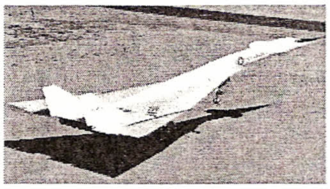 

UNITED STATES AIR FORCE ACADEMY
DEPARTMENT OF AERONAUTICS

AE 315 – Fundamentals of Aerodynamics

Fall 2007	**GR #1**	Lesson 16 – 24, 25 September 2007
125 Points	**CLOSED BOOK/NOTES**	

ACADEMIC TESTING MATERIAL

THIS EXAMINATION IS NOT RELEASED FROM ACADEMIC SECURITY UNTIL 1900, 25 Sept 07.
DO NOT REVEAL ITS CONTENTS TO, OR DISCUSS IT WITH ANYONE UNTIL THEN.

Allowed Reference Materials

(1) Calculators – definitions, concepts, equations (any text) input into calculators is prohibited.
(2) Aero 315 Supplemental Data Book
(3) One side of a 3x5" Note Card
(4) Ruler or Straight Edge

Name: Gabriel Staples TOTAL SCORE (125 pts): 95.5 = 76.4%

21.5
22.5
44
+ 3.5 Bubble
47.5

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1. (4 points) Who was known for being the first to propose separate mechanisms for lift and propulsion?
a. Montgolfier Brothers
b. Wright Brothers
c. Sir George Cayley
d. Adam Sandler

2. (4 points) What famous designer is the father of the P-38, the SR-71, and the F-104, and started a covert design group called the "Skunk Works"
a. Sir George Cayley
b. Igor Sikorsky
c. Kelly Johnson
d. Theodore Roosevelt

3. (4 points) When designing the A-10, the designers initially investigated the tanks they wanted to destroy. Then they looked at the armor on the tanks. Next they examined what properties a bullet would require to damage a tank. Around this bullet, they designed the gun, and then the plane. The initial investigation of the tank and the bullet would fall under what step of the 5-step design process for the A-10?
a. Collect information
b. Create solutions
c. Preliminary design
d. Detail design

4. (4 points) The hydrostatic equation relates what three properties?
a. Velocity, temperature, and density
b. Pressure, density, and velocity
c. Area, velocity, and density
d. Pressure, density, and height

5. (4 points) If you are observing a flow phenomenon that includes changes in area, velocity, and density, which fundamental law would be the best choice for studying the phenomenon?
a. Conservation of Momentum
b. Conservation of Entropy
c. Conservation of Energy
d. Conservation of Mass

6. (4 points) When doing an experiment in a wind tunnel, you measure the flow everywhere across a single cross-section at the same time. You find that the four fundamental aerodynamic properties only vary by 0.1% everywhere in this cross-section. Due to this, you decide that it is a good choice to use which of the following assumptions when analyzing the flow.
a. Isobaric
b. Steady
c. 1-D
d. No body forces

7. (4 points) An industrial processing plant has two identical pipes with identical nozzles at the downstream ends. Water flows through one pipe and air flows through the other. For the same initial velocity (above 330 ft/s), and assuming no temperature change, air will generally ________________?

a. speed up more than water due to changes in density (as long as flow is subsonic)
X **b.** speed up less than water due to changes in density (as long as flow is subsonic)
c. have the exact same characteristics as water since everything else is the same (as long as flow is subsonic)
d. stop flowing due to the change in density (as long as flow is subsonic)

8. (4 points) The hydrostatic equation says that:
a. For a given density, as a particle's height in a liquid increases, it will experience greater pressure
✓ **b.** For a given density, as a particle's height in a liquid increases, it will experience less pressure
c. For a given density, as a particle's height in a liquid decreases, it will experience less pressure
d. For a given density, as a particle's temperature rises, it will experience less pressure

9. (4 points) An aircraft is flying with a constant true airspeed vector pointed due North. A wind begins blowing from the West. If the pilot does not turn left to compensate for the crosswind, what effect will the wind have on the aircraft's ground speed?
a. groundspeed increases
b. groundspeed decreases
X **c.** groundspeed doesn't change
d. crosswinds don't happen

10. (4 points) The correction from V_e to V_T is primarily a correction for what?
a. pressure
b. velocity
X **c.** temperature
d. density

11. (4 points) Which of the following is NOT an assumption required for use of Bernoulli's Equation?
– **a.** Friction doesn't matter or apply
X **b.** Forces due to gravity are inconsequential
– **c.** The flow doesn't change with time
d. Changes in velocity are negligible

12. (4 points) When deriving Bernoulli's Equation from the Euler Equation, you must apply one last assumption before integrating. Which assumption?
a. Pressure is constant
b. Friction does not apply
✓ **c.** Density is constant
d. Temperature is constant

13. (4 points) When studying a wing with positive camber vs. the same thickness wing that is symmetric, we expect the C_{Lmax} to be ________ and the α_{stall} to be ________ than the symmetric wing with the same thickness.

a. higher, higher

✓ **b.** higher, lower

c. lower, higher

d. lower, lower

14. (4 points) When designing a new bicycle for the USAFA cycling team, you are trying to decide whether or not to dimple the frame. The frame tubes are all shaped like very thin (0003) symmetric airfoils to reduce pressure drag. What do you decide?

a. You decide to dimple the tubes. The bike tubes are streamlined and thin, so the skin friction drag is minimal. So, the goal is to reduce pressure drag by keeping a laminar boundary layer as long as possible.

✓ **b.** You decide not to dimple the tubes. The bike tubes are streamlined and thin, so the pressure drag is minimal. So, the goal is to reduce skin friction drag by keeping a laminar boundary layer as long as possible.

c. You decide not to dimple the tubes. The bike tubes are streamlined and thin, so the skin friction drag is minimal. So, the goal is to reduce pressure drag by never transitioning to a laminar boundary.

d. You decide to dimple the tubes. The bike tubes are streamlined and thin, so the pressure drag is minimal. So, the goal is to reduce skin friction drag by transitioning to a turbulent boundary layer as soon as long as possible.

15. (4 points) While designing the follow on to the C-17, you are trying to figure out which high lift device will help shorten take-off distance the most. You decide to use:

a. very large plain flaps. If they are really large you are increasing camber a lot and can create a higher C_{Lmax}.

b. multiple plain flaps. This way you can adjust each one independently and get exactly the C_{Lmax} you require.

✓ **c.** multi-stage Fowler flaps. Not only do they increase C_{Lmax} by changing the camber and reducing separation, but they also increase wing area.

d. split flaps. They will increase the camber and delay separation over the flap so you can increase C_{Lmax} the most.

16. (4 points) If all of the assumptions for Bernoulli's Equation had held in the Airfoil Lab, what would you expect the relationship between Total pressure in the wind tunnel and static pressure in the room to be?

a. Total pressure in the wind tunnel will be higher than the static pressure in the room because there is a dynamic pressure component in the wind tunnel.

b. Total pressure in the wind tunnel will be lower than the static pressure in the room because there is a dynamic pressure component in the wind tunnel.

✓ **c.** Total pressure in the wind tunnel will be the same as static pressure in the room because the static pressure will drop exactly the same amount as dynamic pressure rises in the wind tunnel.

d. Total pressure in the wind tunnel will be lower than static pressure in the room because the static pressure will drop in the wind tunnel and the dynamic pressure remains constant.

X 17. (4 points) What is a good estimate for the lift and drag for a C-5 that is flying in cruise across the ocean?

a. Lift = 5,000,000,000 lbs, Drag = 300,000 lbs
b. Lift = 50,000 lbs, Drag = 5,000 lbs
c. Lift = 500,000 lbs, Drag = 30,000 lbs
d. Lift = 500,000 lbs, Drag = 500,000 lbs

From the airfoil lab: As the airfoil goes to higher α, it acts more like a blunt object. Because of this, we want as high a **18.** __________ as possible so that the air will **19.** ____________ sooner. By doing this, the air will not **20.** ___________ as early, and the airfoil will have a higher α_{stall} and c_{lmax}.

X 18. (4 points)

a. Magnetic Reynold's Number
b. Prime Number
c. Knudsen Number
d. Avogadro's Number
e. Reynold's Number
f. Ted's Number

✓ 19. (4 points)

a. Separate
b. Reverse
c. Slide
d. Turbo-late
e. Slow-down
f. Transition

✓ 20. (4 points)

a. Separate
b. Excite
c. Slide
d. Turbolate
e. Pressurize
f. Transition

The next few pages contain different work-out problems. You may choose **ANY TWO** work-out problems (***Only two will be graded, so if you do more, mark which ones are to be graded***). Each problem will be worth 22.5 points, so both together are worth 45 points. Also, some of the work-out problems have bonuses. You may do any of the bonuses for extra credit, whether you did the work-out problem for points or not.

21.5

Problem 1 (22.5 points) As a budding aeronautical engineer, you are asked to help set-up a new racing league. This new league will challenge all drivers and car designers with large jumps, sections of the track that are perpendicular to the ground, loops, and inverted sections. As part of this, you are asked to help design the track so that the proposed "common lay-out car" can drive upside down safely. You need to figure the lowest velocity the car has to travel to remain on the track upside down. That way you can make sure there is enough of a straight section for the cars to get to that velocity before going upside down. The "common lay-out car" will weigh 1,500 lb, fully loaded. It will have an identical front and rear spoiler with a **negatively cambered** NACA 4415 airfoil. While the spoilers can be rotated, for the on-track sections they will be mounted at -6°. These spoilers have a chord of 1.5 ft and a span of 12 ft. Lastly, the spoilers have an efficiency factor of 0.9 and the Reynold's number of the car is roughly 3 million. The track will be built here in Colorado Springs at 7,000 ft.

What is the minimum velocity required to keep the car on the track when the track is inverted?

(Hints: You may assume the lift created by each spoiler is the same, and that there is no lift or downforce created by the body of the car.)

Bonus (5 pts.) The car produces exactly 1500 lbs of lift in a certain configuration (altered α of the spoilers to create lift and not down-force) at 200 mph. To cross one of the proposed jumps, it will need 3000 lbs of lift. With the same spoiler configuration (α) as is used to produce the 1500 lbs of lift at 200 mph, what velocity would the car have to go to make the jump?

Given: NACA 4415

$\alpha = -6^\circ$ in the direction to produce more lift, so it $= +6^\circ$ on chord

$c = 1.5$ ft each

$b = 12$ ft each

weight $= 1500$ lb

$e = .9$

$\alpha_{L=0} = -4^\circ$

$Re = 3 \times 10^6$

$\rho = .001927$ slug/ft³

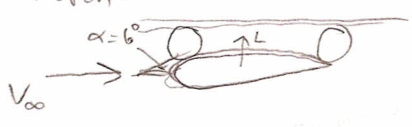
altitude $= 7000$ ft

$C_{\ell\alpha} = \cancel{1.05/\text{deg}}$ No 0.1/deg (-1)

Find: V_{min} to keep car inverted on track

Assume: Standard atmosphere, Lift of each spoiler is the same; No downforce created by car's body

Sketch:



Estimate: maybe < 200 mph

Check: it is reasonable. A car can drive that fast, & it is not way slow

Solution: $L = C_L q S$

$AR = \frac{b^2}{S} = \frac{12^2}{18} = 8$

$S = b \cdot c = 12(1.5) = 18\ ft^2$

$C_{L\alpha} = \dfrac{\cancel{1.05/\text{deg}}}{1 + \left(\dfrac{57.3\text{deg}(\cancel{1.05})}{\pi(.9)(8)}\right)} = \dfrac{1.05}{1 + 2.66} = \cancel{0.2869}$ 0.08/deg

$C_L = \frac{.2869}{\text{deg}}(6\text{deg} - (-4^\circ)) = 2.869$

$L = 2.869/\text{spoiler}$

$q = \frac{1}{2}\rho V^2 = \frac{1}{2}\, .001927 \frac{\text{slug}}{ft^3} \cdot V^2$

there are 2 spoilers so times 2

$1500 = 2(2.869)\left(\frac{1}{2}(.001927)V^2\right) 18\ ft^2$

$V^2 = \dfrac{1500\ lbs}{2(2.869)(.5)(.001927)(18)}$

$V^2 = 15{,}073.2$

$\boxed{V = 122.8\ ft/s}$

$122.8 \frac{ft}{s} \cdot \frac{60\ s}{min} \cdot \frac{1\ mile}{5280\ ft} \cdot \frac{60\ min}{hr} = \boxed{83.7\ mph}$ 8

22.5

Problem 2 (22.5 points) You are flying an aircraft at 30,000 feet with an airspeed of 400 ft/sec. At your angle of attack, the lift coefficient for your wing is 0.7. The wing area is 2000 ft^2 and the wing span is 100 ft. For your flight Reynolds number and angle of attack, the airfoil profile drag coefficient is .008 and e is 0.9. Determine the wing drag. What fraction of this is induced drag?

Given: Alt = 30,000 ft

$V = 400\ ft/sec$

$\alpha =$

$\rho = .000891\ \frac{slug}{ft^3}$

$C_L = .7$

$S = 2000\ ft^2$

$b = 100\ ft$

$C_d = .008$

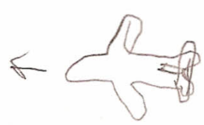
$e = .9$

$D =$

Find: wind drag, D

Assume: standard atmosphere

Sketch:



30,000 ft

Estimate: induced drag will be a larger portion of total drag

Solution: $D = C_D q S$

$q = \frac{1}{2}\rho V^2 = \frac{1}{2}(.000891)\left(400\ \frac{ft}{s}\right)^2$

$= 71.28\ \frac{lb}{ft^2}$

$S = 2000\ ft^2$

$C_D = C_d + C_{Di}$

$C_{Di} = \frac{C_L^2}{\pi e AR} = \frac{.7^2}{\pi(.9)(5)} = 0.03466$

$AR = \frac{b^2}{S} = \frac{100^2}{2000} = 5$ units

$C_D = .008 + 0.03466 = .04266$

$D = .04266\left(71.28\ \frac{lb}{ft^2}\right)\left(2000\ ft^2\right) = \boxed{6{,}081.6\ lb}$

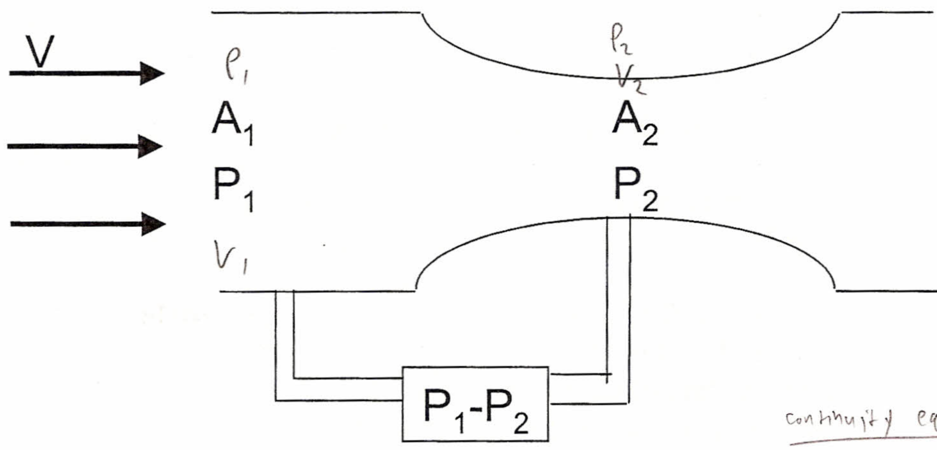
$D_{induced} = C_{D\,ind}\, q S = 0.03466(71.28)(2000) = \boxed{4941.13\ lb}$

$\frac{4941}{6081.6} \times 100 =$ $\boxed{81.2\%\ \text{of wing drag is induced}}$

or $\frac{C_{Di}}{C_D} = 81.29\%$

check: it is true ✓

Problem 3 (22.5 points) An instrument used to measure the airspeed on many early low speed airplanes during the 1910-1930 time period was the venturi, sketched below. This simple device is mounted on the airplane where the inlet velocity is essentially the same as the freestream velocity. Knowing that $A_1/A_2=4$ and $P_1-P_2 = 4000\ N/m^2$, find the airplane's velocity for a 2000 m standard day.



Given: $\frac{A_1}{A_2} = 4$

$P_1 - P_2 = 4000\ \frac{N}{m^2}$

$h = 2000\ m$

ρ_1 (table) $= .81935\ kg/m^3$

Find: airplane's velocity

Assume:
- Standard day
- 1-Dimensional
- Steady
- incompressible
- inviscid flow
- negligible body forces
- flows along a streamline

Sketch: (given)

Estimate: "low speed" means $V < 100\ m/s$

Check: ✓ it is less than 100 m/s. It is reasonable.

Solution:

continuity eqn:

$\dot m_1 = \dot m_2$

$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

$\rho_1 = \rho_2$

$A_1 V_1 = A_2 V_2$

$\frac{A_1}{A_2} V_1 = V_2$

$4 V_1 = V_2$

Units: ✓

$\sqrt{\frac{N}{m^2}\frac{m^3}{kg}} = \sqrt{\frac{kg\ m\ m^3}{s^2\ kg\ m^2}} = \sqrt{\frac{m^2}{s^2}} = \frac{m}{s}$

Bernoulli's eqn

$P_{0_1} = P_{0_2}$

$P_{\infty_1} + \frac{1}{2}\rho V_{\infty_1}^2 = P_{\infty_2} + \frac{1}{2}\rho V_{\infty_2}^2$

$P_1 - P_2 = \frac{1}{2}\rho V_2^2 - \frac{1}{2}\rho V_1^2$

$4000\ \frac{N}{m^2} = \frac{1}{2}\rho (4V_1)^2 - \frac{1}{2}\rho V_1^2$

$= 8\rho V_1^2 - \frac{1}{2}\rho V_1^2$

$4000 = 7\frac{1}{2}\rho V_1^2$

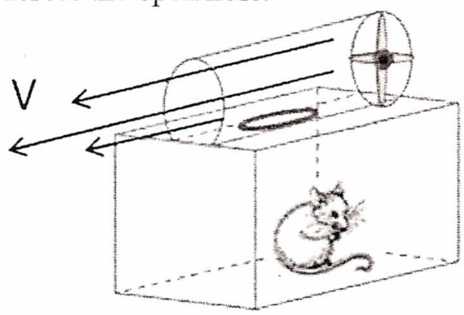
UNITS!

$V_1 = \sqrt{\frac{4000}{7.5\rho}} = \sqrt{\frac{4000}{7.5(.81935)}}$

$\boxed{V_1 = 25.5\ m/s}$

23.02 m/s

Problem 4 (22.5 points) A group of very crazy USAFA biology majors wants to conduct tests on the auditory sensitivity of field mice to changes in pressure altitude. As they are conscientious about the well being of the mice, they want you to construct a mobile pressure altitude chamber that they can carry with them to the field to perform real-time testing without having to bring the mice back to the lab. You spend a couple of hours in the workshop and come out with the contraption shown below, which consists of a small glass box that is air-tight, except for a small opening near the top. Across the opening, you have constructed a ducted fan assembly that has the sole purpose of blowing air across the open hole.



a. If the crazy biology majors are testing mice in Pike's National Forest at 9000 ft on a standard day, how fast must the air blow across the opening to change the air pressure inside by just 75 lb/ft^2? Assume none of the blown air spills into the chamber.

b. Will this be a pressure increase or a pressure decrease?

c. Unfortunately, the fan you purchased is only capable of increasing the air velocity up to the point where the effects of compressibility begin to become significant. If the crazy biology majors want to increase the pressure altitude to 12,000 ft, will they be able to use your mobile altitude chamber? Why or why not? Assume they are still at 9000 ft, standard day conditions.

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+3

Problem 5 (22.5 points) The wing of the Cessna T-41 can be modeled as a straight, untapered wing with a wing area of 175.4 ft^2 and a span of 35.83 feet. It uses a NACA 2412 airfoil. If the T-41 is cruising at an angle of attack of 2.5 degrees at its cruise velocity (120 knots) at 12,000 feet, what is the induced drag created by the wing? How much does the airplane weigh? (Assume an elliptic lift distribution).

Given: $S = 175.4\ ft^2$

$b = 35.83\ ft$

NACA 2412

$\alpha = 2.5^\circ$

$1k = 1.69\ ft/s$

$V = 120$ Knots $= 202.8\ \frac{ft}{s}$

$h = 12{,}000\ ft$

$e = 1$ (elliptical wing)

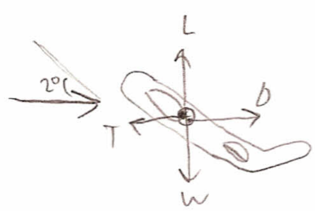
$\alpha_{L=0} = -2^\circ$

Find: Induced drag created by wing (d_i)

weight of plane

Assume:

Sketch:



Estimate: D_{ind} will be less than the weight of the plane. Lift will be much higher than drag.

Check: ✓ it's good

Solution:

$$Re = \frac{\rho V \bar{c}}{\mu} = \frac{.001648(202.8)(4.9)}{3.493\times10^{-7}} \approx 4.69\times10^6$$

$$\bar{c} = \frac{175.4\ ft^2}{35.83\ ft} = 4.90\ ft$$

$$\rho = .001648\ \frac{slug}{ft^3}$$

$$\mu = 3.493\times10^{-7}\ \frac{slug}{ft\,s}$$

$$C_{l\alpha} = \left(\frac{.4-0}{1.9+2}\right) = \frac{.4}{3.9} = 0.1/deg$$

$$c_d = .0065\ ✓$$

$$C_{L\alpha} = \frac{.1}{1+\frac{57.3(.1)}{\pi(7.32)}} = .08/deg$$

$$AR = \frac{b^2}{S} = 7.32\ ✓$$

$$C_L = .08(2.5 - -2) = .08(4.5) = .36\ ✓$$

$$C_{Di} = \frac{C_L^2}{\pi e AR} = \frac{.36^2}{\pi(7.32)} = .00564\ ✓$$

$$D_i = C_{Di}\,q\,S = .00564(33.9)(175.4) = \boxed{33.5\ lbs}$$

D_i

$$q = \frac{1}{2}\rho V^2 = \frac{1}{2}(.001648)(202.8)^2 = 33.89$$

$$W = L = C_L q S = .36(33.89)(175.4) = \boxed{2140.0\ lbs}$$

weight

Problem 6 (22.5 points) You are designing a new combat aircraft which will use a version of the General Electric F404 turbofan jet engine. At its on-design condition, the engine requires a mass flow rate of 5 slugs per second of air. You are designing an inlet which is sized to feed the engine air at this rate when the aircraft is flying at 500 knots true airspeed in standard day 30,000 ft conditions. Answer the following questions about this situation:

1. How big should you make the inlet, or in other words, what should be the cross-sectional area of the inlet mouth?

2. If the flow area of the engine's compressor is 8 ft^2 and the flow velocity for the on-design condition at the compressor face is 500 ft/s, what is the air density at that point for that operating condition?

3. If, for this operating condition, at a point halfway along the engine's inlet duct, the pressure is 6 psi and the air temperature is 30 degrees F, what is the air density at that point?

4. Describe at least one feature that you could include in your inlet that would allow for additional inlet area to provide sufficient airflow to the engine when it is operating at lower speeds or higher altitudes.

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Problem 7 (22.5 points) A U2 is flying at an altitude of 11000m with a true air speed of 366 knots. The angle of attack is 6 degrees.

The wingspan is 24.4m. We suppose that the wing is rectangular with a chord of 2.25m and an airfoil NACA 2412. The efficiency factor of the wing is e=1.

1. Calculate the Reynolds number
2. Find the 2D lift and drag coefficients C_l and C_d for the current angle of attack
3. Calculate the 3D lift coefficient C_L (Hint : Find $\alpha_{l=0}$, calculate $C_{l\alpha}$ then $C_{L\alpha}$ and deduce C_L)
4. Calculate C_D
5. Calculate the lift and the drag created by the wing

Problem 8 (22.5 points) As a recent graduate of the test pilot school, you are given the opportunity to be the flight test engineer on the Air Force's newest experimental fighter. The new plane uses a variable geometry engine inlet to maximize performance; the size of the inlet exit is fixed, while the size on the entrance is variable. Your boss has asked you to determine the ideal size of the entrance for this flight. During this flight the altimeter reads 45,000 ft, while your perfectly positioned air speed indicator reads 300 knots. You previously measured the exit area to be $12.5 ft^2$. You also know that the velocity at the exit of the inlet can't exceed 484 ft/sec. Additionally, a probe located at the exit of the inlet indicates that the temperature there is 400.8°R, and the pressure is $340.6 lb/ft^2$. Assume standard day conditions exist at the entrance to the inlet.

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Blank Page 2 For Extra Calculations