AIDAA
XIX CONGRESSO NAZIONALE AIDAA
17-21 settembre 2007
FORLÌ (FC)

FLIGHT TEST ON ULTRALIGHT MOTORGLIDER, AERODYNAMIC MODEL ESTIMATION AND USE IN A 6DOF FLIGHT SIMULATOR

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ABSTRACT

The present paper deals with flight test activities performed by the authors on the Lambada ultralight motorglider. A novel complete instrumentations has been used, which allows a fast, reliable and accurate flight data acquisition and post-processing. The data acquired on board are sent to a ground station through a radio-modem. The data link allows a real-time flight data visualization.
Lambada is a motorglider built in Czech Republic and it is produced in two versions of different spans and wing surfaces. The plane is all-composite. The wing section is equipped with a flap with a slot. The flap is also a flaperon.
Flight tests and measurement of flight data were particularly focused to the accurate modelling and characterization of the airplane itself by means of system identification techniques. An example of how this has been possible for the above airplane is reported.
This paper illustates also how the aerodynamic database obtained through flight tests is used with a 6DOF flight simulator operated by the authors at the University of Naples. The simulator is also provided with a force reproduction system on the cockpit controls. The force feedback model has been implemented by the authors and resulted in an enhanced realism in piloting efforts.

1. INTRODUCTION

The present paper deals with flight test activities performed on Lambada ultralight motorglider by the ADAG (Aircraft Design and Aeroflightdynamics Group) research from University of Naples, Dipartimento di Ingegneria Aerospaziale. Flight tests have been performed with a recently acquired instrumentation designed for fast, reliable and accurate flight data acquisition and post-processing.

The available flight instrumentation is composed by the following items: (*a*) an "acquisition box" controlled by a fast PC for the acquisition and control of 32 channels (through a National Instruments A/D internal board); (*b*) an *X-Bow* inertial platform, which acquires 3-axis accelerations, 3 angular rates and 3 angles (pitch, roll and heading); (*c*) a GPS module by Novatel; (a) pressure sensors for air-data measurements, (*e*) a pitot probe mounted on the wing for angle of attack and angle of sideslip measurement. All the data are acquired on board and sent to a ground station through a radio-modem. The data link allows a real-time flight data visualization. Details of how the instrumentation is arranged in a typical flight test on a light aircraft such as the one analysed here are given later on in the paper.

Flight data are gathered and analised in order to extract both airplane's performance data and aerodynamic database. The latter is then exploited in the 6DOF flight simulation facility operated by the authors at the University of Naples. An outline of this system is also given in the paper.

2. THE AIRPLANE

Lambada is a motorglider built in Czech Republic with the following main characteristics: double-seat, single-engine, mid-wing, crew members sit one next to each other. It is produced in two versions of different spans and wing surfaces: UFM 11 and UFM 13. The airplane is all-composite. The UFM 11 wing is equipped with a lifting flap with a slot. The UFM 13 wing is equipped with a flaperon, a small wing fulfilling the function of lifting flap and deflecting in 5°, 9° and 16° positions. The rear tail is of the T-shape. The carriage is three-wheeled with controlled front wheel or two-wheeled with controlled tail wheel. The main wheels are braked. The main carriage legs are made of laminate springs. The UFM 13 Lambada may be equipped with removable wing extensions. The extensions increase the spread, slimness and performance of the plane.

Wingspan	13 (15) m	Min. speed	63 km/h
Lenght	6,6 m	Cruising speed	150 km/h
Height	1,95 m	Max. speed	200 km/h
Wingarea	12,6 m2		
MTOW	472,5 kg	Glider ratio cca.	1:26 (30)
Empty weight	265/280 kg	Climbing solo	3,5/7 m/s
Aerofoilsection	SM 701	MTOW climbing	2,5/5 m/s
Engine, Rotax 912 UL	80 HP	Min. sink rate	1,1 m/s
		Fuel tank	1 or 2×50 lt
		Number of seats	2

Table 1: Main characteristics of Lambada *motorglider*

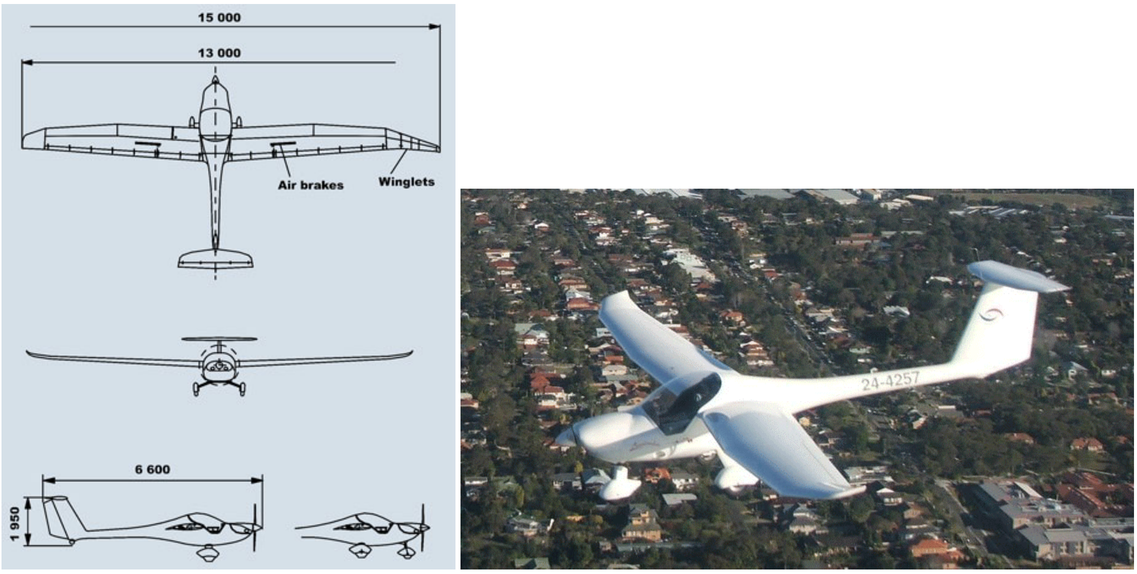

Figure 1: Three-view and aerial photograph of the Lambada *motorglider*

3. INSTRUMENTATION

The motorglider presented above has been instrumented for the purpose of performing specific flight tests, focused on the determination of main performance characteristics and high fidelity aerodynamic database extraction. Flight tests on light and ultralight aircraft have been one of authors' focus in recent years and the details of past experiences are found in ref. [1] to [6]. Here are presented some further details of the novel instrumentation recently acquired.

The whole data acquisition system consists in a central unit, named *CSYS* (Central SYSstem), see fig. 1. It includes an airborne Pentium PC equipped with dedicated cards for the conditioning and control of signals. All signals come from a set of flight sensors appropriately connected to central unit.

The CSYS is a transportable and complete data acquisition system, designed for the gathering of flight data, their storage on magnetic support and their transmission in real time. It integrates a differential GPS and is easily interfaced with an AHRS platform, see fig. 2. When equipped with an external radio modem the system is able to transmit the data in real time to a remote ground station.

The PC is equipped with a National Instruments card, which is the main building block of the data acquisition hardware. Multiplexing, conditioning and signal control technologies are embedded into the PC box. The CSYS is able to acquire 32 analogue channels and 6 digital channels; it has 4 analogue output ports, 4 USB ports and other typical PC connections. The system consists of the following functional subsystems: (*i*) the main box, fig. 1, (*ii*) a GPS box, fig. 3, (*iii*) a power box for servos and actuator motors, fig. 6 (right), (*iv)* a radio-modem box, fig. 6 (right), (*v*) a terminal board box, (*vi*) a box for the air data boom and auxiliary pressure gauges, (*vii*) a palmar unit A730.

The main box contains a PC with a Pentium IV, 3GHz processor. The features of such computer were chosen in order to accomplish all the tasks required by a typical flight data acquisition session and for future flight control management. Fig. 1 shows the main box with the PC. The main box, related connections and all sensors were mounted on board, in the place reserved to luggage. Fig. 1 (right) and fig. 6 (right) show the main box and its supporting structure as mounted on the aircraft.

*Figure 1: Acquisition box (*CSYS*), internal cards and external view*

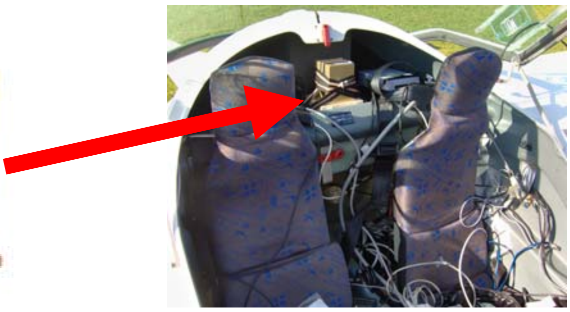

Figure 2: Inertial platform (AHRS) and mounting position inside the cockpit

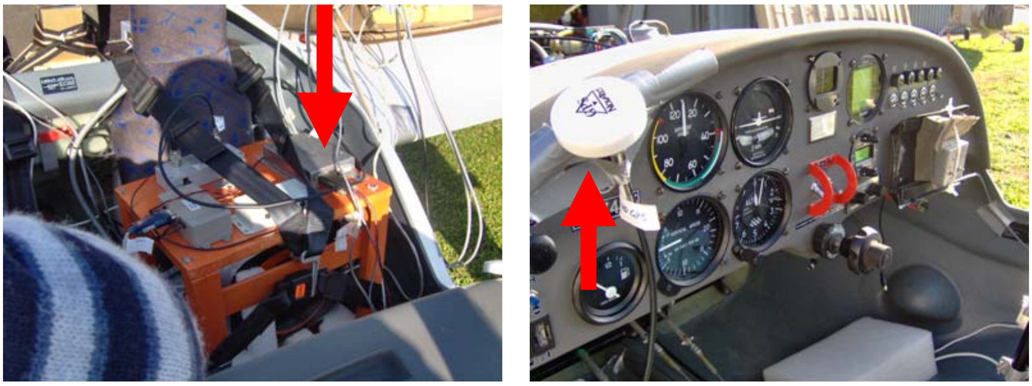

Figure 3: GPS box (left) and antenna (right)

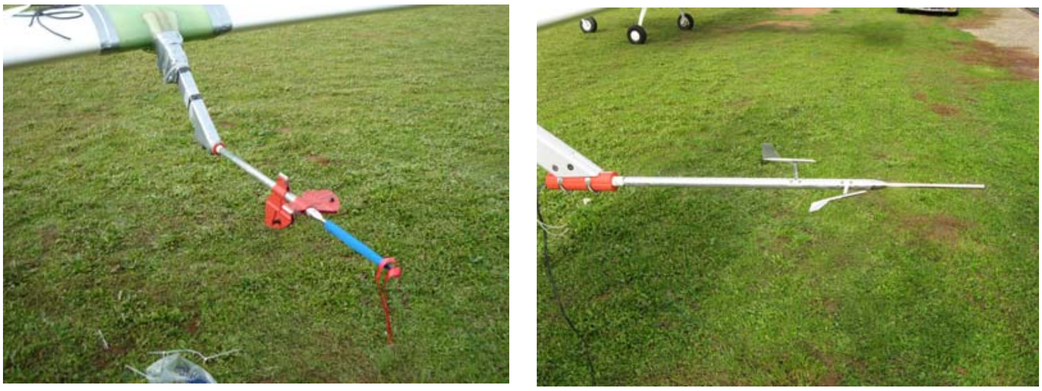

Figure 4: Air data boom mounted on the left wing leading edge

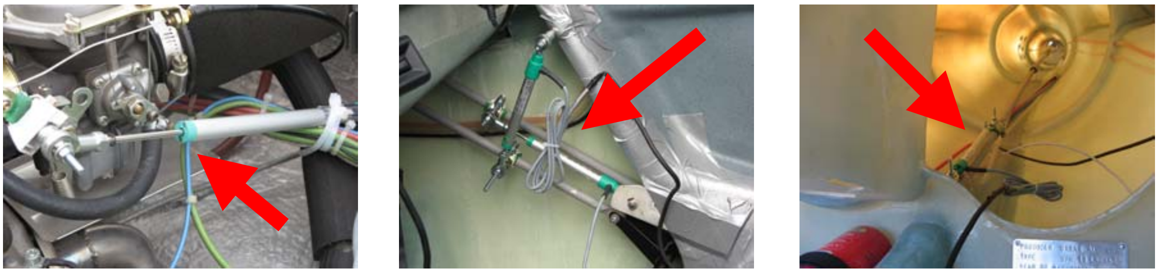

Figure 5: Potentiometers mounted on throttle (left), ailerons/flaps (center) andelevator (left)

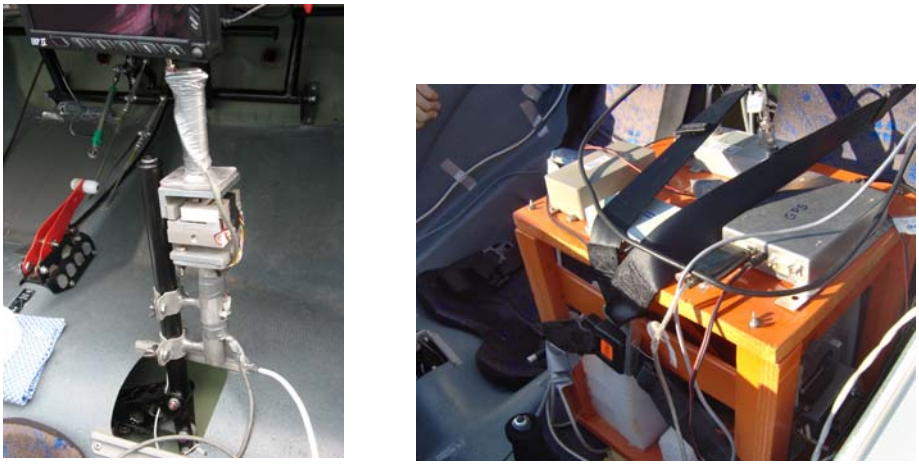

Figure 6: Load cell mounted on the stick (left) and acquisition box (right)

The CSYS unit has 32 analogue channels grouped as follows: channels 1 to 7 connected to the air data boom (fig. 4), channel 8 and 17 to 24 connected to the AHRS platform, channels 9 to 16 and 25 to 32 free and user configurable. Air data channels and platform channels are special channels while all user configurable channels are conditioned by an instrumentation amplifier INA128. Each user channel is modifiable by means of a dedicated resistance.

4. SENSORS FOR FLIGHT DATA ON-BOARD ACQUISITION

The aircraft is equipped with sensors for the acquisition and measurement of flight data. In particular, a set of potentiometers has been installed on the aircraft to measure the deflection of aerosurfaces, see fig. 5. Inside the cabin, near the aircraft centre of gravity, an inertial platform has been mounted for the purpose of measuring accelerations, attitude angles and angular rates, see fig. 2.

Pressure transducers have been installed to measure the anemometric speed and altitude. A special sensor for the measure of flow angles, i.e. angle of attack and sideslip, has been acquired and mounted on the aircraft, see fig. 4. The installation of this sensor on the left has required a dedicated streamlined support fitted to the wing profile.

Another piece of equipment recently acquired is a differential GPS, see fig. 3. This is an high accuracy device, capable of observing variations in the aircraft position up to values as small as 20 to 30 cm.

Particular care has been taken in mounting a load cell on the control stick in order to measure the piloting effort, see fig. 6 (left). More visual details of the overall instrumentation are seen from figures 2 to 6 we show some pictures of the above sensors as mounted on the aircraft.

5. FLIGHT DATA MANAGEMENT AND ANALYSIS SOFTWARE

Besides CSYS specific software, which has been provided by the equipment supplier, we have developed a dedicated Matlab set of tools to manage and analyse flight data. These tools enable the visualization in real time of signals coming from all the channels and their calibration. All the programs are written in Matlab 7.0 and designed to be fast and simple. The aim is to allow flight test engineers to analyse quickly the data, even on the flight field, to gain a feeling on how well the measurement are being done, and possibly stop and adjust the sensors for optimal data acquisitions.

The above software include the following main features: fast visualization of quantities acquired by the GPS card and the main acquisition box, data processing via Matlab graphic tools, map management and flight trajectory analysis.

A set of stored data and file naming conventions is also implemented within the software. This is needed when many acquisition are planned and a huge amount of data from many manoeuvres might end up to be saved in the CSYS storage devices. The software is also able to track some specific time windows in the data, which are triggered by the pilot through a dedicated switch when he wants to mark some particular phase of a manoeuvre. For example, the switch turns out to be very useful in take-offs and landigs when supposedly stalls or slow manoeuvres are scheduled.

The software is able to split up the row data while they are measured and stored saving as many files as many times the pilot acts upon the switch. A particular feature of this software resides in the topography and GPS acquisition management. The actual three-dimensional trajectory is displayed and appropriately related to a standard earth reference frame. The trajectory is also displayed with the help of the popular *Google Earth* application, showing the variation of a user selected quantity along the flight path.

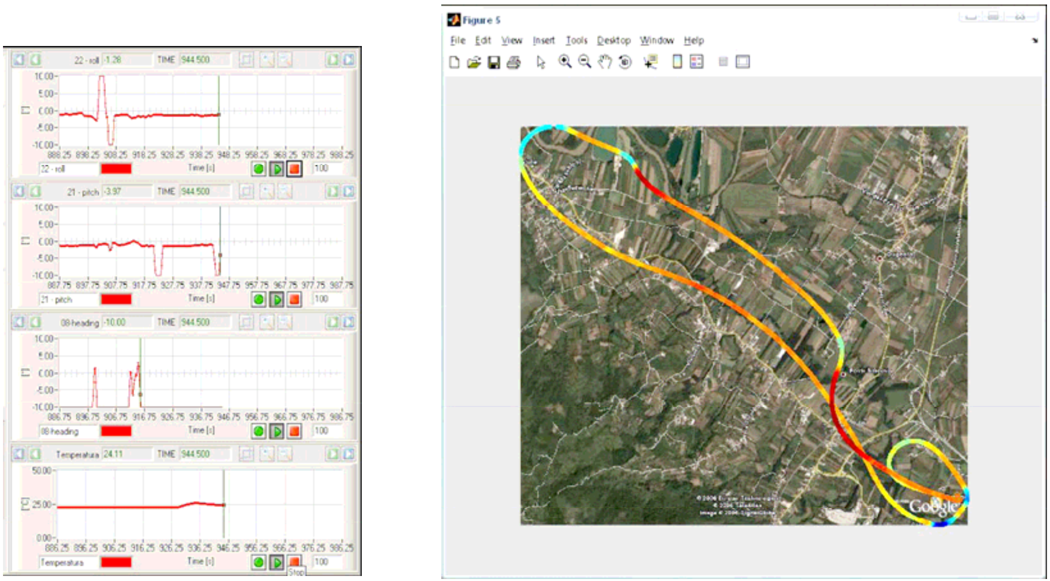

Figure 7: Example of signal plots by the management application provided with CSYS (left); trajectory acquired during a flight and variation of aircraft bank angle superimposed on a real map

6. PERFORMANCE DATA ANALYSIS

In fig. 8 to 11 we report examples of performance measurement on the *Lambada* motorglider. The plots in fig. 8 shows the measured and estimated rate of climb at different altitudes (left) and the aerodynamic efficiency (right) as a function of true airspeed as determined from power-off descending flight manoeuvres.

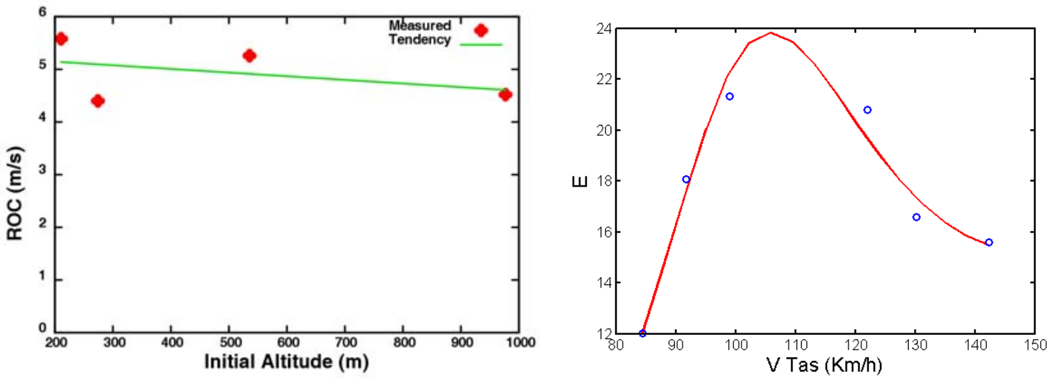

Figure 8: Rate of climb versus initial altitude (left);
estimated aircraft aerodynamic efficiency versus flight speed (right)

In fig. 9 we report the stick force (*SFe*) in symmetric flight as a function of calibrated airspeed (left) and the elevator deflection in terms of true airspeed (right). Fig. 10 shows two speed polars, i.e. the top plot is a curve of the sink rate (*Vz*) versus the total speed (*V*); the second plot in the same figure reports the sink rate and the flight path angle (γ) versus the ground speed (*Vx*, the tests had place in a relatively calm air).

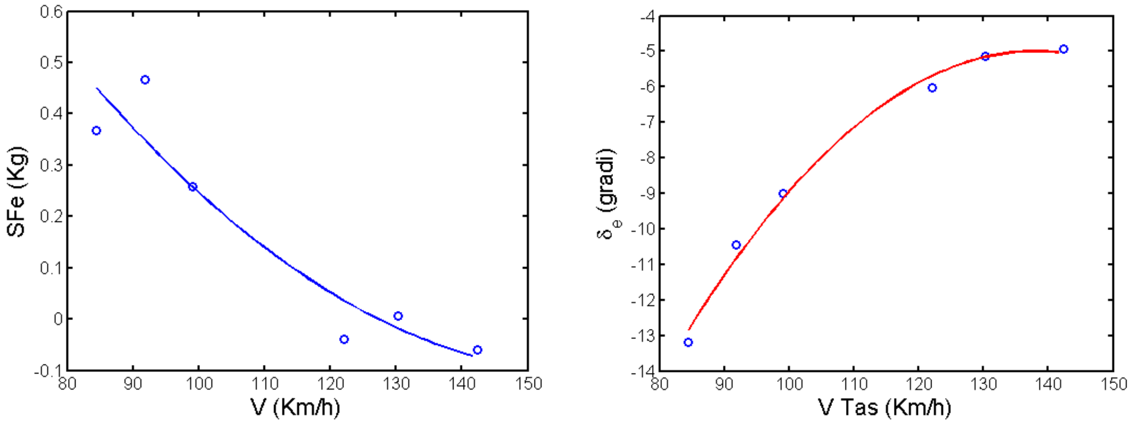

Figure 9: Stick force (left) and Elevator deflection (right) versus speed in level flight

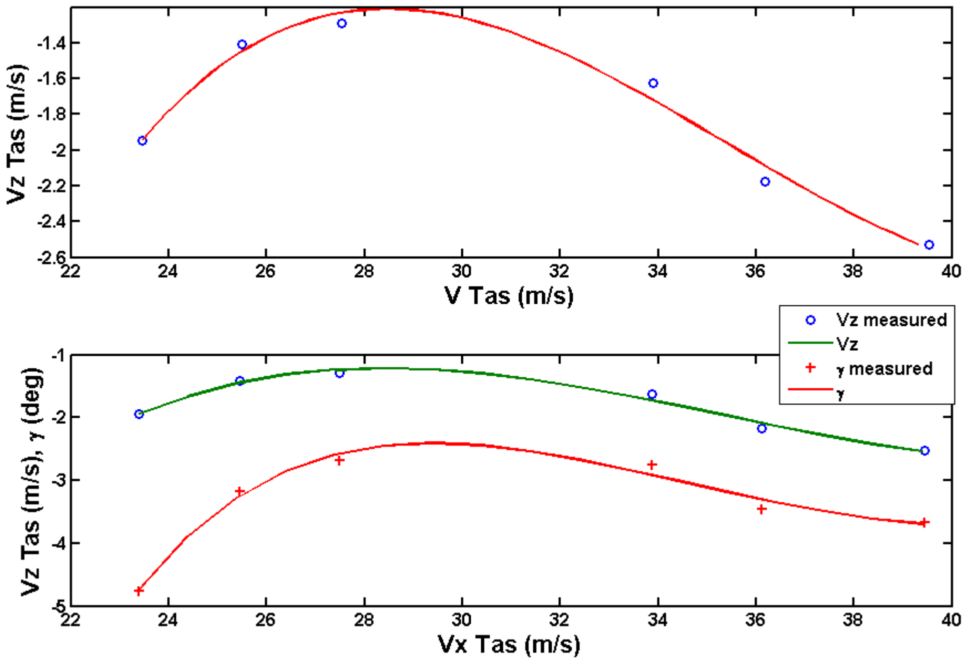

Figure 10: Speed polars

Fig. 11 shows the stick force ($F \equiv SFe$) versus load factor (n) in coordinated, constant altitude turning flight. A value of stick force gradient of about 0.70 Kg/g can be obtained from interpolation of measured data.

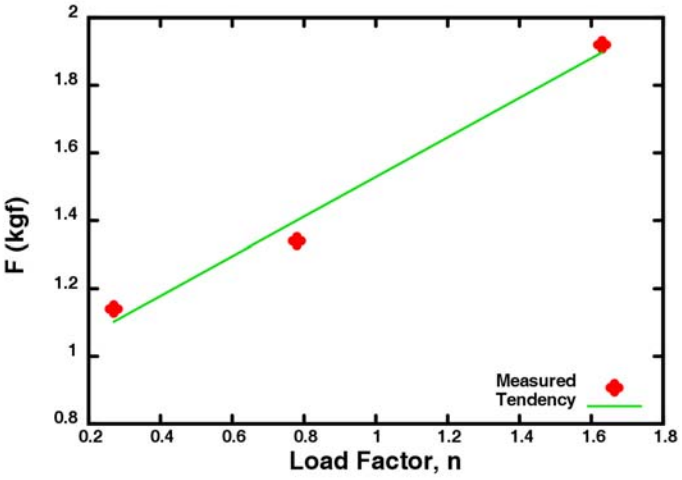

Figura 11: Stick force load factor in turning flight

7. SYSTEM IDENTIFICATION OF LAMBADA MOTORGLIDER

The flight test activities and the measurement of flight data presented in this paper were particularly focused to the accurate modelling and characterization of the aircraft itself by means of system identification techniques.

From recorded flight data it is possible to reconstruct an high fidelity aerodynamic model of a given aircraft when the manoeuvre and flight conditions are properly scheduled in advance. An example of how this has been possible for the *Lambada* motorglider is reported below.

The test pilot were asked to perform some particular manoeuvres, most of them starting from trimmed flight. Actual pilot inputs were measured together with all the possible flight parameter response time histories. By processing the data with a dedicated software, mainly based on the book by Jategaonkar [6] and on authors' previous works [2,3], the aerodynamic model has been literally extracted by iteratively perturbing a set of unknown aero-dynamic coefficients until the simulated responses do not match with the measured ones. The mathematical details of system identification techniques are found in references [2,3,6].

As an example of parameter estimation, below we report some representative time histories. In fig. 12 is shown an example of longitudinal manoeuvre as actually commanded by the pilot. The ideal elevator deflection should have been a double step pull-push/push-pull manoeuvre.

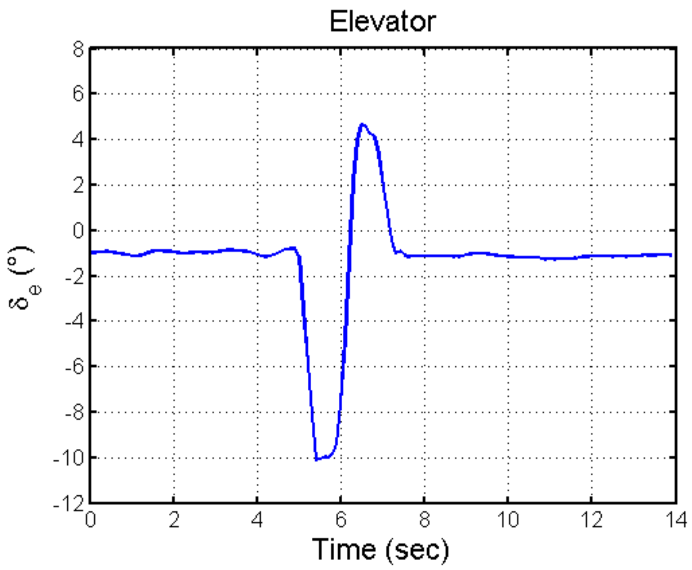

Figure 12: Time history of commanded elevator deflection

The measured and estimated responses of the above manoeuvre are reported in fig. 13 and 14. The first one shows time responses of longitudinal rotational rate *q* (top), longitudinal rotational acceleration (middle), and forward acceleration *ax* (bottom).

The measured and estimated responses of the true airspeed (top), angle of attack (middle), and elevation angle (bottom) are finally reported in fig. 14.

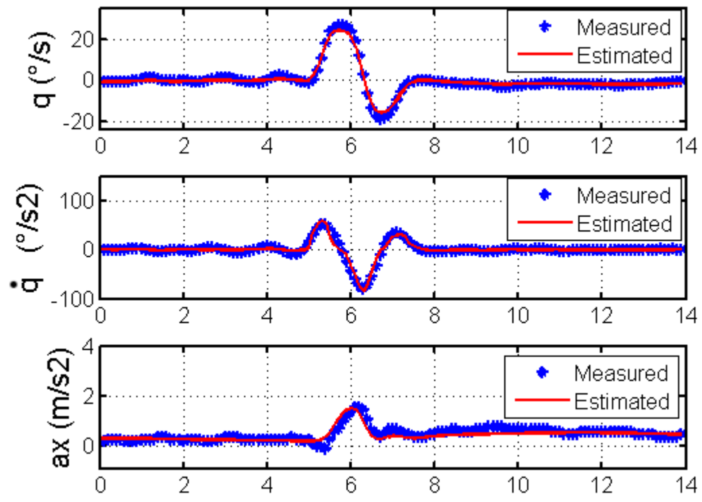

Figure 13: Responses of longitudinal rotational rate q (top), longitudinal rotational acceleration (middle), and forward acceleration ax (bottom)

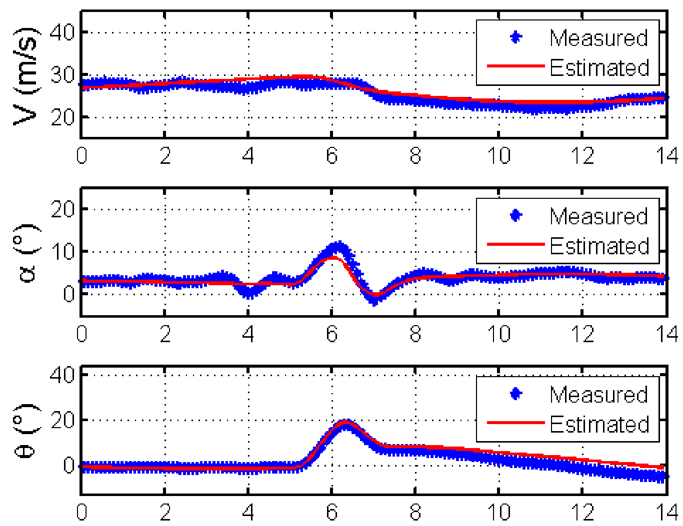

Figure 14: Airspeed, angle of attack, elevation angle responses

In tab. 2 we report as a result of the aircraft system identification process the main estimated, longitudinal aerodynamic characteristics of Lambada aircraft.

CD_0	0.0260
CD_α	0.8050
CL_0	0.2016
CD_α	6.4271
Cm_0	-0.0016
Cm_α	-0.7663
Cm_q	-36.9188
$Cm_{\delta e}$	-2.1121

Table 2: Main longitudinal aerodynamic characteristics of Lambada *motorglider*

8. 6DOF FLIGHT SIMULATOR

The results of aircraft system identification, i.e. the aerodynamic databases, are naturally used in flight simulation practice. A 6DOF flight simulation facility is operated by the authors at the University of Naples. The whole system has been designed to be operated both as a driving simulator and as a flight simulator. The simulator is a full scale facility, including real vehicle mock-ups, a motion system, and a large projection system, see fig. 15 (left). The authors have worked mainly on the flight simulation side. The flight simulator cockpit has been conceived as a generic cabin of a small aircraft, see fig. 15 (right). The chosen software module that guides the various components of the system is based on *FlightGear/JSBSim*, see ref.s [7] to [12]. FlightGear is a civilian open-source flight simulator comparable to Flight Simulator from Microsoft. JSBSim is the default flight dynamics model (FDM).

The simulation of aircraft motion, the cockpit instrument panel and flight controls, the outside scenery are all managed by a number of instances of FlightGear talking to each other via net protocols. Moreover, the simulation is supported by two other software modules that control: (*i*) the motion platform, in conjunction with the external view generation module, in order to give a proper acceleration feel to the user, and (*ii*) a force reproduction system on the cockpit controls that adds realism to the piloting task. Details about all these modules are given in the paper by Coiro et al. [7,8].

Particular effort has been spent into the development of the simulation facility to implement hinge moment equations in the simulation software in order to reproduce a realistic piloting effort and to obtain a reliable closed-loop force-feedback system on all aircraft commands (elevator, ailerons and rudder). The system is also able to reproduce force-free aero-surface response.

9. CONCLUSIONS

Flight test activities have been performed on Lambada motorglider. A new, fast and reliable flight test instrumentation has been used and presented in the present paper. Some indication about developed software for flight data acquisition and analysis in post-processing phase have been outlined. In the paper some interesting results of measured aircraft performances have been presented and shown.

Flight test activities and the measurement of flight data were particularly focused to the accurate modelling and characterization of the airplane itself by means of system identification techniques. From the analysis of recorded flight data it is been possible to assess aircraft performances (i.e. speed polar and max efficiency) and to reconstruct the aerodynamic model. To do that the manoeuvers and flight conditions were properly scheduled in advance.

In this paper has been presented also how the aerodynamic database obtained through flight tests have been transferred to a 6-DOF flight simulation laboratory operated by the authors at the University of Naples. The simulator is a full scale facility that include a real scale vehicle mock up, a motion system, and a large, fixed projection system. The aim of the flight simulator is twofold: (*i*) serving as a research tool for model characterization and for the investigation of flying qualities of very-light and ultra-light aircraft; and (*ii*) offering a training options to the pilots of such airplanes. For these reasons the simulator cockpit has been conceived and set up as a generic cabin of a general aviation aircraft.

Figure 15: Projected images in front of the moving cabin during simulation(left); virtual indicators and moving map inside the aircraft cockpit (right, top); flight controls (right, bottom)

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