From Concept to Cosmos: A Journey through Project Management Principles and NASA's Best Practices

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Scope of the Presentation

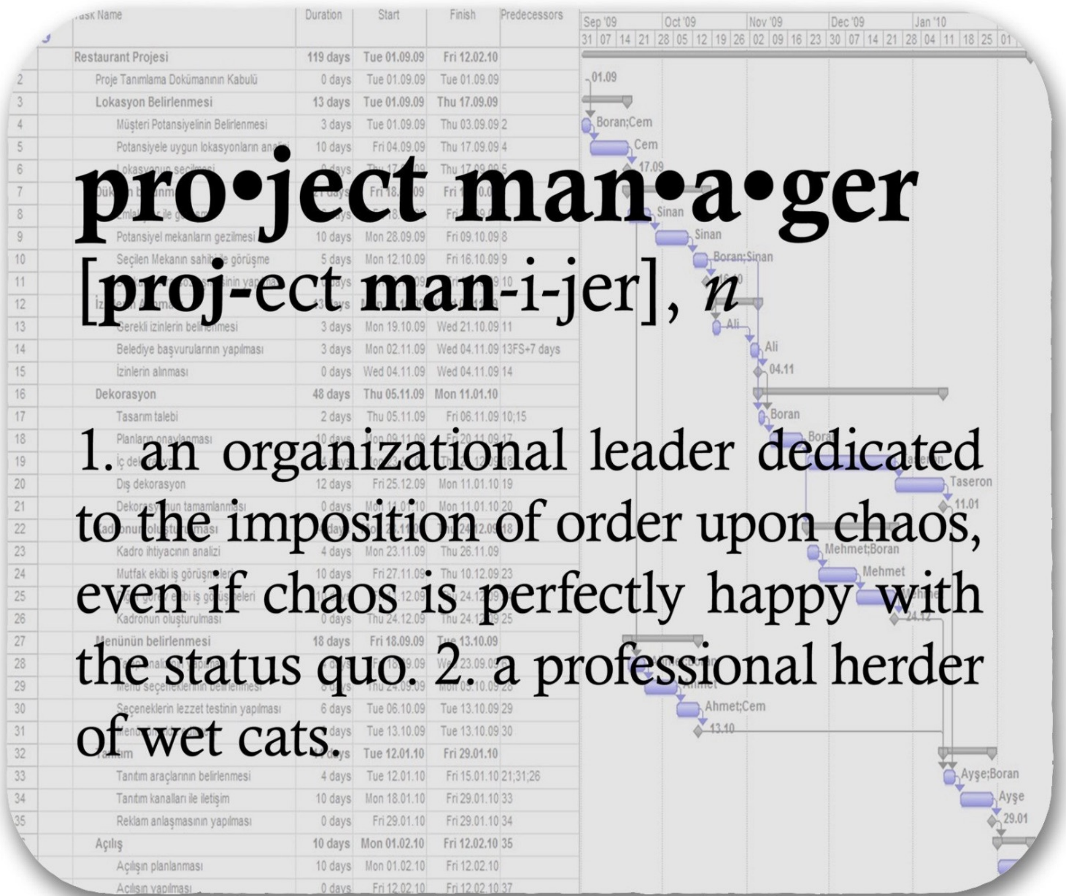
- References
- Basics of Project Management
- Beginnings of the Space Age
- Managing a Project for a NASA Space Mission
- Case Studies in Space Missions (or Stories)
  - Deep Space 1
  - Mars Climate Orbiter Failure Lessons Learned
  - The Last Mission of the Space Shuttle Challenger

References

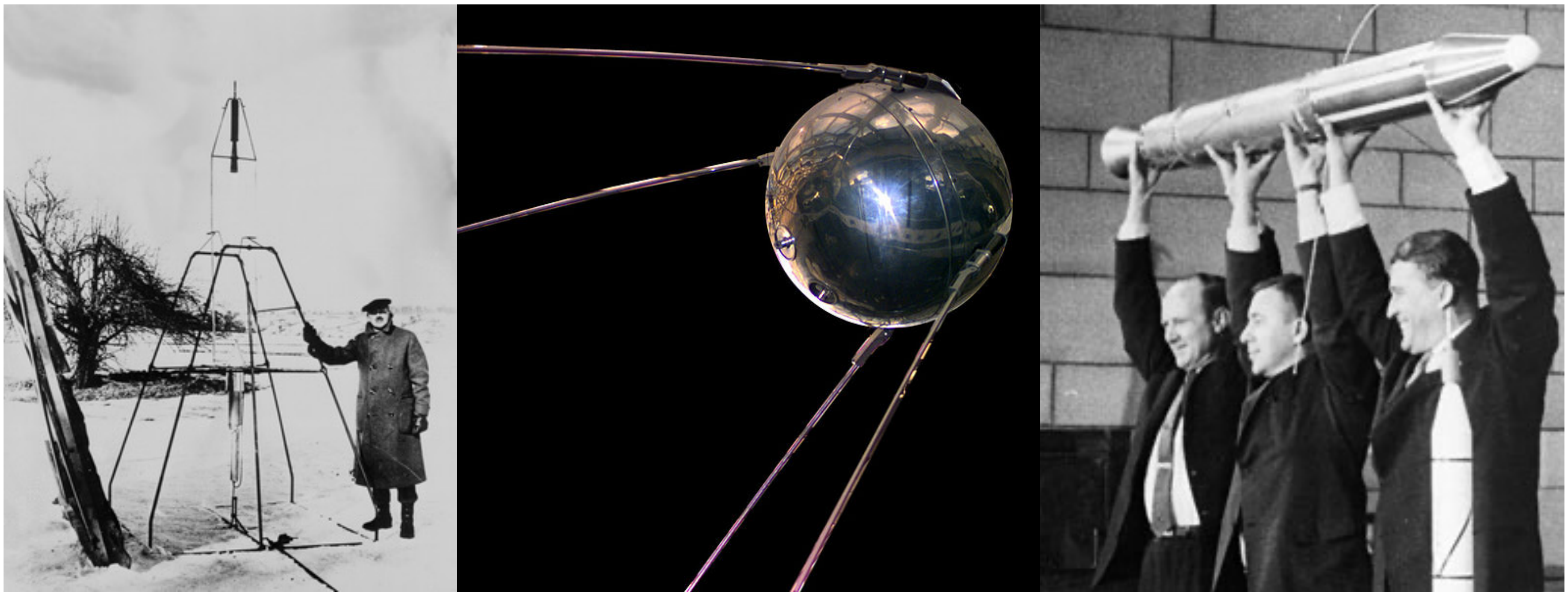
1. A Guide to the Project Management Body of Knowledge (PMBOK Guide), 7th Edition and the The Standard for Project Management, 2021.
2. NASA Space Flight Program and Project Management Requirements w/Change 2, NPR 7120.5F, August 03, 2021.
3. NASA Space Flight Program and Project Management Handbook. NASA/SP-2014-3705, September 2014.
4. NASA Systems Engineering Processes and Requirements, NPR 7123.1D, July 05, 2023.
5. NASA Lessons Learned Web Site: https://llis.nasa.gov
6. Deep Space 1: " Controlling Risk on Cost-Capped, Schedule-Driven, Technology Validation Projects (1998)": https://llis.nasa.gov/lesson/1033
7. Mars Climate Orbiter Failure Lessons Learned: https://llis.nasa.gov/lesson/641
8. Lessons Learned from Challenger: https://sma.nasa.gov/news/safety-messages/safety-message-item/lessons-from--challenger#:~:text=The%20Challenger%20accident%20taught%20us,silence%20and%20silent%20safety%20program.

Basics of Project Management[1]

- Key Terms and Concepts
  - Project: A temporary endeavor undertaken to create a unique product, service, or result. A temporary nature of projects indicates a beginning and an end to the project work or a phase of the project work.
  - Project management: The application of knowledge, skills, tools, and techniques to project activities to meet project requirements. Project management refers to guiding the project work to deliver the intended outcomes.
  - Project manager: The person assigned by the performing organization to lead the project team that is responsible for achieving the project objectives. Project managers perform a variety of functions, such as facilitating the project team work to achieve the outcomes and managing the processes to deliver intended outcomes.
  - Project team: A set of individuals performing the work on the project to achieve its objectives.


pro•ject man•a•ger
[proj-ect man-i-jer], n
1. an organizational leader dedicated to the imposition of order upon chaos, even if chaos is perfectly happy with the status quo. 2. a professional herder of wet cats.

Beginnings of the Space Age *



* Reference: From page 2 of a presentation by JPLer Brian Muirhead entitled "*Take Risk Don't Fail* - Challenges and Power of Exploration from Space" on March 18, 2023.

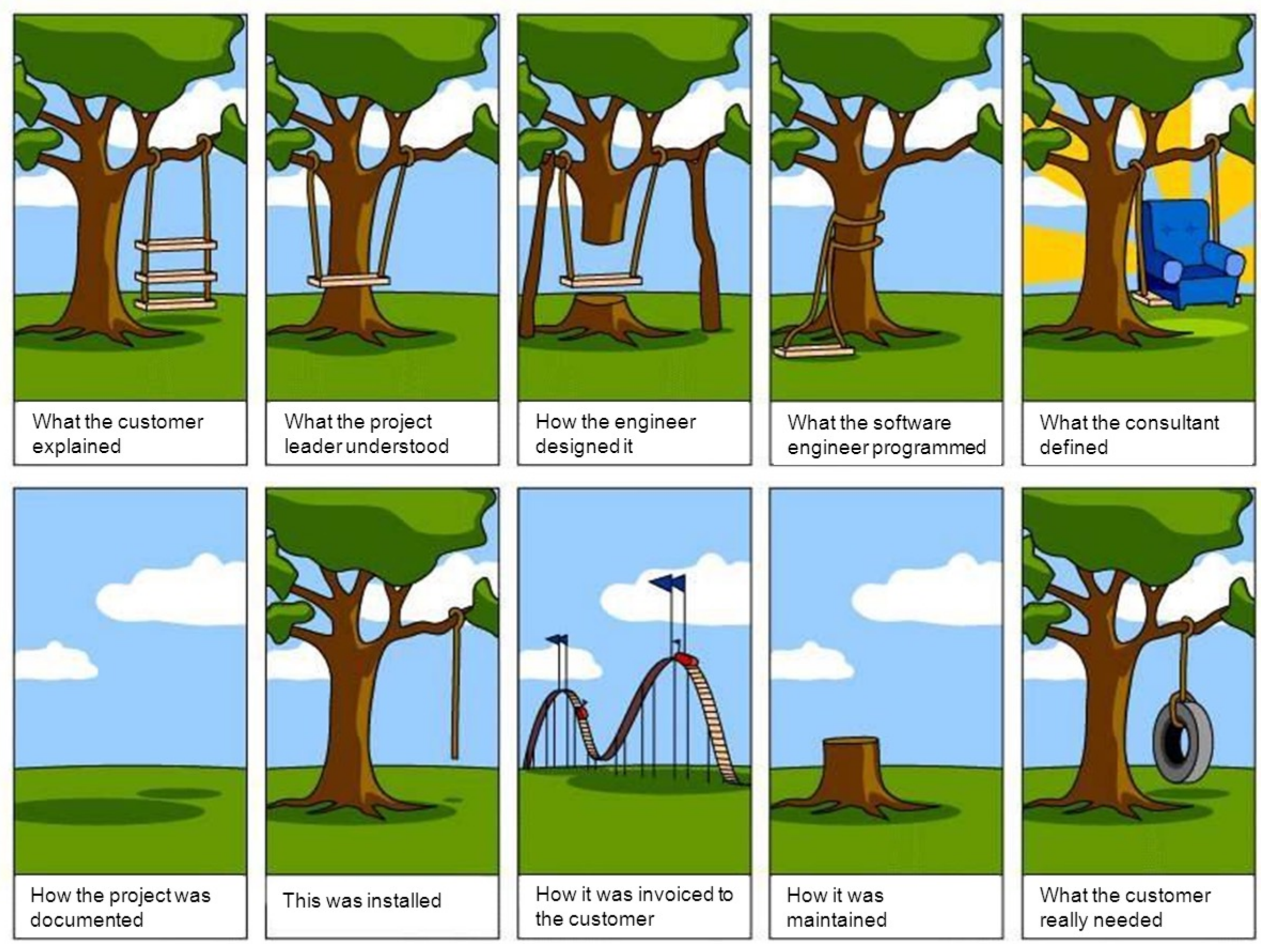
Project Management Principles[1]

Principles serve as a guide for strategy, decision making, and problem solving.

They are intended to guide the behavior of people involved in projects.

Project Management Principles	
Stewardship	Value
Tailoring	Complexity
Adaptability	Team
Stakeholder	System Thinking
Leadership	Risk

A good Project Manager won't let this happen!



CREATE A COLLABORATIVE PROJECT TEAM ENVIRONMENT

TEAM

Project teams are made up of individuals who wield diverse skills, knowledge, and experience. Project teams that work collaboratively can accomplish a shared objective more effectively and efficiently than individuals working on their own.

- Projects are delivered by project teams.
- Project teams work within organizational and professional cultures and guidelines, often establishing their own "local" culture.
- A collaborative project team environment facilitates:
  - Alignment with other organizational cultures and guidelines,
  - Individual and team learning and development, and
  - Optimal contributions to deliver desired outcomes.

EFFECTIVELY ENGAGE WITH STAKEHOLDERS

STAKEHOLDERS

Engage stakeholders proactively and to the degree needed to contribute to project success and customer satisfaction.

- Stakeholders influence projects, performance, and outcomes.
- Project teams serve other stakeholders by engaging with them.
- Stakeholder engagement proactively advances value delivery.

RECOGNIZE, EVALUATE, AND RESPOND TO SYSTEM INTERACTIONS

SYSTEMS THINKING

Recognize, evaluate, and respond to the dynamic circumstances within and surrounding the project in a holistic way to positively affect project performance.

- A project is a system of interdependent and interacting domains of activity.
- Systems thinking entails taking a holistic view of how project parts interact with each other and with external systems.
- Systems are constantly changing, requiring consistent attention to internal and external conditions.
- Being responsive to system interactions allows project teams to leverage positive outcomes.

What can we do to make Deep Space 1 a success?

Everyone must be a system engineer! Try to have fun!
Everyone must be a system engineer! Try to have fun!
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JPL SPECTRUMASTRO

DEMONSTRATE LEADERSHIP BEHAVIORS

LEADERSHIP

Demonstrate and adapt leadership behaviors to support individual and team needs.

- Effective leadership promotes project success and contributes to positive project outcomes.
- Any project team member can demonstrate leadership behaviors.
- Leadership is different than authority.
- Effective leaders adapt their style to the situation.
- Effective leaders recognize differences in motivation among project team members.
- Leaders demonstrate desired behavior in areas of honesty, integrity, and ethical conduct.

OPTIMIZE RISK RESPONSES

RISK

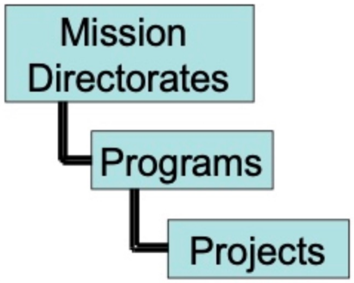
Continually evaluate exposure to risk, both opportunities and threats, to maximize positive impacts and minimize negative impacts to the project and its outcomes.

- Individual and overall risks can impact projects.
- Risks can be positive (opportunities) or negative (threats).
- Risks are addressed continually throughout the project.
- An organization's risk attitude, appetite, and threshold influence how risk is addressed.
- Risk responses should be:
  - Appropriate for the significance of the risk,
  - Cost effective,
  - Realistic within the project context,
  - Agreed to by relevant stakeholders, and
  - Owned by a responsible person.

Was this risk predictable?

Managing a Project for a NASA Space Mission[2, 3]

- Space flight programs and projects flow from the implementation of national priorities, defined in the Agency's Strategic Plan, through the Agency's Mission Directorates, as part of the Agency's general work breakdown hierarchy shown below:

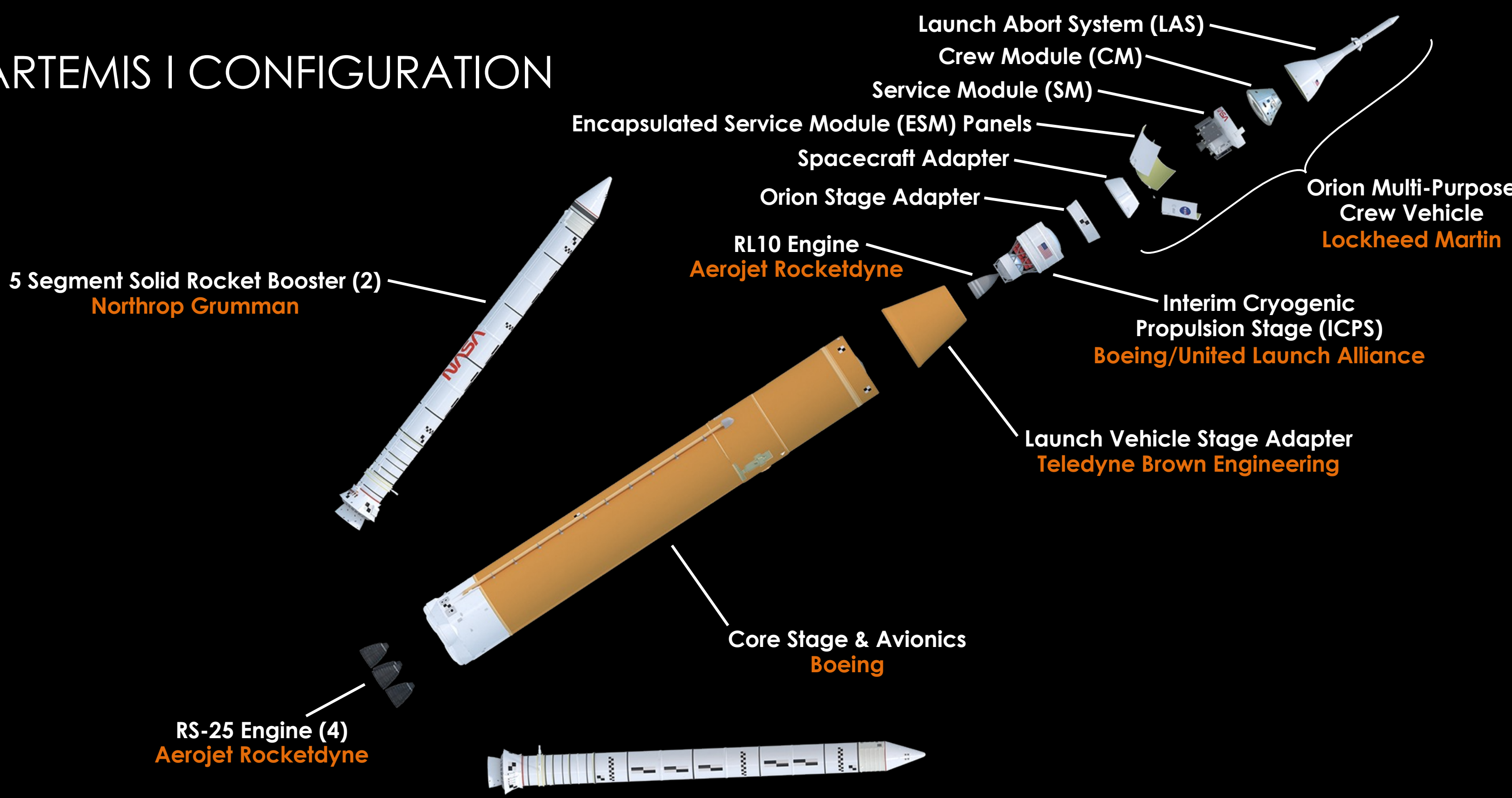


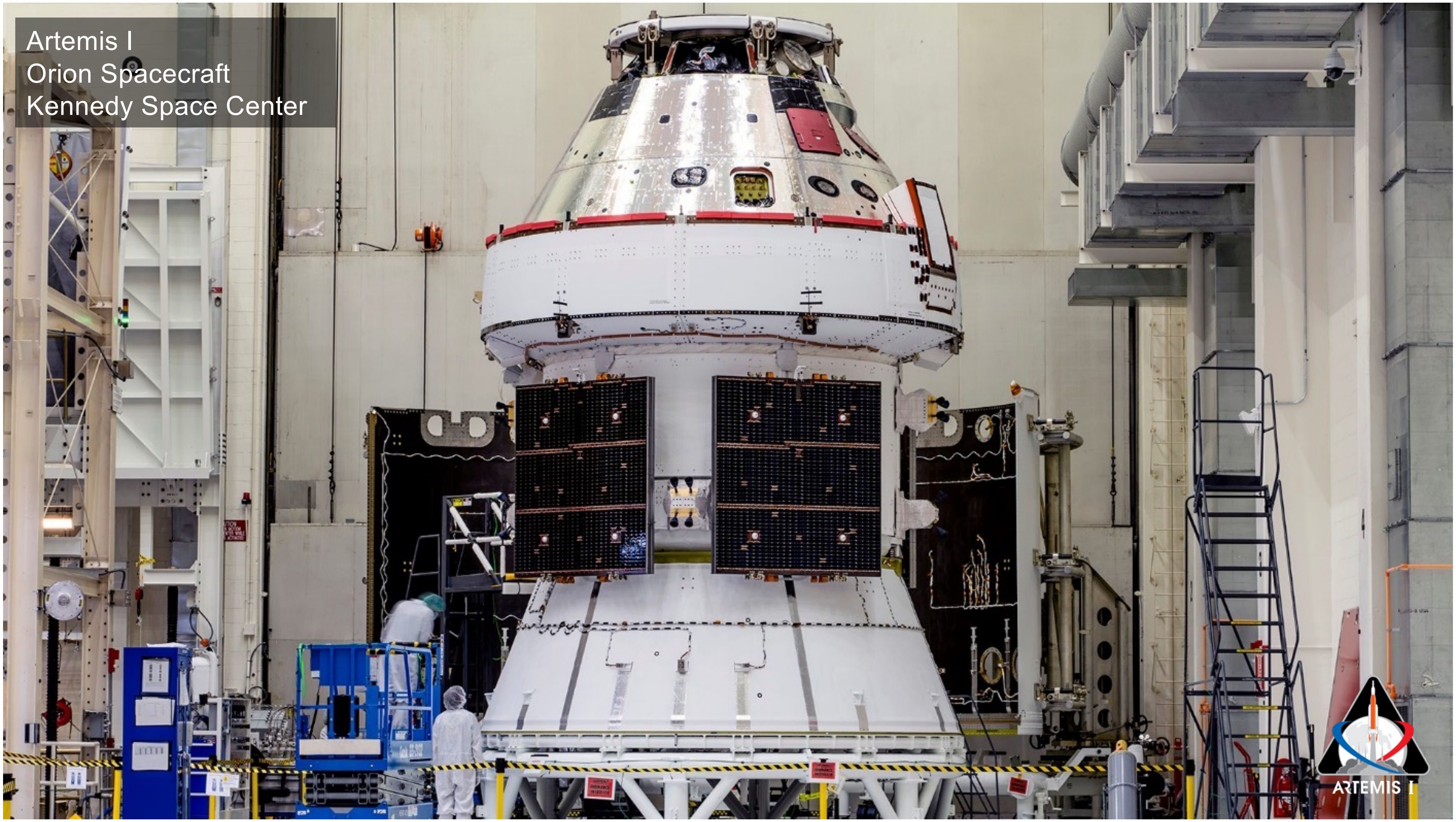
- Program—Programs are a strategic investment by Mission Directorates or mission support offices with a defined architecture and/or technical approach, requirements, funding level, and a management structure that initiates and directs one or more projects. A program implements a strategic direction that the Agency has identified as needed to accomplish Agency goals and objectives.
- Project—Space flight projects are a specific investment identified in a Program Plan having defined requirements, a life-cycle cost, a beginning, and an end. A project also has a management structure and may have interfaces to other projects, agencies, and international partners. A project yields new or revised products that directly address NASA's strategic goals.

NASA's Space Launch System rocket carrying the Orion spacecraft launches on the Artemis I flight test, Wednesday, Nov. 16, 2022, from Launch Complex 39B at NASA's Kennedy Space Center .

NASA'S SPACE LAUNCH SYSTEM
UNIQUE CAPABILITY FOR EXPLORATION

ARTEMIS I CONFIGURATION

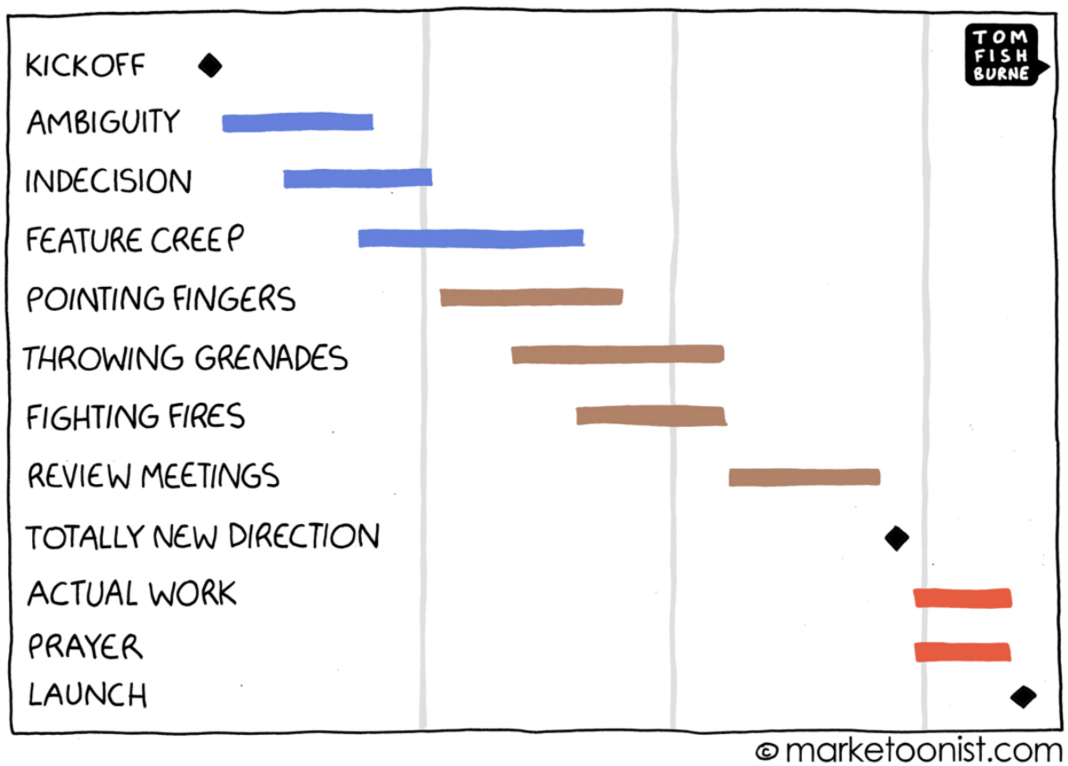



Artemis I
Orion Spacecraft
Kennedy Space Center
ARTEMIS I


NASA’s Perseverance Mars rover landed on Mars on February 18, 2021. It took this selfie over a rock nicknamed “Rochette,” on September10, 2021

the art of project management

FEBRUARY 18, 2018 — 2 COMMENTS



Overview of NASA's Project Management Process

- NASAs project management approach is based on ***life cycles***, ***Key Decision Points (KDPs),*** and evolving *programmatic products* during each life-cycle phase in NASA's process for managing projects, which is:
- **Formulation**—following approval to begin formulation by the **Decision Authority** (NASA AA or MDAA) depending on the complexity of the project) at **KDP-A** projects then begin:
  - **Phase A**: Concept & Technology Development Phase. At the completion of KDP-B the project then begins:
  - **Phase B**: Preliminary Design & Technology Completion Phase
- **Approval (for Implementation)—**acknowledgment by the **Decision Authority** (NASA AA or MDAA depending on the complexity of the project) that the project has met Formulation requirements at **KDP-C** and is ready to proceed to Implementation. By approving a project, the **Decision Authority** commits to the time-phased cost plan based on technical scope and schedule necessary to continue into Implementation.
- **Implementation**—execution of approved plans for the development and operation of the project and use of control systems to ensure performance to approved plans and requirements and continued alignment with the Agency's strategic goals. During implementation the project begin:
  - **Phase C:** Final Design & Fabrication. At completion of KDP-D the project then begins:
  - **Phase D:** System Assembly, Integration & Test, Launch & Checkout. Following **KDP-E** during this effort,
  - **Phase E** begins for a project with operations & sustainment. Following **KDP-F** the project begins:
  - **Phase F** or Closeout.
- **Evaluation**—continual self and independent assessment of the performance of a program or project and incorporation of the assessment findings to ensure adequacy of planning and execution according to approved plans and requirements.

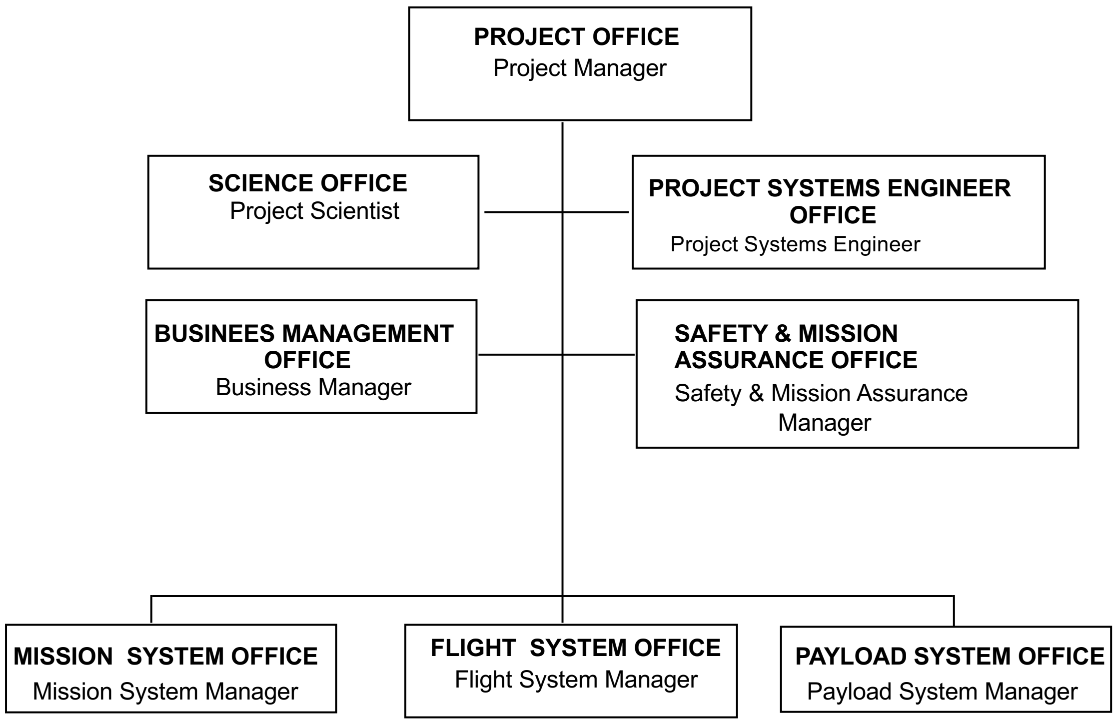
Formulation Key Tasks Prior to Approval (for implementation)

- Identifying how the program or project supports the Agency's strategic goals
- Assessing feasibility, technology, and concepts
- Performing trade studies; assessing and possibly mitigating risks
- Maturing technologies
- **Building teams**
- **Establishing high-level requirements**
- **Requirements flow down, and success criteria**
- **Developing system-level preliminary designs**
- Developing operations concepts and acquisition strategies
- Assessing the relevant industrial base/supply chain to ensure program or project success
- **Preparing plans, cost estimates, budget submissions, and schedules essential to the success of a program or project**; and
- Establishing control systems to ensure performance of those plans and alignment with current Agency strategies.

Building Teams – Key Roles for a Space Mission Project

- **Project Manager** is responsible for the formulation and implementation of the project. This includes responsibility and accountability for the project safety; technical integrity; technical, cost, and schedule performance; and mission success.
- **Project Systems Engineer (PSE)** is responsible for making sure that all of the Systems in a space mission work together so that the space mission meets its objectives.
- **Safety & Mission Assurance Manager** provides independent oversight and support throughout for NASA to ensure the safety of our workforce and facility in the design, development, evaluation, and performance of hazardous operations.
- A **System Manager** on NASA space projects involves overseeing and coordinating the development, integration, and operation of a complex system within space missions. This role is critical to ensure that various components and subsystems of a spacecraft, ground, mission operations, etc. work together harmoniously to achieve the mission's objectives.

Typical Space Mission Organization



The Size of Your Project Management Team should be Appropriate to the Size of Your Team

PSEs and Technology Readiness Level (TRL)

TRL 9
- Actual system "flight proven" through successful mission operations

TRL 8
- Actual system completed and "flight qualified" through test and demonstration (ground or space)

TRL 7
- System prototype demonstration in a space environment

TRL 6
- System/subsystem model or prototype demonstration in a relevant environment (ground or space)

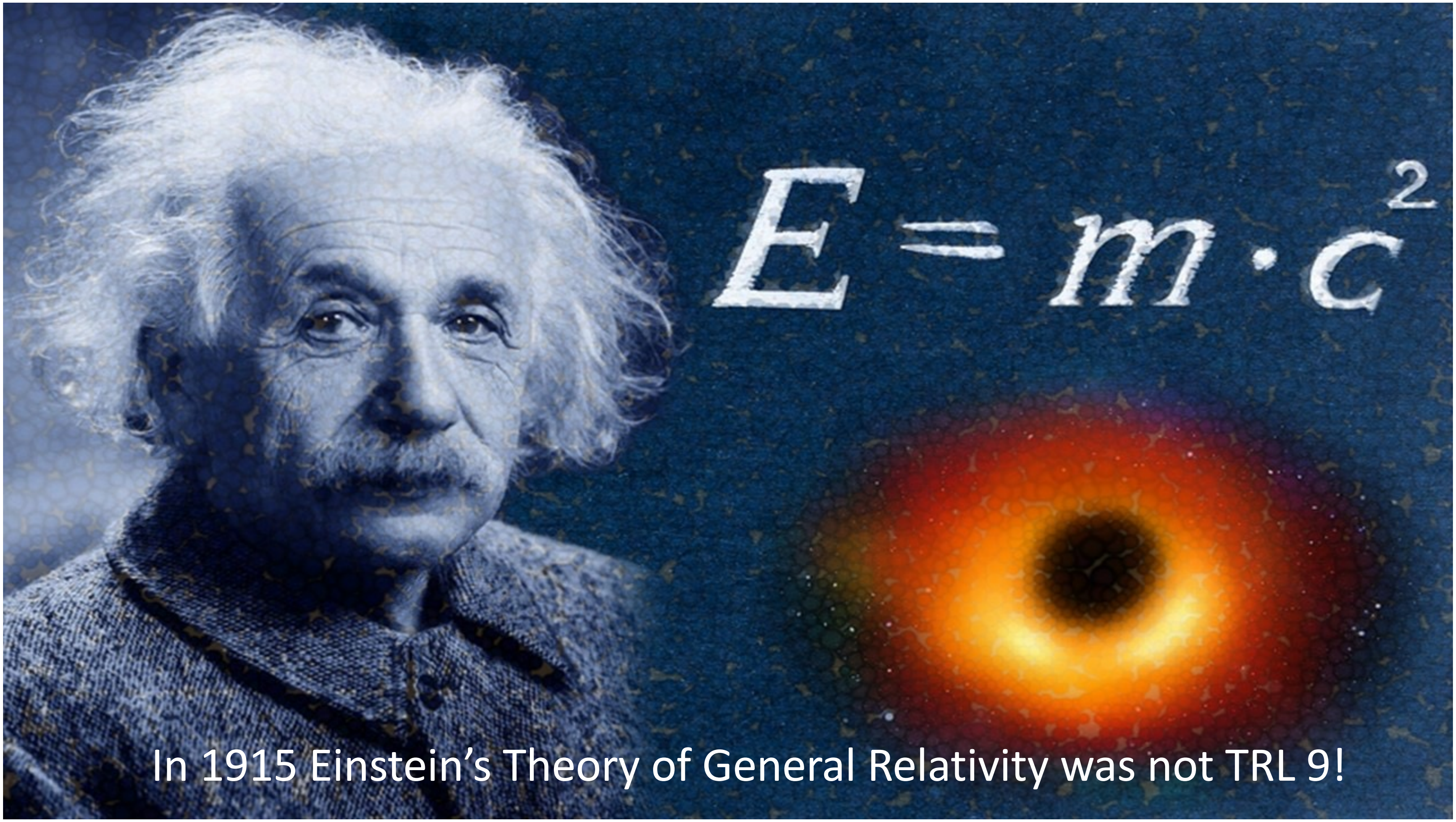
TRL 5
- Component and/or breadboard validation in relevant environment

TRL 4
- Component and/or breadboard validation in laboratory environment

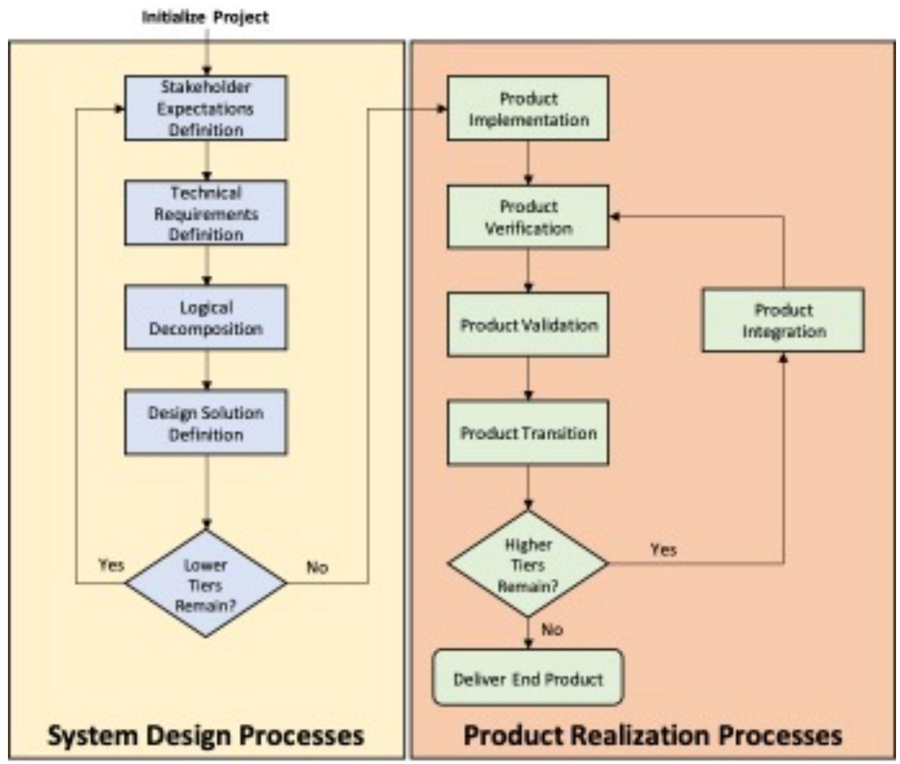
TRL 3
- Analytical and experimental critical function and/or characteristic proof-of-concept

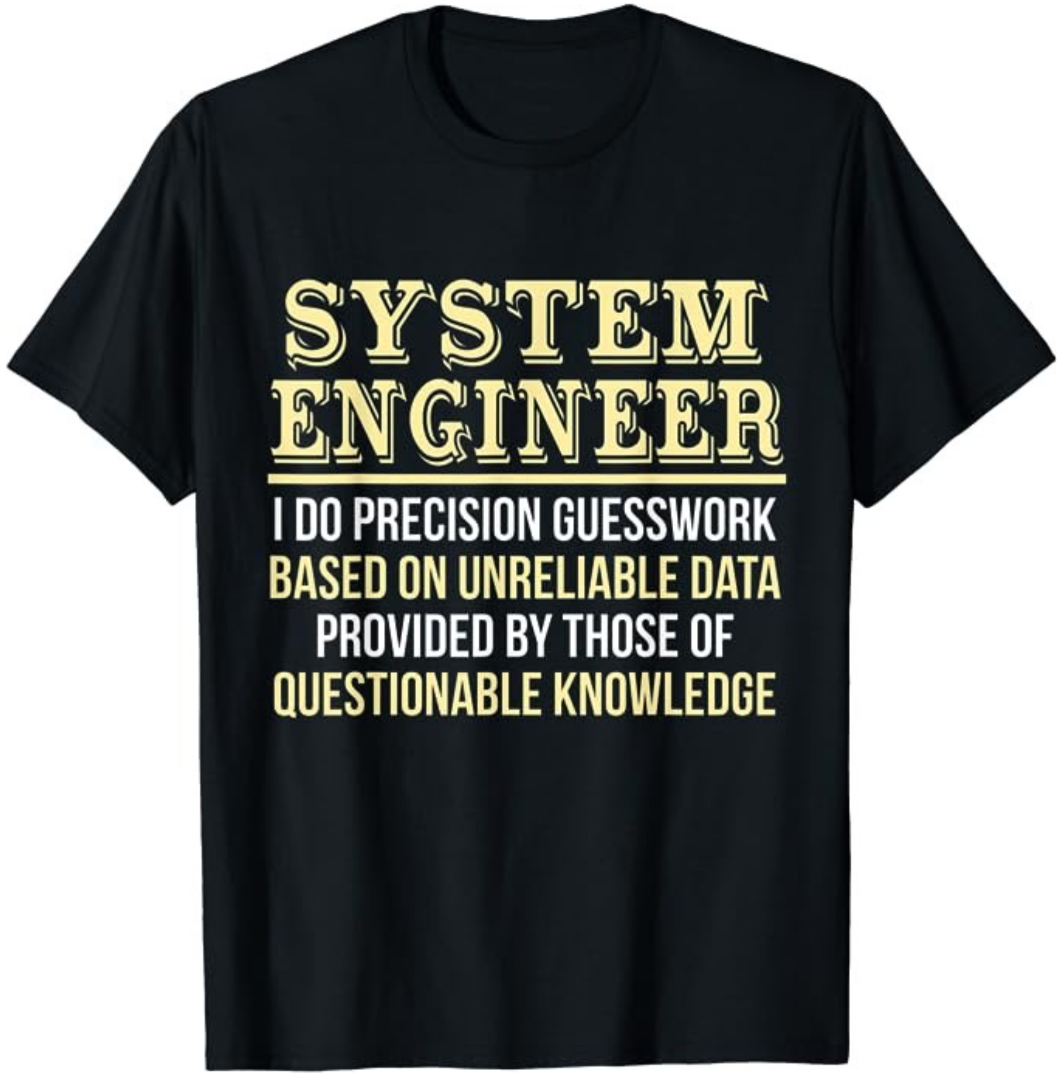
TRL 2
- Technology concept and/or application formulated

TRL 1
- Basic principles observed and reported

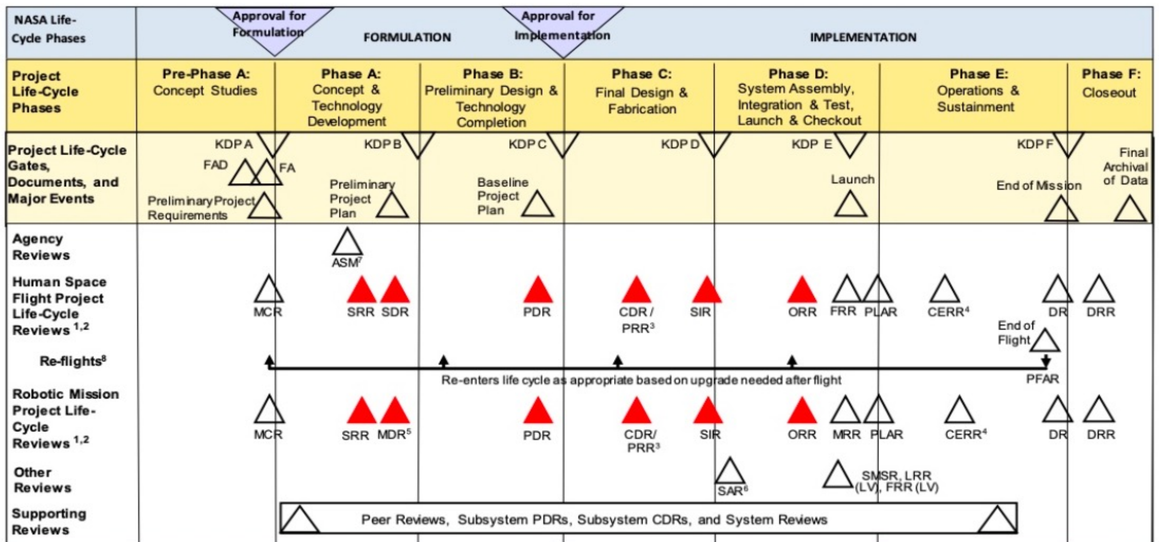

E = m·c2
In 1915 Einstein's Theory of General Relativity was not TRL 9!

Developing System-Level Preliminary Designs[4]




SYSTEM ENGINEER
I DO PRECISION GUESSWORK
BASED ON UNRELIABLE DATA
PROVIDED BY THOSE OF
QUESTIONABLE KNOWLEDGE

NASA Project Life Cycle



FOOTNOTES

1. Flexibility is allowed as to the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.
2. Life-cycle review objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-5.
3. PRR is needed only when there are multiple copies of systems. It does not require an SRB. Timing is notional.
4. CERRs are established at the discretion of Program Offices.
5. For robotic missions, the SRR and the MDR may be combined.
6. SAR generally applies to human space flight.
7. Timing of the ASM is determined by the MDAA or AA, as compliant with NPD 1000.5 and may take place at any time during Phase A.
8. Placement of arrows is notional. See Section 2.2.4.3 for more guidance on reflights.

ACRONYMS

ASM - Acquisition Strategy Meeting
CDR - Critical Design Review
CERR - Critical Events Readiness Review
DR - Decommissioning Review
DRR - Disposal Readiness Review
FA - Formulation Agreement
FAD - Formulation Authorization Document
FRR - Flight Readiness Review
KDP - Key Decision Point
LRR - Launch Readiness Review
LV - Launch Vehicle
MCR – Mission Concept Review
MDR - Mission Definition Review
MRR - Mission Readiness Review
ORR - Operational Readiness Review
PDR - Preliminary Design Review
PFAR - Post-Flight Assessment Review
PLAR - Post-Launch Assessment Review
PRR - Production Readiness Review
SAR - System Acceptance Review
SDR - System Definition Review
SIR - System Integration Review
SMSR - Safety and Mission Success Review
SRB - Standing Review Board
SRR - System Requirements Review

▲ Red triangles represent life-cycle reviews that require SRBs. The Decision Authority, Administrator, MDAA, or Center Director may request the SRB to conduct other reviews.

Expected Maturity State Through the Life Cycle of Projects

KDP Review	Associated Life-cycle Review	LCR Objectives	Overall Expected Maturity State at KDP
KDP A	MCR	To evaluate the feasibility of the proposed mission concept(s) and its fulfillment of the program's needs and objectives. To determine whether the maturity of the concept and associated planning are sufficient to begin Phase A.	Project addresses critical NASA need. Proposed mission concept(s) is feasible. Associated planning is sufficiently mature to begin Phase A, and the mission can likely be achieved as conceived.
KDP B	SRR	To evaluate whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities.	Proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources. The maturity of the project's mission/system definition and associated plans is sufficient to begin Phase B, and the mission can likely be achieved within available resources with acceptable risk.
	MDR or SDR	To evaluate the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints, including available resources. To determine whether the maturity of the project's mission/system definition and associated plans are sufficient to begin Phase B.	

LCR = Life Cycle Review

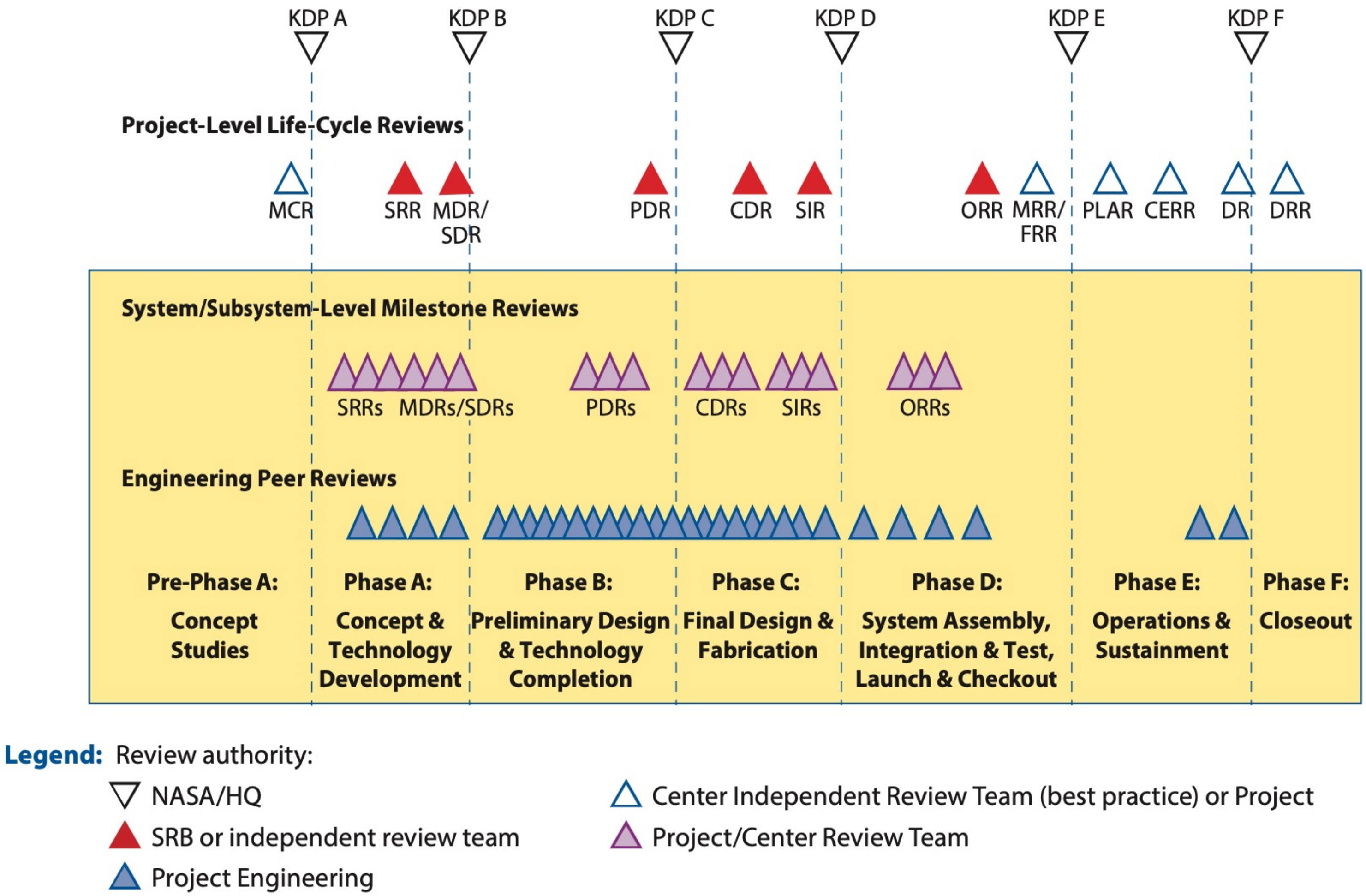
Expected Maturity State Through the Life Cycle of Projects

KDP C	PDR	To evaluate the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation. To assess compliance of the preliminary design with applicable requirements and to determine if the project is sufficiently mature to begin Phase C.	Project's planning, technical, cost, and schedule baselines developed during Formulation are complete and consistent. The preliminary design complies with its requirements. The project is sufficiently mature to begin Phase C, and the cost and schedule are adequate to enable mission success with acceptable risk.
KDP D	CDR	To evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	Project is still on plan. The risk is commensurate with the project's payload classification, and the project is ready for AI&T with acceptable risk within its ABC.
	PRR	To evaluate the readiness of system developer(s) to produce the required number of systems within defined project constraints for projects developing multiple similar flight or ground support systems. To evaluate the degree to which the production plans meet the system's operational support requirements.	
	SIR	To evaluate the readiness of the project and associated supporting infrastructure to begin system AI&T, evaluate whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D.	

Expected Maturity State Through the Life Cycle of Projects

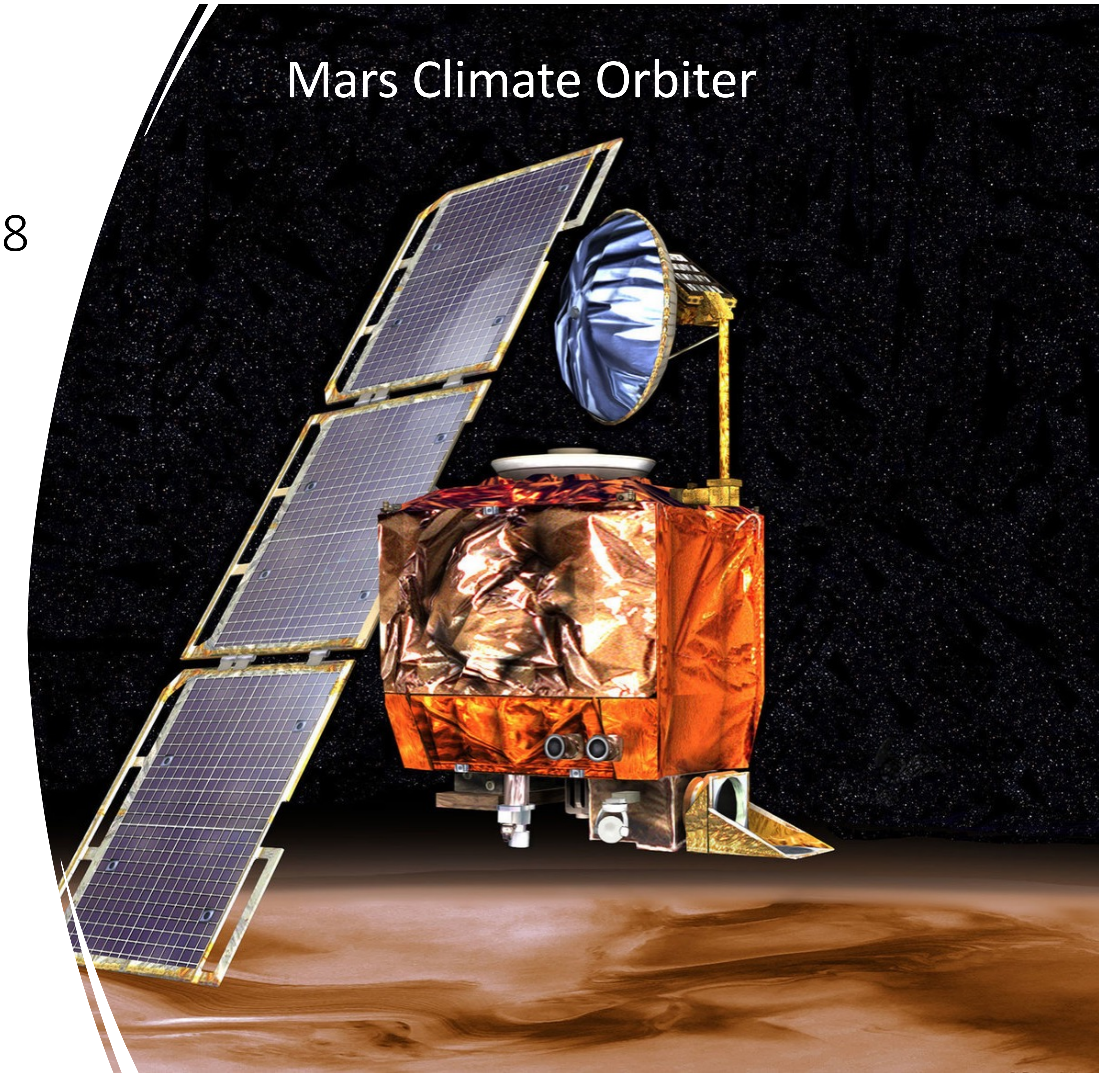
KDP E	ORR	To evaluate the readiness of the project to operate the flight system and associated ground system(s) in compliance with defined project requirements and constraints during the operations/sustainment phase of the project life cycle.	Project and all supporting systems are ready for safe, successful launch and early operations with acceptable risk within ABC.
	MRR or FRR	To evaluate the readiness of the project and all project and supporting systems for a safe and successful launch and flight/mission.	
KDP En (applies only to Single-Project Programs)	PIR	To evaluate the program's continuing relevance to the Agency's Strategic Plan, assess performance with respect to expectations, and determine the program's ability to execute the implementation plan with acceptable risk within cost and schedule constraints.	Program still meets Agency needs and is continuing to meet Agency commitments, as planned.
Non-KDP Reviews	PLAR	To evaluate in-flight performance of the flight system early in the mission and determine whether the project is sufficiently prepared to begin Phase E.	PLAR Expected State: Project is ready to conduct mission operations with acceptable risk within ABC.
	CERR	To evaluate the readiness of the project and the flight system for execution of a critical event during the flight operations phase of the life cycle.	Mission CERR Expected State: Project is ready to conduct critical mission activity with acceptable risk.
	PFAR	To evaluate how well mission objectives were met during a human space flight mission and to evaluate the status of the returned vehicle.	PFAR Expected State: All anomalies that occurred in flight are identified. Actions necessary to mitigate or resolve these anomalies are in place.

Work Led by the Project Throughout the Life Cycle



Case Studies and Lessons Learned [5,6,7,8]

- Key Lessons Learned from the Deep Space 1 Mission
- Mars Climate Orbiter Failure Lessons Learned
- The Last Mission of the Space Shuttle Challenger



Deep Space 1

Launched October 24, 1998

Boeing Delta II launch vehicle lifts off with DS1 on board October 24, 1998

DS1 Mission Summary

- DS1 was part of the New Millennium Program.
  - Mantra is to flight validate new technology.
- DS1 was a technology validation project, designed to flight validate 12 advanced technologies that represent major breakthroughs over current state-of-the-art systems. Other key features of project:
  - Short development time: 2 months pre-project, 36 months development. Phase C/D funding available for development contracts 24 months prior to launch.
  - Launch vehicle: Delta 7326 (selected in July 1996).
  - Launch date was October 24, 1998 from CCAS.
  - Mission designed around an asteroid (Braille) flyby test track in November of 1999.
  - During its extended mission DS1 had a encounter with comet Borrelly in Sept. 2001.
  - Achieved minimum mission success criteria in December 1998.
  - Achieved complete mission success in July 1999.
    - First deep space mission to use SEP.
    - First deep space mission to do autonomous on-board navigation.

DS1 System Overview

Mission

- Twelve advanced technologies (high risk - high payoff) validated via an asteroid flyby “test track” profile

Technology Description	*Technology Suppliers*	*Funding Sources*
Ion Propulsion System	Hughes, Moog, LeRC, SAI, JPL	NASA, Moog, Hughes
SCARLET Solar Concentrator Array	AEC-Able, Tecstar, LeRC, Entech	BMDO, NASA
Small Deep Space Transponder	Motorola	NASA, Motorola
Ka-Band Solid State Power Amplifier	Lockheed Martin (LM), JPL	NASA, Lockheed Martin
Autonomous Remote Agent Architecture	ARC, CMU, TRW, JPL	NASA
Autonomous Onboard Navigation	JPL	NASA
Beacon Monitor Operations	JPL, Univ. of Colorado at Boulder	NASA
Miniature Integrated Camera Spectrometer	SSG, Rockwell, Univ. of Arizona, JPL	NASA, SSG
Miniature Ion and Electron Spectrometer	SwRI, LANL	NASA, SWRI
Low Power Electronics	Georgia Tech., USC, MIT Lincoln Lab	NASA
Power Activation and Switching Module	LM	NASA, Lockheed Martin
Multi-Functional Structures	AF/PL, LM	AF/PL, LM

Spacecraft

- 486kg injected mass - Spectrum Astro is major industry partner
- Spacecraft integration done at JPL with a badge-less SAI/JPL team

Launch Services

- Delta 7326

Ground Segment

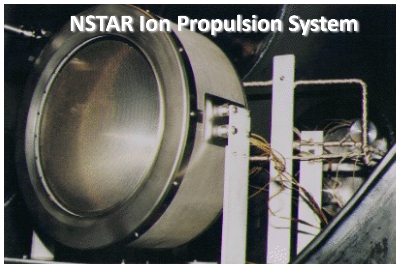
- JPL multi-mission infrastructure with DS1-led ops team

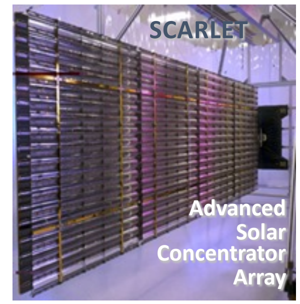
Science

- Taken at appropriate times during the mission (cruise and encounters)

Deep Space 1

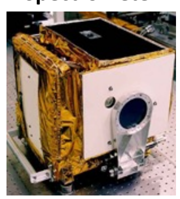
- System Level Validation of 12 Breakthrough Technologies

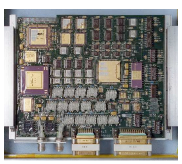




Small Deep Space Transponder

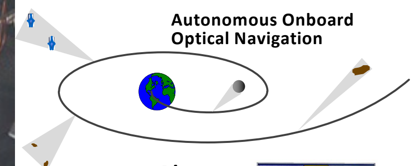
Miniature Integrated Camera Spectrometer



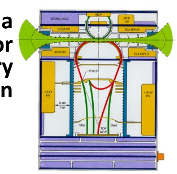


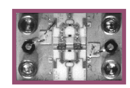
Low Power Electronics

Autonomous Onboard Optical Navigation



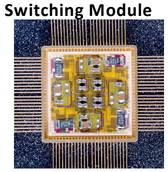
Plasma Experiment for Planetary Exploration



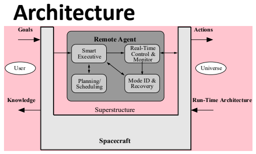


Ka-Band Solid State Power Amplifier

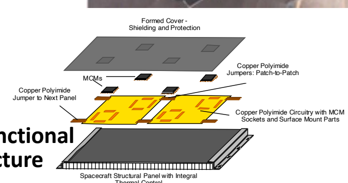
Power Activation & Switching Module

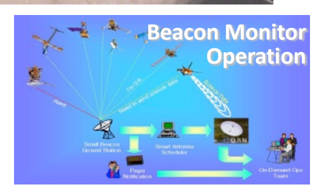


Remote Agent Architecture



Multifunctional Structure





Key DS1 Lessons Learned

No.	Subject/Title	Event(s)	Lesson Learned/Recommendation
1	Risk Management	The project did not have a good risk management plan up front & did not do a good job explaining the "level of risk" to upper management early in the job. This led to the project not having good back-up plans when problems occurred during the development. Also, during the last year of the project, as upper management was being made aware of the risk, the project was exposed to increased reviews and increased work/overtime by project personnel to reduce project risk.	Lesson learned is that a project develop a good risk management plan early in the project. Project should thoroughly communicate risk to upper management to ensure they know the risk that JPL/NASA are being exposed to.
2	Adequate margins	When the deal was made for the project, we had only 11% cost reserve. This was too low and led to us taking too much risk. It also led to us using fewer people, which in turn led to burn out of personnel.	Lesson learned is that a project manager should get adequate reserves/margins (not just cost reserves) for the project up-front or don't do the project.
3	Planning	DS1 had only a 2-month pre-project to plan what it was going to do. This was bad and led to lots of problems. Because of the short pre-project, the level 1 requirements and goals document was not signed off until a year after project start. This late resolution of the level 1's led to a poor definition of the design which in turn led to people having to work extra time later on. This in turn caused burn out of people due to overworking them.	Lesson learned is that a project needs to have an adequate pre-project phase to develop a good plan.

Key DS1 Lessons Learned

No.	Subject/Title	Event(s)	Lesson Learned/Recommendation
4	Simple procedures & communications	DS1 had a simple to understand, 1-page level 1 requirements and goals document. This was signed off by both the Program Office and NASA. It was helpful to the project and the rest of the team to ensure everyone was working to the same sheet of music. It was understood by most people on the project that we could descope goals if we ran into development problems. The Remote Agent (RA) team, unfortunately, didn't understand that we could descope their experiment (because it was a goal). This lack of communication by the project manger caused a big problem when we were forced to de-scope it.	Lessons learned: Have a short, well written level 1 requirements document for a project and ensure you communicate it thoroughly and repeatedly to your team.
5	Timely decisions	The project manager delayed the decision by 2 months to de-manifest the 3D-stack computer and descope the RA technologies. This delay contributed to the 3-month launch delay and 6% cost overrun.	Lesson learned is to be a leader and do the right thing even if people don't like it.
6	Perseverance	The project management staff and a majority of the rest of the team stuck with the project and stayed on it until they were no longer needed (rather than quitting during the middle of the job). This continuity really helped especially after launch because of the difficulty of operating a complex spacecraft.	Lesson learned is to pick your people carefully and work to instill in your team a sense of ownership so that they stick with it until the job is done.

Mars Climate Orbiter Failure Lessons Learned -1

- Driving Event: The Mars Climate Orbiter (MCO) Mission objective was to orbit Mars as the first interplanetary weather satellite and provide a communications relay for the Mars Polar Lander (MPL) which was due to reach Mars in December 1999. The MCO was launched on December 11, 1998, and was lost sometime following the spacecraft's entry into Mars occultation during the Mars Orbit Insertion (MOI) maneuver. The spacecraft's carrier signal was last seen at approximately 09:04:52 UTC on Thursday, September 23, 1999.
- Lessons Learned: The MCO Mishap Investigation board (MIB) has determined that the root cause for the loss of the MCO spacecraft was the failure to use metric units in the coding of a ground software file, "Small Forces," used in trajectory models. Specifically, thruster performance data in English (British Imperial) units instead of metric units was used in the software application code titled SM_FORCES (small forces). A file called Angular Momentum Desaturation (AMD) contained the output data from the SM_FORCES software. The data in the AMD file was required to be in metric units per existing software interface documentation, and the trajectory modelers assumed the data was provided in metric units per the requirements.

Mars Climate Orbiter Failure Lessons Learned -2

- Lessons Learned (Continued): During the 9-month journey from Earth to Mars, propulsion maneuvers were periodically performed to remove angular momentum buildup in the on-board reaction wheels (flywheels). These Angular Momentum Desaturation (AMD) events occurred 10-14 times more often than was expected by the operations navigation team. This was because the MCO solar array was asymmetrical relative to the spacecraft body as compared to Mars Global Surveyor (MGS) which had symmetrical solar arrays. This asymmetric effect significantly increased the Sun-induced (solar pressure-induced) momentum buildup on the spacecraft. The increased AMD events coupled with the fact that the angular momentum (impulse) data was in English, rather than metric, units, resulted in small errors being introduced in the trajectory estimate over the course of the 9-month journey. At the time of Mars insertion, the spacecraft trajectory was approximately 170 kilometers lower than planned. As a result, MCO either was destroyed in the atmosphere or re-entered heliocentric space after leaving Mars' atmosphere.

Mars Climate Orbiter Failure Lessons Learned - 3

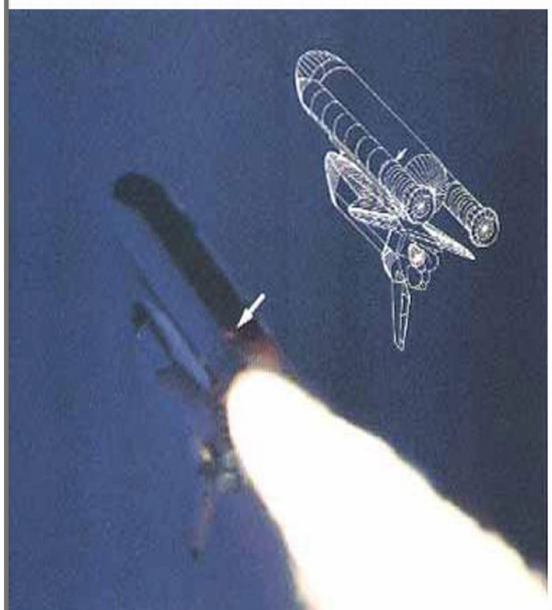
- The root cause of the Mars Climate Orbiter (MCO) mission failure was identified as cumulative navigation errors.
- These errors resulted, in part, from operational procedures and software that were inadequately reviewed, evaluated, and implemented.
- A high degree of formality, anomaly follow-up and close out, selection of reviewers and penetration of technical issues is essential in the review process, including the design, operational, and peer reviews.


National Aeronautics and Space Administration
NASA
Lessons from Challenger
STS-51L: January 28, 1986
Senior Management ViTS Meeting: January 4, 2021
Harmony Myers
Director, NASA Safety Center
This and previous presentations are archived
at sma.nasa.gov/safety-messages

Pre-Launch

- Launch day temperatures as low a -6° C at Kennedy Space Center.
- Thiokol engineers had concerns about launching due to the effect of low temperature on O-rings.
- NASA Program personnel pressured Thiokol to agree to the launch.

Summary of Accident



- Escaping gases were seen from lowest Solid Rocket Booster (SRB) joint at liftoff.
- O-ring resealed during ascent.
- Vibrations and crosswinds caused a catastrophic loss of sealing.
- SRB support structure failed, leading to tank rupture, vehicle loss, and loss of all 7 crew members at 73 seconds into flight.

Contributing Factors

Normalization of Deviance

The space shuttle's SRB problem began with the faulty design of its joint and increased as both NASA and contractor management first failed to recognize it as a problem, then failed to fix it, and finally treated it as an acceptable flight risk*.

Organizational Silence

The decision to launch Challenger was flawed. Those who made that decision were unaware of the recent history of problems concerning the O-rings and the joint and were unaware of the initial written recommendation of the contractor advising against the launch at temperatures < 12°C and the continuing opposition of the engineers at Thiokol after management reversed its position.

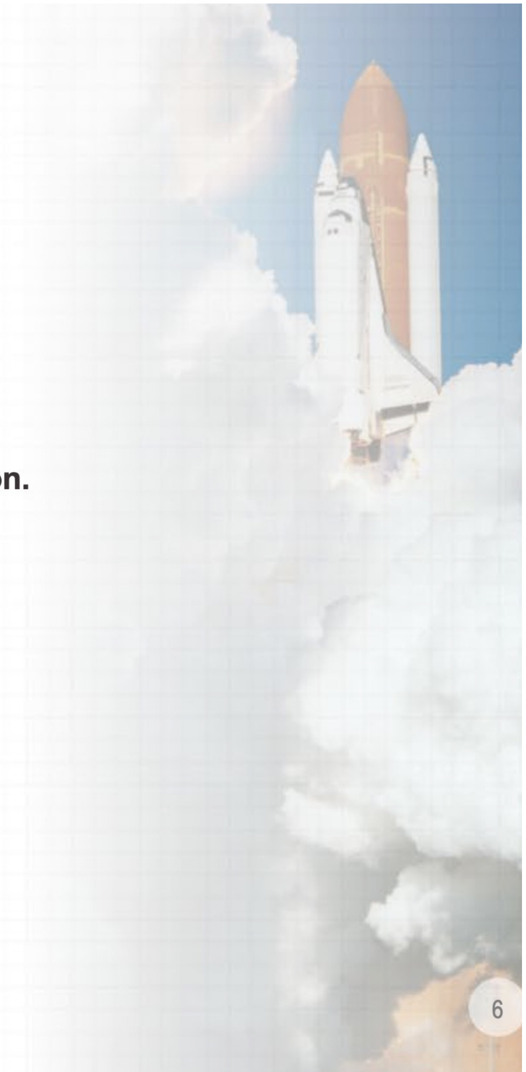
Silent Safety Organization

There were serious ongoing weaknesses in the shuttle Safety, Reliability, and Quality Assurance Program, which had failed to exercise control over the problem tracking systems, had not critiqued the engineering analysis advanced as an explanation of the SRM seal problem, and did not provide the independent perspective required by senior NASA managers at Flight Readiness Reviews.

**Boston College sociology professor Diane Vaughan, author of the book "The Challenger Launch Decision," referred to this as, "The normalization of the technical deviation of the booster joints …"*

Lessons Learned

- **We cannot become complacent.**
- **We cannot be silent when we see something we feel is unsafe.**
- **We must allow people to come forward with their concerns without fear of repercussion.**



Thank you.

STS-51-L crew: (back) Onizuka, McAuliffe, Jarvis, Resnik;
(front) Smith, Scobee, McNair.