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THE PROJECT OF RESEARCH RIG FOR ANALYSIS OF AERODYNAMIC IMPACT OF THE WING IN THE TANDEM WING CONFIGURATION

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Abstract

The paper presents the conceptual project of the research rig to measure the aerodynamic loads on the wings in the tandem wing configuration. The main goal of the project is to check the results of numerical aerodynamic analysis made by MGAERO and Ansys Fluent with results obtained by wind tunnel tests. The model consists of two wings and fuselage. The wings are equipped with aileron on the outer side of the wing and flap in the inner part of the wing. The research rig is currently under construction and will be used for the wind tunnel tests. The final rig will allow to verify the CFD results with real flow around tandem wing model. Moreover, it will allow for dynamic analysis in the future.

Keywords: tandem wing, research rig, tunnel testing

1. Introduction

The tandem wing configuration represents one of the unconventional aircraft configurations, characterised by the presence of two wings (front and rear) which generate lift and are at approximately the same height [1]. The advantages of this configuration include:

- a more compact aircraft and lighter structure due to a smaller span [1],
- greater safety due to delayed stall [1-2],
- less induced drag [1, 3-9],
- no horizontal stabiliser due to the presence of the rear wing [11].

On the other hand, one has to deal with more difficult calculations due to strong aerodynamic coupling and a more complex design [4]. Nevertheless, the advantages of a tandem wing are enough to cause continuous interest in this unconventional configuration. Unmanned Langley Aerodrome was built at the end of the 19th century. In 1907, the flight of manned Blériot VI took place [1]. In 1943, George Miles constructed his Miles M.39B Libellula [12]. In more recent times, Rutan Quickie (Figure 1) first flew in 1977 [13] and the idea for Scaled Composites ATTT was born in 1987 [14]. In 2017, a tandem wing autonomous drone appeared, called SolarXOne [15]. Throughout the years, a lot of research was put into this configuration [1, 3, 5-10, 16-17], but it still remains unexplored, mostly because building a reliable numerical model constantly poses a challenge.

Figure 1 - Example of a tandem wing [3].

The paper presents the conceptual project of the research rig to measure the aerodynamic loads on the wings in the tandem wing configuration. The measured lift, drag and moment coefficients will allow to study the mutual impact between the wings. Additionally, the position of the centre of gravity is going to be adjustable and the research rig is going to be equipped with flaps and ailerons on both wings, allowing for investigating the subject of optimal control in a redundant system.

The main goal of the project is to check the results of numerical aerodynamic analysis made by MGAERO and Ansys Fluent with results obtained by wind tunnel tests. Comparing the results is important because of the possible restriction of use of some mathematical models. Due to complex calculations and not sufficient research into the effects occurring for a tandem wing configuration, comparing the numerical models with each other and with the wind tunnel tests results is necessary. The tests are going to be carried out in a wind tunnel at the Warsaw University of Technology in the Faculty of Power and Aeronautical Engineering. It is a closed-loop wind tunnel with a test section of 2.5 m by 2 m, with a maximum wind speed of 25 m/s. Precise measurements of the loads on a model are made with the use of an aerodynamic balance. The described facility is shown in Figure 2.

Figure 2 – WUT wind tunnel [23].

Both numerical models and a research rig must allow to change the distance between the wings called stagger (Δs), because the influence this parameter has on the results has been shown to be vital [1, 9, 16] and needs to be investigated.

2. The research rig project

The research rig (Figure 3) is designed for tunnel testing. It consists of an aircraft model in tandem wing configuration and a base with an actuator that allows the AoA (angle of attack) of the model to be changed. The most important dimension of the aircraft is its wingspan of 1.5 m. This was chosen so that the model is as large as possible and at the same time the effect of the tunnel walls on the test results is not significant. Since the model is not intended for flight, the most important criterion for the design was stiffness, not mass.

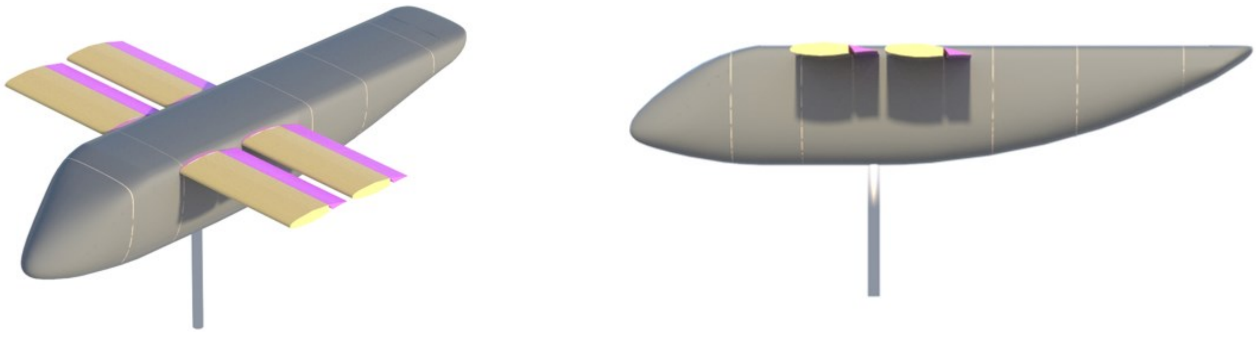


Figure 3 - Research rig.

The research platform is designed to meet the following objectives:

- possibility to move the rear wing (to change stagger),
- possibility to adjust the support point to the position of the CG (centre of gravity),
- ability to mount measuring instruments,
- rear wing wedging angle of 3 degrees,
- possibility to mount the model aircraft to an existing platform with actuator.

During the project, special attention was paid to ease and simplicity of manufacture. The research rig was divided into three main parts (wing, wing-fuselage junction, fuselage-base junction shown in Figure 4).

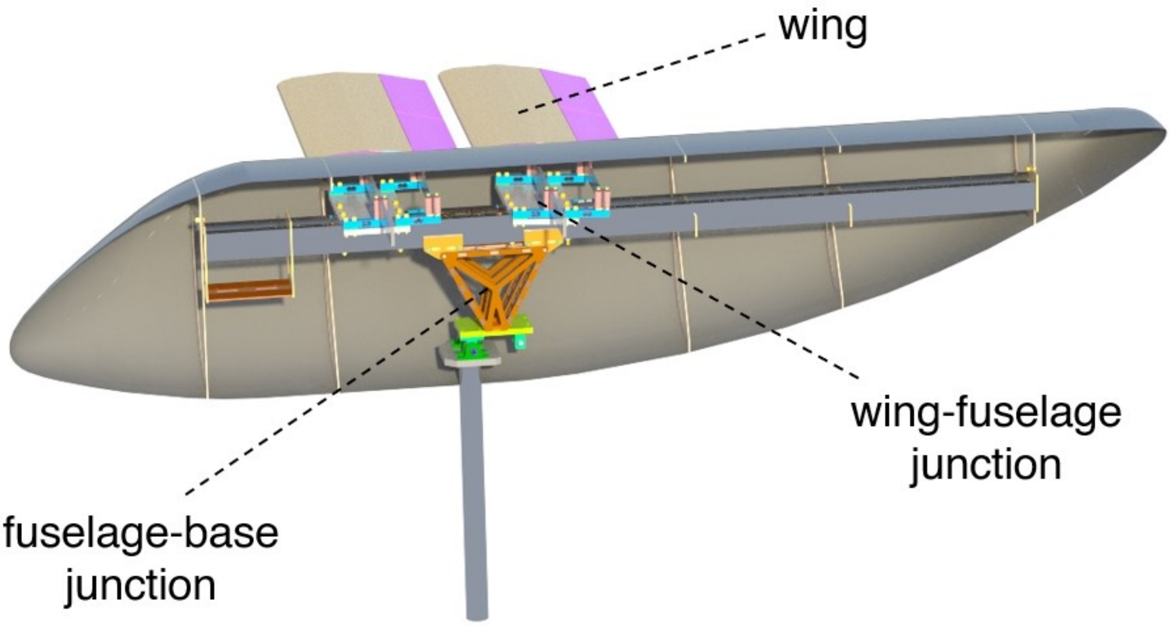


Figure 4 - Research rig CAD model.

2.1. Wing structure

The wing was the most important part of the whole project. The mapping of the profile geometry was particularly important here. In order for the wing to be built in a reasonable amount of time, its main components are the Styrofoam cores. The structure of the wing (Figure 5) consists of two spars, a leading edge, and a coverage. The structural elements are bonded to the core to prevent buckling. This also increases the stiffness of the wing and reduces aeroelastic effects during testing. A box spar has been used in the design to allow easy mounting of measuring devices. To extend the possibility of testing different configurations, it was decided to have separate flaps and ailerons. The coverage and the spar walls were made from homemade two-layer balsa plywood (with fibre orientation +45°/-45°) which should ensure the structure works correctly on shear. The spar flange is made of carbon flat bars.

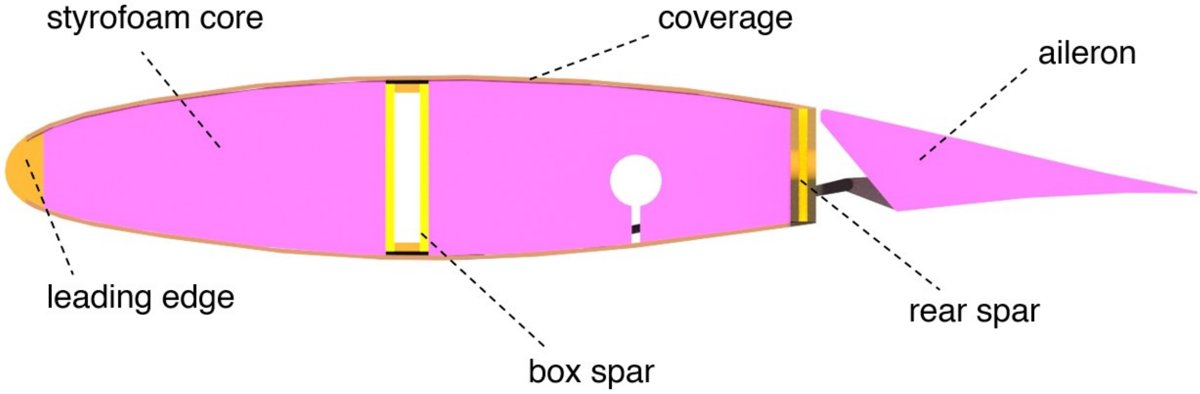


Figure 5 - Wing structure.

Based on the model of kinematics of the servomechanism, it was decided that the whole servomechanism is going to be placed inside the wing. It is beneficial from the point of view of the aerodynamic drag reduction and model's intended use. The model of kinematics is shown in Figure 6, where the extreme positions of the mechanism (M1 and M2) and neutral position (N) are marked.

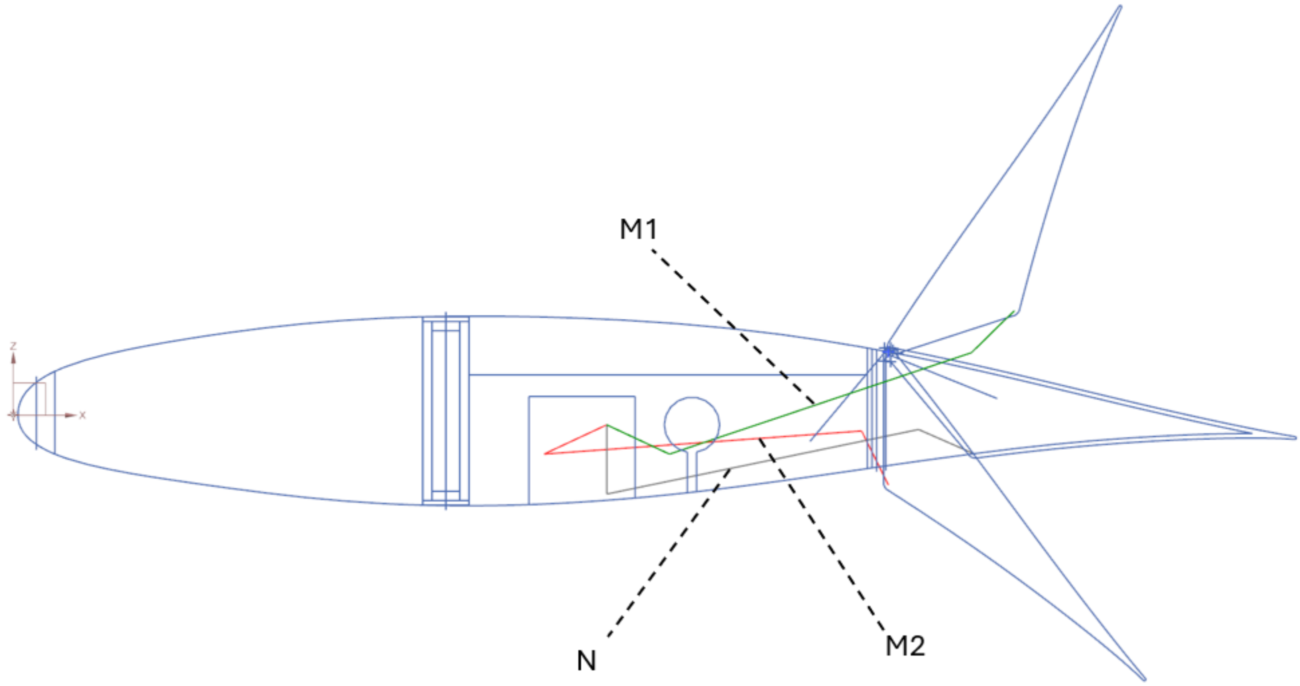


Figure 6 – Kinematics of the servomechanism.

2.2. Fuselage structure

For the other two parts of the project, unusual care was taken to ensure that the station was convenient to use during testing. The wings are mounted to plates in the upper part of the fuselage (Figure 7). This arrangement allows only the upper windscreen of the fuselage to be removed during testing. The plates to which the wings are mounted must be stiff enough not to cause additional measurement errors. The plates are bolted to beams (Figure 8) in which holes have been drilled corresponding to the successive positions of the wing to be tested. The rear plate is set at an angle of 3° (corresponding to the wedging angle of the rear wing). This ensures that the front and rear wings are the same. The beams are supported by a plywood frame (Figure 9) connected to the platform on an actuator. The connection of the beams to the frame is detachable, which makes it possible to adjust the support point of the stand. The whole structure is covered by a wind screen reflecting the shape of the fuselage. There are also frames on the beams to allow installation of the fuselage windscreen and battery placement.

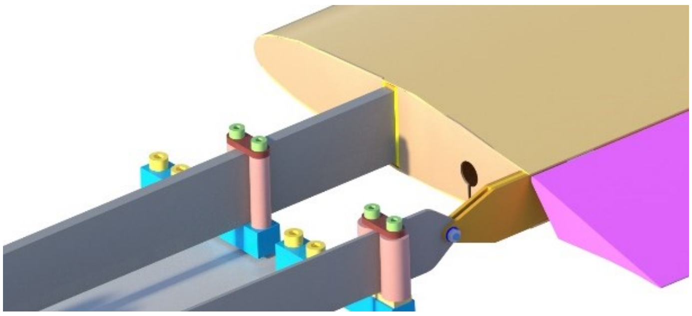


Figure 7 - Wing to plate joint.

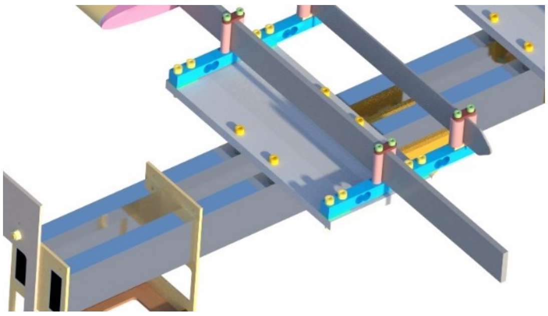


Figure 8 - Plate to beams joint.

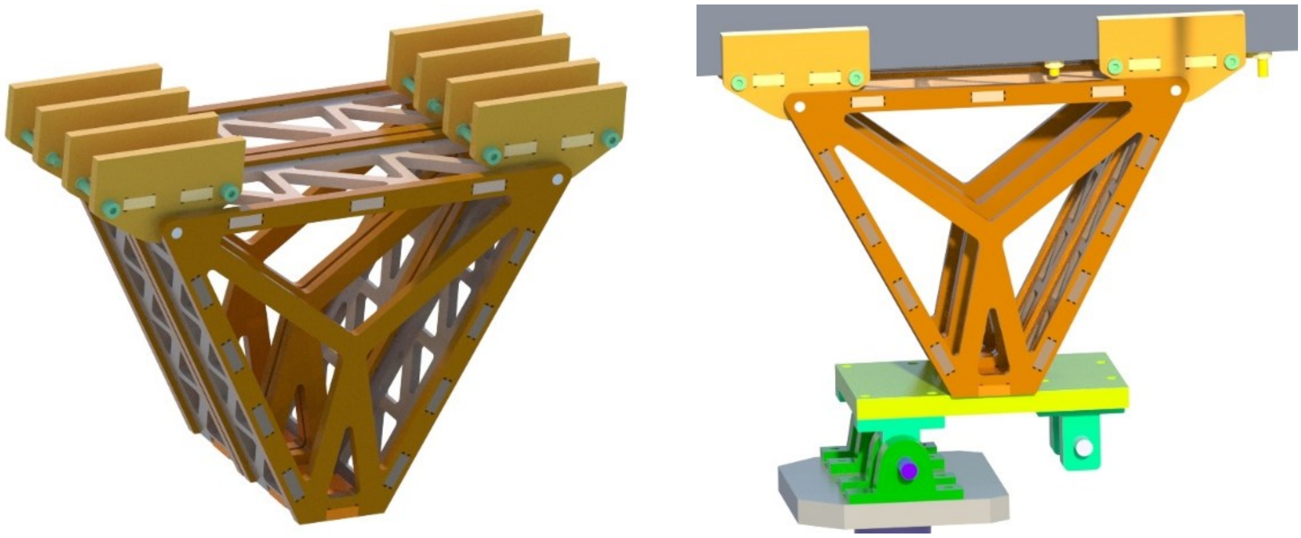


Figure 9 - Plywood frame.

The concept of measurements assumes placing 8 tensometric beams (2 per bayonet; 4 for the front wing and 4 for the rear wing). Such a placement of the beams will allow to measure the normal force and the torque separately for each wing.

3. Aerodynamic analysis

The aerodynamic analysis was performed by two software – MGAERO and Ansys Fluent. MGAERO is a simpler software using Euler's equations and multigrid scheme for computing the flow field around the aircraft [18]. Ansys Fluent, on the other hand, uses Navier-Stokes Reynolds Averaged (RANS) equations, which makes it a more advanced software at the expense of increasing the computational cost (time of computations) [19]. As such, Fluent is considered to give more accurate results, but it takes much longer than for MGAERO. That is why at least part of the calculations from MGAERO needs to be verified by Fluent, so that the former can be used for most of the computations. The details of the numerical models are described in [22]. Figure 10 shows the grid for both software.

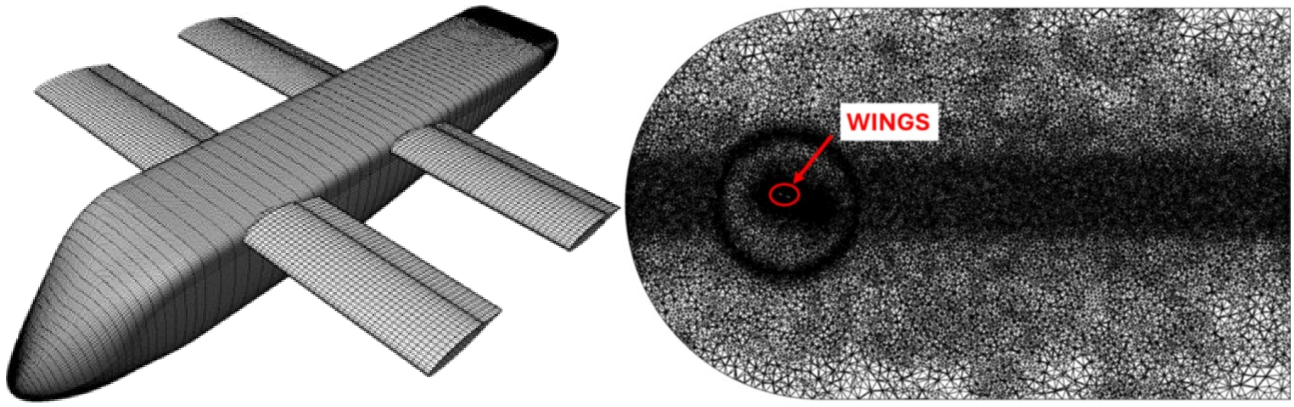
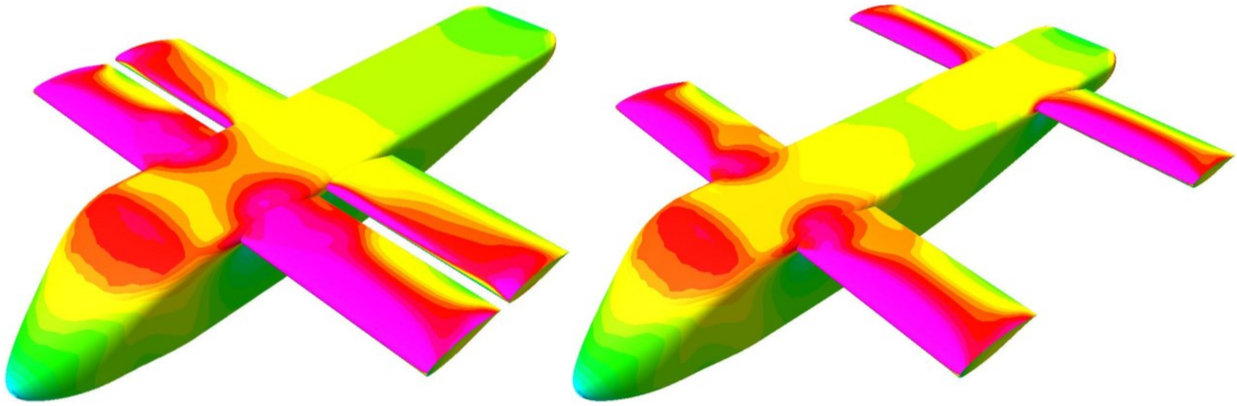


Figure 10 – Grid used in MGAERO (left) and Ansys Fluent (right).

When analysing an aircraft in a tandem wing configuration, it is important to acknowledge the mutual aerodynamic impact of the wings. Figure 11 shows that the pressure coefficient (C_P) distributions vary between different cases of stagger not only on the rear wing, but also on the front wing. As a result, both wings are not equally loaded, so a wing on which higher forces occur needs to be selected for determining aerodynamic loads and for strength calculations.



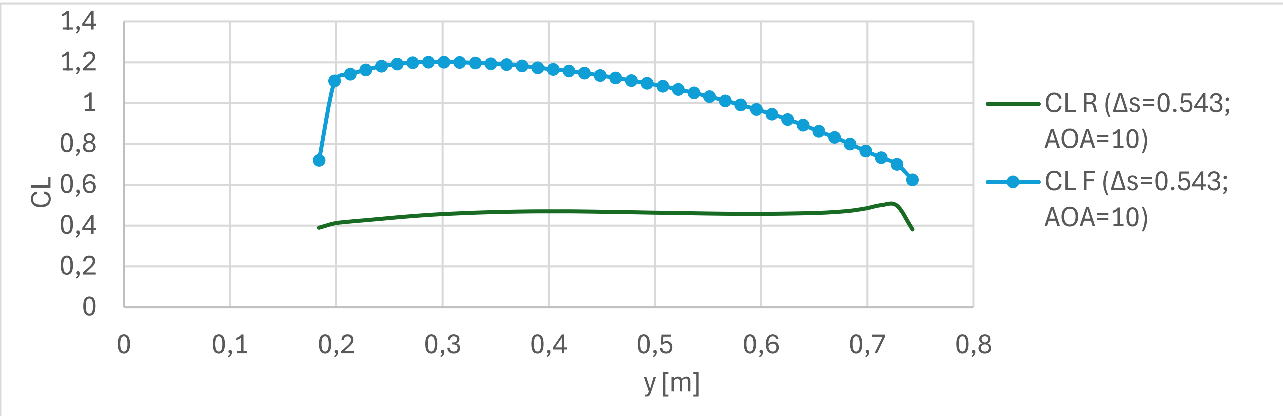
(a) (b)

Figure 11 – C_P distribution from MGAERO at $AoA = 15°$ for Δs equal to (a) 0.54 and (b) 1.8.

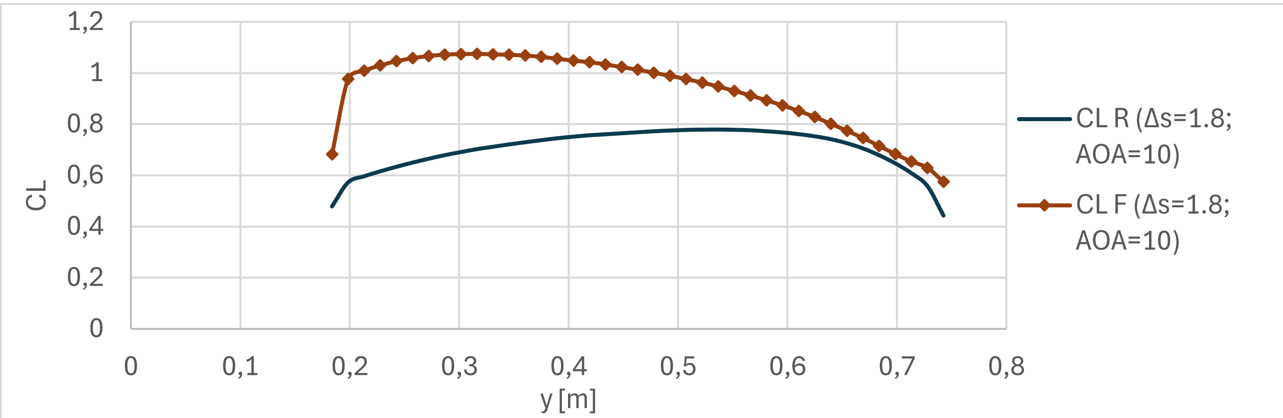
The aerodynamic calculations are described in [22]. The results from both software as for lift are withing acceptable tolerance. In the strength calculations, lift coefficient distributions along wingspan obtained from MGAERO are used. Bigger discrepancies occur for drag, but its influence on the structure of the research rig is incomparably lower than lift's.

4. Aerodynamic loads

The original plan was to design the wings so that they could be used on a flying model that might be built in the future. Therefore, efforts were made to reduce the weight of the wing as much as possible. This was done by analysing the forces that could affect the aircraft during the tunnel tests. The forces were compared for different rear wing settings and different angles of attack. Subsequently, the load cases were determined.



(a)



(b)

Figure 12 - Distribution of lift coefficient on wing (comparison of front (F) and rear (R) wing) for (a) minimum stagger, (b) maximum stagger.

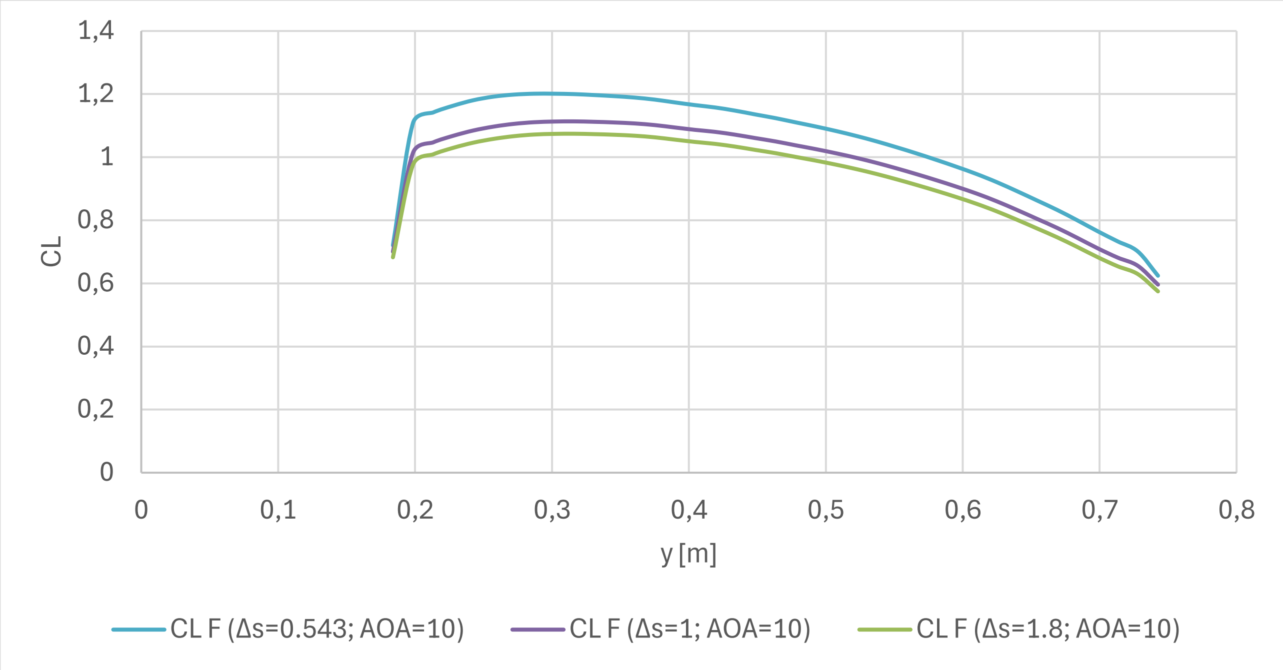


Figure 13 - Distribution of lift coefficient on front wing (comparison of the rear wing positions).

The figures show the distribution of the CL (lift coefficient) by span (CL was compared for the same reference areas and speeds). As can be seen, the higher forces occur on the front wing and for the maximum forward position of the rear wing.

Currently, the aerodynamic calculations do not take the influence of the flaps into account, but since the research rig gives the possibility to conduct the tests with a deflected flap, it had to be considered in strength calculations. As a result, the increase in CL and CM were adopted as described in [24] and based on that the strength calculations with flap were conducted. In Figures 14-16, the distributions of shear force (T), bending moment (Mg) and torsional moment (Ms) stemming from aerodynamic calculations and additional influence from the flap are presented, considering the relief from the wing mass. The chosen method allowed to establish only an approximate increase in coefficients from the flaps, but bigger accuracy is not needed because of the size of the model and oversized structure of the wing (Table 1).

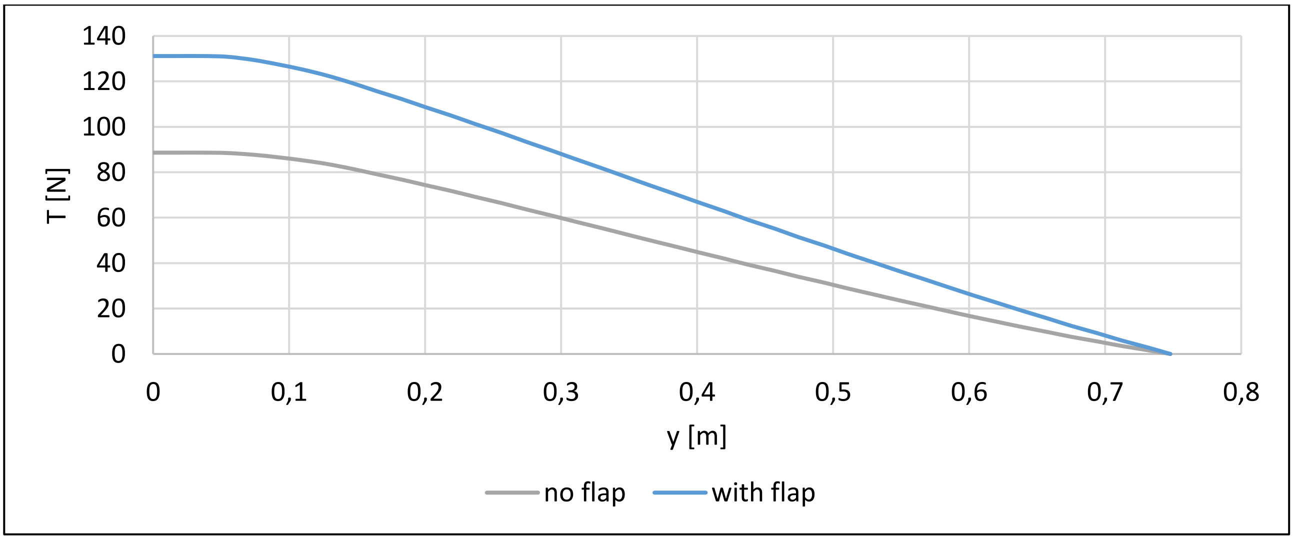


Figure 14 - Distribution of shear force by span.

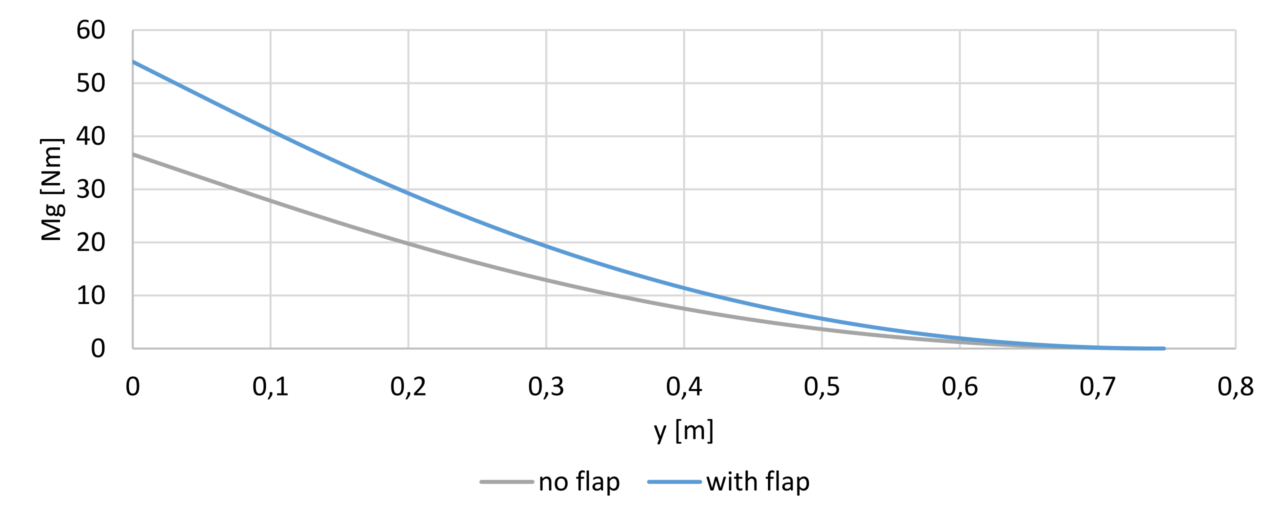


Figure 15 - Distribution of bending moment by span.

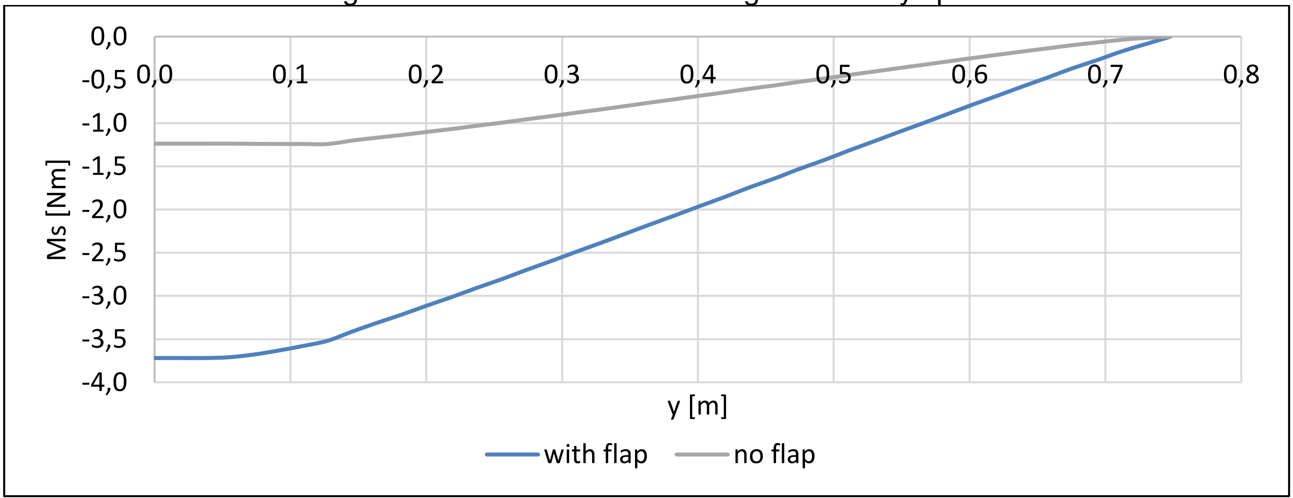


Figure 16 - Distribution of torsional moment by span.

Once the loads had been determined, the stresses in the wing structure were calculated. The model used for the calculations was the double-circular D-box with I-beam shown in Figure 17. Strength calculations were carried out to verify the selected materials and the geometry of the structure components.

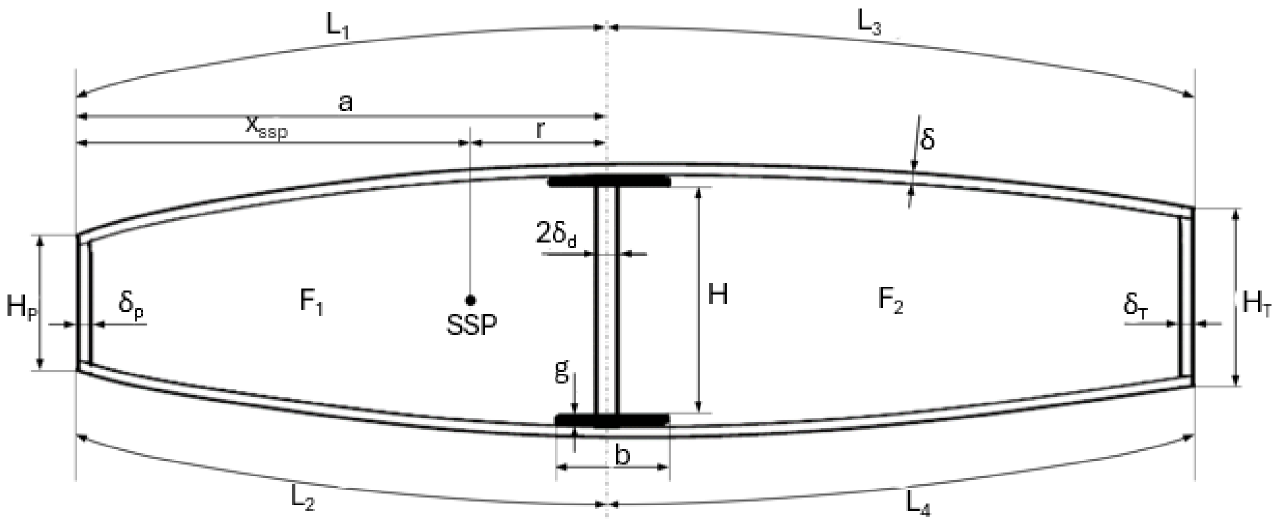


Figure 17 - D-box model used for calculations.

Table 1 - Results of stress calculations.

	stress [MPa]	allowable stress [MPa]	safety margin
box spar flange	135	850	6.3
box spar wall	0.83	10	11.4
coverage	0.34		27.9
leading edge	0.05		190
rear spar	0.17		55.8

Calculations have shown that the structure is sufficiently strong (Table 1). The large safety margins obtained show that the structure is significantly oversized from a strength point of view. However, the fact that this is a small wing and therefore the loads on it are not high has to be taken into account. The design also pays attention to material availability and manufacturability. Consequently, the dimensions of the structure's components had to be such that it could be built. All calculations were done according to [21].

5. Manufacturing

The materials and manufacturing technology for the rig were initially determined at the structure design stage. This was done with precision in subsequent design stages to enable the construction of the platform and to estimate the time required for its fabrication. The most significant factors that were considered during the development of the manufacturing technology were:

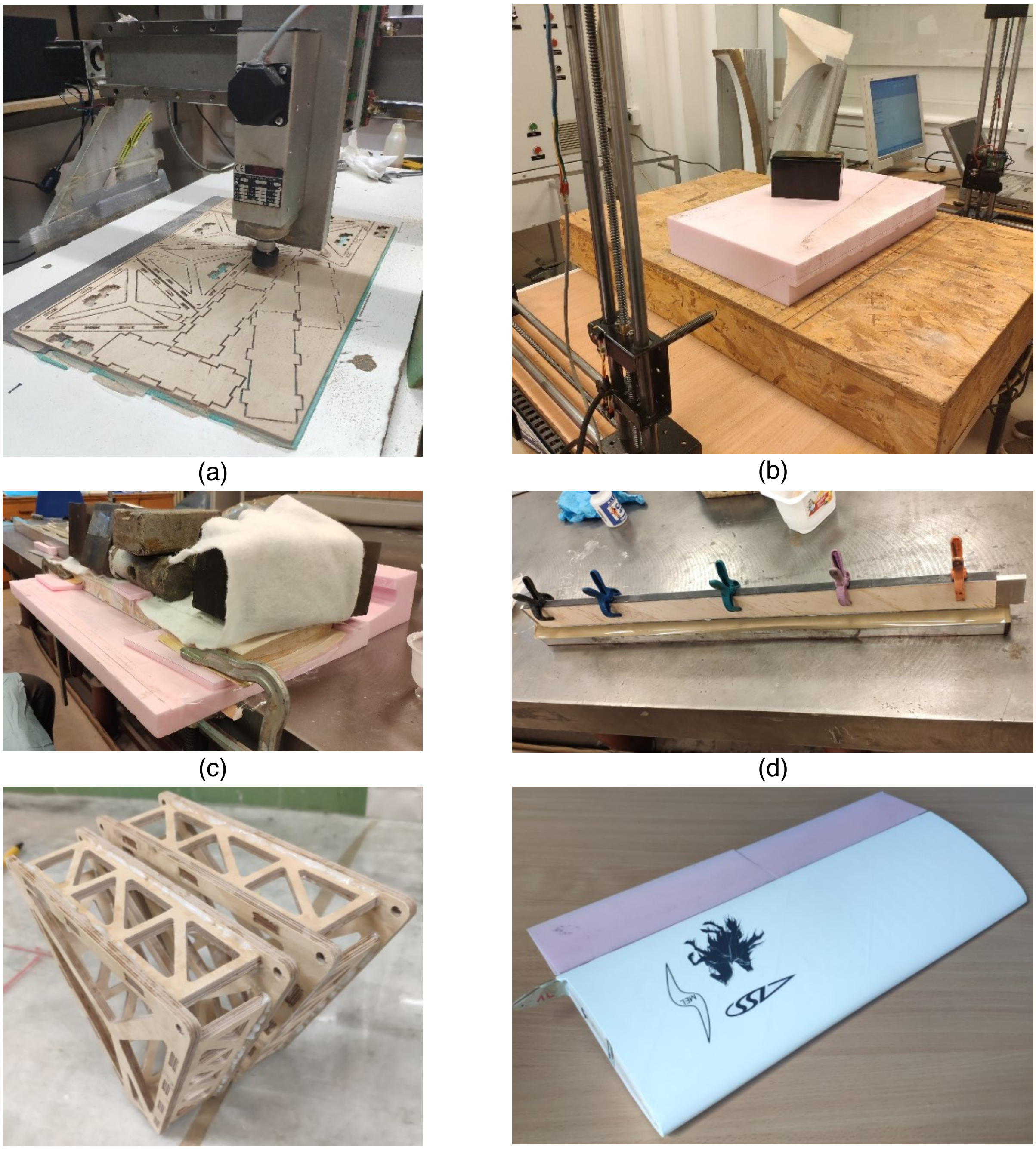
- the simplicity and speed of fabrication,
- the availability and cost of materials,
- the accuracy of the representation of the model,
- the possibility of construction by a single individual.

The most difficult part of the research platform to build was the wing. It is made up of a number of components that had to be made first and then joined together in the right order. The main part of the wing consists of Styrofoam cores to which the structural elements were glued. To maintain the correct profile geometry, the cores were cut on a CNC machine and the fairing was glued in a mold. To improve the surface quality, the wing was covered with modelling foil.

The main steps of the manufacturing of the wing and fuselage are shown in Figure 18:

1. Preparing semi-finished products (a-b).
2. Gluing the box spar (d).
3. Gluing the coverage (c).
4. Covering the wing with foil (f).
5. Gluing plywood frames (e).
6. Laminating the fuselage windshield.

The fuselage section of the research platform is characterised by its less complex design. Many of the joints in this part are bolted, allowing the rig to be assembled and disassembled. For the fuselage, the most difficult part was to position the wings accurately on the plates so that they had no dihedral or sweep. To achieve the correct shape of the outer fuselage windscreen, it is laminated in a numerically milled form.



(a) (b) (c) (d) (e) (f)

Figure 18 - Examples of steps in the manufacturing process.

6. Summary and conclusions

The results of the numerical analyses are in agreement, thereby confirming their validity. The research rig is currently under construction and will be used for the wind tunnel tests. The model being build is characterized by a stiff structure, typical for the laboratory use, where the mass is not of first concern. The wing which has already been build is going to be subject to the static strength test. The final rig will allow to verify the CFD results with real flow around tandem wing model. Moreover, it will allow for dynamic analysis in the future (e.g. analyzing the state of equilibrium). Thanks to the fact that the research rig is equipped with flaps and ailerons, the concept of optimal control of an unconventional configuration can be studied, which remains an unexplored subject in the literature. Combining the CFD analysis from two numerical software with the results obtained from wind tunnel tests will lead to creating a reliable mathematical model of a tandem wing aircraft in the future.

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8. Copyright Statement

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