الجمهورية الجزائرية الديمقراطية الشعبية

République Algérienne Démocratique et Populaire

وزارة التعليم العالي والبحث العلمي

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Département : Génie électrique Et Informatique Industrielle

End-of-study dissertation with a view to obtaining the diploma of master's degree

Specialty

Embedded systems

- Subject –

The state of the art of propulsion systems

Realized by

Abdenour ABDELLAOUI , Moussa BAKHOUCH

Jury members:

M. REZOUG Amar **M.C.A**	President
M. ZAOUI Abdelhalim **Prof**	Supervisor
M. BENSIKADDOUR ELHABIB	Supervisor
M. BOUDIAR Toufik **M.C.A**	Examiner
Mme BELHACHAT Faiza **M.C.A**	Examiner

College year 2021 –2022

Dedications 1

I dedicate this work,

To my dear parents, to my mother for her love and encouragement,

To my father for his support and his trust in me.

To all the members of my family who have supported me throughout my university career, and to all my friends.

Thank you for always being there for me may this report be the best gift I can give you.

Abdenour ABDELLAOUI

Dedications 2

I dedicate this work,

To my dear parents, to my mother for her love and encouragement,

To my father for his support and his trust in me.

To all the members of my family who have supported me throughout my university career, and to all my friends.

Thank you for always being there for me may this report be the best gift I can give you.

Moussa BAKHOUCH

Acknowledgments

First of all, we thank God who gave us this property and has the strength and patience to complete this work.

We would like to express our thanks to our supervisors Mr. Bensikaddour and Mr. Zaoui who directed this work.

We would like to thank the president of the jury, as well as the members of the jury for agreeing to judge this work.

This work that we have done owes a lot to certain people whom we would like to sincerely thank. Finally, we would like to thank all the people who have contributed from near or far, near or far, to the realization of this work.

Tables of contents

La liste des figures et les tableaux……1

Abbreviations list……2

General Introduction……...……3

I The different types of propulsion....4

I.1 Chemical Propulsion....5

I.1.1 Cold Gas Thruster....5

I.1.2 Hot Gas Thrusters....7

I.2 Electric Propulsion....8

I.2.1 Electrothermal Propulsion....9

I.2.2 Electromagnetic propulsion systems....10

I.2.3 Electrostatic Propulsion....10

II Solid propellant propulsion....11

II.1 Design Considerations....11

II.1.1 Nozzle....11

II.1.2 Combustion Chamber....12

II.1.3 Chamber Wall Thickness....12

II.1.4 Engine Cooling....12

II.2 Testing Equipment....12

II.2.1 Gas supply....12

II.2.2 Test Stand....13

II.3 Safety....13

III Description of test benches....14

III.1 Test Bench Architecture....14

III.1.1 Gas supply....14

III.1.2 Measurement system....15

III.2 Automation of the test bench....16

III.2.1 Test Process....16

III.2.2 User interface....17

General conclusion....18

Bibliography list.....19

List of figures and tables.

Figure I-1: types of spacecraft propulsion systems. 4
Figure I-2: MEMS Cold Gas Propulsion Module for 2-3U Nanosatellites.....5
Figure I-3: JPL-MarCO MiPS schematic (left) and system (right).....6
Figure I-4: EPSS — Green Chemical Propulsion System. 7
Figure I-5: PM-200 propulsion system. 8
Figure I-6: Schematic of chemical (in blue) and electric propulsion (in red). 9
Figure II-7: Typical Solid Propellant Rocket Engine. 11
Figure III-8: Engine mount and thrust measurement.. 15
Figure III-9: Test process and timing parameters for rocket engines. 16
Figure III-10: State machine for the test process. 16

Table I-1: Performance of indentified cold gas thrusters CGTs. 6
Table I 2: Performances des propulseurs mono/bi-ergols identifiés. …….8
Table I-3: Performance of resistojets and arcjets 9
Table I-4: Performance of pulsed plasma and vacuum arc Thrusters (Pulsed Plasma Thrusters (PPTs) and Vacuum arc Thrusters (VATs)). 10

Abbreviations list

AND (Ammonium Dinitramide)

ACS (American Chemical Society)

CGT (Cold Gas Thruster)

GUI (Graphical User Interface)

LED (Light-Emitting Diode)

MEMS (Micro-Electromechanical System)

MPDT (Magneto Plasma Dynamic Thrusters)

PPT (Pulsed Plasma Thrusters)

VAT (Vacuum Arc Thrusters)

General Introduction

Solid composite propellants are highly-filled elastomers used prominently as energetic materials for military ordnance and rockets, with commercial applications such as gas generation.

The purpose of a propulsion test bench is to measure, investigate and demonstrate the temporal evolution of thrust as a result of combustion in a rocket engine. When dealing with it exists a lot of parameters to take into consideration such as thrust, temperature, the pressure of the chamber, the mechanical resistance of the engine, etc.

Thus, we aim in this research to demonstrate the different types of solid rocket engines, going deep into the solid rocket engines. And lastly design and technique of a solid-fuel rocket motor testing system.

In the first title, we aim to describe the different types of propulsion systems listed, the main ones are Chemical, Electric, and others. The two main categories will divide into more and more different types of propulsion.

While we were devoting the second title to focusing only on solid propellant propulsion its design, testing equipment, and safety-related to dealing with this type of proposal.

And lastly, the third title describes the test benches and their architecture. Ending with the automation of the test bench

I The different types of propulsion

Propulsion systems is a technological system generates force with the help of an engine or motor and wheels and axles, propellers, or a propulsive nozzle. A rocket propulsion system can be classified depending on its energy source and function. It can also be categorized into different types of vehicles such as missiles, aircraft, and space vehicles. Its size, type of propellant, and number of units are also taken into account. [1]

The most common way of classifying reaction jets is from their source of energy, specifically their dependence on the onboard power. The two main categories are electric and chemical systems, as depicted in Figure I-1.

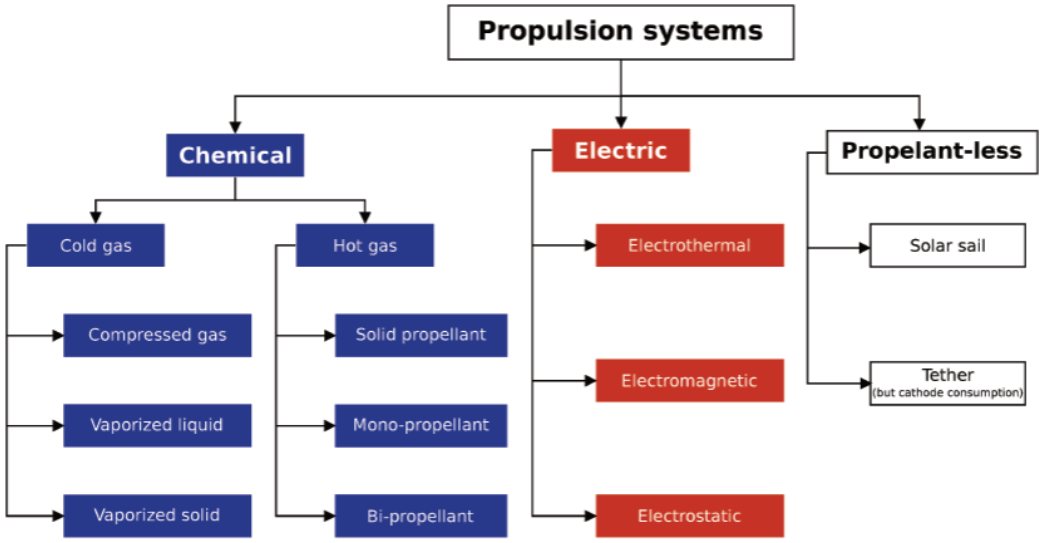


Figure I-1: types of spacecraft propulsion systems. [2]

I.1 Chemical Propulsion

Chemical propulsion generates thrust by accelerating gases at high pressure and/or temperature through a nozzle at high velocity. Chemical propulsion systems have a lower specific impulse than electric propulsion systems, but they have greater thrust-to-power ratios. [2]

I.1.1 Cold Gas Thruster

Cold Gas Thruster (CGT) is a type of propulsion system in which the propellant does not undergo combustion or electromagnetic acceleration. Different variants exist.

I.1.1.1 Compressed Gas

The most basic CGTs are compressed gas thrusters. To generate thrust, the propellant is held under pressure in the thruster and expelled through a nozzle. Despite the fact that such thrusters have a simple and reliable design, their performance is mediocre. Because the thrust produced is dependent on the propellant pressure, it diminishes over the thruster's lifetime. [2]. The MEMS (micro-electromechanical system) propulsion module from NanoSpace was designed to perform the orbit control of the 2U Estelle CubeSat from the QB50 project5 using butane. [3].



Figure I-2: MEMS Cold Gas Propulsion Module for 2-3U Nanosatellites. [4]

I.1.1.2 Vaporizing Liquid

The high vapor pressure of liquid propellants is used in vaporizing liquid thrusters. Their phase transition into gas is caused by expansion. When compared to compressed gas, more propellant can be stored in the same container, but it comes at the cost of higher complexity due to the use of a vaporizer [2]. The JPL Marco Micro Propulsion System from VACCO (see figure I.3), fueled with a two phase propellant, was used on-board the twin-communication-relay CubeSats on their way to Mars. [5].

It must be said that the system from VACCO requires a warm-up phase that highly increases the power consumption (50W), which is usually below 10W for CGTs.

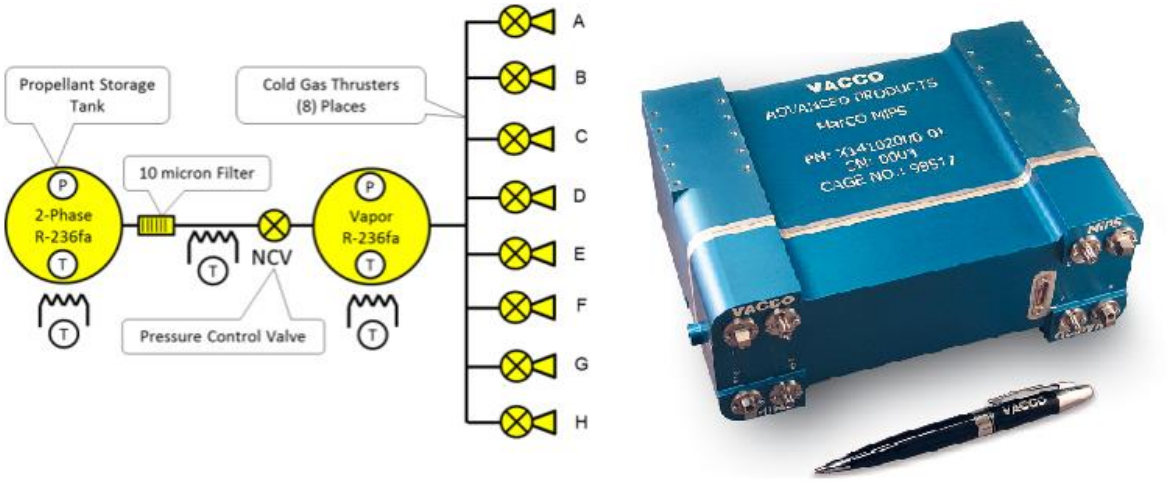


Figure I-3: JPL-MarCO MiPS schematic (left) and system (right). [2]

Model	Mass [kg]	Power [W]	Thrust [mN]	I_{tot}[Ns]	I_{sp} [s]
MEMS	0.280	2	1	40	68
NanoProp 3U	0.350	2	1	40	60
NanoProp 6U	0.900	2	5	80	60
JPL MarCo MPS	3.490	55	25	755	40
NEA Scout MiPS	2.543	55	23	500	40
CuSP	0.690	12	25	60	40
ACS	1.090	5.4	60	115	65
CNAPS	1.890	0.3	31.3	115	45
MEPSI MiPS	0.986	1	53	23	44
MiPS Standard	0.542	10	10	44	40
MiPS end-mounted	0.676	10	10	93	40
C-POD	1.244	5	25	186	40
Palomar	1.063	5	35	85	50

Table I-1: Performance of indentified cold gas thrusters CGTs. [2]

CGTs provide a lot of advantages when it comes to CubeSat integration. A single propellant tank can easily feed numerous thrusters due to their simple construction, offering orbit or attitude control capabilities. VACCO, for example, created the ACS (American Chemical Society) to regulate the Interplanetary NanoSpacecraft Pathfinder in Relevant Environment mission's attitude (NASA). Table I-2 has a more comprehensive list of CGTs.

I.1.2 Hot Gas Thrusters

Cold gases are no longer viable for missions needing higher levels of thrust and impulse, and more energetic fuels generating hot gases are required. The most popular type of space propulsion is hot gas systems. Hot gas propellants are kept in either a liquid or solid condition. To acquire high temperature products that are then discharged into the nozzle, the propellant must undergo an exothermic combustion reaction. As a result, they usually necessitate an extra step over cold gases. They are divided into three types based on the propellant they use. [2].

I.1.2.1 Liquid Mono-Propellant

Liquid mono-propellant systems rely on the decomposition of its single propellant, which is aided by a catalyst. Because of the engine preheating, they demand more power than CGTs. Hydrazine has long been the standard rocket fuel for attitude control, resulting in a rich flight history that CubeSats can learn from. Aerojet Rocketdyne's MPS-120 is a hydrazine propulsion system that is slightly larger than 1U and can offer attitude and orbit control with a total ΔV budget of 209 ms^{-1}. [6]. Because of its severe toxicity, managing hydrazine necessitates strict methods. Many propulsion designers are working on systems that use these "green" propellants, but they confront technological problems such as higher power consumption and higher combustion temperatures. The Green Chemical Propulsion System by NanoAvionics is a 1U propulsion system that runs on a green ADN-based propellant. The Green Chemical Propulsion System by NanoAvionics is a 1U propulsion system that runs on a green ADN-based propellant displayed in figure I-4. [7].

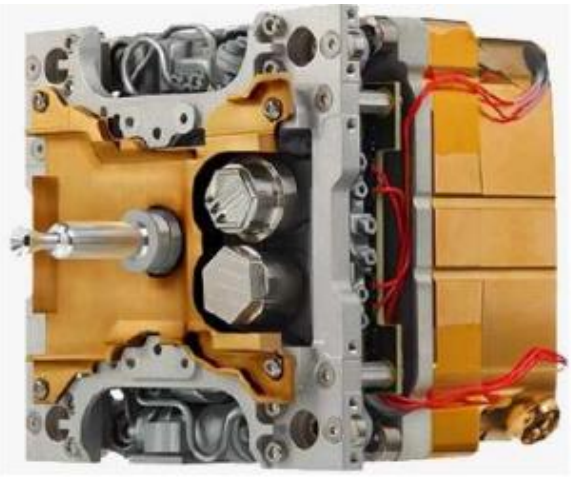


Figure I-4: EPSS — Green Chemical Propulsion System. [8].

I.1.2.2 Liquid Bi-Propellant

A fuel plus an oxidizer make up a bi-propellant system. Before being ejected, the two propellants are self-ignited in a combustion chamber. Such systems offer extremely high V, which was previously necessary for tasks like orbit-rising. The PM400 and PM200 are two bi-propellant systems created by Hyperion Technologies. For 3U and 6U CubeSats respectively. [9]. Table I-3 shows the performance of identified liquid mono- and bi-propellant thrusters.

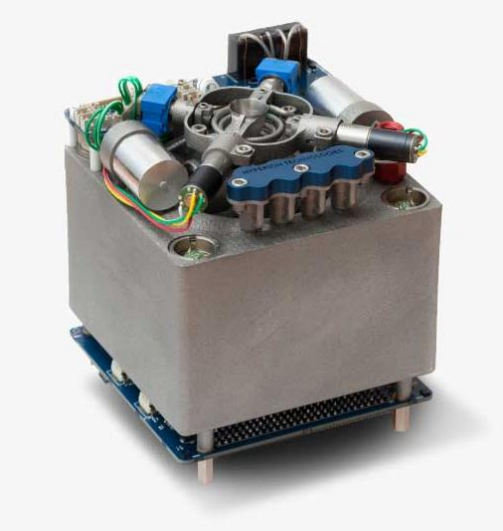


Figure I-5: PM-200 propulsion system. [10].

Table I-2: Performances des propulseurs mono/bi-ergols identifiés. [2]

Model	Mass [kg]	Power [W]	Thrust [mN]	I_{tot}[Ns]	I_{sp} [s]
MPS-120	1.480	10	1	775	210
BGT-X5	1.5	20	0.5	565	220
ADN MiPS	1.797	15	0.1	1.036	200
ArgoMoon PS	2.065	20	0.1	783	190
Lunar Flashlight PS	5	35	0.15	3.320	169
EPSS	1.2	8	0.1	650	200
MPS-130	1.660	25	0.75	1.200	244
PM400	2.025	6	1	1.750	285
PM200	1.410	6	0.5	850	285
HYDROS-C	2.640	25	1.2	2.252	310

I.2 Electric Propulsion

Electric propulsion gets beyond the fundamental constraint of chemical propulsion, which is that the energy of the expelled fuel is solely determined by its chemical energy and flow rate. To eject material at considerably faster speeds, electrical or electromagnetic energy is required. To put it another way,

the electrical energy from the electrical subsystem (solar panels, batteries, etc.) is used to accelerate the fuel and generate thrust. Higher ejection speeds result in increased efficiency right away (less fuel is needed to achieve the same speed increment). Nonetheless, compared to chemical propulsion, the thrust forces produced are substantially smaller. As a result, when it is necessary to conduct maneuvers with very low thrust, V to be obtained is critical (very precise attitude control, etc.) [2]. Figure I-6 depicts the differences between chemical and electric propulsion.

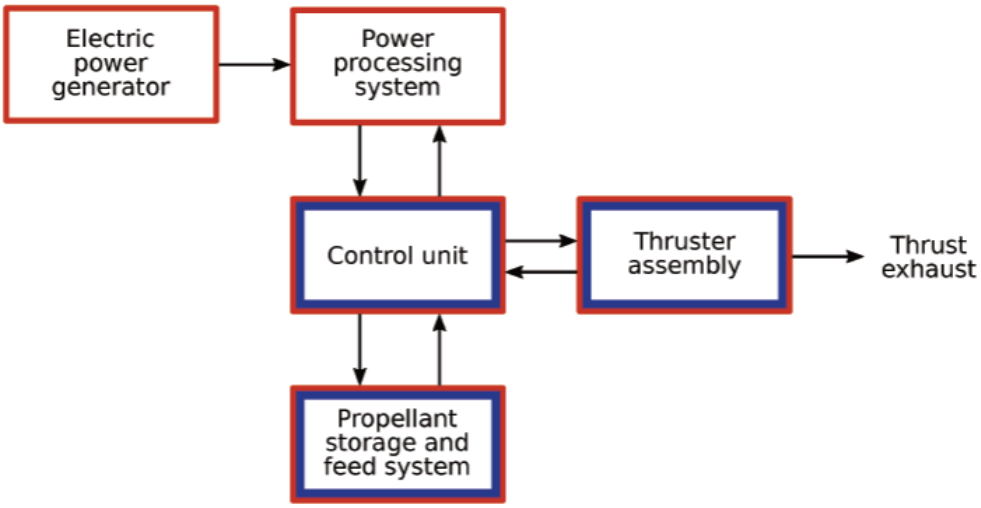


Figure I-6: Schematic of chemical (in blue) and electric propulsion (in red). [2].

I.2.1 Electrothermal Propulsion

These systems have historically been superior to chemical propulsion systems. To give it additional energy, the gas is heated by passing it through an electrically heated surface (resistojets) or through an electric arc (arcjets). The gas that is so heated has a more efficient expansion. Resistojets are somewhat popular for CubeSat applications (see Table I-4).

Table I-3: Performance of resistojets and arcjets [2]

Model	Mass [kg]	Power [W]	Thrust [mN]	I_{tot}[Ns]	I_{sp} [s]
XR-50-050	0.470	50	150	120	49
VHTR	0.5	100	100	246	100
MRT	1.250	15	10	404	150
PUC 0.25U	0.718	15	5	184	70
PUC 0.5U	0.980	15	5	320	70
PUC 1U	1.5	15	5	593	70
MVP	1.2	35	6.7	540	83

I.2.2 Electromagnetic propulsion systems

The conversion of a gas into plasma is used in electromagnetic propulsion. Electrons (with a negative electrical charge), ions (with a predominantly positive electrical charge), and neutral atoms or molecules make up plasma (not electrically charged). The resulting positive ions are then accelerated to very high speeds by electrical energy through Laplace's force $\mathbf{j} \wedge \mathbf{B}$, where j and B are the ion current flow in the plasma and the magnetic field, respectively. This results in a pushing force on the satellite in the opposite direction.

The electromagnetic systems, unlike the electrostatic systems that will be discussed later, emit globally neutral plasma, which is useful for avoiding electrically charging the remainder of the satellite. This family of thrusters includes PPTs (Pulsed Plasma Thrusters), VATs (Vacuum Arc Thrusters) and MPDTs (Magneto Plasma Dynamic Thrusters). [2].

Table I-4: Performance of pulsed plasma and vacuum arc Thrusters (Pulsed Plasma Thrusters (PPTs) and Vacuum arc Thrusters (VATs)). [2].

Model	Mass [kg]	Power [W]	Thrust [mN]	I_{tot}[Ns]	I_{sp} [s]
PPTCUP	0.286	2	40	40	670
NanoPPT	0.350	5	90	190	640
BmP-220	0.5	7.5	20	220	536
L-µPPT	0.750	3	120	785	1000
µCAT	0.240	2.5	50	1180	3000
Plasma Jet Pack	0.800	30	45	4000	5000

I.2.3 Electrostatic Propulsion

Like electromagnetic acceleration, electrical energy is first used to transform the propellant fluid into plasma. The difference is at the level of the acceleration of the ions which is no longer obtained by the Laplace forces but by the application of an electrostatic field **E** creating a Coulomb force($\mathbf{F} = q\,\mathbf{E}$). A cathode is frequently used in such systems to emit electrons that neutralize the exhaust plume, preventing the accumulation of charged particles on the satellite's exterior surface. This makes scaling down CubeSats more difficult.

II Solid propellant propulsion

The solid rocket engine is a relatively basic device that produces thrust by burning propellants and expanding the resulting high pressure gases through a specially designed nozzle. Ignition causes solid propellant burning. The propellant usually consists of solid oxidizer and fuel, Regardless of the propellant's kind or grain, it will chemically react (burn) to produce hot gases that will be accelerated and ejected at high velocity through a nozzle. As a result, the engine gains momentum. The product of mass and velocity is momentum. The reaction experienced by the motor structure due to the expulsion of high-velocity matter is the thrust force of a rocket motor. [11].

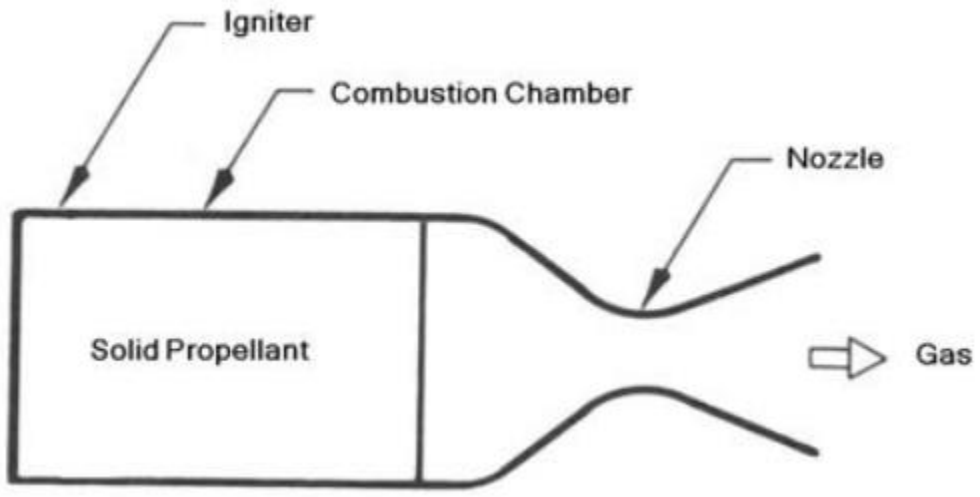


Figure II 7: Typical Solid Propellant Rocket Engine. [11].

As depicted in Figure I-7, a typical rocket motor consists of the combustion chamber, nozzle, and igniter. The combustion chamber is where propellants are burned under high pressure. It must be strong enough to contain the tremendous pressure and temperature generated by the combustion process. The nozzle's function is to transform the chemical-thermal energy produced in the combustion chamber into kinetic energy. It converts the slow moving, high pressure, high temperature gas in the combustion chamber into high velocity gas of lower pressure and temperature. The nozzle converts the combustion chamber's slow-moving, high-pressure, high-temperature gas into a high-velocity, lower pressure, lower temperature gas. The nozzle exit area is the flow area at the conclusion of the diverging section. The nozzle is usually designed long enough (or the exit area is large enough) so that the pressure in the combustion chamber is decreased to the pressure outside the nozzle at the nozzle exit. [11].

II.1 Design Considerations

II.1.1 Nozzle

If the entire propellant flow rate is known and the propellants and operating conditions have been chosen, the nozzle throat cross-sectional area may be calculated. To achieve maximum thrust, the hot gases must now be expanded in the diverging part of the nozzle. As energy is utilized to accelerate the

gas, the pressure of the gas will decrease, and we must now locate the area of the nozzle where the gas pressure equals atmospheric pressure. This area will then be the nozzle exit area. [11].

II.1.2 Combustion Chamber

The characteristic chamber length L^* ,is a parameter that describes the chamber volume necessary for full combustion.

$$L^* = V_C/A_t$$

Where V is the chamber volume in cubic inches (including the nozzle's converging section), and A is the nozzle throat area in square inches. L* is a replacement for determining the reacting propellants' chamber residence time. [11].

II.1.3 Chamber Wall Thickness

The combustion chamber must be able to resist the hot combustion gases' internal pressure. Because the combustion chamber must be physically connected to the cooling jacket, the chamber wall thickness must be sufficient for welding or brazing. [11].

$$S = PD/2t_w$$

P is the pressure in the combustion chamber, D is the cylinder's mean diameter, and t_w is the cylinder wall thickness. Copper is a common material for small water-cooled combustion chambers. [11].

II.1.4 Engine Cooling

Cooled rocket motors have provision for cooling some or all metal parts coming into contact with the hot combustion gases. A rocket engine's energy release per unit chamber volume is enormous, up to 250 times that of a competent steam boiler and five times that of a gas turbine combustion chamber. A rocket engine's heat transmission rate is typically 20 to 200 times that of a competent boiler. As a result, it is clear that the cooling of a rocket engine is critical. The injector is usually self-cooled by the incoming flow of propellants. The combustion chamber and nozzle definitely require cooling. [11].

II.2 Testing Equipment

In this section, we'll go over the auxiliary equipment that's required to run the rocket engine, how it's installed, and how to use it safely. [11].

II.2.1 Gas supply

Gases stored in cylinders at high pressure, Gas cylinders with high pressure should never be dropped or mishandled. Cylinders should be stored in such a way that they do not tumble over or roll accidentally; the ideal method is to stack them or strap the cylinders to an appropriate stand or worktable. The cap should be left on when the cylinders are not in use to protect the cylinder valve.

Several high-pressure gas suppliers publish instruction books on how to care for and utilize high-pressure cylinders. [11].

II.2.2 Test Stand

The amateur rocket engine test platform is a structure with a technique for securing the rocket engine in place. The operator's station, which is technically part of the test stand, should be isolated from the test stand proper by at least 200 feet, with a shrapnel barricade in between. The operator's station should contain the safety guard, the ignition system battery and associated switches, and a mirror system so that the operator does not directly view the operating rocket engine. The test stand should be suitably barricaded to reduce the shrapnel effect in all directions. In case of engine explosion or disintegration, which is the biggest hazard in dealing with small rocket engines. [11].

II.3 Safety

Certain basic safety precautions must be maintained in static testing of rocket engines due to the physical risks involved in handling propellants and controlling the high-pressure combustion process. [11].

During the design, and later, the operation of solid rocket engines, the following general safety precautions shou1d be observed:

1. The operator should be protected by a suitable barricade located some distance (at least 200 feet) from the test unit.
2. Control of switches during engine ignition and steady-state operation should be by remote.
3. A large chemical fire extinguisher (or, at least, a plentiful supply of water) should always be on hand.
4. The operator should not view the test unit directly, but should use a mirror arrangement (somewhat like a periscope) or use a thick layer of reinforced safety glass attached to the operator's barricade. Remember, the primary danger is from shrapnel in the event of engine explosion.
5. The test stand unit should be barricaded on several sides to reduce shrapnel effect in event of explosion.
6. All equipments which directly sense hot gases should not be located in the operator's station, but should be on the test stand and remotely read. This rule does not apply to electrical instrumentation wherein a transducer is located on the test stand and an electrical readout (such as a meter) is located at the operator's station.
7. Warning signals should be given prior to tests to notify personnel that the area is hazardous. A test must never be conducted until the operator has assured himself that all personnel is behind safety barricades or otherwise protected.
8. Personnel should be permitted to work in the test area only if the igniter is removed.
9. Personnel handling propellants should wear safety equipment such as gloves, face shields, or rubber aprons. Remember that most fuels are toxic; do not breathe propellant exposes for even a short time.

10. No smoking is ever permitted anywhere near a test area when propellants are also present, Remember dust from Propellants can travel long distances from the test area and can be ignited at a remote point traveling back to the test stand.
11. A check-off list is helpful when conducting a rocket engine firing and should be made up of both technical events and safety items to be completed prior to the firing.

III Description of test benches

The objective of our project is to create a test bench for a solid propellant engine. In this section, we shall describe the design technique of a solid-fuel rocket motor testing system for its thrust measuring capabilities.

After building a solid rocket engine, it is necessary to conduct many tests to evaluate the rocket engine's performance in order to ensure the stability and safety of the solid propellant rocket motor. The performance of a rocket motor is normally tested in a test bench on the ground before it is launched. [12].

Prior to any rocket flight, ground testing are usually conducted in a test bench to ensure that the desired characteristics and integrity of the designed rocket engine can be maintained. Conducting ground static tests is important since it allows you to ensure that your motor's characteristics are in line with the design parameters. A ground test system, which must be located away from residential areas, must include the following components: a means of securing the rocket engine in place, either horizontally or vertically; equipment to test the chemical properties of exhaust gas; data acquisition system to measure the thrust-time profile; and electronics to control propellant ignition from a safe distance. [13].

A ground test system, as a matter of necessity, must be sited remotely from residential locations and includes the following: a means of securing the rocket engine in place either in a horizontal or vertical position; equipment to test the chemical properties of exhaust gas; data acquisition system to measure the thrust-time profile and electronics to control ignition of the propellant from a safe distance. [13].

III.1 Test Bench Architecture

III.1.1 Gas supply

On the test bench, two gases are required to test a hybrid rocket engine. The first gas is an oxidant, while the second is an inert gas that will be used to purge the system after the test is over. Nitrous oxide is employed as an oxidizer on P7, and nitrogen is used to purge. [15].

It's critical to purge the engine after a test to ensure that there are no combustible or explosive remnants from the test. There are additionally two manual valves that must be opened after mounting the engine and closed after dismounting for safety reasons. The pneumatic valves can be controlled from a save position. A non-return valve near to the engine makes sure that no gases or flames from

the engine can get into the supply lines. Another non return valve in the purging line prevents the nitrous oxide from flowing into the purging line. [15].

III.1.2 Measurement system

There are two quantities of interest for the reaction inside the thrust chamber: pressure and temperature. Both are impossible to measure within the thrust chamber. Between the engine and the none-return valve is a pressure senor that is used to estimate this pressure (Figure I-8). To control the pressure inside the oxidizer tank, another pressure sensor is located near the nitrous oxide tank. [15].

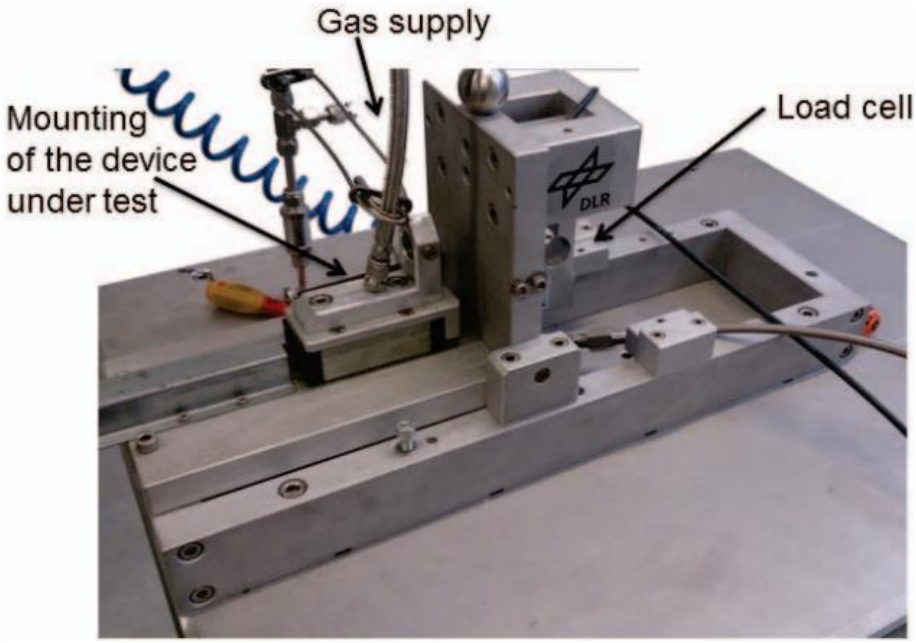


Figure III 8: Engine mount and thrust measurement. [15].

Currently, the temperature can be measured in eight different places, each of which vary from engine to engine. The temperature within the thrust chamber wall, because this permits computing the temperature inside the thrust chamber, and the temperature at the nozzle, because this is where the maximum temperature and hence the largest load for the material the engine is composed of. [14].

III.2 Automation of the test bench

III.2.1 Test Process

Figure I-9 depicts the solid rocket engine testing procedure. The operator terminal can set the pre-ignition time, burning time, and purge time, but the other parameters are fixed.

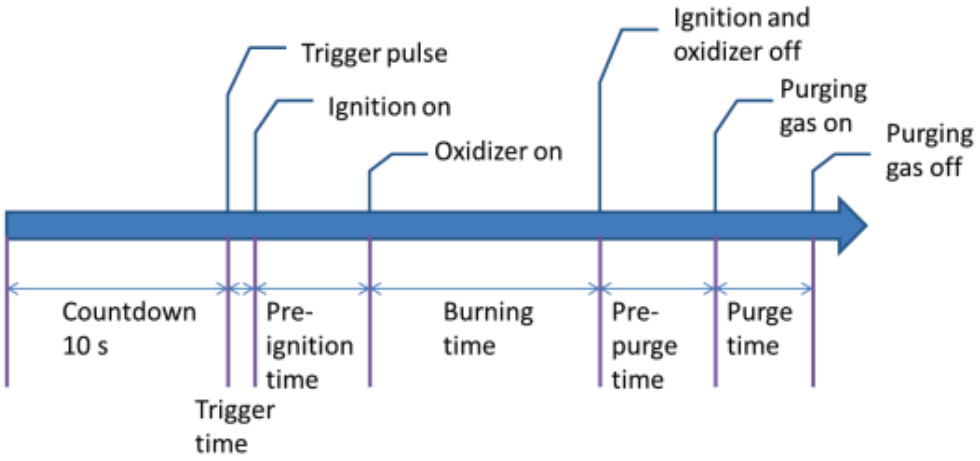


Figure III 9: Test process and timing parameters for rocket engines. [14].

A countdown sequence begins after the process is started. The ignition is then started by sending a trigger signal with its falling edge. A brief pre-ignition interval is required because the pyrotechnic initiator (igniter) requires some time to deploy its energy. It is critical to remember that ignition is impossible without first ensuring that the detonator cap is properly installed and the ignition circuit is all powered. As a result, a manual test using a tiny test current and an indicator LED (light-emitting diode) is carried out. When it is ignited, the fuel burns for as long as the oxidizer is flowing. [14].

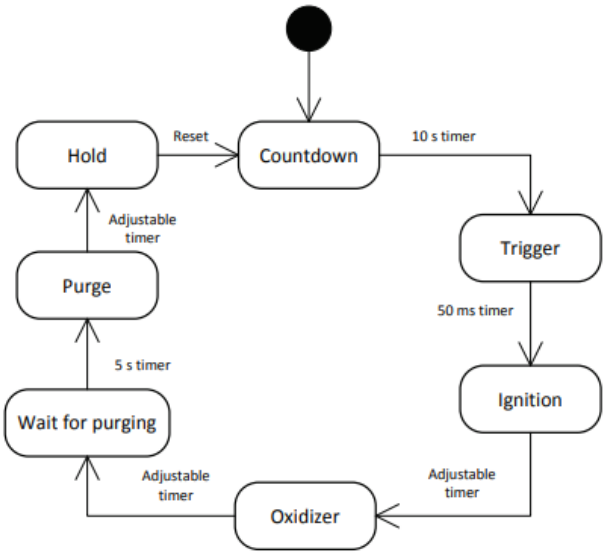


Figure III-10: State machine for the test process. [14].

The system waits until the combustion has assumedly stopped before starting to cleanse the reaction chamber of residual oxidizer and reaction products after the burning period that may be adjusted via the operator terminal. The test system is located within the operator room in a portable control station, while the test bench is outside. [14].

During the exam, no one is permitted to access the test area. In testing with huge engines, camera surveillance and the presence of security staff enforce the safety standards.

III.2.2 User interface

III.2.2.1 Hardware user interface

The hardware user interface consists of a switch panel with the following functions:

- Triggering of the automatic process
- Test of the conductivity of the ignition circuit
- Releasing the ignition
- Saving data acquired from multiple sensor into an SD card

III.2.2.2 The software user interface

The software user interface consists of GUI (Graphical User Interface)

- A section for testing the connection between the user interface and the carte
- A section for choosing the amount and the specific sensor to acquire from
- A section to start ignition/firing countdown
- Multiple graphs panel to display data acquired from multiple sensors
- A section to save data

General conclusion

Going through those major titles we introduced the fundamentals and different types of propulsions and differentiate there their source of energy and their mechanisms. Alongside the study of safety and reliability constraints in the instrumentation of a solid propellant thruster test bench. Lastly, we end with an in-depth general description of test benches that contains the outside architecture gas supply, measurement system, the automation of the test bench, its process, and the importance of the user interface.

Bibliography list.

[1]. Sutton, G. P. and Biblarz, O., Rocket Propulsion Elements, 1987

[2]. Quinsac, Gary, Use of off-the-shelf components for the propulsion of nanosatellites: at what price?, 2019

[3]. U. Kvell, M. Puusepp, F. Kaminski, J.-E. Past, K. Palmer, T.-A. Grönland, Proceedings of the Estonian Academy of Sciences, 2014

[6]. R. K. Masse, C. B. Carpenter, D. T. Schmuland, J. Overly, and M. Y. Allen, CubeSat High-impulse Adaptable Modular Propulsion System (CHAMPS), 2013

[7]. NASA, State of the Art of Small Spacecraft Technology, 2019

[9]. S. Powell, T. Knop, and S. Engelen, Experimental evaluation of a green bi-propellant thruster for small satellite applications, aug 2016.

[11]. Ziraksaz, M. H., How to Design, Build and Test Small Solid Propellant, 2012

[12]. Francisco Teloken, Tiago Cassol Severo, Matheus Poletto, Development of a vertical static test bench for amateur rocket engines, 2018

[13]. O. O. Babayomi, C. A. Osheku, M. A. L. Adetoro, A. Okon, A. O. Opasina, Low cost ground test equipment for atmospheric rocket flights using embedded systems, 2013

[14]. Tobias Neff, Markus Rehberger, Ansgar Meroth, Thrust test bench for student rocket engines, 2016

[15]. S. Powell, T. Knop, and S. Engelen, Experimental evaluation of a green bi-propellant thruster for small satellite applications, aug 2016.

[4]. global, spacewatch, https://https://spacewatch.global/.global/

[5]. VACCO, JPL MarCO Micro CubeSat Propulsion System, http://www.cubesat-propulsion.com/jpl-marco-micro-propulsionsystem/

[8]. NanoAvionics, CubeSat Propulsion “EPSS” – Green Chemical Propulsion, 2019, http://n-avionics.com/propulsionsystems/small-satellite-green-chemical-propulsion-system-epss/

[10]. space, aac clyde, https://www.aac-clyde.space/what-we-do/space-products-components/pm200

Abstract

Through this study, we establish the constraints and requirements on on-board instrumentation in terms of reliability and safety. Knowledge of the operating environment of the thruster also sets the selection criteria for the sensors and on-board electronic components according to the working conditions (temperature range, mechanical vibration, very fast acquisition of certain signals, etc.)

Keywords: Propellant test bench, Solid propellant propulsion, Measurement system

Résumé

A travers cette étude, nous établissons les contraintes et les exigences de l'instrumentation embarquée en termes de fiabilité et de sécurité. La connaissance de l'environnement de fonctionnement du propulseur fixe également les critères de sélection des capteurs et des composants électroniques embarqués en fonction des conditions de travail (gamme de température, vibration mécanique, acquisition très rapide de certains signaux, etc.)

Mots-clés : Banc d'essai d'ergols, Propulsion à propergol solide, Système de mesure

الملخص

من خلال هذه الدراسة ، وضعنا القيود والمتطلبات على الأجهزة على متن الطائرة من حيث الموثوقية والسلامة. تحدد معرفة بيئة تشغيل المحرك أيضًا معايير الاختيار لأجهزة الاستشعار والمكونات الإلكترونية الموجودة على متن الطائرة وفقًا لظروف العمل (نطاق درجة الحرارة ، والاهتزاز الميكانيكي ، والاكتساب السريع جدًا لإشارات معينة ، وما إلى ذلك)

الكلمات المفتاحية: منصة اختبار الدفع ، الدفع بالوقود الصلب ، نظام القياس