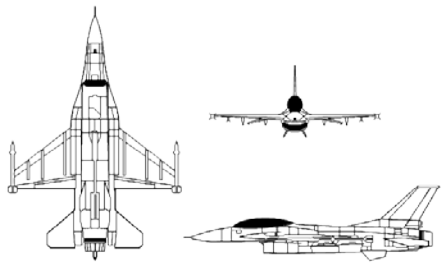
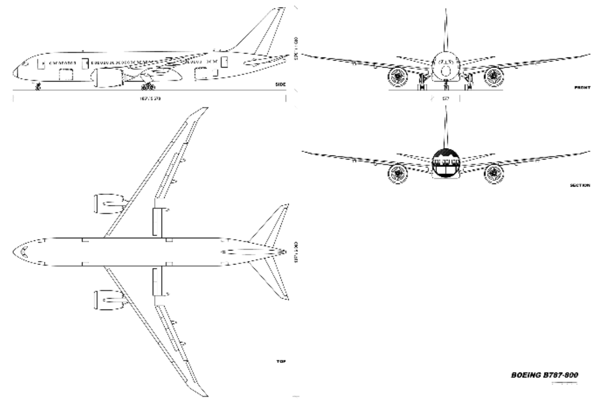
Experimental Laboratory 1: Low-Speed Aerodynamics of the Lockheed Martin F-16 and the Boeing 787 Dreamliner





ASEN 2004: Vehicle Design and Performance
Assigned: Wed 18 Jan 2017

Lab Reports Due: Thurs 9 March 2017, at the beginning of lecture

1 OBJECTIVES

1.1 Investigate the low-speed aerodynamic characteristics of the F-16 Fighting Falcon.

1.2 Determine how external stores affect the low-speed aerodynamic characteristics of the F-16.

1.3 Determine the low-speed aerodynamic characteristics of the Boeing 787 Dreamliner and compare the results with that of the F-16.

2 REQUIRED DELIVERABLES

2.1 Attendance at every lab period is required. Instructions for weekly tasks and the group report will be presented during the scheduled lab time.

2.2 Prepare a written group report of the results of your laboratory testing and analysis. Use the ASEN 2004 lab report guidelines provided in D2L for a short and precise report style. Every group member is required to write part of the report.

3 BACKGROUND AND PROCEDURE

3.1 Part 1: Low-Speed Aerodynamics of the Lockheed Martin F-16

In ASEN 2002 you investigated the pressure distribution and subsequent lift on an airfoil (based on a three-dimensional wing that spanned the test section). Since the focus of ASEN 2004 is the design and performance of aerospace vehicles, the present experiment is designed to use the wind tunnel to examine the low-speed aerodynamic characteristics of 2 aircraft: one with a low aspect ratio wing (F-16) and one with a high aspect ratio wing (B 787).

Specifically, we will start with two **1/48-scale** (length-wise) models of the Lockheed Martin (formerly General Dynamics) F-16 Fighting Falcon. Details of F-16 models tested at supersonic speeds can be found in NASA-TP-3355_1993 (posted on D2L) and used for comparison of trends if desired.

Because many manned and unmanned aircraft carry instruments, weapons, fuel tanks, etc. under the wings, one of the purposes of this experiment is to investigate the change in the aerodynamic properties of the F-16 model from the "clean" configuration to the configuration loaded with external stores ("dirty" configuration).

For this semester, each group will test one of the three models: Clean, Dirty or 787. Each group will analyze the data from all three models.

For a design and performance analysis we are interested in the coefficient of lift, C_L, the coefficient of drag, C_D, and the moment coefficient about the model center of gravity, C_M, all with respect to the angle of attack, α. Of particular interest is the *drag polar* (C_D vs. C_L) and a longitudinal stability plot C_M vs. α. Also plot C_L and C_D vs. α.

3.1.1 Background Information

1. On the sting balance being used, the Normal Force strain gauge bridges are differentially wired for direct reading so no arithmetic is involved in separating Normal Force and Pitching Moment as in conventional sting balances.

   The maximum load ranges are:

Normal Force/(Side Force):	25	lbs. (111.2 N)
Axial Force:	10	lbs. (44.5 N)
Pitching Moment/(Yawing Moment):	50	inch-lbs. (5.6 Nm)

   There is no need to worry about exceeding these values in this lab, but this information could be useful to know for future work.

2. Assuming the error at each sample set point is random, the sampled values then follow a normal distribution centered on the mean value $\bar{x}$:

   $$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

   The standard deviation for a small sample size of $n \leq 20$ is defined as:

   $$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2\right]^{1/2}$$

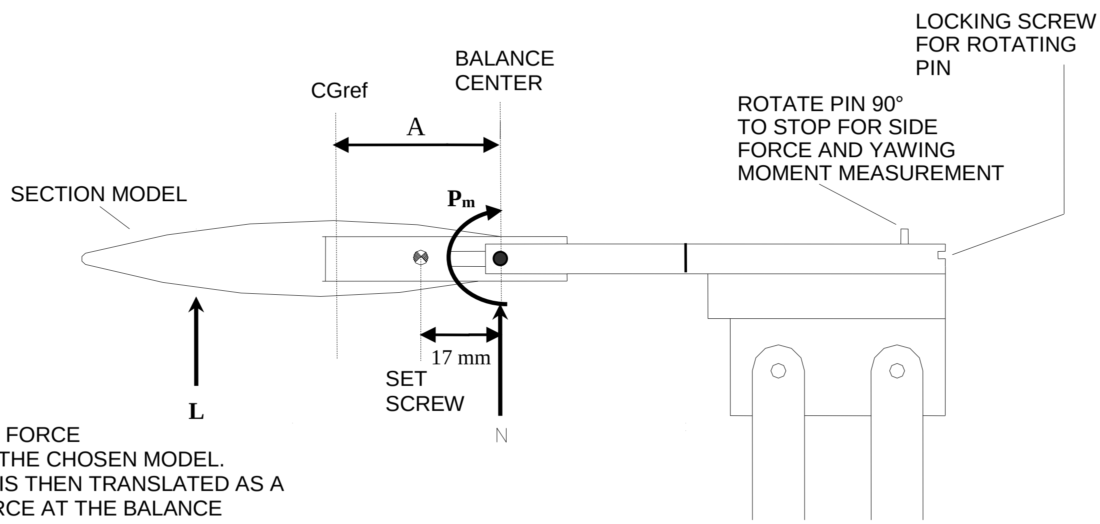
   Use these formulas to compute error bars of width $\pm 2\sigma$ for data analysis for the lab.

3. To convert the Normal Force and Axial Force to Lift and Drag components the following formulas should be used:

$$\text{Drag} = N \sin \alpha + A \cos \alpha$$
$$\text{Lift} = N \cos \alpha - A \sin \alpha$$

where α = angle of attack
N = Normal Force
A = Axial Force

4. The moment about the center of gravity (CG) reference point must be converted from the moment about the sting balance center measured by the LabVIEW VI.



NOTE:
L IS THE LIFT FORCE APPLIED ON THE CHOSEN MODEL. THIS FORCE IS THEN TRANSLATED AS A NORMAL FORCE AT THE BALANCE CENTER OF THE STING BALANCE.

NOTE:
PITCHING MOMENTS (Pm) READ ON LABVIEW VI ARE MOMENTS ABOUT THE BALANCE CENTER.

NOTE:
CGref = 0.3*cbar
THE DISTANCE FROM THE BALANCE CENTER TO THE CGref ON THE **CLEAN** MODEL IS:
A=14.4mm.

THE DISTANCE FROM THE BALANCE CENTER TO THE CGref ON THE MODEL WITH STORES, “**DIRTY**” MODEL IS:
A=15.5 mm.

THE DISTANCE FROM THE BALANCE CENTER TO THE CGref ON THE **787** MODEL IS: **A= 63.0mm**.

TRANSFER OF MOMENTS:
KNOWING THE PITCHING MOMENT ABOUT THE BALANCE CENTER (Pm) AND THE NORMAL FORCE (N) AS READ FROM LABVIEW VI, THE PITCHING MOMENT ABOUT THE CENTER OF GRAVITY POINT (Pm_{cg}) IS

$$P_{m_{cg}} = P_m - N(A)$$

IF N=0, A PURE MOMENT IS BEING APPLIED TO THE STING.

3.1.2 Wind Tunnel Set-Up and Operational Procedure

DESCRIPTION OF WIND TUNNEL AND APPARATUS

The AEROLAB Educational Wind Tunnel is of the Eiffel or Open Circuit type with a 12"x12" test section. The airspeed is infinitely variable from 0 to 64.8 m/s (145 mph).

All instrumentation is recorded digitally using National Instruments data acquisition hardware and a desktop PC. A LabVIEW VI is used to control airspeed and display and zero all sensor data. The available sensors/measurements used in this lab are the sting balance for Normal force, Axial force and Pitching moment; the airspeed pressure (dynamic pressure and a conversion to airspeed); the angle of attack of the sting (specimen); and the atmospheric pressure and temperature sensors.

HAZARDS TO AVOID

1. **The Test Section door is held open by a red latch. Do not try to close door without releasing latch. Do not let the door fall, it is brittle acrylic and could crack.**

2. **Do not leave any loose articles (such as screws, screwdriver) in wind tunnel as they will be launched into the fan and cause damage to the fan blades.**

3. **Check for any loose parts of test article before turning on the airspeed.**

4. **Do not open Test Section door with fan (air speed) running.**

5. For an emergency stop, press the red Stop button located on a small box to the right of the control panel. If necessary, turn off main 440V power switch mounted on wall behind wind tunnel.

6. Do not stand behind or near the rear of the wind tunnel during testing. It compromises the airflow in the tunnel and loose objects may be ejected from the fan causing personal injury.

PITOT PROBE INITIAL SETUP
Confirm that the pitot tube is installed in the test section door and that it is level.

STING BALANCE and MODEL INITIAL SETUP

1. If the sting balance and model are not already installed, contact Trudy Schwartz or Bobby Hodgkinson for assistance. Do not attempt to install the delicate strain gauge balance or the delicate aircraft models without assistance.
2. Level the aircraft model Angle of Attack (AoA) in pitch using the silver hand screw located beneath the test section and the aircraft specific level mount block.
    a. Ensure aircraft model is also level in roll. If not contact lab assistants.

PROCEDURE:

1. **1.** Verify/activate the following five switches:
   - **a.** The main 440V power switch is turned ON (located on the far left wall).
   - **b.** SCXI chassis power is turned ON (located on the platform below the test section).
   - **c.** Instrument panel power is turned ON (the switch to the left of the monitor should be deflected up).
   - **d.** The HP 6205 power supply under the SCXI chassis is turned on.
   - **e.** The emergency stop button is disabled (i.e. turned clockwise).

2. Open the WT2016.vi located in your ASEN 2004 class folder. Run the VI by clicking the “arrow” button in the upper left corner. The user must input the local air density in the window that displays. Use the passcode given to bypass this calculation.

3. The VI will prompt you for the filename and location to store logged data. At this point the VI is displaying data only and it is NOT logging data.

- **a.** Be sure to follow the proper naming convention “MODEL’_GXX.CSV for your group number. Refer to the group assignment spreadsheet on D2L.

4. Before setting a desired airspeed, you must zero the relevant sensors that you plan to use to remove initial offsets.

- **a.** Zero the pressures by clicking on the Pressures tab and click on the “Zero Pressure and Airspeed” button. NOTE: The airspeed pressure is the dynamic pressure determined by the difference of the stagnation port of the pitot tube minus the static port. This pressure is displayed and recorded for reference and is also converted to a velocity (displayed on the right side of the VI). Remember, zeroing the airspeed pressure also zeroes the airspeed.
- **b.** To zero the sting balance, click on the Forces tab and click on the “Zero Forces and Moment” button. The VI will pause for about 30 seconds until the zeroing is complete. Wait until data begins scrolling on the plot before continuing.
- **c.** To zero the angle of attack, first make sure that the sting and/or specimen is set to a zero angle of attack. The angle of attack of the sting may be adjusted using the hand screw located below the test section. Then click on the Angle of Attack tab and the “Zero Angle” button.

5. You will be covering the angle of attack (AoA) range $-8° \leq \alpha \leq 20°$ in 2° increments, even angles for even numbered groups and odd angles for odd numbered groups.

- a. When performing the experiment, the angle of attack should be changed manually by carefully moving the mechanism until you receive the desired angle of attack to within one decimal place, i.e. for desired angle -8 set to -8.0x which is one zero past the decimal point. Start at your lowest AoA, either -8 or -7 deg, and progress up through your highest AoA. (Testing in the reverse order could cause hysteresis in the AoA mechanism AND could change how the flow separates in the wind on section of testing. Testing should be done with attached flow first and then progress up in AoA.) Send 20 samples to the datafile for each AoA.

6. First perform a wind off measurement for your range of angle of attack measurements. With the airspeed turned off, record the normal and axial forces due to the weight of the model as it translates to the normal and axial direction for each angle of attack.
    a. Press ‘send the samples to file’ to record 20 data points for each AoA.
    b. Tip: Write down the actual wind off angle of attack for the dataset you save. It is more important that the wind on angle of attack is precise relative to the wind off angle of attack than to the assigned angle of attack (i.e. accuracy).
    c. NOTE: In order to maintain the same ‘zero’ angle of attack between the wind off and wind on measurements DO NOT stop the .vi after the wind off measurement. The wind on measurements will be appended in the same file as the wind off measurements.
7. Rotate the silver hand screw to set the aircraft back to the first, lowest angle of attack and increase the airspeed to 25 m/s for the wind on test.
    a. Adjust the angle of attack if necessary to closely match each wind off angle that was achieved above.
    b. NOTE: The real time controller will adjust the voltage to the fan as needed to maintain the desired airspeed within tolerances. As the AoA changes, the blocked area changes which will require the voltage to the motor to compensate.
    c. Wait for the airspeed to stabilize and press ‘send the samples to file’ to record the data for each AoA.
8. Return the model to the zero angle of attack. Stop the .vi. Verify the data file was saved correctly. Rename (or use ‘save-as’) your data file according to the assigned naming convention and upload it to the shared directory on the ASEN 2004 class folder.

NOTE: If you stop and restart the Wind Tunnel VI you will have to re-zero all of the sensors as well as the model.
NOTE: Be careful not to change any of the sensor zeros while the fan motor is running otherwise you may have to power down the wind tunnel and re-trim the sensor signals.

MISC:

CONTROLLING AIRSPEED
Airspeed is controlled from a dial within the VI. To achieve a specified airspeed, either rotate the dial until the desired airspeed is shown in the numeric readout accompanying it, or simply enter the desired airspeed in the numeric entry.

LOGGING DATA WITH THE VI
The VI logs data in the folder specified by the user.

The VI will only log data to the current log files when you click the “Send Samples to File” button located in the upper left corner of the VI, under “Inputs”. Every time this button is pressed it appends 20 samples to the current log file.

Keep track of each AoA that you press the send samples button. A digital counter on the VI displays how many times you have sent data to the file.

TURN OFF PROCEDURE
(Confirm that you are the last group to perform this test before powering down system.)

1. Perform the following:
   a. Turn OFF (down) the Instrumentation Panel switch.
   b. Turn OFF (down) the SCXI chassis switch.
   c. Turn OFF (press) the HP 6205 power supply button.
   d. Turn OFF (down) the 440V panel switch and lock the padlock.

3.2 Part 2: Low-Speed Aerodynamics of the Boeing 787 Dreamliner

Next, we will move on with one **1/225-scale** (length-wise) model of the Boeing 787 Dreamliner.

We've seen that military aircraft such as the F-16 carry instruments, weapons, fuel tanks, etc. under the wings; commercial aircraft also exhibit a "dirty" configuration consisting of flaps, landing gear and engine cowls during reverse thrust on landing. We will not be investigating the 787's "dirty" configuration.

For a design and performance analysis, again we are interested in the coefficient of lift, C_L, the coefficient of drag, C_D, and the moment coefficient about the model center of gravity, C_M, all with respect to the angle of attack, α. Of particular interest here is the *drag polar* (C_D vs. C_L) plot to compare with that of the F-16. Also plot C_M and C_L vs. α.

1. Repeat Parts 3.1.1 and 3.1.2 with the 787 Dreamliner model.

4 OBJECTIVES (Questions to be answered in lab report – use your plots to make comparisons)

1. What is the primary effect on the aerodynamic coefficients of the F-16 from the addition of external stores?
2. Why are stores not carried on the upper surface of the wing?
3. What is the minimum landing speed for the F-16 model, both in the "clean" and "dirty" configurations? Minimum landing speed for military aircraft is specified as 1.2 * V_{stall}. If there is a difference, what might cause it?
4. What is the minimum landing speed of the full-scale "clean" F-16, at the altitude of the Lab, according to the wind tunnel speed and the standard atmosphere? Assume the aircraft weighs 30,000lb at landing.
5. What is the static longitudinal stability $dC_M/d\alpha$ of the "clean" F-16 model at $\alpha = 0$? The $dC_L/d\alpha$ at $\alpha = 0$?
6. If static margin (SM) is defined as – $(dC_M/d\alpha)/(dC_L/d\alpha)$, what is the static margin of the "clean" F-16 model at $\alpha = 0$?

7. What is the minimum landing speed for the 787 model? Minimum landing speed for civilian aircraft is specified as 1.3 * V_{stall}.
8. What is the minimum landing speed of the full-scale 787, at the altitude of the Lab, according to the wind tunnel speed and the standard atmosphere? Assume the aircraft weighs 360,000lb at landing. Note: This speed will be extremely high since we are landing it “clean” without accounting for the effects of flaps, gear drag, and thrust reversal upon landing. Airplanes landing in certain emergency situations (loss of hydraulics) actually have to land at these high speeds!
9. What is the static longitudinal stability $dC_M/d\alpha$ of the 787 model at $\alpha = 0$? The $dC_L/d\alpha$ at $\alpha = 0$?
10. What is the static margin of the 787 model at $\alpha = 0$? Which model exhibits more longitudinal static stability – the “clean” F-16 or the 787? Is this what you expected? Why or why not?
11. Which aircraft model exhibits a higher lift-to-drag (L/D) ratio – the low aspect ratio F-16 or the higher aspect ratio 787? Why?