TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 69, Issue Special III, July, 2026

TERRAFLYER – HYBRID VEHICLE SERVING HUMANITY

Silviu-Mihai PETRIȘOR, Emmyly PAVEL, Ionuț-Cristian ȚOPA

Abstract: *The objective of this paper is to develop and analyze an innovative technological concept –* ***TerraFlyer****,* ***a hybrid mobile platform capable of terrestrial movement and autonomous vertical take-off and landing (VTOL)****. The project aims to integrate the advantages of ground mobility with those of air mobility into a single system, through an adaptable mechanical architecture and high-precision electronic control. TerraFlyer was designed based on the need to overcome the limitations of conventional vehicles in terms of terrain accessibility, autonomy, and operational versatility. The project proposes an interdisciplinary approach, integrating principles of mechanical engineering, aerodynamics, robotics, and control electronics. In addition to describing the system architecture, simplified performance calculations, a functional analysis of the main components, and the practical steps of modeling, printing, and assembly are presented.*

Keywords*: VTOL, Pixhawk 4, hybrid vehicle, civil intervention, technological humanism, avant-garde element*

1. INTRODUCTION

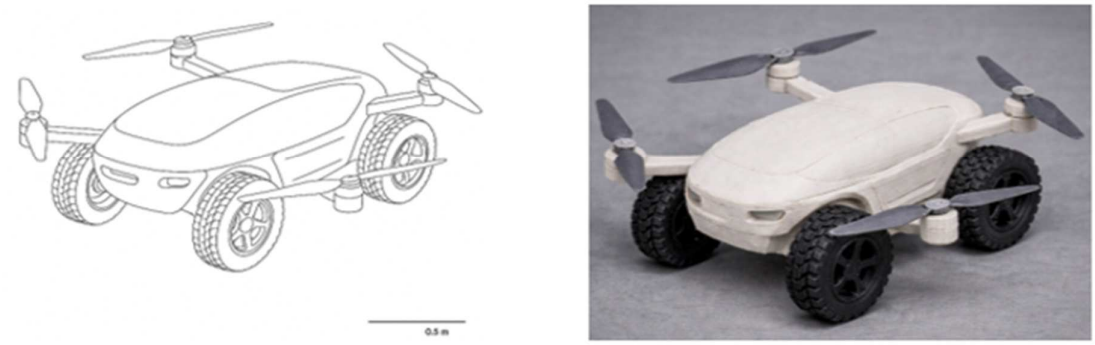
The accelerated progress of mechatronic technologies and autonomous systems has favored the emergence of hybrid concepts capable of overcoming the limitations imposed by traditional means of transportation. In this context, vertical takeoff and landing (VTOL) vehicles have become an area of major interest, both in civil research and in military or logistical applications [1].

The integration of these principles into a dual mobility system—terrestrial and aerial—opens up new avenues for research and development, and the **TerraFlyer** project is part of this contemporary trend.

TerraFlyer is *an experimental multi-mode platform* designed to combine the robustness and stability of a ground vehicle with the versatility of an autonomous aerial system. By adopting a 3D-printed modular structure, the project aims to reduce weight, optimize interior space, and enable rapid maintenance. The propulsion system is coordinated by a Pixhawk 4 controller, a central element of the flight architecture, which allows for a smooth transition between *ground* and *air* modes of operation.

The concept was born out of a desire to demonstrate that a low-cost prototype, built from affordable commercial components, can achieve performance comparable to industrial models. Thus, *TerraFlyer becomes a demonstration project*, intended not only to validate core engineering principles, but also to support *the development of complex technical skills*. It involves the full cycle of product realization: from CAD design and iterative modeling, to additive manufacturing (3D printing) and post-processing, followed by electronic integration and system-level assembly.

At a time when autonomous systems are a strategic pillar in the development of modern society, TerraFlyer (fig. 1) stands out as an *example of innovation, constructive simplicity, and operational efficiency*, contributing to a practical vision of the future of integrated mobility.



a) b)

Fig. 1 TerraFlyer technological product**: a)** 3D model, **b)** model printed at a scale of 1:1

2. PROJECT OBJECTIVES

The main objective of the TerraFlyer project is to conceive, design, model, and build a hybrid land-air vehicle with a modular structure and dual propulsion system, capable of operating autonomously in various terrain conditions.

By judiciously combining modern mechatronic components with a lightweight, 3D-printed architecture, the aim is to develop a functional experimental platform that can be adapted to multiple areas of application.

2.1 General objectives

- development of a *hybrid prototype* that integrates ground travel and vertical flight into a single coherent system;
- implementation of *unified control* based on the Pixhawk 4 controller, capable of automatically managing the transition between ground and air modes;
- optimizing *energy efficiency* by calculating the balance between traction, weight, and electric motor consumption;
- *CAD design* and modeling of main components: chassis, body, VTOL arms, propulsion system, and electronic tray.

2.2 Specific objectives

1. Creating a modular mechanical structure using 3D printing technologies with composite materials (PLA, PETG, carbon-reinforced).
2. Integration of the mixed propulsion system, consisting of: two T-Motor MN701S motors for ground travel, four T-Motor MN4014 motors for VTOL lift and stabilization.
3. Simulation and validation of dynamic stability in transition phases (takeoff, level flight, landing).
4. Creating a functional prototype that can be tested under controlled conditions.
5. Analysis of the advantages, limitations, and development prospects for the practical implementation of the concept.

The goal of the project is to show that it's *possible to make an autonomous hybrid vehicle* using low-cost components and modern tech, which will be a demo platform for applied research and technical training.

3. FUNCTIONAL ARCHITECTURE

3.1 Ground Module – Land Mobility

Ground movement is provided by four 3D-printed wheels with a soft rubber layer, driven by two T-Motor MN701-S servo motors [2] (Fig. 2). Front steering is controlled by servomotors synchronized by Pixhawk 4. The system is capable of operating on mixed terrain: mud, sand, shallow water.

Inspired by hybrid designs proposed in recent literature [3], the terrestrial module was designed to meet the requirements of mechanical stability and high energy efficiency.

Components: 4 3D-printed wheels with soft rubber coating for optimal grip, horizontal propulsion provided by two T-Motor MN701-S servo motors with directed flow, steering

controlled by integrated servo motors, coordinated by Pixhawk 4.

3.2 Air Mode – Vertical Takeoff and Landing (VTOL)

Vertical lift is provided by four T-Motor MN4014 servo motors, each equipped with a dedicated propeller (Fig. 3). Flight control uses PID algorithms integrated into Pixhawk 4 [4].

The transition from ground to air is achieved automatically by switching the kinematic mode, according to the hybrid control methodologies described in the literature [3]. The platform maintains stable flight and can perform prolonged hovering with vector thrust control.

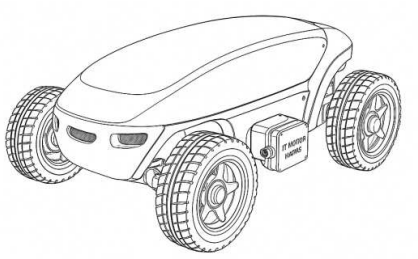
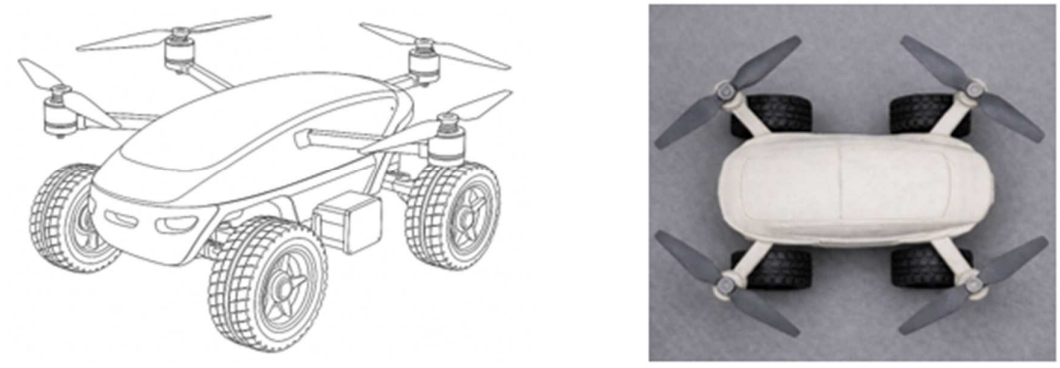


Fig. 2. Architecture of the ground module proposed in the prototype design

Components: 4 vertical T-Motor MN4014 servomotors with dedicated propellers, stabilization and hover control via PID algorithms implemented in Pixhawk 4 firmware, autonomous transition from ground to air without external intervention, vector control for maintaining stability in dynamic conditions.



a) b)

Fig. 3. Architecture of the air module proposed in the prototype design: a) 3D model, b) prototype model view

3.3 3D Printed Modular Structure

The vehicle structure is made of 3D-printed PLA/ASA composite material, with folding arms for easy transport. The structural optimization concepts come from recent studies published in the literature on additive manufacturing for robotic structures [5].

The casing has an aerodynamic configuration, thus protecting the internal components of the technological product (batteries, ESCs, control system, etc.) and reducing drag in flight.

Components: lightweight chassis made of PLA/ASA composite material, resistant to impact, shock, and vibration; folding arms for compact transport; aerodynamic fairing optimized for low drag; internal compartment for LiPo 6S battery, controller, ESCs, and sensors.

3.4 Mechanical structure

The mechanical architecture of the prototype consists of six main subassemblies:

1. *Lower chassis* – load-bearing element made of 3D-printed composite material (carbon fiber reinforced PETG), which ensures the rigidity of the assembly and serves as a base for mounting the wheels, VTOL arms, and electronic tray (Fig. 4a).

2. *Upper body (aerodynamic cover)* – curved part, designed to reduce drag and protect the internal system, with a fluid design inspired by aeronautical shapes (fig. 4b).

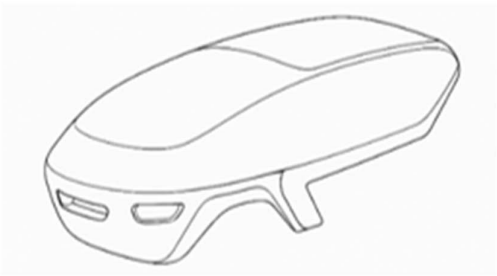


Fig. 4a. Lower chassis

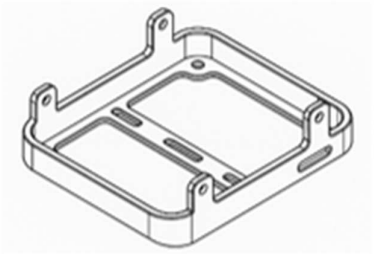


Fig. 4b. Aerodynamic cover

3. *Sliding VTOL arms* – four telescopic arms integrated into the chassis, which extend automatically when Air mode is activated. Each arm is equipped with an MN4014 motor and a variable pitch propeller (fig. 4c).

4. *Ground propulsion system* – two T-Motor MN701S motors, located on the front and rear axles, which independently drive the wheels, allowing for differential steering and traction control (fig. 4d1).

5. *Wheels* – with a diameter of 500 mm, fitted with synthetic rubber tires and ABS rims, providing stability on mixed terrain (fig. 4d2).

6. *Electronic tray* – internal platform that supports the Pixhawk 4 controller, ESC units, 6S Li-Po battery, and telemetry system (Fig. 4d3).

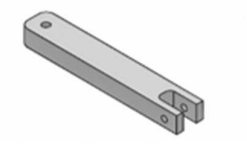


Fig. 4c. Sliding VTOL arm

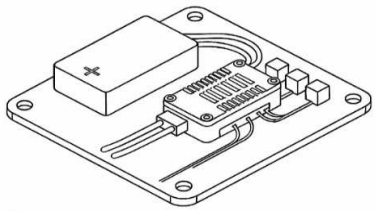


Fig. 4d$_1$, 4d$_2$, 4d$_3$. final assembly of components

3.5 Electronic and control structure

The TerraFlyer's electronic system is based on a distributed control architecture, in which Pixhawk 4 acts as the central control unit.

Navigation data is collected from accelerometer, gyroscope, and GPS sensors, and propulsion commands are transmitted via ESCs to the electric motors.

The transition between ground and Air modes is performed automatically, based on an algorithm that detects vibration level, altitude, and travel speed.

3.6 Operating principle

In *terrain mode*, TerraFlyer uses electric wheel traction, moving autonomously with the help of proximity sensors and a front camera. When *Air mode* is activated, the VTOL arms slide out from inside the chassis, and the MN4014 propellers generate the lift force needed for vertical takeoff. The Pixhawk system automatically adjusts the speed of each rotor to maintain flight stability.

Upon landing, the arms retract to their original position, bringing the vehicle into its terrestrial configuration. This mixed architecture gives the TerraFlyer design *increased mobility and unique adaptability*, making it suitable for applications in challenging environments where conventional vehicles cannot operate.

4. ESTIMATED ANALYSIS: TRACTION–WEIGHT RATIO

The estimated total mass M of the technological product is 7.276 kg, including the payload of 2 kg. The four MN4014 vertical engines generate a total thrust T of 10.4 kgf, thus achieving a T/M ratio of 1.43, which ensures stable lift and safe maneuverability [2]. The result is in line with the parameters recommended in the literature for VTOL vehicles with average payloads [3].

The functional analysis of the TerraFlyer vehicle aims to determine the main technical parameters necessary for efficient and optimal operation in both modes: *terrestrial and aerial* (VTOL).

The simplified calculation aims to establish correlations between *total weight, traction force, power developed by motors, and energy autonomy* of the system.

4.1 General vehicle parameters

Table 1 shows the parameters adopted and calculated for the design and operation of the technological product.

Table 1

Operating parameters of the designed vehicle

Parameter	Parameter symbol	Adopted value	SI unit
Total weight (including battery)	M	8.5 (3.224)	kg
Wheel diameter	D	0.5	m
Number of VTOL engines	n	4	Pcs.
Number of traction motors	n_t	2	Pcs.
System voltage	U	22.2	V (Li-Po 6S)
Control type	-	Pixhawk 4	-

4.2 Calculation of lift force (VTOL mode)

In order for the vehicle to take off vertically, the total force generated by the four MN4014 engines must exceed the weight of the system:

$$F_{total} \geq m \cdot g, \text{ [6]} \quad (1)$$

where: $m = 8.5$ kg, $g = 9.81$ m/s^2, and the total force is:

$$F_{total} = 4 \cdot F_{motor} \geq 8.5 \times 9.81 = 83.4 \text{ N.} \quad (2)$$

It follows that *each motor must provide a minimum of 21 N of static thrust*. T-Motor MN4014 motors can develop *up to 24–26 N*, *providing a safety margin of approximately 15%* in hover mode. The prototype consists of four propellers, each with a length of 19 cm calculated from the axis of rotation, each propeller being able to provide a maximum traction of 6 kgf.

4.3 Calculation of ground traction

In terrestrial mode, the traction force is calculated using the following formula:

$$F_t = \frac{P}{v}, \text{ [6]} \quad (3)$$

where: $P = 250$ W/motor, $v = 2.5$ m/s (estimated ground speed). Then,

$$F_t = \frac{500}{2.5} = 200 \text{ N.} \quad (4)$$

This value allows *for stable travel on mixed terrain*, with a climbing ability of up to 25°.

4.4 Energy independence

The total energy stored in the 10000 mAh 6S Li-Po battery is calculated using the following formula:

$$E = U \times C = 22.2 \times 10 = 222 \text{ Wh, [7]} \quad (5)$$

and the estimated consumption will have the following values: Ground Mode 120 W, Air Mode 500 W, resulting in the corresponding travel time:

$$t_{ground} = \frac{222}{120} = 1.85 \text{ h}, t_{air} = \frac{222}{500} = 0.44 \text{ h.} \quad (6)$$

Therefore, *the autonomy is ~1h50 min on the ground* and *~26 minutes in flight*, depending on the load and environmental conditions.

4.5 General functional analysis

From a functional perspective, the TerraFlyer prototype meets the following engineering requirements: balance between weight and propulsion force; dynamic stability in both modes; mechanical compatibility between traction and VTOL systems; optimized energy consumption for maximum operating time.

These parameters confirm the technological *feasibility of the concept*, demonstrating that the vehicle can operate efficiently in civil or research missions.

5. ENERGY AND CONTROL SCHEME

The system is powered by a LiPo 6S battery (10000 mAh), with distribution to independent ESCs for terrestrial and aerial modes.
Pixhawk 4 manages the mode transition between modes, and flight data is processed in real time through QgroundControl [8].

The control architecture follows the principles used by NASA eVTOL UAVs [9], but in a miniature, low-cost civilian implementation. *Components* - main power source: 6S LiPo battery, 10000 mAh, distribution to separate ESCs for ground and air propulsion, main control via Pixhawk 4 with mode management via dedicated software (QGroundControl), integrated sensors: gyroscope, accelerometer, GPS, barometer, and real-time telemetry.

The process of creating the TerraFlyer prototype followed a logical sequence of engineering steps, starting with virtual modeling and continuing with the physical production of components through 3D printing, assembly of propulsion systems, and complete electronic integration.

5.1 CAD modeling and file preparation

Three-dimensional modeling was performed using Autodesk Fusion 360 software, where each component was designed separately (chassis, aerodynamic cover, wheels, VTOL arms, electronic tray), then assembled into a single unit. The files were exported in .STL format for 3D printing and .DXF format for possible laser cutting.

FEM (Finite Element Method) analysis was used to verify the stress distribution in the chassis and at the arm attachment points, confirming a *maximum deformation of 0.8 mm under nominal load*.

5.2 3D Printing

The architecture components were printed on *a modified Creality Ender 3 printer*, using *carbon fiber reinforced PETG filament* for the chassis and ABS for the upper body.

Printing parameters: layer height: 0.2 mm; fill density: 60% for the chassis / 40% for the body; nozzle temperature: 245°C; bed temperature: 80°C.

The total printing time was approximately 48 hours, divided into four separate sessions. After printing, the parts were *cleaned, deburred, and dimensionally tested* for assembly compatibility.

5.3 Mechanical assembly

The assembly stage included mounting the following architecture elements on the prototype structure: *VTOL arms sliding* on the internal rails of the chassis; *MN4014 and MN701S motors* on dedicated supports; *3D-printed wheels* with a synthetic rubber layer for grip; *electronic tray* inside the lower casing.

The joints were made with *M3 and M4 screws* made of OLC 45 stainless steel, and the vibration points were dampened with silicone inserts. After complete assembly, the structure was tested for rigidity and symmetry, confirming the correct alignment of the axes.

5.4 Electronic integration

The Pixhawk 4 controller was installed centrally, connected to the ESCs dedicated to each motor. The 6S Li-Po battery was mounted under the tray to maintain a low center of gravity. The telemetry system and GPS antennas were positioned at the top of the body to avoid electromagnetic interference.

The sensors and ESCs were calibrated using QGroundControl, setting the PID parameters and acceleration curves [10]. After calibration was complete, the TerraFlyer underwent *static tests and dynamic movement tests* in controlled environments, confirming its stability in both modes of operation.

6. ADVANTAGES, LIMITATIONS AND IMPLEMENTATION SCENARIOS

6.1 Technological and design advantages

The TerraFlyer prototype stands out thanks to a number of engineering advantages that set it apart from conventional hybrid platforms, such as:

1. Modular and easy-to-maintain architecture – all structural components can be replaced

individually thanks to the segmented design and standardized connections.
2. Low production cost – the use of printable materials (PETG, ABS) and commercial components (Pixhawk 4, T-Motor) makes the project affordable and replicable.
3. Operational versatility – the ability to switch between Ground and Air modes allows the vehicle to be used in a variety of environments, including hard-to-reach areas.
4. Intelligent autonomous control – the integration of the Pixhawk 4 controller and PID algorithms ensures stability and adaptability to environmental conditions.
5. Optimized energy efficiency – uniform weight distribution and intelligent consumption management allow for high autonomy in terrestrial mode.
6. Sustainability and quick repairs – parts can be remade using local 3D printing, reducing waste and maintenance time.
7. Aerodynamic design – the fluid body reduces drag and improves flight stability.

6.2 Limitations and disadvantages

Although overall performance is remarkable for an experimental prototype, there are a number of limitations that can be improved in subsequent development phases, as follows:

1. Limited flight time – flight time of approximately 25–30 minutes is restricted by the energy capacity of the Li-Po battery.
2. High weight of the lower structure – although reinforced PETG provides strength, its density limits the thrust-to-weight ratio.
3. Software complexity – synchronization between the two operating modes (Ground ↔ Air) requires rigorous calibration and a precise algorithm.
4. Sensitivity to weather conditions – crosswinds and high humidity can affect flight stability.

The main disadvantage is the reduced energy autonomy in VTOL mode, which limits the operational duration to short missions (less than 30 minutes) compared to conventional drones.

6.3 Practical implementation scenarios

The TerraFlyer vehicle has the potential to be implemented in a wide range of civil and technical applications, being an effective solution for:

• Infrastructure monitoring – inspection of pipes, cables, bridges, or hard-to-reach industrial areas;
• Emergency response – delivery of medical kits, sensors, or equipment to isolated areas;
• Research applications – geospatial data collection or agricultural land monitoring;
• Security and patrol – use as an autonomous observation vehicle, with optical cameras and thermal sensors;
• Education and technical training – demonstration platform for the study of hybrid mechatronic systems.

Its large-scale implementation would require further weight optimization, increased energy density, and the integration of an auxiliary solar charging system. However, even at its current stage, TerraFlyer demonstrates a high level of technological maturity (TRL3), representing a solid foundation for advanced applied engineering projects.

7. CONCLUSIONS

The results obtained within the TerraFlyer project confirm *the technological feasibility of a hybrid vehicle with VTOL capabilities*, intended for civil, logistical, and emergency response applications.

By combining autonomous control, electric propulsion, and 3D-printed structure, the possibility of creating a multifunctional, efficient, and easily reproducible platform in educational or industrial environments has been demonstrated.

The project highlighted that *the intelligent integration of land and air mobility* is not just a design exercise, but a concrete direction for the development of modern mechatronic systems.

Modular architecture, unified control, and structural adaptability provide a functional model for new-generation autonomous vehicles.

8. REFERENCES

[1] Parfenov R., Petrişor S. M. (2019). Contributions on the practical realization of an innovative technological product type UAV destined for research missions in risk areas, *A XIX-a Conferinţă Internaţională Multidisciplinară „Profesorul Dorin PAVEL - fondatorul hidroenergeticii româneşti”*, Cluj-Napoca, 20-21 September 2019, in *Proceedings: Ştiinţă şi Inginerie, vol. 35/2019*, MEGA&AGIR Publishing House, Cluj-Napoca, ISSN 2067-7138, pg. 47-58.

[2] T-Motor (2023). MN4014 & MN701-S Series Motor Specifications, in *T-Motor Technical Data Sheet*.

[3] Gibson K., Xu J. (2021). Amphibious UAV Design for Search and Rescue Missions, in *IEEE Aerospace and Electronic Systems Magazine*, vol. 36, no. 8, pp. 24–35.

[4] PX4 Autopilot Team (2024). PX4 Autopilot User Guide – Pixhawk 4 Documentation, in *Open Source Flight Control Project*, online: https://docs.px4.io.

[5] Campbell A. (2020). 3D Printing for Aerospace and Robotics Applications, in *Elsevier Publishing House*, Oxford.

[6] Petrişor S. M. (2013). Industrial Robots – Concept, Modeling, Design and Implementation, in *Verlag LAP LAMBERT Academic Publishing, OmniScriptum GmbH & Co. KG, Heinrich-Böcking, Saarbrücken,* Deutschland/Germany, ISBN-13: 978-3-659-47184-1, ISBN-10: 3659471844, 392 pg.

[7] Zhang L., Chen X. (2023). Design and Dynamic Modeling of a Hybrid VTOL Drone for Civil Applications, in *Journal of Intelligent & Robotic Systems*, Springer, vol. 108, no. 3, pp. 455–470.

[8] Atencia C. R., Camacho, D. (2018). Extending QGroundControl for Automated Mission Planning of UAVs, in *Sensors Journal*, MDPI, vol. 18, 2339, online: https://www.mdpi.com/1424-8220/18/7/2339.

[9] NASA Aeronautics Research Mission Directorate (ARMD) (2022). Urban Air Mobility and eVTOL Concept Studies, in *NASA Technical Reports*.

[10] Siegwart R., Nourbakhsh I. and Scaramuzza D. (2022). Introduction to Autonomous Mobile Robots, *MIT Press Publishing House*.

TerraFlyer – vehicul hibrid în slujba umanității

Rezumat: Lucrarea de față are ca obiectiv dezvoltarea și analiza unui concept tehnologic inovator – TerraFlyer, o platformă mobilă hibridă capabilă de deplasare terestră și zbor vertical autonom (VTOL – Vertical Take-Off and Landing). Proiectul urmărește integrarea într-un singur sistem a avantajelor mobilității terestre cu cele ale mobilității aeriene, printr-o arhitectură mecanică adaptabilă și un control electronic de înaltă precizie. TerraFlyer a fost conceput pornind de la nevoia de a depăși limitările vehiculelor clasice în ceea ce privește accesibilitatea terenului, autonomia și versatilitatea operațională. Proiectul propune o abordare interdisciplinară, integrând principii de inginerie mecanică, aerodinamică, robotică și electronică de control. Pe lângă descrierea arhitecturii sistemului, sunt prezentate calcule simplificate de performanță, o analiză funcțională a componentelor principale, precum și etapele practice de modelare, imprimare și asamblare. În final, sunt evaluate avantajele și dezavantajele sistemului, posibilitățile de implementare practică și scenariile de utilizare civilă și tehnologică, evidențiind potențialul produsului TerraFlyer-ului de a deveni o soluție viabilă pentru aplicații logistice, de supraveghere sau intervenție rapidă.

Silviu-Mihai PETRIȘOR, Ph.D, Dipl. Eng. Habil., Professor, “Nicolae Bălcescu” Land Forces Academy, Technical Science Department, robmilcap@gmail.com, +40 269 432 990, 3-5 Revoluției Street, Sibiu, Romania, and University of Oradea, 1 Universității Street, Oradea, Romania.

Emmyly PAVEL, Cadet, emmylyp01@gmail.com, +40 269 432 990, “Nicolae Bălcescu” Land Forces Academy, 3-5 Revoluției Street, Sibiu, Romania.

Ionuț-Cristian ȚOPA, Ph.D student, Eng., topaionutcristian@gmail.com, +40 269 432 990, “Nicolae Bălcescu” Land Forces Academy, 3-5 Revoluției Street, Sibiu, Romania, and University of Oradea, 1 Universității Street, Oradea, Romania.