

Aerodynamics and Longitudinal Static Stability of a Blended Wing Body Aircraft with Canard and Twin Tail Boom Configuration at Low Reynolds Numbers via Vortex Lattice Computations

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ABSTRACT

This study investigates the aerodynamic characteristics and longitudinal static stability of a novel unmanned blended wing body aircraft featuring a canard and twin tail boom configuration. Conducting aerodynamic analysis at relatively low Reynolds numbers is essential for small unmanned aerial vehicles to determine optimal elevator deflection angles during the preliminary design phase. The study employs a vortex lattice method (VLM), a low-fidelity approach known for its computational efficiency and reliability, within the VSPAero suite. Study cases include wing-body configuration only, combination with canard, combinations with canard and tails and combination with all components with various canard and tail deflection angles. The results show that this wing-body, canard, and twin tail configuration can exhibit a favourable lift-to-drag ratios of 15.0 at trim lift coefficient 0.5 with +5-degree canard elevator deflection and -5-degree horizontal tail elevator deflection. This strikes a good balance between performance efficiency and flight stability crucial for sustained flights. In terms of longitudinal stability, the aircraft demonstrates inherent stability at around 25 percent static margin, primarily due to the strategic placement and sizing of the centre of gravity, canard and twin tail surfaces.

Introduction

The blended wing body aircraft configuration, characterized by its seamless integration of wing and fuselage, offers several advantages over conventional aircraft design, including enhanced aerodynamic efficiency and increased internal volume (Liu & Whidborne, 2021; Wang et al., 2022). However, the integration of a canard and twin tail boom configuration introduces unique challenges and opportunities,

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particularly when operating at relatively low Reynolds numbers with respect to normal manned aircraft, which are characteristic of unmanned aerial vehicles (Wauters & Degroote, 2018; Giacomini & Westerberg, 2025). This study therefore focuses on understanding ideal aerodynamic interactions and longitudinal static stability characteristics of such a novel aircraft configuration under specific flight conditions (Boschetti et al., 2004). The inherent complexities arise from the interplay between the blended wing body's lift-generating fuselage, the additional control surfaces provided by the canards, and the stabilizing influence of the twin tail booms (Odendaal et al., 2024). The quantification of aerodynamic variables and stability coefficients is paramount for predicting aircraft performance and ensuring safe flight operations, especially for unmanned aircraft (Loya et al., 2018). BWB in tail-less form often longitudinally less stable than a conventional type and almost impossible to be controlled manually in flight due to its unstable dynamic behaviour. Adding canards only helps in providing additional control but only worsens longitudinal stability. Adding horizontal tail is the solution to ensuring good longitudinal static stability while minimizing additional drag only if the setup is optimised. Hypothetically, optimising control surface trim angle shall ensure both stability and aerodynamic efficiency if done right. Practically the process is either expensive, i.e. via wind tunnel experiment, or time consuming, i.e. via computational fluid dynamic simulation.

To address these challenges, low-fidelity computational methods, such as the Vortex Lattice Method, are particularly attractive due to their computational efficiency, enabling rapid design iterations during the conceptual and preliminary design phases (Hasan et al., 2023; Joshi et al., 2025; Islam et al., 2025). Specifically, this research employs the Vortex Lattice Method for its capability to efficiently compute aerodynamic coefficients and stability derivatives, providing a robust framework for initial design assessments (Salem et al., 2024). A discussion on benchmarking unconventional configurations with conventional aircraft: the box-wing study case (Zhang et al., 2020). This approach enables systematic evaluation of key design parameters, such as canard-wing-tail positioning, without incurring the computational expense of higher-fidelity methods like Computational Fluid Dynamics (Marqués, 2017; Yang et al., 2018). Moreover, unconventional aircraft configurations, such as the blended wing body with canards, often present unique challenges in stability and trim, despite their potential for extraordinary performance characteristics (Goetzendorf-Grabowski, 2023). This necessitates a fundamental, ideal and simplified investigation into their static stability margins, particularly concerning the longitudinal axis, to ensure predictable flight behavior and controllability.



Fig. 1. Baseline-II BWB UAV prototype.

This paper investigates the aerodynamic characteristics and longitudinal static stability of a blended wing body aircraft, namely Baseline-II BWB-UAV (as shown in Fig. 1) augmented with a canard and twin tail boom at relatively low average Reynolds numbers of 1,000,000 utilizing the Vortex Lattice Method. This methodology is well-suited for the preliminary design phases, as it provides a balance between computational cost and accuracy for predicting lift, drag, and moment coefficients, as well as crucial

stability derivatives (Salem et al., 2021b). Furthermore, the Vortex Lattice Method can be employed to predict induced drag and stability aerodynamic derivatives, while the lift line theory can be used to estimate the aerodynamic properties of the wings and the static stability and trimming requirements from control surfaces (Salem et al., 2024; Singh et al., 2022). This approach enables the rapid evaluation of various design iterations and the identification of optimal configurations that satisfy aerodynamic performance and stability criteria (Salem et al., 2023). For information, Baseline-II BWB UAV was originally designed with tailless configuration but with canard as control effector. However, short take-off and manually stable (without electronic stability augmentation) control requirements cause the canard to change its role to providing additional lift for STOL and twin tail boom control surfaces were introduced to provide natural longitudinal stability. Specifically, this research aims to determine the impact of integrating a canard and twin tail boom on the overall longitudinal static stability and aerodynamic efficiency of a blended wing body.

Literature Review

VLM is particularly well-suited for preliminary design phases due to its computational efficiency, allowing for rapid assessment of various planform configurations inherent to BWB geometries (Joshi & Thomas, 2023). This efficiency is crucial for multidisciplinary design optimization processes where numerous design parameters must be evaluated iteratively. Furthermore, the integration of VLM with optimization algorithms, such as BOBYQA, significantly accelerates the exploration of design spaces, facilitating quicker iterations and improvements in conceptual and preliminary wing design (Islam et al., 2025). The adaptability of VLM in conceptual design also stems from its ability to model complex aerodynamic interactions, providing valuable insights into the fundamental flow physics influencing BWB performance characteristics (Kumar et al., 2025; Sarojini et al., 2024). VLM's inherently low computational cost also makes it an ideal candidate for integration into physics-infused machine learning frameworks, where it can serve as a low-fidelity physics model to enhance the generalization capabilities of data-driven approaches, especially when high-fidelity datasets are sparse (Oddiraju et al., 2023).

VLM computations on BWB aircraft have consistently demonstrated their effectiveness in predicting key aerodynamic parameters, such as lift coefficients and pitching moments, which are critical for stability and control assessments during the early design stage. This is particularly valuable for unconventional configurations like BWBs, where extensive experimental data may not be readily available, thus relying on efficient computational tools for initial performance estimations (Sung et al., 2025). Moreover, VLM can effectively model the complex aerodynamic interactions between different aircraft components, offering insights into how design modifications, such as the incorporation of winglets, influence overall lift and drag characteristics (Ishrak et al., 2024). However, it is important to acknowledge that while VLM provides a robust framework for preliminary analysis, it typically underestimates complex flow phenomena such as vortex-induced drag and flow separation, which become more pronounced in the high angle-of-attack regimes relevant to BWB aircraft (Joshi & Thomas, 2023). This limitation necessitates the development of hybrid approaches that integrate VLM with higher-fidelity tools or experimental data to achieve a more comprehensive understanding of BWB aerodynamics, especially for scenarios involving complex vortex dynamics or flow separation (Aubeelack et al., 2023; Bohari et al., 2017). Despite these limitations, the general aerodynamic trends and correlations between performance and design variables obtained from VLM solvers remain highly valuable for the conceptual design phase of innovative airframe concepts, given their low computational cost and flexibility for parametric analyses (Salem et al., 2021a).

While BWB aircraft traditionally eschew empennage for reduced wetted area and drag, the integration of canard or tail surfaces introduces complexities in aerodynamic interaction that VLM can model to assess their impact on stability and control (Luo et al., 2024). Specifically, VLM can quantify changes in lift distribution, pitching moments, and static margins arising from the aerodynamic interference between these control surfaces and the blended wing-body fuselage (Liou et al., 2019). For instance, VLM can investigate how the vortex shedding from a canard surface impinges on the main wing, altering its effective angle of attack and potentially influencing lift generation or flow separation characteristics (Larkin & Coates, 2017). This capability is crucial for understanding the trade-offs between enhanced control authority and potential drag penalties introduced by such additional surfaces, especially in unconventional BWB configurations where traditional stability mechanisms are altered.

Previous studies have investigated the impact of horizontal tail, canards, and winglets on BWB designs, demonstrating how CFD can predict the resulting lift coefficient variations and aerodynamic characteristics (Saad et al., 2019). The method's ability to swiftly evaluate diverse configurations of elevons as longitudinal control effector makes it an indispensable tool for designers seeking to optimize stability and maneuverability in BWB aircraft but with time cost much longer than wind tunnel's experiment (Goetzendorf-Grabowski, 2023; Wang et al., 2022). Alternatively, the judicious placement and sizing of these surfaces, informed by semi-empirical computation via multi-disciplinary optimisation (MDO), can effectively mitigate adverse stability characteristics inherent in tailless BWB designs without significantly compromising their aerodynamic efficiency (Rostami et al., 2023). However, it is crucial to recognize that the simplified aerodynamic assumptions in MDO's semi-empirical method may not fully capture the intricate flow interactions introduced by these additional lifting surfaces, particularly at high angles of attack or in scenarios involving complex unsteady aerodynamics (Sepulveda et al., 2019). On the other hand, VLM often serves as an initial screening tool, with promising designs then subjected to higher-fidelity computational fluid dynamics analyses to validate and refine the aerodynamic predictions, particularly for highly integrated and interacting components (Ruh et al., 2023). Despite these limitations, VLM remains an invaluable tool for preliminary design, offering a rapid and efficient means to assess the aerodynamic impact of various control surface configurations on BWB aircraft and becomes an enabler for multi-disciplinary optimisation (MDO) process involving balance between aerodynamic efficiency, stability, controllability and flight performance (Natale et al., 2020; Raza et al., 2024; Stephens et al., 1999).

VLM computation validation often involves comparing its predictions against experimental data from wind tunnel tests or higher-fidelity computational fluid dynamics simulations (Sgueglia, 2019). This process is essential for verifying the accuracy of VLM-derived aerodynamic coefficients and ensuring the model reliably predicts aircraft performance across various flight regimes (Cipolla et al., 2016). For instance, comparisons between VLM results and experimental data have shown good agreement for lift and pitching moment coefficients at small angles of attack, particularly for configurations without significant flow separation. Nevertheless, VLM's predictive capabilities for stability derivatives and control surface effectiveness have been corroborated against wind tunnel data, demonstrating its utility for preliminary design evaluations of aircraft configurations, including unconventional layouts (Nae, 2010). For example, studies on PrandtlPlane aircraft have leveraged VLM to successfully predict aerodynamic behavior, with these predictions subsequently validated through wind tunnel tests, confirming VLM's adequacy for preliminary design phases (Cipolla et al., 2018). The method's ability to model complex geometries, including multiple lifting surfaces and their interactions, allows for comprehensive validation against diverse experimental set-ups (Denieul, 2016). These comparative analyses often reveal the method's strengths in capturing linear aerodynamic characteristics but also highlight its inherent limitations when confronted with non-linear flow phenomena or conditions where viscous effects become prominent (Botero et al., 2022).

Methodology

VSPAero utilizes an advanced vortex lattice method that discretizes the lifting surfaces into a network of horseshoe vortices, enabling the computation of aerodynamic forces and moments through the application of the Kutta-Joukowski theorem and boundary conditions at collocation points (Joshi et al., 2025). However, VLM's inherent assumptions, primarily relying on potential flow theory, limit its applicability in accurately predicting non-linear aerodynamic phenomena and viscous effects. The governing equations for VLM typically involve solving a system of linear equations derived from satisfying the impermeability boundary condition at control points on each panel. This system determines the strengths of the individual vortex elements, which are then used to calculate the pressure distribution and subsequently the total aerodynamic forces and moments acting on the aircraft. Please take note that results in this paper serve to find preliminary optimal setup for canard and tail elevators where a balance between aerodynamic efficiency (namely lift-to-drag ratio, L/D) and longitudinal static stability must be met. In other words, one needs to find the highest possible $(L/D)_{max}$ at trim lift coefficient that ensures positive longitudinal static stability at comfortably good static margin.

Fig. 2 shows the flowchart of this research where the work begins with specifying geometric parameters of the BWB aircraft components, namely the blended wing-body, canard, horizontal tail and twin vertical tail in terms of span, chords, plan area, airfoils position, and other geometric parameters. These parameters are used to create geometric three-dimensional model of the aircraft in the chosen vehicle sketch pad suite. Not only must each span section be specified with chord, airfoil specification, quarter-chord sweep angle and leading-edge longitudinal position among others, tessellation number of each section must also be considered to ensure geometrical shape accuracy. A low tessellation number in x-direction will make the leading edge of aerofoil looked jagged and not rounded while a high tessellation number will ensure the aerofoil shape is close to the actual curve. Furthermore, tessellation number in both longitudinal (x) and spanwise (y) determines the total number of panels and nodes that OpenVSP Degen (Degeneration) command will generate when all of aircraft components have been merged into a single object. In this case, the BWB aircraft is designed with 6 wing-body sections per half span where there are 130 subsections in total (Tessellation y = 101). Longitudinally, each airfoil section is further divided into 100 subsections (Tessellation x = 101), therefore making the total number of panels (mesh) on the BWB model 13,000 not counting canards, horizontal tail and vertical tails. This is perfectly in line with the suggested minimum number of panels for accurate aerodynamic prediction of all-wing, tailless BWB aircraft, which is around 7,000 – 10,000 depending on complexity of design (Botero et al., 2022; Nae, 2010).

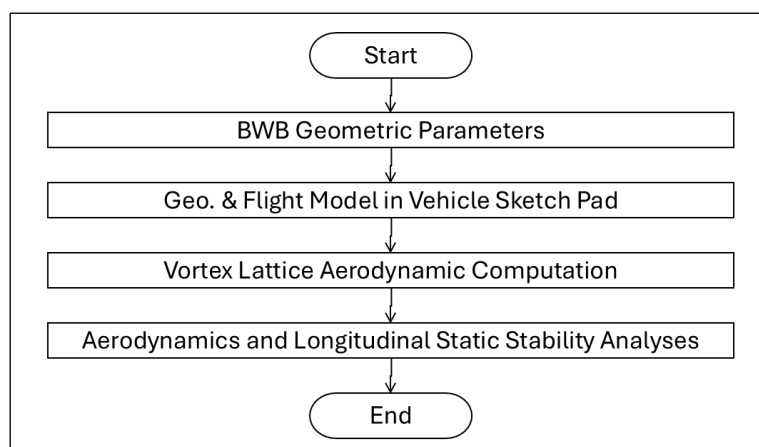


Fig. 2. Research workflow.

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The modelling process is shown in Fig. 3. The 3D surface mesh panels for each aircraft components are degenerated into flat plate representation of it. This degenerated model is then used by VSPAero to execute VLM computation and present its simulation results for further analyses. One added feature of VLM computation within VSPAero suite is the ability to predict stall lift and angle of attack. 3D wing stall in Vortex Lattice Method (VLM) computation is determined using nonlinear VLM that couples linear VLM with 2.5D viscous data from airfoil polars. This method accounts for 3D effects by extending 2D airfoil stall characteristics to finite wings, capturing stall behavior up to and beyond the stall point. Stall is identified by analyzing the resulting force and moment coefficients, with a drop in the lift coefficient and increase in the drag coefficient, and by monitoring the separation of flow from the wing. This feature also allows for estimation of parasite drag using empirical methods.

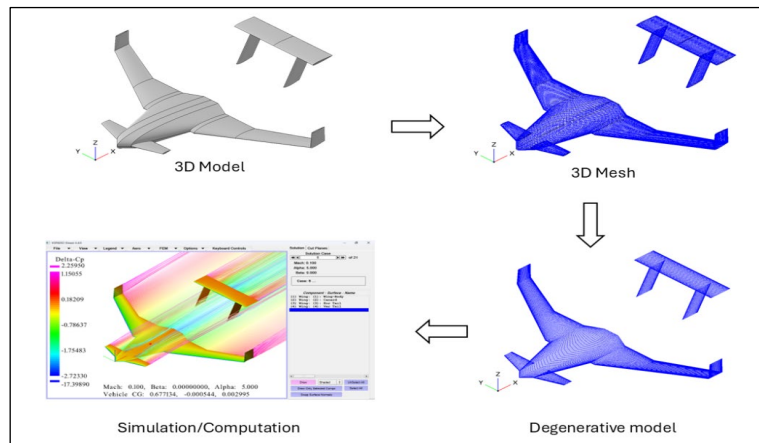


Fig. 3. VLM computation process within VSPAero suite.

Table 1 shows important parameters of computation and cases in this research. As mentioned before there are 13,000 mesh panels on this 2.86 m wingspan BWB aircraft with body length of 1.2 m and mean chord of 0.59 m giving planform BWB area or reference area of 1.084 m². Reference area for aircraft design refers of the wing planform area. In this case, since the body is also the main lifting component, wing-body planform area is considered as reference area. Adding canard and tail, in practice, does not change the reference area, in fact one must maintain it for aerodynamic and stability analysis consistency. This allows for clear observation of the impact of canard and tail to the wing-body which constitutes the original configuration of the aircraft. Overall length of this aircraft is slightly more than 2.25 m including horizontal tail. Reference centre of gravity is at 0.80 m behind the tip of the nose or right at the forward section of the proper wing connected to the delta, highly swept body. Operating speed of this small BWB UAV is around 34 m/s or approximately at Mach 0.1 at sea level altitude with air density of 1.225 kg/m³ ISA. Operating range of angle of attack (α) is between 0° to +20° and there are nine (9) cases of simulation or computation. It begins with BWB only case before adding canard on the next case, then horizontal tail and then twin vertical tails – all in clean configuration without control surface deflection. After these cases, the computation is extended to five (5) more control surface deflections namely $\delta_h = -5^\circ$ and $\delta_h = -10^\circ$ for horizontal tail elevator cases, $\delta_c = +30^\circ$ and $\delta_c = +60^\circ$ for canard elevator cases and one case where $\delta_c = +5^\circ$ and $\delta_h = -5^\circ$. The BWB+C case results will be compared with wind tunnel results published in Wisnoe et al. (2017) where the study was limited to the same blended wing-body design with canard configuration only. In conclusion, the study conducted here extends aerodynamic prediction, but only via quick VLM computation, from bare wing-body setup to the impact of canard and horizontal tail separately, impact of all components combined, and impact of all components combined with selected control surface deflections cases.

Table 1. Parameters of computation and cases

Parameter	Value	Remarks
Algorithm	Vortex Lattice Method	VSPAero
Tessellation	131 x 101	Y x X
Panels	13,000	Surface panels on BWB
Ref. Area, S	1.084 m ²	BWB planform only
Ref. chord, c	0.592 m	BWB planform only
Ref. Span, b	2.860 m	Including wing tip
Ref. CG	0.800 m	From nose
AoA range	0.0 – 20.0°	Operating range
Mach	0.10	34 m/s at sea level
Reynold No., Re	1,000,000	Approximated Re
Stall model	2D $C_{l_{max}} = 1.50$ (NACA2412)	Based on BWB airfoil
Control Grouping	Canard elevator & horizontal tail elevator	Longitudinal stability
Computed cases	1. BWB only	BWB
	2. BWB + canard	BWB+C
	3. BWB + canard + hor. tail	BWB+C+H
	4. bwb + canard + hor. tail + ver. tails	BWB+C+H+V
	5. BWB+canard+hor. tail (-5°) + ver. tail	BWB+C+H(-5)+V
	6. BWB+canard+hor. tail (-10°) + ver. tail	BWB+C+H(-10)+V
	7. BWB+canard(+30°)+hor. tail + ver. Tail	BWB+C(+30)+H+V
	8. BWB+canard(+30°)+hor. tail + ver. Tail	BWB+C(+60)+H+V
	9. BWB+canard(+5°)+hor. tail(-5°) + ver. Tail	BWB+C(+5)+H(-5)+V

Results and Discussion

Fig. 4 shows plots of lift coefficients versus angle of attack, drag coefficient, lift-to-drag ratio and pitch moment coefficient for the blended wing-body plus canard case (BWB+C). The figure shows comparisons between VLM computation and wind tunnel experiment results published by Wisnoe et al. (2017) at the same flow regime. The reason behind choosing BWB+C case is that the wind tunnel model tested before consists of both BWB and canard. Readers may find that the results for lift, drag and moment coefficients here are larger than the published plots because of adjustment in the reference area. The published reference area uses all lifting component planform areas, both wing-body and canard, whereas this paper only uses wing-body planform area as reference. Since the latter is smaller in magnitude then the value of these coefficients must be larger for the same amount of force and moments. Secondly, the adjustment must also be made to the mean chord since the former takes canard area into account while the latter do not, hence, the reference mean chord for the VLM's cases is smaller than the wind tunnels. Fig. 4 shows that VLM computation trends agree with wind tunnel results but only up to +10 degrees angle of attack which is well within its linear lift region which is between $0^\circ \leq \alpha \leq 10^\circ$ or $C_L \leq 0.8$. Above this angle of attack, the VLM simulation is unable to simulate the same flow separation trends on the wing as in Wisnoe et al. (2017). Even within linear lift regime, the VLM plots really show their ideal magnitudes – having 5.0% larger lift coefficient, 10.0% smaller drag coefficient and 20% higher lift-to-drag ratio than the wind tunnel plots. Similar trends are observed for the pitch moment plots within linear lift range but differ tremendously after $\alpha = 10^\circ$ due to VLM's inability to model separation of flow and turbulent at wing-body trailing edge region unlike CFD method. So far, the VLM computations are fairly acceptable within linear lift region but require higher fidelity computational method for cases outside it.

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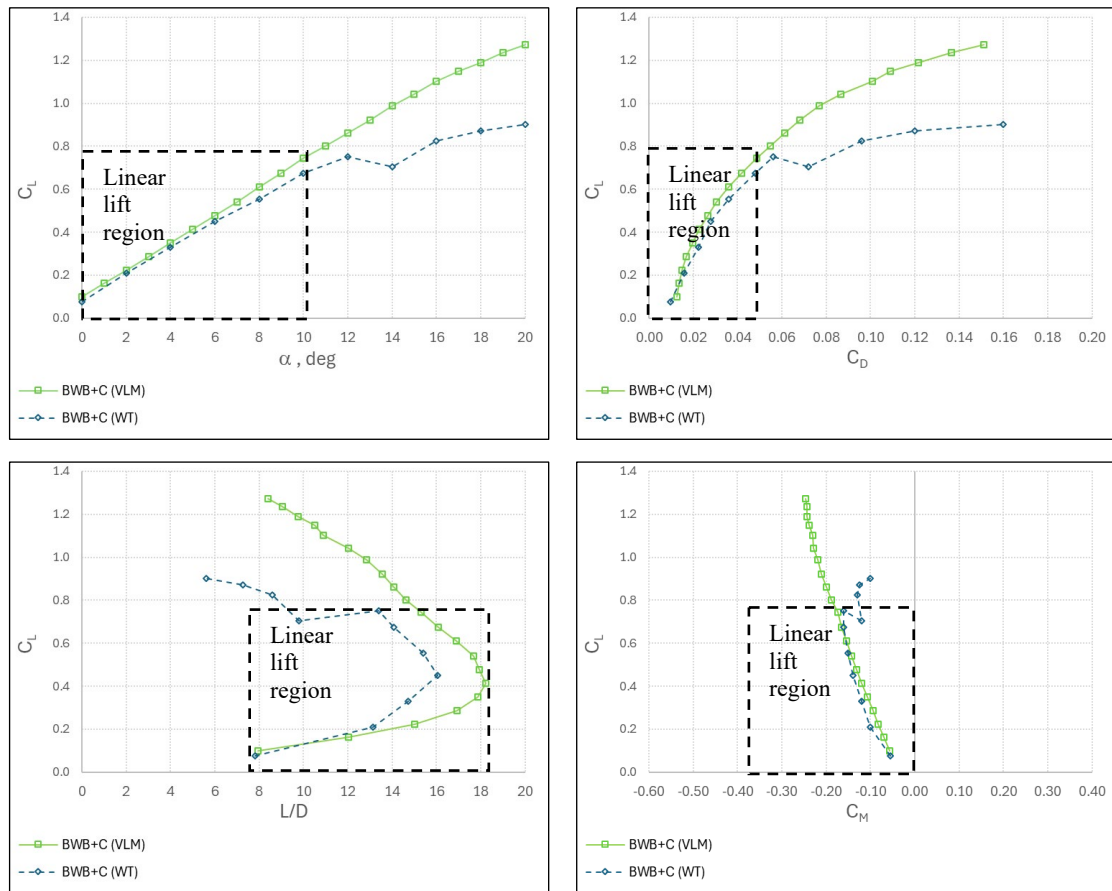


Fig. 4. Comparison between VLM and wind tunnel experiment (Wisnoe et al., 2017) for BWB+C case.

Fig. 5 shows an example of pressure contour and airflow visualizations for the first four cases (BWB, BWB+C, BWB+C+H, and BWB+C+H+V) to observe differences between single BWB and addition of control surface components beginning with canard, horizontal tail and twin vertical tails at zero angle of attack to understand the interaction between these components and its impact to overall BWB aircraft aerodynamic performance and longitudinal stability. Qualitatively, subtle differences in the pressure contour are observed, especially over the wing when the canard is added to the front section of the body. Quantitatively, the highest and lowest pressure coefficient limits for all cases shown at zero angle of attack are similar between $C_{p,min} \cong -0.3$ to $C_{p,max} \cong +3.0$. The canard expands the low-pressure area ($C_p \leq -0.2$) to a portion of wing roots approximately 10% more than wing-body setup only. This difference become obvious when horizontal tail and twin vertical tails are added where lower pressure spots are observed on the wing root much clearer and larger up to 50% of total wing-body area than the previous two cases indicating accelerated airflow on top of it due to interactions of wing-body with canards, horizontal tail and vertical tails. There is only slight difference on the delta body though, however, airflow visualization indicates that downwash from the canard does affect the BWB outer body and inner wing sections. Airflow from canard and BWB does not affect the horizontal tail and the twin vertical tail due to their height and orientation, respectively.

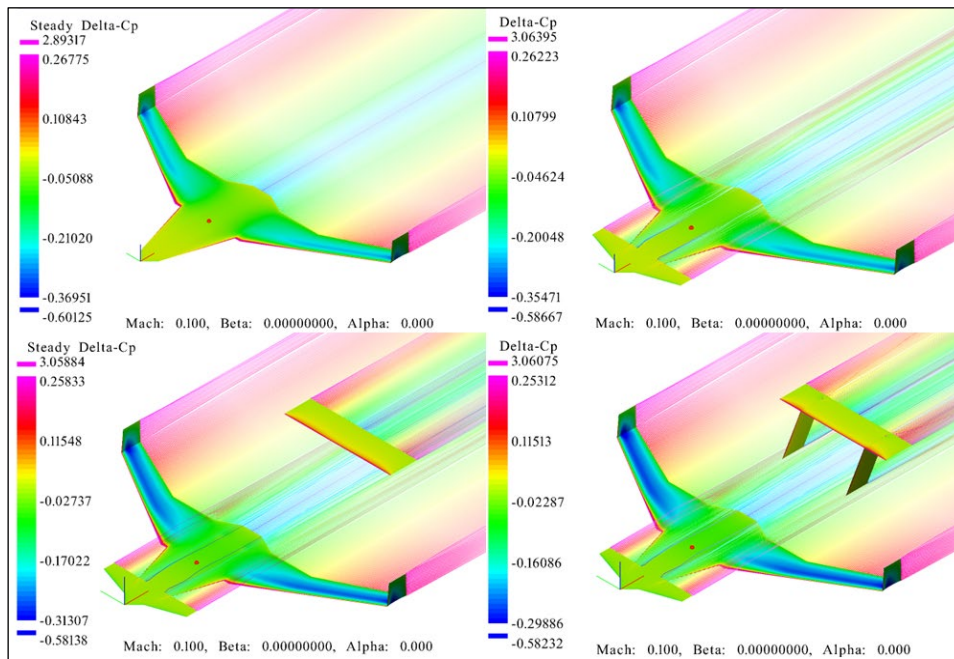


Fig. 5. Pressure contour and flow visualization for four clean configuration cases.

Fig. 6 shows lift coefficient C_L versus angle of attack α plots of all nine cases. For BWB only case, the lift coefficient at zero angle of attack starts at around $C_L \approx 0.10$ increases almost linearly with a slope of approximately $dC_L/d\alpha \approx 0.07/^\circ$ and tops up at maximum lift coefficient $C_{Lmax} \approx 1.20$ at operational limit angle of attack $\alpha = 20^\circ$. Adding canard increases the slope slightly to $dC_L/d\alpha \approx 0.073/^\circ$ with maximum lift at $C_{Lmax} \approx 1.26$ at the same angle of attack limit. With canard and horizontal tail in picture, the slope increases more to $dC_L/d\alpha \approx 0.08/^\circ$ and $C_{Lmax} \approx 1.40$. The effect of horizontal tail is more prominent than canard due to the former is larger than the latter. Adding twin vertical tails does nothing in terms of lift coefficient. The remaining five cases involving canard elevator and horizontal tail's elevator deflection δ (downward is positive) all have similar slope of between $dC_L/d\alpha \approx (0.073 - 0.08)/^\circ$ and maximum lift at $C_{Lmax} \approx 1.20 - 1.40$. deflecting control surfaces does nothing significant to the whole BWB aircraft.

Drag polar plots are shown in Fig. 7 where most cases are packed together between parasite drag coefficients of $C_{D0} \approx 0.01 - 0.02$ and increase parabolically as lift coefficient increase while keeping the difference between cases within $C_D \approx 0.01$. Exceptions are observed for cases BWB+C(+30)+H+V and BWB+C(+60)+H+V. These two cases, while having parasite drag just slightly higher at $C_{D0} \approx 0.022 - 0.025$, its increase in drag is more prominent, climbing quickly parabolically separating themselves from the rest as lift coefficient increases. These two cases are when the canard's elevator is deflected at relatively large angle (+30 to +60 degrees) thus disturb the flow on wing-body behind it and increases drag.

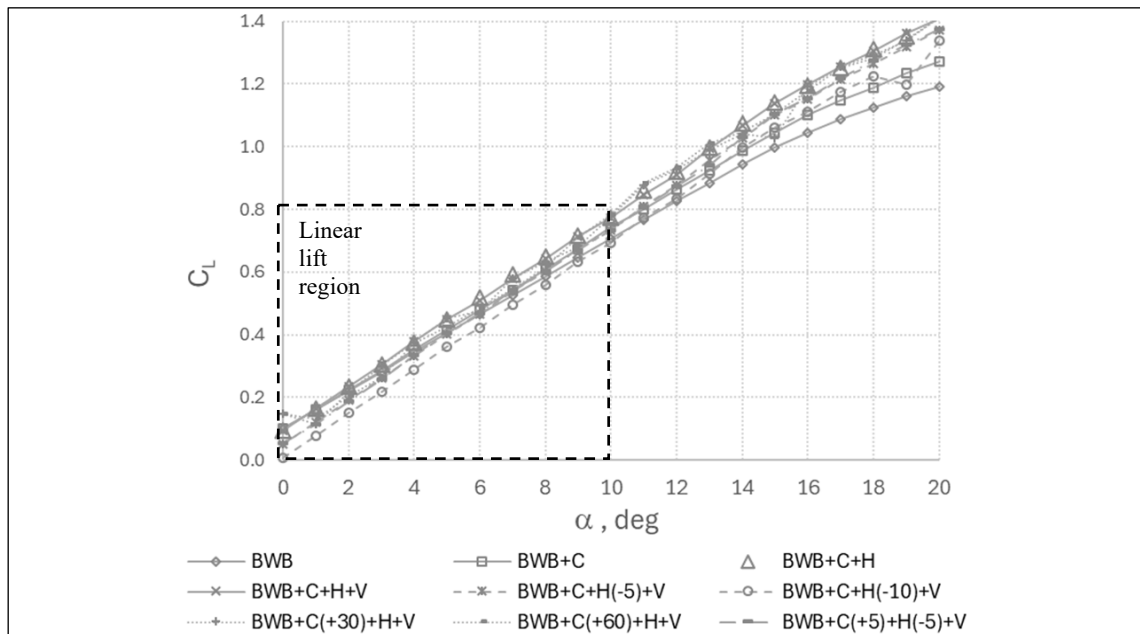


Fig. 6. C_L - α plots of BWB cases (note: C – canard, H – hor. Tail, V – ver. Tail).

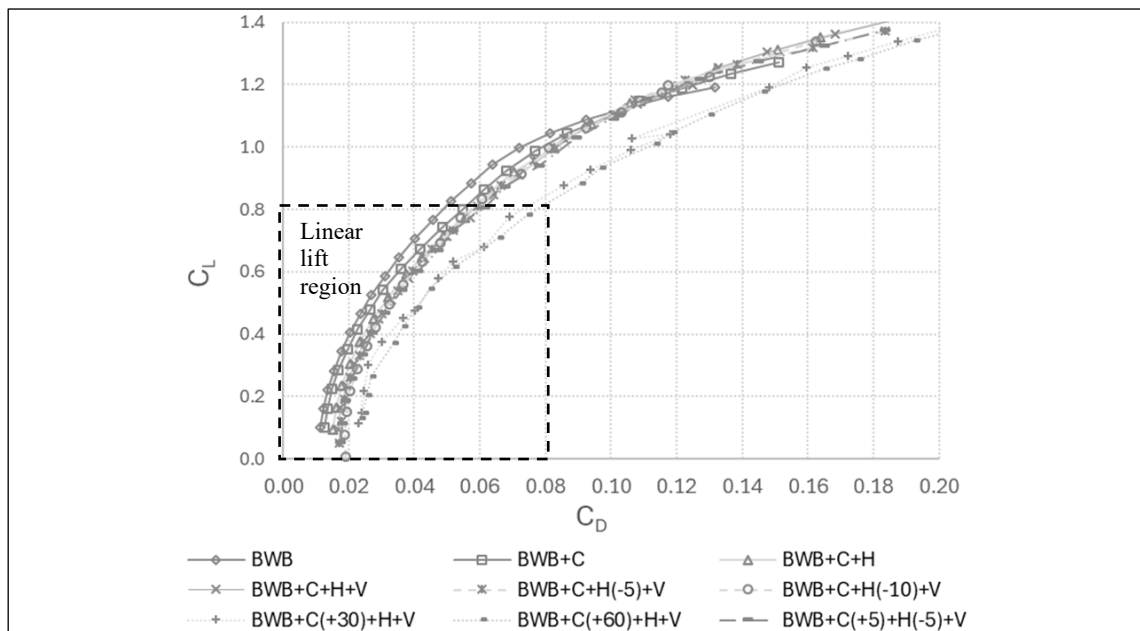


Fig. 7. C_L - C_D plots of BWB cases (note: C – canard, H – hor. Tail, V – ver. Tail).

The lift-angle of attack and drag polar plots in Figs. 6 and 7 bring us to Fig. 8 where lift coefficients are plotted against lift-to-drag ratios L/D for all cases. These are plotted quite unusually where L/D s is normally plotted in y-axis rather than x but here they are plotted in opposite axis (x-axis) for consistency with the rest of the graphs (where C_L is in y-axis). From the figure, the L/D plots follow the usual trends – climb steep at low lift, maximizes at optimal lift and descent shallow at higher lift coefficients. The ultimate maximum lift-to-drag ratio $L/D_{max} \approx 20.0$ for, of course, the BWB only case. Adding canard adds drag more than lift does thus it drops 9.0% to $L/D_{max} \approx 18.2$. Add horizontal tail, it drops 11.0% more to just $L/D_{max} \approx 16.0$ or just merely 80% of wing-body only L/D_{max} . The horizontal tail sits on the twin vertical tail so no one can deny its existence thus reduce the ratio to $L/D_{max} \approx 15.3$ or just 76.5% of the highest L/D_{max} . Small but negative horizontal tail elevator deflections do not affect the lift-to-drag ratio by much, and it still lingers around 15.0 or 75.0% of wing-body only setup. On the contrary, deflecting the small canard to large deflection angles spoils the purpose of having BWB in the first place – the ratio drops tremendously to just $L/D_{max} \approx 12.0$ meaning 40.0% drop compared with wing-body only configuration. A little canard's elevator deflection with a little horizontal tail's elevator deflection at 5.0 degree each in opposite direction for optimal flight trimming purposes (final case) maintains its ratio to around 15.0.

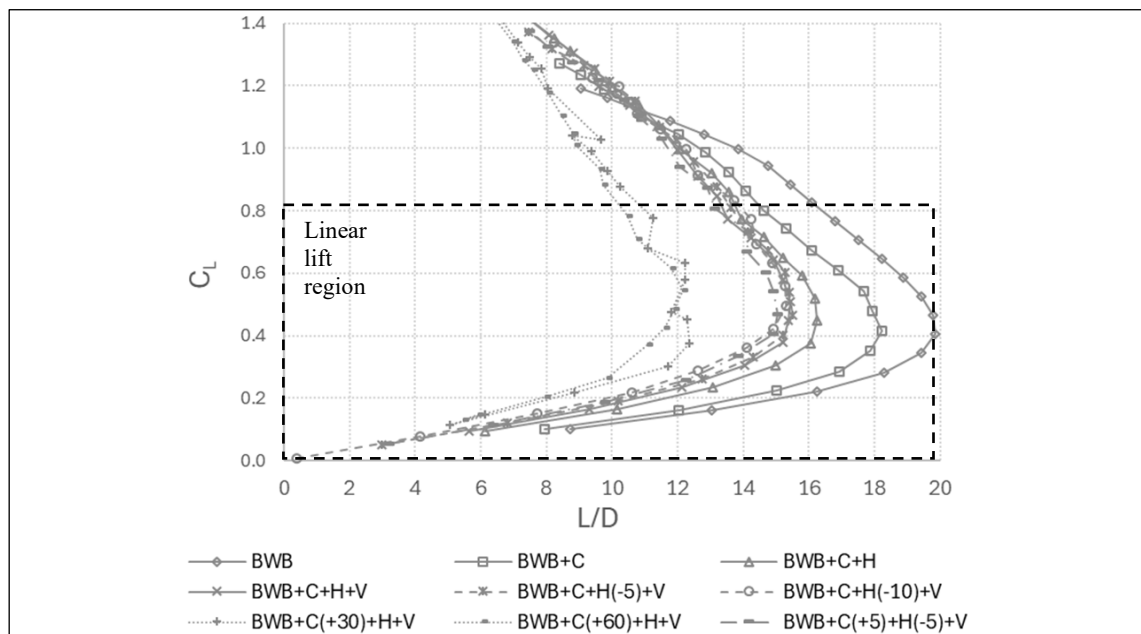


Fig. 8. L/D plots of BWB cases (note: C – canard, H – hor. Tail, V – ver. Tail).

Fig. 9 shows lift versus pitch moment coefficient plots that defines its longitudinal static stability. For all cases, the negative slopes ranging from $dC_M/dC_L \approx -0.4$ to -0.2 are the first sign of longitudinally stable flight where their static margin is between $K_n \approx 20\% - 40\%$ of its mean chord. However, not necessarily all of them are good. For the first four cases where there are no elevator deflections, the pitch moment coefficient at zero lift $C_{M,0}$ is negative or near zero, indicating poor trim lift coefficient $C_{L,trim}$ and angle of attack α_{trim} not suitable for flight. For information, trim condition is established when the pitch moment coefficient is zero (equilibrium, longitudinally) thus trim lift or trim angle of attack here reflect the equilibrium flight condition where the aircraft is static (but fly at constant velocity). With horizontal tail's elevator deflection of $\delta_h = -5^\circ$, trim lift is at $C_{L,trim} \approx 0.3$ – good but not trim at its L/D_{max} . Deflecting more to $\delta_h = -10^\circ$ trims its lift to $C_{L,trim} \approx 0.9$ – high lift but not efficient too. Deflecting canard's

elevator to high angles $\delta_c = +30^\circ, +60^\circ$, which is common in short take-off and landing setup in high-performance fighter aircraft such as JAS-37 Viggen, trims its lift to around $C_{Ltrim} \cong 0.4 \pm 0.02$ and closer to their L/D_{max} s but the maximum ratios for both are already low at around 12.0. By deflecting $\delta_c = +5^\circ$ and $\delta_h = -5^\circ$, the trim lift is at $C_{Ltrim} \cong 0.5$ right at its $L/D_{max} \cong 15.0$ thus this strikes the best balance between aerodynamic efficiency (hence, performance) and longitudinal static stability (and controllability too). In addition, this configuration gives static margin of 25% mean chord which is quite decently conservative (safe) in term of flight stability.

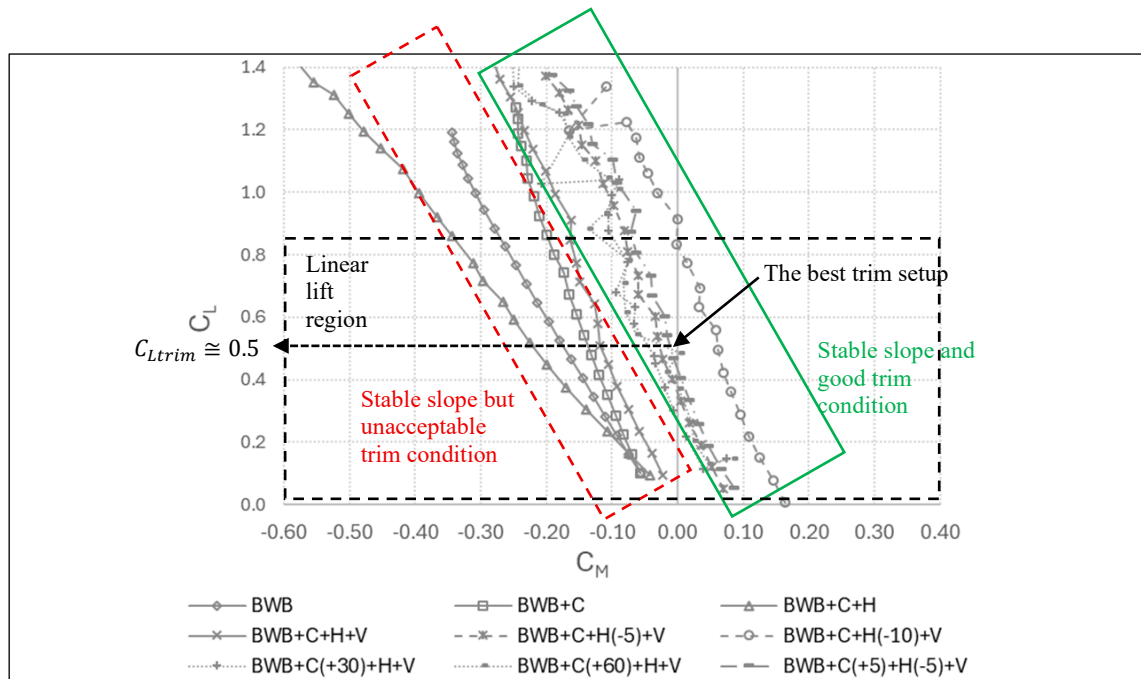


Fig. 9. C_L - C_M plots of BWB cases (note: C – canard, H – hor. Tail, V – ver. Tail).

In overall, one can have high maximum lift-to-drag ratio L/D_{max} to 20.0 with clean (no elevator, canard deflections) setup but practically unable to fly in equilibrium thus failed to adhere to one of the conditions for longitudinal static stability while setting $\delta_c = +5^\circ$ and $\delta_h = -5^\circ$ on canard and elevator, respectively, ensures equilibrium flight at maximum lift-to-drag ratio of $L/D_{max} = 15.0$ with comfortably “light” handling (controllability) due to relatively low 20% static margin. Having horizontal stabilizer as addition to wing-body-canard setup provides wide trim lift capability where elevator deflection $\delta_h = 0^\circ \rightarrow -10^\circ$ corresponds to trim lift $C_{Ltrim} = 0.0 \rightarrow 0.8$ covering the whole linear lift region and limiting the control from entering unpredicted separation and stall regions outside of it.

Conclusion

Achieving a balance between aerodynamic performance and longitudinal static stability is paramount in guaranteeing effective and safe flight. Ideally, a blended wing-body aircraft shall be tailless in configuration since, in this case, has high lift-to-drag ratio. Practically, although there are advanced stability augmentation systems, a longitudinally stable aircraft is more reliable and safer. Having large positive elevator deflection on canard combined with BWB does give better trim lift but its drag penalty reduces lift-to-drag ratio so

much it defeats the purpose of having blended wing-body. A little negative elevator deflection on the horizontal tail, on the other hand, serves better in providing wide range of trim lifts with insignificant reduction of lifts thus ensuring respectable lift-to-drag ratio around 15.0. Last but not least, small positive deflection of canard and small negative deflection of horizontal tail elevators (five degrees each) puts the trim lift coefficient right at the right spot where the lift-to-drag ratio is maximum. The right setup has been found for the BWB aircraft studied here and further studies in the near future will include the high-fidelity computational fluid dynamics simulations.

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Conflict of Interest Statement

The authors agree that this research was conducted in the absence of any self-benefit, commercial, or financial conflicts, and declare the absence of any conflicts of interest with the funders.

Authors' Contributions

The authors confirm their contribution to the paper as follows: study conception and design: Rizal Nasir; data collection: Rizal Nasir; analysis and interpretation of results: Rizal Nasir, Zamri Omar; draft manuscript preparation: Rizal Nasir, Zamri Omar. All authors reviewed the results and approved the final version of the manuscript.

Data Availability/ Supplementary Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request and shall be emailed to the corresponding author's address.

Ethics Statement

The authors declare that this research did not involve human or animal subjects. All experimental procedures were performed following the institutional Safety, Health, and Environmental (HSE) protocols of Universiti Teknologi MARA.

Reference

- Aubeelack, H., Segonds, S., Bès, C., Druot, T., Brézillon, J., Bérard, A., Duffau, M., & Gallant, G. (2023). Surrogate model development for optimized blended-wing-body aerodynamics. *Journal of Aircraft*, 60(2), 437–448. <https://doi.org/10.2514/1.c036790>
- Bohari, B., Bronz, M., Bénard, E., & Borlon, Q. (2017). Conceptual design of distributed propeller aircraft: linear aerodynamic model verification of propeller-wing interaction. 7th European Conference for Aeronautics and Aerospace Sciences (pp. 1-16). EUCASS Publisher. <https://doi.org/10.13009/eucass2017-445>
- Boschetti, P. J., Cárdenas, E. M., & Garcia, N. R. (2004). Experimental aerodynamic study of UAV wind tunnel model for low Reynolds Number. 22nd Applied Aerodynamics Conference and Exhibit (p. 4969). AIAA Publisher. <https://doi.org/10.2514/6.2004-4969>
- Botero, E., Clarke, M., Erhard, R., Smart, J., Alonso, J. J., & Blaufox, A. (2022). Aerodynamic verification and validation of SUAVE. AIAA SciTech 2022 Forum (pp. 1-16). AIAA Publisher. <https://doi.org/10.2514/6.2022-1929>
- Cipolla, V., Frediani, A., Oliviero, F., Rossi, R., Rizzo, E., & Pinucci, M. (2016). Ultralight amphibious PrandtlPlane: the final design. *Aerotecnica Missili & Spazio*, 95(3), 125–135. <https://doi.org/10.1007/bf03404721>
- Cipolla, V., Salem, K. A., & Bachi, F. (2018). Preliminary stability analysis methods for PrandtlPlane aircraft in subsonic conditions. *Aircraft Engineering and Aerospace Technology: An International Journal*, 91(3), 525–537. <https://doi.org/10.1108/aeat-12-2017-0284>
- Denieul, Y. (2016). Preliminary design of control surfaces and laws for unconventional aircraft configurations [Doctoral thesis, University of Toulouse]. Retrieved from <https://hal.archives-ouvertes.fr/tel-01482103>
- Giacomini, E., & Westerberg, L. G. (2025). CFD analysis of transition models for low-Reynolds Number aerodynamics. *Applied Sciences*, 15(18), 10299. <https://doi.org/10.3390/app151810299>
- Goetzendorf-Grabowski, T. (2023). Flight dynamics of unconventional configurations. *Progress in Aerospace Sciences*, 137, 100885. <https://doi.org/10.1016/j.paerosci.2023.100885>
- Hasan, Y. J., Roeser, M. S., Hepperle, M., Niemann, S., Voß, A., Handojo, V., & Weiser, C. (2023). Flight mechanical analysis of a solar-powered high-altitude platform. *CEAS Aeronautical Journal*, 14(1), 201–223. <https://doi.org/10.1007/s13272-022-00621-2>
- Ishrak, M. S., Shuvo, M. A. N. B., Tasnim, F., & Patnaik, S. S. (2024). Experimental study of the effect of different winglet configurations on the lift and drag characteristics of BWB aircraft. *Regional Student Conferences* (pp. 1-10). AIAA Publisher. <https://doi.org/10.2514/6.2024-90206>
- Islam, S. M. T., Xu, Y., & Zaw, N. C. (2025). Low-fidelity rapid wing design optimization approach for UAV. *International Conference on Advanced Unmanned Aerial Systems* (pp. 213-223). Springer. https://doi.org/10.1007/978-981-96-3240-4_23
- Joshi, H., & Thomas, P. (2023). Review of vortex lattice method for supersonic aircraft design. *The Aeronautical Journal*, 127(1317), 1869–1903. <https://doi.org/10.1017/aer.2023.25>
- Joshi, H., Thomas, P., Tan, C., & Wu, H. (2025). Improved vortex lattice method for drag prediction of supersonic wings using shock cone modelling. *Engineering with Computers*, 41(5), 3815–3831. <https://doi.org/10.1007/s00366-025-02192-2>

<https://doi.org/10.24191/jmeche.v23i3.11599>

- Kumar, J. K. A., Prabhu, K. S., Veerendra, A. S., Shastry, Y. B. S., & Srinivas, G. (2025). A comprehensive review of aerodynamic performance evaluation for aircraft wings and engines: insights into experimental, numerical, and theoretical approaches. *Aerospace Systems*, 1-30. <https://doi.org/10.1007/s42401-025-00366-w>
- Larkin, G., & Coates, G. (2017). A design analysis of vertical stabilisers for Blended Wing Body aircraft. *Aerospace Science and Technology*, 64, 237–252. <https://doi.org/10.1016/j.ast.2017.02.001>
- Liou, M. F., Kim, H., Lee, B., & Liou, M. S. (2019). Aerodynamic design of integrated propulsion–airframe configuration of a hybrid wing body aircraft. *Shock Waves*, 29(8), 1043–1064. <https://doi.org/10.1007/s00193-019-00933-z>
- Liu, S. Q., & Whidborne, J. F. (2021). Observer-based incremental backstepping sliding-mode fault-tolerant control for blended-wing-body aircrafts. *Neurocomputing*, 464, 546–561. <https://doi.org/10.1016/j.neucom.2021.08.069>
- Loya, A., Maqsood, K., & Duraid, M. (2018). Quantification of aerodynamic variables using analytical technique and computational fluid dynamics. *International Journal of Mechanical, Industrial and Aerospace Sciences*, 12(10), 991–997. <https://doi.org/10.1999/1307-6892/10009701>
- Luo, S., Eng, T. Z., Tang, Z., Ma, Q., Su, J., & Bugada, G. (2024). Multidisciplinary optimization of aircraft aerodynamics for distributed propulsion configurations. *Applied Sciences*, 14(17), 7781. <https://doi.org/10.3390/app14177781>
- Marqués, P. (2017). Advanced UAV aerodynamics, flight stability and control. *Advanced UAV Aerodynamics, Flight Stability and Control: Novel Concepts, Theory and Applications* (pp. 1–30). John Wiley & Sons. <https://doi.org/10.1002/9781118928691.ch1>
- Nae, C. (2010). VLM tool for IDS integration. *INCAS Bulletin*, 2(1), 37–48. <https://doi.org/10.13111/2066-8201.2010.2.1.5>
- Natale, N., Salomone, T., Stefano, G. D., & Piccolo, A. (2020). Computational evaluation of control surfaces aerodynamics for a mid-range commercial aircraft. *Aerospace*, 7(10), 139. <https://doi.org/10.3390/aerospace7100139>
- Oddiraju, M., Amin, D., Piedmonte, M., & Chowdhury, S. (2023). Physics-infused machine learning based prediction of VTOL aerodynamics with Sparse datasets. *AIAA Aviation 2023 Forum* (pp. 1-11). AIAA Publisher. <https://doi.org/10.2514/6.2023-4376>
- Odendaal, D. U., Smith, L., Craig, K. J., & Sanders, D. S. (2024). Computational investigation of the aerodynamic performance of an optimised alternative fuselage shape. *Aircraft Engineering and Aerospace Technology: An International Journal*, 96(11), 1–9. <https://doi.org/10.1108/aeat-11-2023-0297>
- Raza, H., Maqsood, A., & Masud, J. (2024). Altering flight stability characteristics of a high-performance aircraft through wing strake modification. *The Aeronautical Journal*, 128(1327), 2105–2125. <https://doi.org/10.1017/aer.2024.32>
- Rostami, M., Bardin, J., Neufeld, D., & Chung, J. (2023). EVTOL tilt-wing aircraft design under uncertainty using a multidisciplinary possibilistic approach. *Aerospace*, 10(8), 718. <https://doi.org/10.3390/aerospace10080718>
- Ruh, M. L., Sarojini, D., Fletcher, A., Asher, I., & Hwang, J. T. (2023). Large-scale multidisciplinary design optimization of the NASA lift-plus-cruise concept using a novel aircraft design framework [Preprint]. *arXiv*. <https://doi.org/10.48550/arxiv.2304.14889>

- Saad, N. M., Wisnoe, W., Nasir, R. E. M., Ali, Z. M., & Askari, E. S. S. (2019). Aerodynamic analysis of blended wing body - unmanned aerial vehicle (BWB-UAV) equipped with horizontal stabilizers. 5th International Conference on Mechatronics and Mechanical Engineering, 256, 2004. <https://doi.org/10.1051/mateconf/201925602004>
- Salem, K. A., Cipolla, V., Palaia, G., Binante, V., & Zanetti, D. (2021a). A physics-based multidisciplinary approach for the preliminary design and performance analysis of a medium range aircraft with box-wing architecture. *Aerospace*, 8(10), 292. <https://doi.org/10.3390/aerospace8100292>
- Salem, K. A., Palaia, G., & Carrera, E. (2024). A discussion on benchmarking unconventional configurations with conventional aircraft: the box-wing study case. *CEAS Aeronautical Journal*, 15(4), 1069–1090. <https://doi.org/10.1007/s13272-024-00758-2>
- Salem, K. A., Giuseppe, P., Vittorio, C., Vincenzo, B., Davide, Z., & Mario, C. (2021b). Tools and methodologies for box-wing aircraft conceptual aerodynamic design and aeromechanic analysis. *Mechanics & Industry*, 22, 39. <https://doi.org/10.1051/meca/2021037>
- Salem, K. A., Palaia, G., Quarta, A. A., & Chiarelli, M. R. (2023). Preliminary analysis of the stability and controllability of a box-wing aircraft configuration. *Aerospace*, 10(10), 874. <https://doi.org/10.3390/aerospace10100874>
- Sarojini, D., Ruh, M. L., Yan, J., Scotzniovsky, L., Orndorff, N. C., Xiang, R., Zhao, H., Krokowski, J. J., Warner, M., van Schie, S. P. C., Cronk, A., Guibert, A. T. R., Chambers, J. T., Wolfe, L., Doring, R., Despins, R., Joseph, C., Anderson, R., Ning, A., Gill, H., Lee, S., Cheng, Z., Cao, Z., Mi, C., Meng, Y. S., Silva, C., Chen, J. S., Kim, H. A., & Hwang, J. T. (2024). Review of computational models for large-scale MDAO of urban air mobility concepts. *AIAA SciTech 2024 Forum and Exposition* (pp. 1-63). AIAA Publisher. <https://doi.org/10.2514/6.2024-0377>
- Sepulveda, E., Smith, H., & Sziroczák, D. (2019). Multidisciplinary analysis of subsonic stealth unmanned combat aerial vehicles. *CEAS Aeronautical Journal*, 10(2), 431–442. <https://doi.org/10.1007/s13272-018-0325-0>
- Sgueglia, A. (2019). Methodology for sizing and optimising a Blended Wing-Body with distributed electric ducted fans [Doctoral thesis, University of Toulouse]. Retrieved from https://depozit.isae.fr/theses/2019/2019_Sgueglia_Alessandro.pdf.
- Singh, S., Stappert, S., Bussler, L., Sippel, M., Küçükösman, Y. C., & Buckingham, S. (2022). Full-scale simulation and analysis of formation flight during in-air-capturing of a winged reusable launch vehicle. *Journal of Space Safety Engineering*, 9(4), 541–552. <https://doi.org/10.1016/j.jsse.2022.09.005>
- Stephens, C. H., Arena, A. S., & Gupta, K. K. (1999). CFD-based aeroservoelastic predictions with comparisons to benchmark experimental data. 37th Aerospace Sciences Meeting and Exhibit (p. 0766). AIAA Publisher. <https://doi.org/10.2514/6.1999-766>
- Sung, N., Spreizer, S., Elrefaie, M., Samuel, K., Jones, M. C., & Ahmed, F. (2025). BlendedNet: a blended wing body aircraft dataset and surrogate model for aerodynamic predictions. *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (pp. 1-16). ASME Publisher. <https://doi.org/10.1115/DETC2025-168977>
- Wang, L., Zhang, N., Liu, H., & Yue, T. (2022). Stability characteristics and airworthiness requirements of blended wing body aircraft with podded engines. *Chinese Journal of Aeronautics*, 35(6), 77–86. <https://doi.org/10.1016/j.cja.2021.09.002>
- Wauters, J., & Degroote, J. (2018). On the study of transitional low-Reynolds number flows over airfoils operating at high angles of attack and their prediction using transitional turbulence models. *Progress* <https://doi.org/10.24191/jmeche.v23i3.11599>

in *Aerospace Sciences*, 103, 52–68. <https://doi.org/10.1016/j.paerosci.2018.10.004>

Wisnoe, W., Nasir, R. E. M., Saarani, W. A. M., Saad, N. M., & Mamud, M. A. A. (2017). Wind tunnel tests of UiTM blended wing body - unmanned aerial vehicle (BWB-UAV) prototype. *Journal of Mechanical Engineering*, SI 4(3), 234-245.

Yang, T., Zhiyong, L., Neng, X., Yan, S., & Jun, L. (2018). Optimization of positional parameters of close-formation flight for blended-wing-body configuration. *Heliyon*, 4(12), e01019. <https://doi.org/10.1016/j.heliyon.2018.e01019>

Zhang, M., Bartoli, N., Jungo, A., Lammen, W., Baalbergen, E., & Voskuijl, M. (2020). Enhancing the handling qualities analysis by collaborative aerodynamics surrogate modelling and aero-data fusion. *Progress in Aerospace Sciences*, 119, 100647. <https://doi.org/10.1016/j.paerosci.2020.100647>



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