The Thermodynamic Process of a Jet Engine

Throughout the world, automobiles have been extremely helpful in allowing people to travel to far places within a relatively short period of time. But when moving to places across the globe, automobiles often are an inefficient method of travel. Aircraft’s enable an even faster way for people to reach their destinations. For an airplane with a large mass to be able to lift off the ground, it must be equipped with an engine that can create a great amount of propulsion. Engineers are constantly studying ways to increase the engine’s efficiency. One method they use to analyze these processes is to use the subject of thermodynamics. Thermodynamics, the study of how energy and heat are related, is useful with engines because there can be wasted energy released from the engine unintentionally in the form of heat. Each part of an aircraft’s engine typically undergoes a thermodynamic analysis so that it can efficiently contribute to the engine’s ultimate goal of creating propulsion. In the following paragraphs we will discuss the overall cycle’s process, show how scientists and engineers analyze parts of the system, and describe each phase of the cycle with some thermodynamically important values.

Overall Process

While the aircraft is flying through the air, the inlet allows air to rush into the engine through the diffuser. The pressure of air rises slightly as it is decelerated in the diffuser. The air moves from the diffuser to the compressor, where it is compressed. The compressed air is then mixed with fuel in the combustion chamber, where the mixture is burned at constant pressure. The high-pressure and high-temperature combustion gases partially expand in the turbine, producing enough power to drive the compressor and other equipment, hence the net work output of the entire jet-propulsion cycle is zero. The gasses expand in the nozzle to the ambient pressure and leave the engine at a high velocity. The gases that exit at this high velocity is what creates the thrust needed to propel the aircraft. When analyzing this process, some assumptions must be made. It is assumed that the turbine work is equal to the compressor work. Also the process in the diffuser, compressor, turbine, and nozzle are all isentropic.

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1 Heat- an energy interaction where its driving force is a temperature difference. Heat describes molecules at the microscopic level, which act in a random and disorganized fashion. The more random and disorganized, the higher the heat.

2 Work- internal energy that is not heat, is considered work. More specifically, it is the energy transfer created by a driving force over a distance.

3 Ambient- the surrounding environment’s properties

4 Isentropic- an isentropic process is one where there is no change in entropy
Energy Balance for Thermodynamic Analyzation

When analyzing any portion of the cycle, the energy balance equation for a control volume is used. The equation is as follows:

\[ \dot{Q} - \dot{W} = m_e(h_e + v^2_e + gz_e) - m_i(h_i + v^2_i + gz_i) \]

This is used to determine the device’s input and output quality’s, where

\[ \dot{Q} = \text{heat transfer} \quad m = \text{mass} \]
\[ \dot{W} = \text{work transfer} \quad h = \text{enthalpy} \]
\[ \text{anyvariable}_e = \text{exit state properties} \quad v = \text{velocity} \]
\[ \text{anyvariable}_i = \text{initial state properties} \quad g = \text{gravitational constant} \left(9.81 \frac{m}{s^2}\right) \]
\[ z = \text{vertical position relative to the ground} \]

Phases of the Jet Cycle

Phase 1: Diffuser

A diffuser is a device that increases the pressure of the air travelling through it by slowing it down. The cross-sectional area of a diffuser increases in the flow direction, causing the fluid to expand. For diffusers, heat transfer, work, and potential energy\(^5\) can be considered 0 due to their miniscule contribution to thermodynamic change. The diffuser at the inlet of the jet engine allows the air to be slowed before it heads to the compressor.

Phase 2: Compressor

A compressor a device used to increase the pressure of a gas. The air traveling from the diffuser enters the compressor to compress the gas so that can be used in the combustion chamber. A compressor needs a work input. For a jet engine, the work input needed comes from the work the turbine creates later in the cycle. It is assumed that the heat transfer, kinetic energy\(^6\), and potential energy changes from the initial state to the exit state do not change, hence they are zero in the energy balance equation for a control volume.

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\(^5\) Potential Energy- the energy of a mass due to its elevation in a gravitational field. PE = mass*gravity*height

\(^6\) Kinetic energy- the energy associated with mass’s that are moving. Any mass in motion has a kinetic energy. KE = ½(mass*velocity\(^2\))
**Phase 3: Combustion chamber**

Combustion is the chemical reaction during which a fuel is oxidized and a large quantity of energy is released. During a combustion process, the components that exist before the reaction are called reactants and the components that exist after the reaction are called products. An important portion for scientists to analyze during a combustion process is the enthalpy of reaction. This is defined as the difference between the enthalpy of the products at a specified state and the enthalpy of the reactants at the same state for a complete reaction. Entropy and temperature increase as it completes the cycle through the chamber. This new high temperature and high pressure gas is ideal for the next process, passing into the jet’s turbine.

**Phase 4: Turbine**

The purpose of a turbine is to create energy from the movement of the blades within the device. Fluid passes through the turbine, causing the blades to rotate and create work. The work energy created is transferred to the compressor, so that it can take the work and use it to compress the air flowing through the engine. There is often little heat transfer through turbines, for they are typically well insulated. The gas that passes through loses its previous qualities as a high pressure high temperature gas. Its thermodynamic properties are not as important as they previously were once it leaves the turbine, for it will be going through the nozzle next.

**Phase 5: Nozzle**

A nozzle is a device that increases the velocity of the fluid at expense of pressure. The cross-sectional area of a nozzle decreases in the flow directions. For nozzles, heat transfer, work, and potential energy can be considered 0 due to their miniscule contribution to thermodynamic change. The kinetic energy involved in this part of the process is one the most important properties, considering the high velocity of the gas. This high velocity creates the thrust to propel the jet forward.

**Conclusion**

For years scientists and engineers have used these techniques to create incredible propulsion systems. Jet engines are one of them, involving the use of typical devices that can adapt a gas to obtain necessities to make the engine run. There is always work being done to hopefully make the cycle more efficient, and a thermodynamic analyzation of the process is one of the many way of looking at the engine. Each part of the engine plays a significant role in the final result of creating thrust for the jet to move.

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7 Enthalpy- a quantity that is equal to the internal energy of a system plus the product of a systems pressure and specific volume.

8 Entropy- a measure of randomness at the microscopic level.