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Research Article

ACTIVE AEROELASTIC CONTROL PERFORMANCE AT HIGH SUBSONIC SPEEDS

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ABSTRACT

The primary purpose of control surfaces is to change the effective camber of an aerofoil and the lift coefficient can be modified by deflecting it. On an airplane design, the control surface sizing is an important issue that enhances the maneuvering capability of any aircraft in flight. It is well known that the loss of control happens in a specific speed range of an airplane and the control effectiveness decreases in proportion to the incremental velocity. Hence, the efficiency of the control surface is an important parameter for enhancing the flight safety against different aeroelastic anomalies. The leading edge control deflection at high subsonic speeds of an airplane is a novel methodology to reduce the control reversal problem by optimizing the elastic wing twist. The aerodynamic forces and the resulting aeroelastic influences caused by the leading edge controls are focused in the present article. The wing with a leading edge control surface is designed, and its effects on aerodynamic and structural characteristics are found by using fully coupled Computational Fluid Dynamics (CFD)/ Computational Structural Dynamics (CSD) solver. The multi-surface unconventional airplane control is implemented to overcome the static aero elastic instabilities competently.

Keywords: Aero Elasticity, Control Effectiveness, Active Controls, Reversal, CFD.

INTRODUCTION

Airplane structures are not entirely inelastic and structural deformation brings changes on aerodynamic forces due to rise of aeroelastic phenomena. The additional aerodynamic force makes the structure to deform more which leads to produce higher aerodynamic forces in a feedback sequential approach. The condition of equilibrium is attained, or diverges unfortunately when the aerodynamic forces happen to be greater than structural damping forces. The science of aeroelasticity is the mutual interaction among the inertial, structural and aerodynamic forces. The mixture of these forces causes an airplane or wing structure to become statically and dynamically unstable. Further the aeroelasticity is classified in to static and dynamic aeroelasticity. The interaction among aerodynamic and elastic forces on an elastic structure is called static aeroelasticity. And the interactions among elastic, aerodynamic and inertial forces are called dynamic aeroelasticity.

In an airplane, two significant static aeroelastic problems are occurring during cruising flight. Divergence takes place as the elastic twist of the wing suddenly increases against the torsional stiffness and it becomes difficult to compute theoretically.The functionality of leading and trailing edge control surfaces get reversedbecause of the control reversal arises merely in the wing structure through ailerons (e.g. the direction of rolling moment related with a given aileron moment is reversed).

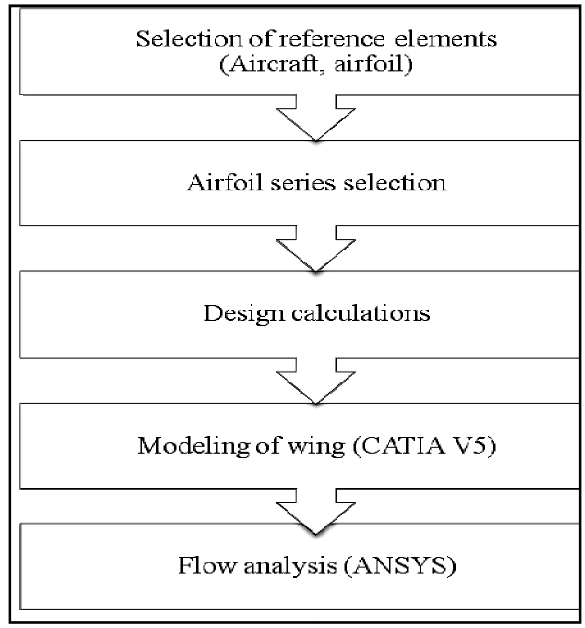
The combination of elastic, aerodynamic and inertial forcesacts on a structural member obvious to an airstream, have a significant influence on fluid structure interactions. Some of these phenomena are associated with high risk and indications to structural breakdown. A regular analysis is needed to reach an adverse effect on the controllability of the aircraft. The reversal speed is nothing but an unexpected response of the airplane gives the impression throughcontrol surfaces deflectionaway from a critical speed. Because of insufficient torsional stiffness of the wing, theairflow maybe huge enough that the force produced by the ailerons twists the wingitself counteracting the conventional effect of the control input. The aeroelastic interfaces determine airplane loads and influence flight performance in four primary areas. They are wingand tail surface lift re-distribution that changes external loads from initial loadscalculated on rigid surfaces. The stability derivatives through lift effectiveness, disturbs static and dynamic control features of flight such as aircraft trim and dynamic response. Control effectiveness, including aileron reversal that limits maneuverability. By coupling advanced Computational Fluid Dynamics (CFD) tools & Computational Structural Dynamics (CSD) tools, a moreaccurate portrayal of the nonlinearities of the flow and the aeroelastic effects of thewing can be considered.The question of controlling nonlinear aeroelastic responses of a prototypical wing section with structural nonlinearity using leading and trailing-edge control surfaces is described[1]. The investigation of the flow field[2] over a wing model at Reynolds numbers ranging from 250 to 2000 using Particle Image Velocimetry (PIV) method, and related with the flow obtained by three-dimensional time-dependent Navier-Stokes simulations is refined. The vortex control concept for slender and nonslender delta wing is detailedin depth in several articles in the past[3]. The occurrence and relative importance of the flow control include vortex formation, instabilities and break down. The flow separation and reattachment also plays an important role in the effectiveness of the control surface.

Recently, the impact of comb-like leading edge of barn owl wing on the flow field and aerodynamic performance by time resolved force measurement and Particle-Image Velocimetry (PIV) method is analysed[4]. The control efficiency[5] of a series of leading-edge vortex flaps for a nonslender delta wing at a moderate Reynolds number is projected. The flow development over delta wings is highly complicated since the interaction of the angle of attack with the delta wing geometry leads to the appearance of a pair of well organized counter-rotating leading-edge vertical structures[6]. The common incentive is the improvements of aircraft performance and stability by the intentional use of aeroelasticeffects[8]. The purpose of active separation control to improve the aerodynamic enactment is well described by many aeroelasticians[10]. Such articles describe more about the control laws thatare derived by the kinetic aerodynamic energy concept[11]. The leading edge control surface and the trailing edge control surface will be made more operative from this concept. The flutter suppression can be controlled by suppression of two flutter modes which increases the dynamic pressure without damaging the design model[13]. To improve the design of aircraft wing structure uncertainty problem is taken in to account at a specified altitude and improve effectiveness of the control surface. The entire model gets damaged if the weight is reduced to increase the aerodynamic performance. With the intention of reduced weight of the model stiffness and strength of the model is also gets reduced. From the above conception, it is taken in to account to improve the aerodynamic performance without increasing the weight. The effectiveness of the leading edge control surface and the control motions are unspecified at high subsonic speed is to be analyzed. It benefits to realize the use of present numerical solution techniques and experimental methods applied in the field of aeroelasticity.

METHODOLOGY

The presentarticle focuses on designing of 3D wing with leading edge control surface in CATIA V5 and analyzed with the help of ANSYS workbench. ANSYS offers a complete collection of engineering simulation solution sets providing access to virtually any field of engineering simulation that a design process requires.

STEPS INVOLVED IN AIRCRAFTMODELLING:



SELECTION OF AIRPLANE WING MODEL:

The **Airbus A380** is a double-deck, wide-body, four-engined jet airliner. The aircraft A380-800's original configuration carried 555 passengers in a three class configuration or 853 passengers in a single class economy configuration. The cruising flight segment is selected for analyzing a aircraft wing reversal problem. The common wing design approach sacrifices fuel efficiency on this model.

S.NO	parameters		Dimensions
1.	Length		72.73m
2.	Wing Span		79.75m
3.	Wing Area		$845m^2$
4.	Height		24.45m
5.	Empty Weight		276,800kg
6.	Max. Take-Off Weight		575,000kg
7.	Cruising Speed		M= 0.85
8.	Range		15,700km
9.	Service Ceiling		13136m
10.	Engines		4 × GP7270
11.	Thrust		340kN each
12.	Aspect ratio		7.5
13.	Wing sweep		33.5^0

AIRFOIL SELECTION:

Selection of Airfoil depends on thickness, lift co-efficient, drag co-efficient and length of the chord. Performance mainly depends on lift and drag co-efficient.

- selected airfoil: NACA 0012
- -% camber
- 12 -maximum thickness, here 0.12c

MATERIAL SELECTION:

Aluminum 7075 T6 material is selected for light weight and high strength.

DESIGN FORMULATION:

Aspect Ratio:

Aspect Ratio is defined as the ratio of wing span to the surface area of wing.

$$AR = \frac{b^2}{s} = \frac{b}{C_{avg}} \qquad (3.1)$$

Taper Ratio:

Taper ratio is defined as the ratio of tip chord to root chord of the wing.

$$\lambda = \frac{C_{tip}}{C_{root}} \qquad (3.2)$$

Root Chord:

$$C_{root} = \frac{2C_{avg}}{1+\lambda} \qquad (3.3)$$

Tip Chord:

$$C_{tip} = \lambda C_{root} \qquad (3.4)$$

Mean Aerodynamic Chord:

$$MAC = \left(\frac{2}{3}\right) C_{root} \frac{\left(1+\lambda+\lambda^2\right)}{\left(1+\lambda\right)} \qquad (3.5)$$

Location of MAC:

$$y_{mac} = \frac{b\left(1+2\lambda\right)}{6\left(1+\lambda\right)} \qquad (3.6)$$

MODELLING OF WING AND CONTROL SURFACE CONFIGURATION:

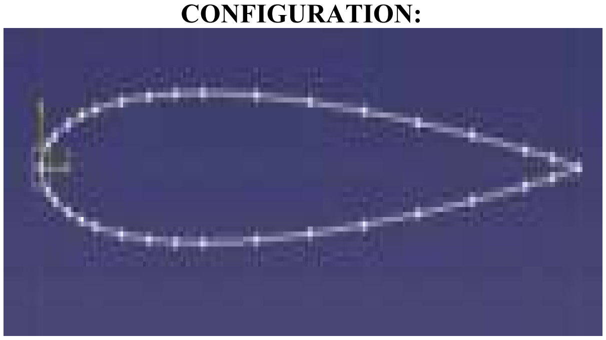


Figure 1: NACA 0012 Airfoil

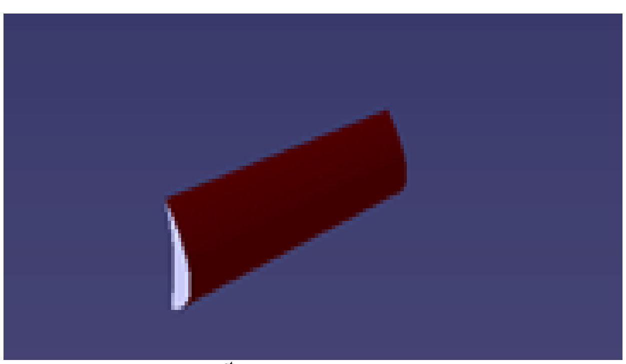


Figure 2: 1st Leading edge control surface

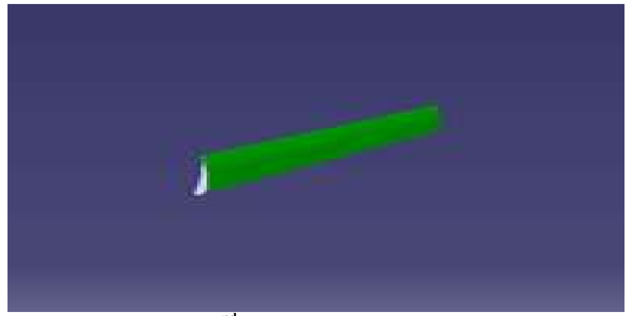


Figure 3: 2nd Leading edge control surface

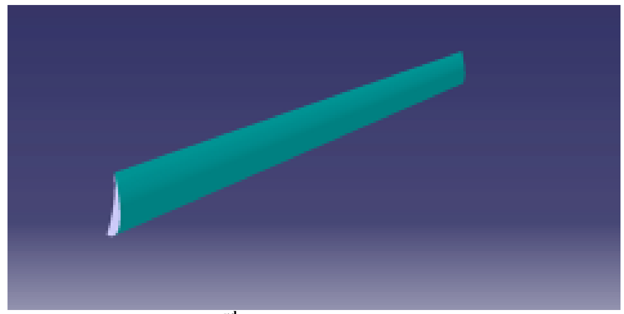


Figure 4: 3rd Leading edge control surface

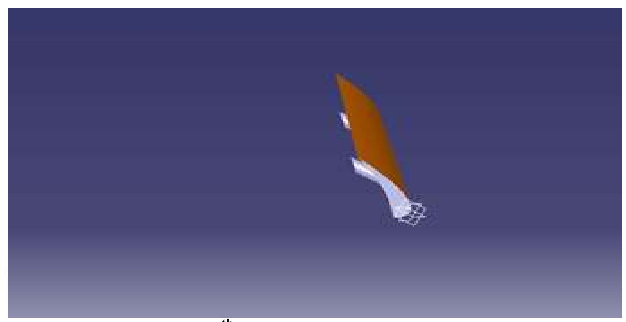


Figure.5. 4th Leading edge control surface

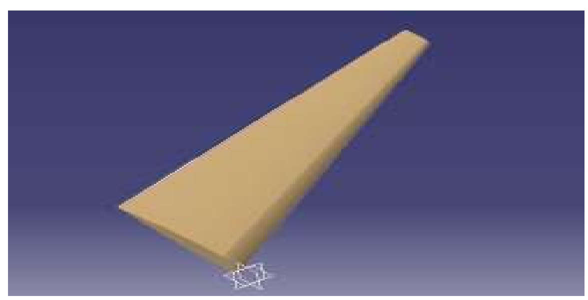


Figure 6: Wing without control surface

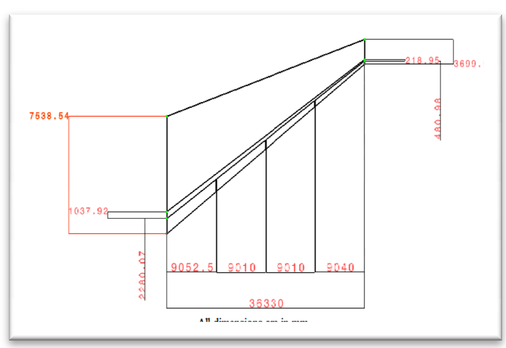


Figure 7: Dimensions of the wing model

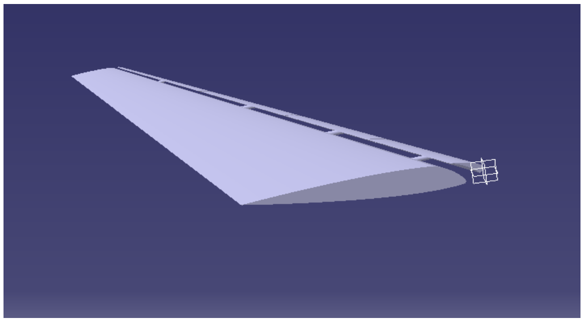


Figure 8: Wing with control surfaces

Pressure contour:

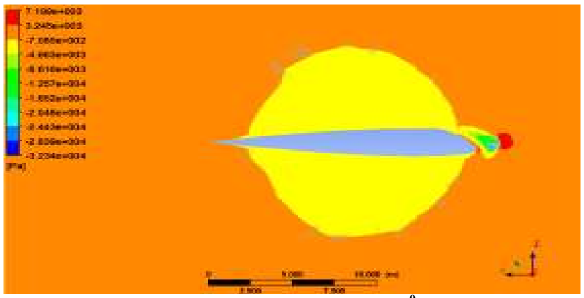


Figure 9: Dynamic pressure distribution at 1^0 control deflection

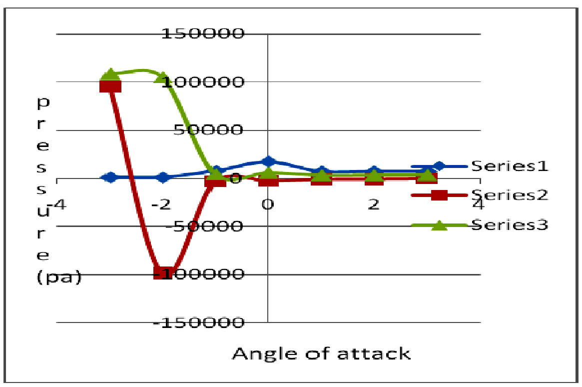


Figure 10: Angle of attack vs pressure

The dynamic pressure distribution over the wing at 1 degree deflection of the control surface is shown in the fig. 9. The pressure ditributions at various angle of attack at three different sections of the wing is shown in fig. 10. From the plots,it is observed that the maximum pressure region is located at the leading edge and the it decress at the mid section and again increases near the trailing edge.

Velocity contour:

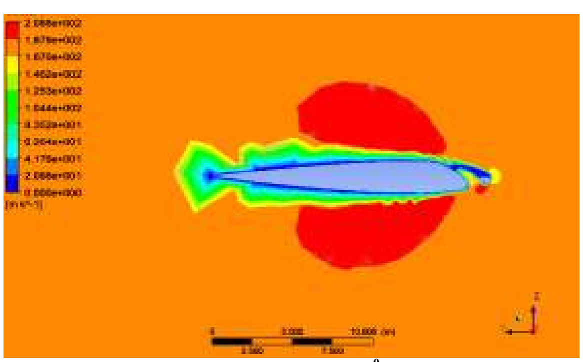


Figure 11: Velocity distributions at 1^0 control deflection

The velocity distribution over the wing at 1 degree deflection of the control surface is shown in the fig. 11. The velocity ditribution at various angle of attack at three different sections of the wing is shown in fig. 12. From the plots,it is observed that the maximum velocity falls at the mid section and decreases at the trailing edge.

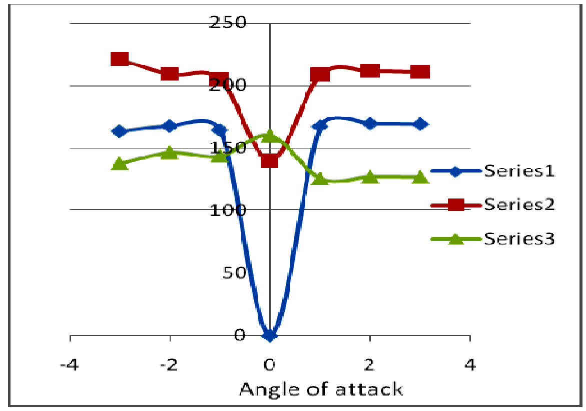


Figure 12: Angle of attack vs velocity

The airfoil selected for the design of the wing is shown in fig. 1. There are four leading edge control surfaces is designed on the wing and each of the control surface is shown in fig. 2, 3,4,5. And finally the full dimension of the wing is shown in fig. 7. The wing is designed using CATIA tool is shown in fig. 8 is used for the analysis process.

Comparison of coefficient of pressure:

S.NO	Angle of attack	Max.Cp	Min.Cp
1	0	0.9534	-1.4248
2	1	0.9853	-1.5641
3	2	1.0003	1.5423
4	3	0.9544	-1.6618
5	-1	0.9744	-1.4426
6	-2	0.9743	-1.3659
7	-3	0.9631	-1.2564

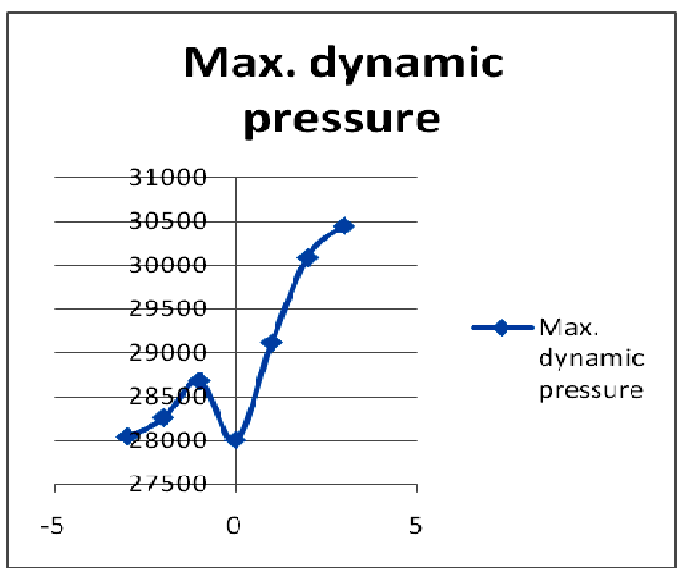


Figure 13: AOA Vs maximum Dynamic pressure

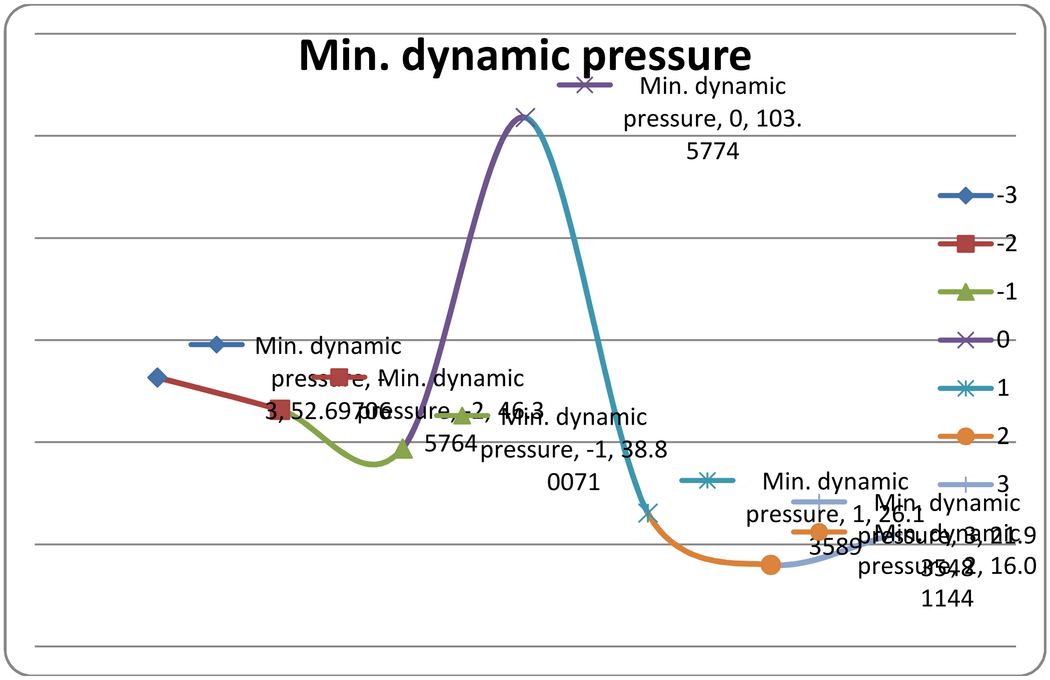


Figure 14: Angle of attack vs minimum dynamic pressure

As the deflection of the control surface increases dynamic pressure also increases as shown in the fig. 13. Similarly, minimum dynamic pressure also increases as the deflection increases that is shown in the fig.14.

Angle of attack	Coefficient of lift	Coefficient of drag
0	1.30504	0.15720
1	1.28446	0.15579
2	1.27586	0.15111
3	1.27274	0.15399
-1	1.31271	0.15579
-2	1.32537	0.15860
-3	1.32731	0.15961

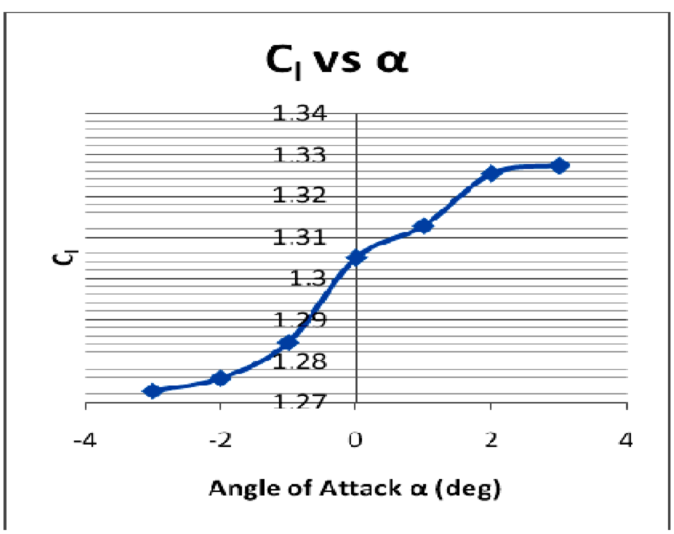


Figure 15: Angle of attack vs coefficient of lift and drag

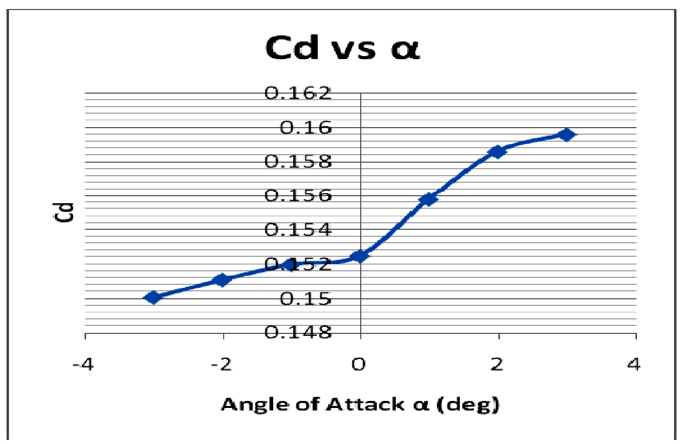


Figure 16: Angle of attack Vs Coefficient of lift and drag

From the above graphical representation it is identified that as the angle of attack increases coefficient of lift as well as the drag increases till the stall limits.

CONCLUSION

The literature review presented in the introduction part of the articledescribesthe significance ofstatic aeroelastic phenomena and control effectiveness. Among the various methods used to achieve better control effectiveness, Multisurface control strategy is cost effective and simple one to introduce in the existing systems. Once the total bending and torsion coupling is identified the mathematical model of an airplane wing with leading edge control surface combination can be analyzed using FEA tools. The selection of suitable airfoil, wing structural material and other parameters of the airplane wingareassumed from the existing successful designs. The CFD behavior of the modeled wing structure is analyzed using

ANSYS workbench. Then, the dynamic pressure is computed for different anglescontrol deflections by keeping the wing at zero incidence and concluded that as the dynamic pressure increases the lift increases.This incremental lift can be utilized to control the total forces and moments acting on the wing structure through novel control systems design.

REFERENCES

1. Sushma Gujjula, Sahjendra N. Singh, WoosoonYim, Adaptive and neural control of a wing section using leading- and trailing-edge surfaces, Elsevier, Aerospace Science and Technology, 2005, pp. 161–171.
2. Yossef Elimelech, Dmitry Kolomenskiy, Stuart B.Dalziel, H.K.Moffattc, Evolution of the leading-edge vortex over an accelerating rotating wing, Elsevier, Procedia IUTAM 7, 2013, pp. 233 – 242.
3. Gursul, Z.Wang, E.Vardaki, Review of flow control mechanisms of leading-edge vortices, Progress in Aerospace Sciences 43, 2007, pp. 246–270.
4. Andrea Winzen, Benedikt Roidl, Stephan Klän, Michael Klaas, Wolfgang Schröde, Particle-Image Velocimetry and Force Measurements of Leading-EdgeSerrations on Owl-Based Wing Models,Journal of Bionic Engineering 11, 2014, pp. 423–438.
5. Jinsheng Cai ,Shucheng Pan, Wenfeng Li, Zhengke Zhang,Numerical and experimental investigations of a nonslender delta wing with leading-edge vortex flap, Elsevier, Computers & Fluids 99, 2014, pp. 1–17.
6. Marilena Kyriakou, Dimitrios Missirlis, Kyros Yakinthos, Numerical modeling of the vortex breakdown phenomenon on a delta wing with trailing-edge jet-flap, Elsevier.,International Journal of Heat and Fluid Flow 3, 2010, pp. 1087–1095.
7. Ira D. Jacobson and Maris Lapinst., Application of Active Controls Technology toAircraft Ride Smoothing, August 1977, Vol. 14, No. 8.
8. Johannes Schweiger, Johann Krammer, Active AeroelasticAircraftand Its Impact On Structure And Flight Control Systems Design,ADP010474 thru ADP010498, Structural Aspects of Flexible Aircraft Control, 1998.
9. Jeffry Block and Heather Gilliatt, Active Control Of An Aeroelastic Structure, AIAA Meeting Papers on Disc, A9715114, 1997, AIAA Paper 97-0016.
10. Ralf Petz, Wolfgang Nitsche, Active Control Of Separation On Two And ThreeDimensional High-Lift Configurations, ICAS, 2006.
11. Nissim E, Recent Advances In Aerodynamic Energy Concept For Flutter Suppression And Gust Alleviation Using Active Controls, NASA TN-D-8519, 1987.
12. LaTunia Pack Melton and Chung-Sheng Yao, Active Control of Separation from the Flap of a Supercritical Airfoil, NASA Langley Research Center, Hampton, VA 23681.
13. Waszak MR, Flutter SuppressionFor The Active Flexible Wing Control System Design And Experimental Validation,AIAA-92-2097-CP, 1992.
14. Sousa VC., Enhanced aeroelastic energy harvesting by exploiting combined nonlinearities: theory and experiment, Smart Materials and Structures, 2011.
15. Bisplinghoff RL, Ashley H. and Halfman H, Aeroelasticity. Dover Science, 1996.
16. Collar AR., The first fifty years of aeroelasticity, Aerospace.2 5, 1978, 12–20.
17. Nissim E and Lottatit I, Active Controls for Flutter Suppression andGust Alleviation in Supersonic Aircraft, Vol. 3, No. 4, July-August 1980.
18. Hodges DH. and Pierce A., Introduction to Structural Dynamics and Aeroelasticity, Cambridge, 2002.
19. Dimitriadis G, University of Liège, Aeroelasticity: Lecture 6: Flight testing.
20. Bruce Ralphin Rose J and Jinu GR, Influence of aeroelastic control reversal problem in the airplane lateral stability modes, ProcIMechE Part G: J Aerospace Engineering, SAGE Publications, 2015, Vol.229, No. 3, pp. 517 – 533.
21. Dowell EH., A Modern Course on Aeroelasticity.
22. Fung YC., An Introduction to the Theory of Aeroelasticity. Dover, 1994.
23. Hodges DH. and Pierce, A., Introduction to Structural Dynamics and Aeroelasticity, Cambridge, 2002.
24. Wright JR. and Cooper JE., Introduction to Aircraft Aeroelasticity and Loads, Wiley 2007.
25. Sasongko RA, Gunawan L, Akbar M, The Development of 3 DoF Wing Section Model for Aeroelastic and Active Control Wind Tunnel Experimental Tests, ICAS, 2010
26. Lapins M., Application of Active Controls Technology to Aircraft Ride Smoothing Systems, Ph.D. Dissertation, University of Virginia, May 1975.

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