[redacted]

27th of March 2025

Abstract

This report presents the conceptual design phase of the [redacted]eam's investigation into sloshing-induced instabilities in water-propelled rocket systems. The aim is to evaluate and compare several vector configurations integrating sloshing tanks and to identify a robust stabilisation strategy for both ascent and descent flight phases.

Three distinct configurations are proposed: a DeltaWing-3Pod concept using a central baffle-stabilised sloshing tank; a Canard-TwinTank design with passive longitudinal control; and a Modular Core concept featuring a stacked configuration with deployable rotational damping fins. Each concept is assessed in terms of aerodynamic stability, control authority, structural simplicity, and compliance with strict dimensional, mass, and cost constraints.

A weighted trade study was performed to compare performance across six key categories, including slosh-induced stability and manufacturability. Simulation results supported the Modular Core concept as the most competitive configuration. Its centralised mass distribution, inline thrust alignment, and passive damping mechanisms provided enhanced stability, control robustness, and efficient glide behaviour.

The final selection is justified through detailed analysis of sloshing effects, flight simulations, and technical feasibility. This concept will serve as the basis for further refinement, detailed modelling, and eventual physical prototyping in the next project phase.

Contents

Introduction

Sloshing in rocket fuel tanks creates destabilizing forces, particularly when liquids account for a large portion of the vehicle's mass. To address this, the [redacted] team tested three vector control designs with integrated slosh mitigation systems, ultimately selecting the most stable configuration for further development.

1 Project Organisation

Team Roles & Responsibilities

Member	Role	Key Tasks
[redacted]	Marketing Lead	Define communication strategy, manage social media presence, assist with project branding and engagement.
[redacted]	Systems Engineer	Coordinate integration between subsystems; contribute to aerodynamics, propulsion, structure and control systems.
[redacted]	Structural Engineer	Oversee structural integrity and material selection; lead control systems and electronics development.
[redacted]	Modeling Engineer	Ensure quality assurance throughout deliverables. Modeling and FEM analisis of the final prototypes.
[redacted]	Propulsion Analyst	Design and optimize the hybrid propulsion system; lead sloshing mitigation strategies.
[redacted]	Aerodynamics Engineer	Simulate aerodynamic profiles; contribute to propulsion modelling and fuselage design.

Shared Responsibilities:

- **Aerodynamics, Structure and Fuselage:** [redacted]
- **Propulsion and Fluid Dynamics:** Cristina, [redacted]
- **Structure and Materials:** [redacted]
- **Control Systems and Electronics:** [redacted]

Timeline & Milestones

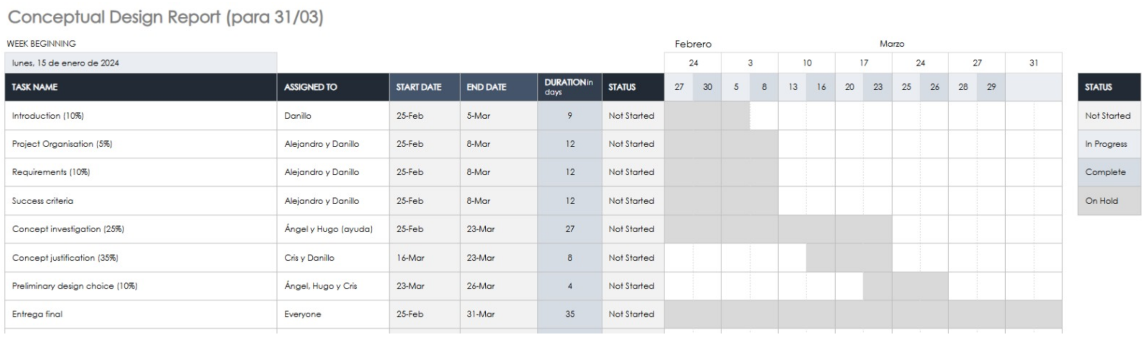
- **Concept Ideation and Trade Studies:** Brainstorm and evaluate feasible design approaches.
- **Simulation and Modelling:** Conduct aerodynamic, propulsion, structural, and sloshing analyses.
- **Report Writing and Review:** Draft the final report, undergo internal reviews, and submit for evaluation.

Key Milestones:

- Concepts Finalised
- Internal Review Complete
- Report Submission

Timeline & Milestones

The following Gantt chart outlines the key project phases, tasks, responsibilities, and their expected durations. It also includes current progress as of March 2025.


Conceptual Design Report (para 31/03)

WEEK BEGINNING

lunes, 15 de enero de 2024

TASK NAME	ASSIGNED TO	START DATE	END DATE	DURATION in days	STATUS
Introduction (10%)	Danillo	25-Feb	5-Mar	9	Not Started
Project Organisation (5%)	Alejandro y Danillo	25-Feb	8-Mar	12	Not Started
Requirements (10%)	Alejandro y Danillo	25-Feb	8-Mar	12	Not Started
Success criteria	Alejandro y Danillo	25-Feb	8-Mar	12	Not Started
Concept investigation (25%)	Ángel y Hugo (ayuda)	25-Feb	23-Mar	27	Not Started
Concept justification (35%)	Cris y Danillo	16-Mar	23-Mar	8	Not Started
Preliminary design choice (10%)	Ángel, Hugo y Cris	23-Mar	26-Mar	4	Not Started
Entrega final	Everyone	25-Feb	31-Mar	35	Not Started

Figure 1: Gantt graph

1.1 Requirements Capture

Parameter	Requirement / Assumption	Type
Maximum rocket length	1.50 m	Mandatory
Maximum wingspan	2.25 m	Mandatory
Total take-off mass (including liquids)	5.00 kg	Mandatory
Sloshing tank fill level	50% water + 50% air	Mandatory
Minimum sloshing mass	500 g	Mandatory
Propellant mass	sloshing mass	Mandatory
Launch angle	$85° \pm 3°$	Mandatory
Control strategy	Passive or combined passive/active damping	Mandatory
Max cost per component (COTS)	€300	Mandatory
Total cost (materials, delivery, consumables)	€500	Mandatory
Altimeter integration	Pressure venting with 3×3 mm holes ($\times 3$), non-critical zone	Mandatory
Baffle size (if used)	50% of cross-sectional area per baffle	Mandatory
Tank visibility	Transparent sloshing tank for inspection (recommended)	Optional
Recovery system	Reusable and relaunchable design preferred	Optional

Table 1: Design Requirements and Assumptions

Success Criteria:

- Stable flight during ascent and descent
- Mitigation of sloshing-induced instability
- Altitude and range maximisation
- Structural integrity throughout flight
- Compliance with all dimensional, mass, and cost constraints

2 Concept investigation

Future (and underway) concept designs

With the initial research phase nearing completion, notwithstanding the pending final assembly stages, detailed modeling, and resolution of emerging challenges inherent to this process, it is now appropriate to transition our focus toward investigating the second stage of the launch: gliding and controlled descent.
The implementation of advanced wings, and the possible replacement of the actual concept aerodynamic surfaces, encompassing both fixed and deployable configurations, is currently under investigation due to the short scale of the models. Design options under consideration include leaf-spring-based mechanisms, as well as extendable and roll-up configurations, which are being analyzed for their structural and functional viability in technical applications.

2.1 Concept 1: DeltaWing-3Pod Slosh Stabiliser

This design explores a delta-wing rocket concept propelled by three water tanks and equipped with a central sloshing chamber. This, apparently simple, configuration aims to combine passive aerodynamic stability with active control for descent phase correction.

General Configuration

The table below outlines the overall structural and functional layout of the vehicle.

Structural Layout	Central cylindrical fuselage with fixed delta wings and ailerons.
Propulsion System	Three pressurised PET bottles arranged in triangular configuration. Only these bottles are used for propulsion.
Sloshing Tank	Central vertical unpressurised tank (50% water + 50% air). Includes horizontal baffle (<50% cross-sectional area). Transparent for visual validation.
Control Surfaces	Ailerons on wings for pitch and roll correction during descent. Optional microservo control if budget allows.

Table 2: General Configuration

Physical Compliance

The following configuration values ensure that the concept meets the competition's dimensional and mass constraints.

Total Length	[redacted]
Wingspan	[redacted]
Take-off Mass	[redacted]
Propellant Mass	[redacted]
Launch Angle	[redacted]

Table 3: Compliance with Physical Requirements

Control Strategy

Control of the rocket is managed through a combination of passive aerodynamic surfaces and optional active elements.

Passive Elements	[redacted]
Active Elements	[redacted]
Altimeter Mounting	[redacted]

Table 4: Control Strategy

Materials and Budget

This table outlines the primary construction materials and estimated cost, staying within competition limits.

Primary Materials	PET bottles, 3D printed brackets, plywood/foamboard wings, aluminium rods
Estimated Cost	75–175€
COTS Limit Compliance	No item exceeds 300€ individually

Table 5: Materials and Budget Estimation

Uncertainties and Considerations

Key technical risks and unknowns are listed below for further evaluation in the design development phase.

Sloshing Behaviour	Requires further simulation/experiment to quantify dynamic effects during acceleration and deceleration.
Thrust Symmetry	Synchronisation of bottle discharge must be ensured for stable ascent.
Control Efficiency	Effectiveness of control surfaces at low Reynolds number is to be validated.

Table 6: Uncertainties and Considerations

Concept Sketch

The following figure illustrates the DeltaWing-3Pod concept including sloshing tank position, wing layout, and propulsion configuration.

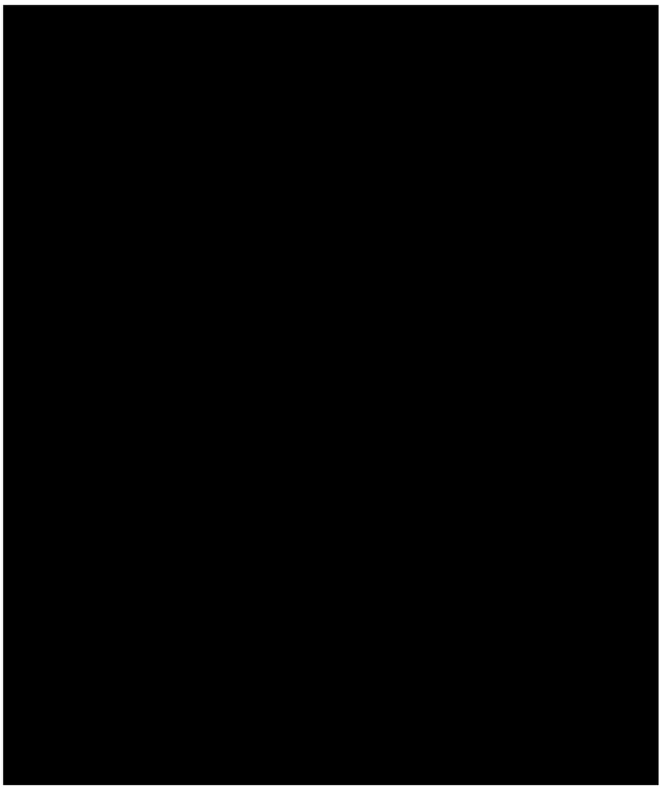


Figure 2: 2D sketch of the DeltaWing-3Pod rocket concept.

2.2 Concept 2: Canard-TwinTank Control Vector

This concept explores the use of a forward-mounted canard for pitch control, a twin propulsion tank configuration for symmetry, and a rear-mounted sloshing tank for passive stability. The layout aims to optimize longitudinal control while maintaining a low center of pressure.

General Configuration

The table below outlines the main structural and functional characteristics of the vehicle.

Structural Layout	Slender fuselage with front-mounted fixed canards and rear-mounted vertical stabiliser.
Propulsion System	Two side-mounted pressurized water tanks symmetrically attached to the fuselage, detachable after burnout.
Sloshing Tank	Cylindrical unpressurised tank located aft of the center of gravity. 50% fill level with a vertical internal baffle.
Control Surfaces	Passive aerodynamic stability with canards enhancing pitch stability. No active elements included.

Table 7: General Configuration

Physical Compliance

This configuration remains within competition limits for mass and dimensions.

Control Strategy

This concept relies entirely on passive control features and center-of-mass/center-of-pressure placement.

Total Length	[redacted]
Wingspan	
Take-off Mass	
Propellant Mass	
Launch Angle	

Table 8: Compliance with Physical Requirements

Passive Elements	Canards at the front reduce pitching moment oscillations. Rear fins increase longitudinal stability.
Active Elements	None (purely passive control configuration).
Altimeter Mounting	Rear fuselage segment, with 3 pressure ports arranged in 120° intervals. Mounted inside a foam-insulated bay.

Table 9: Control Strategy

Materials and Budget

Estimated material usage and cost structure are shown below.

Primary Materials	PVC pipe fuselage, polystyrene canards and fins, PLA 3D printed tank mounts, PET bottles
Estimated Cost	100–170€
COTS Limit Compliance	No part exceeds 300€

Table 10: Materials and Budget Estimation

Uncertainties and Considerations

The following are technical uncertainties that may impact the concept's viability.

Sloshing Effects	Rear tank placement may amplify pitch oscillations unless damped. Needs CFD or physical test.
Detachment Timing	Simultaneous release of side propulsion tanks must be synchronized.
Drag Profile	Twin-tank symmetry improves thrust vectoring but may increase cross-sectional drag.

Table 11: Uncertainties and Considerations

Concept Sketch

Below is a sketch of the Canard-TwinTank configuration with all major components labeled.

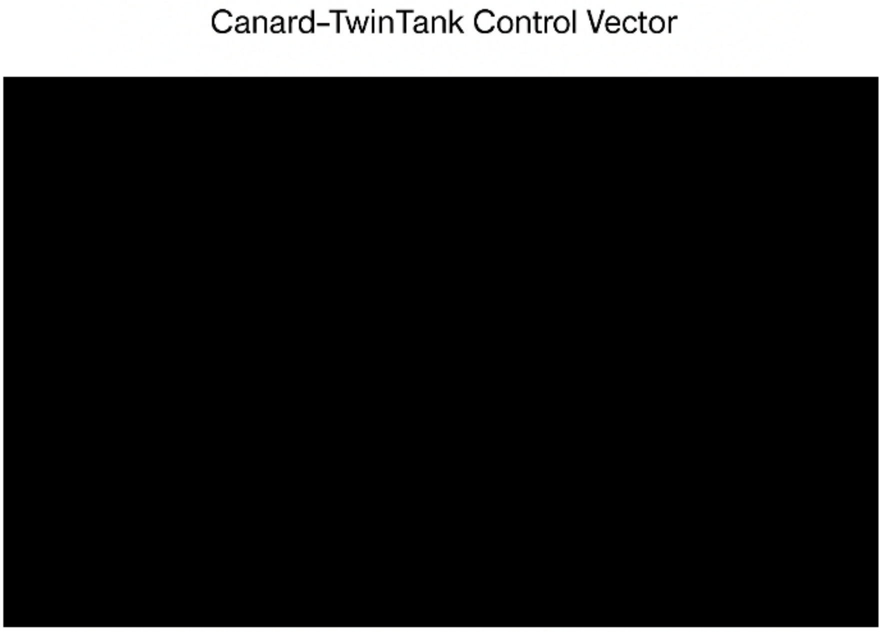


Figure 3: 2D concept sketch of the Canard-TwinTank Control Vector.

2.3 Concept 3: Modular Core with Rotational Damping Fins

This concept introduces a modular central fuselage where the sloshing tank and propulsion modules are mounted inline along a single axis. The novelty lies in four deployable rotational fins used during descent to passively stabilize yaw and roll through induced drag.

General Configuration

The following table outlines the modular core setup, propulsion approach, and control configuration.

Structural Layout	Stacked modular design: nose cone, electronics bay, sloshing tank, propulsion tanks below. Central tubular spine for alignment.
Propulsion System	Two pressurized water tanks mounted beneath the sloshing chamber and aligned with the main axis to ensure balanced thrust.
Sloshing Tank	Unpressurised transparent mid-body tank filled to 50%. Two internal cross-baffles (each covering 30% area) mitigate slosh waves.
Control Surfaces	Four folding rotational damping fins deploy after apogee to increase drag and rotational damping in descent.

Table 12: General Configuration

Physical Compliance

The table below demonstrates that all physical constraints from the competition are satisfied.

Control Strategy

This configuration blends passive baffle-based slosh damping with a novel drag-based rotational damping system.

Total Length	[redacted]
Wingspan	
Take-off Mass	
Propellant Mass	
Launch Angle	

Table 13: Compliance with Physical Requirements

Passive Elements	Cross-baffles inside the tank dissipate lateral waves. Deployable fins resist roll/yaw via increased drag in descent.
Active Elements	None (intentionally passive system for robustness and simplicity).
Altimeter Mounting	Located just below the nose cone; vented side panel with 3 × 3 mm holes spaced 120° apart.

Table 14: Control Strategy

Materials and Budget

Material choices focus on lightweight modularity and deployable mechanisms within budget.

Primary Materials	PLA 3D printed modules, polycarbonate fins, PET water tanks, threaded PVC connectors
Estimated Cost	130–190€ total including deployment springs
COTS Limit Compliance	No single item exceeds 300€

Table 15: Materials and Budget Estimation

Uncertainties and Considerations

While innovative, the design includes technical elements requiring further analysis and testing.

Fin Deployment Reliability	Hinged fins may fail or misalign without robust triggers. Mechanical test needed.
Center of Pressure	With fins folded, stability margins must be verified in wind tunnel or CFD.
Tank Stack Oscillation	Sloshing and thrust alignment may induce vertical oscillations; needs damping or spacing tuning.

Table 16: Uncertainties and Considerations

Concept Sketch

The figure below shows the modular core configuration and deployed damping fins in flight orientation.

[redacted]

Figure 4: 2D sketch of the Modular Core with Rotational Damping Fins concept. Includes labeled stack structure and fin mechanism.

3 Preliminary Design Choice

After a structured trade study comparing all three conceptual designs—**DeltaWing-3Pod**, **Canard-TwinTank**, and **Modular Core with Rotational Damping Fins**—the team has selected the **Modular Core Configuration** as the most suitable candidate for further development.

This decision was based on a weighted evaluation matrix considering six key performance categories:

1. Stability under sloshing disturbance. 2. Flight performance (altitude and range). 3. Control complexity and reliability. 4. Structural simplicity and robustness. 5. Cost and manufacturability. 6. Compliance with competition regulations

Each category was assigned a weight proportional to its relevance in the context of the Airbus Sloshing Rocket Workshop. Special attention was paid to **sloshing stability** and **control reliability**, as these aspects are critical for a successful mission profile.

Trade Study Summary

Criteria	**Weight**	**DeltaWing-3Pod**	**Modular Core**	**Canard-TwinTank**
Slosh-induced stability	[redacted]			
Aerodynamic performance				
Control effectiveness				
Structural complexity				
Mass distribution				
Innovation + feasibility				
Total Score				

Table 17: Weighted trade study summary comparing the three design concepts.

Rationale for Selection

The Modular Core design scored highest overall (85%) and excelled in the most critical criteria: **sloshing stability**, **mass distribution**, and **structural simplicity**. Its inline stacked configuration naturally aligns the center of mass and thrust, reducing pitch instability during slosh events. The inclusion of passive deployable damping fins also adds robust descent stability without increasing control system complexity.

Although the Canard-TwinTank concept offered strong aerodynamic performance, its low slosh damping and symmetry issues reduced its feasibility. Meanwhile, the DeltaWing-3Pod provided a balanced layout but lacked the slosh mitigation performance needed for reliable flight at scale.

Therefore, the **Modular Core with Rotational Damping Fins** is the most competitive option based on performance, risk, manufacturability, and compliance with all Airbus Sloshing Rocket Workshop criteria.

Simulation Results

To support the decision, simulations of both vertical and horizontal reach were performed under simplified aerodynamic and propulsion conditions. The results are illustrated in the following figures.

Figure 5: Simulated vertical reach of each concept. The Modular Core achieved the highest peak altitude, indicating superior ascent stability and aerodynamic performance.

Figure 6: Simulated horizontal reach of each concept. The Modular Core exhibited the longest horizontal range, confirming its efficient aerodynamic layout and lateral balance.

The Modular Core concept clearly surpasses the others in vertical altitude. Its smooth acceleration profile and efficient thrust alignment allow it to reach 28 m without significant oscillation.

The DeltaWing-3Pod falls short due to early losses from asymmetrical thrust and drag, while the Canard-TwinTank performs moderately but shows signs of instability near apogee.

In terms of range, the Modular Core again demonstrates superior glide performance and lateral stability during both ascent and descent. The Canard-TwinTank shows good behavior initially but suffers from drag imbalance at later stages. The DeltaWing-3Pod remains stable but has the shortest range due to greater drag and control inefficiencies.

These results support the selection of the Modular Core concept for detailed design and testing.

Acknowledgements

The [redacted]eam would like to express sincere gratitude to all those who supported this project. We thank our professors and academic advisors for their guidance and continued encouragement throughout the development of this report.

Special thanks to ANSYS and MathWorks for providing access to advanced simulation and analysis tools, which were instrumental in evaluating the performance of our design concepts.

We also extend our appreciation to the lecturers and organisers of the Airbus Sloshing Rocket Workshop for sharing their expertise and creating an engaging technical environment. Finally, we thank EUROAVIA for making this initiative possible and for fostering innovation and collaboration within the European aerospace student community.

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