

# AERODYNAMIC STUDIES ON THE FLOW CHARACTERISTICS OF INTAKE DUCTS

*by*

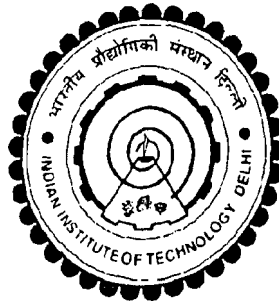
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Submitted

in fulfillment of the requirements of the degree of  
**DOCTOR OF PHILOSOPHY**

to the



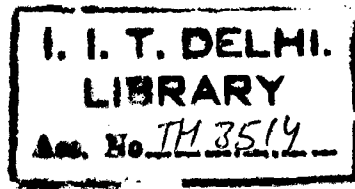
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**NOVEMBER 2007**

- ① Internal Aerodynamics.
- ② Aerodynamics studies
- ③ Intake ducts.



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*Dedicated to*  
***My Parents, My Teachers***  
*and*  
***My Wife Suparna***

- ① Aerodynamic studies
- ② In take ducts

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## C E R T I F I C A T E

This is to certify that the thesis entitled "**Aerodynamic Studies on the Flow Characteristics of Intake Ducts**" being submitted by **KRISHNENDU SAHA** is report of bonafide research work carried by him under our supervision. This thesis has been prepared in conformity with the rules and regulations of the Indian Institute of Technology Delhi, New Delhi. We further certify that the thesis has attained a standard required for a Ph. D. degree of the Institute. The research reported and results presented in the thesis have not been submitted, in part or full to any other institute or university for the award of any degree or diploma.



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## ABSTRACT

Intake ducts supply air to the propulsion system through a multi-stage compressor. Among the various types of intakes, side scoop type intakes are often used for single and dual engine high-speed aircrafts breathing system. Intake is one of the most important components of the air induction system in high speed fighter aircrafts, as it has vital effect on the engine performance. With the advent of supersonic airplanes, the improvement of intake performance became a major challenge for the researchers. The intake needs to serve various functions, such as, decelerating the flow efficiently, high static pressure recovery, minimum total pressure loss and minimum total pressure distortion.

In depth review of the literature shows that the investigations reported on the curved ducts or diffusers are plenty where as studies available in the open literature for twin intake ducts are rather few in number. In view of the scanty literature on twin intake ducts, it was been concluded that there is need to carry out a systematic analysis on twin intake ducts. The three major phases of the present investigation are experimental study, validation of the Computational Fluid Dynamics (CFD) code and parametric investigation.

The experimental study has been carried out in a low speed wind tunnel with an air supply unit consisting of a single stage centrifugal blower having a maximum air flow capacity of approximately  $10 \text{ m}^3/\text{sec}$  at ambient conditions. The blower is coupled to an electric motor of 125 HP having an RPM of 3000. The blower troughs air to an open ended settling chamber (cross-section of  $80 \times 80 \text{ cm}^2$ ) through a diverging cone and

series of flow straighteners. A forebody-twin intake duct assembly is kept just after the settling chamber for the experimental investigation having semi-elliptic inlet cross-section. The intake duct consists of two S-shaped diffusing limbs having an area ratio of 2.0, angle of turn of  $22.5^\circ/22.5^\circ$  and 300 mm length merging into a common straight circular duct of 160 mm diameter and 160 mm length. Experiments have been conducted at  $0^\circ$ ,  $5^\circ$  and  $10^\circ$  yaw angles. The experimental investigation has been carried out at a freestream velocity of 11.6 m/s by adjusting the opening of the sliding gate provided at the suction of the blower. The inlet velocity ratio has been set to 1.2 by controlling the mass flow in the intake by adjusting a control valve provided downstream of an orifice meter for all the yaw angles. The measurements have been presented in the form of normalized longitudinal velocity distributions, normalized crossflow velocity vector plots, iso-contours of normalized static pressure, normalized total pressure and performance parameters, like, the static pressure recovery coefficient, the total pressure loss coefficient and the total pressure distortion coefficient for the worst  $60^\circ$  sector (DC60). The flow parameters have been normalized based on the freestream quantities (mean velocity magnitude and dynamic pressure). The values of static pressure recovery coefficients, total pressure loss coefficients and distortion coefficient show a weak dependence on yaw angle.

Numerical studies on transition S-shaped diffusing ducts and have been done after validating the CFD code FLUENT against the experimental results of Anand [2002] on circular S-shaped diffuser and the present experimental results on Y-shaped diffusing ducts. Validation of the CFD code has shown that the RNG  $k - \epsilon$  turbulence model gives better prediction compared with the standard  $k - \epsilon$  turbulence model for S-shaped

diffusers due to the superior capability of RNG  $k - \epsilon$  model to capture the transverse pressure gradients in the ducts having streamline curvature. The matching achieved using the standard  $k-\epsilon$  and the RNG  $k-\epsilon$  turbulence models is almost close with deviation being slightly more for the standard  $k-\epsilon$  model for forebody-twin intake duct assembly, but time taken for convergence was much less in case of standard  $k-\epsilon$  model. Thus for Y-shaped intake duct the standard  $k-\epsilon$  model has been used.

In the parametric investigations, three different studies have been carried out. In the first stage, the effect of inlet shape has been carried out for S-shaped transition diffusing ducts, which is mainly used in dual engine aircrafts at an inlet velocity of 60 m/sec for all the cases. In this investigation, semicircular, semi-elliptic-1, semi-elliptic-2, semi-oval, rectangular and square shaped inlets were studied with circular outlet for all cases. The values of performance parameters show that the S-shaped diffusing duct with elliptic-2 inlet has the best performance followed by the semicircular shaped inlet duct, whereas square shaped inlet S-duct shows the worst performance.

In the second stage, the inlet shape effect for twin intake duct at an inlet velocity of 40 m/sec has been carried out. In this study, semi-circular, semi-elliptic-1, semi-elliptic-2 (inverse of the major to minor axis ratio of semi-elliptic inlet), semi-oval, rectangular and square shaped inlets were analyzed having constant circular outlet for all cases. This study reveals that the elliptic-2 shaped intake duct has the best performance as compared to the other shapes. The comparative performance analysis also shows that the square shaped inlet is having the worst performance. It is observed that the DC60 is the minimum for the semi-circular inlet, which is followed by the elliptic-2 duct.

In the final stage of computational study, flow analysis has been carried out for forebody-intake configuration having semi-elliptic inlet cross-section at inlet velocity ratio of 0.7 and 40 m/sec free stream velocity. The semi-elliptic-1 duct has been selected based on the performance of the twin intake ducts of various inlet shapes. This study has been done for a range of yaw angles from  $0^\circ$  to  $30^\circ$  and range of pitch angles from  $0^\circ$  to  $30^\circ$ . Further, various combinations of yaw and pitch angles have also been studied between the ranges from  $10^\circ$  to  $30^\circ$ . Non-uniformity of the flow increases in forebody-twin intake duct assembly with the increase of yaw and pitch angles due to the asymmetric flow entry to the two limbs of the intake duct due to forebody.

The present investigation gives considerable insight on flow field in the intake ducts that can help in their design. The investigation reveals that inlet shape affects the flow physics significantly inside the intake duct. The incidence angle of the freestream flow on the forebody-intake duct configuration has a dominant effect on the duct flow characteristics and this has been analyzed in the present study fairly extensively.

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