R10: Programmatic Assessment (3 of 3)

Recommendations:

(R10.1) Establish MSR as a Tightly-Coupled Program consisting of three projects (SRL, MAV, and ERO/CCRS).

(R10.2) Set separate programmatic baselines (i.e., Management Agreements, Agency Baseline Commitments) for SRL, MAV, and CCRS, reporting to the MSR Program Office (according to NPR 7120.5).

(R10.3) UFE must be re-established at a minimum of 30% for each project in order to manage risks (i.e., SRL, CCRS, and MAV should be given UFE at the project level in order to manage risks to a 70% confidence level).

(R10.4) If the most important budgetary constraint is annual cost, NASA HQ should provide commitments for annual cost ceilings in order to guide the development of the go-forward program, while de-emphasizing lifecycle cost as a critical measure of MSR programmatic success.

(R.10.5) To increase the probability that the MSR program can succeed within the directed annual budgetary constraints, the Program should consider a range of options including launch delays and alternate architectures that provide greater architectural robustness and resiliency.

(R10.6) Conduct the Program PDR only after all of the projects have demonstrated at their PDRs/KDP-Cs that they have congruent technical, schedule, and cost baselines

(R10.7) Postpone programmatic baselines (MAs/ABCs) for SRL, MAV, and CCRS until credible technical baselines can be achieved for the present architecture or alternative architectures that add greater robustness and resiliency. Programmatic baselines must then be established with robust reserves in order to ensure that the projects have the resources required for mission success

Allowing SRL, MAV, and CCRS to be managed as separate projects under a revised, Tightly-Coupled Program structure will enable each project to have responsibility, authority, and accountability over its portion of the program work. The Tightly-Coupled Program structure will also enable each project to manage to its own MA/ABC with individual project control over budgets, reserves/UFE, and schedules, while reporting to the MSR Program Office as appropriate and in accordance with NPR 7120.5F. Schedules for each project should be managed separately but cooperatively, and should be carefully integrated at the Program level. Baselines for each project should not be set until budgetary constraints are aligned with credible technical baselines that have been carefully studied through an analysis of alternative architectures that add robustness and resiliency for the enhancement of mission success.

F11: Independent Review Structure (1 of 2)

The Independent Review structure lacks visibility into the integrated technical and programmatic plan, and the structure is not consistent with the scope of the three major Projects (SRL, MAV, ERO/CCRS).

- In the present approach, SRL, MAV, and CCRS conduct separate (i.e., not integrated) technically-focused gate reviews in coordination with the MSR SRB Chair and in concert with the respective Institutional Directors.
- ERO conducts independent gate reviews that are chartered by ESA.
- At the lower-level PDRs, an institutional JCL was conducted for SRL only. No independent JCL analyses were conducted for any of the Projects.
- The lower-level PDRs conducted were not uniform and did not include an independent assessment of an integrated technical and resources baseline.

The current program has struggled with performing independent reviews in a way that is consistent with the NPR 7120.5F requirement such that all of the key program elements receive thorough and independent review. Despite best intentions, IRTs at the institutional level are necessary but not sufficient to assure comprehensive and uniform review. For example, SRL, MAV, and CCRS are not presently subject to a review process that meets the standards that are expected of a Class A mission of this magnitude and complexity.

A key step in addressing the shortcomings of the review structure is to create a tightly-coupled program that accommodates SRL, MAV, and CCRS as separate projects such that each project has an SRB functioning within the requisite 7120.5F framework while also supporting the Program-level MSR integration requirements. In this way, all key elements of the project will be subject to a uniform standard of review and will be subject to a uniform level of programmatic reporting and analysis that can then be effectively rolled up into the Program-level assessment.

R11: Independent Review Structure (2 of 2)

Recommendations:

- (R11.1) As a Tightly-Coupled Program, establish separate SRBs for SRL, MAV, and CCRS that provide independent programmatic assessment (including JCLs) and adhere to conflict-of-interest and independence screening as described in the NASA SRB Handbook.
- (R11.2) The program SRB should comprise a cross-cut of independent program-level experts combined with the Chairs and a subset of other relevant members from the individual projects SRBs.
- (R11.3) Each MSR Independent Review Team (IRT) activity should be retained with the addition of SRB cross-cutting support but with the traditional focus of supporting the needs of the executing institution.
- (R11.4) Perform SRB-chaired PDRs and establish individual baselines for each of the Projects.
- (R11.5) In accordance with NPR 7120.5F, JCL analysis is required at KDP-C for the Projects (SRL, MAV, CCRS) with the Program-level SRB integrating those analyses into a broader programmatic assessment of the end-to-end effort at KDP-II.
- (R11.6) PDR entrance and success criteria leading to KDP-C should include an assessment of the integrated technical and resources baseline.
- (R11.7) The Program and each MSR Project (SRL, MAV, and CCRS) should report to their respective SRBs on a quarterly basis.

F12: Culture and Communication (1 of 2)

Each of the contributing organizations has a dramatically different engineering and management culture as well as a strong basis to their historical mission experience. This influences the organizations' approaches to risk management, communications, testing, and verification and validation. Miscommunication can arise frequently across these cultural lines.

- The Program introduced what it calls a "Federated Model" for collaboration in order to give each organization autonomy over its engineering, assurance, and management processes. The Program's intent was to avoid the perception that one organization is controlling another. However, this arrangement has exacerbated miscommunications by reifying distinctions between organizational cultures. This arrangement has limited penetration into shared technical issues.
- Amid so many convoluted partnerships, members of MSR have a limited ability to develop deep cross-cultural literacy and the understanding that is necessary to work effectively across institutional lines.
- Certain elements of the MSR organizational structure are exacerbating cultural differences and miscommunications. Issues include multi-institutional politics, confusing phase and domain reporting pathways (i.e., cross-organizational phase leads with limited authority), and limited interactions between engineers in the ranks across these organizations.
- A shared mission culture can help to ease miscommunications. Currently, there is no shared "MSR mission" identity across all members. It is noted that the ESA team has shown the emergence of a shared "MSR subculture," and JPL-SRL/MSFC-MAV are developing deeper understanding.
- The co-located nature of the Program Office, the SRL development, and CCRS components at JPL are creating additional confusions and limitations on communicating directly with their appropriate chain of command.
- The team normalized the limited in-person interactions experienced during COVID-19 such that it has persisted post-lockdown. The MSR team has never met in person. Most team members we spoke with have not visited the institutions and individuals with which they are collaborating most closely (i.e., MSFC and JPL). Limited in-person interactions limits the development of cross-cultural visibility and understanding.

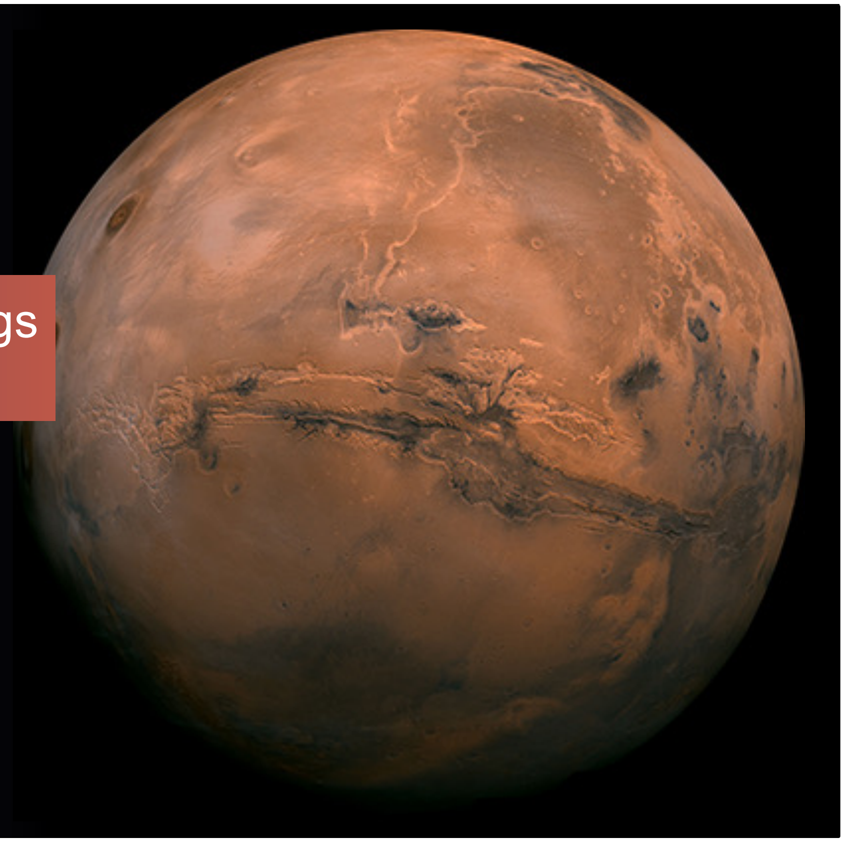
MSR team members understand the importance of culture to their mission. Many team members are meeting the challenges of working across the cultures of their respective organizations. These findings highlight areas where a deeper understanding of the cultural differences can dramatically improve MSR's response to these challenges.

R12: Culture and Communication (2 of 2)

Recommendations: Clarifying the organizational structure, simplifying programmatic partnerships, investing in cultural interfaces with depth, enabling visibility and exchange across organizations, and providing intercultural training will go a long way toward resolving these issues and providing technical penetration on shared issues from campaign planning to shared V&V plans.

- [R.12.1] Establish SRL/MAV and ERO/CCRS as individual programmatic partners in order to allow each grouping to focus on building intercultural bridges between organizations.
- [R.12.2] Clarify the domain and phase structures, enable multi-institutional group members to communicate directly and make decisions across institutions, and empower those groups to resolve conflicts. This approach will develop cross-site visibility and shared understanding.
- [R.12.3] Invest in periodic and sustained in-person interactions between engineers working on parallel or related tasks across programmatic partners (i.e., the domains). The MSR Program Office should fund and facilitate team members visiting their collaborators in other institutions as part of developing intercultural fluency and inter-organizational visibility. In-person gatherings of sub-groups with multi-institutional representations should occur at a regular cadence in order to supplement online meetings.
- [R.12.4] The MSR Program should facilitate intercultural training among team members in order to facilitate conflict resolution and better understanding of engineering and management issues.
- [R.12.5] Place team members on location at a collaborating institution, as ESA has done at Goddard Space Flight Center.
- [R.12.6] Document multi-organizational decisions and changes in order to ensure robust multi-institutional communication, baseline control, and flowdown.

Additional Important Findings and Recommendations



F13: Verification and Validation (1 of 2)

The MSR Verification and Validation (V&V) program is not sufficiently mature. Evidence indicates that the integrated V&V program is underscoped and underfunded.

- MSR has highly-coupled and complex elements (SRL, ERO, MAV), which require carefully considered and possibly unique approaches to V&V.
- MSR appears to be following the precedent of past programs in underscoping V&V, including the development of a robust V&V plan for fault management.
- Examples of V&V concerns:
  - No integrated test is planned for CCRS capture and orientation of the OS in Mars orbit.
  - The SRL/MAV interface test (VECTOR plus ignition test) is not well defined.
  - Only one funded test is planned for SRL parachute deployment, even though this is the largest and most complex parachute ever flown on a planetary mission.
  - FM CCRS has no dynamic environmental tests with the ERO spacecraft after final integration. Concerns include dynamic couplings and workmanship verification.
  - The Sample Transfer and Handling System requires a V&V plan (including test and closed-loop verification at different physical locations) that is very complex, poorly defined, and resides under split responsibilities.

R13: Verification and Validation (2 of 2)

Recommendations:

- (R13.1) Develop integrated and detailed V&V plans (with credible schedules and costs) to a level of confidence that is appropriate for this flagship mission prior to completion of preliminary design review activities.
- (R13.2) Ensure that each integrated V&V activity has properly recognized and scheduled the development of all required ancillary elements including flight software, ground software, ground support equipment, hardware-in-the-loop, testbeds, and simulations.
- (R13.3) Ensure clear system V&V leadership and coordination across elements. Ensure reasonable time and staffing allocations to complete proper V&V of the integrated systems.
- (R13.4) Address fault management and contingency planning in the development of detailed V&V plans.

F14: Cross-Organization Engineering Management (1 of 2)

A multi-layered phase-lead engineering approach was intended to provide oversight for the entire MSR campaign and to overlap with the cross-organizational/project domain engineering working groups. The approach has resulted in a large and complex engineering organization with multiple paths of communication and reporting, unclear lines of responsibility and authority, and a significant amount of coordination required among the various teams.

- For example, the launch, rendezvous, and capture phase organization includes multiple sub-phases due to the complex integrated and time-dependent operations of SRL and ERO.

JPL's phase-lead engineering organization approach has proven to be an excellent model for complex functional mission development and operational planning for JPL-run missions. However, the model has been expanded greatly for MSR to also include the ERO/CCRS mission. This expanded model adds an extra layer of phase leads at the Program layer. This additional layer was introduced with the intention of eliminating gaps between mission phases at the campaign level. However, this structure is causing more confusion and adding extra layers of required review, communication, and coordination. Additionally, this structure further dilutes accountability and in sum will have a negative impact on both the project and mission's overall success.

The phase-lead model is intended to have a single person with responsibility and authority for the success of a specific part of the mission. This model has been expanded with three program-level phase positions created to oversee operational planning and mission design, where there are interface handoffs and overlap between ERO/CCRS and SLR/MAV. Additionally, there are now nested or sub-phase leads reporting to these program leads, with co-leads at contributing organizations. This requires significant coordination and communication, resulting in a potentially unproductive workload on team members. Unlike the phase lead model of prior JPL missions, MSR's multi-mission architecture and multi-layered phase organization have also put phase leads in the difficult position of having responsibility but no real authority to direct phase team members who are from outside organizations.

The phase lead structure also overlaps with and is at odds with the domain working groups. These groups were created with the intention of handling the cross-organization and engineering interfaces between the Projects. The roles and responsibilities between phase leads and domain leads are also poorly defined and create additional organizational confusion.

R14: Cross-Organization Engineering Management (2 of 2)

Recommendations:

- (R14.1) Restructure the engineering organization by removing overlapping layers in the phase-lead organization and by strengthening cross-project-domain working groups.
- (R14.2) Transition the phase lead role from the Program Office to the Project Offices so there is only one layer of phase leadership.
- (R14.3) Elevate the responsibility of the two cross-project domains (backward planetary protection, OS) so that these domains are integrating all activities associated with their domain across the program.
- (R14.4) MSR must continue to retain strong cross-organizational engineering management of the integrated system's functionality, operations, and interfaces.
  - All system elements must be represented, independent of the schedule relationship between the individual Projects.

The phase and domain lead organization should be restructured according to the recommended decoupling of the ERO and SRL missions. This recommendation aims to ensure thorough consideration of the existing organizational structure's ramifications, encompassing both the negative and positive aspects of the structure's overlapping roles and responsibilities.

The program needs to adopt alternative phase/domain structures that are more easily communicable within the team, entail fewer leaders and team members needing constant updates, and involve fewer review and coordination meetings while still effectively covering the necessary mission phases. This approach will allow JPL to focus on managing and stabilizing campaign-level cross-project interfaces, with individual Projects having the autonomy and clear authority to manage their phases and design. Cross-organizational working groups need to have representation from all contributing organizations, regardless of technical and programmatic coupling. This representation will efficiently increase awareness of technical issues and solutions. For the updated organization, the decision-making authority, accountability, and responsibility of each phase and domain element at the Project and Program level should be clearly documented and communicated internally to Project and Program team members and also to external stakeholders.

F15 and R15: Telecommunications Infrastructure

There is risk inherent in limiting the telecommunication architecture to ERO, which is a single, new orbital relay asset.

- Alternative telecommunication relay assets would allow decoupling of ERO and SRL launch dates, and would substantially reduce schedule dependencies.
- Determination of the initial OS orbital parameters, through ranging of the MAV beacon at orbital insertion by an active orbital asset, is essential to the ability of the ERO to find and capture the OS in a timely manner.
- Telecommunications capability directly affects the efficiency of the surface mission to retrieve the samples, which is a critical factor because of the tight surface operations timelines.
  - A High Gain Antenna (HGA) on SRL would provide the ability to increase operational efficiency and resiliency.

Recommendations:

- (R15.1) Formally include other (existing and future) orbital assets in the baseline concept of operations, and plan on managing those assets in order to maximize MSR robustness.
- (R15.2) Extend the NASA-ESA agreement to include use of TGO as a telecommunication relay link for SRL.
- (R15.3) Add back the HGA on the SRL for robustness and resiliency.

Orbit knowledge is a function of the initial state knowledge and the time of propagation. These parameters do not change meaningfully after delivery of the OS to orbit by the MAV. The key is the observation of the MAV beacon by orbital telecommunications assets to confirm adequate orbit parameters. This knowledge will confirm a ~10 year orbital lifetime of the OS.

F16 and R16: Helicopter Accommodation Risk Balance

The current architecture includes helicopters as a backup capability to deliver samples to the SRL out of concern for Perseverance's reliability and longevity. This backup adds cost and poses accommodation challenges that add risk to SRL.

- The need for a backup sample delivery capability to SRL is clear in the present architecture. While direct delivery of samples by Perseverance provides more samples and is lower risk because it is a more controlled operation, the long-term viability of Perseverance cannot be assured.
- If Perseverance loses its ability to deliver samples:
  - A single helicopter is currently enough to deliver the backup Three Forks 10 sample cache (although with less than desired unencumbered timeline margin). One helicopter alone provides most of the benefit to the overall MSR reliability.
  - Two helicopters are required in order to meet Class B equivalent reliability via the redundant helicopters, and to allow full surface timeline margin to be maintained early in development.
- Helicopter capability is limited by Mars atmosphere and site safety conditions. Accommodation on SRL is significantly constrained by the small amount of volume and mass available and by unique initial release and takeoff challenges.

Recommendation:

- (R16.1) If mass and accommodation complexity of two helicopters are driving the SRL design in a way that jeopardizes design closure of the system and/or creates significant risks (to SRL in general, or helicopter accommodation in particular), a single higher-reliability helicopter accommodation solution is better than two compromised helicopters (or no helicopter) in order to preserve the capability as part of the present architecture.

The sample return helicopter (SRH) helicopter accommodation on the Sample Return Lander (SRL) is very different from Mars Perseverance and Ingenuity heritage since the only viable location for the helicopters on SRL is on top of the lander. The aerodynamics associated with this location is quite different from the flat surface take-off that Ingenuity has demonstrated to date on Mars. The location is also significantly volume and mass constrained location, creating a new initial take-off environment with complex local geometry.

F17 and R17: Technical Baseline Management and Change Control

The technical baseline is not yet formally controlled, proposed changes are not thoroughly coordinated with all affected parties, and changes are implemented without full understanding of cost and schedule ramifications.

- The differences in the standard change control processes at participating organizations create additional confusion as well as a latency in the processing of the changes.
- The result is that not all affected parties define the baseline in the same way at the same time.

Recommendations:

- (R17.1) As a large program with multiple partners, MSR must have a rigorous and thorough baseline management and change control process at the top level in order to ensure that all interfaces and associated high-level requirements are fully socialized, documented, and controlled.
  - Starting now, the Program needs to establish a mechanism to document and communicate the working baseline (e.g., a Baseline Description Document [BDD]) for each Project and at the Program level. The contents should at a minimum include those issues that drive system schedule, cost, and impact to partner organizations. There should also be an effective baseline management process and change control process (including impact assessment).
  - The formal baseline management and change control process that rigorously follows the standard NASA guidelines should be implemented by PDR.
  - A key goal of decoupling is to enable agility at the lower levels due to the rigor and stability that are induced by formal control of the higher-level requirements.
  - In coordinating the various change control processes at the different MSR organizations, focus should be placed upon maintaining common baselines.

All MSR organizations must operate under a common set of assumptions and possess comprehensive awareness of the trades and issues that affect all stakeholders. Technical trades, issues, and decisions that impact fundamental assumptions should be swiftly communicated and mutually agreed upon before more formal and time-consuming modifications are made to configuration-controlled documentation.

MSR campaign and project systems engineering should establish an agile and efficient method for documenting and disseminating design and interface assumptions and decisions. This process should evolve to be fully in alignment with NASA standards by the Preliminary Design Review (PDR). For example, a baseline description document can serve as a rapid means of conveying the current baseline before the more formal configuration control change process is initiated. Disciplinary analysis teams and design teams could then cite this document as the foundation for their modeling and analysis outcomes. Any potential trades or deviations from the baseline would have a clearly defined reference design as a starting point. The baseline control process needs to consider partner organization processes and any MSR organizational changes related to the recommended decoupling of the ERO and SRL missions.

F18 and R18: Launch Vehicles

The mass margins against launch vehicles' performance are insufficient or lack adequate understanding to support the SRL/MAV and ERO/CCRS.

NASA/LSP:

- Mass growth of SRL has or will impact the launch vehicle competitive procurement plans.
- LSP has provided Mission Design planning under the assumption of using the NLS contract for launch vehicle capabilities without a full understanding of SRL mission-unique requirements.
- Initial reports show that mass and other requirements are at the upper end of available LV performance.

ESA/Ariane:

- Ariane is evolving to the Ariane 6.4, a variant of the Ariane 6 commercial launch vehicle family.
- Uncertainty in the Ariane 6.4's induced environments and the resultant margins are impacting the ERO/CCRS structural interface.
- Performance and other driving interface requirements and considerations are not visible to NASA.
- The Ariane 6 certification process is not visible to NASA.

Recommendations:

- (R18.1) SRL is encouraged to increase the interactions with LSP in order to keep the trade space open to options as the mission requirements including mass and performance are settled.
- (R18.2) The NASA/ESA agreement should provide visibility into development and certification of the vehicles.

The Launch Services Program (LSP) Office at NASA/KSC provides launch and payload processing services for NASA robotic missions, including launch vehicle mission assurance. LSP partners with USSF and NRO to fulfill its role. This role includes commercial Acquisition, Program Management, Analysis (including targeted IV&V), Launch Vehicle Certification, Engineering (Fleet insight @ Design and Production centers including targeted RO locations), Mission Integration (including independent requirement verifications), and Launch Operations.

LSP has provided Mission Design planning for the past two years. This planning was done under the assumption of NLS launch vehicle capabilities without consideration of mission-unique impacts to launch vehicle performance requirements. Initial reports from all LV providers as part of the Coupled Loads Analysis (CLA) are that challenging mission requirements include mass, components below the separation plane, and potential thermal control needs. Backup 2030 opportunities are equally or more challenging.

F19 and R19: Workforce Capacity and Expectations Post COVID-19

Post COVID return to work policies for on site work are uneven.

- COVID had a significant impact during the formulation phase.
- JPL has defined policies for onsite presence that are adaptable by the PM to specific Project needs.
- The GSFC and MSFC Center Directors have communicated a sense of urgency for onsite presence for flight projects and other commitments but are subject to bargaining agreements for implementation.
- ESA has defined policies for onsite presence that are adaptable to needs. Execution of policy is not considered an issue by ESA.

Recommendation:

- (R19.1) The MSR Program will require a commitment for onsite presence in order to enable the monitoring of progress, delivery of hardware, and prompt disposition of risks and issues. Plans seem to have accounted for the inefficiencies of the current hybrid approach, but expectations should be clearly stated for the many functions that require an onsite presence. NASA and ESA should be proactive and prepare for a sustained onsite effort of highly-skilled personnel beyond the present levels (possibly 10-15% higher) during implementation.

The Psyche IRB (2022) revealed communication and coordination challenges imposed by the pandemic lockdown circumstances and the lack of collocated work. While MSR is in an earlier phase of development, decisions have been made with poor visibility. This situation establishes a cultural pattern of collaboration under poor communication practices. Research has repeatedly shown that repetitive, singular, or solo-authored tasks are best done remotely, but integrative projects and planning phases require in-person time for effective and efficient completion. At the time of writing of this report, center work-from-home capabilities vary and are influenced by local labor negotiations as opposed to a result of attending to the requirements of the job at hand or broader workplace reforms.

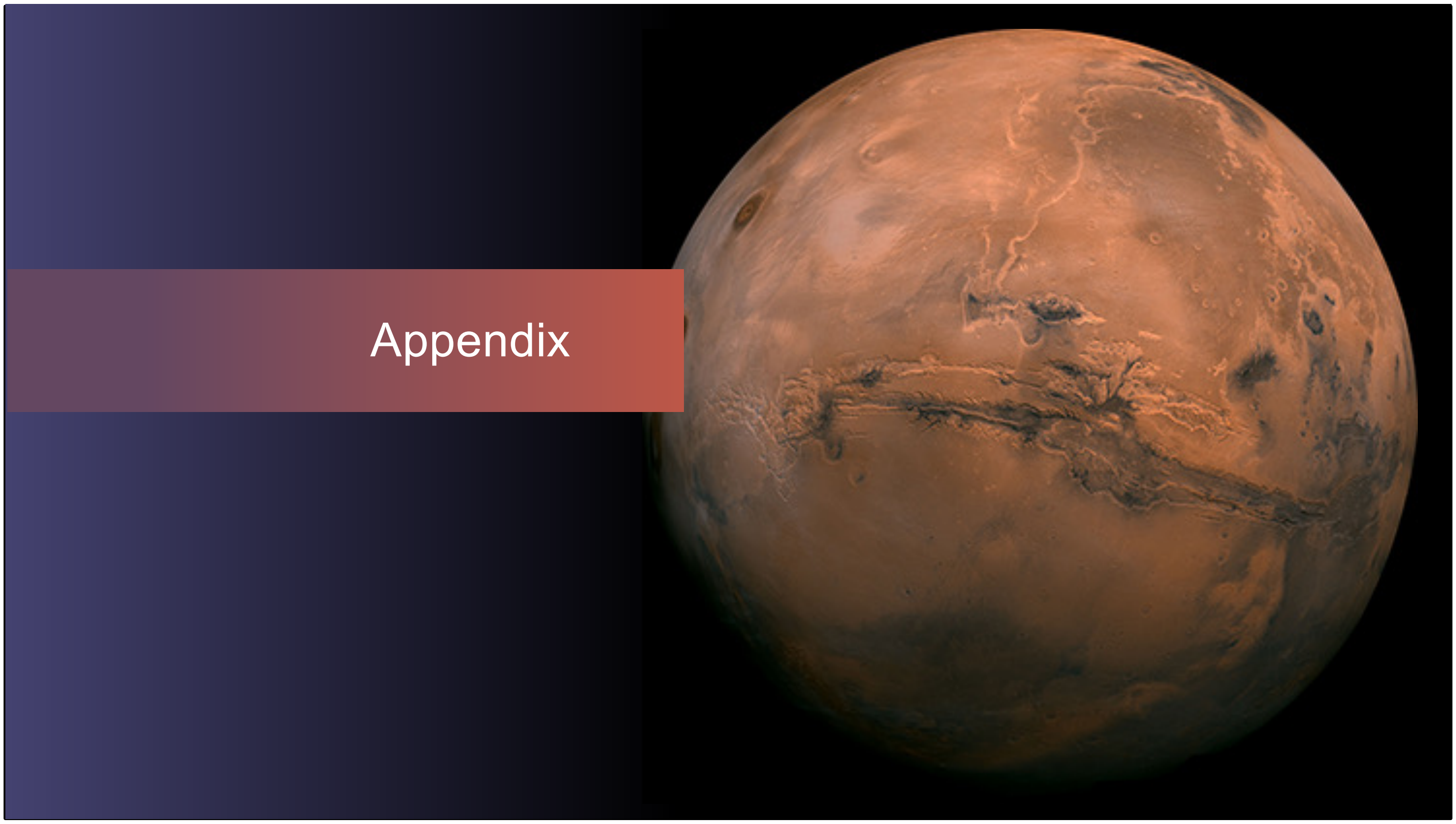
F20 and R20: Supply Chain

Supply chain issues continue to plague the industry post-pandemic at the part/component level, and in the cost and availability of qualified contracted labor.

- There is a shortage in manufacturing capacity and skilled/experienced personnel throughout the industry, particularly in avionics, flight software, and composite structures. These shortages make it difficult to meet commitments.
- JPL's ability to hire key personnel has been impressive, but onboarding and training adds inefficiencies.
- NASA, JPL, and ESA have accounted for higher costs and inefficiencies in plans to deal with personnel, parts and manufacturing. However, uncertainties remain, and inflation is expected to remain high.
- ESA reliance in US parts providers is an added complexity because of priorities given to procurements originating in the US.

Recommendation:

- (R20.1) Simplifying and finalizing designs and procurements are important in order to adapt to the changing market. Supply chain management should be specifically added as a responsibility to designated existing Program and Project personnel, or new positions should be added in order to address issues and to ensure critical review so surprises are minimized.


Appendix

MSR IRB-2 Detailed Schedule

Activity	May				June					July				August					September				
	30-6	7-13	14-20	21-27	28-3	4-10	11-17	18-24	25-1	2-8	9-15	16-22	23-29	30-5	6-12	13-19	20-26	27-2	2-8	3-9	10-16	17-23	24-30
IRB Kick Off																							
Plenary 1																							
IRB Sub Panels																							
Plenary 2																							
IRB Sub Panels																							
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IRB Sub Panels																							
Plenary 4																							
Sub Panels/Report Draft																							
Final Report																							
Report to SMD																							
Report to NASA																							
Report to Stakeholders																							