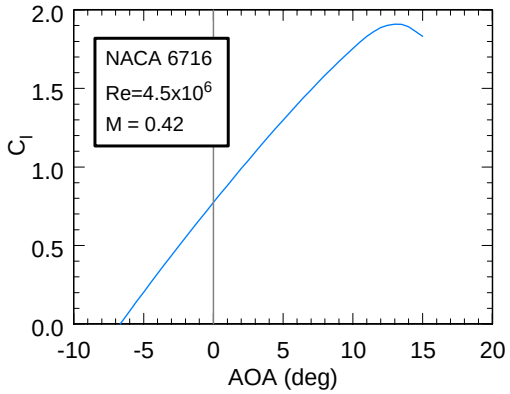
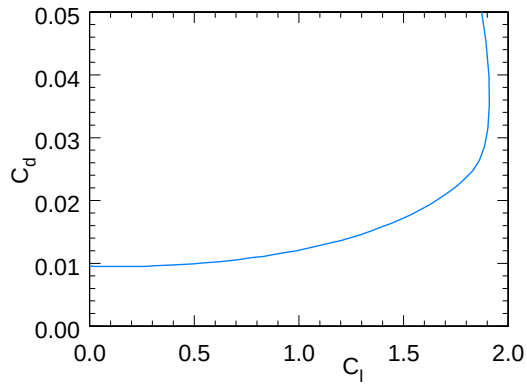
1. Fill in: The wing tip vortices induce a _____ velocity behind a finite wing. This gives rise to _____ drag.

2. What are the two requirements for longitudinal static stability?

3. The following data were collected for a 2D airfoil section. Sketch the generic trends for a 3D (finite) wing on the same axes.



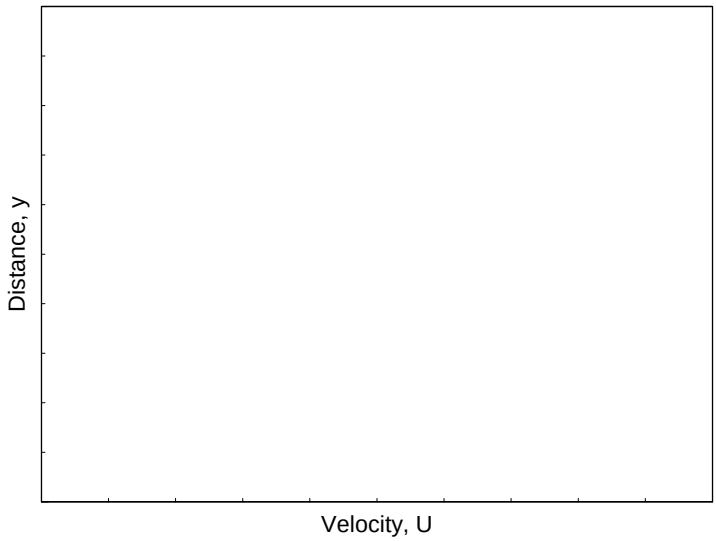


4. Which of the following is the most accurate statement of Archimedes Principle?

a) The volume of a fluid displaced by a body immersed in the fluid is equal to the volume of the body.
b) The buoyant force on a body immersed in a fluid is equal to the weight of the fluid displaced.
c) The buoyant force on a body immersed in a fluid is equal to the mass of the body times the density of the fluid displaced.
d) All are equally accurate.

5. Define the thermal-lapse rate for the atmosphere: $a \equiv$ _____. For the troposphere, the lapse rate is _____ (positive/negative/zero).

6. Plot the flow velocity along the boundary layer for laminar and turbulent flow on the same graph. Label the freestream, the thickness, and the gradient at the wall.

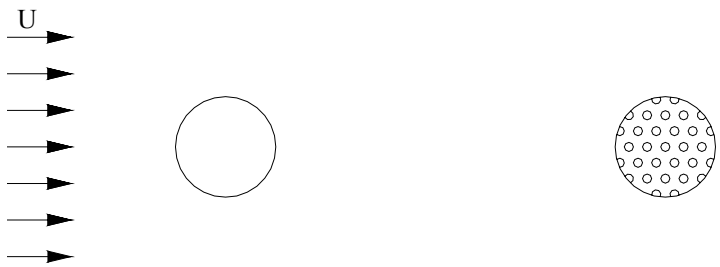


7. Why do we use non-dimensional force and moment coefficients?

8. List the assumptions used to derive Bernoulli's equation for gases:

a) Negligible gravitational forces _____.
b) _____.
c) _____.
d) _____.
e) _____.

9. Sketch the streamlines around a smooth sphere and a dimpled sphere. Assume a Reynolds number less than 375,000.



10. Consider the longitudinal static stability of a 500-lb JDAM with thin, flat tail fins, falling after release. (By convention, a nose-up pitching moment is positive).
a) What is the equilibrium angle-of-attack?
b) Describe the function of the tail fins.
c) Would fins on the center of the body, or nose be effective for this task?

11. Why are the main wings of birds and airplanes cambered? (Aside: most insects' wings are not cambered).

12. The airfoils found on many missiles, the main wing of acrobatic (stunt) airplanes, and the horizontal and vertical tails of most airplanes are not cambered, but instead symmetric. Why?

13. Cite the three strategies (not devices) used with high lift configurations (Many vehicles, such as the one below, use all three).

1. For the NACA 2415 airfoil section (no-flap, Re = 9×10^6), find:
a) The angle of attack for zero lift : α_{L_0} = _____
b) The maximum lift coefficient: $C_{L_{\max}}$ = _____
c) Lift coefficient at 0 deg angle of attack: $C_L\big|_{\alpha=0}$ = _____
d) At what angle-of-attack is the drag minimized? $\alpha\big|_{C_{D_{\min}}}$ = _____
e) Pitching moment coefficient at 0 deg angle of attack $C_{m_{C/4}}\Big|_{\alpha=0}$ = _____

f) Maximum lift to drag ratio: $(C_L/C_D)_{\max}$ = _____

g) A model using this airfoil is mounted in the Eiffel tunnel. It spans from wall to wall (4 ft, with no 3D effects), with a 1 ft chord length. The tunnel is operating at a dynamic pressure of 40 lb/ft² at standard day conditions (ρ = 0.00238 slug/ft³). Show all work below.

i) What is the lift at zero angle-of-attack? _____ lbs

ii) What is the drag at zero angle-of-attack? _____ Lbs

2. A low-speed wind tunnel (M < 0.3) has a rectangular test section with parallel walls. Due to the growth in thickness in the boundary layer from the entrance to the exit of the test section, the effective area at the exit plane is 98% of the effective area at the entrance plane. Through the insight of Ludwig Prandtl, we know that even viscous flows can be accurately treated as inviscid outside of the boundary layer.

a) If the speed at the entrance to the test section is 120 fps, in an empty tunnel with no model, what is the speed at the exit plane?

b) Given standard sea level density and a static pressure of 2,000 psf at the entrance plane, what is the static pressure at the exit plane?

c) This effect is called "horizontal buoyancy" and can measurably affect the observed drag on a model. Will the horizontal buoyancy increase or decrease the drag from what might be measured in free flight?

3. A rectangular finite wing is undergoing a test in a low speed wind tunnel. The information at right is germane to this test. At one test point, the lift is measured to be 193 lb. For this specific point, determine:

a) The test lift coefficient.

b) Test angle-of-attack (for the 3D wing)

c) Lift-to-drag ratio

Finite Wing Test
2D Section: NACA 64-210
Span: 4 ft
Chord: 10 in.
Wing efficiency factor: 0.87
Test airspeed: 180 mph
Conditions: Std. sea level

A Mars airplane (like the ARES) needs to be designed to operate at an altitude of 3 km in the Martian atmosphere. The limits of this layer of the atmosphere are defined by the data given. NOTE: For Mars, g_0 = 3.702 m/sec² and the atmosphere is mostly CO_2 (R = 189.0 J/kg-K).

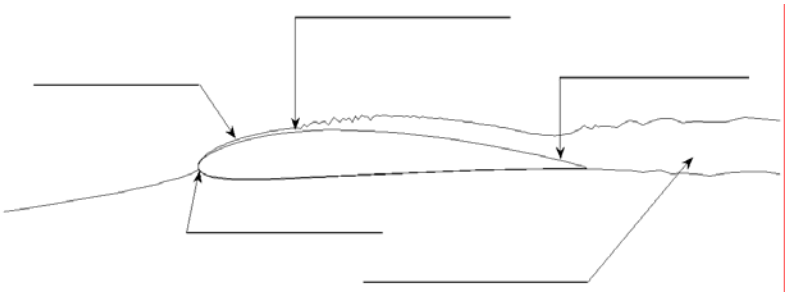
h (km)	T (°C)	p (mb)
0	5.0	8.000
7	-1.9	4.855

a) Identify the type of atmospheric layer represented by this data.

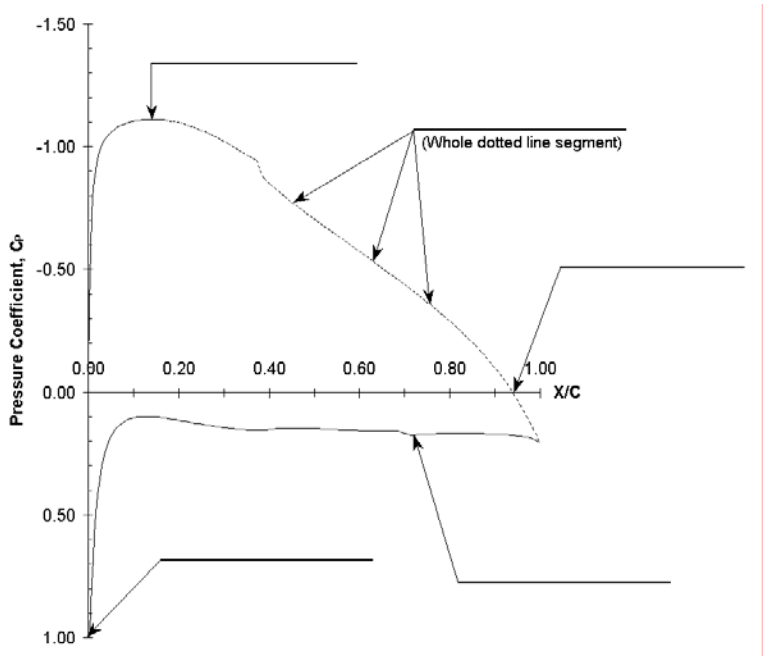
b) Calculate the temperature at 3 km. Express your answer in °C.

c) Calculate the pressure at 3 km. Express your answer in mbar.

QUESTION 2. Boundary Layers. Below is a representation of the boundary layer growth and the pressure distribution for a NACA 4412 airfoil test. Note that both figures do not represent the same angle of attack. Use the list at the right to provide the BEST label for each of the 10 parts.



NACA 4412 airfoil at 14º AOA

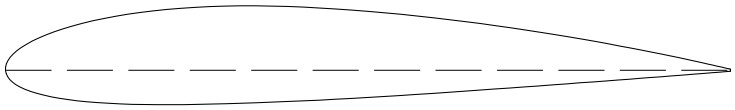


NACA 4412 airfoil at 5º AOA

A. Adverse Pressure Gradient
B. Favorable Pressure Gradient
C. Inviscid Region
D. Laminar Boundary Layer
E. Neutral Pressure Gradient
F. Point Corresponding to Freestream Pressure
G. Point Corresponding to Max. Pressure
H. Point Corresponding to Min. Pressure
I. Pressure > Freestream Pressure
J. Separation Point
K. Stagnation Point
L. Transition Point
M. Turbulent Boundary Layer
N. Turbulent Wake

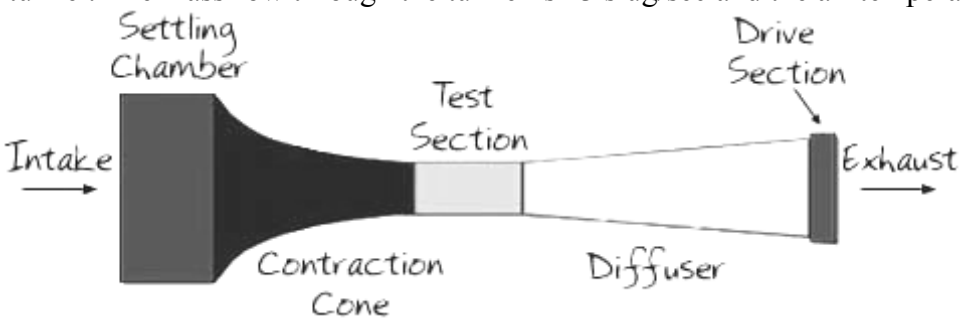
QUESTION 3A. Derive the momentum (Euler's) equation.
QUESTION 3B. Derive the hydrostatic equation.

QUESTION 4. Airfoil Geometry. The NACA 2412 airfoil section is shown below (not drawn to scale). Describe as much of its geometry as possible.



Thickness (% chord)	=	_____
Maximum Camber (% chord)	=	_____
Location of Max. Camber (% chord)	=	_____
Approx. Minimum Ordinate (% chord)	=	_____
Approx. Maximum Ordinate (% chord)	=	_____

QUESTION 5. Wind Tunnel Problem. The following wind tunnel test of a Formula 1 race car is being run in Bogotá, Columbia. Assume the tunnel is of the open-loop variety, as shown below, very similar to the USNA Eiffel wind tunnel. The massflow through the tunnel is 43 slug/sec and the air temperature is 95 °F.



a. What is the total pressure in the settling chamber <u>and</u> in the test section?
b. What is the freestream density?
c. Calculate the velocity in the settling chamber <u>and</u> in the test section.
d. What is the freestream pressure (test section static)?
e. Circle the flow regime experienced in this wind tunnel test:

INCOMPRESSIBLE SUBSONIC COMPRESSIBLE
TRANSONIC SUPERSONIC

QUESTION 7. Stability and Control. A Thermic-18 glider has been balanced for trimmed flight with the CG at h = 0.70. Its stability can be represented by:

$$C_{m_{CG}} = 0.0833 - 0.0106 \cdot \alpha_A \qquad \text{(Note: } \alpha_A \text{ is in degrees)}$$

a. What is the trim AOA?
b. If the neutral point is at $h_{NP} = 0.851$, what is the static margin?
c. What must be the lift curve slope of this configuration?
d. Calculate the new slope (C_{m_α}) if we want to trim the glider at maximum L/D (4º AOA).
e. What is the new static margin and CG position?

QUESTION 8. Engine Sizing. The Grob G-115C Bavarian has a tapered wing with the geometric characteristics shown at right. It is aerodynamically represented by the following drag polar:

$$C_D = 0.0268 + 0.0525 \cdot C_L^2$$

a. What is the minimum possible airspeed for sea level flight? Put your answer in knots [NOTE: fps=kts*1.689].
b. What are the thrust and horsepower required at this point?
c. If we want a maximum airspeed of 155 kts at sea level, what are the thrust and horsepower required at this point?
d. Select the appropriate engine for the Bavarian:

- ❑ Teledyne Continental IO-240-A (125 hp)
- ❑ Lycoming IO-360-L2A (160 hp)
- ❑ Lycoming IO-540-AB1A5 (230 hp)

W=1,950 lbs
b=32.81 ft.
$\bar{c} = 4.01$ ft
C_{Lmax}=1.4 (no flaps)
C_{Lmax}=1.7 (60° flaps)
n_{max}=+6/-4

QUESTION 9A. Turning Flight. Consider a Grob G-115C Bavarian in turning flight at a constant altitude of 5,500 feet. Use the aircraft data presented on page 5.

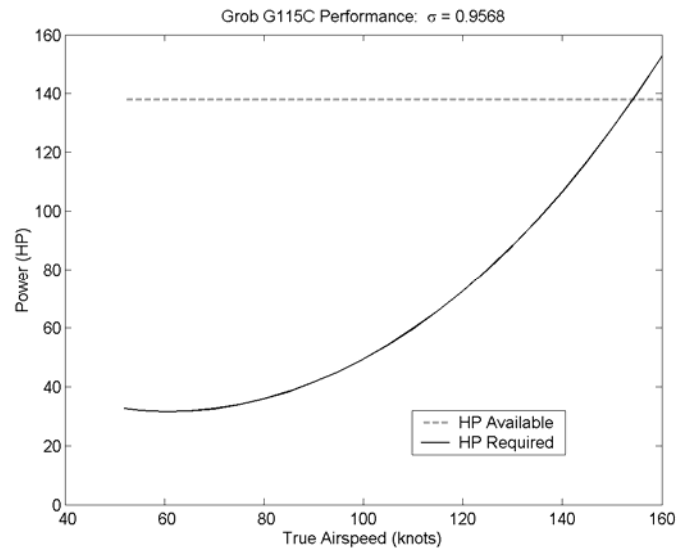
a. If the aircraft rolls into a 60º bank, what lift is required to maintain altitude? What is the corresponding load factor?
b. What is the minimum airspeed required to make this turn with no flaps?
c. Calculate the turn radius and turn rate.
d. What is the minimum airspeed required to make this turn with 60º flaps?
e. Calculate the turn radius and turn rate.

QUESTION 9B. Rate of Climb. Consider the Grob G-115C Bavarian lifting off from the airport in Zurich (elevation 1,500 ft). The expression for the required horsepower is given by:

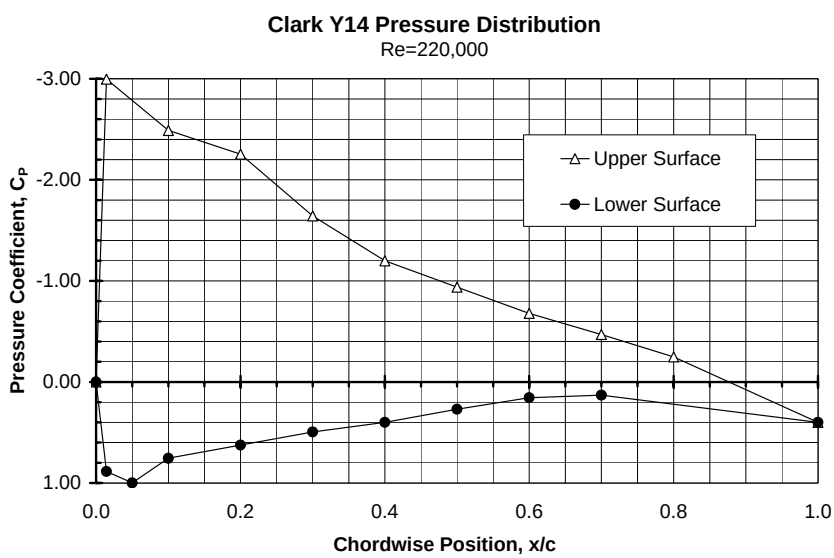
$$HP_{req} = \left(7.281x10^{-6}\right)\cdot V^3 + \left(2.429x10^3\right)\frac{1}{V}$$

Use additional aircraft data presented on page 5.

a. What is the airspeed required for maximum rate of climb?
b. What is the maximum rate of climb?
c. What is the climb angle based on the vertical velocity of part a?
d. If the airspeed increases to 120 knots, what is the rate of climb?
e. If the altitude were increased, would the maximum rate of climb INCREASE or DECREASE? Would the velocity required for maximum rate of climb INCREASE or DECREASE?



QUESTION 10. Pressure Distribution. This pressure distribution was obtained for a Clark Y14 airfoil at 11° AOA:



a. Where on the airfoil is the pressure equal to the freestream pressure (Note the surface and the chordwise position)?
b. WHERE is the maximum pressure on this airfoil (Note the surface and the chordwise position)?
c. WHERE is the minimum pressure on this airfoil (Note the surface and the chordwise position)?
d. WHAT is the minimum pressure on this airfoil if p_T=2,118 psf and p_∞=2,104 psf in the wind tunnel test section? This represents a test conducted in the incompressible flow regime.
e. Perform a reasonable approximation of the lift coefficient for this airfoil.

QUESTION 11. Airfoils and Wings. Suppose you need to calculate the forces on a wing having an NACA 4415 section with a chord length of 50 inches. Use standard sea level conditions at 100 mph airspeeds.

a. Assume an infinite wing at 8º AOA. What is the lift curve slope?
b. Calculate the lift, drag, and moment about the AC per unit span.
c. Now assume a rectangular wing at 8º AOA with a span of 27 ft. The span efficiency factor is 0.940. What is the lift curve slope?
d. What is the lift coefficient for this wing at this angle of attack?
e. What is the drag coefficient for this wing at this angle of attack?

QUESTION 1. Historical Perspective. Fill in the blanks with the correct information. Be as complete as possible.

The first manned flight was accomplished on November 21, 1783 by a _____ built by the Montgolfier brothers. It wasn't until 16 years later that the concept of the airplane, with a fixed wing for generating lift and a separate mechanism for propulsion, was originally proposed. The man who envisioned this was _____. He also built and flew small model gliders of his configuration.

It took about a hundred years before full-size manned gliders were built and successfully flown. _____, also known as the "Glider Man," had made huge strides understanding the mechanics of flight by building and flying his own designs from 1891 until his death following a glider crash in 1896. The Wright brothers were intensely interested in his work, and sought the same approach, to understand *how* to fly before attempting to build a flying machine.

Orville and Wilbur Wright achieved the first flight of a powered, manned aircraft on December 17, 1903. They had selected Kill Devil Hills, in _____, as their site because of the tall dunes and prevailing winds.

The "Aeronautical Triangle" was a relationship that dominated the early development of aeronautics in the United States during the period from 1886 to 1916. This relationship involved the Wrights, _____, and Glenn Curtiss. The second person listed had competed intensely with the Wrights to fly a manned airplane. Curtiss had achieved notoriety and success because his airplane designs had much better flying qualities that the Wright designs. They were statically stable, making them easier and safer to fly.

QUESTION 2. True/False. Circle the most appropriate answer. Write in a justification if you feel it's necessary.

T F Pressure drag cannot exceed friction drag.

T F Profile drag is composed of form drag and friction drag.

T F Parasite drag includes the "drag at zero-lift."

T F Larger aspect ratio wings will produce lower drag than smaller aspect ratio wings of the same planform area.

T F A thick airfoil section will have a higher drag than a thin airfoil section.

T F Lift is the result of high-velocity particles impinging on the airfoil lower surface.

T F Wing stall is the result of boundary layer separation.

T F A sphere never produces lift, only drag, because it is symmetric.

T F A cambered airfoil with no circulation still produces lift because it is asymmetric.

T F A thick airfoil section will have a higher lift than a thin airfoil section.

T F For longitudinal static stability, the aircraft CG must be ahead of the neutral point.

T F For longitudinal static stability, the aircraft CG must be behind the wing AC.

T F Both maximum L/D and minimum power required occur at the same airspeed for steady, level flight.

T F In turning flight, it is impossible to maintain the same altitude because the lift is many times greater than the weight of the aircraft.

T F A Piper Cub can always out-turn an F/A-18E Super Hornet.

3B. Minimum Thrust Required. Assume the drag polar has the following form:

$$C_D = C_{D_0} + K C_L^2$$

With:

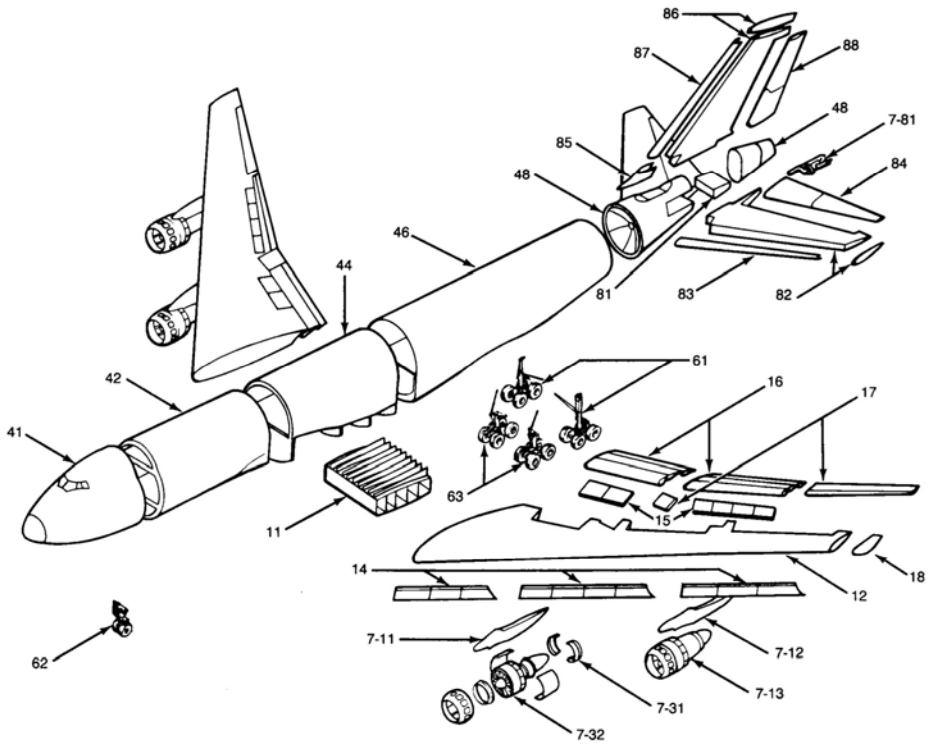
$$D = C_D \, q \, S$$
$$L = C_L \, q \, S$$

a. State the 2 conditions for steady, level flight.
b. Using these conditions, derive the equation for thrust required as a function of dynamic pressure only.
c. Determine the dynamic pressure at which the T_{req} is a minimum.
d. Show that the C_L required for this solution is the same as that for maximum L/D ($C_L = \sqrt{C_{D_0}/K}$).

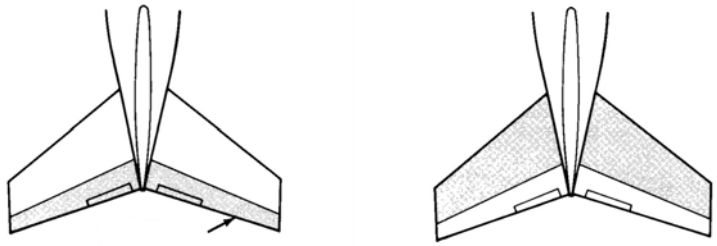
QUESTION 6. Aircraft Drag Polar. The Boeing 747-400 is the most recent operational derivative of the 747 family. Using the data and charts at the end of this exam, answer the following questions:

a. What is the wing aspect ratio?
b. What is the maximum *wing* loading? Include the proper units.
c. What is the maximum *thrust* loading (thrust-to-weight)? Include the proper units.
d. What is the <u>minimum</u> L/D required for steady, level flight?
e. Assume the Oswald efficiency factor for the whole airplane is 0.808.
f. Write out the equation for the drag polar for the whole airplane. Plug in the values of the constants.
g. From the drag polar information, calculate the maximum L/D ratio for the 747-400.

QUESTION 4 (20 pts). Fill-in. Fill in the blanks with the appropriate aircraft component names.

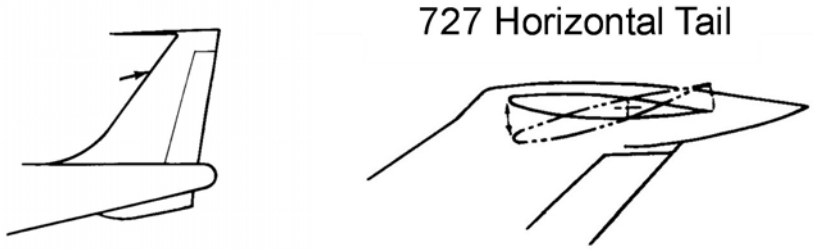


a. The assembly of part numbers 41, 42, 44, and 46 is called the _____.
b. The assembly of part numbers 48, 81-88, and 48 is called the _____.



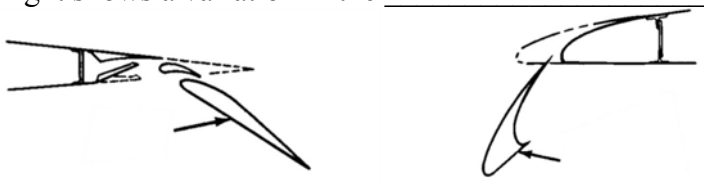
c. The shaded surface on the left is the _____.
d. The shaded surface on the right is the _____.

e. This line indicates the _____.

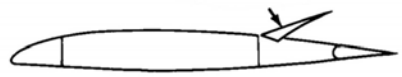


f. The surface on the left is called the _____.

g. The diagram on the right shows a variation in the _____ angle.



h. The device on the left is known as a _____.
i. The device on the right is known as a _____.



j. This device is known as a _____.

QUESTION 5. Match the load limits (sustained) with the airplanes.

_____	747-400 commercial airliner	A	$+n_{max} \approx 3.0$
_____	Beechcraft Bonanza (GA utility category)	B	$+n_{max} = 4.4$
_____	Lockheed-Martin F/A-22 Raptor	C	$+n_{max} = 6.0$
_____	Pitts S-2 aerobatic airplane	D	$+n_{max} = 7.5$
_____	T-45 Goshawk Navy trainer	E	$+n_{max} = 9.0$

QUESTION 7. Longitudinal Static Stability. A 747-400 is cruising at an altitude of 30,000 ft. It is balanced such that $h = 0.35$. Clearly state and circle any assumptions you make along the way. The value of C_{m_0} is 0.223 and the neutral point is at $h_{NP} = 0.758$. Assume the lift curve slope of the airplane is $a = 0.0873$ deg^{-1}.

a. What is the static margin?
b. Calculate the stability derivative, C_{m_α}.
c. Write out the stability equation for the pitching moment coefficient about the center of gravity.
d. Calculate the trim AOA for this flight condition.

QUESTION 9A. A glider descends from an altitude of 18,000 ft and travels 54.2 miles in 34 minutes, 18 seconds before touching down. This is the maximum range possible for this glider.

a. What is the minimum glide angle?
b. What is the maximum L/D?
c. What are the velocity and the required C_L at 10,000 ft?
d. Make a generic sketch of two lift curves on the same axes: one for a glider with AR=12 and one with AR=20. Clearly label each curve.

Glider Data
W = 1,800 lbs
b = 48 ft
AR = 12
e = 0.81

QUESTION 9B. The Boeing 747-400 takes off at 160 KEAS. The thrust required is given by:

$$T_{req} = \left(9.2513x10^{-2}\right)V^2 + \frac{6.5340x10^9}{V^2}$$

a. What is the C_L required for takeoff?
b. How is this lift coefficient typically accomplished?
c. What are the thrust and power required for takeoff?
d. Calculate the maximum rate of climb at this airspeed at sea level. Assume the rated engine thrust and put your answer in units of ft/min.

QUESTION 10. Consider the Mirage 2000 as characterized by the basic data shown. Assume air combat maneuvers (ACM) at an altitude of 15,000 ft.

a. What is the significance of the corner velocity for ACM?
b. Explain what would happen if n exceeds n_{max}.
c. What is the resulting bank angle for a maximum-g turn?
d. Calculate the corner velocity (in KTAS) at this altitude.
e. Calculate the minimum turn radius.
f. Calculate the maximum turn rate in deg/sec.
g. **True or False?** The Mirage 2000 can out-turn a Piper Cub.

Mirage 2000
W_{GTOW} = 33,000 lbs
W_{combat} = 20,899 lbs
S = 441.8 ft²
$(T/W)_{combat}$ = 1.05
$C_{L,max}$ = 1.2 (no flaps)
n_{max} = 9.0

Data for the Boeing 747-400 commercial airliner

Whole Airplane

W_{GTOW} = 875,000 lbs
W_{empty} = 376,000 lbs
Length = 231.83 ft
Fuselage Diameter = 21.33 ft
Engines = 4 General Electric CF6-80C2B5F's
Rated Thrust = 62,100 lbs each engine
C_{D0} = 0.0139
r = 0.0085

Wing

b_w = 211.46 ft
c_{r_w} = 54.30 ft
c_{t_w} = 12.93 ft
MAC = 26.48 ft
S_w = 5,600 ft²
$C_{m_{AC_w}}$ = -0.035
a_w = 0.0873 deg^{-1}
ε_0 = 0.5°
$\frac{d\varepsilon}{d\alpha}$ = 0.314 deg/deg

Tail

b_t = 72.41 ft

S_t = 1,529 ft^2

a_t = 0.0691 deg^{-1}

ℓ_t = 95.43 ft

i_t = 3.5°

η_t = 0.95

QUESTION 1. Fill in the blanks with the correct answer. Be as complete as possible.

a. _____ was known as the "Glider Man."
b. The first man to fly was _____.
c. The first heavier-than-air aircraft flew on this date: _____.
d. The four pillars of aerospace engineering are aerodynamics/astrodynamics, _____, _____, and structures.
e. Buoyancy is best understood using _____ Principle.
f. The three equations of fluid motion we studied in EA203 were the _____, _____, and _____ equations.
g. Profile drag consists of _____ and _____ drag.
h. _____ drag is higher for lower aspect ratio wings.
i. Airfoil stall is due to _____, which can be greatly impacted by a/an _____ pressure gradient.
j. Lift is attributed to _____.
k. The appropriate wing area used in aerodynamics is the _____ area.
l. The empennage includes the _____ and the _____.
m. _____ is the aircraft weight divided by the wing area.
n. _____ is the engine thrust available divided by the aircraft weight.

QUESTION 2. Sketch the streamlines around the following spheres. Label the stagnation point, the separation point(s), and the wake.

U_∞

$Re_d = 1x10^6$

$\omega = 0$ rad/sec

U_∞

$Re_d = 1x10^5$
$\omega = 0$ rad/sec

$Re_d = 1x10^5$
$\omega = 60$ rad/sec

QUESTION 3. Indicate whether the statement is **True** or **False**. If the statement is false, suggest a correction to make it true. True statements are worth 2 points and False statements are worth 4 points.

T F Variation of pressure through the atmosphere is a power-law relationship with altitude.

T F Friction drag cannot exceed pressure drag.

T F Parasite drag includes C_{D_0} .

T F Larger aspect ratio wings will produce lower lift than smaller aspect ratio wings at the same geometric AOA.

T F Spherical objects can't produce lift, only drag, because the surface distance is equal on both the upper and lower surfaces.

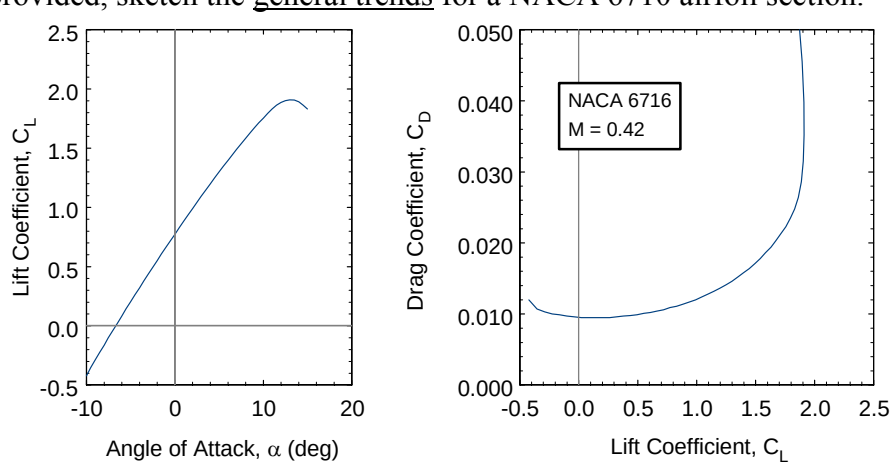
T F A cambered airfoil section will have higher lift than a symmetric airfoil section at the same AOA.

T F Both maximum L/D and maximum thrust required occur at the same lift coefficient for steady, level flight.

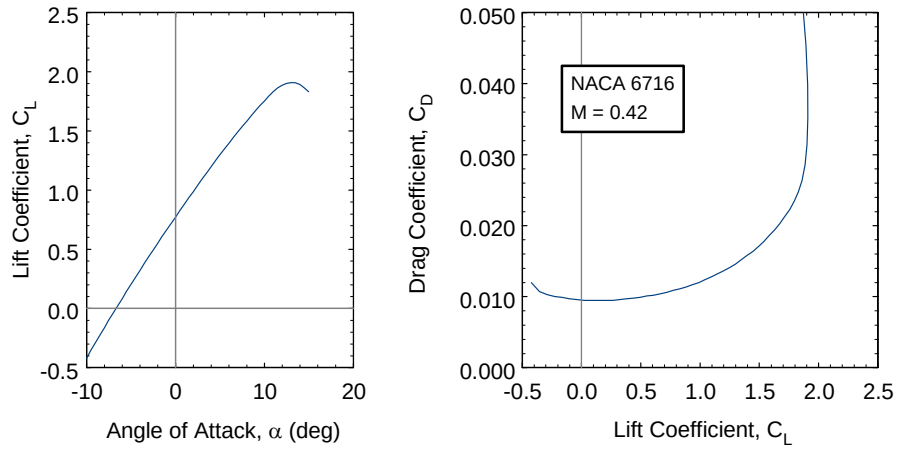
T F Finite wing drag is composed of induced drag and friction drag.

QUESTION 4. The root section of the Fairchild A-10A wing is a NACA 6716 airfoil section. The aerodynamic characteristics are shown in the plots of the lift curve and the drag polar.

a. On the plots provided, sketch the general trends for a NACA 6710 airfoil section.



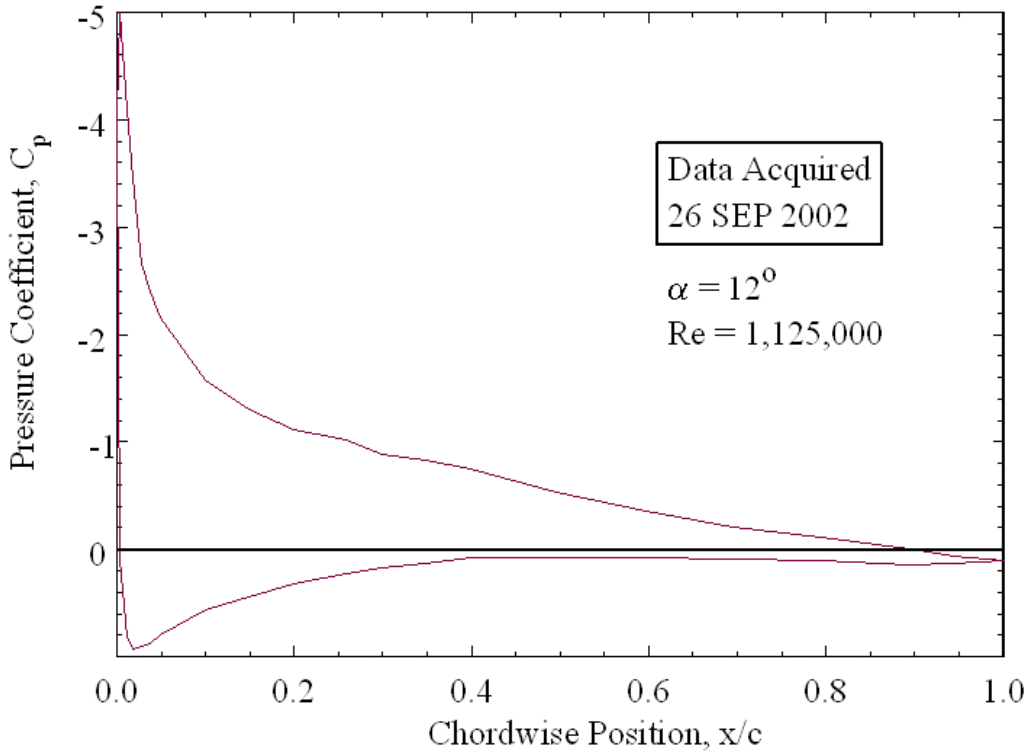
b. On the plots provided, sketch the general trends for a NACA 2716 airfoil section.



QUESTION 6. An F-16B is maintaining steady, level flight at $M = 1.05$ at an altitude of 33,000 ft. A Pitot probe is used to measure the total pressure in flight.

a. Calculate the total pressure if we assume an incompressible flow.
b. Why is this result invalid?
c. Will the true total pressure be higher or lower than this value?
d. Classify this flow regime:

- ❑ Incompressible
- ❑ Transonic
- ❑ Hypersonic
- ❑ Subsonic Compressible
- ❑ Supersonic
- ❑ Ultrasonic



QUESTION 7. Midshipmen from EA303 acquired wind tunnel pressure data on a full-span airfoil model with a chord of 12 inches and a span of 31 inches. The tests were conducted at a freestream velocity of U_∞ = 175 ft/sec at a density altitude of 2000 ft. The static pressure in the test section was 1011.6 mbar.

a. What are the freestream, total, and minimum pressures for this airfoil? Put your answers in lb/ft².
b. Based on the given pressure distribution, make a reasonable estimate of C_ℓ for this airfoil.
c. Calculate the lift per unit span and the circulation produced by this airfoil.

QUESTION 8. The F-16B lifts off at 140 KEAS. At the corresponding Reynolds number, the drag polar is determined to be:

$$C_D = 0.019 + 0.117\,C_L^2$$

a. What are the wing aspect and taper ratios?
b. What are the required lift and drag coefficients at liftoff?
c. What is the Oswald efficiency factor for this configuration?
d. Calculate the thrust required to maintain steady, level flight at 140 KEAS.

(+10 BONUS) Calculate the maximum L/D ratio.

F-16B Air Combat Configuration
W = 24,800 lbs
Engine = F-110-GE-100 (27,000 lbs rated thrust)
Airfoil = NACA 64A204
C_{D_0} = 0.0190
r = 0.027
S = 300.0 ft²
b = 32.83 ft
c_r = 16.29 ft
c_t = 3.70 ft
Λ = 40°

QUESTION 9. The following velocity profile for a laminar boundary layer was measured on the trailing edge of a 1m-long flat plate:

$$\frac{u}{U_\infty} = 1.84\frac{y}{\delta} + 1.74\left(\frac{y}{\delta}\right)^2 - 6.13\left(\frac{y}{\delta}\right)^3 + 4.64\left(\frac{y}{\delta}\right)^4 - 1.09\left(\frac{y}{\delta}\right)^5$$

The velocity over the plate is 65 m/sec and the boundary layer thickness is 3.03 mm. The temperature and pressure are 20°C and 1010 mbar, respectively. You may assume the thickness of the plate to be infinitesimal.

a. What is the Reynolds number for this problem?
b. Calculate the wall shear stress on the plate.