Numerical Investigation on Variable Chevron Nozzle Using CFD

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Abstract -The main objective of this work is to design and analysis of five CD nozzles with different numbers of chevrons using ANSYS R2 2021. The geometries of the nozzles were modelled inSOLIDWORKS and analysed using computational fluid dynamics (CFD) to determinetheir exit Mach number, static pressure, static temperature, and acoustic power level. Theresults show that increasing the number of chevrons in the nozzle decreases the exit Machnumber and static pressure, but increases the static temperature and acoustic power level.The 6-chevron nozzle was found to have the highest exit Mach number and the loweststatic pressure, while the 12-chevron nozzle had the lowest exit Mach number and thehighest static pressure. These findings can be used to optimize the design of CD nozzlesfor various applications in aerospace engineering.

Keywords–Design, Computational Investigation,chevron nozzle,.

I. INTRODUCTION

Jet noise is a significant environmental issue associated with aircraft operations, particularly during take-off and landing. The noise produced by jet engines can have a negative impact on nearby communities, affecting their quality of life and causing health concerns. It can also restrict the number of flights that can operate during certain hours,leading to economic impacts.Jet noise is caused by the mixing of exhaust gases with the surrounding air, resulting in turbulence and pressure fluctuations that generate sound waves. The velocity of the exhaust gases, the temperature of the exhaust, and the geometry of influence this noisethe exhaust nozzle.

In today, the commercial engines are significantly more powerful and very lessnoise produces compare to commercial aircraft, which were used in 70s and 80s. Even though, the reducing noise from aircraft in locality surrounding airports (aerodromes) isstill in work. Aircraft manufacturers are works more and more to design engine, whichregulate the noise in airport localities. While aircraft take-off and landing engine have highload to produce more thrust, which will tends to give more noise compare to the aircraft atsky. Most research has been applied on jet engine nozzles to accelerate the mixing of theshear layers without reducing performance. Out of all noise sources, aircraft noise isconsidered as the second most disturbing noise (1st Rocket launch noise).People are very much concerned about the quality of their surroundings that noise isquoted as the first reason of bother. Nozzles are used to increase the velocity to be morethrust and control the uniform direction of air fuel mixture flow come from turbine. Innozzle, the static energy (due to flow after turbine) is converted into kinetic energy that kinetic energy create shear between flow, and surrounding because of this noise willproduce in jet engine. That is why it is necessary to reduce noise from the exhaust of nozzlefor that we can do change in dimensions of nozzle and we can change geometry ofnozzle.Chevron is a triangular tooth pattern on the circumference edge of exhaust nozzles are being implement on modern jet engine nozzles that help to reduce noise from theresulting jet. Chevrons are used to reduce the acoustic level at the exhaust. The successfulapplication of chevron nozzle to the aircraft engine is Boing747-8, which is powered byGEnx-2B67 engine and ROLLS-ROYCE Trent 1000 jet engine.

There has been various approaches to reducing jet noise over the years, includingthe use of sound-absorbing materials and changing the design of the engine and theaircraft. One promising approach is the use of variable chevron nozzles, which have beenshown to reduce jet noise significantly. Research into jet noise reduction is ongoing, withthe aim of developing quieter and more environmentally friendly aircraft.

1.1 JET NOISE

When air passes over the aircraft's airframe, it causes friction and turbulence, whichresults in noise. Planes land with their flaps down which creates more friction andproduces more noise than a plane with its flaps up. Engine noise is created by the sound ofthe engine's moving parts and by the sound of air being expelled at high speed. Most ofthe engine noise comes from the exhaust or jet behind the engine as it mixes with the airaround it.The level of noise generated varies according to aircraft size and type, and can differeven for identical aircraft depending on factors such as weather conditions. Aircraftengines do not produce as much lift in hot weather when the air is less dense, this mayresult in the aircraft flying at a lower altitude during takeoff. Other factors may includeweight of the aircraft, including passengers, baggage, cargo, and the amount of fuelon-board. In addition, the direction in which the aircraft is travelling may affect the noisegenerated over a particular location at Edinburgh Airport aircraft take off either to the eastor the west of the runway dependent on wind direction. The majority of the time (70%)aircraft will take off to the west. Aircrafts have been getting progressively quieter asdesign and engine technology have advanced. It is expected that today's airlines will beoperating quieter aircraft in the future.

1.2 WHY TO REDUCE JET NOISE?

Jet noise is a significant environmental issue associated with aircraft operations, particularly during take-off and landing. The noise produced by jet engines can have anegative impact on nearby communities, affecting their quality of life and causing health concerns. It can also restrict the number of flights that can operate during certain hours,leading to economic impacts.Jet noise is caused by the mixing of exhaust gases with the surrounding air, resultingin turbulence and pressure fluctuations that generate sound waves. The velocity of the exhaust gases, the temperature of the exhaust, and the geometry of the exhaust nozzle influence this noise.There has been various approaches to reducing jet noise over the years, includingthe use of sound-absorbing materials and changing the design of the engine and theaircraft. One promising approach is the use of variable chevron nozzles, which have beenshown to reduce jet noise significantly.Research into jet noise reduction is ongoing, with the aim of developing quieter andmore environmentally friendly aircraft.

1.3 INTRODUCTION TO CHEVRON NOZZLE

Nozzle design is an important aspect of fluid dynamics with significant applications in various engineering fields, such as rocket engines, gas turbines, and internal combustionengines. A nozzle is a device that increases the velocity of a fluid by reducing its pressurethrough a small opening or constriction. The design of a nozzle plays a critical role in determining the performance, efficiency, and safety of many engineering systems.This report focuses on the design and analysis of a convergent-divergent (CD)nozzle with chevrons using computational fluid dynamics (CFD) simulations. The mainobjective of this project is to optimize the CD nozzle design by evaluating the impact ofchevron geometry on the flow characteristics and performance of the nozzle. The projectaims to contribute to the field of nozzle design by providing insights into the effects ofchevron design on nozzle performance and the potential benefits of using chevrons in CDnozzles.The report is organized into everal sections, beginning with a review of thebackground and importance of nozzle design in various engineering applications. This isfollowed by a description of the methodology used in the design and analysis of the CDnozzle with chevrons, including the design process, meshing, boundary conditions, andsimulation settings. The results and analysis section presents the findings of the CFD simulations, including velocity profiles and acoustic power levels for the baseline nozzle,6-chevron nozzle and 10-chevron nozzle designs. Finally, the report concludes with adiscussion of the implications of the results and the potential future directions for nozzledesign research.

II. DESIGN OF CHEVRON NOZZLE

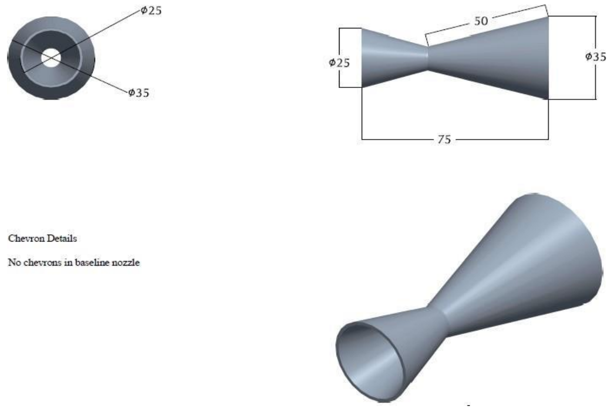


Figure 1: Baseline NozzleSide

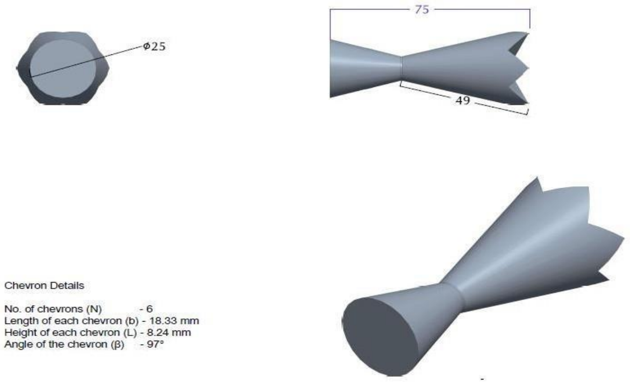


Figure 2: Nozzle with 6 Chevrons

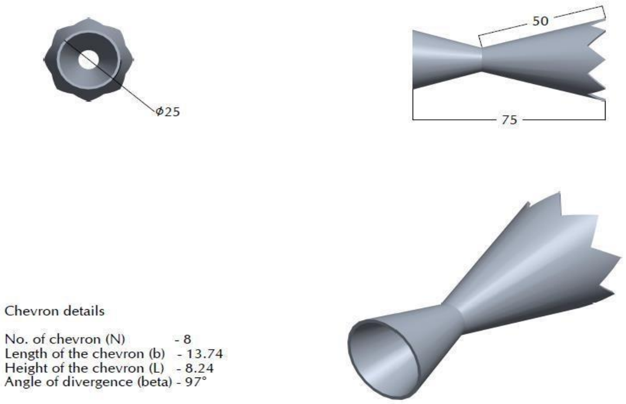
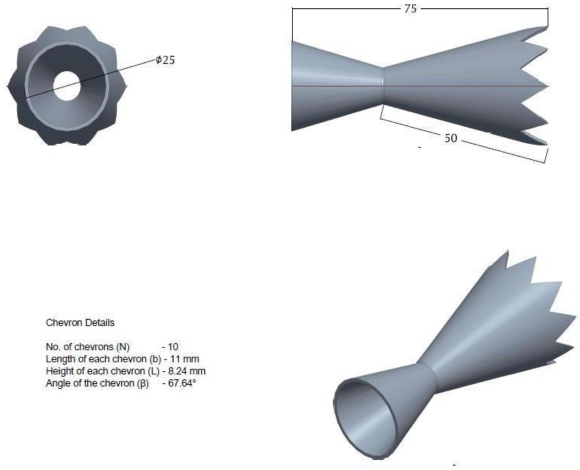


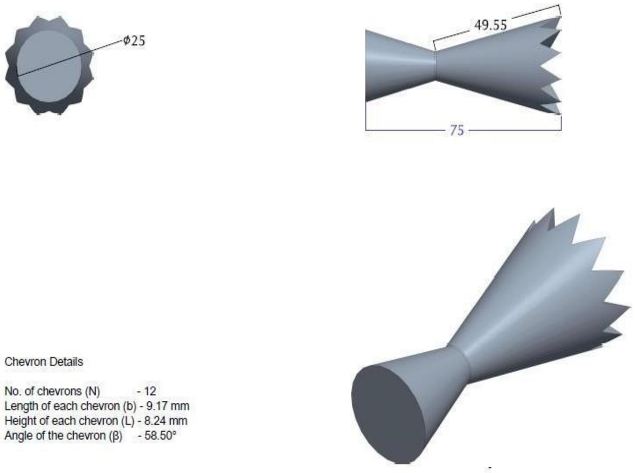
Figure 3: Nozzle with 8 Chevrons



Chevron Details

No. of chevrons (N) - 10
Length of each chevron (b) - 11 mm
Height of each chevron (L) - 8.24 mm
Angle of the chevron (β) - 67.64°

Figure 4: Nozzle with 10 Chevrons



Chevron Details

No. of chevrons (N) - 12
Length of each chevron (b) - 9.17 mm
Height of each chevron (L) - 8.24 mm
Angle of the chevron (β) - 58.50°

Figure 5: Nozzle with 12 Chevrons

III. MESHING OF CHEVRON NOZZLE

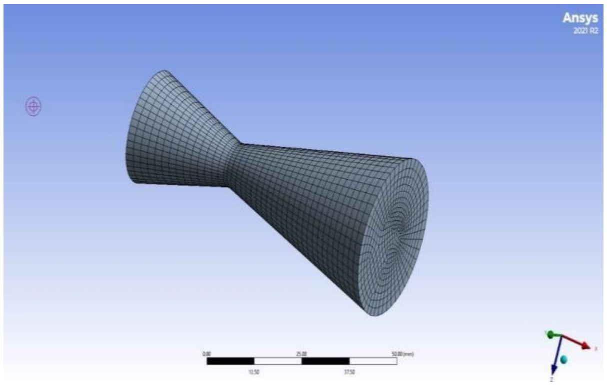


Figure 6: Meshing of baseline nozzle

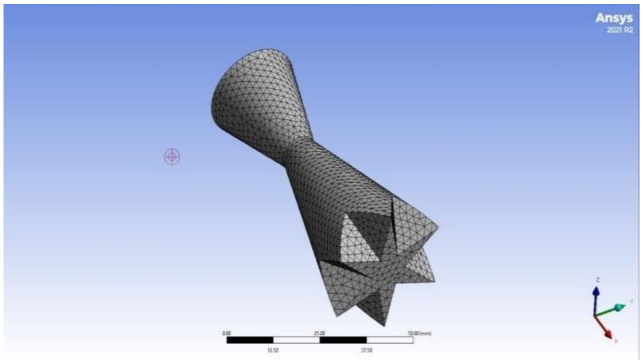


Figure 7: Meshing of 6 Chevron nozzle

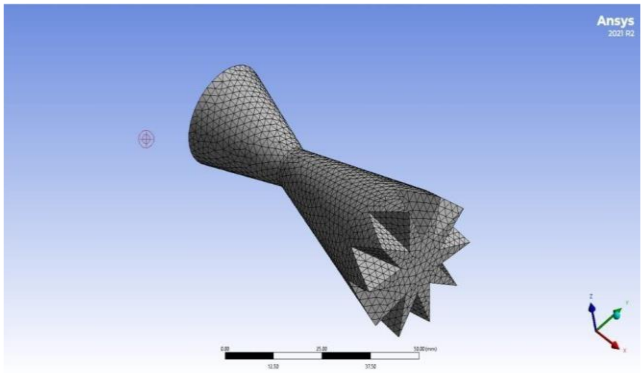


Figure 8: Meshing of 8 Chevron nozzle

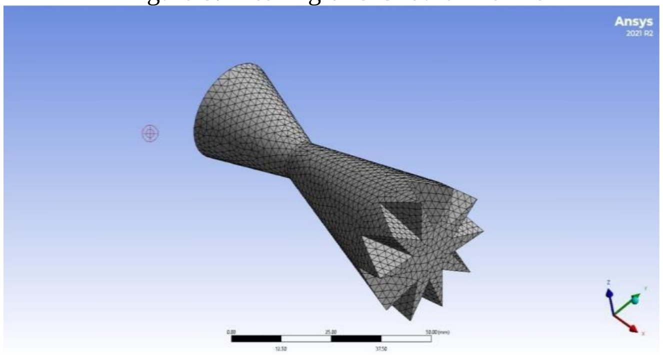


Figure 9: Meshing of 10 Chevron nozzle

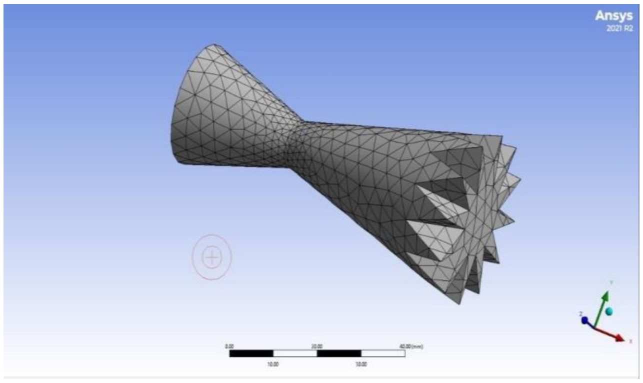


Figure 10: Meshing of 12 Chevron nozz

IV. COMPUTATIONAL INVESTIGATION

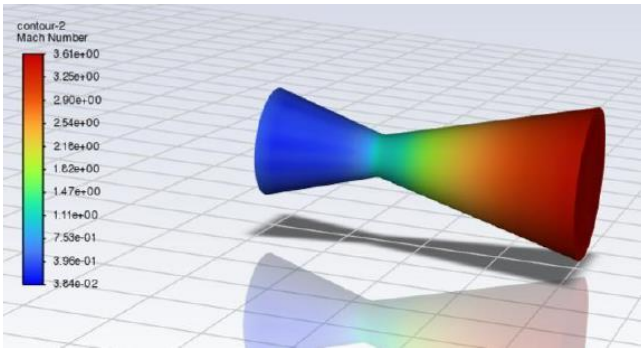


Figure 11: Mach Contour for baseline nozzle

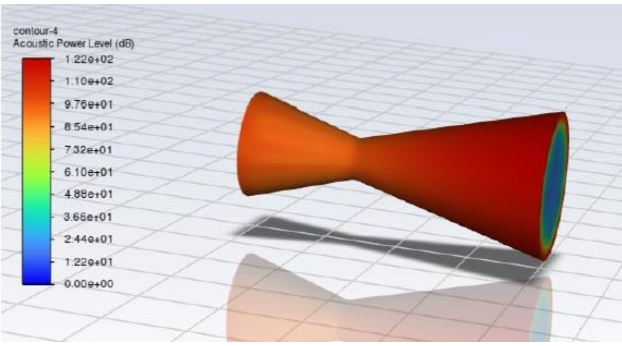


Figure 12: Acoustic Contour for baseline nozzle

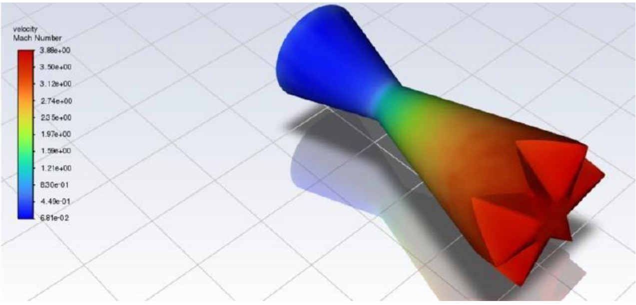


Figure 13: Mach Contour for 6-chevron nozzle

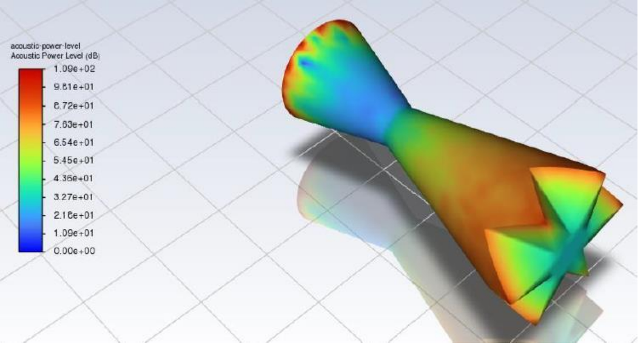


Figure 13: Acoustic Contour6-chevron nozzle

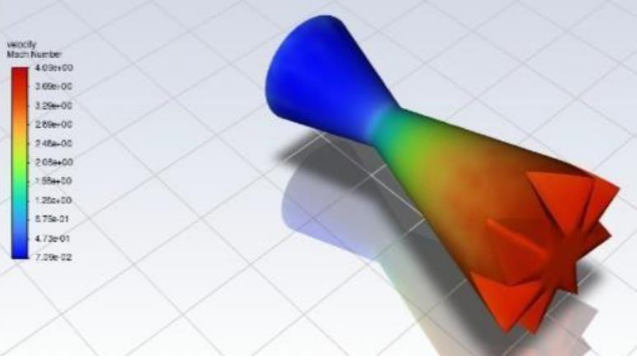


Figure 14: Mach Contour for 8-chevron nozzle

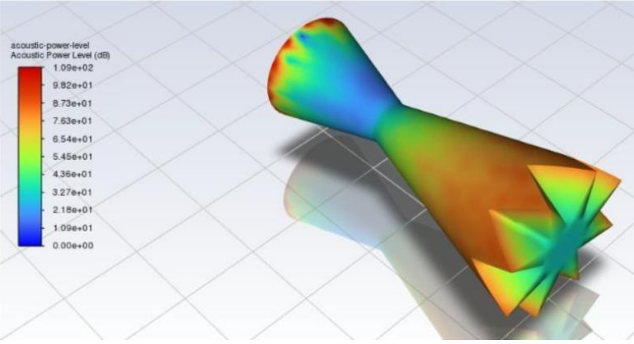


Figure 15:Acoustic Contour for 8-chevron nozzle

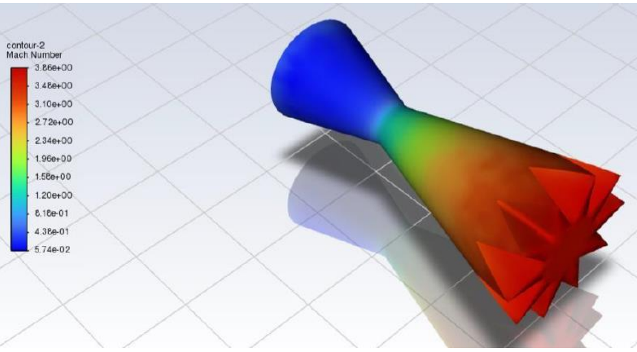


Figure 16: Mach Contour for 10-chevron nozzle

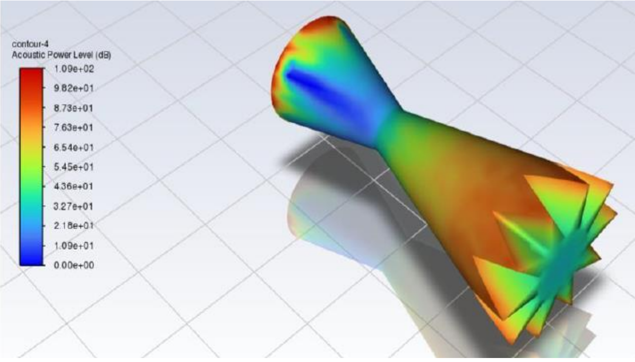


Figure 17:Acoustic Contour for 10-chevron nozzle

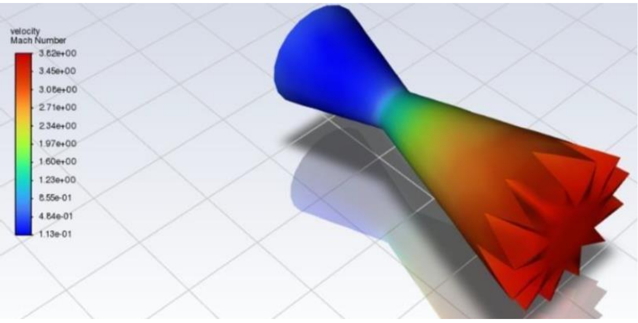


Figure 18: Mach Contour for 12-chevron nozzle

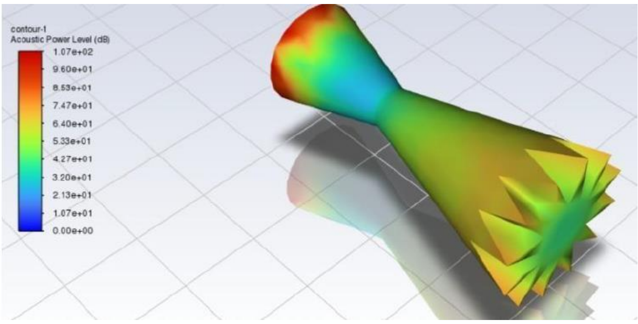


Figure 19: Mach Contour for 12-chevron nozzle

In this study, five convergent-divergent nozzles with different numbers of chevrons were designed and analysed using ANSYS Fluent. The baseline nozzle without chevrons servedas the reference. The numerical results were obtained for the exit Mach number and theexit acoustic power level.It was found that the addition of chevrons to the nozzle resulted in an increase in the exitMach number and a decrease in the exit acoustic power level. Among the designed nozzles, the 6-chevron nozzle showed the best performance in terms of the highest exitMach number and the lowest exit acoustic power level. The 10-chevron nozzle also showed improved performance compared to the baseline nozzle.However, the 8-chevron and 12-chevron nozzles showed a decrease in the exit Machnumber and an increase in the exit acoustic power level compared to the baseline nozzle.These results indicate that the addition of chevrons can have both positive and negativeeffects on nozzle performance, depending on the number and arrangement of chevrons.Overall, the results of this study provide valuable insights into the design and optimizationof convergent-divergent nozzles with chevrons for various engineering applications.

V.CONCLUSION

In conclusion, the design and analysis of five CD nozzles with different chevron angles were conducted using ANSYS Fluent. The baseline nozzle with no chevronsproduced an exit Mach number of 3.61, whereas the 6-chevron nozzle produced an exit Mach number of 3.88, and the 10-chevron nozzle produced an exit Mach number of 3.86.

The 6-chevron nozzle also showed the highest acoustic power level at the nozzle exit, indicating a higher noise level. The 8 chevron and 12 chevron nozzles produced exit Machnumbers of 3.69 and 3.45, respectively.Based on the results, it can be concluded that increasing the number of chevrons inthe nozzle increases the exit Mach number, but also increases the noise level. Therefore,the design of the nozzle should consider a trade-off between the desired Mach number andthe acceptable noise level. The results of this study can be used to optimize the design ofCD nozzles for various applications, such as rocket propulsion systems and supersonicaircrafts.

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