

# Articulated Upper Bodies for Dexterous Manipulation

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# ***ROBONAUT***

## **Objective:**

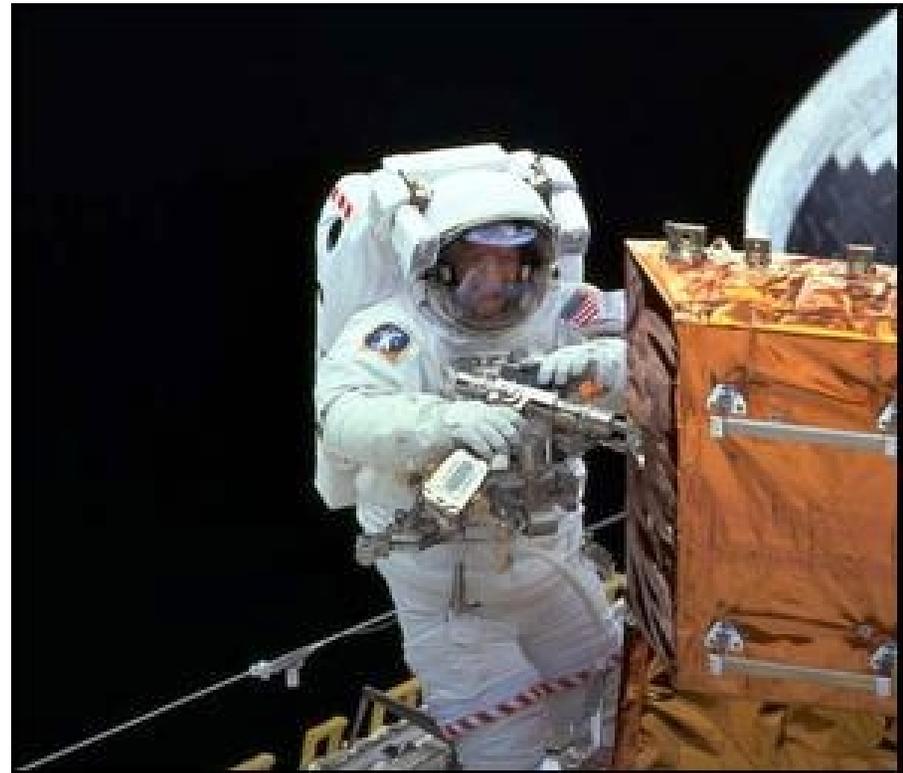
*To develop a space robot with dexterous capability exceeding that of a suited Astronaut.*

## **Missions:**

- Astronaut's Assistant (takes risks and burdens)
- Minuteman: Robot on call
- Virtual surrogate to other worlds

# NASA's Reliance on EVA

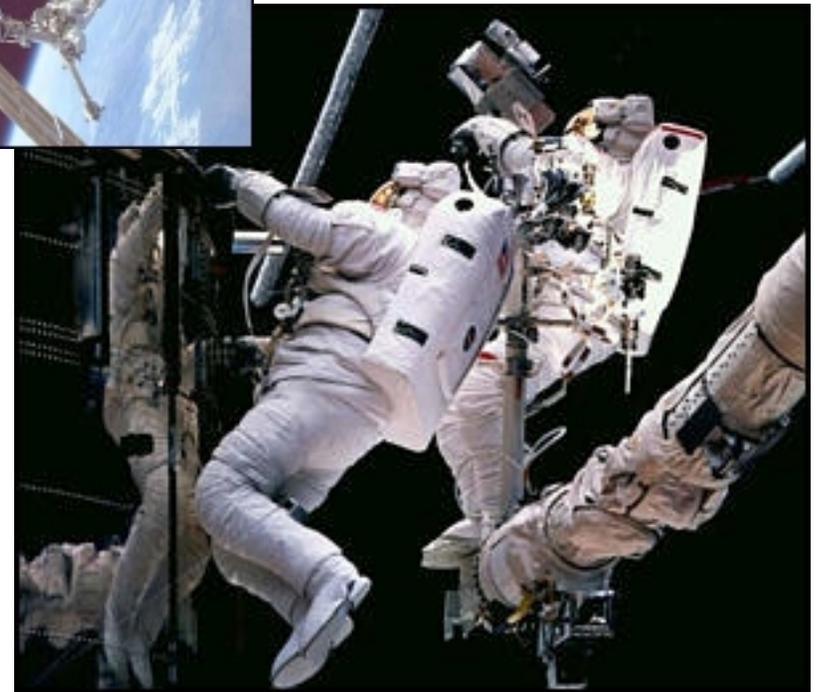
- Long Term Investment in EVA capabilities
  - Shuttle and Station
  - Hundreds of satellites
- EVA roles
  - Contingency
  - High Dexterity
- Opportunity
  - Need for human form
  - Working with EVA tools



STS-103 Astronaut Claude Nicollier works at a storage enclosure, using one of the Hubble power tools

# NASA's need for Human-Robot Teams

- EVA History
- Effective Teams
  - Natural communication
  - Complimentary skills
- Challenges
  - Safety
  - Autonomy
  - Surface Operations



STS-82 EVA Astronauts Steven L. Smith left and Mark C. Lee on RMS arm.

# ***ROBONAUT*** Hand

## Mechanical Design

- 5 Fingers
- 12 DOF Hand
- 2 DOF Wrist
- Human scale
- 5 lb Finger tip strength
- 6 lb hand/forearm weight

## Electrical Design

- Embedded avionics
- Motors mounted in forearm
- 43 Sensors

## Control

- Finger joint position control
- Finger tip force control

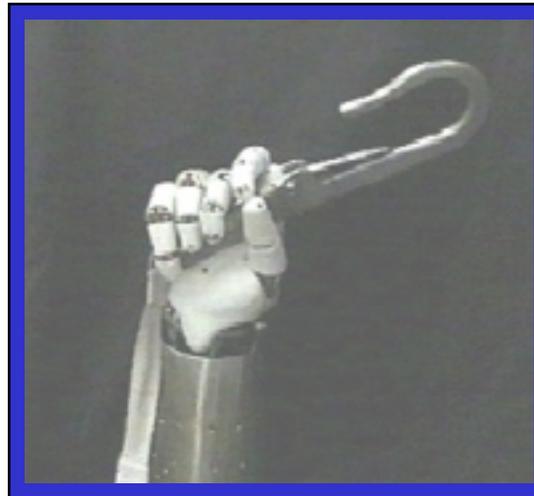


Photo of 5 DOF ***ROBONAUT*** Arm

# *ROBONAUT* Arm

- Mechanical Design
  - 5 DOF upper arm
  - 7 DOF with wrist
  - Human scale
  - 1:1 strength/weight
- Electrical Design
  - Embedded avionics
  - 16 Sensors per joint
  - Dual 6 Axis load cells
- Control Design
  - Cartesian Kinematics
  - Impedance Control
  - Hard real time system



Photo of 5 DOF *ROBONAUT* Arm

# *ROBONAUT* Head & Neck

- Mechanical Design
  - 2 DOF Neck
  - Common with arm
  - Protective helmet
  - Recessed cameras
- Electrical Design
  - Embedded avionics
  - Stereo color cameras
- Control
  - Helmet tracking
  - Real time control

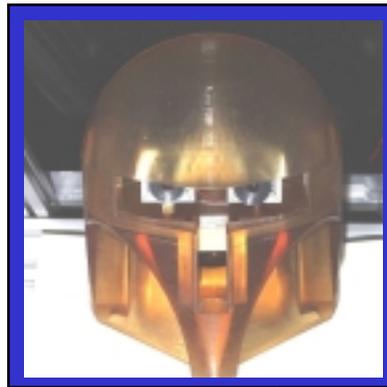
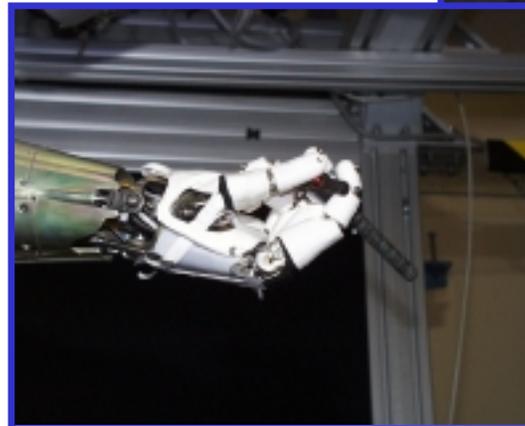
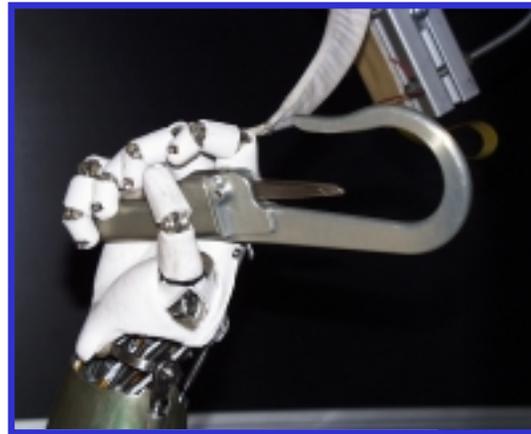


Photo of 2 DOF *ROBONAUT* Neck and Head

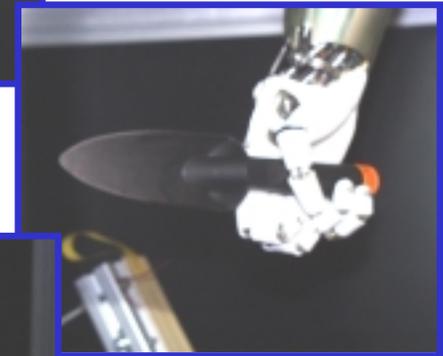
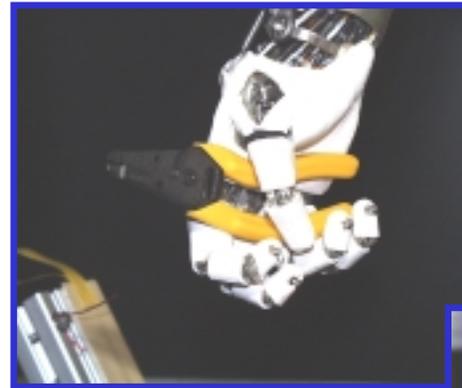
# Experiments with EVA Tools

- ***ROBONAUT*** Status
  - December 1999
  - 40 Hours of Life
- Tools Attempted
  - (H) Torque Tool
  - (H) Tether Hook
  - (H) Velcro
  - (H) Fabric Tool Kit
  - (H) Large PIP Pin
  - (M) Small PIP Pin



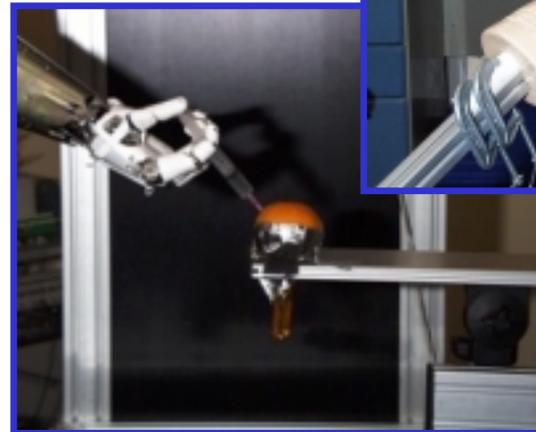
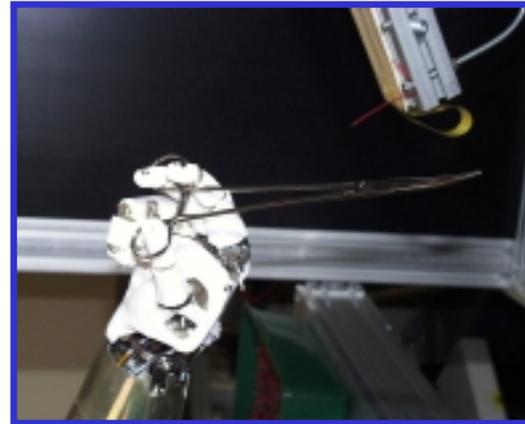
# Experiments with Scientific Tools

- ***ROBONAUT*** Status
  - May 2000
  - 100 Hours of Life
- Tools Attempted
  - (H) Wire Cutter
  - (H) Wire Stripper
  - (H) Power Drill
  - (H) Flashlight
  - (M) Socket Wrench
  - (M) Crescent Wrench
  - (L) Pick



# Experiments with Medical Instruments

- ***ROBONAUT*** Status
  - November 1999
  - 20 Hours of life
- Instruments Attempted
  - (H) Forceps
  - (H) Arthroscopic Camera
  - (H) Tweezers
  - (M) Locking Forceps
  - (M) Syringe
  - (M) Stapler
  - (M) Retractor
  - (L) Suction Bulb
  - (L) IV Needle
  - (L) Scalpel



# Hypothesis

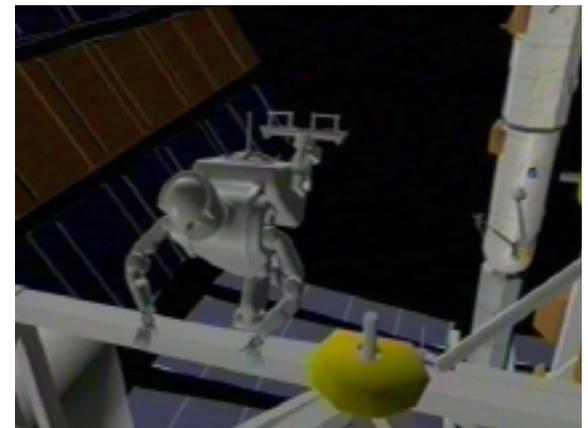
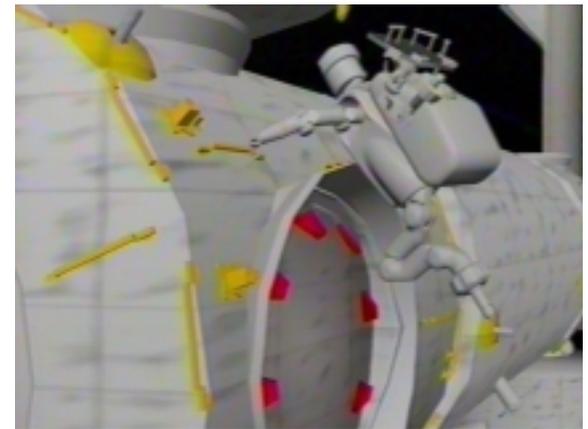
An articulated waist joining a (dexterous) upper body to a (mobile) lower body maximizes workspace dexterity and reduces the need for micronavigation of the base.

Or in other words.....

When humans step up to (or sit down at) a worksite, our waist enables efficient positioning of our arms, avoiding the need to constantly move our body with our legs.

# Hyper Redundant System

- 50 DOF System
- Bifurcated Chains
  - Branching
  - Dual Arms
  - Multi fingered hands
- Serial Chains
  - Fingertip 17 DOF (6)
  - Eyes 12 DOF (2)
  - Body 7 DOF (1)



Animations of **ROBONAUT** climbing on International Space Station exterior

# Primates

- **Waist**
  - Skeletal void
  - Musculature
- **Small Monkeys**
  - Long slender waists
  - Arboreal
- **Great Apes**
  - No waist
  - Terrestrial
- **Humans**
  - Reappearance of waist
  - Worksite dexterity

Order	Sub order	Infra order	Super family	Family	Sub family	Tribe	Common Term	
<b>P R I M A T E S</b>	<b>Prosimians</b> <small>(Note: As there are many ambiguities surrounding prosimian classification, I use the common term and classification rather than a formal taxonomic category.)</small>						Loris Lemur Tarsier	
	<b>Anthropoidea</b>	<b>Platyrrhini</b>					New World Monkey	
		<b>Catarrhini</b>	<b>Cercopithecoidea</b>				Old World Monkey	
			<b>Hominioidea</b>	<b>Hylobatidae</b>			Gibbon	
				<b>Hominidae</b>	<b>Ponginae</b>		Orang	
					<b>Homininae</b>	<b>Panini</b>		Gorilla Chimp
						<b>Hominini</b>		Human

# Primates: Skeletal Structure

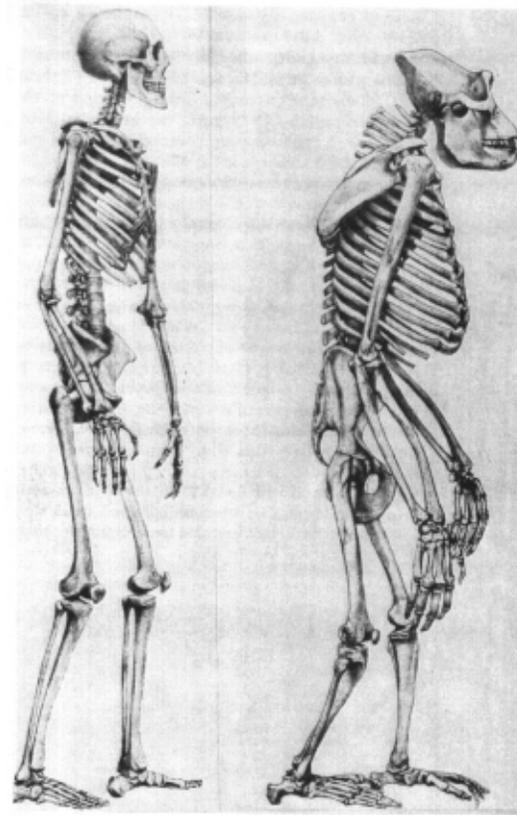
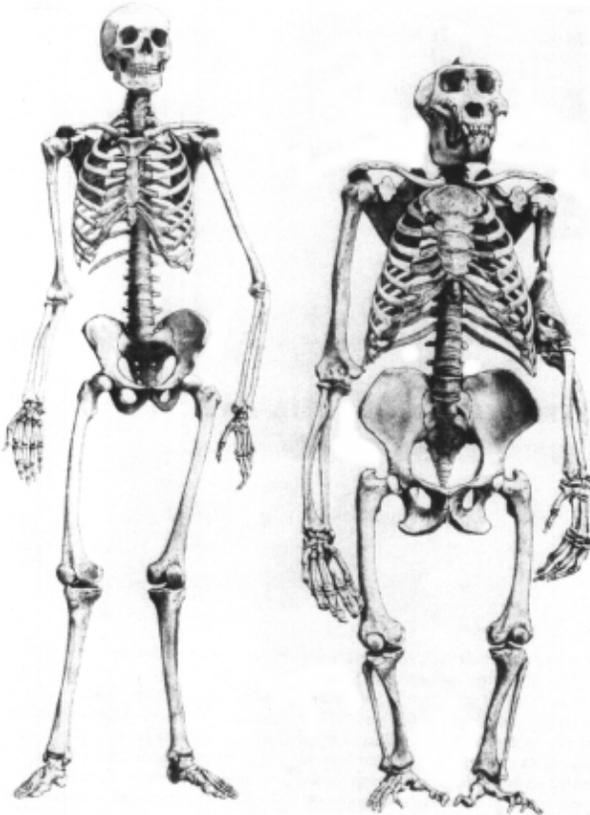


Baboon

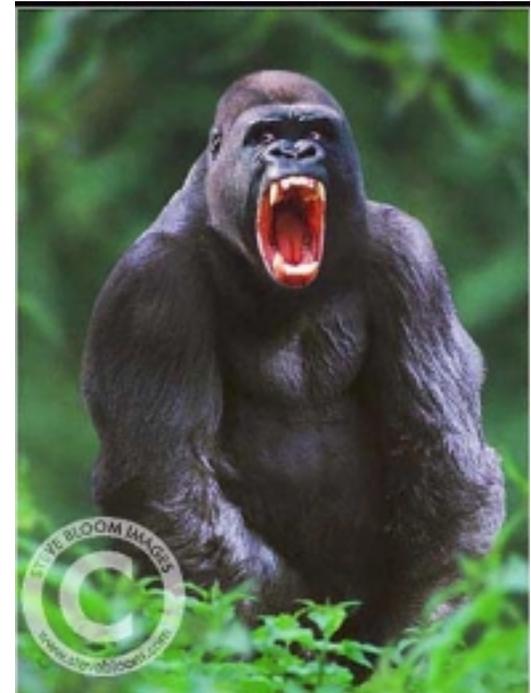
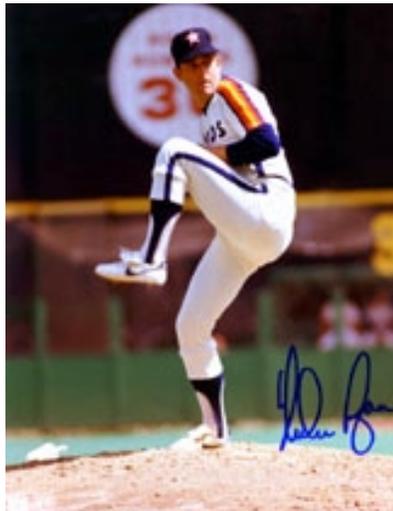


Gorilla

# Primates: Human vs. Gorilla



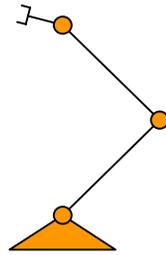
# Primates: Musculature



# Workspace of a Serial Manipulator

## Reachable Workspace

The 3D loci of points at which the arm can place its POR

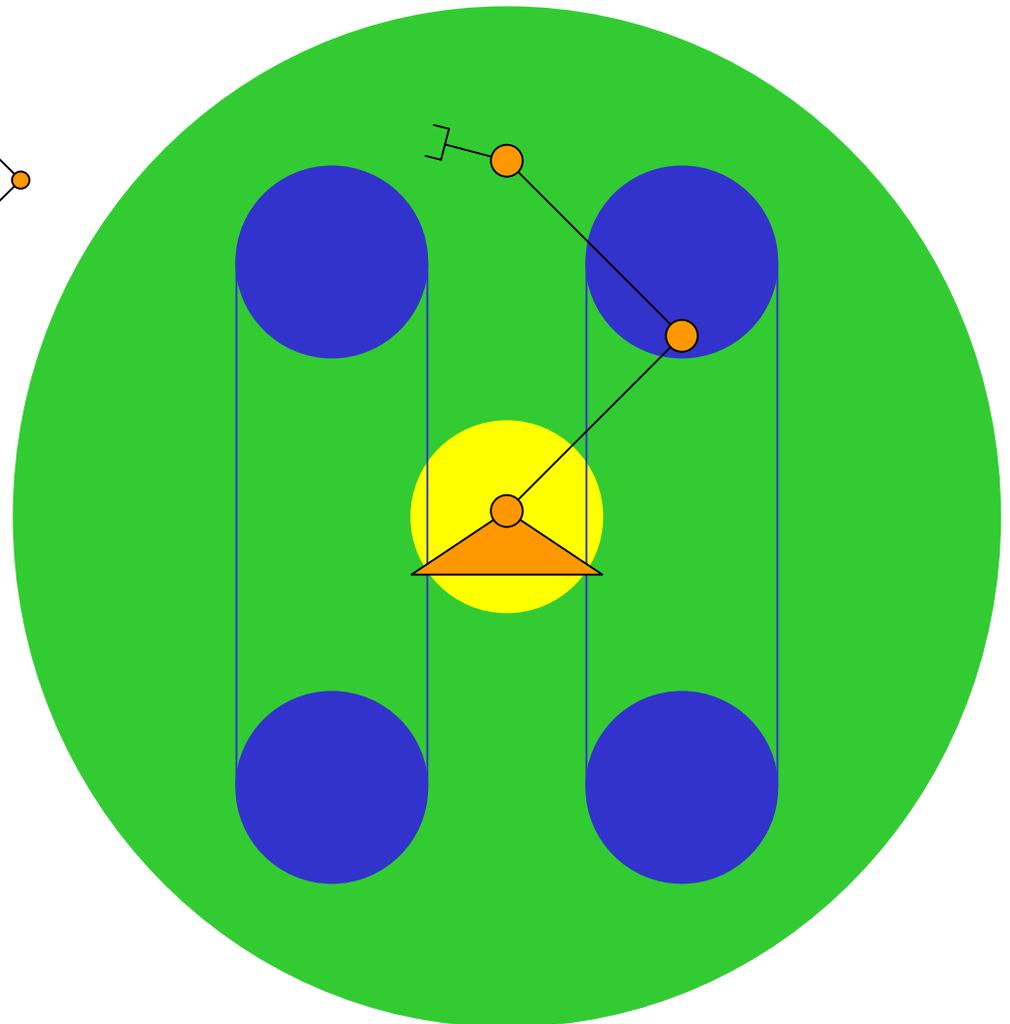


## Dexterous Workspace

The 3D loci of points at which the arm can place its POR at any orientation

## Exclusion Zones

Internal regions that can not be accessed due to link proportions or joint limits



# Workspace of Dual Arm Systems

## Maximize Union of Reachable Workspaces

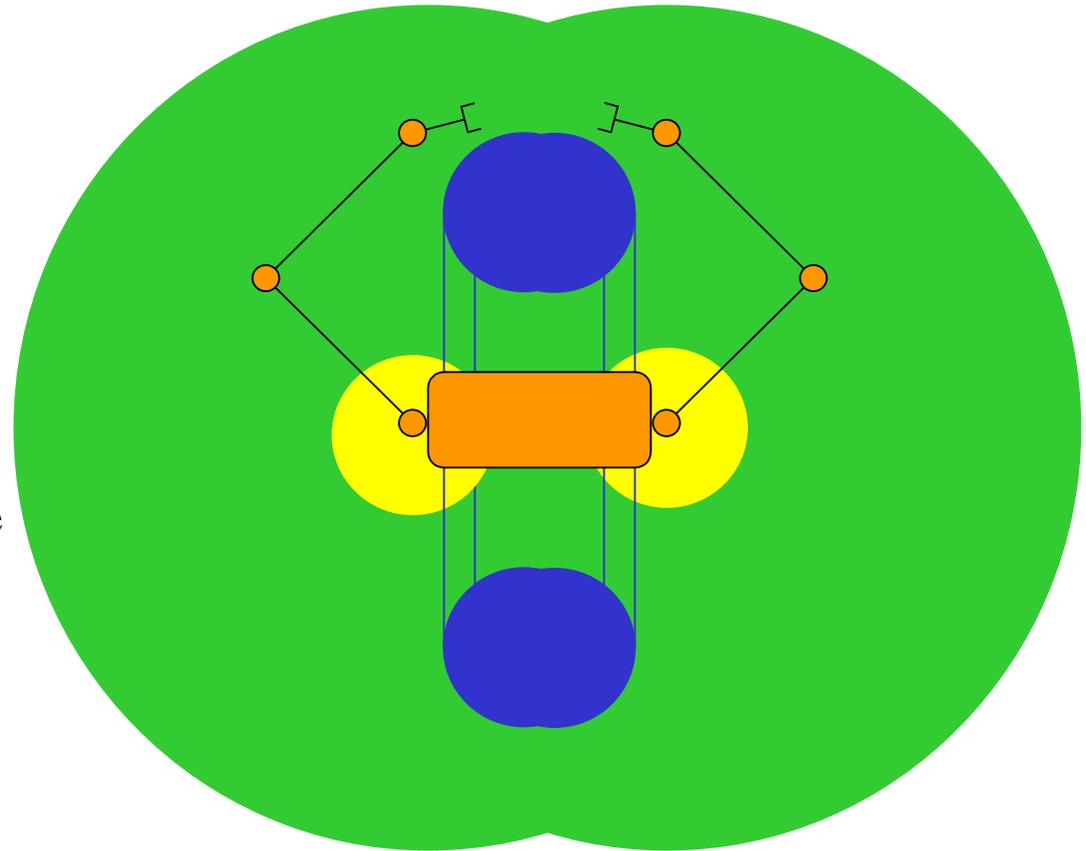
The 3D loci of points at which the arm can place its POR

## Maximize Intersection of Dexterous Workspaces

The 3D loci of points at which the arm can place its POR at any orientation

## Exclusion Zones

Potentially eliminated



# Workspace on a Mobile Base

- Fixed Placement
  - Shoulders rigidly mounted
  - Wide shoulder separation
- Excellent Reachable Union
  - Large workspaces
  - Left and right coverage
  - Good overlap w/ ground
- Limited Dexterous Intersection
  - These are strong, not dexterous arms
  - Orientation limits intersection
  - Intersection only in front



Sandia ARMMS System

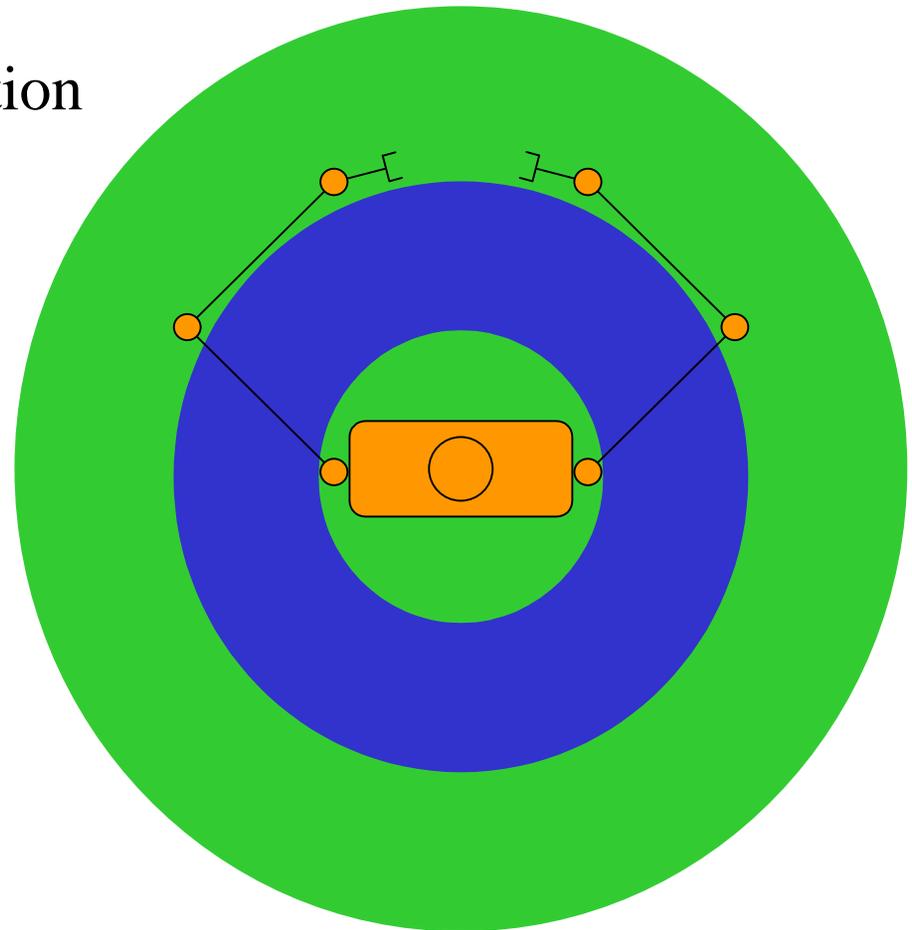


# Workspace Articulated Upper Body

Single Axis Waist: Spine Rotation

Union of  
Reachable Workspace  
Expanded moderately

Intersection of  
Dexterous Workspaces  
Swept into spherical shell

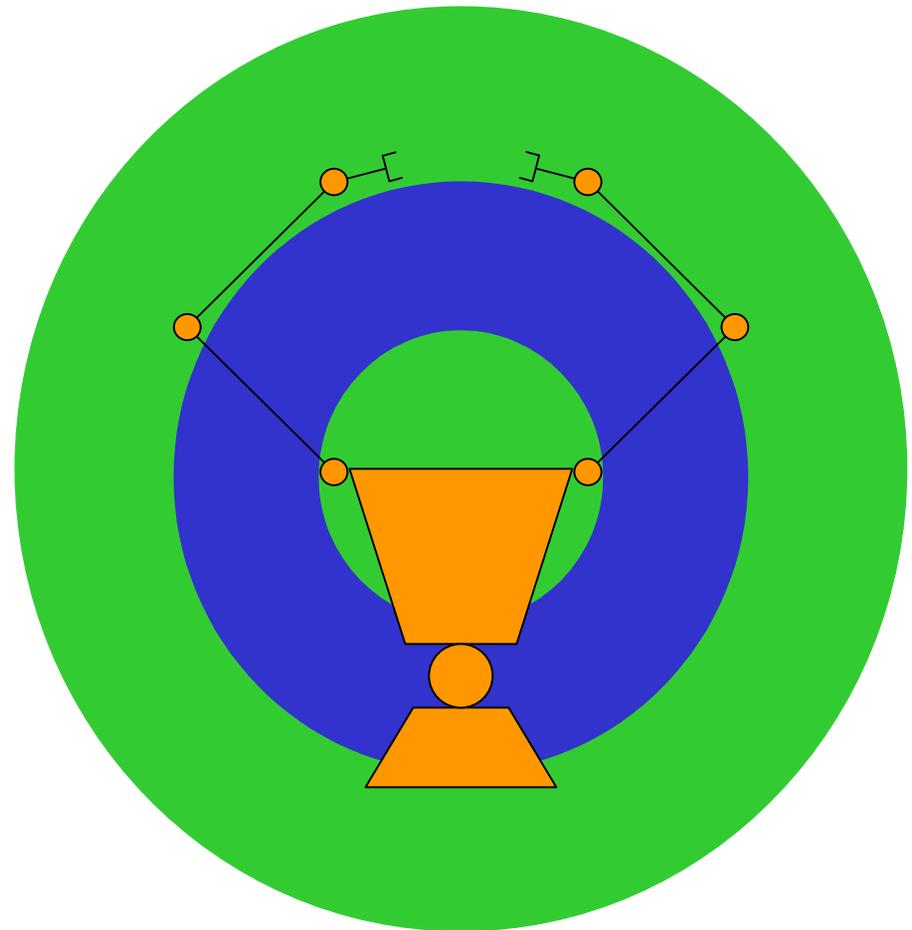


# Workspace Articulated Upper Body

3 Axis Waist: Roll-Yaw-Pitch

Union of  
Reachable Workspaces  
Expanded massively

Intersection of  
Dexterous Workspaces  
Swept into expanded spherical  
shell





# *ROBONAUT* Overview

- Sophisticated upper body system with dual arms
  - 2 Human scale arms (2x7 DOF)
  - 2 Dexterous hands (2x12 DOF)
  - Articulated neck (2 DOF)
  - Articulated waist (3 DOF)
- Intuitive Control
  - Advanced telepresence interfaces
  - Hard real time control
  - Instinctual levels of autonomy
- Versatile, capable system



Photo of teleoperator controlling *ROBONAUT*

# ***ROBONAUT*** FY00 Advances

- Single Task Trials
  - EVA Tools
  - Engineering Tools
  - Geological Science tools
- Added Right Wrist
- Added Left Arm
- Added Left Hand
- Added Waist & Torso
- Added Left Limb Control
- Added Voice interface
- Tested Force Feedback

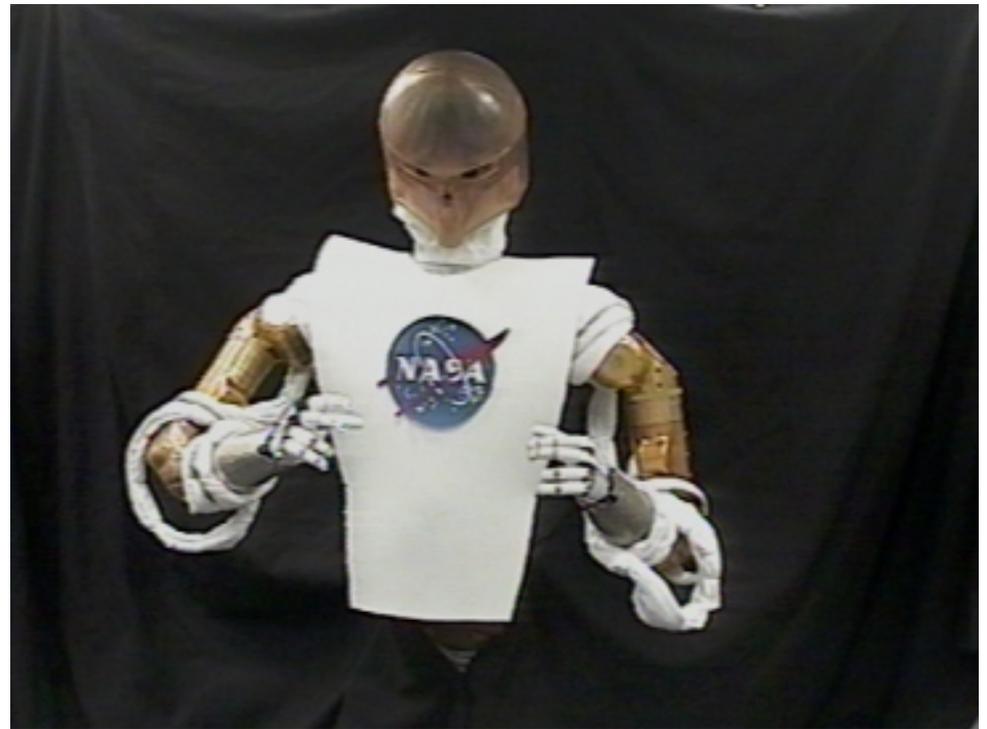
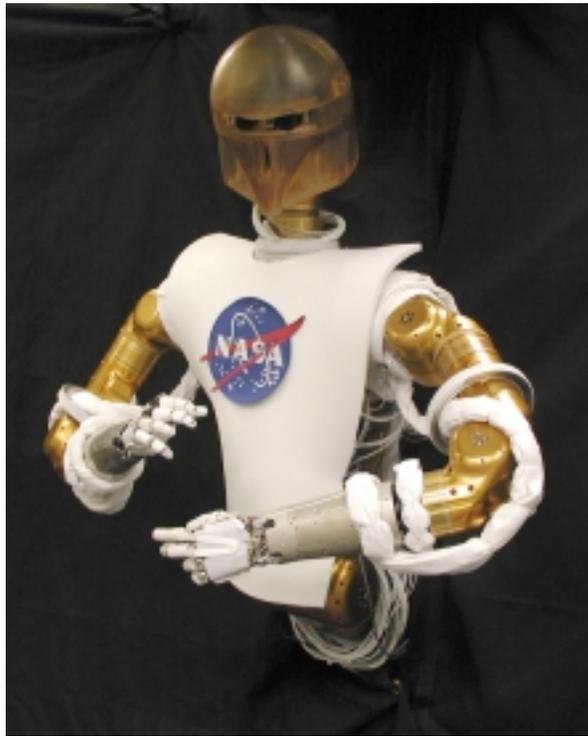


***ROBONAUT***  
Fall 1999

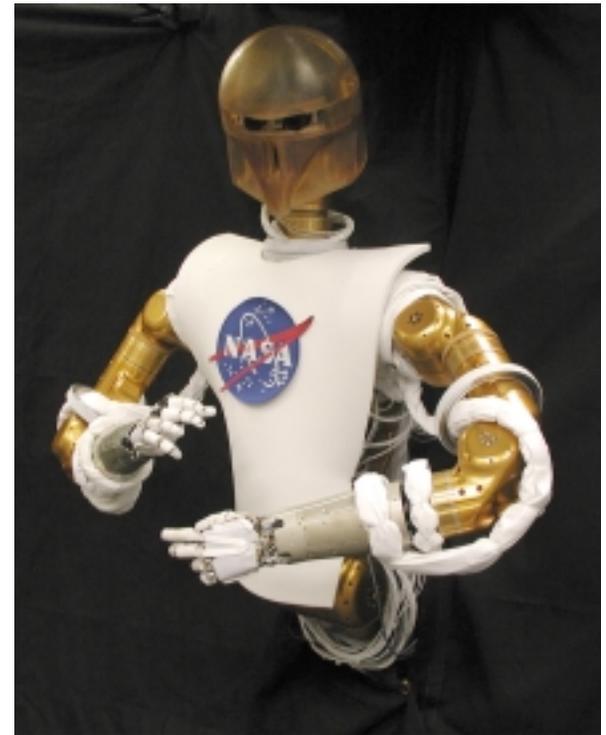
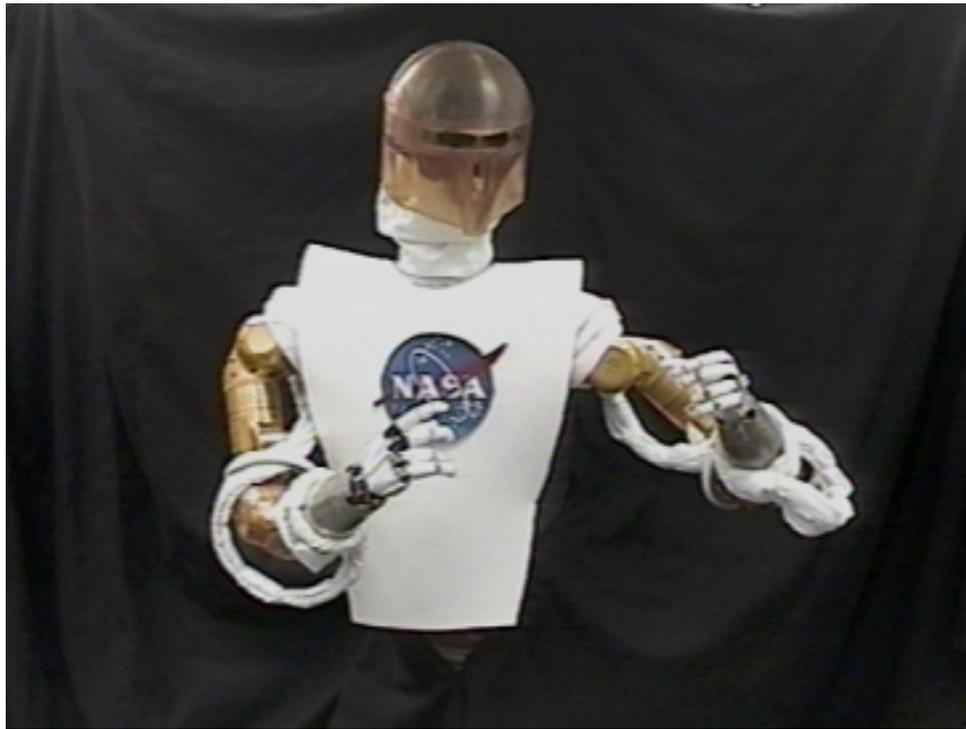


***ROBONAUT***  
Fall 2000

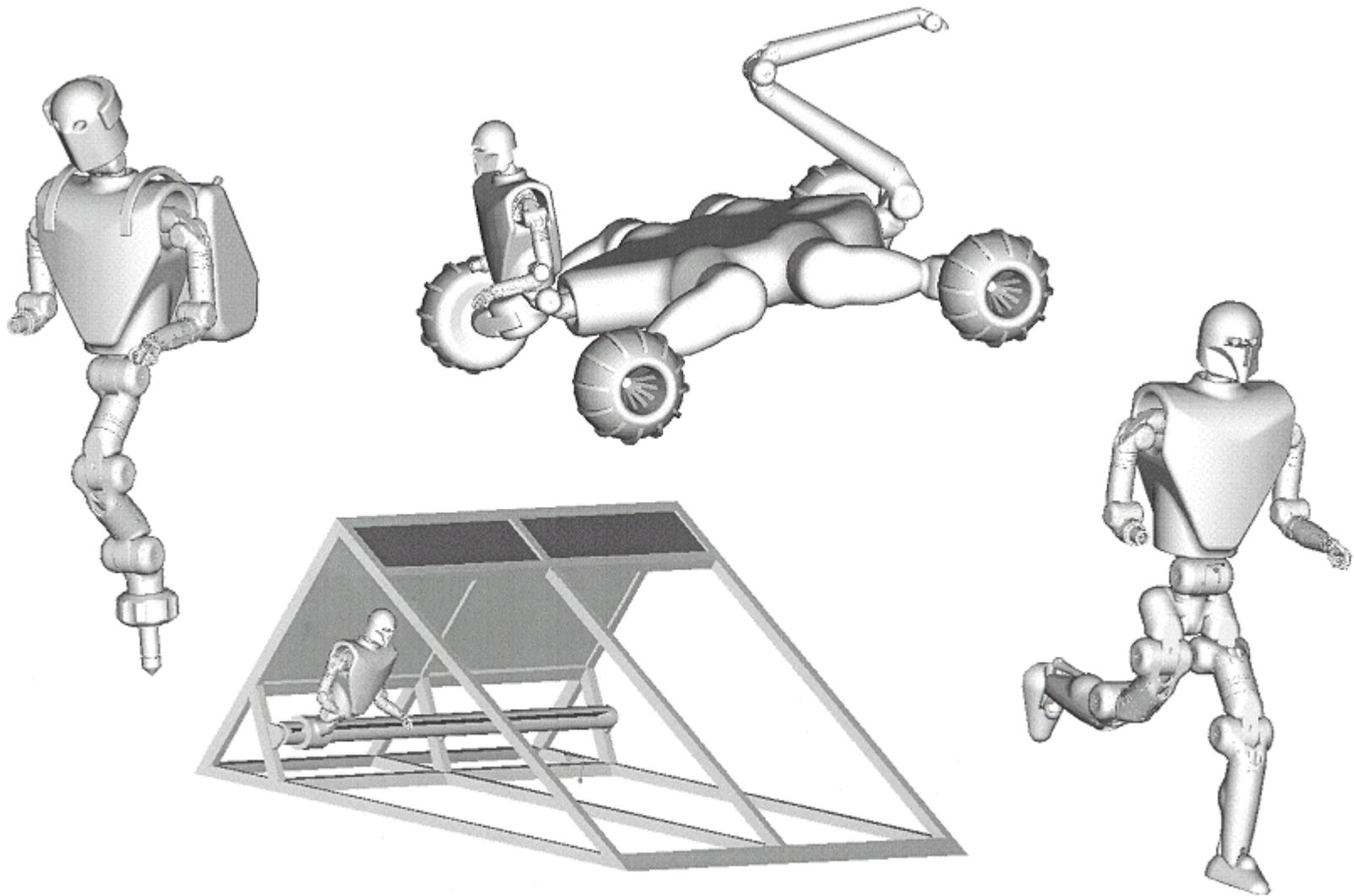
# *ROBONAUT* Articulated Upper Body



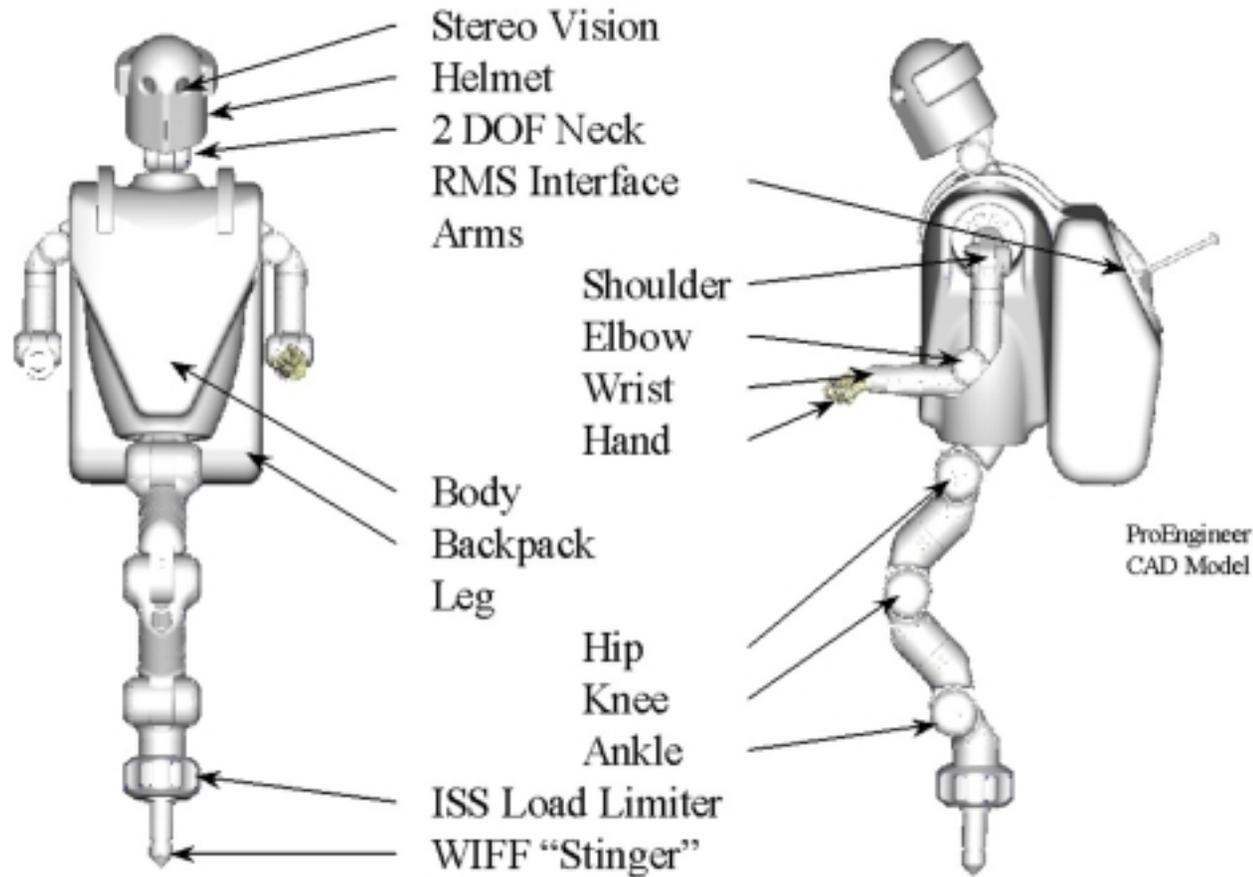
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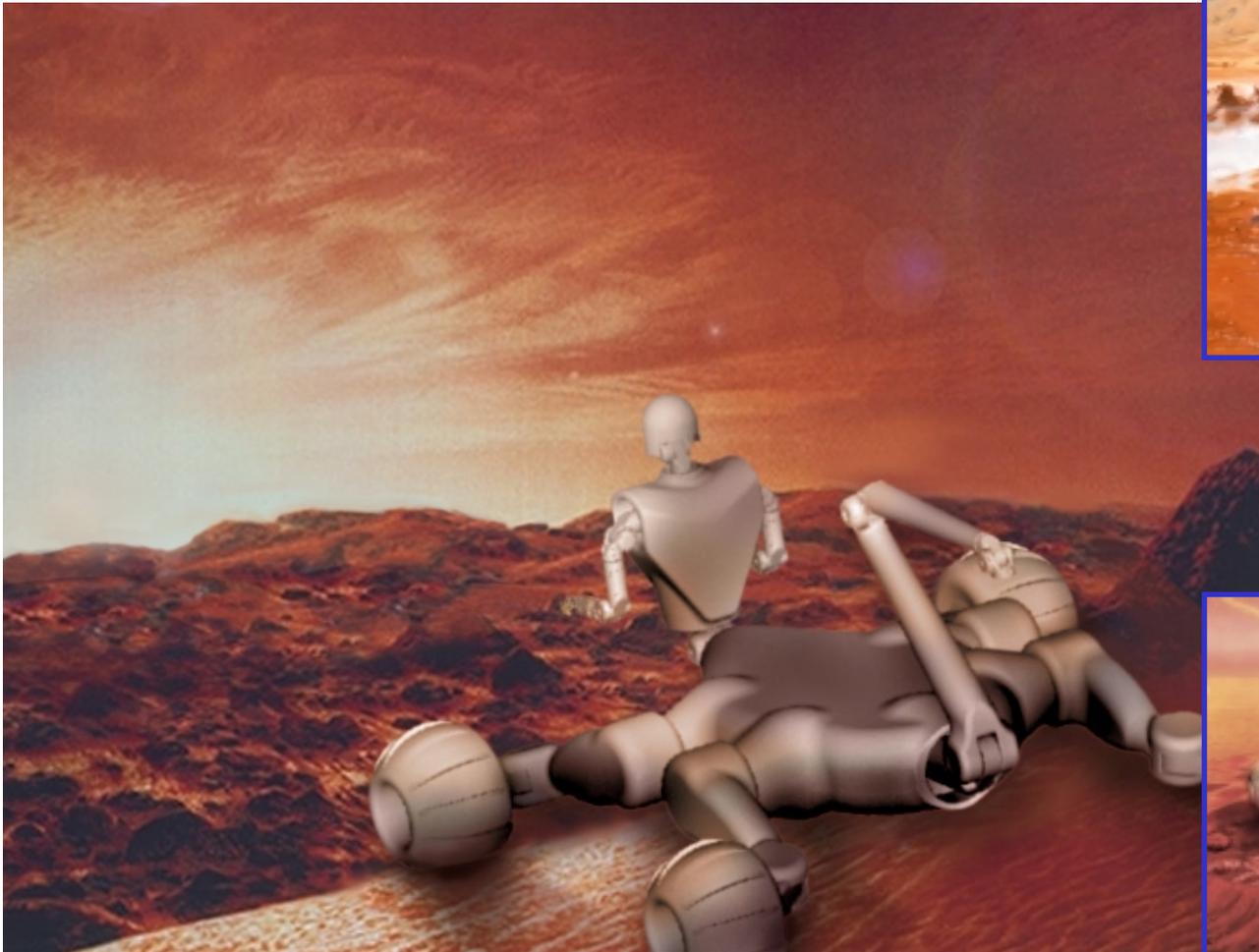
# ***ROBONAUT: Mobility Options***



# ***ROBONAUT: Anatomy for 0g Work***

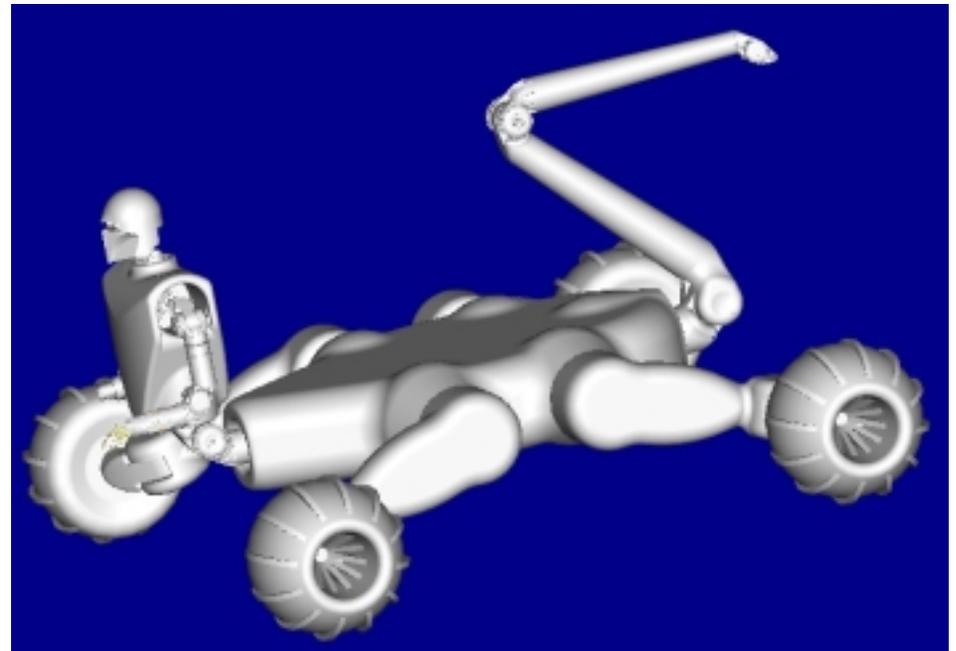


# Surface Exploration: *CENTAUR*



# *CENTAUR*

- Mobile Work System
  - Dexterous Upper Body
  - Rover Chassis
- Planetary Exploration
  - Robotic Colony Work
  - Geologic Exploration
  - Search and Rescue
  - Habitat Assembly
  - Human Assistant



ProEngineer Model of *CENTAUR* Concept

# *CENTAUR* Concepts

