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Detailed Study on valved Pulsejet Engine Combustion Analysis

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ABSTRACT: These studies focus on the comprehensive analysis of the valved pulsejet engine has been numerically investigated using Ansys (CFD) program. Pulsejet engines, known for their intermittent thrust and simplicity, are experiencing a resurgence across various domains. This review synthesizes insights from historical milestones to contemporary investigations in pulsejet propulsion. It defines pulsejets as pressure-gaining devices, exploring variants like wave rotors and pulse detonation combustors, renowned for their ability to induce over 5% pressure gain through sinusoidal pressure oscillations. Advantages include reduced NO_x emissions and adaptability for turbine integration. The paper delves into pulsejet combustion, spotlighting mechanisms like turbulent flame ignition and auto-ignition from heated walls. Acoustic oscillations within pulsejets, particularly the quarter-wave tube and Helmholtz resonator modes, are elucidated. Challenges in miniaturizing pulsejets, with limited residence time and heat dissipation, are addressed. Numerical simulations clarify gas dynamics, acoustics, and chemical kinetics for downscaled pulsejets. The potential of valveless pulsejets in unmanned aerial vehicles is noted. The need for a holistic theoretical model governing pulsejet operation is emphasized. Historical contributions by figures like Marconnet and Schmidt are acknowledged. In conclusion, this concise review integrates historical foundations, contemporary explorations, and miniaturization challenges, underscoring the need for ongoing research to harness pulsejets' unique attributes across diverse applications.

I. INTRODUCTION

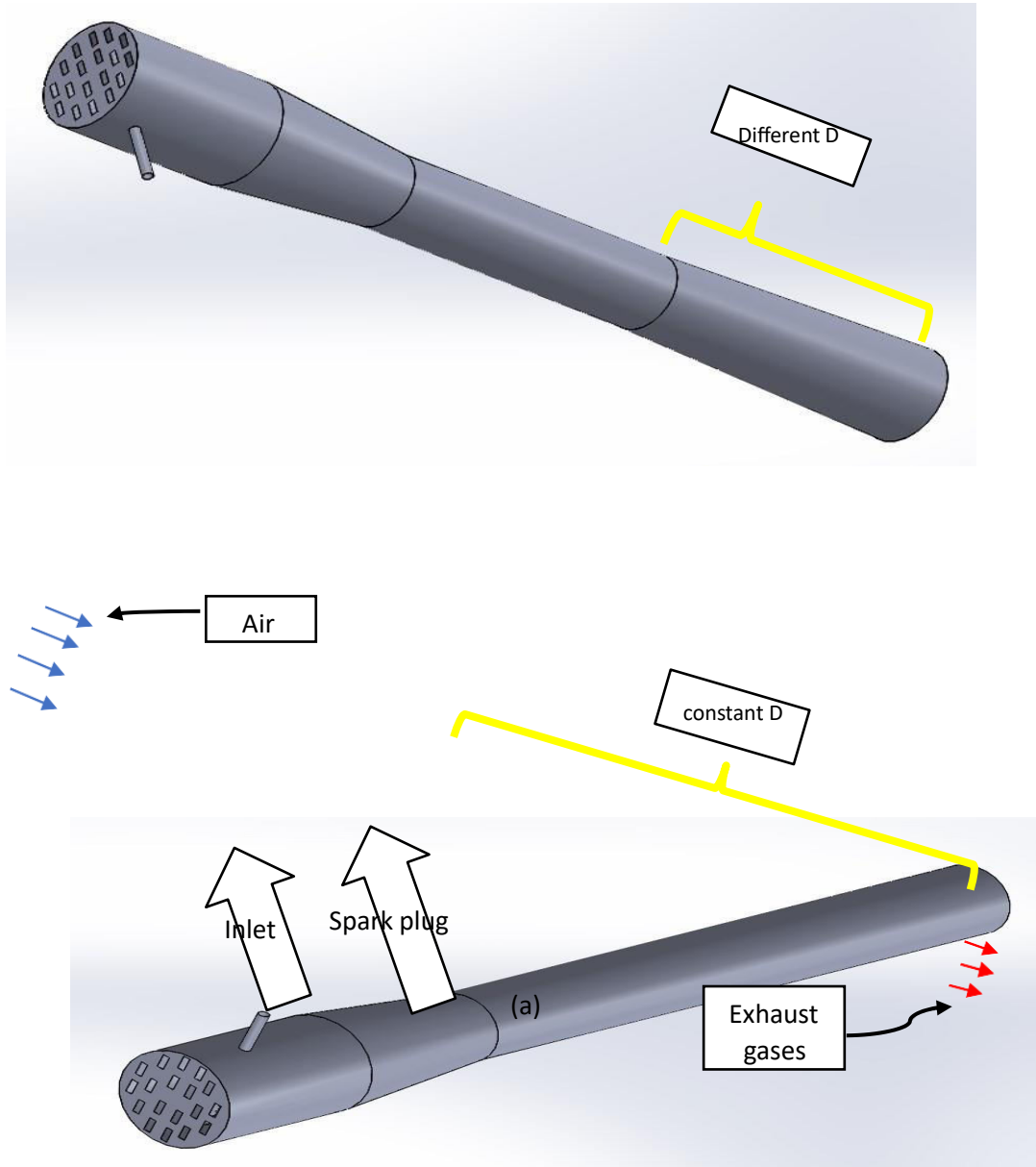
Geller et al [1] The introduction of this paper begins by defining a pressure gain combustion device as one that increases stagnation pressure, contrary to the Brayton cycle, which typically incurs pressure losses. Various combustors, such as wave rotors, pulse detonation combustors, and rotating detonation combustors, have been proposed to achieve this pressure gain through periodic unsteadiness. Pulsejets, in particular, are noted for potentially causing a more than 5% gain in pressure due to sinusoidal pressure oscillations. The advantages of pulsejets are highlighted, including their potential for integration with turbines due to their lower impulse loading compared to pulse detonation combustors. The paper also emphasizes the historical and diverse applications of pulsejets, ranging from powering V-1 bombs to industrial boilers. Additionally, the lower NO_x emissions of pulsejet combustors due to their high operating frequency are mentioned. The combustion process in pulsejets is discussed, focusing on a Rayleigh criterion-type combustion process involving in-phase pressure increase and heat addition. The exact combustion mechanism remains to be fully understood, with various proposed possibilities such as turbulent flame ignition, auto-ignition from heated walls, and shockless explosion combustion. The paper also addresses the acoustic oscillations within pulsejets, mentioning two main modes of oscillation: the quarter-wave tube and the Helmholtz resonator. It emphasizes the need to study pulsejets in depth, especially focusing on larger-scale engines like the Argus As 014, known for powering the V-1 flying bombs during World War II. The Argus engine's significance is highlighted, and the paper aims to analyze it using modern instruments to gain insights into both its unique characteristics and lesser-known features of pulsejets in general. The historical and technical aspects of the Argus As 014 engine, including its valve system, design considerations, and thrust, are discussed. The introduction concludes by underscoring the importance of this analysis in addressing existing research limitations and enhancing understanding of pulsejets. Isac et al [2] Pulsejets are simple engines with no established mathematical laws governing their working, leading to trial-and-error modifications. Previous analyses have provided insights into specific processes in pulsejets, but no single model has sufficiently

explained all the processes. The systemic nature of the processes involved in pulsejets requires further understanding of how they work and what makes them work. This article discusses the pulsejet engine, highlighting its simplicity in design and manufacturing. It acknowledges the lack of a comprehensive mathematical law governing pulsejet operation, making modifications and advancements challenging. However, despite this unpredictability, academics and scientists have attempted to develop theoretical models to understand how pulsejets work. The thermodynamic cycle of a pulsejet, explaining the stages of combustion, pressure changes, and the intake of fresh reactants. It emphasizes the need for a better understanding of the systemic processes involved in pulsejet engines. The historical background section mentions early pioneers in pulsejet research, such as Marconnet and Schmidt, and their contributions. It also mentions the Argus AS 109-014 engine used in World War II and post-war research, including Project Squid and French engineers' work. The paper highlights Dudley Smith's numerical model and the research done at North Carolina State University since 2004, demonstrating the feasibility of small-scale pulsejets. The introduction also discusses the experimental work conducted on valveless pulsejets, emphasizing the aim of understanding the effects of geometric variations. It points out the convergence of experimental and numerical studies with the goal of scaling down valveless pulsejet designs for use in micro-air vehicles (MAVs) and the use of propane as fuel in both types of research. T. Geng et al [3] The pulsejet is a simple propulsion device that does not require turbomachinery or moving parts, making it lightweight and ideal for thrust generation. The pulsejet was originally developed by the Germans during WWII for the V-1 'buzz bomb' and gained attention due to its impressive acoustic emission at 50 Hz. However, pulsejets received little attention after the late 1950s due to their low thermodynamic efficiency compared to gas turbine engines. This paper focuses on the investigation of a small-scale pulsejet with an overall length of approximately 8 cm, which is the smallest pulsejet reported to the author's knowledge. The goal is to understand the physical phenomena affecting pulsejet operation, scalability, and efficiency through modelling gas dynamics, acoustics, and chemical kinetics. The paper also highlights the advantages of valveless pulsejets for miniaturization due to their extremely simple design. Challenges in micro-propulsion devices include limited residence time, heat loss to walls, and the need for careful design of the fuel injection system, combustion chamber, and inlet geometry. Qun Wan et al [4] The paper investigates the feasibility of a 2-cm micro-pulsejet by numerically simulating the gas dynamic phenomena within the exhaust tube and comparing them with those for a larger pulsejet. The study focuses on pressure wave propagation, rarefaction wave generation, and the minimum pressure required to open the reed valves for fresh reactant intake. The characteristic operating frequency of the pulsejet is found to be approximately inversely proportional to its length. The boundary layer thickness in the micro-pulsejet is estimated to play a significant role due to the viscosity effects, which cannot be neglected. The paper aims to analyze the distributions and progressions of pressure, density, velocity, and temperature for both large and micro-pulsejets. The scaling down of the micro-pulsejet does not affect the minimum pressure required to open the reed valves. The thrust of the pulsejet is proportional to its cross-sectional area if the viscous effects are negligible, but in the micro-pulsejet, the thickness of the viscous boundary layer is comparable to the radius of the jet tube, resulting in a larger thrust reduction. The boundary layer effect is limited in the micro-pulsejet, and the pressure and rarefaction waves can propagate through the inviscid core region of the tube. H. Firmansyah et al [5] The paper discusses the design and analysis of a valveless pulsejet, which is a propulsive system that can be widely applied, especially in unmanned aerial vehicles (UAVs) like target drones. The designed valveless pulsejet is investigated numerically to check its performance, and the simulation results show that the engine's static thrust is 52.9 N, which is 19% higher than the target thrust. The simulation setup used for the analysis of the designed pulsejet is validated by comparing its results with a valveless pulsejet simulation for the same model, providing a higher level of confidence. The design method used for the valveless pulsejet is based on a reference for designing a valved pulsejet, which has been experimentally validated. However, the higher thrust obtained in the simulation may be due to the design method, which is best suited for valved pulsejets. The next step after the numerical analysis is the construction and testing of the pulsejet in real-time to verify the results. [5] W.L. Roberts et al [6] The research paper discusses the pulsejet engine combustor, which exhibits a net pressure gain between the intake and exhaust, resulting in higher exhaust pressure compared to intake pressure. The combustion process in the pulsejet engine is influenced by flight mach numbers, with lower mach numbers leading to lower explosion pressure and higher specific fuel consumption. Altitude has only a slight influence on the specific combustion in the pulsejet engine. The pulsejet engine can use various types of fuel, including gases, liquids, and solids. At high altitudes, the volume of air passing through the engine per second decreases due to thin air, resulting in decreased thrust. The ratio of fuel to air burned in the engine needs to be within a certain range, and with reduced air supply, less fuel can be burned, limiting achievable thrust. Increasing the amount of fuel in the pulsejet engine leads to higher explosion pressure and better explosion efficiency, resulting in increased thrust and lower specific fuel consumption. Sevda et al [7] the feasibility of a 2-cm micro-pulsejet by numerically simulating the gas dynamic phenomena within the exhaust tube and comparing them with a larger pulsejet. The minimum pressure generated by the pressure wave in the combustion chamber is critical for opening the reed valves

and allowing fresh reactants to enter. It is shown that both large and micro-pulsejets have a low enough minimum pressure. The characteristic operating frequency of the pulsejet is approximately inversely proportional to its length. The boundary layer thickness in the micro-pulsejet is significant, and viscosity plays an important role. Scaling down the micro-pulsejet does not affect the minimum pressure at the closed end, which is necessary for opening the reed valves. The frequency scales linearly with the inverse of the tube length. The boundary layer occupies a significant percentage of the cross-section, and viscosity plays an important role, particularly in the rarefaction wave. However, the pressure and rarefaction waves can still propagate through the core region of the tube and generate thrust and open the reed valves, respectively. The thrust of the pulsejet is proportional to its cross-sectional area if the viscous effects are negligible. However, in the micro-pulsejet, the thickness of the viscous boundary layer is comparable to the radius of the jet tube, resulting in a larger thrust reduction when scaling down the pulsejet. T. Geng et al [8] The pulsejet, due to its simplicity, may be an ideal micro propulsion system. In this paper, modern computational and experimental tools are used to investigate the pulsejet is an unsteady propulsion device that generates intermittent thrust. Due to its simple design and near-constant-volume combustion, the 15-cm valveless pulsejet is investigated using modern computational and experimental tools. Gas dynamics, acoustics, and chemical kinetics are studied to understand the physical phenomena affecting pulsejet operation, scalability, and efficiency. Numerical simulations are performed using CFX to model the 3-D compressible viscous flow in the pulsejet. The Westbrook-Dryer single-step combustion model is used to simulate the turbulent flow and reaction rate. The pulsejet is run on hydrogen fuel at this length scale. The paper aims to provide physical insight into the pulsejet cycle and discusses the comparisons between simulation results and experimental data.

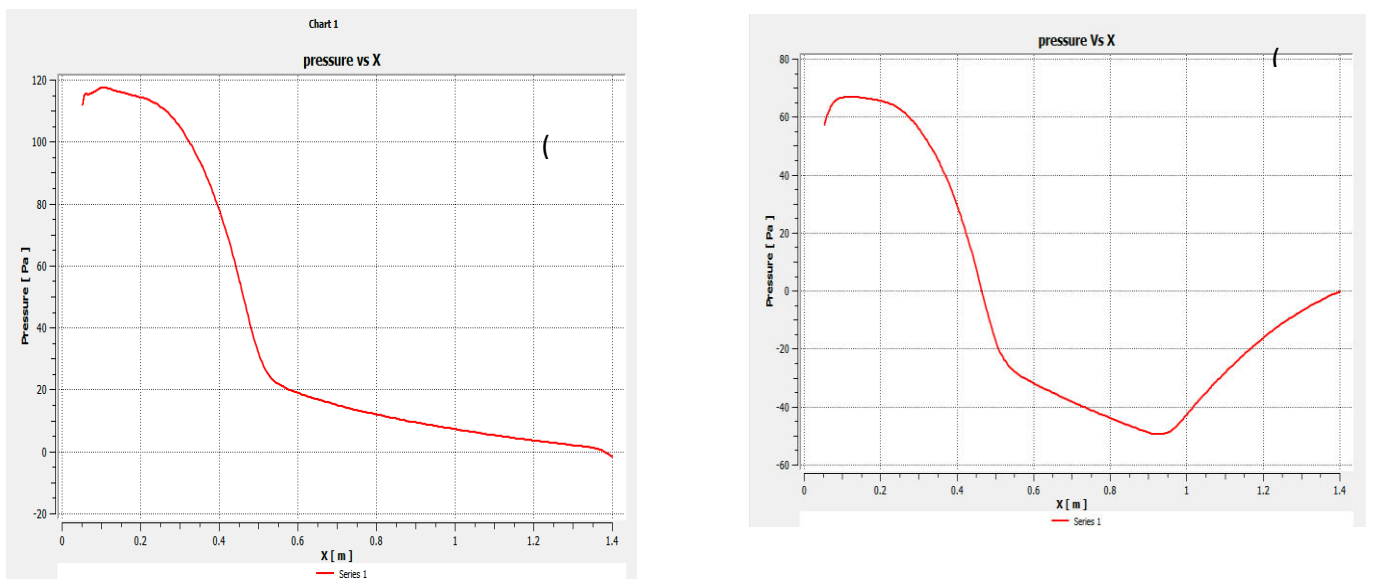
Anand et al [9] The study aims to investigate the behavior of valved-pulsejet combustion using ethanol and gasoline fuels with twelve different geometries. The study includes measurements of pressure inside the engine, pressure acoustics outside the engine, and thrust. The twin-peak behavior is observed in pressure inside the engine, thrust, and microphone with both fuels, indicating the presence of another phenomenon accompanying the acoustic field of the pulsejet engine. Ethanol fuel produces higher peak pressure values than gasoline due to its short-burst combustion behavior. Thrust and peak pressure are highly non-linear with respect to the geometry of the pulsejet engine, and different pulsejet configurations can produce the same amount of thrust. The empirical equation developed to predict the operating frequency suggests that the pulsejet's operating frequency is dependent on its geometry. Pulsejet is a propulsion system that utilizes aero-thermodynamic concepts and does not have any rotary parts, making it simple and cost-effective. Valveless pulsejets have gained attention for their potential applications in unmanned aerial vehicles (UAVs), particularly target drone UAVs, due to their low cost. Early studies on valveless pulsejets were conducted by Tao Geng and Fei Zheng, focusing on numerical and experimental investigations of valveless pulsejets. Tao Geng studied micro pulsejets with various designs and configurations, while Fei Zheng investigated high-speed valveless pulsejets. These studies were conducted at North Carolina State University, and further experimental investigations have been carried out there. [9]

Wan et al [10] The pulsejet engine is an unsteady propulsion engine that produces discontinuous thrust and has disadvantages such as high vibration, high noise level, and high fuel consumption. Despite these disadvantages, the pulsejet engine has advantages such as a high thrust-to-weight ratio, a simple design, and the ability to deliver intermittent thrust at zero velocity, making it suitable for take-off vehicles. the pulsejet engine consists of a tube with a valve system, allowing air to enter the combustion chamber, ignition, fuel injection systems, and the tailpipe (exhaust). Pulsejets are classified as valve, valveless, and pulse detonation engines. The pulsejet engine was first developed by Martin Wiberg in 1906, and further advancements were made by Karavodin and Marconnet in 1907. The pulsejet engine gained significant development during World War II, particularly with the German engineer Paul Schmidt's creation of the Schmidt Argus V1 pulsejet engine. [10]

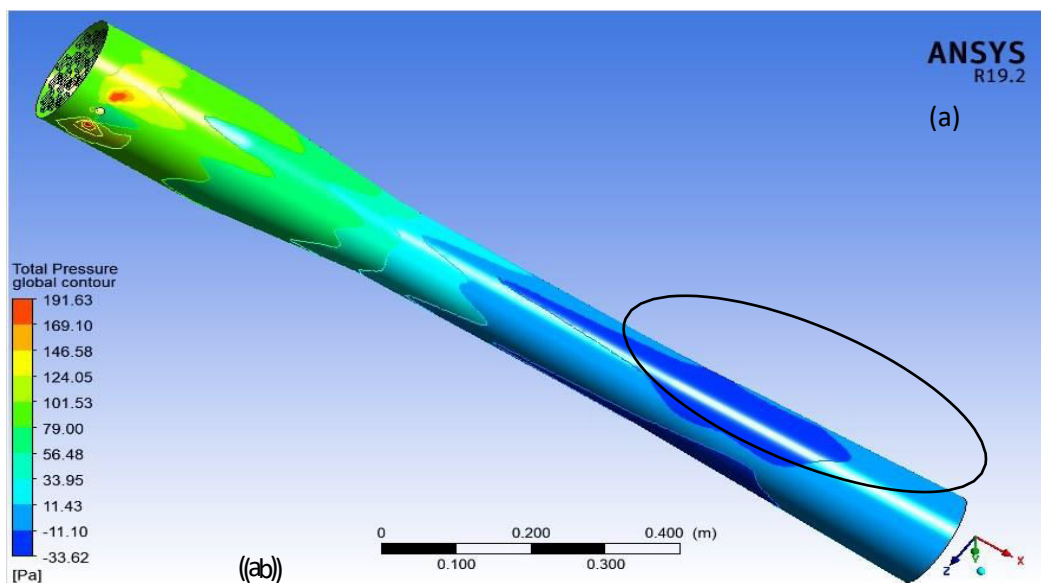


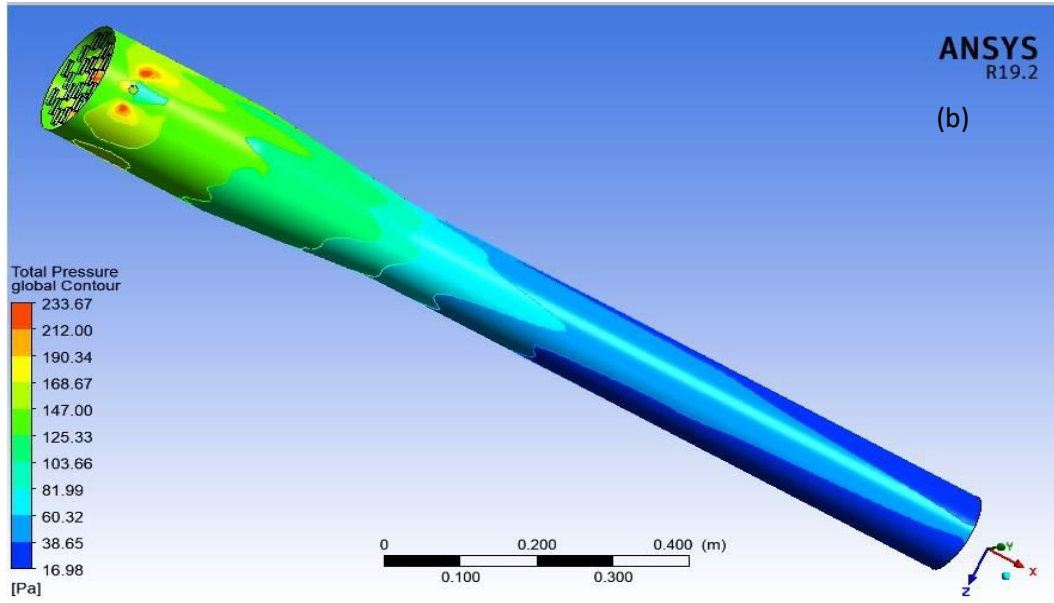
III. RESULT AND DISCUSSION

The two curves below (Figure 4) show essential values. First, the maximum pressure generated in the combustion chamber in the Constant D case is twice the value compared to the second case; this makes the engine with Constant D tailpipe more efficient because of its higher compression ratio. The second is the divergent shape in Different D case did not let the combustion chamber pressure reach to its maximum value in the moment of an explosion.



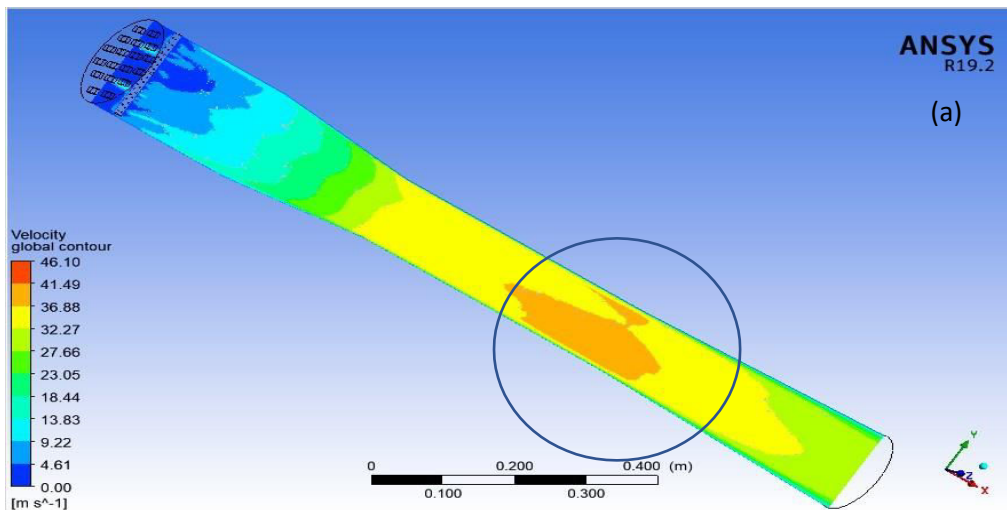
Pressure curves along with engine body (a) Different D ,(b) Constant D
Figure 4 shows the profile of pressure in general, but figure 5 explains the distribution of pressure on the engine body has been shown.





. Total pressure distribution (a) Different D (b) Constant D.

Due to the combustion presented in Figure 6b and 7b, the velocities (velocity and the velocity component in the x-direction) values increase gradually after the combustion chamber until reaches its greatest value at the last 45cm of the exhaust. In the second case, as shown in Figures 6a and 7a, the matter is so different, the velocities are decreases once it enters into the diffuser section of the exhaust pipe. The difference in maximum velocity concentration between the two cases is due to the effect of divergent shape on the behavior of exhaust gas flow.



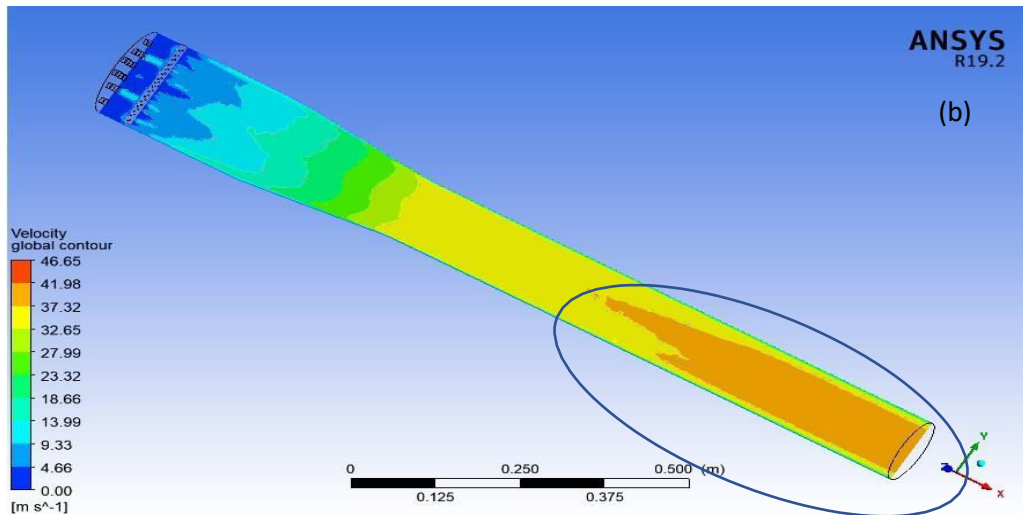


Figure 6. Velocity contour (a) Different D (b) Constant D.

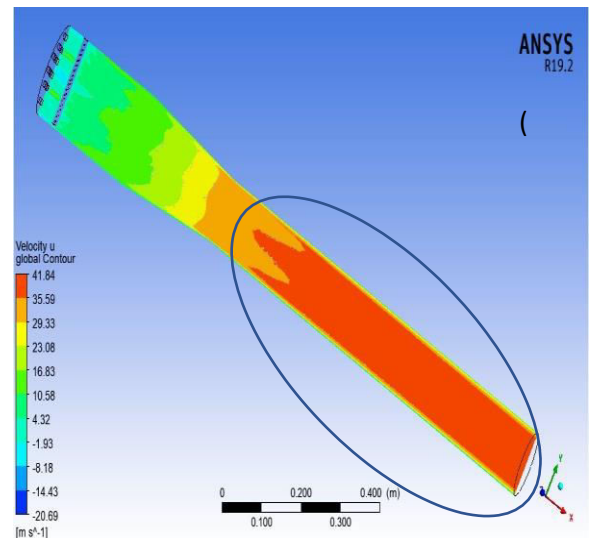
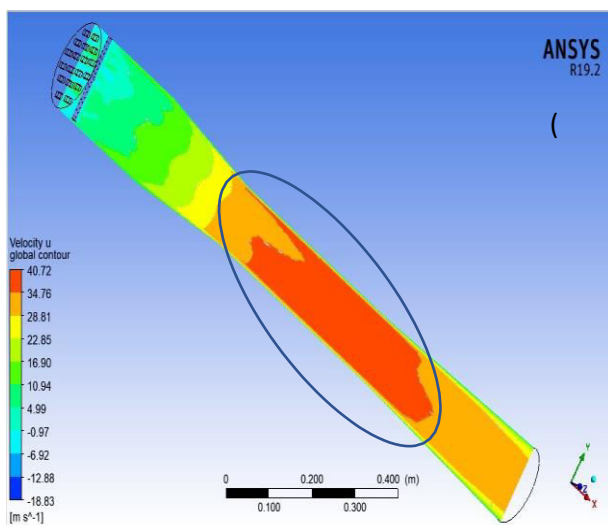


Figure 7. u-velocity (in X -direction) contour (a) Different D (b) Constant D.

The cross-section contour for u-velocity in the exit zone has been shown in Figure 8. In the DifferentD case (Figure 8a), the velocity grows from 16.9 m/s to 22.8 m/s, then to 28.8 m/s, finally reach to fully developed velocity at 34.7 m/s. This linear increase in the wide boundary layer of the flow field is terrible, especially in the exit zone of the jet engine. The Constant D case (Figure 8b) has a relatively small boundary layer thickness, and the flow reaches to fully developed velocity of 41.8 m/s. The difference in the value of fully development velocities and boundary layer thickness in the two cases return to the different the centering of maximum velocity along the tailpipe

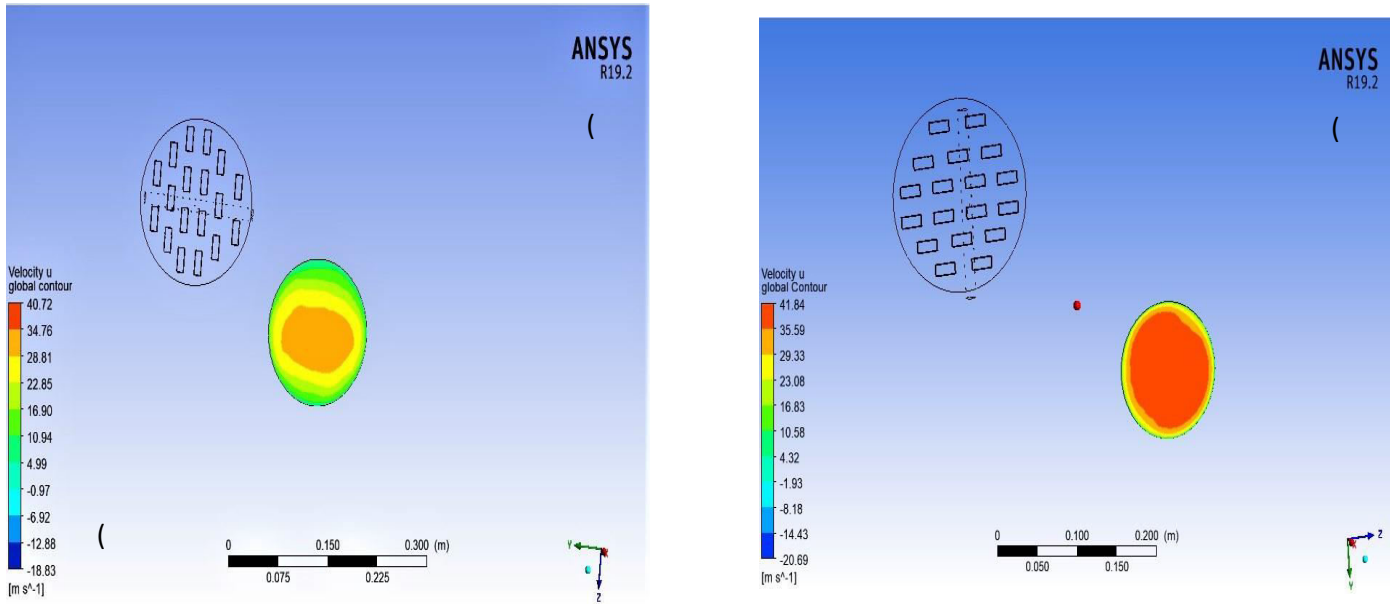


Figure 8. Boundary layer and U velocity (in X-direction) at the exit plain (a) Different D (b) Constant D.

Figure 9 explains the velocity profile in the two cases and explains that in Different D cases how the velocity suddenly decreases when exhaust gases enter to the last 45 cm of the engine.

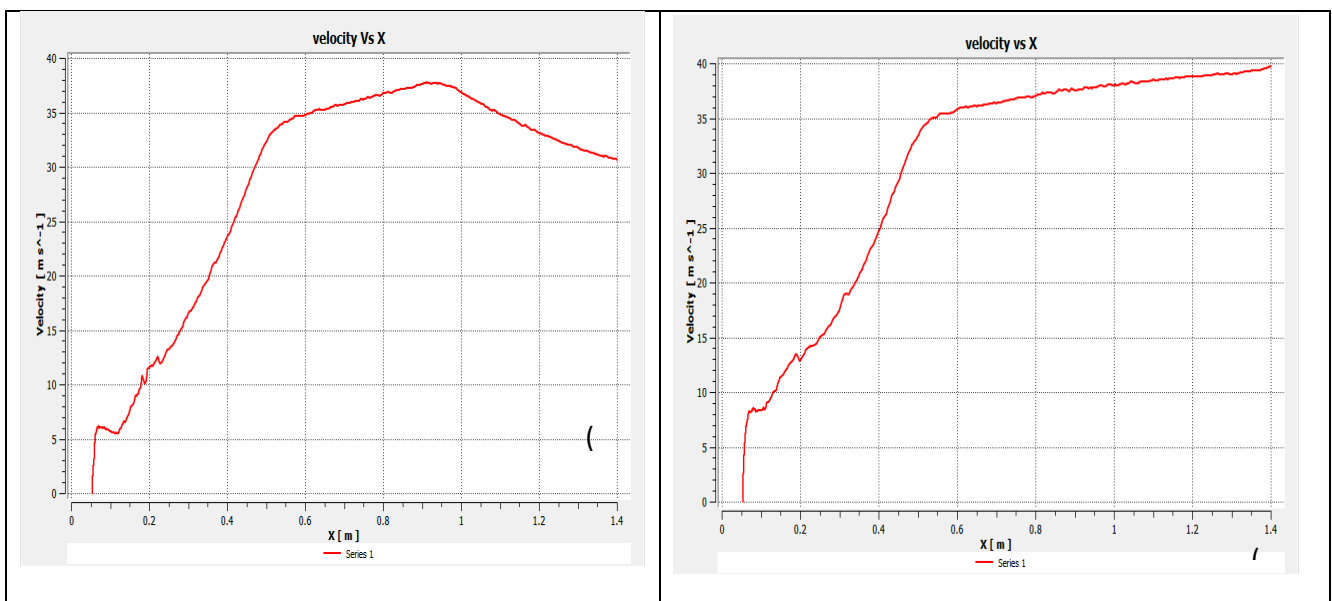


Figure 9. Velocity propagation curve along with engine body (a) Different D (b) Constant D.

Temperature degree was somewhat similar in the two cases; only the different D case temperature is greater by 10% from the other case, Figure 10.

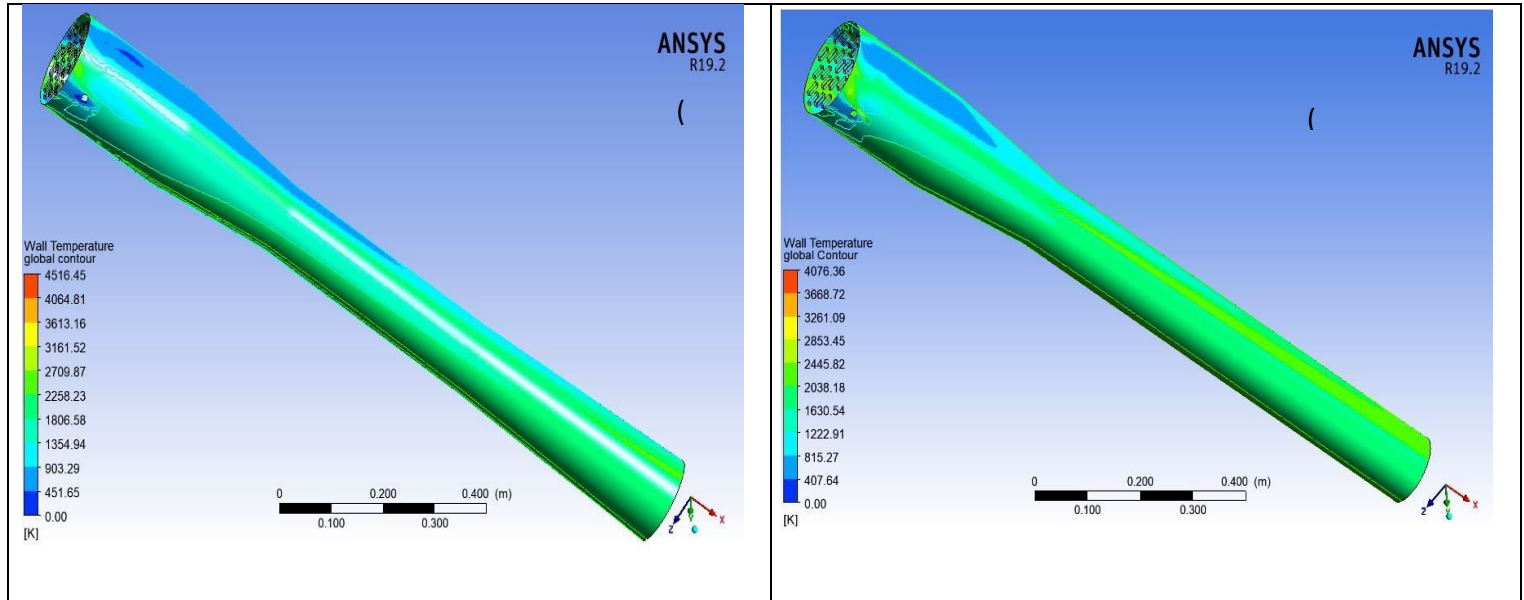


Figure 10. Temperature distribution at the wall (a) Different D (b) Constant D.

IV. CONCLUSIONS

After grasping the main ideas from the mentioned papers, the key points that can be summarized is as follows. Pulsejet engines, with their distinctive characteristics and simplicity, offer an intriguing field for future research and development. The scope of pulsejet engines encompasses several promising avenues, each with its potential for advancements and innovations. the scope of pulsejet engines is broad and promising, offering numerous opportunities for research and development across various domains. As technology advances and our understanding of pulsejet engines deepens, their potential for applications in propulsion and beyond will continue to expand. The divergent shape Different in D case did not let the combustion chamber pressure reach to its maximum value in the moment of the explosion; therefore, the magnitude of pressure in the engine with constant diameter exhaust pipe was greater by twice from the other case, also make the pressure curve of different D case was simply rather strange. the maximum velocity was the same in the two cases but centered in the mid-length of the tailpipe of Different D case and distributed. The temperature distribution almost the same in the two cases, but the engine has a different diameter tailpipe generate temperature greater than the second case by 10%. the boundary layer in the pulsejet engine is variable and cannot be negligible. when flow inside the engine is subsonic, the pulsejet engine that has a constant diameter exhaust pipe was having better compression ratio and gas dynamic than the different D case.

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