Section 9. Implementation Strategies and Problems

- Techniques Applicable to All Programs
- Reducing Cost in New Missions
- Reducing Cost in Ongoing Programs
- Problem Areas in Implementing Dramatic Cost Reduction
- Summary — Maintaining Balance and Perspective

BACKGROUND

- Prior sections have focused on the processes, philosophy, and technology of reducing cost
- The goal of this section is to be pragmatic — to provide a recipe for implementing the cost reduction process in both new and ongoing programs
- Much of the section deals with implementation problems
  - Cost has always been a concern in the space program
  - In prior programs, many of which are too expensive by today's standards, people generally made the best decisions possible within the constraints placed on them
  - Implies we need to find ways to change the rules
  - In addition, we need practical recommendations on how to deal with problems within the framework of the acquisition environment we live in

Making major cost reductions is almost never easy, but it can be done.

- We begin by looking at techniques applicable to essentially all missions interested in creating a program for reducing life-cycle cost

INITIAL STEPS APPLICABLE TO ALL MISSIONS

- **While these are simple top level procedures, they are also important first steps to getting a full-scale cost reduction program underway**

Technique or Action	Comment
1. Determine real objectives and constraints	Is the **real** goal to minimize cost, to keep work in-house, to support specific organizations and technologies, or to maximize performance?
	1a. Convince the organization that reducing cost is a high priority.
	1b. Be willing to trade between cost, risk, and performance.
2. Look for innovative solutions	Major cost reductions rarely come from standard, formal engineering processes
3. Make cost data known	The task is hard enough with good cost data and essentially impossible without it
4. Reward low cost	Provide positive incentives to both people and organizations — give them a bonus rather than a smaller budget next year
5. Use the existing knowledge base	Reinventing the wheel is rarely economical. Using new approaches and processes should not mean ignoring 30 years of space experience. There are several concrete approaches to building on existing knowledge:
	5a. Books and literature
	5b. Courses
	5c. Commercial software tools
	5d. Becoming a part of the low-cost community
	5e. Taking advantage of the knowledge of others

NOTES ON STARTING OUT

- **STEP 1. Determine Your Real Objectives**
  - — If our major goal is technology transfer or maintaining the existing infrastructure, then buying a very low cost satellite on-orbit doesn't get us where we want to go
  - — Objectives are almost never quantitative
    - It is the process of *mission engineering* that attempts to meet our broad, qualitative mission objectives at minimum cost and risk
- **STEP 2. Actively Search for Innovative Solutions**
  - — If is critical since major cost reductions will not come from negotiating lower prices on the solar array
- **STEP 3. Make Cost Data Known** — It is critical to getting the job done
  - — Often it is the government which most strongly resists this step
  - — Note: We use "cost" and "price" interchangeably
    - Making the profit (= price – cost) public is normally not done in commercial systems and may be counterproductive by focusing attention on a relatively small budget element that has little potential for adjustment
- **STEP 4. Provide Positive Rewards for Low Cost**
  - — Guard against the trap of rewarding shifting costs to another organization or pushing them downstream where they will cost more
    - Makes mechanical milestones (15% reduction this year) counterproductive

ORGANIZATIONS OFFERING PROFESSIONAL COURSES IN SPACE TECHNOLOGY

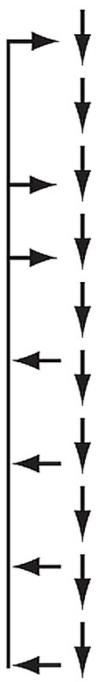
Offerer	Representative Courses	Where Available
American Institute of Aeronautics and Astronautics (AIAA), Washington, DC	Very broad range — including “Space Cost Engineering”, “Space System Design”, “Launch Vehicle Design”, plus many technical courses	Nationwide
Microcosm, Inc., Torrance, CA	“Space Mission Engineering”, “Reducing Space Mission Cost”, “Design of Low-Cost Space Missions”	Nationwide, Canada, Europe
Applied Technology Institute (ATI), Clarksville, MD	Broad range—including “Spacecraft Systems Design and Engineering”, “Launch Vehicle Systems Design and Engineering”, plus multiple technical courses	Mostly Washington, DC area
George Washington University (GWU), Washington, DC	“Low-Earth Orbit Satellite Systems”, “Space System Principals and Applications”, plus satellite communications and power	Washington, DC

REDUCING COST IN NEW PROGRAMS

- By far the largest impact on cost occurs during concept exploration
  - — Establishes the scale, tone, and philosophy of the program which are ultimately the major cost drivers
- There is a key paradox in the high cost of space missions
  - — The government is primarily responsible for creating the high cost environment
    - One of the major customers
    - Makes the rules and establishes the environment in which we build and launch satellites
  - — Government cannot, by itself, fix the problem
    - Government action is limited by well-intentioned rules and regulations
    - We want to cut costs, but we don't want to give up issues of worker safety, fairness, or open competition that have gotten us here
    - We cannot legislate either Common Sense or the Lockheed Skunk Works
- What the government can do (and must, if we are to succeed) is to create an environment in which low cost is both possible and rewarded
  - — It is then up to the contractors to find pragmatic solutions that balance performance, reliability, and cost
- The following charts provide a recipe to initiate a broad life-cycle cost reduction program more-or-less within the context of the current acquisition environment

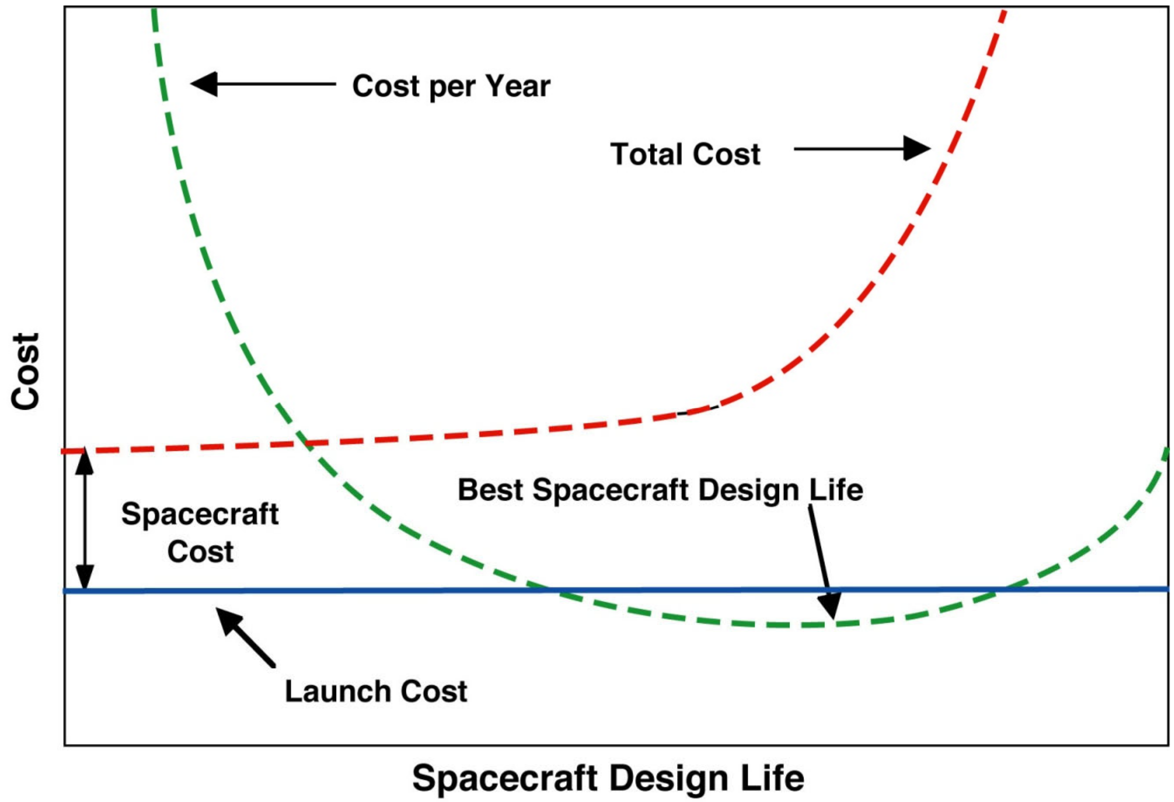
THE SPACE MISSION ENGINEERING PROCESS

- ***Space Mission Engineering*** **is the basic process of designing the mission to meet its overall objectives at minimum cost and risk**
  - **The principal method of reducing cost during conceptual design**
  - **Described in detail in Chapters 3–6 of *Space Mission Engineering: the New SMAD [2011]***
  - **"Design-to-Cost" is one quantitative implementation of the space mission engineering process**

Typical Flow	Step	Where Discussed
	***Define Objectives and Constraints***	
	1. Define the Broad (Qualitative) Objectives and Constraints	Sec. 3.3
	2. Define the Principal Players	Sec. 3.4
	3. Define the Program Timescale	Sec. 3.4
	4. Estimate the Quantitative Needs, Requirements, and Constraints	Sec. 3.5
	Define Alternative Mission Concepts or Designs	
	5. Define Alternative Mission Architectures	Sec. 4.1
	6. Define Alternative Mission Concepts	Secs. 4.2, 4.3
	7. Define the Likely System Drivers and Key Requirements	Sec. 4.4
	Evaluate the Alternative Mission Concepts	
	8. Conduct Performance Assessments and System Trades	Sec. 5.3
	9. Evaluate Mission Utility	Sec. 5.4
	10. Define the Baseline Mission Concept and Architecture	Sec. 5.5
	11. Revise the Quantitative Requirements and Constraints	Sec. 5.5
	12. Iterate and Explore Other Alternatives	Sec. 5.5
	Define and Allocate System Requirements	
	13. Define System Requirements	Sec. 6.1
	14. Allocate the Requirements to System Elements	Sec. 6.2

- Trading on Requirements is Key
  - — The system should be a compromise between what we want and what we can afford
- *System Drivers* — the principal parameters which dominate system performance, cost, risk, and schedule — should be the focus of system trades
- *Driving Requirements* — the principal system requirements which are most responsible for system performance, cost, risk, and schedule — should be the focus of requirements trades
- *Mission Utility* = numerical evaluation of *Measures of Effectiveness* — these are the quantitative expression of how well mission objectives are met
  - — Critical throughout mission life — for system design, to sell the program, and to keep it sold if it's still worth doing
- Solutions that dramatically reduce cost typically come from innovative approaches to one or more of four top-level system trades
  - — Concept of Operations
  - — Subject (What the spacecraft interacts with)
  - — Type and complexity of payload
  - — Orbit

MISSION DESIGN LIFE — AN EXAMPLE OF TRADING ON REQUIREMENTS



Hypothetical Curve of Cost vs. Mission Design Life. In principle, curves such as this should be used to set the Mission Design Life requirements. In practice, such curves rarely exist.

This is the type of process we would like to use to set all mission requirements.

WHAT IS INVOLVED IN THE MISSION ENGINEERING PROCESS?

- Should be done as part of overall systems engineering
  - Can be done either by the organization that buys the system, by the prime contractor, or jointly
- Involves trading on requirements
  - Must be done with the approval and agreement of the procurement group
- Involves evaluation of mission utility and system effectiveness
  - Must involve close interaction with the end user to ensure that strong utility is preserved

The Three Key Issues Are:

- The system must represent a compromise between what we want and what we can afford.
- It must demonstrate sufficient mission utility to warrant the cost.
- At all levels requirements must be expressed in terms of what is desired rather than how to achieve it to ensure that trades continue and that technical insight flows upward into the system requirements.

ADDITIONAL COST REDUCTION TECHNIQUES FOR CONCEPT EXPLORATION

Technique or Action	Comment
5. Trade on requirements	Requirements must be based on a balance between what is wanted and what can be achieved within the cost constraints
6. Develop a small-team approach	Perhaps the single most important management step that can be taken
7. Use available hardware & software	Use commercial components wherever possible
8. Look for trades among major program elements	Major trades that reduce cost frequently require moving responsibility and budget between organizations
9. Design for multiple launch vehicles	Reduces both cost and risk of delays
10. Use larger design margins	Reduces cost and risk, increases reliability and flexibility, reduces operations complexity & cost
11. Increase onboard processing and low-cost autonomy	Replace mechanical functions with software, particularly in multiple spacecraft; avoid AI and other high-cost autonomous systems; develop sufficient autonomy that the user can operate the ground system
12. Compress the schedule	Do not reduce time or funding spent on up-front mission engineering
13. Expedite decision making	Must create a process, both within the contracting (or constructing) organization and within the funding organization, for rapid, responsive decision making

- **Steps 1–4 are on Chart 9-4**
- **Details of these approaches are discussed in Sections 2–5**

AREAS WHERE CUTTING COST IS FREQUENTLY COUNTERPRODUCTIVE

- **Mechanical across-the-board cuts are rarely effective**
- **Much like software development — reducing planning and preliminary design does not save money**
- **Weakest area of most small, fast programs — insufficient planning and trades**

Area	Comment
1. Up-front Mission Engineering	Strong mission engineering is essential. Ignorance is rarely of value in reducing life-cycle cost.
2. Operations Planning	Frequently not sufficiently taken into account during mission design — this oversight can significantly increase life-cycle cost.
3. Exploring Options	Can be done in parallel with ongoing engineering. Options for reducing cost should be explored throughout the mission life.
4. Selling the Program	The program must be sold to the funding groups and continue to be sold throughout the program life. Canceled programs are not cost effective.
5. Program End-of-Life	Virtually all of the money has been spent. A very small investment in capturing and retaining knowledge can be extremely valuable in reducing cost for future programs.

REDUCING COST IN ON-GOING PROGRAMS

- Typically the early design phases of a mission were lost in antiquity
  - — Concept exploration for Chandra as a follow-on to HEAO-B was done in the mid-70s; the program has had continuing strong support throughout the astronomy community and was finally launched in 2000
- In all mission phases, we should
  - — Conduct the program to minimize cost and risk
  - — Sell the program and keep it sold, if it's still worth doing
- Most of the cost locked in during concept exploration — but this does not imply we can't reduce cost throughout the life-cycle
  - — Exception: in the lowest cost programs, the duration is typically very short (<18 months), and the least expensive approach is to define a low-cost solution and proceed to build the spacecraft

The key to success is to initiate a pro-active program to look for cost-reduction methods.

- Must be done with the approval of key program personnel (otherwise it won't get implemented), but not by them (or it will get in the way of progress)

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PROCESS FOR INITIATING A COST-REDUCTION PROGRAM FOR ON-GOING MISSIONS (USES PROCESS STEPS 1–4)

Step	Comment
5. Use the Existing Knowledge Base	Reinventing the wheel is rarely economical. Using new approaches and processes should not mean ignoring 35 years of space experience.
6. Initiate an Ongoing Mission Engineering Program	The Mission Engineering activity should conduct system trades, reassess mission utility, and develop explicit cost-reduction strategies 6a. Identify driving requirements 6b. Can driving requirements be reduced? 6c. Identify system drivers 6d. Look for major alternatives
7. Review List of Techniques at Front of this Section	Ask which of the overall mission cost reduction techniques might be applicable to the mission being evaluated
8. Create Cost Reduction Incentives	Need to both reward cost reduction and encourage reasonable risk
9. Look for Alternative Sources of "Income"	Reduce the effective cost by increasing the utility, expanding the number of users, or sharing the cost
10. Obtain Independent Review and Feedback	A key element of innovation is to obtain the ideas and opinions of others and to have a thoughtful review of the approaches planned and the reasons for them
11. Look for Ways to Reduce Operations Costs	Because operations is the last major program element, there is the potential for reducing cost even when the program is well underway if properly planned
12. Document Reasons for Key Decisions	Others need to understand key decisions as the program evolves so that reassessments can be done when needed

CONTINUING THE MISSION ENGINEERING AND SYSTEM TRADE PROCESS

- The goal is to ensure we are continuing to meet our mission objectives at minimum cost and risk
- Way to do this is to start each major mission phase with a formal review of:
  - — Broad mission objectives, including non-technical ones
  - — Source of the principal requirements and identification of system drivers and driving requirements (these may well change as the system evolves)
  - — Analysis of mission utility as a function of principal system drivers
  - — Assessment of the state-of-the-art for any new technologies that could potentially significantly reduce system cost
- The system drivers and driving requirements will typically be apparent — they will be the ones causing never-ending frustration among the system engineers and that everyone is trying to reinterpret to make them more achievable
  - — If all else fails, reduce them to reduce cost (also time and frustration)
  - — Express requirements in terms of what, not how

Reduce the demand for high tech solutions — Remember the Space Pen.

MOST COMMON DRIVING REQUIREMENTS FOR SPACE MISSIONS

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 on-board processing
Communications	Coverage availability of ground stations or relay satellites	Coverage, timelines, 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 & timing)	Orbit, scheduling, payload field of view and 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)

MOST COMMON SPACE SYSTEM DRIVERS

Requirement	What it Affects
Coverage or Response Time	Number of satellites, altitude, inclination, communications, architecture, payload field of view, scheduling, staffing requirements
Resolution	Instrument size, altitude, attitude control
Sensitivity	Payload size, complexity; processing, and thermal control; altitude
Mapping Accuracy	Attitude control, orbit and attitude knowledge, mechanical alignments, payload precision, processing
Transmit Power	Payload size and power, altitude
On-Orbit Lifetime	Redundancy, weight, power, and propulsion budgets, component selection
Survivability	Altitude, weight, power component selection, design of space and ground system, number of satellites, number of ground stations, communications architecture

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PRINCIPAL PROBLEM AREAS IN IMPLEMENTING METHODS FOR DRAMATIC COST REDUCTION

Problem	Most Common Cause	Positive Steps
1. Failure to trade on requirements	Don't want to be non-responsive or identify a requirement as difficult	Make formal requirements trades a part of the system exploration process
2. Constraining trades to too low a level	Politically sensitive — may involve shifting cost and responsibility among major groups	Conduct trades between elements explicitly and early in the program
3. Postponing or avoiding assessment of alternatives	Budget constraints plus problem of giving a program the appearance of instability	Maintain a strong systems engineering organization with the responsibility for assessing alternatives
4. Failing to take advantage of prior knowledge base	Lack of adequate books and training; "Not invented here" syndrome	Bring in experienced review team
5. Insufficient trades during concept exploration	Low budget; need to make the program look advanced and well-defined	Undertake systematic mission engineering
6. Poor requirements definition	Traditionally requirements are too detailed and specify **how** rather than **what** is needed	Review the requirements with these problems in mind
7. Poor data processing trades	Perceived need to lock in computer hardware selection prior to software design or requirements definition	Almost unavoidable in today's environment; provide large (400%) margin in computer sizing (See SMAD Sec. 16.2)

PROBLEM AREAS IN IMPLEMENTING DRAMATIC COST REDUCTION

- **Most problems in implementing mission engineering and cost reduction programs are the result of the environment or the acquisition process, rather than poor technology or erroneous decisions**
  - — **Most common recurring problems listed in chart on the next page**
- **Failing to trade on requirements is typical of the problem**
  - — **Should be a balance between what we want and what we can afford**
  - — **Government and contractors demand fairness when dealing with the government community**
    - **Implies there should be a fixed set of requirements to bid against**
    - **If not, another contractor can argue "I could have done it even cheaper if I would have known you were going to drop that requirement"**
  - — **Once requirements are defined contractors will go to great lengths to meet them**
    - **Don't want to be non-responsive**
    - **Jobs tend to go to those who say "Yes Sir, No Problem," rather than those who say, "It sure would be easier if you didn't need that 24 hr. turn-around"**
- **Solution is to make formal requirements trades a part of the system engineering process, specify what and not how, and maintain open communications**

SUMMARY OF IMPLEMENTATION RULES FOR REDUCING COST

- **Address cost directly, make cost data known, and treat it as any other design variable**
- **Look explicitly for new ways to solve the problem, to work in conjunction with other groups or assets, or redefine the problem to make it more tractable**
- **Reward low cost with something other than a reduced budget**
- **Make use of the existing small and low-cost satellite knowledge base**
- **Use reasonable (i.e., large) design margins — design systems to be manufactured, not engineered**
- **Develop a "small team" approach — open communications, rapid decision making, ability to change the rules when things don't work**
- **Continue the mission engineering process throughout the program**

> - **Build Volkswagens, not Ferraris.**
> - **Look for a balance between what you want and what you can afford.**