Tutorial Raumfahrzeugentwurf
Spacecraft Technology / Design

Main goal of tutorial is to give insight on important topics in spacecraft design. After this lecture everybody should have the ability to understand a spacecraft design and be able to lead a new design process.

Overview

Tutorial 1: System Design Process

Spacecraft and Mission Design

Matthias Killian
m.killian@tum.de
Phone: 089-28916008
Room: MW 2607 (Garching)

Take home from lecture

- What project phases does ESA/NASA use?
- What happens in those phases
- What are the crucial phases in terms of money, time, personnel
- How to get to good requirements

Why do we need a Design Process?

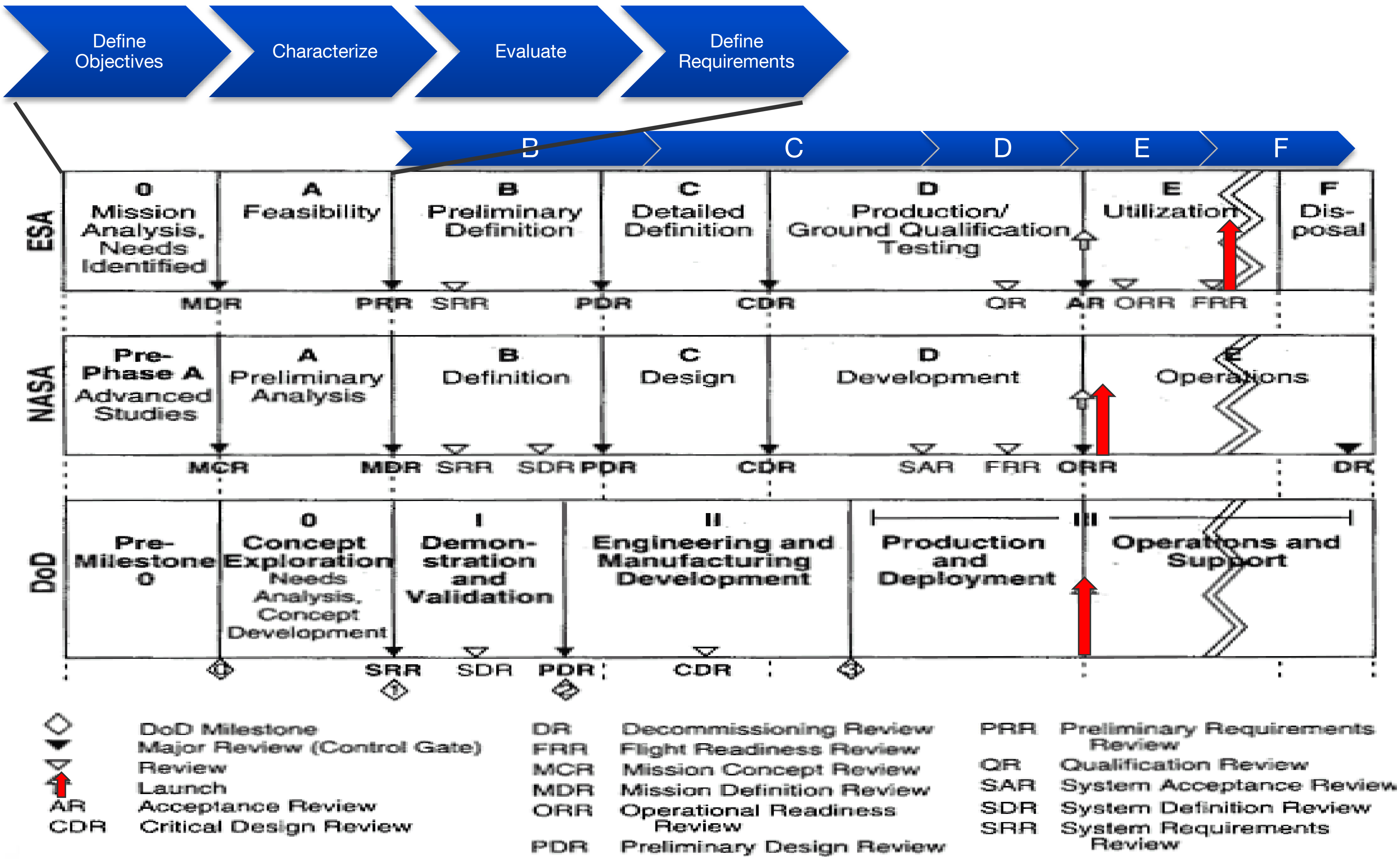
- Manage the complexity of design activities
- Multidisciplinary design as a communication and negotiation problem
- Risk mitigation

Mission Analysis & Design Process

Define Objectives	•1. Define broad objectives and constraints •2. Estimate quantitative mission needs and requirements
Characterize Mission	•3. Define alternative mission concepts •4. Define alternative mission architectures •5. Identify system drivers •6. Characterize mission concepts and architectures
Evaluate Mission	•7. Identify critical requirements •8. Evaluate mission utility •9. Define baseline mission concept
Define Requirements	•10. Define system requirements •11. Allocate requirements to system elements

- Define Objectives: What? & Why?
- Characterize Mission: How can it be done?
- Evaluate Mission: Which Options do we have?
- Define Requirements: Write it down properly!

Project Cycle

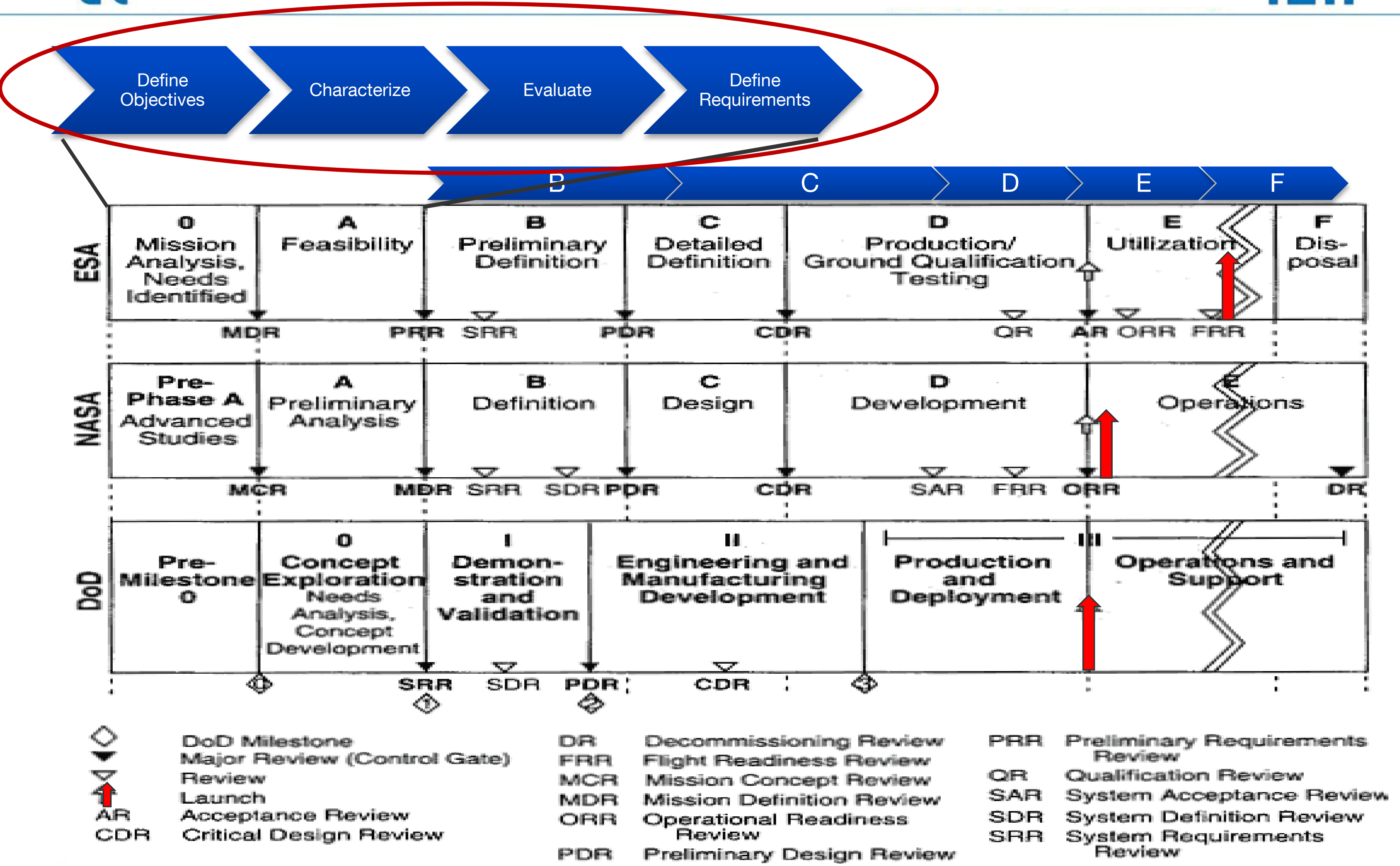


Discussion

MOVE 2

Objective	Objective	Objective
Entwicklung und Flug einer neuartigen, entfaltbaren Leichtbaustruktur	auf Basis des Cubesat Standard (2U)	Ausbildung
No influence on satellite design so far, depending on payload	Strict restriction on volume and weight	Restriction on man power and money
Objective does not restrict design – bad?	Maximum 20*20*22 cm and 2.66 kg As a results of that, also high influence on maximum power, temperatures, orbit etc.	Does not restrict design, but • Unexperienced people • Risk of bad design

Project Cycle



Step 1: Define Broad Objectives and constraints

Theory	FireSat	Camping
Define Broad Objectives and constraints *Most broad statement what the system should do.*	Mission Statement: Due to the high impact of forest fires the US need a more effective system to identify and monitor them. It would also be desirable to monitor fires all around the world. The Forest Service Officers will use the data in the field.	Mission Statement: Next week I want to go camping and fishing in a quiet area. It would be nice to have a small town nearby to buy some groceries.

Objectives → Characterize → Evaluate → Requirements → Phase B – F

- International Space Station objectives?

From Memorandum of Understanding NASA & Roskosmos, Article 2.3:
http://www.nasa.gov/mission_pages/station/structure/elements/nasa_rsa.html

The Space Station will enable its users to take advantage of human ingenuity in connection with its low-gravity environment, the near-perfect vacuum of space and the vantage point for observing the Earth and the rest of the Universe. Specifically, the Space Station and its evolutionary additions could provide for a variety of capabilities, for example:

- - a **laboratory in space**, for the conduct of science and applications and the development of new technologies;
- - a **permanent observatory** in high-inclination orbit, from which to observe Earth, the Solar System and the rest of the Universe;
- - a **transportation node** where payloads and vehicles are stationed, assembled, processed and deployed to their destination;
- - a **servicing capability** from which payloads and vehicles are maintained, repaired, replenished and refurbished;
- - an **assembly capability** from which large space structures and systems are assembled and verified;
- - a **research and technology capability** in space, where the unique space environment enhances commercial opportunities and encourages commercial investment in space;
- - a **storage depot** for consumables, payloads and spares; and
- - a **staging base** for possible future missions, such as a permanent lunar base, a human mission to Mars, robotic planetary probes, a human mission to survey the asteroids, and a scientific and communications facility in geosynchronous orbit.

Step 2: Estimate quantitative mission needs and requirements

Theory	FireSat	Camping
Estimate quantitative mission needs and requirements	What resolution does my instrument need?	How many fishes do I want to catch per day?
	How long should the satellite operate?	How big should they be?
	How much does one satellite cost?	When do I want to go fishing?

Step 2 example space shuttle

- Early Space Shuttle design


Airforce objective: Deploy & retrieve satellites over the territory of the Soviet Union. The Space Shuttle shall return to its base after one orbit, in order to avoid detection.

What are the consequences of this objective in terms of quantitative requirements?

Quantitative requirements:

Deploy & retrieve satellites over the territory of the Soviet Union.

- High inclination orbit required, e.g. polar orbit

The Space Shuttle shall return to its base after one orbit, in order to avoid detection.

- Large cross range required

→ A large cross range can be achieved by **delta-wings** rather than straight wings.

Take-away: Objectives often have a huge impact on the design of space systems.

Step 3: Define Alternative Mission Concepts

Theory	FireSat	Camping
Define Alternative Mission Concepts	Low/High orbit?	Coast/Boat?
	Constellation (How many satellites)	How many fishing rods?
Explains what the system does in which order → Timeline	Sensor type (IR)	What kind of lure (worm)?
	Measure data, collect data, send data to ground	Go on the boat, go to the middle of the lake, throw out the rod, wait….

Step 4: Define Alternative Mission Architectures

Theory	FireSat	Camping
Define Alternative Mission Architectures *What else do you need to fulfill the mission (ground support, launcher, communication, …)*	Ground network / data relay satellite LEO launcher / GEO launcher	Travel to the camping site by car/plane/bus? Is there a town to shop for groceries or do you have to bring everything with you.

Step 5: Identify system drivers

Theory	FireSat	Camping
Identify system drivers	Observation frequency	Boatsize
	Resolution	Fishing Rod quality and quantity
	Data Rate What limits Driver: Antenna Size What Driver limits: Amount of information sent to the user	

Question

- What are the system drivers for a manned Mars mission?

Step 6: Characterize mission architectures

Theory	FireSat	Camping
Characterize mission architectures (most involved step) *Hard Facts*	<u>Orbit:</u> Inclination 50° Apogee 500 km … <u>Power Subsystem:</u> 150 watts 28 Volt <u>Budgets:</u> Mass, Power, Link, …	<u>Boat:</u> Crewsize: 2 Motor: Type XYZ Mileage: 100 km Power: 10 W <u>Tent:</u> …

Step 7: Identify critical requirements

Theory	FireSat	Camping
Identify critical / driving requirements	Required Resolution (sensitivity) Required Coverage	Fishing capacity of boat, fishing rod Cooking capacity of barbecue equipment

Step 8: Evaluate Mission Utility

Theory	FireSat	Camping
Evaluate Mission Utility *Find out which concept is the most efficient. Estimate which results you can get for how much money.*	Coverage and detection of fires for different orbits / constellations / sensor types Compare to other options (ground system for fire warning)	No. of fishes = f ($,time)

Objectives → Characterize → Evaluate → Requirements → Phase B – F

Step 9: Define Baseline Mission Concept

Theory	FireSat	Camping
Define Baseline Mission Concept *One set of elements that works.*	Payload: IR Sensor Constellation: 2 satellites Orbit: 450km Total Power: 250W	Travel by car Fishing Rod: Type XYZ Lake: Comox Lake Camping Site: Campell River Type of Fish available: Prawn, salmon ….

Step 10: Define System Requirements

Theory	FireSat	Camping
Define System Requirements	The system must be able to detect a wildfire within the timeframe of 12 hours. It must cover all of the national surface area within 24 hours.	The fishing trip must enables us to go fishing for at least 5 hours per day. We must be able to grill at least 2 fish per day.

Step 11: Allocate Requirements to subsystems

Theory	FireSat	Camping
Allocate Requirements to subsystems	Sensor: The sensor must be able to detect heat sources on the ground which are larger than 1 km. The sensor must have a minimal sampling rate of 5 Hz.	Boat: The boat must carry a minimum of 1 person of at least 80 kg It must be able to transport the crew and payload with a minimal velocity of 10 miles/hour

Phase B: Preliminary Definition

Theory	FireSat	Camping
Preliminary Definition of system Translating the requirements into technical specifications	<u>IR-Sensor:</u> Range: 800 km Wavelength: 800 nm Output: 12 Volt Sampling Rate: 5 Hz Size: 10*25*8 mm Weight: 0.9 kg	<u>Fishing Rod Type XY:</u> Weight: 1 kg Rod material: Fiberglass Length: 2 m Lure: Worms String material: Nylon

Phase C: Detailed Definition

Theory	FireSat	Camping
Detailed definition of the concepts from previous phase. Start of acquisition process Determine Interfaces →Production Document	Technical Drawings of components Interface Control Documents Request proposal from suppliers	Check fishing rod catalogs / boat rental possibilities

Phase D: Production/Ground Qualification/Testing

Theory	FireSat	Camping
Production of the flight hardware of the spacecraft Ground Qualification and Testing	Building MockUps Manufacturing and buying of all subsystems Assembling subsystems Sensor tests Launch vibration, acceleration tests	Buying of fishing rod, tent, barbecue Assemble tent in your own yard Test the fishing rod

Phase E: Utilization

Theory	FireSat	Camping
Overall Tests and initialization phase (E1) and operation phase (E2)	Build up of satellite constellation Launch and Early Orbit phase (LEOP) On Orbit Tests for Payload Nominal Operations	Last equipment check before boarding the boat Driving to the middle of the lake Setting up the fishing rod Waiting for fish…

Phase F: Disposal

Theory	FireSat	Camping
After End of Life system must be disposed properly	Deorbiting Strategy	Remove your trash from camping site

Reviews

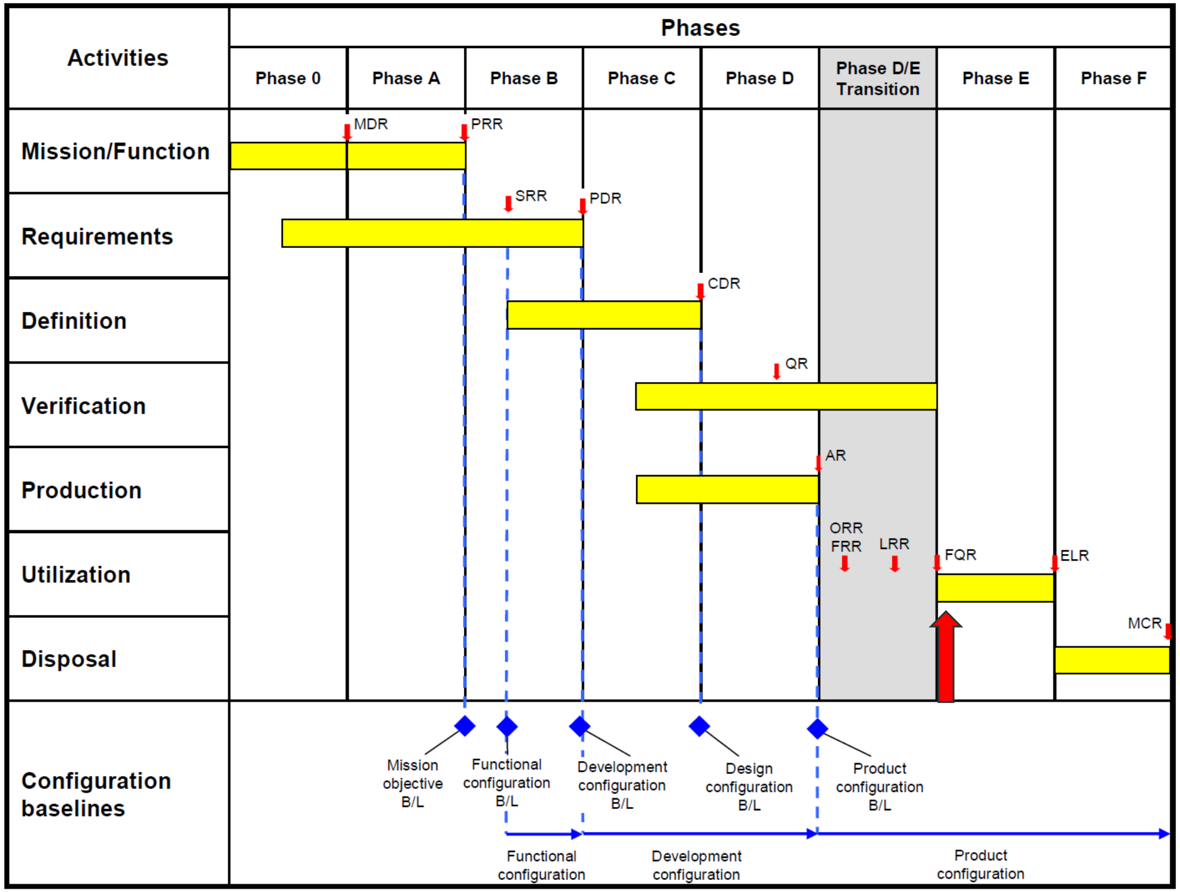
- Reviews is often implemented as **mile-stones** in the **project plan** (i.e. at end of a phase).
- The goal at a review is to verify the following:
  - The goals for the phase are accomplished,
  - The results in the current phase coincides with the specifications stated in the previous phase.
- Should induce a **critical and independent evaluation** of possible problems with corresponding solutions.

Reviews

- **The reviews follow the life-cycle of the different phases in a project:**
  - **This means that in the Feasibility Phase and Preliminary Definition Phase the reviews proceed from upper to lower levels, from system level to component level.**
  - **Thereafter from the Detailed Definition Phase to the Utilization Phase the reviews proceed from lower levels to upper levels, from component level to system level.**

- **Within ESA (and NASA) the project management practice, and also the reviews, are standardized:**
  - **„Space Project Management Organization and Conduct of Revi (ECSS-M-30-01A)**

Phase	Abb.	Name (engl.)
End 0	MDR	Mission Definition Rev.
End A	PRR	Preliminary Requ.s Rev.
B	SRR	System Requ.s Rev.
End B	PDR	Preliminary Design Rev.
End C	CDR	Critical Design-Rev.
D	QR	Qualification Rev.
End D	AR	Acceptance Rev.
E	ORR	Operational Readiness Rev.
E	FRR	Flight Readiness Rev.
E	LRR	Launch Readiness Rev.
E	FQR	Flight Qualification Review
F	ELR	End of Life Rev.


Activities
Phases
Phase 0
Phase A
Phase B
Phase C
Phase D
Phase D/E Transition
Phase E
Phase F
Mission/Function
Requirements
Definition
Verification
Production
Utilization
Disposal
Configuration baselines
MDR
PRR
SRR
PDR
CDR
QR
AR
ORR
FRR
LRR
FQR
ELR
MCR
Mission objective B/L
Functional configuration B/L
Development configuration B/L
Design configuration B/L
Product configuration B/L
Functional configuration
Development configuration
Product configuration

Useful links

NASA Systems Engineering Handbook

http://foiaelibrary.gsfc.nasa.gov/_assets/doclibBidder/tech_docs/5.%20NASA%20SP-6105%20Rev%201%20(Sys%20Eng%20Handbook).pdf

NASA ESAS study

http://www.nasa.gov/pdf/140649main_ESAS_full.pdf

Airforce ISS case study

http://spacese.spacegrant.org/uploads/images/ISS/ISS%20SE%20Case%20Study.pdf