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THE PROSPECT FOR THE LAUNCHE OF A MINI UNMANNED AERIAL VEHICLE FROM AN UNMANNED SURFACE VEHICLE

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ABSTRACT

Due to the growing interest in the problems of cooperation among unmanned vehicles, in the article the proposition of the system for launching a mini unmanned aerial vehicle (mini-UAV) from an unmanned surface vehicle (USV) has been presented. The solution differs from the previously used in this that instead of the commonly used rotorcrafts it concerns the ability to start the mini aircraft with the help of pneumatic or rubber launcher. The results of the computer simulation have confirmed the possibility of implementation of that kind of system.

Key words:
mini unmanned aerial vehicle (mini-UAV), unmanned surface vessel (USV), pneumatic launcher.

Research article

INTRODUCTION

Unmanned aerial vehicles are used on an increasingly wider scale in diverse areas of activity. Compared with manned vehicles they generate lower costs, enable faster vehicle replacement with another, and also real time environment monitoring and remote control without exposing the health and life of humans.

Currently unmanned vehicles carry out mostly tasks of a military nature (i.e. reconnaissance, detection, destruction and putting mines, the transport of weapons, attacking the surface, underwater and air targets, identification of contamination and their neutralization), and not military nature (ecological monitoring, patrolling and surveillance, hydrographic and weather data collection, etc.). The realities of the modern battle field show that unmanned units have permanently engraved to the arsenals of all types of forces. NATO forces, mainly naval forces, for many years have been looking for solutions that might counteract asymmetric threats. Currently there is a lack of vessels, which would be constructed and dedicated to these kinds of tasks. Therefore, navies are looking for different solutions and measures to be able to fend off these asymmetric attacks, which at the moment are very likely on the high seas [2].

Unmanned systems capabilities are on the rise each year, so that in the near future they will be able to play a decisive role in military activities. The marine environment monitoring and the exchange of data with other unmanned systems, command centers or weapon systems make unmanned vehicles extremely effective and dangerous weapons. The demand for unmanned vehicles also occurs in many rapidly developing areas, and their parameters and equipment would make possible to take up dangerous jobs from people. Conducting research on their development is possible due to the progress of science in areas such as information technology, electronics, and mainly in robotics. In many countries around the world including: Germany, Canada, France, Japan, the United States of America research and development activities to construct such vehicles for a wide range of applications are carried out [2].

In the article the possibility of cooperation of a mini unmanned aerial vehicle with an unmanned surface vehicle is examined, as the cooperation between these types of vehicles, to a large extent, will extend the range of applications of these units. This is also dictated by the fact that in the world literature there is occasional information on the topic of the UAVs' deployment and launching from a small unmanned surface vessel.

THE ANALYSIS OF TECHNICAL SOLUTIONS OF THE LAUNCH OF UNMANNED AERIAL VEHICLES FROM THE NAVAL VESSELS

As already mentioned, the use of unmanned aerial vessels on naval vessels is still marginal one, and the research activities on the cooperation between them are only being developed. So far, in the navies, the UAVs are commonly deployed on boards of large naval surface vessels, however the fundamental problem is the launch of UAVs from small units. Below are presented the current possibilities of the launch of small UAVs from the different types of maritime units.

The launch of a UAV from the deck of a naval surface vessel or a surfaced submarine

Mini unmanned aerial vehicles of a lightweight structure do not require any additional devices to assist the launch. Their use is beneficial, as they do not take up additional board space in order to install the launcher. It is necessary, however, the presence of a crew member who would perform the start of a mini-UAV (fig. 1 and 2).

Fig. 1. The launch from a hand of an AQUA PUMA mini-UAV [10]

Fig. 2. The launch from a hand of a mini-UAV from the surfaced submarine [13]

The launch of a UAV from a submarine in the periscope submersion

While a submarine remains under water is very difficult to detect and capture it as a target. The situation changes when it receives information and stays on the surface or the periscope submersion. The idea of equipping a submarine with the UAV designed for reconnaissance, that can be launched in the periscope submersion makes, however, a conventional submarine a very dangerous weapon.

The German company Gabler Maschinenbau GmbH, Lübeck leads in this type of solutions. It offers a modular system called Triple-M — the universal mast designed to be mounted on submarines.

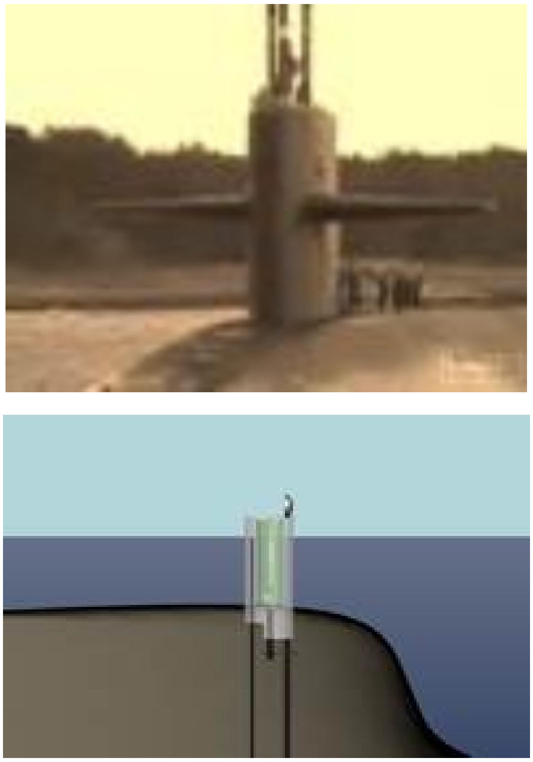

Fig. 3. The mast mounted on a submarine [11]

An interesting solution that can launch a mini-UAVs, is VOLANS Launcher. The VOLANS system is based on the existing German Aladin UAV, specifically a modified version of Aladin with folding wings that was used by Dutch and German troops in Afghanistan.

The submarine equipped with such arrangement emerges to the periscope depth and raises the watertight container in the upper position. Opens its hatch and using hydraulic equipment issues mechanical catapult with the Aladin UAV. The top of mast with the UAV launcher extends over the water surface allowing the ejection of an unmanned aerial vehicle in the air.

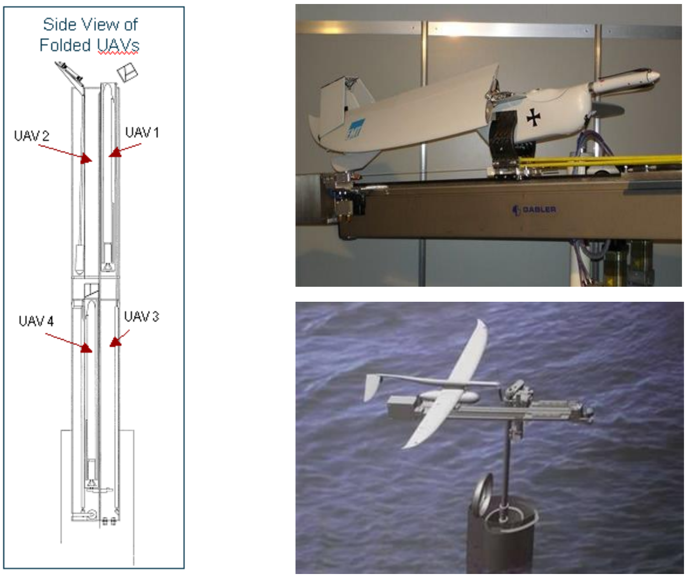

Fig. 4. The VOLANS system with an Aladin UAV and its modified version [14]

The launch of an UAV from the deck of a small USV

So far, there are few research centers designing the launch system for unmanned aerial vessels from the decks of small USVs. In most cases, the rotorcraft UAVs are used, while for airframes they are manned units, where the operator takes care of the UAV launching from a specially designed launcher (fig. 5).

Fig. 5. The launch of a Silver Fox mini-UAV from the board of a USV [7]

The launch of a medium sized and large UVS using a launching system

This is the most popular way to launch unmanned aerial vehicles from decks of large naval vessels. The most commonly used are pneumatic launchers. They are prevalent due to the greatest degree of reliability and relatively small size compared to the magnitude of casting strength produced by them. In addition, the startup mechanism allows to control the initial phase and adjust the impart speed.

Fig. 6. The launch of a UAV from the launcher mounted on the board of a naval vessel [12]

The launch of an UAV using a rocket accelerator

Many unmanned aerial vessels are equipped with the RATO rocket accelerators, allowing to shorten the take-off distance up to fourfold (e.g. Hunter from 700 to 200 m). The downside is that rocket accelerators may be used only once, and moreover they leave a clear track, in the form of a stream of hot exhaust gases and smoke.

Fig. 7. The launch of a Pioneer UAV [1]

THE PROJECT OF THE COOPERATION SYSTEM OF A SMALL UNMANNED SURFACE VESSEL WITH A MINI UNMANNED AERIAL VESSEL MOUNTED ON ITS BOARD

The only one available in the country unmanned surface vehicle is the 'Edredon' USV, constructed as a part of the development project under the name 'The unmanned multi variant floating platform for the protection of the State maritime services activities' conducted by the Naval Academy, Gdynia, Poland, during the period 2009–2011 [3].

Fig. 8. 'Edredon' USV during mission at sea [16]

In order to select the unmanned aerial vehicle that could be deployed on the 'Edredon' vehicle, three Polish designs (PR-9 'Tukan', BSL-X1, PR-3 'Gacek') and two foreign ('Aladin', 'Dragon Eye') were considered. After the analysis of these designs, for further consideration the PR-3 'Gacek 'UAV (fig. 9) was accepted. It has been designed by a group of students of the Faculty of Mechanical Engineering and Aviation at Rzeszow University of Technology (the beginning of the research project year 2006). The PR-3 'Gacek' is the shoulder-wing, cantilever, monoplane with the classical control surfaces, and it is powered by two electric motors. The PR-3 'Gacek' was chosen due to its dimensions and the satisfactory flight characteristics. The take off can be done with the hand release, which means that to assist its take off there is no need to generate large forces and the landing may be classical or parachute assisted [8].

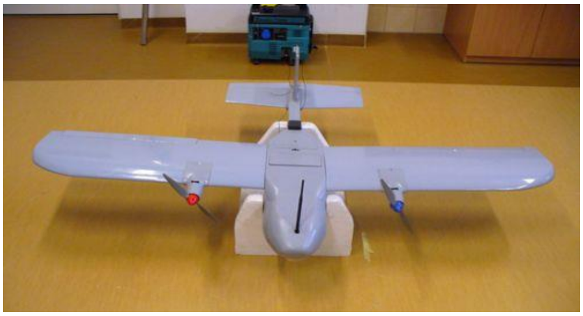

Fig. 9. PR-3 Gacek's view from the front site [15]

The boundary dimensions of the hull of the PR-3 'Gacek':
- length of the hull: 1.39 m;
- the width of the hull: 0.20 m;
- wing length: 0.70 m;
- wings width: 0.34 m;
- length of the lower panel in contact with trolley: 0.518 m

are presented in figures 3, 10 and 11:

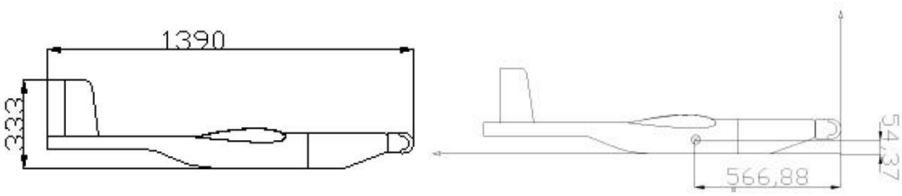

Fig. 10. The hall measurements of the PR-3 'Gacek' UAV from the lateral profil [8]

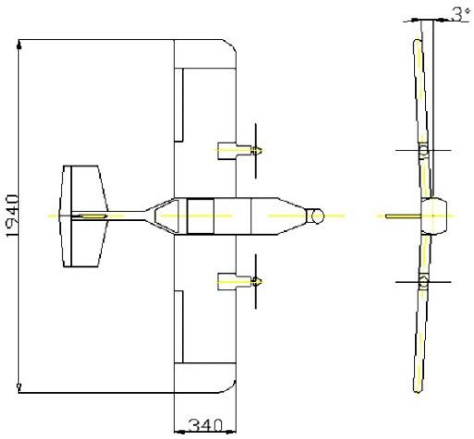

Fig. 11. Hall measurements of the PR-3 'Gacek' UAV from the top profil [8]

The following shows the schematic diagrams of two relevant types of aircraft catapult. The first one shows the pneumatic aircraft catapult. To start the catapult uses a pneumatic actuator, powered from the compressed air tank. Opening the valve regulating the air flow causes the admitting factor to the actuator, then its displacement, thereby resulting in displacement of the cradle with the plane. For each meter of the piston displacement moves the cradle with the plane one meter along the launching rail. The second schematic diagram shows the rubber aircraft catapult. The catapult startup mechanism works through the use of the rubber ropes (3). Before moving the cradle (4) with the airplane (2) along the launching rail (1) is moved to the start position of the launching rail, thereby stretching the elastic cord set, whereupon it is secured by the block system. In order to start the aircraft the block system is released, the elastic cord set goes back to the natural state, pulling the cradle with the aircraft at the same time [2].

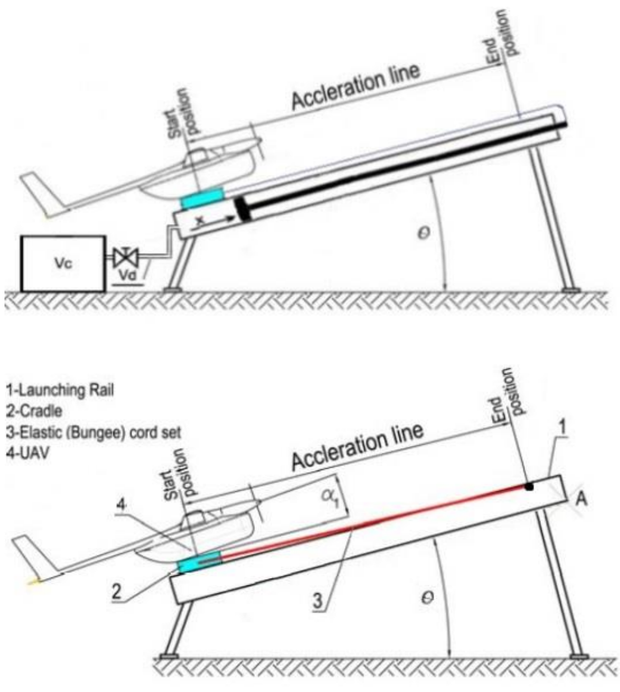

Fig. 12. Schematic diagrams pneumatic and rubber launchers [own study based on 5]

The forces necessary to launch the UAV were determined on the basis of the UAV's technical data and the space available on the vehicle — the last one, the space, conditioned the length of the aircraft catapult definition.

A mathematical model of the pneumatic aircraft catapult was depicted on figure 13 [6].

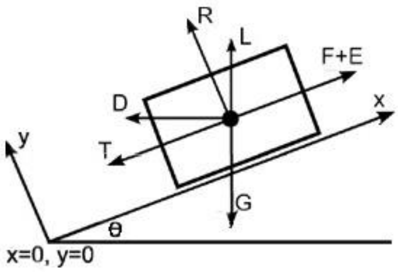

Fig. 13. The mathematical model for the pneumatic aircraft catapult [6]

Differential equation that describes the motion of the cradle-plane system along the launching rail and derivation of strength necessary to launch the UAV takes the form below.

Equations of motion for the layout:

The projection of forces on the y axis

$$R - Gcos\theta + Lcos + D = 0. \tag{1}$$

The projection of forces on the x axis

$$F - T - Dcos - Gsin\theta = m\ddot{x}. \tag{2}$$

Determination of reaction force from the first equation

$$R = Gcos - Lcos\theta - Dsin\theta. \tag{3}$$

Features that occur in the above equations:

$$L = C_z \frac{\rho v^2}{2} S; \tag{4}$$

$$L = \frac{C_z \rho S\,(\dot{x}cos\theta - vw)^2}{2};$$

$$D = C_x \frac{\rho v^2}{2} S; \tag{5}$$

$$D = \frac{C_x \rho S(\dot{x}cos\theta - vw)^2}{2}.$$

Substituting:

$$G = mg; \tag{6}$$

$$T = \mu R; \tag{7}$$

$$T = \mu(Gcos - Lcos\theta - Dsin\theta);$$

$$T = \mu mgcos\theta - \frac{\mu C_z \rho Scos\theta}{2}(\dot{x}cos\theta - vw)^2 - \frac{\mu C_x \rho Ssin\theta}{2}(\dot{x}cos\theta - vw)^2;$$

$$M = Lsin\theta - Gsin\theta - Dcos\theta; \tag{8}$$

$$M = \frac{C_z \rho Ssin\theta}{2}(\dot{x}cos\theta - vw)^2 - \frac{C_x \rho Scos\theta}{2}(\dot{x}cos\theta - vw)^2 - mgsin\theta.$$

Setting and substituting into the equation of force in the layout:

$$F - T + M = m\ddot{x}; \tag{9}$$

$$F - \mu mgcos\theta - \frac{\mu C_z \rho S}{2}(\dot{x}cos\theta - vw)^2 cos\theta - \frac{\mu C_x \rho S}{2}(\dot{x}cos\theta - vw)^2 sin\theta + \frac{C_z \rho S}{2}(\dot{x}cos\theta - vw)^2 sin\theta - \frac{C_x \rho S}{2}(\dot{x}cos\theta - vw)^2 cos\theta - mgsin\theta = m\ddot{x}.$$

To put it simply:

$$A1 = \frac{\mu C_z \rho Scos\theta}{2} + \frac{\mu C_x \rho Ssin\theta}{2} + \frac{C_z \rho Ssin\theta}{2} - \frac{C_x \rho Scos\theta}{2}.$$

$$A2 = \mu mgcos\theta + mgsin\theta$$

$$F - A2 + A1(\dot{x}cos\theta - vw)^2 = m\ddot{x}.$$

Assuming that the expansion of air is the adiabatic process, the following dependency is satisfied:

$$pV^{1.4} = const. \tag{10}$$

Therefore, an expression that describes the pressure in the system when valve is opened takes the form:

$$p_0 V_c^{1.4} = p(V_c + V_d + Ax)^{1.4}. \tag{11}$$

The formula that defines the power equation:

$$F = Ap(x); \tag{12}$$

$$F = Ap_0 \left(\frac{V_c}{V_c + V_d + Ax}\right)^{1.4}. \tag{13}$$

To put it simply:

$$A3\left(\frac{V_c}{V_c + V_d + Ax}\right)^{1.4} - A4 + A5(\dot{x}cos\theta - vw)^2 = m\ddot{x},$$

where: $A3 = \frac{Ap_0}{m}$; $A4 = \frac{A2}{m}$; $A5 = \frac{A1}{m}$, where:

R — reaction force;
T — friction force;
G — gravitational force;
Θ — sheer angle of the launcher;
F — force acting on the cradle-aircraft system from the actuator;
E — the thrust of the engines;
L — the lift force generated by the wings of the aircraft;
D — aerodynamic drag force;
S — aerodynamic surface of wings;
V_c — the volume of the pressure container;
V_d — the volume of the system linking the pressure cylinder and the actuator with the volume of servo-motor with zero exit;
A — the surface of the piston;
x — coordinate that specifies the direction along the launcher;
y — coordinate that specifies the direction perpendicular to the launcher;
μ — resistance coefficient;
g — acceleration of gravity;
m — the mass of the cradle-aircraft system;
vw — wind speed;
ρ — specific gravity of air;
d — the density of the air during the take-off level;
C_z — the coefficient of lift force;
C_x — coefficient of aerodynamic drag;
p_0 — the initial pressure;
p — instantaneous pressure;
l — the length of the cable connecting the pressure container and the actuator;
r — radius of the cable connecting the pressure container and the actuator.

Based on an earlier analysis of the pneumatic launcher calculations and the publication *Increasing Launch Capability of a UAV Bungee Catapult* [5] the mathematical model of the rubber launcher (fig. 14) was accepted and the equation of motion as well as the formula that defines equation of the of motion were set next page.

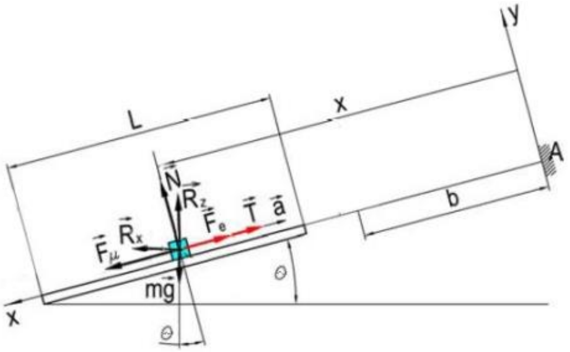

Fig. 14. The mathematical model for the rubber launcher [own study]

The projection of forces on the y axis

$$N - Gcos\theta + R_z sin\theta = 0. \tag{14}$$

The projection of forces on the x axis

$$F_\mu + N - F_e - T(1 - \dot{x}) = m\ddot{x}. \tag{15}$$

Through the substitution of:

$$N = mgsin\theta; \tag{16}$$

$$F_e = q(x - b); \tag{17}$$

$$F_\mu = \mu\, mgcos\theta. \tag{18}$$

One gets the equation for the force in the x axis in the following form

$$m\ddot{x} = \mu mgcos\theta + mgsin\theta - q(x - b) - T(1 - \dot{x}). \tag{19}$$

It can be rearranged to the final form:

$$\ddot{x} + \frac{T}{m}\alpha\dot{x} + \frac{q}{m}x = g(\mu cos\theta + sin\theta) + \frac{q}{m}b. \tag{20}$$

In the above equations it was assumed that:

T — tension force of the rubber;
N — reaction force;
G — gravitational force;
R_z — aerodynamic drag force;
F_e — force dependent on the elasticity of the rubber;
F_μ — the force of friction;

Θ — sheer angle the launcher;
g — acceleration of gravity;
m — the mass of the cradle-aircraft system;
q — stiffness of the rubber;
μ — resistance coefficient;
b — the length of the rubber before stretching;
α — gain coefficient.

In order to calculate the necessary parameters the Wolfram Mathematica integrated system was used. Many trials for three basic parameters: the road, speed and acceleration of launching were made.

The origin of the coordinate system should be taken at the beginning of the impetus road of the cradle (x = 0). The x axis is directed along this road, and the direction perpendicular to it means the y axis.

For calculations, the following assumptions were taken:
(a) for the pneumatic launcher:
1) drive: pneumatic,
2) length: 1 m,
3) the length of the cable connecting the pressure cylinder and the actuator: 0.67 m,
4) radius the cable connecting the pressure cylinder and the actuator: 0.0041 m,
5) take-off weight (trolley and aircraft system): 8 kg,
6) acceleration of gravity: 9.8 m/s^2,
7) wind speed: 0; 3; 10 m/s,
8) specific weight: 1.182 kg/m^3,
9) sheer angle the launcher: 10°,
10) aerodynamic surface of wings: 0.652 m^2,
11) drag coefficient: 0.1,
12) power factor: 1.18,
13) coefficient of aerodynamic drag: 0.018,
14) the piston area: 0.00080384 m^2,
15) pressure container volume: 0.002 m^3,
16) the volume of the system linking the cylinder and the actuator together with the volume of the cylinder with zero exits: 0.000078 m^3,
17) the initial pressure: 250 000 Pa;

(b) for the rubber launcher:
1) drive: rubber cords,
2) length: 1 m,
3) acceleration of gravity: 9.8 m/s^2,
4) the mass of the cradle-aircraft system: 9.8 kg,
5) tensioning force of the rubber: 300 N,
6) the rubber rigidity: 800; 900; 1000 N/m,
7) sheer angle of the launcher: 10°,
8) drag coefficient: 0.1,
9) the rubber length priori to stretching: 0.5 m,
10) gain factor: 0.35.

After carrying out the numerical tests for mapping out the characteristics of the basic parameters of the launcher and the analysis of their functionality on the 'Edredon' unmanned surface vehicle, it was concluded that the best solution would be to use the pneumatic launcher. This type of launcher generates the most compatible parameters needed for launching the PR-3 'Gacek' unmanned aircraft vessel.

The following are examples of characteristics of launching parameters (pathway, speed, and acceleration) obtained for the wind speeds 0 m/s and 3 m/s.

The received waveforms of ejection distance are presented in the chart below:

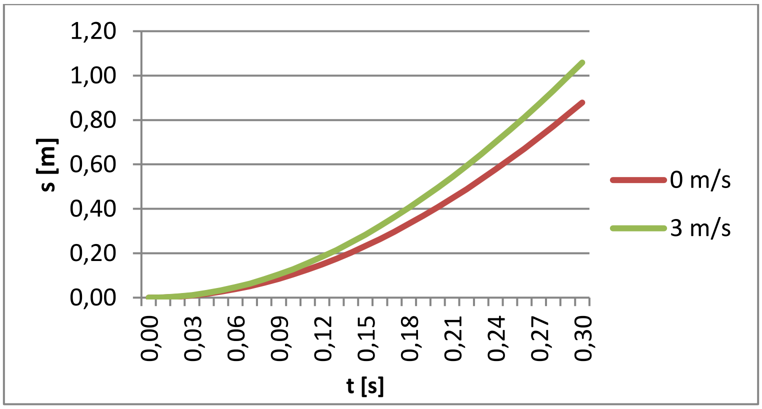

Chart 1. Waveforms of the distance as the function of time [own study]

The received waveforms of ejection velocity are presented in the chart below:

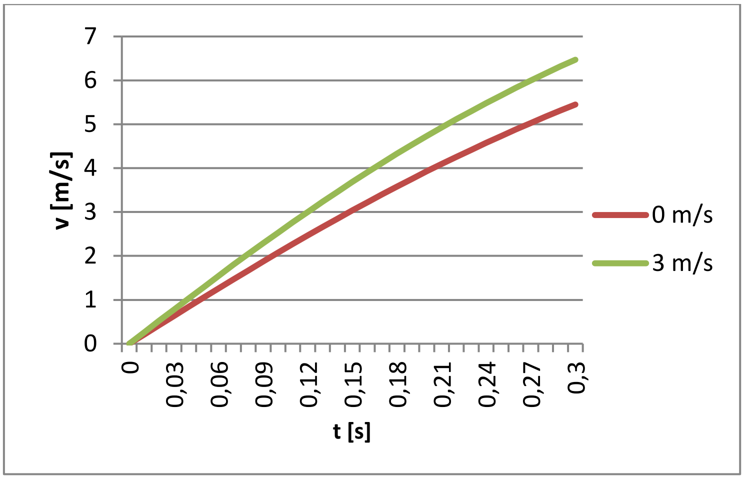

Chart 2. The waveforms as velocity as the function of time [own study]

The received waveforms of acceleration are presented in the chart below:

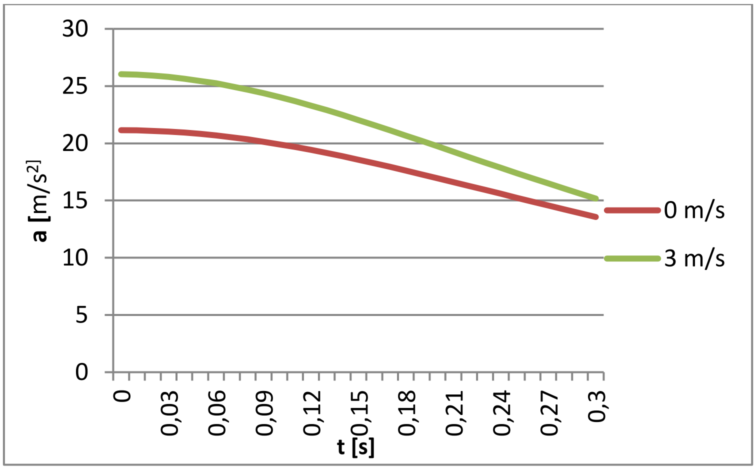

Chart 3. The waveforms of acceleration as the function of time [own study]

After evaluating of all the need data, the design of the launcher in the MegaCAD environment was developed. To develop the design the actual items, that have been selected on the basis of simulation research were used. A pneumatic actuator of two--sided action with one-sided piston rod, and inhibitory unit, and the guide fitted for marine conditions was used. The two rails are mounted in parallel, providing the constructional space saving.

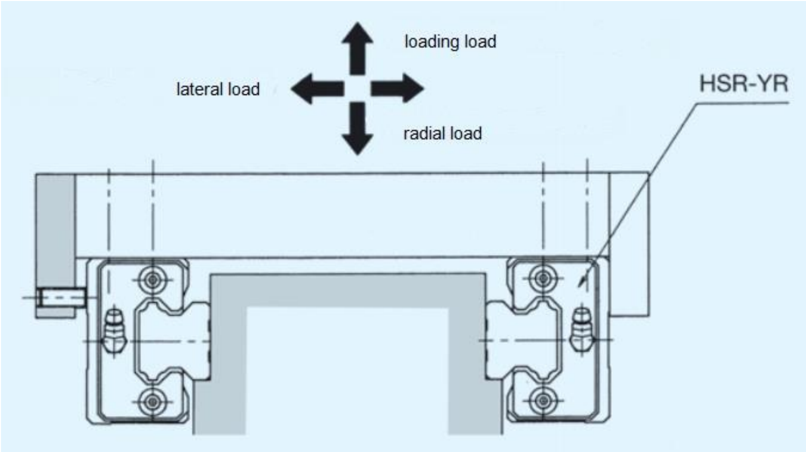

Fig. 15. The mounting of the guides [9]

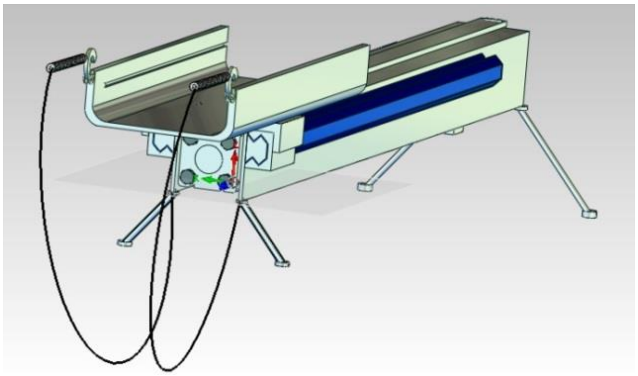

Fig. 16. The design of the launch pad in the MegaCAD environment [own study]

The start platform in the launch pad was designed for the the PR-3 'Gacek' hull dimensions. The design has taken into account the possibility of significant banking caused by the waves of the sea, which could contribute to the loss of the UAV's position stability on the launcher. The launching platform is designed in the shape of a letter 'U', in order to fit in the lifting surface of the PR-3 'Gacek'. At the height of 2/3 of cradle lateral sides, two dents of the length of 0.513 m and dimensions 0.005 x 0.005 m were done. In turn, on the side of the hull of the PR-3 'Gacek' two protrusions, matching with the dents on the cradle walls, were done. Such solution ensures stability in the case of banking caused by waves. Thus, the UAV placed on the launcher, cannot move from side to side, and backward. In order to prevent the UAV forward displacement, special locking pawls were applied, which latch in the eyelets specially mounted on the PR-3 ‘Gacek’ hull. The latch is fastened to the spring from which a metal cable of the length of 0.8 m leaves, and its other end is attached the to a U-iron of the launcher. When the cradle with the starting platform is put in motion, the metal cable tightens up, the pawl is inclined and released from the mesh, and thus the UAV can move forward and be launched. The springs provide cushioning for links during stretching the cord, to secure that excessive casting force does not lead to breakage of the cord or the trigger.

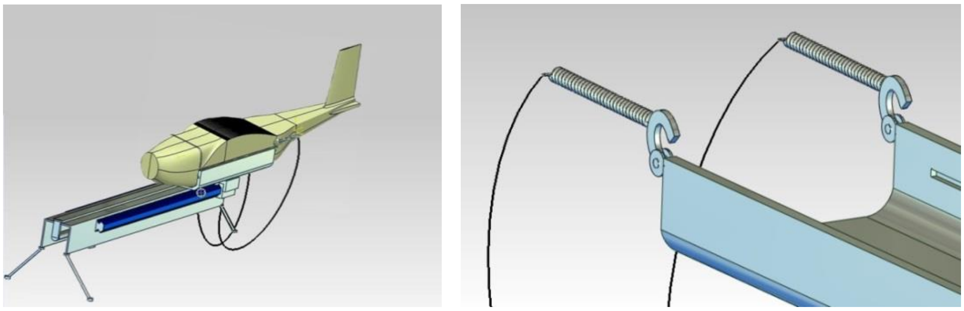

Fig. 17. The hull of the PR-3 ‘Gacek’ placed in the launcher framework and the protections on the launcher platform own elaboration

Presented below are the technical drawings representing the cross sections of the ‘Edredon’ USV, on the basis which the drawings showing the launcher fastening to the ‘Edredon’ USV from the profile of the side and top were created. In figure 18 the red points indicate the fixing points of the launcher.

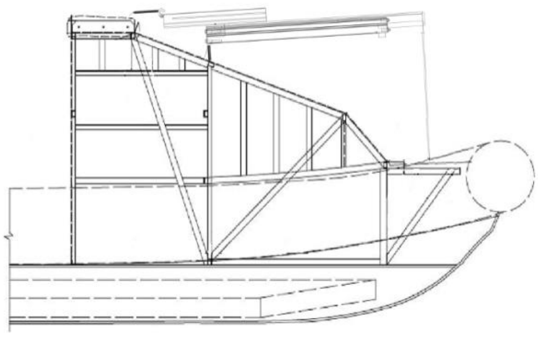

Fig. 18. The installation of the launcher on the ‘Edredon’ USV, the side profile [own study based on 4]

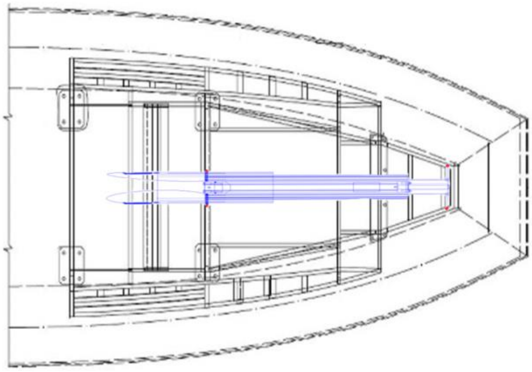

Fig. 19. Installation of the launcher on the 'Edredon' USV, the top profile [own study based on 4]

The control of both vehicles is provided by the mobile command posts placed in the container. Such a solution allows the use of vehicles on any area of the Polish coast or water basin, providing its high mobility.

Fig. 20. The command post of the 'Edredon' USV [4] and the concept of fitting the VOLANS launcher on 'Edredon' [own study]

The operator from the command post has the ability to perform all operations related to the simultaneous control of the USV, and the UAV deployed on its board. An additional element of the command post is the software for the remote start of the UAV based on its board and the control of its flight from the command post.

Fig. 21. The design of the PR-3 'Gacek' control system placed in the USV 'Edredon' container [own study based on 4]

SUMMARY

The purpose of this article was to present the design of conceptual system of cooperation of a unmanned surface vehicle with the unmanned aerial vehicle based on it. It is quite innovative research field and few research centers proceed this way. The research papers made available in the literature of the world are sporadic and describe the essence and purpose of the research in a very narrow range. The performed analysis and calculation confirms the claim that it is possible to launch an unmanned aircraft vessel from the deck of an unmanned surface vehicle.

On the base of the simulations in the Wolfram Mathematica integrated system, the actual elements such as actuator, air cylinder, that were used for the initial construction design of the launcher, have been chosen.

In the long run, it is necessary to develop an unified system of cooperation between vehicles. In both vehicles should work the same control algorithm, further works should also be lead towards the recovery of a UAV, as well as ability to control the two vehicles by one operator.

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PERSPEKTYWA STARTU MAŁEGO BEZZAŁOGOWEGO STATKU POWIETRZNEGO Z BEZZAŁOGOWEGO POJAZDU NAWODNEGO

STRESZCZENIE

W związku z rosnącym na świecie zainteresowaniem problemami współpracy między pojazdami bezzałogowymi w artykule przedstawiona została propozycja systemu pozwalającego na start małego bezzałogowego statku powietrznego (UAV) z małego bezzałogowego pojazdu nawodnego (USV). Rozwiązanie to różni się od dotychczasowych tym, iż zamiast stosowanych powszechnie wiropłatów rozpatrzono możliwość startu płatowca przy użyciu wyrzutni pneumatycznej lub gumowej wspomagającej start. Wyniki symulacji komputerowej potwierdziły możliwość realizacji takiego systemu.

Słowa kluczowe:
bezzałogowy statek powietrzny (UAV), bezzałogowy pojazd nawodny (USV), wyrzutnia pneumatyczna.

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