Europa Explorer Operational Scenarios Development

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In 2007, NASA conducted four advanced mission concept studies for outer planets targets: Europa, Ganymede, Titan and Enceladus. The studies were conducted in close cooperation with the planetary science community. Of the four, the Europa Explorer Concept Study focused on refining mission options, science trades and implementation details for a potential flagship mission to Europa in the 2015 timeframe. A science definition team (SDT) was appointed by NASA to guide the study. A JPL-led engineering team worked closely with the science team to address 3 major focus areas: 1) credible cost estimates, 2) rationale and logical discussion of radiation risk and mitigation approaches, and 3) better definition and exploration of science operational scenario trade space. This paper will address the methods and results of the collaborative process used to develop Europa Explorer operations scenarios. Working in concert with the SDT, and in parallel with the SDT's development of a science value matrix, key mission capabilities and constraints were challenged by the science and engineering members of the team. Science goals were advanced and options were considered for observation scenarios. Data collection and return strategies were tested via simulation, and mission performance was estimated and balanced with flight and ground system resources and science priorities. The key to this successful collaboration was a concurrent development environment in which all stakeholders could rapidly assess the feasibility of strategies for their success in the full system context. Issues of science and instrument compatibility, system constraints, and mission opportunities were treated analytically and objectively leading to complementary strategies for observation and data return. Current plans are that this approach, as part of the system engineering process, will continue as the Europa Explorer Concept Study moves toward becoming a development project.

I. Introduction

The development of operations scenarios was a central part of the 2007 Europa Explorer mission concept study from the start. The development was an interactive collaboration among the members of the Science Definition Team (SDT) led by Bob Pappalardo from JPL and Ron Greeley from Arizona State University, the study lead, Karla Clark, and engineers from the operations scenario study team. The work of the mission study, including the operations scenarios, is documented in the 2007 Study Report[1].

The starting point for the operations scenario development was the work done in the 2006 study[2]. The 2006 study did not develop detailed operations scenarios but did develop operations concepts for single orbits that would deal with challenges in collection and return of large data volumes with constrained on-board data storage. Flight

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system design concepts were established using only available or near term technology components. The resulting spacecraft and mission design were used as initial conditions in the 2007 mission study.

Working in concert with the SDT, and in parallel with the SDT's development of the science value matrix, key mission capabilities and constraints were examined and challenged. The SDT considered science goals that were considered to be achievable within the scope of an affordable mission context. The science scenarios were the conceptual connection between the mission and system design and the desired science goals and instrumentation. Scenarios were generally defined as the description of the operational use of the proposed flight system (payloads and subsystems), the ground system, and trajectories. Specifically, data acquisition and return strategies, geometric or mission event constraints, and science priorities with time ordered observing strategies are included. Only the proposed scenarios for the Europa orbital mission phase are discussed in this paper.

The SDT began by developing the science goals and measurement objectives along with a science value assessment process. In parallel, the SDT began simulating simple data collection and return scenarios for the instruments under consideration. These simple scenarios were needed to assess the ability of a candidate instrument to meet the science objectives as part of an integrated system. Basic instrument operations constraints, interactions, and coverage estimates were developed and presented in the first sessions. Flight system resource needs were considered, constraints were determined, and data return strategies were developed. Orbit-by-orbit scenarios were also developed and higher order scenarios for science campaigns were sketched out to estimate the progress of achievement of the science goals during the mission. Finally, the SDT laid out the strategy for coordinated targets with high resolution (and high rate) instruments. The data allocation strategy for the coordinated targets was based on coverage and resolution of the instruments rather than direct allocation of data volume.

Some key system parameters estimated and traded were telecom rate, DSN tracking schedule, mass memory capacity, and phasing of campaign goals. Instrument parameters such as power, mass, data rate, data volume allocations, operations timing constraints, co-observing issues, and data reduction and compression factors were also considered.

II. Proposed Europa Explorer Mission Overview

The mission duration for the 2007 Europa Explorer Study from launch to the end of the primary Europa science phase is about 9 years. The first 6 years would be needed to deliver the flight system to Jupiter and would be devoted to launch, cruise, and preparation for Jupiter Orbit Insertion (JOI) and Jupiter system science operations. Following JOI, the mission would undertake a series of gravity assist flybys of the Galilean satellites Ganymede, Callisto, and Europa to reduce the propellant requirements to achieve orbit at Europa. The gravity assist flybys and other aspects of the Jovian Tour trajectory represent opportunities for close and far observations of the Galilean satellites and Jupiter. The Europa Orbit Insertion (EOI) maneuver would begin a one-year Europa Science phase that would complete the primary mission. Following the Europa Science phase, and given funding approval, an Extended Europa Science phase would commence, lasting for the remainder of the useful life of the flight system. When the flight system becomes non-operational or when it runs out of propellant for orbit maintenance, it would, within weeks to months, crash into Europa. This is the driver for the proposed mission's stringent planetary protection requirements.

III. Tracing Measurement Objectives to Science Goals

Several guiding National Research Council and NASA documents have emphasized the relevance of Europa exploration to highest priority science goals. These include: COMPLEX's report *A Science Strategy for the Exploration of Europa* [COMPLEX 1999], the Solar System Exploration Survey [SSES 2003] (aka "Planetary Science Decadal Survey"), OPAG's Scientific Goals and Pathways report [OPAG 2006], the 2006 Solar System Exploration Roadmap [SSER 2006], the 2007 NASA Science Plan [NSP 2007], and the Vision for Space Exploration document [VSE 2004].

The trace from objectives to investigations to measurements to instruments is captured in the Europa Explorer Traceability Matrix. A high level summary of the trace to investigations is shown in Figure 1. Lettered Objectives A through E are considered Priority 1, and each is deemed by the SDT to be of equal priority. Lettered Objective F is considered a Priority 2 objective according to the NASA-directed ground rules of the 2007 study, and so must not drive spacecraft or payload capabilities. Investigations are listed in priority order within each objective.

In the course of the SDT meetings a series of general instrument options were considered to answer the science measurement objectives. Operations needs for each instrument such as data rate, extent, frequency, and quality of observations were determined. After initial assessments of overall operations scenarios, two planning payloads were identified for the mission study. A Floor planning payload was identified to meet the minimum science objectives

as determined by the SDT. A Baseline planning payload of 11 instruments (exclusive of the telecom system) was identified and was used to allow the scientists and engineers to develop a complete mission concept that addressed the science objectives within a reasonable set of requirements and constraints. The planning payload enabled engineers to understand what requirements would be imposed by different payload elements. The actual instruments would be the result of an Announcement of Opportunity (AO) selection process carried out by NASA.

Goal		Science Objective	Science Investigation
Explore Europa and investigate its habitability.	A. Ocean	**Characterize the ocean and deeper interior.**	A1. Determine the amplitude and phase of the gravitational tides.
			A2. Determine the induction response from the ocean over multiple frequencies.
			A3. Characterize surface motion over the tidal cycle.
			A4. Determine the satellite's dynamical rotation state.
			A5. Investigate the core and rocky mantle.
	B. Ice	**Characterize the ice shell and any subsurface water, and the nature of surface-ice-ocean exchange.**	B1. Characterize the distribution of any shallow subsurface water.
			B2. Search for an ice-ocean interface.
			B3. Correlate surface features and subsurface structure to investigate processes governing communication among the surface, ice shell, and ocean.
	C. Chemistry	**Determine global surface compositions and chemistry, especially as related to habitability.**	C1. Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability.
			C2. Relate compositions to geological processes, especially communication with the interior.
			C3. Assess the effects of radiation on surface composition, albedo, sputtering, and redox chemistry.
			C4. Characterize the nature of exogenic materials.
	D. Geology	**Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.**	D1. Characterize magmatic, tectonic, and impact features.
			D2. Search for areas of recent or current geological activity.
			D3. Investigate global and local heat flow.
			D4. Assess relative surface ages.
			D5. Characterize the physical properties of the regolith, and assess processes of erosion and deposition.
	E. External	**Characterize the magnetic environment and moon-particle interactions.**	E1. Characterize the magnetic environment.
			E2. Characterize the ionosphere and neutral atmosphere and their dynamics, with implications for surface interactions.
			E3. Characterize relationships between the magnetic field and plasma.
			E4. Characterize the global radiation environment.
	F. Neighbors	**Determine how the components of the Jovian system operate and interact, leading to potentially habitable environments in icy moons.**	F1. Determine the nature and history of the geological activity and interior evolution of the Galilean satellites.
			F2. Understand the processes that determine the composition, structure and dynamics of the Jovian atmosphere as a type example of a gas giant planet.
			F3. Study the interactions between Jupiter's magnetosphere and its satellites.

Figure 1. High Level Traceability Matrix. *Color-coding for each investigation corresponds to the science objective to which it most closely pertains as traced from the themes in the Decadal Survey and 2006 Solar System Exploration Roadmap.*

IV. Proposed Scenario Analysis

A. Operations challenges

The radiation environment at Europa limits the amount of on-board data storage available. Mass memories of 1–2Gb could be reasonably accommodated in the flight system design. For the purposes of the mission study, 1Gb of mass memory was allocated to science for data collection and return. Because of this, operations constraints were needed to manage the acquisition and return of very large daily data volumes. For the Europa Science phase these constraints could include:

- Downlink of all data on the orbit collected
- Collection of data mainly during downlink sessions
- Preclusion of mass memory allocations for data retransmission
- Scheduling of continuous DSN 70m tracking (or equivalent)
- Use of X-band for highest link reliability (based on weather)

These operations constraints remove consideration for data retransmission, discontinuous DSN coverage, and prioritization and queuing of data products. On-the-fly data reduction, compression, processing, packetization and management can still be accommodated and is necessary in most cases.

B. Scenario Simulations

During SDT meetings, science objectives and instrument characteristics for the planning payload were developed. Simulations were run to determine how well scenarios under discussion performed. For example, it was discovered that instrument data rates were too high for single orbit repetitive observing strategies but by alternating orbits for certain instruments, global imaging coverage and profile distribution would meet science goals. Four types of analysis and simulation were used to characterize Europa orbit scenarios. First, a minute-by-minute simulation for a single orbit was constructed to model the data flows of the instruments, mass memory and telecom downlink.

This was later modified to simulate multiple orbits to assess the alternating orbit scenarios. Second, using SOAP (Satellite Orbit Analysis Program), the geometric performance of the imaging fields of view and ground track spacing for profiling instruments was simulated for the same scenarios used in the data flow models. Third, a simple model was used to estimate, based on residual downlink data volume after repetitive mapping operations, the number of coordinated targets that could be acquired within the memory resources of the orbiter. This was an average value and care was taken to evaluate how often targets could be collected. Fourth and last, an accounting model was used to evaluate the overall campaign-based strategy for the entire science phase. Based on proposed campaign durations, data rate changes due to changing Europa-Earth range over time, and campaign priorities,

Inputs		WAC	MAC	NAC	IRS-P	IRS-I	IPR	TI	UVS-PL	UVS-I	LA	MAG	INMS	PPI
Raw data rate (Mb/s)		0.4	3	15	0.03	30	30	0.043	0.005	4	0.012	0.004	0.0015	0.002
Mapping orbit duty cycle		40%	0.0%	0.0%	40%	0.0%	45%	80%	100%	0.0%	100%	100%	100%	100%
Data reduction rate		4	4	4	2.5	2.5	107	2	1	2	1	1	1	1
Uncompressed Dvol (Mb)		1344	0	0.0	99	0	111780	285	41	0	99	33	12	17
Compressed Rate (Mb/s)		0.100	0.75	3.7500	0.012	12.000	0.280	0.022	0.0050	2.0000	0.0120	0.0040	0.0015	0.0020
Total Dvol/Orbit #1 (Mb)	(0.32)	336.0	0.0	0.0	40.3	0.0	0.0	143.2	41.4	0.0	99.4	33.1	12.4	16.6
Total Dvol/Orbit #2 (Mb)	(0.32)	0.0	0.0	0.0	40.3	0.0	1059.8	143.2	41.4	0.0	99.4	33.1	12.4	16.6
Total Dvol/2Orbit (Mb)		336.0	0.0	0.0	80.6	0.0	1059.8	286.4	82.8	0.0	198.7	66.2	24.8	33.1

Figure 2. Example Instrument Characteristics. *Data rates, duty cycles, and data reduction factors are used as inputs to the data flow model.*

summary data was estimated for the overall science performance with respect to stated goals.

Figure 2 shows the instrument characteristics of raw data rate, data reduction factor, observation duty cycle and generated data volumes per orbit for the planning payload. The payload would consist of a Wide Angle Camera (WAC), Medium Angle Camera (MAC), Narrow Angle Camera (NAC), Infrared Spectrometer (IRS, in point and imaging modes), Ice Penetrating Radar (IPR), Thermal Instrument (TI), Ultraviolet Spectrometer (UVS, in profiling and imaging modes), Laser Altimeter (LA), Magnetometer (MAG), Ion and Neutral Mass Spectrometer (INMS), and a Plasma and Particle Instrument (PPI). The example shown is for Campaign 1 at 200 km orbit altitude. Campaigns 2, 3, and 4 have similar characteristics but would be at 100 km orbit altitude. Some instrument rates are twice as fast at the lower altitudes because the pixel rates are faster due to range and ground speed. This table is used as the instrument input to the data flow model for instrument characteristics.

The data flow simulation results for Campaign 1 are shown as an example in Figure 3. Similar analyses were performed for all proposed campaigns. The red plot line shows the available accumulated downlink data volume (occultations are shown and include DSN lockup times). The green line shows the data collected as an accumulation to compare with the downlink capability. The dark blue line shows the state of the SSR at each minute. Each instrument's data collection scenario is represented in the plot and the simultaneous and accumulated impacts are characterized. The example shows accumulation in the SSR during occultations when only a few low rate instruments are assumed to be operating. These scenarios show a small 10-15% depth of use on the SSR and only during occultations, leaving ample room for coordinated target data collection with either the ~400 Mb imaging type or the 900Mb radar type on most orbits. As the Earth-Europa range decreases over the mission, data rates increase

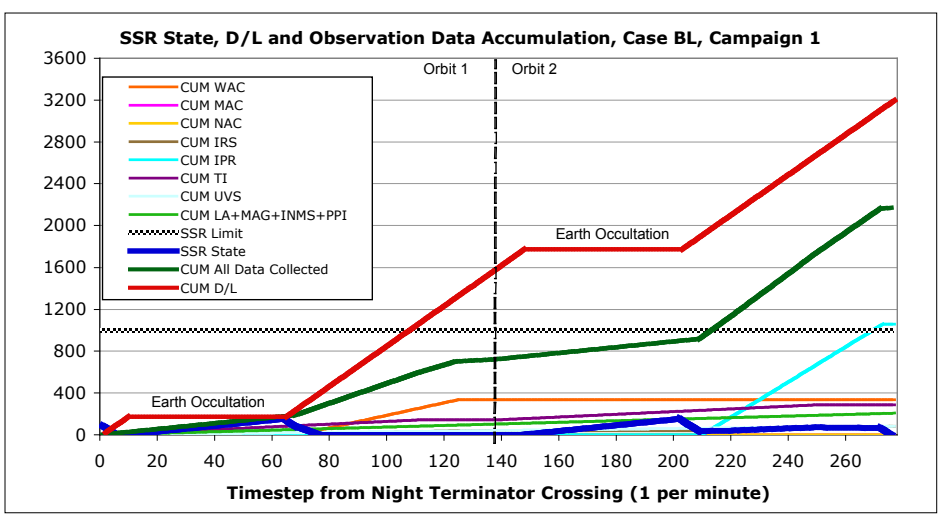

Figure 3. Example Data Flow Simulation Results. *2-orbit simulation with one sample per minute. Plot shows downlink data volume accumulation, data collection accumulation for each instrument and for all data collected (after data reduction), and SSR volume state for each minute. Orbit period, occultations, and downlink telemetry lockup durations are included.*

and subsequent campaigns gain data volume benefits.

Coordinated targets were collected only when analysis of upcoming data takes and downlink data volume shows there would be sufficient data volume available. Target locations would be selected based on lists of pre-selected targets by type and extent and could be automatically selected to fill data volumes as they become available. This planning would occur on the ground with sequence uplink approximately once per week, and with ephemeris updates several times per week.

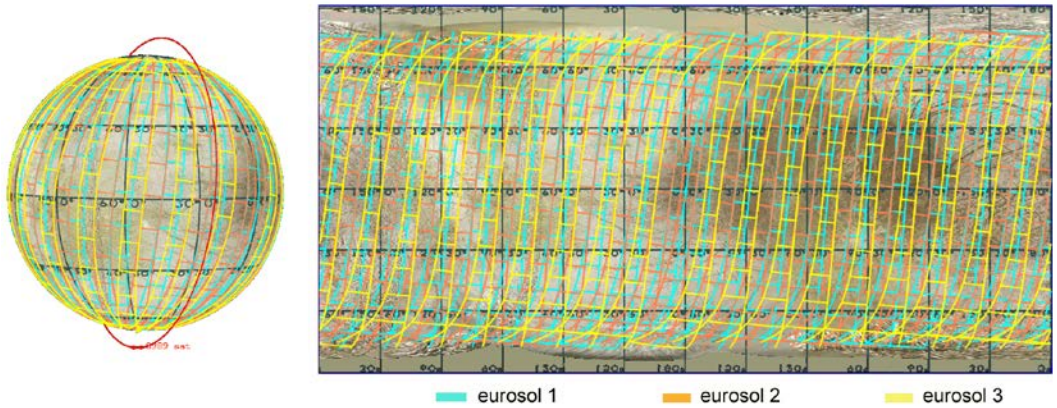

Figure 4. Example Global Coverage for the Wide Angle Camera (WAC). *It is simulated using an orbit analysis program that uses timing from the baseline scenario.*

An example of global coverage for the WAC in baseline Campaign 1 is shown in Figure 4. Global color coverage would be complete in 3 eurosols (Europa day or orbit around Jupiter) or about 10 days. Global stereo coverage could be achieved in another 10 days, leaving 8 days in Campaign 1 for margin. This margin is useful for orbiter and instrument checkout and trim maneuvers immediately after EOI. A several day delay in the start of mapping could be tolerated and still achieve the Campaign 1 science goals.

The performance of the baseline mission is shown in Figure 5. Performance in this context is represented by measures of daily data volume for global mapping and profiling goals, and for coordinated targets and the totals for each campaign. The number of targets per day and per campaign is also shown, as are percentage distributions for

	Campaign 1: Global Framework						Campaign 2: Regional Processes						Campaign 3: Targeted Processes								
Reference S/C (Baseline)	Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)	Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)	Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)	Total Targets	% total vol	Total Vol (Gb)
Data Volume	10.7	6.6				**483**	11.7	7.5				**804**	3.1	20.0				**486**			**1773**
WAC	1.1		6%			**31**	2.9		15%			**122**	0.2		1%			**3**		9%	**156**
MAC[1]	0.0	0.7	4%	12 T	**333**	**15**	0.0	1.3	7%	11 T	**441**	**53**	0.0	1.5	6%	12 T	**254**	**30**	**1028 T**	6%	**98**
NAC[2]	0.0	0.9	5%	12 T	**329**	**18**	0.0	1.6	8%	11 T	**441**	**66**	0.0	4.5	19%	30 T	**630**	**95**	**1400 T**	10%	**179**
IRS[3]	0.4	1.3	10%	12 T	**328**	**54**	0.7	1.3	11%	11 T	**441**	**86**	0.7	1.6	10%	12 T	**254**	**47**	**1024 T**	11%	**187**
IPR[4]	5.5	1.8	43%	3 T	**70**	**218**	5.5	1.8	38%	2 T	**84**	**306**	0.0	10.8	47%	12 T	**252**	**227**	**406 T**	42%	**750**
TI	1.5		9%			**42**	0.5		2%			**19**	0.2		1%			**4**		4%	**65**
UVS	0.4	1.6	12%	14 T	**383**	**58**	0.4	1.5	10%	13 T	**525**	**81**	0.4	1.7	9%	14 T	**298**	**45**	**1205 T**	10%	**184**
LA	1.0		6%			**29**	1.0		5%			**44**	1.0		4%			**22**		5%	**94**
MAG	0.3		2%			**10**	0.3		2%			**15**	0.3		1%			**7**		2%	**31**
INMS	0.1		1%			**4**	0.1		1%			**5**	0.1		1%			**3**		1%	**12**
PPI2	0.2		1%			**5**	0.2		1%			**7**	0.2		1%			**4**		1%	**16**

[1] MAC targets are 1 minute duration (71 km @200 km, 78 km @100 km)
[2] NAC targets are 15 seconds duration
[3] IRS targets are each 400x400 pixels, 128 Mb
[4] IPR targets are each 30 Mb/s x 30 s, 900 Mb

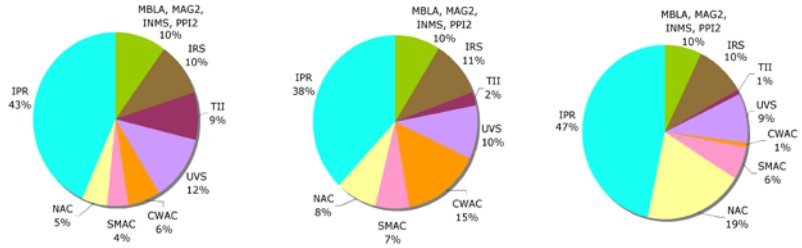

Figure 5. Example Science Data Volume Performance. *Shows data volume per instrument by campaign and total for mission, both as Gb and as percentage, and numbers of targets per campaign.*

the different representative instruments. The totals column shows that the baseline scenario would enable collection of data over more than the desired 1000 targets in the first 3 campaigns. The values for IPR, UVS and NAC are different reflecting different goals for their targets. IPR takes very large observations (900 Mb) and could not collect at the same time as the imagers (a larger SSR would enable simultaneous targeting for a subset of the total target set). UVS would collect two stellar occultation targets at the limb of Europa each day. The NAC would collect high resolution target sets for characterizing potential future landing sites. This would occur in Campaign 3 and could extend well into Campaign 4.

C. Summary of resulting scenario for the Europa science phase

The science scenario while in Europa orbit is designed to obtain the highest-priority observations early in the Europa Science phase. The earliest and highest priority goals, to be accomplished in the first 4 weeks, include 2 global maps, 1–2 degree global grids from the 5 profiling instruments, and several hundred coordinated targets of high interest sites. After the initial campaign, the orbit altitude would be lowered and higher resolution global maps, additional profile grids and hundreds more coordinated target observations would be collected to answer regional process questions. The third month of the Europa Science phase would be devoted almost entirely to acquiring coordinated targets to answer local-scale science questions. To meet these science objectives, the flight system would need to acquire and return an average 20Gb per day. To balance power, mass, and data volume, continuous tracking by DSN 70m stations (or equivalent) would be needed to return these data volumes. The final portion of the Europa Science phase, lasting 9 months, would be devoted to addressing new questions discovered in the initial observations.

The Europa Science phase would be one year long and represents the accomplishment of all of the high priority science goals of the mission. Data collection would span four major campaigns:

- Campaign 1 - Global Framework at 200 km orbit for 8 eurosols (~28 days),
- Campaign 2 - Regional Processes at 100 km orbit for 12 eurosols (~43 days),
- Campaign 3 - Targeted Processes at 100 km for 6 eurosols (~21 days), and
- Campaign 4 - Focused Science at 100 km for 74 eurosols (~273 days).

Science data collection would be continuous and repetitive with continuous fields and particles, altimetry, thermal imaging, and ultra-violet and infrared spectroscopy profile data collection, along with alternating orbit global imaging and radar sounding. This repetitive data collection represents about two thirds of the daily average downlink data volume. On orbits when additional data volume is available, targeted data acquisitions comprising IPR profiles, MAC, NAC, UVS and IRS images would be collected. Except for the low rate instruments, all observations would be taken with Earth (and the DSN) in view, enabling rapid downlink of high rate science data. Sequences for repetitive mapping activities would be uplinked once per week. Lists of targets to be acquired via on-board targeting software would be developed and uplinked to the flight system every few days. Quick look data processing, mapping assessment, and target selection processes would all be rapid, needing about one day each. Data return would be via continuous 70 m tracking. Data rates would be determined every orbit based on the conditions for DSN elevation angle and Jupiter radio (hot body) noise for that orbit. These variable data rates would increase the average data volume returned by nearly 50% over traditional methods. One additional 34 m DSN station would be scheduled each day to allow two-way Ka-band Doppler tracking for gravity science.

The final 9 months of the Europa Science phase would focus on addressing new questions arising from data collected in the first 26 eurosols (92 days) and on characterizing potential landing sites for future missions.

V. Sizing the Mission and Systems

The scenario analysis models were intended to allow the assessment of flight system performance parameters. The power generation by the proposed radioisotope power system was sized based on the power use profile as shown in Figure 6. Time varying power consumption was modeled over two orbits and required system margins of 43% were applied. For times when payload power consumption rose above the power generation levels, battery use and depth of discharge was modeled. This modeling determined whether system power was adequate or insufficient for the mission scenarios. If power availability was insufficient, decisions on whether to change the power subsystem design or to constrain the payload complement, power modes, or observing scenarios could be made based on this analysis. Excess power availability was tracked for potential use in scenario trades or for potential reductions in the power system design.

Power use would vary primarily by instrument modes, observing profiles, and telecom downlink profiles for TWTA power mode and HGA gimbal motion. With the addition of power modes for targeted data collection, the same simulation that was used for data flow analysis (see Figure 3) was used to evaluate the power profile.

Variations in telecom mode (TWTA low power mode and occultation duration) and TWTA power level are common elements between the two models since TWTA power is directly related to downlink rate.

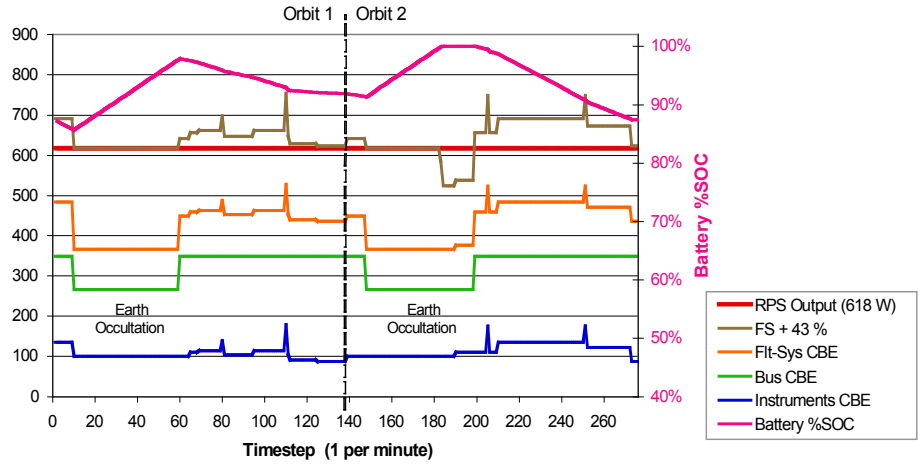

Figure 6. Two Orbit Estimated Power Profile. *The plot shows the estimated power generation, consumption, and battery levels over two orbits. Maximum expected target data collection is modeled.*

Flight system mass is generally insensitive to operations scenarios (except for delta-V for orbit changes, which is analyzed separately). There is a secondary effect of data flow analysis and power modeling in that changes to desired data rate can lead to changes in HGA diameter (mass impact) or TWTA power level (potential mass impact from power system).

VI. Establishing Science Value

In parallel with the scenario development and simulation effort, a value metric was developed by the SDT to assess the benefits of the payload options. The SDT estimated science value ratings for each measurement in the Traceability Matrix as they pertain to the relevant science investigation, for both the baseline and floor mission and

		FLOOR SCIENCE CAMPAIGNS					BASELINE SCIENCE CAMPAIGNS				
		1 Global Framewrk		2 Regional Proc.		3 Targ. Proc.	1 Global Framewrk		2 Regional Proc.		3. Targ. Proc.
Instrument		1A	1B	2A	2B		1A	1B	2A	2B	
A1a. Telecom system.	A1a.	3	3	4	4	5	3	4	4	5	5
A1b. Laser altimeter.	A1b.	3	4	5	5	5	4	5	5	5	5
A2a. Magnetometer.	A2a.	2	4	4	4	4	2	4	4	4	5
A3a. Laser altimeter	A3a	4	5	5	5	5	4	5	5	5	5
A3b. Telecom system.	A3b.	3	3	4	4	5	3	4	4	5	5
A4a. Telecom system.	A4a.	2	2	3	4	4	2	3	4	5	5
A4b. Laser altimeter.	A4b.	2	2	3	4	5	2	3	5	5	5
A5a. Telecom system.	A5a.	2	2	3	3	4	2	2	3	3	4
A5b. Laser altimeter.	A5b.	2	2	3	3	4	2	2	3	3	4
A5c. Magnetometer.	A5c.	1	2	3	4	4	1	2	3	4	5
B1a. Radar sounder (nominally ~50 MHz, with ~10 MHz bandwidth).	B1a.	2	2	3	3	4	3	3	4	4	5
B1b. Wide-angle camera (stereo) and laser altimeter.	B1b.	1	2	3	4	4	1	2	3	4	4
B2a. Radar sounder (nominally ~5 or 50 MHz, with 1 MHz bandwidth).	B2a.	1	2	2	3	4	1	3	3	4	5
B2b. Wide-angle camera (stereo) and laser altimeter.	B2b.	1	2	3	4	4	1	2	3	4	4
Total score (of 370):		*108*	*138*	*184*	*208*	*242*	*146*	*207*	*270*	*304*	*351*
% score:		*30%*	*38%*	*50%*	*57%*	*66%*	*40%*	*57%*	*74%*	*83%*	*96%*
Eurosols into orbital mission:		*4*	*8*	*14*	*20*	*26*	*4*	*8*	*14*	*20*	*26*
Days into orbital mission:		*14*	*28*	*64*	*71*	*92*	*14*	*28*	*64*	*71*	*92*

5	Definitely addresses full science investigation.
4	May address full science investigation.
3	Definitely addresses partial science investigation.
2	May address partial investigation.
1	Touches on science investigation.
0	Does not address science investigation.

4 Focused Science: Follow up on discoveries.

Figure 7. Science Value Ratings. *Summary of baseline mission science value ratings at the investigation level. The full measurement-level Science Value Matrix is not shown but can be found in Reference 1.*

instrument scenarios. Figure 7 summarizes the floor and baseline mission science value ratings at the investigation level. These science value ratings were estimated across the proposed mission campaigns for all observation scenarios.

VII. Future Efforts

Work continues on the Europa Explorer mission concept in 2008. Upon completion of the 2007 studies and their independent review, NASA Headquarters elected to continue studying two outer planet flagship mission concepts: Europa Explorer and Titan Explorer. More recently, NASA and the European Space Agency (ESA) agreed that the ESA-led Cosmic Vision missions have related science and mission goals and are collaborating on formulating joint science and mission goals for the Titan-Saturn system and for the Europa-Jupiter system. The Europa Explorer and Titan Explorer follow on studies will focus on resolving issues identified by the independent review, and on redesigning the missions to meet revised ground rules. The revisions of the guidelines that pertain to operations scenarios would include a life cycle cost constraint of $2.1B for a NASA only mission and may include international contributions of up to $1B to improve upon the science floor. Another new guideline is to assume that DSN capabilities would include Ka-band downlink in the mission era and that 34m DSN stations would be used to return all mission science data sets.

VIII. Conclusions

The operations scenarios as documented in the 2007 Europa Explorer Mission Study Final Report[1] were noted by the NASA independent review board as a major strength. The review board also noted major strengths in science operations plans, science data acquisition strategies and the traceability matrix; and minor strengths in the overall operations plans and science campaign strategy.

The processes described above successfully yielded comprehensive operations scenarios that were tied directly to science measurement objectives and to system design parameters. Concurrent modeling and collaborative problem solving allowed rapid consideration of science and system design concepts. Project managers, system engineers, program sponsors and most importantly, science team members were able to quickly assess the impact of science requirements and measurement objectives on flight system design, resource usage (mass, power, cost), and integrated science achievement metrics. The process was relatively simple in concept and required simple tools. The key to success was that project and science leadership required a collaborative process that provided insight into the end-to-end system design and the assessment of mission performance in terms of science objectives. The same processes are currently in use in the 2008 mission study.

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References

Reports, Theses, and Individual Papers

[1] 2007 Europa Explorer Mission Study: Final Report, JPL D-41283, November 2007

[2] Europa Explorer Data Return Issue Report, JPL D-34113, February 2006

Related web sites

Outer Planets Flagship Mission Program website http://opfm.jpl.nasa.gov/