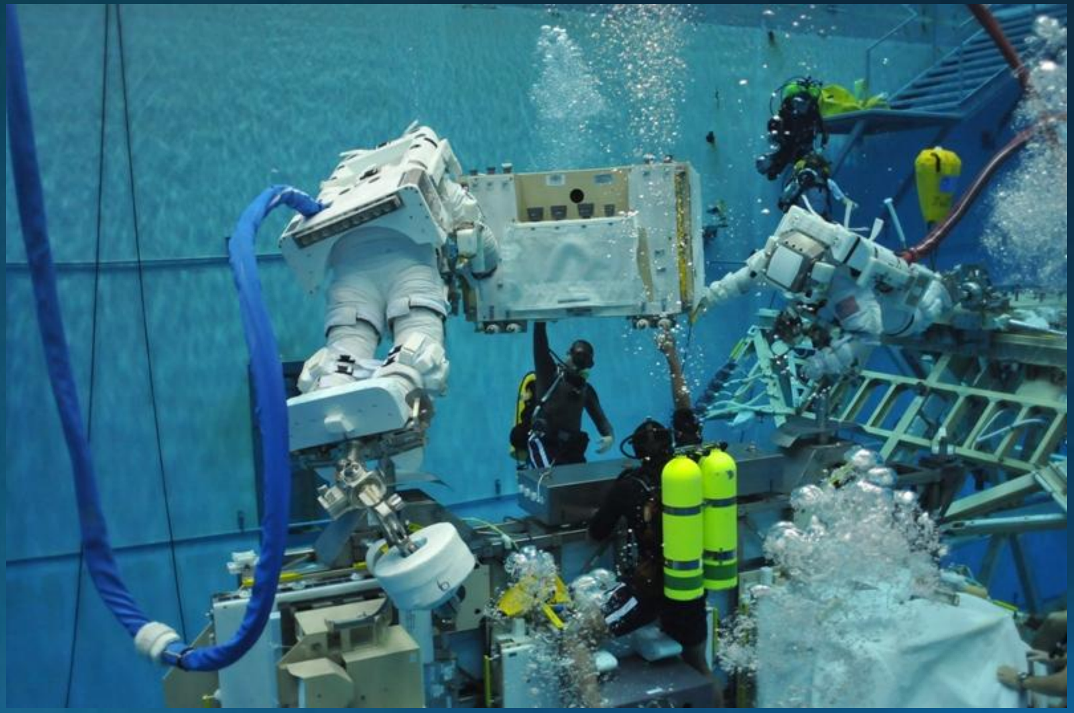


Virtual Reality: 3-D perspective of hardware & interaction between hardware, crew, & spacecraft; inertia of large hardware; however, site-specific

Test Philosophy: Why

- Highly integrated, complex, costly, & risky activities need a robust test facility

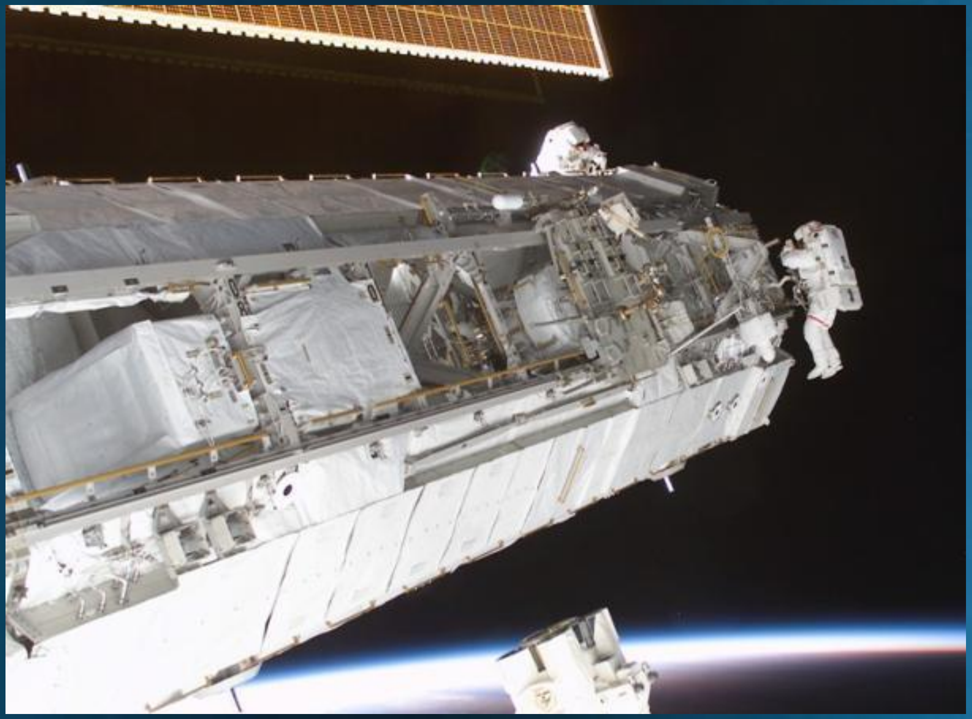
- Hardware design evaluation:
  - Translation with equipment
  - Tether point & handrail locations
  - Clearances for glove & tool access
  - Free-float or foot restraint
  - Single or dual crewmember
  - Single or dual-handed
  - Body positioning
  - Torquing
  - Reach
  - Robotic assist



126 EVAs (~840 sortie hours) to build ISS - most complex tasks performed in human spaceflight history

- Hardware certification:
  - Flight hardware requirements closure
  - Rationale to accept hardware in violation of EVA requirements
  - Verification tests

- *What about analysis:*
  - Not ideal for highly complex systems requiring many assumptions
  - More assumptions → less accurate results
  - Insufficient software modeling capabilities



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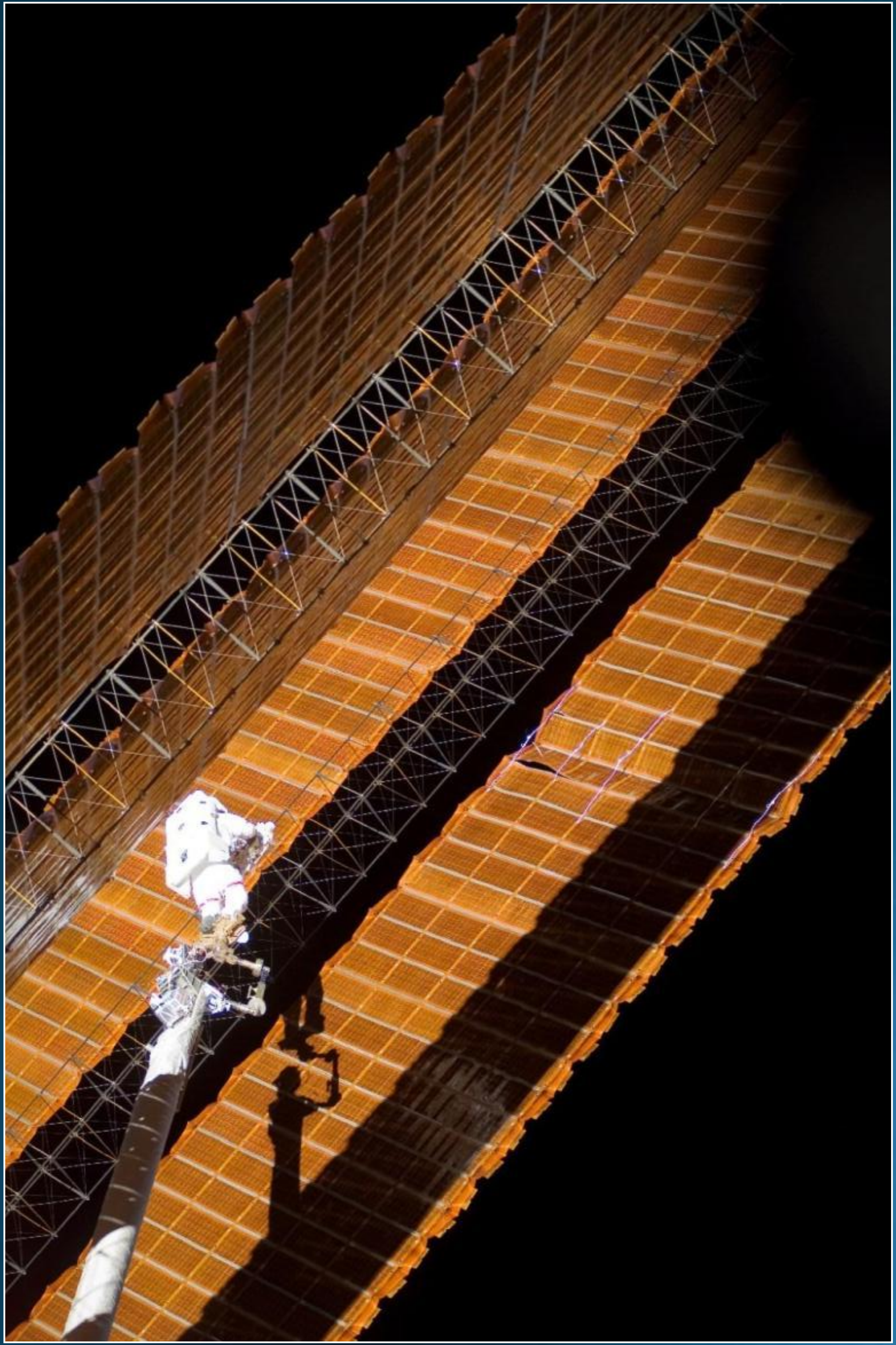
Test Philosophy: Applicable Phases

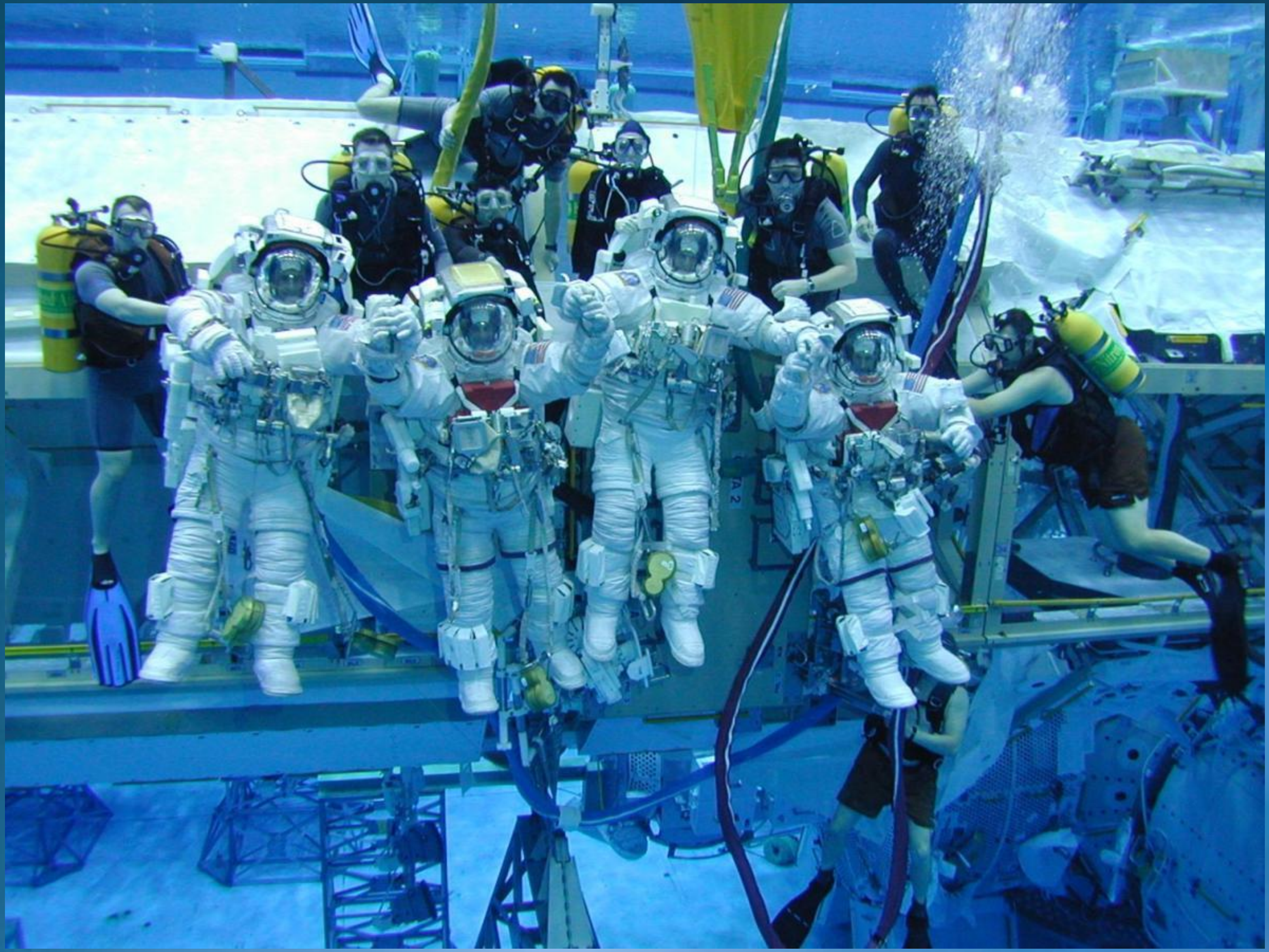


- **Pre-PDR or Requirements Phase:**
  - Broad hardware concepts & hardware feasibility
  - Low- & medium-fidelity mockups
  - Adequacy of requirements
- **Between PDR & CDR Phase:**
  - Hardware operability in integrated ISS vehicle configuration
  - Medium- to high-fidelity mockups
  - Majority of development & verification testing
- **After CDR Phase:**
  - Validate operations steps & timelines
  - High-fidelity mockups
  - Integrating single tasks into full-length EVAs – minor hardware redesigns

Hardware Development Test Philosophy: Crew Selection

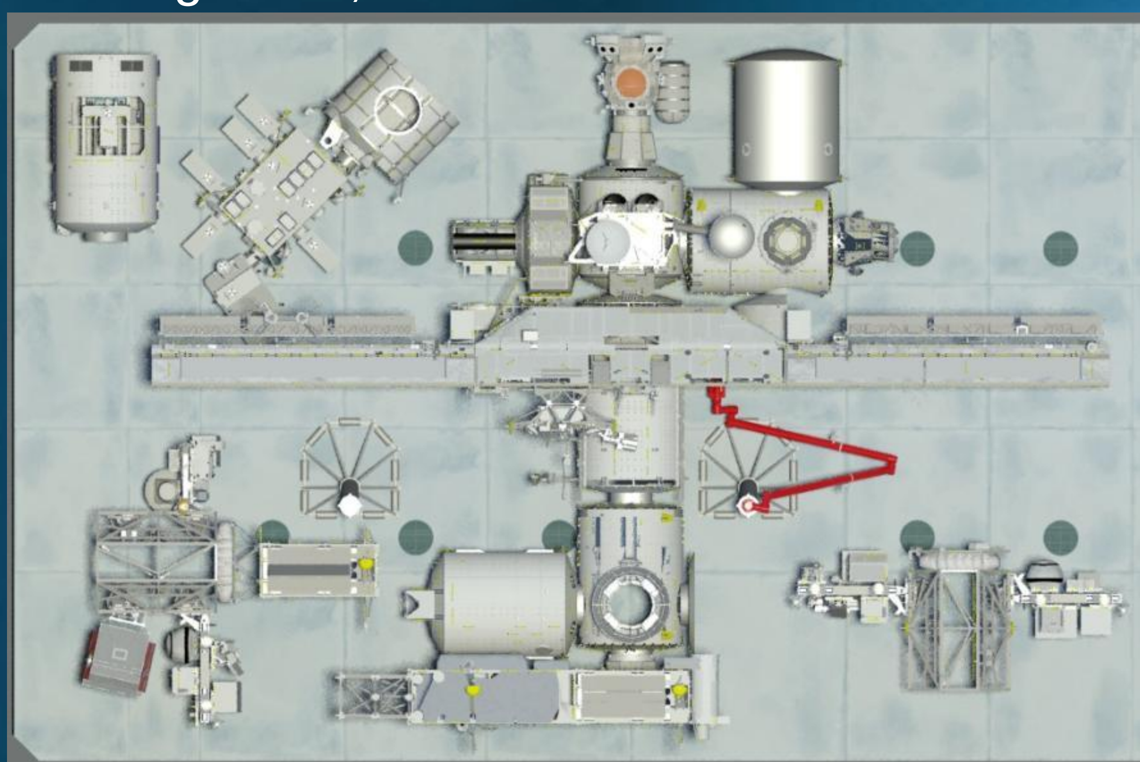
All are EVA-qualified & can make suggestions

- **Anthropometrics:**
  - Feasibility - matching worksite to work envelope
    - Breadth of heights
    - Range of arm lengths
    - Various girths
- **Skill level & experience mix:**
  - Not all perform at the same level
  - More skill & experience → more accurate & thorough feedback
  - ISS contingency & maintenance – any available crewmember
- Six astronauts for official crew consensus



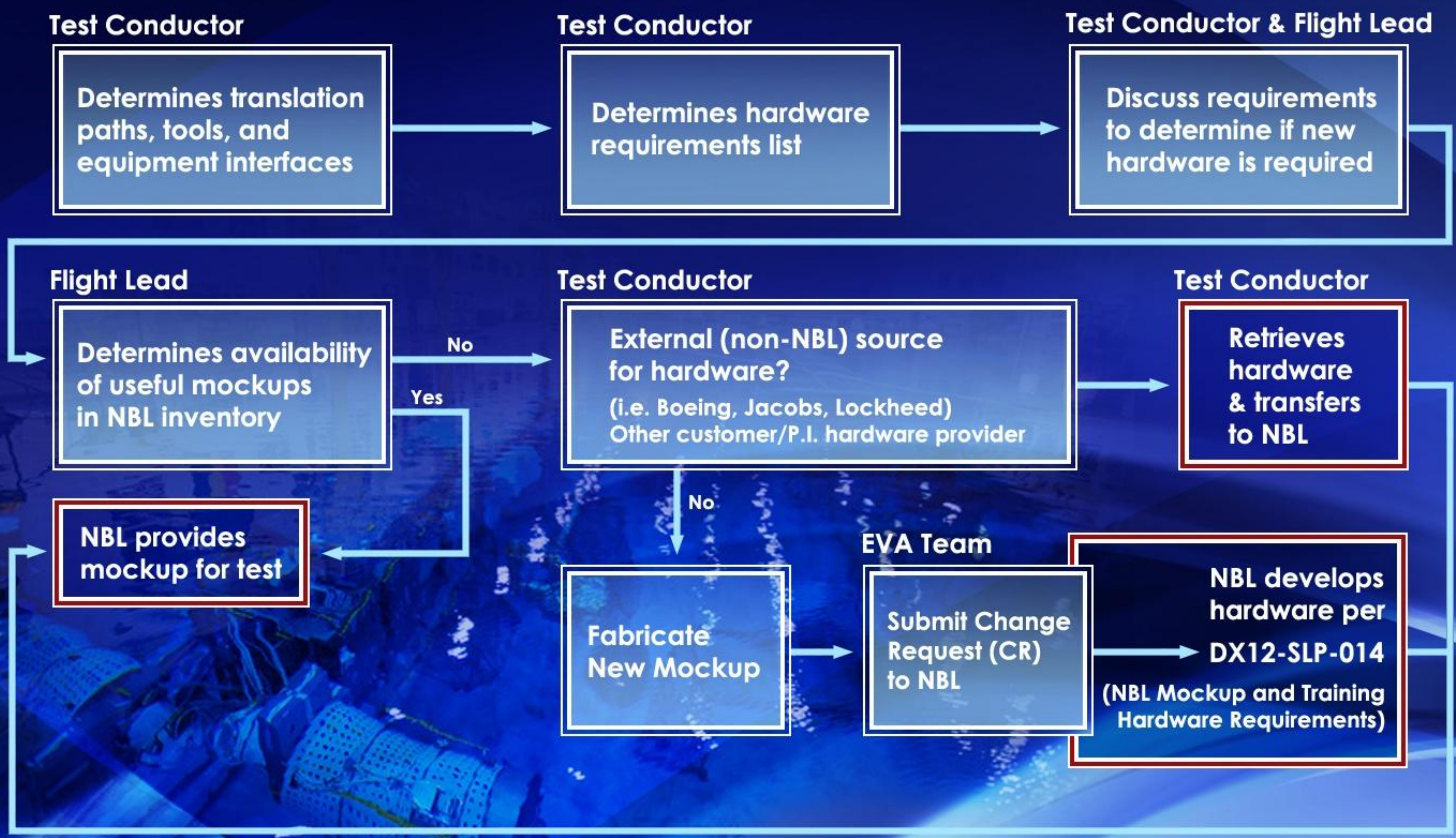
Facility & Test Setup for Hardware Development

Facility features:
- High bays for staging & maintenance
- 10-ton overhead bridge cranes
- Underwater digital video & audio
- Breathing gas & water cooling through life support umbilicals
- Operations staff:
  - Two safety divers, one utility diver, one camera diver – per subject per test
  - Test director, subsystem operators, suit engineers, suit technicians



Test events:
- 4-hour scuba run
- 6-hour engineering run
- Three 6-hour suited crew runs, two crew per day

NBL Mockup/Hardware Development Flow



Test Hardware & Mockups

- Fidelity based on training & testing requirements:
  - Flight-like, functionally active, operable, static
  - Class I, Class II, Class III
- Development testing – shorter timelines, unique requirements:
  - Trade-off between cost, fidelity, & schedule
- Special materials proved for long-term use in pool environment:
  - Stainless steel - hi-fi interfaces, bolts, Nodes, etc.
  - Fiber-reinforced plastic – trusses
  - Kydex – skins
  - Ultra-High Molecular Weight (UHMW) polyethylene – small volumetric mockups
- Features to reduce drag, maximize buoyancy:
  - Large lightning holes
  - Embedded foam

Large Volumetric Mockup – Node 2

Small Hi-fi Mockup – Node 2 heat exchangers with functional interfaces

Test Planning – Roles & Responsibilities

Planning requires multiple roles & typically takes 2 to 4 months

Title	Role	Organization
Principal Investigator	Test requestor	Various
EVA office representative	Determines content to test & prioritizes objectives	NASA/EVA Office (XA)
Test engineer/EDVT lead	Test planning & documentation, lead test conductor	NASA Engineering (EC7)/Jacobs
Mission Operations Directorate (MOD) representative	Provides operations expertise, procedure inputs, & mockup requirements	NASA/EVA Operations (DX32)
Crew Office representative	Selects crew for test, writes crew consensus report	NASA/Astronaut Office (CB)
NBL flight lead	Coordinates pool configuration	NASA/Raytheon (DX12)
NBL project lead	Mockup designer & builder	Raytheon (DX12)

NBL EVA Development & Verification Planning Flow

Test Team

EVA Office	(XA)
Engineering	(EC)
Operations	(MOD)
Crew Office	(CB)
NBL	(Flight Lead)
Hardware Providers / PIs	

Customer

Customer (EVA Office - XA) identifies test request

Test Requestor

Principal Investigator (PI) assigned (Test Requestor)

Test Conductor

Test Engineer/Lead Test Conductor (TC) assigned

Test time frame established w/ NBL Long Range Planning (LRP)

Test Conductor

Leads Kickoff meeting & weekly planning meetings w/ Test Team to develop and coordinate:

- Background
- Schedule
- Objectives
- Actions
- Hardware Status
- Pool Configuration

2-4 Months Before Test

Flight Lead & Test Conductor

Communicate objectives and pool setup requirements w/ NBL dive operations in Preliminary Configuration meeting

1-2 Months Before Test

Crew Office

Crew Office (CB) arranges crew/subject support for test

1-2 Months Before Test

Flight Lead & Test Conductor

New Hardware needed?

No

Yes — See Section V: Hardware (Mockups)

Test Conductor

Develops/Coordinates Test Deliverables

- Hazard Analyses
- Test Plan
- Detailed Test Procedures
- Crew Briefing Package
- TRR Package (if needed)
- Pre-Dive Forms (to NBL)
- Tools Requests (to tools provider) (USA)

1-3 Weeks Before Test

USA Provides Tools

Test Conductor

Conducts Crew Briefing, Scuba Run, and Suited Runs

Flight Lead

Generates configuration checklists

Dive Team

Configures pool/high bay for test/briefing

Daily Operations & Conducting the Test

Daily Operations:
- Morning briefings – subjects, dive team
- Final tool, hardware, & pool setup
- Suit donning, dive, weighout
- Test conducting - 6 hours or objectives complete
- Suit doffing, post-dive debriefing & crew commentary

Working Console:
- Real-time decisions ensure desired objectives are met
- Pre-emptive direction to divers
- Unforeseen test results, pool-use conflicts, delayed starts, suit or mockup issues
- Quick re-planning to drop, reorder, or modify tasks
- Added safety protocols for robotic arm use
- Maximizing facility & personnel time

Data Collection:
- Task accomplishment – success, tools used, foot restraint settings, number of crew, procedure changes
- Video, audio, & still photo
- EDVT Report
- Crew Consensus Report (CCR)

Test Reports

- **Quick Look Report (3 days)**
  - Objectives accomplished
  - Safety issues or anomalies
  - Selection of photos

- **EDVT Test Report (~4-8 weeks):**
  - Delta objectives
  - Hardware changes
  - Final test configuration
  - Observations & results (with photos)
  - Final detailed test procedures
  - CCR

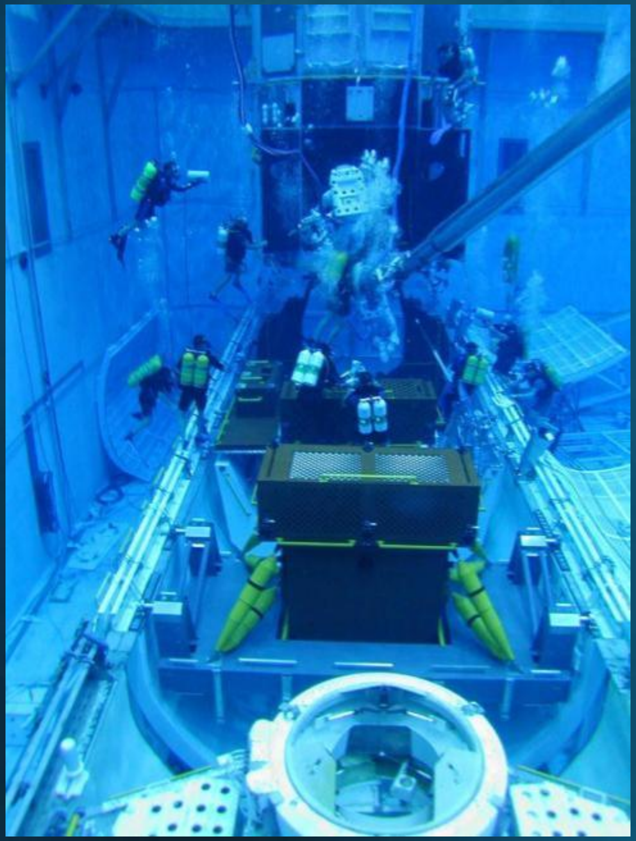
- **Crew Consensus Report (~4 weeks)**
  - Official CB position
  - Rates test objectives, EVA hardware, & task acceptability – "EVA Hardware & Task Ratings"
  - Requirements verification

EVA Hardware & Task Ratings

Category	Description
Acceptable (A)	Design changes are not required, although recommendations may be included to improve hardware operations.
Unacceptable 1 (U1)	Design changes are required. Retesting is not required; however, drawing review and/or shirtsleeve inspection of flight or high-fidelity hardware is required to verify adequacy of design changes.
Unacceptable 2 (U2)	Design changes are required. Retesting is required to verify the adequacy of design changes.
Inconclusive (I)	No crew consensus can be reached due to inadequate hardware fidelity, inappropriate test conditions or environment, or an insufficient number of test subjects used. Retesting will be required unless specified otherwise.

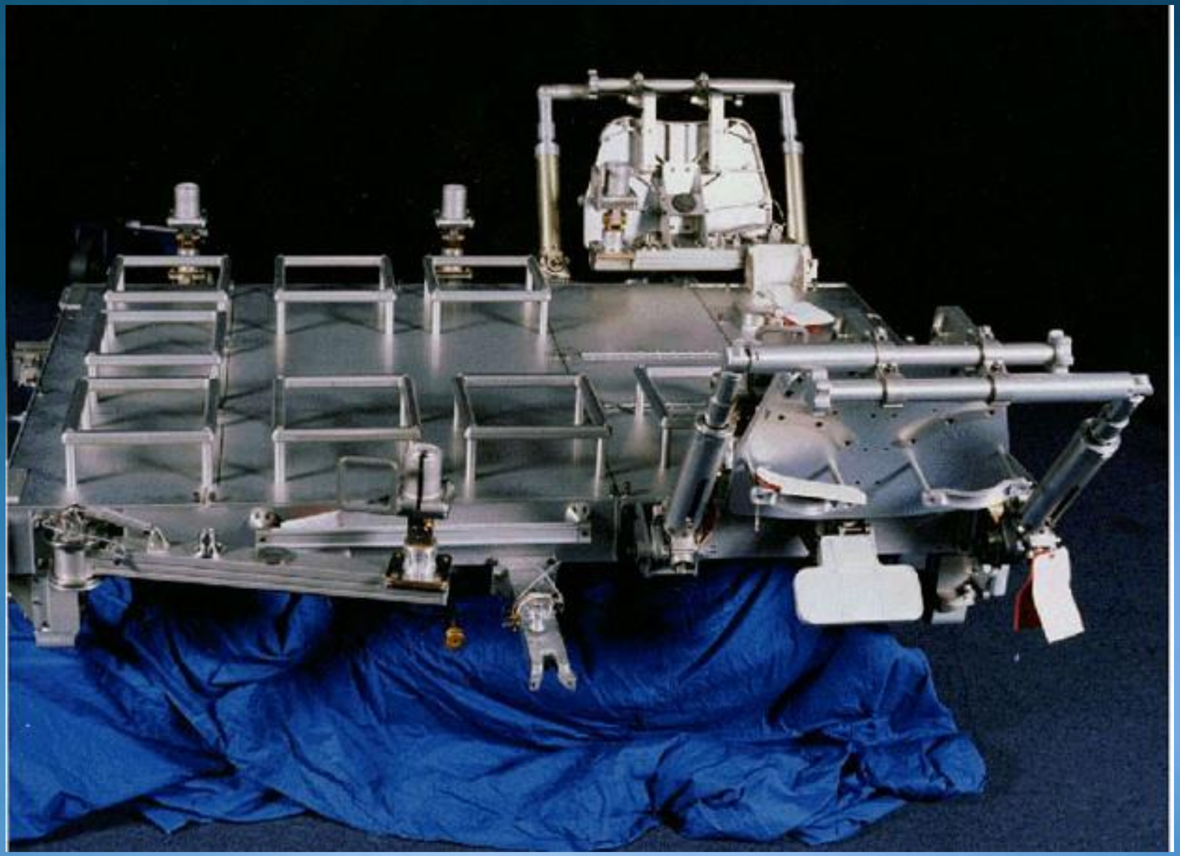
NBL Successes & Challenges

Success – Hubble Servicing



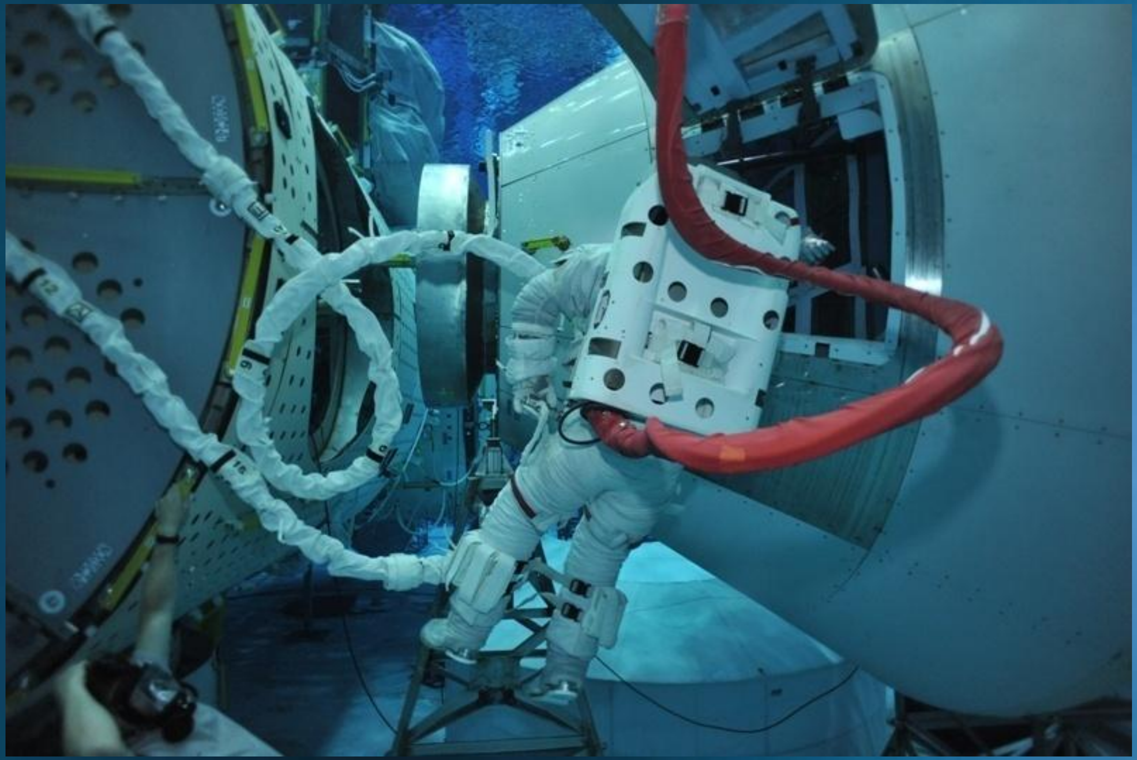
Tasks not originally thought possible in EVA were vetted; specialized new tools were developed & evaluated

Underutilization- CETA Carts



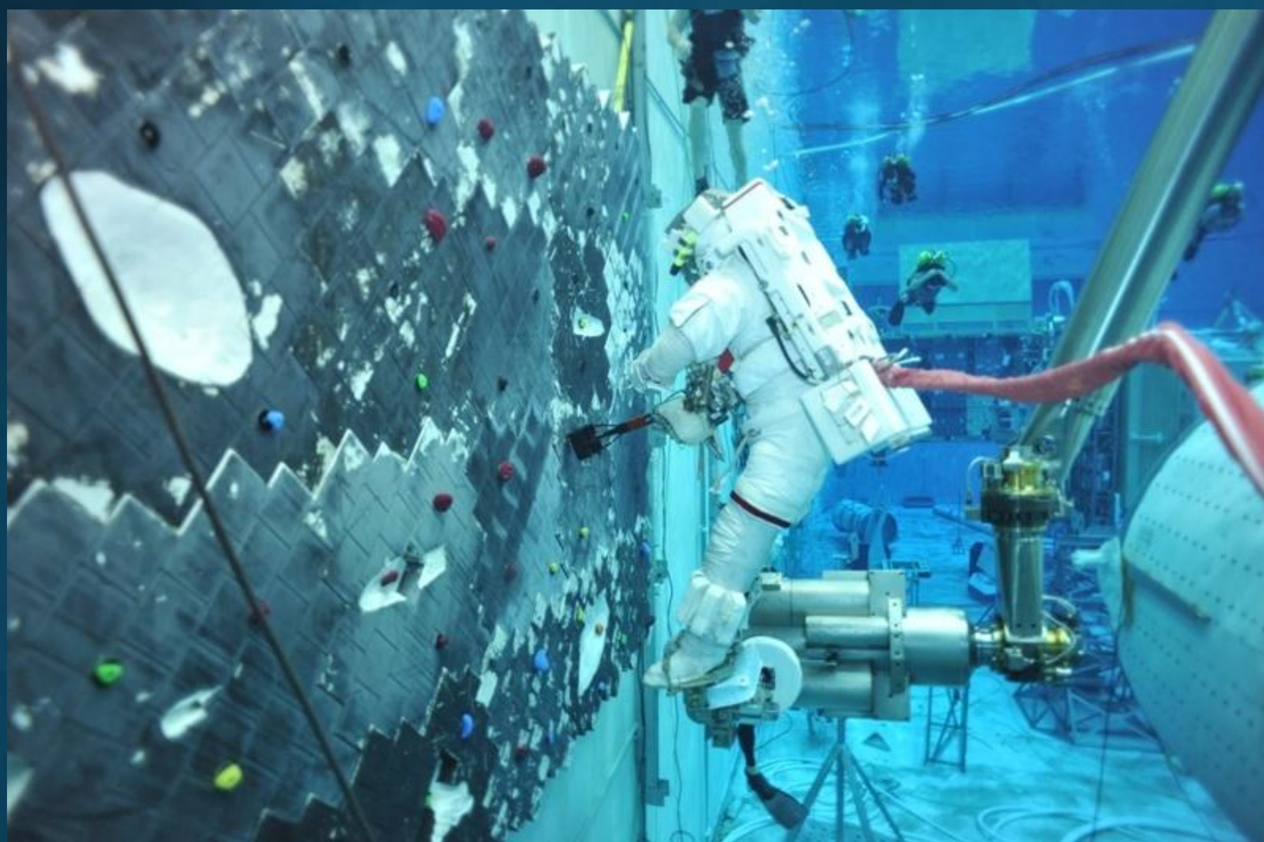
Part-task testing only – evaluation of integrated operations concept would have revealed inefficiencies, potentially cancelled project, saved $$

Constellation – Related Testing



- Free-float installation, removal, & stowage of handrails along Altair to Orion translation path
- Hatch opening & closing operations
- Hatch ingress & egress
- All of the above with:
    - Umbilical to Orion
    - Umbilical to Altair (or other vehicle docked with Orion)

Near-Earth Asteroid Exploration-Related Testing



Rock sampling in micro-gravity environments:

- Robotic arm to represent station-keeping vehicle
- Shuttle tile repair wall to represent asteroid

- Varying asteroid spin speeds
- Various sampling methods:
  - Off-the-shelf tools
  - ISS EVA wipes
  - Empty gloved hand

Future Uses & External Customers

- For external customers, NBL & test teams must be adaptable to the following:
  - Unique operational needs
  - New paradigms
  - Prototypical hardware with more organic, bare-bones approaches to development
  - Shorter, more intense timelines
  - Methodologies & perspectives vastly differing from NASA & government

- NBL commercialization Use Readiness Review (URR) Sept. 2011:
  - Commercial activities to comply with all applicable federal, state, & local requirements; & national consensus standards
  - Use NBL consistent with their normal governing practices rather than unique NASA requirements

- Current & previous external uses:
  - Energy industry – develops & troubleshoots procedure before deep-water use
  - Sensors & advanced imaging, scanning devices, academic research related to human testing

- Potential external uses: Autonomous Underwater Vehicles, ROVs, Atmospheric Diving Systems, intermediate step toward sea trials, EVA for visiting vehicles, new space stations

Conclusions

- Extraordinary facility to establish the human interface in a reduced-gravity environment

- For Shuttle, Hubble, & ISS Programs, NBL was used to evaluate EVA hardware through all phases of the life cycle

- No other facility has all the capabilities necessary to make system integration testing & timeline development for new technologies efficient & productive:
  - Shuttle TPS – not designed for EVA servicing:
    - Post-Columbia testing of innovative operations concepts possible through NBL
    - Re-use of tile board for NEA evaluations
  - Hubble – cost of EVA testing in NBL was fraction of on-orbit EVA cost:
    - Millions of on-orbit dollars have been saved by vetting EVA operations in the NBL first
  - CETA carts - Inadequate up-front testing wasted money, time, project resources

- Testing results in life-cycle cost savings by ensuring hardware meets operational requirements

- *Imperative that future spacecraft designers realize the importance of the NBL even in early phase of hardware design*

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