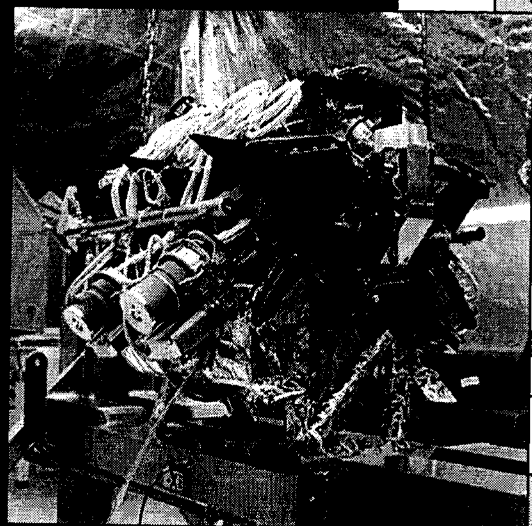
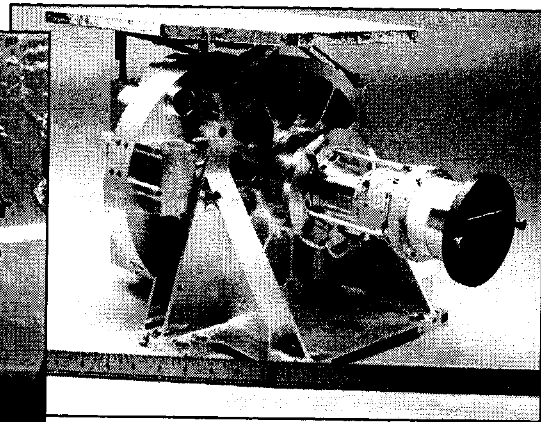

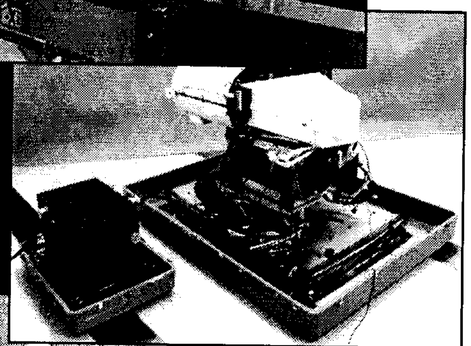
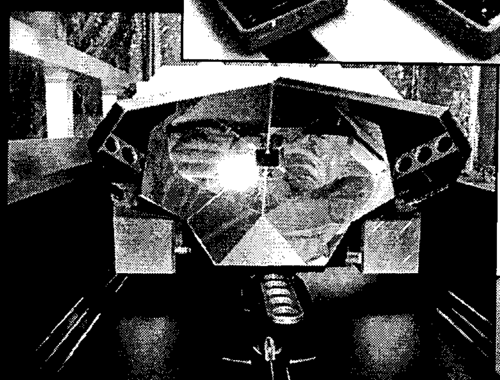
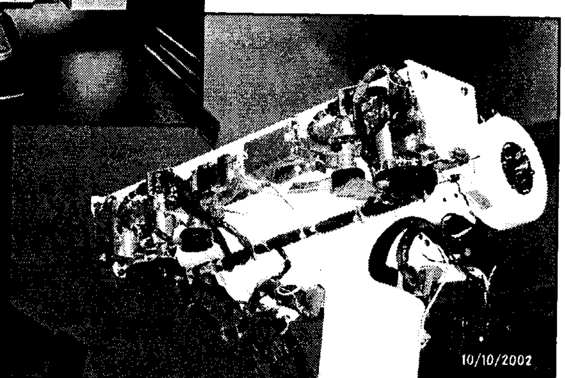


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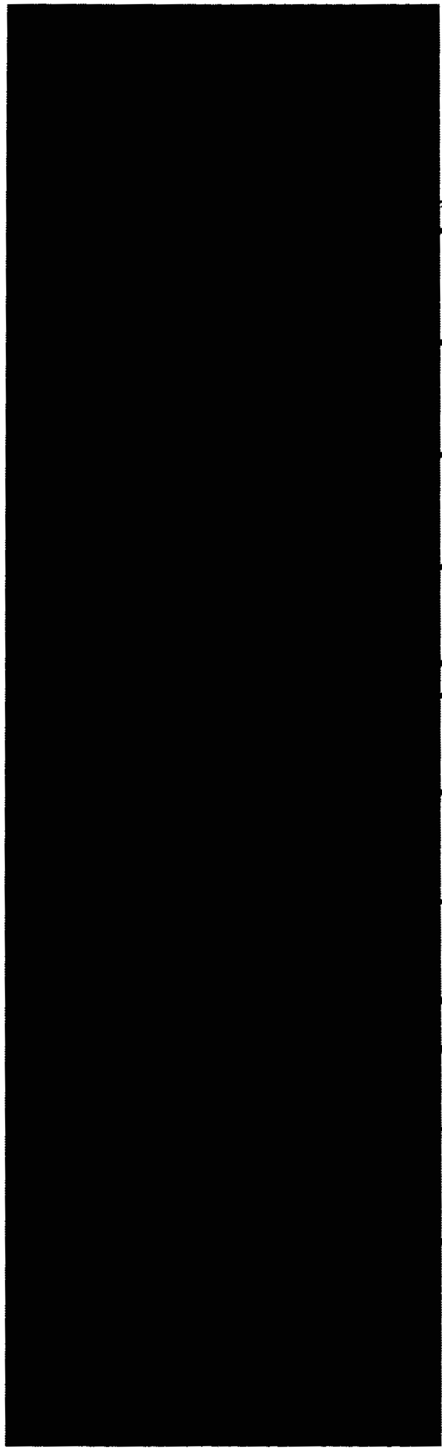
In Situ Technology & Experiment Systems

# Topics

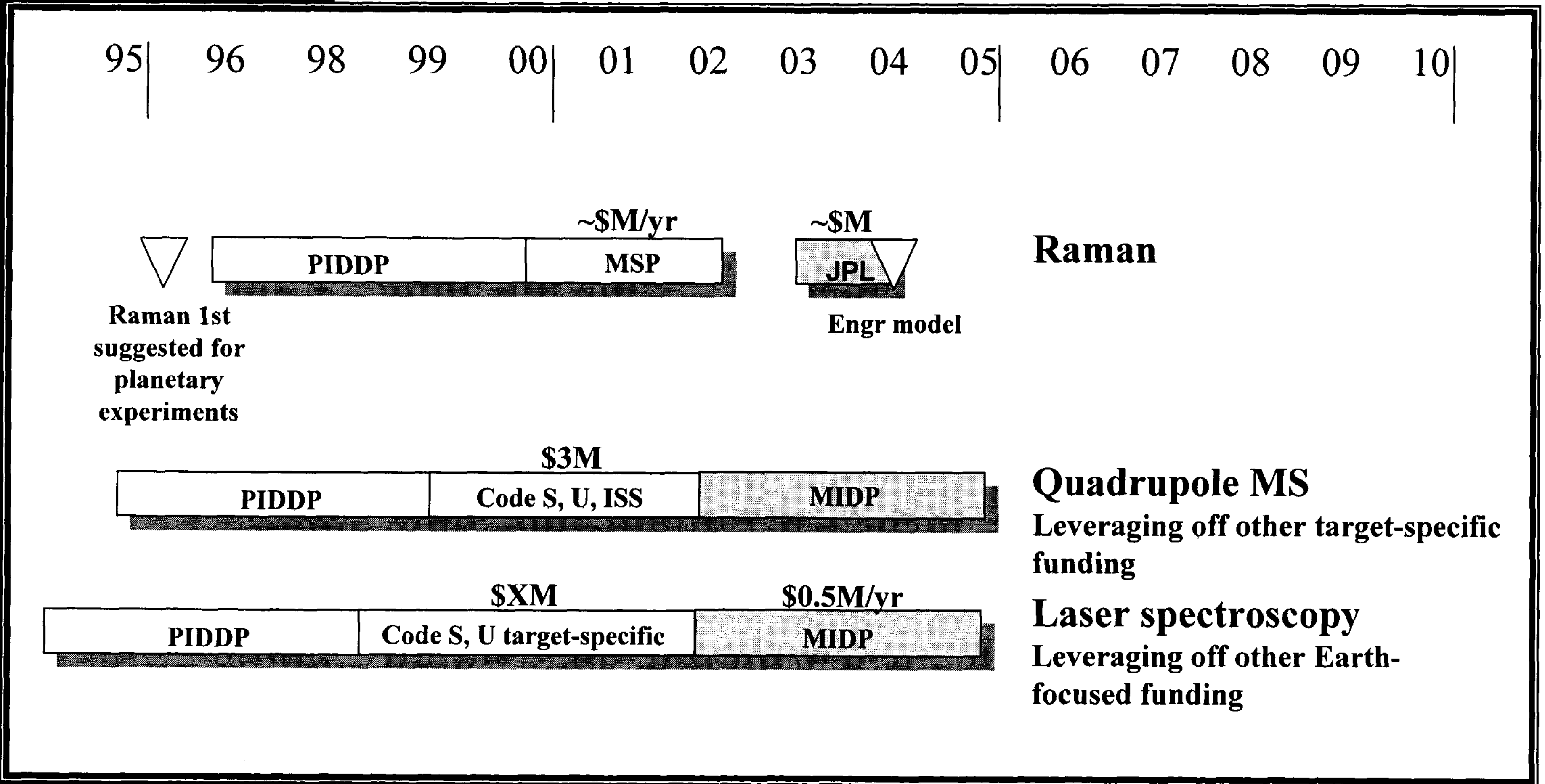
- **Example timelines for instrument development**
- **What you should do now rather than later**
  - Bounding the scope
    - Functionality
    - Accommodations
    - Environments
  - Architecture and design issues
- **Development roadmap for an instrument**



# NASA's Technology Readiness Levels

- **TRL 9** Flight system proven
- **TRL 8** Flight system qualified
- **TRL 7** Prototype demonstrated in space environment
- **TRL 6** Prototype demonstrated in relevant environment
- **TRL 5** Component/breadboard validated in relevant environment
- **TRL 4** Component/breadboard validated in laboratory
- **TRL 3** Critical function demonstrated (proof of concept)
- **TRL 2** Technology concept formulated
- **TRL 1** Basic principles observed

# Development Timeline Examples



# Functionality

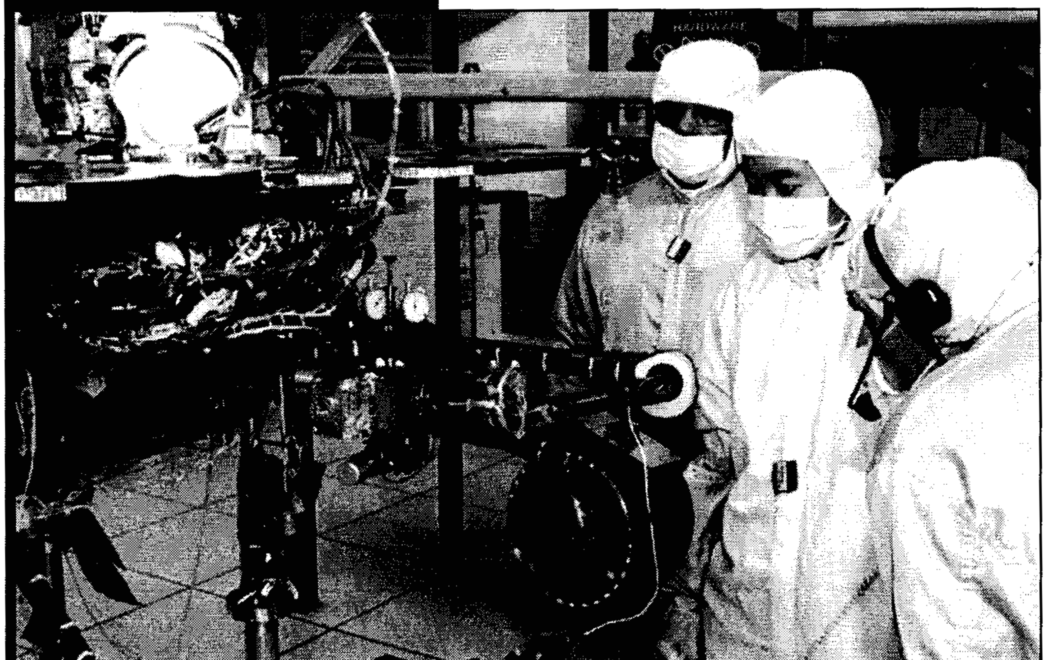
- **Map science objectives into system performance requirements**
  - Flush out issues related to meeting science needs
  - Solidify the goals of instrument performance
  - Will point to requirements on mission and host vehicle
- **Define expected science scenarios**
  - How will the instrument be used in meeting the science objectives
  - Look at the micro- and macro-scale operation from short-term sampling sequences through data acquisition strategies over the mission duration
  - Will further help define what the instrument and the host vehicle needs to do

# Accommodations

- **The instrument draws on valuable host vehicle resources**
- **Practical considerations need to drive the instrument development for it to successfully compete for a ride**
  - 1.5–6 kg/instrument average on Mars Polar Lander
  - 5–28 ave Watts/instrument on Mars Polar Lander
  - Science payoad on MSL ~35 kg, MER ~5 kg, MPF ~
- **You will need interfaces consistent with the host vehicle, especially if you expect to be able to demonstrate your instrument on prototype vehicles**
  - Look at past PIPs for examples
- **Many future missions have been scoped in terms of payload mass, volume, power. Research these to get a feel of severity of the constraint envelope**

# Strive to be vehicle friendly...

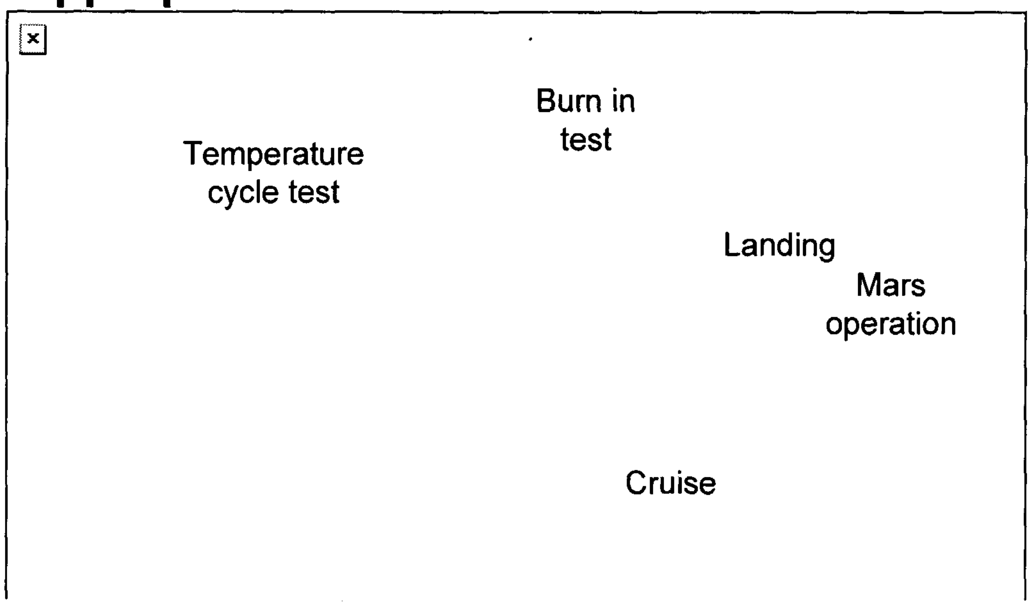
- **Wash U / JPL Raman missed its ride in part because it was not sufficiently rover friendly**
  - Required critical placement against rock
  - Delicate optical fibers connecting head and spectrometer
  - These interface issues placed unacceptable requirements on rover placement and the arm mechanism



- **Subsequently, the team has redesigned several components**
  - Effective depth of sampling now much greater, relieving placement constraints
  - Incorporated innovative jacketed fiber technology, providing needed robustness and tolerance for arm motion for storage and sampling

# Environment

- **Consider all environments**
  - All phases of the mission
  - Ground-based demonstrations
  - Development testing
- **Temperature extremes—from transport to the launch vehicle to variations on the planet surface**
- **Radiation, pressure, humidity, wind, dust, UV, planetary protection**
- **Doing this now will help you end up with a risk-retired and appropriate instrument**



# Things you should worry about sooner than later—

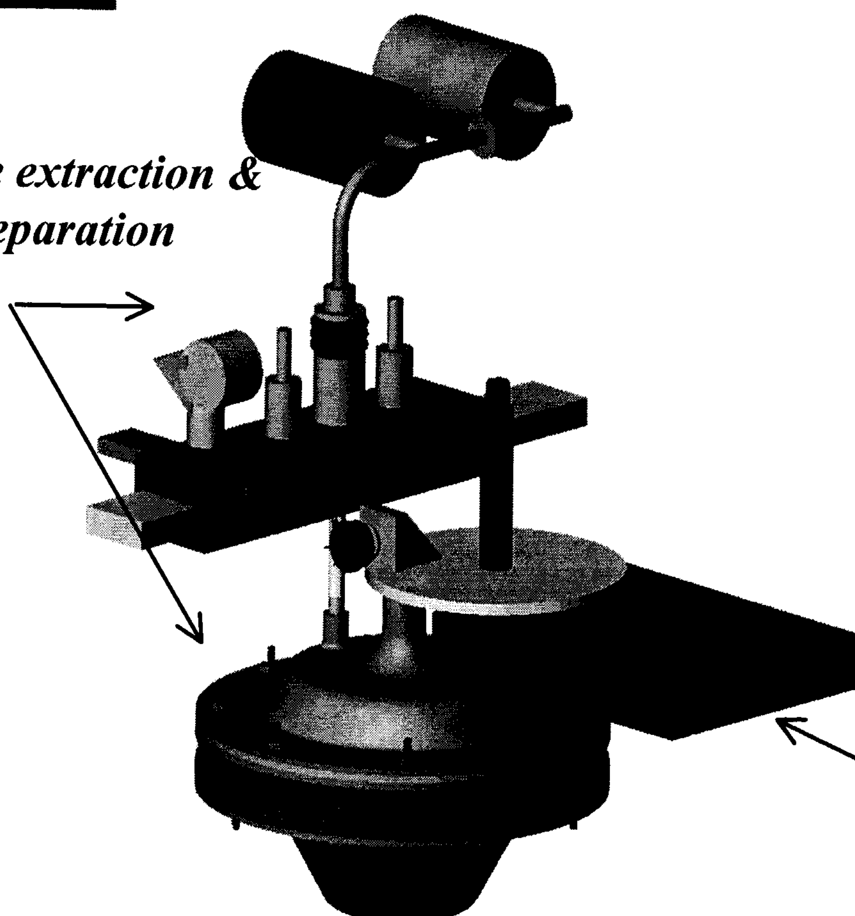
- **Relates mostly to a flight instrument, but early consideration can acceleration your development schedule considerably**
  - **Instrument architecture**
  - Margins
  - **Mechanical design**
  - **Thermal design**
  - **Electronics design, parts, and packaging**
  - Software
  - Optical design
  - **Reliability & Product assurance**
  - **Planetary protection & contamination control**
  - Ground support equipment
  - **Science calibration & performance validation**

# Instrument Architecture

- **Produce a functional block diagram of the instrument**
  - ↗ Look at different ways to implement, considering the pros and cons of each
  - ↗ Develop a measure error budget caused by the design limitations and operational environment
  - ↗ Examine each possible implementation to see if it offers any advantages in terms of redundancy or partial success in the event of a failure
  - ↗ Compare mass, power, performance, reliability, and cost—then select the instrument architecture

# Instrument Architecture

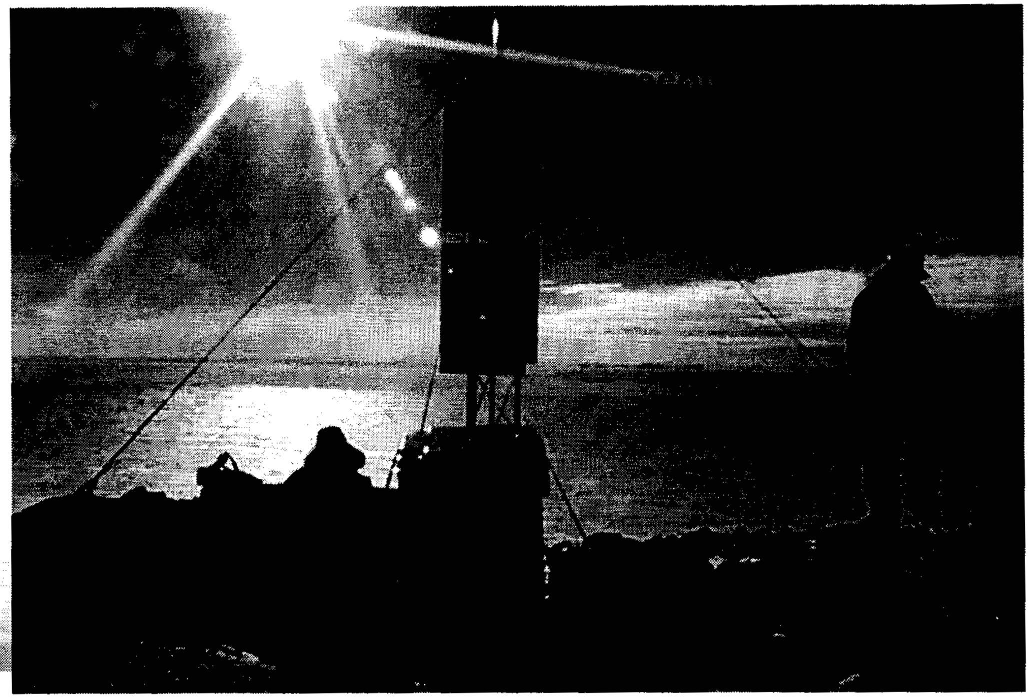
- **Don't leave sample handling and preparation for the end!**

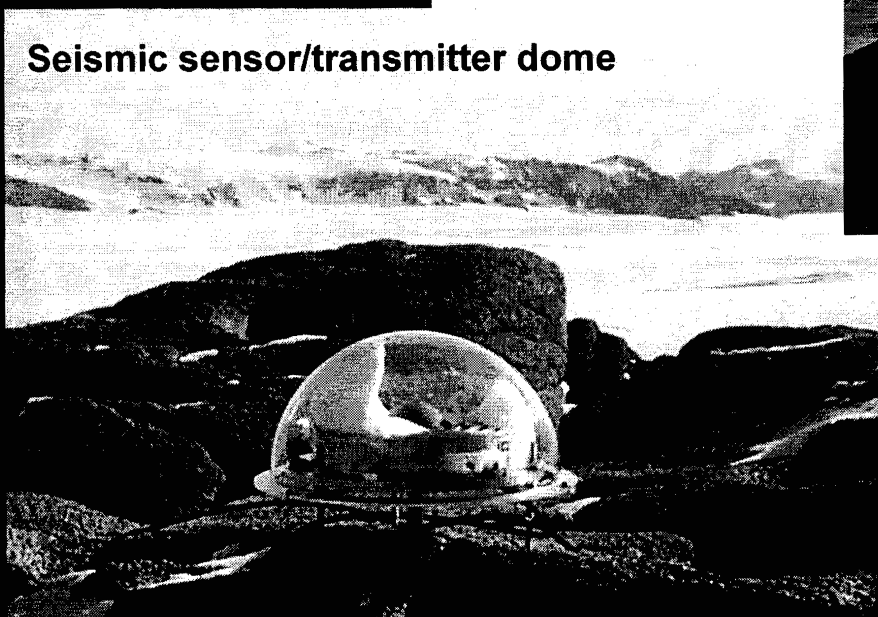



**UC San Diego**
**UC Berkeley**
**JPL**

# Thermal Design

- **Thermal control—scheme to manage the energy flow to achieve a desirable thermal state**
- **Determine all possible external & internal environments**
  - Temperature: extreme high/low, diurnal variations
  - Atmosphere: high/low pressures, vacuum, opacity
  - Solar flux intensity/variation, incident angle, duration
  - Wind speeds/direction, dust storms, humidity
  - Additional external s/c, orbiter, lander structures for thermal radiation interaction
  - Thermal dissipation of electronics & other devices as f(t)
  - Physical configuration of s/c and orientation
- **Can instrument be kept within allowable flight operating and non-operating temperatures?**
  - Passive control—isolation or enhancement of radiative & conductive/conventive surfaces (insulation, surfaces with special IR emissivity/solar absorptivity, standoffs, baffles)
  - Active control—the addition or removal of heat (heaters or pumped fluid system





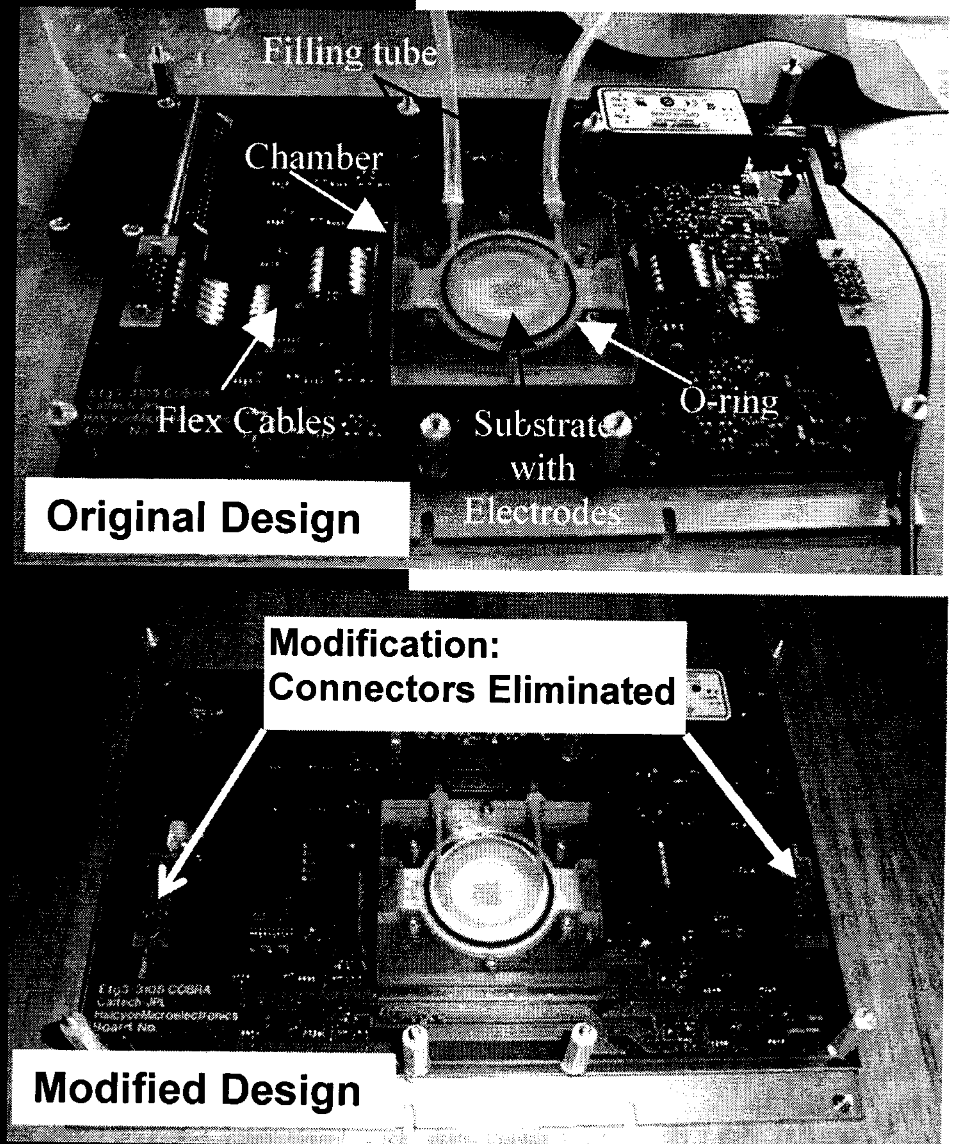

- **Ambient Temperatures Similar in Extremes and Diurnal Variation**
- **Wind Conditions Similar in Unpredictable Wild Changes**
- **Solar Conditions Could Be Low on the Horizon**

- **Similarities in thermal design for equipment assembly**
  - Insulation enclosure to minimize overall heat losses
  - Thermal coupling of equipment components to maximize thermal inertia

# Electronics Design, Parts, Packaging

- **Part selection**
  - Breadboard—demonstrate functionality of design; commercial parts OK
  - Brassboard (engineering model for flight)—"form, fit and functionally equivalent"
    - All interfaces (mechanical, structural, thermal, electrical) flight-like and resource targets met
  - Flight model—all parts must meet the environmental and reliability requirements (with margins) specified for the mission
    - Includes temperature, total dose ionizing radiation, single-event effects
    - Example: parts rated to 20 Krads must be used for a mission expecting 10 Krads exposure with a rad design margin of 2
  - Most COTS devices have unknown reliability—screening & qualification evaluation will have to be done
  - Do a part list review when you transition from bread to brassboard

# Part Availability Issue

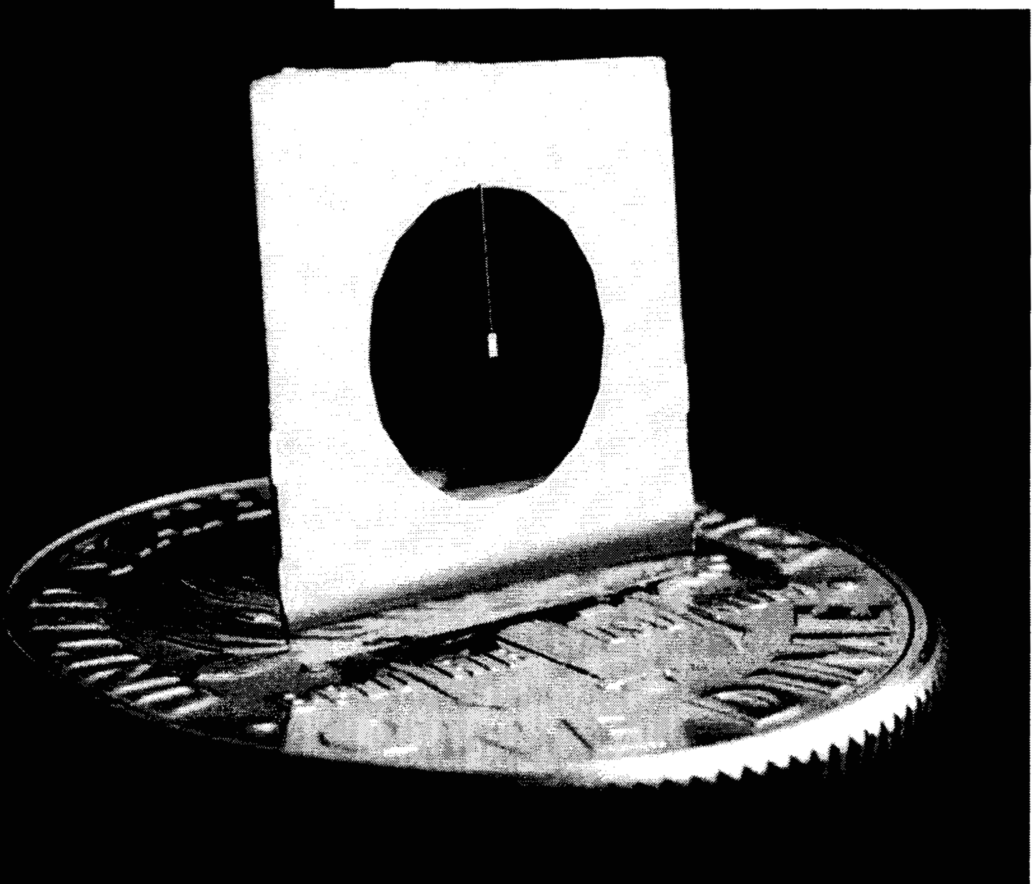


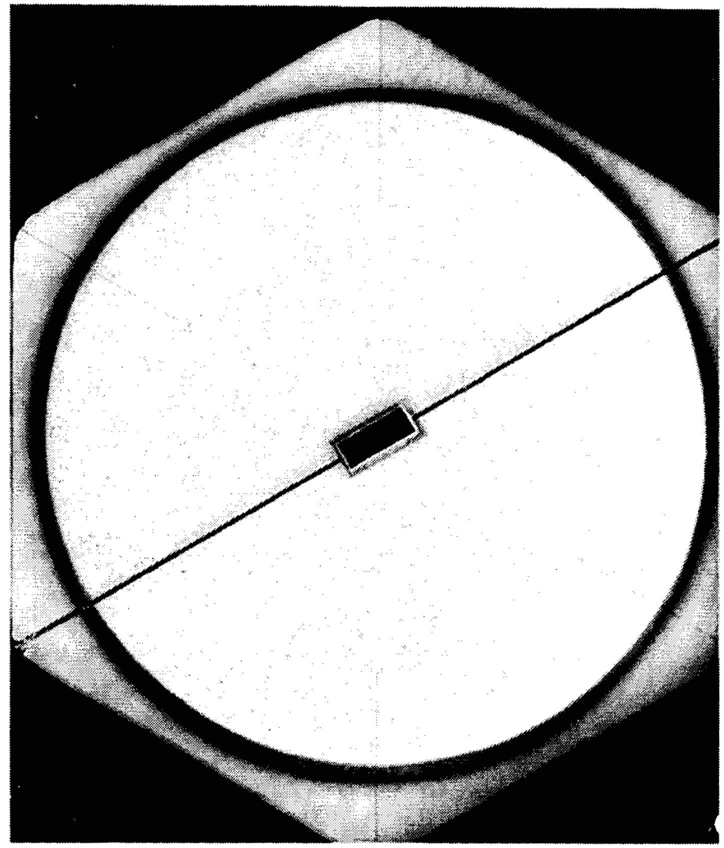

Electronic tongue

- **Design Principle:**
  - Designer must identify part availability issues
  - Gather all parts before beginning design
- **Example: Electronic tongue**
  - Connectors assumed available
  - Part supplier wanted $6,000 to manufacture 3000 parts with 12 month delivery
  - Solution: Redesign to utilize available connectors

# Advanced Electronic Packaging

- Advanced packaging can improve performance and save resources





- Lack of significant space track record means higher risk—money & time is needed

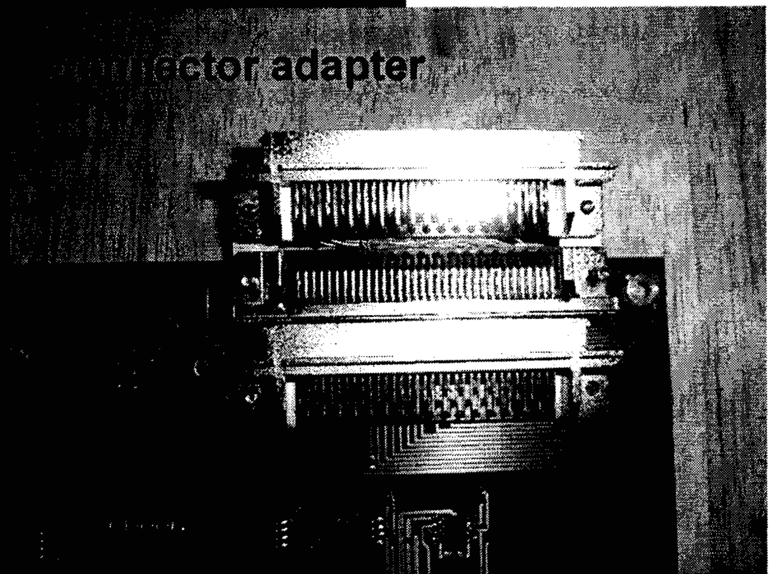
# Mechanical Design

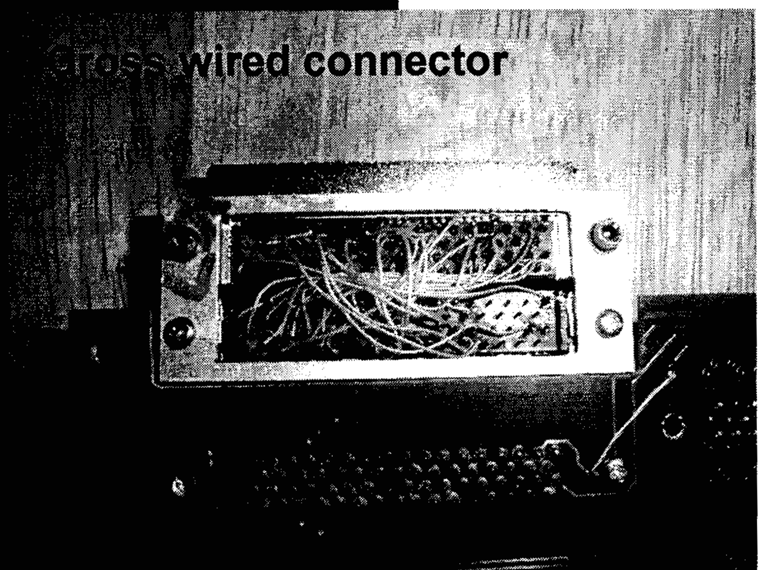
- **Reducing a workbench-sized breadboard to fit within the constraints of a flight instrument requires materials, packaging, and fabrication techniques to be traded off to optimize mass, volume, strength and cost**
  - Configuration is the key—establish the "big picture" layout with CAD before you dive into details (will change as the instrument matures or requirements change)
- **Think about the flight load—**
  - maximum structural loading your instrument may see during all expected conditions including launch, cruise, landing, ground handling, and thermal environment
- **Al alloys are common for brassboards**
  - As you approach flight-like, Al, various steels, Ti, and composite laminates (to mention only a few) will likely be needed for strength, weight, and functionality.
- **Outgassing, CTE mismatch, embrittlement at cold temperatures, galling… should have your attention**

# Tips from the ME's

- **Mechanisms design (pointing systems, deployment systems, pyro devices, covers, latches, booms, etc.)—require a broad range of engineering disciplines and tools**
  - Use kinematic designs where ever possible
  - The vast number of mechanisms employed in flight systems have resulted in comprehensive references
- **Use a single fabrication shop—experience has shown that there is a consistent savings in cost of 25 to 100% when fabricating new mechanism systems**
- **Precision parts machined at one vendor at 25°C and another at 22°C can make a difference in tolerance stack-up**
- **Practices that ensure high reliability**
  - Simplicity of design
  - Avoid cost-saving measures that are likely to lower reliability
  - Use designs that compensate for potential human errors
  - Use parts & materials with proven heritage
  - Tight controls on the manufacturing process
  - Design to accommodate the effects of transportation, handling, & storage

# Fit Check Issue




- **Design Principle**
  - Designer must reduce “lack of fit” issues.
  - Recommendation: Gather all parts and perform fit check using the CAD drawings.

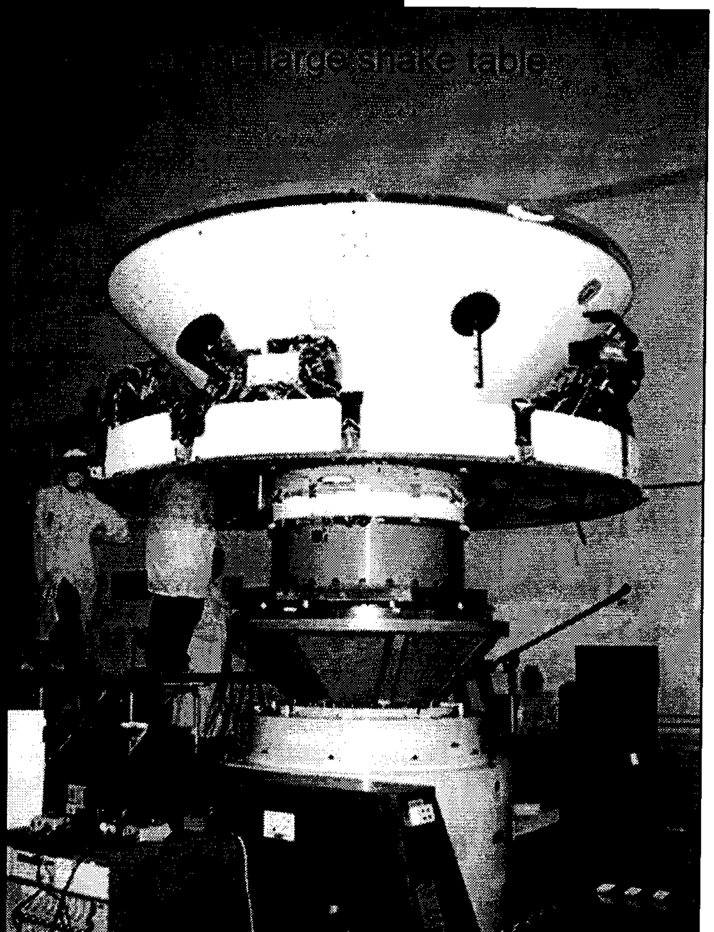
- **Example**
  - Connector wired backward.
  - Solution: Fabricate an connector adapter and cross wire.
  - Redesign electronics board to correct the problem.

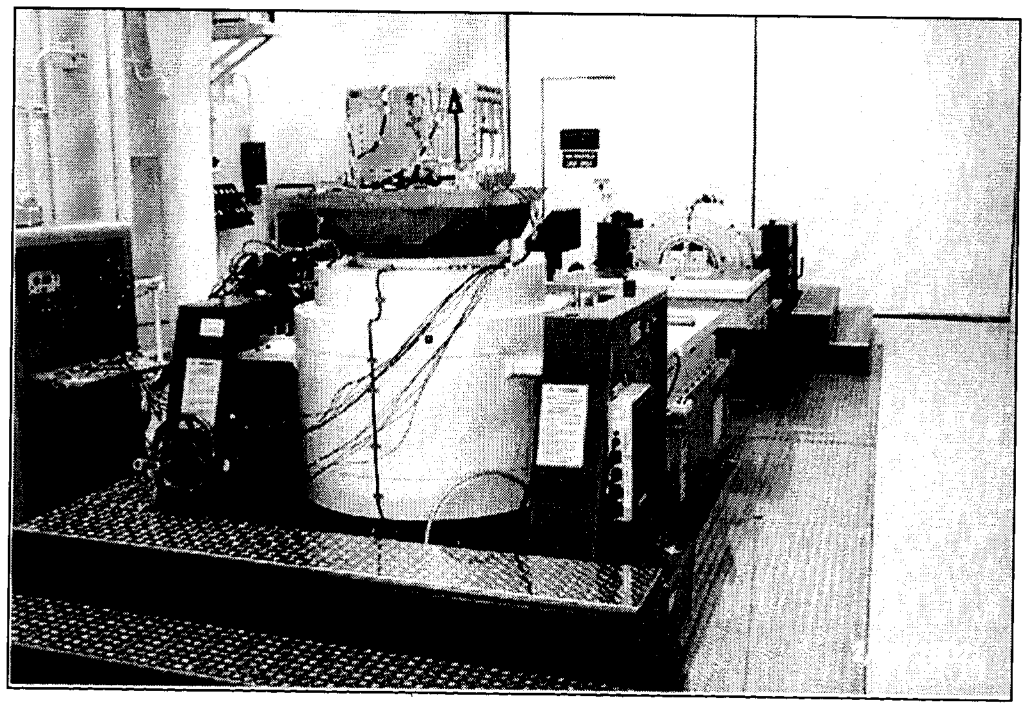
# Reliability Assurance Engineering

- **Environmental requirements and testing**
  - Ground, transportation, launch, cruise, orbit, entry, descent, and landing environments
- **Reliability analysis**
  - Various analysis techniques to validate functionality under flight conditions: failure scenarios, extreme operating conditions, etc.
- **Quality assurance**
  - Assure delivery of all project requirements
  - Ensure deliverables are developed according to a quality process
- **Problem/failure reporting**
  - Controlled, closed-loop system for identification, reporting, analysis, corrective action, and retest
- **Safety**
  - Personnel and equipment safety is as important as project achievement & risk tolerance

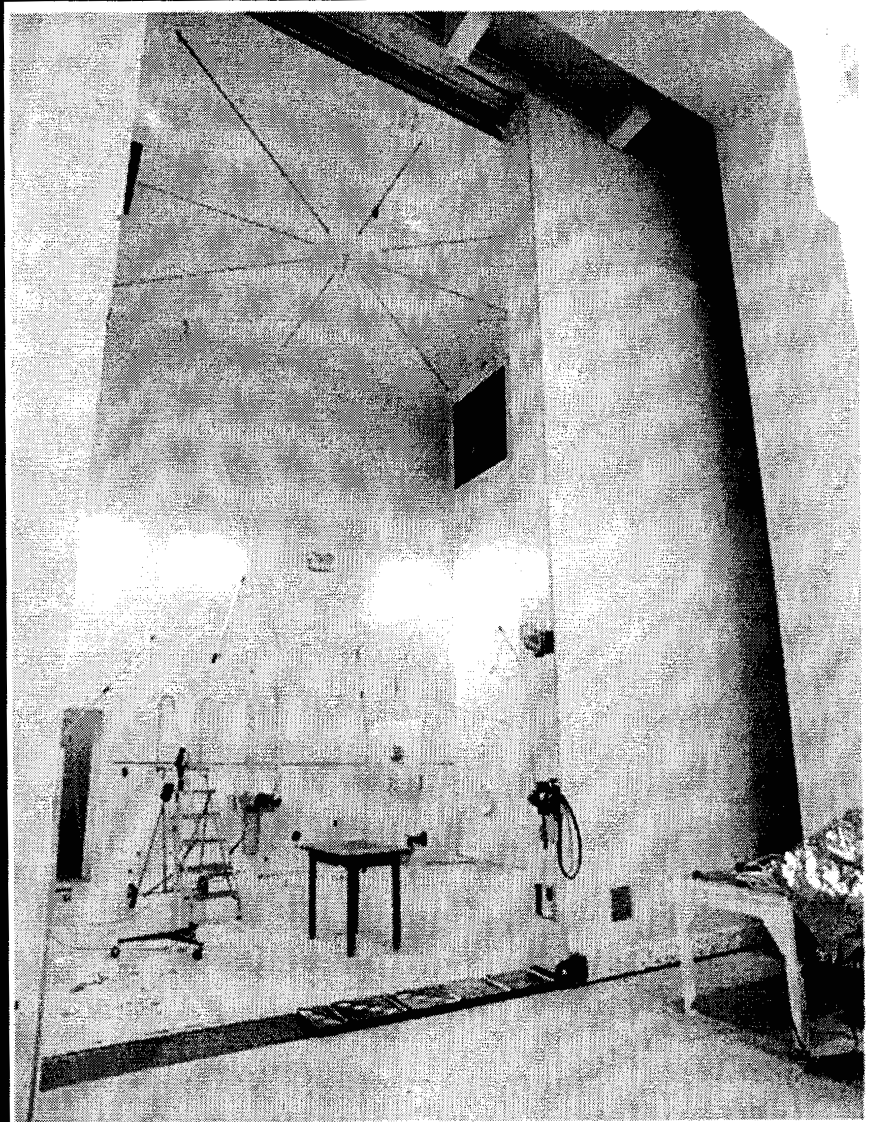
# Environmental Test: Launch Vibration

- **Dynamic environment driven by launch vehicle and s/c & instrument configuration**
- **Vibration, acoustics, and shock**
  - JPL has 4 vibration exciters, 10,000 to 58,000 force pounds and displacement of 1.5-inch double amplitude
  - Pyroshock up to 2,000 gs





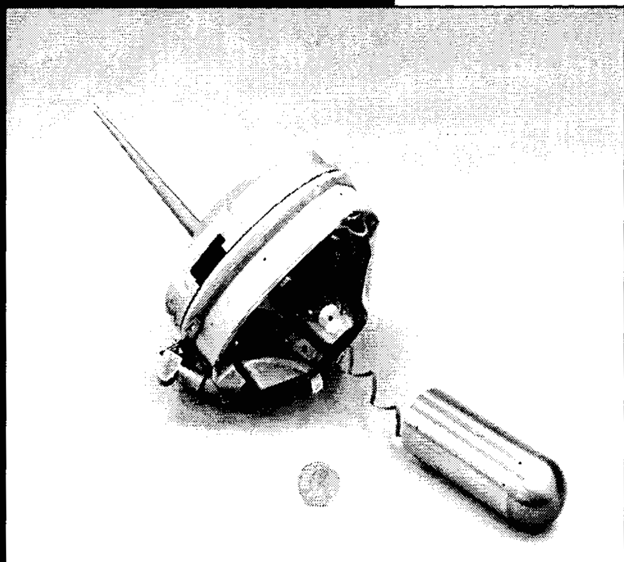
# Environmental Test:  Acoustic



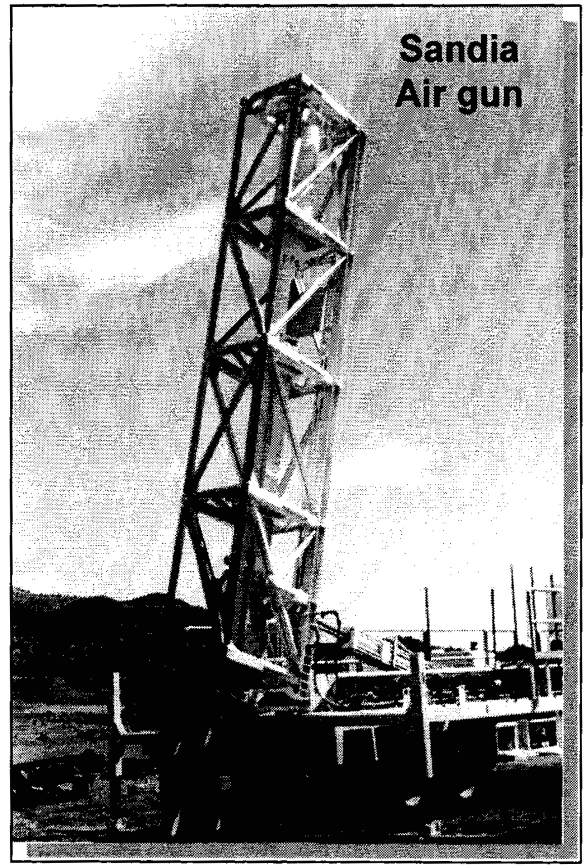
Acoustic Reverberation Chamber

- **Simulates noise generated at liftoff**
- **Acoustic noise chamber**
  - 10,900-cubic-foot reverberation chamber capable of 155 dB
  - 22 feet wide, 18 feet deep, 26 feet high
- **Large, Class 10K clean room**

# Impact Extremes—DS2

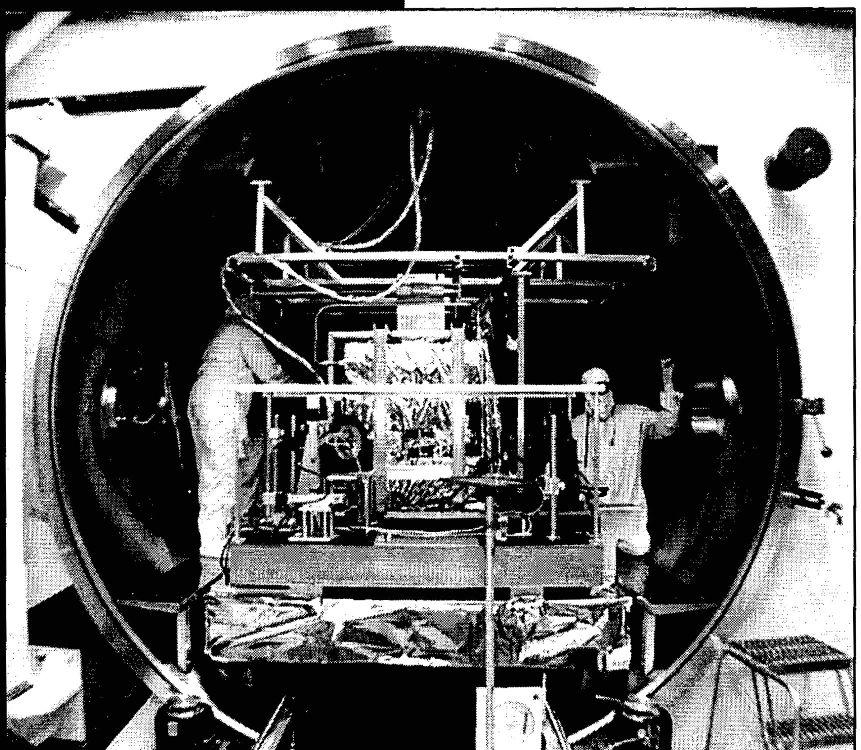


- SiC backbone, electronics with microcontroller, power electronics, instrument electronics, motor, drill
- Science TDL, temperature sensor, accelerometer




- **30,000 (fore) to 60,000 (aft) Gs deceleration at impact**

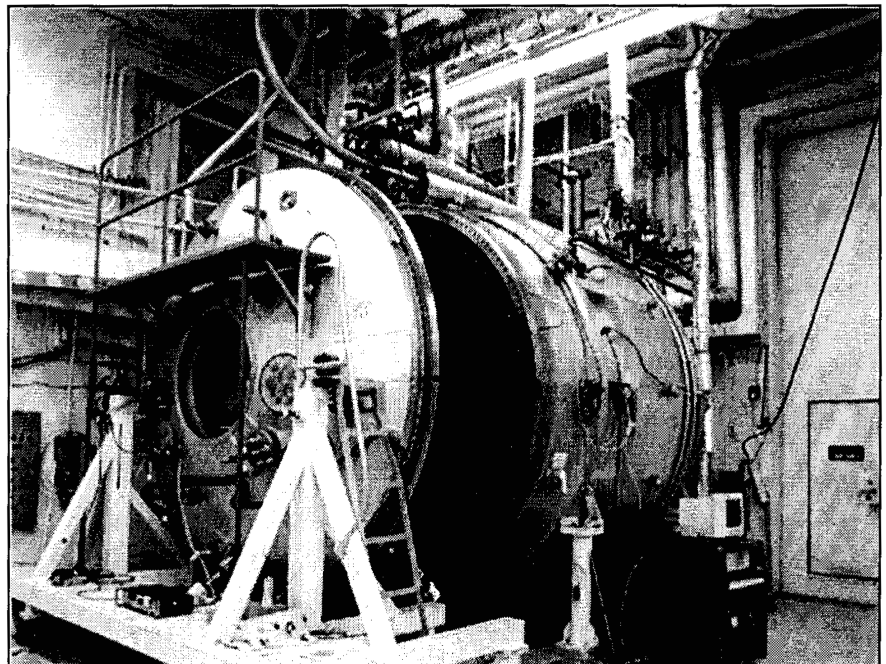
# Environmental Test: Thermal-Vacuum



11-ft thermal-vacuum chamber

- Important to include transient analysis from one extreme to another (cycle)
- DS2 forebody tested from +20˚C to -120˚C

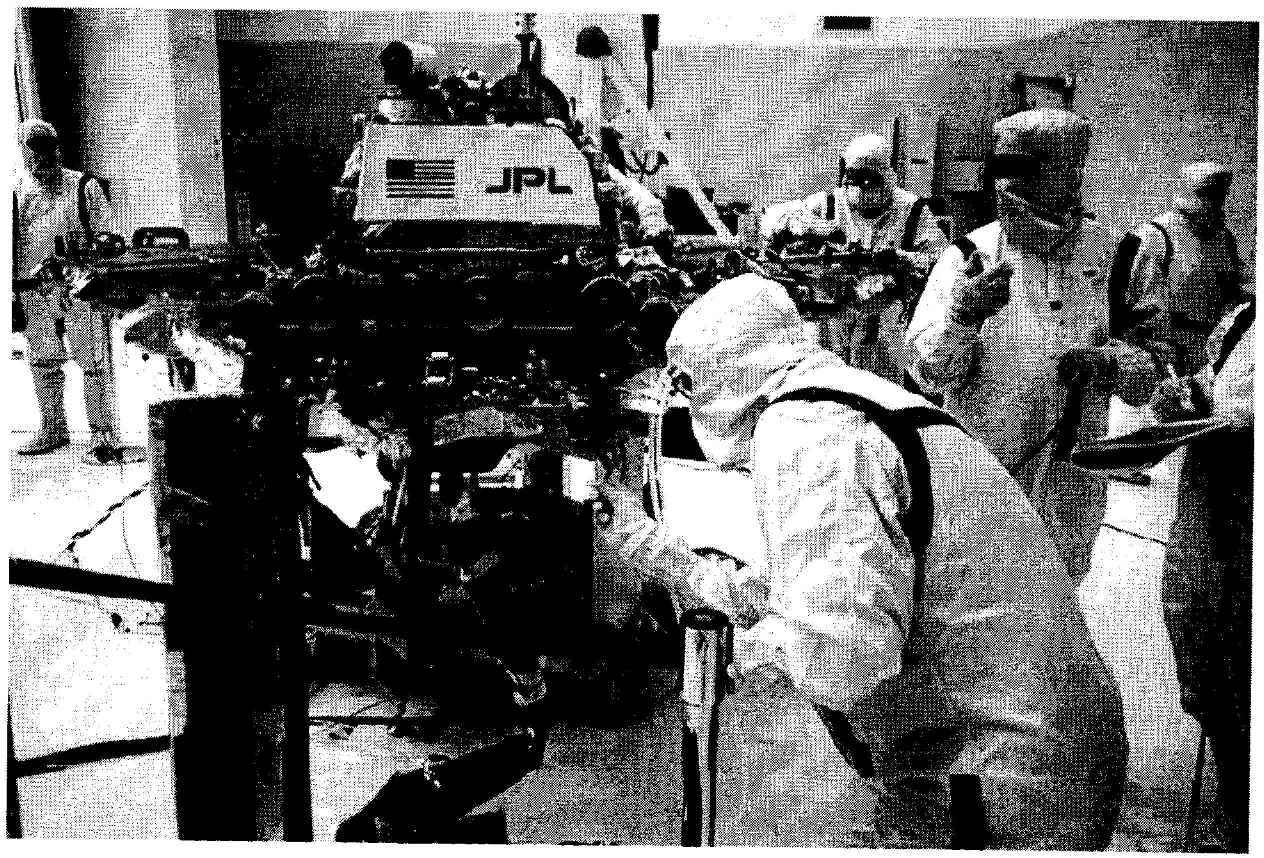
- ↗ 3 to 25-ft dia chambers
- ↗ Solar simulator up to 2.7 Suns
- ↗ $1E10^{-6}$ Torr and temperatures from −185 °C to +130 °C



10 ft dia x 8 ft deep thermal-vacuum chamber

# Planetary Protection & Contamination

- **Contamination control (particulates & molecular contamination) versus planetary protection (biological & organic contamination)**



# H/W Requirements for PP

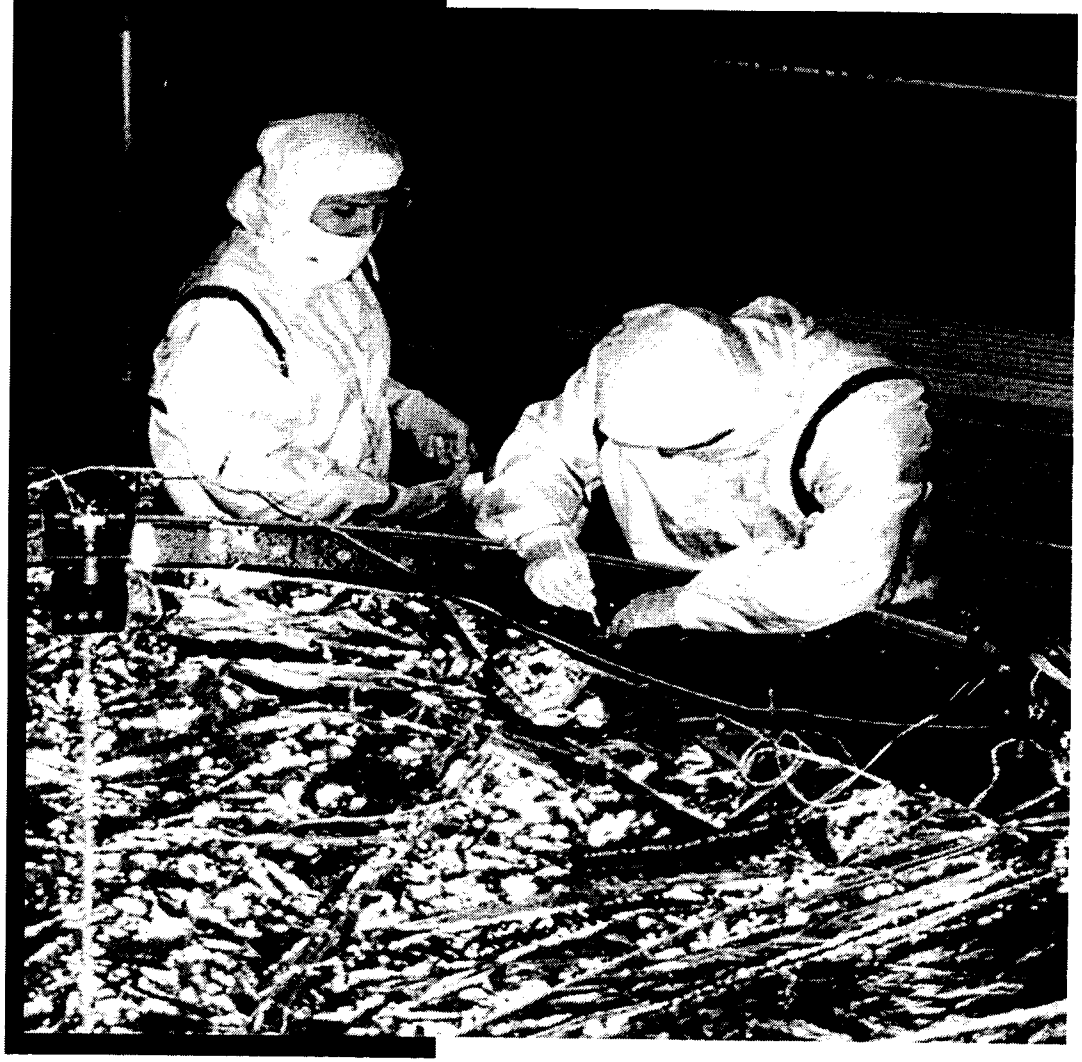
- **Category III: orbiters to Europa; Mars orbiters without adequate orbital lifetime**
  - Class 100K clean room assembly/maintenance
  - Stringent limit on spores (bacteria) on surfaces, in joints, and in the bulk of nonmetallic materials (total spores)
  - Organic material inventory (archival samples of materials present in large quantities)
- **Category IV: landers or probes to Mars and Europa**
  - Without life detection, Category IV-A: as above, except stringent limits on accountable (unprotected) surfaces only
  - With life detection, Category IV-B: as above, but with the strongest limit on total spores (baseline is sterility)
  - Category IV-C: special places
- **Category V: Earth return**

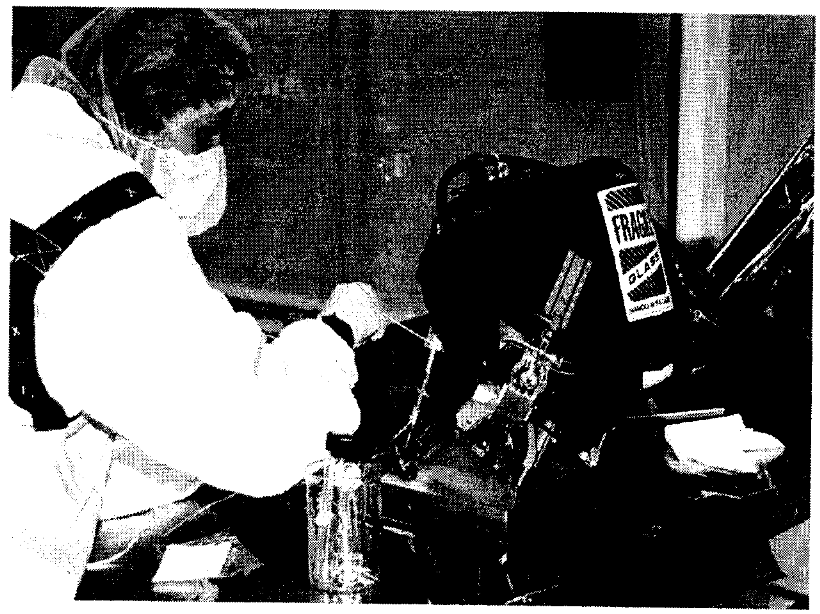
# Approaches for H/W with Rigorous PP Requirements

- **Designing for cleanability**
  - Smooth surfaces
  - Accessibility before closeout
- **Minimizing accountable surfaces**
  - Isolation by high-efficiency particulate air (HEPA) filters or sealing
- **Designing for microbial reduction**
  - Tolerance for process (e.g., heat at 105°C or more)
  - Especially important for impacting hardware, with bulk spore burdens
- **Designing for recontamination prevention**
  - Closed at closeout (no gaps)

# Accountable Surfaces

- Accountable (unprotected) surfaces must tolerate sampling with damp swabs or wipes





Swab sampling of surfaces on DS-2 microprobe assemby

# Isolation by HEPA filter

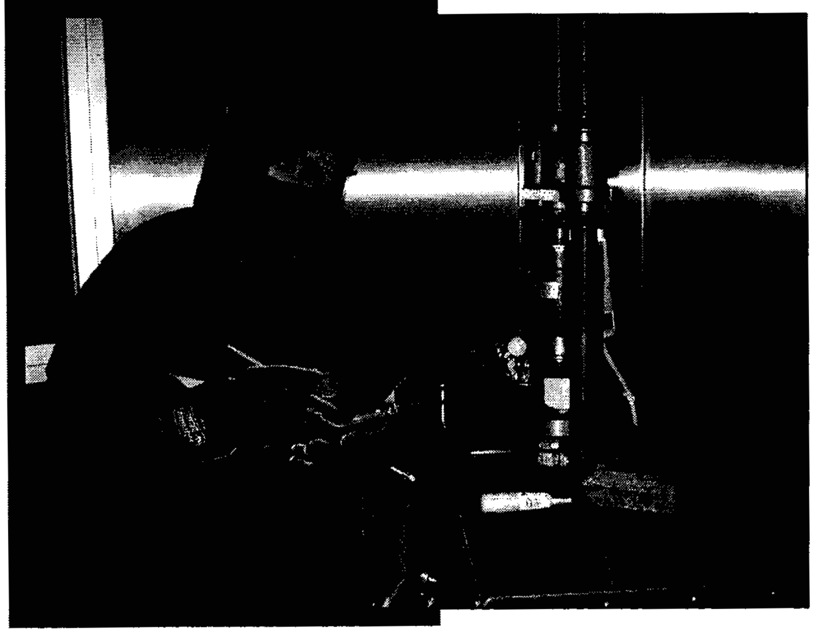
- **MPF on Mars by Sojourner camera, showing the integrated subsystem assembly (ISA) HEPA filter; interior of ISA exempt from burden account**

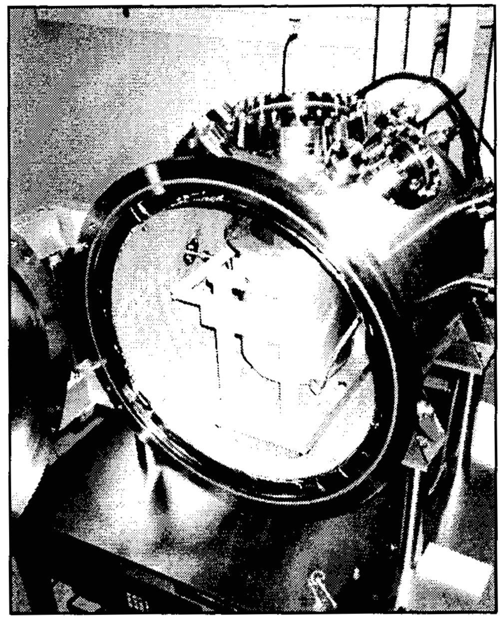
# Microbial Reduction Processes

- **Dry heat microbial reduction**
  - Process specifications exist
  - Optimal in range of 110°C to 125°C (50 to 5 hours)

- **Hydrogen peroxide plasma**
  - Requires bioindicator or proxy
- **Other modalities (radiation, UV...) require validation**

# R&D Instrument Performance Verification





- *In Situ* missions require realistic materials and environments in which to test and validate new technologies and systems to prove performance before flight and operation
- Conduct extensive testing and simulation in conditions as similar to actual flight conditions as possible
- Develop simulants according to ISO and ASTM standards with full documentation

# Conclusion

- **Develop a roadmap for your instrument**
  - ↗ Consider both risk and practicality
  - ↗ Concretely assess your design/technology issues & define how to reduce the risk in each (a brief risk management plan)
  - ↗ For each risk, identify potential consequences and what mitigation strategies can be taken (and by when). Focus on—
    - Where you might have trouble meeting functional requirements
    - Where the technology is not ready
    - Where you might not have enough schedule to develop/procure
  - ↗ You don't have the funds to develop a flight-worthly instrument, but you can demonstrate that there is a pathway should you be selected for flight

# Acknowledgements


- Contributors to Mars Miniature Instruments Resource Book
- Jack Barengoltz, Planetary Protection
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