

Influence of Control Surfaces in Aircraft Wing Control Reversal Problems-FEA and CFD Analysis

N. Rajamurugu¹, S. Yaknesh² and J. Anbarasi³

*¹Department of Mechanical Engineering,
Apollo Engineering College, Chennai.*

*²Department of Mechanical Engineering,
St. Joseph's Institute of Technology, Chennai.*

*³Department of Aeronautical Engineering,
KCG institute of Technology, Chennai.*

Abstract

In the present work, 3-D wing with control surfaces has been taken for investigating the problems of static aero elasticity – in particular control reversal problem. To give an insight in to these problem, a 2D airfoil with leading edge slat is analyzed by using GAMBIT and FLUENT. Later a 3-D swept back wing with control surfaces, designed and investigated using CFD/MSE Nastran/Patran is at the velocity of 210 m/s for 15 degree deflection if ailerons. To avoid the wing twist caused by aileron deflection, flap has been deflected in order to create a negative twist so that aileron swing can counteract by flap. This has been validated by carrying out the stress analysis of the 3-d wing. Computational analysis also carried out to investigate the effect of sweep as well as the control surfaces at the control reversal speed. This shows that to get the rolling power at the reversal speed the control surface which is located near to the root will alter the pressure distribution and hence aileron reversal can be offset.

Keywords: Control reversal-sweptback wing-low speed analysis-CFD.

1. Introduction

Fluid structure interaction will lead to physical phenomena where inertial, elastic and aerodynamic forces, acting on a structural member exposed to an airstream, have a

significant influence. Some of these phenomena are associated with high risk and can lead to structural failure. A reliable analysis of these phenomena is therefore needed to elaborate the wing design and take decisions. Aileron reversal is when the control surfaces reach an adverse effect on the controllability of the aircraft. Beyond a critical speed, called "reversal speed", an unexpected response of the aircraft appears with control surfaces deflection. Due to an insufficient torsional stiffness of the wing, the airflow may be great enough that the force generated by the ailerons twists the wing itself counteracting the intended effect of the control input. Aeroelastic interactions determine airplane loads and influence flight performance in four primary areas: Wing and tail surface lift redistribution that change external loads from preliminary loads computed on rigid surfaces; Stability derivatives, including lift effectiveness, that affects flight static and dynamic control features such as aircraft trim and dynamic response; Control effectiveness, including aileron reversal, that limits maneuverability; Aircraft structural dynamic response to atmospheric turbulence and buffeting, as well as structural stability, in particular flutter. By coupling advanced computational fluid dynamics (CFD) tools and computational structural dynamics (CSD) tools, a more accurate portrayal of the nonlinearities of the flow and the aeroelastic effects of the wing can be captured. Mostafa .S and A. ElsayedRamin[1], Accurate Stick Model Development for Static Analysis of Complex Aircraft Wing-Box Structures AIAA 2009. This Paper investigated the process of generating a wing stick model is investigated. Ales Kratochvíl in his journal [2] "Aeroelasticity analysis of wing UL-39" Journal of aircraft 2003. The computation of modal and flutter characteristic, investigating ailerons effectiveness and determines torsion divergence critical velocity at right half-wing of the aircraft UL-39. Christian Reschke and, Thiemo Kier, presented the paper "An Integrated Model for Aeroelastic Simulation of large flexible Aircraft using MSC.Nastran" [3] Robotics and mechatronics, 2004. Newer computational methods can now incorporate the structural flexibility of the wing. The inclusion of flexibility allows for a better correlation between computational and experimental data [5].

2. Project Scope and Analysis

2.1 Scope:

Study of control motion of wing and static aeroelastic existing problem due to control motion. Study of structural response of aeroelastic high aspect ratio swept wing at reversal speed. Study of existence solved technique for aeroelastic instability. Computing the force exerted on aileron due dynamic pressure of air when aileron is deflected by theoretical relation .Computational design of swept wing with multiple control surfaces in high subsonic flow. Computation analysis of wing with control surface deflection when pressure force acting on aileron shaded area.

2.2 WingModelling

AerofoilNACA 64-210; Span-60m;Sweep angle-30 Deg;Aspect ratio-8.7;Sweep at c/4 point0-25.51 deg; Taper ratio-0.4;Root chord-10m;Tip chord-4m;Max. thickness of airfoil-10% of chord;Aileron location-6m from tip; Flap location-8.7m from root;Mean aerodynamic chord-7.43 m; Aileron span-7.5m; Flap span-3.3m

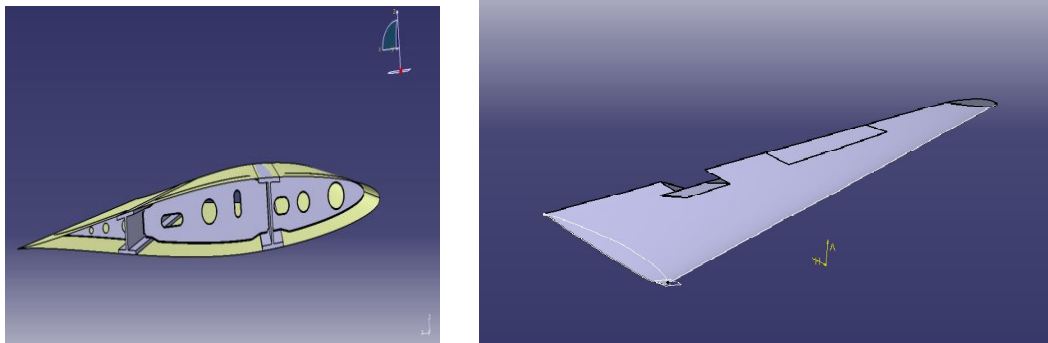


Fig. 1: wing model with ribs and spars, twisted wing assembly

S. No	Velocity m/s	Displacement (mm)	Max Stress MPa	Max Strain MPa
1	80	933	91.24	1.24
2	90	1057	102.66	1.39
3	100	1175	114.05	1.55

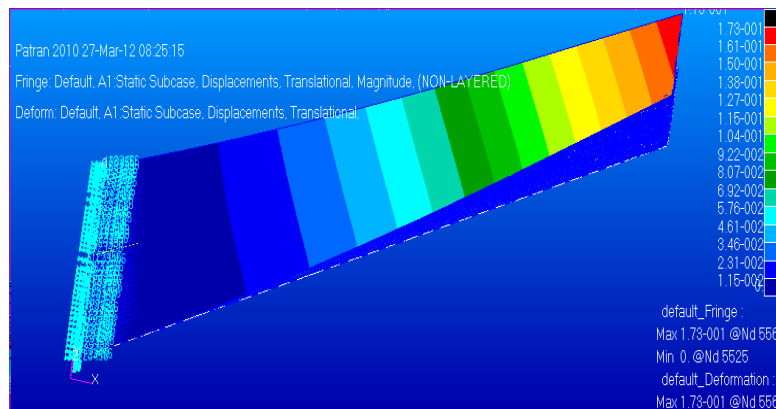


Fig. 2: Deformation of wing at 90m/s at Load 2287.5N (6 flap deflection)Table.1Values for 6 deg deflection of aileron.

Table 2: Twist variation at tip.

S. No	Velocity(m/s)	Twist at tip due to aileron deflection(deg)	Twist at tip due to flap deflection(deg)
1	90	2.8	2.1
2	110	3.04	2.2
3	150	3.3	2.5
4	180	3.7	2.9

Analysis of wing with control surface is done by varying angle of attack and velocity. Boundary condition is pressure acting on aileron shaded area and span wise lift distribution on the elastic axis. Incremental lift due to aileron deflection are calculated by theoretical calculation. By having this boundary condition computation model is analyzed for 3 deg, 6 deg, 9 deg and 15 deg. At velocity 240m/s and 15 deg deflection of aileron have Max displacement at tip is 3.078 mm. From the displacement, stress and strain plot. Max Principle stress max principle strain displacement at tip is increase with incremental of aileron deflection angle and incremental of velocity. Aileron produces torsion twist which can be counteracting by the control surface located near the wing.

3. CFD Analysis

In this study, the half-symmetric model was imported into GAMBIT as a STEP file and cleaned up using the “Heal Geometry” option during the import itself. To improve geometric connectivity and duplicate-face issues, the geometry was cleaned up and patched using “Clean Up Tools

After cleanup, a brick was created around the aircraft as a part of defining a flow volume, aligned such that the symmetry plane of the aircraft and the symmetry plane of the brick coincided and are stitched together to form a single virtual face. The brick’s high-level geometry (volume) is deleted leaving behind its low-level geometry (faces) and subsequently stitched to form a virtual flow volume.

Table 3: boundary conditions.

AILERON	WALL
FARFEILD	PRESSURE FAR FIELD
SYMETTRY	SYMMETRY
WING	WALL

If the mesh characteristics and growth are not controlled, then highly skewed elements might be formed that can adversely affect numerical computations for the resultant mesh. Hence to tackle such problems, an option called “Size Functions” that can be used to specify the rate at which volume mesh elements change in size in

proximity to a specified boundary. For this reason, two types of size functions were created and attached to control the mesh sizes in the regions adjacent to the airplane geometry surfaces.

4. Results and Discussions

Case I: comparison plots for the Ideal wing between computational and wind tunnel results.

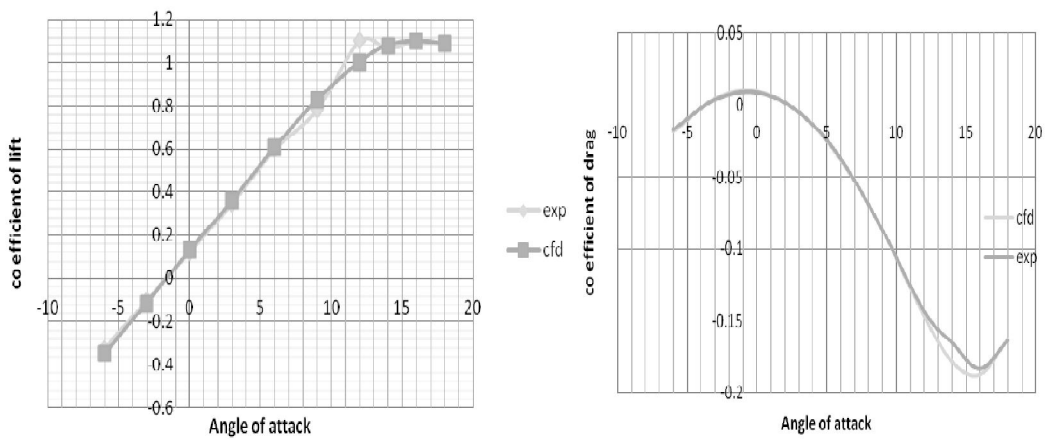


Fig. 6: Comparison plot of C_l vs. α without any control surface deflection Figure 9.34 comparison plot of C_d vs. α without any control surface deflection.

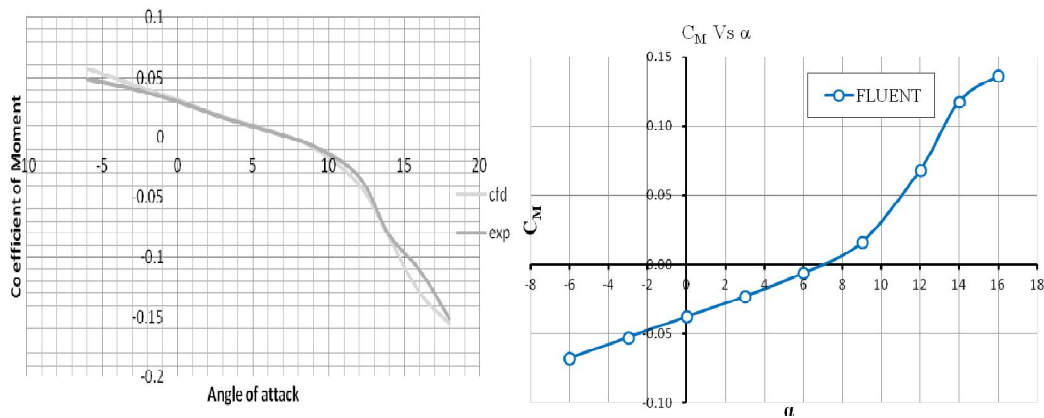


Fig. 8: Comparison plot for C_m vs. Angle of attack, without any control surface deflection Fig9., plot of C_m vs. α for the aileron deflection for 3 degrees.

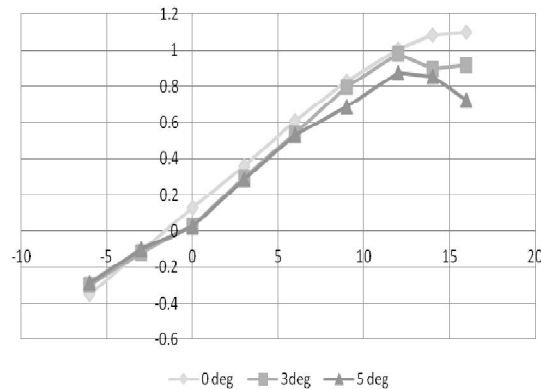


Fig. 10: Comparative C_l vs. α plots for various angle of aileron deflections.

From the above test data, it is very clear that with increase in sweep angle, there is a decrease in the lift generated and so is the case with the lift coefficient. Decrease in drag produced as well which is also apparently the same trend shown by the drag coefficient. This clearly validates the findings from the CFD analysis which have been corroborated hence conclude deformation at tip is high, Stress and strain near the root is high, At velocity 210m/s for 15 deg deflection of aileron have Max displacement at tip this will have the adverse effect control motion if the aileron deflection will cause wing twist at tip, Tip will stall before root at that time aileron is ineffective to create the rolling power. Flap deflection created the negative twist so that aileron twist can be counteracting by flap. To get rolling power at reversal speed, we want to operate control surface which is located near the root.

References

- [1] Mostafa .S and A. ElsayedRamin, Accurate Stick Model Development for Static Analysis of Complex Aircraft Wing-Box Structures, AIAA ,2009
- [2] Ales Kratochvíl, “Aeroelasticity analysis of wing UL-39”, Journal of aircraft, 2003.
- [3] ChristianReschke and ,Thiemo Kier, “An Integrated Model for Aeroelastic Simulation of large flexible Aircraft usingMSC.Nastran”, Robotics and mechatronics,2004.
- [4] ShaoKe, Wu Zhigang and Yang Chao “Analysis and Flexible Structural Modelling for Oscillating Wing Utilizing Aeroelasticity” Chinese journal of aeronautics 21 (2008)402-410.
- [5] Daniella E. Raveh, “Computational-fluid-dynamics-based aeroelastic analysis and structural design optimization—a researcher’s perspective”, AIAA 98-2421.

- [6] Ajaj, M.I. Friswell and W.G. Dettmer, "Modelling of an Adaptive Torsion Wing Structure R.M.", AIAA 2011-1883.
- [7] J.-S. Baea, D.J Inmana and I. Leeb , " Effects of structural nonlinearity on subsonic aeroelastic characteristics of an aircraft wing with control surface", *Journal of Fluids and structures* 19(2004) 747-763.
- [8] WeiweiZhang and ZhengyinYe , "Effect of control surface on airfoil flutter in transonic flow" *Acta Astronautical* 66 (2010) 999-1007.

