16.00 Introduction to Aerospace and Design
Problem Set #3

AIRCRAFT PERFORMANCE FLIGHT SIMULATION LAB

Note: You may work with one partner while actually flying the flight simulator and collecting data. Your write-up must be done individually. You can do this problem set at home or using one of the simulator computers. There are only a few simulator computers in the lab area, so not leave this problem to the last minute. To save time, please read through this handout completely before coming to the lab to fly the simulator.

Objectives
At the end of this problem set, you should be able to:
• Take off and fly basic maneuvers using the flight simulator, and describe the relationships between the control yoke and the control surface movements on the aircraft.
• Describe pitch - airspeed - vertical speed relationships in gliding performance.
• Explain the difference between indicated and true airspeed.
• Record and plot airspeed and vertical speed data from steady-state flight conditions.
• Derive lift and drag coefficients based on empirical aircraft performance data.

Discussion
In this lab exercise, you will use Microsoft Flight Simulator 2000/2002 to become more familiar with aircraft control and performance. Also, you will use the flight simulator to collect aircraft performance data just as it is done for a real aircraft. From your data you will be able to deduce performance parameters such as the parasite drag coefficient and L/D ratio.

Aircraft performance depends on the interplay of several variables: airspeed, power setting from the engine, pitch angle, vertical speed, angle of attack, and flight path angle. Roughly speaking, the elevator control on an aircraft controls the angle of attack of the aircraft. The resulting pitch angle, airspeed, and vertical speed then depend on the power setting from the engine.

1. Introduction and Use of the Flight Simulator
Spend time using Microsoft Flight Simulator 2000/2002 to learn to take off and fly an aircraft. We suggest that you use a simple single engine aircraft model (i.e., Cessna 182) since they are simpler and more stable than some of the other aircraft. Use the on-line tutorial as needed to help you learn what the basic controls and instruments are, and how to operate the aircraft in a stable way. At a minimum, you should be able to start the simulation, and control power, pitch, and roll angle to take off, fly on a straight heading, make shallow turns, climb, descend, and fly at a level altitude.

In addition to the on-line help in the flight simulator, we in the A/A department have set up a web page to help you get introduced to the flight simulator:
http://web.mit.edu/aeroastro/flightsimlab/Introduction.htm

2. Airspeed and Vertical Speed Performance in a Steady Glide

We will focus on collecting performance data from an aircraft in a steady glide. We will use a Schweizer 2-32 glider rather than a powered aircraft, which simplifies some of the calculations. You will put the glider into a series of steady flight conditions and record speed and vertical speed (descent rate). Using these data, you will build a plot that describes how these parameters are related, and then you will be able to compute some of the critical aerodynamic performance parameters, such as parasite drag coefficient and L/D ratio. These data would be very important to a prospective buyer, for example. The methods you will use are similar to what might be done when evaluating an actual aircraft.

First, you can measure some of the characteristics of the Schweizer 2-32 sailplane before you take off:

Weight (W):	850 lb
Wing span (b):	57 ft
Mean wing chord (c):	3.15 ft
Aspect Ratio (AR):	18.05
Wing area (S):	180 ft^2

(a) Set up the flight simulator for a Schweizer 2-32 sailplane. Go to your favorite airport to fly. The simulator will start on the ground, so we'll need to simulate a tow to altitude using the *slew* feature. Press 'y' to enter slew mode, and then the F4 key to gain altitude rapidly. F3 will gain altitude at a slower rate, and F2 will hold the altitude. F1 decreases altitude. Using the slew feature, climb to 10,000 ft.

(b) Press 'y' again to enter normal flying mode. Keep the glider flying straight and pitch the nose to hold a steady attitude. If you hold that attitude by moving the control yoke as necessary, the aircraft will eventually reach an equilibrium airspeed and descent rate. You can also make fine adjustments to the elevator position by using the trim button on the yoke, or the 1 and 7 keys on the number pad of the keyboard if you don't have a yoke. Note that this aircraft's instruments show airspeed in miles per hour, and vertical speed is given in feet per minute. The airspeed readout is called *indicated airspeed*.

(c) Once the aircraft is stabilized, re-renter slew mode and climb back up to a little more than 10,000 ft. Restart normal flight, and continue to hold the steady attitude until you descend at least to 9,500 ft.

(d) After passing through 9,500 ft, start the Flight Analysis Tool (from the Options menu – if the menu bar is not showing, press the <Alt> key). In the Flight Analysis tool, you can get a readout of the aircraft's speed (NOTE: in *knots*), the current altitude (in feet), and the current time (hours:minutes:seconds). Record the speed, altitude, and time on a sheet of paper. Using the slider bar at the bottom of the Flight Analysis window, back-up time until it is at the point where the aircraft was back at approximately 10,000 ft. Record the exact altitude and time. From the data at these two times, you can compute the vertical speed more accurately than you can by

viewing the cockpit instruments while trying to hold the nose steady. Compute and record the vertical speed for the given airspeed you flew by taking the change in altitude over the change in time.

(e) Repeat steps (b) – (d) to generate data for at least five different airspeeds. Try to take data down to approximately 50 MPH (or 43 knots) and up to approximately 140 MPH (120 knots). To hold the low speeds, the nose will be pitched up enough that you cannot see the horizon from the forward view. In this case, you may find it easier to use the yoke to hold a constant airspeed rather than a constant pitch attitude. Pull back to slow down, push forward to speed up (this only works if the aircraft is not stalled). You may also find it easier to use number pad 1 and 7 to slowly set the elevator position in small increments. At low speeds close to stall, the dynamic model is not very accurate and the glider may begin oscillating with increasing magnitude in pitch. Try to maintain constant pitch or increase your airspeed slightly by pitching down to avoid operating right at stall. The more data points you collect, and the more accurately you collect them, the better your solution will be in the next steps. It is important to collect the data at similar altitudes, however, so be sure to re-slew each time back to 10,000 ft.

Airspeed measurement

We need to be careful now in how we treat airspeed measurements. The airspeed indicator (and the Flight Analysis tool) show what is termed *indicated airspeed*. Indicated airspeed is measured from a pitot tube that computes the difference between the stagnation pressure (P_0) that is measured at the tip of the pitot probe, and the static pressure (P) that is measured on the side of the pitot probe [see Eqn. 3.16, p. 44 in *Interactive Aerospace and Design*]. From Bernoulli's equation, the airspeed can then be computed:

$$v = \sqrt{2\frac{P_o - P}{\rho}}$$

Although the airspeed indicator can measure the pressure terms in the above equation, it cannot measure the air density. So, the airspeed indicator in the cockpit has been calibrated such that at standard sea level conditions (i.e., when $\rho = 1.2$ kg/m^3) the speed shown on the dial equals the true speed of the aircraft through the air. In a sense, you can think of the airspeed indicator as a *dynamic pressure gauge* (because dynamic pressure = P_0-P) that has been calibrated to show the actual airspeed for that dynamic pressure if the aircraft is at sea level in standard conditions. So, an indicated airspeed reading of 100 MPH means that the dynamic pressure is such that were the aircraft at sea level, it would be traveling at a true speed of 100 MPH through the air.

At high altitudes, however, a given indicated airspeed based on the pressure difference (P_0-P) actually means that the aircraft is moving more quickly through the air because the air density is less than at sea level. At 10,000 ft, air density is about 0.75 its value at sea level. So, an aircraft at 10,000 ft with an indicated airspeed of 100 MPH means that its dynamic pressure is the same as it would be if it were at sea level going 100 MPH. Equating these two values of dynamic pressure:

$$\frac{1}{2}\rho_{SL} v_{SL}^2 = \frac{1}{2}\rho_{10000} v_{10000}^2$$

where v_{SL} is the true airspeed at sea level, v_{10000} is the true airspeed at 10,000 ft, etc.

or

$$v_{10000} = \sqrt{\frac{\rho_{SL}}{\rho_{10000}}} v_{SL}$$

or,

$$v_{10000} = 1.154 v_{SL}$$

So, the true airspeed of an aircraft at 10,000 ft is approximately 15% larger than its indicated airspeed. An indicated airspeed of 100 MPH then is actually a true airspeed of 115 MPH. Again, this is because the air is less dense so the aircraft must actually move at a higher velocity to generate the same dynamic pressure. All of the aerodynamic coefficients are defined with respect to true airspeed, so we need to convert the indicated airspeeds to true airspeeds.

(f) Using the above relation for true airspeed at 10,000 ft and the attached sheet on longitudinal-plane dynamics, construct a table that contains the following information for each flight condition (watch your units!):
    indicated airspeed (ft/s)
    true airspeed (ft/s)
    vertical speed (ft/s)
    flight path angle (deg)
    Lift force (lb)
    L/D Ratio
    C_L
    C_D

(g) Plot vertical speed vs. true airspeed. What speed should this glider fly at to maximize its time aloft? (Hint: maximum time aloft for a glider occurs at the minimum descent rate)
(h) Plot L/D ratio vs. true airspeed. What speed should this glider fly at to maximize its gliding range?
(i) Plot C_D vs. C_L. From your plot, estimate C_{D0} and the wing efficiency factor e.
(j) From aircraft performance theory, the maximum L/D ratio and the speed at which the best L/D ratio occurs are:

$$\left(\frac{L}{D}\right)_{max} = \frac{1}{2}\sqrt{\frac{\pi e AR}{C_{D_0}}}$$

and

$$v_{max_{L/D}} = \sqrt{\frac{2W}{\rho S \sqrt{C_{D_0} \pi e AR}}}$$

compare the maximum L/D and speed for best L/D you found in part (h) against the theoretical predictions from the above two equations.

Aircraft Longitudinal-Plane Dynamics
Replace Figure 4.3 in the book with this figure and the following definitions.
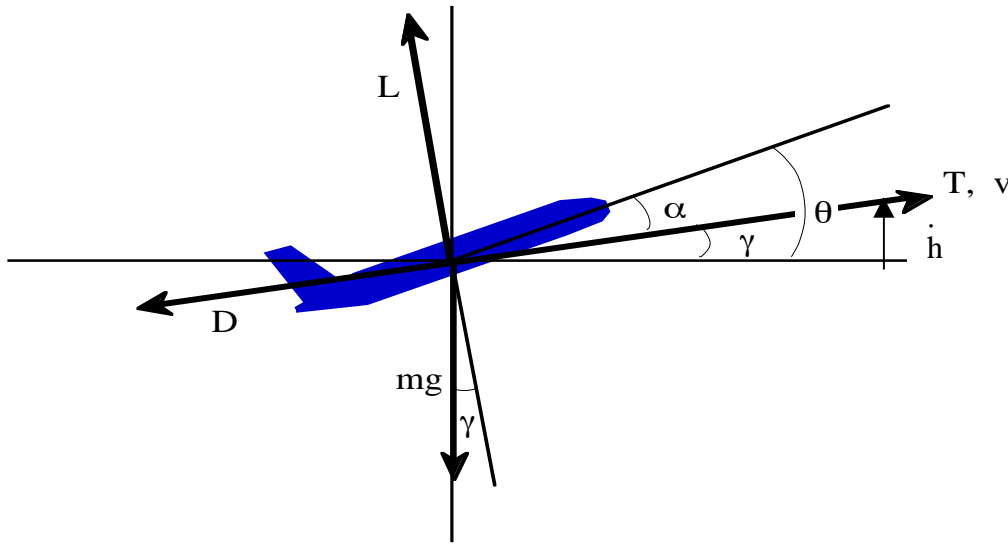
Definitions
Pitch angle (θ): angle from horizon to aircraft x-body axis (line passing through the plane's nose)
Flight path angle (γ): angle from the horizon to the aircraft's velocity vector
Angle of attack (α): angle from the aircraft's x-body axis to the velocity vector
True airspeed (v)
Lift (L): defined perpendicular to the velocity vector
Drag (D): defined parallel and opposite to the velocity vector
Thrust (T): defined along the velocity vector (simplification) [though in our case, T = 0 anyway]
Weight (W): directed downwards

Vertical speed ($\dot{h}$): $\dot{h} = v \sin(\gamma)$, so $\gamma = \sin^{-1}\left(\dfrac{\dot{h}}{v}\right)$

Force Balance in Steady Flight
Forces perpendicular to the flight path: $L = W \cos(\gamma)$
Forces tangential to the flight path: $T = D + W \sin(\gamma)$
In a glide, T = 0, and $L/D = \cot(\gamma)$

Other information
1 knot (kt) = 1 nautical mile per hour
1 MPH = 1 statute mile per hour
1 nautical mile = 6080 ft
1 statute mile = 5280 ft

Air density at

0 ft:	0.00237 slug/ft^3
9,500 ft:	0.00178 slug/ft^3
10,000 ft:	0.00175 slug/ft^3