BACKGROUND: PROPULSION SYSTEMS

MAE 150R, Rocket Propulsion Systems

In general, **propulsion** deals with the act of changing the motion of a body. In general, a **force** is provided that changes the body's velocity, moves a body from rest, or overcomes retarding forces when a body is propelled through a medium. **Jet propulsion** is locomotion where the momentum of ejected matter accompanies motion or imparts motion to a device.

The main types of jet propulsion devices are

> **Rockets**, in which thrust is produced by ejecting stored matter, which is called the propellant. Such devices are generally classified according to the type of propellant/energy source used (chemical, nuclear, electrical, solar, etc.). Since rockets are not dependent on using the surrounding medium as part of the propulsion system, they are well suited for space transportation systems.
>
> **Air-Breathing Engines**, or "duct propulsion devices", in which the surrounding medium (air) is utilized as the "working fluid", rather than the stored propellant. Such devices are classified according to the specific features and components of the thermodynamic cycle present in the engine (turbojets, turbofans, ramjets, turboprops, etc.). Since air-breathing engines utilize the surrounding medium (air) and do not require the storage of all propellant components, they are well suited for aircraft transportation systems as well as ground-based power generation devices.

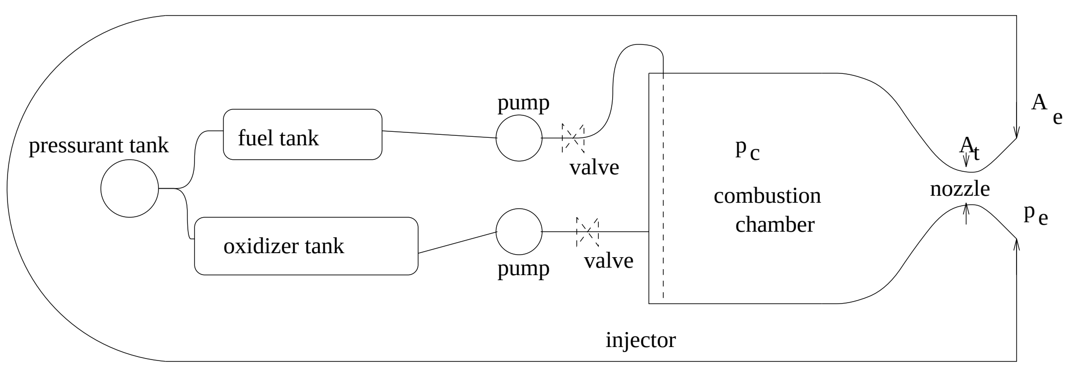
In MAE 150R there will be ONLY an emphasis on rocket engines. For more information and background on air-breathing engines, take the MAE 150P course.

General characteristics of rocket and air-breathing engines may be outlined as follows. In both cases, the production of **thrust** for the engine takes place through the generation of very high exhaust velocities (high exhaust momentum) from the device.

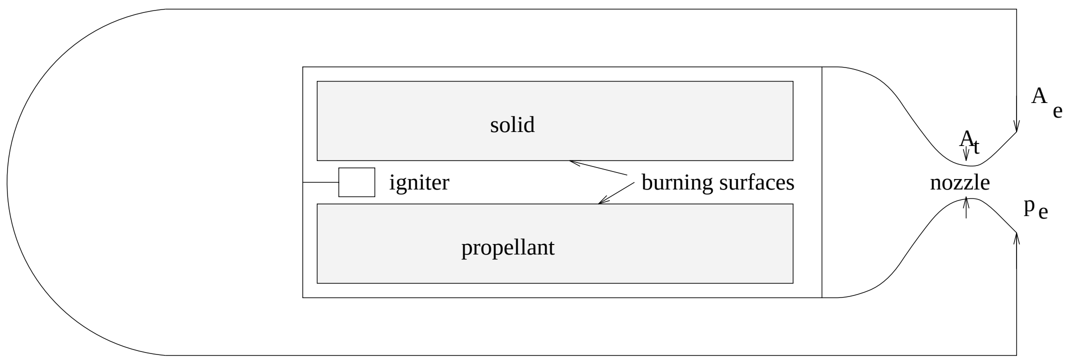
1. **Rocket Engines**

   (a) **Chemical Rocket Engines** utilize high pressure combustion reactions for the generation of thrust. During such a reaction, propellants are burned, forming high temperature and high pressure products of combustion, which are expanded through a nozzle and exhausted at high velocities from the vehicle. There are several types of chemical rocket engines.

   i. **Liquid Propellant Rockets** utilize propellants which are stored in the liquid phase for the combustion reaction. Such propellants can be "bipropellants" (liquid fuel and liquid oxidizer which mix and react) or "monopropellants" (liquid of a single chemical composition which combusts). The liquid propellants are fed under high pressure conditions into a thrust chamber (or combustion chamber), where atomization, mixing, ignition, and burning take place. Liquid propellant rockets are used for space launch as well as orbit maintenance and maneuvering. A generic liquid propellant rocket system is shown below.

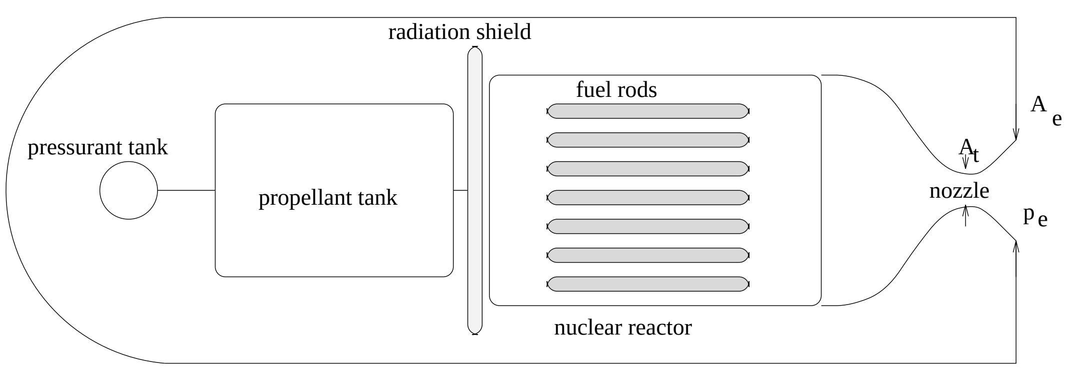


   ii. **Solid Propellant Rockets** utilize propellants which are stored in the solid phase for the combustion reaction, with burning taking place at the solid propellant surface. Once ignited, the propellant charge (or "grain") burns fairly smoothly on exposed surfaces, which can take a variety of different shapes. Solid rocket motors often serve as boosters for space launch vehicles. A sample solid propellant rocket schematic is shown below.

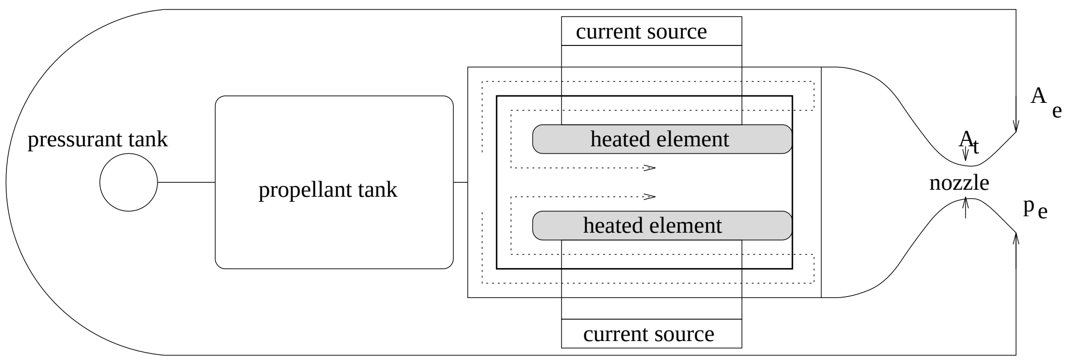


iii. **Hybrid Rockets** store propellant in two different states, solid and liquid. Hybrid systems most commonly consist of solid fuel and liquid oxidizer. They have the advantages of increased safety, versatility, and robustness, but are less efficient in terms of the combustion process than in purely liquid or solid systems.

(b) **Nuclear Rocket Engines** deliver heat to a working fluid (usually liquid hydrogen) by means of a nuclear energy source such as a fission reactor, a radioactive isotope decay source, or a fusion reactor. The high pressure, high temperature working fluid is then expanded and accelerated in an exhaust nozzle. A sample schematic of a nuclear (fission) rocket is shown below, with the reactor as a heat source.

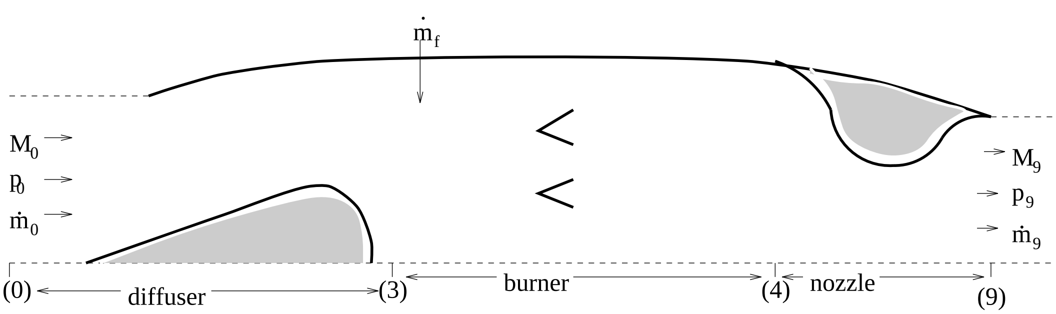


(c) **Electric Rocket Engines** are of two basic types: *electrothermal propulsion*, which uses electrical energy to heat a propellant flow (via heat transfer from surfaces or direct deposition of heat into the flow), and *electromagnetic/electrostatic propulsion*, in which electrostatic forces applied to charged particles can accelerate matter to very high speeds (this includes ion propulsion and plasma propulsion). An example of an electrothermal propulsion devices, a resistojet, is shown below.



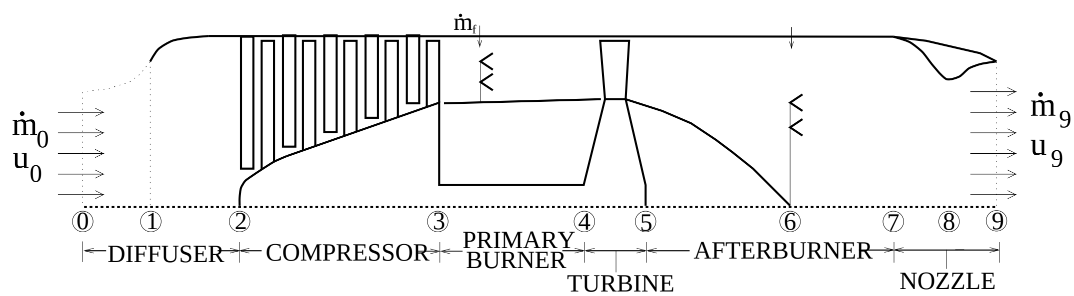
2. **Air-Breathing Engines**

   (a) **Ramjet Engines** are conceptually the simplest of air-breathing engines, in that there are no rotating components. In the ramjet, air enters through a supersonic inlet where is it slowed and pressurized, then it is mixed with fuel and burned in the combustion chamber, then the gaseous products are expanded in the nozzle and exhausted from the vehicle at a speed exceeding that of the entering air. Ramjets typically operate in the flight Mach number range between 3 and 7, and are more often used for missile propulsion than for high speed aircraft propulsion. A schematic of the generic ramjet engine is shown below.



(b) **Turbojet Engines** have improved performance over the ramjet at subsonic as well as low supersonic speeds, although the complication and added weight associated with rotating components (compressor and turbine) are present in the turbojet. Here, in addition to the static pressure rise created by a diffuser or inlet, the compressor raises the air pressure and temperature prior to mixing and combustion with fuel in the combustion chamber. The combustion gases then enter the turbine, and are expanded through the turbine, doing work on the turbine, which is used in turn to drive the compressor. Further expansion of the gases occurs in the nozzle, where again the gas is exhausted at a higher velocity than that of air entering the engine. In some cases, an afterburner is added downstream of the turbine for additional thrust; this is generally used for high performance aircraft in which the added fuel consumption is not of significant concern.

An example of the generic turbojet engine with an afterburner is shown below.



(c) **Turbofan or Turbobypass Engines** are examples of means by which the fuel efficiency of the basic turbojet engine may be improved. Here there is a second turbine added downstream of the compressor-drive turbine, and this additional power from the second turbine is used to drive a fan that pumps air through a secondary burner-nozzle (turbobypass) or nozzle (turbofan) system. This air then "bypasses" the main engine flow, but provides additional thrust for the overall engine.

(d) **Turboprop or Turboshaft Engines** are also similar to the turbojet, except that they utilize a propeller to provide most of the propulsive thrust for the vehicle. The propeller and compressor are both driven by turbine(s). These engines are highly fuel efficient in comparison to the turbojet engine itself, although the speed and range of the vehicles are generally more limited. Turboprop engines are often used in small commuter aircraft, while turboshaft engines are used for helicopter propulsion. A sample turboprop engine schematic is shown below.