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Agenda

- Identifying alternative mission concepts
- Identifying alternative mission architectures
- Identifying system drivers
- Characterizing mission architecture

2

Mission Characterization

- Initial process of selecting and defining space mission
- Goal – to select best overall approach from available wide range to execute mission
- Typically lowest cost/most cost-effective approach – provide traceable rationale to decision makers
- Unconstrained number of mission options is huge – orbits, launch systems, spacecraft, mission concepts

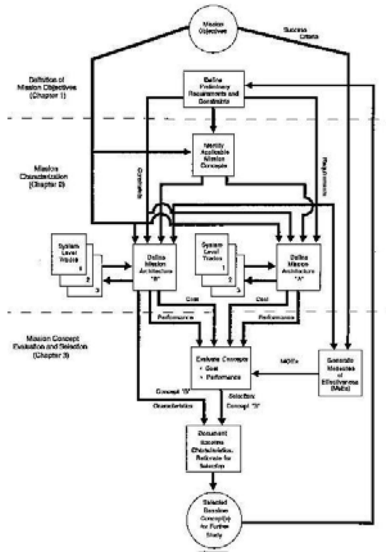
3

Mission Characterization

- Goal – reduce number to manageable level, without discarding options that offer significant advantages
- Use requirements and constraints
- Need to define each concept to a meaningful level for comparison

4

Mission Characterization



5

Terms

- Mission concept (Concept of operations) – broad statement of how mission will work in practice
- Mission operations – provides details of how people will operate and control the mission
- Mission architecture – mission concept PLUS a definition of each of the major elements of the mission

6

ID Alternative Mission Concepts

- Broad mission concept is most fundamental statement of how the mission will work
  - How it gets data or carries out mission to satisfy end user's needs
- Areas of focus
  - Data delivery (1)
    - How mission and housekeeping data are generated or collected, distributed, and used
  - Tasking, scheduling, and control (2)
    - How system decides what to do in the long term and the short term
  - Communication architecture (3)
    - How various components of system talk to each other
  - Mission timeline (4)
    - Overall schedule for planning, building, deployment, operations, replacement, and end-of-life

7

ID Alternative Mission Concepts

- Defining mission concept consists of defining various options that are available and then selecting most appropriate
- Trades
  - (1) – space vs. ground processing, level of autonomy, central vs. distributed processing
  - (2) – level of autonomy, central vs. distributed control
  - (3) – data rates, timeliness of communications
  - (4) – replenishment and end-of-life options, deployment strategy for multiple satellites, level of timeline flexibility

8

ID Alternative Mission Concepts

- Mission timeline
  - Represents overall schedule for developing, planning, and carrying out the mission
  - Defines whether it is a one-time only scientific experiment or long-term operational activity which requires replacement(s) and update(s) to the spacecraft
- Must decide mission need is immediate or long term
- All has to do with FUNDING!!!

9

Data Delivery

- Two distinct types of data – mission data and housekeeping data
- Mission data – generated, transmitted, or received by mission payload; basic information that is central to what mission is all about
- Mission data has potentially very high data rates associated with it – need may be sporadic
- Processed mission data goes directly to end user

10

Data Delivery

- Housekeeping data – information used to support mission itself (e.g., spacecaft's orbit and attitude, battery temperature and state of charge, status/condition of spacecraft subsystems
- Usually continuous and low data rate
- Often need housekeeping data to make mission data useful

11

Tasking, Scheduling, and Control

- Usually involve very low data rates and substantial decision making
- Emphasize how planning and control decisions are made rather than data management
- Two timeframes
  - Short-term tasking – addresses what spacecraft should be doing at this moment
  - Long-term planning – established general tasks the system should do
- During concept exploration – don't need to know precisely how these decisions are made – need to ID and know how they affect system

12

Tasking, Scheduling, and Control

- Autonomy
  - Less costly systems have minimal tasking and control – can not afford
  - Continuously carry on one or few activities (recovering and relaying radio messages)
  - Expensive systems have autonomy for technical reasons (rapid response i.e., missile detection, very long command delays i.e, interplanetary missions)
  - Need autonomy for long duration missions
    - Control thruster firings (electric propulsion)

13

Mission Timeline

- Overall schedule from concept definition through production, operations, and ultimately replenishment and end of life
- Schedule demands
  - Operational time
  - Budget
- Elements of mission timeline
  - Planning and development – driven by funding constraints and system need date
  - Production – driven by funding constraints, technology development, system need date

14

Mission Timeline

- Elements, cont'd
  - Initial launch – driven by launch availability and system need date
  - Constellation build-up – driven by production schedule, launch availability, and satellite lifetime
  - Normal mission operations – driven by planned operational life and system lifetime
  - Replenishment – driven by production schedule, launch availability, and satellite lifetime
  - End-of-life disposal – driven by legal and political constraints and danger to other spacecraft

15

ID Alternative Mission Architectures

- Mission architecture – consists of mission concept plus a specific set of options for mission elements
  - Subject
  - Payload
  - Spacecraft bus
  - Launch segment
  - Ground segment
  - Mission operations
  - Command, control, and communications architecture
  - Orbit and constellation

16

ID Alternative Mission Architectures

- Typically need
  - Subject
  - Orbit
  - Communications architecture
  - Ground system
- Goal – to arrive at a set of candidate architectures for further evaluation large enough to encompass all approaches offering significant advantages, but small enough to make more detailed definition and evaluation manageable

17

ID Alternative Mission Architectures

- Process
  1. Identify mission elements subject to trade
  2. Identify main options for each tradeable element
  3. Construct a trade tree of available options
  4. Prune trade tree by eliminating unrealistic combinations
  5. Look for other alternatives which could substantially influence how we do mission

18

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Step 1 – ID Mission Elements Subject to Trade

- Look at requirements and constraints to determine which elements have more than one option
- Usually this step greatly reduces number of tradeable elements

19

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Step 2 – ID Main Options for Each Tradeable Element

- In theory – unlimited number of options
- Normally draw from a limited set
- First choose options that apply to our mission and then look for special circumstances which may lead us to consider alternatives

20

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Steps 3 & 4 – Construct and Prune Trade Tree

- Trade tree – a listing of all possible combinations of mission options
- If all options were placed – too long
- As trade tree is constructed need to find ways to reduce number of combinations without eliminating options that may be important
- First step – identify system drivers and put them on top of trade tree
- System drivers – parameters or characteristics that largely determine the system's cost and performance

21

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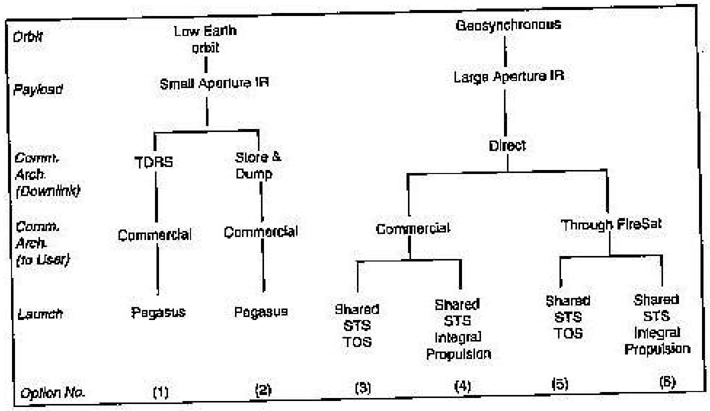
Steps 3 & 4 – Construct and Prune Trade Tree

- Second step – look for trades that are at least somewhat independent of overall concept definition or which will be determined by selection of other elements
- Third step – examine the tree as you are building it and retain only sensible combinations
- Reevaluate trade tree from time to time as system becomes more completely defined

22

Trade Tree Example



23

Step 5 – Look for Other Alternatives

- Defining alternative architectures cannot be purely mechanical
- For nearly any mission – may find new and better ways of doing anything the basic elements do
- A new, low-cost launch vehicle may dramatically change available design alternatives
- Alternative definitions of subject or user may allow major performance improvements or cost reductions
- Key point – alternatives nearly always exist – must be willing to look carefully for them and be willing to revise normal requirements and constraints to meet our fundamental mission objectives

24

ID System Drivers

- System drivers – principal mission parameters or characteristics which influence performance, cost, risk, or schedule *and* which the user or designer can control
- Correctly identifying key system drivers is a critical step in mission analysis and design
- Misidentifying key factors is one of the most common causes of mission analysis error

25

Most Common System Drivers

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	Attitude, 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 on-board 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

26

Most Common System Drivers

Driver	What Limits Driver	What Driver Limits
Number of spacecraft	Cost	Coverage frequency, and overlap
Altitude	Launch vehicle, performance demands, weights	Performance, survivability, coverage (instantaneous and rate), communications
Coverage	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

27

ID System Drivers

- Process
  - ID area of interest
    - Explicitly identify area of interest, typically performance, cost, schedule, or risk
  - ID parameters which measure area of interest
    - Define numerical parameters which measure identified area of interest – important to find parameters which genuinely measure goal rather than ones which simple are easy to compute
  - Develop first-order algorithms
    - Develop formula or algorithm to express first-order estimate for value of parameter identified above – could include either system algorithms or unique algorithms for identified parameter

28

ID System Drivers

- Process, cont'd
  - Examine factors
    - Examine each of factors in the expression identified above – those which can be adjusted and which have strongest effect on result are system drivers
  - Look for possible "hidden drivers"
    - Examine each of first-order algorithms for implicit variables or for factors affecting more than one characteristic

29

ID System Drivers

- The way we define our particular problem or which parameters are available to us, may affect our list of system drivers
- Defining system drivers depends in part on physical and technical nature of problem and in part on constraints imposed on mission analyst
- Usually want to make constraints explicit, so we will know which variables are available for adjustment and which are assumed to be given

30

Characterizing Mission Architecture

- Need to further define mission concepts in enough detail to allow meaningful evaluations of effectiveness
- Step 1 – Define preliminary mission concept
  - Begin with a broad concept and refine this concept as we define various mission elements and how to define them
- Step 2 – Define subject characteristics
  - Controllable subjects & passive subjects

31

Characterizing Mission Architecture

- Step 3 – Define orbit and constellation characteristics
  - Mission orbit profoundly influences every part of space mission development and operation
  - Orbit determines sensor resolution, transmitter power, data rate, spacecraft environment, size and cost of launch and delivery system
  - Characteristics include, altitude, inclination, eccentricity, argument of perigee for non-circular orbits, ΔV budget for orbit transfer, ΔV budget for orbit maintenance, number and relative orientation of orbit planes, number and spacing of spacecraft per orbit plane

32

Characterizing Mission Architecture

- Step 4 – Determine payload size and performance parameters
  - From subject characteristics and orbit characteristics create mission payload concept
  - Six categories – observation or sensing, communications, navigation, in-situ sampling and observations, sample return, and crew life support and transportation
  - More than 90% of current space-system payloads observe, sense, or communicate

33

Mission-Payload Characteristics

- Physical parameters
  - Envelope dimensions
  - Mass properties
- Viewing and pointing
  - Aperture size and shape
  - Size and orientation of clear field of view required
  - Primary pointing direction
  - Pointing direction range and accuracy required
  - Tracking or scanning rate
  - Pointing or tracking duration and duty cycle

34

Mission-Payload Characteristics

- Electrical power
  - Voltage
  - Average and peak power
  - Peak power duty cycle
- Telemetry and commands
  - Number of command and telemetry channels
  - Command memory size and time resolution
  - Data rates or quantity
- Thermal control
  - Temperature limits (operating/non-operating)
  - Heat rejection to spacecraft (average/peak wattage/duty cycle)

35

Characterizing Mission Architecture

- Step 4, cont'd
  - System-level payload trades typically involve user element, selecting a mission orbit, and allocating pointing and tracking functions between payload and spacecraft elements
  - User element trades – involve balancing performance of payload and elements on user's premises to get lowest overall system cost for a given orbit and constellation design
  - Payload versus orbit trades typically balance resolution advantages of low altitudes against fewer spacecraft needed for same coverage at higher altitudes – need a sensor with large aperture and better sensitivity to obtain same resolution at higher altitudes – costs more and needs larger spacecraft and launch system
  - Payload versus spacecraft trades try to meet pointing and tracking requirements at lowest cost

36

Characterizing Mission Architecture

- Step 5 – Select mission operations approach
  - Select and size elements needed to support communications and control of spacecraft and payload
  - Mission operations control center commands and controls spacecraft and delivers data to user
  - Communications architecture – transfers required mission data from payload and housekeeping data from spacecraft down to mission operations control center
  - Must send commands back to spacecraft and meet other requirements (encryption)

37

Mission Operations Characteristics

- Communications architecture
  - Number and distribution of ground stations
  - Downlink and uplink path design
  - Crosslink characteristics
  - Relay satellites used
  - Communications link budget
  - Space-to-ground data rates
- Ground system
  - Use of existing or dedicated facilities
  - Required transmit and receive characteristics
  - Required data handling
- Operations
  - Level of automation
  - Software lines of code to be created
  - Full-time or part-time staffing
  - Number of personnel
  - Amount of commanding required
  - Timeliness of data distribution

38

Characterizing Mission Architecture

- Step 6 – Design spacecraft to meet payload, orbit, and communication requirements
  - Spacecraft and its subsystems support payload in mission orbit
    - Point it and supply power, command and data handling, and thermal control
  - Usually choose launch system that costs the least for the minimum required weight to mission or transfer orbit
  - Once selection is made, spacecraft stowed configuration is constrained by shroud volume

39

Characterizing Mission Architecture

- Step 6, cont'd
  - Key trade is use of integral propulsion
    - Can ride launch system to transfer orbit, then use integral propulsion system to insert into mission orbit
    - Can use dedicated upper stage if needed
  - Another key trade involves guidance of upper stage
    - Often, spacecraft control system can guide upper stage – may allow deletion of equipment from that stage – increasing performance and lowering cost

40

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Spacecraft Characteristics

- General arrangement including payload fields of view
- Functional block diagram
- Mass properties, by mission phase (mass and moments of inertia)
- Subsystems
  - Electrical power
  - Attitude control
  - Telemetry and command
- Subsystems, cont'd
  - Computer
  - Propulsion
  - Communications
  - Primary structure and deployables
  - Unique thermal requirements
  - Timing
- System parameters
  - Lifetime and reliability
  - Level of autonomy

41

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Characterizing Mission Architecture

- Step 7 – Select a launch and orbit transfer system
  - Launch system and its upper stage need to deliver spacecraft and payload to mission orbit or to transfer orbit which spacecraft can reach mission orbit on its own
  - Launch site (determined by launch system) provides for pre-launch processing, checkout, and installation to launch system (usually on pad)
  - Decide between a single spacecraft launch and manifesting two or more spacecraft in a shared launch – saves money, but constrains schedule
  - Launch-system parameters to system level: type of vehicle, cost per launch, flow times for processing and prelaunch activities at launch site

42

Characterizing Mission Architecture

- Step 8 – Determine logistics, deployment, and spacecraft disposal strategies
  - Logistics – process of planning to supply and maintain space mission over time
  - Historically, most life-cycle costs have been locked in by end of concept exploration – must evaluate operations and support mechanisms
  - Must plan for deorbiting or otherwise disposing of satellites at end of their useful life
  - Satellites must be removed from areas such as geostationary ring where they would seriously threaten future missions

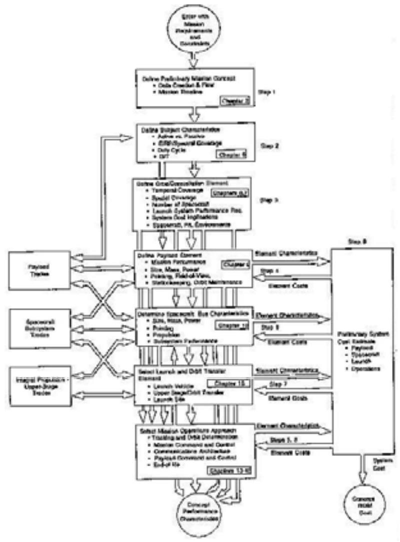
43

Characterizing Mission Architecture

- Step 9 – Provide costing support for concept-definition activity
  - Developing costs for system elements is vital to two objectives
    - Finding best individual mission architecture
    - Comparing mission architectures at the system level
  - Methods for costing
    - Parametric
    - Analogous

44

Characterizing Mission Architecture



45