Air Vehicle Design

AOE 4065 – 4066

I. Foundational Elements

Course Module F1

Design: *An Engineering Discipline*

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AOE 4065-4066:
Capstone Air Vehicle Design (AVD) Course Modules (CMs)

Overview of AVD Courses

I. Foundational Elements

F1. Design: *An Engineering Discipline*

F2. Systems and Systems Thinking

F3. Basics of Systems Engineering

F4. Decision Making with Ethics and Integrity

II. Air Vehicle Design Fundamentals

A1. Purpose & Process

Conceptual Design

A2. Understand the Problem

A3. Solve the Problem

A4. Initial Sizing: *Takeoff Weight Estimation*

A5. Initial Sizing: *Wing Loading and Thrust Loading Estimation*

A6. Cost Considerations

A7. Concept to Configuration: *Key Considerations*

A7A. Configuration Layout: *Drawings & Loft*

Conceptual & Preliminary Design

A8. Trade Studies

A9. Use of Software Tools

A10. Preliminary Design: *Baseline Design Refinement & Validation*

III. Project Management Topics

P1. Basics of Project Management and Project Planning

P2. Project Organization

P3. Roles & Responsibilities of Team Members

P4. Project Execution: *Teamwork for Success*

P5. Project Risk Management

P6. Delivering Effective Oral Presentations

P7. Writing Effective Design Reports

Disclaimer

Prof. Pradeep Raj, Aerospace and Ocean Engineering, Virginia Tech, collected and compiled material contained herein from publicly available sources solely for educational purposes.

Although a good-faith attempt is made to cite all sources of material, we regret any inadvertent omissions.

CRUCIALLY IMPORTANT

CMs only introduce key topics and highlight some important concepts and ideas…but without sufficient detail.

We must use lots of Reference Material* to add the necessary details!

(*see Appendix in the Overview CM)

Outline

F1. Design: *An Engineering Discipline*

F1.1 What Design is

F1.2 How Design is done

F1.3 What differentiates Design from Analysis

F1.4 What the attributes of a Good Designer are

What do we mean by Design?

Merriam-Webster Dictionary

- **Design – verb**
  - **to create, fashion, execute, or construct according to plan**
  - to devise for a specific function or end
  - to draw the plans for
- **Design – noun**
  - **a preliminary sketch showing the main features of something to be executed**
  - the arrangement of elements in a product
  - a mental scheme in which means to an end are laid down

"Perhaps the least understood is how "The Design" is really just a plan. Every part of the [product] development process uses the design as a point of departure, but each deviates in its own way."

- Daniel Newman, VERTIFLITE, Jul/Aug 2021

Conjures up different notions in people's minds!

A Few Definitions of Design by Experts!

Creating the geometric description of a thing to be built.

D.P. Raymer, *Aircraft Design: A Conceptual Approach*, 2012

Design is a process by which human intellect, creativity, and passion are translated into useful artifacts.

NRC, *Theoretical Foundations for Decision Making in Engineering Design*, 2001

Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.

The ABET (Accreditation Board for Engineering and Technology), Definition

Design is an iterative decision-making activity performed by team of engineers to produce plans by which resources are converted, preferably optimally, into systems or devices to meet human need.

T.T. Woodson, *Introduction to Engineering Design*, 1966

Alas, No Universal Definition of Design!

Designing an Object is a Creative Act

But Creativity Alone May Produce Useless/Impractical Artifacts

Convergent Bicycle

The Coffeepot for Masochists

The Uncomfortable Wine Glass

The Camouflage Cup
(cut out plastic cup)

Engineering Design is "Creativity with Purpose!"

Source: https://www.pinterest.com/laragtorres/impossible-objects/

Essence of Design

"Well-designed objects are easy to interpret and understand. They contain visible clues to operation. Poorly designed objects can be difficult and frustrating to use."

- Donald Norman, *The Design of Everyday Things*

Source: Internet

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How One Does "Engineering Design"

By Executing an Integrated Set of 3 Major Activities

1. Decision Making

- the act or process of deciding something especially with a group of people
- *Decision is a determination arrived at after consideration of relevant factors*

2. Creative Synthesis

- combination of parts or elements so as to form a whole
- combining of often diverse conceptions into a coherent whole

3. Analysis

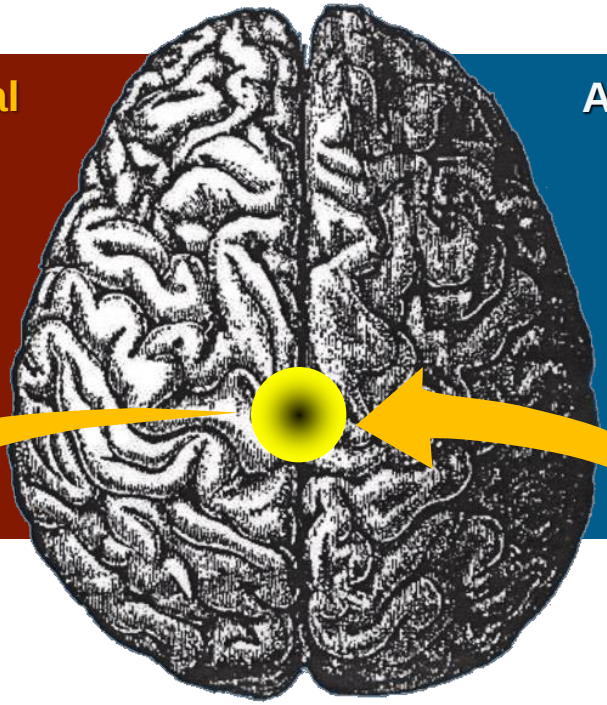
- a detailed examination of anything complex in order to understand its nature or to determine its essential features: a thorough study
- separation of a whole into its component parts

Design is an *Integrated Mental Activity…*

Judicial Mind (Left Brain)

Deductive Analytical

- Rigid Rules
- Critical Thinking
- Rational
- Logical
- Converge
- One Answer



Creative Mind (Right Brain)

Associative Creative

- No Rules
- Uncritical Thinking
- Irrational
- Illogical
- Diverge
- Alternatives

3. Analysis

2. Creative Synthesis

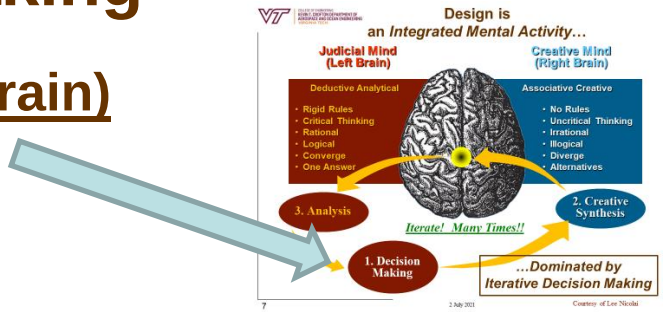
Iterate! Many Times!!

1. Decision Making

…Dominated by Iterative Decision Making

Source: Adapted from Lee Nicolai's lecture slides

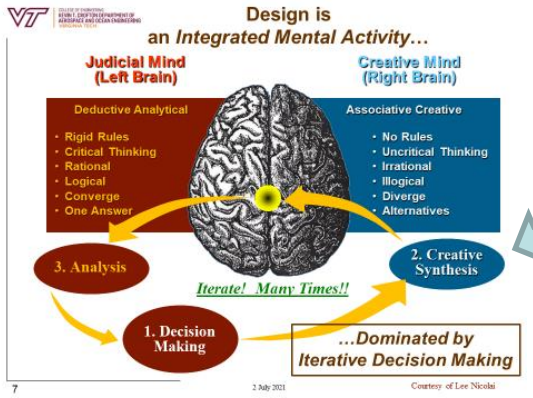
1. Decision Making



- **Deductive analytical mental activity (Left Brain)**
- **Key Decisions need to be made in three major design stages**
  - **Initial Design Stage – Set the rules**
    - ***Define the problem*: Analyze Requirements to determine--What must the system do? How well? Under what conditions? What is the product?**
    - ***Determine the design drivers*: Performance, cost, safety, environment, etc.**
    - ***Investigate who the customer is* and what *his Measures of Merit* (*MoMs*) are**
    - ***Determine concept/configuration selection criteria:* Requirements & MoMs, both technical and programmatic**
    - ***Develop Design Guidelines:* *Disciplinary Requirements flow down* to teams**
    - ***Identify competition*: Whom/what we have to beat**
    - ***Gather a lot of relevant data:* Identify potential options for meeting disciplinary requirements**
  - **Intermediate Design Stage – Select feasible solutions**
    - ***Create viable concepts, apply Concept Selection Criteria to select a few promising ones, assess their feasibility, and downselect "good" ones***
  - **Final Design Stage – Select the *best* solution and quit**
    - **Remember: *There are no right answers, only a best answer at a given point in time!***

Source: Adapted from Lee Nicolai's lecture slides

2. Creative Synthesis



- **Associative creative mental activity (Right Brain)**

- **Ignore the rules (*Rules Stifle Creativity*)**

- **Develop viable* design solutions (e.g., vehicle concepts)**
  - ***Brainstorm***
  - ***Sky Is The Limit … the more the better***
  - ***Out-of-the-Box Thinking***
  - ***Non-judgmental***

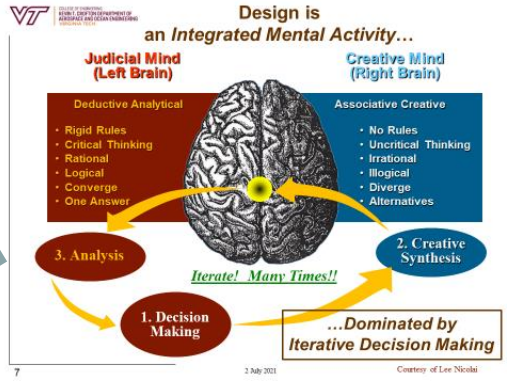
- **Define assumptions to support design candidates**

***Viable**--capable of becoming actual: *'we think it will work'*

Source: Adapted from Lee Nicolai's lecture slides

3. Analysis

- **Deductive analytical mental activity (Left Brain)**



- **Apply the rules**
- **Test design candidates with analysis**
  - ***Design work-up on each candidate***
  - ***Assess feasibility of each candidate***
  - ***For each feasible* candidate, estimate quantified values of chosen Measures of Merits (MoMs)***
- **Conduct sensitivity analysis of assumptions**
  - ***Are assumptions reasonable?***
  - ***How robust is design?***
- **Conduct tradeoff studies to answer 'what if' questions**

***Feasible**—realizable: *'we know it will work'*

Source: Adapted from Lee Nicolai's lecture slides

Three Cornerstones of Design: I-C-E

Integration

Designers are responsible for integrating all parts, making sure they all fit together.

Requires broad understanding of all aspects of design, manufacturing, and operations.

Boeing 777: "3 Million Parts flying in tight formation!"

Customer

Focus on the needs of customer's customer. The product must work as promised. But sell more than a quality product, sell a quality experience (be easy to deal with as well).

"Design is not just what it looks like and feels like. Design is how it works."

-- Steve Jobs

"If it looks good…it flies good."

-- Kelly Johnson

Experience

"Experience is what you get when you don't get what you wanted. And it can be the most valuable thing you have to offer." *-- Randy Pausch*

The more you do, the more experienced you become.

Iterative decision-making is at the core of all design efforts

What is a Good Design?

A product that satisfies all customer Needs *and Wants* while ensuring that it is

- **D**istinctive – *notable*
- **E**legant – *clever but simple, and therefore attractive*
- **S**imple – *not complicated, easy to work with, intuitive*
- **I**ngenious – *cleverly and originally devised and well suited to its purpose*
- **G**reen – *minimizes [eliminates?] negative environmental impact*
- **N**ovel – *new or unusual in an interesting way*

Magical!

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Design Problems are Different from Analysis Problems

- ***Problem:*** **Estimate the required lift coefficient of an airplane in cruise, i.e., in a level steady (unaccelerated) flight**

- ***Approach:*** **From flight mechanics, we know that in cruise**

$$L = W = 0.5\,\rho\,V^2\,S\,C_L$$

- **Given airplane weight, W, flight speed, V, altitude (for density, ρ), and wing area, S, there is only one value of C_L which we can determine using $C_L = W / (0.5\,\rho\,V^2\,S)$**

Analysis (closed-form)

- **If we know only the airplane weight, W, different combinations of flight speed, V; density, ρ, at cruise altitude; and wing area, S, yield different values of C_L. *Designer's challenge is to find the "best" combination*!**

Design (open-ended)

Design is a Distinct Engineering Discipline, and Designer's Choices have Far-reaching Implications!

Analysis is Characterized by Closed-form Problems

Table 2. Example of an aero/performance problem cast in close-form and open-ended format

Problem statement: Determine the stall speed at LAX airport for a 2-place General Aviation aircraft at 30° flap deflection with the following characteristics:

Item	Closed-form problem
Pilot/pax baggage	392 lb
Fuel weight	147 lb
Empty weight	1136 lb
Airfoil	NACA 2412
Wing area	159.5 ft^2
Flaps	Single Slot $C_f/c = 0.2$ 33% span
Wing span	33.3 ft
Aspect ratio	6.95
WIng taper ratio	0.7
Wing sweeps	0
ANSWER	42 kts

Analysis

All items have specified input values—given!

Only one right answer of stall speed!

Source: Nicolai, L.M., "Viewpoint: An Industry View of Engineering Design Education," International Journal of Engineering Education, Vol. 14, No. 1, p. 7-13, 1998

Design is Characterized by Open-ended Problems

Table 2. Example of an aero/performance problem cast in close-form and open-ended format

Problem statement:	Determine the stall speed at LAX airport for a 2-place General Aviation aircraft at 30° flap deflection with the following characteristics:	
Item	Closed-form problem	Open-ended problem
Pilot/pax baggage	392 lb	392 lb
Fuel weight	147 lb	147 lb
Empty weight	[illegible]	920 lb (less wing)
Airfoil	NACA 24[illegible]	TBD
Wing area	[illegible]	TBD
Flaps	[illegible]	TBD
Wing span	[illegible]	TBD
Aspect ratio	[illegible]	TBD
WIng taper ratio	0.7	TBD
Wing sweeps	0	TBD
ANSWER	42 kts	Depends on wing design

Most of the items have no specified input values! These are design parameters.

Designers select values of design parameters to obtain *desired* stall speed!

Design Challenge: Find the "Best" combination!

Answer depends on selected values of design parameters!

Source: Nicolai, L.M., "Viewpoint: An Industry View of Engineering Design Education," International Journal of Engineering Education, Vol. 14, No. 1, p. 7-13, 1998

An Open-ended Design Problem Does Not Have Just One Right Answer!

There is No Single Right Answer, but one must produce a "Complete Answer" in order to find a "Best" answer!

The Complete Answer has Four (4) Parts

- ***Answer***—application of proven fundamental approaches
- ***Assumptions*** *Surrounding the Answer*—must be documented
- ***Sensitivities*** *About the Answer*—aka trade-off studies
- ***Fallback*** *Position*—outgrowth of tradeoff studies

This "Mandate" Distinguishes the Design Discipline from All Others in Engineering Curricula.

Source: Courtesy of Eric Schrock

Design and Analysis:
Key Characteristics

Design	Analysis
• *Unknown Unknowns**	• *Known Knowns**
• *Unpredictability*	• *Predictability*
• *Uncertainty*	• *Certainty*

Good analysts provide good data.

Good designers use good data and sound judgment to produce good designs!

"…there are **known knowns; **there are things we know we know**. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also **unknown unknowns—the ones we don't know we don't know**."*

– Donald Rumsfeld, Feb 2002

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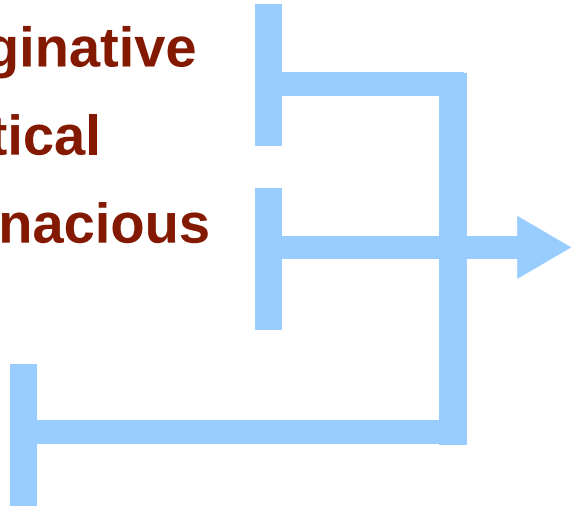
Attributes of a Good Designer

- Creative, imaginative
- Objective, critical
- Stubbornly tenacious
- Flexible
- Cooperative
- Independent



Ambidextrous thinker*
(Controlled schizophrenic)

Add three more—and you have a GREAT Designer!

- Passionate
- Visionary
- Nympholepsy (yearning for the unachievable)

***The pairs of attributes shown cannot be exhibited simultaneously without short circuiting the brain. One can (and must) learn to switch reflexively from left brain to right brain as need may arise. This can be done, and one can learn how to do it.**

Courtesy of Lee Nicolai

Characteristics of Good Designers

- **Always asking questions**: Curious about everything
- **Great associative power:** Ability to recognize and draw upon parallels in other fields for ideas (implies that designers have eclectic interests and often roam far afield in science and engineering – said to be "interested in everything.")
- **"Idea Machine":** Presented with a problem, always seem to respond with a flood of ideas, then look to interactions with associates to sort out the good from the bad
- **Strong inner directed personalities:** are sure of themselves, able to accept with equanimity the guffaws at the poor solutions they propose along with the kudos for success

"Improving Engineering Design,
Designing for Competitive Advantage"
NRC Publication

A *Great* Designer: Kelly Johnson

Clarence Leonard "Kelly" Johnson (1910-1990)
Founder of the world-renowned Skunk Works®

Recipient of
1983 National Security Medal

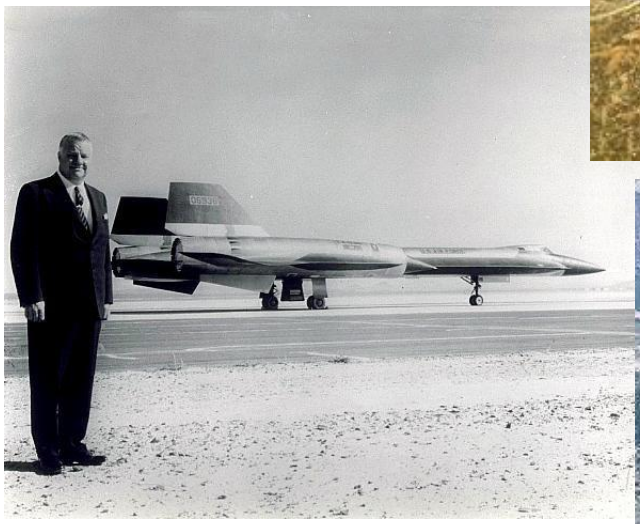


Image Source: Internet

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