# University of Houston SICSA Systems Engineering Overview: Functions & Interfaces

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# Space Architecture…

…theory and practice of designing and building inhabited environments in outer space…

…design of living and working environments in space related facilities, habitats, surface outposts and bases, and vehicles…

# Contents

## Systems Engineering & Integration

# NASA Systems Engineering Handbook

NASA/SP-2007-6105 Rev1

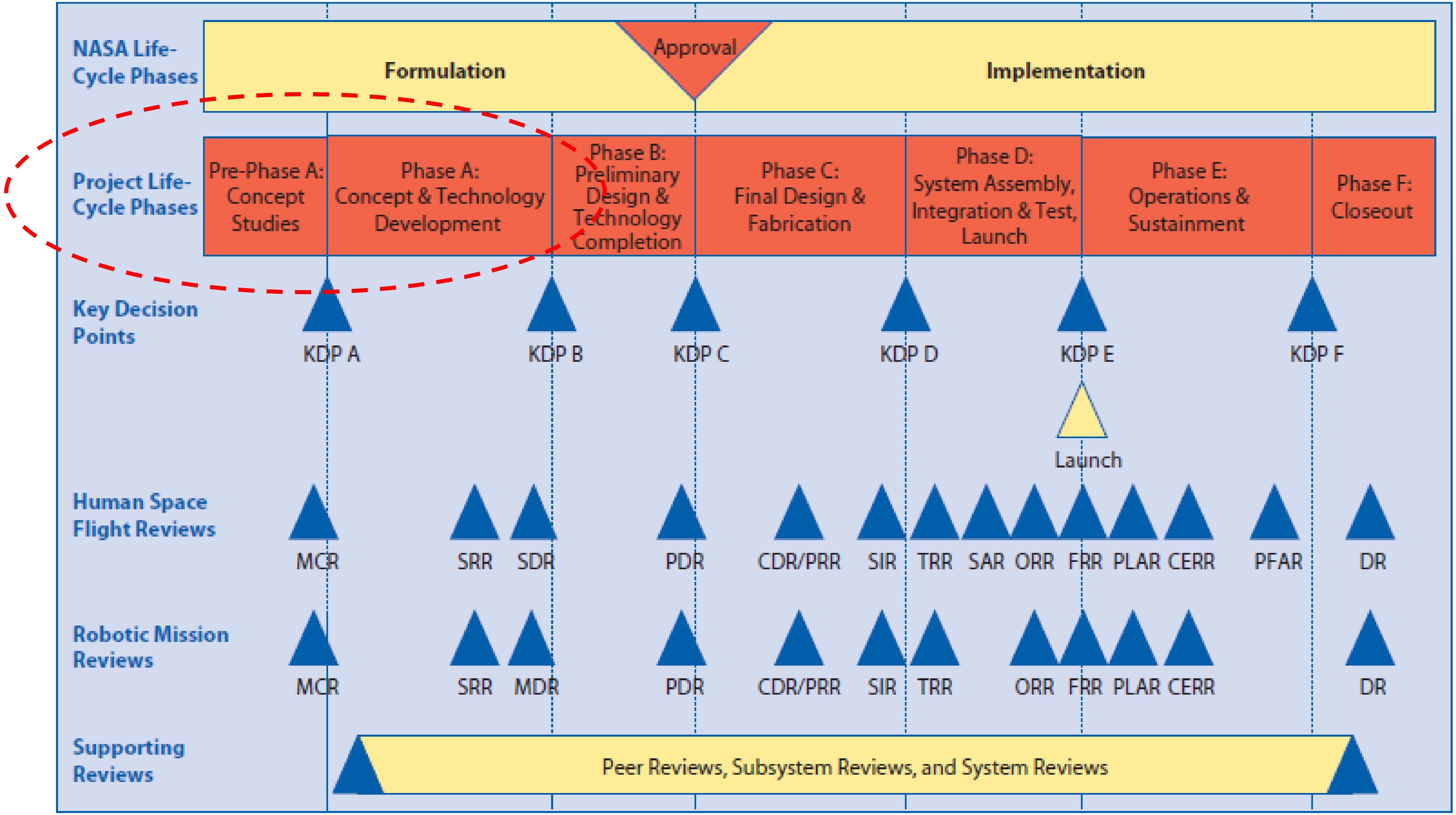
Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system. A "system" is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce system-level results.

**Synergy** is the creation of a whole that is greater than the simple sum of its parts. The term *synergy* comes from the Attic Greek word συνεργία *synergia*[1] from *synergos*, συνεργός, meaning "working together".

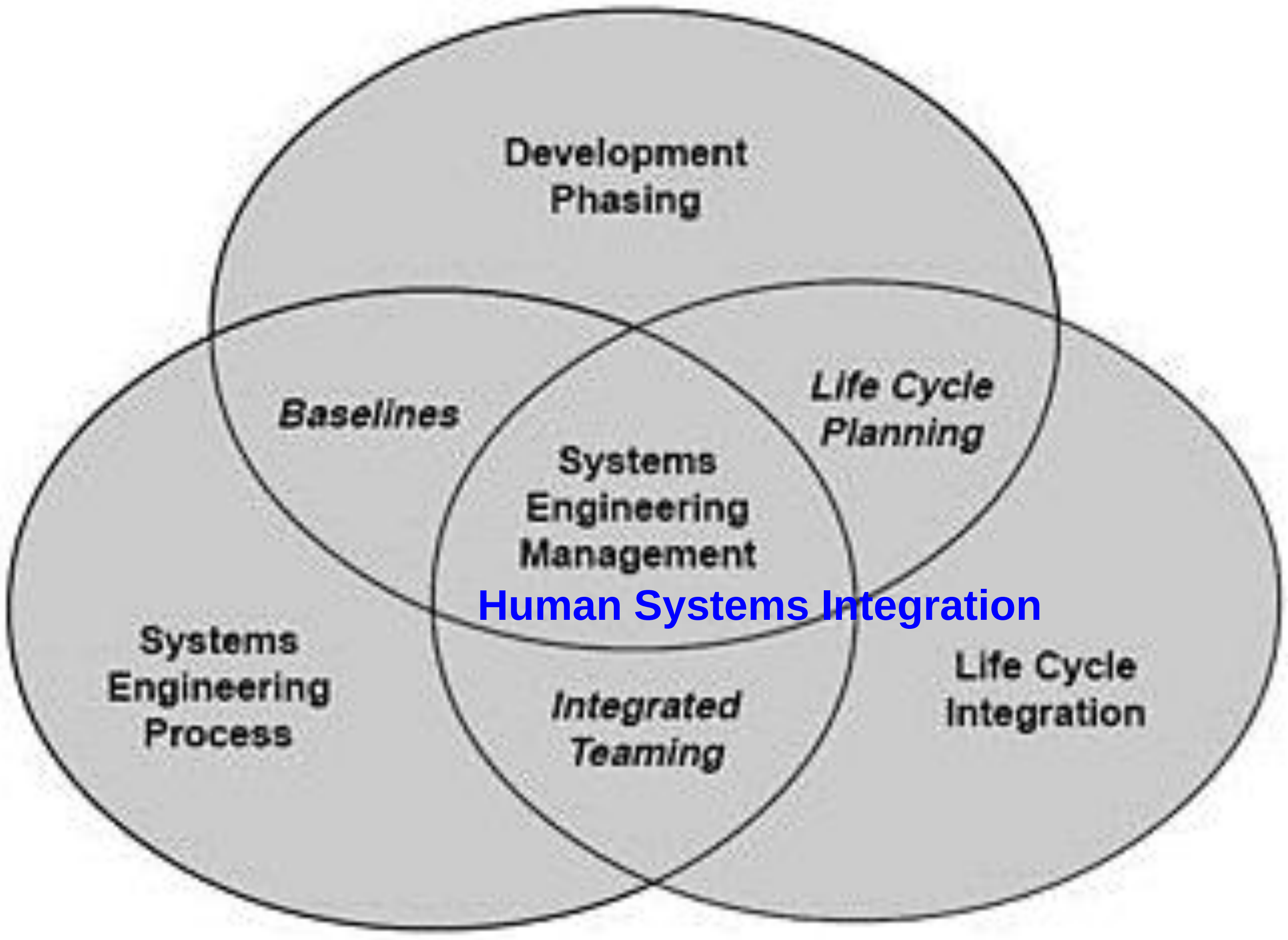
# Systems Engineering

- Systems engineering is an interdisciplinary field of engineering that focuses on how to design and manage complex engineering systems over their life cycles. Issues such as requirements engineering, reliability, logistics, coordination of different teams, testing and evaluation, maintainability and many other disciplines necessary for successful system development, design, implementation, and ultimate decommission become more difficult when dealing with large or complex projects. Systems engineering deals with work-processes, optimization methods, and risk management tools in such projects. It overlaps technical and human-centered disciplines such as industrial engineering, control engineering, software engineering, organizational studies, and project management. Systems engineering ensures that all likely aspects of a project or system are considered, and integrated into a whole.
- The systems engineering process is a discovery process that is quite unlike a manufacturing process. A manufacturing process is focused on repetitive activities that achieve high quality outputs with minimum cost and time. The systems engineering process must begin by discovering the real problems that need to be resolved, and identify the most probable or highest impact failures that can occur - systems engineering involves finding elegant solutions to these problems.
- https://en.wikipedia.org/wiki/Systems_engineering

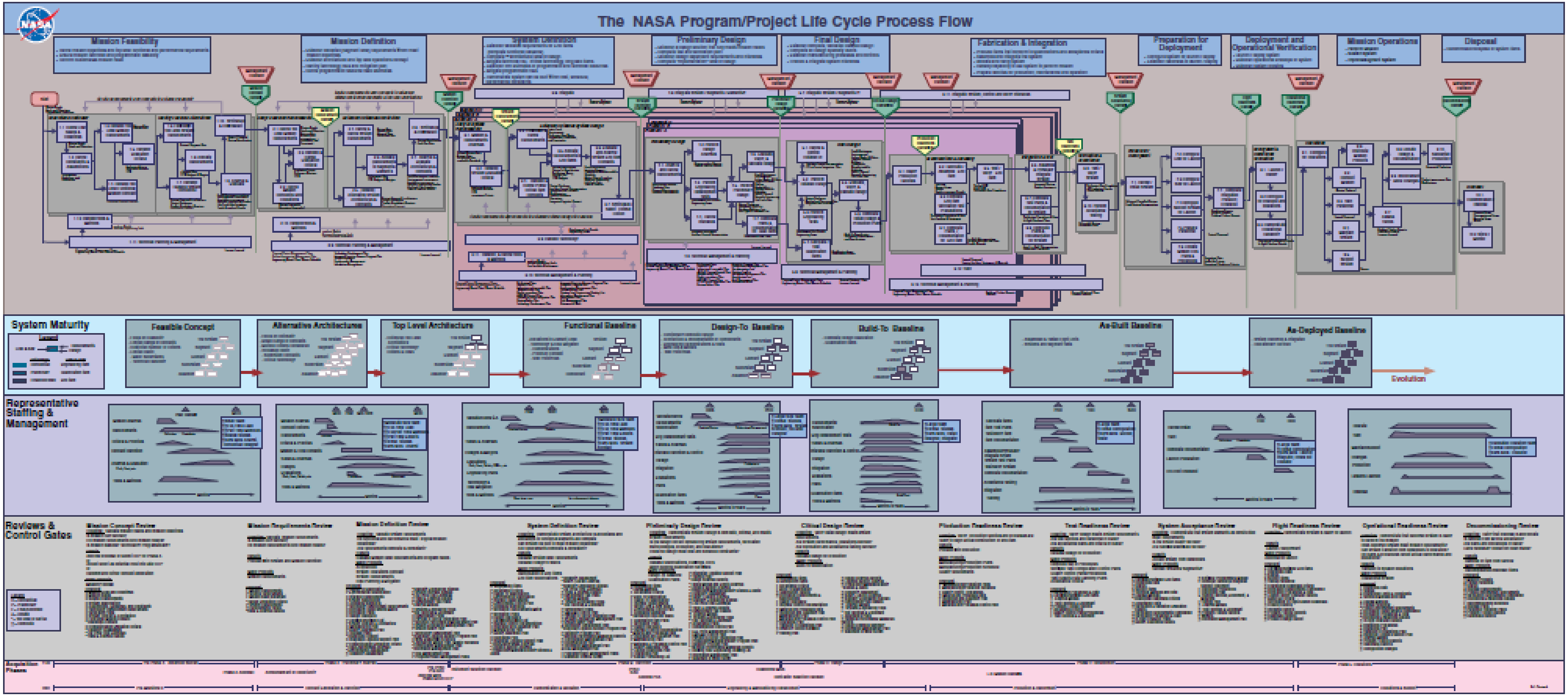
# NASA Project Life Cycle



# Systems Engineering



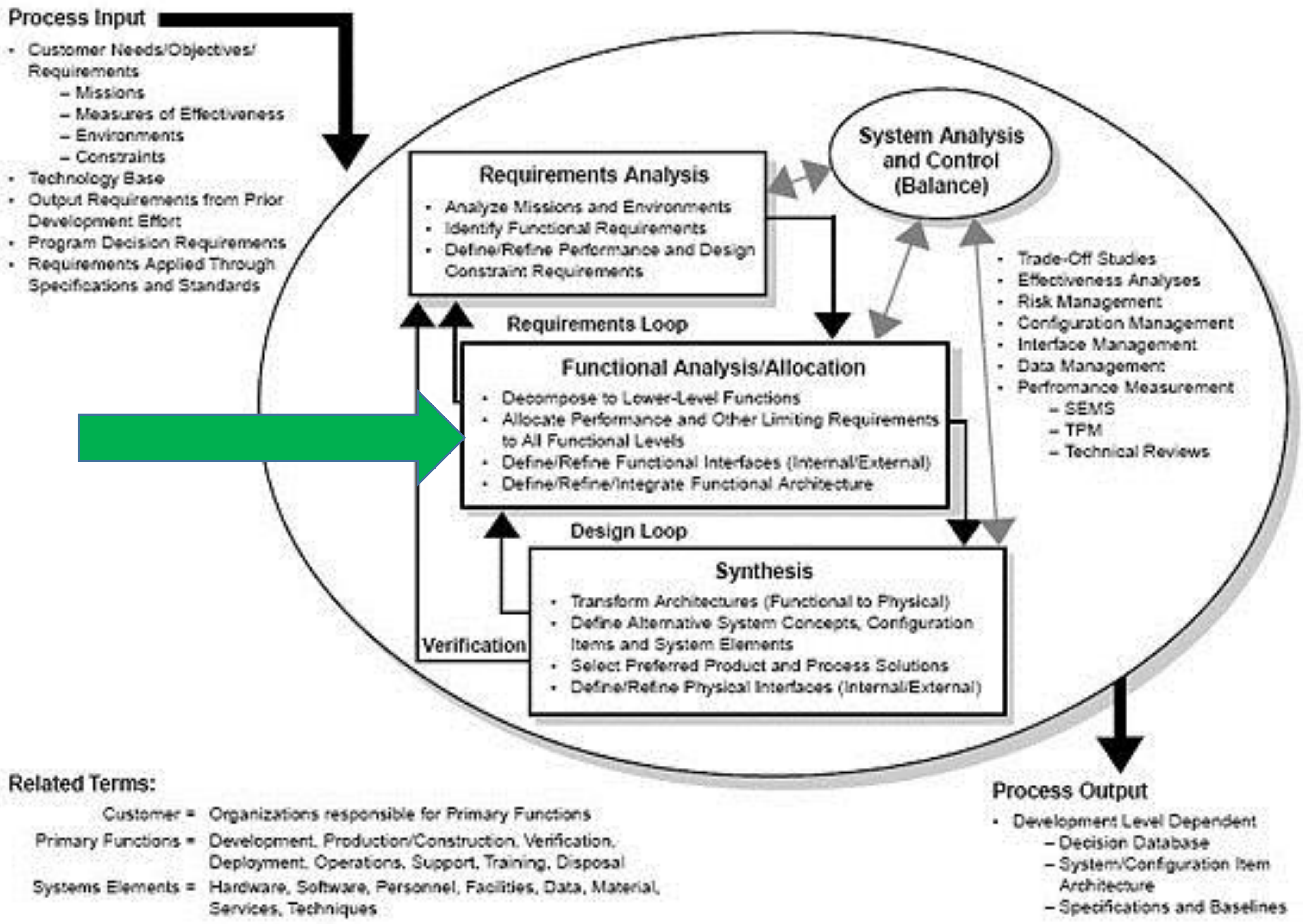
# Systems Engineering Process



# NASA Project Life Cycle - Acroynms

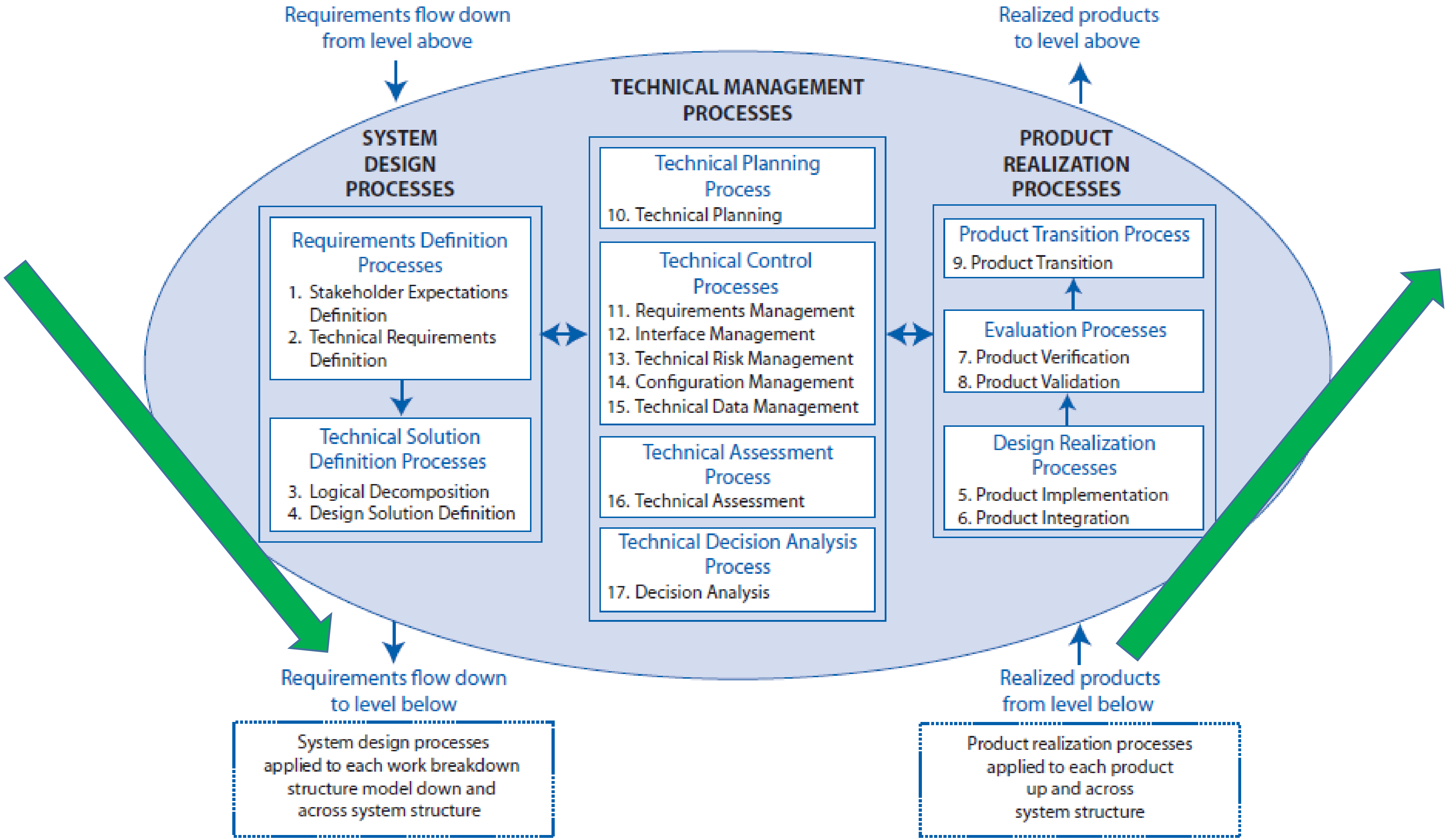
| | |
|---|---|
| CDR | Critical Design Review |
| CERR | Critical Events Readiness Review |
| DR | Decommissioning Review |
| FRR | Flight Readiness Review |
| KDP | Key Decision Point |
| MCR | Mission Concept Review |
| MDR | Mission Definition Review |
| ORR | Operational Readiness Review |
| PDR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

# SE Process



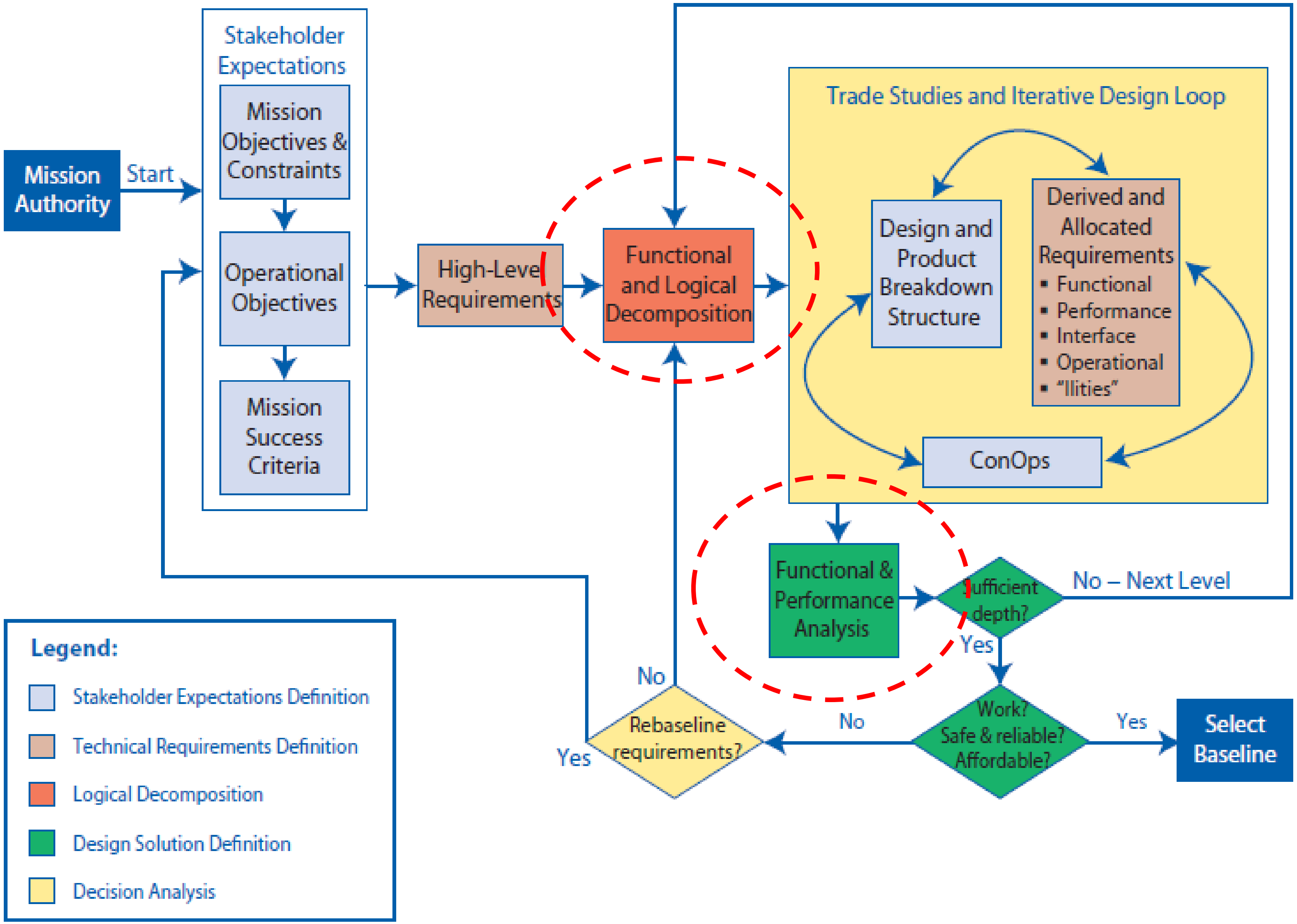
Process Input
• Customer Needs/Objectives/ Requirements
– Missions
– Measures of Effectiveness
– Environments
– Constraints
• Technology Base
• Output Requirements from Prior Development Effort
• Program Decision Requirements
• Requirements Applied Through Specifications and Standards
Requirements Analysis
• Analyze Missions and Environments
• Identify Functional Requirements
• Define/Refine Performance and Design Constraint Requirements
System Analysis and Control (Balance)
• Trade-Off Studies
• Effectiveness Analyses
• Risk Management
• Configuration Management
• Interface Management
• Data Management
• Perfromance Measurement
– SEMS
– TPM
– Technical Reviews
Requirements Loop
Functional Analysis/Allocation
• Decompose to Lower-Level Functions
• Allocate Performance and Other Limiting Requirements to All Functional Levels
• Define/Refine Functional Interfaces (Internal/External)
• Define/Refine/Integrate Functional Architecture
Design Loop
Synthesis
• Transform Architectures (Functional to Physical)
• Define Alternative System Concepts, Configuration Items and System Elements
• Select Preferred Product and Process Solutions
• Define/Refine Physical Interfaces (Internal/External)
Verification
Process Output
• Development Level Dependent
– Decision Database
– System/Configuration Item Architecture
– Specifications and Baselines
Related Terms:
Customer = Organizations responsible for Primary Functions
Primary Functions = Development, Production/Construction, Verification, Deployment, Operations, Support, Training, Disposal
Systems Elements = Hardware, Software, Personnel, Facilities, Data, Material, Services, Techniques

# SE Overview



Requirements flow down
from level above
Realized products
to level above
TECHNICAL MANAGEMENT
PROCESSES
SYSTEM
DESIGN
PROCESSES
PRODUCT
REALIZATION
PROCESSES
Technical Planning
Process
10. Technical Planning
Requirements Definition
Processes
1. Stakeholder Expectations
Definition
2. Technical Requirements
Definition
Technical Control
Processes
11. Requirements Management
12. Interface Management
13. Technical Risk Management
14. Configuration Management
15. Technical Data Management
Product Transition Process
9. Product Transition
Evaluation Processes
7. Product Verification
8. Product Validation
Technical Solution
Definition Processes
3. Logical Decomposition
4. Design Solution Definition
Technical Assessment
Process
16. Technical Assessment
Design Realization
Processes
5. Product Implementation
6. Product Integration
Technical Decision Analysis
Process
17. Decision Analysis
Requirements flow down
to level below
Realized products
from level below
System design processes
applied to each work breakdown
structure model down and
across system structure
Product realization processes
applied to each product
up and across
system structure

# Inter-relationship among System Design Process



# Functional Definitions

- Functional Analysis: The process of identifying, describing, and relating the functions a system must perform to fulfill its goals and objectives.
- Functional Baseline: The functional baseline is the approved configuration documentation that describes a system's or top-level Configuration Item's performance requirements (functional, interoperability, and interface characteristics) and the verification required to demonstrate the achievement of those specified characteristics.
- Functional Decomposition: A sub-function under logical decomposition and design solution definition, it is the examination of a function to identify sub-functions necessary for the accomplishment of that function and functional relationships and interfaces.

# Functional Decomposition

- Functional requirements define what functions need to be done to accomplish the objectives.
- Performance requirements define how well the system needs to perform the functions.
- Each function is identified and described in terms of inputs, outputs, and interface requirements from the top down so that the decomposed functions are recognized as part of larger functional groupings. Functions are arranged in a logical sequence so that any specified operational usage of the system can be traced in an end-to-end path to indicate the sequential relationship of all functions that must be accomplished by the system.

# Functions

- Process:
  - Walk through the ConOps and scenarios asking the following types of questions:
  - what functions need to be performed,
  - where do they need to be performed,
  - how often,
  - under what operational and environmental conditions, etc.
  - Thinking through this process often reveals additional functional requirements.

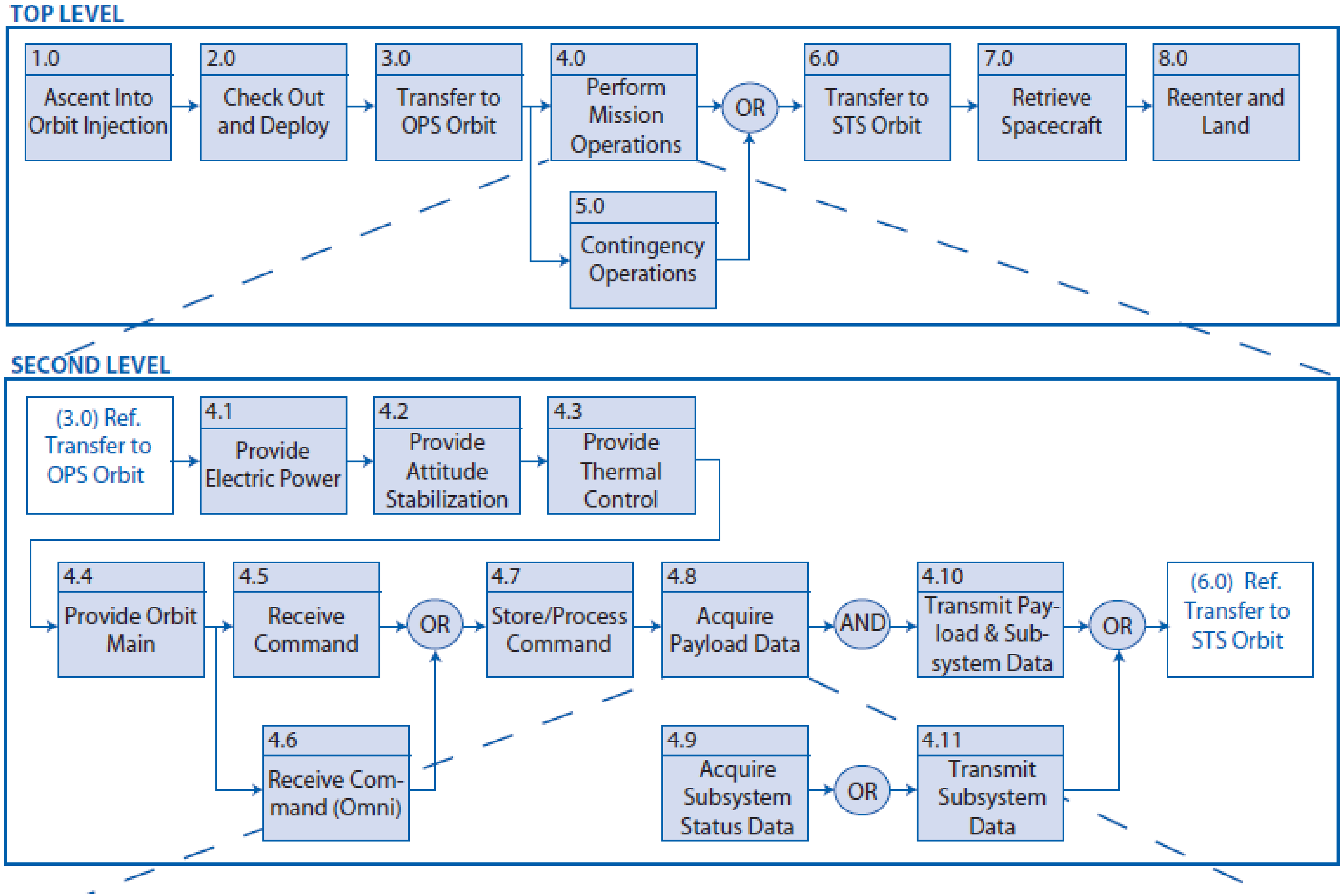
**Example of Functional and Performance Requirements**

- **Initial Function Statement**
  - The Thrust Vector Controller (TVC) shall provide vehicle control about the pitch and yaw axes.
  - This statement describes a high-level function that the TVC must perform. The technical team needs to transform this statement into a set of "design-to" functional and performance requirements.
- **Functional Requirements with Associated Performance Requirements**
  - The TVC shall gimbal the engine a maximum of 9 degrees, ± 0.1 degree.

# Functional Flow Block Diagrams

- Functional analysis can be performed using various methods, one of which is Functional Flow Block Diagrams (FFBDs).
- FFBDs define the system functions and depict the time sequence of functional events. They identify “what” must happen and do not assume a particular answer to “how” a function will be performed. They are functionally oriented, not solution oriented.
- FFBDs are made up of functional blocks, each of which represents a definite, finite, discrete action to be accomplished.
- The functional architecture is developed using a series of leveled diagrams to show the functional decomposition and display the functions in their logical, sequential relationship.
- Diagrams are laid out so that the flow direction is generally from left to right. Arrows are often used to indicate functional flows. The diagrams show both input (transfer to operational orbit) and output (transfer to STS orbit), thus facilitating the definition of interfaces and control process.

# FFBD - Example



# Example: Exploration Habitat Functionality

| Discipline | Function Title |
|---|---|
| Structures | Human-Rated Pressurized Volume |
| | System Volume |
| | Habitable Volume |
| | Stowage Volume |
| | Internal and External Loads |
| | Micrometeoroid Protection |
| | Inter-module Viewing (through hatch) |
| | Extra-Vehicular Activity (EVA) Translation Aids |
| | Grapple Fixtures and Robotic Accommodations |
| | Structural Health Monitoring |
| Mechanisms | IDSS-compliant Docking and Undocking |
| | Robotic Lander Berthing Capture and Structural Mating |
| | Hatches for Crew and Cargo |
| | Electrical Bonding |
| | Transfer of Air, Data, and Power |
| Power | Power Distribution |
| | Power Storage |
| | Power Management |
| | Power Quality Conditioning and Conversion |
| Thermal | Passive Thermal Control |
| | External Component Thermal Control |
| | Internal Component Liquid Cooling |
| | Cabin Air Cooling and Condensation Control |
| | Avionics Air Heat Rejection |
| | Heat Rejection |

| Discipline | Function Title |
|---|---|
| ECLSS (Air) | Cabin Air Humidity Control |
| | Air Circulation within Modules |
| | Air Circulation between Modules |
| | Cabin Air Trace Gas Contaminants Control |
| ECLSS (Env Monitor) | Major Constituent Gases ($O_2$, $CO_2$, $H_2O$, and $N_2$ or Pressure) Measurement |
| | Cabin Air Trace Gases Measurements for Nominal Levels |
| | Cabin Air Trace Gases Measurements for Non-Fire Contingency Events |
| ECLSS (Waste) | Trash and Waste Stowage |
| Fire Safety | Detect Fires |
| | Suppress Fires |
| | Measure Trace Gases in Cabin Air from Combustion or Pre-combustion Off-nominal Events |
| Crew Systems | Vehicle Lighting |
| | Intra-Vehicular Activity (IVA) Translation Aids |
| | In-situ Active Space Radiation Crew Effective Dose and Dose Rate Measurements |

| Discipline | Function Title |
|---|---|
| Avionics/ FSW | Sensor and Effector Data Collection and Transmittal |
| | Audio System that supports Caution and Warning Annunciation |
| | Flight Software Execution and Data Processing |
| | Ground Commanding and Telemetry |
| | Crew Displays and Controls |
| | Data Storage |
| Comm | Element to Element Communication Hardline |
| GN&C | Rendezvous and Berthing/Docking Sensors |
| | Rendezvous and Berthing/Docking Targets |
| Imagery | Imagery from Internal Fixed and Hand-Held Cameras |
| | Imagery from External Fixed and EVA Helmet Cameras |
| EVA | EVA to Vehicle Interfaces (EVA wireless comm) |
| | EVA Egress or Ingress |
| Science | External Science and Research Accommodations |
| Robotics | Enabling EVR Maintenance Tasks |

# example: Additional Functions

| Discipline | Function Title |
|---|---|
| Power | Power Distribution |
| Avionics/ FSW | Crew Displays and Controls |
| ECLSS (Air) | Cabin Air Particulate Control |
| | Cabin Carbon Dioxide Removal |
| ECLSS (Env Monitor) | Cabin Air Particulate Measurements |
| ECLSS (Water) | Crew Potable Water Distribution and Dispensing |
| | Maintain Safe, Low Levels of Microbial Life in Potable Water |
| | Maintain Safe, Low Levels of Microbial Life in Waste Water |
| | Cold Water Dispensing |
| | Potable Water Storage for Crew Use |
| | Fluids Transfers between Storage Locations (CWC) |
| ECLSS (Waste) | Crew Urine Collection and Addition of Required Pretreat |
| | Crew Feces Collection |
| | Microbial Safety Control |
| | Trash and Waste Stowage |
| Crew Systems | Crew Medical Care |
| | Private Crew Quarters (4) |
| | Private Crew Waste Compartment |
| | Food Preparation |
| | Crew Dining |
| | Private Communications (in sleep quarters) |

# Habitation Operations

## Crew Operations - IVA

**Sustain crew on lunar surface for mission.** These functions are necessary to insure the safety of the crew. It also includes providing the functions necessary to sustain the crew from a health and well being perspective.

## Crew Operations – Supporting EVA

**Enable Redundant EVA Function & Enhanced EVA Capability.** These functions are necessary to provide the crew with additional means to conduct routine EVAs. The extent provided is driven by the mission duration and the number of EVAs required to conduct that mission.

## Mission Operations

**Enable Enhanced Mission Operations Capability.** These functions are those that enable the lunar surface crew to conduct surface operations in concert with the Earth based mission control. For longer surface stays it should also establish autonomy from the Earth based "mission control" enabling command and control with other surface assets such as rovers, landers, etc.

## Science Operations

**Enable IVA Bio/Life Science & GeoScience Capability.** These functions are necessary to conduct the science involved with the mission. It can include sample collection, sample analyses, sample prioritization and storage, and any sample return required. It also is meant to include any specific "environmental" requirements specific to Life Science or GeoScience

## Logistics & Maintenance Operations - IVA & EVA

**Enable Maintenance, Resupply, & Spares Cache.** These functions are those that allows for maintaining the surface assets during recognized maintenance intervals. It also includes those functions necessary to resupply the habitat(s) with consumables (both pressurized and unpressurized) to support the crew for the mission. Lastly, it also includes the functions necessary to deliver and store the necessary spares related to the maintenance as well as unexpected failures.

# Habitation Operations and Functional Elements

Crew Operations (enable sustainability of 4 crew on lunar surface for 7-180 days)

EVA Operations (enable redundant EVA function & enhanced EVA capability)

Mission Operations (enable enhanced mission operations capability)

Science Operations (enable enhanced IVA bio & geo science capability)

Logistics Operations (enable resupply & spares cache)

- Structure and Environmental Protection
- Power Management and Distribution
- Life Support
- Thermal Control
- Lunar Surface Science and Technology Demonstrations
- Communications
- EVA Support
- Crew Accommodations

# Human Exploration Systems

**Elements**

- Crew Return Vehicle
- Exploration Habitat
- Space Exploration Vehicle
- Propulsion Stage
- EVA Capabilities
- Power Generation & Storage
- Deep Space Communications

**Exploration Habitat Systems**

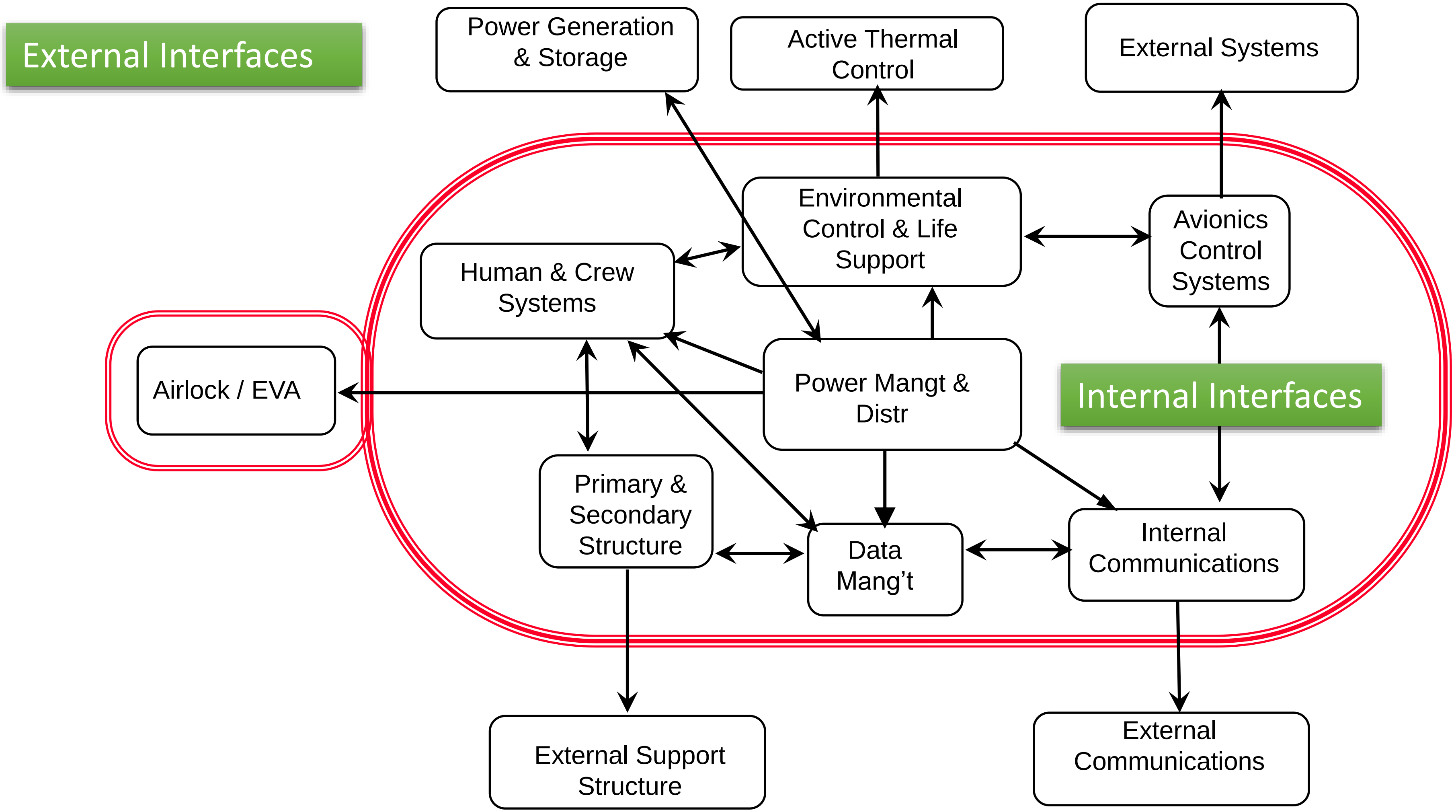
- Environmental Protection
- Life Support
- Power Management & Distribution
- Thermal Control
- Crew & Medical Systems
- Laboratory Systems (Geo & Life Science)
- Logistics, Repair & Manufacturing

# Interfaces

## Interface Requirements

- It is important to define all interface requirements for the system, including those to enabling systems. The external interfaces form the boundaries between the product and the rest of the world.
- Types of interfaces include:
  - operational command and control,
  - computer to computer,
  - mechanical,
  - electrical,
  - thermal,
  - data.
- One useful tool in defining interfaces is the context diagram (see Appendix F), which depicts the product and all of its external interfaces.
- Once the product components are defined, a block diagram showing the major components, interconnections, and external interfaces of the system should be developed to define both the components and their interactions.

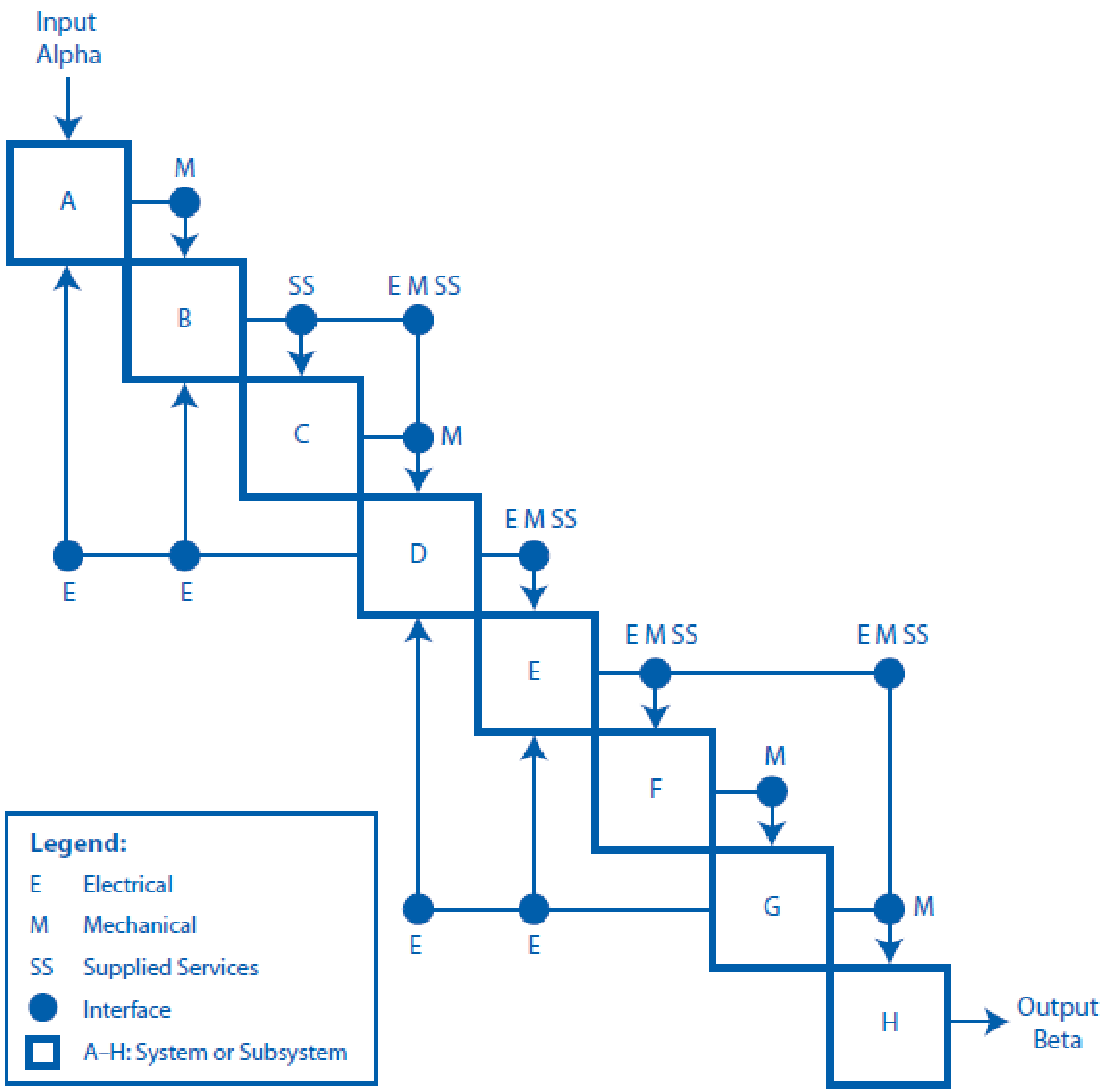
# Habitation Elements & Interfaces



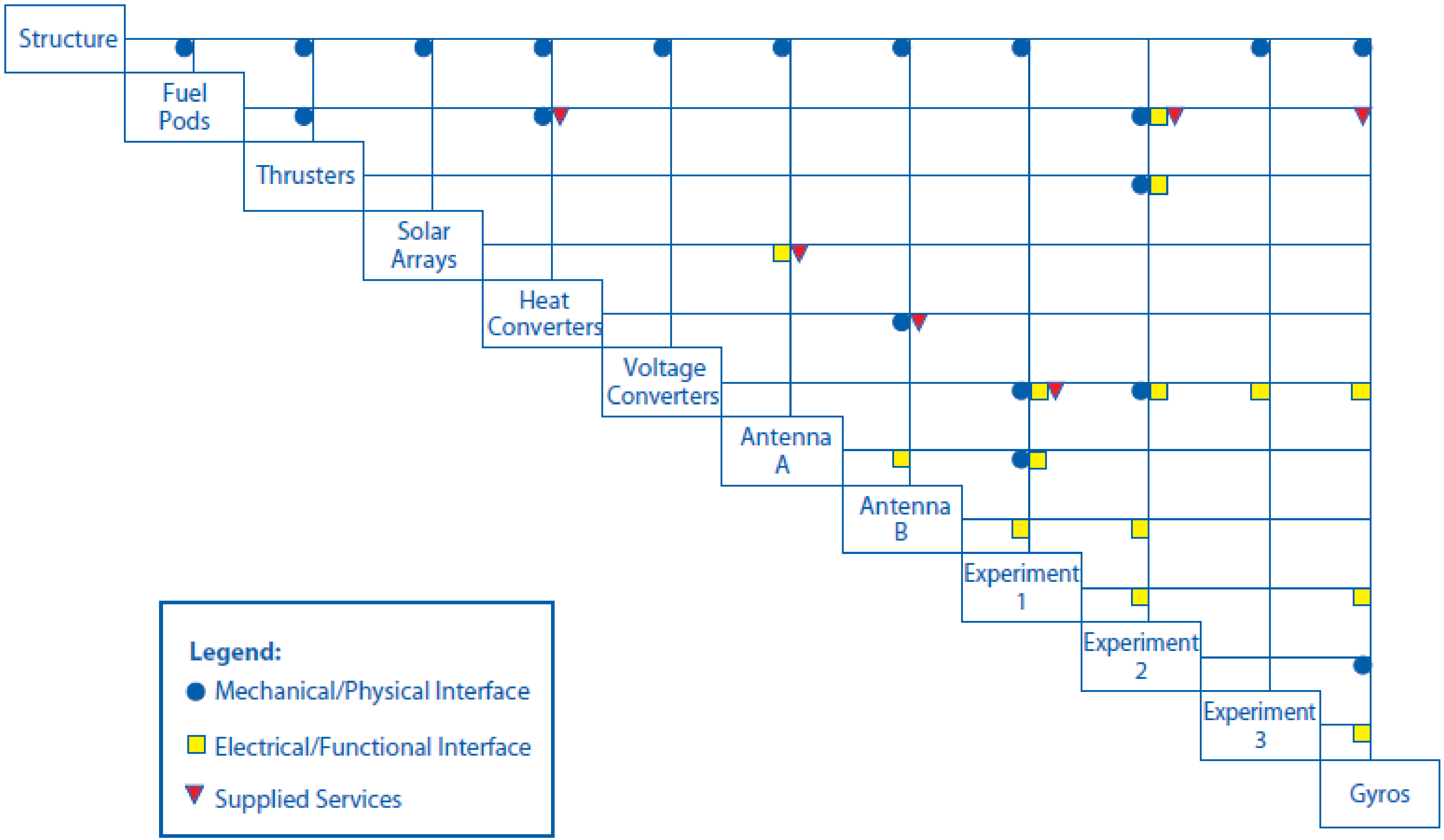
# $N^2$ Interface Diagram

- An N-squared (N2) diagram is a matrix representation of functional and/or physical interfaces between elements of a system at a particular hierarchical level.
- The N2 diagram has been used extensively to develop data interfaces, primarily in the software areas. However, it can also be used to develop hardware interfaces.
- The system components are placed on the diagonal. The remainder of the squares in the NxN matrix represent the interfaces.
- The square at the intersection of a row and a column contains a description of the interface between the two components represented on that row and that column.
    - For example, the solar arrays have a mechanical interface with the structure and an electrical interface and supplied service interface with the voltage converters. Where a blank appears, there is no interface between the respective components.

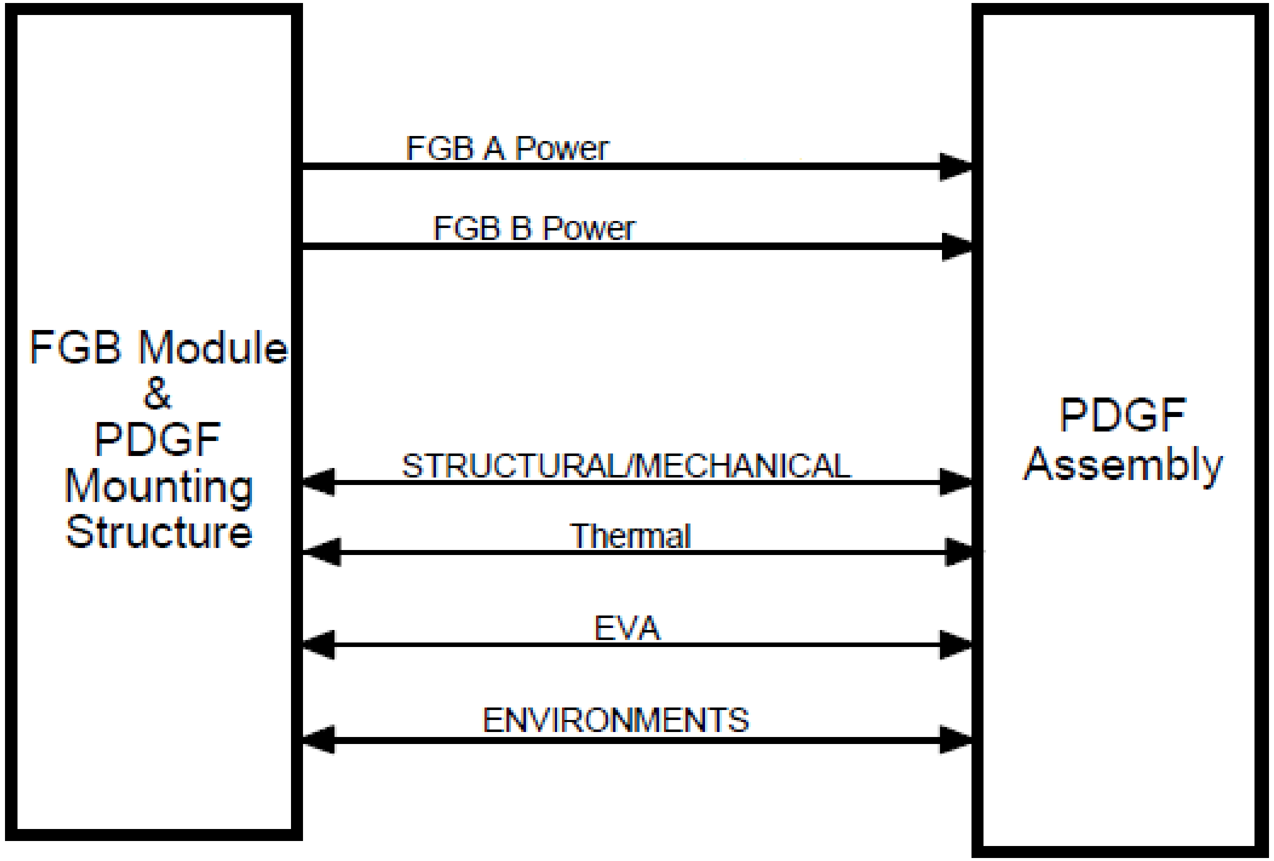
# $N^2$ Interface definition Process



# N$^2$ Interface Diagram - example



# FGB MODULE TO PDGF ASSEMBLY FUNCTIONAL INTERFACE DIAGRAM



# Testing Interfaces

# *Habitat Demonstration Unit*

## 2010 Fit Check w/ Rover