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CFD ANALYSIS OVER A SEAMLESS CONTACT TRAILING EDGE FLAP SYSTEM

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ABSTRACT: This project serves to develop a new flap design concept entitled “seamless contact trailing edge flap (SCTEF)” and analyze it on a regional airliner model. It covers a wide range of engineering work processes and due to the realistic nature and wide scope of the project, it can be made comparable to real life engineering projects, which engineers deal with in their course of work. CAD models are developed in CATIA V5 R19 software.

Computational Fluid Dynamics (CFD) study will be conducted to explore the effect of new flap concept entitled “seamless contact trailing edge flap (SCTEF)” on lift and drag of the regional airliner during takeoff. In this work ANSYS FLUENT 14.5 was used as Computational Fluid Dynamics (CFD) software. The working condition of simulation was considers at the aircraft takeoff just before the rotation speed ‘V_1’. Two configurations (i.e. wing with deflected flap & deflected seamless contact flap) were considered along with an unmodified (no flap deflection) wing as the baseline case. Comparison of lift and drag corresponding to these configurations with baseline configuration (retracted flaps) will be expected to show a definite trend in the results.

CFD analysis has shown that new flap design SCTEF concept improves lift and decreases drag which is nothing but more fuel efficient flights and low noise when taking off.

KEYWORDS: Flaps, Vortices, Computational Fluid Dynamics, ANSYS FLUENT, CATIA.

INTRODUCTION

The aircraft industry has been responding to the need for energy-efficient aircraft by redesigning airframes to be aerodynamically efficient, employing light-weight materials for aircraft structures and incorporating more efficient aircraft engines. Reducing airframe operational empty weight (OEW) using advanced composite materials is one of the major considerations for improving energy efficiency. A NASA study entitled “Elastically Shape Future Air Vehicle Concept” was conducted to examine new concepts that can enable active control of wing aero elasticity to achieve drag reduction. This study showed that highly flexible wing aerodynamic surfaces can be elastically shaped in-flight by active control of wing twist and vertical bending to improve aerodynamic efficiency through drag reduction during cruise and enhanced lift performance during take-off and landing. This theory shows that active aero elastic wing shaping control can have a potential drag reduction benefit. But Conventional flap and slat devices inherently generate drag as they increase lift. The study also shows that conventional flap and slat systems are not aerodynamically efficient for use in active aero elastic wing shaping control for drag reduction. A new flap concept, referred to as seamless trailing edge flap system (SCTEF) was developed to explore the effect on a regional airliner model.

TIP VORTICES

Vortices form because of the difference in pressure between the upper and lower surfaces of a wing that is operating at a positive lift. Since pressure is a continuous function, the pressures must become equal at the tips. The tendency is for particles of air to move from the lower wing surface around the tip to the upper surface (from the region of high pressure to the region of low pressure) so that the pressure becomes equal above and below the wing. The same theory can be assumed for a deflected flap as it has tips on either side. So there will be a tendency for air particles to generate tip vortices.

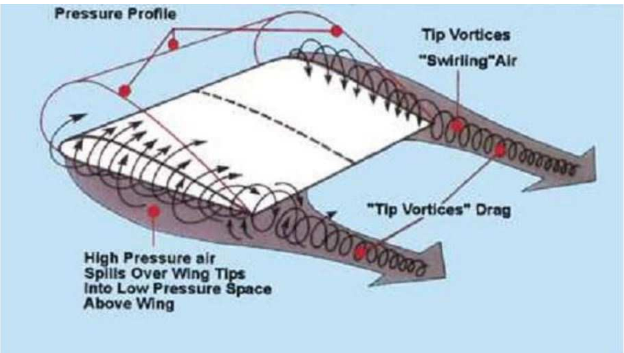


Fig.1: Origin of tip vortices

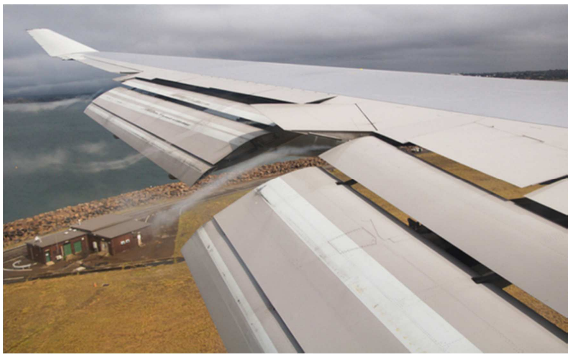


Fig.2: conventional flaps and gap between them

AIRCRAFT MODELS

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French Aeronautics company Dassault Systems. Written in the C++ programming language.

Airfoil was imported from “UIUC Airfoil Data site[12]”named “NASA/LANGLEY MS (1)-0317” and other design parameters are obtained from regional aircraft preliminary design cases. By these design drivers CAD models are developed in CATIA software. The basic aircraft model shown in Fig.3

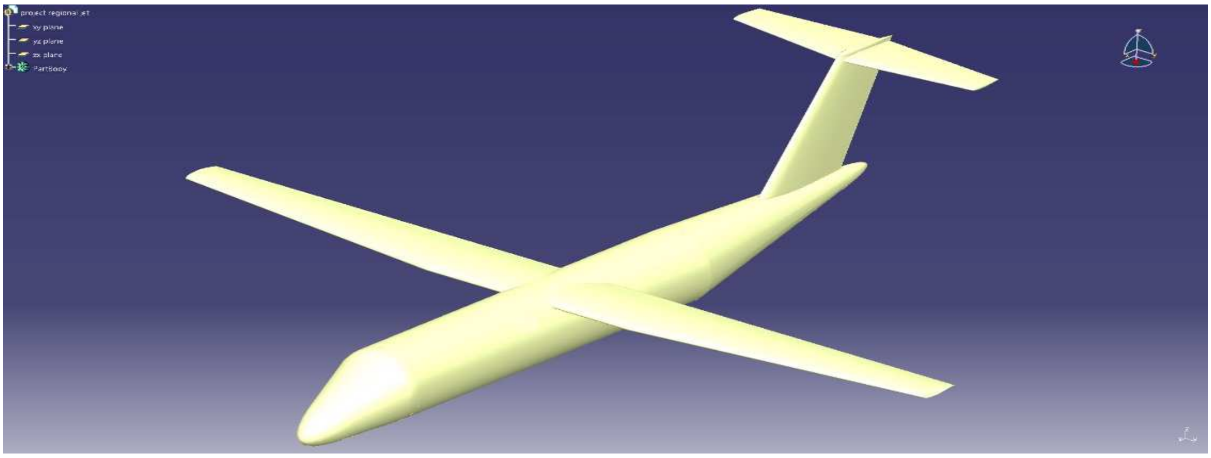


Fig.3: Basic Aircraft model in CATIA software

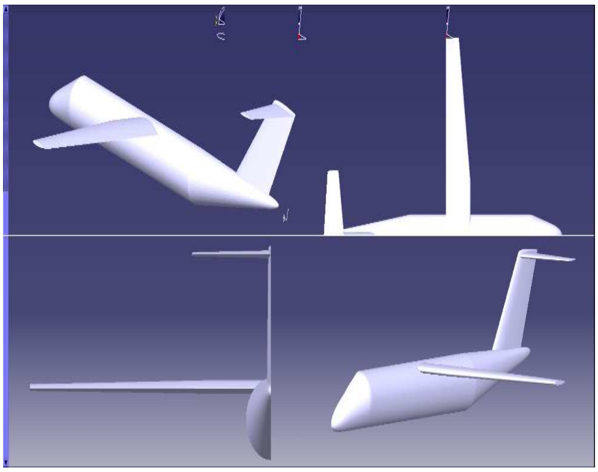


Fig.4: Aircraft without flap

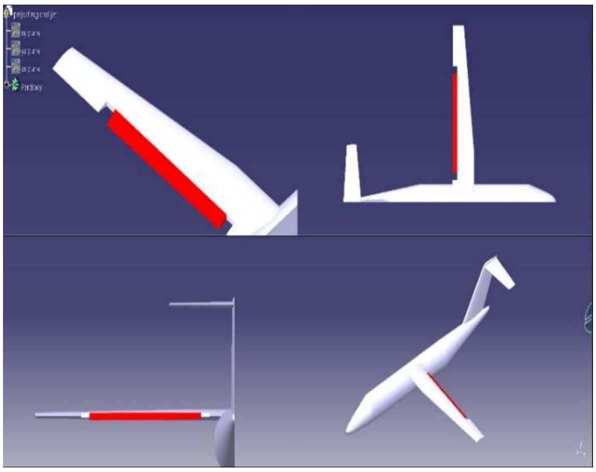


Fig.5: Aircraft with deflected plain flap

Wing section was altered with deflected plain flap is shown in Fig. 5 and seam less contact trailing edge flap (SCTEF) as shown in Fig. 6.

Design	Area	Length
Aircraft with no flap	$0.000192556m^2$	28.14mm
Aircraft with deflected flap	$0.000191634m^2$	28.14mm
Aircraft with deflected SCTEF system	$0.000192666m^2$	28.14mm

Table 1: Design parameters of CAD models

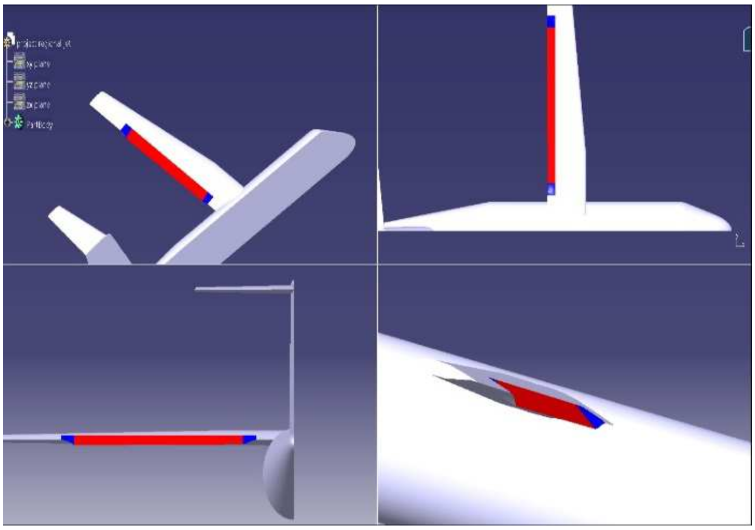
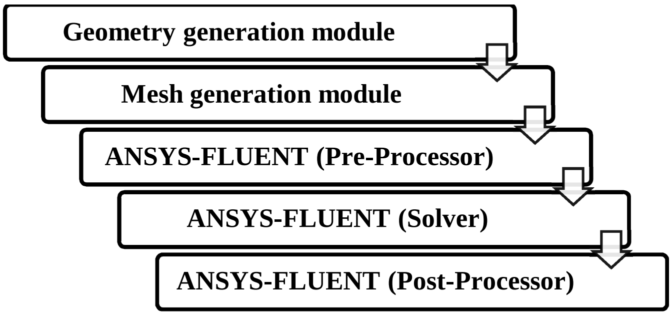


Fig.6: Aircraft with deflected SCTEF system

COMPUTATIONAL FLUID DYNAMICS (CFD)

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. CFD involves fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer based simulation. The technique is very powerful and spans a wide range of industrial and non-industrial application areas.

STRUCTURE OF ANSYS FLUENT



STEPS INVOLVED IN CFD ANALYSIS

Meshing the Continuum

The meshing of the aircraft is done using ANSYS MESH14.5. Here continuum is divided into different named sections like inlet, outlet, symmetry, wall and aircraft as shown in Fig.7 and the required meshing conditions are applied and the continuum is meshed. The aircraft is given a fine mesh size of 0.001mm since it is of most importance and of complex geometry and the rest of the continuum is given a mesh size of 0.01mm. The difference between the elements sizes can be seen in Fig.8.

Design\Mesh statistics	No. of nodes	No. of elements
Aircraft with plain wing	147022	824195
Aircraft wing with deflected flap	215028	1213860
Aircraft wing with deflected SCTEF system	216706	1222607

Table 2: CAD Models Mesh Statistics

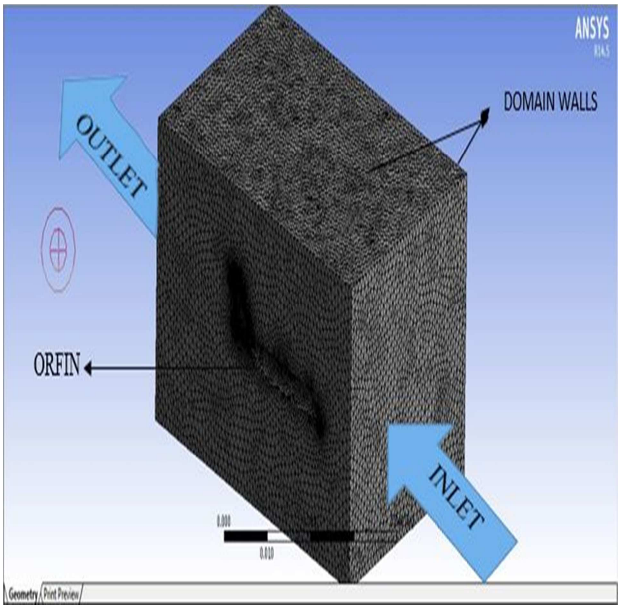


Fig.7: Domain configuration

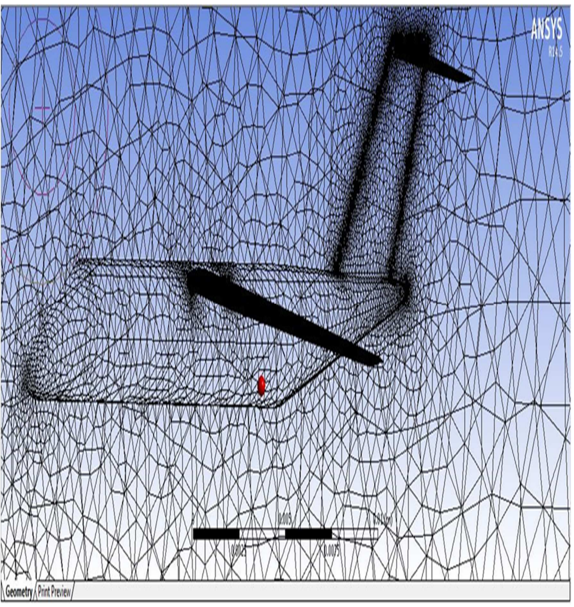


Fig.8: Finely meshed aircraft (ORFN)

SIMULATION OF THE CONTINUUM

The simulation of this continuum is done in ANSYS Fluent 14. In this initially the meshing of the continuum is checked and once the software approves it, the models, materials and boundary conditions are set.

1. Model

The model used for this kind of simulation is the spalart-allmaras (SA) model. This is a single equation model which is consider mostly for boundary layer problems like aerospace, automobile etc. This model is coupled with viscous heating option in our simulation.

2. Materials

The working fluid in this simulation is air at 27^0c and is considered to act on the aircraft at normal atmospheric conditions. The properties of air at 27^0c were given in table 3.

3. Boundary Conditions

The important boundary conditions in an External Flow Analysis are Mach number or velocity at inlet of the continuum and pressure at the outlet of the continuum. As per the data regarding the range of ‘V1’ speed at takeoff for regional class of aircrafts the inlet boundary condition for the continuum is given as 75 m/s. The outlet boundary condition is given as gauge pressure and its value is given as 0 Pa. the symmetry plane (YZ plane) is mentioned as symmetry. The rest of the faces of the continuum are mentioned as wall which means that these faces are under free-slip condition i.e. there is no considerable boundary layer effect on these faces.

4. Monitors

In order to predict the lift force and drag force generating on the aircraft, monitors of lift and drag are engaged along with the residual plots. These monitors needs the data like length, area, flow parameters to calculate the center of gravity (C.G), Aerodynamic center (A.C) of the aircraft. By these calculations it shows the forces acting in the aircraft.

5. *Solution*

Once the boundary conditions are set, the solution methods and controls are set for this simulation. The solution method set for this is the coupled solver. And as for the solution controls the courant number is set to 0.25 and the under relaxation factors for momentum and pressure are set as 0.75 and for the turbulent kinetic energy, turbulent dissipation rate and turbulent viscosity is set to 0.8.

PROPERTIES OF AIR AT 27^0C	VALUES
Density ρ (kg/m^3)	1.1765
Thermal conductivity k (W/m.k)	0.026118
Dynamic viscosity μ (kg/m.s)	1.8538e-05
Specific heat c_p (j/kg.k)	1.0063e+03

Table 3: Properties of air at 27^0c

SECTION	BOUNDARYCONDITIONS	
INLET	Velocity=75 m/s	Temperature=300 k
OUTLET	Pressure outlet=0 pa	Temperature=300 k
AIRCRAFT (ORFN)	Wall-no slip(considering BL effects)	
DOMAIN WALLS	Wall-free slip	

Table 4: Design parameters of CAD models

RESULTS

Pressure counters:

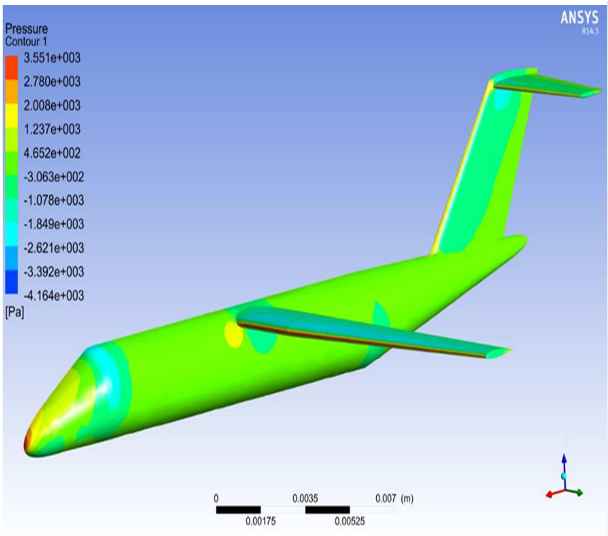


Fig.9: Aircraft without flaps

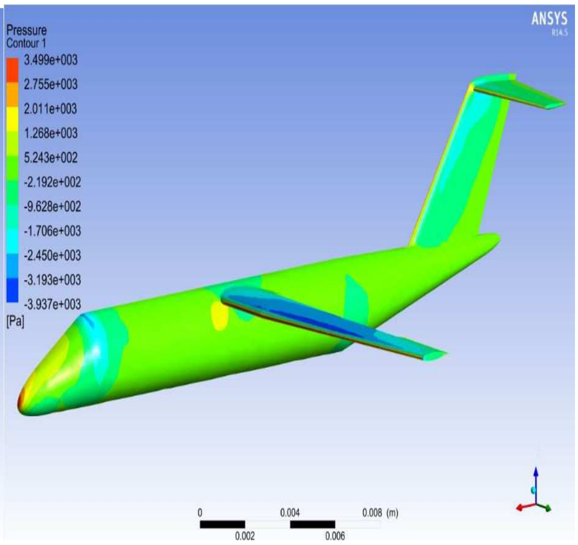


Fig.10: Aircraft with deflected plain flap

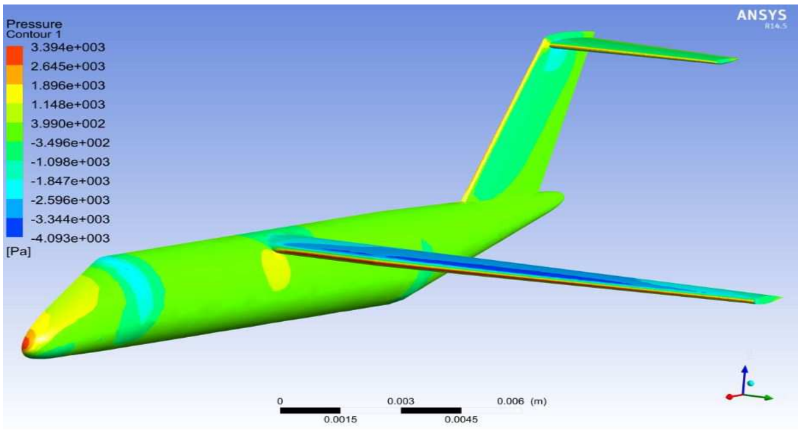


Fig.11: Aircraft with SCTEF configuration

Velocity Magnitude Counters:

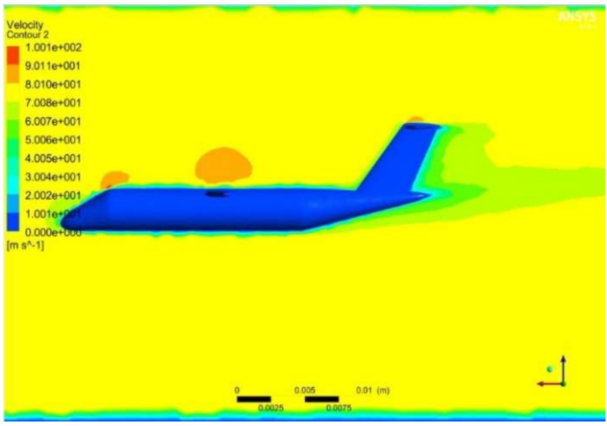


Fig.12: Aircraft with plain flap

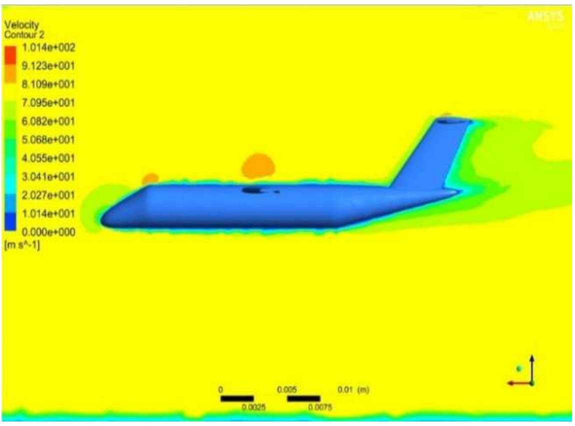


Fig.13: Aircraft with SCTEFzz

Velocity Curls:

Velocity curl in X direction is monitored among three models on a plane created just behind the wing shown as green wall in the figures.

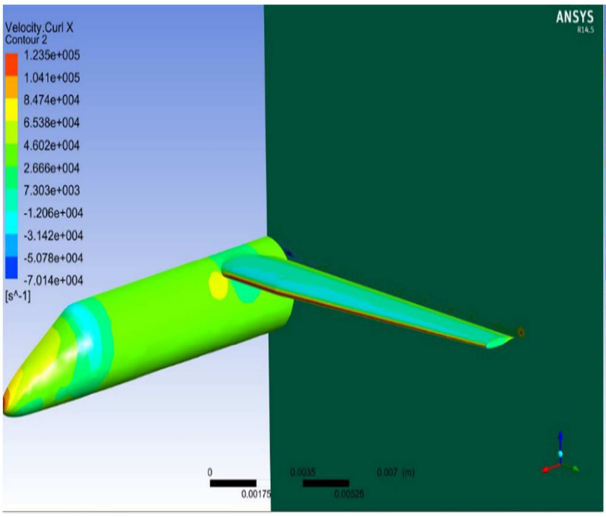


Fig.14: Velocity curl on aircraft without flaps

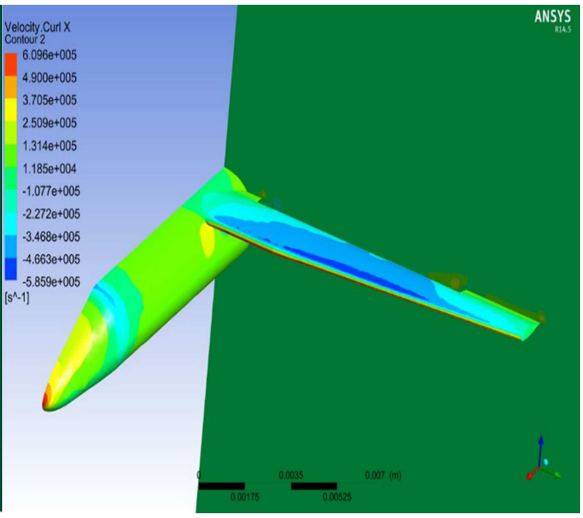


Fig.15: Velocity curl on aircraft with plain flap

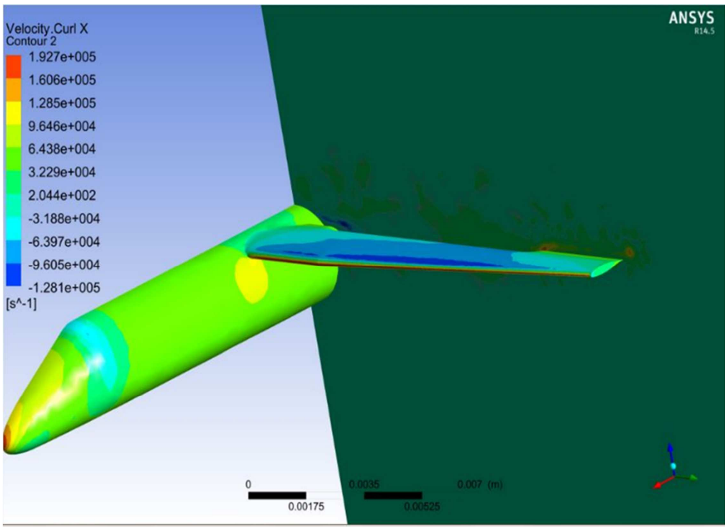


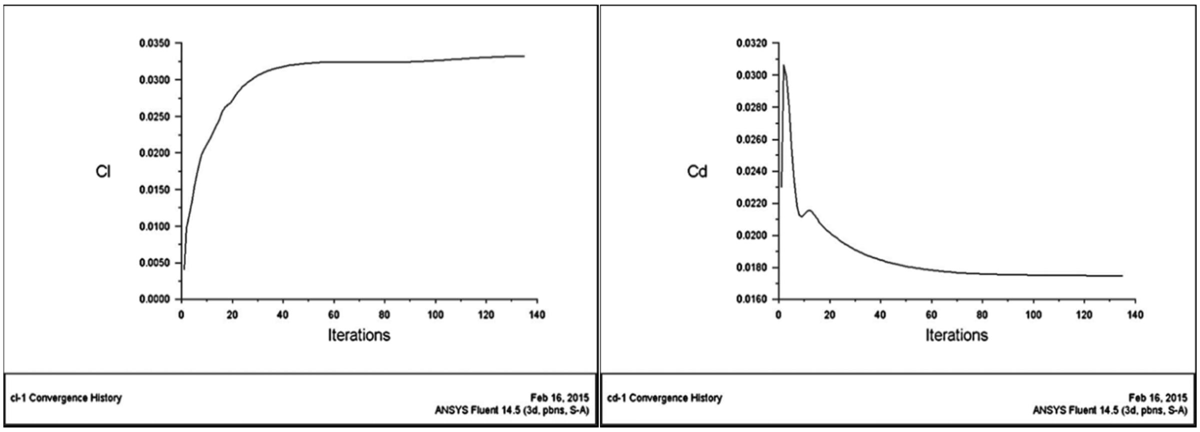
Fig.16: velocity curl on aircraft with SCTEF

From the velocity curls we can observe that aircraft with deflected SCTEF has less vortices when compared with the aircraft with plain flap deflection. Aircraft without flap has even less curl vector than aircraft with deflected SCTEF because it doesn't have any deflections to disturb the air flow pattern. The maximum and minimum values of velocity curls are compared among three models in table 5.

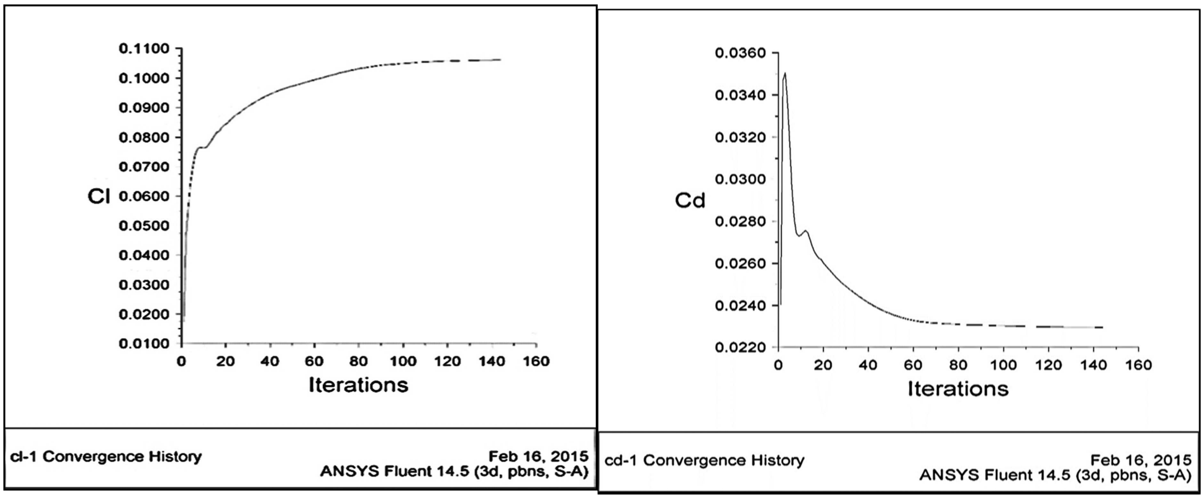
Velocity curl(s^{-1}) \ Model	**Aircraft without flaps**	**Aircraft with plain flap**	**Aircraft with SCTEF**
Maximum	$1.235*10^{005}$	$6.096*10^{005}$	$1.927*10^{005}$
Minimum	$-7.014*10^{004}$	$-5.895*10^{005}$	$-1.281*10^{005}$

Table 5: velocity curl among three models

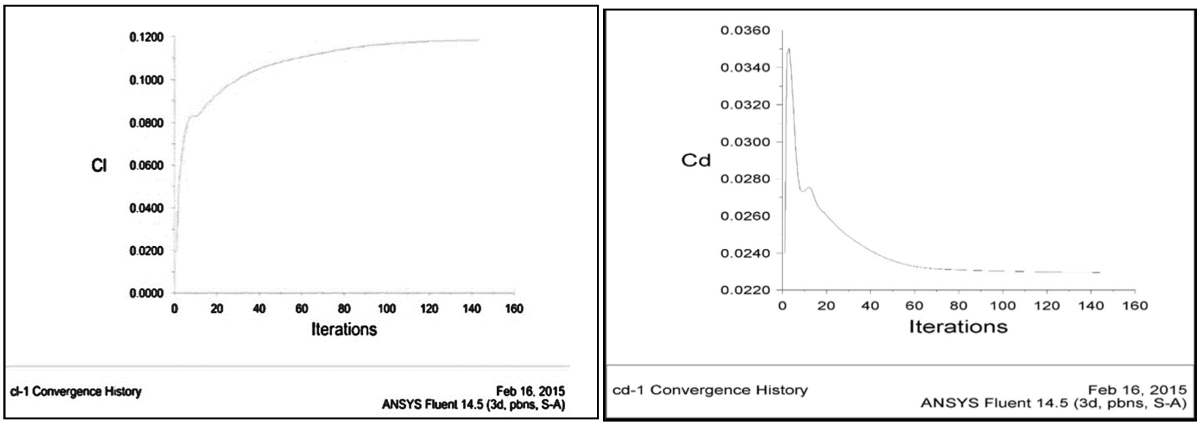
LIFT AND DRAG MONITORS



Graph 1: C_L & C_D monitors of aircraft without flap deflection



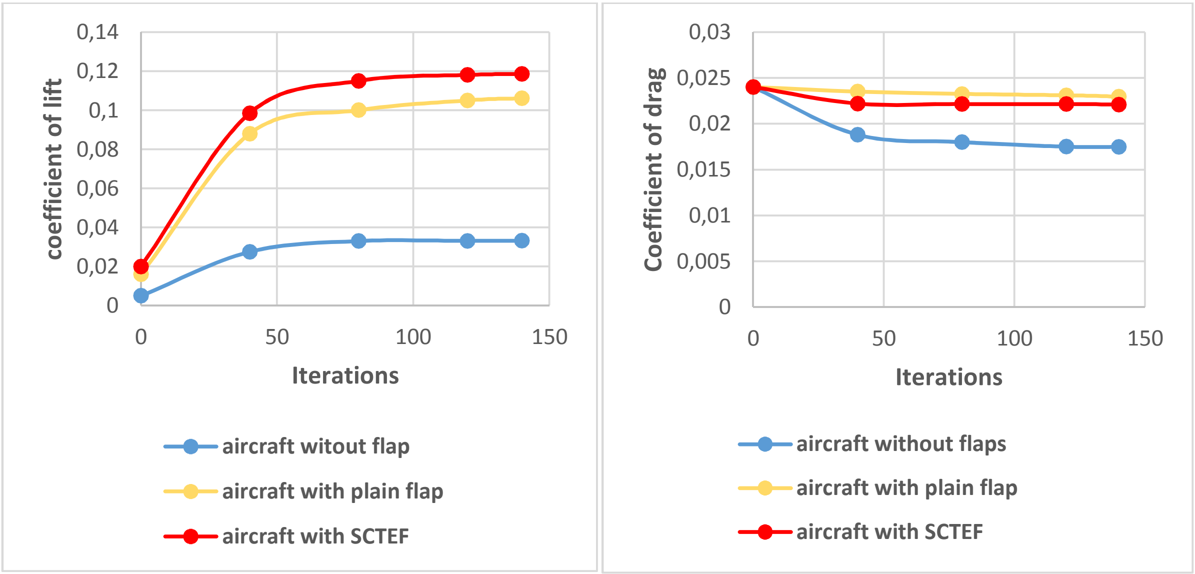
Graph 2: C_L & C_D monitors of aircraft with plain flap deflection



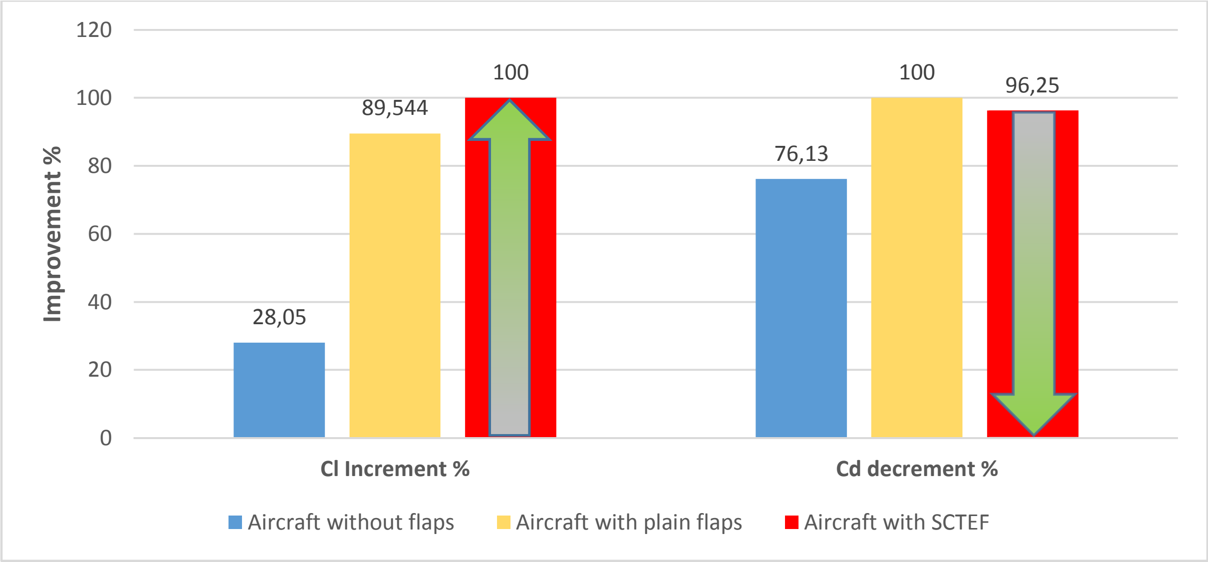
Graph 3: C_L & C_D monitors of aircraft with deflected SCTEF

MODEL	Lift force(N)	Drag force(N)	C_L	C_D	C_L/ C_D
Aircraft without flaps	0.021179N	0.0111384N	0.033241	0.017482	1.90
Aircraft with plain flap	0.0672842N	0.01456N	0.10611	0.022962	4.62
Aircraft with SCTEF	0.075546N	0.0140903N	0.1185	0.022102	5.36

Table 6: CFD analysis results comparison



Graph 4: C_L& C_D comparison among three models



Graph 5: Lift and Drag improvement percentage

From the improvement graph, it is clear that aircraft with SCTEF flap lift has increased 10.456 % & 3.75 % drag has decreased when compared with aircraft with plain flap deflection.

CONCLUSION

Computational fluid dynamics (CFD) analysis was done on three configurations to explore the effect of seamless contact trailing edge flap (SCTEF) with comparison among the other two models. When conventional flaps are lowered, gaps exist between the forward edge and sides of the flaps and the wing surface. By using flexible composite materials flaps will be gapless, forming a seamless transition region with the wing while remaining attached at the forward edge and sides. The improved flap eliminated a major source of airframe noise generation and also improves aerodynamic efficiency.

- Computational fluid analysis on the aircraft model with new concept has shown definite trends in comparison among the other
- Analysis shown that SCTEF flap has improved the lift production by 10.456% and decrease in drag by 3.75% when compared with the plain flap.

- Pressures velocity magnitude and velocity curls are well within the limits with respect to the boundary conditions.

Hence CFD analysis has shown that SCTEF concept improves lift and decreases drag which is nothing but more fuel efficient flights and low noise when taking off. This new concept can be incorporated with the aircraft flap actuation system that makes pilot to engage the system whenever it is needed.

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