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Design and Analysis of Jet Vane Thrust Vectoring Nozzle using CFD and Optimization of Nozzle Parameters

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Abstract

This paper is dealing with optimization of various nozzle parameters (C-D Nozzle) such as Radius of Throat; Divergent angle.2-D model of nozzle is designed in ANSYS 14.5 which is then analyzed with fluent software for exit velocity for various nozzle parameters at the different values. Taguchi design technique is used for optimization of nozzle parameters to get optimum nozzle parameters of jet vane Thrust vectoring nozzle is analyzed for two different operating conditions i.e. one is at standard atmospheric condition and another one is for outer space condition.

Nomenclature

θ	Divergent angle of nozzle	Deg (°)
α	Angle of Attack of vane	Deg (°)
β	Convergent angle of Nozzle	Deg (°)
R_t	Radius of throat	mm
D_i	Inlet Diameter	mm
D_o	Outlet Diameter	mm
D_t	Throat Diameter	mm
V	Velocity	m/s
P_i	Inlet pressure	Pa

Abbreviations

CFD	Computational Fluid Dynamics
TVC	Thrust Vector Control
TV	Thrust Vector

1. Jet Vane TVC

Thrust Vectoring system is a system which is used to control or change the attitude of aerial vehicles such as Aircrafts, Rockets and missiles etc. It changes or controls the attitude of an aerial vehicle by changing the direction of exhaust nozzle to desired direction at appropriate angle. Many kinds of TVC is being used but Jet Vane is one of the efficient TVC configuration used in missiles. Jet Vane TVC system use a vane for Thrust Vectoring .In Jet Vane Thrust Vectoring system, Direction change is attained by changing or deflecting the vane which is located at aft section of the nozzle to appropriate angle.

2. Simulation Parameters

Inlet diameter(mm)	116
Exit diameter(mm)	39
Throat diameter(mm)	14.74
Total Pressure(Bar)	44.1
Total temperature(K)	3400
Convergent Angle(β)	45°

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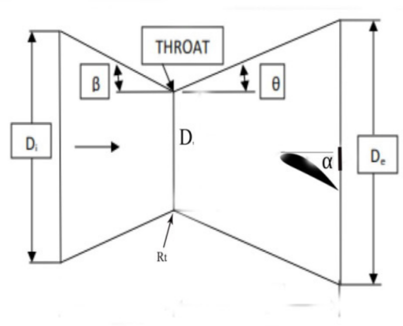
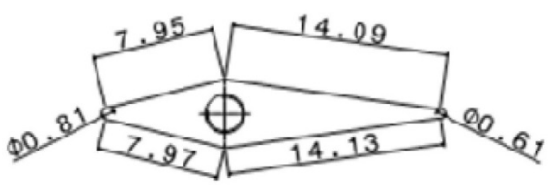


Geometrical parameters of Nozzle 2D Design

Process Parameters

S.No	Divergent Angle θ	Radius of Throat R_t	Angle of attack α
1	7.5°	0 mm	0°
2	15°	12.5 mm	5°
3	30°	22.8 mm	10°



All the dimensions are in mm

3. Taguchi Design

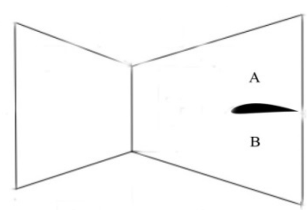
CFD analysis has been done for Jet Vane thrust vectoring nozzle using Taguchi design. By using Taguchi Design (DOE) Design of Experiment, CFD simulation has been carried out for all sets of parameters. In this case nine configurations have been made with three levels. Nozzle parameters such as Divergent angle, Throat radius and angle of attack have been changed for nine configurations of CFD analysis. Two operating conditions (0 Pa and 101325 Pa) were considered for these nine configurations of Nozzle.

4. Analysis by Taguchi Design

Case	θ	R_t	α
1	7.5°	0 mm	0°
2	7.5°	12.5 mm	5°
3	7.5°	22.8 mm	10°
4	15°	0 mm	5°
5	15°	12.5 mm	10°
6	15°	22.8 mm	0°
7	30°	0 mm	10°
8	30°	12.5 mm	0°
9	30°	22.8 mm	5°

5. Simulation Procedure

For CFD Analysis of TVC nozzle, Ansys 14.5 software is used for flow simulation. Nozzle is being designed in ansys fluent. Analysis procedure is carried out with following setup

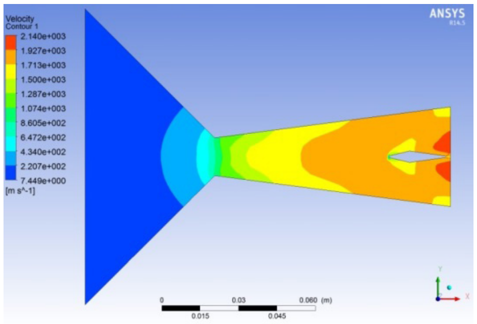


Procedure	Details
Solution Setup-General	Type-Density based Velocity Formulation-Absolute Time-Steady 2D space-Planar
Models	Energy Equation-On Viscous-Inviscid
Materials	Fluid-Air, Density-ideal gas
Cell zone condition	Operating condition= 101325 Pa(1), 0 Pa (2)
Boundary Condition	Inlet Pressure = 44.1e5 pa
Solution	Solution initialization-Standard-Compute from Inlet Run calculation-200 iterations
Results	Velocity contours

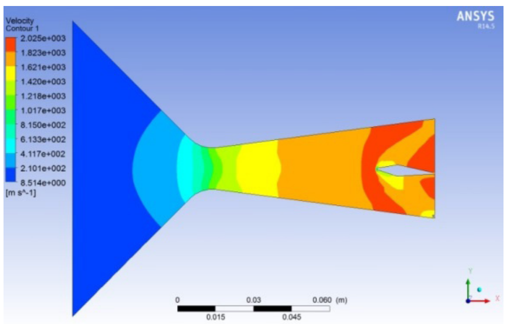
By these boundary conditions analysis has been done and velocity is measured with the help of contours. Since it is a thrust vectoring nozzle so velocity variation between the surfaces above the vane and below the vane is also being measured with the help of probe values, it is denoted as (A/B),

6. Results

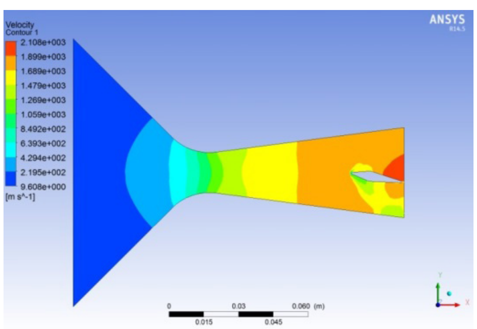
1. Ambient Condition (101325 Pa)



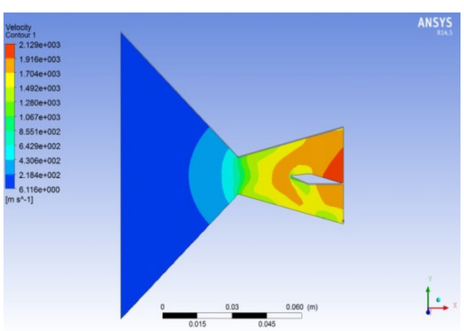
Velocity (θ = 7.5, R_t=0, α = 0)



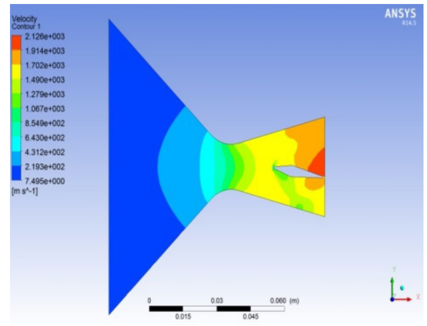
Velocity (θ = 7.5, R_t=12.5, α = 5)



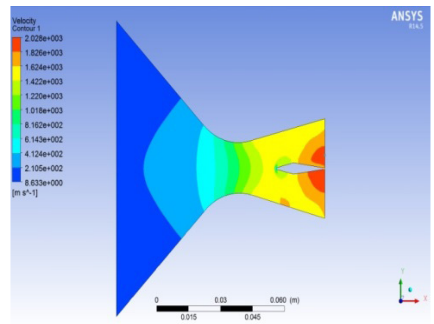
Velocity (θ = 7.5, R_t=22.8, α =10)



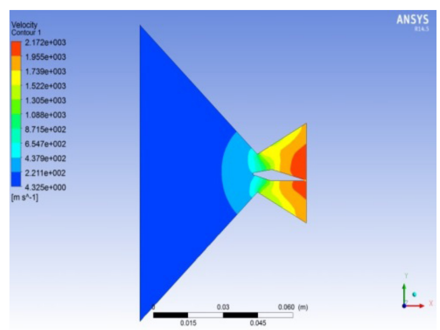
Velocity (θ = 15, R_t=0, α = 5)



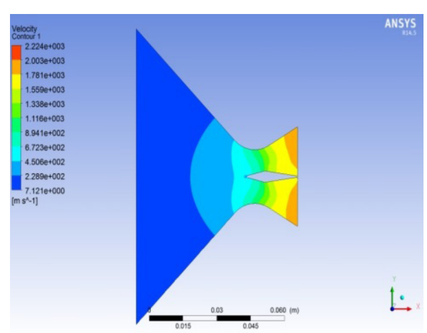
Velocity (θ = 15, R_t=12.5, α = 10)



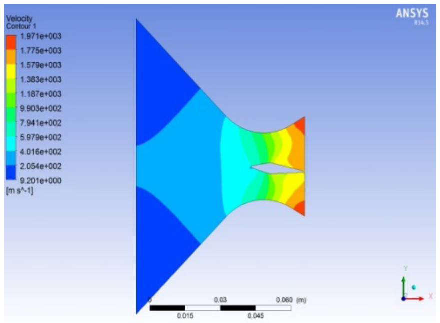
Velocity (θ = 15, R_t=22.8, α = 0)



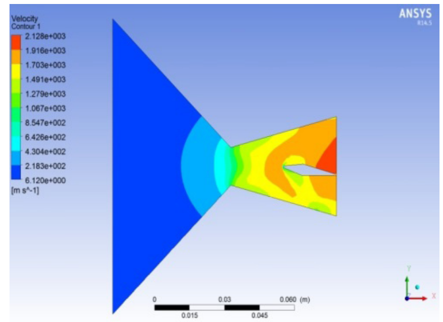
Velocity (θ = 30, R_t=0, α = 10)



Velocity (θ = 30, R_t=12.5, α = 0)

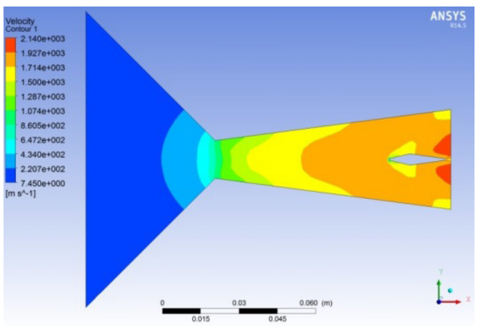


Velocity ($\theta = 30, R_t=22.8, \alpha = 5$)

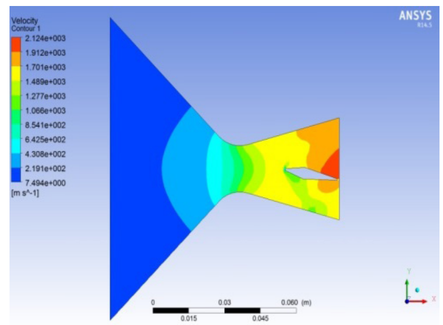


Velocity ($\theta = 15, R_t=0, \alpha = 5$)

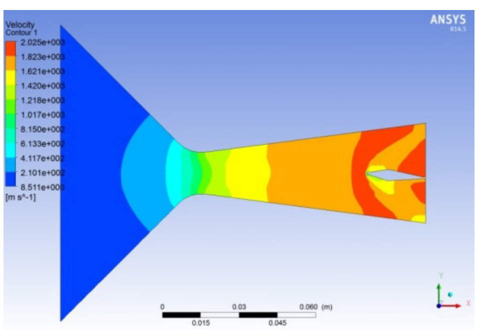
2. Space Condition (0Pa)



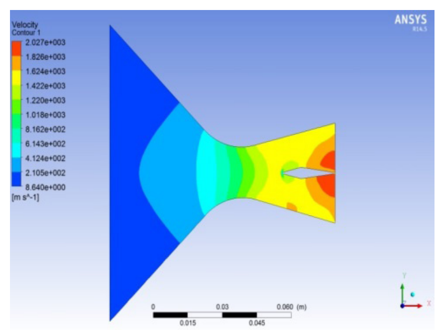
Velocity ($\theta = 7.5, R_t=0, \alpha = 0$)



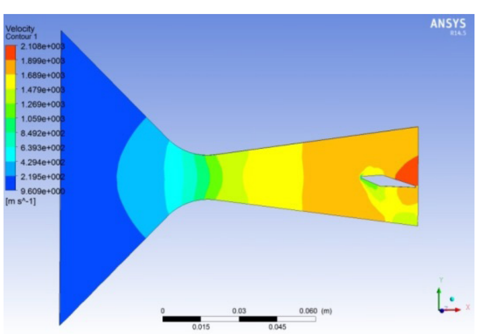
Velocity ($\theta = 15, R_t=12.5, \alpha = 10$)



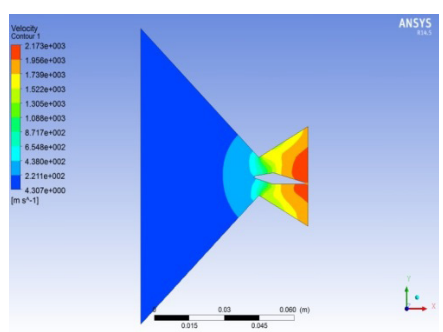
Velocity ($\theta = 7.5, R_t=12.5, \alpha = 5$)



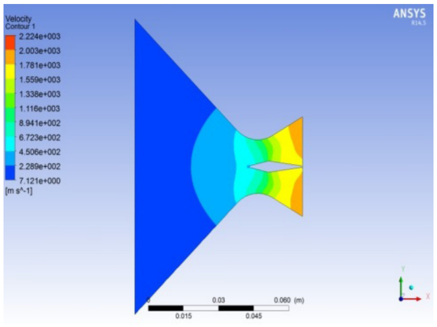
Velocity ($\theta = 15, R_t=22.8, \alpha = 0$)



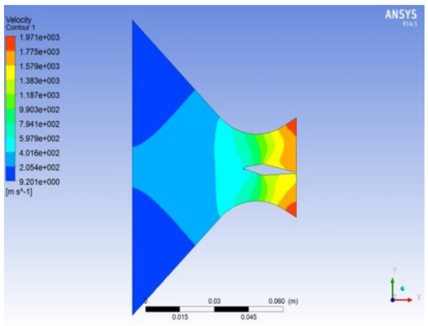
Velocity ($\theta = 7.5, R_t=22.8, \alpha = 10$)



Velocity ($\theta = 30, R_t=0, \alpha = 10$)



Velocity (θ = 30, R_t=12.5, α = 0)



Velocity (θ = 30, R_t=22.8, α = 5)

7. Discussion on Contour Result

In the nozzle exit section of analysis results produce by the velocity contour of the CFD has to be corresponding design parameters. Such as the result based values along by optimal values of nozzle design parameters obtained from following optimization technique. Here with consider the factors of Divergent Angle, Throat Radius and Angle of attack. Also response of velocity values of CFD analysis in two types operating condition applied for optimal parameters of nozzle obtained.

8. Optimization of Divergent Angle at ambient condition

Optimization of divergent angle for ambient condition, Optimum convergent angle is considered at case 7 because velocity at the exit of the nozzle will be larger is better value and it is having minimum thrust loss of 2.9% at even 10° deflection and also good A/B ratio. Optimum Divergent angle for jet vane thrust vectoring nozzle at ambient condition is 30°.

Case	Velocity m/s	Thrust loss %	A/B ratio
1	1835.37	6.40%	50/50
2	1791.99	8.60%	52/48
3	1745.76	11.01%	54/46
4	1796.34	7.70%	53/47
5	1804.9	7.20%	53/47
6	1727.61	11.20%	50/50
7	1920.8	2.90%	53/47
8	1813.49	8.30%	50/50
9	1723.09	12.90%	51/49

9. Optimization of Throat Radius at Ambient Condition

For the optimization of throat radius at ambient condition with the reference above table. Case 2, 5 and 7 gives the good A/B ratio with suitable thrust loss %.Hence Optimum throat radius for Jet vane thrust vectoring nozzle at ambient condition is 12.5mm.

10. Optimization of Divergent Angle at Space Condition

Optimization of divergent angle for space condition, Optimum convergent angle is considered at cases1, 2 and 3 because velocity at the exit of the nozzle will be larger is better value and it is having minimum thrust loss of 7.3%, 8.1% and 9.3% at 0°, 5° and10° deflection and also good A/B ratio. Optimum Divergent angle for jet vane thrust vectoring nozzle at ambient condition is 7.5°.

Case	Velocity m/s	Thrust loss %	A/B ratio
1	1814.52	7.30%	50/50
2	1799.27	8.10%	52/48
3	1776.86	9.30%	54/46
4	1799.87	7.50%	53/47
5	1804.24	7.20%	53/47
6	1738.81	10.60%	50/50
7	1627.66	17.70%	53/47
8	1843.49	6.82%	50/50
9	1729.43	12.50%	51/49

11. Optimization of Throat Radius at Space Condition

For the optimization of throat radius at ambient condition with the reference above table. Case 2, 5 and 7 gives the good A/B ratio with suitable thrust loss %.Hence Optimum throat radius for Jet vane thrust vectoring nozzle at ambient condition is 12.5mm.

12. Conclusion

Jet Vane TVC analysis with the help of CFD and Parameters optimization obtained from the taguchi analysis technique. The following observations were found in the jet vane TVC nozzle of 9(design) × 2(Operating Condition)= 18 times different configuration values of analysis results. Optimum parameters for ambient condition are divergent angle of 30° and Throat radius of 12.5mm. Similarly Optimum parameters for space condition are divergent angle of 7.5° and Throat radius of 12.5mm.Two operating conditions were considered to determine the optimum parameters for nozzle design for both rockets and missiles. Space condition will be suitable for rocket operation and ambient condition will be suitable for operation of tactical missiles.

13. References

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