Development and Deployment of Robonaut 2 to the International Space Station

Abstract:

The development of the Robonaut 2 (R2) system was a joint endeavor with NASA and General Motors, producing robots strong enough to do work, yet safe enough to be trusted to work near humans. To date two R2 units have been produced, designated as R2A and R2B. This follows more than a decade of work on the Robonaut 1 units that produced advances in dexterity, tele-presence, remote supervision across time delay, combining mobility with manipulation, human-robot interaction, force control and autonomous grasping. Design challenges for the R2 included higher speed, smaller packaging, more dexterous fingers, more sensitive perception, soft drivetrain design, and the overall implementation of a system software approach for human safety.

At the time of this writing the R2B unit was poised for launch to the International Space Station (ISS) aboard STS-133. R2 will be the first humanoid robot in space, and is arguably the most sophisticated robot in the world, bringing NASA into the 21st century as the world's leader in this field. Joining the other robots already on ISS, the station is now an exciting lab for robot experiments and utilization. A particular challenge for this project has been the design and certification of the robot and its software for work near humans. The 3 layer software systems will be described, and the path to ISS certification will be reviewed.

R2 will go through a series of ISS checkout tests during 2011. A taskboard was shipped with the robot that will be used to compare R2B's dexterous manipulation in zero gravity with the ground robot's ability to handle similar objects in Earth's gravity. R2's taskboard has panels with increasingly difficult tasks, starting with switches, progressing to connectors and eventually handling softgoods. The taskboard is modular, and new interfaces and experiments will be built up using equipment already on ISS. Since the objective is to test R2 performing tasks with human interfaces, hardware abounds on ISS and the crew will be involved to help select tasks that are dull, dirty or dangerous.

Future plans for R2 include a series of upgrades, evolving from static IVA (Intravehicular Activity) operations, to mobile IVA, then EVA (Extravehicular Activity).

Key Words:

Robot, Dexterity, Safety, Manipulation, Humanoid, Space

Mug Shot:

Development and Deployment of Robonaut 2 to the International Space Station

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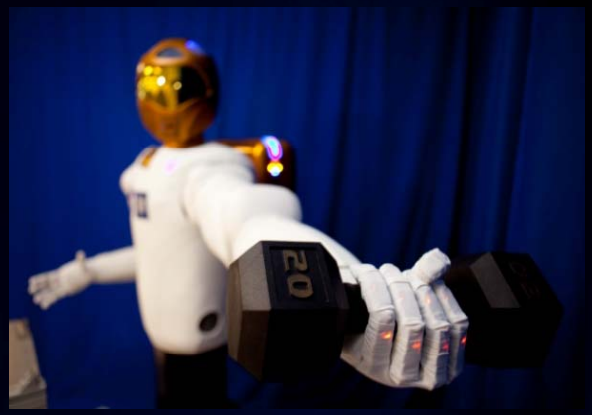
Robonaut Vision:

Build a Robotic Assistant that Can Safely Assist Astronauts, Working in EVA Access Corridors and with EVA Interfaces.



Robonaut 2 (R2) ISS Flight Demo

Brief History
- GM Industrial partnership
- NASA ESMD demonstration
- NASA SOMD ISS payload
- Launched on STS-133

Experimental Objectives
- Test dexterous manipulation in 0g
- Test robot-crew safety in 0g
- Refine control based on tests

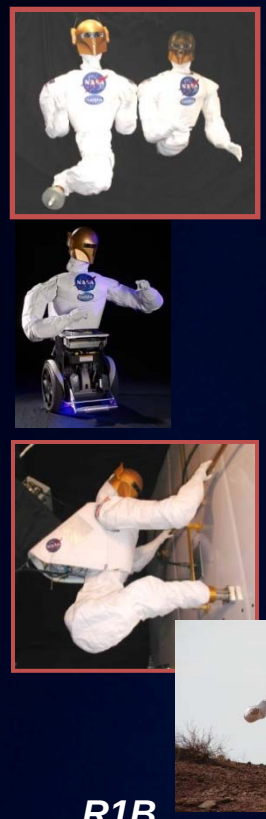
Experiment Phases
- IVA on fixed stanchion & taskboard
- IVA mobile
- EVA mobile

Future Utility
- Transition to ISS EVA asset
- Future robots for beyond LEO
- Terrestrial applications & partners

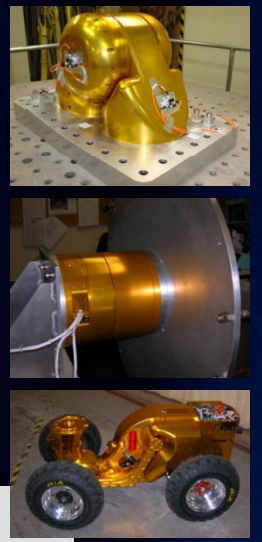
Robonaut 1 History (Distant Past)

- **1998**
  - Subsystem Development
  - Testing of hand mechanism
- **1999**
  - Single Arm Integration
  - Testing with teleoperator
- **2000**
  - Dual Arm Integration
  - Testing with dual arm control
- **2001**
  - Waist and Vision Integration
  - Testing under autonomous control
- **2002**
  - R1A Testing of Autonomous Learning
  - R1B Integration
- **2003**
  - R1A Testing Multi Agent EVA Team
  - R1B Segway Integration
- **2004**
  - R1A Autonomous Manipulation
  - R1B 0g Airbearing Development
- **2005**
  - Development of R1C Joints
  - Supervision Across Time Delay
- **2006**
  - Integrate R1B with Centaur Base
  - Thermal, vacuum and vibe testing of R1C

R1A



R1B



R1C

Robonaut 2 History (Recent Past)

- 2007
  - SAA for GM & NASA
  - R2 concepts
  - Prototype joints
- 2008
  - R2 Single Limb Integration
  - R2A Integrated
- 2009
  - R2A completes first assembly task
  - R2B Integrated
- 2010
  - January ISS decision made
  - February Public Release
  - July R2B Certification
  - August R2B Packed in MPP
- 2011
  - February STS-133 Launch





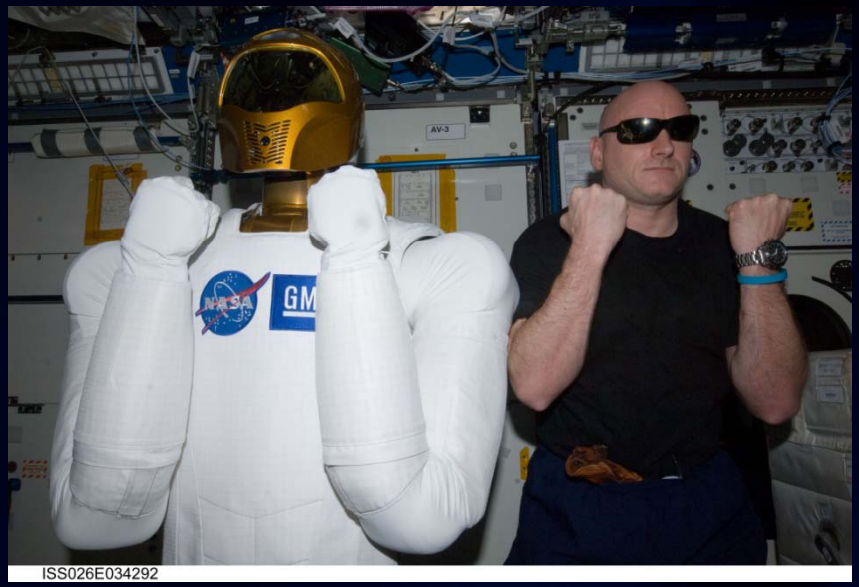
R2A




R2B

Robonaut 2 ISS Update

- **R2 Unpacked 3/15/2011**
  - **Mounted on IVA Stanchion**
  - **Punk'd by Crew**
- **R2 Power Up**
  - **Planned for late May**
  - **Thermal model validation**



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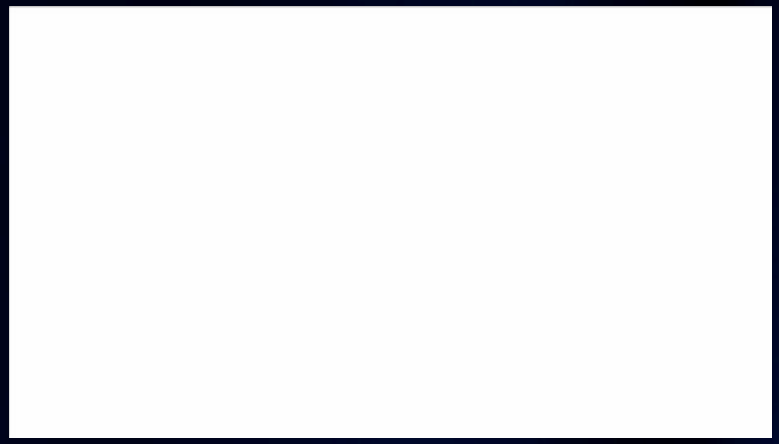
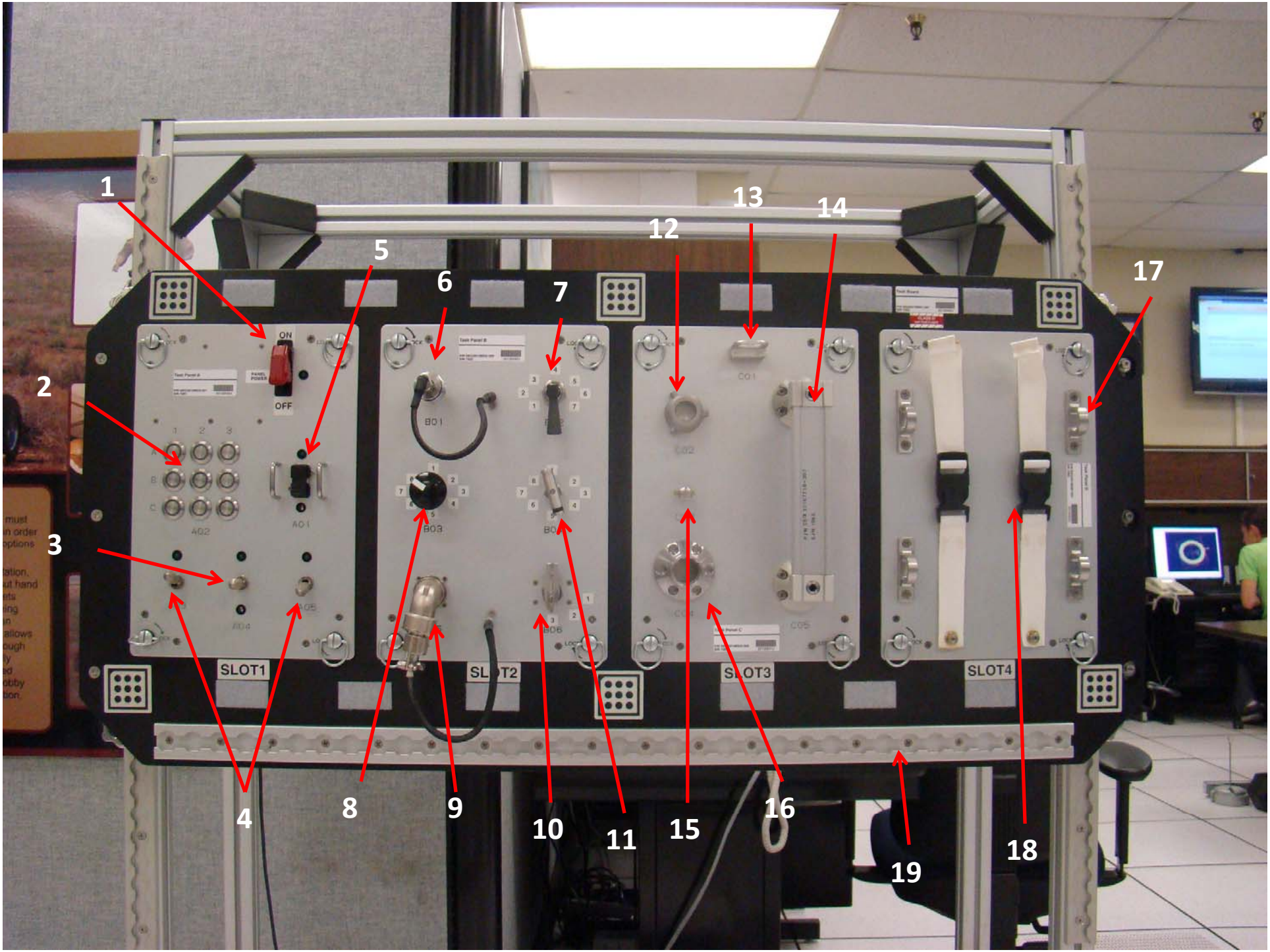
Robonaut 2 Safety

- **ISS Certification**
  - **Approved for work with crew**
  - **No “E-Stop” needed**
- **Includes 3-layer safety software**
  - **Joint force control**
  - **Wrist force control**
  - **Shoulder force control**
- **Force Thresholds**
  - **Pause magnitude threshold**
  - **Stop magnitude threshold**
  - **Stop frequency threshold**

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SLOT1
SLOT2
SLOT3
SLOT4

Task Board Key (See Previous Slide)

- Powered Panel Assy
  1. Non-locking 2-way switch with switch guard
  2. Push button switch array (blue and green)
  3. Locking 3-way switch
  4. Locking 2-way switch
  5. 2-way rocker switch with finger guards
- IVA Panel Assy
  6. Fluid Quick Disconnect (QD) Valve
     - Used for fluid connections on station
  7. Toggle Valve
  8. Metering Valve
  9. Circular connector
     - Used for powered connections on station
  10. Ball Valve
  11. Needle Valve
- EVA Panel Assy
  12. Microconical Fitting
      - Interfaces with the Round Scoop EVA handling tool
  13. Tether Ring Assembly
  14. EVA Handrail Assembly
  15. 7/16” EVA Bolt
  16. EVA Change-Out Mechanism (ECOM) Socket
      - Interfaces with the Body Restraint Tether (BRT) and Multi-Use Tether (MUT)
- Stowage Panel Assy
  17. Tether loops (x4)
  18. Strap Assembly
- Task Board Face
  19. Seat Track

R2 Experimental Objectives

- **Test Dexterous Manipulation in Zero Gravity (0g)**
  - **Why Dexterous?**
    - **Work with EVA interfaces (# of interfaces)**
    - **Compliment other ISS robots (# of tasks)**
  - **Why is 0g Important?**
    - **Gravity dominates force control (New control gains)**
    - **Friction, dynamics are different (New control gains)**

- **Test Human Safety**
  - **Tune force control safety to 0g (New safety limits)**
  - **Tune shock control safety to 0g (New safety limits)**

- **Refine Control Based on Task Tests**
  - **Compare 0g with Earth performance (parameters, time)**
  - **Develop anticipation for new tasks (delta design)**

Robonaut 2 Phase 2

- **Main focus: IVA Mobility**
- **Schedule: 12 months**
- **Development**
  - **Backpack in Development Now**
    - **Battery**
    - **Wireless Comm**
  - **Zero G Climbing Legs in Development Now**
    - **2 Legs for climbing, 1 always in contact**
    - **Seat Track, Hand Rails, WIF spike**
- **Analysis, Testing, and Certifications**
  - **IVA task analysis (house keeping)**
  - **Backpack & legs for launch to ISS**

Robonaut 2 Phase 3

- **Main focus: EVA Mobility**
- **Schedule: 12 Additional Months**
- **Evolution**
  - **Torso/Head Component Upgrades**
    - **Replace convection cPCI with conduction cPCI**
    - **Replace cameras in head**
  - **Other changes based on 2011 TVAC testing**
- **Analysis, Testing, and Certifications**
  - **EVA worksite analysis**
  - **Specific tasks e.g. RPCM blankets, SARJ & tools inspection**
  - **Components for launch to ISS**

Robonaut 2 Future Applications

- **ISS EVA**
  - **Minute Man**
  - **SSRMS and other Modes**
- **Beyond LEO**
  - **Satellite Servicing**
  - **Asteroid Missions**
  - **Precursors**
- **Terrestrial Applications**
  - **GM Partnership**
  - **University Researchers**
  - **Innovation Challenges**