Designing, Modeling and Fabrication of Micro Gasturbine Combustion Chamber

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Abstract

The modelling, fabrication and experimental details of the annular combustion chamber of the micro gas turbine engine are discussed in this paper. There are numerous research work conducted to improve the performance of the micro gas turbine engine. We attempted to increase the overall efficiency of the engine by changing the flow direction to an optimum angle before the air stream reaches the combustion chamber. Following the numerical simulations, the expected raise in the performance was obtained when the flow turns at 30°. The swirl vanes are designed in such a manner that the flow turns to the required angle. The engine is designed in such a way that is can sustain the variation in the fuel flow rate by injecting the fuel at two different directions into the combustion chamber, one parallel to the flow and the second in tangential to the flow. The design further incorporates special provision for cooling the flame tube by adding row of holes on both the inner and outer domes. In order to overcome the fabrication complications the downstream of the combustor has number of holes in place of the slit. To verify the burning performance of the engine a separate plate is bolted the exhaust of the combustor. The final results are measured which confirmed the estimated increase in the performance of the engine under the design condition.

Introduction

Micro Combustor

The current trend towards miniaturization, portability and more in general ubiquitous intelligence, has led to the development of a wide range of new products such as laptops, cellular phones, PDAs, etc. However, the power requirements of such systems have received much less attention: typically, traditional battery-operated electronic systems are used. Nevertheless, the energy density of most fuel types is still 100 times
more than that of the most performing batteries, which makes the use of a fuel-based micro power unit interesting. Such power units can be based on a wide range of operating principles, ranging from fuel cells and thermo-electric devices, to combustion engines and gas turbines. While fuel cells are expected to offer the highest efficiency, micro gas turbines are expected to offer the highest power density.

Gas turbines are amongst the most advanced systems as they combine extreme conditions in terms of rotational speed with elevated gas temperatures (up to 2100 K for military engines). Miniaturization of such a system poses tremendous technical problems as it leads to extremely high rotational speeds (e.g. $10^6$ rpm). Moreover scaling down the system unfavourably influences the flow and combustion process. Fabricating such devices requires new materials to be explored (such as Si$_3$N$_4$ and SiC) and requires three-dimensional micro manufacturing processes.

Heat input to the gas turbine Brayton cycle is provided by a combustor. The combustor accepts air from the compressor and delivers it at an elevated temperature to the turbine (ideally with no pressure loss). Thus, the combustor is a direct-fired air heater in which fuel is burned almost stoichiometric with one-third or less of the compressor discharge air. Combustion products are then mixed with the remaining air to arrive at a suitable turbine inlet temperature. There are many types of combustors, but the three major types are tubular, tubo-annular, and annular. Despite the many design differences, all gas turbine combustion chambers have three features: (1) a recirculation zone, (2) a burning zone (with a recirculation zone which extends to the dilution region), and (3) a dilution zone. The function of the recirculation zone is to evaporate, partly burn, and prepare the fuel for rapid combustion within the remainder of the burning zone. Ideally, at the end of the burning zone, all fuel should be burnt so that the function of the dilution zone is solely to mix the hot gas with the dilution air. The mixture leaving the chamber should have a temperature and velocity distribution acceptable to the guide vanes and turbine. Generally, the addition of dilution air is so abrupt that if combustion is not complete at the end of the burning zone, chilling occurs and prevents completion. However, there is evidence with some chambers that if the burning zone is run over rich, some combustion does occur within the dilution region.

Combustor inlet temperature depends on engine pressure ratio, load and engine type, and whether or not the turbine is regenerative or non-regenerative especially at the low-pressure ratios. The new industrial turbine pressure ratio’s are between 17:1, and 35:1, this means that the combustor inlet temperatures range from 850 F (454 C) to 1200 F (649 C). The new aircraft engines have pressure ratios, which are in excess of 40:1.

**Combustion**

In its simplest form, combustion is a process in which some material or fuel is burned. Whether it is striking a match or firing a jet engine, the principles involved are the same, and the products of combustion are similar.

Combustion of natural gas is a chemical reaction that occurs between carbon, or hydrogen, and oxygen. Heat is given off as the reaction takes place. The products of combustion are carbon dioxide and water. The reaction is

$$\text{CH}_4 + 4\text{O} \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{HEAT}$$
Four parts of oxygen are required to burn one part of methane. The products of combustion are one part of carbon dioxide and two parts of water. One cubic foot of methane will produce one cubic foot of carbon dioxide gas. Oxygen used for combustion occurs in the atmosphere. The chemical composition of air is approximately 21% oxygen and 79% nitrogen, or one part oxygen to four parts nitrogen. In other words, for each cubic foot of oxygen contained in the air, there are about four cubic feet of nitrogen.

Oxygen and nitrogen molecules each contain two atoms of oxygen or nitrogen. Nothing that one part, or molecule, of methane requires four parts of oxygen for complete combustion, and since the oxygen molecule contains two atoms, or two parts, the volumetric ratio of methane and oxygen is as follows:

1\text{CH}_4 + 2\text{O}_2 \rightarrow 1\text{CO}_2 + 8\text{N}_2 + 2\text{H}_2\text{O} + \text{HEAT}

The preceding equation is the true chemical equation for the combustion process. One cubic foot of methane actually requires two cubic feet of oxygen for combustion.

Design Parameters

Inlet

In this section, we study the aerothermodynamics and the design of aircraft engine inlet. The inlet flow field bears no resemblance to exhaust flow field, the presence of adverse pressure gradient in an inlet diffuser leads to a stalling boundary layer behaviour.

The system requirements of an aircraft intake primarily depend on the aircraft mission specification. In general, an aircraft intake system has to be designed to many of the following qualities, Light weight and low cost to manufacture, provide the engine with adequate mass flow rate at a proper mach number at the engine face throughout the flight envelope. Provide spatially smooth flow into the engine compressor, Low installation drag, Provide acoustic absorption of fan/engine noise.
Combustor Design parameters

The design of combustor for aircraft gas turbine engines is a complex and difficult problem that is usually solved by reaching a reasonable compromise between the conflicting requirements. Design involves a broad range of technical discipline including combustion chemistry, fluid dynamics, heat transfer, stress analysis and metallurgy. Although there are many design parameters for a combustor, most experts would include the following in their list of most critical design parameters such as Combustor inlet conditions, Height of the dome, Airflow distribution and cooling air, Combustor exit pressure, Overall total pressure loss, Combustor dome velocity, Pattern factor parameter, Flame tube length, Combustor exit area.

Exit area design

CATIA is one of the leading design software. CATIA can be applied to a wide variety of industries, from aerospace and defence, automotive, and industrial equipment, to high tech, shipbuilding, consumer goods, plant design, consumer packaged goods, life sciences, architecture and construction, process power and petroleum, and services. We used Mechanical design feature for design the exit area.

Stoichiometric air/fuel ratio

The mass balance in a chemical reaction, describing exactly how much oxidizer has to be supplied for complete combustion of certain amount of fuels is generally termed as stoichiometry. This stoichiometric ratio always needs not to be in stoichiometric proportions in combustion problems. On several occasions, excess oxidizer are supplied to ensure complete combustion of fuel in practical devices when quantity of oxidizer exceeds than the stoichiometric proportions, the mixture is termed as fuel lean or lean mixture. In contrast, if less quantity of oxidizer than the stoichiometric quantity is present, the mixture is known as fuel rich or rich mixture. On several occasions, hydrocarbons fuels are burnt in the presence of air. For hydrocarbon fuel represented by $C_XH_Y$, the stoichiometric relation is given below,
\[ \text{C}_8 \text{H}_6 + \alpha \text{O}_2 \cdot (3.76 \text{N}_2) \rightarrow \alpha \text{CO}_2 \cdot (y/2) \text{H}_2\text{O} + 3.76 \text{aN}_2 \]

**Modelling and Fabrication**

![Designed part of diffuser](image1)

**Fig. 5** Cross section of Combustor

**Fig. 6** Diffuser sections

**Fabricated part of diffuser**

**Design part of connector**

![Design part of connector](image2)

**Fig. 9** Connector sections

3.6 Fabricated part of connector

**Design part of casing**

![Design part of casing](image3)

**Fabricated part of casing**

![Fabricated part of casing](image4)

**Fig 8** Casing sections

**Design part of outer casing**
Fig 10  Outer casing sections
Fabricated part of outer casing

Fig 11  Fuel injector
Fabricated part of Fuel injector

Fig 12  Exit plate
Fabricated part of Exit plate

Fig 13  Vane sections
Fabricated part of Vane

Design part of Exit plate

3.13 Design part of Vane

Design part of Dummy solid shaft

Design part of Fuel injector
Fig. 14  Dummy solid shaft

Fabricated part of solid shaft

Design part of Inner flame tube

Fig. 15  Inner flame tube

Design assembly of combustion chamber

Fabricated part of outer flame tube

Fabricated part of outer flame tube

Design part of outer flame tube
We have assembled all the components of the combustion chamber at their respective positions and locations. Before testing of the complete system, we passed air to check any leakage in the system and at the same time performance of the compressor too.

In our first experiment, the fuel pressure level had been taken as 3 bar and the air pressure as 4 bar corresponding exit temperature is noted as 500k. During the next experiment both the pressure of air and pressure of fuel are increased gradually to 6 bar and 5.8 bar corresponding exit temperature is noted as 695k. As with the increase in pressure of the working fluid, exit temperature of the combustion chamber is also increases. Thus, the result shows that our estimated calculation is achieved.

**Conclusion**

In accordance to the Table 1, we have seen that pressure of the fuel is an important parameter of a combustion chamber and it is concerned with the exit temperature. These experimental evaluations have major role in the selection of turbine blade material.

This paper correlates the experiment the relation between working fluid of the combustion chamber and temperature. Finally the result obtain will be helpful for the entire selection of the engine components material.

**Reference**

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