COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATION ON GAS TURBINE COMBUSTION CHAMBER

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ABSTRACT

On a gas turbine engine, the combustion chamber is one of the most important parts to complete the cycle of Brayton. Combustion chamber is used to burn fuel-air mixture to produce energy. This energy are then supply to enter the nozzle and then into the turbine. It is of interest to examine briefly relationship between gas generator speed (Ngg) and efficiencies and also the condition of fuel-air mixture during the combustion. The project needs considerations that dictate the basic geometry of the "conventional" gas turbine combustor. It is also instructive because it helps to define the essential components needed to carry out the primary functions of a combustion chamber. For further step of the project after conducting some experiments, the effort was continued using Computational Fluid Dynamics (CFD) Simulation. The software used was COSMOSFloworks. It was used to observe the flow of the fuel-air mixture during combustion process. There were several factors that affect the level of the efficiency instead of fuel-air mixture ratio that is swirl effect. In the combustion chamber that was being analyzed there was a liner wall with holes drilled around the body to create recirculation (swirl) flow. This factor is also affects the efficiency of the combustion process. Through simulation, the pattern of the flow was observed. The result of the simulation is useful for the design of the combustion chamber and it is useful for further project in order to improve the efficiency of the combustion process.

ABSTRAK

Kebuk pembakaran ialah salah satu komponen yang paling penting untuk melengkapkan Kitaran Brayton di dalam sistem enjin gas turbin. Kebuk pembakaran digunakan untuk membakar gas campuran (udara dan bahan api) bagi menghasilkan tenaga. Tenaga ini kemudiannya memasuki nozel seterusnya memasuki turbin. Ia adalah fokus untuk mengkaji secara ringkas hubungan di antara laju gas generator (Ngg) dan peratus kecekapan serta keadaan gas campuran ketika proses pembakaran. Projek ini memerlukan beberapa fokus yang mencirikan bentuk atau geometri asas kebuk pembakaran bagi enjin gas turbin. Projek ini juga membantu untuk mengenal komponen-komponen penting yang patut diambil kira untuk mengenalpasti fungsi-fungsi utama kebuk pembakaran. Langkah selanjutnya selepas menjalankan beberapa eksperimen ialah mengkaji kitaran aliran gas campuran ketika proses pembakaran mengunakan simulasi Dinamik Bendalir berbantukan computer (CFD). Perisian yang digunakan dalam projek ini ialah COSMOSFloworks. Terdapat beberapa faktor yang mempengaruhi tahap kecekapan kebuk pembakaran selain daripada peratus gas campuran iaitu kesan putaran aliran. Terdapat satu silinder yang ditebuk lubang di sekelilingnya untuk menghasilkan aliran putaran. Faktor ini juga menyumbangkan kepada perkembangan peratus kecekapan bagi proses pembakaran. Melalui simulasi, corak aliran gas campuran telah diperhati. Hasil daripada simulasi ini berguna untuk penghasilan kebuk pembakaran dan berguna untuk projek lanjutan untuk meningkatkan kecekapan proses pembakaran dalam sistem enjin gas turbin.

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CHAPTER 1

INTRODUCTION

1.1 Background

Most modern passenger and military aircraft are powered by gas turbine engines, which are also called jet engines. There are several different types of gas turbine engines, and all turbine engines have some parts in common. All turbine engines have a combustor, or burner [2], in which the fuel is combined with high pressure air and burned [2]. The resulting high temperature exhaust gas is used to turn the power turbine and produce thrust when passed through a nozzle [2]. In this project, there will be simulation analysis on combustion chamber of gas turbine engine. The focus is to study the flow of air and fuel mixture during combustion process and to observe air-fuel ratio for efficient combustion. Over the past several years, Computational Fluid Dynamic (CFD) has been used increasingly to study the fluids motion of internal combustion engine [5]. Design of combustor model is one the important stage because it can affect the whole flow process of internal combustion. Through CFD software the characteristic of the air-fuel mixture flow during combustion can be determined [5]. Two shafts Gas Turbine Machine (P9005) from Cussons Technology Ltd will be the model to be analyzed [4]. The dimensions and the geometry of the combustor that is to be analyzed is depend on the Cusson machine [4].

There are plenty of geometries of gas turbine combustor was developed. The early gas turbine combustor from Britain, Germany, and USA [1] such as whittle vaporizer combustor, De Havilland Goblin [1], Jumo 004 [1], BMW [1] and many more.

This document contains five chapters. The first chapter is introduction that consists of problem statement, objective, and the scopes of the project. It will be discussed the detail about the main objective and solution for the problem. The second chapter will be literature review that will be added with information of the part of the combustor and the function of each part and any information related. Chapter three is methodology section that will be discussed on the way used in this project to make it success and achieve the objective. Gantt chart is used as a reference and guideline. Next chapter will be result and discussion. All data and discussion will be attached here. Finally, it will be conclusion chapter to conclude what the project has achieved as well as the recommendation for further development.

1.2 Problem Statement

It is of interest to examine briefly relationship between gas generator speed and efficiencies and also the condition of fuel-air mixture during the combustion. The project needs considerations that dictate the basic geometry of the "conventional" gas turbine combustor. It is also instructive because it helps to define the essential components needed to carry out the primary functions of a combustion chamber.

1.3 Objectives

1.3.1 To determine the efficiency of the gas turbine combustion chamber.

1.3.2 To study the flow of fuel-air mixture in the gas turbine combustion chamber by experiment and CFD analysis.

1.4 Scopes

The scopes of the work are:

1.4.1 Running a significance experiment to get the efficiency of the combustion process.

1.4.2 Design a gas turbine combustor using CAD software as the model will be Cusson [4] gas turbine combustor unit.

1.4.3 Simulate and analyze the design using CFD CosmosFloworks software.

1.5 Justification

This project will give many benefits to student for further research on gas turbine combustion unit since this part is one of the main parts in the system. Nowadays there are many inventors and companies such as NASA, Rolls Royce [2] and many more of them that compete to create an efficient gas turbine combustor. In this project Cusson [4] gas turbine combustor will be the model to be analyzed using simulation software. It can be analyzed using CFD [5] method. This project has high hope toward the best result of studying the flow of air-fuel mixture during combustion process and also to suggest a perfect geometry of gas turbine combustion chamber for further development as the result of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter elaborates all information of gas turbine combustor regarding theories, components of gas turbine combustor, combustor structure, the flow of the combustion and so on.

2.2 Gas Turbine Engine Parts

Figure 2.1 is a basic turbojet engine. At the front of the engine, to the left, is the inlet at the exit of the inlet is the compressor, which is colored cyan. The compressor is connected by a blue colored shaft to the turbine, which is colored magenta. The compressor and the turbine are composed of many rows of small airfoil shaped blades. Some rows are connected to the inner shaft and rotate at high speed, while other rows remain stationary. The rows that spin are called rotors [7] and the fixed rows are called stators [7]. The combination of the shaft, compressor and turbine is called the turbomachinery [7]. The "Exploded View" button shows you how these parts go together. Between the compressor and the turbine flow path is the combustion section or burner [2], which is colored red. This is where the fuel and the air are mixed and burned [3]. The hot exhaust then passes through the turbine and out the nozzle. The nozzle performs two important tasks. The nozzle is shaped to accelerate the hot exhaust gas to produce thrust [4]. And the nozzle sets the mass flow through the engine.

Here is a slide that compares computer model with a photo of a real, Pratt and Whitney F100 engine [7], The F100 engine is used in the F15 and F16 fighter aircraft [7]. As in the picture, jet engines are complicated pieces of machinery. Jets have a lot of parts which spin on a central shaft. To enclose the spinning parts, a jet engine is shaped like a long cylinder [7].

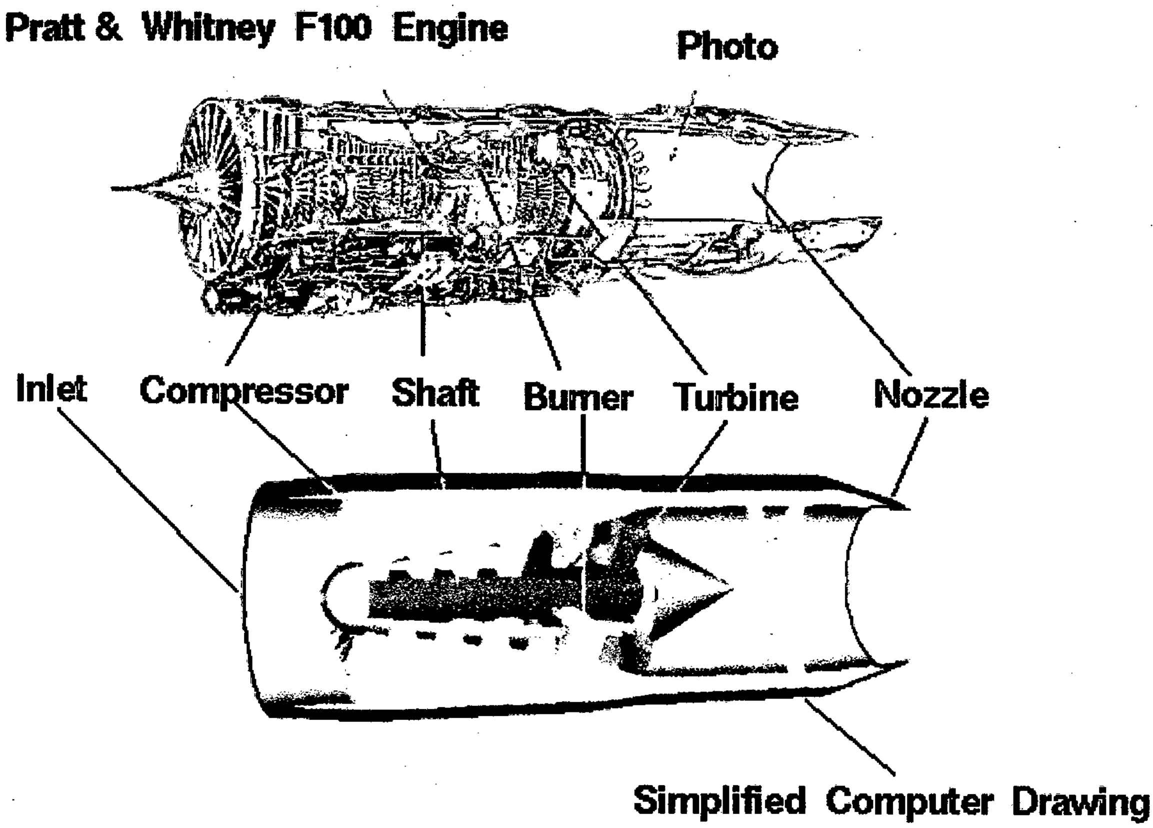

Figure 2.1 Comparison of computer model with a photo of a real, Pratt and Whitney F100 engine [7].

2.3 Combustion

Combustion is a chemical process that burning fuel. Gas turbine engine use internal combustion [7] system to generate thrust. It is all depend on the burning of fuel to produce power.

The original substance is called the fuel, and the source of oxygen is called the oxidizer. The fuel can be a solid, liquid, or gas, although for airplane propulsion the fuel is usually a liquid [7]. The oxidizer, likewise, could be a solid, liquid, or gas, but is usually a gas (air) for airplanes [7].

During combustion, new chemical substances are created from the fuel and the oxidizer. These substances are called exhaust. Most of the exhaust comes from chemical combinations of the fuel and oxygen. When a fuel burns, the exhaust includes water (hydrogen and oxygen) [7] and carbon dioxide (carbon and oxygen) [7].

The exhaust can also include chemical combinations from the oxidizer alone. If the fuel is burned in air, which contains 21% oxygen and 78% nitrogen [5], the exhaust can also include nitrous oxides (NOX, nitrogen and oxygen) [7]. The temperature of the exhaust is high because of the heat that is transferred to the exhaust during combustion.

Because of the high temperatures, exhaust usually occurs as a gas [6], but there can be liquid or solid exhaust products as well. Soot [5], for example, is a form of solid exhaust that occurs in some combustion processes.

During the combustion process, as the fuel and oxidizer are turned into exhaust products, heat is generated. Interestingly, some source of heat is also necessary to start combustion [6]. Heat is both required to start combustion and is itself a product of combustion.

To summarize, for combustion to occur three things must be present, a fuel to be burned, a source of oxygen, and a source of heat. As a result of combustion, exhausts are created and heat is released. The combustion process can be controlled or stopped by controlling the amount of the fuel available, the amount of oxygen available, or the source of heat.

2.4 Brayton's Cycle

The Brayton cycle is a constant-pressure cycle named after George Brayton (1830–1892), the American engineer who developed it. It is also known as the Joule cycle. It was originally invented 18 years earlier by John Ericsson in externally heated, both open and closed, piston engines [2].

2.4.1 History

In 1872, Brayton filed a patent for his "Ready Motor" [2] which, unlike the Otto or Diesel cycles, used a separate compressor and expansion cylinder. Today the Brayton cycle is generally associated with gas turbines.

Like other internal combustion power cycles, The Brayton cycle is an open system, though for thermodynamic analysis it is conventionally assumed that the exhaust gases are reused in the intake, enabling analysis as a closed system [2].

2.4.2 Model

A Brayton-type engine consists of three components:

(i) A gas compressor
(ii) A mixing chamber
(iii) An expander

In the original 19th-century Brayton engine [2], ambient air is drawn into a piston compressor, where it is compressed, ideally an adiabatic isentropic process. The compressed air then runs through a mixing chamber where fuel is added, a constant-pressure (isobaric) [3] process. The heated (by compression), pressurized air and fuel mixture is then ignited in an expansion cylinder [3] and energy is released, causing the heated air and combustion products to expand through a piston/cylinder, another theoretically adiabatic isentropic [3] process. Some of the work extracted by the piston/cylinder is used to drive the compressor through a crankshaft arrangement [2].
The term Brayton cycle has more recently been given to the gas turbine engine. This also has three components:

(i) A gas compressor
(ii) A burner (or combustion chamber)
(iii) An expansion turbine

Ambient air is drawn into the compressor, where it is pressurizing (a theoretically isentropic process) [3]. The compressed air then runs through a combustion chamber, where fuel is burned [3], heating that air (a constant-pressure process)[3], since the chamber is open to flow in and out. There is some backpressure [2] from the turbine. The heated, pressurized air then gives up energy, when it expands through a turbine (or series of turbines) another theoretically isentropic process [3]. Some of the work extracted by the turbine is used to drive the compressor. Figure 2.2 shows the flow diagram of gas turbine.

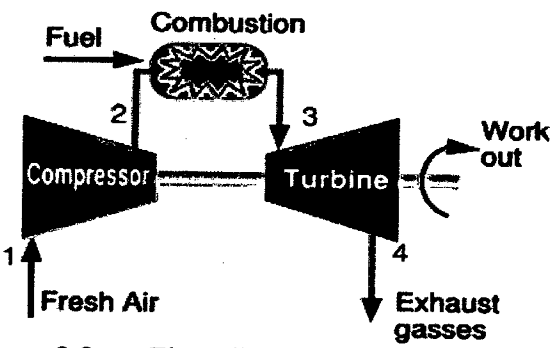

Figure 2.2 Flow diagram of gas turbine [2]

1-2 Isentropic Compression (In compressor)

2-3 Constant-pressure heat addition

3-4 Isentropic expansion (in a turbine)

4-1 Constant-pressure heat rejection

2.4.3 T-s and P-v diagrams

T-s and P-v diagrams of an ideal Brayton cycle [2] are shown in Figure 2.3. Notice that all four process of the Brayton cycle are executed in steady-flow devices. Thus, they should be analyzed as steady flow processes [2]. Brayton cycle depends on the pressure ratio [3] of the gas turbine and the specific heat ratio of the working fluid [3]. The thermal efficiency increase with both of these parameters, which is also the case for actual gas turbines [2]. The highest temperature [3] in the cycle occurs at the end of the combustion process (state 3), and it is limited by the maximum temperature [4] that the turbine blades can withstand. This also limits the pressure ratios [4] that can be used in the cycle. For a fixed turbine inlet temperature T3, the net work output per cycle increases with the pressure ratio, reaches a maximum, and then starts to decrease as shown in Figure 2.3. Therefore, there should be a compromised between the pressure ratio (thus the thermal efficiency) and the net work output. With less work output per cycle, a larger mass flow rate [3] (thus a larger system) is needed to maintain the same power output which may not economical.

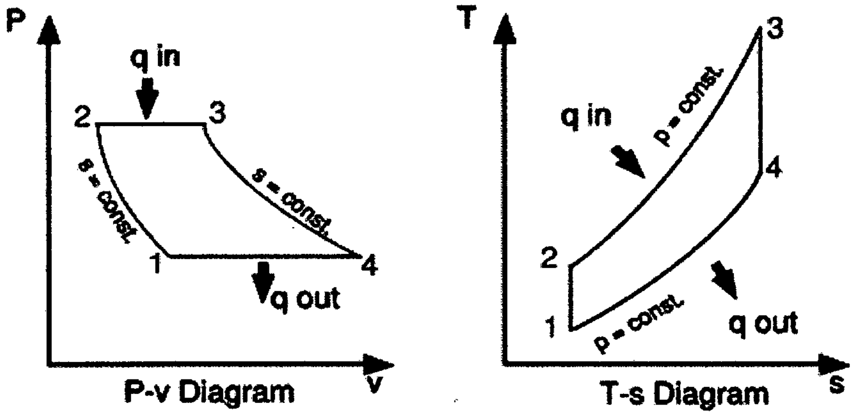

Figure 2.3 Idealized Brayton Cycle [2]

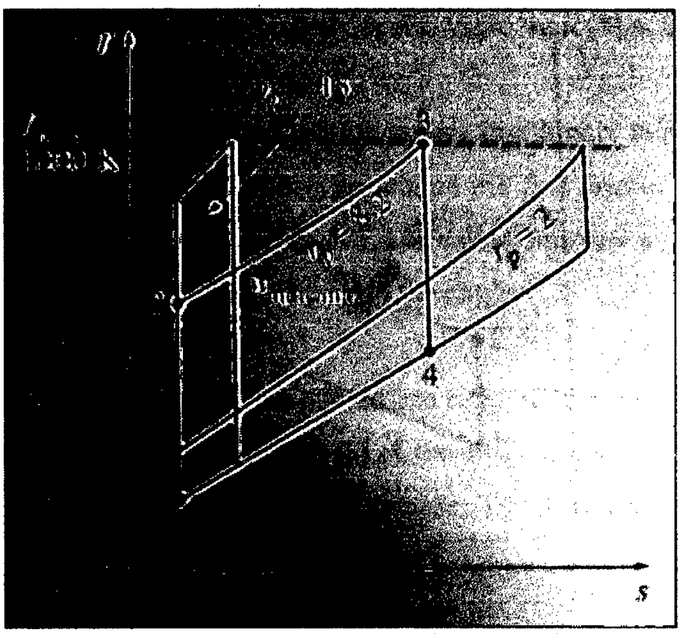

Figure 2.4 For fixed value of Tmin and Tmax, the net work of the Brayton cycle first increases with the pressure ratio, then reaches a maximum at $r_p = (Tmax/\ Tmin)^{[k/2(k-1)]}$ and finally decreases [3].

2.5 Combustion Section

The combustion section contains the combustion chambers, igniter plugs, and fuel nozzles or vaporizing tubes [8].

2.5.1 Combustion Chamber

It is designed to burn a fuel-air mixture and deliver the combusted gases to the turbine at a temperature which will not exceed the allowable limit [8] at the turbine inlet.

Fuel is introduced at the front end of the burner in a highly atomized spray [1] from the fuel nozzles. Combustion air flows in around the fuel nozzle and mixes with the fuel to form a correct fuel-air mixture. This is called primary air and represents approximately 25 percent [8] of total air taken into the engine.

The fuel-air mixture which is to be burned is a ratio of 15 parts of air to 1 part of fuel by weight [8]. The remaining 75 percent [8] of the air is used to form an air blanket around the burning gases and to lower the temperature. This temperature may reach as high as 3500° F [8].

The air used for burning is called primary air- [8] and that for cooling is secondary air [8]. The secondary air is controlled and directed by holes and louvers [8] in the combustion chamber liner.

All combustion chambers contain the same basic elements: a casing or outer shell, a perforated inner liner or flame tube, fuel nozzles, and some means of initial ignition [8].
The combustion chamber must be of light construction and is designed to burn fuel completely in a high velocity air stream [8]. The combustion chamber liner is an extremely critical engine part because of the high temperatures of the flame.

2.5.2 Igniter Plug

The igniter or spark plug is mounted on the combustion chamber casing [4] and positioned. There are two important functions [11] of spark plug.

a) To ignite air-fuel mixture in the combustor.
b) To remove heat from the combustion chamber [11].

Spark plug transmits electrical energy [11] that turns fuel into working energy. The temperature of spark plug ignition must be ensured to be sufficient low to prevent pre-ignition [12]. This is called thermal performance, and is determined by the heat range selected. The spark plug works as a heat exchanger by pulling unwanted thermal energy away from the combustion chamber [11]. The heat range is defined as the ability of the spark plug to dissipate heat. The heat range measurement is determined by several factors [12]:

a) The length of the ceramic center insulator nose
b) The ability of the spark plug to absorb and transfer combustion heat.
c) The material composition of the insulator.

2.5.3 Fuel Nozzles

Fuel nozzle is one of the components that affect the process in the combustion chamber. Fuel is flow from the storage into the chamber through fuel tube. At the end of the tube there is a nozzle. Normal liquid fuels are not sufficiently volatile to produce vapor in the amounts required for ignition and combustion [1] unless they are atomized into a large number of droplets with corresponding vastly increased surface area. The smaller the droplet size, the faster the rate of evaporation [1]. The influence of drop size on ignition performance is of special importance, because large increases in ignition energy are needed to compensate for even a slight increase in mean drop size. Spray quality [1] also affects stability limits, combustion efficiency, and pollutant emission levels. Because of these importance fuel nozzle should be designed wisely in order to provide qualified spray of fuel for efficience combustion process.

2.6 Combustion Method

A combustion method and apparatus for gas turbine engines employs a combustion process and combustion liner structure adapted to promote complete combustion of liquid hydrocarbon fuel [13] and minimize undesired combustion products [13].

Compressed primary air flows radially inward into a prechamber into which fuel is sprayed. Except during start-up, the air is heated. Normally, the air mixes with the fuel and the mixture flows through a throat into a reaction chamber.

The liner wall downstream of the throat defines the reaction zone [13] and a dilution zone [13] to which secondary air is admitted.

In starting combustion, the air is admitted with a very considerable degree of swirl, causing recirculation [9] from the reaction chamber into the prechamber to facilitate ignition and promote fuel vaporization and stable combustion. The quantity of primary air increases along with the fuel [9], and the primary air swirl is reduced or terminated so that the flame front is blown out of the prechamber into the reaction zone and no combustion takes place in the prechamber in the operating regime.

A method of generating combustion products for operating a gas turbine comprising compressing air [4], heating the air, flowing a portion of the heated compressed air as primary air into a prechamber, supplying fuel to the prechamber, mixing the fuel and primary air and varporizing the fuel in the prechamber [1], discharging the air-fuel mixture through a throat into a reaction chamber, burning the fuel in the reaction chamber, flowing the remainder of the heated compressed air as