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EUROPA LANDER

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ABSTRACT

An Europa Lander mission has been assigned high priority for the post-2005 time frame in NASA's Space Science Enterprise Strategic Plan. Europa is one of the most scientifically interesting objects in the solar system because of the strong possibility that a liquid water ocean exists underneath its ice-covered surface. The primary scientific goals of the proposed Europa Lander mission are to characterize the surface material from a recent outflow and look for evidence of pre-biotic and possibly biotic chemistry. The baseline mission concept involves landing a single spacecraft on the surface of Europa with the capability to acquire samples of material, perform detailed chemical analysis of the samples, and transmit the results to Earth. This paper provides a discussion of the benefits and status of the key spacecraft and instrument technologies needed to accomplish the science objectives. Also described are variations on the baseline concept including the addition of small auxiliary probes and an experimental ice penetration probe.

INTRODUCTION

In cooperation with NASA's Solar System Exploration Subcommittee (SSES), the Jet Propulsion Laboratory (JPL) is conducting a series of studies to assess the feasibility of planetary science missions proposed for launch in the 2006-2010 time frame. This report describes the results of two of these studies, dealing with concepts for an Europa Lander mission[1,2]. The first studied a baseline single lander mission as the simplest option potentially capable of satisfying the highest priority science objectives. The second examined enhancing options including a broader instrument set, additional small landers, and ice descent experiments. Included here are discussions of the science objectives, the major design trade-offs, the resulting mission concepts, and the enabling technology developments.

Europa is scientifically interesting because of the strong possibility that a liquid water ocean exists underneath its ice-covered surface[3]. If a subsurface ocean exists on Europa, it can be assumed to contain both organic molecules and heat sources from tidal effects, the decay of radioactive elements, and geophysical mechanisms. Europa's subsurface ocean environment may be similar to that of the deep ocean hydrothermal vents on Earth where remarkable life forms have been detected. The possibility of finding traces of biotic or pre-biotic materials from recent ocean outflows on the planetary surface has led to a high science interest in a Europa Lander mission.

SCIENCE OBJECTIVES AND MEASUREMENTS

Science and Measurement Objectives

This section presents the science and measurement objectives for the Europa Lander mission as established by the Prebiotic Chemistry Campaign Strategy Working group. The fundamental objective is: Land on and/or penetrate into one or more surface sites and access very young material (material as recently exposed to the surface as possible) in order to complete the following science and measurement objectives:

(IA) Characterize the near-surface composition, any organic chemistry, salts and indicators of high-temperature water-rock interaction, at depths below the radiation processing depth.
  a. At a minimum, this should involve one capable lander or penetrator; the possibility of additional simpler surface stations should be examined.
  b. Sample material from at least 1 decimeter below the surface.
  c. Determine the organic and other molecular composition (anions, cations, salinity, and volatiles (CO_2, CH_4, O_2, etc.)) at high sensitivity.
  d. Determine the elemental and isotopic composition, especially those potentially indicative of high-temperature rock-water interactions [e.g., Mg] and those relevant to primary biological productivity [such as P, $^{12}C/^{13}C$ and $^{14}N/^{15}N$].
  e. Characterize physical chemistry [pH, redox potential].

(IA) Determine the compositional, geophysical, and geological context for the surface sites on a global, regional, and especially local (~5–10 km proximity) scale.
  a. Compositional: Characterize the global, regional, and local compositional context of the surface sites
  b. Geophysical: Analyze the subsurface structure, ice thickness, and possibly local heat flow at one or more sites on Europa. Measurements would include seismic, magnetotelluric, thermal mapping and subsurface temperature (heat flow) measurements.
  c. Geological: Characterize the global, regional, and local geological context of the surface sites.

(IA) Search for indications of Europan biology, including chemical or isotopic signatures of potentially diagnostic non-equilibrium processes.
  a. Structural and compositional analysis of organics and refractories.
  b. Microscopic analysis.
  c. Stable isotopes.

(IB) Prepare for a subsequent ice-shell penetration mission.
  a. Characterize the subsurface structure, ice thickness, and local heat flow at one or more sites on Europa. Measurements would include seismic, magnetotelluric, and subsurface temperature measurements.

Instruments

Sample instrument sets based on technology projections for the appropriate timeframe were defined to provide an understanding of the corresponding demands on mission resources.

1. Baseline Option

For the baseline option the instrument set is intended to be the minimum capable of satisfying the 1A requirements. This includes a descent imager to establish the geological context of the landing site, a panoramic imager to provide local site documentation, a visible/near IR point spectrometer, a seismometer, an aqueous chemistry experiment (addressing bulk chemical properties including redox potential, pH and electrical conductivity), a gas chromatograph/mass spectrometer (GCMS), and a Raman spectrometer for molecular analysis. Table 1 provides key parameters for each instrument. The content of the data field is intended to represent the total data required for the mission for each instrument, regardless of downlink time available. An exception exists for the seismometer, where the number entered represents a data rate which should be sustained for the life of the lander and link. This provides a total of 10.8 kg of instrumentation.

Table 1: Lander Instruments for Baseline Option

	Mass, kg	Power, W	Data, Mb
Descent Imager	0.2	1.0	50.0
Panoramic Site Imager	2.5	2.0	170.0
Visible/Near-IR Point Spectrometer	1.0	1.0	2.0
Seismometer	0.5	1.0	1.0/hr
Aqueous Chemistry	1.1	2.0	2.0
GCMS	3.0	15.0	2.0
Raman Spectrometer	2.5	0.5	2.0

2. Full-Science Option

The "full-science" option instruments included the baseline set (with, in some cases, adjusted parameters) plus three additions. These were an optical microscope, an elemental analysis experiment (addressing organics and biology) and a set of environmental sensors (concerned with ambient temperature, insolation, etc.). The full-science option imposes a total load of 12.9 kg on the spacecraft.

Table 2: Lander Instruments for Full-Science Option

	Mass, kg	Power, W	Data, Mb
Descent Imager	0.2	1.0	50.0
Panoramic Site Imager	2.5	2.0	170.0
Visible/Near-IR Point Spectrometer	1.0	1.0	2.0
Seismometer	0.5	1.0	1.0/hr
Aqueous Chemistry Instrument	1.1	2.0	2.0
GCMS	3.0	15.0	2.0
Raman Spectrometer	3.0	3.0	2.0
Microscope	0.4	3.0	50.0
Elemental Analysis Instrument	1.0	3.0	2.0
Environmental sensors	0.2	0.2	

3. Auxiliary Landers

Several deployment options were studied, all with the same set of instruments on each probe: an aqueous chemistry station, a chemistry microlab for detection of organics, a molecular absorption spectroscopy experiment, and a set of environmental sensors.

Table 3: Auxiliary Lander Instruments

Instrument	Mass, kg	Power, W	Data, Mb
Aqueous Chemistry	1.1	2.0	2.0
Chemical Microlab for Organics	1.0	1.0	2.0
Molecular Absorption Spectroscopy (TDLs)	1.0	6.0	2.0
Environmental Sensors	0.2	0.2	

MISSION DESIGN

These studies assume a launch in the 2007-2009 time frame. The original specification was for a direct transfer to Jupiter, but the energy requirements of this mission were prohibitive. Instead, a launch to a C_3 of 35 km^2/sec^2 followed by a triple Venus gravity assist trajectory was selected. This lowers the launch requirements but has the undesirable effect of increasing the Earth-Jupiter trip time from 3 to 6.5 years.

The mission design minimizes the propulsion energy requirement to arrive in orbit by performing a satellite tour after braking into Jovian orbit. This will crank the orbit energy down using gravity assist combined with propulsive maneuvers. A Ganymede flyby as the spacecraft approaches Jupiter reduces the required energy for Jupiter orbit insertion and perijove raise maneuvers, resulting in a 200-day orbit. There follows a sequence of outer Galilean satellite flybys augmented by propulsive maneuvers to reduce the energy of the orbit until it is inside Ganymede's orbit. Then, a series of reverse Europa flybys pump the orbit down to a 6:5 resonance with the target satellite. Europa orbit insertion burn follows, with the spacecraft ending up in a 100-km orbit around the satellite. Descent to the surface is from this orbit. The spacecraft velocity changes for arrival at Jupiter, satellite touring, and Europa orbit and descent are shown in Table 4.

The baseline landed mission covers three rotations of Europa for a total encounter duration of 10.5 days. In these 10.5 days, the instrument suite will collect a total of 145 Mb of data. Europa will be in view of the Earth roughly 24 hr every rotation.

Table 4: Breakdown of Spacecraft Velocity Changes

Mission Event	ΔV (m/s)
Jupiter Orbit Insertion/Perijove Raise	750
Europa/Callisto Tour	310
Europa Tour and Orbit Insertion	350
Descent to surface	2200
Margin for g-loss (10%)	360
Total ΔV	3970

SPACECRAFT SYSTEMS

This section describes the baseline lander. A dominating factor in the design of a Europa Lander spacecraft is the radiation environment in which the lander must operate. The study estimated a 2 Mrad total dosage at the end of the mission. The system design is based on the planned third delivery from the Deep Space Systems Technology (X2000) Program. This program has been established to develop new technology for deep space missions and to deliver prototypes of flight qualified systems and subsystems incorporating the technology. The third X2000 delivery, scheduled for 2006, will include very light weight radiation-hard avionics. The radiation hardening is expected to be at about 1 Mrad at the component level, so some shielding will be required for most components. A few components (e.g., gyros) will not be radiation hard and will require substantial shielding.

Table 5. Spacecraft Mass and Power

	Mass (kg)	Power (W), Surface Operations
Payload		
Drill	6	
Instruments	10	1
Bus		
Attitude Control	18	16
Command & Data	1	3
Power	12	10
Propulsion	52	0
Structure	138	0
Spacecraft Adapter	15	
Cabling	14	
Telecom	8	27
Thermal	25	13
Shielding	15	
Bus Total	298	
Spacecraft Total (Dry)	314	70
Mass/Power Contingency	94	21
Spacecraft with Contingency	408	91
Propellant & Pressurant	933	
Spacecraft Total (Wet)	1341	
Delta 4 M+ Launch Capability	1730	

A high level of redundancy was used throughout the design because of the long duration of the mission. Mass and power estimates for the spacecraft systems are shown in Table 5.

ENHANCEMENTS TO THE BASELINE LANDER

The first enhancing option looked at the mass and power costs of increasing the science payload to the "full science" instrument set described above. Launch mass and cost for this and other cases described below are compared with the baseline lander case in Table 6. This section also summarizes the results of studying several options for deployment of the auxiliary landers:

1. Deploy from main lander after it lands.
2. Deploy from main lander in a hovering mode ("local probes").
3. Deploy from main lander during descent.
4. Deploy from main lander while in a 100-km orbit ("global probes").

Also included in Table 6 are estimates for an enhanced science payload and for deployment from the main lander of an experimental ice descent probe.

TABLE 6. COMPARISON OF ENHANCEMENT CASES

CASE	BASELINE	FULL SCIENCE	LOCAL PROBES	GLOBAL PROBES	ICE DESCENT EXPERIMENT
DESCRIPTION	SINGLE LANDER WITH MINIMUM INSTRUMENTATION FOR 1A OBJECTIVES	SINGLE LANDER WITH EXPANDED INSTRUMENTATION	BASELINE LANDER + 3 AUXILIARY PROBES WITHIN 15 KM OF MAIN	BASELINE LANDER + 3 WIDELY DISPERSED AUXILIARY PROBES	BASELINE LANDER, EXPERIMENTAL PROBE DESCENDS 100 M
PAYLOAD INCREASE (KG)	-	10	55	180	20
LAUNCH MASS (KG)	1340	1520	2200	3000+	1700
COST ($M,FY99)	370	390	510	540+	400

A common problem with Options 1–3 is how to get the data back from the auxiliary landers to the main lander for relay to Earth. After considering several innovative schemes, the team chose one in which a transponder would be launched vertically from the main lander. Telecom requires a 300 s total flight time of which 180 s is used for bent pipe data transfer. The launch velocity is 195 m/s and maximum altitude 15 km for a 300 s flight time. This method was considered practical given the small size of the transponder (a few hundred grams).

Option 1 deploys the auxiliary landers from the main lander after it lands. To achieve a 5-km separation from the main lander would require a launch velocity of 81 m/s at 45° above the horizontal. The maximum altitude is 1250 m, flight time 88 s, and impact speed 81 m/s. System designers considered both rocket and compressed gas launchers. This option was considered impractical given the mass and volume of the auxiliary landers and was dropped from further study.

Option 2 is to drop the auxiliary landers from main lander as it moves across the surface in a hovering mode. Hovering is expensive in terms of ΔV cost, and it is necessary to minimize the hover time. As a point design, the three auxiliary landers and the main lander land in a 15 km line. The hover time is minimized by increasing the horizontal velocity of the main lander along this line. However, if the horizontal velocity is too large, the auxiliary lander impact velocity will exceed 100 m/s. A horizontal velocity of 75 m/s was assumed at a hover height of 1 km. The auxiliary lander impact speed is 91 m/s. The hover duration is 200 s, and the hover ΔV cost is 260 m/s. An additional 75 m/s is required to stop the main lander giving a total of 335 m/s for

Option 2. This option was analyzed by Team X resulting in a total launch mass of 2200 kg.

A modification of Option 2 is to drop the auxiliary landers in some pattern other than a straight line. In this case the ΔV requirement is increased because the horizontal velocity direction must be changed each time an auxiliary lander is dropped.

Option 3 is to deploy the auxiliary landers during main lander descent. The trajectory will be a curved path from the descent ellipse to the landing site. Since there will be a component of horizontal velocity, there is an opportunity to drop the auxiliary landers in a straight line along the surface. The landers could be separated by considerably more than 5 km. This option needs further study.

In Option 4 each probe applies a 21 m/s retro impulse to descend from the 100 km orbit to a periapsis of 2 km. At periapsis, the probe applies another retro-impulse to cancel the 1450 m/s horizontal velocity. The probe falls to the surface impacting at 72 m/s. The main lander would stay in orbit for a few days to relay the data from the auxiliary landers.

The last option in Table 6 represents a technology experiment to try out a probe that uses radioisotope heat sources to melt its way downward through the ice to depths of 100 m or more. Periodically the probe would drop off small transponders to form a link for communicating with the surface base.

TECHNOLOGY NEEDS

Several technology advances are needed to enable useful science return from a landed mission on Europa. The spacecraft will require novel, lightweight, radiation-tolerant components and, in the current landing scenario, must be able to perform an autonomous precision landing on Europa's surface while avoiding poorly defined hazards. New technologies are also necessary for the miniaturized instruments which will perform the desired scientific investigations.

Radiation-Tolerant Components

All of the avionics and instruments on the proposed Europa Lander will require radiation-hard electronics. The capability to survive a total ionizing dose (TID) of ~1 Mrad or greater was assumed in estimating shielding mass. The availability of radiation-hard space-qualified electronics is perhaps the most critical technology requirement for enabling future Europa missions and is being addressed in the Europa Orbiter design for many of the applicable functions. In addition to radiation-hard electronics, other instrument components (i.e. optical fibers, optical detectors, charged-particle detectors) must be designed or modified to survive in Europa's harsh radiation environment without the need for massive radiation shielding.

Devices for Acquiring, Distributing, and Processing Surface Material

The specific sample-handling strategies will depend on the instruments, but at least four types of general sample handling devices are likely to be needed by the proposed Europa Lander mission. These are; a drilling and coring device for acquiring samples at depths of up to a meter below the surface, a sample distribution device, a vacuum-sealable chamber for melting water-ice in Europa's high vacuum environment, and sample purification and concentration systems consisting of membrane and/or microfluidic devices.

Lightweight, Low-Power Instruments

Important technology developments for Europa Lander instruments can be divided into two categories: reducing the mass and power requirements of existing instruments while increasing or maintaining the science return, and developing entirely new instruments to study pre-biotic and biotic chemistry. Development of smaller, more capable instruments is required to meet the science goals of the mission.

Autonomous Landing and Hazard Avoidance

The surface of Europa has been described as being "rough at all scales". Images from precursor missions will be used to establish the desired landing zones but will not identify hazards at the scale of the lander. As a result, the lander must be extremely robust or must be able to autonomously avoid large surface irregularities.

Propulsion Technologies

Table 5 shows that propulsion systems account for more than 80 percent of the launch mass so propulsion technology advances can have a significant payload impact. This includes both specific impulse increases and component mass reductions. Although not covered in this study, advances in low thrust propulsion technology (solar electric or solar sail) have been found in other studies to be potentially beneficial to a Europa mission.

CONCLUSIONS

A Europa Lander mission satisfying the objectives of the SSES could be feasible for launch in the 2007-8 timeframe with appropriate investment in the technology areas described in the previous section. More work is needed to find an affordable way to visit more than one site.

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