Seven Axioms of Good Engineering (SAGE)

Case Study Based Learning

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Topics

My Involvement with NASA

Motivation

Development of Seven Axioms of Good Engineering Course

Structure of Course in Terms of Knowledge Transfer

The 7 Axioms

Case Studies

Some Thoughts

Course Philosophy:

- Having the right concept has a huge impact on cost and performance. It’ s difficult to “fix” this later.
- Understanding the problem and making good decisions as part of the solution is as important as having a numerically correct answer.
- Good design is timeless. Our materials, technology and analytical capabilities are far superior to those in the past, but we seem to make the same mistakes. We ignore the lessons of the past at our own peril.
- “Engineers need to be continually reminded that nearly all engineering failures result from faulty judgments, rather than faulty calculations.” - Ferguson

SAGE

- Design Axioms
- Case Study Learning
- Communication in the Design Process
- Development of a Design Philosophy
- LEARN from "FAILURE"

The goal of this course is to convey an appreciation of the axioms of good design by the review of NASA and other case studies.

The common characteristics of design failures and the techniques for avoiding them will be examined.

SAGE Development Process

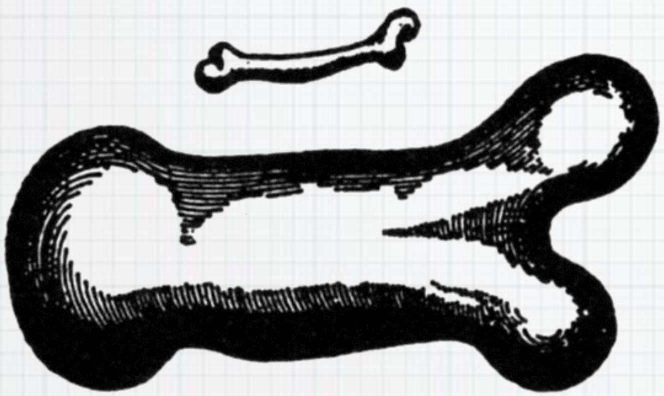
- Started in 2002.
- Co-development of a custom course for NASA. Worked closely with NASA APPEL in development, evaluation, refinement, and prototyping.
- Lots of productive back and forth on the course goals, teaching methods, and outcomes.
- Seven axioms was an outcome of this back and forth.
- Course was internally piloted for APPEL persons and then piloted at MSFC for a greater group of stake holders.

The Seven Axioms of Good Engineering

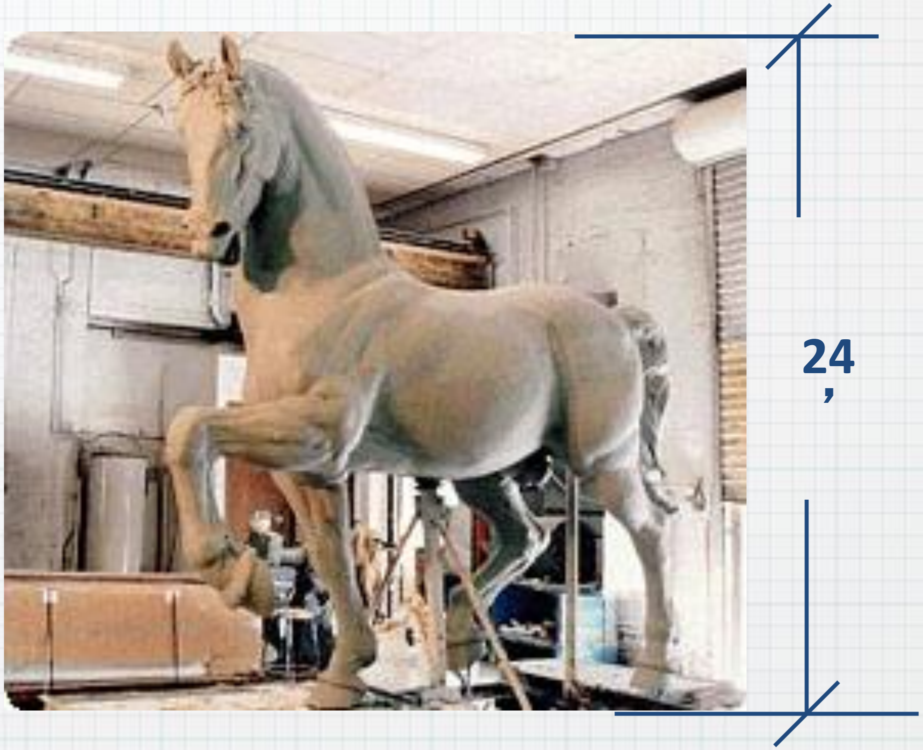
1. Avoid a Selective Use of Historical Design Data
2. Extrapolate Existing Data into Unknown Regions of the Design Space Only with Extreme Caution
3. Understand the Design's Sensitivity and Robustness
4. Always Test Against Physicality
5. Guard Against Unanticipated Loads and/or Failure Modes
6. Avoid Highly Coupled Systems unless a Strong Benefit is Shown
7. Ensure a Human Understanding of How the System Works

Teaching Axiom 2: Design Space

Galileo’s Animal Bone



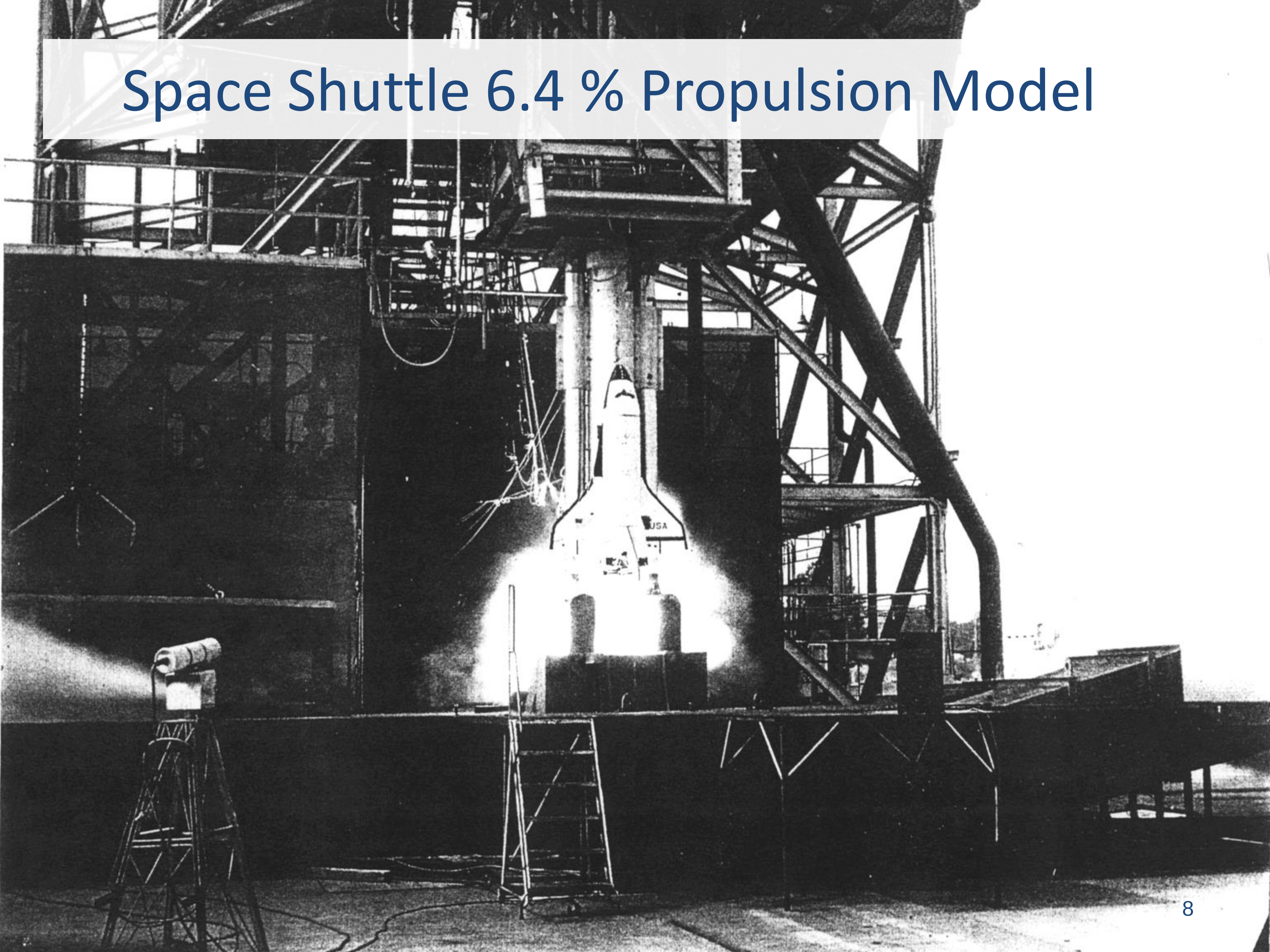
vs.



Leonardo’s Horse

Axiom # 2: Extrapolate Existing Data into Unknown Regions of the Design Space Only with Extreme Caution

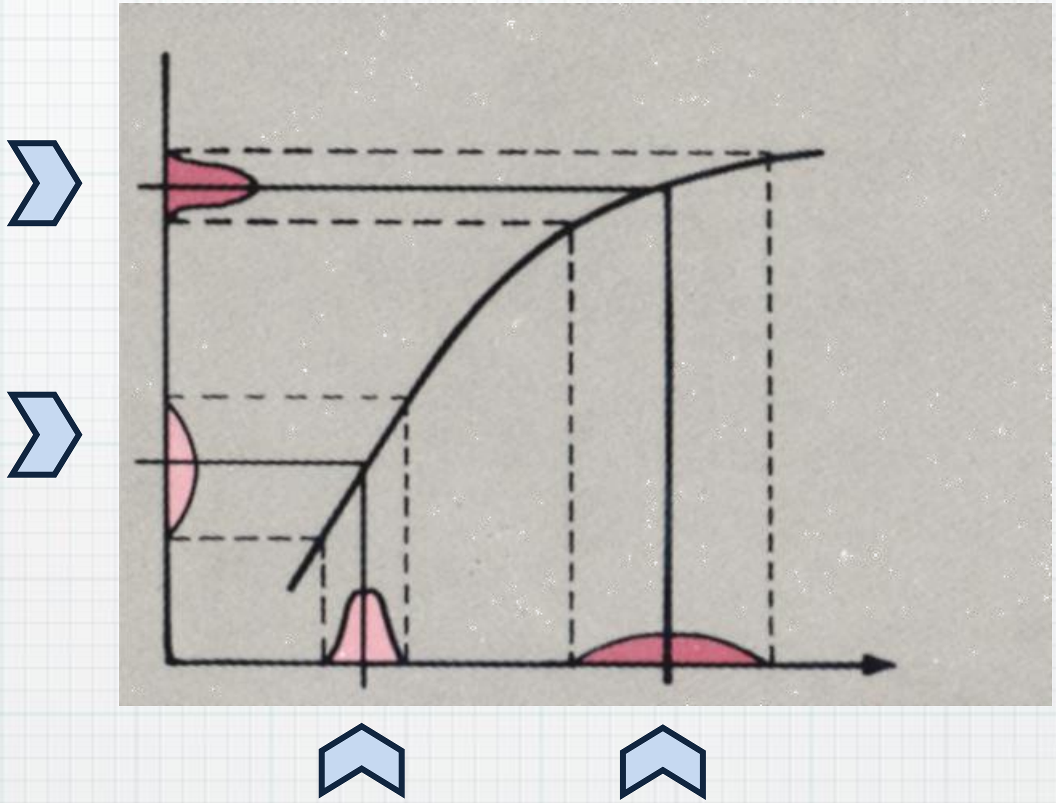
Space Shuttle 6.4 % Propulsion Model



Teaching Axiom 3: Sensitivity and Robustness:

A Visual Example of Taguchi's Method

Which Output is Better?

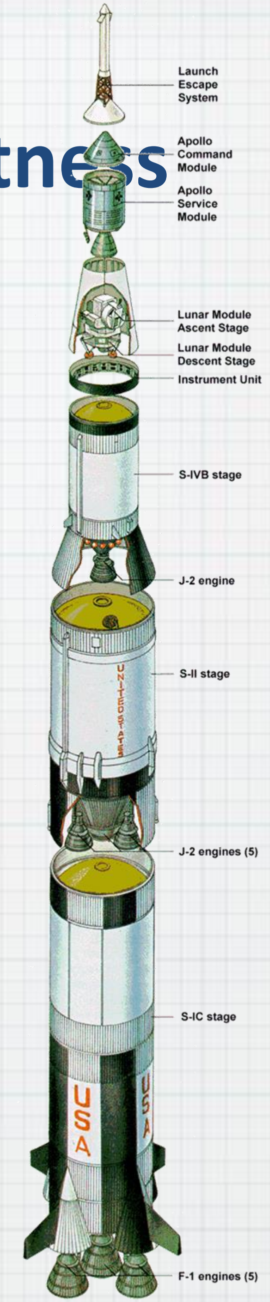


Two Possible Input Points

Apollo Program as an Example of Robustness

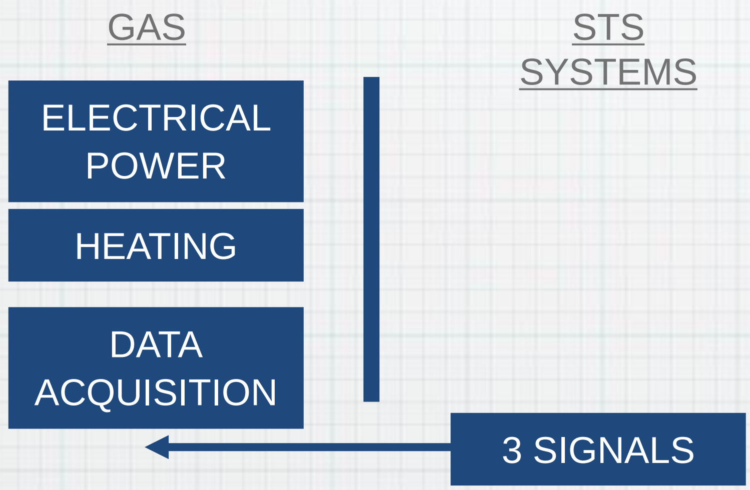
During this time, requirements indicated that four F-1s on the S-1C stage and four J-2s on the SII stage would meet performance requirements.

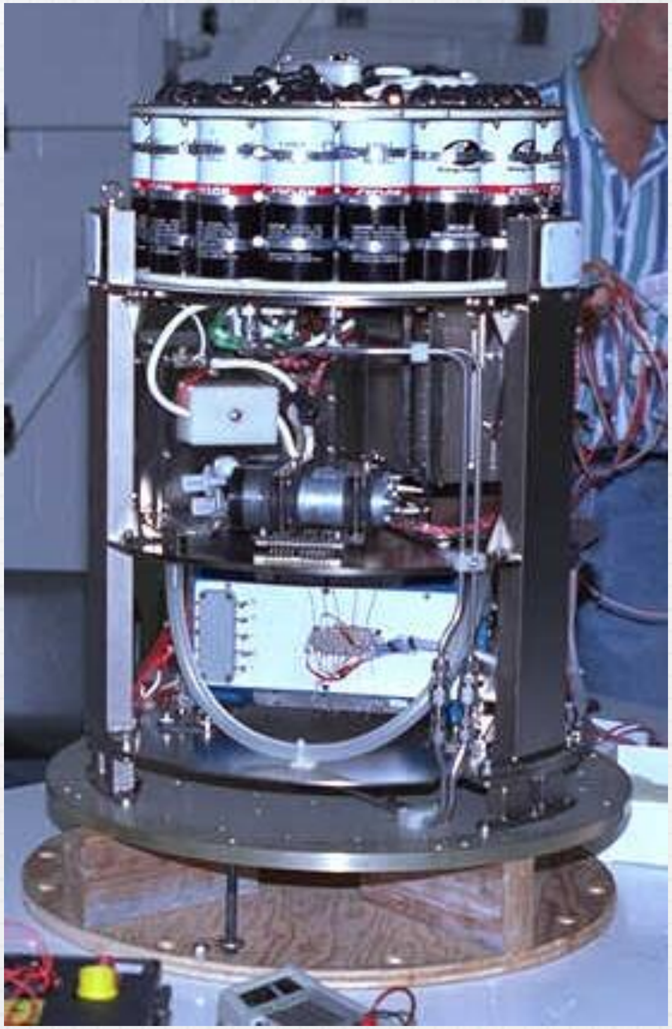
However, it was decided to equip the S-1C with five F-1s and the SII with five J-2s. This was a good decision because it compensated for weight growth, addition of margins, and the added missions using the Lunar Rover and the Skylab mission.



Teaching Axiom 6: Highly Coupled Systems

- Coupled systems are full of interdependencies.
- An idea that is associated with a systems-level approach
- “Getaway Special” as an example of system uncoupling





Axiom # 6: Avoid Highly Coupled System Unless Strong Benefit is Shown

What Do I Mean by a Case Study?

- All case studies are given by a theme.
- Need case study in the classic business, medical, and law point of view.
  - Open ended
  - Don’t tell the answer
  - Motorcycle trip
- Many types of case studies at NASA.
  - Some general
  - Domain specific knowledge
- Surprisingly most case studies are written by writers or amateur historians and not NASA.
- Parts of 17 case studies used.
- I will highlight DC-3 Pioneer 10 Suspension Bridge

Case Study: Development of the DC-3 Aircraft

What made this such an iconic design?

Why was it successful.

What can be generalize about design from this case study?

Customer Specifications

TRANSCONTINENTAL & WESTERN AIR, INC.
10 RICHARDS ROAD
MUNICIPAL AIRPORT
KANSAS CITY, MISSOURI

August 2nd,
19 32

Douglas Aircraft Corporation,
Clover Field,
Santa Monica, California.

Attention: Mr. Donald Douglas

Dear Mr. Douglas:

Transcontinental & Western Air is interested in purchasing ten or more trimotored transport planes. I am attaching our general performance specifications, covering this equipment and would appreciate your advising whether your Company is interested in this manufacturing job.

If so, approximately how long would it take to turn out the first plane for service tests?

Very truly yours,

Jack Frye
Vice President
In Charge of Operations

JF/GS
Encl.

N.B. Please consider this information confidential and return specifications if you are not interested.

TRANSCONTINENTAL & WESTERN AIR, INC.

General Performance Specifications
Transport Plane

1. Type: All metal trimotored monoplane preferred but combination structure or biplane would be considered. Main internal structure must be metal.

2. Power: Three engines of 500 to 550 h.p. (Wasps with 10-1 supercharger; 6-1 compression O.K.).

3. Weight: Gross (maximum) 14,200 lbs.

4. Weight allowance for radio and wing mail bins 350 lbs.

5. Weight allowance must also be made for complete instruments, night flying equipment, fuel capacity for cruising range of 1080 miles at 150 m.p.h., crew of two, at least 12 passengers with comfortable seats and ample room, and the usual miscellaneous equipment carried on a passenger plane of this type. Payload should be at least 2,300 lbs. with full equipment and fuel for maximum range.

6. Performance

Top speed sea level (minimum)	185 m.p.h.
Cruising speed sea level - 79 % top speed	146 m.p.h. plus
Landing speed not more than	65 m.p.h.
Rate of climb sea level (minimum)	1200 ft. p.m.
Service ceiling (minimum)	21000 ft.
Service ceiling any two engines	10000 ft.

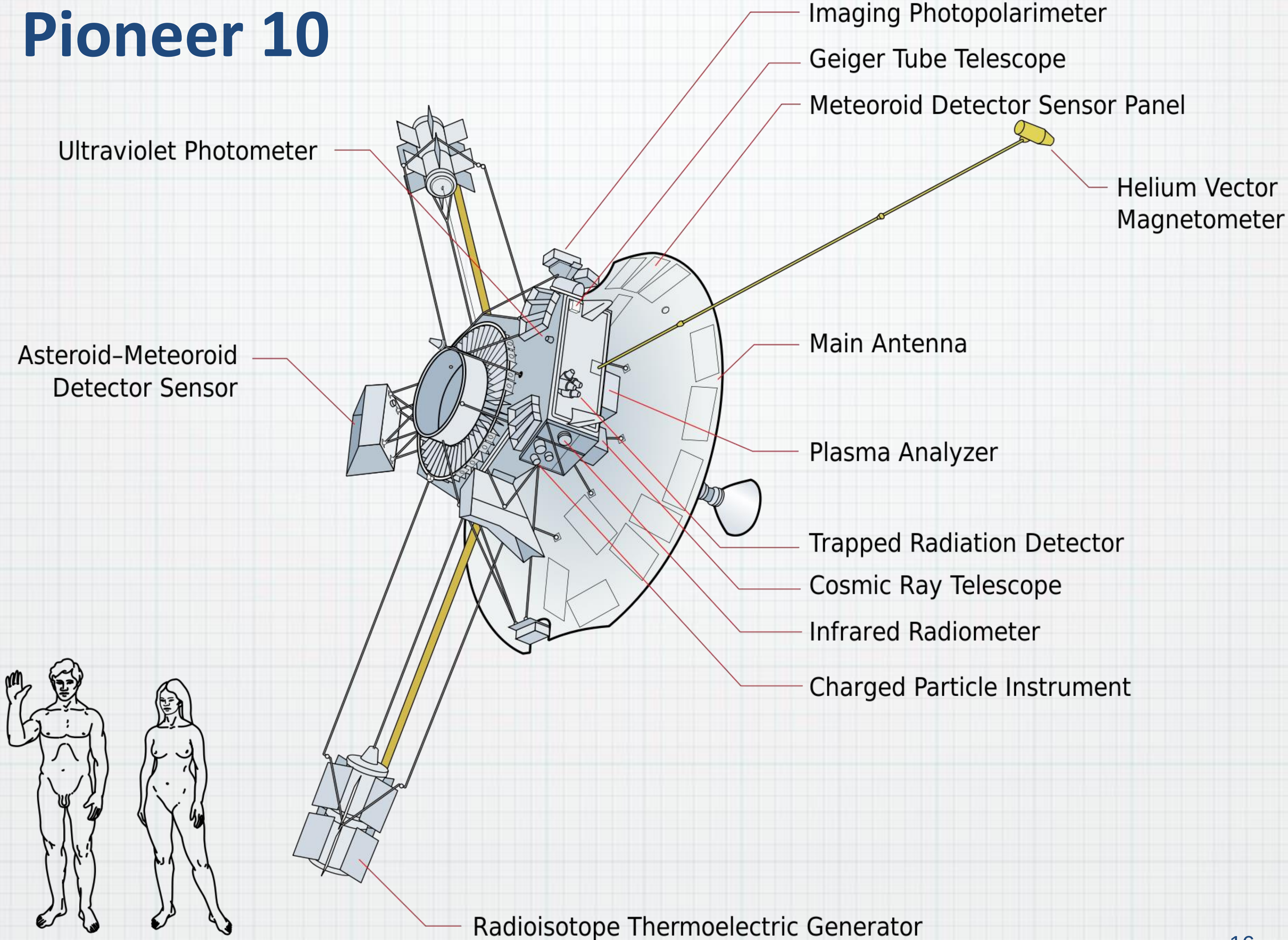
This plane, fully loaded, must make satisfactory take-offs under good control at any TWA airport on any combination of two engines.

Kansas City, Missouri.
August 2nd, 1932

DC-3: Lessons Learned for Design of a New Product

1. Know what the customer wants and needs, not what they tell you.
2. In development take a reasonable calculated risk, otherwise nothing moves forward.
3. You don't always need new technology to create a successful design. Great designs can simply be a nexus of existing technology.
4. Get physical fast. Balance testing and analysis.
5. Be willing to make your own successful product obsolete. If you are in business others are doing this anyway.

Pioneer 10



Imaging Photopolarimeter
Geiger Tube Telescope
Meteoroid Detector Sensor Panel
Ultraviolet Photometer
Helium Vector Magnetometer
Asteroid–Meteoroid Detector Sensor
Main Antenna
Plasma Analyzer
Trapped Radiation Detector
Cosmic Ray Telescope
Infrared Radiometer
Charged Particle Instrument
Radioisotope Thermoelectric Generator

Pioneer 10: Lessons Learned for Product Development on a Limited Schedule/ Budget

1. Avoid technology push projects if at all possible. If unavoidable limit technology development to a single area (Snap19 RTG).

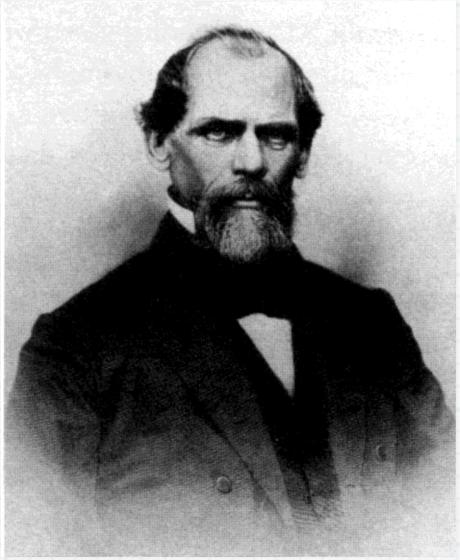
2. Get a good design and finalize it. Don't continuously revise.

3. Emphasis on simple solutions.

4. As design lead always hold the last 10% of your most important parameter (mass, volume, cost) back to distribute when needed at the end.

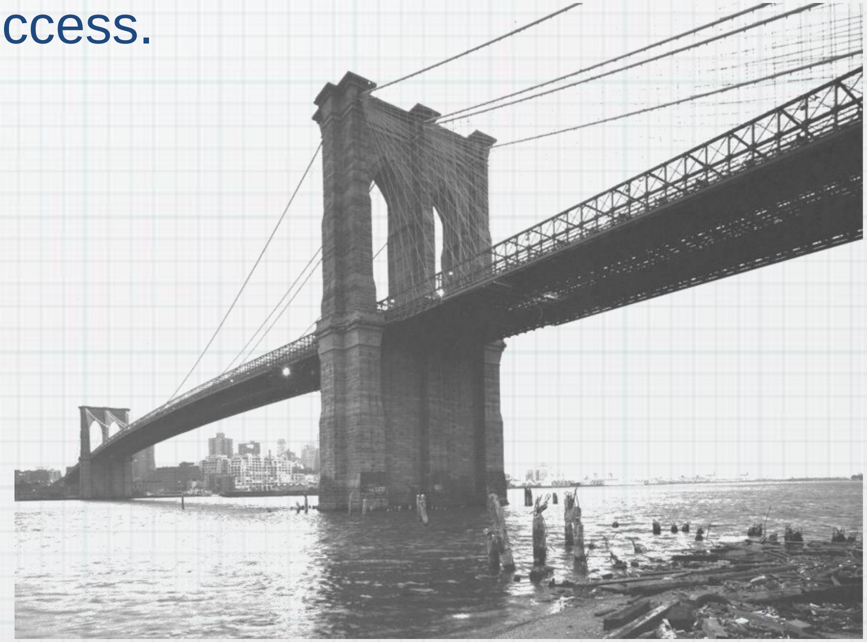
5. Superior interpersonal and teambuilding skills.

Development of Suspension Bridges

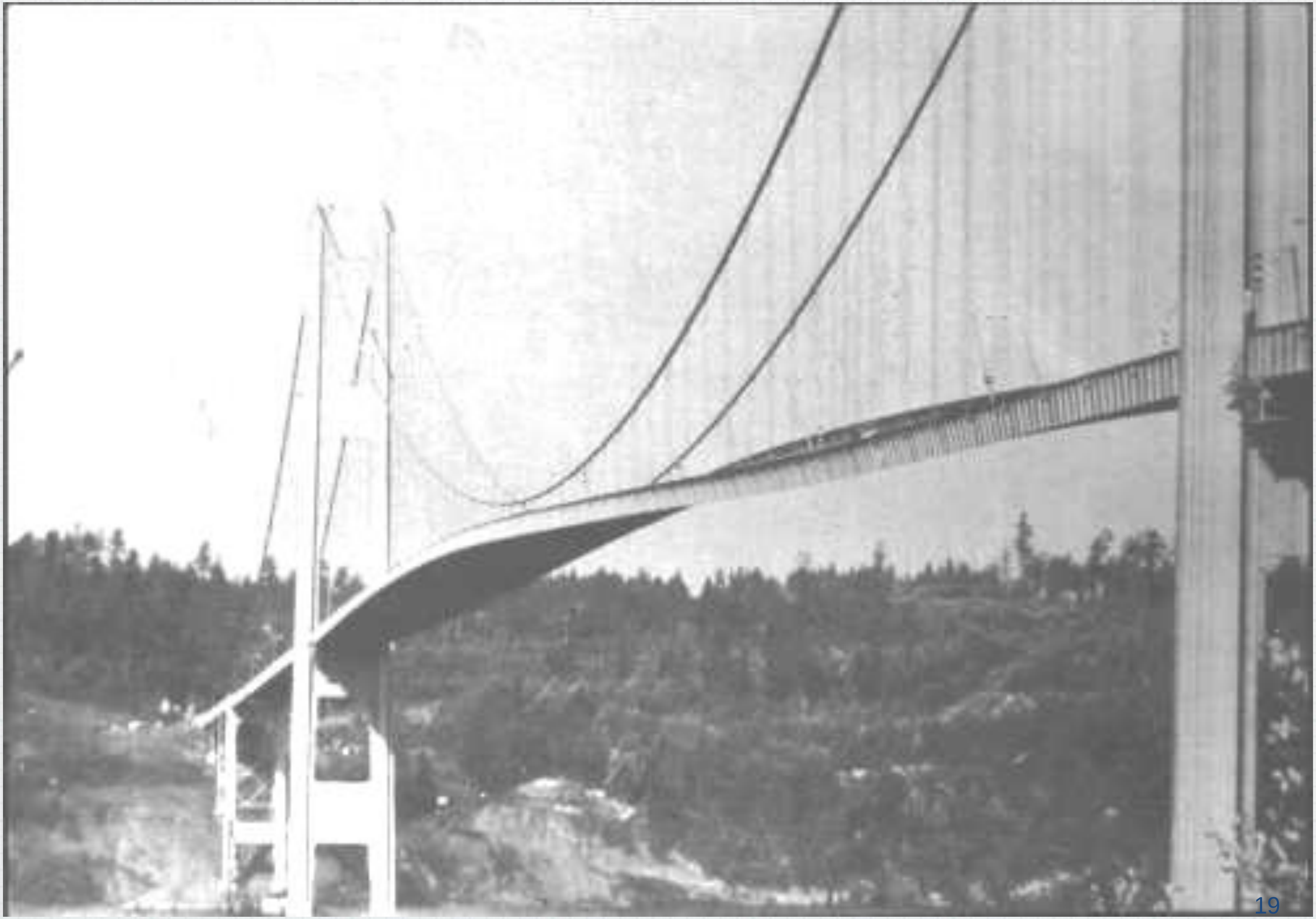


John Roebling

A long and wandering path through design starting with failure leading to a period of success.

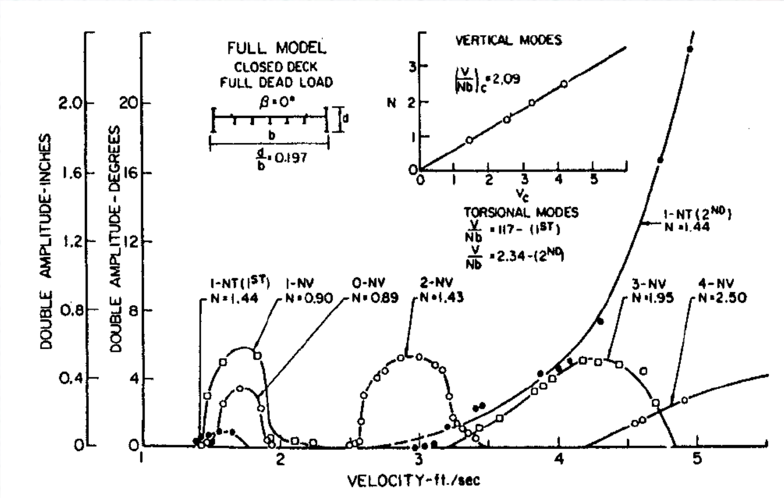


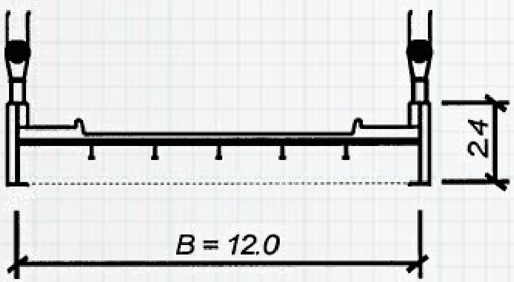
Tacoma Narrows Bridge

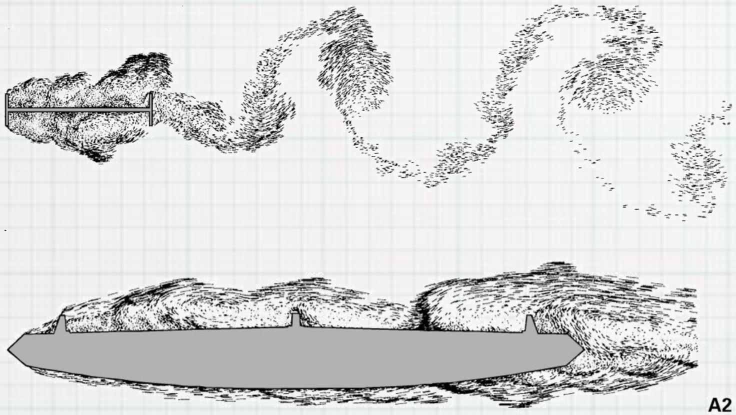


Tacoma Narrows Bridge

Design hubris gone too far?







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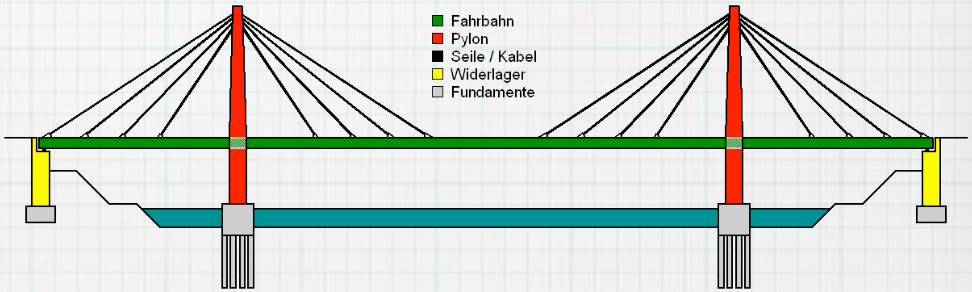
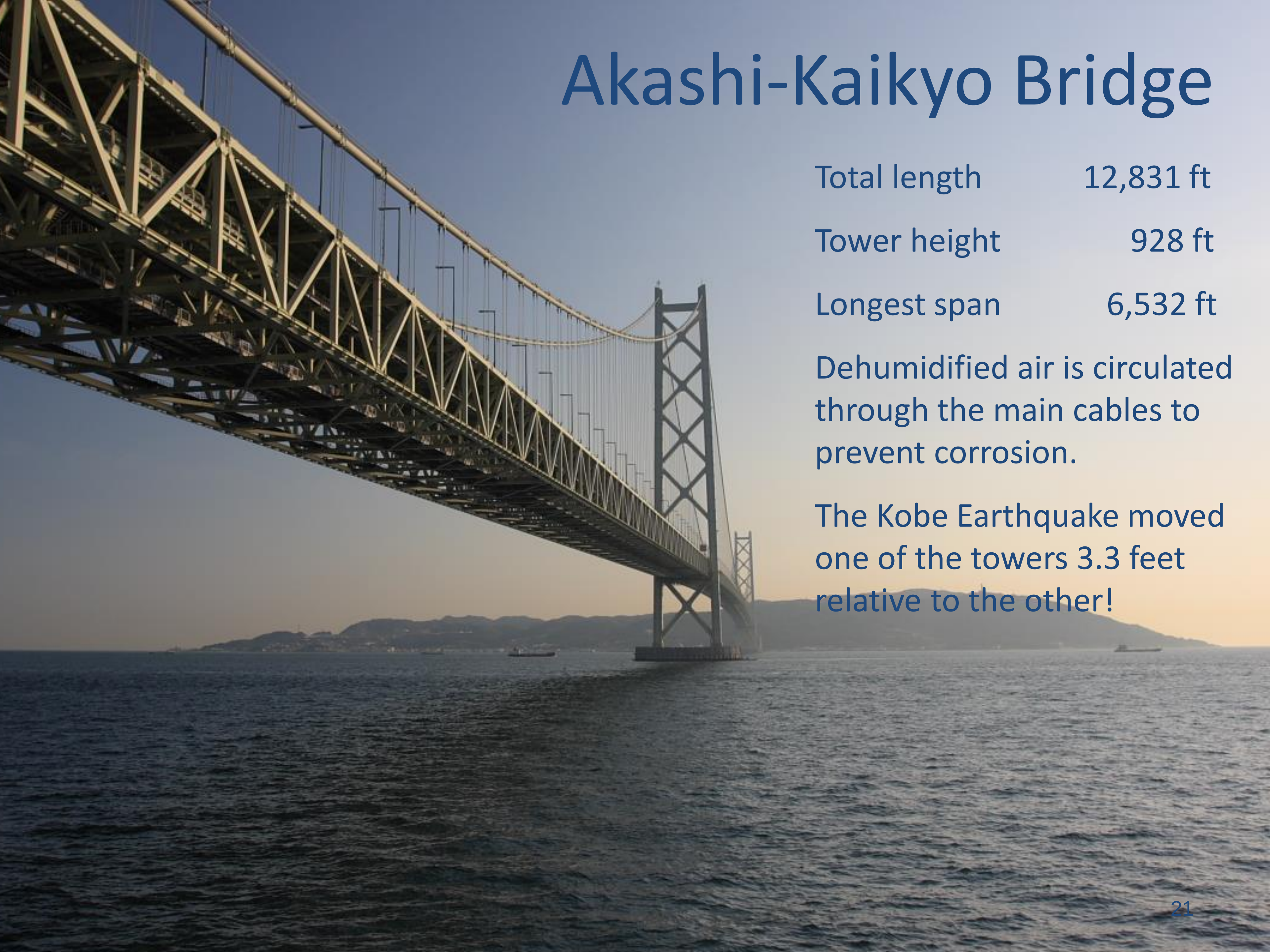
Still unknown issues of failure.



Failure of new system?

Has failure biome obsolete?



Akashi-Kaikyo Bridge

Total length	12,831 ft
Tower height	928 ft
Longest span	6,532 ft

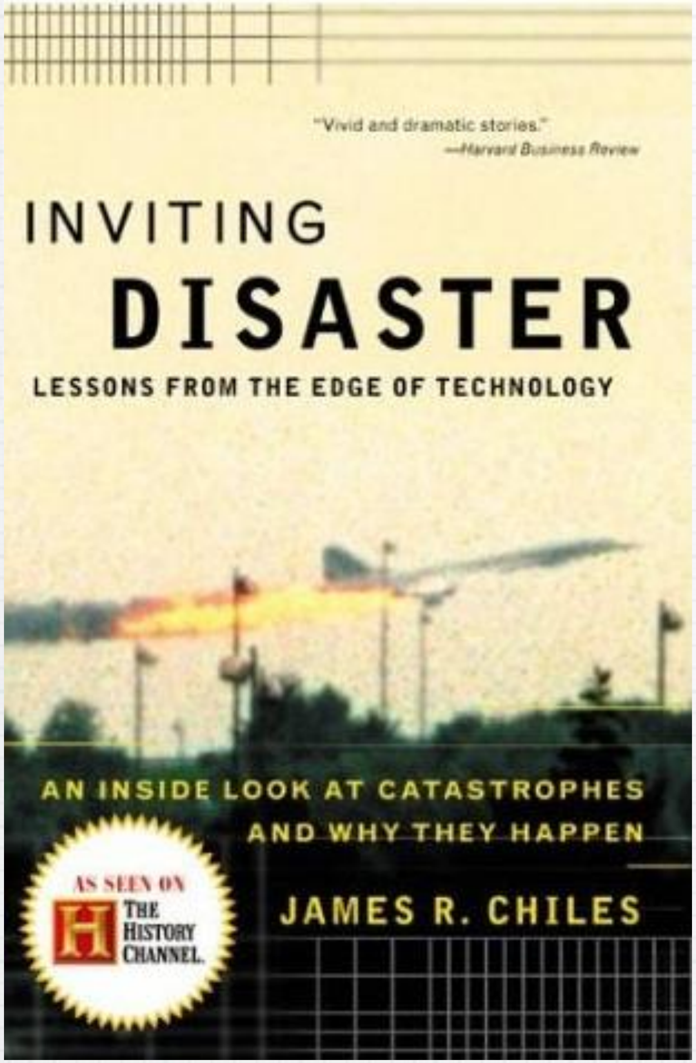
Dehumidified air is circulated through the main cables to prevent corrosion.

The Kobe Earthquake moved one of the towers 3.3 feet relative to the other!

Suspension Bridge Case Study Lessons Learned

1. How do you ensure knowledge transfer across multiple generations?
2. It can be difficult to define exactly when you have taken too much margin out of a system.
   - Stages of product development
3. It can be difficult to predict all failure modes in complex systems.
4. Do we ultimately need to learn from failure in all systems?

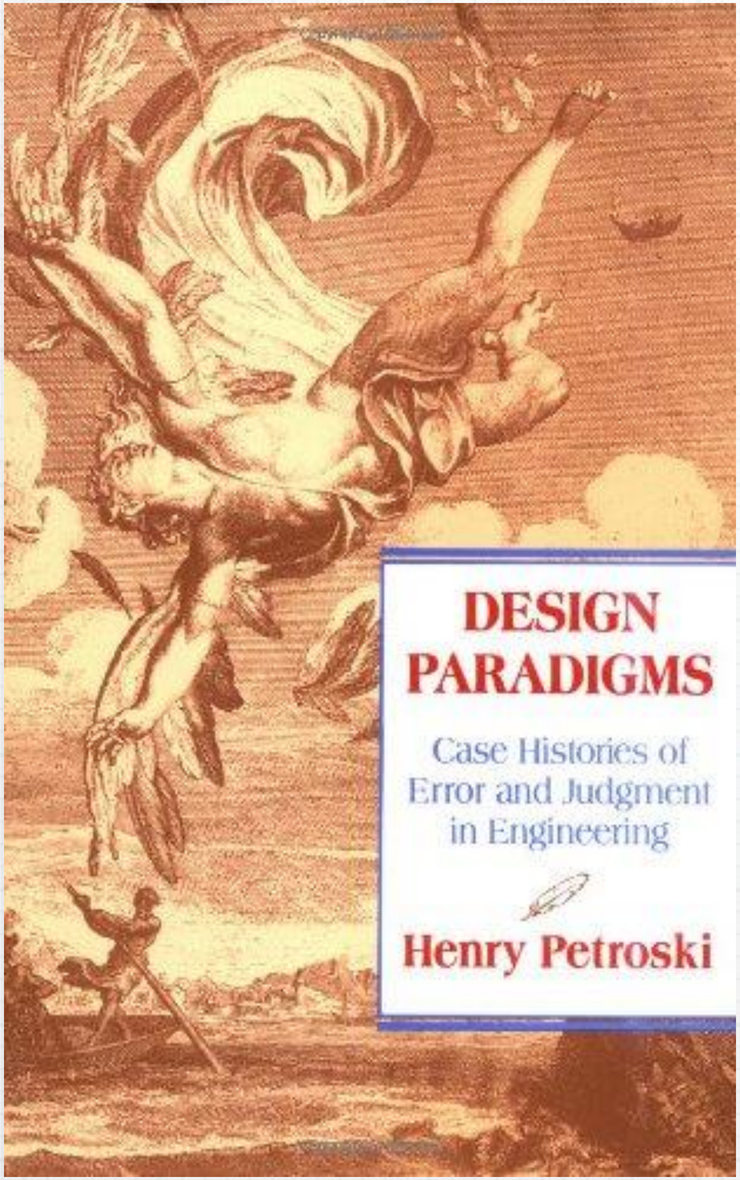
The Books and the Case Studies



Selected case studies regarding complex systems and the ability of human's to respond to them.
- "cognitive lock"

Case Studies:

- Design of Twin Towers
- Ocean Ranger
- Hubble Space Telescope Primary Mirror
- Apollo 13 LOX Tank



Discusses the concept of “learn from failure”.

Most of it is focused on the history of the suspension bridge and the lessons that can be learned from it.

Generational Learning.

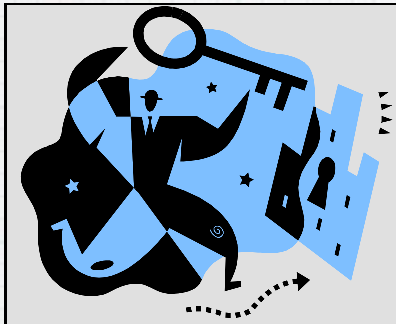
Reduction of Margin.

Questions about the future failure of cable-stayed bridge designs.

Biggest issue with the current books is the classes time to read them before class and that they are getting “long in the tooth.”

Concluding Thoughts

- These types of focused case study courses engage students and can be successful. Story telling does resonate with people.
- Newer case studies would probably, in part, focus on a different set of teaching themes.
- If new hires are critical how process information in information management systems is important.



TEACHING MILLENNIAL STUDENTS

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Key considerations and implications

- Do not make assumptions about students' backgrounds
- Do not make assumptions about what students may or may not know, especially in the area of writing -- assess and access prior knowledge and skills
- Be aware of signs of referential non-recognition
- Be aware of youth culture as trends may be tied to areas of interest, and this awareness will help you connect with current or known examples and meaningful metaphors

General Characteristics	Examples of Educational Implications	Samples of Actions Taken
Have heightened techno skills and ability to access information	• Professorship has changed -- no longer an expert, now simply a person with expertise • Found information may be perceived as carrying equal weight • Naiveté about credibility, quality, and reliability of sources, or timeliness, accuracy, or authenticity of information • Plagiarism may not be perceived as morally or ethically wrong • Main ideas need to be stressed as opposed to details, or if dwelling on details, place within the contextual relationship of main ideas. • Need for simplified information first.	• In online learning environments have clear rules of social engagement (netiquette) • Have students investigate sources and authors – other writings, academic credentials, political backgrounds of sources • Establish, discuss, and publish clear plagiarism policies • Course requirements need to encourage critical thinking and appraisal • Model critical thinking as you go through scholarly investigations • Share exemplary databases and websites pointing out indicators of excellence Offer simple overviews before concentrating on details placing facts and data in larger contexts

Discussion

Learning Objectives (Reference)

- Demonstrate the value of case studies in critical thinking.
- Identify and explain the 7 classical types of design errors and how to avoid them.
- Develop your analysis of case study dilemmas providing rationale to support your actions and decisions.
- Explain the importance of non-analytical aspects involved in the design process.
- Integrate design data into design knowledge.
- Extract key decision-making aspects associated with the engineering process from case studies.
- Explain how to incorporate lessons learned into everyday design processes.