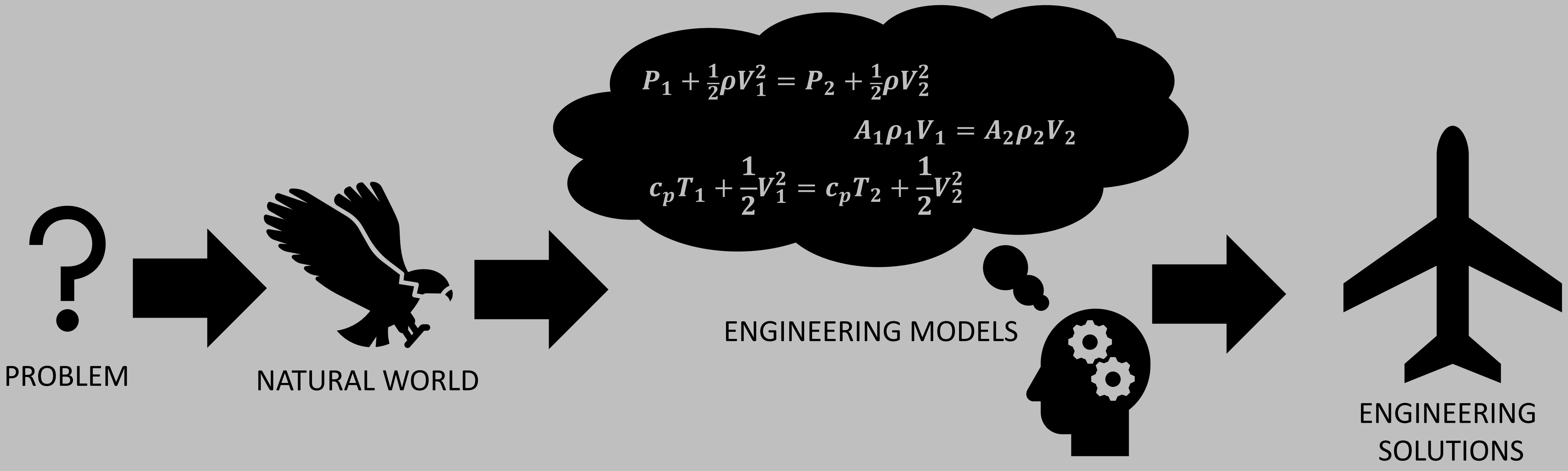
Aerospace Vehicle Modeling

What do you do when no one tells you the "Givens"?

"…the basic aerodynamic properties of the airplane are described by [the drag polar equation], we consider both C_{Do} and e [Oswalds] ***as known aerodynamic quantities, obtained from the aerodynamicist."***

-- Anderson, Intro to Flight Textbook

Engineering Models

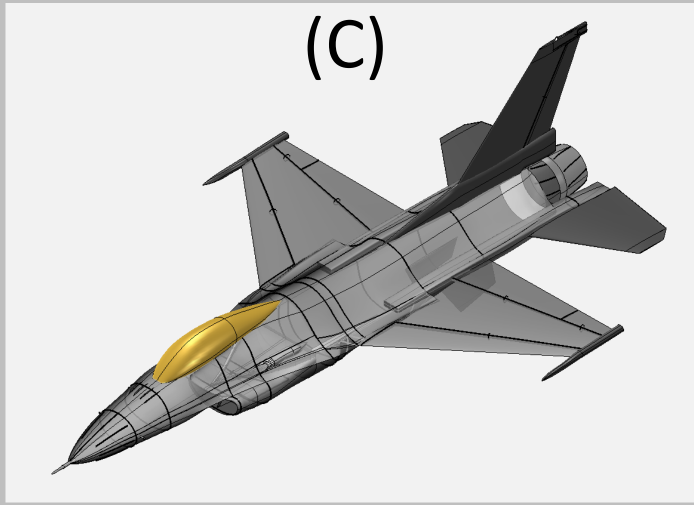


» These skills are at the heart of what it means to be an engineer!

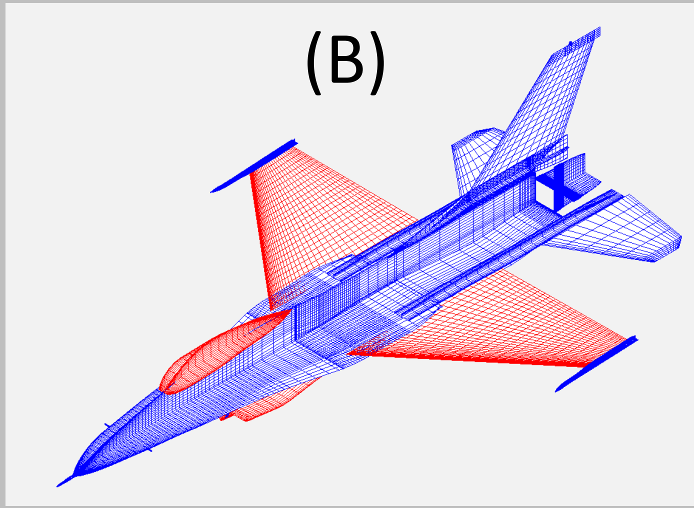
Which Of the Following are “Models”?

(A)

(C)



(B)



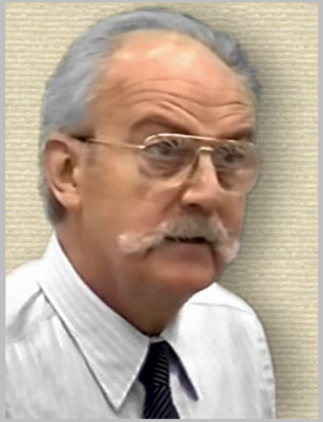
(D)

Don't Fall in Love with Your Models…

» Models are inherently flawed
  » Higher-order models are not always better
  » There is tremendous value in using first-order models in design

"Since all models are wrong the scientist must be alert to what is importantly wrong. It is inappropriate to be concerned about mice when there are tigers abroad."

--George E.P. Box



"To design a flying machine is nothing; to build it is not much; to test it is everything."

-- Otto Lilienthal

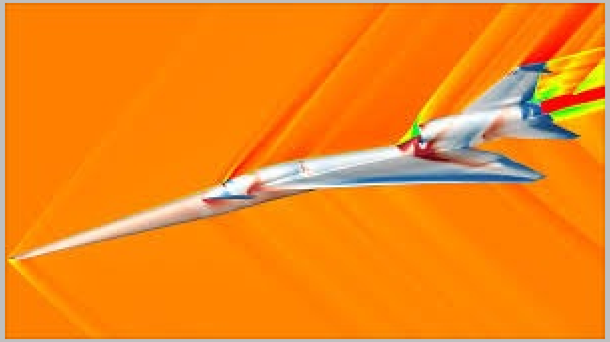
» It is necessary to validate a model's range of usefulness & gain knowledge where models are inadequate
  » Benchmarking
  » Experimentation / Tests
  » Prototyping

Not All Models are Equal

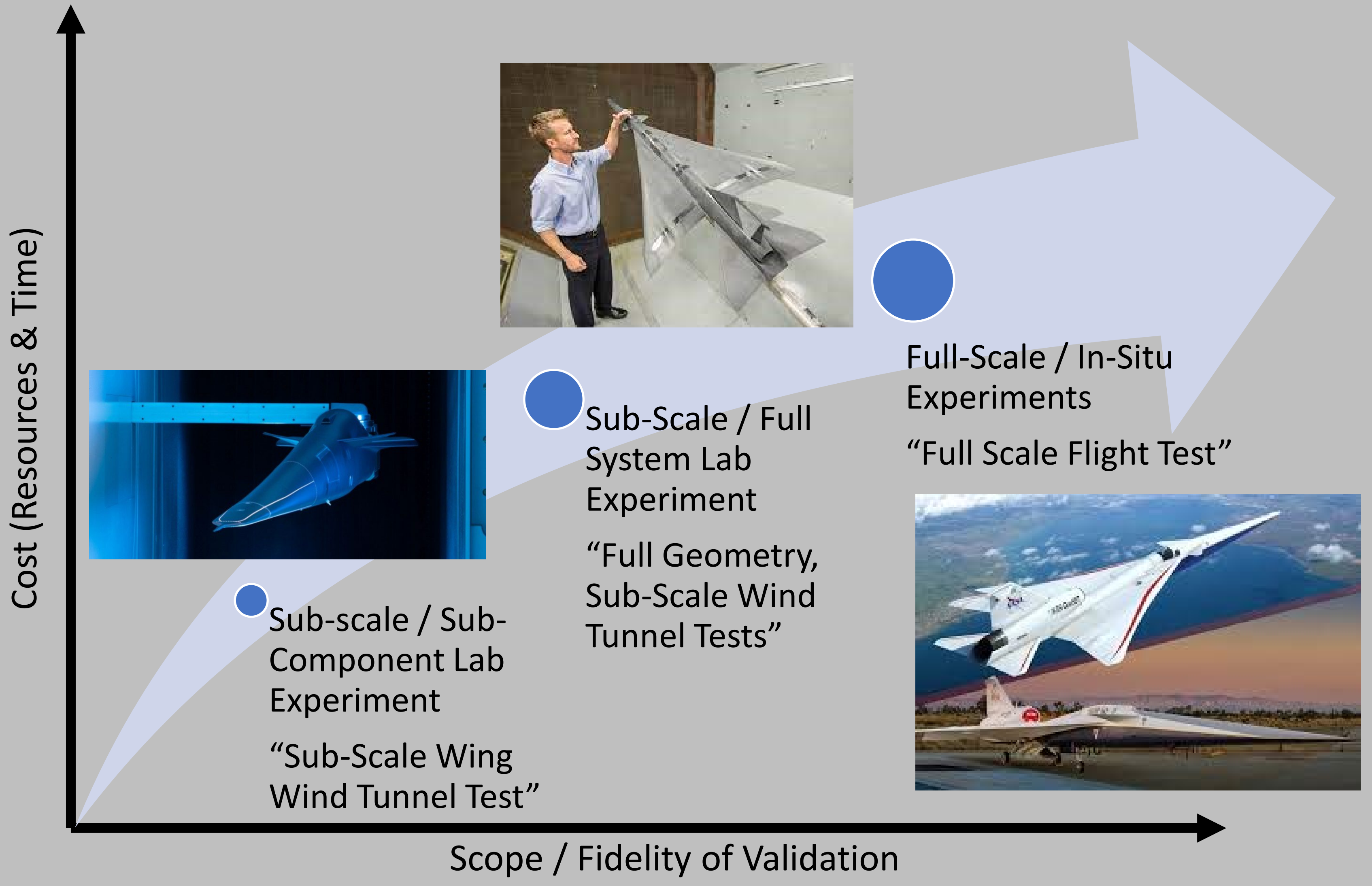
- You need to understand the basis for models to understand their limitations
- General Types of Models Used in Design
  - **Physics Based (Fundamental Models)**
    - Wide spectrum of fidelity (think Assumptions / Simplifications)
    - Can still have significant error due to application of assumptions / simplifications
    - Preferred for conceptual design, when possible, but can be costly / infeasible to utilize for a complex system
  - **Statistical / Historical Based (Fitted Models)**
    - Projected based on statistical models of historic or experimental data
    - Can be accurate, but must consider basis and sample size of data set
    - Generally, you should try to avoid doing design trade studies / optimization with statistical models (but we often do it)
    - Heavy use of statistical models based on historic data may contribute to suppression of innovation (re-inventing)
- Designing aircraft typically uses a mixture of physics-based and statistical-based models
- ***What does this mean about characterizing uncertainty in aircraft design model predictions?***

Model Validation

- **Model validation is a continuous process, not a discrete step**
  - Occurs throughout the design life cycle phases
  - Occurs at several levels of your system
    - Component to Full System
    - Controlled Environment to In-Situ



Engineering Model



Design Modeling Code Overview

» **Download Lab Modeling Code Template from Canvas**

» **ASEN 2804 Perspective on Coding**

» **WARNING:** Preserving dependencies across design parameters is essential for any conceptual aircraft design software

  » Depends largely on macro code design and structure

  » If you break dependencies across your models, your results and conclusions may be invalid!

  » **DO NOT CHANGE EXISTING CODE STRUCTURE, VARIABLE NAMES OR FUNCTION INPUTS/OUTPUTS!**

  » **What can you change? The underlying models!**

» **Milestone 1A: Aerodynamic & Weight Model Take-home Quiz (Due NLT 3 Feb)**

Modeling Code General Framework

Component	Key Design Variable Inputs	Engineering Models	Primary Output	Secondary Outputs
Fuselage (body)	?	?	❑ $(C_{Do})_{fuselage}$ ❑ $(C_{Do})_{misc}$	?
Wing	?	?	❑ $(C_{Do})_{wing}$	?
Horizontal / Vertical Stabilizer	?	?	❑ $(C_{Do})_{ht\ or\ vt}$	?

Code Framework	Design Input File	Model Functions	Output Tables & Plots	Output Tables, Plots, Structs
	Configuration Geometry Reflects Primary Design Choices!	Geometry Inputs fed into engineering models		Once you have the drag polar model, you can determine flight performance*

$$C_{Do} = (C_{Do})_{fuselage} + (C_{Do})_{Wing} + (C_{Do})_{ht} + (C_{Do})_{vt} + (C_{Do})_{misc} + (C_{Do})_{L\&P} + (C_{Do})_{X} + \cdots$$

Project Code Structure Template Step-Thru

- Open Design Input File
- Standard Code Structure

Aerodynamic Modeling

Design Input File: Aircraft Geometry Modeling

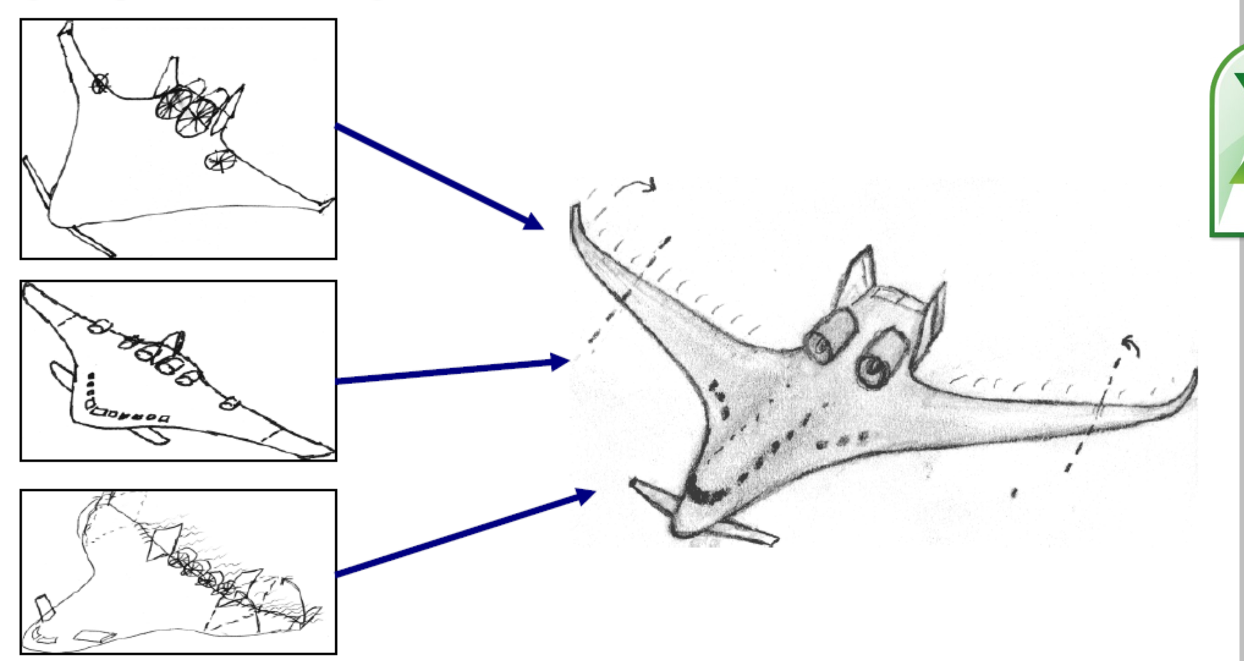
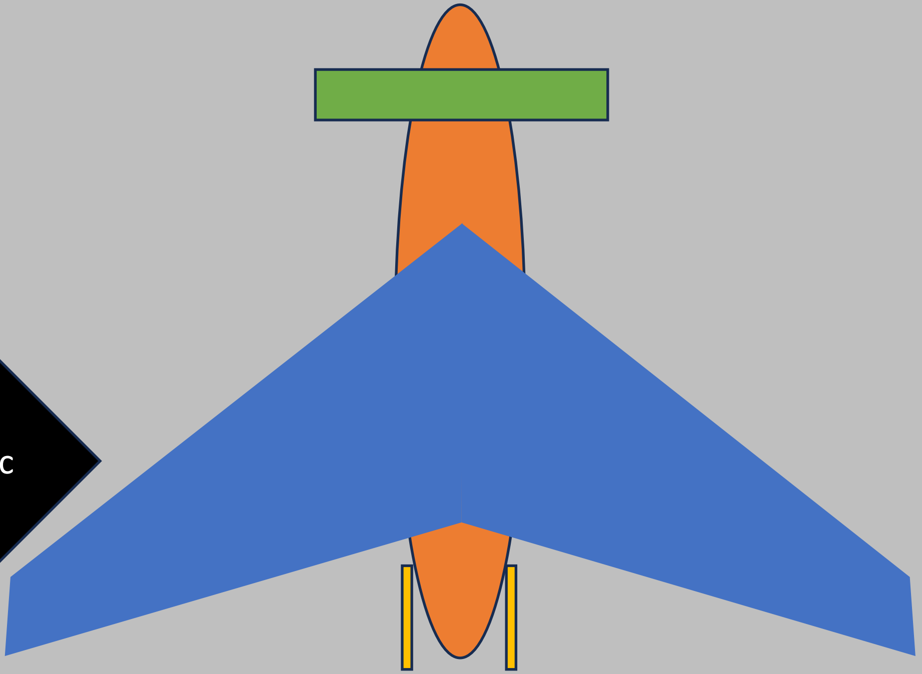
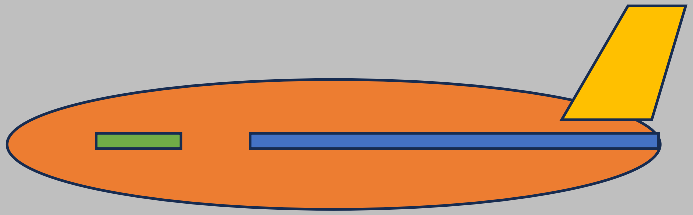


Figure 3.13 – Concept sketches

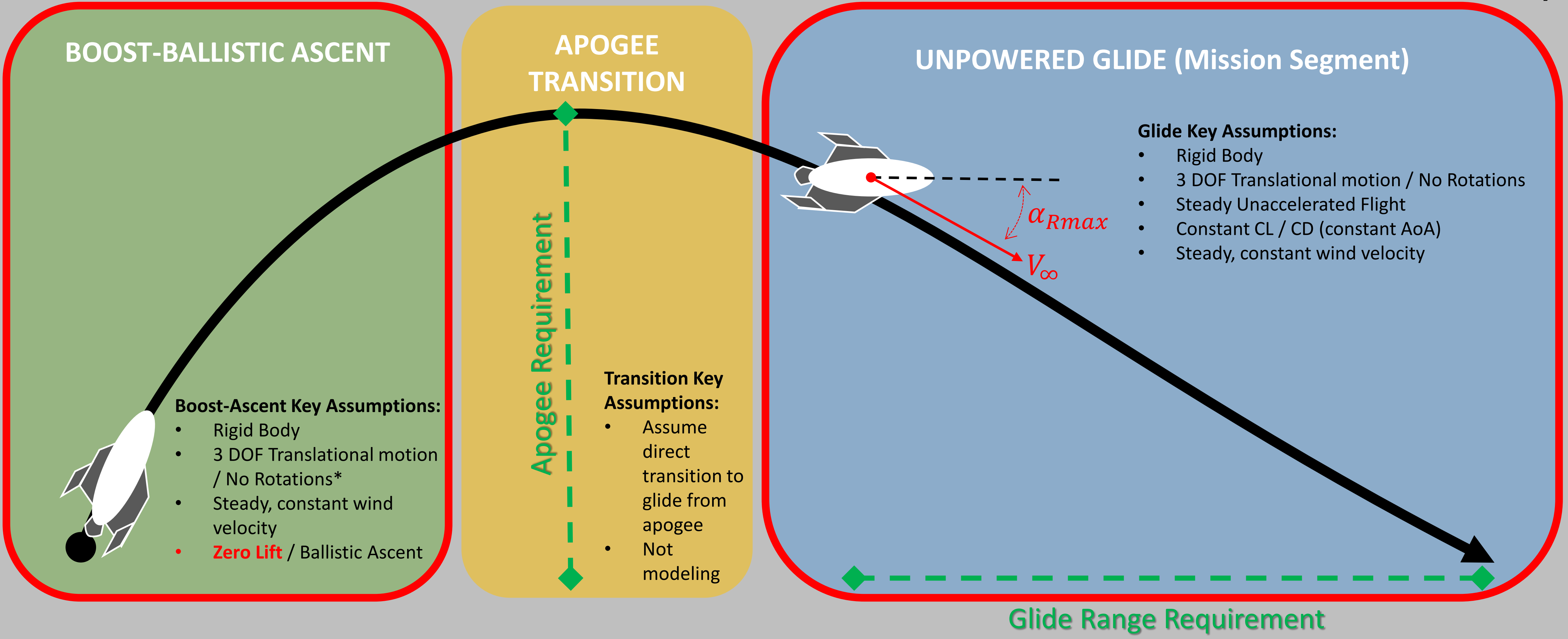
Source: Subsonic Ultra Green Aircraft Research: Phase I Final Report (NASA/CR-2011-216847), Marty K. Bradley and Christopher K. Droney, Boeing Research & Technology, Huntington Beach, California

Roughly Define Geometry w/ Basic Shapes

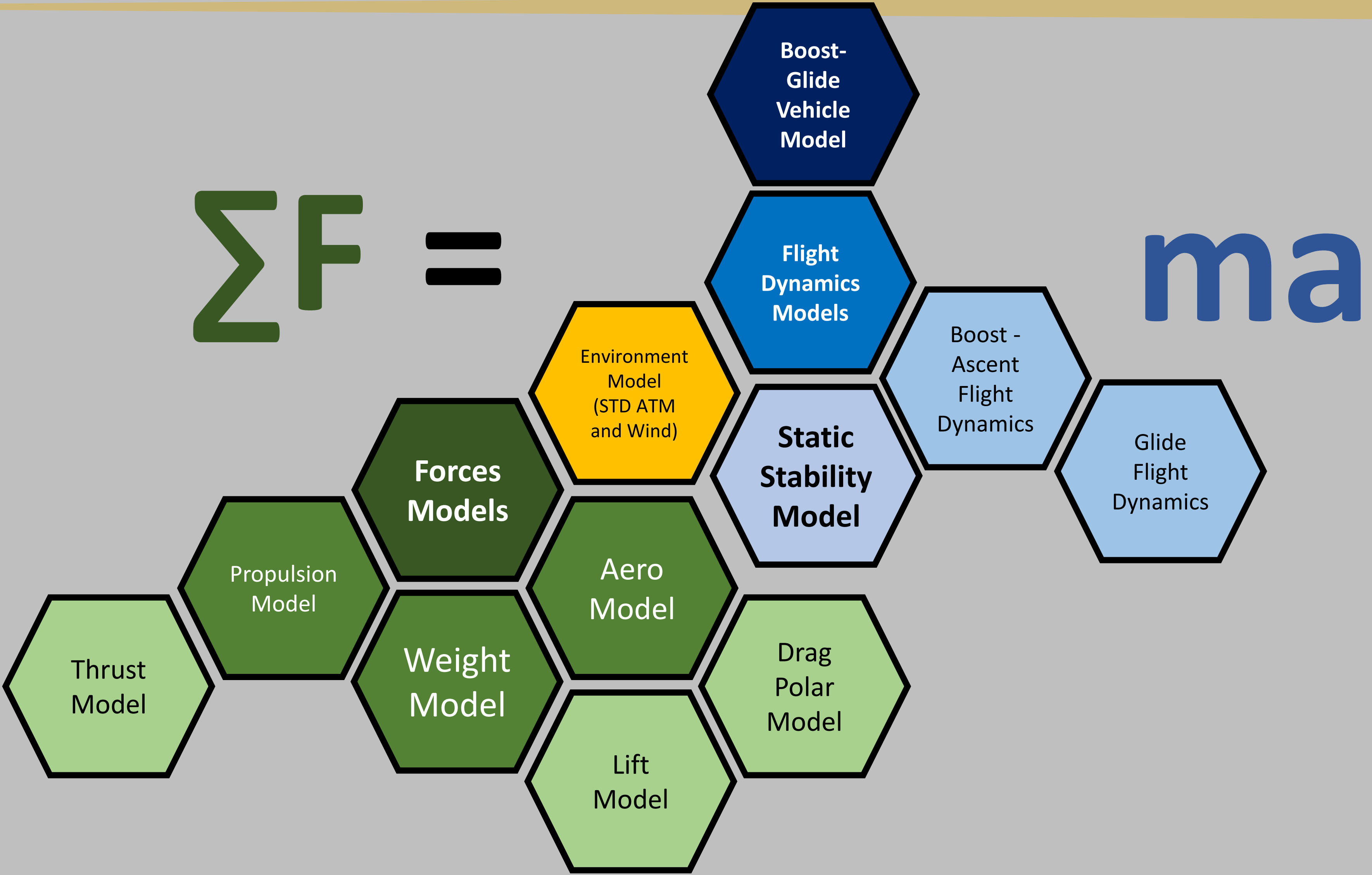




Project Introduction: Boost-Glide Vehicle Concept of Operations



Lab Modeling Breakdown



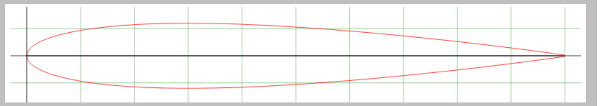
Validating Lift and Drag Aerodynamic Models

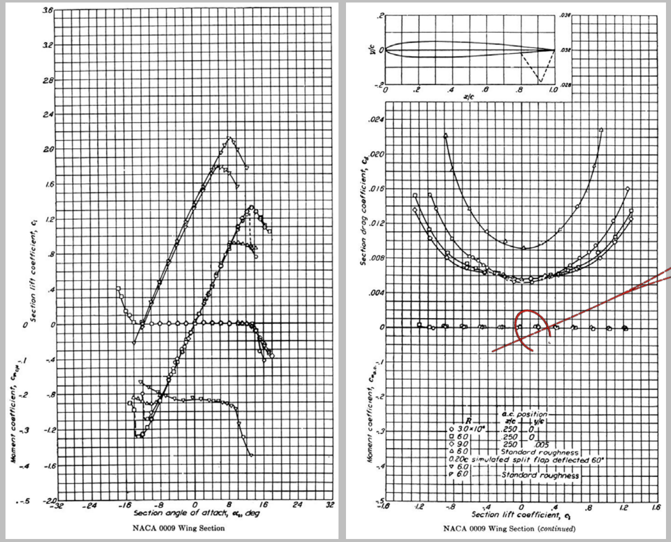
- **In-Class Benchmarking Activity**
  - Modeling existing aircraft to evaluate suitability of models
  - Aim for dynamically similar aircraft (Mach, Re)
  - Aim for similar configuration or shape
  - Must have "truth" data for aircraft to compare with model predictions
- **For this project, we will use the Tempest UAS**
  - Pros:
    - Known geometry and performance values
    - Close dynamic similarity (Mach and Re)
  - Cons:
    - Known CFD data, but not flight test or wind tunnel (using a model to validate a model…not ideal)
    - Shape is not typical of boost-glide configurations

Modeling Aircraft Lift

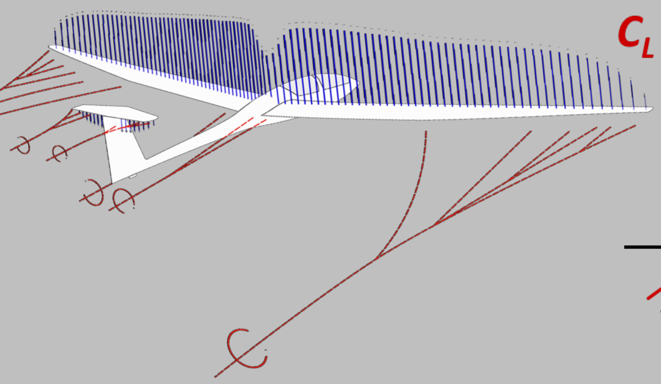
» Aligned with ASEN 2704 lecture for estimating 3D Wing Lift with one additional model for span efficiency

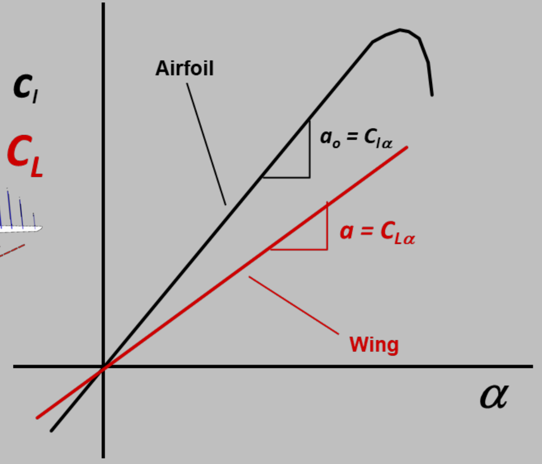
Determine Airfoil → Gather 2D airfoil lift and drag coefficient data → Estimate Span Efficiency based on wing planform geometry → Estimate 3D Wing Lift Curve Slope (Assuming Wing Lift = Aircraft Lift)





http://airfoiltools.com





Estimation of Wing Span Efficiency

- Primary wing parameters that impact span efficiency are those related to spanwise lift distribution
  - Aspect ratio (AR)
  - Taper ratio (λ)
  - Sweep angle
  - Statistical model derived from Hoerner data by Nita-Scholz (See Reference):

$$e_{no\_sweep} = \frac{1}{1 + f(\lambda) \cdot AR}$$

Where: $f(\lambda) = 0.0524\lambda^4 - 0.15\lambda^3 + 0.1659\lambda^2 - 0.0706\lambda + 0.0119$

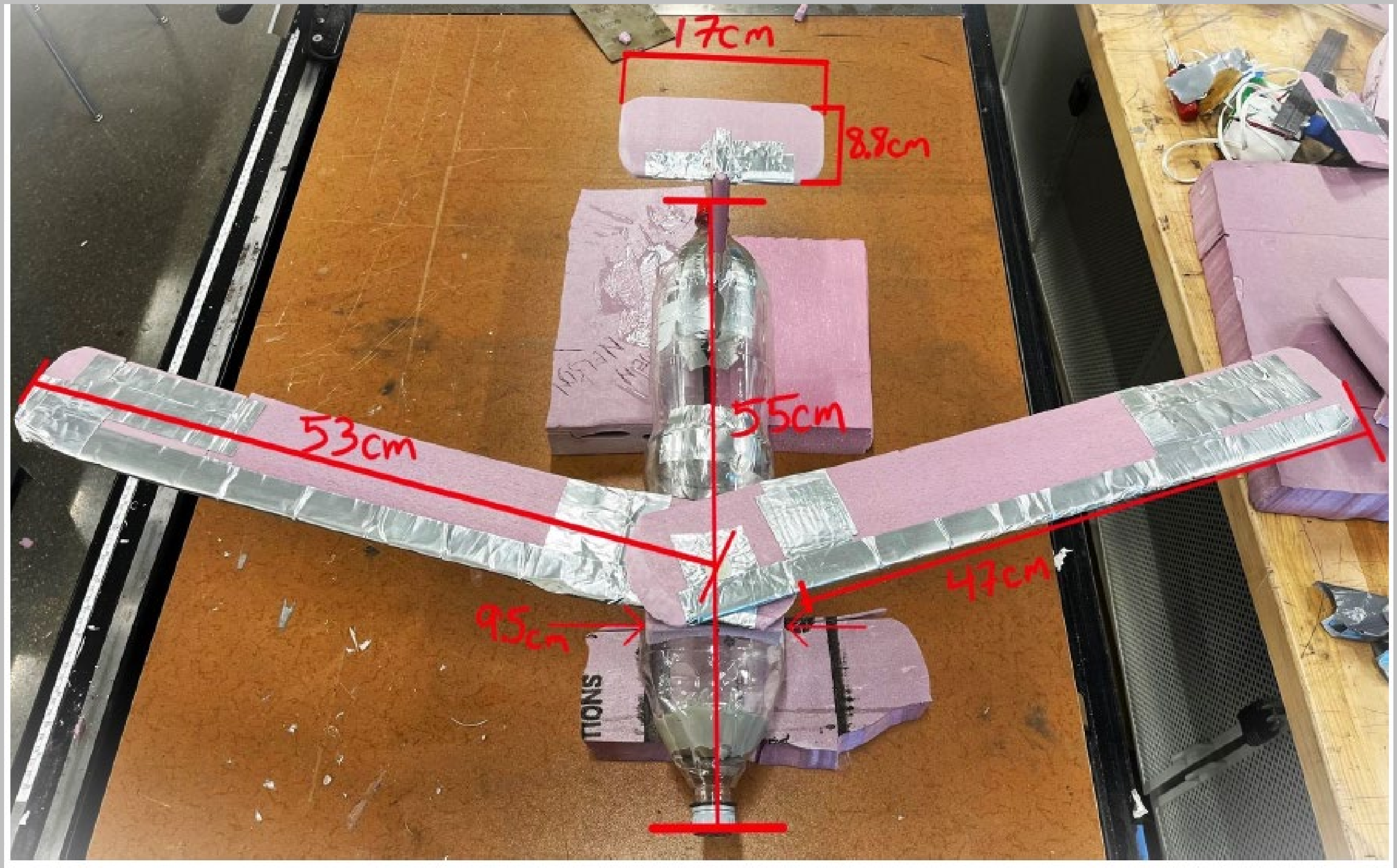
$$e_{\_sweep} = e_{no\_sweep} \cdot \cos\left(Sweep_{quarter\_chord}\right)$$

- References:

  - Hoerner, S.F.; Fluid Dynamic Drag; Published by Author,1965.
  - Nita, M.; Scholz, D.; Estimating the Oswald Factor from Basic Aircraft Geometrical Parameters; Hamburg University of Applied Sciences, 2012.

Modeling Aircraft Weight

- A basic weight model is provided in the template
  - Very simplistic based on common material densities
  - You will need adjust it later when you fabricate your prototype
- **WARNING: Do not leave this course thinking that the weight model for aerospace vehicle design is simple or not important!**
  - One of the most difficult and consequential models in reality
  - Has often been the reason for aircraft failures or cancellation of projects



Tasks for Remainder of Lab

- » Become familiar with code structure and input file (Remember…you have a quiz on this)
- » Model the Tempest geometry into your Design Input File (Row 1)
- » Complete the WingLiftDrag.m function by inputting in the span efficiency model
- » Be able to run the main script Wing Lift & Drag Model and Weight Function Calls
- » Work on Team Formation

- » Active Assigned Tasks

Milestones (Major Graded Events)			
Date			Task
Start	End	Duration	
1/16/2025	1/17/2025	1	Wood / Composite Shop Training Completion (Individual)
1/24/2025	1/24/2025	0	Design Teams Finalized NLT 24 Jan 5pm
2/3/2025	2/3/2025	0	Milestone 1 Sub-Task A: Aerodynamic & Weight Modeling Quiz Due (Individual)