FLOW STUDIES IN THE ANNULUS OF A CAN TYPE MODEL GAS TURBINE COMBUSTOR

by

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CERTIFICATE

This is to certify that thesis entitled, **FLOW STUDIES IN THE ANNULUS OF A CAN TYPE MODEL GAS TURBINE COMBUSTOR,** being submitted by **ABDUR RAHIM**, 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.

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ABSTRACT

Combustor is an integral part of a gas turbine power-generating unit. It receives air from a compressor and delivers it to the turbine at an elevated temperature; it is highly desirable to have this done with better overall efficiency and smoke free combustion. The rise in air temperature is achieved by burning of fuel in combustor. Initial burning occurs with nearly one-third of the compressor discharge. The combustion products are then mixed with the remaining compressed air in stages in the liner to arrive at a suitable temperature and velocity at the exit of the combustor. Therefore, the primary function of a gas turbine combustor is to achieve a mixture, which can sustain continuous combustion, and to maintain, or stabilize, this combustion over a wide range of operating conditions. This is achieved by controlled mixing of fuel and air. In general the combustor has three main components i) diffuser, ii) casing-liner annulus, and iii) liner. The flow pattern in the annulus has a substantial effect on the liner flow pattern and influences the level and distribution of liner wall temperature. With the advent of high bypass ratio engines, heights of annulus have reduced. Therefore, manufacturing tolerances, differential expansion and distortion during operation can produce significant variation in geometry, leading to circumferential non-uniformities in the flow which may lead to asymmetric flow distribution through different liner holes.

A review of the relevant literature on gas turbine combustor highlighted the need to study the shape of liner dome and its effect on the flow behavior in the dump and annulus regions under varying inlet and dump-gap positions in order to optimize performance parameters. Parametric studies are also

required for the development of CFD code to design the combustor. The objectives of the present investigation are:

1. To investigate the effect of liner position (dump-gap) on the flow distribution around the liner in the annulus space in terms of velocity, pressure and wall pressure distribution for different dome shapes with non-swirling and swirling flows at inlet.
2. To validate/calibrate a commercial CFD code and carry out parametric investigations for the flow characteristics in the annulus space.

To meet the above objectives, an experimental test rig was fabricated. An isothermal flow study in the annulus of a model can-combustor has been carried out. Three different dome shapes of liner viz. hemispherical, ellipsoidal-H and ellipsoidal-V have been investigated for each dump-gap and inlet condition. Measurements have been carried out in the dump and annulus regions of the model can-combustor using a three-hole pressure probe and a constant temperature hot wire anemometer.

The whole experimental study is divided into four parts: Part 1 consists of experimentation on combustor model without liner just to validate various previous studies as given in literature. Part 2 consists of the experimental study of a combustor model having a hemispherical domed shape liner for three dump-gaps viz. 0.5, 1.0 and 1.5 at four inlet conditions; non-swirling, 15°-swirling, 30°-swirling and 45°-swirling flows. The main conclusion drawn from Part 2 of the study was that the flow characteristics and performance parameters are almost similar for the dump-gaps 1.0 and 1.5 with dump-gap 1.0 showing better all round performance. Hence, dump-gap 1.5 can be omitted for the further studies. Part 3 is the experimental study of combustor model having ellipsoidal-H dome shape for two dump-gaps at the same four inlet conditions. From this study and previous studies, it has been observed that dump-gap of 1.0 and 30° swirling flow has the highest value of pressure recovery and minimum pressure loss. Therefore, for Part 4 of the study, a model having ellipsoidal-V dome shape liner has been studied for dump-gap of 1 and 30° swirling flow only. For all the inlet conditions and dump-gaps, the following parameters have been measured:

i. Wall pressure distribution along the liner and the casing.
ii. Velocity and pressure characteristics at six cross-sections along the length of casing using three-hole probe.
iii. Velocity and turbulence intensity distribution using hot-wire anemometer.

The data generated using three-hole probe and hot-wire anemometer were analyzed to evaluate the dynamic parameters namely,

i. Axial velocity distribution
ii. Tangential velocity distribution
iii. Static pressure distribution, and
iv. Turbulence intensity distribution.

The mass-averaged static pressure and mass-averaged total pressure at inlet and exit are calculated to get the coefficients of static pressure recovery and total pressure loss respectively.

The experimental results were used to calibrate the commercial CFD code, FLUENT. The calibrated CFD code was used for establishing the effects of inlet swirl, dump-gap and divergence of the casing wall.

The salient conclusions drawn from the experimental and computational investigations are:

1. For non-swirling flow, wall recirculation zone (WRZ) size reduces with decreasing dump-gap for any given liner dome shape. The reduction is only marginal for the range of dump-gap investigated.
2. No central recirculation zone is formed for no swirl and weak swirl at inlet for the body shapes and dump-gaps investigated. For moderate to high swirl, central recirculation zone (CRZ) is formed at the symmetry axis and depending on the other parameters, its origin is at the jet exit plane or it is blown-off.
3. Comparing the axial velocity profiles it is clear that as the pre-swirl increases, the recirculation zone on the casing reduces in axial extent.
4. Overall, it appears that increasing pre-swirl reduces the casing recirculation and makes the velocity and pressure profiles in the annular region more uniform, only up to a certain point. Beyond that the uniformity deteriorates due to the drop in pressure in the core region.
5. Looking at the axial velocity data and the static pressure recovery, it appears that hemispherical and ellipsoidal-H domes with a dump gap of 1.0 and pre-swirl of 30° have the best performance since the C_P value is close to the maximum observed and the flow becomes uniform at the shortest axial distance.

6. The CFD code predicts the flow reasonably well, giving confidence that further parametric studies could be conducted on the computer.
7. A good match was obtained for the mean velocity profiles and static pressure profiles between the experimental data and numerical simulation over most of the flow (except in the high shear and high acceleration zones of the dump region).

CONTENTS