Ten Principles
for Successful Space Programs

Objectives:
- Introduce—and help you embrace—ten principles that lead not only to successful space missions but also to efficient space programs and organizations
- Show how to apply these principles within all levels of the program or organization
- Spur thought

Audience: All leaders, managers, supervisors, and senior engineers involved in specifying, designing, building, and testing spacecraft or launch vehicles and their components

Course developed and taught by Tom Sarafin and Poti Doukas

Course Topics

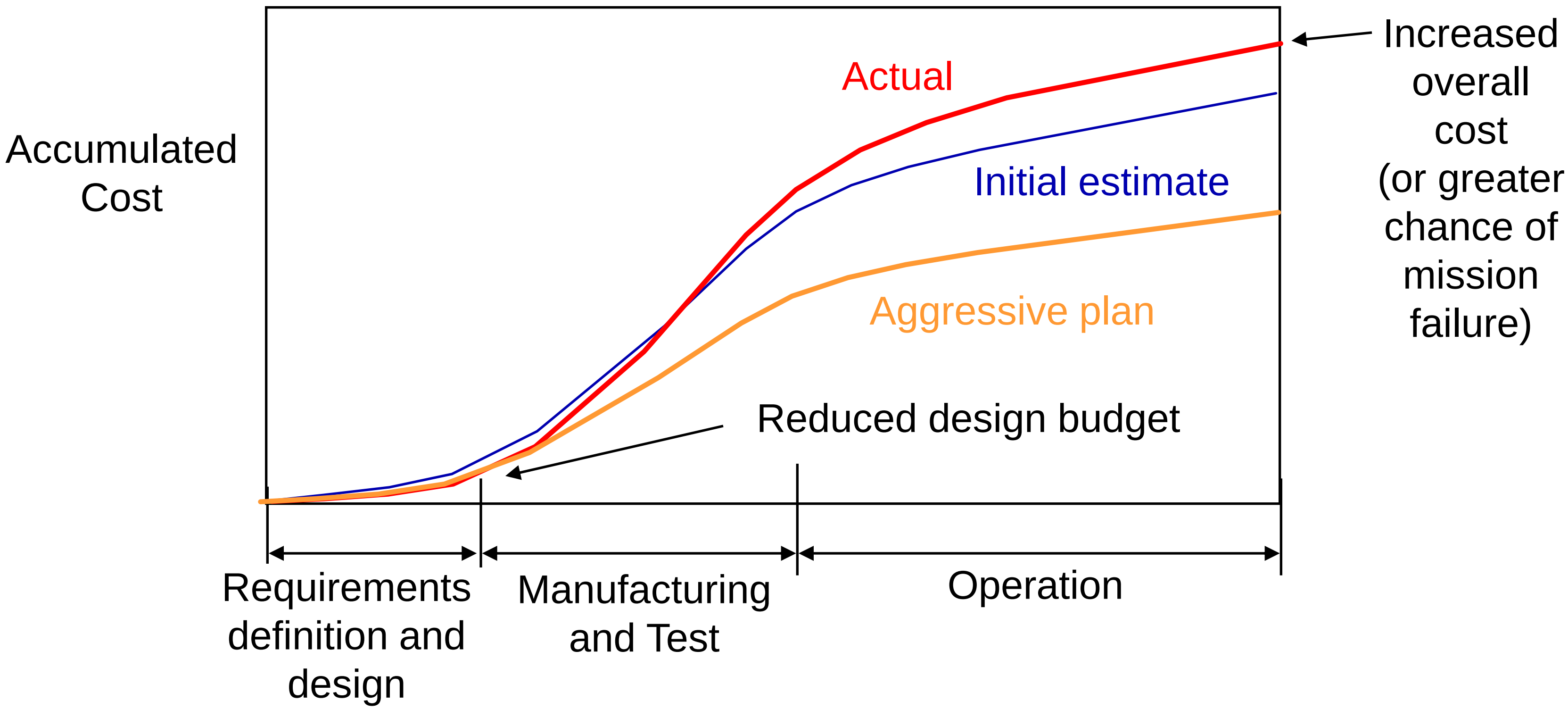
Introduction

1. What Makes Space Missions So Challenging?
2. Finding Solutions: Ten Principles
3. Establishing a Quality-focused, Mission-Success Culture
4. Building an Effective Team
5. Instilling Ownership and Responsibility in Contractors
6. Following a Sound Engineering Process for System Development
7. Reducing Cost and Risk By Design
8. Managing Risk with a Quality System
9. Responsibly Accepting Risk

Summary

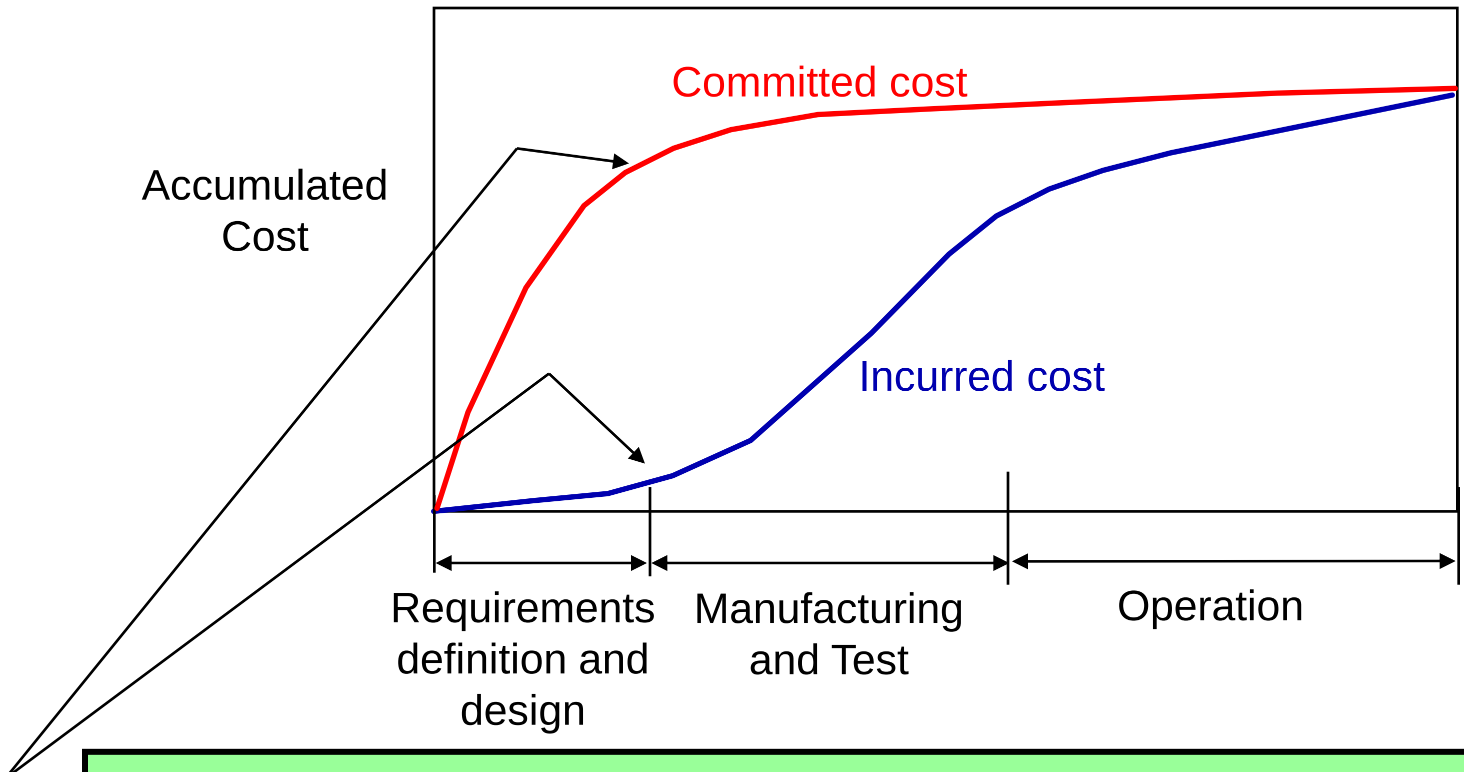
What Usually Happens When We Cut the Design Budget

Problems arise after the design is released. We spend a lot of time and money building things, analyzing them, testing them, and putting out "fires."



Cutting the design budget often leads to <u>higher</u> overall cost!

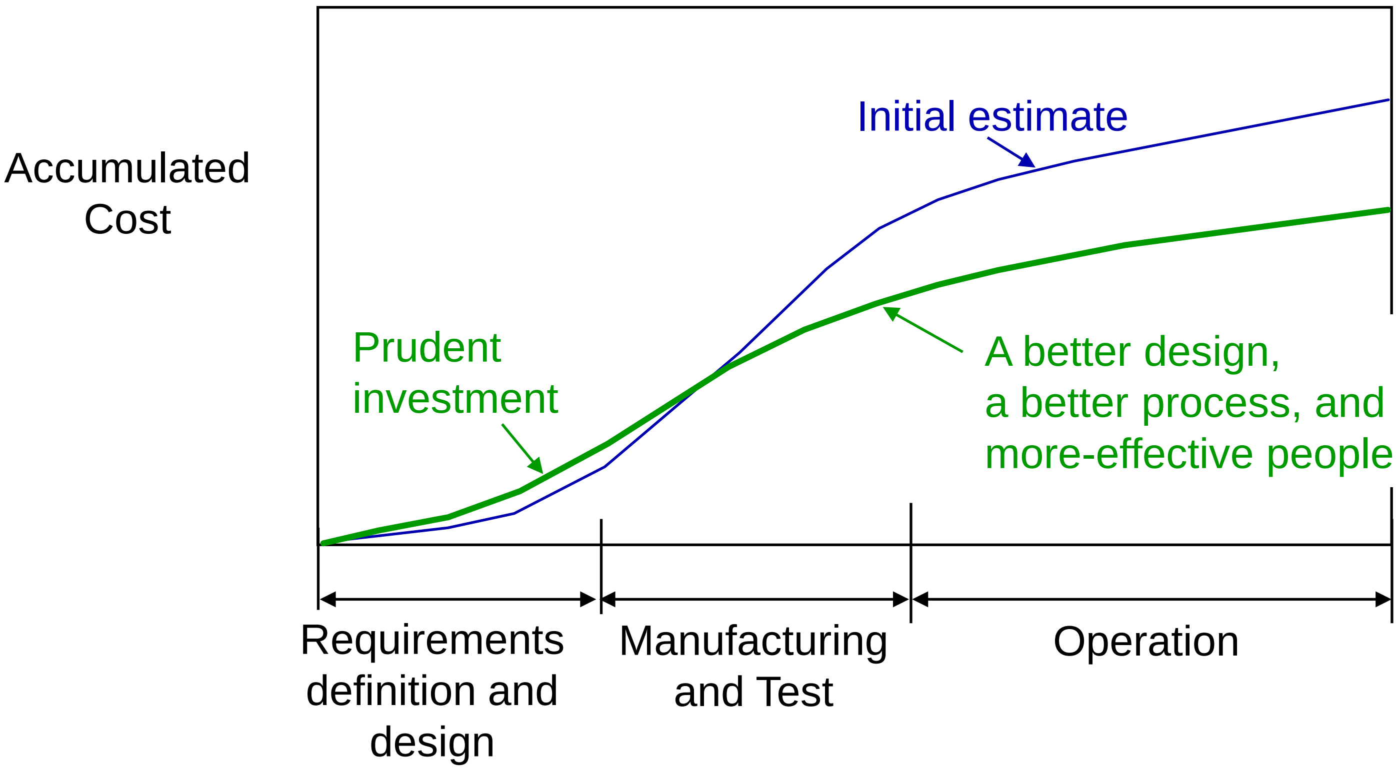
Understanding How Committed Cost Builds



Usually at least 90% of the total cost is determined by the time the design is released, when only 10% to 20% has been spent.

What we do up front is most important!

The Logical Solution: Reduce the overall cost by investing up front!



But how do we get on the right path?

Here's the Dilemma ...

If we increase the design budget, do we really expect to save money?

- History tells us …
  - Engineering costs are proportional time on a program. Decrease the time until launch and we'll save money.
  - Giving engineers more time up front will NOT give us a better design. They'll just fill the available space.
    - More detail and unneeded accuracy

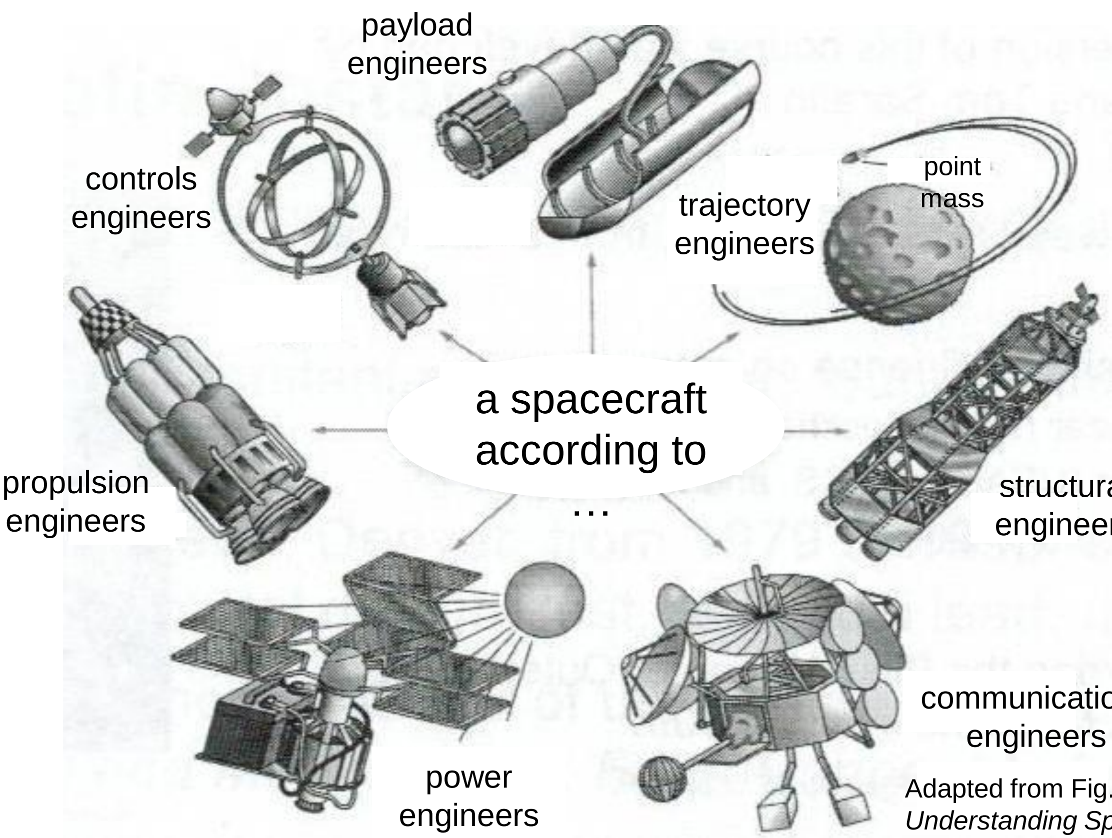
It's difficult to refute this!

- How it should work:
  - More resources up front should allow us to do better engineering
  - Better engineering will give us a better design
    - Easier to build
    - Easier to test
    - Easier to handle and integrate
    - Easier to operate
  - A better design reduces TOTAL cost
  - A better design improves the chances of success

Easy to say but hard to do!

Adapted from a chart by the late Ron Humble

Giving More Time and Budget to Over-specialized Engineers Does Not Work!



Adapted from Fig. 11-25 in *Understanding Space*, 2nd ed., Jerry Jon Sellers

In trying to improve efficiency, we tend to staff our programs with highly specialized engineers

Long term, though, this strategy backfires, as these specialized engineers evolve into influential, decision-making roles

We're starting to identify a solution, at least in part. Let's continue down this path by strengthening our understanding of our industry …

What Makes Space Missions So Hard?

- **If something fails during or after launch, we usually can't fix it**
  - Not like a car
  - or a cell phone
- **The space-mission customer has a huge stake in success**
  - The customer funds the system development and thus has the most to lose
  - Not like a car or a cell phone

We have to get it right the first time.

And we must convince many people before launch that we will do so.

Faster, Better, Cheaper—Can we get all three?

YES!

- **But the focus has to be on *better*!**
- If we do something *better*, ..
  - It will be *faster*
    - More efficient
    - Simpler design
    - Easier to analyze, build, and test
    - Fewer problems (higher quality)
  - It will be *cheaper*
    - Same reasons as for faster
  - And we'll have a successful mission!

Note the definition of "better"!

To most people, "faster, better, cheaper" means *faster* and *cheaper* (slashed budgets and compressed schedules), with no real plan for *better*.

***Better* requires more effective people, a more efficient organizational structure, and improved processes, teamwork, and communication.**

Ten Principles for Successful Space Programs

1. Invest in knowledge and understanding
2. Adopt the right attitude: quality and mission success first
3. Instill ownership and responsibility
4. Constantly strive to improve communication and teamwork
5. Follow a sound engineering approach
6. Reduce total cost through good engineering and good management, not by compromising quality
7. Keep everything as simple as possible
8. Establish an effective quality system that involves everyone
9. Be willing to accept risks, but only those you and the other stakeholders truly understand
10. Make sure you—and everyone else--have enough time, resources, and freedom to do things right

The Three Root Causes of Poor Quality from an Individual

1. **Lack of understanding**, which could be …
   - of how something works (e.g., physics)
   - of how one decision affects other people or aspects of the system
   - of what is expected by someone else
   - of things that can go wrong
   - the result of poor communication

You don't know how to do it right

2. **Lack of care**
   - Lack of rigor or discipline
   - Lack of personal responsibility and a sense of ownership
   - Lack of follow through
   - Not believing something is important

You don't care enough to do it right

3. **Lack of needed resources**
   - Which makes it hard to care

You don't have the time, tools, facilities, or external support

If poor quality is endemic at an organization, it is because management has created an environment that leads to the above!

Quality Applies to Everyone

- Think of quality as a measure of "goodness" for a product: usefulness, timeliness, dependability, value, etc.
- Everyone produces products and has customers, and everyone uses products from other people:
  - Data
  - Requirements
  - Drawings
  - Reports
  - Presentations
  - Email

Your company may have a Quality Assurance group, but ensuring quality is <u>everyone's</u> job!

- Producing products of high quality requires an understanding of your customers (product users) and how they will use those products.

A focus on quality from top down throughout an organization improves efficiency and thus reduces cost <u>and</u> increases the chances of a successful space mission.

Fostering The Right Attitude in the Trenches


Image courtesy NASA

"You'd better be willing to swing from that structure over a den of alligators."

Paul Knox, stress-analysis supervisor for the Manned Maneuvering Unit program at Martin Marietta Astronautics in 1980, to a junior stress analyst, Tom Sarafin, who was about to sign an engineering drawing for the first time

By everything you say and do as a leader, a manager, or a supervisor, send the message that quality and safety are top priorities.

And find ways to instill ownership and responsibility in everyone.

Effective Mentoring

What works:

- Junior engineers, senior engineers, and supervisors seated together
  - An office large enough to seat perhaps 2 to 5 people; not a bullpen
  - No barriers that inhibit questions and frequent discussions
- Clarifying and emphasizing the mentoring responsibility to senior engineers and supervisors

What doesn't work:

- Engineers isolated in cubicles; tear them down!
- Supervisors separated from engineers
- Senior engineer assigned to be a mentor for a specific junior engineer,
  - yet not seated next to the junior engineer
  - with scheduled times for mentoring

Mentoring is a natural process when a junior engineer shares the office with a willing and able senior engineer or supervisor

Are Your Contractors Part of the Team?

- Do you trust your contractors and suppliers?
  – Are they working hard to make you successful?
  – Or are they doing the least possible to get paid?
- If your answers aren't what you'd like them to be, ask yourself why:
  – Do your contractors inherently do poor-quality work?
  – Or do they just not want to do good-quality work for you or your company?
- **How do you treat your contractors?**
  – Take time to build relationships with your contractors or subcontractors
  – Every time you're at the contractor's facility, schedule time to visit or meet with the team

The quality of your product is only as good as the quality of your suppliers

Treat your contractors as you treat your customers!

Ownership and Responsibility for Procured Items

- A product (or system) ***requirement*** is something the product must do or some characteristic the product must have.
- A ***verification activity*** is something intended to demonstrate that the product or system will do what it's supposed to do.
- ***Verification criteria*** are the ground rules by which we judge the success of a verification activity.

Customer owned (or derived by contractor)

Contractor owned (but must be acceptable to customer)

Verification is part of ensuring quality, which is the contractor's job!

For a procured item, anything relating to quality or probability of success is the contractor's responsibility.

If we, as customer, specify how the quality assurance and verification must be done, we take responsibility from the contractor.

Verification activities and criteria should not be specified as requirements!

Specifying How to Achieve Quality Won't Ensure that You Get It

Myth: "To ensure quality products from contractors, thoroughly specify required tests, analysis criteria, and quality control measures."

Reality:

Specifying tests, criteria, and excessive standards ...

- invites engineers to quit thinking; focuses them on the wrong things
  - perceiving tests and analyses as requirements rather than as activities meant to build confidence
  - losing sight of the product's performance requirements
- leads to …
  - contractors not addressing unanticipated issues as they arise because there's no requirement to do so
  - unnecessary work addressing issues that don't apply to the specific product
  - losing sight of the product's performance requirements
  - squabbles, lack of trust, antagonistic relationships, and lack of teamwork
- demoralizes everyone; causes people to stop caring
- **gives YOU the responsibility for the product, not your contractor. You're to blame if it doesn't work!**

A Process for System Development

Step

1. Define objectives
2. Identify driving requirements
3. Develop concepts
4. Derive requirements
5. Evaluate concepts
6. Nail down requirements
7. Finalize design
8. Build system
9. Verify compliance
10. Implement system

Iterate (steps 1–5)

We start with objectives and a few driving performance requirements and constraints.

Most requirements derive from our design solution.

Up to a point in the process, requirements and designs should evolve simultaneously.

This process is intentionally simplified to better illustrate how requirements evolve along with the design.

Not detailed here are all the steps taken to plan verification, anticipate and prepare for downstream events such as manufacturing and handling, and establishing confidence incrementally along the way.

Key Points from this Section

- Make sure you understand when weight is not critical so you can emphasize reducing manufacturing cost
- Think ahead: Design to accommodate downstream events such as manufacturing, integration, and test
- Keep everything as simple as possible
- Design to minimize parts
- Design an adaptable structure
- Standardize materials, fasteners, connectors, and other commonly used items

A better design leads to reduced cost and reduced risk!

So How Do We Avoid or Reduce Risk?

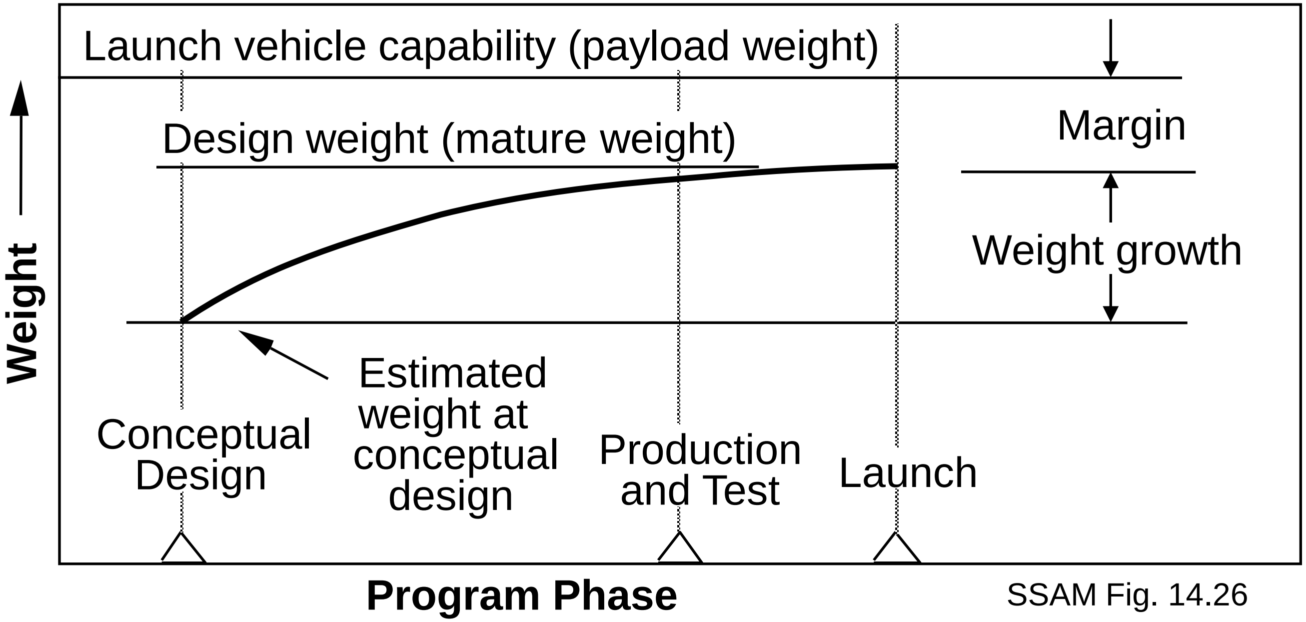
- Some risks are outside our control (e.g., new LV), but most we can do something about:
  - Human errors, omissions, overruns, late deliveries, lack of follow through.
- We avoid such problems with a quality system
  - Overall, a ***quality system*** is a controlled way of doing business to ensure an organization's products are of high quality
  - At a personal level, a ***quality system*** is a controlled way of doing your job to ensure your products are dependable and useful—we all provide products
- The overall quality system includes the collection of quality systems at various levels (personal, department, subsystem) and coordinates interfaces between them
- Much of the quality system should be standard throughout the organization, but some will be customized for any particular program or project
  - e.g., program-specific plans for verification and quality assurance

By reducing errors and defects and improving efficiency, a well-designed, effective quality system also reduces cost and schedule time

A quality system is a management system!

Understanding Weight Growth and Weight Margin

Weight inevitably grows during the course of the program ...



SSAM Fig. 14.26

Design weight = estimated weight multiplied by growth factor

Growth factor = 1 + growth allowance (decreases as the program progresses)

A similar approach is used to manage power growth.

- ***Weight-growth allowance (contingency)*** is the weight added to your current best estimate to account for uncertainty and omissions (has averaged about 25% overall for spacecraft between proposal and completion [ref. Hawkins*]).
- ***Weight margin*** is the difference between the allowable weight and the design weight (predicted weight including the growth allowance).

* Results of survey of 16 commercial and military S/C. K. Hawkins, “Space Vehicle and Associated Subsystem Weight Growth”, Paper # 1816, presented at the 1988 Conference of the Society of Allied Weight Engineers.

What Does It Mean to "Understand" a Risk?

"Yes, I understand there is a risk, but I'm willing to accept it."

Sorry, this doesn't cut it. If this is all you understand about the risk, it is <u>irresponsible</u> to accept it.

- Risk is unavoidable. We assess it by understanding two things:
  - Probability (likelihood) of failure
  - Consequence of failure

You can't responsibly accept a risk unless you have some understanding of both the probability and consequence of failure.

And make sure all stakeholders buy in on the decision!

Removing Subjectivity with Expected Cost of Failure

If we can estimate both the cost of failure and the probability of failure (a percentage), we can combine them:

***Expected Cost of Failure* = Cost of Failure × Probability of Failure**

The expected cost of failure tells us how much we should be willing to spend to eliminate a risk.

Estimating probability of failure requires a meaningful statistical database, as is used for reliability analysis

Example of Probabilistic Risk Assessment Using Expected Cost of Failure

- Program Information:
  - Your organization is in the midst of the concept exploration stage of a program for a fleet of three spacecraft (same design)
  - You are on a team developing a verification plan for the program
  - You value each spacecraft at $100,000,000
  - There will be no dedicated qualification test article. The first flight vehicle will undergo protoflight environmental (acoustic and thermal vacuum) testing; the other two will receive acceptance-level testing.
  - Historical data indicates that thermal vacuum testing tends to be more effective than acoustic testing at uncovering workmanship-related problems.
- As a cost-saving measure, someone on the team suggests deleting the acceptance acoustic test for the second and third vehicles, pending successful completion of the test on flight unit #1.

What considerations must be taken into account to properly evaluate this risk?