Europa Spacecraft Configuration Optimization for the Solar Powered Vehicle

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***Abstract*—A mission to Europa has been on the minds of NASA and JPL for many years. After the Galileo mission to Jupiter in the 1990s there have been various proposals for missions to the Jovian moon. The most recent proposal, previously named the Europa Clipper, has gone through numerous iterations of spacecraft configurations on its road to becoming an official NASA project in June of 2015. Most of these configurations included options for either multi-mission radioisotope thermoelectric generators (MMRTGs) or solar power. In 2014, the decision was made to focus on solar arrays as the source for spacecraft power. The decision to move forward with a baseline design that utilized only solar arrays as its power system meant that some configuration choices had to be re-evaluated. Initially, a configuration was adapted to keep as much of the previous spacecraft design the same while replacing MMRTGs with solar panels. This proved to be difficult as the arrays presented a slew of new challenges that the nuclear vehicle was not optimized for. The solar arrays needed to be large due to Jupiter's substantial distance from the Sun. This meant that many of the instrument and radiator FOVs would now be obstructed, or would receive reflected light and heat from the large panels. Also, the mass of the panels meant that mounting near the bottom of the spacecraft would be sub-optimal as the wings would cause major disturbance to the vehicle as they oscillated in their deployed state. Another major, and possibly the largest, concern was the fact that as the high gain antenna pointed to Earth for communication, the Ice Penetrating Radar (IPR) would cast a large shadow on the cell-side of the array. This resulted in an estimated 10% power loss to the vehicle. On top of all this, NASA announced the selection of the instruments that would fly on the Europa mission and replace the notional instrument suite that had been used to develop and submit the project proposal. The selected instruments, while not varying widely from the notional suite, did come with a new set of challenges including a size increase over the notional package, thus requiring more room for accommodation. They also introduced new features not previously addressed by the notional package, such as a two-axis gimbal on one of the imagers. Additionally, two new instruments, an ultraviolet plume-hunting spectrograph, and an atmospheric dust analyzer we added to the payload and presented new challenges not previously covered in the proposal. Finally, additional payloads were under consideration, such as a 250kg ejectable payload that would be released at Jupiter and would accomplish flybys of some of the other Jovian moons. All of this resulted in a drastically different "family" of configurations that were capable of addressing these issues, and staying flexible to the numerous potential changes that could come. This paper discusses the details of the various configurations considered to address these items, and the configuration concepts that were selected as the baseline for moving forward with the proposal.**

TABLE OF CONTENTS

1. INTRODUCTION

The Galilean moon Europa has been an intriguing topic within the science community for many years. Missions to interrogate the moon have been proposed to NASA throughout the past decade and a half, with none surviving long enough to reach official project status. Listed as a top priority in the 2013 - 2022 Visions and Voyages for Planetary Science Decadal Survey, a mission to explore Jupiter's moon Europa has been on the minds of NASA and the global science community ever since the Galileo spacecraft explored the moon from an orbit around Jupiter in the 1990s. For the past two and a half years, the Jet Propulsion Laboratory, in partnership with the Johns Hopkins University Applied Physics Laboratory have been developing a concept called the Europa Clipper, which was selected to move into the formulation phase as an official NASA project in June of 2015. Before selection of the instruments that would fly on the Europa spacecraft, the project used a notional, or reference instrument suite in order to perform the design and trade studies necessary to develop the spacecraft. Prior to becoming an official project, an Announcement of Opportunity (AO) was released that allowed science teams around the world to propose instruments and experiments to comprise the science payload for the mission. The Announcement of Opportunity for Clipper was created at a time when the vehicle's baseline power system used radioisotope thermoelectric generators. In May of 2015 NASA announced the selection of the nine instruments that were chosen as the science payload to fly on the proposed

978-1-4799-1622-1/14/$31.00 ©2015 IEEE
The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Europa mission. In anticipation of the selected instruments being different than the notional instrument package that had been used to develop the spacecraft concept, and the fact that the spacecraft's power system had been significantly changed, a major configuration overhaul was needed in order to tailor the spacecraft around the challenges and opportunities presented by the selection of solar power and the new instrument suite. The project is currently in the process of trading three configuration options that came out of that overhaul: configurations 2C, 2D-1, and 2D-2. This paper presents the details of the configuration overhaul, and offers the current state of the trade as we march to closure by the end of the 2015 calendar year.

2. MISSION OVERVIEW

Flyby Approach

The proposed Europa Mission is a unique approach to exploring the Jovian moon that takes advantage of multiple "fly-bys" of Europa while orbiting Jupiter. This allows the spacecraft to spend a maximum amount of time interrogating the moon as it performs each flyby, while it utilizes the other portion of its Jupiter orbit to communicate with Earth, and plan the next portion of its science tour. By utilizing a large, looping orbit of Jupiter, the vehicle would spend a majority of its time outside of the harsh radiation field generated by Jupiter's magnetic field. This increases the lifetime of the mission by only performing necessary science observations while in the area of high radiation. The mission will perform approximately 43 flybys or Europa, taking 10 hours to perform each flyby. The other portion of the spacecraft's orbit of Jupiter, on the order of weeks, is an ideal time to communicate with the Earth and plan the next flyby according to the data received. It is also an ideal time to continue in-situ observations of phenomena such as measuring magnetic field strength, and characterizing the plasma field of Jupiter.

Nadir and Ram$_{CA}$

A notable characteristic of the Europa mission's flyby is that the spacecraft would perform a slew about its X-axis in order to maintain pointing of the instruments mounted to the Nadir platform (Nadir instruments) to the Nadir point of the moon. As the spacecraft gets close to the moon, the slew rate increases up to the point that the craft reaches its closest approach—as close as 25 km from the surface of Europa for some flybys—at which point the Nadir instruments would be looking perpendicular to the velocity direction. The velocity direction at this point in the flyby is dubbed the "Ram direction at closest approach" (Ram$_{CA}$). Some instruments (named the Ram instruments) require pointing in the Ram$_{CA}$ direction in order to sample the particles that the spacecraft flies through during its close encounter with Europa. The Ram$_{CA}$ direction is always perpendicular to Nadir. As the spacecraft departs from closest approach, the slew rate begins to decrease, again to maintain Nadir pointing through the second half of the flyby, out to approximately 66,000 km. With this method, the Nadir and Ram$_{CA}$ directions make up a coordinate system for the spacecraft that can be used to fully define the orientations of the science Nadir and Ram instruments during the flyby, regardless of the configuration of the rest of the vehicle. Figure 1 shows the Nadir and Ram$_{CA}$ with respect to the spacecraft coordinate system for one of the three configuration options, 2C, discussed later in this paper. Discussions about the reorientation of the instruments about the spacecraft axes can be thought of as rotations of the spacecraft about the "science coordinate frame" defined by the Nadir and Ram$_{CA}$ directions. In effect, this re-orientation means that the spacecraft will be in a different orientation with respect to Europa while the Nadir and Ram instruments are pointed nominally with respect to Europa for the flyby.

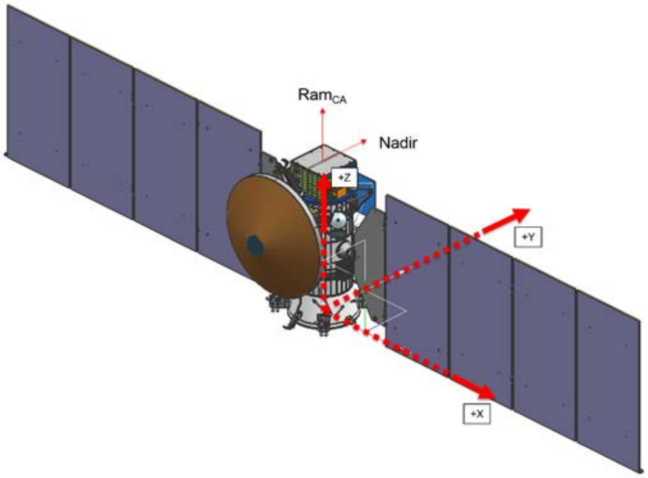

Figure 1 Ram$_{CA}$ and Nadir directions for configuration 2C (instruments removed for clarity)

Trajectories

Direct—The nominal trajectory to deliver the Europa spacecraft to the Jovian system involves the use the NASA's Space Launch System (SLS). Still in development, the SLS launch vehicle is potentially powerful enough to propel the spacecraft on a direct path to Jupiter, as shown in figure 2. This path would take the spacecraft less than three years to reach its destination. Although this could potentially introduce a harsher launch environment, the benefits to this path would be numerous. Cutting down on the cruise phase of the mission when compared to other gravity-assist trajectories means that the mission lifetime requirement could be reduced by up to 5 years depending on the launch date. It also means that the science return would be realized much earlier after launch. But, due to the lack of certainty in the SLS that is still being designed, built and tested, other options are still being considered. And because no other launch vehicle currently exists with the capabilities of the SLS, gravity assist methods by other solar system bodies must be considered.

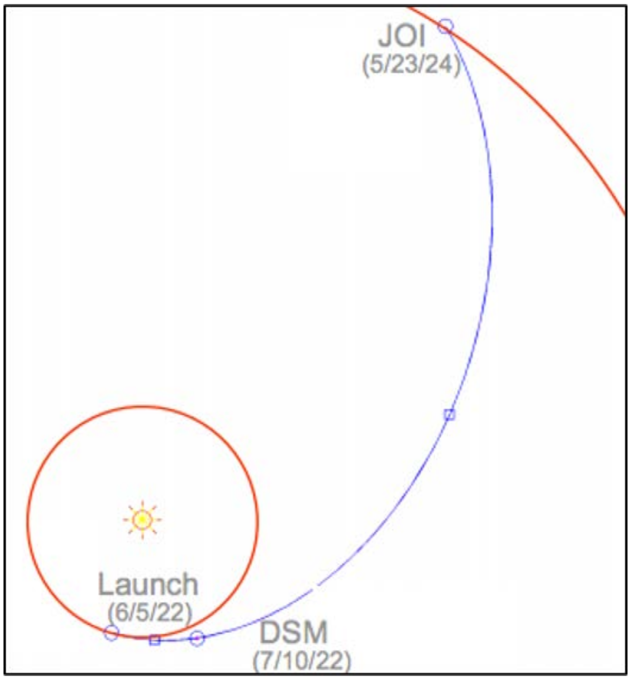

Figure 2 Direct Trajectory (SLS Launch Vehicle)

VEEGA—The VEEGA (Venus-Earth-Earth Gravitational Assist) trajectory is a viable approach that is within the capabilities of the alternate launch vehicles being considered (namely the Delta-IV Heavy and the Atlas-5 launch vehicles). This trajectory requires a considerably longer cruise phase of up to 7.5 years, and would also require that the spacecraft survive a closer approach to the Sun at 0.65 AU as the spacecraft gained velocity with a Venus flyby. This trajectory, although not the current baseline, must be considered in all vehicle configuration options as it represents a real possibility that the spacecraft would need to survive this much harsher cruise environment. Figure 3 depicts the VEEGA trajectory.

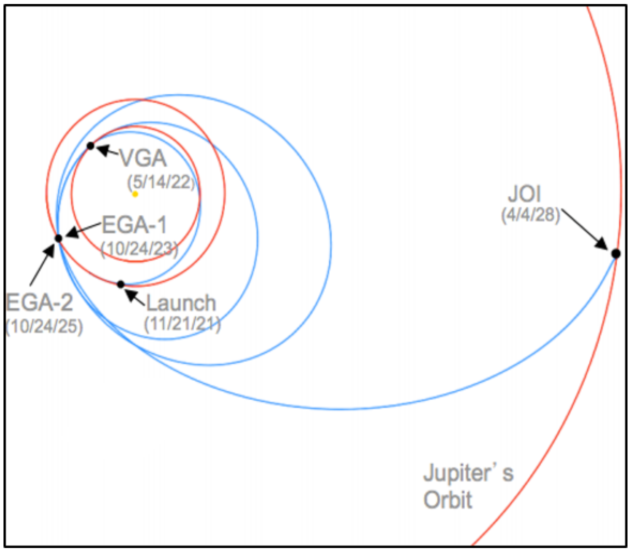

Figure 3 VEEGA Trajectory (Atlas V 551 Launch Vehicle)

Selected Instruments

The original solar configuration, just after selection of the solar power system is depicted in figure 4. Figures 5 and 6 show an overview of the major changes to the spacecraft configuration, with the HGA moved to the side of the vehicle, the solar array moved to the center of the vehicle, and the various changes to the accommodation of the instruments, described below.

EIS—The Europa Imaging System (EIS) is a suite of two cameras that would image the surface of Europa during each flyby. Both cameras are currently accommodated on the Nadir platform of the spacecraft. The Wide Angle Camera (WAC) would take wide field of view images of the surface to aid in the characterization of the topography of Europa's icy shell. The WAC replaces the Topographic imager from the notional instrument suite. The second camera in the EIS suite is the Narrow Angle Camera (NAC). The NAC replaces the Reconnaissance camera from the notional instruments, and is the highest resolution imager of the pair. The NAC is a dual-gimbal camera tasked with characterizing the terrain of surface at the local level. NAC images could be used in order to build up a high resolution mosaic of the surface of Europa and to propose and select potential landing sites for future missions.

E-THEMIS—The Europa Thermal Emission Imaging System takes the place of the notional Thermal Imager. As its name suggest, the imager would look at the thermal emissions coming from Europa's ice shell and would look to provide insight into the internal structure and activity happening in the proposed global ocean below.

ICEMAG— The Interior Characterization of Europa using Magnetometry (ICEMAG) instrument is a suite of 4 magnetometers (2 pairs of fluxgate and Scalar-Vector-Helium magnetometers) that would work in conjunction with each other to characterize Europa's effect on Jupiter's magnetic field as it orbits the planet. ICEMAG would look to determine the composition of the interior of the moon and confirm the presence of a salty liquid-water ocean beneath an icy outer shell.

MASPEX—The Mass Spectrometer for Planetary Exploration/Europa (MASPEX) instrument would use the Europa spacecraft's velocity relative to the moon to analyze the constituents of Europa's nearly nonexistent atmosphere through mass spectrometry. The instrument would help characterize the particles surrounding the moon, and determine the makeup of the surface materials that have been expelled above Europa's surface.

MISE—Replacing the Short Wave Infrared Spectrograph (SWIRS), the Mapping Imaging Spectrometer for Europa (MISE) instrument would investigate the composition of the surface materials of the moon's ice sheath. A major challenge of accommodating the MISE instrument is providing a spacecraft configuration that allows MISE's thermal radiator to have a clear enough view to keep its temperature around the 80 K required for its sensor to work.

PIMS—The Plasma Instrument for Magnetic Sounding (PIMS) replaces the notional Langmuir probe and would look to characterize the magnetosphereic and ionospheric plasma fields surrounding Europa. The primary task of the PIMS instrument is to decouple the effects of the plasma field on Jupiter and Europa's magnetic fields in order to correctly interpret the data returned by the ICEMAG instrument.

REASON—The notional Ice Penetrating Radar (IPR) is replaced by the Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) antenna. Functioning much like the notional instrument, the REASON instrument would use dual frequency sounding (9 MHz and 60 MHz) to probe Europa's ice shell and provide data on the internal structure and horizons, including the ice-ocean interface.

SUDA—An additional instrument not originally a part of the notional package, the Surface Dust Mass Analyzer (SUDA) would measure the particles being ejected from the surface of Europa in the form of plumes that potentially originate from the ocean below. SUDA is another Ram$_{CA}$ instrument that would share a similar view to the MASPEX instrument as both instruments look to characterize the particles in motion around Europa.

UVS—The next generation in a series of ultraviolet spectrographs that have flown in previous missions (most recently seen in the news on the New Horizons mission to Pluto) the Ultraviolet Spectrograph/Europa would serve as the spacecraft's plume hunter as it would characterize Europa's exosphere by measuring the spectrum of light in the UV wavelength. UVS would also employ a secondary viewing port capable of measuring the composition of Europa's horizon during solar occultation.

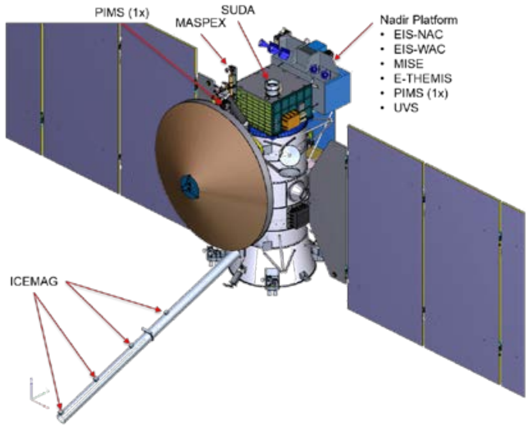

Figure 5 One of the three proposed configuration changes, 2C

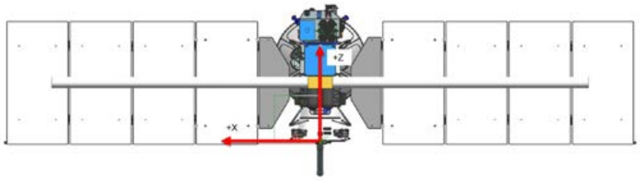

Figure 6 Back of configuration 2C (nadir looking out of page)

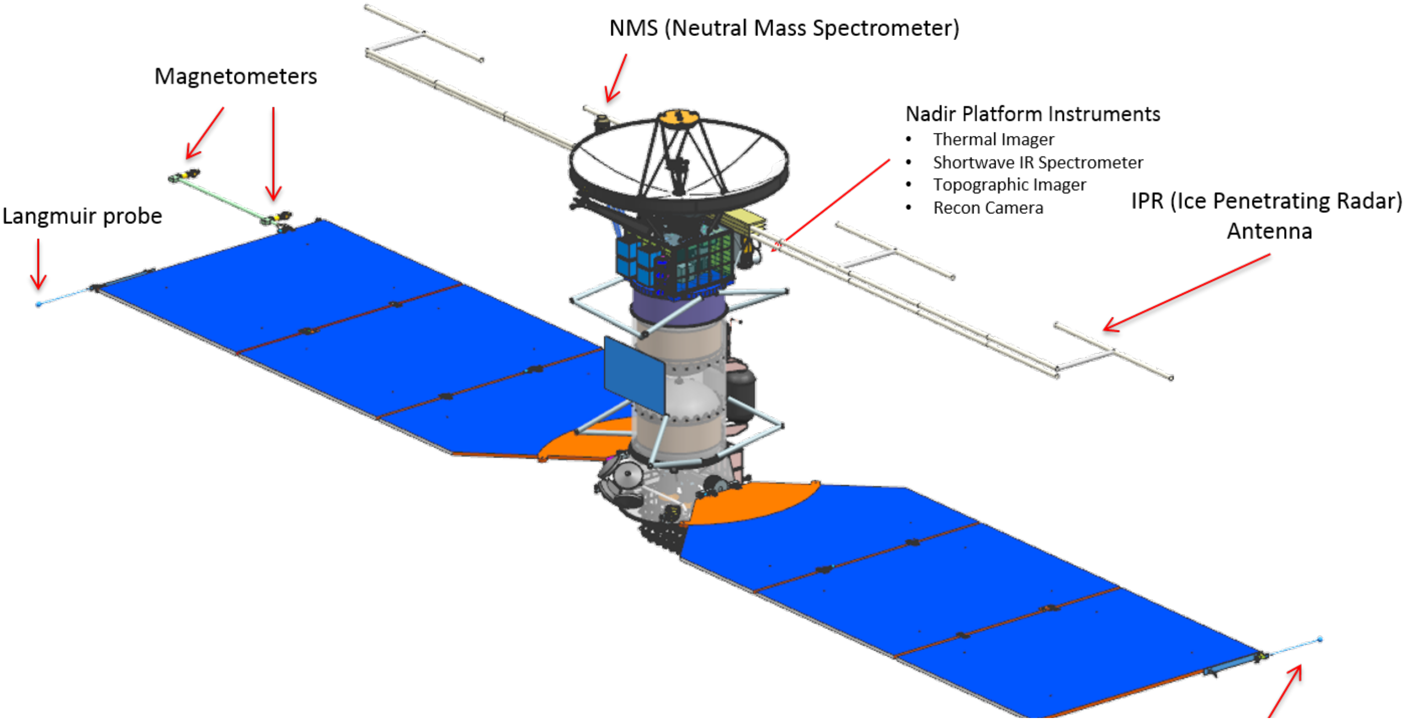

Figure 4 Notional Instruments on Previous Baseline Spacecraft

3. CONFIGURATION CHALLENGES

Selected Instruments Challenges

Nadir Instruments Size—The Nadir instruments from the notional package were placed on a platform on the +Y side of the Avionics Vault, as shown in figure 7. Since the announcement of the selected instruments, the size of the Nadir platform necessary to accommodate the new instruments has nearly doubled. An increase in the assumed envelopes of the MISE and EIS-NAC instruments on account of the fact that that these two instruments have a deploying thermal radiator cover and a 2-axis gimbal, respectively, meant that significantly more room would be needed to house them. Added to this was the addition of two other instruments to the Nadir platform. The PIMS instrument, replacing the notional Langmuir Probes, expressed the need for 3 fields of view, one of which would be directed at Nadir. The UVS instrument, one of the two selected instruments that was not considered in the notional package, also required a Nadir view. As a consequence, the platform needed to increase in size in order to place these two instruments on the platform with the rest of the Nadir facing payloads. Figure 8 illustrates the Nadir platform with selected instruments.

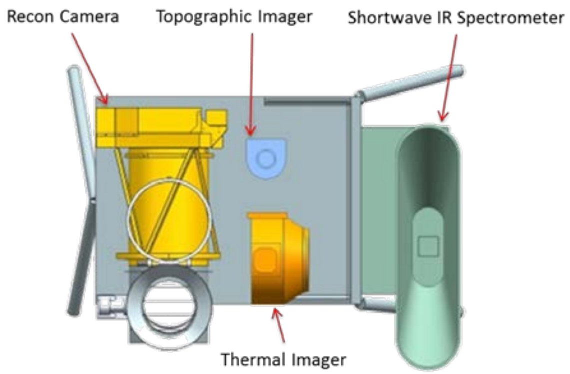

Figure 7 Nadir Platform with Notional Instruments

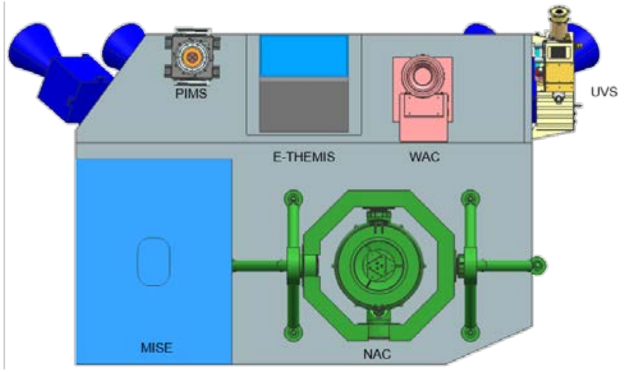

Figure 8 Nadir Platform (Configuration 2C) with Selected Instruments

Nadir Instruments Fields of View—The combination of all of the Nadir instruments fields of view take up a significant, nearly hemispherical, portion of the sky that is seen by the +Y side of the spacecraft. Finding homes for the other instruments and spacecraft components (like the high gain antenna, ICEMAG, and REASON antenna) meant that effectively one half of the spacecraft was unavailable for placement, as shown in figure 9. On top of this some instruments had significant thermal radiator field of view needs that meant that in addition to needing a clear view to the Nadir direction, another open portion of the spacecraft would be necessary. This was especially true for the MISE instrument which required an extremely cold, 80 K temperature on its radiator surface.

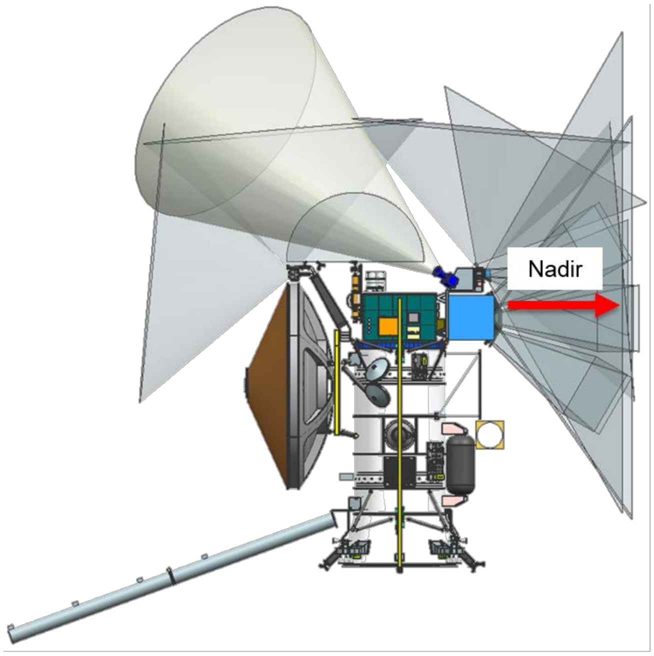

Figure 9 Side view of configuration 2C with Instrument Fields of View

Ice Penetrating Radar/Spacecraft Interaction—Providing a spacecraft accommodation for the notional Ice Penetrating Radar (IPR) was a primary focus of the spacecraft development long before the start of the configuration change. The placement of any of the large conductive components that make up the spacecraft are vital to the produced antenna pattern of the IPR, and as a consequence, the configurational decisions that are made must consider the effect on the IPR any time a change is proposed. Earlier analysis of the IPR antenna pattern/spacecraft interaction suggested that symmetry of the vehicle structure behind the IPR was a beneficial characteristic that provided the best opportunity for a good antenna pattern. The previous baseline spacecraft, shown in figure 10 with the high gain antenna (HGA) located above the IPR, and the large solar array wings placed all the way on the bottom of the vehicle structure was not an ideal configuration for providing a robust accommodation for the IPR. Figure 11 shows an improved configuration for the REASON antenna, with the antenna placed parallel to the center axis of the solar arrays, thus providing better symmetry and less distortion of the antenna pattern.

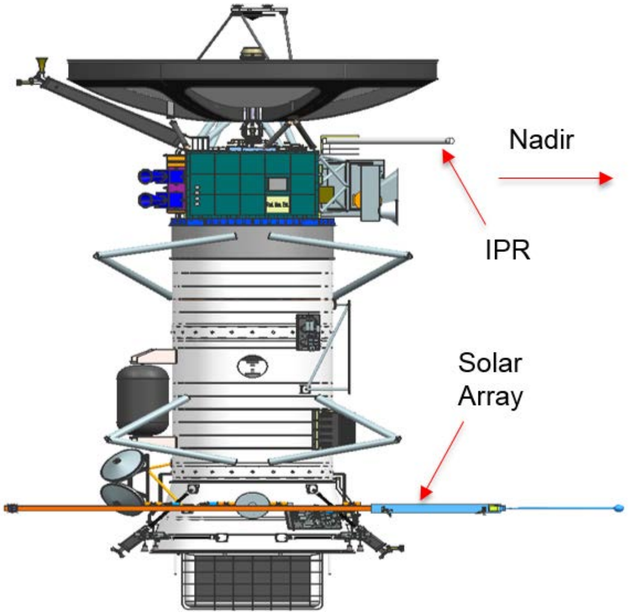

Figure 10 Previous baseline spacecraft IPR placement asymmetric to Solar Array

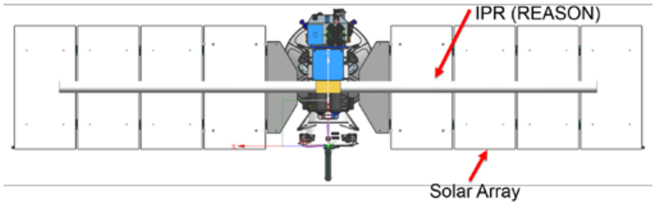

Figure 11 Configuration 2C REASON placement symmetric to Solar Array

Magnetometer Move from Solar Array—Prior to the selection of the instruments for the Europa mission, accommodation work was underway in order to reconsider the placement of the magnetometer sensors on a boom attached to the end of one of the solar array wings. One major reason for this consideration was the fact that the magnetometers had a precise attitude knowledge requirement. This meant that in order to avoid placing an attitude measuring system on the spacecraft, the angular positions of each magnetometer needed to remain stable and known any time the sensors were taking data. Seeing that Jupiter's magnetic field is one of the largest structures in the Solar system, the magnetometers would likely be taking data continuously, meaning their attitudes would need to stay stable even as the spacecraft occasionally entered the shadow of Jupiter and dropped to very low eclipse temperatures. This, coupled with the desire to keep the spacecraft subsystems as separate and modular as possible drove the decision to move the sensors off of the solar array and onto a dedicated boom. When the ICEMAG instrument was chosen as a 4 sensor instrument system, the decision to use a boom became even more necessary. Changing to a boom accommodation meant that a spacecraft that had become significantly more crowded due to instrument selection now had another object to find a home for and ensure that that home did not interfere with any other payload's ability to perform their required functions.

Issues with Transition from MMRTG Configuration

The decision to move from a radioisotope power system and rely solely on the Sun's energy to power the spacecraft had many ramifications. These effects ranged from large-scale performance degradation to integration and test complexity. Of the many effects caused by the power source conversion, some had more potential detrimental effects that warranted higher-level mitigation.

Solar Array Shadowing—Most notable of the configuration challenges was the shadowing of the solar arrays by the IPR antenna and HGA. With the IPR located at the top of the Spacecraft, just under the HGA, the antenna would cast a large shadow on the deployed arrays when the S/C Z-Axis was pointed at the Sun, resulting in an estimated 10% power loss to the flight system. This effect was also seen by the HGA casting a shadow on the Solar Arrays (although to a lesser extent) which resulted in an unusable area of the Solar Panels near the S/C body. This problem was intensified by the fact that at Jupiter, the solar flux is minimal, and the vehicle must be continually pointed at the Sun in order to keep the batteries charged enough for the next flyby. Coupled with the fact that the very large solar array wings necessary to meet the power requirements were approaching the limit on their size due to stiffness and mass concerns, increasing the size of the solar array had the drawback of decreasing the controllability of the vehicle, and in turn making it harder to meet stringent instrument pointing requirements.

Poor CG Location—Another effect was the fact that the Solar Arrays were attached to the S/C in the same vicinity that the MMRTGs were for the nuclear powered vehicle, at the bottom of the Spacecraft. This location made sense for the nuclear powered vehicle as it kept the CG height to a minimum, and the excess heat from the MMRTGs could be harvested to keep the propulsion system warm. But, maintaining the same attachment location for the Solar Arrays meant that the input from any forces imparted by the Solar Arrays onto the Spacecraft (i.e. due to being excited in their deployed mode) would happen far from the vehicle GC. This in turn would cause a rocking of the S/C about its CG, which would make controlling the vehicle much more difficult from a GNC (Guidance, Navigation, and Control) standpoint.

Integration, Test & Launch Loads—Other issues that had existed but had gone unaddressed were items related to Integration and Test difficulties due to the very high stack height of the vehicle. With a top mounted HGA, the vehicle was extremely tall meaning that hardware integration would require large scaffolding to provide the correct access. It also meant that system level testing would be difficult as the large shaker table at JPL cannot support a vehicle of that height. The thermal-vacuum chamber door would also not allow for a vehicle this tall to enter the chamber without first removing the HGA and lifting it up inside the chamber; and then transporting the vehicle into the chamber and lowering the HGA down on top of it. A top mounted HGA also meant the top of the vehicle was inaccessible for lifting operations and other methods (i.e. large frames, holes in the HGA) would be needed to lift the stacked vehicle. On top of this, the taller vehicle would likely see higher loads and displacements as the spacecraft was cantilevered on the top of the rocket during launch.

250 + 50 kg Additional Payload

On top of the challenges presented by the selected instruments, and the decision to move to an all solar-powered spacecraft, an additional request to consider the effects and capability of housing a 250 kg releasable payload with an additional 50 kg of mass allocated to accommodating it was given to the project. The size of the payload was estimated to be on par with the size of the spacecraft's avionics vault, and as such, placement on the top of the spacecraft looked like a frontrunner in the accommodation approach. However, the HGA's placement on the top of the meant that the next best option was to place the probe on the side of the spacecraft. This presented some immediate challenges, such as the fact that the center of gravity of the spacecraft would shift significantly after the release of the payload. The project had recently moved to an array of fixed thrusters as the delta-v and attitude control system thrusters, meaning that the propulsion system would need to be tailored to the CG of both configurations, without the ability to change its primary thrust axis.

4. CONFIGURATION 2

Mitigating Solar Array Shadowing

The major configuration change used as a mitigation for many of the issues with the Spacecraft was the HGA relocation to the -Y side of the vehicle. Moving this large structure means that the Ice Penetrating Radar is behind the vehicle when the HGA and Solar Arrays are pointed at the Sun, eliminating the shadowing of the Arrays by the IPR. This major change also has secondary effects: the shadowing from the HGA on the Solar Arrays has been reduced by moving the HGA and Solar Array close together.

Increasing Available Field of View Area

Moving the HGA to the side of the vehicle also created a larger field of view for the instrument sensors and radiators. The previous baseline configuration made the +Y side of the vehicle available for the Nadir instruments, but left little other area for the thermal radiators. The HGA on top of the spacecraft, the large solar arrays, and the propulsion module meant that the +Z, +/-X, and –Y directions, respectively, all had major obstructions to radiator fields of view. Relocating the HGA to the –Y side opened up the +Z portion of the sky, meaning that another nearly 2-Pi steradian field of view was available.

Integration &Test Simplification

The reconfiguration also reduced the height of the vehicle by a significant amount. This brought the CG of the vehicle down and decreased cantilevered distance from the launch vehicle interface to the top of the spacecraft. The expectation is that the vehicle would experience lower load levels during the launch phase. This also helped alleviate the difficulty in testing the vehicle at JPL. The thermal chamber door would now easily accept the height of the vehicle, making thermal-vacuum testing significantly less complicated. It also meant that the large vibe-test shaker could fit the entire vehicle on top of it for system level vibration testing. Eliminating the need to remove the HGA for this test meant that the system could be tested as a fully integrated assembly, reducing risk and avoiding writing a waiver for testing in a non-flight-like configuration.

Downside to Configuration Change

Thermal Testing Complexity—The configuration change was not easy to accommodate across the board. For example, the side mounted HGA meant that system level thermal-vacuum testing in JPL's 25-foot space simulator would be more complicated than with an axially stacked vehicle. The magnitude of the solar flux produced by the solar simulator drops off with distance moving radially away from the center of the light beam. With the old configuration placing all of the hardware under the shade of the HGA, the solar flux levels that are anticipated at Venus could be fully realized on the HGA surface. But, because of the side mounted HGA in the configuration 2 family, the spacecraft would need to be placed horizontally in the chamber to point the HGA at the solar simulator. This meant that the while the HGA would receive the correct solar flux levels, the sun-shades and other hardware farther away from the center of the light patch would not. This would require a Test-As-You-Fly waiver, as it would violate the requirement to test hardware in the same environments that they see in operation.

Additional Sun Shielding—One of the primary reasons for placing the HGA on top of the spacecraft in the previous baseline configuration was to use it as a sunshield for protecting the other spacecraft components as the vehicle traveled through the inner-cruise phase, including a potential Venus fly by. By relocating the HGA to the side of the vehicle, a much larger frontal area must be shaded. Sun shades both above and below the HGA were employed as a means for eliminating direct exposure of the spacecraft body to the Sun. One component that cannot be placed behind the Sun shades are the roll-control thrusters on the –Y side of the vehicle. Preliminary analysis was performed by the thermal team in order to determine the effect of direct sunlight down the throat of the thruster nozzle, and the results look favorable for the engine's survival. Although the implementation of Sun shades will require additional detailed work in order to balance the heat flow through them, the shades provided an achievable means for accommodating the HGA on the –Y side of the spacecraft.

5. CONFIGURATION 2 VARIANTS

Configuration 2C

The original Nadir direction of the MMRTG-based configuration in the +Y direction was preserved in the configuration named 2C. Keeping the Nadir facing instruments looking the same direction as before, but without the large 3m HGA mounted to the top the structure meant that the +Z direction could be utilized for instrument radiators. It was also beneficial in that the entire S/C body, including the HGA and the Solar Array wings were now positioned in between the Nadir instruments and the Sun during nominal operations, acting as a thermal shield for the payload. It also avoided the launch fairing contamination risk of having the Nadir instruments point vertically when in the launch configuration. Another driving factor behind the need to change configurations was the desire to maintain symmetry of the spacecraft body to the IPR antenna in order to preserve the antenna pattern produced by the radar. Earlier studies had shown that positioning the IPR asymmetrically with respect to the spacecraft had negative effects on the pattern that could make it impossible to meet science requirements. Another beneficial aspect of the 2C configuration is that it cleared the top of the spacecraft and allowed the Ram instruments to enjoy a full, 2-pi steradian field of view in the Ram_{CA} direction. This greatly reduced the risk of contamination of the Ram_{CA} instruments by ensuring that particles had an unobstructed path into their inlets. Also, being placed away from other structures reduced the risk of particles scattering off of the spacecraft (either by outgassing or bouncing off of the spacecraft) and finding their way into the instrument inlets.

In anticipation of the instrument package changing after instrument selection, the desire to open up the clear sky field of view around the instruments was big. Moving the HGA off of the top of the Vault meant that the instruments were not only less constrained in their radiator FOVs, but now had the option of reorienting the Nadir direction with respect to the spacecraft.

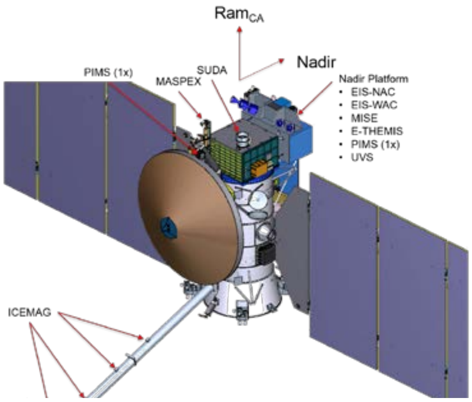

Figure 12 Configuration 2C Overview

Configuration 2D

Moving the High Gain antenna opened up the +Z side of the vehicle meaning it was now available as a viewing direction for the Nadir facing instruments. As a potential option, illustrated in figure 12, configuration 2D was developed with the Nadir viewing instruments pointed in the direction of the Spacecraft +Z axis. This transition was effectively a rotation of the Nadir platform about the spacecraft X-axis, meaning the spacecraft would point its long axis at the center of Europa for each flyby. Moving the HGA off of the top of the vehicle and changing the Nadir direction meant that the instruments would have a larger clear FOV (essentially 2-pi steradian) to look to Europa, and at the same time would be able to utilize the +Y view for thermal radiators. This also meant that the instrument radiators were pointed away from the sun during all nominal operations, including the potential Venus flyby at 0.65 AU, and the long cruise to Jupiter.

To provide the best possible accommodation of the REASON instrument, the antenna was placed on the top of the spacecraft in order to provide as close to a symmetric spacecraft as possible relative to REASON. Previous studies had shown that the spacecraft body and even the HGA were not major contributors to the distortion of the IPR antenna pattern. The solar arrays were the biggest driver due to their size and amount of conductive material. This meant that a home on the top of the vehicle would leave the solar arrays symmetrically displaced about the axis of the Radar, in either the edge on or normal gimbal configuration. The distance of the IPR could also be tuned in order to find the optimal distance from the spacecraft. This would be driven by the 60 MHz antenna as its wavelength is on the order of the size scale of the spacecraft.

Configuration 2D-1—Configuration 2D-1 was considered for a more specific definition to the general 2D configuration. 2D-1 pointed the Ram_{CA} direction at the spacecraft +Y axis, as seen in figure 13. This benefited the Ram instruments greatly by decoupling their viewing directions from the HGA. Because of the nature of the changing Ram direction as the spacecraft flies by Europa but preserves Nadir pointing, Ram instruments have an effective field of view of nearly 2-pi steradians (hemispherical). Giving them the side of the spacecraft that does not share its view with other large structures like the HGA or the Magnetometer Boom means a higher chance at getting science data that is free from any spacecraft-borne contaminants. A potential downside of this configuration is the fact that the -Y facing roll control thrusters are directed into the field of view of the Ram_{CA} instruments. Although the thrusters are not used during the nominal flyby (the spacecraft is controlled by reaction wheels at that time) there is still the risk of contaminating the Ram_{CA} instruments when the thrusters are operated.

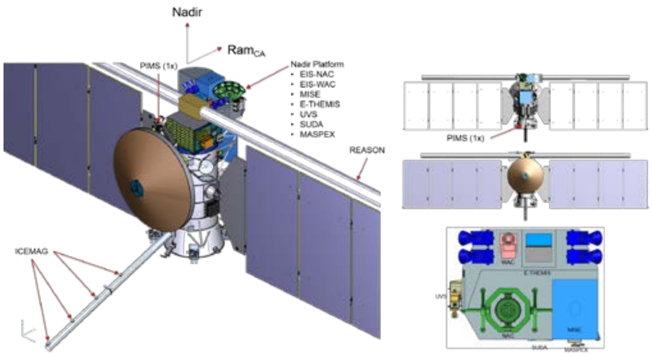

Figure 13 Configuration 2D-1 Overview

Configuration 2D-2

Configuration 2D-2 maintains the +Z Nadir pointing of the 2D family, but is rotates the instruments 180 degrees about the Nadir axis to point the Ram instruments to the -Y direction, co-boresighted with the HGA, shown in figure 14. This configuration allows for the Magnetometer Boom to be placed on the +Y side of the vehicle, ensuring that it will be protected from the Sun in nominal operations and moving it away from many of the spacecraft structures that could exceed the instrument's magnetic cleanliness requirement.

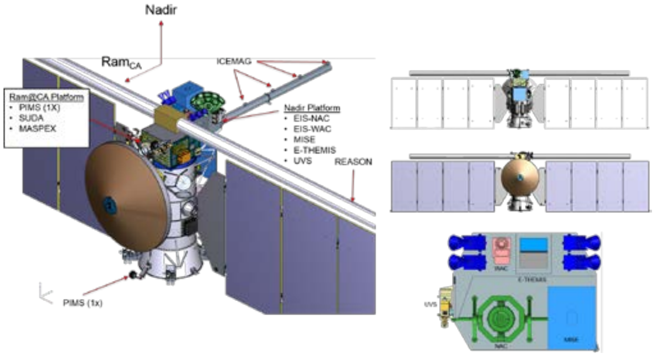

Figure 14 Configuration 2D-2 Overview

6. CONCLUSIONS

With a goal of choosing a baseline configuration by the end of the 2015 calendar year, the current results of the Europa Mission's spacecraft reconfiguration effort have been beneficial to not only the accommodation of the selected instrument payload, but to the majority of the spacecraft's multiple subsystem developments. A vehicle which is more robust to integration and testing, spacecraft in-flight control, launch loads, and may others has been developed with the 2C and 2D type configurations. Some reduced capacity on the modularity of the spacecraft's subsystems, and an increase in the complexity of the thermal testing story have shown to be acceptable when compared to the benefits realized by the major configuration change. The primary goal of the reconfiguration was to optimize the vehicle after the decision to change the power system to rely solely on solar energy. As a result, the project team was able to increase the ability of the Flight System to meet its science objectives, by creating a vehicle that is centered on it instruments.

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BIOGRAPHY

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