ISOTHERMAL FLOW STUDIES IN A REVERSE-FLOW GAS TURBINE COMBUSTOR

by

SANJEEV BHARANI

DEPARTMENT OF APPLIED MECHANICS

Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY, DELHI

DECEMBER, 1997

भा॰ प्रौ॰ सं॰ दिल्ली
I. I. T. DELHI
पुस्तकालय/LIBRARY
परिग्रहण सं॰
Acc. No TH-2522

TH
536-33:621.438
BHA-I

I. I. T. DELHI
PROCESSED
LIBRARY

Dedicated to

My Teachers,

My Grand Parents, Parents,

My wife Rekha, daughter Shubhrika,

My Engineer and Doctor Uncles & Doctor Aunt

CERTIFICATE

This is to certify that the thesis entitled, **Isothermal Flow Studies in a Reverse-Flow Gas Turbine Combustor**, being submitted by **Sanjeev Bharani**, has been prepared under our supervision in conformity with the rules and regulations of the **Indian Institute of Technology, Delhi**. We further certify that the thesis has attained a standard required for a **Degree of Doctor of Philosophy** of the institute. The research reported and results presented in the thesis have not been submitted, in part or full, to any institute or university for any degree or diploma.

(S N Singh)
Professor
Dept. of Applied Mechanics
Indian Institute of Technology Delhi
New Delhi- 110 016, India

(D P Agrawal)
Professor
Dept. of Mechanical Engineering
Indian Institute of Technology Delhi
New Delhi- 110 016, India

ACKNOWLEDGEMENT

I wish to express my sincere gratitude towards my supervisors, Prof S N Singh and Prof D P Agrawal for their invaluable teaching and incessant support and encouragement through out the period of my Ph.D work. I am deeply indebted with their love and inspiration towards sincere and hard work. My feelings can further be expressed as--

गुरुर्ब्रह्मा गुरुर्विष्णुः गुरुर्देवो महेश्वरः।
गुरुः साक्षात्परब्रह्म तस्मै श्रीगुरवे नमः॥

Gururbrahmā gururviṣṇu gururdevo maheśvaraḥ.
Guruḥ sākṣāta parabrahma tasmai śri gurave namaḥ.

In addition to my supervisors, Prof V Seshadri, Dr Srinivas V Veeravalli and Dr Ratan Mohan were other teachers, without whom I would have missed some of the important learning during this period. I am highly thankful to them. I wish to thank Mrs Agrawal, Mrs Singh and Mrs Seshadri for their love and affection conferred on me and my family. This made my stay over here, away from my home town and family members, less miserable. I feel also indebted to Prof S M Yahya and Prof P K Sen for imparting me knowledge of their subjects.

Experimental work, needs lot of efforts in designing, fabrication and installation of the required set-up. This was not possible without the help of staff of Gas Dynamics and Fluid Mechanics Laboratories. Mr Rameshwar, Mr Shambhu, Mr Harbhajan Singh, Mr Kundan Singh, Mr Ramswaroop, Mr Rakshapal, Mr Roopram, Mr Diwan Singh, and Mr Sher Singh concerned with these laboratories helped in this work, at various levels as and when needed. Special thanks are due for Mr Sitaram, Mr T R Bhogal and Mr Onkar Singh for their best efforts in supporting me for completing my experimental work in time.

I am thankful to all other faculty member, staff members of the office, the workshop, and the other laboratories of the Applied Mechanics Department who have taught, helped and assisted, respectively, at different point of time to go ahead with this work. Thanks are due also to Mr B B Arora, for tracing figures nicely and to Mr Ramesh Makhija, Mr P Sudhakar, Mr Madan Gopal and Mr Bali for their kind help.

It is well known that friends and batchmates make the surrounding lively and keep the enthusiasm in order to propel further for the target. During my stay on the campus for the present work, Mr Rakesh Mishra, Mr B K Gandhi, Mr Umesh Kumar and Mr R M M Gowda, gave me the same, for the successfully completion of the Ph.D work. I also feel my self fortunate to have a friend like Mr Pankaj Jain, who has always inspired me to acquire knowledge and excel in the engineering field.

For a human being, home remains the first school and the elder family members as first batch of teachers, who build foundation of a child's future. Same is true for me too. I am grateful to my grand parents, parents, uncles and aunt for the inspiration and moral values given to me which has helped to do my work sincerely and faithfully. My better half, Rekha and my dear daughter Shubhrika needs special mention for their love, constant support, patience, adjustments and giving me happy moments to endure this long and tedious path of learning. I wish, future will give me opportunity to replenish some of the moments which they have sacrificed during this period.

I also wish to extend my sincere thanks to the Governing Body and the Director of Shri G S Institute of Technology and Science, Indore, for giving me an opportunity to do Ph.D work at IIT, Delhi. I am also thankful to all the Professors and my colleagues of Mechanical Engineering Department for their support in pursuing this study and sharing my teaching load during the period of study leave.

Sanjeev Bharani

ABSTRACT

Combustor forms an integral part of a gas turbine power generating unit. It receives air from a compressor and delivers it at an elevated temperature to a turbine. The rise in air temperature is achieved by burning fuel in a combustor. The combustion products are then mixed with the additional air to achieve a suitable velocity and temperature profiles at the turbine inlet. In aircraft gas turbine engines, where frontal area and weight are also critical, mainly annular combustors are preferred over can type or can-annular type. Annular combustors offer maximum utilisation of available volume with minimal light-around problem, less requirement of cooling air and are suitable for high temperature applications. Selection of a particular type and layout of the combustor is determined largely by engine specifications but it is also strongly influenced by the desirability of using the available space as effectively as possible. For large aircraft engines, the combustor is invariably of the straight-through type, while for small engines, due to whirling problem of the high speed shaft, annular reverse-flow combustors are widely used. Extensive review of the literature revealed that most of the reported work pertains to straight-through combustors. However, conclusions drawn from these studies are not directly applicable for the design of reverse-flow combustors. Literature on the reverse-flow combustors is limited to the simplified geometries.

With limited data available on the reverse-flow combustors, development of computational fluid dynamic (CFD) capabilities in respect of them have also been slow. There is a need for comprehensive investigations on these combustors to generate data base covering various aspects of its design. Parametric studies are also required for the development of CFD capabilities to design these combustors. The gap in

knowledge on various aspects of the reverse-flow combustor has prompted the present study.

Annular passages in the combustor geometry play an important role and the flow characteristics in these passages directly affect the flow splits through the primary, secondary, dilution and cooling holes of a liner. The flow split through the primary holes govern the fuel and air mixing while split through the secondary and dilution holes decides the completion of burning and final temperature profile at the combustor outlet, respectively. The flow split through the cooling holes keeps the liner wall temperature under control. Performance of combustor is dependent on these splits occurring at various identified liner zones.

Recognising their importance, the present study has investigated the effect of inlet conditions on the flow characteristics in annuli and the flow splits through various liner holes. For achieving these objectives, separate test set-ups were designed and fabricated to carry out tests, under isothermal conditions, on the 120° sector model, the plane model and the prototype combustor of the reverse-flow type. Effect of inlet velocity profiles and Reynolds number on the flow characteristics in the outer annulus and at the exit plane of the 120° sector model have been investigated. In the plane model, effects of inlet Reynolds number and the pitch to diameter ratio have been studied to establish the flow characteristics in the annuli, in the liner and at the turn-section outlet. Measurements in the liner and the inner annular passage were done only for the plane model, as the inner annulus and the liner were not accessible for the other two geometries by intrusive probes. Exit flow for different inlet flow configurations have also been measured for all the geometries. Results of the model studies have been compared with the measurements taken in the outer annulus and the exit plane of the prototype combustor for the purpose of establishing correlation. In addition to this, the effect of dump-gap and inlet swirl on the flow characteristics in the outer annulus and at the exit have been studied in the prototype combustor.

Measurements were taken with two miniature (OD= 1.0 mm) three hole probes using null-technique and the differential pressures were noted with 'Debro' micromanometers (least count= 0.01 mm). Different measurement planes were identified in the models and the prototype combustor in order to evaluate axial and tangential/transverse velocities and the static pressure, at different measurement locations in the test geometries. A standard single hot wire probe with 'DANTEC' 56C01 constant temperature anemometer system has also been used to measure the flow characteristics in all the three geometries. The velocity measured by the hot wire were found within ± 1.0 % of the values obtained by the three hole probe.

Flow predictions have also been done by adapting and upgrading a finite volume code. In these studies, nonorthogonal curvilinear grid were generated and the flow computations were done in the annuli of the plane model and in the outer annulus of the prototype combustor. For modelling the flow in the annular passage(s), different rows of the liner holes have been represented by an equivalent area slit at their respective positions. Predicted results have been compared with the relevant experimental results.

Based on these studies, the following broad conclusions are drawn;

1. Comparison of results obtained on prototype combustor and the combustor models establish that, while the sector model could provide an insight into the

order of magnitude and qualitative comparison, the 'plane model' could be used for in depth understanding of flow in reverse-flow combustors with varying inlet conditions and geometric parameters.

2. In absence of any obstruction in the outer annulus, flow remained axial at every plane of measurement.

3. Dump-gap has been identified as an important parameter which influence velocity distribution and the flow split through the liner holes. In the present combustor design, 2 mm dump-gap has been found as an optimum gap which provide uniformly distributed axial and tangential velocities at respective planes, without the inlet swirl.

4. Without the inlet swirl, flow split through the outer dilution and primary holes was nearly 30 % and 8 %, respectively. Increase in the inlet swirl (up to S= 0.55) changes the flow split slightly through the outer liner surface and the turn-section. For higher swirl (S=0.84) large changes have been observed at each plane of measurement. Further, increase in the inlet swirl intensity results in uniform axial velocity distribution and flat tangential velocity profile at the exit.

CONTENTS