Aerodynamic Modeling

Modeling Drag Polar

Modeling Drag Polar Concept Review

Whole Aircraft Drag Polar

$$C_D = \boxed{C_{D_o}} + \frac{C_L^2}{\pi \cdot \boxed{e_o} \cdot AR}$$

- C_{Do}
  - "Parasite Drag" or zero-lift drag coefficient
  - All drag that is independent of lift for *all components*
    - Includes airfoil profile drag at zero lift (skin friction & pressure drag)
    - Interference Drag
    - Wave Drag at zero lift
  - DOES NOT include increase in pressure drag variation w/ lift
  - Generally treated as "constant" in subsonic flight
- C_{Di}
  - "Induced Drag"
  - All drag from all aircraft components that are dependent on lift
  - Includes pressure drag variation w/ lift
  - Includes increase in drag due to downwash
  - e_o = Oswalds Efficiency Factor
    - Models more than just induced drag due to downwash
    - Whole aircraft / Fuselage effects

- Key Modeling Parameters
  - Parasite Drag Coefficient
    - Raymer Component Build-Up Model
  - Oswalds Efficiency Factor Model
    - Lots of model options!
- Which version of the drag polar does our model use?
  - Simplified (assumes min drag at zero lift)
  - Expanded (min drag at a positive value of lift)

$$C_D = C_{D_o} + k_1 C_L^2 + k_2 C_L$$

$$C_{Do} = C_{Dmin} + k_1 C_{LminD}^2$$

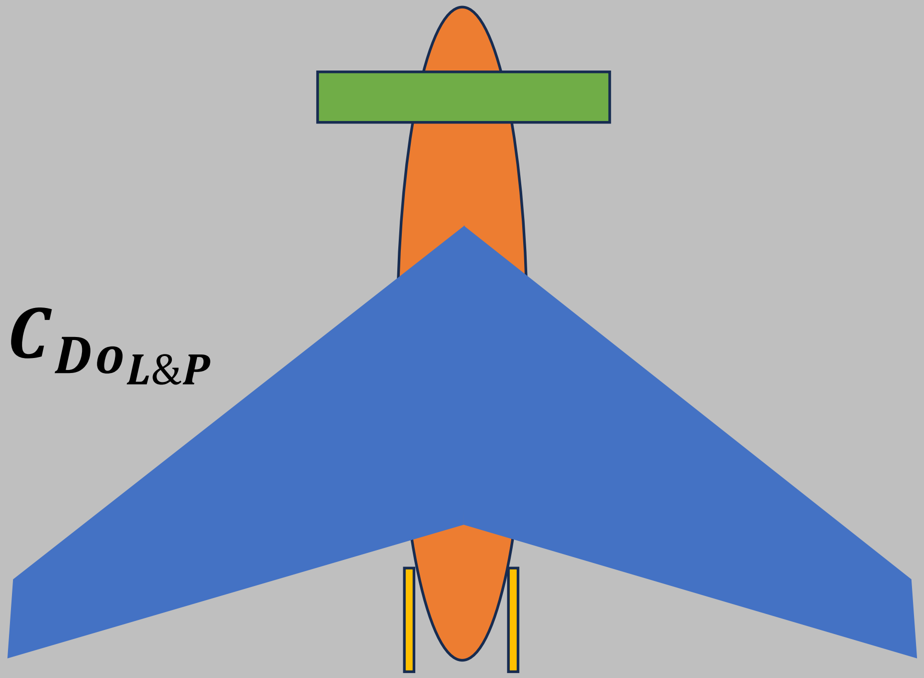
$$k_1 = \frac{1}{\pi \cdot e_o \cdot AR}$$

$$k_2 = -2k_1 C_{L_{minD}}$$

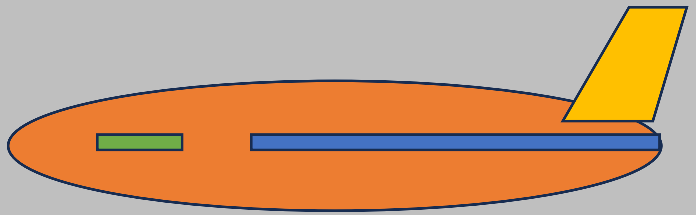
Parasite Drag: Expanded Analytical Modeling

- Raymer Component Build-up Method Model (Subsonic)
  - Mixture of fundamental and empirical models

$$(C_{D_o})_{Total} = \underbrace{\frac{\sum C_{f_c} \cdot FF_c \cdot Q_c \cdot S_{wet_c}}{S_{ref\_w}}}_{\text{Summation all aircraft components}} + C_{Do_{misc}} + C_{Do_{L\&P}}$$



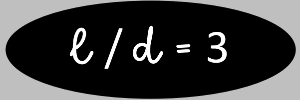
What do all these variables represent?



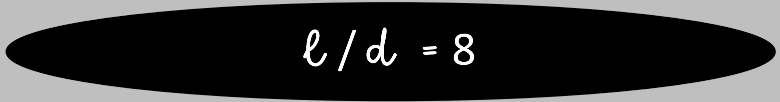
Source: Raymer, D., Aircraft Design: A Conceptual Approach, 6th Ed.

Parasite Drag Model: Fuselage Fineness Ratio

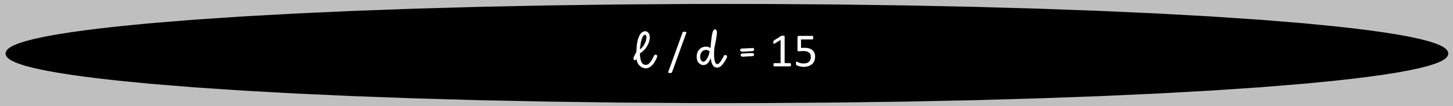
- Fineness Ratio is the ratio of fuselage length to fuselage diameter (ℓ / d)
- What should you consider when selecting the fineness ratio for an aircraft?
  - Is there a downside to high or low fineness ratios?
  - What shape has the least amount of surface area for a given volume? Why does that matter?



Bare minimum (3)



Typical Subsonic Aircraft (6 – 8)



Typical Supersonic Aircraft (10-15)

Parasite Drag Model: Fuselage

- **Model Source:** Raymer, D., Aircraft Design: A Conceptual Approach, 6th Ed.
  - Derived from a blend of USAF DATACOM model (empirical) and theoretical models
- **Known Limitations:**
  - Assumes streamlined fuselage shapes
  - Generally, better suited for fineness ratios greater than 5
  - Subsonic model, may not be suitable for the very low mach numbers of this lab (< mach 0.1)

$$\left(C_{D_o}\right)_{fuselage} = \underbrace{\frac{C_{f_f} \cdot FF_f \cdot Q_f \cdot S_{wet_f}}{S_{ref\_w}}}$$

$$C_{f_f} = \frac{0.455}{(\log_{10} Re)^{2.58}(1 + 0.144M^2)^{0.65}}$$

Where Re is the lower of:

$$Re = \frac{\rho V \ell}{\mu} \quad \text{or} \quad Re_{cutoff} = 38.21\left(\frac{\ell}{k}\right)^{1.053}$$

$$FF_f = \left[0.9 + \frac{5}{f^{1.5}} + \frac{f}{400}\right]$$

$$f = fineness\ ratio\ (\ell / d)$$

$$Q_f = 1.0$$

Surface	k (ft)	k (m)
Camo paint on aluminum	3.33 x 10^{-5}	1.015 x 10^{-5}
Smooth Paint	2.08 x 10^{-5}	0.634 x 10^{-5}
Sheet metal	1.33 x 10^{-5}	0.405 x 10^{-5}
Polished sheet metal	0.5 x 10^{-5}	0.152 x 10^{-5}
Smooth molded composite	0.7 x 10^{-5}	0.052 x 10^{-5}

Parasite Drag: Wings and Other Lifting Surfaces (Horizontal/Vertical Stabilizers)

- **Model Source:** Raymer, D., Aircraft Design: A Conceptual Approach, 6th Ed.
  - Derived from a blend of USAF DATACOM model (empirical)
  - I eliminated the wing sweep and mach correction in this FF model for this lab
- **Known Limitations:**
  - Assumes max thickness of airfoil at < 30% of chord (better for low subsonic aircraft)
  - Assumes airfoil shaped wing sections (streamlined)
  - Subsonic model, may not be suitable for the very low mach numbers of this lab (< mach 0.1)

$$\left(C_{D_o}\right)_w = \frac{C_{f_w} \cdot FF_w \cdot Q_w \cdot S_{wet_w}}{S_{ref\_w}}$$

$$C_{f\,lam} = \frac{1.328}{\sqrt{Re_L}} \quad \text{or} \quad C_{f\,turb} = \frac{0.074}{{Re_L}^{0.2}} \qquad \textit{Flat Plate Approximation from ASEN 2702}$$

$$FF_{wing} = \left[1 + \frac{0.6}{(x/c)_{max}}\left(\frac{t}{c}\right) + 100\left(\frac{t}{c}\right)^4\right]$$

Typical values: 1.1 – 1.4

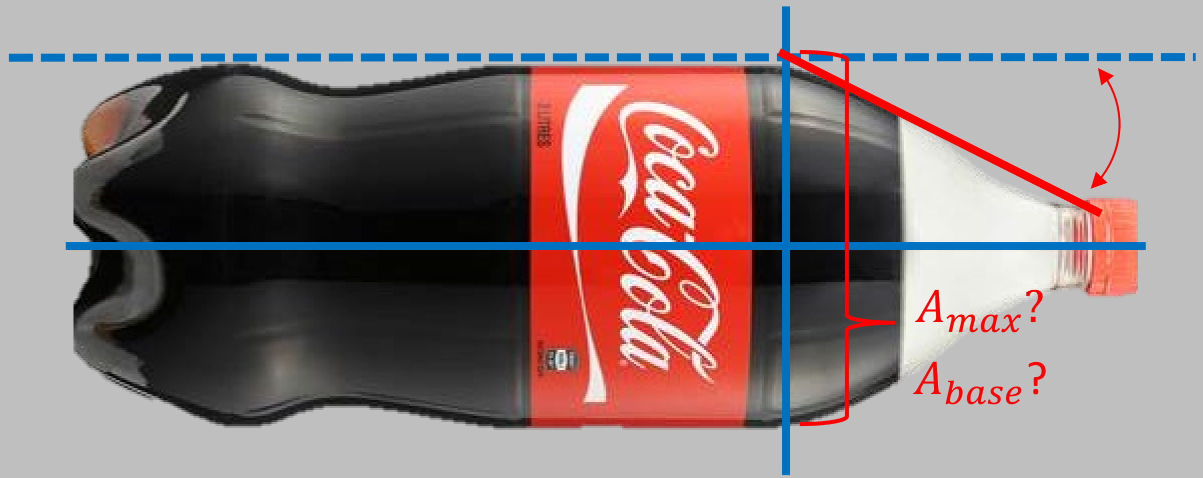
$$Q_{wing} = 1.1 - 1.4$$

Typical values for large aircraft to accounts for interference drag.
The smoother the interface (fillets), the lower the value.

Parasite Drag: Miscellaneous Drag Modeling (Base Drag)

- **Misc Base Drag:** Addition to fuselage form factor (FF) due to an aggressively sloped or blunt aft end (greater than 12 - 15 degrees).
  - **Model Source:** Raymer, D., Aircraft Design: A Conceptual Approach, 6th Ed.
    - Bonner, E., Clever, W., and Dunn, K., “Aerodynamic Preliminary Analysis System II-Part I-Theory,” NASA Contractor Report 165627, 1981. (empirical)
  - **Known Limitations:**
    - Subsonic model, may not be suitable for the very low mach numbers of this lab (< mach 0.1)
    - Derived from X-15, Lifting Body, and Space Shuttle flight test results

$$\left(C_{D_o}\right)_{Total} = \frac{\sum C_{f_c} \cdot FF_c \cdot Q_c \cdot S_{wet_c}}{S_{ref\_w}} + \underbrace{C_{Do_{misc}}} + C_{Do_{L\&P}}$$



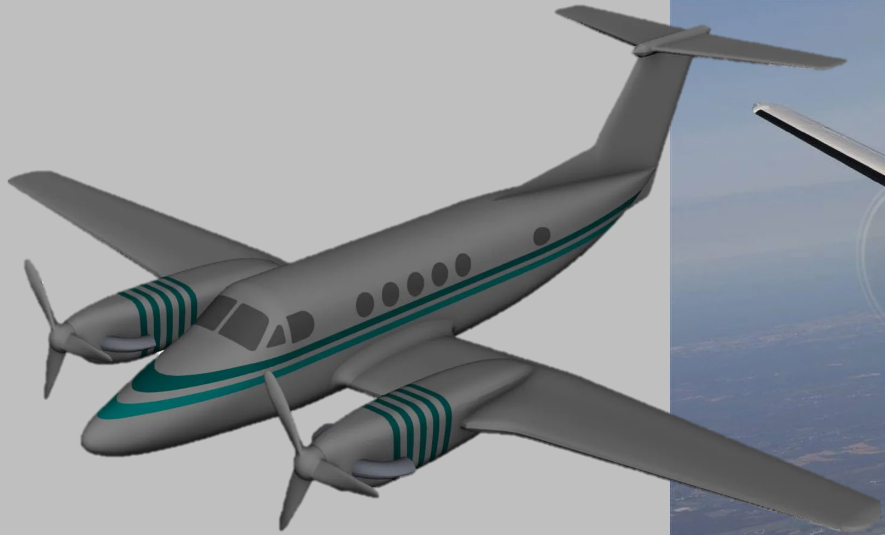
$$C_{Do_{misc}} = \left(\frac{D}{q}\right)_{Base} \left(\frac{1}{S_{ref\_w}}\right)$$

$$\left(\frac{D}{q}\right)_{Base} = \left[0.139 + 0.419(M - 0.161)^2\right] A_{base}$$

Abase determined at cross section where aft end departs from smooth streamline.

Parasite Drag: Leakage & Protuberance Drag Modeling

- **L&P Drag:** Drag due to holes, cavities, gaps and things that stick out in the flow that were not a component of the original design shape



Parasite Drag: Leakage & Protuberance Drag Modeling

- **L&P Drag:** Drag due to holes, cavities, gaps and things that stick out in the flow that were not a component of the original design shape
  - **Model Source:** Empirical percentage added to parasite drag coefficient after totaling all components.=
    - Typically, 3– 15% of total parasite drag, but not easy to precisely model
  - **Known Limitations:** Very imprecise estimate

$$\left(C_{D_o}\right)_{Total} = \frac{\sum C_{f_c} \cdot FF_c \cdot Q_c \cdot S_{wet_c}}{S_{ref\_w}} + C_{Do_{misc}} + \underbrace{C_{Do_{L\&P}}}$$

$$\left(C_{D_o}\right)_{L\&P} = \left(\frac{\sum C_{f_c} \cdot FF_c \cdot Q_c \cdot S_{wet_c}}{S_{ref\_w}}\right) \cdot \underbrace{0.15}$$

Percent of Added L&P Drag (3 – 15% Typical)

Aircraft Aerodynamic Modeling

Induced Drag: Oswalds Efficiency Factor Models

Induced Drag: Expanded Modeling

- Modeling whole aircraft induced drag largely about modeling Oswalds Efficiency Factor

$$C_D = C_{Do} + \frac{C_L^2}{\pi \, e_o AR}$$

- Lots of different models for Oswalds exist!
  - You're provided a research paper on Canvas
  - It's up to you to evaluate it and another model of your choice
- Take time to understand the models and variables!
  - Lots of different variables that use different nomenclature from what we use in this course
  - Understand the basis as most of these models are based on empirical data from specific types of aircraft

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ESTIMATING THE OSWALD FACTOR
FROM BASIC AIRCRAFT GEOMETRICAL PARAMETERS

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Abstract
This paper provides a sufficient accurate estimation method for the span efficiency factor, e, during the preliminary design stage. First, several approaches are identified from an exhaustive literature study and the accuracy and logic of these approaches are assessed. Second, a simple and logical general form is proposed as evaluation method for the Oswald factor for conventional configurations. The method starts with the calculation of a theoretical Oswald factor that accounts for the two parameters taper ratio and sweep – one depending on the other for a maximum Oswald factor. It then corrects the theoretical Oswald factor for the fuselage influence, zero lift drag influence and Mach number influence, making use of statistical aircraft data. Third, the paper delivers a method to calculate the Oswald factor for non-planar configurations, hence covering both conventional and unconventional designs. Out of the non-planar configurations, more attention is given to the wing with winglets, wing with dihedral and the box wing. For the box wing configuration an additional equation is proposed. The method proposed for estimating the Oswald factor is simple and accurate, with deviations under 4 %. It requires only few basic aircraft geometrical parameters and is useful for an efficient implementation into code for aircraft design optimization.

Click on paper to go to Canvas link for paper

What Design Parameters / Geometry Inputs are Needed for the Induced Drag Model?

Component	Chosen Design Variable Inputs	Derived Inputs	Primary Derived Output	Secondary Derived Outputs
Entire Aircraft (typical design variables come from wing and fuselage)	❑ Depending on what Oswald models you use, you may need to add some additional design input variables ❑ Likely, you already have everything you need already defined	❑ There are most likely some additional derived values unique to the model you choose	❑ Oswalds Efficiency Factor (e_o)	❑ Not generally used in other aspects of your model analysis

Let's consider the baseline Oswalds model from your assignment (Cavallo):

$$e_o = 1.78(1 - 0.045 * AR^{0.68}) - 0.64$$

Let's consider the baseline Kroo's model from the paper:

$$e_o = \frac{1}{Q + P \cdot \pi \cdot AR} \qquad Q = \frac{1}{u \cdot s} \qquad u = e \qquad s = 1 - 2\left(\frac{d_F}{b}\right)^2 \qquad P = 0.38 \cdot C_{Do}$$

Tasks for Remainder of Lab

- Continue modeling the Tempest geometry into your Design Input File
- Complete the **WingLiftDrag.m** model function code (span efficiency & 3-D lift curve slope models)
- Complete the **ParasiteDrag.m** model function code using component drag build up models
- Complete the **InducedDrag.m** model function code
  - Review research paper provided on Oswald's Efficiency Factor Models
  - Determine as a team which models you will evaluate
- Code should be functioning for the in-lab benchmarking discussion next lab (next Tue/Wed)
- Finalize Team Formation

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)

Questions?