Abstract

An infrared suppression system (IRSS) is an indispensable component of combat vehicles such as helicopters, ships, tanks, etc. Ejector diffuser, a passive IRSS device, is employed to suppress the infrared signatures originating from the exhaust gases and heated metal body of these vehicles. The mechanism of IRSS is based on the mixing of hot exhaust gases with the entrained ambient air before exiting the ejector diffuser with minimum back pressure is highly desirable so as to not affect the gas turbine performance. Ejector diffuser is a combination of a standalone ejector and a diffuser with slots. The performance of an ejector diffuser depends upon a larger number of geometrical and dynamical parameters. Inspite knowing the importance of an ejector diffuser for a combat vehicle yet the literature present in the open forum is scanty due to confidential nature of the application. Based on the available literature survey, various shapes of ejector diffuser such as circular, rectangular and oblong has been studied. Also, the effect of some of the geometrical parameters have been reported. However, no work related to the modification of slot shape by providing guidance at the slot has been conducted. The emphasis of the current work is to systematically investigate the various slot configurations such that higher performance can be achieved. The current study is conducted in two phases:

Experimental Study

Four ejector diffuser configurations are fabricated and are individually tested using a blower test rig. The four ejector diffuser configurations are broadly categorized as (i) inline slot with no guidance at the slot, and (ii) inline slot with guidance at the slot. Within

each category, there are two types of diffusers based on the slot area namely (i) constant slot area and (ii) increasing slot area. Thus the four ejector diffuser configurations are:

1. No guidance at the slot ejector diffuser with constant slot area (NGCA)
2. No guidance at the slot ejector diffuser with increasing slot area (NGIA)
3. Guidance at the slot ejector diffuser with constant slot area (GCA)
4. Guidance at the slot ejector diffuser with increasing slot area (GIA)

The experimental data has been obtained in terms of velocity profiles at multiple locations in the ejector diffuser using Five-hole probe. Static pressure taps are used to obtain wall static pressure. Resistance thermal detectors are used to obtain temperature profile in the case of hot flow conditions. Constant temperature hotwire anemometer is used to calculate nozzle inlet turbulence intensity. The experimental data is analysed to determine the effect of Reynolds number by varying it as $Re_{nz} = 7.3 \times 10^4, Re_{nz} = 1.2 \times 10^5, Re_{nz} = 1.8 \times 10^5, Re_{nz} = 2.3 \times 10^5$ for GCA. The analysis of flow and mass entrainment characteristics shows that the performance is independent of Reynolds number for the range investigated. Analyses of mass entrainment for all configurations shows that GIA entrains maximum ambient air. Comparison between the increasing slot area and constant slot area shows that the increasing slot area configuration for both the guided-slot and no-guided-slot ejector diffuser entrains higher ambient air. Analysis of static pressure recovery reveals that NGCA and NGIA recover approximately 1.75 times more static pressure compared to GCA and GIA.

Numerical Study

The numerical methodology adopted to carry out the simulation studies is first validated against the in-house experimental results and with the data available in the literature after having carried out grid sensitivity and order of convergence studies. The numerical results are broadly discussed in terms of local and cumulative mass entrainment ratio, thermal characteristics, and static pressure recovery. Following numerical investigations are carried out to understand the performance and flow characteristics of the inline slot ejector diffuser:

1. **Optimization of Standalone Ejector:** This study is conducted for a standalone ejector such that the optimized ejector could be used for the complete ejector diffuser. In the first part, effect of nozzle inlet Reynolds number on mass entrainment is carried out for the ejector. The mass entrainment characteristics are found to be independent of Reynolds number when $Re_{nz} > 10^5$. In the second part, effect of standoff distance (SD) and mixing tube area ratio (AR_{mx}). on the performance of a circular air-air ejector is carried out. Standoff distance is varied in the range of $1D_{nz} < SD < 4D_{nz}$ where D_{nz} is the nozzle diameter while the AR_{mx} is varied over the range $1.25 < AR_{mx} < 4$. It is found that the performance of ejector diffuser is independent of SD when AR_{mx} lies between 2 and 2.5. Analysis of peak velocity at the inlet of mixing tube indicates that the jet does not expand beyond the mixing tube diameter for the ejector configurations having $1.25D_{nz} \leq SD \leq 2.5D_{nz}$ and $2.0 \leq AR_{mx} \leq 2.5$. In the third part, the length of the mixing tube is varied over the range $4D_{nz} \leq L_{mx} \leq 16D_{nz}$. It is found that when the mixing tube length exceeds $8D_{nz}$ it does not affect the performance of ejector. However, longer mixing tube helps in the flow development and the mixing of secondary and primary air.

2. **Investigation of Inline-slot Ejector Diffuser** Systematic studies are carried out to investigate the performance of various configurations of inline-slot ejector diffuser. Following studies are undertaken:

    (a) **Effect of Reynolds Number on Ejector Diffuser Performance:** The nozzle inlet Reynolds number is varied in the range of $4.3 \times 10^4 \leq Re_{nz} \leq 4.2 \times 10^5$. The local and cumulative mass entrainment ratio variations were within $\pm 1\%$, and the variations in C_p is within $\pm 1.5\%$. It is concluded that the performance of inline-slot ejector diffuser is independent of the Reynolds number when $Re_{nz} > 4.3 \times 10^4$.

(b) **Effect of Guidance at the Slot:** Performance comparison is carried out between the two configurations of inline slot ejector diffusers with guidance at the slot (guided-slot case) and other having no guidance at the slot (no-guided-slot). Keeping all other geometrical and dynamical parameters consistent, the curved-guided-slot case achieves higher cumulative mass entrainment ($> 3.5\%$) as well as lower wall temperatures throughout the diffuser wall (nearly ambient temperature 300K). However, the limitation of the guided-slot case is lower static pressure recovery compared to the no-guided-slot case.

(c) **Effect of Slot Area:** Another critical design parameter for inline slot ejector diffuser is the slot-area. In this study, the slot-area along the length of the diffuser is varied as a function of the area of the first slot. Three variations are studied as (i) increasing slot area, (ii) constant slot area, and (iii) decreasing slot area. It is found that the performance of increasing slot area configurations is better than constant and decreasing slot area cases.

(d) **Effect of Slot Guidance Shape:** More variations of the shapes of the guidance at the slot are investigated namely (i) curved guidance at the slot with trailing edge parallel to diffuser wall, (ii) straight plate guidance at the slot. Analysis of the performance shows that significant difference in the performance is observed between the straight plate guidance and curved plate guidance. However, no difference in the performance is observed between the two configuration of curved-plate guidance (Flow exit from the guidance parallel to the diffuser axis or parallel to the diffuser wall).

(e) **Effect of Straight Plate Inclination:** More configurations of straight plate guidance at the slot are investigated by varying the angle of the plate formed between the slot and diffuser axis over the range $0^\circ \leq \theta \leq 28^\circ$. Higher mass entrainment and better thermal characteristics are observed with increasing plate angle while pressure recovery reduces with increase in plate angle.

(f) **Study of Hybrid Slot Plate Guidance:** Design modifications to straight plate guidance at the slot is introduced by fusing two plates having angles of 0° and 28°, referred as hybrid slot. Two new design; (i) a hybrid guidance at the first slot only while other slots having straight plate guidance of 28° (Hybrid_first_slot) , and (ii) hybrid guidance at all the slots (Hybrid_all_slot) are investigated. It is found that the Hybrid_first_slot configuration beside higher mass entrainment and better thermal characteristics also recovers maximum static pressure.