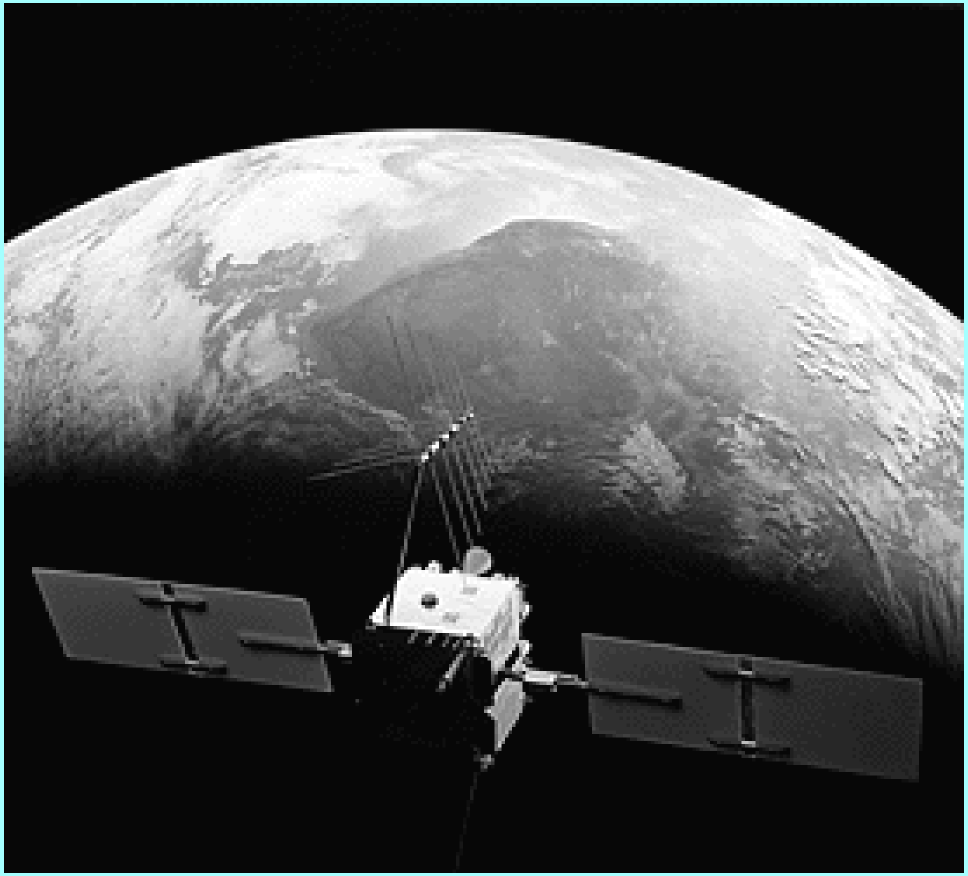
Space Mission Analysis



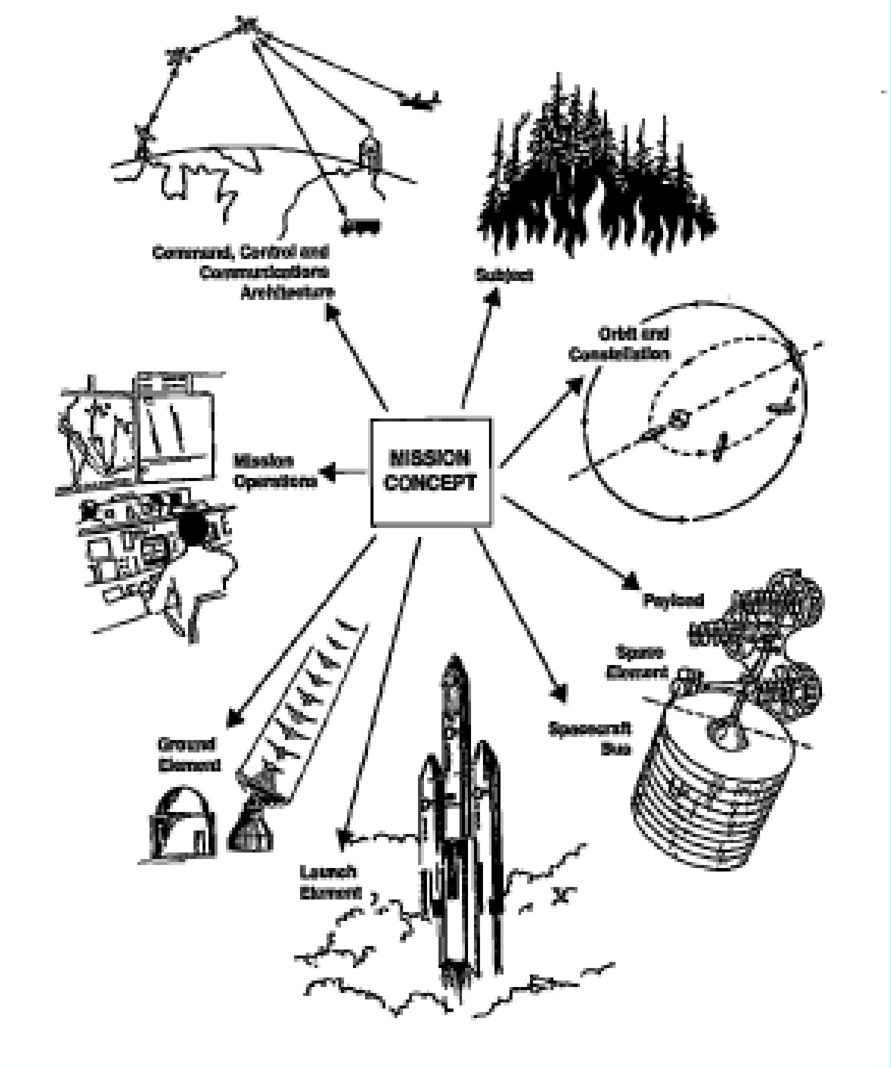
SPCE 5045

Session 2 Topics

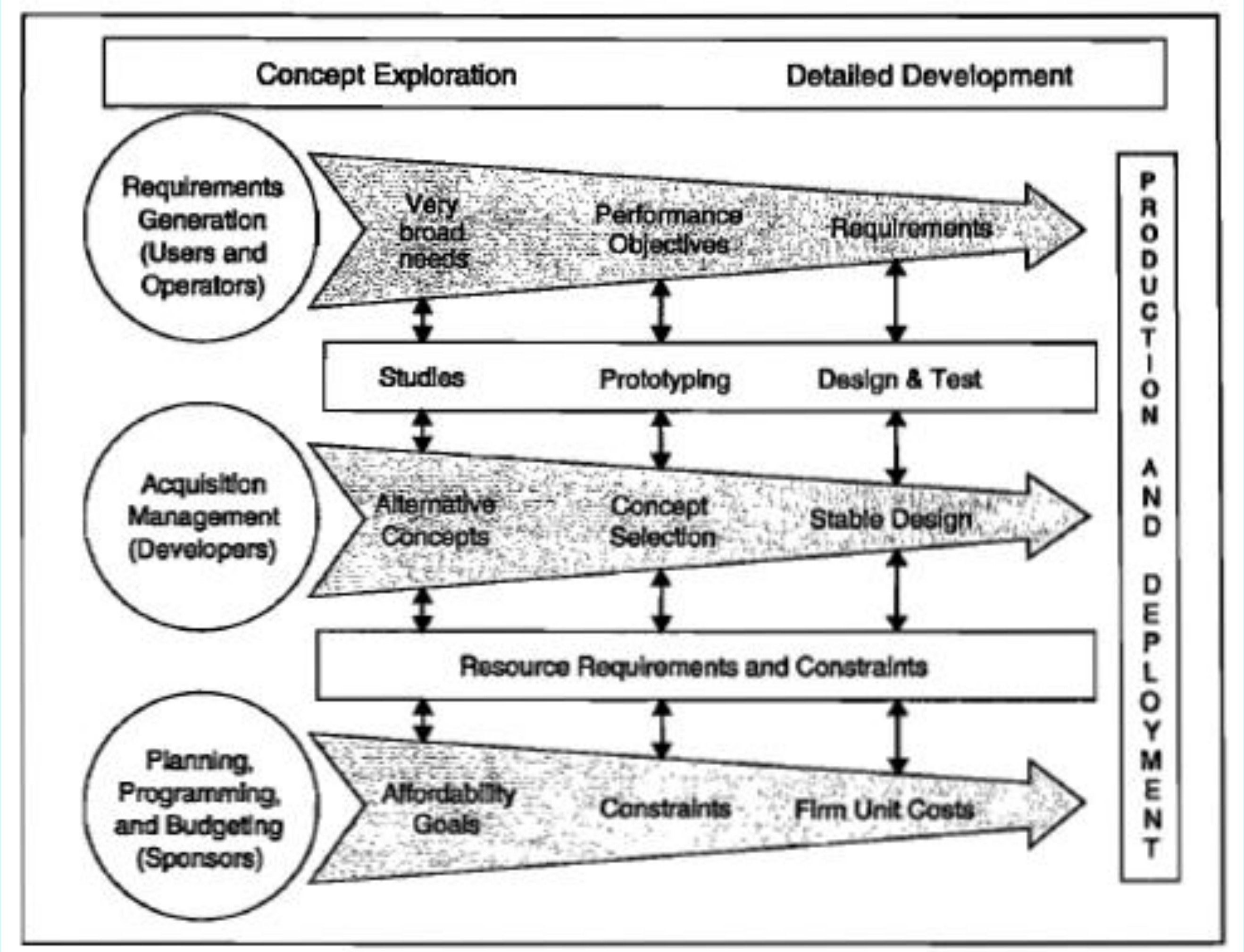
- Space Mission Concept Definition
- Mission Analysis
- Trade studies
- Requirements process
- Specifications
- Standards

Space Mission Concept Definition

Space Mission Architecture



Mission Concept



Concept Exploration and Definition	
Needs Analysis	**Concept Development**
Generate potential requirements based on Mission objectives Concept of operations Schedule Life-cycle cost and affordability Changing marketplace Research needs National space policy Long-range plan for space Changing threats to national defense Military doctrine New technology developments Commercial objectives	Reassess potential requirements generated during needs analysis Develop and assess alternative mission operations concepts Develop and assess alternative space mission architectures Estimate performance, life-cycle cost, schedule, risk supportability, produceability, funding profiles, return on investment

Table 4-8. Principal Elements of the Mission Timeline

Element	Typically Driven By	Where Discussed
Planning and Development	Funding constraints System need date	Sec. 3.3 Sec. 3.4
Production	Funding constraints Technology development System need date	Sec. 3.3, Chap. 14 Sec. 1.4 Sec. 3.4
Initial Launch	Spacecraft completion Launch availability System need date	Chap. 14 Chaps. 26, 27 Sec. 3.4
Constellation Build-up (if applicable)	Production schedule Launch availability Satellite lifetime	Sec. 23.6 Chaps. 26, 27 Sec. 3.4, Chap. 30
Normal Mission Operations	Planned operational life Satellite lifetime (planned or failure constrained)	Chap. 29 Sec. 3.4, Chap. 30
Replenishment	Production schedule Failure of on-orbit satellites Launch availability Satellite lifetime (planned or failure constrained)	Sec. 23.6 Chaps. 23, 24 Chaps. 26, 27 Sec. 3.4, Chap. 30
End-of-Mission Disposal	Legal and political constraints Danger to other spacecraft	Chap. 30 Sec. 7.5

Mission Analysis

Analysis Type	Goal	
Feasibility Assessment	To establish whether an objective is achievable and its approximate degree of complexity	Quick, limited detail
Sizing Estimate	To estimate basic parameters such as size, weight, power or cost	
Point Design	To demonstrate feasibility and establish a baseline for comparison of alternatives	
Trade Study	To establish the relative advantages of alternative approaches or options	More detailed, complex trades
Performance Assessment	To quantify performance parameters (e.g., resolution, timeliness) for a particular approach	
Utility Assessment	To quantify how well the system can meet overall mission objectives	

Common System Drivers (Table 4-16)

Driver	What Limits Driver	What Driver Limits
Size	Shroud or bay size, available weight, aerodynamic drag	Payload size (frequently antenna diameter or aperture)
On-orbit Weight	Altitude, inclination, launch vehicle	Payload weight, survivability; largely determines design and manufacturing cost
Power	Size, weight (control is secondary problem)	Payload & bus design, system sensitivity, on-orbit life
Data rate	Storage, processing, antenna sizes, limits of existing systems	Information sent to user; can push demand for onboard processing
Communications	Coverage, availability of ground stations or relay satellites	Coverage, timeliness, ability to command
Pointing	Cost, weight	Resolution, geolocation, overall system accuracy; pushes spacecraft cost
Number of Spacecraft	Cost	Coverage frequency, and overlap
Altitude	Launch vehicle, performance demands, weight	Performance, survivability, coverage (instantaneous and rate), communications
Coverage (geometry and timing)	Orbit, scheduling, payload field of view & observation time	Data frequency and continuity, maneuver requirements
Scheduling	Timeline & operations, decision making, communications	Coverage, responsiveness, mission utility
Operations	Cost, crew size, communications	Frequently principal cost driver, principal error source, pushes demand for autonomy (can also save "lost" missions)

Alternative Architecture Derivation

Step
A. Identify the mission elements subject to trade.
B. Identify the main options for each tradeable element.
C. Construct a trade tree of available options
D. Prune the trade tree by eliminating unrealistic combinations.
E. Look for other alternatives which could substantially influence how we do the mission.

Table 5-2. Principal Areas for Key System Trades

Area	Principal Issue	Where Discussed
Mission Objectives	What are we really trying to accomplish?	Sec. 4.1
Critical Requirements	What are the requirements that are hard to meet and, therefore, drive cost, risk, and schedule?	Sec. 4.4
Mission Concept	How do we get the information and data and how do we get the results to the end user?	Sec. 4.1
Subject	What do we want to look at or measure to get the information we want?	Sec. 15.2
Type and Complexity of Payloads	What spectral band do we work in and how do we measure it? How many payloads?	Sec. 15.1
Orbit	A specialized orbit or one of a continuum?	Chap. 10
Number of Spacecraft	A single satellite or a constellation?	Chap. 10

(See Table 5-3 for examples)

Trade-off Possibilities

Element of Mission Architecture	Can be Traded	Reason
Mission Concept	Yes	Want to remain open to alternative approaches
Subject	No	Passive subject is well defined
Payload	Yes	Can select complexity and frequencies
Spacecraft Bus	Yes	Multiple options based on scan mechanism and power
Launch System	Cost only	Choose minimum cost for selected orbit
Orbit	Yes	Options are low, medium, or high altitude with varying number of satellites
Ground System	Yes	Could share NOAA control facility, use dedicated FireSat facility, or direct downlink to users
Communications Architecture	No	Fixed by mission operations and ground system
Mission Operations	Yes	Can adjust level of automation

FireSat Trades

Element	Option 1	Option 6
Mission Concept	IR detection of fires with results put on a map and transmitted	IR detection of fires with results put on a map and transmitted
Subject	Characteristics defined by the specification	Characteristics defined by the specification
Payload	Small-aperture IR	Large-aperture IR
Spacecraft Bus	Small, 3-axis	Mid-size, 3-axis
Launch System	Pegasus	STS, integral propulsion
Orbit	Low-Earth, 2 satellites, 2 perpendicular polar planes	Geosynchronous, 1 satellite centered over west coast of U.S.
Ground System	Single, dedicated ground station	Single, dedicated ground station
Communications Architecture	TDRS data downlink; commercial links to users	Direct to station; results relayed to users via FireSat
Mission Operations	Continuous during fire season, partial otherwise	Continuous during fire season, partial otherwise

Table 5-4. System Trade Process for Parameters with Multiple Effects

Step	FireSat II Example	Where Discussed
1. Select trade parameter (typically a system driver)	Altitude	Sec. 10.2
2. Identify factors which affect the parameter or are affected by it	Coverage Deployment strategy and coverage evolution Orbit period Time in view Eclipse fraction Response time Number of spacecraft needed Launch capability Resolution Radiation environment Communications Lifetime	Sec. 10.2.1 Sec. 10.6.2 Sec. 9.1.5, App. I Sec. 8.4 Sec. 8.2.4 Sec. 10.2.1.4 Sec. 10.6.1 Sec. 10.3.2, 26.2.2 Sec. 10.2.2.1 Sec. 7.3 Secs. 16.2, 21.1 Sec. 9.4.4
3. Assess impact of each factor	Can launch up to 1,800 km Best coverage above 600 km Resolution—lower is better Survivability—higher is better, but not much	—
4. Document and summarize results	Launch Coverage Resolution Survivability	Fig. 5-1
5. Select parameter value and possible range	Altitude = 700 km Range = 600 to 800 km	In text

Table 5-12. Definition of the Initial Baseline and Major Alternatives for FireSat II and SCS.

Element	FireSat II Baseline	FireSat II Major Alternatives	SCS Baseline	SCS Major Alternatives
Subject	Heat from fire	—	Handheld receiver	Cell phone with wire antenna to boost signal
Payload	IR sensor	Possibly multiple spectral bands	Software defined radio; bands TBD	—
Spacecraft Bus	SmallSat bus, body-mounted arrays, integral propulsion, Earth pointing	May want steerable payload to look specifically at forests	200 kg SmallSat bus with deployable arrays and fixed crosslinks fore and aft	Mass of the spacecraft can be a continuous variable depending on the equipment and launch
Ground Segment	Dedicated ground station in CONUS	Commercial, pay-per-pass ground system	2 dedicated ground stations for redundancy	Commercial, pay-per-pass ground system
Mission Operations	Single facility doing both fire detection and commanding	Single facility doing commanding and monitoring of the on-board fire detection	Single facility doing both payload and constellation control	—
Command, Control, and Communications Architecture	Direct link from ground segment to FireSat II	—	Continuous link from ground station in CONUS to all of the satellites	—
Orbit	2 satellites in LEO orbit at inclination = 60 deg	1 satellite in GEO stationed over CONUS	3 satellites in circular, equatorial orbits at 20,000 km; supplemented with 3 more equatorial or 3 polar	TBD satellites in elliptical orbits—not as good, but more traditional
Launch Segment	Pegasus or Minotaur I	Secondary launch on a larger vehicle	All 3 satellites launched on a single EELV	Single launches on Pegasus or Minotaur 4
Mission Concept	Fire detection by trained analysts at mission ops facility; fire data relayed back through FireSat II and down to end user	On-board fire detection and monitoring sent directly to end user with data going from time-to-time to monitoring activity	Fixed crosslinks provide continuous connectivity to CONUS with only 1 hop from anywhere within 50 deg of the equator	—

Table 6-1. Critical Issues in Requirements Development

Critical Features of System or Subsystem Requirements:

- Should be based on the fundamental mission objectives
  1. Mission or payload derived
  2. Flow down from basic requirements
- Should be part of the system trade process
- Should state what is to be done (e.g., pointing, mapping, and timing), rather than how to do it (orbit, attitude, and on-board clock)
- Are the quantitative expressions of how well the objectives are met, recorded in the system specification

Types of Requirements:

- *Functional requirements* = how well it must perform
- *Operational requirements* = how it is to be used
- *Constraints* = what limitations are imposed on the system

Elements which Should be Documented for Each Requirement in the System or Subsystem Specification:

- *Function* = what is to be done
- *Performance requirement* = how well it has to be done
- *Verification* = how the performance is to be verified

  1. Inspection 2. Test 3. Analysis

Key Element which Should be Documented (though typically omitted from the system specification):

- *Reason* = *why* it is required

Requirements Activities and Processes (1)

Needs Analysis
- Defining mission requirements
- Defining environment
- Identifying mission drivers and constraints
- Technology programs

Concept Development
- Identifying critical driving requirements and associated risks
- Developing operations and design concepts
- Cost estimates
- Functional analysis and major interfaces
- System studies and simulations
- Prototyping and assessing technology

Requirements Activities and Processes (2)

Concept Validation

- Tailored system and segment definitions
- Preliminary internal interface requirements
- Preliminary system standards
- Preliminary requirements flowdown
- Integrated system validation including test planning
- Transition planning
- Validating technology

Design and Implementation

- Detailed requirements flowdown
- Developing formal design documentation and interface control
- Integrating and testing the system
- Demonstrating and verifying the system
- Test procedures and reports

Requirements Baseline

1. Identify the customer and user of the product or services. A customer may be a procuring agent but not the ultimate user and both must be understood.
2. Identify and prioritize customer/user objectives and needs for the mission to be accomplished.
3. Define internal and external constraints.
4. Translate customer/user needs into functional attributes and system characteristics. Quality Function Deployment is one tool to do this.
5. Establish functional requirements for system and provide for decomposition to elements.
6. Establish functional flow and representative for its performance of functions.
7. Translate functional attributes into technical characteristics which will become the requirements for the physical system.
8. Establish quantifiable requirements from all the above steps.
9. Through the use of block diagrams expressing interfaces and hardware/software/data relationships for the system level.
10. From the architecture expressed by step 9 at the system level, decompose the functional requirements and characteristics sets to successive lower levels, i.e., the next level defining the basis of the elements of the system.
11. At all the steps above, iteration with preceding activities is necessary both to test the assumptions made and to reconcile higher levels of requirements and functional implementation.

Table 6-2. Example of Top Level Mission Requirements

Requirement	Factors which Typically Impact the Requirement	FireSat II Example
FUNCTIONAL		
Performance	Primary objective, payload size, orbit, pointing	0.12 K sensitivity at 300 K 500 m resolution 500 m location accuracy
Coverage	Orbit, swath width, number of satellites, scheduling	Daily coverage of 750 million acres within continental US
Responsiveness	Communications architecture, processing delays, operations	Send registered mission data within 30 min to up to 50 users
Secondary Mission	As above	Land and sea surface temperature, high resolution water vapor imagery and crude winds over the continental US
OPERATIONAL		
Duration	Experiment or operations, level of redundancy, altitude	Mission operational at least 10 yrs
Availability	Level of redundancy	98% excluding weather, 3-day maximum outage
Survivability	Orbit, hardening, electronics	Natural environment only
Data Distribution	Communications architecture	Up to 500 fire-monitoring offices + 2,000 rangers worldwide (max. of 100 simultaneous users)
Data Content, Form, and Format	User needs, level and place of processing, payload	Location and extent of fire on any of 12 map bases, average temperature for each 30 m^2 grid
CONSTRAINTS		
Cost	Manned flight, number of spacecraft, size and complexity, orbit	< $20M/yr + R&D
Schedule	Technical readiness, program size	Initial operating capability within 5 yrs, final operating capability within 6 yrs
Regulations	Law and policy	NASA mission
Political	Sponsor, whether international program	Responsive to public demand for action
Environment	Orbit, lifetime	Natural
Interfaces	Level of user and operator infrastructure	Comm. relay and interoperable through NOAA ground stations
Development Constraints	Sponsoring organization	No unique operations people at data distribution nodes

Aspects of “Operability”

- 1. **visibility/observability**: the extent to which the system provides the operations team with usable information about the configuration, status, and performance of the system.
- 2. **commandability/controllability**: the extent to which the operations team can place the flight system in the desired state and produce the desired outcome via commanding.
- 3. **predictability**: the extent to which the operations team is able to predict, with some certainty, the outcome of the execution of a planned event.
- 4. **flexibility**: the extent to which the operations team can reconfigure components to maximize or optimize component utilization, to circumvent anomalous components, provide options, to increase robustness.
- 5. **robustness**: the extent to which the system maintains performance under perturbations and prevents and contains errors.
- 6. **autonomy**: the extent to which the system manages nominal or contingency operations without ground intervention.
- 7. **efficiency**: the extent to which the operations team can optimize the use of time and resources.
- 8. **testability**: the extent to which the operations team can verify and validate system components and test assets.
- 9. tractability: the extent to which the operations team is freed from the need to pay attention to, or “care and feed” the system.

Standards

- See section 6.6; page 119

Next Week

- Catch up on your reading!
- Introduction to Space Environment and Space Mission geometry (Chapters 7&8)
  - Now we start getting in detailed engineering so be sure you understand these 2 chapters
  - Expect some mathematical homework from these chapters
- Homework #1 due 2 February (see Canvas Session 2 tab)