What is Systems Engineering? & What Does a Systems Engineer Do???

Guest Lecture

for Senior Design class
Howard University

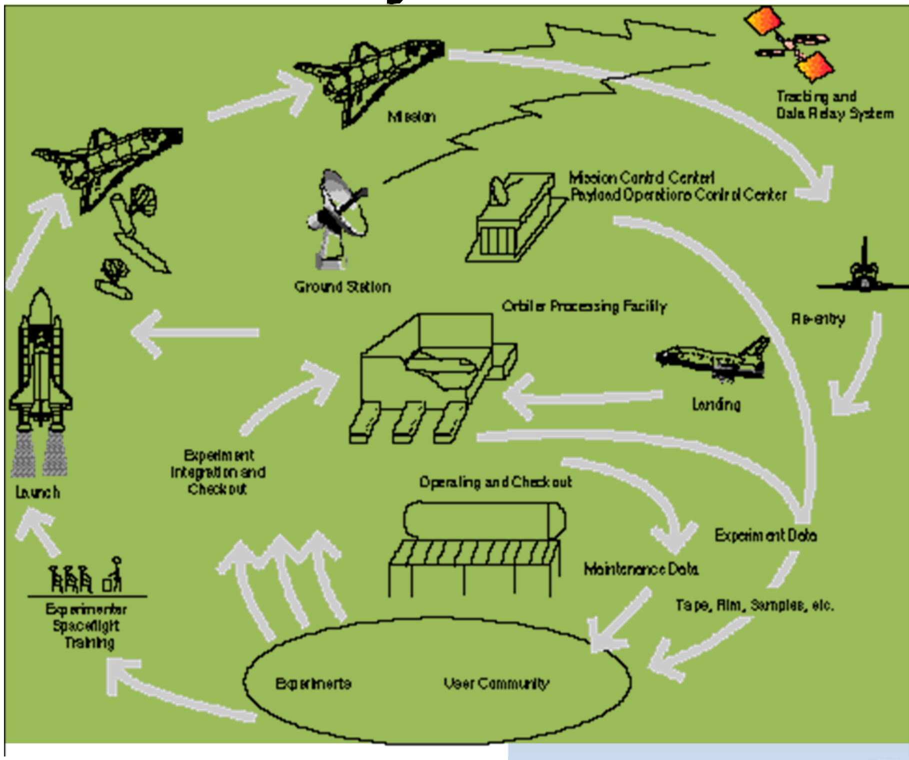
by

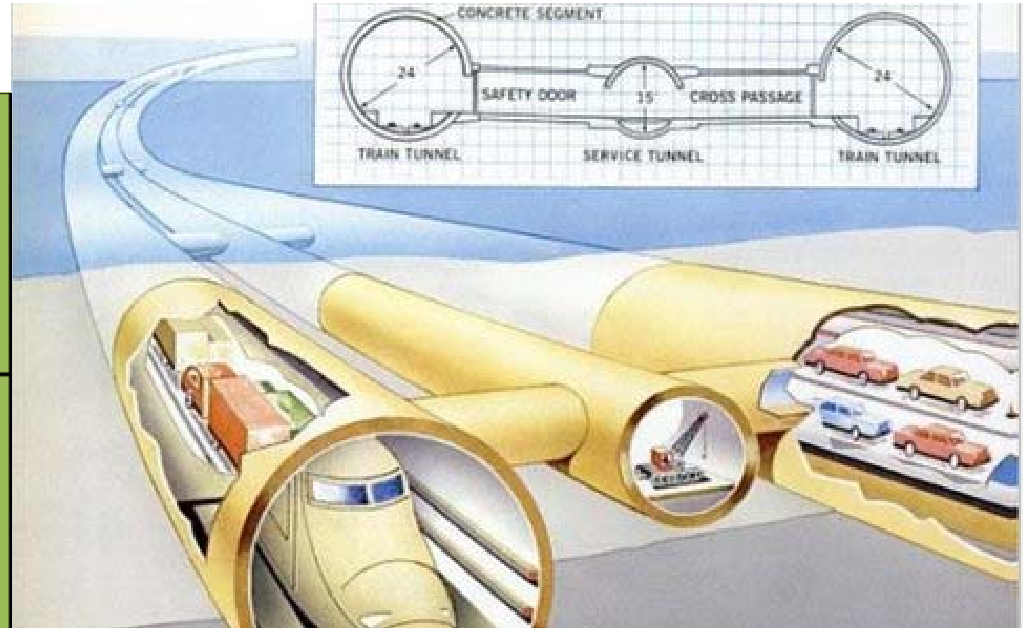
Jeffrey Volosin

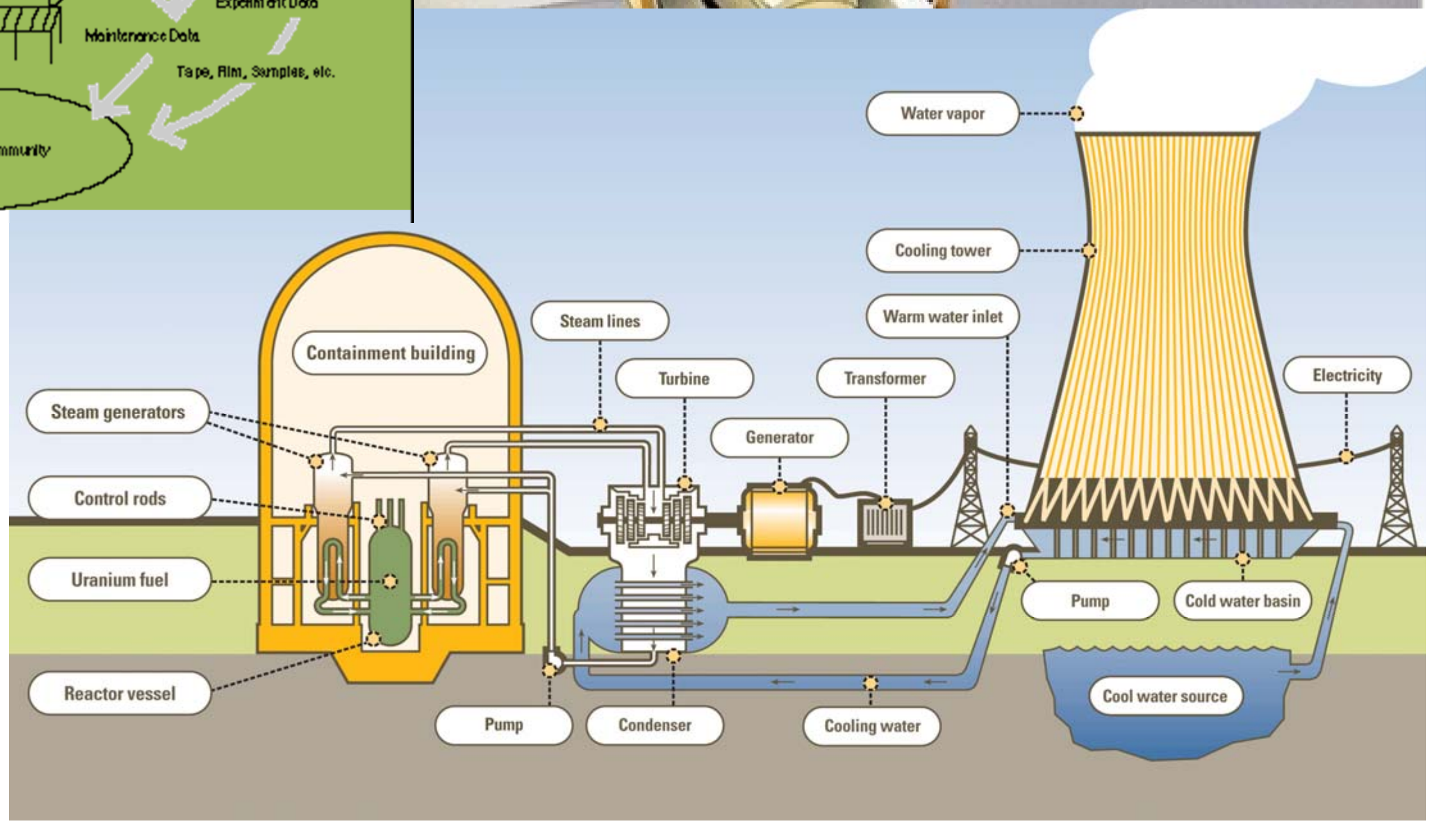
NASA

Engineering

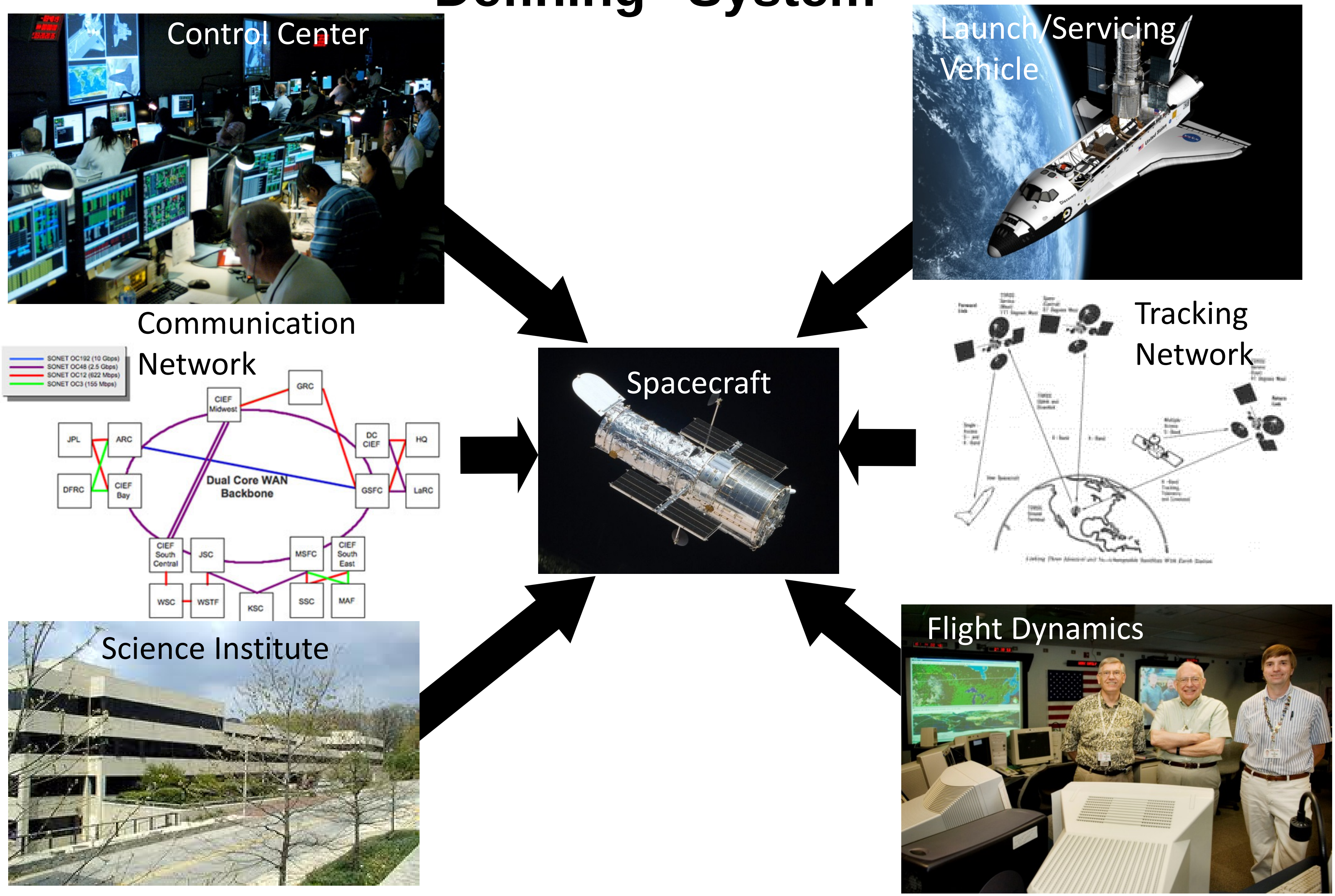
System


Tracking and Data Relay System
Mission
Mission Control Center/
Payload Operations Control Center
Ground Station
Orbiter Processing Facility
Re-entry
Landing
Launch
Experiment Integration and Checkout
Operating and Checkout
Experiment Data
Maintenance Data
Tape, Film, Samples, etc.
Experimenter Spaceflight Training
Experiments
User Community

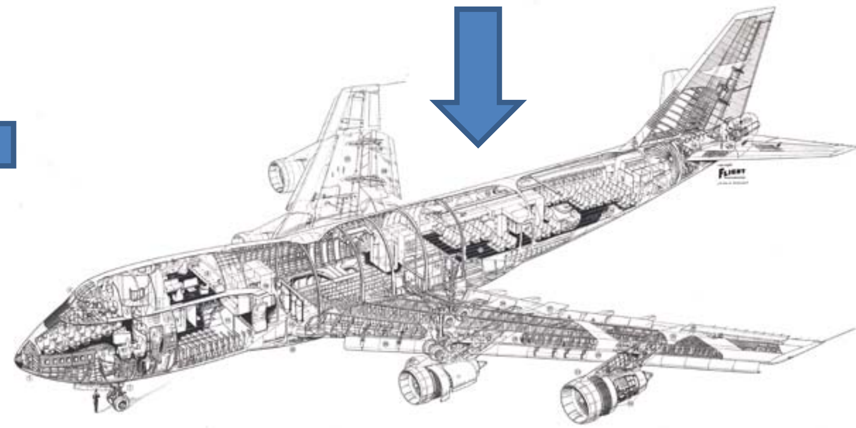

CONCRETE SEGMENT
SAFETY DOOR
CROSS PASSAGE
TRAIN TUNNEL
SERVICE TUNNEL
TRAIN TUNNEL

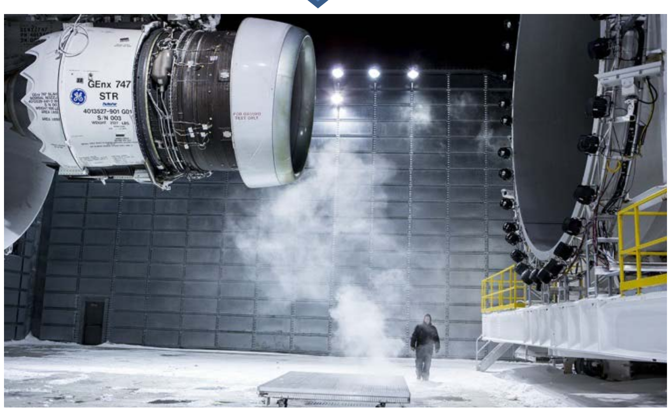

Water vapor
Cooling tower
Warm water inlet
Steam lines
Containment building
Turbine
Transformer
Electricity
Steam generators
Generator
Control rods
Uranium fuel
Pump
Cold water basin
Reactor vessel
Cool water source
Pump
Condenser
Cooling water

Defining “System”

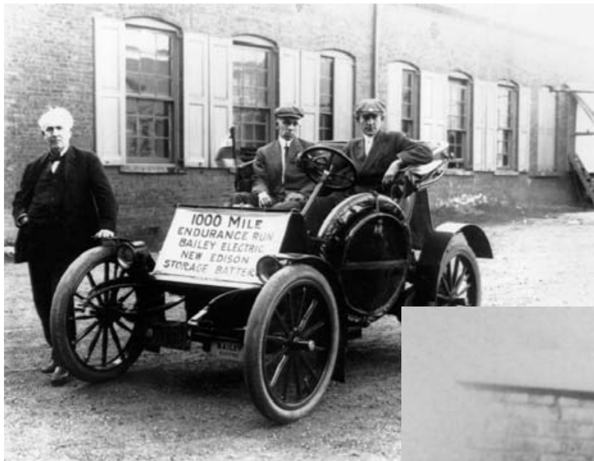


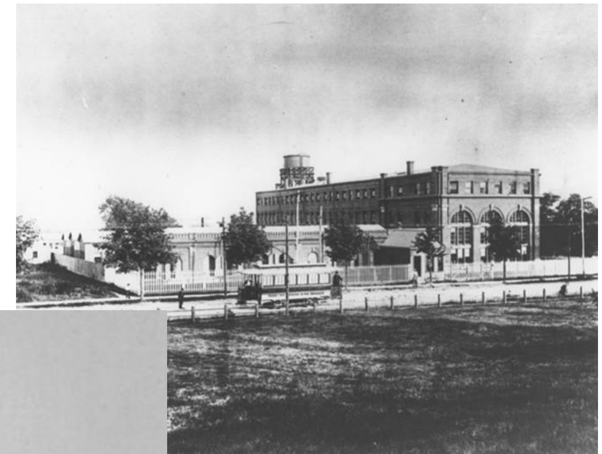
Systems Engineering





Thomas Edison
Invention Factory





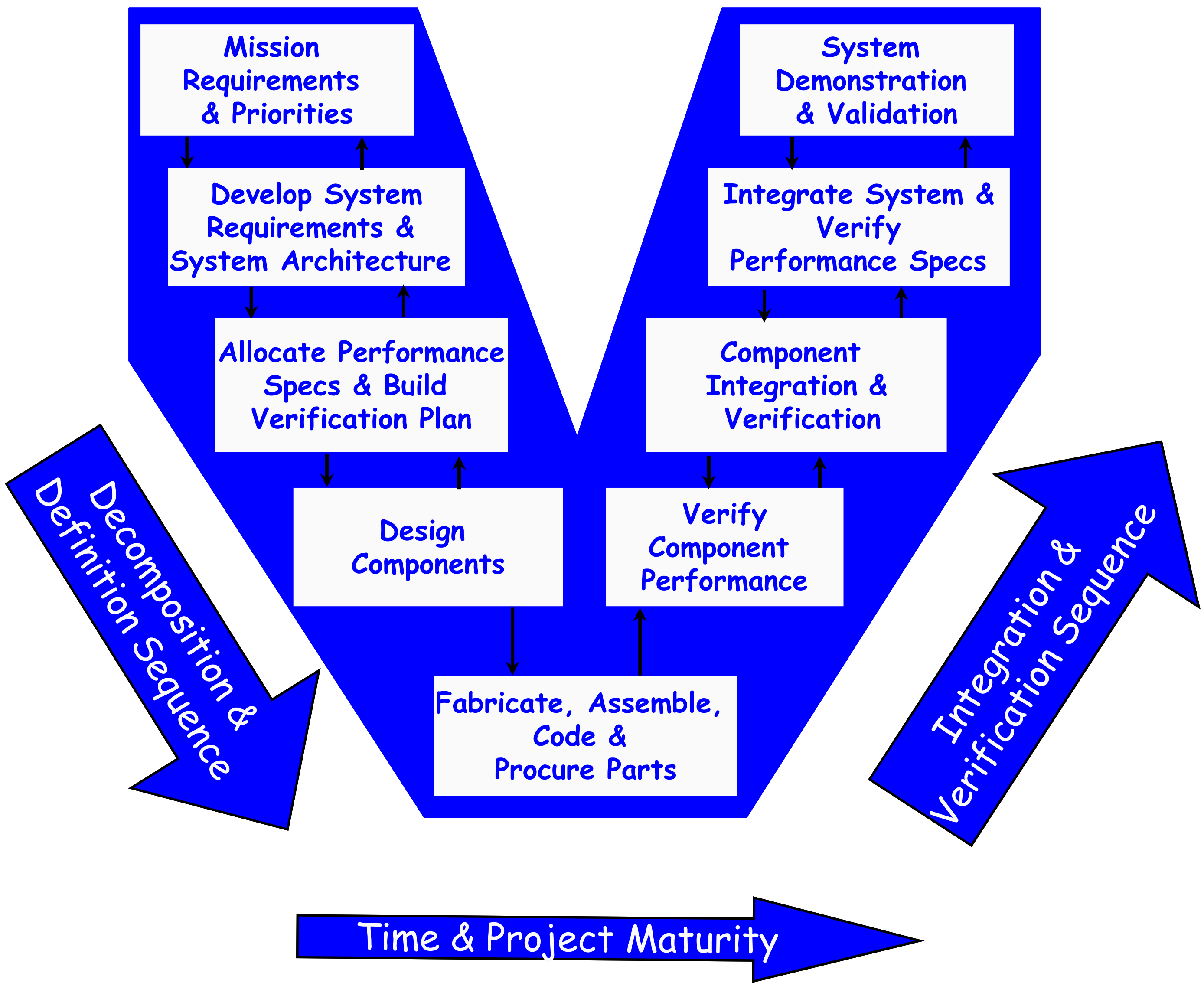

TRANS WORLD
TWA


WESTERN

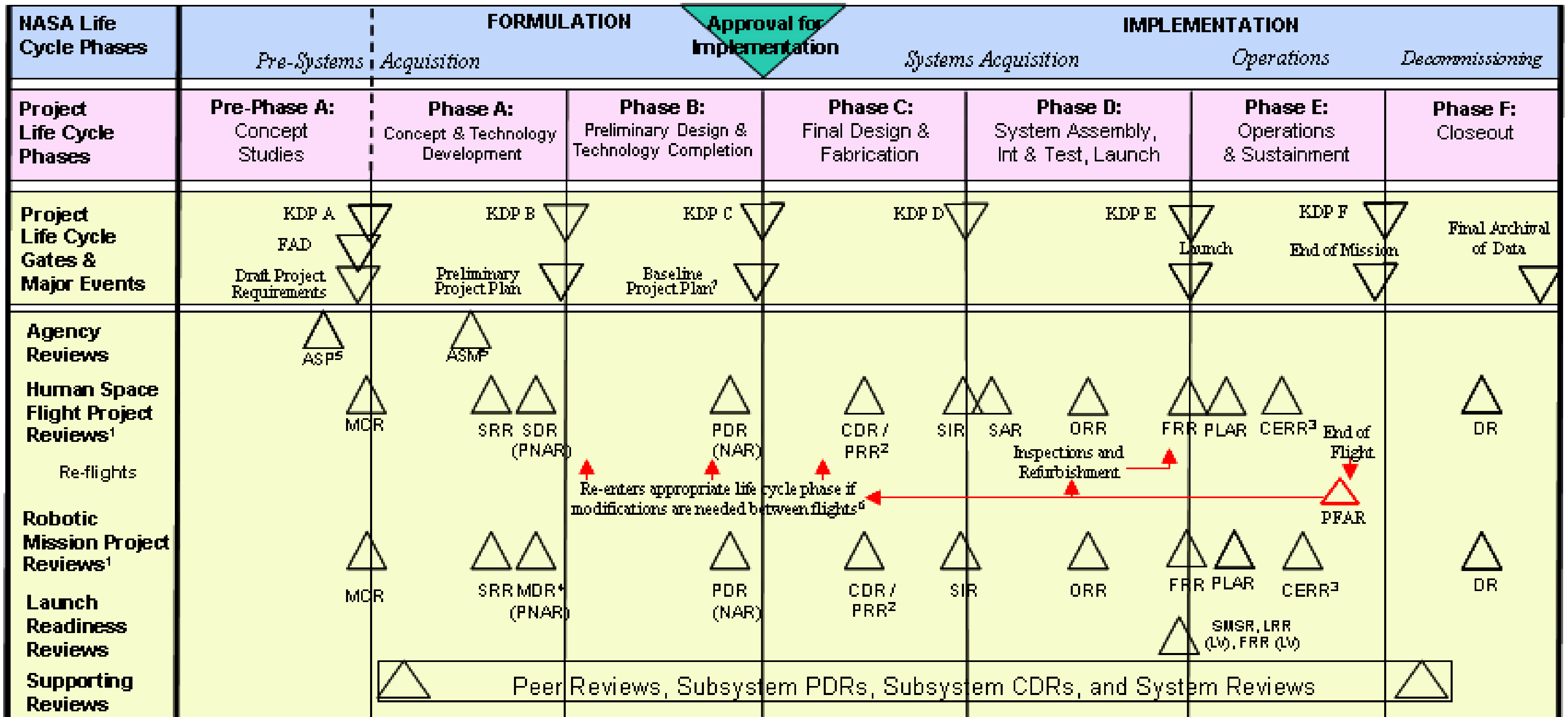

485004

Skunkworks

The Systems Engineering 'Vee'
Decomposition – then - Integration



NASA Systems Engineering Timeline



FOOTNOTES

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ACRONYMS

ASP—Acquisition Strategy Planning Meeting
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CERR—Critical Events Readiness Review
DR—Decommissioning Review
FAD—Formulation Authorization Document
FRR—Flight Readiness Review
KDP—Key Decision Point
LRR—Launch Readiness Review
MCR—Mission Concept Review
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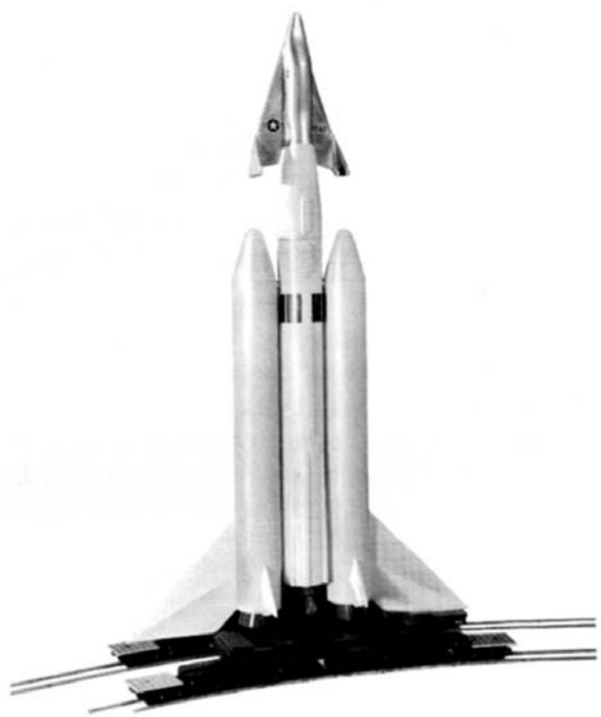
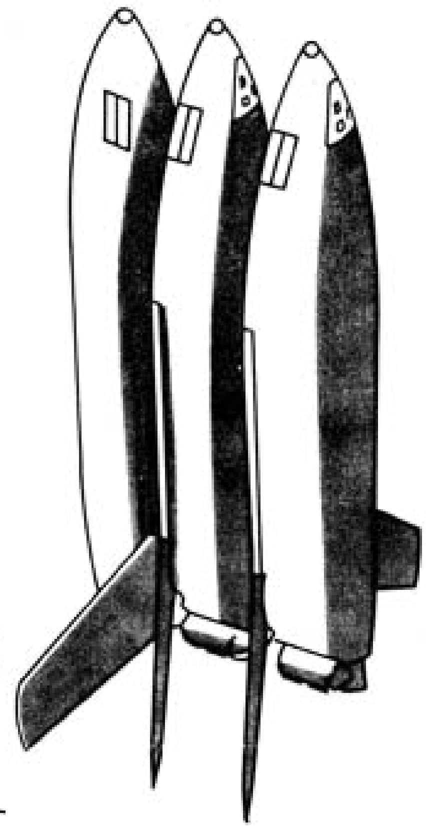
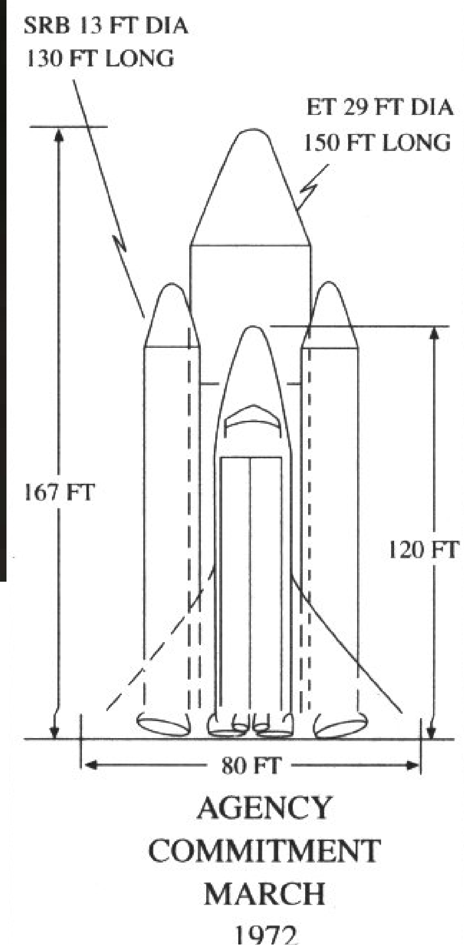
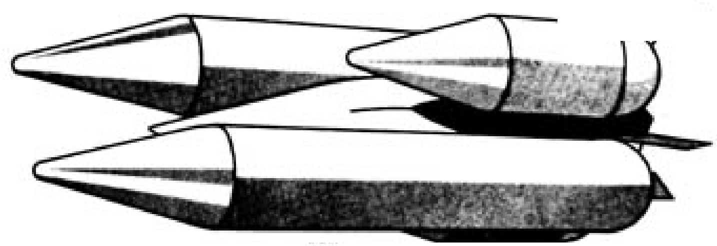
PLAR—Post-Launch Assessment Review
PNAR—Preliminary Non-Advocate Review
PRR—Production Readiness Review
SAR—System Acceptance Review
SDR—System Definition Review
SIR—System Integration Review
SMSR—Safety and Mission Success Review
SRR—System Requirements Review

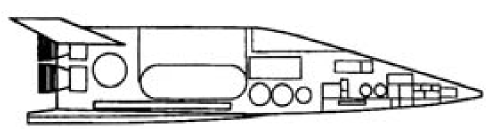
Space Shuttle

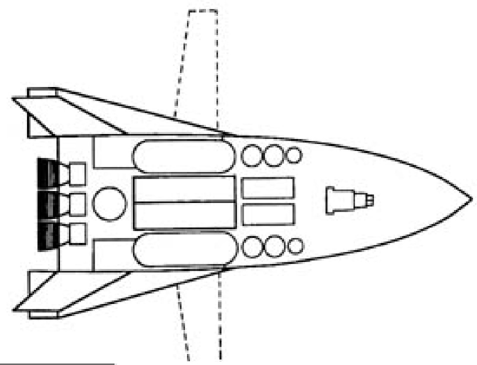




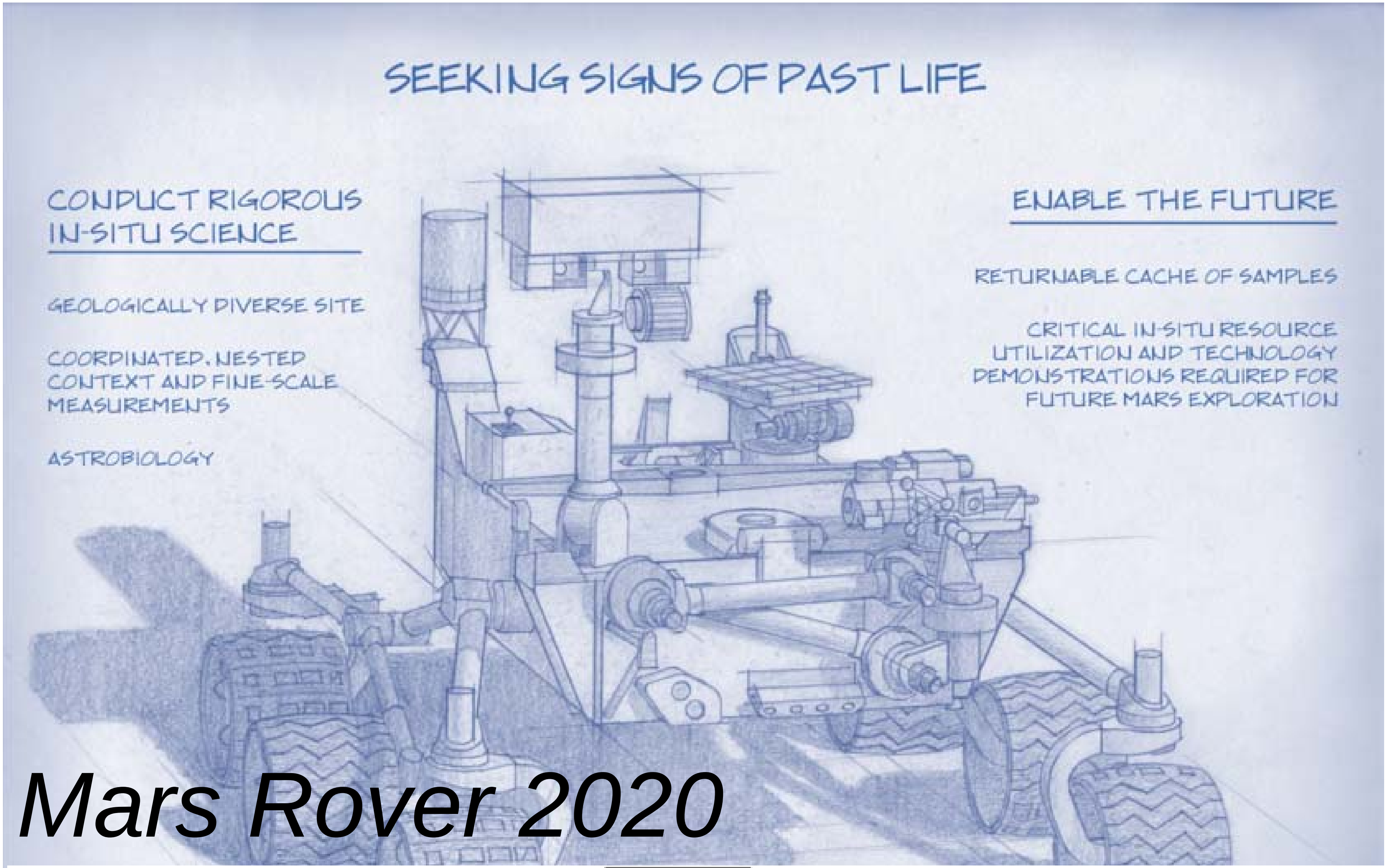








NASA Life Cycle Phases	**FORMULATION** *Pre-Systems*	*Acquisition*		**Approval for Implementation**	**IMPLEMENTATION** *Systems Acquisition*	*Operations*	*Decommissioning*
Project Life Cycle Phases	**Pre-Phase A:** Concept Studies	**Phase A:** Concept & Technology Development	**Phase B:** Preliminary Design & Technology Completion	**Phase C:** Final Design & Fabrication	**Phase D:** System Assembly, Int & Test, Launch	**Phase E:** Operations & Sustainment	**Phase F:** Closeout



Mars Rover 2020

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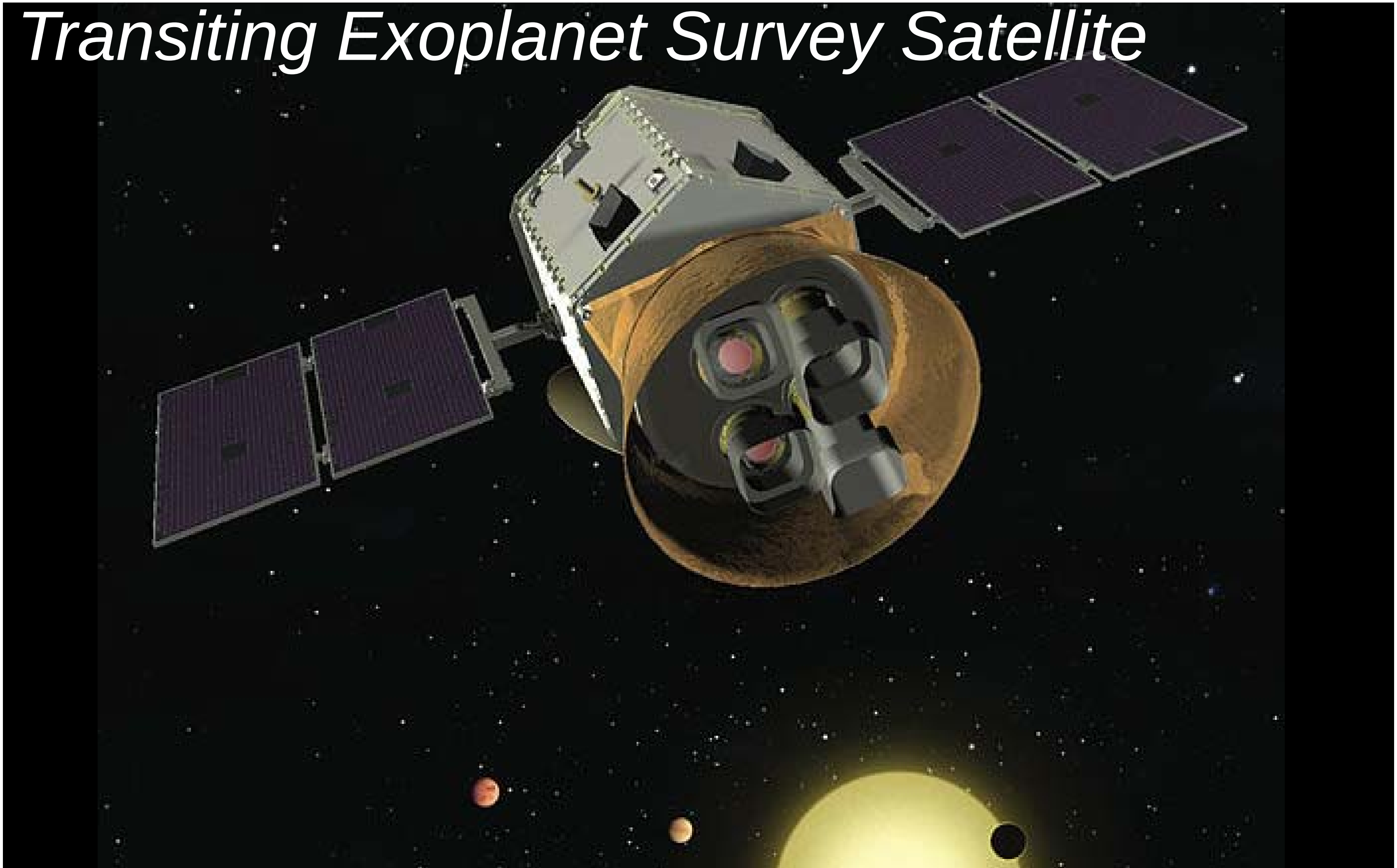
Transiting Exoplanet Survey Satellite



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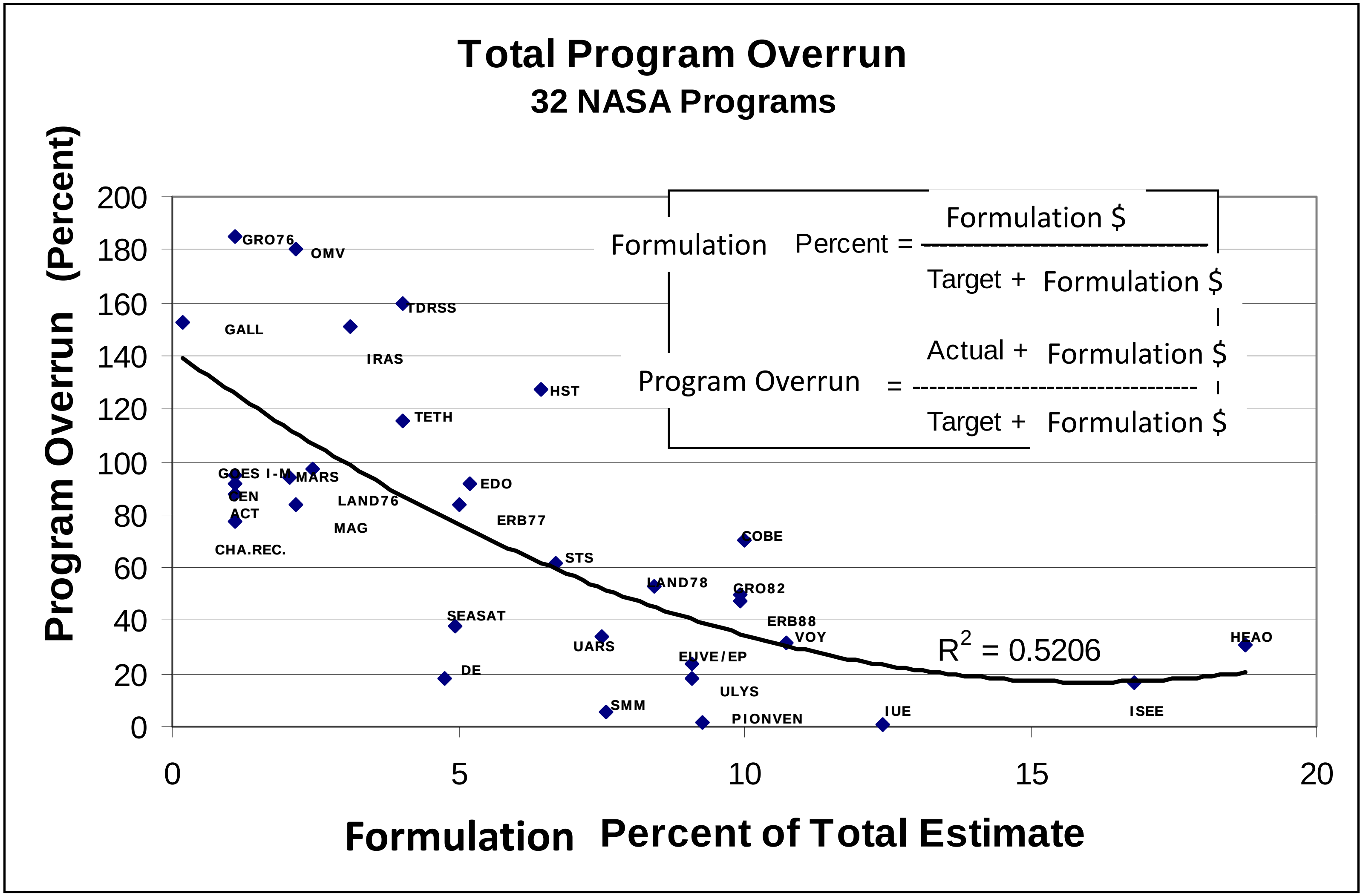
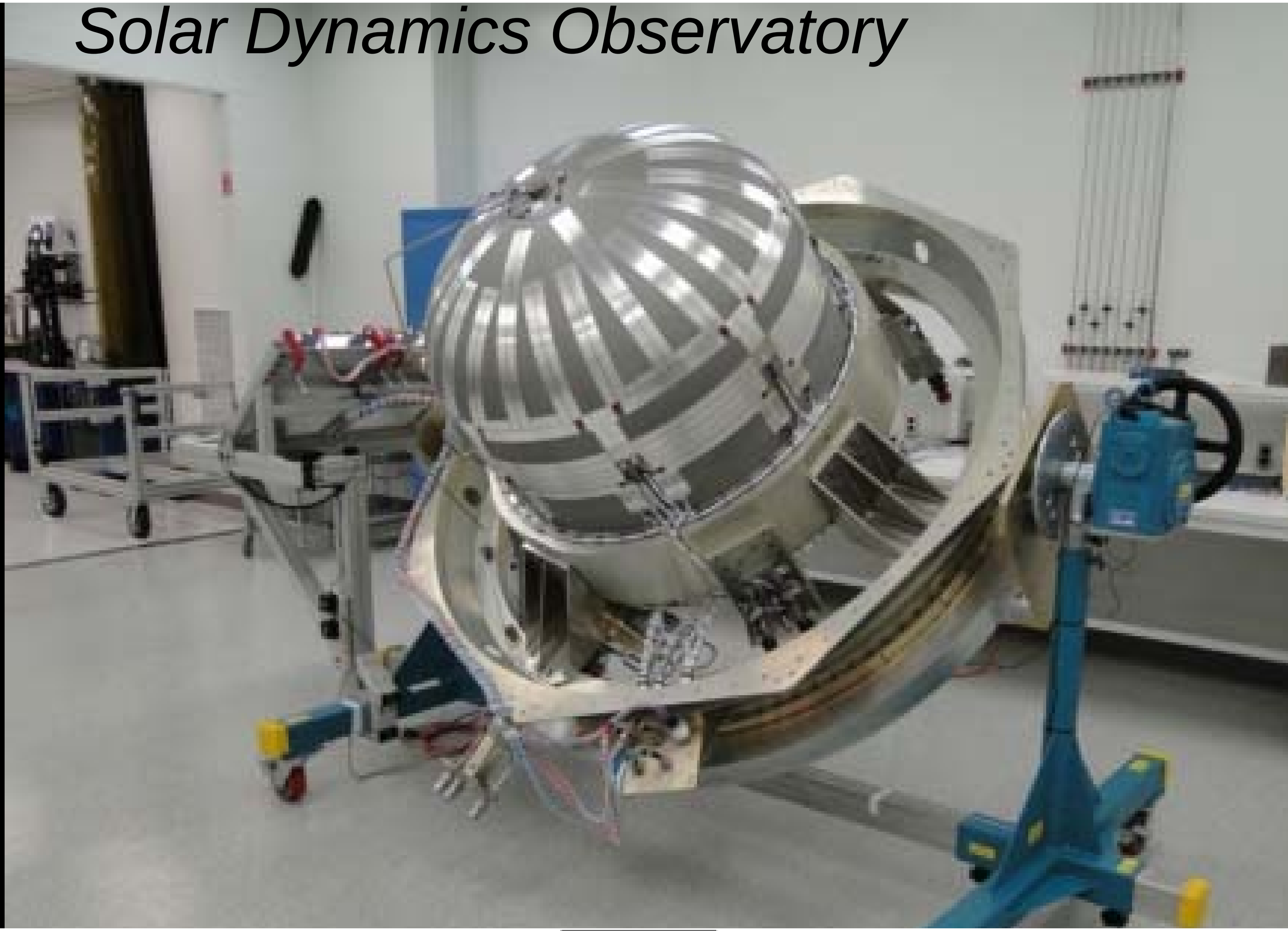
Formulation Phase Investment Critical to Managing Cost



Solar Dynamics Observatory



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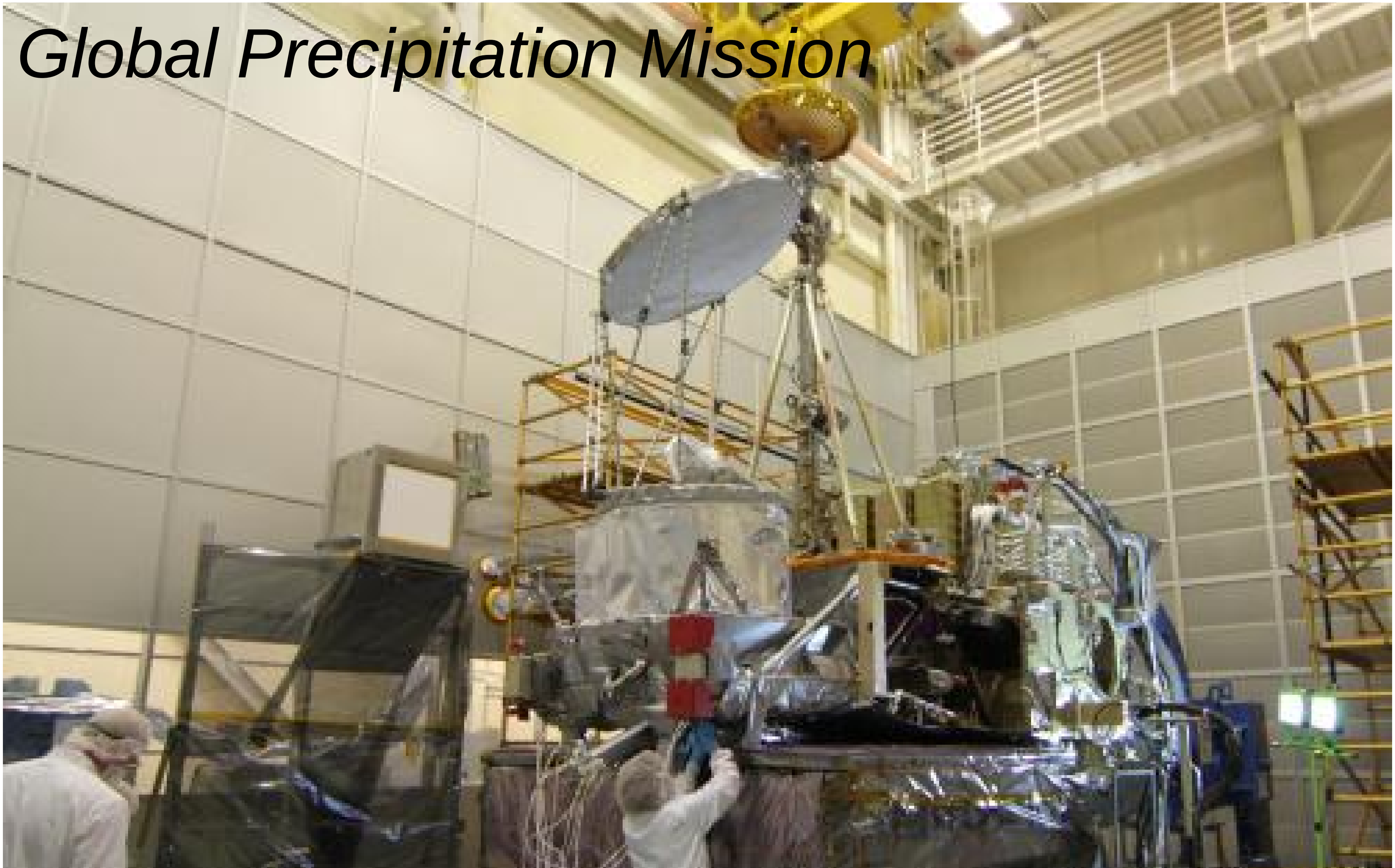
Global Precipitation Mission



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Tropical Rainfall Measuring Mission

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Space Shuttle

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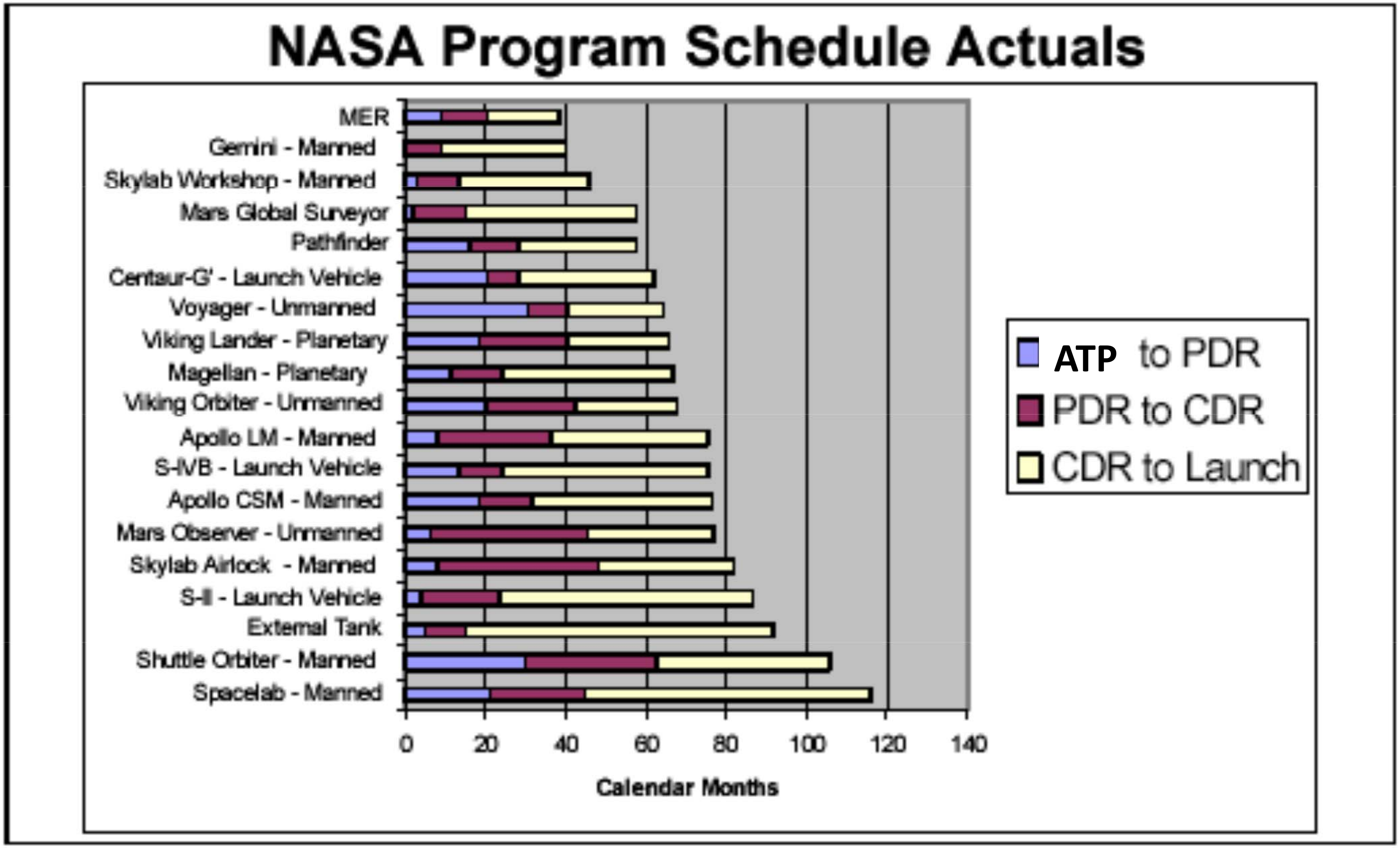
NASA Project Development Times Vary Widely



ATP-PDR = Phase A/B; PDR-CDR = Phase C; CDR-Launch = Phase D

NASA Systems Engineering Processes

- Scope
- Architecture
- Requirements
- Functional Decomposition
- Part Selection
  - Utility Curves
  - Robust Design
- Trade Study
- Contingency & Margin
- Cost Estimating
- Risk Management
- Technology Decisions
- Trade Trees

Scope Dimensions

Need
Explains why the project is developing this system from the stakeholders' point of view

Goals
Broad, fundamental aim you expect to accomplish to fulfill need.

Objectives
Initiatives that implement the goal.

What is the minimum that the stakeholders expect from the system for it to be successful?

Scope is a definition of what is germane to your project.

Assumptions
Examples:
Level of technology
Partnerships
Extensibility to other missions

Mission
Defining and restricting the missions will aid in identifying requirements

Budgets

Schedules

Constraints
External items that cannot be controlled and that must be met, which are identified while defining the scope

Authority and Responsibility
Who has authority for aspects of the system development?

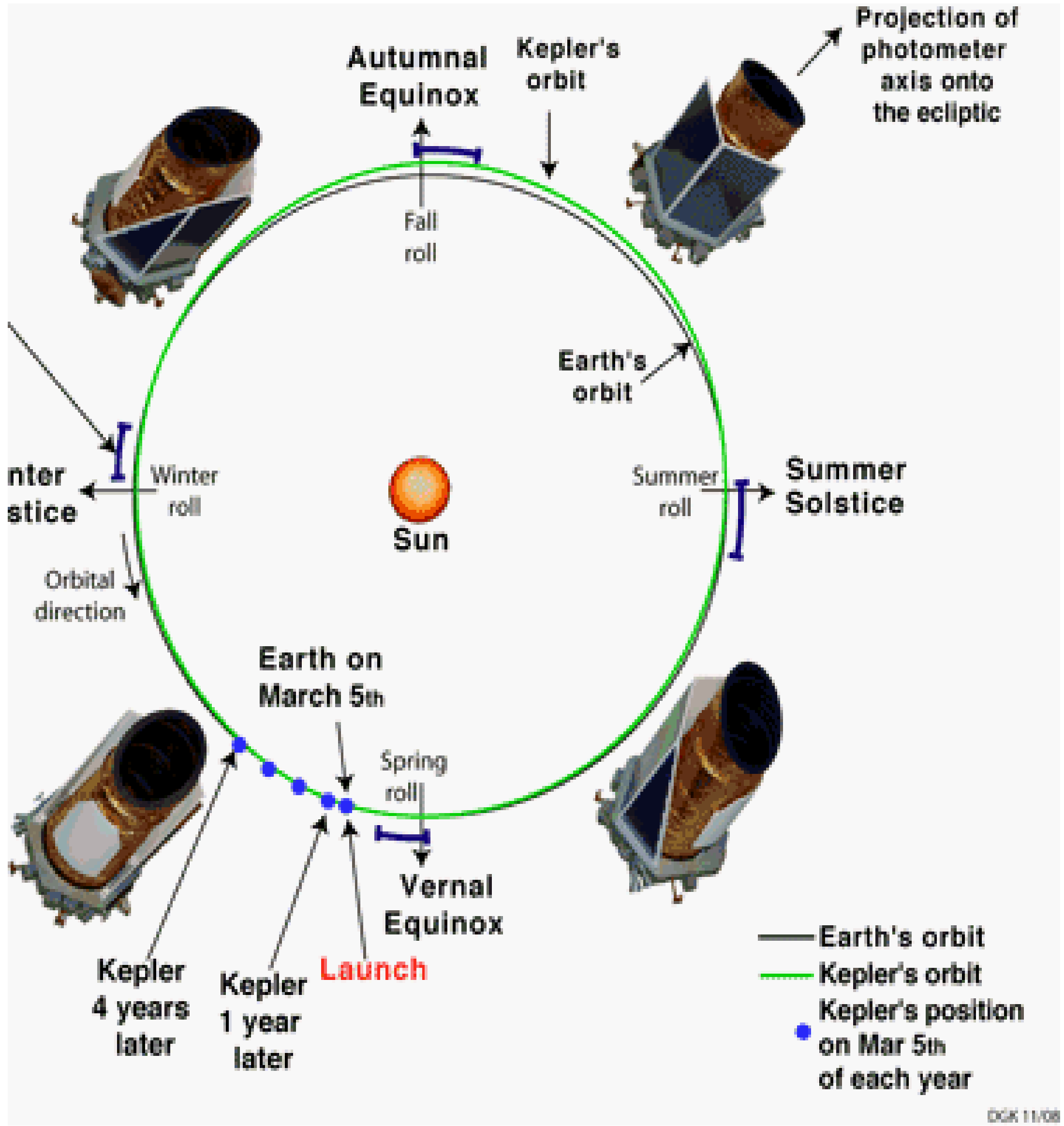
Operational Concepts
Imagine the operation of the future system and document the steps of how the end-to-end system will be used

Scope Example: Kepler

- Need: Find terrestrial planets, especially those in the habitable zone of their stars, where liquid water and possibly life might exist.
- Goal: Discover dozens of Earth-size planets in or near the habitable zone and determine how many of the billions of stars in our galaxy have such planets
- Objective: Explore the structure and diversity of planetary systems.
- Mission or business case: Survey a large sample of stars from space

Scope Example: Kepler

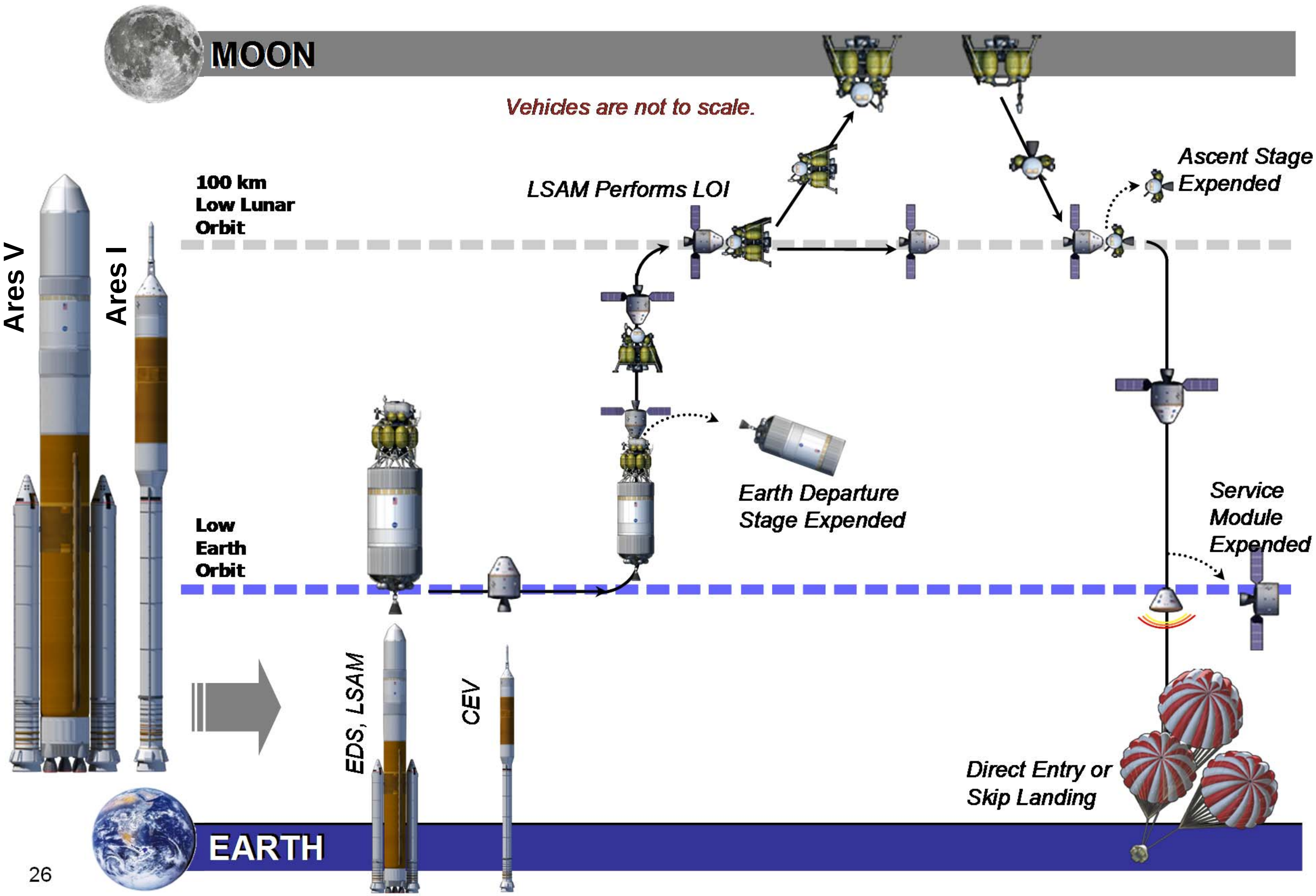
Operational Concept: Use a Delta II launch vehicle to place a 0.95m telescope (capable of capturing light from 12th magnitude stars) and photometer having a field-of-view of 105 square degrees (field should include over 100,000 stars – and a sensitivity that would detect the Earth transiting the Sun from a significant distance) in an Earth-trailing solar orbit for a period of 3.5 years (allowing for measuring planet transits over multiple "years"). Point the telescope constantly at the Cygnus-Lyra region (except when downlinking data). Downlink data through the DSN sites, with science data (downlinked monthly) going to the ARC Pipeline facility for processing and engineering data (downlinked twice each week) going to the Mission Operations Center at the University of Colorado. After processing, all data is stored at the Space Telescope Science Institute in MD.

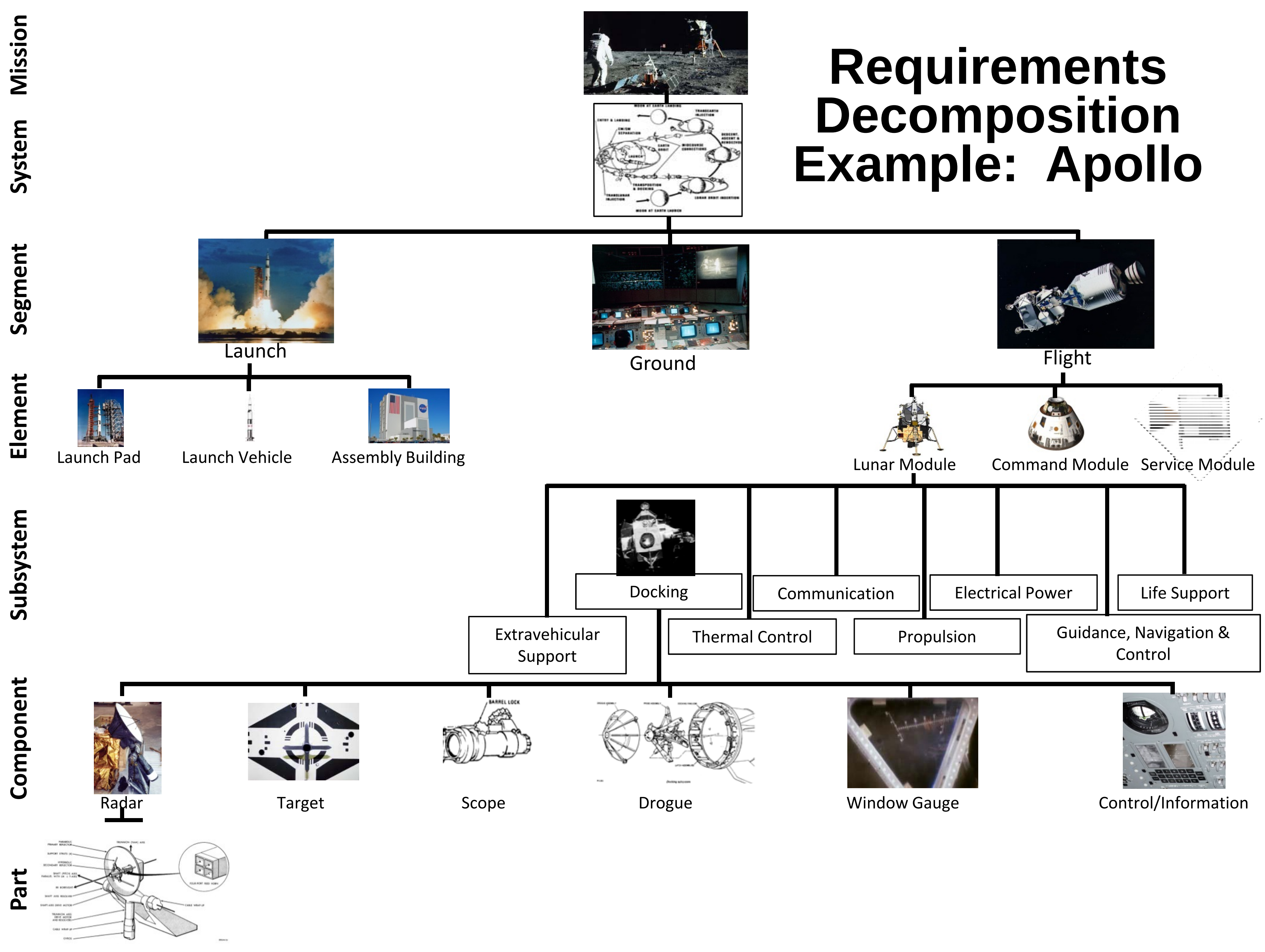


Scope Example: Kepler

- **Assumptions**: There are Earth-sized planets orbiting stars within the chosen FOV that are orbiting edge-on as seen from Earth. Also, that variations seen in the photon count from stars in the FOV can be correlated to orbiting Earth-like planets (versus star-spots or other output variations)
- **Constraints**: Total mass must be below 1,000 kg (to launch on Delta II to required orbit)
- **Authority and Responsibility**: NASA Science Mission Directorate, Astrophysics Division, Exoplanet Program Office (JPL), Kepler Project Office (ARC), Data Processing Pipeline (ARC), Mission Operations Center (University of Colorado), Data Archive (Space Telescope Institute), Launch (KSC Launch Services Program), Observatory Development (Ball Aerospace)
- **Budget**: $550M total funding available
- **Schedule**: Must launch by 2009

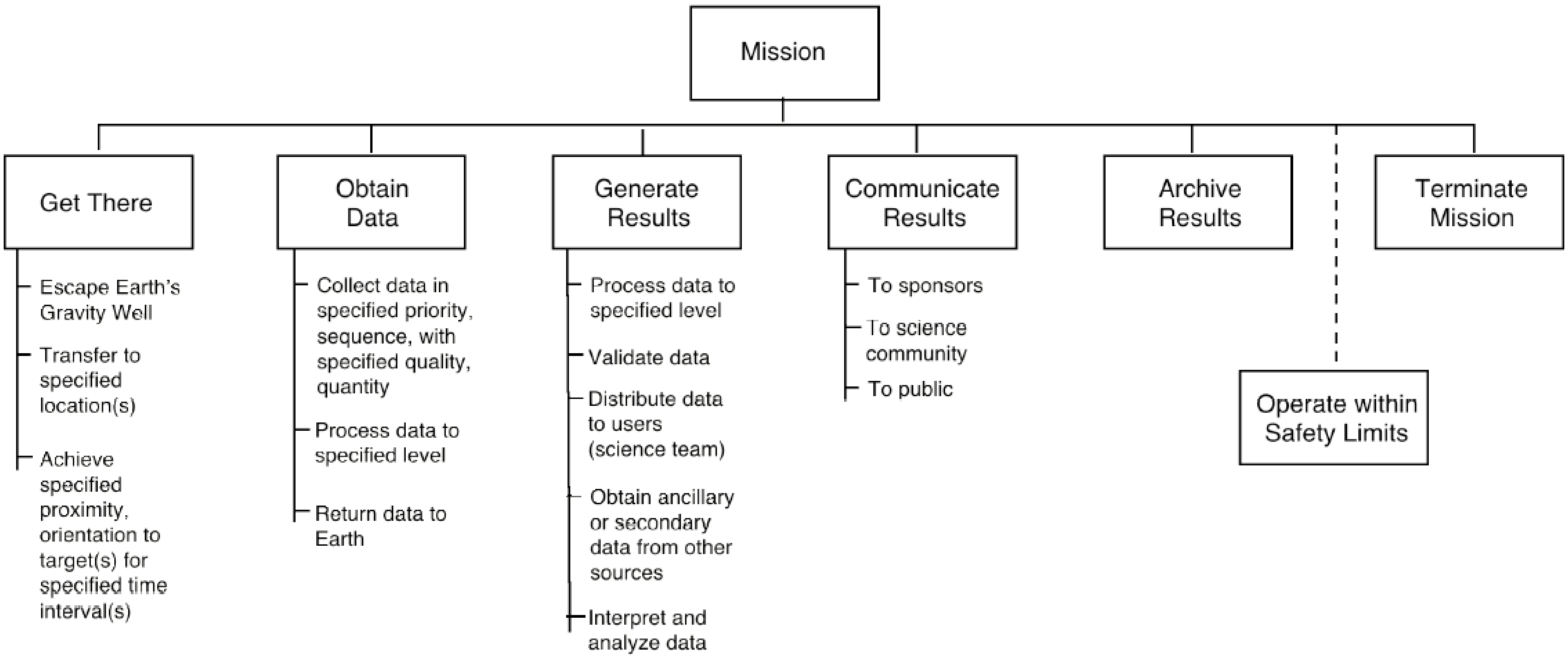
Architecture Example: NASA Constellation Program Lunar Sortie Mission (2006)





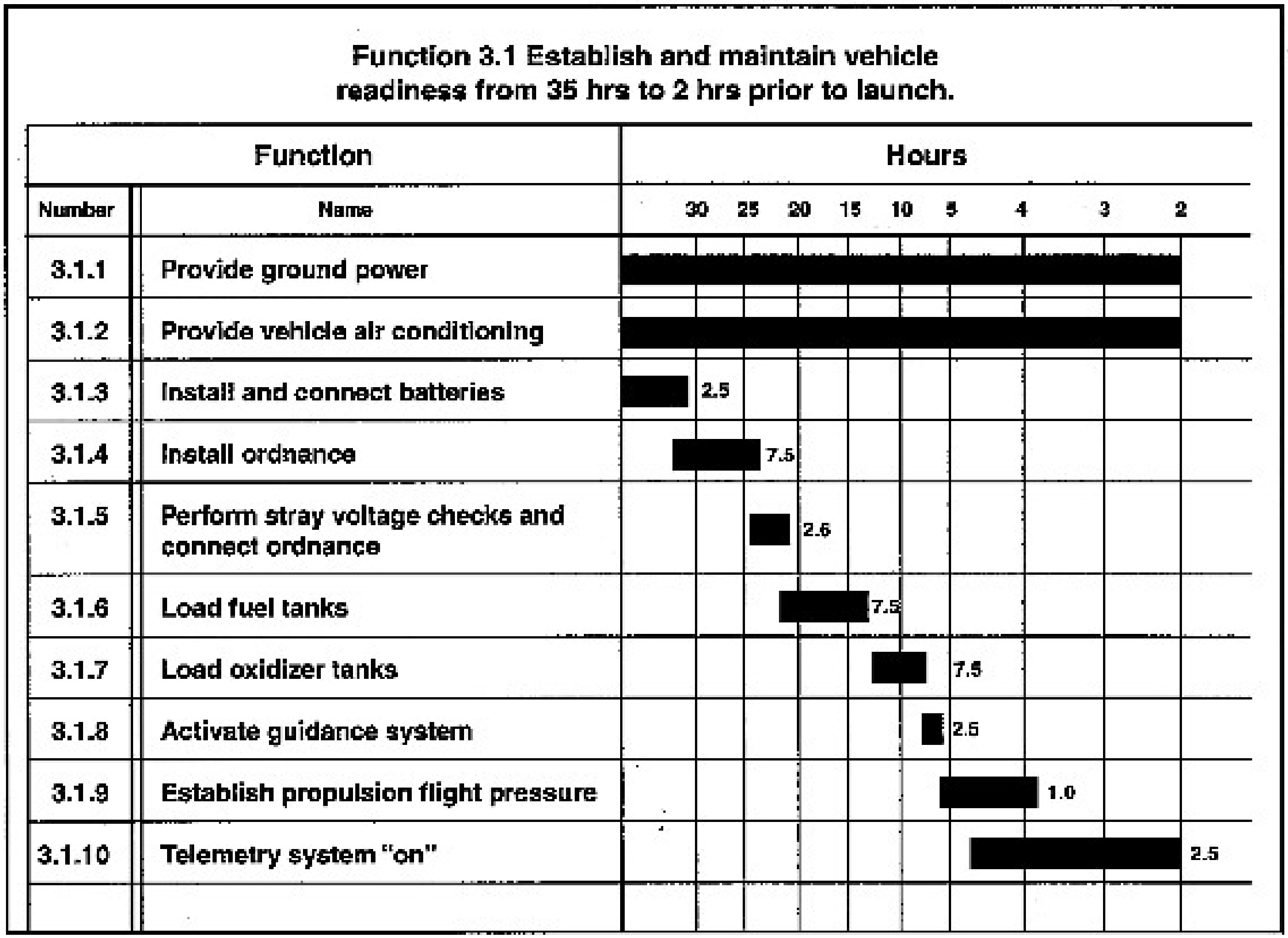
Requirements Decomposition Example: Apollo
Mission
System
Segment
Element
Subsystem
Component
Part
Launch
Ground
Flight
Launch Pad
Launch Vehicle
Assembly Building
Lunar Module
Command Module
Service Module
Docking
Communication
Electrical Power
Life Support
Extravehicular Support
Thermal Control
Propulsion
Guidance, Navigation & Control
BARREL LOCK
Radar
Target
Scope
Drogue
Window Gauge
Control/Information

Functional Decomposition Example
NASA Space Science Mission
Functional Flow Block Diagram



Applicable to:
- Flybys
- Orbiters (Earth and Planetary)
- In situ missions
- Constellations
- Heliocentric observers
- Sample return missions
- Occultation experiments

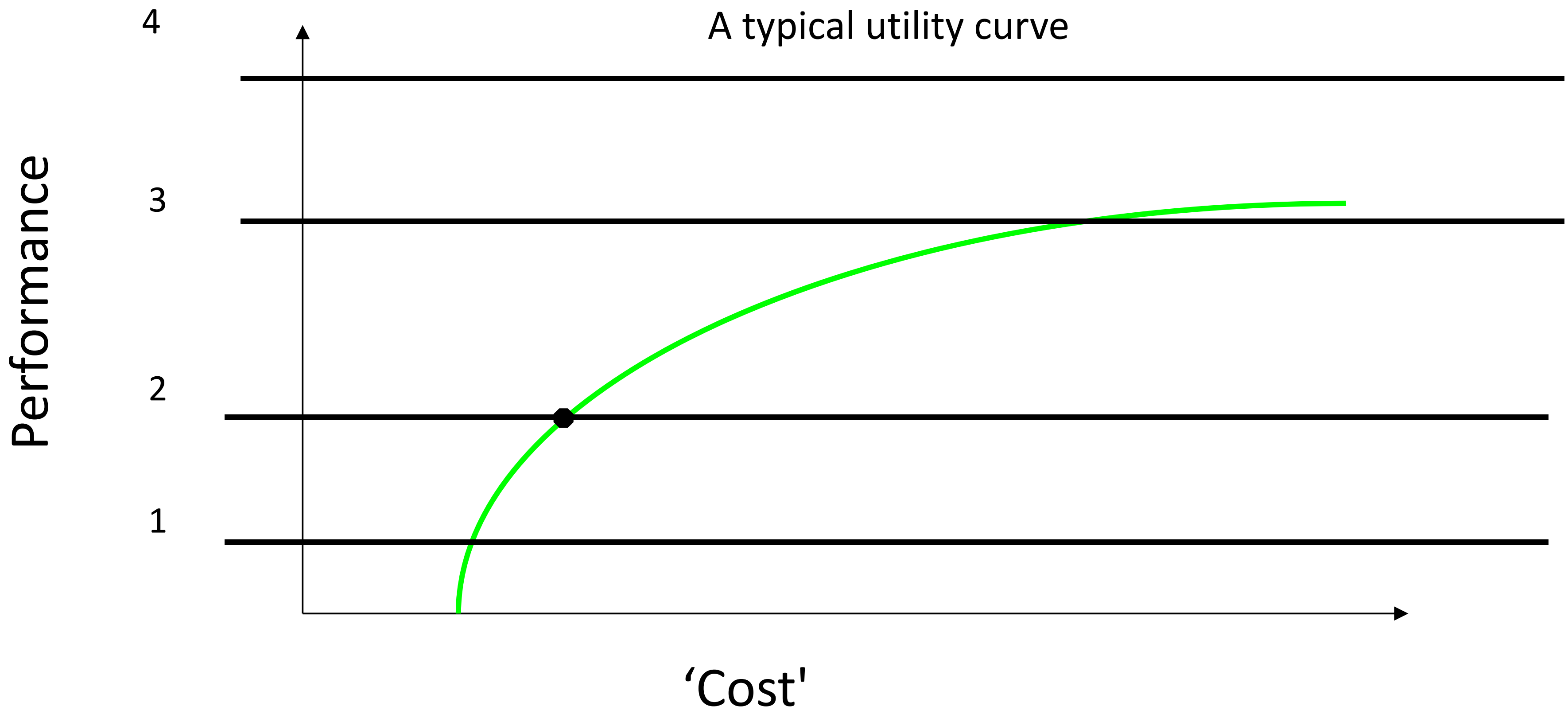
Functional Decomposition Timeline Example



Example shows the time required to perform function 3.1.
Its sub-functions are presented on a bar chart showing how the timelines relate.
Note: function numbers match the FFBD.

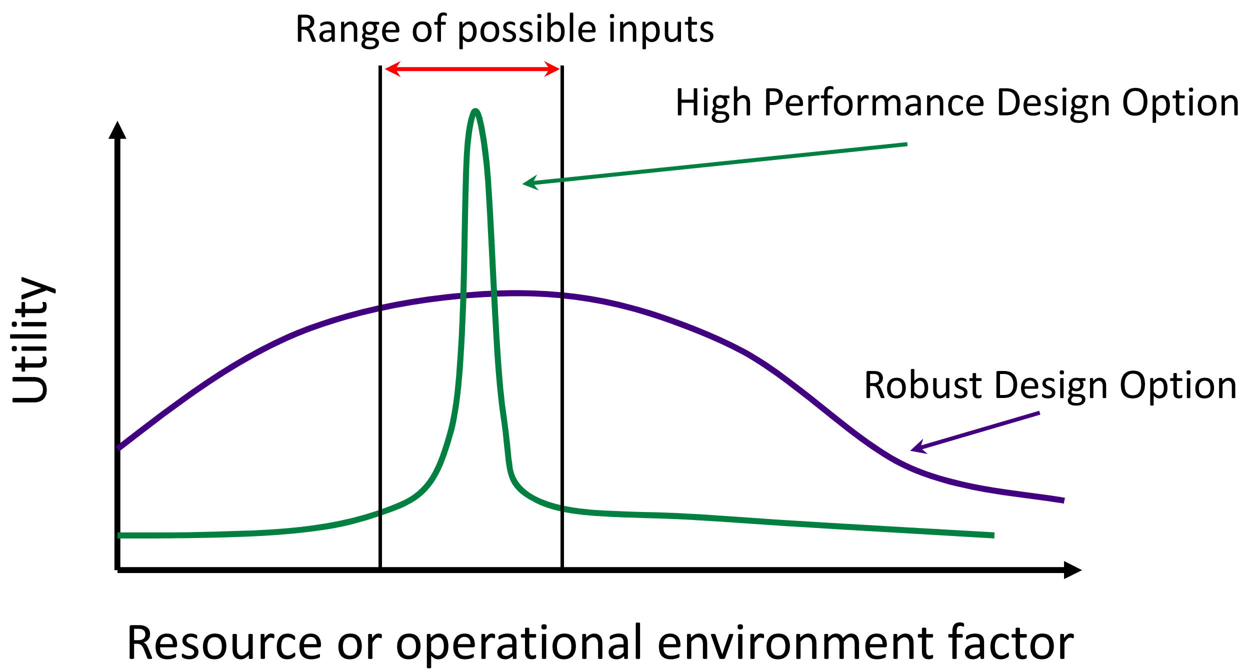
Selecting Parts and Components
Utility Curves

- Use performance-resource curves (utility curves) to identify break points.
- "Performance" factors should be defined by requirements and "figures of merit"



Selecting Parts and Components
Robust Design

- **Robustness** is a measure of the ability of a system to absorb changes in requirements, constraints or failures while reducing the impacts on the performance, functionality, or composition of the mission or system. Two different design options are shown - one with high performance, one with robust performance.

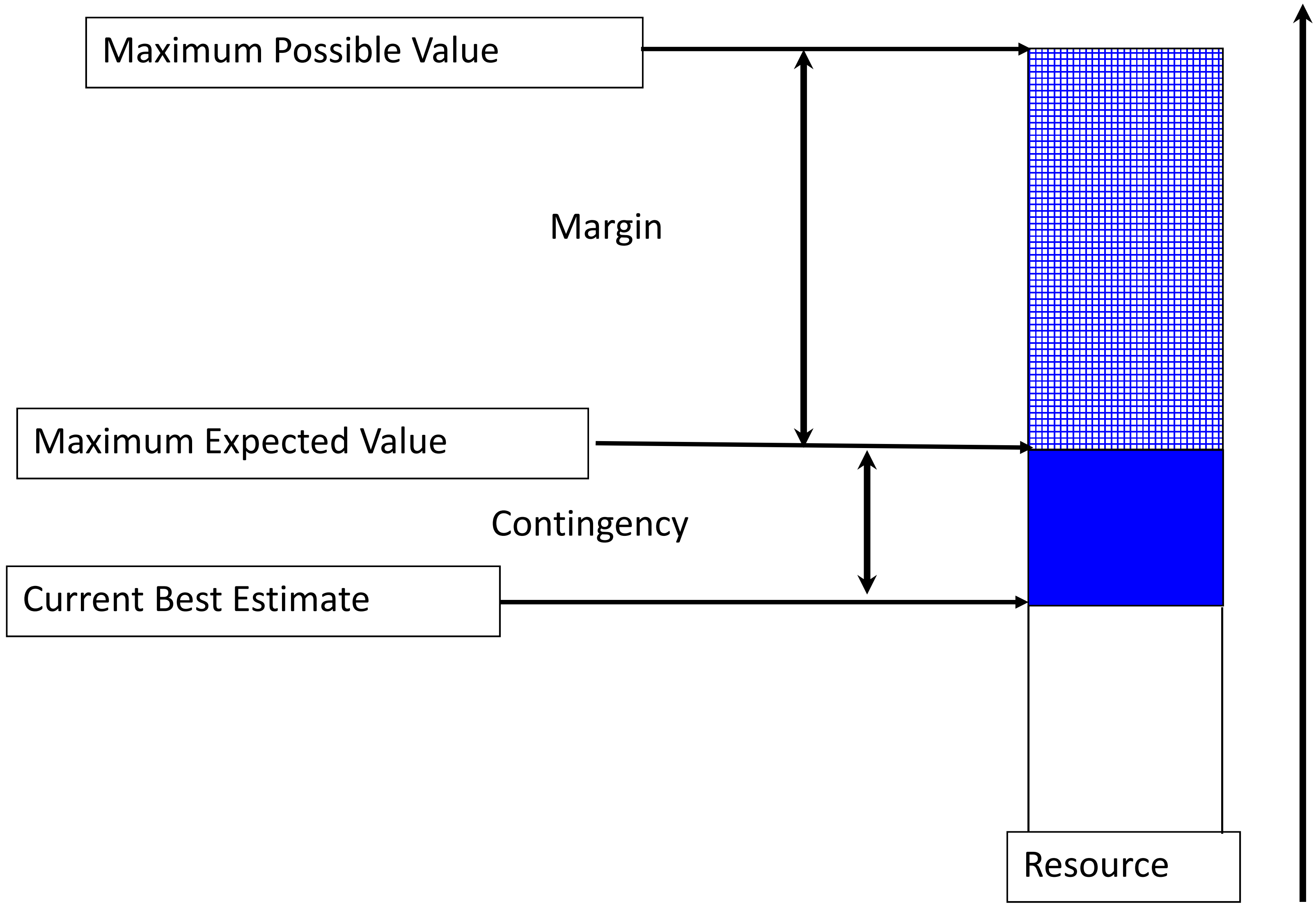


Trade Study Decision Matrix Example

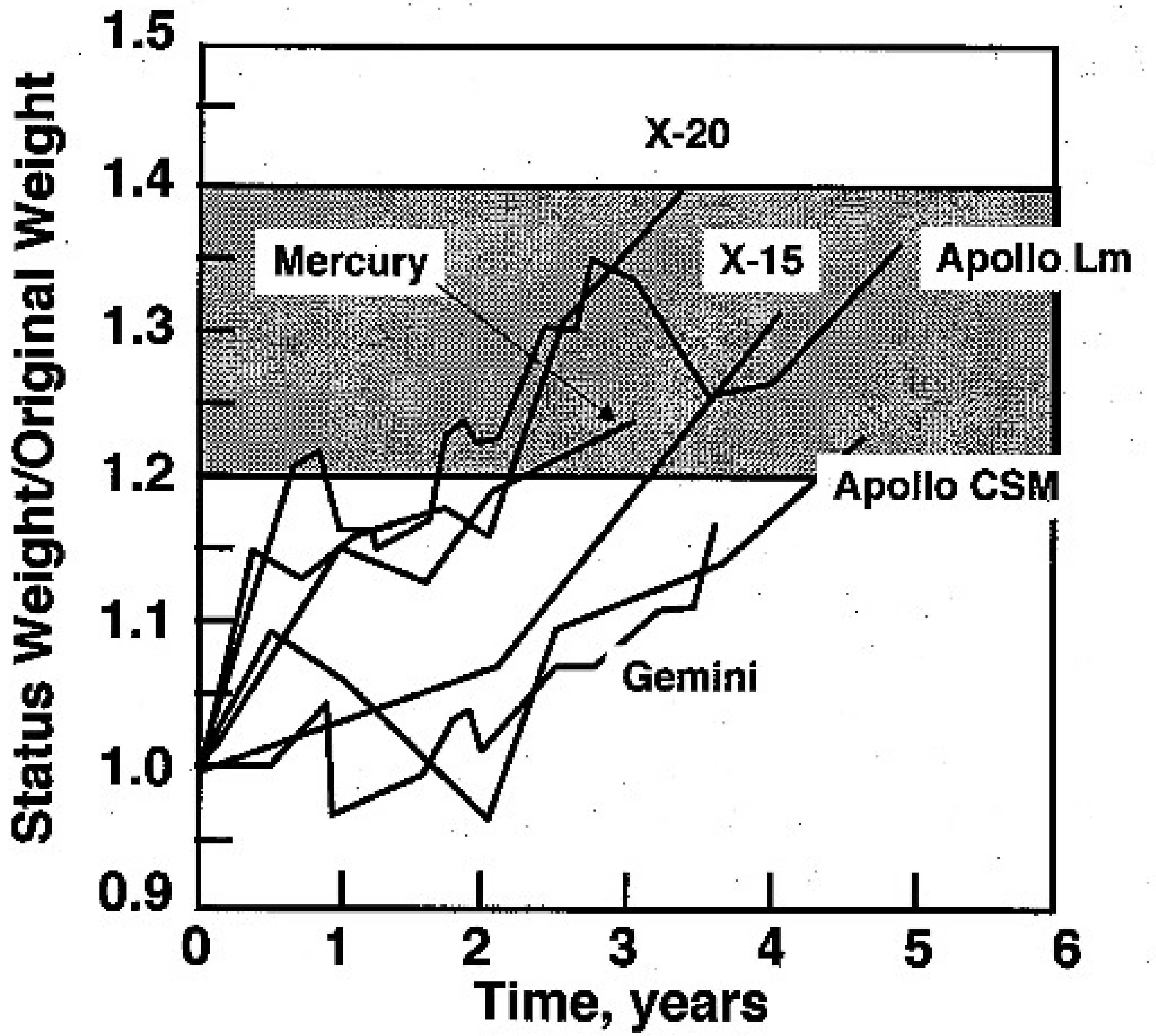
Decision Matrix Example for Battery			ENTER SCORES	Extend Old Battery Life	Buy New Batteries	Collect Experient Data With Alternative Experiment	Cancelled Experiment
CRITERIA	Mandatory (Y=1/N=0)?	Weight	SCALE				
Mission Success (Get Experiment Data)	1	30	3 = Most Supportive 1 = Least Supportive	2	3	3	0
Cost per Option	0	10	3 = Least Expensive 1 = Most Expensive	1	2	3	1
Risk (Overall Option Risk)	0	15	3 = Least Risk 1 = Most Risk	2	1	2	3
Schedule	0	10	3 = Shortest Schedule 1 = Longest Schedule	3	2	1	3
Safety	1	15	3 = Most Safe 1 = Least Safe	2	1	2	3
Uninterrupted Data Collection	0	20	3 = Most Supportive 1 = Least Supportive	3	1	2	1
WEIGHTED TOTALS in %		100%	3	73%	60%	77%	0%

Preferred Solution

Contingency & Margin



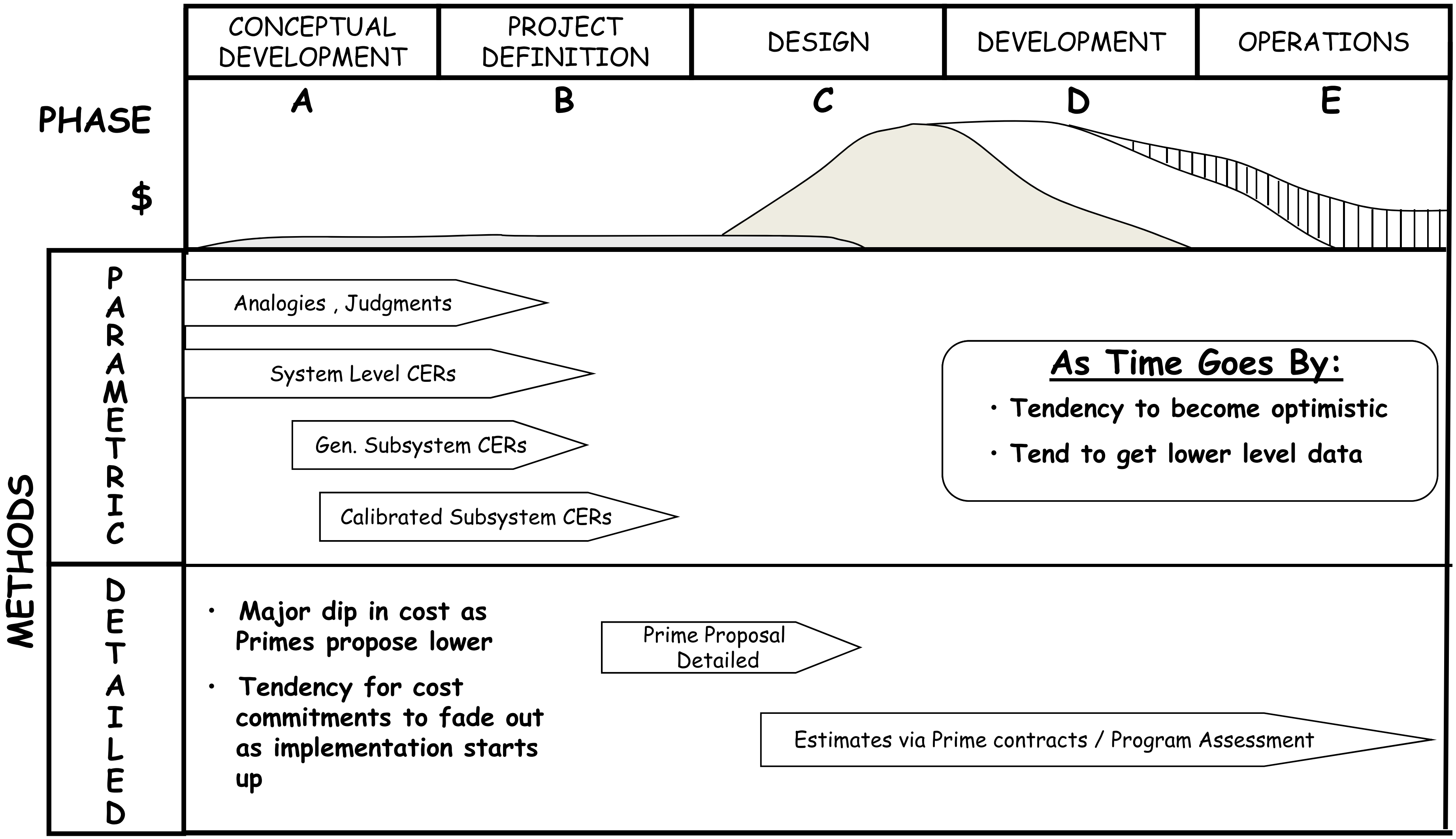
Contingency Adjustment by Technical Maturity



Contingency Adjustments by Mission Phase

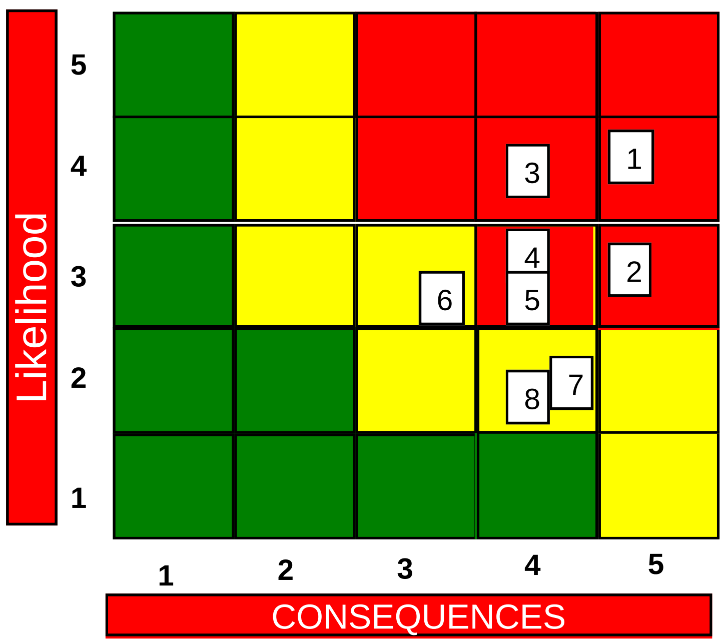
	Project Phase / Parameter	Pre-Phase A	Phase A	Phase B	Phase C
Technical	Weight	25-35%	25-35%	20-30%	15-25%
	Power EOL	25-35%	25-35%	15-20%	15-20%
	Pointing Accuracy	X2	X2	X1.5	X1.5
	Pointing Knowledge	X2	X2	X1.5	X1.5
	Pointing Jitter	X3	X3	X2	X2
	Propellant	30-35%	30-35%	20-25%	10-15%
	Data Throughput	30-40%	30-40%	20-30%	15-25%
	Data Storage	40-50%	40-50%	40-50%	30-40%
	RF Link Margin	6 dB	6 dB	6 dB	4 dB
	Torque Factor	X6	X6	X4	X4
	Strength Factor (Ultimate)	2.1	2.1	2.1	1.75
Prog.	Cost (Including De-Scope Options)	25-35%	25-35%	20-30%	15-20%
	Schedule	15%	15%	10%	10%

Cost Estimating Techniques



Risk Management Example
SOFIA Project

SOFIA Risk Matrix



Criticality L x C
- High
- Med
- Low

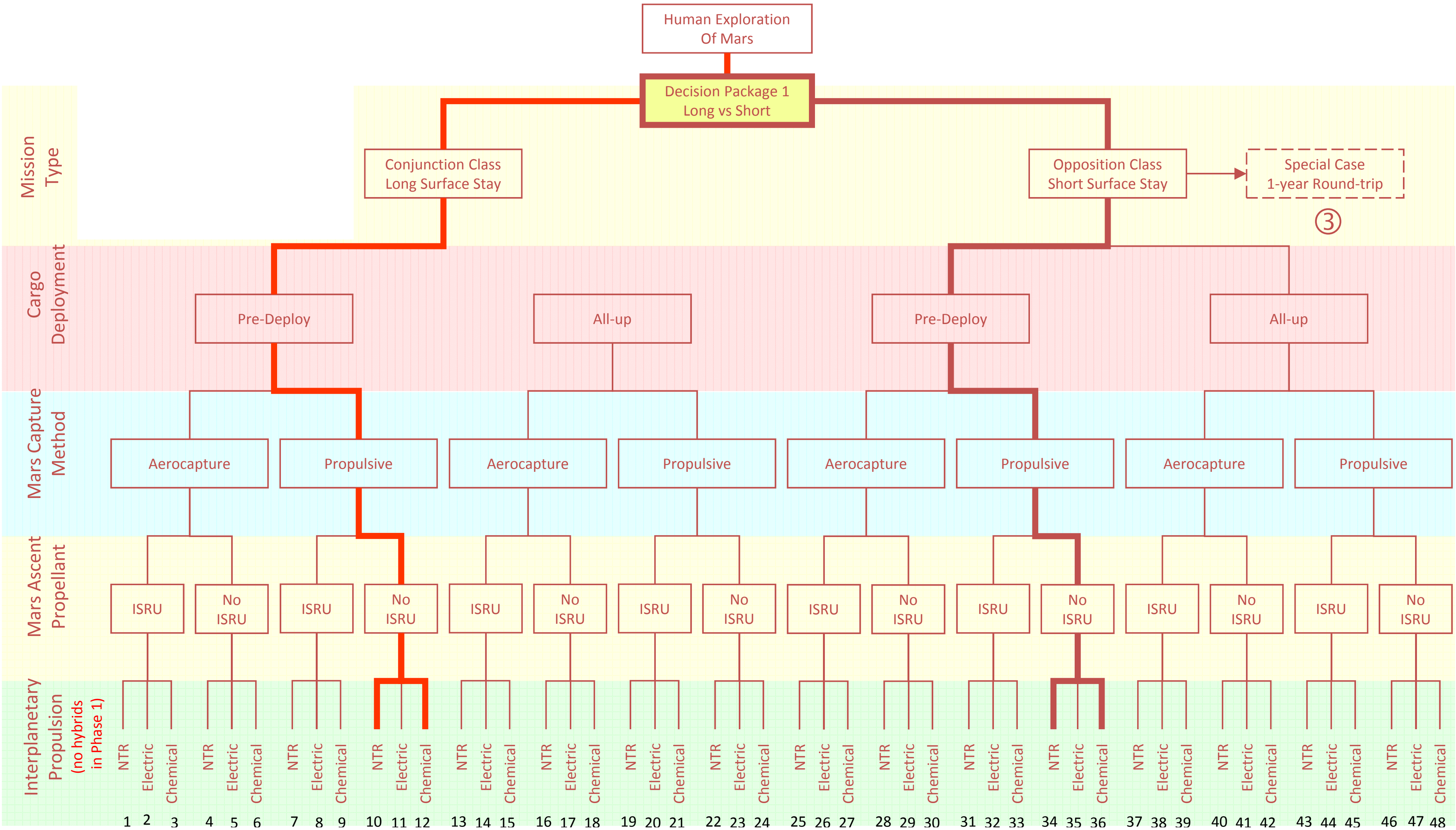
Trend
- ⇩ Decreasing (Improving)
- ⇧ Increasing (Worsening)
- ⇨ Unchanged
- ☐ New Since Last Period

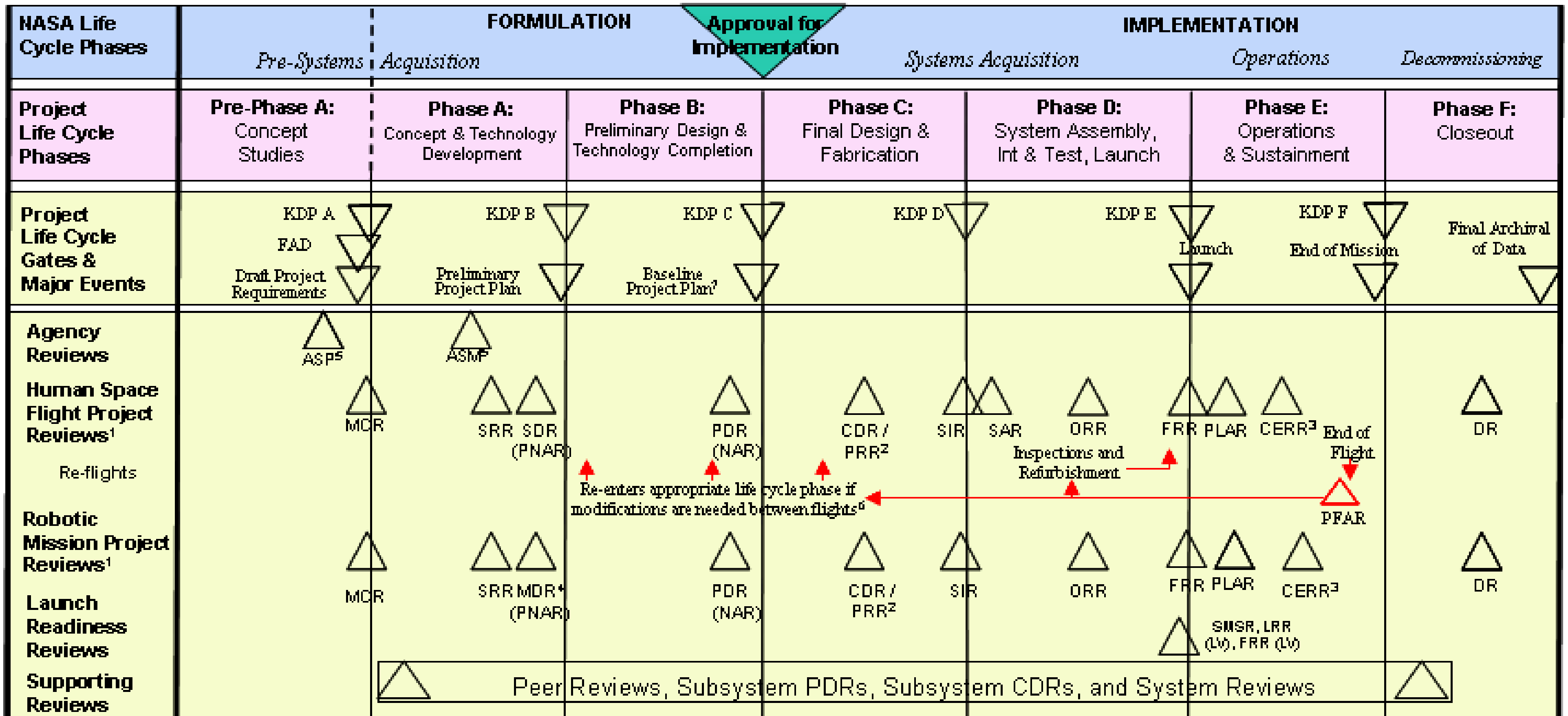
Approach
- M - Mitigate
- W - Watch
- A - Accept
- R - Research

Rank & Trend	Risk ID	Approach	Risk Title
⇨ 1	DFRC-34	R	Landing Gear Door System Failure
⇨ 2	DFRC-12	M	Sched Integration problems structure vs.. avionics
⇨ 3	DFRC-07	W	Cost growth for engine components
⇨ 4	DFRC-24	A	Quality Control Resources insufficient
⇩ 5	DFRC-01	W	Avionics software behind schedule
⇩ 6	DFRC-11	R	Payload Capacity & Volume Trade-offs design issues
⇨ 7	DFRC-04	R	Limited Flight Envelope, due to technical issues
⇨ 8	DFRC-02	R	More flight testing may be required for Soft V&V

Technology Decisions
Heritage vs. Advanced Technology

Top-level Trade Tree-Example
Human Mars Mission





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