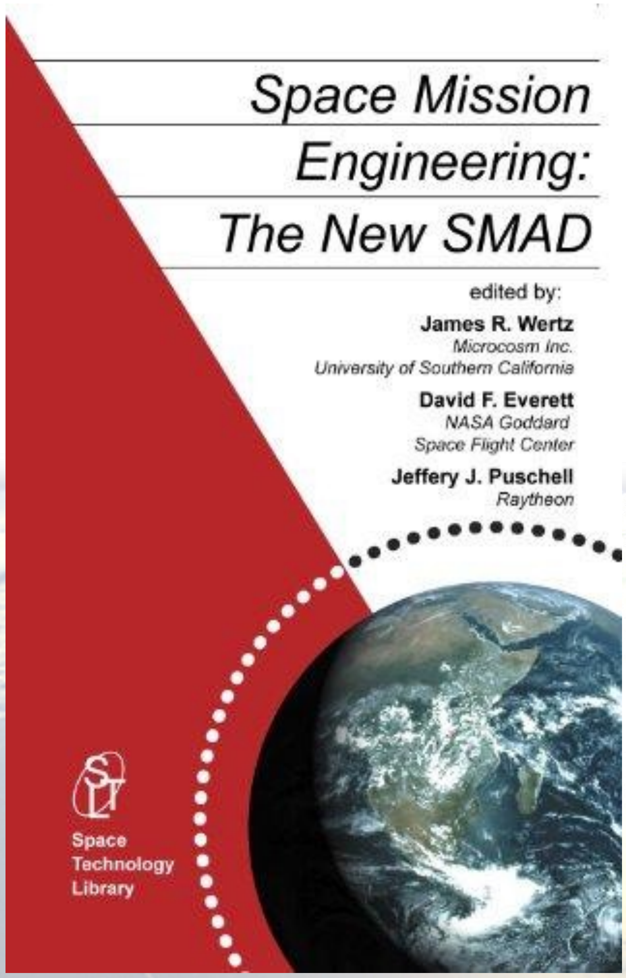
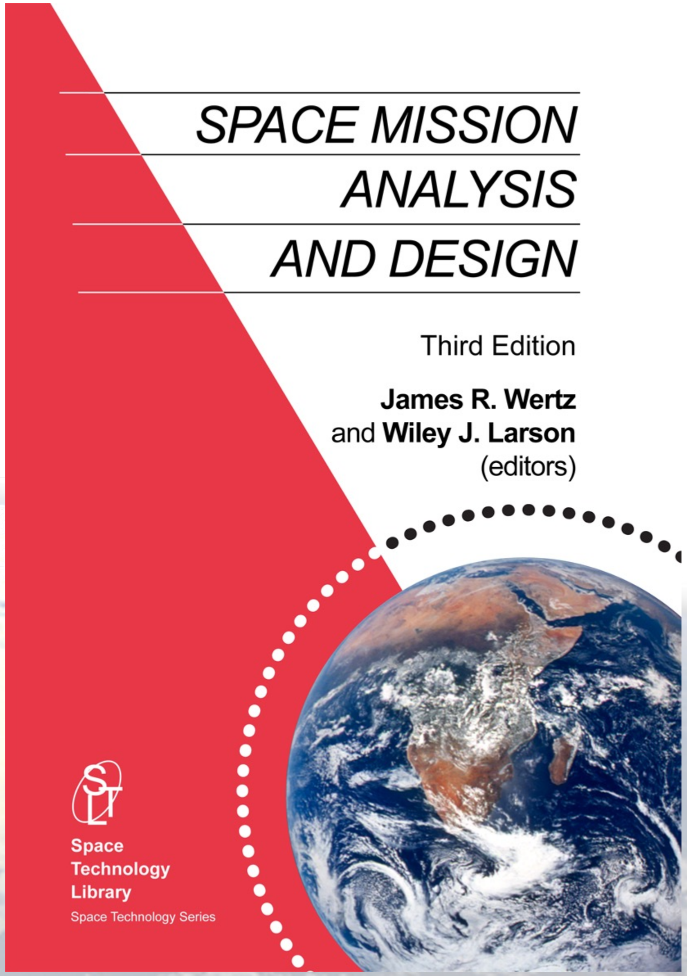
Space Systems Overview

16/18-873
Fall 2023

Books



Space Mission
Engineering:
The New SMAD
edited by:
James R. Wertz
Microcosm Inc.
University of Southern California
David F. Everett
NASA Goddard
Space Flight Center
Jeffery J. Puschell
Raytheon
Space
Technology
Library



SPACE MISSION
ANALYSIS
AND DESIGN
Third Edition
James R. Wertz
and Wiley J. Larson
(editors)
Space
Technology
Library
Space Technology Series

Space System

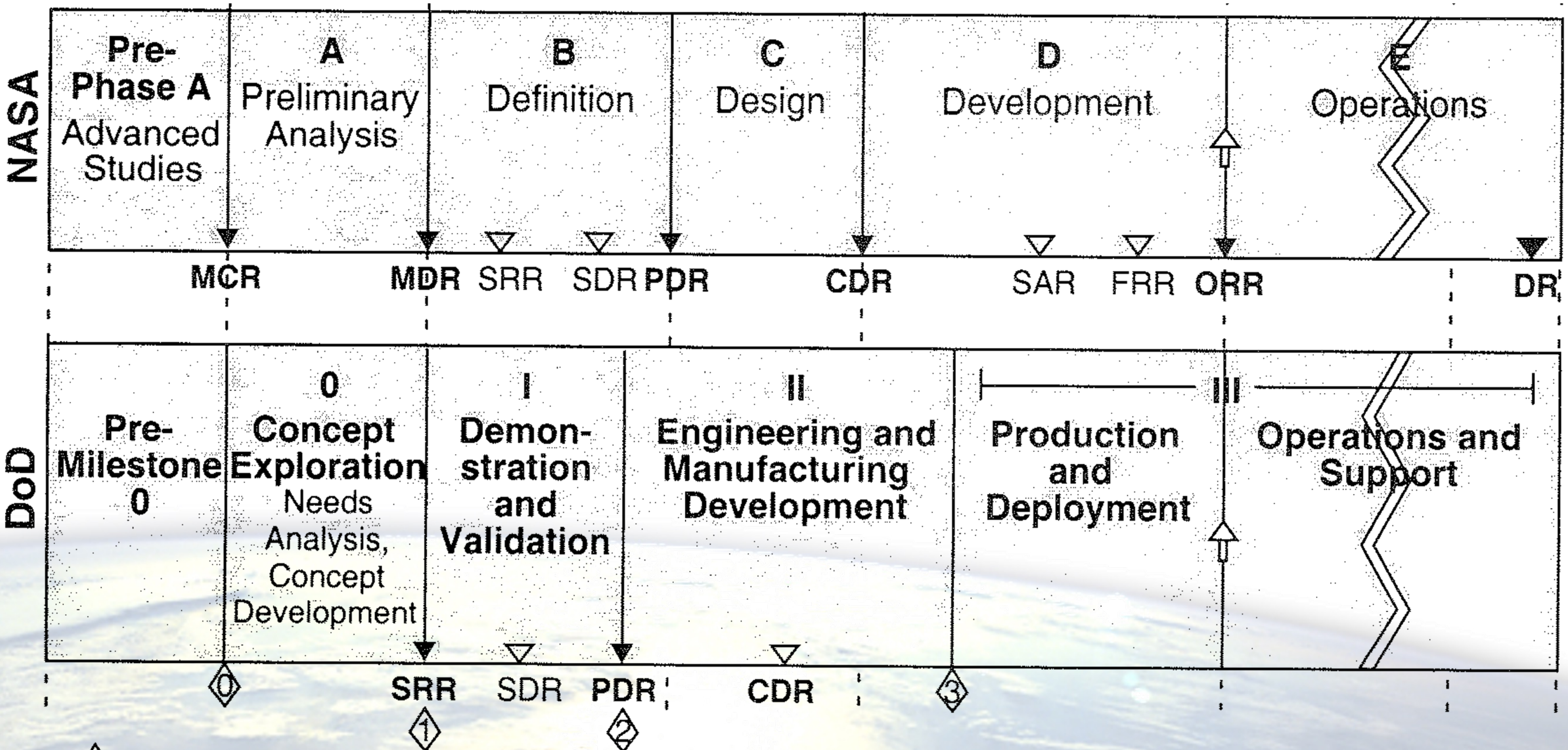
- Ground Segment
- Launch Segment
- Space Segment

Spacecraft Life Cycle

- Life Cycle: sequence of events during the system's life
  - Begins with concept development and design
  - Ends with disposal


ROCKET MOTOR
U.S. ARMY
NO STEP

Spacecraft Life Cycle



DoD Milestone
Major Review (Control Gate)
Review
Launch
AR Acceptance Review
CDR Critical Design Review
DR Decommissioning Review
FRR Flight Readiness Review
MCR Mission Concept Review
MDR Mission Definition Review
ORR Operational Readiness Review
PDR Preliminary Design Review
PRR Preliminary Requirements Review
QR Qualification Review
SAR System Acceptance Review
SDR System Definition Review
SRR System Requirements Review

Mission Operations

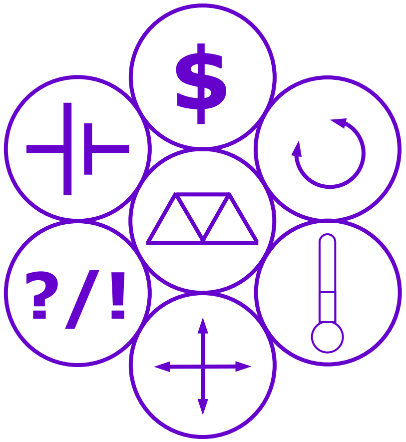
- Concept of Operations (CONOPS)
  - What does the spacecraft do
  - When is it done
  - Who does it

TABLE 14-1. Developing a Mission Operations Plan. Many items are detailed by Boden and Larson [1995]. See text for a discussion of each step.

Step	Key Items
1. Identify the mission concept, supporting architecture, and performance requirements (Chap.1)	• Mission scope, objectives, and payload requirements • Mission philosophies, strategies, and tactics • Characteristics of the end-to-end information system • Identify performance requirements and constraints
2. Determine scope of functions needed for mission operations (Sec. 14.2)	• Identify functions necessary for different mission phase • Functions usually vary for different mission concepts and architectures. Combine or eliminate if possible
3. Identify ways to accomplish functions and whether capability exists or must be developed (Sec. 14.2)	• Where functions are accomplished (space or ground) • Space-based crew capabilities • Degree of automation on the ground • Degree of autonomy on spacecraft and for flight crew • Software reuse (space and ground)
4. Do trades for items identified in the previous step.	• Try to define operational scenarios before selecting options. These trades occur within the operations element and include the flight software
5. Develop operational scenarios and flight techniques	• *Operations scenarios* and *flight techniques* are step-by-step activity descriptions. Identify key issues and drivers • Develop scenarios and flight techniques for functions from step 2 and options selected in step 4
6. Develop timelines for each scenario	• Timelines identify events, their frequency, and which organization is responsible. They drive the characteristics for each operations function
7. Determine resources needed for each step of each scenario	• Allocating hardware, software, or people depends on what, how quickly, and how long functions must be done
8. Develop data-flow diagrams (Sec 2.1.1)	• *Data-flow diagrams* drive the data systems and the command, control, and communications architecture
9. Characterize responsibilities of each team	• Identify organizations involved and their structure, responsibility, interfaces, and size. To be cost-effective, minimize the number of organizations and interfaces • Develop training plan for ground team and flight crew
10. Assess mission utility, complexity, and operations cost driver	• Refine development and operations costs each time you update the Mission Operations Plan
11. Identify derived requirements	• Identify derived requirements and ensure consistency with top-level requirements • Identify cost and complexity drivers • Negotiate changes to mission concept and architecture
12. Generate technology development plan	• If the technology to support mission operations doesn't exist, generate a plan to develop it
13. Iterate and document	• Iteration may occur at each step • Document decisions and their reasons

Classical Subsystems

Classical Subsystems



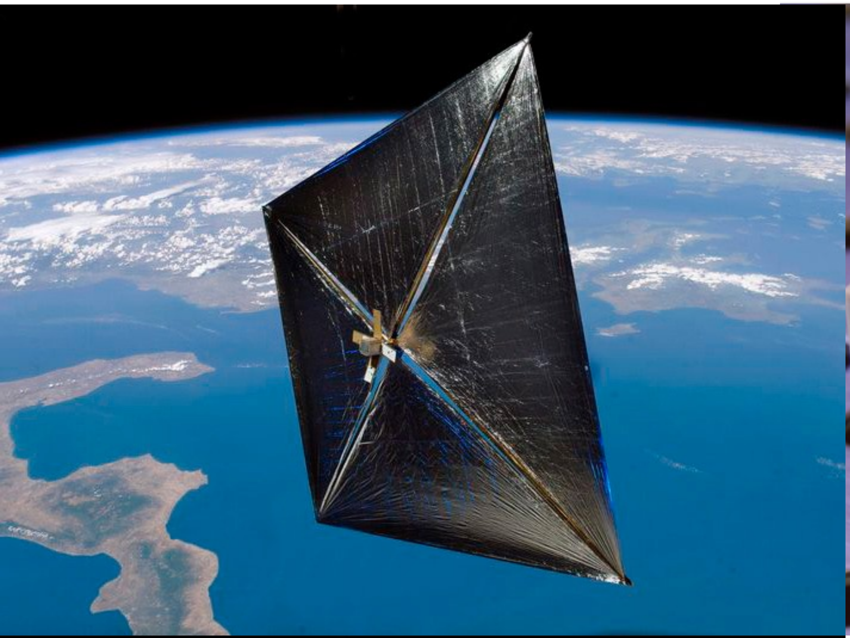
- Propulsion
- Power
- ?/! Telemetry and Command (T&C)
- Structure
- Thermal
- Attitude control (AKA ACS, ADCS, ADCNS, ADACS, or GNC)
- $ Payload

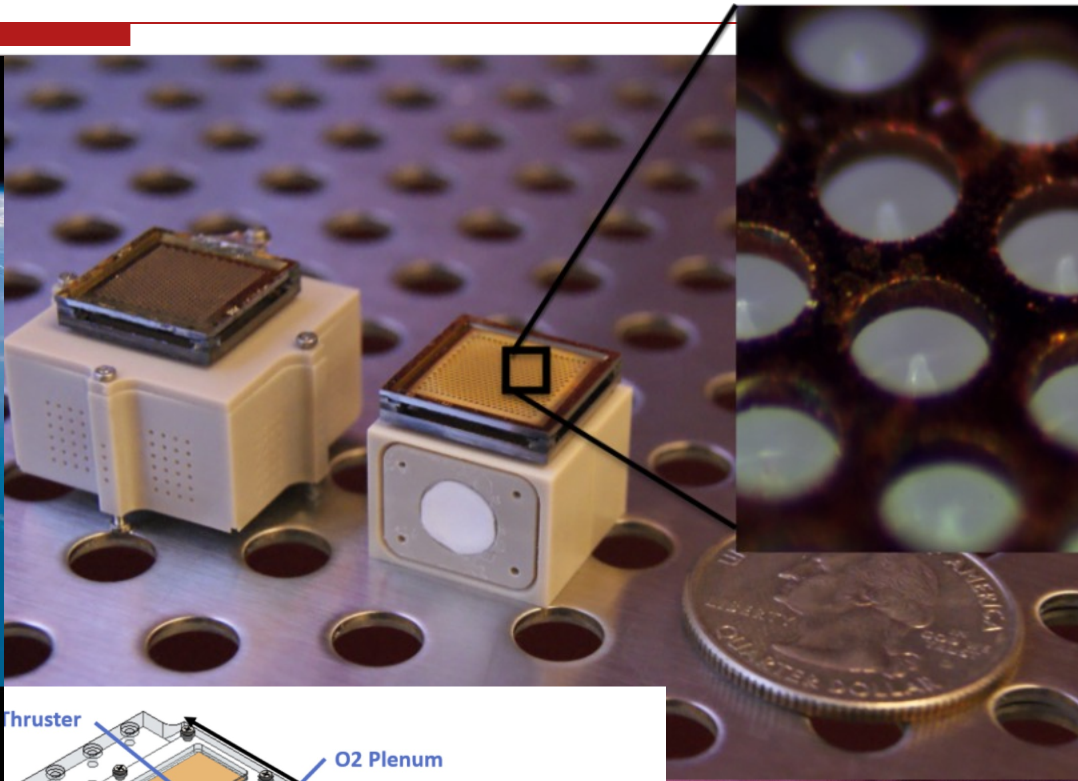
Propulsion

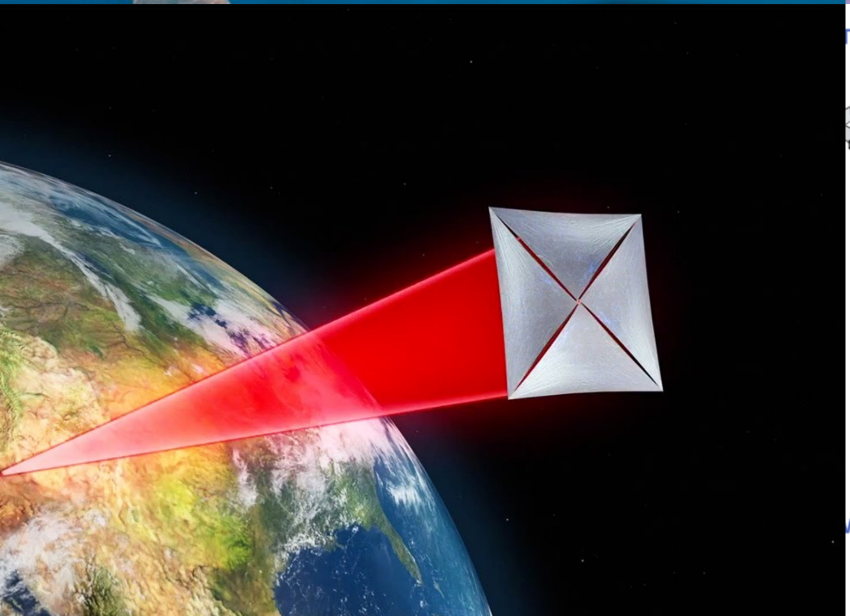
Propulsion

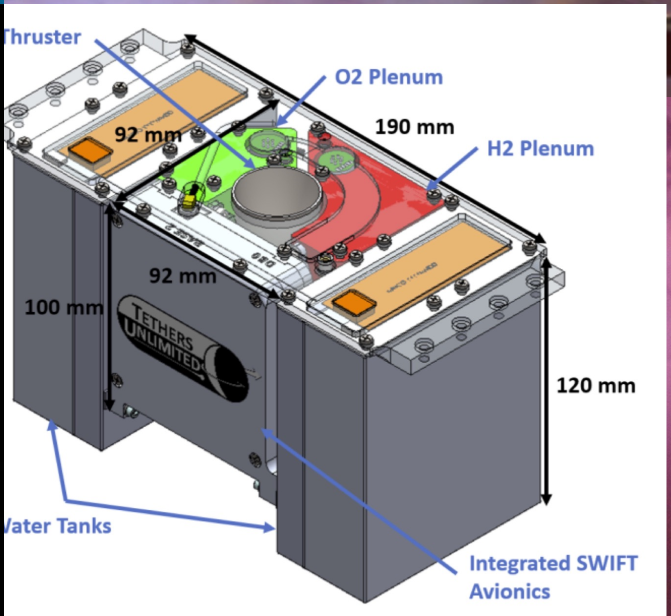
- There are many types of propulsion subsystems
  - Chemical (solid & liquid)
  - Electric (ions & plasma)
  - Propellantless (tethers, drag)
  - External (beamed power, mass drivers)
- Generally
  - High thrust is accompanied by low efficiency.
  - High efficiency requires high power

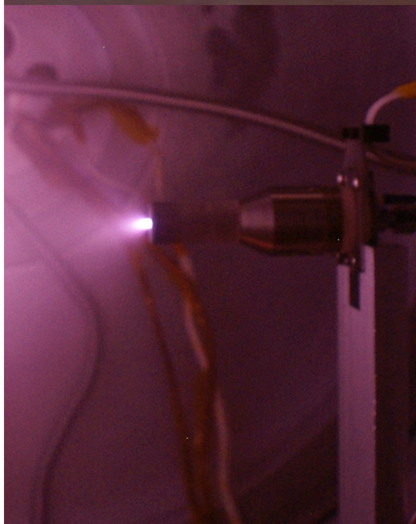
Propulsion








Thruster
O2 Plenum
190 mm
H2 Plenum
92 mm
92 mm
100 mm
120 mm
TETHERS UNLIMITED
Water Tanks
Integrated SWIFT Avionics



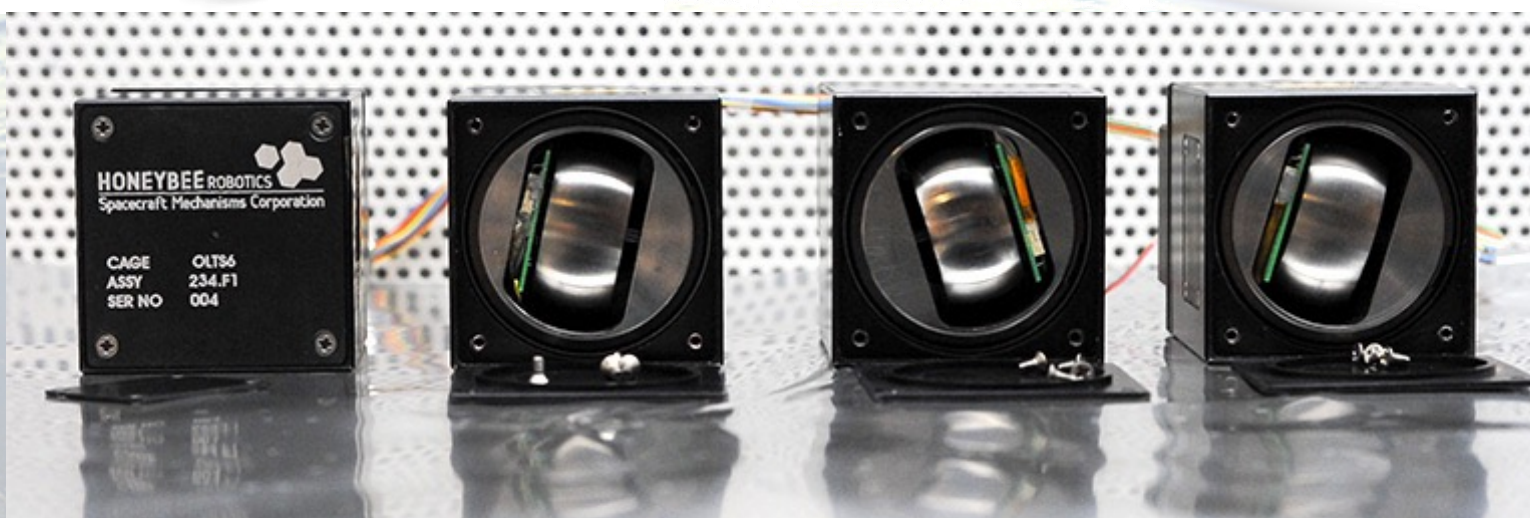
Propulsion

- Propulsion can apply both force and torque and can therefore affect both position and attitude.
- Propulsion usually involves limited resources (expendables), which cannot be replenished.
  - So, although propulsion can be the most useful form of actuation, exhausting the expendables ends the mission.
  - Other forms of actuation can apply torque without using expendables and are preferred for attitude control.
- Propulsion is the only way to effect orbit control.

ADCNS

- Attitude Determination
  - Where is the spacecraft pointing?
  - Blend sightings of magnetic field direction, sun, earth, and GPS to create an optimal estimate of the three-dimensional rotation (or orientation, or attitude)
- Attitude Control
  - Use actuators to drive the attitude estimate to a desired value
- Navigation
  - Estimate position
  - Control that too
- The physics of rotations is uncoupled from translation
  - You can’t translate via torques
  - You sometimes can rotate via forces, but only when they act at a distance, producing a moment.

ADCNS


HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation
CAGE OLTS6
ASSY 234.F1
SER NO 004

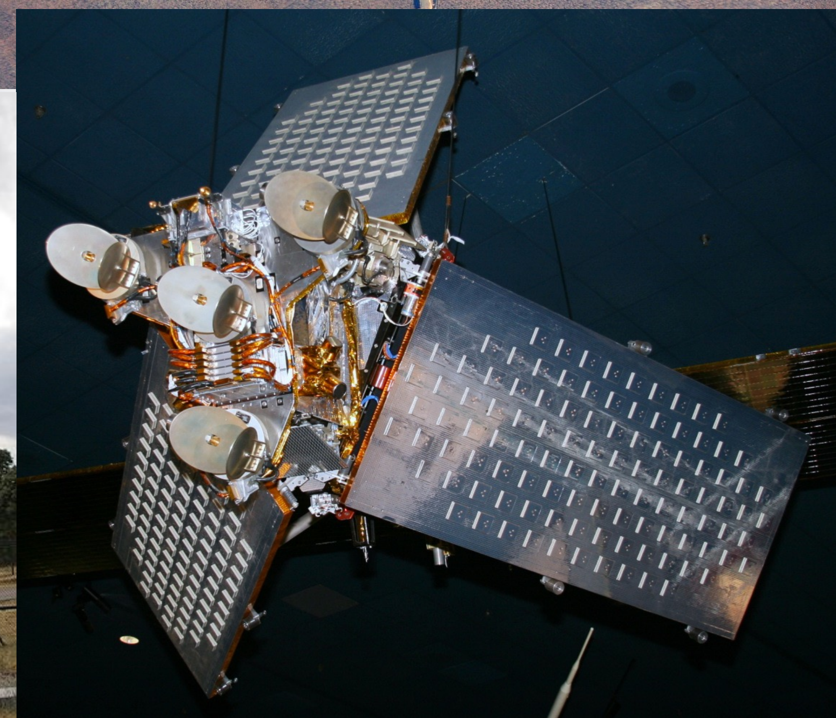
ADCNS

- Pointing Error Budget
  - What are the individual sensor errors?
  - What are the disturbance torques on the spacecraft?
  - What is the resolution/accuracy of your actuators?
  - Where are the errors in your dynamics model?
  - What are your pointing requirements?

Telemetry & Command ?/!

- Telemetry: data from the spacecraft
- Command: data to the spacecraft
- Crosslink: data between spacecraft
  - E.g. NASA's TDRS satellites
- T&C includes these responsibilities:
  - Receive & decode commands
  - Create telemetry stream & send it
  - Manage frequencies (deal w/ FCC & Ground station)
  - Maintain link budget

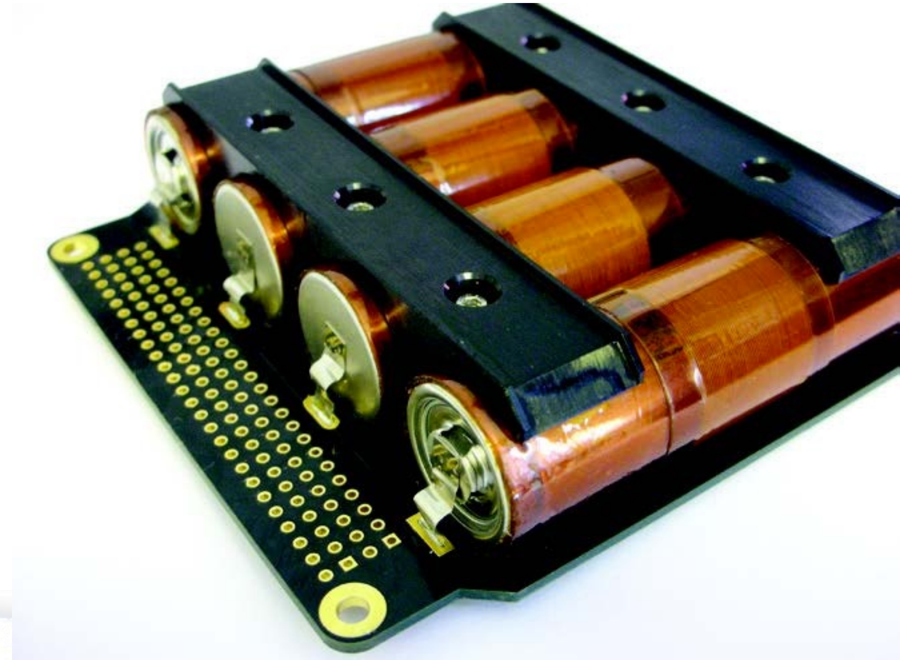
Telemetry & Command

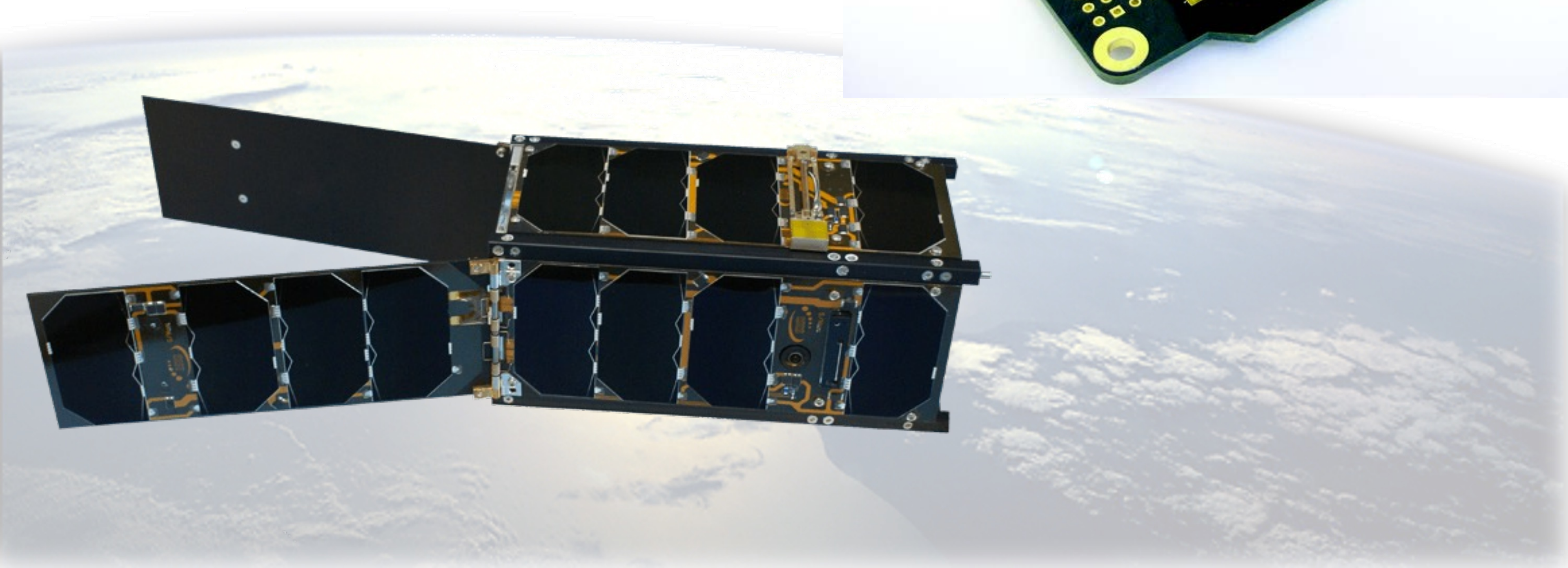


Power

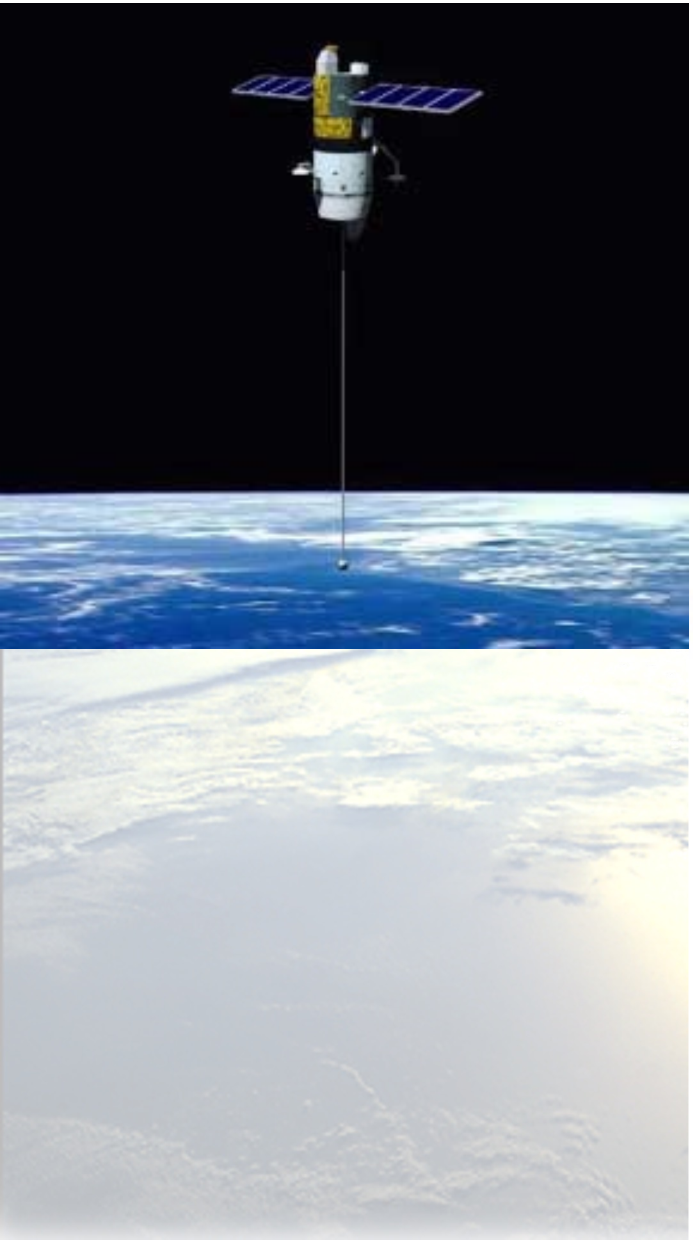
- Acquire, store, distribute, regulate
- Create a power budget
  - Worst case power per orbit -> size solar cells
  - Worst case storage -> size batteries
  - Worst case instantaneous power -> size electrical bus components

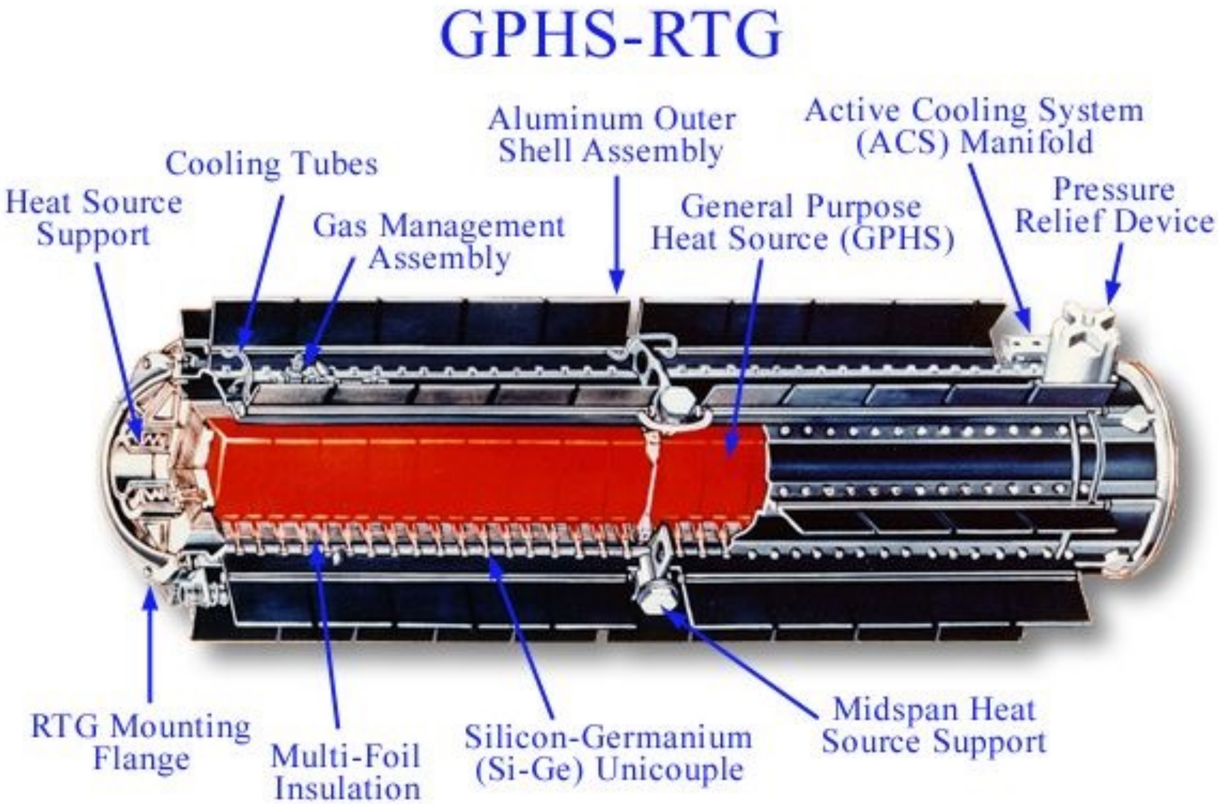
Power





Power



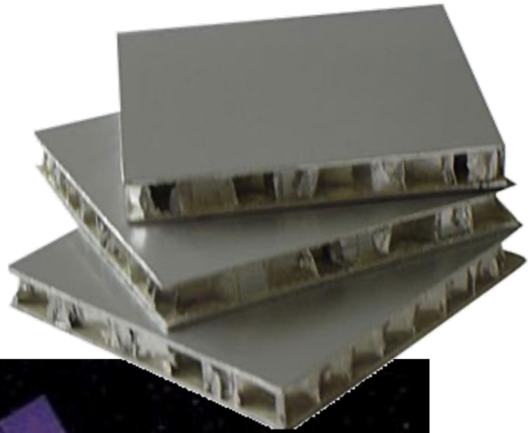

GPHS-RTG
Aluminum Outer Shell Assembly
Active Cooling System (ACS) Manifold
Cooling Tubes
Heat Source Support
Gas Management Assembly
General Purpose Heat Source (GPHS)
Pressure Relief Device
RTG Mounting Flange
Multi-Foil Insulation
Silicon-Germanium (Si-Ge) Unicouple
Midspan Heat Source Support

Structures

- The only reason we have structure is because of the launch vehicle
  - Huge static & dynamic loads (vibration)
  - Frequency-dependent behaviors (need a stiff enough spacecraft so no resonances appear)
  - Keep the components in the same place
- Once in orbit, the spacecraft barely experiences any loads. Spin, propulsion, attitude control, environmental disturbances are millions of times less powerful than launch.

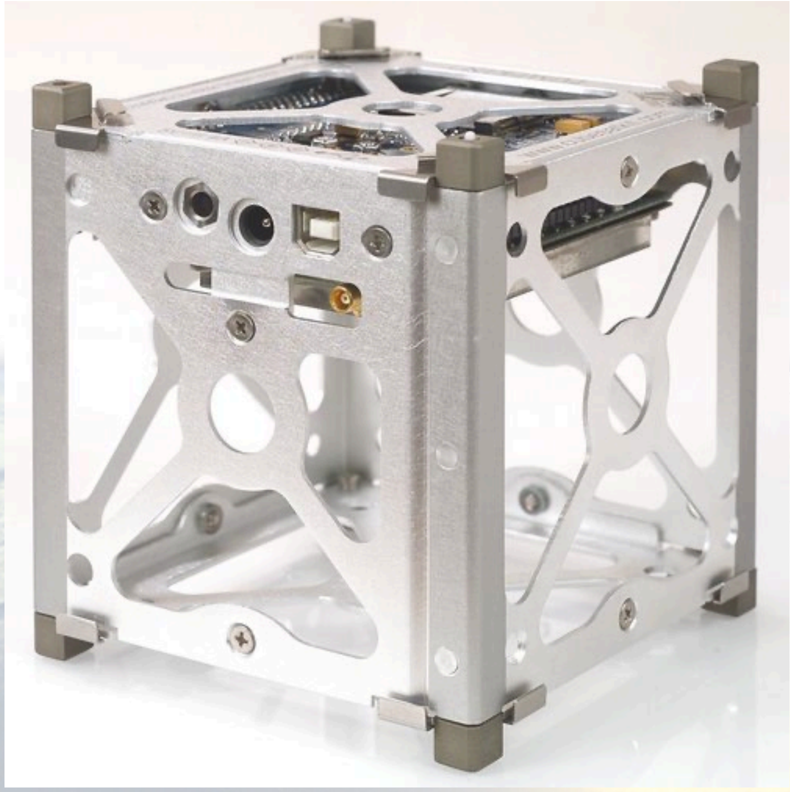
Structures

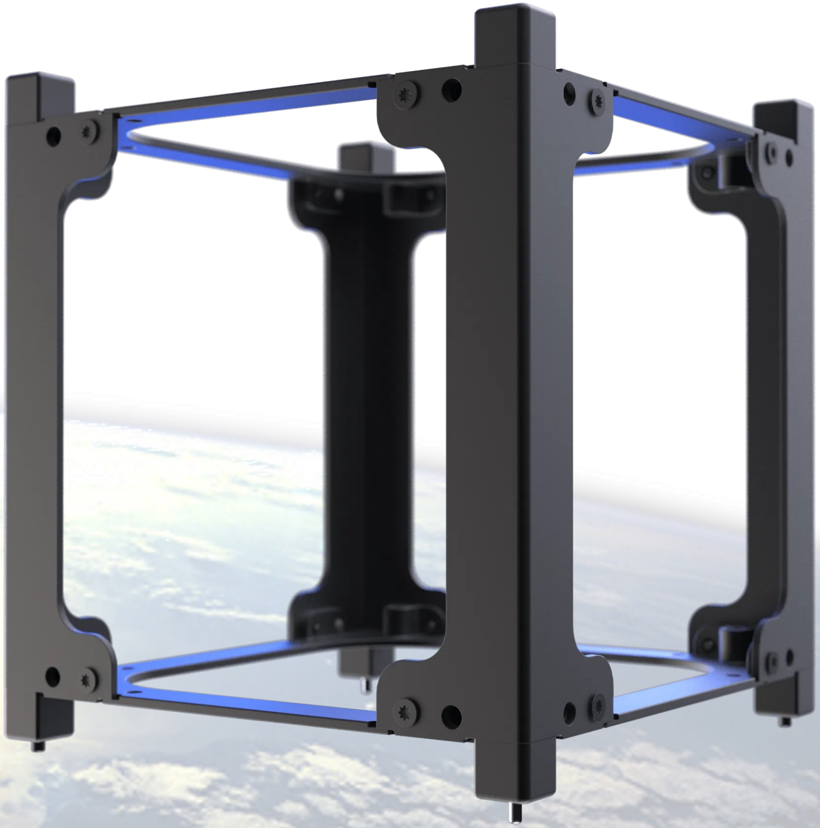
- Technologies
  - Most spacecraft are built of aluminum honeycomb panels with composite facesheets.
  - Design process:
    - What components?
    - What loads?
    - What's the *minimum* structure?
    - DON'T start with structure first



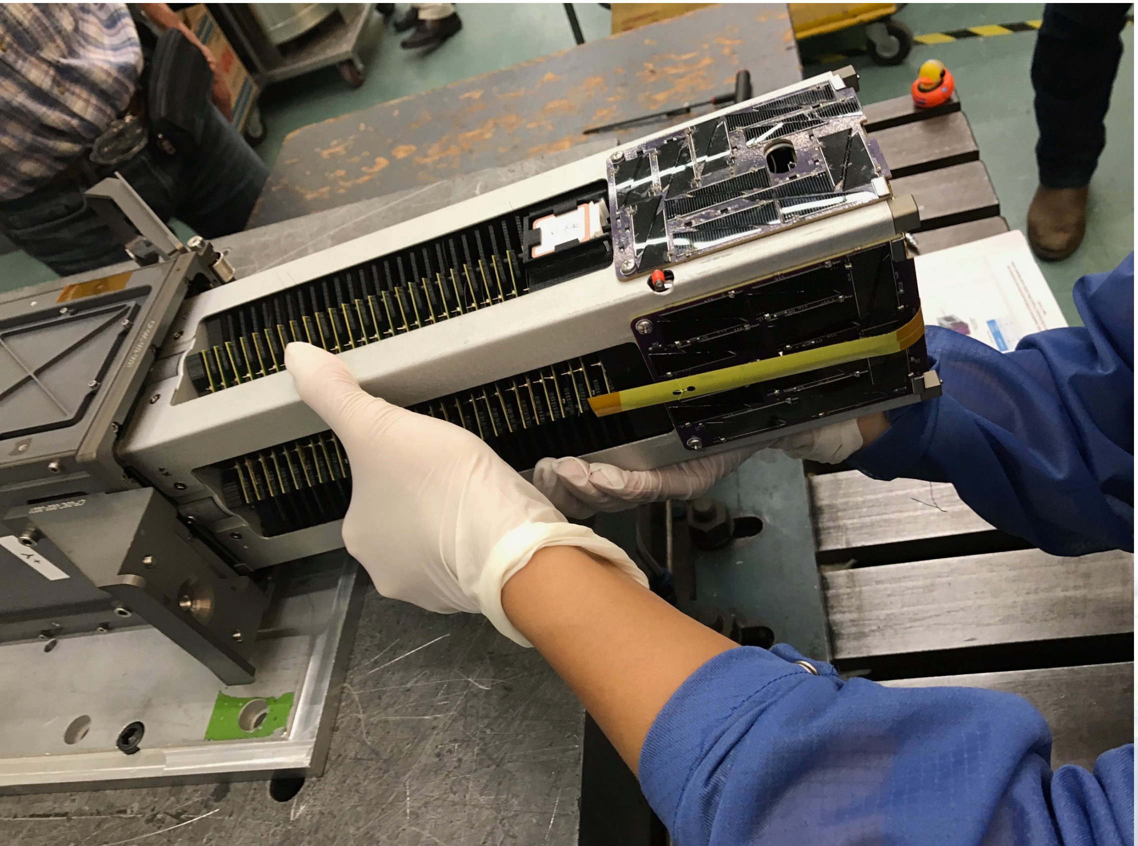
Structures

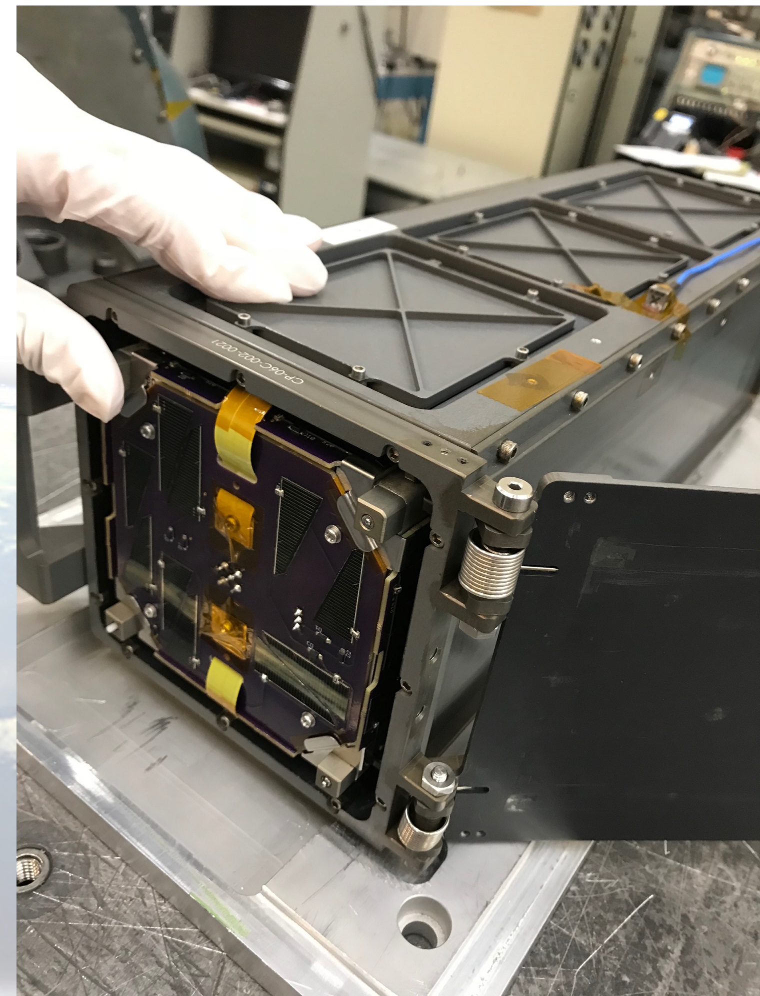
- CubeSat Structures





Structures





Structures

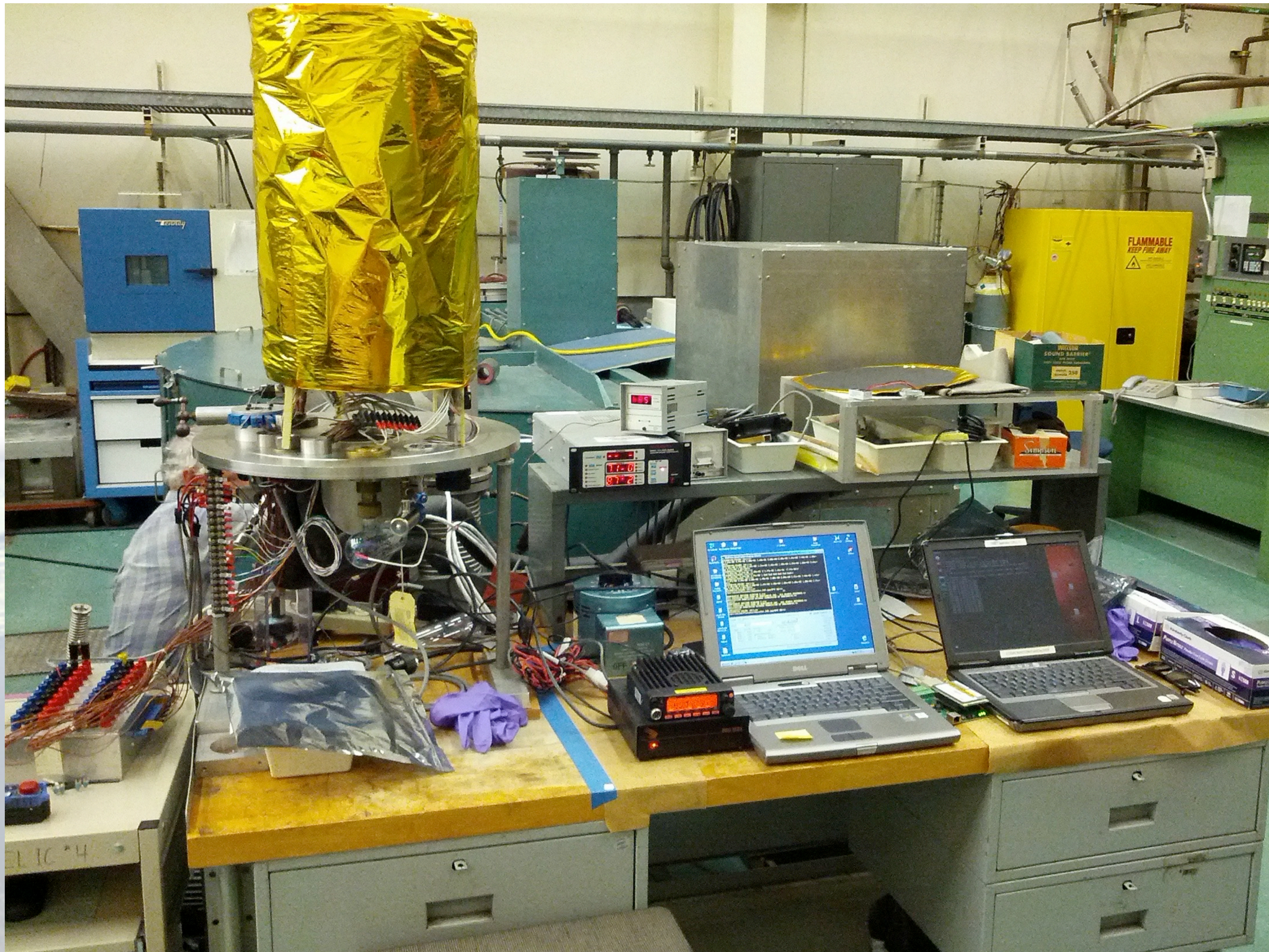
Survivability

- Although the thermal subsystem is a key one on spacecraft, we consider thermal to be a subset of a larger set of space-environmental issues:
  - Thermal
  - ESD
  - Radiation
  - Material behavior in space

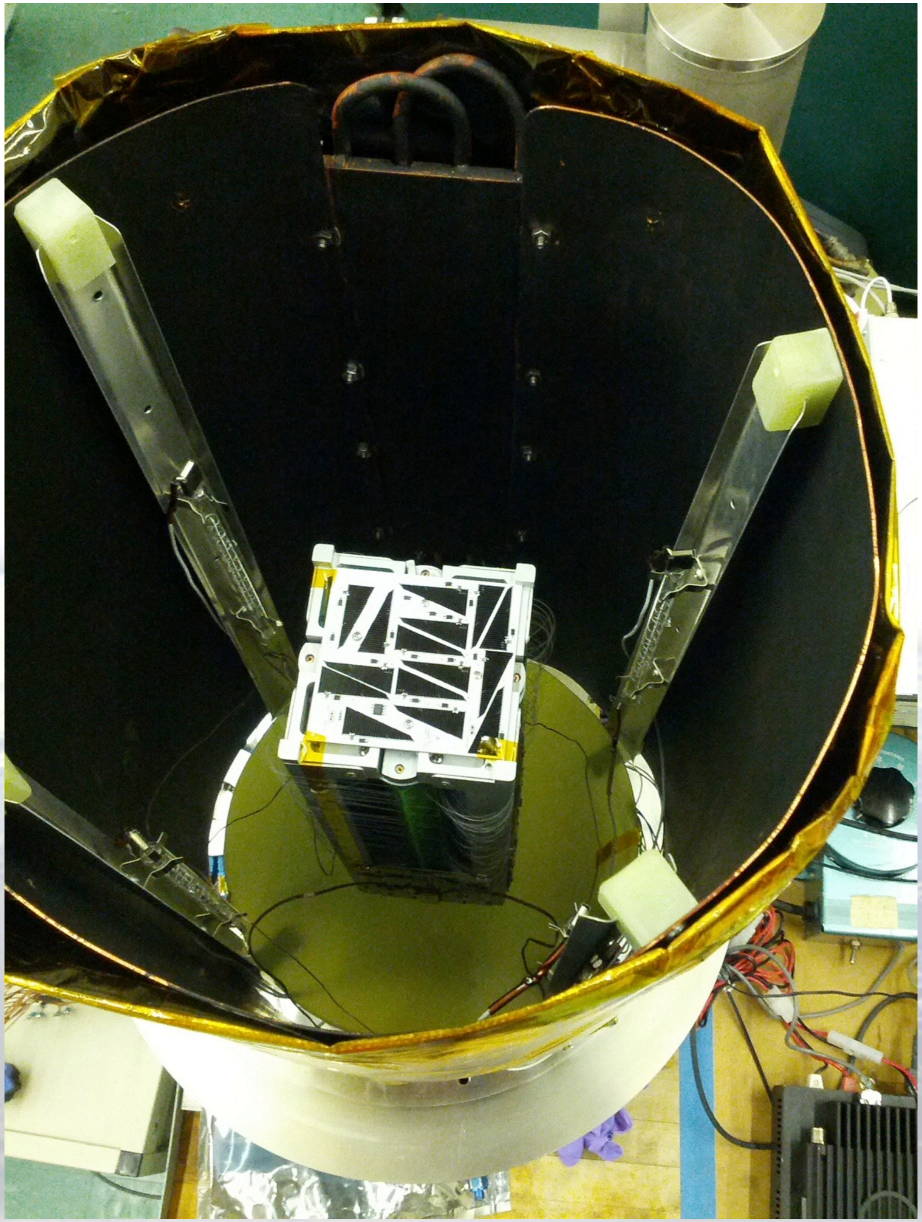
Thermal

- There is no air to help cool or insulate things: conductive & radiative heat-transfer only
- Typical solutions require heaters, radiators and mechanical conduction paths.
- Sometimes active thermal control is used:
  - Heat pipes (ammonia working fluid & convective pumping)
  - Cryocoolers, peltier devices, et al.
- Worst-case design is usually too conservative. Averaging temperatures is not conservative enough. You need a statistical view, and you need to understand the sequence of events (including attitude)

Thermal



Thermal



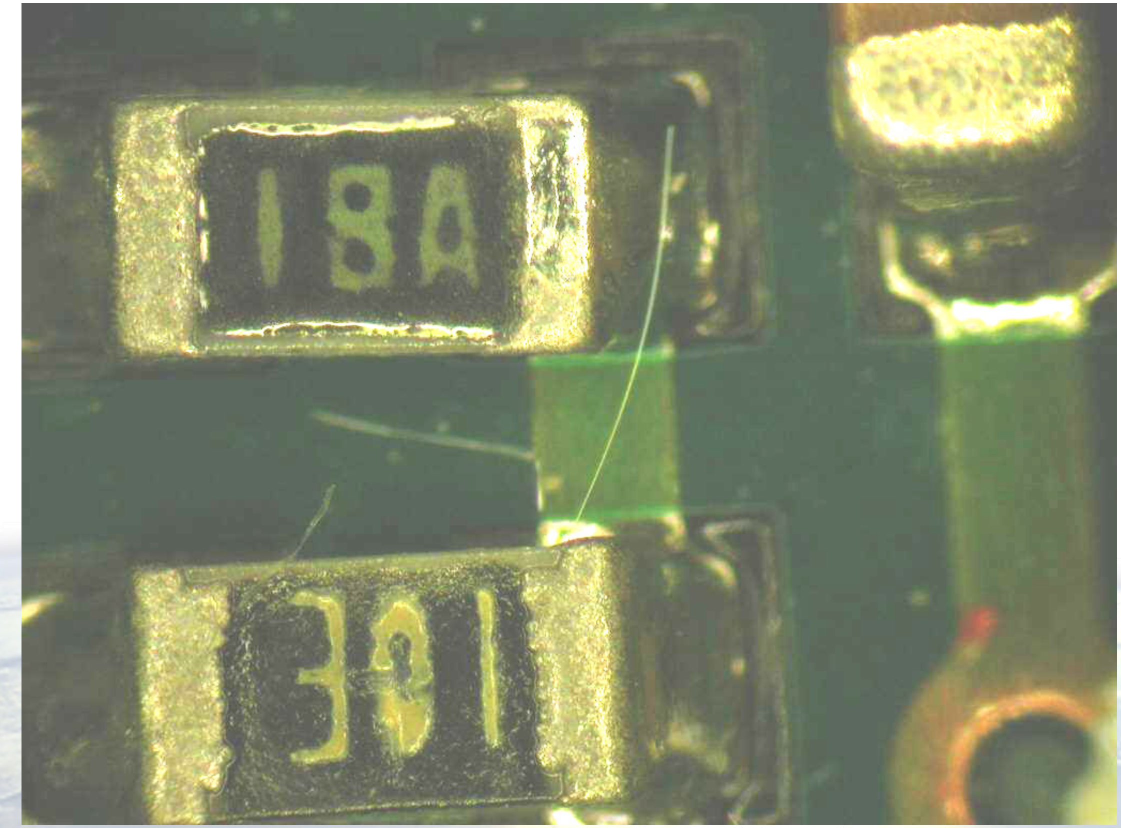
ESD

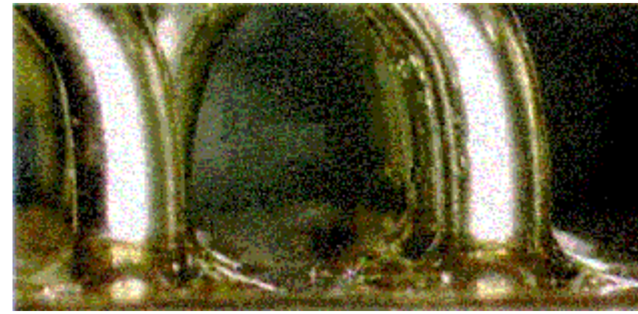
- Multiple charging effects on spacecraft
  - Photoelectric effect
    - Solar photons cause electrons to be ejected from metal surfaces
    - Leads to accumulation of positive charge on sun-exposed surfaces
  - Plasma
    - Fast moving electrons lead to accumulation of negative charge
  - 10s of kilovolts can be reached!
  - Arcing between different parts of the spacecraft can destroy components

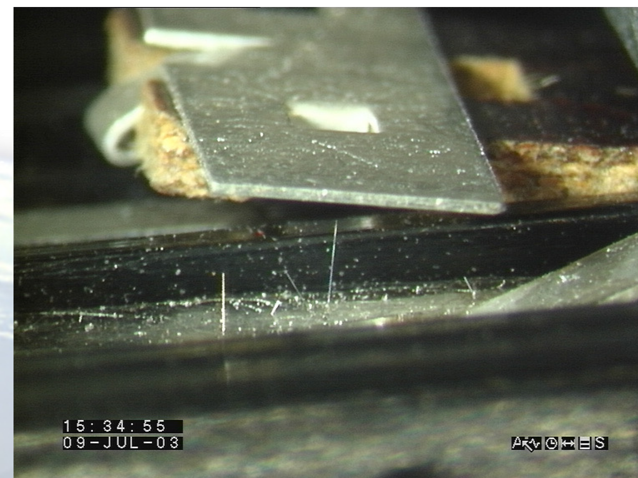
Radiation

- High radiation environment from Earth's (and some other planet's) magnetic fields
- Two different issues
  - Single event upsets (SEUs)
  - Total Ionizing Dose
- Electronics must be "hardened" to withstand radiation
  - Watchdog circuits
  - Voting circuits
  - Special semiconductors

Tin Whiskers



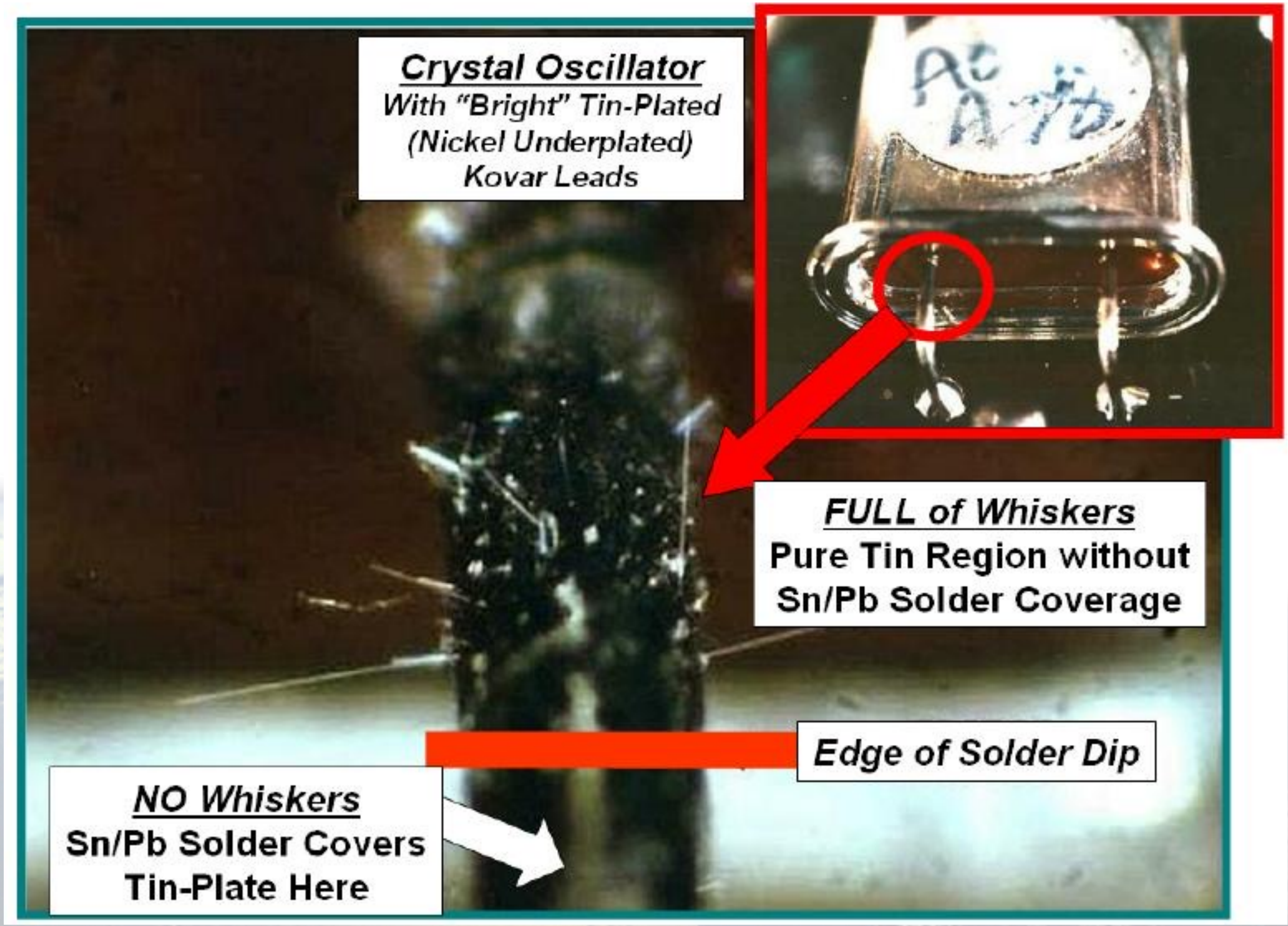




Whiskers Dislodged from RF Enclosure

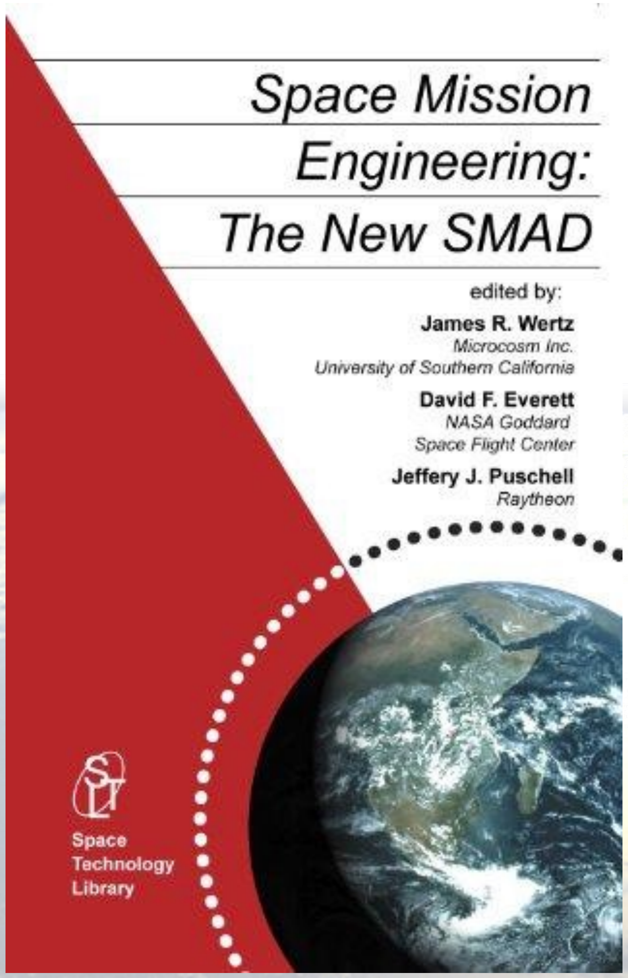
http://nepp.nasa.gov/WHISKER/

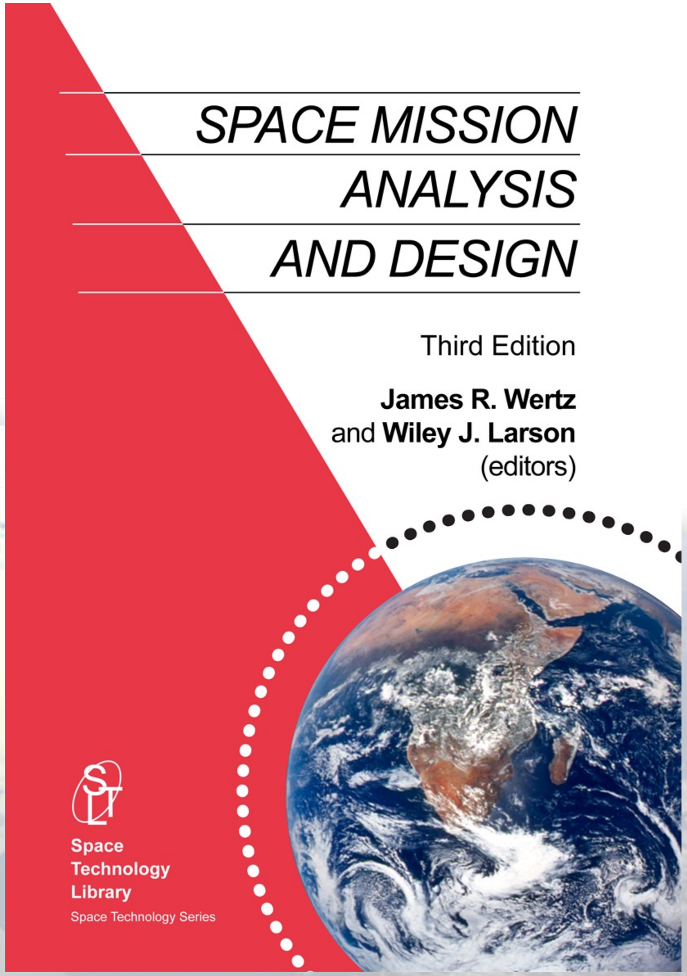
Tin Whiskers



Suggested Reading

- SMAD and SME CH. 14





Budgets

- Mass budget (mechanical)
- Power budget (avionics)
- Link and data budgets (comms)
- Pointing error budget (GNC + vision)
- Navigation error budget (GNC + vision)