Stability & Control Project

Stick-Fixed Analysis on the 18D Beechcraft

By Jose A. Rocha-Puscar

Introduction

The objective of this project was to achieve a 10% stability margin for the Beechcraft Model 18, utilizing parameters derived from the publicly available engineering drawings of the aircraft. The first phase involved parameterizing the wing, horizontal tail (HT), vertical tail (VT), and fuselage by obtaining key measurements such as aspect ratio, chord root and tip lengths, sweep angles at the leading edge, quarter chord, and half chord, among others. Following this, the stability of the aircraft was assessed under three distinct conditions: Glider, Windmilling Power (WP), and Full Power (FP).

In the Glider condition, multiple methods were employed, including Multhopp's method and Gilruth & White's method. Finally, the side force and its gradient were calculated, along with an evaluation of the stick-fixed lateral stability. It is important to note that no stick-free analysis was conducted for this project.

Methodology

As previously mentioned, we extracted dimensional data about the aircraft from publicly available blueprints and the service and maintenance manuals. The following tools were employed for this purpose:

- Engineering scale
- Ruler
- Protractor

Additional data that were not obtainable from the blueprints were sourced from the Type Certificate Data Sheets (TCDS), the DATCOM Manual, *Abbott and Von Doenhoff's Theory of Wing Sections,* and NACA Technical Report 824.

In the first figure, measurements of the fuselage, including the incidence angles of each section, are presented. The fuselage is designed with these angles to allow the pilot to maintain a clear view of the runway during landing while pitching up and to reduce the risk of a tail strike. Most of the fuselage data was utilized to calculate stability terms using Gilruth and White's method and Multhopp's method, both of which account for the effects of upwash and downwash on the fuselage.

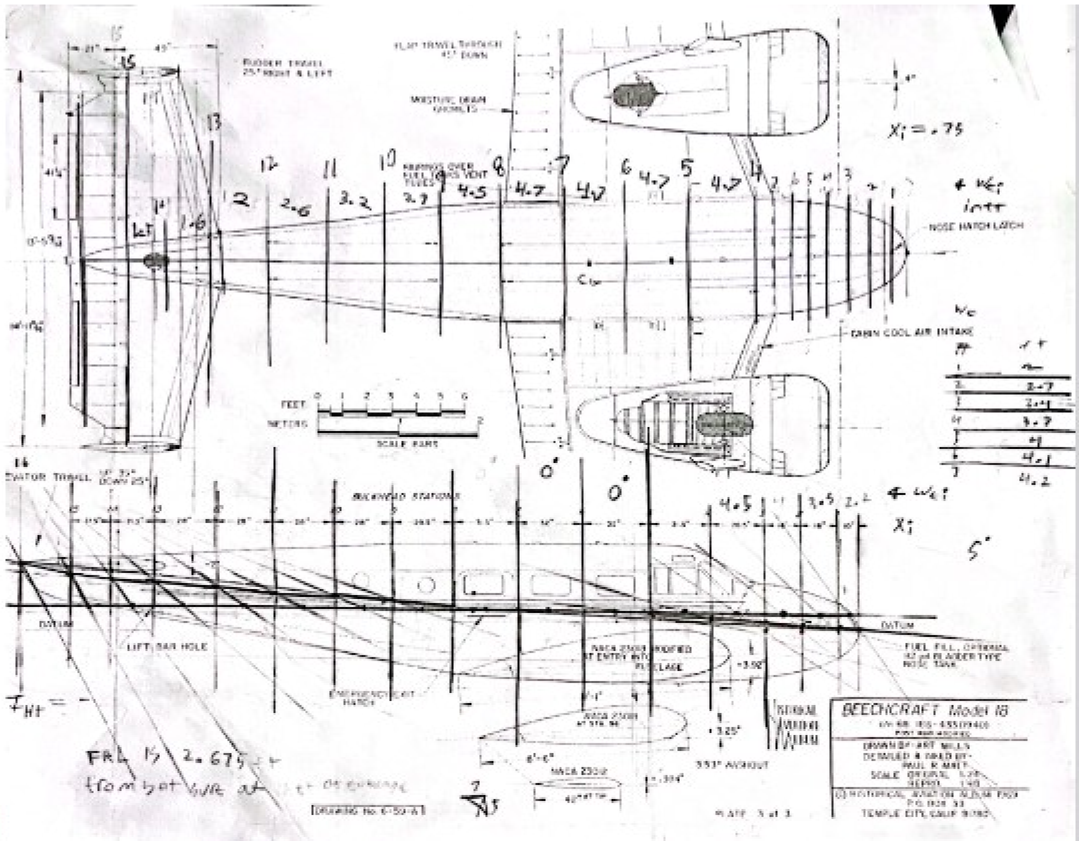

Fig 1 Drawing No. 6-59-A Side and Top View

For the wing and engine, the drawing in Figure 2 was utilized to obtain parameters such as the exposed chord root length, engine nacelle length, and common angles along the chord. Some assumptions were also necessary based on the drawing. For instance, the sweep at the leading edge (LE) was observed to vary. Since no data or equations were provided to account for wings with varying LE sweep in this project, it was decided to use a protractor to measure the angle between the exposed chord tip and chord root.

The wing is based on a NACA 23018 airfoil at the root, modified, and a NACA 23012 airfoil at the tip, which led to another assumption: due to the lack of detailed information about the modifications, the entire wing was treated as an unmodified NACA 23018. The Horizontal Tail (HT) and Vertical Tail (VT) were identified as NACA 0012 airfoils with no modifications.

To address other necessary assumptions, Figures 3 and 4 (not scaled) were compared with Figures 1, 2, and 5 (scaled). This comparison allowed for more accurate values, particularly in determining the location of the center of gravity (CG) and making assumptions regarding the wing's LE sweep. The comparison was achieved by geometrically referencing specific design elements, such as window locations, and aligning the non-scaled blueprints with the scaled ones. Lastly, Figure 5 was exclusively used to determine certain parameters related to the Vertical Tail.

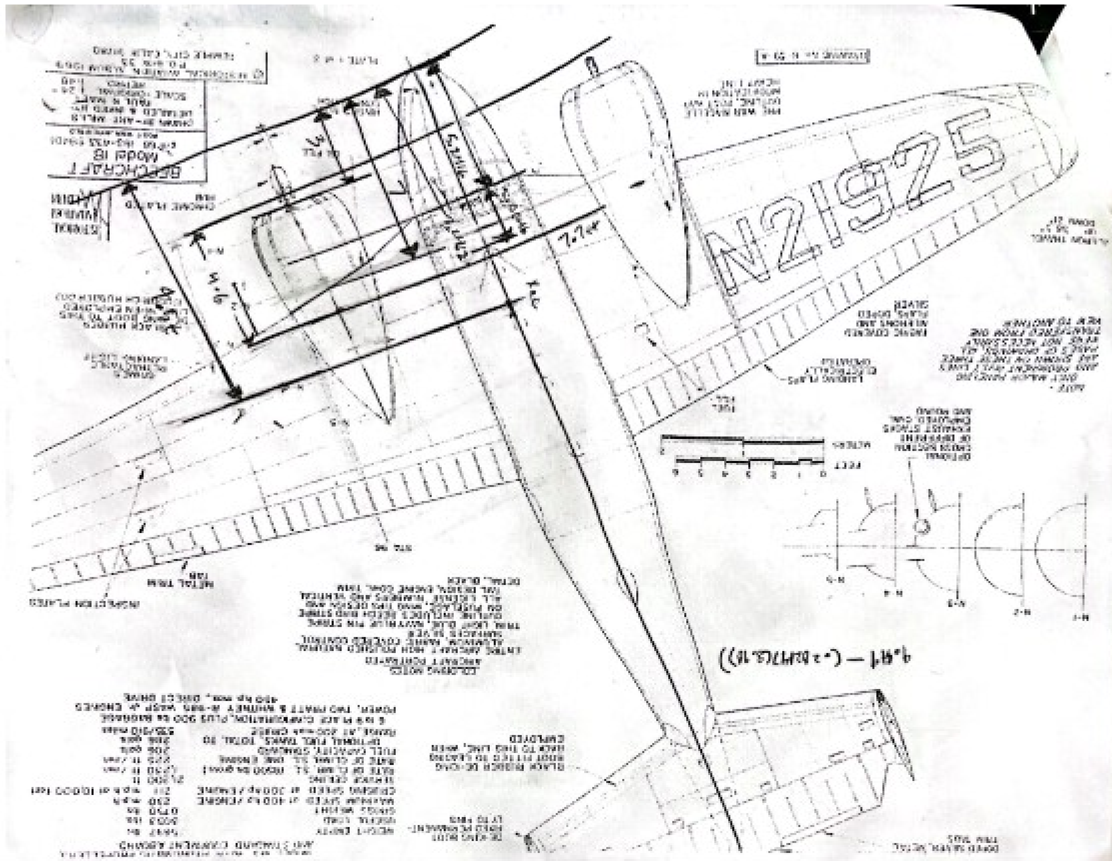

Fig 2 Drawing No 6-59-A Top View Only

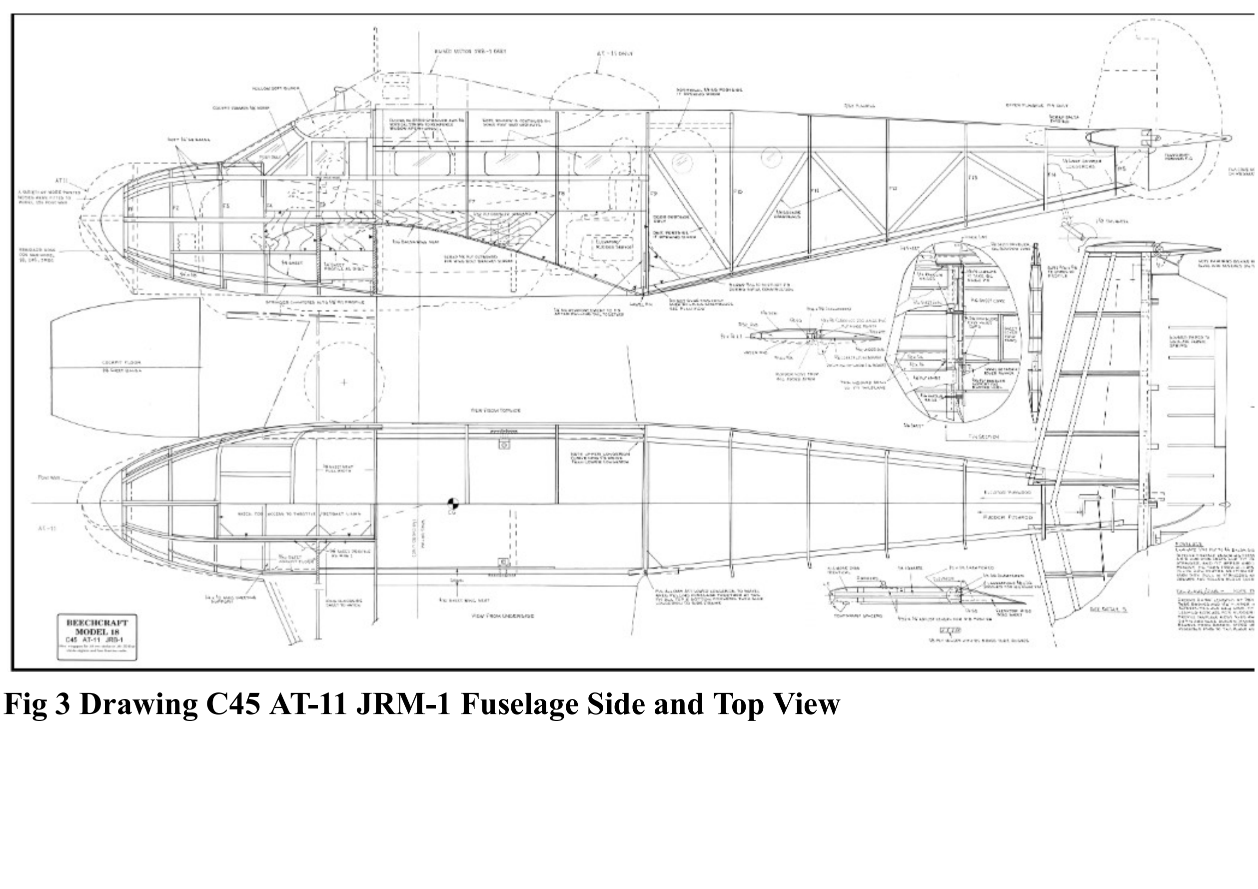

Fig 3 Drawing C45 AT-11 JRM-1 Fuselage Side and Top View

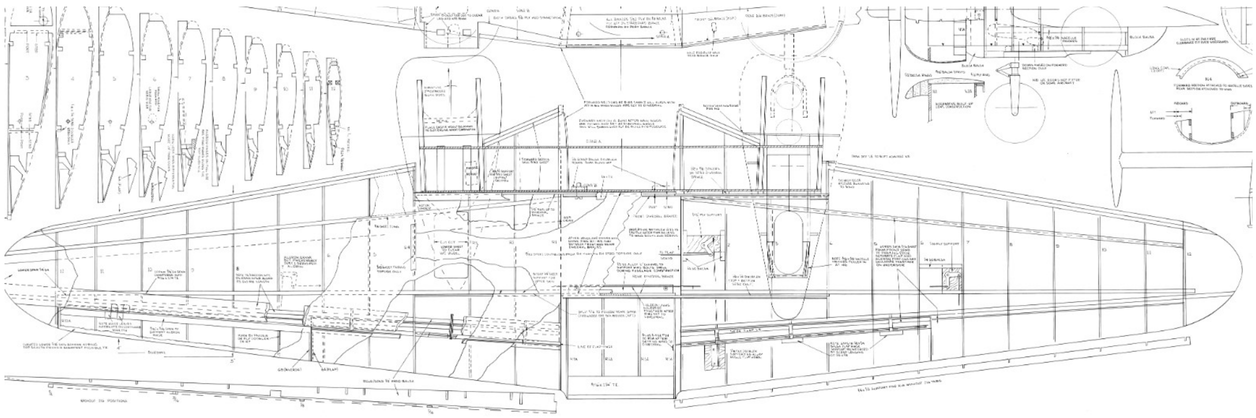

Fig4 Drawing C45 AT-11 JRB-1 Wing View Top View

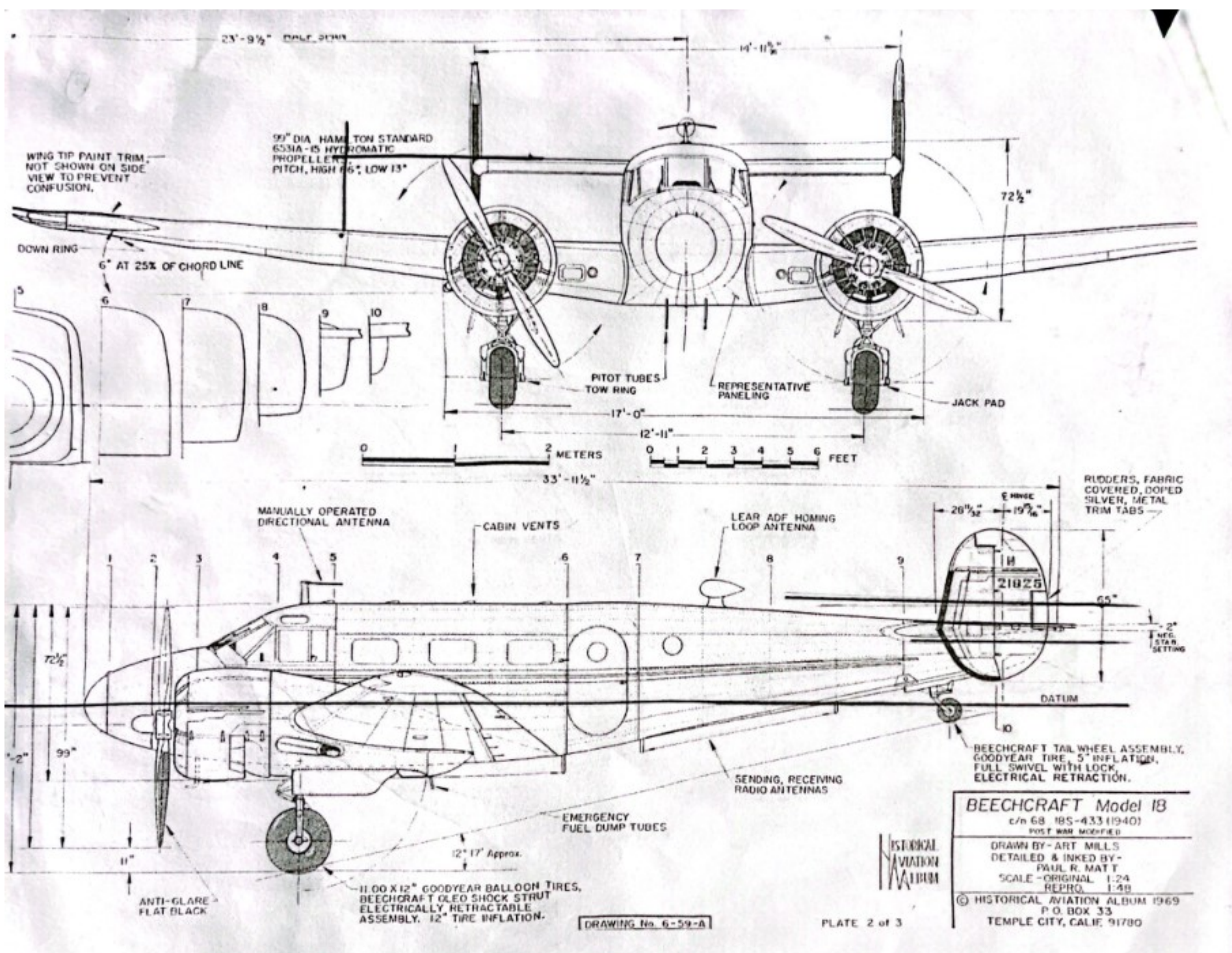

Fig5 Drawing No 6-59-A Front and Side View of Aircraft Exterior

Results & Discussion

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Wing Parameterization Section

Theoretical Wing Area: 351.1584 ft^2
Aspect Ratio: 6.4477
Mean Chord : 8.0598 ft
Y distance from Chord Root to MAC: 9.8112 ft
X distance from Wing Apex to Centroid: 6.0345 ft
X distance from Wing Apex to MAC: 2.0046 ft
Sweep at Quarter Chord: 7.0000 degrees
Sweep at Half Chord: 2.3620 degrees
Lift Curve Slope Datcom Eq: 0.0778 per deg
Alpha Not L: 0.2032
Corrected Cmac for Twist Angle and Mach affects: 0.0015
The Location of the Aerodynamic Center is 28.2147% of C_Bar

Horizontal Tail Parameterization Section

Horizontal Tail Theoretical Area: 77.5400 ft^2
Aspect Ratio: 2.9047
Mean Chord: 5.1953 ft
Y distance to MAC from Chord Root: 3.5906 ft
X distance to Centroid from Wing Apex: 3.3282 ft
X distance to MAC from Wing Apex: 0.7305 ft
Sweep at Quarter Chord: 9.0362 degrees
Sweep at Half Chord: 6.5382 degrees
Lift Curve Slope Datcom Eq: 0.0538 per deg
Theroetical Downwash Gradient is 0.4466
Actual Downwash Gradient is 0.4263
The Location of the Aerodynamic Center is 25% of C_Bar
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Figure 6 Matlab Window Output For Planform Parameters

When determining the stability of the aircraft, the initial step involves parameterizing the dimensional and aerodynamic characteristics of the aircraft's planforms and fuselage. The following dimensional parameters were measured for the wing: chord length at the tip (3.5 ft), chord length at the root (11.2597 ft), semi-span (23.7917 ft), and leading-edge sweep (11.5479 degrees). For the horizontal tail, the measured parameters include chord length at the tip (4.5 ft), chord length at the root (5.833 ft), semi-span (14.974 ft), and leading-edge sweep (11.5 degrees). These four parameters allow us to derive the calculated values presented in Figure 6.

The location of the aerodynamic center (a.c.) for the horizontal tail is at 25% of the chord, as expected for a symmetrical airfoil. However, for the wing, the aerodynamic center is slightly aft of 25%. Typically, NACA 4 and 5 series airfoils have the aerodynamic center positioned slightly forward of 25%. In this case, the aft position of the aerodynamic center could be attributed to assumptions made during the analysis, such as the chosen value for the leading-edge sweep, which might have influenced this shift.

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Stability of Aircraft and its Components Section as a Glider

Multhopp's Method:
Cm_alpha_f for the Model 18 glider: 0.0038 per deg
Cm_alpha_n for the Model 18 glider: 0.0031 per deg
Cm_alpha using Multhopp method for Cmalpha_f: -0.0100
The Nuetral Point using Multhopp method for Cmalpha_f: 0.3909

Gilruth and White's Method:
Cm_alpha using G&W method for Cmalpha_f: -0.0138
The Nuetral Point using G&W method for Cmalpha_f: 0.4363

Nomarl Linearized C_L_alpha Eq
C_L_alpha for a glider Model 18 configuration is: 0.0839 per deg

Stability of Aircraft and its Components Section for windmilling & full power

The neutral point Wind Milling Power (No_wpm) is: 0.2943
The neutral point under Full Power (No_wpf) is: 0.2143
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Fig 7: Matlab Output Window For Aircraft Stability Glider Condition

Before explaining the results, it's essential to understand why Gilruth & White's (G&W) method and Multhopp's method were used to determine the nose-up pitching moment of the fuselage. Both methods serve the purpose of accounting for the upwash and downwash effects on the fuselage and nacelle. The key difference lies in their approach: G&W's method is formula-based, derived from wind tunnel test data, whereas Multhopp's method is more analytical, drawing on the hull of an airship and Prandtl's lifting line theory. Multhopp's method is used in the DATCOM manual, and its values will be applied in the calculation sections related to powered flight conditions.

The neutral point is defined along the length of the fuselage, with the nose representing 0% and the tail 100%. In the glider or no-power case, a neutral point value of 0.4 (or 40%) is expected, and this value was obtained using both methods, with G&W's method yielding a slightly higher value. Additionally, given that the fuselage generally contributes to destabilization, the nose-up pitching moment with respect to the angle of attack (AoA) is negative for both methods.

When power is applied, the neutral point moves forward by 0.10 from its no-power position to the windmilling power position. This shift in the neutral point follows a consistent trend, with reasonable increments observed. It is important to note that the center of gravity (CG) should always maintain a safety margin of at least 3% from the neutral point to ensure the aircraft stabilizes after reacting to external forces or if the pilot releases the controls.

In the figure below, our stick-fixed stability calculations are presented, illustrating how the aircraft responds to certain external forces. For example, the side force gradient indicates how much the side force changes in response to changes in the sideslip angle. This metric is crucial for determining the aircraft's lateral stability; if the side force gradient is too low, the aircraft may be more prone to sideslip and harder to control, whereas if it's too high, the aircraft could become overly sensitive. In our case, a reasonable value was obtained, suggesting that the aircraft’s lateral behavior will be predictable. The remaining values also fall within their expected ranges.

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Side Force Gradient Calculation

The calculated side force gradient is: -0.0014 per deg

Stick-Fixed Directional Stability
C_Nbeta for the aircraft configuration is: 0.0016 per deg

Stick-Fixed Lateral Stability
C_lbeta for the aircraft configuration is: -0.0009 per deg
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Fig 8: Matlab Output Window Stick Fixed Stability & Side Force Gradient

Conclusion

In conclusion, the stability analysis of the Beechcraft Model 18D, conducted through parameterization of its planform dimensions and aerodynamic characteristics, confirms that the aircraft maintains a satisfactory stability margin across different flight conditions. By utilizing both Gilruth & White's empirical method and Multhopp’s analytical approach, we were able to accurately assess the fuselage's influence on the aircraft’s nose-up pitching moment and neutral point. The analysis reveals that the neutral point shifts appropriately with power application, and the center of gravity remains within a safe margin, ensuring stability. Furthermore, the lateral stability, as indicated by the side force gradient, falls within an acceptable range, suggesting predictable and manageable handling characteristics. Overall, the methods employed have provided a robust understanding of the aircraft’s stability, supporting the design’s adherence to expected aerodynamic principles and ensuring reliable performance in various operating conditions.