Award-Winning Innovative Aircraft Design Projects at Politecnico di Milano

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ABSTRACT

In the "Aircraft Design" course at Politecnico di Milano, M.Sc. Aeronautical Engineering, students are called to team up and carry out a complete conceptual and preliminary design for a new aerial vehicle. Often, during this process, bright, innovative ideas emerge in an effort to improve on preceding realizations and find new, more sustainable solutions. Some of these projects have been submitted to various international design competitions. Four highly successful projects, namely Flybrid, a hybrid-electric regional liner, finalist in Fly Your Ideas 2013; Nibbio, a dual-propulsion morphing tilt-rotor, second place in AHS 2014; Flynk, an all-electric air taxi, winner of AIAA 2015; and Hybris, a structural-battery enabled hybrid-electric 4-seater, winner of RAeS 2016, are illustrated, together with the main characteristics and educational outcomes of the "Aircraft Design" course.

KEYWORDS: *aircraft design, electric aircraft, morphing tilt-rotor, air-taxi, structural batteries*

1 INTRODUCTION

Among the subjects traditionally taught in the M.Sc. in Aeronautical Engineering at the Politecnico di Milano, the "Aircraft Design" course offers the students an opportunity to develop the original conceptual and preliminary design of an aircraft. Several projects among those developed in recent years have been submitted to various international design competitions, achieving a remarkable success rate. The present paper introduces four recent design proposals that earned a place in the upper three rankings of four different contests. These are project "Flybrid" (Fig. 1, left), awarded in the Airbus-sponsored Fly Your Ideas 2013 challenge; project "Nibbio" (Fig. 1, right), awarded in the AHS International Graduate Student Design Competition in 2014; project "Flynk" (Fig. 2, left), awarded in the AIAA Graduate Student Design Competition in 2015; and project "Hybris" (Fig. 2, right), awarded in the Royal Aeronautical Society General Aviation Design Challenge in 2016.
In the following, after a presentation of the "Aircraft Design" graduate course and some of its peculiar characteristics, the main features of these projects are briefly addressed. As pointed out in the discussion, the interested reader may refer to more detailed illustrations in the literature [1-5].

Figure 1: Artist's impressions of the "Flybrid" hybrid-electric regional liner (left) and the "Nibbio" morphing tilt rotor (right).

Figure 2: Artist's impressions of the "Flynk" all-electric air taxi (left) and the "Hybris" hybrid-electric 4-seater (right).

2 THE AIRCRAFT DESIGN GRADUATE COURSE

2.1 General characteristics

The "Aircraft Design" graduate course is a long-standing characteristic of the MSc educational program in Aeronautical Engineering at the Politecnico di Milano. Following a revision of the program, it was changed from a mandatory course into an elective in the year 2011 and is now typically attended by graduate students belonging to the "Flight mechanics and systems" track, one of the five recommended tracks in Aeronautical Engineering (in the Italian system, a student may also compose a personalized track himself, subjected to a mandatory approval by the school officials).

The focus of the course is the conceptual and preliminary design of manned or unmanned aircraft, mainly in the fixed-wing category. The course consists of lectures and exercises, concentrated in the first half, and design laboratories, mostly held in the second half. Between two and four seminars lectured by experts invited from the industry are held every year. They mainly come from aircraft manufacturing companies, such as Leonardo Aircraft, Piaggio Aerospace, Pipistrel, Blackshape Aircraft, and Solar Impulse. The course is not based on a specific textbook, but a range of suggested references is provided and referred to whenever appropriate [6-11].

The students are required to conceive and design an aircraft, starting from a relatively loosely defined theme bestowed by the teacher. As this leaves them a wide amount of freedom of interpretation, they first perform a thorough market study, before defining appropriate mission requirements. Design specifications are drafted on this basis and the conceptual design is approached with the preliminary sizing and the choice of the configuration, engines, and onboard systems. Subsequently, disciplinary in-depth analysis and design is carried out to complete the preliminary design of the integrated vehicle. This includes: the aerodynamic design, with special emphasis on lifting surfaces, control surfaces and high-lift devices; the structural design; the design of the propulsion system, possibly including the propeller design; the design of other on-board systems, such as landing gear, hydraulic system electric system, etc.; the weight and balance characteristics; performance and flying qualities; the definition of operational usage and possibly of ground support systems. Finally, an estimation of costs and project economics is derived. The fundamental idea is thus to learn how to perform a conceptual and preliminary design of an aircraft by actually doing it.

Therefore, while theory lectures introduce the design framework, present the methodologies and discuss typical problems, and exercises give examples of applications of the above methods, the laboratory hours are available for developing a project.

2.2 Project development

As anticipated, a fundamental requirement in the course is the development of an original conceptual and preliminary design of aircraft. This is carried out within a team of maximum eight students, with a recommended size of four to six students. This size is motivated by the experience collected in the past, as a lower number would imply too high a workload, and a higher number may end up in excessive project complexity and difficulties related to task segregation and mutual interaction. Indeed, while student teams are encouraged to form on their own initiative, trying to obtain the most favorable 'mix' of capabilities, with at least one student responsible for each discipline (aerodynamics, structures, flight mechanics, systems, propulsion, etc.), a fundamental aim of the course is to provide the opportunity for all students to be involved in all project phases and to obtain intimate knowledge of the whole work performed, instead of only one's own specific disciplinary work package. This would clearly be hindered by too large a team.

Once a team is formed, a Team Leader is designated. Teammates are encouraged to burden their Team Leader with actual coordinating tasks, not only as a point of contact or spokesperson. In fact, teams are pushed to get the best from their group activity by setting up an appropriate project management plan. This includes setting clear deadlines for the various tasks, monitoring the design process throughout its full duration, planning periodic revisions and assessing the project state in relation to what was planned, continuously identifying problems and risks, and providing appropriate solutions and mitigating actions. Often, *ad-hoc* methods are developed, to cope with specific design needs, from initial sizing to various disciplinary design optimizations.

Given the special character of the student assignments, the course teacher and assistants are continuously available for tutoring, helping in reviewing the project status and providing technical support if needed. In addition, every year, current students attend a lecture presented by a team of students of the previous year, chosen among the most successful. The past students illustrate their experience, with the aim of getting inspiration, profiting from lessons learned and other elements that can be useful to the current students' ongoing activity.

Often, among the themes available, one or more are fit for the participation in an international design competition. This opportunity is clearly declared and recommended, as normally it is not difficult to match the requirements for participation with those that apply for the course project. In all cases to date, the difference between contest and course requirements did not compel to redo parts of the work. The typical situation is that course requirements include contest ones as a subset, so that teams need to perform some work in addition to that strictly needed for contest participation.

2.3 Project evaluation

In the "Aircraft Design" course, the final evaluation consists in the project assessment and an oral examination. The project is assessed through the evaluation of a written technical report and of an oral presentation that is typically carried out in two hours (120-150 slides). All members of the team must participate actively in the project presentation. When the presentation is carried out, the oral examination is also held, by questioning the students on specific elements of their project, as well as various course topics.

The project design report is required to fully detail the work done and the tools produced by the team, using either Italian or English. The contents must include the items detailed in Table 1.

Table 1: Project design report content

Report items
1. Theme description
2. Work organization within the group
3. Analysis of the theme, market study, state of the art, certification framework
4. Emission of requirements, design specifications, mission profiles, technological and economic constraints, etc.
5. Initial sizing of weight, thrust-to-weight/power-to-weight ratio and wind loading
6. Comparative analysis of possible candidate configurations
7. Selection and motivation of a configuration
8. Design of the fuselage
9. Design of the wing (including high-lift devices), tail, control surfaces, trim, etc.
10. Selection and integration of propulsion (including propeller, if applicable) and on-board systems
11. Structural sizing
12. Analysis of weight performance, center-of-gravity travel
13. Performance analysis (including trimmed polars, flight envelope, point and integral performance)
14. Static stability and control in level and maneuvering flight
15. Dynamic stability and flying qualities
16. Cost analysis
17. Drawings (3-view, internal arrangements, etc.)
18. Conclusions, comparison of results with existing products, critical evaluation in reference to initial goals
19. Bibliography & sitography

The final evaluation criteria are: completeness, accuracy and depth of the analysis of the proposed design solutions; detail and in-depth analysis of specific critical topics; evaluation of sensitivity/robustness and criticalities of the proposed design solutions; possible use of refined analysis tools (such as in the estimation of aerodynamic characteristics); possible use of optimization techniques and parametric studies; approach to work planning and level of interaction within the group; style, completeness and clarity in the oral exposition, the written presentation, and the written report; ability to answer questions posed by the teaching staff.

2.4 Educational outcomes

In the "Aircraft Design" course, the students are involved in the whole conceptual and preliminary design process, starting from the preliminary studies that motivate the determination of mission requirements and other design specifications. A strong emphasis is given to the selection process of a design solution among multiple candidates at all levels, when a reasonable choice is required to be firmly grounded and motivated, often with respect to the results of the preliminary studies.
Of course, designing an original flying machine from scratch is an exciting experience, and is perceived by the students as one of the most fruitful activities in their last year of studies. Their work in often characterized by a very effective blend of creativity and inspiration, mixed with solid technical skills and convincing results.
The educational results of the course may be summarized as follows:

- the students apply technical competence and out-of-the-box thinking to the solution of a problem that is initially only summarily sketched, finding the related real-life implications and then determining quantitative requirements that will drive the design process;
- the students develop the notion of an aircraft as a complex system of several interacting subsystems and experience the impact of this interaction in the design process;
- the students apply in an integrated, multidisciplinary fashion a large set of notions, methods and experiences matured in previous disciplinary studies;
- the students develop important qualitative elements in learning, such as initiative and self-criticism, use of technical language and English language, written and oral communication abilities (reporting and final presentation);
- the students enjoy a long-term, intense, goal-oriented teamwork, developing abilities that have not necessarily been acquired in previous activities, such as project planning and monitoring, exploiting of diversity and effective sharing of choices, results, insight within the team.

In addition, in some cases, students are involved in the preparation of a scientific paper, as in [1-5], and in the subsequent presentation of these works at international conferences or other public events. As anticipated, in the recent past, a remarkable series of awards was bestowed to teams formed in the "Aircraft Design" course in some of the most prestigious international student design competitions. Also, a number of projects displayed a degree of maturity and timely approach to current market needs that led to the interest of several companies for possible industrial developments. Another proof of this substantial quality is the submission of a patent [12] directly issued from the latest of the award-winning projects, the Hybris.

3 PROJECT FLYBRID

3.1 The "Fly Your Ideas 2013" competition

The 2013 edition of the "Fly Your Ideas" international student competition sponsored by Airbus and supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO) was a challenge for students worldwide to develop new ideas promoting a greener aviation industry (not necessarily new aircraft designs). This was the third edition of this biennial contest from its start in 2008-2009, and the first time a student team from Politecnico di Milano was involved.
Teams were invited to participate in a three-round process. In Round 1, a concise proposal had to be submitted through an online questionnaire. After assessment by committees composed of Airbus staff and industry experts, a selection was carried out. Surviving teams competed in Round 2, where a substantial written report and a three minute-long video were submitted. Again, the material was assessed and a final selection was accomplished, ending with five finalists. These teams were

requested to give a final presentation to a jury composed of top-level Airbus staff and industry experts. The winning team and the runner-up team received substantial prize money.
The number of teams participating in Round 1 totaled 618, with over 2,500 students from 82 countries. Only 102 teams were chosen to compete in Round 2, with 32 of them from Europe. Among the five finalists, the only European team selected was Team Flybrid. Team Flybrid formed during the Academic Year 2012-2013 as one of the design groups within the Aircraft Design graduate course at Politecnico di Milano. They resolved to participate with a proposal focused on a highly innovative aircraft for future regional aviation, and its related operational strategy and infrastructure.

3.2 The Flybrid concept

The Flybrid project is essentially based on novel regional airliner concept for the 2030s scenario. The market study led to size a 90-passenger aircraft for a 700 km design mission, intended to be effective in missions with a block range between 250 and 1,000 km. These range figures emerged from the thorough analysis of the companies which operate the ATR and Q400 turboprops worldwide, considering 959 routes. In order to deliver a cost-efficient airplane with a highly reduced environmental impact, a hybrid-electric solution was investigated. In particular, given the considerable amount of batteries necessary and the drawbacks of battery in-flight recharge due to duration and low energy-efficiency, a parallel hybrid solution with pre-charged battery packs was devised.
In this parallel architecture, a turboshaft engine is mechanically coupled with an electric motor (EM) to provide shaft power to the propeller, and the battery pack feeding the EM is not recharged in flight (Figure 3). This, compared to a serial hybrid architecture, allows to discard the need for an additional electric generator driven by the turboshaft and all the connected mechanical and electric components, saving weight and reducing complexity. Indeed, a careful sizing of the airplane in both serial and parallel variants showed a reduction in cost by 5% and emissions by 10% in favour of the latter.

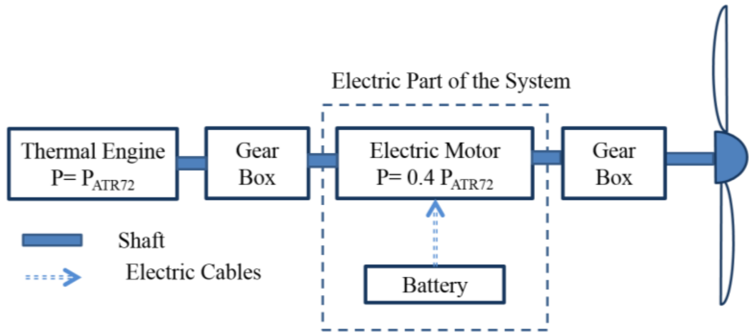

Figure 3: Flybrid's parallel hybrid-electric powertrain schematics.

An apparent penalization is the sizing of the turboshaft according to conventional procedures, so that the aircraft would be able to perform the mission even without batteries onboard. This choice entails a number of advantages in terms of airworthiness, operational flexibility and safety. Indeed, it is assumed that such an airplane would sustain lower certification burdens compared to a more optimized design involving an undersized internal combustion engine (ICE), given that in this case electrical power is not crucial to insure performance and safety. As an example of operational flexibility, such an aircraft would be able to operate without any restrictions from airports not endowed with a battery management service. In addition, the proposed solution naturally improves safety margins in all phases of flight in case One-Engine-Inoperative (OEI) emergency conditions, when operating the live propulsive unit in hybrid mode would boost the power available above 50% nominal maximum power required.
A characteristic element in the project integration is the design of the pre-charged battery packs. These are conceived to be hosted in specially modified Unit Load Devices (ULDs), i.e. standard-sized containers that are routinely handled in airports, to be carried in the aircraft cargo bay (Figure 4). Battery units are sized to store 400 kWh, giving a good trade-off between the contrasting needs to embark large energy amounts and to limit the time necessary for battery loading/unloading on ground. In the Flybrid design, up to nine modified ULD-shaped battery packs can be boarded. Only

the required number of batteries are loaded at each mission, depending on mileage, thus optimizing the airplane's weight. Battery operations would be integrated with normal ground operations, with exhausted batteries unloaded together with normal baggage containers and replaced with pre-charged ones. A dedicated area of the airport is envisaged for battery collection, repository and recharge. As this may imply very large amount of batteries involved in the continuous on-airport recharge process, a remarkable opportunity may be seized in implementing such areas as storage nodes within the land-based electric grid, opening up promising scenarios within the "smart grid" policy being implemented in many countries worldwide [13,14].

Figure 4: Flybrid's modified ULD-shaped battery pack for cargo bay loading.

Table 2 provides the main Flybrid specifications in terms of weight and predicted performance. In a typical short-haul flight, savings compared to conventional solutions may be substantial. For example, with a 550 km route and 70 passengers on board, CO_2 emissions are reduced by more than 40% and total mission cost by more than 30%. A detailed illustration of the preliminary studies, design methodology and main outcomes of the Flybrid project can be found in [1].

Table 2: Main Flybrid specifications

Maximum take-off weight	32,500 kg_f
Maximum payload weight	9,600 kg_f
Maximum fuel weight	5,000 kg_f
Maximum battery weight	3,600 kg_f
Cruising speed	560 km/h
Maximum range (90 pax)	750 km
Ceiling	7,000 m

4 PROJECT NIBBIO

4.1 The 31st Annual AHS International Student Design Competition

The American Helicopter Society (AHS) International announced the 31st edition of its Student Design Competition in 2014, sponsored by AgustaWestland (now Leonardo Helicopters). The sponsorship rotates between some of the major VTOL (Vertical Take-off and Landing) world-class manufacturers plus the U.S. Army. The contest challenges students to design a vertical lift aircraft that meets specified requirements. Two categories are available: undergraduate and graduate. Each of the winning teams is awarded a cash stipend, plus other benefits such as an invitation to the AHS International Annual Forum and Technology Display to present their projects. It was the first time a student team from Politecnico di Milano was involved.

The 2014 competition challenged students to respond to a Request for Proposal (RFP) for an experimental VTOL aircraft intended to achieve exceptional performance, including sustained hover with efficiency not lower than 75%, high useful load capability, long-range cruise with a lift-to-drag ratio of at least ten, and sustained flight at airspeeds between 300 and 400 kn (or 550 and 740 km/h), which is about three times the maximum speed of today's helicopters.

The only Italian team participating was Team Caurus, which scored the second place and "best new entrant" awards. Team Caurus formed during the Academic Year 2013-2014 as one of the design groups within the Aircraft Design graduate course at Politecnico di Milano. They chose to participate with a proposal focused on a high-performance tilt-rotor aircraft, the "Nibbio" (Italian for the kite bird of prey, *Milvus Milvus*), which is characterized by two peculiar design choices.

4.2 The Nibbio concept

The Nibbio is a novel morphing VTOL concept aimed at solving the drawbacks inherent to the tradeoff between the requirements for efficiency in both vertical flight and high-speed cruise. The severe and mutually contrasting requirements of the RFP called for the development of radically new design solutions. After an in-depth study of the potential market for such a vehicle, additional requirements have been set by Team Caurus, in order to define, more than a mere demonstrator, a possible platform for tasks such as corporate business and air-taxi, off-shore transportation, Search and Rescue (SAR), Emergency Medical Service (EMS), and law enforcement.
The choice of the configuration was of paramount importance to the subsequent design. In fact, since a conventional tilt-rotor cannot fully satisfy the demanding RFP performance requirements, due to the impossibility to optimize its prop-rotor simultaneously for hover and cruise conditions, a novel solution was devised to overcome this inherent limitation. The key element is represented by the design of a unique dual-propulsion system. This involves the use of two separate optimized devices for hover and cruise, with the former being a morphing system: two large, tractor, foldable rotors are employed in vertical and low speed flight, while two pusher propellers empower high speed flight (Figure 5, left).

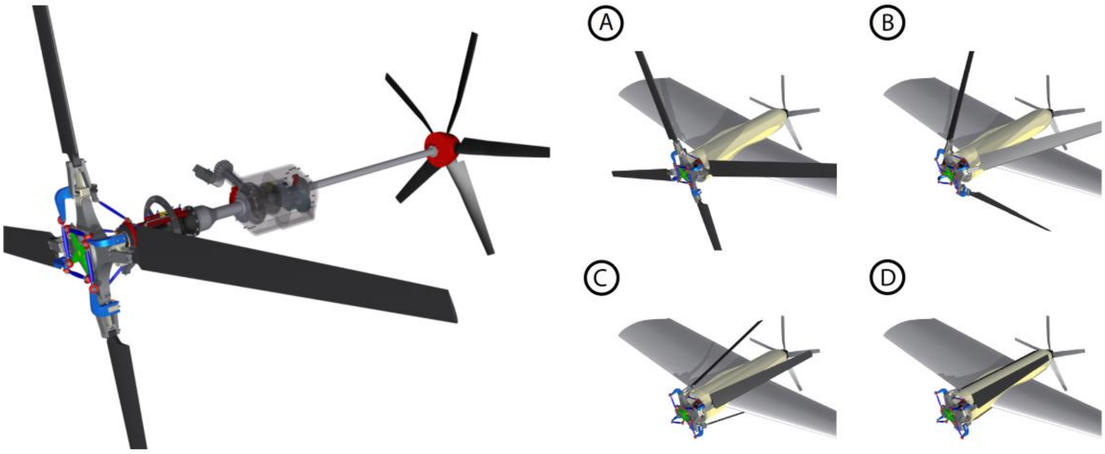

Figure 5: Nibbio's propulsive arrangement with front rotor, rear propeller and nacelle transmission system (left), and blade folding sequence (right).

The conversion maneuver from low to high speed flight is performed as follows: after vertical take-off and climb in "helicopter mode", low-speed forward flight is initiated; then nacelles are tilted and rear propellers are activated, before stopping and folding the rotors; at this point, high-speed flight in "airplane mode" can be achieved.
The gimballed hingeless rotor is designed to be slowed down until full stop during the transition from low to high speed flight. Once stopped, the blades are appropriately feathered, then folded and stowed within dedicated slots on the nacelle to minimize their impact on vehicle drag (Figure 5, right). The structure of the rotor hub was specifically designed to perform blade folding in flight. When the folding system is activated, a dedicated electric motor generates a torque that is amplified and transmitted by the elliptical gearbox to a folding wheel or "spider", which forwards the motion onto the folding arms using ball joint links.
The resulting design is a complex, but exceptionally performing, compound tilt-rotor with a partially tilting wing, endowed with slender nacelles supporting each a front foldable rotor and a rear propeller, able to carry six to nine passengers with a very promising cost-effectiveness. In fact, the maximum specific range achieves 0.56 NM per pound (4.08 km per kg) of fuel, about 16% lower than that of turboprops of the same class, while being nearly 15% higher than that of typical business jets. Figure 6 shows Nibbio's remarkable payload-range performance, derived by the high cruise efficiency in "airplane mode", which radically improves on current VTOL vehicles, including the Bell Boeing V-22 and AgustaWestland AW609 tilt-rotors and the Airbus Helicopters X3 compound helicopter.
The main Nibbio specifications are provided in Table 3. A detailed illustration of the preliminary studies, design methodology and main outcomes of the Caurus Nibbio project can be found in [2,3].

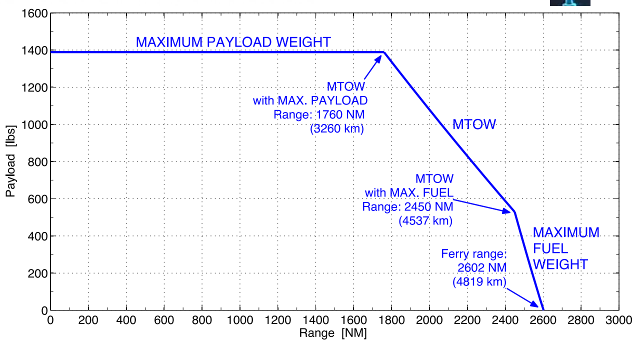

Figure 6: Nibbio's payload-range diagram.

Table 3: Main Nibbio specifications

Engine power	2 x 1,342 kW
Wingspan	16.0 m
Length	11.5 m
Height	3.0 m
Rotor diameter	6.5 m
Max gross weight	5,000 kg_f
Range	3,370 km
Service ceiling	13,800 m
Maximum airspeed	740 km/h

5 PROJECT FLYNK

5.1 The AIAA Graduate Student Design Competition 2014-2015

The American Institute of Aeronautics and Astronautics (AIAA) Foundation announced the 2014-2015 edition of its annual Student Design Competition in 2014. The contest calls students to provide a solution to a RFP, preparing a design report in which they describe such solution, testing the hypothesis, evaluating its effectiveness, and possibly doing some cost analysis. Two categories are available: undergraduate and graduate. Each of the winning teams is awarded a cash stipend, plus other benefits such as invitation to the AIAA Aviation Forum and Exposition to present their projects. It was the first time a student team from Politecnico di Milano was involved.
The 2015 competition RFP focused on the design of an air taxi system that must operate in large metropolitan areas such as New York or San Francisco, with either VTOL or STOL (Short Take-off and Landing) capability. In addition to the design of the aircraft, an operations model of the air taxi corporation was requested, as well as adequate cost and revenue models demonstrating the viability of the proposed system. The proposed solution, framed in the year 2020, had to be of better value than future solutions of automobiles, rail and airline service – which is a fairly severe requirement.
The only Italian team participating was Team Flynk (a contraction of "flying link"), which scored the first place. Team Flynk formed during the Academic Year 2014-2015 as one of the design groups within the Aircraft Design graduate course at Politecnico di Milano. They resolved to participate with a proposal focused on a novel very-short haul passenger aircraft powered by electric propulsion.

5.2 The Flynk concept

The Flynk is an innovative all-electric, 9-passenger STOL airplane designed for low-fare air taxi missions used for mass commuter transportation, in an attempt to contribute to the improvement of the quality of life in large metropolitan areas. The challenging RFP inspired a thorough preliminary study to investigate the actual needs of a metropolitan community. New York City was chosen as the area to be serviced, as its residents face the longest commuting times among workers in the thirty largest cities in the U.S.A., spending an average of 6 h 18 m per week on the road. In order to better outline their needs, an online survey was posted on a social network, gathering over 200 replies.
Based on this survey, five primary requirements have been identified for a competitive air transportation system: affordable fares, low noise emission levels, reliability, passenger comfort, and faster connection than its competitors.

These include elements already present in the RFP, while other elements emerged that contributed to the definition of the Flynk air taxi system design specifications. Among these, it was found that the location of take-off/landing spots is of strategic importance, in order to minimize the need for additional, unwelcome ground transportation means. Also, unmanned solutions were discarded in favor of piloted aircraft, given the importance of "perceived" safety for interviewed potential customers.

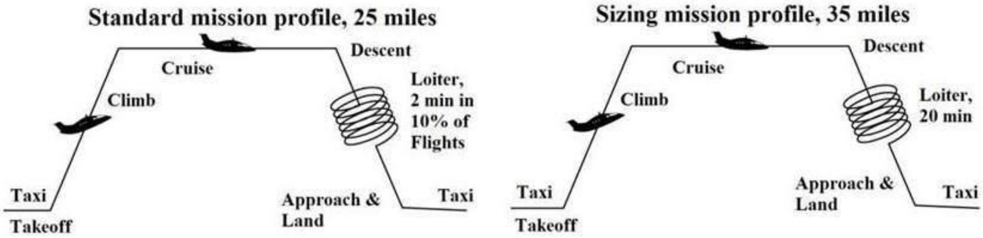

Figure 7: Flynk's mission profiles.

Based on the market study, a "Standard Mission" profile was determined, composed by taxi to runway threshold, take-off, climb to cruise altitude, cruise for 25 mi (or 40 km), descent, loiter for two minutes, approach, landing, taxi to apron (Figure 7, left). Candidate configurations were sized in order to achieve the best performance for the Standard Mission, while retaining the capability to complete a more demanding task, the "Sizing Mission" profile, where the cruise leg amounts to 35 mi (or 56 km) and loiter lasts for 20 minutes (Figure 7, right). Cruise speed was required to be not lower than 290 km/h, in order to guarantee an average block speed over 180 km/h, while cruise altitude was set at 500 ft (or 150 m) AGL (Above Ground Level). Given the atypical mission, the widest possible array of manned air vehicle types potentially applicable was considered in the choice of the configuration, including traditional and compound helicopters, gyroplanes, tilt-rotors, and fixed-wing airplanes. Based on the scores attributed to each configuration with respect to economic performance, noise impact, average speed, robustness, and VTOL capability, a decision-making process was carried out and the fixed-wing STOL emerged as the best configuration. Also, an all-electric configuration was preferred, because it was found that, for the peculiar missions addressed, it outperforms conventional and hybrid-electric types not only with regard to environmental impact (both chemical and noise emissions), but even concerning economic performance. Four engine-propeller groups power the aircraft, with nacelles partially buried in the wing thickness. The 6-blade propeller was designed to meet severe noise requirements. Given the very short missions and the need for quick ground operations between flights, non-replaceable batteries were chosen, to be subjected to high-voltage fast recharge.
High STOL performance are achieved by a careful design of the lifting surfaces, which include a slightly oversized wing, with largely oversized trailing edge double-slotted flaps, compared to traditional designs (Figure 8). This solution increases the actual wing surface by 21% and, together with the blown-wing effect from propellers, allows reaching lift coefficient values in excess of 4.0. A further contribution to exceptional field performance comes from the partially-tilting wing-tip nacelles.

Figure 8: Flynk's fully-extended flap configuration.

The envisaged operations model features a network of sixteen airfields in the New York Metropolitan Area, five of which inside Manhattan. Routes have been designed in compliance with Air Traffic Management (ATM) rules, paying attention to avoid flying over Manhattan and other heavily populated areas, with two main airways located over the Hudson River and the East River. The Flynk

service was then simulated in full working condition, to calculate separations between traffic in the two main routes. The number of vehicles required for the service was estimated as 72, including backup aircraft.
The main Flynk specifications are provided in Table 4. A detailed illustration of the preliminary studies, design methodology and main outcomes of the Flynk project can be found in [4].

Table 4: Main Flynk specifications

Engine power	4 x 110 kW
Wing surface	20 m^2
Aspect ratio	9.4
Max payload weight	915 kg_f
Max gross weight	2,870 kg_f
Runway length	150 m
Cruising speed	370 km/h

6 PROJECT HYBRIS

6.1 The 1st RAeS First Annual General Aviation Design Competition

The Royal Aeronautical Society (RAeS) announced the first edition of its Annual General Aviation Design Competition – E-conditions Fixed-Wing Aircraft Design Challenge in 2015. This international competition was not reserved to students, but open to any interested design team, and saw the participation of groups of professionals, in additions to university teams. The winning team was awarded a cash stipend, plus an invitation to the RAeS General Aviation Conference "Advanced Design of Light Aircraft" to present their project. It was the first time a student team from Politecnico di Milano was involved in a RAeS-sponsored contest.
The contest aimed at promoting innovative designs, in an attempt to encourage a drastic renovation of light aviation in the UK. E-conditions represent a new means to operate an aircraft without a Certificate of Airworthiness or a Permit to Fly established by the RAeS and the British Civil Aviation Authority. The competition called for fixed-wing aircraft using any form of power source.
The only Italian team participating was Team Hybris (from "hybrid" and the Greek topos *ὕβρις*), which scored the first place. Team Hybris formed during the Academic Year 2015-2016 as one of the design groups within the Aircraft Design graduate course at Politecnico di Milano. They resolved to participate with a proposal focused on a highly innovative 4-seat airplane with a promising potential in reducing the environmental impact of General Aviation (GA) operations, as well as operating costs.

6.2 The Hybris concept

The Hybris is a groundbreaking concept for an airplane with a promising potential in reducing the environmental impact of GA, as well as operating costs. A thorough market study, including a survey aimed at UK Aero Clubs and pilots, was carried out to identify needs, desiderata, competitors and other useful preliminary information. As a result, high operational cost stood up as the main problem, followed by internal and external noise. Desiderata include traditional aft-tail, low-wing, tricycle landing gear configuration; range between 300 and 500 NM (or 550 and 920 km); cruising speed between 115 and 155 kn (or 210 and 290 km/h), at an altitude ranging among 2,000 and 5,000 ft (or 600 and 1,500 m); maximum altitude of 10,000 ft (or 3,000 m); between two and four passengers. On this basis, current (Piper PA28, Cessna 172, Cirrus SR22) and near-future (Pipistrel Panthera) competitors have been analysed and mission requirements have been drafted to improve on them.
In view of the lightest possible environmental impact, pure electric propulsion was considered, but soon abandoned because of the limitations in range. These apply, although much less severely, also to a serial hybrid-electric configuration, where an ICE is employed to produce electric energy through a generator, without mechanical connections to the propellers, which are driven by EMs. In order to enhance on-board energy storage, structural batteries (SB) were considered. These are innovative multi-functional materials, similar to structural composites, but capable of storing electrical energy. Therefore, SB may be employed in the airframe, contributing to structural strength, while at the same time allowing additional electric energy to be stored, replacing structurally-useless, heavy classic batteries.
The outcome is a radically innovative design for an aft-tail, low wing, single propeller, tricycle retractable landing gear, 4-seat airplane, in which a great part of the airframe is made by SB, with

only the upper wing surface and the movables using classic Carbon-Fiber Reinforced Polymer (CFRP) composites. This configuration is depicted in Figure 9. The concept of an integrated SB airframe is the subject of a pending patent [12].

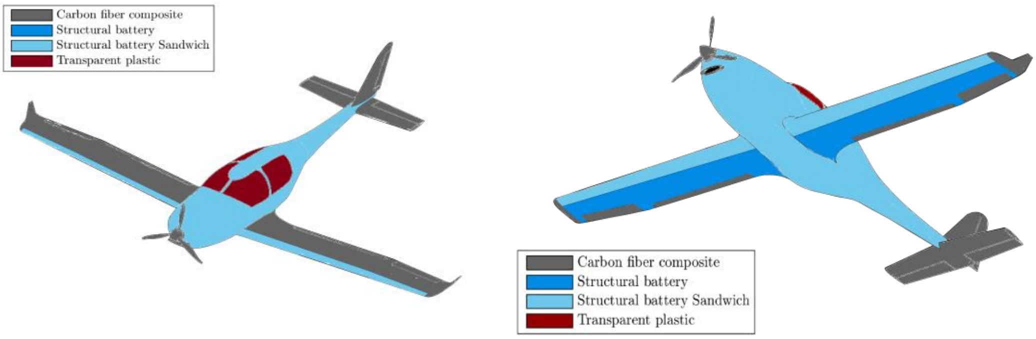

Figure 9: Hybris' airframe materials.

The coupled sizing of propulsion and airframe was carried out to allow to take-off and complete the first climb segment in pure-electric mode, up to 3,000 ft (or 900 m) AGL. Then the ICE is turned on to power the climb to cruise altitude. When this is reached, ICE power provides the required shaft power and a surplus recharge the batteries. When descending below 3,000 ft AGL, the ICE is turned off and the aircraft lands in pure-electric mode. Therefore, ICE emissions vanish in the most environmentally-critical flight phases, i.e. terminal maneuvers. Moreover, given the possibility to recharge batteries during flight, this configuration does not require any special recharging facility on the airfields.
Based on a fairly pessimistic performance level for SB, degraded by 40% with respect to the values expected in the year 2020, the final design features 45% of the structural weight made by SB. On the other hand, SB form 73% of the total mass of batteries. This entails a modest MTOW saving, but at the same time the predicted range performance (Figure 10) make Hybris fully comparable with its most modern competitors, at operational costs that, under reasonable assumptions, may be 22% and 17% lower compared to the Cirrus SR22 and Pipistrel Panthera, respectively.

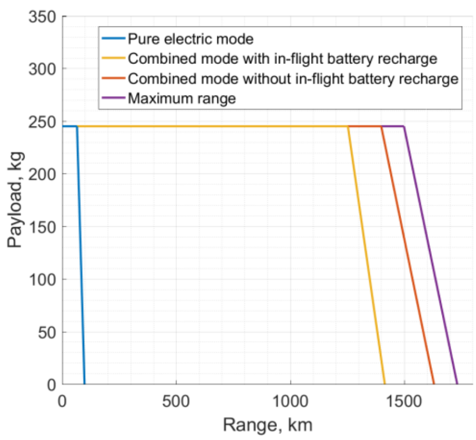

Figure 10: Hybris' payload-range diagram.

Table 5: Main Hybris specifications

EM max power (continuous/transient)	60/150 kW
Wingspan	10.5 m
Length	11.5 m
Max gross weight	1,275 kg_f
Range	>2,200 km
Cruising speed	280 km/h
Cruise altitude	2,400 m

Table 5 provides the Hybris main specifications. A detailed illustration of the preliminary studies, design methodology and main outcomes of the Hybris project can be found in [5].

7 CONCLUDING REMARKS

In the "Aircraft Design" course at Politecnico di Milano, remarkable projects involving the conceptual and preliminary design for innovative aerial vehicles have been presented over the years. Recently, at least one of these projects was submitted to an international design competition each year. In particular, four projects, participating in four different contests, were ranked between third and first place: Flybrid (2013), Nibbio (2014), Flynk (2015), and Hybris (2016). The paper discussed the approach adopted in the "Aircraft Design" course and its educational results at large. The four award-winning projects were introduced very concisely, due to the limited amount of space, discussing the most original design choices and the key elements that contributed to their success. The interest aroused around these four concepts, at a research level and within the industry as well, is a strong motivation to pursue the "Aircraft Design" course approach further on, in an effort to provide a highly formative and thrilling experience to young engineers engaged in their M.Sc. studies, while eliciting new ideas for the progress of aviation at large.

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