Airbus Sloshing Rocket Workshop

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Abstract

This work explores the feasibility of a water propulsion rocket designed for the Airbus Sloshing Rocket Workshop competition of 2025, focusing on the sloshing phenomenon in aircraft and its impact on flight stability. The primary objective is to analyze how sloshing affects performance parameters—height, flight time, and horizontal distance—and to develop stabilization strategies to optimize these metrics. The study integrates theoretical modeling, computational simulations, and experimental data to assess the dynamics of water propulsion and sloshing behavior under varying conditions. Findings indicate that uncontrolled sloshing significantly disrupts rocket stability, reducing flight time and horizontal distance, while height remains marginally affected. Implementing passive stabilization techniques, such as internal baffles, mitigates sloshing effects, improving flight time and distance significantly. Active control systems, though more complex, offer further enhancements, achieving near-optimal performance across all metrics. The investigation concludes that our approach is viable for the competition and the provided sloshing is effectively managed. Passive stabilization proves sufficient for baseline competitiveness, while active systems unlock maximum potential, aligning with the goal of optimizing flight performance. These insights contribute to the broader understanding of fluid dynamics in aerospace applications and provide a practical framework for future designs in similar contexts.

Chapter 1

Introduction

Water rockets represent a fascinating and practical application of fluid dynamics and propulsion principles, using pressurized air to expel water, generating thrust in accordance with Newton's third law. Their simplicity makes them an ideal educational tool, while also presenting real engineering challenges, particularly with regard to stability and control during flight. A critical factor for this competition is the phenomenon of sloshing, which refers to the movement of liquid within a partially filled container. This effect can significantly impact rocket dynamics, leading to instability and variations in flight trajectory.

One relevant case where this phenomenon was a key factor is the *Starship IFT-2* flight. During and after the Separation Stage, the continuous generation of opposing forces resulted in severe sloshing of fuel against the fuel supply lines. In addition, intense vibrations caused the fuel to create numerous gas bubbles, which negatively affected crucial components such as fuel supply lines, turbines, and combustion elements. As throughly explained in [6].

Another example is the second test flight of *Falcon 1*. Here, the *LOX slosh* was the primary contributor to some oscillations in the upper stage control system, that grew in pitch and yaw axes and eventually induced a noticeable roll torque. This ended in the explosion of the rocket. *Falcon 1 did not use slosh baffles in the second-stage tanks, as simulations conducted prior to flight indicated that slosh instability was considered a low risk. Given that there are no gust or buffet effects in space, the simulations did not take into account perturbations that occurred due to the hard slew maneuver after stage separation.* [5]

1.1 Lessons from the AIRSloths Team and Competitive Insights

Inspired by the AIRSloths team [4], winners of the previous Airbus Sloshing Rocket Workshop, we sought to incorporate key points of their approach. Their success was based on a deep understanding of fluid-structure interaction, using an innovative tail fin configuration and optimizing the tank geometry to control the liquid motion. We also took a deep look at the simulations they used to realize their project by exploiting the potential of Matlab and Simulink software. These tools have proven to be extremely effective in the development and implementation of their prototype. From their work, we understood the importance of considering various factors to carry out quality work. This understanding served as a starting point for us to elaborate on other aspects that will be explored in subsequent stages of the competition, such as the forces and moments that occur during the flight trajectory and the different equations of motion that describe these characteristics based on initial conditions at take-off.

1.2 Lessons from IST-Aeros Team

As part of our investigations, we also studied other successful teams from previous years. A good example is the IST-Aeros Team, who conquer third place in the 2019 competition. [3]

Upon further study of their work, we discovered different approaches and alternatives that we found valid for carrying out our work. This included taking cues from their rocket design alternatives to determine which one was optimal. From their work, we also took cues on various design tactics, especially regarding the prototyping of the models. In particular, we gained deeper knowledge of the technical aspects that *Eng. Dana Arabiyat* and the *Eng. Abdel Rahman Alomari* had taught us in the first webinar of this edition. Due to time management issues, we had not fully understood their real advantage, but thanks to their insights, we were able to verify and leverage the potential of tools like the *Pugh Matrix*.

1.3 Further Research

In order to gain a deeper understanding of the mechanics behind sloshing and its impact on vehicle stability, we reviewed the foundational studies by *Bouscasse, Colagrossi, Souto-Iglesias, and Cercos-Pita*, that is to say: *Mechanical energy dissipation induced by sloshing and wave breaking in a fully coupled angular motion system. Part I: Theoretical formulation and Numerical investigation* [1] and *Mechanical energy dissipation induced by sloshing and wave breaking in a fully coupled angular motion system. Part II: Experimental Investigation* [2]. Their two-part research delves into the energy dissipation mechanisms induced by sloshing and breaking waves within a coupled angular motion system.

- Part I: develops a theoretical and numerical model, providing insights into the coupling effects between fluid motion and rigid body dynamics. The study employs Smoothed Particle Hydrodynamics (SPH) and Computational Fluid Dynamics (CFD) simulations to analyze wave formation and dissipation.
- Part II: validates these theoretical models through experimental investigations, examining energy dissipation for different liquid viscosities (water, sunflower oil, glycerine) and varying excitation amplitudes.

These studies demonstrated that wave breaking significantly contributes to energy dissipation, altering the angular dynamics of the container and providing valuable insights into how sloshing can be both a destabilizing and a controllable effect in engineered systems, aspects that as previously mentioned we exploited when completing our work.

Seeing the requirements and the success formula, we set our goal to minimize the weight at take-off, trying to attain as much height at apogee and horizontal distance. We would use the minimum sloshing mass allowed by the rules, ensuring minimal destabilizing effects, even though this would mean a compromise in the success formula.

As we lacked deep knowledge in aerodynamics and advanced simulation tools, we decided to take an alternative approach during this phase of the competition. Instead of conducting lengthy and detailed simulations of every aspect of our rocket, we decided to use the results from the reviewed literature as a baseline and inspiration. Our approach involved conducting as many tests as possible, rapidly prototyping our different ideas to gather experimental data. This would allow us to iteratively approximate the flight score from the success formula 1.1 by inputting the collected values of various parameters (e.g., height at apogee, horizontal distance, time of flight, payload, and weight at takeoff).

$$Flight\ score = (\sqrt{Horizontal\ distance(m)^2 + Altitude(m)^2} + Time(s)) \times \frac{Payload(kg)}{Takeoff\ Weight(kg)} \tag{1.1}$$

We would always keep the costs of the materials minimal. This would also allow us to discard some ideas with relative ease and speed. These tests also allowed us to have a reference to define our success criteria during the final stage of the competition.

Chapter 2

Project Organization

Our team is made up of five members, with whom we have made three groups to be able to distribute the work equally based on the personal experiences of each individual member, their skills and in a certain way their preferences:

- **Structures and Materials Selection -** 2 members: Responsible for the CAD prototyping, choice of systems configurations, sizing, testing.
- **Sloshing Analysis and Aerodynamics -** 2 members: Responsible for studying the recommended literature, to find analytical relations and typical design approaches. Performing extensive CFD analysis.
- **Stability and Control -** 1 member: Responsible for choice of the control and actuation mechanisms. Modeling in Simulink of the dynamics.

2.1 Timeline

- `01 February - 07 February`:
  - Bibliography review.
  - Storming ideas.
  - Subdivision and assignment functions and tasks to each team member.
- `8 February - 15 February`:
  - Exploring the different conceptual ideas for the rocket.
  - Design of the first conceptual ideas, CAD models and mock-up prototypes.
  - Familiarization with the different software tools for simulation and modeling.
- `16 February - 28 February`:
  - Testing all the ideas proposed during the brainstorm.
  - Discard the solutions that were not aligned with the requirements and goals set by the team.
- `01 March to 20 March`:
  - Deciding for the final conceptual configuration and for all the different subsystems and mechanisms.
  - Dimensioning and testing of the different subsystems.
  - The manufacturing of the release system successfully achieved airtight and watertight sealing.
- `20 March to 25 March`:

- Verification and more testing.
- Achieving a pressure of 100 psi in the bottle while maintaining air-tightness and structural integrity which proved to be challenging.

Requirements Capture

Parameter List		
Subsystem/parameter	Mandatory	Optional
Mass and Weight	- Maximum take-off weight: 5 kg (liquids + structures)	
Dimensions	- Maximum length: 1.5 m - Maximum wing span: 2.25 m	
Propellant tank	-Tank pressure: < 10 atm = 147 psi -Propellant: water -Total mass of propellant less than or equal to the mass of sloshing liquid. -Only air can be used as an inflation gas.	-more than 1 propellant tank can be used. -Optimum fill ratio should be used for the propellant tank(s)
Sloshing tank	- 1 unpressurized sloshing tank containing a minimum of 500 ml and filled half-way - a control system for the sloshing liquid must be included -Baffles cannot cover more than 5o % of its cross sectional area.	
Launch and flight	-Vertical launch with an offset of 5 degrees from the vertical axis. -Re-launch with minimal maintenance at least two times more. -Can only jettison propellant. -Remote release mechanism from a minimum of 5m away.	-Staging allowed -Wings and similar systems allowed -High altitude at apogee -Fly long horizontal distances
Manufacture	-Vehicle design shall allow for manufacture during final stage of the competition -a location for mounting the altimeter must be designed	
Costs	- Cost of off-the-shelf parts < 300 euro - Total cost < 500 euro	- Cost-efficient solution

2.2 Success criteria

- The rocket reaches a height of 12 meters at the apogee.
- Opening of the wings at apogee in a time window of 0.5 seconds.

- The pressure chamber reaches a pressure of 100 psi without exploding or letting the air scape.
- The rocket glides at least 6 meters of horizontal distance, maintaining a relatively small angle of inclination, with a controlled oscillation due to the movement of the sloshing liquid.
- A soft landing with little to no damage in the structure, mainly in the wings and nose.
- Re-launching with minimal maintenance at least two times more.

Chapter 3

Concept Investigation

The overall flight is divided into two main phases: *vertical flight until the apogee* and *decent phase until it lands.*

During the brainstorming session we thought of a system consisting of two stages that would separate at a certain point in the ascent flight, just like real rockets with multiple stages, losing weight during each separation. Aiming for maximum height as a parameter to optimize the overall flight, while losing in horizontal distance traveled. The first stage would consist of three cylinders made with bottles of water placed symmetrically around a central body of some generic light material, which would be the second stage, consisting of the propellant water tank and the tank containing the sloshing liquid, as shown in Figure 3.1

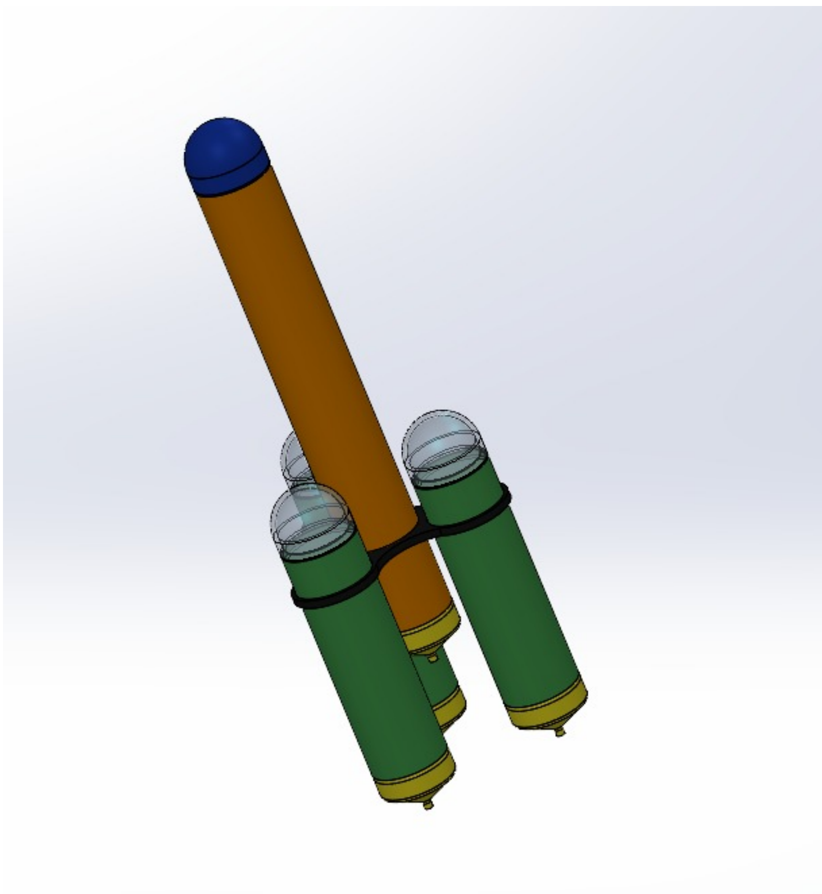

Figure 3.1: First idea: rocket of 2 stages

But, as remarked in the requirements capture section, the propellant mass could not be greater than the sloshing water mass, meaning that in order to have that much of propellant mass we would need at least the same amount of sloshing water, which would be problematic for control and stability of our rocket during flight, and would also increase the weight over passing the weight at take off limit of $5kg$.

So targeting maximal height alone would not be enough. Therefore, we place our eyes on the horizontal distance and time of flight. Several ideas were studied, based on the work of IST-Aeros Team. The main concepts that we would explore in depth were (Shown in Figure 3.2, 3.3 and 3.4):

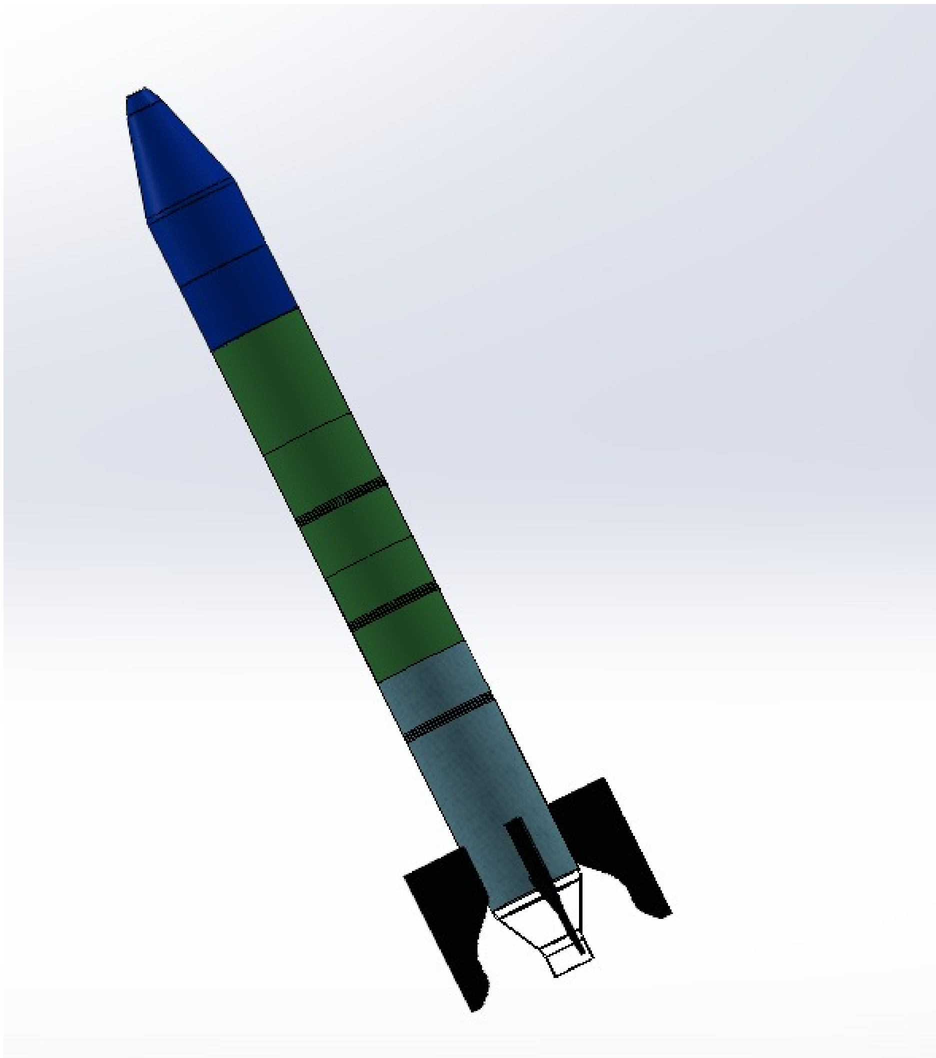

Figure 3.2: CAD: Gliding Rocket

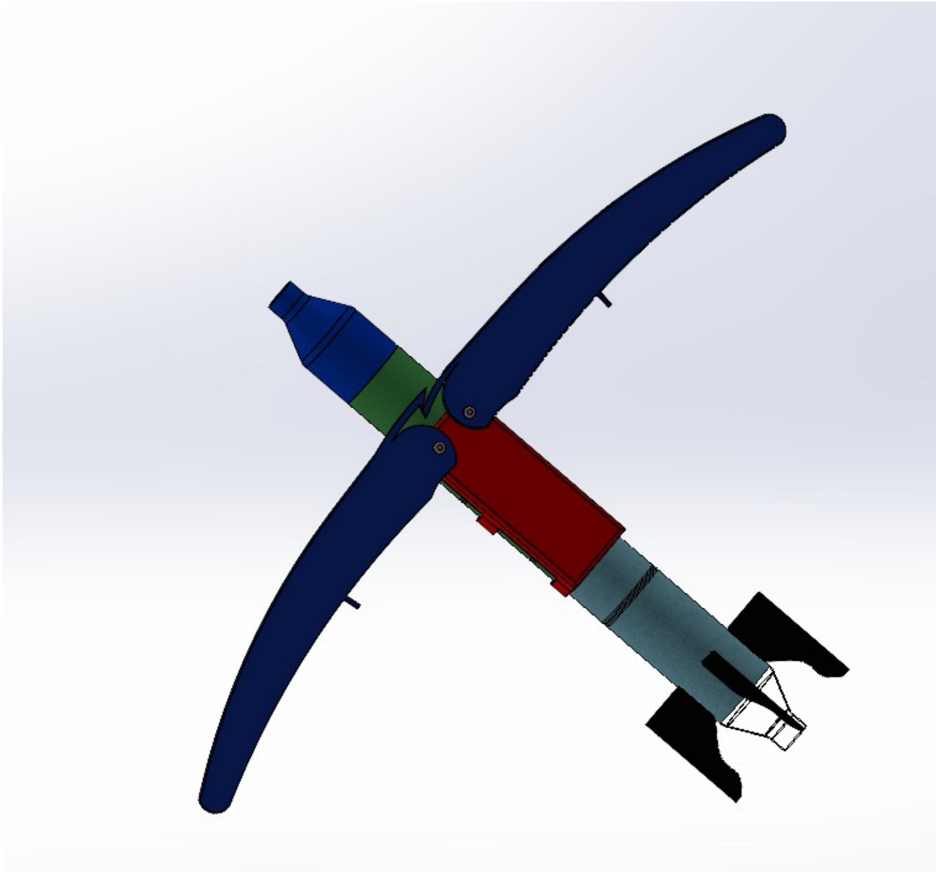

Figure 3.3: CAD: Rocket with retractable solid wings

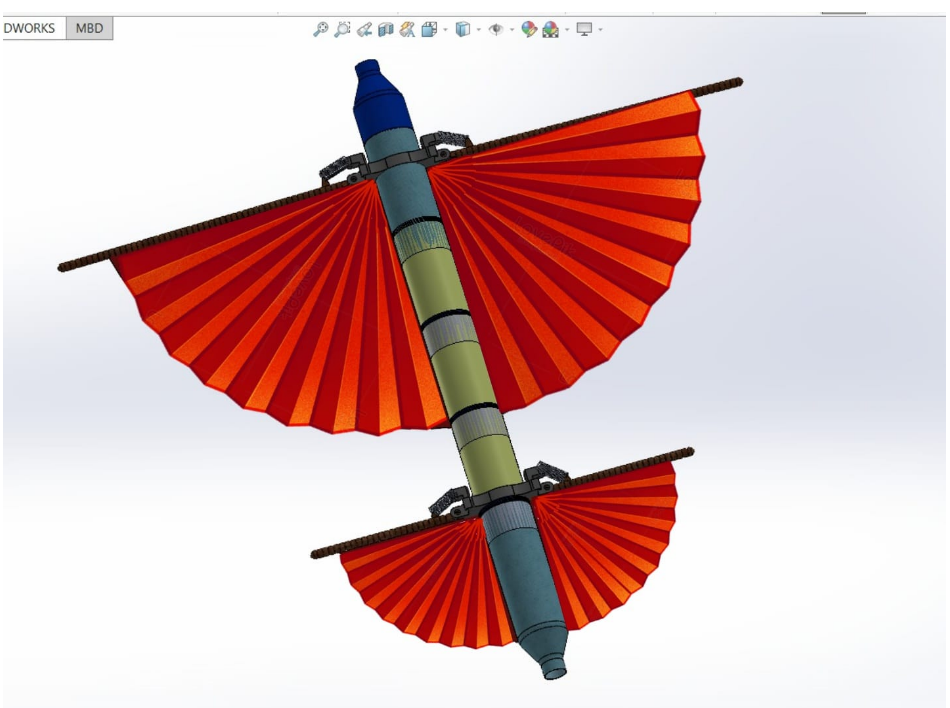

Figure 3.4: CAD: Rocket with retractable wings in a hand-fan-like shape

- **Rocket with fixed little wings:** This would have the sloshing tank in the upper part, both for simplicity in the construction, and because it elevates the center of mass which helps with the stability from the point of view of aerodynamics. This, like the one mentioned before with the 2 stages, focuses on maximizing vertical height. It features a slender body with a streamlined nosecone. This design stands out for its simplicity and lightweight. The flight performance is expected to yield the greatest apogee among the concepts presented in this work due to low drag and weight. It would have the fins placed at the bottom as a passive control mechanism that would maintain the rocket pointed upward.

  Improving the score with a low Take-off-weight, and allowing rapid construction, testing, and maintenance for re-use, as it had less components than our other approaches. Additionally, during tests, it was observed that as the near to the apogee, once the tank would be almost empty, where the sloshing liquid is would make the rocket to turn, plummeting to the ground with the nose pointing down. This would reduce the horizontal distance and time of flight. Additionally, it damaged the structure of the rocket, especially at the nose, and at the union between the different parts that conform the propellant tank. This would affect the re-usability, potentially delaying the maintenance and re-launch, as if the sealed made with the special glue is broken, we would have to reapply the glue and wait for it to be dry.

So, the idea of having some kind of wider wings was very tempting, as it would allow for a softer landing and improve the horizontal distance and time of flight.

Fixed wings were relatively simple to build and re-use, however, these are not optimal during the ascent phase, as they cause lateral drag, offsetting the ascending trajectory to a more bent trajectory from the beginning, which insides directly in the maximum height at apogee. Still, these were used during testing for their simplicity, where we could observe this deviation from the vertical trajectory during the first flight phase.

As an initial solution, we considered adding a parachute to ensure a softer landing. However, this idea turned out to be impractical at the time due to the scarcity of materials, the structural complexity of the release mechanism and the limited time available. Integrating such a structure into our design would have increased weight and introduced significant aerodynamic factors to take into account that would complicate the analysis and testing. As a result, it was poroposed as an alternative solution the implementation of retractable wings, which would deploy right after apogee, offering an optimal solution for both phases of the trajectory. Of course, the transition between the two phases could be critical: the rapid deployment of the wings, influenced by inertia, could generate oscillations and destabilize the attitude of the rocket (in particular the inclination angle). For the implementation of such a system there were identified two fundamental approaches:

- **Rocket with solid retractable wings:** This concept introduces a very interesting approach for our prototype because it allows the rocket to adjust the position of its wings based on flight conditions, which could optimize aerodynamic performance, improve control, and increase re-usability through the various phases of the trajectory, such as launch, climb, and landing. Inspired by the F-14 Tomcat's variable geometry wing system, which allows the wings to rotate relative to the fuselage to adapt to different flight conditions, our design would apply a similar principle of aerodynamic adaptability to achieve superior efficiency and functionality compared to fixed-wing or wingless rockets.

  During the initial climb, reducing drag is essential to maximize speed and conserving water propulsion energy. Retracted or swept-back wings reduce the surface area of the rocket exposed to the airflow, lowering drag. This allows the rocket to climb more efficiently, potentially reaching higher altitudes with the same amount of propellant. This would also ensure a smooth ascending phase without unneccessary structural stress or drag. During the descent phase, deploying thw wings can provide lift and control, allowing for a smoother landing, improving its reusability for multiple launches.

  While the benefits are compelling, implementing retractable wings on our bottle rocket does pose some engineering challenges. However, these can be addressed within the constraints of our design:

  - *Weight and Complexity:* Adding a wing mechanism adds weight and complexity, which could impact the rocket's performance, as a solution we can use lightweight materials such as thin plastic sheets or lightweight composites, along with simple mechanical systems (e.g. rubber bands or small springs) to minimize weight and complexity. The design will be optimized to ensure that the benefits, such as increased horizontal distance traveled outweigh the increase in mass.

– *Structural Integrity:* The rocket will experience relatively high external impulsive forces during launch and landing, so the wing mechanism must withstand these stresses without breaking. To achieve this we can use robust materials such as reinforces plastics or lightweight metal alloys, and design the wings to lock securely into place during critical trajectory points, reducing risk of failure. Additionally, the rapid deploying or retracting of the wings could destabilize the rocket, inducing oscillations around the pitch axis, that coupled with the sloshing liquid motion, would move the center of mass of the rocket, impacting directly in the attitude. So precise timing for the triggering mechanism and wing positioning are essential to get the right change in the attitude of the rocket so that the next phase (gliding phase) would occur as planned.

- **Rocket with retractable wings and tail, unfolding in a hand-fan-like shape:**

To support the decision process, a Pugh decision Matrix was created (presented in Table 2). This a qualitative technique used to rank the multi-dimensional options of an option set.It basically consists of establishing a set of criteria and a group of potential candidate designs. It's needed to have on reference candidate design, while the others are compared to this reference and are ranked as better, worse or same, based on each criterion. We also weight the criteria in base to it's importance incluence. Doing similar to IST-Aeros team, we choose as a reference the rocket glider with the fix fins.

Decision Matrix				
Criteria	**Weights**	**Baseline Design (Rocket Glider)**	**Solid Deployable Wing**	**Fan-Like Wing and Tail**
Descent Controllability	4	0	+2	+2
Re-usability	4	0	+2	+1
Payload to TOW ratio	3	0	-2	-1
Flight Time	2	0	+1	+2
Horizontal Distance	3	0	+2	+2
Height to Apogee	3	0	-2	-1
Cost	1	0	-2	-1
Final Score	-	0	+2	+5

Table 3.1: Pugh Matrix

So, based on the results from the Decision Matrix, the most attractive option to us was the **rocket with hand fan-like deployable wings**. The weights and grading are based on our requirements and mainly the results from the tests.

Some aspects remain uncertain and requiere further analysis and testing which are expected to be done during next phase of the competition:

- **Wing Deployment Reliability:** Deploying wings in mid-flight is a major uncertainty. There were concerns about the timing (deploying too early or late), the mechianism jamming or one wing failling to deploy, and the structural shock when the wings snap open. These issues could lead to loss of control pr even break-up if not throughly engineerd tested.

- **Aerodynamic behvaiour and optimal shape of the wing:** Further simulations are requiered to have an optimized shape. CFD simulations are expected to be done in the next phase of the competition.

- **Sloshing and Control:** The main uncertainty we have is the sloshing control mechanism as fewer tests were done with this. The dynamics are yet to be simlated with our system to ensure that the coupling between the sloshing and oscillation of the rocket happen. Nevertheless, this was not the case during testing, which is a good thing.

Chapter 4

Concept Justification

All our design proposals consist in some kind of cylinder with 2 tanks (sloshing tank and 1 propellant tank), then the addition of wings, or other structures for flight performance improvement, as well as the different parameters would vary from concept to concept. The sloshing liquid is in the top of the rocket. This is fundamentally to elevate the center of mass, as it should be as far as possible in the upwards direction from the center of pressure, to have more torque in order to be more stable from the point of view of aerodynamics.

To quantify the effects of sloshing and optimize the design, various formulas and calculations are employed:

1. **Center of Pressure (CoP) and Torque**: The CoP is determined based on the shape and distribution of aerodynamic surfaces. Torque is calculated using the formula:

$$\vec{\tau} = \vec{r} \times \vec{F} \tag{4.1}$$

where $\vec{\tau}$ is the torque, $\vec{r}$ position vector from the Center of Gravity to the CoP, and $\vec{F}$ is the aerodynamic force, as shown in the figure 5 Our goal obviously is to maximize this torque in order to stabilize the rocket.

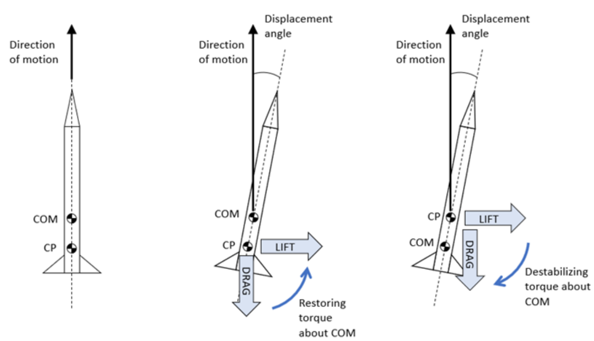

Figure 4.1: Rocket Stability Diagram

2. **Sloshing Dynamics**: Models typically incorporate equations of motion for the fluid, often employing Lagrangian or Eulerian methods to simulate fluid dynamics within the tank. This process generally involves solving the *Navier-Stokes equations*, which govern fluid motion, while accounting for the free surface and energy exchanges that occur as the fluid sloshes. These equations describe the evolution of the fluid's velocity field, taking into consideration forces like pressure, viscosity, and external influences such as gravity and the rocket's acceleration. In the context of sloshing, the *Navier-Stokes equations* help analyze the fluid's movement within the container, which directly impacts the rocket's stability and control. By accurately solving these equations, it's possible to predict the behavior of the liquid, its influence on the rocket's overall dynamics, and identify necessary adjustments to mitigate issues like tipping, instability, or loss of control during flight. This approach plays a crucial role in optimizing both the design

and performance of the rocket, ensuring smoother trajectories and enhancing mission success. Additionally, a deeper understanding of the fluid's behavior under various conditions helps us to implement targeted solutions, such as baffles or active control systems, to reduce the adverse effects of sloshing and improve the rocket's efficiency.

To control the sloshing motion, the most attractive idea was to have a passive control, always because of simplicity. So we went for the option of using baffles. There are different types:

- logitudinal baffles: along the length of the tank.
- transverse baffles: across the tank.
- ring baffles: circular shapes, common in spherical tanks, which is not the case of our rocket.

Other ideas were too complicated or directly not allowed by the rules of the competition.

From these 3 we choose a to use transverse baffles in a arcs. A shown in fig (number) This choice is more casual than for the rest of systems, as we didn't do many test of this system. But, it's fundamentally based on the work of IST-Aeros Team. However, during testing without the sloshing control system, we manged to get good results for our sucess criteria.

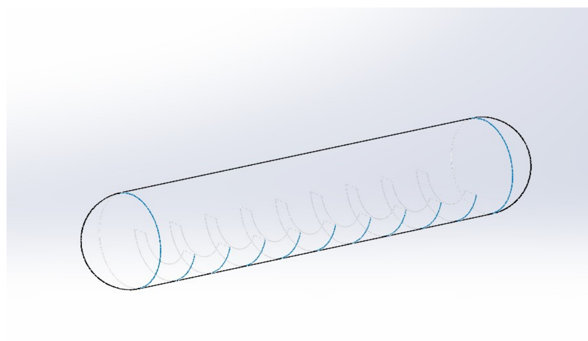

Figure 4.2: Sloshing tank representation with baffles

The propellant tank is, of course, at the bottom. There is a launch tube, passing through the nozzle in the propellant tank, connecting the internal pressurized air with the external air, finishing on top of the water, so that it would not allow the water to come out during the filling time.

Having this as core guidelines, the team explored multiple rocket design to meet project goals. Each concept is born mainly from the requirements stated by the team and justified partially by the insights extracted from the literature review and also from our experimental results from the test executed.

A design aspect to consider is the diameter of the cylinder and the nose shape (angle) as they influence directly the drag force:

$$F_D = \frac{1}{2}\rho v^2 C_D A \tag{4.2}$$

Where F_D is drag force, ρ is the air density, v is the velocity of air relative to the rocket, A is the cross sectional area, and C_D is the drag coefficient, that ultimately depends of the shape of the nose and the diameter.

Additionally, the diameter influence negatively the internal tension in the walls of the presurized tank, as explainned in the equation (4), for a specific material, increasing the diameter would decrease the maximum pressure that the tank could withstand. In fact in some of the tests executed, we reached this critical point, and the rocket would just explode.

$$\sigma = \frac{PD}{t} \tag{4.3}$$

Where σ is the tension of pressurized cylinder walls, P is the pressure of the contained air, D is the diameter of the cylinder and t is the wall width.

The tests were the base of our final decisions. These could be sumarized in the following categories:

- Testing the rocket alone with no wings at all: mainly to study the integrity of the structure, particularly the glued joints, as well as the liberation mechanism, the o-rings for the sealing.

- Testing the rocket + stabilizing fixed fins: to study the influence of these fins in both, ascent and gliding phase.
- Testing the rocket + fixed light wings: this would give us insights about response to lateral forces and lift, during both phases.
- Testing the rocket + deployable wings in a hand-fan-style: mainly to study the trigger point for the liberation of the wings, and the interaction with the sloshing motion.

  All of these were done with and without damping mechanism for the sloshing liquid so we could compare the data.

Our 3 design approaches:

These justified the concepts presented in the former section "Concept Investigation":

- **High-Altitude Baseline Rocket** It would had a slender body and fixed stabilizing fins. This concept targets the maximum height at apogee. The propellant mass would be limited by the sloshing mass, which itself would be set at minimum. This is justifies by the fact that larger mass could make the sloshing motion more complicated to control, and also increase the landing impact, potentially affecting structural integrity. additionally, there is the well know phugoid oscillation, which combined with the sloshing phenomenon, could be critical for the controlled flight during the gliding phase. having the volume for the tanks fixed, we decided to make them as long as possible, in order to reduce the diameter, for the reasons explained before.
- **Rocket with solid retractable wings** This is an alternative to the fixed wings rocket option, mentioned before in the Concept Investigation section; which has the problem of the lateral force right away from the take-off and on, that would deflect the trajectory. It would increase drag in both phases: during the gliding, it compensates the drag with the lifts offered by the wings, but during the ascending phase it would just be a problem. These are the main reason on why we consider the retractable wings, so that we could optimized for both phases, and reach high altitude as well as large horizontal distance and time of flight. Of course this would increase decrease the payload to TOW ratio.

  We thought about using fiberglass as a reinforcement for the whole body, including the wings, but it has a dry time of 7 days at least, meaning that it would be hard to manufacture the whole thing during the final competition.

  Especially for the wings, an alternative was to use polyurethane which is very light and easy to work with. The problem with it is that it's very fragile to impacts, which is unavoidable as the rocket is supposed to land. The solution is to cover it very tight by some rigid sheet like plastic or acrylic, so that even is it breaks, it will no change the shape or dynamics of the system.

  Another alternative was to use carbon fiber for the wings. This is harder to work with and expensive, and since we were testing the different shapes of the wing profile, it was not a good option to rapid prototyping with low cost.

  Flexible acrylic was better option at least during this phase of the competition.
- **Rocket with retractable wings and tail, unfolding in a hand-fan-like shape**

  Similar to the one with solid retractable wings, this design would target the same parameters to optimize. The main difference, is that the wings would be lighter, meaning that during their release, the impact on the attitude, and therefore on the trajectory, due to intetia would be less. These would be made out of light material such as polypropylene.

  The tests shown that this approach, without any kind of tail would create a rolling motion during flight and not be stable at all. This design would sin of having a high drag force. But the light weight, the large surface area generating lift compensate it. Adding a tail for control is essential. Also having a heavy nose for passive pitch stability. Additionally, the airfoil should have some curvature to glide effectively; and the wings should have a slight dihedral angle for stability, as shown in the Figure 4.3

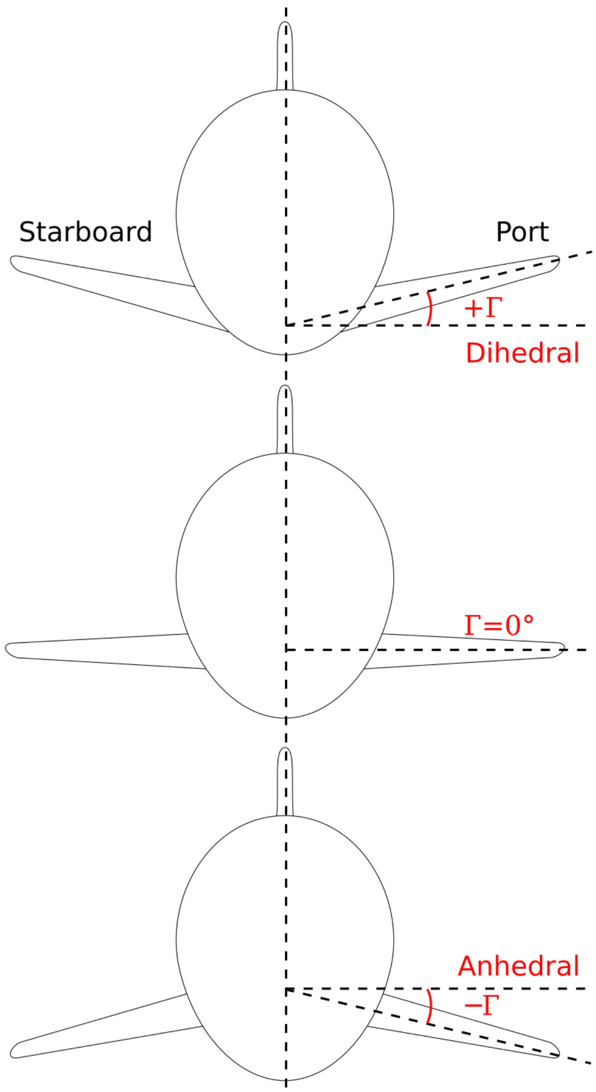

Figure 4.3: Dihedral and anhedral angles in an aircraft

Chapter 5

Preliminary Design Choice

Through the analysis, testing and explanations provided in the former chapters, the team decided for the approach of a **rocket with retractable wings in a hand-fan-like-style**.

- **Alignment with Team Requirements**
  - The choice of retractable wings allows for maximum efficiency in both the ascent and descent phases.
  - Retractable wings minimize drag during the ascent phase, aiding in reaching greater heights, which is a key requirement. Once at apogee, the wings deploy to enhance control and provide lift, allowing for smoother descent and increasing the horizontal distance.
- **Design Optimization**
  - The hand-fan-like wing shape was selected because it combines the benefits of providing substantial surface area for lift during descent, without creating excessive drag during ascent.
  - This design allows the wings to provide optimal lift during descent, promoting stability and a smoother landing, which also contributes to the reusability of the rocket, a crucial aspect of your project.
  - The retractable nature of the wings helps address potential drag issues during the ascent, making it a more efficient design compared to fixed-wing solutions that would have caused significant drag in the early stages of the flight.
- **Stability and Control**
  - The wing deployment mechanism was carefully considered, ensuring that deployment occurs after reaching apogee, thus minimizing the risk of destabilizing the rocket. This addresses concerns of sudden shifts in flight dynamics, particularly with the sloshing liquid.
  - The hand-fan shape provides additional stability compared to simple fixed wings, as it distributes aerodynamic forces more evenly during descent. The addition of a tail further ensures pitch stability, especially important given the rocket's relatively high center of mass due to the sloshing liquid.
- **Testing and Feasibility**
  - The design was chosen after extensive testing of various configurations. The rocket with solid fixed wings showed promising results but failed to maintain trajectory during ascent, making it unsuitable for achieving the high altitude required. On the other hand, the hand-fan-like wings demonstrated the best balance between ascent performance and descent stability.
  - The tests on the retractable wings also confirmed that baffles as a sloshing control mechanism worked well within the system, providing a simple and effective solution to minimize the destabilizing effects of sloshing during flight.
- **Material and Cost Considerations**

  - The design choice of lightweight materials such as polypropylene for the wings was influenced by the need for low weight and ease of construction. This was essential in meeting the competition's cost constraints and ensuring rapid prototyping.
  - The use of materials like flexible acrylic for wing construction, combined with the robust mechanism for deployment, also allowed for a cost-efficient design, fulfilling the requirement for the total cost of the rocket to remain under the 500 euro limit.

- **Future Refinements and Adjustments**
  - While the hand-fan-like wing design was the most optimal based on testing, further simulations and fine-tuning will be required in future stages, particularly to optimize the aerodynamic shape and ensure reliable wing deployment timing. These refinements will further enhance the rocket's performance in the next phases of the competition.

For our tests the follwing picture show the different systems that were used. As can be seen from the pictures, the cost of the materials for the tests was very low, on the team's personal budget. Every solution stands for their simplicity yet high effectiveness. Refined and more tuned versions of the different systems are intended to be used in the competition.

In addition to the rockets, the other systems neccesary for the laucnch and flight are presented in the pictures bellow:

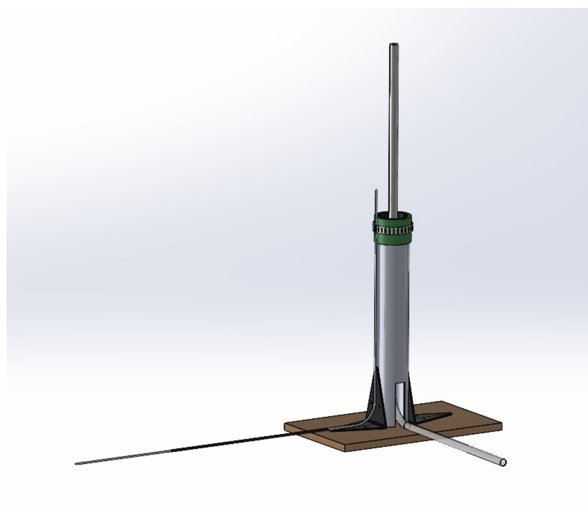

Figure 5.1: Launcher system

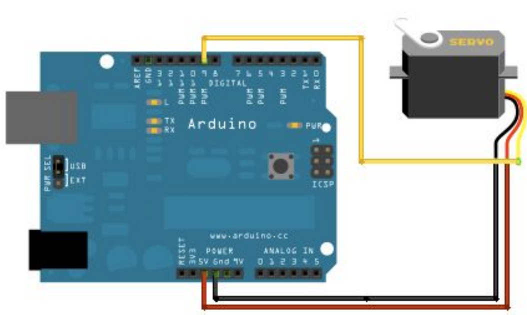

Figure 5.2: Control system to trigger the release of the wings.

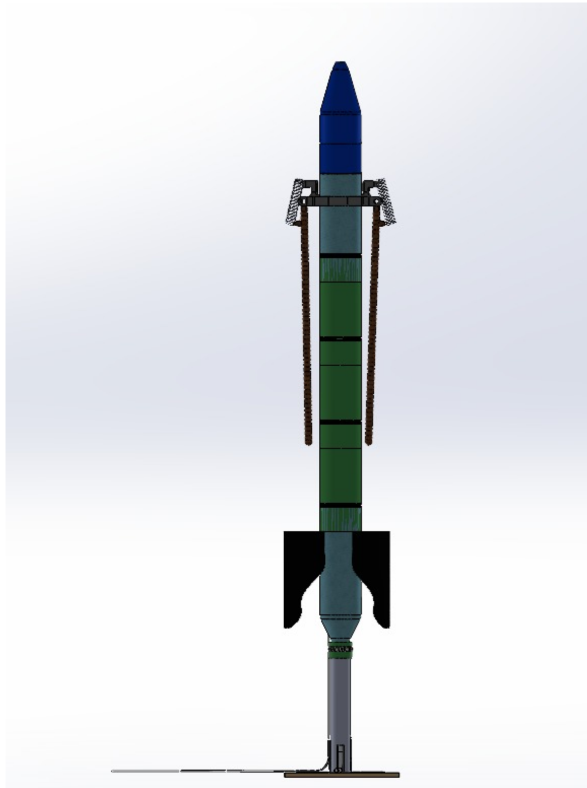

Figure 5.3: Control system to trigger the release of the wings.

Fig 6.2 (The whole system CAD)
Fig 7.1 (The final rocket with the wings - real)
Fig 8.1 (The lauch system -real)
Fig 9.2 (The wing deployment mechanism - real)
From our tests, the dimensions that had the better performance were:

- Length of the rocket: L = 1300 mm
- Diameter of the cylinder: D = 70 mm
- Diameter of the nozzle hole: d = 9mm
- Length of the wing: l = 550 mm

In the next phase of the competitions, simulations will validate these results, and provide more efficient dimensions.

Chapter 6

Appendix

Here are some pictures from the tests. Which you can explored deeper in our website: https://guajirosdicalabria.netlify.app

Figure 6.1: Testing team preparing for launch

Figure 6.2: Take-off: Testing the release mechanism

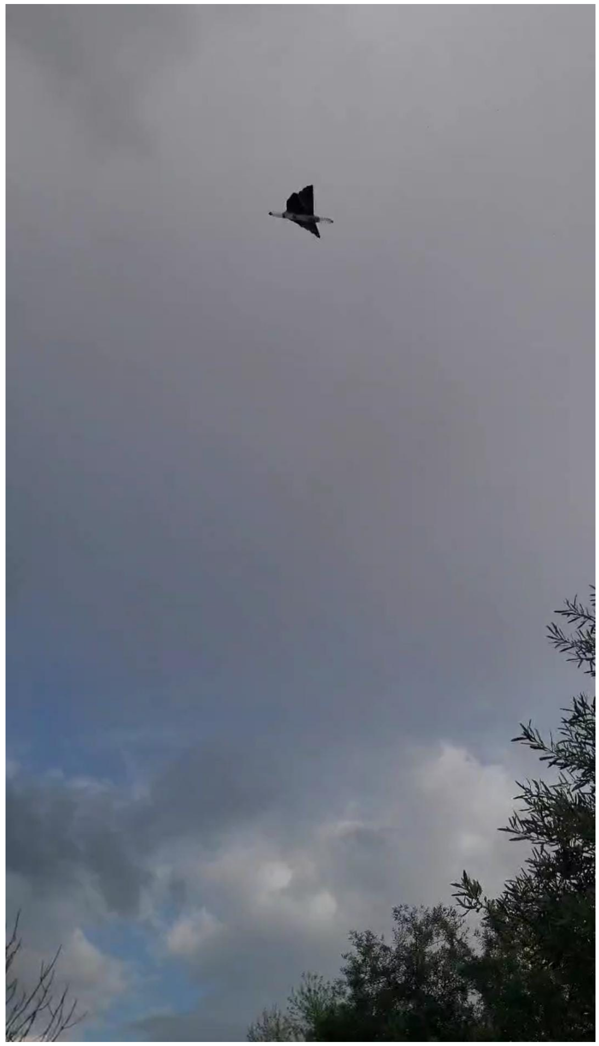

Figure 6.3: Gliding with the hand-fan-like wings

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[3] [5] [6]. [4] [1] [2]