Strategic Mechanical Engineering Technologies at JPL

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Some material adapted from presentations by Charles Elachi and Erik Antonsson

NASA’s Vision and Mission

- NASA Vision:
  - To improve life here;
  - To extend life to there;
  - To find life beyond.

- NASA Mission:
  - To understand and protect our home planet;
  - To explore the universe and search for life;
  - To inspire the next generation of explorers as only NASA can.
JPL’s Mission

We enable the nation to explore space for the benefit of humanity.
Our Mission is:

1. To explore our own and neighboring planetary systems
2. To search for life outside the Earth’s confine
3. To further our understanding of the origins and evolution of the Universe and the laws that govern it
4. To make critical measurements to understand our home planet and help protect its environment
5. To apply JPL’s unique skills to address problems of national significance and security
6. To enable a virtual presence throughout the solar system by creating the Interplanetary Network
7. To inspire the next generation of explorers

JPL is an Operating Division of Caltech

JPL has a dual character:
- A Federally-Funded Research and Development Center (FFRDC) under NASA sponsorship.
- A division of Caltech, staffed with 5,400 Caltech employees.
- Director is a Vice-President of Caltech

JPL is a major national research and development (R&D) capability supporting:
- NASA programs,
- Defense programs and civilian programs of national importance compatible with JPL capabilities

- JPL is a child of Caltech, founded in 1936 as a graduate student project under Professor Theodore von Kármán
- JPL led the development of US rocket technology in WWII
- After Sputnik, JPL was transferred to NASA upon its creation in 1958
- JPL developed the first US satellite, Explorer 1
- JPL spacecraft have explored all the planets of the solar system except Pluto,
JPL’s Matrix Organization

Caltech
Jean-Luc Chopin, President

Jet Propulsion Laboratory
Charles Elachi, Director
Gary Totten, Deputy Director
Tom Mathis, Associate Director, Flight Projects and Mission Success
Pamela Manz, Associate Director, Communications
Jim Johnson, Associate Director, Chief Financial Officer
Tanya Meeks, Associate Director, Chief Human Resources
Paul DeNatale, Chief Technologist

Exploration Systems Technology Office
Raul Vazquez, Director

Office of Communications and Education
Jeanne Bremer, Manager

Office of Legislative and International Affairs
Brett O’Toole, Manager

Human Resources
Casandra Hardt, Director

Office of Safety and Mission Assurance
Matt Lenzano, Director

Office of the General Counsel
Henry Falakian

JPL Business Summary

- FFRDC
- Managed by the California Institute of Technology for NASA
- One of 10 NASA Field Centers
- $1.7 billion business base
- ~ 5,000 employees and contractors
- 177 acres
- 134 buildings and 57 trailers
- 670,000 net square feet of office space
- 860,000 net square feet of non-office space (e.g., labs)
Where are we now?

NASA has more than 50 missions exploring our solar system (some examples)

Duck Bay: Site of Opportunity's descent into Victoria Crater
Mars program architecture: Next decade

- 2011: Cassini mission
- 2013: Mars Science Laboratory
- 2016: Cassini mission
- 2018: Mars Sample Return
- 2020+: Mars Sample Return

Cassini is in the middle of its 4-year tour
Future solar system exploration: Flagship Mission Studies

Water, organics, and prebiotic chemistry... the evolution of habitable environments

Current astrophysics missions

- Hubble Space Telescope
- Spitzer Space Telescope
- Galaxy Explorer (GALEX)
- Chandra X-ray observatory
Future astrophysics activities

- Beyond Einstein program
  - NAS NRC committee empanelled to recommend first mission.
  - JPL responsible for LISA U.S. payload. GSFC is project manager.
  - NASA HQ currently considering JDEM project organization.

- SMEX/MIDEX
  - NuSTAR extended Phase A final review will be conducted this summer

New ways to see a changing Earth

- Atmospheric Infrared Sounder (AIRS) provides monthly global temperature
- Jason provides global sea surface height maps every 10 days
- Gravity Recovery and Climate Experiment (GRACE) provides monthly maps of Earth's gravity
- QuikSCAT provides near global (90%) ocean surface wind maps every 24 hours
- Multi-angle Imaging Spectro Radiometer (MISR) provides monthly global aerosol maps
- Tropospheric Emission Spectrometer (TES) provides monthly global maps of ozone
- Microwave Limb Sounder (MLS) provides daily maps of stratospheric chemistry
- CloudSat provides monthly maps of cloud ice water content
Examples of Earth Science missions from NAS Decadal Survey, 2010-2016

- SMAP (Soil Moisture Active Passive)
- ICESat-2 (Ice, Cloud, and land Elevation Satellite)
- DESDynl (Deformation, Ecosystem Structure, and Dynamics of Ice)
- HyspIRI (Hyperspectral/IR Imagery for land surface vegetation and minerals?)
- ASCENDS (Active Sensing of CO2 Emission over Nights, Days, and Seasons)
- SWOT (Surface Water/Ocean Topography)
- ACE (Aerosol/Clouds/Ecosystems

Deep space exploration enabled by NASA’s Deep Space Network (DSN)
Technology Planning

- Identify those critical areas of advanced technology research and development in which:
  - JPL should lead,
  - JPL should partner with other leading organizations,
  - JPL should acquire technology from other organizations.
Strategic Science & Technology Investment Planning Process

1. What are the key exploration goals or science questions?
2. What measurements are needed to address those questions?
3. What instruments & missions are planned to make those measurements?
4. What scientific capability is needed at JPL/Campus to achieve the above?
5. What other capabilities are being targeted to address those questions (computational modeling, laboratory simulation, etc.)?
6. What technologies are needed to achieve the above?
7. What technologies and engineering capability are needed at JPL (or campus)?
8. What infrastructure is needed to achieve the above?
9. What are the present capabilities and funding outlook at JPL in each of the above?
10. What actions and investments are needed, and timing? What are the investments needed over the next 5 years?
11. What critical alliances/partnerships/consortia are needed. Why and when?

Advanced Technology Research & Development at JPL

JPL has identified 12 Strategic Technology R&D areas.

The definition of "strategic" used here is:

Areas of technology that have two salient characteristics:

1. They are of critical importance to JPL's ability to achieve its exploration goals and answer its science questions.

2. They are areas where JPL makes a unique or distinguishing contribution.
Technology Areas of Strategic Importance

1. Large Aperture Systems (Optical, IR and Radar; Filled and Sparse)
2. Precision Flying
3. Detectors and Sensors
4. Cryogenic Systems
5. In-situ Planetary Exploration Systems
6. Planetary Protection Systems
7. Survivable Systems for Extreme Environments
8. Deep Space Communications
10. Engineering Systems
11. Mission System Computing and Avionics
12. Utilization of High Capability Computing

"Pull" vs "Push" Technologies (top-down vs bottoms-up)

A balanced technology portfolio requires a mix of "push" vs "pull" technologies.

"Push" (Bottoms-Up)
- We will try to concentrate on the "right" technologies, but we are not smart enough to always get it right
- We do not want to preclude any potential breakthrough developments
- We always want to encourage creative "out-of-the-box" thinking
- We always want to encourage entrepreneurial activity

"Pull" (Top-Down)
- Identified mission customers for candidate technologies
- We must try to pick what we want to be good at; we can't be good at everything
- Provide focal points for the division, the rest of the Laboratory, and external customers
- Provide a rationale for allocating scarce resources
Funding to reach given TRL — Generic pattern

Criteria for Selection of Strategic Technology Focus Areas—Mechanical Systems Division

- Compatible with the JPL Mission
- Alignment with the JPL Strategic Technology Plan
- Enabling to future mission sets
- The Division can make a unique contribution
- Required for the health of enabling Division product lines
- Required for the health of enabling Division capabilities
Overlay of Mechanical Systems Division Technology Portfolio onto JPL Strategic Technology Portfolio

<table>
<thead>
<tr>
<th>JPL Strategic Technology Area</th>
<th>Div 35 Technology Competency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Large Aperture Systems</td>
<td>1.1 Lightweight structures, deployment and stabilization</td>
</tr>
<tr>
<td>(Optical, IR and Radar; Faded and Sparse)</td>
<td>1.2 Thermal management</td>
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<td>1.3 Metrology &amp; figure control</td>
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<td>1.4 Integration &amp; test</td>
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<td>1.5 Integrated modeling</td>
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<tr>
<td>2 Precision Flying</td>
<td>2.4 Precision microthruster propulsion</td>
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<tr>
<td>3 Detectors and Sensors</td>
<td>3.3 In-situ instruments</td>
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<tr>
<td>4 Cryogenic Systems</td>
<td>4.1 Space-worthy multi-Kelvin coolers</td>
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<td></td>
<td>4.2 Integrated coolers &amp; detectors/receivers</td>
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<tr>
<td></td>
<td>4.3 Cryo-systems to cool large telescope apertures</td>
</tr>
<tr>
<td>5 In-situ Planetary</td>
<td>5.1 Entry, descent, and landing precision landing &amp; hazard avoidance</td>
</tr>
<tr>
<td>Exploration Systems</td>
<td>5.2 Mobility surface, subsurface, submarine, atmospheric</td>
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<tr>
<td></td>
<td>5.3 Sample collection and handling, preparation, distribution &amp; storage</td>
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</tbody>
</table>
## Overlay of Mechanical Systems Division Technology Portfolio onto JPL Strategic Technology Portfolio (cont)

<table>
<thead>
<tr>
<th>JPL Strategic Technology Area</th>
<th>Div 35 Technology Competency</th>
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<tbody>
<tr>
<td>6 Planetary Protection Systems</td>
<td>6.1 Sanitation of space systems</td>
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<td></td>
<td>6.2 Particle transport modeling</td>
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<td>6.3 Cleaning of organs &amp; validation</td>
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<td>6.4 Materials development &amp; spacecraft design</td>
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<td>6.5 Sample containment &amp; Earth return</td>
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<td>7 Survivable Systems for Extreme Environments</td>
<td>7.2 Systems to survive hypervelocity impacts</td>
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<td>7.3 Systems for extreme temperatures</td>
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<td>8 Deep Space Communications</td>
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<td>9 Deep Space Navigation</td>
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<tr>
<td>10 Engineering Systems</td>
<td>10.1 Model-based engineering design</td>
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<td>10.3 Collaborative engineering environments</td>
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<td>10.4 Visualization</td>
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<tr>
<td>11 Flight Computing and Avionics</td>
<td></td>
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<tr>
<td>12 Utilization of High Capability Computing</td>
<td>12.2 Coupled/integrated physics-based models</td>
</tr>
</tbody>
</table>

## Mechanical Systems Division Technology Portfolio Focus Areas

- **Planetary Protection**
  - World-class capability, NASA center of expertise
- **Large Aperture Systems**
  - Expertise in lightweight structures synergistic with institutional expertise in radar and optics
- **Cryogenic Systems**
  - Required for cutting-edge far infrared NASA missions
- **Advanced Propulsion Technology**
  - Successful technology infusion and ongoing R&D enabling for next generation JPL missions
- **Integrated Modeling**
  - Coupled/integrated physics-based modeling

- **Surface Mobility Systems**
  - Expertise in the development of evolutionary, flight-proven mechanical mobility systems
- **Entry, Descent, and Landing**
  - Unique mechanical system design and analytical capabilities integrated into a multi-disciplinary system design
- **Sample Handling Systems**
  - End-to-end mechanical system design integrating instruments, actuators/mechanisms, and robotics
- **Survivable Systems for Extreme Environments**
  - Systems operating under extreme thermal, pressure, and hypervelocity environments
Spacecraft Mechanical Engineering Section

Robotic Exploration

- Asteroids & Comets
- Anchor & Sample Systems

- Planetary Rovers
- Ices Penetrators
- Sub-Sea Robots

- Asteroid Mobility Systems
- Sensor Web Deployment

- Robotic Drills
- Mini-Core Devices
- Rover-Mounted
SPIDERBOT: Sensor web network of Autonomous Robots

Traversing rough and varying terrain such as the surface of Mars can make space exploration difficult. How, then, can scientists collect valuable data and materials effectively and economically?

Assessing Systems Architectures for Compliance with Planetary Protection Requirements

Task Objective: Integrate Planetary Protection into System Planning

- Develop a factor-based model to estimate the contamination level for a set of techniques (PP architectures) for a particular mission architecture
- Validate these models
- Develop cost estimation tools to evaluate various techniques for achieving PP compliance for a particular mission architecture

Funding and Milestones

<table>
<thead>
<tr>
<th>Activity</th>
<th>Leader</th>
<th>Budget</th>
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<tr>
<td>CALA</td>
<td>Dr. Andy Gay</td>
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<tr>
<td>CAVI</td>
<td>Dr. Young Lin</td>
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<td>CARPET</td>
<td>Mike Davis</td>
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<thead>
<tr>
<th>Milestone</th>
<th>Description</th>
<th>Status</th>
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<tbody>
<tr>
<td>Year 1</td>
<td>CALA model complete and CARPET validated with simulated mission data where possible</td>
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<tr>
<td>Year 2</td>
<td>CALA test used to evaluate candidate architectures in Europe</td>
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<tr>
<td>Year 3</td>
<td>CARPET test used to evaluate candidate architectures in Europe</td>
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</table>
High Temperature Sample Acquisition

Description
Develop and demonstrate the technologies required to build a functional sample acquisition system for Venus surface operation. The key technologies are motors, sensors, and cabling.

Overall Task Objectives
- Understand key motor design parameters at 570°C (magnetic permeability, wire limitations, thermal stresses in windings, motor commutation sensor design)
- Functional test a motor and sensor at 570°C
- Build and test gearbox at 570°C
- Test cabling flexibility and life at 570°C

<table>
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<tr>
<th>Task</th>
<th>01</th>
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<td>Proprietary Motor and Encoder Design</td>
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<td>Pressure Heating Sample Environment</td>
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<td>Pressure Motor and Encoder Fabrication</td>
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<td>Set-up Implementation in Building 179-157</td>
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<td>Test Motors and Motors at High Temp.</td>
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<td>Test Gearbox</td>
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<td>Test Motor and Encoder Cabling</td>
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<td>Test Motor and Encoder Flexibility</td>
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<td>Test Motor and Encoder Life at 570°C</td>
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</tbody>
</table>

Task Manager
Michael R. Johnson
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Key Personnel
Robert Troy
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Propulsion & Materials Engineering Section

Nanocomposite Mirror Technology

Micro-thrust test facility

Scanning Electron Microscopy

NEXIS Thruster Operation
**Colloid Thruster Task**

**Description**
Increasing thrust range of a colloid thruster via electrostatic beam focusing

**Overall Task Objectives**
- Improve colloid thruster technology for precision formation flying
- Increase thruster (single emitter) throttling range
- Reduce beam divergence (potential for sc contamination)
- Achieve improved performance by optimization of extracting electrode geometry

<table>
<thead>
<tr>
<th>Task</th>
<th>Oct</th>
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<td>Design Characterization</td>
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</tbody>
</table>

**Task Manager**
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**Ion Thruster Technology Task**

**Description**
Reduce cost and risk of the ion thrusters for JPL SEP Missions

**Overall Task Objectives**
Enable make/buy decision for NSTAR thruster procurement
- Utilize JPL expertise developed from Prometheus
- Resolve thruster design and fabrication issues to produce in-spec performance
- Evaluate commercially-built XIPS thruster to replace NSTAR
- Apply thruster with heritage of 32-on-orbit to station keeping applications
- Develop throttle table for NASA primary propulsion applications
- Utilize XIPS life test data and JPL life-modeling codes to predict throughput for NASA applications

<table>
<thead>
<tr>
<th>Task (FY18)</th>
<th>Q1</th>
<th>Q2</th>
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<td>NSTAR thruster evaluation</td>
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<td>NSTAR gas flow test</td>
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<td>NSTAR thruster testing</td>
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<td>XIPS performance evaluation</td>
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<td>XIPS testing at JPL</td>
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<td>Final report</td>
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<td>JPL (annual G&amp;C test)</td>
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<td>Proposed</td>
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<td>256</td>
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</table>

**Task Manager**
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**Partners**
JPL Propulsion Flight Systems (3533)
L-3 Communications
Hall-Effect Thruster Life Modeling Task

Description
Development and application of computer models to determine the service life of Hall-Effect Thrusters (HET) for JPL Discovery-Class Missions

Overall Task Objectives
- Model the acceleration channel erosion by energetic ions
- Model the orificed hollow cathode plasma to predict keeper life
- Apply the validated models to predict the service life of the BPT-4000 thruster at operating conditions relevant to Discovery-class missions.

Task Manager
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Colin Katz

Partners (Not funded by R&T)
- Aserjet
- APRL, Edwards

Thermal & Cryogenic Engineering Section

Plank Sorption Cooler Compressor on Vibration Table
Large Aperture Cryo-cooling

- Possibly the most difficult Large Telescope System Technology Initiative (LTSI) challenge
  - Cooling the full aperture (10+ meters) to achieve zodiacal background limited IR/FIR performance requires
    - Cooling to ~4-10K with 1K accuracy, and 1mK stability
    - Equivalent to scaling SIRTF to 15 meters
  - Passive cooling (NGST approach) limited to 35K-40K at 1AU
  - Sunshield backside re-radiation (90%) degrades NGST beyond 10µm
- Current cryocooler technologies offer a point of departure for LTSI investments.
  - Stored/Recycled Cryogens - Today's state-of-practice
  - 20K JPL sorption/J-T cooler in production for ESA Planck mission
  - Demonstrate 6 Kelvin turboalternator for NGST in late 2000
  - Demonstrate 9 Kelvin turbo-Brayton cooler for NGST in 2003
- Future directions
  - More effective sunshield concepts
  - More efficient turbo-Brayton coolers will enable mirror cooling with low input power
  - Demonstrate 10-15K sorption-based J-T cooler
  - High efficiency cryogenic heat transfer in gossamer aperture materials

Sub-K Cooler Development/Integration

Description of the task

Future Far-IR instruments will have requirements which current sub-K coolers cannot meet:
- 5-10 year life
- Continuous cooling to 60 mK
- Staging from mechanical cryocoolers at 4-6 K (issues of temperature and peak power)

This effort will develop critical technology for sub-Kelvin flight cryocoolers for integration into JPL instruments to cool focal planes for far-IR and sub-mm astrophysics missions.

The technology developments will emphasize a path to the production of flight-qualifiable sub-K cooler systems which are designed to operate optimally with detectors, forming instruments which are easier to test and to integrate with spacecraft, while also yielding products to be used in ground validation of measurements.

"Leading Candidate" for baseline architecture; system-level analysis will yield baseline
Computational Methods Development

Description
- Analysis-driven systems engineering and optimization design tool for precision deployable structures

Overall Task Objectives
- Enable integrated analysis and optimization via finite element-based, common model approach for thermal, structural, and optical aberration analyses
- Deliver an industrial-strength code that complements JPL's design processes and COTS tool usage
- Provide an extensible platform for state-of-the-art methods research and rapid prototyping of capabilities not available in commercial codes

Integrated analysis capability facilitates development of detailed system-level model

Venus Lander Pressure Vessel

Description
- A lightweight, high-strength pressure vessel with an integrated thermal control system for Venus Landers and Deep Atmospheric Probes

Overall Task Objectives
- Develop pressure vessel with ~1/4 mass of Ti shell
- Demonstrate survivability for 10+ hours in Venus environment
- Demonstrate integrated pressure vessel and thermal control system technology

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<tr>
<th>Task</th>
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<tr>
<td>Pressure Vessel</td>
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<td>Identify Relevant Pressure Vessel Materials</td>
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<td>Identify Relevant Thermal Control Technologies</td>
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<td>Identify Test Facilities</td>
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<td>Evaluate Concepts for Pressure Vessel Testing</td>
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<td>Design Thermal Control Technologies for Testing</td>
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<td>Design Subscale Integrated System</td>
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<td>Fabricate Thermal Control Technologies</td>
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<td>Generate Test Plans, Procedures</td>
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<td>Conduct Thermal Technology Performance Testing</td>
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<td>Conduct Pressure Vessel Sample Testing</td>
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<td>Conduct Test Results with System Models</td>
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<td>Total Cost (K)</td>
<td>350</td>
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<td>500</td>
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Partners
- JPL Mechanical Engineering (352)
- JPL Materials (353)
- Brush-Wellman
- FMW Composites
- XA Associates
Instrument Mechanical Engineering Section

Installation of the SIM TOM-3 Compressor

Large Mirror Technologies

- ESA/HERSCHEL Telescope
  - 2 meter composite prototype by COI
  - Cryogenic performance at FIR wavelengths
  - Demonstrated 9 kg/m²
- Carbon/Silicon Carbide - CSiC
  - IABG (German) Product
  - 0.5 meter prototype demonstrated
  - Projected capability below 10 kg/m²
- Sintered Silicon Carbide
  - Astrum & BOOSTEC
  - New Technology, 1.3 meter demonstrated
  - Licensed in US
  - Projected capability below 10 kg/m²
- COI Ion Figured Cyanate Ester
  - Concept for visible light optics
  - Projected 5 kg/m²

COI Herschel Prototype
IABG CSiC
1.3 m Brazed Mirror Assembly
**Large Aperture Mirror Technology**

- Lightweight Concepts to Enable 1 kg/m² and less systems

**Precision Deployable Structures Testbeds**

**Description**
A next generation facility for measuring large deployable apertures

**Overall Task Objectives**
- Develop a ground testing facility in Bldg 299 clean room
  - Allow development and testing of up to 2-m diameter single-petal and up to 4-m six-petal deployable test bed.
  - Include a gravity off-load system.
  - Provide thermal (< 1 deg C for 12 hrs) and seismic (< 0.0001 G rms) and acoustic stability.
- Build a precision deployable structures testbed.
  - Single petal test articles will have 1 m petals.
  - Six petal test article will be 3 m in diameter.
- Measure
  - Modal response of the test articles from 0-100 Hz.
  - Deployment with an accuracy of 5 mm during deployment.
  - Deployment Accuracy with 1 micron absolute and 10 nanometers relative.
- Develop a conceptual design tool for rapid (<1 work-week) conceptual design of large aperture systems.

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**Partners**
- JPL INTERFEROMETRY METROLOGY AND OPTICS (3854)
USDC: a Lab-on-a-drill

Web Sites

http://surp.jpl.nasa.gov/

http://scienceandtechnology.jpl.nasa.gov/
Concluding remarks

- Partnerships:
  - JPL benefits from partnerships in all areas of technology R&D
  - These partnerships take many forms, from supplier-customer relationships to research collaborations
- JPL has many existing technology R&D collaborations with Universities.
- In general, JPL is not a provider of R&D resources for Universities, rather JPL can be a partner to strengthen the ability of a collaboration to attract research resources.
- We welcome partnership and collaboration discussions.

Technology Flowdown Process
End of File