Problem 1 (23 pts)

Short answer/calculation:

(5 pts) Label the following five sections of the turbojet engine:

\[\text{Inlet} \quad \text{Combustor} \quad \text{nuzzle}\]

\[\text{Compressor} \quad \text{turbine}\]

(4 pts) List four effects of viscosity.

1. Heating
2. Boundary layer separation
3. Turbulence
4. Drag

(6 pts) The normal and axial force on an airplane at 4° angle-of-attack is 1500 N and 110 N, respectively. What are the lift-to-drag ratio and the glide slope angle at this condition?

\[\sum F_y = N \cos 4° - W + A \sin 4° = L\]
\[\sum F_x = A \cos 4° - N \sin 4° = D\]

\[\frac{N \cos 4° - W + A \sin 4°}{A \cos 4° - N \sin 4°} = \frac{L}{D}\]

\[\cot^{-1} \frac{L}{D} = \text{glide slope}\]
(4 pts) Questions regarding excerpts from 747:

Who was the head engineer of the 747 program (subject of the book)?

What internal Boeing program was considered the flagship program during the mid-60s, receiving more man-power than the 747 program?

Safety was a major design consideration on the 747; as such many of the major systems had ________________ redundancy.

To achieve a higher cruise Mach number than previous subsonic jet aircraft, what did designers do to the wing? _______________

(4 pts) True/False

T / F: Turbojets are more fuel efficient than turboprops.

T / F: The vertical tail placed aft of the aircraft CG assists static directional stability.

T / F: Thrust available increases as density decreases.

T / F: The name of the computer program to use with the assigned wing design project that you should be working on over the next two weeks is JavaFoil.

Bonus (4 pts):

Since the last exam when the space shuttle Atlantis returned back to Earth, the International Space Station has had two spacecraft dock and visit. Name the spacecraft and the corresponding host space agency.

JA XA

What large international company recently won a contract, beating out Boeing, to supply air tankers to the Air Force? What city in Alabama will this greatly affect?

Airbus Huntsville Mobile

Bonus (4 pts added on HW Score)

Attend the second “So, you want to be a CEO” seminar for the spring 2008 term. Dr. Jim Niedhoefer, the founder and CEO of Aerotonomy, Inc., will be presenting the seminar at 3:00 pm on Wednesday April 9, 2008, in the Mortar Board Room (room 300) of the Ferguson Center. Aerotonomy is a small high-tech aerospace engineering company based in Atlanta, GA. Jim is a graduate from our AEM department.
A NACA 65-210 airfoil spans the width, 1.0 m, of a wind tunnel test section; thus, it acts like an infinite span wing (no tip effects). The chord is 0.35 m. The resulting lift curve is shown below. The Pitot-static probe in the test section measures a static pressure of 94.5 kPa and a stagnation pressure of 100.2 kPa. The air density is 1.22 kg/m³ and the gas constant for air is 287 m²/(s²·K). Answer the following questions:

a) What is the test section velocity?

b) What is the test section Mach number? (Hint: you need to find the temperature)

c) What is the lift generated by the airfoil (no flap deflection) at 2° angle-of-attack?

d) **Bonus:** If a model was placed in the tunnel that did not span from side to side, would you expect the measured lift curve slope to be the same as shown below. Explain.

No because there would then be induced drag on the wing being wing tip vortices. This would shift the Cl curve down.
a) \[ p_1 = 94.5 \text{ kPa} \quad p_o = 100.2 \text{ kPa} \quad p = 1.22 \text{ kg/m}^3 \]

\[ \bar{v} = \sqrt{\frac{2(p_o - p)}{p}} \quad \bar{v} = \sqrt{\frac{2(100.2 \text{ kPa} - 94.5 \text{ kPa})}{1.22 \text{ kg/m}^3}} \]

\[ \bar{v} = 96.66 \text{ m/s} \]

\[ \bar{w} = 96.7 \text{ m/s} \]

\[ p + \rho \frac{\bar{v}^2}{2} = p \]

\[ \rho \frac{\bar{v}^2}{2} = p_o - p_1 \]

b) \[ \alpha = \sqrt{\frac{k RT}{\rho}} \]

\[ \frac{94.5 \text{ kPa}}{(1.22 \text{ kg/m}^3)(287 \text{ m}^2/\text{s} \cdot \text{K})} = T = 269.89 \text{ K} \]

\[ a = \sqrt{\frac{(1.7)(287)(269.89)}{1.4}} \]

\[ a = 400 \times 0.81 \text{ m/s} \]

\[ M = \frac{\bar{v}}{a} = \frac{96.66 \text{ m/s}}{400 \times 0.81 \text{ m/s}} \]

\[ M = \frac{0.2}{1} = M \]

C) \[ C_L @ 2^\circ \text{ AOA} = 0.3 \]

\[ L = C_L q \bar{S} \quad q = \rho \frac{\bar{v}^2}{2} \]

\[ q = \frac{(96.66 \text{ m/s})^2}{2 \times (1.22 \text{ kg/m}^3)} \]

\[ q = 5699.32 \text{ Pa} \]

\[ L = C_L q \bar{S} \]

\[ L = (0.3)(5699.32 \text{ Pa})(1.0 \text{ m} \cdot 0.35 \text{ m}) \]

\[ L = 598.42 \text{ N} \]

\[ L = 598 \text{ N} \]

\[ L = 598 \text{ N} \]

\[ \text{Low due to } C_L \]
Problem 3 (21 pts)

Show all work; box or underline final answers!

a) Assume the airfoil in the previous problem (1 m span by 0.35 m chord) is modeled as a flat plate. If the free stream velocity is 60 m/s and the kinematic viscosity is $1.40 \times 10^{-5}$ m$^2$/s, estimate the skin friction drag over the wing assuming a turbulent boundary layer.

\[
D = \frac{0.074}{5 \sqrt{R_e_l}} q S
\]

\[
R_e = \frac{V_c V}{\nu}
\]

\[
S = 0.35 \text{ m}^2,
\]

\[
q = \frac{\left(60 \text{ m/s}\right)^2}{2} \left(1.22\right) = 2196 \text{ Pa}
\]

\[
R_e = \frac{\left(60 \text{ m/s}\right) \left(0.35 \text{ m}\right)}{\left(1.40 \times 10^{-5} \text{ m}^2/\text{s}\right)}
\]

\[
D = \frac{0.074 \cdot 0.35 \text{ m}^2 \cdot 2196 \text{ Pa}}{5 \sqrt{1500000}}
\]

\[
D = 3.309 \text{ N}
\]

\[
D = 3.31 \text{ N}
\] 

b) If the flow was laminar, would the skin friction drag be more or less? (No calculation required)

More \(\rightarrow\)

c) Identify another source of drag that becomes important for each of the following conditions:

- Angle-of-attack increases towards stall: ***pressure drag***
- Wing aspect ratio decreases: ***induced drag***
- Mach number exceeds one: ***wave drag***

\(-2\) Top and Bottom of Airfoil
Problem 4 (20 pts)

Show all work; box or underline final answers!

An airplane has the following characteristics:

\[ W_{\text{max}} = 1,000,000 \text{ N} \]
\[ S = 260 \text{ m}^2 \]
\[ C_{L_{\text{max}}} = 1.5 \text{ (at take-off)} \]
\[ (L/D)_{\text{max}} = 21 \]
\[ \text{AR} = 9 \]

a) If the airplane is cruising (flying) at \((L/D)_{\text{max}}\), what is the required cruising thrust?

b) If the designed take-off distance is 1500 m, estimate the necessary take-off thrust at SSL \((\rho = 1.225 \text{ kg/m}^3)\).

c) Why would the take-off distance be longer than the estimate above?

d) Based on the thrust, weight and aerodynamic parameters, what type of airplane do you think is described: a general aviation propeller aircraft, a large passenger jet, a fighter jet or a sail plane?

\[
T_R = \frac{W}{(C_L/C_D)} = \frac{\frac{C_L}{C_D} \cdot \frac{L}{D}}
\]

\[
T_R = \frac{1,000,000 \text{ N}}{260} = 4.77 \times 10^4 \text{ N}
\]

\[
d_{T_{\text{O}}} = \frac{1.44 W^2}{(9.8 \text{ m/s}^2)(1.225 \text{ kg/m}^3) C_{L_{\text{max}}} T S}
\]

\[
T = \frac{1.44 W^2}{d_{T_{\text{O}}}} = \frac{1.44(1 \times 10^6 \text{ N})}{(1500 \text{ m})(9.8 \text{ m/s}^2)(1.225 \text{ kg/m}^3)(1.5)(260 \text{ m}^2)}
\]

\[
T = 2.05 \times 10^5 \text{ N}
\]

c) If density decreases or temperature increases

d) A large passenger jet