The Evolution of Rocket Engines and Their Role in Humanity's Quest for Interstellar Travel

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0.1 Prohlášení

Prohlašuji, že jsem svoji seminární práci vypracovala samostatně a veškeré použité zdroje a další podkladové materiály uvádím v seznamu použitých zdrojů.

Datum: Podpis:

Contents

0.2 Introduction

0.2.1 Objectives and Structure of the Work

(Outline what this paper aims to achieve and how it is structured.)

0.2.2 Background and Motivation

(Discuss why humanity strives for space and interstellar travel, and how propulsion technology is central to that goal.)

0.3 Theoretical Part

0.3.1 Early Concepts and the First Rocket Engine

(Briefly cover early gunpowder rockets and pioneers like Tsiolkovsky, Goddard, Oberth.)

0.3.2 Classification of Propulsion Systems

Propulsion is defined as *"the action or process of propelling"* (*"to drive forward or onward by or as if by means of a force that imparts motion"*). By the Merriam-Webster Dictionary.

It can also be defined as "the act of changing the motion of a body with respect to an inertial reference frame."[4]

In engine propulsion, the most common way to achieve such thing is via *chemical combustion*. The energy can also be supplied by *solar radiation*, or a *nuclear reactor*. As such, the varios types of propulsion can be generally divided up into three categories:

- chemical propulsion
- nuclear propulsion
- solar propulsion

Propulsion Device	Energy Source[a]			Propellant or Working Fluid
	Chemical	Nuclear	Solar	
Turbojet	D/P			Fuel + air
Turbo-ramjet	TFD			Fuel + air
Ramjet (Hydrocarbon fuel)	D/P	TFD		Fuel + air
Ramjet (H_2 cooled)	TFD			Hydrogen + air
Rocket (chemical)	D/P	TFD		Stored propellant
Ducted rocket	TFD			Stored solid fuel + surrounding air
Electric rocket	D/P		D/P	Stored propellant
Nuclear fission rocket		TFD		Stored H_2
Solar heated rocket			TFD	Stored H_2
Photon rocket[b]		TFND		Photon ejection (no stored propellant)
Solar sail			TFD	Photon reflection (no stored propellant)

[a] **D/P** developed and/or considered practical; **TFD** technical feasibility has been demonstrated, but development is incomplete; **TFND** technical feasibility has not yet been demonstrated.
[b] Essentially a really big light bulb.

Table 1: Energy Sources and Propellants for Various Propulsion Concepts[4]

Input in rocket propulsion systems is either heat or electricity. Useful output thrust comes from the kinetic energy of the ejected matter and from the propellant pressure on inner chamber walls and at the nozzle exit; thus. rocket propulsion systems primarily convert input energies into the kinetic energy of the exhausted gas. The ejected mass can be in a solid, liquid or gaseous state. Often, combinations of two or more states are ejected. At high enough temperatures, the ejected mass can also be in a state of plasma.[4]

0.3.2.1 Duct Jet Propulsion

Duct jet engines, more commonly called "air breathing" engines, are engines which utilize airflow that is then energized inside a duct. They use atmospheric oxygen to burn fuel stored onboard. This class includes the following:[4]

- turbojets
- turbofans
- ramjets
- pulse jets

- scramjets[3]

They are mentioned here mainly as to provide a background and comparison to rocket propulsion engines.

Feature	Chemical Rocket Engine or Rocket Motor	Turbojet Engine	Ramjet Engine
thrust to weight ratio, typical	75:1	5:1, turbojet and afterburner	7:1 at Mach 3 at 9,144m (30,000ft)
Specific fuel consumption[a]	8 - 14	0.5 - 1.5	2.3 - 3.5
Specific thrust[b]	5,000 - 25,000	2500 (low Mach[c] numbers at sea level)	2700 (Mach 2 at sea level)
Specific impulse[d]	270 sec	1600 sec	1400 sec
Thrust change with altitude	Slight increase	Decrease	Decrease
Thrust vs. flight speed	Nearly constant	Increases with speed	Increases with speed
Thrust vs air temperature	Constant	Decreases with temperaure	Decreases with temperature
Flight speed vs. exhaust velocity	Unrelated, flight speed can be greater	Flight speed always less than exhaust velocity	Flight speed always less than exhaust velocity
Altitude limitation	None; suited for space travel	14,000 - 17,000 m	20,000 m at Mach 3, 30,000 m at Mach 5, 45,000 m at Mach 12

[a] Multiply by 0.102 to convert to $kg/(hr-N)$.
[b] Multiply by 47.9 to convert to N/m^2
[c] Mach number is the ratio of gas speed to local speed of sound (See Equation eq:Mach Number(Appendix .1.1)).
[d] *Specific impulse* is a performance parameter (See Equation eq:Specific Impulse(Appendix .1.1))

Table 2: Comparison of Several Characteristics of a Typical Chemical Propulsion Rocket Propulsion System and Two-Duct Propulsion Systems[4]

Out of all of the ducted engines, the *turbojet engine* is the most widely used.

0.3.2.1.1 Ramjet Engine

For supersonic flight in the speeds above Mach 2, the *ramjet engine* (which is a pure ducted engine) is the best suited within the earth's atmosphere. Its compression is purely gas dynamic and thrust is produced by increasing the momentum of the subsonic compressed air as it passes through the ramjet in a very similar manner to the functionality of *turbofan* and *turbojet* engines, just without any compressor or turbine hardware.[4]

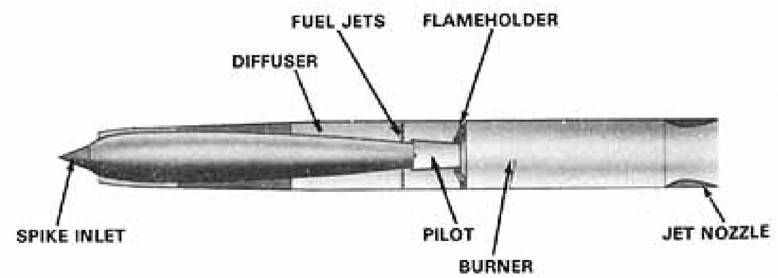

Figure 1: Simplified schematic of a ramjet engine with a supersonic inlet (a converging/diverging flow passage)[2]

Ramjets with subsonic combustion and hydrocarbon fuels have an upper speed limit of approx. 5 Mach; Hydrogen fuel with hydrogen cooling raises this maximum to at least 16 Mach.

0.3.2.1.2 Scramjet Engine

The Scramjet engine is a ramjet engine utilizing *super sonic combustion*. Which allows for much freeer and faster air flow than *turbojet* or *ramjet* engines.

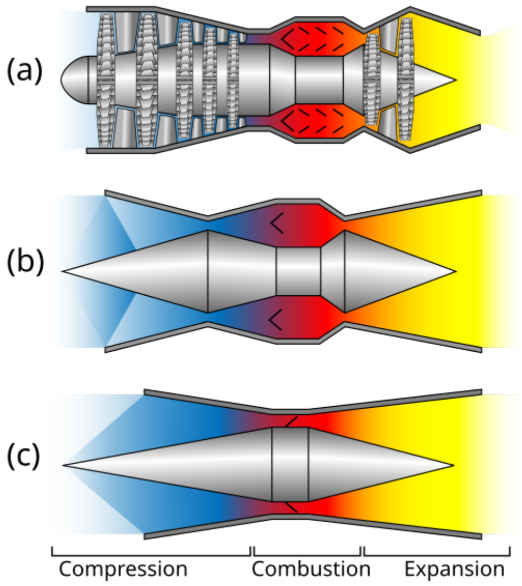

Figure 2: The compression, combustion, and expansion regions of: (a) turbojet, (b) ramjet, and (c) scramjet engines.[1]

So far, Scramjet engines have only been used in a few prototype vehicles and military experiments. A Scramjet relies on high vehicle speed to compress the incoming air forcefully before combustion (hence sc (*supersonic combustion*) **ramjet**), but whereas a ramjet decelerates the air to subsonic velocities before combustion using shock cones, a Scramjet has no shock cone and slows the airflow using shockwaves produced by its ignition source in place of a shock cone.[3;6]

0.3.2.2 Rocket Propulsion

(Describe chemical and non-chemical rockets, key principles like Newton's Third Law.)

0.3.3 The First Rocket to Reach Space

(Discuss V-2 and its influence on later designs.)

0.3.4 The Saturn V F-1 Engine

The engine who got man to the moon upon the widely known Saturn V rocket was the Rocketdyne F-1 gas-generator cycle single combustion chamber liquid-propellant rocket engine.[7]

It is the most powerful single-nozzle liquid-fueled engine ever used and was placed upon the first stage of Saturn V.[7]

0.3.5 Post-Saturn Developments

(Space Shuttle Main Engine, RD-170, Merlin, Raptor, etc.)

0.3.6 Emerging Propulsion Technologies

(Ion engines, nuclear thermal propulsion, solar sails, and antimatter or fusion concepts.)

0.3.7 Theoretical Framework for Interstellar Propulsion

(Discuss concepts like Project Daedalus, Breakthrough Starshot, Alcubierre drive, etc.)

0.4 Practical Part

0.4.1 Hypothesis

0.5 Conclusion

.1 Appendix A: Definitions

.1.1 Equations

.1.1.1 Mach Number

The Mach number (M or Ma), often only Mach, is a dimensionless quantity in fluid dynamics representing the ratio of flow velocity past a boundary to the local speed of sound.[5]

$$M = \frac{u}{c} \tag{1}$$

where:

- M is the local Mach number,[5]
- u is the local flow velocity with respect to the boundaries (either internal, such as an object immersed in the flow, or external, like a channel), and[5]

- c is the speed of sound in the medium, which in air varies with the square root of the thermodynamic temperature.[5]

.1.1.2 Specific Impulse

The *specific impulse* I_s represents the thrust per unit propellant ”weight” flow rate. It is an important figure of merit of the performance of any rocket propulsion system, a concept similar to kilometers per liter or miles per hour as applied to an automobile. A higher number often indicates a better performance. If the total propellant mass flow rate is $\dot{m}$ and the standard acceleration of gravity is g_0 (with an *average* value at the Earth's sea level of 9.8066 m/sec^2 or 32.174 ft/sec^2), then

$$I_s = \frac{\int_0^t F\,dt}{g_0 \int_0^t \dot{m}\,dt} \tag{2}$$

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