Project Prometheus and Future Entry Probe Missions

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What Is Project Prometheus?

- Program to develop a broad range of nuclear power & propulsion techs
  - Nuclear electric power & propulsion (NEPP)
    - Fission reactors with thermal-to-electric conversion systems
    - High-power ion propulsion systems
    - Advanced electric propulsion (e.g., magnetoplasma dynamic (MPD) systems?)
  - Nuclear thermal propulsion (NTP)
    - Newly considered; higher thrust at lower $I_{SP}$
  - Radioisotope power systems (RPS)
    - RTGs, mini-RTGs
    - Milliwatt thermoelectric systems
    - Stirling power systems

- ...for the Space Science & Space Exploration communities
  - Anywhere in the solar system, regardless of solar energy availability
    - Outer solar system
    - Permanently shadowed regions
  - Potential power source for human exploration programs
What Capabilities Can Project Prometheus Offer?  
What Mission Types Are Being Considered?

- **Capability**: very high total energy from fission-based systems
  - High power (kW to MW) for long durations (> a decade)

- **Capability**: very high propulsive delta-V
  - Ion propulsion specific impulse (thousands of seconds)
  - Ion-propulsion-level accelerations (~10^{-4} m/s^2) for more than a decade
    - Anywhere in the solar system, independent of heliocentric distance

- **Missions considered**: ones making appropriate use of the technologies
  - Need very high post-launch delta-V (10’s of km/s)
    - Chemical systems can provide up to a few km/s
    - Pushing a large payload to a relatively low delta-V is *not* efficient use of NEP
  - Need high power (10’s of kWe or more), for years, at the destination
    - High power science instruments
    - High data rate telecommunications
Jupiter Icy Moons Orbiter (JIMO)

Fission-Powered Vehicle

- Turbine-generated electric power, ~100 kWe
- Ion propulsion (probably Xenon propellant)
  - $I_{sp}$ 6000 - 9000 s
  - Delta-V capability tens of km/s
- When propulsion system is not active, high power is available for science instruments
  - Extremely high data rates
- Launch 2011-2013?
- Some mission designs might allow delivering Jupiter entry probes
  - Significant impact to mission
    - Payload mass
    - Mission duration
How Are Mission Opportunities Changing?

– Decadal Survey priorities were based on Pre-Project Prometheus tech
  • Priorities for science objectives only partly influenced by technical feasibility
  • Flight schedule priorities heavily influenced by tech development schedules

– Project Prometheus re-arranges technical feasibility
  • Feasibility limitations by power or propulsion apply to fewer missions
  • Multiple ways this can affect mission schedules; examples:
    ♦ A mission’s high-priority science is enabled sooner by NEPP
    ♦ Earlier implementation of one mission pushes another mission later
    ♦ Prospect of greater science return with NEPP implementation pushes it later

– Lower-priority missions steered to Discovery, New Frontiers Programs
  • Example: Terrestrial-planet atmospheric entry missions
  • NASA faces a “mission size gap” between New Frontiers Program & Project Prometheus
Missions Of Interest a Year Ago

– Some mission concepts directly involve atmospheric entry vehicles
  • Venus In Situ Explorer ("VISE"; New Frontiers candidate)
  • Venus Sample Return
  • Jupiter Polar Orbiter With Probes ("JPOP"; New Frontiers candidate)
  • Titan Explorer
  • Neptune Orbiter With Probes (NASA Vision Mission concept)

– Other concepts might add entry probes, but then-current designs did not have them
  • Venus Aeronomy Probe
  • Io Electrodynamics
  • Saturn Ring Observer
Missions Now Being Considered
For Further Study

Science direction from Decadal Surveys and NASA-convened groups

• Example: Second Outer Planets Forum held June 21-22, 2004

Project Prometheus Advanced Missions Office is tasked with studies

• Decisions about which missions to study are made at NASA HQ
• Studies are performed by the multi-center “Team Prometheus” led by JPL
• Missions deemed highest priority for near-term studies:
  - Saturn / Titan (study largely completed)
  - Neptune / Triton (study just began; considered directly applicable to Uranus)
  - Kuiper Belt (multiple objects)
  - Interstellar Precursor / Heliopause
  - Comet Cryogenic Sample Return
  - Multiple Asteroid Rendezvous and Sample Return

Top two missions on the list potentially involve entry probes

• **Saturn** entry probes; **Titan** mobile surface/atmospheric platform (aerobot?)
• **Neptune** (also, **Uranus**) entry probes; **Triton** lander?
Galileo-Style (Conventional) Probe Delivery

- Delivery from approach, several months before probe entry
- Orbiter on entry trajectory; release, then small delta-V deflects & times
- Orbiter is overhead of probe during its descent
Conventional Delivery and Support of Multiple Probes

Targeting Maneuvers, ~6 mo before encounter

Carrier/Relay Spacecraft (CRSC)

CRSC receives data during a polar flyby, then plays it back from heliocentric orbit

Locus of potential entry sites is roughly a circle of radius ~30° lat, centered opposite the approach direction

To Sun

~100 mil km!
How Entry Probe Delivery From an NEP Vehicle Is Different

- Delivery from approach
  - Delivery vehicle can (sometimes, must) accelerate continuously after release
    - E.g., to achieve capture into orbit
    - Can result in untenable data relay situations
      - Large distances between probe and orbiter at entry
      - Orbiter zenith angle (seen from probe) is too large for useful communications
  - Mitigating this problem can have large impacts on the orbiter
    - Major changes in trajectory design, causing increases in required delta-V
    - Adding a dedicated relay subsatellite, with a cost and complexity penalty

From Balint et al., 2003
How Entry Probe Delivery From an NEP Vehicle Is Different

Delivery from near-circular orbit

- Orbiter must expend propellant to carry probe into orbit
- Imposes large delta-V requirements on the entry probe
  - Large delta-V just for entry
  - Timing increases delta-V
  - For orbits larger than several planetary radii, entry speed may not be too different from "on-approach" situation
- Unless the orbit radius is the right size, angular rates can be quite different

[Diagram showing orbital positions and delta-V vectors]
How Entry Probe Delivery From an NEP Vehicle Is Different

Delivery from eccentric orbit

- Orbiter must expend propellant to carry probe into orbit
- Smaller delta-V requirements on the entry probe
  - Smaller timing penalty
  - Might be possible to perform the delta-Vs with the orbiter
    - Apoapse must be high for sufficient operations time
- Probe-orbiter distance smaller
- Overflight altitude must not be too low
  - Need reasonable overhead time
- Greatly increased flexibility in entry locations
Concluding Remarks

Still, many future opportunities for entry probe missions

- Many science objectives at many potential destinations
- Available mechanisms for implementing missions have changed
  - Gap between New Frontiers and “Flagship”

Opportunities for methodological & technological innovation

- Design space for delivery and support has not been exhausted
  - Many avenues for new ideas
  - Old ideas are being “dusted off”
- Design of entry vehicles themselves is not significantly altered
  - One exception: possible addition of in-space delta-V capability

Realizing missions requires significant community consensus about mission objectives