SNC Advanced Manipulator Technology for Spacecraft Servicing

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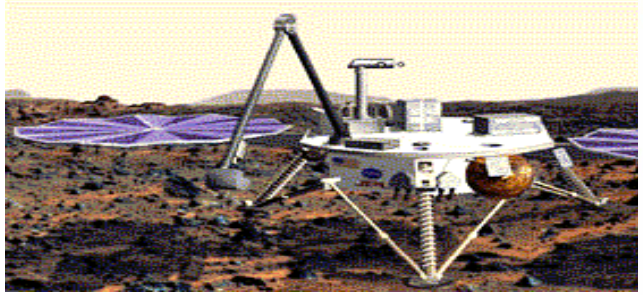
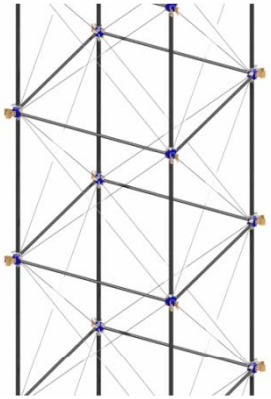
- The Space Systems Group is merging of several small spacecraft technology companies
  - SpaceDev, Inc
    - SpaceDev
    - Starsys
  - MicroSat Systems, Inc (MSI)

Spacecraft Mechanisms

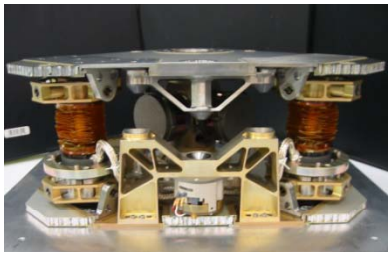
- We invent, design, build and test the structures that move and the things that make things move; motors, hinges, structure, latches
- More than 3000 mechanisms and subsystems on more than 300 spacecraft

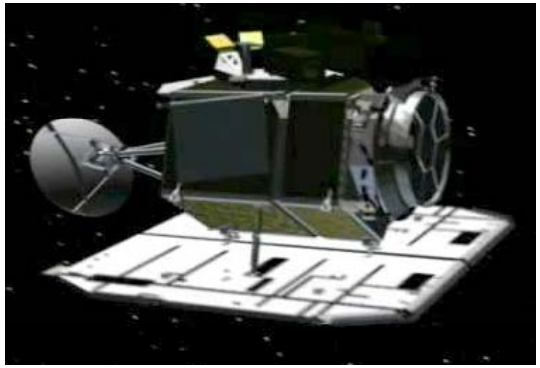
Components





Electromechanical Systems



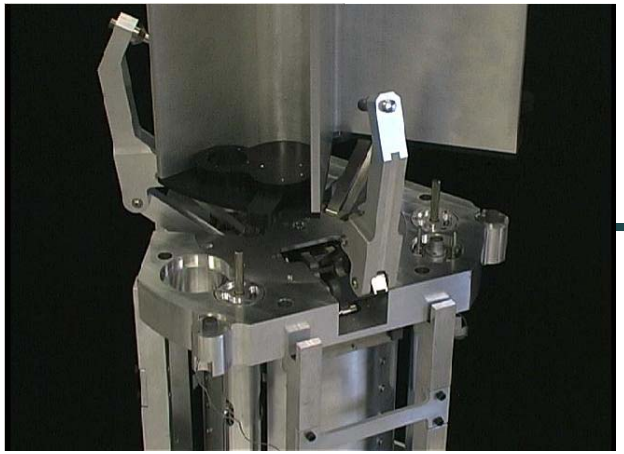


Mechanical Systems

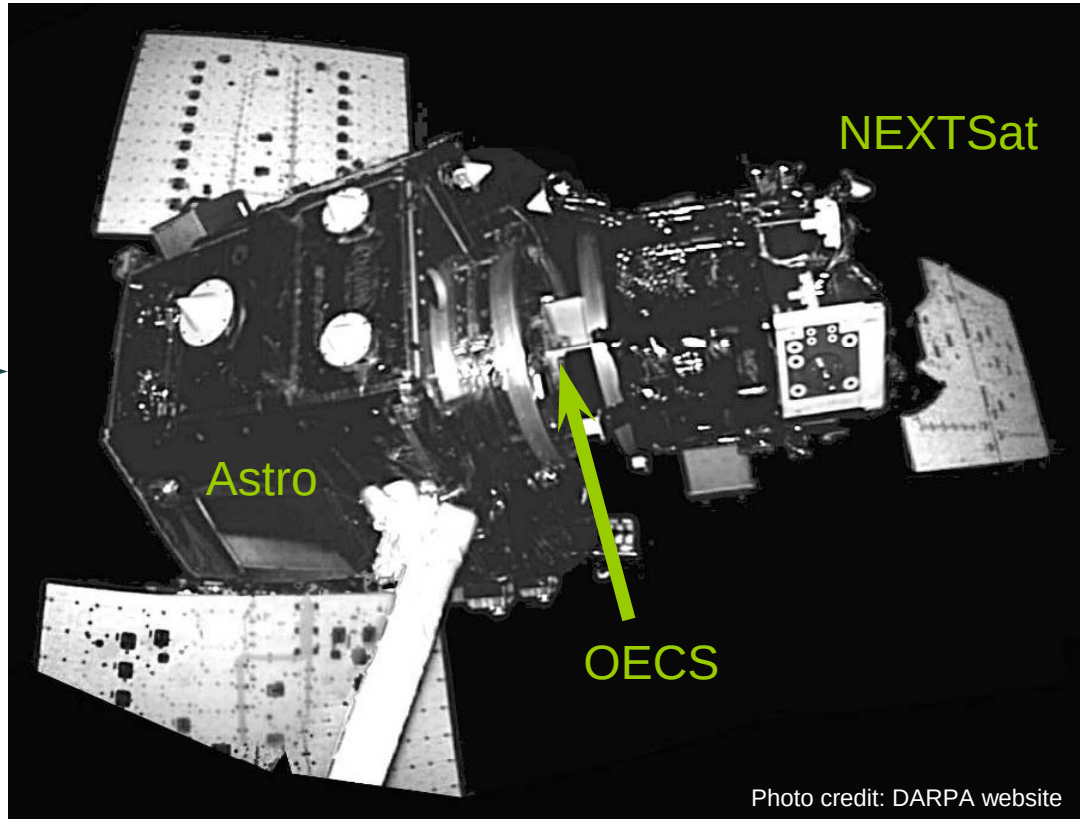
Orbital Express

- SNC has experience and heritage in remote servicing applications through the Orbital Express program
- SNC provided several subsystems and design support for critical functions
  - Launch adapter fitting (including release systems) between Astro and NEXTsat
  - Capture system including control electronics, proximity sensor, and electrical connections
  - Personnel now at SNC provided design support for fluid transfer system
- Successful autonomous capture
  - Robotic manipulator assisted
  - Unassisted (each spacecraft under independent attitude control)

Orbital Express Flight

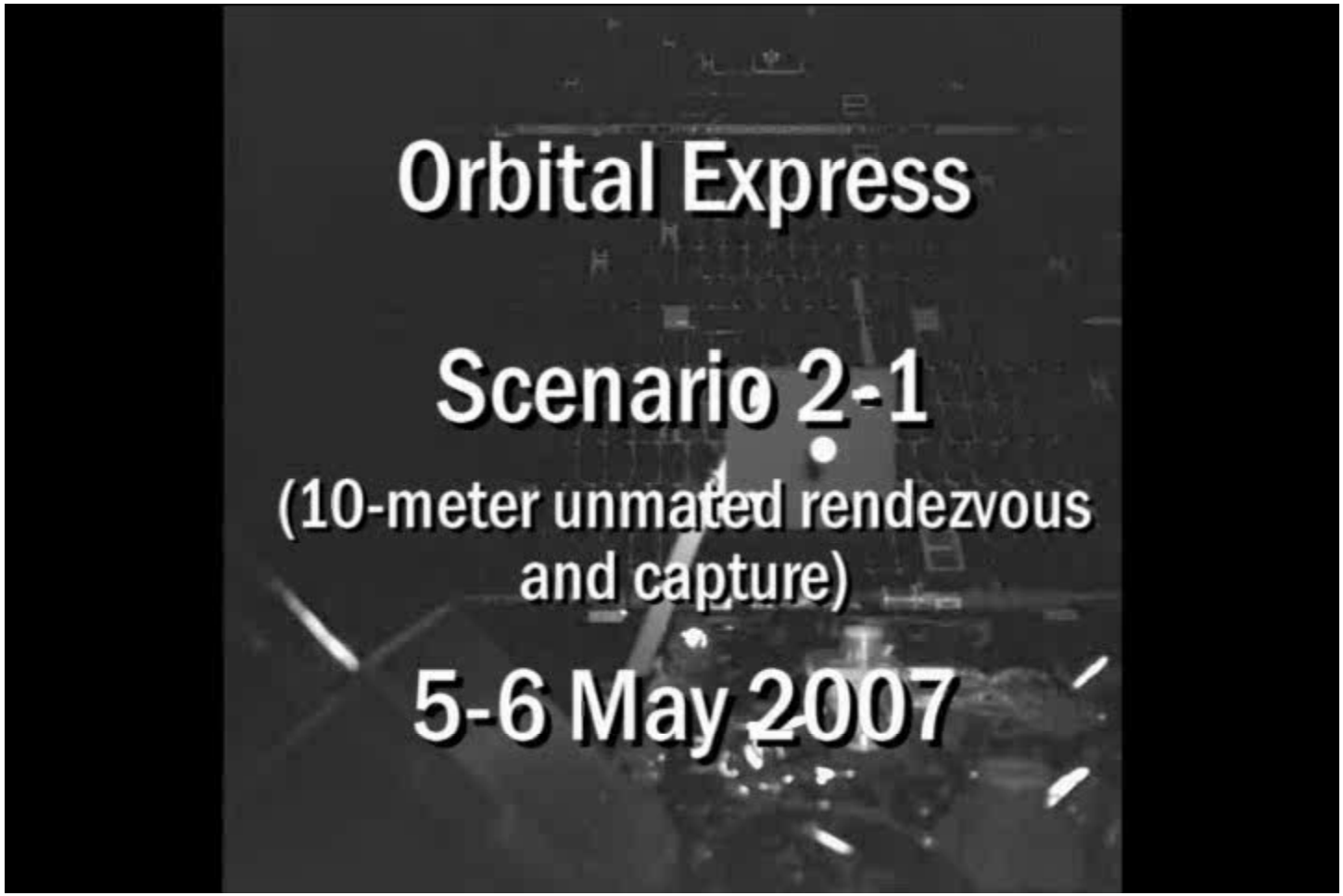


Orbital Express Capture System (OECS)



OECS shown in flight with spacecraft mated

OE Capture Video



Insert Movie here:
OE Rendezvous and Capture GSFC Servicing Workshop.wmv

Servicing Applications

- Manned and unmanned servicing applications
  - Routine maintenance
    - Replenishment of consumables: fuel, cryogenic fluids, etc
    - Replacement/Upgrade of components: electronics, etc
  - Remote servicing for unplanned problems
  - Orbit adjustment
  - Spacecraft reconfiguration
- Many of these tasks are considered beyond the capability of existing space manipulators
- SNC's configurations have been developed to specifically address current limitations

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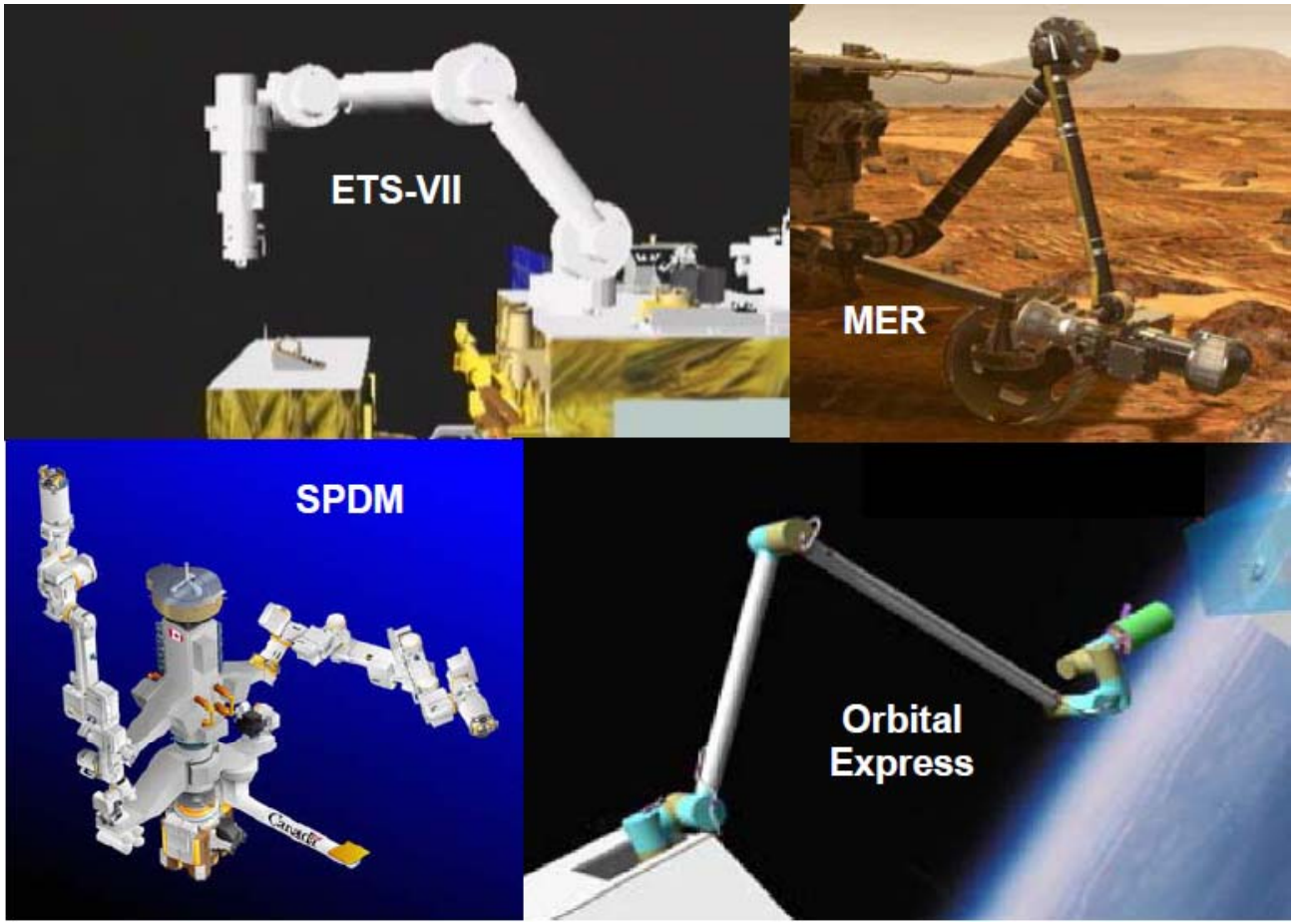
Existing Space Manipulators



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Kinematics

- Forward kinematics are single-valued and simple (calculate tool position and attitude from joint angles)
- Trajectory planning and control requires inverse kinematics (calculate joint angles and motion to create desired tool state)
- Typical serial revolute manipulators
  - Characterized by multiple copies of offset joint
  - Easier to design, more difficult to control
  - Extensive calculations for inverse kinematics
    - Choices between multiple solutions
    - Can be highly nonlinear and multi-valued
    - Driver is number and type of offsets between successive joints
  - Pre planning and simulation needed to avoid collisions and violation of range limits

Real Time Operation Issues

- Advance planning of real time changing conditions is impossible
  - Direct human control
  - Autonomous “variable-horizon” task planners
- An arm with multiple offsets can find itself in the wrong kinematic branch
  - May require backtracking to move to another solution
  - Tool may have to move away from the target
    - Arm stops moving unexpectedly
    - Confuses operator with un-commanded motion in different direction
- Existing robotic arms that have flown in space have multiple axis offsets and complex multi-valued kinematics.
  - Task planning is difficult
  - Execution is unreliable when planning is not done

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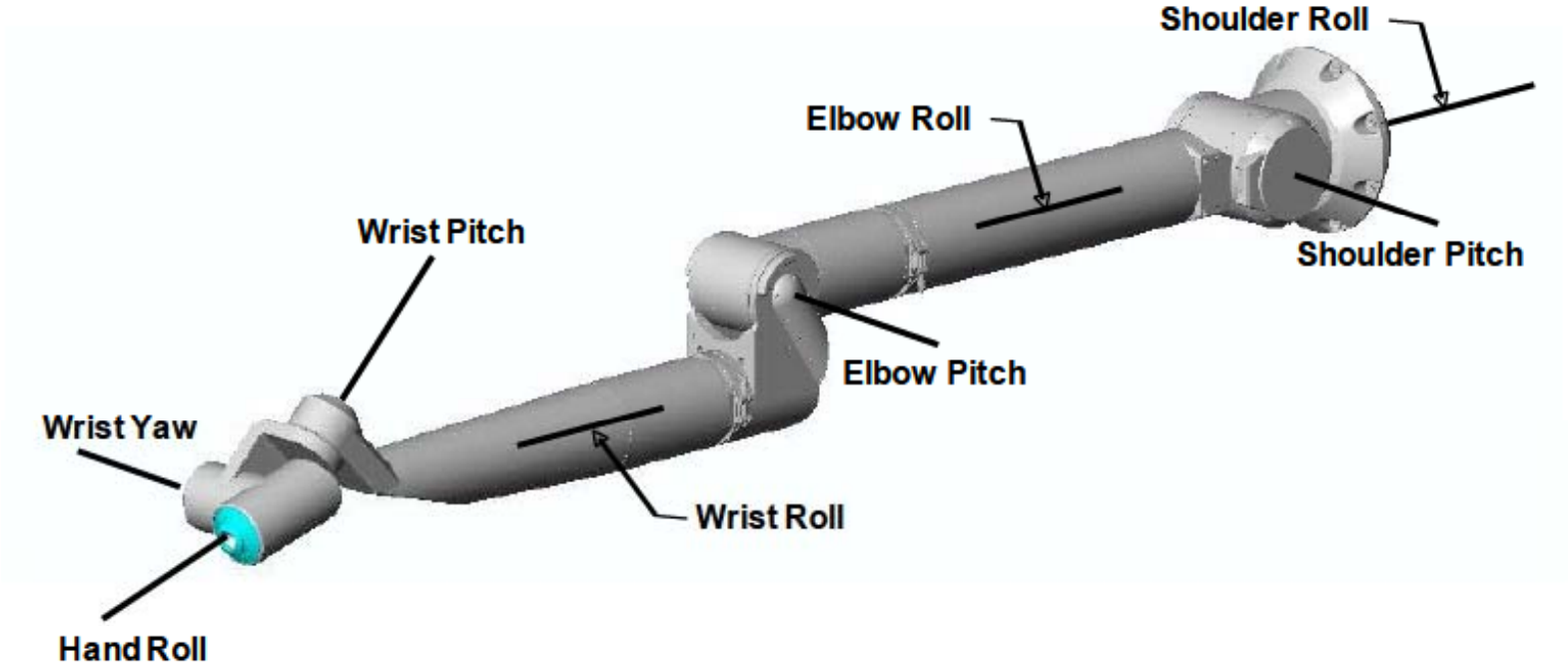
SNC Manipulator Features

- Minimized offsets
- Resulting inverse kinematics are simpler with single solutions
  - Tool trajectory implies position of wrist center
  - Shoulder always fixed relative to base
  - One sided elbow
- Only potential self-collision is wrist contacting shoulder if tool is working too close to shoulder.

8 DOF Axes



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Optimal Redundancy

- For general use a 6 DOF minimum is required for full tool control
- Judicious inclusion of one or more additional DOF improves workspace coverage and ease of use
  - Typical manipulators use a 7th DOF to control should-elbow-wrist plane to help avoid collisions
  - SNC's manipulator includes 8th DOF
    - 4 DOF – Shoulder to wrist
    - 4 DOF – Wrist to tool
    - Additional DOF in each group allows for robust avoidance of collisions and singularities
    - Allows inverse calculations to be separated into two 4th order problems which, together, are easier than a single 6th or 7th order problem

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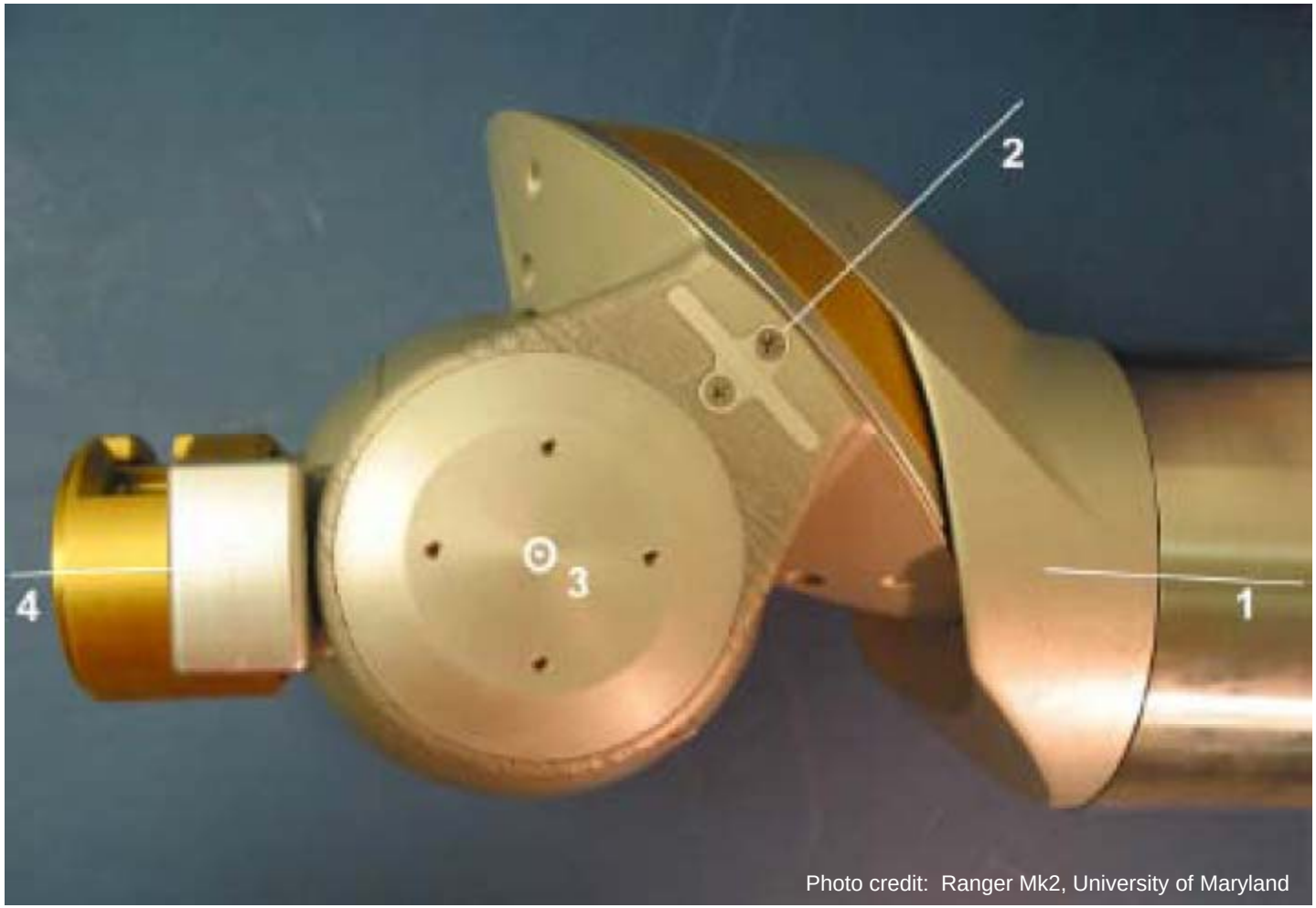
Wrist Axes



Wrist Dexterity and Tool Workspace

- SNC's wrist configuration is characterized by a short wrist to tool (WT) distance
  - Better dynamic response in small spaces
  - Less arm motion required to accommodate tool movement
- Short WT distance combined with skew Roll-Pitch-Yaw-Roll (sRPYR) configuration
  - Improved angular range over conventional Roll-Pitch-Roll (RPR) or orthogonal Roll-Pitch-Yaw-Roll (oRPYR) wrists
- Singularity avoidance
  - Only one sRPYP singularity is possible
  - Easily avoidable due to redundant wrist DOF

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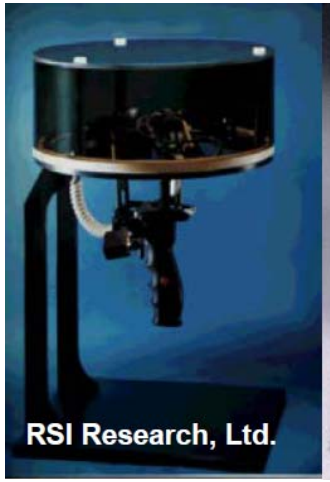
Controls

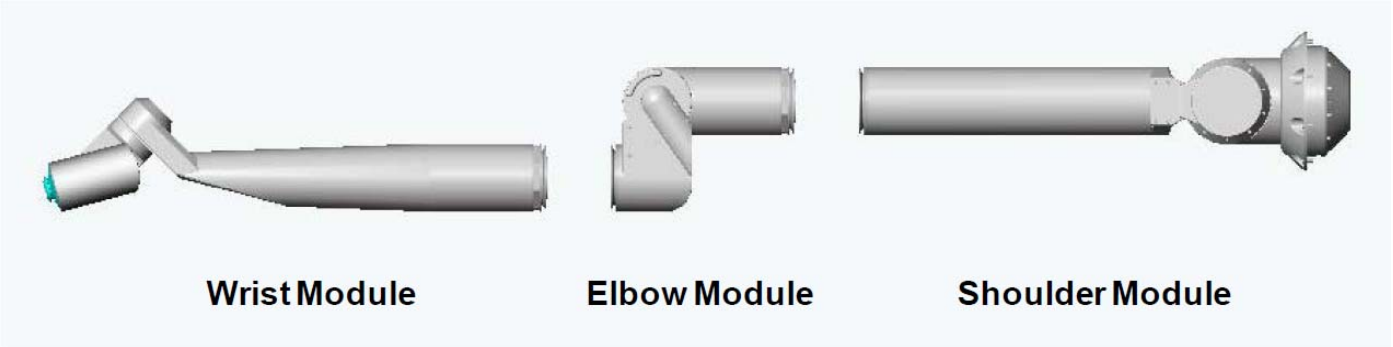
- Traditional
  - Two stick control inputs
  - Rate control
    - Difficult to stop at desired location
    - Speeds must be limited for safety
    - Motion generally limited to one axis at a time
- SNC Configuration
  - Position control
    - Natural, easy
    - 6 DOF one hand controller
    - One operator can operate two arms simultaneously
    - Speed does not need to be artificially limited

Examples of Controllers

Traditional Two-stick Controller



6 DOF Position Controllers



Modular Sections

- Self contained control, sensor, and drive electronics
- Power and communication connectors

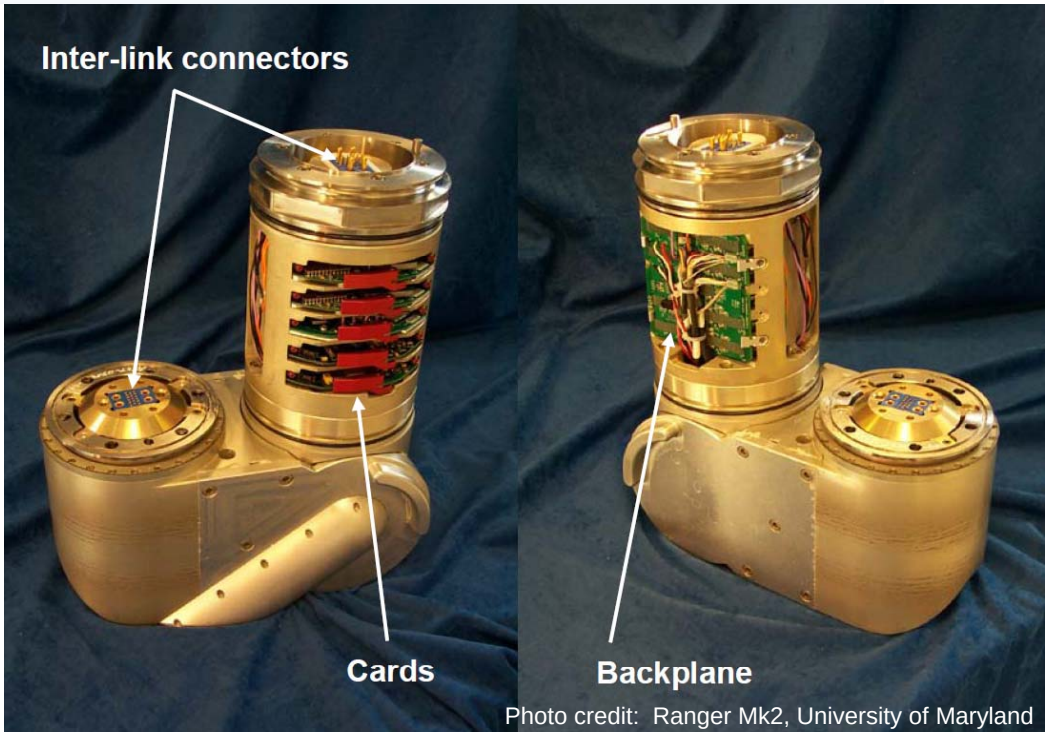


Photo credit: Ranger Mk2, University of Maryland

Future Capability

- The Dream Chaser human spacecraft is currently under development at SNC supported by NASA CCDev funding
- Deployment of a dexterous manipulator on the Dream Chaser could provide a highly capable commercial servicing capability
  - Highly maneuverable space vehicle
  - Human presence for real-time operation
  - Operational system will have rapid response time
- Crew has options for servicing
  - Extra-vehicular activity (EVA)
  - Robotically assisted EVA
  - Fully robotic


esa
Dream Chaser
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