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Theoretical and Computational Investigation on Swept Back Wing using CFD Method

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Abstract. The principles of flight deals with the motion of air and forces acting on an aircraft. The theoretical aspects of aircraft deals with four different forces. The main aim of the study was to analyse the Swept Back Wing for Supersonic and Hypersonic Mach Regimes at various angles of attack. The geometry and analysis were done using Ansys-Fluent. Calculations were done for constant air velocity altering only the angle of attack. The findings present up the contours of pressure and velocity along with evaluation of lift, drag and its coefficients.

Keywords: CFD, Swept Back Wing, Pressure, Velocity, Drag and Lift, Drag Coefficient, Lift Coefficient, Mach number, Angle of Attack

1. Introduction

As the thrust is generated by the aircraft (thrust changes the inertia of the wing), the air into which the aircraft flies splits into two sections at the wing's leading edge, passing above and below the wing at different speeds to reach the trailing edge at the same time. Since the upper surface of the wing is curved, the air moves faster and stretches out creating a low-pressure region over it. The air flowing below the wing moves in a straight line as it is a flatter surface thus with the same speed and pressure. Here the air speeds up on a curved surface as it has to travel lesser distance as compared to the path of the lower part of the wing which is a straight line. As high pressure moves towards low pressure, the air beneath the wing pushes the wing to move upwards. The wing is lifted by a force perpendicular to the wing. When the lift is greater than the weight, the aircraft flies. When the thrust is greater than the drag, the aircraft can move forward. Sweeping the wings back make them feel like they are flying slowly. It delays the onset of the supersonic air flow (speed greater than the speed of sound) over the wing which delays the wave drag. The air above the surface of the wing is not always greater than the speed of sound. First it attains the supersonic speed then it comes below it. As the air flows above the wing it creates pressure waves which are equal to the speed of sound therefore it cannot move forward. Instead, they build up into massive pressure. This pressure is known as a shock wave which generates a lot of drag. Air flowing over the wing crosses a massive pressure boundary which sucks energy out of it causing drag. Air can also loose energy which causes it to separate it from the wing causing drag again. Sweeping the wing backwards delays the supersonic flow by reducing the amount of acceleration of the air over the wing. Generally, air flow over the wing travels parallel to the chord line in case of no sweeping of the wing. But in this case, the airflow has two components due to the sweeping effect, one which is parallel to the chord line and the other which is perpendicular to the chord line. Only the air flow which is parallel to the chord line accelerates therefore reducing the amount of the air accelerating above the wing surface. This delays the air speed reaching the speed of sound which lets us fly at a higher Mach number before creation of the shock waves. Aerodynamic efficiency is a measure that tests a design to generate aerodynamic forces for efficient flight. It is done by calculating the lift/drag ratio. Lift coefficient relates the lift generated by a lifting body to the fluid density around the body, the fluid velocity, and an associated reference area. The drag coefficient is used to quantify the drag or resistance of a wing in an airy environment. Here we are concerned with the changes in the values of the lift and drag with the simultaneous changes in the angle of attacks of the wing which belong to supersonic, hypersonic approaching and hypersonic regimes.

2. Literature Review

Ragamshetty et.al (2022) examined the wing by treating the root chord, which is fixed, and the tip chord, which is free. To determine how much deformation, stress, and strain the wing has undergone, a static structural analysis of the wing is performed. In order to lessen noise and prevent vibration, modal analysis is used to determine the wing's natural frequency.[1] Lin et.al (2022) examined the effect of the Reynolds number on the flying wing common research model with a large sweep angle and small aspect ratio is studied by numerical simulation.[2] Khan et.al (2022) looked into the modification of the air foil, out-of-plan transformation, and wing planform, research has been done to improve wing performance. The study showed that, among all wing planforms, a rectangular wing has a high lift and drag coefficient. Additionally, it demonstrates that symmetric air foils with an angle of attack (AoA) of 0° will not generate any lift. The airflow from the wing root to the wing tip is altered, but the tip vortices are also heightened. [3] Yi et.al (2021) examined the dynamic properties of the missile at various swept back angles which are investigated using a 3D model of the missile and a CFD simulation. It is examined how the missile lifts and drags under various sweeps, and it is discovered how the varied sweep angle affects the overall body's aerodynamic properties.[4] Inamdar et.al (2021) discussed the functions of swept wings, flexible wing structures, and aerofoils.[5] Radhakrishnan P et.al (2021) analysed the wing's aerodynamic performance with ANSYS Fluent software, and the results were then carefully interpreted to determine how the wing's shapes and performance affected each other.[6] Gao et.al (2020) looked into caret inlet applications and the 3D SSI of two intersecting wedges with back-sweep angles. In order to explore the flow-field features of the flows, a theoretical method known as "spatial dimension reduction" was combined with numerical simulations. In-depth discussions were held regarding the wave configurations and their structures, the homogeneity of the feather field, and the effectiveness of the overall pressure recovery.[7] Zhou et.al (2020) studied the characteristics of the Busemann-type supersonic biplane's fluid-structure interaction under design conditions. The primary elastic properties of the wing structure have been considered in a theoretical two-dimensional structure model. The fluid-structure dynamic system of the supersonic biplane is investigated using the two-way computational fluid dynamics/computational structural dynamics (CFD/CSD) coupling method in conjunction with unsteady Navier-Stokes equations. [8] SetoguchiIn et.al (2020) investigated the phenomenon of the separation vortex from the leading edge, in the low-speed and high angle of attack regime, the aerodynamic characteristics of a supersonic business jet with a forward-swept wing were numerically evaluated.[9] Kosinov et.al (2019) studied experimentally and numerically to determine how changes in the mild angle of attack affect the laminar turbulent transition in the swept-wing supersonic boundary layer.[10] Kishi et.al (2019) resolved the design issues using a multi-fidelity approach that included a hybrid surrogate model assisted by evolutionary computation in order to decrease the necessary computation time. The compressible Euler equation and the linearized compressible potential equation were used as high- and low-level fidelity solvers, respectively, to assess aerodynamic performance. [11] Eppink et.al (2019) ascertained the effects of a backward-facing step on transition in a low-speed stationary crossflow-dominated boundary layer, experimental measurements were carried out on a swept flat-plate model with an air foil leading edge and imposed chordwise pressure gradient.[12] Gong et.al (2018) carried out an aerodynamic optimization research for a morphing-wing aircraft with changeable sweep, span, and chord length to find the best configurations for subsonic, transonic, and supersonic circumstances, properties of disturbances, which include dispersion relations and amplification rates over a broad range of wave inclination angles.[13] Mochizuki et.al (2018) suggested using canard wings to enhance the aerodynamic properties of delta wings. Examining canard wings' ability to enhance aerodynamic properties in a low-speed region is the goal of this study. Four wing models with various canard shapes are used to perform CFD analysis.[14] Aravinth et.al (2018) studied a number of cases by varying the sweep angle of the trapezoidal plate for flutter calculations at various Mach numbers from low to high supersonic free stream circumstances. Using a newly developed 3D enhanced piston theory, the dynamic aeroelastic behaviour of a trapezoidal wing (EPT) was analysed. [15]

3. Methodology

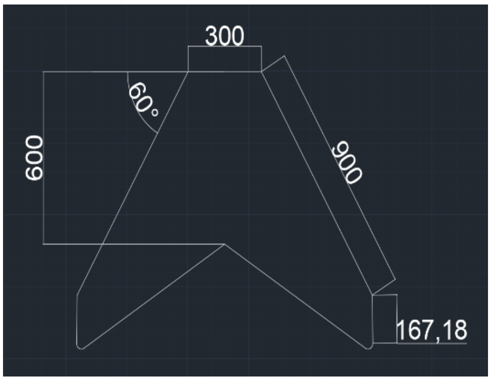


FIGURE 1. Dimensions for a swept back wing with an angle of attack of 60 degrees

Geometry: The swept back wing was created using Ansys (Fluent) Design modeler. The basic geometry for all the angle of attacks is same as given in Figure. All the dimensions in the alongside figure are in mm. The fillet was set to 0.02m for the corners of the wing. This significantly reduced drag as airflow improved, making it even more fuel efficient. The wing has a thickness of about 0.04m. The calculations were made based on the concept in Figure 2. for calculating Mach numbers for different angle of attacks. The calculations are made for a wing with a critical Mach number (M_{cr}) = 2.Critical Mach number is the speed at which the air flowing above the wing surface reaches the speed of sound.

Sr. No.	Angle of attack	Mach No.	Mach Regimes
1	30°	2.30	Supersonic
2	45°	2.82	Supersonic
3	60°	4.00	Supersonic
4	70°	5.88	Hypersonic
5	78°	9.62	Hypersonic

Sr. No.	Mach No. Range	Mach Regimes
1	1.20–5.00	Supersonic
2	5.00–10.00	Hypersonic

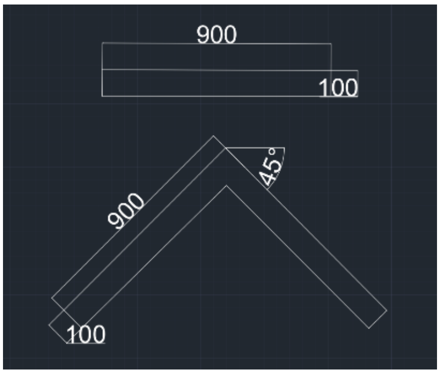


FIGURE 2. Sweeping the wing backwards with an angle of about 45 degrees

Consider the plane view of a straight wing. Assume this wing has a critical Mach number (M_{cr}) = 1. Now assume that we sweep the wing back through an angle of, say, 45°, as shown in Figure. The wing, which still has a value of M_{cr} = 1, now "sees" essentially only the component of the flow normal to the leading edge of the wing; i.e., the aerodynamic properties of the local section of the swept wings are governed mainly by the flow normal to the leading edge: angle made by the leading edge with the normal. Hence, the critical Mach number for the swept wing with a angle of attack of 45° would be as high as 1/cos 45° = 1.73.

Body	Solid
Volume	0.023853 m^3 = 0.02m^3
Surface Area	1.347 m^3 = 1.34 m^3
Faces	11
Edges	27
Vertices	18
Shared Topology Method	Automatic

After designing the wings, enclosure was used to enclose the wing in a surface for further simulations.

Mesh: Meshing was done by using Ansys (Fluent) Meshing. Creation of inflation i.e., boundary was made for analysis. A numerical grid is applied to wings and its boundary during meshing, which is comparable to meshing in finite element simulations.

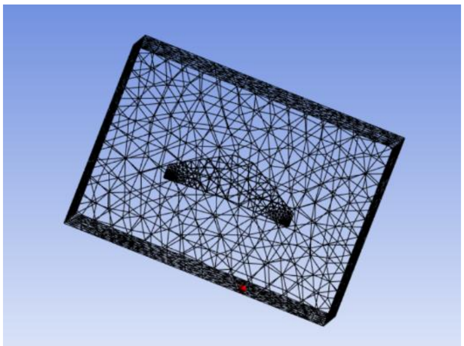


FIGURE 3. Mesh generated for the swept back wing

Element Order	Linear
Element Size	0.25 m
Growth Rate	1.20
Max Size	0.51
Bounding Box Diagonal	5.10 m
Maximum Layers	5
Nodes	17548
Elements	74837

Next step was to name the different sides of the boundaries for deciding the inlet and outlet for air transfer. For the wings, 4 surfaces were named which were mainly- inlet, outlet, walls, and wings.

Setup & Solutions: Boundary conditions were set using Ansys (fluent) fluent. The mesh was firstly converted to a polyhedral for better and faster calculations. Then the below conditions were set up.

Fluid Material Name	Air
Velocity Specification Method	Magnitude, Normal to Boundary
Velocity Magnitude	60 m/s
Turbulent Intensity [%]	5.00
Turbulent Viscosity Ratio	10
Viscous Model	k-omega (2 equation)
k-omega Model	SST
Model Constants	Default
Turbulent Viscosity	None

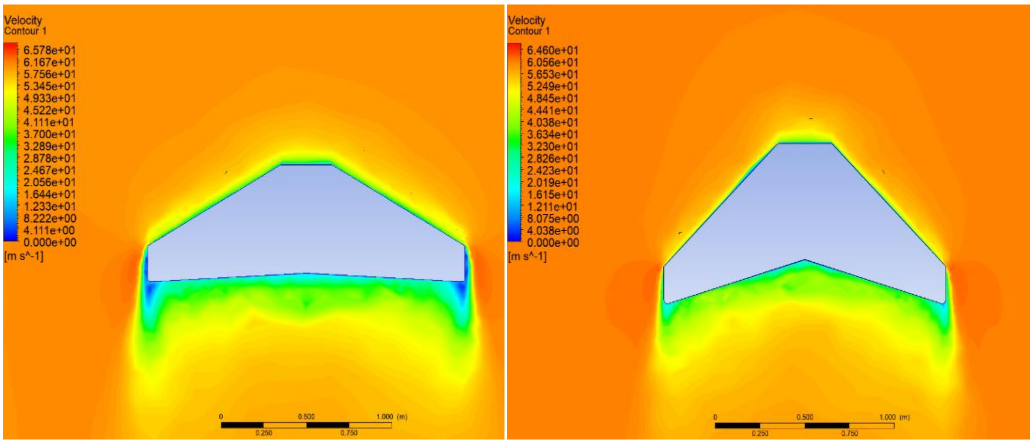
The parameters were set in Report Definitions. They were namely- Lift and Drag and their respective coefficients. After Initializing, Number of iterations was set to 200 and the parameters were calculated. Velocity and Pressure Contours were plotted along a plane.

4. Results and Discussion

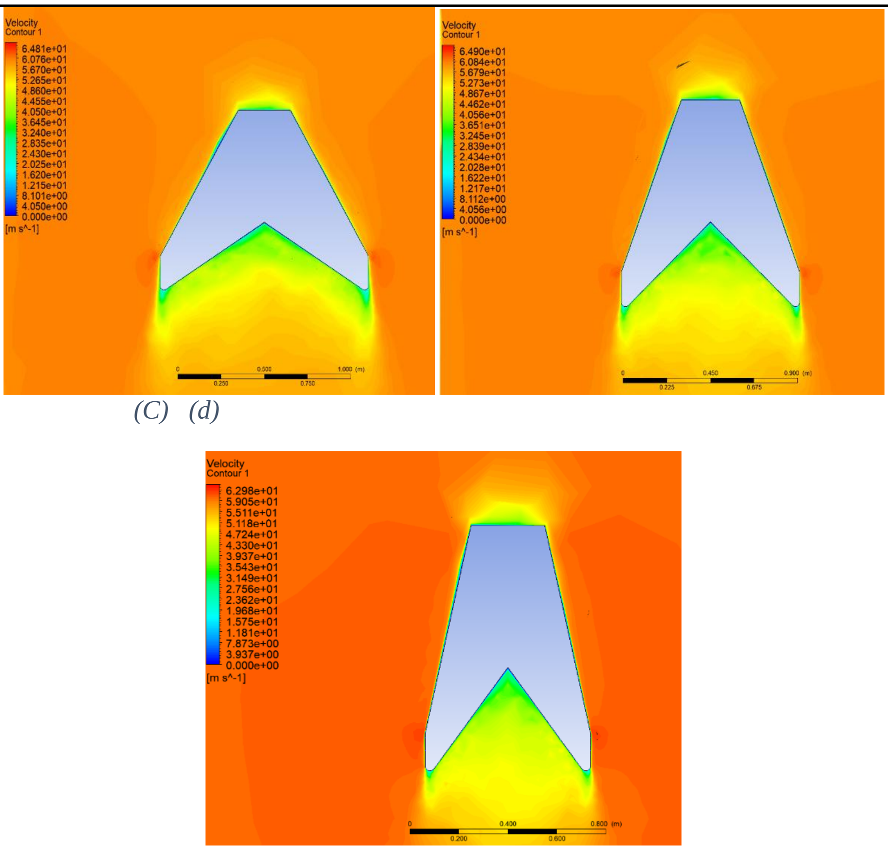
The results of the CFD simulations were plotted down as velocity and pressure contours.

TABLE 1. Comparison of Final readings

Angle of Attack [Degree]	Mach No.	Drag[N]	Drag Coefficient	Lift[N]	Lift Coefficient	Lift / Drag [in 10^{-4}]
30	2.30	192.29	313.94	0.15	0.25	7.8
45	2.82	128.73	210.18	0.14	0.24	1.08
60	4.00	83.00	135.52	0.13	0.22	1.56
70	5.88	59.16	96.59	0.02	0.03	3.38
78	9.62	43.51	71.04	0.09	0.14	20.6



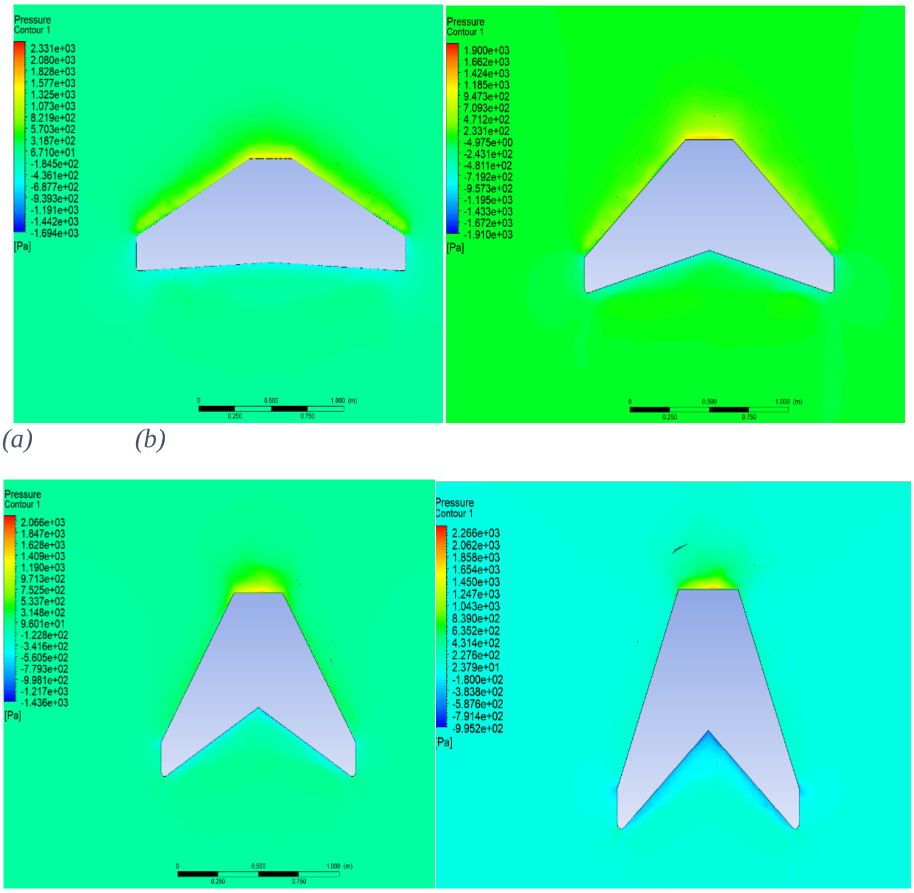
(a) (b)



(C) (d)

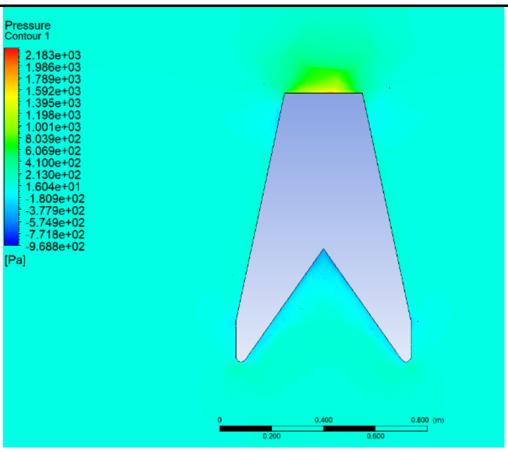
(e)

Figure 4. Velocity contours of 30, 45-, 60-, 70- and 78-degrees Angle of Attack respectively



(a) (b)

(c) (d)



(e)

FIGURE 5. Pressure contours of 30, 45-, 60-, 70- and 78-degrees Angle of Attack respectively

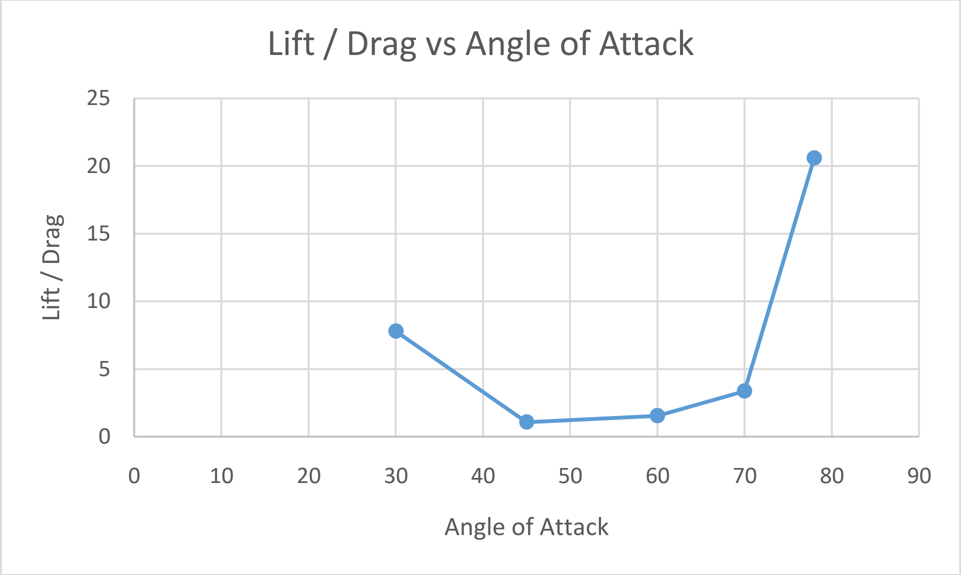


FIGURE 6. Plot of Lift/Drag vs Angle of Attack

5. Conclusion

First a swept back wing was designed for different Mach numbers which followed its CFD analysis using Ansys fluent to know about the behaviour of the wing in supersonic, hypersonic approaching and hypersonic conditions. As the angle of attack increases, the amount of lift and drag created by the swept back wing decreases. For the wing with a Mach number of 9.62, the amount of lift generated is 0.09N which is more than that of the wing with a Mach number of 5.88 which has a lift of about 0.02N. This is because the former wing is completely hypersonic whereas the latter wing is hypersonic approaching. Coefficient of lift and drag are maximum for angle of 30 degrees. The drag force is considerably large as compared to the lift force. The lift over drag ratio is maximum for the hypersonic wing of Mach number 9.60 and minimum for supersonic wing with Mach number 2.30 from figure 6. This tells us that the hypersonic wing produces larger lift and smaller drag at a speed of 60 m/s.

Reference

[1]. MounikaRagamshetty, T Sai Deepthi, V Anil, T Akhil, A Shiva Kumar, Design and Finite Element Analysis of Aircraft Wing, International Journal of Research Publication and Reviews, 3(7), 2022, pp 995-1006

[2]. Peng Lin, Jifei Wu, Lianshan Lu, NengXiong, Dawei Liu, JichuanSu, Guangyuan Liu, Yang Tao, Junqiang Wu, Xueqiang Liu, Investigation on the Reynolds Number Effect of a Flying Wing Model with Large Sweep Angle and Small Aspect Ratio, Aerospace 9, 9(523), 2022, https://doi.org/10.3390/aerospace9090523

[3]. Salman Khan, Muhammad Sohail Malik, Massab Junaid, Ali TurabJafry, To investigate and compare the wing planform's effect on the aerodynamic parameters of aircraft wings using computational, Research Square, 2022, https://doi.org/10.21203/rs.3.rs-1806010/v1

[4]. Lin Yi, Yu Li, Liangzheng Ma, YuntuAo, Ying Wang, Analysis of aerodynamic characteristics of missile with different sweep angle under supersonic condition, Journal of Physics: Conference Series, 2021, doi:10.1088/1742-6596/1802/4/042003

[5]. AdvaitInamdar, Narayan Thakur, Deepak Pal, Akshat Mohite, FLEXIBLE WING STRUCTURE AND VARIABLE-SWEEP WING MECHANISM, International Research Journal of Engineering and Technology (IRJET), 8(3), 2021

[6]. Radhakrishnan P, Ramanan G, Chandan Gowda H R,Meghana C K, Chaithra A N, Aerodynamic Performance Analysis of a Variable Sweep Wing for Commercial Aircraft Applications, ACS Journal for Science and Engineering, 1(1), 2021, https://doi.org/10.34293/acsjse.v1i1.5

[7]. X.Gao, G.X.Xiang, W. J.Tang, X. Z. Jie, X. Huang, J.Y. He, S.A. Liu, Investigations on the complex fows induced by dual-swept/dual ramp wedges in supersonic fows, Sci Rep, 10 2020, https://doi.org/10.1038/s41598-020-66676-5

[8]. Hao Zhou, Gang Wang, Zhikan Liu, Numerical analysis on flutter of Busemann-type supersonic biplane air foil, Journal of Fluids and Structures, 92, 2020, https://doi.org/10.1016/j.jfluidstructs.2019.102788

[9]. Nao Setoguchi, Masahiro Kanazaki, Low-Speed and High Angle of Attack Aerodynamic Characteristics of Supersonic Business Jet with Forward Swept Wing, AIAA Scitech 2020 Forum, 2020, DOI: 10.2514/6.2020-0534

[10]. Alexander Kosinov, Nikolai Semionov, YuryYermolaev, Boris Smorodsky, GlebKolosov, Aleksey Yatskikh, Alexander Semenov, The influence of moderate angle-of-attack variation on disturbances evolution and transition to turbulence in supersonic boundary layer on swept wing, Proc IMechE Part G: J Aerospace Engineering, 234(1), 2020, pp. 96–101, https://doi.org/10.1177/0954410019852804

[11]. Yuki Kishi, Shinya Kitazaki, AtthaphonAriyarit, Yoshikazu Makino, Masahiro Kanazaki, Planform dependency of optimum cross-sectional geometric distributions for supersonic wing,90, 2019, pp. 181-193, https://doi.org/10.1016/j.ast.2019.03.057

[12]. Cheng Gong, Bao-Feng Ma, Shape Optimization and Sensitivity Analysis of a Morphing-Wing Aircraft, International Journal of Aeronautical and Space Sciences, 20,2019, pp. 57-69, https://doi.org/10.1007/s42405-018-0110-7

[13]. Jenna L. Eppink, Richard W. Wlezien, Rudolph A. King, MeelanChoudhari, Influence of a Backward-Facing Step on Swept-Wing Boundary-Layer Transition, AIAA JOURNAL, 57(1), 2018, https://doi.org/10.2514/1.J057437

[14]. Saya Mochizuki, Gouji Yamada, Aerodynamic characteristics and flow field of delta wings with the canard, MATEC Web of Conferences, 145, 2018, https://doi.org/10.1051/matecconf/201814503010

[15]. Dinesh Aravinth, ParitoshShinde, Ajay Misra, Mahesh M. Sucheendran, HamedFaghanpourGanji, DYNAMIC AEROELASTICITY OF A TRAPEZOIDAL WING USING ENHANCED PISTON THEORY,2018, DOI: 10.2514/6.2018-1443