

Effect of Tab Geometries on Subsonic Jet Mixing

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Mixing enhancement of jet finds several applications in aerospace field. Enhanced mixing in jet propulsion application is to reduce the plume temperature and suppress infrared radiation. Rapid mixing results in a reduced noise level by the alteration of turbulent structures. Also, the mixing augmentation of the fuel and air in the combustion chamber improve combustion efficiency. Jet mixing enhancement devices can be classified into two categories: active control device and passive control device. Active control device requires the auxiliary power source to modify the jet characteristics, whereas, the passive control device draw its controlling energy directly from the flow to be controlled. These both active and passive control devices are improving the jet mixing enhancement effectively. Among these control devices, the passive control devices are highly desirable because no external power source is required. The passive control devices simply modify the nozzle geometry or use some vortex generating devices like tab at the nozzle exit. A tab is a small protrusion placed at the nozzle exit, which generates counter-rotating streamwise vortices that improves the jet mixing. Control of jets using the tabs was first investigated by the Bradbury and Khadem (1975) [1]. They found that the tab plays significant role in distorting the jet and reduce potential core length drastically in subsonic Mach number. Later, Samimy et al. (1991) studied the effect of tabs on supersonic jets [2]. It was observed that the faster velocity decay and reduced core length with the insertion of tabs. Subsequent researchers identified the two possible sources of vorticity generation, when the flow over the tab [3]. The first and dominant source comes from the pressure hill formed upstream of the tab. The flow deceleration upstream of the tab increases the pressure that, together with the nozzle wall, produces pair of counter-rotating vortices. The second source is

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due to the pressure gradient across the tab cause to fluid roll up from high pressure region to low pressure region across the tab. Subsequently, the generated vortex become a streamwise in nature as it is convected downstream in the jet shear layer. Tab with a uniform cross section shed vortices of uniform size. If the tab is modified to produce varying size of vortices, this will be beneficial in mixing point of view [4]. The manipulation of size and strength of the vortices can be achieved by varying the half-width of the tab [5]. Thus, the triangular tab was chosen since it has varying cross-section from root to tip. Earlier studies mainly focused on jet controlled with triangular tab at supersonic Mach numbers [6, 7]. But, very few studies available in jet controlled with triangular tab at subsonic Mach numbers. With this in mind, the present study aims to investigate experimentally the mixing efficacy of triangular tab at subsonic Mach numbers. The experiments were carried out in an open jet-test facility available at the Madras Institute of Technology, Chennai. Photographic view of jet facility is depicted in Figure 1. A compressor, storage tanks, gate valves, a pressure controlling valve, and a settling chamber comprise the jet-test facility. A control valve supplied air from the storage tank to the settling chamber. The desired Mach number at the nozzle exit can be achieved by adjusting the pressure in the settling chamber. The experimental model used in the present investigation was axisymmetric convergent nozzle of exit diameter 20 mm. Tab geometries of triangular and rectangular configurations were chosen in the present study. Two tabs were located diametrically opposite locations at the exit of axisymmetric convergent nozzle. The blockage area of both tabs was maintained same as 5% when deployed at the nozzle exit. The experiments were conducted at subsonic Mach numbers of 0.4 and 0.6, corresponding nozzle pressure ratios (p_0/p_a) of 1.12 and 1.28. To study the mixing efficacy of triangular tab the qualitative and quantitative measurements were carried out. Pitot pressure measurements along the jet centerline were used to calculate the potential core length. The Shadowgraph system was used to visualize the shock-cell structures existed in the under expanded jet of NPR 2.0 and 3.0. Pitot probe mounted on the three dimensional traversing system was used to perform the pressure measurements in the jet field. The inner and outer diameters of Pitot probe are 0.4 mm and 0.6 mm respectively. The Reynolds number calculated based on the probe diameter at Mach numbers of 0.4 and 0.6 are 5.4×10^3 and 8.6×10^3 respectively, which is much higher than the troublesome number of 500 [8]. Thus, the viscous effect will not cause any error in

Pitot pressure measurements. One end of the probe faces the flow in jet field and other end is connected to the 16-channels pressure scanner. The transducer can average up to 250 samples per second to give a mean single value. This pressure scanner can calculate pressures of up to 2.1 MPa. The pressure transducer has a full-scale accuracy of 0.15. The centerline pressure decay of uncontrolled and jet controlled with tabs at Mach 0.6 are shown in Figure 2. The measured Pitot pressures along jet axis have been made non-dimensional with settling chamber pressure and plotted against the non-dimensional axial distance. For uncontrolled jets, the potential core length extends about $5D_e$. When the rectangular and triangular tab is inserted at the nozzle exit, the potential core shortened for about $3.8D_e$ and $3.2D_e$, respectively. The reduction in potential core length of tab-controlled jets suggests enhanced mixing and faster spreading in comparison to the uncontrolled jet. And, the maximum reduction in core length of 36% was achieved with triangular tabs. The Shadowgraphic images clearly reveal that the waves prevailing in the tab-controlled jets are significantly weaker than those in the uncontrolled jet.

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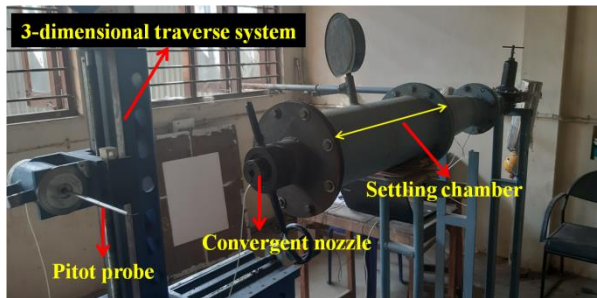


Figure 1: Free jet-test facility

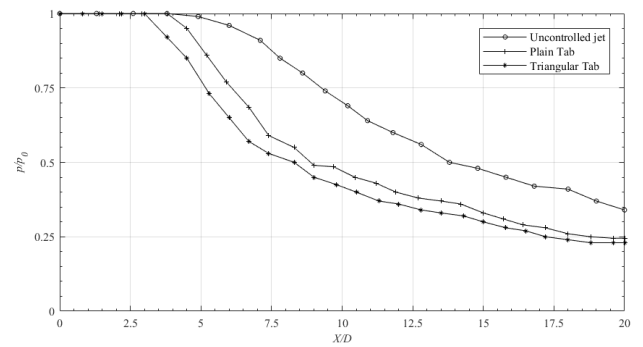


Figure 2: Centerline pressure decay of uncontrolled and controlled jets at Mach 0.6