Software Engineering for Human Spaceflight

Dr. Steven E. Fredrickson

Spacecraft Software Engineering Branch / ER6
NASA Johnson Space Center

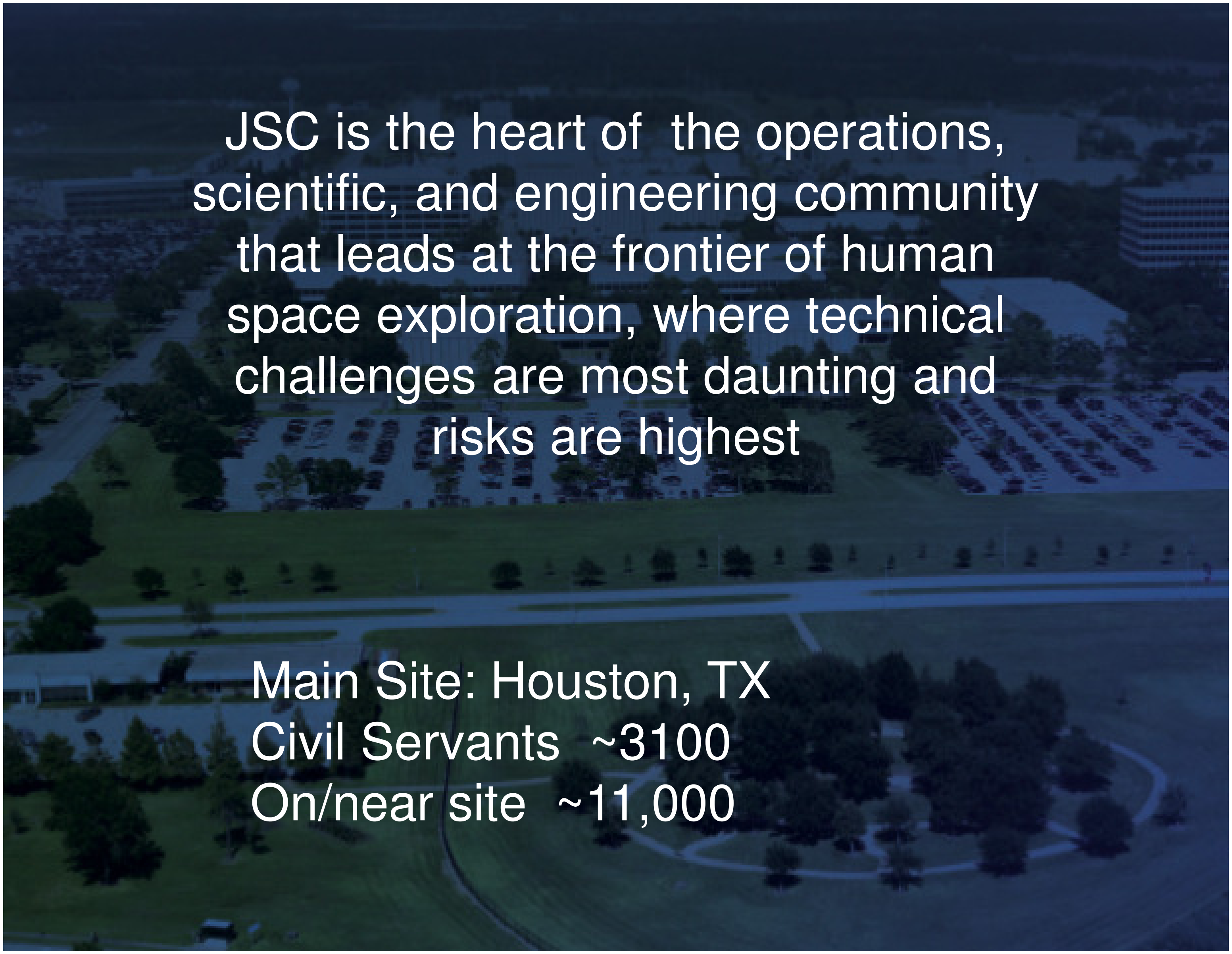
The Spacecraft Software Engineering Branch of NASA Johnson Space Center (JSC) provides world-class products, leadership, and technical expertise in software engineering, processes, technology, and systems management for human spaceflight. The branch contributes to major NASA programs (e.g. ISS, MPCV/Orion) with in-house software development and prime contractor oversight, and maintains the JSC Engineering Directorate CMMI rating for flight software development. Software engineering teams work with hardware developers, mission planners, and system operators to integrate flight vehicles, habitats, robotics, and other spacecraft elements. They seek to infuse automation and autonomy into missions, and apply new technologies to flight processor and computational architectures. This presentation will provide an overview of key software-related projects, software methodologies and tools, and technology pursuits of interest to the JSC Spacecraft Software Engineering Branch.

Software Engineering for Human Spaceflight

19 September 2014

Dr. Steven E. Fredrickson
Chief, Spacecraft Software Engineering
Mail Code ER6
NASA Johnson Space Center

NASA Johnson Space Center (JSC)

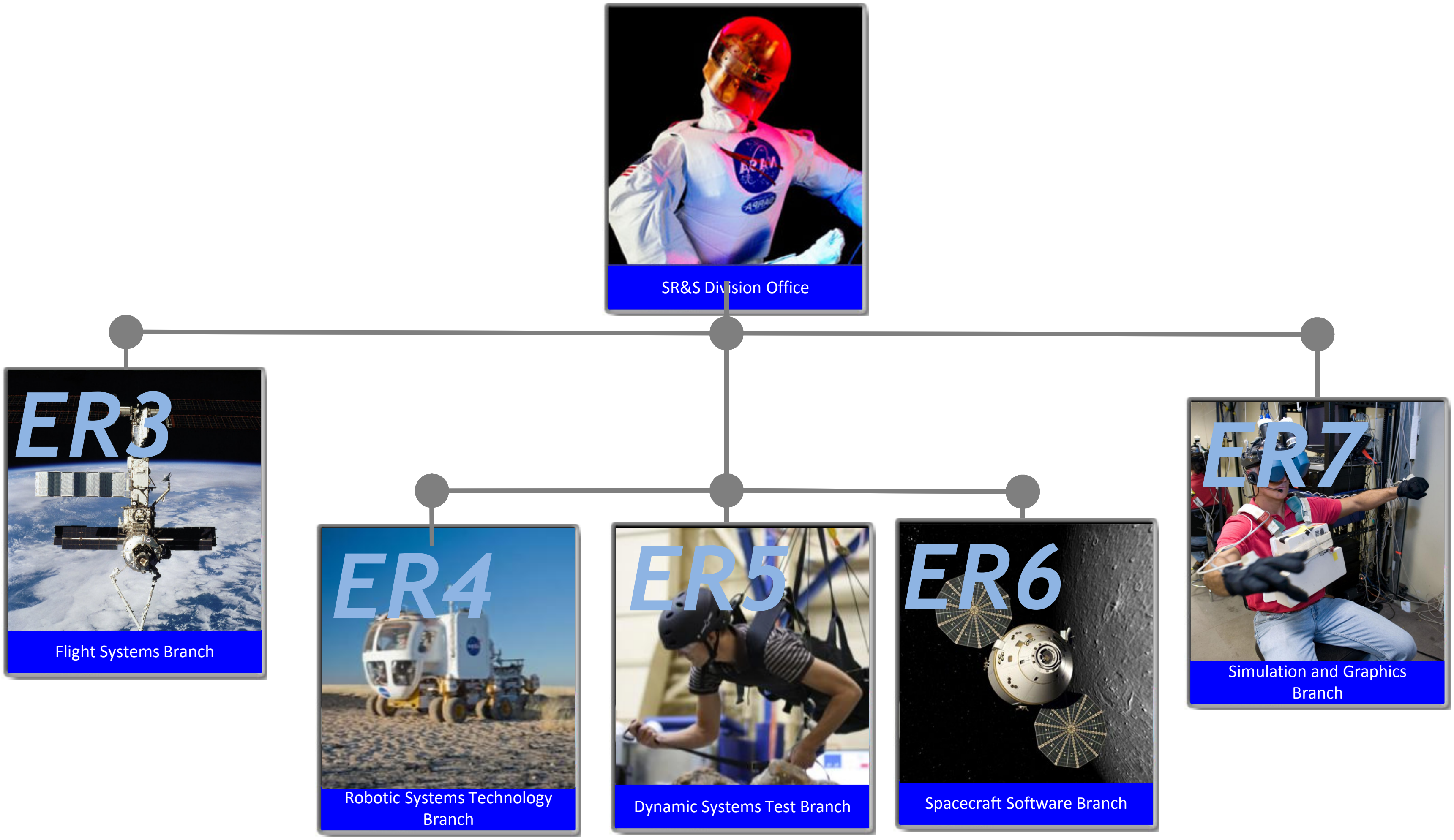


JSC is the heart of the operations, scientific, and engineering community that leads at the frontier of human space exploration, where technical challenges are most daunting and risks are highest

Main Site: Houston, TX
Civil Servants ~3100
On/near site ~11,000

JSC Engineering Directorate

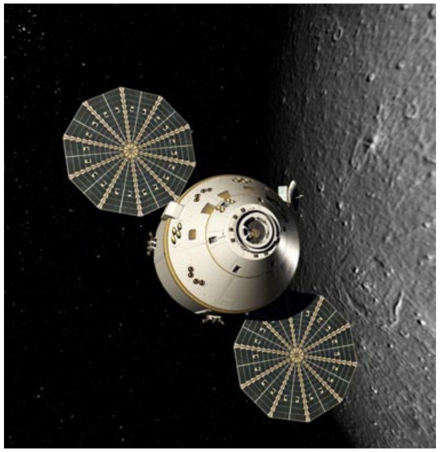
Software, Robotics and Simulation Division (ER)



Spacecraft Software Branch (ER6)

ER6 Responsibilities:

- "GFE" Software for ISS and Other Customers
- MPCV/Orion Software System Management and in-line software development
- Software technology development and software for advanced projects



JSC ER6 Expertise Overview

- Spacecraft Software Engineering Branch/ER6 is the Engineering Directorate's organization for:
  – Flight software systems engineering and integration (SE&I)
    - Full spectrum of spacecraft software functions, e.g., Vehicle Systems Management (VSM), Command and Data Handling, Communications and Tracking, etc.
  – Software advanced technology development

- Flight software SE&I accomplished via three organizing principles and related technologies
  – Robust, proven software architecture base
  – Detailed process definition and management
    - CMMI Maturity Level 3 Organization
  – Tools and technologies for reliable software implementation

JSC ER6 Software Expertise

- Software Development
  - Flight and ground systems
  - Real-time, mission-critical, embedded software development
  - Software integration and hardware in-the-loop testing
  - Vehicle systems management
    - Fault detection, isolation and recovery software
    - Automation for human workload reduction
    - Flight safety enhancement
    - Resource management
  - Automation and Robotics
    - Hardware/software integration for human robotic systems
    - Teleoperation and autonomous system control
    - Automation for operations

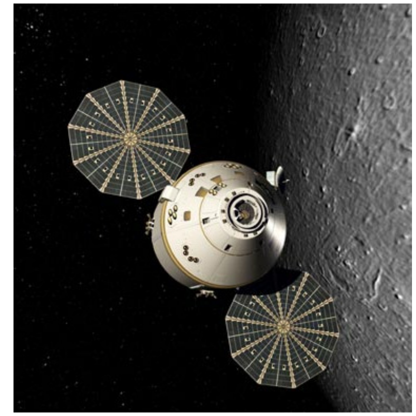
JSC ER Software Expertise (Continued)

- Software Testing and Simulation in conjunction with ER7
  - Advanced simulation environments allowing integration of software developed for many different platforms
  - Integration of multiple models into a single simulation
    - Real-time analysis
    - High-accuracy analysis
- Software Project Management and Consulting
  - Experience on multiple complex spacecraft programs
  - Proven experience integrating across NASA organizations
  - CMMI compliant processes
  - Systems analysis
  - Software architecture for spacecraft within a larger system

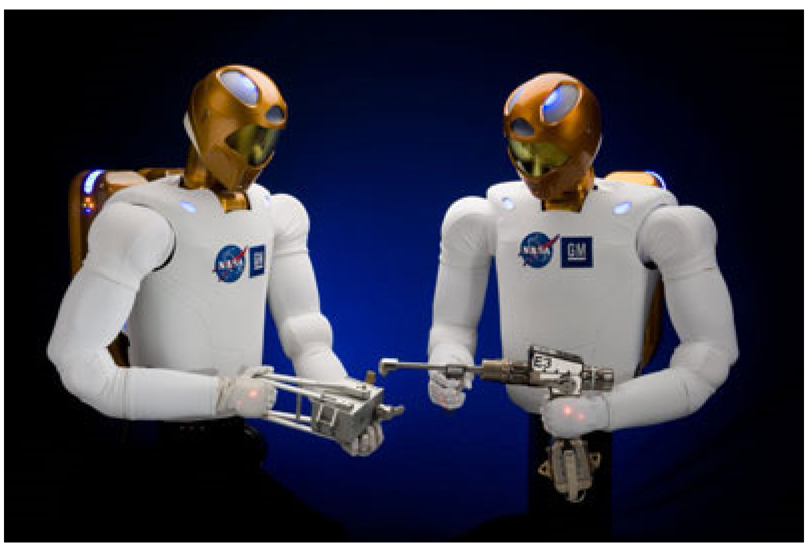
JSC ER Software Expertise (Continued)

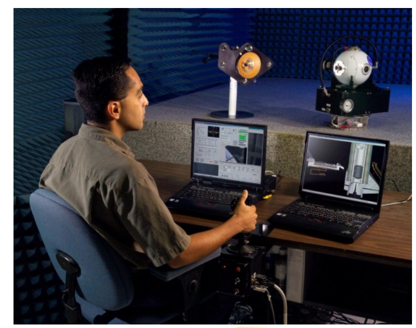
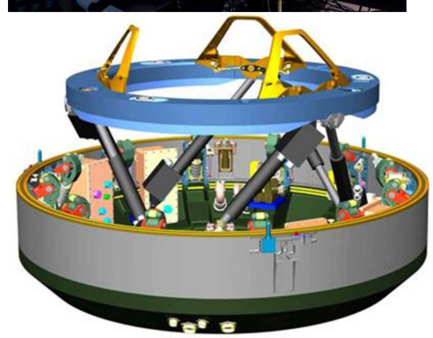
- Spacecraft Software Development



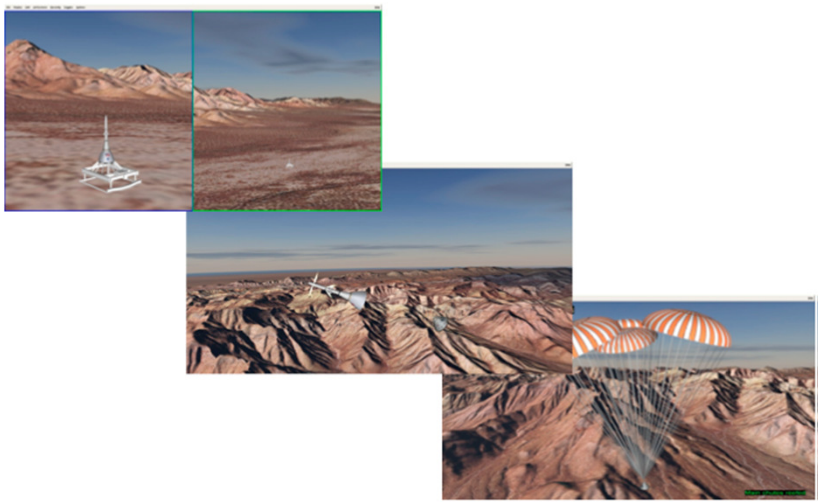
- Automation and Robotics

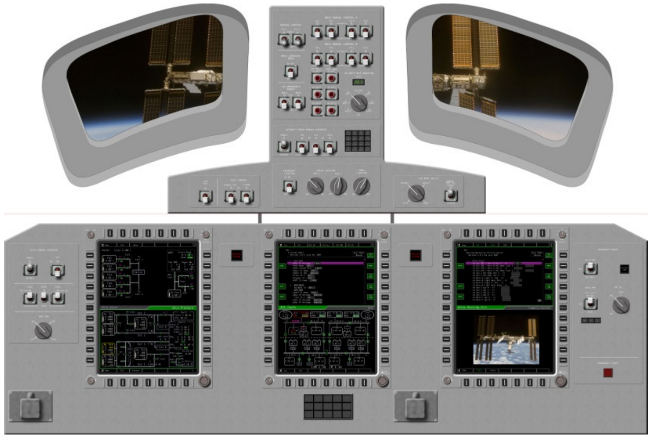


JSC ER Software Expertise (Continued)

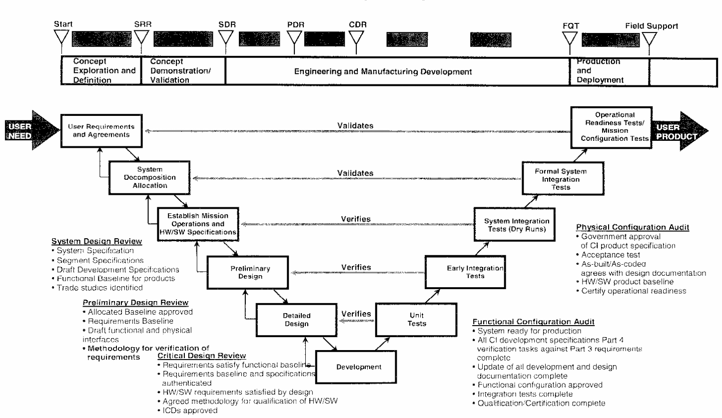
- Software Simulation and Testing





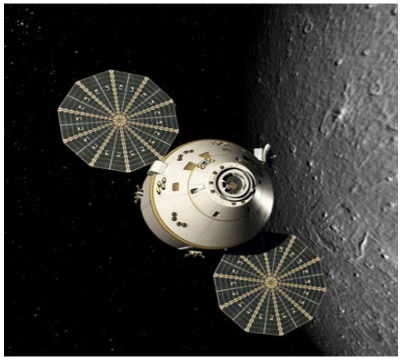
- Software Project Management and Consulting Services

Figure 4.0 Project Lifecycle



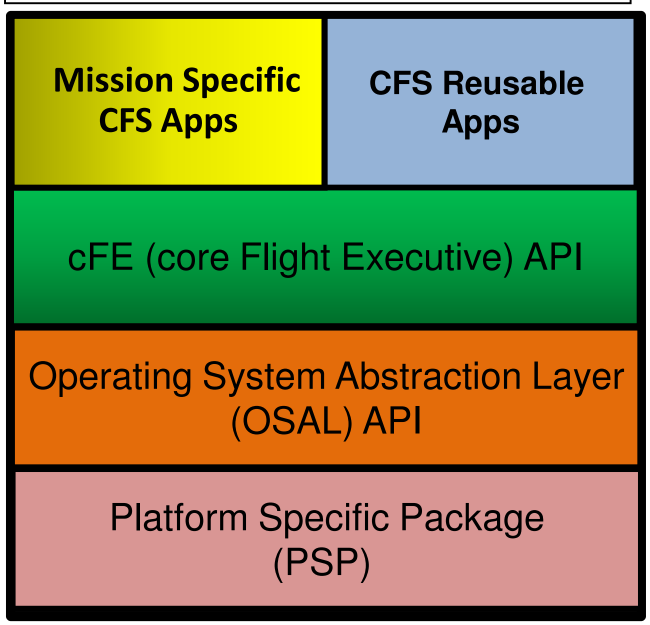
Spacecraft Software Engineering Branch (ER6)
Current Projects and Activities

- Software Engineering Leadership
  - EA SEPG Chair (
  - JSC SEPG Chair and rep to NASA software working group (
  - JSC rep to NASA Mission Software Steering committee (
  - EA SSET – CMMI Level 3
- MPCV/Orion System Management
  - Flight software
  - Software T&V / Kedalion
  - Vehicle System Management
  - Data integration & software tools and Processes (
  - Simulation Software
- GFE Software
  - ISS Simplified Aid for EVA Rescue (SAFER)
  - ISS Advanced Resistive Exercise Device (ARED)
  - ISS Countermeasures System Software (CMSS)
  - ISS LIDS/NDS (Low Impact Docking System / NASA Docking System)
  - ISS C2V2 formulation and oversight
  - ISS Tissue Equivalent Proportional Counter / Advanced Radiation Instrument (TPEC/ARI)
- AES Software
  - Morpheus VTB
  - AEMU (Advanced Extravehicular Mobility Unit)
  - Deep Space Habitat
  - AMO (Advanced Mission Operations)
  - RadWorks/REM
  - RPM Lander
  - CATALYST
  - Core Flight Software
- STMD IR&D/Advanced Development
  - STMD Autonomous systems
  - Augmented Reality IR&D
  - Ontologies / Semantic search
  - E-Procedures
  - Intelligent system SE&I
  - MED prototype software
  - JSC institutional support software applications

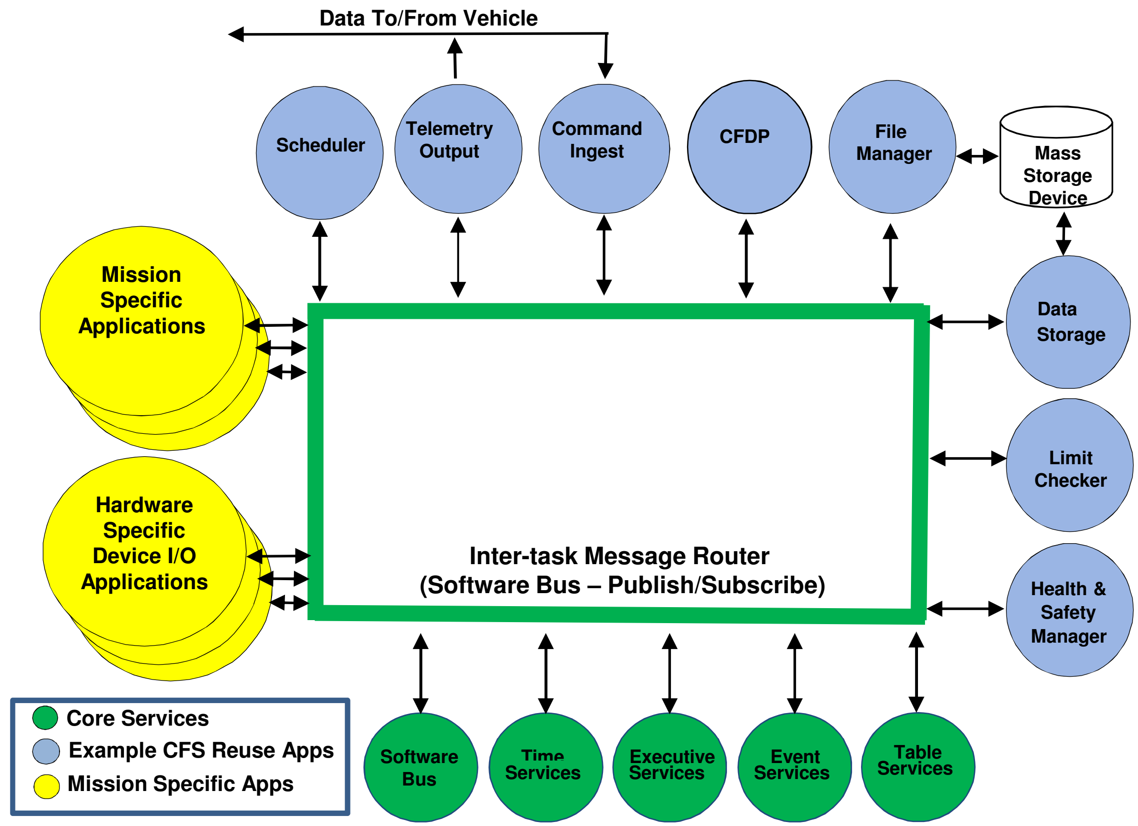


Core Flight Software (CFS) Architecture

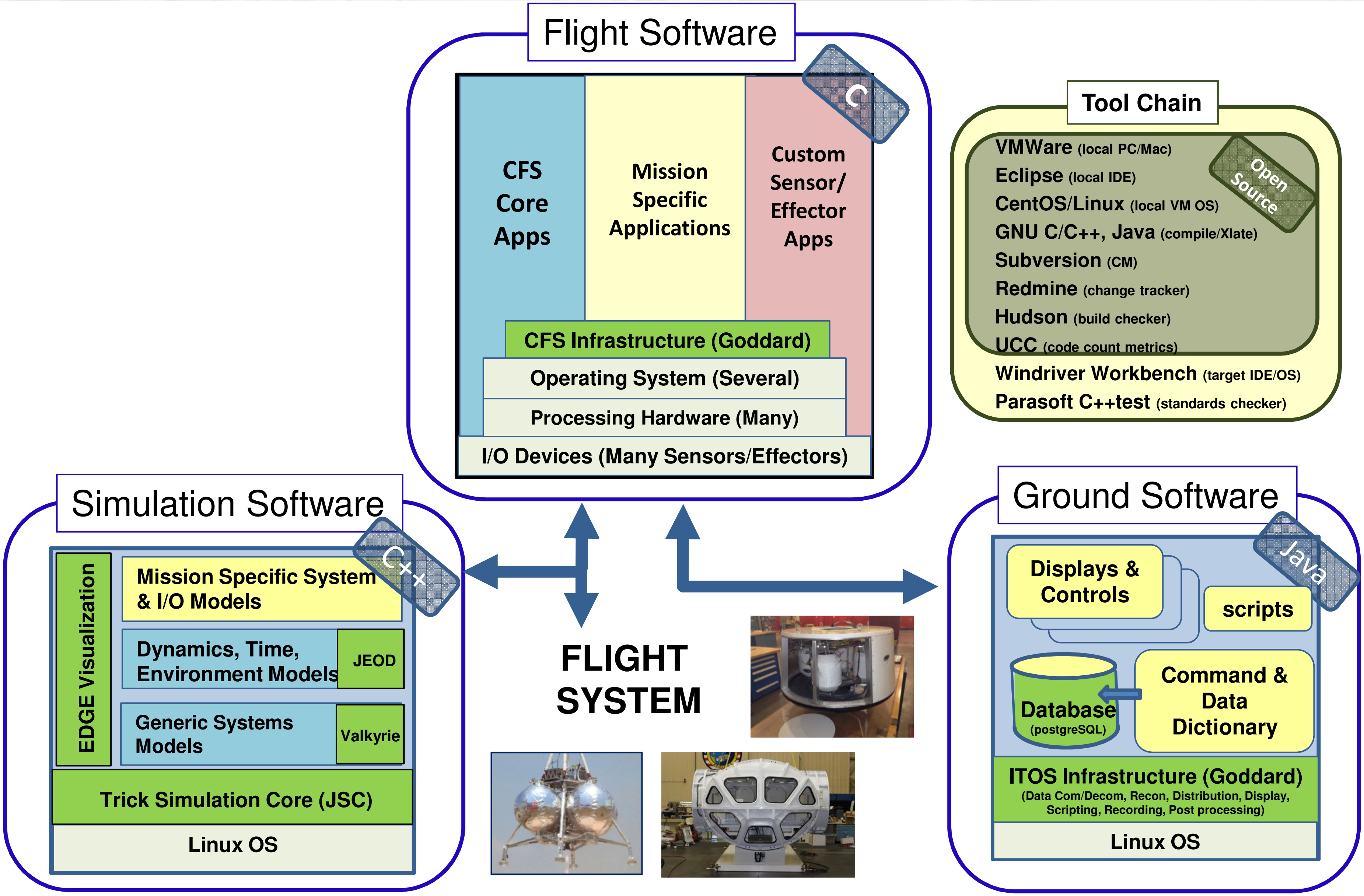
Core Flight Software System Architectural Layers



Typical CFS Application Software Architecture

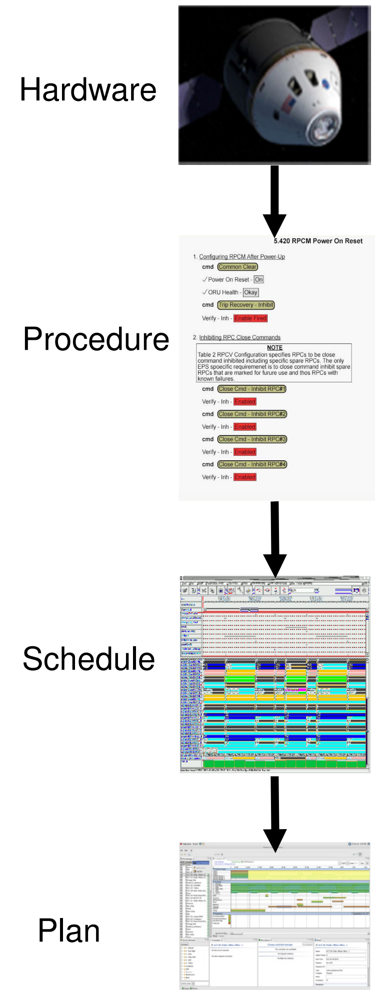


Software Development Triad – Built upon Reuse



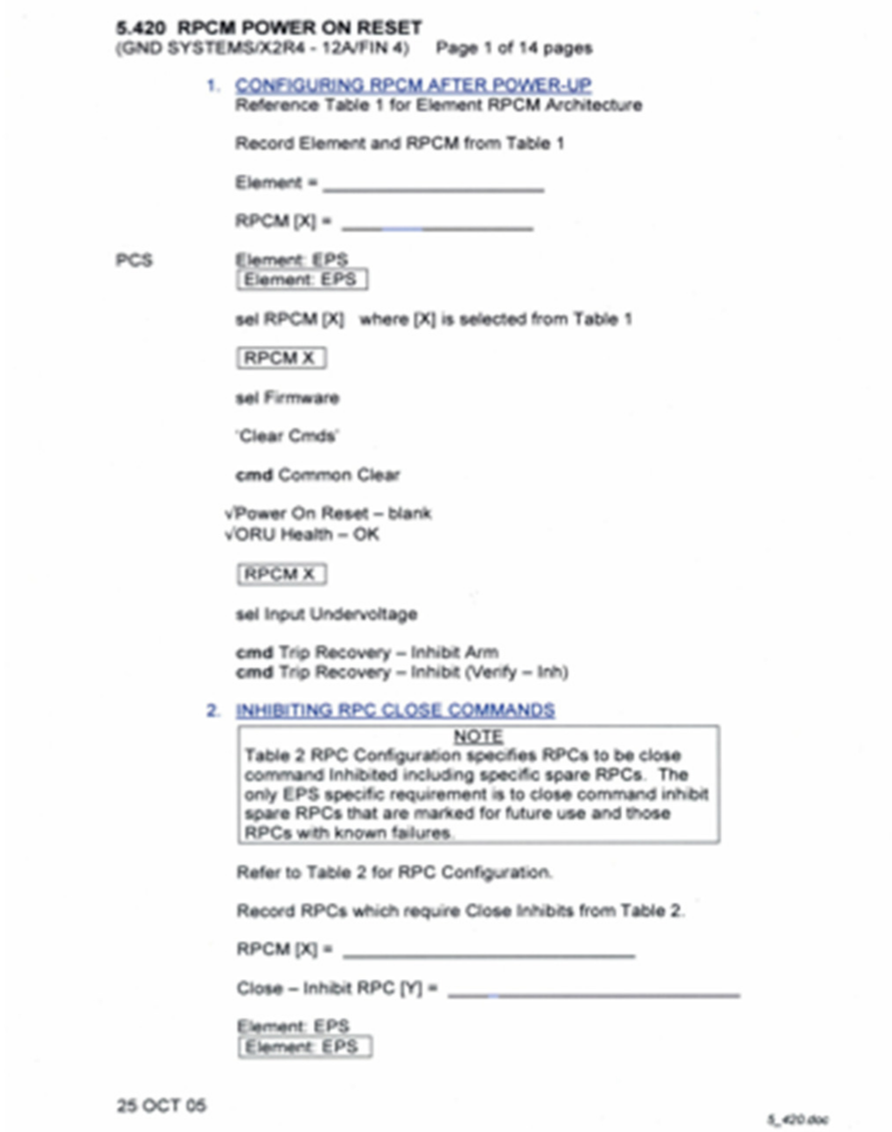
Procedure Background

- Mission Operations: Overview
  - Crew operate equipment using *procedures*
  - Mission Control staff operate equipment remotely using procedures
  - Mission Control staff maintain operations *schedules and plans*
  - Staffing, equipment configuration and manifests also require scheduling and planning



Flight Procedure

- Procedures are critical to conduct any complex operation
- Procedures contain knowledge about how to operate systems to achieve mission goals
- Procedures are the approved means by which a user operates a system
- Users of procedures include crew, flight controllers, instructors, mission designers, payload community, etc.



5.420 RPCM POWER ON RESET
(GND SYSTEMS/X2R4 - 12A/FIN 4) Page 1 of 14 pages

1. CONFIGURING RPCM AFTER POWER-UP
Reference Table 1 for Element RPCM Architecture

Record Element and RPCM from Table 1

Element = ____________

RPCM [X] = ____________

PCS Element: EPS
Element: EPS

sel RPCM [X] where [X] is selected from Table 1

RPCM X

sel Firmware

'Clear Cmds'

cmd Common Clear

√Power On Reset – blank
√ORU Health – OK

RPCM X

sel Input Undervoltage

cmd Trip Recovery – Inhibit Arm
cmd Trip Recovery – Inhibit (Verify – Inh)

2. INHIBITING RPC CLOSE COMMANDS

NOTE
Table 2 RPC Configuration specifies RPCs to be close command Inhibited including specific spare RPCs. The only EPS specific requirement is to close command inhibit spare RPCs that are marked for future use and those RPCs with known failures.

Refer to Table 2 for RPC Configuration.

Record RPCs which require Close Inhibits from Table 2.

RPCM [X] = ____________

Close – Inhibit RPC [Y] = ____________

Element: EPS
Element: EPS

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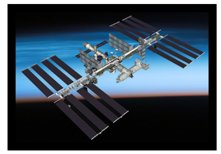
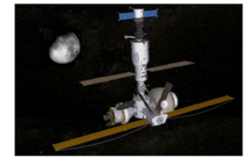
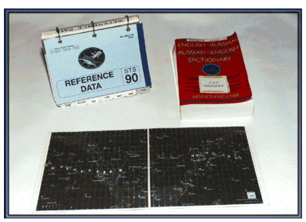
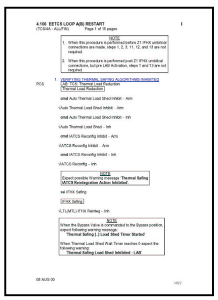
Evolution of Procedures



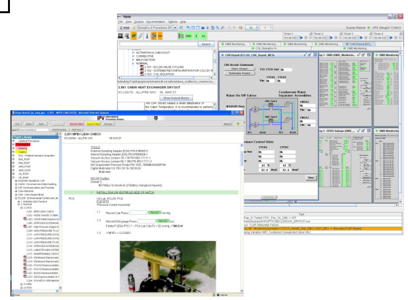




Apollo & Space Shuttle—Paper

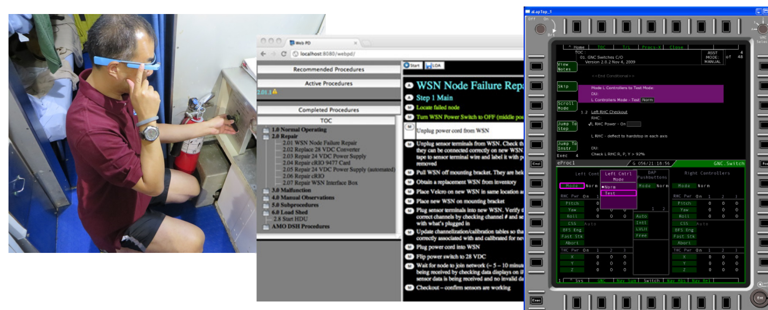


Early ISS—PDF



Current ISS—IPV/XML

- No Automation or Computer Oversight



Orion; Enhanced XML (PRL)

- Computer Oversight
- Automation

Deep Space Exploration- AR-eProc;

- PRL Extension
- Machine Vision and Marker-less Registration

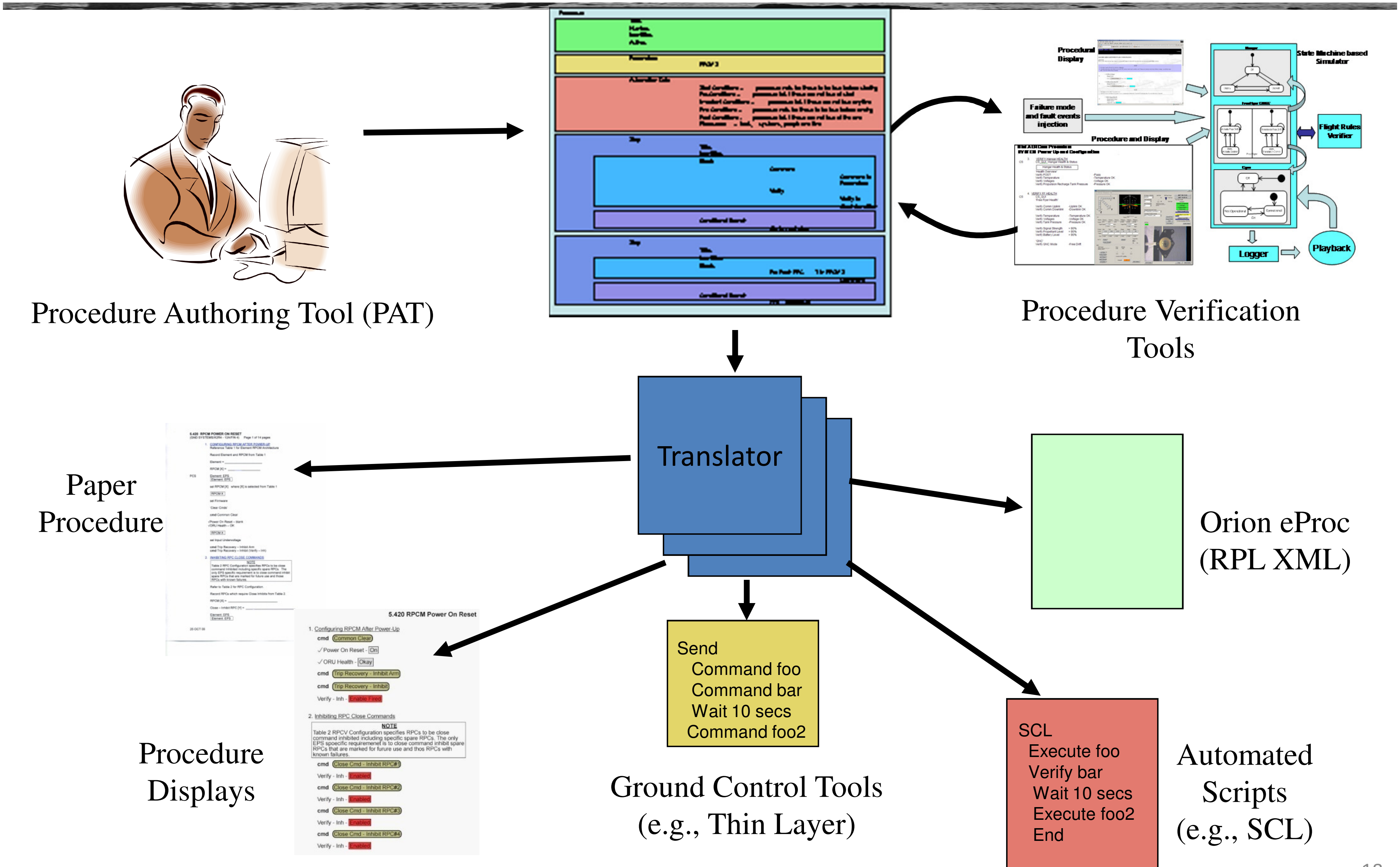
Procedure Requirements

- Need support for automating procedure execution
  - Commands and telemetry
  - Safety conditions/context
  - Explicit control structures
- Don't want to lose human readability
  - Capturing "look-and-feel" of current procedures
  - Presentation of procedure content in a human-friendly way
- Improve quality of execution
  - Improved ease of use
  - Reduction of human error
  - Improved situational awareness
- Interleave human actions with automated scripts

- Use *<u>Procedure Representation Language</u>*
  - Capture and formalized the above stated requirements
  - Started from NASA ODF standards and construct support automation

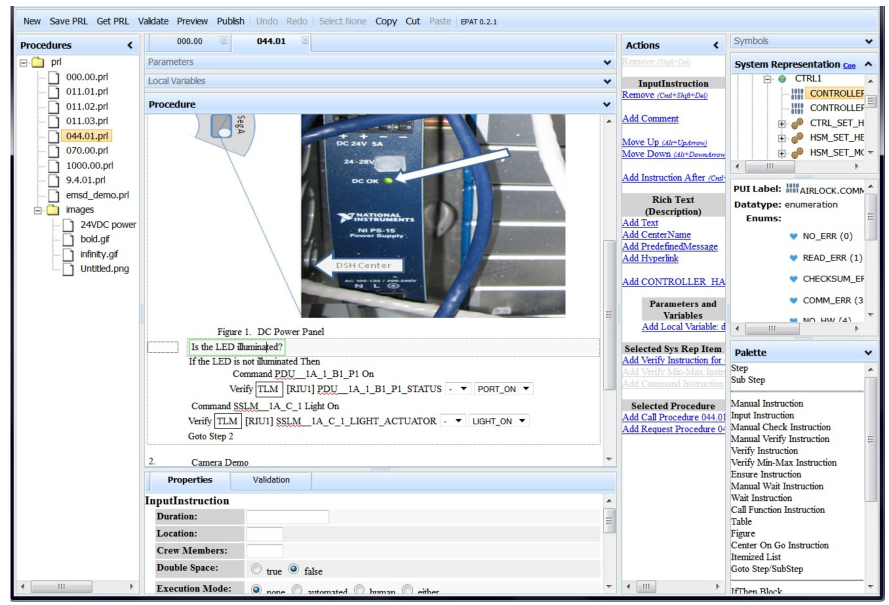
Uses of PRL

Procedure Representation Language (PRL) file

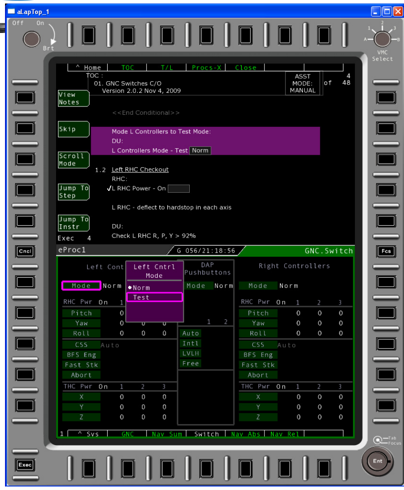


Advanced Procedure Authoring Tool

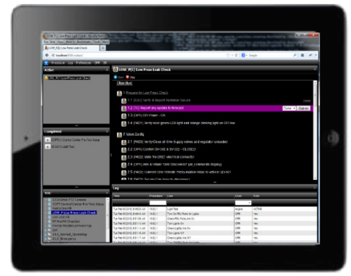
- Full PRL features
- Full PRL compliant
- Drag-n-drop user interface
- Leverage on web based & html5 technologies
- Benefits
  - No executable download or plug-in installation require
  - Centralized application deployment
  - More robust media support from html5 better integration editing, viewing and execution



Procedure Viewer & Executor

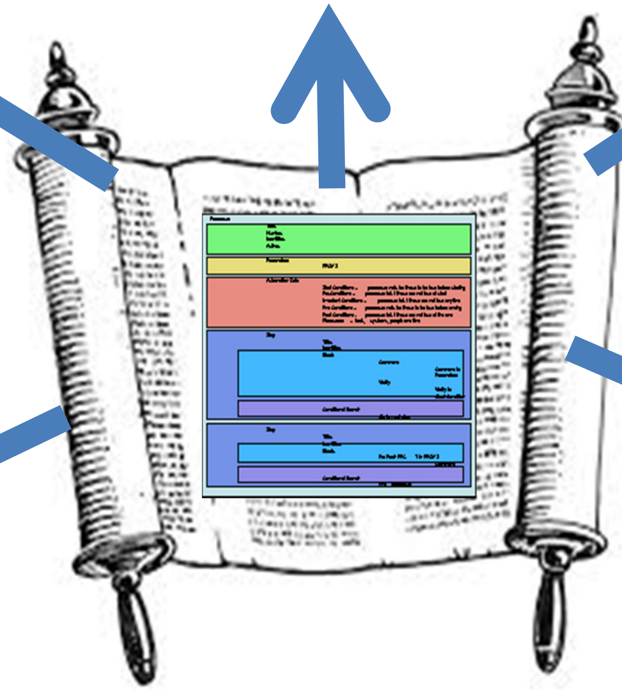


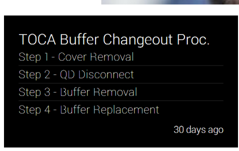
Orion eProc–Flight Deck – focus on Edge Keys Display & Keyboard-less interaction



WebPD – Focus on C&W Integration

AR-eProc– Focus on mixed reality interaction with tablet device





Google Glass – Focus on Mobility & mobile interactions

AR-eProc– Focus on mixed reality interaction hands-free operation

Capture Rich Procedure Content Once and Use It Everywhere

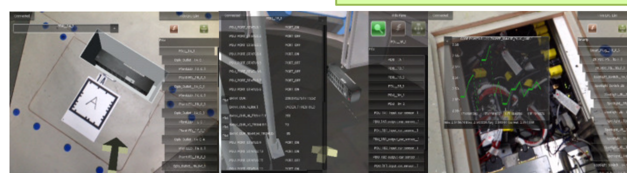
Augmented Reality Training Assistance

Technology Infusion
- JSC IR&D
- AES/AMO, OCT/AS
- ISS DTO

Technology Collaboration
- Google / Glass Project
- Methodist Hospital

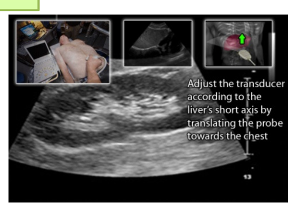
The AR-eProc Vision

AR ARED – Augmented reality Advanced Resistive Exercise Device Cylinder Evac. Procedure



AR DSH Locator - Deep Space Hab augmented reality assets monitoring

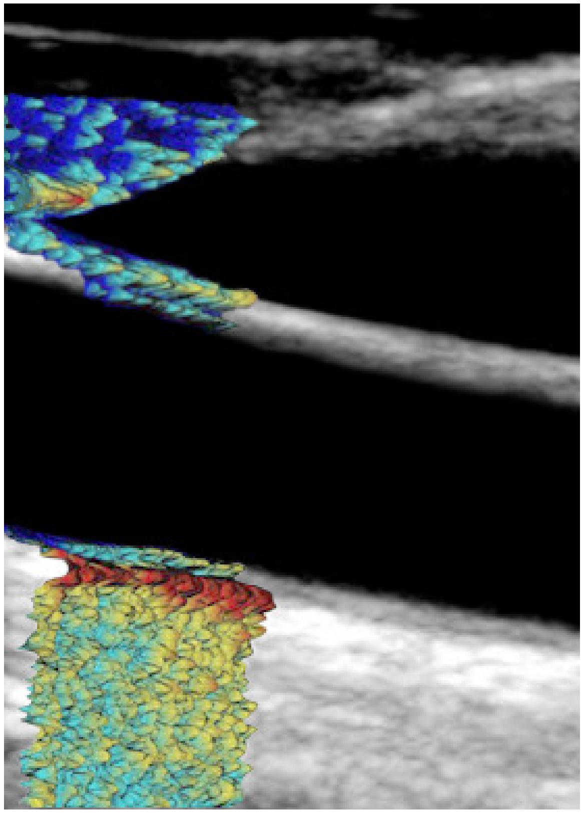
Autonomous Operation



AR Ultrasound - Autonomous guidance

AR TOCA - Augmented reality Total Organic Carbon Analyzer Buffer Change Out Procedure

Future Direction: Autonomous Operations



1. Image detection software depiction of anatomical landmarks which define an adequate carotid image superimposed over an actual carotid artery ultrasound image

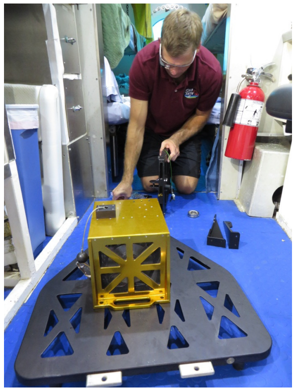
2. Robonaut 2 being remotely guided through carotid artery ultrasound imaging technique

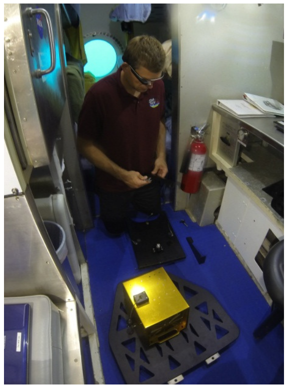
SEATEST II: Just-in-time training & procedure execution with Glass

Miniature Exercise Device (MED):

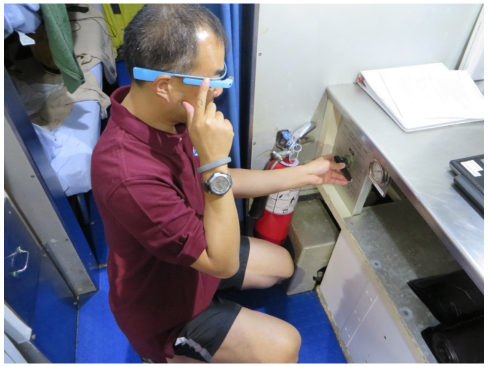
a. Equipment Assembly Task

b. Equipment Dis-Assembly Task

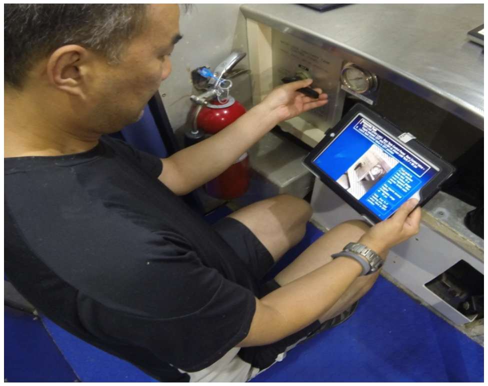




Just-in-time (JIT) training of a Sani-tank purge



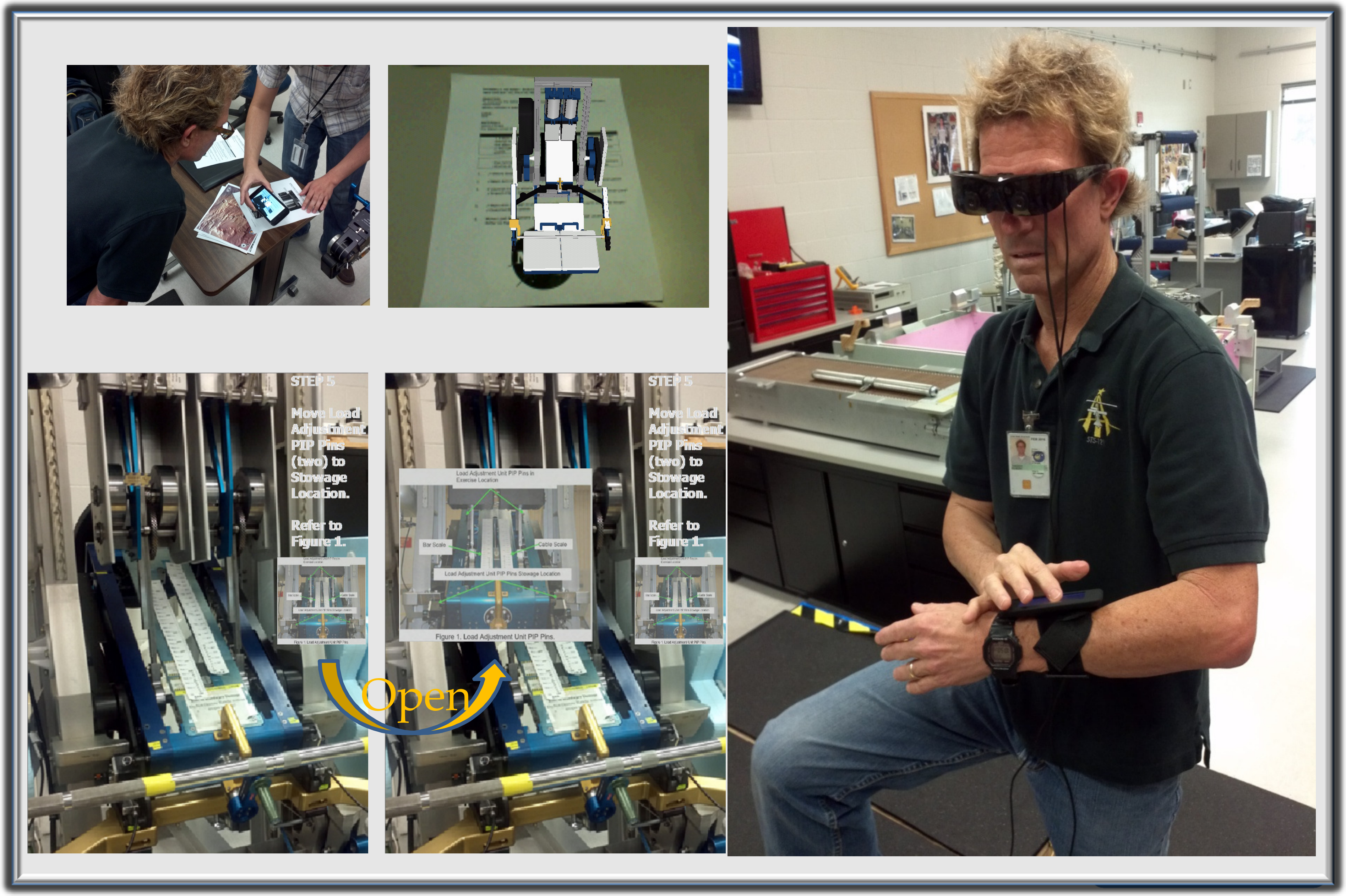
After the task was completed using the Google Glass – the same JITT material was viewed on an iPad



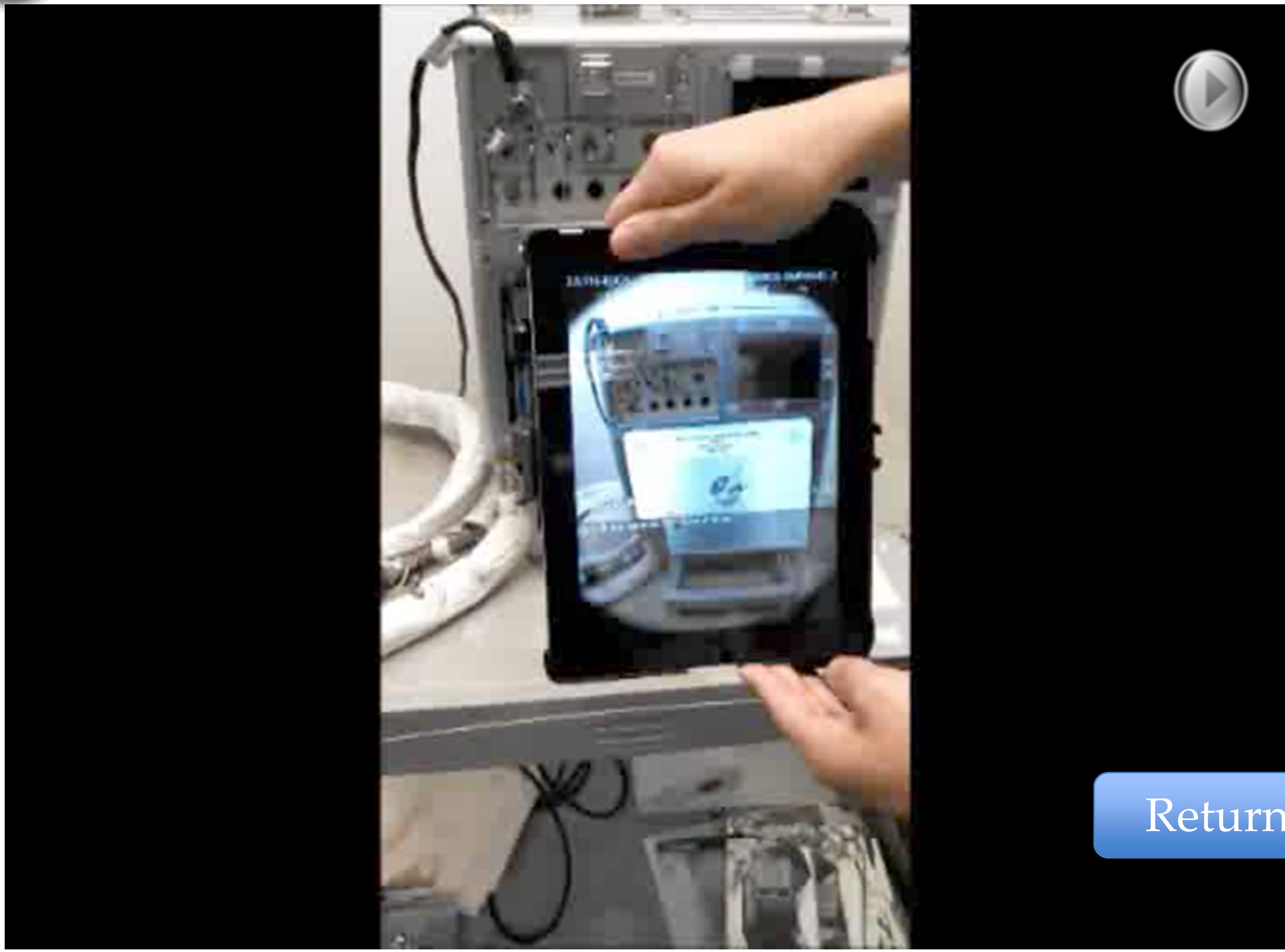
Return

Augmented Reality to Enhance Crew Medical Training

Augmented Reality (AR-eProc ARED)



Augmented Reality (AR-eProc TOCA)



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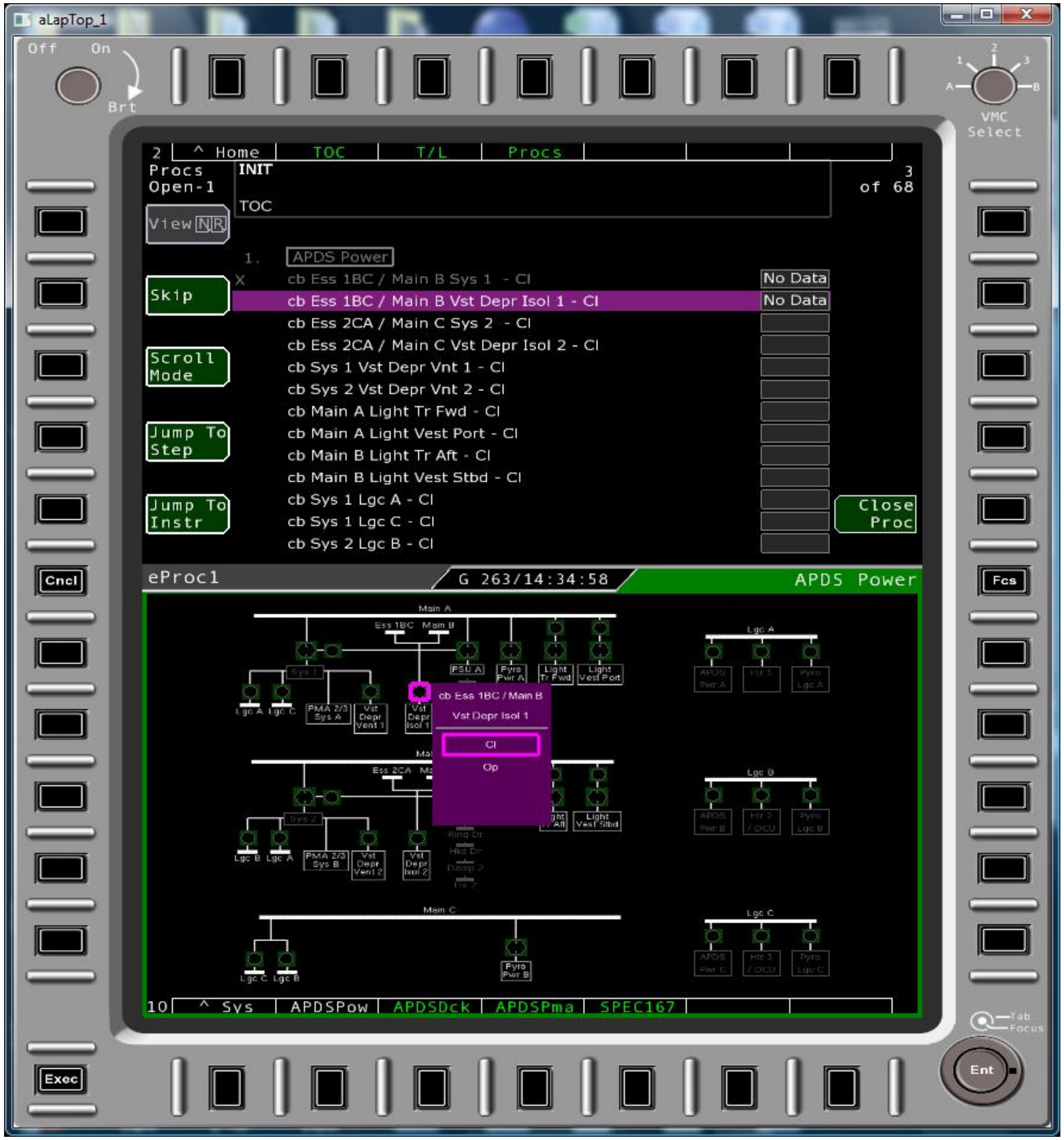
Orion Electronic Procedures



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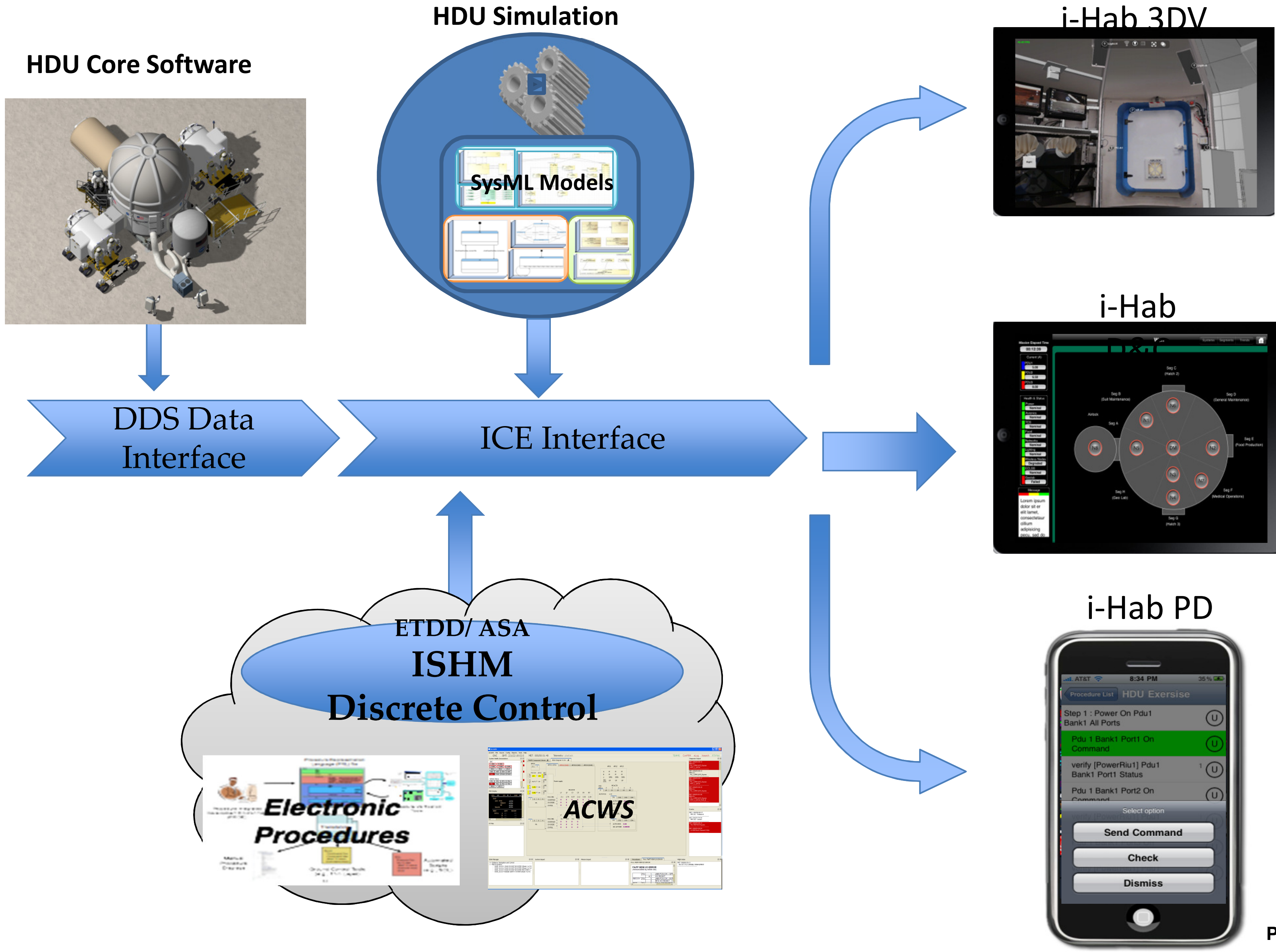
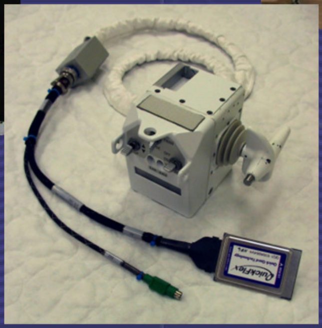
Intelligent Distributed Habitat



Other Projects

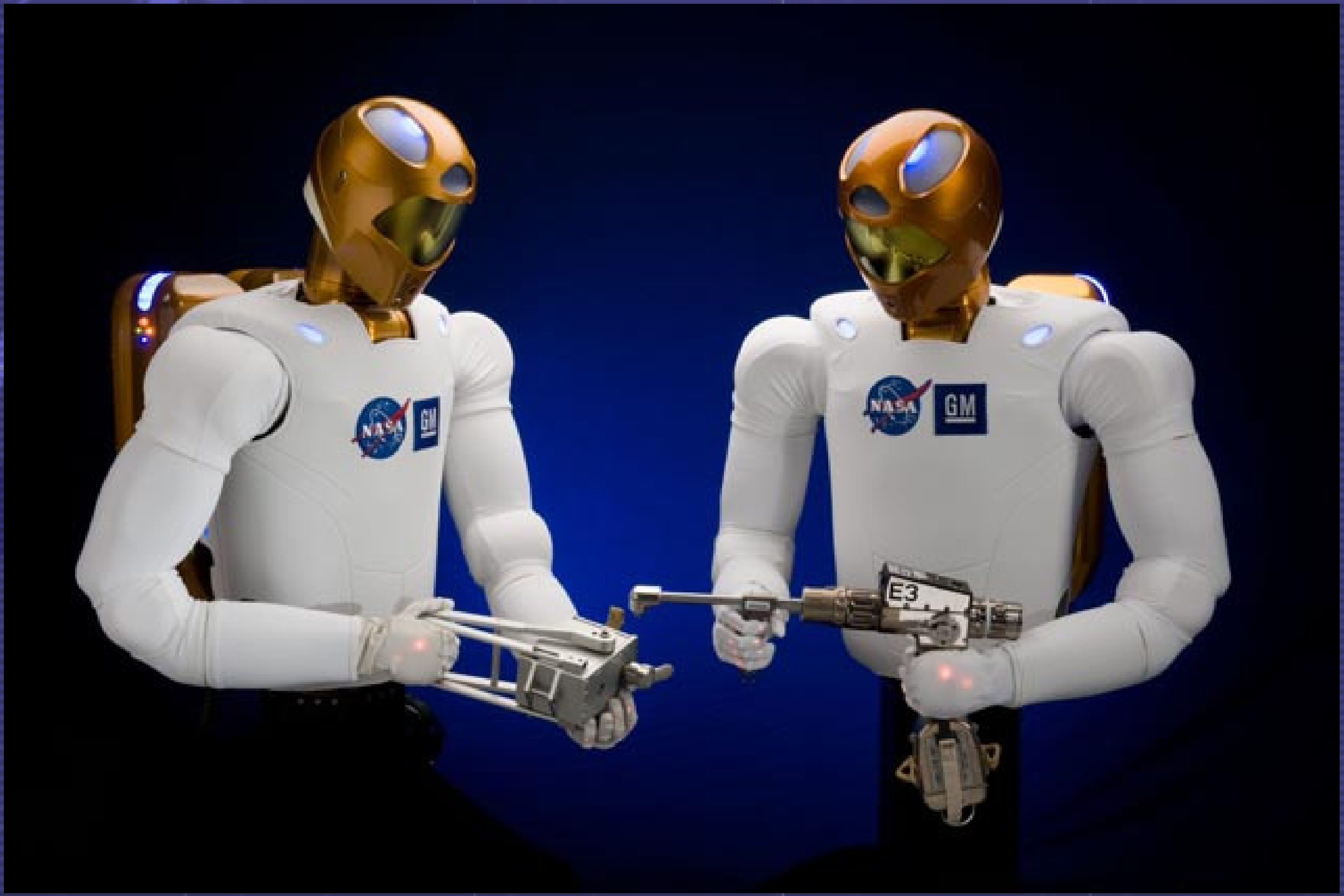
SAFER

SIMPLIFIED AID FOR EVA RESCUE (SAFER)



SAFER On-Board Trainer (SOT)

Robonaut 2

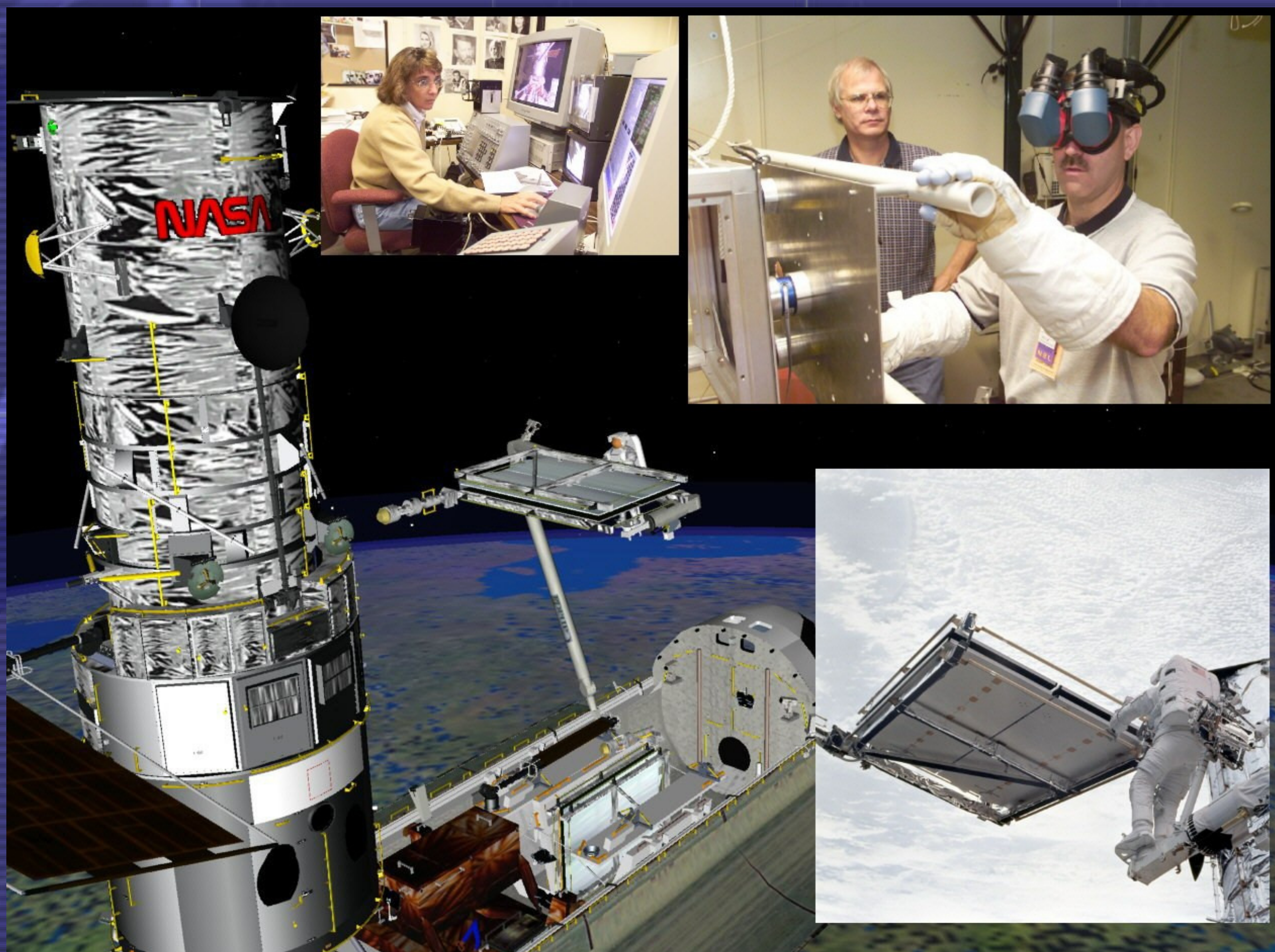


Robonaut 2 on Centaur 2

R-2A at launch of R2-B

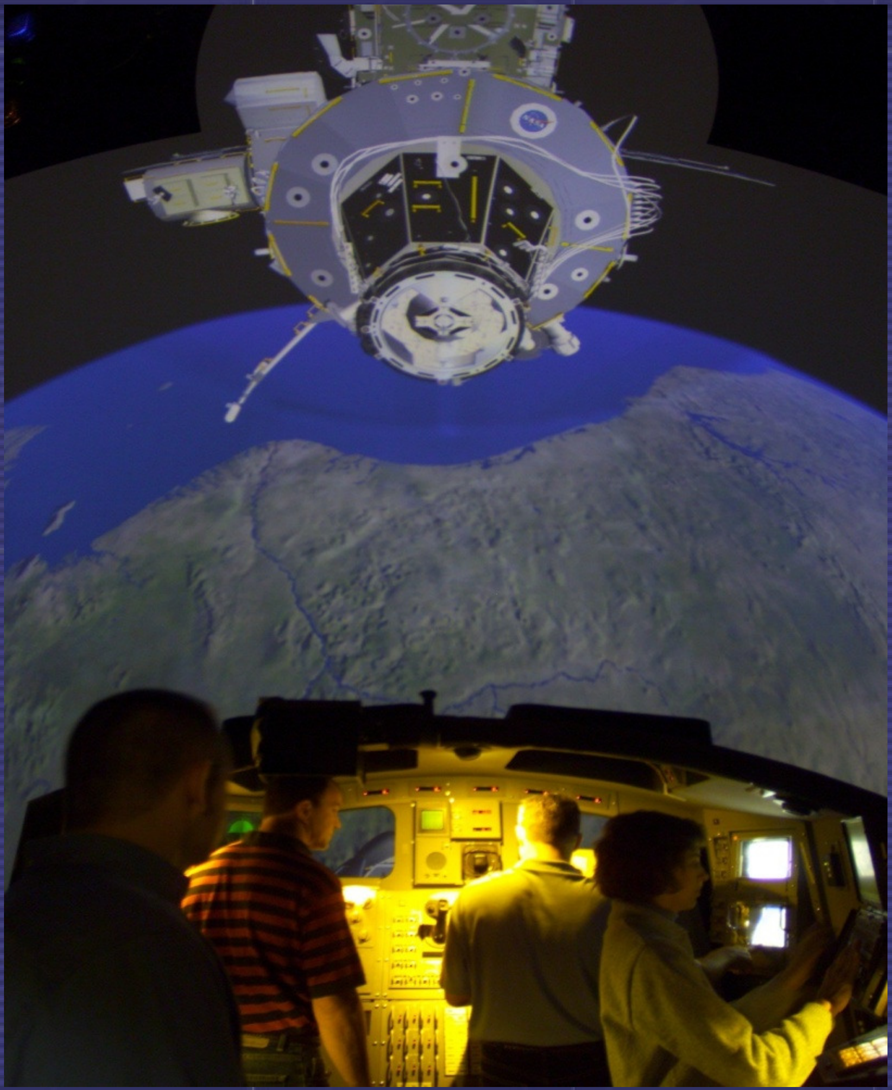
R2 on ISS

Virtual Reality Laboratory (VRL)



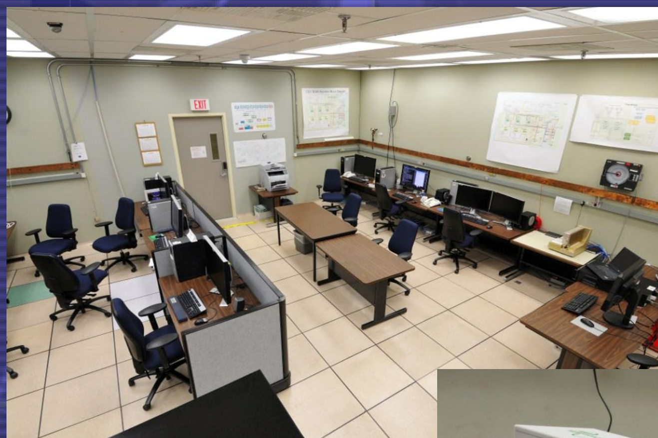
Virtual Reality Lab

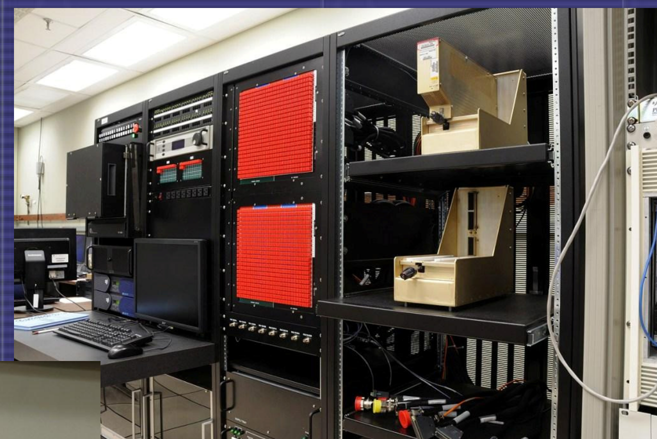
Systems Engineering Simulator



SES On-orbit Simulation in the "Dome"

MPCV/Orion Testing





Kedalion Lab

Miniature Exercise Device

- Miniature Exercise Device (MED) is a small, compact, lightweight exercise device that is capable of supporting high-intensity exercise for deep space missions
- Based on R2 joint technology
- Utilizes torque control to manage cable resistance
- System capable of greater than 300 lbs of resistive force
- MED actuation system ~10 kg
- Proof-of-Concept testing successfully completed
- Supports customized exercise protocols
- Future work will incorporate EMG sensing to close exercise control loop around muscle activity

X1 Exoskeleton

- The X1 is designed as an assistive walking aid for astronauts re-acclimating to gravity environment after long duration spaceflight
  - Post ISS long duration
  - Mars transit
- X1 capabilities have been expanded to provide exercise to crew during the mission
- X1 also functions as a dynamometer to assess changes in strength during spaceflight
- X1 is currently being expanded to include an upper body exoskeleton for similar benefits

ARGOS

Active Response Gravity Offload System Specs

• Dimensions of Structure	41 ft x 24 ft x 18.5 ft
• Horizontal Travel	37 ft x 17 ft
• Vertical Travel	15 ft
• Offload Force [Max Payload Weight ?]	750 lbs
• Vertical Velocity of a 750 lbs load	4 ft/s
• Vertical Acceleration of a 750 lbs load	29 ft/s^2
• Vertical Velocity of a 250 lbs load	10 ft/s
• Vertical Acceleration of a 250 lbs load	88 ft/s^2
• Horizontal Velocity	9.8 ft/s
• Horizontal Acceleration	13 ft/s^2

Active Response Gravity Offload System Applications

- Micro G (ISS, L1, L2, Asteroids, HEO, Martian Moons)
- Lunar G (Lunar Surface)
- Mars G (Martian Surface)
- Terrestrial Rehabilitation

Spidernaut

AERCam

Automated Extravehicular Robotic Camera (AERCam)

Rovers

Lunar Rover Prototype - “Chariot”

Space Exploration Vehicle

Interest in Joining Us?

Find out more about NASA JSC career entry options at:

pathways.jsc.nasa.gov

Current application period closes 26. September 2014

Backup