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Conceptual Studies on Aircraft Roll Using Jets of Air

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Abstract

The study aims at exploring a new and innovative method that can be used to maneuver aircrafts (rolling in particular). We intend to replace the existing control surface-based control method (which has lasted for centuries) with jets of air creating localized thrust from Newton's III law in order to replicate the effect. The work includes the determination of the control force produced by the control surface deflections and replicating it with the force produced by jets of air giving rise to same magnitude of force by using the method of solid modelling &CFD analysis.
Keywords: Control force, Jet interaction Force, Rolling Motion, Orifice, Nozzle force.

1. Introduction

A modern commercial airliner is a very advanced and sophisticated machine. Its design has changed drastically since the flying machine made by the Wright Brothers. We now have fly by wire and other modern technologies which were not thought of previously. The aviation industry is constantly trying to improvise on the current technology in order to improve the fuel efficiency, safety and comfort of passengers etc. There are three primary control surfaces used for navigation of the airplane. They are rudders, ailerons and elevators. They are used to control the yaw (sidewise), roll (about its longitudinal axis) and pitching movement respectively. These control surfaces add weight to the aircraft which in-turn reduces fuel economy.

This study aims to reduce the weight, improve safety and reliability of the control systems. This is being done using jet based maneuvering systems. The air from the compressor is delivered through ducts to the jet openings, which is controlled using a valve mechanism. Reactive forces produced by these jets give the aircraft required amount of control force.

This method helps to reduce the parasitic drag on the aircraft produced by the control surfaces, reduce the weight in order to improve the payload or fuel capacity, improves the maneuverability of the aircraft during turbulence & the effectiveness of the controls during supersonic cruising. The normal control surfaces become less effective under stall & very high-altitude flight, but the jet-based control can be used even under these conditions. Moving parts are reduced due to control surface, there won't be any structural failure, less maintenance and lubrication requirement.

2. Objectives and Problem Statement

The main objective of this project is to determine the control force (lift generated by the control surfaces) & then determine the discharge rate required to produce the same amount of control force, this is done in order to determine the percentage of the compressor air required to make the maneuver & to verify the feasibility of the proposed idea in the full-scale aircraft.

This project focuses on the replacement of the ailerons with a jet-based control system that uses the compressor bleed air in order to maneuver the aircraft. The main issue with the current method of maneuvering the aircraft by the control surfaces is weight. The hydraulic systems of an airplane contribute significantly to the weight of the aircraft and replacing this with the jet-based system has many advantages: there is a high reduction in induced drag of the aircraft as there are no separate control surfaces, reduction of the structural weight as there is no hydraulic fluid or their delivery system involved.2.1 Subheadings

3. Design Considerations:

For our design and analysis, we are considering Dassault Falcon 7X, a Large-cabin aircraft. It is a three-engine cantilever monoplane with a low-positioned highly swept wing. All the three engines being Pratt & Whitney Canada PW300, with Maximum thrust: 23.24 kN, bypass ratio 4.5 and pressure ratio 20.58:1.The range of it is about 5,950 nautical miles (11,020 km).It also has a max take-off weight of 5175 kg.

Fig.1. Dassault Falcon 7X

3.1 Theoretical Calculations

Feasibility check was carried out for the replacement of ailerons. Velocity of jet required to produce necessary thrust in order to mimic the control force produced due to deflections encountered during the flight of a commercial aircraft.

$$Tn = \dot{m}Ve$$

$$Fcs = \frac{\rho V^2 S}{2} Cl$$

$$Cl = 2\pi\alpha$$

Where Tn is the nozzle thrust

ṁ is the mass flow rate

Ve is the exit velocity

Fcs is the force produced by the control surfaces

ρ is the density

V is the free stream velocity

S is the area of the control surface

Cl is the coefficient of lift

The above formulae will be used to determine the value of force from the control surface (CS) and the nozzle force with a known mass flow and exit velocity.

Equating the two equations, we get the required velocity of jet necessary to produce 95N force in order to replicate 5o deflection of aileron to be 650 m/s.

The area of orifice required to support the calculated mass flow rate and the calculated velocity is,

$$A = \frac{\dot{m}}{\rho Ve} = 0.056m^2$$

where A is area of holes

ṁ is the mass flowe rate

ρ is the density of air

Ve is the exit velocity

requiring 29 holes of diameter 5 cm or any possible variation so that we get the total area as obtained above.

Considering the Engine specifications, we have the following details.

Engine Inlet Diameter= 0.8128m

Engine inlet area=0.519m2

Cruise speed =236.11m/s

Cruise height=14km (41,000 ft)

Take Off speed= 114 knots=58m/s

Mass flow rate:

$$\dot{m} = \rho AV$$

This gives at cruise condition

$$\dot{m} = 0.287 \times 0.519 \times 236 = 35.15 kg/s \text{ (per Engine)}$$

$$\dot{m} \text{ (for 3 Engines)} = 35.15 \times 3 = 105.45 kg/s$$

Similarly, in take-off condition,

$$\dot{m} = 36.87 \text{kg/s (per Engine)}$$

$$\dot{m}(3 \text{ Engines}) = 36.87X\ 3 = 110.6 \text{ kg/s}$$

Area of aileron S=1.45m^2(from CAD model),

$$Lift = Fcs = \frac{\rho V^2 S}{2} Cl$$

$$Cl = 2\pi\alpha$$

So, the lift increment produced by deflection of 5^o at cruise condition is, (Fcs indicates force by control surface)

$$Fcs = 0.5*0.287*250^2*1.45*(2*\pi*5*(\pi/180)) = 7130.6N$$

For Take-off Condition

Fcs =1647 N (Increment in lift)

3.2 Design of model for the Analysis

As we have the CAD model of the complete aircraft in a wireframe geometry. Opening it in the CATIA V5 the model is shown below

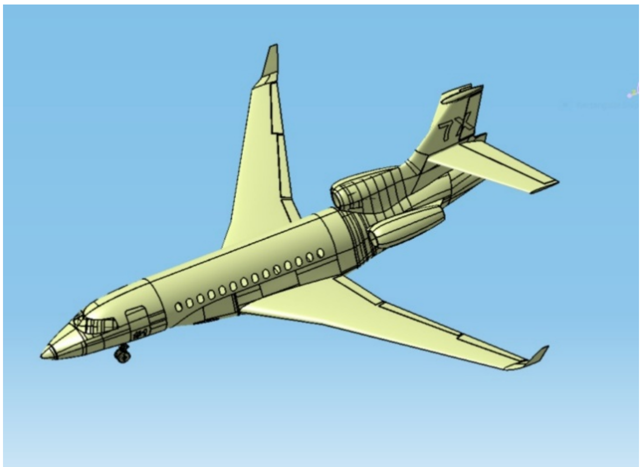

Fig.2. CAD Model of Falcon 7X, in wireframe geometry

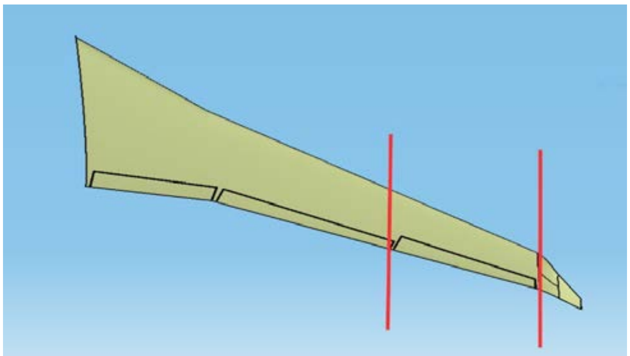

Fig.3. Separated wing from the body of aircraft

As shown in the Fig.3 the cross section selected in such a way that the freestream air goes on the wing as it designed shown by two red lines in the same figure. After creating two surfaces along the respective lines parellely going into the plane of book and cutting the wing only in a region when the control surface is present. After making it a closed surface and converting to solid part it appears as in following figure.

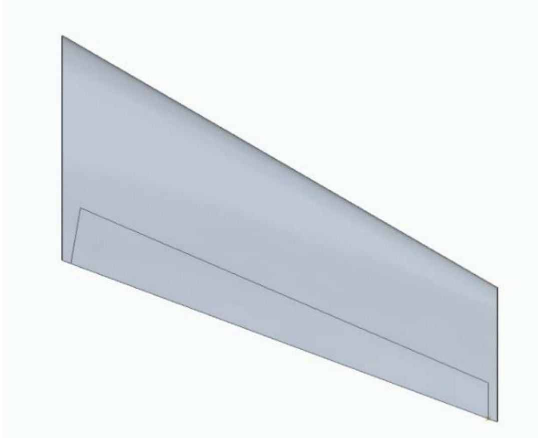	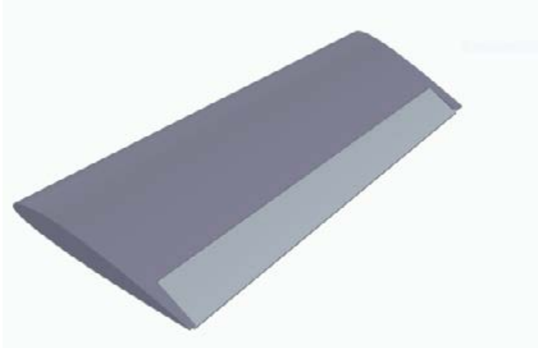
Wing cut section over the length of aileron	Wing cut section with 5^o aileron deflection

Fig.4. Wing cut sections designd

When we take the cut section of the wing and remove the control surface and introduce a control surface deflected 5^o downwards so that giving out more force by increasing the camber. We'll proceed with these two parts for the analysis at take-off /Landing conditions and at the Cruise altitude (41,000 ft).

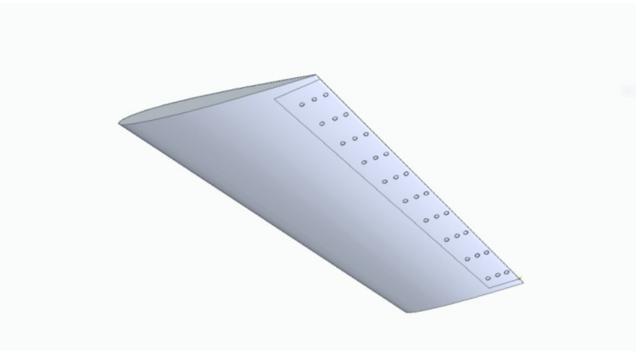

Fig.6.Typical arrangement for the jets of air on the wing

4. Numerical Simulation of the CAD Model

For this work Fluent module of ANSYS 18.1 is used. The aim of this simulation is to validate the theoretical calculations done previously.

The analysis in this study is done in two sets, the first half we determine the actual force that is generated by the deflection of the control surface & the second part we determine the interaction force that is generated by the interaction of the jets with the external environment & the boundary layer over the wing. This interaction force can give a positive effect or the effect can be negative, which disrupts the force that is produced by jetting out air from the nozzles. This is shown in the formula given below:

Control Force = Nozzle Thrust Force + Jet Interaction Force

The control force here is determined by finding the difference in lift produced between the no deflection of aileron case & the 5^o deflection of the aileron case. This is the force that we need to generate using our jets. The nozzle thrust here is already been calculated using the thrust equation. The jet interaction force is calculated from the difference between the analysis values of the airfoil with jets & the no deflection condition of aileron.

The models analyzed are as follows:

1. Take-off/landing with no aileron deflection
2. Take-off/landing with 5^o aileron deflection
3. Take off / land with Jets on top surface
4. Take off / land with jets on bottom surface
5. Cruise with no deflection
6. Cruise with 5^o aileron deflection

7. Cruise with Jets on top surface
8. Cruise with jets on bottom surface

4.1 Importing and Geometry Setup

The designed wing cut sections were converted to .igs format and imported to Fluent. The enclosure of dimension 7m*4m*7m was created in order to simulate the surrounding atmospheric properties. The geometry was differentiated with the surrounding using Boolean. Similar enclosure and Boolean was obtained for the remaining conditions as well.

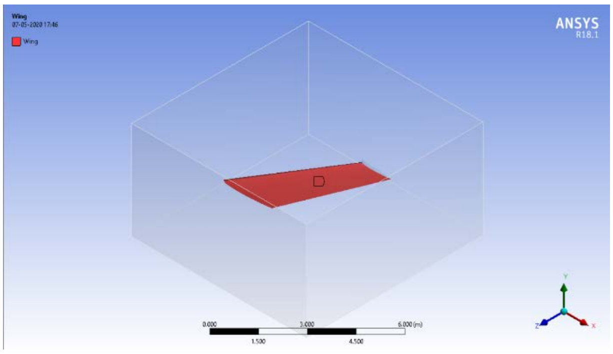

Fig.7. Wing section to be analyzed placed in an enclosure

4.2 Meshing

A mesh of high quality was generated in order to obtain accurate results. Meshing of all the three models were done by varying the relevance factor & face meshing. The suitable relevance factor was selected based in the grid independence study. The mesh used is tetrahedral mesh.

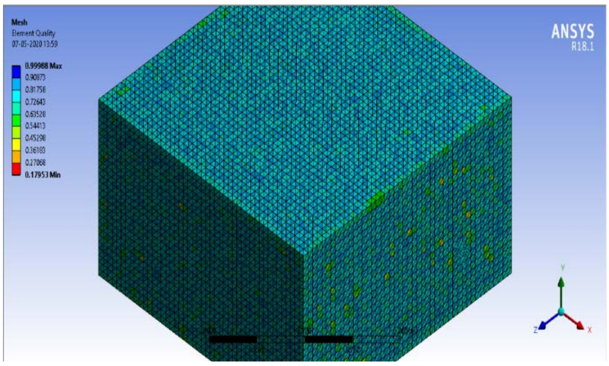

Fig.8. Meshed volume in the space.

4.3 Solver details & Boundary Conditions

The solver used and subsequent details are as follows:

Table.1 Solver Details

Solver	Pressure Based
Time	Steady
Model	Viscous Laminar
Material (FLUID)	Air
Solution Initialization	Standard (From Inlet)

Boundary conditions used for analysis are given as follows, Table.2 Boundary Conditions

Boundary Conditions (Take-off/Landing)		Boundary Conditions (CRUISE)	
Density (Fluid)	1.225kg/m^3	Density (Fluid)	0.287kg/m^3
Inlet (Zone Velocity)	58.6467 m/s	Inlet (Zone Velocity)	250 m/s
Jet Holes (Zone velocity)	640m/s	Jet Holes(Zone velocity)	791m/s

5. ANSYS Results

5.1 Wing with no jets (Original Wing)

The numerical analysis to get the forces required at takeoff/landing and cruise conditions taking the original wing with no jets is performed. After setting all the boundary conditions as specified above and running the simulations, we obtain the results for the flow around the wing section as follows.

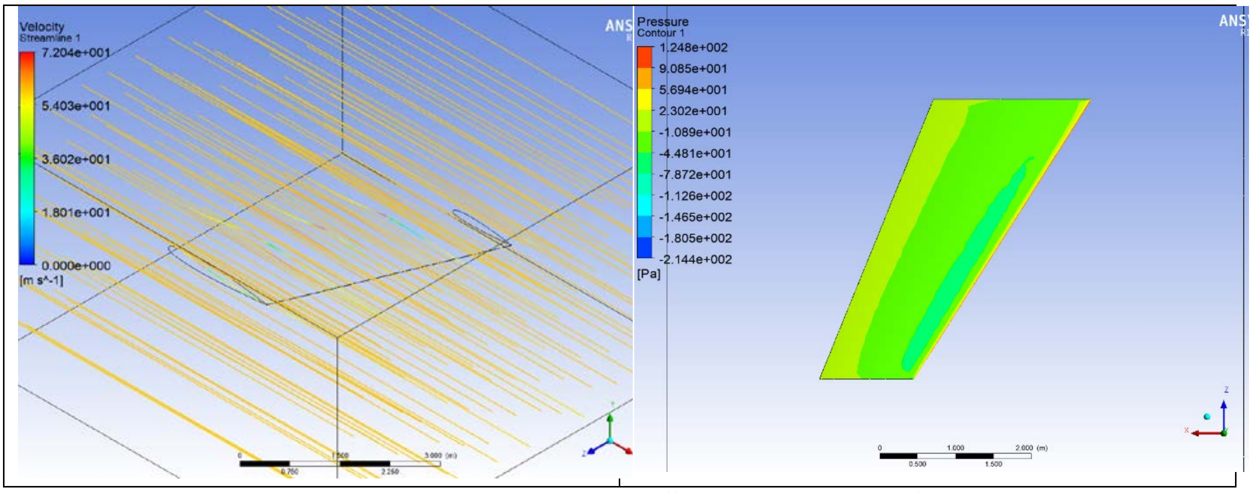

Fig.9. Velocity and Pressure contours at Take-off /landing with no aileron deflection.

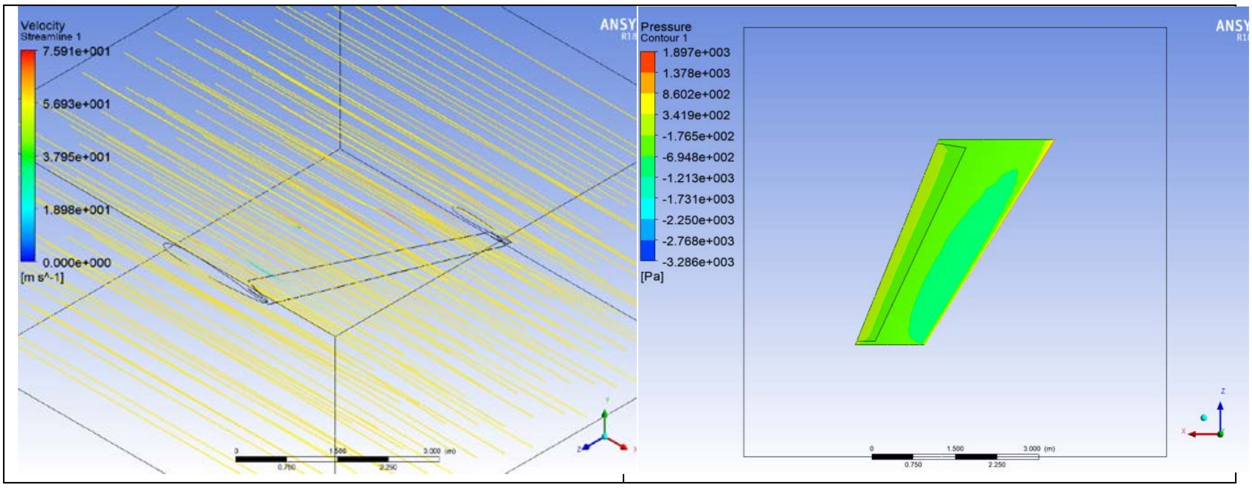

Fig.10 Velocity and Pressure contours at Take-off /landing with 5° aileron deflection.

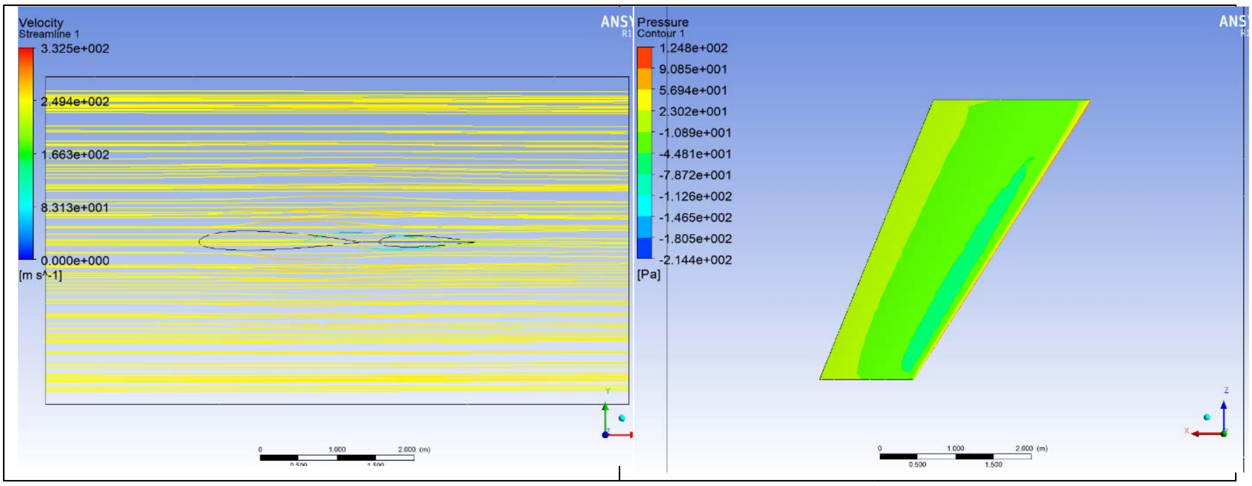

Fig.11. Velocity and Pressure contours at cruise with no aileron deflection.

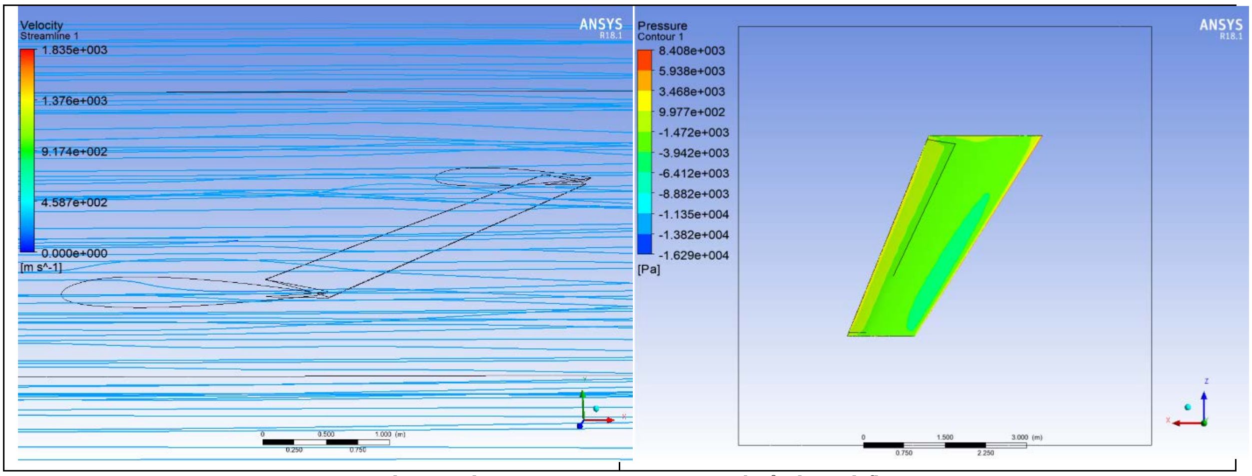

Fig.12. Velocity and Pressure contours at cruise with 5º aileron deflection.

The values of forces obtained from the simulation results are as follows:

Table.3 Forces at all conditions

Condition of operation	Aileron Deflection in Degrees	Lift Force (N)	Drag Force (N)
Take-0ff/ landing	0	399.67	265.5
	5	2637.98	263.74
Cruise	0	2855.40	450.84
	5	11740.1	796.01

5.2 Wing with Air Jets

Now as we have the additional force that is produced by the control surface deflection and trying to produce the same force by the jets whose air is drawn from the engine inflow. Assuming that the interaction of jet and free stream produces no effect on lift we find the required jet velocity and it is found that jet speed value at take-off condition is 203m/s and at cruise 791m/s this speed can be obtained by specially designing the CD nozzle for jet. Analysis results of this are done and results obtained as follows.

As ANSYS only takes up to 10 velocity outlets so we have designed the 9 jets of 9cm diameter. This is obtained as

$$N = \frac{0.058}{\pi r^2}$$

Where

N is number of holes,
r is the radius of holes,
$0.058m^2$ is total area of jet for the required force.

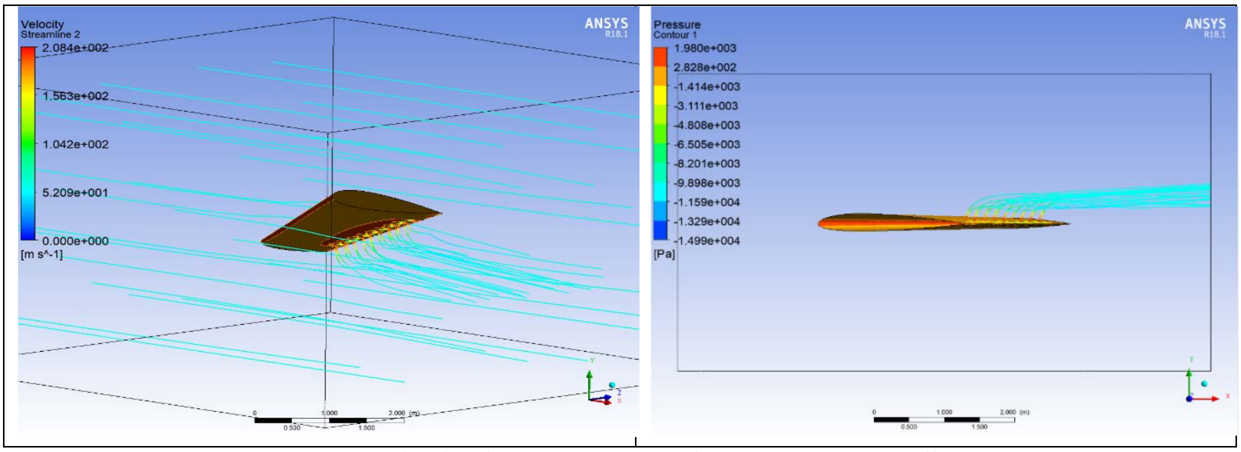

Fig. 13 Velocity streamlines of jet flow from bottom and top surfaces respectively at take-off /landing condition

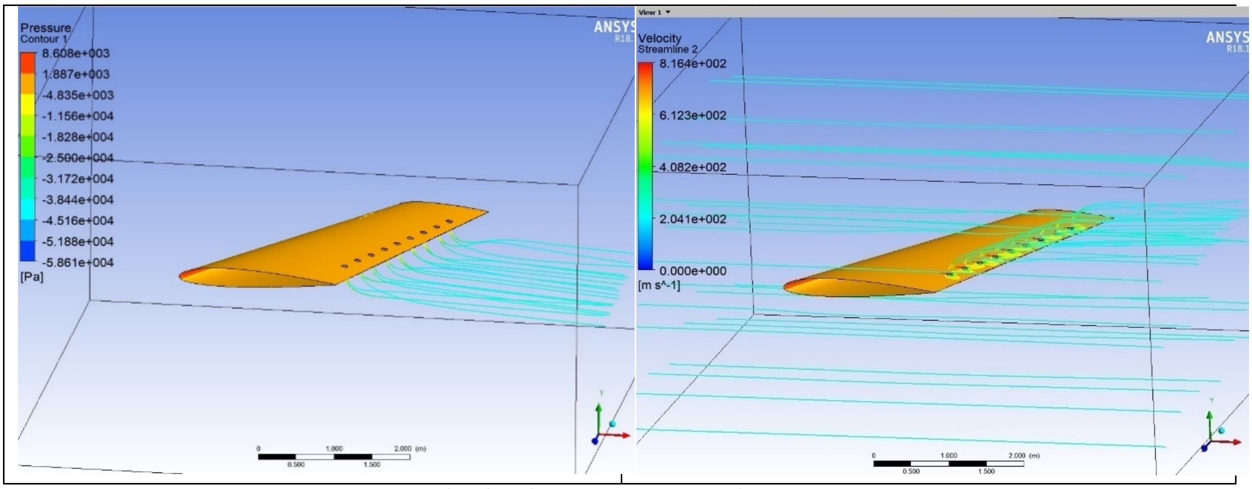

Fig. 15 Velocity streamlines of jet flow from bottom and top surfaces respectively at Cruise condition

Tabulating the forces obtained by the jet simulations:

Table.4 Forces by Jets of Air on wing (values are in N)

		At take-off/landing	At Cruise condition
Jet from top	Lift	-22.7	313.471
	Drag	-140.07	1463.06
Jet from bottom	Lift	1467.74	6474.34
	Drag	329.33	1293.01

5.3 ANSYS Results Verification

Fluid interaction due to formation of vortices, Stall regions or shocks as shown as the incremental lift generated by wing using jets.

$$T(\text{Required}) = T_R = \text{Thrust}_{\text{Nozzle}} \pm \text{Thrust}_{\text{Fluid Interaction}}$$

Let us assume this Thrust by fluid interactions as 'X' as it is unknown, and nozzle thrust as T_N,

If

$$Tn = \dot{m}Ve,\ T_N = T_R,\ X=0,$$

$$\dot{m} = 10\% \text{ of the engine mass flow rate.}$$

In take-off/landing condition:

Analysis of wing in neutral Position:

Lift force = 399 N

Analysis of wing for 5^o deflection

Lift force = 2637 N

Resulting in

Lift increment = 2238 N

Using area of exit as constant = 0.058 m^2

We know,

$$Ve = \frac{T}{\dot{m}}$$

Gives,

$$Ve = \frac{2238}{(0.1 * 110)} = 203 m/s$$

Analyzing the above configuration of given velocity,

Holes on top surface:

Lift = -22.6 N

Lift increment = -22.6 -399 = 421 N

Holes on bottom surface:

Lift = 1467 N

Lift increment = 1457-399 = 1068 N

These above values are the 'X' values and giving the corrected thrust required as 1817 N and 1170 N for top and bottom surfaces respectively. This leading to reduction of mass flow requirement from 10 % to 5.3% and 8% for bottom and top surface jets operation respectively.

Similar Calculations for the cruise condition gives the following results for the values of 'X' and Thrust required by the jet as,

For Top Surface jet X= 2541 N

For bottom surface jet X= 3589 N

So, the thrust required after correcting with X we have 6344 N and 5296 N for top and bottom surfaces respectively. This reduced the mass flow of 10% to 6% and 7% respectively.

Theoretical and simulation results go hand in hand thus verifying that introducing such a system for the roll motion of the aircraft is possible with multiple advantages as discussed.

6. Conclusions

The goal of replacing the ailerons with the jets of air is accomplished. Since we are able to replicate the force produced by the control surface deflection using jets of air being ejected from the nozzle openings on the wing surface, we can conclude that the study is giving a positive result.

Other maneuvers can also be made possible by new techniques as differential drag method for yaw control such, which remains for the future scope of our work.

References

[1] Paul D. McClure, 5 Dec. 2006, 'Passive jet spoiler for yaw control of an aircraft', Patent no. US 7143983 B2.
[2] Seelam Jamala Reddy, 2016, 'Numerical Analysis of different fluids passing through small orifices with respect to radial low'
[3] https://shodhgangotri.infibnet.ac.in/handle/123456789/4844
[4] J. Roskam, D. Kohlman and W. Wentz,16 Aug 2012, 'Spoilers for roll control of light airplanes'

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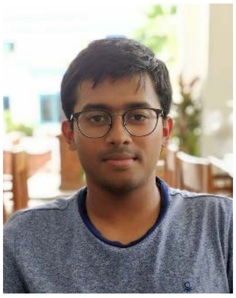

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