Aileron Effectiveness in the Presence of Aeroelastic Deformations

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Abstract

This study pursues medium-range, transonic transport aircraft configuration which had a cruise Mach of 0.82 and flight mission that is similar to that of Airbus A340-300. In this article, focus on more than one field of interest in aeronautics is combined with each other. The aircraft flying at Mach about 0.82 and the corresponding deformations are taken into account. This deformation produces disturbance in the flow field behind the surface where it occurs. The disturbed flow field affects the performance of control surface and its effectiveness. The cantilever wing with an aileron control surface is designed, and its effects on aerodynamic and structural characteristics are computed by using partially coupled Fluid Structure Interaction solver. From the aeroelastic fluid-structure interaction analysis results, flight dynamics characteristic of control surface effectiveness are computed. The effectiveness of a single aileron control surface in the absence of other control surfaces is used for validating the experimental results.

Keywords - *Aero-elastic Deformation, Aileron Effectiveness, CFD/CSD, FSI, Partially Coupling*.

I. INTRODUCTION

An important area of research is in the field of aeroelasticity. There is no specific solution for described problem because uncertainty and unsteady condition are very high and totally non-linear in nature. The history of commercial aircraft shows that the aircraft industry has pursued a cantilever wing aircraft configuration. Many advanced technologies have been applied to make the current cantilever design more and more efficient. The modern era of commercialized air travel, the industry has been dominated by a cantilever-wing aircraft configuration. This cantilever-wing is used in every aircraft application from fighter jets to cargo planes. The modern aircraft has several control surfaces on its cantilever wing. If an aircraft is flying at its cruise altitude the effect of control surfaces more important during an uncertainty conditions.

The main objective of the work is to find an effectiveness of an aileron control surface in the presence of aeroelastic deformation, which is occurs due to the flow field around it. The Partially coupled FSI solver is used to find an exact fluid interaction with structural component of an aircraft, mainly in lifting surface (wing). A.G.Striz.et.al (1994) [1] describes that to minimize the structural weight of a transport aircraft wing subject to stress while preventing any occurrence of aeroelastic instabilities in the flight envelope and optimizing roll effectiveness is achieved by the finite element based multidisciplinary optimization code ASTROS. Stefan Keye.et.al (2009) [2] assumed the aerodynamic loads into account of the structural deformations at cruising flight conditions. Ivan Malcevic.et.al (2002) [3] simulation of fluid and structure interaction with dynamic interfaces based on a Lagrangian flow formulation and finite element structural meshes. Shahyar Z.Pirzadeh.et.al (2000) [4] develops an adaptive unstructured grid refinement technique and successfully applied to several 3D inviscid flow test cases. In all cases accurate solutions have been generated efficiently. Scott A.Morton.et.al (1998) [5] develops an implicit time-accurate approach to aeroelastic simulation with attention to the issues of time accuracy, structural coupling, grid-deformation strategy, and geometric conservation.

Brian A.Robinson.et.al (1991) [6] describes that the modified CFL3D three-dimensional unsteady Euler/Navier-Stokes code for the aeroelastic analysis of wing. Marilyn J.Smith.et.al (2000) [7] evaluates that to identify mathematically suitable methods to transfer information between fluid and structural interface grids. Robert E.Bartels.et.al (2005) [8] develops that the mesh deformation scheme for a structured grid NS code.

A.K.Slone.et.al (2004) [9] describes the Dynamic FSI problems were involved by employing the unstructured meshes in three dimensional configurations. D.J.Mavriplis.et.al (1999) [10] develop complete geometry to drag polar analysis capability for 3D high-lift configurations. Z.Qin.et.al (2002) [11] develops that aeroelastic model to investigating the flutter and critical aeroelastic response in the compressible high subsonic flight speed. J.C.Newman.et.al (1999) [12] demonstrates that computationally efficient, high- fidelity, integrated static aeroelastic analysis procedure. J.S.Bae.et.al (2004) [13] investigates the nonlinear aeroelastic characteristics of an aircraft wing with a control surface. Z.Wang.et.al (2010) [14] presents a computational aeroelastic tool for nonlinear-aerodynamics / nonlinear-structure interaction. Ralf Mertins.et.al (2005) [15] presents the mesh generating strategy for wing-aileron configuration.

W.K.Londenberg.et.al (1993) [16] computes Navier-Stokes solutions about a supercritical airfoil with aileron deflection by using the CFL3D code coupled with various turbulence models. Among those, Baldwin-Barth turbulence model presented the best agreement with experimental pressures and sectional lift coefficients. J.Li.et.al (1999) [17] solves the Euler and Navier-Stokes equation for describing flow phenomena around a wing-aileron configuration was effectively done by using the grid generation technique which is combination of zonal grids and patched grids. Antony Jameson.et.al (2010) [18] wings were designed without the aid of modern high-fidelity simulation and multidisciplinary optimization tools. Kyung-Seok Kim.et.al (2010) [19] for several decades, aeroelastic analyses that take into account a geometric structural nonlinearity had been conducted on the rotor blades of helicopters.

Paul G.A.Cizmas.et.al (2010) [20] develops a multigrid parallel algorithm for a nonlinear aeroelastic analysis. Brian P.Danowsky.et.al (2010) [21] explores the flutter problem with various methods to reduce the computational time for uncertainty analysis. Florian Blanc.et.al (2010) [22] computes control surfaces aerodynamics with flexibility effects was presented.

II. PARAMETER SELECTION AND MODELING

A. Selection of Aircraft

A service range of 13,700 Km, Airbus A340-300[2] is custom made to meet the needs of the 300-seat long-range aircraft services and increased flight frequencies at lower costs. The cruise segment is selected for analysing an aircraft wing.

B. Selection of Airfoil

Selection of Airfoil depends on thickness, lift co-efficient, drag co-efficient and length of the chord. Aircraft performance mainly depends on lift and drag co-efficient. The co-efficient carried out wind tunnel data [23]. Among these factors NACA 64-209 is chosen for aircraft wing and NACA 0012 is chosen for aileron control surface that has no vibration at transonic speed. Absence of control surface vibration at cruise transonic speed is required to predict specific total deformation.

C. Material Selection

Among various material, Aluminum 7075 T6 [1] material is selected for this proposed problem which has light weight and high strength. The uniformity of material is ease to design and analysis.

Mathematical Modeling of the wing was designed with Spars, Ribs, and Stringers [24]. The three dimensional model of an aircraft wing and aileron control surface combination was designed with help of design calculations [25] and existing data [1], [2] and then was modeled by using CATIA V5 as shown in Fig 2.1. This design of a wing structure control surface configuration is more realistic case compared to the experimental rectangular wing and AGARD wing.

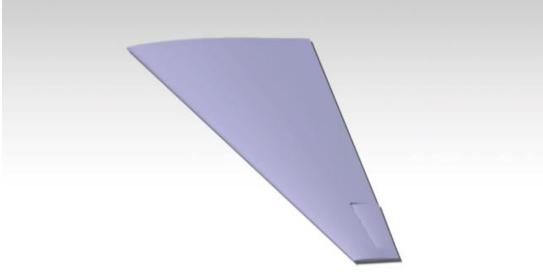

Figure 2.1 Wing-Aileron Configuration

III. NUMERICAL RESULT

A. Unstructured Grid

A fine tetrahedron grid generated on the both the control volume and wing model as show in the Fig 3.1 and Fig 3.2.

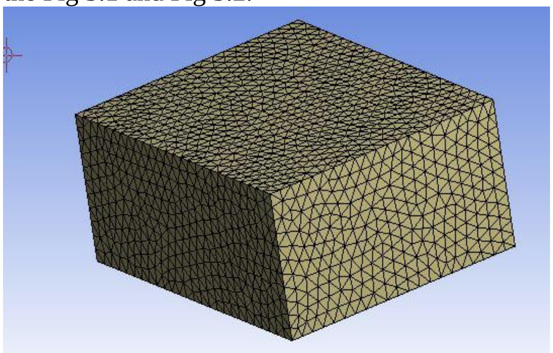

Figure 3.1 Control Volume Mesh

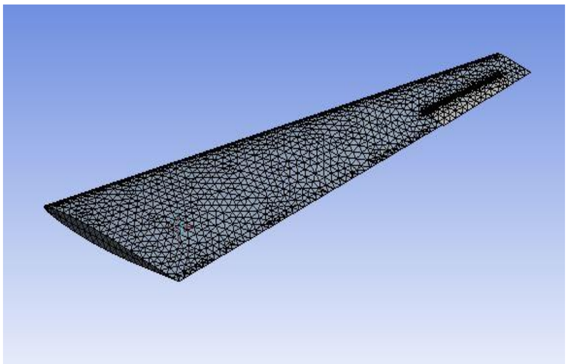

Figure 3.2 Wing-Aileron Grid View

The meshing statistics of the wing and control volume are given in the Table 3.1

Table 3.1 Mesh Statistics

S.No	Properties	Wing-Aileron Grid	Control Volume
1.	Element Type	Tetrahedron	Tetrahedron
2.	No. of Nodes	221884	2426950
3.	No. of Elements	133612	1342163

B. Boundary Conditions

The Control volume is kept at aircraft cruise altitude, the standard cruise altitude atmospheric conditions are given to the flow field analysis. The flow around a wing model considered as a turbulent flow. The turbulent kinetic energy (k) and specific dissipation rate (ω) shear stress transport 2-equation method is applied for the turbulent flow. The numerical value of the boundary conditions are given in the Table 3.2

Table 3.2 Boundary Conditions

S.No	Properties	Altitude at 11000 m
1.	Density	0.36408 kg/m^3
2.	Pressure	22622.78 Pa
3.	Temperature	216.15 K
4.	Dynamic Viscosity	0.0000142 kg/ms
5.	Speed of sound	294.9402 m/s
6.	Velocity	0.82 Mach

The root of the wing model is changed into a fixed support in structural analysis. The imported pressure load from the fluid flow solver is applied on the fluid solid interface faces. The imported pressure load is converted to the structural load which gives the deformation and other structural analysis results.

C. Analysis Methodology

The Partially coupled model means that the structural response lags behind the fluid flow field solution. This method treats the fluid and structure as two separate modules and updates the CFD and CSD variable separately in the fluid structure interfaces. The Fig 3.3 shows that partially coupled analysis first solves the fluid flow governing equation to obtain an air loads which are imported in a static structural analysis which solves structural governing equation to obtain structural results.

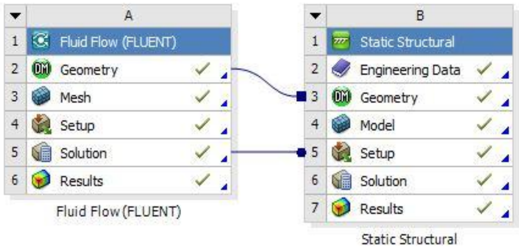

Figure 3.3 Partially Coupled Analysis in ANSYS

D. Fluid Flow Solution

The aileron control surface deflected by 3deg from -18 to +18 degree the lift and drag coefficient associated with control deflection to be plotted in a graph, Fig 3.4 and Fig 3.5 shows that the control deflection angle verses aerodynamic coefficient as lift and drag respectively.

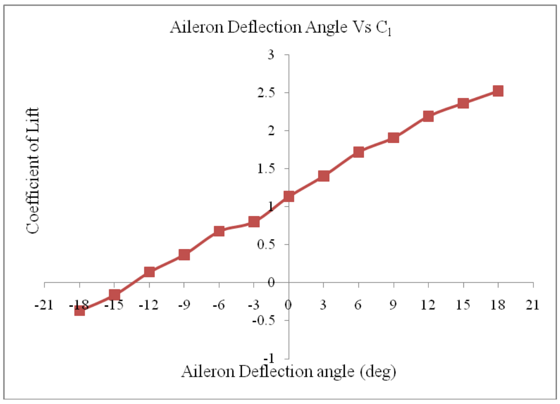

Figure 3.4 Coefficient of Lift and Drag Vs Aileron Deflection Angle

Fig 3.4 revels that increasing angle of deflection from negative to positive, coefficient of lift also increases which means that air loads acting on the structural component increases[26].

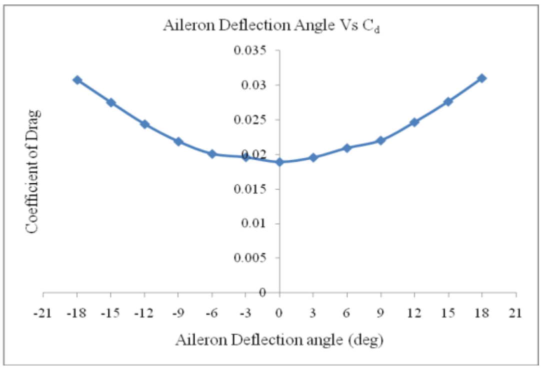

Figure 3.5 Coefficient of Drag Vs Aileron Deflection Angle

Fig 3.5 revels that increasing angle of deflection from negative to positive, coefficient of drag has almost in the range of 0.02 to 0.03. The drag has least values as compared to lift.

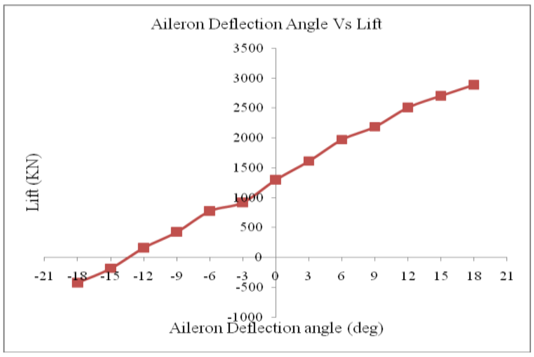

Figure 3.6 Lift Vs Aileron Deflection Angle.

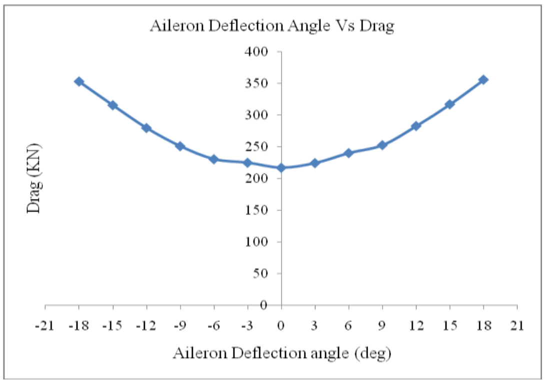

Figure 3.7 Drag Vs Aileron Deflection Angle.

The lift and drag are commonly called as airloads and their values are obtained from the fluid flow analysis results. These are load are varied with aileron angle of deflection which shown in Fig 3.6 and Fig 3.7. The plots are similar to that of coefficient of lift and drag.

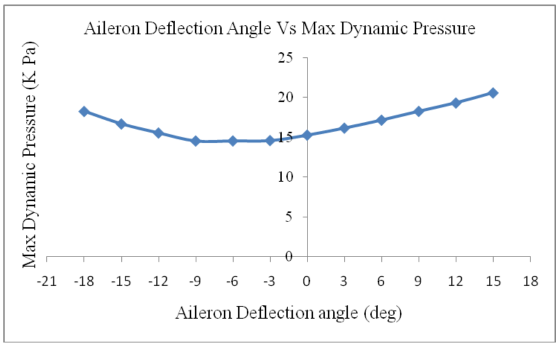

Figure 3.8 Maximum Dynamic Pressure Vs Aileron Deflection Angle.

The max dynamic pressure of the wing and Aileron control surface combination as shown in Fig 3.8 which shows that deflection of control surface is either positively increased or negatively increased the value of maximum dynamic pressure is increased which leads to the more loads on the wing surfaces.

E. Structural Analysis Output

The pressure loads are imported from each fluid flow analysis. The import pressure load is converted to the structural load which is acting on the surface of the wing and aileron. The Von-Mises Equivalent stress and Total Deformation values are obtained by solving structural governing equation.

The aileron control surface deflected in a direction either positive or negative the Total deformation increases from that of the initial non-deflected condition. The total deformation on the wing and control surface combination with chosen material is acceptable limit by comparing the results with literature [1].

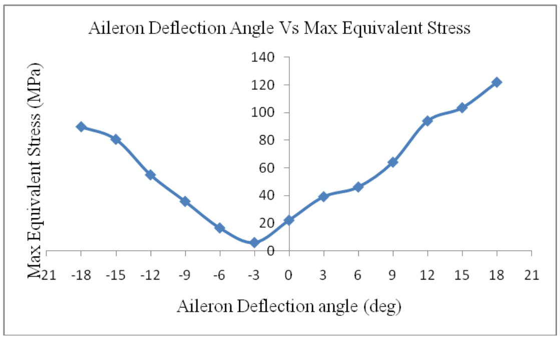

Figure 3.9 Max Equivalent Stress Vs Aileron Deflection Angle

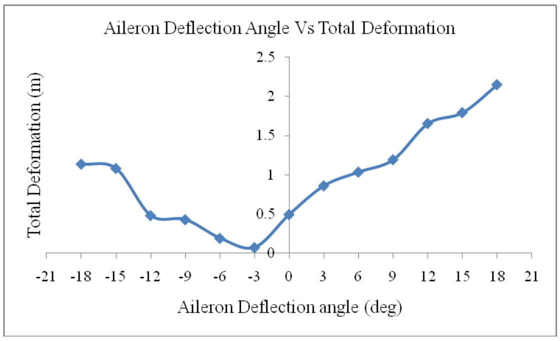

Figure 3.10 Total Deformation Stress Vs Aileron Deflection Angle

Aircraft at its cruising altitude flying at Mach number 0.82 shows that less structural deformation for chosen aluminum 7075-T6 material at low angles of deflection of aileron, after that it will be increased. Fig 3.9 and Fig 3.10 show that Equivalent maximum von-Mises stress and Total deformation increases as increasing the angle of deflection of the aileron control surface either in positive or negative respectively. The positive angle of deflection of the aileron control surface has more deformation compare to negative one.

IV. CONCLUSIONS

The partially coupled fluid structural interaction analysis of a wing and aileron control surface combination was done by using ANSYS workbench. By varying angle of aileron control surface, Air loads are evaluated. The chosen Aluminum 7075-T6 material offers less deformation in the considered flight envelope.

V. FUTURE WORK

For more accuracy, the fully coupled FSI analysis can be carried out. The results from analysis, aileron effectiveness in the presence of deformation will be evaluated. Fabricate a model with uniform Aluminum material will be taken into experiments. Experimental results obtained from the wind tunnel tests and compared to numerical results.

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