SPST470 - Intro to Space Mission Design: Space Robotics

Craig R. Carignan - Lead Manipulator Controls
Gardell G. Gefke - Ranger Program Manager
Brian J. Roberts - Ranger NBVII Integration Lead

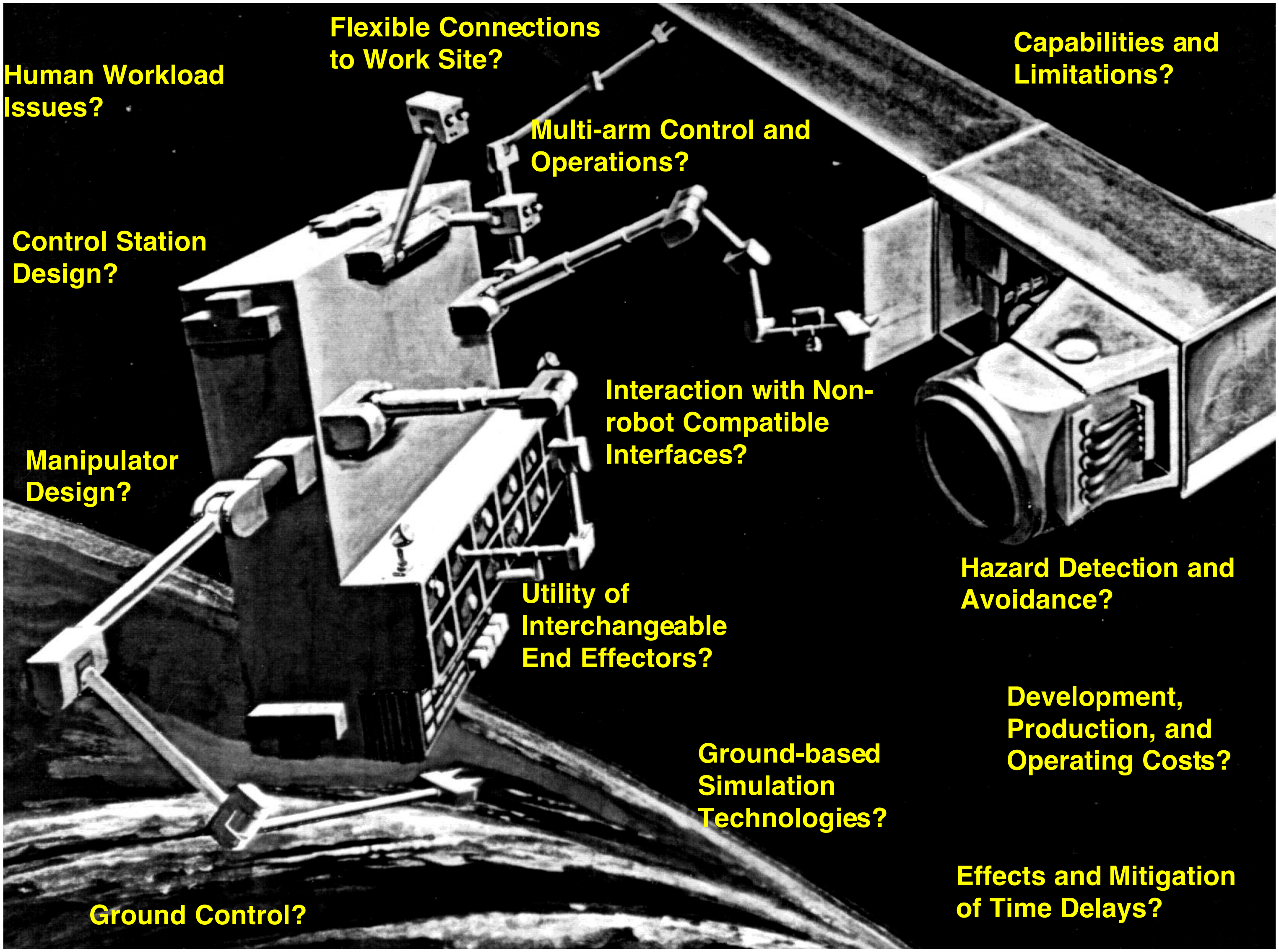
University of Maryland, College Park
Department of Aerospace Engineering
Space Systems Laboratory

`http://www.ssl.umd.edu`

Seminar Outline

- A Brief History of Space Robotics
- On-Orbit Servicing Assets at the SSL
- Evolution of the Ranger Program
- Ranger Telerobotic Shuttle Experiment
- Manipulator Arm Development and Compliant Control Testing
- Ranger NBV Operations at SSL NBRF and NASA/MSFC NBS
- Ranger NBVII Dexterous Arm Integration and Testing

What are the Unknowns in Space Robotics?

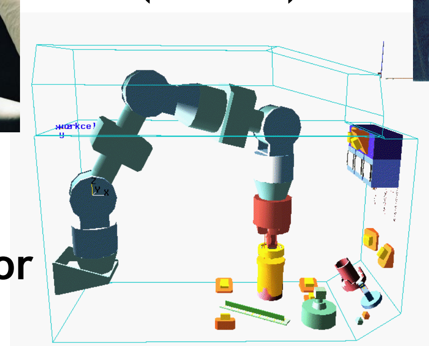


History of Space Robotics

Mission	Year	Agency	Vehicle	Location
Canadarm	1982	CSA/SPAR	STS-2+	SS cargo
ROTEX	1993	ESA/DLR	STS-55	SpaceLab2
Charlotte	1995	NASA/MDAC	STS-63	SpaceHab3
MFD	1997	NASDA/Toshiba	STS-85	SS cargo

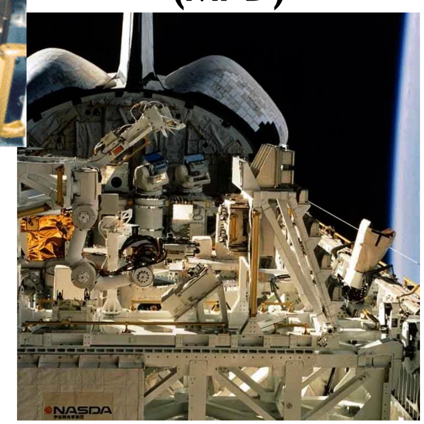
CanadArm or Space Shuttle Remote Manipulator System (SSRMS)

Robot Teleoperation Experiment (ROTEX)



Charlotte IntraVehicular Robot (IVA)

Manipulator Flight Demonstration (MFD)



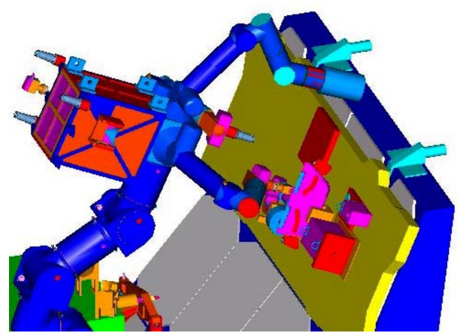
“Mobile” Space Robots

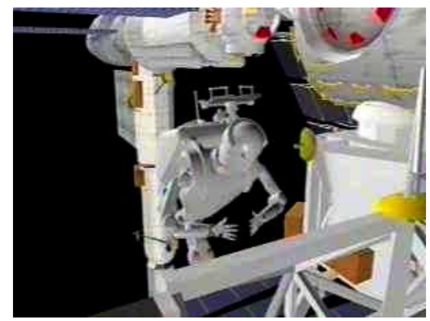
Mission	Year	Agency	Vehicle	Location
ETS-VII	1997	NASDA/Toshiba	H-1	LEO
MSS	2001+	CSA/MDRobotics	STS-100+	ISS
RangerTSX	200X	NASA/UM	STS-???	SS cargo bay
Robonaut	200X	NASA/JSC	STS-?,ISS	EVA

Experimental Test Satellite #7 (ETS-VII)

Mobile Servicing System (MSS)

Ranger Telerobotic Shuttle Experiment (RTSX)





“Robonaut”

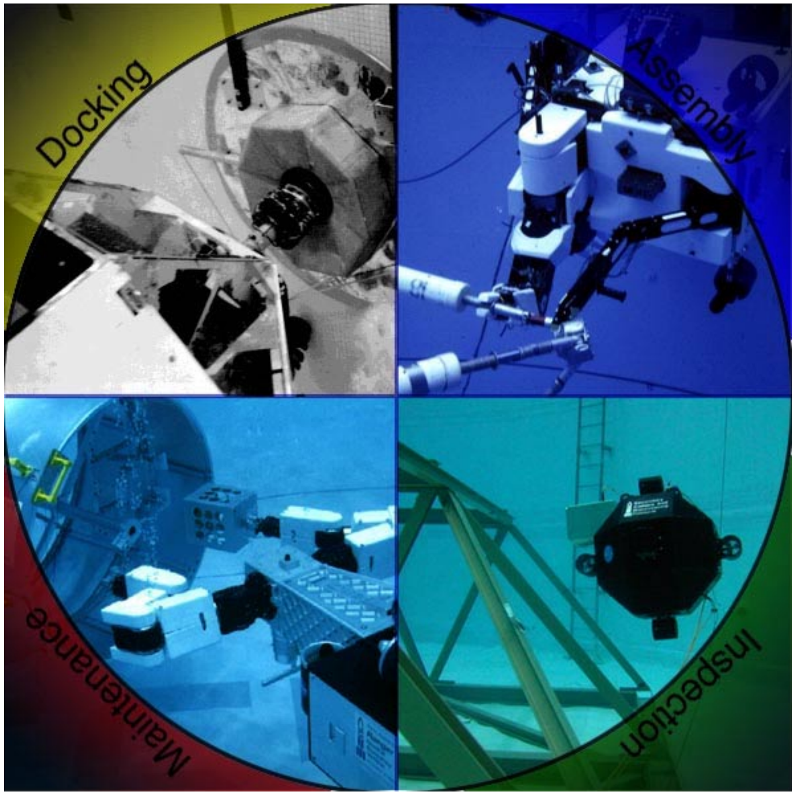
Ranger-Class Space Robots

How the Operator Interacts with the Robot

How the Robot Interacts with the Worksite

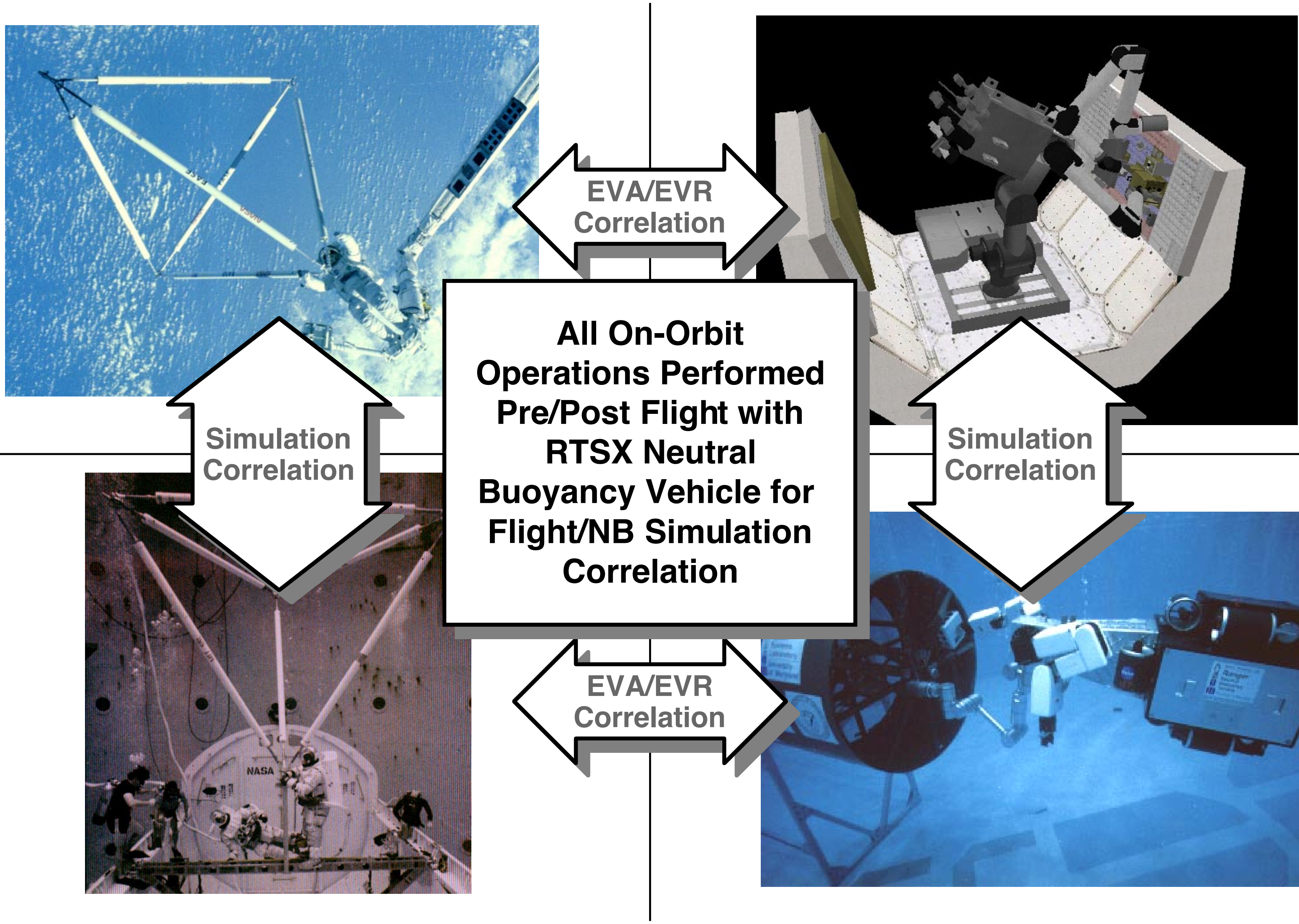
	Locally Teleoperated	Remote (Ground) Teleoperated	Supervisory/ Autonomous Control
Specialized Robotic Interfaces	SSRMS MFD MSS/SPDM	Charlotte IVA	ROTEX ETS-VII
EVA Compatible Interfaces		Ranger TSX	
Human Compatible Interfaces	Robonaut		

On-Orbit Servicing at SSL



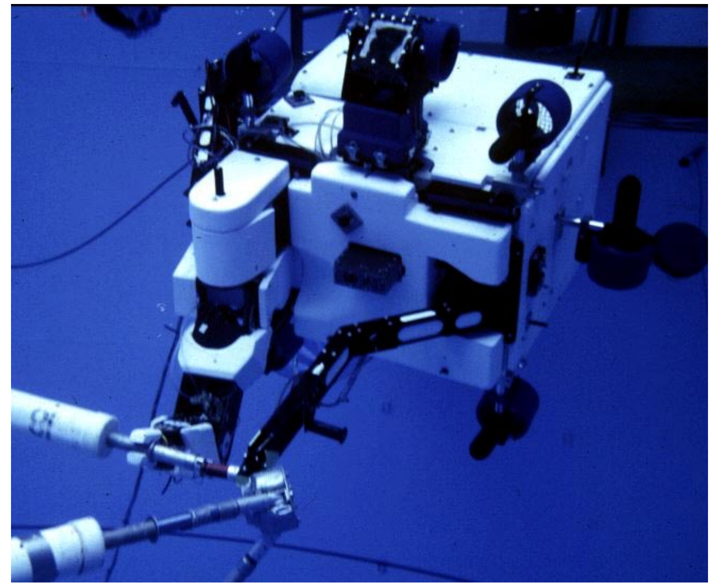
- **Development and testing of multiple complete robotic systems capable of performing complex space tasks end-to-end:**
  - **Docking**
  - **Assembly**
  - **Inspection**
  - **Maintenance**
- **Facility for evaluating systems in a simulated 6 degree-of-freedom (DOF) microgravity environment**
- **Expertise:**
  - **Autonomous control of multiple robotic systems**
  - **Design of dexterous robotic manipulators**
  - **Adaptive control techniques for vehicle dynamics**
  - **Use of interchangeable end effectors**
  - **Investigation of satellite missions benefiting most from robotic servicing**

Why Neutral Buoyancy?



Beam Assembly Teleoperator (BAT)

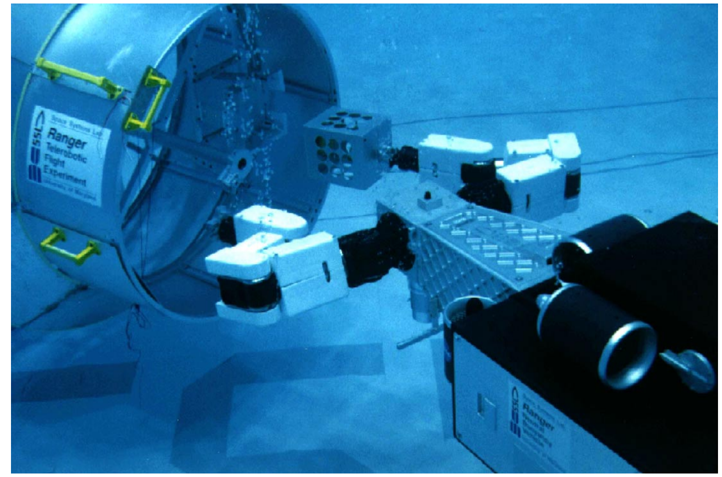
- **Free-flying robotic system to demonstrate assembly of an existing space structure not robot friendly:**
  - 6 DOF mobility base
  - 5 DOF dexterous assembly manipulator
  - Two pairs of stereo monochrome video cameras
  - Non-articulated grappling arm for grasping the structure under assembly
  - Specialized manipulator for performing the coarse alignment task for the long struts of the truss assembly

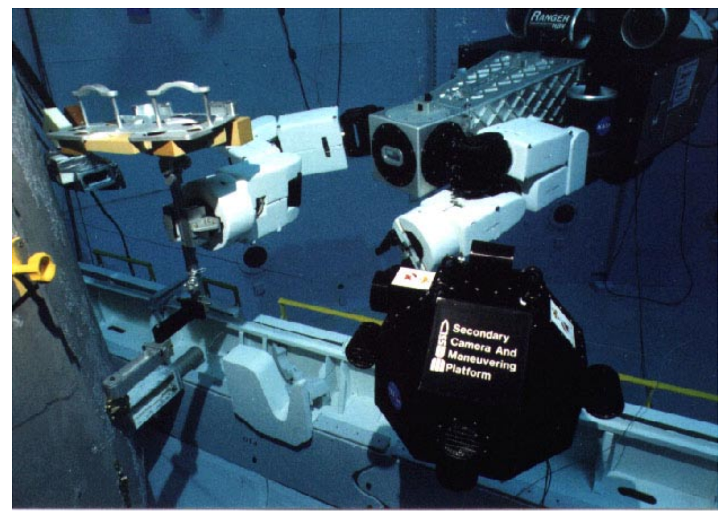


- **Operational from 1984 to 1995**
- **Achievements:**
  - Combination of simple 1 DOF arm with dexterous 5 DOF manipulator proved to be a useful approach for assembly of a tetrahedral structure
  - Demonstrated utility of small dexterous manipulator to augment larger, less dexterous manipulator
  - Assisted in the simulated change out of spacecraft batteries of Hubble Space Telescope

Ranger Neutral Buoyancy Vehicle (RNBV)

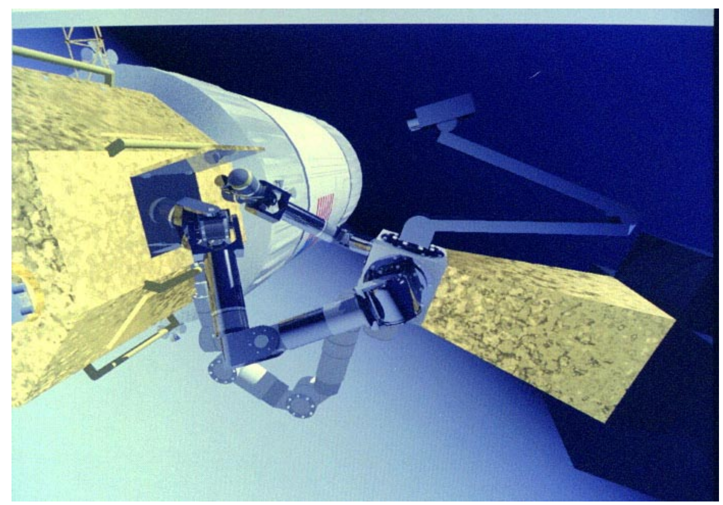
- Ranger Neutral Buoyancy Vehicle (NBV) operational since 1994
- Incorporated improvements over BAT (2x7dof arms, narrower shoulder, etc.)
- Robotic prototype testbed for satellite inspection, maintenance, refueling, and orbit adjustment
- Demonstrated robotic tasks include ORU replacement, electrical connection, dual-arm operation, and free-flight





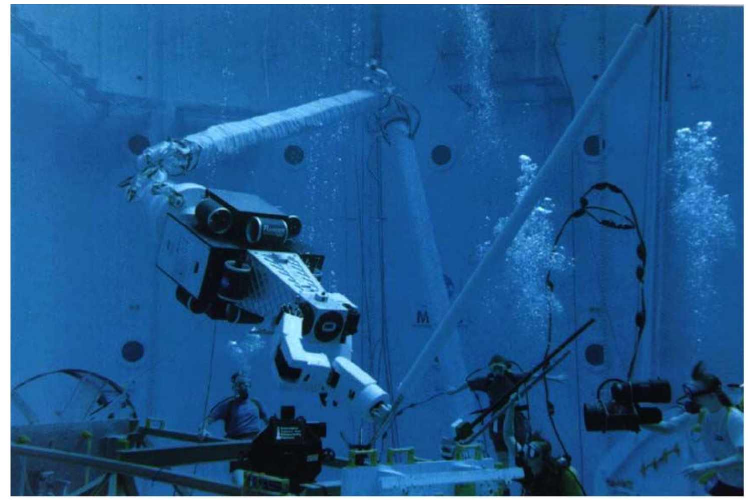
Ranger Telerobotic Flight Experiment (RTFX)

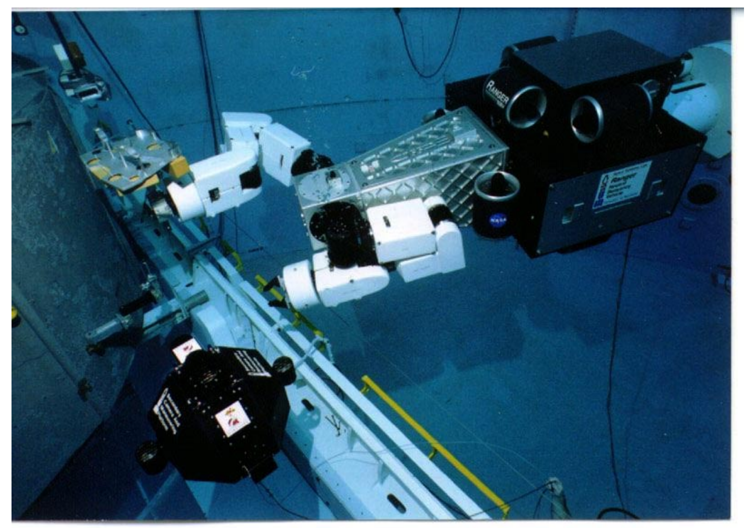
- Project funded by NASA's Code S and started in 1992
- Goal was to demonstrate telerobotic satellite servicing in Earth orbit
- >1000 mile orbit required for LOS communication
- High orbit and weight required a Delta-class ELV
- Redirected as a Space Shuttle launch payload in October, 1996



Ranger/Remote Manipulator System (RRMS)

- Ranger TFX at end of RMS
- $2M to run power/data umbilical down RMS
- Two-arm contact required at all times to react loads
- Ranger failure could mean jettisoning the RMS
- Concerns with stiffness and modal excitation of RMS
- Two pilots minimum required to operate Ranger and RMS
- Complex interface effects on training, safety, and ops

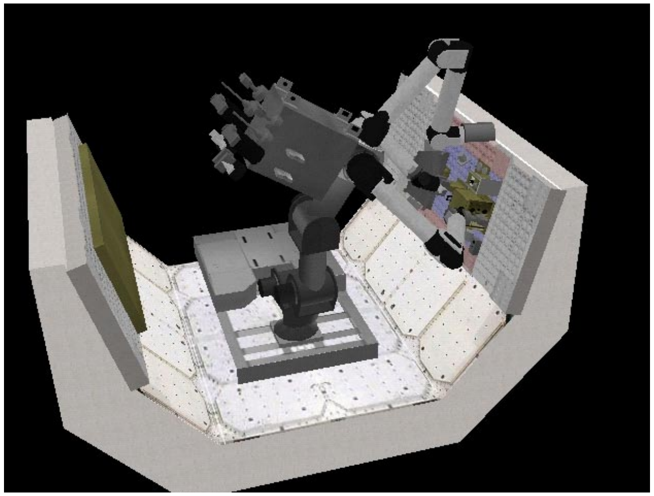


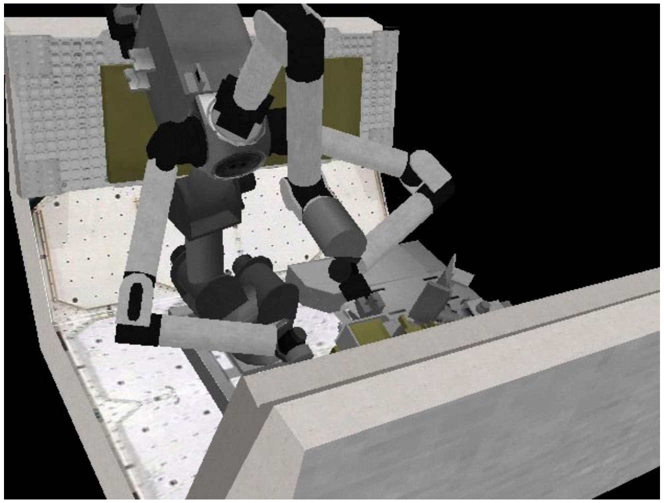


Space Systems Laboratory
University of Maryland

Ranger Telerobotic Shuttle Experiment (TSX)

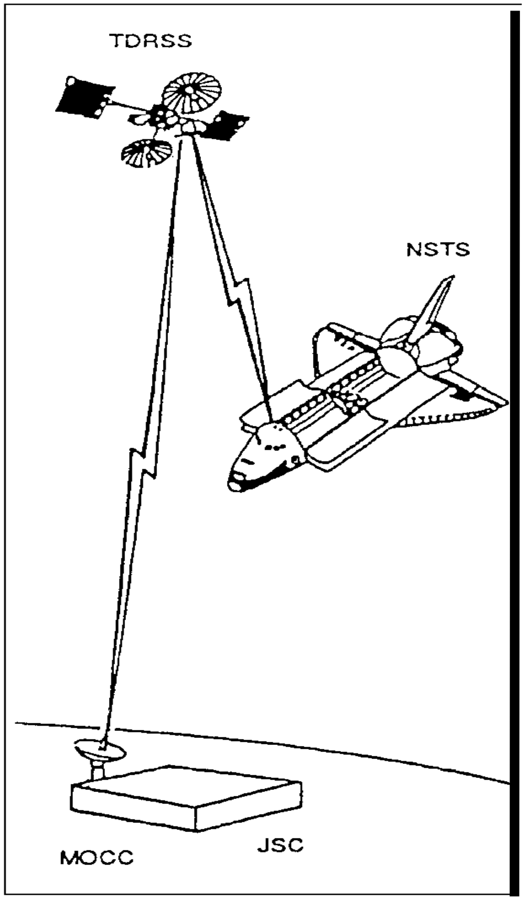
- Robot attached to a Spacelab pallet within the cargo bay of the orbiter
- Controlled from orbiter and from the ground
- SS payload eliminated need for spacecraft bus (power and communication from orbiter)
- More benevolent thermal environment in cargo bay than as unattached payload
- Robot not expended at end of mission; EVA recovery option

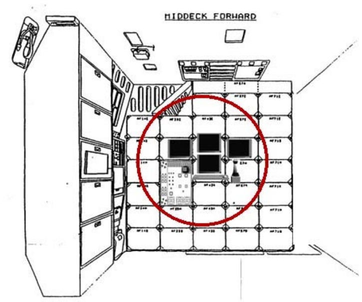




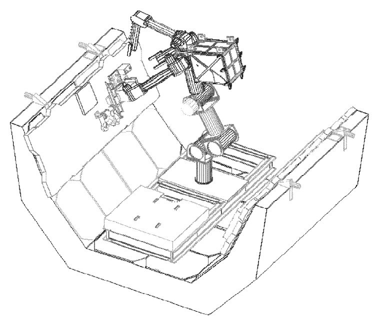
Space Systems Laboratory
University of Maryland

Ranger Flight Experiment Concept Overview

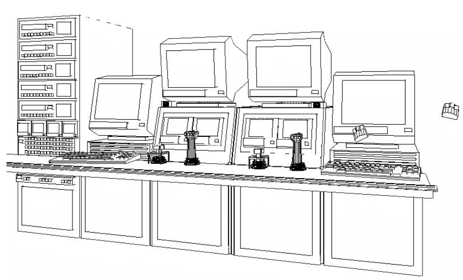




On-Orbit Control:
- Crew Operated from Middeck Locker
- SGI-based Control Station
  with 3 DOF Hand controllers
- AFD Switch Panel for Latches



Payload Bay Elements:
- Spacelab Pallet Carrier
- Ranger Robot
- Task Elements
- Power Distribution Equipment



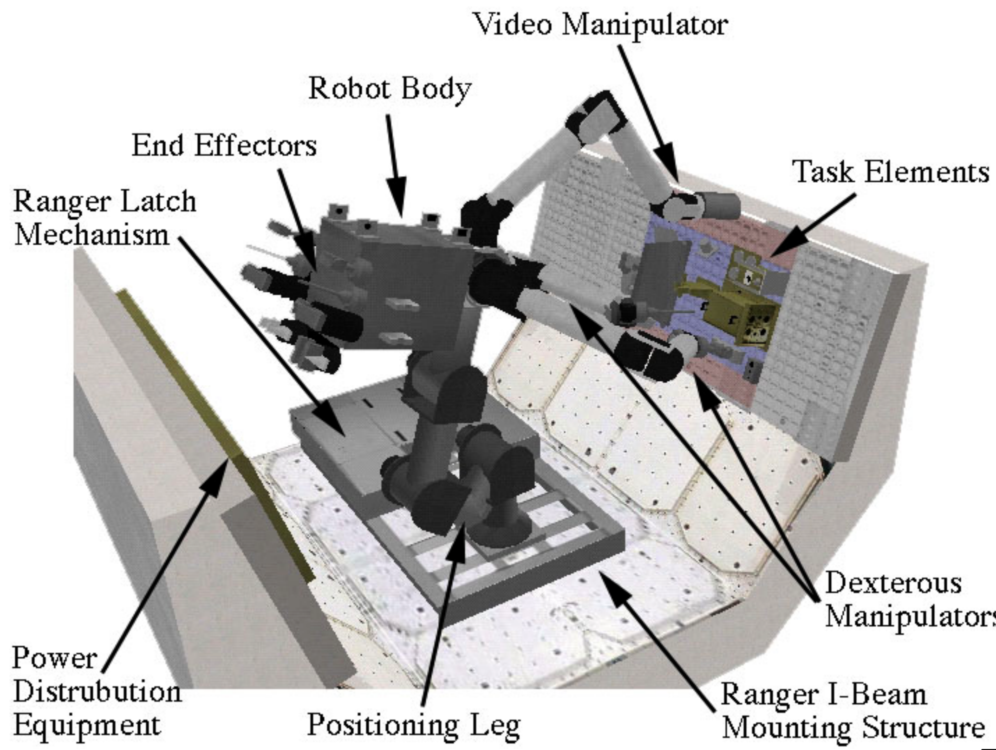
Ground Control:
- Located in JSC PCC
- UMD Control Station
- Video Monitoring
- Mission Monitoring

Mission Overview

- Fundamental mission requirements are for on-orbit and ground operation of task elements
  - On-orbit control from Flight Control Station (FCS) in middeck
  - Ground control from Ground Control Station (GCS) in PCC
    - Command and telemetry link (KU-2 & KU-3) via TDRS and Orbiter comm
- Inflight operations segmented into a series of 12 (TBD) test sessions of approximately 4 hours duration per session
  - Multiple operations of various task elements
  - On-orbit and ground control
  - One crewmember required during all operations periods
- Task elements include ORUs (ISSA and HST), EVA support equipment, and taskboard items
  - Task complexity ranges from very simple to very difficult
- Orbit insensitive — benign thermal environment preferred
- No planned EVA/RMS operations

Robot’s Characteristics

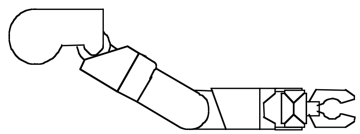
- **Body**
  - Internal: main computers and power distribution
  - External: end effector storage and anchor for launch restraints
  - Head: 12” cube
- **Four manipulators**
  - Two dexterous manipulators
    - 5.5″ diameter, 48″ long
    - 8 degrees of freedom
    - 30 lb of force and 30 ft-lbf of torque at end point
  - Video manipulator
    - 5.5″ diameter, 55″ long
    - 7 degrees of freedom
    - Stereo video camera at end
  - Positioning leg
    - 9.5” diameter, 75” long
    - 6 degrees of freedom
    - 25 lb of force and 200 ft-lbf of torque; can withstand 250 lbf at full extension with brakes engaged



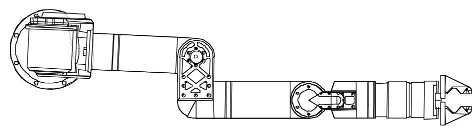
~1500 lbs weight; 14′ length from base on SLP to outstretched arm tip

RTSX Manipulator Lineage

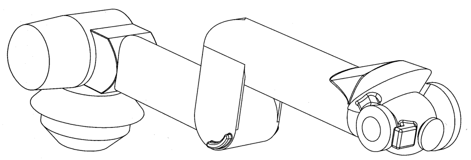
Roboticus Dexterus



BAT Dexterous Arm (5 DOF)
ca. 1984

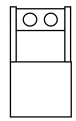


Ranger Dexterous Arm Mk I (7 DOF)
ca. 1994

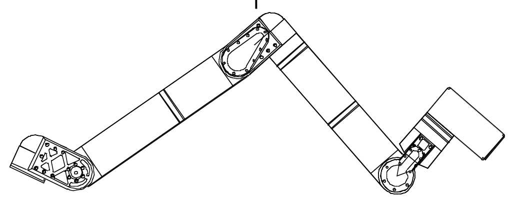


Ranger Dexterous Arm Mk II (8 DOF)
ca. 2001

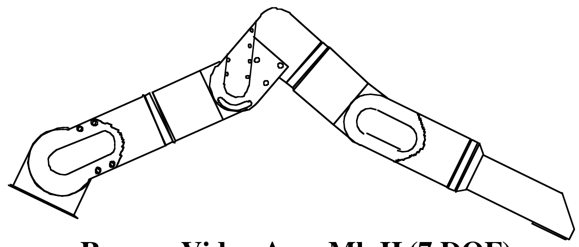
Roboticus Videus



BAT Tilt & Pan Unit (2 DOF)
ca. 1984

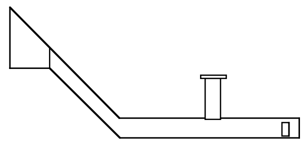


Ranger Video Arm Mk I (6 DOF)
ca. 1996

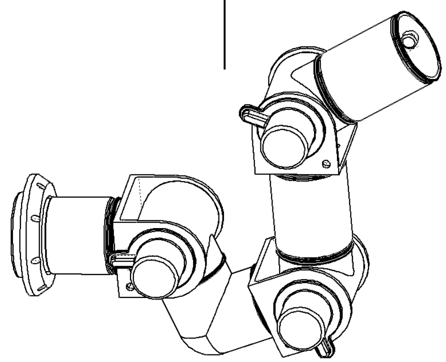


Ranger Video Arm Mk II (7 DOF)
ca. 1996

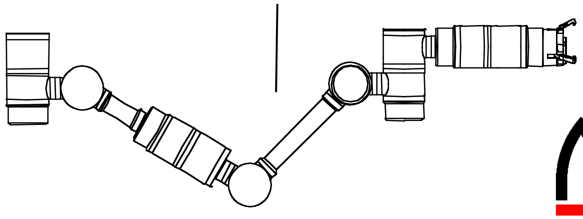
Roboticus Grapplus



BAT Grapple Arm (0 DOF)
ca. 1984

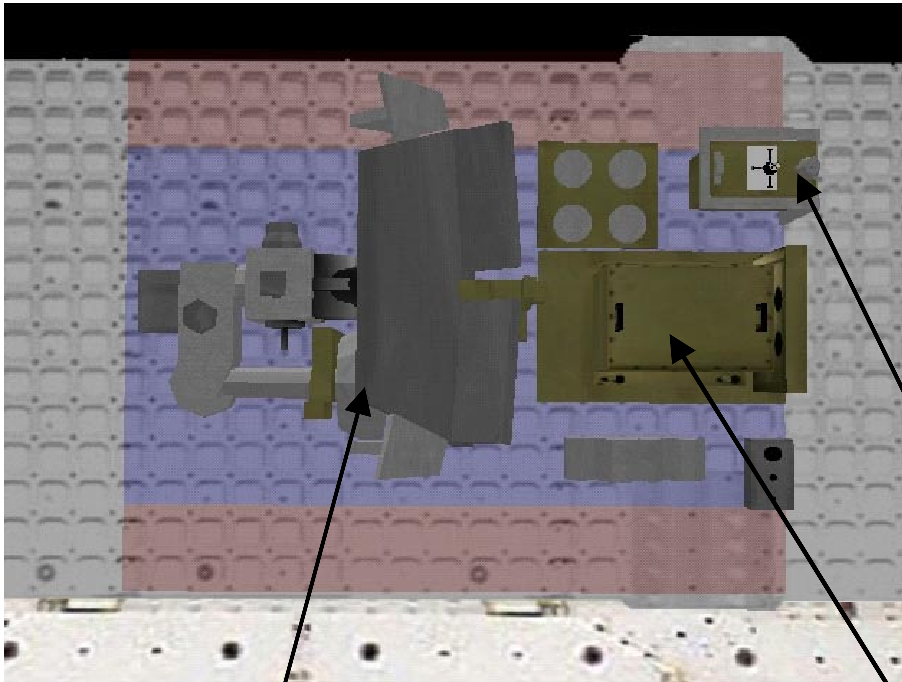


Ranger Positioning Leg (6 DOF)
ca. 1998

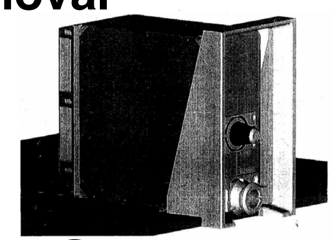


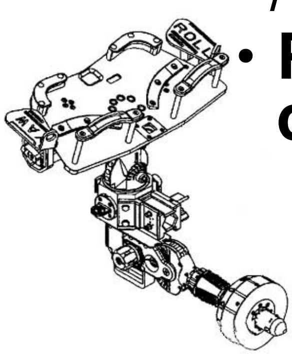
Ranger Grapple Arm (7 DOF)
ca. 1996

Task Suite

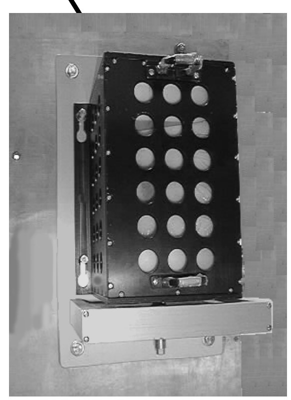


- **Taskboard**
  - Static force compliance task (spring plate)
  - Dynamic force-compliant control over complex trajectory (contour task)
  - High-precision endpoint control (peg-in-hole task)
- **Robotic ORU task**
  - Remote Power Controller Module insertion/removal





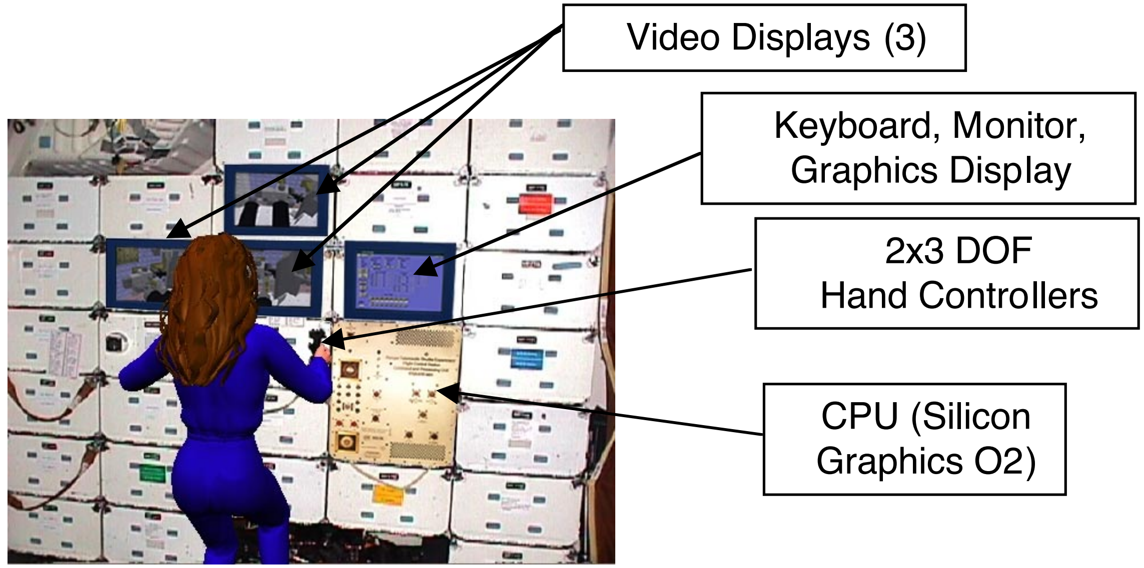
- **Robotic assistance of EVA**
  - Articulating Portable Foot Restraint setup/tear down



- **Non-robotic ORU task**
  - HST Electronics Control Unit insertion/removal

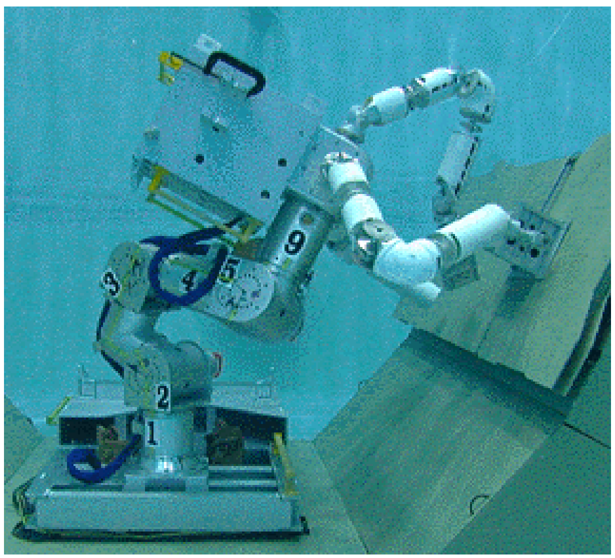
Operating Modalities

- **Flight Control Station (FCS)**
  - **Single console**
  - **Selectable time delay**
    - **No time delay**
    - **Induced time delay**



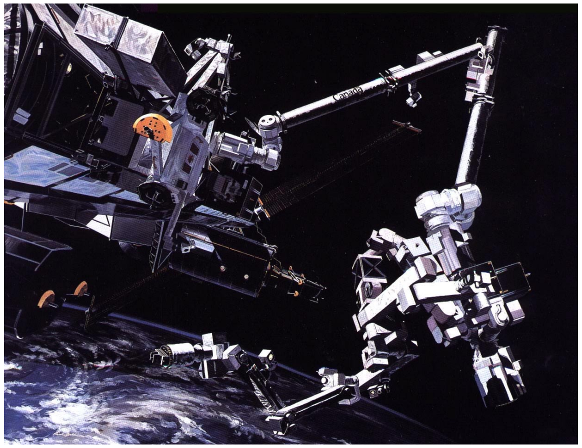
- **Ground Control Station**
  - **Multiple consoles**
  - **Communication time delay for all operations**
  - **Multiple user interfaces**
    - **FCS equivalent interface**
    - **Advanced control station interfaces (3-axis joysticks, 3-D position trackers, mechanical mini-masters, and force balls)**

Engineering Test Units (Ranger NBVII)

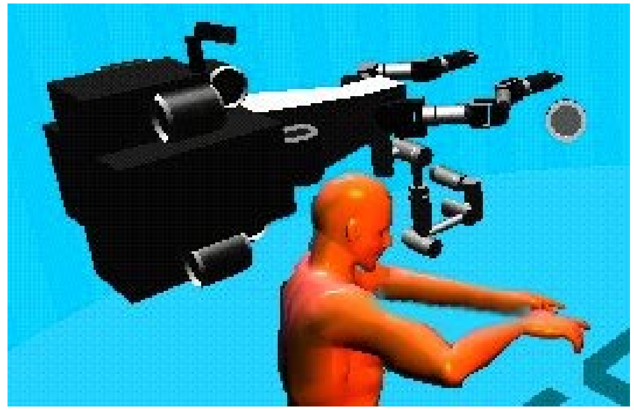


- **RNBV II is a fully-functional, powered engineering test unit for the RTSX flight robot. It is used for:**
  - **Refining hardware**
  - **Modifying control algorithms and developing advanced scripts**
  - **Verifying boundary management and computer control of hazards**
  - **Correlating space and neutral buoyancy operations**
  - **Supporting development, verification, operational, and scientific objectives of the RTSX mission**
  - **Flight crew training**
- **An articulated non-powered mock-up is used for hardware refinement and contingency EVA training**

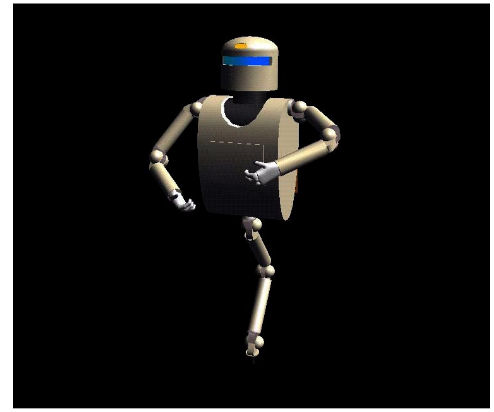
Results of a Successful Ranger TSX Mission



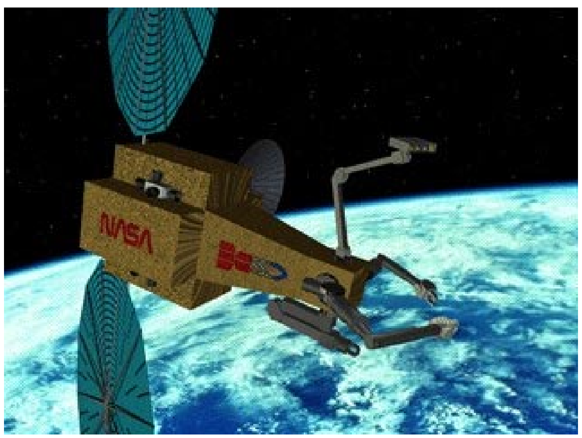
Demonstration of Dexterous Robotic Capabilities



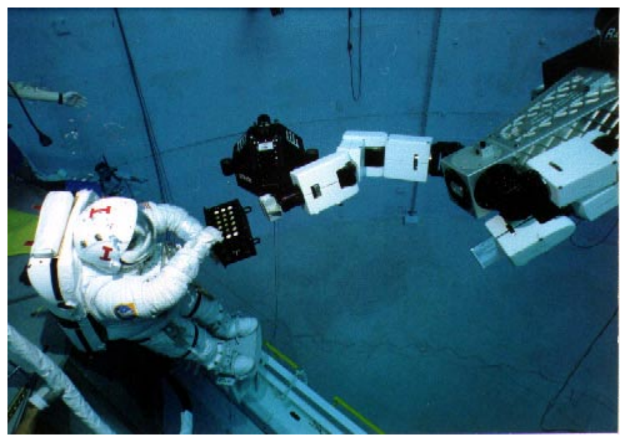
Understanding of Human Factors of Complex Telerobot Control



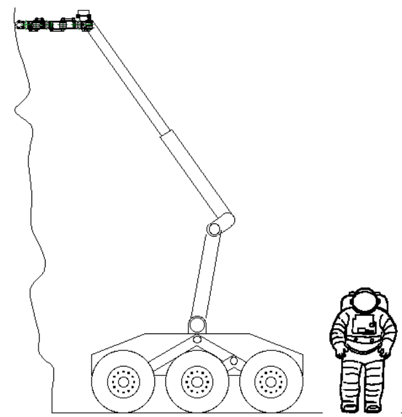
Pathfinder for Flight Testing of Advanced Robotics



Precursor for Low-Cost Free-Flying Servicing Vehicles



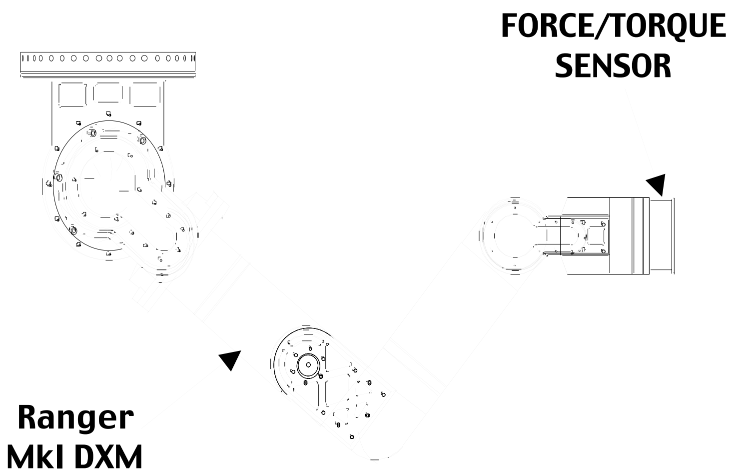
Lead-in to Cooperative EVA/Robotic Work Sites



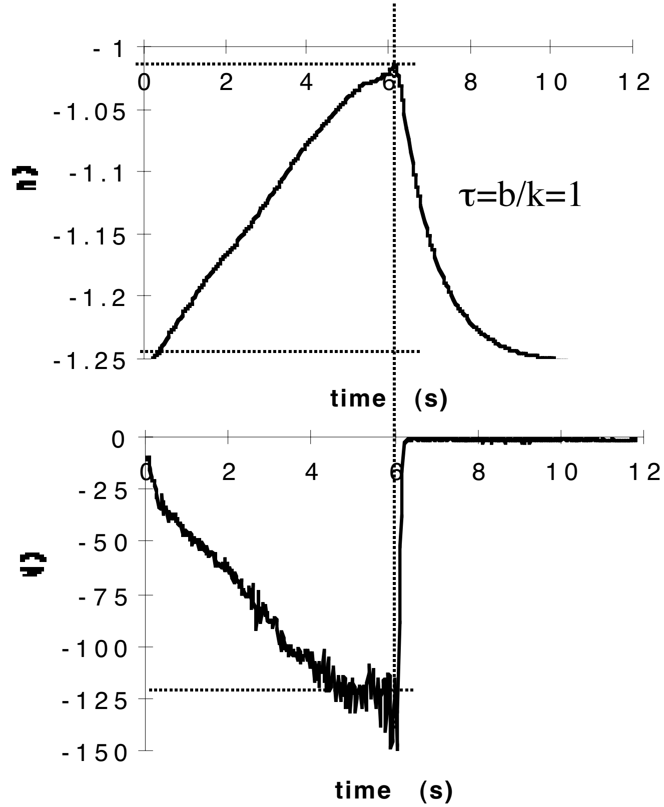
Dexterous Robotics for Advanced Space Science

Testing
&
Operations

Ranger DXM MkI Impedance Testing



CLIP#1 (RNBV-DXM impedance tests)

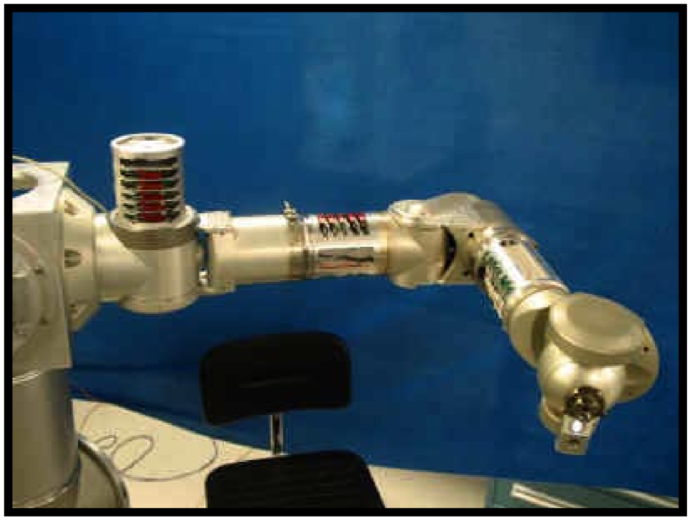


DESIRED IMPEDANCE: K_{des} = 500 N/m
B_{des} = 500 N/m/s

MEASURED IMPEDANCE: K=125/0.24=520
τ = 1 sec^{-1}

Ranger DXM MkII Integration & Testing

CLIP#2 (RNBVII – 4 DOF wrist tests)



CLIP#3 (RNBVII – DXM MkII tests)

For more images and video on Ranger NBVII integration & testing, please visit our data webpage at http://ranger.ssl.umd.edu/data/

Ranger NBVI Operations

CLIP#5 (RNBV – NASA/MSFC ops)

CLIP#4 (RNBV – SSL/NBRF ops)