A novel divertless thrust vectoring nozzle using the counter-circulation aerodynamic effect: Maximal Aerodynamic Yaw Actuator-MAYA

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Abstract: *During the second half of the 20th century, Henri Coanda had extensively studied the Coanda effect and also it's application for high lift devices that use –in one way or another- super circulation. A previous work has been done for using the Coanda effect to generate perpendicular forces to the aircraft trajectory– including aircraft specifically designed to attain short take off such as the An-72 and YC-14.*

Dwelling on the same principles, the author had tried to imagine and test a 2D thrust vectoring device using differentiated super circulation on two flat surfaces placed near the jet exhaust. The success of this endeavor has been limited because the forces produced were not as great as anticipated. However, the numerical simulations indicated the presence of another, opposite effect, more powerful and potentially more useful than the first: the counter circulation.

This paper describes the working principles of a two dimensional thrust vectoring nozzle aiming satisfy the need for a conventional rudder to control yaw and also shows the prospect of upgrading it to a 3D thrust vectoring nozzle.

Key words: thrust vectoring, Coanda effect, super -circulation, counter circulation.

1. INTRODUCTION

The phenomenon of super-circulation has been considered for high lift devices ever since Henri Marie Coanda proposed his lenticular aerodyne in 1938. Effectively, the aerodyne proposed by Coanda attained lift not by diverting the stream of the compressed air it used – although that effect is not undesirable nor negligible - but by generating a down pressure on the aircraft upper surface.

Aircraft such as the Antonov An-72 and MiG 21 both use this phenomenon in what is known as Upper Surface Blowing (USB) and Upper Blown Flaps (UBF) to attain lift at lower aerial velocities or, in the MiG 21 case to achieve better maneuverability.

It is the purpose of this paper to introduce the super circulation effect discovered by Coanda to a new branch of the aeronautical science, namely/that is/ the thrust vectoring.

Authors have long been contemplating this idea, Ref. [1] describes a Coanda effect nozzle for the pitch control and Ref [2] offers a solution to divert the main stream of the jet in order to vector the thrust.

All of the above use the Coanda effect but none utilizes the supercirculation, a more particularized part of it.

Previous CFD studies [3], have shown the potential of divertless circulation control thrust vectoring nozzles.

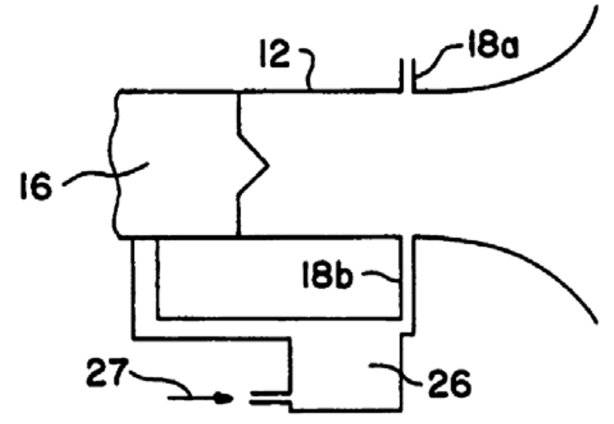

Fig. 1 Fluidic controlled thrust vectoring nozzle Gilbert, Northrop Grumman WO Patent WO1996020867A1

2. INITIAL STUDY

Early attempts to generate a lateral force by supercirculation yielded contradictory results, because the effect appeared to be unattainable on flat surfaces.

A case study is presented in figure 2; the general concept with it was to vary the dynamic pressure on one of the walls of the nozzle in order to obtain an equal and opposite variation in static pressure. However, it can be seen that the change in dynamic pressure had no significant impact on the static pressure plot, rendering the thrust vectoring unit useless.

However it has becomes obvious that differences in static pressure may be obtained even if they are opposite to the expectations dictated by Bernoulli's law.

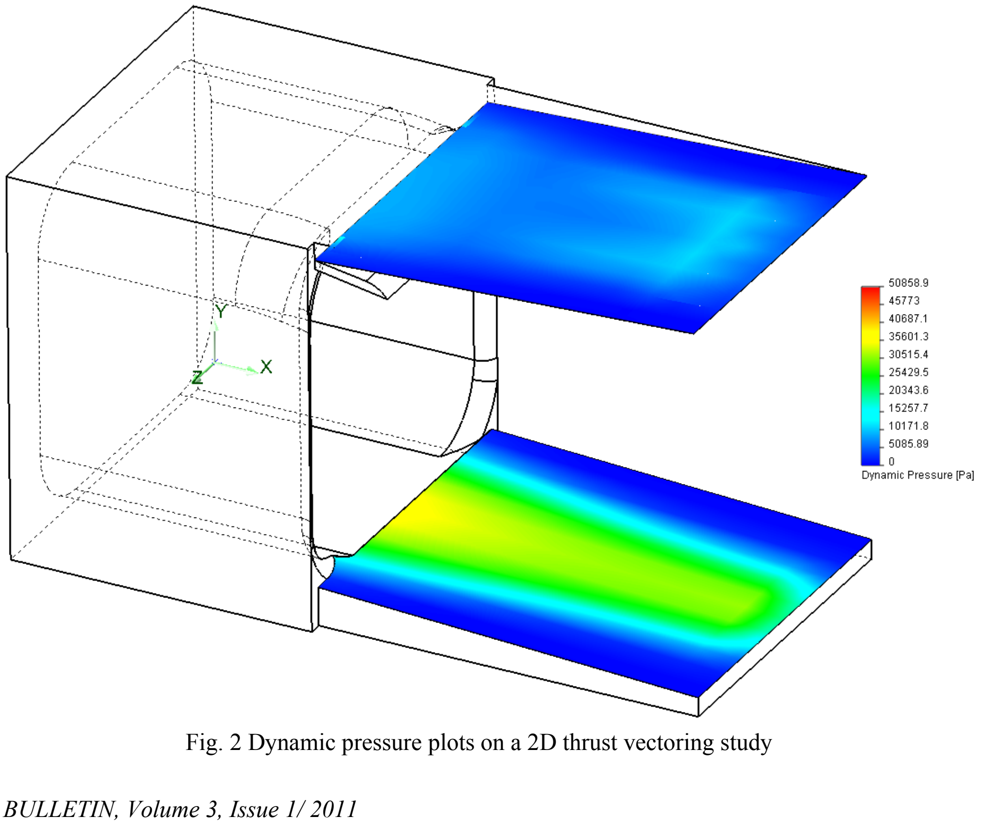

Fig. 2 Dynamic pressure plots on a 2D thrust vectoring study

Tests have been carried out on various velocities; this particular setting depicts a 250 m/s exhaust velocity.

It can be seen that the dynamic pressure is substantially altered by the upper spoiler however, as figure 2 shows, there's little change in the static pressure.

Testing conditions were ISA + 20K; at 250 m/s jet exhaust velocity.

Table 1

Parameter	Value	X-component	Y-component	Z-component	Surface area [m^2]
Force [N]	18.1448	3.11621	-17.8752	-0.0344236	0.0219134
Shear Force [N]	1.28126	1.28079	0.0339532	-0.00725691	0.0219134
Torque [N*m]	2.14811	0.892328	0.158	-1.94761	0.0219134
Torque of Shear Force [N*m]	0.0793134	-0.00268632	0.0645618	-0.0459911	0.0219134
Heat Transfer Rate [W]	0	0	0	0	0.0219134
Normal Force [N]	18.003	1.83542	-17.9091	-0.0271667	0.0219134
Torque of Normal Force [N*m]	2.10379	0.895015	0.0934382	-1.90162	0.0219134
Surface Area [m^2]	0.0219134	0.00126552	0.000271266	-0.000209109	0.0219134
Uniformity Index [ ]	1				0.021253

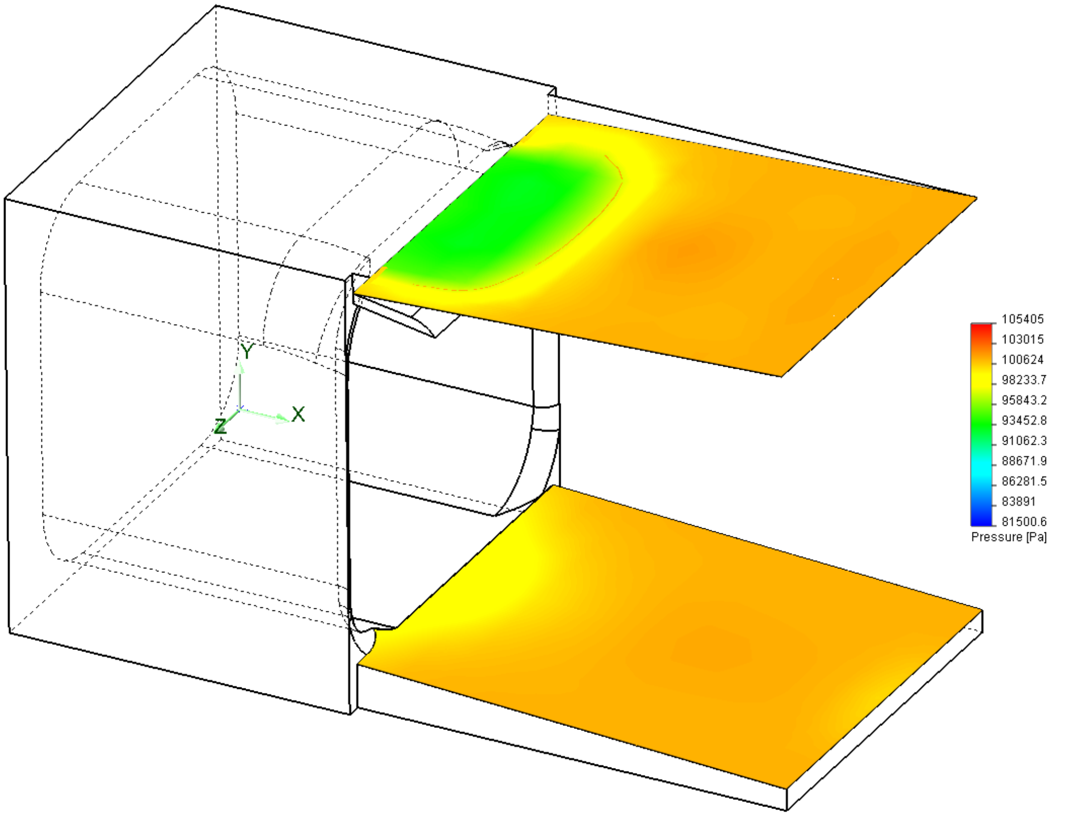

Fig. 3 Static pressure plots on the surfaces of the above setup, little effect is visible near the region directly below the spoiler.

3. THE 2D DIVERTLESS THRUST VECTORING TECHNIQUE

A different approach was needed and further study into the phenomenon provided a surprising aerodynamic effect to which we will refer as “counter-circulation” as the effects are the exact contrary of the expected super-circulation.

Another case study is presented henceforth, detailing both static and simulated in-flight performances. The concept uses mobile ramps to selectively attach the exhaust jet onto the side surfaces of the thrust vectoring assembly. In doing so lateral forces are obtained due to increase of the static pressure on the side surface with the fluid attached to it.

In this variant we use a chamfered polygonal nozzle with four sides, more specifically a squared one for ease of use but not limited to that respective geometry. The need for simulating in-flight conditions leads to the use of a fore body with the purpose of emulating a section of fuselage.

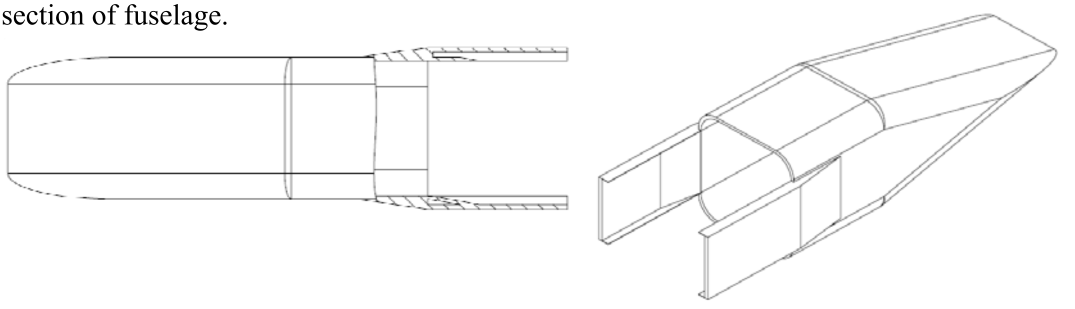

Fig.4 MAYA nozzle top view (left) and 3D isometric view (right

Computational fluid dynamics tests have been carried out on ISA+20K conditions with jet exhaust velocities of 300m/s and 330m/s, the results showed a significant lateral force improvement with the 330 m/s exhaust.

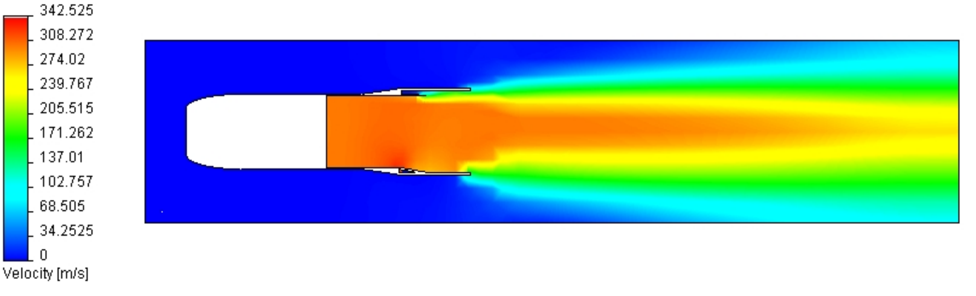

Fig.5 velocity plots of the nozzle on a static test reveals little deviation of the jet in spite of the lateral force obtained by pressure differences on the two side surfaces.

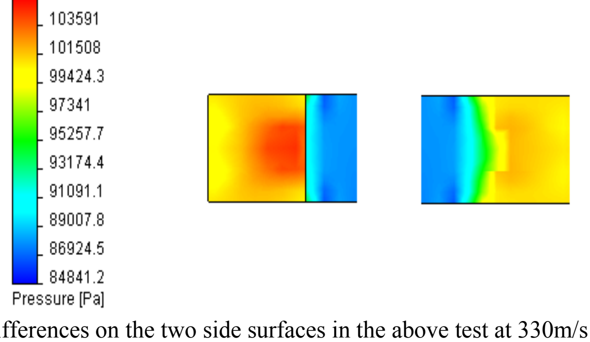

Fig. 6 Static pressure differences on the two side surfaces in the above test at 330m/s exhaust yielding a total force of above 900 N.

Simulating the in-flight conditions have been carried out at ISA + 20K , ambient velocity of 150 m/s and exhaust velocity of 330 m/s. Integrated parameters over the lateral plates can be seen in table 2.

Table 2

Parameter	Value	X-component	Y-component	Z-component	Surface area [m^2]
Force [N]	949.602	-946.733	1.55297	73.747	0.150854
Shear Force [N]	20.0189	0.496802	-0.0535277	20.0127	0.150854
Torque [N*m]	508.23	-1.03334	-508.229	-0.242696	0.150854
Torque of Shear Force [N*m]	2.83372	0.0183481	2.83363	0.0133958	0.150854
Heat Transfer Rate [W]	0	0	0	0	0.150854
Normal Force [N]	948.754	-947.23	1.6065	53.7343	0.150854
Torque of Normal Force [N*m]	511.063	-1.05169	-511.062	-0.256092	0.150854
Surface Area [m^2]	0.150854	-0.0168511	-0.000264399	0.00299797	0.150854
Uniformity Index [ ]	1				0.150854

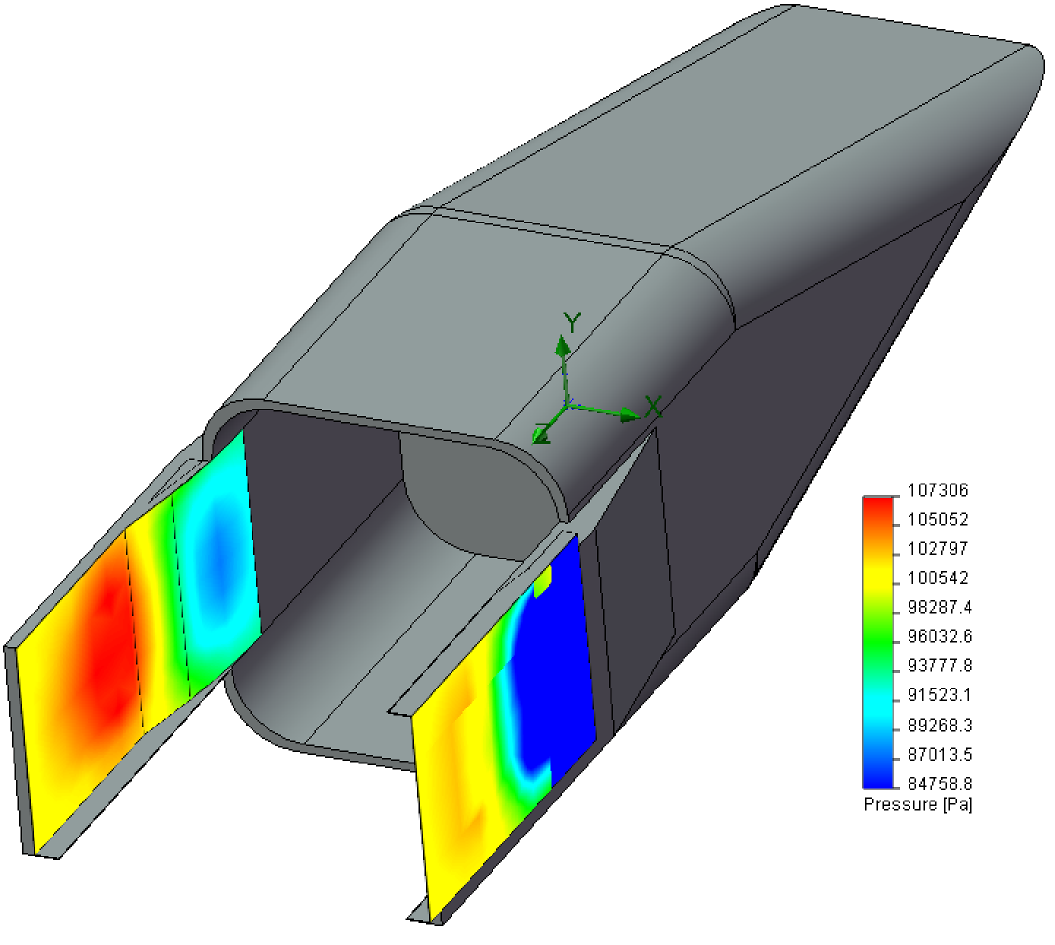

Fig. 7 Static pressure plots of the side surfaces of the above setup.

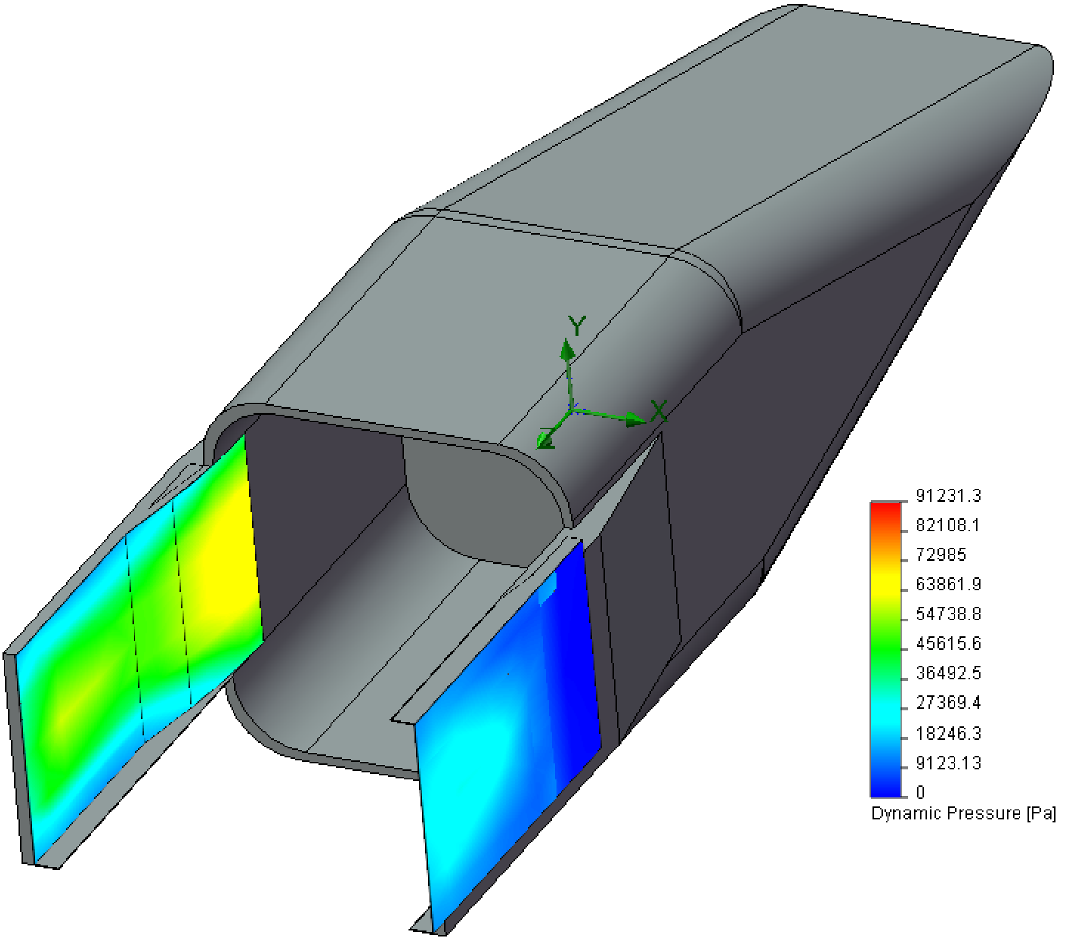

Fig.8 Dynamic pressure is also higher on the counter circulated surface

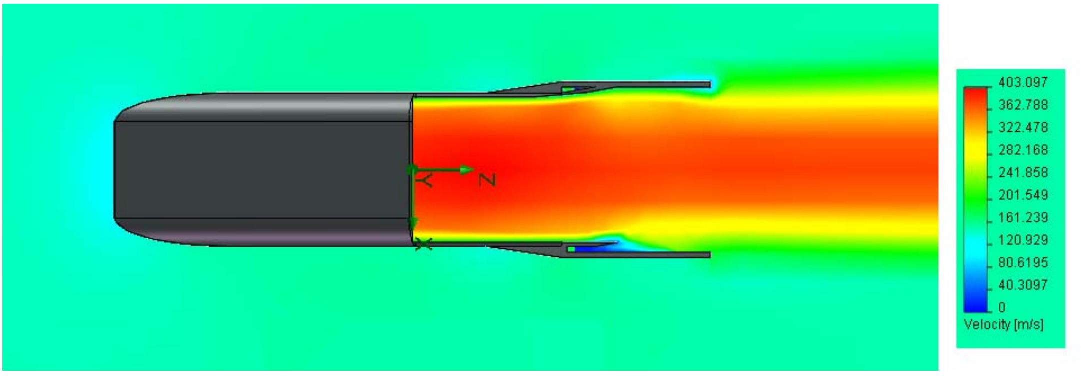

Fig. 9 Velocity cut plot reveals little to no diversion of the main jet exhaust in spite of the high lateral forces obtained trough counter circulation

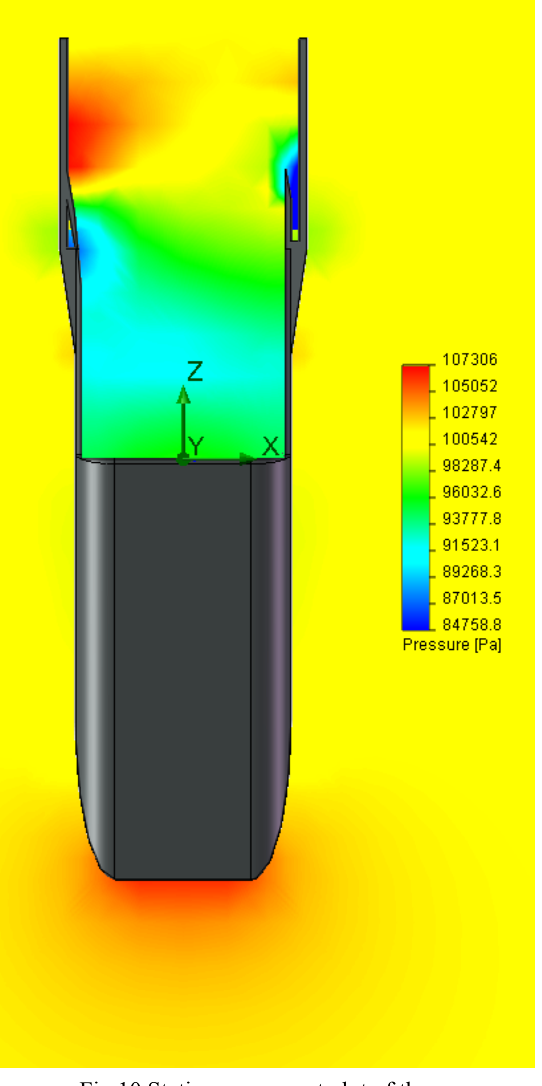

Fig.10 Static pressure cut plot of the mean part of the nozzle

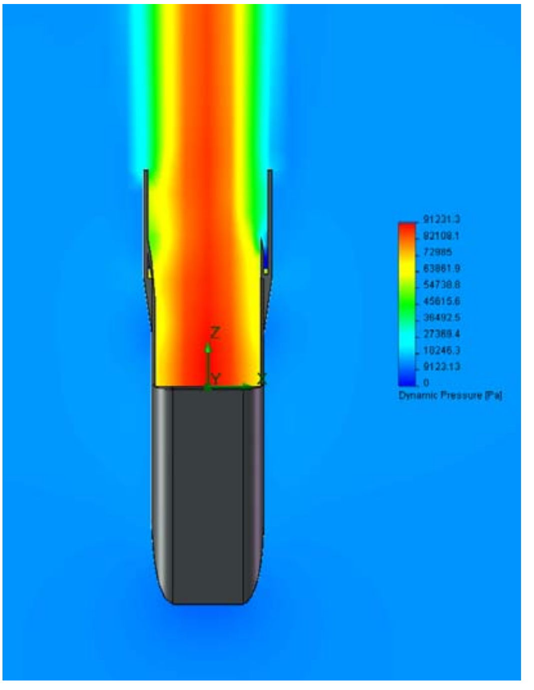

Fig.11 Dynamic pressure cut plot of the jet

4. COMMENTS AND CONCLUSIONS

A two dimensional divertless thrust vectoring system has been tested, under both on-ground conditions and in-flight conditions with positive results in all cases.

Findings by interpreting the CFD simulations revealed that, under certain cases supercirculation is rather connected to the Coanda effect rather than to Bernoulli's law. This is in correlation with the experimental findings of certain authors quoted as reference.

The concept of counter-circulation is explored as means of obtaining lateral forces in nozzles without diverting the main jet exhaust.

This technique showed positive results, obtaining the lateral forces needed for vectoring not by influencing the jet but by selectively using the jet to increase the total pressure and hence, the static pressure, on the desired plate.

Such technologies have a potential to be used on 3D units, providing full thrust vectoring capabilities with minimal reconfiguration of the base aircraft.

Further parametric research is needed to fully describe the counter-circulation phenomenon in order to make such devices more energy efficient and thus, economically viable.

5. REFERENCES

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