Spacecraft System Engineering
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- Chapter 20, Fortescue et al
  - Program Phases
  - Techniques
  - Concurrent Engineering
  - Case Study: CryoSat

NASA-SP-610S Definition of System Hierarchy

- System
  - Segment
    - Element
      - Subsystem
        » Assembly
          • Subassembly
          • Part
Program Phases: 
*Project Life Cycle for Major Systems*

- Pre-Phase A (advanced studies)
- Phase A (feasibility)
- Phase B (detailed definition)
- Phase C (design guidelines)
- Phase D (development guidelines)
- Phase E (mission operations and data analysis)

*NASA-SP-610S, 1995*

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Pre-Phase A (advanced studies)

*“find a suitable project”*

Pre-Phase A—Advanced Studies

**Purpose:** To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. **Major Activities and their Products:** Identify missions consistent with charter identity and involve users. Perform preliminary evaluations of possible missions. Prepare program/project proposals, which include:

- Mission justification and objectives
- Possible operations concepts
- Possible system architectures
- Cost, schedule, and risk estimates.

Develop master plans for existing program areas. **Information Baselined:** (nothing)

**Control Gates:**
- Mission Concept Review
- Informal proposal reviews

*NASA-SP-610S, 1995*
Phase A (feasibility)
“find a worthwhile project”

Phase A—Preliminary Analysis

Purpose: To determine the feasibility and desirability of a suggested new major system and its compatibility with NASA’s strategic plans.

Major Activities and their Products:
- Prepare Mission Needs Statement
- Develop top-level requirements
- Develop corresponding evaluation criteria/metrics
- Identify alternative operations and logistics concepts
- Identify project constraints and system boundaries
- Consider alternative design concepts, including: feasibility and risk studies, cost and schedule estimates, and advanced technology requirements
- Demonstrate that credible, feasible design(s) exist
- Acquire systems engineering tools and models
- Initiate environmental impact studies
- Prepare Project Definition Plan for Phase B

Information Baseline:
(nothing)

Control Gates:
- Mission Definition Review
- Preliminary Non-Advocate Review
- Preliminary Program/Project Approval Review

Figure 20.1 Phase A system engineering flow diagram
Phase B (detailed definition)

“define the project and establish a preliminary design”

Phase B—Definition

Purpose: To define the project in enough detail to establish an initial baseline capable of meeting mission needs.

Major Activities and their Products:
- Prepare a Systems Engineering Management Plan
- Initiate configuration management
- Prepare engineering specialty program plans
- Develop system-level cost-effective/viable model
- Resolve mission needs as functional requirements
- Identify science payloads
- Establish the initial system requirements and verification requirements matrix
- Perform and archive trade studies
- Select a baseline design solution and a concept of operations
- Define internal and external interface requirements
- Define verification approach and plans
- Identify integrated logistics support requirements
- Establish technical resource estimates and firm life-cycle cost estimates
- Develop statement(s) of work
- Initiate advanced technology developments
- Revise and publish a Project Plan
- Reaffirm the Mission Needs Statement
- Prepare a Program Commitment Agreement

Information Baseline:
- System requirements and verification requirements matrix
- System architecture and work breakdown structure
- Concept of operations
- “Design-to” specifications at all levels
- Project plans, including schedule, resources, assumptions, strategies, and risk management

NASA-SP-610S, 1995

Phase C (design guidelines)

“complete the system design”

Phase C—Design

Purpose: To complete the detailed design of the system (and its associated subsystems, including its operational systems).

Major Activities and their Products:
- Add remaining lower-level design specifications to the system architecture
- Refine requirements documents
- Refine verification plans
- Prepare interface documents
- (Repeat the process of successive refinement to get “build-to” specifications and drawings, verification plans, and interface documents at all levels)
- Augment baselined documents to reflect the growing maturity of the system: system architecture, verification requirements matrix, work breakdown structure, project plans
- Monitor project progress against project plans
- Develop the system integration plan and the system operation plan
- Perform and archive trade studies
- Complete manufacturing plan
- Develop the end-to-end information system design
- Refine Integrated Logistics Support Plan
- Identify opportunities for pre-planned product improvement
- Confirm science payload selection

Information Baseline:
- All remaining lower-level requirements and
Phase D (development guidelines)

“build, integrate, and verify the system, and prepare for operations”

Phase E—Operations

**Purpose:** To actually meet the initially identified need or to grasp the opportunity, then to dispose of the system in a responsible manner.

**Major Activities and their Products:**
- Train replacement operators and maintainers
- Conduct the mission(s)
- Maintain and upgrade the system
- Dispose of the system and supporting processes

**Information Baselined:**
- Mission outcomes, such as:
  - Engineering data on system, subsystem and materials performance
  - Science data returned
  - High resolution photos from orbit
  - Accomplishment records (“firsts”)
  - Discovery of the Van Allen belts
  - Discovery of volcanoes on Io.
  - Operations and maintenance logs
  - Problem/failure reports

**Control Gates:**
- Regular system operations readiness reviews
- System upgrade reviews
- Safety reviews
- Decommissioning Review
Overview of Space Project Cycle: V Diagram

System Engineering Techniques

Figure 20.2. System engineering boundaries. (Figure reproduced from [1] by permission of ESA on behalf of the ESSC members)
Expansion/Translation of Top-Level Requirements

Orbit Options for Astronomy Missions
Design Drivers

Tradeoffs


System Mass and Power Budgets

Concurrent Engineering

Figure 20.5 Alternative approaches to space system design
"Waterfall" vs. Concurrent Design

NASA JPL Team X

http://jplteamx.jpl.nasa.gov/
European Space Agency Concurrent Design Approach

Figure 20.7 The ESA approach to the creation of an Integrated Design Environment

http://www.esa.int/Our_Activities/Space_Engineering_Technology/CDF

Process

Figure 20.8 Conceptual model of the mission and spacecraft design process. The ovals represent the disciplines, the boxes represent aggregated key parameters, the arrows are interactions and data exchange. Each discipline contributes, directly or indirectly to the definition of the main mission parameters (or key parameters)
Spiral Model of the Design Process

Mission analysis

Mission requirements analysis

Sub-system design

Cost analysis

Risk assessment

Design verification

Key parameter A

Key parameter B

Key parameter C

Figure 20.9 CE Iterative process: Spiral Model representation. In the example, point T is the target value of key parameter A

Design/Development Team

Integrated Product Development Teams

The detailed evaluation of product and process feasibility and the identification of significant uncertainties (system risks) must be done by experts from a variety of disciplines. An approach that has been found effective is to establish teams for the development of the product with representatives from all of the disciplines and processes that will eventually be involved. These integrated product development teams often have multidisciplinary (technical and business) members. Technical personnel are needed to ensure that issues such as producibility, verifiability, deployability, supportability, trainability, operability, and disposability are all considered in the design. In addition, business (e.g., procurement) representatives are added to the team as the need arises. Continuity of support from these specialty discipline organizations throughout the system life-cycle is highly desirable, though team composition and leadership can be expected to change as the system progresses from phase to phase.

NASA-SP-610S, 1995
**Design Process Model**

*Figure 20.10  The CDF Integrated Design Model (IDM)*

**ESA Concurrent Design Facility**
Hardware/Software Infrastructure for Concurrent Design

Benefits of Using Concurrent Design

• Reduced design time
• Reduced errors
• Increased quality
• Project management visibility
• Top-level change control
• Knowledge of how modules interface
Case Study: CRYOSAT

- CryoSat-1 failed to reach orbit
- CryoSat-2 launched April 2010


Mission Characteristics

- CryoSat-2's mission: study the Earth's polar ice caps, measuring and looking for variation in the thickness of the ice.

- Primary instruments:
  - SIRAL-2, the SAR/Interferometric Radar Altimeters, which use radar to determine and monitor the spacecraft's altitude in order to measure the elevation of the ice. Two SIRAL instruments are installed aboard CryoSat-2.
  - Doppler Orbit and Radio Positioning Integration by Satellite, or DORIS, is used to calculate precisely the spacecraft's orbit. An array of retroreflectors allow measurements to verify the orbital data provided by DORIS.

- Launch and Early Orbit Phase operations: April 2010

- The spacecraft underwent six months of on-orbit testing and commissioning.
Precision Measurements from Space

http://emits.sso.esa.int/emits-doc/ESRIN/7158/CryoSat-PHB-17apr2012.pdf

Designing the System

http://emits.sso.esa.int/emits-doc/ESRIN/7158/CryoSat-PHB-17apr2012.pdf
Payload: Re-use and Innovation

What Makes It Tick?

Putting It Together

CryoSat Launch

Separation of CryoSat from Dnepr 3rd Stage
Next Time:
*Product Assurance*