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Results you can touch: The interdisciplinary aerospace engineering design project

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Abstract: Results you can touch: The interdisciplinary aerospace engineering design project

Within the Interdisciplinary Design Project in Aerospace Engineering, students design unmanned aerial systems for search and rescue tasks. This includes the preliminary design (e.g. aerodynamic design), detailed design (e.g. structural design) and, so far, implementation in a simulation environment. In the current semester, the design is to be brought from the computer into the air. The Chair of Flight Mechanics and Flight Control is providing the electronic and mechanical components (motors, flight computer, etc.) for this purpose. The aircraft structure is to be manufactured by the students themselves. A state-of-the-art laser cutter is available to them for this purpose, which the Chair was able to procure as part of the tender for teaching/learning projects of the Faculty of Mechanical Engineering. This allows the structural parts to be cut quickly and efficiently in wood. The self-built flight system is being evaluated in the wind tunnel and flight tests.

Im Rahmen des Interdisziplinären Entwurfsprojektes Luft- und Raumfahrttechnik entwerfen Studierende unbemannte Flugsysteme für Such- und Rettungsaufgaben. Dies umfasst den Vorentwurf (z.B. Aerodynamische Auslegung), Detailentwurf (z.B. Strukturauslegung) und, bisher, die Implementation in eine Simulationsumgebung. Im laufenden Semester soll der Entwurf vom Computer in die Luft gebracht werden. Hierfür stellt die Professur für Flugmechanik und Flugregelung die elektronischen und mechanischen Komponenten (Motoren, Flugrechner, etc.) zur Verfügung. Die Flugzeugstruktur soll von den Studierenden selbst gefertigt werden. Hierfür steht ihnen ein hochmodernes Laserschneidgerät zur Verfügung, das die Professur im Rahmen der Ausschreibung für Lehr-/Lernprojekte der Fakultät Maschinenwesen beschaffen konnte. Dieses erlaubt den schnellen und effizienten Zuschnitt der Strukturteile in Holzbauweise. Das selbstgebaute Flugsystem wird im Windkanal und Flugversuch evaluiert.

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1. Introduction

In the summer semester 2023, the Chair of Flight Mechanics and Flight Control hosted the course "Interdisciplinary Design Project Aerospace Engineering" for the second time. In this project, groups of four to five students design and test a small unmanned aerial system (sUAS) specifically for search and rescue missions. sUAS are virtually predestined for this field of application and their market is therefore growing rapidly [1]. The operation of autonomous aircraft under changing wind and weather conditions is also a central field of research at the Chair of Flight Mechanics and Flight Control [2].

In the course of the semester, participants go through the typical phases of any development project: preliminary design, detailed design including constructive implementation and the implementation and verification of the concept. The latter also takes place practically for the first time in the current year. Students receive standardized commercial-off-the-shelf (COTS) components and construction materials from the chair for implementation. With the help of the laser cutter sponsored by the faculty, the structural components can be produced from the design documents in a short space of time. The assembly is carried out by the students themselves. Similar to large aircraft construction, a wind tunnel test precedes the final flight test.

Such a project requires a high degree of cooperation, self-organization and interdisciplinary thinking from those involved in order to effectively process the various subtasks and bring them together into a meaningful whole. This is all the more important as the task now also includes practical implementation. A large number of detailed solutions must be developed, checked for technical feasibility and ultimately implemented in practice. At the same time, the computational verification remains in the simulation environment, but is reduced in scope compared to the first iteration in favour of the design and practical implementation [3]. A realistic implementation of the overall project is also an essential concern of the course, even beyond the practical implementation. This includes realistic requirements, the development of specifications, reviews, progress meetings and the presentation of milestones in combination with deliverables. These are subjected to strict reviews in the form of presentations.

By working in small groups and regularly checking progress, intensive interaction with each other and with teachers is strongly encouraged and promoted. This trains crucial skills in dealing with each other. In addition, the learning progress of individual participants can be closely monitored and specific problems can be addressed. This allows students to be better supported and challenged individually.

2. Concept of the module and procedure in the first year

The practical implementation of the project in an airworthy model was part of the concept from the very beginning, but could not be put into practice in the first year due to the lack of available production capacities. Instead, the project initially took place exclusively on paper or on the computer [3]. The theoretical tasks were correspondingly more extensive: A separate fuselage was part of the design, a wider range of propulsion options were available for selection, and the simulation was to be carried out more extensively. These sub-areas were later restricted in consideration of the workload.

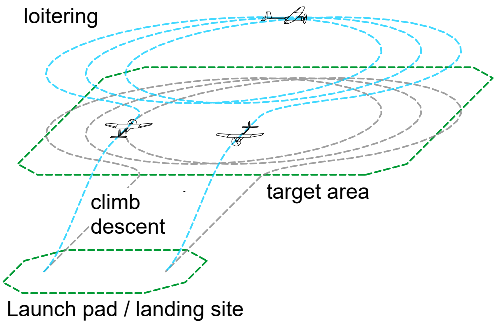

Fig. 1: Illustration of the flight path on a typical search-and-rescue mission.

The project starts with the specification of a apparently realistic operational situation for a small unmanned aerial system: missing persons are to be searched for and found in a target area that is difficult to access (Fig. 1). To do this, the UAV must carry a small camera with the necessary data transmission system as a payload and be able to cover a certain distance to the location. At the beginning, it is launched by hand and climbs independently to its operational altitude. It must operate in the target area for a specified time and search for the missing persons. After returning to the starting point, it lands in a safety net. Sufficient speed and range reserves must be provided in order to complete the mission even in adverse wind conditions. The specifications differ slightly between the groups. This variation is intended to promote the diversity of the designs and the independent work of the groups.

Based on the requirements, which are summarized in a specification sheet, a preliminary design must be developed at that meets these requirements. The aerodynamics are central to this phase; essentially, a suitable wing airfoil must be selected and the necessary lifting surface determined. XFOIL [4], an easy-to-master calculation program based on a 2D panel method with superimposed boundary layer calculation (Fig. 2), serves as a tool for this.

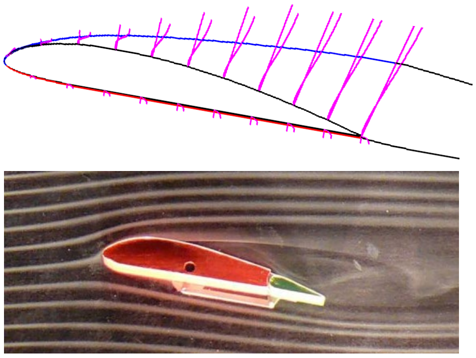

Fig. 2: XFOIL calculation of the flow around an airfoil at a very low Reynolds number (Clark Y, $Re=5 \cdot 10^4$, $\alpha=10°$, top) compared to the flow visualization (bottom).

Using simple approaches to induced drag and empirical methods for estimating the wall friction on the remaining surfaces [5], an initial polar diagram is created (Fig. 3). This is the starting point for the preselection of drive and battery from a given portfolio.

In the next phase, the detailed design, the actual wing geometry is created with the tip, dihedral and ailerons. The tail unit with elevator and rudder must also be dimensioned. The program Athena Vortex Lattice (AVL) [6], which is based on a vortex lattice method, provides the flight mechanical derivatives (Fig. 4).

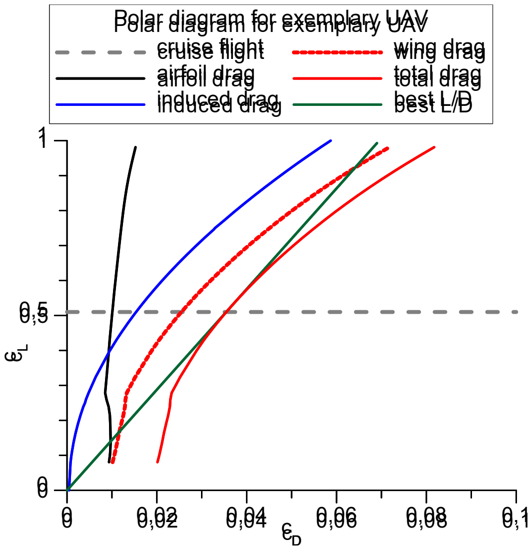

Fig. 3: Representation of an initial polar curve estimated using simple methods (lift and drag in the form of nondimensional coefficients)

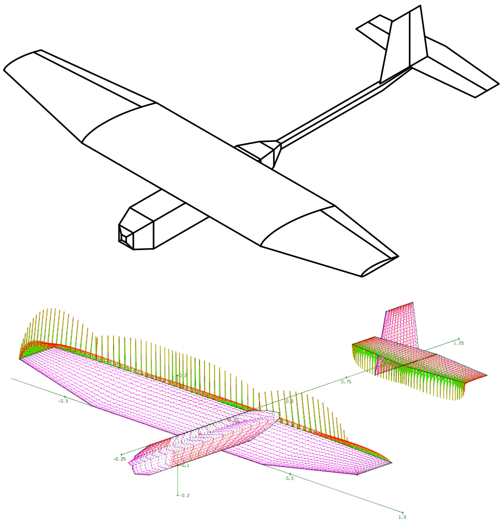

Fig. 4: Geometry of 2023's exemplary design (top) and implementation as a vortex lattice model in AVL (bottom).

Of particular interest is the neutral point position, which determines the permissible center of gravity range in which the aircraft remains stable and controllable. This center of gravity range must be calculated by the students on the basis of the relevant moment equilibria. On the basis of this, the students must position all system components necessary for flight operations (battery, telemetry, Pixhawk flight computer, GPS, etc.) in the fuselage.

A simple structural estimation is also part of the task, both with regard to the final mass and the strength.

The aerodynamic and flight mechanics parameters obtained up to this point are used for implementation in the simulation environment developed in-house, which has been a central component of the course to date.

All calculations with the data from XFOIL and AVL must be carried out in Matlab [7], which makes the solution paths traceable and errors easier to find. In addition, a clean implementation in Matlab allows the students to carry out the necessary iterations in the design process more quickly. The simulation is carried out in the Matlab environment Simulink.

3. Innovations in the summer semester 2023

The main and central innovation is the practical implementation of the design. The funded laser cutter and self-financed components are used for this purpose. This realizes a fundamental component of the methodological-didactic concept of the module: there is a motivating goal with a tangible result. Furthermore, the participants learn about the many small obstacles in the practical implementation of a design, how to deal with them and how to overcome them.

As a result, the focus of the work packages is shifting more towards the actual design. A reference-sUAS (Fig. 4, 7, 8) was designed, constructed and built at the chair in advance. This allowed the lecturers to better estimate the effort required for the individual process steps and to provide the students with more targeted support.

During the design and construction of the UAV, a large number of detailed solutions must be developed and implemented. While the global structure of the wing in spar-rib design with covering is still relatively straightforward, the complexity increases considerably when it comes to the recesses for the control surfaces, the positioning of the actuators and push rods or the removable connection of the wing to the fuselage, including the intersections and cable feedthroughs.

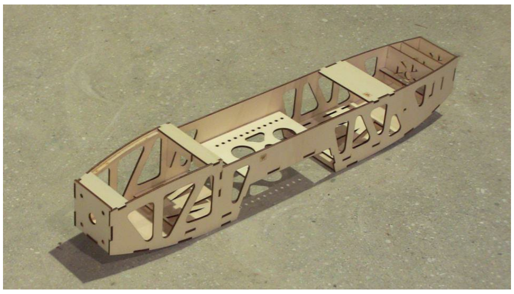

Fig. 5: Standardized box fuselage in the shell construction, still without covering.

A certain simplification and thus reduction of the workload is achieved by tightening the specifications for the available components. The standardized box hull is prefabricated by the chair (Fig. 5).

The tail boom is a simple carbon fiber tube, which allows an uncomplicated variation of the tail unit lever arm. The choice of motors and batteries has also been restricted (Fig. 6). The propeller to be used is predefined.

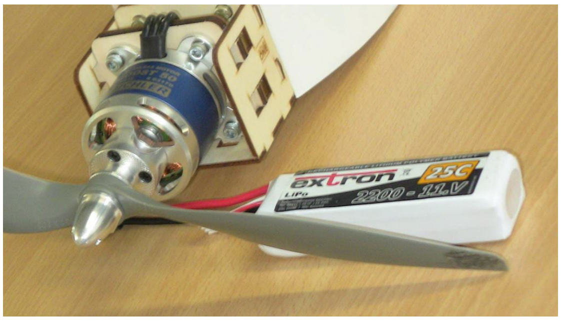

Fig. 6: Motor, propeller and flight battery from the upmarket range of model-making accessories

The wings and tail unit are to be designed and constructed by the students, using the classic spar-rib construction method. It is to be made of aircraft plywood in accordance with the available technology. The laser cutter enables fast and efficient production of the many individual parts as well as simple positioning devices for assembly. The groups assemble the parts themselves under the guidance and supervision of the teaching and workshop staff.

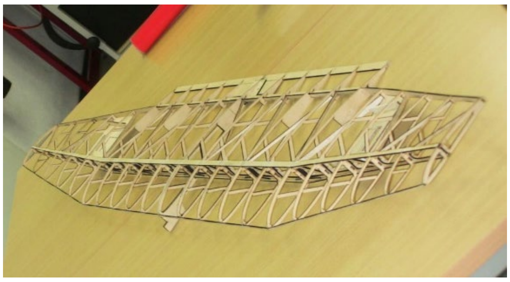

Fig. 7: Spar rib structure of the wing for the reference SUAS.

The finished wing frame (Fig. 7) is then covered with modelling film to create a smooth, closed surface (Fig. 8). For fine adjustment of the center of gravity, the positions of the individual system components in the fuselage can still be moved. In addition, the installation height and angle of the electric motor can be adjusted. The thrust vector should run through the center of gravity as far as possible in order to minimize the thrust-induced pitching moment.

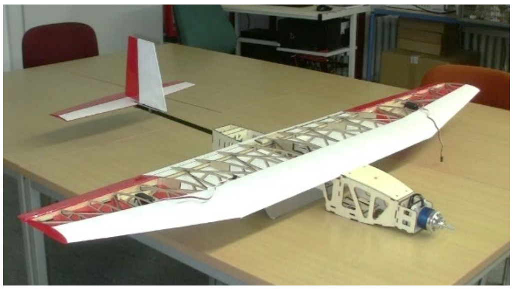

Fig. 8: First estimation of the actual center of gravity on a prism.

Flight control is performed centrally via a Pix hawk autopilot [8]. The Pixhawk flight computer is programmed using QGroundControl [9] on the basis of the flight dynamic properties and controller designs obtained in the simulation. The combination of QGroundControl and Pixhawk makes it easier for students to program autopilots and mission planning (flight routes etc.). QGroundControl also functions also acts as a ground station for the operation of the sUAS.

The interaction of the electronic and mechanical components must then be tested and optimized.

Up to now, the wind tunnel test is still being carried out with a fairly simple tethering, with which the effect of the control system can be demonstrated and checked.

To compensate for the considerable additional work involved in detailed design and construction, the scope of the simulation has been reduced and only a written report is required at the end of the project. The regular presentations on the progress of work have been retained, thus encouraging everyone to keep up the documentation.

4. Increased experience in the 2nd year

Extensive experience was also gained by the participating teachers themselves, who had previously had very little contact with model aircraft construction. This includes the handling of materials, e.g. laser cutting, the range of properties of the semi-finished products supplied, the time required for post-processing and assembly. The concept of the spar-rib composite with interlocking plug-in connections, which are finally fixed with adhesive, proved to be fundamentally suitable. The limitation of the laser cut to flat contours of largely constant thickness makes manual reworking necessary for diagonal stiffeners in particular, which are needed to ensure sufficient torsional stiffness. The center of gravity of the reference model came as a surprise: it was initially significantly more tail-heavy than assumed in the design.

It turned out that, not unexpectedly, the devil is in the details: a solution must actually be found for every little problem. This is particularly true for moving connections and linkages/actuators. A concrete example of another detail is the measurement of the dynamic pressure and thus the airspeed, a key parameter for determining the current flight attitude.

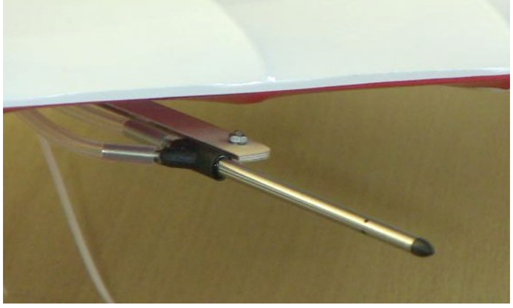

Fig. 9: Pitot-static tube from the model making supplies for taking static and total pressure in front of the wing leading edge

The points at which the total and static pressure are measured for this purpose are always influenced by the flow around the aircraft itself, which in turn depends on the flight attitude. The variable deviation must therefore be estimated and a suitable correction introduced (Fig. 9, 10).

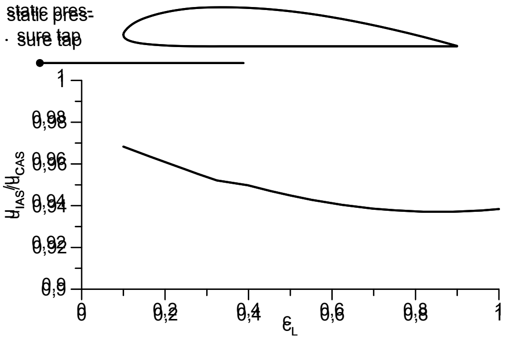

Fig. 10: Error to be expected in the displayed airspeed due to the effect of the pressure field of the wing airfoil on the measurement position (XFOIL calculation)

When the students worked together on site, very specific group dynamics could be observed, which can vary greatly from one group to another. Basically, as in the previous year, the working methods of all groups were characterized by a high level of motivation and great ingenuity and a strong willingness to experiment.

The placement of the course in the timetable (Fr., 1st and 4th lesson) proved to be even less favourable than in the previous year, which meant, for example, that there was not enough time to prepare meaningful questions for the subsequent consultation after the tasks had been handed out. In addition, there were overlaps with other courses with compulsory participation (excursions). The additional dates offered for independent but supervised work were used extensively.

On-going construction work in the wind tunnel building caused some considerable restrictions. This situation posed an additional challenge, but one that could be overcome through mutual understanding among those involved.

The final step was a simplified wind tunnel test with the completed models in a tethered suspension (Fig. 11). This proved that the designs were stable in the airflow in the required speed range.

5. Outlook

In the future, more detailed wind tunnel measurements are planned, which will allow the calculated characteristics to be checked on the real object and thus establish a continuous connection between the predictions of the design and the actual flight characteristics. Student research projects or final theses for a balance with a suitable measuring range are being advertised.

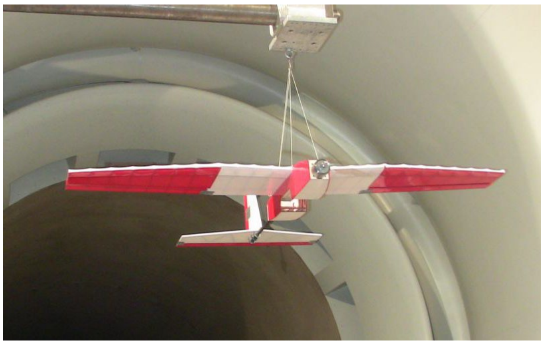

Fig. 11: Model in the wind tunnel on a simple restraint with blocked control surfaces

As part of an ongoing diploma thesis, the characteristic field of a typical propeller was measured in the wind tunnel. This enables a more precise estimation of the performance data, particularly with regard to range and flight duration. A comparison of the actual characteristics with predictions from XROTOR [10] then allows extrapolation to the performance data to be expected in reality for any configuration.

On the material side, the use of thinner plywood and even rigid cardboard is also being considered. On the one hand, this enables the production of lighter structures with a more favourable center of gravity, and on the other hand, it also makes it possible to achieve planked curved surfaces that are characterized by a higher aerodynamic quality. It also makes it easier to produce closed profiles with higher torsional stiffness (nose box) so that diagonal stiffeners can be largely dispensed with.

Fig. 12: Group 1 in front of their design "SN-23 Penguin"

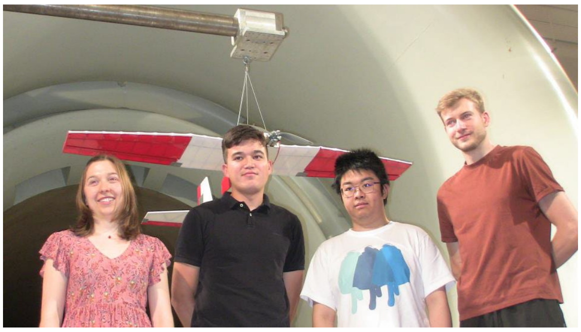

Fig. 13: Group 2 in front of their "FeuerFalke" design

Acknowledgments

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