# Multidisciplinary Design Labs: experiences at DIA-PoliMI

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## Abstract

The paper, after introducing an overview of Aerospace Engineering courses organization, describes the Design-Lab teaching activity offered to the third year undergraduate students and reports a critical analysis of six years of activity, that involved till now 478 students. During the presentation will be illustrated the encountered difficulties, in particular related to the large number of participating students, and on the other hand the positive feedbacks received from the students. Two examples of Design-Lab will be reported and finally an overview of future implementation of these multidisciplinary activities into the reshaped Aerospace Engineering course organization, for a better CDIO implementation purpose, will be provided.

## 1. Introduction

The recent project to reform the Italian University system has introduced some important innovations in the organization of the academic curricula, to comply with the decisions taken by EU Ministers in Bologna in 1998. This project is based on two main aspects: the introduction of Credit Transfer System and the so called 3+2 year structure system.

The European credit transfer system has been introduced to provide a measure of the workload of each course in terms of teaching hours and of the effort that is required for students to pass the examination. The latter includes class attendance, class work, laboratory work and individual study. One credit corresponds to a workload of about 25 hours and the yearly workload for an average study course corresponds to about 60 credits.

The 3+2 system is the new teaching organisation in which the old five-years degree is split into a bachelor and a master degree. The Bachelor of Science (B.Sc.) is an undergraduate degree obtained after a three-year course of study and it is aimed at providing a strong foundation in the core scientific subjects as well as more specialized, professional training. During the third year, the student has to choose between two predefined path: the first one is devoted to students that want to enter directly the job market after the bachelor, the second one is for students that are willing to obtain a master degree. The Master of Science (M.Sc.) is awarded after two more years of study and provides a rigorous advanced training in more highly specialized areas. Those who already have a B.Sc. in a different field or have attended a vocational school and want to obtain a M.Sc. certificate must first obtain the necessary credits. A sketch of the Aerospace Courses is reported in Figure 1.

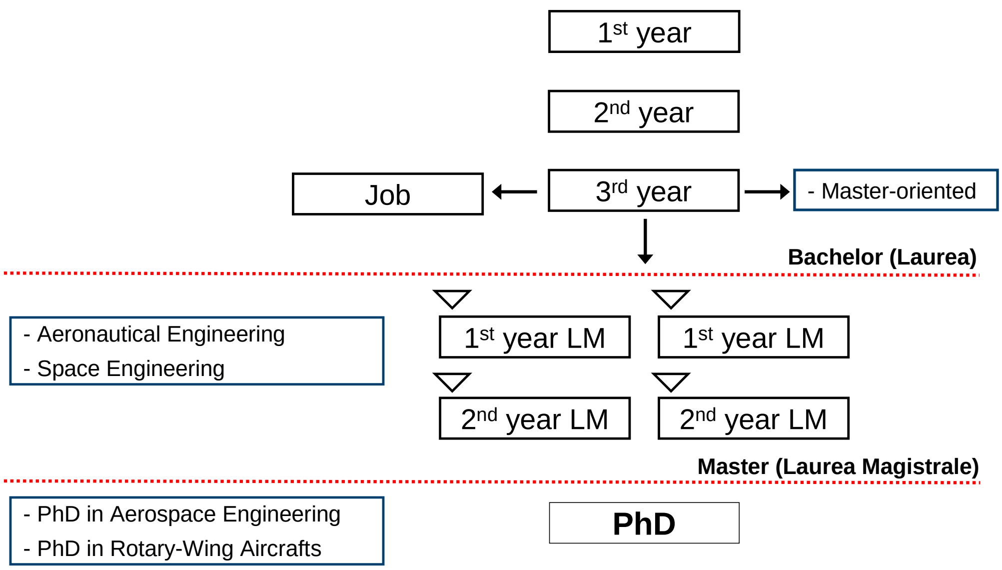


Figure 1: The Aerospace Engineering course organization at Politecnico di Milano.

The Bachelor degree in Aerospace Engineering is awarded to students obtaining at least 180 credits in fundamentals sciences, e.g. mathematics, physics, information technology, in industrial engineering courses and in sector specific studies, such as flight mechanics, fundamentals of aerospace engineering, aerospace systems and alike. A budget of credits is allocated for other activities, including design laboratories, stages, final examination.

Two different Master courses are available: the Master in Aeronautical Engineering and the Master in Space Engineering, that have been designed with the following long term objective. The qualification of people mastered in Aeronautics Engineering allows students to fill job positions characterised by full autonomy and responsibility in space and aircraft industries, public and private companies specialised in aerospace design, production and testing, airlines, air traffic management authorities, military air forces, aeronautics department of other armies and companies for the design and production of devices for which aerodynamics and lightweight structures are relevant design topics. Qualification in diverse subjects allows students to be hired not only in aeronautical companies but also where advanced methods and technologies are applied. The Master in Space Engineering provides the skills needed to fully develop the activities related to the design, analysis and verification of space missions. In this field peculiar profiles have been evidenced: mission analysis, thermo-structural design of space systems, design of propulsive and power subsystems, attitude and orbital control, communication and operation with ground stations, integration of space systems and after-launch operations.
Both degrees are awarded on the basis of 120 credits. The teaching activities are related to: courses mainly focused on the completion of the aeronautic and space scientific knowledge, aerodynamics, flight mechanics, systems, structures and numerical methods, space systems design, space propulsion. A final graduation project, requiring theoretical, numerical or experimental activities, is reported in the Master thesis and defended in front of a committee of eleven professors.

During the redesign of the aerospace engineering curriculum carried out six years ago, a multidisciplinary activity, called Design-Lab, has been introduced for group of students during the third year of Bachelor studies. This activity, quite new in the framework of aerospace engineering curricula, was introduced with the following aims:

- Introduce multidisciplinary engineering aspects and combining them with the fundamentals
- Give the students the chance to cover a complete design cycle of an aerospace or non aerospace product, from initial design to manufacturing
- Introduce Team Working experience in the student curricula

It must be emphasized that although the Department of Aerospace Engineering was not part of the CDIO organization when Design Lab were introduced (2002), their inspiration principles and implementation fit the CDIO Syllabus.

Involving groups of five to twenty students, Design-Labs have represented a real test-bed for new ways of teaching. Some examples of already completed design-labs are: a sailing boat for a national student competition, the Formula Student racing car, a multi-role electric-powered UAV, micro UAVs and space robots. Two kind of Design-Labs projects have been organized during last six years: short Design-Labs, that had to be concluded within one semester, and long Design-Labs, complex projects spanning over few years and involving diverse groups. Figures 2 and 3 show the number of Design-Labs offered during last six academic years and the total number of students involved, respectively.

Recently, the need to improve the new teaching organization designed six years ago has been clearly recognized by the Italian academic community. In the new teaching system, shorter courses were introduced to broaden the students expertise at both bachelor and master level, resulting however in a large increase in the overall number of classes to be taken. In this respect, the University Ministry has published an emendement, called DM270, which limits the maximum number of exams required for bachelor and master degrees to 20 and 12, respectively. To implement this new rule, the Faculty of Aerospace Engineering has updated the original course organization. In reshaping the Aerospace curriculum, three main goals have been considered as follows

- to increase the content of science and engineering fundamentals
- to obtain a more realistic distribution of courses in terms of number and collocation during the career

- to allow for students to choose elective courses to tune their curricula

The update of the aerospace courses organization, that will become effective starting from September 2008, represents a chance for the implementation of new teaching frameworks in response to the CDIO recommendations.

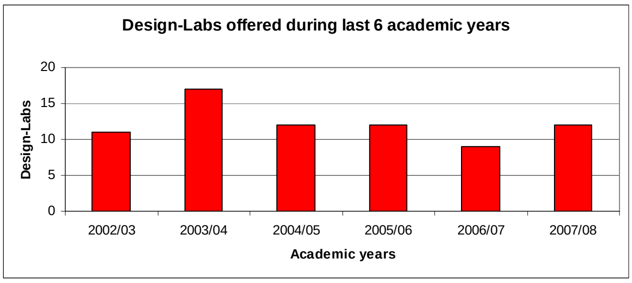


Fig. 2: Number of Design-Labs offered during last six academic years.

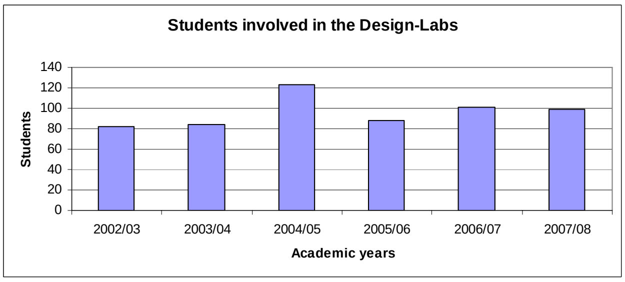


Fig. 3: Students involved in the Design-Labs during the last six academic years.

The present paper reports on the activities carried out during the last six years within the Design-Labs, multidisciplinary final year projects for Bachelor students. The experience gained during these six years is used to design the new Aerospace Engineering Curricula, with new classes starting from October 2008, within the requirements of the CDIO.

## 2. Design-Lab structure

To comply with the main requirements previously reported, each Design-Lab moves from a so-called Design Proposal, which is formulated by the teaching staff of the Aerospace department. Each Design Proposal is then made available to students by means of a Call of Interest. A list of Proposals is prepared by the staff of the Aerospace Engineering Department and submitted to the attention of students before the last semester. Each proposal is described in detail to allow the student to choice and includes: a description of the general frame, a preliminary breakdown of the activities flow into work packages (WP), an estimation of the resources needed during each WP, the competences required (also with respect to the syllabus of some courses) and skills to be acquired during the project.
Each Design Proposal is based on two kind of input: the Design Requirements and the Work Structure. In particular, the introduction of a Work Structure allows to:

- split the project into small Work Packages (WPs);
- define the Core Engineering Fundamental Knowledge requested by each WP;
- define the priority level of each WP.

Each Design Proposal can be offered to the students, even not strictly related to the aerospace field, with the only constraint that it must have a multidisciplinary content. Some of the proposals are restricted to a specific area, so they are representative of a specific engineering activity for a work group: in this case students simply have to understand and perform the required tasks and the project presents no uncertainties.
Other activities strictly interpret the true sense of this exercise pushing the students to approach the different faces of a design: problem analysis, conception, design, documentation, manufacturing and testing. In some cases the job cannot be concluded within the time frame available; a kind of relay is envisaged between students of different years, so that the subject of the Design-Lab. exercise is the witness transmitted from one year to the next in terms of documentation, results and, maybe, physical objects.
Students assigned to a task, supervised by a professor and assisted by a tutor, are requested to detail the activities with reference to the specific goal, to evaluate the consistency between the proposed activity plan and the task goals, to identify the technological keys, to allocate the resources and work time in order to achieve the goal. In this way also the fundamentals of team-work management are acquired. Obviously this kind of proposal requires much more effort to staff in terms of both planning and supporting students in their job. A financial support is also required to supply the hardware and consumables needed for the manufacturing.

As an example, Tables 1 and 2 report the Design Requirements and a summary of the Work Structure (showing four WPs out of a total of nine), respectively. These Figures refer to the Design-Lab offered for the first time during 2002/03 academic year having as objective the design of a multi-role electrical powered UAV.

| **DESIGN REQUIREMENTS** | |
|---|---|
| **Main target** | **Design and manufacturing of a multi-role UAV** |
| **Payload** | ≥ 1.5 *Kg* |
| **Typical payload configuration** | Data logger, telemetry device, camera, GPS navigation system |
| **Propulsion system** | Electric, ducted fan |
| **Stall speed** | ≤ 10 *m/s* |
| **Max load factor** | ± 4 *g* |
| **Endurance** | ≥ 1 hr |
| **Other characteristics** | • RPV and UAV control configuration<br>• Take-off by means of hand launch<br>• Safety parachute |

Table 1: Design requirements table for the multi-role UAV Design-Lab.

| **WORK STRUCTURE** | |
|---|---|
| ***WP N. 1*** | |
| ***Fundamental knowledge*** | Aircraft Conceptual Design |
| ***Description*** | Definition of best UAV configuration in terms of dimensions, wing and tailplane configuration, propulsion system |
| ***Priority (high, medium, low)*** | High |
| ***Number of students*** | 2 |
| ***Minimum target*** | Complete aircraft configuration definition |
| ***WP N. 2*** | |
| ***Fundamental knowledge*** | Aerodynamics, flight mechanics |
| ***Description*** | Wing airfoil choice and main aerodynamic indices calculation |
| ***Priority (high, medium, low)*** | High |
| ***Number of students*** | 2 |
| ***Minimum target*** | Definition of the aerodynamic configurations that satisfy design requirements |
| ***WP N. 3*** | |
| ***Fundamental knowledge*** | Aerospace Structures and Technologies |
| ***Description*** | Analysis of possible fuselage structural configurations and choice of best manufacturing technologies |
| ***Priority (high, medium, low)*** | High |
| ***Number of students*** | 2 |
| ***Minimum target*** | Fuselage structure configuration definition |
| ***WP N. 4*** | |
| ***Fundamental knowledge*** | Aerospace Propulsion, Fluidynamics |
| ***Description*** | Choice of propulsion system, choice of fan configuration and definition of air intake geometry |
| ***Priority (high, medium, low)*** | High |
| ***Number of students*** | 2 |
| ***Minimum target*** | Propulsion configuration frozen |

Table 2: Work Structure for the multi-role UAV Design-Lab.

## 3. Targeted students and available resources

The Design-Labs were offered to groups of five to a maximum of twenty students, divided into small teams of two students each. Because most of the activities are to be carried out in the laboratories, such a small number of students is recommended. The target students were 3rd year undergraduate Aerospace Engineering

students who already have basic knowledge of mechanics, engineering, mathematics, design and fundamentals of aerospace engineering.
All the experimental activities related to the Design-Labs are carried out into the laboratories available at Campus La Masa in Milano, where the Aerospace Engineering Department is located. World-class experimental facilities are available for teaching and research activities, allowing for structural testing, including modal analysis, fatigue and crash testing, aerodynamic testing and manufacturing of full scale components. Among the others, three are the more frequently used laboratories during the Design-Labs activities, i.e. the Aerodynamic, the Structural Testing and the Composite Materials laboratories, see Figure 4. In particular, these laboratories offer the following facilities

- Aerodynamic lab: close circuit low speed wind tunnel, 1x1.5m test section, 55 m/s max. speed;
- Structural Testing lab: different kind of testing machines for material characterization;
- Composite Materials lab: autoclave, clean room 4x3m, hot plane press, oven, foam cutting machine.

Figure 4: Low speed wind tunnel, MTS mechanical testing machine and autoclave.

## 4. Example 1: CVV (Centro Volo a Vela) Design Lab Experience

The CVV Project (in Italian *glider flight center*) has been offered as a Design-Lab starting from the 2003/04 academic year, with an ambitious project goal: the design of a side-by-side two seats glider to be developed in the frame of ultra-light regulations. The glider is intended for advanced training: thanks to the side-by-side position the interaction between instructor and the pilot is greatly increased.

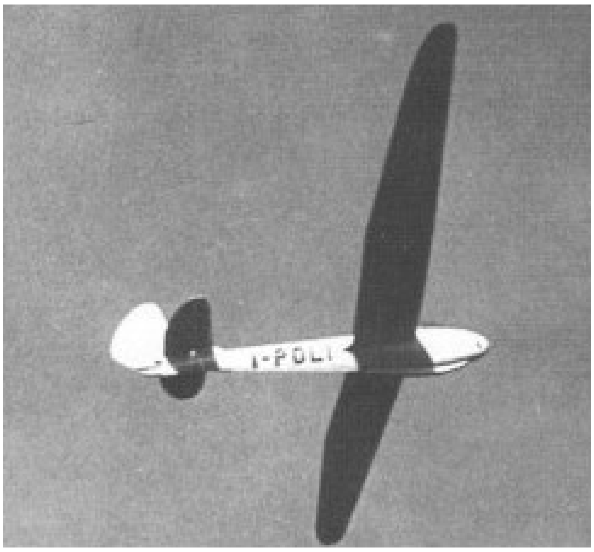


Fig.5: *Pinguino*, the first glider designed by Politecnico.

The acronym CVV recall the original *Center for Studies and Experiments with Gliders* created in the '30s as an initiative of a group of students of Politecnico di Milano, and particularly of Liberato De Amicis. This Center designed a number of advanced-concept gliders. Figure 5 shows the historical *Pinguino*, marked I-POLI, the first glider designed by Politecnico di Milano's Center. The Design Requirements table for the CVV Project is reported in Table 3. Being the resources and the time available within a single Design-Lab clearly insufficient to complete the whole project, the CVV Project has been split into smaller labs and it has been under way since 2004 as a continuous work in which a new group of students is involved each year. The new group gather information and experiences from the previous one and starts working on its specific subject. Table 4 shows the main geometric properties of the glider as obtained during the design and optimization activities, while Figure 6 shows a pictorial view of the glider.

| **MAIN DESIGN REQUIREMENTS** | |
|---|---|
| **Main target** | **Design and manufacturing of a of a side-by-side two seats glider to be developed in the frame of ultra-light regulations** |
| **Seats** | 2 |
| **Width** | 16 m |
| **Length** | 6.6 m |
| **Height** | 1.92 m |
| **Empty weight** | 230.6 kg |
| **Max take-off weight** | 410.6 kg |
| **Wingload (max/min)** | 392/277 $N/m^2$ |

Table 3: the glider Design Requirements table.

| | |
|---|---|
| Wing weight | 121 kg |
| Fuselage weight | 100 Kg |
| Wing width | 15.56 m |
| Wing surface | 10.28 m |
| Wing aspect ratio | 23.54 |
| Averaged tapering ratio | 0.375 |
| Mean Aerodynamic Chord | 0.70 m |

Table 4: Aircraft data.

Fig.6: A pictorial view of the glider.

Table 5 shows the evolution of activities during the academic years, starting from 2004, where also the number of involved students is reported.

| Year | # of students | Activities |
|---|---|---|
| 2004 | 11 | Statistical analysis<br>Load evaluation and wing preliminary structural design<br>Cockpit design<br>Landing gear design trade-off<br>Spoiler design |
| 2005 | 5 | Preliminary design of flight commands<br>Stabilizer: Preliminary structural design |
| 2006 | 13 | Stabilizer: second iteration of structural design<br>Wing: second iteration of structural design<br>Aileron: preliminary design<br>Flap: wind tunnel model of flapped wing |
| 2007 | 12 | Integration of procedures for: weight, balance and stability analysis<br>Stabilizer: manufacturing process design<br>Landing gear: preliminary design<br>Integration of procedures for: load evaluation and preliminary sizing of structures<br>Progetto del modello per prove aerodinamiche di un aliante biposto |
| 2008 | 6 | Stabilizer: manufacturing<br>Stabilizer: Static test rig set-up<br>Design of a fuselage model for wind-tunnel testing |

Table 5: activities evolution during academic years.

During these years the permanent staff involved in the project was composed by two professors and an experienced tutor from an aircraft company; other professors have been engaged on specific problems.
The design has been developed starting from the design of an existing glider to fulfil category and specification requirements. Due to the availability of maquettes, the wing geometry has not been modified as far as airfoils and tapering are concerned, while a change in the sweep angle has been introduced to meet balance requirements; this greatly reduced the design degrees of freedom. The fuselage has been modified in the front part, to arrange two pilots, and in the rear part, to fulfil stability and trim requirements.

### 4.1 The *CVV Company*

The activities within the CVV project are managed by a *project-chief* with a wide work experience of high responsibility roles in a aircraft company. Students are organized in small units each with a specific target in the design process. Weekly meetings, with the presentations performed by each group, allow for coordination, exchange of information and for planning maintenance, so that each participant is aware of problems, progresses and results, concur to general discussion, brain storming and choices trade-off. MSc students are periodically involved when more advanced technical skills and competences are needed. These students, usually working in smaller groups, are mainly devoted to theoretical or numerical activities. Professors cooperating to the project play an intermediate role between the project leader and peer co-worker.


Fig. 7: Students at work during manufacturing of glider components.

The participation to the hand-work is strongly recommended to all participants, professor, students and tutors, see Figure 7. To make students more familiar with the glider world, the technologies and design solutions, visits to a company specialised in small aircraft and glider maintenance and repair are carried out periodically; flight experiences have also carried out (Figure 8).


Fig.8: visits to a company specialised in small aircraft and glider maintenance.

“Old style” activities are sometimes envisaged to allow a deeper insight of the problems, e.g the manufacturing of a fuselage mock-up suitable for ergonomic evaluations, as shown in Figure 9.

Fig. 9: Ergonomic studies of the two seats cabin.

## 4.2 The stabilizer

The design of the stabilizer, started two years ago with a preliminary design, has been concluded in the summer of 2008 with the manufacturing of the prototype shown in Figures 10 and 11. The prototype has been statically tested by the students. During the development of the design the participants used both computer code developed on purpose, mainly for the structural design, while commercial codes have been used for more general activities, e.g. CATIA for drawing and 3D assemblies.
The mold of the stabilizer skins have been manufactured using a CNC equipment, while the composite layers have been cut and layered by students by hand; skins have been placed in a vacuum bag and the cure has been carried out in a oven. Molds for ribs and spars have been manufactured by profiling wood blocks. Also in this case structural elements have been layered by hand; the cure has been carried out in an autoclave. The design choices and practical problems encountered during the work have been largely discussed within the design group.

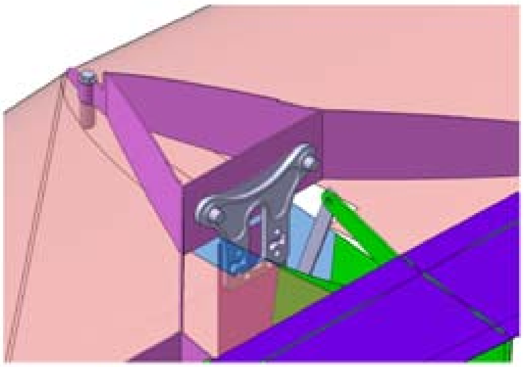

Fig. 10: CATIA solid model of the vertical/horizontal tail connection (left) and Stabilizer mould in preparation (right)

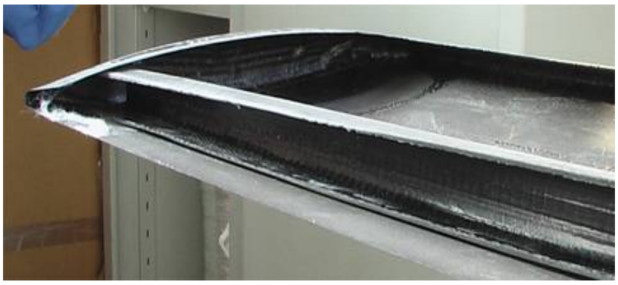

Fig. 11: Stabilizer tip detail before skin assembly (left) and a participant with his “creature” (right)

### 4.3 The fuselage wind tunnel model

To evaluate the effects of the wing-fuselage intersection on the aerodynamic performances a wind-tunnel model has been designed. A 2 students group has been assigned to this task. They used CATIA for modelling the geometry. According to the suggestions they received by aerodynamicist from the Aerospace Engineering Department, the students decided to manufacture the internal structure, see Figure 12, mainly with numerically controlled machinery; the outer skin is to be manufactured using a rapid prototyping system. After a trade off study, the students decided for the structure depicted in the following picture, where it is evident the box conceived to host a six components load cell. The skin is made in pieces so that the external shape can be slightly modified according to wind tunnel test results.

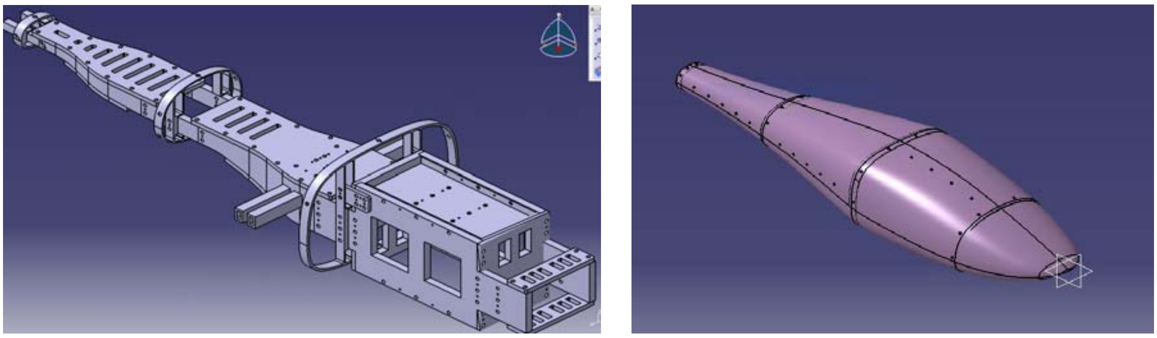

Fig. 12: Fuselage wind tunnel model

## 5. EXAMPLE 2: *Mille e una vela* Design Lab

The aim of the project *Mille e una vela per l'Università* (in english *1000 sails for the University*) is to design and build a sailing boat and have students compete against teams from Italian and foreign Universities. This activity has been promoted by Università degli Studi Roma Tre. The sailing boat has to be made of wood (at least 70%), to exploit the hand craft capabilities of the students with the support of university laboratories, to promote the adoption of non polluting materials, and to limit the economical costs.
This Design-Lab was offered to the third year undergraduate students for the first time during the 2006/07 academic year, based on the design requirements listed in Table 6:

| **MAIN DESIGN REQUIREMENTS** | |
|---|---|
| **Main target** | **Design and manufacturing of a sailing boat able to fulfill the characteristics defined by the '1000 e una vela' competition rules** |
| **Maximum length** | 4.60 m |
| **Maximum width** | 2.1 m |
| **Must height** | 7.3 m |
| **Maximum immersion of the hull** | 1.1 m |
| **Minimum weight** | 80 kg |
| **Area of sails (main sails and jib)** | 33 $m^2$ |
| **Gennaker** | 17 $m^2$ |

Table 6: The sail boat Design Requirements table.

During 2007, two boats have been built at Politecnico di Milano following one and the same original design made by a student of the Design Faculty. The original sketch of the sailing boat is shown in Figure 13. One of the boat (named *Techné*) has been built at the *Laboratorio Allestimenti* from the Design Faculty. The second one (named *Polis*) has been realized by students enrolled in the Aerospace Engineering course of the Industrial Engineering Faculty. Intermediate phases of the manufacturing process are shown in Figure 14.

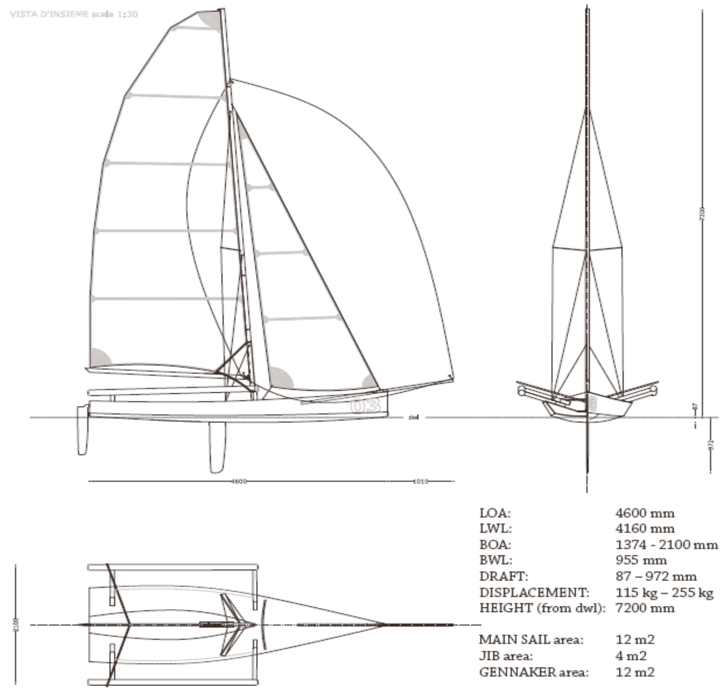


Fig. 13: The original sketch of sail boat.

Fig. 14: Manufacturing of the sail boat.

The students involved in the construction of the boat have also been in charge of some verification and optimization. Structural analyses have been performed in order to identify and verify the most critical parts of the structures (Figure 15). The drift and the sails have been designed, choosing the most performing profiles and shapes, which have been validated using a sail performance evaluation software (Figure 16). Moreover, a VPP (Velocity Prediction Program) has been written to predict the behaviour of the boat in different wind conditions given some parameters (Figure 17). Tests have been performed in order to validate the codes and to compare the performances of the two boats equipped with different drifts.

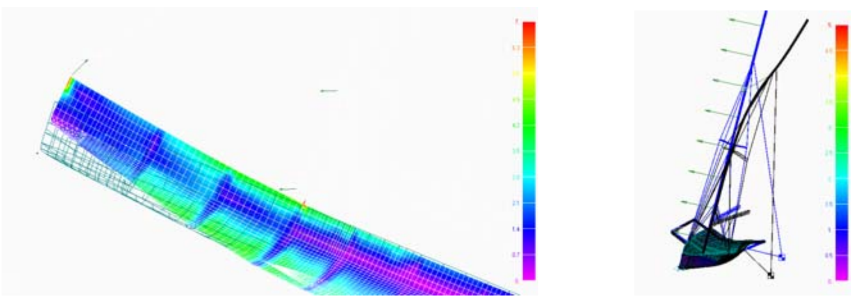

Fig. 15: Structural analysis results.

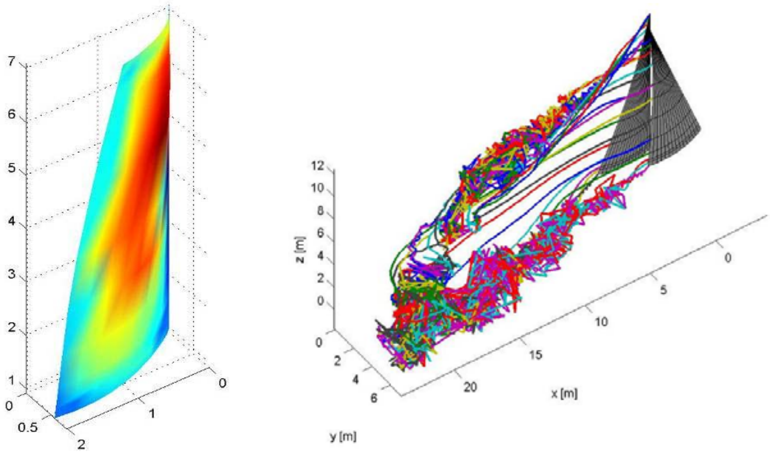


Fig. 16: Numerical simulation of sails behavior.

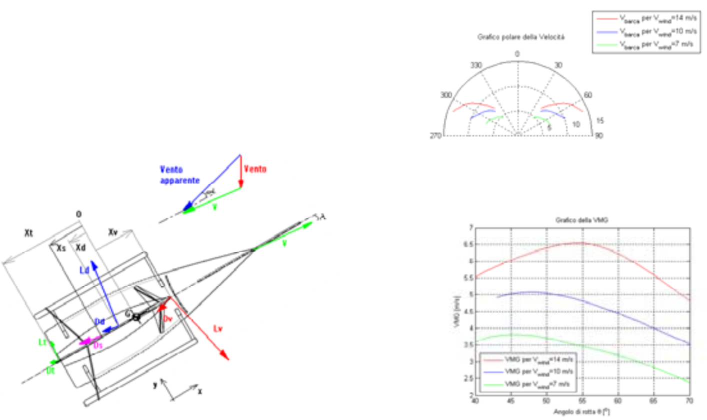


Fig.17: The Velocity Prediction Program output.


Fig.18: The preliminary test campaign of *Polis* sailing boat.

Fig.19: Pictures taken during the final competition and the trophy won by the Department of Aerospace Engineering.

Boat races took place in Porto Santo Stefano (GR) on September 23-25, 2007. The Universities that took part in the event were: Alma Mater Studiorum (Bologna), Università degli Studi (Firenze) with two boats, Università degli Studi di Roma Tre (Roma) with two boats. The boat of Dipartimento di Ingegneria Aerospaziale of Politecnico di Milano won the trophy, second place for the other boat of Politecnico di Milano (Figure 19).
Works and improvements on the boats are continuing and, this year (2008), the races will take place in the beginning of October. More universities will participate and we hope to be able to achieve the same outstanding results of last year.

## 6. Discussion and conclusions

From our experience within the Design-Lab activities and from the feedback obtained by the students involved in these activities, the following positive conclusions can be drawn:

- Engineering challenge for students: in most cases the proposed activities force students to find the method to smartly apply their own knowledge to a new problem
- Enrolment into an object oriented activity: the student attention is focused on a specific engineering goal, while the academic approach is often devoted to the acquisition of a technical knowledge with no reference to a specific problem
- Attention focusing on aspects often neglected in the academic approach: the needs for the conclusion of the design cycle, i.e. the manufacturing of pieces of hardware, change the students perspective in approaching the problem

On the other side, many critical aspects have been singled out. These include:

- The effort required to maintain a list of high level proposals: the project is addressed to more than one hundred students each year; so 10-12 projects have to be defined each year with unavoidable scattering in terms of formative contents, even with always high technical contents.
- Commitment required to students: often the effort required to students, specially due to a limited experience in practical activities, is high; even if the student approach is absolutely enthusiastic the time needed to conclude the project can exceed the allocated time slot,
- Resources in terms of tutoring and supervising: the surveillance and the tutoring of such a large number of students require a large and well prepared staff. The tutors are to be available for approximately six months but for few hours each week. The participation of non academic tutors, whose collaboration is highly recommended to introduce an industrial point of view to complement the academic one, can be difficult because of such a time scheduling. As discussed in the CVV section, the contribution of non academic tutors is therefore targeted to the overall organization of the work team, with academic staff being devoted to the supervision of specific activities.
- Financial support towards expenditures: the most successful projects require the purchase of material components and equipments with relevant costs. For the time being, no financial support is available from institutions other than the Department itself.

According to these remarks and to the considerations previously presented in the paper we decided to reduce the list of Design Laboratory Exercises proposals to the most representative ones from the engineering point of view and to enroll students on the basis of a voluntary participation. The acquisition of engineering skills, e.g. team-working, reporting and technical writing, oral presentation capabilities, problem solution oriented mentality, will be pursued by a set of small didactic units spread in many elective courses, so that these skills will be part of the engineering heritage of most Aerospace Engineering students.

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