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Modeling and analysis of 3d thrust vectoring nozzle to reduce heat signatures

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Abstract: In today's time when whole world is looking for 5th generation combat aircraft, it has become necessary for us to go with the flow to save our country. With upcoming aircraft projects of HAL such as FGFA and AMCA, it is soul need to develop our own stealth technology to keep our upcoming aircrafts comparable to any other next-generation aircraft. Stealth technology is a sub-discipline of military tactics and passive electronic countermeasures, which cover a range of techniques used with personnel, aircraft, ships, submarines, missiles and satellites to make them less visible (ideally invisible) to radar, infrared, sonar and other detection methods. An aircraft exhaust nozzle contributes a significant heat signature. One means to reduce heat signature is to have a non-circular tail pipe (a slit shape) to minimize the exhaust cross-sectional volume and maximize the mixing of hot exhaust with cool ambient air.

Thrust vectoring is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine(s) or motor in order to control the attitude or angular velocity of the vehicle. In the extreme, deflection of the jets in yaw, pitch and roll creates desired forces and moments enabling complete directional control of the aircraft flight path without the implementation of the conventional aerodynamic flight controls. 3D thrust vectoring enables the aircraft to maneuver in all the three axis. Rectangular cross-section nozzle significantly reduces heat signatures of the aircraft but in turn it also reduces the performance of the aircraft and reduces the efficiency of the engine.

These issues can be overcome by using a nozzle which can change its cross-section from circular to non-circular or near to it. This will enable the pilot to change the cross-section of the nozzle as per requirement depending on the war scenario. This is the first aircraft nozzle ever built which can change its cross-section to reduce heat signatures and can provide 3D thrust vectoring at the same time.

This work includes the modeling of various shapes of the nozzles such as circular and elliptic at various vectoring angles and comparing the results with the conventional shape. The temperatures obtained at the exit of the elliptic nozzle is less when compared to the other types and hence heat signatures generated by this nozzle is comparatively low.

Keywords—Heat signatures, Circular Nozzle, Elliptical Nozzle, Exit Temperature, Angles of tilt, ANSYS Fluent

1. Introduction

THRUST VECTORING IS THE ABILITY OF AN AIRCRAFT, ROCKET, OR OTHER VEHICLE TO MANIPULATE THE DIRECTION OF THE THRUST FROM ITS ENGINE(S) OR MOTOR IN ORDER TO CONTROL THE ATTITUDE OR ANGULAR VELOCITY OF THE VEHICLE. THRUST-VECTORING FLIGHT CONTROL (TVFC) IS OBTAINED THROUGH DEFLECTION OF THE AIRCRAFT JETS INTO THE PITCH, YAW AND ROLL DIRECTIONS.

Figure.1 Thrust Vectoring Nozzle

In the extreme, deflection of the jets in yaw, pitch and roll creates desired forces and moments enabling complete directional control of the aircraft flight path without the implementation of the conventional aerodynamic flight controls (CAFC). When TVFC is implemented to complement CAFC, agility and safety of the aircraft are maximized. For aircraft, the method was originally envisaged to provide upward

Vertical thrust as a means to give aircraft vertical (VTOL) or short (STOL) takeoff and landing ability. Subsequently, it was realized that using vectored thrust in combat situations enabled aircraft to perform various maneuvers not available to conventional-engine planes. To perform turns, aircraft that use no thrust vectoring must rely on aerodynamic control surfaces only, such as ailerons or elevator; craft with vectoring must still use control surfaces, but to a lesser extent.

1.1 Methods of Thrust Vectoring

Type I – Nozzles whose base frame mechanically is rotated before the geometrical throat.

Type II – Nozzles whose base frame is mechanically rotated at the geometrical throat. Variable Cross-section 3D thrust vectoring nozzle with reduced infra-red signatures

Type III – Nozzles whose base frame is not rotated. Rather, the addition of mechanical deflection post-exit vanes or paddles enables jet deflection.

Type IV – Jet deflection through counter-flowing or co-flowing auxiliary jet streams i.e. Fluid-based jet deflection.

2. INFRA-RED SIGNATURES

The term infrared signatures used by defense scientists and the military to describe the appearance of objects to infrared sensors. An infrared signature depends on many factors, including the shape and size of the object, temperature and emissivity.

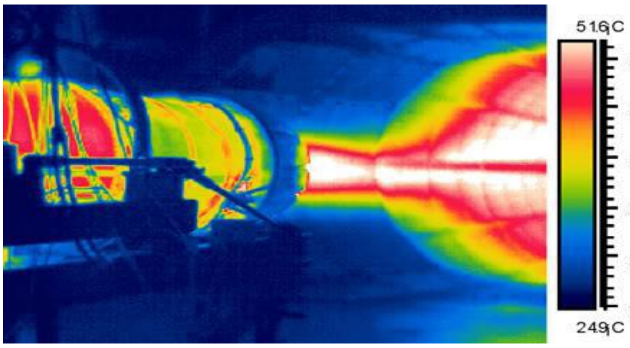


Figure.2 Thermal Image of exhaust of an aircraft nozzle

Infrared stealth is an area of stealth technology aimed at reducing infrared signatures. This reduces a platform's susceptibility to infrared guided weapons and infrared surveillance sensors, and thus increases the platform's overall survivability. Infrared stealth is particularly applicable to military jets because of the detectable engines and plumes from non-stealth aircraft, but it also applies to military helicopters, warships, land vehicles and dismounted soldiers.

The apparent temperature difference method of defining infrared signature gives the physical temperature difference (e.g. in Kelvin) between the object of interest and the immediate background if the recorded radiance values had been measured from perfect blackbody sources. Problems with this method include differences in radiance across the object or the immediate background and the finite size of the detector's pixels. The value is a complex function of range, time, aspect, etc.

In the design phase, it is often desirable to employ a computer to predict what the infrared signature will be before fabricating an actual object. Many iterations of this prediction process can be performed in a short time at low cost, whereas use of a measurement range is often time-consuming, expensive and error-prone.

2.2 Brief Background of Project

Stealth technology is a sub-discipline of military tactics and passive electronic countermeasures, which cover a range of techniques used with personnel, aircraft, ships, submarines, missiles and satellites to make them less visible (ideally invisible) to radar, infrared, sonar and other detection methods.

Stealth technology is not a single technology. It is a combination of technologies that attempt to greatly reduce the distances at which a person or vehicle can be detected; in particular radar cross section reductions, but also acoustic, thermal, and other aspects. Many countries have developed stealth technology to reduce Radar Cross-section (RCS) of the aircraft, but it has been a terrible problem for the scientists and engineers to develop a technology to reduce infra-red signatures of fighter aircrafts

An exhaust nozzle contributes a significant infrared signature. One means to reduce IR signature is to have a non-circular tail pipe (a slit shape) to minimize the exhaust cross-sectional volume and maximize the mixing of hot exhaust with cool ambient air. Often, cool air is deliberately injected into the exhaust flow to boost this process. Sometimes, the jet exhaust is vented above the wing surface to shield it from observers below, as in the B-2 Spirit, and the unstealthy A-10 Thunderbolt.

Thrust vectoring is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine(s) or motor in order to control the attitude or angular velocity of the vehicle. Thrust-Vectoring flight control (TVFC) is obtained through deflection of the aircraft jets into the pitch, yaw and roll directions. In the extreme, deflection of the jets in yaw, pitch and roll creates desired forces and moments enabling complete directional control of the aircraft flight path without the implementation of the conventional aerodynamic flight controls. 3D thrust vectoring enables the aircraft to maneuver in all the three axis.

Rectangular cross-section nozzle significantly reduces infrared signatures of the aircraft but in turn it also reduces the performance of the aircraft. In an interview of Director of Lyulka-Saturn (Manufacturer of aircraft engines of Russia) in 1998, he stated that:

"In the late 1980s, we were engaged in the development of the flat nozzle too and conducted a thorough research. The distance cannot be increased because this would lead to an increase in the overall length of the aircraft, a loss of thrust, etc. While transforming the circular gas stream into the flat one, the nozzle, developed by Mr. Ryzhov, was losing 14-17% of thrust.

Secondly, the other primary problem is weight. The circular TVC nozzle produces only tensile stress while the flat one exerts bending stress as well. Those stresses require special measures to be taken to ensure the nozzle strength in order to avoid deformation of the nozzle. Those measures mean additional weight. The flat nozzle made of metal is heavier than the circular one by approximately half a ton. This reduces the thrust to weight ratio of the aircraft which is very important factor of a fighter aircraft."

Therefore, the disadvantages of rectangular cross-section aircraft nozzle are:

a) Thrust loss

b) Increased weight of aircraft-nozzle assembly which in turn reduces thrust to weight ratio of the aircraft.

c) Increase in length of engine and nozzle which also increases overall length of the aircraft.

d) More difficulty in achieving 3D thrust vectoring due to complex design.

e) Maneuvering issues

These all issues can be overcome by using a nozzle which can change its cross-section from circular tonon-circular or near to it. This will enable the pilot to change the cross-section of the nozzle as per requirement depending on the war scenario.

3. PROJECT OBJECTIVES

1. To model Elliptical shape nozzle and circular thrust vectoring nozzle in ANSYS workbench.
2. To obtain geometrical and boundary conditions for circular nozzle.
3. To compare both Elliptical shape nozzle and circular thrust vectoring nozzle for same conditions in fluent.
4. To Analyze the heat signatures/temperature at nozzle exit for different angles of tilt.

4. LITERATURE REVIEW

The study of background of various kinds nozzle showed that variety of nozzle and their mechanisms were invented and tested in the history but none of them were able to satisfy the need of a modern next generation aircraft. The nozzles used in the present aircrafts in service compromise with either thrust vectoring, or infra-red signatures. Such famous examples of aircrafts are:

A. F-22 Raptor which reduces infra-red signatures but compromises with thrust vectoring as it has 2D thrust vectoring.

B. Su-PAK/FA which has 3D thrust vectoring but lacks infra-red signatures reducing nozzle.

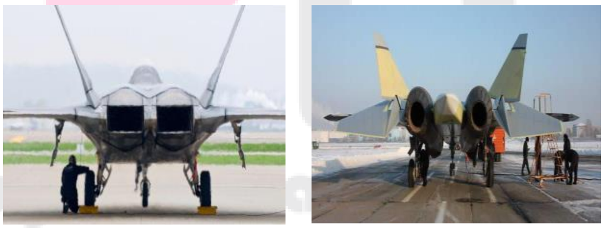


Figure.3 3D thrust vectoring nozzle (Right), Infra-red signatures reducing nozzle (left)

These observations directed our study towards a nozzle which can have benefit of both thrust vectoring and reduced infra-red signatures.

5. METHODOLOGY

Our aim is to develop a nozzle which can reduce infrared signatures like a rectangular cross-section nozzle and give performance like circular cross-section 3D thrust vectoring nozzle. This can be achieved by providing 2 hinge points on the nozzle flaps on horizontal mid axis. When the top and bottom actuators will push the top and bottom flaps, the flaps attached to the hinge joint will move closer which will give

elliptical shape to the cross-section of nozzle which is close to rectangular shape. The exhaust coming out of the nozzle will mix with the ambient air and the infrared signatures will be minimized.
A jet engine is also made to test the nozzle. The engine is made from Borg-Warner S-210G turbocharger. A separate combustion chamber is also made with low by-pass ratio for afterburners. The engine will be an afterburning engine.

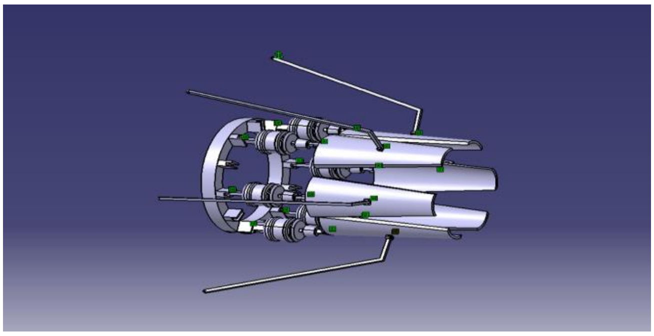


Figure.4 3D thrust vectoring nozzle

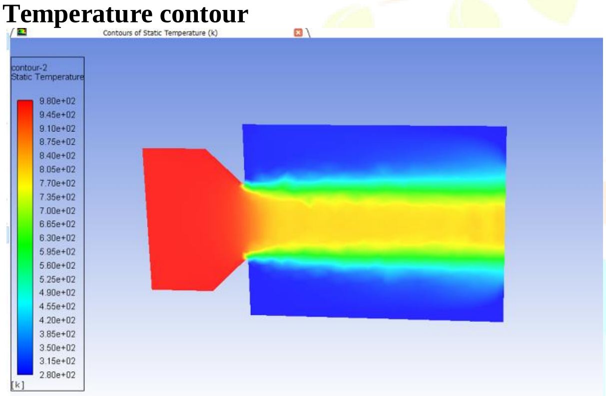
5.1 Thermal Analysis of Nozzle using ANSYS Fluent workbench

To check reduction in infra-red signatures of the nozzle, one needs to analyze the conventional nozzle as well as the new improved nozzle and compare both of them. The thermal analysis of the nozzles can estimate the thermal radiations emitted by the exhaust and therefore it will in turn tell us about the reduction in infra-red signatures.
To analyze the heat reduction in the exhaust of circular cross-section nozzle as well as elliptical cross-section nozzle, ANSYS Fluent package is used. To obtain accurate results, the software run several iterations for both the nozzles.

5.2 Initial boundary condition

6. CASE 1: ZERO-DEGREE CIRCULAR NOZZLE

Temperature contour



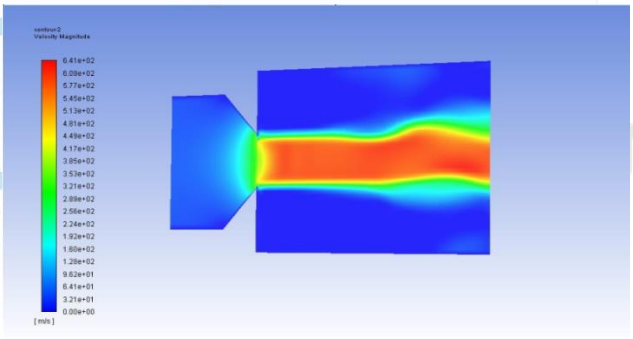


Figure: 8 velocity at exit of the nozzle

Figure: 5 Temperature at exit of the nozzle is 910k

6.1Velocity contour

Parameter	Selected input
CFD solver	Density-based
Energy equation	On
Viscous model	Realizable, K-€ model
Inlet pressure	2 bar
Inlet temperature	980k

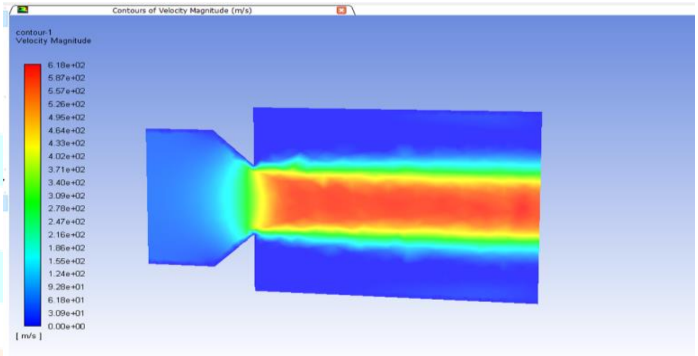


Figure: 6 velocity at exit of the nozzle

6.2 ZERO-DEGREE ELLIPTICAL NOZZLE

Temperature contour

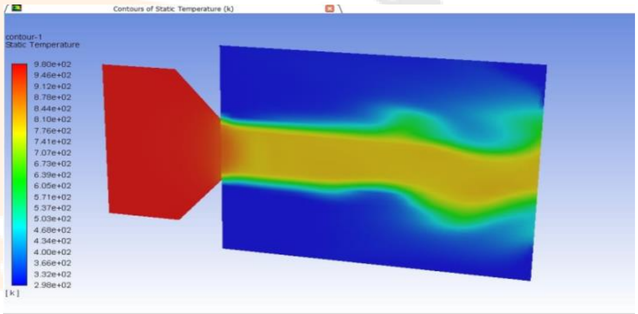


Figure 7: Temperature at the exit of the Nozzle is 830k

Velocity contour

7. CASE 2 :10 ^{0} CIRCULAR NOZZLE

Temperature contour

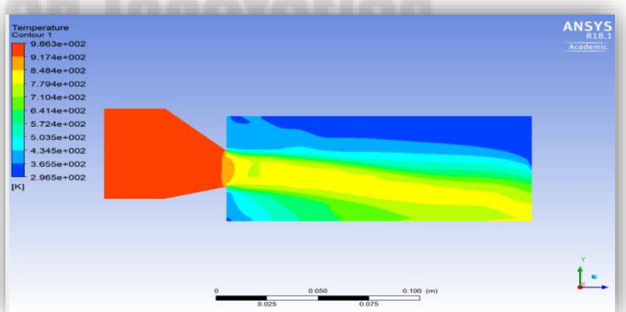


Figure 9: Temperature at the exit of the Nozzle is 848k

10 ^{0} ELLIPTICAL NOZZLE

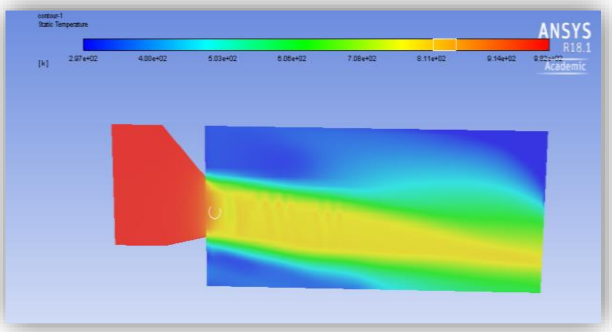


Figure 10: Temperature at the exit of the Nozzle is 820k

8. Conclusion

Thrust vectoring offers great advantages for modern military aircraft, in return for relatively small changes in the aircraft, and is clearly the way to go for the future.
High temperature concentration area is less in elliptical cross-section nozzle as compared to circular cross-section nozzle.
The result obtained from the analysis shows significant reduction in the temperature of the exhaust. This reduction in temperature of exhaust will in turn reduce the heat signatures.
With a small change in shape of a nozzle ,which would reduce heat signatures and improve stealth technology.
It will produce a very important stepping stone for the introduction of this technology into service.

Future scope

1. This project can be carried out further for different pressure and angle of tilt.
2. Heat signature can be evaluated using different software which would give a better accuracy.
3. Fabrication of **3D thrust vector nozzle** assembly and conduct performance.

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