

Project Assignment #3  
Cruise and Approach Analysis of BWB  
Due: October 19 at the end of lab

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## 1 Objective

The objective of this Project Assignment is to determine if the approach and cruise design constraints can be met by the BWB. This determination will be made using the aerodynamic models developed and validated in the previous Project Assignments.

## 2 Operating Condition Specifications and Constraints

### 2.1 Cruise

1. Cruise altitude is 39,000 feet
2. Mach number,  $M_\infty = 0.85$
3. Assume cruise weight is Maximum take-off weight (MTOW), and  $MTOW = 800,000$  lbs.
4. 5% static stability margin (see Section 4 for more on static stability).
5. Flaperons are not to be deflected in cruise.

### 2.2 Approach & Stall

1. Approach speed = 150 knots (set by air traffic safety)
2. If the sectional  $c_{l_{\max}} < 1.2$ , then slats will not be needed in the design. With slats, then  $c_{l_{\max}} = 1.6$ . Note: these limits will set the maximum lift and, therefore, determine the stall speed. In either case with or without slats, the winglet  $c_l$ 's are not required to be below  $c_{l_{\max}}$ .
3. Approach speed =  $1.3 \times$  stall speed (for safety)
4. Aircraft is carrying full payload with 25% fuel remaining. Assume aircraft empty weight is 400,000 lbs, payload is 200,000 lbs, and fuel weight is 200,000 lbs.
5. 5% static stability margin at approach and stall speeds.
6. Flaperons can be deflected in approach and stall conditions, but, the same flaperon deflections must be used for both.

### 3 Flaperons

The BWB has five flaperons which can be deflected to achieve the approach operating constraints. Note, flaperons can act both as flaps and ailerons; thus, positive (downward) and negative (upward) deflections are permitted. The location and size of the flaperons are given in Table 1.

Flaperon #	$y_{start}$ (ft)	$y_{end}$ (ft)	$x_{hinge}/c$
1	10	20	0.9
2	70	90	0.7
3	90	110	0.7
4	110	120	0.7
5	120	130	0.7

Table 1: Flaperon span and hinge locations.

**IMPORTANT NOTE:** A new AVL input file is required to deploy the flaperons. This file can be downloaded from the MIT Server using the link for the AVL input files (this link has an archive file with the new input data for flaperons).

### 4 Static Stability & Margin

This section is a quick review of static longitudinal (i.e. pitch) stability of an aircraft. It is not comprehensive, but will be enough to complete the project. For more, consult your notes from Dynamics (16.07).

The basic concept behind static stability is to determine whether or not an aircraft will restore itself to steady, level flight conditions when the angle of attack is perturbed. First, note that in steady, level flight, the aerodynamic moment about the aircraft’s center of gravity must be zero, i.e.

$$M(x_{cg}) = 0, \tag{1}$$

Since the location at which the aerodynamic moment is zero is known as the center of pressure,  $x_{cp}$ , then Equation (1) requires,

$$x_{cp} = x_{cg}. \tag{2}$$

Summarizing this, the aerodynamic center of pressure must coincide with the aircraft’s center of gravity in steady level flight.

**ASSUMPTION:** For the remainder of the project, we will assume that the aircraft’s center of gravity can be made to coincide with it’s center of pressure. In practice, this is achieved through a combination of weight balancing to move the center of gravity (e.g. moving passengers, cargo, or fuel) and trimming the aircraft to move the center of pressure (e.g. deflecting ailerons or flaps).

Unfortunately, a design that achieves  $x_{cp} = x_{cg}$  may still be statically unstable. For an airplane to be statically stable, if the angle of attack changes then a restoring moment must occur to return the aircraft to the steady level angle of attack. Specifically, if the angle of attack increases, then the moment at the aerodynamic moment at the center of gravity should be nose down (i.e. negative). Analogously, if the angle of attack decreases, then the moment at the aerodynamic moment at the center of gravity should be nose up (i.e. positive). Mathematically, this requires that,

$$\frac{dM_{cg}}{d\alpha_\infty} < 0. \tag{3}$$

If  $dM_{cg}/d\alpha_\infty > 0$ , then an increase in the angle of attack would increase the moment and cause a further increase in the angle of attack (i.e. an unstable feedback). Furthermore, We will assume that the lift increases (decreases) when the angle of attack increases (decreases), i.e.,  $dL/d\alpha_\infty > 0$ . Then, Equation (3) can also be written as,

$$\frac{dM_{cg}}{dL} < 0. \quad (4)$$

The moment at one location ( $x_0$ ) can be related to the moment at another location ( $x_1$ ) through,

$$M(x_1) = M(x_0) + (x_1 - x_0)L.$$

Using this we can relate the moment at the center of gravity to the moment at the aerodynamic center,

$$M_{cg} = M_{ac} + (x_{cg} - x_{ac})L. \quad (5)$$

Differentiating with respect to  $L$  gives,

$$\frac{dM_{cg}}{dL} = \frac{dM_{ac}}{dL} + (x_{cg} - x_{ac}).$$

Since  $dM_{ac}/dL = 0$ , then the requirement for static stability (i.e. Equation 4) can be equivalently written as,

$$x_{cg} < x_{ac} \Rightarrow x_{cp} < x_{ac}. \quad (6)$$

In other words, the center of pressure must lie in front of the aerodynamic center for an aircraft to be statically stable.

The static stability is usually reported in a non-dimensional number known as the stability margin,

$$\text{Margin} \equiv \frac{x_{ac} - x_{cp}}{c_{mac}}. \quad (7)$$

For example, a 5% margin implies that,

$$\frac{x_{ac} - x_{cp}}{c_{mac}} = 0.05.$$

If an aircraft is not statically stable, then its margin will be negative.

It is also possible to show that  $M_{ac} > 0$  for static stability. This conclusion can prove useful when determining the flaperons' deflections required to achieve the approach operating constraints. To prove this, note that  $M_{cg} = 0$  (required for steady level flight),  $x_{cg} < x_{ac}$  (required for static stability), and assuming  $L > 0$ , then Equation (5) directly leads to  $M_{ac} > 0$ .

In summary, three equivalent ways to state the condition for static stability are,

$$\frac{dM_{cg}}{dL} < 0, \quad x_{cp} < x_{ac}, \quad M_{ac} > 0.$$

## 5 Required Tasks

Note: the points for each of the tasks is given with each item.

## 5.1 Cruise Analysis

- (5 pts) Determine the cruise lift coefficient.
- (5 pts) Using AVL, estimate the cruise angle of attack.
- (5 pts) Using AVL, estimate  $x_{ac}/c_{mac}$ ,  $x_{cp}/c_{mac}$ , and the stability margin at cruise.
- (10 pts) Plot  $x_{ac}/c_{mac}$  and  $x_{cp}/c_{mac}$  versus  $C_L$  from  $C_L = 0$  to twice the cruise  $C_L$ .

## 5.2 Approach Analysis

Note: for approach, you will need to determine flaperon deflections that can (hopefully) meet all of the operating constraints. This may or may not be possible. If it is possible, there will likely be more than one solution, you just need to find one.

In the following list of required tasks, use your ‘best’ flaperon settings that either meet or come closest to meeting all of the constraints.

- (10 pts) For approach and stall conditions, calculate the Mach numbers and the required  $C_L$ 's.
- (5 pts) What were the deflection angles for the five flaperons?
- (5 pts) Did you need to use slats with these flaperon settings?
- (5 pts) For approach and stall conditions, use AVL to estimate  $x_{ac}$ ,  $x_{cp}$ , and the static margin.
- (30 pts) Describe the method you used to determine your ‘best’ flaperon settings. If you could not find a set of flaperon deflections that met all constraints, provide a rationale for which constraint(s) you decided to relax.
- (5 pts) Plot  $c_l(y)$ ,  $c_l(y)c(y)/c_{mac}$ , and the induced angle of attack (i.e. using the Trefftz plane plot) at the approach conditions.
- (5 pts) Plot  $c_l(y)$ ,  $c_l(y)c(y)/c_{mac}$ , and the induced angle of attack (i.e. using the Trefftz plane plot) at the stall conditions. Also include a zoomed in version of this plot which highlights the  $c_l$  range around the  $c_{l_{max}}$  constraint. For example, if you are using slats, zoom in the plot from approximately,  $1.4 < c_l < 1.8$ . Reminder: the winglet is not required to have  $c_l$ 's below the maximum limit.
- (10 pts) Plot  $x_{ac}/c_{mac}$  and  $x_{cp}/c_{mac}$  versus  $C_L$  from  $C_L = 0$  to the stall  $C_L$ . For this plot, fix the Mach number at the approach conditions.

**Note on Printing Trefftz Plot:** To print the Trefftz plane plot, use the command ‘h’. This will append the current plot to a PostScript file called **plot.ps**. This file can then be converted to many other file formats including PDF.

## 5.3 Report Conventions

- Only one report is required for each person.
- Include a breakdown of how the work was accomplished between you and your partner.
- Both partners must sign the report.