Robonaut 2 - The First Humanoid Robot on the International Space Station and its Spinoff Technologies

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Overview

Why Robots?
Robonaut Motivation
GM Relationship
Robonaut Evolution
Robonaut 2 (R2) Capabilities
Preparing for ISS
Journey to Space
On Board ISS
Toward an EVA R2
Technology Spinoffs

Why Robots?

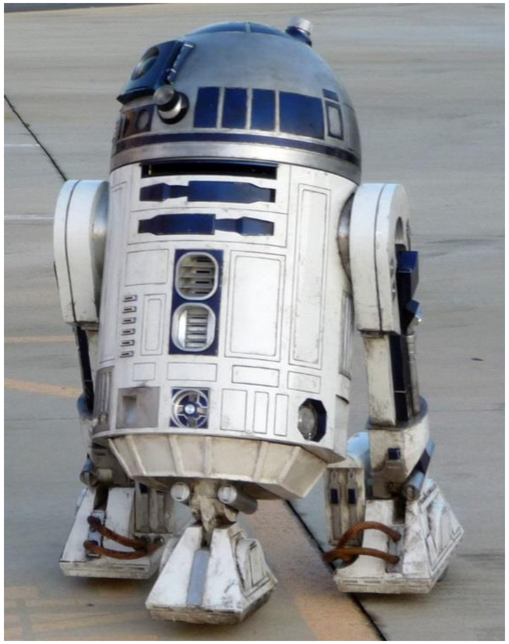
Science Fiction has given us many ideas for how robots can interact with human society.

As robot designers we are primarily focused on the 3 D's

Dangerous

Dirty

Dull



Why a Humanoid?

- Humans are very adaptable to performing many different tasks.
- The space environment that humans work in has been designed with humans in mind.
- A robot that can use the existing tools and work environment has many advantages.

Robonaut Motivation

Capable Tool for Crew

- Minuteman capability to investigate external problems
- Assist before, during and after activities

Share EVA Tools and Workspaces

- Human Like Design

Increase IVA and EVA Efficiency

- Worksite Setup/Tear Down
- Robotic Assistant
- Contingency Roles

Astronaut Nancy Currie works with 2 Robonauts to build a truss structure during an experiment.

Robonaut Development History

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 Segwanaut Integration

2004

- R1A Autonomous Manipulation
- R1B 0g Airbearing Development

2005

- DTO Flight Audit
- Begin Development of R1C

2006

- Centaur base
- Coordinated field demonstration

ROBONAUT
Fall 1998

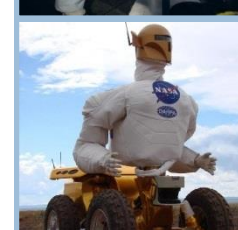
ROBONAUT
Fall 1999

ROBONAUT
Fall 2000

ROBONAUT
Fall 2001

ROBONAUT
Fall 2002

ROBONAUT
Fall 2003



ROBONAUT
Fall 2004

ROBONAUT
Fall 2006

R2 – Successful Government-Industry Collaboration

NASA / GM partnership

- In early 2007, GM and NASA began the R2 development
- GM embedded 7 engineers onsite at JSC, working with equal numbers of NASA and Oceaneering Space Systems (OSS) Engineers
- Formed a "Badgeless" team
- Phase 1 completed in 2011

Why did GM approach NASA?

- World wide search for experienced development partner
- Looking for a robot that could do work
- Identified Robonaut development at JSC as a good match in terms of common goals and maturity level

Project Goals

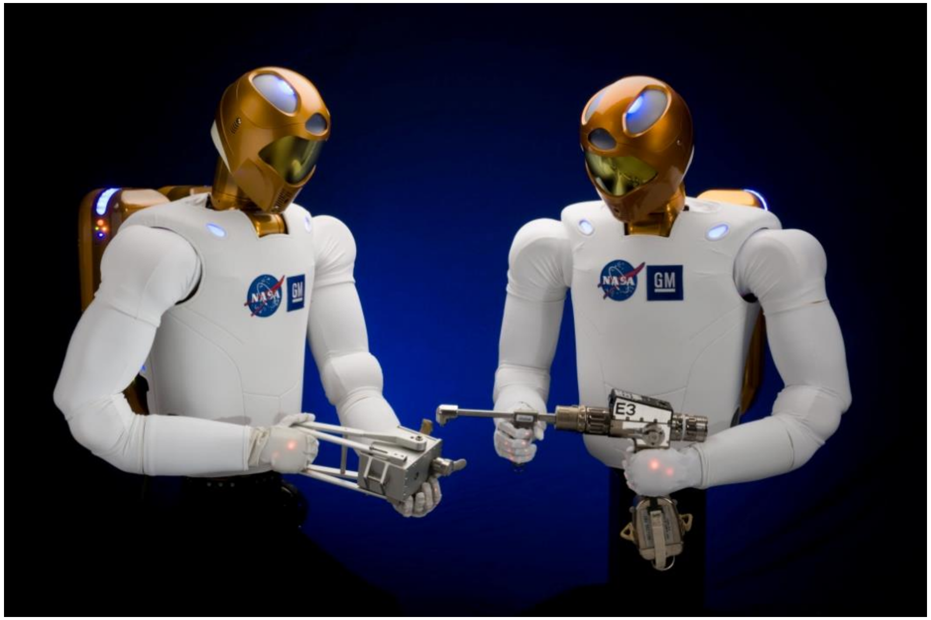
- Exploit "Humanoid Dexterity"
- Automate "Non Traditional" Applications
- Ergonomically difficult tasks

Robonaut Series

Robonaut 1 (R1)

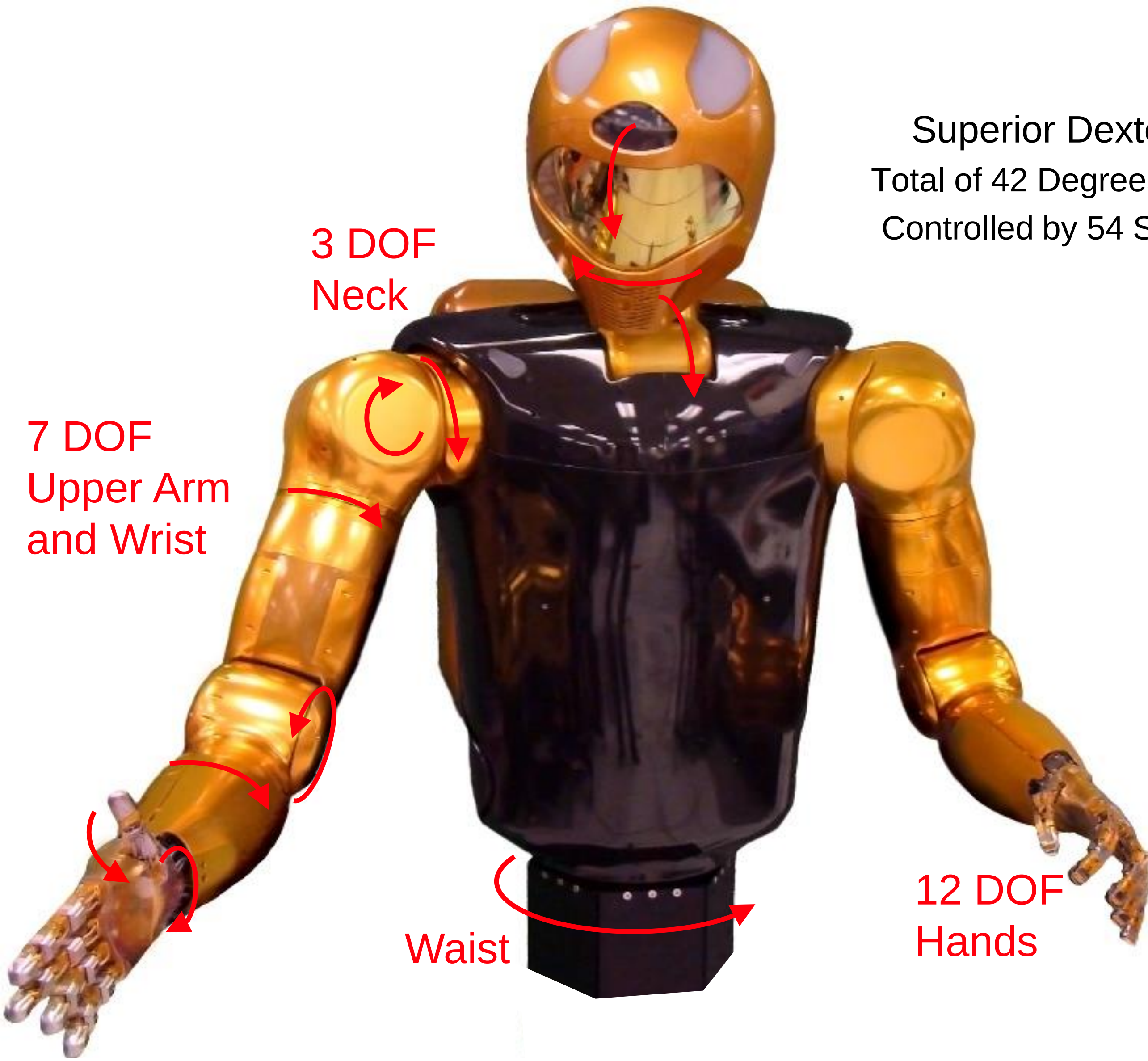
Excellent

Robonaut 2 (R2)



Better

Robonaut 2 Introduction



Superior Dexterity

Total of 42 Degrees of Freedom

Controlled by 54 Servo Motors

Robonaut 2 Introduction

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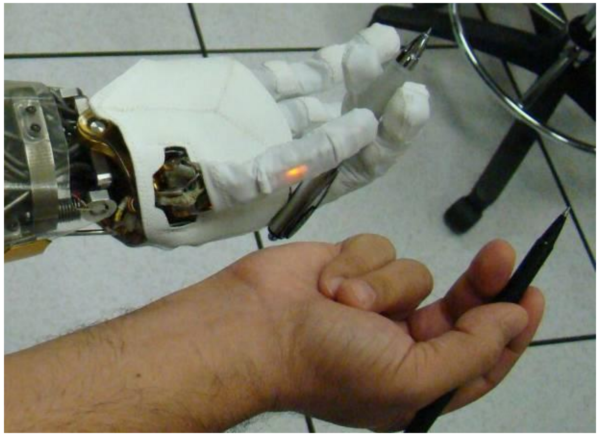
On Board ISS

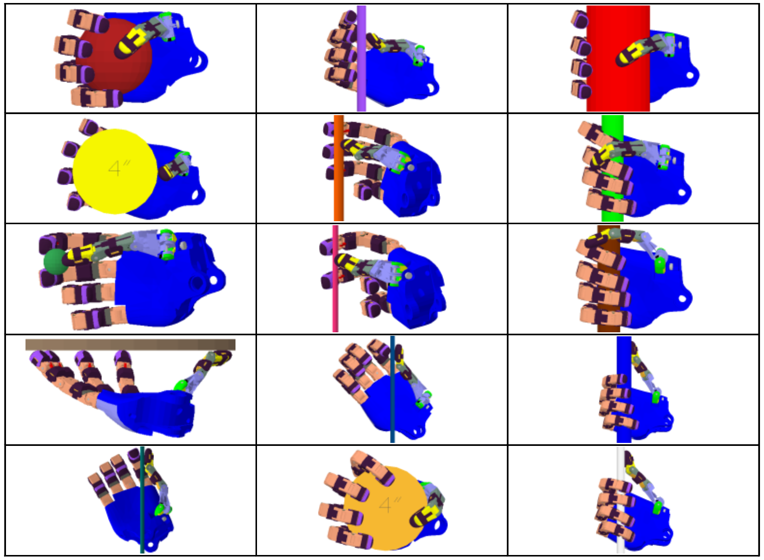
Future Activities

Hand Dexterity

- 4 DOF Thumb
- Dexterous fingers
- Grasping fingers
- Approaching human joint travel
- High friction grip surface
- Fine motion
- Tendon Tension
- Wide range of grasps

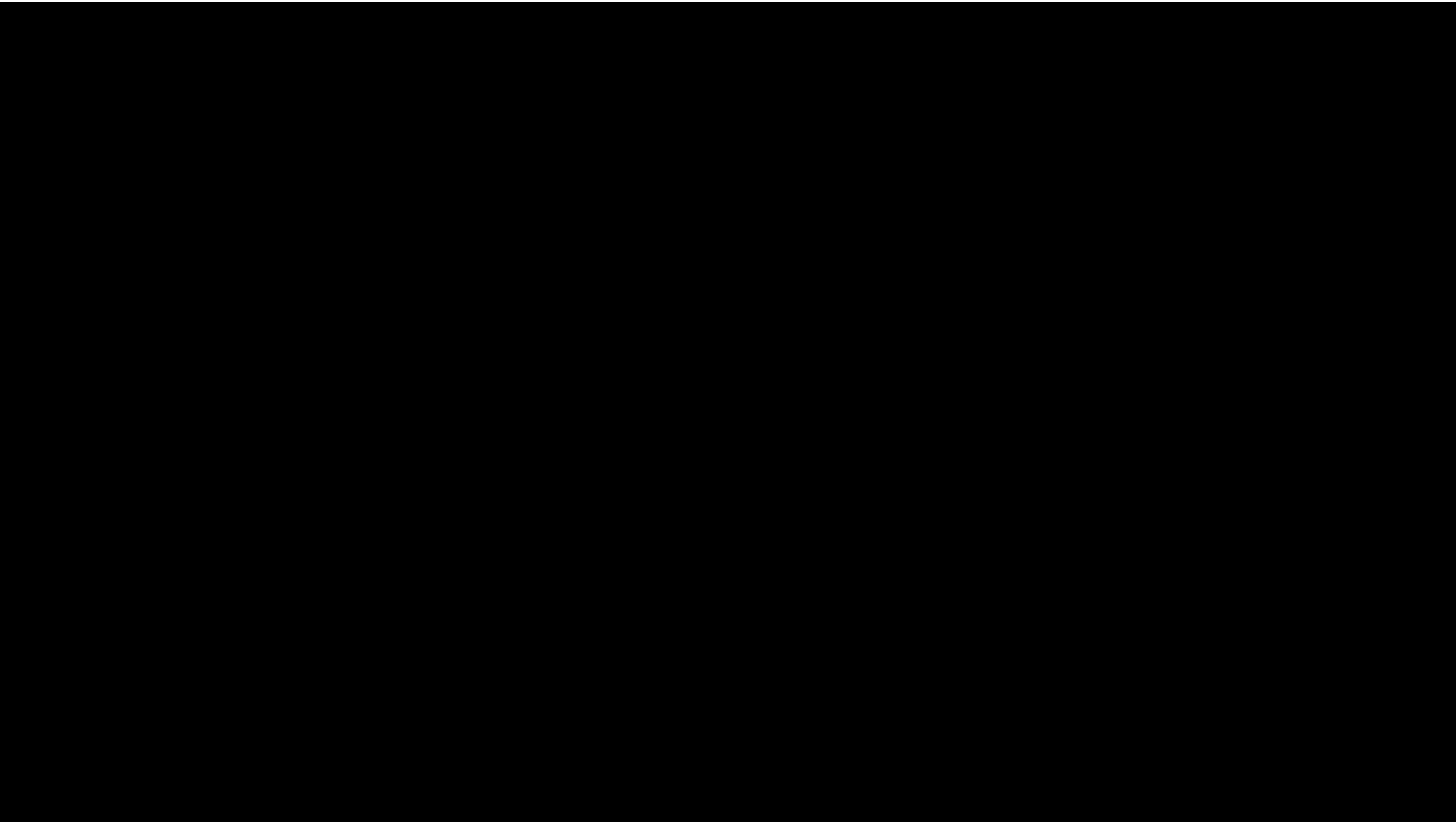


Human Like Grasps: Pen



Cutkosky Grasps

Finger Dexterity – Knob Turn



Finger Impedance Control

Tactile System

Extremely Small

Integrated Load Cells

6 Axis

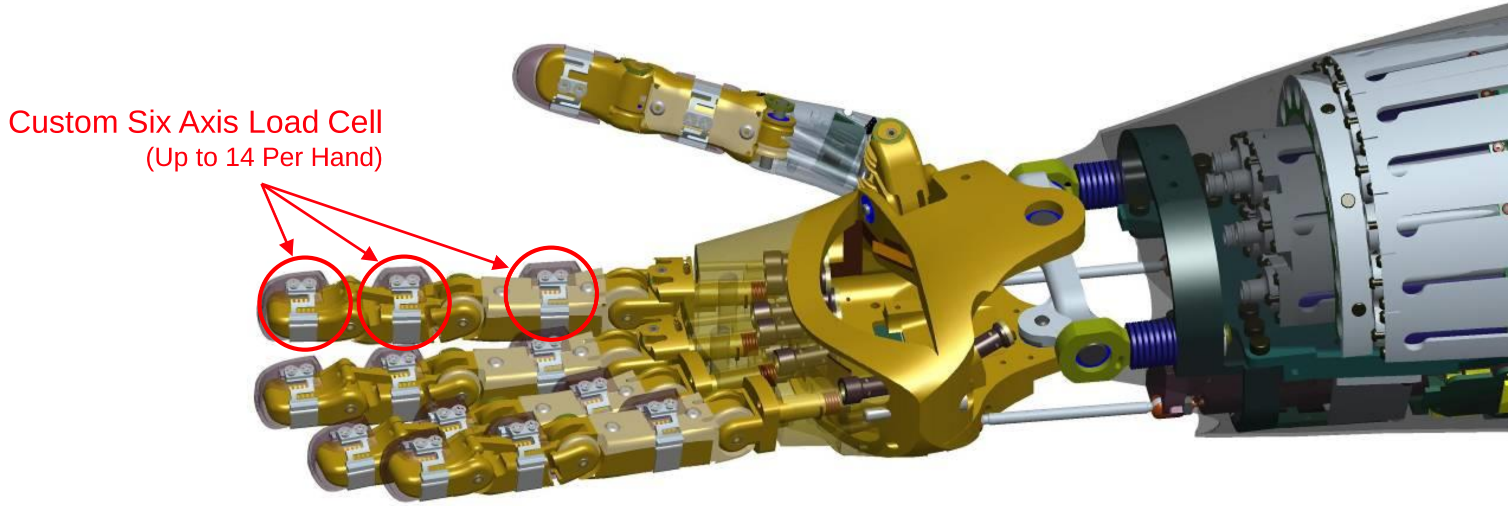
Up to 14 per Hand

Serialized Data

Gram sensitive

US Patent 7,784,363 B2

Load Cell



Finger Haptics

Arm Control

Series Elastic Control

- Embedded Springs
  - US Patent App. 20100145510
- High resolution absolute position sensing
- Joint level torque control
  - 10Khz loop
- Variable compliance

Modular Joint Electronics

- Highly integrated
- Redundant processing
- Local A/D
  - Noise reduction

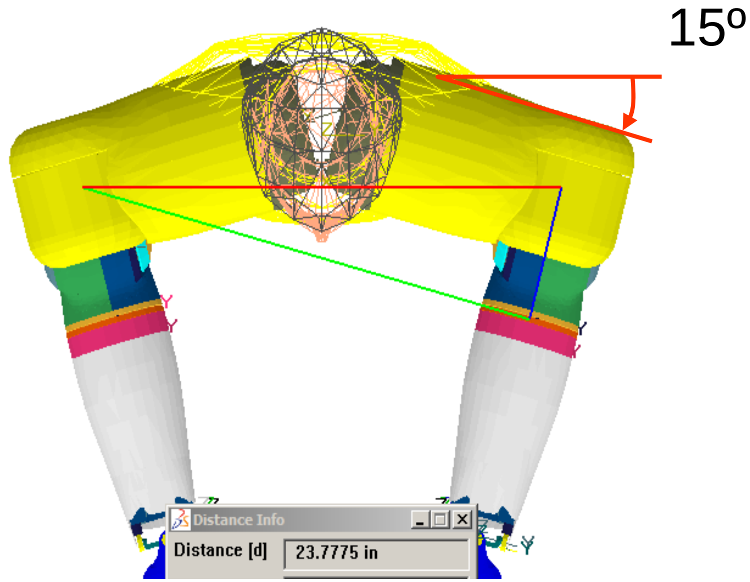
Torsional Spring

Plug-in SuperDriver

Workspace

Dual Arm Workspace

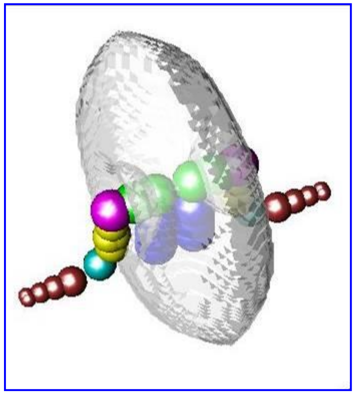
- Maximized through Arm Placement
- 15 degree shrug angle
- Increases workspace in front of Robot -



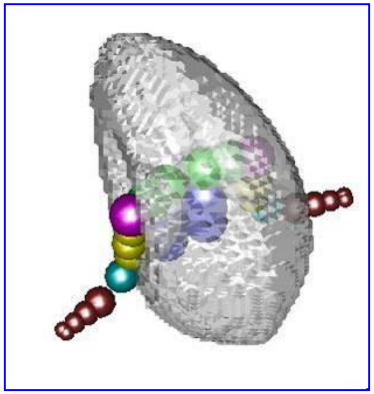
Shoulders with Shrug

Body Mobility

- Waist Degree of freedom
- Extend dual arm workspace over 360 degrees



No Shrug



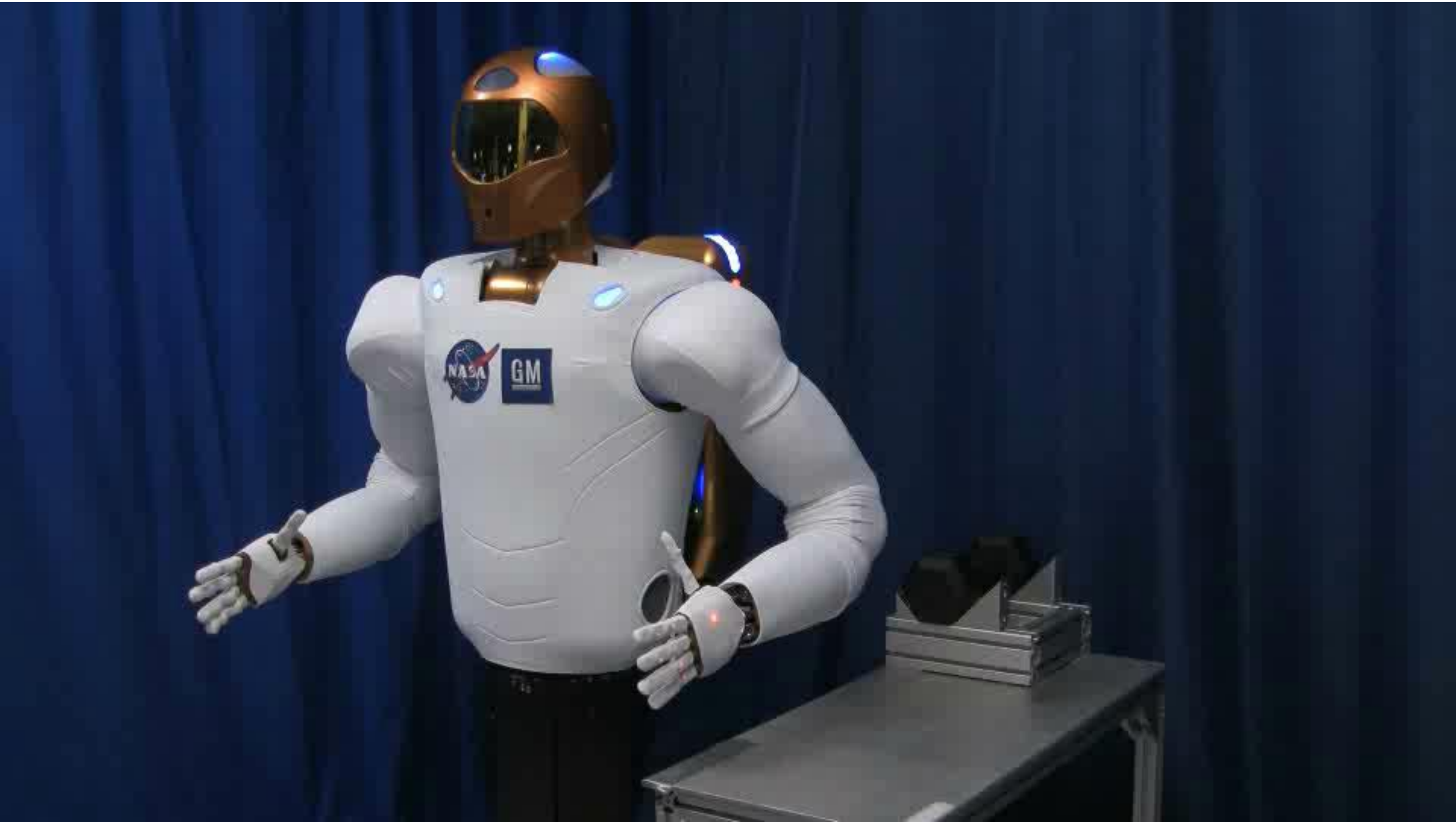
Shrug

Strength

Minimum 20 lb lift capability

Exceeds human endurance at human strength

Differentiator



Neck/Head

Neck

- Three Degree of Freedom
- Inspired by Human Spine
  - Double pitch joints
- Enhanced viewing close to body

Head Sensor System

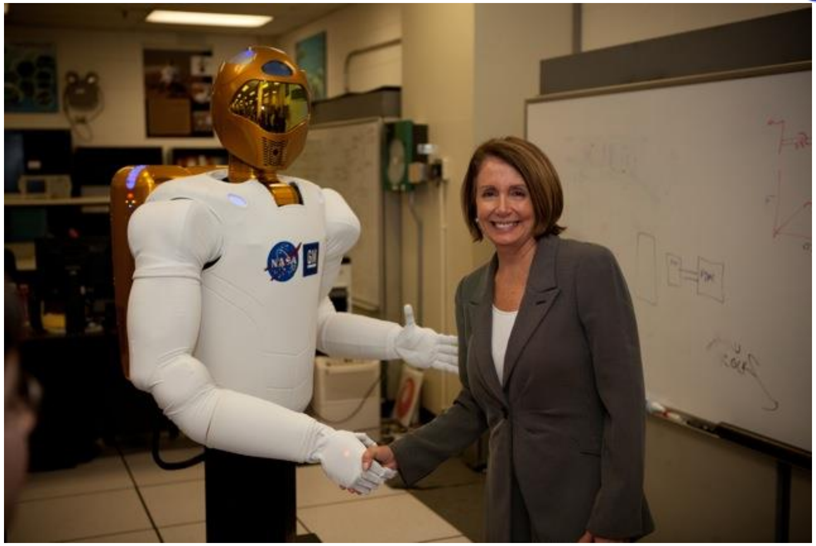
- Workspace visual data
- Mounted on Atlas of Neck
  - Stereo high resolution Cameras
  - Infrared camera for growth
  - Auxiliary lighting

Neck Photo

Human Interaction

Size

- Smaller than R1
  - Internal wiring – 16 conductors
  - 32" wide
- Comparable to human
- Soft skin with padding



Designed to Interact with People

Safety

- Force limiting
- Unintentional Contact Sensing
- Multi-level Sensors
  - Position
  - Force/Torque
  - Cross checks
  - Heartbeats

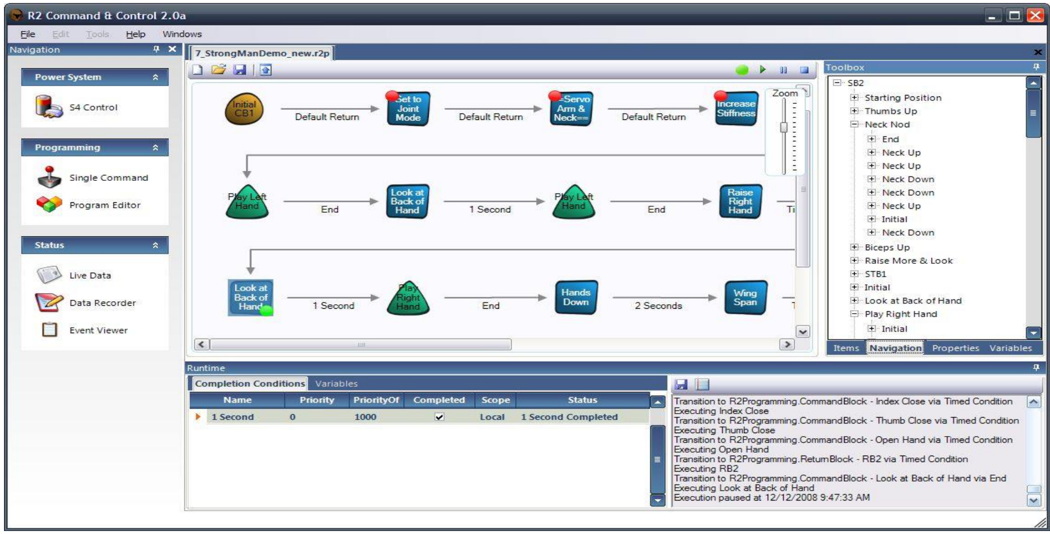
Force Limited at Multiple Levels

Force Control

Human Interface - Controller

User Interface

- Menu based
- Startup with minimal typing
- Easy to use
  - Even I can run the robot
  - I have even built scripts
  - Cady and Paolo



Skills toolbox

- Primitive Blocks
- Controller
  - Zero-g motion
  - Cartesian control
  - Stiffness control
- Predefined grasps
  - Drill
  - Multi-Layer Insulation

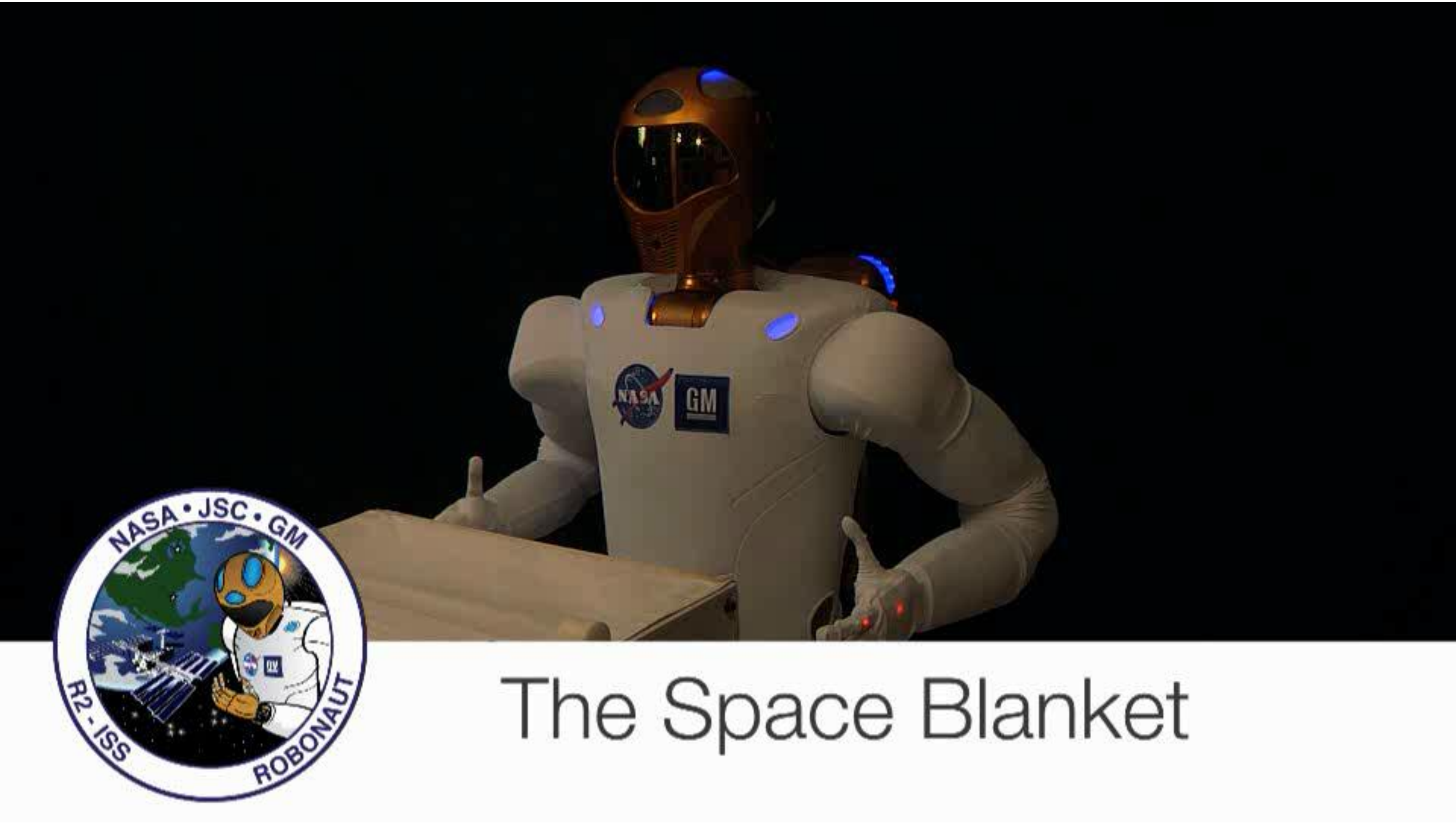
Semi-experienced R2 Operator

Human Interface - Teleoperation

- Teleoperator Interface
  - Intuitive
  - Immersive (very)
  - Investigative
- Programming Tool
- Flexible Interface
  - Unstructured tasks

Washington DC Demonstration

Flexible Material Application



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Future Activities

R2 on Space Station

Putting A Robot On ISS-IVA Takes Us a Long Way Towards Maturation

- Space Vehicle(s)
- Micro-gravity
- EMI/Radiation environment
- Crew Interaction/Safety

Earn Stripes

- Task board operations
- Low risk IVA crew tasks
- Learning to “Walk”

Engage ISS Inspection and Maintenance Community

Education/Public Relations

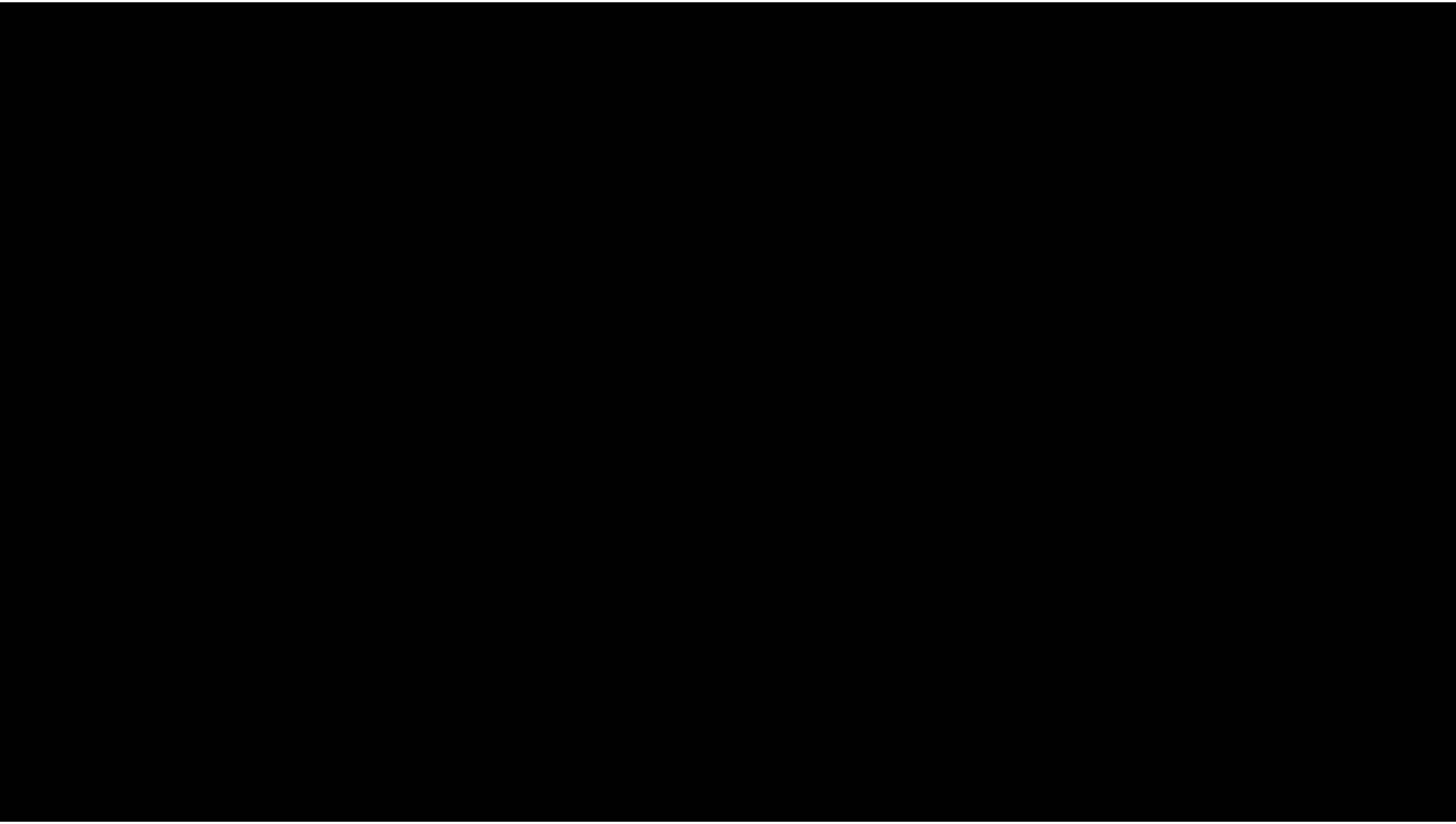
Preparing For Shuttle Launch and ISS

Audits

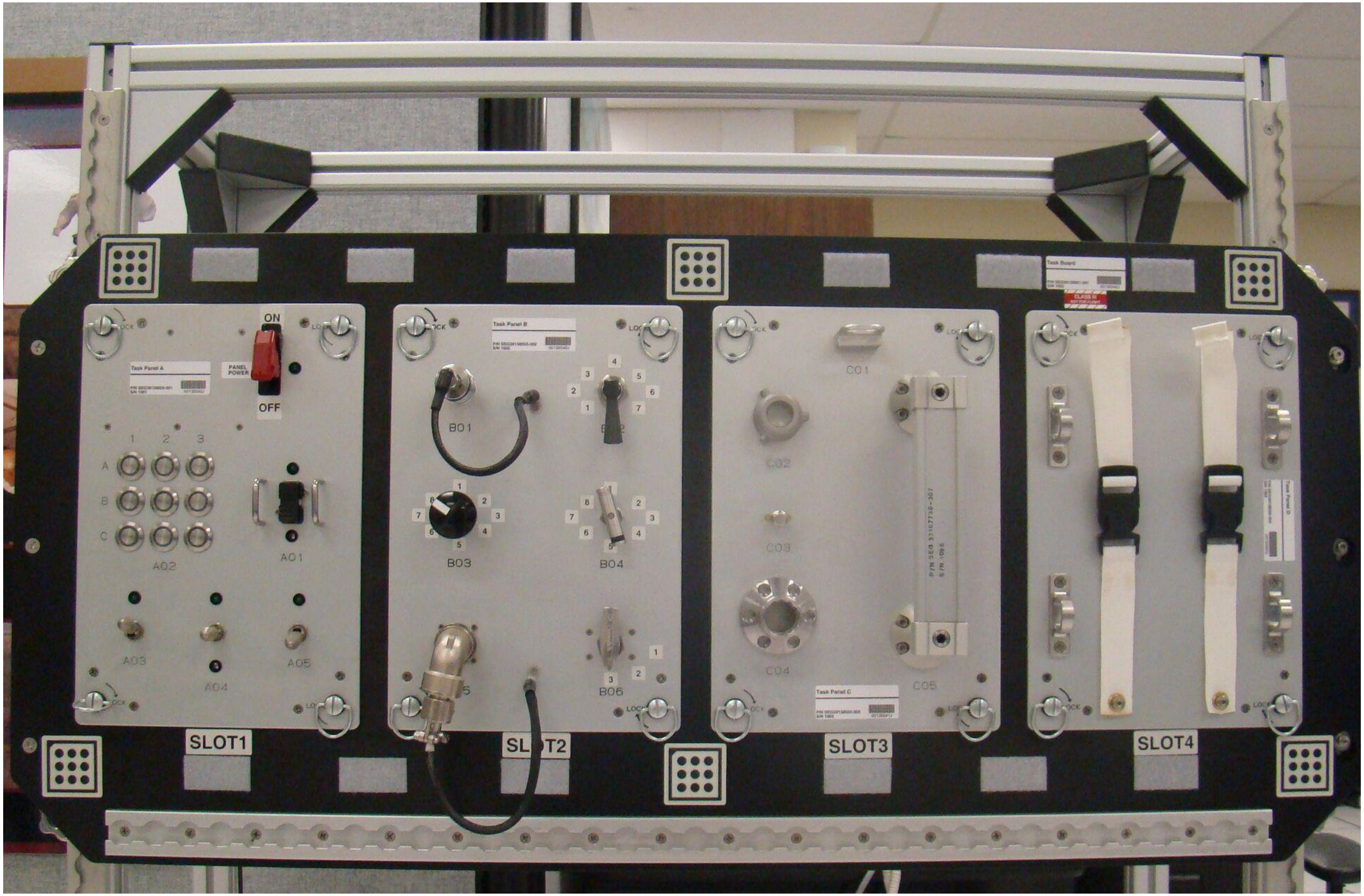
- Materials
- Vibration
- Acoustics
- Grounding
- Safeties
- Video/Comm

Development Testing

- Radiation
- EMI
- Power quality
- Acoustics
- Vibration

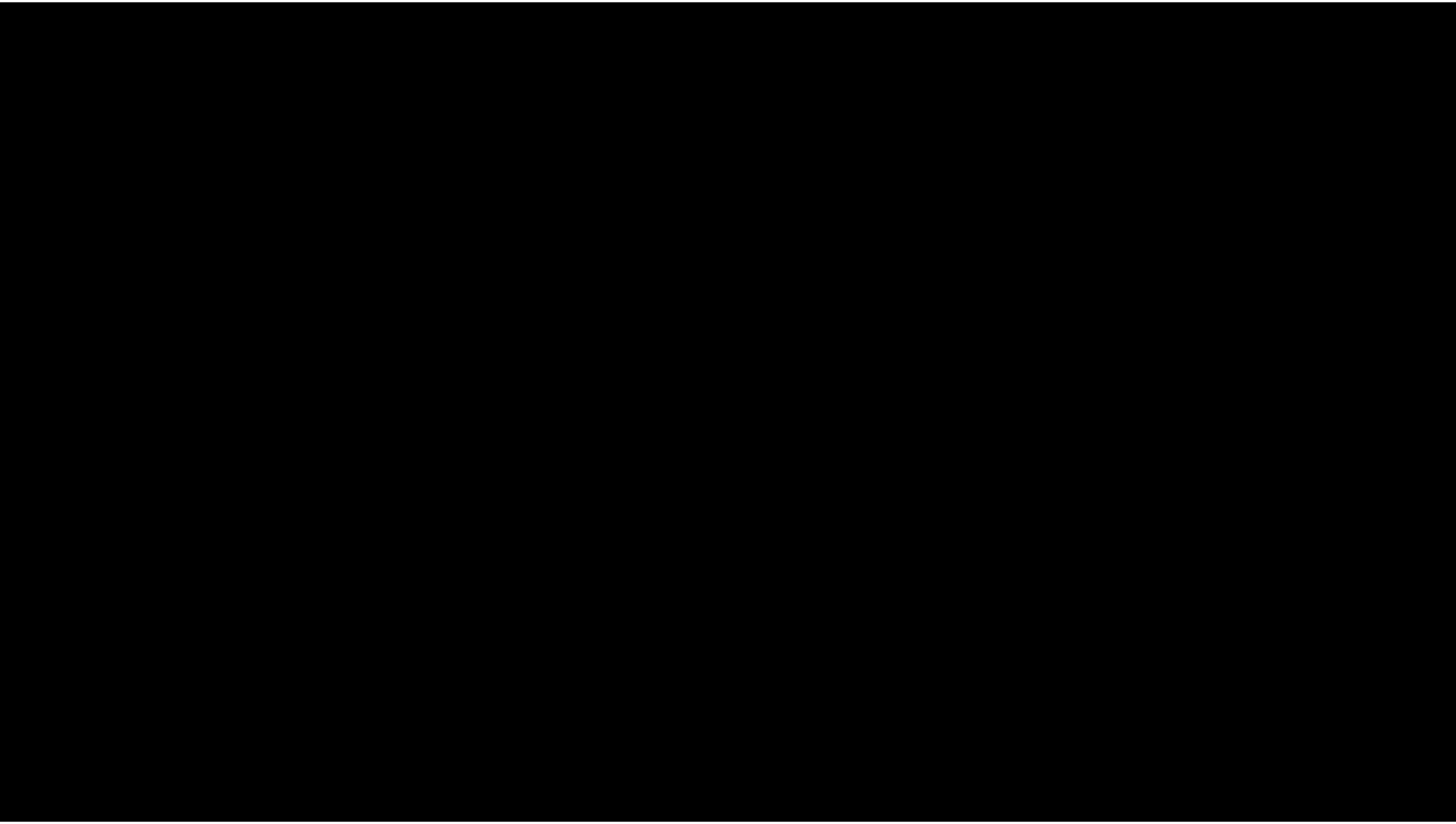


R2 on Space Station



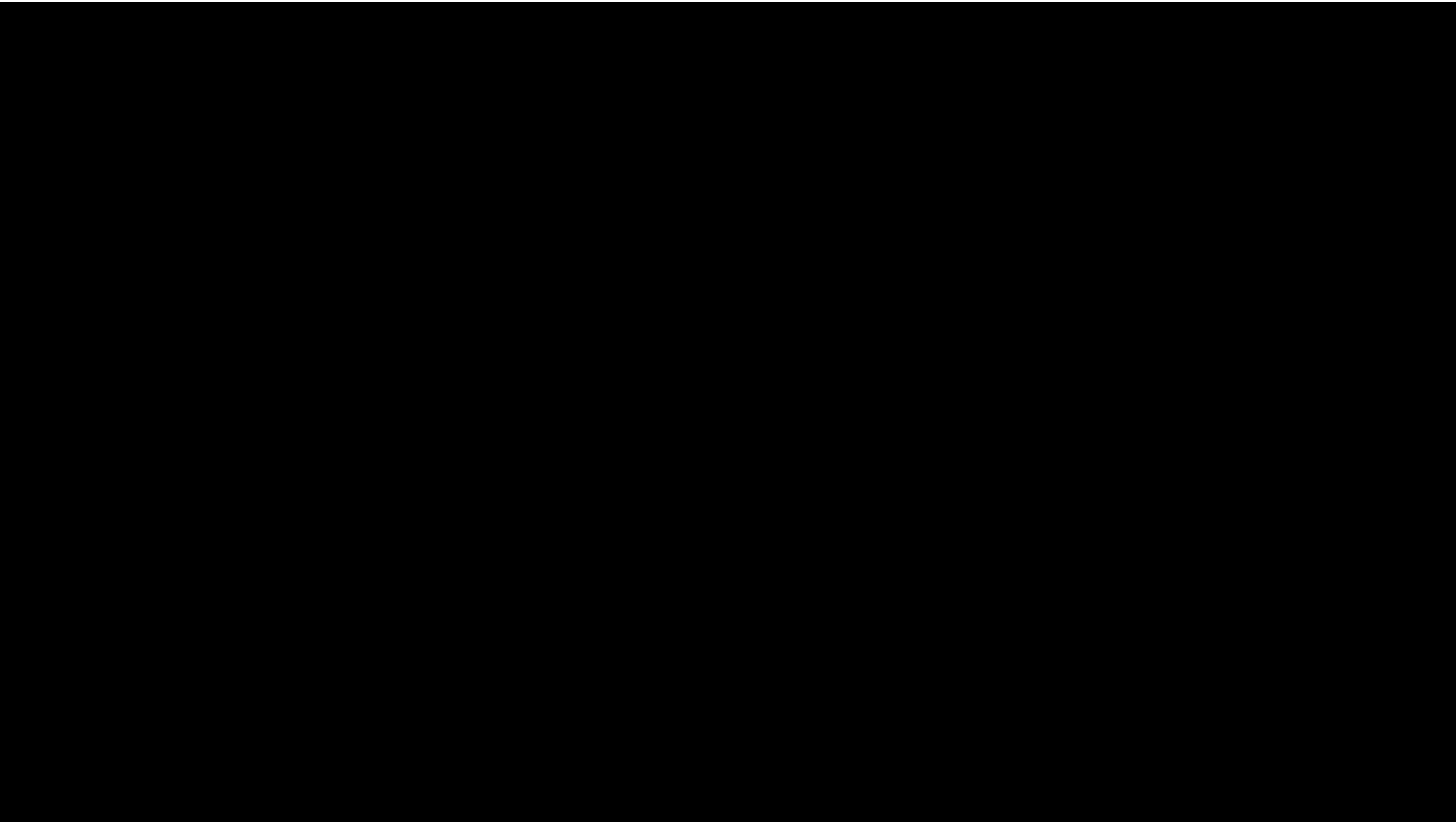
ISS Modular Task Board

Practicing for ISS – Task Board Development



R2 Ground Unit

Crew Training – Teleoperation Training



Journey to Space

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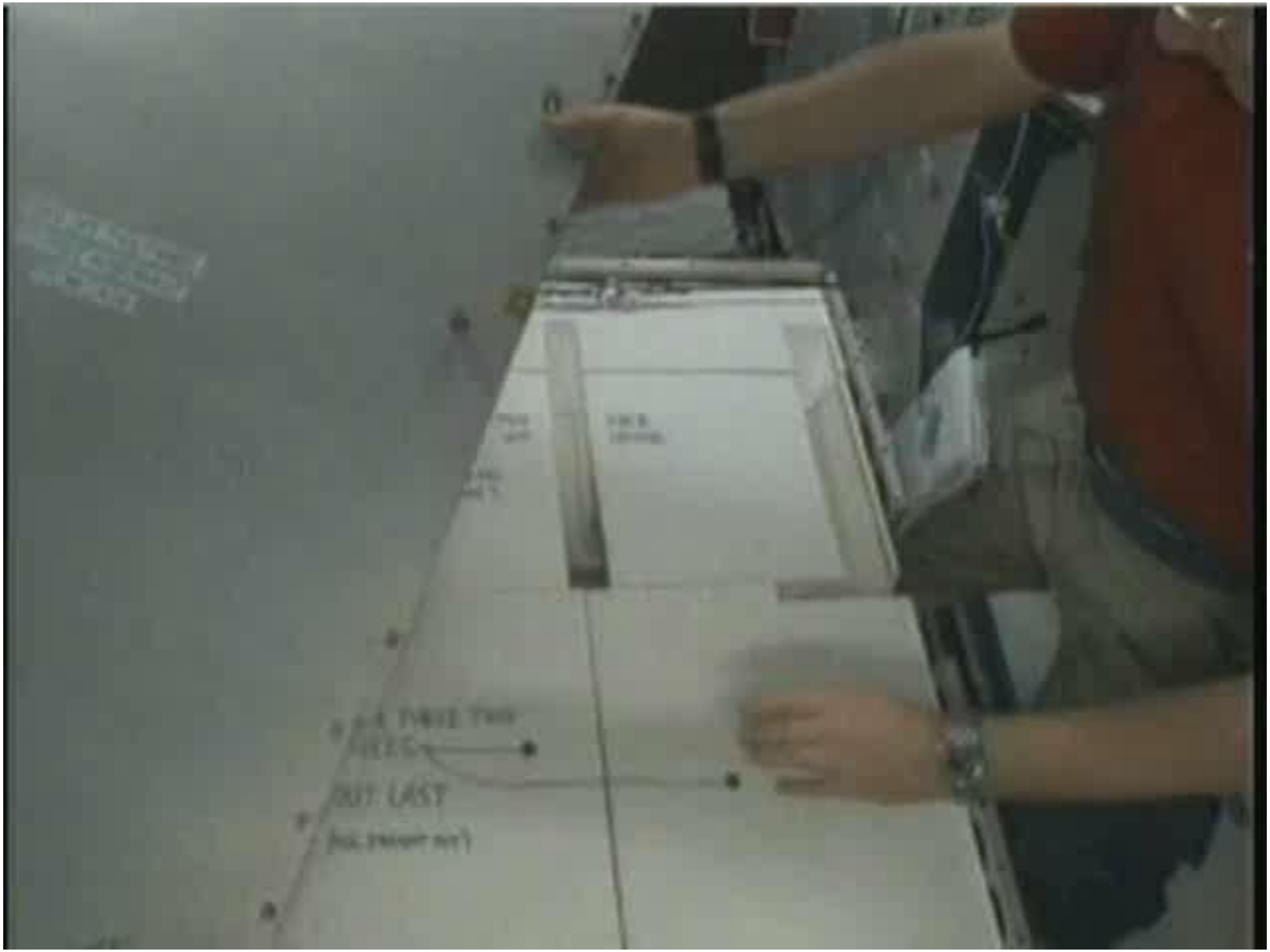
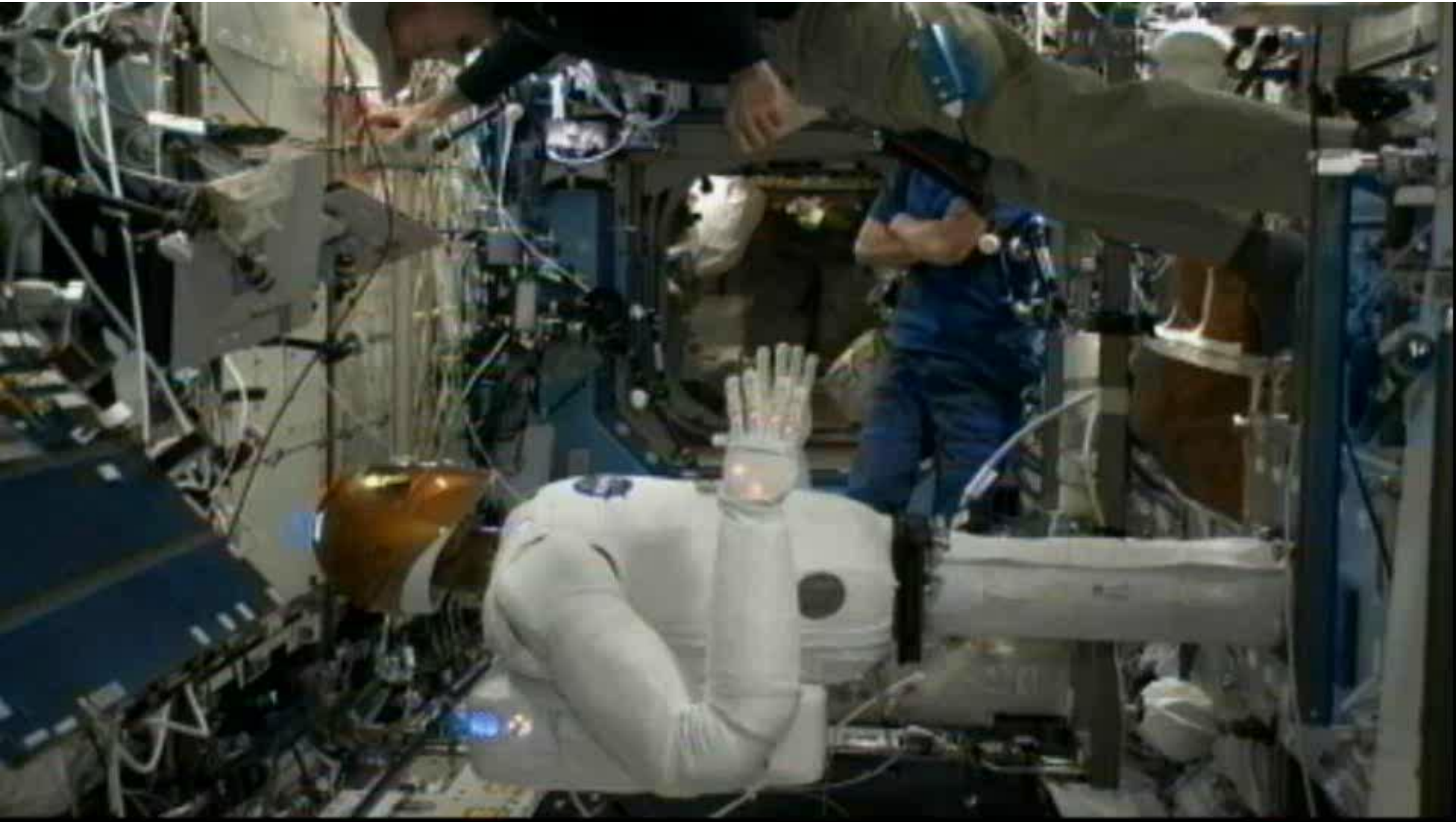
R2 Unpack Video



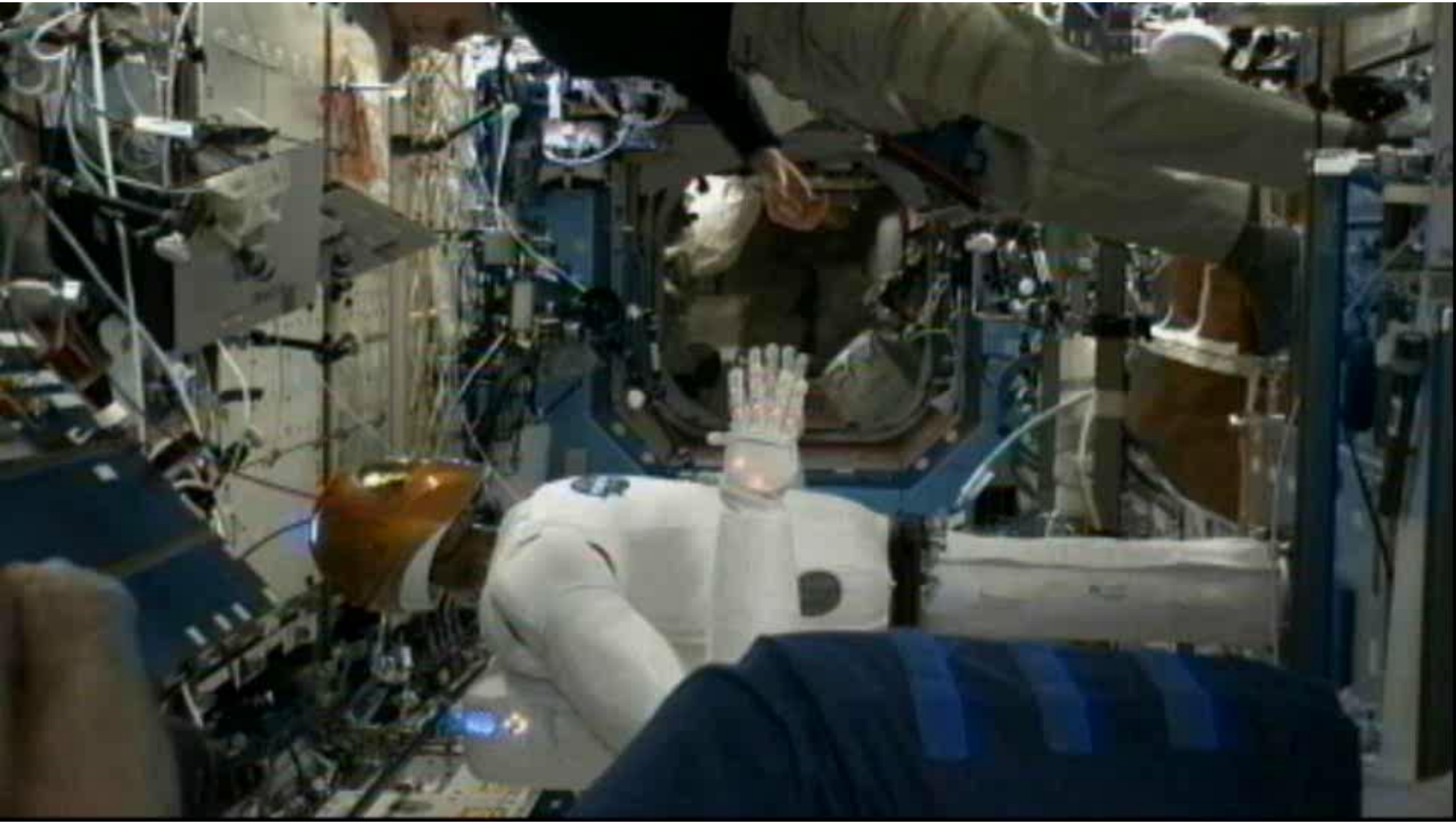
R2 Setup on ISS – Power Soak

First Humanoid Robot In Space - Motion

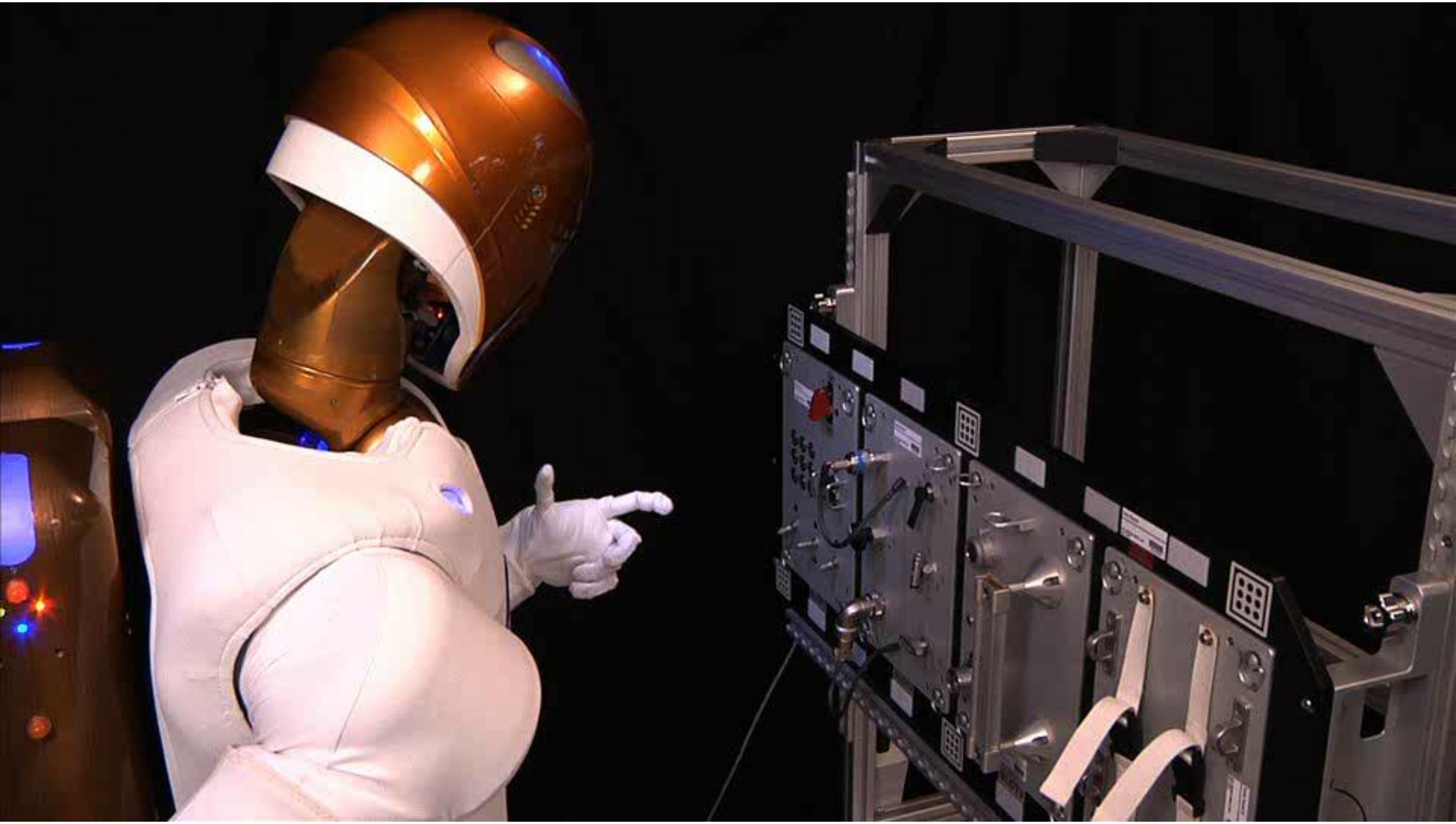
First Humanoid Robot In Space - Hello



First Humanoid Robot In Space – Human Interaction

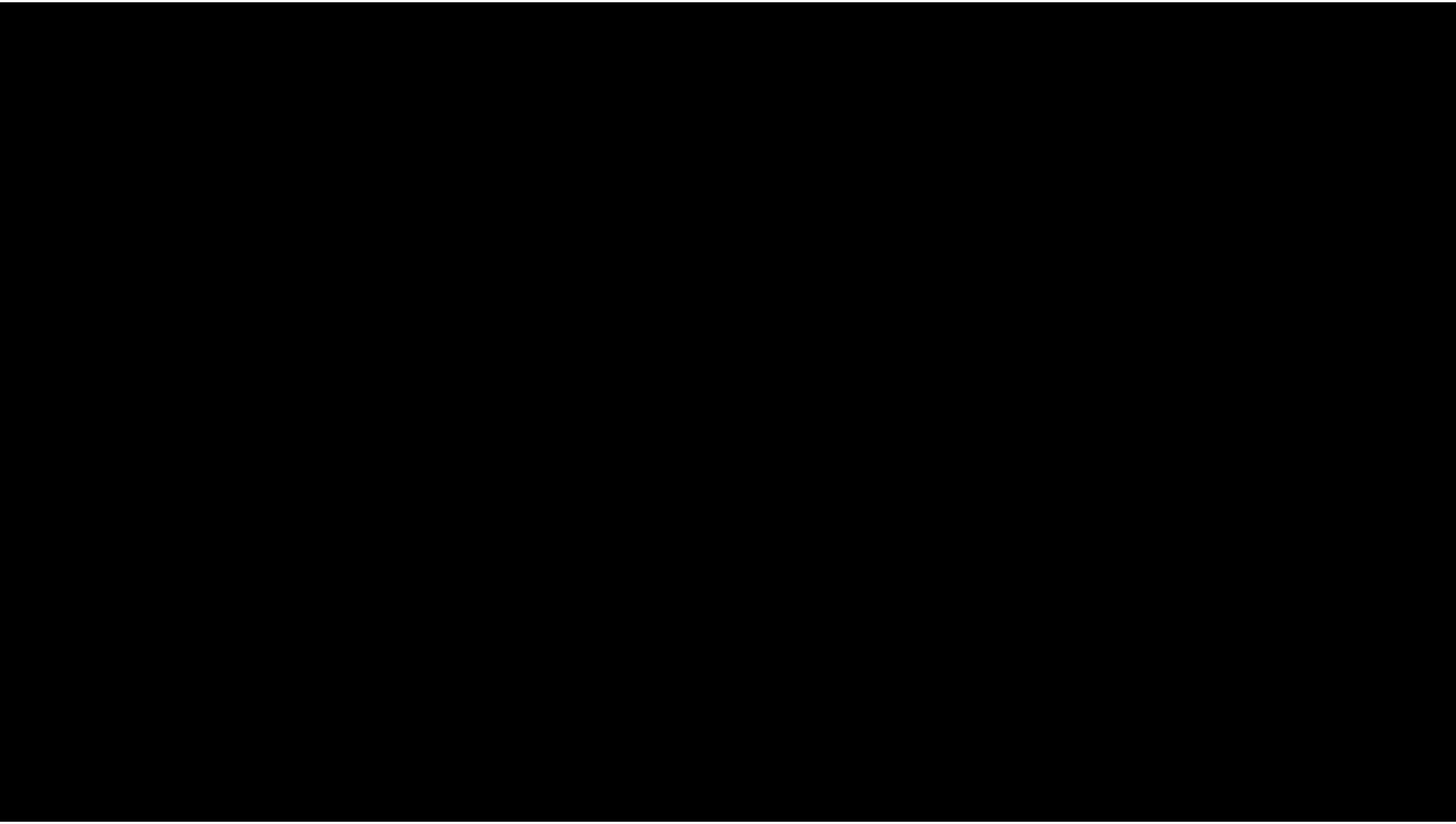


First Humanoid Robot In Space – Power Pane



First Humanoid Robot In Space – Tool Use

First Humanoid Robot In Space – IVA Panel



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IVA Mobility

Need to learn more about climbing in zero-g

ISS IVA is the perfect laboratory

- Buy down risk early

Gain experience for EVA

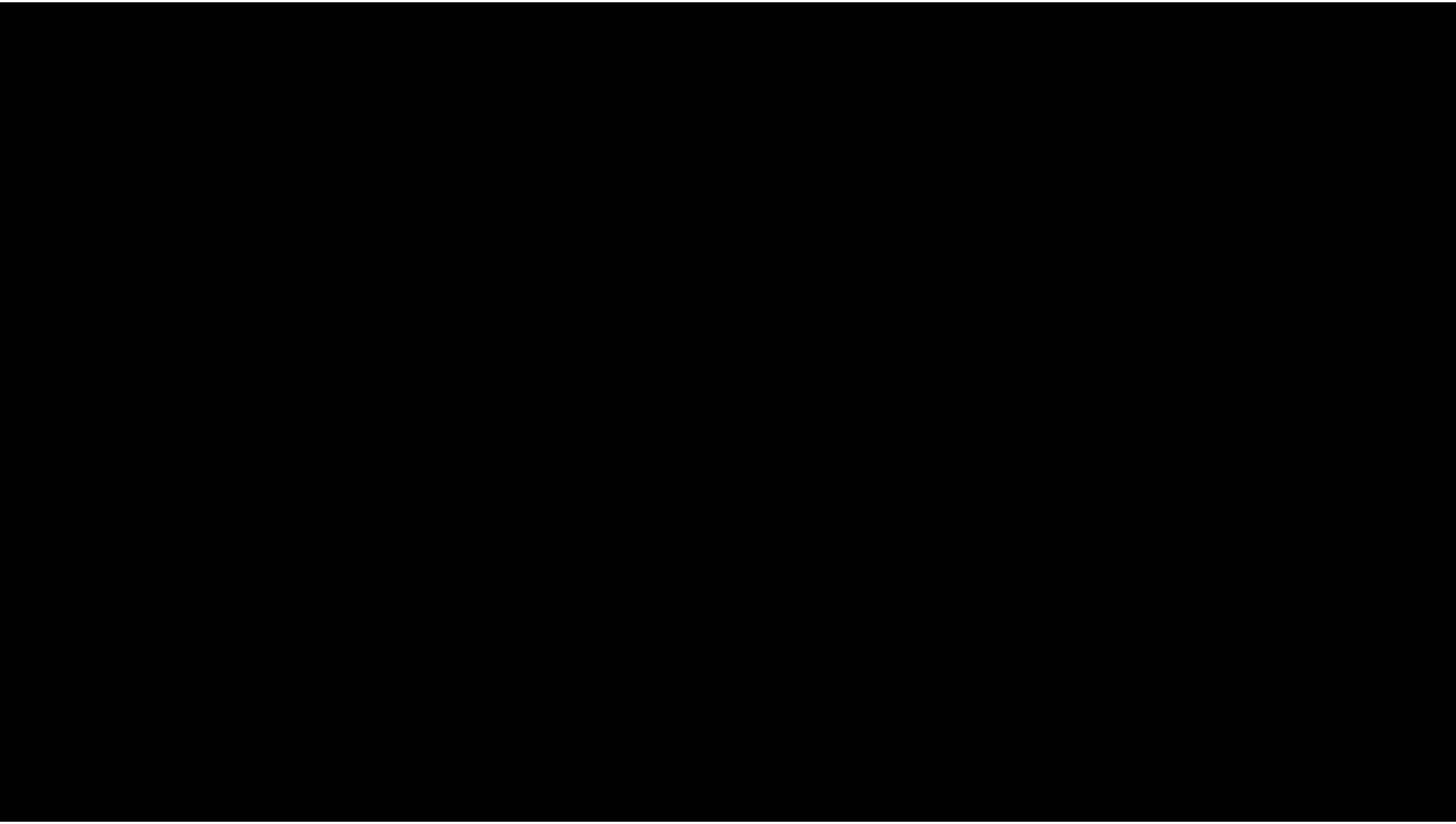
- Forces
- Gaits
- Ops concepts

Assist crew with IVA tasks - payoff

- Clean filters
- Inside rack inspection
- Inventory management
- Instrument monitoring
- New tasks are being presented

Climbing in ISS

IVA Mobility



IVA Mobility

EVA – Big Payoff

Worksite prep/tear down (60-90 minutes on each end)

- APFR setup
- Configure EVA Tools
- Retrieve/Stow tools
- Visual inspection under the skin
- Inspection of hoses, flexible lines
- Remove/replace MLI

Assist SPDM

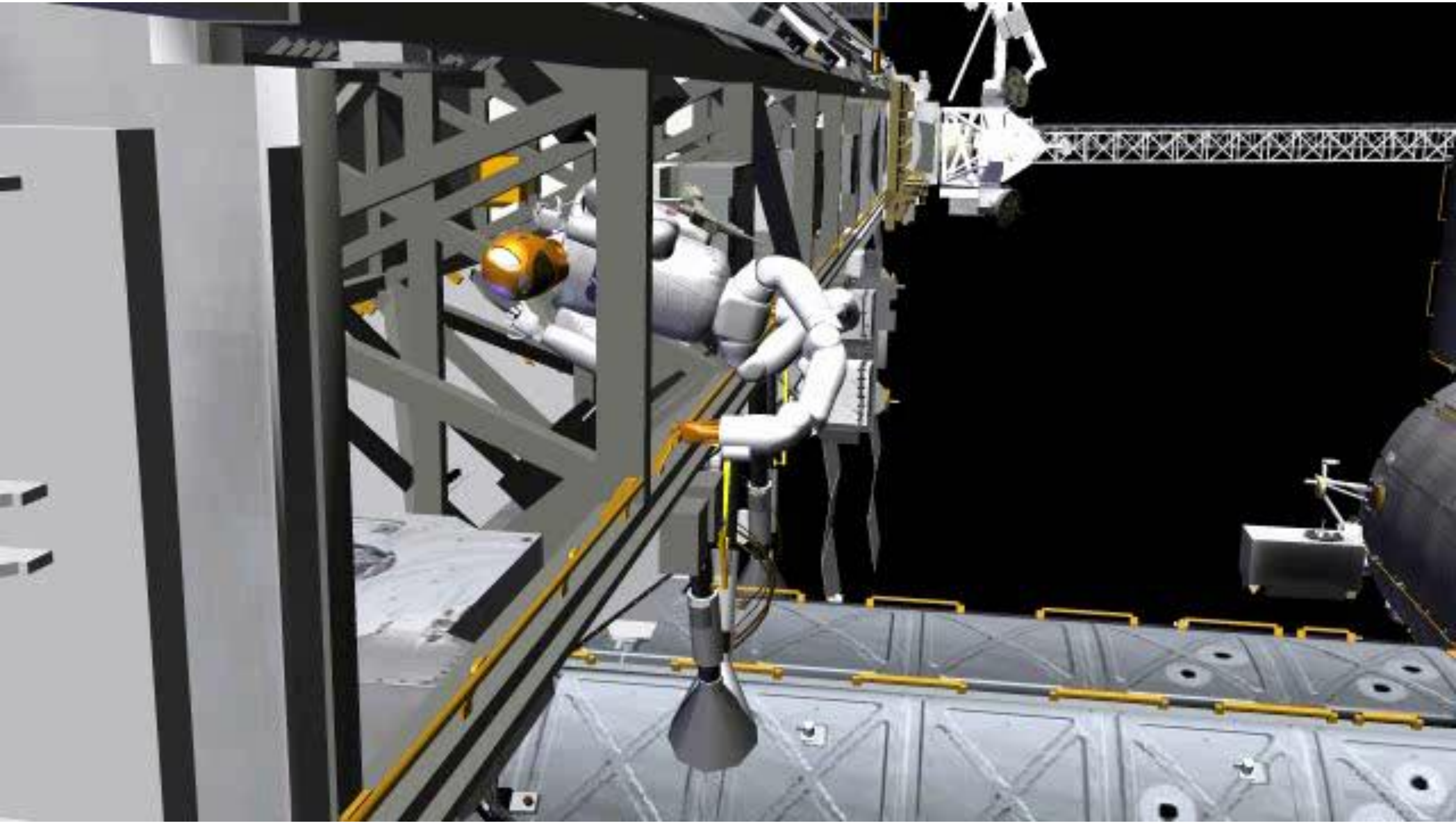
- Remove, replace MLI

Assist with big 12 tasks

- Work side by side with crew
- Provide temporary fixes
- Perform portions of task

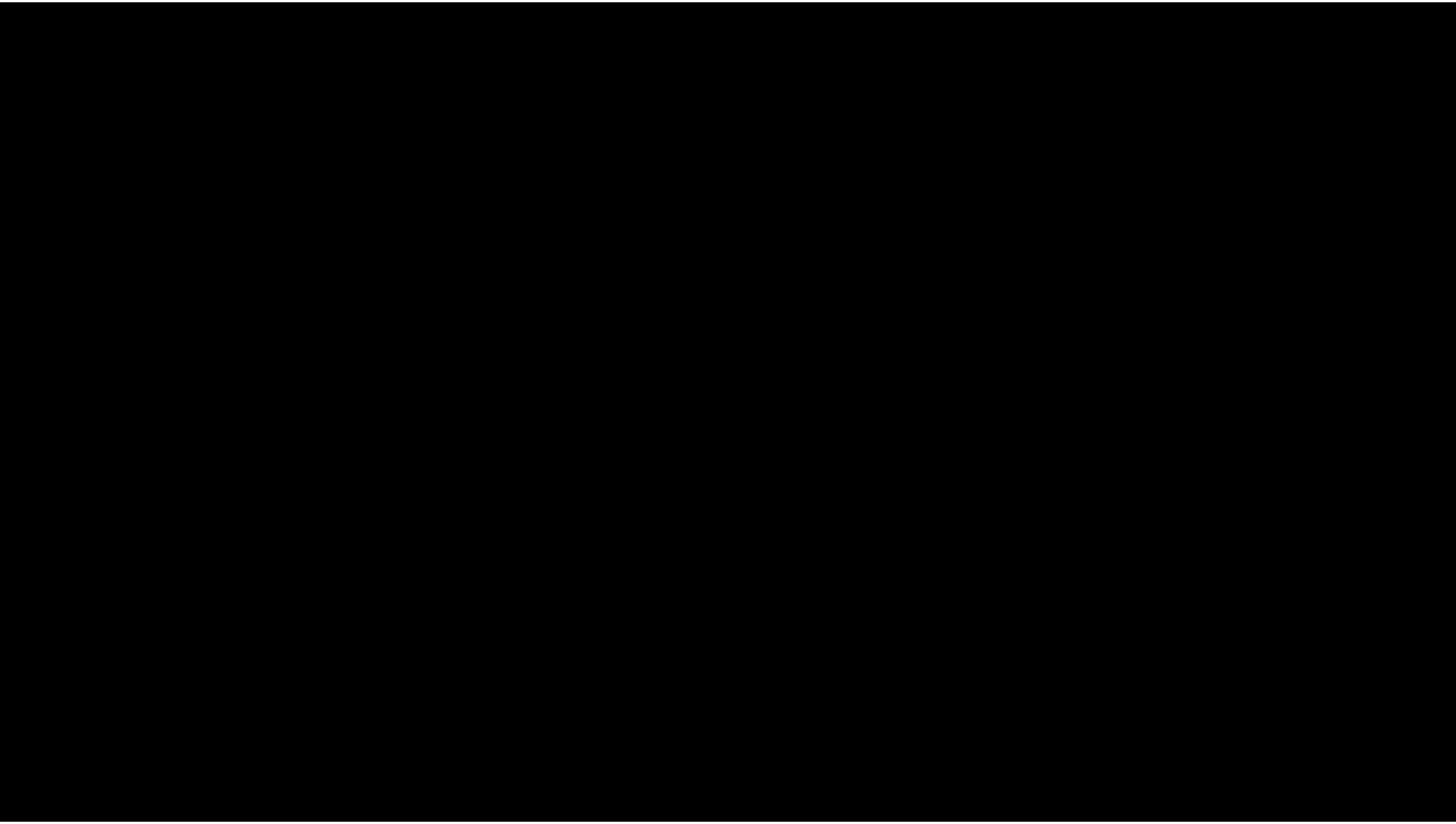
Acquiring Grapple Bar

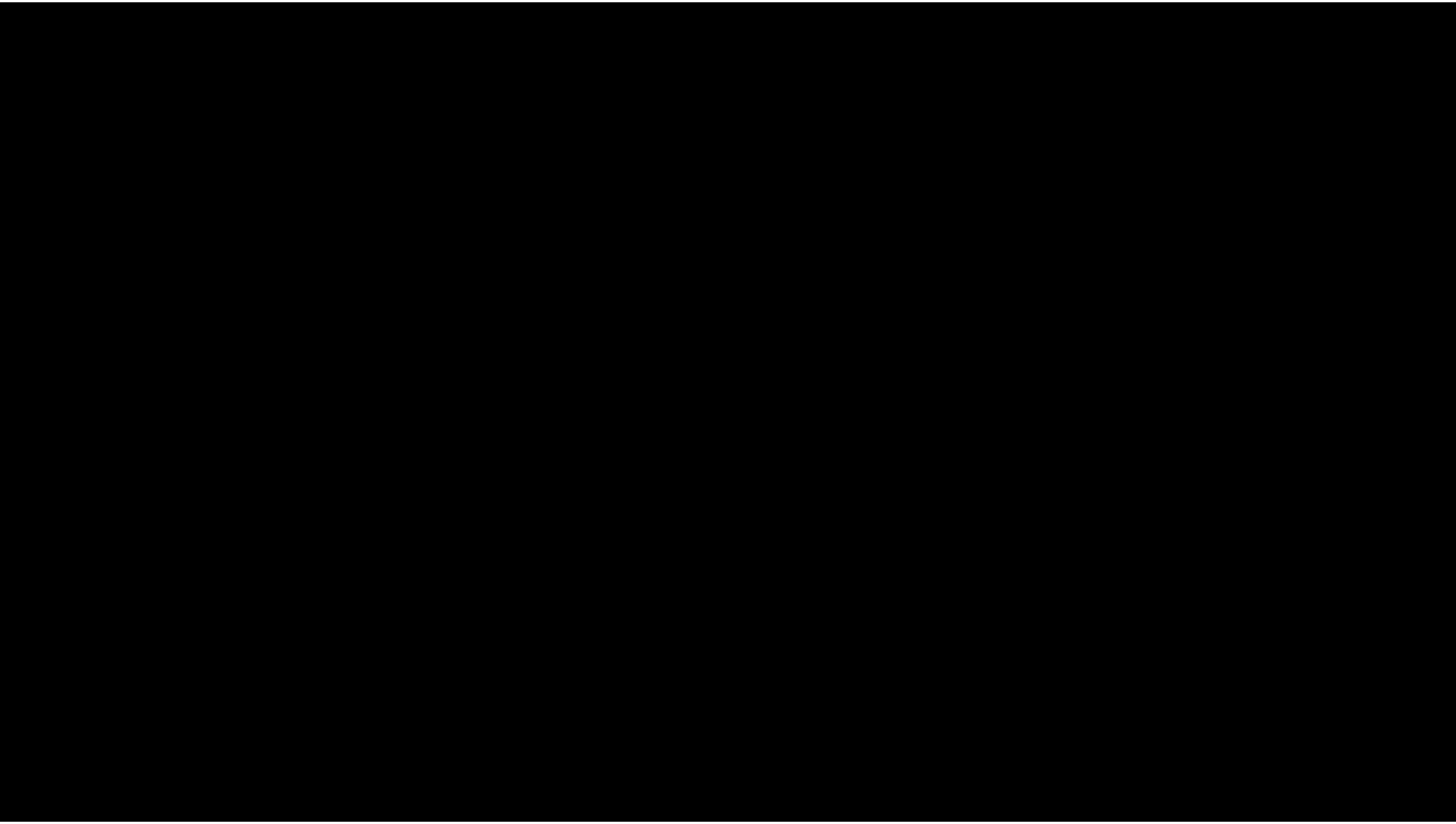
EVA Mobility

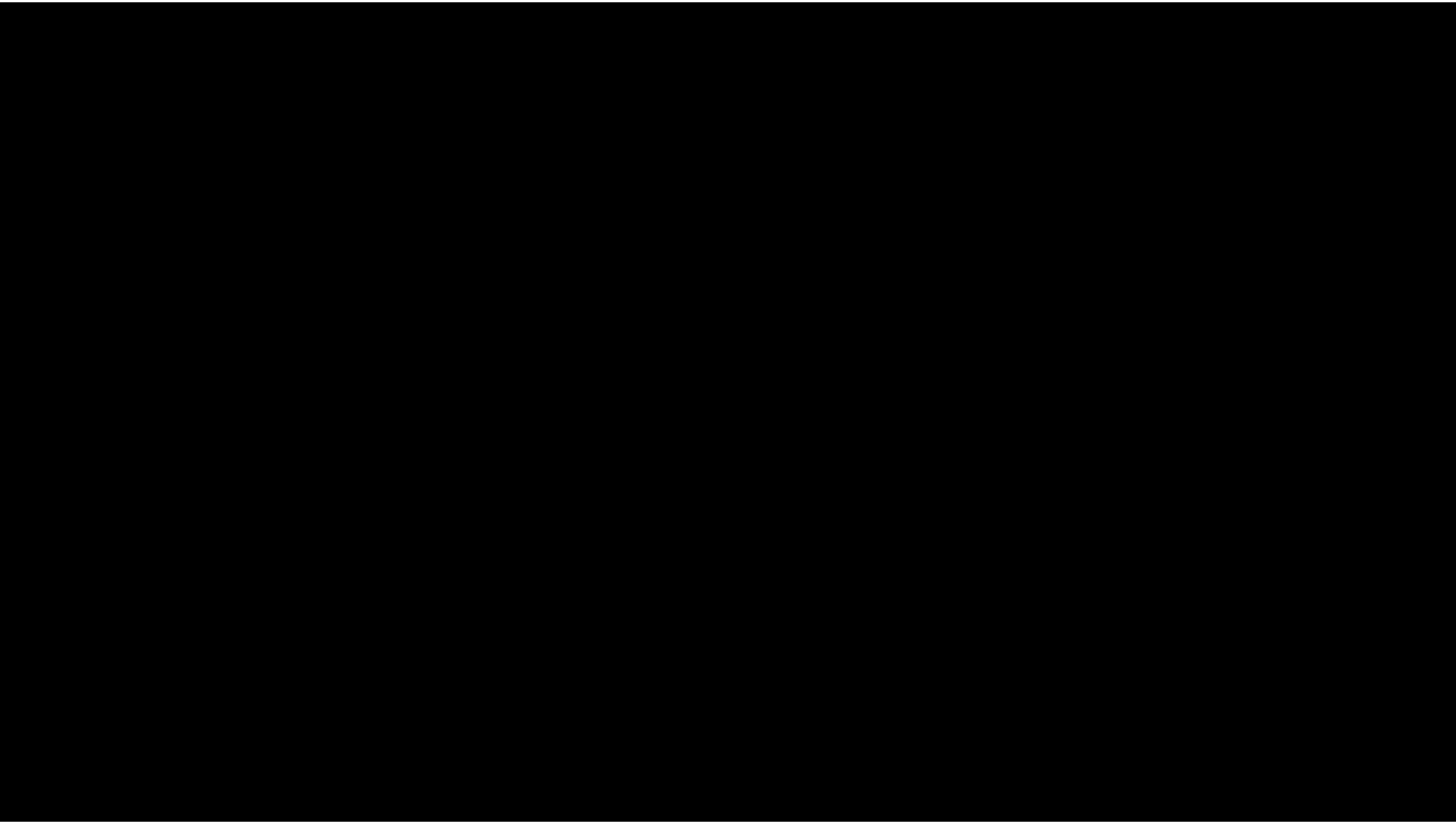


R2 Spinoff Capabilities and Technologies

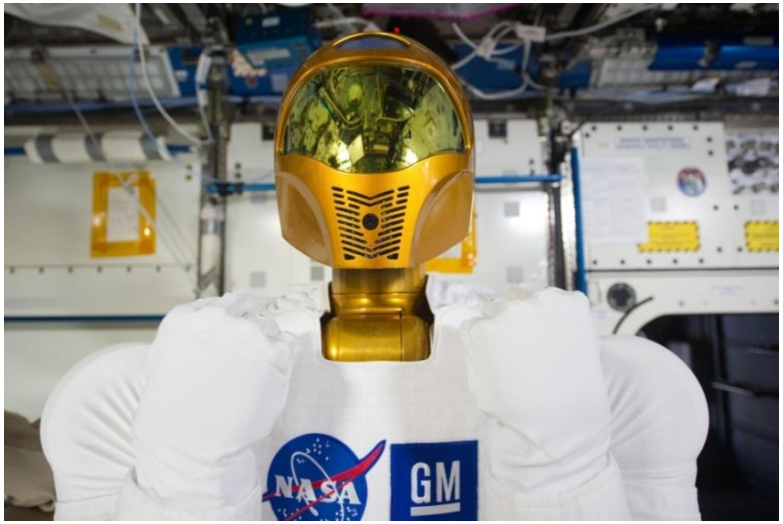
Planetary Capability – Supervised Geologist







R2 on Space Station

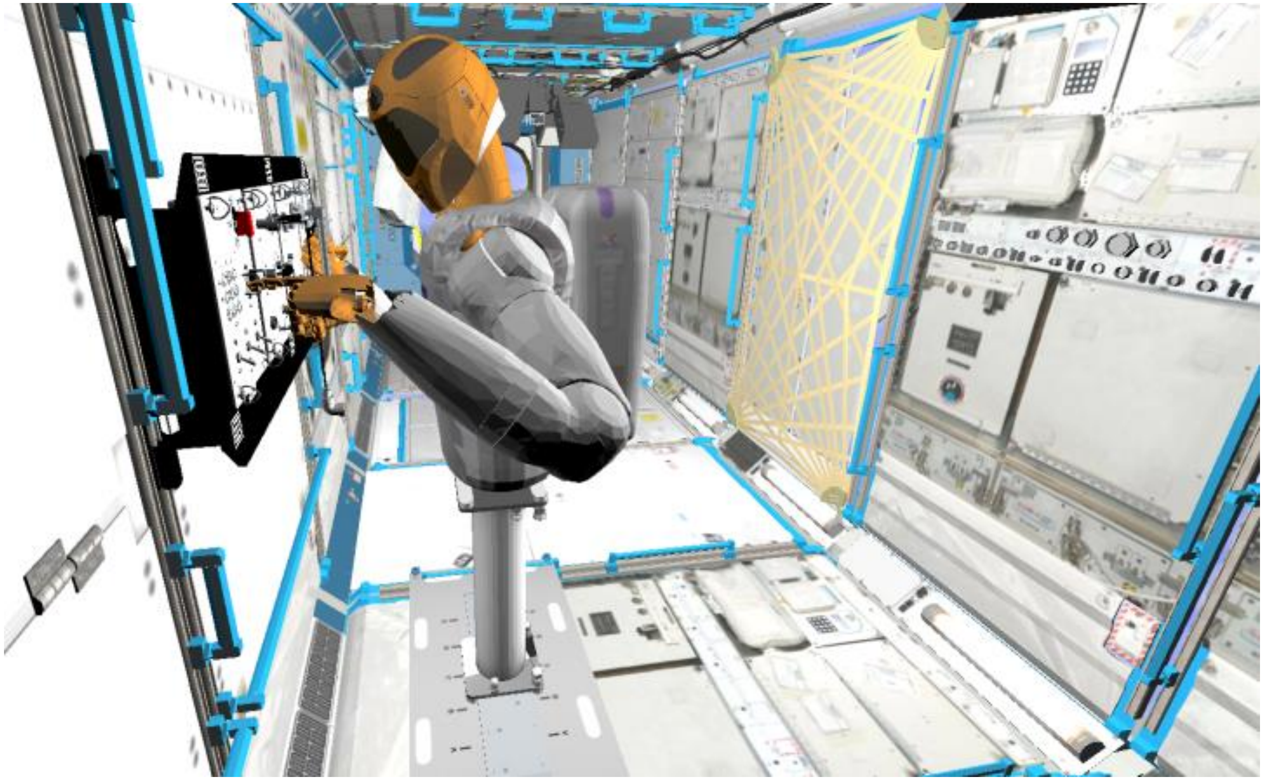


Learn More About R2:

http://robonaut.jsc.nasa.gov/

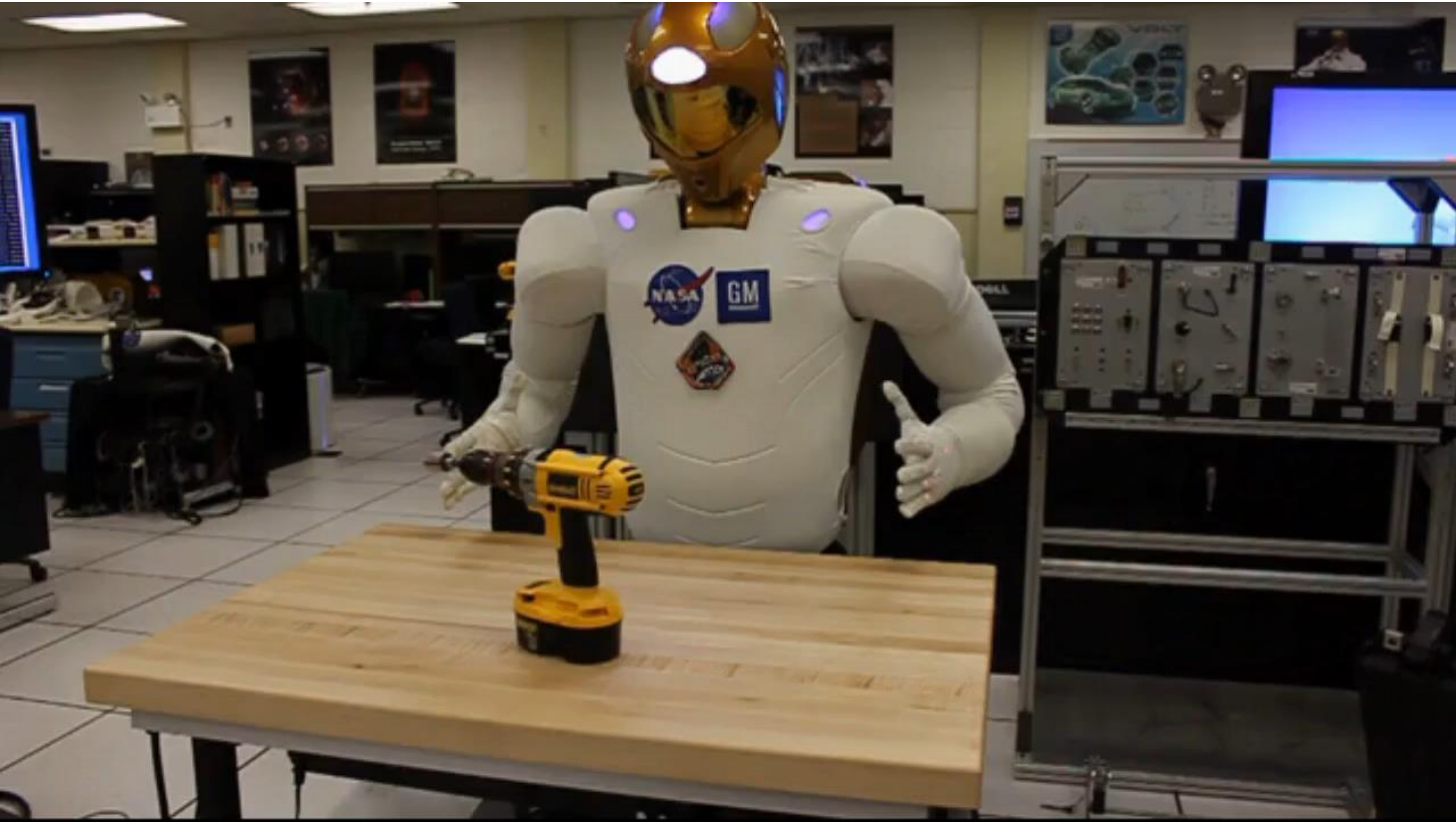
Backup

ROS Simulation – Publically Available



Legs Coming Soon

Using Tools – Drill Training



Using Tools – Tightening Bolts