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Strategic Mechanical Engineering Technologies at JPL

Greg Davis

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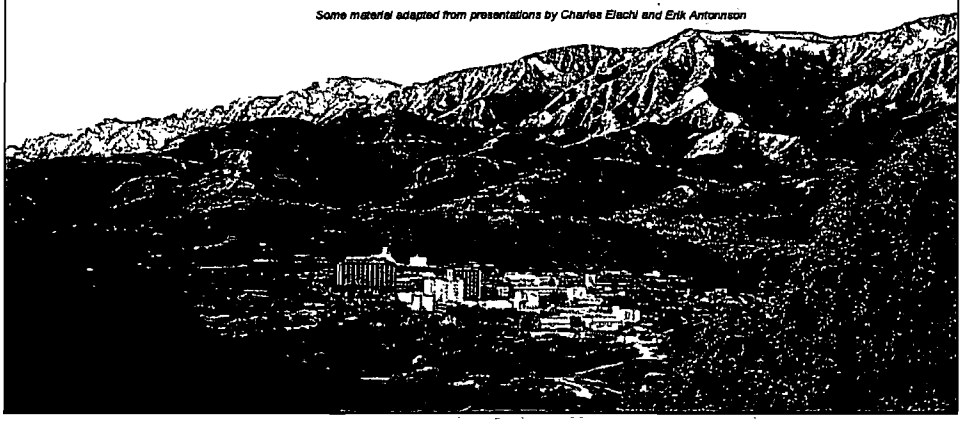
California Institute of Technology

Some material adapted from presentations by Charles Elachi and Erik Antonnson



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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*

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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*

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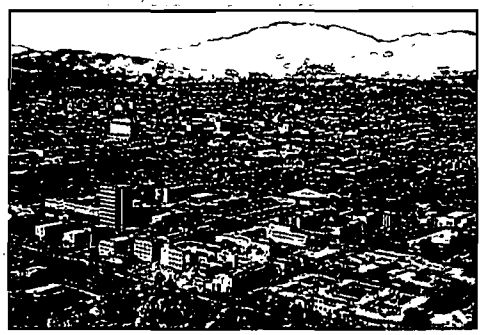
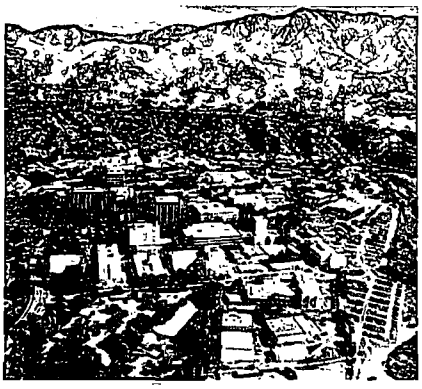
JPL is an Operating Division of Caltech



- 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 U S satellite, Explorer I
- JPL spacecraft have explored all the planets of the solar system except Pluto.



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

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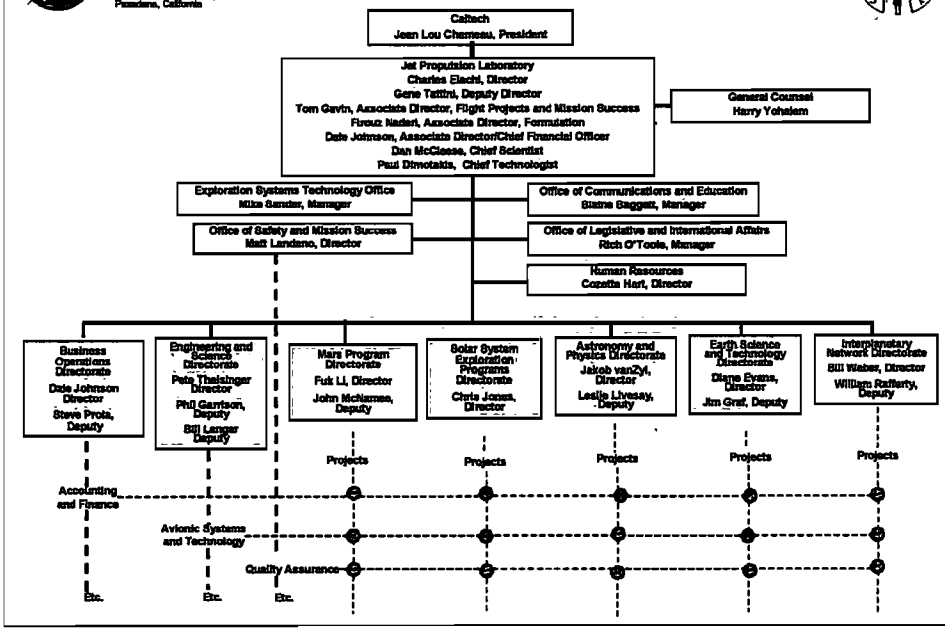
JPL's Matrix Organization



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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)

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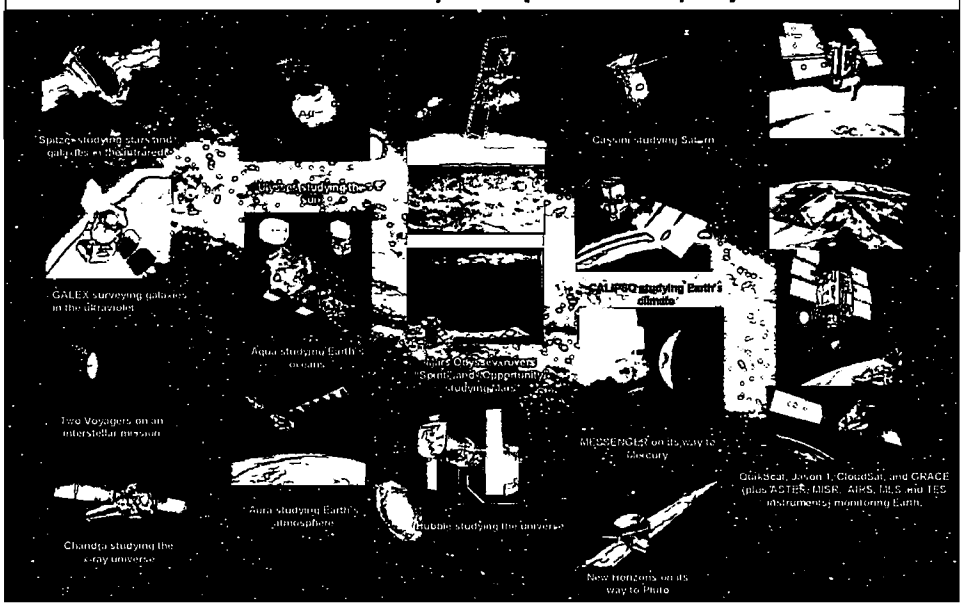
Where are we now?
NASA has more than 50 missions exploring our solar system (some examples)



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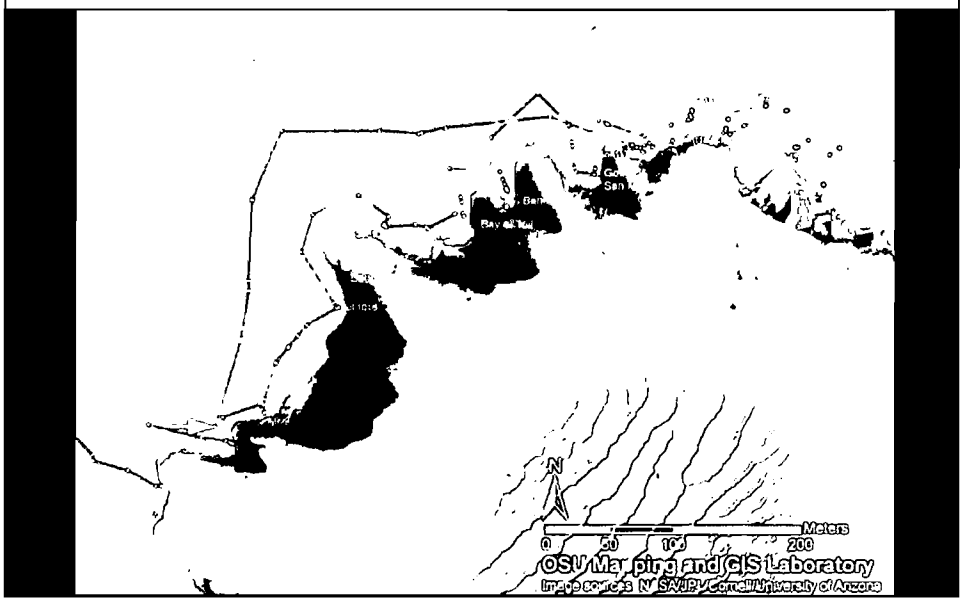
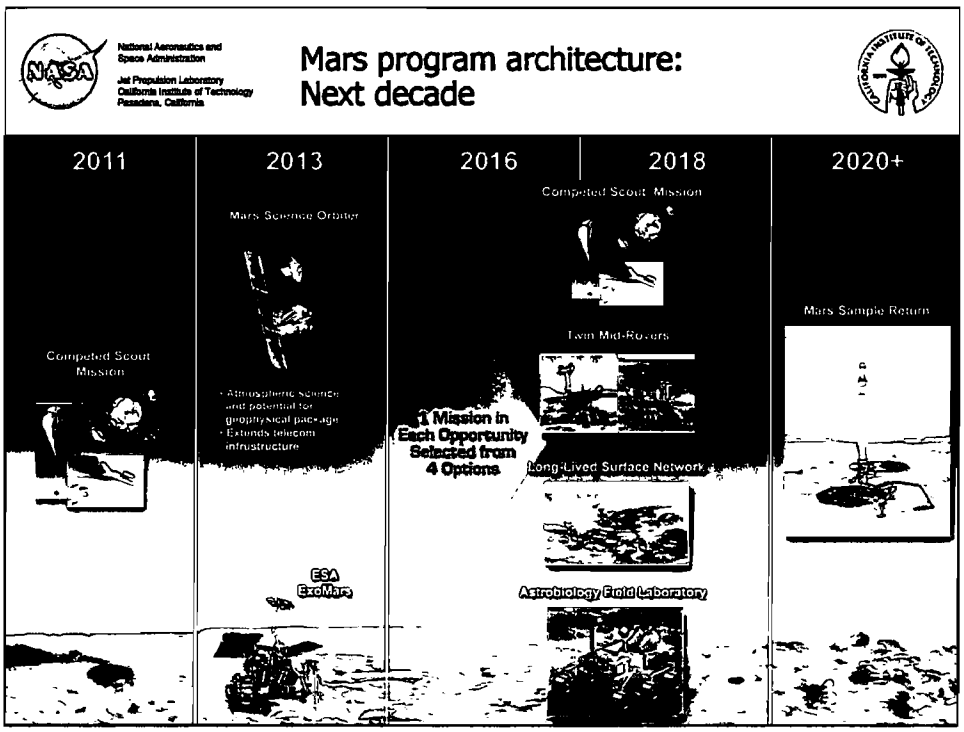
Duck Bay: Site of Opportunity's descent into Victoria Crater

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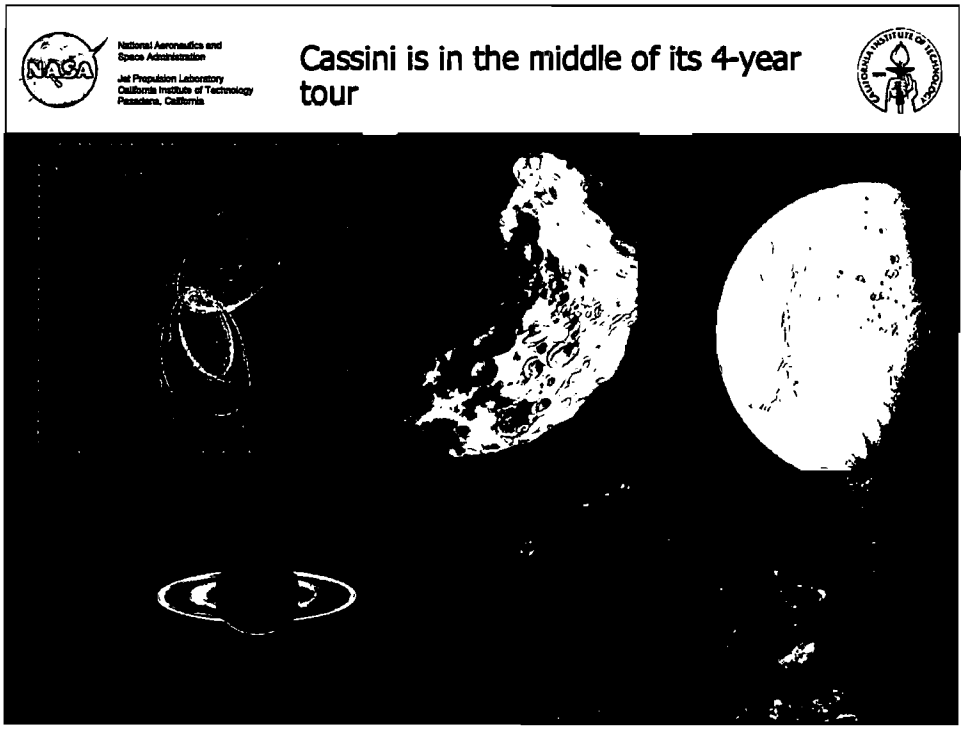
Mars program architecture: Next decade
2011
2013
2016
2018
2020+
Competed Scout Mission
Mars Science Orbiter
Competed Scout Mission
Mars Sample Return
Twin Mid-Rovers
1 Mission in Each Opportunity Selected from 4 Options
Long-Lived Surface Network
ESA ExoMars
Astrobiology Field Laboratory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Cassini is in the middle of its 4-year tour

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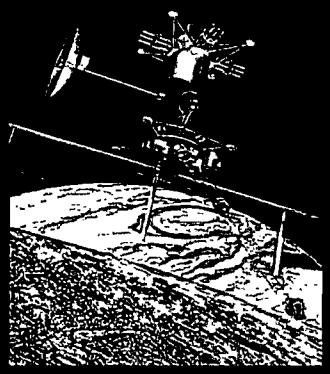
Future solar system exploration: *Flagship Mission Studies*

Europa Explorer



Titan Explorer

Jupiter System Observer

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

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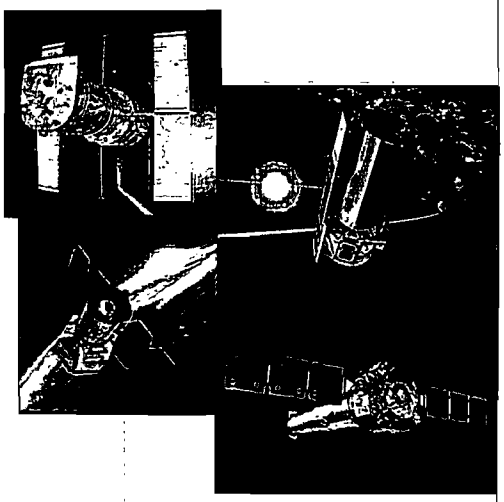
Current astrophysics missions

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



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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

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New ways to see a changing Earth

Atmospheric Infrared Sounder (AIRS) provides monthly global temperature

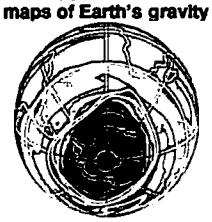
Jason provides global sea surface height maps every 10 days

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

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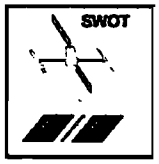
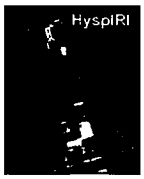
Examples of Earth Science missions from NAS Decadal Survey, 2010-2016

- SMAP (Soil Moisture Active Passive)
- ICESat-II (Ice, Cloud, and land Elevation Satellite)
- DESDynI (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





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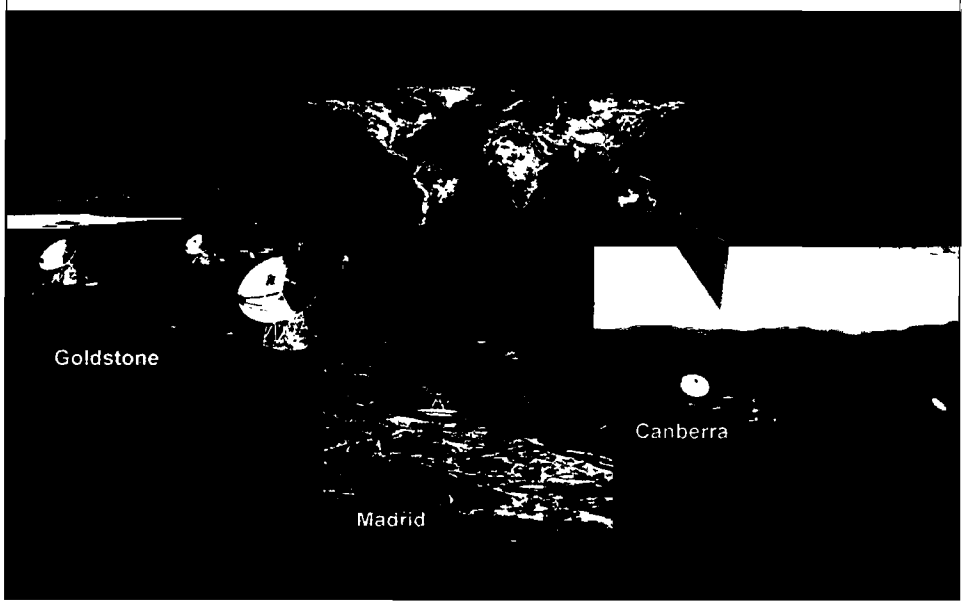
Deep space exploration enabled by NASA's Deep Space Network (DSN)



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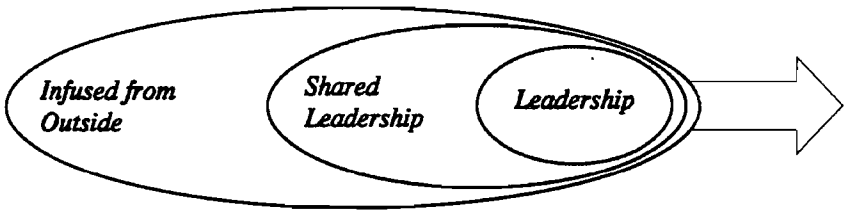
Technology Planning

- 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.



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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?

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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.

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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
9. Deep Space Navigation
10. Engineering Systems
11. Mission System Computing and Avionics
12. Utilization of High Capability Computing

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"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 <u>always</u> want to encourage creative "out-of-the box" thinking
- We <u>always</u> 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

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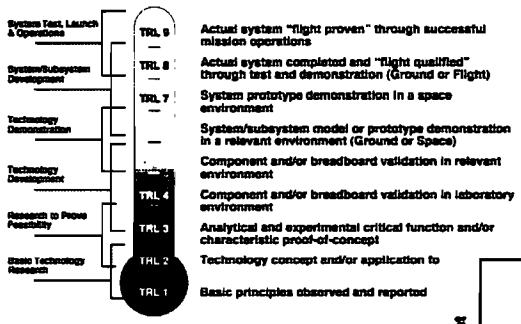
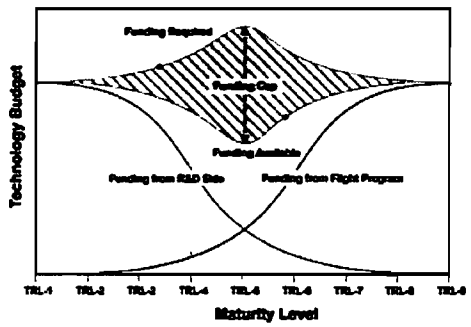
Funding to reach given TRL — *Generic pattern*





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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

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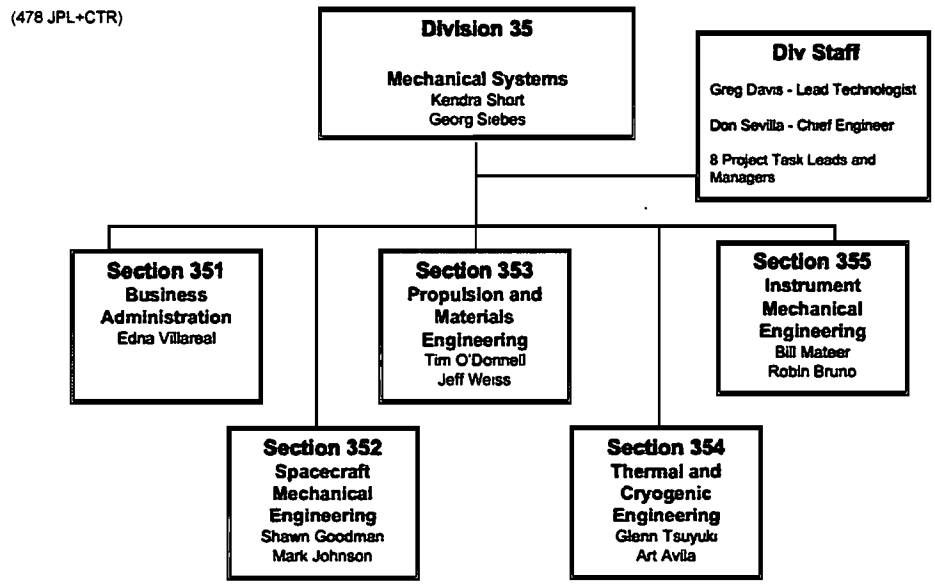
Mechanical Systems Division Org Chart

(478 JPL+CTR)



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Overlay of Mechanical Systems Division Technology Portfolio onto JPL Strategic Technology Portfolio

JPL Strategic Technology Area	Div 35 Technology Competency
1 Large Aperture Systems (Optical, IR and Radar; Filled and Sparse)	1 1 Lightweight structures, deployment and stabilization 1 2 Thermal management 1 3 Metrology & figure control 1 4 Integration & test 1 5 Integrated modeling
2 Precision Flying	2 4 Precision micro/nano propulsion
3 Detectors and Sensors	3 3 *In-situ* instruments
4 Cryogenic Systems	4 1 Space-worthy milli-Kelvin coolers 4 2 Integrated coolers & detectors/receivers 4 3 Cryo-systems to cool large telescope apertures
5 *In-situ* Planetary Exploration Systems	5 1 Entry, descent, and landing precision landing & hazard avoidance 5 2 Mobility surface, subsurface, submarine, atmospheric 5 3 Sample acquisition and handling preparation, distribution & storage

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Overlay of Mechanical Systems Division Technology Portfolio onto JPL Strategic Technology Portfolio (cont)

JPL Strategic Technology Area	Div 35 Technology Competency
6 Planetary Protection Systems	6 1 Sterilization of space systems 6 2 Particle transport modeling 6 3 Cleaning of organics & validation 6 4 Materials development & spacecraft design 6 5 Sample containment & Earth return
7 Survivable Systems for Extreme Environments	7 2 Systems to survive hypervelocity impacts 7 3 Systems for extreme temperatures
8 Deep Space Communications	
9 Deep Space Navigation	
10 Engineering Systems	10 1 Model-based engineering design 10 3 Collaborative engineering environments 10 4 Visualization
11 Flight Computing and Avionics	
12 Utilization of High Capability Computing	12.2 Coupled/integrated physics-based models

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Mechanical Systems Division Technology Portfolio Focus Areas

Planetary Protection
World-class capability, NASA center of expertise

PP on MER

Large Aperture Systems
Expertise in lightweight structures synergistic with institutional expertise in radar and optics

IAE in orbit

Cryogenic Systems
Required for cutting-edge far infared NASA missions

AIRS Coolers

Advanced Propulsion Technology
Successful technology infusion and ongoing R&D enabling for next generation JPL missions

NEXIS

Integrated Modeling
Coupled/integrated physics-based modeling

Mirror Segment Thermal Distortion

Surface Mobility Systems
Expertise in the development of evolutionary, flight-proven mechanical mobility systems

2 generations of Rovers

Entry, Descent, and Landing
Unique mechanical system design and analytical capabilities integrated into a multi-disciplinary system design

EDL on Mars

Sample Handling Systems
End-to-end mechanical system design integrating instruments, actuators/mechanisms, and robotics

ASTEP proposal

Survivable Systems for Extreme Environments
Systems operating under extreme thermal, pressure, and hypervelocity environments

Titan Explorer

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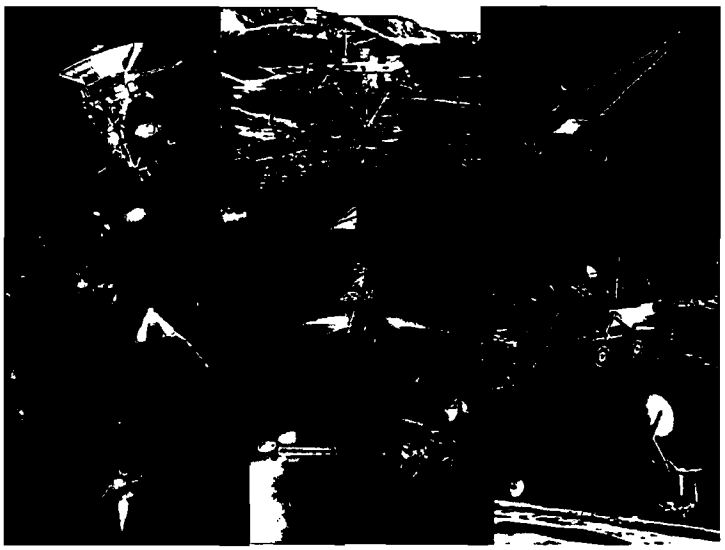
Spacecraft Mechanical Engineering Section



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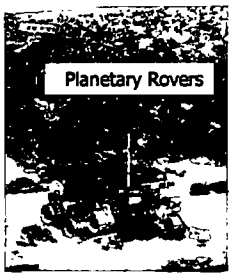
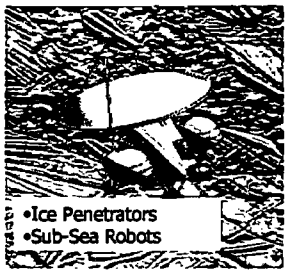
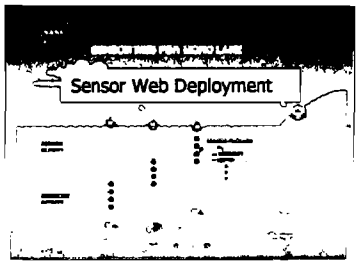
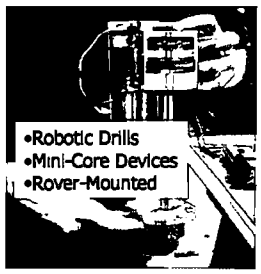
Robotic Exploration









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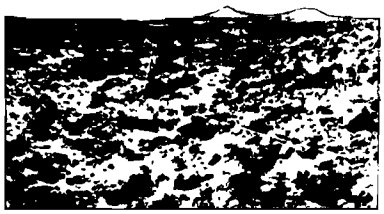
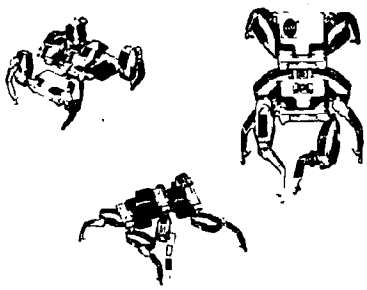
SPIDERBOT: Sensor web network of Autonomous Robots

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?





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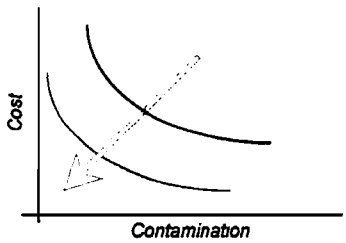
Assessing Systems Architectures for Compliance with Planetary Protection Requirements



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

Principal Investigator **Dr. Jason Kastner**
Initiative Leader: **Dr. Greg Davis**
Steering Committee Leader **Dr. Jim Cutts**

Activity Title	Leader	Section
CoLA	Dr Andy Spry	352
CAVA	Dr Ying Lin	352
CoRCET	Mike Evans	312

Funding and Milestones

FY 06 (BK)	FY 07 (BK) Plan	FY 08 (BK) Plan
$540 ($655 Proposed)	$1200	$1220

Milestones	Date
CoLA model components and CoRCET validated with historical mission data where possible	Year 1
CoLA tool used to evaluate candidate architectures to Europe	Year 2
CoRCET tool used to evaluate candidate architectures to Europe	Year 3

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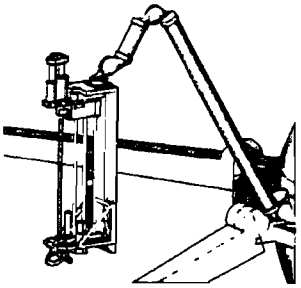
High Temperature Sample Acquisition



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

Task	FY 05				FY 06				FY 07			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Locate High Temperature Test Chamber												
Procure Motor and Resolver Design												
Procure Vibrating Sample Magnetometer												
Procure Motor and Resolver Fabrication												
Set up Magnetometer in Building 170-207												
Test Magnetic Motor Materials												
Receive Motor and Resolver								Δ				
Test Motor and Resolver at High Temp.												
Assemble Gearbox to Motor												
Test Actuator and Cabling												
Total Cost (K$)	185				125				700			
Original Proposal Plan Cost (K$)	400				600				700			

Task Manager
Michael R Johnson
(818) 354-9577
Michael R Johnson@jpl nasa gov

Key Personnel
Robert Troy
(818) 393-2948
Robert F Troy@jpl nasa gov

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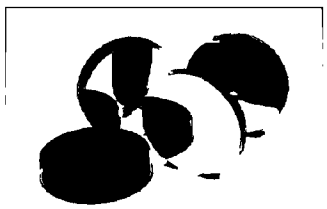
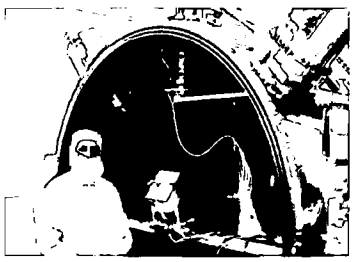
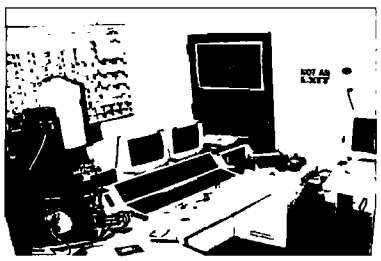
Propulsion & Materials Engineering Section



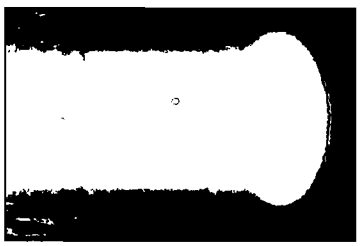
Nanolaminate Mirror Technology



Micro-thrust test facility



Scanning Electron Microscopy



NEXIS Thruster Operation

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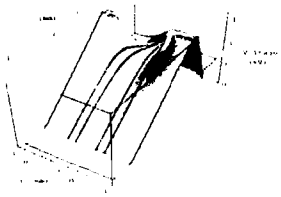
Colloid Thruster Task



Task Manager
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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

Task	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Beam Characterization												
Electrode Design												
Electrode Manufacturing												
Electrode Testing												
Report/Post												

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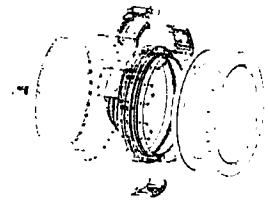
Ion Thruster Technology Task



Task Manager
Dan Goebel
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Partners
JPL Propulsion Flight Systems (3533)
L-3 Communications

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 in 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

Task (FY06)	Q1	Q2	Q3	Q4
Ion Thruster Technology				
NSTAR thruster evaluation				
NSTAR grid fabrication study				
NSTAR in-house fab study				
XIPS preliminary testing (@L-3)				
XIPS life assessment				
XIPS performance assessment				
XIPS testing at JPL				
Final report				
Total Cost ($k) 226	19.8	118.7	87.8	58.9

TBD (around GRC tests)
Proposed

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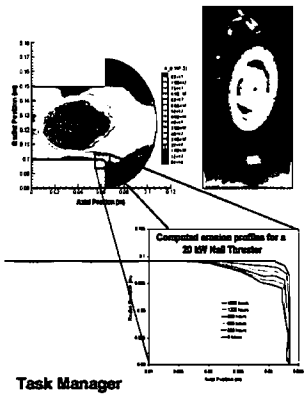
Hall-Effect Thruster Life Modeling Task

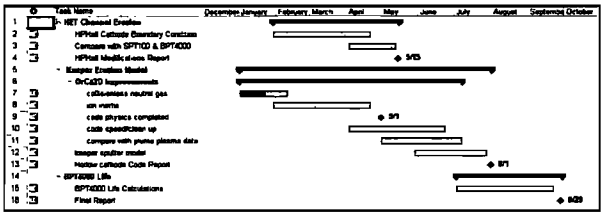


Description

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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Co-I Ira Katz

Partners (Not funded by R&TD)

- Aerojet
- AFRL Edwards

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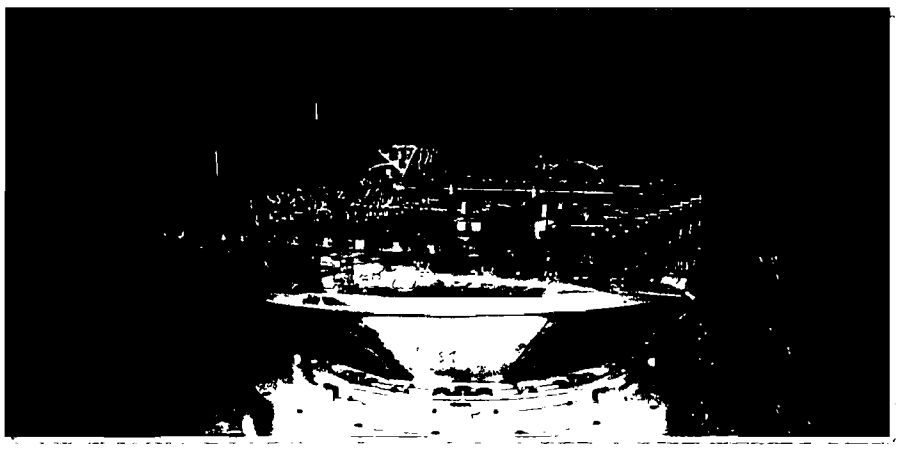
Thermal & Cryogenic Engineering Section



Plank Sorption Cooler Compressor on Vibration Table

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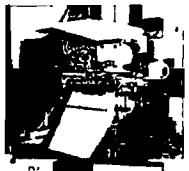
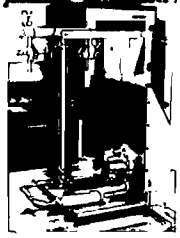
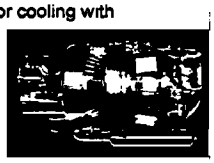
Large Aperture Cryo-cooling





- 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 reradiation (90K) dominates 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 6 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



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Sub-K Cooler Development/Integration

Description of the task

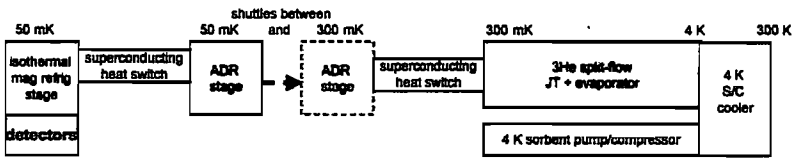
PI: Chris Paine
Co-I: Warren Holmes
Technicians. Jon DePow, Dan Barber

Future Far-IR instruments will have requirements which current sub-K coolers cannot meet:
5—10 year life
continuous cooling to 50 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 mission

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 instruments.

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



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Computational Methods Development

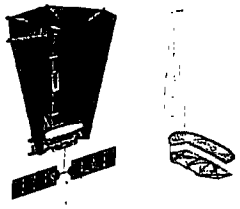
Description

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

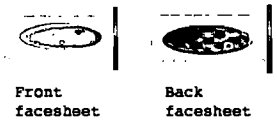
Overall Task Objectives

- 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 ···



Propagates thermal, structural & dynamic effects down to optical elements and mounts ···



And computes aberrations from which optical merit functions & sensitivity matrices can be assessed and optimized···

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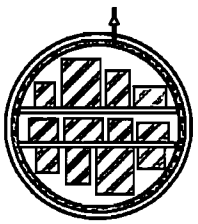
Venus Lander Pressure Vessel



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 ~½ mass of Ti shell
- Demonstrate survivability for 10+ hours in Venus environment
- Demonstrate integrated pressure vessel and thermal control system technology

Task Manager

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Partners

- JPL Mechanical Engineering (352)
- JPL Materials (353)
- Brush-Wellman
- FMW Composites
- XC Associates

Task Pressure Vessel	FY05	FY06	FY07
Identify Relevant Pressure Vessel Materials			
Identify Relevant Thermal Control Technologies			
Identify Test Facilities			
Fabricate Samples for Pressure Vessel Testing			
Design Thermal Control Technologies for Testing			
Design subscale integrated lander system			
Fabricate Thermal Control Technologies			
Develop Test Plans, Procedures			
Conduct Thermal Technology Performance Testing			
Conduct Pressure Vessel Sample Testing			
Correlate Test Results with System Models			
Total Cost ($K)	300	338	550

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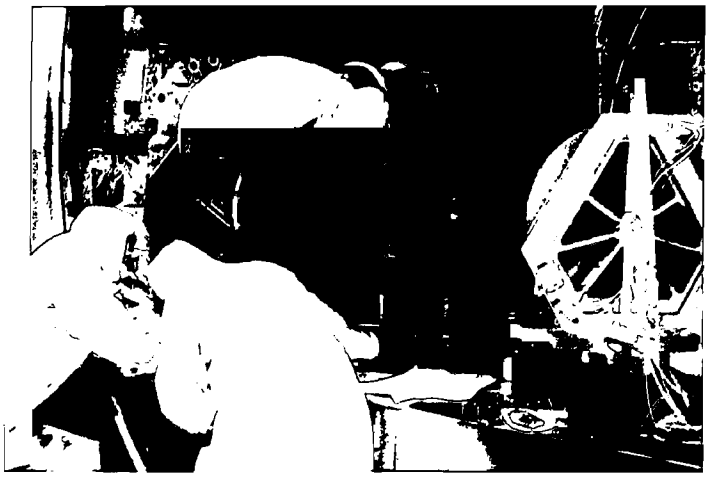
Instrument Mechanical Engineering Section



Installation of the SIM TOM-3 Compressor

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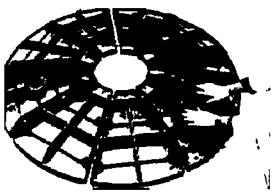
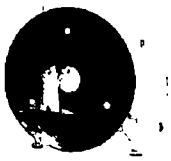
Large Mirror Technologies

- 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
  - Astrium & 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





MMS/BOOSTEC Sintered SiC
1.3 m Brazed Mirror Assembly

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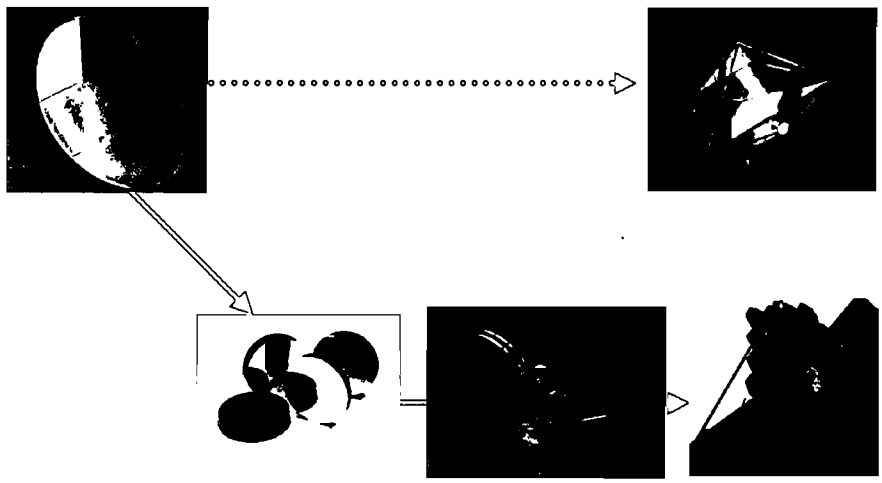
Large Aperture Mirror Technology

- Lightweight Concepts to Enable 1 kg/m^2 and less systems



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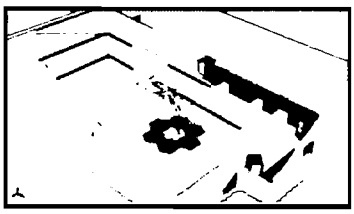
Precision Deployable Structures Testbeds



Task Manager
Greg Agnes
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Partners
- JPL INTERFEROMETRY METROLOGY AND OPTICS (3834)

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 an up to 4-m six-petal deployable test bed.
  - Include a gravity off-load system
  - Provide thermal (<0 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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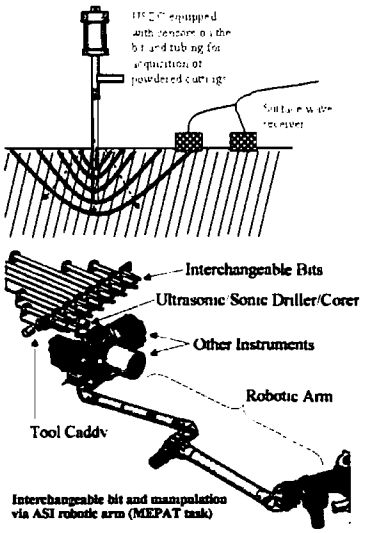
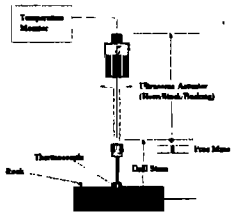
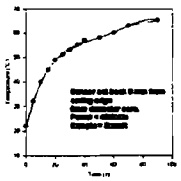
USDC: a Lab-on-a-drill

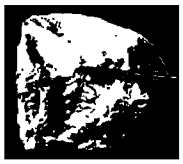
(NDEAA Lab, Yosi Bar-Cohen)

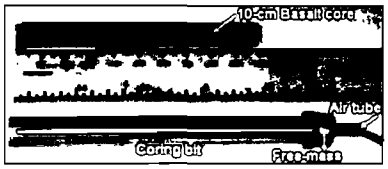


Interchangeable bit and manipulation via ASI robotic arm (MEPAT task)









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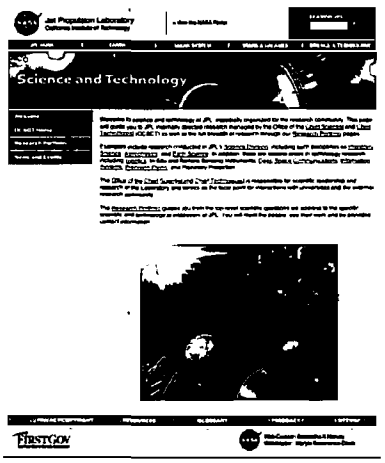
Web Sites

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

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



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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.

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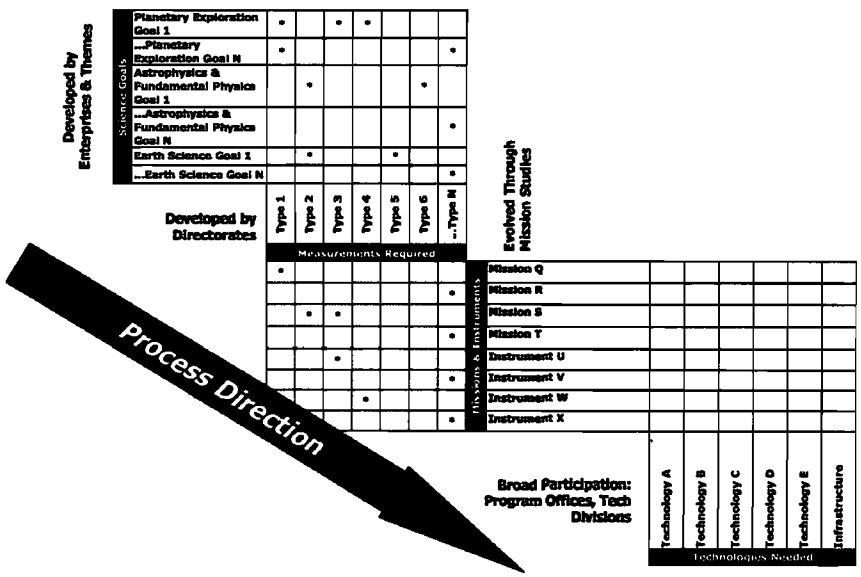
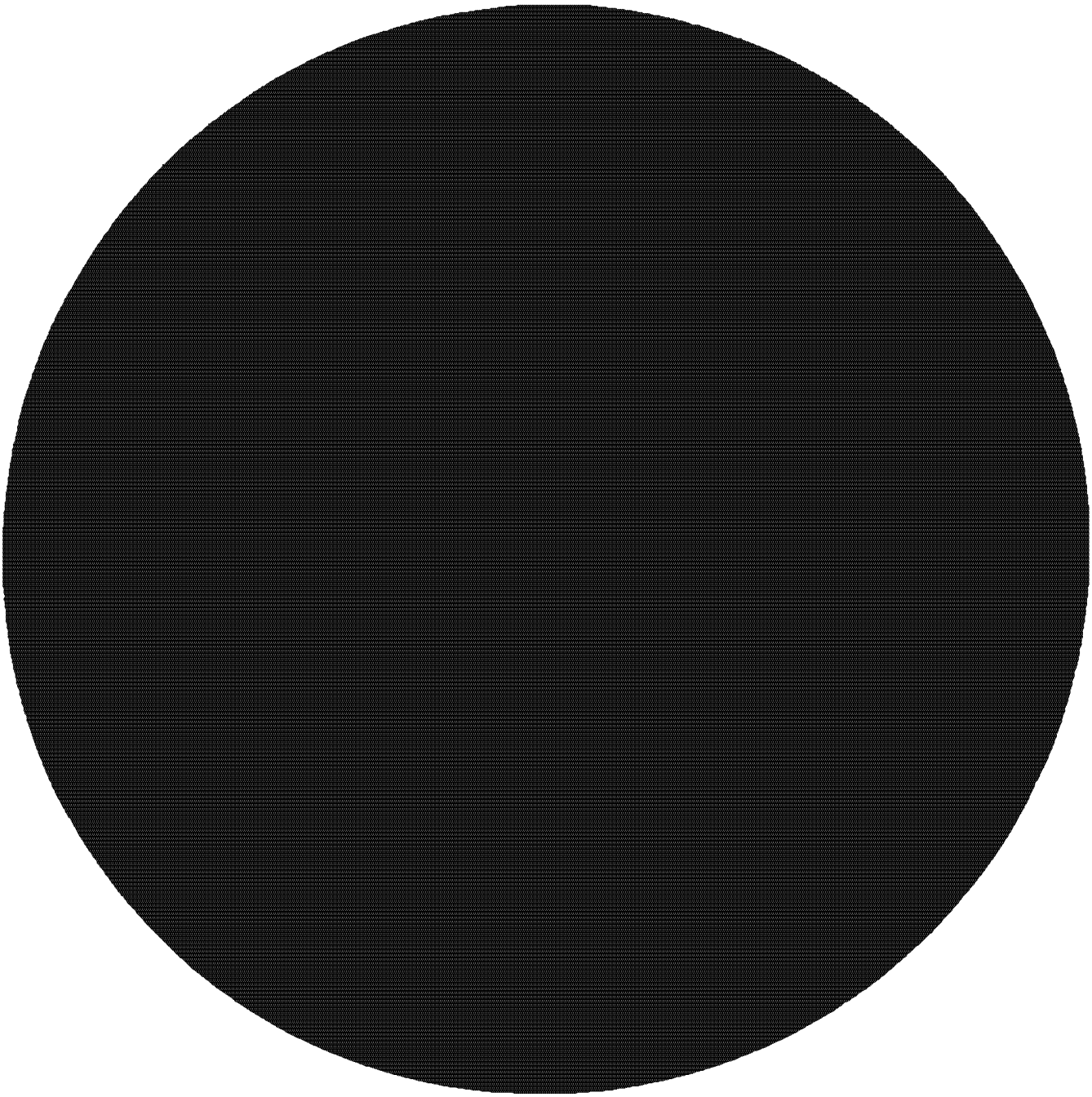
Technology Flowdown Process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