Robonaut's Return to ISS

POIWG Main Forum
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Jonathan Rogers
Robonaut Deputy Project Manager
NASA/JSC
jonathan.m.rogers@nasa.gov

Overview

- Intro to Robonaut 2
- Brief history of R2 on ISS
  - Tasks completed and lessons learned from torso-only ops
  - Mobility upgrade
  - Anomaly and troubleshooting efforts
- Repair and Upgrades
  - Cause of the anomaly
  - System improvements
- Plans for return to ISS
  - Unpacking, checkout
  - Russian Joint Research opportunity
- Ties to future work
  - Technology demonstrator for Gateway robotic capabilities

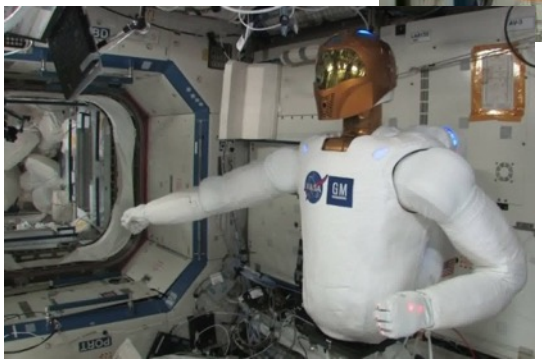
Robonaut 2 (R2)

- Started in 2007 with GM
  - Leveraged Robonaut 1 technology (1998-2006)
- Shared common goals with industry
  - Use humans' tools
  - Safely share humans' workspace
  - Do real (useful) work
- Project announced in early 2010
  - Two functioning R2 units
  - GM and NASA tasks demonstrated in lab environment

Robonaut 1, Units A & B

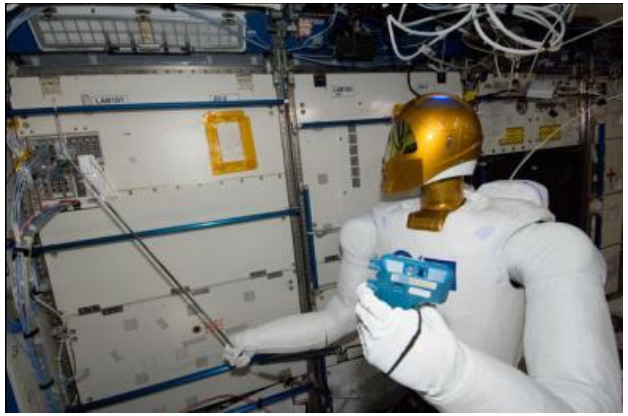
R2 Goes to ISS

- ISS Decides to Fly R2 on STS-133
  - Payload route chosen (Tech Demo)
  - MOD involvement limited to JSL
- R&D Lab Unit Converted to IVA Flight Unit
  - 5 month sprint
- Ops Scenario Defined
  - Fixed base
  - Task board activities
- Flown and Delivered to ISS
  - First motion – Oct 2011
  - First humanoid robot in space



Successes On Orbit

- Free Space Activities
  - Including PAO activities
- First Tool Use
  - New view of VelociCalc readings for Ground Personnel
    - Augmented with machine vision
  - Manipulated RFID tool
- Task Board Ops
  - Buttons, switches, and knobs
  - Integrated machine vision
  - Force guided manipulation
  - Handrail cleaning
  - Softgoods manipulation
- Teleoperation
  - Softgoods manipulation
  - Floating object capture



Torso Lessons Learned

- Conservative Safety Approach Hindered Performance
  - The right initial approach – first non-caged robot inside a space vehicle
  - Safety given top priority during initial checkout
  - Safety systems pushing processors to the limit
    - Frequent false positives
  - Safety limits and configuration not easily changed
    - Required approval from Safety Review Panel

- Learned About Operating a Complex System in Space
  - Performance ground testing was not a perfect match to flight
    - Found a few communication issues
    - Subtle differences between flight and cert robots.

Mobility Upgrades Improve R2

- Designed, built, and qualified climbing legs
- Upgraded Processors
  - Went from two 750 MHz PowerPC processors to three Core i7 processors
  - Operating system changed from VxWorks to Ubuntu Linux
  - Implemented ROS – Robot Operating System, an open-source robotics software framework
- New Control Architecture
  - Higher performance
  - Improved safety system
    - Two fault tolerant system approved by the Safety Review Panel
- Improved Strategies
  - Removing unnecessary safeties
  - Limiting momentum not velocity
  - Refined safety limits
  - Pause before issuing a fault and disabling motor power (“soft stops”)

Post-Upgrade Anomaly

- Installation went smoothly
  - Great work from Swanny
- Initial checkouts successful
  - Sensors were healthy
  - All boards communicating
- Processors stopped responding during software upgrade session
  - Came back with reboots, but uptime became less and less
  - Eventually processors wouldn't boot

On-orbit Troubleshooting and Return

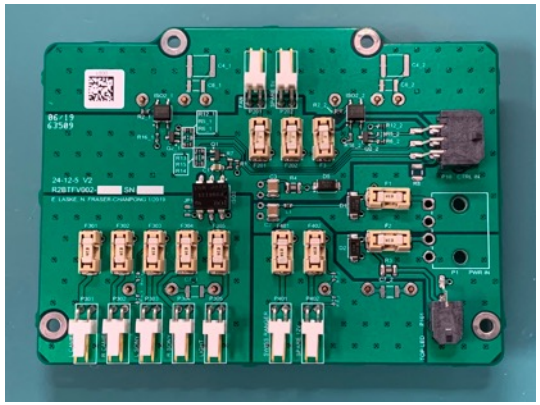
- Worked with 6 crewmembers over 10 sessions to troubleshoot
  - Replaced cards & processors in computer chassis
  - Took measurements with digital multimeter and USB oscilloscope
  - Attempted to bypass suspected bad cable
- Engineering team developed a plan to send a bypass harness
  - Data from crew activities showed that R2 had a degraded 24V power return cable from the computer chassis
  - Went to ISS Program with this plan, but the big-picture decision was to bring R2 home for a proper repair
- R2 was packed up in Feb 2018 and returned on SpaceX-14
  - Arrived in Robonaut lab at JSC in May 2018

Cause of Anomaly

- Fault diagnosed as a missing return wire for computer chassis power
  - On-orbit troubleshooting results put team on the right track for a quick confirmation once home
  - Current returned through an alternate, undersized path
  - A connector in the backpack overheated and opened
  - This issue would have been very difficult to repair on-orbit
- Cause identified as improperly managing return currents in design
- Fault was present in the torso-only configuration, but the lower-power processors operated within the capacity of the sneak circuit

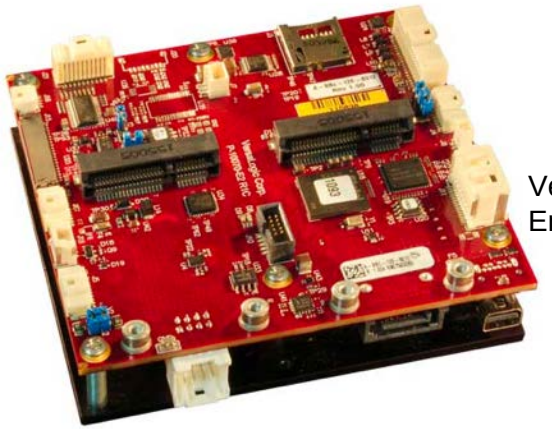
System Improvements

- Did full electrical assessment of flight and cert Robonaut units
  - Compared to a workhorse engineering unit
- Identified and resolved three more potential sneak circuits
- Improved distribution of safety power
- Upgraded the network gateway
- Replaced chassis power supply
- Closed an NCR against excessive force controls
  - Originated when our battery backpack got delayed (later cancelled) late in the development of the mobility upgrades
- Operating system and robot software upgrades
  - Ubuntu 16.04 and ROS Kinetic



Isolated DC-DC converter for Robonaut's head sensors

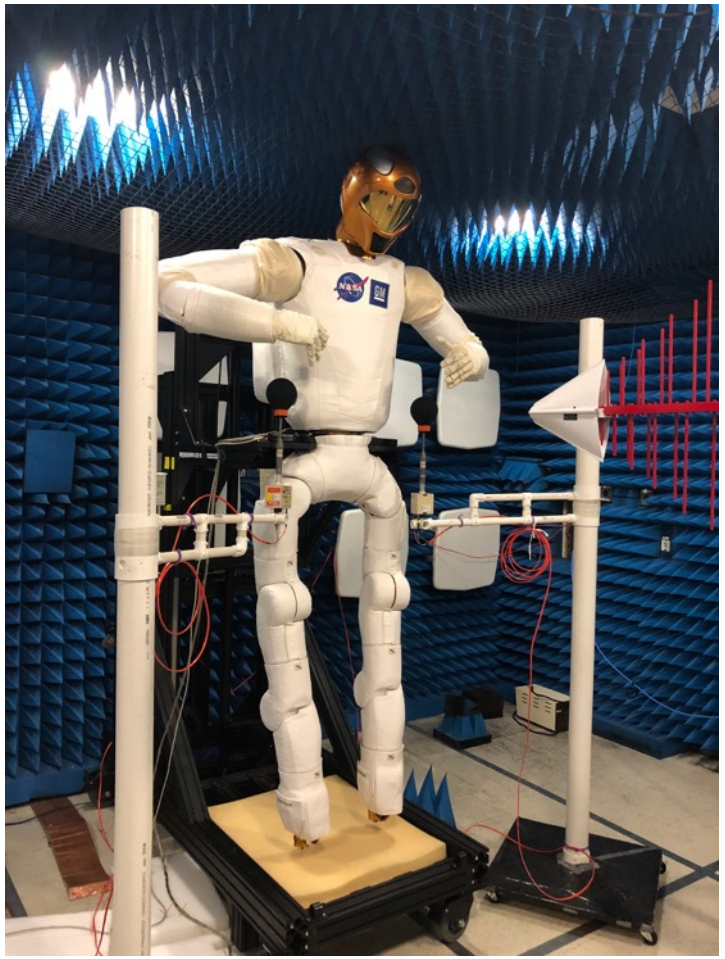
DigiPower cPCI Power Supply



VersaLogic *Raven* Embedded Processing Unit

Path for Return to ISS Operations

- Currently working through final verifications before flight
  - As of 3/26/19, not yet assigned to a flight but on IPL
  - Project's internal schedule has targeted an October 2019 flight
  - Restricted to Cygnus or SpaceX vehicles due to size of Robonaut
  - Will require backpack removal for launch and crew install on ISS
- Checkout activities will ensure system is healthy after launch
  - Discussed doing this as an initial Russian Joint Research activity
  - Training US crews on expected packing configuration and basic ops
  - IPV has an OBT translated into Russian, estimate 30-45 minutes to review



Overview of Crew-Tended Checkout

- Crew Time:
  - US Crew time listed is for a ground-trained USOS crew member
  - RS Crew time listed is for a non-ground trained Russian crew member
  - Sessions require support of either Russian or US crew, but not both
- Assumes proficiency gained with the following activities:
  - Video setup following the second session
  - Manual unstow/stow after the first and third sessions

Session	Target	Inc	US Crew	RS Crew	Activity
1	November*	61*	4:50	6:15	Mobility Checkout
2	December*	61*	1:35	2:15	Mobility Session #1
3	January*	62*	1:35	2:15	Mobility Session #2
4	February*	62*	1:35	1:35	Contingency Re-test Session #1
5	March*	62*	1:35	1:35	Contingency Re-test Session #2
			11:10	**13:55**	**Total Estimated Crew Time**

* Notional schedule dependent on Robonaut's return to ISS and assumes backpack is installed prior to Session 1

Autonomous Logistics Demonstration

June 2018

- Supported by AES Logistics Reduction Project
  - Milestone Aug. 2020 to demonstrate a robotic collaboration task where Robonaut and Astrobee work to locate and retrieve a CTB located by REALM.

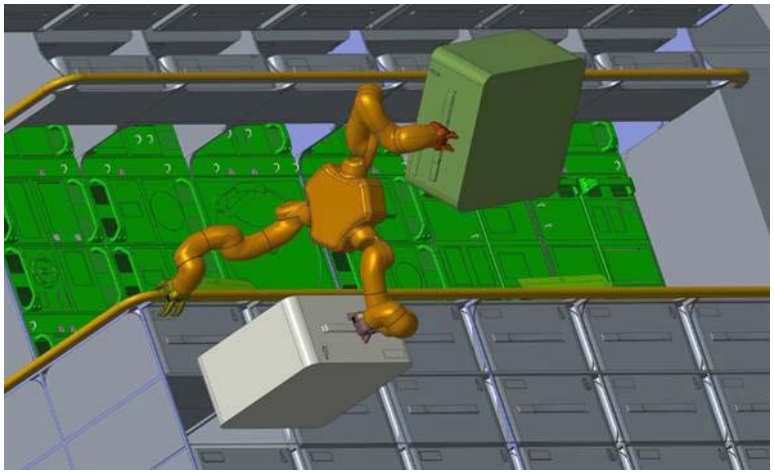
- [Video removed due to eDAA size limitation]
  - Previously approved via eDAA TN57977

Why Return Robonaut to ISS?

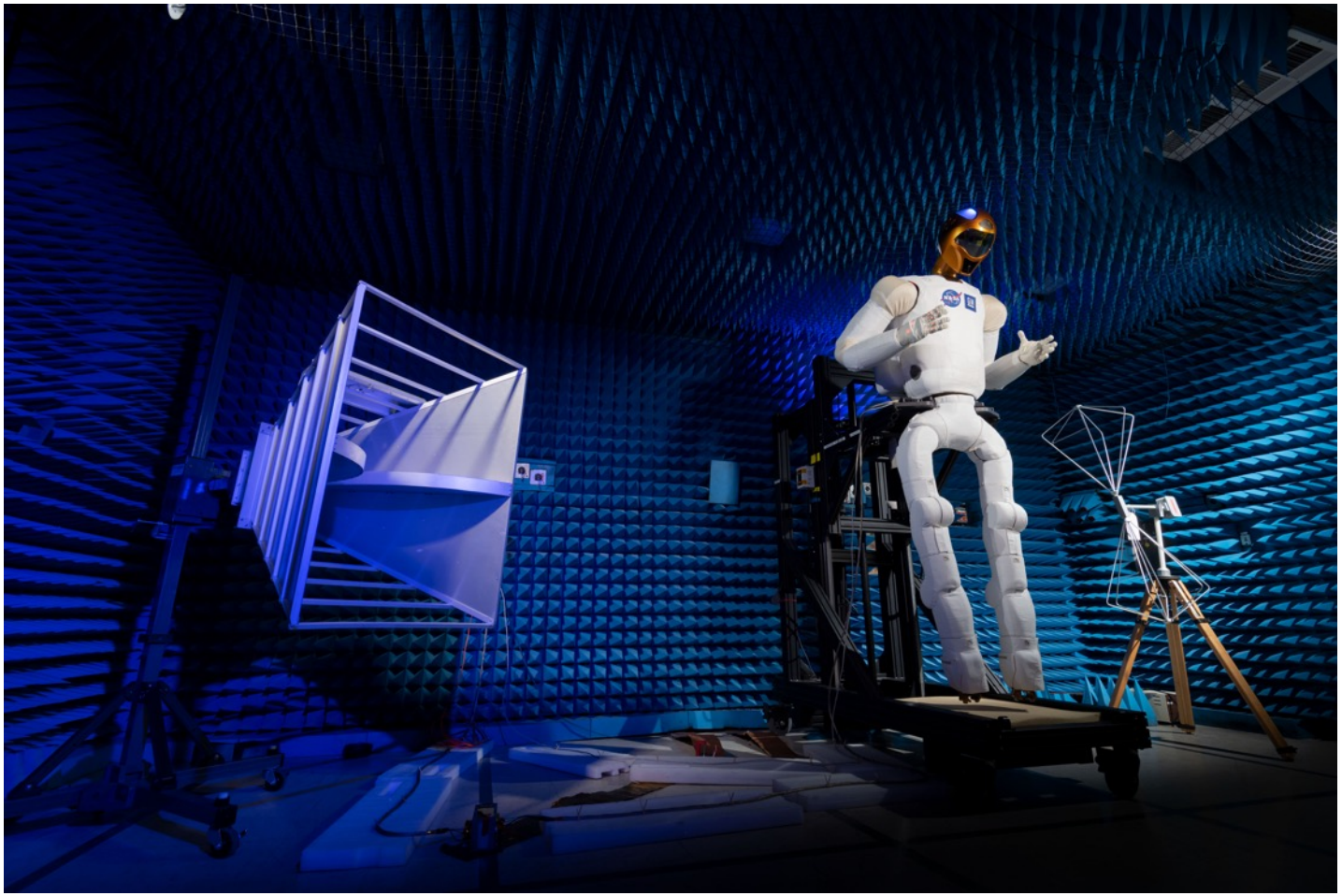
- Robonaut offers a unique platform for TRL advancement
  - An investment has already been made - let's benefit from it
  - Robonaut is a stable platform that is human-safe
  - R2 has history of tech transfer to other manipulators, like the industrial UR5
  - Successful spinoffs like MED2 and RoboGlove
- Gain additional experience on ISS to refine Gateway Intravehicular Robotics (IVR) design and OpsCon

Testbed for Gateway Technologies

- Use Robonaut on ISS as a testbed for robotic caretaking capabilities needed for Gateway
  - Test strategies for climbing mobility in a cluttered environment
  - Advance supervised autonomy for robotic tasks over time-delay and limited bandwidth
  - Investigate manipulation and vision processing commanding over a distributed computing architecture
  - Execute candidate tasks to demonstrate robotic capabilities with REALM and Astrobee
  - In the future, leverage the SPHERES model to allow collaborators to test their own technologies on Robonaut



Questions?



BACKUP

Climbing Will Teach New Lessons

- R2 IVA is a Test Environment
  - ISS is being used as a laboratory
  - Gain experience with gaits, forces and ops concepts
  - Problems will be found and solved
  - Robot must prove itself before each new “step”

- Station is a Cluttered Environment
  - Climbing strategies will develop with testing and updates

- Big Robot
  - Some ISS stakeholders will be concerned with robot proximity
  - Procedures will accommodate stakeholders

- Will not translate as fast as some folks want
  - That’s ok

Successes On Orbit