DEVELOPMENT OF SOLID PROPELLANT ROCKET MOTOR

THAQIF NAQIUDDIN BIN AHMAD AZHAR

SCHOOL OF AEROSPACE ENGINEERING

UNIVERSITI SAINS MALAYSIA

2021

ENDORSEMENT

I, Thaqif Naqiuddin bin Ahmad Azhar with this declare that all corrections and comments given by the supervisor and examiner have been considered and rectified accordingly.

(Student's signature)

Name : Thaqif Naqiuddin bin Ahmad Azhar

Date : 27 July 2021

(Supervisor's signature)

Name : Dr A.Halim Kadarman

Date : 28 July 2021

(Examiner's signature)

Name : Dr Sarjit Singh Sidhu Junior

Date : 29 July 2021

DECLARATION

This thesis is the result of my investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree

(Student's signature)

Name : Thaqif Naqiuddin bin Ahmad Azhar

Date : 26 July 2021

STATEMENT 1

This thesis is the results of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

(Student's signature)

Name : Thaqif Naqiuddin bin Ahmad Azhar

Date : 26 July 2021

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available to outside organisation.

(Student's signature)

Name : Thaqif Naqiuddin bin Ahmad Azhar

Date : 26 July 2021

ACKNOWLEDGEMENTS

Thanks to Allah as I have finished my final year project. Special thanks to my supervisor, Dr. A. Halim Kadarman, for his guidance, supervision, and support for this project. His guidance is essential in helping me to complete this project successfully.

In addition, I would also like to thank the technical staff from the School of Aerospace Engineering, Mr. Hasfizan, and Mr. Shahar, that gives me a lot of knowledge and hands-on skill regarding rocket engineering. Thank them for their help in the process of preparing solid propellant and conducting the static test. I have learned many hands-on experiences in fabricating the propellant grain from them. Not to forget, my thanks to Mr. Abdul Hisham, who provides help in cutting materials. To Mr. Mohd Najib, I would like to thank him very much for his help preparing my materials and tools for the fabrication process. Not to forget Mr. Mahmud and Mr. Shukri for their help in welding, drilling, and also soldering the components needed.

Finally, I want to express my heartfelt gratitude to my parents, wherever they are, especially to my mother and father, as well as to my siblings, for their constant encouragement and support. Additionally, I want to express my gratitude to everyone who assisted me in this endeavor, whether directly or indirectly.

To them, I dedicated this thesis

ABSTRACT

This thesis aims to describe the process of building a solid rocket motor using a single-stage model rocket. This thesis also suggests an alternative test stand that can be built with an automated system. The finding and analysis of the rocket were obtained from the test conducted. The performance and capability of the test stand were also observed. The simulation was also run using SOLIDWORKS to test the performance of the motor casing. After through some research, more finding was discovered in maximising the performance of the rocket. In conclusion, this thesis proves that a test stand can be built to test the rocket's performance. The engineering principles also can be learned in building this rocket.

ABSTRAK

Model roket boleh dipertimbangkan bagi tujuan kajian dan penyelidikan. Dalam tesis ini, penerangan mengenai proses pembuatan roket pepejal model peringkat tunggal dan enjin yang kukuh telah dibincangkan. Tesis ini juga menerangkan bahan yang digunakan dalam pembuatan bahan bakar pepejal. Ia juga mengandungi langkah untuk membina sebuah tempat ujian statik. Kaedah dan pengiraan yang dilakukan adalah hasil dari pembacaan dan penyelidikan melalui jurnal-jurnal serta makalah ilmiah yang berkaitan. Simulasi kepada badan roket turut dijalankan menggunakan perisian SOLIDWORKS bagi melihat ketahanan badan roket. Setelah melalui kajian dan penyelidikan, terdapat lebih dapatan yang menunjukkan prestasi roket yang boleh dimaksimakan serta penambah baikan yang boleh dibuat terhadap tempat ujian. Rangkumannya, tesis ini menunjukkan bahawa tidak mustahil untuk membina sebuah roket dengan bahan bakar pepejal dan memaksimakan prestasinya serta pembinaan tempat ujian statik adalah mampu dibina sendiri. Pelbagai prinsip merangkumi berbagai-bagai cabang kejuruteraan turut boleh dipelajari dalam tesis ini.

Contents

List of Figures

List of Tables

Nomenclature

Symbol	Description	SI unit
A^*	area of throat	m^2
P_0	chamber pressure	Pa
k	ratio of specific heat	
P_e	exit pressure	Pa
P_a	ambient pressure	Pa
A_e	exit area	m^2
K_n	ratio of area of burning to area of throat (A_b / A^*)	
ρ_p	density of propellant	kg/m^3
r	burn rate	m^3/s
c^*	characteristic exhaust velocity	m/s
a	burn rate coefficient	
n	pressure exponent	
F	thrust	N

Chapter 1 Introduction

1.1.General overview

A rocket is a type of engine that moves forward or upward by using the thrust produced by itself. Newton's Third Law stated that there would be reaction with the same magnitude for every action but in the opposite direction. Thus, rocket use this concept in its operation. For all type of rockets, the exhaust will be formed fully by using the propellant that has been placed inside the rocket earlier. The exhaust will be produced backwards, and this will lead to a force that push the rocket forward. This is the simplest way to explain how a rocket move. For solid-propellant technology, it is not too much to say it could be count as the eldest technical development in jet propulsion technology field.

People in previous civilisation had discovered this theory and make use of it. Thus, the development of this technology is not a new thing. It has been used ever since 13th century as the Chinese and Arabic people use the rocket during a warfare. Around A.O. 850, gunpowder appears to have emerged in China as an accidental result of alchemists' work on its constituents - saltpeter (potassium nitrate), sulphur, and charcoal. Based on some archaeologist research, they found that Chinese engineers had their first flying rocket as early as 1150 A.D. This early age of rocket was build up using bamboo tube as the body, then filled with the gunpowder. On ignition, the rocket fly using the thrust produced by the products of combustion which escaped through a small hole at the end of the tube with a high velocity. These rockets were known as "running rats".

In the next few generations, the Indians, the Arabs and the Mongols also build up their own rockets. A lot of trial and error has been done in order to achieve their desired performance of solid propulsion rocket; mostly for military use.

For the past few decades, the technology in rocket field has undergo rapid development and improvement through research and studies that has been carried out.

In the early stage modern world, European people also had to explore rocket technology. For example, an English engineer, William Congreve, built a solid-propellant rocket that could fly as far as 300 yards. These rockets were being used in Britain-United States War and some other conflicts.

Apart from military purposes, this technology also had been used for space exploration. A Russian teacher, Konstantin Ziolkovsky (1857-1935), worked on research to figure out a way to send a vehicle from earth to space. In 1903, he established a paper titled "Exploration of Space with Reactive Devices," which suggests that a man could escape from earth's gravity force with the help of a rocket. Based on his calculation, he came out with an idea called a multistage rocket.

Now, the application of solid rocket motor technology had been common things around the world. According to NASA(Hunley, 1999), some famous boosters and history also use the solid rocket propellant. The list is shown in the table below.

Table 1-1 Key missiles and rocket boosters (Hunley, 1999)

Missile or booster	Motor manufacturer	Propellant	*Isp**	Grain configuration	Operational date
Sergeant	Thiokol	AP/polysulfide	ca. 185	5-point star	1962
Polaris A1					
Stage 1	Aerojet	AP/Al/polysulfide	ca. 230	6-point star	1960
Stage 2	Aerojet	AP/Al/polysulfide	ca. 255	6-point star	1960
Polaris A2					
Stage 2	Hercules Powder Company	AP/nitrocellulose/ nitroglycerine/Al	ca. 260	12-point star	1962
Polaris A3					
Stage 2	Hercules Powder Company	HMX/Al/AP/ nitrocellulose	ca.280	Slotted cylindrical centre port	1964

Minuteman 1					
Stage 1	Thiokol	AP/PBAA/Al	ca. 245	6-point star	1962
Stage 2	Aerojet	AP/polyurethane/Al	ca. 270	4-point star	1962
Stage 3	Hercules Powder Company	AP/HMX/ nitrocellulose/ nitroglycerine/Al	ca. 275	Core and slotted tube-modified end burner	1962
Titan 3 solid-rocket motor	United Technology Corporation	AP/PBAN/Al	ca. 265	8-point star and circular perforation	1965
Space Shuttle solid-rocket motor	Thiokol	AP/PBAN/Al	ca. 245	11-point star and tapered perforations	1981

1.2.Mission Statement

In this project, there has been a list of missions to be accomplished. The missions are:

a) Design and fabricate a solid propellant rocket motor (SPRM)

b) Run an experimental firing test of rocket motor using solid propellant consist of Potassium Nitrate

c) Design automated test stand using a load cell and Raspberry Pi

d) Assembly with the rocket body and launch the rocket from the launchpad

1.3.Objectives and Aim

This project aims to design, fabricate and test a solid-propellant rocket motor that will have the capability to withstand the 30-bar pressure. The objectives of this project are:

a) To design and fabricate solid-propellant rocket motor

b) To fabricate propellant grains (Potassium Nitrate) using cold casting methods

c) To run a static test using an automated test stand and analyse the performance of the rocket motor

d) To assemble and launch the rocket

Chapter 2 Literature Review

2.1.Preface

The solid-propellant rocket motor operation begins with activating an ignition mechanism, which initiates a chemical reaction on the solid surface of the perforation. A simple solid rocket motor cannot be turned off once ignited because it contains all of the propellants needed for combustion in one chamber. The propellant grain burns on the entire inner surface of the perforation after combustion until the fuel runs out. The heated gases produced by solid combustion pressurise the inside of the chamber before being expelled through a nozzle, which accelerates them and produces the thrust required to travel(Alemayehu, 2020).

Based on the statement above, we can say that there are several significant components for a solid rocket motor to operate:

- Propellant grain
- Igniter
- Motor casing
- Nozzle

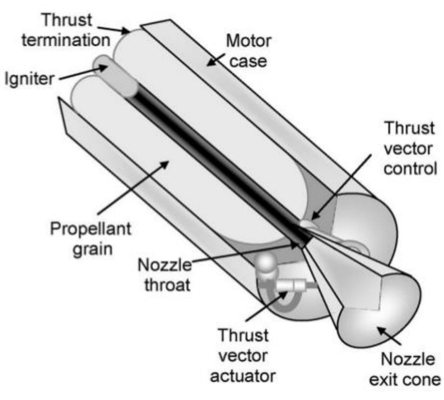

Figure 2.1 Cross-section of a typical solid-fuel rocket motor (*SATELLITE TECHNOLOGY*, 2011)

Figure 2.1 shows a typical solid rocket motor cross-section. However, the parts may vary based on the mission and special needs for the rocket operation.

Besides, J.D. Mattingly, in his explanation, stated that the propulsion process begins with propellant transportation via the Propellant Feed System; following energy conversion via the Energy Conversion System, which turns the Energy Source (Propellant) into energised particles; and finally, particle acceleration via the accelerator, with the high-speed particles discharged out of the propulsion system as exhaust, producing thrust(Mattingly, 2006).

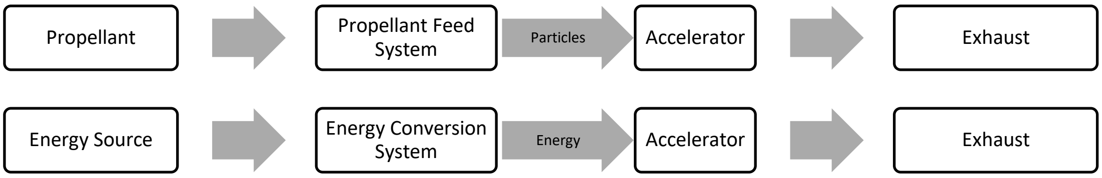

Figure 2.2 Workflow of a rocket propulsion system (4)

Mohamad Izwan Ghazali discussed his research on solid propellant for Solid Rocket Motors in their Design Fabricate and Test Small Rocket Motor article (SRMs). This project focuses on optimum design-based SRM characteristics, including approaches for optimum design selection and fabrication, COSMOS analysis, and static thrust testing. The researcher had previously focused on the principles of solid rocket engine design and manufacture. When designing and producing a design, the two most critical factors to consider are processability and mechanical strength. The theoretical performance of the propellant was determined using the CHEM program. (Ghazali, 2012).

2.2.Propellant Grain

The oxidiser, fuel, and binder are the three essential components of solid propellant. While liquid-fuelled rocket engines have a wide range of propellant compositions, solid propellants have a much smaller selection. Instead of choosing a specific propellant for a specific application, each manufacturer has its own optimised propellant mixture. The most common commercial propellant comprises two or more chemical components that combine to produce heat and gaseous materials. Strong propellants have been used since the dawn of time and were based on gunpowder, a combination of charcoal, sulphur, and saltpetre until the twentieth century. Fundamentally, modern propellants are identical to these early mixtures. While chlorates and perchlorates are now more widely used, the oxidant is typically one of the inorganic salts such as potassium nitrate (saltpetre). Sulphur is sometimes found in the oils, and carbon is present in the form of the organic binder(Maxwell and Young, 1961).

In Mechanics and Thermodynamics of Propulsion (Hill and Peterson, 1992), the authors state that there are two types of solid propellants based on the fuel and oxidant distribution. When the fuel and oxidant are combined into a single molecule, the propellant is said to be homogeneous. The most common type of homogeneous solid propellant is a combination of nitroglycerin and nitrocellulose [C3H5(N02) J-C6H 102(N02)3] with small amounts of additives.

Table 2-1 Typical Double-Base Propellant (Hill and Peterson, 1992)

Material	Weight %	Purpose
Nitrocellulose (13.25%N)	51.40	Polymer
Nitroglycerin	42.93	Explosive plasticiser
Diethyl phthalate	3.20	Nonexplosive plasticiser
Ethyl centralite	1.00	Stabiliser
Potassium sulfate	1.20	Flash suppressor
Carbon black (added	0.20	Opacifying agent
Candelilla wax (added)	0.07	Die lubricant

According to, he classified grain into five families that are commonly used (Davenas, 1993):

- **Solventless double-base extruded propellants (EDB):** principally consisting of nitrocellulose and nitroglycerine. Extrusion through a die with the desired form generates the configuration. The outside diameter is limited to roughly 300mm due to equipment limits. Additional machining of the grain is available.
- **Cast double-base propellants (CDB):** similar to EDB, these propellants are made by pouring a solution of nitroglycerine and triacetin into a mould containing nitrocellulose-based casting powder.
- **Composite modified cast double-base propellants (CMCDB):** similar to CDB, but with the addition of RDX, HMX, or ammonium perchlorate to the casting powder, as well as possibly nitroglycerin.
- **Composite propellants** composed of a non-energetic polymeric binder and ammonium perchlorate, which may contain aluminium powder.
- **High-energy propellants** based on an energetic binder that has been highly plasticised with a liquid nitric ester, as well as RDX or HMX, which may also contain ammonium perchlorate and aluminium and is referred to as XLDB (crosslinked double-base), even if the binder contains little or no nitrocellulose and the formulation contains a high concentration of energetic solids.

To immobilise the propellant and avoid premature burning of the grain's outer surface, the SRM grain is bonded to the casing. Debonding can be a major issue; hence additives are used in propellant formulations to increase bonding properties. Although thermal cycling can cause fatigue cracks, thermal loads during storage are normally low (0.1 MPa). Shrinkage during the cure is more problematic, as it causes tensions at the case boundary. Debonding from the matrix can occur when there is a high concentration of stress in the vicinity of oxidiser particles, especially large ones. Cure shrinkage stress can be alleviated by raising the temperature slightly above the cure temperature. The mechanical properties of HTPB-based propellants were observed to alter just slightly during accelerated aging at 60–65 8C, which corresponded to as much as 15 years at ambient temperature (Mason and Roland, 2019).

2.2.1.Configuration

The most basic thrust principle is derived from the linear burning of a cylindrical grain (as in a cigarette): a constant burning area provides constant thrust. However, this form has drawbacks: the burning area is confined to the cross-section of the cylinder, and the flaming rim would come into touch with the motor's wall. Because of the thermal damage to the casing, active cooling of the wall is not possible with a solid motor, and this sort of charge shape can only be utilised for low thrust and for a short time.

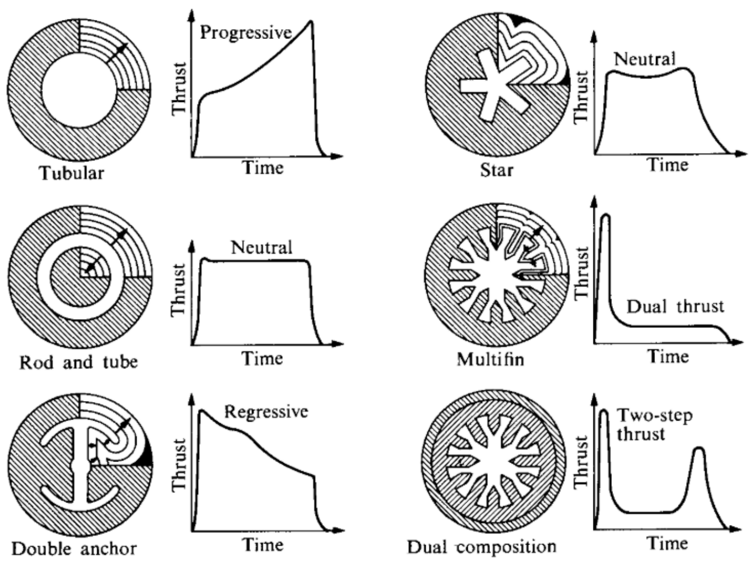

Figure 2.3 Grain configuration and their thrust profile graph plot (Hill and Peterson, 1992)

Some of the configuration explanations are also stated by (Maxwell and Young, 1961), which is explanations are as follows:

Table 2-2 Propellant grain behaviour

Grain Profile Configuration	Explanation
Tubular	Often known as progressive, it is the most straightforward. The area of the burning surface increases linearly with time, as does the circumference of the circular cross-section; thus there is a linear increase in mass flow rate and thus thrust.
Star	The most often utilised - generates a quasi-constant thrust because of the convolutions of the cog shape, the initial burning area is rather extensive; when the cog 'teeth' burn away, the loss of burning area is balanced by the rising area of the cylindrical component This profile is simple to cast and good at maintaining a nearly constant mass flow rate.
Rod and tube	This shape gives a totally flat thrust profile because burning takes place on both the outside surface of the inner rod and the inner surface of the outer cylinder. The increase in the burning area on the cylinder's inner surface compensates for the decrease in the burning area on the rod's outer surface.

From (Sutton and Biblarz, 2001), the explanation of the other configuration in terms of L/D ratio, pressure-time burning characteristics and CG shift, and details of the propellant grain profile are also discussed. The explanations are tabulated below:

Table 2-3 Characteristics of propellant grain with different configurations (Sutton and Biblarz, 2001)

Configuration	Web Fraction	L/D ratio	Volumetric Fraction	Pressure-time Burning Characteristics	C.G. Shift
End Burner	>1.0	NA	0.90 - 0.98	Neutral	Large
Internal burning tube (including slotted tube, trumpet, conocyl, finocyl)	0.5 – 0.9	1-4	0.80 – 0.95	Neutral[a]	Small to moderate
Segmented tube (large grainst)	0.5 – 0.9	>2	0.80 – 0.95	Neutral	Small
Internal star[b]	0.3 – 0.6	NA	0.75 – 0.85	Neutral	Small
Wagon Wheel[b]	0.2 – 0.3	NA	0.55 – 0.70	Neutral	Small
Dendrite[b]	0.1 – 0.2	1 - 2	0.55 – 0.70	Neutral	Small
Internal – external burning tube	0.3 – 0.5	NA	0.75 – 0.85	Neutral	Small
Rod and tube	0.3 – 0.5	NA	0.60 – 0.85	Neutral	Small
Dog bone[b]	0.2 - 0.3	NA	0.70 – 0.80	Neutral	Small

[a]Neutral if ends are unrestricted, otherwise progressive
[b]Has up to 4 or sometimes 8% silver and thus a gradual thrust termination
NA: not applicable or not available

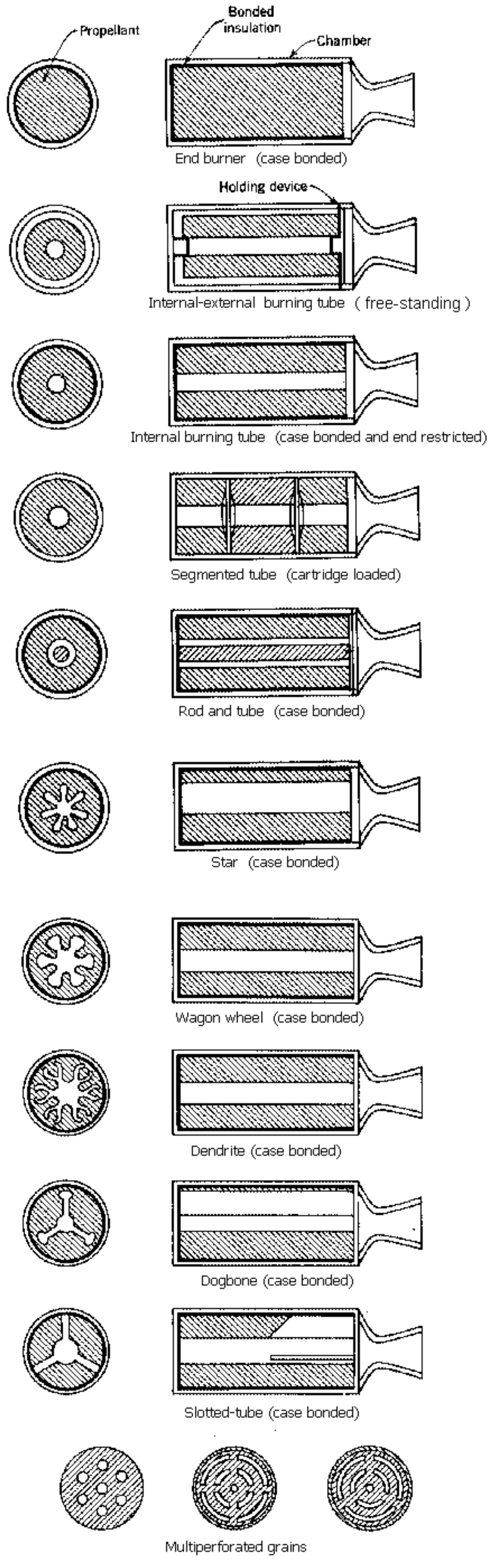

Figure 2.4 Other configuration for solid propellant (Hill and Peterson, 1992)

For every type of propellant made by different substances, the burn rate will be vary based on two factors: ambient temperature of combustion and the chamber pressure. For example, an ammonium perchlorate based propellant that is burned on a 1000 psi chamber will have a lower burn rate with an ammonium perchlorate based propellant that is burn on a 2000 psi pressure. Also,if the same propellant are burned in different ambient temperature, the propellant that is burned in a higher ambient temperature will have a higher burn rate.

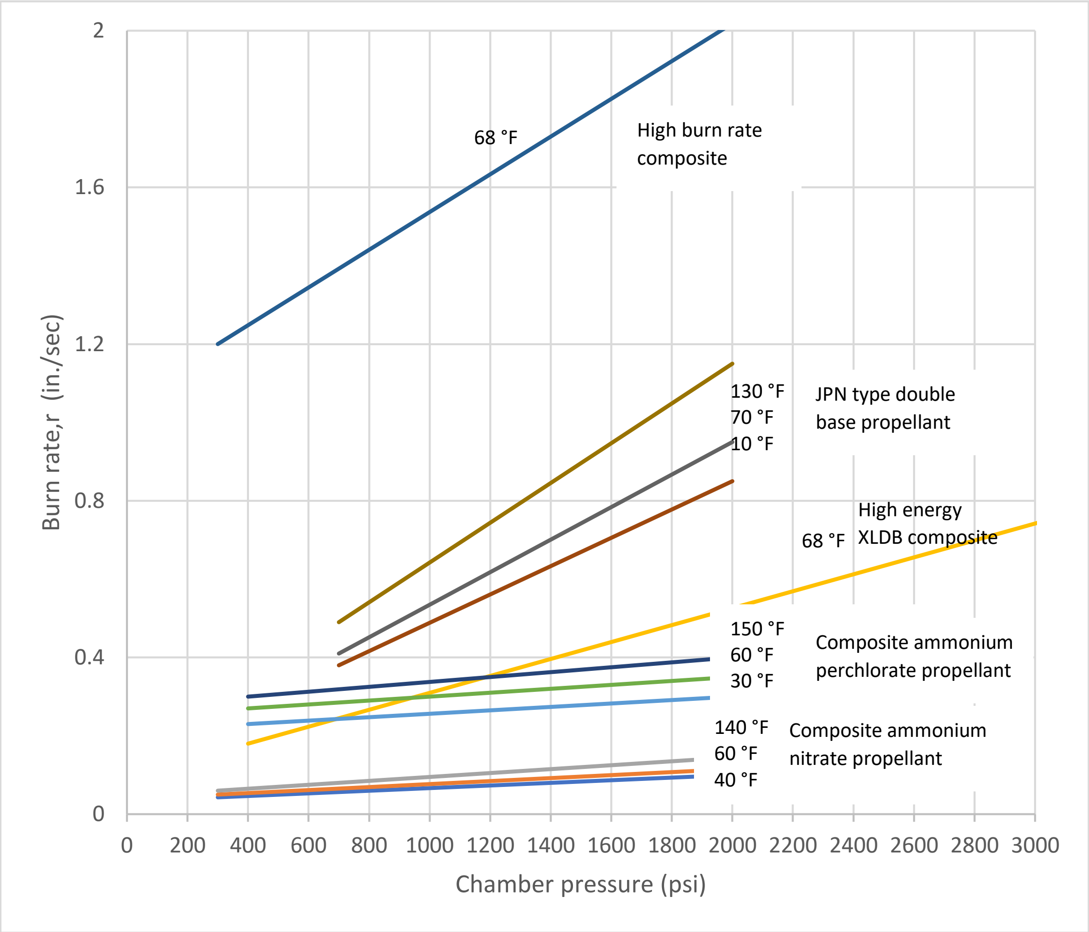

Figure 2.5 Figure 2.5 Chamber pressure and ambient temperature effect on burn rate

2.3.Igniter

Heat generation, heat transfer from the igniter to the motor grain surface, spreading the flame over the entire burning surface area, filling the chamber free volume (cavity) with gas, and elevating the chamber pressure without severe anomalies such as overpressures, combustion oscillations, damaging shock waves, hang- fires (delayed ignition), extinguishment, and chuffing are all part of solid propellant ignition. The heat and gas needed for motor ignition are produced by the igniter in a solid rocket motor(Sutton and Biblarz, 2001).

These aforementioned composite solid rocket propellants are inherently difficult to ignite, especially where ammonium nitrate is utilised as the solid oxidant. Ammonium nitrate-binder composite solid rocket propellants have a relatively high auto-ignition temperature (e.g.,600 F.), and while their specific heats are relatively high, their heat transfer coefficients are low. Moreover, the ignitability of these propellants often varies due to condensation of moisture, variations in propellant surfaces due to extrusion phenomenon, curing, etc. As a result, it is often difficult to completely ignite these propellants in a reproducible manner throughout a wide range of temperature conditions. (Walden, 1961)

Based on (Jain *et al.*, 2020), there are few types of igniter :

2.3.1.Nozzle cap-based igniter

For tiny rocket motors, nozzle cap-based igniters have been designed. Due to space limits, provision of electrical connections, and other factors, putting the igniter near the head-end in propulsion systems is tricky. In such instances, it's also preferable to have an ejectable igniting mechanism to avoid carrying any dead weight and avoid excessive transient pressure peaks.

Design features

- The igniter is mounted on an ejectable nozzle cap
- An electrical connection is also possible with the nozzle cap.
- Nozzle cap ensures sealing of gases generated by the igniter
- A hot gas jet goes through the throat and ignites the propellant surface using a nozzle cap-based igniter.

Operational Features

The nozzle cap has metallic circular sectors inserted in it that serve as contact points for electrical connections. A specifically constructed metallic plunger provides a second electrical contact. Squibs are used to start the igniter, which receives electrical power through these contact points. Squibs start the primer charge, which then kicks off the main charge. Gases produced by the combustion of the charge mass are directed towards the propellant surface via a torch-like arrangement. The canister is usually made of stainless steel, while the priming assembly is made of a high-strength aluminium alloy. Glass-filled phenol-formaldehyde composite material is used to make the cap.

The igniter charge is made up of BKNO3 pellets. In sophisticated rocket engines where igniters can't be put anywhere else, nozzle cap-based igniters are quite handy. Propeller loading at the head end can be improved, as it is at the nozzle end. During its flight, this ejectable type of igniter has no weight penalty on the system. In most tactical missiles and rockets, these igniters are used.

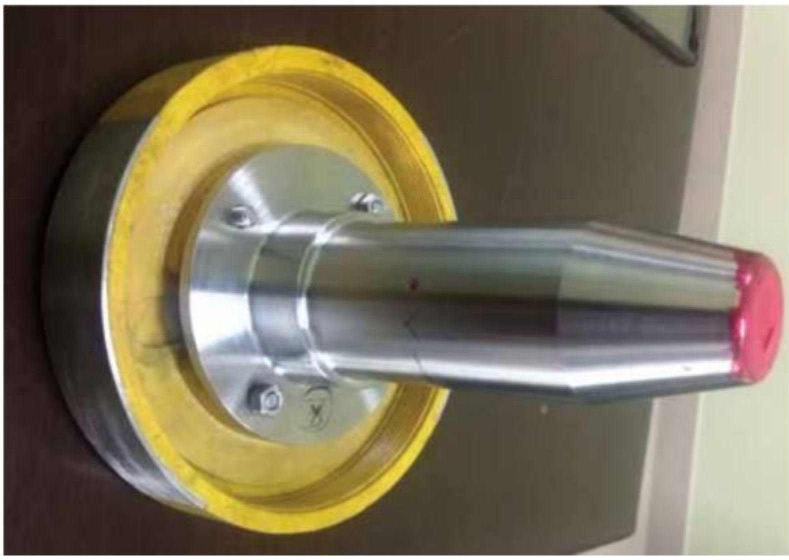

Figure 2.6 Nozzle cap based igniter (Jain *et al.*, 2020)

2.3.2.Throat based igniter

Because there isn't enough space at the nozzle diverging end of a smaller rocket motor to configure a nozzle cap-based igniter due to length or diameter constraints, the igniter is installed on the motor's throat. The material used in the construction is intended to give sufficient ejection pressure and ensure that the igniter is ejected smoothly and without damage through the throat. The material used in the construction is intended to give sufficient ejection pressure and ensure that the igniter is ejected smoothly and without damage through the throat.

Design Features

- The igniter can be ejected.
- To ensure gas sealing at the throat, igniter hardware uses a seal.
- Gunpowder, BKNO3 granules, and pellets make up the charge mass, each serving a specific purpose.
- The throat is sealed by an O-ring seated at the igniter's neck.

Operational Features

A throat-based igniter is used in the Squib-based igniting system. The squib wires are removed from the back of the igniter and secured with a tapered disc butting the divergent to the nozzle end at the divergent end. An electrically triggered squib ignites the granules, gunpowder, and pellets. Due to the pressure impact of gunpowder, burning pellets are ejected from the canister into the main combustion chamber. The propellant surface is ignited, resulting in a long-lasting ignition. Once enough pressure has been built up inside the chamber, the igniter is released from the throat by deforming the collar at which it was held. The igniter canister is made of soft materials like aluminium to ensure smooth ejection of the igniter down the throat. Throat-based igniters of this composition become extremely important in high L/D motors where simultaneous ignition at the head and nozzle ends is required. Like the nozzle cap-based type, this structure aids in improved propellant loading and simplified connections at the head end. Long-distance solid propellant motors typically use these igniters.

Figure 2.7 Throat based igniter (Jain *et al.*, 2020)

2.3.3.Retainable Igniter

In many cases, igniters that can withstand the rocket motor's entire burn time are preferred. These types of igniters are known as retainable igniters. The thermal severity during the burn period is the main issue in ensuring the safety of these igniter types. As a result, the metallic canister containing the igniter composition, which is made of Maraging Steel or a similar material, is adequately insulated with carbon phenolic or another material. These igniters are usually found at the head end, but they can also be found at the nozzle end in some cases.

To start retainable igniters, pyro-cartridges are commonly used. Because it can be at the end of all assemblies, pyro-cartridge deployment is recommended from a safety standpoint during storage, transit, and testing of larger missiles. Squibs have a more fragile design than pyro-cartridges.

Design Features

- Pyro-cartridge based initiation
- Outside thermal protection is provided for the igniter canister.
- During the first 15 to 25 minutes of burning, the thermal insulation should remain intact.

Operational Features

Pyro-cartridges are used to start the igniter charge mass. The pellet-shaped charge mass burns and emits gases through a number of flash holes. The igniter only lasts 50 milliseconds, but once the rocket motor is turned on, it must withstand extremely high temperatures and motor pressure from the outside. The insulating layer protects the interior metal canister even after charring and mechanical degradation.

Because ejection of the igniter is not possible in long-duration motors, retainable igniters are required. During the motor's burn, the igniter is exposed to extremely high temperatures. These igniters are usually found at the motor's head end.

Figure 2.8 Retainable igniter (Jain *et al.*, 2020)

2.3.4.Continuous Multipoint Initiation Igniter

A Toroidal motor igniter has been developed by HEMRL. The motor is made up of an unusual toroidal design with a mean diameter of around 2 metres and eight evenly spaced nozzles. There are 11 pairs of ports in total on the composite propellant motor, for a total of 22 ports. The igniter is made up of eight arc-shaped aluminium cylinder tubes with a thickness of 0.5 mm that are connected by a T-shaped adaptor to form a circular ring with a diameter of about 2 metres that precisely matches the PCD of propellant ports. The aluminium tubes are filled with 384 g of BKNO3 composition.

Design Features

- Simultaneous ignition using pyro-cartridges from multiple points
- The shape of the igniter is torroidal.
- Although the total igniter is divided into multiple segments for ease of fabrication and assembly, it functions as a continuous igniter.
- Because the canister material is located at the nozzle end, it is consumable.

Operational Features

- The electric source initiates the initiator located at the pyro holder.
- Pyro flash travels through an annular channel in the casing of a motor and is diverted in two opposite directions to ignite two igniter segments.
- This is a single interface; similarly, there are numerous interfaces evenly spaced around the circumference.
- These igniters are advantageous for igniting multiple ports simultaneously when placed over a large PCD. They are also useful for motors with a large free volume (up to 100 L) and where high initiator redundancy is required.

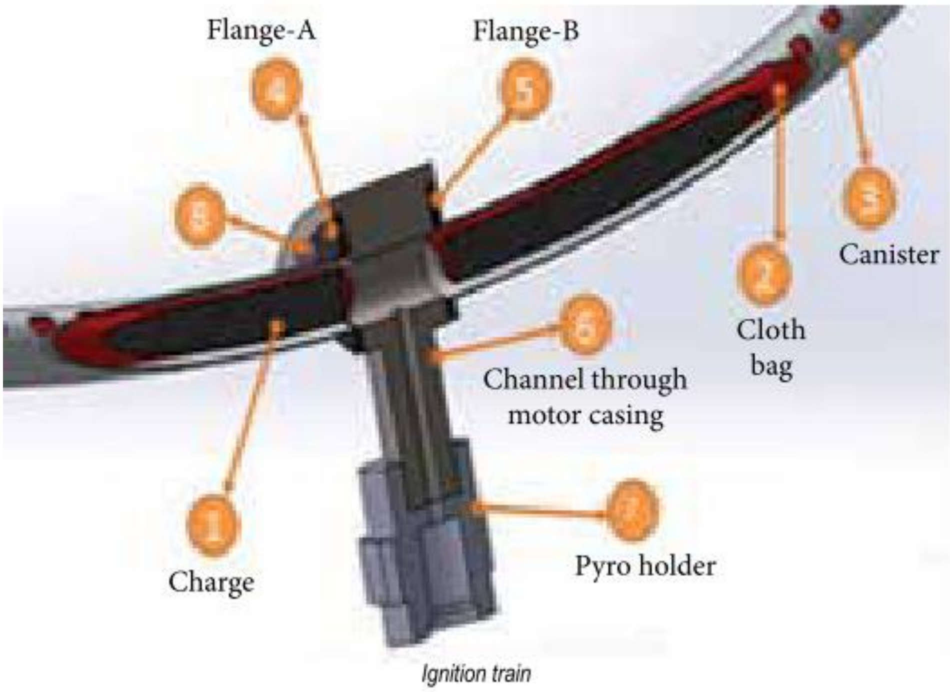

Figure 2.9 Continuous multipoint initiation igniter (Jain *et al.*, 2020)

2.4.Nozzle

From (Stephenson, 2018)Almost all solid rocket nozzles are cooled using ablative cooling. A solid rocket nozzle is constructed of steel or aluminium shells (housings) designed to withstand structural loads (the largest of which are the motor operating pressure and the nozzle TVC actuator load), as well as composite ablative liners bonded to the housings. The ablative liners are designed to insulate the steel or aluminium housings, provide the internal aerodynamic contour necessary for combustion gases to expand efficiently and generate thrust, and ablate and char in a controlled and predictable manner to avoid heat accumulation that could harm or significantly weaken the structural housings or bonding materials. The thickness of ablative liners in solid rocket nozzles is chosen to keep the adhesive bond line between the liner and the housing below the temperature at which the adhesive structural properties degrade during motor activity.(Sutton and Biblarz, 2001).

To design a nozzle, here are some of the variables that need to be considered(Team, 1975):

- Design pressure
- Predicted pressure-time trace (defines average pressure, firing duration, restarts, and coast time if any)
- Propellant properties – chamber temperature, thermodynamics constraint, thermochemical properties
- Throat size (area/diameter, initial or final)
- Acceptable throat-size change
- Expansion ratio

The nozzle exit pressure, P_{exit} must equal the atmospheric pressure, P_{atm}, near to the nozzle exit for an optimum functional nozzle. When $P_{exit} > P_{atm}$, the flow experiences over-expanded flow, while when $P_{exit} < P_{atm}$, the flow experiences under-expanded flow. These erratic fluxes reduce the propulsion system's overall efficiency, but they are unavoidable. Extending nozzles and other mechanisms and subsystems are designed to ensure that the exhaust gas exit pressure is equal to air pressure (Stephenson, 2018).

2.5.Motor casing

A liquid-fuelled engine's combustion chamber is very thin. It has just the right diameter for proper mixing and is long enough to allow propellant droplets to evaporate. A solid motor's combustion chamber also serves as a fuel storage area, and it is huge. Furthermore, since high thrust is often needed, the throat diameter is larger. In modern rockets, the pressures faced by both of them are about the same—around 50 bar. Designing a large vessel to withstand high pressure and high temperature, on the other hand, is much more complex than designing a smaller vessel. The skin must withstand the strain, and as the diameter grows, so must the thickness, which has a significant impact on the mass due to the wide surface area. (Maxwell and Young, 1961)

Casings are often made of metal alloys. Titanium alloys and aluminium alloys are utilised in smaller rockets, while nickel alloy steels are employed in larger rockets. They are made to seem like cylindrical shells with flared ends for joints. For specialized casing, complex welding and heat treatment fixtures and methods have been developed. The casings are put through a series of quality control checks for strength, toughness, weld soundness, and hydraulic pressure. Thermal insulation is installed on the inside of the casings to protect them from hot gases. End covers, nozzles, and handles are all included in the casing. Composite materials, such as fibre reinforced plastic (FRP), can also be used for casings. This type of enclosure is light and robust (Rajesh, Suresh, and Mohan, 2017).

Here are some significant considerations that should be taken during the design casing stage:

- The case and closure should be the minimum size and optimum shape required to fulfil the propellant grain design and clearances for auxiliary equipment
- The minimum mechanical properties of the case material should be more than needed by fracture mechanics theory and design safety factors

Hence, table below show list of materials which are commonly used in building a rocket motor casing.

Table 2-4 Mechanical properties for materials used for motor casing (Sutton and Biblarz, 2001)

Material	Tensile Strength, N/mm^2 (10^3 psi)	Modulus Elasticity, N/mm^2 (10^3 psi)	Density, g/cm^3 (lb/in.^{3})	Strength to Density Ratio
		Filaments		
E-glass	1 930 – 3 100 (280 – 450)	72 000 (10.4)	2.5 (0.09)	1 040
Aramid (Kevlar 49)	3 050 – 3 760 (370 -540)	124 000 (18.0)	1.44 (0.052)	2 300
Carbon fiber / graphite fiber	3 500 – 6 900 (500 – 1 000)	230 000 – 300 000 (33 – 43)	1.53 – 1.80 (0.055 – 0.065)	2 800
		Binder (by itself)		
Epoxy	83 (12)	2 800 (0.4)	1.19 (0.043)	70
		Filament-Reinforced Composite Material		
E Glass	1 030 (150 – 170)	35 000 (4.6 -5.0)	1.94 (0.07)	500
Kevlar 49	1 310 (190)	58 000 (8.4)	1.38 (0.05)	950
Graphite IM	2 300 (250 – 340)	102 000 (14.8)	1.55 (0.056)	1 400
		Metals		
Titanium Alloy	1 240 (180)	110 000 (16)	4.60 (0.166)	270
Alloy Steel (heat treated)	1 400 – 2 000 (200 – 290)	207 000 (30)	7.84 (0.289)	205
Aluminium alloy 2024 (heat treated)	455 (66)	72 000 (10.4)	2.79 (0.101)	165