Investigation of flow over a BWB at different angles of attack

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Contents

Introduction

- Blended Wing Body (BWB)
  - Unconventional configuration which integrates wing and fuselage into single lifting surface
  - No clear dividing line between wings and main body of the aircraft

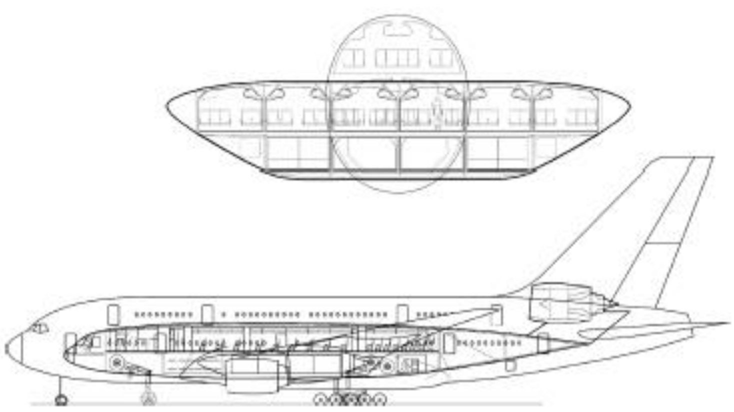
Depiction of conventional Tube and Wing design (extreme left) with BWB configuration (B1 Lancer in center left, B2 bomber in center right) and flying wing design (extreme right)[26]

Introduction

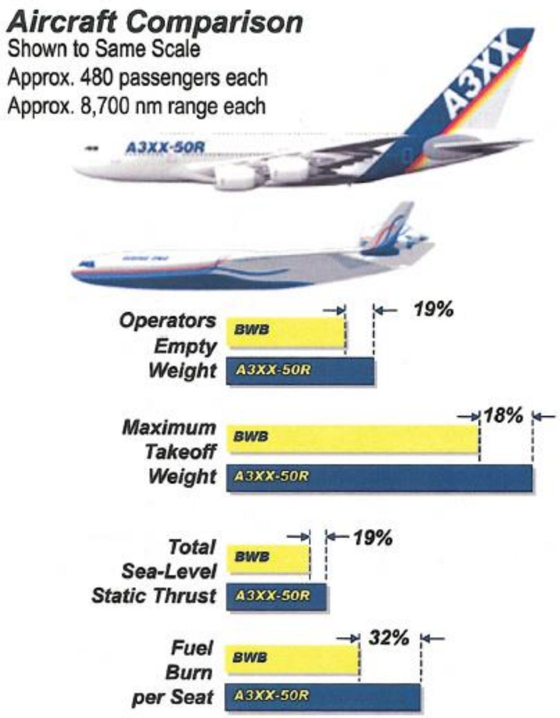
- Potential advantages
  - low wetted area to internal volume ratio
  - smooth varying cross-section distribution
- Potential challenges involved
  - Challenging design as tight coupling between aerodynamic performance, trim and stability
  - Concerns for commercial airliner applications regarding passenger safety, comfort and cabin pressurization
  - Several tailless designs could have inherent instability hence require special airfoils (with positive pitching moment) and fly by wire systems

Literature Review

- Liebeck, R. H.[5][15] worked on designing a subsonic transport Blended wing body aircraft
- Designed the BWB platform for Boeing with varied size aircrafts for different carrying capacity (such as BWB-450, BWB-250)



Interior volume of BWB-450 aircraft compared to A380-700

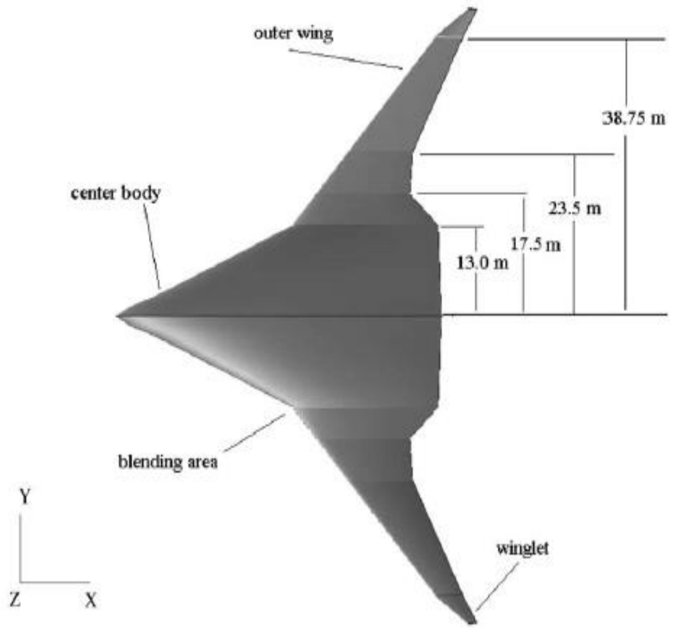


2004

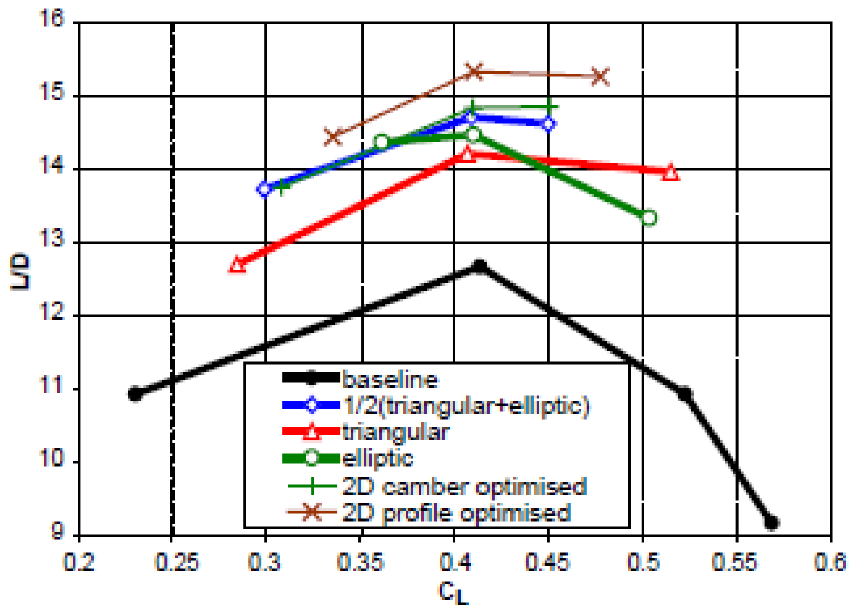
Aircraft comparison given by Liebeck, R. H.

Qin et. al., 2004[1]

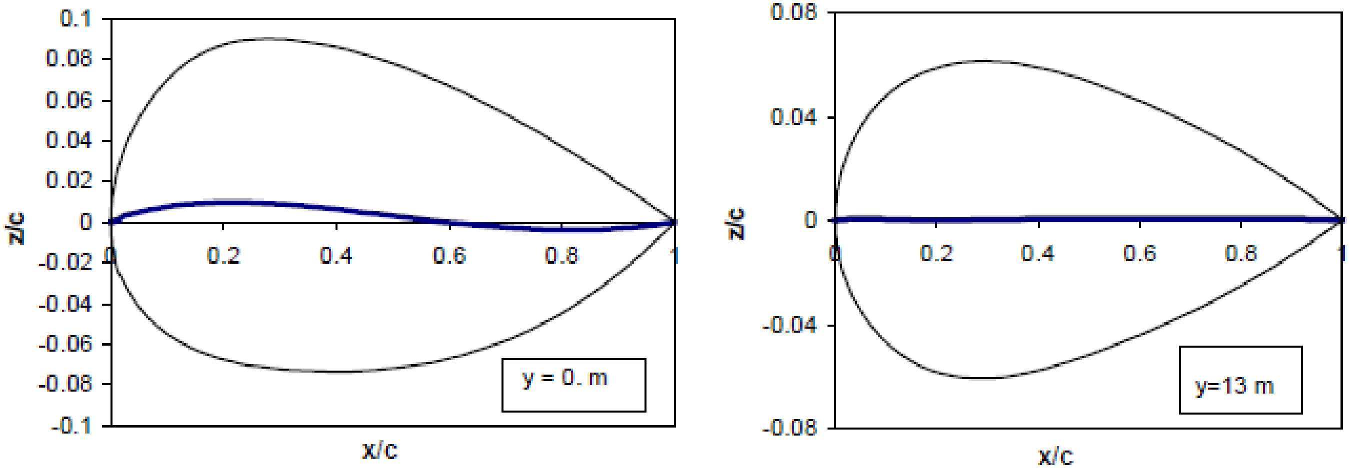
- Titled: Aerodynamic considerations of Blended Wing Body Aircraft
- Aerodynamic analysis of baseline configuration
- Aerofoil optimization and surface optimization for design cruise condition for a commercial BWB followed by 3d surface optimization



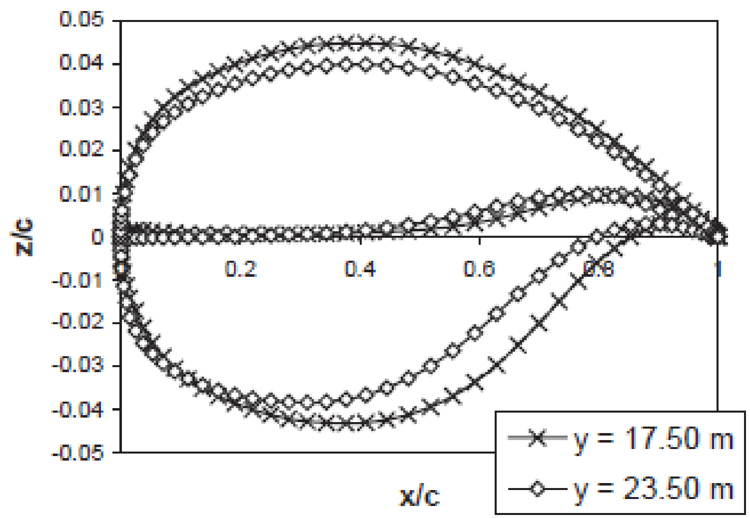
Baseline design taken by N.Qin et al.



Comparison of design near cruise design conditions



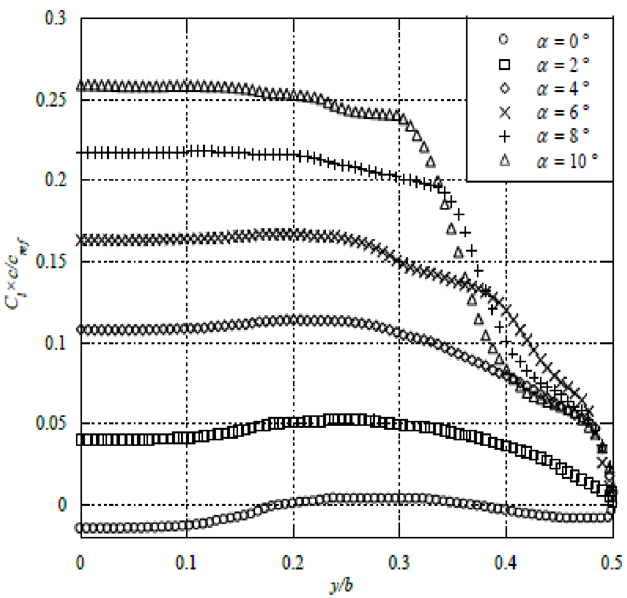
Root (left) and wing tip (right) airfoil sections

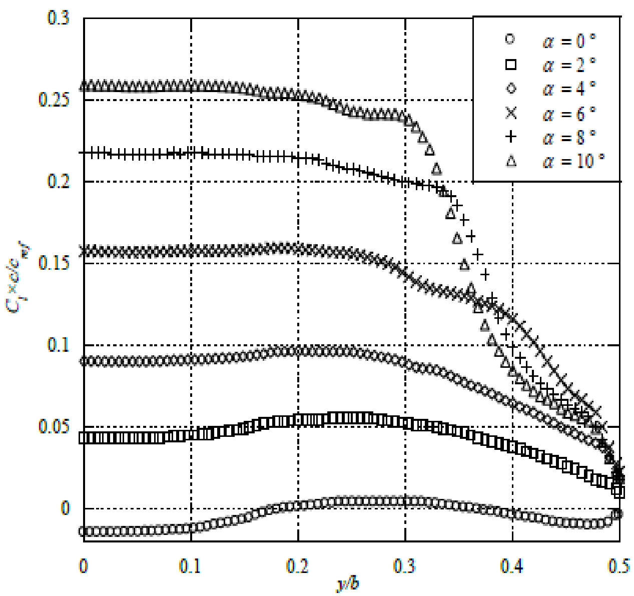


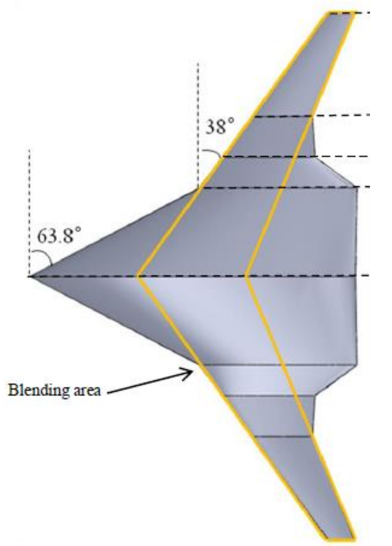
Airfoil sections for intermediate region

Masashi et. al., 2015[2]

- Titled: Experimental Study on Aerodynamic Characteristics of Blended-Wing-Body by a Wake Integration Method
- Aerodynamic characteristic of the BWB in low speed flows using the wake measurement
- Winglet taper ratio: 0.25
- Winglet airfoil: NACA0012

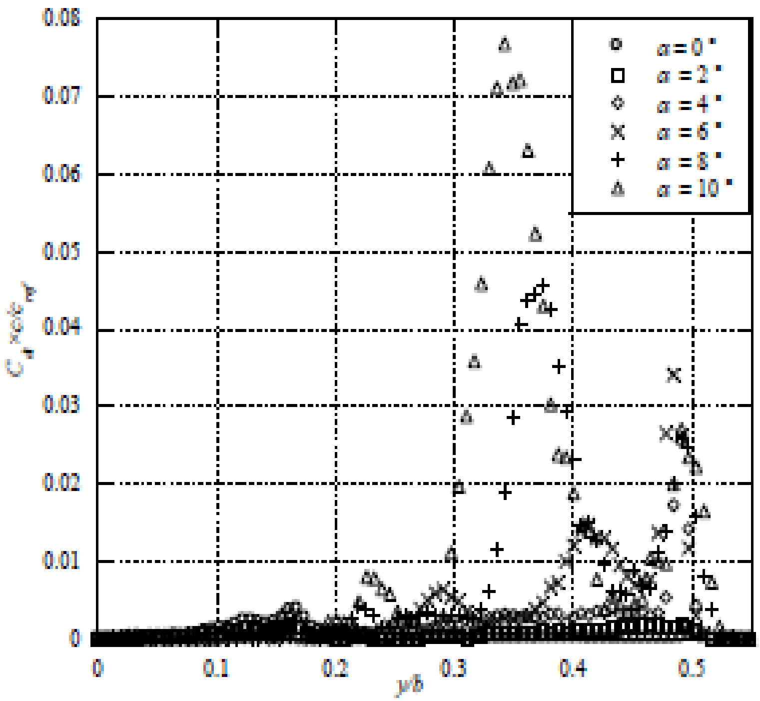


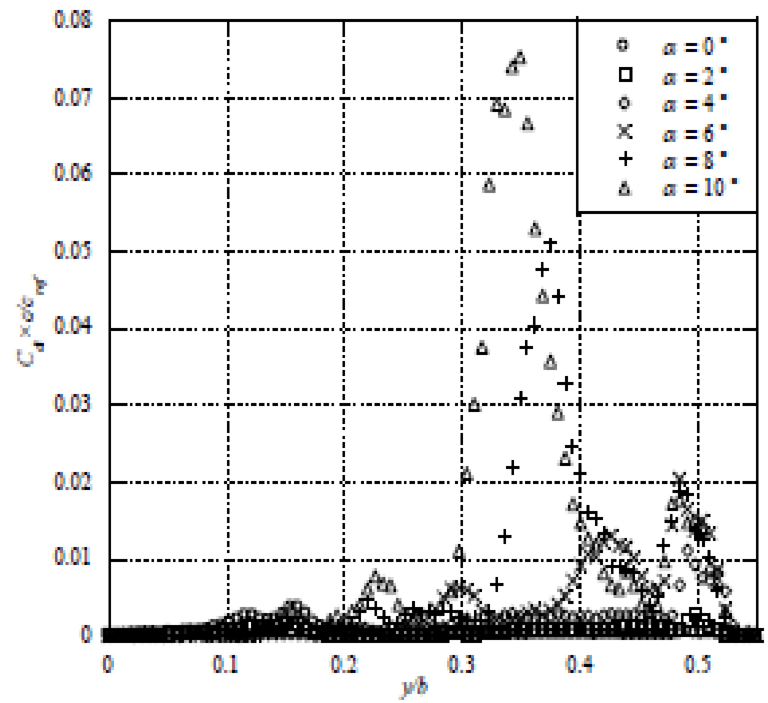




Analysis model

Comparison of spanwise lift coefficient for baseline (left) and design with winglets (right)

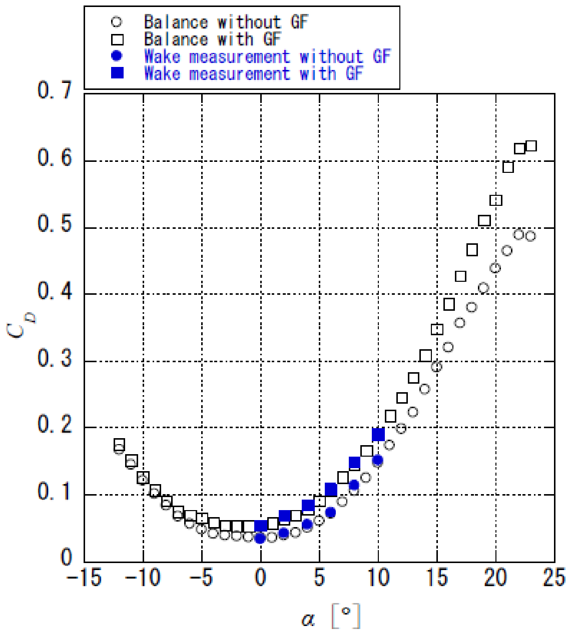




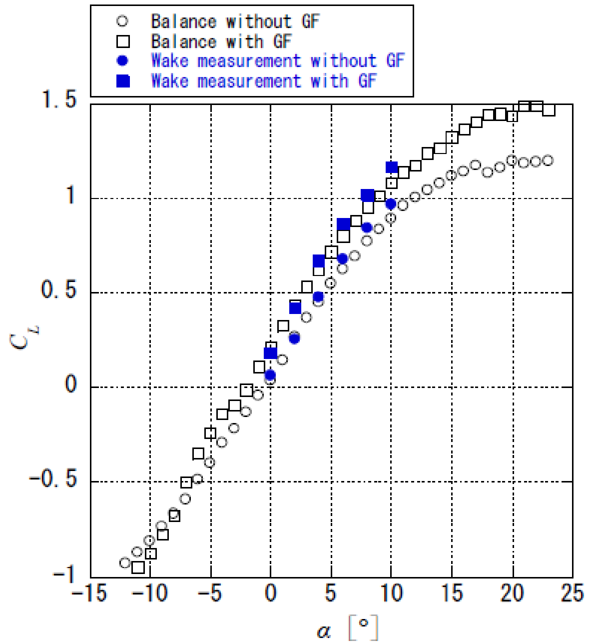
Spanwise induced drag coefficient for baseline model
(left) and with winglets (right)

Tatsuya et. al., 2019[3]

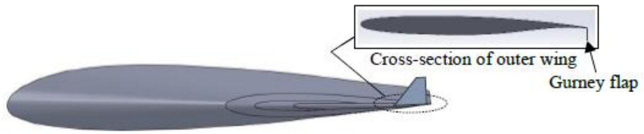
- Titled: Wake Measurements on Blended Wing Body with Gurney Flaps in Low Speed Flows
- Investigated the effect of a Gurney flap (GF) on the BWB configuration and compares it to the baseline (similar to one given by Masashi Kashitani et al.[2])



C_D vs angle of attack



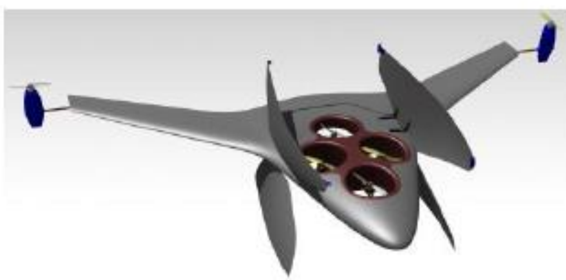
C_L vs angle of attack



Model with Gurney flap

Parisa et. al., 2019[19]

- Titled: Aerodynamic Design of Long-Range VTOL UAV
- Hybrid UAV design
- Analysis carried out for location of center body for the same
- Vertical location of VTOL drive also discussed



VTOL UAV concept as given by Parisa Footohi et al.[19]. Left figure corresponds to VTOL mode and right figure corresponds to cruise mode

Other literature

- Chen et. al., 2017[11] have discussed about modelling of a hybrid BWB UAV
  - Quad rotor configuration at wing tips
  - Analysed for various wind conditions
- Rodzewicz Mirosław , Goraj Zdobysław and Tomaszewski Adam, 2018[17] had worked on UAV designs for Antarctic conditions
  - A comparison of performance between delta wing UAV and BWB UAV carried out
- Panagiotou et al., 2017[10] worked on a design of Medium Altitude Long Endurance (MALE) UAV
  - BWB configuration
  - 3 BWB configurations designed and compared
- Geoffrey Larkina and Graham Coates, 2017[18] worked on design of vertical stabilizer for BWB configuration
  - Baseline similar to the one given in reference 3
  - Twin stabilizer configuration discussed

Dual stabilizer model[18]. Left one with vertical and right one with stabilizers inclined at an angle

- Some papers such as by Daniel J. Thompson, 2011[13] and Kai Lehmkuehler et al., 2012[14] discussed about fabrication of BWB UAVs and testing them in flight
- And many others which were focussed on design optimization[8][9][11][16]

- From the literature review,
  - Limited studies on low Reynolds number performance of BWB
  - Limited studies on flow physics over BWB

Influencing factors on flow over BWB

- Reynolds number
- Sweep angles
- Angle of attack
- Airfoil configuration

BWB as Unmanned Aerial Vehicles (UAVs)

- BWB configuration can offer several potential advantages as UAV platform
  - Improved efficiency can improve range and endurance
  - High internal volume can allow for high payload carrying capabilities
  - Since the crafts are unmanned, cabin pressurization is not an issue
  - Larger lifting surface can promote hybrid designs for multirole applications

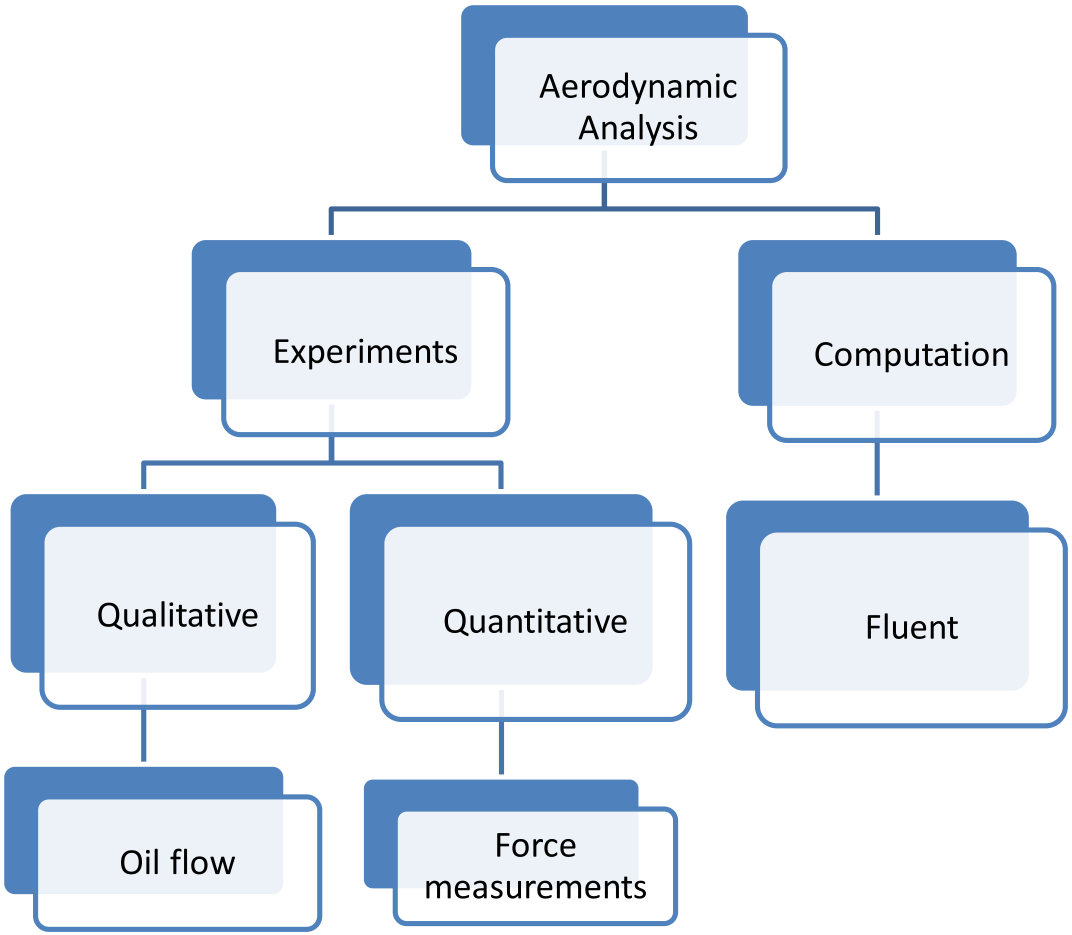
X-48 Boeing prototype in test flight[24]

Monica-1, Antarctic exploration UAV[17]

Objective

- Study of BWB flow physics at a typical angle of attack and effect on flow physics with variation in angle of attack at low speeds to study the feasibility for UAV applications

Research Methodology



Low subsonic wind tunnel

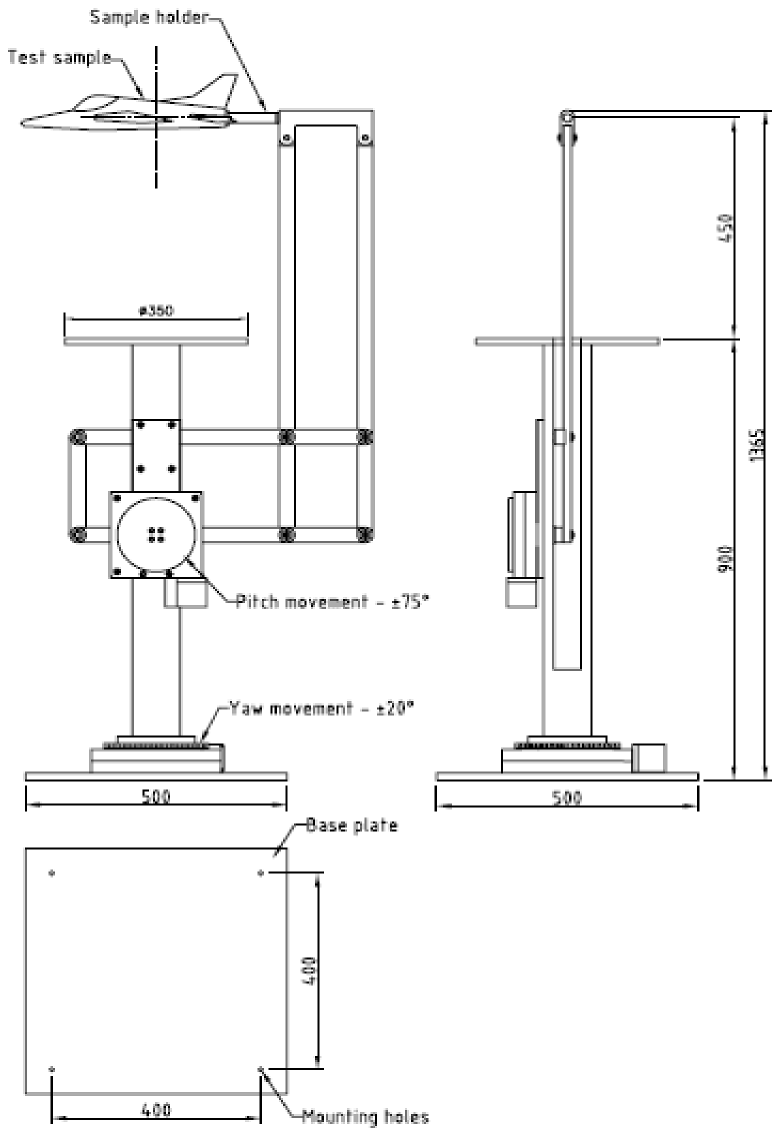
Speed Range: 10-30m/s

Test section: 600mm X 600mm

Research Methodology

- Experimental Techniques
  - Force measurement
    - 5 component strain gauge balance
    - Power Supply (Low Noise DC 3 volts)
    - Signal Conditioner (Filter : 10Hz)
    - DAQ (National Instruments)
  - Flow visualization
    - Optimum mixture of Carbon soot, Oil, Oleic acid

Incidence Mechanism



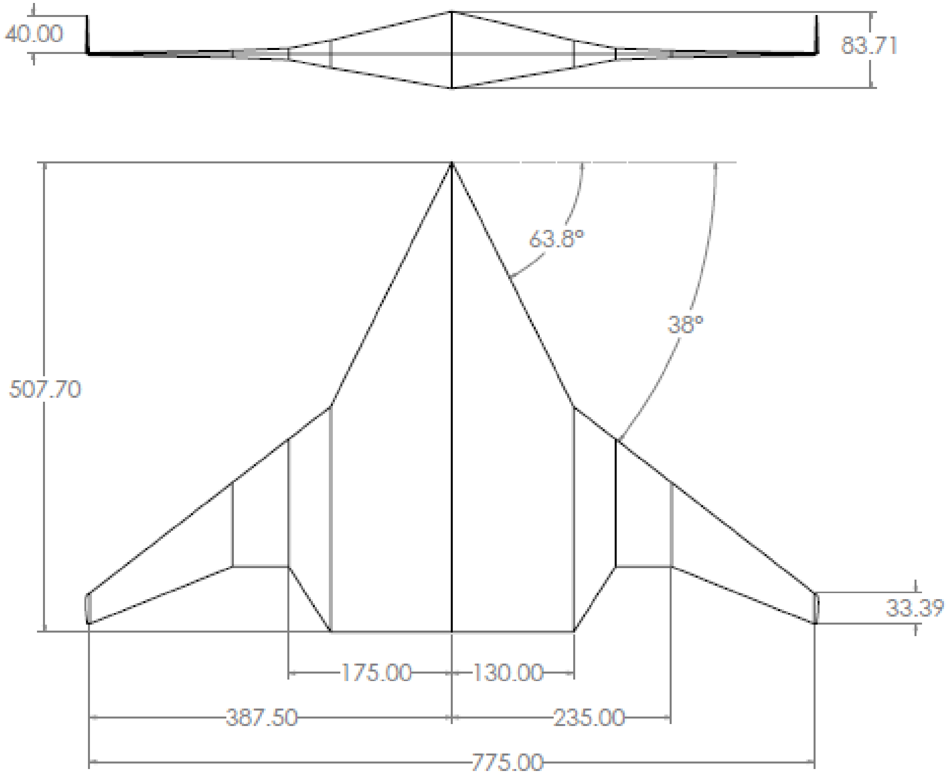
Molmarc model: HO-PY-WT01
Pitch range: ±75 degrees

Yaw range : ±20 degrees

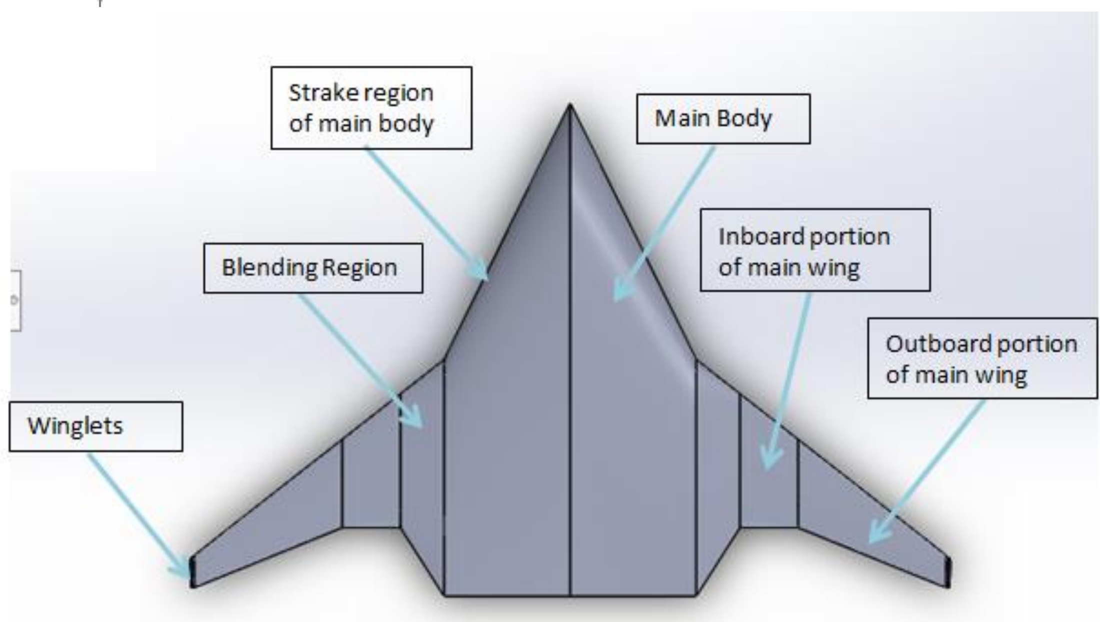
The model was mounted at the sample holder and the setup was observed to have negligible vibration under test conditions.

Model specifications

Specification	Full Scale Model[3]	Scaled Down Model
Root Chord	507.7mm	187.85mm
Span (b)	775mm	286.75mm
Mean Aerodynamic Chord (MAC)	123mm	45.52mm
Reference Area (S_{ref})	82400.00mm^2	11310.68mm^2
Sweep Angle (Center Body)	63.8^0	63.8^0
Sweep Angle (Wing)	38^0	38^0
Re (based on MAC)	58500	58500

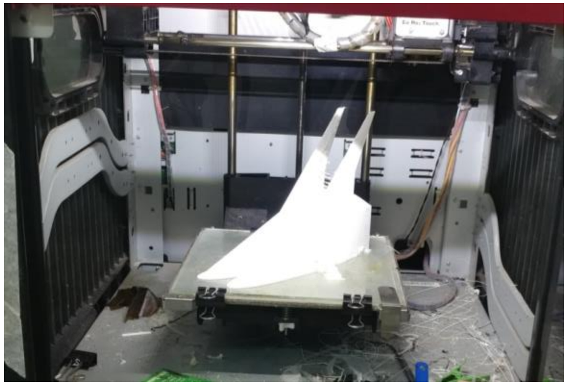


Model with key dimensions

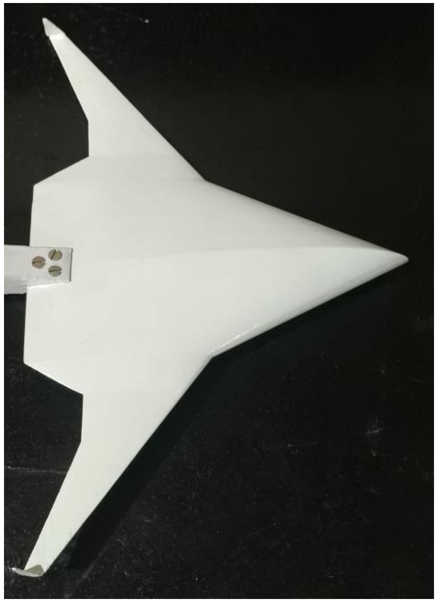


Model with indicated regions

- Model fabrication
  - Fabrication by 3D printing, using Fused Filament Fabrication (FFF) process.
  - Material used for printing: PET-G
  - Post processing for preparing model for tests



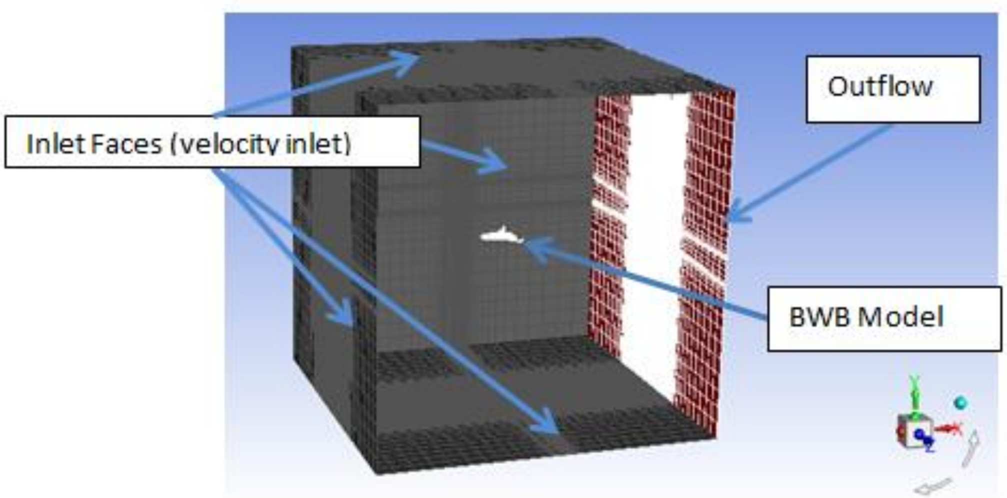
3D printed model in the printer

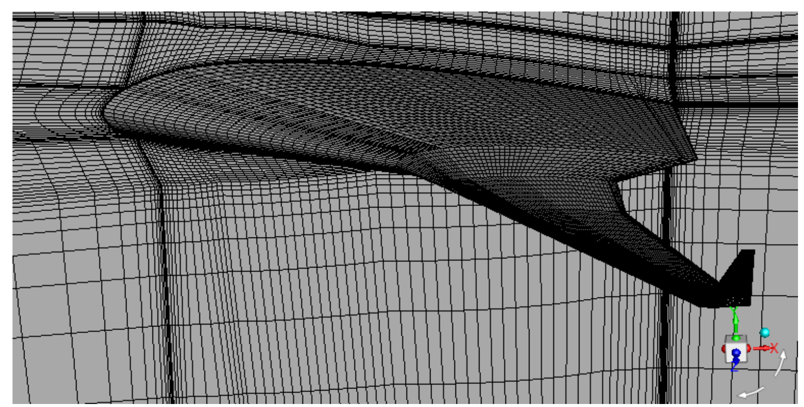


Fabricated model

Computation

- Grid size: 2.25 million
- Spalart – Allamaras one equation turbulence model
- Second order discretisation was used for spatial and temporal terms
- Residual of the order of 10^{-5}
- Reynolds number: 58500

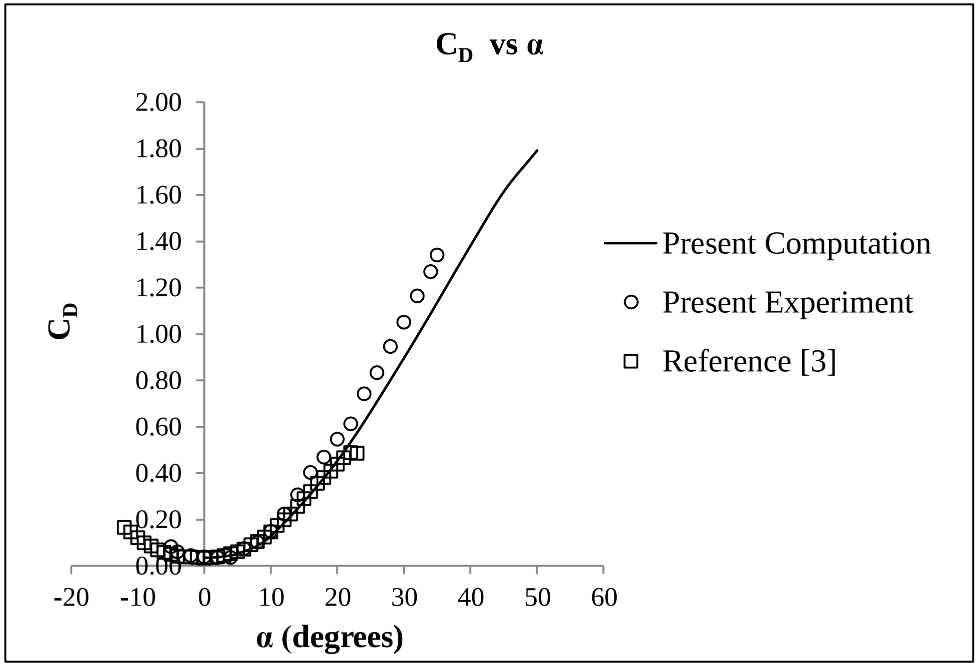




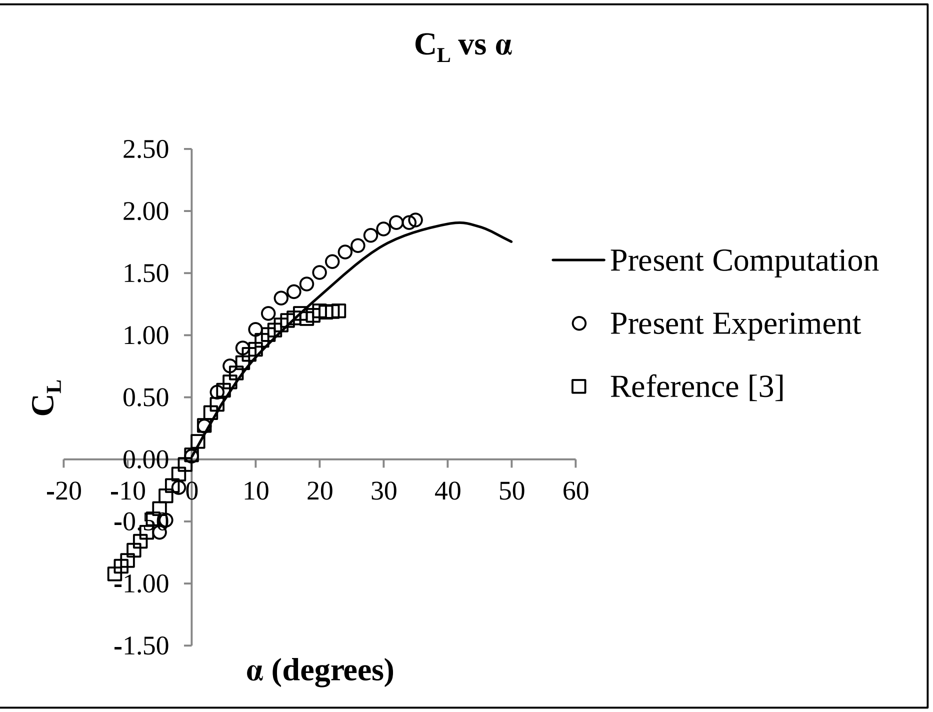
Grid independence test

Grid	Number of elements	C_L value at 10 degrees angle of attack	C_D value at 10 degrees angle of attack
Grid 1	1.8 million	0.8262	0.1280
Grid 2	2.25 million	0.8250	0.1265
Grid 3	2.47 million	0.8249	0.1262
Experiment	-	1.063	0.1531

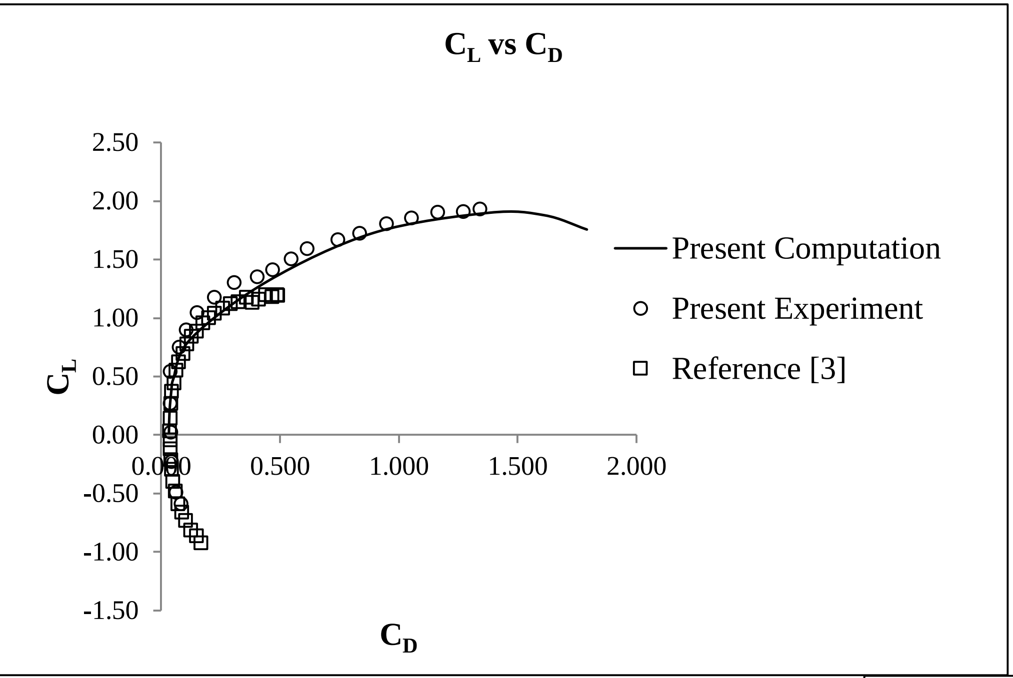
Results and Discussion



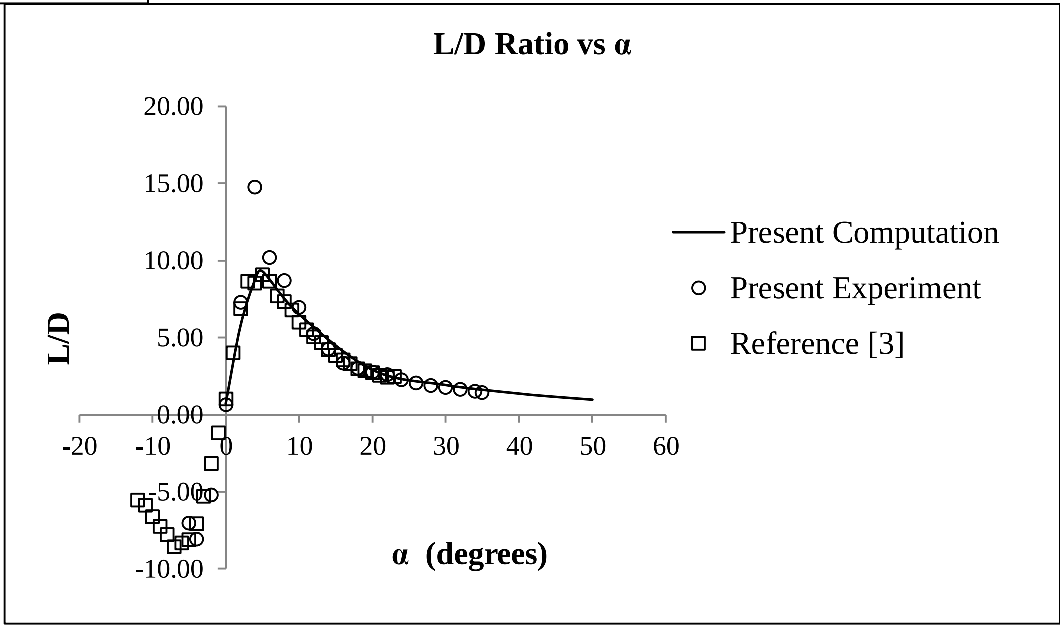
Comparison of lift coefficient at different angles of attack



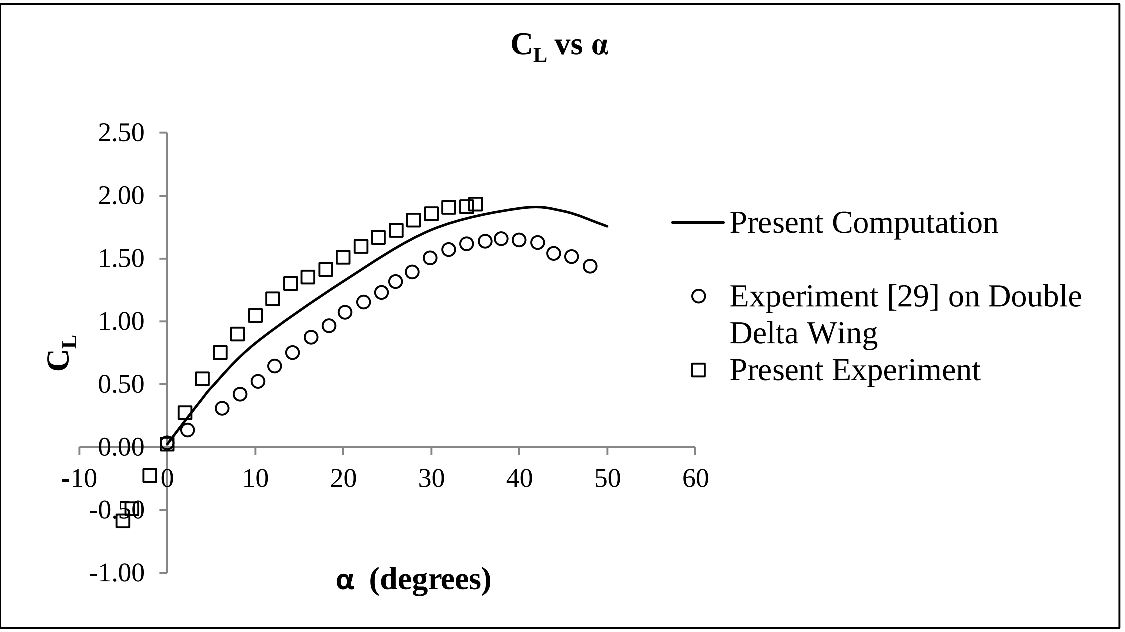
Comparison of lift coefficient at different angles of attack



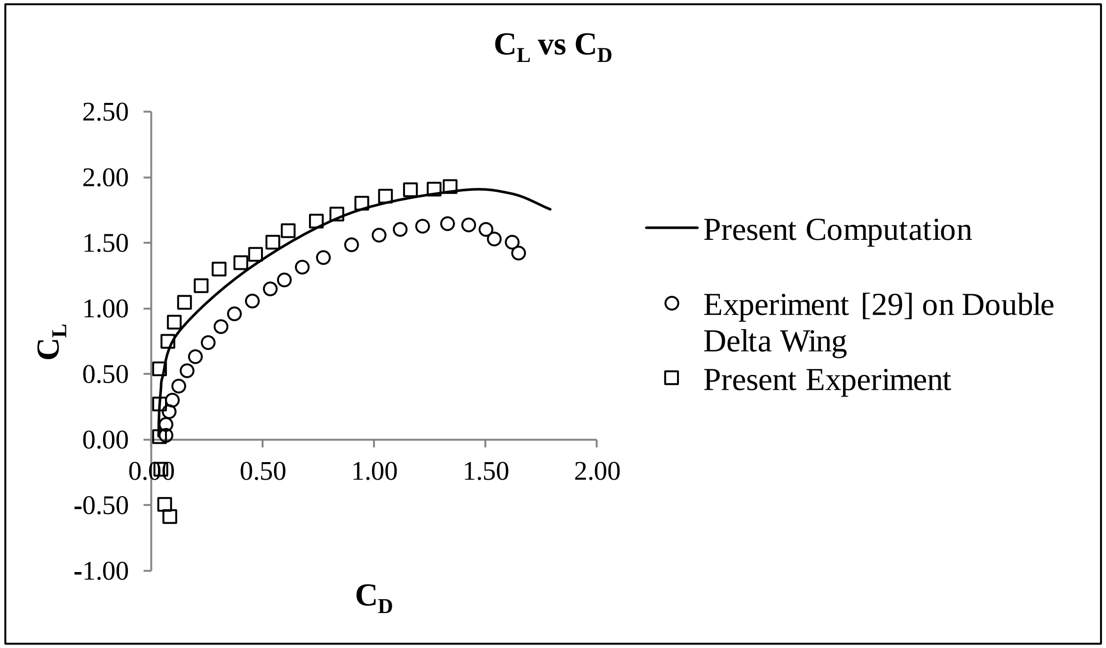
Comparison of lift coefficient vs drag coefficient



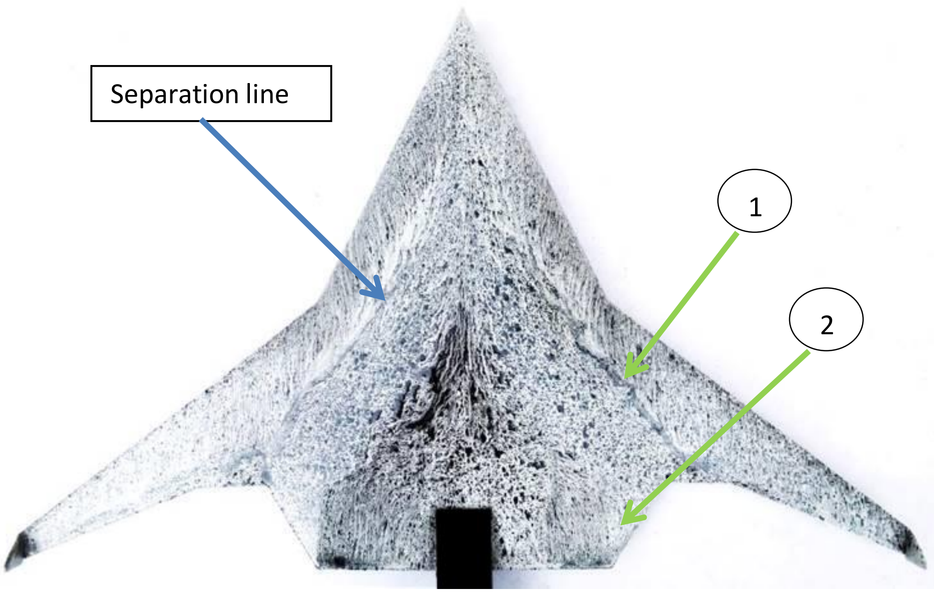
Comparison of L/D ratio with angle of attack



C_L vs α, for double delta wing[29] and present study (experimental and computation)

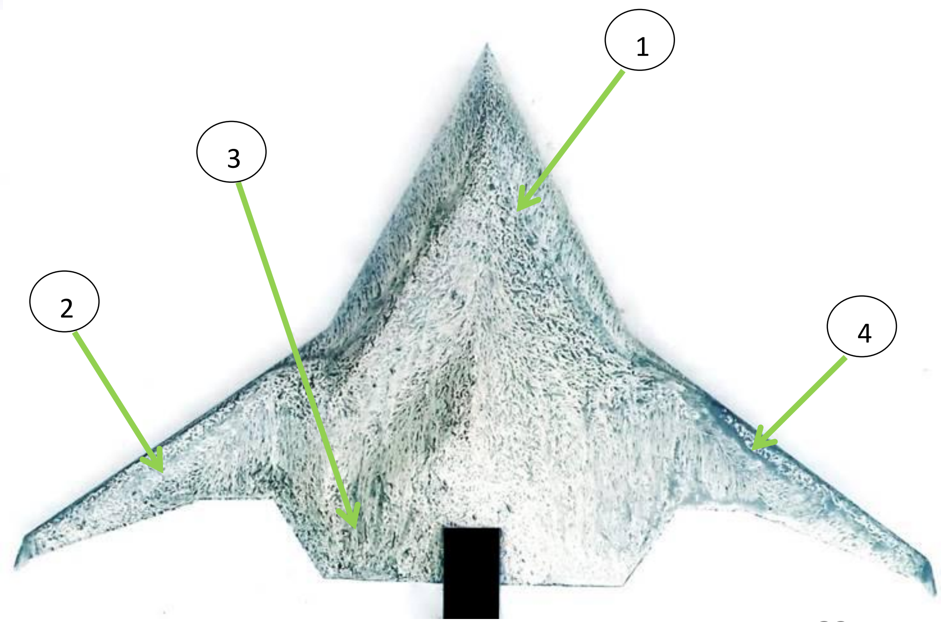


C_L vs C_D for double delta wing[29] and present study (experimental and computation)

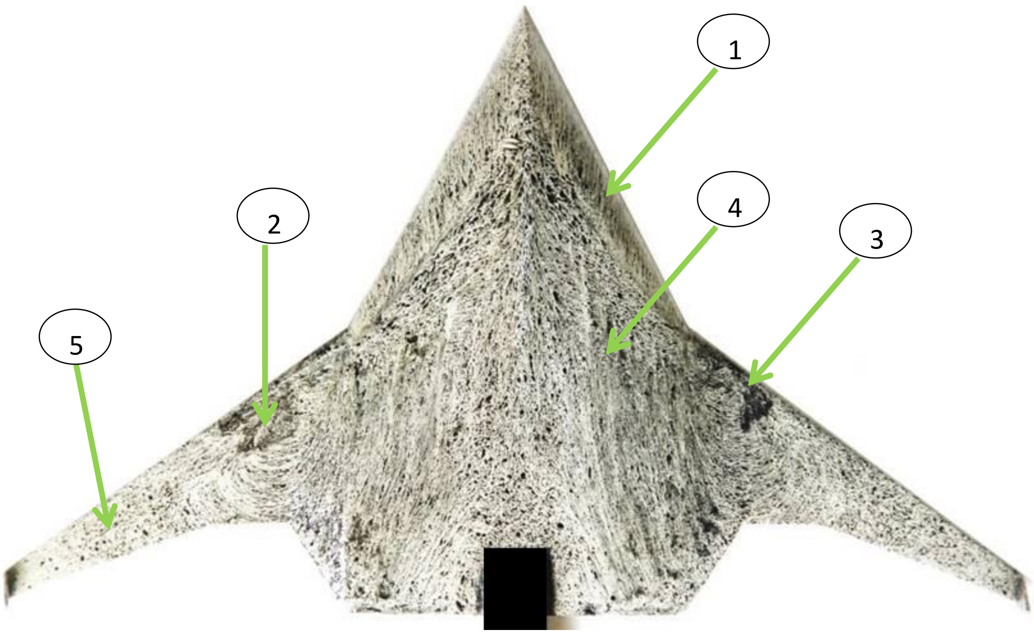


Oil flow at 0^0 angle of attack

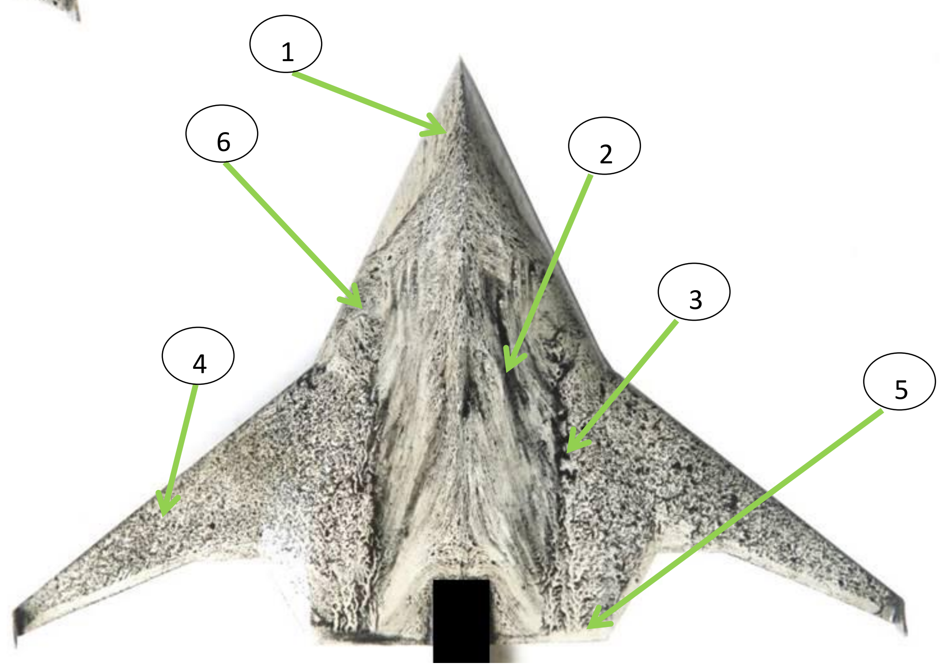
:Indicates a location on BWB marked with a number



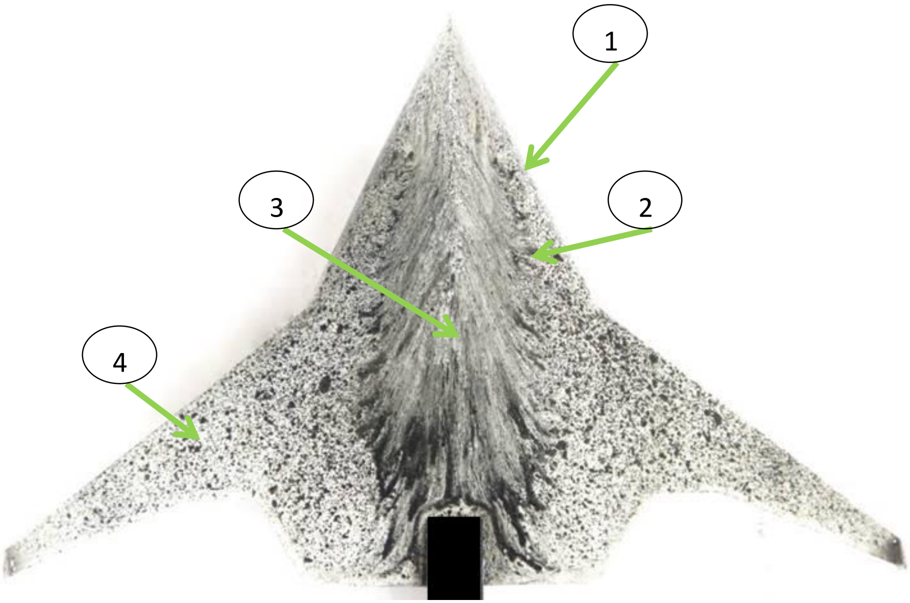
Oil flow at 5^0 angle of attack



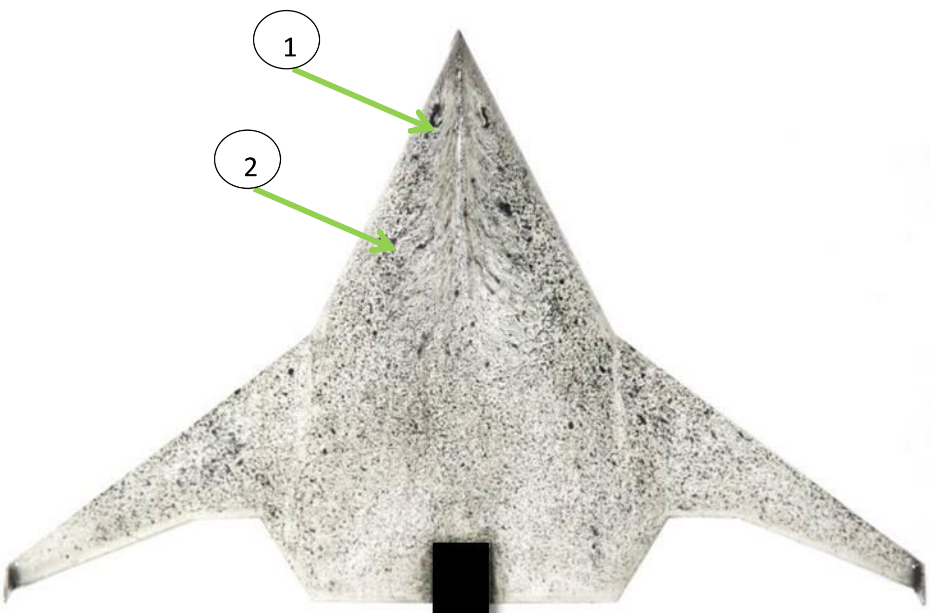
Oil flow at 10^0 angle of attack



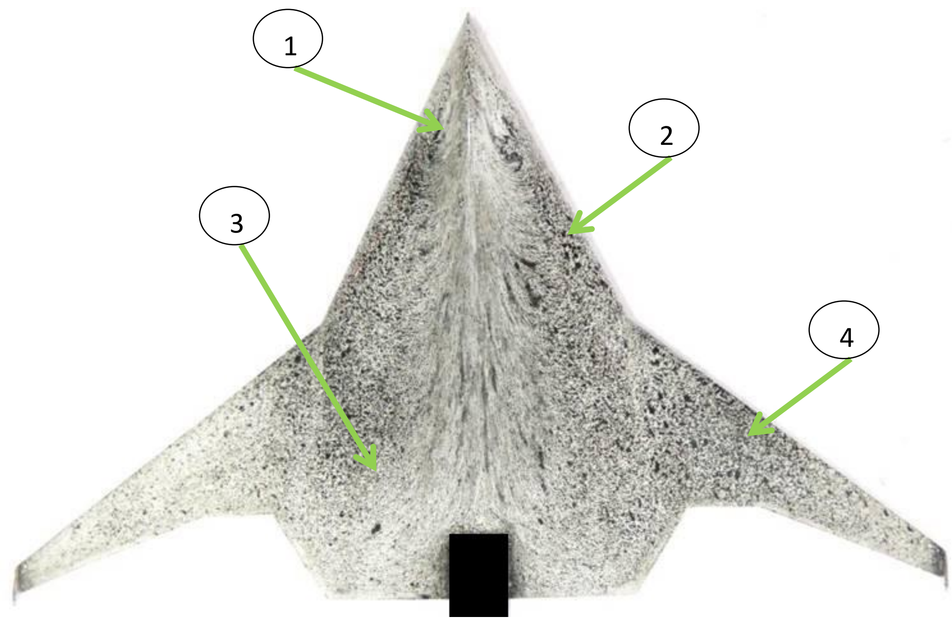
Oil flow at 20^0 angle of attack



Oil flow at 30^0 angle of attack



Oil flow at 50^0 angle of attack

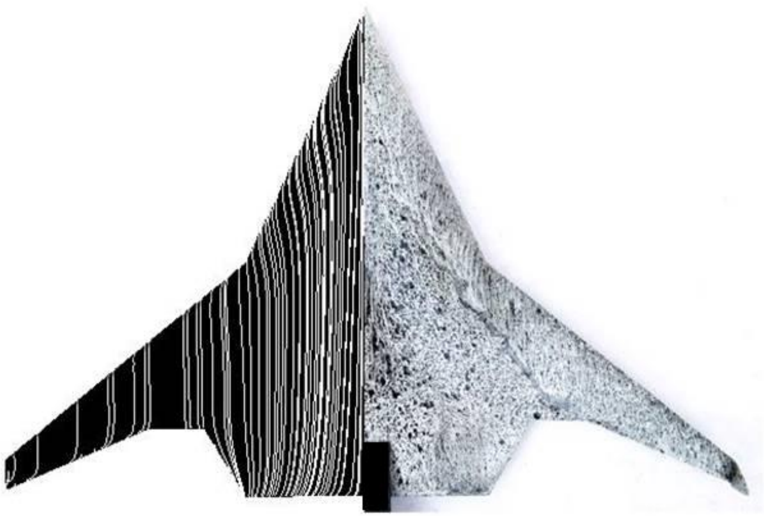


Oil flow at 40^0 angle of attack

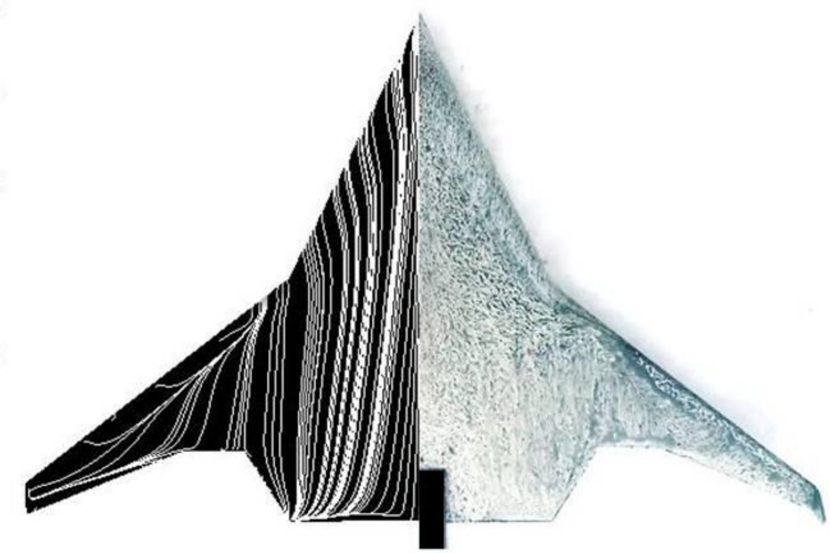
Computation and experiment data comparison

- The following section discusses the flow physics over the BWB model by comparing oil flow and different flow contours from computation

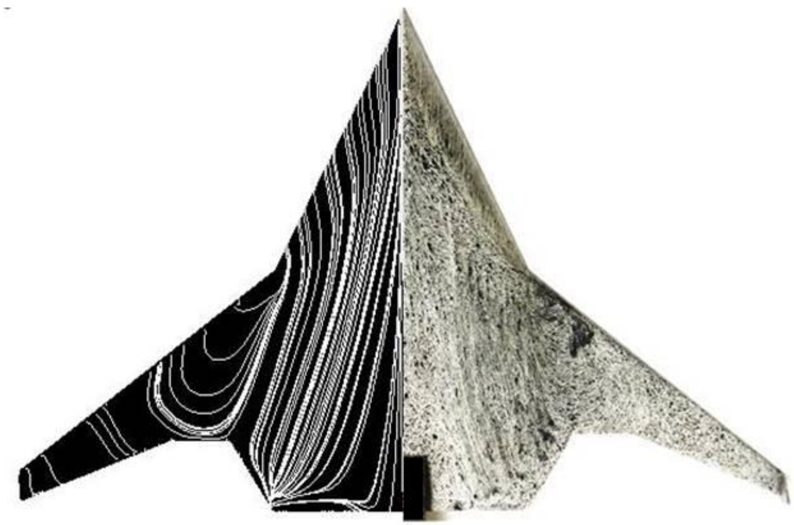
CFD Streamlines and oil flow



Streamlines from CFD with oil flow pattern, 0 degrees angle of attack

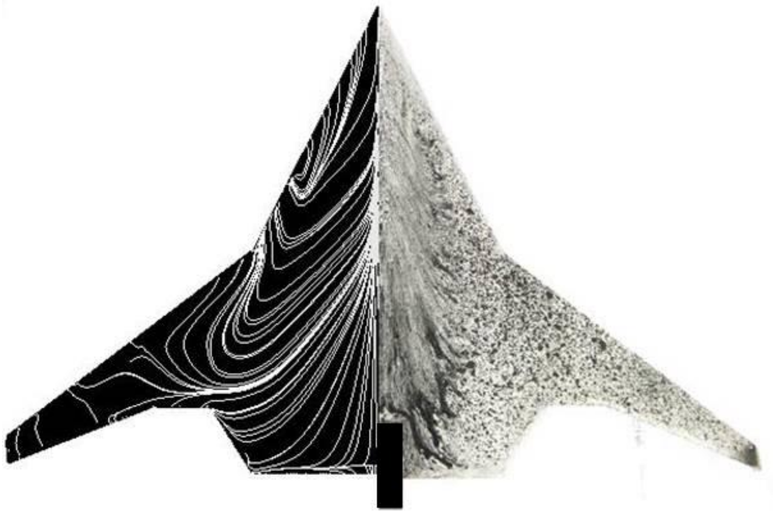


Streamlines from CFD with oil flow pattern, 5 degrees angle of attack

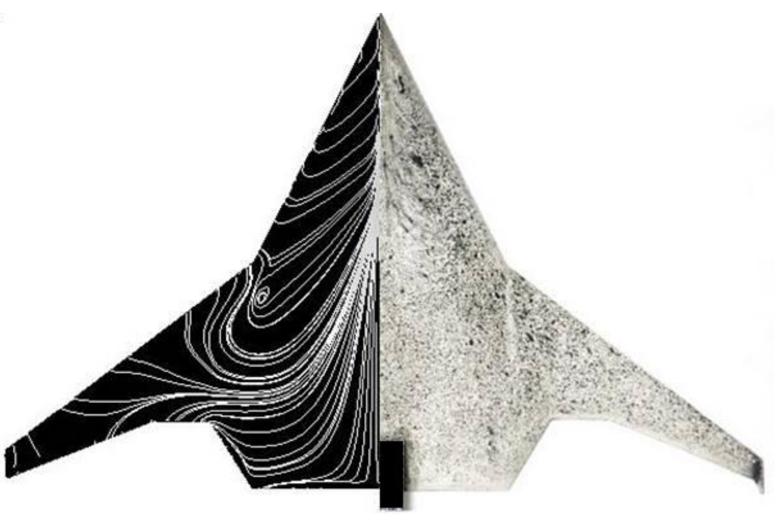


Streamlines from CFD with oil flow pattern, 10 degrees angle of attack

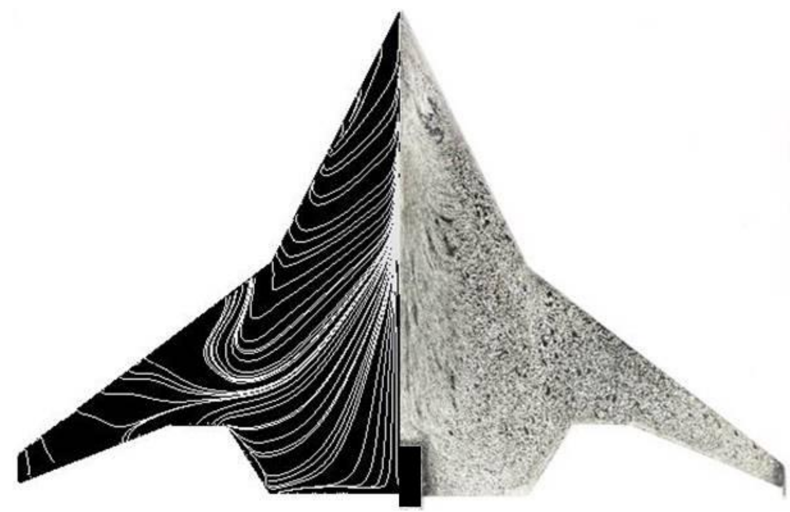
Streamlines from CFD with oil flow pattern, 20 degrees angle of attack



Streamlines from CFD with oil flow pattern, 30 degrees Angle of attack

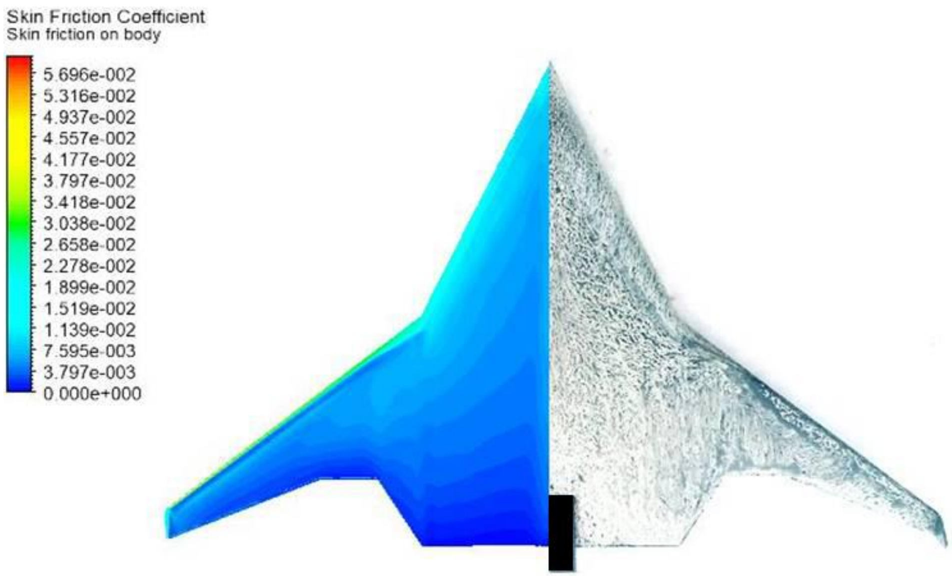


Streamlines from CFD with oil flow pattern, 50 degrees Angle of attack

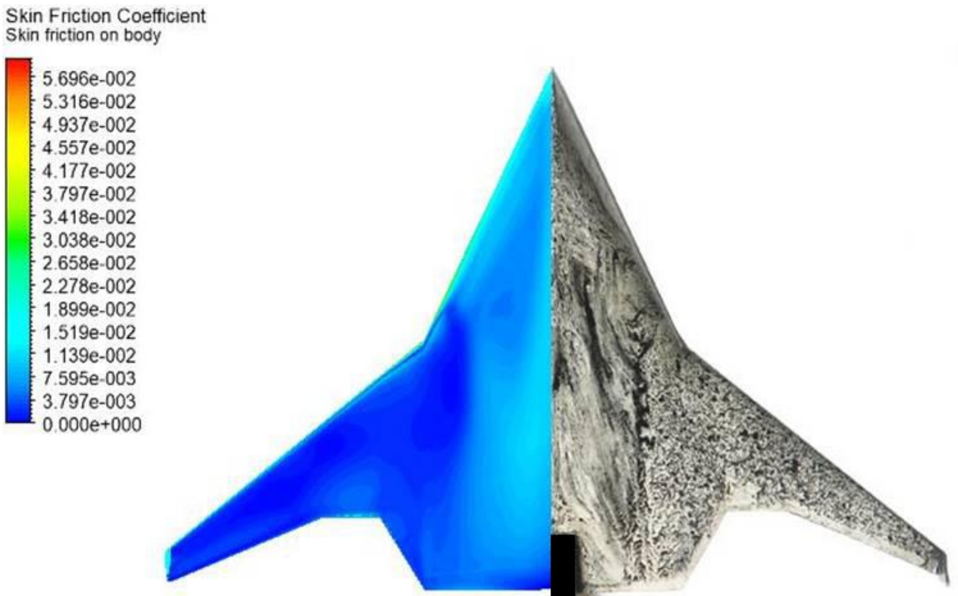


Streamlines from CFD with oil flow pattern, 40 degrees Angle of attack

Skin friction with oil flow

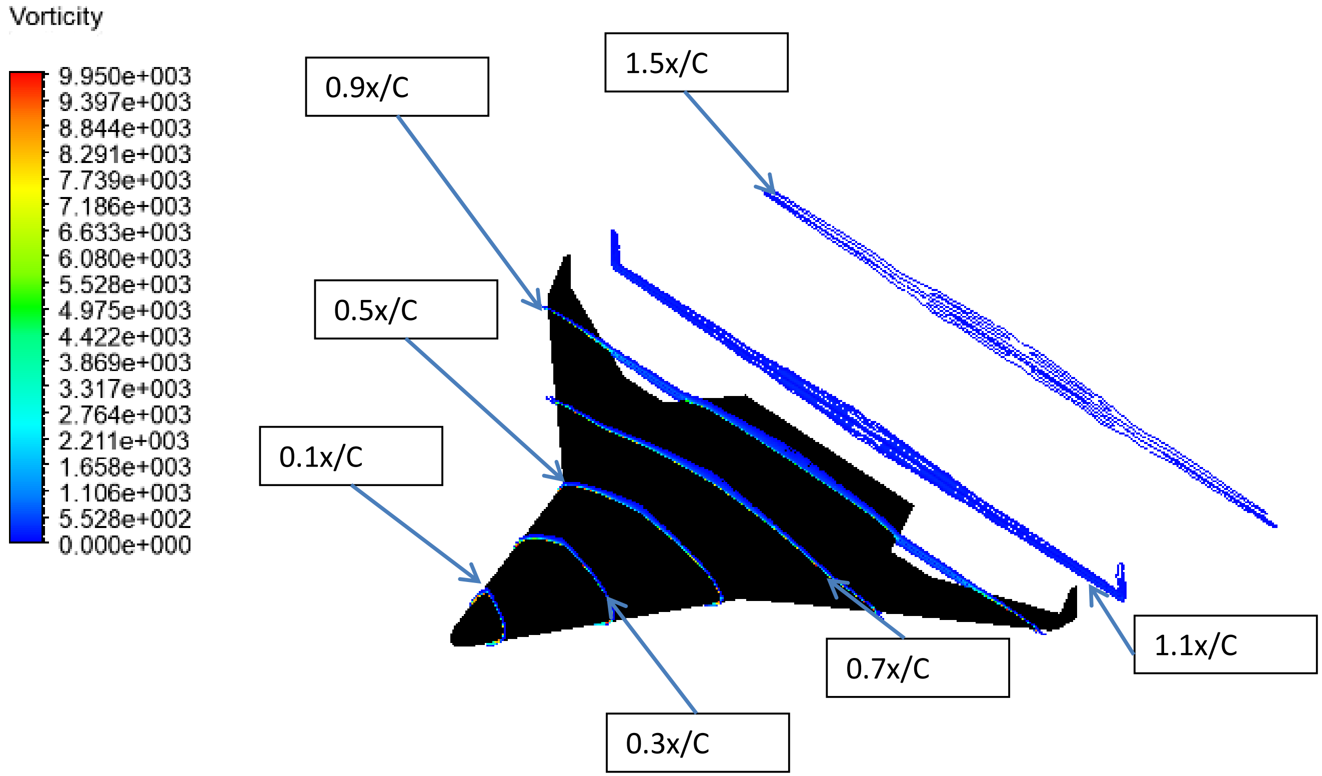


Skin friction coefficient with oil flow pattern, 5 degrees angle of attack

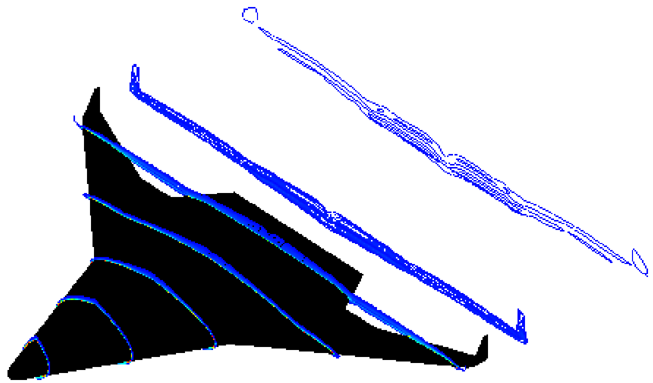


Skin friction coefficient with oil flow pattern, 20 degrees angle of attack

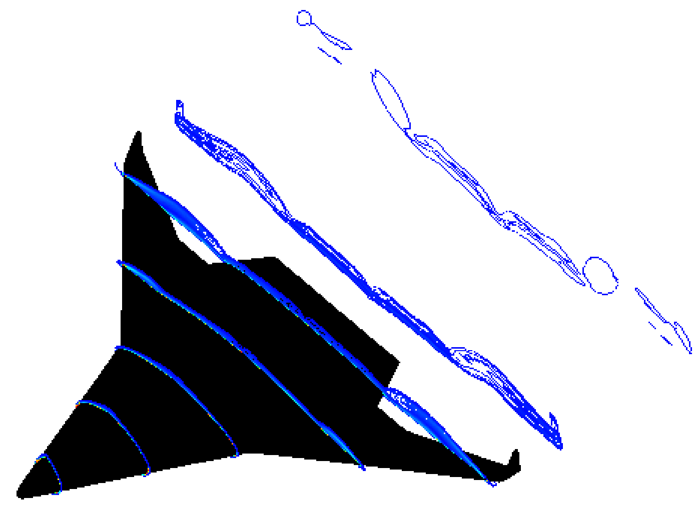
Vorticity Contours



0 degrees vorticity contours at different x/C

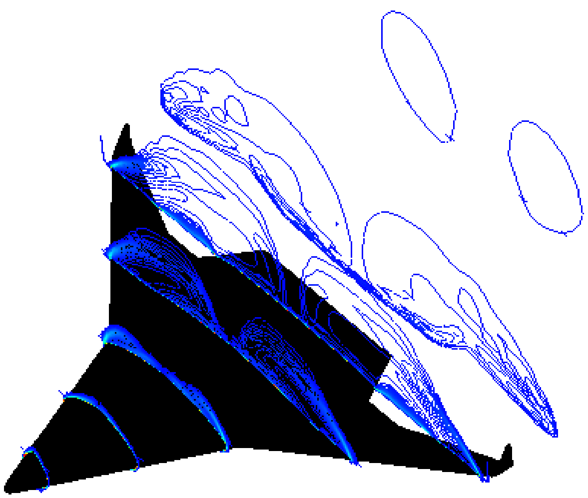


Vorticity contours at different x/C at 5 degrees angle of attack

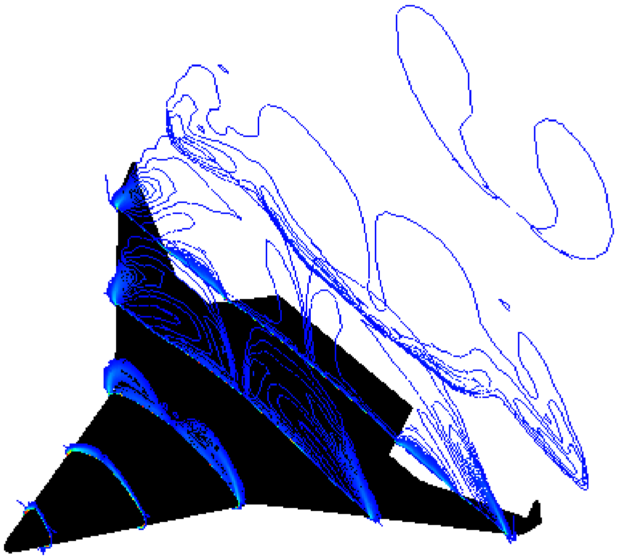


vorticity contours at different x/C at 10 degrees angle of attack

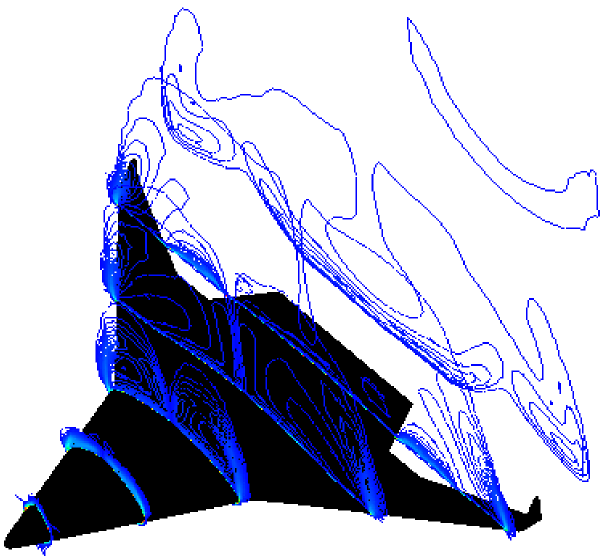
Vorticity contours at different x/C at 20 degrees angle of attack



Vorticity contours at different x/C at 30 degrees angle of attack



Vorticity contours at different x/C at 40 degrees angle of attack



Vorticity contours at different x/C at 50 degrees angle of attack

Conclusion

- BWB configuration was able to generate good amount of lift in low Reynolds number flows
- BWB configuration exhibits stall at very high angle of attack due to the contribution of center body to the lift production
- Stall observed close to 40 degrees angle of attack
- Max L/D Ratio was observed to be at low angles of attack close to 5 degrees
- BWB exhibits better aerodynamic efficiency compared to 65/40 degree double delta wing[29].
- At high angles of attack, rear mounted and wing mounted control surface might lose effectivity
- Immense potential as a UAV configuration given good internal volume, high stall angle of attack and better aerodynamic efficiency compared to DDW[29] at low Reynolds number.

References

1. Qin, N., Vavalle, A., Moigne, A. L., Laban, M., Hackett, K., and Weinerfelt, P., "Aerodynamic Considerations of Blended Wing Body Aircraft", Progress in Aerospace Sciences, Vol. 40, pp. 321-343, 2004
2. Masashi Kashitani, Yoshie Suganuma and Hisashi date, Shinichiro Nakao, Yoshihiro Takita and Yutaka Yamaguchi, "Experimental Study on Aerodynamic Characteristics of Blended-Wing-Body by a Wake Integration Method", AIAA SciTech, 5-9 January 2015, Kissimmee, Florida, 53rd AIAA Aerospace Sciences Meeting
3. Tatsuya Yamada, Masato Taguchi, Nguyen Thai Duong, Masashi Kashitani, Kazuhiro Kusunose and Yoshihiro Takita, "Wake Measurements on Blended Wing Body with Gurney Flaps in Low Speed Flows", AIAA SciTech Forum, 7-11 January 2019, San Diego, California, AIAA SciTech 2019 Forum
4. P. Panagiotou and K. Yakinthos, "Parametric aerodynamic study of Blended-Wing-Body platforms at low subsonic speeds for UAV applications", AIAA AVIATION Forum, 5-9 June 2017, Denver, Colorado, 35th AIAA Applied Aerodynamics Conference
5. Liebeck, R. H., "Design of the Blended Wing Body Subsonic Transport," Journal of Aircraft, Vol. 41, No. 1, pp. 10-25, 2004
6. N Qin, A Vavalle, A Le Moigne, M Laban, K Hackett, P Weinerfelt, "AERODYNAMIC STUDIES FOR BLENDED WING BODY AIRCRAFT", 9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, 4-6 September 2002, Atlanta, Georgia
7. Jorrit van Dommelen and Roelof Vos, "Conceptual design and analysis of blended-wing-body aircraft", Proc IMechE Part G: Journal of Aerospace Engineering 2014, Vol. 228(13) 2452–2474
8. Zhoujie Lyu and Joaquim R. R. A. Martins, "Aerodynamic Shape Optimization of a Blended-Wing-Body Aircraft", 51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, 07 - 10 January 2013, Grapevine (Dallas/Ft. Worth Region), Texas

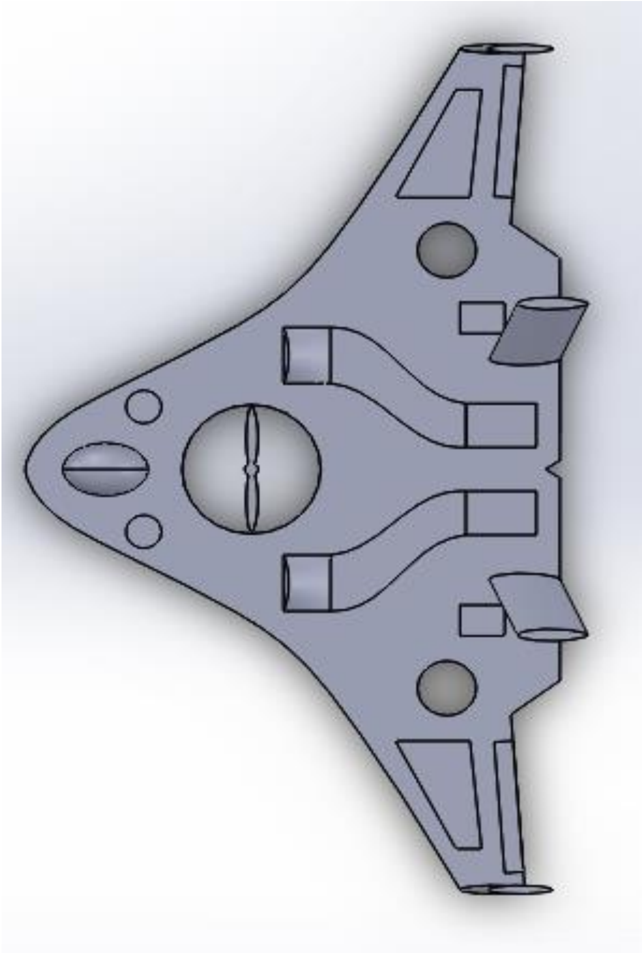
References

9. Zhoujie Lyu and Joaquim R. R. A. Martins, RANS-based Aerodynamic Shape Optimization of a Blended-Wing-Body Aircraft", Fluid Dynamics and Co-located Conferences, June 24-27, 2013, San Diego, CA, 21st AIAA Computational Fluid Dynamics Conference
10. P.Panagiotou, S.Fotiadis-Karras, K.Yakinthos, "Conceptual Design of a Blended Wing Body MALE UAV", Aerospace Science and Technology, November 2017
11. Chen Zeng, Rosa Abnous, Souma Chowdhury, "Aerodynamic Modeling and Optimization of a Blended-Wing-Body Transitioning UAV", AIAA AVIATION Forum, 5-9 June 2017, Denver, Colorado, 18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference
12. Malcom Brown and Roelof Vos, "Conceptual Design and Evaluation of Blended-Wing-Body Aircraft", AIAA SciTech Forum, 8–12 January 2018, Kissimmee, Florida, 2018 AIAA Aerospace Sciences Meeting
13. Daniel J. Thompson, Joshuo Feys, Michael D. Filewich, Sharif Abdel-Magid, Dennis Dalli, and Fumitaka Goto, "The Design and Construction of a Blended Wing Body UAV", 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, 4 - 7 January 2011, Orlando, Florida
14. Kai Lehmkuehler , KC Wong and Dries Verstraete, "Design and Test of a UAV Blended Wing Body Configuration", 28^{th} International Congress Of The Aeronautical Sciences, ICAS 2012
15. R. H. Liebeck, "Blended Wing Body Design Challenges", AIAA/ICAS International Air and Space Symposium and Exposition: The Next 100 Y, 14-17 July 2003, Dayton, Ohio
16. Nimeesha B. Kuntawala, Jason E. Hicken and David W. Zingg, "Preliminary Aerodynamic Shape Optimization Of A Blended-Wing-Body Aircraft Configuration", 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, 4 - 7 January 2011, Orlando, Florida
17. Rodzewicz Mirosław , Goraj Zdobysław and Tomaszewski Adam, "Design and testing of three tailless unmanned aerial vehicle configurations built for surveillance in Antarctic environment", Proc IMechE Part G: Journal of Aerospace Engineering 0(0) 1–17

References

18. Geoffrey Larkina and Graham Coates, “A design analysis of vertical stabilisers for Blended Wing Body aircraft”, Aerospace Science and Technology, February 2017
19. Parisa Footohi, Adrien Bouskela and Sergey Shkarayev, “Aerodynamic Design of Long-Range VTOL UAV”, AIAA SciTech Forum, 7-11 January 2019, San Diego, California, AIAA Scitech 2019 Forum
20. Michael Becker and David Sheffler, “Designing a High Speed, Stealthy, and Payload-Focused VTOL UAV”, 2016 IEEE Systems and Information Engineering Design Conference (SIEDS '16)
21. ANSYS Fluent Theory guide ANSYS® Fluent Theory Guide, 17.0, help system, ANSYS, Inc
22. Overview on Reflex Gliders by Jeff Goin, April 14, 2019, http://www.footflyer.com/overview-on-reflex-gliders/
23. Andreas Kamilaris1and Francesc X. Prenafeta-Boldú, Disaster Monitoring using Unmanned Aerial Vehicles and Deep Learning, Institute for Food and Agricultural Research and Technology (IRTA)Barcelona, Spain
24. Boeing X-48, https://en.wikipedia.org/wiki/Boeing_X-48, 2020
25. J. I. Hileman, Z. S. Spakovszky, M. Drela, “Airframe Design for “Silent Aircraft””, 45th AIAA Aerospace Sciences Meeting and Exhibit, Jan 8-11, 2007, Reno, Nevada
26. Blended wing body, https://en.wikipedia.org/wiki/Blended_wing_body, 2020
27. Wheatstone bridge circuit with formula and applications, May 31, 2016, https://physicsabout.com/the-wheatstone-bridge/
28. S Siouris and N Qin, “Study of the effects of wing sweep on the aerodynamic performance of a blended wing body aircraft”, Proc. IMechE Vol. 221 Part G: J. Aerospace Engineering, 2007
29. Ahmad Z. Al-Garni, Farooq Saeed and Abdullah M. Al-Garni, “Experimental and Numerical Investigation of 65 Degree Delta and 65/40 Degree Double-Delta Wings”, JOURNAL OF AIRCRAFT, Vol. 45, No. 1, January–February 2008
30. NI 6036E data card specification, http://www.ni.com/pdf/products/us/4daqsc202-204_ETC_212-213.pdf
31. R.L. MALTBY, “Flow Visualization in Wind Tunnels Using Indicators”, April 1962, pg. 29-38

Thank You



Questions?