Experimental Investigation of Double Delta Wings with Different Angles of Attack at Subsonic Speeds

G. Balaji, A. Bharath Kumar, R. Divya, G. Boopathy, N. Seenu, and G. Santhosh Kumar

Abstract

The wind tunnel experimental study has been carried out on a double delta wing of different geometrical configurations such as 80°/45°, 75°/45° and 70°/45° sweep angles given as Model I, Model II and Model III with various freestream velocities from 10 to 40 m/s with a step of 10 m/s in Hindustan Institute of Technology and Science, Chennai, Low Speed Wind tunnel (HITSLSWT). The experiment is conducted for the measurement of lift and drag forces using single component force balance. The investigation was done to look into the effects of changing the double delta wing's leading edge sweep angles. Three different models have been tested at various angles of attack ranging from 0° to +16° and 0° to −16° with 4° and four different freestream velocities based on the delta wing's chord. It is observed that the influence of variation of leading edge sweep angles affects the performance of aerodynamic characteristics of the model. The increase in angle in attack with increased velocity gives better aerodynamic performance. This paper provides good insight into the aerodynamic force measurement of double delta wing and the low-speed performance of the models.

G. Balaji (✉) · A. Bharath Kumar · R. Divya
Department of Aeronautical Engineering, Hindustan Institute of Technology and Science, Padur, Chennai, 603103, India
e-mail: gbalajihits@gmail.com

A. Bharath Kumar
e-mail: abharathkumar2002@gmail.com

G. Boopathy
Department of Aeronautical Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Technology and Science, Chennai, 600062, India

N. Seenu
Department of Mechatronics Engineering, Hindustan Institute of Technology and Science, Padur, Chennai, 603103, India
e-mail: nseenu@hindustanuniv.ac.in

G. Santhosh Kumar
Department of Mechanical Engineering, University College of Engineering, Bharathidasan Institute of Technology Campus, Anna University, Tiruchirappalli, Tamil Nadu, India

Keywords

Double delta • Wing • AOA • Aerodynamics force • Subsonic speed • Wind tunnel test

1 Introduction

Moreover, the double delta wing configuration gives a low drag value at supersonic speed and to further improve the aerodynamics performance of the double delta wing thin or sharp leading edges are imposed on it. Due to differences in pressure around the wing, flow at the leading edge splits and flows spanwise over the upper surface. But, in this research work, the aerodynamics characteristic of the double delta wing has been investigated at a very low subsonic speed, and three different configurations as 80°/45° model, 75°/45° model and 70°/45°model were experimentally investigated. Saha and Majumdar (2013) Based upon the wing model's length of the root chord, experimental and numerical analysis was conducted to visualize the flow on the surface of a single beveled, sharp-edged and 76°/40° double delta wing at free stream Reynolds number of 2×10^5 with varying angles of attack. Comparing the experimental and CFD data of the flow visualization shown for the double delta wing leads to this conclusion.

Ashwin Kumar et al. (2018) performed the numerical and experimental study at a freestream velocity of 20 m/s on a double delta wing with a sweep of 81/45. It has been noted that measuring the forces showed that the double delta wing's lift and drag increase while increasing the angles of attack. Additionally, studies done to acknowledge the impact on the leading-edge shape, showed that at low speeds, a blunt leading edge of a double delta wing obtains greater lift compared to a prominent leading edge delta wing. Further, at the leading edge, a delay occurs due to the principal separation, this causes a majority of the vortex to be postponed. The experiments and computations showed a fair amount of agreement.

M. Sumesh et al. (eds.), *2nd International Conference on Smart Sustainable Materials and Technologies (ICSSMT 2023)*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-031-50024-4_20

Al-Garni et al. (2008) conducted the experimental and numerical investigation of aerodynamics performance on 65 single delta and 64°/45° double at different pitch angles and side slip angles. When results are compared, it is seen that the predictions of the CFD are similar to the calculations done theoretically at angles with zero sideslip as well as showing good agreement between the various experimental experiments. et al. (2015) conducted a numerical study of different aerodynamic characteristics of single delta wing and double delta wing. It was observed that the new design, when applied to single delta wings and double delta wings, results in a reduction in drag for every angle of attack. Additionally, the ratio of lift and drag is improved and the overall efficiency of the single delta wing and double delta wing is improved by the suggested new design's drag reduction. Mahdavi and Reza (2021) conducted the experimental study over a cranked–delta wing for merging of the vortex at speeds in the subsonic range. The study came to the conclusion that if there is any increase in the angle of attack, the communication among both vortices gets increased, causing the vortex on the inner part to flow outward while the vortex on the outer part flows inward. Further, the vortices combine with one another at a high angle of attack, where the breakdown in the vortex migrates to the surface of the wing at a specific angle of attack and causes the suction peak to collapse and spread spanwise. The angle of attack at which vortex bursting passes onto the surface of the wing coincides with the earlier investigations about the aforementioned longitudinal uncertainty, according to surface pressure measurements.

Manshadi et al. (2016) did an experimental analysis of flow pressure and velocity distribution on the cranked double delta wing at Reynolds number 2×10^5 and the corresponding freestream velocity is 20 m/s on two different sweep angles of 55° and 30°. It was observed that with an increase in the angle of attack, the drop in pressure also increases, the vortices are widened, and the vortices along the wing are moved inside and far from the surface. Naimuddin et al. (2014) conducted the experimental investigation of a compound delta wing and observed that the vortices on the wing surface enlarge as the angle-of-attack increases and explode at higher angles of attack. Additionally, the outcomes might offer useful information for wing structural design and vortex bursting management. Hu et al. (2021) carried out the numerical and experimental study on characteristics of lift for a double delta wing at various numbers of reduced frequency. It was discovered that the hysteresis effect for the lift was amplified by raising the lowered frequency of pitching. The virtual camber effect caused due to pitching might dominate the field of motion as soon as the reduced frequency increases to a certain level, which could reduce the influence of the geometry of the wing for lift characteristics.

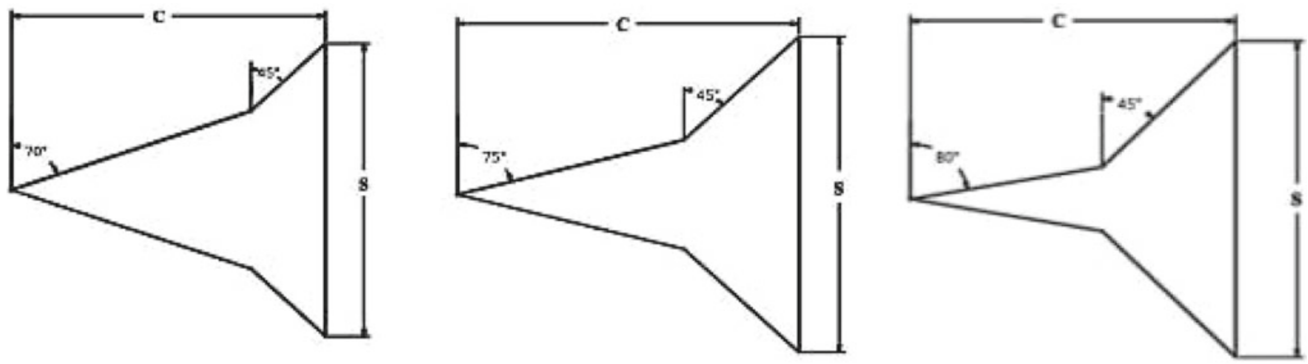
Bilakanti et al. (2013) conducted an Experimental study on a Double delta Wing Model for its flow characteristics with a Leading Edge rounded to 80°/45°. It is discovered that the flow of leeward vortex over a double delta wing with an 80°/45° rounded leading edge with deflection in the control surface and without deflection in the control surface has been studied for angle of attacks that ranges from 0° to 20° sideslip conditions are zero for Reynolds Number that ranges from 3.6 to 4.36 million at different range of transonic and subsonic speeds. Grismer and Nelson (1995) conducted the experiment on subsonic speed on a double delta wing for both without and with sideslip was carried out on a strake or wing platform, under static and dynamic conditions. Both static aerodynamics and dynamic aerodynamics of an 80°/60°/0.6 double-delta wing were explored for various angles of attack for both without and with sideslip using various factors such as flow visualization, force, and moment studies.

The effects of different Reynolds number over the 76/40° double delta wings were examined by Verhaagen (2002). It was noted that the Reynolds number seemed to have minimal impact on the flow over the wing. Strong Reynolds numbers showed significant effects on the interplay between the wing vortices and the strake on the wing panels for Reynolds numbers less than 105/m. At large Reynolds numbers, the interaction between these vortices is minimal for low angles and strong if the angle is higher than 10°.

In this research work, force measurement on the double delta with three different configurations such as 70°/45° model, 75°/45° model and 80°/45° model is investigated in the low-speed wind tunnel located at Hindustan Institute of Technology and Science, Chennai. The three configurations of double delta model are named Model I, Model II and Model III as shown in Fig. 1a–c investigated for different freestream velocity condition such as 10, 20, and 40 m/s. The three double delta model is inclined to different angles of attack that range from 0° to 16° in the positive scale and 0° to −16° in the negative scale with a step of 4°. The three-component force measurement is used to measure the lift force and drag force. The geometric diagrams of double delta wing configurations as seen in Fig. 1a–c.

2 Experimental Setup

The experiments were conducted out at Hindustan Institute of Technology and Science's low-speed wind tunnel that operates in a subsonic range (HITSLSWT), with test section dimensions as 600 mm × 600 mm × 1200 mm (Width × Height × Length) Subsonic Wind Tunnel at Low Speed. The Tunnel is capable of operating with a maximum freestream velocity of 50 m/s in the wind tunnel test section. The wind



(a) Model-I (70°/45°) (b) Model-II (75°/45°) (c) Model-III (80°/45°)

Fig. 1 The schematic diagram of three different double delta wings

tunnels were calibrated before conducting the experiment and calculated the turbulence to be less than 5% and the blockage ratio was less than 5%. The length of the wind tunnel test is 1200 mm which is split into two partitions to conduct the force measurement and pressure measurement. The wind tunnel operates in an open circuit continuous flow and experiments were carried out for various freestream velocities and corresponding Reynolds Number 2×10^4 and at a velocity of 10 m/s. A schematic illustration of a low-speed wind tunnel facility is seen in Fig. 2. The three different configurations of the double delta wing were tested at various angles of attack from 0° to 16° and 0° to −16° with a step of 4°. The experimental setup mainly consists of a suction-type low-speed subsonic wind tunnel, three-component force measurement and three different configurations of experimental models.

Experiments were conducted on three different configurations of double delta wing models with sweep angles 80°/45°, 75°/45°, 70°/45° having sharp leading edges and rectangular trailing edges. Three configurations of the experimental sharp edge double delta wing double delta model are named Model-I, Model-II, and Model-III as shown in Fig. 3a–c. The models were fabricated of teak wood. The leading edge is beveled with a single bevel at a 20° angle. The models were further smoothened, and polished and finishing was done. The models have been further polished, smoothed, and finished. A three-component balance was utilized to measure the lift force, drag force and pitching moment exerted on the three different configurations of double delta models. The three-component balance (WBAL–00103) was manufactured by the Sunshine product used for carrying out the experiments.

Fig. 2 Low-speed subsonic wind tunnel facility (HITSLSWT)

(a) Model-I (70°/45°) (b) Model-II (75°/45°) (c) Model-III (80°/45°)

Fig. 3 Experimental model of different configurations of double delta wing

3 Result and Discussion

3.1 Effect of Lift Force on Various Configurations of Double Delta at Subsonic Speed

Figure 4a–c shows the force distribution of three different geometries of double delta wings at various angles of attacks and freestream velocity. This experiment is conducted for a limited angle of attack from 0° up to 16°. It is observed that lift forces increase with an increase in the angle of attack and free stream velocity depicted in Fig. 4a–c. In Fig. 4b, it observed that a maximum lift force of 6N occurs for the velocity of 40 m/s due to strake flow intersecting with wing flow leading to maximum lift force occurring in Model-II.

3.2 Effect of Drag Force on Various Configurations of Double Delta at Subsonic Speed

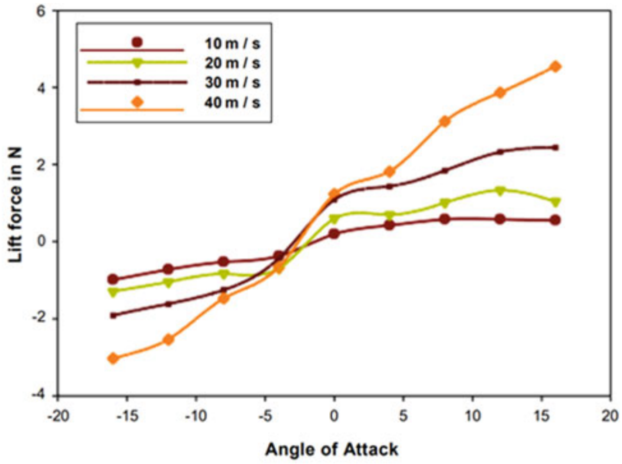
Figure 5a–c shows the drag force distribution of three different geometries of double delta wing for various angles of attack and freestream velocity. This experiment is conducted for a limited angle of attack from 0° up to 16°. It is observed that drag forces remain uniform for every angle of attack and show drag forces increase for the negative angles of attack depicted in Fig. 5a–c. The drag forces increase as the nose cone angle of the double delta wing increases as seen in Fig. 5a–c and the maximum drag force value of 22 N at 40 m/s observed the Model-III (b) due to strake flow and wind intersect with tip flow of the double delta wings lead to increase the drag force as shown in Fig. 5c.

3.3 Effect of Pitching Moment on Different Configurations of Double Delta at Subsonic Speed

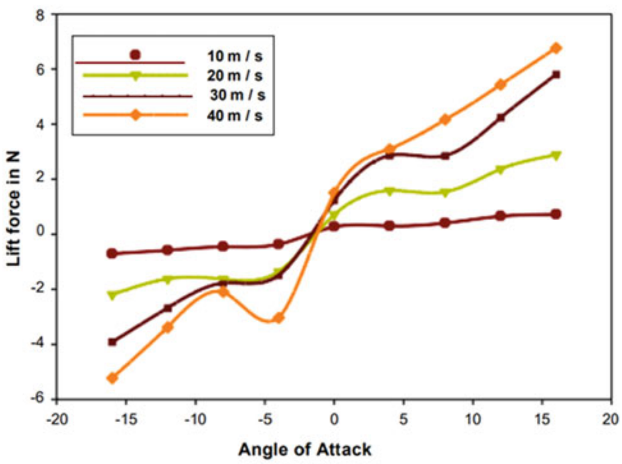
Figure 6a–c shows the pitching moment distribution of three different geometries of double delta wing at various angles of attack and freestream velocity. Due to the three-component balance's operating range, this experiment is only conducted over a limited range of attack angles, from 0° to 16°. It is observed that the pitching moment is increased with an increase in all angles of attack and conversely the pitching moment magnitude decreases with an increase of the nose cone angle. The maximum pitching moment magnitude observed at the Model-I of 15 Nm in Fig. 6a. Also, it is observed that the maximum deviation of change pitching moment induced on the double delta wing due to strake flow vortices caused by nose cones.

4 Conclusion

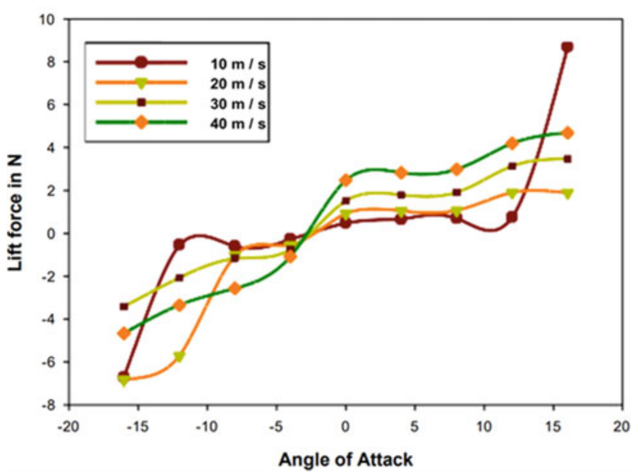
An experimental investigation of different configurations of double delta wings was carried out in the low-speed wind tunnel. The main objective of this study was to investigate the lift force, drag force and pitching moment induced in different configurations of the double delta wings such as 70°/45°, 75°/45° and 80°/45° corresponding to Model-I, II and III, respectively, for different freestream 10 m/s, 20 m/s, 30 m/s and 40 m/s and various angles of attack. It is observed that the force measurement indicates that with increasing the freestream velocity and angle of attack there is an increment in lift force and drag force on the sharp edge double delta wing. Also, various experiments were performed to understand various effects due to the sharp



a. Lift distribution on Model-I (70°/45°)

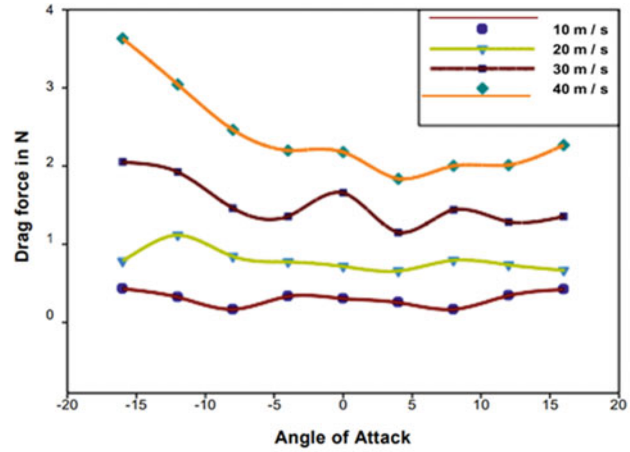


b. Lift distribution on Model-II (75°/45°)

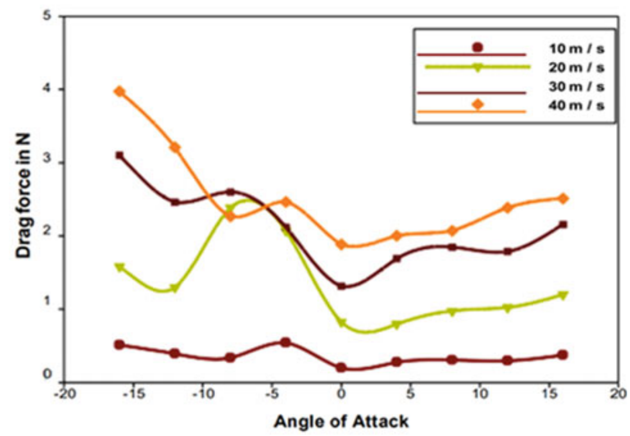


c. Lift distribution on Model-III (80°/45°)

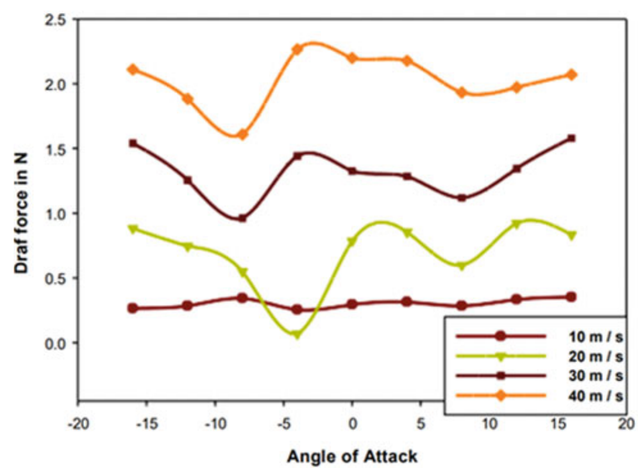
Fig. 4 Lift force distribution over the double delta wing model



a. Drag distribution on Model-I (70°/45°)



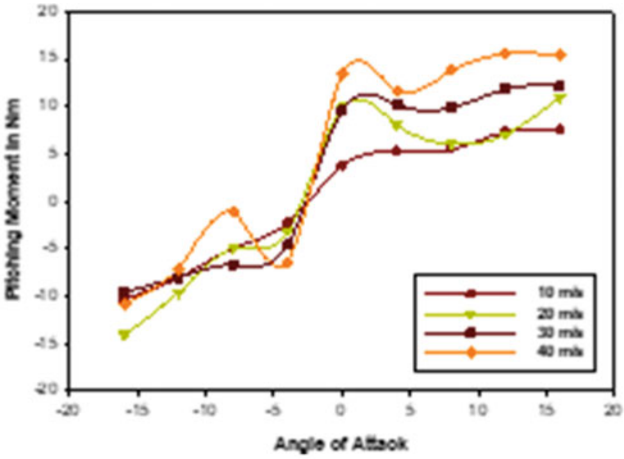
b. Drag distribution on Model-II (75°/45°)



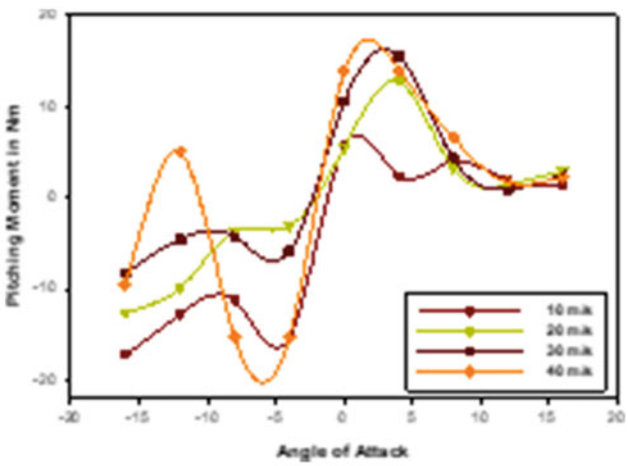
c. Drag distribution on Model-III (80°/45°)

Fig. 5 Drag force distribution of double delta wing model

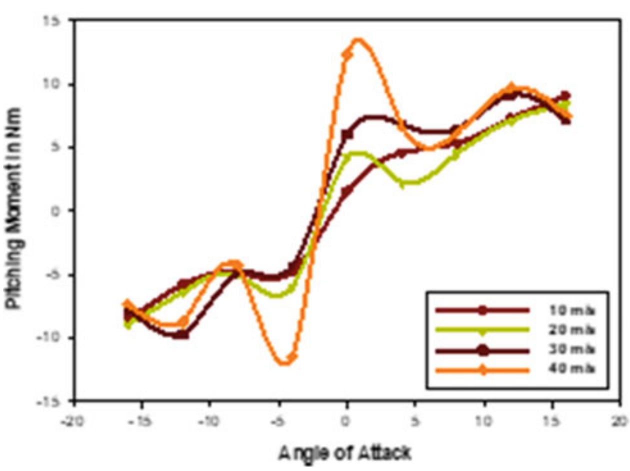
leading-edge shapes for the three different configurations of double delta wings at low speeds. The pitching moment is drastically varying in the model-I as compared to other models. Overall, the results of the comparison of lift force, drag force and pitching moments show good agreement with experiments.



(a) Pitching Moment distribution on Model-I (70°/45°)



(b) Pitching Moment distribution on Model-II (75°/45°)



(c) Pitching Moment distribution on Model-III (80°/45°)

Fig. 6 Pitching moment distribution of double delta wing model

References

Al-Garni, A. Z., Saeed, F., & Al-Garni, A. M. (2008). Experimental and numerical investigation of 65-degree Delta and 65/40 degree double-delta wings. *Journal of Aircraft, 45*(1), 71–76.

Ashwin Kumar, B., Kumar, P., Das, S., & Prasad, J. K. (2018). Effect of leading-edge shapes on 81/45 double-delta wing at low speeds. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 232*(16), 3100–3107.

Bilakanti, S., Bharat, K., Dubey, R., Sivaramakrishnan, A., & Ganeshan, V. (2013). Experimental investigation of the flow over an 80/45 rounded leading edge double- delta wing-body model. In *51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition* (p. 249).

Dsouza, C. V. (2015). Numerical simulation of 65° delta wing and 65°/40° double delta wing to study the behaviour of primary vortices on aerodynamic characteristics.

Grismer, D. S., & Nelson, R. C. (1995). Double-delta-wing aerodynamics for pitching motions with and without sideslip. *Journal of Aircraft, 32*(6), 1303–1311.

Hu, T., Zhao, Y., Liu, P., Qu, Q., Guo, H., & Akkermans, R. A. (2021). Investigation on lift characteristics of double-delta wing pitching in various reduced frequencies. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 235*(14), 2081–2094.

Mahdavi, Z. F., & Reza, S. M. (2021). An experimental investigation of the vortex merging over a cranked-delta wing at subsonic speed. *Journal of Aerospace Engineering and Mechanics*, *5*(1).

Manshadi, M. D., Eilbeigi, M., Sobhani, M. K., Zadeh, M. B., & Vaziry, M. A. (2016). Experimental study of flow field distribution over a generic cranked double delta wing. *Chinese Journal of Aeronautics, 29*(5), 1196–1204.

Naimuddin, M., Chopra, G., Sharma, G., & Sharma, G. (2014). *Experimental & computational study on compound delta wing*. Aeronautical Engineering Department, Manav Rachna International University, Faridabad, ResearchGate.

Saha, S., & Majumdar, B. (2013). Modeling and simulation on double delta wing. *International Journal of Advanced Computer Research, 3*(1), 201.

Verhaagen, N. G. (2002). Effects of Reynolds number on flow over 76/40-degree double-delta wings. *Journal of Aircraft, 39*(6), 1045–1052.