DEVELOPMENT OF WIRELESS IGNITION SYSTEM (WISys) FOR SOLID ROCKET MOTOR

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EXAMINERS APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
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I hereby declare I have checked this report and in my opinion, this report project is adequate in terms of scopes and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this report is my own, except for quotations and summaries, which have been duly acknowledged. The report has not been accepted for any other degree and is not concurrently submitted for award of other degree.

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Dedicated To My Family

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ABSTRACT

Wireless igniter system (namely WISys in this research) is a modern type igniter system, which utilizes the concept of radio frequency (RF) communication between a transmitting device and a receiving device and also the usage of a specified designated igniter. This type of igniter system is now becoming the main focus in most rocketry industries, especially for small scale solid rocket motor (SRM). The main purpose of using a wireless igniter system is because it can provide secure feeling when conducting experiment and testing, especially when it comes to the matter of explosive materials. The main components that a wireless igniter system must have include a transmitter, a receiver and an igniter. In this research, both the transmitter and receiver were designed to be function able at various ranges and the maximum communication range must reach up to 100 meters. Therefore, selection for wireless communication module is very significant and here the XBee-S1 Starter Kit from Cytron Technologies was used as the main wireless communication module. With its ability to communicate with another XBee-S1 Starter Kit as far as 100 meters range and simplicity of performing configuration and synchronisation, the XBee-S1 Starter Kit module is simply the best choice, especially for those who are unfamiliar with radio frequency communication. Moreover, the power supply for the ignition must be at least 12V so that there is sufficient heating energy to ignite the pyrolant contained inside the igniter within 3 to 5 seconds. For a good igniter, the igniter must possess good characteristics, such as made from stainless steel, sustainable material, high melting point, able to withstand very high pressure and temperature, high resistance to rust, small size and portable, light weight and tough. So, igniter with these characteristics will be able to store enough pressure inside the combustion or primary chamber to achieve complete combustion of the pyrolant before it is forced out from the igniter into the thrust chamber of rocket motor to burn the propellant grains. As a conclusion, with high pressure inside the primary chamber the velocity inside the chamber would be low. Hence, the burning rate of the pyrolant would also be slower. With this condition achieved, the pyrolant inside the igniter could be burnt completely.

ABSTRAK

Sistem pencucuh tanpa wayar (iaitu WISys dalam kajian ini) adalah sejenis sistem pencucuh moden, yang menggunakan konsep komunikasi frekuensi radio (RF) antara peranti pemancar dan alat penerima dan juga penggunaan pencucuh tertentu yang ditetapkan. Sistem pencucuh jenis ini kini menjadi tumpuan utama dalam industri roket, terutama bagi motor roket pepejal (SRM) kecil. Tujuan utama menggunakan sistem penyala tanpa wayar adalah kerana ia boleh memberikan rasa selamat apabila menjalankan kajian dan ujian, terutama apabila ia perkara itu melibatkan bahan-bahan letupan. Komponen utama yang sistem penyala tanpa wayar perlu miliki termasuk pemancar, penerima dan pencucuh. Dalam kajian ini, kedua-dua penghantar dan penerima telah direka untuk berfungsi pada pelbagai jarak komunikasi dan jarak maksimum mesti mencecah 100 meter. Oleh itu, pemilihan untuk modul komunikasi tanpa wayar adalah sangat penting dan di sini Kit Permulaan XBee-S1 dari Cytron Technologies telah digunakan sebagai modul utama komunikasi tanpa wayar. Dengan keupayaan untuk berkomunikasi dengan Kit Permulaan XBee-S1 yang lain sejauh 100 meter dan pelaksanaan konfigurasi dan penyegerakan yang mudah, Modul Kit Permulaan XBee-S1 adalah semata-mata pilihan yang terbaik, terutama bagi mereka yang tidak biasa dengan komunikasi frekuensi radio. Selain itu, bekalan kuasa untuk pencucuhan mesti sekurang-kurangnya 12V supaya ada tenaga pemanasan yang mencukupi untuk mencetuskan pembakaran pyrolant yang terkandung di dalam pencucuh dalam tempoh 3 hingga 5 saat. Untuk pencucuh yang baik, ia juga mesti mempunyai ciri-ciri yang baik, seperti diperbuat daripada keluli tahan karat, bahan mampan, takat lebur yang tinggi, mampu menghadapi tekanan dan suhu yang sangat tinggi, rintangan yang tinggi terhadap karat, saiz yang kecil dan mudah alih, ringan dan kuat. Jadi, pencucuh dengan ciri-ciri ini akan dapat menyimpan tekanan yang cukup di dalam ruang pembakaran atau ruang utama untuk mencapai pembakaran pyrolant yang lengkap sebelum ia terpaksa keluar dari pencucuh dan masuk ke dalam ruang teras motor roket untuk membakar bijirin dorongan. Kesimpulannya, dengan tekanan tinggi di dalam ruang utama halaju di dalam ruang itu akan menjadi rendah. Oleh itu, kadar pembakaran pyrolant juga akan menjadi lebih perlahan. Dengan keadaan ini dicapai, pyrolant di dalam pencucuh itu boleh dibakar sepenuhnya.

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LIST OF SYMBOLS

A	Ampere
A	Area
D	Diameter
I	Electric current
K	Kelvin
L	Length
m	Mass
P	Power
P	Pressure
Pa	Pascal
P_{cig}	Maximum Igniter Pressure
R	Electrical Resistance
R	Reinberg Constant
R_{rig}	Average Igniter Pressure Trace Slope
V	Voltage
v	Velocity
V	Volt
V	Volume
$\boldsymbol{\pi}$	Pi = 3.142
ρ	Density
Ω	Ohm

LIST OF ABBREVIATIONS

A/DC	Analogue to Digital Converter
AP	Ammonium Perchlorate
CMDB	Composite Modified Double-Base
DC	Direct Current
EARco	Experimental Aerospace Research
FYP	Final Year Project
IEEE	Institute of Electrical and Electronics Engineers
KP	Potassium Perchlorate
LED	Light Emitting Diode
NC	Nitrocellulose
NG	Nitro-Glycerine
NiCad	Nickel-Cadmium
NiMH	Nickel-Metal Hydride
OEM	Original Equipment Manufacturer
PC	Personal Computer
RF	Radio Frequency
RNX	Richard Nakka's Experimental
SRM	Solid Rocket Motor
SS304	Stainless Steel
WISys	Wireless Ignition System

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

The goal of this research was to develop a wireless ignition system (WISys) for solid rocket motor (SRM) that would be operated safely within a transmission distance range up to 100 meters. This igniter would have very minimum ignition time lag but has maximum fire-spreading interval and chamber-filling interval. Although there are many types of ignition system for rocket, the main challenge in this research was to design and fabricate a wireless ignition system that is compatible for the solid rocket propellant fuelled by ammonium perchlorate based solid.

Wireless ignition system is a modernized ignition system that uses radio frequency (RF) to communicate with another RF device. The RF used is the licence free frequency which is normally at 2.4 GHz. The purpose of using this frequency is because it will not interfere the local network signals which will later cause disturbance to the people around the testing area and will only allow the operator to access the firing signal. Hence, there was an assurance for safety operation.

In modern rocketry, there usage of wireless ignition system is very important especially when it comes to the matter involving the safety of the operator and other participants in the rocket research team. The usage of wireless ignition system would greatly reduce the risk of accident and injury to occur during development period, experiment as well as practical testing. Besides, Malaysia is still on a journey to become a developing country with many global recognition achievements and achievement in rocketry is never less important.

1.2 PROBLEM STATEMENTS

In this research, there were a few challenges that arose which affected the result of the research. These problems which will arise based on the priority include:

i. Why would the wireless ignition system be used in solid rocket motor?
ii. What electronic components and materials would be considered to fabricate the prototype of wireless ignition system?
iii. What would be the appropriate method to fabricate the wireless ignition system?
iv. What would affect the performance of the wireless ignition system?

1.3 OBJECTIVE

The main objective for this study is to fabricate a wireless ignition system that could be operated safely within a transmission distance range up to 100 meters (m).

1.4 SCOPES OF STUDY

There are four main scopes that will be covered throughout this study, which are:

i. Reviewing on types of igniters and ignition system
ii. Designing and fabricating a prototype wireless ignition system
iii. Analysing and testing the ignition and wireless ignition system
iv. Data analysis and evaluation

1.5 RESEARCH OVERVIEW

Chapter 1 discusses the introduction to the Final Year Project (FYP) title. In this chapter, there were brief explanations about the title itself, the problem statements that will lead to the completion of the study, the main objective of the study, the four main scopes of study that covered this research and lastly there is a research overview that briefly explains and summarises the contents in Chapter 1 until Chapter 5.

Chapter 2 is the literature review done in fulfilment for the completion of this research. This chapter is the summary of several research papers be joined together and to perform the study on solid rocket motor (SRM) and its available ignition systems which are compatible and updated. The reviews consisted of introduction to SRM, types of igniters used for SRM, the types of pyrolants used for each type of existing igniter and brief details on the development of wired ignition system used for solid rocket motor. Chosen criteria were developed to be refereed in fabrication of the prototype ignition system for this research.

Chapter 3 explains about the research methodology used throughout the research which serves as the guideline for the entire research. In this chapter, the subjects to be discussed include the method of designing the circuit for wireless system and also the igniter for the system. The ignition system to be created in this research is a prototype wireless ignition system which consisted of a combination of electrical and electronic circuits that will be connected to a prototype igniter. The design covered the development of a transceiver or transmitter and a receiver or Relay box for the wireless ignition system as well as the prototype igniter.

Chapter 4 is the about results and discussions for this research which were obtained based on assumptions, theoretical calculations, computer analysis and simulations as well as experiment and testing. This chapter discussed in detail the design criteria and factors of influence that will affect the result of the entire research.

Chapter 5 is the conclusion for the entire research which summarized and brie
explained the outcome of the research. Nevertheless there were recommendations t
would help to improve the development of the wireless ignition system.

CHAPTER 2

LITERATURE REVIEW

2.1 SOLID ROCKET MOTOR (SRM)

Solid rocket motor (SRM) is the oldest type of rocket (Ward 2010), which was firstly introduced during ancient China with the creation of gunpowder for firework, as mentioned in the book of Brief History of Rockets. The term “motor” is generally used for a solid rocket. SRM is a simple, efficient device with very few moving parts, more compact and smaller in size if compared to the size of a liquid rocket.

SRM or solid propellant rocket, as shown in Figure 2.1, is basically a combustion chamber tube that is packed with a propellant containing fuel and oxidizer. It utilizes the propellant for the ignition of solid rocket motor to produce thrust. This solid propellant has high density and combustion rate as well as being insensitive to shock, vibration and acceleration (Mohd. Jaafar et al. 2004). Moreover, the quantity of propellant itself provides the largest load to the rocket motor.

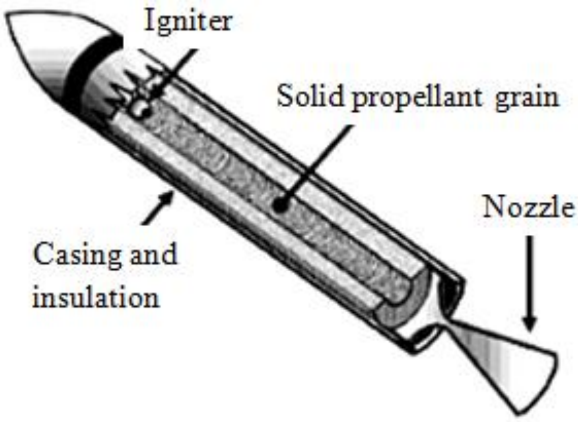

Figure 2.1: Schematic of solid rocket motor (SRM)

Source: Ward 2010

However, the propellant is a one-time used propellant, where its combustion is unable be stopped until it is completely combusted. The percentage of having debris after combustion also cannot be zero or neglected. Hence, the ignition system designed has an important role to make sure the completion of combustion in the combustion chamber tube can be achieved. A solid rocket motor normally consists of a propellant grain, an igniter, a motor case, a protective internal insulation and a nozzle as shown in Figure 2.2 (Moore 2008).

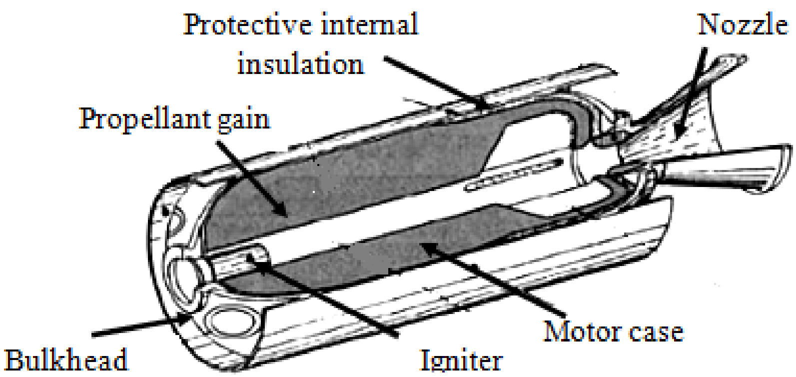

Figure 2.2: A typical solid propellant rocket motor with the igniter located at the bulkhead and a nozzle at the exit

Source: Moore 2008

In this study, the main ignition system will consist of an igniter as the actuator, being energized by current flowing through it and the entire electrical circuit of the receiver (Sutton et al. 2010). The igniter used is a pyrotechnic igniter that generally initiated by a squib, also known as a primer charge or glow plug, which releases a sensitive pyrotechnic upon receiving an ignition signal from the transmitter (Ward 2010).

2.2. MOTOR CASE

Generally the motor case must have good mechanical properties with minimal cost and weight. So, the selection of a motor case must consider the following conditions (Sutton et al. 2001):

i. The burning characteristics of propellant grain which also include the product of gas flow field in the grain cavity.
ii. The selection of case geometry design based on material, shape, expansion coefficient and maximum allowable peak pressure.
iii. The ability to withstand high pressure load in a short time period since the SRM's pressure increases within a few milliseconds to maximum operating pressure where this pressure is transmitted through the propellant to the motor case.

From the above conditions, it is clear that the motor case serves as a high pressure vessel that contains propellant grain which is responsible for the high pressure generation (Sutton et al. 2001). Therefore, the case is generally made from steel or aluminium tube. According to Encyclopedia Britannica Inc. about Rocket, a motor case usually has a head-end dome containing an igniter and an aft-end dome that supports the nozzle.

According to the third condition, the motor case must be able to withstand the high pressure load from the combustion within the case. Otherwise, the pressure can lead to possible case deformation, which induces a strain field in the propellant and stresses at the bond line. Eventually, this could lead to undesirable propellant cracks, high pressurisation in the motor and possible motor damage (Sutton et al. 2001).

2.2.1 Protective Internal Insulation

The protective internal insulation of SRM is attached to the inner side of the rocket motor. It is responsible to protect the interior of the motor case and nozzle regions from high temperature due to propellant combustion by the mechanism of ablation. The insulation material absorbs heat generated by the hot gas through the change in its physical or chemical state and increasing in its temperature, resulting in the depletion of surface material. This ablative insulation is divided into three zones which are the virgin-material zone (located against the motor wall), decomposition zone and the reaction or char zone, as shown in Figure 2.3 (Sutton et al. 2001).

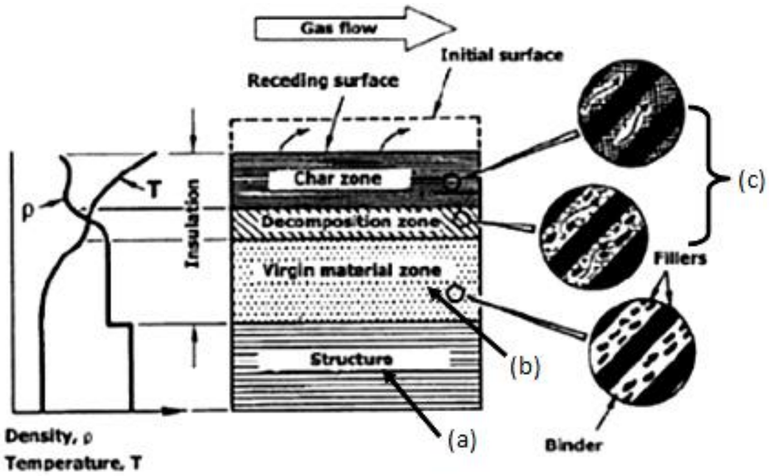

Figure 2.3: Schematic of ablative insulation zones, where a) Structure layer represents the motor case or nozzle material, b) The virgin-material zone protects the structure and c) The decomposition and char zone experience the high temperature associated with the gas flow

Source: Sutton et al. 2001

The virgin-material zone has minimal changes in chemical properties with heat transfer by conduction. This zone protects the structure by keeping the temperature low since it consists of several layers of filters and binders. The next layer of insulation which is the decomposition zone increases its temperature, resulting to decomposition and eventually loss of polymer weight. This zone undergoes endothermic process since the heat transfer is by conduction and pyrolysis dominates this zone. Finally, in the char zone, the decomposition due to convection heat transfer leads to the formation of carbon residue that can lead to char build-up or eventually extraction of char off the insulation surface from the internal hot gas flow (Sutton et al. 2001).

Furthermore, the insulation also functions to inhibits burning on undesirable portion of propellant, such as back or sides of the propellant; buffering the transmission of case stain into propellant; sealing the case, joints and fittings to prevent pressure loss and hot product damage; lastly, guiding the combustion products into the nozzle without failure. Therefore, selection of a good ablative insulator material is important to motor life spend since it will experience surface regression due to the harsh motor environment caused by chemical and physical effects.

The chemical effects are from the surface reactions of char layer with propellant gases and subsurface reactions due to pyrolysis in decomposition and char zones. On the other hand, the physical effects are due to the impingement and shear stress by skin friction, thermal stress by heat transfer and spallation due to internal pressure (Sutton et al. 2001).

2.3 NOZZLE

The nozzle represents the bottom most location in the SRM where the combustion products and gases (exhaust) exit. The nozzle is used to constrict and expand the existing flow, thereby controlling the internal chamber pressure and velocity of the rocket motor.

There are several types of nozzles commonly used for SRM, such as fixed, movable, submerged, blast tube and thrust vector control (Mohd. Jaafar et al. 2004). A fixed nozzle is a simple, stationary nozzle attached externally to the exit of a rocket motor. A movable nozzle is slightly submerged in the rocket motor which uses a flexible sealed joint or bearing that can run the pitch and yaw for thrust vector control of the rocket. A submerged nozzle has a significant portion of the nozzle submerged within the motor case which reduces the motor length. Therefore, it is an advantage to be used for strategic missiles, such as silo and submarine launched. Furthermore, this nozzle is stationary but experience hot gas flow on the inner and outer surfaces as well as internal and external pressure (Sutton et al. 2001).

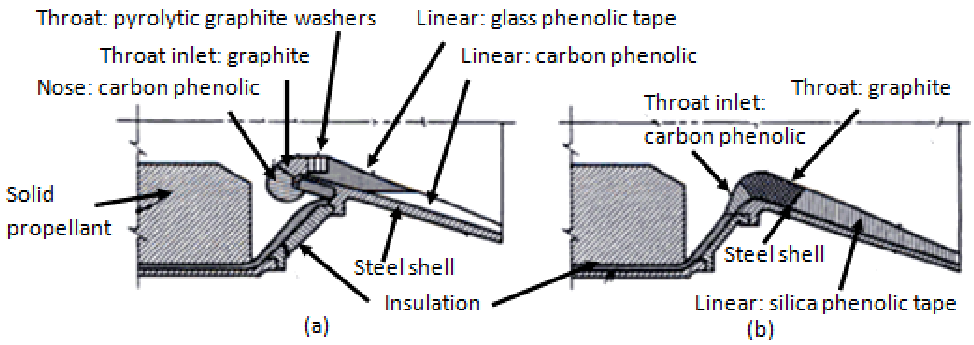

Figure 2.4: Two types of SRM nozzles, which are (a) Partially submerged nozzle and (b) External nozzle

Source: Sutton et al. 2001

Most modern SRMs will use the type of nozzle, namely convergent-divergent nozzle. For this particular nozzle, the convergent and divergent sections of this nozzle can be conical, contoured or even bell-shaped as shown in Figure 2.4. The specific impulse can be determined through engine thrust divided by the mass flow rate of propellants which indicate the effectiveness of the thrust chamber to convert propellant into thrust. The increase in specific impulse with an increase in combustion chamber pressure is almost totally caused by the increase in expansion ratio through the rocket motor’s nozzle (Sutton et al. 2001).

The operating temperature, pressure and gas velocity vary from region to region, with the gas velocity ranging from nearly stagnant Mach number of less than 0.1 to Mach number of 1.0 at the throat of nozzle to the supersonic Mach number greater than 5 at the exit plane.

Figure 2.5: Convergent-divergent nozzles for rocket motor

Source: Mohd. Jaafar et al. 2004

2.4 SOLID PROPELLANTS

The selection of propellants for the high performance SRM is made by considering some of the desirable characteristics as follows:

i. has high gas temperature,
ii. high performance or specific impulse,
iii. high density,
iv. good mechanical and bond properties,
v. good aging characteristics,
vi. good ignition properties,
vii. predictable burning rate,
viii. low temperature sensitivity,
ix. low moisture absorption,
x. minimal sensitivity of burning velocity to pressure, temperature and gas velocity, and
xi. non-toxic exhaust gases.

However, it is impossible to have all the characteristics in one solid propellant alone (Sutton et al. 2001). Therefore, different types of propellants are created to cover all of these characteristics and they could be classified into three main classes. These three classes of propellants include colloidal, composite and composite modified double-base (CMDB) propellants.

The first propellant class, the colloidal propellants or homogenous propellants, which are usually doubled-based since they commonly contain a mixture of two compounds. They were used in early solid rockets and containing high molecular weight compounds in which fuel and oxidizer elements are contained within the same molecule. These compounds are relatively unstable and capable of combustion in the absence of all other materials. Hence, its manufacturing is very hazardous. The most commonly used doubled-based propellant contains nitro-glycerine (NG) and nitrocellulose (NC), and having a non-toxic, smokeless exhaust (Ward 2010).

The composite propellants, also known as heterogeneous propellants contain separate oxidizer particles (finely grounded crystalline particles) that are imbedded into practical polymer binder (powdered light metals). This binder is commonly also function as a combustible fuel, known as a fuel binder. The propellants have better grain's performance so they are high performance and stable. They also have better burn rate control than double-based propellants and often preferred for motor that needs long-term storage. Unfortunately, the addition of light metals, such as aluminium powder, and other chemical compounds creates a toxic and smoky exhaust which is hazardous. Moreover, they have expensive manufacturing process since the process requires complex facilities.

Lastly, there are composite modified double-based (CMDB) propellants, a heterogeneous mixture of double-based colloidal propellants and composite propellant compounds, such as ammonium perchlorate (AP) to achieve stoichiometric combustion. The CMDB propellants have much better performance and storage stability than a purely colloidal propellant but producing a less toxic and smoky exhaust than a pure composite propellant. Furthermore, the propellants are generally manufactured with lower production costs. The solid propellant fuelled by sugar propellant and ammonium perchlorate based solid propellant is an example of CMDB propellant (Ward 2010).

2.5 IGNITERS

The combustion of propellants can be accomplished by an igniter or a hypergolic ignition process. The main focus in this review will be only on the igniter because it is commonly used in rocket models (Ward 2010). The igniter can be mounted externally or internally to the motor case as shown in Figure 2.6.

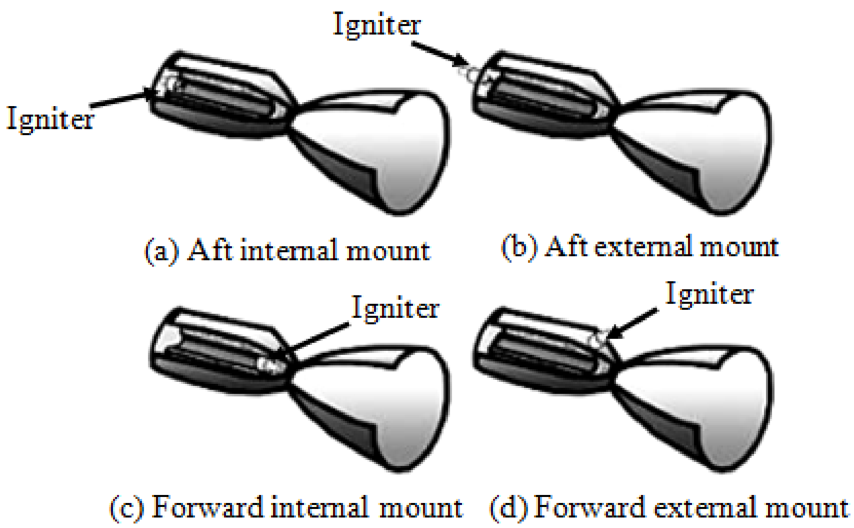

Figure 2.6: Igniter mounting locations for SRM

Source: Ward 2010

The most important characteristics for an igniter include its ability to produce products at very high flame temperature, be chemically stable and insensitive to electromagnetic radiation or interference. The igniter must have a high burning rate and have a maximum bulk density. Lastly, it must have a minimum ignition delay and produce very minimum igniter debris (Ward 2010).

The igniter can be classified into two classes, which are the pyrotechnic and pyrogen. Both these igniters are initiated by a squib or primer charge which releases a sensitive pyrotechnic upon receiving the ignition signal but pyrotechnic igniter is most preferred for rocket model.

2.5.1 Pyrotechnic Igniter

The first classification of igniter is the pyrotechnic igniters that can be further categorized as either unconfined or fully confined igniters. The unconfined igniters are the simplest, cheapest and light weight pyrotechnic igniters because they depend on the motor's thrust chamber and nozzle for confinement during ignition. The nozzle is sometimes sealed by a starter disc to facilitate confinement. However, they are very difficult and dangerous to support and maintain (Ward 2010).

For example, the commonly used unconfined igniter is the basket igniter, as shown in Figure 2.7. This type of igniter is different from the other two igniters. Its ignition occurs in stages which made it possible to control the flame pattern and burn time. The igniter has an ignition chamber with two separated igniton sections which are the booster charge section and the main charge section of the chamber. Upon receiving an ignition signal, an initiator squib releases a sensitive pyrotechnic into the booster section to ignite the booster charge containing booster pellets. The heat from the booster charge passes through the vent plate and ignites the main pellets of the main charge housed in the ignition chamber or basket. By having two sections within a single chamber, the igniter must weigh heavy and may have vibration problems due to stages ignition.

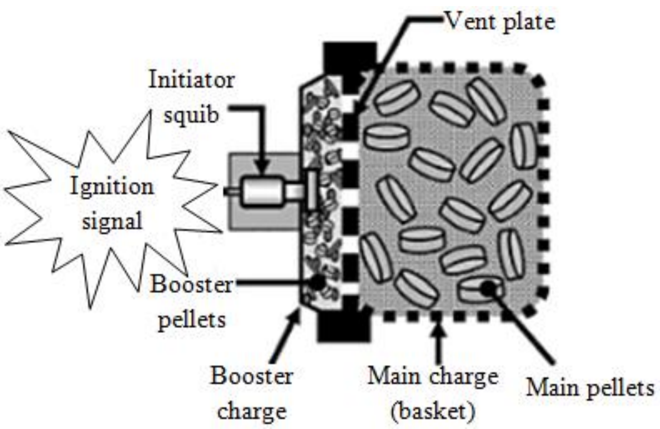

Figure 2.7: Basket igniter

Source: Ward 2010

The second category pyrotechnic igniters are the fully confined igniters which also known as rupture or burst igniters, where the ignition material is completely contained. This ignition material is made of solid explosives or propellant pellets. When an ignition signal is received, the squib burns and ignites the ignition material (propellant pellets). This ignition material burns quickly over a large surface area which causes the pressure within the ignition chamber to increase. The high pressure gas inside the ignition chamber eventually bursts in specific directions through the weaken sections (tiny holes) of the chamber and spreads the burning material into the motor and ignites the grain, for example the powder can igniter (Figure 2.8). The use of powder can igniter in small rocket motors is a norm because it has good directional control but the energy release rate is still uncontrollable (Ward 2010).

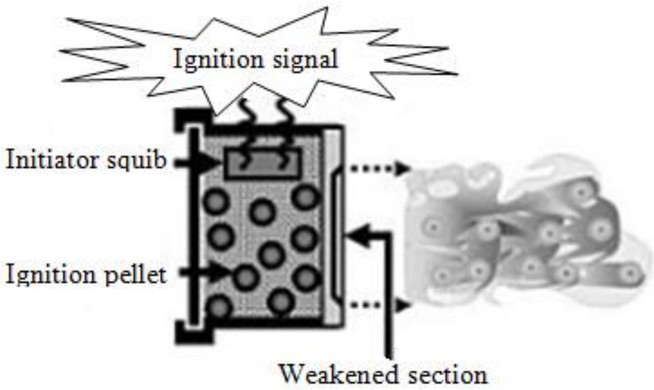

Figure 2.8: Powder can igniter

Source: Ward 2010

2.5.2 Straw Igniter

A straw igniter is a type of pyrotechnic igniter that was used for igniting the sugar-propellant rocket motors. The igniter is made up of a length of polyethylene plastic drinking straw filled with a charge of ignition powder which is why it received the name "straw igniter".

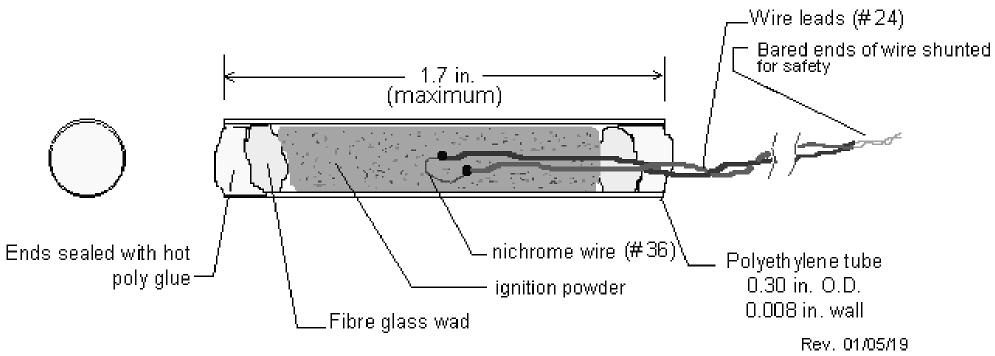

Figure 2.9: Rocket motor's straw igniter

Source: Nakka 2008

This igniter is sealed at both ends using polyethylene hot-melt glue. The nickel-chromium or nichrome wire has high resistance and it serve as the heating filament or bridge wire which is soldered to the ends of the copper wire leads using a solder. Other than nichrome wire, a strand or two of coarse steel wool may be used instead or it can be replaced with a strand of fine copper speaker wire (Nakka 2008).The thin nichrome wire can be tricky to solder so the easy and secure way is as illustrated below:

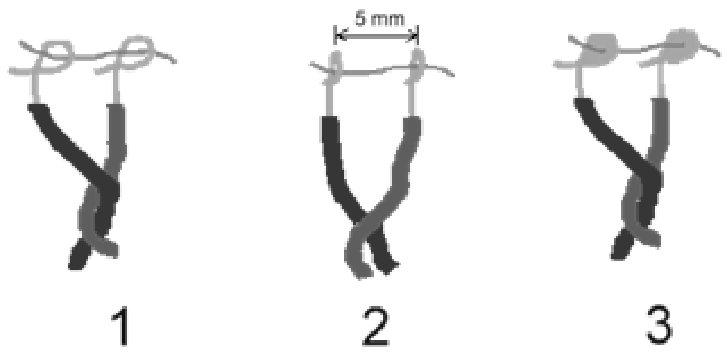

Figure 2.10: Secure method to solder nichrome wire

Source: Nakka 2008

i. After the electrical leads' insulations are stripped, closed loops are formed using needle nose pliers and the nichrome wire is then threatened through the loops.

ii. Once the wire is in the loops, the spacing between the loops is adjusted such that the gap of the nichrome wire between the loops is about 5mm.
iii. The adjustment is maintained by brushing the loops lightly with acid soldering paste.
iv. Then, the loops are heated and filled with solder by using a solder or a soldering gun. The capillary action will make this much easier to perform.
v. The nichrome wire will now be embedded in the solder. For perfection verification, a magnifying glass is used to inspect the loops whether they are fully filled with solder or not. Excess paste is removed by swirling the igniter in alcohol.

The ignition powder charge used for this igniter was a black powder mixture comprising of a mixture of 75% potassium nitrate, 15% charcoal and 10% sulphur. For further safety during storage, the bared ends of the wire leads are shunted or twisted together to eliminate the possibility of inadvertent current flow through the igniter (Nakka 2008).

The firing system for this igniter was an electrical power source generated by a pair of rechargeable nickel-metal hydride (NiMH) batteries due to the excellent current delivery capability. This pair consists of two 3.6V cells if 300mAh each, wired n series which deliver a generous current at 7.2V. These cell phone batteries also have excellent cold-weather performance which reduces the possibility of system malfunction during cold weather.

2.5.3 Mini-Bulb Igniter

A mini-bulb igniter is a simple pyrotechnic that uses a Xmas tree mini-bulb instead of utilizing a nichrome bridge wire. The advantages of this igniter is that it has the lowest cost and miniature in size which makes it convenient to fit within a soda straw and uses minimal amount of electrical power to fire the charge. So, it can be considered as an improved straw igniter.

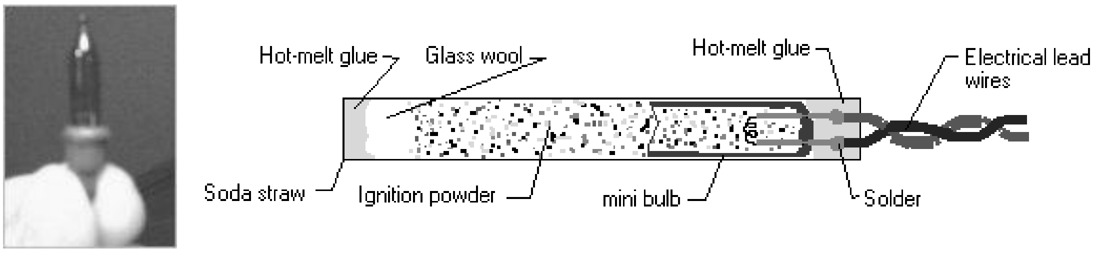

Figure 2.11: Mini-bulb igniter

Source: Nakka 2008

When a high voltage as minimum as 9V is applied to the thin tungsten filament, it will instantly vaporise due to high resistance which results to an extreme increase in temperature. In relevant to this vaporising process, the igniter is referred to as an exploding bridge wire igniter. This design is based on the a concept pioneered The igniter is designed in reference to a concept pioneered by Rob Furtak, a rocketry experimenter, who has successfully used the Mini-bulb igniter in his rocketry work. Beside, this igniter is also applicable for motor ignition or firing a parachute ejection charge (Nakka 2008).

The construction of this igniter begins with the removal of the plastic base of the mini-bulb and then be discarded to expose the two copper wire leads that will be scraped clean of its oxide. The bulb is then carefully broken open by slowly squeezing the upper half of the glass bulb with a bench vice. Furthermore, it is necessary to cover the bulb with a cloth rag to capture the tiny shards of glass which shattered when the vacuum seal or glass is broken. Nevertheless, a safety glass must be wore upon conducting this process to prevent any injury that could harm the eyes. Plus, the operator should carefully conduct this process so that no damage is done to the filament bridge wire or the lower portion of the bulb.

Most Xmas bulbs have a very fine wire or a piece of foil that covers the base of the leads where the filament is attached to and soldered together with the leads wires. The other ends of the lead wires should be stripped and shunted for safety purpose which will help to maintain continuity in case one of the bulbs in a string burns out. The proper method to remove the shunt is to use a fine pick or a pair of tweezers. An ohmmeter is used subsequently to check the connectivity of the filament but no battery should be connected across the leads because the filament may get burn as it is now being exposed to oxygen in surrounding air. The ohmmeter test for connectivity also will be influence with false indication (Nakka 2008).

Next, the mini-bulb is placed within a 5cm length of polyethylene soda straw and the ends near to the leads are sealed with hot-melt polyethylene glue. Then, ignition powder with mass of approximately 1 gram is carefully loaded and tamped very often to eliminate empty spaces. Finally, a small ball of glass wool or fibre glass is tamped and the end is sealed with the hot-melt polyethylene glue.

2.5.4 Ultra-Low Current Igniter

An ultra-low current igniter was developed by Ken Tucker for the Experimental Aerospace Research (EARco) to increase the safety of rocketry. This igniter is a low electrical powered igniter which required only 20mA at 1.2V, equivalent to 25mW of electrical power to ignite. So, this design is very reliable and useful in cold weather operation which greatly reduces a typical battery's available power (Nakka 2008).

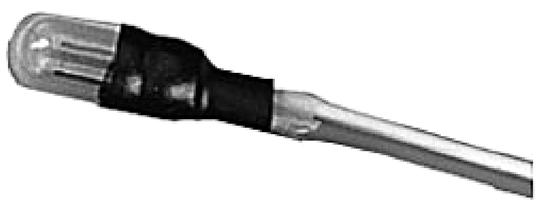

Figure 2.12: Mini lamp for ultra-low current igniter

Source: Nakka 2008

This igniter may be applicable for motor ignition or firing a parachute ejection charge. The safety in rocket experiment is a priority. It is the same for reliable parachute ejection systems operation. For any system that may create hazardous condition in the event of an igniter malfunction, a very reliable and redundant igniter may be a good choice (Nakka 2008).

The construction of this igniter is explained as following. Firstly, the bulb resistance was measured using an ohmmeter with a common resistivity values between 20 ohms to 30 ohms. After that, a hole is ground through the bulb by grinding process using a fine file or polishing stone. The progress of grinding is inspected using a magnifying glass. During grinding, the vacuum within the bulb drown air and some of the shards inward. So, the glass should be ground with the filament perpendicular to the hole to avoid impact from the glass shards onto the filament.

After the grinding process, the resistivity value reading of the bulb is to be measured again and the value should be the same. Then, some black powder is carefully placed into the bulb through the hole in a quantity sufficient to be loose because tight packaging could damage the bridge wire. The bridge wire will explode and vaporise when heated which will land on the powder. So the powder is unnecessary to be in direct contact with the bridge wire. Once again an ohmmeter reading is taken to ensure the fine condition of the filament. Then, a little Scotch tape was used to cover the hole so that the powder will not spill out from the hole.

The igniter will produce an ignition equivalent to that of a match when fired which exhaust through the hole. However, this ignition may be not enough so a secondary burn may be required.

This igniter was placed in a long tube which has almost the same diameter as the igniter. It was filled with black powder and the ends were sealed. So, the igniter's potential will amplify [6]. Besides having an advantage of being shock-proof, it also requires a very low electricity supply allowing numerous redundant igniters be arranged in parallel with the igniter power supply (Nakka 2008).

2.5.5 Ferocious Igniter

The ferocious igniter was introduced as a solution for igniting RNX (Richard Nakka's Experimental) propellant grains. Since this epoxy-based propellant has a higher decomposition temperature, a hotter and more sustained burn is required. Hence, ferocious igniter was designed as an igniter that used a more energetic oxidizer together with epoxy as a binder. Moreover, it burns with a hot flame for about two seconds, reliably lighting as RNX composite propellant grain (Nakka 2008).

In order to construct a ferocious igniter, a nichrome bridge wire is soldered to a pair of electrical leads similar to that used for straw igniter. For motors with small throat diameter, a fine gauge wire of 30AWG wrapping wire should be used. This wire is applicable only if the igniter is installed at the grain outer surface rather than in the grain core. Next, a pyrolant coating is prepared using fine potassium perchlorate (KP) which is ground using mortar and pestle, finely ground sulphur and high grade epoxy.

A polyethylene sheet with dimension of (25x25) mm^2 is cut out from plastic sandwich bag for each igniter. The igniter leads are placed such that the bridge wire is centered onto one of the poly squares. A dab of pyrolant with approximately the amount of a pensil's eraser is placed onto the pyrolant as shown in Figure 2.13.Later, the second poly square is placed over the pyrolant and is pressed down carefully so that the bridge wire is fully embedded. The resulting thickness should be lesser or equal to 3mm to avoid fracture of pyrolant coating upon firing. If the igniter is installed at grain outer surface, the pyrolant should be pressed until a thin disc of approximately 2mm thick is formed which is recommended for both the Epoch motor and Paradigm motor (Nakka 2008).

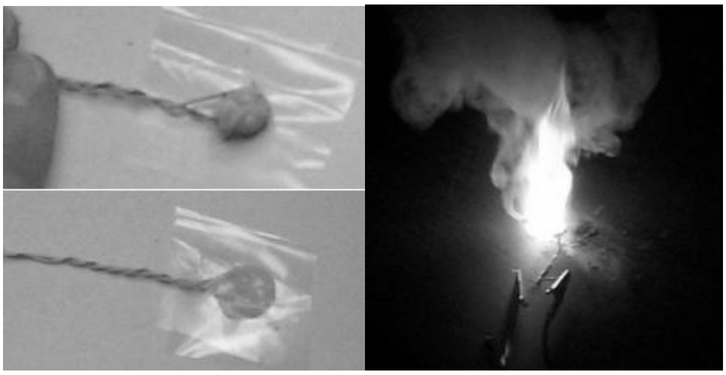

Figure 2.13: Ferocious igniter, where Top left: Pyrolant is applied onto poly sheet, Bottom left: Sealing of pyrolant by pressing it between two poly sheets and Right: Combusted Ferocious igniter

Source: Nakka 2008

The igniters are then left to cure at room temperature and after curing the poly sheets are peeled off. Now, the cured igniters are ready to be trimmed as required. Moreover, the curing temperature for the igniter may be set at 65^{o}Cusing a dedicated shop oven for a more rapid curing. This igniter has proven to be highly reliable because no misfired occurred during thirty motor firings (Nakka 2008).

For the preparation of the pyrolant, a small amount of epoxy mixture is prepared according to the manufacturer recommended resin to hardener ratio, where one and a half grams of epoxy is sufficient for four to five igniters. Next, a sufficient amount of sulphur is sprinkled onto the epoxy to colour the mixture in yellow or light amber. Then, the mixture is blended well using a wooden craft stick for at least two minutes. The blending can be done in a plastic “pan” cut from a 2 litres soda bottle which works well as a disposable mixing pan. Lastly, KP is added, a little at a time, until the resulting mixture resembles a stiff paste.

2.5.6 Spit Fire Igniter

According to Richard Nakka’s Experimental Rocketry (January 2008), this spit fire igniter was the best igniter used to ignite composite propellant. Rob Furtak managed to carry out this prolonged research project into developing a hot burning a success with an outcome that the igniter became a reliable igniter.

This igniter is created based on the concept of mini-bulb igniter but a pyrolant is used instead of a black powder composition to coat the bridge wire or filament. The pyrolant is made of a neoprene binder combined with the well blended Thermex powder, a composition of 65% potassium perchlorate (KP), which is finely ground and have up to 200 meshes, 20% charcoal which was ball milled, 10% aluminium powder with 400 meshes and 5% red ferric oxide (Nakka 2008).

For this igniter, a different method is used break open the mini-bulb to expose the filament. It is assumed that the most reliable method of doing this is to place the glass ampoule of the bulb into the jaws of a workshop vice and then the vice is closed slowly with care. The bulb glass ampoule will suddenly crack leaving the filament totally exposed. For safety purpose, the bulb is wrapped completely with a suitable cloth to capture the glass fragments when the glass shatters and safety glass is necessary when performing this step. It is known that most Xmas bulbs have a very fine wire or a piece of foil that is wrapped around the base of the two leads that the filament is attached to. The shunt should be removed with a fine pick or a pair of tweezers to avoid false indication by ohmmeter with the filament being intact to it. The oxidized copper-plated electrical leads should be lightly scrapped with a hobby knife or sandpaper to ensure good electrical conduction.

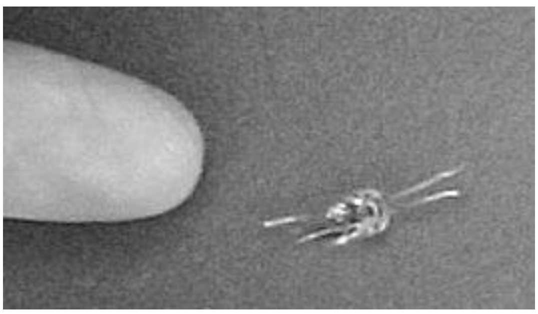

Figure 2.14: A fractured glass ampoule mini-bulb that has exposed filament

Source: Nakka 2008

Next, the Thermex powder is added to a small quantity of neoprene contact cement with mass ratio of approximately 2:1 which is blended well using a craft stick. The finished pyrolant blend should be as viscous as toothpaste. Once this condition is fulfilled, it is then placed onto the mini-bulb filament with a twirling motion around the filament itself by using a toothpick. The filament should be fully covered and the pyrolant should be extended down to the base of the mini-bulb to enable a more resilient finished igniter.

The igniter is then left to cure in a room with a slightly increase in temperature which takes a few hours or less. Once curing is complete, it is tested for continuity using ohmmeter, where the range of resistance should be approximately 3 ohm to 5 ohm. The leads should be shunt by twisting them together for safe storage of the completed igniter (Nakka 2008).

Figure 2.15: A completed spit fire igniter (Left) and Spit fire igniter's burning behaviour (Right)

Source: Nakka 2008

It is important to understand the danger of using solid propellant in an igniter because the use of excess black powder charge than the one shown in Figure 2.16 may lead to initial pressure spike. This over-pressurization during the start up of a rocket motor could lead to motor failure due to shear of safety bolts used to retain the rocket motor head. The size of igniter for small rocket motors can cause significant effect on the motor chamber pressure curve.

2.5.7 Pyrogen Igniter

The pyrogen igniter is the second classification of igniter type. This igniter can be considered as a very small or miniature rocket mounted at the motor's bulkhead which ignites the motor grain by expelling its exhaust gases into the rocket motor's thrust chamber. The motor grain could achieve nearly instantaneous ignition because of the high velocity, particle-laden flame emanated from the pyrogen.

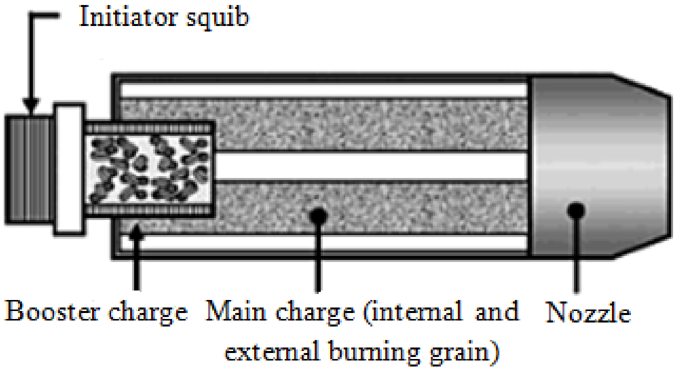

Figure 2.16: Pyrogen igniter

Source: Nakka 2008

Rather than using a sensitive pyrotechnic, its initiator squib burns the propellant (booster pellets) of the booster charge directly. The heat from the booster charge spreads into the main charge to ignite the internal and external burning grain. The burning grain eventually increases the pressure insides motor and be released through the nozzle to create much higher pressure or thrust for the rocket to take off (Ward 2010). This type of igniter is effective for starting smaller sized rocket motors but provides superior motor starts when used in large motors (Nakka 2008).The application of pyrogen igniter can be found from Kappa rocket motor and the igniter's structure is shown in Figure 2.17.

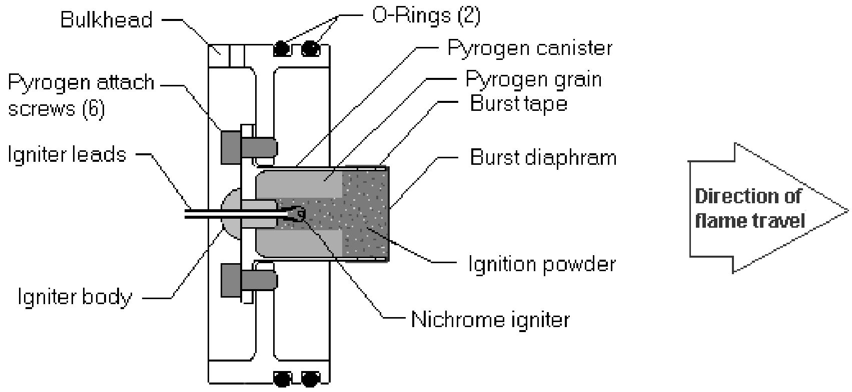

Figure 2.17: Pyrogen/bulkhead assembly for Kappa motor

Souce: Nakka 2008

This particular pyrogen uses cast potassium nitrate or sucrose propellant as its grain because it is easy to ignite and has rapid burning rate. Its ignition is due to the black powder charge which is contained within the pyrogen canister by a burst diaphragm and it is responsible for the aid pressurization of the motor (Nakka 2010).

2.6 OPERATION OF IGNITION SYSTEM

The basic operation for an SRM can be using manual operating ignition, wired ignition system or a wireless ignition system. These are the three types of ignition systems used to ignite an igniter. A manual operating ignition is just an ordinary ignition that requires the operator to personally ignite the igniter using a match or lighter. This type of ignition is very common traditional method to ignite fireworks and also traditional rockets.

The most commonly used ignition system for modern SRM is the wired ignition system. The wired ignition system is electrically ignited using an electrical power source connected by long wire, as shown in Figure 2.18. The system consists of an engine igniter, an igniter to control box patch cord assembly, an ignition control box, a roll of extension wire and an ignition button box (Nakka 2008).

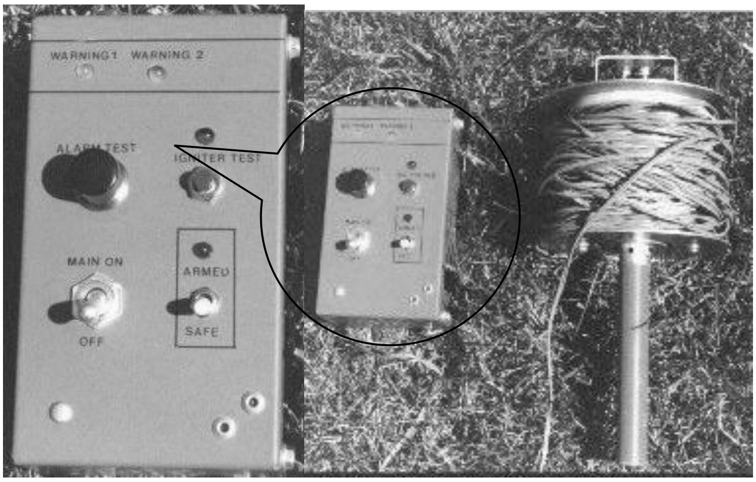

Figure 2.18: Ignition control box (Left) with roll of extension wire (Right)

Source: Nakka 2008

The igniter is installed into the engine just prior to load the rocket onto the launch pad. The igniter leads are then attached to a long patch cord assembly that is plugged into the control box. However, the long patch cord assembly will be left unplugged until just prior to final launch procedures. The main purpose for using the long patch cord is to locate the control box at a safe distance away from the launch pad. The intention is to protect it from the blast upon lift off, which would be unpredictable and also to protect it from the corrosive exhaust residues (Nakka 2008).

The launching of rocket is initiated when the push-button switch mounted in the ignition button box is pressed. Moreover, the push-button switch is connected in series to a key operated switch. It is plugged into connectors located on the spool which holds the extension wire. The extension wire could be speaker wire, which is a fine gauge, stranded and duplex wire, because it normally has a total length of 100 feet (30.48m).

The ignition or launch control box is powered by four AA Nickel-cadmium (NiCad) rechargeable batteries which supplies 5.2V direct current (DC) power source. The batteries also power the engine igniter and the control circuit. The circuit permits a pre-launch continuity check of the engine igniter by passing a small current of

25mAflowing through it and utilizes an light emitting diode (LED) indicator for confirmation.

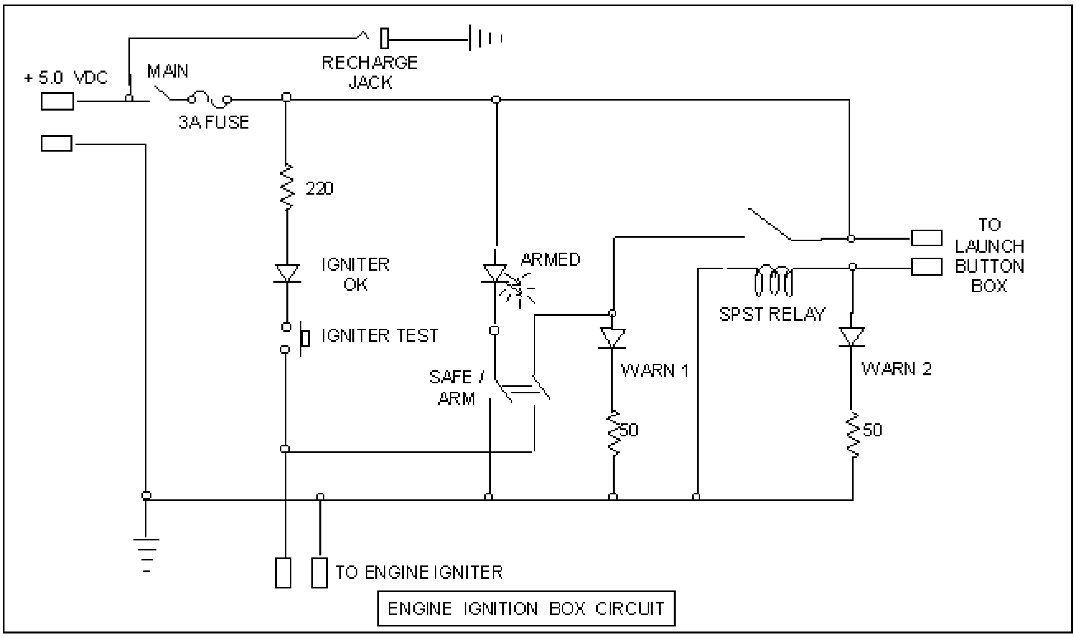

Figure 2.19: Electrical schematic of ignition control box

Source: Nakka 2008

The possibility of having a premature engine ignition is eliminated using the Safeguards that are built into the system. The three LEDs of different colours are indicators for various warning conditions. For an instance, a blinking red LED flashes when the SAFE/ARM select switch is switched to ARM, which is normally done just prior to launch countdown. The WARN1 and WARN2 LEDs indicate any relay fault. WARN1 LED indicates closed contacts which is a condition that could occur if the contacts became fused due to a short in the igniter circuit. Therefore, the usage of a 3A fuse is necessary for redundant protection against this matter.

Apart from that, the WARN2 LED indicates a shorting condition to the ignition button box or switches provided both are being in the closed position (Nakka 2008). As the circuit is completely closed, the electrical signal is sent to the initiator squib of the igniter to heat up the heating element (wire) of the igniter, which will burn the propellant grain as it becomes red hot.

2.6.1 Operation of Igniter

An igniter functions in a very similar way to a standard incandescent light bulb. The igniter wire has the same function as a filament installed in a light bulb. When voltage is supplied to igniter, current flows through the wire and got heated up to a high temperature due to high resistivity. It then becomes red hot until melting point is almost achieved. Thus, the pyrolants in contact with it are burnt as a result from heat transfer. Once the igniter wire reaches its melting temperature, the wire melted and electricity is cut off. However, the burning continues independently because of spontaneous reaction between the pyrolants' molecules. Therefore, the main function for an igniter is to utilise the heat transfer to begin an ignition in SRM.

Upon burning, the combustion throws off burning bits of the pyrolants in all directions which mostly land on the rocket motor propellant. Hence, the propellant is ignited and the motor starts to operate resulting to thrust development for rocket motor. Since an igniter is a one-time use device, the igniter wire only needs to stay hot long enough to ignite the pyrolants which usually takes only a split second. As mentioned earlier, the igniter wire will experience extreme heat and melt in one spot or entirely. The current obviously stops flowing at this moment and no more heat are generated.

The ignition of the grain by an igniter occurs as a series of rapid events. The process begins when an igniter receives an ignition signal from the actuator when current flows through the circuit. When the circuit is completed, the igniter is initiated and combustion occurs within a few seconds. The combusted igniter produces a hot gas which flows into the main thrust chamber.

Within the chamber, the heat is transferred from the hot gas to the grain surfaces. Thus the grain surfaces ignite and spread until all of the exposed grain surfaces are burning. In other word, the grain surfaces must experience complete and unstoppable combustion. As a result, an equilibrium operating pressure and flow rate is achieved in the thrust chamber, where the high thermally energised combusted gases are converted to kinetic energy in the exhaust or nozzle developing the thrust for the solid rocket motor (Ward 2010).

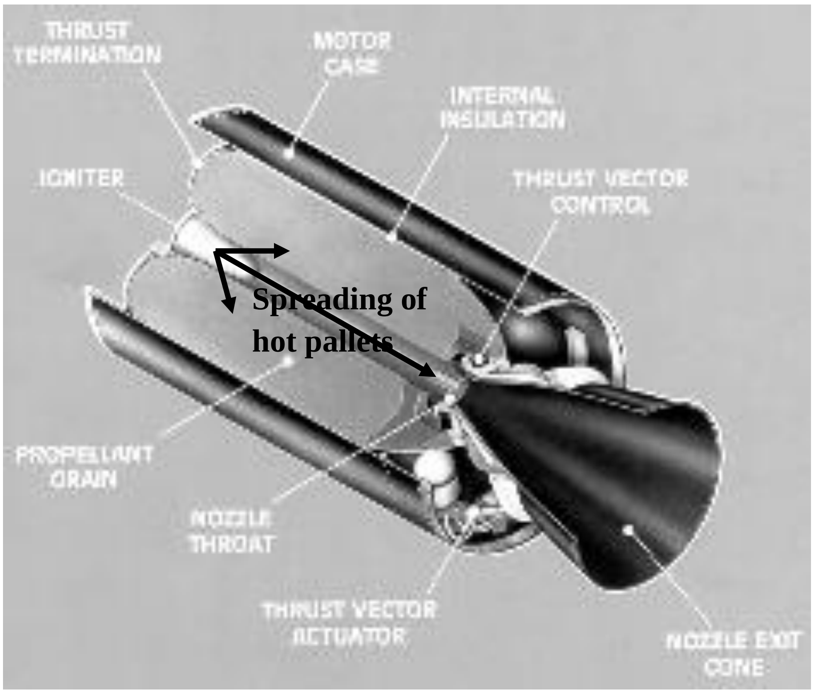

Figure 2.20: Ignition process, cited from Solid Rocket Motors web page, https://engineering.purdue.edu/~propulsi/propulsion/rockets/solids.html

The igniter wire can be made from many different materials with good conductivity but the most common ones are tungsten and nichrome. Nichrome is an alloy of nickel and chromium. It has higher resistance than other common wire used to conduct electricity, such as aluminium or copper. It even has a much higher resistance than iron, steel, or stainless steel. Tungsten wire is used as replacement of nichrome wire if it is unavailable because it also has high resistance although the resistance value may be lower than that of nichrome.

Furthermore, there are several other factors that could affect the operation and construction of an igniter and they include the properties of the wire, such as length, diameter, material, heat dissipation capability as well as voltage capacity. However, the least affective properties of a wire are its heat dissipation capability. So, another reason for using tungsten or nichrome wire as heating element is due to its very small diameter (thin wire) which leads to the high resistance for current flows.

Knowing that igniter wire is dipped in pyrolants has proven that there is an immediate contact between these two elements which is an advantage for pyrolants combustion requirement. Besides, the heat transfer occurred is mostly due to conduction and some radiation with very minimum heat dissipation. This indicates that heat generated from the igniter wire is transferred to the pyrolants with an efficiency of nearly 100 percents. When a sufficient amount of heat is successfully transferred to the pyrolants, only then will the pyrolants ignites and burns to its fullness (Ward 2010).

The lead wires or the connecting wires are compulsory to able to continuously carry current needed by the igniter without heated up while the igniter wire itself must achieve a very high temperature and at the same time have very high melting point. Therefore, the lead wires should have low resistance which means the conductor will probably be copper and the gauge should be between 24ga to 16ga, with the size is reduce along with increasing number, but will depend on the design. On the other hand, the igniter wire needs to be very thin and have very high resistivity compared to that of the lead wire.

Moreover, we must understand that there is actually a trade off between the diameter of the wire and resistivity since a smaller diameter wire when add together could have similar total resistance as a larger diameter wire with more resistivity. The main exception in this trade off will be the large power requirement for the larger diameter wire to achieve the same temperature in the same time which is due to its larger volume and mass.

2.7 IGNIITION SYSTEM CRITERIA

In order to construct the best ignition system, the best criteria must be selected. The following is the selection of ignition system criteria:

i. Pyrotechnic’s ferocious igniter since the success rate for ignition was 100% guarantee,

ii. Pyrolants mainly consists ammonium perchlorate (AP) based propellant,
iii. Tungsten wire since it can be available in the soldering gun as the heating coil,
iv. Wireless ignition system which is becoming the main focus for modern rocketry, and
v. Aft internal mount installation because it can provide much more stable thrust.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 METHODOLOGY

The research methodology that covered throughout the research includes the method used to construct a prototype wireless ignition system, in short namely WISys, which consisted of the construction of the electronic and electrical circuits for the wireless system and the prototype igniter, the installation for prototype igniter into the ignition chamber and also the method to collect data for the functional ability of the system, especially through simulation.

In order to accomplish this research, the review on ignition system was done first, followed by the designing and fabricating of the prototype wireless ignition system and igniter. Then, a test was performed to identity the success rate of the prototype wireless ignition system and igniter. Lastly, the data collected from the simulation and testing were analysed and problems were solved for further improvement.

The connectivity of the transceiver and receiver is indicated by the LED indicator bulbs which lighted up when the circuits were completed or closed, and turned off when the circuit was opened or disconnected. For safety, the circuit would be protected with a protective box made from plastic or Perspex, which is tough, light weight and could act as an insulator.

The methodology for the prototype igniter explained about the construction of the igniter based on materials and design or drawing after going through some simulations which would justify the assumptions for good igniter criteria. For each of these methodologies, detail information for the designs was included.

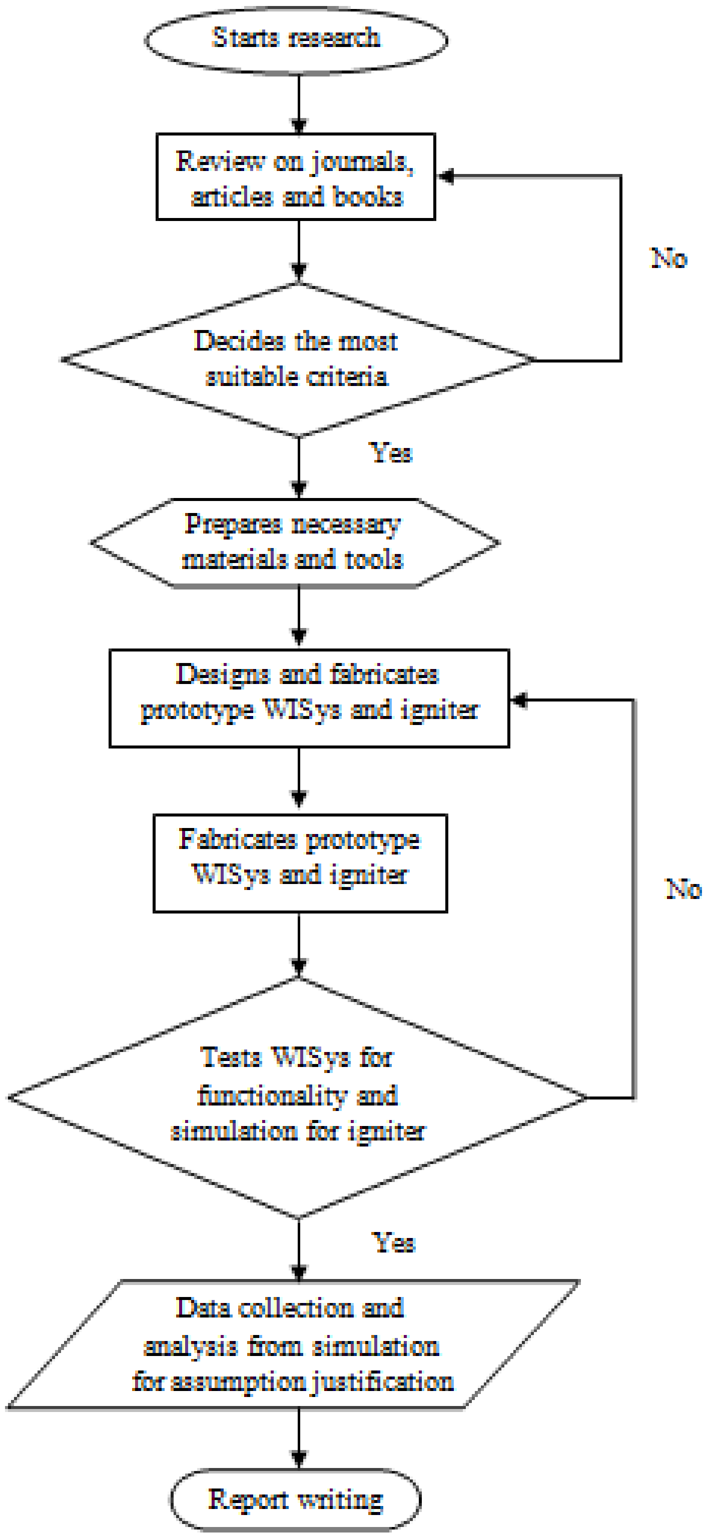

Figure 3.1: Flow chart for Final Year Project research methodology

Based on Figure 3.1 that summarized the entire research for developing a wireless ignition system for solid rocket motor, this research began with very clear understanding about the main problems, objective and scopes of study for the research. This level of understanding was gained by reviewing countless journals, articles and books related to the researched topic. Among all the referred reading materials, only a few were really compatible to this research, where some of them were selected based on the uniqueness and slight difference in their contents and experimental results.

In the literature review, the entire review should contain only brief detail about solid rocket motor components while there must be detail descriptions about the types of igniters and the most common ignition system used for solid rocket motor, especially for small scale solid rocket motor. After completing the review, a final decision was made to categorise the best criteria for the prototype of the wireless ignition system (WISys) and igniter. Unsatisfied criteria upon this selection led to another review but if the criteria were accepted and agreed by the supervisor then the next step of this research would be carried out, which was to prepare the necessary materials and tools for conducting this research.

In the preparation stage, the materials that were purchased included SS304 stainless steel with two different diameters (1in. and ½in.), two units of XBee Starter Kit, some electronics and electrical components and soldering lead. For the tools being used in this research, the soldering gun and other tools required for fabricating wireless igniter system were used, such as test pen, multimeter and pliers. Meanwhile, the machines and tools used to fabricate the prototype igniter included lead machine and milling machine as well as their tools, such as center drill, drills of different diameters and tapper.

After fabricating the prototypes, testing was done on the wireless igniter to determine its functionality and defects which would lead to permanent damage to the circuit system. Therefore, the circuit undergone several times remaking before the final and simplified system which would be easy to use was created. Furthermore, simulations were done to identify the changes in pressure and velocity profiles within the prototype igniter. So, the results obtained were discussed and weaknesses or limitations arise at the end of this research were provided with solutions.

3.2 WIRELESS IGNITION SYSTEM

Based on the selected ignition criteria in Chapter 2, the wireless ignition system was chosen prior to the development of solid rocket motor (SRM) in modern era. So, the ignition system designed for this project consisted of a combination of electrical circuit and electronic circuit, whereby there was a circuit for a transceiver or transmitter and another circuit for a receiver or Relay box which would be connected to the prototype igniter. Therefore, this prototype wireless ignition system had two devices which are the transmitter and the receiver.

3.2.1 Construction of Transmitter and Receiver

For the construction of the transmitter and receiver, the main wireless module used was the XBee-S1modules that communicate with each other using radio frequency (RF) for controlling. Besides that, the best material used to make the casing is plastic or Perspex due to its properties, which is light, provides insulation from electric current, do not rust, and has good strength. The antenna used would be either a thin wire or thin steel or aluminium tube insulated by plastic as shown in Figure 3.1. Both devices will have LED indicators which lighted up when the circuit's switch was turned on and lighted off when the switch was turned off. The yellow LED indicator was the most important indicator since it indicates the connectivity of the XBee-S1 module to the power supply.

For transmitter, the green LED indicated the pre-launch of the rocket motor and when the launch button was pressed it will send an RF signal to the receiver to ignite the igniter, which eventually fires the rocket motor. Similarly, the green LED indicator of the receiver indicated the pre-launch of rocket motor which showed whether the circuit was completely connected or there was failure at the components. Moreover, it was the green coloured LED that indicated the "Safe" switch on the Relay box. If the relay circuit was completed, then only the "Arm" red LED indicator lighted up which indicated that igniter was connected to the high voltage power source of the receiver, beginning to heat up the igniter wire (tungsten) as the launch button on the transmitter was pressed.

During the process of energizing the relay of the circuit, the signal from the transmitter will trigger the receiver's wireless module to energize the relay coil so as to change the low voltage circuit to the much higher voltage circuit which can be up to 18V in order to ignite the igniter's pyrolant. When this happened, the green LED indicator turned off and the red LED indicator was switched on.

Figure 3.2: Transmitter (Left) and receiver (Right) for wireless ignition system

For safety of the ignition system, the igniter was connected to a long twin copper wire, with both ends were soldered to alligator clips. So, the igniter will ignite only when both ends of the igniter wire were connected to the alligator clips which eventually completing the ignition circuit. Furthermore, the receiver was placed firmly at a safe distance away from the launching platform so that it will not be damaged during launching.

Figure 3.3: Connection between the igniter wire and alligator clips

3.2.2 Electrical and Electronic Components

For the electrical circuit, the electrical and electronic components used included twin copper wire that was used to connect all the components and circuit to the power source; two circuit boards components placement and assembly; four AA NiCad rechargeable batteries that will provide 5.2V power supply; two 9Vbatteries to provide sufficient current to the igniter wire; a few resistors, LED indicators, relays and other required electronic components that will reduce or regulate the flow of current of the circuit.

These components will be arranged on the circuit boards according to the designated circuit diagram and soldered to the board using the soldering gun and solder to connect all the components in the circuit. This electrical circuit was connected to the XBee-S1 Starter Kit circuit to form a complete receiver circuit, which was then attached to the igniter wire in the rocket body to launch the rocket. It was basically used together with the electronic transmitter as the main ignition system for this project.

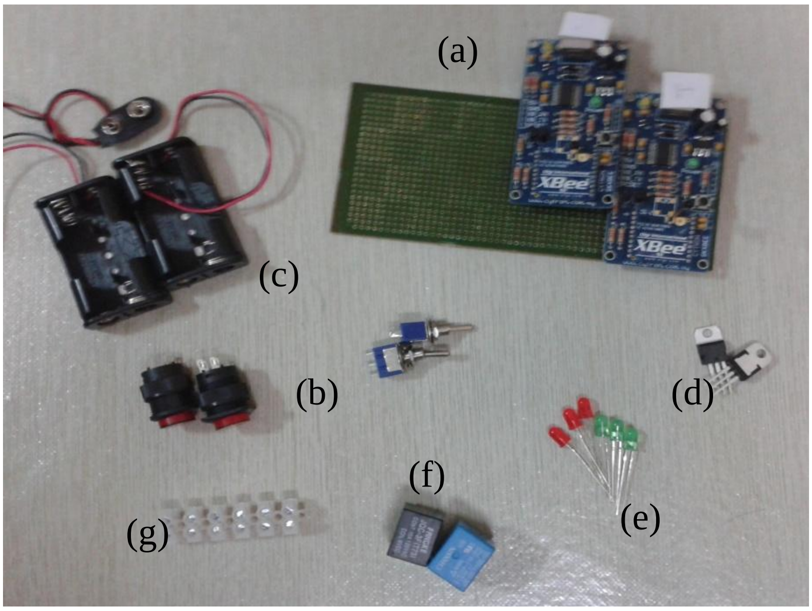

Figure 3.4: Electronic and electrical components used in development of wireless igniter system, where a) Veroboard and XBee, b) Switches, c) Batteries connectors (9V) and holders (1.5V), d) Regulators, e) LED indicator lights, f) Relays and g) Wire connectors

For the electronic circuit, the main circuit used was Xbee-S1 Starter Kit which was a wireless module that uses RF for communication (see Figure 3.2). The remaining work was only to connect it to the electrical circuits of the receiver and transmitter, where there should be at least four simple wires of different colours be used. The red wire was used to connect the module to a 5V power supply; black wire was used for grounding the circuit, white wire and blue wire were to be connected to the different pins of the module in the circuit. It was important not to use power supply higher than 5.5V; otherwise, the Xbee-S1 module will be damaged.

Since the Xbee-S1 Starter Kit was needed in both the transmitter and receiver, there will be two units of this starter kit required. One unit will be used as the main signal transmitting unit in the transmitter while the other one will be used as the main signal receiving unit in the receiver. Both of these Xbee-S1 Starter Kits will need to be programmed before use. Therefore, the X-CTU software was needed to set the source or destination address by using generating coding to execute accurately the required functions [11].

Figure 3.5: Xbee-S1 Starter Kits (8cm x 4cm) for wireless ignition system

The Xbee-S1 Starter Kit or Xbee Original Equipment Manufacturer (OEM) RF module was engineered to achieve Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 standards. At the same time, the invention also supported the requirements of having low cost and low power wireless sensor networks. Xbee-S1 Starter Kit was used for wireless communication in robotic as a component in the transceiver or transmitter and receiver. This module was verified to have long range data integrity and low power consumption which acted as its most useful advantages.

The Xbee-S1module was provided with a maximum indoor communication range of 30m and a maximum outdoor line sight of 100m. It has a power down current that was less than 10μm. Moreover, this module comes along with a small pin with a low voltage requirement of 3.3V for operation and has been developed to convert it into a 5V operating device. Furthermore, it also offered connection to personal computer (PC) with USB for more user friendly configuration and solutions [11].

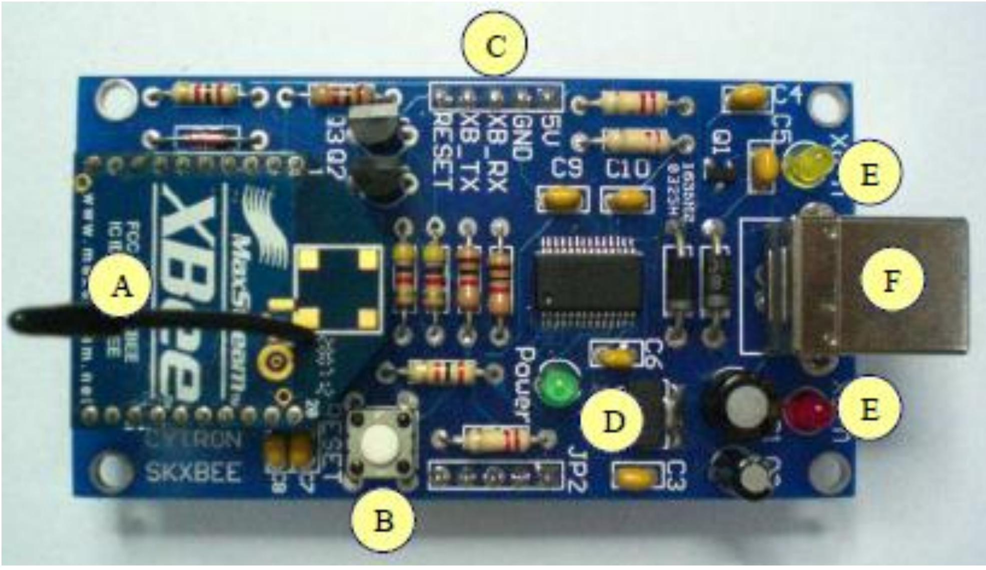

Figure 3.6: Xbee Starter Kit components

Source: MaxStream 2006

Table 3.1: Labelling and description for main components in XBee Starter Kit

Label	Function
A	Digital International XbeeS1 module.
B	An on-board reset button for Digital International Xbee S1 module.
C	5-ways header pins to supply external power and for interface to microcontroller with a limitation of power supply up to 5V only.
D	An on-board power indicator green LED with maximum operating power capacity of 3.3V.
E	Two LED indicators are readily available in red and yellow colours respectively which are used to indicate USB's transmitter and receiver status. Therefore, red LED indicates USB's transmitter activity while yellow LED indicates USB's receiver activity.
F	A ready-to-use USB B type socket for personal computer (PC) or laptop connectivity and functions for configuration as well as connectivity between two similar Digital International Xbee S1 modules.

3.2.3 Operation of Wireless Ignition System

The wireless ignition system functioned using the two main devices, which were transmitter or transceiver and receiver or Relay box. The receiver was actually indirectly connected to the igniter through the twin copper wire.

Firstly, the switch of the transmitter was turned on allowing 5.2V power supply (batteries) in the transmitter to supply current through the circuit and eventually lighted up the LED indicator, especially the green LED indicator of the XBee-S1 module, if there was no failure at any of the components in the circuit. In this condition, the transmitter was in pre-launch mode which awaits the rocket motor to be launched.

Next, the receiver’s switch was turned on to supply the 5.2V power supply to the wireless module so that it was active to receive RF transmission from the transmitter and also stand by to trigger the relay circuit to ignite the igniter, which was indicated by the red LED indicator. This relay circuit was named as relay box since there were two indicators and another high power source with 12V to 18V supply connected to the relay.

When the “Safe” LED indicator (green colour) lighted up, it indicated the circuit was connected and already in pre-launch mode. When the “Arm” LED indicator (red colour) lighted up, the igniter circuit was actually being connected. So when the launch button on the transmitter was pressed, it will transmit a RF signal through the antenna to the receiver’s antenna to trigger the relay so that it switched the circuit to the igniter circuit and eventually complete the high voltage circuit without damaging the low voltage wireless module. When this happens, huge current will flows through the igniter circuit to the igniter wire.

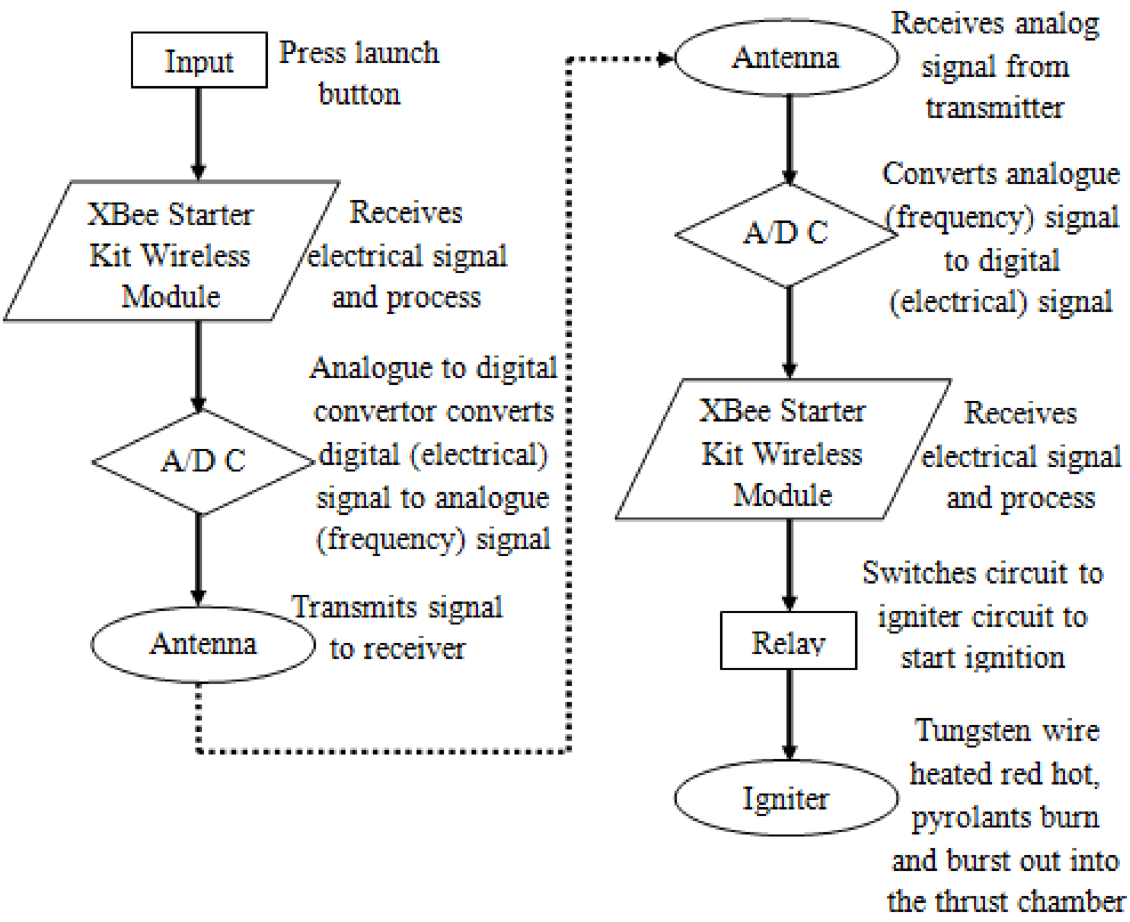

Figure 3.7: Block diagram for the operation of transmitter and receiver

From above figure, the process on how the transmitter would communicate with the receiver was explained. When an operator gave an input by pressing the launch button of the transmitter, the XBee Starter Kit wireless module will receive the electrical signal generated as the circuit was completed. The module interpreted and processed the signal to initiate the analogue to digital converter (A/DC). A/DC would convert the digital signal to analogue signal and then transmitted the signal to the receiver through the antenna.

The receiver's antenna received the signal; A/DC was initiated to convert the analogue signal (frequency) to digital signal, which was the opposite to the conversion in transmitter. The XBee Starter Kit wireless module in receiver detected the signal and completed the entire Relay box circuit by triggering the relay. Hence, ignition began because high voltage was supplied to the tungsten wire in the igniter which burnt the pyrolants as the wire turn red hot. Burning pyrolants produced high pressure and this pressure forced the burning pyrolants into the thrust chamber.

3.2.3.1 Operation of Igniter

The igniter for this system received the high voltage source from the two 9V batteries with just low resistance twin copper wire to allow huge current flows through the circuit to the igniter wire.

From the finding in the previous chapter, the most suitable igniter wire for this ignition system would be tungsten wire because it is easy to find, such as in the heating compartment of the soldering gun. The reason for selecting tungsten wire was because of its mechanical properties, which is having very small diameter or thin and good electric conductor. Moreover, the most important property of this wire is its high resistivity due to the small diameter of the wire.

As current flows through the thin wire, it experienced restriction or resistance to flow. Hence, the most of the electrons will gather between the tungsten wire or also known as bridge wire and eventually heated up the wire until it reached very high temperature which happened in just two seconds. When the wire became red hot and eventually melted, it will burn the pyrolants inside the igniter which was located very close to the wire and ignition began. Although the tungsten wire easily became red hot, the electric wire or copper wire must have low resistance to electricity but fairly high resistance to heat to allow continuous flow of current through the circuit.

The selected pyrolants, which were made of sugar propellant fuel and ammonium perchlorate oxidizer, with addition of some aluminium powders and steel wools, ignited and burned vigorously because of their high reactivity and the just enough tiny spaces between them. As the pyrolants burn, high pressure and temperature was created inside the ignition chamber. When the pressure was too high due to the increasing temperature inside the chamber, the burning pyrolants eventually burst out from the chamber into the thrust chamber containing solid propellants and burned the propellants.

3.3 INSTALLATION OF IGNITER

The most suitable and preferred installation or mounting position for the SRM was the aft internal mount because it can provide much more stable thrust. When the igniter ignited and burst, the solid propellant grain will burn from the most top of the thrust chamber and ended before the exhaust or nozzle. Besides that, with the reverse thrust due to the ejecting high pressure gas out of the nozzle will help to deploy the recovery system for the SRM using some mechanisms after reaching the maximum height or distance.

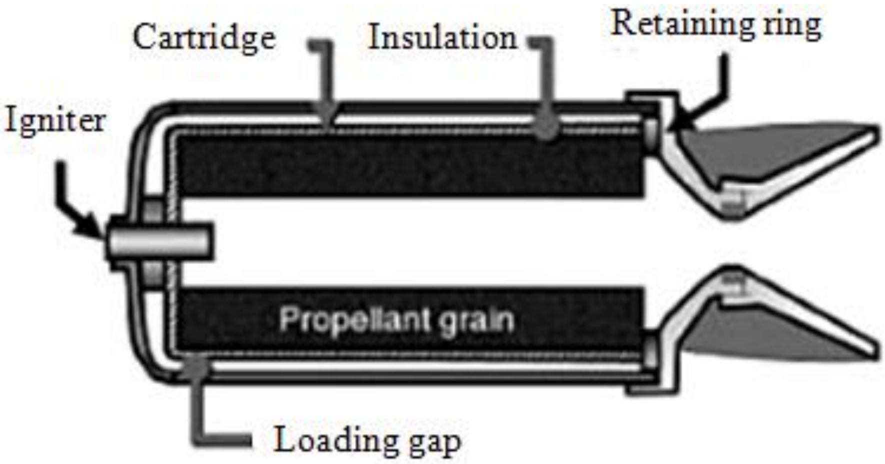

Figure 3.8: Schematic of rocket motor and igniter position

Source: Ward 2010

3.4 METHODS IN DATA COLLECTION AND ANALYSIS

Regarding the method to test the functional ability and performance of the ignition system, the most effective and common method was to perform a strand burner test or static burning test and flight test. A strand burner was a device or structure to test the performance, especially the burning rate of propellant combustion environment in the motor [12].

Instead of testing the performance of propellant combustion in the motor, in this research the purpose of undergoing this test was to justify the performance of the pyrolants and the igniter before being mounted into the SRM. The experimental procedure for this strand burner was very simple since the main process was to ignite the pyrolants inside the strand burner. Then, the burning rate was measured by collecting the data gained by the sensors (strain gauges) which has been processed by the data acquisition system. Lastly, the data was analysed and calculated to justify the performance.

After the strand burner has been a success, next was to test the ignition system in a real SRM. The main aim in this test was to verify the burning rate with the result obtained from the strand burner test and the functional ability of the wireless ignition system in several firing test. The results should include its functional ability to ignite the rocket from various firing range within a 100m parameter, the burning rate of the igniter to begin igniting the solid propellant grains in the thrust chamber and lastly the reusability of the ignition system for several firing tests, which was whether it could successfully function throughout the testing period without failure.

Figure 3.9: MK-1 strand burner model and testing cited from Examples of test strands for solid, liquid and hybrid rocket motor testing, http://aeroconsystems.com/cart/ts-pics

3.5 IGNITION SIMULATION ASSUMPTIONS

Assumptions are very important to ease the process of performing simulation. For this research, there were eight basic assumptions being considered when trying to design a new igniter. This analysis should begin by assuming the usage of a gaseous type igniter mounted in the forward end of the SRM combustion chamber [13]. The reason for using gaseous type was because we could easily choose the suitable representation of hot gases which flow through the igniter chamber.

Next, the assumptions could proceed towards the eight basic assumptions made for the development of an igniter model which will be discussed as follow [13]:

i. The chamber free volume and propellant surfaces are constant during the ignition transient
ii. The combustion gases must obey the Ideal gas law
iii. The analysis is quasi-steady in the sense that no consideration was made for the direct effects of propagating pressure waves although temporal and spatial variations in pressure were permitted. The burning rate in the main motor was calculated at the head and aft ends of the motor and was assumed to vary linearly along the propellant grain.
iv. The gas flow is one-dimensional
v. The nozzle flow is choked throughout the ignition transient
vi. The characteristic exhaust velocity, C* of the main motor is linearly related to the chamber pressure, P_c

$$C^* = K_a + K_b P_c$$

where, K_a and K_b are constants determined from thermochemical data.
vii. The characteristic exhaust velocity of the igniter propellant C^*_{ig} is constant
viii. The igniter pressure trace can be represented by a piece-wise linear approximation such that:

$$P_{cig} = P_{mig}\frac{t}{t_1}\ for\ t < t_1$$

$$P_{cig} = P_{mig} - R_{rig}\ (t - t_1)\ for\ t > t_1$$

where, P_{cig} is the maximum igniter pressure and R_{rig} is the average igniter pressure trace slope.

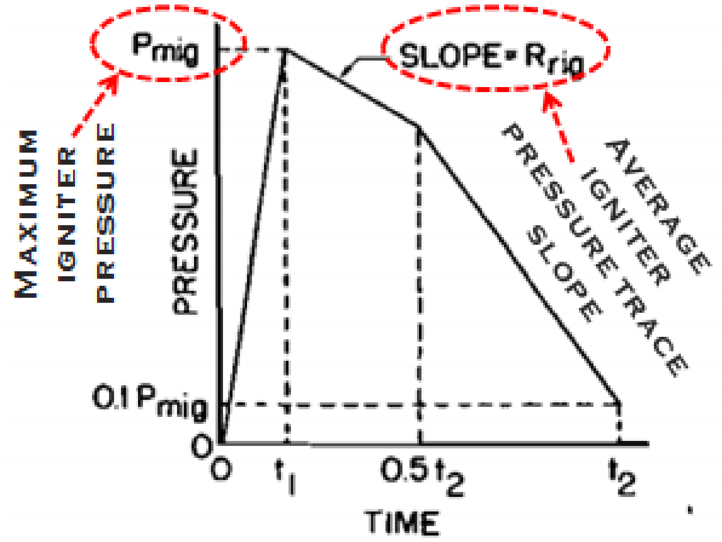

Figure 3.10: Igniter pressure-time trace representation

Source: Foster Jr. 1982

The equations assumed that the igniter chamber has higher pressure than that of in main motor chamber. If the main motor chamber pressure is higher than the igniter chamber pressure, the igniter pressure is set equal to the main motor pressure.

Among these eight assumptions, the most relevant assumption that could assist the simulation for the prototype igniter in this research would be the eighth assumption because comparison can be made between the reference graph and the obtained graph.

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULTS

The results obtained included the flow simulation results for the prototype igniter which was based on the selected assumption where the igniter pressure was higher than the thrust chamber's pressure but the setup should assumed that both pressures should be equal. Therefore, the simulation was supposed to represent the flow of hot gases during the combustion of pyrolants. Another results obtained was the evident that verified the successful functionality of WISys through communication connectivity. The success in connectivity indicated that the transmitter was actually successfully triggered the receiver to perform its operation.

4.1.1 SST01 Prototype Igniter

The prototype igniter consisted of an igniter and an igniter chamber. This design was based on the combination of both the SRM's and missile's igniters. There are a total of 20 holes with diameter of 4mm which began from the middle part of the igniter until the bottom of the igniter. The igniter chamber consisted of three separated parts which are the bulkhead, primary chamber (a 1in. tube) and secondary chamber (a ½in. tube) which was shown in Figure 4.1.

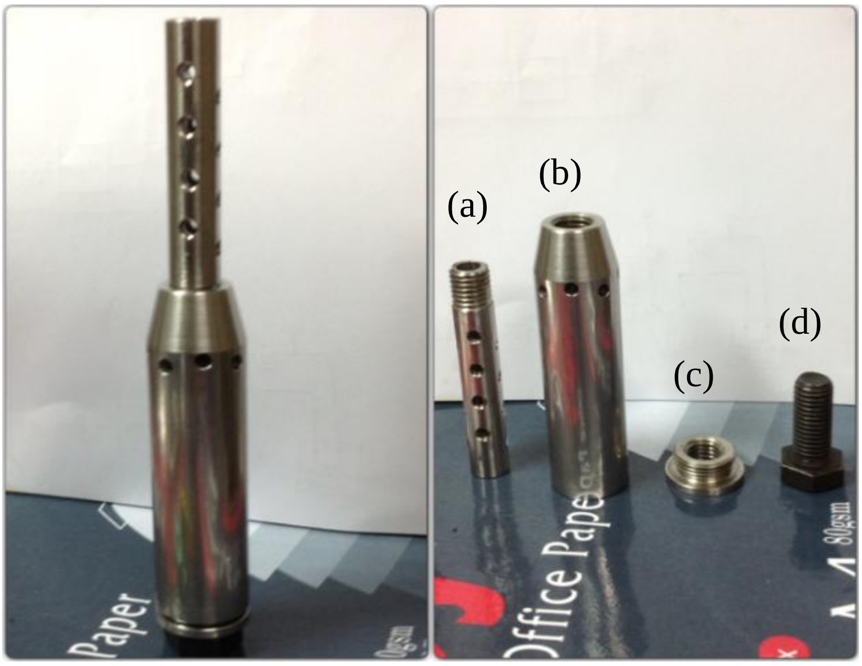

Figure 4.1: SST01 prototype igniter (Left), where a) Secondary chamber, b) Primary chamber, c) Bulkhead and d) Main igniter

The main igniter which is the M12 bolt that had been drilled through the center has a diameter ranging from 5mm to 10mm and it was used to place the electrical wire that had been welded together with the tungsten wire. The characteristics of the igniter are as follows:

i. This igniter is made from stainless steel (SS304) to avoid rust.
ii. It is small in size, tough and portable.
iii. It is designed to provide enough ignition burning rate to steadily burn the propellant
iv. It can be used continuously for several more ignitions without experiencing any defect.
v. It is also designed with flexibility to meet the requirement for rockets of different sizes and operations.

4.1.2 Simulation Analysis

4.1.2.1 Case One: Pressure At 5 Bars and Temperature At 393.2K

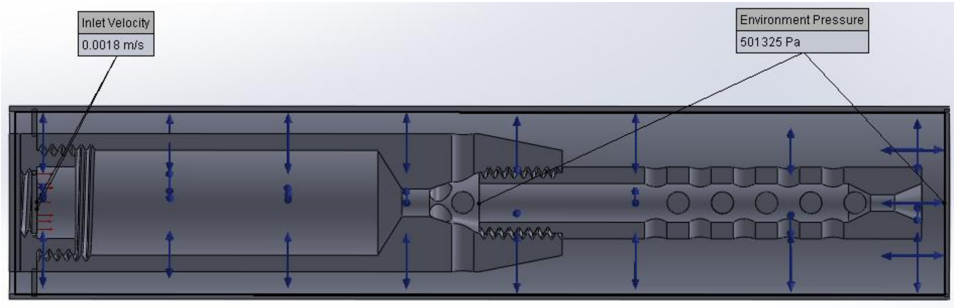

Figure 4.2: Cross-sectional area of prototype igniter (Middle) obtained from Solidworks software responsible for first simulation

For this case which was the preliminary case, the pyrolants' gases were represented by superheated steam since there was no configuration selection for ammonium perchlorate (AP). The pressure was setup as 5 bars or 501.325kPa for both the internal (igniter) and external (environment) pressures and the inlet velocity was set as 0.0018ms^{-1}. The temperature was set at 393.2K by assuming that the high pressure was a result from the accumulative pressure due the continuous burning of pyrolants. The wall roughness for stainless steel was set as 0.02mm. Moreover, the prototype igniter was meant for small scale SRM, which was a thick 5cm diameter PVC tube.

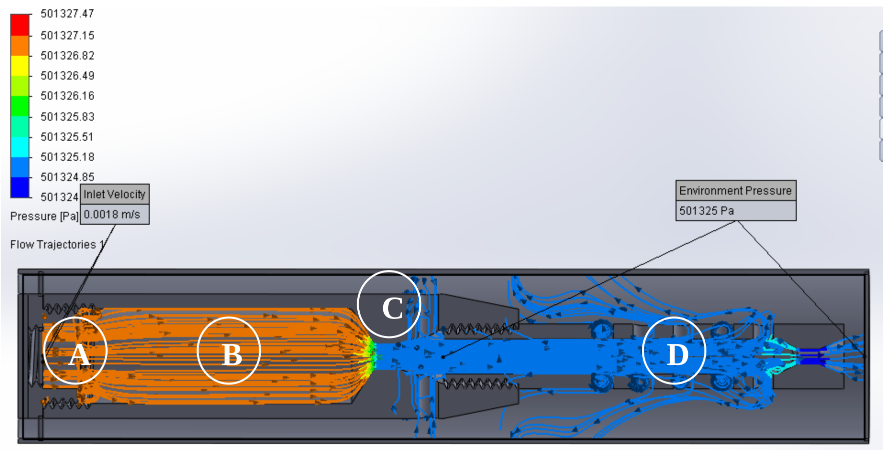

Figure 4.3: Simulation flow trajectories for 5 bars pressure inside the prototype igniter

From above Figure 4.3, it was clearly showed that the inlet velocity was $0.0018ms^{-1}$ and the environment pressure was 501325Pa or 501.325kPa. The pressure was set to be the same for both the igniter and the surrounding because an early assumption made was aiming for the study of combusting or burning behaviour of hot vaporised pyrolants gases where both the internal and external pressures was already reaching equilibrium.

However, since there was no ammonium perchlorate (AP) fluid or gas property was given for the configuration selection steam was used to represent the hot AP gases without considering the density but only to study the behaviour of the hot gases inside the igniter.

At point A, the pressure was very high since the velocity was very low. However, there was no significant change in pressure between point A and B because the combusting pyrolants were located along that region of primary chamber. Therefore, the dark orange trajectories lines and arrows for pressure were generated.

When the flow reached the nozzle, huge pressure drop occurred due to a sudden increased in velocity and hence yellow and green flow trajectories lines and arrows were shown at point C.

As the flow passed through the nozzle and flowed through the secondary chamber, the pressure began to loss through the holes into the thrust chamber bringing along the red hot pyrolants particles into the thrust chamber to burn the propellant grains inside the rocket motor. Therefore, dimmed light blue flow trajectories lines and arrows were generated at point D to indicate the pressure lost.

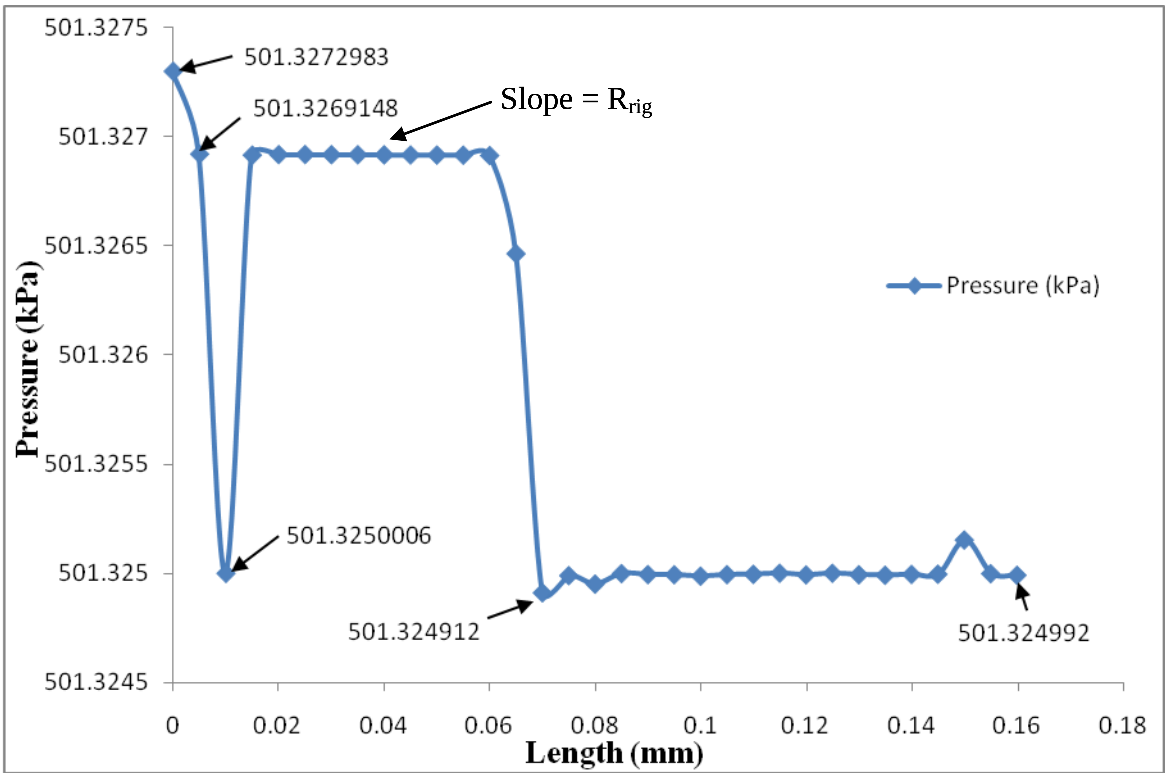

Figure 4.4: Graph of Pressure in kPa versus Length in mm for Case One

Figure 4.4 showed the graphical result obtained from the simulation (shown in Figure 4.3), which only involve the internal gaseous pressure within the igniter chamber with respect to the length or position in meter along the center of the igniter chamber.

From this graph, the assumption made was both the igniter chamber and the thrust chamber of SRM have the same pressure which was at 501.325kPa or 5 bars and the inlet velocity was at 0.0018ms^{-1}. This assumption was made by considering that the ignition had already taken placed.

According to Figure 4.4 with the inlet velocity to be at 0.0018ms^{-1}, the maximum pressure was obtained at that point which was recorded to be at 501.3272983kPa or 501.327kPa. As the pressure travelled along the igniter, the pressure began to reduce since the hot gases were travelling from a smaller area to a larger chamber area. Within the primary chamber, the pressure was reduced until 501.3250006kPa or 501.325kPa, which was just before it entered the primary chamber.

Once the hot gases entered the primary chamber, the pressure began to shoot up to 501.3269148kPa or 501.326kPa since the velocity of hot gases decreased gradually when the velocity decreased after entering a larger area from a smaller area. This had fulfilled the Bernoulli's principle which mentioned that fluid pressure is inversely proportional to the velocity of fluid.

As the hot gases entered the nozzle, the velocity increased greatly and hence resulting to the great decreased in pressure which was reduced once again to501.324912kPa or 501.3249kPa. Later, it increased again but in small values since the secondary chamber's area was much smaller than the primary chamber.

Lastly, the hot gases exited the igniter into the thrust chamber with a pressure of 501.324992kPa or 501.325kPa. Moreover, the average igniter pressure trace slope, R_{rig} was much linear than the reference (shown by Figure 3.10). This less steep slope indicated that the burning rate of the pyrolants inside the igniter was very consistent and slow which provide even better efficiency than the conventional igniter. Hence, the performance of the igniter was successfully improved.

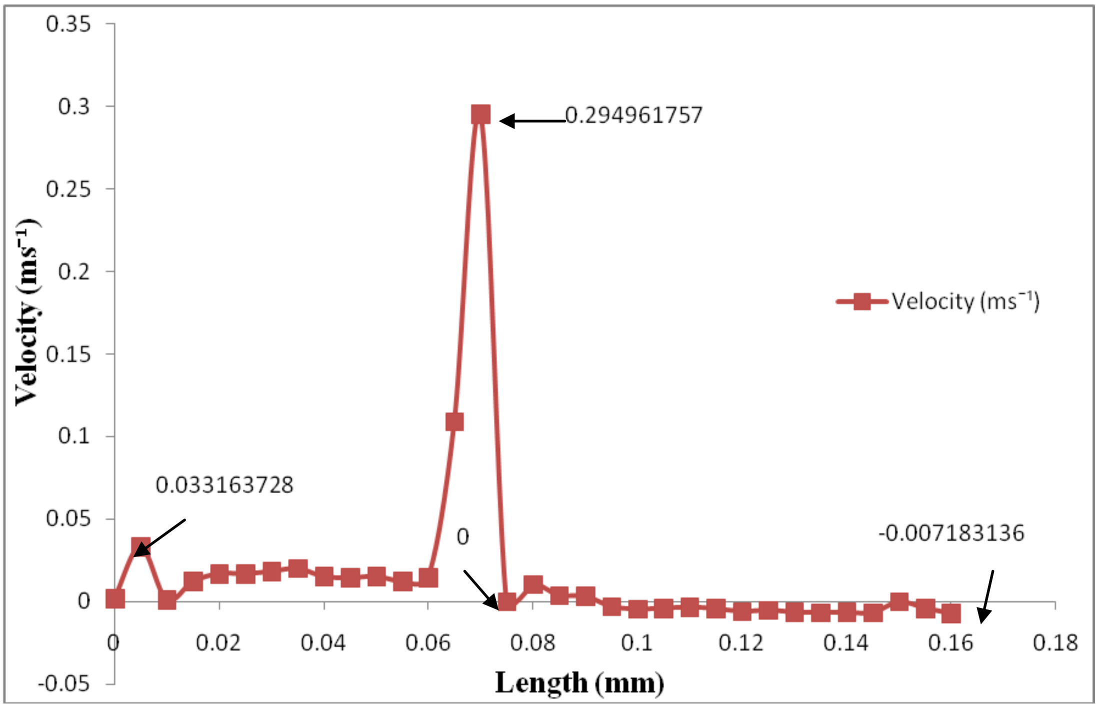

Figure 4.5: Graph of Velocity in ms^{-1} versus Length in mm for Case One

Figure 4.5 showed the graphical result obtained from the simulation, which only involve the hot gaseous velocity travelling within the igniter chamber with respect to the length or position in meter along the center of the igniter chamber. From this graph, the inlet velocity was assumed to be starting $0.0018ms^{-1}$. This assumption was made by considering that the ignition had already taken placed.

From Figure 4.5 the inlet velocity was at $0.0018ms^{-1}$ and had slight increment at the beginning due to the small inlet which provided an effect similar to an orifice. When it entered the primary chamber, the velocities did not show significant difference until the hot gases reached the nozzle.

As soon as it was inside the nozzle, the velocity shot up to maximum which was at $0.294961757ms^{-1}$. After exiting the nozzle, the velocity reduced greatly to $0ms^{-1}$ and than rose again as the hot gases travelled along the secondary chamber with smaller diameter than the primary chamber.

Since the prototype igniter was designed to have 20 small holes in secondary igniter, the velocity of the hot gases was expected to reduce as it passed through the igniter due to the openings to spread the red hot pyrolant particles into the thrust chamber of SRM. Due to this release action of hot gases resulting to pressure lost, the velocity was expected to be decreasing even further.

Lastly, the hot gases entered the nozzle exit of the secondary chamber resulting to another increase in velocity and totally exiting the chamber with lower exiting velocity which was at $-0.007183136ms^{-1}$.

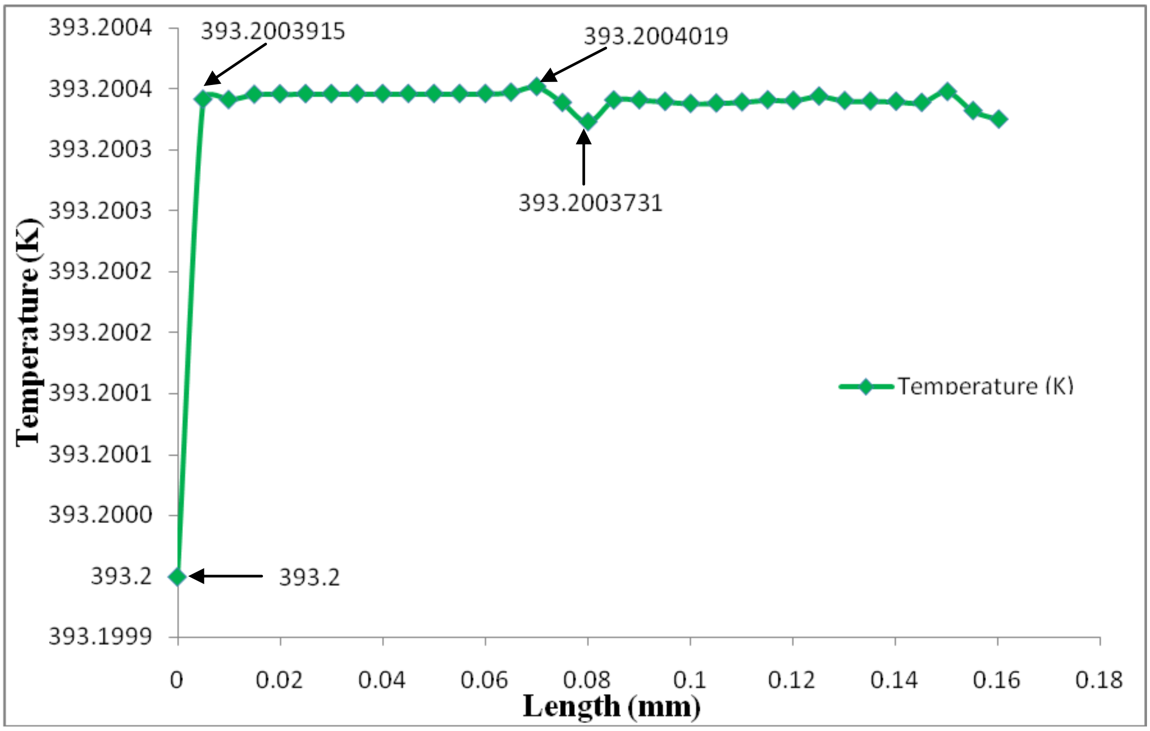

Figure 4.6: Graph of Temperature in K versus Length in mm for Case One

From Figure 4.6, we can identify that there was an increased in the hot gases temperature value as hot gases flowed through the igniter although the amount was actually very small, which was about 4.59×10^{-5}K. However, this situation was acceptable because the temperature was already at a very high value which was during the combustion process inside the igniter. According to Ideal Gas Law, pressure of a fluid increases as the temperature of the fluid increases. Therefore, this graph had proven that the relationship between the hot gases pressure and the temperature is valid.

4.1.2.2 Case Two: Pressure A 8 Bars and Temperature At 670.85K

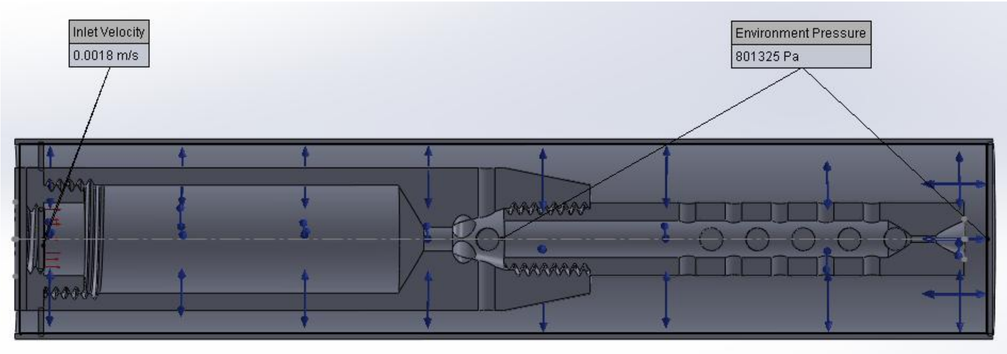

Figure 4.7: Cross-sectional area of prototype igniter (Middle) obtained from Solidworks software responsible for second simulation

For this case, the pyrolants' gases still were represented by superheated steam since there was no configuration selection for ammonium perchlorate (AP). The wall roughness for stainless steel was set as 0.02mm. However, the pressure for case two was setup as 8 bars or 801.325kPa for both the internal (igniter) and external (environment) pressures and the inlet velocity was still set as $0.0018ms^{-1}$. The temperature was set at 670.85K after calculation by considering the steam's density at 8 bars pressure and the relationship in Ideal Gas Law.

$$PV = mRT$$

$$P = \frac{m}{V}RT$$

$$P = \rho RT$$

where, Density, ρ = 4.162 kgm^{-1}, Expected volume, V = $10.3285x10^{-6}m^2$,Reinberg constant, R = $0.287kJkg^{-1}K^{-1}$, Pressure, P = 801.325kPa, Mass, m = $4.2987x10^{-5}kg$

Example of calculation:

$$P = \rho RT$$

$$T = \frac{P}{\rho R} = \frac{801.325}{4.162\ (0.287)} = 670.85K\ (2d.p.)$$

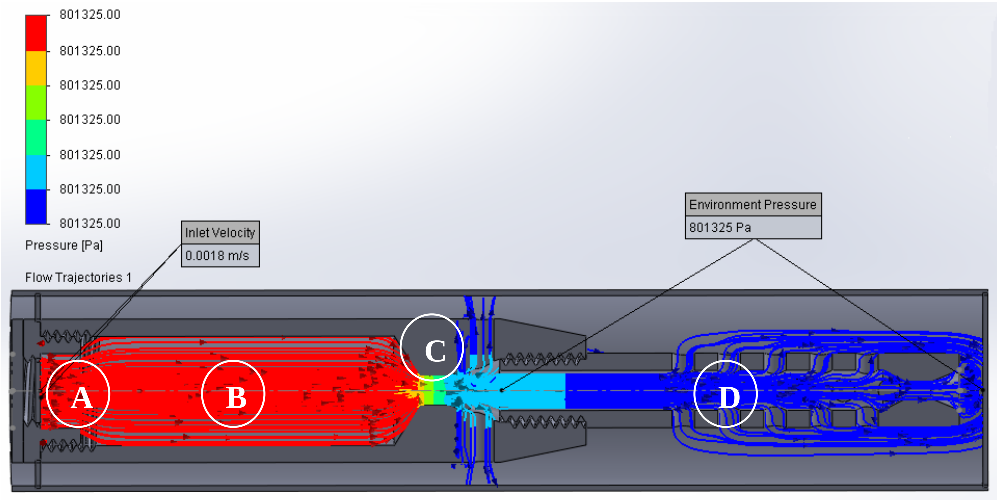

Figure 4.8: Simulation flow trajectories for 8 bars pressure inside the prototype igniter

Figure 4.8 showed that the inlet velocity was 0.0018ms^{-1} but the environment pressure was changed to 801325Pa or 801.325kPa. The pressure setting was also based on the same assumption made in the previous case, which was to study burning behaviour of hot vaporised pyrolants gases where both the internal and external pressures had reached an equilibrium state. Similar to the Case one, steam was selected in place of ammonium perchlorate (AP).

The hot gases pressure was very high at point A since the velocity was very low. Plus, the pressure change between point A and B was very small because the combusting pyrolants were located along that region of primary chamber. Therefore, the red trajectories lines and arrows for pressure were generated along the main chamber.

When the flow entered the nozzle of the main chamber, huge pressure drop occurred as a result from the increased in velocity of hot gases and hence yellow and green flow trajectories lines and arrows occurred at point C.

As the flow passed through the nozzle and flowed through the secondary chamber, the pressure began to loss through the holes around the chamber into the thrust chamber. The flow brought along the red hot pyrolants particles into the thrust chamber to burn the propellant grains inside the rocket motor. As a result, dark blue flow trajectories lines and arrows were generated at point D to indicate the pressure lost through the secondary chamber.

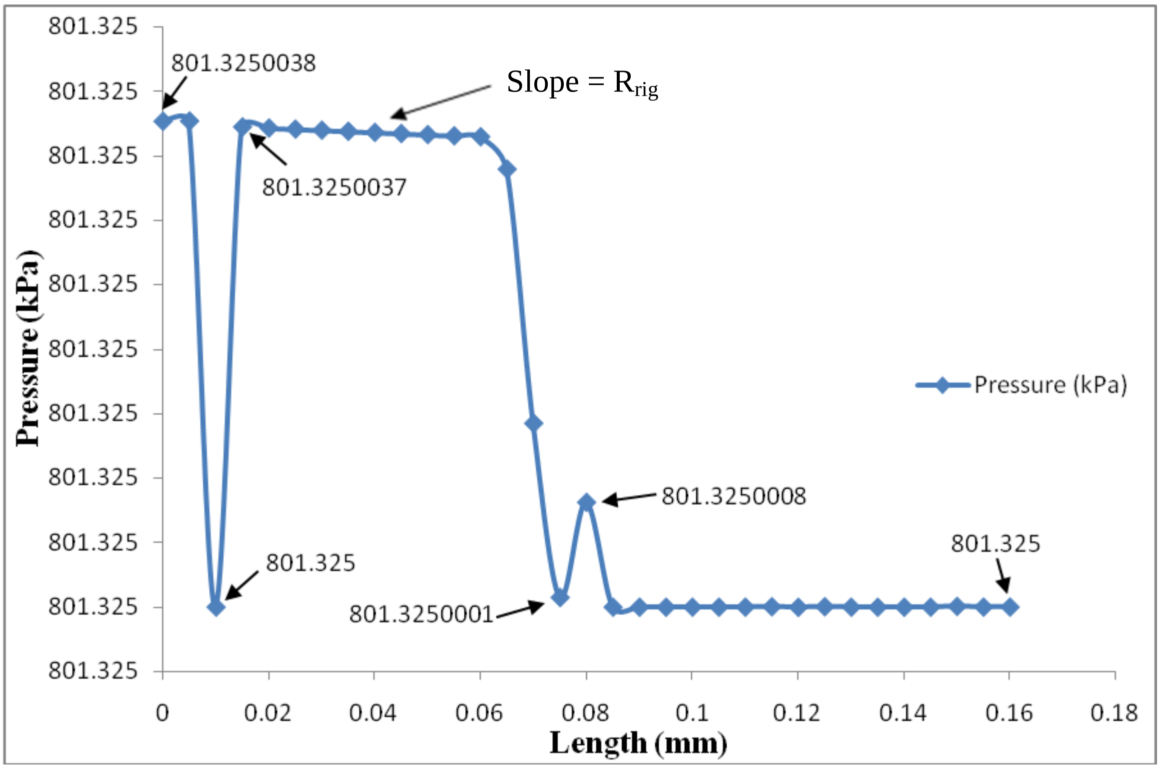

Figure 4.9: Graph of Pressure in kPa versus Length in mm for Case Two

Figure 4.9 showed the graphical result obtained from the simulation (shown in Figure 4.8), which only involve the internal gaseous pressure within the igniter chamber with respect to the length or position in meter along the center of the igniter chamber as mentioned in Case One.

Moreover this graph also assumed that the igniter chamber and the thrust chamber of SRM have the same pressure which was at 801.325kPa or 8 bars and the inlet velocity remain the same at $0.0018ms^{-1}$. This assumption was made by considering that the ignition was at an extreme stage of combustion.

According to Figure 4.9 with the inlet velocity to be at $0.0018ms^{-1}$, the maximum pressure was obtained at that point which was recorded to be at 801.3250038kPa or 801.325kPa. As the pressure travelled along the igniter, the pressure began to reduce since the hot gases were travelling from a smaller area to a larger chamber area. Within the primary chamber, the pressure was reduced until 801.325kPa, which was just before it entered the primary chamber.

Once the hot gases entered the primary chamber, the pressure began to shoot up to 801.3250037kPa since the velocity of hot gases decreased gradually when the velocity decreased after entering a larger area from a smaller area. This had fulfilled the Bernoulli's principle which mentioned that fluid pressure is inversely proportional to the velocity of fluid.

As the hot gases entered the nozzle, the velocity increased greatly and hence resulting to the great decreased in pressure which was reduced once again to 801.3250001kPa. Later, it increased again but in small values since the secondary chamber's area was much smaller than the primary chamber to 801.3250001kPa and later drop again since there were 20 holes surrounding the secondary chamber.

Lastly, the hot gases exited the igniter into the thrust chamber with a pressure of 801.325kPa. Moreover, the average igniter pressure trace slope, R_{rig} was much linear than the reference (shown by Figure 3.10). This less steep slope indicated that the burning rate of the pyrolants inside the igniter was very consistent and slow which provide even better efficiency than the conventional igniter. Hence, the performance of the igniter was successfully improved.

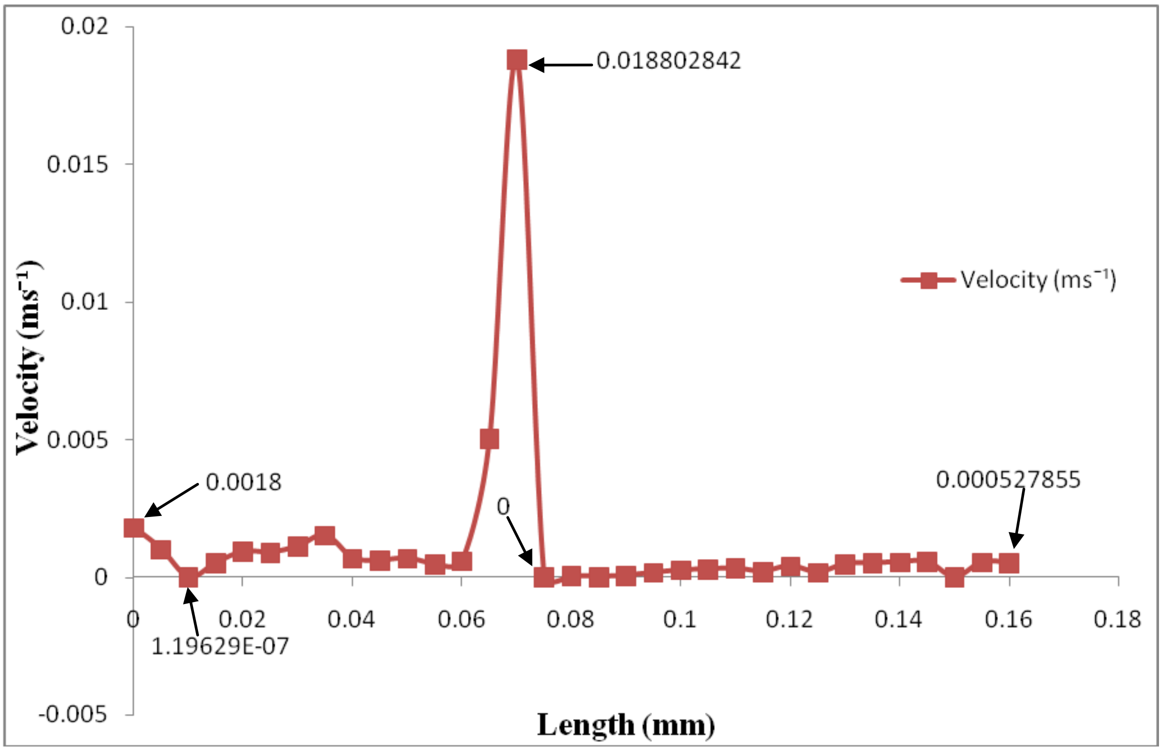

Figure 4.10: Graph of Velocity in ms^{-1} versus Length in mm for Case Two

Figure 4.10 showed the graphical result obtained from the simulation, which only involve the hot gaseous velocity travelling within the igniter chamber with respect to the length or position in meter along the center of the igniter chamber. The configuration was exactly the same as mentioned previously.

From Figure 4.10 the inlet velocity was at $0.0018ms^{-1}$ and there was a slight decrement at the beginning due to the small inlet which provided an effect similar to an orifice. When the hot gases entered the primary chamber, the velocities did not show significant increment until the hot gases reached the nozzle.

As soon as it was inside the nozzle, the velocity shot up to maximum which was at $0.018802842ms^{-1}$. The reason for the big difference in the maximum values for Case One and Case Two was due to the assumptions made which specified the conditions from which the results were to occur. After exiting the nozzle, the velocity reduced greatly to $0ms^{-1}$ and than rose again as the hot gases travelled along the secondary chamber with smaller diameter than the primary chamber.

Since the prototype igniter was designed to have 20 small holes in secondary igniter, the velocity of the hot gases was expected to reduce as it passed through the igniter due to the openings to spread the red hot pyrolant particles into the thrust chamber of SRM. Due to this release action of hot gases resulting to pressure lost, the velocity was expected to be decreasing even further.

Lastly, the hot gases entered the nozzle exit of the secondary chamber resulting to another increase in velocity but in a very small amount and totally exiting the chamber with lower exiting velocity which was at -0.007183136ms^{-1}.

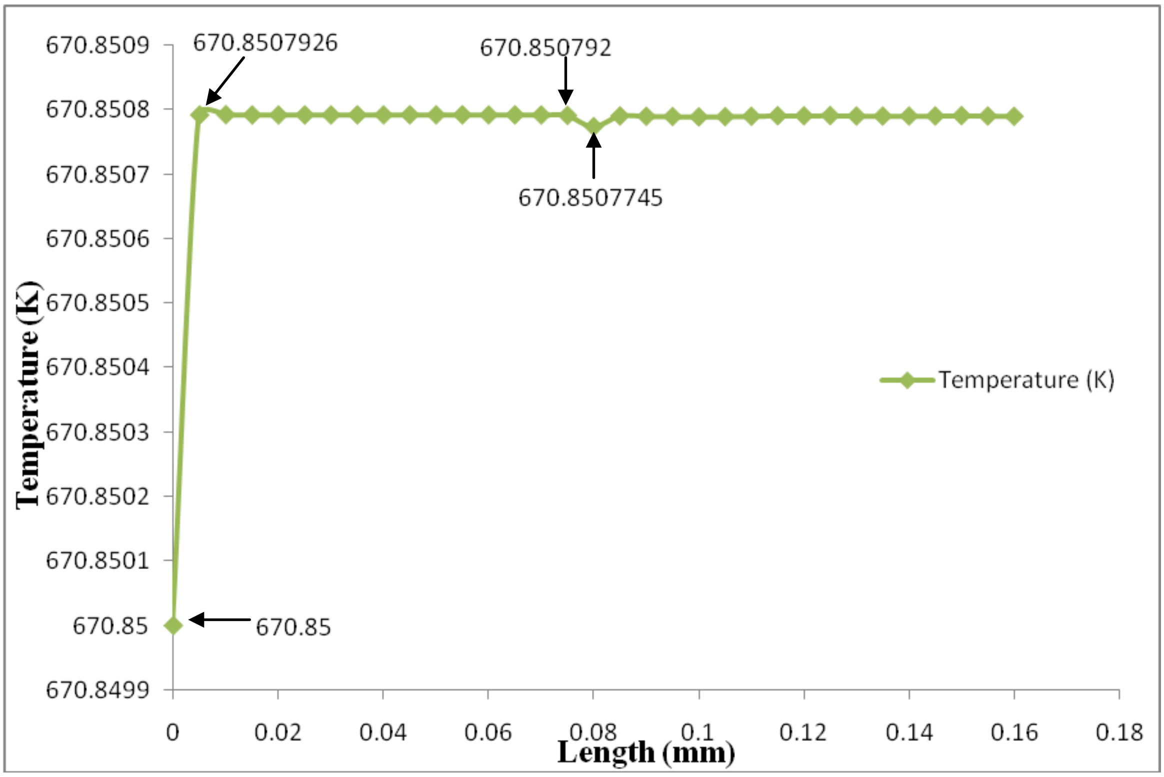

Figure 4.11: Graph of Temperature in K versus Length in mm for Case Two

From Figure 4.11, we can identify that there was an increased in the hot gases temperature value as the hot gases flowed through the igniter although the amount was actually very small. Similar to Case One, this situation was acceptable because the temperature was already at a very high value which was during the combustion process inside the igniter. Moreover, from the graph we can notice that the temperature difference was way much smaller than that of Case One, which was only 1.75x10^{-5}K.

According to Ideal Gas Law, pressure of a fluid increases as the temperature of the fluid increases. Therefore, this graph had proven that the relationship between the hot gases pressure and the temperature is valid.

4.1.3 WIRELESS IGNITION SYSTEM

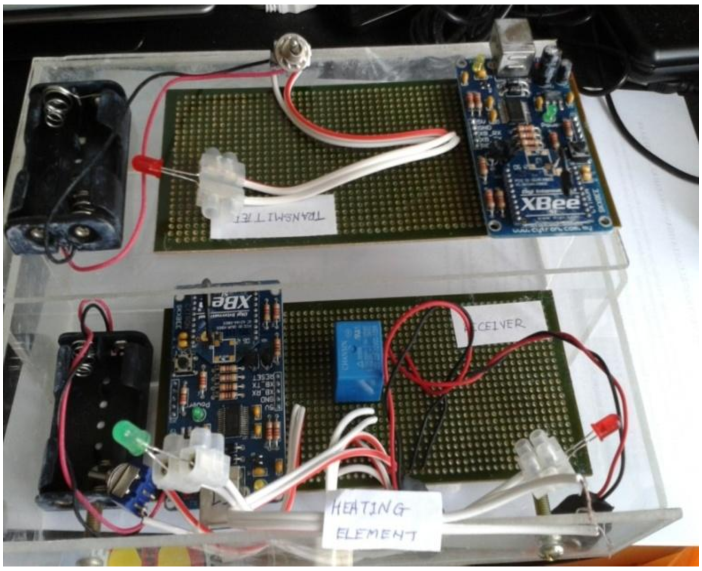

Figure 4.12: Preliminary wireless ignition system using Cytron Technology wireless circuit as control system, where Top: Transmitter and Bottom: Reciever

The wireless ignition system or WISysis an electronic circuit which is powered by electricity supplied from the batteries. Therefore, it is very logical that Ohm's law was an important formula in verifying the continuity of the circuit's current and voltage. As a result from this consideration, the Ohm's law was used throughout the entire research for circuit inspection to ensure the safety and continuity for each electrical and electronic component. Moreover, a multimeter was used to inspect the circuit connectivity and the output current for each components in the WISys circuit. The Ohm's law formulations and parameters used in this research were as mentioned below:

$$V = IR$$

$$P = VI = \frac{I^2}{R} = \frac{V^2}{R}$$

$$A = \pi r^2 = \frac{\pi D^2}{4}$$

$$R = \frac{\rho L}{A} = \frac{4\rho L}{\pi D^2}$$

Parameter descriptions:

V = Voltage (V), I = Current (A), R = Resistance (Ω), P = Power (W), L = Length (m), D = Diameter (m), A = Area (m^2), ρ = Density (Ωm) and π = 3.142 (3d.p.)

Example of calculation:

Based on EVEREADY 1222 datasheet cited from *Product Datasheet*, data.energizer.com/PDFs/1222.pdf, a 9V Eveready battery has approximately would have 180 ohms (Ω) of resistance when operated for half an hour per day.

Resistance = 180Ω

Voltage = 9V

Quantity = 2 batteries (to initiate ignition)

So,

$$P = \frac{V^2}{R} = \frac{18^2\ V}{180\ \Omega} = \frac{324\ V}{180\ \Omega} = 1.8W$$

$$P = VI$$

$$I = \frac{P}{V} = \frac{1.8W}{18\Omega} = 0.1A$$

Therefore, the power that can be generated by the batteries throughout half an hour period for the igniter would be 1.8W and the current supplied would be 0.1A for two 9V batteries.

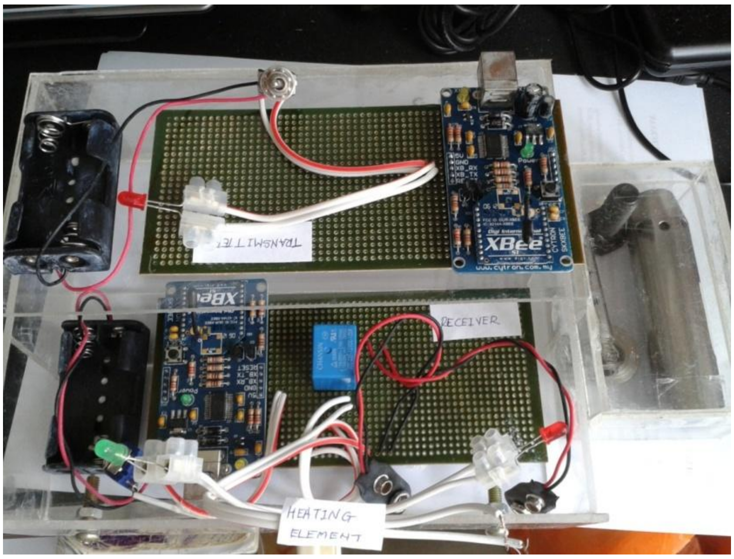

Figure 4.13: Preliminary wireless ignition system together with the igniter

4.1.4 WISys Connectivity Result

The WISys communication range that must be achieved at the end of this research should be up to 100m. Therefore, the XBee-S1 module was configured for operating range test using specific software known as X-CTU. With this software, the transmitter and receiver communication range was able to be tested in both indoor and outdoor condition.

As shown in Figure 4.10, the XBee-S1 module was successfully detected by the computer and was ready to be configured to suit the communication address. The confirmation of a functioning XBee-S1 module was shown by the left figure where there was a statement that verified the connectivity of the transmitter and receiver. If the communication with modem was “OK”, then we can proceed to continue the configuration by synchronising the communication address. For this configuration, the transmitter’s address and the receiver’s address should be inversed to each other. For example, if the transmitter’s address was “1100”, then the receiver address should be “0011”.

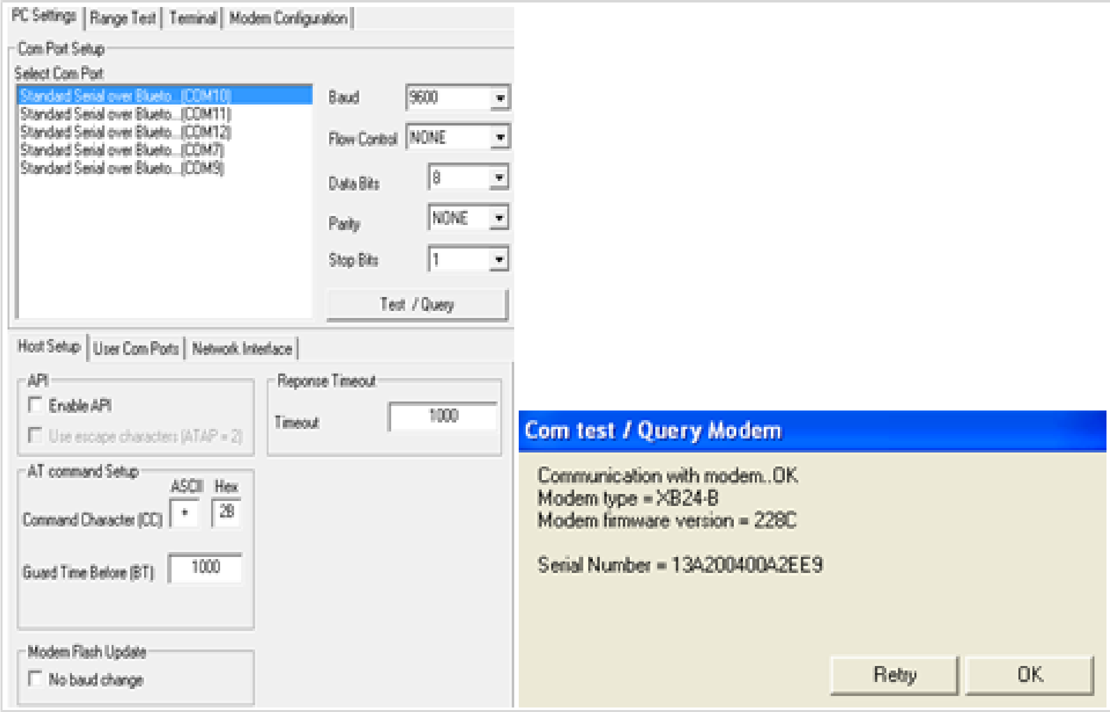

Figure 4.14: Xbee-S1 wireless module is detected and functioning

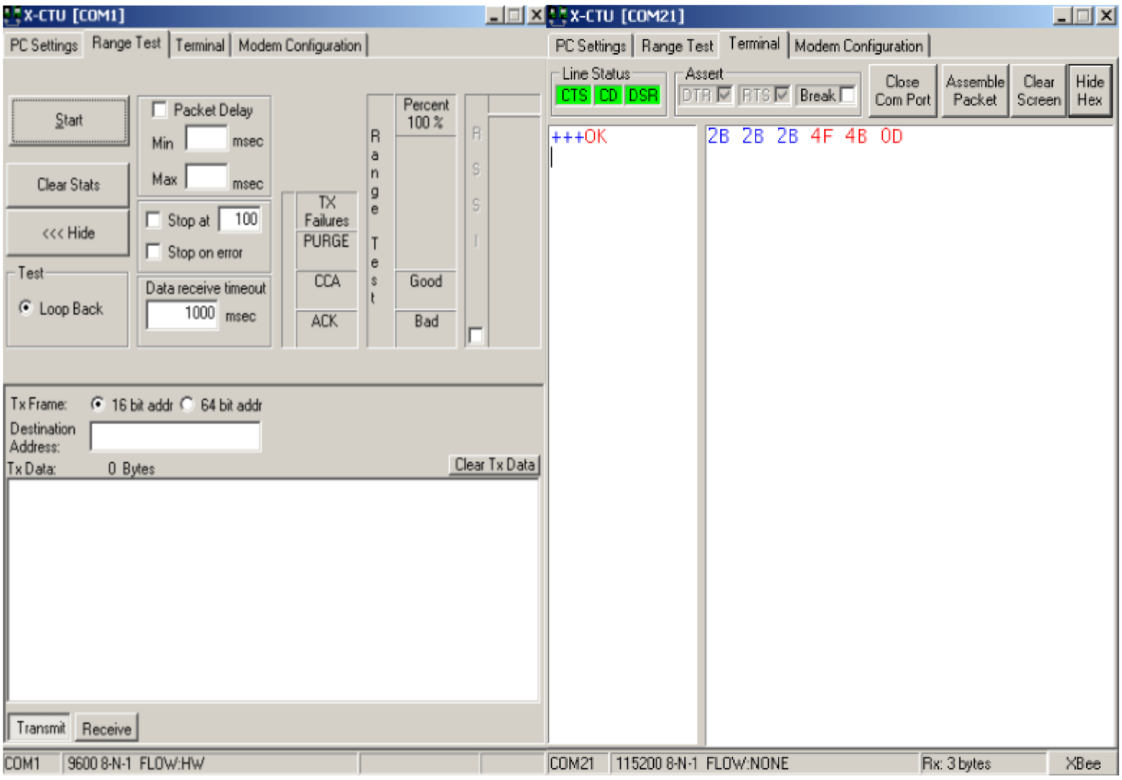

Figure 4.15: Successful wireless connection between transmitter and receiver

After all the necessary configuration was completed, the range testing for communication between the transmitter and the receiver was activated by clicking on the “Start” selection button. After waiting for a moment, the communication result was shown to be “OK” (shown in Figure 4.15), which indicated that the devices were successfully communicating with each other. For clearer operating range, the devices were tested in both indoor and outdoor condition and also with different distance between the two devices.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

As a conclusion for this entire research, I hereby summarised all the data obtained from the analysis and testing, justifications for the findings that was achieved throughout the entire research as well as the limitation that was encountered along the process of completing this research.

First and foremost, after going through proper literature study on the ignition system for solid rocket motor I had found that the development of a wireless ignition system for solid rocket motor was very important in rocketry study because we are now living in an era where technology was used to improve and benefit the life of human beings.

Therefore, Malaysia's rocketry study should not just focus on merely wired ignition system which depending on the direct power supply to the solid rocket motor. Instead, we should encourage ourselves to move further ahead along with the flow of time by developing a friendly and easy to used wireless igniter system which I had named as WISys in this research.

In order to build a friendly and easy to used wireless ignition system, the WISys was developed to have a transmitter and a receiver that were built by using two radio communication modules, namely XBee-S1 Starter Kits, in each of the devices. These high technology and compact wireless modules were easy to be configured and assembled to the electronic circuits and would only required very low voltage to operate which is only 3.3V but the output voltage that was used to initiate the burning of the pyrolant was 18V. Apart from having both the transmitter and receiver, this WISys also included a prototype igniter which was made of stainless steel. The igniter was portable and easy to store because of its small size which was only 1in. and½in. in diameters and also can be disassembled and reassembled.

During the period of developing WISys, it is important to know that WISys was fabricated in stages. The transmitter and receiver were fabricated starting with the designing of the most appropriate and simple circuit that could function as effective as or better than the wired ignition system available nowadays. After having the finalised circuit design, the WISys circuits were developed using all the necessary soldering tools and also multimeter to inspect the circuits for malfunction. The designing and analysis carried out for fabricating the prototype were very important so that the prototype igniter had better burning rate result and flow trajectories than the available igniters which were justified when compared to the graph in Figure 3.10.

However good a wireless ignition system can be, it would still be a big problem if the wireless ignition system could not achieve its full potential. Therefore, it is significant to make sure that during the configuration of the XBee-S1 modules there would be no weakness, especially the inference of communication frequency and the continuity of the wireless ignition system's operation. This WISys would be able to initiate the burning of pyrolant within 3 seconds and also both the transmitter and receiver can continuously communicate with each other as long as the batteries' life spend have not reach their minimum. Moreover, WISys was tested to be able to function up to 100 meters communication range.

As for the prototype igniter, the simulation was the most important process in this research. This was because the hot gas represented by steam in place of aluminium perchlorate, which was unavailable in the simulation configuration was able to show the flow trajectories for both the pressure and velocity of the hot gas or steam as it passed through the igniter until it exited the igniter.

In order to successfully perform the simulation, initial assumptions were made where by the igniter and the thrust chamber were already reaching equilibrium pressure which was at 501.325 kPa and having an inlet velocity of 0.0018 ms^{-1}. From Figure 4.5, it was stated that the pressure inside the primary chamber, especially at the inlet was the highest, which gave a value of P_{max} = 501.327.2983 Pa at a velocity of V = 0.0018ms^{-1}. Moreover, the primary chamber was always supposed to be the main chamber where the igniter pyrolant was placed. Therefore, this was another reason for the high pressure existed inside the primary chamber.

Likewise, when the pressure was the highest in the primary chamber, the hot gas velocity was the highest in the nozzle of the primary chamber which was at V_{max} = 0.294961757 ms^{-1}. This was because the hot gas had just passed through the primary chamber's nozzle. While the lowest velocity, that was at V_{min} = -0.007183136 ms^{-1} was obtained at the exit of the secondary chamber just before the hot gas was completely entering the thrust chamber with much higher pressure compared to that within the secondary chamber. Plus, the temperature difference along the igniter at equilibrium internal and external pressures was very small which was only $\Delta T = 2.88 \times 10^{-5}$ K.

Last but not least, there were some limitations that greatly affect the overall result of this research. They included the unavailability of strand burner which was used to study the behaviour of the flare released from the igniter, the rocketry thrust test laboratory and compound, and the complexity of the wireless ignition system which required further study on wireless communication for fully independent wireless ignition system, which may involve the study of Java programming language.

5.2 RECOMMENDATIONS

From the limitations mentioned in conclusion, I had come out with four recommendations which would give more hopes and achievement to this research. These recommendations would be a benefit to the Faculty of Mechanical Engineering and also the university since the development of this wireless ignition system or WISys could still have the potential to be a well-known research. Hence, I recommended that:

i. The testing equipments, such as strand burner, could be available in Faculty of Mechanical so that experiment and testing could be carried out in Universiti Malayisa Pahang (UMP) itself rather than performing them at other university.

ii. A thrust test laboratory could be built in Faculty of Mechanical Engineering so that the rocketry group and projects can have a permanent and convenient laboratory to perform more testing and at the same time improve the value and significance of rocketry projects in UMP.

iii. The development of WISys could be continued with the implementation of Java programming language which would further improve the independency of the WISys in term of radio communication.

iv. The WISys could be improved further by implementing mobility and build-in installation which would be installed inside the solid rocket motor itself so as we could build a guided SRM.

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APPENDICES

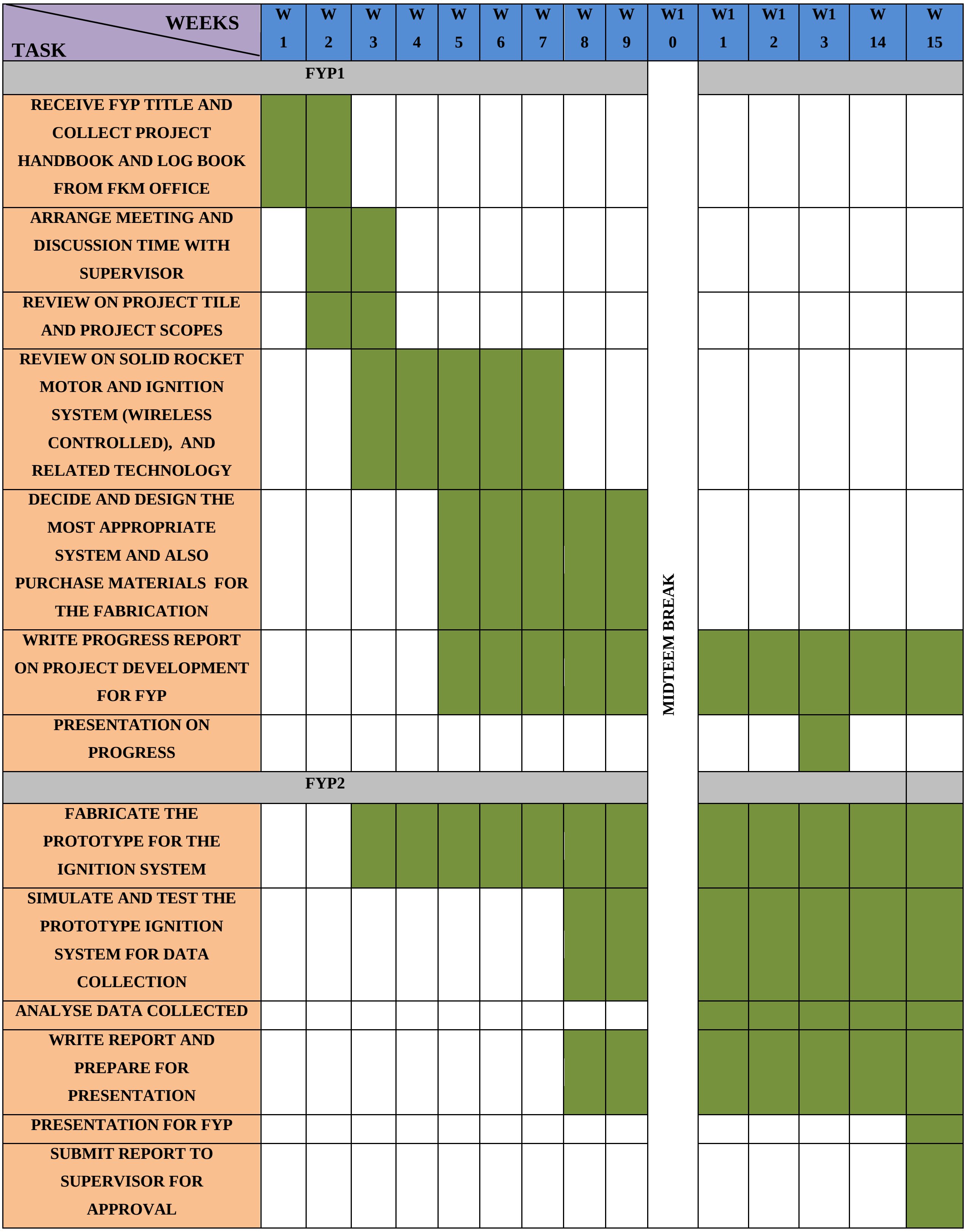

Figure 6.1: Gantt chart for FYP research development

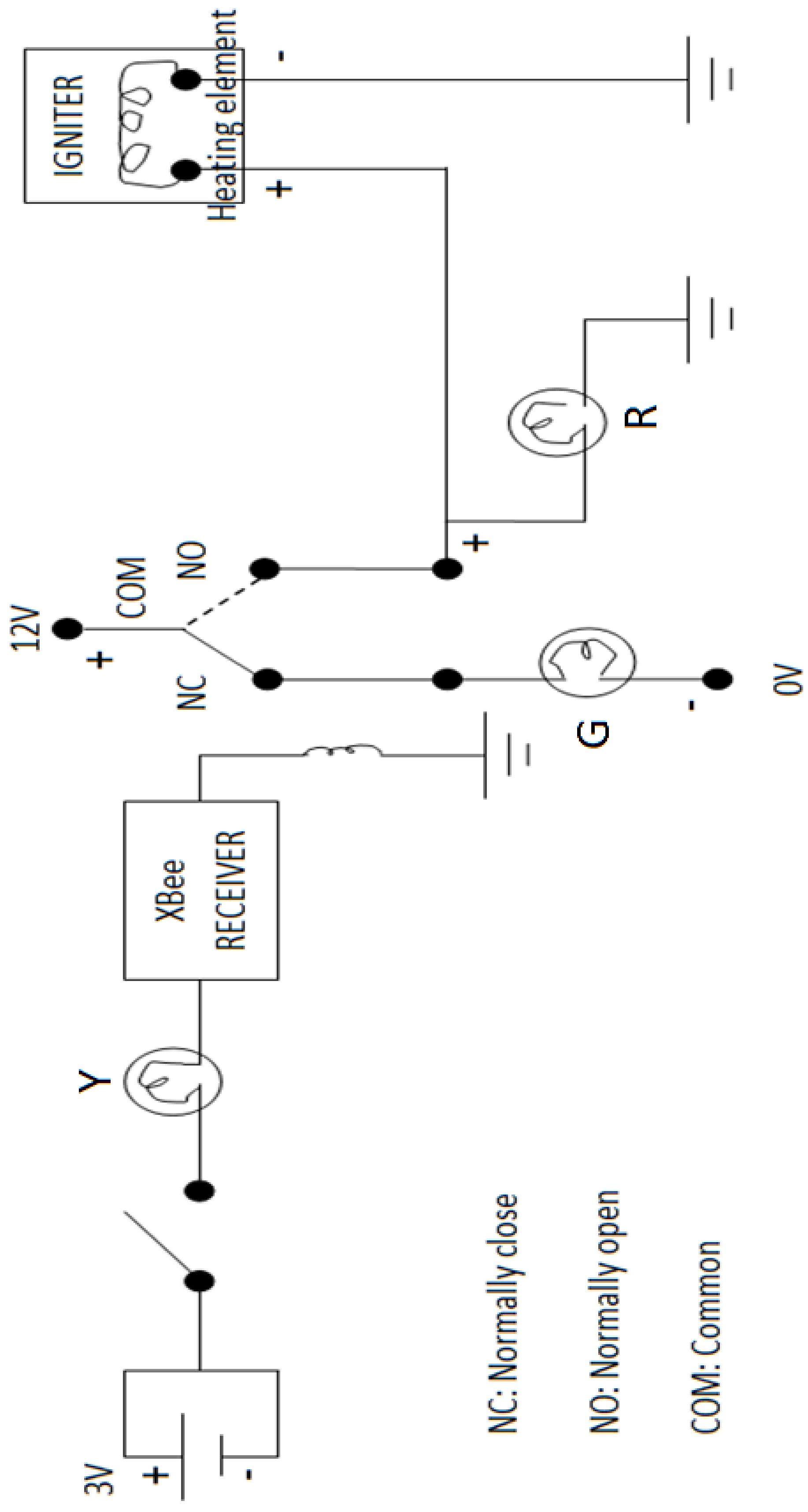

Figure 6.2: Draft schematic circuit diagram for receiver or Relay box

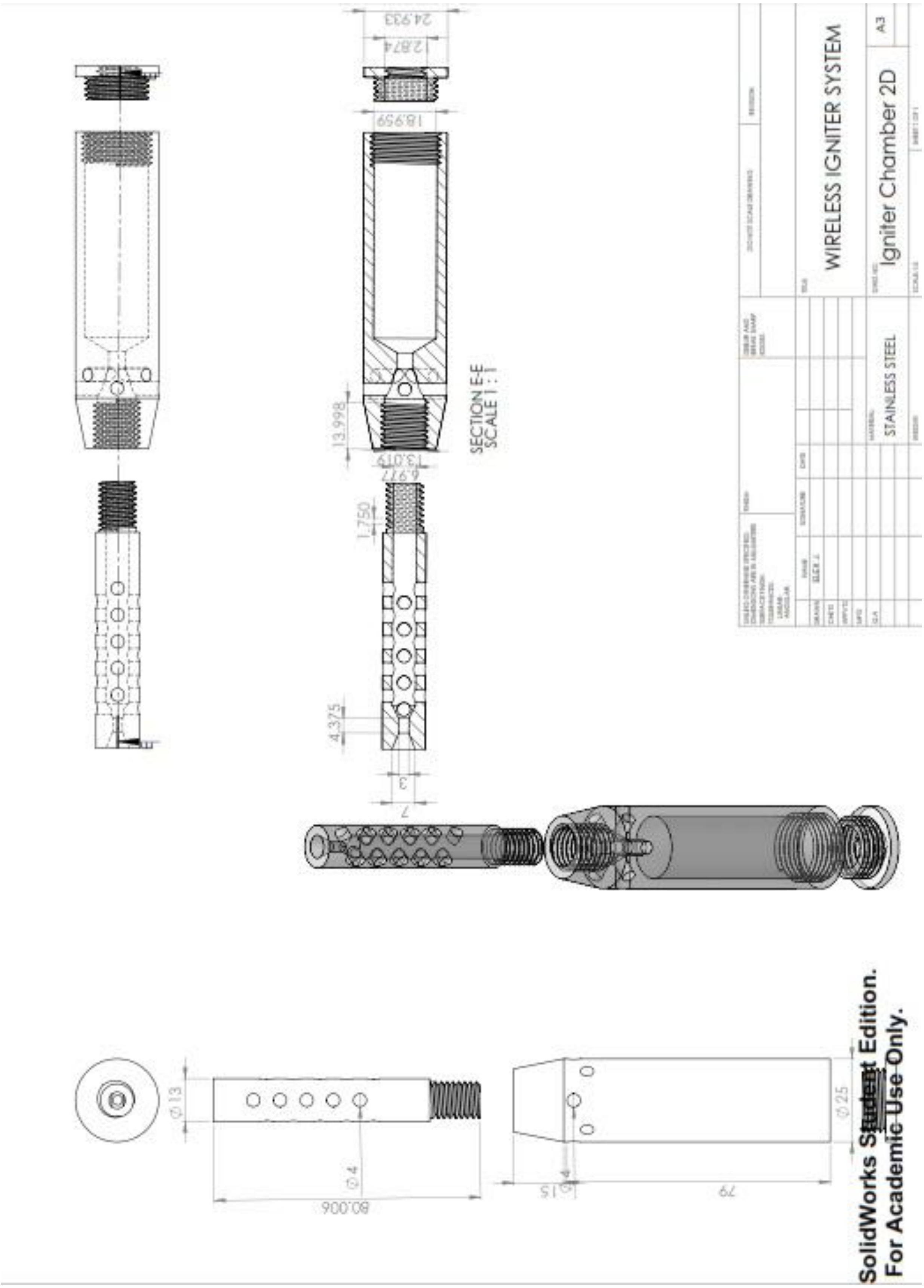

Figure 6.3: Igniter chamber for SRM

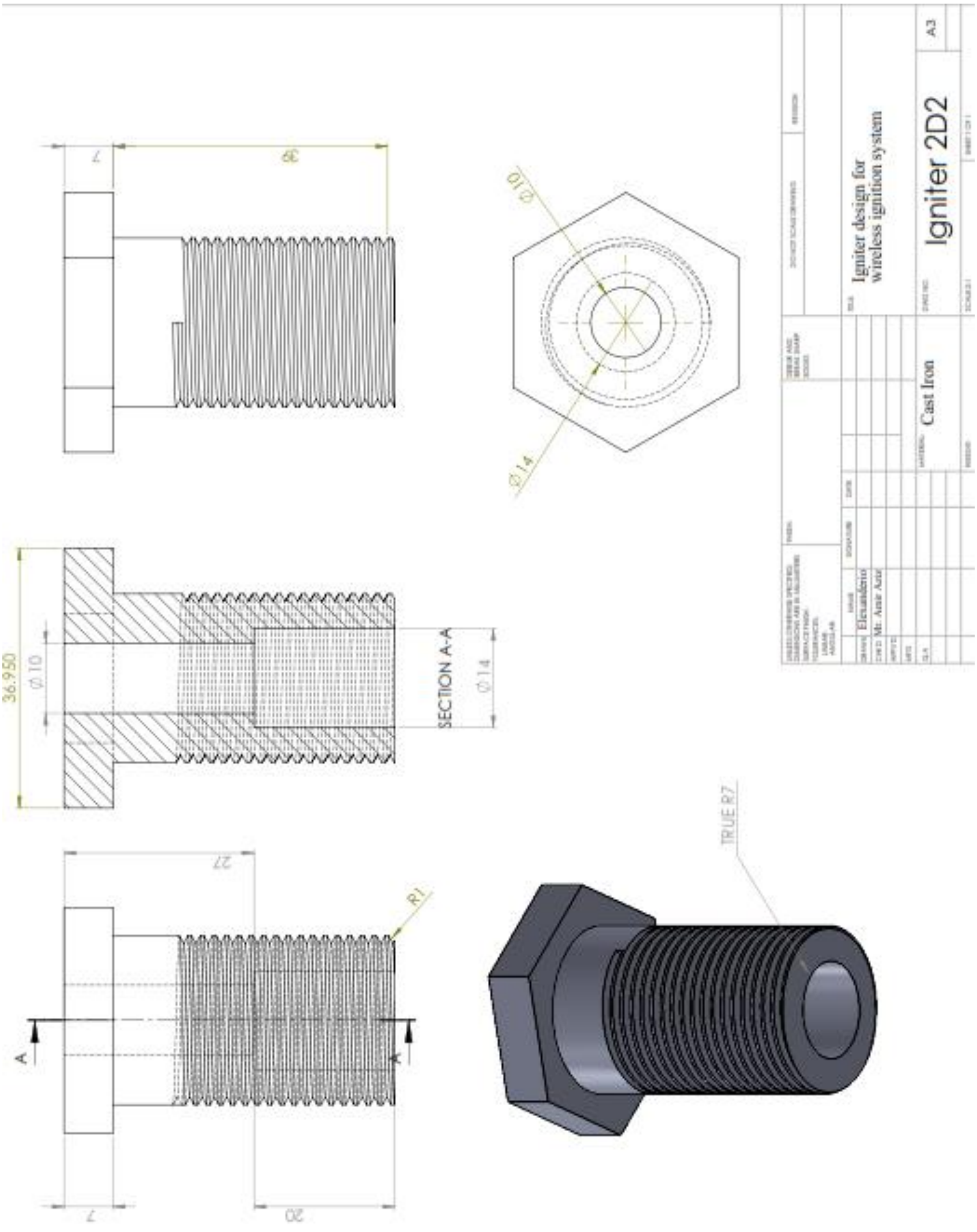

Figure 6.4: Igniter for SRM

Table 6.1: Table of data collected for Case One simulation

Length (mm)	Pressure (kPa)	Velocity (ms^{-1})	Temperature (K)
0	501.3272983	0.0018	393.2
0.005	501.3269196	0.033163728	393.2003915
0.01	501.3250006	0.001261793	393.2003912
0.015	501.3269148	0.012161728	393.2003956
0.02	501.3269173	0.01700175	393.2003959
0.025	501.3269177	0.016984481	393.2003961
0.03	501.3269173	0.018375221	393.2003961
0.035	501.3269167	0.020149905	393.2003962
0.04	501.3269164	0.015355521	393.2003962
0.045	501.3269159	0.01443744	393.2003962
0.05	501.3269154	0.015393216	393.2003962
0.055	501.326915	0.012345023	393.2003962
0.06	501.3269129	0.014542415	393.2003962
0.065	501.3264637	0.108968044	393.2003973
0.07	501.324912	0.294961757	393.2004019
0.075	501.3249906	0	393.2003888
0.08	501.3249514	0.010520044	393.2003731
0.085	501.3249998	0.003915278	393.2003909
0.09	501.3249952	0.003436295	393.200391
0.095	501.3249946	-0.002877321	393.2003897
0.1	501.3249878	-0.004315574	393.2003881
0.105	501.3249949	-0.003902812	393.2003884
0.11	501.3249964	-0.003152206	393.2003893
0.115	501.3250016	-0.004203568	393.2003911
0.12	501.3249937	-0.005796402	393.2003906
0.125	501.3250014	-0.005101246	393.2003941
0.13	501.3249944	-0.006241581	393.2003904
0.135	501.3249922	-0.006561663	393.2003901
0.14	501.3249958	-0.006362802	393.2003898

0.145	501.3249971	-0.006574124	393.2003889
0.15	501.3251534	0	393.2003978
0.155	501.3249995	-0.003845748	393.2003822
0.16	501.324992	-0.007183136	393.2003752

Table 6.2: Table of data collected for Case Two simulation

Length (mm)	Pressure (kPa)	Velocity (ms^{-1})	Temperature (K)
0	801.3250038	0.0018	670.85
0.005	801.3250038	0.001015573	670.8507926
0.01	801.325	1.19629E-07	670.8507931
0.015	801.3250037	0.000524154	670.8507927
0.02	801.3250037	0.000929863	670.8507926
0.025	801.3250037	0.000901264	670.8507926
0.03	801.3250037	0.001126855	670.8507927
0.035	801.3250037	0.001526694	670.8507928
0.04	801.3250037	0.000689098	670.8507928
0.045	801.3250037	0.000616685	670.8507928
0.05	801.3250037	0.000690414	670.8507928
0.055	801.3250037	0.000478881	670.8507928
0.06	801.3250036	0.000599099	670.8507928
0.065	801.3250034	0.005024451	670.8507928
0.07	801.3250014	0.018802842	670.8507926
0.075	801.3250001	0	670.850792
0.08	801.3250008	5.39706E-05	670.8507745
0.085	801.325	1.9247E-05	670.8507911
0.09	801.325	6.70883E-05	670.8507907
0.095	801.325	0.000163678	670.8507903
0.1	801.325	0.00025656	670.8507896
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0.145	801.325	0.000570449	670.8507911
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