



DESIGN BUILD AND FLY: A STUDENT APPROACH TO THE CREATION OF AN RC DRONE FOR UNIVERSITY COMPETITION

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Abstract

This article presents the activities carried out as part of a technical-educational initiative which involved numerous aerospace engineering students from the University of Pisa. This initiative consists of the study and creation of a drone, according to pre-established technical specifications, with which the students themselves will participate in the international Air Cargo Challenge 2024 competition which will take place in AACHEN (Germany). The students involved, about 30 units, were divided into subgroups based on the planning of the activities: CAD modelling, aerodynamics, structures, flight mechanics, electronics and propulsion, manufacturing, business relations and associates, media. The drone project had to comply with the tender specifications which require the disassembly and transport of the aircraft inside a box of pre-established dimensions. Other constraints concern the completely electric propulsion system: the type of batteries, the type of engine to be used and the maximum electric current with which to drive the engine. Once the drone configuration was chosen, the aerodynamic study was initially conducted with calculations based on methods extracted from the technical literature subsequently refined through Computational Fluid Dynamics and Finite Element analyses. A similar approach was followed for the definition of the structural layout and for the analyses of the aeromechanical characteristics of the drone. The main structures of the drone, fuselage, wings and tail planes, are made entirely of composite material. The team designed the molds for the hand lay-up of the components and directly took care of the production and assembly of the drone's structures. During the production phase, all flight control systems were obviously integrated as well as the substructure containing the payload envisaged by the tender specifications. Finally, flight tests of the drone were finally carried out in preparation for the actual race. In addition to the technical aspects, the team of students organized events to disseminate their activities, also aimed at young students from local technical high schools. Overall, the initiative, although very demanding, allowed a group of young engineering students to conduct an important training experience from a technical, scientific and human point of view.

Keywords: university education, team, drone, design, manufacturing

1. Introduction

LeanIng Project is a University of Pisa student initiative born and developed to design and build a model RC aircraft for an international competition, the Air Cargo Challenge (ACC).

The ACC is an international university competition that takes place every two years and consists of a series of challenges that the teams have to accomplish during a final period of flight tests, competing against each other in order to obtain the maximum score in the three different categories evaluated: efficiency of the flight, travelled distance and payload carried. All the activity of the teams have to be documented in a technical report that is evaluated and contributes to the final score. The regulations for the ACC 2024 [1], which will be held in Aachen (Germany) from the 9th to the 13th of July 2024,

were published on the 7th of August 2023, thus resulting in a total of eleven months available to design and build the entire competition drone from zero. Another reason why this type of competition was interesting for the team since the very beginning lays its root in the fact that the study of hybrid-electric propulsion systems is currently of great interest also in the aerospace field. In fact, researches in this sector are also underway at the University of Pisa ([2],[3]) justified by an ever-increasing focus on environmental protection issues [4].

The current team formed in the first months of 2023 and, together with the help of some professors of the Aerospace Engineering faculty, this project has given to 27 Aerospace Engineering students the opportunity to challenge themselves with completely new problems, facing the reality of working in a big group to carry out a complete design of a complex system and then build it in a short amount of time. Moreover, the organization of the team was entirely defined and managed by the students, including the design schedule determination, the management of the team structure and the search for financial support both from university and from external companies.

This paper aims to give a qualitative overview of the activity of the student team during the last year in preparation for the competition, highlighting the fundamental features that make this initiative an important addition to the course of study of the members and how these features allow the students to gain experience and acquaintance in the aeronautical engineering design process.

2. Organization

2.1 Time management

The day the regulations of the ACC 2024 were released marked the start of the design of the competition drone. The organization of the team, composed of 27 students of the Aerospace Engineering Faculty, has been differentiated depending on the main design milestones: Conceptual, Preliminary and Detailed Design Reviews (**Figure 1**). At each design milestone the team went through reviews of the entire design, enhancing the decision-making process and the complete documentation of the work done.

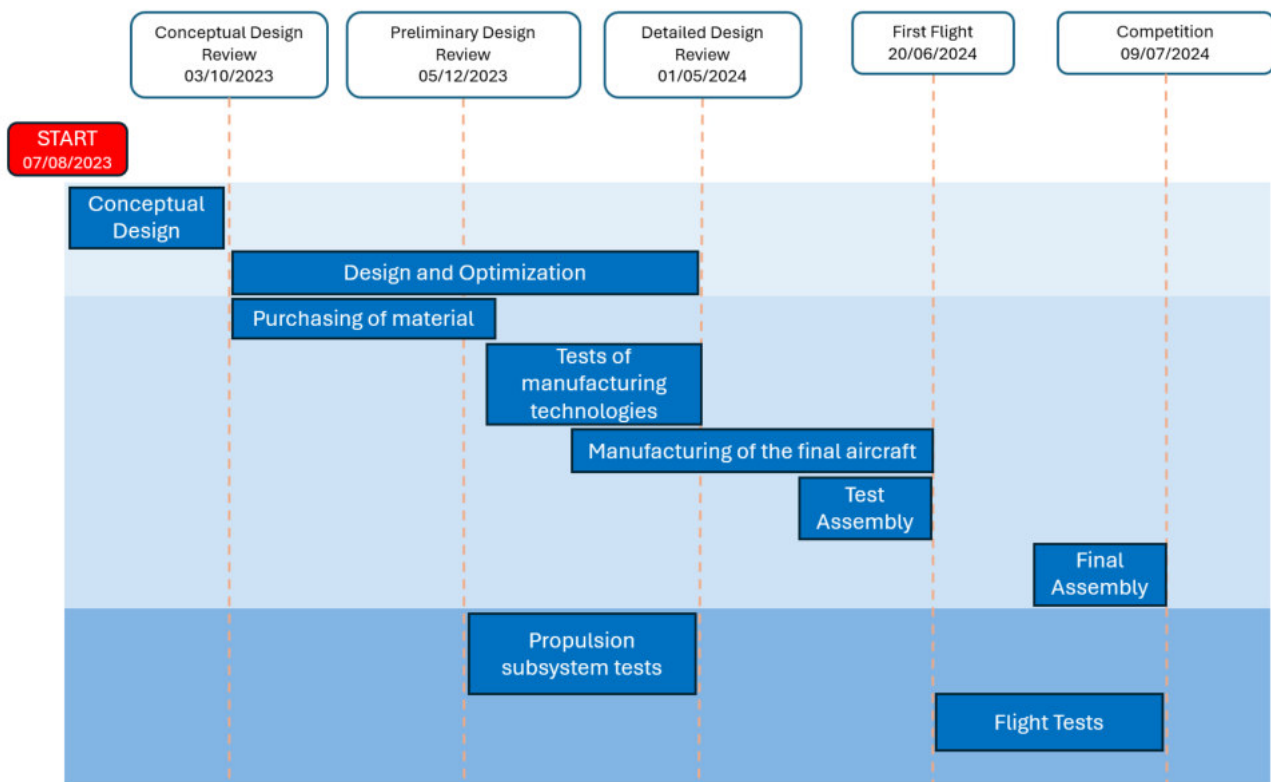


Figure 1 – High level Gantt chart of the project with milestones.

The milestones serve as indicators of passage from a phase of the design to the next one, allowing a good plasticity of the structure of the team. The reason to this lies in the will of having a team

structure that allows to work as efficiently as possible throughout the whole project, facing changing situations and increasing complexity of the tasks to be accomplished.

2.2 People management

The team is organized into 6 technical departments: Aerodynamics, Structural Analysis, Flight Mechanics, Manufacturing, Electronic and Propulsion, CAD modelling. Plus 2 non-technical ones: Business Relations, Social Media.

From the Preliminary Design Review on, the technical departments cooperated in a matrix-form diagram, since the birth of two more departments, for a more component-oriented design: Wing and Tail, Fuselage and Landing Gear.

Every department has a manager, who is responsible for the organization of the work in his/her group. The goals for every department are established at every milestone and are divided into smaller tasks, assigned to departments' member by the manager, who is accountable for the accomplishment of the tasks in the assigned time.

Managers continuously communicate with each other and the team leader to be aware of the developments of the other departments, ensuring the coherence of design choices. The work has been carried out thanks to a structured organization of meetings between the members of each department, between managers and general meetings with all the team members (**Figure 2**).



Figure 2 – Managers (left) and general (right) meetings.

The team leader is responsible for the organization of the whole team and the generic schedule of the work, through the definition of milestones and the general technical objectives for each phase. He is the interface with the University and supervises the bureaucratic procedures to ensure the correct timing for competition's deadlines. The team leader, together with Business and Relations manager, is responsible for the financial management.

2.3 Financial management

The first step in the organization of the team was the establishment of a solid bond with the University. We have engaged some professors of the Aerospace Engineering course, who helped us in solving many technical and organizational situations. Thanks to the support of these professors, we were able to obtain a room where we could do our meetings and a small workshop inside the department where we manufacture our aircraft.

Thanks to the Business Relations department, we got in contact with many companies, searching for services and support in tasks for which we couldn't find help inside the University.

We received both economic and technical support from external companies.

The first half of the project has been completely funded by University of Pisa, with which we completed the purchasing of the totality of the material we needed for the manufacturing of the aircraft, we bought the tools for the set up of the workshop, we paid the application for all the 8 members to

the competition and we covered the costs for a course on the utilization of CFD software and for the cooperation with aircraft modelling experts.

In the first part of 2024 we could not be in the conditions of receiving another funding from the University, so we searched for other industrial and institutional partners that could sponsor the remaining foreseen expenses. This slowed down remarkably our work, in particular the starting of the manufacturing phase, since we had to rethink some of the solutions we chose, while relying on University's grant for 2024.

The team has been able to collect 5 new sponsors, that allowed us to cover the costs for the trip of the team to Aachen and to finish on time the aircraft manufacturing, enabling several flight tests before the competition. The team is associated to EUROAVIA Pisa [5], and the management of the sponsorships are considered into the Business Report of the association.

3. Design and Manufacturing

The starting point for the design process was the regulation of the competition. The main constraints are on the type (RC, fixed wing, single electric motor) and size of the aircraft, and on the propulsion system. The dimensions of the aircraft are limited by the size of the transportation box, where the disassembled aircraft has to fit in. The sum of height, width and depth of this box has a maximum limit of 1400 mm. The power available is limited by a constraint on the type of batteries to be used (LiPo, max 3S), on the choice of the motor (fixed, T-Motor® AT2826 KV900) and on the maximum current that can flow in it (30 A). The payload is made of billiard balls of fixed dimensions and weight, and should be arranged in a way in which they do not touch each other. The mission that the aircraft have to accomplish during the flight tests is also outlined. After the take off, it consists of by 90 s of flight during which the energy efficiency of the drone is evaluated, followed by other 90 s over which the drone has to maximize the flight distance. Many other smaller limitations and indications were given in the document, which guided the design choices of the team.

3.1 Methods

During the conceptual design phase, all the departments worked in synergy in order to define a set of requirements and find the configuration of the aircraft to be developed. Once the configuration was selected, the team entered the preliminary design, during which the departments started working more independently, pursuing a set of objectives that included mainly the determination of the gross dimensions of the aircraft and the definition of the characteristics of all the subsystems, taking into consideration the regulations' limits. Then, in the detailed design phase, the team carried on in parallel the final studies to optimise the performance of the aircraft and its manufacturing.

The fundamental dimensions were determined using an algorithm as a support. This was developed by the team members using the MATLAB® software, and aimed to, given the model inputs and constraints (regulatory and physical), provide a configuration primarily characterized by the parameters W (total aircraft weight), S (reference area of the aircraft, i.e. wing plan surface), C_{D_0} , and K , which maximizes the score regarding flight tests. The algorithm relies fundamentally on an input block, which includes a performance database of various propellers under different flight conditions [6]. For the brushless motor and the electric system analytical models were formulated ([7], [8]). The Electronic and Propulsion subunit worked on the models in order to integrate the analytical one for the powertrain elements with the performance data of the propeller from the producer's database to have a complete model of the system. From the algorithm output results, the team chose a strategy that favors configurations leading to a higher-than-average amount of payload compared to other solutions that may focus on different strategies and thus yield different scores. After the creation of the numerical models for the propulsion subsystem, the Electronic and Propulsion subunit started the design of the power-train test bench, a tool to determine the real capabilities of the motor and propeller coupling, together with the verification of the battery chosen.

In the aerodynamic project, a wide range of sources were used, from classical literature [9] to Computational Fluid Dynamics (CFD) simulations and simplified models (Zero Level Methods), to guide the design choices.

The starting point was the design of the wing, subdivided into four comparable sections, in order to best respect the constraints dictated by the limits on aircraft dimensions. The arrangement and organisation of the payload was the basis for the fuselage design. The main objective was to reduce the drag coefficient (C_D), according to the constraints and objectives outlined in the Preliminary Design phase. Emphasis was placed on take-off performance and the search for an optimal balance between economy cruise and fast cruise using optimisation algorithms.

The starting point for the airfoils selection was the creation of a database of profiles, both for the wing and the tail, optimised for low Reynolds numbers, based on documents from experimental tests [10]. After identifying the most promising profiles, which were represented in a surrounding of our design point, two decision matrices (one for the wing and one for the tail) were created, from which the finally chosen profiles were derived.

From an aerodynamic point of view, the wing design tried to meet the requirements chosen after the preliminary design phase, also seeking to consider other aspects such as packaging constraints, lift coefficient sensitivity to attitude, tolerances in manufacturing methods.

As a first analysis method, in order to explore many solutions, it was decided to implement a LLT model in a MATLAB® script to evaluate the aerodynamic performance based on various geometric parameters. This approach proved to be formative in that it enabled the team members to comprehend the impact of geometric parameters (wing twist, taper, etc.) on the performance of the isolated wing and to identify the inherent limitations of the methodology employed.

In relation to checks with XFLR5 [11], using a panel method, a discrepancy was noted between the results of the LLT and the panel method. CFD analyses on the selected configurations confirmed the trends, leading to the effective choice of wing configuration.

As far as the flap profile study is concerned, we have chosen a plain flap architecture, which is characterised by being a simple, reliable and economical device. On the other hand, it offers limited performance in terms of increased lift. Analysing this solution in detail, as a first approach we chose to compare results obtained with Xfoil [12] and CFD, the latter with a $k - \varepsilon$ turbulence model. This model was chosen because it shows good results for larger flux classes than zero or one-equation models and is widely validated. Those obtained by CFD were selected as reference values, but the trends shown by Xfoil were then reconfirmed in CFD. The combined use of CFD and XFLR5 allowed to analyse the 3D model of the flapped wing (**Figure 3b**), estimating its performance.

With the CFD tool the Aerodynamics subunit analysed also the fuselage (**Figure 3a**) and the entire aircraft, allowing the team to optimise the shape of all the aerodynamic surfaces.

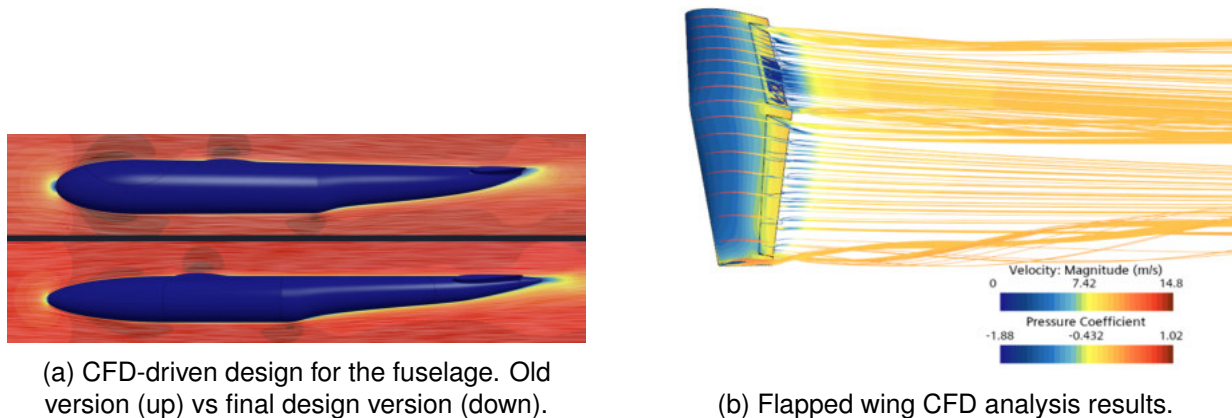


Figure 3 – Complete CAD models

The Flight Mechanics subunit had as its main scopes the definition of an optimal shape for the tail, the design of primary control surfaces, the determination of the desired aircraft's center of gravity and computations for the stability and maneuverability. The first step was to compare the most common configurations of the tail plane, namely the traditional, T-tail, and V-tail, using both knowledge acquired through academic study and insights gained through collaboration with industry experts. For each of these configurations, the strengths were analyzed and any potential issues due to construc-

tion limitations and design techniques were highlighted. The final choice of the team was the V-tail configuration, which represented an exciting and challenging learning opportunity. In fact, during the academic course, this type of tail was not studied in detail, so it was necessary to gather new study material to achieve proper sizing. Based on hypotheses related to conventional studies, the goal of the team was to adapt the sizing of a standard tail, with a conventional vertical and horizontal tail plane, to that of a V-tail through empirical and comparative techniques. The free parameters representing this geometry must, however, satisfy requirements imposed by both the fulfillment of certain performances, e.g. a predetermined acceleration during takeoff maneuver, and constraints set by other departments. The study of these requirements was developed using programs such as MATLAB® and XFLR5, which, used iteratively, led to the satisfaction of the following constraints: fixing the overall center of gravity position as the payload varies; adequate stability margin, lower than 20%; limited dimensions due to competition regulations restrictions. The extensive use of MATLAB® also included the analyses for the ruddervators, the tail control surface, and the wing ailerons. Finally, the team implemented it in the creation of a model to study the roll performance of the drone.

The CAD model (**Figure 4**) was developed by the team using SOLIDWORKS®, and was used to visualize all the design choices and to verify the fulfillment of the competition requirements.

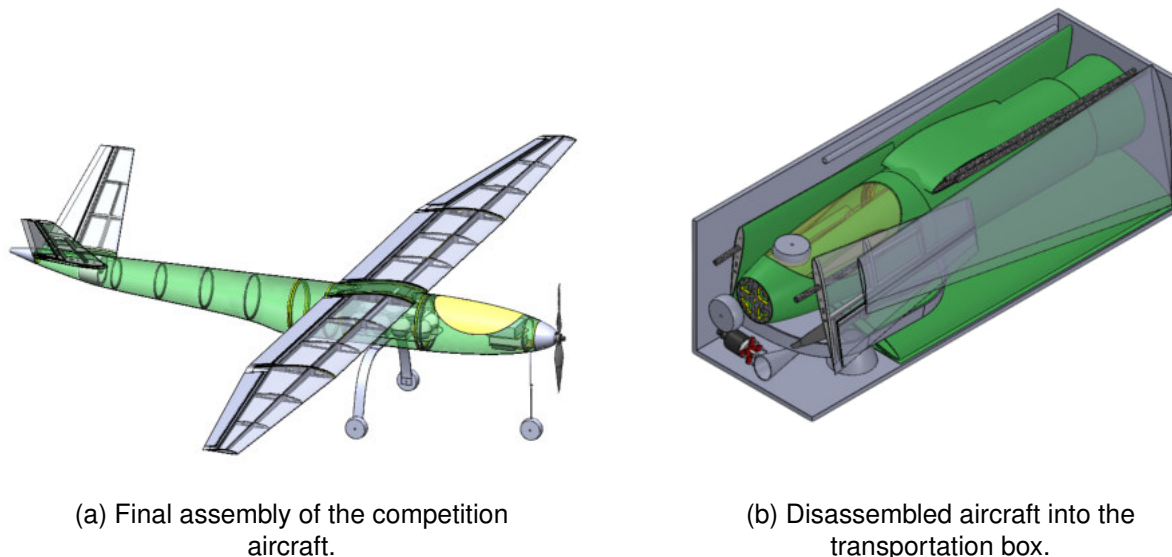


Figure 4 – Complete CAD models

As well as the other departments, also the Structural Analyses one started from the competition regulations, which highlighted the importance of considering practical constraints early in the design process, such as the transportability of the model, which had to fit inside a box of limited dimensions. It became evident that the wing and the fuselage needed to be divided into multiple parts, so that the typical aircraft structures studied during lectures had to be adapted to solve this unusual problem. In order to maximize the structural strength to weight ratio, the team decided to use composite materials. A first trade off was performed in order to choose the exact materials and techniques to manufacture the model, based on past competitions' reports, textbooks and airmodels' manufacturers suggestions.

To reduce crafting costs and complexity, the team decided to fabricate every element using only hand wet lay-up lamination technique (**Figure 5**) and to realize the molds where to laminate the composites fabrics cutting the shape directly from extruded polystyren (XPS) sheets, thanks to the support of the Research Center E. Piaggio at University of Pisa and their CNC cutting machine, **Figure 6**.

A solid contact between the sandwich layers is really important, also to give the aerodynamic shape to the fabrics. To do that, the quickest and most reliable way is to cure the parts under pressure inside a vacuum bag letting the laminated parts rest inside the bag for at least a day, **Figure 7**.



Figure 5 – Composite hand lay-up technique.

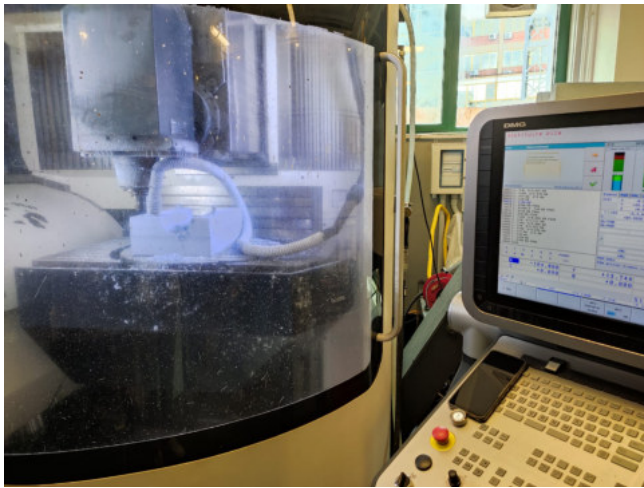


Figure 6 – XPS mould for the fuselage during (left) and after (right) the CNC machining.

The internal components, as spars and ribs, were obtained internally by the team starting from carbon fiber sandwich plates laminated and cured at room conditions, then cut in shape by an external company using a CNC machine.

The last phase was to glue together all the external components realised in two separate pieces in order to position the structural parts and servomotors components inside, **Figure 8**.

For the payload structure layout, the design process began after the preliminary optimization. As an output, it was determined that the payload consists of eleven balls, and a prototype was modeled using SOLIDWORKS®.

For the half-wing, two different loading conditions were investigated with FE analyses: cruise flight at maximum load factor and the static load test (included in the regulations), in which the aircraft must be lifted at the wingtips.

The first case involved the spar, which was fixed at the centre of the fuselage, the weight load and the aerodynamic load. The second case is the static test, that only involves the weight load, while the wingtip is fixed. This latter analysis revealed at first a rather severe deflection, showing that the skin between the two central ribs of each wing segment could be too weak to support the entire load by itself.

Moreover, in both conditions high stresses were observed on the ribs' hole, whose size was significant compared to the profile thickness. Thus, longitudinal reinforcing elements were included, resulting in a slight increase in the weight of the structure, but reducing the deflection by over 30%, **Figure 12**.



Figure 7 – Vacuum bagging for the wings.

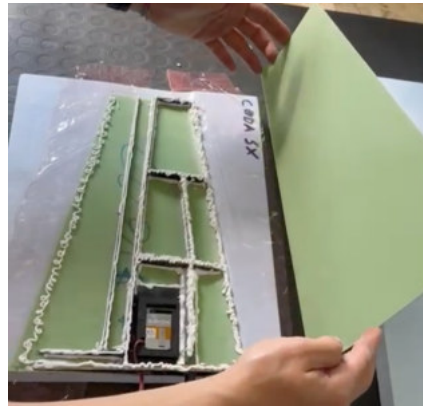


Figure 8 – Bonding of the internal structure with the skin.

The tail structure was only analyzed under flight conditions, and it did not show any critical issues.

3.2 Challenges

During the design phase, the team members has to improve their skills in the use of many software packages (XFLR5, Ansys®, Star CCM+®, MATLAB®, SOLIDWORKS®) useful for the design phases. This has represented a limit, because it slowed down the development at some points, but also an opportunity for the students to better learn these software packages, that are extensively used in the industry and research fields.

The greatest challenge in the aerodynamic design, indeed, has been the application of Computational Fluid Dynamics and Aerodynamics, outside of the didactic field, contextualised in a practical case of interest.

In particular, the study of the most appropriate turbulence models for the case under examination and the conscious use of commercial codes proved useful.

In fact, as a further analysis, a comparison was made between the $k-\varepsilon$ turbulence model and $k-\omega$ SST, aware of the limitations of the former and using the latter as a possible remedy. In terms of results, no notable differences were found in the linear zone, while a tendency of the $k-\varepsilon$ to overestimate the $C_{L_{max}}$ and delay stall was observed.

Another critical aspect was the correct centering of the aircraft. This depends on all the internal masses that compose it and their relative positions. In particular, the fundamental assumption on which the team based itself consists in the arrangement of the macro-components, e.g. the engine block, GPS block and tail, based on the landing gear position

After collecting sufficient material and in collaboration with our team of pilots, a fixed tricycle configuration was chosen, with all struts attached to the fuselage, and consequently, the main parameter of this design phase was identified in the position of the main landing gear relative to the aircraft's center of gravity. The main uncertainty about this point was represented by the precision with which we could estimate the weight of the parts that were to be built.

The time was the main constraint, and together with the unavailability of a place where to build the aircraft in the first half of the project made impossible for the team to have an empirical way to verify the correctness of the composite parts weight estimations.

The final verification of the actual center of gravity was then postponed to the end of the manufacturing period, when all the parts could be weighted in the final assembly configuration.

For what concerns the manufacture process, most of the challenges concerned the resolutions of errors and problems that emerged during the usage of composites materials.

First of all, the realization of an "hand-made" workshop inside the Engineering Department of the University of Pisa delayed the start of the building phase of the model, also limiting the usage of machinery to small hand-tools.

Moreover, the university had no availability for a heated chamber, so Epoxy Resin with a room temperature cure has to be chosen, thus lengthen the production times.

To realize the molds where to laminate the composites fabrics, at first instance, 3D printed parts with polylactic acid (PLA) filament were produced in collaboration with an external company. Even if they offered a good resistance under pressure and good surface finishing, due to the high porosity of the material, the skin tended to remain attached to the mold surface.

The 3D print solution was really effective, but the high costs and long production time led the choice of the molds to a different technology, the realization of molds from XPS sheets, which resulted in problems of separation of the final product from the mold and poor surface finishing.

This was avoided using a Mylar® release film sheet to cover the mold surface, applying a certain pressure in order to eliminate air bubble between the sheet and the moulds that would deform the final product shape.

Many parts has to be produced multiple times since the fiber ply not always adhered with the core, and often the Airex® plies shifted their position during the vacuum thus creating a false shape, in particular for the fuselage complex geometries.

Finally, the laminated external products final cuts were performed by hand, thus not ensuring the perfect designed dimensions and/or alignment with other parts; so many hours has been spent during the assembly of the model to finishing the various surfaces and joints which resulted in the delay of the scheduled flight tests.

Another obstacle was represented by the manufacture of the rear part of the fuselage. In fact, it has a complex geometry with a sharp change in diameter, thus a different solution has to be chosen in order to realize the component without shape irregularities. Without using the sandwich design, 3 plies of glass fiber (90°, 45°, 90°) were laminated into the molds interspersed with carbon fiber stripes to reinforce the geometry and increase the stiffness.

The presence of multiple parts presented an interesting educational challenge that arises from the need to design many joints. During the weekly meetings, team members proposed their ideas for those structures through brainstorming, allowing to cultivate problem-solving skills.

For each solution, advantages and disadvantages were discussed and analysed, but due to the inexperience in aeromodelling production, existing joints solutions were later taken into account and compared with the initial ideas. In this way, the team learned the importance of continuous consultation with the manufacture department to verify the feasibility of each solution.

Due to higher loads, the wing-fuselage joint was the most difficult one to design. The fuselage features an integral protrusion, shaped like the wing profile, to which the wing can be attached. The protrusion is internally reinforced with two ribs transferring loads to two frames through some slots. Initially, those slots were designed in the lower part of the ribs, but it was later noted that the lift would tend to pull up the ribs and separate them from the underlying frames. Hence, the slots were finally made in the upper part of ribs.

The payload structure came through an iterative design process. The first structure consisted of three 3D printed plates with holes, to accommodate the balls on two different layers, but practical experiments revealed that this solution lacked the required stiffness. The final structure was redesigned to include multiple hemispherical surfaces, ensuring a generous contact area with the payload, thus

a safer immobilization. In addition, the diaphragms avoid contacts between the balls, in accordance with the regulations.

3.3 Results

The final results of the design and manufacturing processes are condensed in the final assembly, shown in **Figure 9a**, taken from the conference held by some team members at the high school ITIS G. Galilei in Arezzo (IT), **Figure 9b**.



(a) Complete assembly of the drone during a conference at high school Galileo Galilei.



(b) Prof. Luca Decembri, Dean of ITIS G. Galilei, introduces the seminar by the LeanIng Project team.

Figure 9 – June 8, 2024 - Arezzo, Italy: Seminar by the LeanIng Project team at high school ITIS Galileo Galilei of Arezzo.

The main features are the following:

- wingspan = 2.84 m
- wing plan surface = 0.65 m^2
- wing airfoil E392

- tail airfoil S9032
- wing divided in 4 segments
- fuselage divided in 2 segments
- total length = 1.53 m
- transportation box dimensions = 0.86x0.275x0.265 m
- MTOW = 57 N

The drone has been designed to bring 11 billiard balls, 175 g each, for a total of 1925 g of payload. The external structure of wings, tail and fuselage is composed of a $90 \frac{\text{g}}{\text{m}^2}$ glass fiber single ply - 1.2 mm PVC foam sandwich. The internal components, such as spar and ribs, are made of a $160 \frac{\text{g}}{\text{m}^2}$ plain weave carbon fiber - 3mm and 6mm PVC foam sandwich. The different parts of the wings are joint together and with the fuselage using 1.5 mm thick carbon fiber tubes of different diameters. M3 bolts are used to fix in the correct position the various wing segments and a pin is used as a redundancy. The landing gear is designed with a tricycle configuration.

The propeller chosen is an APC 14x7E, while the batteries capacity are: 2700 mAh for the main, 1000 mAh for the secondary.

The final dry weight of the aircraft is about 3.7 kg, thus making the maximum payload fraction more than 0.5.

4. Formation and Training

4.1 Manufacturing techniques learning

During the manufacturing phase of the project, the students got the chance to put into practice all the knowledge about composite materials and manufacturing techniques acquired during the academic years, and for the first time to actually craft and build the results of a projected design.

Since the team didn't have any direct experience in this field, some meetings and workshop with a aircraft modelling shop owners were organised, one of whom is also our pilot, that guided the students during the critical phases of the construction. In particular, the various process of the wet-lay-up lamination using vacuum bag techniques were deeply analysed and acquired.

Because of the many challenges faced during the crafting of the model and for the "hand process" techniques, many ongoing adjustments has to be made thus developing fast thinking skills in the students that had to find feasible solutions on the spot, often different from the designed ones in order to guarantee compatibility between the parts and structures of the model.

Moreover, the team developed the capability of understanding of how to improve and reinforce critical areas of the structures starting from the structural analysis, thus enhancing the ability to translate concept ideas into realistic solutions in order to better understand and visualize structural designs.

4.2 CFD workshops

During the final phase of the aerodynamic project, CFD was used on a large scale. The prerequisite skills to start using the programmes of interest were acquired through a four-day course held by our partner Cubit Innovation Labs (**Figure 10**). Initially, the methodology for approaching a CFD project was presented. Particular emphasis was placed on the importance of the sensitivity analysis phase of the calculation grid and the choice of the optimal solver for our case, in relation to the available computational resources and the current design phase. Subsequently, exercises took place with practical aeronautical examples of interest to us, in which we were confronted with problems relating to the use of the software itself. In the final part of the course, theoretical topics such as the analysis of complex models (DES) and optimisation were covered in depth.

This course was therefore a starting point for the continuation of the subsequent analyses, during which there was always the opportunity for discussion and advice with the course trainers. In addition to this, practical tips were learnt, such as preparing the geometry for a CFD simulation, analysing a 2D profile at low Reynolds numbers, using symmetries and managing grid parameters to reduce the computational costs of the problem without precluding the goodness of the result.

The main difficulties encountered were initially related to the different approach of CFD compared to Zero Levels Methods and the search for a good compromise between the result and the computational costs.



Figure 10 – CFD course at Cubit Innovation Labs, Cascina (PI), Italy.

4.3 Powertrain test-bench production

Initially, a study was conducted to determine which sensors could be used to acquire the data that needed validation. It was decided to use the same telemetry imposed by regulation to measure the engine-battery system parameters and a dynamometer to measure thrust. Using the manuals it was understood how the sensors worked and how to integrate them. A remote control was employed to provide inputs to the system, transmitting commands via the receiver. The structure was designed, and the market cost of the necessary materials was assessed. The test bench, shown in **Figure 11**,

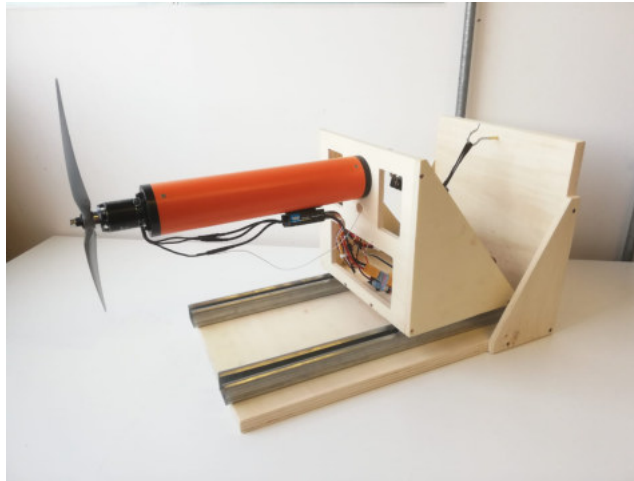


Figure 11 – Powertrain test-bench final assembly.

was then made by the team members by cutting plywood panels into simple geometries and joined using special screws. The carriage and support were made first. On the carriage, wheels were mounted using self-locking bolts and nuts; on the support, rails were attached using screws. Having verified that the assembly met the requirements, the motor spacer and the hooks for the dynamometer were mounted; the former is made from a PVC pipe and wooden blocks, the latter were bought. Using Velcro tape, the electronic components were attached and connected, and then a test was conducted to verify their operation. Once the assembly was completed, the bench was transported to conduct the test campaign. This experience provided insight into the difference between the design phase

and the implementation phase, in which design errors emerge if the difficulties of the technologies that have been envisioned are not known. Moreover, delays were encountered in the construction due to staggered delivery times of the materials, resulting in a postponed test campaign. Once the test bench was completed, the test campaign started. The Electronic and Propulsion department organized the tests over several days to obtain measurements that best represented the operating conditions of the aircraft model.

Using the data taken from the tests, some design parameters were reconsidered, leading to the final specifications. This experience highlighted the importance of considering available technologies in production, designing machinery within a defined budget, and addressing logistics and data validation issues. Knowledge of programs such as SOLIDWORKS® and MATLAB® was further deepened. How to use much of the tools in this field and how to use them safely was learned, gaining greater awareness of the processes involved in manufacturing. The discussion, coordination, and trust among team members played a crucial role in overcoming the aforementioned challenges.

4.4 Composites material FEM analyses

The main purpose of the FE structural analysis was to qualitatively detect potential critical areas and compare different structural solutions. Despite having studied the basics of Ansys® in university lectures ([13], [14]), modelling sandwich composite material required the use of ACP module [15], which has been initially approached through self-learning, by reading and watching tutorials. This has proven to be quite challenging, as well as finding the correct engineering properties, having to consider the inevitable inaccuracies of manufacturing techniques. In addition to using high safety factors, the analysis results were checked with the help of Professors to exclude gross mistakes. Combining self-learning with expert feedback was essential, as the first results were quite inaccurate, although the main ACP functions were successfully learned.

The collaboration with the CFD Team was crucial for obtaining realistic aerodynamic loads. A MATLAB® code was developed by the structure subunit to calculate the pressure acting on many points located on the entire surfaces of the wing and the tail. Those points were chosen either as the nodes of the mesh used in Ansys® or as the nodes of a more dense mesh created separately on SOLIDWORKS®. This allowed to obtain the exact coordinates of the points to which the loads had to be applied, **Figure 12**.

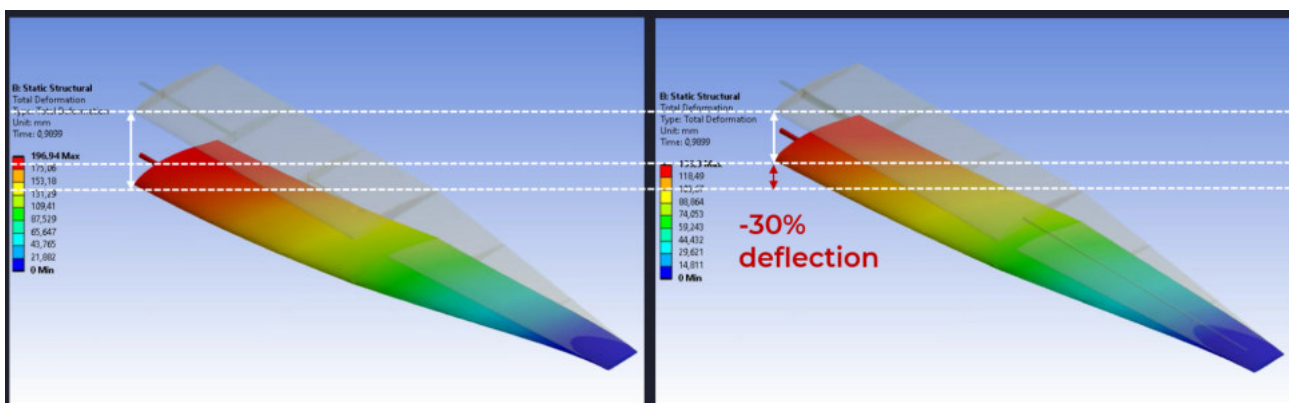


Figure 12 – Comparison: deflection of the Initial Structure VS deflection of the structure with added reinforcements.

4.5 Business relations

The first step in order to set up a system to contact as many as possible companies and to rapidly manage their answers, was to create a list of companies with their respective contacts. This activity allowed for improved use of spreadsheets, maintaining order and precision, and filtering information rationally. Already known companies served as a starting list for the Business Relations department, which then was expanded by looking for local and non-local businesses. Contacting some companies

was easy thanks to the clear and precise contact details provided on various websites, while with others it was more complicated to identify the right contact person. Among the companies contacted, few responded to the emails, and it often took a long time to get a response. On the other hand, phone contact proved to be more effective, allowing for direct and immediate dialogue, as well as online and in person presentation, although it was often more difficult to contact companies in the latter ways. Since it was necessary to reach out to many companies, it was crucial to understand how to approach them, which linguistic register to use, what to say and what to avoid, and how to promote the project without straying from reality. This experience taught to the team members the importance of managing expectations and not taking rejections personally. The main lesson learned was the importance of not giving up and continuing to persevere, constantly seeking for new contacts and collaboration opportunities despite the negative responses.

5. Conclusions

The paper describes in some detail the activities carried out by a group of students from the aerospace engineering course at the University of Pisa for the conception, design and implementation of a radio-controlled aircraft for the participation in the international Air Cargo Challenge 2024 competition. The student team is called LeanIng Project, and it is composed of 27 students (**Figure 13**). The aircraft will have to fly in compliance with a predetermined regulation dictated by the event organization and will carry a payload having a mass of about 2 kg. The overall mass of the aircraft turns out to be about 6 kg. The wingspan of the configuration is about 2.8 m with a aspect ratio of about 12.4. The initial stages of the work involved the student group in organizing the team and submitting a proposal for an educational project funded by the University of Pisa. The team was organized into working subgroups: CAD modelling, aerodynamics, structures, flight mechanics, electronics and propulsion, manufacturing, business relations and social media. For each subgroup, a leader was identified who managed the exchange of information among team members during the course of activities. Overall supervision was overseen by a single student in charge and representative of LeanIng Project. The main aspects of the study phases involved the aerodynamic design of the aircraft and the design of the supporting structures integrated with the propulsion system. Aerodynamic design was initially performed using traditional methods taken from the relevant literature, and CFD numerical analyses were performed as a second step. A similar procedure was followed for structural design. In the refinement stage, computational techniques based on the finite element method were used. For the fabrication of the fuselage, wings, and tail surfaces, the team decided to use composite materials. For this purpose, small equipment and basic materials were acquired for the production of these components. Mold design and lamination of structural components were carried out entirely by the team's students. At the same time, the all-electric propulsion system was studied and tested on a small testbench, and the aircraft's control electronics were acquired and integrated. The tests made it possible to define the required performance during competition flight and optimize the choice of battery system and propeller. The flight mechanics subgroup defined the aeromechanical characteristics of the aircraft and provided practical guidance on the drone's centering, stability, and maneuverability characteristics. The team's activities conducted mainly within the Department of Civil and Industrial Engineering at the University of Pisa, supervised by a number of faculty members in the department, took place over a period of more than a year. The initiative was widely publicized by both organizing seminars and disseminating information on social channels. The organization of the team and the planning of the work were conducted in the first person by the students, who demonstrated remarkable organizational and operational skills. The initiative as a whole, although particularly challenging, proved to be highly impactful from the point of view of the training and growth of the students involved and made it possible to implement a form of integrated and applied teaching that proves to be of strong interest to young engineering students.

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Figure 13 – 2024 LeanIng Project team picture in Piazza dei Miracoli, Pisa. [16]

- Aitronik Srl®
- ITALPROGETTI Spa©
- PermTech Srl
- AvMap Srl©
- BDF Electrical Systems Srl©
- Metis 3DLab srls
- Centro Stampa Faccini©
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