

Design and Develop Science Missions

March 26, 2025

Access to Space for All
Systems Engineering Webinar Series



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Useful References



1. NASA System Engineering Handbook, NASA SP-2016-6105 (Rev 2)
<https://www.nasa.gov/reference/systems-engineering-handbook/>
Concept of Operations Outline, Appendix S
<https://www.nasa.gov/reference/appendix-s-concept-of-operations-annotated-outline/>
2. NASA Systems Engineering Processes and Requirements, NPR 7123.1 (version D)
https://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7123_001D_&page_name=main
3. NASA Space Flight Program and Project Management Requirements, NPR 7120.5 (version F)
<https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E>
4. NASA Research and Technology Program and Project Management Requirements, NPR 7120.8 (version A)
https://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_008A_&page_name=main
5. Risk Classification for NASA Payloads, NPR 8705.4 (version B)
<https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8705&s=4B>
6. NASA Science Mission Directorate <https://science.nasa.gov/learn/>
7. System Engineering Curriculum Intro, 20210021839, <https://ntrs.nasa.gov/citations/20210021839>



Webinar Overview:



This webinar will conclude by providing an overview to design a concept mission applying various processes and tools described over the course of this series. This overview includes:

- What is defined as a science mission?
- What segments make up a science mission?
- What steps and processes are taken to design and develop a science mission?
- What are examples of a science mission design?

Purpose:
To provide attendees with information and knowledge of how to design and develop science missions.



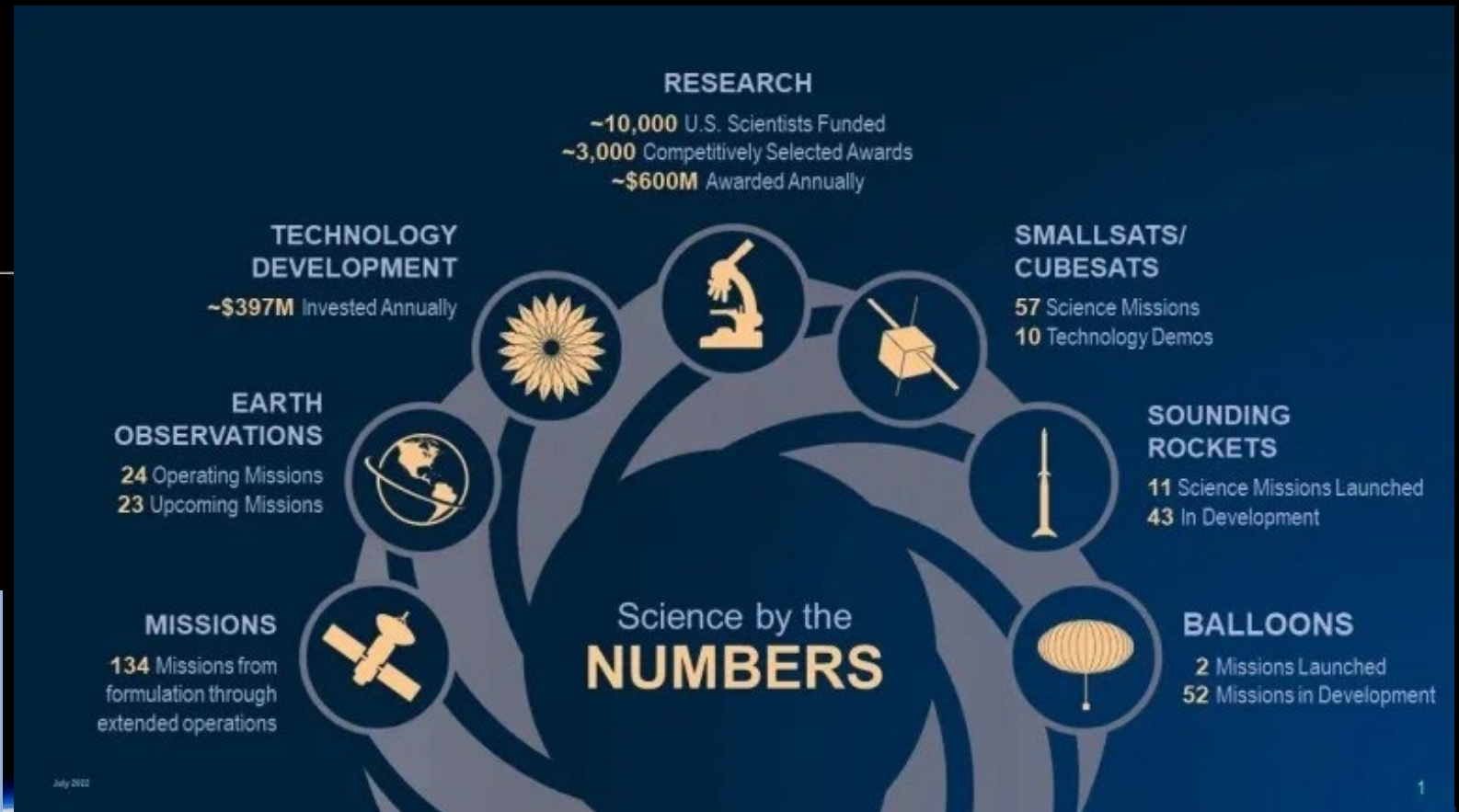
What is defined as a science mission?

For NASA, a science mission, managed by the Science Mission Directorate (SMD), is defined as a spaceflight mission primarily focused on scientific research and exploration, encompassing disciplines such as:

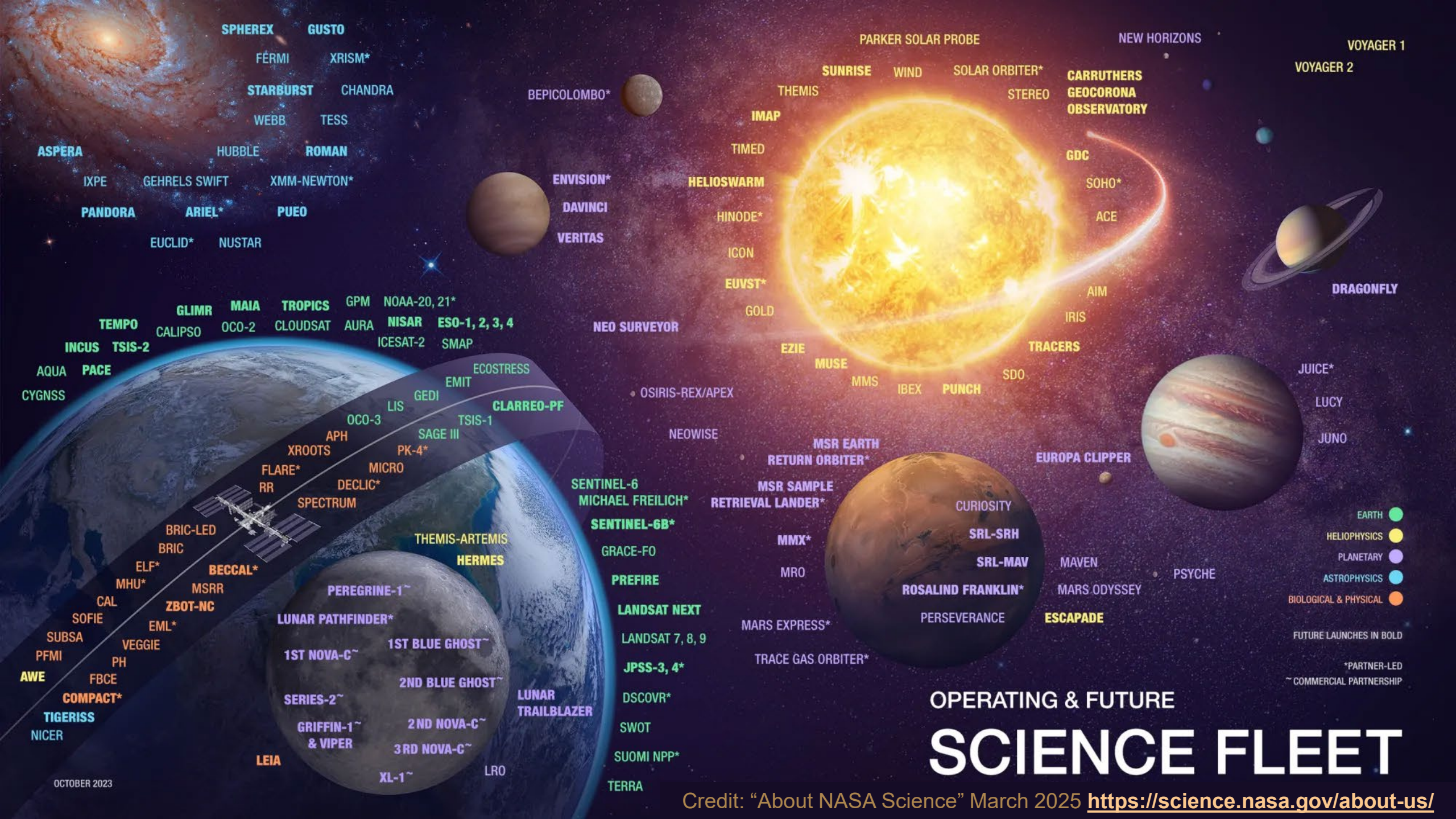
- Earth science
- Heliophysics
- Planetary science
- Astrophysics

with the goal of advancing scientific understanding and potentially benefiting humanity.

Science missions are usually driven by NASA Science Mission Directorate strategic plans, whereas the exploration missions may be driven by a Presidential directive.



Credit: "About NASA Science" March 2025 <https://science.nasa.gov/about-us/>



What segments make up a science mission?



A NASA science mission can be broken down into several segments:

- Launch segment: Launch vehicle and related services used to get the spacecraft into space.
- Space segment: Spacecraft and various components like orbiters, landers, rovers, and instruments used to collect data.
- Ground segment: Ground stations and mission control centers that communicate with the spacecraft, receive data, and manage the mission.
- User segment: Scientists and the public who will use the data collected by the mission for research and education.



NPR 7123.1 Description of Concept of Operations

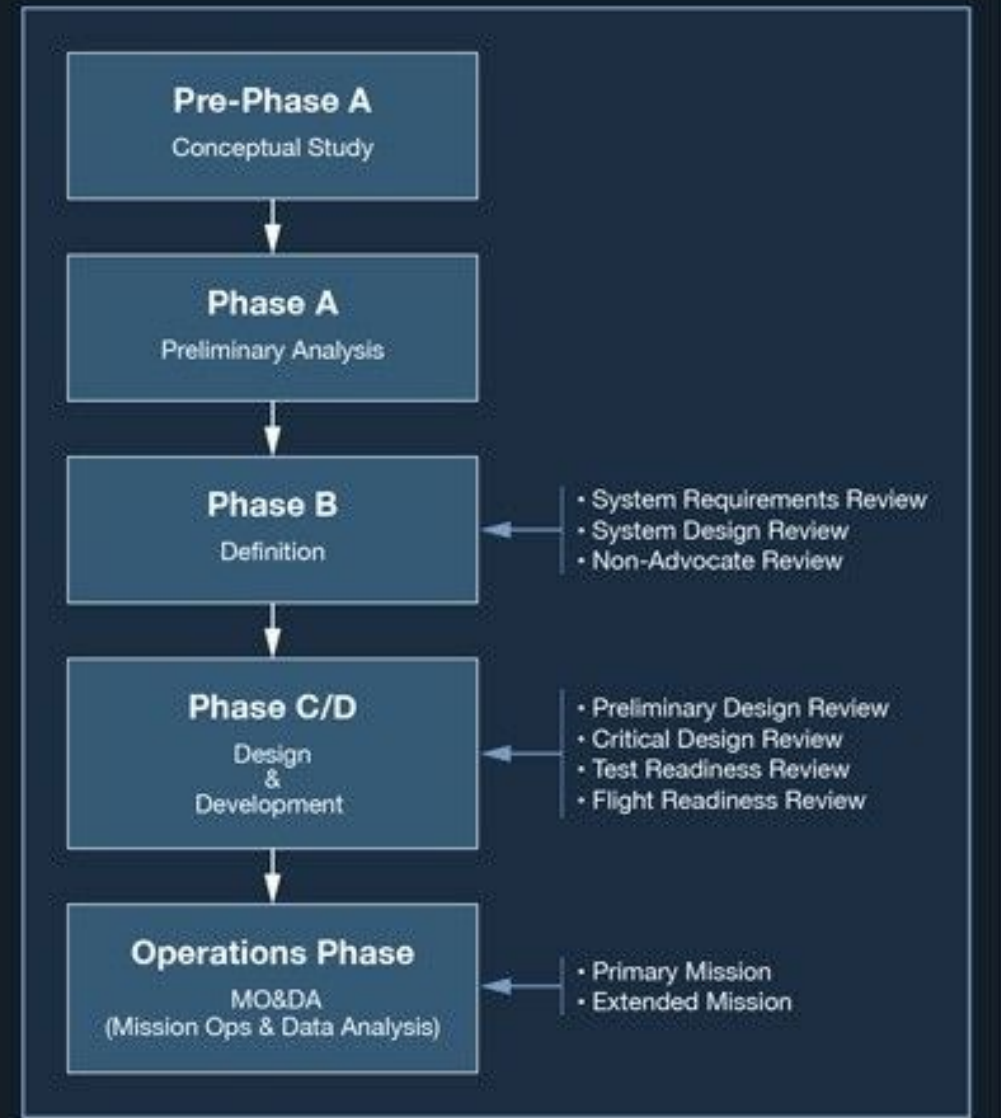
Developed early in Pre-Phase A, describes the overall high-level concept of how the system will be used to meet stakeholder expectations, usually in a time sequenced manner. It describes the system from an operational perspective and helps facilitate an understanding of the system goals. It stimulates the development of the requirements and architecture related to the user elements of the system. It serves as the basis for subsequent definition documents and provides the foundation for the long-range operational planning activities (for nominal and contingency operations). It provides the criteria for the validation of the system. In cases where an Operations Concept (OpsCon) is developed, the ConOps feeds into the OpsCon and they evolve together. The ConOps becomes part of the Concept Documentation.



What steps and processes are taken to design and develop a science mission?



- Pre-Phase A, Conceptual Study
- Phase A, Preliminary Analysis
- Phase B, Definition
- Phase C/D, Design & Development
- Phase E, Operations Phase



NASA Space Flight Project Life Cycle, from NPR 7120.5

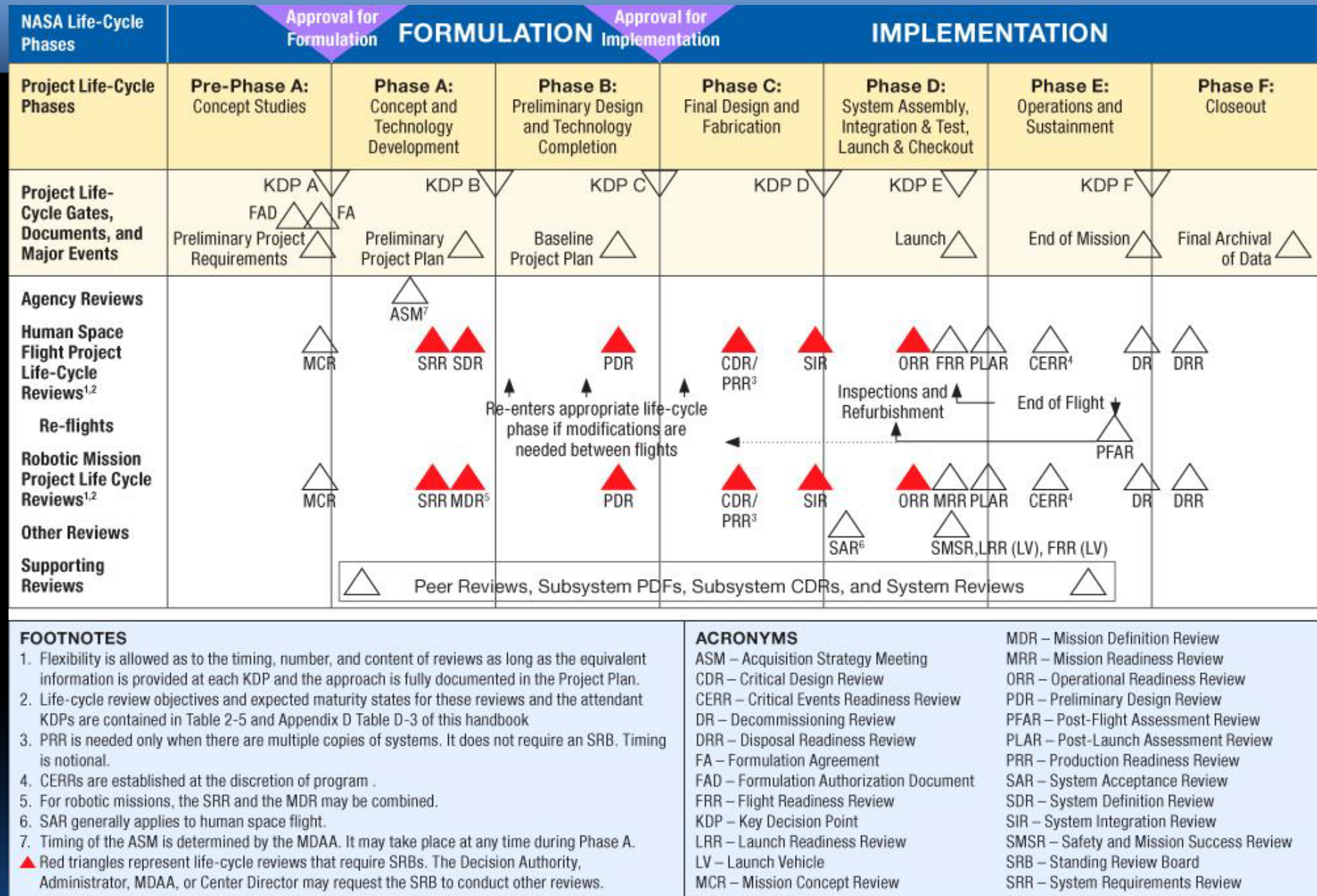


FIGURE 3.0-1 NASA Space Flight Project Life Cycle from NPR 7120.5E

Risk Classification for NASA Payloads, NPR 8705.4



- Classification levels define hierarchy of risk combinations for NASA payloads by considering various factors.

Table C-1 Mission and Instrument Risk Classification Considerations

Priority (Relevance to Agency Strategic Plan, National Significance, Significance to the Agency and Strategic Partners)	Very High: High: Medium: Low:	Class A Class B Class C Class D
Primary Mission Lifetime	Long, > 5 Years: Medium, 5 Years > – > 3 Years: Short, 3 Years > – > 1Years: Brief, < 1 Year:	Class A Class B Class C Class D
Complexity and Challenges (Interfaces, International Partnerships, Uniqueness of Instruments, Mission Profile, Technologies, Ability to Reservice, Sensitivity to Process Variations)	Very High: High: Medium: Medium to Low:	Class A Class B Class C Class D
Life-Cycle Cost	High: Medium to High: Medium: Medium to Low:	Class A Class B Class C Class D

SE Handbook Interpretation

- Other considerations for designating a risk tolerance class may exist that are not explicitly expressed in NPR 8705.4.
- Ultimately, the mission or instrument risk tolerance class is designated by the Mission Directorate.

TABLE 3.11-1 Example of Program/Project Types

Criteria	Type A	Type B	Type C	Type D	Type E	Type F
Description of the Types of Mission	Human Space Flight or Very Large Science/ Robotic Missions	Non-Human Space Flight or Science/Robotic Missions	Small Science or Robotic Missions	Smaller Science or Technology Missions (ISS payload)	Suborbital or Aircraft or Large Ground based Missions	Aircraft or Ground based technology demonstrations
Priority (Criticality to Agency Strategic Plan) and Acceptable Risk Level	High priority, very low (minimized) risk	High priority, low risk	Medium priority, medium risk	Low priority, high risk	Low priority, high risk	Low to very low priority, high risk
National Significance	Very high	High	Medium	Medium to Low	Low	Very Low
Complexity	Very high to high	High to Medium	Medium to Low	Medium to Low	Low	Low to Very Low
Mission Lifetime (Primary Baseline Mission)	Long. >5 years	Medium. 2–5 years	Short. <2 years	Short. <2 years	N/A	N/A
Cost Guidance (estimate LCC)	High (greater than ~\$1B)	High to Medium (~\$500M–\$1B)	Medium to Low (~\$100M–\$500M)	Low (~\$50M–\$100M)	(~\$10–50M)	(less than \$10–15M)
Launch Constraints	Critical	Medium	Few	Few to none	Few to none	N/A
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities	Significant alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Achievement of Mission Success Criteria	All practical measures are taken to achieve minimum risk to mission success. The highest assurance standards are used.	Stringent assurance standards with only minor compromises in application to maintain a low risk to mission success.	Medium risk of not achieving mission success may be acceptable. Reduced assurance standards are permitted.	Medium or significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.	Significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.	Significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.
Examples	HST, Cassini, JIMO, JWST, MPCV, SLS, ISS	MER, MRO, Discovery payloads, ISS Facility Class payloads, Attached ISS payloads	ESSP, Explorer payloads, MIDES, ISS complex subrack payloads, PA-1, ARES 1-X, MEDLI, CLARREO, SAGE III, Calipso	SPARTAN, GAS Can, technology demonstrators, simple ISS, express middeck and subrack payloads, SMEX, MISSE-X, EV-2	IRVE-2, IRVE-3, HiFIRE, HyBoLT, ALHAT, STORM, Earth Venture I	DAWNair, InFlame, Research, technology demonstrations

Impact of Risk Class on Technical Products



TABLE 3.11-2 Example of Tailoring NPR 7120.5 Required Project Products

	Type A	Type B	Type C	Type D	Type E	Type F
Example Project Technical Products						
Concept Documentation	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Mission, Spacecraft, Ground, and Payload Architectures	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Project-Level, System and Subsystem Requirements	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor
Design Documentation	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor
Operations Concept	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Technology Readiness Assessment Documentation	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Human Systems Integration Plan	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Heritage Assessment Documentation	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Safety Data Packages	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor
ELV Payload Safety Process Deliverables	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Not Applicable
Verification and Validation Report	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Operations Handbook	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Not Applicable
End of Mission Plans	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Mission Report	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor	Tailor

From SE Handbook

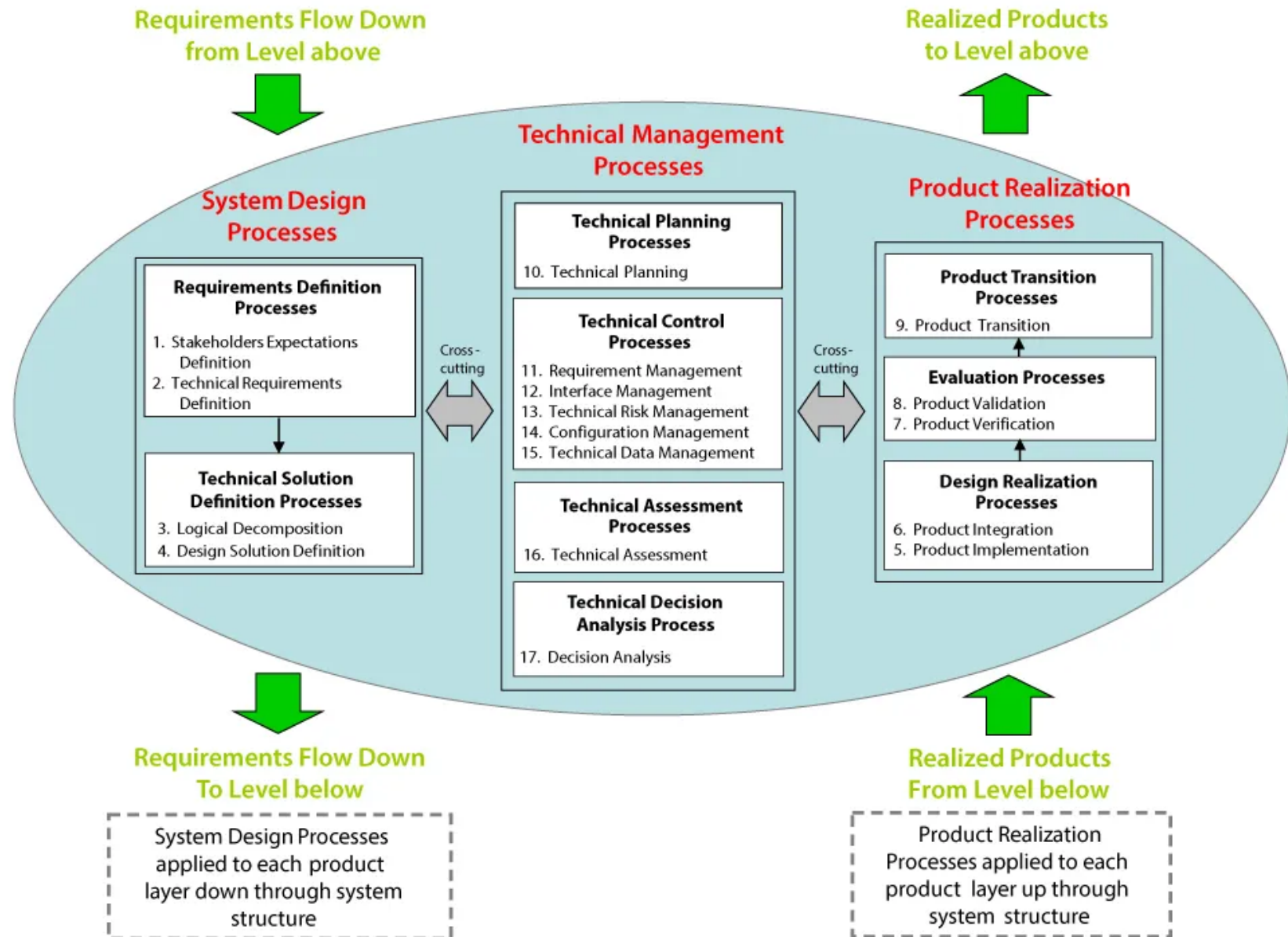
	Type A	Type B	Type C	Type D	Type E	Type F
Example Project Plan Control Plans						
Risk Management Plan	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Not Applicable
Technology Development plan	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Not Applicable	Not Applicable
Systems Engineering Management Plan	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Software Management plan	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor	Tailor
Verification and Validation Plan	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor	Tailor
Review Plan	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Tailor
Integrated Logistics Support Plan	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Not Applicable
Science Data Management Plan	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor	Not Applicable
Integration Plan	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor
Configuration Management Plan	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor
Technology Transfer (formerly Export) Control Plan	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor
Lessons Learned Plan	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant	Tailor	Tailor
Human Rating Certification Package	Fully Compliant	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable

The Common Technical Processes and the SE Engine, from SE Handbook



The 17 processes and their interactions & flows are illustrated by the systems engineering “engine”.

Processes of the SE engine develop and realize end products.



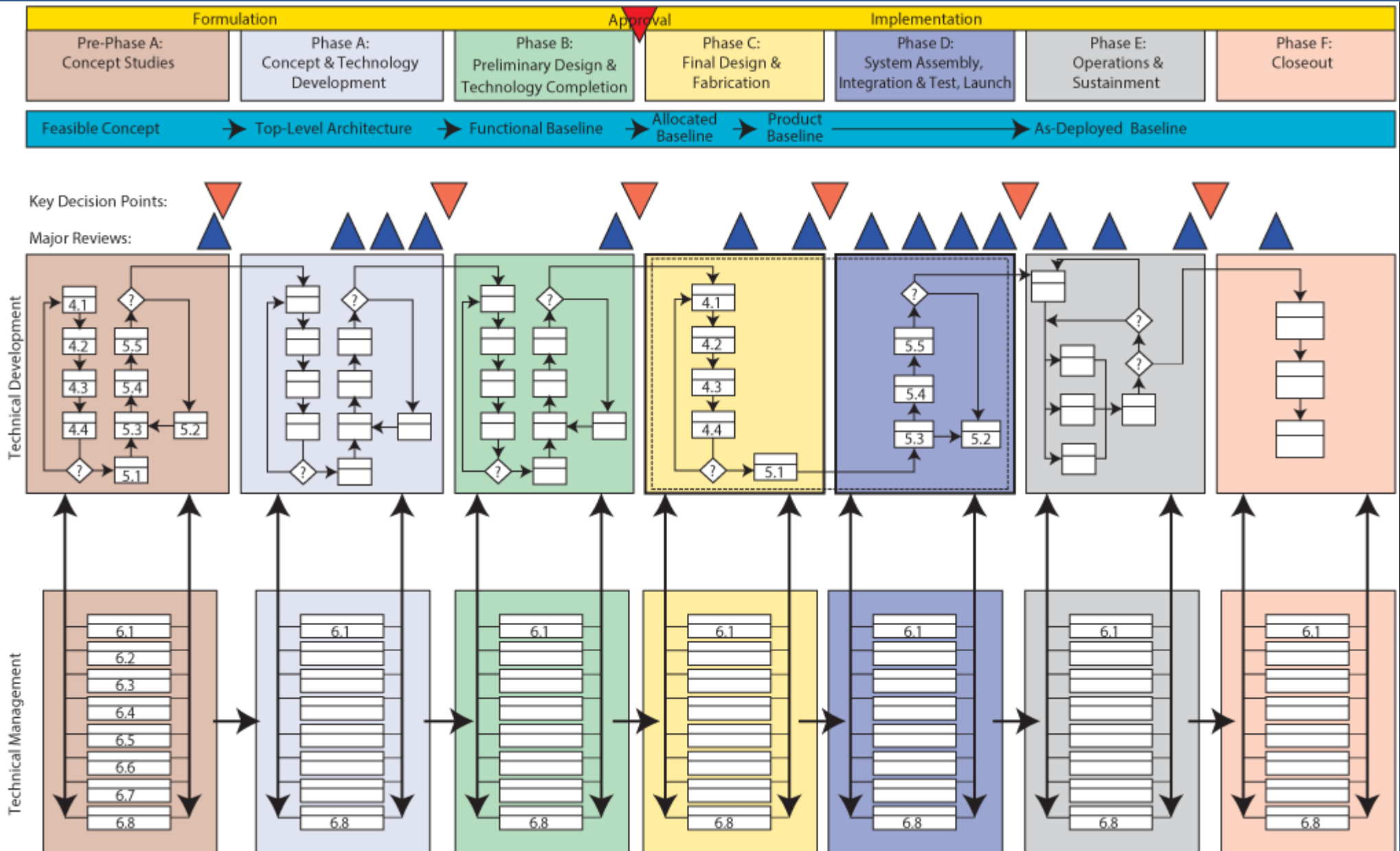
SE Engine by Project Phase, from SE Handbook



Project
System
Maturity

Technical
Develop-
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Processes

Technical
Manage-
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Processes



Example of a Science Mission Design

Example material from:



System Engineering Curriculum Intro, 20210021839,
<https://ntrs.nasa.gov/citations/20210021839>



Example of a science mission design



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1.2 An Engineering Example

Throughout this document, a real-world engineering project example will be presented to clarify the SE concepts. In this project, a satellite will orbit the Earth. An imaging instrument will be mounted on the satellite, pointed towards the Earth. As the satellite orbits, the imaging instrument will collect data to detect fires on the Earth's surface.

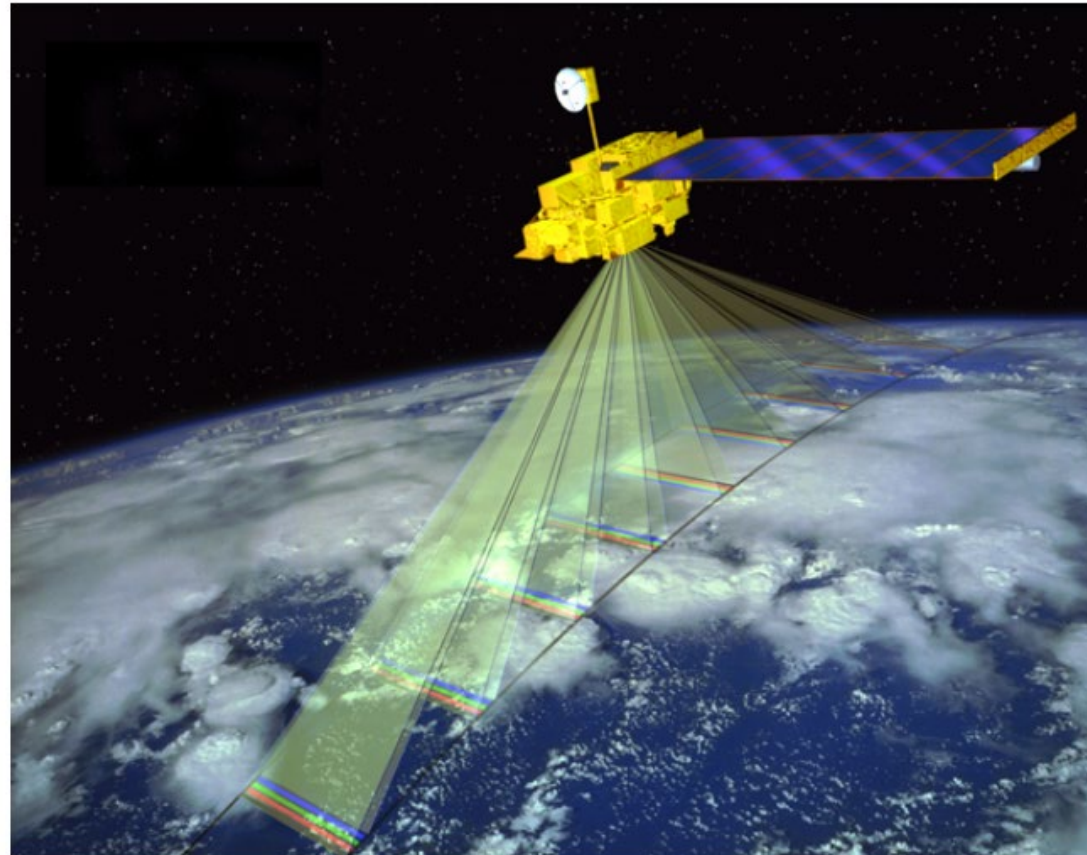


Figure 1 – Artist's Concept of the Terra Satellite - NASA

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20210021839,
<https://ntrs.nasa.gov/citations/20210021839>

Example: Imaging Spectroradiometer (Concept Studies)

An imaging spectroradiometer is a light measurement tool which can measure the light emitted from a light source. However, in the *Concept Studies* phase of the project, the engineering team must consider multiple technologies. Since the goal of the project is to design, build and operate a sensor that detects and conveys the information necessary to detect fires, the engineering team will consider multiple sensing technologies.

While some of the sensing technologies will be high risk, ultimately, the engineering team will select a technology that considers the technical capability, cost, and schedule constraints.



Concept & Technology Development



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Example: Imaging Spectroradiometer (Concept and Technology Development)

During the *Concept and Technology Development* phase, an imaging spectroradiometer technology will be selected by the project team. Also, working with stakeholders, optimal spacecraft orbits will be determined, launch opportunities will be identified, and the concept of operations will be developed. For example: in support of fire detection, the imaging spectroradiometer data collection approach, the data distribution methods and the operational data usage approach will be determined.



Concept of Operations



System Engineering Curriculum Intro,
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<https://ntrs.nasa.gov/citations/20210021839>

Example: Imaging Spectroradiometer Used for Fire Detection (Concept of Operations)

An imaging spectroradiometer is a light measurement tool which can measure the light emitted from a light source. Spectroradiometers are used in many applications, including LED measurement, the detection of oil slicks, solar ultraviolet radiation measurement and fire detection.

An example of an imaging spectroradiometer is shown in Figure 3 below:

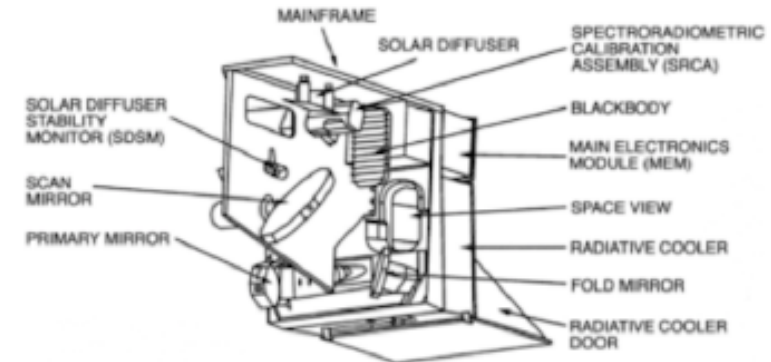


Figure 3 – The Moderate Resolution Imaging Spectroradiometer (MODIS)

Source: NASA Goddard Space Flight Center

For the planned concept, the imaging spectroradiometer is mounted on a spacecraft. As the spacecraft orbits the Earth, the imaging spectroradiometer measures and distributes data on light sources on the Earth's surface that are used to detect fires.

Some satellites that observe the Earth have a nearly polar orbit. These satellites move around the Earth from pole to pole, taking about 99 minutes to complete an orbit. During half of the orbit, the satellite views the daytime side of the Earth. At the pole, satellite crosses over to the nighttime side of Earth. As the satellites orbit, the Earth turns underneath. By the time the satellite crosses back into daylight, it is over the region adjacent to the area seen in its last orbit. In a 24-hour period, polar orbiting satellites will view most of the Earth twice: once in daylight and once in darkness. For the project, the imaging spectroradiometer would be mounted on a spacecraft operating in a polar orbit.

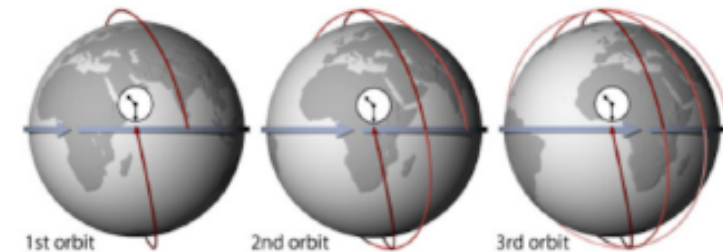


Figure 4 – Path of Satellite Orbiting Earth (Polar Orbit)

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Example: Imaging Spectroradiometer Used for Fire Detection (Requirements)

Based on the ConOps, at this phase, the initial requirements will be established:

Sample Requirements	
1.0	The imaging spectroradiometer shall have the ability to detect fires from Space
2.0	The imaging spectroradiometer shall be able to transfer spectroradiometer data to the spacecraft bus
3.0	The imaging spectroradiometer shall be able to measure imaging data during day or night from the Earth's surface
4.0	The imaging spectroradiometer measurement parameters shall be configurable

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Example: Imaging Spectroradiometer (Requirements Flow Down)

During the *Preliminary Design* phase, the project team will develop lower-level requirements. The requirements will define the capabilities of the imaging spectroradiometer or the properties of the spectroradiometer that meets the stakeholder's objectives to detect fires from space. Based on the ConOps, at this phase, the sample flow down requirements are presented in the table below:

Sample Flow Down Requirements	
1.0	The imaging spectroradiometer shall have the ability to detect fires from Space
1.1	The imaging spectroradiometer shall have the ability to detect the thermal signature of fires on the Earth's surface
1.2	The imaging spectroradiometer shall have the ability to detect fires from a low Earth orbit (up to 1,200 miles above the Earth)

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Example: Imaging Spectroradiometer Data Storage (Design Trade-offs)

An imaging spectroradiometer, will be hosted on a spacecraft operating in a low Earth polar orbit. The spacecraft will not have continuous access to Earth-based ground stations to collect data. The spacecraft will not always be in view of an applicable ground station. As a result, the imaging spectroradiometer will need the ability to store data, between transmission opportunities. However, when considering the design of the imaging spectroradiometer, the system weight, power and size of the storage device will be constrained by the limited operations specifications of the spacecraft. Based on these parameters, the storage design will need to consider the trade-offs between the size of the storage, based on spacecraft operational constraints, versus the risk of not collecting enough data to meet the mission objectives. Solutions that reduce the risk and meet the storage requirements will likely be expensive, due to the cost of a specialized miniaturized solution. As a result, cost will be a consideration in the design as well.



Preliminary Design & Technology Completion



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Example: Imaging Spectroradiometer (Preliminary Design and Technology Completion)

During the *Preliminary Design and Technology Completion* phase, the design of the imaging spectroradiometer will be completed. Any additional design changes beyond this point are expected to be refinements. Additionally, the hardware components will be selected, and software modules understood.

This phase culminates with a preliminary design review allows stakeholders and subject matter experts to review the design and its alignment with the requirements.



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[https://ntrs.nasa.gov/citations/
20210021839](https://ntrs.nasa.gov/citations/20210021839)

Example: Imaging Spectroradiometer (Final Design and Fabrication)

During the *Final Design and Fabrication* phase imaging spectroradiometer undergo final design and will be fabricated. This phase will culminate with a baseline hardware build, the completion of the software build and system interfaces to the spacecraft.



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[https://ntrs.nasa.gov/citations/
20210021839](https://ntrs.nasa.gov/citations/20210021839)

Example: Imaging Spectroradiometer (System Assembly, Integration and Test, Launch)

During the *System Assembly, Integration and Test, Launch* phase, the imaging spectroradiometer will be tested (verified) to determine if the device meets the project requirements, based on system analysis, inspection and demonstrated capabilities. Next, the imaging spectroradiometer will be integrated within the spacecraft system. It will then be tested (validated) again, to determine if it meets the intended purpose of the requirements, while operating within the spacecraft. All other elements of the spacecraft will be assembled, then the spacecraft will be launched into space. Once in space, the capabilities of the imaging spectroradiometer will be validated again.



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<https://ntrs.nasa.gov/citations/20210021839>

Example: Imaging Spectroradiometer Used for Fire Detection (Sustaining Engineering)

During Phase E, the imaging spectroradiometer will be operating in space and measuring light from the Earth's surface. Data from the imaging spectroradiometer will be transmitted to the spacecraft communications system. From the spacecraft, the data will be transmitted to resources on the Earth. The sustaining engineering elements in Phase E will include remote sensing and measurement, data transmission and system maintenance.



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20210021839](https://ntrs.nasa.gov/citations/20210021839)

Example: Imaging Spectroradiometer (Operations and Sustainment)

During the *Operations and Sustainment* phase, the imaging spectroradiometer will collect imaging data, discern which collected information represents fires on the Earth's surface and transmit the fire-related information to the spacecraft's communications system. Additionally, during this time operational changes may be made to the imaging spectroradiometer, based on things such as spacecraft orbital timing, cloud cover of events of interest on the Earth's surface. Furthermore, the imaging spectroradiometer may require maintenance related software updates over the lifetime of its operations.



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<https://ntrs.nasa.gov/citations/20210021839>

Example: Imaging Spectroradiometer (Closeout)

During the *Closeout* phase, systems decommissioning, and disposal are completed. Additionally, data from the imaging spectroradiometer should be analyzed. The imaging spectroradiometer will be mounted on a spacecraft in low earth orbit. When the spacecraft reaches the end-of-life, the orbit will be deorbited. This is accomplished by allowing the orbit to slowly decay until the satellite eventually burns up in the Earth's atmosphere.



Questions?



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