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A NOVEL TRANSPORT MODULE CONCEPT FOR VERTICAL TAKE-OFF AND LANDING UNMANNED AERIAL VEHICLE TRANSPORTATION OF UNMANNED GROUND VEHICLES

Abstract

This paper describes the design and testing of a modular docking station for a fixed-wing vertical take-off and landing drone to be used in conjunction with an unmanned ground vehicle. The solution enables autonomous engagement and disengagement of payloads through a controlled rail-guided system and visual docking with a quick response marker using a binocular camera module. A novelty of the proposed module lies in the fact that the primary mounting mechanism does not remain integrated with the drone after deployment; instead, it is designed as an integral part of the transport module itself and is released together with it. This approach distinguishes the system from conventional solutions in which the main attachment structure stays onboard the aerial platform, and it expands the flexibility of payload delivery and deployment scenarios. The payload assembly was designed in Autodesk Fusion 360 and manufactured in polyethylene terephthalate glycol-modified plastic using fused deposition modeling 3D printing on a Bambu Lab X1 Carbon printer. Structural analysis using finite element methods was performed to evaluate the displacement, stress, strain, and reaction forces of the module's structure under operational loads. Advanced simulations suggest that the design satisfies mechanical protection requirements, additional proof will be gathered through flight testing. The system could be implemented to deploy unmanned ground vehicles from the air or for a drone to land on mobile ground vehicles, demonstrating its versatility in robotics and automation.

Key words: autonomous robotics, drones, VTOL, UGV, modular docking system, payload mechanism, 3D printing, PETG, delivery.

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Introduction

Nowadays, the popularity and scientific interest in drones and Unmanned Aerial Vehicles (UAVs) are steadily increasing. This trend may be attributed to the expanding range of applications and the growing diversity of aerial vehicles. Deliveries through UAVs pose an opportunity for developing local logistics, specifically for densely populated urban areas [1–3]. The advancement of such a system may require not only drones and their communication and interaction systems but also transportation and delivery modules for various goods, ranging from medicines to food products. This would not only enhance the technical capabilities of drones, but also improve their overall safety [1, 4].

The processes that come with the delivery have a lot of problems to solve. To make certain there are no issues with the steady ascent, release, and retrieval of the cargo, one of the key problems to solve is vertical correction (adjustment along the Z axis). For this purpose, the participants of AlphaPilot competition along with their advisors devised an optimization model which at a velocity of 5 m/s tracked and navigated through the obstacles with close to 100 precision percent success rate [5]. In addition, analyzing the performance of vertical delivery with an aerial drone as compared to a conventional elevator (assuming a single elevator in the building), shows that UAVs exhibit drone dominance in average delivery time and energy efficiency. Conversely, elevators outperform drones in overall delivery efficiency for given wait time constraints and when order volume is heavily loaded above 0.66 orders per household [2].

An equally important consideration is defining the equipment, in particular, the drone controller which determines the extent to which advanced algorithms on path optimization could be stored, the level of artificial intelligence integration, processing speed, and the quality of stabilization. The Arduino Uno is one of the cheapest and easiest to program microcontrollers. A modular system of multiple drones was developed on this platform where the drones could vertically attach to each other, thus increasing their payload capacity by combining their power resources [3].

For the development of more complex intelligent systems, platforms such as NVIDIA Jetson Xavier [5, 6], FPGA [4], or fully professional equipment, such as the specialized PixHawk controller [7–9] are utilized. In one study, the combination of PixHawk with a Raspberry Pi 3B (3 GB RAM) enabled the creation of a system for installing signaling spheres on high-voltage power lines [10].

Aside from the use of controllers, certain specialized modules are designed to customize drones for particular functions. For example, the drone fitted with a device containing two robotic arms which enables it to operate as controlled remote arms through augmented reality (AR) [11]. In another study, a module was developed using rods made of a sufficiently elastic material. This design enabled the protection of the payload during its release from the drone’s flight altitude by forming a "shield" around the cargo [12]. A modular system was also employed in the integration of drones into traditional delivery systems using trucks. This system functioned as a docking and battery-swapping station, enabling seamless interaction between drones and ground transport [13].

Based on the analysis of the studies, the main difficulty with such concepts stems from their software-centric exploitation of cyberattacks, as well as the risk of rogue behavior during the incorporation of new system modules [1, 4]. Nevertheless, attempts to solve these issues have already been initiated. In the research concerning the drone developed to carry signaling spheres to high-voltage power lines, provisions were made for a magnetic lock module as a countermeasure to electrostatic interference caused signal disruption [10].

The main goal of this research is to fuse a fixed-wing VTOL drone with a module for transporting payloads designed for releasing an unmanned ground vehicle (UGV). One of the most important design features is limiting the distance between the payload and the landing site to reduce the possibility of damaging the UGV. In this case, the drone will land on the payload to minimize the risk during release. A separate case worth emphasizing is the use of the drone within a collaborative robotic system [14]. The structure could extend the operational capabilities of monitoring missions in highly hazardous areas [15] and may also serve as a foundation for logistics systems in Smart City environments [16-18].

While some existing projects propose combining the UGV and the drone into a single integrated device [19], this article considers a different concept based on a new approach to module design. In the proposed concept, the transport module is attached to the drone rather than permanently integrated with the ground vehicle. After release or delivery, the module is detached together with the payload, thereby reducing the structural burden on the drone during subsequent operations.

The most important result of this study lies in the creation of a new release and communication module aimed at efficient deployment and post-release interaction with a UGV. This could advance multidisciplinary research focused on autonomous multi-robot cooperative missions, autonomous navigation in complicated terrains, logistics automation, and related fields. In addition, the novelty of the proposed concept lies in the fact that the main attachment mechanism is not left as a permanent part of the drone structure, but instead forms part of the transport module itself and is released together with it. This distinguishes the proposed approach from conventional solutions in which the primary mounting structure remains onboard the aerial platform.

An assessment of the developed module's structural performance and reliability will be carried out through virtual testing using Autodesk Fusion 360 simulation tools. The evaluation will include the following mechanical characteristics: safety factor, von Mises stress, displacement, reaction force, and strain. Among these parameters, displacement is considered the most important. Excessive deformation under load may impair the precise positioning and secure holding of the payload during post-flight operations. A high displacement value can indicate low rigidity, which increases the likelihood of misalignment or oscillation during deployment. Therefore, to ensure the stability and operational integrity of the system, the critical goal is to maintain bounded and predictable displacement. These parameters will guide iterative improvements in the module's structural design aimed at increasing its durability and performance in actual operational environments.

The main contribution of the study is formulated as follows:

A modified design of a transport module has been developed for carrying unmanned aerial vehicles (UAVs) using VTOL-type UAVs, with the aim of reducing the structural load on the drone after the payload has been detached. Unlike traditional solutions, the main mounting mechanism is integrated into the transport module itself and detaches along with it, which increases the system's flexibility for use in delivery and robotic interaction tasks.

A 3D model of the transport module has been developed in Autodesk Fusion 360, incorporating a rail-based docking mechanism, alignment using a QR code, the use of a binocular camera for positioning, and servo-driven locking of the module during transport of the unmanned aerial vehicle (UAV).

A physical prototype of the transport module was designed and manufactured from PETG using 3D printing technology, which made it possible to test in practice the feasibility of integrating the module with the UAV fuselage and mechanically connecting it to the UAV.

A structural analysis of the developed module was carried out using the finite element method in Autodesk Fusion 360, including an analysis of displacements, Mises stress, strains, support reactions and the safety factor under a typical operational load.

Thus, problem statement is to develop a new concept of a module for attaching an unmanned ground vehicle to a drone for transportation, with the ability to detach this module from the drone during flight, and to evaluate its structural characteristics using a CAD-based application.

This article has the following structure: Section 1 serves as an introduction, which includes an analysis of the popularity of drones and the rationale for designing modules for them. This is followed by Section 2, which covers methodology and includes subsections on creating a conceptual design for a new module, selecting materials for its 3D printing, and constructing it using the program Fusion 360. Next comes section 3 - a demonstration of the work and its metrics. The final section, 4, presents the conclusion of the whole work, further research in this area, and limits.

Materials and methods

The development of the payload transport module (PTM) presented in Figure 1 involved a sequential work approach the fused reference study, digital modeling, simulation as well as physical testing. It started with an actual aerial transport system selection as a conceptual guide, and then proceeded to construct a 3D model of the drone using 3D scanning methods.

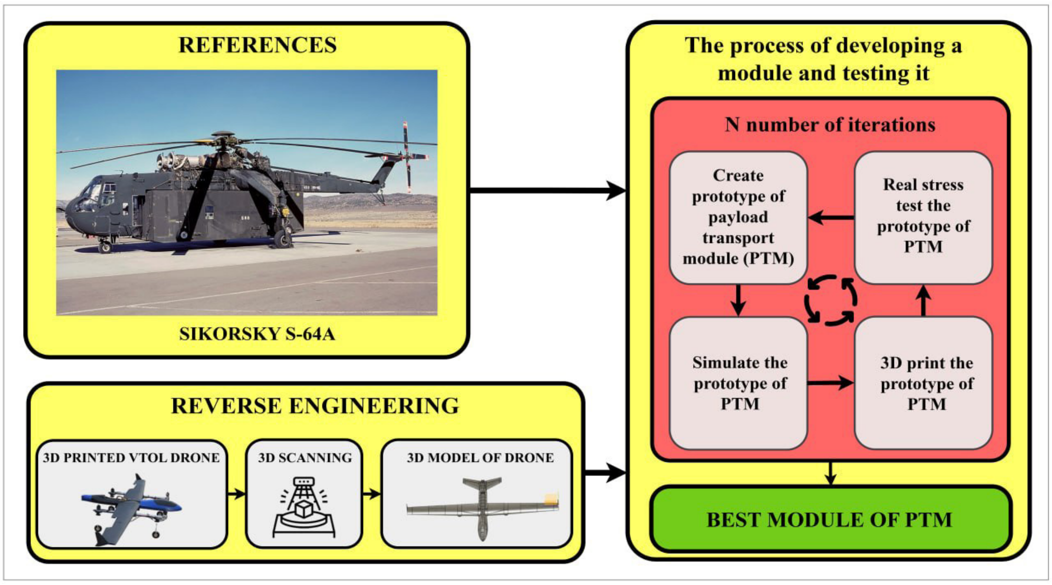

Figure 1 – Structural scheme of the payload transport module (PTM)

After this, a preliminary design of PTM was created and evaluated through structural simulations. Some of the results were based on a physical prototype which was 3D printed and tested under actual loading conditions. The model which best balanced performance in both virtual and experimental evaluations was chosen as the final model.

A structural assessment of the proposed design was conducted using the finite element method (FEM) in a linear static stress formulation. The numerical study was performed in Autodesk Fusion Simulation as a Static Stress analysis, in which the mechanical response of the structure under prescribed loads and boundary conditions was evaluated by solving the global equilibrium equation [20–24]:

$$Ku = f \tag{1}$$

where K is the global stiffness matrix, u is the is the nodal displacement vector, and f is the global load vector. The external loading included gravitational acceleration and three applied forces of 20 N each, while the support conditions were represented by fixed constraints that suppressed translational motion in all x-, y- and z-directions. Gravity was applied as 9,807 m/s^2, along the negative z-axis.

The displacement field was approximated by shape functions such as:

$$u^{(e)}(x, y, z) = N(x, y, z)q^{(e)} \tag{2}$$

where N is the matrix of shape functions, q^e is the vector of nodal degrees of freedom for element e. Under the small-strain assumption, the strain field was obtained from (2):

$$\varepsilon = Bq^{(e)} \tag{3}$$

where B is the strain-displacement matrix. The stress field was then computed using the constitutive relation for a linear isotropic elastic material,

$$\sigma = D\varepsilon \tag{4}$$

where D is the elasticity matrix.

The material assigned to the structure was plastic, characterized by a Young's modulus of 2780 MPa, a Poisson's ration of 0.4 and a yield strength of 54.4 MPa. These properties were used to construct the constitutive matrix and to evaluate the stress-based failure criterion.

To assess the stress state of the structure, the equivalent von Mises stress was used as the primary strength criterion [25]:

$$\sigma_V M = \sqrt{\frac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\ \sigma_1)^2]} \tag{5}$$

where σ_1, σ_2, σ_3 are principal stresses.

The total displacement magnitude was evaluated as:

$$u_{tot} = \sqrt{u_x^2+u_y^2+u_z^2} \tag{6}$$

where u_x, u_y, u_z are the displacement components along the global coordinate axes. Structural safety was estimated using the factor of safety defined as:

$$n = \frac{\sigma_y}{\sigma_V M} \tag{7}$$

where σ_y is the yield strength of the material and $\sigma_V M$ is the equivalent von Mises stress at the point of interest (5). This formulation enabled identification of the most critical stress locations and quantification of the available safety margin with respect to yielding.

The element stiffness matrix was formed in the standard FEM form as:

$$K^{(e)} = \int_{V^e} B^T D B dV \tag{8}$$

and the global stiffness matrix was assembled from all elements as:

$$K = \sum_{e=1}^{n} A^{(e)T} K^{(e)} A^{(e)} \tag{9}$$

where $A^{(e)}$ is the assembly operator. After application of the prescribed constraints and loads, the resulting linear system was solved to obtain the displacement field, from which strains, stresses, reaction forces, and safety factors were subsequently derived.

Conceptual design of the drone

A fixed-wing VTOL drone weighing approximately 4.5 kilograms served as the foundation for the system's development, classifying it as a small UAV. The detailed technical specifications are presented in Table 1.

To explore existing concepts and engineering solutions related to modular systems for lifting and transporting payloads, archival materials on the experimental Sikorsky S-64 helicopter demonstrated in Figure 2 were studied [26]. This aircraft, designed by Igor Sikorsky (1962), provided valuable insights into the structural principles of aerial cargo transport.

Particular attention was given to the lifting assemblies of the referenced helicopter, which essentially functioned as a rail-mounted crane system. This configuration allowed the mechanism to fold during flight and landing, making it relatively convenient to operate.

However, as previously noted, the drone used in this project weighs only 4.5 kilograms, and integrating such a heavy system would significantly reduce its overall payload capacity. As a result, an innovative solution was proposed: to shift the modular mechanism onto the payload itself - in this case, an unmanned ground vehicle (UGV).

Table 1 – Components of the fixed-wing VTOL

Component	Model	Purpose
1	2	3
Thermal-resistant p. rts	Overture PETG	For components exposed to heat
Flight controller	Holybro Kakute H743 Wing	Main control unit for flight management
GPS module	Micro M10	Navigation and position tracking
Airspeed sensor	MATEKSYS Digital Airspeed Sensor	Measures air velocity during flight
Transmitter	RadioMaster TX16S + TBS Crossfire Module	Remote control of the drone
Receiver	TBS Crossfire Nano RX Pro	Receives control signals from the transmitter
ESC (speed controller)	Axisflying Argus Pro 65A (4-in-1)	Controls motor speeds
Motors	Brotherhobby Tornado T5 3115 640Kv	Provides thrust for flight
Propellers (front/rear)	13*8 APC / 12*6 APC	Generates lift and propulsion
Tilt servos	RDS3218 (25 kg*cm)	Tilts motors to control thrust direction
Control surface servos	EMAX ES08ma (12 g)	Controls stabilizers and rudders
Control surface linkage	HobbyPark Nylon Control Horn Kit	Mechanical linkage system
Video transmitter (VTX)	DJI O3 Air Unit	Real-time video transmission
Gimbal	HEQ G-Port 3-Axis	Stabilized camera platform
Gimbal power supply	12V BEC 3A	Provides stable power to the gimbal
FPV goggles (First Person View)	DJI Goggles 3	Video feedback and navigation interface
Battery	6S3P Li-ion 13,500 mAh (Molicel 21700 P45B)	Power supply for the entire drone

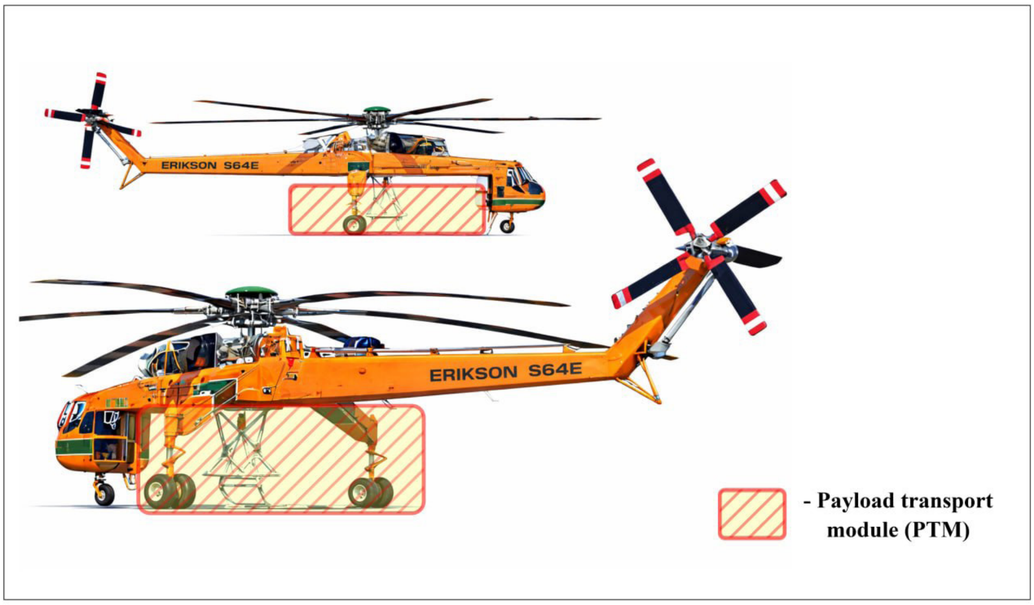

Figure 2 – The payload mechanism of Sikorsky S-64

This approach dramatically reduces energy consumption during the drone's unloaded flight phase, offering a more efficient and lightweight alternative to traditional aerial lifting designs.

Composite selection

Based on its mechanical and thermal properties, a lightweight structural polymer was chosen for a payload lifting and transport module, which Table 2 shows. The material offers an optimal balance between strength and weight, which is critical for small UAV platforms with strict mass limitations, having a density of 1.3 g/cm^3.

This plastic will be able to bear moderate mechanical loads without permanent deformation because the material's yield strength and ultimate tensile strength are 90 MPa. Moreover, its yield strength and ultimate tensile strength are both rated 90 MPa which ensures the module will withstand both static and dynamic stresses while flying, landing, and releasing payloads.

Table 2 – Material properties selected for the payload transport module

Property	Value	Reason for selection
1	2	3
Density	1.1 g/cm	Lightweight; reduces overall drone mass
Young's modulus	2.78 GPa	Provides sufficient stiffness for structural integrity
Poisson's ratio	0.4	Suitable for predicting deformation behavior
Yield strength	54.4 MPa	Withstands stress during payload handling
Ultimate strength	54.4 MPa	Maintains integrity under maximum loading
Thermal conductivity	0.24 W/(m*°C)	Minimizes heat transfer under solar exposure
Thermal expansion coefficient	6.7*10-5 °C	Maintains dimensional stability during flight
Specific heat capacity	1600 J/(kg*°C)	Helps dissipate heat and avoid overheating

Moreover, the specific heat capacity of the material assists in moderating the rise in temperature due to heat being absorbed, in addition to highlights thermal stability. It has a thermal conductivity of 0.2, which means it will keep its shape while the operating temperate clefts can change.

The combined properties make the selected polymer a good candidate for 3D-printing of the payload module because it requires thermal stability and strength with low weight.

3D Modelling in Fusion 360

Autodesk Fusion 360 was selected as the primary CAD software for designing the 3D model of the payload module for the VTOL drone. The choice was driven by its extensive capabilities in modeling complex 3D geometries, high precision in exported designs, integrated structural analysis tools, and access to a vast component library - even in the free student version, which makes it especially suitable for academic research and prototyping.

The mounting mechanism itself was developed as follows. The unmanned ground vehicle (UGV), equipped with a top-mounted connector, autonomously navigates beneath the VTOL drone, aligning itself with a visual marker in the form of a QR code as shown in Figure 3.

Positioning accuracy is ensured by means of a stereo vision system using a binocular camera module (Dual IMX219), which allows the UGV to precisely dock with the aerial platform before lift-off. The module is secured in place using a Tower Pro SG90 micro servo, which is presented in Figure 4.

Once the payload (UGV) is successfully attached, the QR code marker located beneath the drone is retracted upward to enhance the aerodynamic profile of the airframe. This mechanism is actuated by an additional servo, which lifts the drone approximately 2 centimeters off the ground, allowing the marker to fold into the body and minimizing drag during flight. It is noted that the initial idea with a rail-guided movement for the module was maintained for seamless controlled docking alignment. In later phases of the project, this component was physically realized with 3D printing, the results of which, along with their evaluation, will be discussed in the Results section.

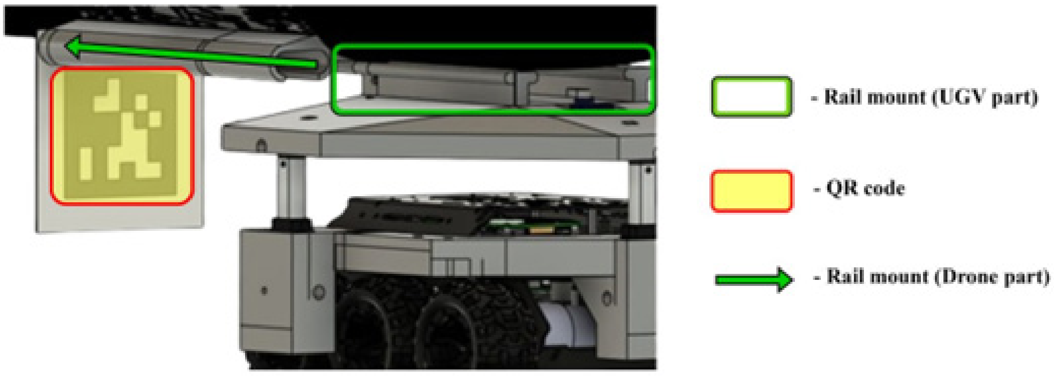

Figure 3 – Correcting and driving UGV under the drone by QR code

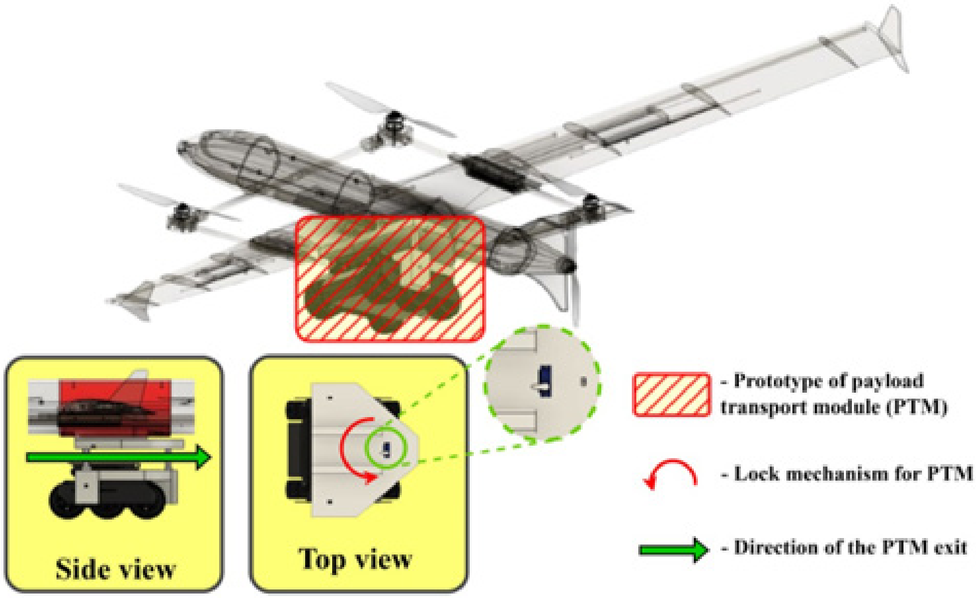

Figure 4 – Rail mount for drone and UGV transportation module

Results and discussion

The Results section includes the final result of the work as well as the main physical characteristics of the module.

Figure 5 illustrates the Drop-Ship system, where the drone is landed, scans the QR marker with binocular stereo vision, and payload locking is performed underneath.

The last version of the payload transport module was created by utilizing a black PETG filament which has good strength properties and heat resistance. The extrusion temperature during the printing process was set at 255 degree of Celsius and the mass of the extracted material after printing the module was about 4 kg. The whole process took about 8 hours on a high-precision Bambu Lab X1 Carbon 3D printer.

The construction of the module enables full integration with the drone fuselage, resulting in a monolithic printed structure. The UGV interface featured M3 bolts and nut welds on the ground docking rails of the vehicle to facilitate consistent and robust mechanical alignment between the two platforms.

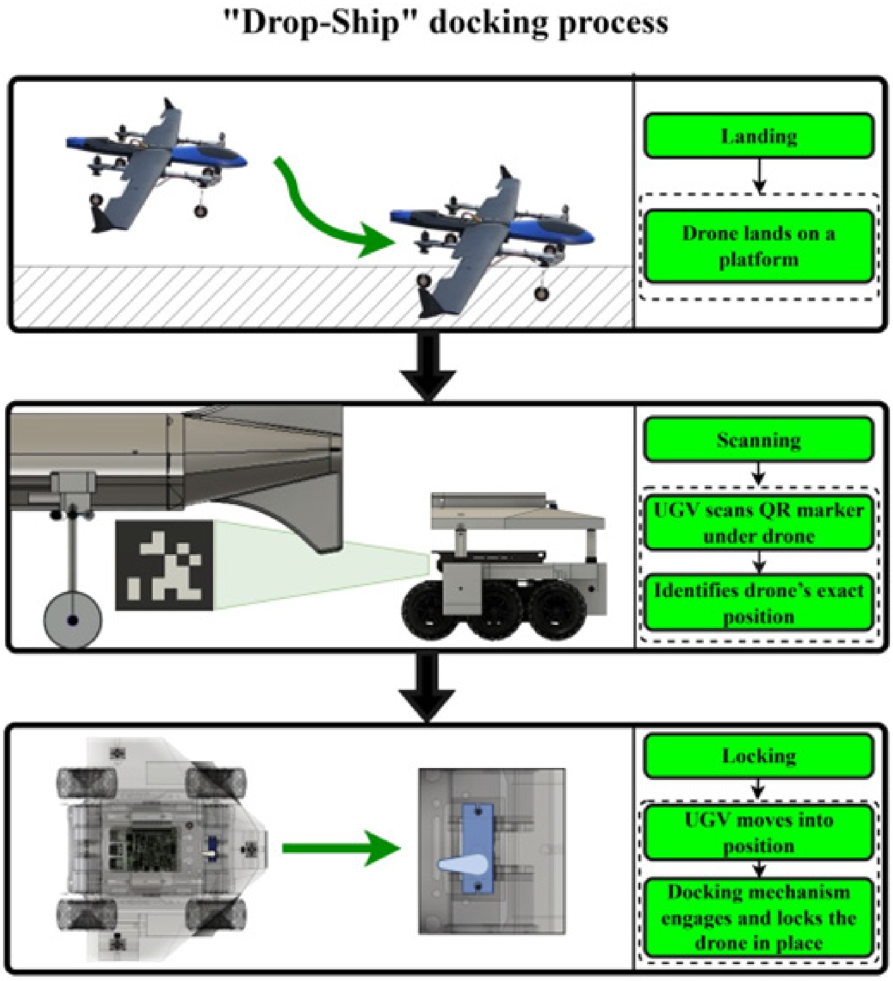

Figure 5 – Structural scheme of the landing, UGV payload attachment and takeoff

A comprehensive logic for the fully autonomous docking and takeoff prototype was also implemented. The diagram depicts the drop-ship system in which the drone lands, uses binocular stereo vision to scan the QR marking, and executes payload locking beneath.

The Figure 6 presents the final prototype of the drone docked with the UGV is shown. This picture illustrates the successful integration of the modular design into functional hardware.

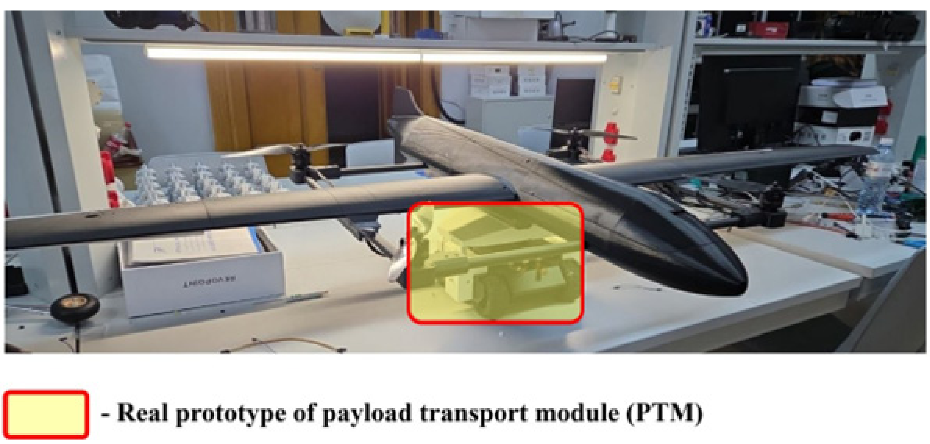

Figure 6 – Real printed prototype of the transportation module

The finalized prototype demonstrated the possibility of structural integration with both the VTOL drone and the UGV, validating the feasibility of the proposed modular docking approach.

Structural performance evaluation

During the evaluation phase, the structural performance of the payload module was analyzed in Autodesk Fusion 360 using finite element method (FEM) simulation. The results included measurements of displacement, von Mises stress, safety factor, reaction forces, and strain under a typical operational load case.

Displacement received focus as one of the primary parameters in regard to the vertical and payload alignment that connects mechanically. The simulation showed that maximum displacement of 0.2785 mm occurred at the upper edge of the guide rails, which is within the tolerances defined. The value exceeds the tolerable mechanical ranges required for docking with the, thus, overall displacement contour remains subdued and localized, showing an anchored and rigid structural behavior response. A displacement field plot is given in Figure 7.

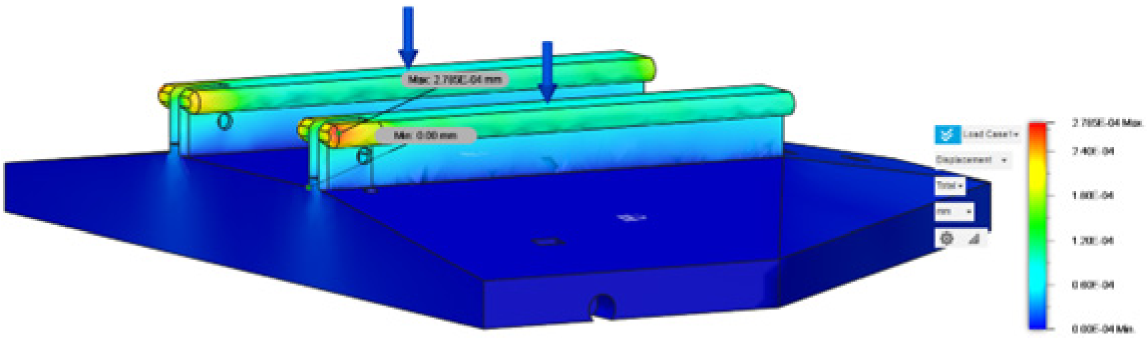

Figure 7 – The displacement coefficients of the transportation module

Other parameters, such as stress and strain, remained well below the material limits. The Table 3 below summarizes the key outcomes of the simulation study.

Table 3 – Summary of the structural simulation results for the payload module

Parameter	Max value	Interpretation
1	2	3
Safety factor	15.0	Far above critical threshold; structure is overdimensioned
Von Mises stress	0.464 MPa	Much lower than yield strength (90 MPa); indicates safe operation
Displacement	0.2785 mm	Low displacement; ensures precision during payload locking
Reaction force	1.191 N	Localized at attachment points; within acceptable range
Strain	1.913*10-4	Minimal deformation; good elasticity without plastic change

Initial simulation results indicate that the design meets structural requirements under nominal load conditions; however, these findings will be further validated through physical testing in upcoming stages of the project.

Conclusion

This study devised and prototyped a modular payload docking and transport system which incorporates a fixed-wing VTOL drone with an unmanned ground vehicle (UGV). Additive manufacturing processes were used to build the docking mechanism out of PETG which meets design specifications and was verified through simulation which showed that the essential structure met the mechanical design criteria for nominal loading. Systems for alignment are based on QR code tracking and binocular vision while payload securing is implemented using servo locking.

The described methodology is promising not just for the deployment of payloads from aircraft, as it allows for UGVs to be air-transported, or for drones to land on mobile ground vehicles, which would augment task autonomy in inspection logistics and robotics.

As the next phase of development, integrated system mounting on a custom platform will allow for real world testing and evaluation of the aerodynamic and structural performance of the system.

Although the outcomes are encouraging, many limitations still exist. Currently, the system operates using exact interaction and communication via timing, as the locking and unlocking steps are executed commandingly within a sequence. In addition, finding the best drone-UGV mass balance was a remarkably complicated issue that affected the system's stability and efficiency. The expenses related to the materials, sophisticated 3D printing, and the equipment onboard may also create obstacles when trying to scale up or implement in more austere settings.

Subsequent tasks will include optimization of docking control algorithms, structural efficiency, and testing with varying payload endurance and safety requirements.

The contribution of this work lies in the development of a new concept for a transport module designed to carry an unmanned ground vehicle using a VTOL-type UAV, in which the main mounting mechanism is integrated into the transport module itself and detaches together with the payload, rather than remaining on board the aircraft. Based on the proposed concept, a three-dimensional model of the transport module has been developed, featuring a rail-based docking mechanism, alignment via a QR marker, the use of a binocular camera for positioning, and servo-driven locking during transport. In addition, a lightweight module design was proposed and implemented, manufactured using 3D printing with PETG, which enabled the creation of a physical prototype and a preliminary engineering assessment of its integration with UAVs and UAS. To verify the structural integrity of the design, a structural analysis was performed using the finite element method in a linear static formulation, including an assessment of displacements, von Mises stresses, strains, support reactions and the safety factor. The proposed approach offers the following advantages: it reduces the structural load on the UAV after payload separation, it expands the possibilities for modular interaction between aerial and ground-based robotics, it allows the use of additive technologies for rapid prototyping and design modification, it creates a foundation for the further development of cooperative robotics systems, logistics and the autonomous deployment of ground-based platforms.

Limitations of the proposed approach. The size of the UAV to be transported under the current implementation is strictly limited by the dimensions of the transport module and must not exceed 250 mm by 250 mm, whilst the UAV's mass is limited to up to 2 kg. Furthermore, at this stage, the paper presents the results of numerical modelling, 3D prototyping and preliminary structural assessment, whilst tests of the system under real flight conditions have not yet been conducted. This means that the aerodynamic influence of the module on the UAV's behaviour, the system's stability during actual landing, docking and subsequent take-off, as well as the influence of external environmental factors, have not yet been fully experimentally verified.

Future work. In the future, the authors plan to conduct tests of the developed transport module under real flight conditions, including verification of the landing, levelling, docking, securing and transport stages of the unmanned aerial vehicle (UAV). A separate area of further research will be optimising the module's configuration, including improving its geometry, mass, stiffness and the layout of the mounting elements, with the aim of increasing reliability, reducing structural loads and expanding the system's operational capabilities. Future research will also examine the module's operation with various RTS variants, assess the system's behaviour under varying payload masses, and explore ways to enhance the autonomy of interaction between the airborne and ground-based platforms.

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ТІК ҰШЫП КӨТЕРІЛУ ЖӘНЕ ҚОНУ МҮМКІНДІГІ БАР ҰШҚЫШСЫЗ ӘУЕ АППАРАТЫ АРҚЫЛЫ ҰШҚЫШСЫЗ ЖЕРҮСТІ ПЛАТФОРМАСЫН ТАСЫМАЛДАУҒА АРНАЛҒАН ЖАҢА КӨЛІКТІК МОДУЛЬ ТҰЖЫРЫМДАМАСЫ

Аңдатпа

Мақалада ұшқышсыз жерүсті платформасымен бірлесіп жұмыс істеуге арналған, қанатты, тік ұшып көтерілу және қону мүмкіндігі бар ұшқышсыз әуе аппаратына арналған модульдік түйістіру станциясының жобалануы мен сынақ нәтижелері қарастырылады. Ұсынылған шешім бағыттаушы рельстік жүйе мен бинокулярлы камера модулі арқылы quick response маркері негізінде жүзеге асырылатын көру жүйесінің көмегімен пайдалы жүкті автономды түрде бекіту және ажырату мүмкіндігін қамтамасыз етеді. Ұсынылып отырған модульдің басты ғылыми-тәжірибелік жаңалығы оның негізгі бекіту механизмі жүк түсірілгеннен кейін дрон құрылымында сақталмай, керісінше, көліктік модульдің ажырамас бөлігі ретінде орындалып, сол модульмен бірге ажыратылатындығында. Бұл тәсіл негізгі бекіту торабы әуе платформасының өзінде қалатын дәстүрлі шешімдерден ерекшеленіп, жүкті жеткізу және орналастыру сценарийлерінің икемділігін арттырады. Пайдалы жүкке арналған құрастырма Autodesk Fusion 360 бағдарламалық ортасында жобаланып, Bambu Lab X1 Carbon 3D-принтерінде қабаттап балқытып қалыптастыру технологиясы арқылы полиэтилентерефталат-гликоль типті пластик материалынан дайындалды. Модуль конструкциясының жұмыс жүктемелері кезіндегі орын ауыстыруы, эквиваленттік кернеуі, салыстырмалы деформациясы және реакция күштері соңғы элементтер әдісі негізінде құрылымдық талдау арқылы бағаланды. Жүргізілген кеңейтілген модельдеу нәтижелері ұсынылған конструкцияның механикалық беріктік пен қорғаныс талаптарына сәйкес келетінін көрсетеді, алайда бұл қорытындыларды толық растау үшін қосымша ұшу сынақтарын орындау қажет. Ұсынылған жүйе ұшқышсыз жерүсті платформасын әуе кеңістігінен түсіру үшін де, сондай-ақ дронның қозғалыстағы жерүсті платформасына қонуы үшін де қолданылуы мүмкін, бұл оның робототехника және автоматтандыру салаларындағы әмбебаптығын дәлелдейді.

Түйін сөздер: автономды робототехника, дрон, VTOL, UGV, модульдік түйістіру жүйесі, пайдалы жүк механизмі, 3D басып шығару, PETG, жеткізу.

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НОВАЯ КОНЦЕПЦИЯ ТРАНСПОРТНОГО МОДУЛЯ ДЛЯ ПЕРЕВОЗКИ БЕСПИЛОТНЫХ НАЗЕМНЫХ АППАРАТОВ С ПОМОЩЬЮ БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ С ВЕРТИКАЛЬНЫМ ВЗЛЕТОМ И ПОСАДКОЙ

Аннотация

В данной статье описываются проектирование и испытания модульной стыковочной станции для беспилотного летательного аппарата с вертикальным взлетом и посадкой, предназначенного для использования совместно с беспилотным наземным транспортным средством. Данное решение обеспечивает автономное присоединение и отсоединение полезных нагрузок посредством управляемой рельсовой системы, а также визуальную стыковку с помощью маркера quick response с использованием модуля бинокулярной камеры. Новизна предлагаемого модуля заключается в том, что основной крепежный механизм не остается интегрированным с дроном после развертывания; вместо этого он спроектирован как неотъемлемая часть самого транспортного модуля и отсоединяется вместе с ним. Такой подход отличает систему от традиционных решений, в которых основная крепежная конструкция остается на борту воздушной платформы и расширяет гибкость сценариев доставки и развертывания полезных нагрузок. Узел полезной нагрузки был спроектирован в Autodesk Fusion 360 и изготовлен из пластика типа полиэтилентерефталат-гликоль с помощью 3D-печати методом наплавления на принтере Bambu Lab X1 Carbon. Для оценки смещения, напряжений, деформаций и сил реакции конструкции модуля под рабочими нагрузками был проведен структурный анализ с использованием метода конечных элементов. Результаты углубленного моделирования показывают, что конструкция соответствует требованиям механической защиты, дополнительные подтверждения будут получены в ходе летных испытаний. Система может быть использована для развертывания беспилотного летательного аппарата с воздуха или для посадки дрона на мобильные наземные транспортные средства, что демонстрирует ее универсальность в области робототехники и автоматизации.

Ключевые слова: автономная робототехника, дроны, БПЛА типа VTOL, БПТ, модульная стыковочная система, механизм полезной нагрузки, 3D-печать, PETG, доставка.