National Aeronautics and
Space Administration
Mary W. Jackson Building NASA Headquarters
Washington, DC 20546-0001

Reply to Attn of: Science Mission Directorate

Summary of NASA Responses to Psyche Independent Review Board

As a result of the Psyche Mission's missed 2022 launch opportunity an Independent Review Board (IRB) was jointly chartered in July 2022 by the Science Mission Directorate Associate Administrator (SMD AA) and the JPL Director. The Psyche IRB found many factors that contributed to the missed launch opportunity, some specific to the Psyche Project and some relevant to the JPL Institution as a whole.

The IRB fully met the scope of its review as laid out in the Terms of Reference. We want to thank A. Thomas Young for Chairing the IRB and thank all the members for their considerable time and effort. The team worked diligently and cooperatively with numerous employees in open and forthcoming conversations to gain a thorough understanding of the contributing factors. The findings and recommendations are divided into those that are specifically relevant to the Psyche Mission, and those that have broader JPL Institutional implications that may impact other flight projects.

After thorough consideration of the IRB's findings and recommendations, NASA and JPL concur that both short term and longer-term actions are required to prevent broad reoccurrence of issues that led to the missed 2022 Psyche launch opportunity to reduce the likelihood of future mission delays or failures.

Psyche presents a unique opportunity to study up-close and personal a metal world and will shed additional light on the formation of mysterious planetary bodies in our solar system. NASA will support Psyche continuing development for a launch targeted in October 2023.

Thomas H. Zurbuchen, Ph.D.
Associate Administrator
Science Mission Directorate
NASA Headquarters

Laurie A. Leshin, Ph.D.
Director
Jet Propulsion Laboratory

Psyche IRB Recommendations

11/4/2022

Psyche

General

- Develop plan forward that prioritizes and completes development activities.
- Establish a new launch date with sufficient margin to have high confidence in success.
- Review work performed in last several months before the launch delay, to assure it is at the required level of excellence with no embedded problems.
- Conduct a detailed review and assessment of "use-as-is" problem dispositions and "unverified failures."

NASA Response: NASA concurs. The Psyche project has developed a plan forward that would support a Launch Readiness Date of October 2023, with additional schedule margin, though many task details remain to be refined. NASA has accepted the new plan and will fund Psyche to continue development to the October 2023 launch date. The plan includes re-assessment of work completed to date and problem dispositions. The JPL institutional leadership will thoroughly review the progress against plans and provide additional support as needed to ensure mission success. Likewise, NASA Headquarters, the Program Office, and the Standing Review Board will work closely with JPL and Psyche every step of the way to ensure mission success. Specifically, the PSD and PMPO staff will maintain close watch on the project's progress against plan and provide support where appropriate to maintain schedule.

Management and Communications

- Establish and implement processes to assure open, credible, and responsive communications both vertically and horizontally throughout the Psyche Project.
- JPL Director, senior management, and Line management must establish and implement processes that assure significant insight into flight-project execution and participation in resolution of problems and risks.
- The role of the Line management function in elevating concerns needs to be emphasized and strengthened.

NASA Response: NASA concurs. The Psyche project has implemented organizational changes to address communication barriers inside the team, added additional team feedback tools and venues for vertical and horizontal information flow to senior project management, and augmented the standard metrics and reporting. JPL will initiate revisions to its flight project oversight practices to assure the line management, senior management and the JPL Director achieve significant insight into ongoing project execution. JPL will provide a safety net to identify and elevate concerns related to flight project execution in a timely manner. NASA's PSD and PMPO will increase their in-person presence at JPL and

KSC going forward to work more closely as part of the Psyche team and gauge the team's ability to communicate, and act on issues and concerns as they arise.

Staffing

- Provide additional 10–12 full-time, experienced leaders at all levels of project.
- Adequately supplement and maintain project staffing to support the replan.
- Special attention should be given to assigning/maintaining a Project Chief Engineer, GNC Cognizant Engineer, and Fault Protection Lead Engineer.

NASA Response: NASA concurs. The Psyche project has added appropriately experienced leaders and project staff throughout the project, appointing a Project Chief Engineer, GNC Cognizant Engineer, Lead for Fault Protection, and has made improvements to the team structure to meet the work-to-go requirements. JPL is strengthening its existing process for managing staffing issues across multiple projects, with extra attention to ensure Psyche's staffing needs are met while not risking higher priority missions. JPL is expected to regularly update NASA on staffing status on all projects in multiple forums at both project and portfolio levels.

COVID-19 Related

- Reestablish informal communications, such as "walking the floor" and "drop-in discussions."
- Remote and hybrid work must be minimized on Psyche to give the team the best opportunity to coalesce in a short time.

NASA Response: NASA concurs. The completion of Psyche requires increased simultaneous on-site presence to facilitate informal communications and mission success. As many organizations struggle with how best to balance onsite and offsite work following the post-COVID societal changes, the Psyche project manager will set project hybrid work policy, within the bounds of JPL telework policy, considering the need for in-person work during remaining phases of the project while also considering team morale and equity across the staff.

Project Metrics

- Develop a detailed, integrated, resource-loaded, and adequately margined and verified schedules for all remaining work.
- This must include sufficient task completion milestones in key areas like V&V, system integration and test, and mission ops preparations, such that progress in these areas can be readily tracked.
- Establish and implement a management information and reporting system that produces a credible and timely assessment of status, risks, and issues against this integrated baseline (described above).

NASA Response: NASA concurs. The Psyche team has created a detailed plan to ensure mission success which is supported and endorsed by JPL leadership. A fully integrated, resource-loaded plan is expected to be completed in the next two months. JPL and NASA will determine report content, frequency, and formats to more clearly convey regular, thorough assessments against the integrated baseline. At a minimum, the new format will not allow metrics to be rolled up in a way that conceals lower-level deficiencies or measurements against a moving plan.

SRB Review Process

- The SRB process must be strengthened such that there is discrimination between "normal" activities and serious issues that will highlight critical factors impacting a project's success.
- Guidelines given to projects for status reporting should be clear and unambiguous (e.g., for "green," "yellow," and "red" color-coding).
- The response to the SRB-reported issues and concerns must be thoroughly reviewed by the SRB, Management Center, and NASA authorities on a regular basis until satisfactory resolution is achieved.

NASA Response: NASA concurs with the intent of these recommendations, specifically that there are at least two areas of the SRB practices that need strengthening: clear communication and appropriate follow up to issues that should not be set aside until the next Life Cycle Review (LCR). NASA will consider changes to the expectations from SRBs and their reports, as well as implement appropriate follow up from Program Offices and Headquarters. NASA will also assess whether any LCR Success Criteria or other SRB approaches need to be modified.

JPL/MAXAR Relationship

- The Psyche experience provides an excellent opportunity to document best practices for future collaborations between NASA and commercial spacecraft providers in areas such as:
- Early and sustained in-depth interactions to develop mutual understandings of cultural and process differences
- Ensuring interfaces between the two organizations are correct, complete, and adequately documented and reviewed by subject-matter experts
- Contract structure

NASA Response: NASA concurs; clear communications and frequent in-depth interactions among all parties throughout the entire lifecycle are essential for developing effective working relationships across organizations, ensuring clarity and balance of expectations and capabilities, and for successful execution of the contracted effort. Early and careful consideration of contract structures and their implications, with clear roles and responsibilities documented for implementation, informs appropriate contract mechanism selection and aids in successful execution of the effort.

JPL Institution

Flight Project Workload

- Flight projects must be fully staffed with appropriately experienced personnel from the beginning, particularly in systems engineering, GNC, FSW, and Avionics.
- Balance must be achieved between the workforce needs of flight projects and the available JPL workforce.
    - Timing of achieving this balance is critical.
    - Psyche is an example of the major problems this imbalance is causing today.
- IRB believes that by the end of March 2023, significant corrective actions must be implemented to achieve balance.
- For any corrective actions requiring more time, a detailed plan of action must be developed and approved by JPL, Caltech, and NASA.

Response: JPL Concurs. JPL is committed to doing all that is necessary to fill critical roles on Psyche and other missions given the high levels of work related to several ongoing high priority large missions and is committed to meeting near-term milestones and upcoming launch dates. NASA intends to postpone the VERITAS launch readiness date to no earlier than 2031 (approximately a three-year delay). This postponement will provide some offset to both the workload/workforce imbalance for at least three years, and to the increased funding required to continue Psyche towards a 2023 launch. JPL is moving forward instituting new internal staffing approaches and working with industrial partners to support staffing needs.

Line Organization Issues

- Repopulate the Line organization with experienced leaders and engineers to reestablish the Line organization as an equal partner with flight projects during implementation.
- Add experienced people and include them in the effort to achieve balance.
- Address the Division 31 (Systems Engineering) /34 (Avionics) staffing, accountability, and coordination issues.
- Continually examine the issues between and within Divisions 31 and 34 because of the importance of these Divisions to the execution of flight projects.

Response: JPL Concurs. JPL will redouble its efforts to strengthen leadership at all levels of the line and project organizations. JPL is committed to strengthening its leadership in a purpose-driven, forward-looking manner which recognizes that the future demands more in how the institution partners technically, and in how JPL supports our teams moving forward.

Senior Management Engagement

- JPL Director must establish regularly scheduled meetings, formal and informal communications, and "drop in" visits to facilitate necessary engagement on major flight projects, communicate priority, and maintain cognizance of status.
- Prioritize the large number of activities competing for senior management's attention to focus on those in greatest need and importance such that commitments to NASA and the various stakeholders are met.
- Senior management should develop and codify in JPL's Flight Project Practices the metrics that will be employed for tracking progress during the critical prelaunch period.

Response: JPL Concurs. JPL has made changes in leadership, organizational structure and reviews, which along with other actions are designed to increase institutional insight and oversight of our missions, including but not limited to Psyche, Clipper and NISAR.

Hiring and Retention

- JPL must develop the capability to successfully hire and retain mid-level people in this new environment.
- JPL must develop approaches for the career growth and retention of critical and high-potential personnel.
- JPL must characterize problems with retention and develop incisive and decisive actions to address the problems identified.

Response: JPL Concurs. JPL's established hiring, retention and development procedures will be strengthened to be more aggressive and efficient in the search for new talent and retaining our internal talent. Additional steps will be taken to identify industrial partners to engage with to support our work. Caltech is fully committed to our approach as we move forward.

Hybrid Work Environment

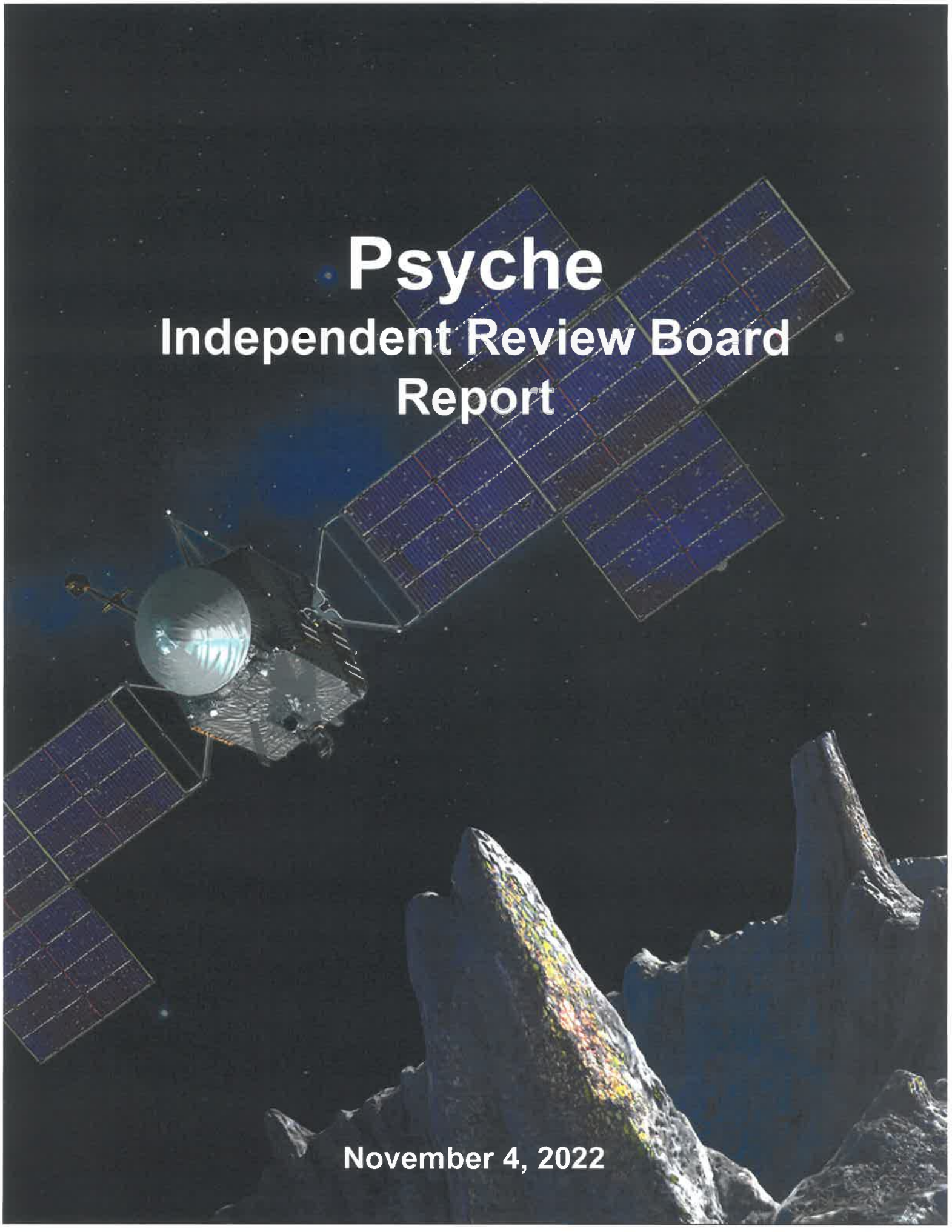
- JPL should immediately revisit its policy for hybrid work to make it more effective and better reflect the evolving needs of flight projects in different mission phases.
- Carefully consider which tasks, project phases, and circumstances permit hybrid and remote work arrangements.
- Any hybrid work arrangements should recognize the need for in-person interactions. In addition, it is critically important that early-career employees work alongside seasoned employees for their long-term development.
- Inefficiencies in productivity and communications associated with hybrid work must be included in the workforce, cost, and schedule plans for flight projects.

Response: JPL Concurs. The execution and completion of projects and the day-to-day operation of JPL requires communications and in-depth interactions that must occur with more onsite work across teams than was possible during the pandemic, while also respecting the strong desire of people everywhere for more flexibility in getting their work done. In support of this, JPL is developing an updated telework policy which will be released in the near future. This policy will have the endorsement of JPL's managing organization, Caltech.

Caltech Governance

- Caltech should develop a more rigorous annual review and evaluation approach for the JPL Director and the performance of the Laboratory.
- Caltech should have a better understanding of the JPL institutional issues and play a supporting role in addressing them.
- JPL should strengthen the quality of flight projects status presentations to Caltech.

NASA Response: NASA concurs with the intent of these recommendations. NASA recognizes that as the primary operator and manager of JPL, it is prudent that Caltech have a thorough understanding of the challenges faced by the institution and, where appropriate, assist with finding solutions that promote mission success. JPL and Caltech have already strengthened Caltech's review and awareness of institutional issues and insight into flight projects and will continue to do so in alignment with the IRB's recommendations. NASA will coordinate further with Caltech management to implement these recommendations via the JPL contract.



Psyche
Independent Review Board Report

November 4, 2022

Establishment of Psyche IRB*

- Psyche development problems resulted in significant schedule delays, making it impossible to launch in 2022 with acceptable risk.
- Psyche IRB was established by Thomas Zurbuchen, NASA Science Mission Directorate (SMD) Associate Administrator, and Laurie Leshin, Jet Propulsion Laboratory (JPL) Director, to investigate the cause(s) for the delay and recommend corrective actions.

* Independent Review Board (IRB)

During development, the Psyche Project team encountered a significant number of technical issues and worked to resolve them to meet the planned launch. In May 2022, the Psyche mission experienced a slip of the primary launch period. The project requested more time to prepare for launch, and the launch period officially slipped to the contingency period. However, in June 2022, it was determined that due to late delivery of Guidance, Navigation, and Control (GNC) flight software (FSW); incompatibilities within the system testbeds; and additional issues, a 2022 launch was not viable with acceptable risk.

Following this decision, NASA and JPL jointly established the Psyche IRB to investigate the causes for the delay and recommendations for corrective action.

Psyche IRB Charter

- Determine project, institutional, and all other issues that were responsible for the Psyche launch delay.
- Determine why there was a lack of visibility into the factors driving this launch delay.
- Review Psyche's path forward to maximize the probability of mission success.
- Identify lessons learned with utilizing the Maxar commercial bus.
- Determine if Psyche issues are unique to Psyche or indicative of broader JPL institutional issues.
- If broader institutional issues are identified, determine corrective actions appropriate for current and future missions.

The Psyche IRB charter is based on the Terms of Reference (ToR) jointly established by NASA and JPL.

Review Methodology

- IRB meetings on-site at JPL, over 15 full days during July–September 2022
- Structured reviews
- Informal sessions
- Personnel interviews
  - Individuals and groups—77 people were interviewed
  - Representing different levels of Psyche Project, Maxar, JPL, and Caltech organizations
- Extensive IRB deliberations and discussion

The Psyche IRB employed a deliberate and focused methodology to conduct the review. This process included multiple face-to-face meetings held at JPL to conduct structured reviews, organized presentations, formal and informal sessions, and interviews with over 77 project and institutional personnel representing various levels of responsibility. The personal and panel interviews were invaluable to understanding the perspectives of key Psyche and institutional participants. This coordinated effort helped to give the IRB members a good understanding of the issues leading up to the launch delay.

The IRB was asked to meet again in October 2022 to review the Psyche Project's proposed replan for achieving an October 2023 Launch Readiness Date (LRD).

Psyche IRB Schedule Summary

July–October 2022

Activity	Jul.	Aug.	Sep.	Oct.
Formulate IRB Charter and Membership	ToR* Jul. 12			
IRB Fact-Finding and Working Meetings	Jul. 19–21	Aug. 9–11	Aug. 16–18	Aug. 30–Sep. 1	Sep. 20–22
IRB Briefing to SMD and JPL Leadership				Oct. 13
IRB Narrative Report Completion				Oct. 17–20
Psyche Continuation/ Termination Review				Oct. 25

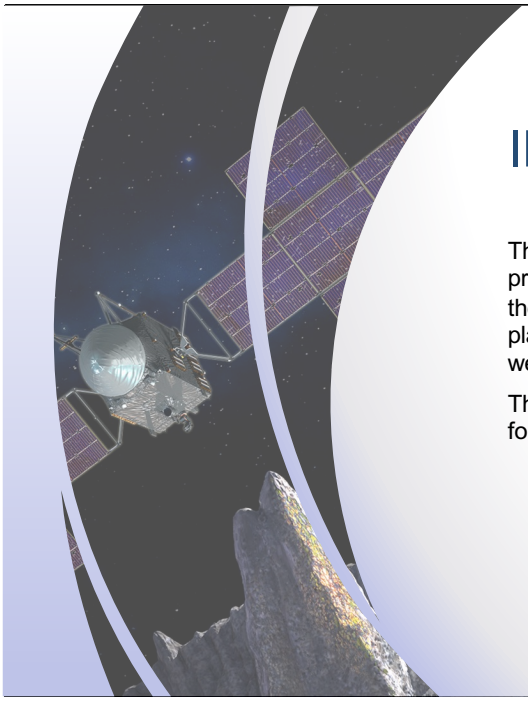
* Terms of Reference (ToR)

Psyche IRB Membership

- Allen Bacskay, Ex-Officio, NASA Retired, Psyche SRB Chair
- Steven Battel, Battel Engineering, President
- Doug Bernard, JPL, Deputy Chief Engineer
- Antonio Elias, Orbital ATK, Retired
- Orlando Figueroa, NASA, Retired
- Robyn Haleski, JPL, MSR SRL Avionics and Flight Software Product Delivery Manager
- Fiona Harrison, Caltech, Chair, Division of Physics, Mathematics and Astronomy
- Tom Jedrey, JPL, Europa Clipper Deputy Flight System Manager
- Gentry Lee, JPL, Chief Engineer for Planetary Science Directorate
- Fuk Li, JPL, Retired
- David Mitchell, NASA HQ, Chief Program Management Officer
- Ellen Ochoa, NASA, Retired
- James O'Donnell, NASA GSFC, NESC GNC Technical Discipline Team
- Jessica Samuels, JPL, MSR CCRS JPL Flight Segment Manager
- Janet Vertesi, Princeton University, Associate Professor of Sociology
- A. Thomas Young (Chair), former NASA, Lockheed Martin Corp., Retired

Karen Gelmis, NASA HQ, Review Manager
Sam Thurman, JPL, Associate Review Manager

Joan Salute, NASA HQ, Observer
William Knopf, NASA HQ, Observer



IRB Acknowledgments

The IRB greatly appreciates the extraordinary support and professionalism provided by NASA and JPL. All requests from the IRB were positively acted upon in a timely manner. The planning of meetings and establishment of meaningful agendas were exceptional.

The people with whom the IRB interacted were open, honest, forthcoming, and dedicated to mission success.

Psyche
General Observations

Psyche Overview

- Competitively awarded, cost-capped, Principal Investigator (PI)–led Discovery class mission:
  - PI: Lindy Elkins-Tanton, Arizona State University
  - Selected for implementation in 2017
  - Mission total cost approximately $1B
- Scientific objective is to study the unique metal-rich Psyche asteroid.
- Project management is performed by JPL, as proposed to NASA by the PI.
- Program management is provided by the Planetary Mission Program Office at Marshall Space Flight Center for NASA's Planetary Science Division.

More information about the Psyche mission is available on the mission website.

Psyche Science Overview

- The Psyche mission plays a unique role in NASA's planetary science program that cannot be replaced by any other planned mission.
- Psyche will investigate a previously unexplored type of solar system small body—the largest metal planetesimal—with fundamental goals:
  - Understand a building block of planet formation.
  - Explore the interior of a differentiated body to understand the interiors of terrestrial planets like Earth.
  - Examine a world made not of rock or ice but of metal.

More information about the Psyche mission's science objectives is available on the mission website.

IRB View of JPL Historical "Formula for Project Success"

- Experienced project team with capabilities necessary for project success
- Motivated and committed project personnel, dedicated to engineering and scientific excellence
- Engaged JPL senior leadership with detailed knowledge of project status and issues
- Engaged Line management providing both independent technical assessment and the assignment of properly experienced personnel
- Informal safety net provided by highly integrated and committed JPL workforce

While many factors lead to mission success and the Lab's excellence, the IRB developed this list of key attributes that, in the Board's opinion, have historically led to JPL's successes.

Psyche Scorecard Up to Launch Delay

- Experienced project team with capabilities necessary for project success…….. X
- Motivated and committed project personnel, dedicated to engineering and scientific excellence……... ✓
- Engaged JPL senior leadership with detailed knowledge of project status and issues…….. X
- Engaged Line management providing both independent technical assessment and the assignment of properly experienced personnel…….. X
- Informal safety net provided by highly integrated and committed JPL workforce……... X

While the IRB found the project team to be exceptionally hardworking and dedicated to Psyche's success, the Board noted that the Laboratory fell short on the rest of these key practices. The IRB has noted in its findings that some of these issues were exacerbated by external events such as the COVID-19 pandemic.

Psyche
Findings and Recommendations

Psyche Findings and Recommendations

General

Findings

- IRB agrees that late Guidance, Navigation, and Control software delivery and lack of testbed maturity are the proximate causes of the Psyche launch delay.
- IRB assessment is that additional issues could have led to a launch delay on their own:
  - Open flight software issues
  - Incomplete verification and validation (V&V), including fault protection
  - Operational readiness

The final GNC FSW build was delivered to the testbed in early 2022, approximately eight months late. This build had all of the necessary GNC algorithms, though there were hundreds of GNC control parameters and fault protection behaviors not yet determined. In addition, the integration of the Maxar bus simulation with the JPL testbeds was insufficiently robust to execute many of the GNC tests.

After the project added experienced GNC subject-matter experts to assess and resolve the problems, the subject-matter experts quickly raised concerns about the ability to make either the primary or contingency launch window due to GNC and verification and validation (V&V) problems. JPL commissioned an Institutional Tiger Team, and the project and Tiger Team personnel worked intensely, exploring all issues and identifying required tasks to make a 2022 launch opportunity with acceptable risk. Ultimately, with Tiger Team concurrence, JPL management and the Psyche Project made the formal recommendation to the SMD Planetary Science Division to stand down on the 2022 launch opportunity.

During the push to prepare for a 2022 launch, it became clear that although the GNC FSW and its V&V were the most apparent problems, there were other serious issues that would have led to the launch delay. These issues included a large number of open FSW issues, incomplete definition of fault protection behaviors, incomplete V&V, and insufficient plans and preparation for mission operations.

Psyche Findings and Recommendations

General

Recommendations

- Develop plan forward that prioritizes and completes development activities.
- Establish a new launch date with sufficient margin to have high confidence in success.
- Review work performed in last several months before the launch delay to assure it is at the required level of excellence with no embedded problems.
- Conduct a detailed review and assessment of “use-as-is” problem dispositions and “unverified failures.”

It is vital for the Psyche Project to make an objective assessment of all remaining development, testing, and mission operation planning activities, with all of these activities prioritized and completed. A detailed plan to complete all remaining activities necessary before launch and a thorough Integrated Master Schedule with realistic, credible task durations must be established. This will allow the project to select a new launch date with sufficient margin that will ensure a high probability of success.

During the effort to make the 2022 launch date, there were a number of problem closures that were given a “use-as-is” disposition. In addition, there were unverified failures (i.e., a failure that could not be duplicated). The project must conduct a detailed review and assessment of all issues that were accepted as “use as is” or unverified failures to ensure they do not result in unacceptable residual risk.

Psyche Technical Work-to-Go for Launch (1/3)

- Problem/Failure Report (PFR) and Developmental PFR Closures:
  - Revisit prior “use-as-is” PFR closures
- Guidance, Navigation, and Control (GNC):
  - Multiple GNC scenario tests on system testbeds: nominal and off-nominal behaviors
  - Support for multiple Operations Readiness Tests (ORTs), Scenario-Derived Tests, and Mission Scenario Tests
  - Ops procedure development (launch, initial checkout, cruise)
  - GNC operations tool development
  - GNC V&V for launch, cruise ops

The purpose of these work-to-go slides is to provide an illustrative (though inexhaustive) list of the technical work that needs to be performed in order to get Psyche ready for launch. As shown, while there is a significant amount of GNC work, there is also a large amount of work in other areas, including addressing FSW issues, V&V, fault protection, and mission operations.

Psyche Technical Work-to-Go for Launch (2/3)

- Flight Software (FSW) Completion:
  - Multiple FSW loads to be developed, as needed, to respond to PFR closures and regression tests
- Flight System V&V:
  - Complete system testbed certification
  - FSW V&V on testbeds, some selected testing on the spacecraft
  - Complete burn-down of approximately 1,000 remaining requirements (encompassing system and all subsystems, including GNC and fault protection)

Psyche Technical Work-to-Go for Launch (3/3)

- Completion of Assembly, Test, and Launch Operations (ATLO)
  - Remaining functional and system-level testing, launch vehicle encapsulation, and launch operations
- Mission System (Mission Ops/Ground Data System + Mission Design/Navigation) Completion and Operational Readiness
  - Develop ground tools
  - Complete flight rules, ops team training, various products and tools
  - Develop GNC momentum management strategy and operations tools
  - Complete confirmation of all days in selected launch period; establish Launch Readiness Date (LRD)
  - Trajectory development, ORT, and other planning
  - Sequencing and link management, initial spacecraft checkout, and cruise phase testing
- Potential Hardware Modifications
  - Modifications to the Power Conditioning Unit and portions of the Psyche Compute Element; any mods planned for spring of 2023
- Complete Prelaunch Reviews (ORR, SMSR, KDP-E, FRR, LRR)

The project identified possible hardware modifications that might be needed on either the Power Conditioning Unit or the Psyche Compute Element. If these are needed, the project needs to plan and execute the modifications to minimize the risk to both the hardware and schedule.

Psyche Findings and Recommendations

Management and Communications

Findings

- Major communication failures on Psyche resulted in project management not recognizing the seriousness of issues until too late to resolve them in time for a 2022 launch.
- Psyche team members raised alarms but felt their concerns were not being heard and/or acted upon at multiple levels of management.
- No formal Independent Technical Authority (ITA) dissents were raised on Psyche.
- A culture of “prove there is a problem” led to important issues raised by team members being disregarded.

The PI and Project Manager both endeavored to set the tone for a strong project culture with positive communication. However, limited staffing and lack of experienced personnel in key flight systems areas—particularly V&V, GNC, software, and fault protection—combined to create significant communications issues.

The IRB observed deficiencies in both formal and informal channels of communication, and multiple failures to act decisively upon the information shared. A combination of factors including continued problems with staffing, budget pressure, and remote work caused by COVID-19, created an environment where working-level personnel were challenged to prove that a problem existed before schedule and/or budget relief was provided or to change baseline plans. Team members experienced the normalization of deviance with respect to understaffing, high stress, inadequate scheduling, and pushback against worker intuition.

In this context, several of the workers raised issues and concerns to their project and Line managers, and felt their inputs were dismissed with little or no visible action taken. Line managers and Line chief engineers reported feeling they lacked the authority to solve these problems and therefore did not take any additional action. Concerns were also not elevated explicitly through the ITA to the appropriate levels to address with the project.

Psyche Findings and Recommendations

Management and Communications

Findings, cont'd

- Senior management changes in JPL's Planetary Science Directorate, including three leadership changes and a reorganization within the last two years, had an adverse effect on Psyche.
- Senior and Line management did not recognize Psyche development problems in time to take corrective action to prevent the launch delay.
- Senior management did not penetrate project execution sufficiently to recognize seriousness of the development issues.
- High demands on management's time to continually balance staffing requirements contributed to the launch delay.

The changes and transition in leadership in JPL's Planetary Science Directorate (4X), coupled with the level of work and demands from high-visibility planetary missions (e.g., Europa Clipper, Mars Sample Return [MSR]) created an environment in which missions such as Psyche did not receive the attention necessary to deal with the staffing and experienced-personnel challenges they were facing.

Multiple layers of management, including senior management, did not make appropriate use of common indicators to penetrate and understand actual project status. Examples include timeliness of the testbeds, timeliness of closed-loop simulations, operational readiness, an integrated view of the software and hardware products being delivered to testbeds and/or the ATLO environment, and the increasing number of open Developmental PFRs and PFRs against flight articles.

Psyche Findings and Recommendations

Management and Communications

Recommendations

- Establish and implement processes to assure open, credible, and responsive communications both vertically and horizontally throughout the Psyche Project.
- The JPL Director, senior management, and Line management must establish and implement processes that assure significant insight into flight-project execution and participation in resolution of problems and risks.
- The role of the Line management function in elevating concerns needs to be emphasized and strengthened.
- The workforce should be trained that the ITA should be used for elevating unresolved issues of any nature, including programmatic.

Going forward, the role of the Line management function in elevating concerns, both technical and programmatic in nature, needs to be emphasized and strengthened. The reporting mechanisms and metrics also need to be strengthened to properly reflect status, risks, and issues. In addition, the workforce should be reminded that the ITA can and should be used to elevate unresolved issues of any nature, including programmatic.

The fresh perspective offered by external, expert oversight can combat the normalization of deviance and address issues of risk to flight-project execution. Projects must seek opportunities to bring in such experts, even if on a brief rotation, and incorporate their viewpoint in the resolution of problems and risks.

Projects are also “imprinted” by their initial environmental, leadership, managerial, and resource conditions. Unless expressly addressed, these continue to resonate in project culture and organization long after such conditions have changed. The inadequate staffing and oversight that imprinted Psyche’s culture in this critical domain must be addressed with new processes, a fresh infusion of expert personnel, and renewed attention from managers and Lab leadership.

Psyche Findings and Recommendations

Staffing

Findings

- Multiple staffing issues resulted from JPL having more project work than can be supported by the available workforce:
  - Inexperienced managers and technical personnel in multiple project positions
  - Worker burnout
  - Inadequate staffing
  - Excessive number in stretch assignments
  - Lack of mentoring
  - High turnover
- Key project positions were not staffed:
  - Lack of a Project Chief Engineer
  - Lack of a GNC Cognizant Engineer (CogE) contributed to late GNC subsystem technical definition, development, and testing

Given the number of projects at JPL that required experienced personnel, the Lab was not able to staff the Psyche Project with either the number of personnel needed or individuals with the proper experience levels. Some (both management and technical) positions were staffed with inexperienced people. In some cases, individuals were experienced in roles different from those they were asked to fulfill on Psyche. While a few such “stretch assignments” can be positive, on Psyche there were too many stretch assignments, and there was inadequate mentoring from either coworkers or the Line.

The number of individuals on the project in key areas such as flight system engineering and GNC was inadequate and remained less than that required to keep on schedule for long stretches of time. This contributed to worker burnout.

A Project Chief Engineer is a senior technical person on the project whose job is to detect and fix project-wide technical problems as they arise. The Psyche Project did not have a person filling this role.

A GNC CogE takes intellectual charge of the end-to-end technical performance of the subsystem, including all interfaces with other subsystems, and assures that the ATLO and testbed testing will be adequate to validate that the subsystem (in the system) will perform as required in space. The GNC CogE position is one that needs to continue throughout launch and commissioning—and this person makes sure that the ops team is adequately trained on the subsystem. The Psyche Project did not have a person filling this role.

Psyche Findings and Recommendations

Staffing

Recommendations

- Provide additional 10–12 full-time, experienced leaders at all levels of the project.
- Adequately supplement and maintain project staffing to support the replan.
- Special attention should be given to assigning/maintaining a Project Chief Engineer, GNC CogE, and Fault Protection Lead Engineer.

The areas on Psyche that need attention are significant enough that the Psyche IRB recommends that additional experienced leaders be brought on to the project beyond the leaders in place when the slip was announced. In the IRB's opinion, 10–12 such leaders are needed.

The project requires staff augmentation—particularly in GNC. The IRB recommends that JPL find the additional staff required to allow the replan to succeed. Key positions that the project must assure are staffed (and maintained) with capable people are Project Chief Engineer, GNC CogE, and Fault Protection Lead Engineer.

Psyche Findings and Recommendations

COVID-19 Related

Findings

- COVID-19 is a contributing factor to the issues that led to a launch delay and the lack of visibility of these issues within JPL.
- Resulting remote work substantially reduced informal communications:
  - "Walking the floor" and "drop-in discussions" did not happen.
  - Various teams within Psyche became more isolated.
- Remote and hybrid work arrangements persist and pose a high risk to remaining Psyche Project development.

COVID-19 did not cause all the problems on Psyche, but it played a contributing role. Existing problems with staffing were heightened by significant turnover in key areas at JPL. Remote work conditions exacerbated the isolation of various teams, impeding team integration. The inability of the right group of people to be together in the testbed environment delayed uncovering problems and inhibited the ability to learn the spacecraft system. The Psyche Critical Design Review (CDR) also took place during the first weeks of lockdown in spring of 2020, impeding the Standing Review Board's (SRB's) ability to pick up on situational cues and accurately gauge project progress.

Important for these COVID-19–related findings was the lack of informal communication that the project team suffered in the absence of face-to-face interactions. In the past, JPL's success typically relied on senior members of projects and technical line organizations "walking the floor," dropping in for conversations at office doorways, or chatting in the cafeteria. Without these informal communication mechanisms, contextual cues and situational awareness were lost. Team members working the floor found it difficult to report problems up the chain over Webex, especially when attendees kept their cameras off.

Research has found that the kind of team isolation and difficulties in team consolidation experienced on Psyche were common to other organizations during the lockdown period of the COVID-19 pandemic. The lockdown conditions contributed significantly to the question of why Psyche and JPL leadership did not know of the severity of the problems with GNC and V&V until it was too late to correct course. As an example, it is notable that team members exchanged valuable project information at the Christmas party in 2021, the first time team members had been face-to-face in over a year and a half.

Psyche Findings and Recommendations

COVID-19 Related

Recommendations

- Reestablish informal communications, such as “walking the floor” and “drop-in discussions.”
- Remote and hybrid work must be minimized on Psyche to give the team the best opportunity to coalesce in a short time.

Informal communication is an important safety net for any project. In-person interactions that allow for informal communication produce multiple mechanisms and avenues for reporting and conveying important contextual information. Going forward, the Psyche leadership must take advantage of the in-person opportunities on Lab to “walk the floor” and engage with workers at all levels of the organization. Informal activities such as lunch gatherings and social events can support the transfer of key contextual information. Such opportunities should be proactively pursued to encourage information flow and exchange among project personnel.

Prior studies of hybrid and remote work arrangements indicate that trust can fray in remote settings, and working apart discourages integrative activities. Going forward, Psyche team members must reestablish trust and communication pathways, and conduct highly time-intensive, integrative work as a team. The IRB recommends that, given these exceptional circumstances, the team should minimize remote work conditions.

Psyche Findings and Recommendations

Project Metrics

Findings

- Lack of meaningful progress metrics and risk assessment hindered visibility into, and the ability to highlight and elevate, issues.
  - Inadequate and unrealistic Integrated Master Schedule minimized the value of traditional "actuals vs. plan" metrics to assess progress.
  - Risk assessments did not accurately communicate project health (i.e., many yellow risks, no red risks). Based on interviews, there was an aversion to "going red" by project management.
  - Project schedule and progress-tracking metrics masked true development status.
- Project focused on hardware development and problem resolution, and neglected software and other non-hardware areas of activity.

On Psyche, the schedules and metrics were insufficient for project managers to identify and assess problems. Key Psyche non-hardware developments, in particular the GNC software, the testbed implementations, and the overall V&V effort, were never properly represented in either the Integrated Master Schedule or the progress metrics.

The specific schedules and metrics developed by the Psyche Project team for these non-hardware areas were often too general and/or unrealistically optimistic, and hence masked the true technical risks and schedule inadequacies. As a result, by the time the true statuses of the Psyche non-hardware issues were identified and understood, it was too late to mitigate the problems to achieve a launch in 2022 with acceptable risk.

Psyche Findings and Recommendations

Project Metrics

Recommendations

- Develop a detailed, integrated, resource-loaded, and adequately margined and verified schedule for all remaining work.
  - This must include sufficient task completion milestones in key areas like V&V, system integration and test (I&T), and mission ops preparations, such that progress in these areas can be readily tracked.
- Establish and implement a management information and reporting system that produces a credible and timely assessment of status, risks, and issues against this integrated baseline (described above).

A general problem with JPL schedule-management methods in the non-hardware areas becomes particularly problematic leading up to launch. Psyche and JPL must recognize this inadequacy and develop a solid, internal project schedule approach for these areas, with proper details and progress metrics, to make certain that all key elements necessary for launch are being properly tracked and that untoward items are identified quickly and mitigated on a timely basis.

Specifically, resource loading on the Psyche go-forward plan must recognize that some of the same people involved in completing GNC development and V&V work are also involved in development of the GNC operations tools. In addition, the schedule for V&V must go beyond a level-of-effort approach and include milestones that can be tracked so that the actual progress is evident.

Psyche Findings and Recommendations

SRB Review Process

Findings

- Psyche Standing Review Board (SRB) reports for the Preliminary Design Review (PDR), Critical Design Review (CDR), and System Integration Review (SIR) identified schedule performance as a risk to the LRD.
- Psyche agreed that schedule was an issue, noting that they had appropriately mitigated the identified concerns. The project's position was accepted by all authorities, including the Psyche SRB, JPL, Program Office, and NASA HQ management.
- This SRB activity was consistent with the overall NASA/JPL review process for Psyche. The net result was that this concern by the SRB was not adequately mitigated in the go-forward plans for Psyche—an issue that was exacerbated by the excessive duration between SRB reviews post-SIR.

The ToR document established by NASA to provide the high-level requirements levied on the Psyche IRB had a specific reference to the effectiveness of the SRB within the Psyche review process.

NASA Procedural Requirement (NPR) 7120.5 documents the requirements and process for how SRBs are infused into the overall project life-cycle review structure. SRBs are formed early in the project life cycle and are responsible for conducting the major project life-cycle reviews in accordance with NPRs 7120.5 and 7123.1. SRBs are populated with subject-matter experts who are independent of the project. The SRB is responsible for providing an independent assessment of the project's readiness to proceed coming out of the life-cycle reviews. The SRB presents its assessment to the project, responsible institutional management, and NASA management.

The Psyche SRB reviewed the project at PDR (March 2019), CDR (May 2020), and SIR (December 2020). Psyche schedule performance was cited as the largest risk coming out of the CDR and SIR. The SRB noted at SIR that schedule was the single most significant issue moving forward and had to be managed going forward to ensure the LRD. The long duration after the SIR precluded the SRB from following up on the schedule issue.

The project and JPL acknowledged the schedule issue; however, it was not clear to the Psyche IRB how the path forward to resolution was implemented or validated by NASA.

Psyche Findings and Recommendations

SRB Review Process

Recommendations

- The SRB process must be strengthened such that there is discrimination between “normal” activities and serious issues that will highlight critical factors impacting a project’s success.
- Guidelines given to projects for status reporting should be clear and unambiguous (e.g., for “green,” “yellow,” and “red” color-coding).
- The response to the SRB-reported issues and concerns must be thoroughly reviewed by the SRB, Management Center, and NASA authorities on a regular basis until satisfactory resolution is achieved.

The Psyche problem exposed challenges inherent in the current SRB process. Technical status and programmatic updates between the current gate reviews will allow the SRB to achieve deeper insight into project technical and programmatic status.

The IRB recommends that NASA consider changes to the overall SRB process of how independent reviews are formed and conducted, with the goal of improving both rigor and depth of insight achieved through every step of the review, evaluation, and reporting process. Changes should be considered for providing definitive guidance on color-coded status reporting. Great care must be exercised in the color-coded (i.e., green, yellow, red) assessments to properly and consistently reflect the status. For example, red scores should never be aggregated with green and yellow to obscure the severity of a red score.

While projects present plans to close issues, a closed-loop process needs to be put in place to ensure implementation.

Psyche Findings and Recommendations

JPL/Maxar Relationship

Findings

- Maxar supplied the spacecraft chassis for Psyche, including the structure, power, and electric propulsion subsystems, under a fixed-price contract; Maxar also provided simulation software, testbed equipment, and personnel for a joint ATLO campaign.
- Maxar has built and developed multiple spacecraft using electric propulsion for Earth orbital applications but no deep space applications prior to Psyche.
- JPL teamed with Maxar early during proposal development and continued a strong working relationship throughout the design phase, aided by frequent and extended face-to-face interactions between the two teams.
- The COVID-19 pandemic prevented the planned team-to-team immersion of ATLO personnel, scheduled to happen before the joint ATLO, and as a result, the early stages were inefficient and hindered the melding of culture, procedures, and expectations.
- Misunderstandings between the two partners about the details of the joint testbed simulations significantly delayed the V&V activities and contributed to the launch delay.

Maxar is an experienced contractor with a proven and cost-effective product line specific to its core geosynchronous satellite business. Thus, when considering cost, schedule, and performance, there is a natural alignment of Maxar's capabilities with a broad range of NASA interests, including Psyche. As would be expected, the business focus of Maxar and the mission focus of JPL for Psyche has resulted in some unique stresses on both the management side and technical side of the many interfaces required to achieve a successful mission.

The JPL and Maxar teams invested considerable time, energy, and effort in building their relationship, resulting in exemplary collaboration in many areas. However, there were differences in the definition and capabilities of testbeds and simulations that were uncovered late in the collaboration. Maxar also did not have the detailed knowledge of their heritage design that JPL expected. This significantly delayed V&V activities and contributed to the launch delay.

Psyche Findings and Recommendations

JPL/Maxar Relationship

Recommendations

- The Psyche experience provides an excellent opportunity to document best practices for future collaborations between NASA and commercial spacecraft providers in areas such as:
  - Early and sustained in-depth interactions to develop mutual understandings of cultural and process differences
  - Ensuring interfaces between the two organizations are correct, complete, and adequately documented and reviewed by subject-matter experts
  - Contract structure

Use of an Earth-orbiter supplier—primarily commercial telecom and remote sensing—for NASA/JPL applications has clearly shown that there are significant differences in the developmental philosophies of the two types of organizations. One organization may be developing a one-of-a-kind spacecraft and mission nominally for deep space, while the other is focused on standard design and operations in Earth orbit. These are significant differences in business models that must be accounted for in the development process. For the contract vehicle, the ramifications for this type of development should be thoroughly evaluated.

Proper evaluation of supplier capabilities and comparison to the capabilities needed for the mission are mandatory for a teaming relationship like this. Critical capabilities assumed by the project (e.g., closed-loop simulation on the actual spacecraft and the Maxar simulation capabilities) may not be available and must be identified early to avoid issues.

Extensive team interactions on a continuing basis are also required to help maintain mutual understandings between the organizations and to ensure that cultural and process differences are identified and resolved, regardless of external factors like COVID-19. Residence of project personnel at the commercial vendor's site is highly recommended.

Psyche Findings and Recommendations

JPL/Maxar Relationship

Lessons Learned

- JPL and other NASA Centers can partner with commercial providers but only if there is early and sustained in-depth interaction between personnel to develop mutual understandings of cultural and process differences. Good detailed interface documents are required but do not replace the face-to-face meetings to ensure interpretation of the interface documents is clear.
- Contract structure is an important element of any partnership between a NASA entity and a commercial provider. The differences between supplying hardware and software/simulations or level-of-effort support must be clearly understood at the outset. A fixed-price contract can only work if what is to be supplied is clearly understood at the detailed level by both partners.

See text on previous page.

Psyche
Summary and Conclusions

Psyche Project Summary and Conclusions

- Psyche is a project with significant scientific merit, which can greatly contribute to our knowledge of a unique class of metallic asteroids and add to our understanding of the solar system.
- The PI set a commendable tone of collaboration from the project's outset and continues to prioritize relationship building with project team members at all levels.
- Psyche's issues are much more extensive than originally understood when the launch was delayed. These include but are not limited to:
  - Significant staffing shortages and insufficient personnel with relevant experience
  - Communications issues
  - Hybrid work schedules
  - Software and system testbed development
  - V&V, including fault protection system
  - Operational readiness
  - Shortcomings in programmatic metrics
- Psyche issues require significant corrective action, including the addition of new, experienced personnel at all levels of the organization.
- Many Psyche issues are the direct result of JPL institutional issues.
- COVID-19 was a contributing factor in the various Psyche issues.
- **The IRB has reviewed the go-forward plan and believes JPL has established an executable plan for a 2023 launch.**

JPL Institution
General Observations

JPL Institution – General Observation

Many Psyche issues are not unique to Psyche and are indicative of broader institutional issues.

JPL Institution
Findings and Recommendations

JPL Institution Findings and Recommendations

Flight Project Workload

Findings

- JPL currently has an unprecedented workload with the concurrent implementation of 6 large spaceflight projects, plus numerous smaller missions and scientific instruments:
  - Two projects are Flagship class (Europa Clipper, Mars Sample Return).
  - Two projects are Discovery class (Psyche, VERITAS).
  - Two projects have significant payload development efforts (SWOT, NISAR).
- Large imbalance exists between workload and available JPL resources:
  - Most acute in lack of experienced managers; systems engineers; and GNC, FSW, and Avionics engineers
  - Imbalance represents a root cause for the Psyche issues
  - Adversely affects all flight project activity at JPL

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JPL is unable to staff its flight projects with the requisite number of experienced personnel. The total number of personnel is also an issue. JPL's current development flight project workload is the broadest and most demanding in the history of the Laboratory.

In addition to two Flagship planetary science missions (Europa Clipper and MSR), major flight projects currently in development include two planetary Discovery missions (Psyche and Venus Emissivity, Radio science, InSAR, Topography, and Spectroscopy [VERITAS]) and two missions for which JPL is providing large and complicated radar instruments (Surface Water and Ocean Topography [SWOT] and NASA-ISRO Synthetic Aperture Radar [NISAR]), along with the necessary system engineering for the instruments. JPL has many other flight projects underway, including Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) and the upcoming radar instrument for EnVision.

All these flight projects require experienced personnel. Staffing challenges exist in key areas like GNC, FSW, avionics, and systems engineering.

JPL Institution Findings and Recommendations

Flight Project Workload

Recommendations

- Flight projects must be fully staffed with appropriately experienced personnel from the beginning, particularly in Systems Engineering, GNC, FSW, and Avionics.
- Balance must be achieved between the workforce needs of flight projects and the available JPL workforce.
  - Timing of achieving this balance is critical.
  - Psyche is an example of the major problems this imbalance is causing today.
- IRB believes that by the end of March 2023, significant corrective actions must be implemented to achieve balance.
- For any corrective actions requiring more time, a detailed plan of action must be developed and approved by JPL, Caltech, and NASA.

JPL workforce issues must be addressed, or there will be more launch delays and possibly mission failures. It is urgent that workforce balance be achieved in the near future to minimize negative impacts to future flight missions.

The IRB recommends that a major, focused effort be undertaken at JPL to achieve the required workforce balance on its flight projects. The IRB believes that this balance can be achieved by strategically selecting from the options noted on the next page.

Because of the urgency of this issue, the IRB recommends that as many corrective actions as possible be in place by the end of March 2023 and that plans for additional corrective action be reported at the same time. The corrective actions to achieve workforce balance should be developed by JPL and approved by NASA and the California Institute of Technology (Caltech).

Options to Achieve Workforce Balance within JPL

- No new flight projects until balance is achieved
- Cancel, redirect, or delay a flight project
- Transfer required talent from non-flight projects within JPL to flight projects
- Focused personnel training and development in key areas
- Significantly increase use of industry prime and support services contractors
- Increase use of and collaboration with other NASA Centers
- Aggressive recruitment and hiring
- Accept the risk of layoffs

See text on previous page.

JPL Institution Findings and Recommendations

Line Organization Issues

Findings

- Significant erosion of technical acumen in the Line organization:
  - Prevents Line organization from adequately engaging with flight projects, independently assessing status, identifying problems, working with projects to develop solutions, and providing mentorship.
  - Represents loss of critical safety net.
  - Technical leadership has migrated from the Line organization to the flight projects.
  - Without this Line organization capability/safety net, Psyche issues will become the norm and not the exception.
  - The IRB recognizes the institutional need for more experienced managers and lead engineers is a primary cause of this erosion.

In the Line organization, there has been significant erosion in recent years of the technical ability to exercise good judgment and make sound decisions in various technical domains across all current projects.

The source of this erosion is due to multiple factors: Foremost is the significant increase in the number of flight development activities (instruments and full missions) that JPL supports; this has required the experienced cadre to be spread thin on the various projects and has had a corresponding effect on the Line organization—that is, the transfer of Line leaders to projects. The spectrum of large and small projects has exacerbated this problem. Additionally, the rise of the commercial space industry in recent years has resulted in competition for experienced personnel, particularly in the systems engineering, GNC, and FSW areas. Finally, the IRB observed that in the systems engineering discipline, the employee-to-supervisor ratio has become high, resulting in difficulty in effective training, development, and personnel management.

This erosion of the experience base of the Line organization has led to the degradation of a critical and independent safety net for flight projects. It is important that this be addressed so that the Psyche issues do not become the norm.

JPL Institution Findings and Recommendations

Line Organization Issues

Findings, cont'd

- Division 31 (Systems Engineering) and Division 34 (Autonomous Systems*) issues:
  - Modern space systems are complex, highly integrated, and rapidly evolving, especially in the domains of these two divisions.
  - The magnitude of responsibility in these technical areas has necessitated the partitioning of their work into two divisions.
  - Ambiguity and confusion exists between the two divisions in terms of roles and responsibilities and accountabilities.
  - The hybrid work environment has exacerbated these issues.
  - Both are critically understaffed, especially in terms of engineers with flight project experience.

* Division 34 includes the Avionics, FSW, GNC, and Robotics product areas for JPL.

Modern space exploration systems are complex with highly integrated functions. These systems demand strong system engineering and highly capable avionics systems with associated FSW. With the magnitude of these demands across multiple flight projects at JPL, these activities have been allocated to two technical divisions: the Systems Engineering Division (Division 31) and the Autonomous Systems Division (Division 34). The avionics activities, including GNC system and FSW, are performed by Division 34.

The activities between the two divisions, however, are highly interdependent, requiring strong collaboration, shared accountability, and clear definition of roles and responsibilities. Examples of interactions include development of requirements on avionics systems, capabilities for FSW, and the system V&V activities. Insufficient delineation of roles and responsibilities and the shift to hybrid work have increased ambiguity and confusion across the two divisions. These long-standing issues are not unique to Psyche and are likely affecting other missions.

These two divisions are critically understaffed, and there is an acute shortage of personnel with relevant flight project experience across JPL in the key disciplines of these two divisions.

JPL Institution Findings and Recommendations

Line Organization Issues

Recommendations

- Repopulate the Line organization with experienced leaders and engineers to reestablish the Line organization as an equal partner with flight projects during implementation.
- Add experienced people and include them in the effort to achieve balance.
- Address the Division 31/34 staffing, accountability, and coordination issues.
- Continually examine the issues between and within Divisions 31 and 34 because of the importance of these Divisions to the execution of flight projects.

The technical Line organizations must be strengthened to reestablish them as equal partners with flight projects. The Line organizations' role in proper oversight of the technical activities provides a safety net to ensure the quality of the technical products for mission success.

It is, therefore, critical to add more experienced personnel to various technical line areas. These added personnel will further address any required development in the personnel in their respective areas.

The long-standing issues of the roles and responsibilities of Divisions 31 and 34 must be addressed promptly with clear delineation of roles, responsibilities, and shared accountability. The Divisions should also examine and implement approaches to maximize collaboration among teams. As flight system technical design and project development practices evolve, these issues should be examined on a continual basis.

JPL Institution Findings and Recommendations

Senior Management Engagement

Findings

- JPL senior management did not adequately penetrate Psyche Project status.
- The large number of small projects, instrument developments, etc., dilutes JPL senior management's attention, contributing to a lack of appropriate levels of engagement in the execution of major flight projects.
- JPL's management review process and tracking metrics during the critical prelaunch period are inadequate.

The flight project reviews by senior management generally focused on the status as provided by the projects. The independent set of questions, templates, and progress indicators that the projects were required to address were inadequate to penetrate and uncover potential issues. Thus, as an example, when the Psyche Project focused on hardware issues, so did JPL management. JPL management failed to question the project on the status on software, testbeds, and V&V progress, which should have been done on a regular basis. The result was an inadequate understanding of Psyche status, illustrating that the management review process and tracking metrics weren't satisfactory. In addition, the templates failed to adapt appropriately to the phase of the project. In later project phases, for example, operations, software, and V&V require extra attention.

A significant challenge for JPL leadership is that members of senior management have an enormous workload associated with both major flight projects and a myriad of smaller projects and instrument developments. Trying to stay up to speed on all of these, combined with failure to prioritize time proportionately to the project scale, leads to a lack of an appropriate level of engagement in the major flight projects.

JPL Institution Findings and Recommendations

Senior Management Engagement

Recommendations

- JPL senior management must establish regularly scheduled meetings, formal and informal communications, and “drop-in” visits to facilitate necessary engagement on major flight projects, communicate priority, and maintain cognizance of status.
- Prioritize the large number of activities competing for senior management’s attention to focus on those in greatest need and importance such that commitments to NASA and the various stakeholders are met.
- Senior management should develop and codify in JPL’s Flight Project Practices the metrics that will be employed for tracking progress, especially during system I&T and V&V.

Senior management, including the JPL Director, is accountable for the success of JPL’s flight projects. To maintain cognizance of the actual status of flight projects, senior management, including the JPL Director, must establish regular meetings, formal and informal communications, and “drop-in” visits to facilitate necessary engagement as well as communicate priorities.

Given the large number of activities that JPL is currently engaged in, senior management’s attention must be prioritized to focus on the major flight projects in order to meet commitments to NASA and other stakeholders. As noted elsewhere, by addressing the workforce issues aggressively, less time from senior management will be needed to move around key personnel.

Given that multiple levels of independent reporting paths failed to uncover the issues that led to the Psyche delay, JPL must review all independent lines of reporting from project personnel to senior Lab leadership, including ITAs, to strengthen communications and penetration of issues.

It is imperative that senior management develop and codify in JPL’s Flight Project Practices the metrics that will be employed for tracking progress, particularly leading to the critical prelaunch period.

JPL Institution Findings and Recommendations

Workforce Issues

- Hiring and Retention
- Remote and Hybrid Work

JPL Institution Findings and Recommendations

Hiring and Retention

Findings

- JPL is experiencing difficulty attracting and retaining necessary experienced workforce, especially in critical areas such as Systems Engineering, GNC, FSW, and Avionics.
- Local competition and aggressive hiring from commercial space firms and start-up firms have changed the position of JPL and its competitiveness in hiring, including compensation and remote work options.
- Incoming workforce has different expectations about career opportunities and mobility.

The explosion of commercial space activity is well documented and has occurred at a time when the engineering educational and training pipeline cannot expand fast enough to keep up with demand across the entire national space enterprise. In addition, many social media companies recruit and hire individuals from the same available pool of engineers. Commercial companies are offering substantially higher salaries and promise rapid advancement for top graduates while, in parallel, “poaching” experienced engineers from JPL and other NASA Centers.

Because JPL’s engineers gain unique experience and the ability to build complex robotic capabilities for space, they are even more attractive to companies that aspire to enter this domain. These companies enjoy physical proximity to JPL, easing the engineers’ decision to leave. Loss of expertise due to attrition, poaching, or other reasons is hard to replace without several years of training and mentoring.

The problem for JPL is especially acute in the GNC, FSW, robotics, avionics, and systems engineering areas, not only because of external competitive demands but also because all of JPL’s missions have parallel high internal demands for these critical disciplines. Thus, there is a perfect storm, with outside competitive pressures and inside demand pressures affecting the availability of these critical resources. These pressures also limit mentoring and training opportunities needed for less experienced staff and recent hires.

JPL Institution Findings and Recommendations

Hiring and Retention

Recommendations

- JPL must develop the capability to successfully hire and retain mid-level people in this new environment.
- JPL must develop approaches for the career growth and retention of critical and high-potential personnel.
- JPL must characterize problems with retention and develop incisive and decisive actions to address the identified problems.

To be successful in this highly competitive environment, JPL needs to offer timely, competitive salary and opportunity packages. Having an effective counter capability is critical for retaining expert staff.

As part of an effective retention strategy, JPL should address mentorship and stages of career advancement for Lab personnel.

JPL Institution Findings and Recommendations

Hybrid Work Environment

Findings

- The current JPL policy for remote and hybrid work will have an adverse impact on flight projects.
  - Remote/hybrid work heightens barriers between sub-teams, which impedes communication and integration.
  - Without appropriate in-person interaction, remote/hybrid work can increase miscommunications and create reporting problems up the chain.
  - Physical access to shared resources, i.e., testbeds, helps build team rapport and familiarity with the spacecraft.
- At present, it is difficult to estimate the impact of remote/hybrid work on flight project schedule and budget planning.

The current JPL policy for hybrid work has high heritage in the COVID-19 remote work period; however, hybrid work as performed under COVID-19 exacerbated well-known problems with distributed teams, as characterized in over 30 years of literature and study. This includes the escalation and personalization of task conflict, the exacerbation of team silos, and the poor performance of integrative tasks. Recent studies of the COVID-19 lockdown period indicated heightened barriers and the loss of innovative ties between groups. The Psyche case showed persistent miscommunications in attempts to report problems up the chain. Under hybrid work conditions, information asymmetry can accrue between in-person and remote participants.

Typically, these issues are remediated with appropriate degrees and judicious choices of in-person interaction, often around shared hardware, software, or other tasks. Without careful consideration about how, when, and under which conditions teammates come together, JPL cannot hope to leverage the strengths of both styles—in person and remote—to the benefit of missions. Additionally, information is lacking about the true impacts of hybrid or remote work. Because the COVID-19 lockdown was such a dysfunctional situation, data from that period cannot be reliably interpreted to generate effective cost or schedule models.

JPL Institution Findings and Recommendations

Hybrid Work Environment

Recommendations

- JPL should immediately revisit its policy for hybrid work to make it more effective and better reflect the evolving needs of flight projects in different mission phases.
- Carefully consider which tasks, project phases, and circumstances permit hybrid and remote work arrangements.
- Any hybrid work arrangements should recognize the need for in-person interactions. In addition, it is critically important that early-career employees work alongside seasoned employees for their long-term development.
- Inefficiencies in productivity and communications associated with hybrid work must be included in the workforce, cost, and schedule plans for flight projects.

Research indicates that remote work conditions are inefficient and more challenging when performing integrative tasks, communicating nuance and context, and exploring engineering and technical solutions. While there can be advantages to remote or hybrid work arrangements, collaborative teamwork is a fundamental aspect of implementing large-scale, multidisciplinary projects. Intensive in-person interaction is necessary to ensure timely and efficient delivery of flight projects.

The characteristics of the required work must match the advantages of remote, hybrid, or in-person arrangements. Design, assembly, hardware and software testing/verification, and initial operational periods of a flight project are critical moments where in-person collaboration is required. For areas or periods of time where hybrid work is appropriate, it is recommended that the project designate specific days of the week so that the workforce is on-site at the same time, as well as implement industry-proven telework practices and promote research into best practices. JPL should augment hybrid or remote arrangements through periodic, intensive on-site activities to leverage the power of in-person work.

JPL Institution Findings and Recommendations

Caltech Governance

Background

- To be a good steward of JPL, Caltech is responsible for:
  - Appointing the JPL Director and evaluating his/her performance
  - Developing an in-depth understanding and being proactive in addressing strategic challenges, risks, and opportunities for the Laboratory
  - Maintaining insight into the status and progress of JPL's flight projects
  - Instituting corrective actions to address issues or deficiencies identified

As the managing authority for the Prime Contract with NASA, Caltech has oversight responsibility that includes appointing the JPL Director and evaluating his/her performance on an annual basis. It is appropriate for Caltech, as part of their stewardship, to delegate leadership of JPL to a Director.

As the managing authority, Caltech must have an in-depth understanding of the strategic needs and challenges of the Laboratory, as well as help the Laboratory identify strategic opportunities. Caltech must also maintain insight into the status and progress of JPL's flight projects at a level that enables the Institute to help senior JPL leadership address issues and risks as they arise.

JPL Institution Findings and Recommendations

Caltech Governance

Findings

- There are deficiencies in Caltech's awareness of flight project status and progress.
- Caltech hasn't been sufficiently engaged in helping JPL address its workforce challenges.

Recommendations

- Caltech should have a better understanding of the JPL institutional issues and play a supporting role in addressing them.
- JPL should strengthen the quality of flight projects status presentations to Caltech.
- Caltech should develop a more rigorous annual review and evaluation approach for the performance of the Laboratory Director.

The IRB was provided a redacted sample of briefings given by JPL to the JPL Committee of the Caltech Board of Trustees. These briefings, as provided, are at an inadequate level for Caltech leadership to understand the challenges facing the Lab. Few briefings that address strategic challenges and risks were provided. Caltech should devise ways of improving the depth of insight into Lab-wide factors affecting flight project success.

Caltech should establish a more rigorous annual review process for the JPL Director. As is standard practice for NASA Center Directors, and generally for other individuals with similar executive and budgetary authority, this review should include input from direct reports. In addition, feedback from the NASA Associate Administrator for the SMD and others would enhance the effectiveness of the Director.

In the near term, to help JPL address its hiring and retention challenges, Caltech should help JPL to tailor hiring and compensation practices to meet the current needs of the Laboratory. Caltech should do what it can to support the JPL Director and leadership as the Lab navigates the current situation of its high workload.

JPL Institution
Summary and Conclusions

JPL Institutional Summary and Conclusions

- JPL Institutional issues:
  - Inadequate flight project staffing, in both number of personnel and experience
  - Erosion of Line organization technical acumen
  - Insufficient JPL senior management engagement in flight projects
  - The post-pandemic work environment
- These issues are having a significant adverse impact on the implementation of JPL flight projects.
- Many of Psyche's issues are a direct result of the JPL institutional issues.
- Corrective actions are urgently needed, and failure to act will result in more "Psyches" and potentially in-flight failures.

The JPL institutional issues are serious and require urgent action. JPL, NASA, and Caltech must be engaged in the resolution of these issues.

While corrective actions will be challenging, successfully addressing these issues by March 2023 is critical. This will maintain JPL as a world-class space flight organization that is central to NASA and the U.S. space program. The IRB is optimistic that the necessary corrective actions will be implemented.

Acronyms

ATLO	Assembly, Test, and Launch Operations
ATK	Alliant Techsystems
Caltech	California Institute of Technology
CCRS	Capture, Containment, and Return System
CDR	Critical Design Review
CogE	Cognizant Engineer
FRR	Flight Readiness Review
FSW	Flight Software
GNC	Guidance, Navigation, and Control
GSFC	Goddard Space Flight Center
HQ	Headquarters
I&T	Integration and Test
IRB	Independent Review Board
ITA	Independent Technical Authority
JPL	Jet Propulsion Laboratory
KDP	Key Decision Point
LRD	Launch Readiness Date
LRR	Launch Readiness Review
MSR	Mars Sample Return
NESC	NASA Engineering and Safety Center

Acronyms

NISAR	NASA-ISRO Synthetic Aperture Radar
NPR	NASA Procedural Requirement
ORR	Operational Readiness Review
ORT	Operations Readiness Test
PDR	Preliminary Design Review
PFR	Problem/Failure Report
PI	Principal Investigator
SIR	System Integration Review
SMD	Science Mission Directorate
SMSR	Safety and Mission Success Review
SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer
SRB	Standing Review Board
SRL	Sample Retrieval Lander
SWOT	Surface Water and Ocean Topography
ToR	Terms of Reference
V&V	Verification and Validation
VERITAS	Venus Emissivity, Radio science, InSAR, Topography, and Spectroscopy