Planetary Exploration Requirements and their impact on Biomorphic Research

Dr. Butler Hine
Deputy Manager, Intelligent Systems Program
NASA Ames Research Center
bhine@mail.arc.nasa.gov
(650) 604-4756

Robotic Planetary Exploration Requirements

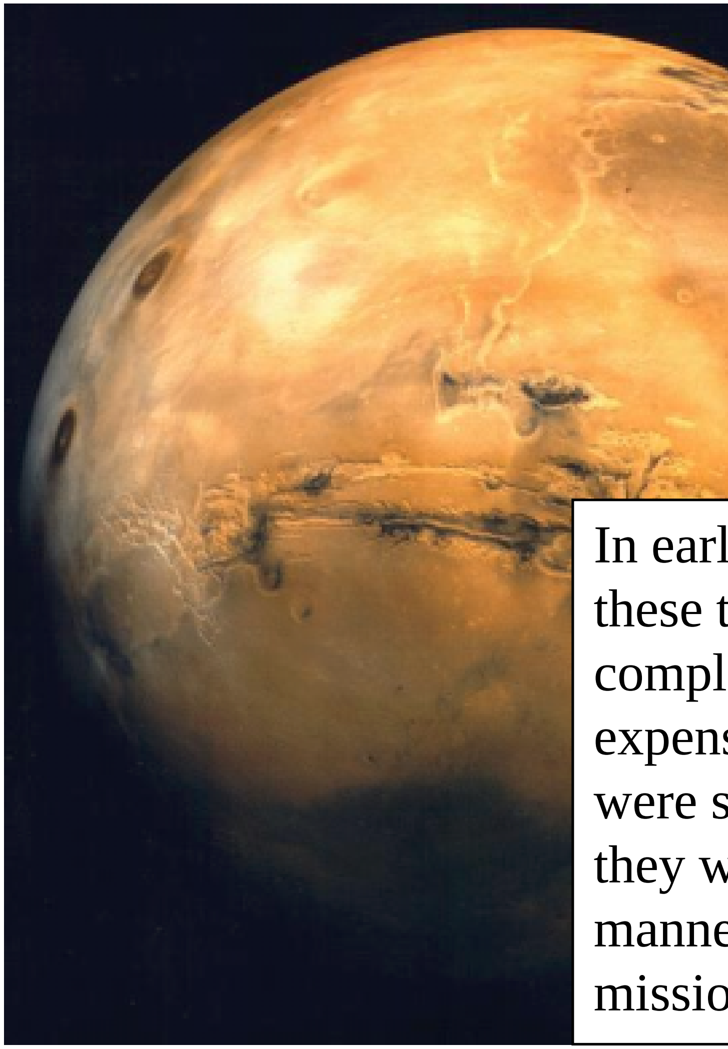
- Mobility in very rugged terrain
  - The most interesting science sites are often the most inaccessible
- Sensing
  - Multispectral Science Imagers
  - Stereo and Ranging
  - Navigation
- Manipulation
  - Sample/Measurement Preparation
  - Sample Acquisition
  - Digging/Drilling
- Communications
  - Low-bandwidth
  - Time-delayed
- Decision-making
  - Path-planning
  - Resource Utilization
  - Health and Safety

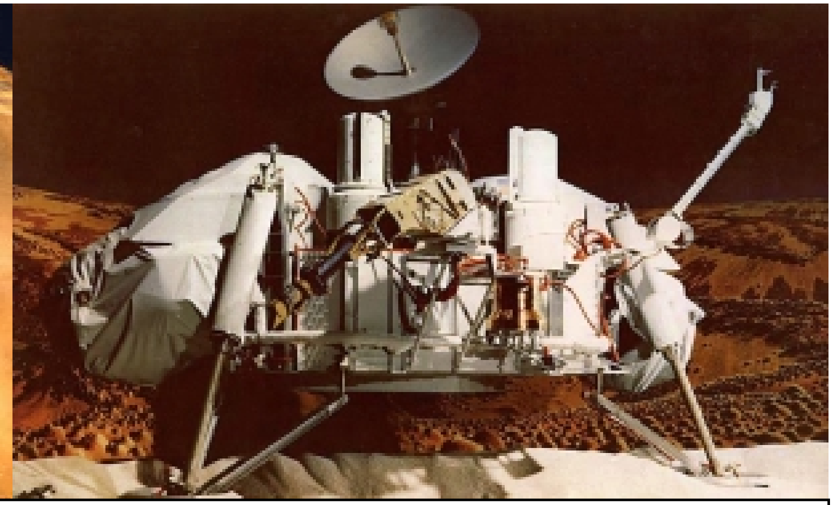
Mission Design Trades

Designs involve a trade-off between:

- Capability of the System
  - Science Return
  - Complexity
  - Reliability
- Mission Resources
  - Mass
  - Power
  - Consumables

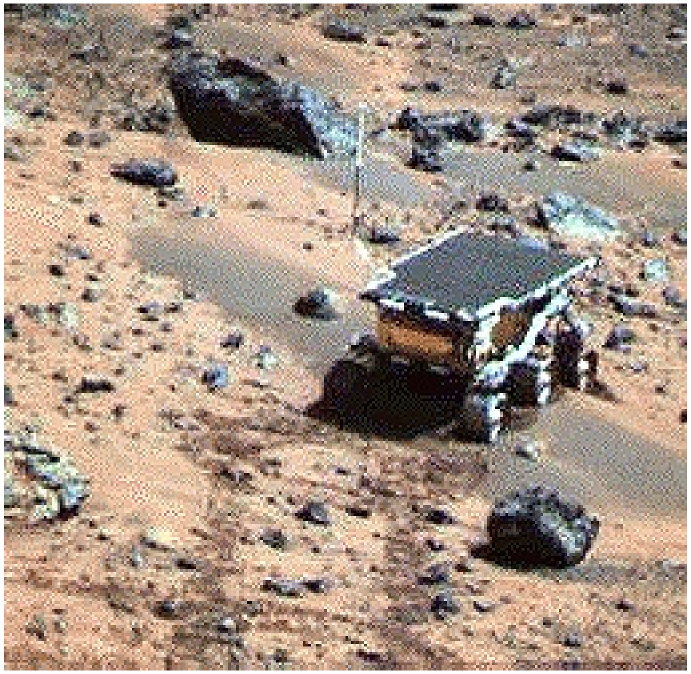
Earlier Design Philosophy

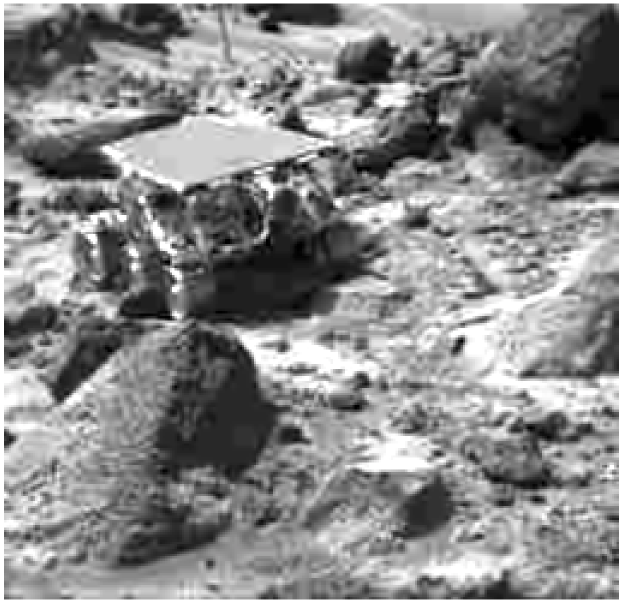




In earlier decades of space exploration, these trades often resulted in very large and complex spacecraft with very capable (and expensive) instrumentation. These systems were so expensive to design and build that they were operated in a very risk-adverse manner. It was not acceptable for these missions to fail.

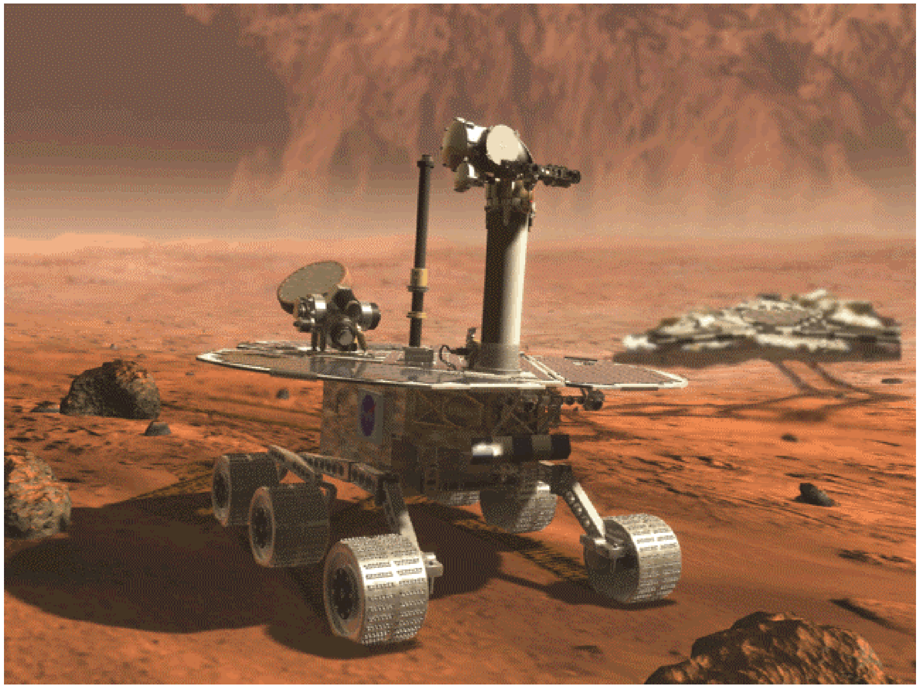
Recent Design Philosophy





In more recent years we have experienced a shift towards smaller and less expensive spacecraft (with less capability). Because these systems were less expensive and flew more often, a certain amount of increased mission risk was deemed acceptable as a result of more aggressive use of new technology.

Current Design Philosophy



Having experienced the extreme ends of this cost/capability spectrum, we are currently seeing a shift back towards the middle ground with larger and more capable systems with increased use of new technology. We are still oriented towards risk-adverse operations, however, which limits the amount and quality of science return from currently planned exploration missions.

Promise of Biologically-Inspired Systems

Biological organisms overcome many of the limitations of current state-of-the-art robotic exploration systems in several areas:

- Increased Mobility: Access and Safety
- Efficient Sensor Processing and Interpretation
- Compliant and Dexterous Manipulation
- Efficient Communication/Coordination Strategies
- Computationally-Efficient Decision-Making

The following discussion will focus on Mobility…

Wheeled Mobility (traditional)

Wheeled or tracked mobility schemes are relatively simple to control, but have severe constraints on the type of terrain they can traverse.

Walking Mobility (traditional)

Walking systems developed for planetary exploration use rigid mechanical structures and traditional low-level control techniques.

Walking Mobility (biologically-inspired)

U. Saranli, M. Buehler and D. E. Koditschek, “Design, Modeling and Preliminary Control of a Compliant Hexapod Robot," in *IEEE Int. Conf. on Robotics and Automation,* San Fransisco, CA, April 2000

Mobility platforms inspired by the strategies used by terrestrial organisms to handle rough terrain, such as compliance and redundant locomotion could allow smaller rover designs to explore rich science locations out-of-bounds to more conventional mobility designs such as wheels or tracks.

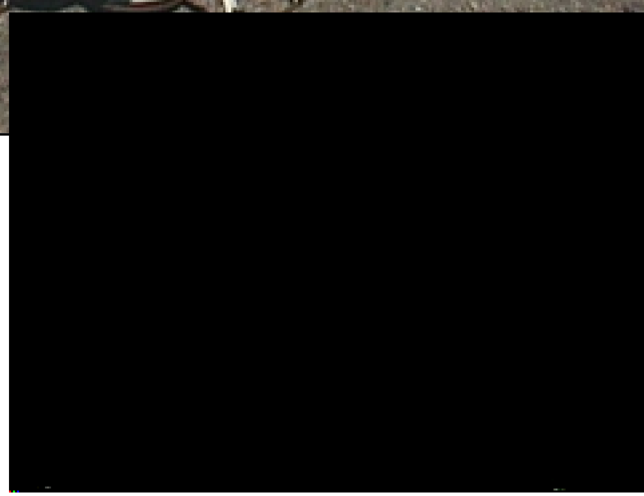
Walking Mobility (biologically-inspired)

Frank Kirchner (GMD: Bonn): Robot Scorpion

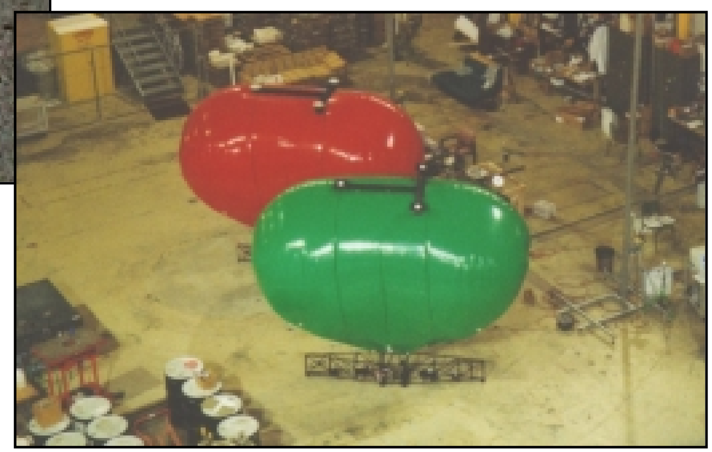
Air Mobility (traditional)

NASA Ames
Autonomous Rotorcraft

Sikorsky Cypher



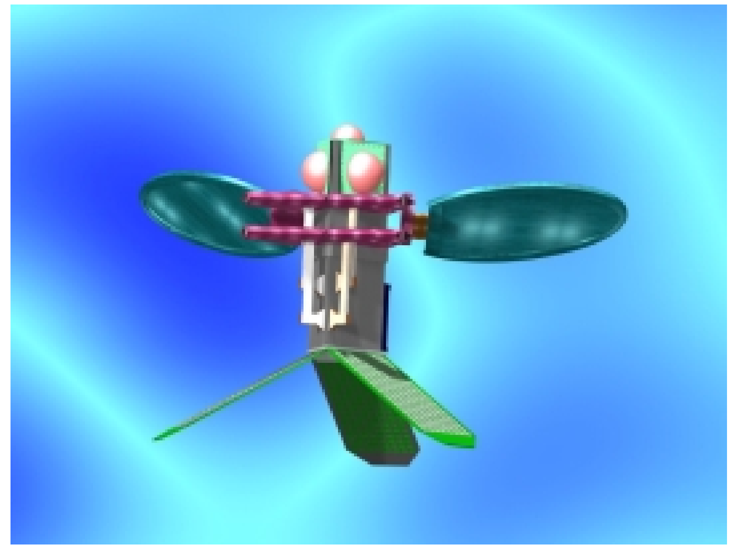
Georgia Tech Aerial Robotics



Stanford/MIT Formation Blimps – J. How

Air Mobility (biologically-inspired)

Nathan Chronister's E Bird
The first micro electric ornithopter.

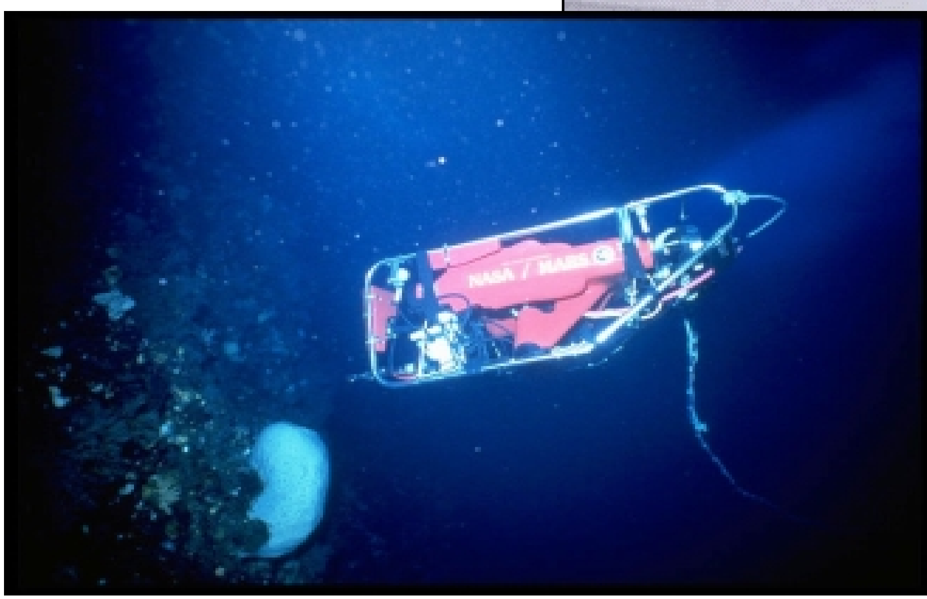


Micromechanical Flying Insect (MFI) Project
R.S. Fearing, et al., UCB

Alternative mobility strategies, such as micro-fliers, can provide access to even the most difficult terrain.

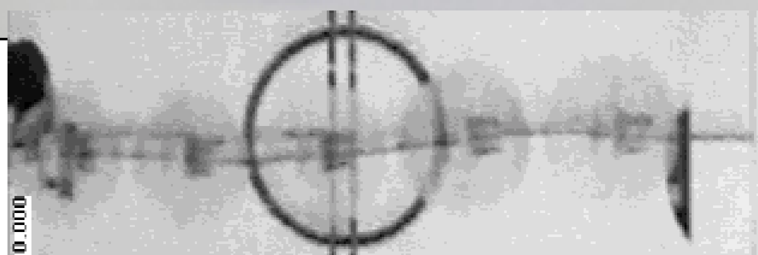
Underwater Mobility (traditional)

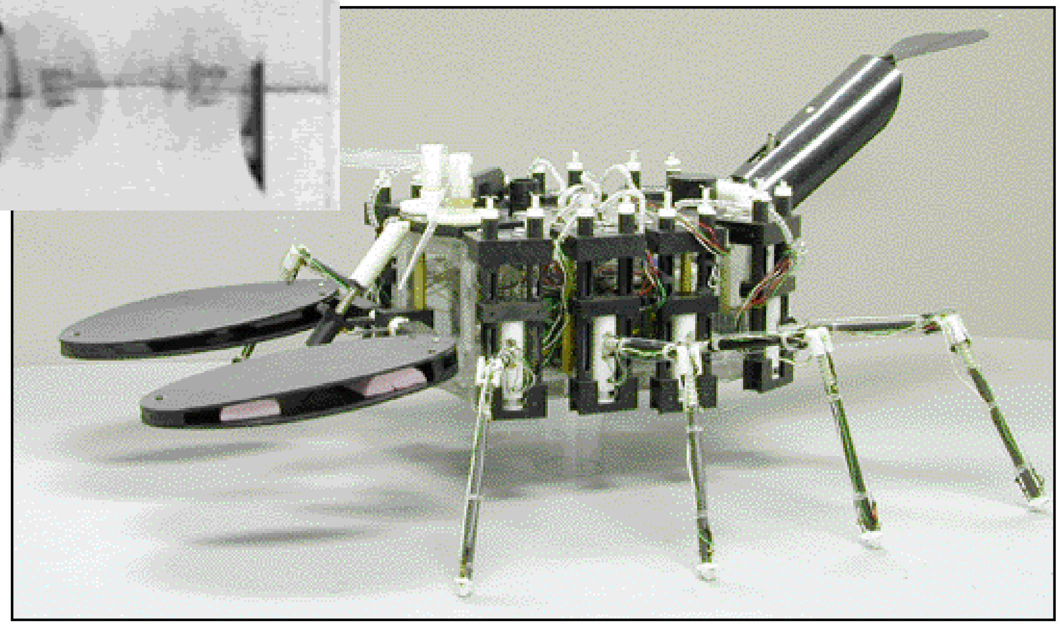
TROV – NASA Ames



Autonomous Benthic Explorer (ABE) - WHOI

Underwater Mobility (biologically-inspired)





Ayers., J., et al. (1998) A Modular Behavioral-Based Architecture for Biomimetic Autonomous Underwater Robots. In: Proc. of the Autonomous Vehicles in Mine Countermeasures Symposium. Naval Postgraduate School.

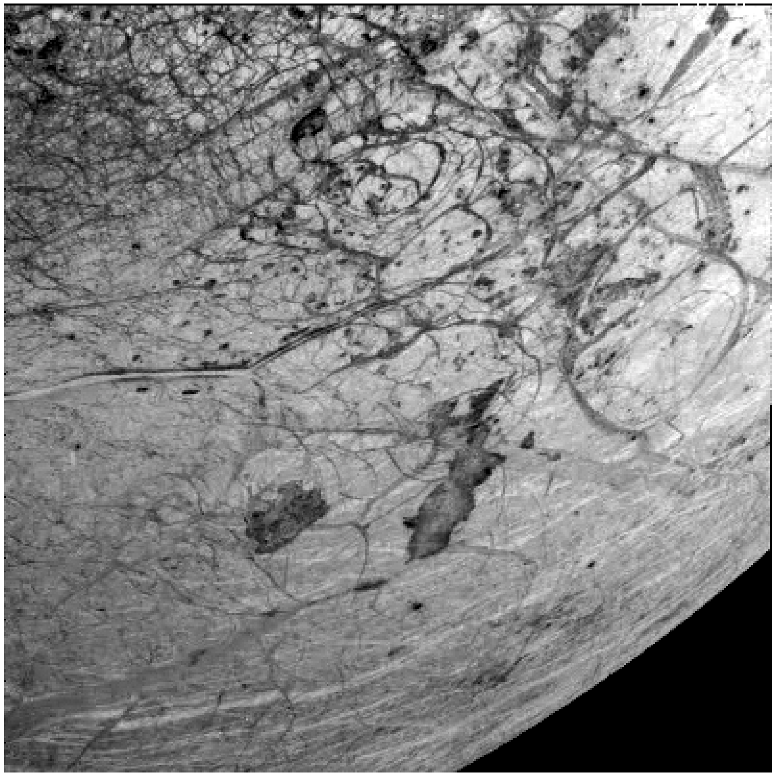
An Extreme Mission Example

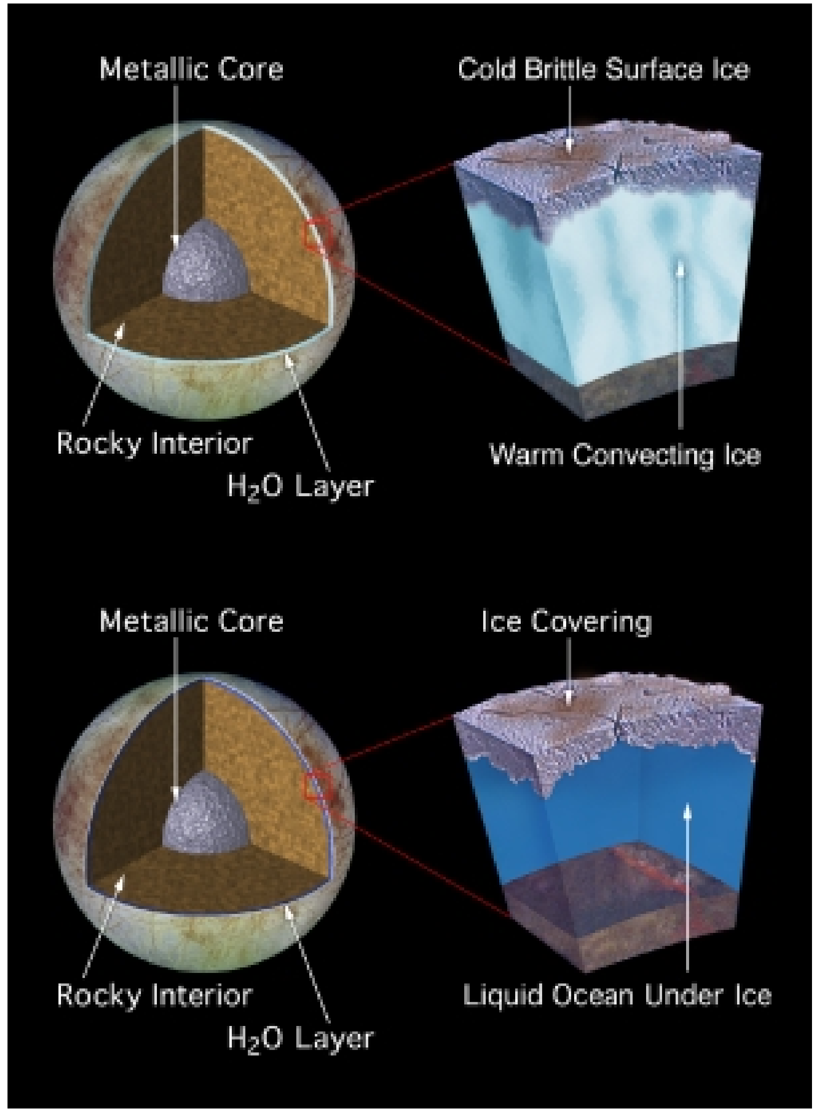
An example mission which represents extreme conditions and provides a rich set of constraints for planetary exploration robotics is the exploration of Europa's possible ocean.

Evidence for a Liquid Ocean

- Few impact craters, indicating a young surface (<10M years)
- Orbital resonance of Io, Europa, and Ganymede produce tidal kneading, which results in a hot interior
- Radio signal analysis of Galileo's trajectory measures the gravitational field, and hence the internal mass distribution: iron core, rock, water crust (~100Km thick)
- Surface features indicate hard ice floating on a flowable medium (chaos regions, diapir "blobs", morphology of impact craters)
- Stress patterns from tidal kneading swept the surface over time, indicating that the surface is rotating faster than the interior (surface is floating on liquid bearing)
- Temperatures at higher latitudes are higher at night, indicating strong internal thermal source.
- Magnetometer readings indicate that there is an induced magnetic field, such as produced by a conductive liquid reacting to Jupiter's magnetic field

Possible Internal Structure





Mission Profile for a Europa Sub

Goal: *Search for Life*

- Europa landing
- Comm/Power infrastructure deployment
- Ice crust penetration
- Initial liquid characterization
- Initial mapping survey
- "Normal" liquid characterization
- Trace signature tracking
- Vent characterization and sampling

Mission Requirements

- Adaptable Surface and Underwater Mobility
- Continuous Vehicle Health Management
- Mission planning
- Resource scheduling
- Environmental map building
- Tracking and navigation
- Sample collection
- Target-of-opportunity identification

A JPL proposal for a Europan ocean explorer

Conclusions

Adapting engineering solutions derived from observing biological organisms to robotic exploration missions can result in increased science return, decreased mission complexity, and increased survivability. The use of mobility, sensing, manipulation, communications, and decision-making strategies that work very well in nature can ultimately result in a huge increase in the amount and quality of the science returned