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1. Revision history

Issue	Description	Publication date
7.1	• 2025 Baseline	18/02/2025
7.2	• Added Central core and booster interface diagram (Figure 2.1) • Removed independent nozzle part. Now directly integrated into launch interface (table 4) • Modification of PHY-02 : mass increased from 2.5 to 5 [kg]	04/03/2025
7.3	• Update of Figure 3 and table 4 according to 2025 configuration • Addition of budget information in Section 15 • Addition of requirement INT-03 • Modification of PHY-02 : changed from “dry” to “wet and increased to 7kg • Addition of section 12.3 about the launch procedure	18/03/25

2. Abbreviations

AGL	Above ground level
SRAD	Student researched and developed
COTS	Commercial off-the-shelf
GSE	Ground support equipment
TBD	To Be Defined
TA	teaching assistant
LC	Launch control

3. Introduction

This document provides the necessary guidelines and requirements to follow for the Space Propulsion ENG-510 project. The project is meant for groups of 4-5 students, with 1.5 ECTS per student.

The goal is to provide a launch vehicle powered by pressurized gas and water. Design verification and qualification upon lift-off will be verified through the bi-weekly exercises and additional reviews if necessary. Questions and discussions on the Moodle forum are highly encouraged.

4. Project description and objectives

The project aims to design, build, test, and successfully launch a water rocket, and retrieve it in good condition with an adequate recovery system. In 2025, the added difficulty is the requirement of having additional detachable side boosters. The main objectives are the following:

- Practical application of the course content.
- Structural development of the launcher and booster.
- Dimensioning of the water-based propulsion system.
- Integration and testing of a recovery mechanism.
- Develop a simple simulation tool for the thrust curve and flight trajectory.
- System engineering and project management.
- Having fun! Please reach out if this is not the case!

5. Requirements

The following list of requirements is mandatory, requirements that have not been verified will result in a NO GO for the team until being verified. The different requirements type are

MS	Mission
FCT	Function
CONF	Configuration
PHY	Physical
SAF	Safety
INT	Interfaces
VF	Verification
DGN	Design

Table 1 – Technical requirements to follow for the course project

Ref	Description	Verification method
MS-01	The launch vehicle shall reach an apogee between [10] m to [200] m (AGL)	On-board altitude measurement, simulation
MS-02	The launch vehicle shall deploy a parachute at apogee	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
MS-05	The launch vehicle shall have two external water-based booster	Design

MS-06	All external booster shall separate after burnout and optionally deploy a parachute	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 (food colorant is allowed)	Design, visual confirmation during launch pad operations
FCT-04	Max pressure for modified COTS or SRAD pressure vessels at launch is [16] bar	Design, will be regulated by GSE operators
FCT-05	Core stage and booster stage shall be pressurized at the same pressure value	Design
DGN-01	Any active electronics shall be powered only once the launch vehicle is sitting vertically on the launch pad	Design
PHY-02	The maximum wet mass of the launch vehicle shall be [7] kg	Measurement
PHY-03	The maximum height of the launch vehicle shall be [150] cm	Measurement
PHY-04	All side boosters shall have the same volume. The central core can have a different volume	Design
SAF-01	No pyrotechnics (e.g. black powder) shall be used	Design
SAF-02	The pressure vessels shall be made of non-brittle material to avoid shrapnel in case of failure. (Example of brittle material: PVC, acrylic, plexiglas)	Design
INT-01	Propulsion systems shall fit on the GSE pressurization fitting (Figure 3)	Design, possibility to test-fit beforehand
INT-02	All pressure vessels shall possess a standard thread (Section 11)	Design
INT-03	All nozzle exit plane shall be situated in the same plane	Design
VF-01	All pressure vessels utilizing PET bottles as its primary structure shall pass a hydrostatic pressure test at [1.1]x the nominal launch pressure	Test, measurements
VF-02	If the pressure vessel utilizes materials other than PET as its primary load-bearing structure (such as Aluminium), it must successfully pass a hydrostatic pressure test at [1.5]x the nominal launch pressure.	Test, measurements
VF-03	Calculation/simulation of thrust generated by each propulsion module shall be provided prior to lift-off (Section 8)	Calculation and analysis

VF-04	Calculation/simulation of flight trajectory of the launch vehicle shall be provided prior to lift-off (Section 9)	Calculation and analysis

6. Available material

Component orders on Mouser.com (electrical components), Distelec (Various) and Swaytronic (LiPo batteries) will be performed during week 7 of the semester. You can list your needs on the appropriate document on the Moodle page of the course. Other website of interests are Digitec, Reichelt, Ali express,... The SPOT, SKILL, or Robopoly (see Section 7) also offer a variety of mechanical and electrical components. Table 2 presents some popular choices for a basic avionics. Note that any component can be used, table 2 is only an example. Some components may also be directly available through the TA (barometer, accelerometer, SD card shield).

The ground support equipment for the launch, the static fire test bench, some standard interface components (see Table 4), and the hydrostatic pump are provided by the TA.

Table 2 – Suggestion of components

Product description	Product link
Microcontroller	Raspberry pi pico
Micotrontroller	Arduino nano
Barometer	BMP280
3 axis accelerometers	MPU6050
SD card shield	SD card shield

7. Manufacturing

Manufacture and storage of the hardware can be done at the DLL building, at the makerspace named “The SPOT”. 3D printer, metal working tool and machine and electronics-related tooling are available.

Figure 1 - DLL building location on campus, image is not up to date: the actual building looks brand new and has white vertical strips (image below)

8. Thrust curve modelization

Hint: Use Bernoulli principle to get exhaust velocity
Allowed Hypothesis:

- Water is at atmospheric pressure when exiting nozzle.
- Fluid speed in tanks is negligeable.
- Adiabatic expansion of pressurizing gas.

9. Flight simulation

Allowed hypothesis:

- 1D flight (simulation along a vertical axis)
- Acting forces: thrust + weight + aerodynamic drag

10. Parachutes

Parachutes will be lent by the EPFL Rocket Team. They will be shared between the teams during the launch day. The available dimensions are listed in Table 3.

Table 3 – Available parachutes and their size

#	# of chutes Avalable	Dimension [cm]	Type	Mass [g]
TBD	TBD	TBD	TBD	TBD

To choose the right parachute, you have to define the descent speed limit using the equation below:

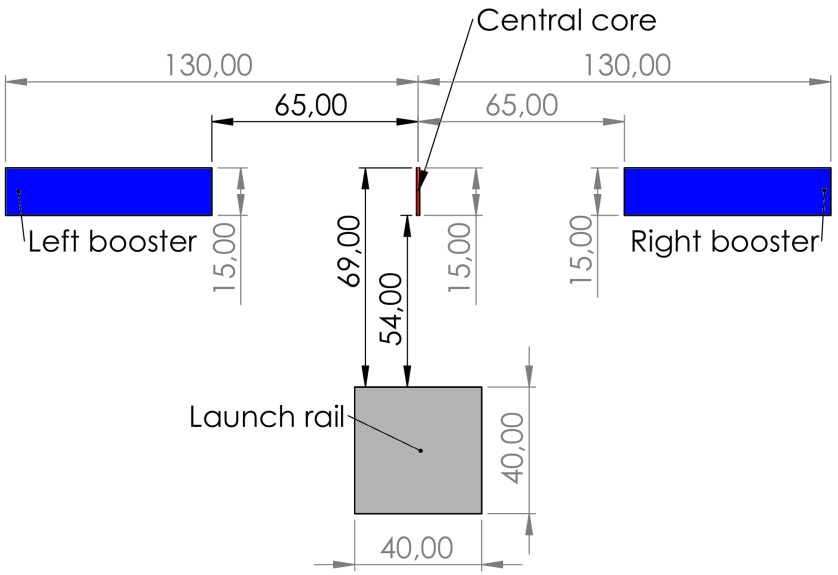
$$V = \sqrt{\frac{2 \cdot M_{tot} \cdot g}{\rho \cdot S_{eff} \cdot C_d}}$$

Where $V\ [m/s]$ is the descent speed, $M_{tot}\ [kg]$ is the vehicle dry mass, $g = 9.81\ m/s^2$ is the gravitational acceleration, $\rho = 1.23\ kg/m^3$ is the atmospheric density, $S_{eff}\ [m^2]$ is the parachute area, and $C_d \approx 1.5$ is the parachute's drag coefficient. You can also use only calculators

11. Airframe/pressure vessels

Figure 2 indicates the mandatory dimensions that all PET bottles used in the project shall have**.** This corresponds to the standard thread of most of the usual drink (Most of the water brand, coca cola,...) Figure 2.1 represents a top view of the launch pad and indicates the range of dimension that is allowed for the boosters, the central core, and the distance between the center of the central core and the boosters. The rectangles represent the allowable position for the center of each pressurized sections. The central core shall be aligned with the middle of the rail, with its center lying between 54 and 69 [mm] away from it.

Note that all nozzles shall be situated in the same plane/be at the same height relative to the ground.



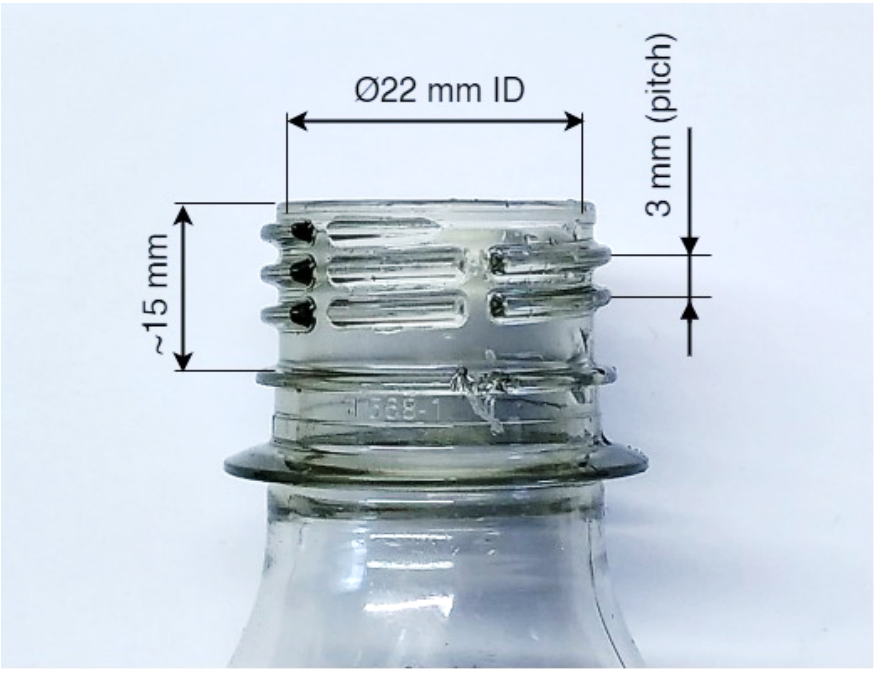


Figure 2.1 – Top view of the allowed position for the center point of the central core (red area) and lateral booster (blue area) relative to the launch rail (gray square)

Figure 2.2 – Standard bottle neck and thread dimensions to follow.

12. Ground support equipement (GSE) interface and nozzle

The ground segment is provided to the team unless explicitly described as otherwise.

12.1. GSE interface

The following interface is proposed. The teams are expected to discuss with the TA if changes for a specific design are required.. The team can freely modify the exit diameter of the rocket by adding part number 1.A (figure 3) to alter the burn duration and thrust as needed. Nozzle exit diameter is changed directly on part 1, either by asking the TA or modifying the cad available on moodle.

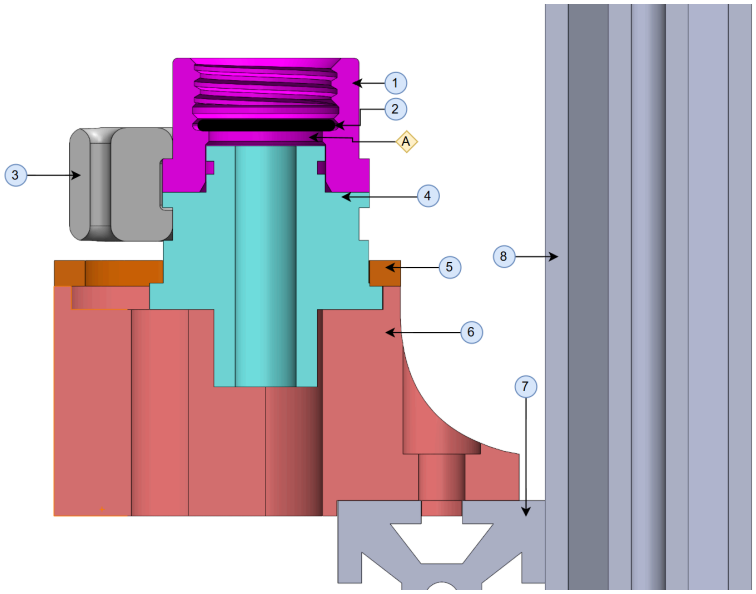


Figure 3 – Pressurization interface on GSE

Table 4 – Description of each part used for GSE interfacing and nozzle

Ref	Description	Comment
1	PET bottle adapter/nozzle	Provided **by** each team. Rocket launch pad interface. CAD is available on moodle, to be 3D printed at the SPOT if using a custom dimension.Standard 22mm exit port version will be provided.
A	Nozzle	Dimension to be modified to change the water exit port diameter. Ask the TA if you need to modify and print it and cannot do it yourself
2	O-ring	Provided **to** each team. Seals the PET bottle adapter against the PET bottle
3	Launch clamp	Provided **to** each team. Clamp retaining the rocket on the ground. Disconnect to launch

4	Filling interface	Provided **to** each team. Connects to the PET bottle adapter for filling
5	Filling interface clamp	Provided **to** each team.
6	Main ground interfacet	Provided **to** each team.
7	Launch pad	Provided **to** each team.
8	Launch rail	Provided **to** each team.

12.2. Fluid diagram

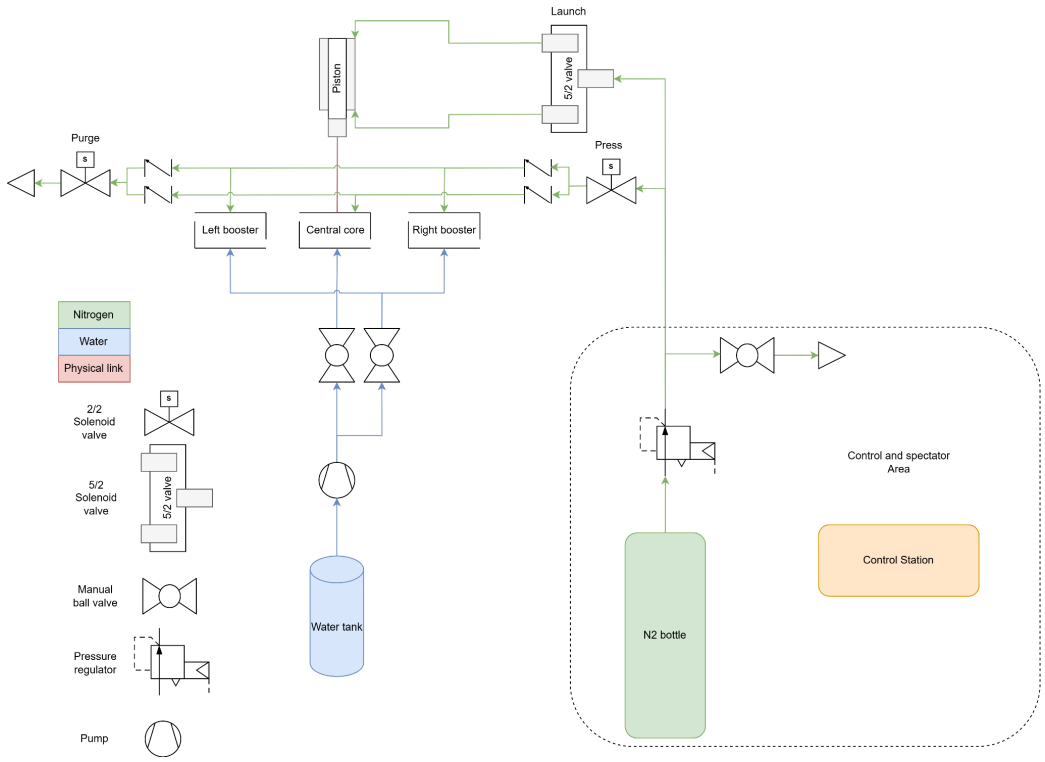


Figure 5 – Diagram of GSE and launch Control (LC) (work in progress)

12.3. Launch procedure

The approximate launch procedure is as follows:

- Install the rocket on the ground interface.
- Install the ground interface on the rail.
- Power up the avionics.
- Fill the booster water tanks using the GSE pump and valves.
- Fill the central core water tank using the GSE pump and valves.
- Evacuate the pad.
- Pressurize all three cores to the same pressure. Pressure will be controlled and measured by the control station.
- Trigger the launch mechanism.

13. Testing

Launch vehicle pressurization fittings will be the same on the GSE (launch rail), the test stand, and the water pump for hydrostatic tests.

13.1. Vessels hydrostatic testing

Modified COTS pressure vessels and SRAD pressure vessels have to pass a hydrostatic pressure test (pressurization with water) at 1.1x the nominal launch pressure (see VF-02). A water pump that can reach a pressure up to 100 bar will be available at the SPOT on demand. All testing activities shall be notified to the teaching assistant. The TA shall be present during the first test. Specific threaded cap for hydrostatic testing will be provided with the adequate plumbing fitting.

Successful hydrostatic test means that once pressurized, the pressure vessel is able to keep 90 % of the test pressure duThe approximate launch procedure is as follows:ring at least 30 s.

14. Helpful resources

Those resources are meant to help you in the early design phase and verify your calculations. Your own calculations/simulations shall still be presented in the course's exercises.

Rocket dynamics - how to keep a rocket flight stable by passive methods.

Le vol de la fusée, stabilité et trajectographie - Complete document about the stability of model rockets. Pages 5 to 15 are the most relevant.

Open rocket – Simple software Useful for design, flight simulation, and CP-CG positions

Fusion 360 - Free CAD software for students, useful to design the parts of the rocket

15. Budget

Each team is awarded a budget of **150 CHF**, which is distributed between the group order in weeks 6–7 and personal purchases. In the case of personal purchases, one person per group can be reimbursed by following the procedure found on Moodle. Note that reimbursement can only take place if proper receipt copies are provided. Only one person per group can submit a reimbursement request, which must be done at the end of the semester in order to reduce the workload for the eSpace staff.

16. Bi-weekly exercises

Assignment # 1 -25.02.2025 : Organize your project
1-pager with description of your project organization in terms of participants + roles. Also you should define the first level of H/W needed, the functions to be fulfilled, the different mission phases, main requirements, verifications to be performed, schedule with short description of main tasks.

Assignment # 2 - 11.03.2025 : Define Ground I/F
1-pager with definition of your need w.r.t. Ground Support Equipment: How many stages / bottles do you have, which pressure do you foresee, which Water mass is considered, how do you intend to fill the Water and when (on the launch pad), is there a need for a launch tower, anything else? Do you need a pressure measurement for your electrical system, …?

Assignment # 3 - 25.03.2025: Performance Analysis
1-pager with the performance analysis of your Water rocket including theoretical description of the equations involved and the results including graphs like altitude over time, speed over time, mass over time, pressure over time.

Assignment # 4 - 15.04.2025: Verification Plan
1-pager with description how you intend to verify the main requirements like booster separation, parachute deployment, safe-landing (maximal speed during landing), maximal altitude below 200 m, vertical lift-off by test, by analysis, by review of documents or by demonstration during assembly. Here the main focus is really separation and parachute. You should check, how you can check your system prior to launch of the complete rocket. When you test it, verify it only during the launch, the risk is very high.

Assignment # 5 - 28.04.2025: Qualification Review
Final report (5 pages) with description of you Water rocket (description of all products used, fluidical architecture, electrical architecture, mass budget, propellant budget, pressure budget, launch phases, verifications performed, …).

Practical # 1 - 14.05.2025: Trial launch
Test-launch of your Water rocket.

Practical # 2 - 27.05.2025: Lift-off
Evaluation launch of your Water rocket.