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[1]Tomasz Muszyński,
[2]Piotr Trzciński,
[3]Karol Kostrzewa,
[4]Adrian Sieczek,
[5]Mariusz Rybarczyk

THE DEVELOPMENT OF A CONCEPT OF AN UNMANNED GLIDER-TUG - PART 2

The State School of Higher Education in Chełm; Pocztowa 54
22-100 Chelm, Poland
E-mails: [1]tmuszynski@pwszchelm.edu.pl, [2]trzcinski12644@student.pwszchelm.pl,
[3]kostrzewa13382@student.pwszchelm.pl, [4]sieczek12587@student.pwszchelm.pl,
[5]rybarczyk13430@student.pwszchelm.pl

Abstract*—The article presents the development of the unmanned glider tug project, a description of the stages of a new technical solution, submitted to the patent office in December 2017 and developed to date. The proposed towing system consists of a universal drone ground control station and a tugboat rigidly connected to the sailplane. The proposed solution is aimed at reducing operating costs and limiting the number of people necessary to service sailplane flights.*

Index Terms—Unmanned aerial vehicle; tug; wind tunnel; lifting force; drag force; flight test.

I. Experimental Research in the Wind Tunnel

The aim of the test was to check the aerodynamic characteristics of the version 4 tug model - made in the form of a flying wing with tail tips at the wing tips serving simultaneously as elements supporting the wing and a combined sailplane and tug unit. The glider model was based on the SZD-55 Promyk geometry (Fig. 1).

The above mentioned system should theoretically behave like a duck system (deflection of the flaplets causes a turning moment in relation to the *Y* axis of the system). The characteristics of the longitudinal equilibrium of the combined sailplane with the tug and the general influence of the deflection of the streams behind the wing of the tugboat on the aerodynamic characteristics of the combined sailplane with the tug were unknown.

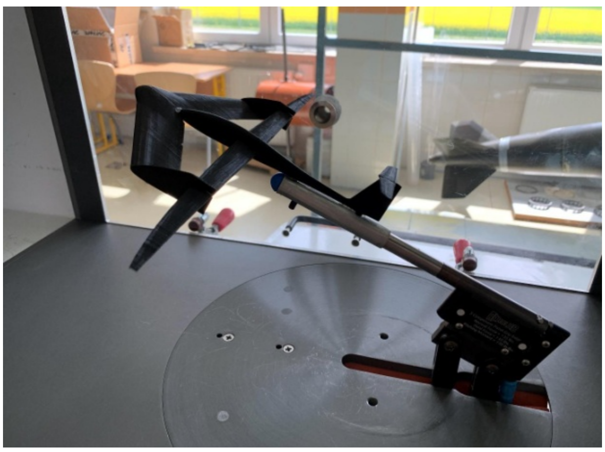

Fig. 1. Combined tugboat assembly with sailplane – version 4 [1]

The system was tested in the Aerolab low-speed wind tunnel located in the fluid mechanics laboratory at the Center for Engineering Studies belonging to the State Higher Vocational School in Chełm (Fig. 2).

Both geometries were modeled in Siemens Solid Edge and printed on a 3D printer using the FDM method of polylactide (PLA for short). This material showed sufficient strength for this application and was selected as easy and sufficiently detailed material for printing.

An important stage of the research was to determine the best position of the tug in relation to the sailplane, the size often referred to as geometric decal. Decalage equal to zero means zero angle between the chord planes of the tug's wing and the sailplane's wing.

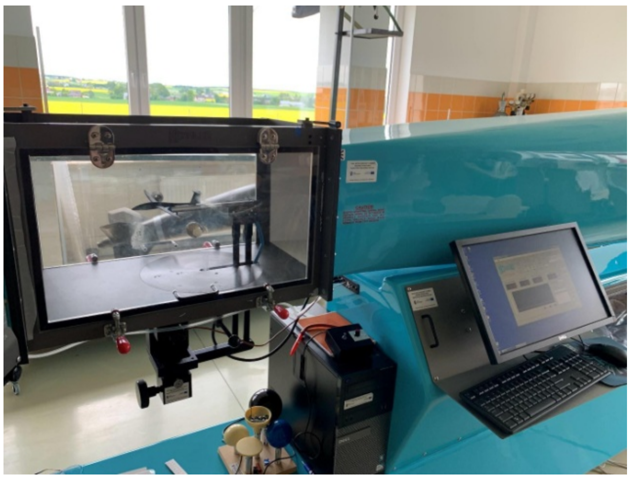

Fig. 2. Aerolab wind tunnel with the attached model of the sailplane [2]

This study will determine the best wedging of the models not only in terms of the aerodynamic forces involved, but also in terms of the stability of the tug-sailplane assembly.

The heeling moment M [N_{cm}] was tested, where the arm was the transverse axis of the system, the normal lift force N [N] and the longitudinal drag force A [N]. Then the lifting force P_y [N] and the drag force P_x [N] were calculated using the following formulas:

$$P_x = A\cos\alpha + N\sin\alpha,$$

$$P_y = N\cos\alpha + A\sin\alpha.$$

The set air velocity with which the system was tested was 15 m/s. Rake angle range $\alpha \in < -16°; 24° >$ (Figs 3 and 4).

Fig. 3. The tested system at different wedging angles between the tug's wing and the sailplane's wing [3]

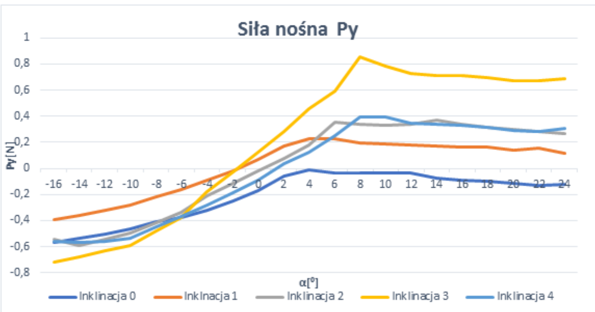

Fig. 4. Lifting force Py of the assembly for individual variants of the tug wing wedge angle in relation to the sailplane

For decal 3, there is the greatest difference in the forces for different angles of attack, while the smallest differences are for decal 0 and 1 (Fig. 5).

In the chart above, we can observe the highest increase in the drag for decalage 3, the smallest for decalage 0, which is consistent with what was expected - larger deviations of the stream behind the front panel cause greater turbulence, which translates into an increase in the total resistance of the tug-sailplane assembly. Due to the stability of the system, a wedge angle between the tug and the sailplane was decided to be +1 degree. Then, the influence of the tug's flap deflections on the characteristics of the tug-sailplane was tested.

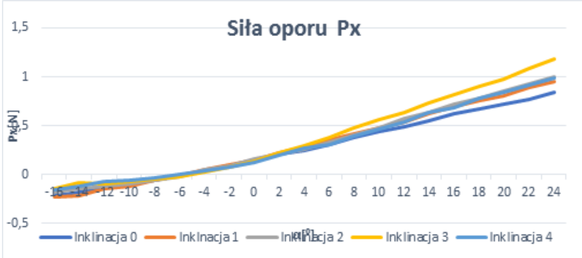

Fig. 5. The drag force P_x for different variants of the tug wing wedge angle in relation to the sailplane wing

For the sake of unification, the tugboat +30 means the tug's flapper flaps upwards 30°, 0 means no flap swing, and –30 means the flapper flaps down 30°.

We can see a significant increase in the normal force for the tug-sailplane system for the downward deflection of the flaplets, and a decrease in this force with the downward deflection of the flaplets. This is a typical characteristic of the duck control system in airplanes. The tugboat's flaps act as a rudder in front of the wing. The results for + 30° and 0° are similar, probably due to strong air turbulence behind the tug's wing, which disturbs the flow of the sailplane's wing (Figs 6 and 7).

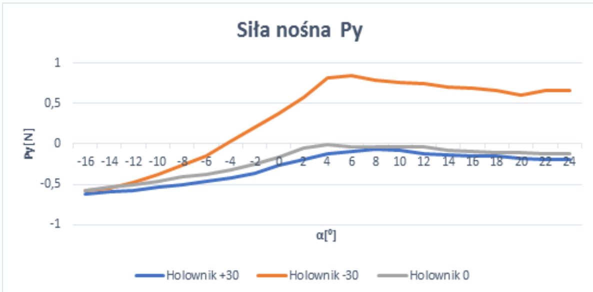

Fig. 6. Lifting force for individual deflections of the tugboat's 3 flaplets

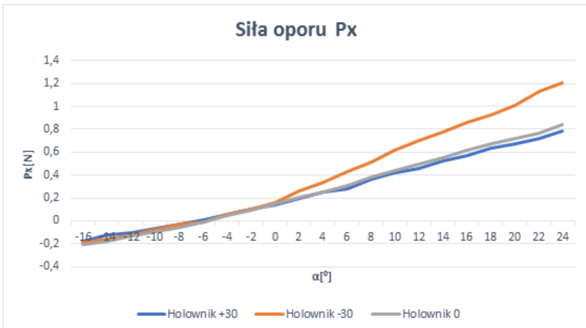

Fig. 7. Graph of the calculated drag force depending on the angle of attack

As the angle of attack increases, we observe an increase in the drag force P_x. The described relationship is best visible for a tug with rudder deflection –30. As a result of the performed calculations, a number of modifications were made, including the reduction of the lifting surface, and the increased slant of the tug's wing to ensure the stability of the combined tug set with the sailplane.

II. Flight Tests of an Unmanned Tug Boat

Initially, it was assumed that it was sufficient to connect the sailplane with the tug based on the towing hooks available on the sailplanes - the front towing line pulled behind the plane and the lower hook to the winch rope. It was also assumed the use of additional two resistance points in the form of an airbag. A model of a flying tugboat was made, weighing about 3.6 kg and a span of 1.6 m. For the towing tests, a sailplane with a span of 5.1 m and a weight of 6.3 kg was used. The tugboat was made according to the design 1 in the low wing configuration, with a towing propeller, two tail beams, between which the fuselage of the sailplane was attached. Already during the flight tests of the tug itself, it turned out that the propeller mounted on a high turret gives a strong heeling moment when adding gas. After several flight tests, it was decided to reduce the height of the turret to 90mm. When attaching the sailplane to the tug, it turned out that in order to obtain the tug's wedge angle in relation to the sailplane + 1o and the angle of attack of the entire assembly at least 10 degrees, the landing gear structure should be changed to a system with a rear wheel. The rigid connection of the UAV with the sailplane was made on the basis of two hooks - the front and the lower one, as well as cushions surrounding the fuselage. It was assumed that thanks to this solution it would be possible to fly the combined UAV and the sailplane with the help of the steering thrust only of the sailplane. The manufactured models of the tugboat in version 2 and the sailplane were verified in the air. 36 flights were made, during which a number of modifications were introduced and the aerodynamic properties of the tug itself and the tug-sailplane assembly were checked.

In practice, even for level flight, it was necessary to control the tug's flaps, which in this case assisted the glider's elevator. The flight in the team thus had the characteristics of a three-plane system, being more akin to a "duck" system than the classic due to the much larger control surface located in front of the wing compared to the control surface located behind the wing. In addition, the "torsional" stiffness of the assembly turned out to be too low - when controlling the tilt of the glider, the wings of the glider and the tug changed their position in relation to each other, which led to the breakdown of both models (Fig. 8).

Fig. 8. Model of the sailplane and UAV-tugboat 2 set with lowered engine turret and landing gear with a back fulcrum [4]

As a result of unsuccessful flight tests, it was found that the torsional stiffness of the assembly was insufficient. Another concept was developed (versions 3 and 4), assuming stiffening of the connection by adding overlays, fixed on the double vertical tail and resting on the leading edge of the glider wing. This solution made it possible to greatly increase the torsional stiffness of the set and to base the roll control in flight in the set solely on the control of the sailplane's ailerons, which are located at a distance from the axis of rotation more than twice as large as the tug's ailerons. However, the conducted flight tests showed insufficient directional stability of the assembly, which led to the models being broken. The likely cause was that both models did not keep the common longitudinal axis. Currently, work is underway to refine the fixed wing version as well as to use the quadrocopter as a tugboat.

III. Conclusions

Due to the fact that we are dealing with a tug-sailplane complex, the results of the experiment are influenced by many aerodynamic factors. Particular attention should be paid to the position of the sailplane in the aerodynamic shadow of the tug. Consideration should be given to synchronizing the flight altitude control by using both the sailplane's and the tug's flap controls. The angle of 1 degree turned out to be the most advantageous angle of the tug in relation to the sailplane due to the longitudinal equilibrium conditions. In addition, it allowed to obtain the highest lifting force and a relatively small increase in the drag force P_x in relation to other wedging angles. The conducted research and tests in research give high hopes for this type of solution for towing gliders, and set a further direction for the improvement of the structure.

Due to the type of tasks performed, the basic control system should be an autonomous system.

The RC manual control system should have two transmitters. The first one should be placed at the flight control center. The second control system should be made in the form of a small panel attached to the structure of the sailplane and should make it possible to control at least the UAV engine thrust by the pilot in the sailplane. In addition, it is necessary to work on the integration of many support systems, such as a camera system with a dedicated image processing system, an auxiliary control system with an autopilot, a stabilization system and GPS navigation. There is also a need for a high-performance audio-video transmission system and a long-range telemetry data transmission system.

Currently, analyzes are also conducted towards the use of electric and combustion units. Electric propulsion seems to be appropriate for a device applicable in training organizations educating pilots for a sailplane license. Preliminary calculations of the electric load show that in the case of hauling a single-person sailplane, the flight duration of more than 15 minutes should be easily achieved, which should be enough for a 10-kilometer radius of operation around the airport.

A UAV-tugboat with a long duration of flight, powered by an internal combustion engine, with a total weight of approx. 160 kg, could be used in organizations where flights with greater flight duration are needed. It will be possible to correct the design assumptions at each stage. The optimal solution will be selected to achieve the assumed flight characteristics of the combined UAV and the sailplane. It will be necessary to accurately determine the characteristics of the system, to determine the optimal sizes of individual UAV elements, including control surfaces.

The described design solution, according to the authors, may be an interesting proposition for gliding training centers, transport companies dealing with the delivery of small products in hard-to-reach terrain. The same UAV – tugboat can be used as a glider towing trolley and a tug for transport systems delivering goods by air.

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[8] Picture of concept by Tomasz Muszyński.

[9] Visualization of concept by Tomasz Muszyński

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Tomasz Muszyński. Doctor of Engineering Science.
Institute of Technical Sciences and Aviation, the State School of Higher Education in Chelm.
Education: Rzeszów University of Technology, (1997).
Research area: aerodynamics, unmanned aerial vehicles (UAV), airplane maintenance.
Publications: 10
E-mail: tmuszynski@pwszchelm.edu.pl

[2]Piotr Trzciński, [3]Karol Kostrzewa, [4]Adrian Sieczek, [5]Mariusz Rybarczyk. Students of mechanical engineering with a specialization in pilotage and aircraft mechanics, Institute of Technical Sciences and Aviation, The State School of Higher Education in Chelm.
E-mails: [2]trzcinski12644@student.pwszchelm.pl, [3]kostrzewa13382@student.pwszchelm.pl, [4]sieczek12587@student.pwszchelm.pl, [5]rybarczyk13430@student.pwszchelm.pl

Томаш Мушинський, Пьотр Трщинський, Кароль Костшева, Адріан Сечек, Маріуш Рибарчик. Розробка концепції бездротового буксира-планера. Частина 2

У статті представлено розробку проекту безпілотного буксира-планера, опис етапів нового технічного рішення, представленого до патентного відомства у грудні 2017 року та розробленого на сьогоднішній день. Пропонована буксирна система складається з універсального наземного поста керування дроном і буксира, жорстко пов'язаного з планером. Запропоноване рішення спрямоване на зниження експлуатаційних витрат та обмеження кількості людей, необхідних обслуговування польотів планерів.

Ключові слова: безпіло́тний літа́льний апара́т; буксир; аеродинамічна труба; під’ємна сила; сила лобового опору; льотні випробування.

Томаш Мушинський. Доктор технічних наук.
Інститут технічних наук та авіації, Державна вища школа у Хелмі.
Освіта: Жешувський технологічний університет, (1997).
Напрям досліджень: аеродинаміка, безпілотні літальні апарати (БПЛА), технічне обслуговування літаків. Публікації: 10
E-mail: tmuszynski@pwszchelm.edu.pl

[2]Пьотр Трщинський, [3]Кароль Костшева, [4]Адріан Сечек, [5]Маріуш Рибарчик. Студенти.
Інженерний факультет, спеціальність «пілотаж та авіамеханік», Інститут технічних наук та авіації, Державний вищий навчальний заклад у Хелмі.
E-mails: [2]trzcinski12644@student.pwszchelm.pl, [3]kostrzewa13382@student.pwszchelm.pl, [4]sieczek12587@student.pwszchelm.pl, [5]rybarczyk13430@student.pwszchelm.pl

Томаш Мушинский, Петр Трщинський, Кароль Костшева, Адриан Сечек, Мариуш Рыбарчик. Разработка беспроводного буксира-планера концепции. Часть 2

В статье представлена разработка проекта беспилотного буксира-планера, описание этапов нового технического решения, представленного в патентное ведомство в декабре 2017 года и разработанного на сегодняшний день. Предлагаемая буксирная система состоит из универсального наземного поста управления дроном и буксира, жестко связанного с планером. Предложенное решение направлено на снижение эксплуатационных расходов и ограничение количества людей, необходимых для обслуживания полетов планеров.

Ключевые слова: беспилотный летательный аппарат; буксир; аэродинамическая труба; подъемная сила; сила лобового сопротивления; летные испытания.

Томаш Мушинский. Доктор технических наук.
Институт технических наук и авиации, Государственная высшая школа в Хелме.
Образование: Жешувский технологический университет (1997).
Направление исследований: аэродинамика, беспилотные летательные аппараты (БПЛА), техническое обслуживание самолетов.
Публикации: 10
E-mail: tmuszynski@pwszchelm.edu.pl

[2]Петр Трщинський, [3]Кароль Костшева, [4]Адриан Сечек, [5]Мариуш Рыбарчик. Студенты.
Инженерный факультет, специальность «пилотаж и авиамеханик», Институт технических наук и авиации, Государственное высшее учебное заведение в Хелме.
E-mails: [2]trzcinski12644@student.pwszchelm.pl, [3]kostrzewa13382@student.pwszchelm.pl, [4]sieczek12587@student.pwszchelm.pl, [5]rybarczyk13430@student.pwszchelm.pl