Compressor Design optimization for a High speed Jet engine

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Abstract. This is a study that is focused on developing an individual design methodology for a centrifugal jet and generating a mixed flow jet for a small turbojet engine by using this methodology. The structure of the methodology is based on the design, modelling and the optimization processes, which are operated sequentially. The design process consists of engine design and compressor design codes operated together with a commercial design code. Design of Experiment methods and an in-house Neural Network code is used for the modelling phase. The optimization is based on an in-house code which is generated based on multidirectional search algorithm. The optimization problem is constructed by using the in house parametric design codes of the engine and the compressor. The goal of the optimization problem is to reach an optimum design which gives the best possible combination of the thrust and the fuel consumption for a small turbojet engine. The final combination of the design parameters obtained from the optimization study are used in order to generate the final design with the commercial design code. On the last part of the thesis a comparison of the final design and a standard radial flow jet is made in order to clarify the benefit of the study. The results have been showed that a mixed flow compressor design is superior to a standard radial flow compressor in a small turbojet application.

1. Introduction

A thorough understanding of blending characteristics of high speed jet with the encompassing is indispensable for the look of the many devices victimization jets, reminiscent of air respiration engines, rockets nozzles, fastening torches, nozzles for cutting applications then on. Jet management acting a central role in hearth conclusion techniques too. In new years, there have been sizable interests within the studies of jet management ways thanks to their potential use in military craft. The most common method of shaping a free jet could be a pressure driven stream of fluid starting up of associate degree porta or nozzle to a quiescent atmosphere. Jet may also be outlined as a free shear layer driven by momentum introduced at the nozzle exit, exhibiting the characteristics that, the magnitude relation of axial distance to radial distance are constant that is found to be regarding eight for jet physicist numbers below zero.2. the worth of this magnitude relation decreases with increase of jet Mach number.

Additionally, the fly attributes ar intensely affected by the idea of the nozzle since that the fly ways out, thickness of the leave lip, the area into that the fly enters, the underlying rate profile of the plane at the nozzle leave, the introduction of the fly with significance the gravity vector, and even the outside assortment of the nozzle. as a result of the enormous rate refinement between the
fly and conjointly the close liquid, a thin shear layer is made at the stream certain and it's phenomenally flimsy. The shear layer is subjected to stream insecurities that in the long run reason the age vortices and conjointly the related turbulent variances because of the shear layer moves downstream. This uncommonly turbulent shear stream entrains close liquid into the fly and improves the stream joining. Therefore, the shear layer and conjointly the stream unfurl along the side outward and conjointly the fly rate diminishes downstream. going to the nozzle exit and on the focal bit of the stream, a section with scholastic degree almost uniform mean rate is named the potential center. in light of the spreading of the shear layer, the potential center inevitably vanishes once shear layers from all sides consolidate. The entrainment and consolidating system proceeds on the so much perspective the potential center district such, the speed circulation in the end unwinds to a protrusive profile. The stream outskirts are taken because of the external area where the speed ways to deal with zero.

2. Literature Survey

High speeds jets are of great importance to Aerospace as well as other industries. Various control techniques have been examined in an effort to increase mixing in the past several years. Compressible mixing flows are encountered in many situations with the two main driving applications, namely the combustion efficiency in high-speed propulsion systems and noise emission by high-speed jet plumes. Both are serious concerns, directly related to the process of mixing in compressible mixing layers. These issues must be addressed before the next generation of high-speed aircraft can be made economically and environmentally feasible. Mixing is also important in the performance of supersonic ejectors, which play a crucial role in chemical lasers (Siegman 1986), entrainment of metal powders into supersonic jets for metal deposition (Wei et al 1992), and in noise and infra-red signature detection for supersonic military aircraft (Papamoschou and Debiasi 1999).

The technological challenge of blending sweetening in compressible flows stems from the inherently low growth rates of supersonic shear layers. several intermixture augmentation strategies used expeditiously in subsonic flows didn't work on elevated philosopher numbers, a number of these strategies were inefficient, as a result of they were used outside their effective vary. all the same, studies of compressible shear flows ar engineered on the information accumulated in subsonic flow analysis. Findings of large-scale coherent structures in subsonic shear layers and their importance to {the intermixture the blending} method crystal rectifier to the event of various mixing management techniques.

3. Experimental Procedure

3.1 EXPERIMENTAL TEST SETUP

Two-arrange corresponding mechanical gadget, equipped for conveying 360 ft³/min of air at a weight of five hundred psi is being utilized in fast flies research center. The mechanical gadget is driven by an a hundred and fifty power unit three area acceptance engine. A cooling water circuit, driven by an independent pump, cools the compacted gas through partner degree between cooler. The compacted gas is then competent a pre-channel comprising of permeable stone candles to dispose of strong contaminants like rust particles and oil beads. relate degree initiated charcoal channel is utilized for better sifting. The compacted gas is dried in an exceedingly double pinnacle self-loader colloid drier. while one pinnacle is being used, a portion of the dried air is warmed and wont to enact the inverse. A stomach kind back weight valve worked by weight alleviation pilot allows the drier to control at five hundred psi, though the weight inside the capacity tanks develops from part to the predetermined stockpiling weight. The packed gas is keep in 3 tanks, having all out limit of 3000 ft³. The passage administration area incorporates an entryway valve took after by a weight direction valve. The weight controlling valve is associated with an aggravating container of three in. distance across thus to a subsidence chamber. The design of the trial stream office research facility is as appeared in Figure three.1. The investigations were directed abuse relate degree open stream office that comprises of a round and hollow subsidence load associated with air mass stockpiling tanks.
Figure 1 eleven demonstrates a schematic draw of the open stream investigate office. The air enters the sinking chamber through the passage area with an entryway valve took after by a weight control valve and a blend length container of three inches breadth. The sinking chamber is associated with the mixing tube by a vast point diffuser took after by 3 screens or firmly coincided matrices set three cm apart to minimize turbulence at the nozzle water. The sinking chamber contains a steady space roundabout area of three hundred metric direct unit inside distance across and 600 metric straight unit length. The sinking chamber has recordings for stagnation weight and temperature estimations. The investigate models zone unit attached at the highest point of the sinking chamber by an opening holder plan, that could be a short pipe like projection with inserted O-ring to hinder release.

Figure 2: Schematic representation of open jet facility

The model to be considered is put over the O-ring, over which an annular holding sleeve with inside strings is screwed firmly. The settling chamber adds up to weight (P0), which is the controlling parameter in the present examination, was kept up consistent amid a keep running by controlling the weight managing valve. The stagnation weight (P0) level in the settling chamber gives diverse Nozzle Pressure Ratios (NPR), characterized as the proportion of stagnation weight to the air weight (P0/Pa) required for any examination. The settling chamber temperature is the same as the encompassing temperature and the back weight is the surrounding weight into which the planes were released. The surrounding temperature of the room was practically consistent inside ± 0.5°C amid a test run. The stagnation weight was kept up with an exactness of ± 0.1%. Amid the exploratory runs, the settling chamber weight was measured by a weight transducer. The
room temperature was measured by a thermometer. The encompassing weight, Pa, was measured by a mercury indicator put in the lab.

3.2 DEVELOPMENT OF PASSIVE CONTROL DEVICE

3.2.1 Requirement of the Passive Control Mechanism

The function of the passive control device is to create instability at the nozzle exit. The tabs are expected to shed streamwise vortices formed due to the presence of pressure uphill in the upstream and pressure valley in the downstream. These vortices shed from the tabs cause increased mass entrainment resulting enhanced mixing of ambient air into the jet core. It is important that every tab should be strong enough to withstand the aerodynamic and mechanical loads.

3.2.2 Tab Configurations

In the mechanism of the design, the shape, geometry and its orientations become important parameters, which influence the evolution of the jet structure. In order to determine the efficacy of various possible configurations of the tabs on the subsonic and supersonic jet evolution, three types of tabs are used namely arc-in tab, arc-out tab and rectangular tab. Types of diameter (d = 0.6 mm, 1 mm, and 1.5 mm) or width were used. The tab was made from filing of cylindrical steel tube. Figure 3.9 shows nozzle with arc-out tabs fixed at the exit.

Figure 3: Experimental model with arc-out at the nozzle exit

3.2.3 Arc-out tab: This type tab is the same as discussed above i.e. arc-in tab but the difference is that in the case of arc-out tab, the concave surface is facing out the flow i.e. in the direction of the flow as shown in the Figures 3.8c, 3.9 and 3.10. So it is named after “arc-out tab”. The length of the tab can be varied from 1 mm to 5 mm with the help of a slot provided at the nozzle lip. In order to compare the effect of arc-in tab and arc-out tab on the axisymmetric jet structure, already existing passive control device as vortex generators such as rectangular tab was used. The thickness of the tab is maintained as 1.5 mm. Rectangular tabs were made of Aluminum sheet. The tab length can be varied from 1 mm to 5 mm. Figures 3.8a and 3.11 shows the nozzle exit with rectangular tab fixed at the nozzle exit.
3.2.4 Experimental model with rectangular at the nozzle exit Blockage:
Blockage ratio is defined as the ratio between the areas of the tab intruding the flow to the area of
the nozzle exit. This parameter is used to study the effect of length as well as width of the tab on
the jet structure. For example, when the length of the tab is varied from 1 mm to 3 mm, then the
blockage is said to be $z_1$ to $z_3$ and if the width of the tab is varied then the blockage is $y_1$, $y_2$, ….. $y_n$

3.2.5 Fixing Mechanism
Slots are provided in the rectangular tab so as to adjust the length and fix it with the nozzle by
screw where the tabs are to be fixed diametrically opposite. For fixing arc tabs, two screws are
provided on either side of the tab with a sheet screwed in both the ends of the sheet. The arc tab
sitting on the nozzle lip is kept in between the screws. The tab is tightened with the help of the
sheet. A schematic of fixing mechanism is shown in the Figure 3.12

To produce a subsonic jet, a convergent nozzle was used. The exit diameter of the nozzle is 10
mm. Material for fabrication of nozzle was chosen brass as it is easy for machining and
fabrication. Inner surface of the nozzle was smooth finished so as to have a smooth internal flow.
Length of the nozzle is 50 mm. The inlet to the flow diameter is 20 mm. Inlet side of the nozzle is
straight for about 10 mm length and was threaded externally in the straight portion to go into the
adapter on which the nozzle is seated. The schematic representation is shown in the Figure . The
experimental model used for the investigation of supersonic Mach 1.76 jet characteristics, was
convergent-divergent nozzle, made of brass with 13.4 mm exit diameter. Schematic diagram of the
base plate with the details of the C-D nozzles is shown below in Figure 6
Figure 6: Schematic diagram of the subsonic convergent nozzle

Table 1: Effect of tab length with constant width

| S.No. | Tab Length (mm) | Tab Width (mm) | Blockage % |
|-------|-----------------|----------------|------------|
| 1     | 1               | 1.5            | 3.82 (z1)  |
| 2     | 2               | 1.5            | 7.64 (z2)  |
| 3     | 3               | 1.5            | 11.46 (z3) |

Table 2: Effect of tab width with constant length

| S.No. | Tab Width (mm) | Tab Length (mm) | Blockage % |
|-------|----------------|-----------------|------------|
| 1     | 0.6            | 1               | 1.53 (y1)  |
| 2     | 1              | 1               | 2.54 (y2)  |
| 3     | 2              | 1               | 3.82 (y3)  |

Table 3: Tab dimensions used for supersonic jet (Mj = 1.76)

| S.No. | Tab Length (mm) | Tab Width (mm) | Blockage % |
|-------|-----------------|----------------|------------|
| 1     | 1.2             | 3              | 5          |
| 2     | 3.52            | 1              | 5          |
4. RESULTS AND DISCUSSION

4.1 CHARACTERISTICS OF SUBSONIC JET

The experimental procedure discussed in chapter 3 is used to study the evolution of Mach 0.6, 0.8 and correctly expanded Mach 1.0 jets delivered by a convergent nozzle of exit diameter 10 mm, with arc-in, arc-out and rectangular tabs at the exit. Jets from the nozzle without tabs are also studied for comparison.

4.1.1 Effect of Tab Length on Subsonic and Sonic Jet

To get an insight to the jet characteristics due to the presence of tab at the nozzle exit issuing subsonic and sonic jet, the tab length was varied from 1 mm to 3 mm in step of 1 mm while the width i.e. diameter of the tab was kept at 1.5 mm. Centerline decay, Mach number profile and iso-Mach contours for the subsonic jet with tabs (arc-in, arc-out and rectangular tab) at the nozzle exit were compared with that of plain jet of nozzle exit Mach number Mj = 0.6, 0.8 and 1.0.

4.1.1.1 Centerline Decay

Potential core region for subsonic and sonic jet is that the region wherever the center line speed is the same because the speed at the nozzle exit. The ratio distributions on the jet center line were calculated from the full pressure and static pressure, assumptive the static pressures across the jet to be an equivalent because the close setting pressure. This assumption is dead valid for subsonic jets, since they're perpetually properly dilated (Shibu Clement and Rathakrishnan 2006). For sonic jet, this assumption is valid only if it's properly dilated. The ratio 'M' distribution on the jet center line is normalized with the jet ratio Mj. The axial distance (X) from the nozzle exit is non-dimensional letter with the nozzle exit diameter (D). ratio decay on the jet center line within the stream wise direction of the exit jet (Mj = zero.6) are given within the Figure four.1a-c for properly diluted condition for 3 completely different tab configurations particularly, arc-in tab, arc-out tab and rectangular tab and also the results were compared with the plain jet. The protrusion (z) of the tab was varied from one millimetre to three millimetre, maintaining the breadth of the tab constant at one.5 mm. For the plain jet, the potential core length extends on the far side 5D and for the jet with arc-in tabs of one millimetre protrusion (z1) at the nozzle exit traditional to the flow, the potential core length was reduced drastically as shown in Figure four.1a. The arc-in tab reduces the core length to second, whereas the arc-out tab reduces the core to a pair of.4D. the oblong tab performs in par with the arc-out tab. With a pair of millimeter protrusion (z2), arc-in tab reduces the core length effectively to one.5D and arc-out tab reduces the core length to a pair of.0D as shown in Figure four.1b. The impact of distorting the jet core is additional pronounced with tab of three millimetre protrusion (z3) as shown within the Figure four.1c. The arc-in tab reduces the core to regarding eighth than the core of plain jet. With arc-out tab at the nozzle exit, there's four-hundredth reduction in core length that is about same for the oblong tab at this blockage.

It is well established that for effective mixing of jet with the ambient air, the jet should entrain the surrounding mass and the entrained mass should be transported towards the centerline. Both the entrainment and mixing process are dictated by vortices. For entrainment of mass, large vortices are to be formed at the periphery of the jet and to transport the entrained mass, small eddies that transport mass should be present. For axisymmetric jet, the jet itself generates both large and small eddied i.e. on leaving the nozzle, the jet with high momentum tries to expand into the ambient of still environment. This produces a differential momentum which leads to the formation of large vortices.

The sizes of the vortices are influenced by the radius of curvature of the nozzle exit from which it is formed. For the jet boundary, the radius of curvature is large and hence the size of the vortices. The large vortices are effective in entraining the mass of ambient air into the jet core and are also highly unstable. These large vortices after entraining the ambient air in to the jet core, breaks into smaller eddies or vortices. These smaller eddies are efficient mass transporters and are
able to travel longer distance along the jet flow and then dissipates in the far field. The process of breaking of large vortices into smaller vortices travels some distance from the nozzle exit which causes the extension of potential core up to 5D approximately. But when a tab is placed at the nozzle exit, smaller vortices are formed along the edge of the tab. These vortices are transverse in nature while leaving the tab but soon become stream wise due to the inertia of the jet flow. The vortices shed right at the tab carries the entrained mass into the jet core towards the centerline which leads to the reduction in length of potential core in the presence of tab at the nozzle exit. When a tab is placed within the jet field, the tab sheds tiny vortices right along its edges. so the 2 rows of tiny vortices square measure shed by the tab right along its length. These vortices square measure thwartwise in nature whereas deed the tab edge however presently become stream wise because of the inertia of the jet flow. Thus, the mass entrained by the jet is carried towards the center line by these tiny sizestreamwise vortices shed by the tab. That is, the blending begins right at the nozzle exit once the tab is at the exit. This causes higher commixture for the controlled jet compared to its uncontrolled counterpart. Also, the effectiveness of the tab depends on the jet ratio. this might be because; the blending action of the stream wise vortices shed by the tab depends on its vorticity and also the interaction time on the market for it. Since the jet ratio influences the convective rate of the vortex shed, it's absolute to influence its potency. Thus, the jet ratio together , tab configuration and its blockage dictates commixture phenomena.

Figure7: Tab at z₁ (Blockage, 3.82%)  
Tab at z₂ (Blockage, 7.64%)

Figure8: Tab at z₃ (Blockage, 11.46%) Centerline Mach number decay at Mⱼ = 0.6

Figure9: Tab at z₂ (Blockage, 7.64%)
5. Conclusion

The results show that, the stream wise vortices shed by the tabs function economical mix promoters each subsonic and sonic jets. The tabs at the nozzle exit scale back the potential core length considerably followed by speedy decay of the center line in any respect levels of blockage and configurations indicating increase in mass entrainment. Radial philosopher profiles and iso-Mach contours indicate quicker unfold within the direction traditional to the tab than on the tab. They additionally show the existence of high ratio zones on either facet of the jet center line. skiaograph photos show that, the quantity of shock-cells is reduced and therefore the shocks square measure weakened considerably by the tabs. Iso-baric contour shows that the tabbed jet reduces the quantity of iso-baric contours, indicating quicker decay of the jet within the direction traditional to the tab than on the tab. The pitot pressure profiles indicate that, once tabs square measure introduced at the nozzle exit, the pitot pressure distribution is greatly created uneven.

Though all the tabs square measure economical in mix promotion, among them, arc-in tab is found to be the foremost economical. With arc-in tab, the utmost core length reduction achieved is eightieth whereas, arc-out and rectangular tabs scale back the core length to regarding four-hundredth for eleven.46% blockage (L= three metric linear unit, d = 1.5 mm). Iso-Mach contours and philosopher profiles for the jet with arc-in tab show the presence of off-cantered peak within the directional traditional to the tab and therefore the peak is a lot of pronounced within the case of arc-in tab indicating the existence of streamwise vortices resulting in quicker decay within the direction traditional to the tab. The reduction in centreline pitot pressure oscillations for the underexpanded sonic jet was ascertained in any respect the tested NPRs (2, 3 and 5). For sonic jet, the core length for the uncontrolled jet extends up to 6D and with the presence of arc-in tab at the (L = one metric linear unit, d = 1.5 metric linear unit ) nozzle exit, there's a forceful reduction in core length to regarding 2nd (66%).

The influence of tab on supersonic axisymmetric jet of Mach one.76 reveals that the arc-in tab is found to be effective in distorting the jet structure each in overexpanded and underexpanded conditions of the jet. At NPR3, Arc-in tab of L = three.52 millimeter and d = one cut the core piece from 5D to 2nd and therefore the cut in core piece within the presence of arc-out tab of same dimensions is from 5D to four.5D only. Arc-in tab of L = one.2 millimeter and d = three millimeter conjointly effective in reducing the potential core and pressure oscillations however arc-out tab is inferior and even it will dot perform for sure. but careful investigations have to be compelled to be dispensed during this facet. At NPR7, that is extremely underexpanded jet, arc-in tab of L = three.52 millimeter and d = one millimeter weakens the pitot pressure oscillation effectively and therefore the core length is reduced to 2nd type 9D more or less. The reduction in potential core thanks to the arc-out tab of a similar dimension is from 9D to 4D solely.

Figure 10: Tab at z3 (blockage, 11.46%) Centerline Mach number decay at Mj = 0.8
image conjointly showed that, effectiveness of the arc-in tab is healthier than arc-out because the arc-in tab disperse the shock-cell structure additional effectively that arc-out tab. Tab is more practical distorting the jet structure, in underexpanded jets than in overexpanded jets.

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