Lateral-Directional Stability Investigation of a Blended-Wing-Body

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Presently at the Von Karman Institute for Fluid Dynamics (VKI), a comprehensive research investigation is being performed on the lateral-directional stability characteristics of a BizJet-class Blended-Wing-Body (BWB). This paper presents the designing attempts using lower order methods and vortex lattice based methodology to get a comprehensive understanding of the aerodynamic performance, followed by and compared with more accurate CFD methods to fine tune the performance. Specific interest is placed in the take-off and landing flight regimes where the BWB is prone stall and departure due to assymetric wind gusts. Differential control effectors on the bottom of the wing, called "belly-flaps", are investigated for lateral-directional control.

Nomenclature

Abbreviations

AVL	Athena Vortex Lattice
BWB	Blended Wing Body
CAD	Computer Aided Design
CFD	Computational Fluid Dynamic
MDO	Multi-disciplinary Design Optimization
VLM	Vortex Lattice Method

Variables

α	angle of attack
β	angle of side slip
$C_{D\ I}$	Coefficient of Interference Drag [Global]
C_{Di}	Coefficient of Induced Drag [Global]
C_l	Coefficient of Lift [Local]
$C_{l\ stall}$	Coefficient of Lift at Stall [Local]
$C_l\ \frac{c}{c_{ref}}$	Coefficient ratio for Lift Distribution
c	Chord length of airfoil
c_{ref}	Mean aerodynamic chord, also $\bar{c}$
F_x	Body Reference Frame, Axial Force
F_z	Body Reference Frame, Normal Force
M_x	Body Reference Frame, Roll Moment
M_y	Body Reference Frame, Pitch Moment

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I. Introduction and Historical Significance

Blended-Wing-Body configurations are based on the concept that the area rule provides a better aerodynamic performance from cross sectional shapes when fuselage, wings, empennage, engine pods, etc., get integrated into a single component resulting in a smooth delta shape wing body configuration. This configuration has been shown to have superior aerodynamic performance - in contrast to their classic wing-and-tube fuselage counterparts - and have reduced sensitivity to aerodynamic flutter as well as potential for increased engine noise abatement. The resulting inner space is demonstrated to cover a larger volume than the classic fuselage supported on cantilevered wings and a crossed T tail. Additionally, when the interior structure of the vehicle can be simplified with a monocoque structure, taking advantage of modern composite materials, it provides superior wing loading and structural strength. Of course without a classic tail elevator to damp the nose up pitching moment, and the vertical tail rudder to damp the yaw and possible rolling aerodynamics, the challenges in lateral roll and yaw stability, as well as pitching moment are not insignificant.

A. Historical Case for Aircraft Design

During the first century of flight, the aircraft design evolved from the canard-wing-tail configuration of the Wright Flyer in 1903, to the modern day tube-fuselage wing-tail configuration, first demonstrated with the Boeing B-47 in 1947. Today, after nearly 60 years after the B-47 (see figure 1), the aircraft design philosophy is relatively unchanged[8] ,[34] . The modern transport, either Boeing 7-series or the Airbus 3-series, or the smaller variants of the Bombardier or Dassault business-jet-class airplanes, still resemble the tube and wing configuration. While this is a well tested and well understood design, there are significant performance advantages to be gained with the evolution away from this classic design. Instead of gaining performance on the order of fractions of a percent, through the use of a higher performing engines, or the addition of winglets on for example the Boeing 737, it is time for a renaissance in aircraft design philosophy where there exists a potential performance increase greater than 20%.

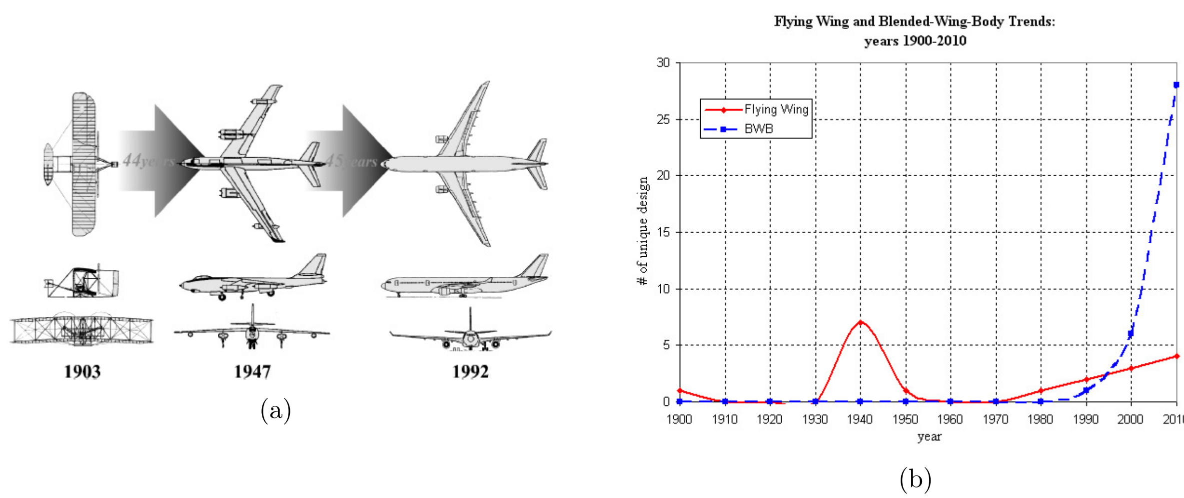


Figure 1. Aircraft evolution during the first century of flight[8] (a), Flying Wing and BWB historical trends based on literature (b).

The flying wing, due to the simplicity of the design and perceived performance advantages, has been a design of interest since man's first flight. Through the 1940's the flying wing received increased interest by the Horten brothers in Germany, and later with Northrop, in America. And it was nearly 40 years before the flying wing emerged as a design in full production, with the B-2 Stealth Bomber, again by Northrop. While the flying wing designs have shown promise, their use in industry has been limited, and has lacked the ability to present a strong case for mass transport of personnel or supplies. During the late-1980's and early-1990's, the BWB emerged as a design capable of transporting 400+ passengers[8] with 20% greater efficiency than the classic design. Since then, the BWB has been on the forefront of research and development, with published designs increasing exponentially, (see figure 1).

B. The Blended-Wing-Body Argument

The BWB configuration provides several specific design and performance advantages over the common tube and wing designs.

1. Drag

Drag reduction can be achieved by the elimination of the interference drag, $C_{D\ I}$, caused by the wing-fuselage as well as tail-fuselage intersections. During take off and landing configurations too, it is envisaged that hanging engines with separate tail fuselage and wing configuration the classic shape is prone to larger acoustic signatures compared to the integrated delta shape where interference effects would be minimized from all-in-one blended wing body shape. Also, due to the absence of a vertical tail, the flying wing or BWB requires either artificial lateral stability or winglets. Artificial lateral-directional stability requires control surfaces placed well outboard, and it is common to employ split ailerons which act as both as ailerons for roll-control, and drag rudders for yaw-control. While this is a clean configuration for low-observables, or stealth applications, it still increases the total drag of the system and therefore reduces the potential range performance. Alternatively, in non-stealth configurations, winglets can be used instead of (or in combination with) split-ailerons. The primary advantage of the winglet is the increase in effective wing aspect-ratio, and thus a reduction in induced drag C_{Di}, while simultaneously providing lateral-directional stability. Finally, a by-product of the BWB design is the inherent "area rule" of the vehicle. The "area rule", discovered by Whitcomb[33] during the 1950's, applies the results of cross-sectional area of a vehicle to the effect on transonic drag. Simply put, transonic drag is reduced when a vehicle exhibits a near-to-theoretical circular distribution of cross-sectional area versus fuselage station along the longitudinal axis of the fuselage.

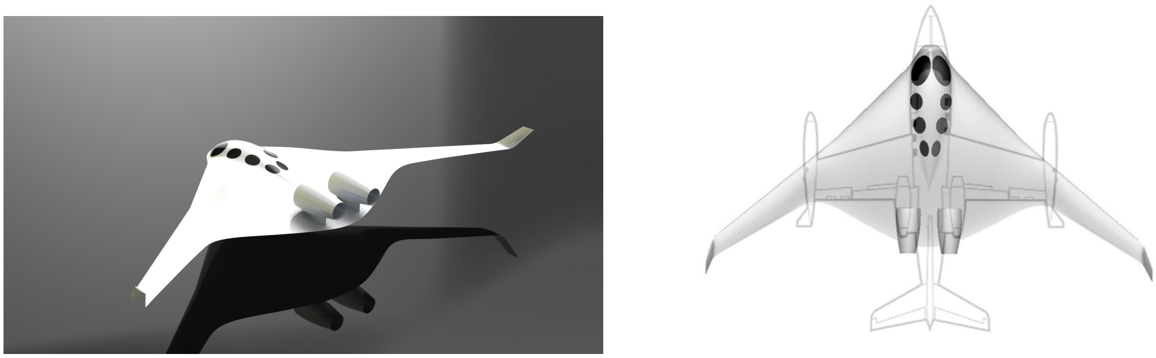
2. Structure & Payload

The BWB further simplifies the aircraft design by integrating the fuselage into the wing volume, thereby displacing the payload mass over the entire wing. This provides significant design advantages, both structurally and economically. Structurally the wing can can be built of a monocoque structure which is self-contained and self-supporting, without the necessity of transferring the load to another structure—a fuselage for example. This simplifies both the design and the manufacturing of such a structure. Economically, the wing-box structure has been used for many years for the placement of fuel. This is done such that as the fuel is burned during flight, the resulting impact on center of gravity of the aircraft is minimized, and the aircraft remains stable as a result. While the placement of fuel remains the same for the BWB, the increased volumetric area of the wing, due to the integration of the fuselage volume into the wing, provides greater storage capacity than what presently exists in the traditional configuration, and at no extra cost in performance. This, would certainly be extremely useful if such configurations were being considered for Trans Atlantic executive business jet type configurations.

3. Challenges and the Present Investigation

While the argument in favor of the BWB certainly is convincing, there exist significant design challenges which must be overcome. First, the lack of a horizontal and vertical tail requires that the pitch and yaw moments must be managed, at all flight conditions, by a short moment arm. Second, also related to the first, is the requirement of lateral-directional stability throughout the flight regime, most importantly at take-off and landing. At takeoff and landing, the high angle of attack conditions make the BWB dangerously susceptible to gust loads which push the local angle of attack to near stall conditions, potentially eliminating control effectiveness of the control surfaces on the trailing edge of the wing.

The present investigation is centered around a 6 seat, business-jet-class airplane, similar to the Lear 23: see figure 2. This configuration was selected because of publically available data[22] from which to make a comparison of the aircraft stability and performance. This paper presents the original design of a BWB configuration which exhibits favorable stability characteristics, as well as significant drag reduction and increased range performance. Particular attention will be addressed in control actuators which restore lateral-directional stability, as well as pitch stability, in the takeoff and landing flight regimes.



(a) (b)

Figure 2. The Roysdon BWB (a), Overlay of the Roysdon BWB with a Lear 23 (b).

II. Modeling Strategies

The Roysdon BWB design philosophy was influenced by the aircraft designs of Burt Rutan[20] as well as the carbon-composite manufacturing capabilities of Composite Engineering Inc.[3] The initial investigation into the BWB design was first to determine a planform which was statically-stable, with aerodynamic characteristics similar to literature([2], [10] thru [16], and [26] thru [32]) and applying the literature results as a basis from which to start a multi-disciplinary design optimization, varying: inboard-to-outboard planform area, wing-sweep, wing-twist, airfoil-family, airfoil-thickness and chord length, see figure 3.

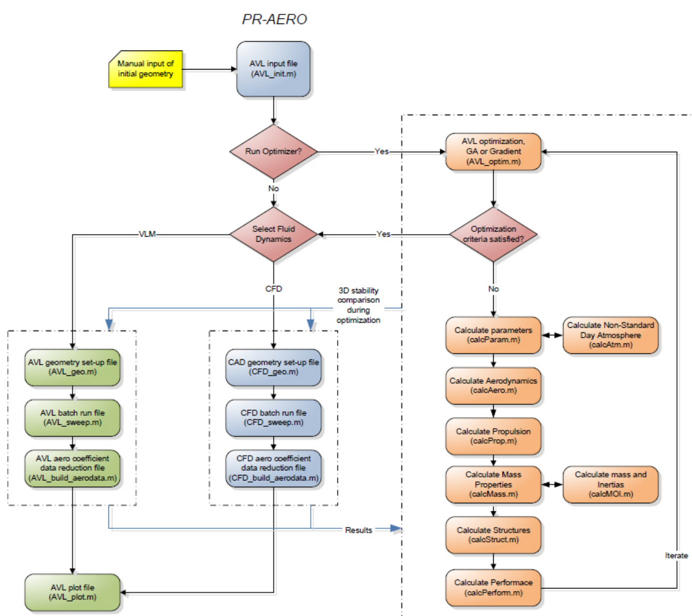


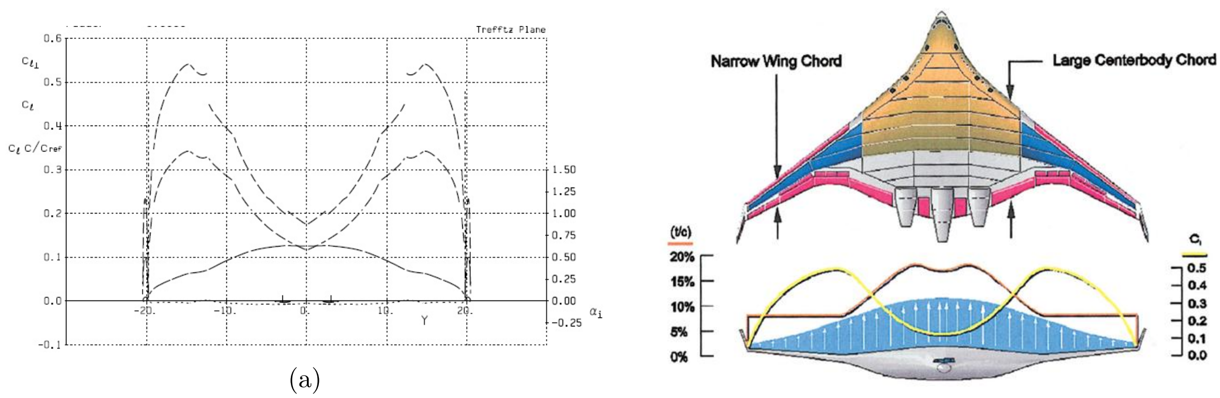
Figure 3. Coupled low-order/high-order MDO routine.

Upon obtaining a preliminary design, a study was performed on the entire angle-of-attack (α) and angle-of-side-slip (β) envelope, with special interest in the lateral-directional stability characteristics. Comparing the stability coefficient results to literature data available in stability and control ([1], [5], [7], [9], and [17] thru [19]), further investigation was made, and an initial 6DOF non-linear simulator was developed in MatLab & Simulink. The non-linear simulation provided a benchmark from which to test the vehicle dynamics for further optimization. Later, tuning of these results would be obtained with higher-order methods, and wind tunnel analysis.

A. Low-Order Methods

The initial investigation managed the pitch moment in two ways; first by creating pitch stability through wing sweep, and second by applying reflexed airfoils on the inboard regions of the BWB and cambered airfoil sections on the outboard regions of the BWB. The reflexed airfoil creates pitch-trim on the inboard section of the BWB, while the cambered airfoil creates two things. First, the restoring pitch-moment, common to cambered profiles, creates pitch stability. And second, the cambered profile, when combined with proper wing twist, creates the optimal lift distribution over the wing.

The pitch stability and lift distribution was obtained by applying a gradient-based optimization routine, coupling MatLab with AVL,[4] a vortex-lattice-method code, and the results are shown in figure 4. The top curve represents the predicted lift coefficient at stall, $C_{l\ stall}$, the second curve is the local lift coefficient at zero angle of attack, C_l, and the third is essentially the total lift distribution $C_l\ \frac{c}{c_{ref}}$. Where c is the local chord length, and c_{ref}, or more commonly known as $\bar{c}$, is the mean aerodynamic chord. The MatLab-AVL optimization obtained a compromise of airfoil-family selection, airfoil thickness, wing sweep and wing twist, based on findings of[10] thru,[16] and[26] thru.[32] And when the initial results are compared with those of the Boeing X-48, we find that the numerical trends are nearly identical.



(a)

(b)

Figure 4. Low-order results of lift distribution (a), Boeing BWB lift distribution[8] (b).

Again applying the MatLab-AVL routine, a batch-mode analysis was performed throughout the flight envelope, with sweeps of the angle-of-attack (α) and angle-of-side-slip (β) envelope at various velocities. The result is an aero-database for the non-linear simulation, and a series of plots which provide a quick-look reference of the aircraft stability coefficients.

Based the MatLab-VLM results, a 3D CAD model was created for CFD analysis and the preparation of the wind tunnel model. Using the CAD model, the "area-rule" of this design was also verified. Figure 5 compares the BWB to the theoretical area-rule, as well as to the reverse-engineered area-rule of the Lear 23 (performed by generating a representative 3D model from a 3-view drawing of a Lear 23).

B. High-Order Methods

A systematic approach was taken (figure 1) for the investigation of the BWB using CFD, first to determine mesh dependencies on the results, and second to provide the "tuning" values needed for the first-order data-base:

The higher-order code in use is STAR-CCM+ v4.04, a product of CD-Adapco. Initially a half-model was tested for mesh dependencies and aerodynamic data comparison to the lower-order methods (see figure 6), after which a full model was created. It was found that good correlation exists in four axes (F_x, F_z, M_x, M_y), between the half-model CFD results and the full-model lower-order code predictions; with an average offset of less than 5%. A brief description of the conditions is provided below:

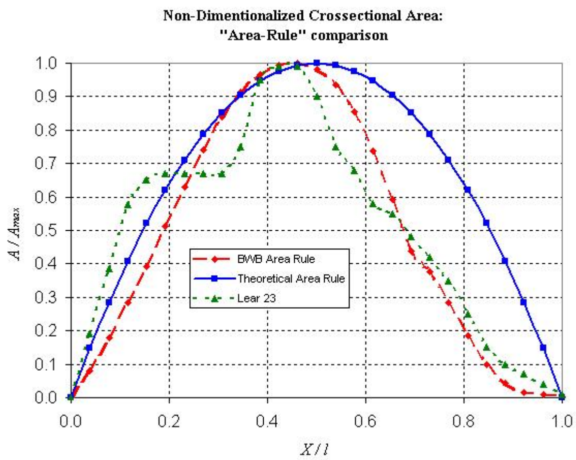


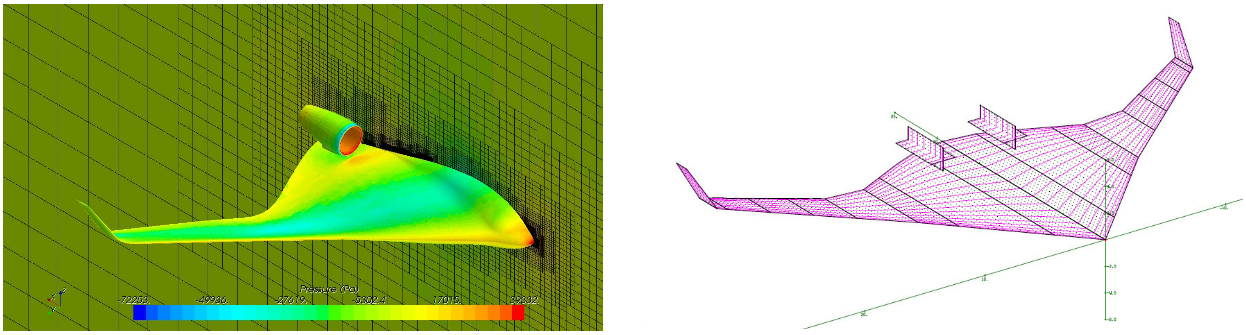
Figure 5. Area-Rule comparison.

Table 1. CFD Test Cases.

Flight Condition	Configuration	Velocity (Mach #)	α (deg)	β (deg)
Cruise	clean	0.735	[-4,0,4,8,12]	[0,2,6]
Takeoff	clean	0.183	[-4,0,4,8,12]	[0,2,6]
Stall	clean	0.098	[4,8,12]	[0,2,6]
Takeoff	flapped	0.183	[-4,0,4,8,12]	[-6,-2,0,2,6]

- Mesh: structured, surface prism cells, with a fast adaptation to the domain
  - Cell size: 0.001 m (min), 2.5 m (max)
  - Cell count: 9.2 million
- Solvers
  - Reynolds Averaged Navier-Stokes
  - 2nd Order segregated flow, convection/ diffusion
  - Turbulent
    * SST (Menter) K-omega turbulence model
    * Compressibility correction
    * All y+ Wall Treatment
- Flow Conditions
  - Standard atmosphere air at 10 km
  - 0.60 Mach
  - Angle of attack = 0, Angle of side slip = 0

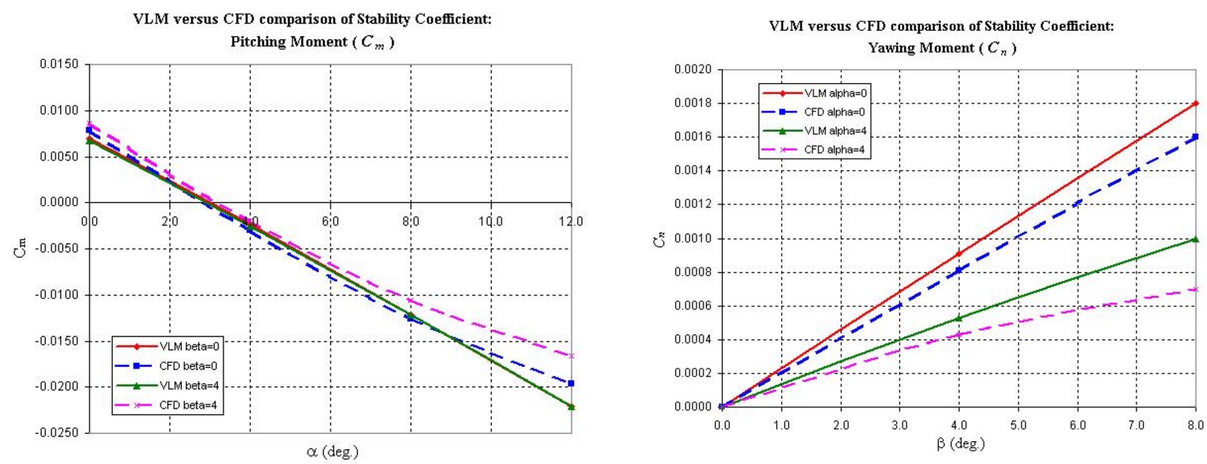
The initial test cases were based on a less than optimum cruise condition, Mach 0.60, because the lower-order results were obtained from in incompressible solver. Once a correlation was obtained between the lower-order method and the CFD, a full test matrix was examined. First looking at the higher Mach numbers, at the optimized cruise condition, Mach 0.73. Followed by more computationally expensive, low Mach numbers, on the order of 0.18 Mach, representing the takeoff and landing flight regimes. In this flight regime, the BWB is prone to lateral-instabilities due to high angles-of-attack combined with asymmetric gust loads or cross-wind. The engine pods were removed on the full model to minimize number of elements in the mesh domain, and the effect on the stability is assumed to be minimal. This is considered an adequate assumption, based on,[2,13] and.[16]



(a) (b)

Figure 6. BWB CFD model pressure contour (a) BWB VLM model (b).

Following the initial investigation of α and β sweeps, a differential control actuator was investigated based on the research by Staelens ([23], [24] and [35]) investigating the pitch-moment stability created by belly-mounted flaps. While Staelens research focused on the longitudinal stability with simultaneous deployment of various belly-flap configurations, this author's investigation is in the asymmetric deployment of similar belly-flaps for lateral-directional control. This design is a common design to model-airplane enthusiasts since the late-1980's[6] &,[25] for slope-soar flying wing gliders, however no literature exists on the differential deployment of belly-flaps on the BWB configuration. Initial CFD and VLM results are presented in figure 7.

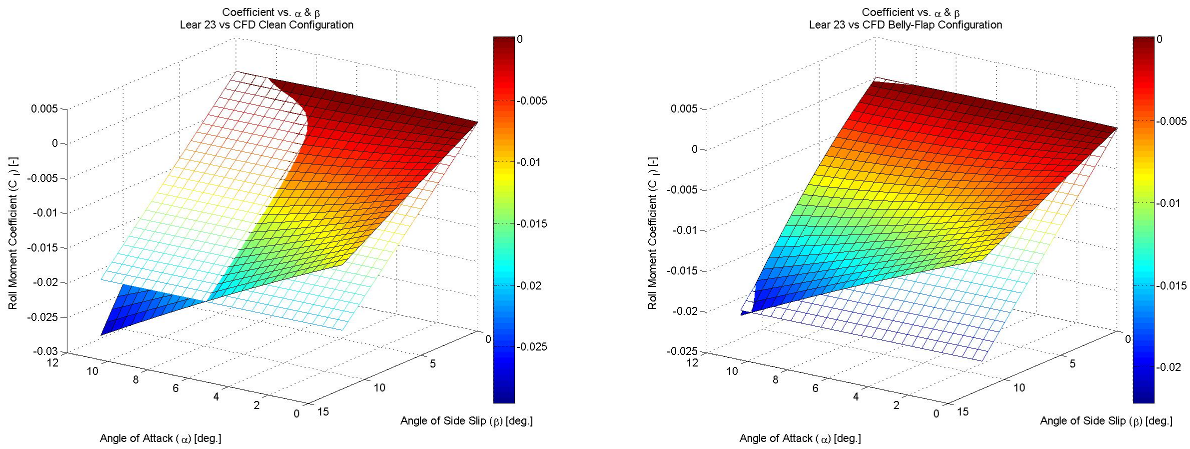


(a) (b)

Figure 7. Coefficient Comparison: Pitch Moment (a), Yaw Moment (b).

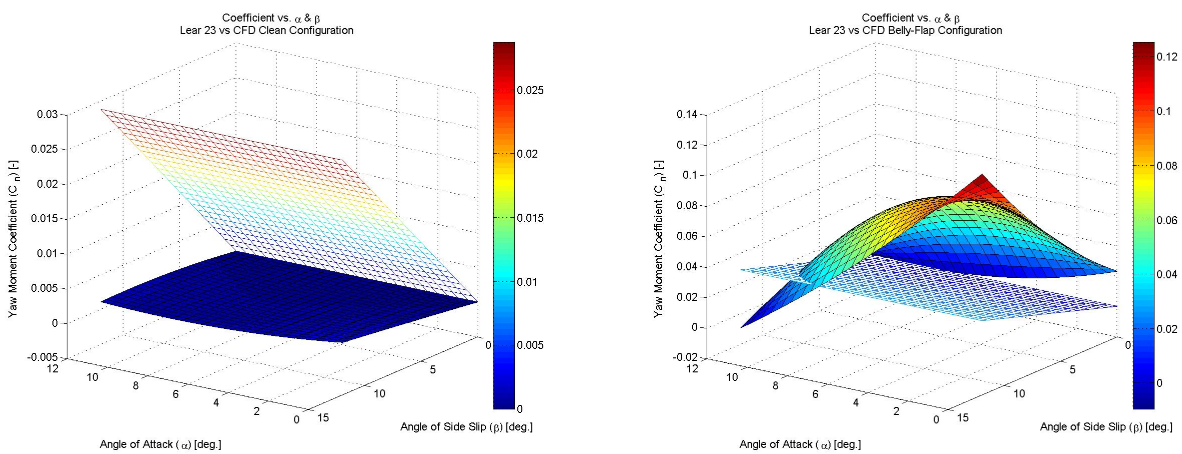
III. Lateral-Directional Results

Previous design and low-order analysis attempts into the lateral-directional stability revealed that the BWB was more stable with the belly-flaps deployed. This result was anticipated, however higher-order methods revealed a strong roll-yaw coupling induced by the belly-flaps. Both single and combined/differential belly-flap configurations were evaluated with flap deployments at 30, 60, and 90 degrees perpendicular to the flow. It was found that single, right-side or left-side only, deployment of the flaps at 60-90 degrees increased the yaw stability dramatically while simultaneously decreasing the roll stability. Further analysis revealed that full flap deployment of one side and partial flap deployment of the opposite side maintained the pitch stability – a similar configuration to Staelen's research – while also providing improved roll and yaw stability. These results have been compiled into surface plots and compared to the lateral-directional stability of a Lear 23, see figures 8, 9, and 10. The findings reveal that the present BWB configuration demonstrates stronger lateral-directional stability (solid-mesh) over the Lear 23 (open-mesh), with the final depicting the streamlines over the BWB with the right-hand flap deployed at 60 degrees, with an angle-of-attack of zero and angle-of-side-slip of 12 degrees.



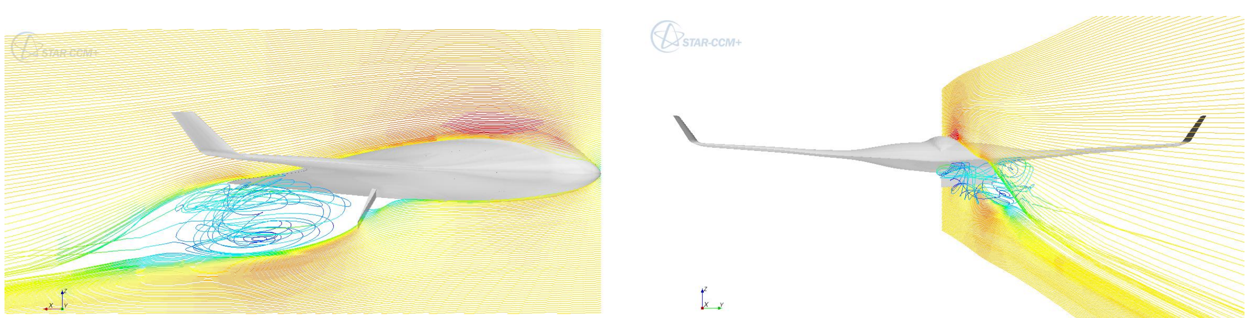
(a) (b)

Figure 8. BWB vs. Lear 23 Roll Moment comparison - BWB no flap (a) BWB belly-flap deployed (b).



(a) (b)

Figure 9. BWB vs. Lear 23 Yaw Moment comparison - BWB no flap (a) BWB belly-flap deployed (b).



(a) (b)

Figure 10. CFD streamline profiles [velocity magnitude] - side (a) aft (b).

IV. Concluding Remarks

The present investigation into the lateral-directional stability of the BWB configuration, reveals that higher-order methods confirm the findings, with increased accuracy, compared with the lower-order methods. Initial results reveal that the present configuration is statically stable, however with 25-40% reduced stability when compared with the BizJet coefficients[22] ,[12] ,[14] . Initial belly-flap analysis improves this stability delta to a range of 10-15% or better. High-order analysis is continuing to validate the use of bell-flap control surfaces for lateral-directional control, and 6DOF flight simulation results, using a high fidelity MatLab-Simulink model for takeoff/balk-landing/go-around maneuvering will be presented in a future report.

Both the advantages and challenges were presented with the original design of a BizJet class BWB configuration, with potential design advantages which could be incorporated into future industrial applications of the BWB design. This is a first level attempt to prove the results of the first order method using more accurate CFD based results. Further confidence in the design will be achieved when the computed results in hand are validated through wind tunnel testing.

V. Acknowledgments

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References

[1]Buffington, J.M., "Tailless Aircraft Control Allocation", AIAA-97-3605.

[2]Carter, M.B., *et.al.*, "Blended-Wing-Body Transonic Aerodynamics: Summary of Ground Tests and Sample Results (Invited)", A47th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, 5-8 January 2009, Orlando, Florida. AIAA-2009-935.

[3]Composite Engineering, Inc., *BQM-167 Aerial Target*, <http://www.compositeeng.com/uav_BQM167.htm>.

[4]Drela, M., Youngren, H., AVL 3.26 User Primer. MIT Aero & Astro. 29 Apr 2006. <http://web.mit.edu/drela>.

[5]Iniguez de Heredia, A., Frichmelt, H., "GN&C Concepts for a Blended Wing Body", AIAA Guidance, Navigation, and Control Comference, 15-18 August 2005, San Francisco, California. AIAA-2005-6351.

[6]Kuhlman, B., Kuhlman, B., "On the 'Wing... the book", vol. 1-4, B^2Streamlines, Washington, 1993-2004.

[7]Leman, T., *et.al.*, "λ_1 Adaptive Control Augentation System for the X-48B Aircraft", AIAA Guidance, Navigation, and Control Comference, 10-13 August 2009, Chicago, Illinois. AIAA-2009-5619.

[8]Liebeck, R.H., "Design of the Blended Wing Body Subsonic Transport", American Institute of Aeronautics & Astronautics Journal of Aircraft, Vol. 41, No. 1, January-February 2004. AIAA-9084-368.

[9]McKeehen, P.D., "Genesis Non-Realtime Simulation of a Tailless Aircraft", AIAA-98-4159.

[10]Mialon, B., Fol, T., Bonnaud, C., "Aerodynamic Optimisation of Subsonic Flying Wing Configurations", 20th AIAA Applied Aerodynamics Conference, 24-26 June 2002, St. Louis, Missouri. AIAA-2002-2931.

[11]Morris, A.M., Allen, C.B., Rendall, T.C.S., "Aerodynamic Optimisation of Modern Transport Wing using Efficient Variable Fidelity Shape Parameterisation", 47th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, 5-8 January 2009, Orlando, Florida. AIAA-2009-1277.

[12]Nelson, R., *Flight Stability and Automatic Control*, McGraw-Hill, 2nd ed., 1997.

[13]Peigin, S., *et.al.*, "Computational Fluid Dynamics Driven Optimisation of a Blended-Wing-Body Aircraft", AIAA

Journal, Vol. 44, No. 11, November 2006. AIAA-19757-954.

[14]Roskam, J., Lan, C.E., *Airplane Flight Dynamics and Automatic Flight Controls*, Darcorporation, Vol.1-2, 2003.

[15]Qin, N., *et.al.*, "Spanwise Lift Distribution for a Blended Wing Body Aircraft", AIAA Journal of Aircraft, Vol. 42, No. 2, March-April 2005. AIAA-4229-140.

[16]Qin, N., "Aerodynamic Studies for Blended Wing Body Aircraft", 9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimisation, 4-6 September 2002, Atlanta, Georgia. AIAA-2002-5448.

[17]Regan, C.D., "In-Flight Stabilty Analysis of the X-48B Aircraft", AIAA Atmospheric Flight Mechanics Conference and Exhibit, 18-21 August 2008, Honolulu, Hawaii. AIAA-2008-6571.

[18]Risch, T., *et.al.*, "X-48 Flight-Test Progress Overview", A47th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, 5-8 January 2009, Orlando, Florida. AIAA-2009-934.

[19]Saephan, S., van Dam, C.P., "Determination of Wing-Only Aircraft Tumbling Characteristics Through Computational Fluid Dynamics", AIAA journal of Aircraft, Vol. 45, No. 3, May-June 2008. AIAA-33730-763.

[20]Scaled Composites, <http://www.scaled.com>.

[21]Schrenk, O., "A simple approximation method for obtaining the spanwise lift distribution", National Advisory Committee for Aeronautics, April 1940, naca-tm-948.

[22]Soderman, P., Aiken, T., "Full-Scale Wind-Tunnel Tests of a Small Unpowered Jet Aircraft With a T-Tail", NASA Ames Research Center, November 1971), NASA TN D-6573.

[23]Staelens, Y. D., Blackwelder, R. F., and Page, M. A., "Novel Pitch Control Effectors for a Blended-Wing-Body Airplane in Takeoff and Landing Configuration", AIAA Paper 2007-68-229, January 2007.

[24]Staelens, Y. D., Blackwelder, R. F., and Page, M. A., "Study of Belly-flaps to Enhance the Lift and Pitching Moment Coefficient of a Blended-Wing-Body Airplane , AIAA Paper 2007-4176, June 2007.

[25]Stokely, H.A., *et.al.*, "Soar-Tech", vol. 1-10, Herk Stokely (Editor), SoarTech Journal, Virginia, 1982-1993.

[26]Valiyff, A., Arjomandi, M., "An Investigation into the Aerodynamic Efficiency of a Tailess Aircraft", 47th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, 5-8 January 2009, Orlando, Florida. AIAA-2009-1436.

[27]Vicroy, D.D., "Blended-Wing-Body Low-Speed Flight Dynamics: Summary of Ground Tests and Sample Results (invited)", 47th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, 5-8 January 2009, Orlando, Florida. AIAA-2009-933.

[28]Wakayama, S., Kroo, I., "The Challenge and Promise of the Blended-Wing-Body Optimisation", AIAA Paper 98-4736, in Proceedings of 7th AIAA Symposium on Multidisciplinary Analysis and Optimization, St Louis, MO, September 1998, pp. 239-250.

[29]Wakayama, S., Willcox, K., "Simultaneous Optimisation of a Multiple-Aircraft Family", AIAA.

[30]Wakayama, S., Kroo, I., "Subsonic Wing Planform Design Using Multidisciplinary Optimization", Journal of Aircraft, Vol. 32, No. 4, Jul.-Aug. 1995, pp.746-753.

[31]Wakayama, S., Page, M., Liebeck, R., "Multidisciplinary Optimization on an Advanced Composite Wing", AIAA Paper 96-4003 presented at 6th AIAA Symposium on Multidisciplinary Analysis and Optimization, Bellevue, WA, September 4-6, 1996.

[32]Wakayama, S., "Multidisciplinary Optimization of the Blended-Wing-Body", AIAA Paper 98-4938, in Proceedings of 7th AIAA Symposium on Multidisciplinary Analysis and Optimization, St Louis, MO, September 1998, pp. 1771-1779.

[33]Whitcomb, R.T., "A Study of the Zero-Lift Drag-Rise Characteristics of Wing-Body Combinations Near the Speed of Sound", National Advisory Committee for Aeronautics, 1952. NACA-RM-L52H08.

[34]Wood, R.M., Bauer, S.X.S., "Flying Wings/Flying Fuselages", 39th AIAA Aerospace Sciences Meeting & Exhibit, Reno, Nevada, 8-11 January 2001. AIAA-2001-0311.

[35]Yann, D.S., *et.al.*, "Computer Simulation of Landing, Takeoff and Go-around of a Blended-Wing-Body Airplane with Belly-Flaps", AIAA Conference, 7-10 January 2008, Reno, Nevada. AIAA-2008-297.