NASA

National Aeronautics and Space Administration

Office of Inspector General

Office of Audits

MANAGEMENT OF NASA'S EUROPA MISSION

May 29, 2019

Report No. IG-19-019

Office of Inspector General

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RESULTS IN BRIEF

Management of NASA's Europa Mission

May 29, 2019

IG-19-019 (A-18-014-00)

WHY WE PERFORMED THIS AUDIT

Scientists believe that Europa, one of Jupiter's 79 known moons, may have a large liquid ocean below its icy surface suitable to sustain life. The National Research Council (NRC)—which publishes a decadal survey of recommended priorities that NASA uses to help plan its science exploration missions—determined in 2011 that an orbiter mission to Europa should be NASA's second highest priority large-scale planetary science mission after the Mars 2020 mission.

Congress has taken a strong interest in the project and since fiscal year (FY) 2013 has appropriated about $2.04 billion to NASA for a Europa mission—$1.26 billion more than the Agency requested. The former Chairman of the House subcommittee that funds the Agency, a long-time advocate for NASA and the Europa mission in particular, was largely responsible for these substantial appropriations. Congress also directed NASA to plan two separate missions—a flyby orbiter known as Europa Clipper and a Lander mission to place scientific instruments on the moon's surface. In FYs 2017 and 2018, Congress directed NASA to use the Space Launch System (SLS), the Agency's heavy-lift rocket currently under development, as the launch vehicle for both missions and specified launch dates of no later than 2022 for the orbiter and 2024 for the Lander. In February 2019, Congress delayed those launch dates by a year to 2023 and 2025, respectively. NASA's Jet Propulsion Laboratory (JPL) has overall project management responsibilities for both missions.

In this audit, we examined NASA's management of the Europa mission relative to achieving technical objectives, meeting milestones, controlling costs, and addressing congressional requirements. To complete this work, we reviewed documents, reports, schedule projections, budget allocations, costs, and risks related to the Clipper and Lander projects, as well as NASA and JPL policies, congressional mandates, and NRC reports. We also compared the Europa mission with other JPL projects and interviewed Clipper and Lander personnel, other NASA officials, and members of the scientific community.

WHAT WE FOUND

Despite robust early-stage funding, a series of significant developmental and personnel resource challenges place the Clipper's current mission cost estimates and planned 2023 target launch at risk. Specifically, NASA's aggressive development schedule, a stringent conflict of interest process during instrument selection, and an insufficient evaluation of cost and schedule estimates has increased project integration challenges and led the Agency to accept instrument cost proposals subsequently found to be far too optimistic. Moreover, Clipper has had to compete with at least four other major JPL-managed projects for critical personnel resources, causing concern that the project may not have a sufficient workforce with the required skills at critical periods in its development cycle.

In addition, although Congress directed NASA to use the SLS to launch the Clipper, it is unlikely to be available by the congressionally mandated 2023 date and therefore the Agency continues to maintain spacecraft capabilities to accommodate both the SLS and two commercial launch vehicles, the Delta IV Heavy and Falcon Heavy. The Agency also has not incorporated associated development and launch vehicle selection risks into the Clipper's joint cost and schedule confidence level (JCL) analysis, a tool used to help determine the likelihood a project will achieve its objectives within budget and on time, thereby prolonging risks that should be resolved prior to establishing the project cost and schedule baseline. Lastly, significant funding from Congress must be maintained to avoid additional delays in the launch schedule and prevent the need to move funds from other projects in NASA's science portfolio. Significantly, FY 2020 will be the first budget cycle in which the mission's most important congressional supporter no longer chairs the House appropriations subcommittee.

Similar to Clipper, the Lander mission will likely face shortages in skilled technical staff given that it is competing with five other major projects at JPL, including Clipper, for the same resources, putting planned activities at risk. Moreover, when we compared the Lander's projected development schedule to other similar NASA robotic missions, we found the congressionally mandated 2025 launch date not feasible, with the earliest possible launch in late 2026. Further, the Lander is currently designed to launch only on the upgraded version of the SLS, a vehicle whose readiness date is highly uncertain.

We also believe that requiring the Agency to pursue a Lander mission at the same time it is developing the Clipper mission is inconsistent with the NRC's recommended science exploration priorities. Specifically, the most recent decadal survey does not include a Europa Lander mission, such a mission will not provide the most optimal science results for the money spent if launched before adequate information is obtained from Clipper, and moving forward with a Lander at the present time would negatively affect the balance and budget of other projects in the planetary science portfolio. Finally, the Lander will essentially require doubling the amount of recent increases in congressional funding the Clipper mission has received while the two projects overlap. The Agency's FY 2020 budget request includes no funding for the Lander and we believe at this point, NASA can utilize the benefits gained from the Lander's preliminary research and commit to the project when the science community makes it a priority and resources are available.

What We Recommended

For the Europa mission to achieve its technical objectives, meet milestones, and control costs, we recommended the Associate Administrator for Science Mission Directorate (1) evaluate current and future critical technical staffing requirements by project over the next 5 years; (2) reassess the Clipper JCL with launch vehicle risks for the Delta IV Heavy, Falcon Heavy, and SLS; (3) evaluate the impact to the Planetary Science Division budget portfolio if Clipper's increased funding levels were disrupted; (4) continue to implement the instrument cost control plan; (5) reassess the Lander project's timeline given resource availability; (6) evaluate the impact that starting Lander Phase-A, delaying the start date, or continuing Pre-phase A research under multiple funding scenarios would have on the entire planetary science portfolio; (7) consider requesting the NRC reexamine the Lander's priority; and (8) coordinate with Congress and other stakeholders to develop achievable project timelines and corresponding funding levels to maintain a balanced science portfolio supportive of NRC priorities. We also recommended the Associate Administrator for Science Mission Directorate, in coordination with the Office of the General Counsel, reassess the process of isolating key project personnel from instrument selection. Finally, we recommended the JPL Director evaluate current and future critical technical staffing requirements, make staffing adjustments to the Clipper project as necessary, and reassess Lander commitments.

We provided a draft of this report to NASA management who concurred with 9 of our 10 recommendations and described corrective actions it has taken or will take. We consider management's comments to all but Recommendation 2 responsive; therefore, those recommendations are resolved and will be closed upon completion and verification of the proposed corrective actions. Management did not concur with Recommendation 2 related to reassessing launch vehicle risks and this recommendation will remain unresolved pending further discussion with the Agency.

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Acronyms

APL	Applied Physics Laboratory
CDR	Critical Design Review
E-THEMIS	Europa Thermal Emission Imaging System
EIS	Europa Imaging System
EUS	Exploration Upper Stage
FTE	full-time equivalent
FY	fiscal year
GAO	Government Accountability Office
ICEMAG	Interior Characterization of Europa using Magnetometry
JCL	joint cost and schedule confidence level
JPL	Jet Propulsion Laboratory
KDP	Key Decision Point
MASPEX	MAss SPectrometer for Planetary EXploration
MISE	Mapping Imaging Spectrometer for Europa
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NRC	National Research Council
OIG	Office of Inspector General
PDR	Preliminary Design Review
PIMS	Plasma Instrument for Magnetic Sounding
REASON	Radar for Europa Assessment and Sounding: Ocean to Near-surface
SLS	Space Launch System
SRB	Standing Review Board
SUDA	SUrface Dust Mass Analyzer
SWOT	Surface Water and Ocean Topography
UVS	Ultraviolet Spectrograph

INTRODUCTION

NASA seeks to understand the planets and smaller bodies that inhabit our solar system to answer questions about their formation, how life evolved on Earth, and the potential for life elsewhere. Since the mid-1960s, NASA has focused on exploring Mars for signs of water and possible evidence of past or current life. As exploration of the solar system expands, scientists believe that Europa, one of Jupiter's 79 known moons, may have a large liquid ocean below its icy surface suitable to sustain life.

In 2011, the National Research Council (NRC) determined that an orbiter mission to Europa to confirm the presence of an interior ocean and study its geological history should be NASA's second highest priority large-scale planetary science mission for the next decade.[1] Congress has taken a strong interest in the project and since fiscal year (FY) 2013 has appropriated about $2.04 billion to NASA for a Europa mission—a remarkable $1.26 billion more than the Agency requested.[2] Coupled with the substantial funding, Congress directed NASA to plan two separate missions to Europa—a "flyby" orbiter known as Clipper and a Lander mission intended to place scientific instruments on the moon's surface. In FY 2017 and 2018 appropriation legislation, Congress also directed NASA to use the Space Launch System (SLS), which is currently under development, as the launch vehicle for both missions and specified launch dates of no later than 2022 for the orbiter and no later than 2024 for the lander.[3]
In NASA's FY 2019 appropriations law, Congress delayed those launch dates by a year to 2023 and 2025, respectively.[4]

In light of the Europa missions' significance to the science community, congressional interest, and budget investment, we initiated this audit to examine NASA's management of the program relative to achieving technical objectives, meeting milestones, controlling costs, and addressing congressional requirements. See Appendix A for details on the audit's scope and methodology.

Background

NASA's Planetary Science Division launches spacecraft and rovers into space to advance scientific knowledge about our solar system and its planetary bodies.[5] In the past, these exploratory missions

[1] NRC, *Vision and Voyages for Planetary Science in the Decade 2013-2022* (2011). The NRC's top priority was a robotic mission to Mars, known as the Mars 2020 rover mission, which is scheduled to launch in July or August 2020 to seek signs of habitable conditions on Mars and past microbial life. The NRC was the research arm of the National Academy of Sciences. In July 2015, the institution became the National Academies of Sciences, Engineering, and Medicine. For simplicity, we use the term NRC throughout the report to refer to both the NRC and National Academies of Sciences, Engineering, and Medicine.

[2] Consolidated and Further Continuing Appropriations Act, 2013, Pub. L. No. 113-6 (2013) provided the first direct funding for a mission to Europa.

[3] Consolidated Appropriations Act, 2017, Pub. L. No. 115-31 (2017) and Consolidated Appropriations Act, 2018, Pub. L. No. 115-141 (2018). NASA is developing the SLS—a two-stage, heavy-lift rocket—to launch the Orion Multi-Purpose Crew Vehicle and other payloads into space.

[4] Consolidated Appropriations Act, 2019, Pub. L. No. 116-6 (2019).

[5] The Planetary Science Division is one of five divisions within NASA's Science Mission Directorate.

generally followed a progressive strategy that begins with flybys, moves next to orbiting, landing, and roving missions, and ends with sample-return missions from those planetary bodies to Earth.[6] Based on extensive interactions with the planetary science community, the NRC develops a comprehensive strategy for recommending priority areas of study and presents those recommendations in a decadal survey report that NASA uses to help plan its science exploration missions.[7]

The NRC follows a disciplined approach in prioritizing its recommendations for exploration flight projects with the goal to develop a fully integrated strategy of flight projects, technology development, and supporting research that maximizes the value of scientific knowledge gained over the decade. Flight projects are prioritized based on four criteria: science return per dollar, programmatic balance, technology readiness level, and available interplanetary flight trajectory opportunities within the decadal period. The most important of those criteria is science return per dollar, which is assessed through scientific community consensus and cost and technical evaluation.[8]

In its 2013-2022 Decadal Survey, the NRC identified Europa as the second highest priority for a planetary flagship mission after the Mars 2020 rover. The NRC concluded that Europa offers one of the most promising places to search for the existence of past or present life in the solar system. Europa could conceivably support life underneath its 4 to 30 kilometer-thick ice crust given the presence of a subsurface ocean that may contain nutrients and energy to support organic activity. NASA's previous Jupiter system flyby missions—Voyager and Galileo—produced insights about the planet and its 79 known moons; however, the amount of data collected was limited by the relatively primitive instruments onboard the two spacecraft.[9]

A Europa mission would be the first major step in understanding the potential for bodies in the outer solar system to serve as a habitat for life. The mission's science objectives include confirming the presence of an interior ocean, characterizing the moon's ice shell, and probing its geologic history, all of which NASA has deemed Level 1 science requirements for the mission.[10] See Appendix B for a further description of the science objectives.

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6 Flyby spacecraft conduct the initial reconnaissance of solar system exploration, flying close enough to a celestial body to collect data but not close enough to get captured by its gravity. Orbiter spacecraft travel to a celestial body and enter into orbit to conduct more in-depth study. Lander spacecraft are designed to reach the surface, while rovers are vehicles designed to move across the surface of a celestial body.

7 Congress recognized the value of the science community reaching a consensus on the strategic selection of NASA priority missions and projects. National Aeronautics and Space Administration Authorization Act of 2005, Pub. L. No. 109-155 (2005) and National Aeronautics and Space Administration Authorization Act of 2008, Pub. L. No. 110-422 (2008) legislatively mandated decadal surveys and a respective midterm review in each NASA science area. However, Congress has the most direct influence on NASA's missions through the appropriation process by funding or defunding specific projects.

8 All space science decadal surveys follow a cost and technical evaluation process using an independent contractor. While cost and technical evaluations vary slightly for each decadal survey, the process seeks to determine the technical maturity of a mission concept and its approximate cost.

9 Voyager 1 and Voyager 2 launched in 1977 and flew by the Jupiter system in March and July 1979, respectively. Galileo launched in 1989, entered orbit around Jupiter in December 1995, and ended its mission by plunging into Jupiter's atmosphere in September 2003.

10 Level 1 science requirements are a project's fundamental and basic set of requirements.

During the 2013-2022 Decadal Survey conducted between July 2009 and February 2011, the NRC estimated a Europa orbiter mission's cost at $4.7 billion.[11] Given this estimate, the NRC advised that both a decrease in mission scope and an increase in the Agency's planetary funds would be needed to make the project feasible; maintain balance among other small, medium, and large missions as well as planetary destinations; and avoid the risk of diverting funds from other projects in the Planetary Science Division's portfolio. If the Division received additional funding beyond Europa's needs, the NRC recommended NASA initiate one of the next priority missions—an orbiter and probe to Uranus, followed by an orbiter to Saturn's moon Enceladus, and a mission to explore the climate of Venus.[12] The NRC estimated these third, fourth, and fifth priority missions would cost $2.7 billion, $1.9 billion, and $2.4 billion, respectively.

Europa Mission Funding

Since FY 2013, Congress's direct funding for Europa missions has totaled just over $2.04 billion or $1.26 billion more than the Agency requested (see Table 1). The former Chairman of the House Subcommittee on Commerce, Justice, and Science, a long-time advocate for NASA and the Europa mission in particular, was primarily responsible for these substantial appropriations.[13]

Table 1: Europa Mission Funding Request and Congressional Appropriations, FYs 2013-2019 (Dollars in Millions)

	Fiscal Year							
	2013	2014	2015	2016	2017	2018	2019	Totals
Funding requested by NASA	$0	$0	$15	$30	$50	$425	$265	$785
Funding enacted by Congress	75	80	100	175	275	595	740	2,040
Increase in the amount Congress funded versus what NASA requested	$75	$80	$85	$145	$225	$170	$475	$1,255

Source: NASA Office of Inspector General (OIG) analysis of Agency budget documentation and congressional appropriations legislation.

In NASA's FY 2013 appropriation, Congress provided the Agency direct funding of $75 million for "pre-formulation and/or formulation activities for a mission that meets the science goals outlined for

[11] In 2016, we reported that the NRC's 2007 Earth Science Decadal Survey tended to underestimate the costs of their recommended missions. In the 2013-2022 Planetary Science Decadal Survey, the committee used a cost and technical evaluation process and analysis that accounted for the actual costs of analogous previous missions in order to generate more realistic cost estimates. NASA OIG, *NASA's Earth Science Mission Portfolio* (IG-17-003, November 2, 2016).

[12] The Venus climate exploration mission includes a carrier spacecraft, gondola and balloon system, mini-probe, and two dropsondes. A gondola is an airtight enclosure suspended from a balloon used to carry instruments. A probe is an unmanned spacecraft that travels through space to collect science information and send data back to Earth. A dropsonde is a meteorological instrument dropped from an aircraft in a planetary atmosphere to take measurements as it falls to the planet's surface.

[13] Congressman John Culberson was elected in 2000 to represent the 7th District of Texas and from 2014 to 2018 chaired the Subcommittee on Commerce, Justice, and Science responsible for NASA's funding. Congressman Culberson lost his reelection bid in November 2018. The current Chairman of the House appropriations subcommittee funding NASA is Congressman José Serrano, who represents the 15th District of New York.

the Jupiter Europa mission in the most recent planetary science decadal survey."[14] While Congress continued direct funding of the Europa mission in subsequent fiscal years, it also added specific mission mandates. For example, in FY 2016 the Clipper mission was directed to launch in 2022.[15] The following year, Congress added a Lander mission to be launched by 2024 and directed that both missions use the SLS rocket. Lastly, in FY 2019 Congress for the first time added direct funding for the Lander mission while delaying the launch dates by a year for both missions, stating:

> $545,000,000 is for an orbiter and $195,000,000 is for a lander to meet the science goals for the Jupiter Europa mission as recommended in previous Planetary Science Decadal surveys: Provided further, that the National Aeronautics and Space Administration shall use the Space Launch System as the launch vehicles for the Jupiter Europa missions, plan for an orbiter launch no later than 2023 and a lander launch no later than 2025, and include in the fiscal year 2020 budget the 5-year funding profile necessary to achieve these goals.[16]

FY 2019 funding for the Europa missions, although not enacted until February 2019, largely reflects the influence of the former Chairman of the House appropriations subcommittee.

Europa Clipper Mission

The Clipper's mission goal is to investigate Europa's habitability including characterizing the ice shell and any subsurface water, understanding the ocean's composition and chemistry, and understanding the formation of surface features. The mission also hopes to identify scientifically compelling sites and hazards for a potential future lander mission to Europa. The mission's payload consists of nine instruments and will use an on-board telecommunication system to perform gravity science measurements (see Appendix B for a more detailed description of each):

- Europa Thermal Emission Imaging System (E-THEMIS) will provide high spatial resolution, multi-spectral thermal imaging of Europa.
- Europa Imaging System (EIS) will use wide and narrow angle cameras to map Europa's surface.
- Interior Characterization of Europa using Magnetometry (ICEMAG) will measure the magnetic field near Europa.[17]
- MAss SPectrometer for Planetary EXploration (MASPEX) will determine the composition of the surface and subsurface ocean
- Mapping Imaging Spectrometer for Europa (MISE) will probe the material composition of Europa.
- Plasma Instrument for Magnetic Sounding (PIMS) will help determine Europa's ice shell thickness, ocean depth, and salinity.
- Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) is an ice penetrating radar instrument designed to characterize Europa's icy crust.

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[14] Pub. L. No. 113-6.

[15] Consolidated Appropriations Act, 2016, Pub. L. No. 114-113 (2015).

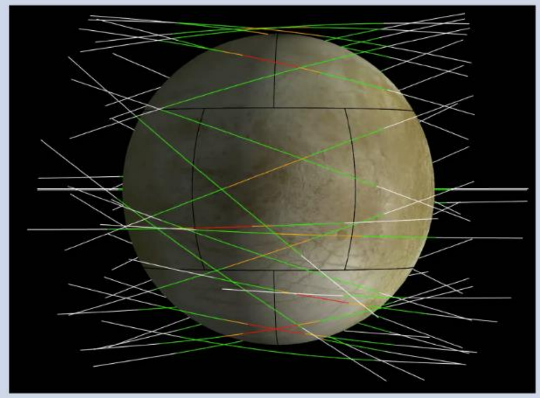
[16] Pub. L. No. 116-6.

[17] In March 2019, the Associate Administrator for Science Mission Directorate terminated development of the ICEMAG instrument citing cost growth concerns and committed to investigating a way to include a simpler, less complex magnetometer on the mission.

- SUrface Dust Mass Analyzer (SUDA) will measure the composition of small, solid particles ejected from Europa.
- Ultraviolet Spectrograph (UVS) will detect the likely presence of water plumes erupting from Europa's surface.

After entering Jupiter's orbit, the Clipper is expected to perform 46 flybys of Europa at altitudes ranging from 25 kilometers to 2,554 kilometers above the surface. It would fly past Europa as frequently as every 2 weeks, providing multiple opportunities to investigate the moon's composition and structure of its interior and icy shell up close and at high resolution. The Clipper's primary mission is planned to last about 3.7 years with additional flybys of Jupiter's moons Ganymede (four) and Calisto (nine), before ending with the Clipper plunging into Jupiter's atmosphere.

Europa Clipper Flybys



Source: NASA.

NASA's Jet Propulsion Laboratory (JPL) is the lead Center and has overall project management responsibilities for the mission including management of subcontracts and instrument integration.[18] JPL is also developing two science instruments for the mission—a magnetometer and spectrometer (see Appendix B for instrument descriptions). The Johns Hopkins University Applied Physics Laboratory (APL) is contributing nearly a third of the total project workforce and is responsible for the spacecraft's propulsion system, radio frequency module, two additional instruments, and project management. APL had also began development of the solar array panel until it was subcontracted to Airbus Defence and Space Netherlands in 2017.

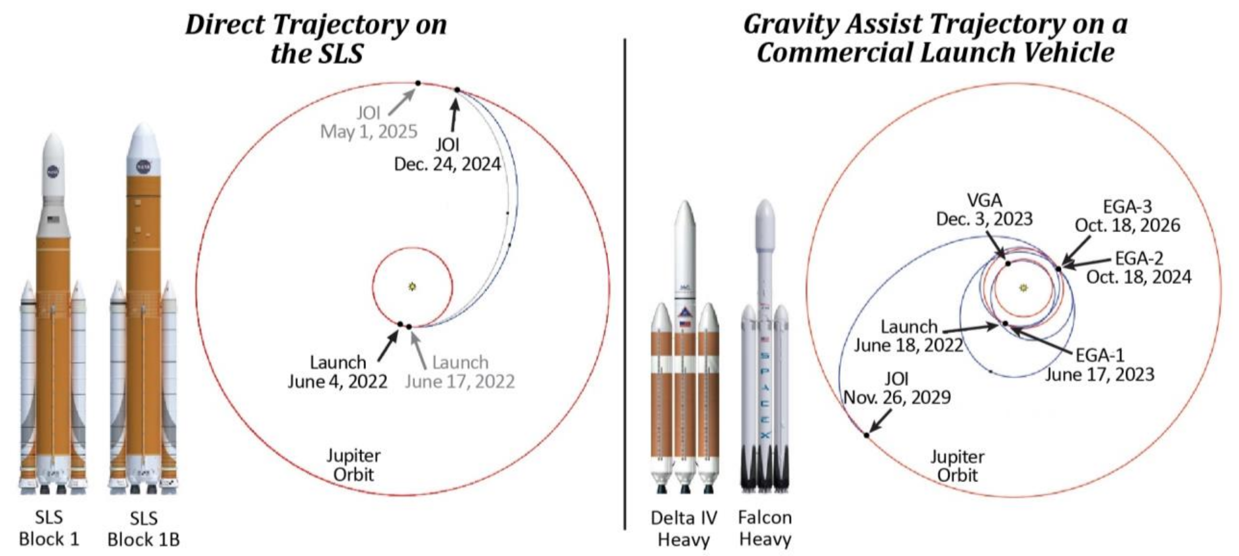
The Clipper initially targeted a June or July 2022 launch but is now working toward a launch in 2023. Because of its mass, the orbiter can only be launched on the SLS or two of the largest commercial launch vehicles—a United Launch Alliance Delta IV Heavy or a Space Exploration Technologies Corporation (SpaceX) Falcon Heavy rocket.

Depending on the launch vehicle, the Clipper has two flight trajectory options: a direct trajectory to Jupiter using an SLS or the more conventional variation of a Venus-Earth Gravity Assist trajectory if flown on a Delta IV Heavy or Falcon Heavy. A gravity assist trajectory, also called a "slingshot" path, uses the gravity of a planet or other astronomical object to alter the path and speed of a spacecraft, thereby enabling a less powerful launch vehicle such as the Delta IV Heavy or Falcon Heavy to carry the same amount of mass to Jupiter as the SLS although the trip will take two to three times as long. Figure 1 shows the flight paths and transit times for a direct trajectory to Jupiter and an Earth-Venus-Earth-Earth Gravity Assist trajectory based on a 2022 launch, consistent with Congress's initial mandate.[19] Specifically, a 2023 launch using a gravity assist trajectory will take the spacecraft 6.6 years to reach Europa versus 2.7 years using the SLS on a direct trajectory.

[18] Located in Pasadena, California, JPL is a federally funded research and development center managed for NASA by the California Institute of Technology.

[19] Other Venus-Earth Gravity Assist variations such as the Earth-Venus-Earth-Earth Gravity Assist and the Venus-Earth-Earth Gravity Assist trajectories and their corresponding flight times are shown in Table 4.

Figure 1: Europa Flight Trajectory Options



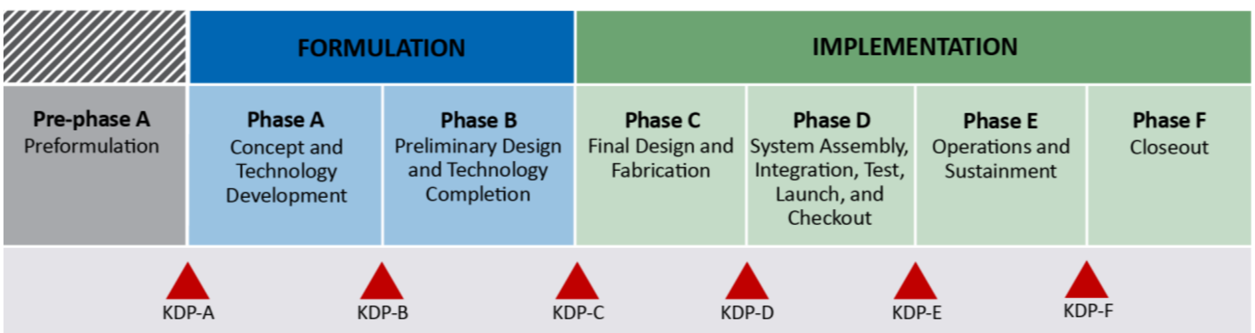
Source: NASA OIG presentation of Agency information.

Note: Jupiter Orbit Insertion (JOI), Venus Gravity Assist (VGA), first Earth Gravity Assist (EGA-1), second Earth Gravity Assist (EGA-2), and third Earth Gravity Assist (EGA-3).

NASA Project Life Cycle and Joint Confidence Level Analysis

As shown in Figure 2, NASA divides the life cycle of its space flight projects into two major phases—Formulation and Implementation—that are further divided into Phases A through F. Formulation consists of Phases A and B, and Implementation is Phases C through F. This structure allows managers to assess the progress of their projects at Key Decision Points (KDP) throughout the process.[20]

Figure 2: Project Life Cycle



Source: NASA Procedural Requirements (NPR) 7120.5E, *NASA Space Flight Program and Project Management Requirements w/Changes 1-16* (August 14, 2012).

[20] A KDP is defined as the point in time when the Decision Authority—the responsible official who provides approval—makes a decision on the readiness of the project to progress to the next life-cycle phase. KDPs serve as checkpoints or gates through which projects must pass during their development.

In Pre-phase A, the Agency conducts a mission concept study before the project enters into formal development. During Phases A (Concept and Technology Development) and B (Preliminary Design and Technology Completion), projects develop and define requirements, cost and schedule projections, acquisition strategy, and project design, as well as complete development of mission-critical technology.

Towards the end of Formulation, project personnel conduct a Preliminary Design Review (PDR) and present results to an independent Standing Review Board (SRB) that assesses the project's development plan.[21] The objectives of the PDR are to (1) evaluate the completeness and consistency of the planning, technical, cost, and schedule baselines developed during Formulation; (2) assess compliance of the preliminary design with applicable requirements; and (3) determine if the project is sufficiently mature to begin Phase C.

To receive management approval to proceed to Phase C, the start of Implementation, a NASA project must pass through KDP-C, including a final assessment of the preliminary design and a determination of whether the project is sufficiently mature. As part of the KDP-C review process, cost and schedule baselines are established against which the project is thereafter measured. To establish these baselines, NASA policy requires that "projects with an estimated life-cycle cost greater than $250 million shall develop a resource-loaded schedule and perform a risk-informed probabilistic analysis that produces a joint cost and schedule confidence level (JCL)."[22] This probabilistic analysis measures the likelihood of completing all remaining work at or below the budgeted levels and on or before the planned completion of Phase D.

Project management performs the JCL analysis using software tools and models that combine cost, schedule, risk, and uncertainty estimates. Once completed, the SRB performs an independent assessment of a project's JCL model. The results of that review and the model are presented to the relevant Directorate Program Management Council or Agency Program Management Council and the Decision Authority, who makes the final budget and schedule determination to establish the Management Agreement and the Agency Baseline Commitment.[23] Another JCL is required during the Implementation phases if a project is rebaselined or upon request from the Decision Authority.[24]

Once approval is received to move from KDP-C to the next phase, the project prepares its final design, fabricates test units that resemble the actual hardware, and tests those components during the first half of Phase C. A second design review, the Critical Design Review (CDR), occurs later in Phase C. The purpose of the CDR is to demonstrate the design is sufficiently mature to proceed to full-scale fabrication, assembly, integration, and testing, and that the technical effort is on track to meet performance requirements within identified cost and schedule constraints. After the CDR, a System

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[21] The SRB is an independent advisory board chartered to assess programs and projects at specific points in their life cycle and to provide the program, Decision Authority, and other senior management with a credible, objective assessment of how the program is progressing relative to Agency criteria and expectations. Composed of independent experts, the SRB provides assessments of the project's technical and programmatic approach, risk posture, and progress against the project baseline and offers recommendations to improve performance or reduce risk.

[22] NPR 7120.5E.

[23] The Management Agreement is regarded as a contract between the Agency and the project manager and provides the parameters and authorities over which the project manager is accountable. The Agency Baseline Commitment contains the cost and schedule parameters NASA submits to the Office of Management and Budget and Congress.

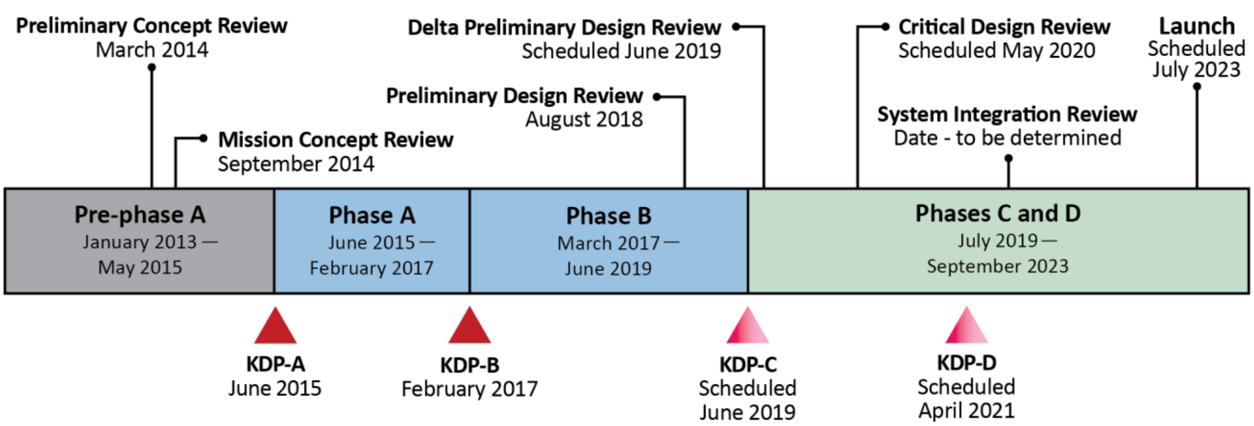
[24] NASA may rebaseline a project when significant changes are required or under the terms of Pub. L. No. 109-155, Section 16613 (b)(f)(4), which requires congressional authorization to continue any project that will exceed the development cost estimate provided in the baseline report by 30 percent or more, or if launch is delayed by 6 months or more.

Integration Review takes place during which the readiness of the project to start flight system assembly, test, and launch operations is assessed. Once all necessary requirements are met, the project may continue into Phase D, which includes system assembly, integration, test, and launch activities. Phase E consists of operations and sustainment, while Phase F is project closeout.

Europa Clipper Project Life Cycle

In June 2015, the Europa Clipper entered into Formulation, Phase A, and in February 2017 entered into Phase B with a target launch date of June 2022.[25] At the KDP-B in February 2017, NASA planned to hold the KDP-C in November 2018, but subsequently delayed the review until 2019 to allow time to focus on issues related to instrument development and integration. For example, during the August 2018 PDR the SRB determined that integration of the solar arrays and REASON instruments was not working as required or at an appropriate level of maturity to meet the PDR requirements; nevertheless, the SRB recommended that the project continue with Implementation while resolving these outstanding issues. The SRB also focused on the project's budget and schedule and found both to be inadequate considering the complexity of the mission. The SRB warned that pressure on instrument development teams to stay within budget may lead them to assume increased risks such as not disclosing emerging integration risks to their managers. The SRB also highlighted that a delay in assigning staff as well as an insufficient number of employees with relevant skills added additional risks to the mission's cost and schedule. Lastly, the SRB recommended that NASA make every effort to validate the SLS as the baseline launch vehicle before KDP-C so project personnel could focus on variables applicable to that particular launch vehicle. Consequently, NASA planned a delta-PDR for mid-2019 to be followed by KDP-C soon after. See Figure 3 for key review and milestone dates.

Figure 3: Europa Clipper Project Life Cycle



Source: NASA OIG presentation of Agency information.

Note: Phase B was initially projected to run through October 2018 but has been extended through June 2019. The Europa Clipper was scheduled to launch in June 2022 but has been delayed to July 2023 (per congressional directive).

[25] NASA Agency Program Management Council, *Europa Clipper KDP-B Decision Memorandum* (February 2017).

Addition of Europa Lander Mission Mandate

In NASA's FY 2016 appropriation, Congress added a lander to the Europa mission and the following year directed that the Lander mission launch no later than 2 years after the Europa Clipper mission.[26] Initial designs of the mission were described in a JPL 2012 Europa Lander study that included a Carrier Relay Orbiter spacecraft to orbit Europa and relay data from the Lander to Earth as well as the use of Advanced Stirling Radioisotope Generators to power both the spacecraft.[27] A subsequent 2016 JPL Europa Lander study determined that a comprehensive search for signs of life on Europa's surface using a lander would require development of sophisticated instruments to perform quantitative organic compositional, microscopic, and spectroscopic analysis on five samples acquired from at least 10 centimeters beneath the surface.[28] In June 2017, NASA determined that the $3.2 billion cost for a lander, not including the launch vehicle, was too high and convened a new team to consider options to reduce mission costs.

In November 2017, team members presented a Pre-phase A report that considered three major re-scope options: (1) relaxing the science requirement from "life detection" to the search for evidence of life or "biosignatures," (2) forgoing the Carrier Relay Orbiter and instead using a larger direct-to-Earth antenna to transmit data, and (3) using solar and battery power instead of an Advanced Stirling Radioisotope Generator.[29] A requirements change from life detection to a search for biosignatures reduces the amount of corroborating data needed; specifically, obtaining five subsurface samples from three to five trenches for life detection can be reduced to obtaining three subsurface samples from one or two trenches for a biosignatures search. Based on the team's assessment, implementing all three changes would reduce mission costs to about $2.7 billion. Due to battery limitations and the high radiation environment on Europa's surface, the proposed lifetime of the Lander is about 22 days.

Status of Space Launch System Development

NASA's development of the SLS is integral to the Agency's efforts to pursue human exploration beyond low Earth orbit. The SLS is a two-stage, heavy-lift rocket that will launch the Orion Multi-Purpose Crew Vehicle (Orion) and other deep space mission payloads. The SLS represents the Agency's largest development of space flight capabilities since launch of the first Space Shuttle in 1981.

As shown in Figure 4, NASA plans to incrementally increase SLS performance capabilities through a series of upgrades to its boosters and upper stage. The initial SLS Block 1 configuration, intended for use on its first uncrewed mission, first crewed mission, and potentially the Europa Clipper mission, is projected to lift 70 metric tons to low Earth orbit. Later launches beginning in about 2024 were expected to use the SLS Block 1B configuration, which includes the Exploration Upper Stage (EUS), to increase upmass capability to 105 metric tons; however, NASA's FY 2020 budget request proposed

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[26] Pub. L. No. 114-113 and Pub. L. No. 115-31, respectively.

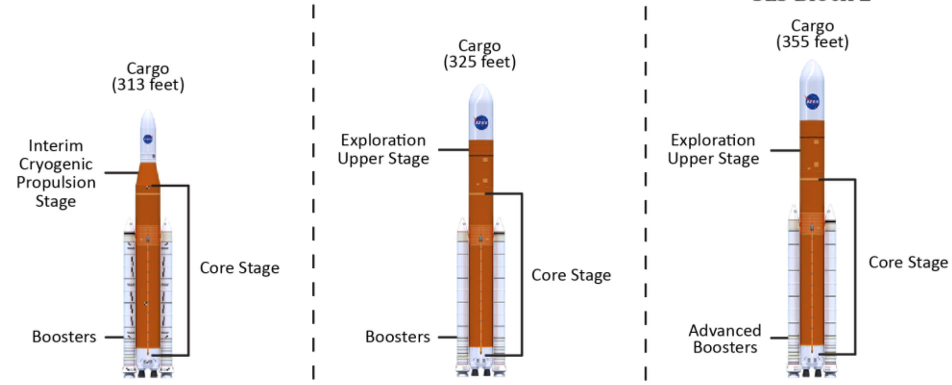
[27] Europa Study Team, *Europa Study 2012 Report* (JPL D-71990, May 1, 2012). The Advanced Stirling Radioisotope Generator is a NASA technology development to advance the efficiency of radioisotope power systems. Radioisotope power systems provide electrical power using heat from the natural radioactive decay of plutonium-238 and are used on NASA missions where other options such as solar power are impractical or incapable of providing the power a mission may need to accomplish its scientific or operational goals.

[28] Europa Science Definition Team, *Europa Lander Study 2016 Report: Europa Lander Mission* (JPL D-97667, February 2017).

[29] The Advanced Stirling Radioisotope Generator was not selected for the Lander mission because the battery and solar power option was deemed sufficient to achieve the mission's science requirements.

deferring the SLS Block 1B final design efforts because of SLS Block 1 development delays.[30] Finally, the SLS Block 2 configuration will replace the solid rocket boosters from Blocks 1 and 1B with advanced boosters that will provide the capability to lift 130 metric tons to low Earth orbit.

Figure 4: SLS Versions and Capabilities



	SLS Block 1	SLS Block 1B	SLS Block 2
Launch readiness date	2020	2024	no earlier than 2028
Upgrades	n/a	Exploration Upper Stage	Advanced Boosters
Cargo payload fairing size (width by height)	5.1 meters by 14.3 meters	8.4 meters by 19.1 meters	10 meters by 27.4 meters
Upmass to low Earth orbit requirement	70 metric tons	105 metric tons	130 metric tons
Upmass to Mars	25 metric tons	35 metric tons	37 metric tons
Upmass to Jupiter	6.3 metric tons	8.3 metric tons	9.3 metric tons

Source: NASA OIG analysis of Agency information as of March 2019.

Initially, the Clipper was planned to launch on the SLS Block 1B configuration on a direct trajectory to Jupiter with a launch readiness date of mid-2022. However, as we last reported in October 2018, production delays to both the SLS Core Stage and EUS make it unlikely that the Block 1B will be ready by 2024.[31] Furthermore, NASA's FY 2020 budget request confirmed the EUS development delay. Given these delays, Clipper project managers had to recalculate their mission requirements and reassess SLS Block 1 capabilities. Although SLS project managers expressed confidence that Block 1 will have the capability to fly on a direct trajectory to Jupiter, as of March 2019 NASA had yet to confirm this capability, and project managers continue to design Clipper with the flexibility to use a variety of launch vehicles.[32]

Because of the congressional mandate, the Lander mission as currently designed can only be launched on SLS Block 1B and would require a planetary gravity assist that would entail a 5-year trip to Jupiter and another 2 to 2½ years to orient the spacecraft and land on Europa.[33]

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30 EUS is an upgraded upper stage that uses four RL-10 engines and will be capable of transporting 35 more metric tons than the SLS Block 1 configuration that uses the Interim Cryogenic Propulsion Stage.

31 NASA OIG, *NASA's Management of the Space Launch System Stages Contract* (IG-19-001, October 10, 2018). The Core Stage is the first stage of the rocket consisting of the fuel tanks and supporting infrastructure.

32 NASA performed a preliminary study in December 2017 that indicated sufficient SLS Block 1 performance to support a Europa Clipper mission.

33 In March 2019, the Lander team determined that other trajectories may be possible with commercial launch vehicles such as the Falcon Heavy but the transit time would be approximately 4 years longer and likely require spacecraft propulsion modifications.

NASA Faces Steep Challenges in Developing Europa Clipper's Science Instruments, Addressing Workforce Gaps, Choosing a Launch Vehicle, and Overcoming Funding Risks

In spite of the robust funding Congress provided early in the Clipper mission's development, NASA needs to address instrument development challenges, workforce shortages, and uncertainties about the availability of the SLS before decision makers have the information required to establish a realistic launch date. We found that NASA's aggressive development schedule coupled with a stringent conflict of interest process during instrument selection increased integration challenges and led the Agency to accept instrument cost proposals later found to be far too optimistic. In addition, although Congress directed NASA to use the SLS to launch Clipper, the Agency has not formally chosen a launch vehicle or incorporated associated development and selection risks into the Clipper's JCL, thereby prolonging launch vehicle and mission profile risks that should be resolved prior to establishing the project cost and schedule baseline. Lastly, a significant funding level must be maintained for several years to avoid delays in the Clipper's launch schedule or to forestall the need to divert funds from other projects in NASA's science portfolio.

Instrument and Workforce Challenges Pose Cost and Schedule Risks

Technical challenges and associated risks are normal with a project of the scale and complexity of Europa Clipper, particularly a mission on such an aggressive schedule. Early funding provided project officials with opportunities to invest in technically challenging areas. For example, by 2015 the project had made advancements with hardware, including test equipment for power subsystems and avionics, an early prototype of a communication radio, and equipment to test materials under harsh radiation and temperature environments. In addition, the early funding helped mature Clipper science instruments, enabling final selections to be made in FY 2015, a full year earlier than planned.

However, the aggressive schedule coupled with a stringent conflict of interest process during instrument selection increased project integration challenges. In addition, NASA accepted instrument cost proposals later found to be far too optimistic. To keep instrument costs under control, NASA instituted, in collaboration with the JPL project team, an instrument cost control plan in 2017 that included de-scope options.[34] Finally, NASA must resolve workforce shortages pertaining to several instrument

[34] The Europa Clipper Project Science Traceability and Alignment Framework, an important tool in the cost control plan, was completed in May 2018.

development teams and the Clipper spacecraft. Therefore, despite gains from early investments, Clipper faces a series of significant challenges that place the project's cost estimates and a 2023 launch date at risk.

Instrument Selection Process

During Pre-phase A, in FY 2012, JPL produced a Europa Study Report that included a basic mission payload using the type of instruments that would be needed to meet Clipper's science objectives.[35] NASA released a public solicitation in July 2014 known as the instrument announcement of opportunity (Europa Instrument Investigation) with proposals to develop the mission's scientific instruments due in October 2014. NASA subsequently selected nine instruments and finalized the instrument suite in May 2015.

To protect against potential conflicts of interest, NASA Headquarters managed the selection of the mission's instruments and in compliance with Office of the General Counsel guidance, largely excluded the JPL Clipper management team from the process because both JPL, and by association APL, had teams submitting instrument proposals. Under a waiver, senior JPL project team members, including the Project Manager, Chief Engineer, and other subject matter experts, were given only 2 to 3 weeks to review the 33 proposals' technical sections with cost and other information redacted. Furthermore, the Clipper Project Manager stated there was insufficient time within an already compressed timetable to complete an in-depth assessment of potential integration challenges of instruments like REASON or the reasonableness of initial costs estimates. We believe Headquarters managers may have identified these integration or cost issues earlier with greater JPL project management participation during the selection process while still mitigating the risks and protecting against potential conflicts of interest.

For example, REASON, an ice penetrating radar that uses high and very high frequencies, has encountered several integration risks stemming from its positioning on the Clipper's solar array.[36] When NASA released the Europa Study Report in 2012, it emphasized a likely nuclear-powered configuration. In May 2014, the announcement was updated to clarify that solar power was also under consideration and that if selected it would change the payload configuration. Consequently, the communications regarding the mission's power options may have led the REASON team to assume in its 2014 proposal that the Clipper's spacecraft architecture would still allow the radars to be positioned apart from the other instruments to reduce interference (see the 2012 Proposal in Figure 5). Given the decision to use solar power, REASON's antennae needed to be positioned at points on the solar array where it is isolated to not interfere with the other spacecraft instruments. However, REASON's electromagnetic emissions may interact with the solar array degrading REASON's data (see current 2018 Layout in Figure 5).

Based on its experience with the Clipper mission, NASA is planning to adjust the process for selecting instruments for the Lander mission to allow project personnel to provide advice on the integration impacts of various instrument and configuration options prior to instrument selection.

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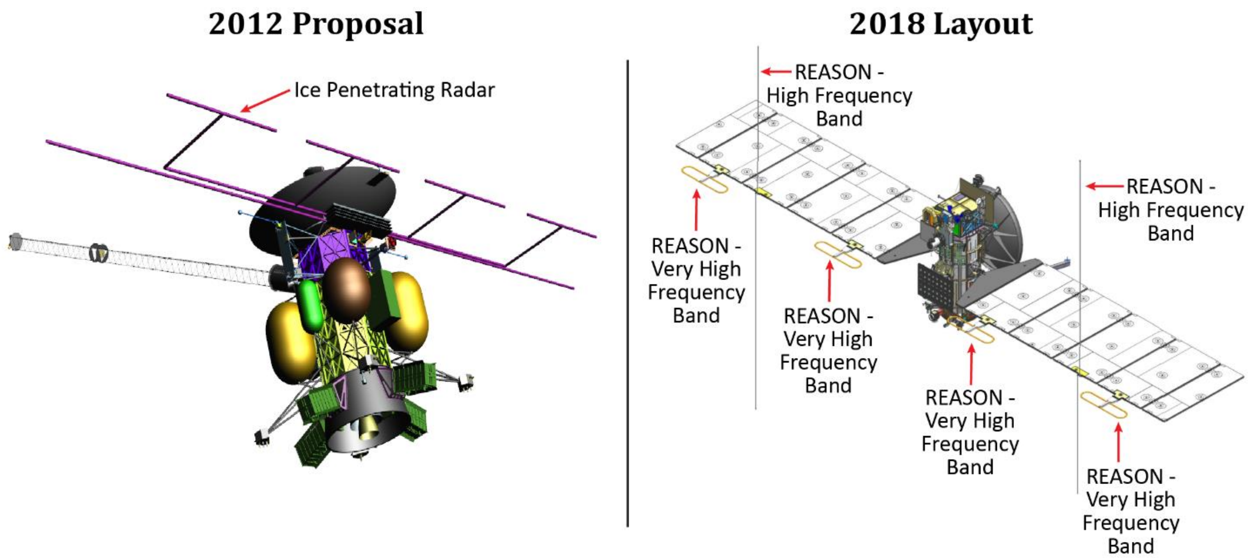
35 JPL D-71990.

36 High Frequency is the range of electromagnetic waves between 3 and 30 megahertz while Very High Frequency or VHF is the range from 30 to 300 megahertz.

Figure 5: Clipper Flight Configurations—2012 Proposal and 2018 Layout



Source: NASA OIG presentation of Agency information.

The placement of REASON on the current version of Clipper has raised concerns about interference from solar panel discharge creating noise for the very high frequency band radar due to its close proximity. In addition, heavy coaxial cables connecting REASON to the antennae need to be radiation shielded and deployable, but the solar array drive actuators used to deploy the panels and cables may not be powerful enough as currently designed. An integrated wing review to assess interference, cable, and actuator concerns took place in January 2019 and the team developed a viable and implementable plan, resolving the key technical issues from the August 2018 PDR that delayed KDP-C.

Projected Instrument Cost Overrun and De-scope Option

In a 2012 audit examining NASA project management practices, we reported on the negative impacts of excessive optimism when NASA program managers develop cost and schedule estimates.[37] We noted that projects often encounter additional challenges as they proceed to integration, the point in the development cycle where NASA missions historically experience schedule delays and the greatest cost growth. The Clipper's initial instrument cost estimates increased 52 percent from May 2015 ($325 million) to June 2016 ($493 million) when project management reassessed instrument costs in preparation for the KDP-B review (see Table 2). In our opinion, this significant cost increase can be primarily attributed to (1) the proposal teams submitting an overly optimistic outlook of the time and expense needed to develop and mature their instruments and (2) NASA's failure to sufficiently evaluate the reasonableness of the cost and schedule estimates of those submissions given the relatively low level understanding of integration issues. As noted earlier, the Agency may have been able to reduce the risk had it found ways to mitigate conflict of interest concerns and solicit more input from senior JPL project staff during the instrument selection process.

[37] NASA OIG, *NASA's Challenges to Meeting Cost, Schedule, and Performance Goals* (IG-12-021, September 27, 2012).

Table 2: Clipper Instrument Costs Estimates and Actual Costs as of February 2019 (Dollars in Millions)

Instrument	Initial Proposed Costs (May 2015)	Revised Cost Estimate (June 2016)	Estimated Cost Increase	Funds Expended as of February 2019
Europa Thermal Emission Imaging System (E-THEMIS)	$23.8	$36.3	$12.5	$31.4
Europa Imaging System (EIS)	54.9	89.2	34.3	40.4
Interior Characterization of Europa using Magnetometry (ICEMAG)	16.6	26.0	9.4	18.6
MAss SPectrometer for Planetary EXploration (MASPEX)	41.5	71.8	30.3	47.0
Mapping Imaging Spectrometer for Europa (MISE)	43.2	85.3	42.1	41.2
Plasma Instrument for Magnetic Sounding (PIMS)	16.8	27.2	10.4	16.6
Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)	81.9	98.9	17.0	64.4
SUrface Dust Mass Analyzer (SUDA)	24.7	30.7	6.0	14.8
Ultraviolet Spectrograph (UVS)	21.6	27.1	5.5	12.3
Total	**$325.0**	**$492.5**	**$167.5**	**$286.7**

Source: NASA OIG analysis of Clipper documentation.

During the KDP-B review in February 2017, the SRB raised concerns about a likely escalation of cost and schedule overruns with the science payload. The SRB recommended that Clipper project management develop a strategy for de-scoping the Level 1 science requirements in the event of excessive growth in project cost, schedule, power, and mass. Since that time, project personnel have updated instrument cost estimates monthly, reporting any costs projected to exceed 20 percent of the rebaselined cost estimates. When instruments are projected to exceed that 20 percent amount and the instrument team cannot identify an acceptable recovery plan, they are subject to a de-scope review.

This monitoring process identified one instrument—ICEMAG—where the projected cost increases exceeded 29 percent of the estimated cost. In March 2019, the Associate Administrator for Science Mission Directorate terminated ICEMAG development and committed to investigating development of a simpler, less complex magnetometer for the mission. The projected instrument development costs vary over time and in February 2019 four other instruments (E-THEMIS, MASPEX, MISE, and PIMS) were also at risk to exceed their rebaselined costs by 20 percent thereby triggering de-scope reviews.

Project managers use a tool known as the Project Science Traceability and Alignment Framework to analyze the impact various instrument combinations may have on a mission's science requirements. The framework also allows NASA management to evaluate the impact of de-scoping different science instruments. For example, as previously discussed ICEMAG went through a de-scope review and in March 2019 the instrument was terminated.[38] The science objectives in Appendix B reflect the specific science goals (or Level 1 science requirements) that the mission must meet.[39]

Technical Workforce Shortages

In unrelated work, both NASA Office of Inspector General (OIG) and the Government Accountability Office (GAO) recently identified significant workforce shortage issues affecting ongoing JPL-managed projects. In January 2018, we reported that NASA's Surface Water and Ocean Topography (SWOT) mission's complex technical issues were exacerbated by the challenge of maintaining sufficient qualified staff to work on the project.[40] Workforce shortages are driven by competing priorities among several JPL projects (including Mars 2020) that require technicians with specific skills. Similarly, in May 2018 GAO noted that several of NASA's major projects have encountered workforce challenges.[41] Three of the major projects highlighted in the GAO report—Europa Clipper, Mars 2020, and SWOT—are managed at JPL.

In October 2018, JPL's Clipper workforce was understaffed by 42 full-time equivalents (FTE). By December 2018, staffing became the top project risk when that number increased to 67 FTE. While this is about 10 percent of the planned 701 FTE for the project during that period, some of these vacancies are in critical areas such as the mechanical and electrical cable harness subsystem, science instruments, and avionics. Furthermore, the current Clipper FTE profile requires increasing the workforce to 717 FTE by May 2019. Achieving this workforce level will become even more challenging as the Clipper competes with at least four other major JPL-managed projects for similar personnel resources—two of which are billion-dollar missions with firm launch dates (see Figure 6). Moreover, the widening gap between planned and onboard staffing between the October and December 2018 timeframe illustrates the challenge JPL faces ramping up its workforce to meet future requirements.

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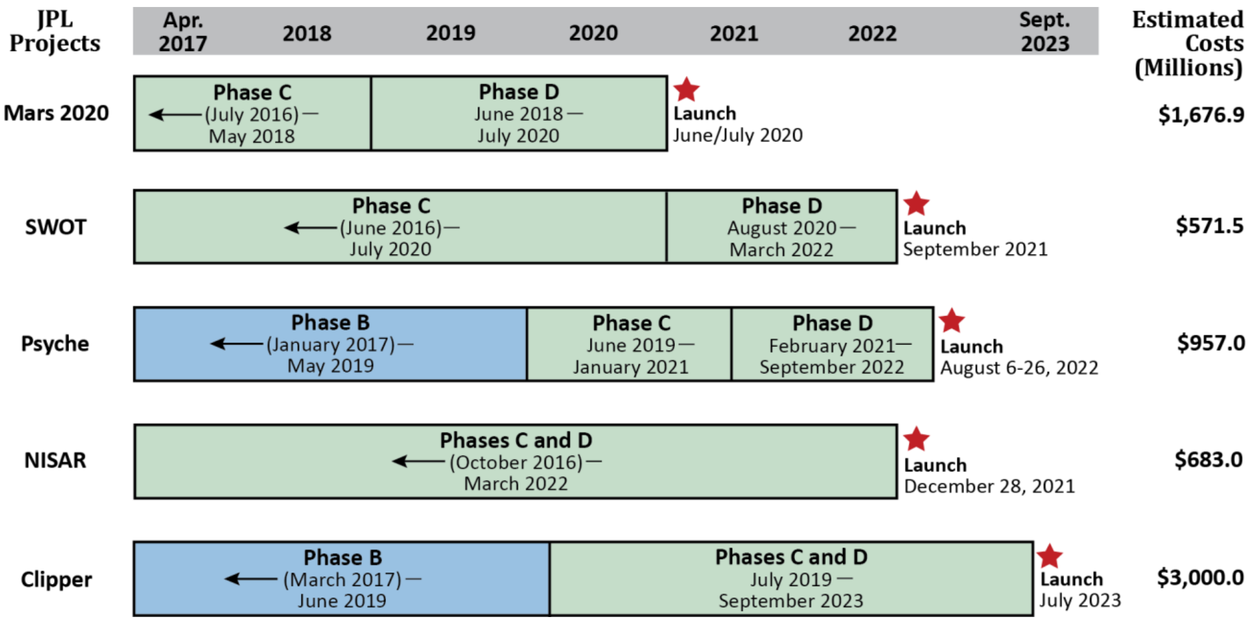
[38] ICEMAG was the primary instrument that supported the Level 1 science requirement of measuring ocean salinity and ice thickness. Alternately, REASON can also independently make these measurements, while PIMS and EIS can be used to support ICEMAG data and EIS and E-THEMIS will enhance the data returned. Using this high-level science framework analysis showed an instrument that was threatening the cost and schedule of the overall project could be de-scoped without completely sacrificing Level 1 science requirements.

[39] Instrument science goals can change over time and those listed in Appendix B were current as of March 2019.

[40] NASA OIG, *NASA's Surface Water and Ocean Topography Mission* (IG-18-011, January 17, 2018). SWOT is a satellite mission scheduled for launch in April 2021 that will undertake a global survey of Earth's surface water, observe the fine details of the ocean's surface topography, and measure how water bodies change over time.

[41] GAO, *NASA: Assessments of Major Projects* (GAO-18-280SP, May 1, 2018).

Figure 6: Major Projects in Development at JPL



Source: NASA OIG analysis of JPL information.

Note: The Psyche orbiter is set to launch in 2022 and will send a spacecraft to the asteroid Psyche to explore the violent history of collisions and accretion that created terrestrial planets. Led by Arizona State University, JPL is responsible for mission management, operations, and navigation. The NASA-ISRO [Indian Space Research Organization] Synthetic Aperture Radar (NISAR) satellite is set to launch in 2021 and will use advanced radar imaging to take measurements of some of Earth's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes, and landslides.

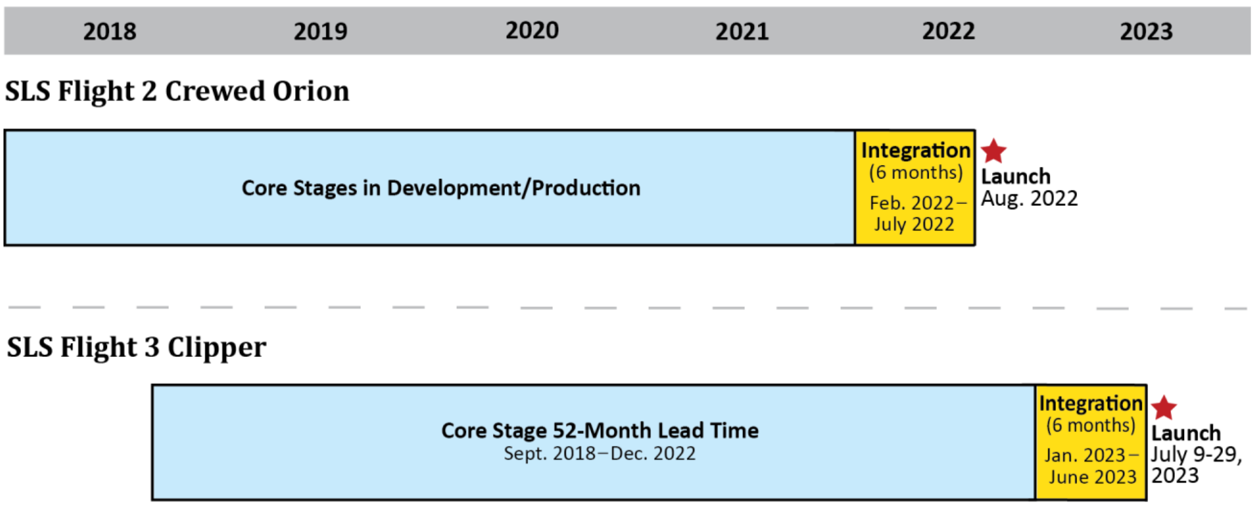
Clipper project officials stated that understaffing has been a persistent issue for the mission in general and at JPL specifically since 2017. During the PDR held in August 2018, the SRB found and project management agreed that many key activities were suffering from late or insufficient staffing. Although Headquarters Science Mission Directorate and JPL Center management officials said they are aware of the issue, the only solution they have proposed thus far has been to move personnel from other JPL projects when they become available, with priority going to whichever project is scheduled to launch soonest. Given this "robbing Peter to pay Paul" approach to filling critical staff vacancies, we are concerned that JPL will be unable to adequately supplement the project's workforce with the required critical skills at critical periods in the mission's development cycle.

SLS Unlikely to Be Available for a 2023 Launch

In legislation first enacted in 2017, Congress directed NASA to launch Clipper on the SLS in 2022, a date subsequently delayed to 2023. However, significant delays in developing the first iteration of SLS coupled with uncertainty about whether SLS Block 1 will have the capability to fly Clipper on a direct trajectory to Europa have raised serious questions about the feasibility of this directive. Further delays in the first uncrewed launch of the combined SLS and Orion crew capsule currently scheduled for June 2020 will have a cascading effect on future SLS missions, including a follow-up crewed launch of the SLS-Orion configuration currently planned for mid-2022.

Beyond these two flights, the Agency has not ordered additional SLS Core Stages. Given that NASA officials estimate needing 52 months lead time from issuing a Core Stage contract to delivery and 6 months for integration, NASA would have had to order the third Core Stage in September 2018 to make a July 2023 launch window (see Figure 7). As of March 2019, NASA had not ordered a third Core Stage. Consequently, even if available, we do not see a possibility for Clipper to launch on the SLS by 2023 unless NASA decides to delay the crewed launch of the SLS and Orion planned for mid-2022 and use this second SLS to launch Clipper.

Figure 7: Development Schedule for Key SLS Components



Source: NASA OIG presentation of Agency information.

Note: Core Stage in development/production means that NASA has ordered the stage and it is in production by the contractor. The third Core Stage contract was not in place as of March 2019. The 52-month lead time is based on current SLS production. NASA has assumed a 48-month lead time for Core Stage production beginning with the third Core Stage. Integration refers to the integration of the launch vehicle component stages and the spacecraft.

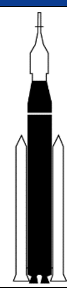
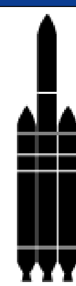
Launch Vehicle Choice and Risks Remain Unresolved

Although Congress mandated that NASA use the SLS, the Agency has not formally chosen the launch vehicle for the Clipper mission. As of March 2019, NASA had not determined whether the SLS Block 1 will have the capability to fly the mission on a direct trajectory to Europa. Moreover, NASA's FY 2020 budget request states, "the Administration believes it would be more appropriate for the Europa Clipper to utilize a commercially procured launch vehicle" as opposed to the SLS. Until NASA decides on a launch vehicle, the Clipper team will continue to maintain spacecraft capabilities and associated risks to accommodate both SLS and commercial launch vehicles and, if a Delta IV Heavy or Falcon Heavy is chosen, planning for longer transit times and the need for additional gravity assist flight trajectories. Launching on a commercial launch vehicle will also subject Clipper to a more severe thermal environment requiring additional thermal and ultraviolet protection, which are already designed into the spacecraft. The risks associated with a gravity assist flight trajectory need to be resolved prior to the Agency establishing the project's cost and schedule baseline. To this end, the SRB in 2018 recommended against keeping multiple launch vehicle design trades, interfaces, and interactions open beyond PDR, currently scheduled for June 2019.[42] Keeping both the SLS and commercial launch vehicle options beyond PDR creates added risks and uncertainties for an already challenging project.

Launch Vehicle Costs

Launching the Clipper on a commercial launch vehicle would be significantly less costly than using the SLS Block 1 even after factoring in the additional years of required transit time. NASA officials estimate the third SLS Block 1 launch vehicle's marginal cost will be at least $876 million while commercial launch vehicle costs are estimated to be approximately $450 million (see Table 3). In its FY 2020 budget request, NASA estimated that using a commercial launch vehicle would save approximately $700 million as compared to using an SLS.

Table 3: Clipper Launch Vehicle Estimated Costs as of March 2019

	SLS Block 1	Delta IV Heavy	Falcon Heavy
			
First flight	2020	2004	2018
Upmass to low Earth orbit (metric tons)	70	25.5	64
Estimated cost (millions)	$876	up to $450	up to $450
Adjust for cost savings of reduced transit time (millions)	-120	-	-
Net cost (millions)	**$726**	**$450**	**$450**

Source: NASA OIG analysis of commercial and NASA launch vehicle data.

Note: Costs are estimates for a launch in 2023. The SLS reduces the transit time to Jupiter by about 4 years compared to the Delta IV Heavy and Falcon Heavy rockets. The SLS cost savings were reported in a memorandum by the Associate Administrators of Science Mission Directorate and Human Exploration and Operations Mission Directorate to the Acting NASA Administrator in May 2017. The estimate was based on an approximate $30 million per year cost to maintain ground staff and other project activities during the commercial launch vehicle's 5-year transit time. These are conservative estimates for a commercial launch during this timeframe; specific launch costs for the Delta IV Heavy and Falcon Heavy are procurement sensitive.

In comparison, the costs for some commercial launch vehicle options could be less for a 2023 launch. Specifically, in 2019 United Launch Alliance is planning to transition to a new rocket—the Vulcan Centaur—as its Next Generation Launch System and start phasing out the Delta IV Heavy launch vehicle, leaving its availability and cost uncertain for future launches. To support a Clipper launch with the Delta IV Heavy, NASA would have to provide more money upfront to keep production lines open and is at risk of having to shoulder some of the cost of maintaining the site required to launch that particular rocket, potentially increasing launch costs significantly if Clipper is the last Delta IV Heavy launch.

[42] PDR was initially conducted in August 2018, but a delta-PDR is scheduled for June 2019.

Finally, although the Falcon Heavy is the lowest cost alternative, it has other qualification issues that we discuss in the following section.

Launch Vehicle Delivery, Transit Times, and Qualifications

As we previously noted, delivery of an SLS to launch Clipper in 2023 appears improbable. According to NASA's Launch Services Program, the Delta IV Heavy rocket could potentially be available by 2023 if ordered in 2019. However, launching Clipper on a commercial launch vehicle instead of the SLS Block 1 will increase transit time to Europa by approximately 4 years. Further complicating the situation, Clipper cannot be launched on a commercial launch vehicle in 2024 because of the lack of planetary alignment to enable a gravity assist (see Table 4).[43] Overall, transit time to Europa will be 3 to 5 years shorter, depending on the launch year, if NASA uses the SLS, enabling Clipper to collect more scientific data prior to launch of a prospective Lander mission.

Table 4: Transit Times From Earth to Europa

	SLS Launch Vehicle			Delta IV Heavy or Falcon Heavy		
	Launch Period	Transit Time (Years)	Approximate Arrival Date on Direct Trajectory	Launch Period	Transit Time (Years)	Approximate Arrival Date on Gravity Assist Trajectory
2022	June 4–June 24	2.5–2.9	Dec. 2024	June 18–July 8	7.4	Nov. 2029 (EVEEGA)
2023	July 9–July 29	2.5–2.7	Jan. 2026	May 24–June 13	6.6	Jan. 2030 (VEEGA)
2024	Aug. 12–Sept. 1	2.6–3.0	Apr. 2027	–	–	None
2025	Sept. 15–Oct. 5	2.8–3.2	July 2028	July 19–Aug. 8	7.0	Aug. 2032 (EVEEGA)
2026	Oct. 16–Nov. 5	2.8–3.1	Aug. 2029	July 19–Aug. 8	6.0	Aug. 2032 (VEEGA)

Source: NASA OIG presentation of JPL data.

Note: Gravity assist trajectories are Earth-Venus-Earth-Earth Gravity Assist (EVEEGA) and Venus-Earth-Earth Gravity Assist (VEEGA). Approximate arrival date is calculated based on the latest launch date during the launch period and the shortest travel time of the transit time range.

Of the three launch vehicles discussed, the Delta IV Heavy has the longest flight history: the first Delta IV variant launched in November 2002 while the first Delta IV Heavy flew in December 2004. A total of 37 Delta IV vehicles have launched through August 2018, 10 of which have been the Heavy variant. All of these launches were successful except the first Delta IV Heavy, which suffered a premature first stage shutdown resulting in its payload failing to reach its intended orbit. In contrast, the Falcon Heavy has only flown two missions, in February 2018 and April 2019, with four future launches manifested from 2019 to 2022. While the U.S. Air Force purchased Falcon Heavy launches in 2018, the vehicle would need to pass additional flight testing (known as Category-3 certification) for high priority, very high complexity, or high-cost payloads—descriptions that apply to the Europa Clipper mission.[44] As part of this NASA certification process, the Falcon Heavy would need to have accomplished

[43] NASA is studying whether the Falcon Heavy could perform a Venus-Earth Gravity Assist resulting in a reduced transit time and reduced thermal exposure near Venus.

[44] NPR 8705.4, *Risk Classification for NASA Payloads (Updated w/change 3)* (June 14, 2004) defines the risk classification of NASA payloads.

three successful flights by the Clipper's launch readiness date.[45] Although the SLS will have had minimal flight history if the Europa Clipper is launched in the 2023 timeframe, senior NASA managers believe the extensive quality assurance testing required to human-rate the vehicle will provide the needed confidence levels to meet the intent of commercial launch vehicle certification requirements.[46]

Clipper Joint Cost and Schedule Confidence Level Unreliable for Informing Management Decisions

The August 2018 JCL for the Clipper mission does not provide a reliable assessment of project cost and schedule because it did not include launch vehicle options and associated risks. A JCL analysis should integrate data on project costs, schedules, risks, and uncertainties to present the likelihood a project will achieve its objectives within budget and on time. NASA policy requires all identified risks, "whether or not they are funded from appropriations or managed outside of the project," be included in the JCL calculation.[47] Furthermore, the *NASA Cost Estimating Handbook* provides guidance to include the launch vehicle in JCL modeling.[48] Doing so allows management to identify cost and schedule risks associated with launch vehicle challenges, options, and alternatives. It also provides objective analysis to inform management decisions prior to the KDP-C review for establishing a project's cost and schedule baseline.

We have previously reported that NASA has not included issues related to launch vehicles in projects' JCL analyses despite Agency requirements.[49] Specifically, we identified instances when cost and schedule were adversely affected due to delivery delays, infrequently used launch vehicles that resulted in multiple launch delays, or the selection of launch vehicles with an unreliable history that were later replaced with another vehicle. For example, the Orbiting Carbon Observatory-2 satellite had to rebaseline its cost and schedule and switch to the Delta II launch vehicle when the initially selected Taurus XL launch vehicle failed in 2011 after an earlier 2009 failure. As a result, the project's life-cycle costs increased from $349.9 million to $467.7 million and delayed the satellite's launch from February 2013 to July 2014.[50]

Although Clipper would be the SLS's first deep space mission, neither the JPL JCL nor the SRB JCL included the risk of an SLS launch vehicle delay or any of the risks and expenses associated with choosing a commercial launch vehicle rather than the SLS. Despite NASA policy requirements and cost

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[45] NASA Policy Directive (NPD) 8610.7D, *Launch Services Risk Mitigation Policy for NASA-Owned and/or NASA-Sponsored Payloads/Missions—Revalidated w/Change 2* (January 31, 2008) describes the Category-3 certification, which includes three successful flights with at least two of those being consecutive without failure, of a common launch vehicle configuration, and completion of extensive NASA technical evaluation, audits, and evaluation of launch vehicle documentation.

[46] SLS is exempt from the requirements of NPD 8610.7D.

[47] NPR 7120.5E.

[48] Section J.1.3.4.4 of "Appendix J: Joint Cost and Schedule Confidence Level (JCL) Analysis" in *NASA Cost Estimating Handbook Version 4.0* (February 2015).

[49] NASA OIG, *Audit of NASA's Joint Cost and Schedule Confidence Level Process* (IG-15-024, September 29, 2015); IG-18-011; and *NASA's Heliophysics Portfolio* (IG-19-018, May 7, 2019). Our report on NASA's management of SWOT (IG-18-011) found risks associated with timely delivery of the SpaceX launch vehicle were not included in the project's JCL analysis. Most recently, the Ionospheric Connection Explorer project, which was originally scheduled to launch in February 2017, did not include its launch vehicle in its JCL analysis and has been delayed by launch vehicle problems multiple times.

[50] Launched in July 2014, the Orbiting Carbon Observatory-2 is NASA's first dedicated Earth remote sensing satellite to study atmospheric carbon dioxide from space.

estimating guidance, NASA project managers said they do not typically include launch vehicle risks in JCL analyses because they consider the launch vehicle as NASA-furnished equipment and thus a risk to the Agency rather than the project. The SRB relied on the project's JCL as the baseline for its analysis and also chose not to include the launch vehicle in its analysis. As a result, the model does not incorporate the probability of SLS development delays, continued availability or cost of Delta IV Heavy launch infrastructure, Falcon Heavy reliability, risks and expenses associated with much longer transit times using a commercial launch vehicle, or the potential impacts these risks would have on the overall mission. Because the JCL models to date failed to include this information, we do not believe the estimates provide a reliable life-cycle cost and schedule projection for decision makers. In our judgement, JCL analyses incorporating launch vehicle risks would provide management with a more realistic cost and schedule for KDP-C and establish a reasonable cost and schedule baseline.

In addition, by modeling different scenarios such as alternate launch vehicles, launch dates, workforce availability, and instrument de-scope options, project managers and decision makers will gain a better understanding of how individual risks affect overall project cost and schedule. For example, in October 2018 the SRB determined that the project's modeling techniques resulted in overly optimistic results. The SRB's JCL assessment determined a very low probability for a 2022 launch and provided a 70 percent confidence level for a 2024 launch at a mission cost between $3.5 billion to $4 billion. If accurate, this cost estimate approaches the level the NRC deemed too expensive (about $5 billion in 2019 dollars) for a Europa mission and resulted in the original Europa orbiter mission being redesigned as the Clipper to avoid negatively affecting NASA's overall planetary science portfolio.

Sustained Funding Needed to Avoid Clipper Launch Delay or Impact to Other Projects

Since Clipper's inception, Congress has consistently increased funding well beyond NASA's requested levels in an effort to enable the mission to meet an aggressive launch date initially set for 2022 but later moved to 2023. However, if the Clipper mission fails to receive adequate funding levels through at least the 2023 planned launch date, the Science Mission Directorate will be challenged to reallocate funds to meet cost and schedule requirements without negatively impacting other projects in NASA's science portfolio. Significantly, FY 2020 will be the first budget cycle in which the mission's most important congressional supporter no longer chairs the House appropriations panel, a leadership change that could result in diminished funding for the Europa mission. Past OIG audits have detailed how funding instability can result in inefficient management practices that contribute to poor cost, schedule, and performance outcomes.[51] Funding instability can apply to both the total amount of funds dedicated to a project and the timing of when those funds are disbursed.

In the Agency's FY 2019 budget request, NASA planned for a 2025 Europa Clipper launch date based on the project's then 5-year budget profile that required an average of $309 million annual investment between FYs 2019 and 2023. In response to the FY 2019 congressional mandate, NASA replanned and provided budget estimates for a 2023 Clipper launch that will require an average of $444 million annual investment for the next 4 years (see Table 5).[52]

[51] IG-12-021.

[52] Pub. L. No. 114-113.

Table 5: Europa Clipper Budgets, FYs 2020-2024

	Fiscal Year					
	2020	2021	2022	2023	2024	5-Year Totals
Estimated budget for Europa 2023 launch (millions)	$592.6	$530.8	$445.1	$207.3	$54.6	$1,830.4
Planetary Science Division budget requests (millions)	$2,622.1	$2,577.3	$2,629.4	$2,402.4	$2,350.9	$12,582.1
Required budget for Europa as a percentage of Planetary Science Division	23%	21%	17%	9%	2%	15%

Source: NASA OIG presentation of Agency budget data.

The risk to a Clipper launch in 2023 increases without sustaining the level of additional funds received since FY 2013. The NRC stated in 2011 that an increase in NASA's planetary budget was necessary to make Europa affordable without eliminating other recommended missions. It further noted that expenditures increase dramatically once project formulation starts and budget reductions to the Planetary Science Division would not only severely impact the Europa mission but also disrupt the entire Division portfolio.

As shown in Table 5, the Planetary Science Division budget requests for FYs 2020 through 2024 are trending generally downward and the funding needed for a Europa mission launching in 2023 would be significant relative to the Division's overall budget. As of September 2018, Clipper had committed to spend approximately $1 billion of its $2.8 billion total estimated cost. Without sustained funding for the project and a corresponding increase in the Planetary Science Division budget, the Division will need to divert funds from other projects, thereby delaying their progress and creating challenges across NASA's entire science portfolio. Moreover, diverting significant funding to support the Clipper mission contradicts the NRC's recommendation to undertake a Europa flagship mission as long as it does not impact other projects in the planetary science portfolio.

In response to recommendations made by the SRB, in October 2018 NASA's Directorate Program Management Council directed (1) the project to rebaseline the mission's plan for a 2023 launch on a SLS launch vehicle while still maintaining compatibility with commercial launch vehicles, (2) the Science Mission Directorate to work with Agency leadership to formalize the launch vehicle selection by March 2019, and (3) the project to recommend changes to Level 1 science requirements to reduce complexities. While the Council's decision and the FY 2019 Appropriation Act helped reduce concerns about the original and highly aggressive 2022 launch date, technical, workforce, launch vehicle, and budget challenges remain until NASA develops a risk-informed and realistic baseline for the mission.

Congressional Directive to Launch a Europa Lander by 2025 Not Feasible

In FY 2017, Congress directed NASA to plan not only a Europa orbiter mission but to launch a Lander mission on an SLS no later than 2024.[53] The Consolidated Appropriations Act of 2019 provided the first direct funding for a Lander—$195 million—while pushing back the launch date to 2025. Nonetheless, NASA will be unable to meet a 2025 launch date due to workforce and schedule risks with the Lander and SLS development. We found a 2025 launch date not feasible and believe that requiring the Agency to pursue a Europa Lander mission at the same time it is working to develop the Clipper mission is inconsistent with the NRC's usual process of strategically selecting and prioritizing flagship missions based on input from the scientific community. In addition, attempts to meet such a timetable would preclude NASA from fully utilizing available Clipper data when developing the Lander to produce the most optimal science. Finally, such a flagship mission will require substantial and ongoing funding for at least the next 10 years and risks adversely affecting the planetary science portfolio as envisioned by the NRC.

Workforce and Schedule Risks Render Lander Launch in 2025 Not Feasible

Similar to the Clipper, the Lander mission has used early funding to buy down project risks and invest in technology development that will benefit Lander and other future missions to icy worlds. Examples include developing advanced Light Detection and Ranging landing technology and cryogenic ice sampling innovations.[54] Despite achievements in addressing early project risks and initiating new technology development, identifying a feasible launch date for the Lander remains elusive.

The Lander launch date has been a moving target—starting with Congress first directing a launch in 2024. Early project documentation, including NASA's Lander Mission Concept Review in June 2017, were predicated on a 2025 launch date. While the FY 2019 Appropriation Act delayed the launch mandate to 2025, a year earlier the Lander project team had determined that 2026 was a more feasible launch date. However, even that timetable presents significant risks due to technical workforce shortages and unrealistic project development schedules that makes it not feasible for NASA to meet a 2025 or 2026 launch date.

Technical Workforce Shortages

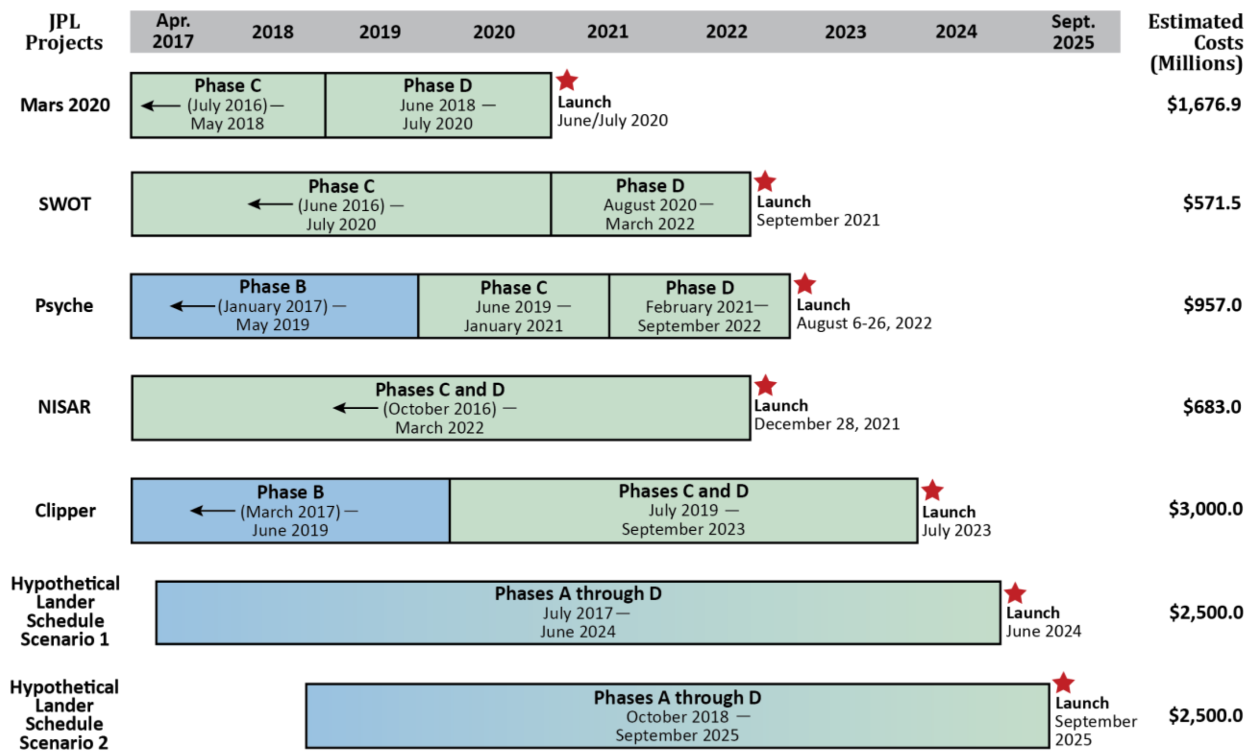
Similar to the workforce challenges faced by the Clipper mission, a major risk facing the Lander mission is the lack of sufficient skilled technical staff to plan and develop the project as it goes forward. Shortages

[53] Pub. L. No. 115-31.

[54] Light Detection and Ranging works on the principle of radar but instead of radio waves uses light from a laser. Cryogenics generally refers to temperatures below approximately -150 degrees Celsius (Europa's surface never rises above -160 degrees Celsius).

at both JPL and APL have already hindered risk reduction work the project planned to complete during Pre-phase A.[55] Lander managers indicated that the team had incorporated workforce risk into their planning and received JPL's commitments for 2019 through 2020 workforce levels, but given Europa Clipper and the other JPL missions' workforce challenges we are skeptical of these commitments. Adding another flagship mission like the Lander, that would need to begin Phase A in 2019 in order to meet a 2026 launch date, will require it to compete for the same resources as five other major projects at JPL. Consequently, we do not believe Lander management will be able to accomplish all its intended project activities within this timeframe (see Figure 8).

Figure 8: Prospective Europa Lander Schedule Relative to Other Major Projects in Development at JPL



Source: NASA OIG analysis of JPL information.

Prospective Lander Schedule Options Not Practical for 2025 Launch

The Lander is in the very early planning stages and does not have a formal project life cycle or cost estimate. Although the most recent congressional enactment has delayed launch of the Lander until 2025, this date is not practical when comparing it to the pace of other similar NASA robotic exploration missions. Using the Clipper's aggressive 7-year schedule as a guide, we determined that even if the Lander had entered Phase A before January 2019, the earliest it could launch would be late 2026. This

[55] APL is working at 60 to 70 percent of Lander's planned workforce for the foreseeable future.

estimate is confirmed by the fact that the Clipper mission, now targeting a 2023 launch, is at best an 8-year development project.

In addition to Clipper, we compared the Lander's potential schedule to the Mars 2020 rover project plan, the most comparable JPL mission in design and scale. Starting Phase A in December 2013, Mars 2020—even with a mature technological development process—will require about 7 years from the beginning of Formulation (Phase A) through launch (at the end of Phase D). In fact, 7 years was also the average time from Formulation to launch (actual or planned) for the six largest and most recent JPL projects—even though each is less costly and less complex than the Lander mission (see Table 6).

Table 6: Comparable JPL Project Development

Mission	Development Cost (Dollars in Millions)	Development (Years)	Actual/Prospective Launch Date	Description
Mars 2020	$1,677	6.7	August 2020	NASA's next rover mission to Mars
SWOT	571.5	8.9	September 2021	Satellite mission to make the first global survey of Earth's surface water
Psyche	957.0	5.7	August 2022	Orbiter mission to investigate Psyche, a unique metal asteroid located between Mars and Jupiter
NISAR	683.0	7.7	December 2021	Satellite mission to observe and take measurements of some of Earth's most complex processes
Juno	742.3	7.1	August 2011	Orbiter mission to investigate Jupiter
Mars Science Laboratory – Curiosity	$1,720.0	8.1	November 2011	Rover mission currently conducting science investigations of rock, soil, and air samples on the surface of Mars

Source: NASA OIG analysis of JPL missions.

If 7 years were the amount of time it takes, on average, for a major satellite or rover project to move from Formulation to launch, the Lander would have had to enter Phase A by the fourth quarter of 2018 in order to launch in 2025.

SLS Block 1B Delivery for 2025 Lander Launch Unlikely

Similar to the Clipper, the Lander management team faces schedule risk due to launch vehicle availability. For the Lander mission's initial design, the SLS Block 1B with the EUS upgrade was the only launch vehicle under development with sufficient power to transport the Lander to Europa. While NASA officials stated during our audit that the EUS configuration will be available for a 2025 launch, our recent SLS audit found that because of Core Stage development issues, production delays, and cost overruns, it is highly unlikely that the Block 1B will be operational in time for a 2025 Lander launch.[56] Specifically,

[56] IG-19-001.

our 2018 audit found that in addition to production delays to the two Core Stages under development, $600 million in contract funds intended for EUS development were used to cover cost overruns incurred by Core Stage production, delaying production of the EUS. NASA's FY 2020 budget request, released in March 2019, stated that the Block 1B configuration with the EUS remains an important future capability. However, SLS's development delays and significant cost overruns require that NASA concentrate in the near term on the successful completion of the first and second exploration missions; therefore, they plan to defer SLS Block 1B final design efforts.

Lander Mission Inconsistent with Strategic Priorities Recommended by the NRC

The 2017 congressional mandate for a Europa Lander mission to launch 2 years after the Clipper mission is inconsistent with broader congressional direction for NASA to follow NRC decadal surveys when planning missions.[57] The 2013-2022 Decadal Survey does not include a Lander mission. As a result, mandating the Lander as the Science Mission Directorate's next flagship mission may not yield the most cost efficient science and may forgo opportunities to collect scientific data from other planetary missions identified as higher-priority by the NRC.

Accelerated Lander Mission May Not Yield Most Optimal Science Value

The NRC follows a systematic, sequential approach when recommending exploration missions to ensure optimal science return per dollar invested. Therefore, prematurely launching a Lander mission to Europa may not yield optimal science in the most cost efficient manner until data collected by the Clipper is analyzed by NASA and the scientific community.

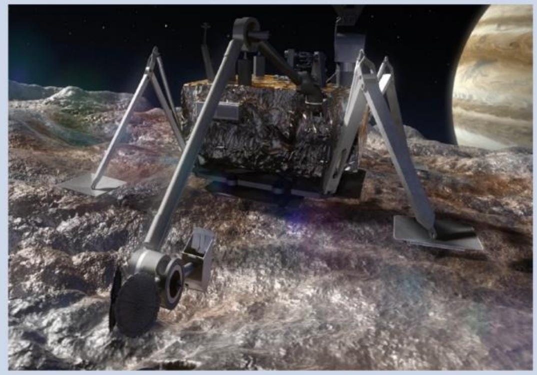
According to the NRC, NASA's Mars Exploration Program has provided a framework for its recommended program of systematic exploration. Beginning in 1965, Mars spacecraft have utilized a progressive exploratory strategy with missions that first consisted of flybys, followed by orbiters, landers, and then rovers. With some overlap, these missions support one another both scientifically and through infrastructure, orbital reconnaissance and site selection, and data that have enhanced the quality of later surface missions.

However, the Lander project team does not believe the Lander's design would be greatly improved by waiting until after the Clipper has completed its mission even though Clipper could provide several years of data to enhance landing site selection while the Lander is en route to Europa. Consequently, the Lander is being planned as a standalone mission. Project managers stated that regardless of the success or failure of the Clipper mission, (1) the Carrier Relay Orbiter spacecraft will orbit Europa and map the Lander's landing locations with higher resolution than the Clipper and (2) the Lander will be sufficiently versatile to land anywhere on Europa, return its own data, and avoid hazardous sites semi-autonomously on its descent.

[57] House of Representatives, Committee on Appropriations Report 115-704 accompanying Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2019 (May 24, 2018).

In its 2013-2022 Decadal Survey, the NRC considered a Europa Lander as a "far-term" mission for multiple reasons, including the lack of good scientific data about Europa and the need for a precursor orbital mission (the Clipper). With so little known about Europa, a lander mission was not seriously considered in 2010 when the Decadal Survey was underway. The panel's reasoning, affirmed in the 2018 NRC Midterm Review, was that waiting until the Clipper has substantially completed its mission would significantly enhance the landing site selection decision, reduce landing risks, and increase the likelihood of the Lander meeting its science objectives.[58] In 2018, the NRC Midterm Review Team concluded data from the Europa Clipper mission could be vital to the design of the Lander, thus requiring that most of the Clipper mission be completed before the Lander moves beyond KDP-A.

Artist's Rendering of the Europa Lander



Source: NASA.

Current Lander Mission Will Cause Imbalance in the Planetary Science Portfolio and Loss of Opportunity for Other Missions

When the NRC made its flight project recommendations for flagship missions in the 2013-2022 Decadal Survey, it considered multiple factors including maintaining a balance in the planetary science portfolio. While the NRC recognized that ultimately NASA would initiate a flagship Europa Lander mission, it prioritized three other exploration missions after Clipper and therefore did not include a Europa Lander mission in the 2013-2022 Decadal Survey. In the panel's view, a balanced portfolio of exploration missions would enhance overall program stability, provide better assurance of a continuing stream of visible results, and help prevent large fluctuations in cost and workforce demands. Consequently, the NRC emphasized a mix of small, medium, and large (flagship) missions to enable a steady stream of new discoveries and the capability to address larger challenges such as sample return missions and outer planet exploration.

Moreover, while the five flagship-class missions (including Clipper) prioritized in the 2013-2022 Decadal Survey have undergone a rigorous NRC prioritization process, the Lander mission has not. Given that Lander represents a second flagship project to Europa, we believe that directing such substantial funding (discussed in the next section) and staffing to another Europa flagship mission at the present time could create an imbalance in NASA's planetary science activities by preventing initiation of missions deemed a higher scientific priority by the NRC. NASA can ask the NRC to reexamine decadal survey priorities outside the normal review cycle when conditions or events would warrant reexamination of NRC priorities established by the decadal survey. We believe the congressional directive funding and establishing a 2025 launch date for the Lander mission qualifies for such reexamination, but to date NASA has not initiated such a process.[59]

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[58] NRC, *Visions into Voyages for Planetary Sciences in the Decade 2013-2022: A Midterm Review* (2018).

[59] Pub. L. No. 110-422, Section 1104(c).

Funding Availability

Similar to Clipper, Congress has funded the Lander mission at levels substantially above what the Agency has requested; however, such a flagship mission will require ongoing substantial funding for at least the next 10 years. According to the most recent Mission Concept Review performed in November 2018, JPL's estimated cost for a Lander mission is approximately $2.8 billion. Congress provided Lander Pre-phase A research funding as part of the increased funding for the overall Europa mission. Specifically, in FY 2016, $29 million out of the $175 million increase for Europa was allotted to the Lander team. The project received allotments of $38 million and $70 million for FYs 2017 and 2018, respectively. In February 2019, Congress appropriated to the Lander its first direct funding of $195 million for FY 2019. As it approaches Formulation, Lander's funding requirements will increase significantly when it enters system design, full-scale fabrication, assembly, integration, and testing.

Prior to FY 2019 when Congress directed NASA to initiate concept research for a Lander mission, the Lander mission was not part of NASA's FY 2019 budget plan. The Agency's FY 2020 budget request includes no funding request for the Lander, citing the Decadal Survey midterm recommendations of assessing Lander in the next decadal survey. As such, Lander's funding has been dictated not by Agency project managers but rather by whatever funds Congress designates for the project.

As of February 2019, NASA had allocated about $332 million of the estimated $2.8 billion for the prospective mission toward Lander Pre-phase A research activities that can benefit not only Lander but also other future planetary science missions to icy worlds. In 2018, NASA conducted a second Lander Mission Concept Review with no firm date for KDP-A—the point at which the project would formally enter the Formulation phase. Therefore, NASA has the flexibility to not proceed with the mission and still retain the benefits gained from its preliminary research. However, historically we have found that once a flagship mission begins it generally becomes a funding priority and any future Planetary Science Division budget shortfalls likely would be met by diverting funds from other portfolio projects.[60]

We believe that adding the Lander to NASA's planetary science portfolio as a flagship mission will essentially require doubling the amount of the recent increases in congressional funding that the Clipper mission has received while the two projects overlap—a tremendous challenge in light of the absence of the mission's primary congressional advocate and the competition for funding among other high priority NASA projects like the Mars Exploration Program and sample return missions.

[60] IG-12-021.

CONCLUSION

Since 2013, Congress has provided about $2.04 billion—$1.26 billion more than NASA requested—to fund exploration of Europa through the development of flyby and lander missions. In addition, Congress directed NASA to use an SLS to launch the Clipper mission no later than 2023 and a lander mission no later than 2025. NASA has invested some of these funds to address technical challenges early and "buy down" risk. Notwithstanding Congress's generous funding for the Europa missions, we found the interdependent risks associated with the Clipper's complex development, staffing shortages, launch vehicle options, and long-term need for significant funding present significant challenges that need to be addressed prior to establishing a realistic launch date. Failure to address these challenges may lead to escalating project costs that could disrupt the wider Planetary Science Division portfolio.

A Europa lander mission faces a similar set of interdependencies and challenges as the Clipper mission plus one: the Lander is currently designed to launch only on the upgraded version of the SLS, a vehicle whose readiness date is highly uncertain. Furthermore, the Lander mission is inconsistent with the NRC's recommended science exploration priorities, will not provide the most optimal science results for the money spent if launched before adequate information is obtained from the Clipper mission, and would negatively affect the balance and budget of other projects in the Planetary Science Division portfolio.

We have consistently reported on NASA's culture of optimism and the positive and negative effects such optimism has on project management. Both of the planned Europa missions are ambitious endeavors that should be grounded in realistic cost and schedule commitments. Given the unresolved technical, workforce, and budgetary challenges, we believe NASA—motivated by congressional mandates—is working towards unattainable Clipper and Lander launch dates. NASA should carefully consider its commitment to congressional and other stakeholders and seek to undertake these missions on a realistic timeline and sustainable budget profile that supports its overall planetary science goals.

Recommendations, Management's Response, and Our Evaluation

For the Europa Clipper mission and prospective Lander mission to achieve their technical objectives, meet milestones, and control costs, we recommended the Associate Administrator for Science Mission Directorate:

1. Evaluate current and future critical technical staffing requirements by project over the next 5 years. Assess each Center's ability to provide needed technical staff in critical skills based on projected surplus or shortfall of personnel for current and prospective projects.

2. Reassess the Clipper JCL with launch vehicle risks for the Delta IV Heavy, Falcon Heavy, and SLS prior to KDP-C and establishing the Agency Baseline Commitment.

3. Evaluate the impact on the entire Planetary Science Division budget portfolio if Clipper's increased funding levels were disrupted and develop mitigation strategies.

4. Continue to implement the instrument cost control plan, including de-scope options, based on balancing cost and Level 1 science requirements for future missions. Include the de-scope option in JCL calculations based on an assessment of the projects' Science Traceability and Alignment Framework.

5. Reassess the Europa Lander prospective project timeline given resource availability, including the SLS Block 1B with the EUS and the inherent project complexities of this magnitude.

6. Evaluate the impact that starting Lander Phase-A, delaying the start date, or continuing Pre-phase A research under multiple funding scenarios would have on the entire Planetary Science Division portfolio and report those estimates to stakeholders.

7. Consider requesting the NRC (now the National Academies of Sciences, Engineering, and Medicine) reexamine the Lander's priority under authority in the NASA Authorization Act of 2008.

8. Coordinate with Congress and other stakeholders to develop achievable project timelines and corresponding funding levels to maintain a balanced science portfolio supportive of NRC priorities.

We also recommended the Associate Administrator for Science Mission Directorate in coordination with the Office of the General Counsel:

9. Reassess the process of isolating key project personnel from instrument selection to balance their additional insight in integration and cost estimation while maintaining fairness in the announcement and mitigating conflicts of interest risks.

To ensure JPL projects have the technical support needed for their missions, we recommended the JPL Director:

10. Evaluate current and future critical technical staffing requirements, make staffing adjustments to the Clipper project as necessary, and reassess Lander commitments.

We provided a draft of this report to NASA management who concurred with 9 of our 10 recommendations. We consider management's comments to all but Recommendation 2 responsive; therefore, those recommendations are resolved and will be closed upon completion and verification of the proposed corrective actions.

Management did not concur with Recommendation 2, stating that Congress directed NASA to use the SLS launch vehicle and that directive justified its decision not to model the other launch vehicles in the project's JCL. We disagree and find this response inconsistent with the Agency's *Cost Estimating Handbook* which states that a JCL analysis should integrate cost, schedule, risk, and uncertainty. The Handbook also states that launch vehicle costs and associated risks shall be included in JCL calculations to ensure they are integrated into the entire project scope to aid management decision making. Although Congress directed NASA to launch the Clipper and Lander missions on an SLS, our analysis found that the vehicle is unlikely to be available for Clipper in 2023. In fact, the Agency's FY 2020 budget request (publicly released in March 2019) proposes to launch Europa Clipper on a commercial launch vehicle, further contributing to the uncertainty around which vehicle will be used to launch Clipper.

Given that the mission's cost, schedule, and risk will be significantly impacted by the choice of launch vehicle, we maintain that performing a JCL analysis for each of the launch vehicle options, to include modeling the likely year of launch, is critical to NASA adequately evaluating its launch vehicle options, inform decision makers, and establish an attainable and reasonable cost and schedule baseline. Therefore, this recommendation will remain unresolved pending further discussion with the Agency.

Management's comments are reproduced in Appendix C. Technical comments provided by management have also been incorporated, as appropriate.

Major contributors to this report include Raymond Tolomeo, Science and Aeronautics Research Director; Stephen Siu, Project Manager; John Schultz; Robert Rose; and Lauren Suls.

If you have questions or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

Paul K. Martin
Inspector General

Appendix A: Scope and Methodology

We performed this audit from June 2018 through April 2019 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence that provides a reasonable basis for our findings and conclusions. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

The overall objective was to assess NASA's management of the Europa mission relative to achieving technical objectives, meeting milestones, controlling costs, and addressing congressional requirements. Our audit was conducted at JPL, Marshall Space Flight Center, and NASA Headquarters.

To assess NASA's management plan to meet technical objectives, mission milestones, and congressional directives, we reviewed project status documents, benchmarked with other JPL projects, and obtained independent insight, identified key risks, and discussed these with NASA and JPL management. Specifically, we obtained and reviewed project phase documents for the Clipper and Lander missions. For Clipper, we reviewed monthly and quarterly status reports, NASA and JPL criteria documents and handbooks, congressional mandates, and NRC reports. We also reviewed and compared changes in schedule projections broadly and evaluated the project's monthly status reports for progress in meeting upcoming milestones. We reviewed project risks and risk mitigation strategies. We evaluated the project pacing and relationship of the Lander to the Clipper as well as to other current JPL projects. We discussed the technical planning, cost to schedule, and congressional requirements with the project, the Planetary Missions Program Office, and Science Mission Directorate management; members of the scientific community and Clipper's review board; and launch vehicle experts from SLS and the Launch Services Program. We obtained and examined internal and external applicable documents related to planetary science research and the Planetary Science Division as well as NASA policy. The documents we examined included the following:

- NRC, *Vision and Voyages for Planetary Science in the Decade 2013-2022* (2011)
- NPR 7120.5E, *NASA Space Flight Program and Project Management Requirements w/Changes 1-16* (August 14, 2012)

To assess NASA's management of controlling costs, we obtained financial documentation and discussed it with Clipper and Lander project management, Solar System Exploration Program management, and Science Mission Directorate management. Specifically, we evaluated management's use of congressional allocations. We obtained and reviewed project budget and actual cost information relative to the budget allocation between the two missions, cost budget by project functions, and corresponding actual costs incurred. We evaluated how the Europa projects within the Solar System Exploration Program impacts other Science Mission Directorate programs and performed steps to identify risks in efficiency. We evaluated NASA management's contingencies in the event that funding were to be disrupted. We reviewed budget data and cost estimates related to launch vehicles including the SLS.

Use of Computer-Processed Data

Our audit conclusions did not rely on computer-processed data. However, our audit used limited computer-processed data that we assessed as reliable. Primarily, we used budget and financial information from the work break down structures from JPL and NASA at Marshall Space Flight Center. We also used figures from the financial statements and budget requests. Additionally, we discussed with Europa project management how their estimates were calculated in both the JPL and SRB JCL models.

Review of Internal Controls

We reviewed the internal controls associated with the Europa Clipper and Lander projects and the Planetary Missions Program Office management assessment of technical, schedule, and cost risks that could impact the launch schedule. We found the project's internal controls appear adequate to manage technical, schedule, and cost risk, and noted areas for improvement as stated in the report. As required by generally accepted government auditing standards, we identified controls that if not functioning properly could increase the risk of fraud, waste, and abuse. Our inquiries indicated that the controls were functioning as intended.

Prior Coverage

During the last 6 years, NASA OIG, GAO, and the NRC have issued seven reports of significant relevance to the subject of this report. Unrestricted reports can be accessed at https://oig.nasa.gov/audits/auditReports.html, http://www.gao.gov, and https://www.nap.edu, respectively.

NASA Office of Inspector General

NASA's Management of the Space Launch System Stages Contract (IG-19-001, October 10, 2018)

NASA's Surface Water and Ocean Topography Mission (IG-18-011, January 17, 2018)

Audit of NASA's Joint Cost and Schedule Confidence Level Process (IG-15-024, September 29, 2015)

NASA's Challenges to Meeting Cost, Schedule, and Performance Goals (IG-12-021, September 27, 2012)

Government Accountability Office

NASA Major Projects: Portfolio Is at Risk for Continued Cost Growth and Schedule Delays (GAO-18-576T, June 14, 2018)

NASA: Assessments of Major Projects (GAO-18-280SP, May 1, 2018)

National Research Council

Visions into Voyages for Planetary Sciences in the Decade 2013-2022: A Midterm Review (2018)

APPENDIX B: CLIPPER SCIENCE OBJECTIVES AND INSTRUMENTS

The Clipper payload will carry a suite of nine science instruments that include cameras, spectrometers, an ice penetrating radar, a magnetometer, and a thermal instrument that will collectively help achieve the science objectives noted in Table 7. The science objectives reflect the specific science goals (or Level 1 science requirements) that the mission must meet. Each of the objectives can be traced to a Level 1 science requirement as previously noted.

Table 7: Europa Clipper Science Objectives and Descriptions

Objective	Description
Ice Shell and Ocean	Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange
Composition	Understand the habitability of Europa's ocean through composition and chemistry
Geology	Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities
Recon	Characterize scientifically compelling sites and hazards for a potential landed mission to Europa

Source: Europa Clipper project documentation.

Clipper's science instruments, descriptions, the entity responsible for those instruments, and the related science objective(s) are listed in Table 8.

Table 8: Europa Clipper Instruments and Descriptions

Instrument	Acronym	Description	Responsible Entity	Science Objective
Europa Thermal Emission Imaging System	E-THEMIS	This heat detector will provide high spatial resolution, multi-spectral thermal imaging of Europa to help detect active sites, such as potential vents erupting plumes of water into space.	Arizona State University, Tempe	• Geology • Recon
Europa Imaging System	EIS	The wide and narrow angle cameras on this instrument will map most of Europa at 50-meter (164-foot) resolution and provide images of areas of Europa's surface at up to 100 times higher resolution.	Johns Hopkins University Applied Physics Laboratory	• Geology • Recon

Instrument	Acronym	Description	Responsible Entity	Science Objective
Interior Characterization of Europa using Magnetometry	ICEMAG	This magnetometer was to measure the magnetic field near Europa and in conjunction with the PIMS instrument, infer the location, thickness, and salinity of Europa's subsurface ocean using multi-frequency electromagnetic sounding. Development of the instrument was terminated in March 2019 and NASA was investigating options for a replacement.	Jet Propulsion Laboratory	• Ice and Ocean
MAss SPectrometer for Planetary EXploration	MASPEX	This instrument will determine the composition of the surface and subsurface ocean by measuring Europa's extremely tenuous atmosphere and any surface material ejected into space.	Southwest Research Institute	• Composition
Mapping Imaging Spectrometer for Europa	MISE	This instrument will probe the composition of Europa to identify and map the distributions of organics, salts, acids hydrates, water ice phases, and other materials to determine the habitability of Europa's ocean.	Jet Propulsion Laboratory	• Composition
Plasma Instrument for Magnetic Sounding	PIMS	This instrument works in conjunction with a magnetometer and is key to determining Europa's ice shell thickness, ocean depth, and salinity by correcting the magnetic induction signal for plasma currents around Europa.	Johns Hopkins University Applied Physics Laboratory	• Ice and Ocean
Radar for Europa Assessment and Sounding: Ocean to Near-surface	REASON	This dual-frequency ice penetrating radar instrument is designed to characterize and sound Europa's icy crust from the near-surface to the ocean, revealing the hidden structure of Europa's ice shell and potential water within.	University of Texas, Austin	• Ice and Ocean
SUrface Dust Mass Analyzer	SUDA	This instrument will measure the composition of small, solid particles ejected from Europa, providing the opportunity to directly sample the surface and potential plumes on low-altitude flybys.	University of Colorado, Boulder	• Composition
Ultraviolet Spectrograph	UVS	This instrument will adopt the same technique used by the Hubble Space Telescope to detect the likely presence of water plumes erupting from Europa's surface. UVS will be able to detect small plumes and provide valuable data about the composition and dynamics of the moon's rarefied atmosphere.	Southwest Research Institute	• Composition

Source: Europa Clipper project documentation.

Appendix C: Management's Comments

National Aeronautics and Space Administration

Headquarters

Washington, DC 20546-001

Reply to Attn of: Science Mission Directorate

MAY 23 2019

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Science Mission Directorate

SUBJECT: Agency Response to OIG Draft Report, "Management of NASA's Europa Mission" (A-18-014-00)

NASA appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "Audit of NASA's Europa Mission" (A-18-014-00) dated April 9, 2019.

In the draft report, the OIG makes ten recommendations intended to enhance the likelihood of the Europa Clipper mission and prospective lander to achieve technical objectives, milestones, and cost controls, as follows:

For the Europa mission and its prospective lander mission to achieve their technical objectives, meet milestones, and control costs, the OIG recommends the Associate Administrator for the Science Mission Directorate:

Recommendation 1: Evaluate current and future critical technical staffing requirements by the project over the next 5 years. Assess each Center's ability to provide needed technical staff in critical skills based on projected surplus or shortfall of personnel for current and prospective projects.

Management's Response: NASA concurs with this recommendation. The Science Mission Directorate (SMD) will continue to direct the Centers to balance priorities and meet their staffing commitments through launch of this flagship mission. The Europa Clipper Mission requires critical workforce availability at Jet Propulsion Laboratory (JPL), John Hopkins University Applied Physics Laboratory (JHU/APL), and to a lesser degree at Goddard Space Flight Center. Staffing commitments are being made, and NASA has directed both JPL and JHU/APL to prioritize the critical technical skills needed by the Europa Clipper team. The current and future staffing plan will be reviewed by the Standing Review Board in June and the SMD Directorate Program Management Council in July.

Estimated Completion Date: July 31, 2019

Recommendation 2: Reassess the Clipper Joint Confidence Level (JCL) with launch vehicle risks for the Delta IV Heavy, Falcon Heavy, and Space Launch System (SLS) prior to KDP-C and establishing the Agency Baseline Commitment.

Management's Response: NASA does not concur with this recommendation. Congress has directed the Clipper to launch on the SLS; therefore, all risks for other launch vehicles were not fully modeled in the JCL. Furthermore, there is only preliminary data for SLS on which to base risk. The Europa Clipper Standing Review Board JCL did include four specific launch vehicle risks:

- Launch Vehicle Requirements (post-CDR) exceed designed values.
- Launch Vehicle Assignment timing.
- SLS Launch Processing Schedule Margin.
- SLS Launch Environment.

Estimated Completion Date: Not applicable.

Recommendation 3: Evaluate the impact on the entire Planetary Science Division budget portfolio if Clipper's increased funding levels were disrupted and develop mitigation strategies.

Management's Response: NASA concurs with this recommendation and intends to evaluate the impact potential reduced funding levels would have on the Planetary Science Division (PSD) portfolio and the Clipper Mission itself during our annual budget review process and after appropriations are released each year.

Estimated Completion Date: June 30, 2019

Recommendation 4: Continue to implement the instrument cost control plan, including de-scope options, based on balancing cost and Level 1 science requirements for future missions. Include the de-scope option in JCL calculations based on an assessment of the projects' Science Traceability and Alignment Framework.

Management's Response: NASA concurs with the recommendation that future missions should balance cost and Level 1 science requirements and implement de-scope options as needed for cost control. The Europa Clipper project will continue to monitor cost, and certain items with high-cost risk will be included in the JCL. The projects' Science Traceability and Alignment Frameworks will be used as intended, primarily as an operational tool to analyze the effects on science due to potential operational scenarios.

Estimated Completion Date: September 30, 2019

Recommendation 5: Reassess the Europa Lander prospective project timeline given resource availability, including the SLS Block 1B with the EUS and the inherent project complexities of this magnitude.

Management's Response: NASA concurs with this recommendation in that projects should continually assess schedule realism accounting for technical challenges and risks as well as determine availability of required resources to meet project milestones. The recent reassessment of the Europa Lander timeline conducted during the FY 2021 budget review process (presented on April 10, 2019) resulted in an estimated launch date of no earlier than 2030. This new launch date estimate provides additional time to reduce technical risks through continued technology development, to evaluate launch vehicle developments and to begin the next decadal survey assessment.

Estimated Completion Date: Completed.

Recommendation 6: Evaluate the impact that starting Lander Phase-A, delaying the start date, or continuing Pre-phase A research under multiple funding scenarios would have on the entire PSD portfolio and report those estimates to stakeholders.

Management's Response: NASA concurs with this recommendation and reviewed the potential mission's timeline, resource estimates, and workforce availability during the recent FY 2021 budget review process. The assessment resulted in an updated launch readiness date of no earlier than 2030. NASA does not intend for the Lander project to affect the PSD portfolio; therefore, it was not included in the FY 2020 President's budget request. Technology development will continue as funding allows.

Estimated Completion Date: Completed.

Recommendation 7: Consider requesting the NRC (now the National Academies of Sciences, Engineering, and Medicine) to reexamine the Lander's priority under authority in the NASA Authorization Act of 2008.

Management's Response: In 2018, the National Academies of Sciences, Engineering and Medicine (NASEM) released their planetary science midterm decadal review report, *Visions Into Voyages for Planetary Science in the Decade 2013-2022 [A Midterm Review]*, which assessed NASA's performance at achieving the goals of the decadal survey at the midway point. As part of their assessment, the NASEM committee reviewed the progress and priority of the Europa Lander mission, including the Pre-Phase A work and studies being conducted at JPL. The committee ultimately recommended that "the results of the Europa Lander studies should be evaluated and prioritized within the overall PSD program balance in the next decadal survey." NASA agrees with this recommendation and is currently preparing for the 2023-2032 survey, which the NASEM will initiate next year.

Estimated Completion Date: Completed.

Recommendation 8: Coordinate with Congress and other stakeholders to develop achievable project timelines and corresponding funding levels to maintain a balanced science portfolio supportive of NRC priorities.

Management's Response: NASA concurs with this recommendation and will continue to actively communicate with the Executive Office of the President, Congress, and other stakeholders in order for those outside the Agency to better understand how NASA fulfills its mission. As part of our annual budget process, NASA's SMD conducts multiple briefings with Congress to provide insight into the President's budget request. These briefings typically include specific funding levels, mission timelines, as well as a description of any major portfolio constraints. Further, SMD responds to follow-up questions or requests for information in a timely manner to ensure relevant program and project material is being shared in a transparent manner.

Estimated Completion Date: May 30, 2019

The Associate Administrator for the Science Mission Directorate in coordination with the Office of the General Counsel:

Recommendation 9: Reassess the process of isolating key project personnel from instrument selection to balance their additional insight in integration and cost estimation while maintaining fairness in the announcement and mitigating conflicts of interest risks.

Management's Response: While NASA believes that the Europa Clipper instrument selection was conducted appropriately, we concur with this recommendation in that we agree to review the overall process to see if there are areas for improvement. In particular, SMD with the Office of General Counsel serving in an advisory capacity where necessary and appropriate, will consider options for additional waivers for modification of other procedures to allow non-conflicted project personnel to provide more significant evaluation earlier in the review process while ensuring fairness is maintained throughout the process.

Estimated Completion Date: October 1, 2019

To ensure JPL projects have the technical support needed for their missions, the OIG recommends the JPL Director:

Recommendation 10: Evaluate current and future critical technical staffing requirements, make staffing adjustments to the Clipper project as necessary, and reassess Lander commitments.

Management's Response: JPL concurs with this recommendation and continues to evaluate current and future critical technical staffing requirements and commitments for the Europa projects. JPL assesses current and future staffing requirements through a series of monthly, quarterly, and annual planning processes. Tactical workforce needs are reviewed at monthly senior leadership meetings involving all on-going projects and the technical line organizations that support them. Quarterly and annual assessments of staffing needs are also performed by the line organizations based on both current efforts and potential future projects. These staffing predictions are used to inform future business development plans at both the institutional and individual line organization levels.

The Europa Clipper Project recently conducted a re-plan consistent with a mid-2023 launch date. The associated staffing needs have been reviewed and approved by JPL leadership. Europa Lander efforts have now been limited to technology maturation and payload accommodation studies; therefore, substantially less JPL workforce is required and largely focused on technology staff who are not involved in flight development work. Nearly all flight development personnel who had previously been supporting early mission development work for Europa Lander have transitioned to support other JPL priorities.

Estimated Completion Date: Completed.

We have reviewed the draft report and have not identified any information that should not be publicly released.

Once again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Peter Meister at (202) 358-1557.

Thomas H. Zurbuchen, Ph.D.

cc:
General Counsel/Ms. Thompson-King
Director, NASA Management Office/Mr. Watkins
Jet Propulsion Laboratory/Dr. Watkins

Appendix D: Report Distribution

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(Assignment No. A-18-014-00)