EAE 129 Midterm Report  
**Longitudinal Static Stability and Control of the Aggie UAV**

Analysis of Preliminary Wind Tunnel Data and Suggestions for Improvement

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**Abstract**

Understanding the stability and control characteristics of an aircraft is essential for ensuring safe and efficient flight performance. This report analyzes wind tunnel data to estimate key aerodynamic and stability derivatives for the Aggie UAV, evaluating its longitudinal static stability. The relationships between the lift coefficient (​), moment coefficient (​​), and angle of attack (​) were examined across different elevator deflections.

The lift coefficient was found to increase linearly with angle of attack, with elevator deflection shifting the curve as expected. The pitching moment coefficient (​) decreased with increasing , confirming the fundamental stability requirement that . However, the shallow slope suggests the aircraft may have weak damping in pitch oscillations.

The stability margin was determined using two approaches (**Stability Margin Equation**). Both methods confirmed that the UAV is longitudinally statically stable (, but the small static margin (~1.5% of the mean aerodynamic chord) suggests it is very close to neutral stability. This could lead to minimal restoring forces after disturbances, requiring careful control inputs to maintain stable flight. To enhance stability, potential improvements include slightly shifting the center of gravity aft, increasing the horizontal tail area, or adjusting control surface effectiveness. Overall, while the **Aggie** UAV meets the criteria for static stability, its marginal static margin may require further refinement for optimal performance. Key calculations are shown on pages 7 and 8.

**Introduction**

Understanding the stability and control characteristics of an aircraft is crucial in aerospace engineering, as it directly affects the vehicle’s safety, performance, and maneuverability. Aircraft stability refers to its ability to return to equilibrium after a disturbance. In this report, I will analyze wind tunnel data to estimate key aerodynamic and stability derivatives for the Unmanned Aerial Vehicle (UAV) the Aggie. By evaluating the relationships between lift coefficient (*CL*), moment coefficient (*Cm*), and angle of attack (𝛼) across different control surface deflections, I aim to assess the aircraft’s longitudinal static stability. These relationships govern the following equations:

**Lift Coefficient Equation:**

**Pitching Moment Coefficient Equation:**

**Aerodynamic Center Equation:**

**Stability Margin Equation(s):**

The first two equations show the different factors that affect each lift coefficient and the pitching moment coefficient. The aerodynamic center equation determines the aircraft's neutral point by relating key aerodynamic properties of the wing and horizontal tail, accounting for their relative contributions to stability and control. The final equation is the most important as it tells us whether the aircraft is longitudinally statically stable. Our aircraft is stable if static margin, SM, is positive, and unstable if SM is negative. Based on the wind tunnel data and our governing equations, is the Aggie stable? With the supporting data, I will show you how the Aggie is stable.

**Results**

**A graph of a graph

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**Figure 1**

The relationship between the lift coefficient () and the angle of attack () for three different elevator deflections is shown in **Figure 1**. The data indicates that as the angle of attack increases, the lift coefficient increases linearly within the tested range. The presence of elevator deflection shifts the curve, with positive increasing lift at a given and negative reducing lift.

A graph of different angles

AI-generated content may be incorrect.**Figure 2**

The relationship between the pitching moment coefficient () and for the three elevator deflections is shown in **Figure 2**. The pitching moment coefficient decreases with increasing angle of attack, indicating a stable aircraft, as one of the main criterions for longitudinal static stability is . However, the shallow slope indicates that the aircraft may struggle to damp out pitch oscillations, requiring further stability improvements. The shift in the curves with elevator deflection confirms the control authority of the elevator.

A graph of different colored lines

AI-generated content may be incorrect.**Figure 3**

The plot of vs. is used to estimate the stability margin (SM), which determines the longitudinal stability of the aircraft. If the change in pitching moment coefficient due to the change in lift coefficient is negative, static margin is positive. We know this from our **Static Margin Equation**. From the plot we see that is negative, therefore static margin is positive, and our aircraft is statically stable.

**Discussion**

Aerodynamic and Stability Derivatives Estimates

The following stability derivatives were found by the **slope equation:**

and are the lift and pitching moment coefficients when their parameters are at 0. In our case, this is when and are equal to 0. Using the plots we see on the curve representing 0 deflection angle with 0 angle of attack:

and

The changes in and with respect to are interpreted as such:

Where

With this and our data we find and

Resulting in and

Positive ensures us that when we increase elevator deflection, our lift will increase and vice versa allowing the aircraft to effectively trim to different flight conditions (cruise, climb, descent). The negative pitching moment derivative due to elevator deflection = -0.012/deg confirms that increasing elevator deflection results in a nose-down moment, which is expected for proper control. However, the relatively small magnitude suggests low control authority, meaning large deflections may be needed to achieve the desired pitch response. This could make fine adjustments difficult and cause sluggish pitch handling. Increasing elevator effectiveness (e.g., by increasing control surface size or deflection range) could improve maneuverability.

Static Stability Analysis

**Figure 3** shows that is in fact negative, which is what we want according to the stability margin equation. With our specific value of we have our static margin,

Using the **Pitching Moment Coefficient Equation**, we can create a function of (

Finally, to find one of the most important components when working with longitudinal static stability, we use the **Aerodynamic Center Equation.**

Provided with the following information regarding our aircraft we can calculate the neutral point: The chord of the wing and the chord of the horizontal tail are the same, which is 6 in. The wing areas of the wing and the horizontal tail are 150 in2 and 30 in2, respectively. The location of the c.g. is = 1.0; the location of the aerodynamic center of the horizontal tail is = 4.0; the location of the aerodynamic center of the wing is = 0.25. (All are defined with the wing’s leading edge as the reference.) = 1.0; = 0; = 1.676, = 3.82, e = 1.0 for both the wing and the horizontal tail.

Before we can compute this, we need to find and using the equation:

Finally, we plug in all our values to find . With this we can also show how the aircraft is stable via the equation . This value comes out to 0.0887, close to what we got using The static margin of 0.0887 is positive, confirming the aircraft is statically stable. However, typical static margin values for a well-balanced aircraft are around 5-15% of the mean aerodynamic chord (MAC). With our aircraft’s MAC being 6 inches, the static margin is about 1.5% of MAC. This suggests that while the aircraft is stable, it is very close to being neutrally stable, meaning it may not exhibit strong restoring forces after disturbances. A larger static margin would improve stability, though at the cost of maneuverability. A small aft shift of the CG (e.g., from 1.0 to 1.2) could also improve maneuverability while keeping the aircraft stable. However, moving the CG too far back could risk making the aircraft neutrally stable or unstable, requiring constant pilot correction. An alternative approach would be to increase the horizontal tail area or adjust its moment arm to improve longitudinal stability.

**Conclusion**

The stability and control analysis of the Aggie UAV, based on wind tunnel data, confirms that the aircraft is longitudinally statically stable. The negative slope of the pitching moment coefficient with respect to angle of attack () satisfies a key requirement for stability, and the positive static margin further supports this conclusion.

However, the calculated static margin of 0.0887 (~1.5% MAC) indicates that the aircraft is very close to neutral stability. While this provides greater maneuverability, it may also result in weak self-correcting tendencies, meaning that the UAV could require continuous pilot or autopilot input to maintain a stable flight path. The low control authority of the elevator, as indicated by = −0.012/deg, may also limit precise pitch adjustments. To improve stability, possible design modifications include shifting the center of gravity slightly aft (e.g., from 1.0 to 1.2) to enhance maneuverability while maintaining stability, increasing the horizontal tail area to provide stronger pitch control, enhancing elevator effectiveness by modifying control surface size or deflection range.

In conclusion, the Aggie UAV exhibits stable but near-neutral longitudinal static stability. While functional for controlled flight, minor adjustments could enhance stability without significantly compromising maneuverability.

**Appendix**

My MATLAB code for the plots and several raw calculations:

A screenshot of a computer program

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A screenshot of a computer program

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A screenshot of a computer

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A screenshot of a math notebook

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A screen shot of a math notebook

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A screenshot of a tablet

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A screenshot of a notebook

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