NORTHROP GRUMMAN

ETC: Engineering, Technology, and Careers

Robotics Course Two
June 3, 2009

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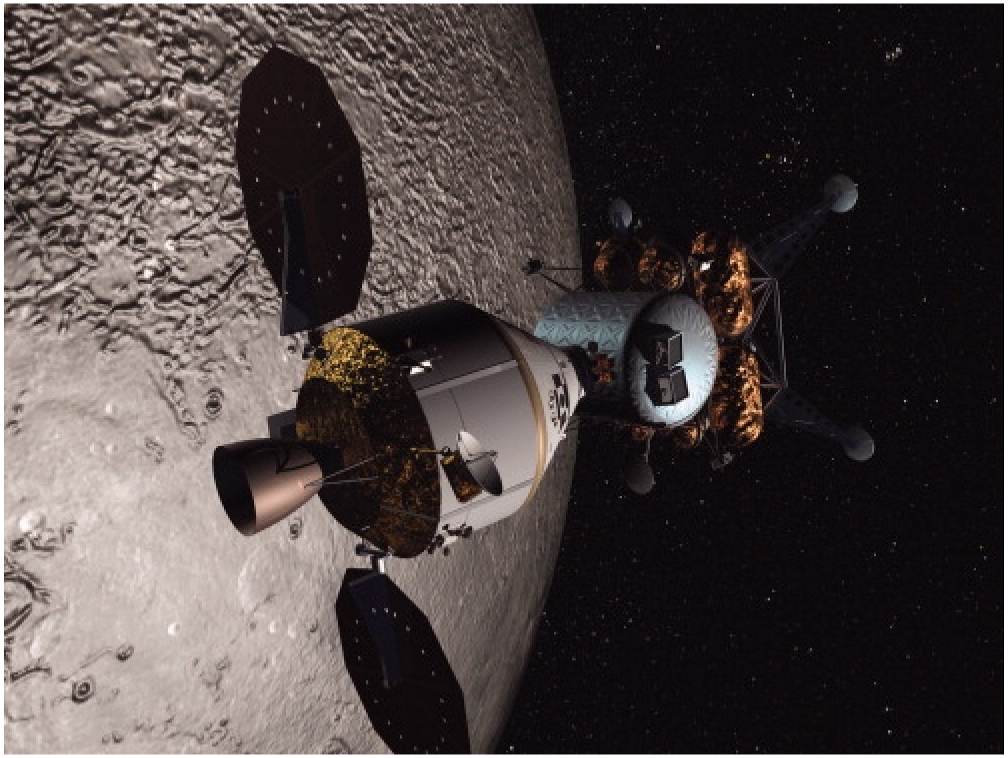
Robotics Topics for Session One

- Destinations in space
- Historical background
- Modern robots in industry and research
- Robotics technologies
  - Manipulation
  - Locomotion
  - Autonomy
  - Machine vision
- Workshop example: requirements for a household robot



Robotics Topics for Session Two

- Robots in space
  - Planetary rovers
  - Orbital robotics
  - NGST project example: AWIMR
- Workshop example: deriving specifications from requirements

Robotics Session Two (cont.): Systems Engineering for Robotics Competitions

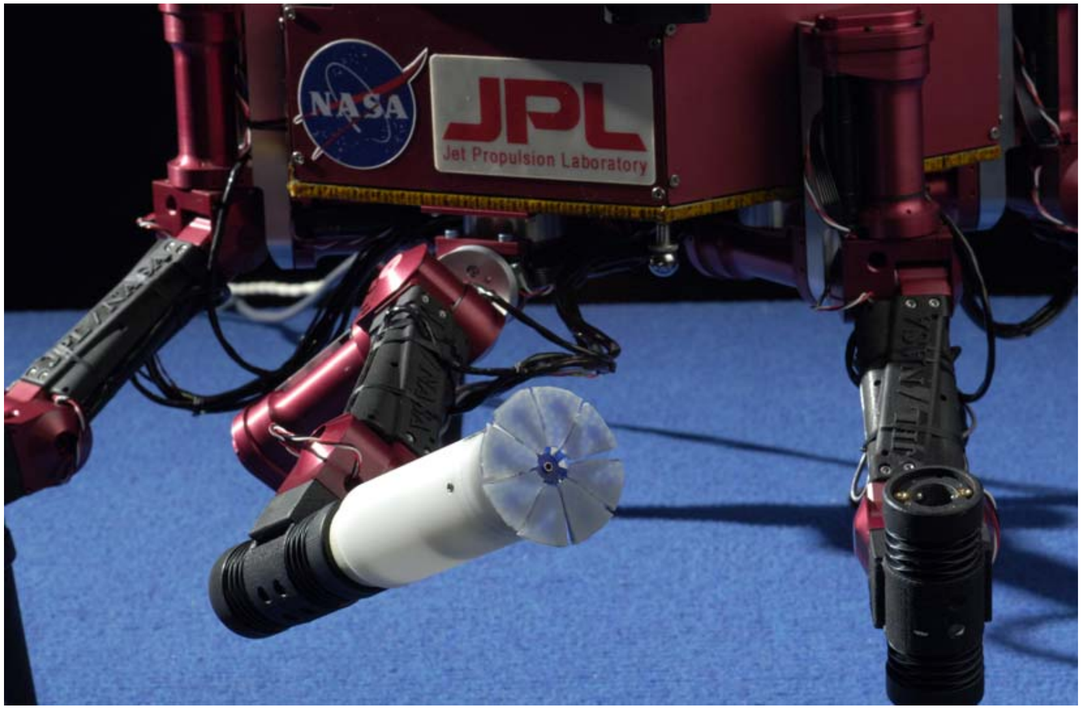
- Systems tasks for FIRST Robotics Competition
  - Compressed schedule with a non-negotiable deadline

Lessons Learned: Task and Algorithm Iteration

- Task trade study
  - Perform a trade study to determine space robot task set
  - Consider tasks within a system context
  - Assign a benefit for each task
  - Task set drives algorithm conceptual design which drives hardware design
  - Hardware design determines mass, power, reliability, and complexity costs: iterate for optimal task set
- Design the robot for the optimal task set
  - Example: a robot that can do all repairs may cost too much in mass and complexity
  - Use task set scenarios (CONOPS) to find out needed capabilities and control requirements early
  - Example: speed of locomotion may be very important; how fast should the robot be? (this is a real driver on costs)

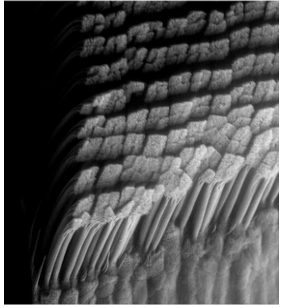
Lessons Learned: Walking Locomotion

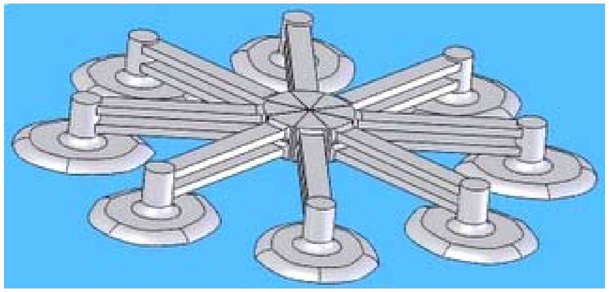
- Primary requirement: maintain a positive grip on the spacecraft!
  - Astronauts sometimes use tethers; not practical for robots
- Mechanical grippers add considerable complexity
  - Additional degrees of joint control
  - Must have something to grab at all locations
- Electrostatic and “sticky foot” grippers have their own drawbacks

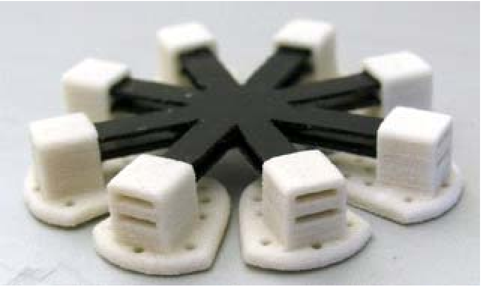


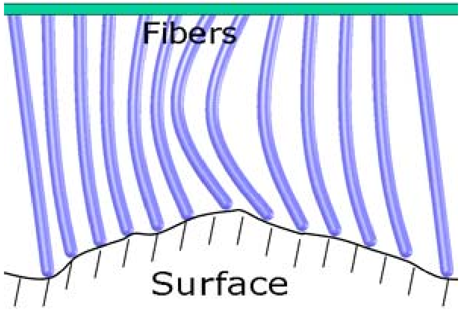
Lessons Learned: Sticky Foot

- Ripple gait
  - A single foot is moved at a time
- Tripod gait
- Pairwise opposed gait









- Can walk on any clean surface
- Requires pull-off force
- Must avoid fragile surfaces
  - Insulation blankets, solar cells, antenna mesh, etc.

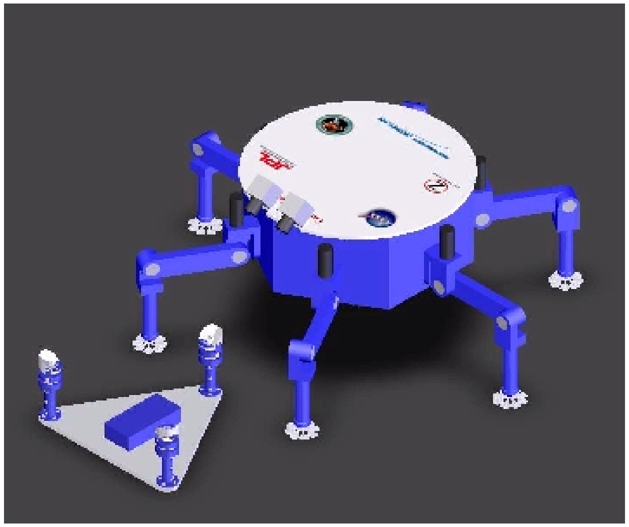
Inspired by the gecko’s micro-fiber sticky foot, polymers such as polydimethylsiloxane provide repeatable sticky force greater than preloading force. We found that sticky feet require attention to the zero-g gait.

Lessons Learned: Navigation

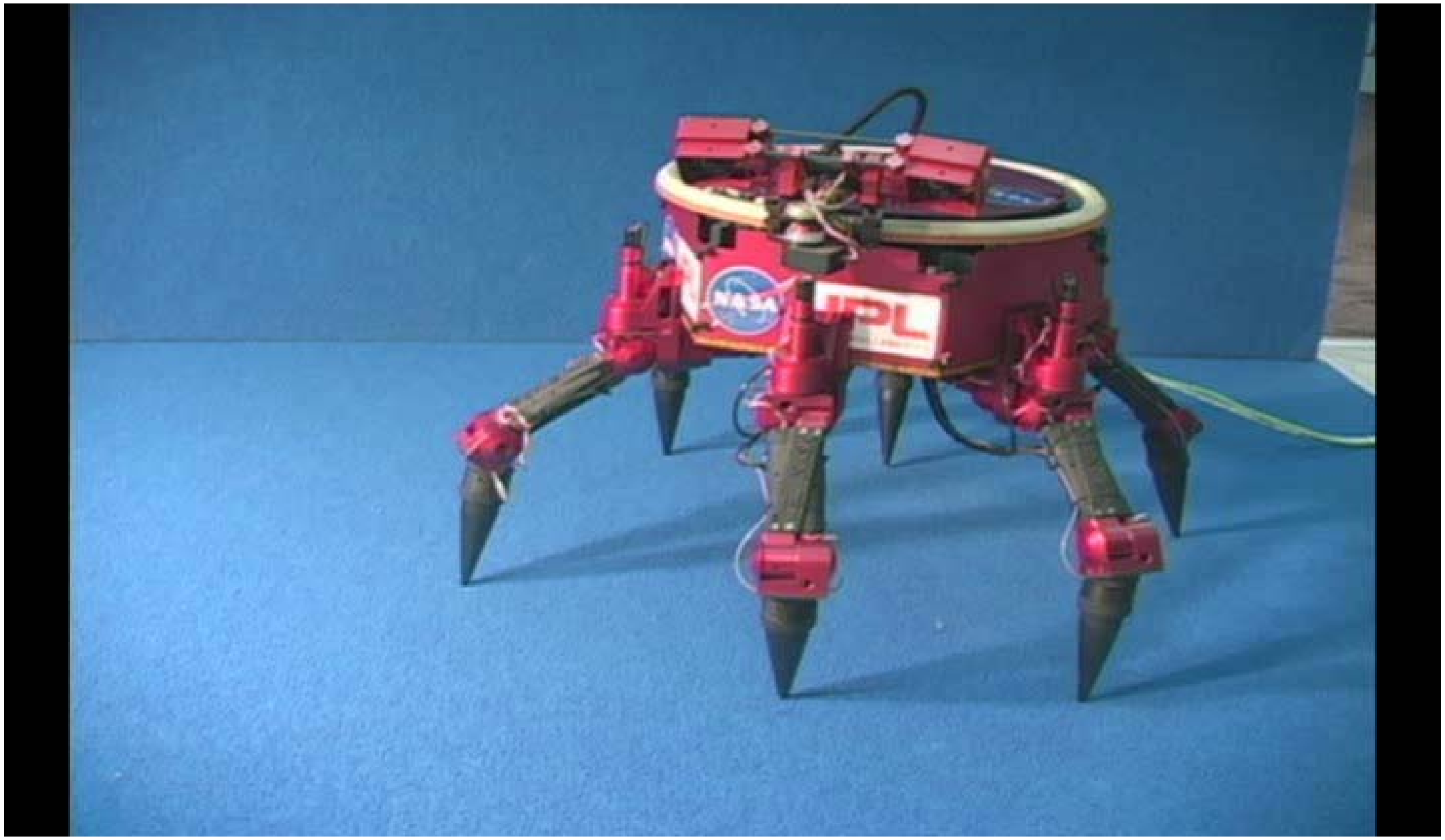
- Routine patrol or directed movement requires re-registration at some distance from charging station
  - Machine vision for navigation adds complexity
  - Bar (block or dot pattern) codes on space vehicle can help
- Obstacle avoidance is essential
- Teleoperated mode requires a high level user interface
  - Need (joystick) commands like “go forward” and “turn right,” not “move this leg” or “move that leg joint.”
  - Teleoperated modes are essential in early testing, so think about this interface early in the program

Lessons Learned: Docking Force

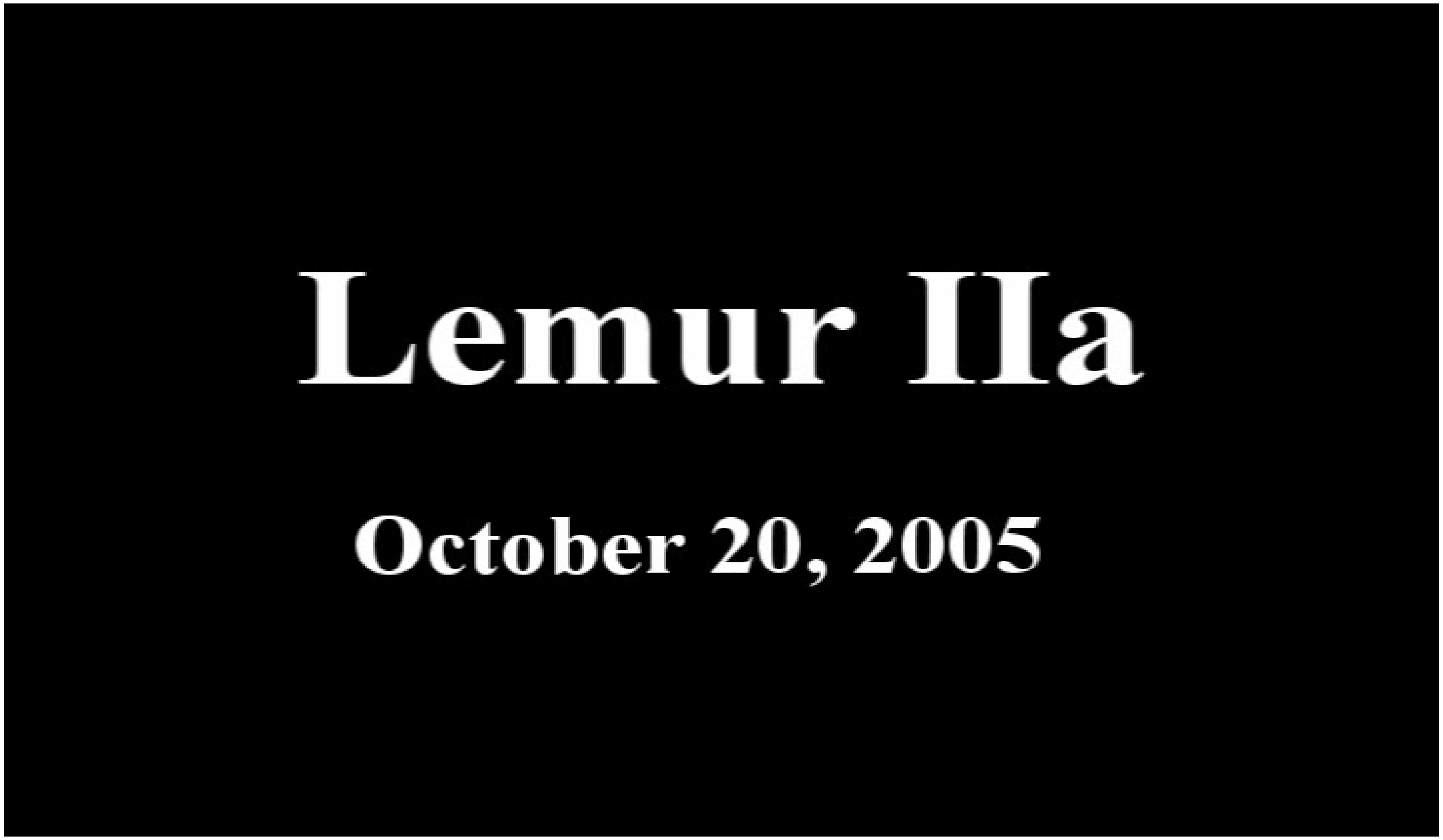
- Sticky feet (in pull direction) may not have enough force margin for docking
  - Sticky feet in shear have more force capability
- Consider pull-in capability for the docking interface
  - Screw drive, toggle, or other latching mechanism
- Force feedback control could be an enabler here



AWIMR movie



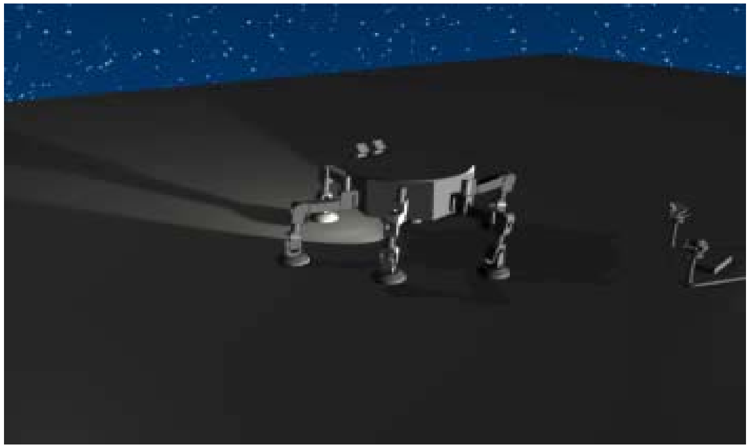
AWIMR movie



Lemur IIa

October 20, 2005

AWIMR movies



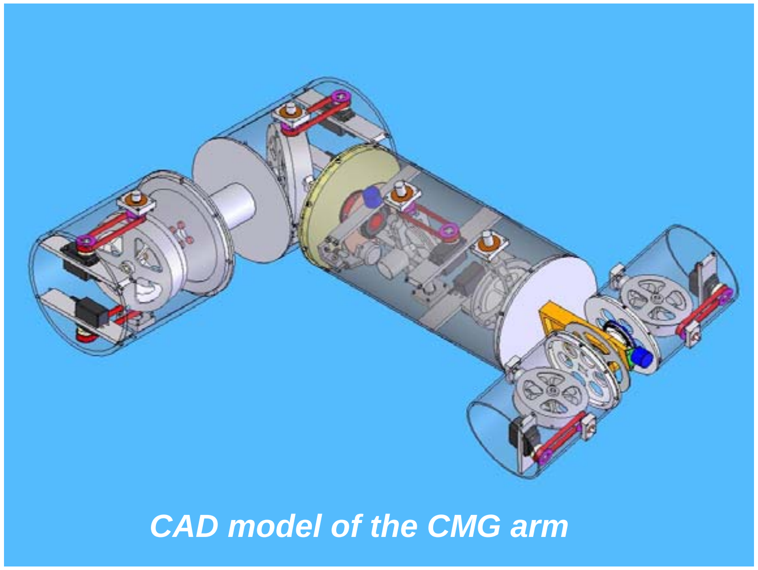
Seq AWIMR Sticky.mov

Seq VisualDockLONG AWIMRV2 .mov

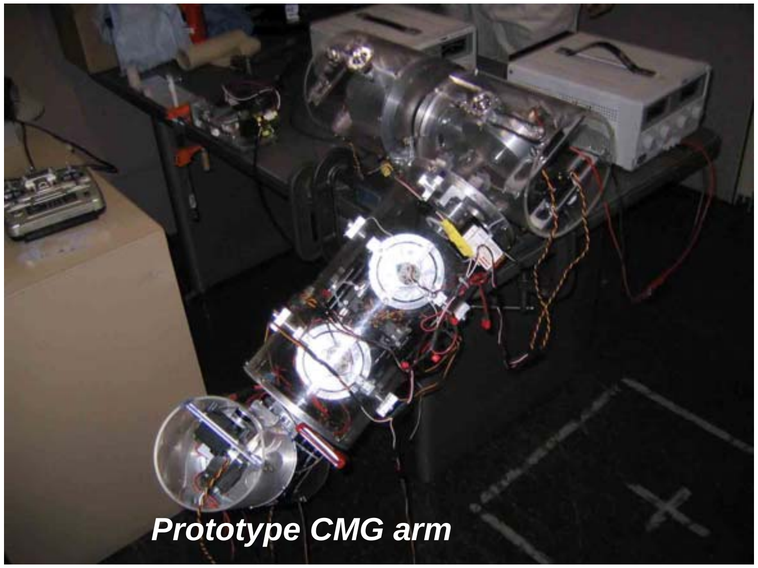
Sequence DockingV2.mov

In-Orbit Construction and Repair

- Low-Power, Agile Robotics
  - **Fundamental principle: one can alter the generalized momentum in a dynamical system without changing the energy**
  - **Our idea:**
    - Gyroscopes can gimbal around, changing the distribution of momentum while at constant spin speed.
    - Exploit this constraint torque, which does no work



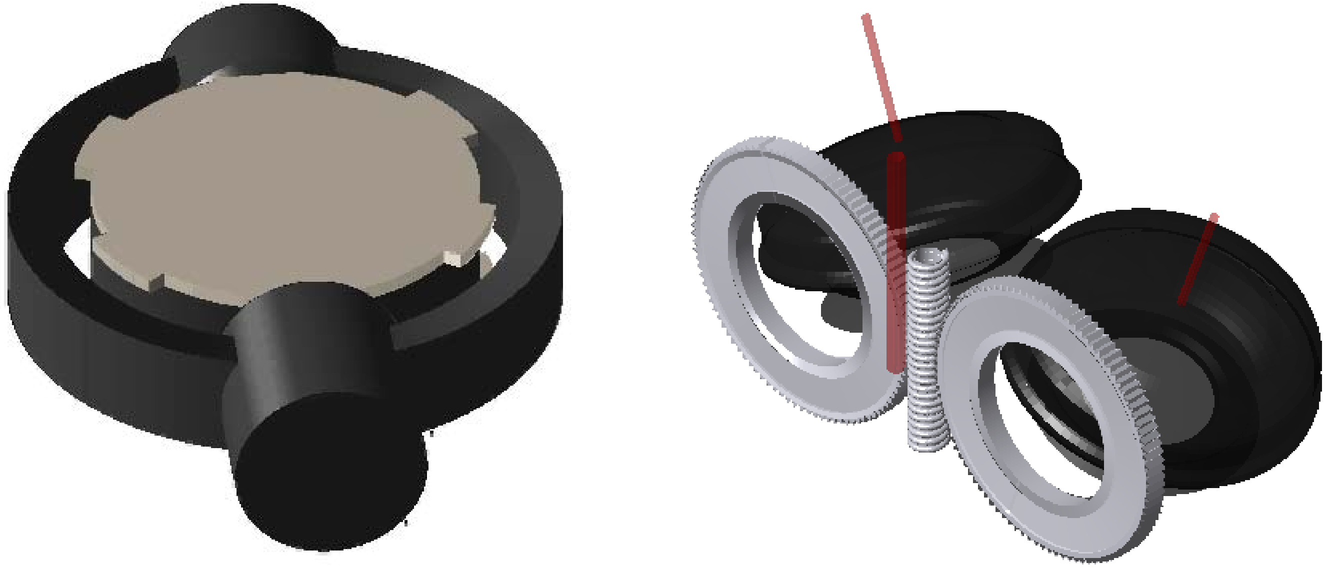
CAD model of the CMG arm



Prototype CMG arm

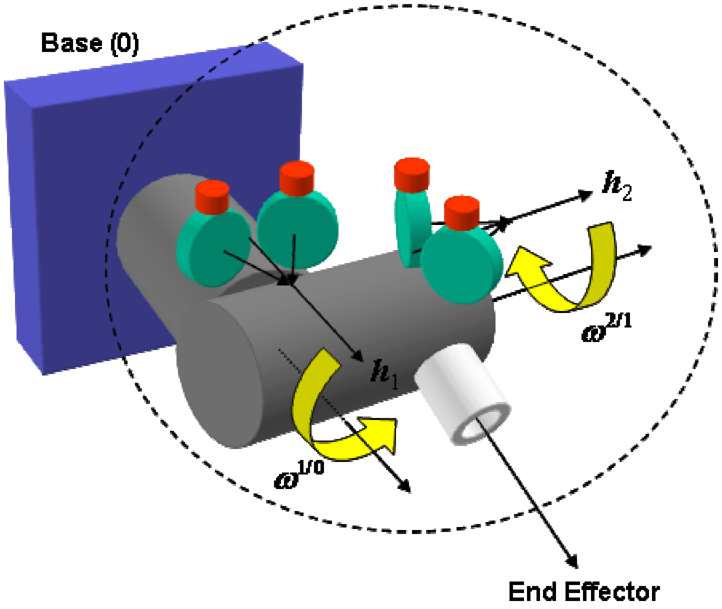
In-Orbit Construction and Repair

- Scissored Pair of CMGs
  - Gimbals are mechanically constrained so that the sum of the two rotors' momentum vectors aligns with a constant axis (like an RWA)
  - Simple control, same low power / high torque



In-Orbit Construction and Repair

- Start with the angular momentum of each composite body
  - Composite body includes body with its attached CMG scissored pair
  - Via a reference configuration



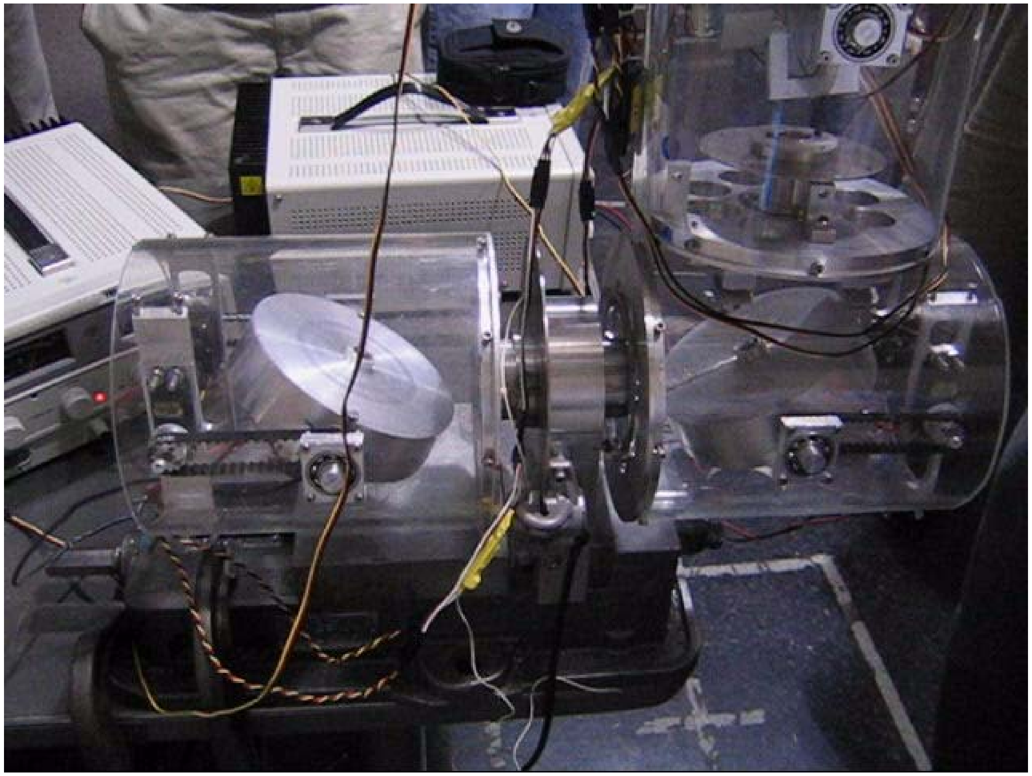
- Compute the torque by taking the time derivative of angular momentum

$$\boldsymbol{H} = \sum_{i=1}^{n} \boldsymbol{H}_i = \sum_{i=1}^{n} \boldsymbol{I}_{iC} \cdot \boldsymbol{\omega}^{i/0} + 2h_i \cos\phi_i \hat{\boldsymbol{e}}_{i1}$$

$$\overset{0}{\boldsymbol{H}} = \sum_{i=1}^{n} \overset{0}{\boldsymbol{H}}_i = \sum_{i=1}^{n} \boldsymbol{I}_{iC} \cdot \overset{i}{\dot{\boldsymbol{\omega}}}{}^{i/0} + \boldsymbol{\omega}^{i/0} \times \boldsymbol{I}_i \cdot \boldsymbol{\omega}^{i/0}$$
$$+2h_i \left(-\dot{\phi}_i \sin\phi_i \hat{\boldsymbol{e}}_{i1} + \boldsymbol{\omega}^{i-1/0} \times \cos\phi_i \hat{\boldsymbol{e}}_{i1} \right)$$

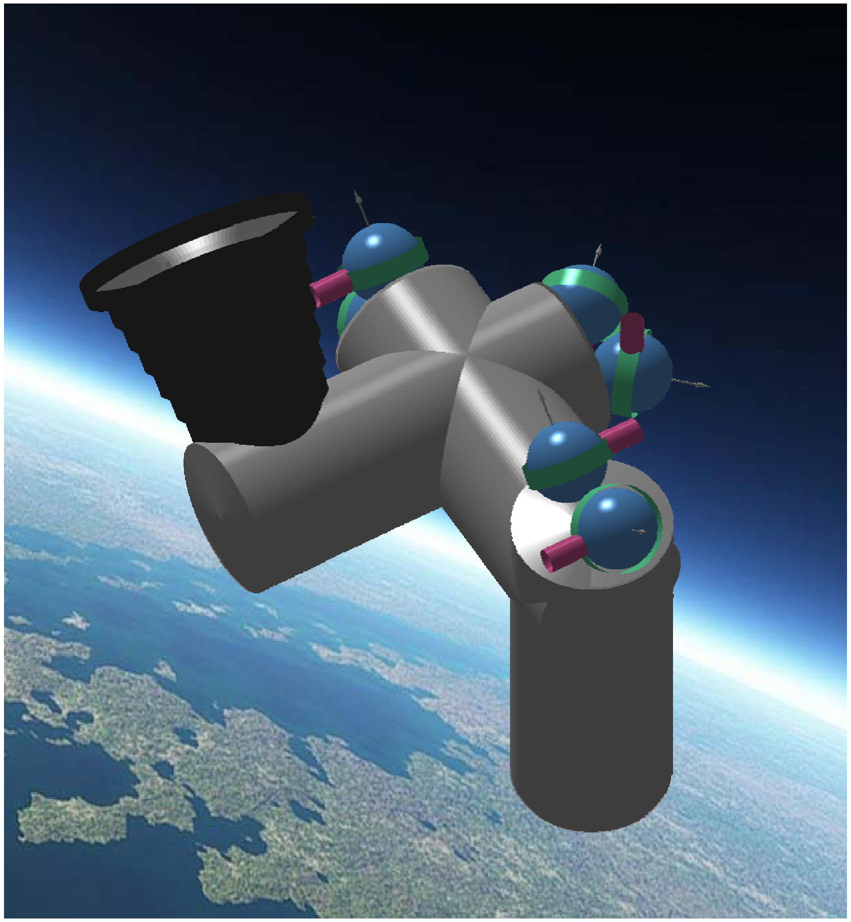
In-Orbit Construction and Repair

- Simulations show better than 90% savings in electromechanical power
- Flight test on NASA's C9 microgravity aircraft in March 2007



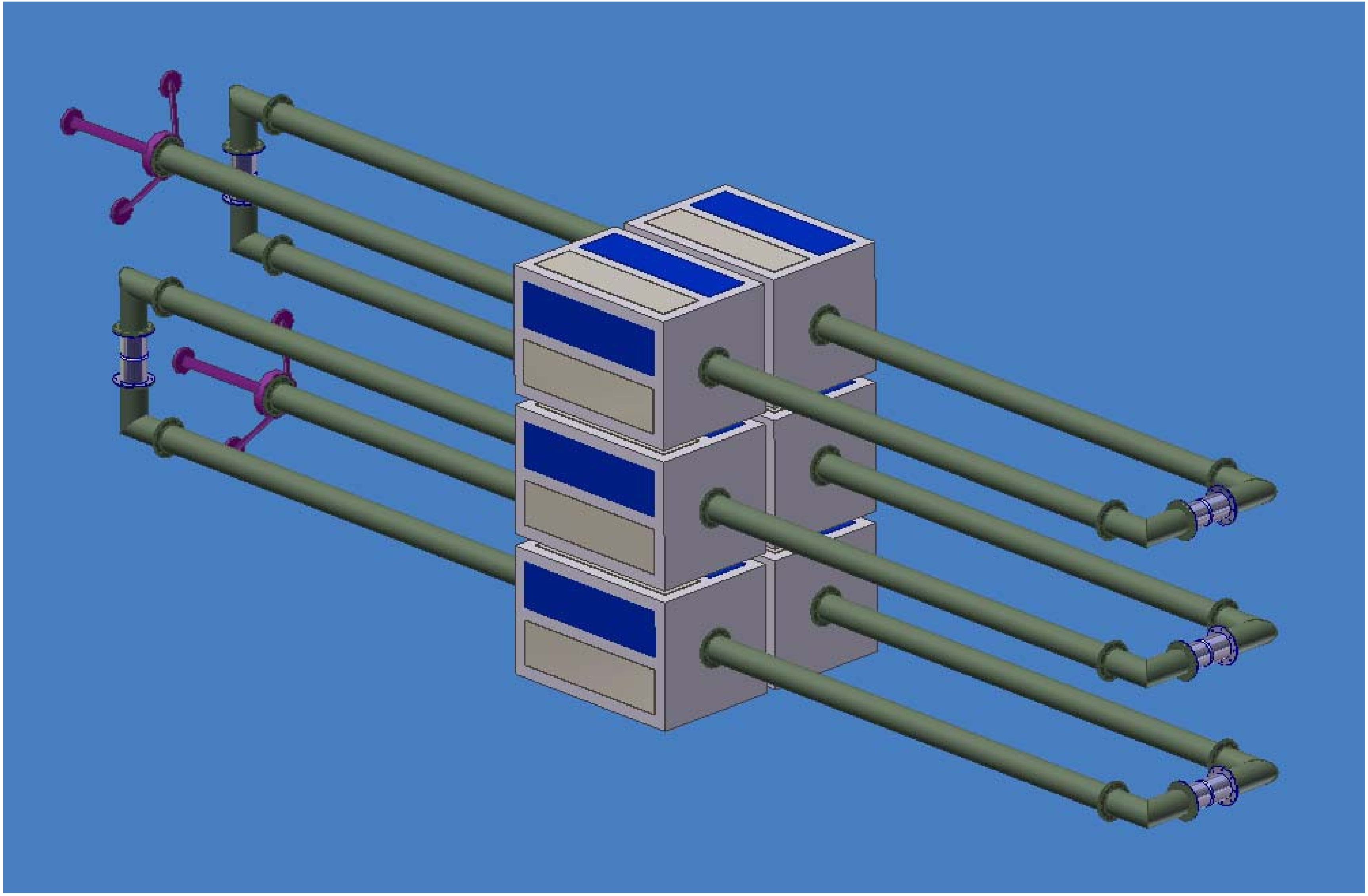
In-Orbit Construction and Repair

- Doing More with Less
  - **Exploit the dynamics:**
  - **Constraint torques do no work**
    - Angular and translational momentum in in-orbit construction tend to be conserved
    - When they're not, momentum unloading by leaning on the environment is possible
  - **Faster, cheaper assembly of spacecraft for the same power: greater productivity**
- High-agility, large-aperture telescopes
- Low-power, high-torque (tele)robotic construction

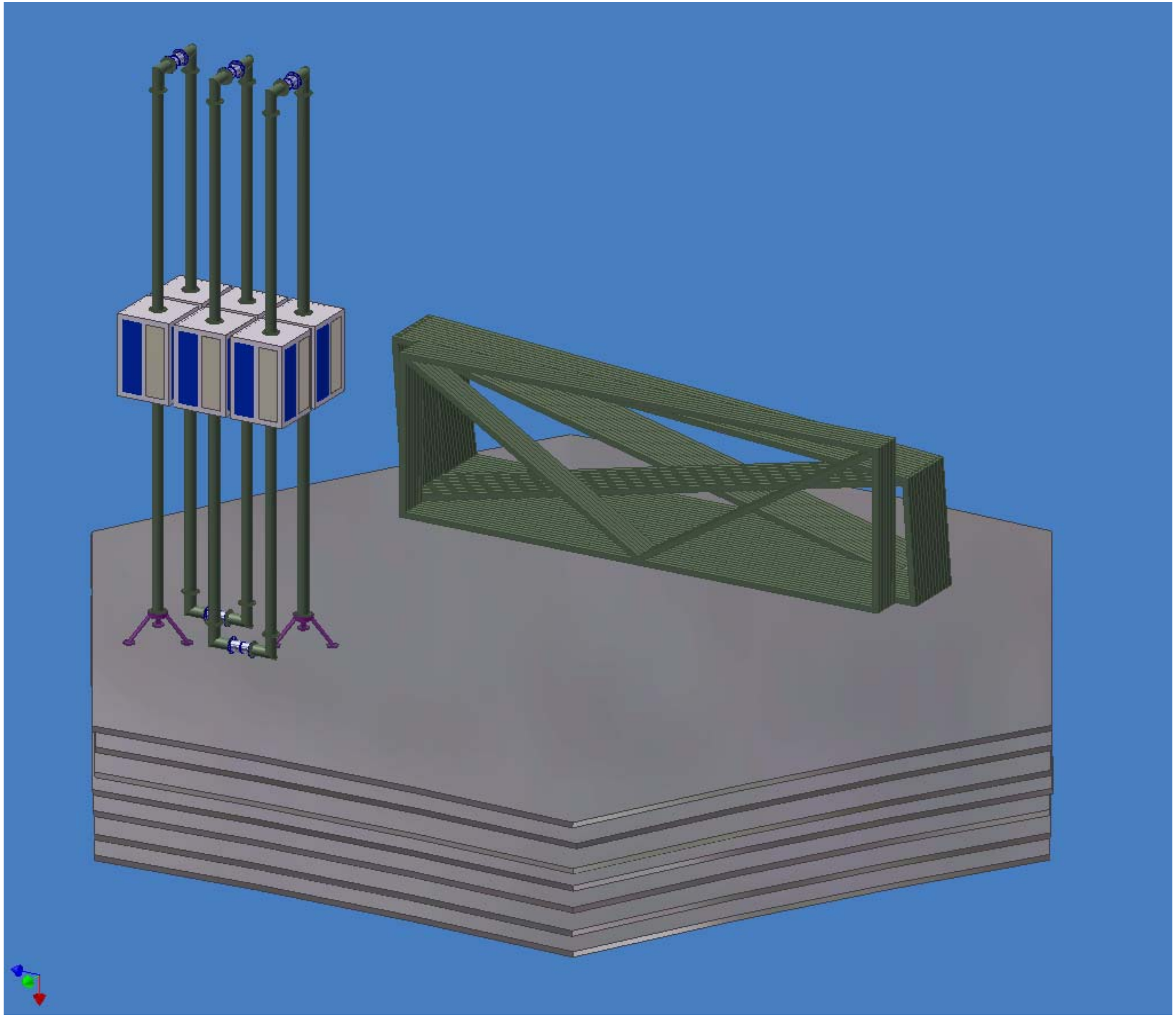


Website: http://mae.cornell.edu/CMG

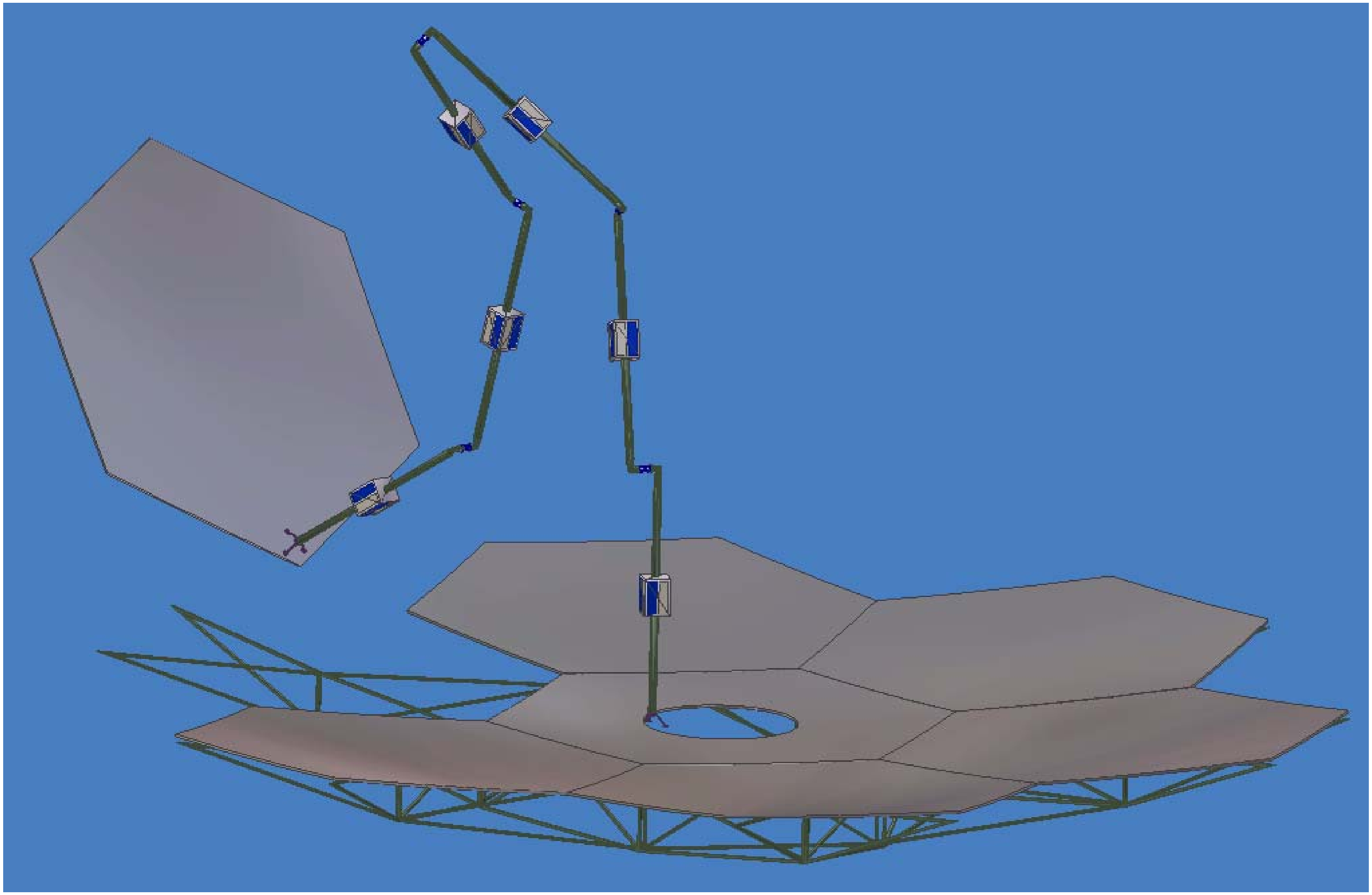
CMG robot arm for space assembly



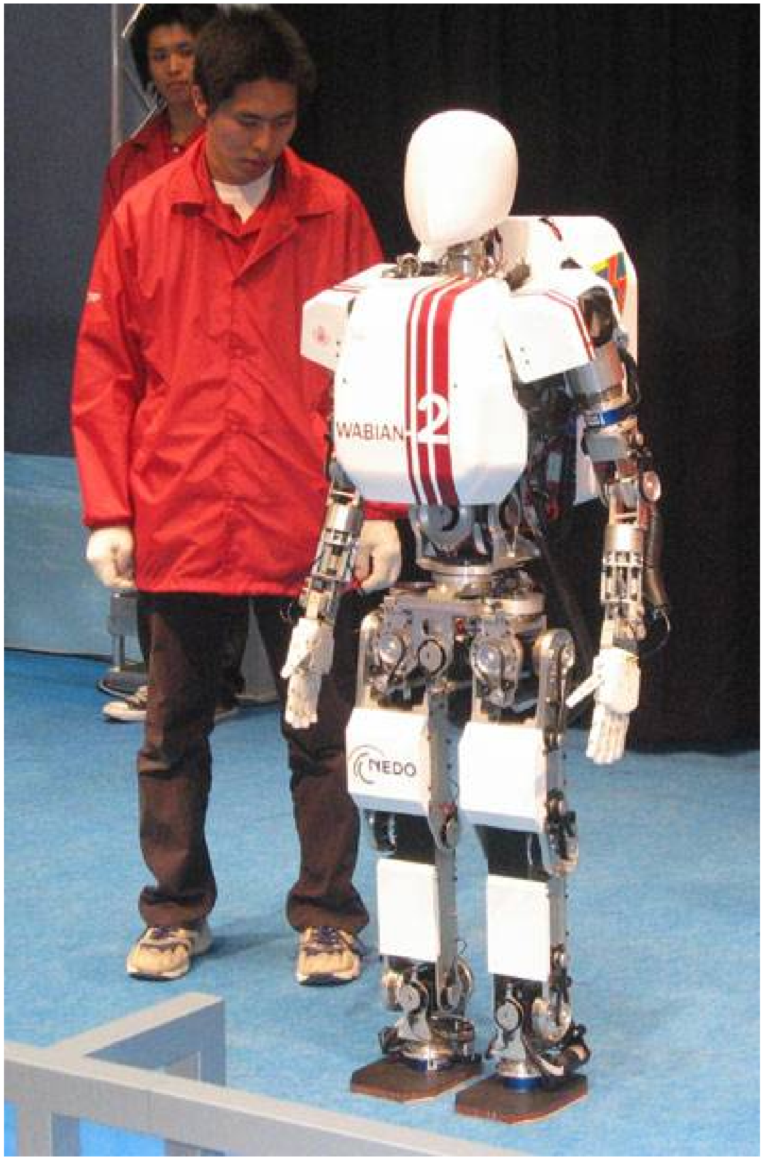
CMG robot arm for space assembly



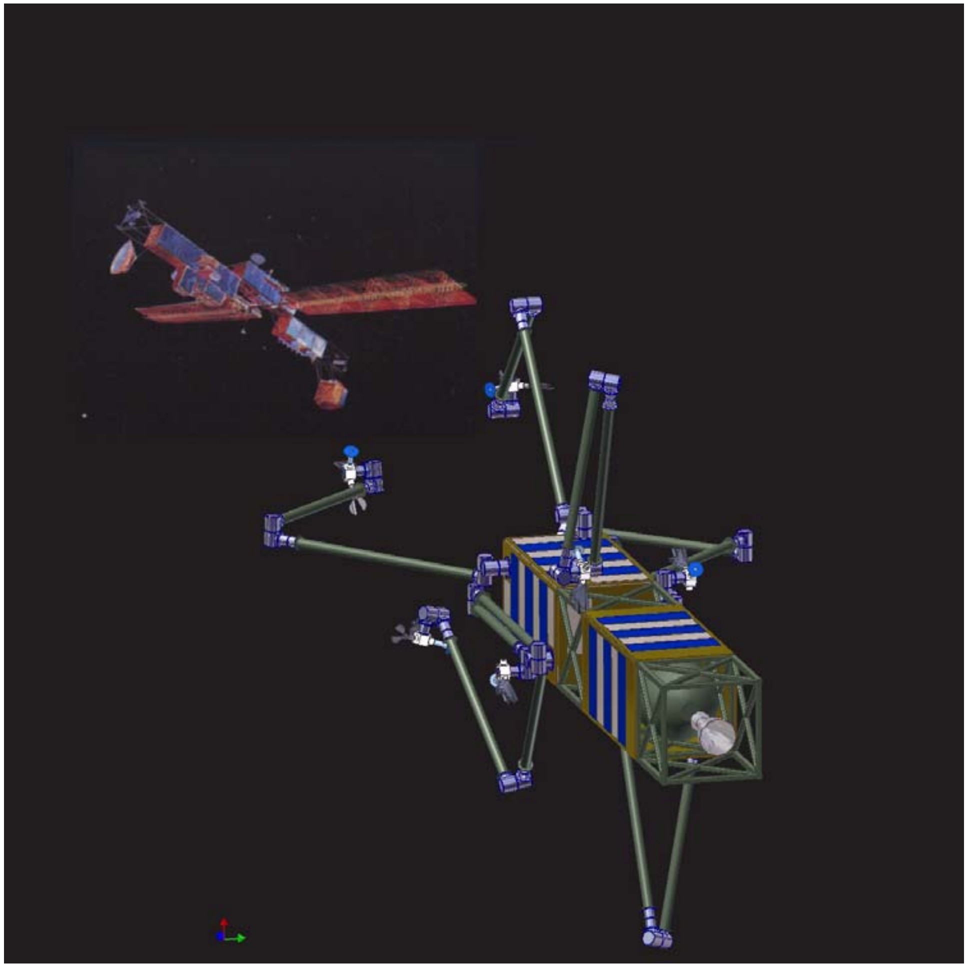
CMG robot arm for space assembly



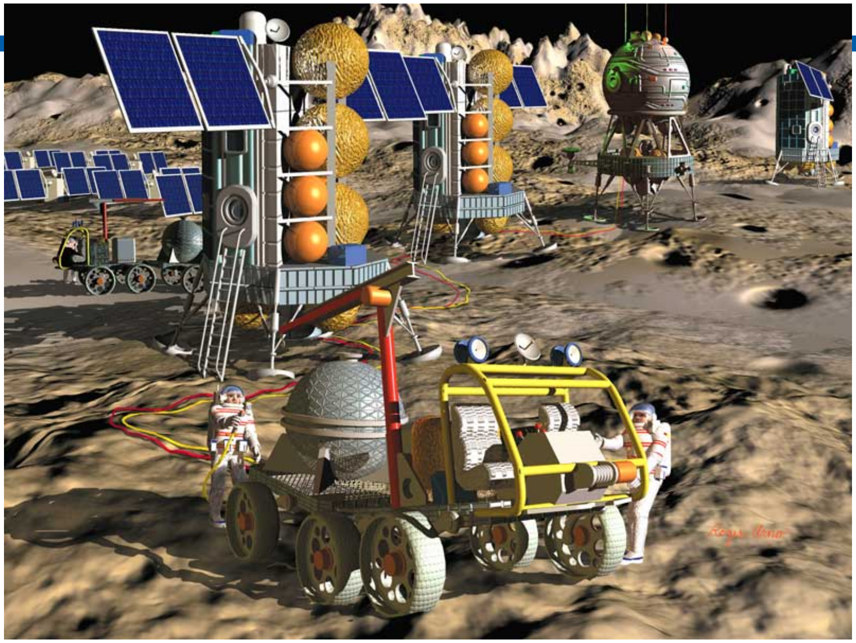
The Future

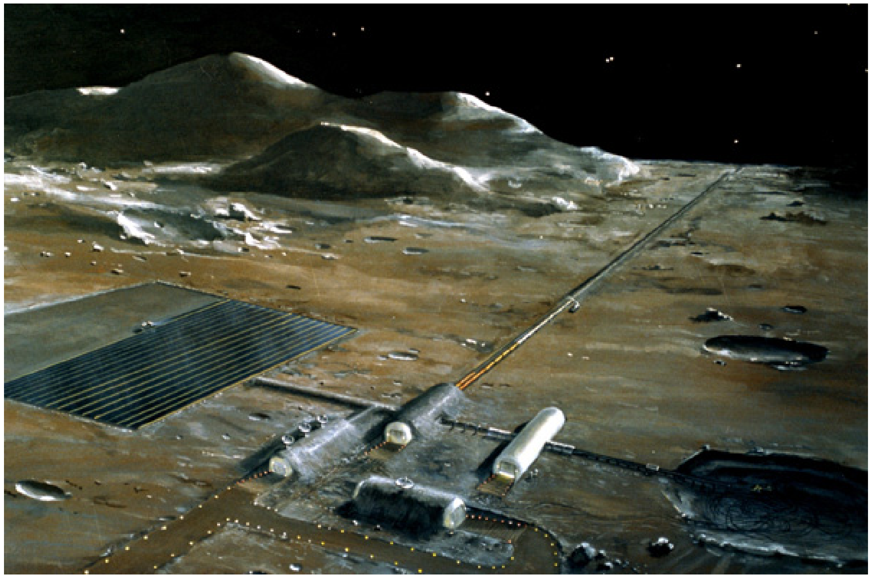


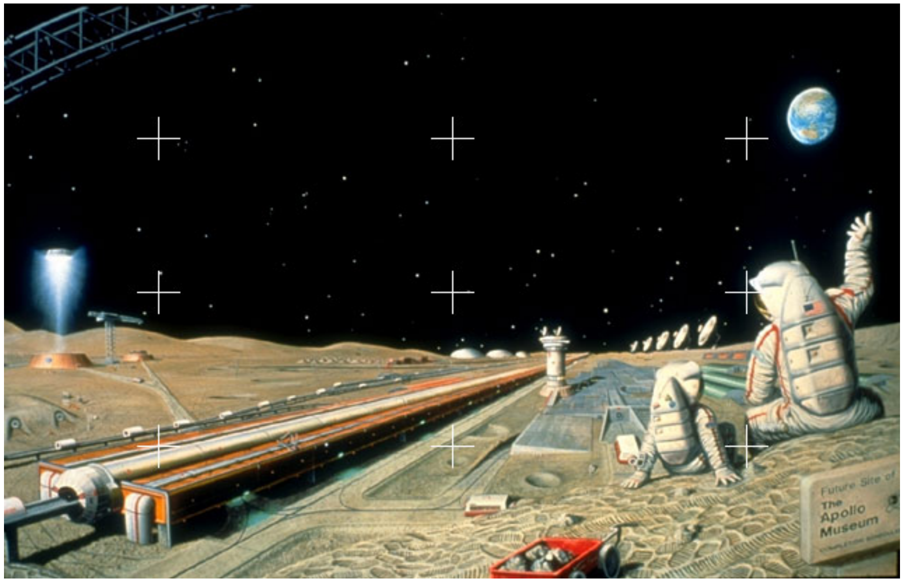
Robo-butler (left).
Satellite repair and assembly (below).

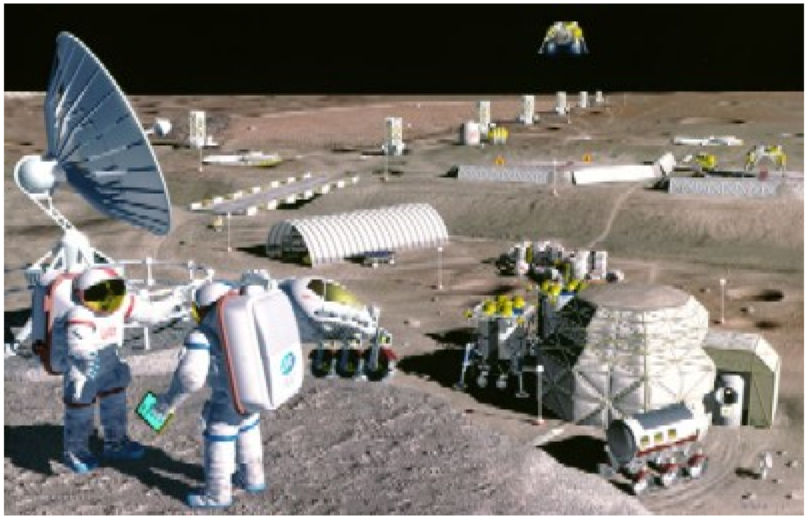


The future

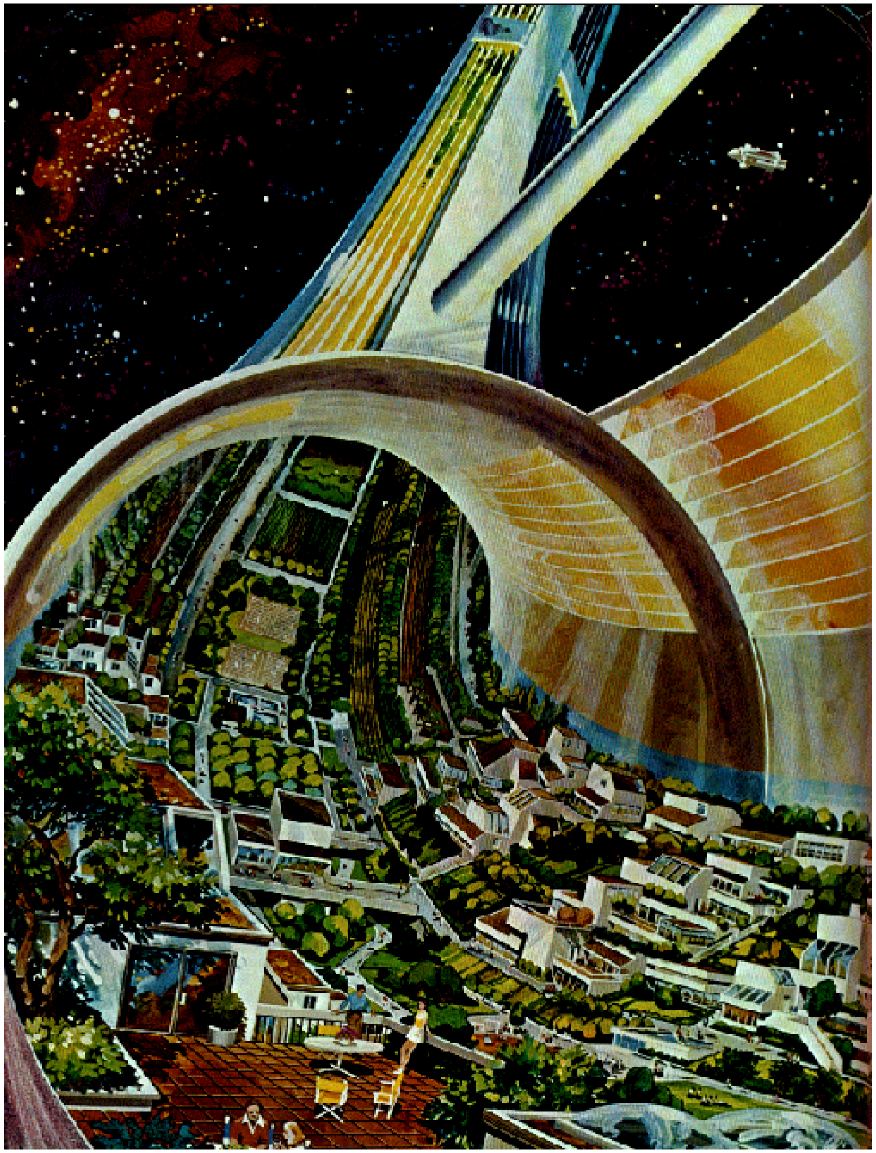




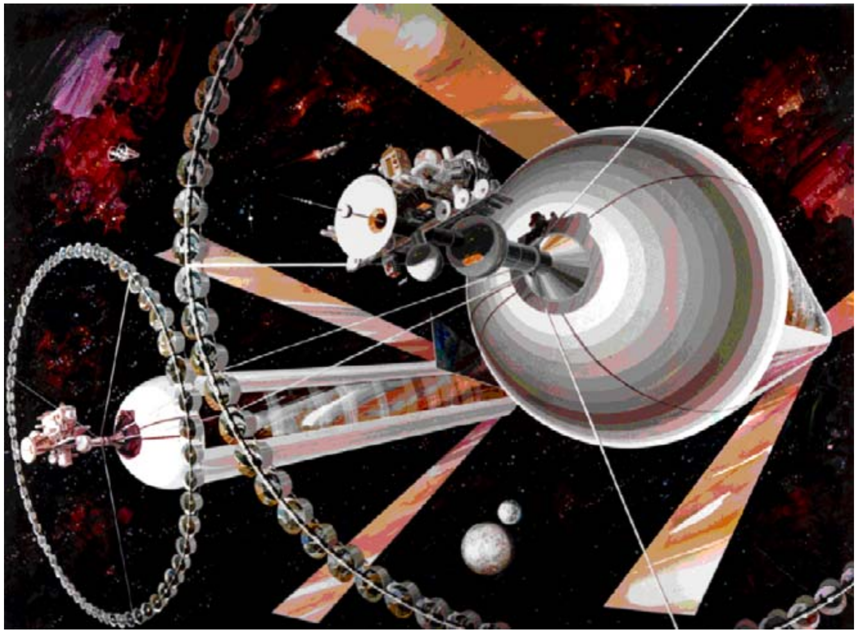




The future



The Red Admiral
www.trekmania.net



Workshop example: deriving specifications from requirements

- A specification describes what a product will do to meet its requirements.
  - A specification is not a design. A design describes how a product will meet its specification.
    - Example:
      - Requirement: The robot should move quickly enough so that people don’t become impatient with it.
      - Specification: The robot shall move at least five feet per second at full speed and shall accelerate (and decelerate) from zero to top speed in two seconds.
      - Design: The robot shall have wheels with a minimum coefficient of friction of 0.8, and shall have a drive power to weight (mass) ratio of 5 watts per kilogram.
- Exercise:
  - Using your team requirements list from the previous session, derive a specification document for the three most important requirements. Present your results in class.

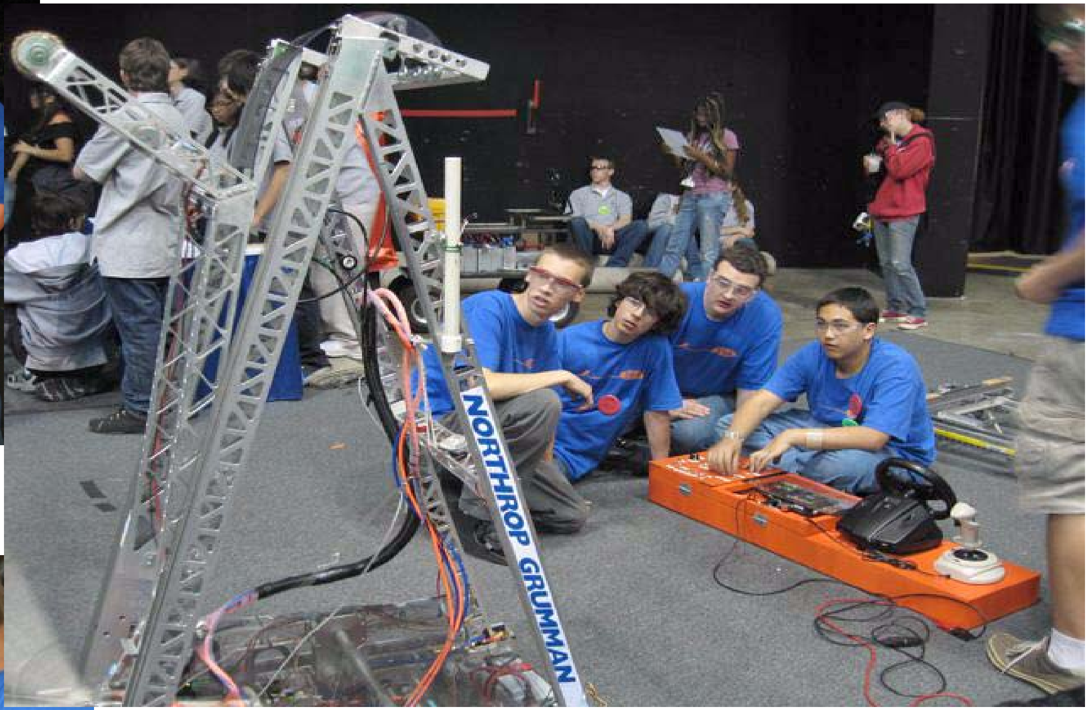
Systems Engineering Process: FIRST

- For Inspiration and Recognition in Science and Technology (FIRST)
  - Started by Dean Kamen in 1993 because he was concerned that our culture was going to hell in a handbasket with our worship of pop stars (such as Britney Spears), athletes, etc.
    - We become what we celebrate, so Dean said “Let’s celebrate science and technology.”
- Now there are 1,500 FIRST high school teams across the country and around the world. You know some of them.
  - MetalCrafters (207)
  - Beach Cities Robotics (294, world champs 2001)
  - BeachBots (330, world champs 2005)
  - Nerd Herd (687)

Systems Engineering Process: FIRST

- We do a full blown systems engineering process in six weeks every year!
  - Study the rules, perform simulations, and analyse scoring, etc. Then brainstorm solutions.
    - Team develops consensus on what the robot should do to win the game.
  - Concept designs: Subteams come up with conceptual models and present their solutions. Team votes on best ones.
  - We lay out a schedule for subsystems design, fabrication, assembly, and test, with subteams for
    - Robot base
    - Manipulators
    - Sensors and controls
    - Software development
- Other tasks include building a practice field, rapid prototyping, project management, community outreach, fundraising, team spirit activities, art, etc.

How We Got to Atlanta (via San Diego)



BCR won the San Diego Regional Competition for FIRST Tech Challenge (FTC) in December 2007. BCR won the San Diego Regional for FIRST Robotics Competion (FRC) in March 2008.

Victory in San Diego FTC!

FIRST Tech Challenge (FTC) uses the VEX Robotics kit parts to build a robot to fit within an 18 inch cube. It has a fully autonomous mode as well as a teleoperated (driver controlled) mode.

Los Angeles (Finalist)

Beach Cities Robotics in Atlanta

Mentors: Andrew, Peter, Ken, and Meredith at the Centennial Park Celebration

In the Fountain at Centennial Park

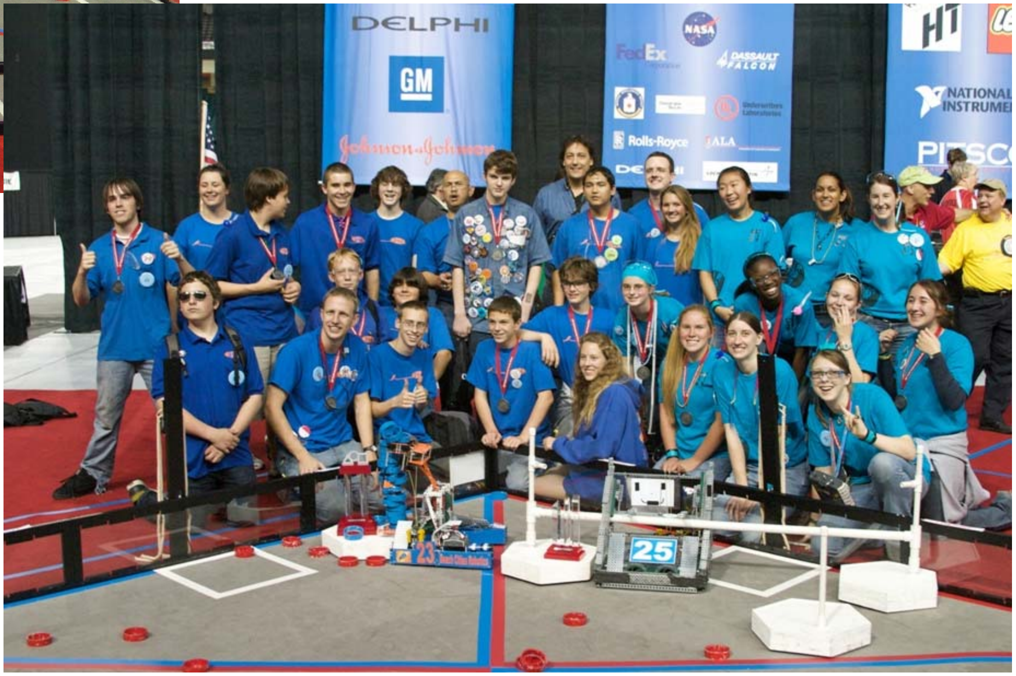
The FRC Pit Crew

FTC!

World Champion Alliance

The FIRST Tech Challenge Winning Alliance was Team 23 “Beach Cities Robotics” from Redondo Beach, California; Team 30 “Mr. T” from Montville, New Jersey; and Team 74 “Team Overdrive” from Bridgewater, New Jersey.

With team 25, finalist



The FTC Robot: Squeaky