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Article

Conceptual Design of an Unmanned Electrical Amphibious Vehicle for Ocean and Land Surveillance

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Abstract: Unmanned vehicles (UVs) have become increasingly important in various scenarios of civil and military operations. The present work aims at the conceptual design of a modular Amphibious Unmanned Ground Vehicle (A-UGV) that can be easily adapted for different types of land and/or water missions with low monetary cost (EUR < 5 k, without sensors). Basing the design on the needs highlighted in the 2021 review of the Strategic Directive of the Portuguese Navy, the necessary specifications and requirements are established for two mission scenarios. Then, a market research analysis focused on vehicles currently available and their technological advances is conducted to identify existing UV solutions and respective characteristics/capabilities of interest to the current work. To study and define the geometry of the hull and the configuration of the A-UGV itself, preliminary computational structural and fluid analyses are carried out to ensure it complies with the specifications initially established. As a result, one obtains a fully electric vehicle with approximate dimensions of 1050 × 670 × 450 mm (length–width–height), enabled with 6 × 6 traction capable of reaching 20 km/h on land, which possesses amphibious capabilities of independent propulsion in water up to 8 kts and an estimated autonomy of over 60 min.

Keywords: modular design; autonomous vehicle; oceanic reconnaissance; land patrol; maritime security; vehicle design; naval operations; environmental monitoring; unmanned systems; surveillance capabilities

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1. Introduction

The development of UVs (e.g., air, land, surface, submersible, and amphibious) has experienced exponential growth that accompanies the inherent technological evolution and the identification of the different needs that are being established by the different areas of the civil and military sectors.

1.1. Related Works

The origins of UVs date back to the end of the 19th century, when Nikola Tesla [1] developed two steel vessels of approximately 1.80 m, equipped with radio receivers that, connected to electromechanical actuators, controlled the steering of the vessel and an electric propulsion system.

The experience acquired during the wars at the beginning of the 20th century, e.g., the Russo–Japanese War (1904–1905) and the First World War (1914–1918), led to the initial development of remotely controlled ground vehicles [2] and vessels that transported an explosive charge with the objective that it would detonate after impact with enemy fortifications. Improvements proceeded, and in the initial phase of the Second World War (1939–1945), the Soviet Red Army used remotely controlled unmanned tanks equipped with machine guns, flamethrowers, smoke canisters, and a 200–700 kg time bomb, with a 1500 m maximum operating range, to reduce combat risk to soldiers [3].

The initial research on autonomous UGVs may be dated back to the late 1960s, with the application of artificial intelligence for controlling vehicles in a project funded by the Defense Advanced Research Projects Agency (DARPA) and developed at Stanford Research Institute. This research led to a mobile wheeled robot, SHAKEY [4,5], with a steerable TV camera, ultrasonic range finder, and touch range sensors connected via radio (RF link) to a central computer (SDS-940) capable of performing autonomous navigation and exploration tasks. Even though SHAKEY never achieved autonomous operation, it paved the ground to define the AI research agenda [6].

In the 1970s, Hans Moravec, leader of the Stanford Cart project, explored navigation and obstacle avoidance issues using a sophisticated stereo vision system, leading to the development of an indoor platform rover [7]. In the early 1980s, the Naval Ocean Systems Center undertook reconnaissance, surveillance, and target-acquisition-oriented UGV projects that could provide a battlefield commander with a direct sensing capability on the battleground and behind enemy lines without endangering human personnel [8]. To develop and refine UGV operational concepts, in the 1990s, the Surrogate Teleoperated Vehicle program, initiated by Robotics Systems Technology, led to a six-wheel all-terrain vehicle operated using stereo TV imagery via either RF or a fiber optic cable datalink and equipped with a GPS receiver improve navigation [9].

In 2003, DARPA announced the Grand Challenge [10], a project to accelerate UGV technology in military missions. Since 2010, the development of UGVs entered a new phase as many automobile manufacturers (e.g., Mercedes-Benz) and IT companies (e.g., Google) started to switch their attention to this field [11]. In the last decade, the exponential growth of artificial intelligence, machine learning, and other deep learning algorithms [12] have contributed to the development of many advanced UGVs with improved capabilities, e.g., sensing and control.

Recent research on UGVs has explored various facets to enhance their functionality and effectiveness. In [13], an evaluation of the performance of UGVs, by optimizing the design parameters for amphibious functionality using the Taguchi method, is presented. In [14], path-planning algorithms are developed for flood rescue support missions, employing a partially observable Markov decision process (POMDP) approach to optimize autonomous vehicle control. In [15], the control issues in Unmanned Amphibious Rescue Vehicles (UARVs) are addressed, and a servo control system based on BP neural network tuning PID controller for improved trajectory-tracking accuracy in flood disasters is proposed. In [16], the focus is on screw-propelled snake-like robots' amphibious locomotion, aiming to understand models and parameters for multi-terrain mobility. Furthermore, [17] presents a terrestrial testing rig for the experimental characterization of screw-propelled vehicle dynamics, which is crucial for validating dynamic models in amphibious robotic vehicles. These studies collectively advance the understanding and capabilities of autonomous amphibious vehicles for diverse applications.

As outlined in the taxonomy laid out in [18], the focus of this work is on achieving either high driving automation or full driving autonomy. This strategic approach aligns with the broader trend observed in the burgeoning field of autonomous electric vehicles, as documented in [19]. Furthermore, it reflects the growing reliance on autonomy across diverse sectors, including industrial settings, as evidenced in [20].

Some relevant state-of-the-art reviews in the civil and military sectors, available in the current literature [21–25], reveal a variety of UGVs that led to classification [25] based on three categories: size, mode of operation, and type of weapon. Each category contemplates four classes. This classification is useful in the design of new (or selection of existing) UGVs to execute one or more types of missions, such as surveillance and reconnaissance, search and rescue, the deactivation of explosive devices, the transport of troops and equipment, and the use of weapons, among others. To fulfill multi-operational scenarios, in the last decade, several UGVs have been developed with enhanced amphibious capabilities (see Table 1). In the realm of UGVs, a range of models, including the UK's Argonaut [26], Canada's Warthog [27] and Moose [28], and the UAE's Agema 6 and Agema 8 [29], offer distinct capabilities. The Argonaut prioritizes versatility and endurance with a 12 h autonomy, while the Warthog and Moose strike a balance between compactness and robustness. Conversely, the Agema models from the UAE excel in speed and agility [13].

Table 1. Specifications of a selection of A-UGVs.

Name/Country	Picture	Dimensions, mm (L $\times$ W $\times$ H)	Weight, kg	Traction (Land/Water)	Speed (Land/Water)	Autonomy
Argonaut [26]/UK		3000 $\times$ 1450 $\times$ 1800	450	Wheels 8 $\times$ 8 and mountable tracks + 2 propellers	25.7 km/h 3.9 kts (water)	12 h
Warthog [27]/Canada		1520 $\times$ 1380 $\times$ 830	280	Wheels 4 $\times$ 4	18 km/h NA (water)	3 h
Moose [28]/Canada		2960 $\times$ 1550 $\times$ 1140	1590	Wheels 8 $\times$ 8	30 km/h NA (water)	6 h
Agema 6 [29]/UAE		2440 $\times$ 1470 $\times$ 1290	442	Wheels 6 $\times$ 6	35 km/h 2.7 kts (water)	6 h
Agema 8 [29]/UAE		3020 $\times$ 1470 $\times$ 2990	602	Wheels 8 $\times$ 8	29 km/h 2.7 kts (water)	6 h

However, none of these UGVs, among others that were surveyed, fully comply with the expected specifications of the envisioned A-UGV established here.

1.2. Motivation and Main Objective

The development of the conceptual A-UGV proposed in this work is motivated by the DEM 2018 REV 2021 [30], in which this work encompasses several lines of action of the strategic objectives from the operational perspective, namely: (a) optimize the presence and control in maritime spaces under national sovereignty or jurisdiction, (b) increase the readiness of operational units and their commitment to support foreign policy, and (c) consolidate knowledge and action within the framework of marine sciences and maritime culture. Additionally, this work is a foundation that aims to further strengthen the presence of Portugal and the Portuguese Navy in NATO exercises, e.g., the Recognized Environmental Picture Augmented by Maritime Unmanned Systems (REP(MUS)).

Another significant motivation for the development of an A-UGV concerns the line of action 8.02 of the DEM 2018 REV 2021 [30], which promotes the reinforcement of the intervention capacity in civilian emergencies, humanitarian emergencies, and post-catastrophe intervention missions. Since forest fires are one of the main hazards in Portugal [31] and often occur in locations of difficult access constrained by rivers and lakes, A-UGVs are an excellent tool for building fire lines for backfire operations and surveying fire perimeters to detect hot spots [32].

Therefore, this work focuses on the conceptual design of an A-UGV with the following characteristics: fully electric, modular (in the sense that it can incorporate different sensors suitable for the mission to be carried out), portable (two-man carriable), and with low production, maintenance, and operational costs.

2. Materials and Methods

The general conceptual product development process [33] is adopted here (see Figure 1) and includes the following phases therein presented. It is important to note that there is a correlation between this methodology and others adopted in the development of naval military projects [34,35], in which all use a sequential and iterative approach to obtain the most efficient and effective final product.

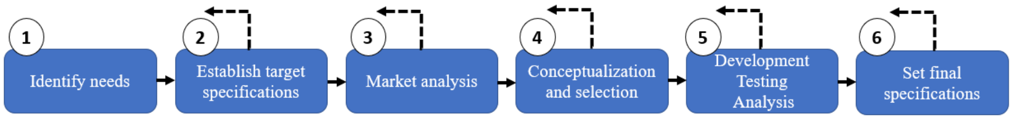


Figure 1. Conceptual product development process.

In line with our project's focus on meeting the requirements of the Portuguese Navy, our primary objective during this phase is to establish specifications tailored specifically to their needs. The detailed design of the A-UGV, including its propulsion system, will be addressed in subsequent stages. As such, the current analysis of the water propulsion system is conducted without specifying its configuration or efficiency.

Following, a summary of each phase of the conceptual product development process is presented.

2.1. Identification of the Needs

The motivations established promote the identification of the needs for the conceptual development of the A-UGV.

2.2. Target Specifications

The target specifications, or (operational) requirements, are thus directly related to the needs identified, providing a precise description of its main characteristics. These translate the identified needs into specific technical parameters that are, at this stage, refined to be consistent with the defined objectives and with the constraints associated with the concept.

2.3. Market Research

A state-of-the-art research survey is conducted to establish a better understanding of the current available solutions, determine their main common characteristics, and analyze the technological advances.

2.4. Conceptualization and Development

The creation of new concepts involves research, innovation, and analysis of associated constraints. By combining the target specifications with the desired characteristics, 3D Computer-Aided Design (CAD) is used to generate conceptual designs of the different components, e.g., the hull, of the A-UGV. At this stage, the material of each component is defined, allowing the CAD model of the vehicle for parameter extraction, e.g., the center of gravity, to be further used in numerical simulations, namely, the structural static and dynamic integrity of the A-UGV.

The choice and conceptualization considered most adequate is based on the evaluation of the two most common configurations, i.e., tracks and/or wheels. To aid in decision-making, empirical considerations are used to assess the main advantages and disadvantages inherent to each configuration. Using the information acquired, and considering the application and the environments in which the A-UGV will operate, a decision is made.

2.4.1. Land Propulsion

For the set configuration, it is now necessary to establish the motors and batteries. The methodology adopted includes an iterative process to estimate the total engine power required that may be expressed as

$$P_T = (m_V + m_L)(\sin\theta + \mu\cos\theta)g\, v_N \tag{1}$$

in which m_V is the total mass of the vehicle (includes the mass of the hull, wheels, motors, and batteries, where the last two are iteratively estimated), m_L is the mass of the payload, θ is the maximum slope angle, g is the gravitational acceleration, μ is the dynamic friction coefficient between the ground and the wheels, and v_N is the maximum rated speed.

The energy capacity of the batteries, C, may be estimated as

$$C = \frac{P_T\, h}{V\, \eta_m\, \eta_b} \tag{2}$$

where h is the autonomy; V is the voltage of the motor; and η_m and η_b are the performance of the engine and the battery discharge, respectively.

Furthermore, the mission profile illustrated in Figure 2, of interest to the Portuguese Navy, is defined as follows: (i) a first 4000 m plane segment followed by a 15° positive slope; (ii) a second 4000 m plane segment followed by a 15° positive slope; (iii) a third 4000 m plane segment followed by a 15° negative slope; (iv) a fourth 4000 m plane segment followed by a 15° negative slope; and (v) a fifth 4000 m plane segment.

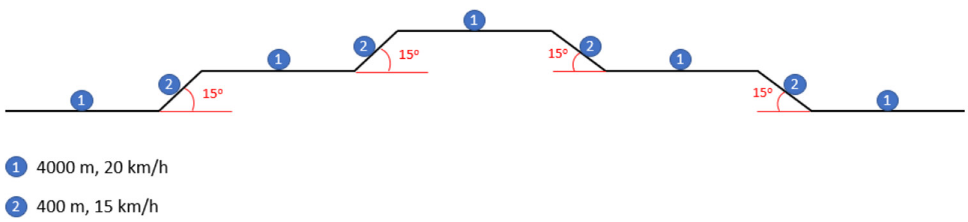


Figure 2. Land mission profile.

It is considered a dynamic friction coefficient (μ = 0.7, approximately that of rubber on cement [36]), and the plane and sloped segments travel at speeds of 20 km/h (maximum projected speed) and 15 km/h, respectively.

2.4.2. Hydrostatic and Intact Stability Analyses

Having established a conceptual model of the vehicle, hydrostatic and intact stability analyses are conducted using in-house naval architecture software (V8). The CAD model of the vehicle (including associated mass properties) is imported in which the height of the water level is defined, leading to a hydrostatic report that includes, among others, the center of buoyancy, the center of gravity, the vertical center of gravity, the metacentric height, and trimming moment [37].

2.4.3. Water Propulsion

To estimate the power required to make the vehicle reach the maximum specified water speed, it is necessary to estimate its drag force. For this, Altair® HyperWorks™ V2023.0 with the AcuSolve™ solver V2023.0 is used, into which the CAD model of the vehicle is imported. After performing a convergence study and based on the computational cost of the simulations, the choice rested on using a domain discretized in 1.1 million trimmed cells. A far field boundary condition, with enough length to minimize the flow disturbance caused by the vehicle, is set, and prism layers, with an all-y+ wall treatment, are used on the vehicle hull, shaft, and wheels for improved discretization of the boundary layers. The time-averaged Navier–Stokes equations are closed by the realizable κ-ε turbulence model that shows better performance for flows involving rotation, boundary layers under strong adverse pressure gradients, separation, and recirculation.

A close volume is used to conduct the simulation, in which the inlet is taken as a velocity inlet, with a velocity of 4.116 m/s (8 kts); the far field boundary is modeled as a pressure outlet with prescribed pressure as

$$\left(p_{working} = p_{static}\ g\ (Z - Z_0)\right), \tag{3}$$

where Z_0 is the waterline level (0.2 m) and $p_{working}$ is set to zero relative to the atmospheric pressure; the other volume walls are taken as symmetry.

To ensure that the established autonomy is fulfilled, and the batteries estimated for the land profile mission, a second mission profile in which the vehicle travels mostly in water is specified. It consists of (i) a first 4 km plane segment, (ii) a second 20 km water segment, and (iii) a third 4 km plane segment. It is considered that there is a dynamic friction coefficient of 0.6 (approximately that of sand or loose gravel) and that the plane and water segments travel at speeds of 20 km/h (maximum projected speed) and 8 kts, respectively.

2.4.4. Static and Dynamic Structural Analysis

As a complement to the conceptual development of this A-UVG, static and dynamic structural analyses are carried out using Altair SimSolid®V2022.3.1, which is a meshless method based on the theory of external approximations [38], to evaluate the design as well as some of the options considered during the conceptualization of the vehicle.

A load that simulates the total weight of the vehicle and its payload is equally distributed and applied in the upward direction on the bottom of all six wheels, and a displacement constrain is applied in all directions at the top edges of the hull (see Figure 3).

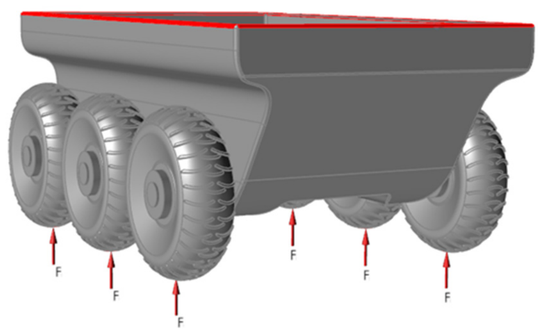


Figure 3. Boundary conditions applied to the CAD model of the A-UGV.

For this, Altair SimSolid® software V2022.3.1 is used, in which the following cases are contemplated:

- Vehicle subject to the static loads (F) on the wheels;
- Vehicle subject to a static critical load (F) on the wheels;
- Vehicle subject to the dynamic step loads (F)on the wheels.

For each case, the Von Mises stress distribution is obtained to identify the locations of maximum stresses and if these present values are below the yield stress of the material.

2.5. Conceptualization and Development

In this phase, the previously defined target specifications are revised and may undergo changes depending on the results of the previous stages. It is essential to establish and respect the defined values considering the constraints inherent to the vehicle's design, the identified limitations, and the compromise between cost and performance.

2.6. Set Final Specifications

In this phase, the specifications initially established are re-evaluated until the establishment of the final specifications is achieved.

3. Results

Based on the methodology and materials previously described, the following results are obtained for the conceptual design of the A-UGV proposed here.

3.1. Identified Needs

The identified needs that this vehicle aims to mitigate can be summarized in the following points:

- Support and increase capacity in civil and military operations;
- Accomplish its mission to reduce the risk for all personnel involved;
- Can operate efficiently on land and in water;
- Lightweight and small-sized vehicle so it can be easily transported and operated;
- Can equip different types of sensors according to the mission;
- Low production, maintenance, and operating costs.

3.2. Target Specifications

Identifying the need allows us to define the initial technical requirements, as outlined below:

- Maximum weight $\simeq$ 45 kg;
- Dedicated propulsion systems for land and water;
- Maximum land speed of 20 km/h;
- Maximum water speed of 8 kts;
- Floatability and stability in water;
- Autonomy > 1 h;
- Independent power sources;
- Hull made of resistant material;
- Production cost less than EUR 5 k.

Note: Design iterations may adjust initial weight, speed, and autonomy targets due to the constraints encountered.

3.3. Market Research

The market research analysis allows the identification of a selection of some A-UVGs that are designed for similar missions and/or with similar capabilities to those intended for the conceptual A-UGV proposed here. These are presented in Table 1 alongside references to some of their main characteristics.

The design of the hull is inspired by the hulls of the vehicles presented in Table 1, with a focus on the identified need for it to be lightweight and have a small-sized A-UGV. Its dimensions are 1050 × 670 × 450 mm (length-width-height) and 2 mm in thickness. The lateral idents allow for the mounting of the six wheels (three on each side), allowing land navigation rather than tracks since they allow higher speeds, increased floatability, easier maintenance, and market diversity availability. The wheels are equipped with an internal electric motor, a common off-the-shelf product that does not occupy space inside the hull, which provides greater redundancy and improved independent wheel traction.

Due to the high yield stress values and availability easiness, the following materials are assumed:

Hull: Zoltek™ PX35 carbon fiber P/TW28-50 (yield stress of σ_Y = 4137 MPa [39]);

Shaft and rims: Aluminum alloy 7075 T6 (yieldstressofσ_Y = 503 MPa [40]);

Tires: Rubber.

Using the methodology and the land mission profile presented in Section 2.4.1, after several iterations, one obtains for m_V = 42.13 kg and m_L = 7.00 kg, a total power P_T = 2400 W, i.e., 400 W per motor. Then, a required energy capacity of the batteries C = 74 Ah is estimated considering h = 1.1 h, V = 48 V, η_m = 0.95, η_b = 0.85, and a safety factor of 1.2.

Based on the resulting energy requirement and through brief research, it was determined that a possible battery configuration involves the installation of four 20 Ah off-the-shelf Li-ion batteries weighing 5 kg each, with dimensions of 245 × 160 × 70 mm.

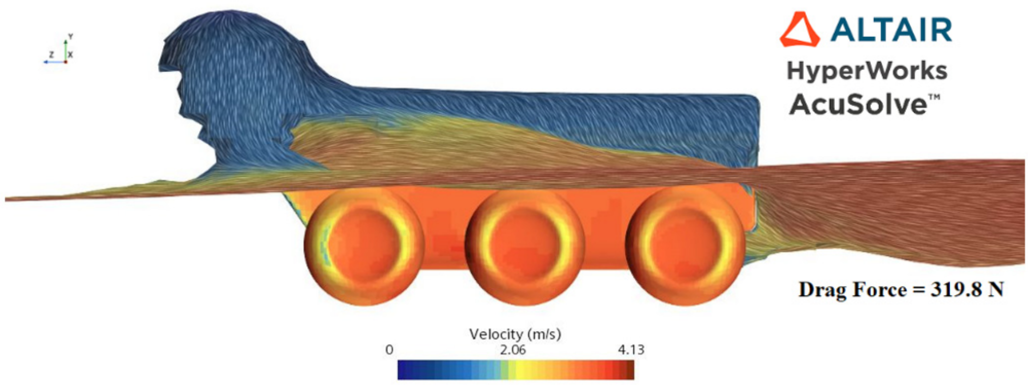
It is noted that an electric voltage of 48 V may be considered relatively high. However, reducing the voltage while maintaining the other variables constant implies increasing the energy capacity of the battery, e.g., a reduction to 12 V leads to a C = 296 Ah and to an increase of approximately 10 kg in batteries, which is undesirable as one wants to minimize the total mass of the vehicle.

Following, hydrostatic and intact stability analyses were conducted, as described in Section 2.4.2. Considering a water level height of 0.2 m, it was then verified that the intact stability of the vehicle is positive, with a metacentric height of 0.360 m.

Next, using Altair® HyperWorks™ V2023.0 with the AcuSolve™ solver V2023.0, the 3D pressure and velocity distributions, as well as the drag force of the vehicle, were estimated (see Figure 4) using the methodology described in Section 2.4.3.

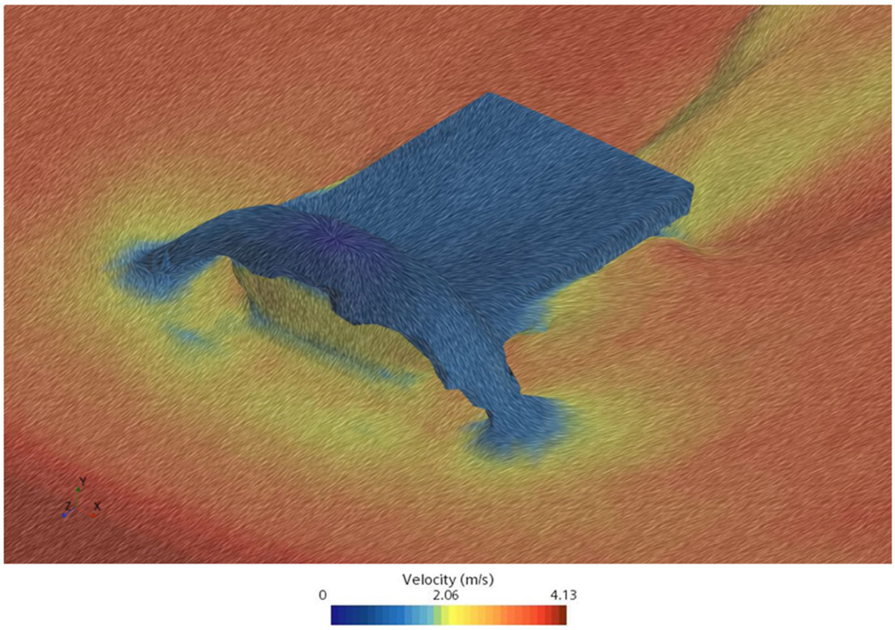
In Figure 4, it is possible to verify a decrease in the speed flow in front of the vehicle. This behavior is due to the interaction of the fluid with the hull of the vehicle which, due to its configuration, leads to the creation of a wave, a splash effect, increasing the pressure distribution exerted by the flow in front of the vehicle. Also, due to the design created at the rear of the vehicle, there is a decrease in the pressure field, leading to a decrease in speed in that region.

By multiplying the total drag force (at maximum speed) of ~320 N (see Figure 4a) by the maximum speed of the vehicle in water, one obtains a maximum power required for the water motor of approximately P_T = 1310 W.



(a)

Figure 4. *Cont.*



(**b**)

Figure 4. Surface pressure and water–air interface with velocity results: (**a**) side view; (**b**) perspective view.

Considering the water mission profile presented in Section 2.4.3, the required energy capacity of the batteries may be estimated using Equation (2) considering the previously estimated required powers for the land and water motors (2400 W and 1310 W, respectively), h = 1.75 h, V = 48 V, η_m = 0.95, and η_b = 0.85. By additionally assuming a safety factor of 1.2, one obtains a total required energy capacity C = 77 Ah, which is available assuming the 80 Ah battery configuration previously established.

3.4. Static and Dynamic Structural Analysis

To assess the structural integrity of the vehicle, static and dynamic structural analyses (see Section 2.4.4) were carried out on the conceptual vehicle with the boundary condition illustrated in Figure 3.

Figure 5a through Figure 5c illustrate the Von Misses stress distribution results when considering the following: Figure 5a, a total applied static load of 500 N; Figure 5b, the critical static load; and Figure 5c, a total applied dynamic step load of 500 N. In Figure 5a, it is possible to observe that the points where the highest stresses are located are some edges and vertices of the hull structure and the shafts that connect the wheels to the hull [41]. However, the maximum stress to which the structure is subjected is approximately 12.6 MPa, located in the shafts. Given that the yield stress of the shaft material is 503 MPa, it is verified that the material can withstand the imposed static load, as in [42].

To locate the first point of failure, the applied load was gradually increased until the maximum stress value was greater than that of the yield stress. It was observed that the shaft was the first component to fail (see Figure 5b), as it presents a stress of approximately 506 MPa (>503 MPa). However, this failure only occurs when the applied total load approximately reaches a critical value of 34.5 kN, which is considerably well above the static and dynamic applied loads [43].

Similarly to the static load case, in Figure 5c, it is possible to observe that the points with the highest stresses are located in some edges and vertices of the hull structure and the shafts that connect the wheels to the hull. However, as the maximum stress to which the structure is subjected is approximately 27.5 MPa, located in the shafts (<503 MPa), it is verified that the material can withstand the imposed dynamic step load.

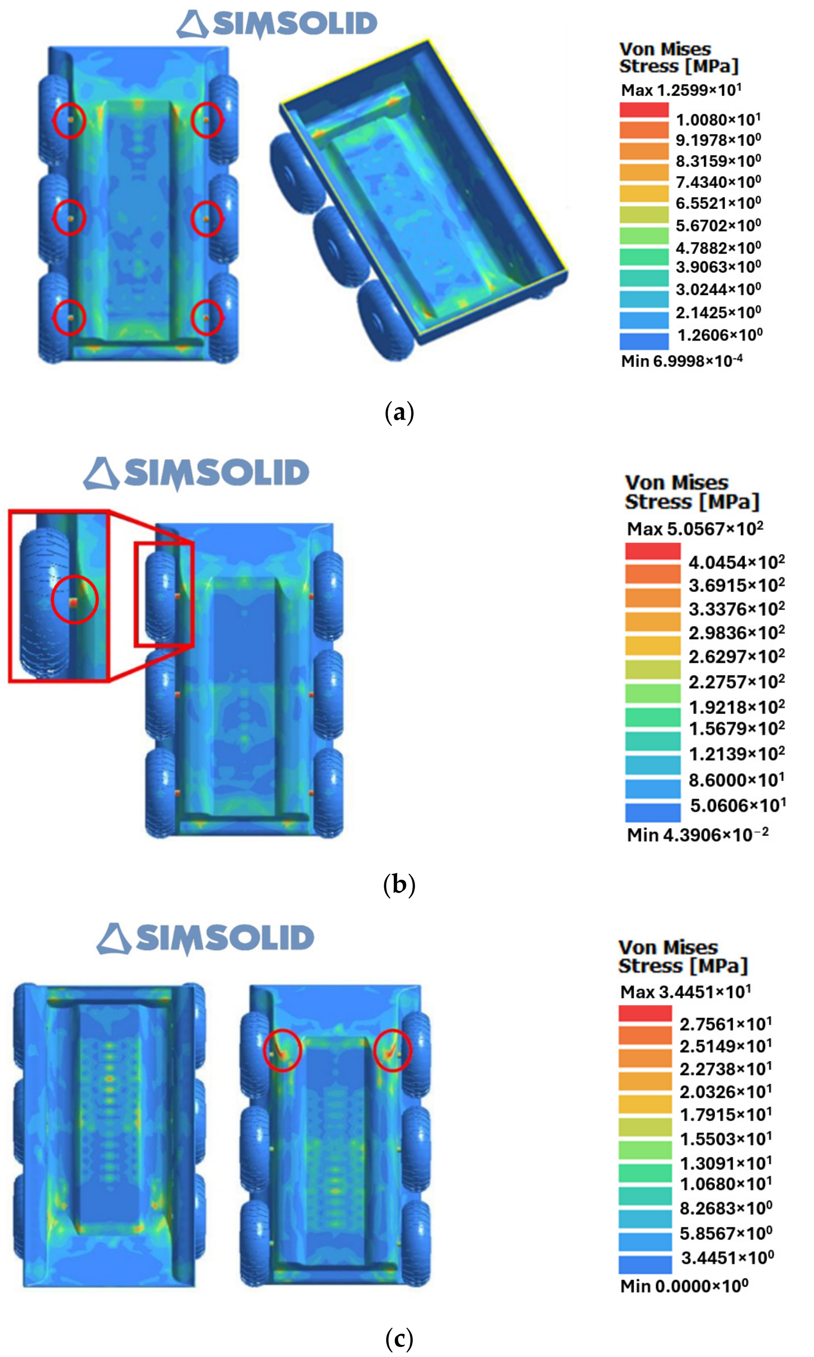


Figure 5. Static and dynamic analysis: (**a**) Static stress results; (**b**) Critical load stress results; (**c**) Dynamic step load stress results. The red circles indicate the maximum stress locations.

These results suggest further research regarding the minimization of the mass of the vehicle and/or the use of materials with lower values of yield stress, which are usually less expensive.

3.5. Final Specifications

The last step of conceptual development is the reconsideration of the specifications initially established. Of the initially imposed specifications/requirements, the only change is the increase in vehicle weight to 50 kg. The reasons that justify this change are the fact that it allows a greater payload, maintaining the number of batteries required with an inherent cost of decreasing the autonomy. This alteration had no negative impact on the fulfillment of the remaining identified needs, making it possible to maintain the maximum speed, stability conditions, and acceptable waterline level.

Thus, the final specifications of the vehicle are as follows:

- Maximum weight of 50 kg;
- Land traction 6 × 6;
- Maximum land speed of 20 km/h;
- Dedicated means of displacement in the water;
- Maximum water speed of 8 kts;
- Buoyancy and stability in water;
- Autonomy greater than 1 h;
- Four Li-ion batteries (80 Ah);
- Hull made of resistant material.

Considering these final specifications, an initial estimate of the production cost of the vehicle while contemplating the materials considered in the structural analysis and off-the-shelf components is presented in Table 2.

Table 2. Estimated production costs of the vehicle.

Components	Cost
Batteries	EUR 1200
Land propulsion (wheels, motor, and shaft included)	EUR 720
Water propulsion	EUR 135
Remote control	EUR 300
Telemetry	EUR 80
Electric cables	EUR 100
Carbon-reinforced fiber	EUR 1000
Mold of the hull	EUR 300
Man labor	EUR 1000
Total	EUR 4835

This leads to a total estimate of EUR 4835. Note that the highest cost is related to batteries and labor. Even so, this initial estimate is below the maximum limit of EUR 5000 initially defined for the vehicle.

Figure 6 illustrates a rendering of the CAD model of the conceptual A-UGV equipped with some sensors, revealing what this vehicle may become in the near future.

Figure 6. Future concept of the A-UVG developed.

4. Conclusions and Final Remarks

It is considered that the conceptual design project of the proposed vehicle is successfully achieved, leading to a fully electric, modular, portable, low-cost A-UGV capable of operating in multi-operational scenarios. The resulting specifications allow the future continuity of this project into a detailed development phase, in which the control and sensor topics must be addressed, allowing the development, construction, and testing of a prototype. New challenges will arise, originating new design iterations and consequently allowing for the fine-tuning of the final specifications of the vehicle.

This work contributes to the application of electric vehicle technology in maritime and terrestrial environments. By leveraging advancements in materials science and computational fluid dynamics, we have demonstrated the feasibility of a modular, fully electric A-UGV with autonomous capabilities poised to enhance surveillance, reconnaissance, and intervention missions. The resulting specifications address the identified needs of both civilian and military applications, providing a versatile, cost-effective solution that aligns with the strategic objectives outlined in the DEM 2018 REV 2021.

Some shortcomings worth mentioning are related to the design of the hull due to its actual configuration, which causes a wave to form, creating a splash effect, which in turn increases the pressure distribution exerted by the flow in front of the vehicle and to the mechanical connections between the wheels and the hull, which are critical points that require further reassessment and detailed structural analysis.

While the conceptual design phase has yielded promising results, several other aspects warrant further investigation. For instance, the integration of advanced sensor suites and communication systems, as well as the development of robust control algorithms, will be critical for enhancing the operational effectiveness and autonomy of the A-UGV. Additionally, the analyses presented here have focused primarily on structural integrity, hydrodynamics, and propulsion systems, leaving aspects such as environmental sustainability and human–machine interaction to be explored in future research. Moreover, while our cost estimates fall within budgetary constraints, ongoing refinement and optimization efforts may be necessary to achieve greater cost-effectiveness without compromising performance.

The next steps in this project will involve transitioning from conceptualization to detailed development, culminating in the construction and testing of a prototype A-UGV. This iterative process will enable the validation of the proposed design choices, address any unforeseen challenges, and iteratively improve the vehicle's capabilities based on real-world feedback.

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