Manipulation of Shock Train for Underexpanded Jets by Tabs

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***Abstract*. This paper presents the influence of tabs on shock trains of Underexpanded jet issuing through a convergent nozzle. The shadowgraph of flow is captured to have an insight of shock structure prevailed in Underexpanded jet. Tabs were attached diametrically opposite. Tabs used in the study were elliptical and perforated elliptical. The blockage ratio was 5%. Shadowgraph pictures were captured for tabs along and normal to the flow for nozzle pressure ratios (NPRs) of 3, 4, 5, 6 and 7. It was observed that elliptical tabs, highly distorts the shock train compared to perforated elliptical tabs. However perforated elliptical tabs are more influential to reduce noise level as well as compensation for thrust loss.**

Keywords: Underexpanded flow, tabs, shock train, distortion, noise, thrust loss

NOMENCLATURE:

D Nozzle exit diameter
M Jet Mach number
NPR Nozzle Pressure Ratio
P_c Centre line pressure
P_0 Settling Chamber pressure

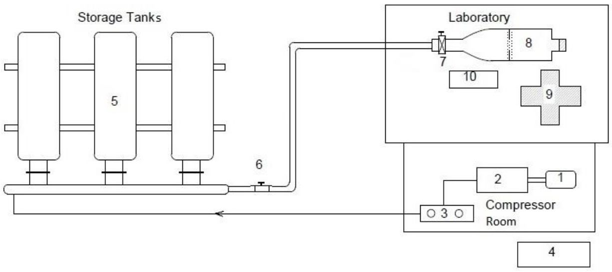
1. INTRODUCTION

The atmospheric pressure is lower than the exit pressure, is called underexpanded. In this case, the flow continues to expand outward after it has exited the nozzle. This behavior also reduces efficiency because that external expansion does not exert any force on the nozzle wall. This energy can therefore not be converted into thrust and is lost. Ideally, the nozzle should have been longer to capture this expansion and convert it into thrust. Discharges fluid at an exit pressure greater than the external pressure this owes to the exit area being too small for an optimum area ratio. The expansion of the fluid is incomplete Further ex For higher external pressures, separation will occur inside the divergent portion of the nozzle .The jet diameter will be smaller than that of the nozzle exit diameter . Separation location depends on local pressure and wall contour. Decreasing external pressure pushes the separation plane out toward the nozzle (optimal altitude is being approached) expansion happens outside of the nozzle. Nozzle exit pressure is greater than local atmospheric pressure. An under expansion in a nozzle is where the gas is expelled at a greater pressure than the atmosphere around it, this causes the plume to expand outwards reducing the efficiency of the thrust.

An over expanded nozzle is where the gas is expelled at a lesser pressure than the atmosphere around it, thus as it leaves the nozzle the gas gets pushed in by the atmosphere reducing the efficiency of the thrust.

As a rocket flies upwards the expansion of the gas in the nozzle is obviously going to change due to the reducing atmosphere, so the nozzle can only be designed for one altitude and will be inefficient for all other altitudes.

The interaction between a normal shock wave and a boundary layer along a wall surface in internal compressible flows causes a very complicated flow. When the shock is strong enough to separate the boundary layer, the shock is bifurcated and one or more shocks appear downstream of the bifurcated shock. A series of shocks thus formed, called “shock train”, is followed by an adverse pressure gradient region, if the duct is long enough. Thus the effect of the interaction extends over a great distance. The flow is decelerated from supersonic to subsonic through the whole interaction region. In this sense, the interaction region including the shock train in it is referred to as “pseudo-shock” in the present paper, as Crocco called it. The shock train and pseudo-shock strongly affect the performance and efficiency of various flow devices. In the present review some fundamental characteristics of the shock train and pseudo-shock are first described. Some simple predictions are made to simulate these very complicated phenomena. Pseudo-shocks appearing in various flow devices are explained. Control methods of the pseudo-shocks are also described. Finally, the current understanding of self-excited oscillation of pseudo-shock is reviewed.



1.80 HP induction motor	6. Gate Valve
2.Reciprocating compressors	7. Pressure Regulating Valve
3. Activated Charcoal filter and Silica gel dryer units	8. Settling Chamber
4. Water Cooling unit	9. Traversing system
5. Storage tanks	10. Instrumentation Desk

Fig 1. Layout of the open jet facility laboratory at TEC

2. EXPERIMENTAL FACILITY AND PROCEDURE

Compressed air is ducted to the settling chamber, where the flow reaches a settled equilibrium. Required stagnation pressure in the chamber can be maintained with the pressure-regulating valve. The stagnant air from the chamber was expanded through a convergent nozzle, fixed at the end of the settling chamber. The pressure in the chamber was controlled to achieve the desired Mach number at the nozzle exit.

2.1. Open Jet

A convergent nozzle of exit diameter 20 mm made of gunmetal was used in this study. The nozzle was fixed at the end of the settling chamber with "O" ring sealing to avoid leak. Required pressures were maintained in the settling chamber to generate the desired NPR for the sonic jet.

2.2. Elliptical Perforated Tab

Elliptical perforated tabs used are made of brass. The major and minor axis were 1.25 mm and 1.5 mm, respectively. Two tabs were placed at diametrically opposite locations at the nozzle exit .The tabs are provided with a slot and positioned in such a way that the arc cavity was facing the flow. The area blockage at the nozzle exit due to the tabs is 5%. For the under expanded sonic jet also, the static pressure is not the same as the surrounding pressure, also, the local static pressure varies from point to point because of the waves prevailing in the jet core. Therefore, it is not possible to convert the measured pressure to velocity. Hence, the pressures
are used by non-dimensionalzing with the settling chamber pressure to represent the jet decay.
In accordance with this finding of Chiranjeevi and Rathakrishnan, the perforated tabs are capable of shedding mixing, promoting small vortices of mixed size is found to promote the jet mixing significantly.

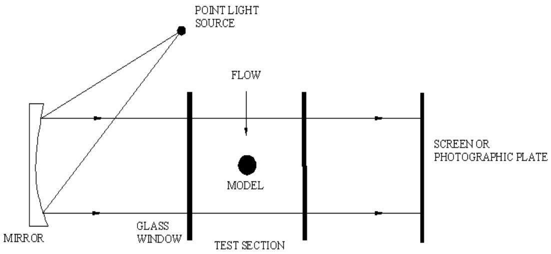


Fig 2. Schematic diagram of shadowgraph setup.

3. RESULTS AND DISCUSSION

3.1 Shadowgraph Technique

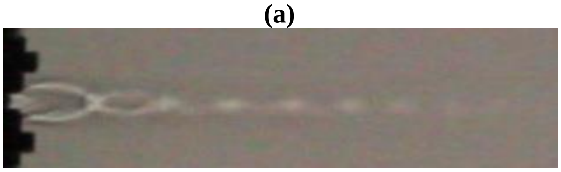
(a)

(b)

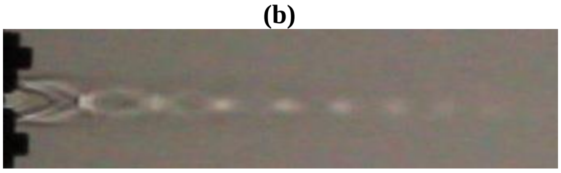
(c)

Fig 3. Shadowgraph pictures (a) Uncontrolled jet (b) Elliptical solid tab (c) elliptical perforated tab at NPR 7, sonic jet.

(a)



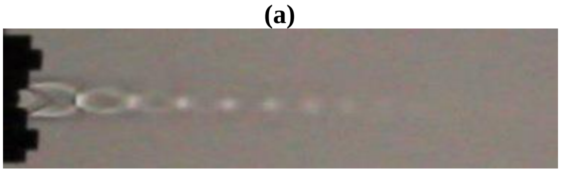
(b)



(c)

Fig 4. Shadowgraph pictures (a) Uncontrolled jet (b) Elliptical solid tab (c) elliptical perforated tab at NPR 6, sonic jet.

(a)



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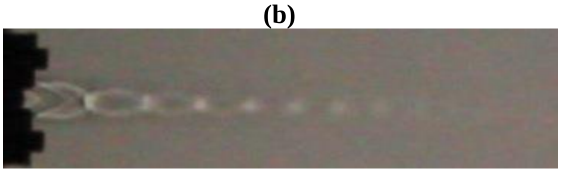


(c)

Fig 5. Shadowgraph pictures (a) Uncontrolled jet (b) Elliptical solid tab (c) elliptical perforated tab at NPR 5, sonic jet.

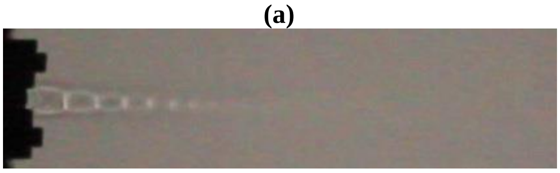
(a)

(b)

(c)

Fig 6. Shadowgraph pictures (a) Uncontrolled jet (b) Elliptical solid tab (c) elliptical perforated tab at NPR 4, sonic jet.

(a)



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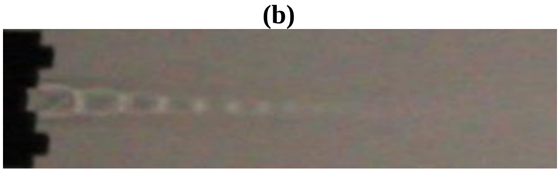

(c)

Fig 7. Shadowgraph pictures (a) Uncontrolled jet (b) Elliptical solid tab (c) elliptical perforated tab at NPR 3, sonic jet.

Figure 3 shows that, when elliptical perforated tabs are introduced at the nozzle exit, the first cell becomes shorter and the fans are perturbed. The flow deceleration by the elliptical perforated tab creates a pressure uphill at the tab face, which together with presence of the wall, produces a pair of counter rotating streamwise vortices. They play crucial role in the dynamics of shear layer. They are also responsible for the bulk of entrainment and transfer of mass and momentum across the shear region.

Figure 4 presents that, the influence of perforation is upto third shock cell, which may be taken as an indication of suppressing jet noise at NPR 6.

Figure 5 represents shock train of elliptical perforation NPR 5. The effect of perforation compared to uncontrolled jet is significant. It is seen from shadowgraph picture that, the third shock cell is partially visible.

Figure 6 shows shock pattern elliptical perforation tab for sonic underexpansion level of 4. Strong expansion fans are visible in the image compared to uncontrolled.

Figure 7 shows that, the elliptical perforation tabs disperse the supersonic zone of flow, making it occupy greater zone of flow field compared to other uncontrolled flow. This causes the waves to become weaker and the jet to spread faster NPR 3.

4. CONCLUSIONS

The present investigation of jet control with perforated tabs at the nozzle exit shows that the velocity decay is faster and core length is reduced drastically as compared to uncontrolled jets at all subsonic and sonic correctly expanded conditions of the present study. The perforated jets also tend to reduce pitot pressure oscillations in core region of underexpanded sonic jet compared to the uncontrolled jet. Thus, the mixing promoting vortices of mixed size shed by perforated tabs are capable of promoting mixing of subsonic and sonic jets. Also, the tabs could be able to weaken the waves in the jet core. The weaker shocks in the controlled jet compared to uncontrolled jet may be regarded an advantage from aero - acoustic point of view, since weaker the shocks, less will be the broadband shock noise component.

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ISSN: 2278-0181
Confcall - 2018 Conference Proceedings

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