EAE 127 Applied Aircraft Aerodynamics

Project 6
Airfoil Performance

Upload all files to the 'Assignments' section on Canvas in a single, compressed (zip) folder, which must contain a '.ipynb' Jupyter Notebook report (all Python code must run), a '.html' hard copy, and all data files necessary to run code. 'Run All' before uploading. (More details: 'EAE127_FAQ.pdf'). DUE: Monday 12/14/20 11:59pm

Fig. 1: Highly modified P-51D *Voodoo* racing aircraft

1 Airfoil Selection Process

You are designing an aircraft that will fly at the Reno Air Races on the race course pictured below in Fig. 2. To be competitive, the aircraft must be fast on the straightaways (low drag) as well as highly maneuverable on the tight turns (high lift). In this project, you will select an airfoil that best achieves these properties.

Fig. 2: Reno Air Races Course

1.1 Design Conditions

Your preliminary study on airfoil performance of the P-51D Mustang aircraft will be done for the following race design conditions:

Wing Area	S	$235 ft^2$
Root Chord Length	c	$8.48 ft$
Wing Span	b	$45 ft$
Cruise Speed	V_{cruise}	$400 mph$
Geometric Cruise Altitude	h	$22000 ft$
Loaded Weight	W	$12000 lbs$
Dynamic Viscosity (at h)	μ	$3.25x10^{-7} \frac{slug}{ft \cdot s}$

From the given parameters, **calculate and report**:

- The **design Reynolds number** Re
- The **3-D lift coefficient** required for **equilibrium, level flight** $C_{L,cruise}$
- The **3-D lift coefficient** required for a **equilibrium, 2g turn** $C_{L,2g}$ at the same speed

You will use these lift coefficients as a preliminary basis for the 2-D design lift coefficients (Design Assumption: $C_L \approx C_l$).

(NOTE: In practice, 2-D and 3-D lift coefficients at a given flight condition will not be the same for a given wing due to the 3-D effects of finite wings. This design assumption represents one possibility for a first step in what would be an iterative design process).

1.2 Airfoil Analysis

Consider three airfoil geometries for this study:

- A symmetric NACA 0012 airfoil
- A cambered NACA 2312 airfoil
- The original P-51D airfoil (laminar flow)

Plot all of the airfoil geometries in a single plot **in true dimensions (e.g. feet)**. Airfoil surface coordinates are provided. **Discuss** the geometry differences.

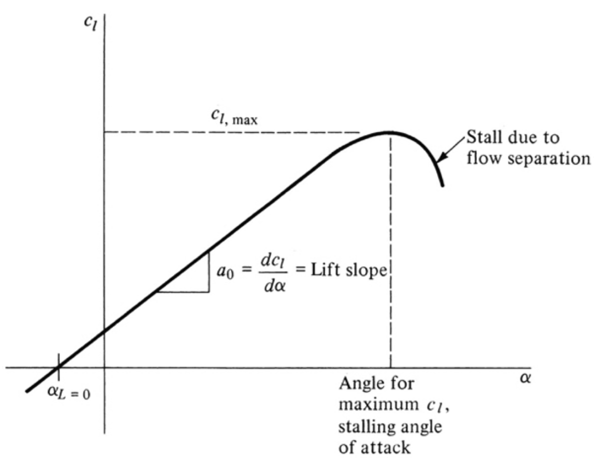

Figure 5.6 Sketch of a typical lift curve.

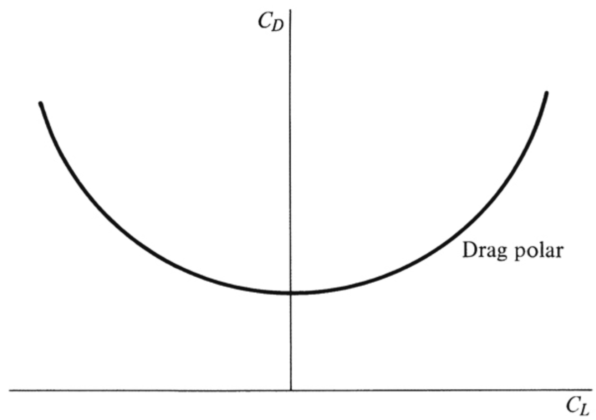

Figure 5.49 Sketch of a drag polar—that is, a plot of drag coefficient versus lift coefficient.

Fig. 3: Example plots of a lift curve (left) and drag polar (right)

For each airfoil, obtain XFOIL polar data (α, C_l, C_d) for viscous flow at the design Reynolds number. **IMPORTANT: Use a fine precision** $\Delta\alpha < 1^o$ so that you can accurately resolve α_{stall}. If your increment is too coarse, you will not be able to determine an accurate peak in the viscous lift curve.

Create four plots total, each containing data for all of the airfoils:

- Viscous **lift curves** (C_l vs. α)
- Viscous **drag polars** (C_l vs. C_d) in two plots:
  a. **Limit x-axis bounds to** $[\mathbf{-2 < C_l < 2}]$ **and y-axis bounds to** $[\mathbf{0 < C_d < 0.025}]$ to see low-angle-of-attack trends like the drag bucket
  b. **No limit on y-axis (**C_d**) bounds** to see high AoA behavior
- **Lift-to-Drag ratio vs AoA** (L/D vs. α)

Comment on the unique trends of each plot. Are some airfoils more similar than others? What **feature does the drag polar for the laminar flow P-51D airfoil have that the others do not**? **How might the drag polars change** for 3D?

1.3 Performance Analysis

Next, you will calculate important design parameters <u>for each airfoil</u> from the polar data. For parameters at specific conditions (e.g. level flight C_l), **use numeric interpolation to find the closest values** (DO NOT simply select the XFOIL result closest to your desired point or visually estimate).

Flight conditions:

Level flight
2g turn
Stall

Flight parameters:

Angle of attack	α
Lift coefficient	C_l
Drag <u>force</u>	D
Lift-to-Drag ratio	L/D

Present your results in tables:

	α	C_l	D	L/D
Level Flight				
2g Turn				
Stall				

Tabulate your results with the list of flight conditions as rows and the list of performance parameters are columns. **Report parameters in the units originally specified**.

Which airfoil **has the greatest angle of attack during level flight**? **Why?**

Considering that you are designing this aircraft to go as fast as possible during <u>both</u> level flight and the 2g turn, **which of the three airfoils is the best design selection?** (Hint 1: what slows your aircraft down? Hint 2: which flight condition will you spend more time at, level or turn?) **Justify your answer.**

2 3D Aircraft Performance

For a general aviation aircraft with:

- Weight = $3000lb$
- Rectangular wing with area $S = 170ft^2$, wingspan $b = 39ft$
- Airfoil: NACA 2412
- Empirical drag polar equation: $C_D = 0.025 + 0.054C_L^2$

Calculate:

- The **drag coefficient at zero lift**
- The value of the **span efficiency factor** (**Derive an expression** from the above drag polar equation and the equation for $C_{D,i}$)
- **L/D** at standard atmosphere sea level and $175mph$ level flight **cruise**