**DEPARTMENT OF AEROSPACE ENGINEERING**

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| Year & Branch | : | **II AEROSPACE** | Semester | : | **IV** |
| Course | : | **23ASB201 - Aerospace Propulsion** | | | |

# UNIT I - INTRODUCTION TO AIRCRAFT PROPULSION

## Overview of propulsion systems and thermodynamic principles

### Propulsion

Propulsion is the action or process used to apply force in a way that causes an object to change its translational motion. Derived from the Latin *propeller*, where pro means "before" and *pellet* means to "drive," we use propulsion to walk across a room, drive a car, fly an airplane, and launch a rocket into space.

A good way to understand propulsion is through Newton's third law of motion, which states that "every action has an opposite and equal reaction." So, when you walk, your foot pushes against the ground, and the ground pushes against you. As described in Newton's second law, since the ground has significantly more mass than you do, you move forward. Similarly, in a rocket engine, gas is expanded through combustion and accelerated to supersonic speeds, causing a reaction against the rocket in an equal and opposite direction.

### Components of a Propulsion System

Propulsion systems consist of two parts. The first is a mechanical power source, and the second is a propulsor that converts that power into a propulsive force.

For a gas-powered automobile, the power source is gasoline combustion, and the propulsion system consists of the engine, drive train, and wheels. In an electric automobile, the power source is the electric potential stored in batteries, and the propulsor is the electric motor, drive train, and wheels. The energy source is often referred to as the fuel, and the propulsor, in which the energy is converted into a force, is usually called an engine or motor.

Engineers use these basic principles around propulsion to design transportation systems that move vehicles across the ground, over and underwater, through the air, and into and across space. The size and mass of the vehicle, along with the medium through which the vehicle travels, often determines the type of propulsion used.

Propulsion systems include subsystems to obtain or store the mechanical power source, a propulsor, and a control system to adjust the forces produced. In the past, most propulsion systems used a single power source and a way to convert that power into a force. However, to obtain greater efficiency, new technologies enable hybrid propulsion systems that combine chemical combustion and internal combustion engines with electric potential stored in batteries and electric motors.

**Types of Propulsors**

Most propulsion systems create a propulsive force through one of four propulsors: limbs, wheels, propellers, or thrust.

**Wheels**

A wheel touching a fixed surface converts a rotational force into a linear force, pushing the object containing the wheel forward. The rotational force, called torque, can be created by various engines and motors.

**Propellers**

A propeller is any device attached to a rotation shaft that consists of multiple thin blades arranged to form a helical spiral that exerts a force upon air or water. The resulting force on the blades creates forward motion. A propeller can be as large as the rotor on a helicopter or as small as a drone's blades. The propellers used in marine applications are sometimes called screws.

**Thrusters**

When the momentum of a working fluid — gas or liquid — is accelerated, it exerts a linear force called thrust. Most applications use heat from combustion to create thrust. In marine applications, thrust can be made with water by an impeller, which converts torque into centrifugal acceleration ducted into an axial flow. An electric field can create thrust using an ionized gas or a plasma.

**Types of Propulsion Systems**

The following is a list of the most common types of propulsion systems:

**Internal Combustion Engines (ICEs)**

The dominant form of propulsion humans use is still the internal combustion engines in automotive, marine, and air vehicles. The power source is the combustion of hydrocarbons. Burning gasoline, diesel, or natural gas creates pressurized gas that pushes against pistons to create a linear force. A crankshaft converts the linear force to a rotational force to drive a wheel or propeller.

**Power Turbines or Gas Turbine Engines**

A power turbine, also called a gas turbine, uses the expanding gasses from combustion as the power source to drive one or more turbine rotors, creating rotational forces that drive a propeller or a wheel. Gas turbine engines are paired with propellers in turboprop aircraft, rotors for helicopters, and propellers or screws in ships and boats. Gas turbine engines can also power heavy-wheeled vehicles such as locomotives or tanks.

**Electric Motors**

Electric motors are increasingly replacing the rotational forces created by piston and turbine-based engines. The energy source for an electric motor is some form of electric potential. Usually, that is a battery pack, hydrogen fuel cell, or transmission line. Running an electrical current through an electromagnet creates an attractive force for another electromagnet or a permanent magnet to generate torque. A shaft transfers the torque to wheels or propellers.

**Air-breathing Jet Engines**

The most efficient and common form of aircraft propulsion is jet propulsion. Every type of jet engine consists of a compressor that creates high-pressure air and a combustion chamber that mixes fuel with the air and burns it, creating thrust. Most jet engines also include a turbine section that extracts energy from the expanding gases to generate torque used to compress the incoming air or drive a ducted propeller, called a fan.

Here are the most common types of air-breathing jet engines:

**Turbojet:** The first forms of jet propulsion only consisted of a compressor stage, a combustion chamber, and a turbine to drive the compressors. They use thrust as their propulsor.

**Turbofan:** To increase the efficiency of a jet engine, an additional turbine section at the rear of the engine drives a propeller at the front of the engine with many blades, called a bypass turbofan. Most modern airliners use high-bypass aircraft engines, in which a fan acting as a propeller generates the majority of the propulsive force rather than thrust from combustion.

**Ramjet:** Ramjets replace the rotating compressors in a standard jet engine with an inlet that reduces cross-sectional area like a funnel, ramming and compressing the air forced into the front of the engine. The primary applications of ramjets are aerospace vehicles that require supersonic speeds. The air flowing through a standard ramjet is reduced to subsonic speeds before the combustor. In a scramjet or supersonic combustion ramjet, supersonic flow into the combustor allows the engine to operate at higher speeds.

**Afterburning jet engines:** An afterburner is an additional combustion chamber added to the rear of the turbine section of a traditional jet engine. Fuel is sprayed into the exhaust flow and ignited, creating significant pressure and additional thrust. Afterburners enable aircraft to achieve supersonic speeds, provide additional thrust for takeoff, or generate emergency thrust for emergency maneuvers in `aircraft during combat.

**Rocket Propulsion**

Rocket propulsion uses a chemical reaction to create extremely high-pressure gases that are then converted into thrust. Rocket engines consist of a fuel system to provide fuel and an oxidizer, a combustion chamber to ignite the fuel and oxidizer to produce the rapidly expanding gases, and a nozzle to convert the pressure into thrust, or momentum in one direction.

Rocket engines can be categorized by their use of solid or liquid fuel:

**Liquid-fuel rocket engines:** A liquid-propellant rocket engine burns a liquid oxidizer, usually liquid oxygen, with a fuel consisting of liquid hydrogen, kerosene, or methane. The fuel is delivered to the combustion chamber using gravity, acceleration, pressure, or turbopumps.

Nozzles are attached to openings in the combustion chamber to convert the expanding gas into directed thrust. Controlling fuel and oxidizer adjusts the amount of thrust produced or turns the engine on or off. The ability to fine-tune the force produced makes liquid-fuel rocket engines the preferred choice for thrusters that provide maneuverability on spacecraft or missiles.

**Solid-fuel rocket engines:** Solid-propellant rocket engines use a mixture of solid oxidizer and solid fuel, called the fuel grain. The grain is cast inside a cylindrical casing with a cylindrical hole running down its length, called the combustion chamber. The first solid-fuel rockets used gunpowder. Now, propellant grain uses a wide variety of complex chemicals. The two solid rocket boosters on NASA's Space Shuttle are the best-known solid rocket engines. Many weapons systems use solid-fuel rocket engines because of the long shelf life of the propellant. However, solid rocket engines are difficult to turn off and restart, and adjusting nozzle geometry is the only way to adjust the amount of thrust produced.

**Hybrid rocket engines:** Hybrid-propellant rocket engines use a solid fuel and a liquid or gaseous oxidizer. The oxidizer, usually liquid oxygen or hydrogen peroxide, is injected into the cylindrical combustion chamber that runs down the length of the cylinder. Because the flow rate of the oxidizer can be started, stopped, and varied during operation, hybrid rocket engines offer more flexibility than solid-fuel rocket engines.

**Steam Engines**

The first form of mechanical propulsion developed by humans was steam engines. Combustion is used as a heat source to boil water, creating high-pressure steam. The pressurized steam pushes against a piston or pistons to create a linear force. A crank converts the linear force into rotational force, called torque, which drives a wheel or a propeller as a propulsor.

**Steam Turbines**

A more efficient way to extract energy from steam is to expand it through a turbine rather than to push a piston. The pressurized turbine pushes against the aerodynamic blades of one or more rotors, converting the pressure into rotational force connected to wheels or a propeller through a shaft. Currently, steam engines are only used in marine applications, in which the heat source is a nuclear fission reactor.

## Thermodynamic Principles for Propulsion Systems

The key thermodynamic principles applied in propulsion systems are primarily based on the First and Second Laws of Thermodynamics, focusing on concepts like entropy, enthalpy, and efficiency to understand how heat energy is converted into kinetic energy to produce thrust within an engine, with the primary goal of maximizing efficiency while minimizing energy loss; this includes understanding heat transfer mechanisms and the limitations imposed by the Second Law through Carnot's theorem.

Key points about thermodynamics in propulsion systems:

- **First Law of Thermodynamics:**

  States that energy cannot be created or destroyed, only transformed, meaning the total energy within a propulsion system remains constant, but can change forms (like chemical energy to kinetic energy).

- **Second Law of Thermodynamics:**

  Explains that the entropy (disorder) of a closed system always increases over time, limiting the maximum efficiency of a propulsion system and highlighting the importance of minimizing energy losses as heat.

- **Carnot Cycle:**

  A theoretical thermodynamic cycle representing the most efficient possible heat engine operating between two temperature reservoirs provides a benchmark for comparing real engine efficiencies.

- **Entropy:**

  A measure of disorder or randomness in a system, with increasing entropy generally indicating a decrease in usable energy.

- **Enthalpy:**

  A thermodynamic property representing the total heat content of a system is crucial for analyzing energy changes in combustion processes within an engine.

- **Heat Transfer:**

  Understanding heat transfer mechanisms (conduction, convection, radiation) is essential for optimizing engine design and minimizing heat losses.

**Applications of thermodynamics in propulsion systems:**

- **Combustion Engine Design:**

  Analyzing the combustion process within an engine to maximize energy extraction from the fuel and optimize efficiency.

- **Jet Engine Analysis:**

  Studying the thermodynamic cycles within a jet engine (like the Brayton cycle) to understand how air compression, fuel combustion, and expansion contribute to thrust generation.

- **Rocket Propulsion:**

  Calculating the specific impulse and propellant efficiency of a rocket engine based on the thermodynamic properties of the propellant.

- **Propeller Design:**
  Understanding the aerodynamic and thermodynamic factors influencing propeller efficiency.