Jassim. 2017. *Int. J. Vehicle Structures & Systems*, 9(3), 139-141
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.9.3.01

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Numerical Study on Skin Friction and Shock Inception in Various Geometries of Supersonic Nozzle

Esam I. Jassim

Dept. of Mech. Engg., Prince Mohammed Bin Fahd University, Khobar, Saudi Arabia
Email: ejassim@pmu.edu.sa

ABSTRACT:

In the present study, a numerical simulation is conducted to predict the influence of convergent-divergent nozzle geometry and NPR on the skin friction and shockwave location. Various shapes of nozzles are numerically simulated using the Computational Fluid Dynamics code. The shock position is examined to demonstrate the impact of nozzle shape on its location. Skin friction is shown to be smoothly decreasing at the divergent part of the nozzle for all NPRs lower than 2.0. However, an inverse behavioural trend was observed at NPR equal to 2. This could be attributed to the fact that the large disturbance of fluid near the wall is the major factor behind such an oddity. The results also show that the shock position is reliant on the nozzle geometry at certain NPR.

KEYWORDS:

Supersonic nozzle; Skin friction; Computational fluid dynamics; Nozzle pressure ratio; Shock wave

CITATION:

E.I. Jassim. 2017. Numerical Study on Skin Friction and Shock Inception in Various Geometries of Supersonic Nozzle, *Int. J. Vehicle Structures & Systems*, 9(3), 136-141. doi:10.4273/ijvss.9.3.01.

1. Introduction

Solid particles and liquid droplets could form during the expansion process of natural gas. The conventional equipment that is currently in use for gas purification is lacking reliability, mostly due to the inability to perform the purification process at minimum problems [1]. Recently, supersonic nozzles have proven to be firm and robust to use as an alternative particle separation device because of their capability to perform the process more efficiently. Recent studies on separating particles using supersonic nozzles have experimentally proved that the application of a shock wave in this manner results in a more efficient separation of the formed particles [2, 3]. It was also found that the separation efficiency significantly improves if the collection of the particles in the collecting zone occurs after the shock wave and body strcutres performance [3,4].

Measurements recorded from experiments proved that supersonic nozzles have privilege over other devices. Their compatibility, energy consumption, and high flow speed, mitigate particle mobility and prevent deposition, making them preferable in capturing tiny particles. Moreover, the total pressure of the natural gas will be recovered due to the formation of the shockwave in the divergent portion of the system. Okimoto and Brouwer [5] experimentally proved that using supersonic nozzles in the natural gas purification process could save up to 20% of compressor power, compared to the current conventional equipment. The objective of the present work is to assess the capability of numerical simulation in predicting the accurate location of the shock, as well as elucidating the impact of the nozzle shape on the position of the shockwave. The information gathered from these numerical models could be used in future research. That is, it could be used to validate experimental measurements used for the optimization of nozzle configuration, shock position, and fluid structure, as well as determining the suitability and efficiency of shock induction in the supersonic nozzle pertaining to particle separation. An experimental set-up is currently under construction to validate the simulation results.

2. Nozzle geometries

For the present case study, six geometries, depicted in Fig. 1, with equal inlet-throat-exit areas are created using GAMBIT software. The geometrical details are presented in Table 1. To construct the six geometries, unstructured tetrahedral cells were used (see Fig. 2 for rectangular nozzle), where their grid density was higher in the divergent part of the nozzle so that the resolution for capturing shocks can be improved. In the anticipated shock area between the throat and nozzle exit, as well as the area around the shock, the mesh size is finer than that of other locations along the nozzle. Flow is assumed to be turbulent and Standard Wall Function turbulence model is enabled. The size of meshes in the boundary layer region is constructed such that Y+ <1 is used to account for the viscous sublayer region.

Table 1: Dimensions of the convergent-divergent nozzle

Parameter	Value
Inlet area	2025 mm^2
Exit area	1454 mm^2
Throat dimensions	53.7×19.4 mm
Exit to throat area ratio	1.4
Length of Convergent Part	60 mm
Length of Divergent Part	117 mm

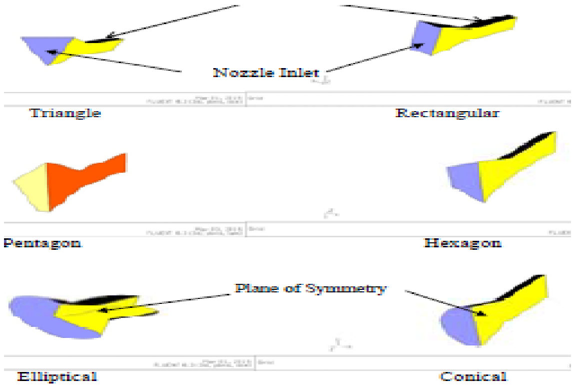

Fig. 1: Schematic of nozzles' geometries

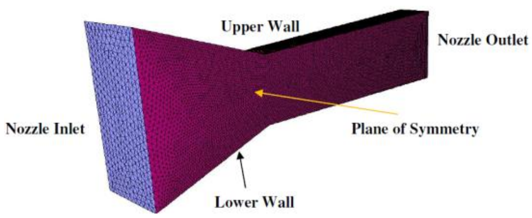

Fig. 2: Meshing sample of rectangular nozzle

3. Grid independency

The investigation of grid resolution presents the discrepancy between the varying grid sizes. Studies have shown that the thickness of the shock wave is of order of 0.1 mm when the gas undergoes severe gradients in the thermo-fluid properties [6, 7]. Hence, sufficient cell resolution should be maintained in the region where the shock is induced. Dharavath et al [7] suggested that the spacing between consecutive grids in the shock region should be within 100 µm. The conclusion is in agreement with the work of Anderson [8]. Accordingly, 3 different sizes of cells were chosen for investigation of grid resolution, namely 0.5 mm, 0.1 mm, and 0.05 mm element sizes. The predicted gas temperatures for the three element sizes are plotted and compared in Fig. 3.

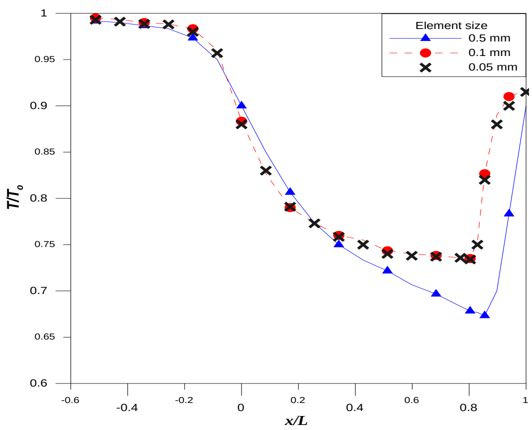

Fig. 3: Independency of Mesh Size

The variation of the static temperature (T) normalized to the inlet stagnation temperature (To) along the nozzle of length (L) for 3 different mesh sizes. Static temperature variation across the shock for 0.5 mm grid size drops substantially in comparison with the recommended grid size (i.e. 0.1 mm). However, such discrepancy almost vanishes when the grid size is shrunk to 0.05 mm. From an optimization perspective, the analysis of grid resolution concludes that 0.5 mm grid spacing is firmly acceptable in the convergent portion while 0.1 mm spacing is more adequate to capture the flow feature (including shock position) in the divergent portion of the nozzle.

4. Results and discussion

Contours of static pressure distribution along the nozzle for side, upper, and lower walls are presented in Fig. 4. There are no noticeable differences in pressure distribution for all walls. This is correct for all NPRs, geometries, and area ratios since the nozzles are symmetric [9]. Accordingly, we present here the skin friction and the variation of static pressure along the nozzle for side wall only and for different geometries. Skin Friction Coefficient is a non-dimensional parameter defined as the ratio of the wall shear stress and the reference dynamic pressure. The Near Wall Model calculates wall shear stress based on the assumption that the law u+= y+ exists in the viscous sublayer.

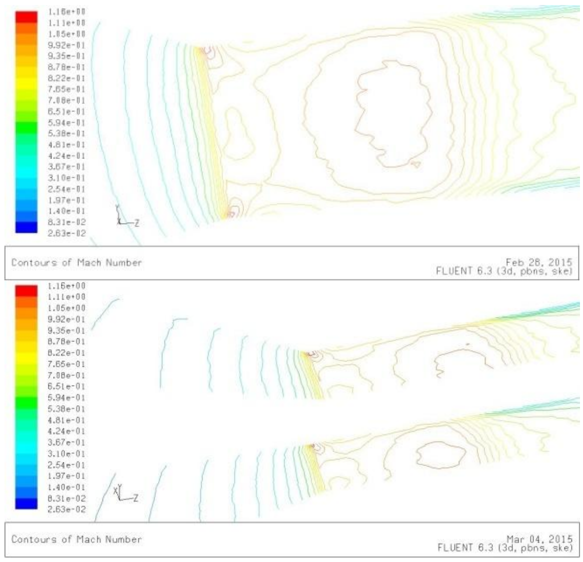

Fig. 4: Contours of static pressure along the rectangular nozzle; Side walls (top), Upper & lower walls (bottom)

Fig. 5 depicts the impact of NPR on local skin friction for a rectangular nozzle. A strong influence of NPR is visible. After a sudden rise near the throat, the skin friction decreases slowly for all NPR, except when NPR is equal to 2. This unusual trend can be attributed to the turbulence near the wall, as seen in Fig. 6. This figure compares the turbulence intensity distribution for two NPRs (including NPR =2) along the nozzle. Unlike other NPRs, the turbulent fluctuation velocity at NPR =2 increases in the direction of fluid flow, creating high disturbances near the wall. Hence, high friction is anticipated. Normalized static pressure is sketched in Fig. 7 against a dimensionless location at NPR = 1.6 for all geometries. Classic behaviour is observed since the pressure decreases along the convergent portion and divergent portion until the shockwave region. An abrupt ascent in the pressure then occurs due to the presence of shock and thus, the remaining divergent part functions as a diffuser in order to recover to ambient pressure in a smooth continuous fashion. There is a slight discrepancy of shock location between different shapes of the nozzle.

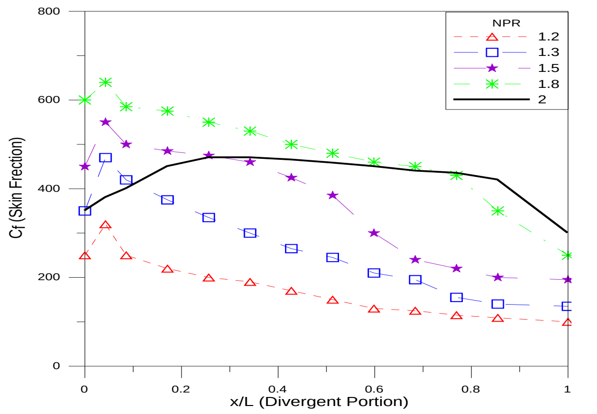

Fig. 5: Cf at various NPR

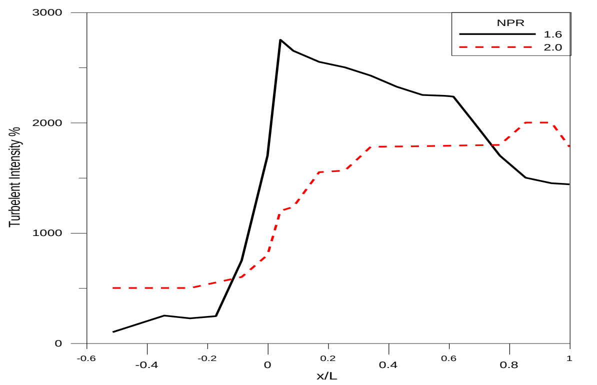

Fig. 6: Turbulence and disturbance intensity at NPR 1.6 and 2.0

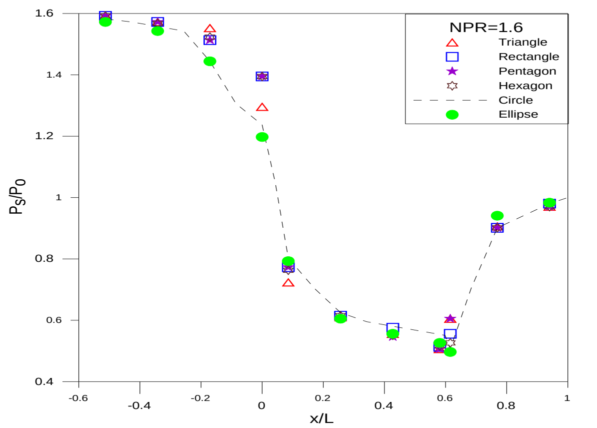

Fig. 7: Normalized static pressure of side wall for different geometries

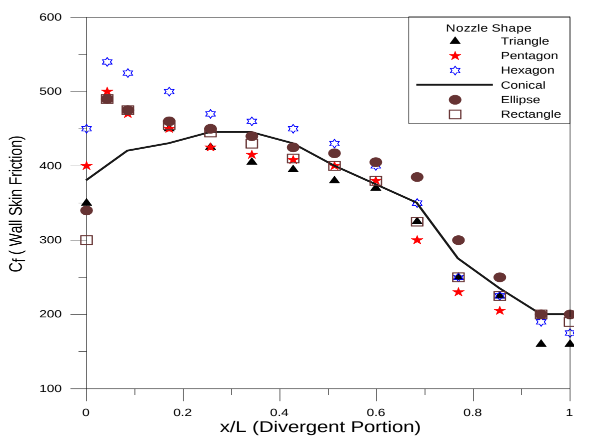

Fig. 8: Cf for different Nozzle Shapes

Fig. 8 shows the variation of skin friction with non-dimensional stream-wise location. Results are representative for all geometries under study. The hexagonal nozzle shows a higher shear wall than other shapes and the triangular nozzle is firmly the lowest. However, such differences shrink as the fluid flows downstream.

5. Conclusions

Normal shock impacts the turbulence of the fluid, eventually forcing small particles in a gas mixture to move toward the nozzle wall, hence increasing the particle-capturing efficiency. In the present study, a 3D-CFD simulation for six nozzle shapes was conducted to examine the influence of nozzle shape on skin friction and shockwave location. CFD outcome proves that the shape of the cross-section plays a significant role on altering the structures of the fluid, including the shockwave position. Skin friction was shown to be smoothly decreasing at the divergent part of the nozzle for all NPRs lower than 2.0. However, an inverse behavioural trend was observed at NPR equal to 2. Perhaps the large disturbance of fluid near the wall is the major factor behind such an oddity.

ACKNOWLEDGMENTS:

Author would like to acknowledge the sponsorship provided by King Abdulaziz City for Sci. & Tech. for funding this project (Project No.: MS-35-211).

REFERENCES:

[1] V. Alfyorov, L. Bagirov, L. Dmitriev, V. Feygin, S. Imaev and J. Lacey. 2005. Supersonic nozzle efficiently separates natural gas components, *Oil and Gas J.*, 5(103), 53-58.

[2] Maatschappij. 2000. *Removing a Gaseous Component from a Fluid*, Shell International Research B.V. Patent No. WO1999001194.

[3] V. Veen. 2001. *Removing Solids from a Fluid*, US Patent No. US6280502 B1.

[4] M. Rajasekaran, V. Hariram and M. Subramanian. 2016. A new minimal part breakup body-in-white design approach and optimized material map strength assessment, *J. Teknologi*, 78(7), 17-22. https://doi.org/10.11113/jt.v78.5597.

[5] F. Okimoto and J. Brouwer. 2002. Supersonic gas condition, *World Oil*, 223(8), 53-58.

[6] M. Gholamian, G.K.M Rao snf P. Bhramara. 2013. Numerical investigation on effect of inlet nozzle size on efficiency and flow pattern in squirrel cage fans, *Proc. IMechE, Part A: J. Power and Energy*, 227(8), 896-907. https://doi.org/10.1177/0957650913504566.

[7] M. Dharavath, P. Sinha and D. Chakraborty. 2010. Simulation of supersonic base flow: effect of computational grid and turbulence model, *Proc. IMechE, Part G: J. Aerospace Engg.*, 224(3), 311-319. https://doi.org/10.1243/09544100JAERO600.

[8] J.D. Anderson Jr. 1990. *Modern Compressible Flow with Historical Perspective*, McGraw-Hill, New York, USA.

A. Khan and T. Shembharkar. 2008. Viscous flow analysis in a convergent-divergent nozzle, *Proc. Int. Conf. Aero. Sci. and Tech.*, Bangalore, India.