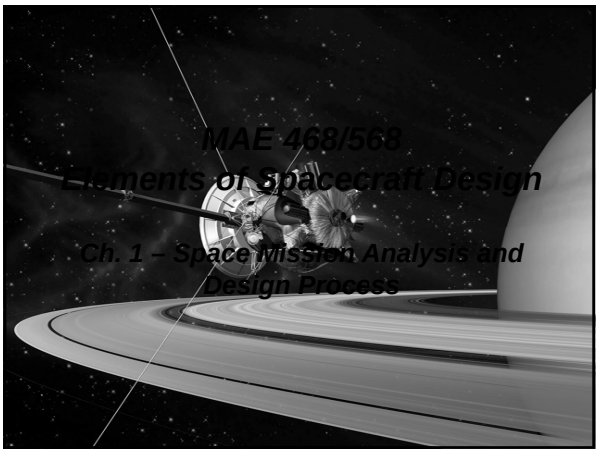

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Agenda

- SMAD introduction and overview
- Space mission life cycle
- Definition of mission objectives
- Preliminary estimate of mission needs, requirements, and constraints

2

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Space Mission Analysis and Design

- Begins with one or more broad objectives and constraints
  - Proceeds to define a space system that meets them at the lowest cost possible
- Broad objectives and constraints are key
- To get most for money spent must require system only what it can reasonably achieve

3

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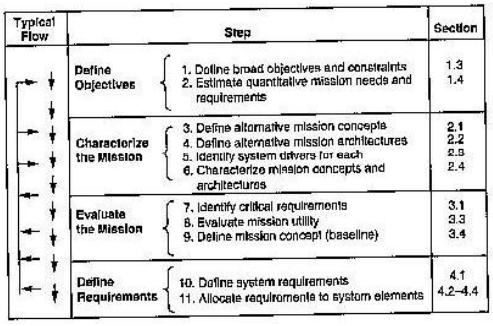
Space Mission Analysis and Design Process



Typical Flow	Step		Section
	Define Objectives	1. Define broad objectives and constraints 2. Estimate quantitative mission needs and requirements	1.3 1.4
	Characterize the Mission	3. Define alternative mission concepts 4. Define alternative mission architectures 5. Identify system drivers for each 6. Characterize mission concepts and architectures	2.1 2.2 2.3 2.4
	Evaluate the Mission	7. Identify critical requirements 8. Evaluate mission utility 9. Define mission concept (baseline)	3.1 3.3 3.4
	Define Requirements	10. Define system requirements 11. Allocate requirements to system elements	4.1 4.2–4.4

4

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Introduction and Overview

- Space is expensive
- Cost – fundamental limitation to nearly all space missions
- Analysis and design are iterative
  - Refining both requirements and methods of achieving them
  - Must repeat process many times for each mission
    - Each one usually lead to more detailed, better defined space mission concept
  - Must continue to look at broad objectives
    - Much pressure for more details
    - New technologies could emerge, new understanding of the problem, fresh ideas and approaches

5

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Introduction and Overview

- Documentation – key
  - Clearly understand and convey to others decision reasons
- Step 1 – define the mission needs to achieve
  - What are our qualitative goals and why?
- Step 2 – quantifies how well we wish to achieve the broad objectives, given our needs, applicable technology, and cost constraints
  - Requirements should be subject to trade as we go along
  - Major error – set requirements too early in process

6

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Introduction and Overview

- Step 3 – developing alternative mission concepts
- Mission concept (concept of operations) – broad statement of how the mission will work in practice
  - Includes issues of how data will be sensed and delivered, how mission will be controlled, and overall mission timeline
- Step 4 – defines alternate combination of mission elements or space mission architecture (mission concept + key mission elements) to meet requirements of mission concept
  - Drivers – key parameters that significantly influence system

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Introduction and Overview

- Step 5 – identify principal cost and performance drivers for each alternative mission concept
  - Number of satellites, altitude, power, instrument size and weight
  - Concentrate effort on parameters having the most impact on design and cost – improves chances of getting best possible design within available budget
- Step 6 – defines in detail what system is and does
  - Determine power, weight, and pointing budgets, decide data processing
  - Budget – numerical list of components for any overall system parameter

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Introduction and Overview

- Step 7 – identify critical requirements
  - Critical requirements – key requirements principally responsible for determining the cost and complexity of the system
  - System drivers are not normally system requirements
- Concentrate on requirements to determine how firm they are, how good we should make them, and how much we will pay for them to achieve our broad objectives

9

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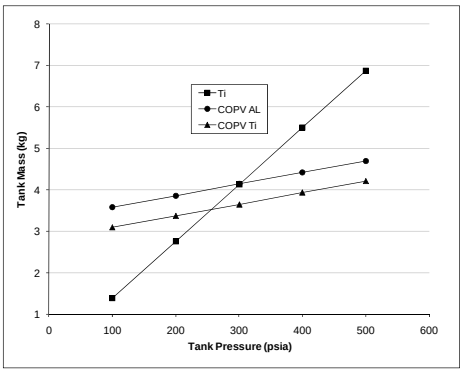
Parametric Analysis



10

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Introduction and Overview

- Step 8 – mission utility analysis – quantify how well meeting both requirements and broad objectives as function of either cost or key system-design choices
- Measures of effectiveness (Figures of merit) – critical performance measures
- Step 9 – select one or more baseline system designs
  - Baseline design – single consistent definition of system which meets most or all of the mission objectives
  - Consistent system definition – set of values for all of the system parameters which fit with each other

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Introduction and Overview

- Baseline provides a temporary milestone against which to measure progress
  - Allows us to limit number of options which must be evaluated
- As system design matures, baseline becomes more firm, eventually becomes the system design
- Remember, baseline is only starting point for iterative trade process – not ironclad definition of mission parameters
- Step 10 – translate broad objectives and constraints of mission into well-defined system requirements

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Introduction and Overview

- Step 11 – flow down (allocate) numerical requirements to components of overall space mission
  - Same way budget allocates weight and power to spacecraft's components

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Space Mission Life Cycle

- Typically four phases
  - Concept exploration – initial study phase that results in broad definition of space mission and its components
  - Detailed development – formal design phase that results in detailed definition of system components
  - Production and deployment – construction of ground and flight hardware and software and launch of first full constellation of satellites
  - Operations and support – day-to-day operation of space system, its maintenance and support, its deorbit or recovery at end of mission life

14

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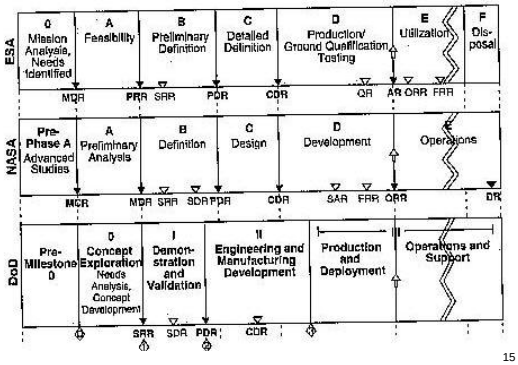
Space Mission Life Cycle



15

Space Mission Life Cycle

- Phases divided and named differently depending on sponsor (group that provides funding)
- Time
  - Large, complex missions – 10 to 15 years to develop, operate 5 to 15 years
  - Small, simple missions – 12 to 18 months to develop, operate 6 months to several years
- Key players
  - Space mission operator, end user or customer, developer
- Commercial space missions are customer driven

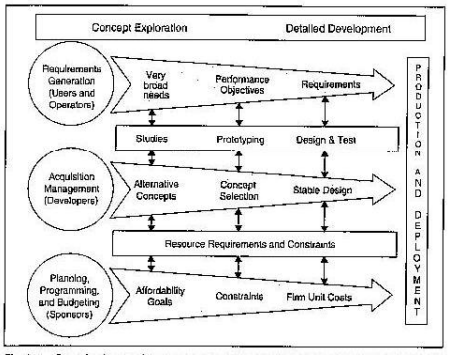
16

Space Mission Life Cycle

- Customers – pay for a service
- Users – receive services that others pay for
- Operators – control and maintain space and ground assets – typically applied engineering organizations (i.e., JPL, APL)
- End users – receive and use products and capability of space mission
- Developer – procuring agent
- Operators and users develop technically and fiscally responsible requirements
- Developer provides necessary product or capability on time and within changing political and funding constraints

17

Concept Exploration



18

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Concept Exploration

- Three activities
  - Users and operators develop and coordinate a set of broad needs and performance objectives based on an overall concept of operations
  - Developers generate alternative concepts to meet the perceived needs of user and operating community
  - Sponsor performs long-range planning, develops an overall program structure, and estimates budgetary needs and available funding to meet needs of users, operators, and developers
- Four key players must closely integrate their areas of responsibility

19

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Concept Exploration

- Divides into needs analysis and concept development
- Goal – assess the need for a space mission and to develop affordable alternatives that meet operator and end-user requirements
- Needs analysis – continuing process which culminates in a new program start
  - Operators and end users develop potential mission requirements
- New program begins with set of mission objectives, concept of operations, and desired schedule

20

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Concept Exploration

- Program initiation milestone
  - Funding organization commits to proceeding through concept development
  - Program receives different levels of scrutiny depending on its scope, political interest, and funding requirements
- Concept development
  - Developer must generate alternative methods of meeting operator's and end user's needs
  - Includes developing and assessing different concepts and components for mission operations

21

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Concept Exploration

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 producability funding profiles return on investment

22

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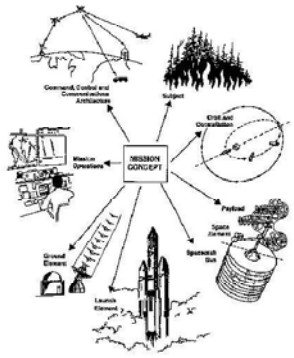
Space Mission Architecture



23

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Space Mission Architecture

- All space missions consist of a set of elements or components – form space mission architecture
- Subject – thing which interacts with or is sensed by the space payload
- Payload – consists of hardware and software that sense or interact with subject
  - Trade off and combine several sensors and experiments to form payload
- Subsystems of spacecraft bus support the payload by providing orbit and attitude maintenance, power, command, telemetry and data handling, structure and rigidity, and temperature control

24

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Space Mission Architecture

- Payload and spacecraft bus – spacecraft, space segment, or launch vehicle payload
- Launch system – launch facility, launch vehicle, and any upper stage required to place spacecraft in orbit
  - Interfaces, payload fairing, associated ground support equipment and facilities
  - Constrains size, shape, and mass of spacecraft
- Orbit – spacecraft's path or trajectory
  - Separate initial parking orbit, transfer orbit, and final mission orbit – may have end-of-life orbit
  - Significantly influences every element of mission, provides many options for trades

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Space Mission Architecture

- Communications architecture – arrangement of components which satisfy mission's communication, command, and control requirements
  - Depends strongly on amount and timing requirements of data to be transferred, number, location, availability, and communicating ability of space and ground assets
- Ground system – fixed and mobile ground stations around globe connected by various data links
  - Allow us to command and track spacecraft, receive and process telemetry and mission data, distribute information to operators and users

26

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Space Mission Architecture

- Mission operations – people, hardware, and software that execute mission, mission operations concept, and attendant policies, procedures, and data flows
- Command, control and communications architecture – spacecraft, communications architecture, ground segment, and mission operations elements

27

Definition of Mission Objectives

- 1st step – define mission objectives
  - Mission objectives – broad goals which system must achieve to be productive
  - Mission requirements and constraints – quantitative expressions of how well we achieve our objectives – balancing what we want against what the budget will allow
- May modify objectives slightly or not at all during concept exploration, often trade requirements throughout the process
- Space mission have several objectives
  - Secondary objectives which can be met by defined set of equipment – some additional objectives may demand more equipment

28

Definition of Mission Objectives

- Nearly all space missions have a hidden agenda
  - Secondary, typically nontechnical objectives
  - Political, social, or cultural – equally real and equally important to satisfy
- Multiple objectives occur when we use a single satellite to meet different demands
- Primary objectives usually are quite stable, secondary objectives may shift to meet user's needs and redefined potential of space mission concept
- Good mission objectives incorporate user needs and, at least indirectly, the space characteristics we are exploiting to achieve them

29

Space Exploitation

Characteristic	Relevant Missions	Degree of Utilization	Sample Missions
Global Perspective	Communications Navigation Weather Surveillance	Some are mature industries; major new advances will come with increased onboard processing	IntelSat GPS NOAA satellites DBS
Above the Atmosphere	Scientific observations at all wavelengths	Well developed; space observatories will continue to dramatically change our view of the universe	Space Telescope GRO Chandra X-Ray Observatory IUE
Gravity-free Environment	Materials processing in space	Now in infancy; may be many future applications	Industrial Space Facility ISS Comet
Abundant Resources	Space industrialization Asteroid exploration Solar power satellites	Essentially none	Space colonies Solar power satellites NEAP
Exploration of Space Itself	Exploration of Moon and planets, scientific probes, asteroid and comet missions	Initial flybys have been done; Some landings done or planned; limited manned exploration	Manned lunar or Martian bases Apollo Galileo

30

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Preliminary Estimates

- Need to transform broad objectives into preliminary set of numerical requirements and constraints on space mission's performance and operation
  - Will largely establish operational concepts that will meet our objectives
- Must develop requirements which truly reflect mission objectives and be willing to trade them as space system is more clearly defined

31

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Preliminary Estimates

- Three areas to look at
  - Functional requirements – define how well system must perform to meet its objectives
  - Operational requirements – determine how system operates and how users interact with it to achieve its broad objectives
  - Constraints – limit cost, schedule, and implementation techniques available to system designer
- Needs, requirements, constraints for a specific mission will depend on mission itself and how we implement it

32

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Preliminary Estimates

- Establishing top-level mission requirements is extremely difficult – depending on mission needs and on perceived complexity or cost of meeting them
- Should iterate the numerical requirements many times in design process
- 1st estimate of mission requirements must come from goals and objectives combined with some view of what is feasible
  - Often look at previous missions

33

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Preliminary Estimates

- Next step – look at "hidden agenda"
  - Contains developer's implicit goals and constraints
  - Recognize developing a space mission depends on political, legal, and economic elements as well as technology
- Preliminary mission requirements should be established subject to later trades

34

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Typical Top-Level Requirements

Requirement	Where Discussed	Factors which Typically Impact the Requirement	FireSat Example
FUNCTIONAL			
Performance	Chaps. 5,10	Primary objective, payload size, orbit, pointing	4 temperature levels 25 m resolution 500 m location accuracy
Coverage	Sec. 7.2	Orbit, swath width, number of satellites, scheduling	Daily coverage of 700 million acres within continental U.S.
Responsiveness	Sec. 7.2.3, Chap. 14	Communications architecture, processing delays, operations	Send registered mission data within 30 min to up to 50 users
Secondary Mission	Chap. 2	As above	4 temperature levels for pest management
OPERATIONAL			
Duration	Secs. 1.4, 10.5.2, 13.2	Experiment or operations, level of redundancy, altitude	Mission operational at least 10 years
Availability	Sec. 10.1	Level of redundancy	98% excluding weather, 3-day maximum outage
Survivability	Sec. 8.2	Orbit, hardening, electronics	Natural environments only
Data Distribution	Chaps. 13, 15	Communications architecture	Up to 500 fire-monitoring offices + 2,000 rangers worldwide (max of 100 simultaneous users)
Data Content, Form, and Format	Chaps. 2, 6, 13, 14	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	Chap. 20	Manned flight, number of spacecraft, size and complexity, orbit	< $20M/yr + R&D
Schedule	Secs. 1.2, 19.1, Chaps. 2, 12	Technical readiness, program size	Initial operating capability within 5 yrs, final operating capability within 8 yrs
Regulations	Sec. 21.1	Law and policy	NASA mission
Political	Sec. 21.1	Sponsor, whether international program	Responsive to public demand for action
Environment	Secs. 6.1, 21.2	Orbit, lifetime	Natural
Interfaces	Chaps. 14, 15	Level of user and operator infrastructure	Comm. relay and interoperable through NOAA ground stations
Development Constraints	Chap. 2	Sponsoring organization	Launch on STS or expendable; No unique operations people at data distribution nodes

35