Space Systems Engineering

- Lecture #04 – September 5, 2024
- Background of Systems Engineering
- NASA program planning phases
- Scheduled milestones
- Requirements document
- Work breakdown structure
- Technology readiness levels
- Project management tools
- Risk tracking

Overview of Systems Engineering

- Developed to handle large, complex systems
  - Geographically disparate
  - Cutting-edge technologies
  - Significant time/cost constraints
  - Failure-critical
- First wide-spread applications in aerospace programs of the 1950's (e.g., ICBMs)
- Rigorous, systematic approach to organization and record-keeping

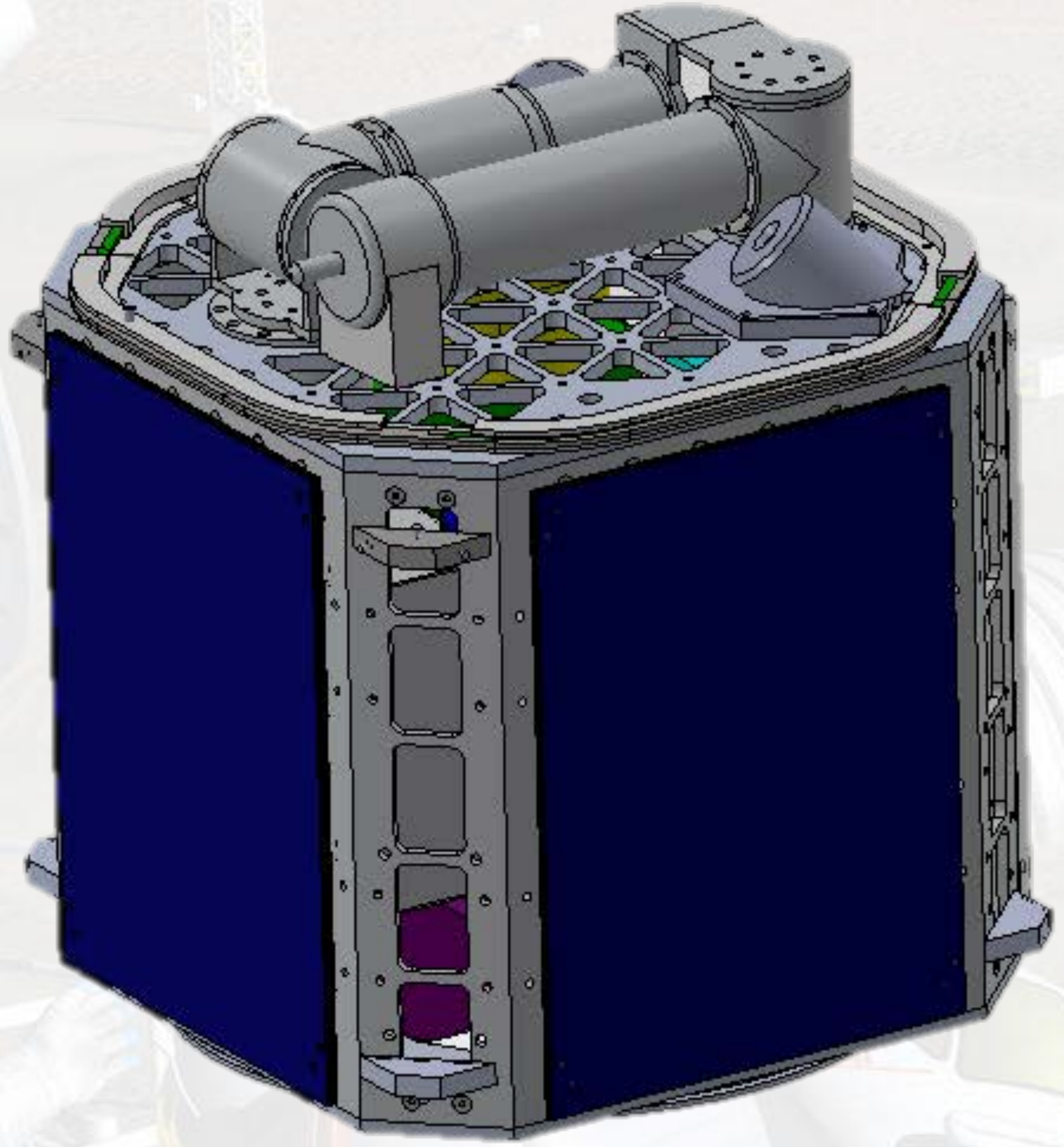
Mission Statement

- Should be a clear, unambiguous, definitive statement of the purpose of the program, and what it will achieve when complete
- Ideally a single sentence that evokes the fundamental rationale for what the program is and why it exists – “elevator pitch”

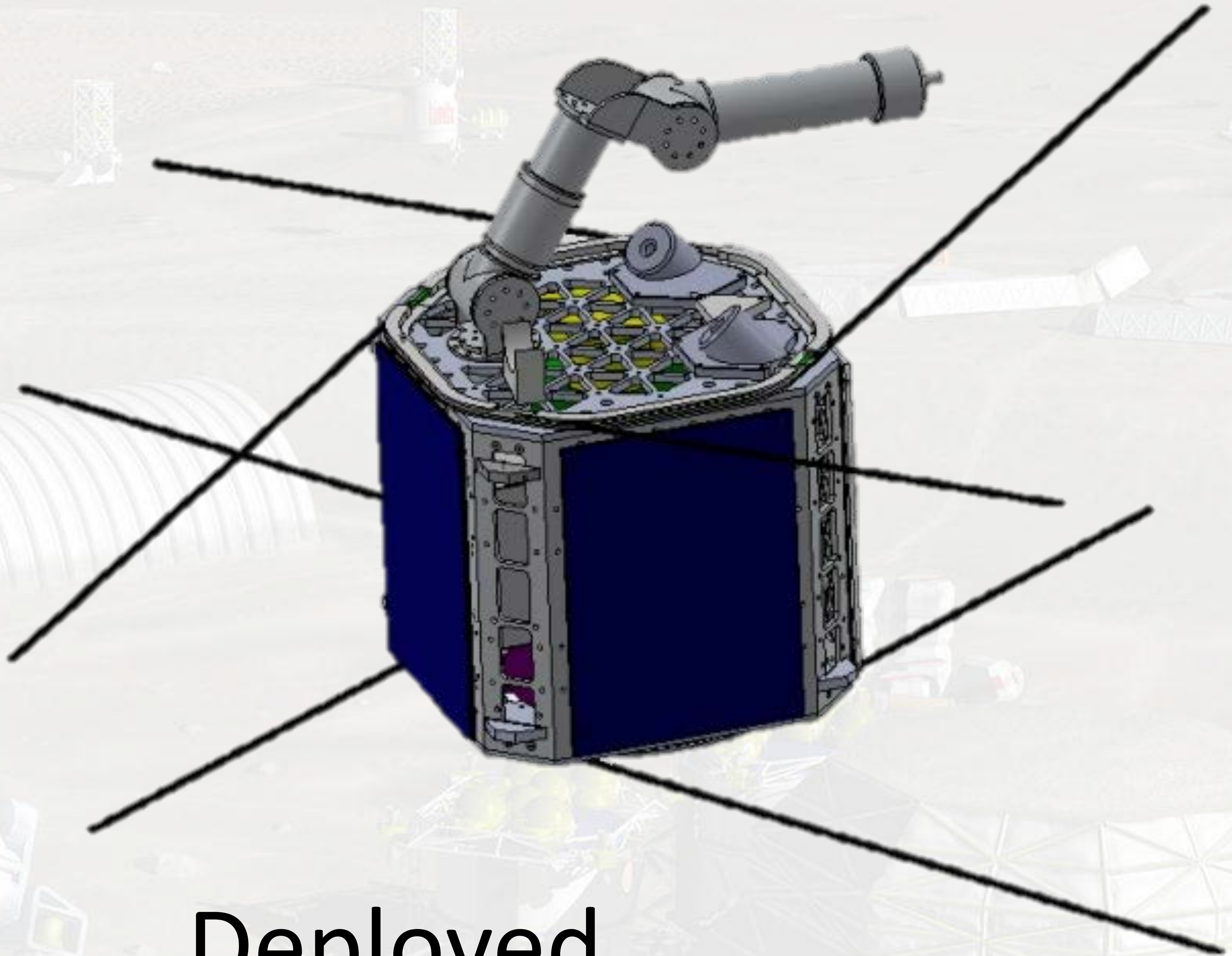
Apollo Program Mission Statement

"I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the Earth."

DYMAFLEX (Dynamic Manipulator Flight Experiment)



Stowed Configuration



Deployed Configuration

DYMAFLEX Mission Statement

- Investigate the coupled dynamics and associated control mitigation strategies for a free-flying vehicle with a high-performance manipulator performing tasks analogous to satellite servicing

Program Objectives

- Breaking down the Mission Statement into 3-6 top-level reasons for the mission
- Next level of explanation of rationale for program
- Usually transfers one-for-one into Level 1 requirements

DYMAFLEX Program Objectives

- Develop a microsatellite in the university environment through a program which maximizes opportunities for students to be involved in all aspects of the development process.
- Leverage three decades of advanced space robotics research in the development and flight demonstration of a space manipulator system
- Investigate the coupled dynamics and associated control mitigation strategies for a free-flying vehicle with a high-performance manipulator performing tasks analogous to satellite servicing

Requirements Document

- The "bible" of the design and development process
- Lists (clearly, unambiguously, numerically) what is required to successfully complete the program
- Requirements "flow-down" results in successively finer levels of detail
- May be subject to change as state of knowledge grows
- Critical tool for maintaining program budgets

Requirements Document Guidelines

- A requirement is a declarative statement of what a system must do in order to meet its mandatory functionality
- A requirement must be standalone; i.e., able to be understood by itself
- A requirement must be stated so that the designed and constructed system can be measured/tested/examined to determine if the requirement was met or not
- A requirement does not mandate how the system must be designed or constructed.
- Requirements should not be phrased in negative statements
  - Except for trivial cases it is impossible to examine a system to determine if a negative statement has been met by a system
  - "Impossible to prove a negative"

Requirements Grammar

- Despite the standard usage in English grammar as a first-person declarative, the verb “shall” is used universally to indicate a requirement, e.g. “The launch vehicle shall have a minimum payload to low Earth orbit of 20,000 kg”
- The verb “will” is used for a non-mandatory goal or desire, e.g. “The first stage will be capable of being reflow 20 times before major maintenance” (Could be an aspirational goal or evolutionary goal, for example)

DYMAFLEX Mission (L1) Requirements

M-1	DYMAFLEX shall include a robotic manipulator
M-2	DYMAFLEX shall be able to move the manipulator sufficiently fast as to cause larger dynamic coupling between manipulator and host vehicle than currently experienced on flown systems
M-3	DYMAFLEX shall be able to downlink telemetry of experiments to validate success of algorithms on the ground
M-4	DYMAFLEX shall operate in an environment where system dynamics dominates perturbations due to environmental effects
M-5	DYMAFLEX shall be able to introduce unknown values to control system by changing the mass configuration of its end effector
M-6	DYMAFLEX shall be able to return to a stable attitude after or during dynamic motions of the manipulator
M-7	DYMAFLEX shall simulate a variety of payload motions to cover desirable sets of future trajectories
M-8	DYMAFLEX shall maximize useful life on orbit by accepting new experiments from the ground

DYMAFLEX System (L2) Requirements

S-1	DYMAFLEX shall be able to perform a minimum set of trajectories: a single DOF, multi-axis linear and extended nonlinear
S-2	DYMAFLEX shall meet launch program's requirements (see UNP7 Users Guide)
S-3	DYMAFLEX shall be able to know its position, orientation, manipulator configuration, and lock state of tip masses
S-4	DYMAFLEX shall have sufficient communications capability to downlink a minimum of TBD Mb of experiment data within life of spacecraft
S-5	DYMAFLEX shall generate sufficient power (# watts TBD) to execute the minimum set of experiments and communicate results to ground
S-6	DYMAFLEX shall have multiple interchangeable tip masses for the manipulator
S-7	DYMAFLEX shall have sufficient computational power to perform realtime kinematic and manipulator control calculations
S-8	DYMAFLEX shall be able to put itself into a safe mode in the event of a critical anomaly

DYMAFLEX ROBO (L3) Requirements

S1-1	ROBO shall have a 4 DOF manipulator
S1-2	ROBO shall be able to change tip masses
S1-3	ROBO shall be capable of minimum end effector velocity of TBD m/s
S1-4	ROBO shall sense joint position, velocity, and torque
S1-5	ROBO shall sense motor controller temperature and current draw
S1-6	ROBO shall not extend below the Satellite interface plane (during or after deployment)

DYMAFLEX STRM (L3) Requirements

S2-1	The STRM shall have a natural frequency of at least 100 Hz with a goal of TBD Hz
S2-2	The STRM shall withstand g's in the x,y,z direction
S2-3	The STRM shall have a factor of safety of 2.0 for yield and 2.6 for ultimate for all structural elements
S2-4	STRM shall have a mass less than TBD grams with a goal of less than TBD grams
S2-5	STRM shall interface with lightband at satellite interface plane with 24 #1/4 bolts
S2-6	STRM shall not extend below Satellite interface plane (during or after deployments)
S2-7	STRM shall provide system with solar panels that will provide sufficient power for experiments
S2-8	STRM shall ensure CG for DYMAFLEX is within envelope (less than 0.5cm from lightband centerline, less than 40cm above satellite interface plane)
S2-9	STRM shall ensure final dimensions of DYMAFLEX meet requirements (50cm x 50cm x 60 cm tall)
S2-10	STRM materials shall meet all outgassing and stress corrosion cracking requirements
S2-11	STRM shall provide adequate venting such that the pressure difference is less then 0.5 psi with a factor of safety of 2

TBD/TBR

- TBD: To be determined
- TBR: To be resolved / reviewed
- Used when you know there should be a requirement but you don’t know what it should be
- Tracked as separate list of TBD / TBR items during development
- Contractors can assume the most advantageous values imaginable for bid preparation and charge for change orders afterwards

NASA HLS Requirements Document

Revision: Initial Release	Document No HLS-RQMT-001
RELEASE DATE: September 27, 2019	Page: 1 of 315
Title: HLS Requirements Document (SRD)	

National Aeronautics and Space Administration

HLS-RQMT-001
Initial Release
RELEASE DATE: September 27, 2019

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

HUMAN LANDING SYSTEM (HLS)
REQUIREMENTS DOCUMENT

⟸315 pages!

Sample HLS Requirements

4.1 Functional and Performance Requirements – Initial

HLS-R-0070 Daylight Operations - Initial

The initial HLS shall be capable of operating in continuous daylight conditions on the lunar surface.

Rationale: The initial mission will be designed to avoid lunar night, eclipse and occultation, such that the HLS will not need to survive periods of darkness on the surface.

HLS-R-0048 EVA Excursion Duration - Initial

The initial HLS shall be capable of supporting EVA excursions lasting a minimum of 4 hours.

Rationale: EVA excursion includes two suited crew, and begins when crew switch from HLS power to suit power, and ends when cabin repress is initiated upon return of crew. Nominal EVA excursion is 6 ± 2 hrs; lower end of that duration is the requirement for initial configuration. Final determination on duration of EVAs will be made by the science and surface operations team. HLS repress time must be compatible with GFE EVA resources in order to fully comply with requirement to support EVA excursions.

Requirements Verification Matrix

- Single spreadsheet tracking all requirements, sources, status, and documentation
- Broken down to successively finer levels of detail (frequently 4-6 levels)
- For a major program, the printed version can run to hundreds of pages
- Ensures that nothing gets overlooked and everything is done for a purpose

Requirements Verification Matrix

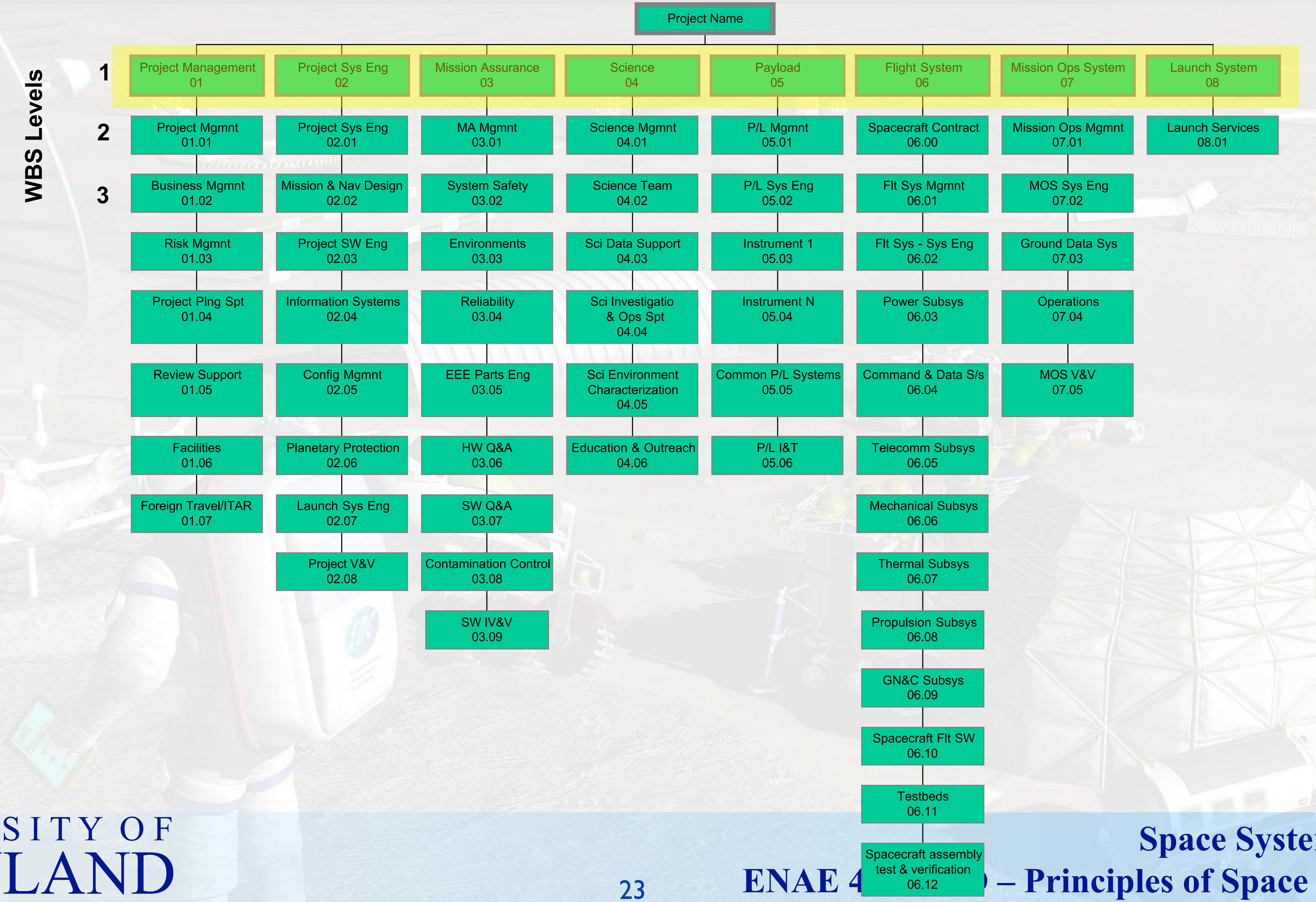
Mission Statement			
1		To investigate the coupled dynamics and associated control mitigation strategies for a free-flying vehicle with a high-performance manipulator performing tasks analogous to satellite servicing	
Requirements			
M		**Mission Requirements**	**Source**
	M-1	*DYMAFLEX shall include a robotic manipulator*	MS 1
	M-2	*DYMAFLEX shall be able to move the manipulator sufficiently fast as to cause larger dynamic coupling between manipulator and host vehicle than currently experienced on flown systems*	MS 1
	M-3	*DYMAFLEX shall be able to downlink telemetry of experiments to validate success of algorithms on the ground*	MS 1
	M-4	*DYMAFLEX shall operate in an environment where system dynamics dominates perturbations due to environmental effects*	MS 1
	M-5	*DYMAFLEX shall be able to introduce unknown values to control system by changing the mass configuration of its end effector*	MS 1
	M-6	*DYMAFLEX shall be able to return to a stable attitude after or during dynamic motions of the manipulator*	MS 1
	M-7	*DYMAFLEX shall simulate a variety of payload motions to cover desirable sets of future trajectories*	MS 1
	M-8	*DYMAFLEX shall maximize useful life on orbit by accepting new experiments from the ground*	MS 1
S		**System Requirements**	**Source**
	S-1	DYMAFLEX shall be able to perform a minimum set of trajectories: a single DOF, multi-axis linear and extended nonlinear	M-7
	S-2	DYMAFLEX shall meet launch program's requirements (see UNP7 Users Guide)	M-4
	S-3	DYMAFLEX shall be able to know its position, orientation, manipulator configuration, and lock state of tip masses	M-1, M-2
	S-4	DYMAFLEX shall have sufficient communications capability to downlink a minimum of 2.1 Mb of experiment data within life of spacecraft	M-3, M-7
	S-5	DYMAFLEX shall generate sufficient power (14.6 watts) to execute the minimum set of experiments and communicate results to ground	M-1, M-2, M-3, M-4, M-6, M-7
	S-6	DYMAFLEX shall have multiple interchangeable tip masses for the manipulator	M-5
	S-7	DYMAFLEX shall have sufficient computational power to perform realtime kinematic and manipulator control calculations	M-1, M-2, M-7
	S-8	DYMAFLEX shall be able to put itself into a safe mode in the event of a critical anomaly	M-6
S1		**Robotic Manipulator (ROBO)**	
	S1-1	ROBO shall have a 4 DOF manipulator	S-1
	S1-2	ROBO shall be able to change tip masses	S-6
	S1-3	ROBO shall be capable of minimum end effector velocity of 50 cm/s (TBR)	M-2
	S1-4	ROBO shall sense joint position, velocity, and torque	S-3
	S1-5	ROBO shall sense motor controller temperature and current draw	S-3
	S1-6	ROBO shall not extend below the Satellite interface plane (during or after deployment)	S-2
S2		**Structure and Mechanisms (STRM)**	
	S2-1	The STRM shall have a natural frequency of at least 100 Hz with a goal of TBD Hz	S-2
	S2-2	The STRM shall withstand g's in the x,y,z direction	S-2
	S2-3	The STRM shall have a factor of safety of 2.0 for yield and 2.6 for ultimate for all structural elements	S-2
	S2-4	STRM shall have a mass less than 27 kg with a goal of less than 25 kg	M-2
	S2-5	STRM shall interface with lightband at satellite interface plane with 24 #1/4 bolts	S-2
	S2-6	STRM shall not extend below Satellite interface plane (during or after deployments)	S-2

Work Breakdown Structures

- Detailed "outline" of all tasks required to develop and operate the system
- Successively finer levels of detail
  - Program (e.g., Constellation Program)
  - Project (Lunar Exploration)
  - Mission (Lunar Sortie Exploration)
  - System (Pressurized Rover)
  - Subsystem (Life Support System)
  - Assembly (CO_2 Scrubber System)
  - Subassembly, Component, Part, ...

NASA Standard WBS Levels 1 & 2

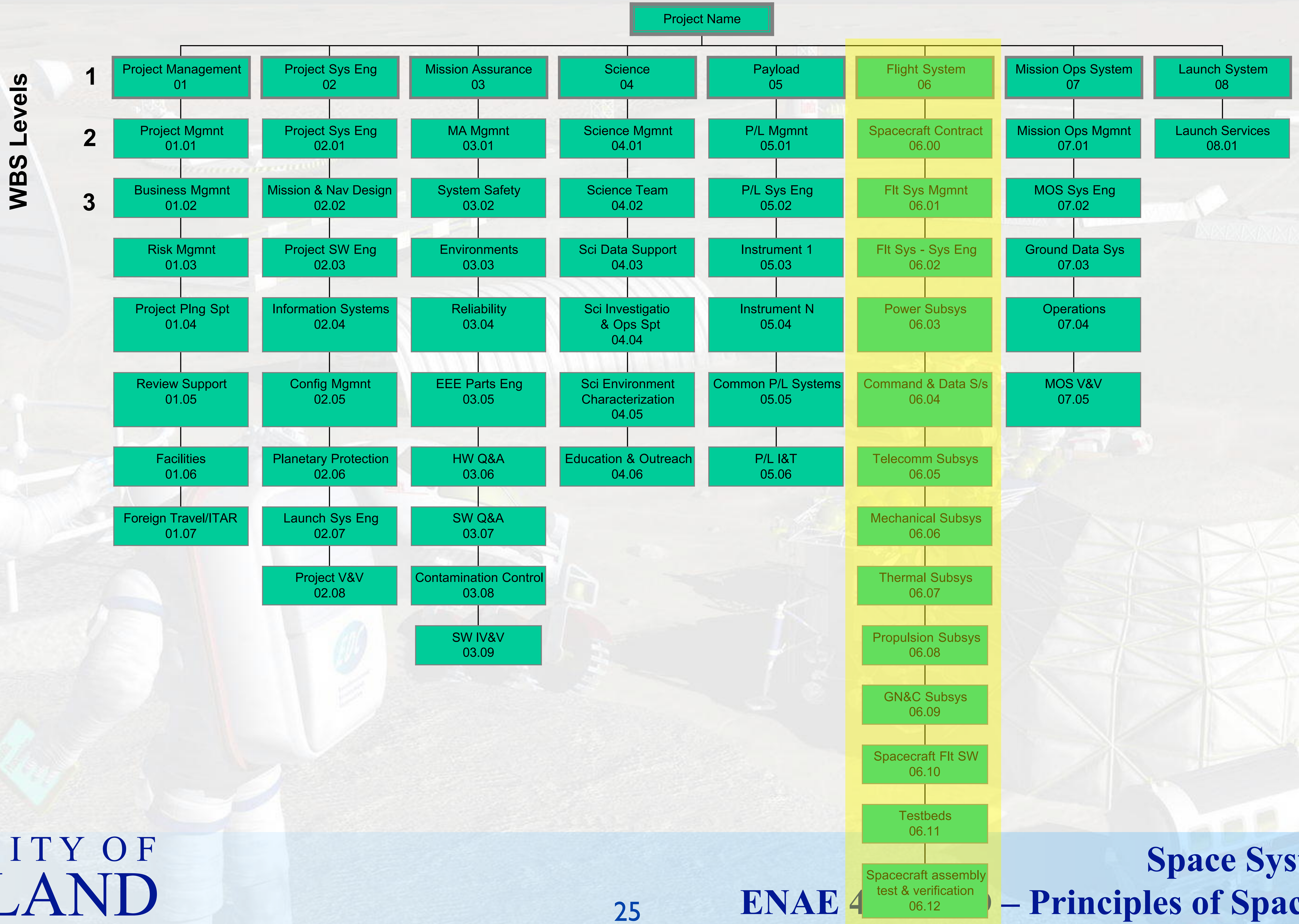
Standard WBS for JPL Missions



Detail across JPL WBS Level II

1. Project Management
2. Project Systems Engineering
3. Mission Assurance
4. Science
5. Payload
6. Flight System
7. Mission Operations System
8. Launch System

Standard WBS for JPL Missions



Detail in JPL “Flight Systems” Column

1. Spacecraft Contract
2. Flight Systems Management
3. Flight Systems - Systems Engineering
4. Power Systems
5. Command and Data Handling Systems
6. Telecommunications Systems
7. Mechanical Systems
8. Thermal Systems
9. Propulsion Systems
10. Guidance, Navigation, and Control Systems
11. Spacecraft Flight Software
12. Testbeds

Akin's Laws of Spacecraft Design - #24

It's called a "Work Breakdown Structure" because the Work remaining will grow until you have a Breakdown, unless you enforce some Structure on it.

Interface Control Documents

- Used to clearly specify interfaces (mechanical, electrical, data, etc.) between mating systems
- Critical since systems may not be fit-checked until assembled on-orbit!
- Success of a program may be driven by careful choices of interfaces
- KISS principle holds here ("keep it simple, stupid")

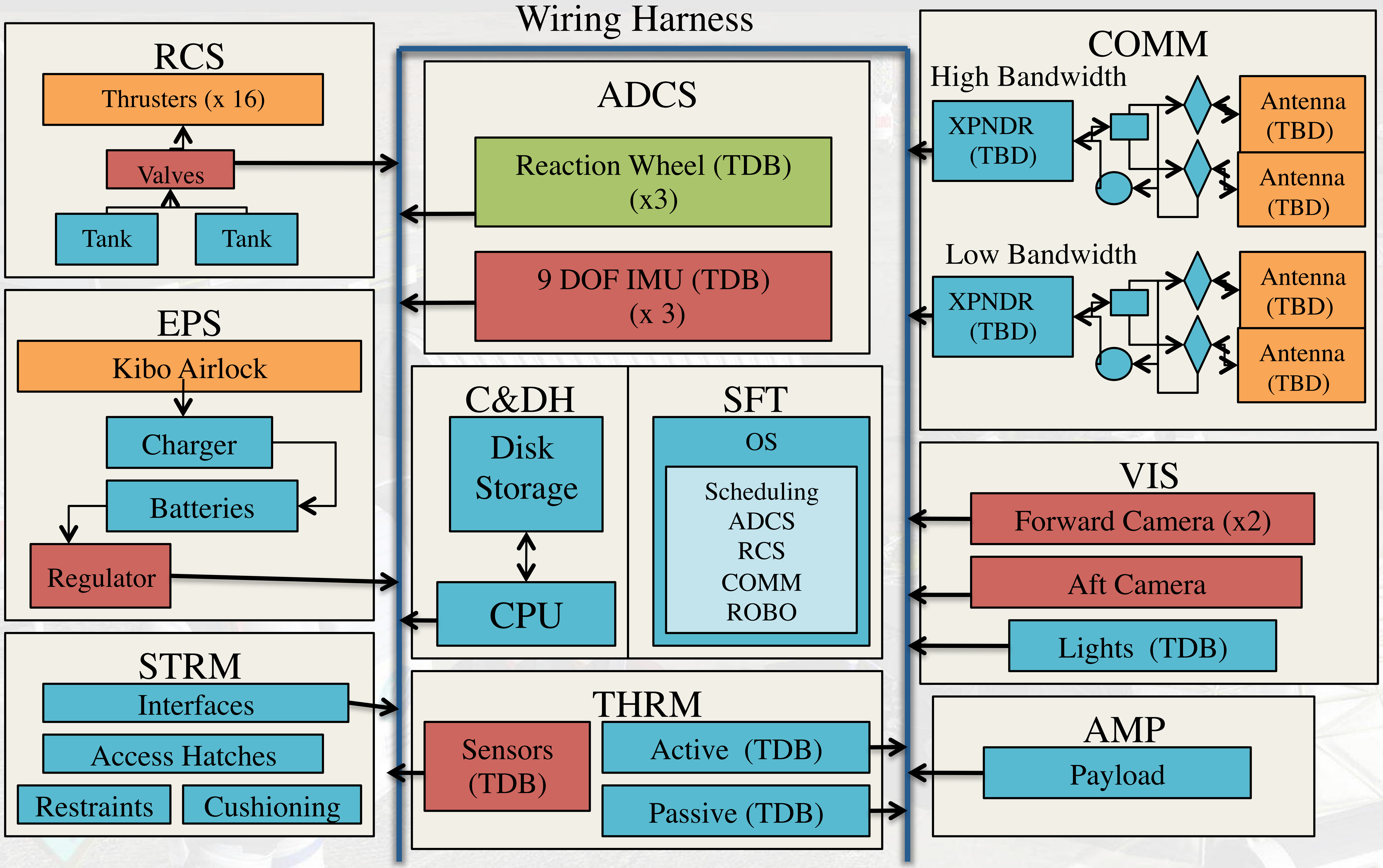
Akin's Laws of Spacecraft Design - #15

(Shea's Law) The ability to improve a design occurs primarily at the interfaces. This is also the prime location for screwing it up.

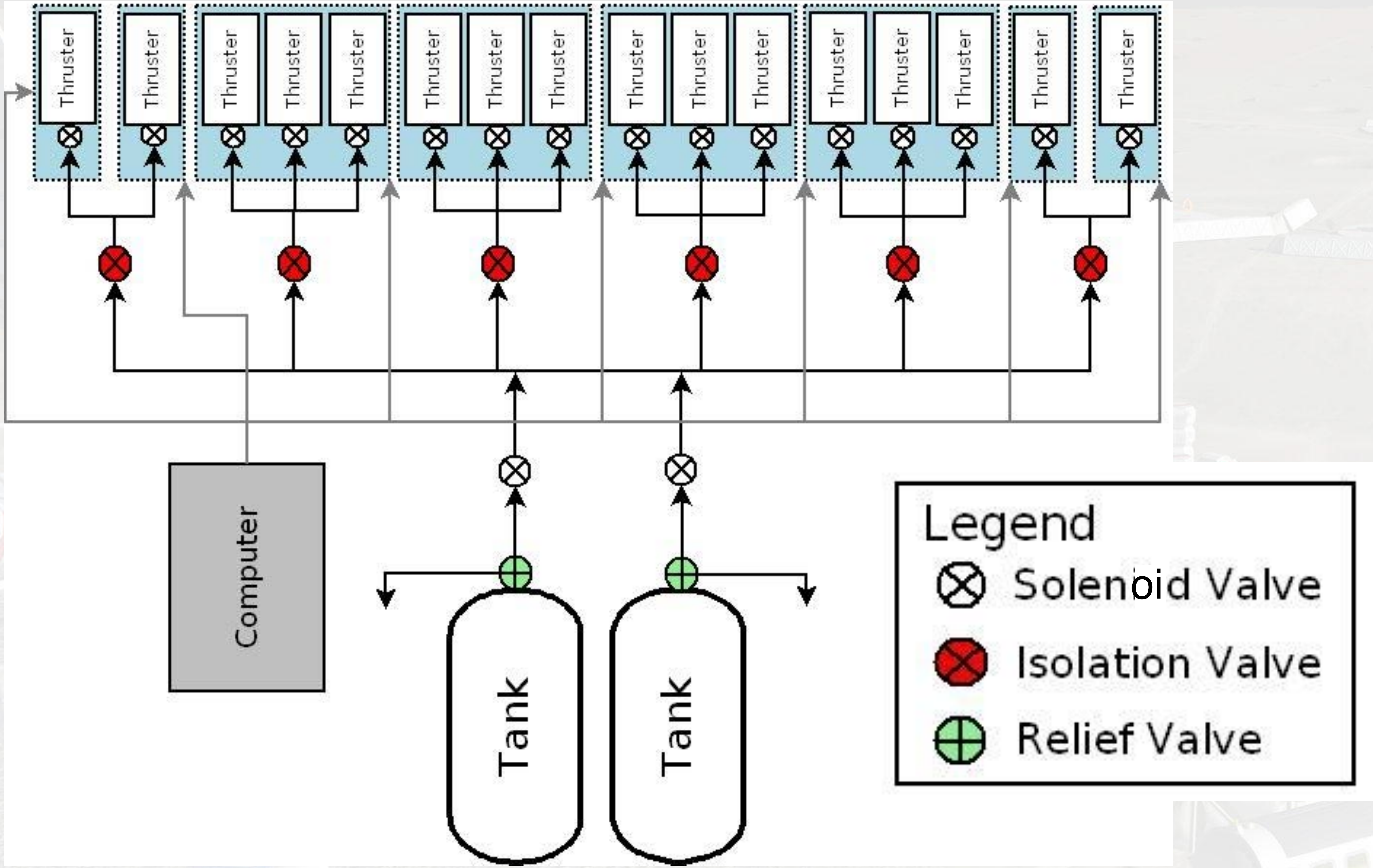
System Block Diagrams

- Shows interrelationships between systems
- Can be used to derive communication bandwidth requirements, wiring harnesses, delineation of responsibilities
- Created at multiple levels (project, spacecraft, individual systems and subsystems)

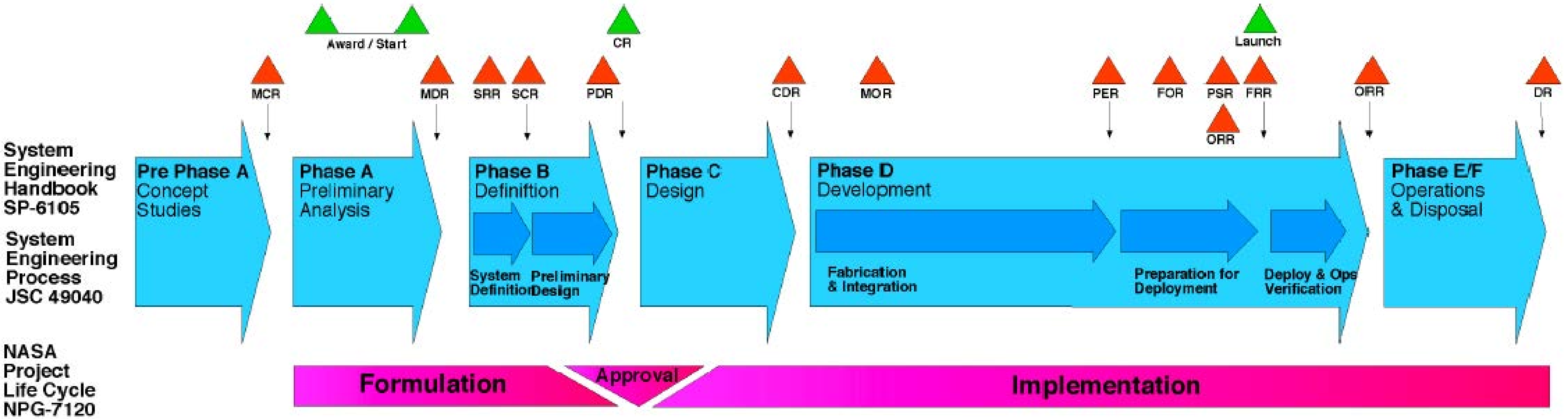
Exo-SPHERES S/C Block Diagram



Exo-SPHERES RCS Block Diagram



NASA Lifecycle Overview



Pre Phase A
- Define the Mission
- Study Multiple Approaches

Phase A
- Define Top Level Requirements
- Choose a single Approach

Phase B
- Complete the Requirements
- Complete Block Diagrams
- Allocation of Functions & Resources
- Definition of Interfaces
- Preliminary design

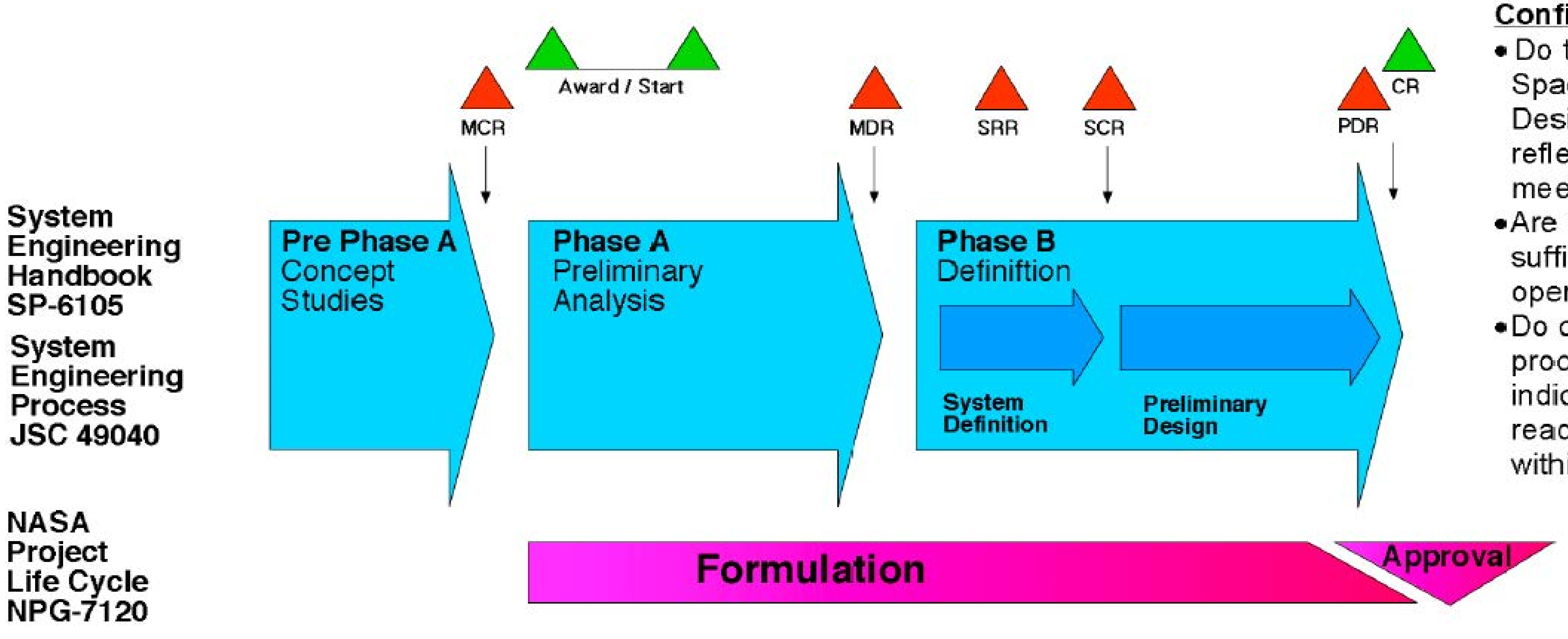
Phase C
- Complete the detailed system design,
- Drawings complete PDL complete

Phase D
- Build, integrate, verify, launch the system, and prepare for operations

Phase E/F
- Operate the system and dispose of it properly

From GPG 7120.5, NASA Goddard Program and Project Management Processes and Requirements

NASA Formulation Stage Overview



Confirmation Review
- Do the Mission Design, Spacecraft and Instrument Design, as presented at PDR reflect a PDR level design that meets science requirements?
- Are Management processes sufficient to develop and operate the mission
- Do cost estimates, control processes, and schedule indicate the mission will be ready to launch on time and within budget

NASA Mission Design Process EMC 1992

Pre Phase A
- Define the Mission
- Study Multiple Approaches
- Show one approach can work, Req, Design, Ops Concept
- MCR: Review Overall Approaches as baseline for Phase A

Phase A
- Studies & Trades Choose a single Approach, "Best Way" including Project Execution Cost and Schedule
- Define Top Level Requirements, Mission Success & Minimum Mission
- MDR: Review baseline for Phase B

Phase B
"Design the Right System"
System Definition:
- Complete the Requirements to Subsystem Level
- Identify Requirements flow between and across subsystems
- SRR: Review Requirements as baseline for final Concept
- Refine Concept, Consistent Req, Design, Ops Concept
- SCR: Review Design & Ops Concept

Preliminary Design:
- Allocation of Functions & Resources
- Complete Block Diagrams
- Requirements flow to Box Level
- Definition of Interfaces to at least Subsystem
- Complete a Preliminary design
- PDR: Review Reqs, Design, Ops as Baseline for Detailed Design

From GPG 7120.5, NASA Goddard Program and Project Management Processes and Requirements

Space Systems Formulation Process

Pre-Phase A

Conceptual Design Phase

Development of performance goals and requirements

Establishment of Science Working Group (science missions)

Trade studies of mission concepts

Feasibility and preliminary cost analyses

Request for Phase A proposals

Space Systems Formulation Process

Pre-Phase A

↓

Phase A

Preliminary Analysis Phase

Proof of concept analyses
Mission operations concepts
"Build vs. buy" decisions
Payload definition
Selection of experimenters
Detailed trajectory analysis
Target program schedule
RFP for Phase B studies

Space Systems Formulation Process

Pre-Phase A → Phase A → Phase B

<u>Definition Phase</u>

Define baseline technical solutions

Create requirements document

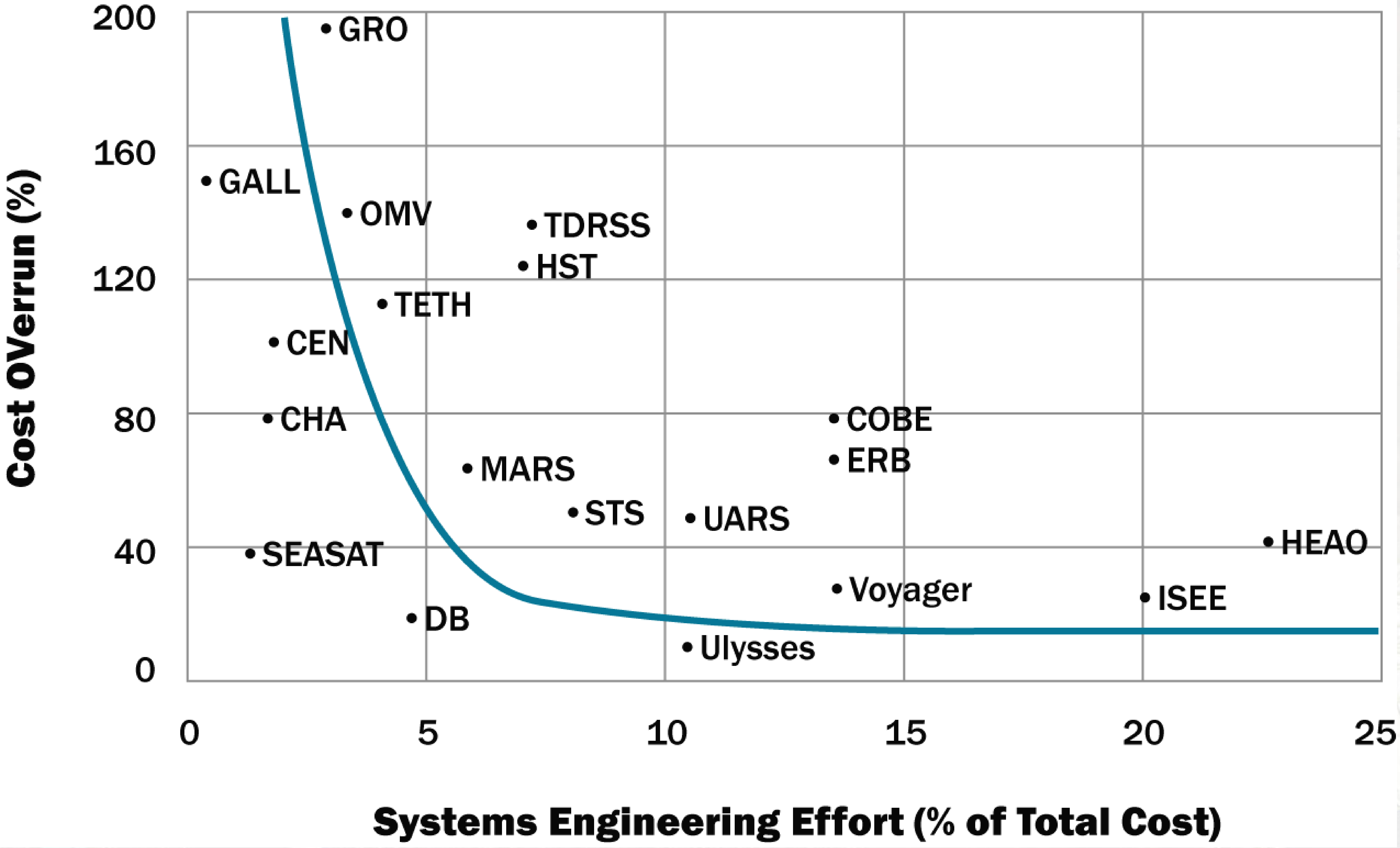
Significant reviews:

- Systems Requirements Review
- Systems Design Review
- Non-Advocate Review

Request for Phase C/D proposals

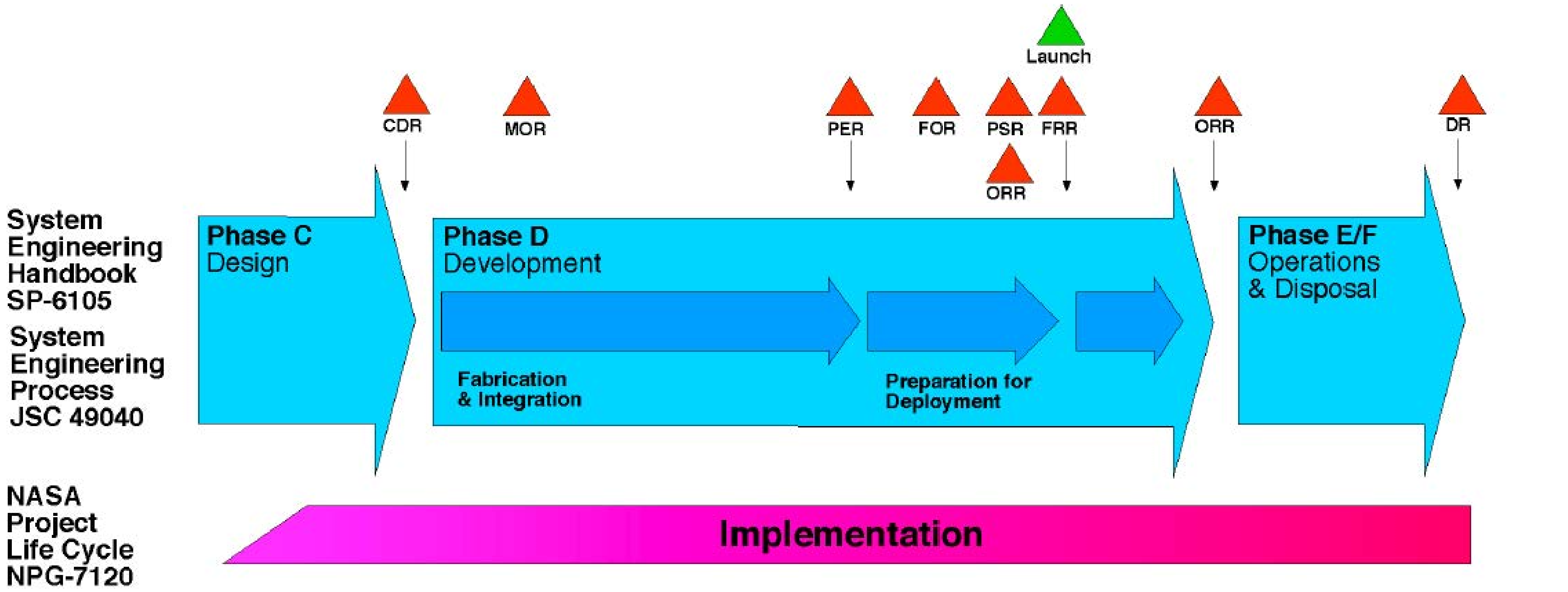
Ends with Preliminary Design Review (PDR)

Historical Implications of Study Phases



from J. A. Moody, ed., *Metrics and Case Studies for Evaluating Engineering Designs* Prentice-Hall, 1997

Implementation Stage Overview



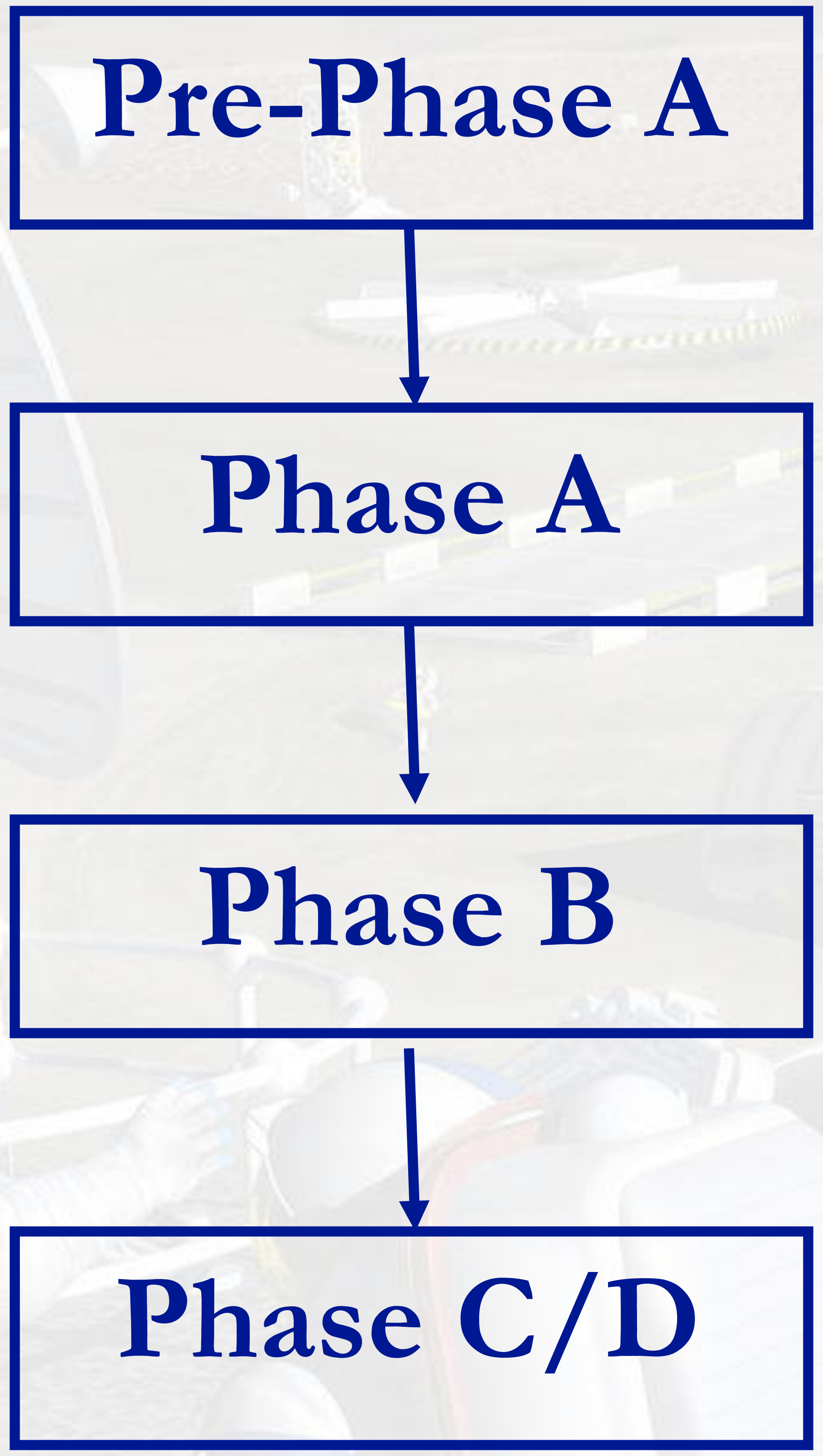
Phase C
"Design the System Right"
Complete the detailed system design,
"Design the System Right"
Drawings complete
PDL complete
CDR: Review Drawings and Test Plans

Pre Phase D
Build, integrate, verify, launch the system, and prepare for operations
Fabrication and Integration
TRR: Test Readiness
PER: Pre-Environmental Readiness
Verification & Preparation for Deployment
PSR: Pre-Ship Readiness
FRR: Flight Readiness
Deployment and Operations Verification
ORR: Operational Readiness

Phase E/F
Operate the system and dispose of it properly
DR: Disposal Review

From GPG 7120.5, NASA Goddard Program and Project Management Processes and Requirements

Space Systems Implementation Process



Development Phase

Detailed design process

"Cutting metal"

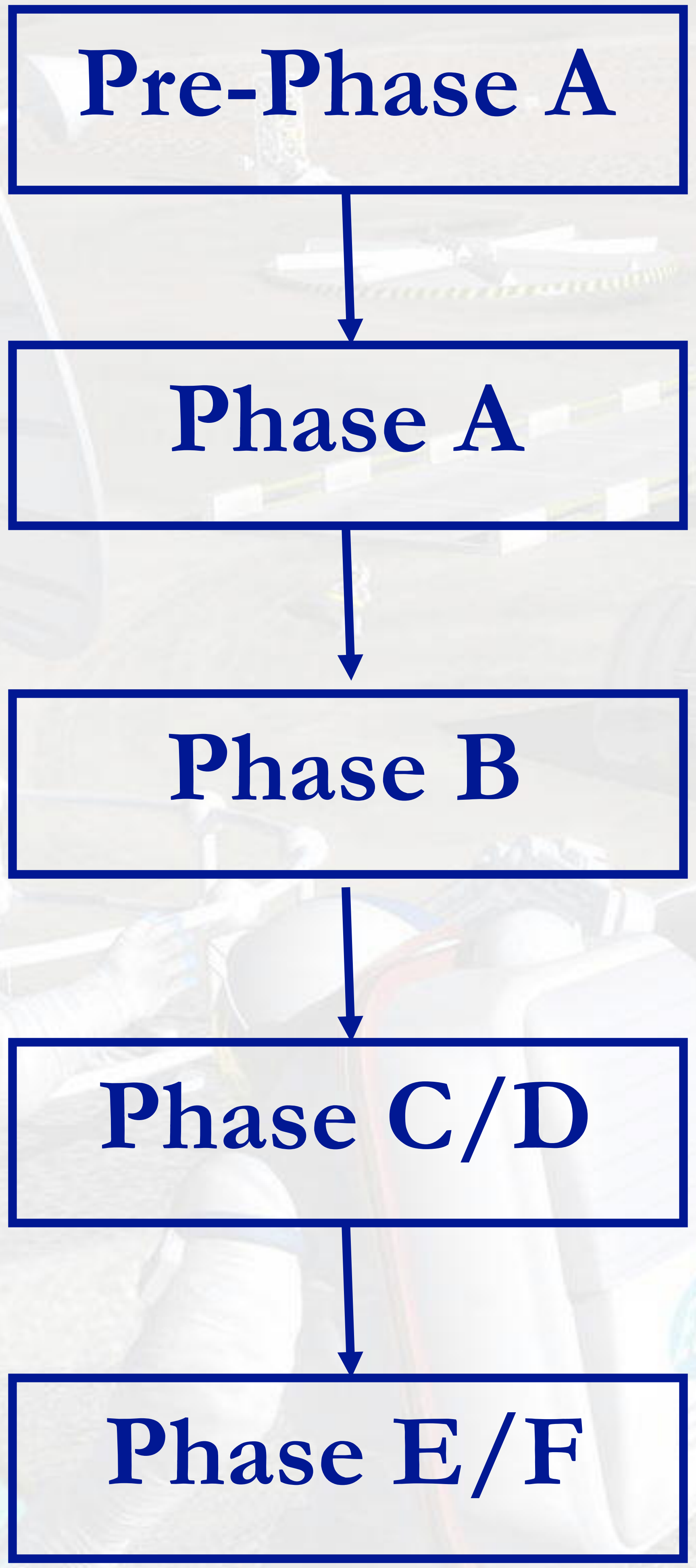
Test and analysis

Significant reviews:

- Critical Design Review (CDR)
- Test Acceptance Review
- Flight Readiness Review

Ends at launch of vehicle

Space Systems Implementation Process



Operations and End-of-Life

Launch

On-orbit Check-out

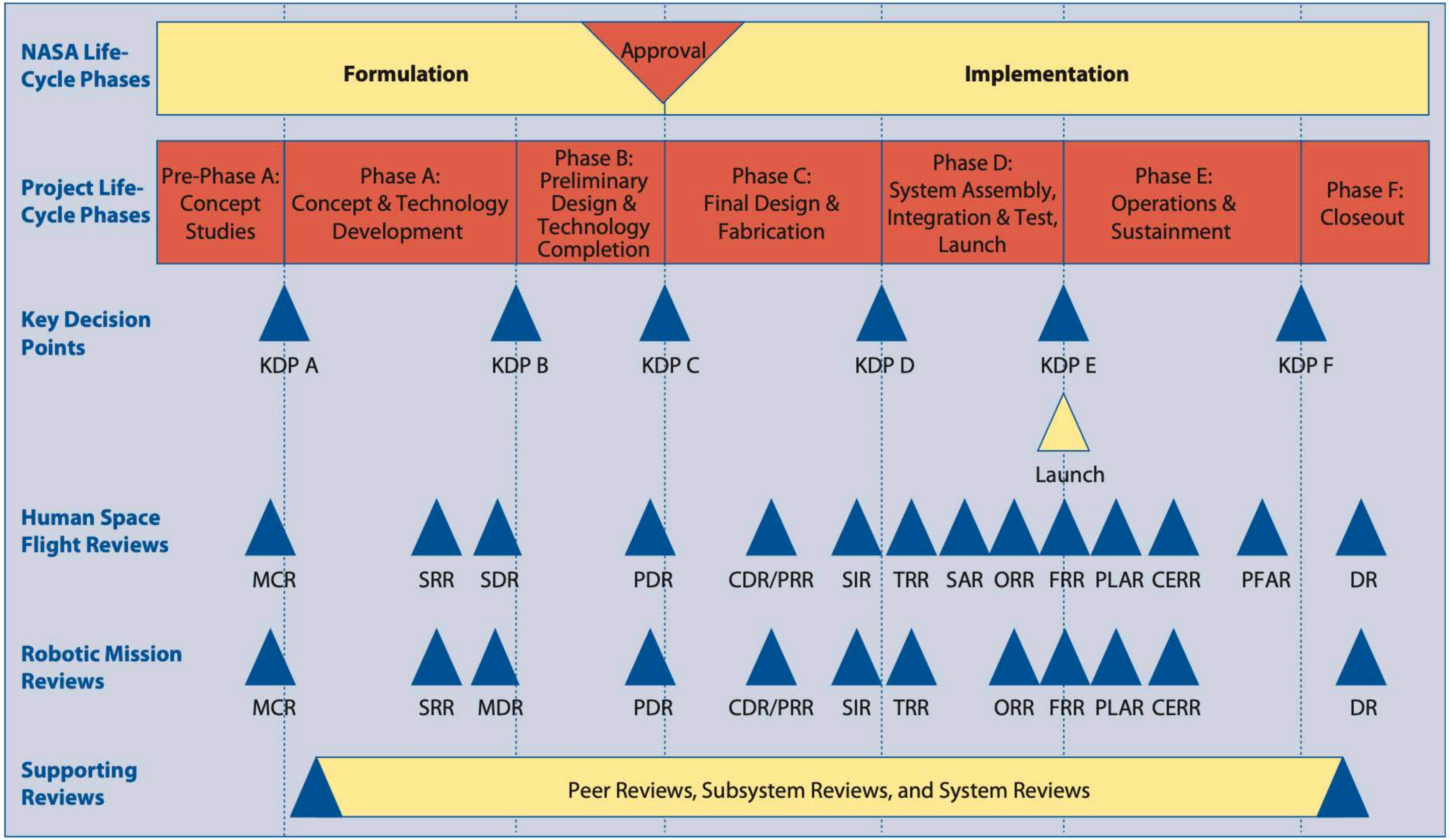
Mission Operations

Maintenance and Troubleshooting

Failure monitoring

End-of-life disposal

NASA Project Life Cycle - Milestones



from NASA SP-2007-6105 rev. 1, "NASA Systems Engineering Handbook"

Program Documentation

ISS Program Documentation Tree

SSP 50200: Station Program Implementation Plans

Payload Safety
- SSP 50062: NASA/CSA Bilateral Safety and Mission Assurance Requirements
- SSP 50145: NASA/NASDA Bilateral Safety and Product Assurance Requirements
- SSP 50146: NASA/RSA Bilateral Safety and Mission Assurance Process Requirements
- SSP 50182: NASA/ASI Bilateral Safety and Product Assurance Requirements
- SSP 50191: NASA/ESA Bilateral Safety and Product Assurance Requirements
- NSTS 1700.7B: Safety Policy and Requirements for Payloads Using the Space Transportation System
- NSTS 1700.7B, ISS Addendum: Safety Policy and Requirements for Payloads Using the International Space Station
- NSTS/ISS 13830: Payload Safety Review and Data Submittal Requirements for Payloads Using the ISS
- IP Transportation Vehicle Safety Documents <TBD D.23>
- NSTS/ISS 18798: Interpretations of NSTS/ISS Payload Safety Requirements
- KHB 1700.7: Space Shuttle Ground Safety Handbook
- SSP 52005: Payload Flight Equipment Requirements and Guidelines for Safety-Critical Structures
- SSP 57025: ISS Payload Interface System Fault Tolerance Document

Transportation Vehicle Requirements
- NSTS 21000-IDD-ISS: Space Shuttle Program-to-Space Station Program IDD
- NSTS 21000-IDD-SML: Shuttle/Payload IDD for Small Payload Accommodations
- NSTS 21000-IDD-MDK: Shuttle/Payload IDD for Middeck Accommodations
- RPO1193: Progress M Cargo Transport Vehicle Technical Description
- <TBD D.18>: IP Transportation Vehicle Documents

SSP 57011: Payload Verification Program Plan

SSP 57057: ISS Payload Integration Template

SSP TBD: IDRD Annex 5, Payload Tactical Plan Blank Book

SSP 52054: ISS Program Payloads Certification of Flight Readiness Implementation Plan, Generic

Payload Integration Agreements
- 57059: Standard Payload Integration Agreement (PIA) for Pressurized Payloads
- SSP 57060: Payload Integration Agreement Increment Addendum Blank Book for Pressurized Payloads
- 57061: Standard Integration Agreement PIA Blank Book for Unpressurized Payloads
- SSP-57062 : Payload Integration Agreement Increment Addendum Blank Book for Unpressurized Payloads
- SSP-57063: Standard Payload Integration Agreement Blank Book for Small Payloads (Pressurized)
- SSP 52000-EIA-ERP: EXPRESS Integration Agreement (EIA) Blank Book for EXPRESS Rack Payloads
- SSP 52000-EIA-EPP: EXPRESS Integration Agreement (EIA) Blank Book for EXPRESS Pallet Payloads
- JFX-<TBD D.4>: PIA Blank Book for JEM Exposed Facility Payloads

SSP 52000-PDS: Payload Data Sets Blank Book
1. Payload Configuration
2. Payload Training Requirements
3. Payload Planning Requirements
4. Ground Data Services Requirements**
5. Payload Operations Requirements
6. Payload Procedures & Displays
7. KSC Technical Requirements
8. KSC Support Requirements
9. Extravehicular Activity Requirements
10. Extravehicular Robotics Requirements

**Unilateral NASA Data Set

Payload Interface Requirements and Verification Documents
- SSP 57000: Pressurized Payloads Interface Requirements Document
- SSP 57003: Attached Payload Interface Requirements Document
- SSP 57001: Pressurized Payload Hardware Interface Control Document (ICD) Template
- SSP 57004: Attached Payloads Hardware ICD Template
- JCX-99041: JEM Pressurized Payloads Standard ICD
- JCX-95055: JEM Exposed Facility Payloads Standard ICD
- <TBD D.5>: APM ICD Template
- SSP 57002: Payload Software ICD Template
- SSP 57010: Generic Payload Verification Plan for Pressurized Payloads
- SSP 57013: Generic Payload Verification Plan for Attached Payloads
- JFX-<TBD D.6>: JEM EF Standard Payload Verification Plan
- JFX-<TBD D.7>: JEM PM Standard Payload Verification Plan
- <TBD D.8>: APM Generic Payload Verification Plan
- <TBD D.10>: RSA Interface Documents

ISS Payload Accommodations Handbooks
- SSP 57020: Pressurized Payload Accommodations Handbook (PAH)
- SSP 57021: Attached Payload Accommodations Handbook
- SSP 52000-PAH-KSC: KSC Payload Launch Site Processing PAH
- SSP 57800: Payload Software Integration and Verification PAH
- MLM-HB-AI-001: Multi-Purpose Logistics Module Cargo Accommodations Handbook
- SSP 50467: ISS Cargo Stowage Technical Manual: Pressurized Volume
- <TBD D.17>: RSA Payloads Accommodations Handbook
- JCX-<TBD D.9>: JEM Payload Accommodations Handbook
- COL-RIBRE-MA-0007-00: Columbus Payload Accommodations Handbook Attached Pressurized Module
- SSP 52000-UG-ERP: User's Guide for EXPRESS Rack
- SSP 52000-UG-EPP: User's Guide for EXPRESS Pallet

Payload Operations Reference Documents
- SSP 50305: Payload to Generic User Interface Definition Document
- SSP 50323: Payload Users Development Guide
- SSP 50254: Operations Nomenclature
- SSP-50313: Display and Graphic Commonality Standard
- SSP 50323: Payload User Development Guide (PUDG) for the Space Station Training Facility (SSTF) Payload Training Capability (PTC)
- SSP 50503: International Space Station Onboard Training Media Requirements
- SSP 58200: Multilateral Payload Regulations
- SSP 58026-01: Generic Payload Simulator Requirements Document Volume 1
- SSP 58304-01: Ground Support Personnel Training and Certification Plan
- SSP 58309: Payload Training Implementation Plan
- SSP 58313: NASA Payload Regulations
- SSP 58700: U.S. Payload Operations Data File Management Plan

NASA Project Life Cycle - Acronyms

CDR	Critical Design Review	PLAR	Post-Launch Assessment Review
CERR	Critical Events Readiness Review	PRR	Production Readiness Review
DR	Decommissioning Review	P/SDR	Program/System Definition Review
FRR	Flight Readiness Review	P/SRR	Program/System Requirements Review
KDP	Key Decision Point	PSR	Program Status Review
MCR	Mission Concept Review	SAR	System Acceptance Review
MDR	Mission Definition Review	SDR	System Definition Review
ORR	Operational Readiness Review	SIR	System Integration Review
PDR	Preliminary Design Review	SRR	System Requirements Review
PFAR	Post-Flight Assessment Review	TRR	Test Readiness Review
PIR	Program Implementation Review		

from NASA SP-2007-6105 rev. 1, "NASA Systems Engineering Handbook"

Design Reviews

- Design team gives a detailed presentation on the current state of the design
- Major reviews are preceded by technical area reviews; each review often takes multiple days
- Panel(s) of experts sit through reviews and use their experience to question decisions, processes, or assumptions
- Issues unresolved verbally result in a formal review item

Review Item Process

- Review board member writes up one-page form – RID ("review item disposition")/RFA ("request for action")
  - What is the perceived problem?
  - What is the suggested action?
- Review board chair and program manager select RIDs that need to be formally tracked
- Team performs analysis and replies to RID author, who can accept or reject
- Review board chair formally closes RID
- List of open items is tracked by team; usually first item in the next review
- If a review goes badly enough, can hold a "Delta review" and do part or all of it over again

Technology Readiness Levels

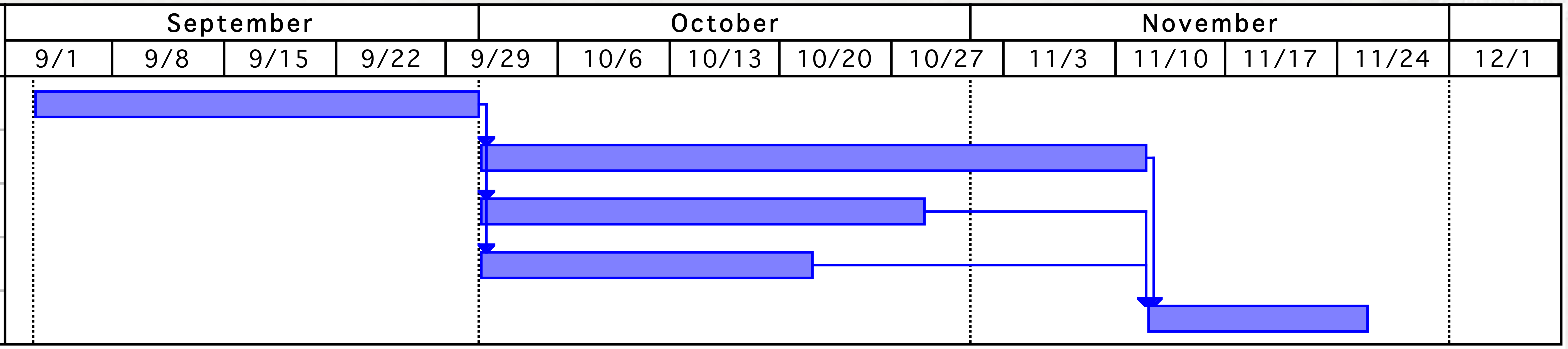
TRL 9	Actual system "flight proven" through successful mission operations
TRL 8	Actual system completed and "flight qualified" through test and demonstration
TRL 7	System prototype demonstration in the real environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment
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

Scheduling

- Need for track schedules to ensure that program is successfully completed on time
- Gantt chart (“waterfall chart”) – shows actual time required, but only implies sequence constraints
- PERT chart – clearly shows dependencies and sequences, but doesn’t give an analog representation of time

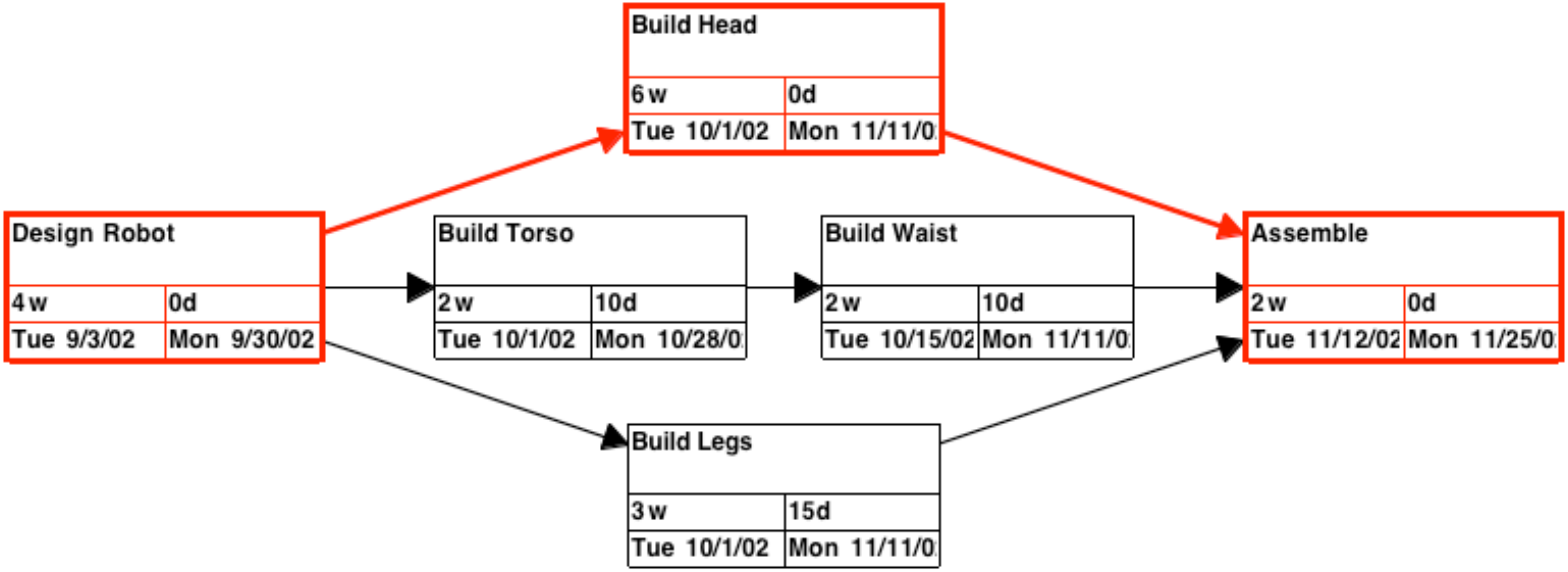
Gantt* Charts

ID	Task Name	Duration	Start	Finish	Predec
1	**Design Robot**	**4 w**	**Tue 9/3/02**	**Mon 9/30/02**	
2	**Build Head**	**6 w**	**Tue 10/1/02**	**Mon 11/11/02**	**1**
3	**Build Body**	**4 w**	**Tue 10/1/02**	**Mon 10/28/02**	**1**
4	**Build Legs**	**3 w**	**Tue 10/1/02**	**Mon 10/21/02**	**1**
5	**Assemble**	**2 w**	**Tue 11/12/02**	**Mon 11/25/02**	**2,3,4**



***developed by Charles Gantt in 1917**

PERT Charts*

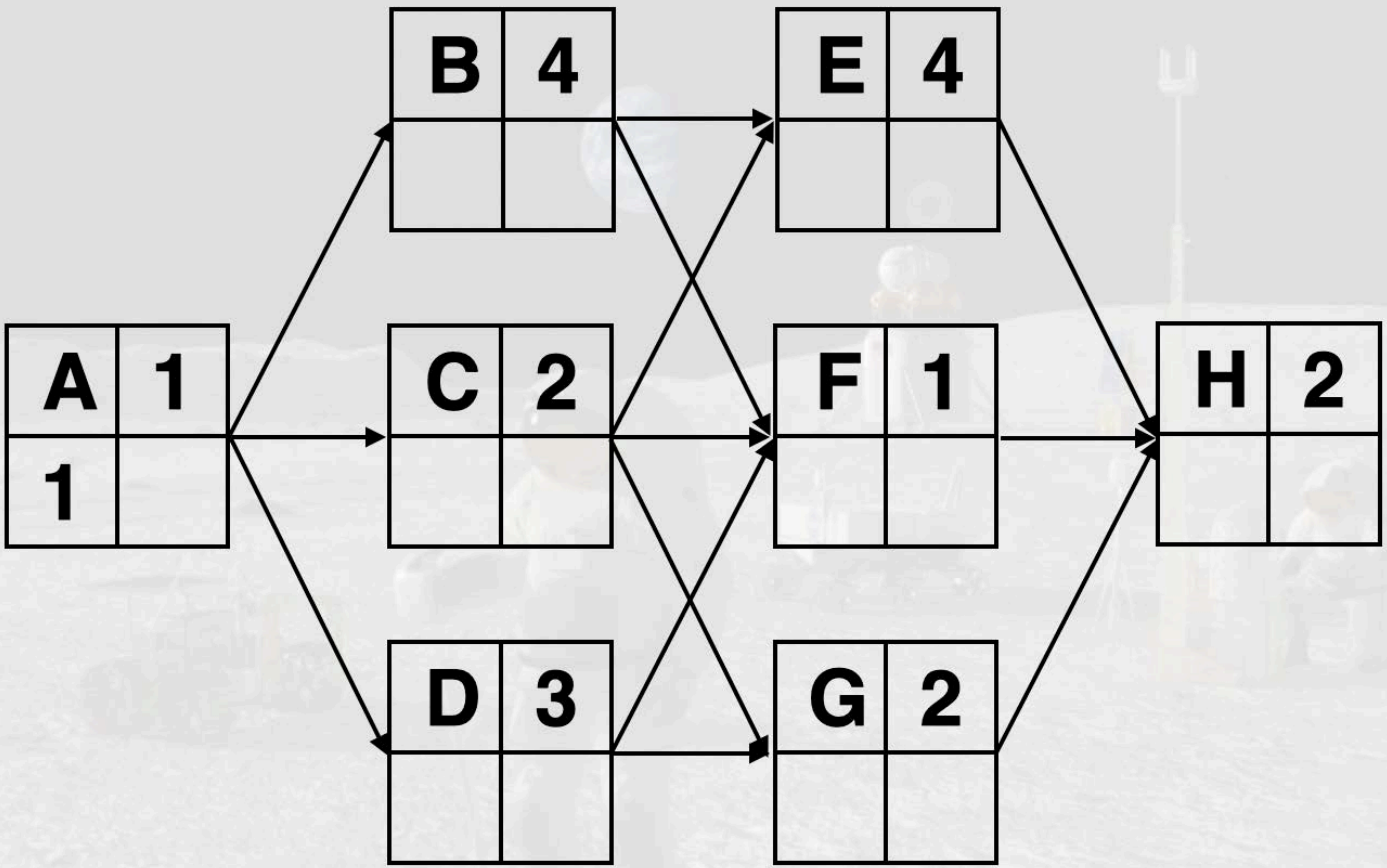


*Program Evaluation and Review Technique

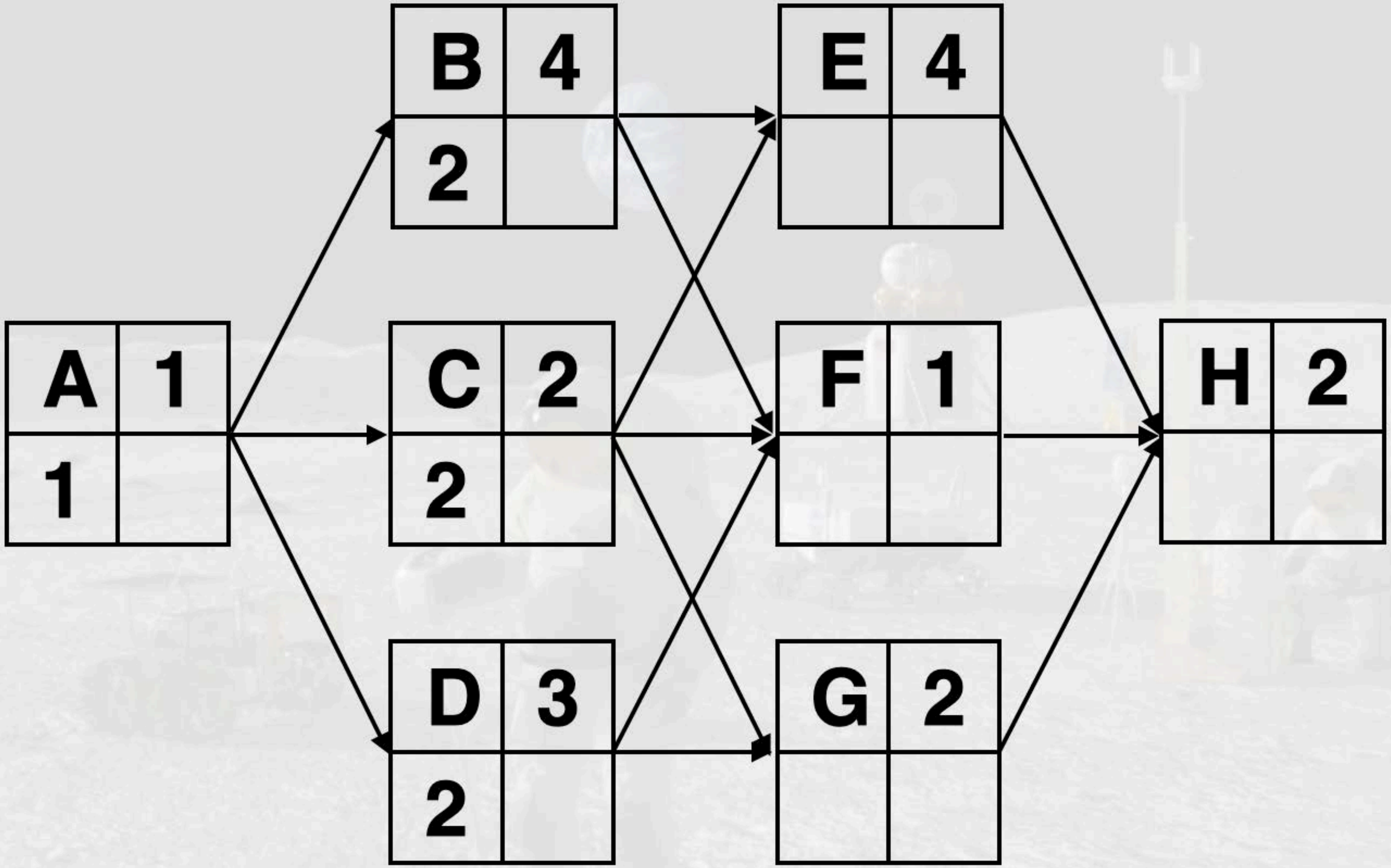
A Simple Approach to PERT Charts – Notation

Task Name	A	1	Task Duration
Earliest Start Time	1	1	Latest Start Time

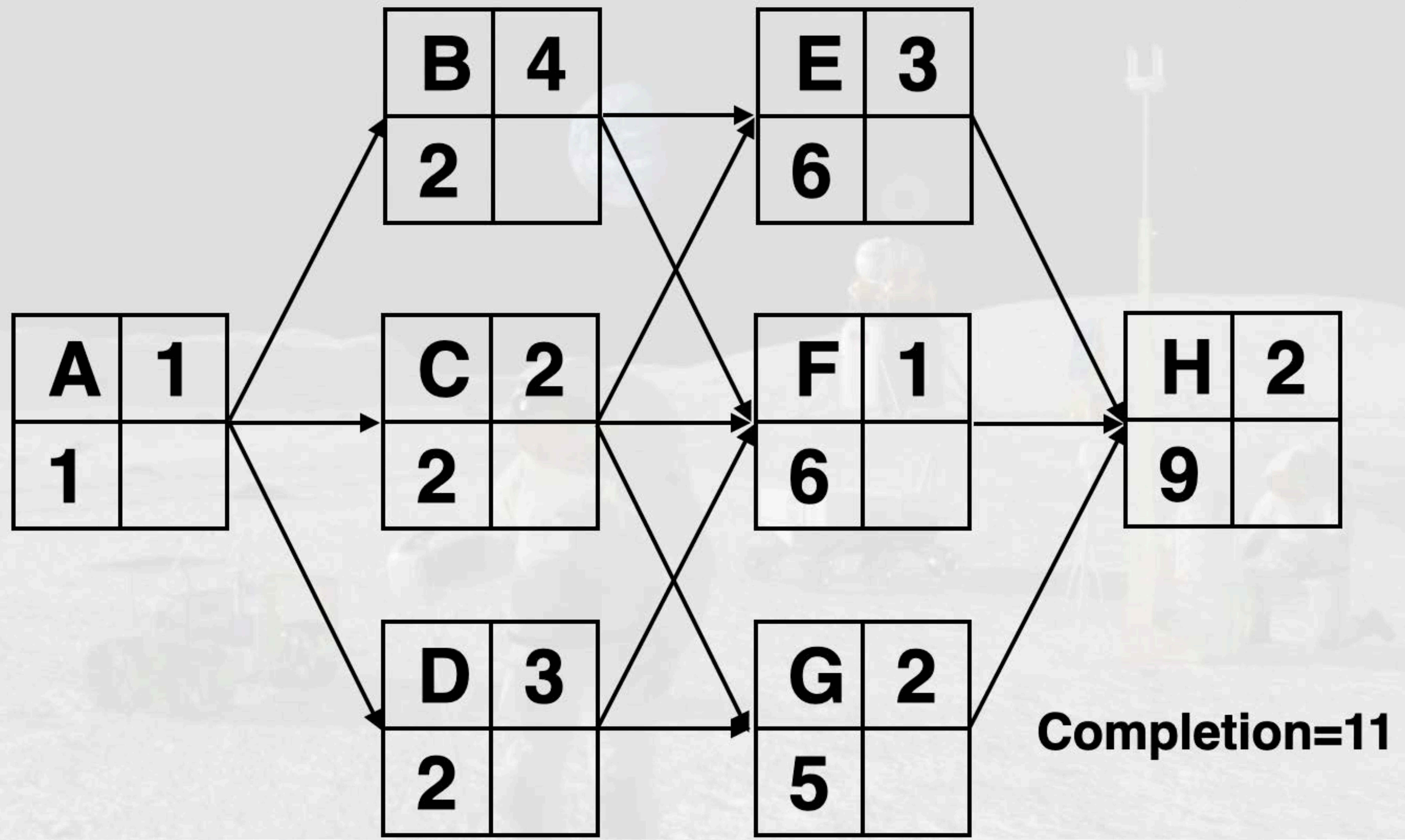
Start With Basic Network Structure



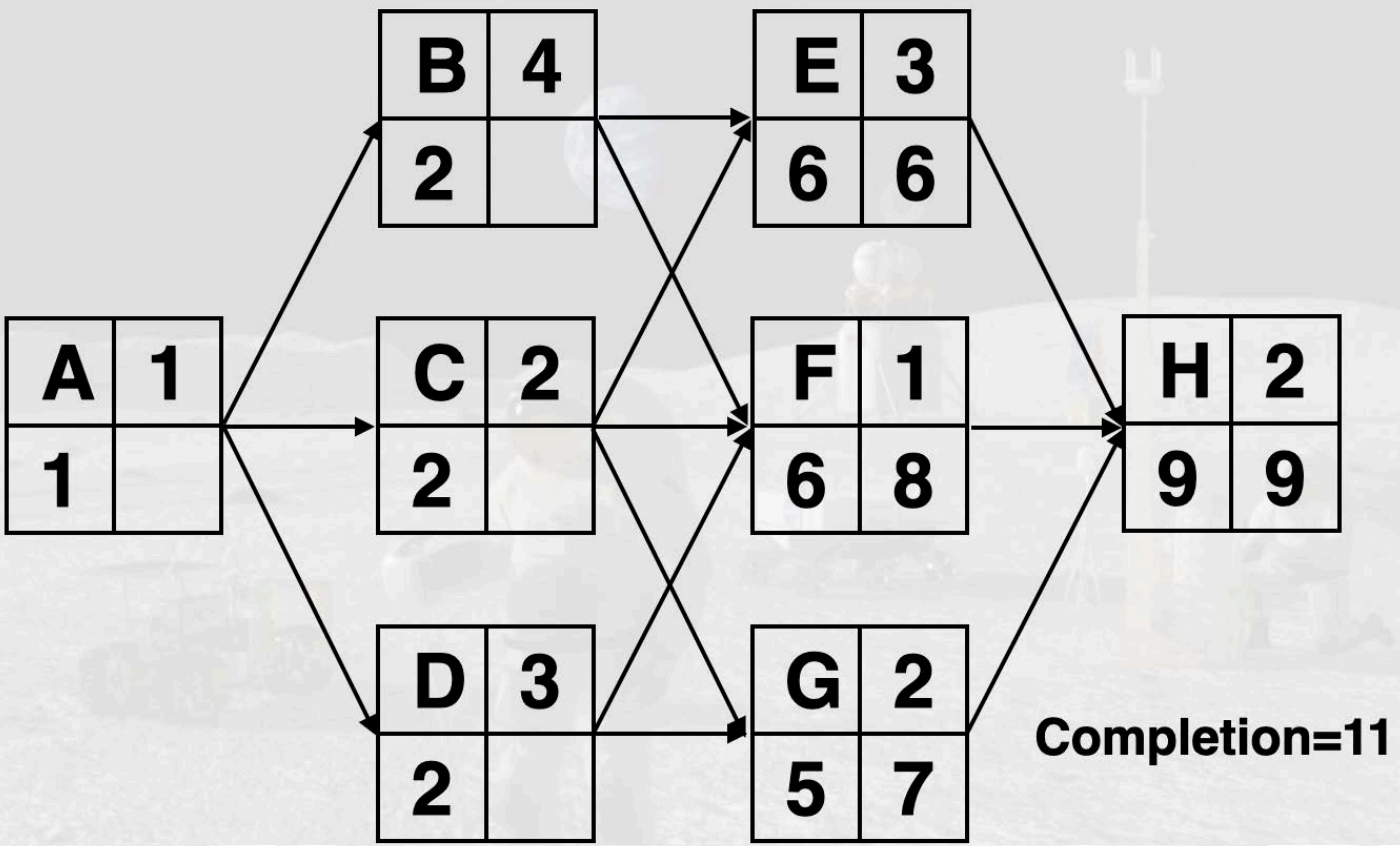
Propagate Forward for Earliest Start Dates



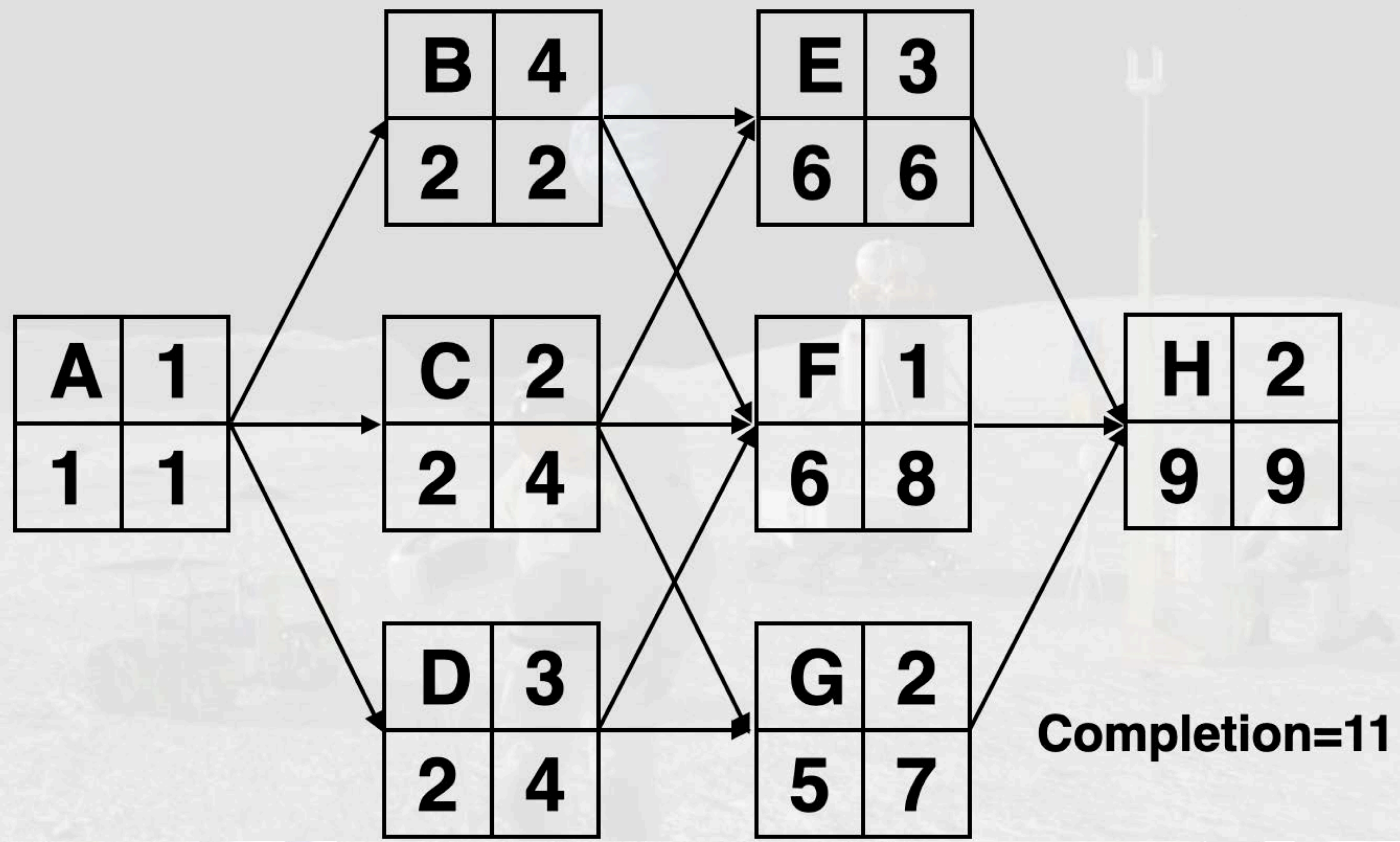
Continue Start Date Propagation to End



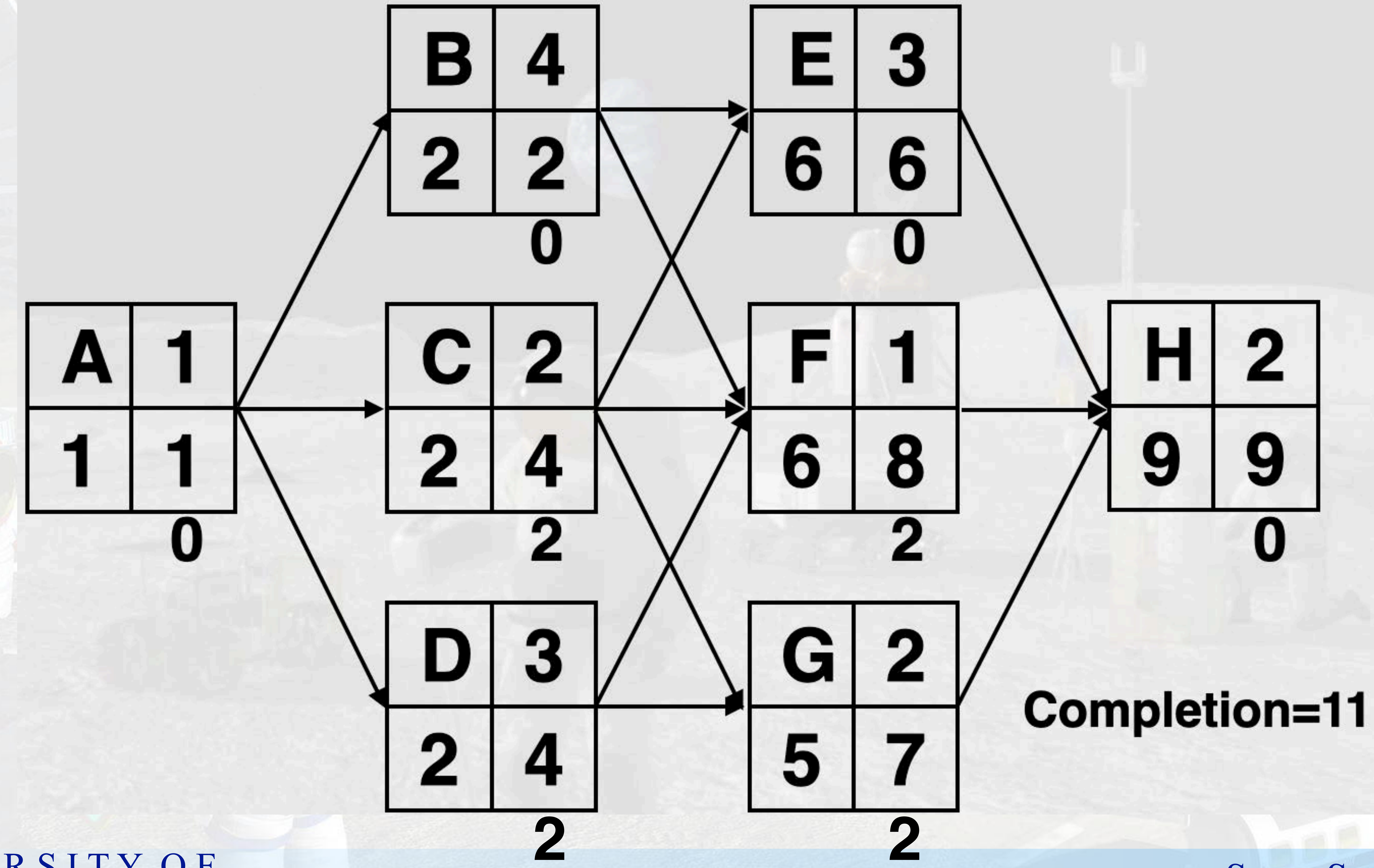
Propagate Backwards to Find Latest Start Dates



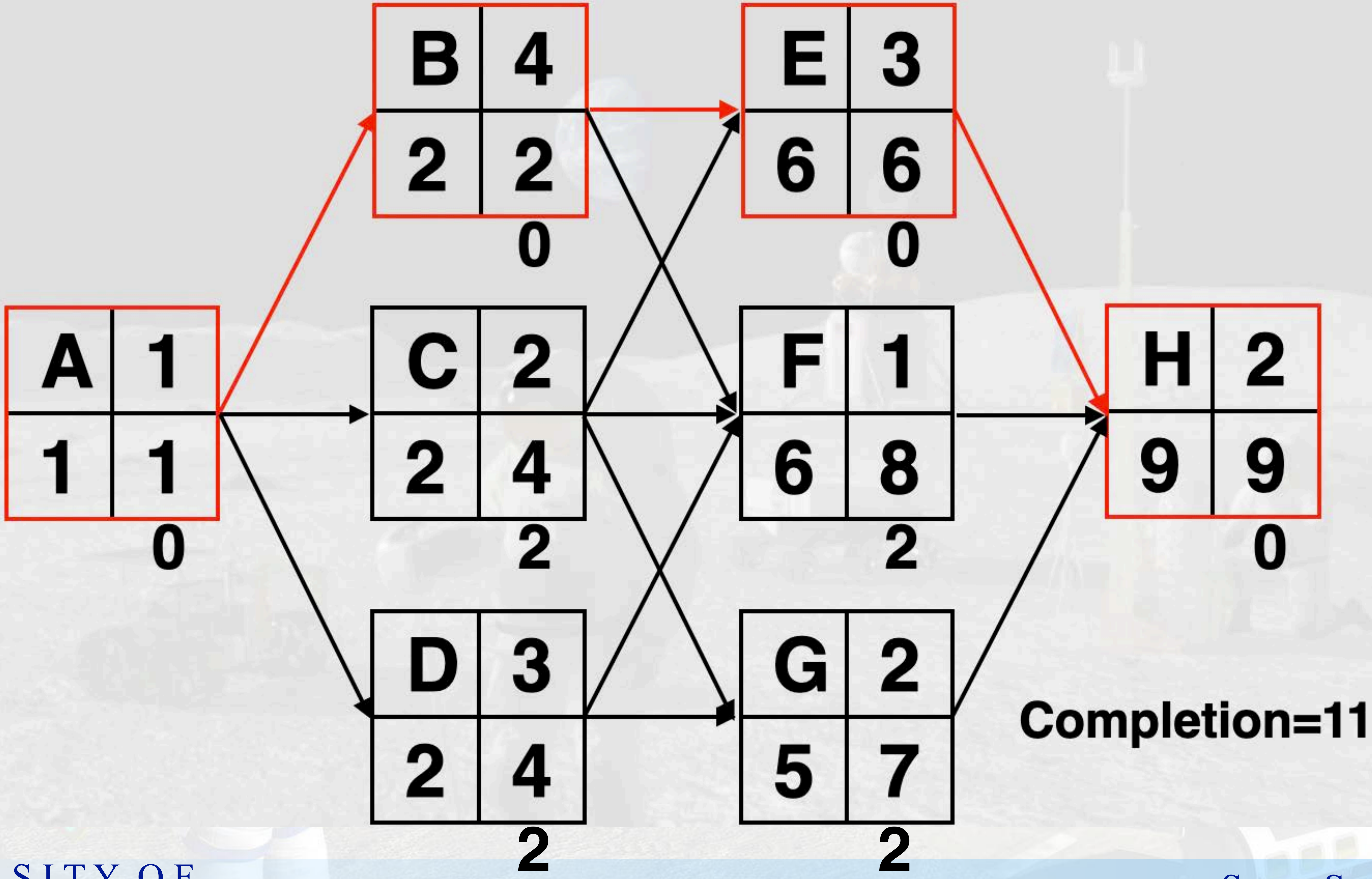
Continue Back Propagation to Starting Task



Difference in Start Dates is the Task Slack Time



Identify Critical Path(s)



Akin's Laws of Spacecraft Design - #23

The schedule you develop will seem like a complete work of fiction up until the time your customer fires you for not meeting it.

Success Criteria

- Part of program formulation phase is to clearly identify observable metrics that will define success
- Generally consists of two sets
  - "Full mission success" represents the minimum case for success in a nominal mission
  - "Minimal success" represents success criteria in the event of degraded capacity
- Important to recognize that even "full mission success" is far below aspirational goals

Risk Tracking

- There are two elements of risk
  - How likely is it to happen? ("Likelihood")
  - How bad is it if it happens? ("Consequences")
- Each issue can be evaluated and tracked on these orthogonal scales
- This is not an alternative to probabilistic risk analysis (PRA) ⇒ discussed in a later lecture

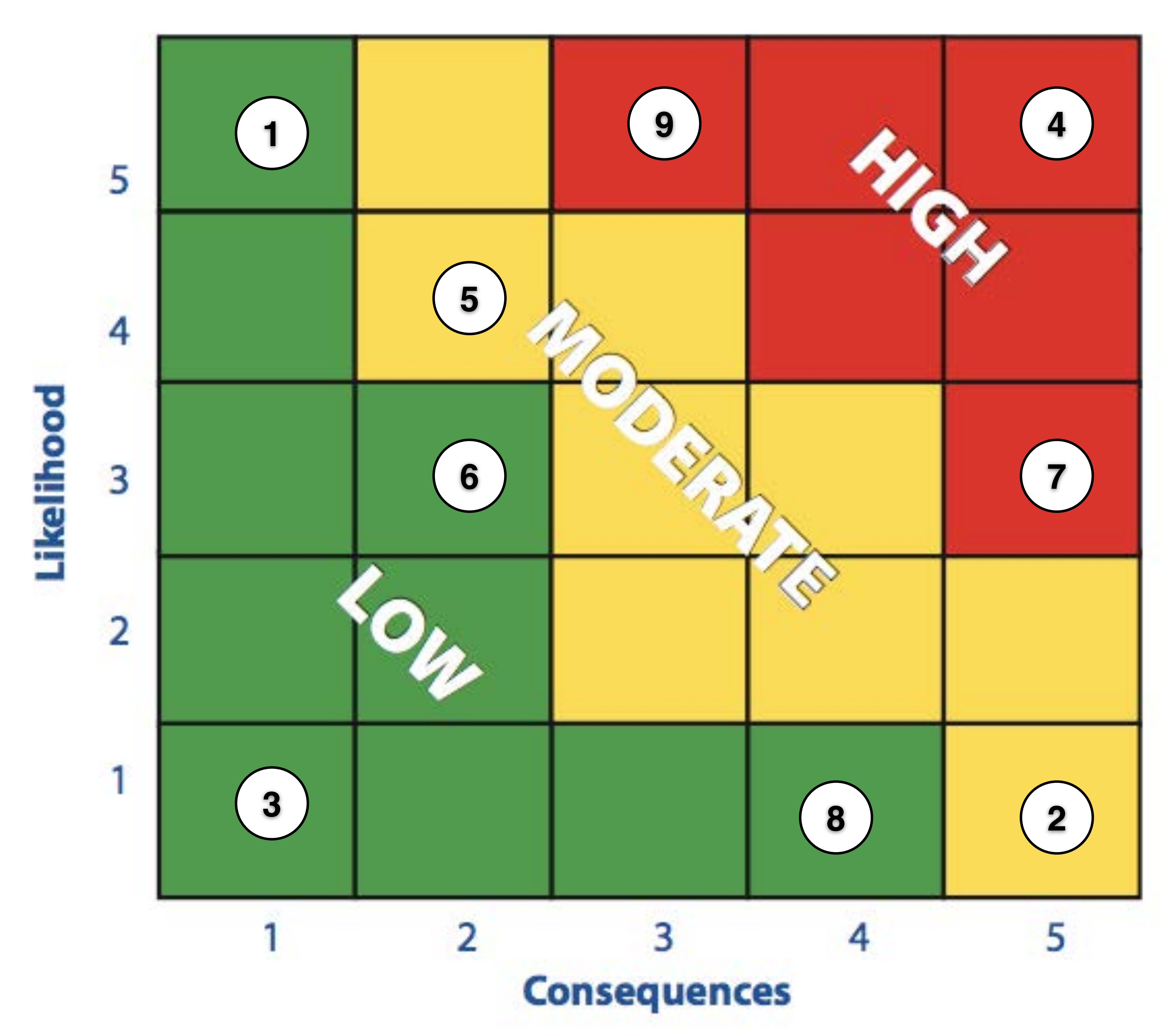
Likelihood Rating Categories

1. Improbable ($P<10^{-6}$)
2. Unlikely to occur ($10^{-3}>P>10^{-6}$)
3. May occur in time ($10^{-2}>P>10^{-3}$)
4. Probably will occur in time ($10^{-1}>P>10^{-2}$)
5. Likely to occur soon ($P>10^{-1}$)

Consequence Rating Categories

1. Minimal or no impact
2. Additional effort required, no schedule impact, <5% system budget impact
3. Substantial effort required, <1 month schedule slip, >2% program budget impact
4. Major effort required, critical path (>1 month slip), >5% program budget impact
5. No known mitigation approaches, breakthrough required to resume schedule, >10% program budget impact

Risk Matrix



Likelihood
5
4
3
2
1
1
2
3
4
5
Consequences
LOW
MODERATE
HIGH
1
9
4
5
6
7
3
8
2

References (Available Online)

- **NASA Systems Engineering Handbook** - SP-6105 - June, 1995 [2.3 Mb, 164 pgs.] (Obsolete, but nice description of NASA's systems engineering approach)
- **NASA Systems Engineering Processes and Requirements** - NPR 7123.1A - March 26, 2007 [3.6 Mb, 97 pgs.] (Current version - pages are almost impossible to read without a magnifying glass)
- **NASA Space Flight Program and Project Management Requirements** - NPR 7120.5D - March 6, 2007 [2.7 Mb, 50 pgs.] (Current version - pages are almost impossible to read without a magnifying glass)
- **NASA Program and Project Management Processes and Requirements** - NPR 7120.5C - March 22, 2005 [1.9 Mb, 174 pgs.] (Older, superceded version, but includes more figures and is readable by mere mortals)
- **NASA Goddard Space Flight Center Procedures and Guidelines: Systems Engineering** - GPG 7120.5B - 2002 [1.7 Mb, 31 pgs.]
- **NASA Goddard Space Flight Center Mission Design Processes** (The "Green Book") [860 Kb, 54 pgs.]
- **NASA Systems Engineering "Toolbox" for Design-Oriented Engineers** - NASA RP-1538, December 1994 [9.1 Mb, 306 pgs]