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Thermodynamic analysis of the part load performance for a small scale gas turbine jet engine by using exergy analysis method

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ABSTRACT

A small scale gas turbine jet engine is analyzed in this study. To understand the performance of the jet engine, experiments are conducted at four different load types (idle, part load one, part load two and full load). According to the load types, the energy and exergy flows of the engine components and the overall jet engine are investigated. Parameters such as specific fuel consumption, fuel exergy depletion, relative exergy consumption and exergetic improvement potential rate are studied to compare the effects of four load types. Exergy efficiencies and exergy destructions are calculated to explain the thermodynamic inefficiencies. The effect of the load type on the exergy efficiency is analyzed for the components and jet engine itself. At the idle and the part load one cases, the maximum exergy efficiencies took place in the gas turbine as 67.8% and 79.4% respectively. For the part load two and the full load cases, the maximum exergy efficiencies are calculated in the combustion chamber as 81% and 80.6% respectively. The maximum exergy destructions took place in the combustion chamber for all of the load types. They were found to be 35 kW, 40.3 kW, 36.6 kW and 47.9 kW.

1. Introduction

Gas turbines are widely used in aircraft, since they are light, small and they have high power/weight ratio. These gas turbines operate according to an open cycle named propulsion cycle. Ideal propulsion cycle is similar to simple ideal Brayton cycle. However, in the propulsion cycle the gases in the turbine do not expand to the atmospheric pressure.

Movement of an aircraft is achieved by accelerating a fluid in the reverse direction of the aircraft's flight direction. This event is performed by a highly accelerated fluid that is in small amount. This is done in a jet or turbojet engine. Air decelerates in the diffuser and its pressure increases. Compressed air exiting from the compressor enters to the combustion chamber. Air is mixed with a fuel and fired at a constant pressure. The exhaust gases at high pressure and temperature are expanded in a turbine to operate the compressor. Finally the gases are expanded to the ambient pressure in a nozzle and leave the engine at a high speed.

In airline industry aircraft performance is an important aspect. It is required to determine how aircraft can be operated efficiently, economically, safely and with little environmental impact. Armed forces study the performance characteristics in order to use aircraft in a manner that provides the greatest possible advantage with more effective support.

Exergy analysis is a key method which identifies the weaknesses of a system. It reveals the potential of the system as the maximum work. The early exergy applications to aircraft engines are done by Clark and Horlock [1] and Lewis [2]. Exergy analysis is applied to various types of aircraft engines such as turbojet, turbofan, scramjet etc.

In some studies the authors carried out exergy analysis on the aircraft engines [3–5] to observe the losses. The exergy destruction values were calculated to compare the components of the engine. Several parameters like specific fuel consumption, fuel exergy depletion, exergetic improvement potential are used to evaluate the performance of the components and the engine itself.

The paper of Amati et al. [6] carried out an exergy analysis of an advanced hypersonic vehicle (scramjet). They explored the scramjet-powered aircraft according to their different fuelling solutions. The results show that a scramjet with an on-board kerosene reformer is advantageous in terms of thrust because of the capability of better explosion of fuel.

There are several energy flows in an aircraft. These are

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pneumatics, hydraulics, electrics, fuel system, propulsion etc. In this study, aircraft engine and related propulsion system is analyzed. The ability of system's energy to do work can be obtained by using exergy metrics. Most of the exergy potential in aircrafts is destroyed in the engines. It is approximately 99% of all [5].

There are various studies using exergy analysis to investigate real aircraft engines. However, experimental studies on real aeronautical vehicles can be complex and expensive. The investigation of a small size turbojet may be very useful to evaluate the performance of real vehicles.

Turan [7] analyzed design parameters for energetic and exergetic performance evaluation of a small turbojet engine. Badami et al. [8] described the results of an experimental and numerical work which was performed on a turbojet engine.

Unmanned aerial vehicles (UAV) can be used to analyze exergy based studies. Because they do not have thermal or pressure based energy systems. Then the aircraft engine can be examined to perform the exergy analysis more accurately. An exergy analysis for a turbofan engine of an UAV (unmanned aerial vehicle) is studied by Şöhret et al. [9]. To make sustainability assessment, the exergy flows of a turbofan engine is examined by Turan [10] to understand the exergetic performance.

There are studies investigating small scale jet engines to analyze parametric values and thermodynamic properties for education purpose. Pourmovahed et al. [11] determined the effect of engine speed on thrust specific fuel consumption (TSFC) and engine emissions. Saad [12] presented a study which combines theoretical background and hands on experience for gas turbine engine. The engine speed, exhaust gas temperature, fuel flow and thrust are monitored.

There are papers studying part load operations of the gas turbines. These works are generally investigating the effects of certain parameters on the part load operating situations. It is known that load type affects the temperature and pressure of the fluid streams and efficiency of the components and the engine itself.

Some studies [13–15] examined the effects of part load performance of gas turbines. Fuel control, variable speed, variable inlet guide vane were parameters to examine the engine. Variable nozzle areas are used to study the engine performances. High turbine exhaust temperature (TET) affects the part load efficiency. The increase in TIT causes higher part load efficiencies. High pressure ratio also exhibits good part load efficiencies. Since two shaft engines have higher TET, they have higher part load efficiencies.

Baheta and Gilani [16] aimed to examine the performance of a gas turbine using exergy analysis method to compare different loading operations. The gas turbine studied was variable stator vane (VSV) type. The components' exergy destruction rates were evaluated for wide range of part load operations.

In the literature, several studies performed by applying exergy analysis to examine gas turbine systems or to analyze part load operations. To the best of the author's knowledge, this is the first time that a gas turbine engine's performance at different loads is investigated by using exergy analysis. Exergy analysis method reveals the inefficiencies in a system. Jet engines operate at higher performance standards when the load is increased. However full load operation is not the best case according to the calculated exergy metrics. In this context, the main objectives of this contribution are (i) to examine the performance of a small gas turbine jet engine using exergy analysis method (ii) to calculate the energy and exergy flows, as well as the exergy efficiencies and exergy destructions of the jet engine components under four different load types (iii) to assess its performance according to certain parameters and also (iv) to investigate the effect of load on the exergy efficiencies of jet engine components.

2. System description

2.1. Jet engine module

The module includes a complete gas turbine system with the following subsystems:

a) Jet engine, comprising compressor (1–2), combustion chamber (2–3) and turbine (3–4).
b) Fuel system, including tank, fuel pump, quick acting gate valve and control electronics.
c) Starter and ignition system with starter motor, auxiliary fuel valve and glow plug.
d) Measuring instruments and controls with temperature, flow rate, speed and pressure.

Jet engine consists of an axial turbine with a direct coupled radial compressor and an annular combustion chamber. The turbine and the compressor form originally the propulsion unit for aircraft.

At the combustion chamber, the air is fed to the flame tube. Liquid fuel is passed from the rear into so-called evaporator tubes. These tubes are used to gasify the fuel and then fuel is mixed with the primary air in the combustion chamber. Combustion gases flow into the diffuser of the turbine and are accelerated. The turbine and compressor wheels are fitted to a common shaft. The exhaust gas jet passes through the nozzle to increase the speed of gases.

2.2. Open gas turbine cycle

The gas turbine operates according to the open cycle, in which the working medium is taken from the environment and returned to it. The schematic demonstration is shown in Fig. 1. In the cycle the working medium (air) is subject to the following changes of state:

a) Adiabatic compression of the cold air in the compressor from ambient pressure (P_1) to pressure (P_2) and consequent temperature rise from T_1 to T_2.
b) Isobaric heating of air between temperatures T_2 and T_3 by heat input. The heat is supplied by combustion of fuel with the atmospheric oxygen in the combustion chamber.
c) The turbine is in the vicinity of the combustion chamber and receives a significant amount of heat. The expansion of the hot air in the turbine results in pressure decrease. Turbine outlet

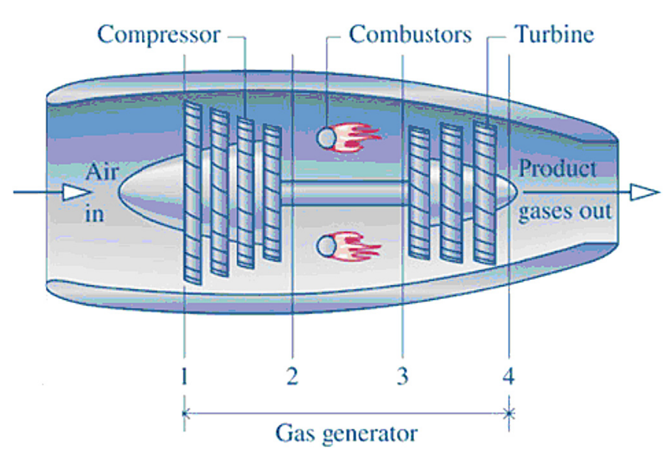

Fig. 1. Jet engine module (adapted from [17]).