Space Propulsion Project - Group 2

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***Abstract*—This report is part of the Space propulsion course by Jäger Markus Hendrik. The main objective of this course is to provide an overview of space propulsion systems and to describe the basic design principles of propulsion systems. The aim of the project is to develop a 1.5 stage launcher based on liquid propulsion. This report responds to the fifth exercise of May 17, 2022: Qualification review.**

I. Design of the Rocket

The designed rocket is a 1.5 stage launcher including one core stage and two boosters. Core stage and booster propulsion are based on liquid propulsion using water and air pressure. To be able to perform a recovery, the upper stage of the rocket can be split in two part, one that hold the hardware, such as the electronic bay and the release mechanism of the parachute, and the other one contains the parachute. The rocket is made of four segments, which are from top to bottom :

- Storage and deploying system of the parachute
- Electronic devices
- Propulsion system : 1 core stage and 2 boosters
- 4 Fins to enhance the stability and the control of the rocket

II. Description of all products used

The core stage of the rocket is composed of two bottles (2L). One bottle for the propulsion mechanism and the other to place the necessary electronic devices and the parachute. Boosters are also made of standard plastic bottles (1,5L).

As far as avionics is concerned, a Raspberry Pi Pico is needed to record data, notice when the rocket has reached its apogee and deploys the parachute. For the Raspberry, a header and the Grove shield for Pico are used, with some Grove cables to connect the sensors to the card.
A barometer detects when the air pressure starts to rise again and an accelerometer calculates when the vertical velocity is zero. The raspberry, the sensors and the parachute are placed in the upper stage of the core stage. A servo motor performs a rotation when the raspberry, using the sensors, detects the apogee, to release one of the elastic band to deploy the parachute. All this avionics is powered by an USB portable battery.

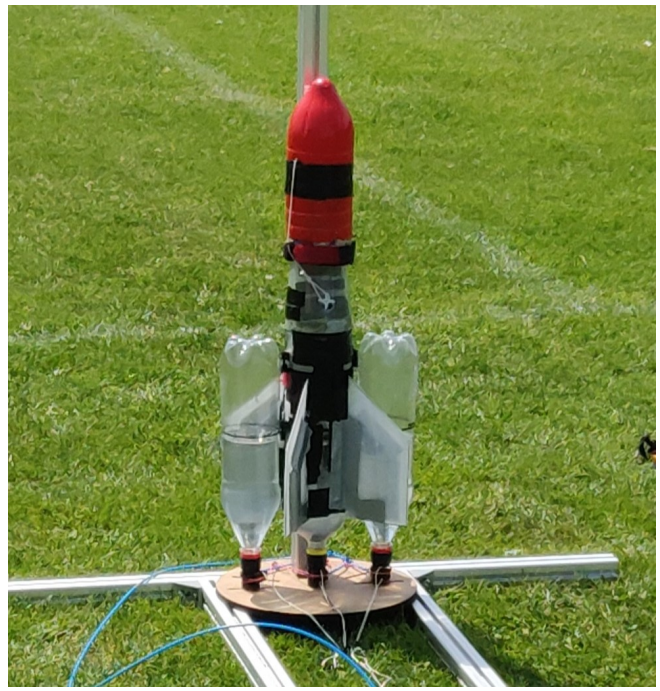

Figure 1. The rocket at the trial launch.

To maintain the boosters along the core stages until separation, they are each one attached to the core stage with three 3D printed pins. Those pins has been fixed using epoxy glue. Also to keep stability and lower the pressure center (Cp) during the flight, four fins are added to core stage, they are made of plastic. A 3D printed nozzle is also added at the extremity of the core stage (explained in part III).

Everything is fixed together mainly with rubber band. All the material used and their corresponding weight are summarized in Table I.

III. Fluidical architecture

The propulsion system of our device is pretty simple. The core stage is filled with air at a precise pressure (7 bar) and with a certain volume of water (0,9L), both optimized to

Items	Weight in [g]
2L soda bottle x2	53 x2
1.5L soda bottle x2	40 x2
Raspberry pi pico	3
Barometer	5
GPIO header	5
Servo Motor	9
3D printed pins	15
Nylon Rope Ø5 mm (0.013 kg/m)	13
Parachute	28
Epoxy glue	5
Rubber band x2	3 x2
Portable battery	77
Fins x4	5 x4
Total	$\sim 376[g]$

Table I
MATERIAL USED AND ESTIMATION OF THE DRY MASS OF THE ROCKET.

reach the highest possible altitude. Two boosters are added on the side of the core stage (7 bar and 0,7L of water) and attached with a system of pins male/female. (figure 2).

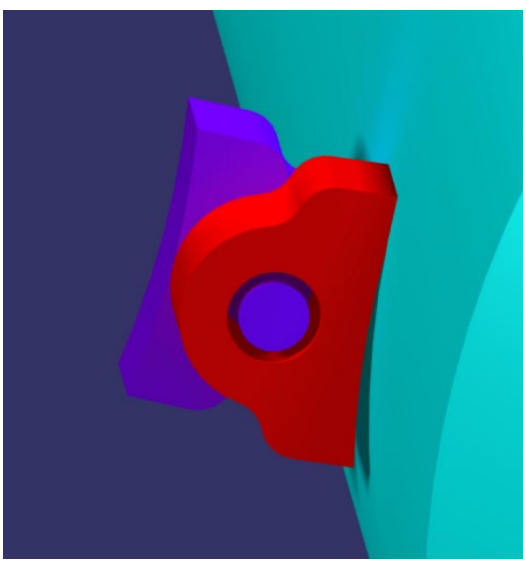

Figure 2. The pin male/female of the attachment system of the booster on the core stage

The idea is the following : At lift off, the boosters provide extra thrust to the rocket. After a certain time, they run out of water and decelerate due to aerodynamic forces and gravity. The reduction of the diameter of the core stage via a nozzle increases the burn time so that it becomes bigger than the burn time of the boosters and allows the boosters to fall while the main core of the rocket continues its journey. When the core stage runs out of water, it also decelerates until it reaches its apogee and then starts to fall.

IV. ELECTRICAL ARCHITECTURE

In order to deploy the parachute at the right moment, the rocket is equipped with some electrical devices :

- A Raspberry Pi Pico
- A barometer
- An accelerometer
- A Servomotor
- A battery

We want the parachute to open when the rocket reaches its apogee. To detect it, we have several possibilities :

- Find a zero velocity in the z-axis
- Find a change in the evolution of the pressure

To be sure not to make any mistake and be robust to noise, we chose to use both the accelerometer and the barometer to detect the right moment. The raspberry pi is used to link all the elements together but needs electrical power to be used, so we have also added a battery. We also use the memory of the raspberry to stock the data collected during the flight.

The architecture of the electrical devices is composed of the outside and the inside parts:
The outside contains the servo motor so that it can perform a rotation outside of the rocket, and the barometer. It is also outside to be able to properly work and measure the current air pressure more precisely. They are both connected with cables to the raspberry pi that is inside the structure.

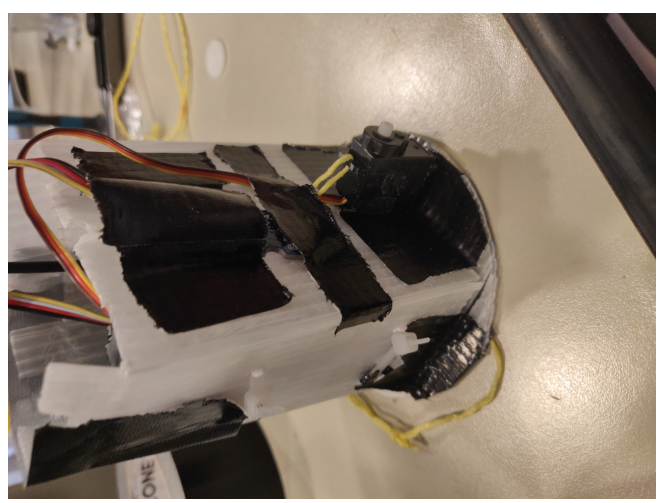

Figure 3. The electrical architecture's outside view.

The inside part is composed of the USB battery, the Raspberry Pi Pico and the accelerometer. All the parts are

linked to the raspberry pi that uses the battery to power itself and the other devices to perform analysis of the flight and release the parachute at the appropriated time. The different parts are taped on the plastic box so that they won't move freely during the phases and it also avoids to break the more fragile devices like the raspberry pi, the barometer and the accelerometer.

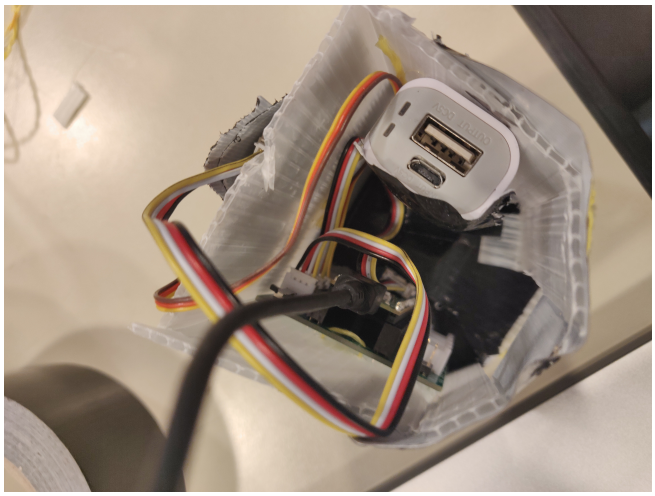

Figure 4. The electrical architecture's inside view.

V. Deployment of the parachute

The parachute is attach above the electronic bay and stands during the ascent phase in the upper half-bottle, which is tighten by two elastic band to the core stage. The servo motor performs a rotation when the raspberry, using the sensors, detects the apogee, to release one of the elastic band to pull the half-bottle part, which leads to the deployment of the parachute.

VI. Budgets

Wet (takeoff) mass	2680 g
Dry mass total	380 g
Propellant core stage	46,7% water
Propellant booster stage	45% water
Pressure core	7 bars
Pressure booster	7 bars

Table II
Budgets of the rocket

VII. Launch phases

The mission needs to follow the different phases (figure 5) in order to perform a nominal flight:

- **Avionics powers in**: Once the rocket is on the launch-pad, the cable between the Raspberry and the battery is connected and powered in.
- **Countdown**: The pressure is then slowly introduced in the core stage and the boosters. After stabilization the countdown began.
- **Liftoff**: Mechanism of the launchpad is released and allows engine ignition and liftoff.
- **End of booster burn and booster separation**: All boosters fuel has been evacuated. No more thrust is given and they automatically fall with gravity.
- **Apogee reached of the center core and center core's parachute deployment**: When apogee is reached and detected by sensors, the electronic activates the servo motor and release the parachute to perform a recovery.
- **Landing of the center core**: If everything went as planning, then the parachute slowly bring back down the launch vehicle without damages.

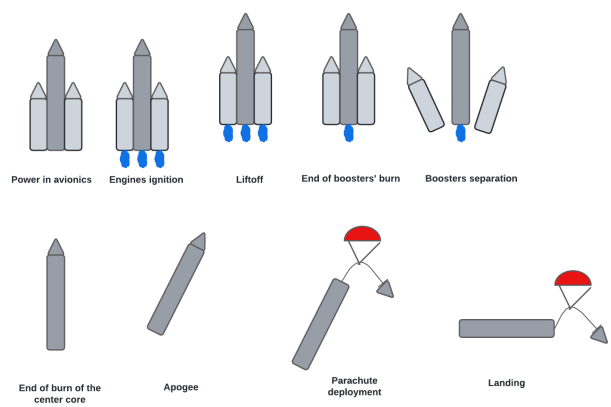

Figure 5. Summary of the mission phases.

VIII. Verifications performed

Prior to the trial launch, several requirements were verified. Following Table III, apogee was estimated by simulation on *Matlab* with the precise mass of the rocket before the launch. And, it will also be tested during the trial launch by analysing the data of the accelerometer and the pressure sensor (MS-01, VF-03/04).

Parachute deployment was verified by triggering an impulsion of the Servo motor with the Raspberry, i.e. by sensing the increase of pressure after the apogee and with a backup timer (MS-02), if it succeeds then launch vehicle should have a safe landing (MS-03).

Requirements FCT-01/02/03, DGN-01/02/03, CONF-01/02/03, SAF-01, INT-01/02 were directly verified by design. During static firing test, on 16.05.2022, the maximum pressure was tested (FCT-04, VF-01).

To ensure a nominal separation of the boosters and the center core the burn time of the boosters was computed in order to have a bigger thrust and a shorter burn than the main core. It was calculated to ensure boosters and core stage are at same pressure (FCT-06). Secondly, the attachment of the boosters on the center core are designed to disconnect by itself (only by gravity) after the end of the burn. Expressed in I, the dry mass of the rocket is approximately 680g and does not exceed 1.5kg and it is bellow 120cm (PHYS-03/04)

The vertical lift-off will be estimated by the calculation of the center of mass and the center of pressure with the software *Open Rocket* to stay aerodynamically stable at launch rail exit and during flight (MS-04). The CG shall be at least one diameter of the rocket ahead of the CP.

To date, all possible verifications has been done. Many of this verification will also be tested during a trial launch on 17.05.2022. All failures and lessons learned will be analysed on the next report in order to succeed during the final launch.

Ref	Description	Verification method
MS-01	The launch vehicle shall reach an apogee between 10 m to 200 m (AGL)	On-board altitude measurement
MS-02	The launch vehicle shall deploy a parachute	Ground test of deployment
MS-03	The launch vehicle shall have a safe landing, such that it can be reused without any modification	Visual inspection after landing
MS-04	The launch vehicle shall be aerodynamically stable at launch rail exit and during flight	Design
FCT-01	All propulsion systems shall initiate at lift-off	Design
FCT-02	All propulsion systems shall exclusively use water and either air or nitrogen for pressurization	Design, visual confirmation during launch pad operations
FCT-03	If applicable, booster stage shall be discarded at "burnout" (i.e. as soon as no more thrust is generated)	Design
FCT-04	Maximum pressure allowed for COTS pressure vessels at launch is [7] bar	Design, will be regulated by GSE operators
FCT-05	Max pressure for modified COTS or SRAD pressure vessels at launch is [16] bar	Design, will be regulated by GSE operators
FCT-06	If applicable, core stage and booster stage shall be pressurized at the same pressure value	Design
DGN-01	Avionics shall be powered only once the launch vehicle is sitting on the launch pad	Design
DGN-02	Parachute shall be attached/detached to/of the rocket using a metal ring	Design
DGN-03	If applicable, all booster and core stage shall have their nozzle/water exit at the same height	Design
CONF-01	The launch vehicle shall be either single stage or 1.5 stage, i.e. 1 core stage or 1 core stage + booster(s)	Design
CONF-02	If applicable, booster total number shall not be greater than [3]	Design
CONF-03	If applicable, booster shall be uniformly spread around the core stage	Design
PHY-01	Airframe/pressure vessels shall possess a standard thread	Design
PHY-03	The maximum dry mass of the launch vehicle shall be [1.5] kg	Measurement
PHY-04	The maximum height of the launch vehicle shall be [120] cm	Measurement
SAF-01	No pyrotechnics (e.g. black powder) shall be used	Design
INT-01	Launch vehicle shall fit on the launch rail profile	Design, possibility to test-fit beforehand
INT-02	Propulsion systems shall fit on the GSE pressurization fitting	Design, possibility to test-fit beforehand
VF-01	All propulsion systems (core stage + boosters if applicable) shall perform at least [one] successful static fire	Test, measurement
VF-02	All modified COTS pressure vessels shall pass a hydrostatic pressure test at 1.1x the nominal launch pressure	Test, measurement
VF-03	Calculation/simulation of thrust generated by each stage shall be provided prior to lift-off	Calculation and analysis
VF-04	Calculation/simulation of flight trajectory of the launch vehicle shall be provided prior to lift-off	Calculation and analysis

Table III
TECHNICAL REQUIREMENTS TO FOLLOW. A GREEN LINE MEANS THAT IT HAS BEEN VERIFIED.