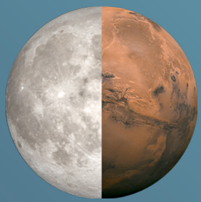
National Aeronautics and
Space Administration

Architecture-Driven Technology Gaps



2024
Moon to Mars Architecture

white paper

Introduction

NASA has a long history of developing new and innovative technologies that empower space exploration and benefit humanity. The next phase of global human space exploration, beginning with the Artemis campaign and defined in NASA's Moon to Mars Architecture,[1] will continue to advance technology.

With a broad array of needs competing for technology development resources, the agency must judiciously target priority technologies that enable NASA to achieve its exploration goals. To this end, NASA has applied rigorous systems engineering processes to develop and prioritize architecture-driven technology gaps to inform technology development investments.

NASA's Moon to Mars Objectives document[2] defines the agency's goals for crewed exploration of deep space. The Moon to Mars Objectives and Strategy document[3] outlines the systems engineering approach that decomposes the objectives into a cohesive and extensible Moon to Mars Architecture. The objectives define *what* NASA wants to achieve; the architecture defines *how* the agency will accomplish them.

NASA's Exploration Systems Development Mission Directorate (ESDMD) leads the integration of the Moon to Mars Architecture and identifies technologies the agency must advance or develop to meet future architecture needs. This year, for the first time, NASA has published a prioritized list of these architecture-driven technology gaps in Revision B of its Architecture Definition Document.[4]

What is a Technology Gap?

A technology gap exists where a performance target defined in the architecture exceeds current capabilities of state-of-the-art technologies, or the capability does not exist at all. The gaps are solution-agnostic — they document a capability need, but do not prescribe a specific technological solution. Left open, the gaps will prevent NASA from achieving all its exploration objectives.

This is a narrow definition: a technology gap is not simply an area of the architecture that requires further work or the initiation of an element. If NASA can initiate a project or program to meet an architectural need using existing technology, then that area is not a technology gap. Architecture-driven technology gaps require entirely new technologies or significant performance advancement in existing technologies to establish a capability needed to achieve the Moon to Mars Objectives.

Technology Push and Pull

Much of NASA's architecture work involves identifying unallocated functions and filling them with new or existing exploration assets or elements, the hardware and systems that enable exploration. However, there are instances where filling a gap in the architecture requires new technology. In these instances, architecture-driven technology gaps provide architecture technology pull. The architecture can also provide pull for new technologies that significantly enhance capabilities. Technology push also exists where technologies do not yet have a traceable planned element or mission for infusion, but capability developers expect that the capabilities will be necessary in the future.

Defining Terms

Technology Pull: innovation to meet documented mission needs.
Technology Push: innovation to meet anticipated mission needs.

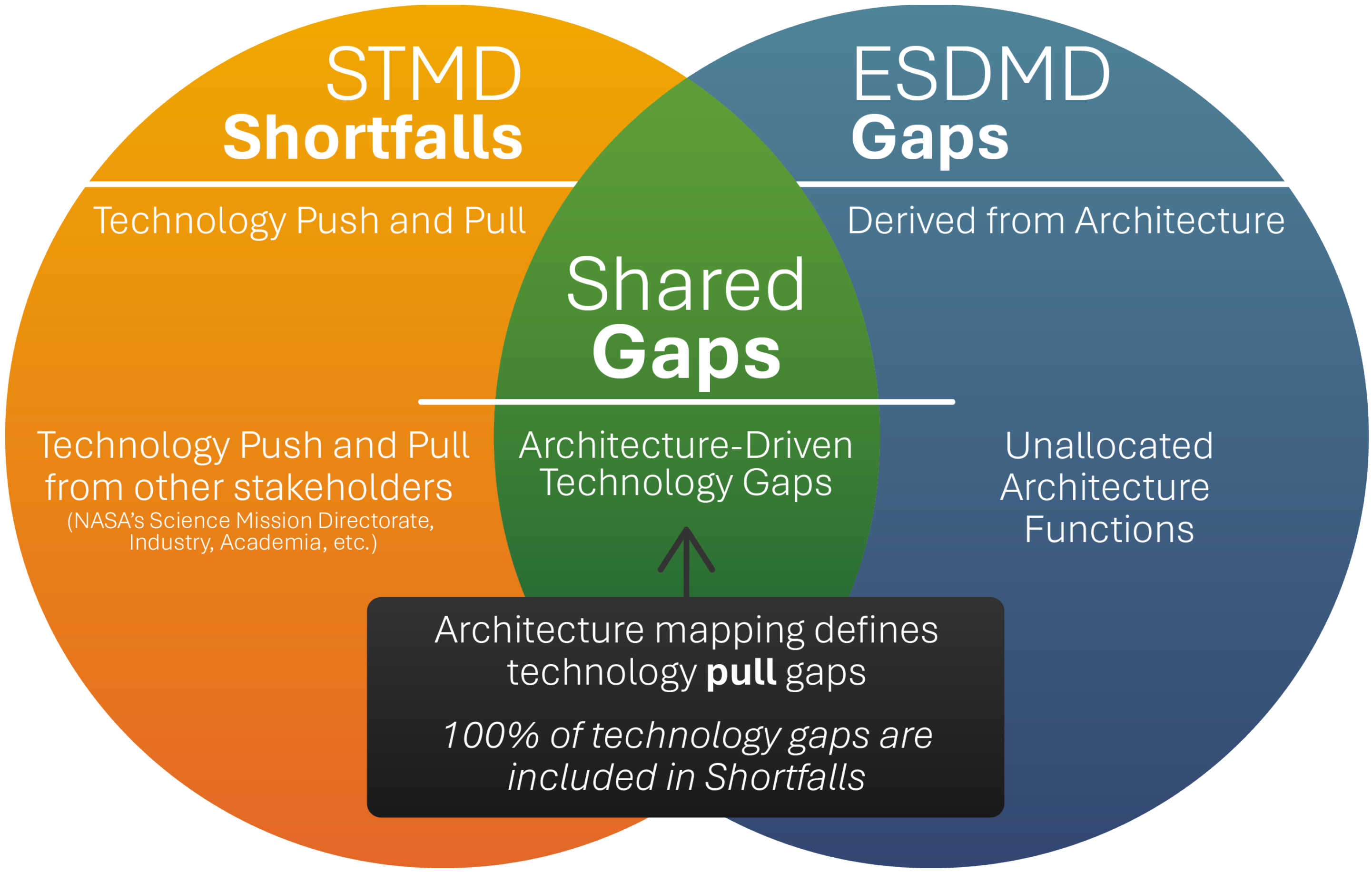


Figure 1: *Complementary and overlapping gap definition efforts by STMD and ESDMD. (NASA)*

Architecture-Driven Technology Gaps and Civil Space Shortfalls

NASA's Space Technology Mission Directorate (STMD) has long considered these complementary concepts in their development portfolio. Their Civil Space Shortfall Ranking[5] published in 2024 reflects some push and a mixture of technology pull from all stakeholders.

A shortfall is a technology area requiring further development to meet future exploration, science, and other mission needs. The term "gap" is widely used across NASA and the aerospace industry and implies both ends of the problem – the current state of the art and the technology performance target needed – are known. In the case of shortfalls, we may only know where we are today.

ESDMD provided STMD with its architecture-driven technology gaps during development of these shortfalls. As such, the Civil Space Shortfalls document includes all the architecture-driven technology gaps, plus ESDMD's ranking of shortfalls for applicability to future human exploration missions. The Civil Space Shortfalls also capture technology needs from across NASA's mission directorates and other sources.

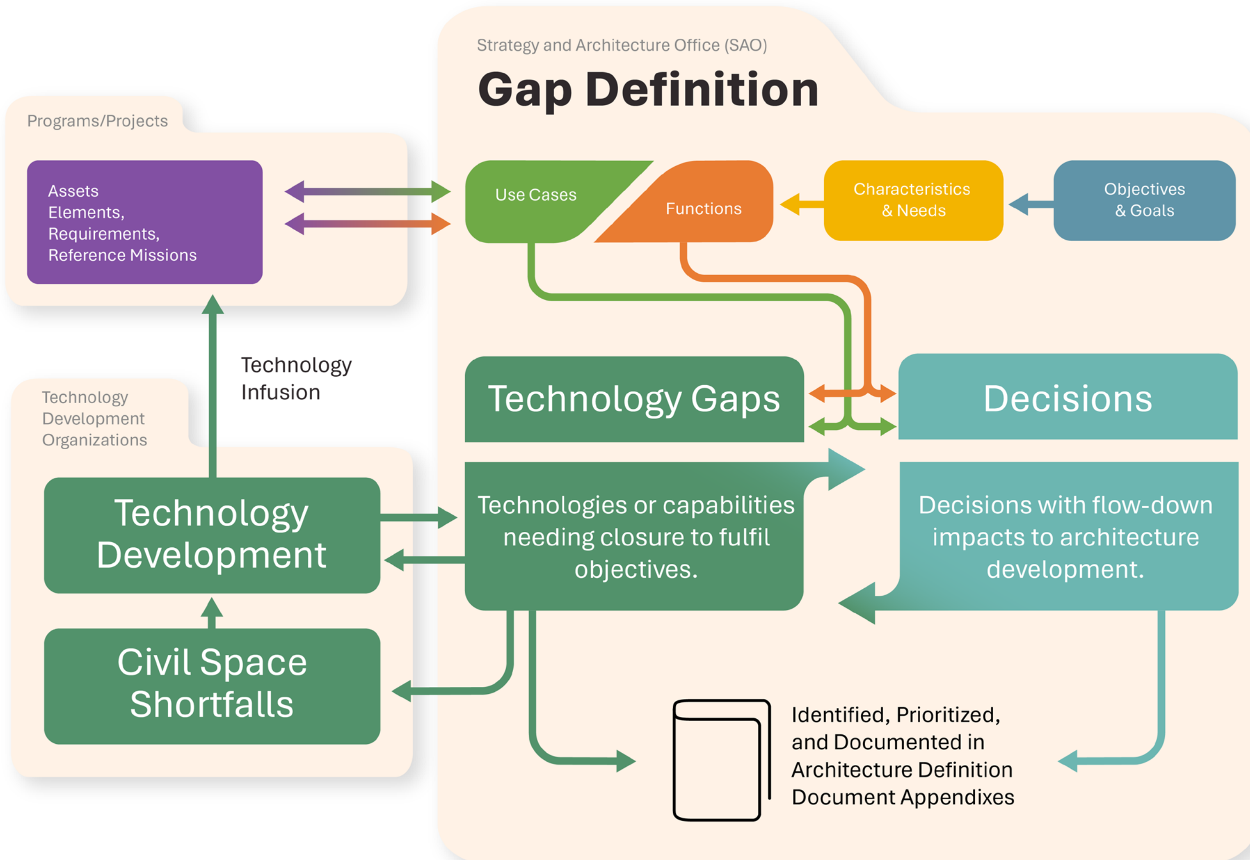
Figure 1 shows the relationship between Moon to Mars architecture gaps — including the architecture-driven technology gaps — and the Civil Space Shortfalls compiled by STMD.

Gap Definition and Traceability

Architecture-driven technology gaps are traceable back to the Moon to Mars Objectives through the gap definition process shown in **Figure 2**. Revision B of the Architecture Definition Document, released alongside this white paper in December 2024, includes a new appendix for architecture-driven technology gaps.

That appendix features a detailed, prioritized list of gaps mapped to their associated use cases, functions, decisions, campaign segments, and sub-architectures. Each documented gap includes a description, architecture impacts and benefits, target performance metrics, current state-of-the-art metrics, and subsidiary "child" gaps.

Specific technology maturation needs derived from the architecture signal a future need or demand; NASA publishes technology gaps to inform industry, academia, and our international partners about the technology development required for future human exploration missions.



NASA identifies technology and capability gaps in the Moon to Mars Architecture through the objective decomposition process. NASA then prioritizes and documents gaps in the Architecture Definition Document and relies on technology development organizations to close them.

Figure 2: *Technology Gap Traceability through the architecture to Moon to Mars Objectives. (NASA)*

Prioritizing Technology Gaps

Prioritizing technology gaps helps NASA optimize limited funding and guides smart investments by external partners toward the agency's most important needs. NASA technology development organizations are already utilizing the architecture-driven technology gaps to drive internal investment strategies.

NASA follows rigorous systems engineering processes and governing principles to define and execute its prioritization process. NASA prioritized the architecture-driven technology gaps using the process shown in **Figure 3**. The agency defined four priority metrics — gap attributes that measure an aspect of architecture preference and can be evaluated for every gap: criticality, urgency, breadth, and depth.

- **Criticality** measures the degree to which closing a technology gap would enable or enhance the Moon to Mars Architecture.
- **Urgency** measures how soon investment in a technology gap is needed to ensure a capability is available for future missions.
- **Breadth** measures the prevalence of a technology gap across sub-architectures.
- **Depth** measures the degree to which closing the gap is dependent on future architecture decisions. (See the Architecture Definition Document appendix on architecture decision roadmapping for more details.)[4]

Each priority metric has a relative weighting (W_x%) defined by the architecture teams to establish its relative importance to the architecture in the overall priority ranking. Applying the prioritization process detailed in Figure 3 results in the priority ranking of the architecture-driven technology gaps published in Revision B of the Architecture Definition Document.[4]

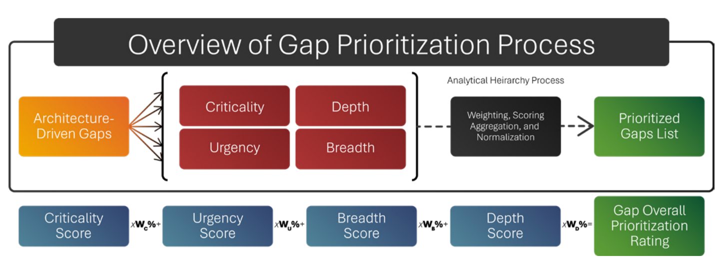


Figure 3: *Architecture-driven technology gap prioritization process flow diagram and weighted gap scoring formula. (NASA)*

Technology Gap Evolution

The current list of architecture-driven technology gaps (and their priority order) will be revised annually. **Table 1** features the five highest priority gaps identified in Revision B of the Architecture Definition Document, published in 2024.[4]

The gaps will evolve as NASA refines the architecture during the annual strategic analysis cycle. NASA will validate, update, add, or close gaps as technologies develop or new needs arise. The priority ranking will also change as NASA makes driving architecture decisions. Updated lists will be published in subsequent revisions of the Architecture Definition Document.[4]

EXAMPLE TECHNOLOGY GAPS (2024)
Lunar Dust Tolerant Systems and Dust Mitigation
Systems to Survive and Operate through Extended Periods of Lunar Shadow
High-bandwidth, High-reliability Surface-to-Surface Communications
Mars Transportation Propulsion
Extreme Environment Avionics

Table 1: *Five high priority technology gaps identified in 2024. The initial list included 56 total gaps, but the gaps will change each year. For the most up-to-date version of the gaps, see the current revision of the Architecture Definition Document. (NASA)*

Key Takeaways

Technology gaps exist when a capability that NASA needs exceeds the current technology state of the art.

Strategic technology investments to close technology gaps enable future Artemis missions.

Architecture-driven technology gaps map to specific architecture segments and sub-architectures and trace to NASA's Moon to Mars Objectives through the Moon to Mars Architecture's use cases, functions, and driving decisions.

Architecture-driven technology gaps are defined and prioritized using rigorous systems engineering processes and principles.

All architecture-driven technology gaps are included in the list of Civil Space Shortfalls developed by NASA's Space Technology Mission Directorate.

Architecture-driven technology gaps and their prioritization will be updated as the architecture evolves and as technology matures.

References

1. **NASA's Moon to Mars Architecture**
   https://www.nasa.gov/moontomarsarchitecture/
2. **Moon to Mars Objectives**
   https://www.nasa.gov/wp-content/uploads/2022/09/m2m-objectives-exec-summary.pdf
3. **Moon to Mars Strategy and Objectives Development**
   https://www.nasa.gov/wp-content/uploads/2023/04/m2m_strategy_and_objectives_development.pdf
4. **Moon to Mars Architecture Definition Document**
   https://www.nasa.gov/moontomarsarchitecture-architecturedefinitiondocuments/
5. **Civil Space Shortfall Ranking**
   https://www.nasa.gov/wp-content/uploads/2024/07/civil-space-shortfall-ranking-july-2024.pdf?emrc=671134d054317

Reference the latest of the architecture-driven technology gaps in the Architecture Definition Document: **https://go.nasa.gov/3CsjcT5**