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Elliptical Tabs as a Mixing Enrichment Tool for Jet Nozzles

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ABSTRACT:

Mixing efficiency helps the thrust gain and jet noise reduction. Aerospace and aviation research communities around the world are constantly demanding cleaner, quieter and more efficient commercial aircrafts. Though there are many sources of noise during flight, one such is deficient mixing of air at the rear of the nozzle, uneven expansion of nozzle and corresponding engine noise is quite dominant. The mixing proficiency is achieved by mixing of cold air at the surroundings with the hot air that exits the nozzle. To reduce the engine noise, elliptical tabs are employed at the exit of convergent nozzle. These are passive noise controllers which create vortices to the outlet flow and entrain the cold mass from the surroundings in order to reduce the noise level. This paper is concerned with the various shapes and sizes of tabs to test the mixing efficiency at different Mach numbers. Further, mixing efficiency is evaluated by both qualitative and quantitative analysis of shadowgraph system and by employing a propitious pressure scanner.

KEYWORDS:

Nozzles; Tab; Pressure ratio; Shadowgraph; Counter-flow; Mixing efficiency

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1. Introduction

The aircraft noise is a huge worry to the individuals who dwell closer to the air terminals. As the quantity of air traffic increments, so does the effect on those expanding numbers who remains close to our bustling air terminals. The administrative reaction to constraining airplane noise is encapsulated in Federal Aviation Regulation (FAR) Chapter 36 in the Unites States and in International Civil Aeronautics Organization (ICAO) Annex 16. Aircraft Manufacturers face the specialized test of making airplane all the while calmer, all the more dominant, and progressively effective. These objectives led the research to apply flow control to one wellspring of aircraft to yield acoustic advantage while limiting the effect on execution [9]. The noise produced by turbulence in the exhaust of strategic airplane engines having low bypass ratio has been the subject of research for well over 50 years. On take-off, for instance from a plane carrying warship deck, engines are normally working in an over extended condition.

In traditional compressible nozzle stream theory, this happens when the weight at the fly exit has extended beneath the surrounding weight. In such circumstances it shows up in the fly crest. In the long run, it will even out the weight. In all actuality, such issue can happen inside the convergent nozzle and supersonic converging-diverging nozzle [11]. The development of future Gas Turbine Engines for propulsion system depends on achieving low and cleaner emissions from the exhaust jet. Future aircraft will be developed with smaller combustion chamber, operating at higher pressure to increase the overall efficiency and reduce significant amount of aircraft noise [13]. Control of jet has turned into a functioning research area because of its huge application potential, for example, improvement of stealth capacities, minimization of base warming, decrease of aero acoustic and so on. Majority of these applications require blending upgrade of the stream, for example the mass from the encompassing entrained by the stream must be blended with the jet liquid mass as quick as expected under the circumstances. To accomplish this blending, advancing little scale vortices should be brought into the stream at the nozzle exit.

Significant number of dynamic and stand-alone strategies has been recognized by the analysts in the last two decades. Among these, latent control as a tab has turned out to be exceptionally well known as a result of its straightforward geometry and effective blending advancing ability. Tab geometries, for example, rectangular, triangular, roundabout, circular segment and so forth have been considered widely. Among these strong tabs, shed blending of the advancing little vortices of uniform size would be valuable. To create such a smaller blended size, commonplace tabs with puncturing over its level face have been utilized in this investigation. Further the hole diameter differing from the circular azimuthal symmetry with sharp corners, were utilized in the present examination [12]. The performance of the solid and perforated tabs was quantified for jet Mach numbers.

2. Background study

The impact of wedge-shaped projections on the advancement of a low-speed jet was examined by Bradbury and Khadem [4]. They found that the fly centerline speed reduction rate was expanded by the wedges when compared to the bluff bodies. Having 900 wedges proved to be the best. The ideal setup of these was two tabs positioned oppositely. This appeared to halve the length of the stream potential center and broadened the investigation of supersonic and under-extended, hot and cold planes. They demonstrated a 'significant' decrease in stream temperature and blending was improved with the tabs. Knowles and Saddington [1] discovered that, for a round fly progression at Mach number of 1.12 and all out temperature of 664 K, the potential center length of the fly could be diminished by around six widths to fewer than two measurements by utilizing two oppositely positioned mechanical tabs.

Subsequent researchers [2-3] have clearly determined that the tab produces a pair of counter-rotating stream wise vortices. The relative magnitude of the peak stream wise vortices was found to be about 20% of that of the peak azimuthal vortices for a tabbed circular jet at a Mach number of 0.3. It was proposed that the distortion introduced by a mechanical tab is due to a pair of stream wise vortices and which must be responsible for the phenomenal entrainment. The investigation involved low-speed tests in water stream and concluded that a couple of oppositely restricted tabs produce stream-wise vortices at far edges. Reeder and Samimy [5] showed a couple of counter 23 turning stream-wise vortices shed from every tab which was twisting the core of the jet. In this way, a second arrangement of stream-wise vortices was observed as radiating from every tab.

Ho et al [6] considered an elliptical tab as shown in Fig. 1 for jet from a contoured nozzle of aspect ratio 2 and demonstrated that the blending rate was a few times higher for a circular or two-dimensional jet. The impact of jet angle was proportionate for a low-speed jet stream from a sharp-lipped hole. Potential center length was observed to be the equivalent. Rectangular nozzles are winding up progressively from mainstream for military airplanes. They offer diminished radar signature. Restricted thrust vectoring can be incorporated generally effectively using rectangular nozzles. Two different explanations behind giving specific consideration to such spouts are that they can be used on stealthy airship (F-117A, F/A-22, B-2). With the help of an annular collar about the outlet of an axisymmetric nozzle as shown in Fig. 2 and Fig. 3, counter flow can be produced.

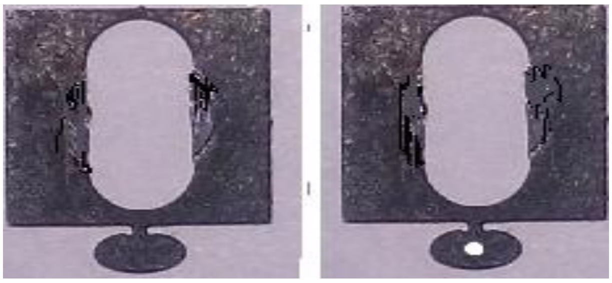

Fig. 1: Elliptical tabs - Solid (Left) and perforated (Right)

Investigations on axisymmetric nozzle have been accounted by Strykowski and Wilcoxon [10]. They utilized laminar, round jets at paces up to 60 m/s and suction speeds through the collar of up to 60% of the essential jet speed. From this, upgraded entrainment was observed however not quantified. Pulsing was explored by Binder and Favre-Marinet [7] as a method for expanding the blending for a low speed stream (6-20 m/s). The jet was pulsed by utilizing a butterfly valve at frequencies of up to 200 Hz with surrendering Strouhal numbers to 0.8, and R.M.S. amplitudes of up to 40%. The potential center length was reached out to just 1D within the sight of expansive abundance pulsations, in contrast to a center length of 5-6D for an unfaltering state stream. So far swirl/whirl has been utilized in the ignition chambers to give proficient blending and flame adjustment. The later is accomplished by utilizing high whirl speeds which prompts pivotal jet inversion on the fly centerline, a condition which most likely should be evaded in a propulsive jet, in any event close to the spout exit. Any whirl in the propulsive planes is effectively dodged by engine designers who places exit direct vanes after the last turbine stage to de-whirl the jet. This appears to have been explored with experimental test followed by full-scale engine examinations [8], which seemed to indicate stream clamour decreases within the sight of whirl.

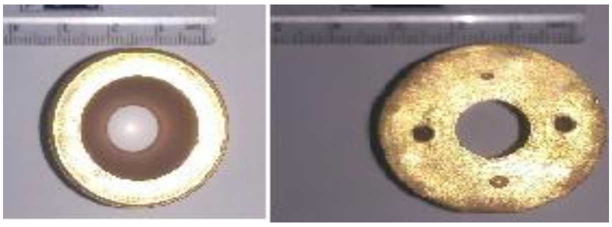

Fig. 2: Fabricated nozzle – Inlet (Left), outlet (Right)

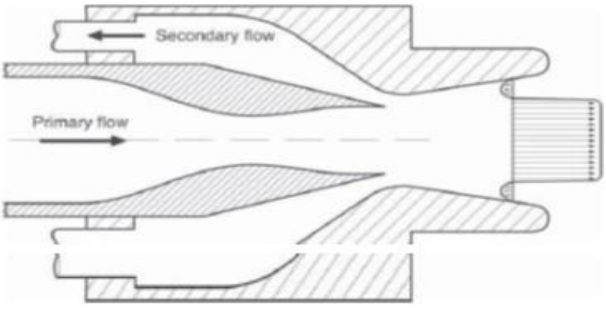

Fig. 3: Axisymmetric nozzle collar arrangement used to create counter flow in supersonic jet

3. Experimental procedure

Two-stage reciprocating compressor (3Numbers), fit for conveying 135 ft3/min of air at a pressure of 185 psi is utilized in this investigation. The blower is driven by 5 HP three stage engine. A cooling water circuit, driven by a pump, cools the packed air through an inter-cooler. The compressed air is then passed through a pre-channel comprising of permeable stone candles to filter out strong contaminants like rust particles and oil beads. An enacted carbon strainer is utilized for better sifting. The compressed air is dried in a double tower self-loader silica gel dryer. The analyses have utilized an open jet set-up comprising of a circular and hollow settling chamber associated with weight stockpiling tanks as shown in Fig. 4. The air enters the settling chamber through the passage segment with an entryway valve through a pressure controlling valve and a blending length container of 30mm width. The settling chamber is associated with the blending tube by a wide-edge diffuser pursued by firmly fit meshes which are set 1 cm apart for limiting the turbulence at the spout channel. The settling chamber has a steady region circular segment of 110 mm inside diameter and 250 mm length. The settling chamber has recordings for estimating the stagnation pressure. Due to complex nature, the jet flow is a turbulent one. The parameters considered to dissect a jet are the reduction in the centerline pressure / Mach number and profiles of pressure / Mach number along the radial and azimuth bearings by utilizing pitot test. The static pressure changes from point to point in the jet field. The measured pitot pressure distribution is plotted in the form of centerline pressure decay and iso-bar or iso-Mach contours. From these plots, the core length, characteristics decay, jet spread, length of the shock cells, number of shock cells present in the core and the strength of the waves present in the core can be assessed. The optical visualization pictures can authenticate the presence of shock cells and the wave strength can be estimated from the pressure plot. Fig. 5 shows a photograph of the experimental setup. The exit diameter of the nozzle used in experiment was 10 mm and compressed air is ducted to the settling chamber, where the flow reaches a settled equilibrium.

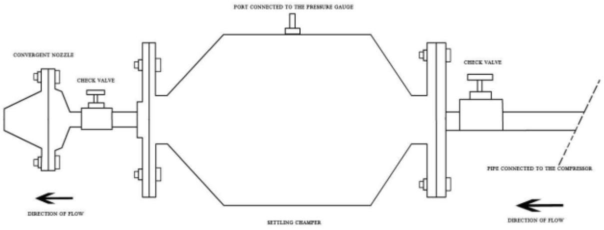

Fig. 4: Layout of open jet test facility

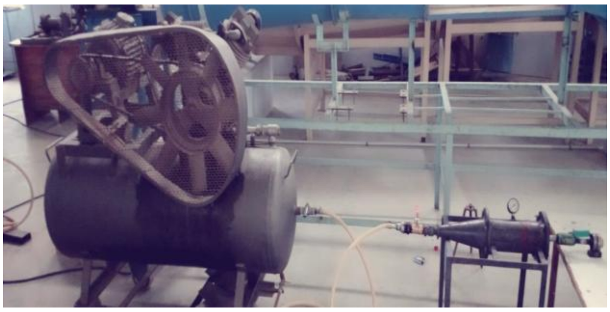

Fig. 5: Experimental set-up

Required stagnation pressure in the chamber can be maintained with a pressure regulating valve. The stagnant air from the chamber is expanded through the convergent nozzle. The pressure in the chamber is controlled to achieve the desired Mach number at the nozzle exit. Single jet flow arrangement is used to carry out the experiments. A pitot tube mounted on a traverse mechanism is aligned at the center of the nozzle exit and moved to the downstream. The pitot tube is connected to a Measurement Systems 1 channel pressure scanner for pressure measurements. The traverse mechanism is used for the movement of pitot tube in all three directions viz. X, Y and Z. The traverse is moved manually using a lever. The pitot tube is fixed to traverse mechanism which moves along with it. The perforated tabs and solid tabs are made up of mild steel. These tabs are provided with a slot and positioned in such a way that the perforation is facing the flow.

Shadowgraph system comprises of a light source, a collimating focal point and a survey screen, as shown in Fig. 6 and Fig. 7. Shadowgraph framework is utilized in this examination for picturing the waves present in the jet stream field. The shadowgraph framework has utilised a sodium light source related to 150mm circular mirror mounted on a stand. The parallel pillar from the mirror was made to go through the jet stream field and was anticipated on the screen. The surface finish of the mirror is sufficient for perception of stun waves and the central length of the mirror is 1.5m. The shadowgraph system is reasonable for imagining the stream field where solid angles exist. Under extended sonic fly, streams produce enormous thickness gradients that lead to a variety in the optical refractive record of light that goes through the supersonic stream. The light beam is reflected wherever there is thickness angle in the stream field. In any case, if the thickness gradient in the jet field is consistent all through, all light beams are avoided by a similar sum and there is no adjustment in the brightening of the image on the screen. When there is an adjustment in the thickness angle, there is an inclination for the light beams to merge or separate. The variety in light of the shadowgraph picture on the screen is relative to the second subordinate of thickness.

Fig. 6: Shadowgraph set-up

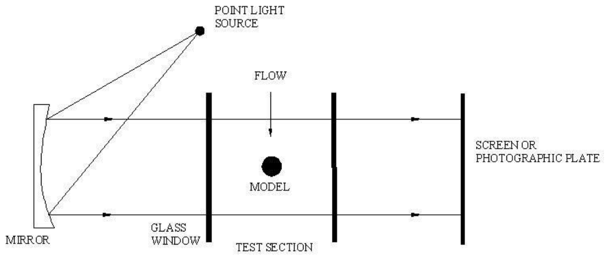

Fig. 7: Schematic diagram of shadowgraph system

4. Results and discussion

At first, the shadowgraph strategy is pursued for the qualitative investigation. Then the pressure scanners are used for the quantitative examination to decide the productive spout tab geometry that achieves the blending advancement at the back of the spout to decrease the commotion level at the stream exhaust. The density variation of the shocks and eddies which are formed at the exhaust of the nozzle are determined for various NPR Values (NPR3-NPR8). The flow patterns are assessed in two views, one is along the tabs and another one is across the tabs. By this process, we can able to see the side view and top view of the flow patterns. Fig. 8 to Fig. 16 show the shadowgraph views along the tabs for all the tests performed. The result is a cross over point at each end, giving the appearance of shock diamond structure in the jet core. The shock development process, however, is different along the two planes. The shock structure has been investigated for uncontrolled jet at sonic with solid and perforated tabs at the exhaust of the nozzle. The density variations of the shock waves correspond to the variations in the mass flow rate at the nozzle exhaust. Greater zone of flow field compared to other controlled and uncontrolled flow. This causes the waves to become weaker and the jet to spread faster. The mixing efficiency of the solid and perforated tabs is studied. The blockage is successfully attained by the solid tabs when compared to the perforated tabs. Mixing of the air and the cold mass entrainment is efficient in the solid tabs rather than the perforated tabs due to uneven distribution of vortices. This reduces the noise at the aircraft exhaust nozzle.

Fig. 8: Shadowgraph along uncontrolled jet at NPR8

Fig. 9: Shadowgraph along uncontrolled jet at NPR5

Fig. 10: Shadowgraph along uncontrolled jet at NPR3

Fig. 11: Shadowgraph along elliptical solid tabs at NPR8

Fig. 12: Shadowgraph along elliptical solid tabs at NPR5

Fig. 13: Shadowgraph along elliptical solid tabs at NPR3

Fig. 14: Shadowgraph along elliptical perforated tabs at NPR8

Fig. 15: Shadowgraph along elliptical perforated tabs at NPR5

Fig. 16: Shadowgraph along elliptical perforated tabs at NPR3

Fig. 17 to Fig. 19 show the plot between p/p_0 and X/D for Mach number of 0.4, 0.6 and 0.8 respectively. For the uncontrolled jet, the energy prevails up to 10 D. At the same time it is 7D and 6D for the perforated and solid tabs respectively. The solid tab associated with thrust loss may be treated as disadvantageous. Therefore solid tabs may be replaced by perforated tabs as an alternative for suppressing the noise level by entrainment of ambient air. For Mach number of 0.6, the energy prevails for elliptical solid tab up to 4.5D whereas for elliptical perforated tab and uncontrolled jet it is of 6.5D and 10D respectively. Even though the energy is minimized to some extent by utilizing solid tabs, thrust loss is the greatest demerit. For Mach number of 0.8, the energy for both the perforated tab and the uncontrolled jet goes up to 7D while for solid tab it is 5.5D. The value p/p0 is 0.85 for the uncontrolled jet. At the same time it is 0.77 and 0.75 for the perforated tab and the solid tab respectively. At a higher Mach number in transonic regions, perforated tabs performed similar to the solid tabs to reduce the energy level by shear layer interaction, which in turn are very useful in suppressing the noise.

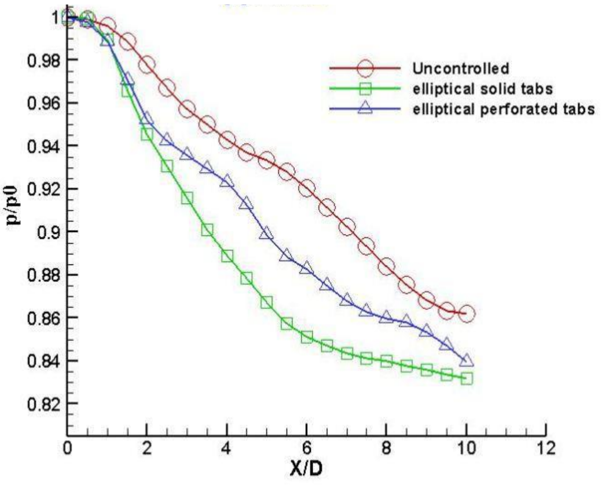

Fig. 17: p/p_0 vs. X/D for uncontrolled, solid elliptical and perforated tabs at Mach number = 0.4

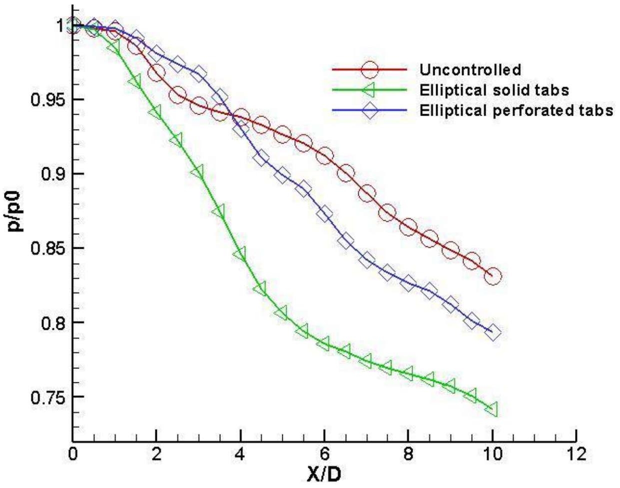

Fig. 18: p/p_0 vs. X/D for uncontrolled, solid elliptical and perforated tabs at Mach number = 0.6

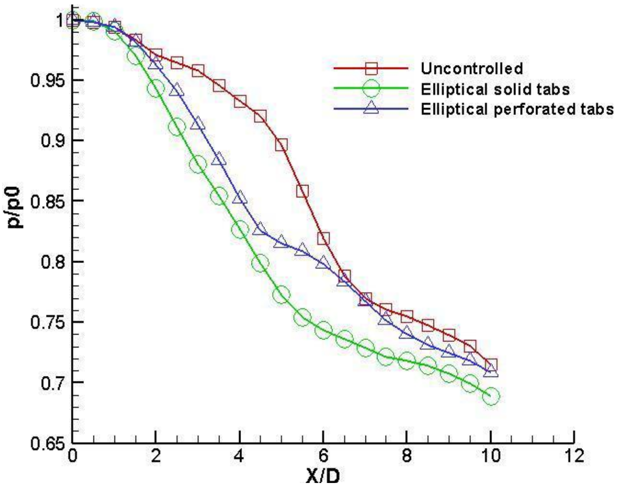

Fig. 19: p/p_0 vs. X/D for uncontrolled, solid elliptical and perforated tabs at Mach number = 0.8

5. Conclusion

At Mach number of 0.4, for perforated tab, the difference between the reference value and experimental value of the prevailed energy is 2%. For the solid tab and the uncontrolled jet, it is 3%. Similarly, at Mach number of 0.6, the difference in prevailed energy is about 2.3% for the perforated tab and 3.1% for the solid and the uncontrolled jet. Thus for the transonic speed (Mach number = 0.8), the energy depletion was the most. Hence incorporation of an elliptical perforated tab at the nozzle exit can reduce the noise.

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