Europa Orbiter Mission Options

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Abstract— In August 2000, an independent assessment of the Europa Orbiter baseline mission was performed to evaluate the planned implementation. As part of this activity, multiple alternative mission concepts were investigated that could meet the full science objectives as well as concepts that could meet a reduced set of science objectives. The results of the study validated the estimated costs of the mission, while recommending a modified mission approach that reduced the overall risk of the mission.

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1. INTRODUCTION

The exploration of Europa, one of the Galilean satellites of Jupiter, is of high priority because of the possibility of discovering a liquid ocean under its icy crust. Europa is strongly affected by the gravitational pull of Jupiter. It is speculated that flexing of Europa's crust induced by Jupiter's gravitational pull creates an environment wherein a liquid ocean could exist between the solid core and the ice crust. Exploration by the Galileo spacecraft provides tantalizing evidence for a liquid layer[1][2], however to conclusively prove its existence requires a mission specifically designed to verify the hypothesis.

The Europa Orbiter mission was designed to make the critical measurements to conclusively verify the existence of the ocean. This mission would also provide important information on the surface and near subsurface environment, and provide precursor information for subsequent landed exploration of this moon.

2. SCIENCE OBJECTIVES AND MEASUREMENTS

The science objectives for Europa orbiter were established by the Europa Science Definition Team (SDT), chartered by NASA to develop the objectives[3]. The SDT recommended a set of Primary (IA) and secondary (IB) objectives, with commentary on possible payloads to achieve these objectives. The objectives are:

Primary IA Objectives:

- Determine the presents or absence of a subsurface ocean
- Characterize the three-dimensional distribution of any subsurface liquid water and its overlying ice layers
- Understand the formation of surface features, including sites of recent or current activity, and identify candidate sites for future lander missions.

Secondary IB Objectives:

- Characterize the surface composition, especially compounds of interest to prebiotic chemistry
- Map the distribution of important constituents on the surface
- Characterize the radiation environment in order to reduce uncertainties for future missions, especially landers

The SDT was specific in stating that they considered the IA primary science objectives were the irreducible set for the mission and that the secondary IB objectives were of high scientific importance but not so critical as to fall within the irreducible baseline. All science investigations that were to be proposed against the Europa Orbiter Announcement of Opportunity [3] were to be primarily assessed on their ability to meet the IA objectives.

The SDT also defined a strawman science payload that was determined to likely satisfy the primary 1A objectives. The payload is:

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- Measurements of Europa's gravity field via Doppler tracking, with a precision sufficient to measure Europa's k2 gravitational Love number to ±0.02
- Laser altimetry, with precision sufficient to measure Europa's h2 tidal height Love number to ±0.02
- Ice penetrating radar, with globally distributed coverage, depth resolution of 100 m at the surface decreasing with depth, spatial resolution at or better than the scale of major surface features, and designed to maximize the likelihood of detection of an ice/liquid interface
- Imaging, producing a global map of Europa in at least two colors and at a resolution better than or equal to 10 meters/pixel

As a result, the Independent Assessment team concentrated exclusively on the IA objectives and the strawman payload for performing this set of mission studies. Actual payloads that may have been proposed to the AO may have other critical mission drivers that were not addressed in these studies.

3. Architecture Options Overview

To meet the science objectives, several observation options are available, as well as multiple mission implementation trades. This leads to a large number of potentially viable architecture options, all of which required investigation to some level of fidelity. The key trades were in three areas: the science objectives, trajectory options and the flight system implementation.

The baseline science objectives for the Europa Orbiter mission include all of the primary IA and the secondary IB science objectives. Within the science community, there is strong support for meeting all of the stated objectives in one mission (indeed as stated above, the SDT feels that the IA objectives are the irreducible set). However, there was some sentiment that a reduced science mission would be viable if it provided significant science value while reducing cost and risk. Two options were defined for reduced science missions. The first option, termed the spatial science missions, assumed that the first IA objective, to unambiguously verify an ocean, was already accomplished. This option concentrated on the spatial measurements that met the surface composition and imaging objectives. The second option, termed the temporal science missions, was specifically targeted to meeting the single objective of verifying the ocean. Within these two options, multiple architectures were developed.

The second key trade area was trajectory. The Europa Orbiter mission baseline was a direct trajectory to Jupiter, launching on a Delta IVH launch vehicle with a new development upper stage. Multiple alternative gravity assist trajectories were available to meet the requirements of the mission, resulting in a reduction in required launch vehicle performance at the cost of an extended cruise phase. Multiple options were considered, however an Earth gravity assist trajectory provided the best performance, and was selected as the preferred alternative.

The third major trade area was in the flight system. The total mass available for the flight system is constrained by the launch vehicle performance at the required C_3. The Europa Orbiter baseline flight system was mass constrained to the point where margin guidelines were exceeded. This lead to descopes of the flight system capabilities to bring the mass of the system back in line with expectations. Options to reduce mass and improve performance were investigated. Table 1 presents the option space that was defined at the start of the mission studies.

Table 1. Mission Options Investigated

1A Full Science Orbiter Baseline Flight System Direct Trajectory	1B Full Science Orbiter Baseline Flight System Indirect Trajectory	1C Full Science Orbiter Minimum Mass/Cost Flight System Direct Trajectory	1D Full Science Orbiter Minimum Mass/Cost Flight System Indirect Trajectory
2A Reduced Science Orbiter Spatial Information Baseline Flight System Direct Trajectory	2B Reduced Science Orbiter Spatial Information Baseline Flight System Indirect Trajectory	2C Reduced Science Orbiter Spatial Information Minimum Mass/Cost Flight System Direct Trajectory	2D Reduced Science Orbiter Spatial Information Minimum Mass/Cost Flight System Indirect Trajectory
3A Reduced Science Orbiter Temporal Information Baseline Flight System Direct Trajectory	3B Reduced Science Orbiter Temporal Information Baseline Flight System Indirect Trajectory	3C Reduced Science Orbiter Temporal Information Minimum Mass/Cost Flight System Direct Trajectory	3D Reduced Science Orbiter Temporal Information Minimum Mass/Cost Flight System Indirect Trajectory
4A Reduced Science Flyby Mission Spatial Information Equatorial Jovian Orbit Baseline Flight System Direct Trajectory	4B Reduced Science Flyby Mission Spatial Information Equatorial Jovian Orbit Baseline Flight System Indirect Trajectory	4C Reduced Science Flyby Mission Spatial Information Equatorial Jovian Orbit Minimum Mass/Cost Flight System Direct Trajectory	4D Reduced Science Flyby Mission Spatial Information Equatorial Jovian Orbit Minimum Mass/Cost Flight System Indirect Trajectory
5A Reduced Science Flyby Mission Spatial Information High Inclination Jovian Orbit Baseline Flight System Direct Trajectory	5B Reduced Science Flyby Mission Spatial Information High Inclination Jovian Orbit Baseline Flight System Indirect Trajectory	5C Reduced Science Flyby Mission Spatial Information High Inclination Jovian Orbit Minimum Mass/Cost Flight System Direct Trajectory	5D Reduced Science Flyby Mission Spatial Information High Inclination Jovian Orbit Minimum Mass/Cost Flight System Indirect Trajectory

4. Full Science Mission Options

In the investigation of the mission options, it becomes apparent that meeting the full science objectives for the Europa Orbiter mission requires a spacecraft in orbit around Europa. Multiple flyby missions could conceivably address a subset of the objectives, however they are limited in the science return at Europa and leave considerable uncertainty in the results.

Primary architecture options investigated were the full science baseline orbiter and the minimum mass/minimum cost orbiter. The first option was an independent assessment of the baseline mission architecture, to develop an understanding of the flight system trade space as baselined by the project, and to develop an independent cost estimate and risk assessment. Multiple trajectory options were developed, including an indirect trajectory option that employed an Earth gravity assist to reduce launch vehicle requirements and increase mass capability. Of the two options (direct trajectory to Jupiter vs. indirect gravity

assist) the indirect trajectory offers much greater performance, allowing a reduction in launch vehicle class and increasing mass margins on the flight system. In the final analysis and recommendations, this becomes the recommended option of the assessment team.

Also investigated were methods to reduce the flight system mass, thus reducing costs across the board. The baseline established by the EO Project was driven higher power requirements by the inclusion of reaction wheels for pointing control. This was determined to be the best way to achieve the precision control necessary for the geodesy measurements. The minimum mass approach attempts to reduce mass and power by deleting the reaction wheels and performing pointing control via Minimum Impulse Thrusters (MIT), operating in couples. To offset the somewhat lower performance in orbit determination, a gimbaled antenna was baselined to provide longer tracking periods. At the same time, the telecom performance is improved over the baseline fixed antenna system, which had discrete observation and telecommunications periods. This option, while offering some promise of reducing costs, resulted in unacceptably low power margins during key mission phases (Jupiter Orbit Insertion [JOI], Europa Orbit Insertion [EOI] and in high power science modes).

5. Reduced Science Mission Concepts

Although the science community strongly believes that the full set of science objectives should be addressed, reduced science concepts were investigated to determine if any provided a high science return while significantly reducing the overall cost. The reduced science missions addressed two primary subsets of the full science objectives: the temporal measurements (which were necessary for the verification of the ocean) and the spatial measurements (which addressed all the other objectives). In addition, both orbiting concepts and flyby concepts were investigated. In all, sixteen different missions were defined that met some reduced set of science objectives, and provided some reduction in mission cost.

The reduced science orbital concepts (the temporal measurement orbiter and the spatial information orbiter) achieved reductions in cost primarily by reducing payload and in modifications of the end game orbit duration. In all cases, the mission design was optimized to meet the reduced science objectives, resulting in the most likely implementation for that concept. In general, the reduced science orbital concepts accomplished little, reducing the science but failing to achieve significant cost savings. The lesson to be learned is that the incremental cost to go from a reduced science to the full science mission is negligible with respect to the implementation of the orbiter itself. The cost of getting there overwhelms the incremental science return cost.

Another set of options that were investigated were the reduced science flyby missions. Several interesting options were presented for meeting the temporal and the spatial science objectives. However, no single mission concept was able to meet what was considered the minimum acceptable science return to be considered a viable alternative.

To meet the science objectives for the temporal studies, techniques were investigated to determine the shape of Europa from flyby imaging and gravity measurements [4]. Using reasonable assumptions on imaging and trajectory determination capabilities, there is the possibility that the geodesy measurements that are needed to verify an ocean could be performed. However, the short timeframe of the mission study did not allow a full investigation of the techniques involved, and considerable uncertainty in the viability of the concept remains.

Two types of flyby missions were defined. The equatorial flyby mission, similar to the Galileo concept, performs multiple flybys of Europa with the spacecraft orbiting in the Jovian equatorial plane. The advantage of such an orbit is that the encounter velocities are relatively low, resulting in high resolution imaging. However, even with an extended Jovian orbiting mission (one year) the total coverage for a spatial information mission was much less than an orbiter. Also, no viable method for obtaining reasonable radar observations was identified. Measuring the shape of Europa using flyby imaging was investigated, however no conclusions were reached on the viability of the concept.

The second flyby mission concept uses a polar orbit of Jupiter, which offers the advantage that the radiation loading is greatly reduced, which would reduce the development costs of the mission by relaxing the radiation design issues. However, this concept has several drawbacks. First, orbital geometry results in significantly fewer close encounters with Europa and each encounter is at a fairly high encounter velocity. Spatial information could be obtained at these encounter velocities, however geodesy information using the imaging and gravity technique was not possible. Overall, while flyby concepts seem to offer options for meeting some reduced set of science objectives at a reduced cost, the end result of the study indicated that significant cost savings were not achieved, while science was significantly degraded.

It is significant to emphasize that although these missions did reduce costs by some amount, no mission concept reduced costs significantly. The conclusion to be drawn is that there is a threshold, or minimum cost, to performing any mission to Europa, and reductions below that cost are not achievable without significant increases in risk.

6. Conclusions

The Independent Assessment team validated that an orbiter mission at Europa was the best way to meet the science objectives for the mission. Examining the baseline mission

architecture, the Independent Assessment team recommended that the Project investigate and potentially adopt the Delta-V EGA mission trajectory, which resulted in a reduction in launch vehicle and an increase in mass margin, with the impact of a greater flight time. The overall cost of the mission was not reduced because cost savings from the reduction in launch costs were consumed by the extended operations period. However, overall implementation risk was reduced by increasing the flight system mass margins.

Alternatives to the full science missions were examined, with the goal of identifying mission concepts that delivered high priority science at a significantly reduced cost. In the end, no alternative mission to the orbiter delivered acceptable science return toward meeting the primary IA objectives while significantly reducing cost.

7. ACKNOWLEDGMENTS

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