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Experiences in Academic Flight Testing Education

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Abstract

Purpose – The paper details the educational Flight Testing activities performed at the Department of Aerospace Science and Technology at the Politecnico di Milano (DSTA-PoliMi), including the development of low-cost, reliable Flight Testing Instrumentation (FTI) and the administration of the graduate course in *Flight Testing*.

Design/methodology/approach – The *Flight Testing* course program closely adheres to the typical content of an introductory course offered in a professional Flight Testing school. However, within academic courses, it has a unique feature: each student is required to plan, perform and report on a real flight test experience, acting as a Flight Test Engineer. Educational activities in this framework have been successfully matched to applied research and technical support for private companies.

Findings – At the educational level, several elements arise that are rarely concentrated within a single course, such as multidisciplinary integration, individual conceive/design/implement/operate (CDIO) project, real-life experimental procedures and techniques, teamwork, communication and reporting, relation with non-academic partners.

Practical implications – Based on the development of a FTI system for light aviation and on the *Flight Testing* course, DSTA-PoliMi has built a solid capability in Flight Testing, introducing graduate students to this specific niche of expertise and empowering co-operation with companies in the light aviation environment, while offering capabilities and tools that are typically regarded as a prerogative of major aerospace companies.

Originality/value – We discuss an original approach to Flight Testing education in an academic setting, that avoids the high costs and complexity connected to certified aircraft flight operations and instrumentation, nevertheless allowing the achievement of significant results, also in applied engineering research.

Keywords Aeronautical engineering education, flight testing education, flight test instrumentation, ultralight aircraft.

Paper type Case study.

Introduction

The present paper discusses on the education and research activities focused on flight testing that have been performed in recent years and that are currently ongoing at the Politecnico di Milano, Department of Aerospace Science and Technology (DSTA-PoliMI), formerly Department of Aerospace Engineering (up to January 2013).

Flight testing has represented a fundamental activity in aeronautics from the 1903 Wrights' flight onwards, being the process of acquiring data related to a flying machine in actual flight. These data refer to the machine's performances, characteristics and handling qualities, as well as to the characteristics of its specific subsystems, such as structures, controls system, power plant, hydraulics, avionics and so on. Among its main goals, flight testing allows to fully assess the behaviour of an aircraft, to determine its safe flight envelope, to validate its design, to verify its operational procedures. Through the use of flight test data, it is also possible to identify the aircraft mathematical model, making more faithful predictions and keeping track of inherent modelling limitations with respect to the real object, allowing for design and procedure optimization. Furthermore, for all kinds of certified aircraft, demonstration through flight testing represents a substantial body of evidence required as a means of compliance to mandatory regulations.

By its very nature, flight testing is a strongly multi-disciplinary activity within aeronautical sciences, since the various engineering disciplines collaborating to the realization of a flying machine are all involved in the trial and verification of its actual behaviour. Typically, this involves aerodynamics, flight mechanics, aircraft structures, propulsion, mechanical systems, electrical systems, hydraulic systems, control systems, human-machine interface and ergonomics, and possibly others. Flight testing theoretical and experimental methodologies are clearly grounded on these disciplines, applied to the specific kind of aircraft considered, together with the fundamental input from the theory and practice of measurement in engineering.

In spite of its importance in aeronautics at large, flight testing as an engineering discipline is rarely considered as 'the' subject of a dedicated graduate course. In fact, only a few universities include such a course within their aeronautical engineering curricula. More often, flight testing theory is included in bits and pieces within more classical academic courses such as *Flight Mechanics*, *Flight Dynamics and Control*, *Experimental Techniques for Aerospace*, and the like. Notwithstanding, exposure of a graduate student in Aeronautical Engineering to the whole flight testing process can be extremely fruitful from a didactic point of view. In fact, a course fully dedicated to the various aspects of flight testing represents an ideal ground to

- check the student's understanding of the aircraft as a complex machine, a *system of systems*, with a considerable degree of interaction between components;
- integrate, synthesize and verify a vast multidisciplinary knowledge base acquired during undergraduate and postgraduate curricula;
- learn to operate in compliance with applicable regulations and procedures in a typical aeronautical working environment;
- approach a specialized technical field with strong links with real-life, industrial problems, techniques, and products.

Seeking these outcomes, Politecnico di Milano offers a unique, dedicated flight testing course to its graduate students earning their master degree in Aeronautical Engineering. Furthermore, a special focus has been placed from the very beginning to addressing this discipline as closely as possible as it is currently implemented and operated in the aeronautical industry. This was made possible through collaboration with renowned experts, and was crowned by the performance of a complete, real flight test mission charged to each student attending the course.

Indeed, the effectiveness of the actual full-scale flight experience finds solid confirmation in the experience of the few institutions that are able to overcome the high organizational and financial burden of conducting flight testing activities on a regular basis. The setup at DSTA-PoliMi, however, differs from that encountered in other cases: for example, at the University of Strathclyde (Stickland and Scanlon, 2004), flight testing is offered at undergraduate level, it consists mostly in demonstration, with limited data post-flight analysis, and a glider is employed; at Delft University (Slingerland *et al.*, 2005), the faculty's longtime connection with NLR (National Aerospace Laboratory of the Netherlands) allows the use of a very sophisticated aircraft, a Cessna Citation II, permanently instrumented with its dedicated *Flying Classroom Instrumentation System*, but flight missions are repeated each year following an established syllabus and undergraduate students do not design the mission themselves; similarly, at Cranfield University, groups of students are trained using an instrumented BAe Jetstream 31 as a 'flying classroom'; at Western Michigan University (Liu and Schulte, 2007), a non-experimental Cirrus model is used, without a complete FTI (Flight Test Instrumentation) system; at Reszow University (Tomczyk, 2008), a PZL M20 Mewa is employed as a flying laboratory, with a strong accent on handling qualities evaluation and control law validation; finally, at West Virginia University (Phillips *et al.*, 2010), a research-driven flight testing laboratory is carried out with undergraduate students using remotely-controlled UAVs (Unmanned Aerial Vehicles). Of course, in some cases, actual flight testing is avoided altogether and the subject is approached via flight simulation (Smith, 2001), (Cotting *et al.*, 2007).

In the following, we shall discuss the characteristics of flight testing education at DSTA-PoliMi, involving the operation of small aircraft belonging to a non-certified category, the in-house development of a complete FTI system specifically devised for such aircraft, and the structure and content of the dedicated graduate course with its flight test experience, fully designed and individually flown by the students.

Background

Involvement of DSTA-PoliMi staff in the discipline of Flight Testing began with earlier experiences in the design and construction or modification of ultralight manned aircraft, as well as fixed- and rotary-wing UAVs. An important step was taken in 1998, when the Department acquired a Tecnam P92 Echo (Figure 1), in order to engage in new research lines and to improve on its education capability. This aeroplane belongs to the upper end of the `three-axis control' category of UltraLight Machines (ULMs). This means that, from a broad Flight Mechanics point of view, it is fully representative of typical fixed-wing, heavier General Aviation aircraft such as those falling in the CS-VLA (EASA, 2003a) or FAR/CS-23 (EASA, 2003b) type certification, without the related considerable costs of operation and maintenance. Since its acquisition, the ULM has been operated directly by DSTA-PoliMi, based at the Baialupo airstrip, some 35 km East of the Politecnico "Bovisa" campus in Milano where the Department offices and laboratories are located.

One of the first activities carried out with the DSTA-PoliMi ULM has been the organization of familiarization flight missions (in some cases a 'first flight' experience) freely available to Aerospace Engineering students, typically in their first undergraduate year, in connection with the course *Istituzioni di Ingegneria Aerospaziale* (*Introduction to Aerospace Engineering*). Students were offered the possibility to fly alongside an instructor pilot for a 20-minute mission in which they could experiment 'first hand' the basic flight manoeuvres: take-off, climb, level flight, turning flight, descent and landing.

This went on for some years, gradually decreasing in volumes, due to difficulties in the management of large groups of students. In the meantime, several MS theses devoted to the study, implementation and experimentation of low-cost flight instruments (such as GPS-based navigation tools, position reporting systems, glass cockpit applications) involved the use of the DSTA-PoliMi ULM, leading to a few initial flight testing activities.

However, a major step towards the engagement in a line of research and educational activities focused on Flight Testing was accomplished with the in-house development of a dedicated FTI suite.

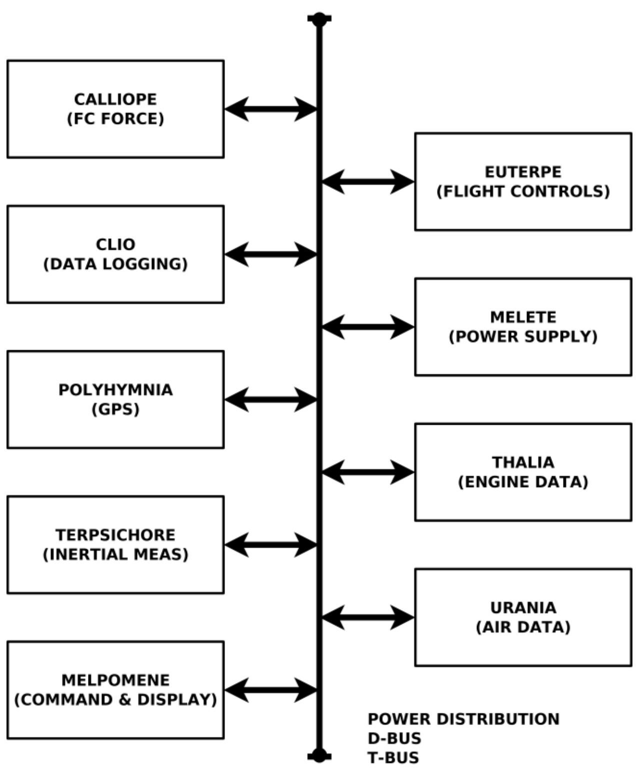
Figure 1 The DSTA-PoliMi ultralight aircraft (Tecnam P92 Echo).

Developing Flight Test Instrumentation

Given the relatively loose regulations for ULMs in Italy, as well as in many other countries, these aircraft are not required to comply with sophisticated type certification requirements such as those included in the CS-VLA or FAR/CS-23 standards, which typically call for a vast array of flight demonstrations. Hence, there is no need for the relevant test campaign and, as a the result, systematic flight testing for this aircraft category is often avoided. In turn this means that no dedicated commercial FTI systems are available on the market.

Resorting to the adaptation of FTI systems currently adopted for higher-category machines cannot be considered as a viable option, given the related considerable financial investment and the typically bulky, heavy and intrusive system configuration, which is unfit for a small machine. However, a real flight testing capability necessarily builds on the usage of a reliable FTI system for data measurement, acquisition and storage, on a regular basis. Therefore, a project for the development of a safe, economic and reliable FTI suite was launched as the core of a PhD project started in 2005 (Rolando, 2008a).

Figure 2 Block diagram of the ``Mnemosine'' FTI system showing its federated architecture.



FTI design

Design requirements have been set in order to achieve the capability to support a wide variety of tasks, such as the determination of flight and airfield performance and flying qualities, the assessment of on-board system performance, the modelling and identification of the aeroplane aerodynamics and engine, the development and testing of innovative sensors. The result of this effort is "Mnemosine", an integrated FTI suite fully designed, developed and implemented at DSTA-PoliMi (Cardani *et al.*, 2007), (Cardani and Rolando, 2009). "Mnemosine" is characterized by a federated architecture in which the system is subdivided in a number of autonomous nodes, as shown in Figure 2. Each node operates independently from each other, being specialized for a specific task: it is endowed with its own processing power, memory, power supply and all the signal conditioning and interface resources required to manage its corresponding sensor or device. All data generated by the component modules are shared over a common communication line: a dual 1 MBit/s CAN (Controller Area Network) based digital data bus. Furthermore, the system makes use of two independent data buses: the D-BUS for measured data communication between nodes and the T-BUS exclusively dedicated to timing information distribution for inter-node synchronization purposes.

The rationale for this architecture primarily lies in the high degree of modularity, flexibility and low intrusiveness achievable. In fact, distributing the various units throughout the aircraft provides the ability to place every module as close as possible to the corresponding sensor, without the need to lay down long, noise-sensitive analogue signal lines. Information is immediately converted to a digital format, processed, time-stamped, and transmitted over an interference-resistant medium. The global impact upon the aircraft is very low, internal space optimization is facilitated, and software partitioning and fault confinement are inherently guaranteed.

FTI implementation and operation

In the current configuration "Mnemosine" is composed of the nodes described in Table 1, each acquiring the indicated subset of parameters and/or managing the indicated operation. The measured set includes over 30 parameters: air data (static pressure, dynamic pressure, outside air temperature, angle of attack, angle of sideslip), inertial kinematic quantities (body-frame acceleration components, attitude angles, angular velocity components), GPS kinematic quantities (Earth-Centered, Earth-Fixed co-ordinates and groundspeed components), flight control positions (stick and pedal position) and piloting forces (stick and pedal forces), engine data (engine RPM). An event counter signal is included and is used to identify single trim points and manoeuvre durations, easing the task of isolating specific sections from the full data streams. A display unit is also provided to allow the crew monitor a few parameters on-the-fly, while performing the test. Data are stored on a memory card removable device in raw binary format to minimize workload and enhance post-processing flexibility.

Table 1 FTI node functions.

Node name	Node task
Urania	Air data acquisition
Terpsicore	Inertial measurement acquisition
Polimnia	GPS data acquisition
	System time generation/distribution
Eutherpe	Flight control position acquisition
Calliope	Flight control force acquisition
Talia	Engine data acquisition
Klios	Data logging
Melete	System power management/distribution
Melpomene	Command and display unit

Off-line post-processing and analysis of flight data is performed on a standard PC. Two procedures are available: a quick one, capable of supporting preliminary verification of the mission, to assess the quality of the testing techniques and suggest improvements or repetition of test points within a few minutes after the mission; and a complete procedure supporting data analysis and reporting where data are filtered and converted into a suitable format, then subjected to appropriate computation procedures. These include, for example, air data processing to obtain altitude, airspeed and climb speed information, DGPS (Differential GPS) augmentation, and GPS/inertial measurement data fusion through a dedicated trajectory reconstruction algorithm.

As of today, "Mnemosine" has been permanently installed on five different ULMs, plus another experimental light aeroplane, requiring very little modifications. Its installation constantly implied minimal impact on the internal ergonomics, so that the five instrumented aeroplanes have been continually available for use in ordinary, non flight test-related activities. The 2013 educational campaign will feature yet another ULM model.

The FTI system "Mnemosine" has been used in over 140 flight test missions to date, showing adequate reliability and performances, fully compliant with its design requirements. Given the current low bus load level, the system has a considerable growth potential, and expansion to include acquisition of structural deformations are currently considered with their corresponding nodes, in view of possible load survey trials. Also, the development of a telemetry capability, studied in Rolando (2008b) to enhance on-line mission ground monitoring and allow real-time data analysis, is currently undergoing.

Teaching Flight Testing

Educational flight testing activities at DSTA-PoliMi achieve their peak with a constant stream of MS thesis projects focused on this topic, as well as a MS course specifically dedicated to Flight Testing. In fact, in the process of re-designing new undegraduate and postgraduate curricula at the start of the century to comply with a substantial national reform of academic studies at large (“ordinamento DM 509”, in compliance to the regulations issued by the “Bologna process”), DSTA-PoliMi planned the activation of a new *Sperimentazione in Volo* (*Flight Testing*) course as a part of the mandatory MS curriculum for Aeronautical Engineers specializing in the area of ‘Systems and Avionics’.

In this way, according to the rationale sketched in the Introduction, DSTA-PoliMi intended to provide some of its Aeronautical Engineering graduate students with the opportunity to engage in a ‘capstone’ type of course, as an ideal ground to check, consolidate and improve his/her own understanding of the aircraft, its systems, its operational use, and at the same time to get involved in a conceive-design-implement-operate (CDIO) kind of activity. Some accounts have been presented in Trainelli *et al.* (2008) and Trainelli *et al.* (2009).

A further evolution is now under development, given yet another reform (“ordinamento DM 270”) being currently implemented. In this renewed framework, the *Flight Testing* course, basically unchanged in terms of content and mode of fruition, is offered as an optional choice available to several specialization paths such as those in ‘Flight mechanics and systems’, ‘Aerodynamics’, ‘Aeronautical propulsion’, ‘Aeronautical Structures’, and ‘Fixed-wing aircraft’.

Course description

The *Flight Testing* course is a unique characteristic of the ‘Laurea Magistrale’ (a two-year cycle available after the bachelor-equivalent three-year ‘Laurea’) in Aeronautical Engineering at the Politecnico di Milano. The course started in academic year 2004-2005 and is offered as one of the final subjects, to be taken in the second half of the second and final year.

From its inception to 2012, the course has been entrusted to top-level experts in the field, currently engaged in performing and managing flight testing activities for world-class aircraft and rotorcraft manufacturers Alenia Aermacchi and AgustaWestland, complemented by DSTA-PoliMi permanent faculty staff. Currently, the course is entrusted to DSTA-PoliMi staff members, while the former external teachers are still co-operating by means of thematic seminars integrated within the course lectures.

The aim of the course is to provide fundamental concepts and skills on the flight testing process, its principles, techniques, operational organization, and practical execution. The course program closely adheres to the typical outline of an introductory course offered in a professional flight testing school, being articulated as follows:

- Flight testing motivation, historical development, process schematics, classification, applicable regulations (with an emphasis on EASA CS-23 and CS-VLA).
- Review of fundamental concepts of aerodynamics, flight mechanics, aeronautical structures, aeronautical propulsion, on-board systems and avionics.
- Flight testing theory and methodologies: air data calibration, aerodynamic performances, steady and unsteady flight performances, static stability and control, dynamic stability and handling qualities, manoeuvrability, flight at high angles of attack, static and dynamic loads, aeroelasticity, propulsion and systems, data reduction.
- Examples of special tests: noise certification, icing, hot weather operations, weapons, flow visualization, vibrations, etc..
- Flight testing instrumentation: parameter set definition, on-board and ground system architectures, data acquisition systems, data processing methods.
- Flight test planning and execution: typical organization, requirement definition, test program (planning, team, procedures, safety issues, documentation), mission planning, flight data processing and analysis, reporting, compliance with applicable regulations.

A fundamental characteristic of this unique course is the provision of a real, complete flight test experience: in fact, each attending student is required to plan, individually perform and report on a complex flight test mission, acting as a Flight Test Engineer (FTE) under all respects. Of course, this requires a considerable investment of time and energy by the teaching staff, given that the flight test experience inevitably implies the need of a much enlarged panel of functions and instruments compared to other, more classical courses, even those with a strong experimental component that can nevertheless be carried out exploiting university laboratories. Here, along with teaching, tutoring and evaluating duties, it is necessary to provide the development and installation of the FTI, as well as to support and coordinate the whole process of the off-campus flight operations involving the aircraft manufacturer, the airfield manager, and the pilot.

The final evaluation focuses in the delivery of a complete flight test report, an oral presentation and discussion based on the flight test experience, and a general oral verification of the student preparation on the topics included in the program of the course.

The course consists of 30 hours of theory lectures, 22 hours of project labs, and a body of varied experimental labs. The latter include

- inspection and familiarization with the FTI system components and functions on the DSTA-PoliMi integration and test rig;
- inspection and familiarization with the airfield, its facilities, ground operations, safety procedures;
- inspection and familiarization with the aircraft and the installed FTI system;
- FTI transducer calibration for the flight controls (stick and pedal) and corresponding control surface deflection;
- in some cases the students performed the FTI air data system calibration in one of the DSTA-PoliMi wind tunnels;
- a number of actual flight test missions, at least one for each attending student.

The typical attendance to the course varies between 12 and 20 students, depending on the year. Most of the students tend to prepare their examination within a few weeks from the end of the course, with a few exceptions reaching a few months. Within the past years, the overall rate of students required to re-submit their examination amounts to 5%.

Flight test experience

During the lab hours, the students, grouped in teams of two, are required to conceive a complex flight test mission comprising several test points related to three or four distinct test topics. These topics are sorted out of the list provided in Table 2, representative of a wide variety of typical flight test activities for fixed-wing aircraft, all relative to mission tasks within the normal flight envelope and not involving special safety concerns for their implementation within an educational framework.

Table 2 Flight test mission themes.
The tested aircraft configurations are Take-off (TO), Landing (LND) and Cruise (CR).

Area	Topic
Air Data Calibration	Static error correction
Field performance	Take-off
	Landing
	Balked landing
Flight performance	Level flight stalls (TO, CR, LND)
	Power-on stalls (TO, CR, LND)
	Turning flight stalls (TO, CR, LND)
	Cruise performance, max airspeed in level flight
	Climb performance (TO, CR, LND)
	Glide performance (TO, CR, LND)
Flying qualities	Static stability and control (TO, CR, LND)
	Manoeuvring stability, roll performances
	Dynamic stability (TO, CR, LND)
On-board systems	Radio range

From this point onwards, the students are immersed in the typical, real-life flight testing process, with its organization, documentation, operational and safety requirements.

Each team prepares a test planning document detailing test requirements and objectives, required aircraft configuration, required instrumentation, flight test conditions, proposed testing techniques and manoeuvres, pass/reject criteria, possible constraints and applicable norms and limitations. The team produces appropriate flight cards, detailing the sequence of test points to be flown, which are subjected to a preliminary verification by the teaching staff. The concern for safety is pervasive in this phase: students are instructed to assess, and in case to mitigate, potential hazards connected to their mission, and a careful revision of their planning is carried out before forwarding their flight cards to the pilot.

On the scheduled day, the team, together with the teaching staff, meets on the airfield with the pilot and a pre-flight briefing is carried out. In this briefing, the proposed mission is analysed and the related flight card is discussed and verified with the pilot and possibly the aircraft manufacturer or operator, with a primary focus on safety issues, as well as on pilot workload and overall suitability.

Subsequently, the flight test mission is performed. During the flight, the student sits in the cockpit with the pilot, acting as the FTE in charge for the mission. This involves co-operating with the pilot in carrying out the test sequence, taking note of instrument readings as appropriate, verifying the correct execution of the planned manoeuvres, and directly checking the behaviour of the aircraft and its systems.

Typically, each team member flies the same mission, or a mission with very limited modifications, This provides the possibility to cross-check the results and mitigates the risk connected to partial data loss, incorrect flight techniques, changing meteorological conditions, and other possible inconveniences.

For the sake of clarity and completeness, it must be noted that no pressure is applied on the student in any way, in case he/she does not feel to actually fly his/her planned mission. Even in the case of a last-minute rejection, the student not flying would nevertheless profit from the data gathered by his team mate, possibly also in his/her behalf, to accomplish the mandatory post-processing and reporting tasks for evaluation. Incidentally, this has never been the case to date.

After the flight, acquired data are downloaded from the FTI on-board data storage unit and preliminarily presented on a PC set up at the airfield. A debriefing with the pilot is carried out in order to comment on the execution of each mission task, possible difficulties, need to repeat specific test points, and the like. After the completion of the mission, stored data are post-processed: acquired signals are first converted to engineering quantities, then these quantities are validated, filtered and sampled as appropriate, providing the test flight results. In the subsequent analysis, these results are related to the test objectives, critically discussed and evaluated.

Concerning post-processing, raw flight data are made available to the students together with a base-level processing tool which produces a platform-independent set of time-history files, one for each acquired parameter. The responsibility of carrying out the complete post-processing activity, including filtering and smoothing, is left to each student team as a qualifying part of the course assignment, and is typically performed by means of spreadsheets and/or high-level scientific software tools available on campus.

The end of this process is the preparation of a flight test final report containing the presentation and discussion of post-processed data, compliance with the requirements, comments, conclusions and recommendations. This document, together with the test planning report, represents a mandatory homework and substantially contributes to the final evaluation.

In order to illustrate the results of the student work, a few examples of elaborations are given in Figures 3 to 6. Figure 3 shows results from air data system calibration tests. The difference between Calibrated Airspeed (CAS) and Indicated Airspeed (IAS) at different values of IAS are drawn with respect to the airworthiness requirements set in CS-VLA 1323 (EASA, 2003a), proving compliance. Figure 4 shows results from a climb performance test mission where multiple sawtooth climbs were performed. The graph displays the results of data reduction in terms of rate-of-climb values versus airspeed values and their best fit that takes into account the maximum level speed condition. From this analysis, the students deduced the best rate of climb and the best angle of climb, together with their characteristic CAS values. Figure 5 shows results from a leftward roll performance (“bank-to-bank”) test carried out at 120 km/h in cruise configuration. The time histories represent bank angle (upper graph), aileron deflection (middle graph), and roll rate (lower graph). In addition to determining compliance to applicable norms, this kind of testing allowed the students to draw some considerations on the symmetry of the rolling behaviour comparing left and right manoeuvres, and quantifying the influence of the propeller. Finally, Figure 6 shows the time histories of a stalling test in take-off configuration. The graphs represents, from upper to lower, the following quantities: CAS, vertical acceleration, elevator deflection, pitch angle, and altitude. The first marker identifies the time instant in which full elevator deflection is reached, while the second marker corresponds to the minimum value of airspeed attained. The airspeed values were duly corrected by windspeed estimation, consequent to the execution of two wind determination tests, before and after the array of stalling tests. The students remarked the stall warning in the form of buffeting, as shown by the acceleration graph, and the elevator-limited nature of this smooth stall.

Figure 3 Example of air data system calibration results (position error correction), framed in the context of CS-VLA airworthiness requirements.

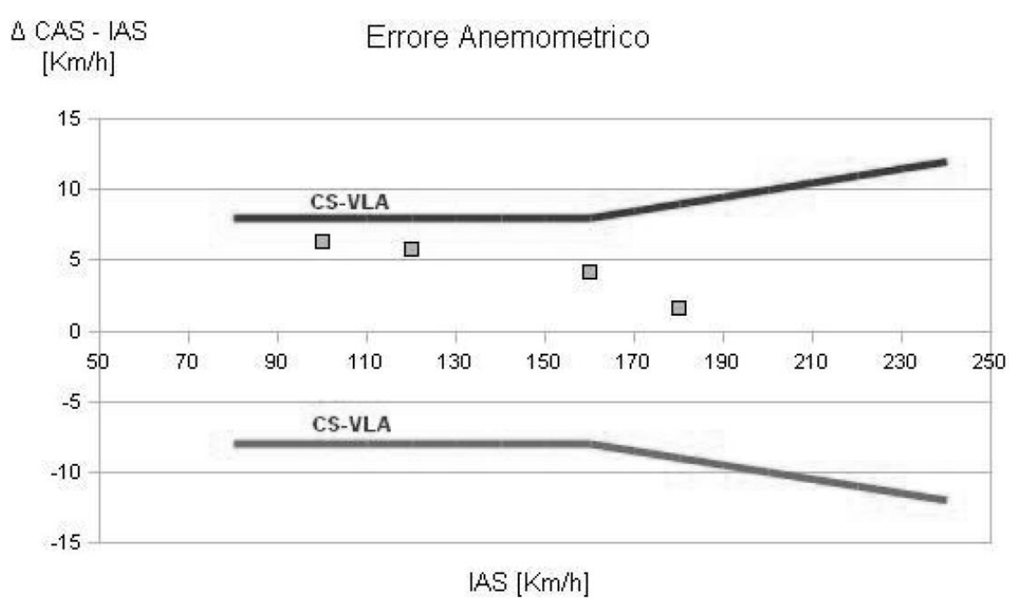


Figure 4 Example of climb performance results.

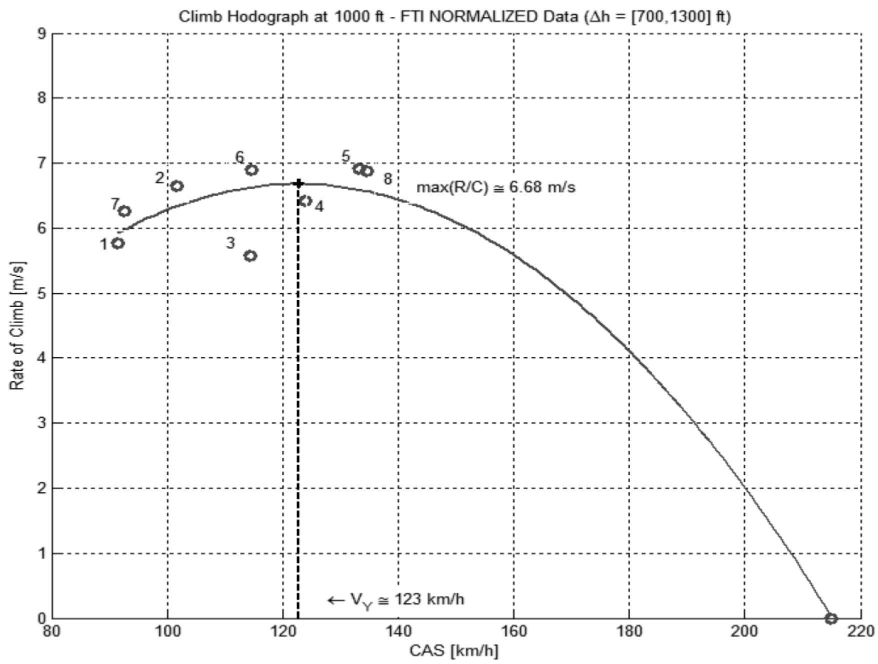


Figure 5 Example of roll performance results.

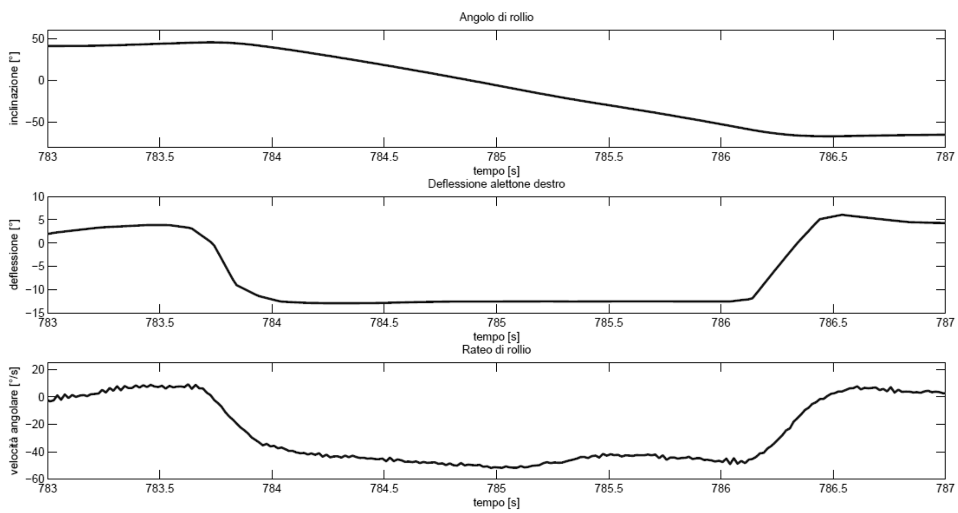
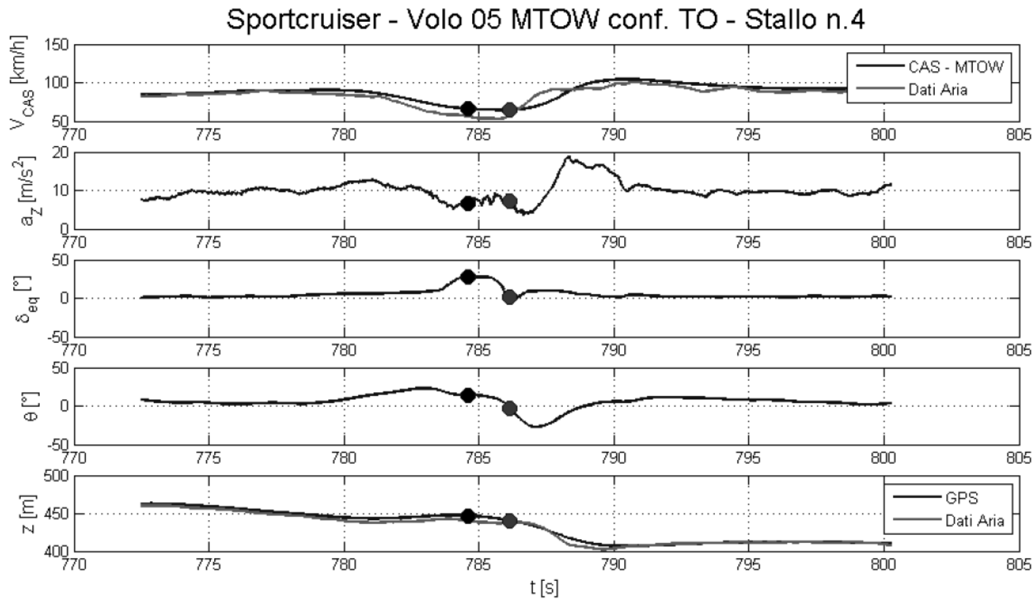


Figure 6 Example of stall testing results.



Flight test campaign

The DSTA-PoliMi ULM, instrumented with the “Mnemosine” FTI suite, has been thoroughly used in the flight test missions related to the *Flight Testing* course during the academic years up to 2007-2008. From 2008-2009 onwards, DSTA-PoliMi teamed up with Club Astra, the association operating the Mezzana Bigli airstrip, and Ing. Nando Groppo Srl, a reputed ULM manufacturer also based on that airstrip, in order to enhance the overall efficiency of the educational flight missions.

As a result, in 2008-2009 the “Mnemosine” system was installed on board the Ing. Nando Groppo Srl “XL” model (Figure 7), in 2009-2010 on the “Trial” model (Figure 8), in 2010-2011 on the “Folder” model, and in 2011-2012 on a CZAW “Sportcruiser”. All these aeroplanes belong to the same category of the Tecnam P-92, which remains DSTA-PoliMi's proprietary flying laboratory, on which the “Mnemosine” system and other instrumentation can be further developed and research activities can be carried out.

Figure 7 The Ing. Nando Groppo Srl “XL” at DSTA-PoliMi laboratories to be fitted with the “Mnemosine” FTI system for the 2008-2009 flight test campaign.

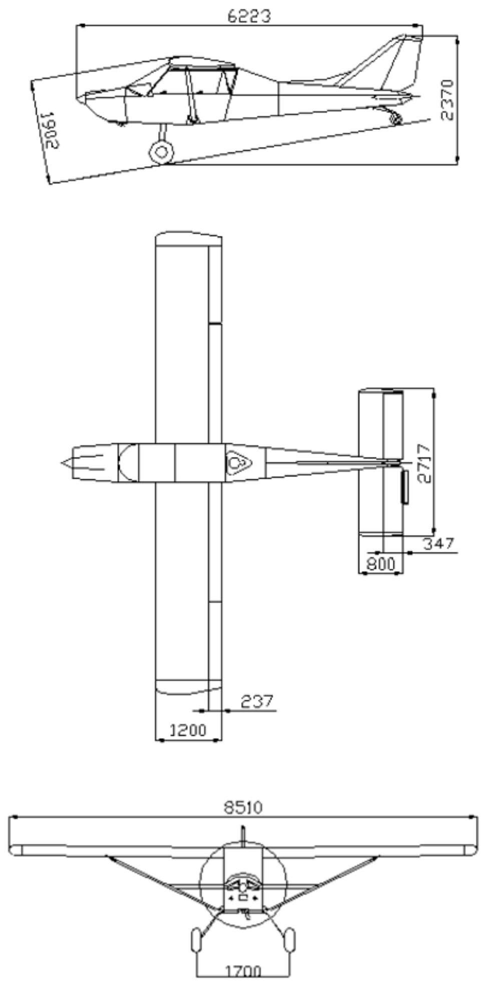
Concerning the 2009-2010 activities, an important element impacting upon the educational flight campaign was the concurrent flight test activity supporting a type certification process for the “Trial” model. In an effort to expand its market on a European scale, Ing. Nando Groppo Srl resolved to apply for certification according to the “LTF-UL 2003 airworthiness requirements for three axis standard control Ultra Light Aircraft” (DFS, 2003). These norms, issued by DULV (Deutsche UltraLeichtflugVerband) and adopted by the German DFS (Deutsche FlugSicherung) authority, encompass typical light aircraft airworthiness requirements, closely matching those included in the CS-VLA regulations that apply to larger aircraft. In turn, CS-VLA requirements, especially those covered in Subpart B “Flight”, are very close to those included in the more widely known FAR-23/CS-23.

DSTA-PoliMi was involved in the scientific and technological support to this demanding activity, contributing to requirement analysis and mission planning, and providing hardware and software resources, including the necessary FTI system.

Therefore, the 2009-2010 educational flight campaign was partly redesigned in order to obtain maximum synergy with the certification needs, contributing to the extensive flight test program established to this end. This program called for covering nearly 200 distinct test points, amounting to about 30 flight test missions.

In this way, by having the students operate using standard procedures, strictly adhering to regulations, as usual with any civilian type certification activities, the educational flight trials effectively produced valuable data for the certification program. Some test items could not be covered within the assigned time lapse, three days in June, 2010, and a few test points had to be repeated. The certification flight campaign was completed in August 2010, after a few more days of trials carried out by Ing. Nando Groppo Srl personnel. Eventually, the airworthiness requirements to be demonstrated in flight were all positively assessed and the completion of the certification procedure was achieved in January, 2011, with the achievement of the type certificate. A detailed account of this activity is found in Trainelli and Rolando (2011).

Figure 8 Three-view of the Ing. Nando Groppo Srl "Trial" model used in the 2009-2010 flight test campaign (quotations in mm).



Indeed, this activity represented an important and severe test for the "Mnemosine" FTI system and an ideal case study for the flight testing capabilities and skills developed at DSTA-PoliMi in the recent years. Together with other experiences carried out by academic institutions in support to industrial needs in the field of flight testing for light aircraft, such as those concerned with the CS-23 certification setting and detailed in Nicolosi et al. (2011) and Nicolosi et al. (2013), the present activity may reveal a groundbreaking experience towards the adoption of sound and systematic flight testing procedures in the currently loosely regulated ULM environment at large, and supporting evidence of the existence of sustainable, reliable and easy-to-use flight testing resources available to minor companies as well as institutions involved in the regulation of light General Aviation.

The previous results must be considered taking into account that many flight test missions have been performed by graduate students, whose only training had been carried out within the *Flight Testing* course. No specialized, lengthy, and expensive training was needed to operate the FTI system, as well as to plan the flight test missions and post-process measured data. At the same time, the pilot involved in the flight campaign, although an experimented flight instructor, was not a professionally trained test pilot. In many missions, the pilot workload was significantly reduced by the presence of the FTE-acting student with respect to single crew operations, and enhanced situation awareness was achieved.

Educational results

To date, over 80 students have passed the examination in *Flight Testing*, going through the flight test experience sketched above, and another 12 are expected to complete the final exam within the current year.

From the above description, it should be apparent that within this course the students are led through the whole flight testing process: from requirement analysis, to test planning, flight operation organization and monitoring, data analysis and final reporting. As it can be easily expected, designing from scratch and working out an array of real flight tests is an exciting and rewarding experience, and is perceived by the students as both one of the most fruitful activities in their last year of studies, and a significant introduction to the world of professional flight operations at large.

The educational outcome of the course can thus be summarized as follows:

- the students deal with the aircraft as a complex system of several interacting subsystems, and look at its behaviour as the product of this interaction, collecting together notions and experience matured in previous, separate disciplinary studies;
- the students put theory side-by-side with practical techniques, which not only have to be understood, but must be actually applied to a real flight mission, with all the real-life shortcomings, adaptation needs, troubleshooting, etc.;
- the students develop important qualitative elements in learning, such as teamwork abilities, initiative and self criticism, use of technical language and English language, written and oral communication abilities (reporting and final presentation);
- the students are exposed to the need of considerable interaction with other players involved other than colleagues and teachers (aircraft manufacturer, airstrip operator, flight test instrumentation specialists, test pilot, flight test manager), anticipating typical working conditions in an industrial environment;
- the students enjoy a distinct job-related flavour, which is inherent to the subject of the course, albeit treated retaining academic rigour.

These results are considered highly valuable from an educational perspective and inspire further development and consolidation of the *Flight Testing* course experience in the next years. Furthermore, the background acquired in this course inspired many students to continue their involvement in flight testing matters, either in their MS thesis projects either at DSTA-PoliMi (at a rate of 2-3 per year) or in the Flight Testing division of world-class aeronautical companies such as Alenia Aermacchi and AgustaWestland (also, 2-3 per year). Notably, a few former students of the course are currently employed by these companies in flight testing-related activities.

Resources

The *Flight Testing* course demands a very unique combination of resources. In fact, in addition to an increased commitment of the teaching staff compared to more typical lecture room and laboratory based courses, supplementary financial resources are needed to sustain the cost of dedicated FTI development and installation, as well as that connected to the implementation of the flight missions. Nevertheless, the overall budget did not prove excessive for DSTA-PoliMi, and the flight test campaign could be performed without problems every year to date.

The instrumentation system, with its many sensors and data acquisition units, amounts to approximately 15,000 €. This limited burden consists mainly on equipment acquisition costs, given the in-house development and implementation of the FTI system, basically at no added manufacturing expenses. Table 3 specifies the main cost items in the FTI, evaluated at the moment of writing, to which less than 3,000 € must be added for the rest of sensor (potentiometers, encoders, etc.) and non-sensor components (data recorder, acquisition boards, wiring, etc.).

Table 3 Representative costs for the most expensive FTI sensors.

Item	Parameters	Budgetary cost
Pitot boom	Total pressure, static pressure, angle of attack, angle of sideslip, outside air temperature	5,000 €
Attitude and heading reference system	Accelerations, angular rates, attitude angles	4,000 €
Stick load cells	Control forces (pitch and roll axes)	1,900 €
Pedal load cells	Control forces (yaw axis)	1,400 €

Costs associated with maintenance have also been kept to very low figures. In fact, the potentially mostly expensive task of Air Data System (pitot boom) periodic calibration has been regularly carried out at no cost either resorting to the DSTA-PoliMi aerodynamic laboratory, or exploiting free access to the Experimental Flight Line instrumentation laboratory at Alenia Aermacchi, Venegono facility.

Concerning aircraft operation costs, two different approaches have been exploited among the years, as mentioned above. In the first 4 years, the DSTA-PoliMi ULM was employed for the flight test campaign. The aircraft was already available as a Department asset since some years, therefore the relevant expenses in this case amounted to a fixed part proportional to the yearly rates for insurance (4,000 €/year) plus maintenance and hangaring fees (5,000 €/year), and a variable part proportional to the actual hours flown every year (approximately around 100 € per hour). This approach gradually showed a number of drawbacks, mainly related to the significant fixed costs and the relatively limited capability in troubleshooting the inevitable inconveniences arising during aircraft preparation and flight activities.

These problems were almost entirely solved switching to a pay-by-the-flight-hour model, by entrusting the management of aircraft preparation and flight execution tasks to professional companies such as Club Astra and Ing. Nando Groppo Srl, whose core activities encompass design, manufacturing and operating ULMs on a regular basis. This resulted in a more efficient and effective support organization on one hand, and a less expensive investment on the other. As a reference, the total cost of the 2012 flight test campaign, with its 16 flight missions, reached 4,000 €. This clearly represents a considerable saving compared to the previous full aircraft ownership and operation model, for which an initial minimum expenditure of 40,000 € must be taken into account for the acquisition of a basic ULM, at current market rates in Italy.

Finally, it must be remarked that it has not been necessary to allocate additional resources for liability matters. In fact, the current university standard student insurance policy fully covers for all on- and off-campus curricular activities. This includes educational flights, such as early familiarization flight activities and flight testing missions.

Conclusion

Flight testing constitutes a highly specialized niche area of expertise that is crucial to aircraft manufacturing and operation, and few universities offer dedicated, comprehensive education in this field. The presented approach, strongly inspired by industrial applications, including constant reference to applicable norms and safety procedures, demonstrates the possibility to run full-scale flight testing in an affordable way, providing each single student with the possibility to acquire hands-on experience on the subject. A visible, successful match of education and applied research goals was accomplished in the year 2009-2010 by co-operating in the type certification of an ultralight aircraft according to rigorous airworthiness requirements. This has been the first of a line of activities dedicated to the penetration of scientifically sound, reliable and rigorous flight testing procedures and tools within the light aviation environment.

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