

Introduction to *Airplane* Design

- Builds on the General Engineering Design Process



Fiat G.91 Pan, Museum of Flight, Seattle, WA

Aircraft Design

Uses the so-called German School of Design approach:

Three Phases in a project

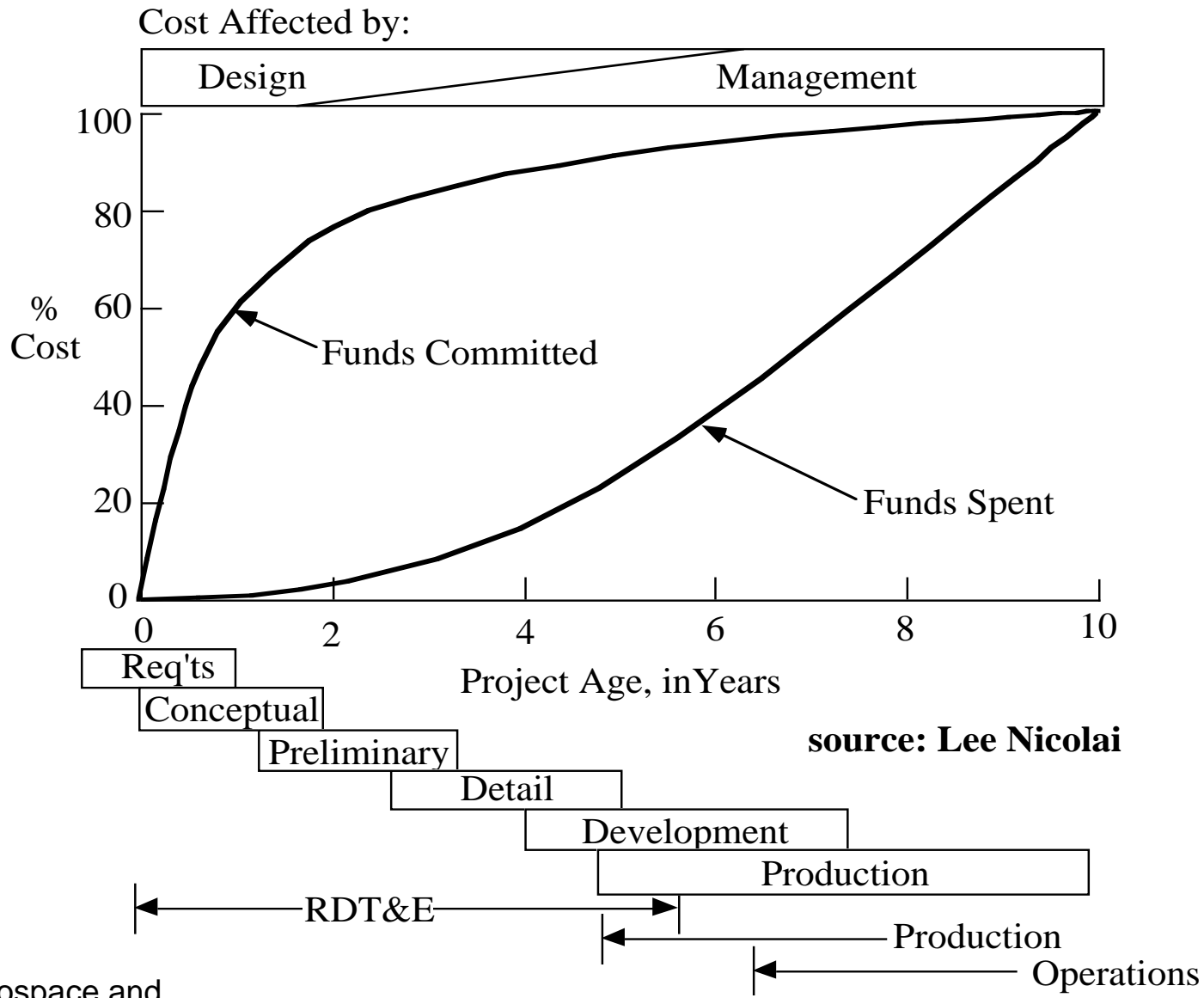
- *conceptual design* - first semester
- *preliminary design* - second semester
- *detail design*

The key issue - Cost

Cost is established at the very earliest stages of design

- Often portrayed as “initial designers are dummies”
 - *But: advanced designers are usually company’s best people!*
- *Reality:*
 - **Requirements drive the cost**
 - » Government often defines the requirements
 - **Pushing the limits to the max is expensive**
 - » Requirement “Creep” exacerbates the cost problem
- The Government claims that the JSF was done much better

Decisions Made Early Determine Cost!



Example: the F-22

- Initially 750 airplanes
- Then 331, goal 380
- Now ~~295~~ - nope 183!
 - Claim to be finding ways to reduce cost in manufacturing,
 - But:
 - » R&D for 750 a/c spread over 295 almost triples per/plane burden
 - » Gov't stretches programs, then minimizes current year spending at huge increase in equivalent annual cost
- Known as *The Death Spiral*
 - Media doesn't help



Picture from USAF Museum web site

Design Stages

- **Conceptual Design** (1% of the people):

- competing concepts evaluated
- performance goals established
- preferred concept selected

What drives the design?

Will it work/meet req't?

What does it look like?

1st cut CFD/WT work

- **Preliminary Design** (9% of the people):

- refined sizing of preferred concept
- design examined/establish confidence
- some changes allowed

Start using big computer codes

Do serious wind tunnel tests

Make actual cost estimate

(you bet your company)

- **Detail Design** (90% of the people):

- final detail design
- drawings released
- detailed performance
- only “tweaking” of design allowed

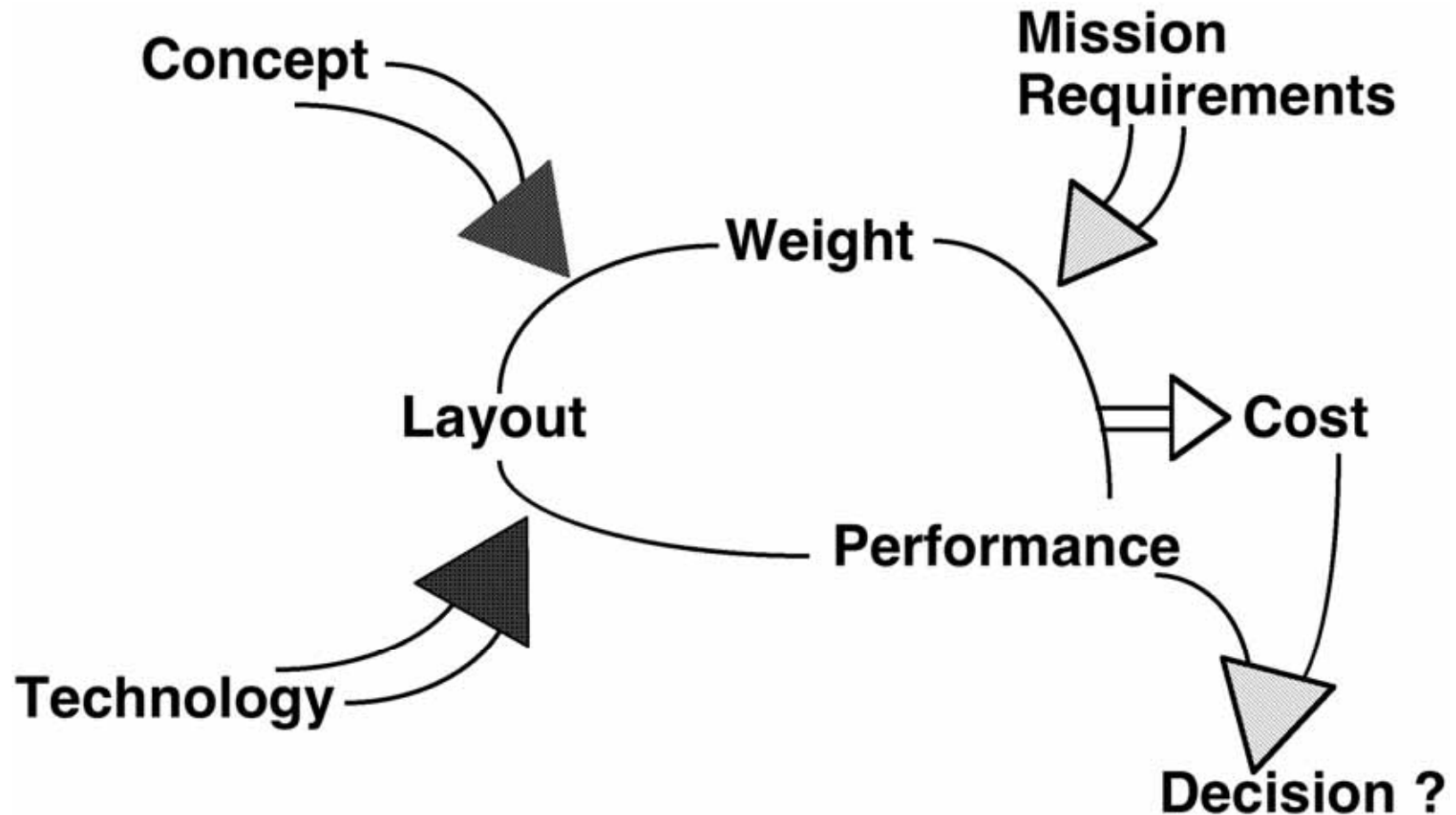
Certification process

Component/systems tests

Manufacturing(earlier now)

Flight control system design

Paul Gelhausen's (NASA*) Design Circle



*Now at AVID

Example: Kelly Johnson & the P-38



Kelly Johnson's six designs for 1937 Army fighter competition: (2) and (3) load two engines in each fuselage; (4) became XP-38.

ATF Concepts - Precursor to F-22

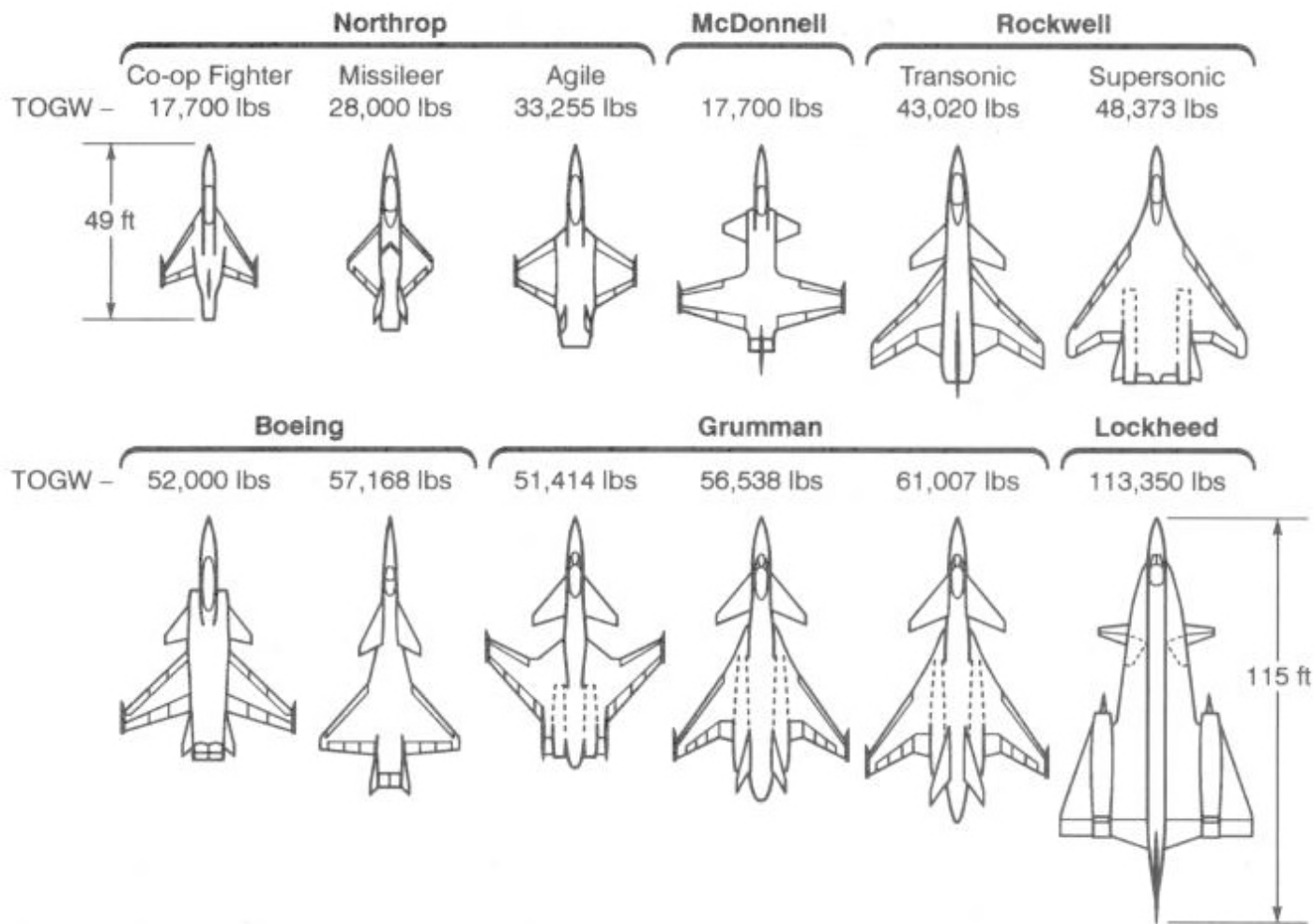
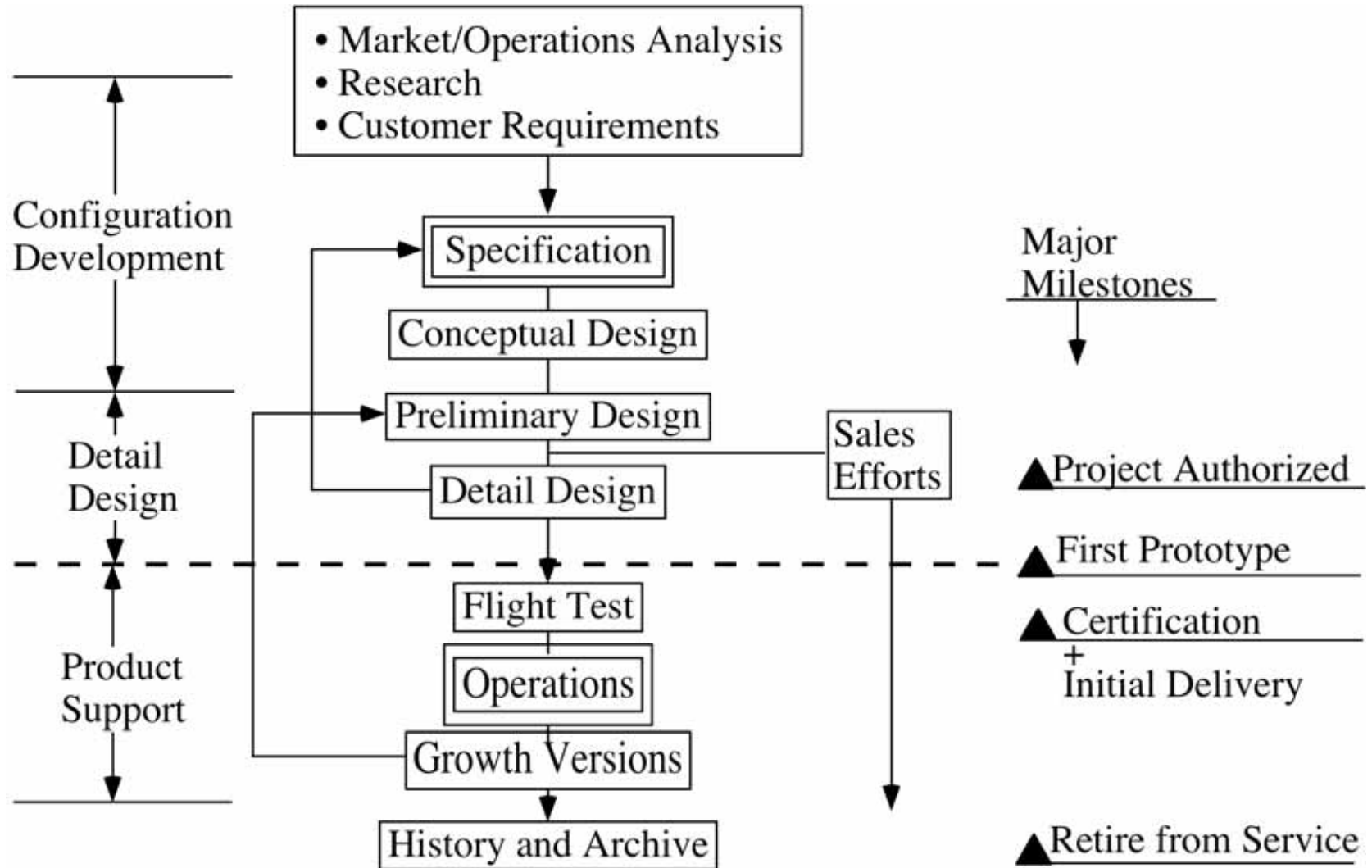


Fig. 8 RFI design concepts sized for air-to-air missions.¹

Advanced Tactical Fighter to F-22 Raptor, David C. Aronstein,
 Michael J. Hirschberg and Albert C. Piccirillo, AIAA Case Study

Civil Aircraft Development Process (McMasters)



Wait, the CEO just called:
we need to answer the call!

- How big is the wing? (the plane weighs 2400 lbs)
- Work in groups of 2 or 3
- Hand in your answer on a single sheet

What did you do?

- Did you follow the process?
 - Requirements
 - Decisions

Some Recent “New” Aspects

- The Customer - finally being brought into the process up front
- Rational ways to evolve requirements
 - tools to use to make decisions
- Concurrent engineering: you must be able to build—economically!
 - manufacturing
 - reliability/maintainability
- Robust design: account for process variation
- Continual improvement/development of a family of products

Review: The Engineering Design Approach:

- evaluate (or define) the requirements
 - customers/regulations, constraints/performance goals
- understand current approaches (what's done now?)
- think of some possible solutions (creativity)
- identify a variety of possible concepts (concept generation)
- concept evaluation (analysis)
- select a preferred concept for development (make a decision)
- do the detail design and make a prototype (analysis)
- test and evaluate-scrutinize
- continually refine the design until it's a viable product

Note: Many of these steps are repeated, it's an iterative process

So What do *you* actually do?

- Reasonable Requirements?
- Technology Choices
 - What materials?
 - What propulsion system? Does it exist?
 - Aerodynamics: Laminar flow? Exploit vortex flow?
- Concepts?
 - Payload packaging
 - Wing planform?
 - Control concept

The Most Remarkable of Them All?

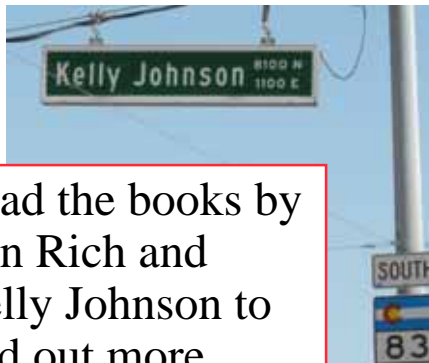
Kelly Johnson's Skunk Works team produced the A-12/SR-71 Mach 3+ aircraft



SR-71C, Hill AFB Museum, Ogden, Utah

A wide variety of versions were produced, each practically a custom airplane

With D-21 mounted on top, this was known as an M-21



Read the books by Ben Rich and Kelly Johnson to find out more



Museum of Flight, Seattle, WA

Want to Read More About Airplane Design?

These books help you get a feel for how it works:

- *Aircraft Design: A Conceptual Approach* by Dan Raymer, especially Chapters 1, 2, and 22.
- *The Anatomy of the Airplane*, by Darrol Stinton
- Clarence L. “Kelly” Johnson with Maggie Smith Kelly, *More Than My Share of It All*, Smithsonian Institute Press, Washington, 1985, paperback 1989.
- Ben R. Rich and Leo Janos, *Skunk Works, A Personal Memoir of My Years at Lockheed*, Little, Brown and Company, Boston, 1994. A lot about the F-117, and Rich’s early experiences. Another view of working for Kelly Johnson.
- Karl Sabbagh, *Twenty-First-Century Jet, The Making and Marketing of the Boeing 777*, Scribner, 1996

In Conclusion

- Design is a challenge
- *Good* Design is important
- **Design can be fun**

F-86 with the skin off,
USAF Museum, Dayton, OH



A million details lie under the skin

Next Time

- Homework due
- Why Airplanes Look Like they Do
- More Battle of the X-Planes

Attributes of an Airplane Configurator*

[* An aeronautical Frank Lloyd Wright or Eero Saarinen - an airplane “architect”]

- An “airplane nut” - fascinated with the *art* and science of aeronautics
- Possess a *breadth* of skill and knowledge (including business practice and economics) anchored in significant *depth* of expertise in one or more core disciplines (e.g. aerodynamics, structures, propulsion, systems, manufacturing, computing/information technology)
- A multidisciplinary “large-scale system” thinker - naturally grasps the essential elements of the entire airplane system requirements before delving into the specific details of design, manufacturing, maintenance, operation, cost, etc.
- Possessed of an “artist’s eye” - a developed and informed aesthetic sense of what an airplane could and should look like (grounded in practical reality)
- Curiosity, and the strong desire and ability to learn for life
- The ability and *self confidence* to think and act “ambidextrously” as a given situation requires
 - Think both *creatively* and *critically*
 - Act independently and as a member of a team
 - Behave with open minded flexibility and stubborn tenacity
- Strong communication skills (written, oral, graphic and *listening*)
- Possess high standards of ethics and intellectual integrity
- Eagerness to take judicious risks and willingness to make mistakes (and learn from them)
- Leadership ability including vision and entrepreneurial skills

Note: It is unrealistic to expect to find any individual who has all the attributes listed in a fully developed and complete form. On the other hand, experience demonstrates that most of the really great designers in the history of our industry possessed an unusual measure of the great majority of these characteristics. Thus, while the breed is rare, the importance of these “key few” to the Ongoing success of our enterprise makes it necessary to make special efforts to cultivate a future generation of such individuals.

Boeing: 737-X, Market-Driven Definition

- after being beaten out by Airbus for the United sales (still) -

- A Family: 100 - 157 seats mixed class
- Designed for simplicity
 - maintain high reliability - proven systems - reduced maintenance cost

The next additions to the family:

- retain existing 737 digital flight deck
 - crew commonality
 - compatible with future operating environment
- interior improvements
 - increased flexibility
 - improved passenger comfort and amenities
- modified wing with chord and span increase
 - 2900 nmi range
 - 0.78 - 0.80 Mach cruise speed
- new engine/nacelle
 - reduced noise and emissions
 - improved operating economics
 - higher thrust
- modified vertical and horizontal tail



Finally: L. Robert Jackson's Tips for Designers

(Structures type from NASA Langley)

- Learn and understand the fundamentals—Yours and other's disciplines
- Think Failure Modes, Reasonable Design Criteria and Load Factors
- Apply simple analytical methods prior to using computer codes,
 - Provides “sanity check” for computer analysis
- Study references
- Learn to use the various codes
- Be independent
- Strive to Advance the Art—Have courage supported by doing your “homework.” Hang in there—It takes longer than you first think
- Salesmanship is part of your job—clear precise presentations at your audience's level of understanding (a good picture is worth 1,999 words—trite but true—learn to sketch to proportion).