THE UNIVERSITY OF TEXAS AT ARLINGTON
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

MAE 3182:

Aircraft Model Aerodynamic Forces and Longitudinal Stability

Version – Spring 2022

I. Learning Objectives

- Use previously defined calibration curves to determine lift, drag and pitching moment for an aircraft model
- Complete data reduction considering model geometry and placement

II. Equipment

- PC with external data acquisition system – Dell PC with PCI-6034E DAQ card
- SCB-68 DAQ connection box
- Pitot tube- Custom made
- Stepper Controller- Velmex Inc. QC110-AR
- LabVIEW software
- Low-speed wind tunnel, Model AF100, TecQuipment Ltd.
- Three Component Balance, AFA3, TecQuipment Ltd.
- Sting mount arm, custom made
- Vought A7- Corsair aircraft model

III. Introduction

Knowing the aerodynamic attributes of an aircraft is critical in determining its performance in different conditions. Obtaining the attributes of a full size aircraft poses a problem due to cost, equipment needed, and the size of the facility required to run the test- in many cases these combine to make full scale testing impossible. The way to circumvent this is to scale down the aircraft and use corrections to predict the characteristics of the full sized aircraft. Since force is dependent on the value of the gravitational constant g, elaborate methods are required to obtain accurate values of g. In this laboratory, we will ignore this aspect for simplicity and merely use the values of the weights used in the previous lab experiment, "AFA3 Force Calibration." In practice, the laborious effort in accurately calibrating force balances is done automatically using computerized rigs which are housed in a temperature-controlled cabin. Finally, force balances and their calibration are governed by test codes.

There are multiple different fixture methods for suspended wind tunnel models, but most use the same notion of u-joints placed geometrically allowing for a number of degrees of translational and rotational freedom, within a specific deflection range. Outside of this deflection range, the accuracy or functionality of the system will decay significantly. Generally, force balances are rugged and designed with a large margin of safety within operating ranges. However, as may be obvious, the model mount arm, being of considerable length, is subject to deflections. The deflections affect the accuracy of the data, especially of moment data. Deflections can also affect force data.

The reaction forces taken from the model in a low speed wind tunnel at different angles of attack are used to determine several aerodynamic characteristics of a full aircraft model. This data then can be used to find the aerodynamic properties of the model which can be used to determine the aircraft's stability. Using a calibration curve previously generated, the intention of this laboratory experiment is to calculate lift, drag and pitching moment on a 1:50 scale model of an A-7 Corsair aircraft model mounted on a sting arm.

IV. Theory

The two philosophies for wind tunnel testing are using a mounting arm normal to the flow direction, or mounting with a sting arm from behind. Mounting from in front of the primary aerodynamic surfaces is usually avoided due to the effect the structure has on the flow. All mounting systems will influence the flow, but placing the mounts rearward of the aerodynamic surfaces limits the effect on the freestream flow quality.

Repeating from the previous lab manual, the aerodynamic forces and moments of interest, the lift force, drag force, and pitching moment are related to the forces measured by the AFA3 (fore, aft, and drag force) as shown in equations 1-3.

$$Lift(N) = Fore(N) + Aft(N) \tag{1}$$
$$Drag(N) = Drag(N) \tag{2}$$
$$Pitching\ Moment\ (Nm) = \big(Fore(N) - Aft(N)\big) * 0.0635 \tag{3}$$

These forces that are measured by the AFA3 force balance are centered at the centerline of the model clamping axis, so they will need to be shifted and modified to be calculated for the aircraft model itself.

V. Experiment Description

A. Apparatus

The AFA3 Force Balance, shown in Figure 1, mounts directly to the wind tunnel and allows for insertion of multiple model types. In the case of this experiment, a sting arm with an aircraft model will be mounted and tested. The aircraft model mounted in the wind tunnel section is shown in Figure 2 and Figure 3.

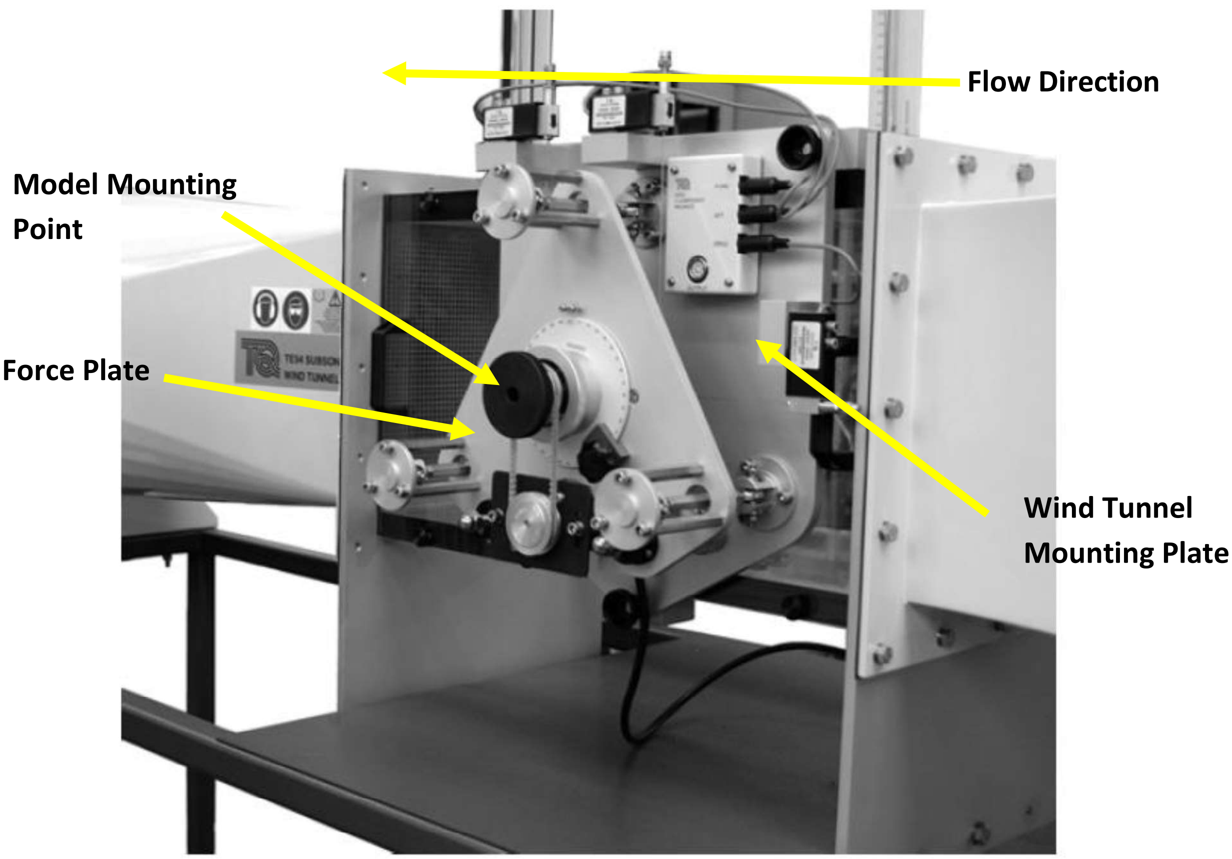

Figure 1. AFA3 mounted on AF100 Wind tunnel located in WH221

During this experiment the static and dynamic pressure of the flow will be calculated and used to determine the freestream velocity of the flow. The pitot tube, seen in Figure 2, is mounted parallel to the leading edge of the aircraft model. The aircraft model will be swept through a series of angles of attack and the lift, drag, and pitching moments will be measured at each angle of attack, from 0 to 20 degrees in 2 degree increments. Using the freestream velocity of the flow and the geometry of the model, the applied lift, drag and pitching moment can be found for the system, and for the model itself.

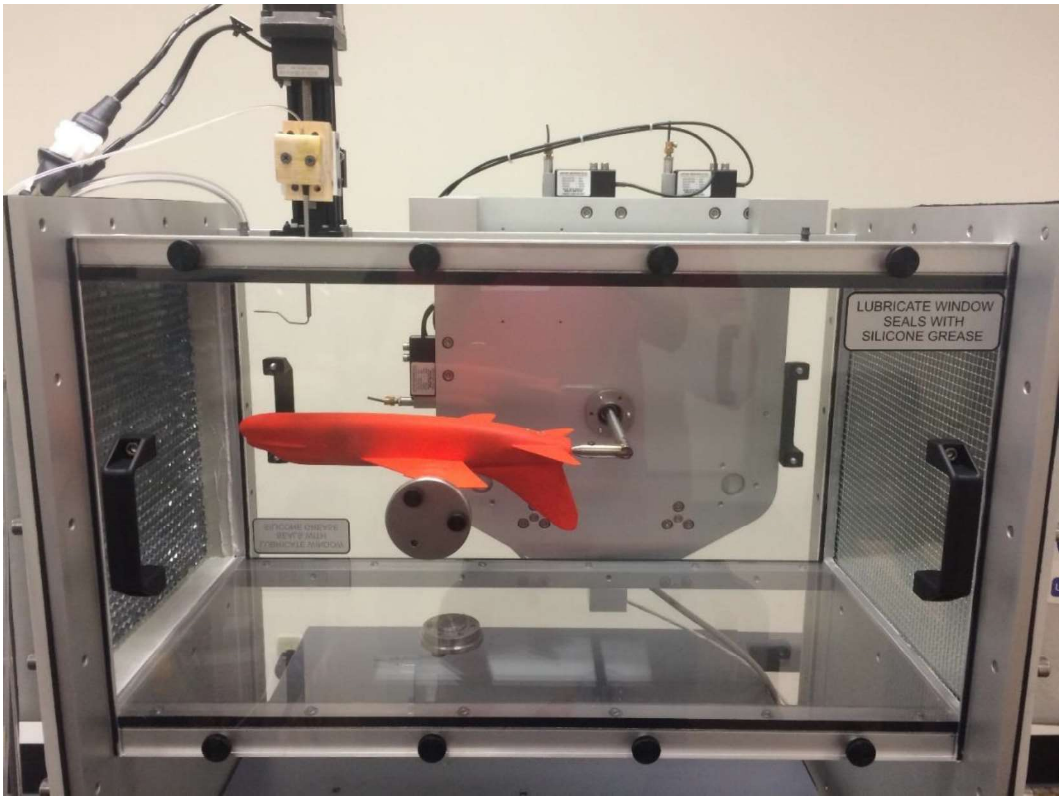

Figure 2. A-7 Corsair aircraft model mounted in the wind tunnel

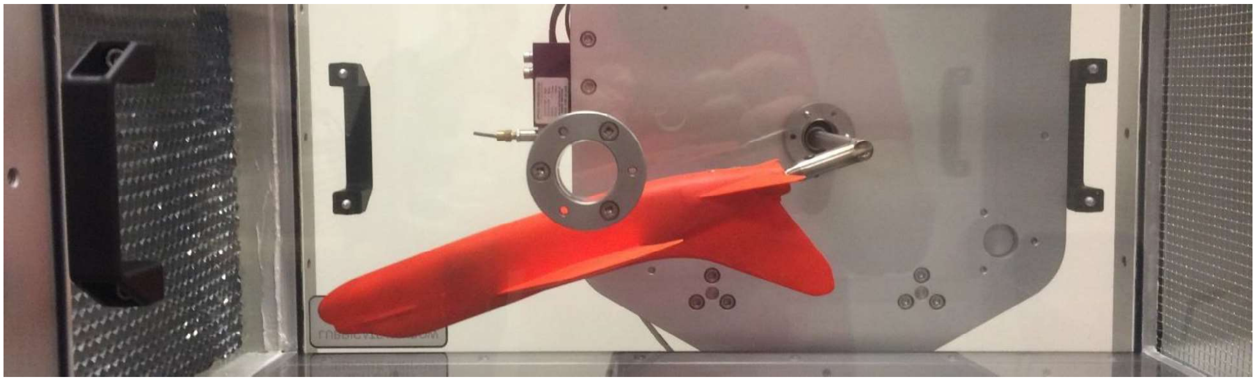

Figure 3. Corsair Aircraft Model at 20 degree angle of attack

Error source: using the wheel to manually change the AOA

B. Experimental Procedure

Using the instructions below, the experimental calculation of the lift, drag and pitching moment generated at the force mounting plate will be measured. During the test the wind tunnel velocity will be set low, because due to the length on the sting arm the model will produce significant moment. To stay within the safe operating conditions of the force balance system, the dynamic pressure of the wind tunnel will be kept below 20 mm H_2O. Data will be collected using the LabView VI Software shown in Figure 4. The experimental instructions are as follows.

1. Switch on the Power Display Module and allow the setup to warm up for at least 15 minutes (manufacturer recommendation)
2. Record the ambient temperature and pressure of the test room.
3. Mount the A-7 Aircraft model onto the sting arm, then insert the sting arm into the mount collar on the AFA3 force balance.
4. Position the aircraft model approximately horizontal (along the flow axis) and ensure the goniometric wheel is set to 0 degrees, as shown in Figure 2. Tighten down the lock collar onto the mount arm.
5. Start the LabView Data Acquisition Software. The values will not read zero because the model and mount are placed in the system. Record the offset voltage readings on the load cells experienced due to the aircraft model's weight.
6. Start the AF100 wind tunnel and set the dynamic pressure to approximately 18 mm H_2O.
7. For data collection, five second increments of data will be taken for each position tested.
   - Once the voltage readings on the LabView VI have stabilized, press the "Record Data" button on the LabView VI.
   - Record data for 5 seconds, then press the "Record Data" button again to stop collecting data- do Not press the "Stop" button on the LabView VI or the data will be saved into separate files.
8. Repeat Step 6 for every 2 degree increment between 0 and 20. There will be 11 data sets in the excel file.

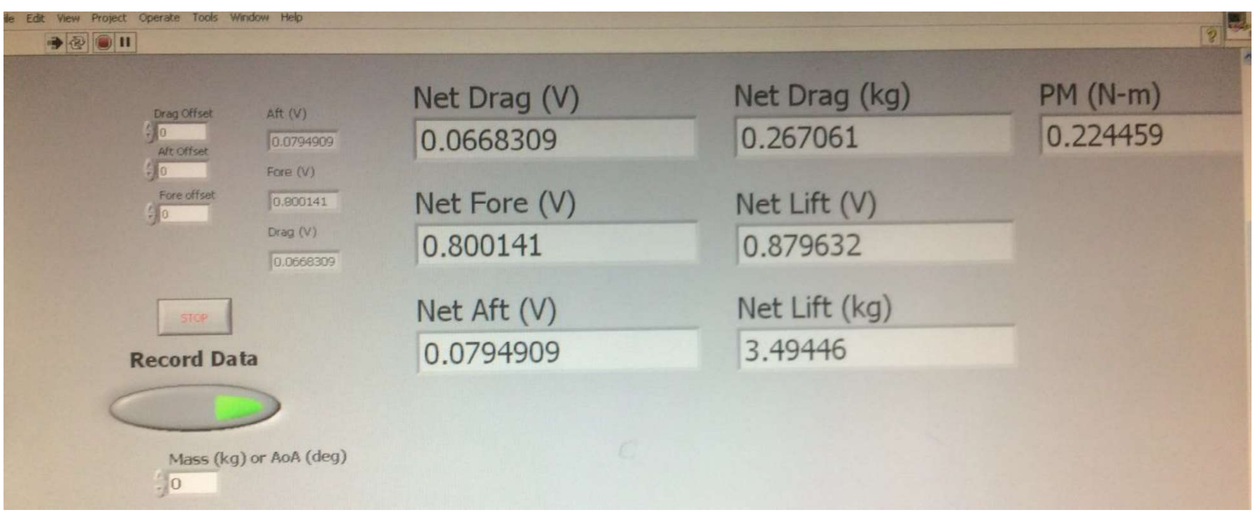

Figure 4. LabView VI window for data collection

C. Data Reduction

The data received from the excel files will need to be reduced to determine the lift, drag and pitching moment for the aircraft model, as well as their non-dimensional coefficients C_L, C_D and C_M. Along with the experimental data excel file, you will also receive an excel file of the calibration curves that you will use for the analysis.

Before we complete the data reduction, we must consider the geometry of the model in question to determine how the data must be properly modified to determine the aerodynamic forces of the model and not the forces applied by the entire mount system. The A-7 Corsair 3 view drawing is shown in Figure 5.

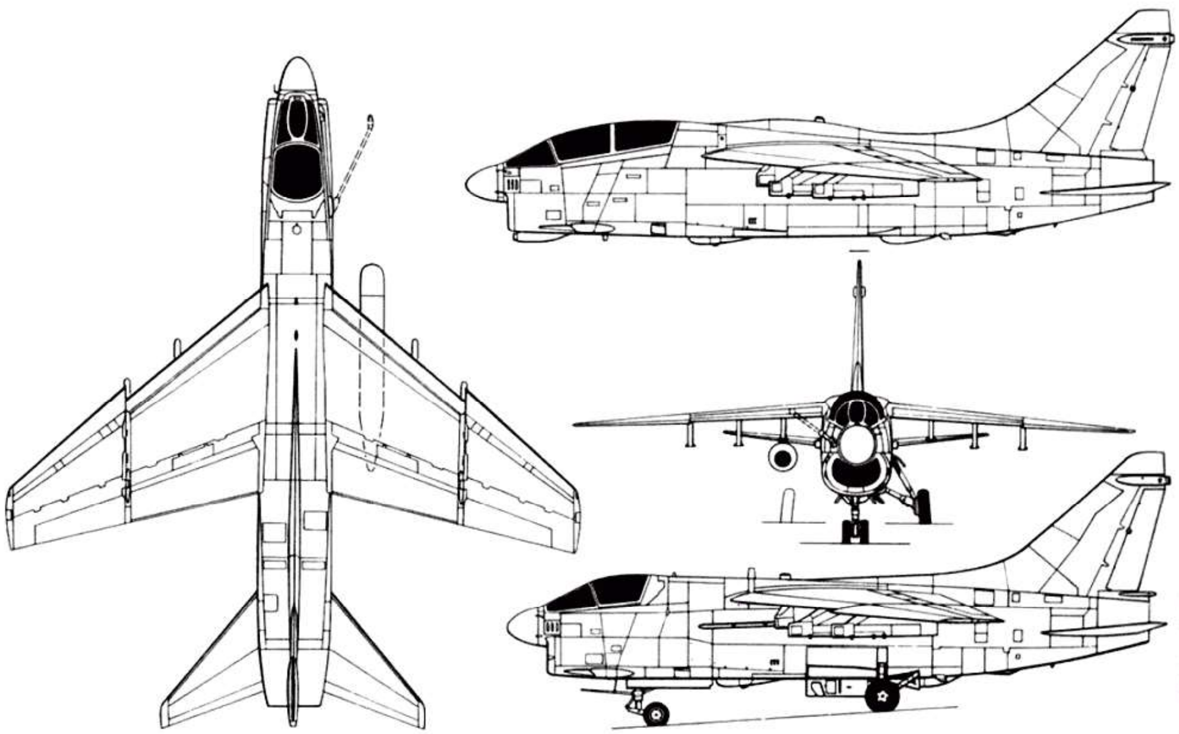

Figure 5. A-7 Corsair Aircraft 3-View Drawing [2]

From this model drawing the Mean Aerodynamic Chord ($\bar{c}$) and approximate CG location can be determined using scaling methods. This information has been given below, along with the primary characteristics of the model, scaled from the original aircraft dimensions.

Table 1. List of Primary Geometric Characteristics of Mount and Aircraft Model

Model Scale	1:50
Model Length	0.287m
Wing Span	0.236 m

Wing Area	0.01393 m^2
Mean Aerodynamic Chord	.0661 m
Distance from rotational axis to total system CG	0.33 m
Distance from rotation axis to nose	0.367 m
Distance from tail of craft to rotational axis	0.045 m
Distance from Rotational Axis to Wing MAC	0.182 m
Distance from Rotational Axis to Original Aircraft CG	0.199 m
Model mounting arm mass	0.31 kg
Model Mass	0.15 kg

The aircraft model itself is not applying forces at the CG of the vehicle, so the forces and moments determined must be determined based upon the distances shown in Table 1. Using basic equations for force and moment conversion, the loads applied at the resolved center (the center axis of the mount) must be reduced further to determine the actual results. The position of the respective CG of the model, the arm, and the assembly are shown below on Figure 6.

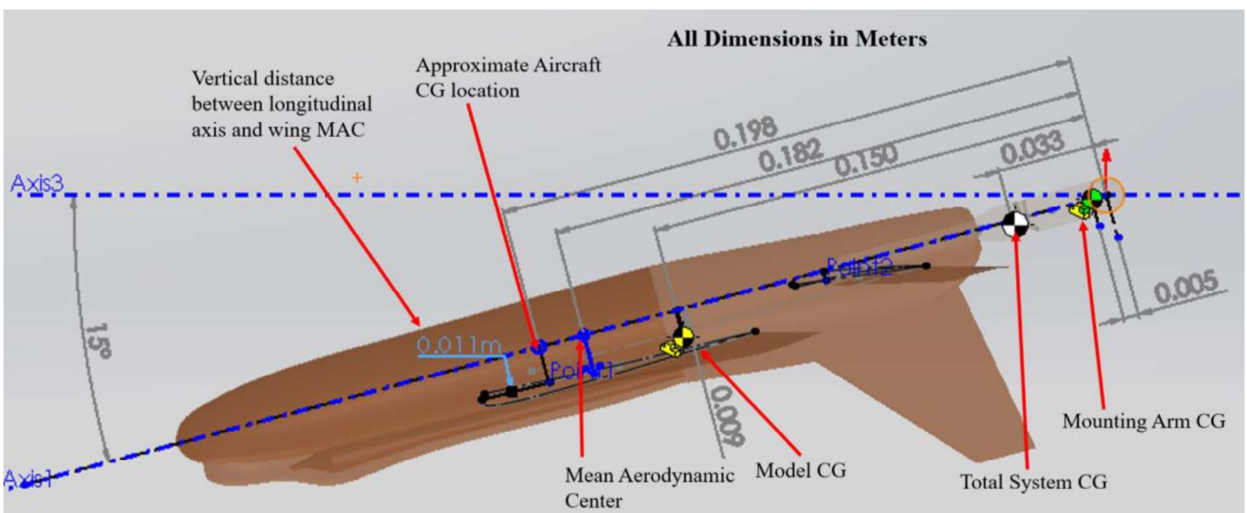

Figure 6. Aircraft Model with dimensions of the position of the MAC, system CG, and original craft CG

To determine the forces and moments on the model using the values shown in Table 1, the following processes must be performed to reduce the data

1. Take the average of each data set for fore, aft, and drag. The first data collected is the still air offset point, which will be used to find the new offset voltages. Then, using the calibration curves

provided determine the loads applied for each of the 11 angles of attack. Remember, because the calibration curves were created in the form, $F = K*(V-V_{offset})+B$, we can take the still air offset voltage for each load cell as V_{offset}, and use the K and B retrieved from the previous calibration.

2. Use the calibration curves supplied to determine the raw lift force and drag forces, in Newtons, applied at the mounting point. Also determine the raw pitching moment applied at the mounting point in N-m
3. Find the resulting coefficients of lift and drag on the tested model using the reference wing area supplied.

$$C_L = \frac{L}{q_\infty S_{ref}}$$

$$C_D = \frac{D}{q_\infty S_{ref}}$$

4. **(Extra Credit)** To determine the pitching moment of the aircraft model, the forces must be resolved to the actual Aircraft CG location, and the pitching moment must be translated to this location. Assuming the dimensions shown in Figure 6 represent the scaled model position of CG and MAC locations, translate the moment generated at the force balance axis to the CG axis.

$$C_{M,CG} = \frac{M_{cg}}{q_\infty S_{ref}\bar{c}}$$

VI. Report Requirements

The report should include an appropriate introduction and procedure. It should be written from the standpoint that you are performing the experiment to determine the aerodynamic forces on the model.

A. Calculate Lift and Drag of the Model

1. Tabulate the lift and drag forces (in Newtons), and pitching moment about the pivot point (in N-m) for all angles of attack.
2. Plot the coefficients of lift and drag vs. angle of attack.
3. Calculate the Reynolds number using the total length of the aircraft as the reference dimension. Discuss the effects of Reynolds number on the testing of this model aircraft? Is this Reynolds number representative of the Reynolds number this aircraft would see in actual operation?
4. Plot the drag polar of the aircraft. Is it possible to determine the zero-lift drag coefficient? If so, what is it?
5. **(Extra Credit)** Plot CM_{cg} vs. angle of attack. Discuss all of the procedure and equations used to find the correct pitching moment about the model center of gravity. Credit will not be given unless the explanation and result are fully correct.

b. Discussion of measurements and results

1. Comment on possible sources of error from this mounting method.
2. The voltages measured by the aft sensor were negative at some points, but no data was taken within the negative range during the calibration. Is this acceptable? Why or why not?

3. Considering the Geometry of the system, is the offset provided sufficient or should the offset be considered for each angle of attack?

References

[1] "AFA3 Three Component Balance User Guide". TecQuipment Limited 2014. DM/MB/AD/0814.

[2] "Vought A-7 Corsair II - Carrier-borne Close Support Aircraft." *Vought A-7 Corsair II - Carrier-borne Close Support Aircraft*. Virtual Aircraft Museum, n.d. Web. 23 Apr. 2016. http://www.aviastar.org/air/usa/ling_corsair.php