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The FREND Robotic Arm

ICRA 2012 Workshop on Robotic Satellite Servicing

Sean Dougherty - Monday, May14th

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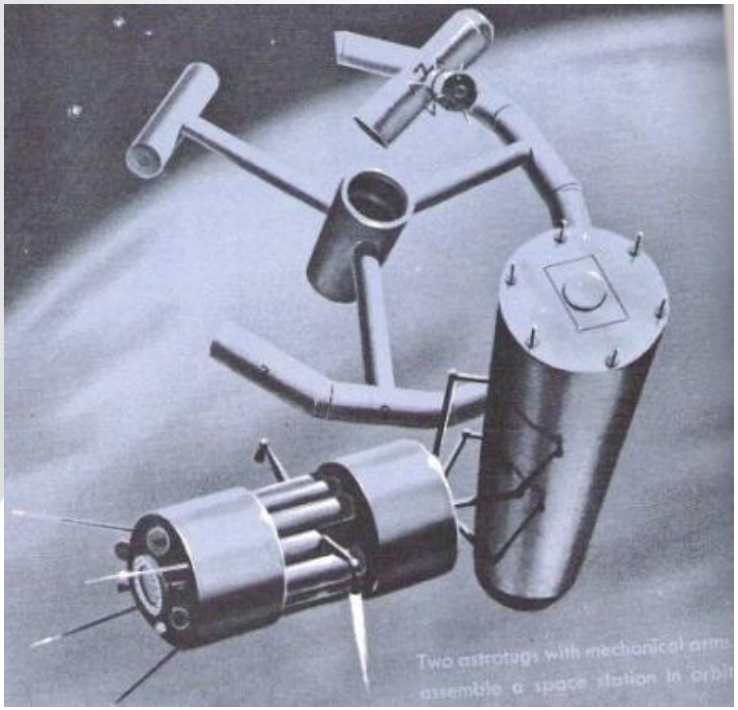
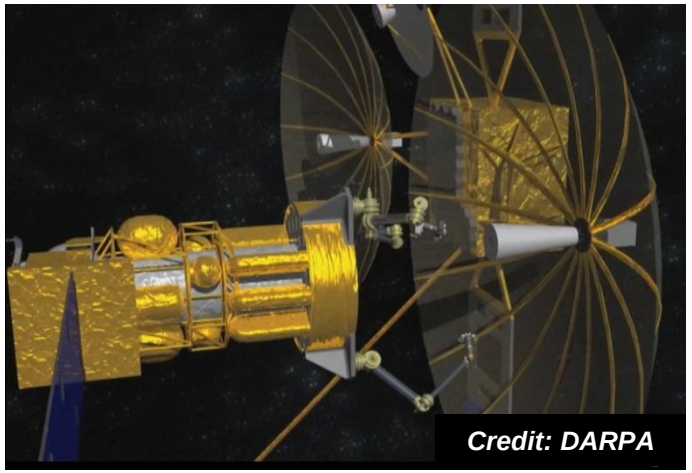
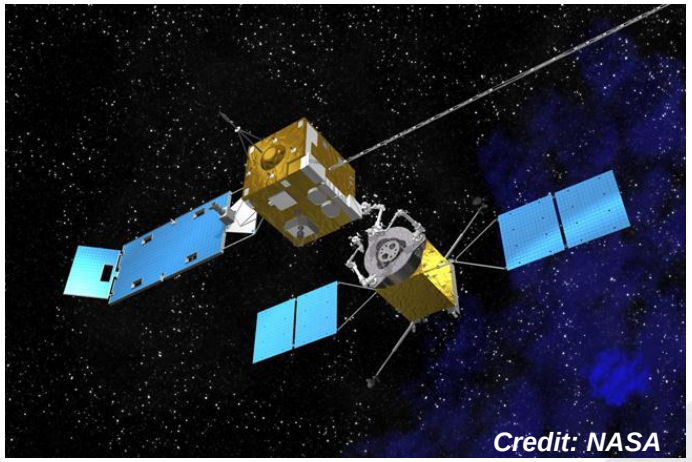
On-orbit Servicing
A long time coming



"Astrotug" *Stations in Space.*
Donald Cox (1960)



DARPA Phoenix Mission Concept



NASA Servicing Mission Concept

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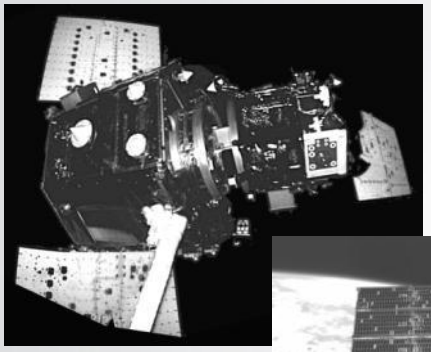
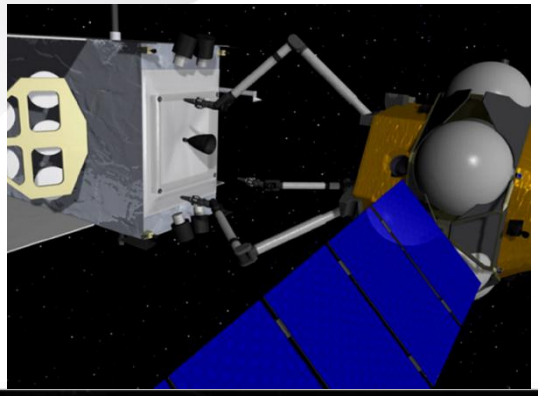
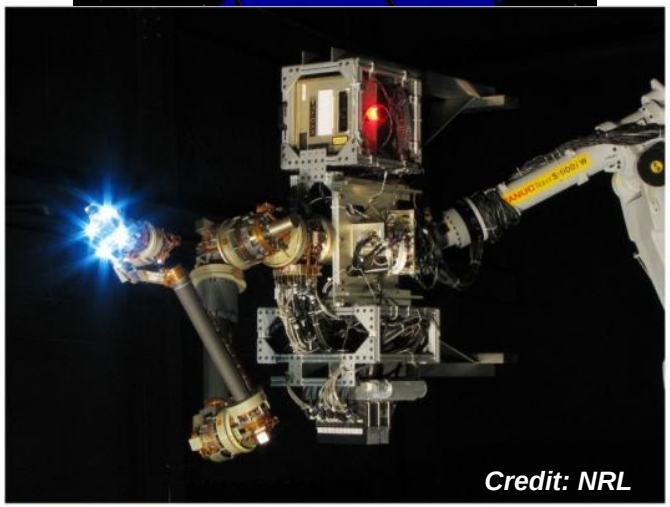
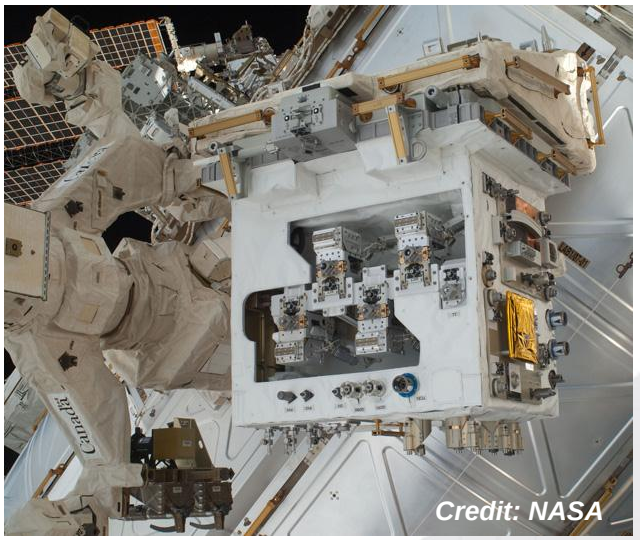
Great Strides Recently







FREND Full Scale Rendezvous and Autonomous Robotics Grapple Testing Using the Naval Research Laboratory's Spacecraft Proximity Operations Testbed



2007: Orbital Express

2008-present: FREND

2012: RRM

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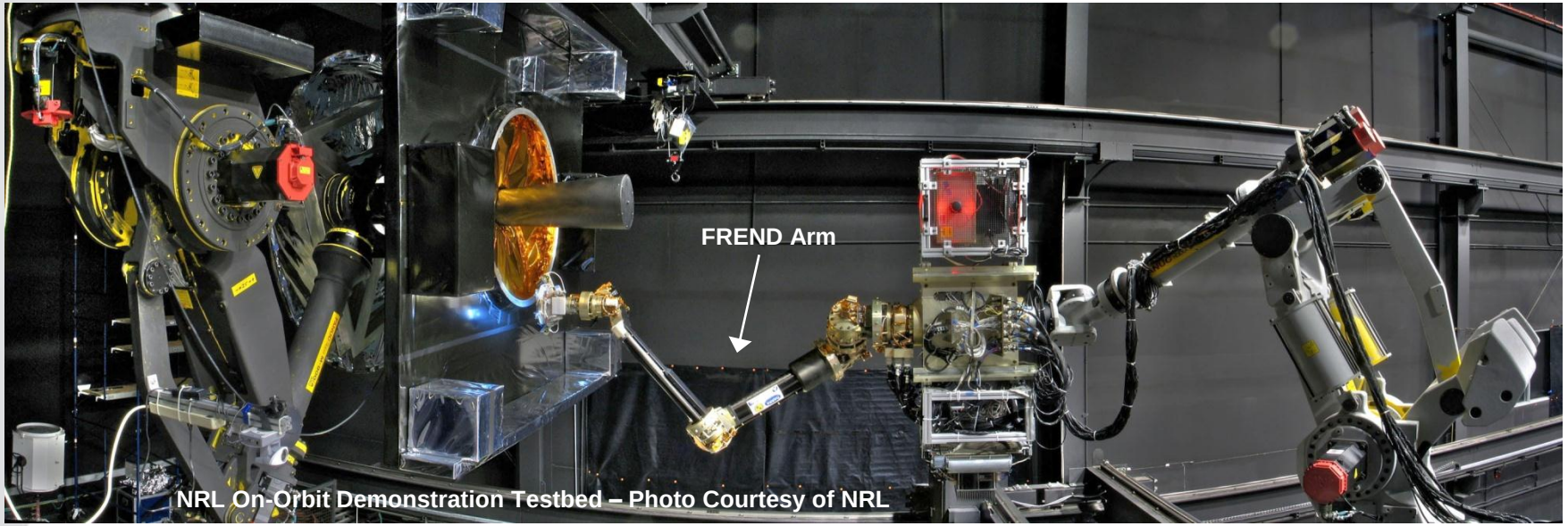
SUMO/FREND Program



- Demonstrate the capability of autonomously executing unaided grapple of a variety of S/C interfaces
  - Proximity Operation Testbed with dual platform motion simulator
  - 7+ DOF Robotic Arm
  - Scanning LiDAR with 6DOF Pose Algorithm
  - Grapple Feature Tracking Algorithm
  - Trajectory Planner, Compliance Algorithm

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FREND Arm Overview

- 7DOF
- 2m
- 78Kg
- 10 Kg Payload
- 15 cm/s Tip Velocity
- ± 1mm Accuracy
- 5.2 Hz Natural Frequency
- F/T Sensing
- Tool Drive EE
- Custom MCBs
- 1g Testable
- Operate in GEO

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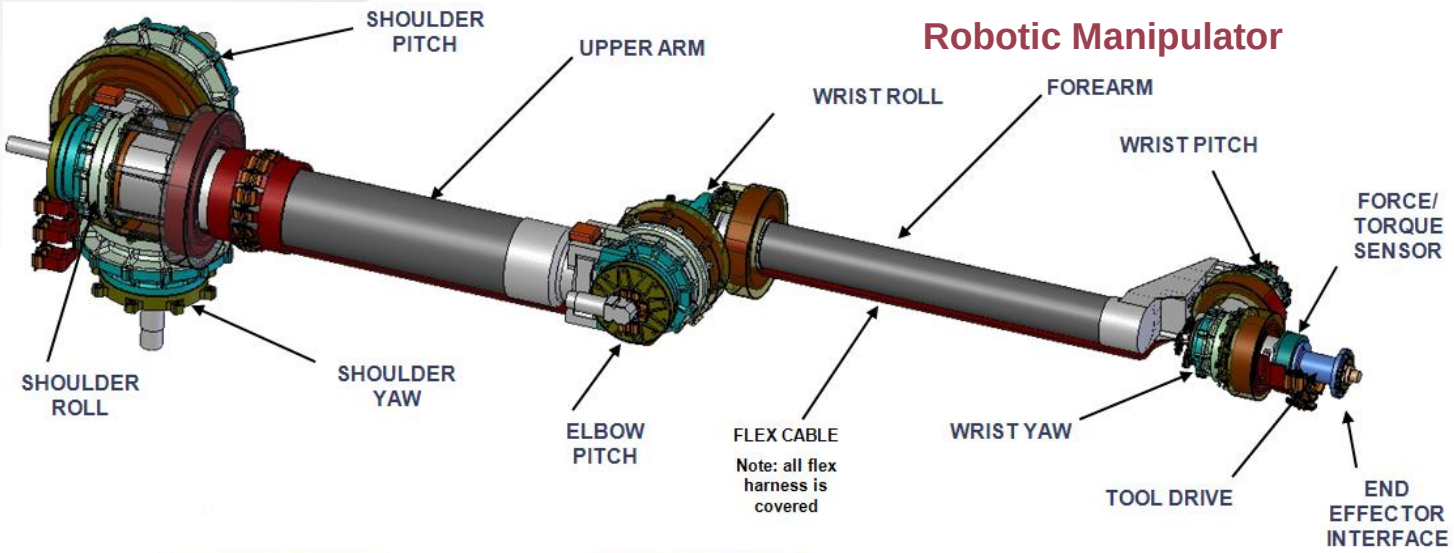
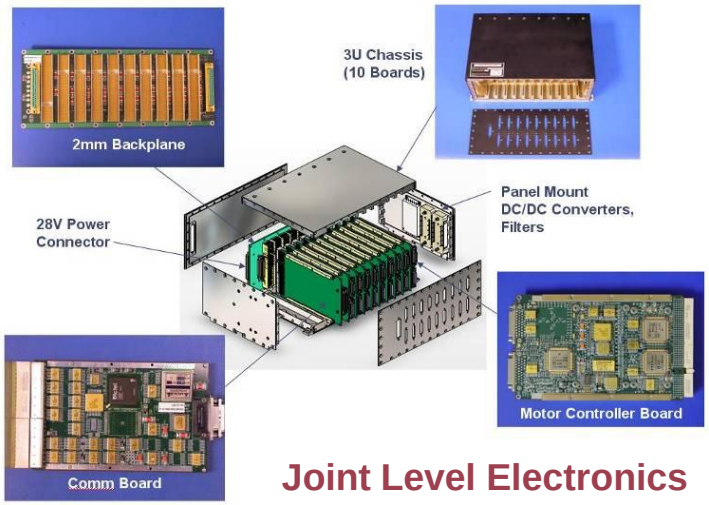
FREND Robotic Arm System Elements

Spacecraft Simulator

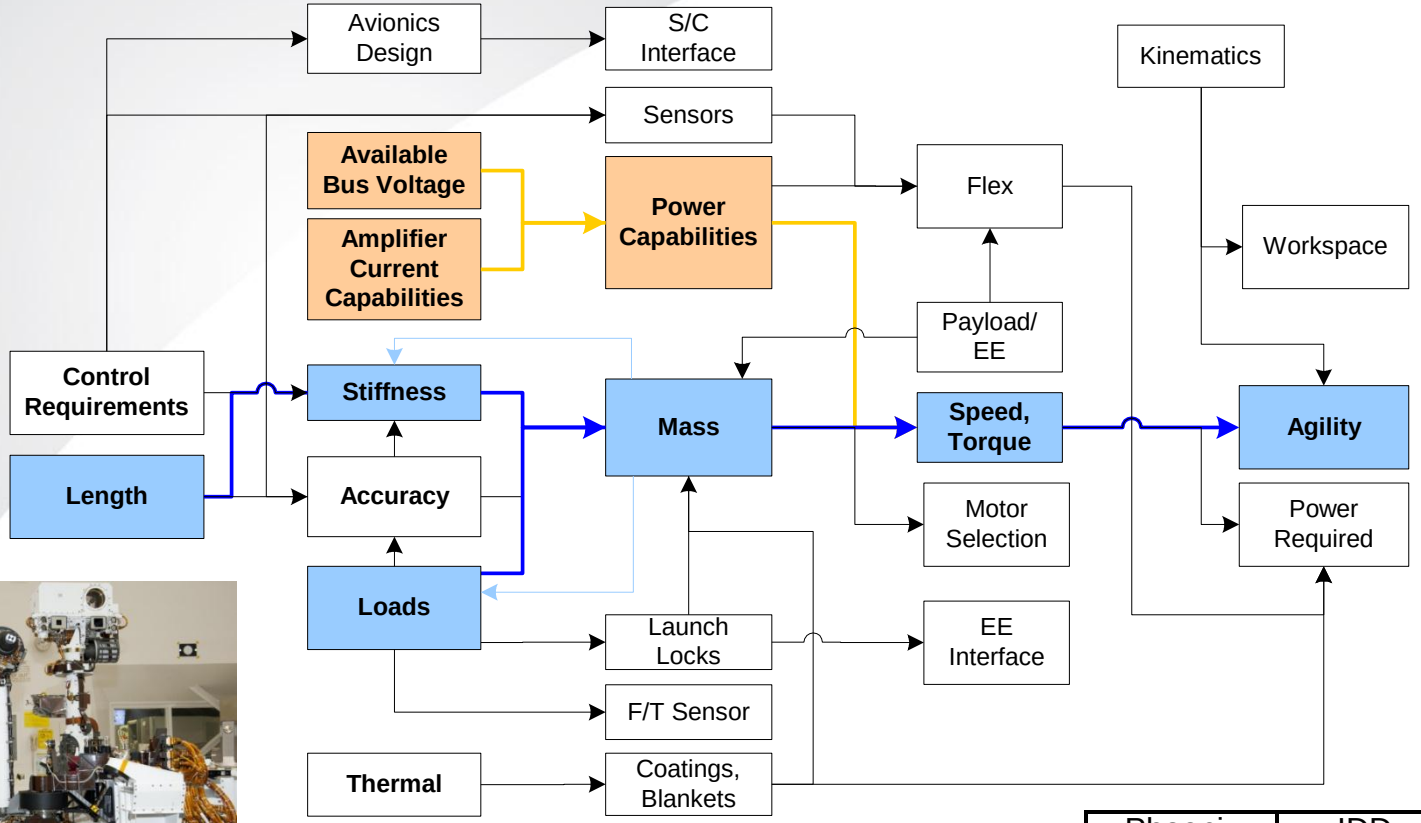
Robotic Manipulator

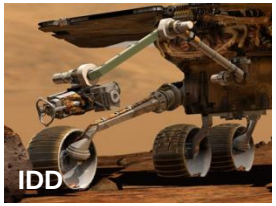




Joint Level Electronics

Arm Optimized for Mission Success





	Phoenix	IDD	FREND
DOF	4	5	7
Length (m)	2	1	2
Mass (Kg)	9	4.2	78
Accuracy (+/- cm)	1.8	0.5	0.1
Payload (Kg)	2.5	2	10
Tip Speed (cm/s)	3.5	1	15
Natural Frequency (Hz)	2	3	5.2

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FREND Arm Driving Requirements

1. Allow grappling of a cup-cone interface located 3” away from satellite structure
2. The arm must maximize dexterity
3. The arm must minimize its stowed volume
4. The arm must achieve a 15cm/s (6cm/s) velocity along its end-effector axis in 75% (95%) of its dexterous workspace
5. The arm must weigh less than 80Kg
6. The arm must support its own weight as well as a 5 Kg payload
7. The arm is required to position a tool tip with a tip linear accuracy of +/- 2mm and an angular accuracy of +/- 0.4 deg
8. The arm must achieve at least a 1Hz closed-loop bandwidth
9. The arm must survive launch loads
10. The arm must be able to operate in GEO

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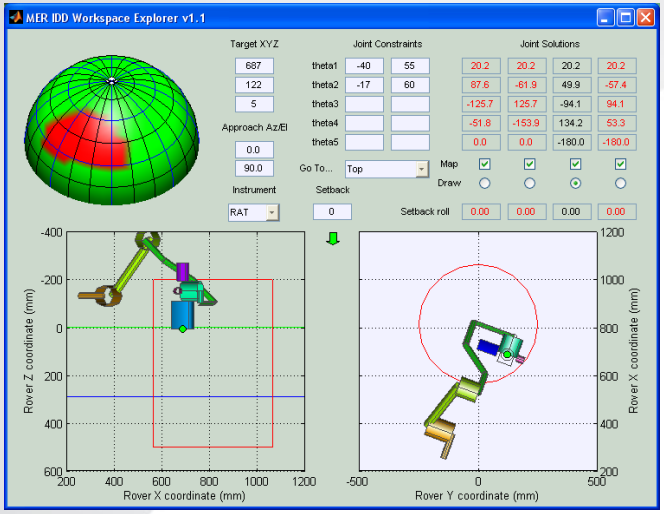
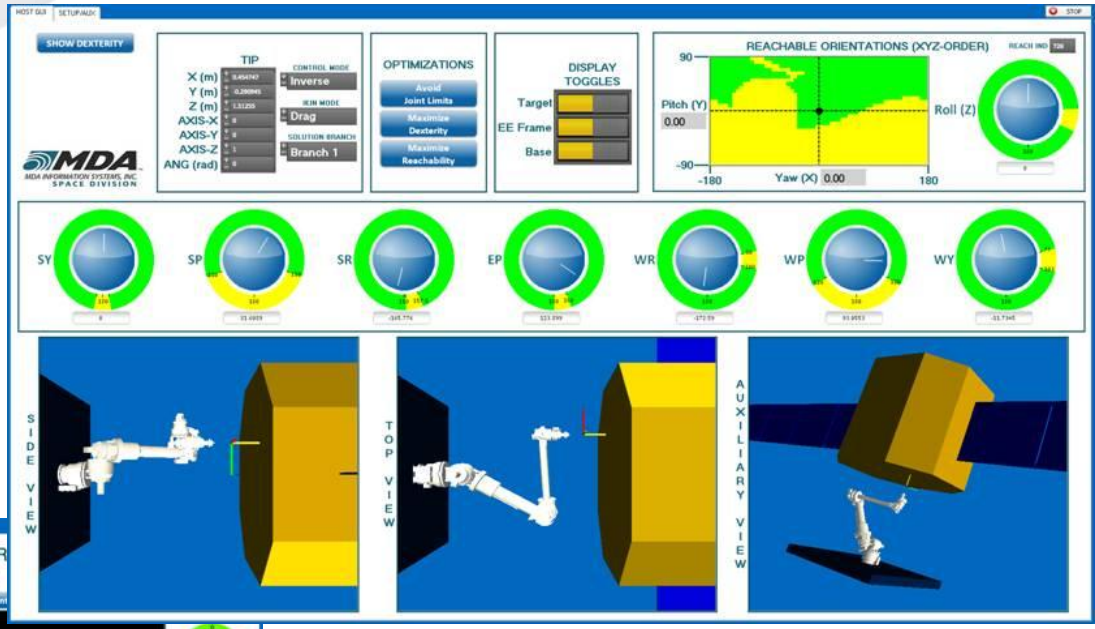
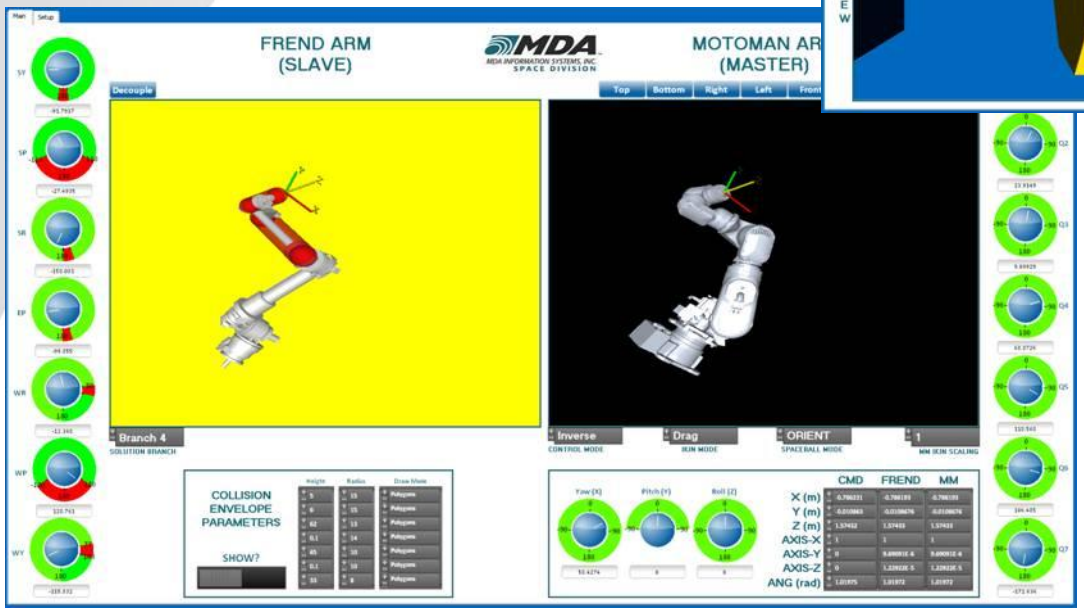
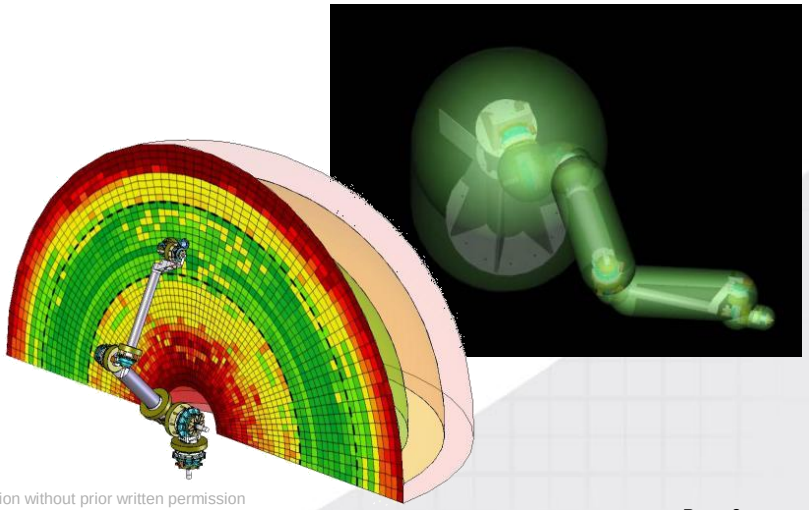
Good Tools Enable Rapid Iteration









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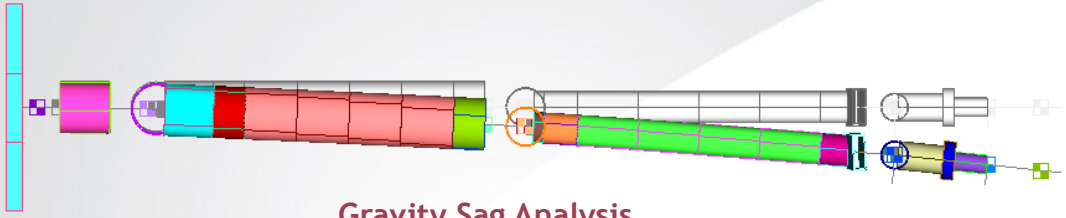
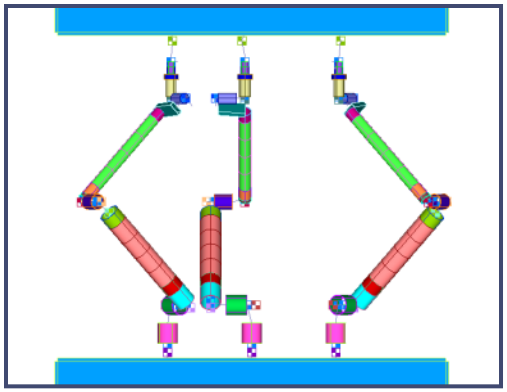
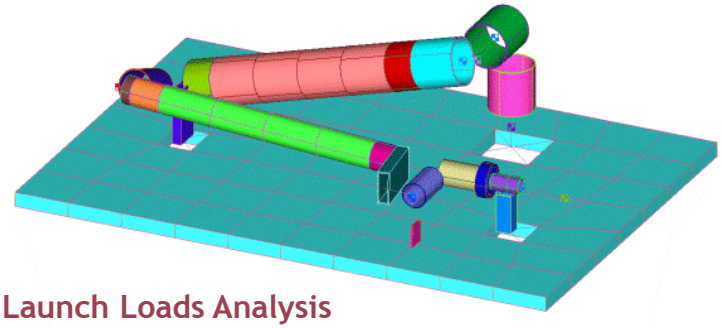
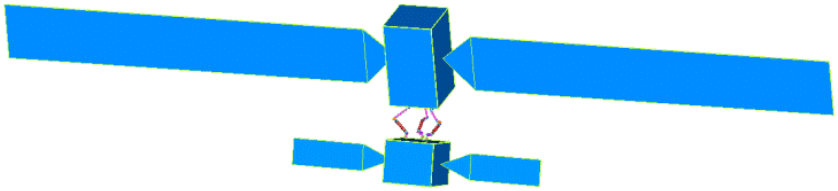


Gravity Sag Analysis

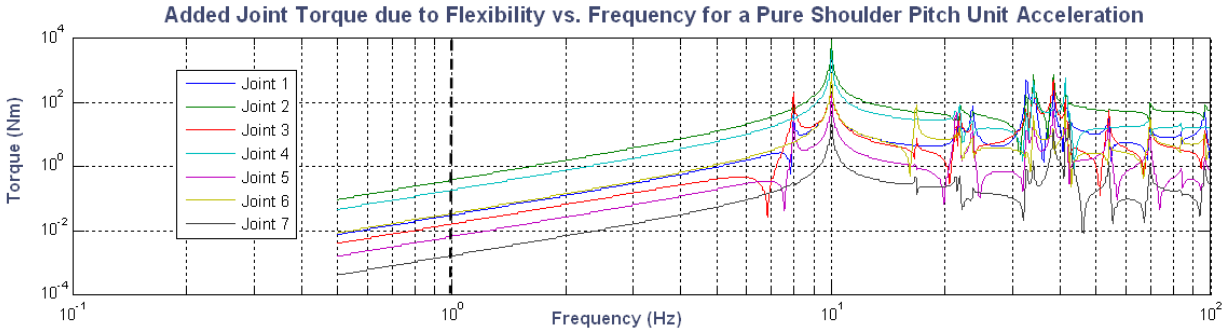




Launch Loads Analysis



Combined Stack Analysis



Flexibility & Stability Analysis

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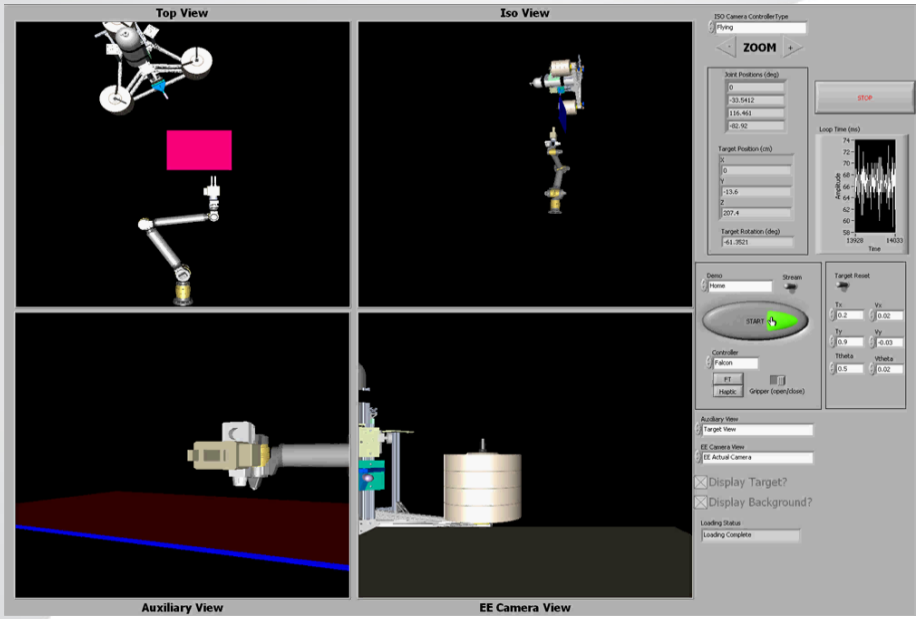
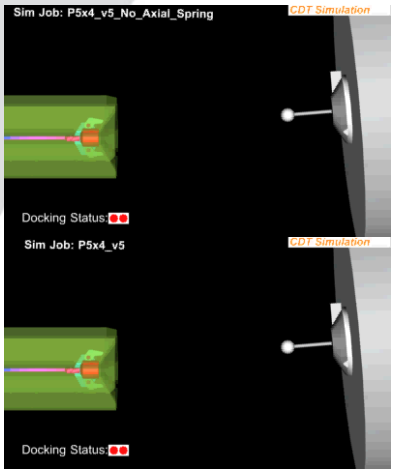
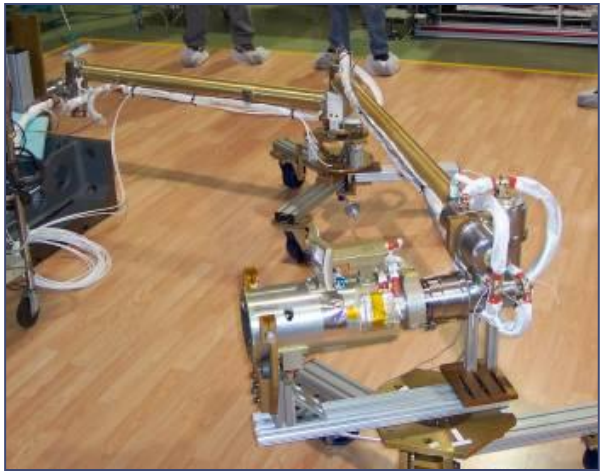
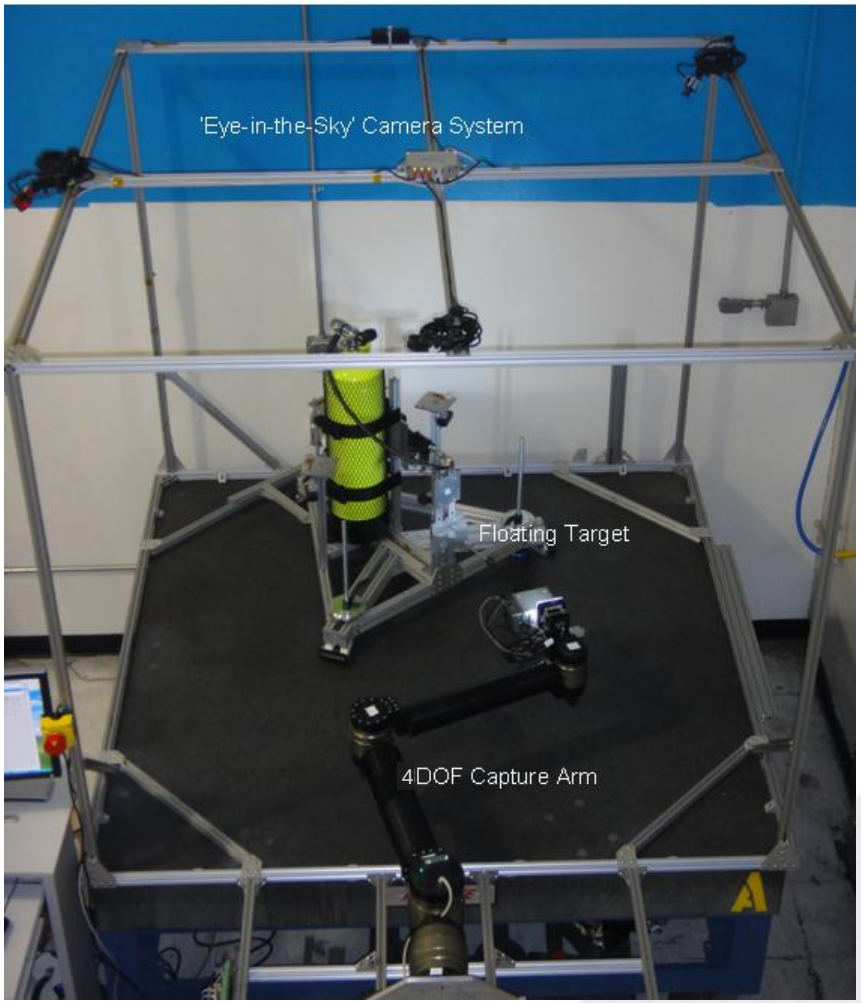
Testing & Validation









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Testing & Validation

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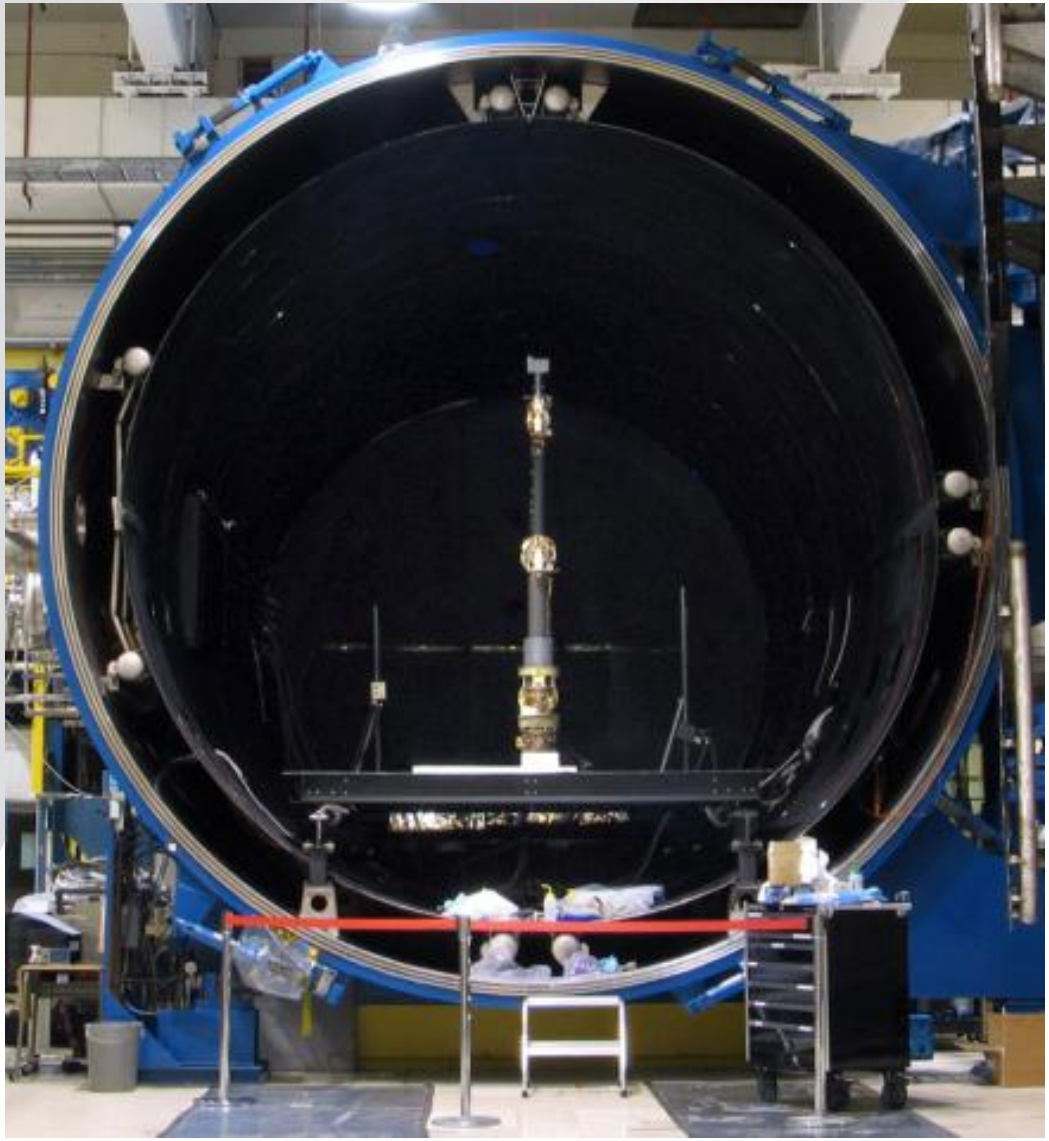

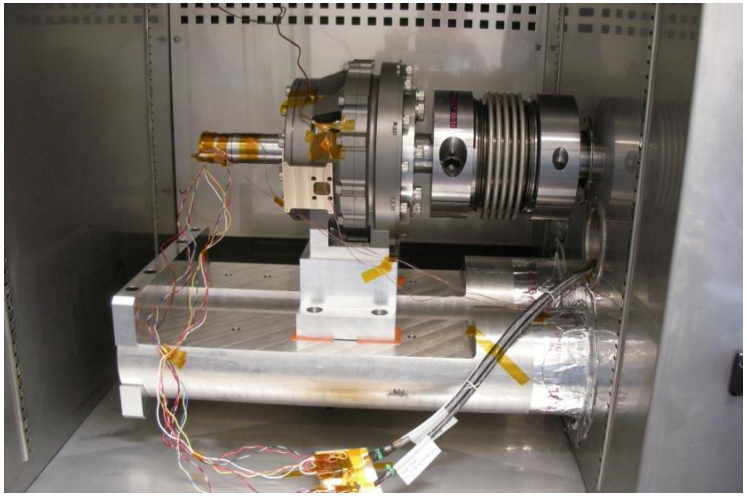

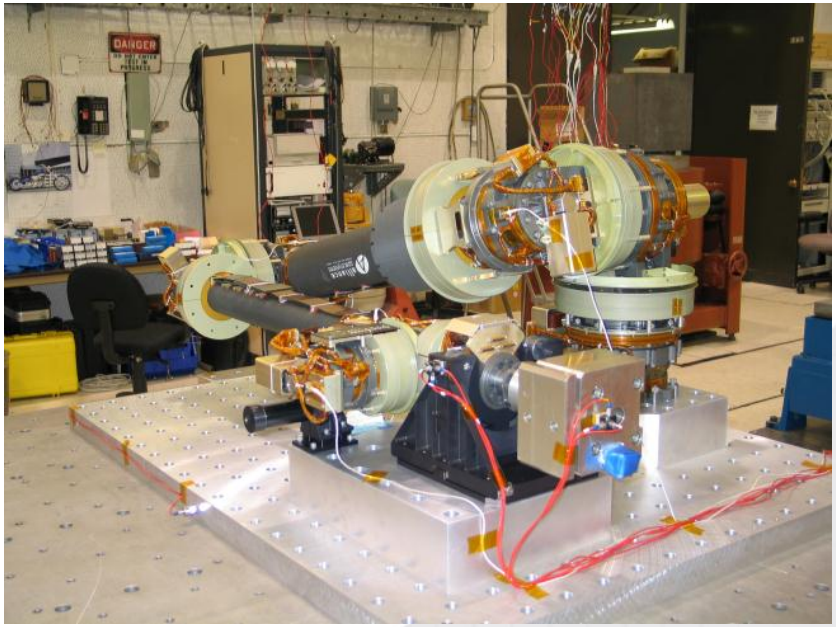

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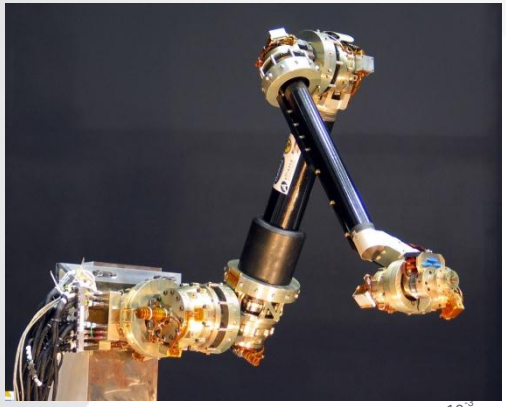
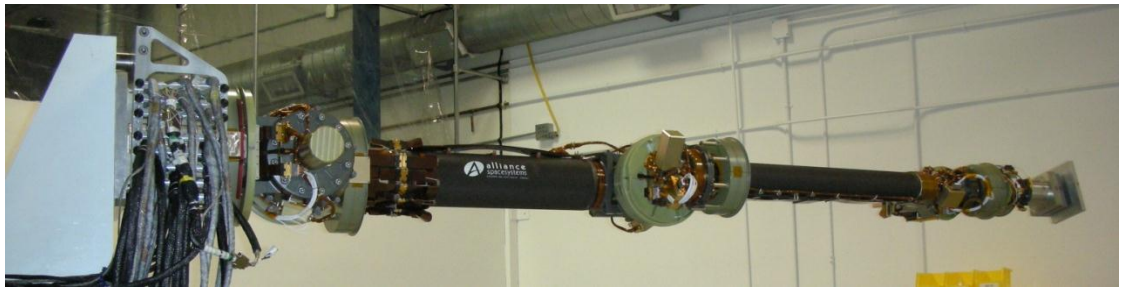
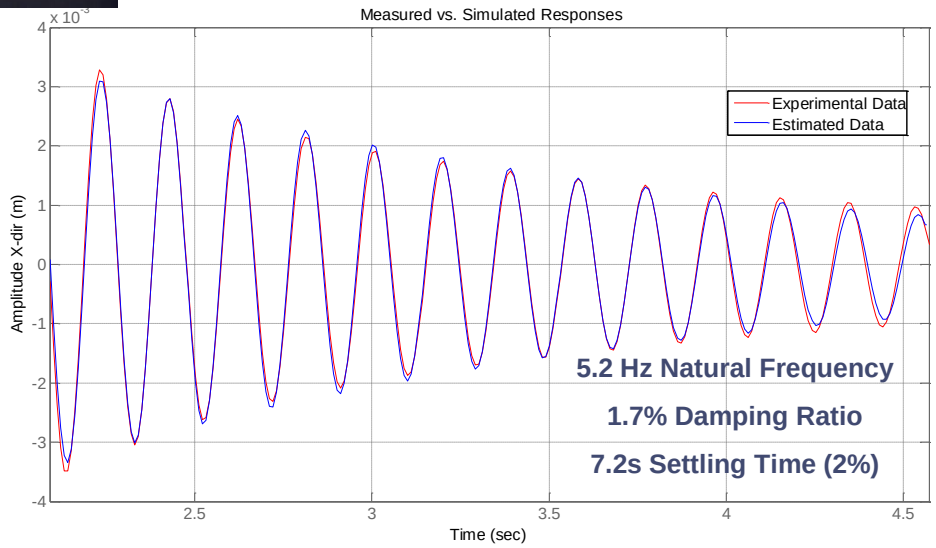
Performance – Natural Frequency







6.4 Hz Natural Frequency in Nominal Pose

5.2 Hz Natural Frequency in Extended Pose

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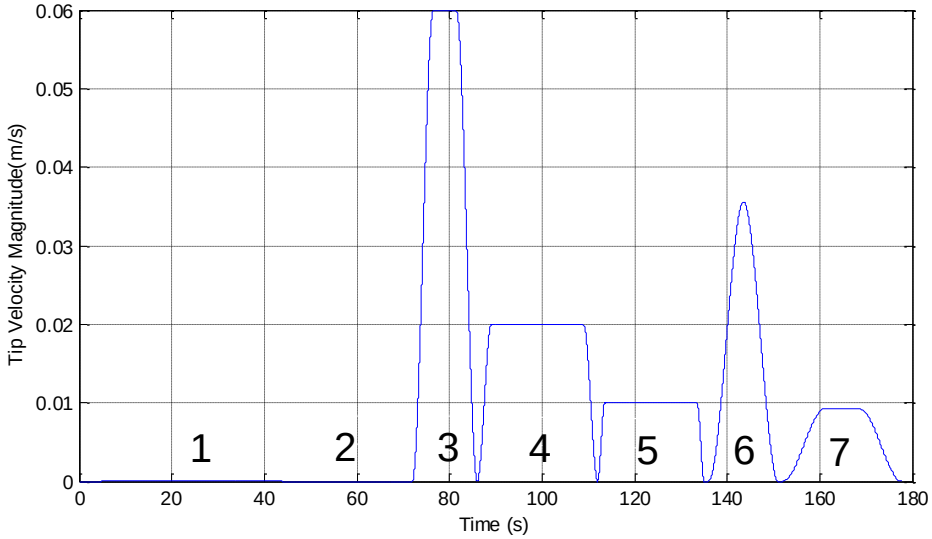
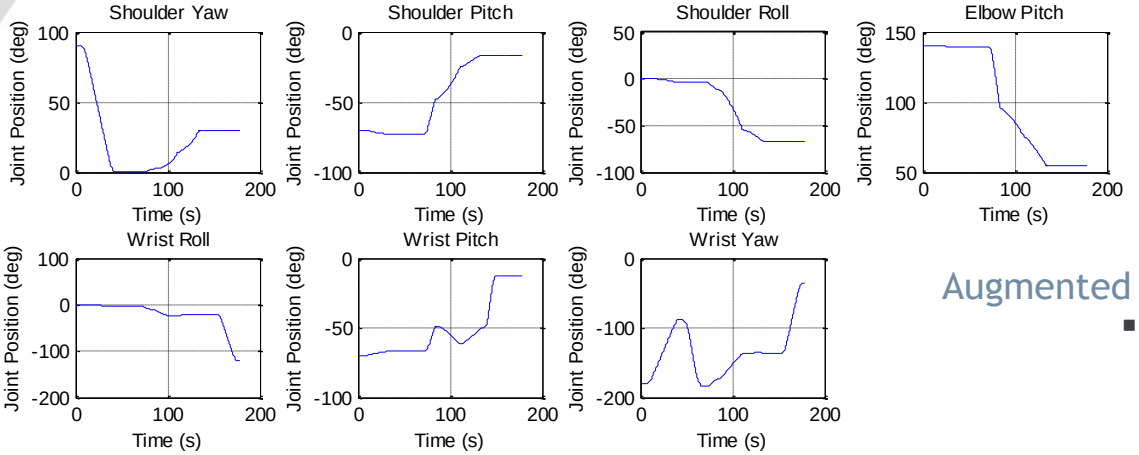
Performance – Arm Relative Accuracy

- Seven-Part Trajectory
  1. Self-Motion
  2. Wrist Yaw Motion
  3. Fast Approach
  4. Lateral Traverse
  5. Slow Plunge
  6. Wrist Elevation
  7. Combine Wrist Yaw-Roll





Augmented Trapezoidal Motion Planner
- Continuous Velocity

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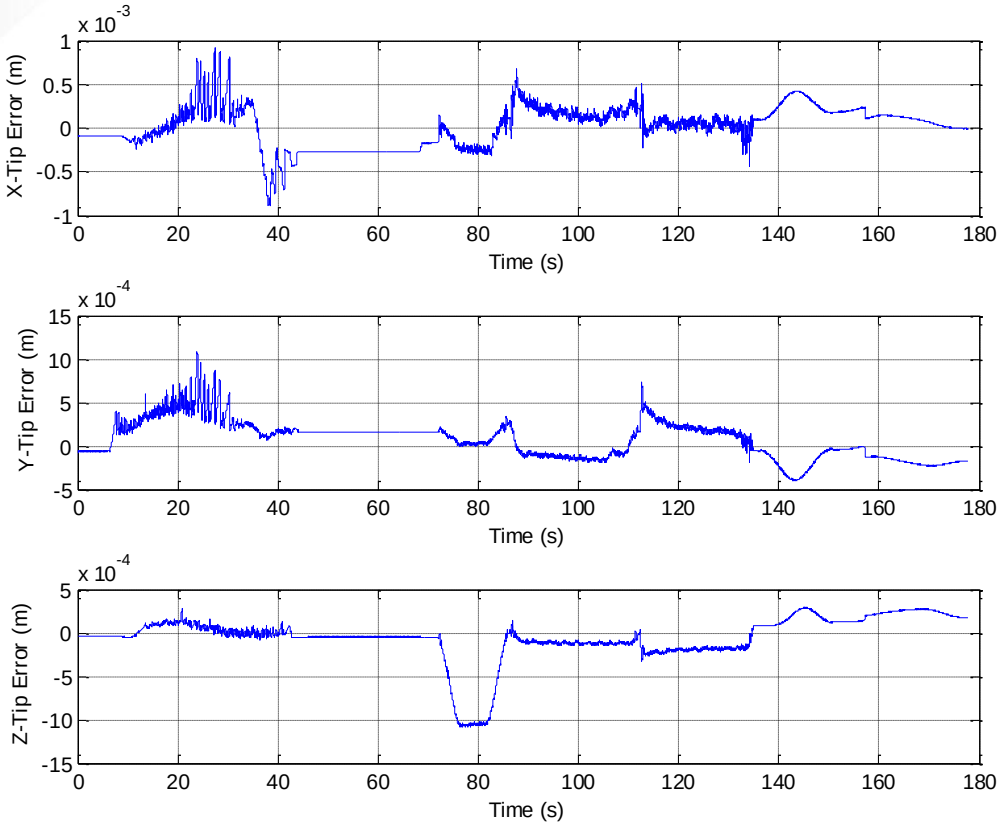
Tracking Error

- In Track Error ≤ ±1mm
- Cross Track Error ≤ ± 0.5 mm



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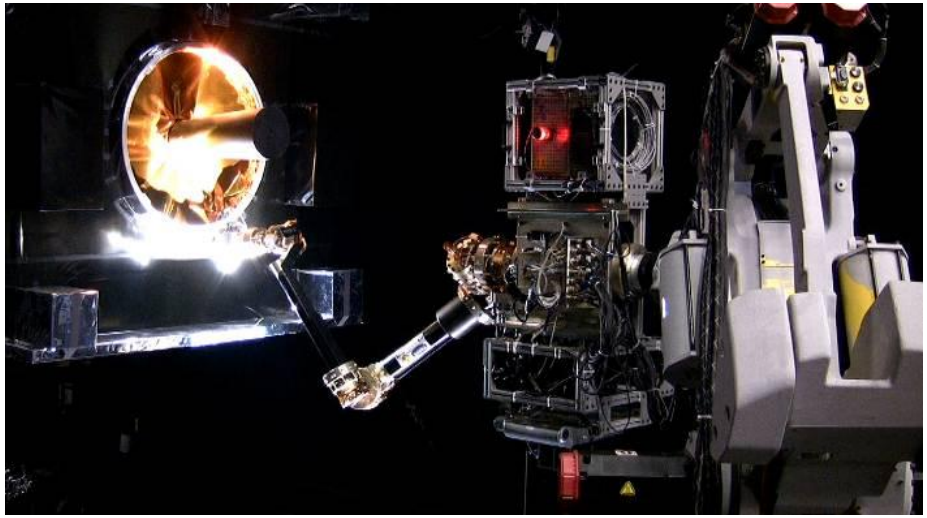
Conclusions

The FREND robotic arm is a new benchmark for space technology

- High dexterity
- High accuracy, absolute position
- High stiffness, high bandwidth
- Novel set of electronics
- Integral FTS, thermal, cabling
- Flight ready
- 1-g testable



Additional Thoughts/Considerations:

- Multi-arm systems are worth the mass
  - If we adopt long-term, multi-target view
  - Arms are a reusable asset – only need to pay to get to orbit once
  - Refueling and high ISP propulsion worth considering
- Autonomous vision still a big challenge
  - Accuracy & bandwidth effect arm design
  - Getting better all the time but still computationally intensive and lighting conditions still challenging
  - Level of target preparedness worth considering