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Design and study on performance of axial swirler for annular combustor by changing different design parameters

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ABSTRACT

Recent technologies have been introduced for gas turbine engine to meet with stringent emission regulations. One of the technologies is to introduce recirculation in the combustion zone to control the residence time and mixing by help of swirling flow. Effect of variation in geometric parameters and inlet mass flow of swirler have been examined in this study by help of CFD. Detailed design methodologies have been proposed in this study to design a series of axial swirler with different vane angles and vane numbers. Substantial variation in swirler performance has been observed by changing vane angle, vane number and mass flow. Four different types of axial and radial velocity profiles have been observed. Turbulence distribution pattern shows double peaks at all positions and reduces with increasing axial distance.

1. Introduction

With the growth in aviation industry and protocols to reduce emissions, there is a need of continuous improvements in technology for gas turbine engines. A modern combustor must satisfy various requirements for being able to deliver the desired performance. Combustor should comply with the requirements including capability of easier ignition and stable operation over a wide range of work conditions, complete combustion, appropriate temperature traverse at outlet and low pressure loss. It is of great importance that all necessary requirements of combustor can be fulfilled while keeping minimum size, weight, cost, while maintaining operating life. Researchers around the world are constantly developing new technologies and concepts to improve the performance of combustors and decrease the emissions from the combustors [1,2].

The swirler is generally mounted in dome of combustors circumferentially and plays an important role in combustion design [3–6]. Swirlers have three basic functions. Firstly, the swirler can create a stable low pressure central recirculation zone that have merits of stabilized and anchored flame close to swirler exit, enhancing mixing between fuel and air and acting as a continuous source of ignition. Secondly, the swirling flow produced by swirler can reinforce the secondary holes recirculation, further increasing the turbulence, which benefits stability of the secondary holes. Finally, the air through the swirler can form a film cooling layer to cool the first section of liner close to the injectors. In order to fulfil all three functions, the swirler must impart a high radial component, since air which still has an axial component reduces the secondary recirculation. In all, the swirler plays a vital role in gas turbine combustors to improve flame stabilization, fuel air mixing and emissions. High turbulence intensities lead to better atomisation for the liquid fuel sprayed from the injectors, which benefits the combustion stability of the combustor [7]. The length of recirculation zone is generally twice bigger as diameter of swirler if operating on diffusion without any effects of secondary airflow [8,9].

Counter-rotating swirler can generally lead to fine atomization than single or co-rotating swirler. However co-rotating swirler can generate less noisy flames than single and counter-rotating swirler. So for some civil application the co-rotating swirler are preferred. Swirlers are also classified according to their vane types, flat vane and curve vane. The angles of swirler vane are generally between 45° and 70° [9]. However, for the curve vane swirler, the angles at inlet and outlet are different. Although curve vane swirler have much stronger

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Nomenclature

A	area (unit: m^2)
AF	air to fuel ratio
CFD	computational fluid dynamics
C	vane chord
D	diameter (unit: m)
FCV	fuel calorific value
M	mass flow (unit: kg/m^3)
NO_x	oxides of nitrogen
P	pressure (unit: Pa)
q	mass flow (unit: kg/m^3)
r	radius (unit: m)
S	vane spacing
SN	swirl number
TET	turbine entry temperature (unit: K)
Z	vane height

Greek symbols

Φ	equivalence ratio
θ	vane angle
σ	solidity

Subscripts

3	compressor exit
4	turbine entry
c	core
cd	dome cooling
cs	swirling air
d	dome
f	fuel
h	hub
hub	hub
p	primary zone
ref	reference
s	swirler
sw	swirler
t	total
v	vane

turbulence intensity than flat vane swirler, pressure losses are relatively greater and manufacturing is more difficult, which consequently increase the cost and are comprehensively applied in bigger engines. Therefore the flat vane swirler is usually preferable for small engines due to simplicity and ease of manufacturing.

Several studies have been carried out on understanding working of a swirler [3,7,10–18]. To the author's knowledge there is no study available in literature which explains systematic design procedure of swirler and performance of varying designs. In this study a series of axial swirler with different vane angles and vane numbers were designed by using pressure drop methods according to the procedure developed and proposed in this study. A computational and analytical study is done to check the effect of the geometric parameters on flow characteristics and the effect of mass flow on pressure drop coefficient. Comparison of different CFD models has also been done to suggest the best model for computational analysis of swirler.

2. Design methodology of swirler

After a comprehensive literature review author's found that there is no literature available on a sound theoretical method of designing an axial swirler. Therefore the empirical methods are used in designing swirler in practice. Typical parameters of swirler need be determined as shown in Fig. 1 when designing axial swirler.

Considering the geometrical parameters in Fig. 1 and performance of combustors, there are two basic methods to calculate the geometry of axial swirler. One is flow drag coefficient method and another is pressure loss coefficient method. The two methods essentially differ in calculating the effective area of swirler, in one method it is determined by flow drag coefficient and in the other one it is determined by pressure loss coefficient.

3. Design of axial swirler

Design of swirler is based on preliminary design of combustors. Therefore design of axial swirler is carried out after finishing the preliminary design of combustor, which provides combustor performance parameter. Model engine [15] gives total pressure at the compressor exit (P_3) as 1644.9 kPa, total temperature at the compressor outlet T_3 as 775 K, turbine entry temperature (TET or T_4) as 1450 K, core mass flow (M_T) as 10.67 kg/s and turbine cooling bleed factor ($C_{cooling}$) as 12% and total pressure loss of combustors (ΔP) as 6%. It gives some geometric dimensions of the combustors including reference area (A_{ref}) as 0.8186 m^2, reference diameter (D_{ref}), chamber depth (H) as 57 mm, length (L) as 180 mm and so on.

The rules of designing the swirler can be summarized as no see through, suitable strong recirculation zone, required mass flow, matching with fuel injectors. For combustors, the mass flow is more important than the recirculation zone, the design of swirler must be carried out for the required mass flow for appropriate air distribution of combustors. Secondly the designed swirler must be suitable for the combustor dimensions and at the same time it must match the fuel injectors.

In this section the axial swirler will be designed according to the given combustor's [15] performance parameters and geometric dimensions. Firstly on the basis of preliminary design results of combustor the mass flow through the swirler need be calculated according to the air distribution, and then the effective area is determined by the pressure loss coefficient method. At the end, sizing of the swirler is carried out. Therefore the methods used in this section are both theoretical and empirical.

3.1. Procedure of calculating axial swirler mass flow

Firstly the air flowing through the core mass flow (M_c) is calculated according to the total mass flow (M_T) and turbine cooling bleed factor ($C_{cooling}$) using Eq. (1).