000000000PE

Light Aircraft Instrumentation to Determine Performance, Stability and Control Characteristics in Flight Tests

Paulo Henriques Iscold Andrade de Oliveira
Rogério Pinto Ribeiro
Ricardo Luiz Utsch de Freitas Pinto
Luciano Saraiva Resende
Leonardo de Pádua Andrade Filho
Bruno Miranda Maschtakow
Daniel Valente Fraga
Federal University of Minas Gerais (Universidade Federal de Minas Gerais)

Domenico Pietro Coiro
Fabrizio Nicolosi
Nicola Genito
University of Naples (Università di Napoli)

ABSTRACT

This paper present the instrumentation procedure used in order to determine the performance, stability and control characteristics of the light aircraft CEA-205 CB-9 Curumim.

The instrumentation used is: i) autonomous acquisition system using micro controllers; ii) solid state inertial platform; iii) pitot probe ; iv) attack and sideslip angle indicators; v) potentiometer on command system; vi) load cell on command system; vii) propeller tachometer; viii) barometer; ix) thermometer and x) GPS.

Assembly and calibration detail procedures are presented with some results obtained on typical maneuvers. This work, in development on the Center for Aeronautical Studies of Federal University of Minas Gerais (UFMG) and on the University of Naples, intend to assembly a system in order to perform low cost flight tests on light aircrafts.

INTRODUCTION

Commercial aircraft industry expends great efforts and costs in flight tests when developing new aircrafts. The experimental aviation field ever looked for a solution in order to permit the execution of flight tests with low costs.

Brazil in last years observed a continuous production growth of this kind of airplanes, but the investments made in the development of flight test equipments are not in the same level. This way, new aircraft developments have been spoiled because the lack of knowledge, mainly in aerodynamic, stability and control characteristics.

The Center for Aeronautical Studies of UFMG had designed and built light airplanes during the last forty years and now is engaged in the development of your own flight test equipments, focused in the needs of Brazilian experimental aviation.

In order to begin this task was established a partnership with University of Naples to receive technical support. The visit of two researchers of University of Naples to Brazil with their own flight test equipment permitted the execution of some preliminary flight tests on CEA-205 CB-9 Curumim ultralight. The procedures used in the instrumentation of this aircraft will be described in this paper.

THE ULTRALIGHT CEA-205 CB-9 CURUMIM

The airplane used on this preliminary flight tests is the CEA-205 CB-9 Curumim. This ultralight aircraft was designed and built on the Center for Aeronautical Studies of Federal University in the early 90’s being the fourth aircraft developed by UFMG.

Curumim is an all-wood, bi-place, single engine, low wing airplane. It is powered by a Limbach L2000B 80HP engine and had already flown more than 200 hours.

Nowadays Curumim is based in Pará de Minas, Minas Gerais (seventy kilometers from Belo Horizonte, where the University has its campus), and is used as a training aircraft and also as a platform for researches made by CEA/UFMG.

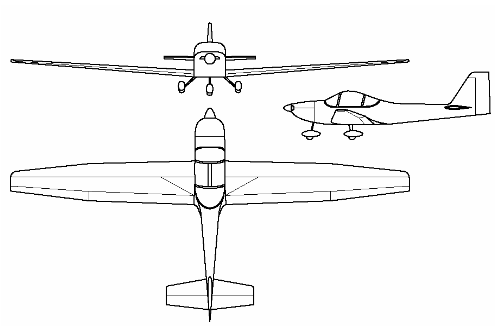

Figure 1. CEA-205 CB-9 Curumim

EQUIPMENT DESCRIPTION

The equipment used in the CEA-205 CB-9 Curumim flight tests consist basically of: i) data acquisition system; ii) inertial platform; iii) calibrated pitot tube; iv) attack and sideslip angle indicator; v) command positions indicators; vi) command forces indicators; vii) propeller tachometer; viii) barometer; ix) thermometer, and; x) GPS.

AUTONOMOUS ACQUISITION SYSTEM – The acquisition system is the core of all flight test equipment. There are, basically, two problems about the acquisition system used for experimental aircraft flight test: i) its price and ii) its size.

The acquisition systems developed for the commercial aeronautical industry must be certificated to be installed at the airplanes and this makes it very expensive when compared with the financials possibilities of the experimental aircraft industries. Furthermore, these kinds of acquisition systems are big and heavy being difficult to be installed inside of a light airplane. Must be observed also that it is very common in experimental aviation single place aircrafts where the pilot must control the airplane and control all acquisition procedures. In this case, computer based acquisition systems are not the best choice and an autonomous system, where the pilot must only start and stop the acquisition, will be preferred.

University of Naples has already developed an autonomous acquisition system to be used in unmanned air vehicles and in light aircraft flight tests. This system was developed over a microcontroller system, and use memory cards to store all data. The microcontroller is a HOBO Tattletale 8v2 based on a 68332 processor, able to acquire 8 analog inputs simultaneously. These analog inputs are converted to digital signal by a 12 bits built-in A/D converter that can perform this conversion in sample rates up to 100 kHz. All the information is recorded on a Compact Flash memory card. A four time multiplexer is used to expand inputs from 8 to 32 channels. This system is also able to managed three serial I/O channels. One of these channels is used to acquire the GPS input and in the future another one will be used by a wireless modem in order to perform telemetric operations.

The firmware of the processor can be written in C or TX Basic language making difference mainly in the processor speed. In this case, the firmware is written in TX Basic, permitting an acquire speed of 10 Hz for the 32 channels plus the GPS.

It is very important to synchronize the GPS signal with the data acquired from the analog inputs and it is a difficult task when is taken in account the acquisition speed. In this system the firmware installed on the main processor of the microcontroller is responsible to put this data synchronized and a detailed presentation about it is out of the scope of this paper.

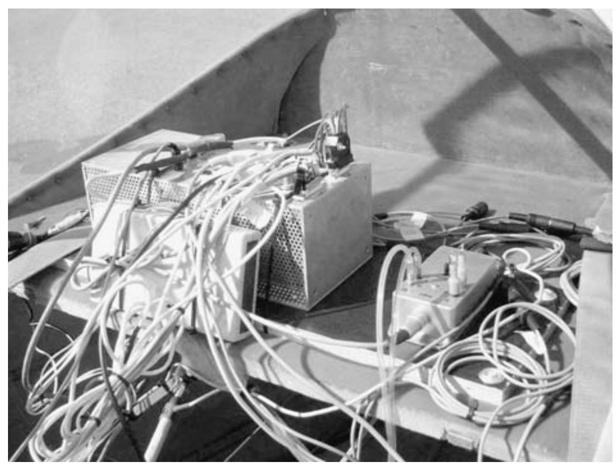

Figure 2 – Data acquisition box

INERTIAL PLATFORM – Another important equipment to perform stability and control flight tests is an inertial platform. This equipment must be able to measure the accelerations (linear and angular) and the attitude (angular) of the aircraft.

A Crossbow VG3000GA solid state inertial platform had been used (Figure 3). The solid state technology permits a very compact and light platform. The acceleration capabilities are also very large (+/- 10g´s) permitting, a very easy handling during the installation and the possibility to perform complex maneuvers during flight tests.

To perform these flight tests two platforms were used: one inside the airplane (Figure 3), which is used to measure the airplane attitude and acceleration, and another one inside the wing tip (Figure 4). This second platform makes necessary in order to measure the torsion deformation of the wing tip, where the pitot tube and the attack angle indicator are installed, relative to the fuselage. For another flight tests this platform is not needed if the wing torsion is known.

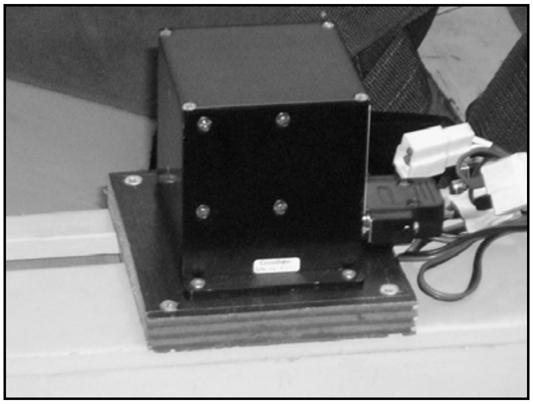

Figure 3. Cockpit's Inertial Platform

The position of the main platform in relation to the aircraft gravity center is very important in order to measure only the rigid body acceleration and attitude. As the CEA-205 CB-9 Curumim is a side-by-side airplane, the main platform were installed over the cockpit console had been moved in order to be exactly over the airplane gravity center.

Figure 4. Wingtip's Inertial Platform Hole

PITOT PROBE – A calibrated pitot probe had been installed near the wing tip for a more accurate measure than using the airplane's original pitot tube. This pitot tube was built by University of Naples using piezoelectric pressure sensors. All the calibration is performed in their wind tunnel and a detailed explanation about this is out of the scope of this paper.

To install this pitot, a fiber glass "glove" was made and fixed to the wing, easily, with adhesive (duct) tapes. This solution is very useful because is not necessary to modifying anything on the airplane's wing, as shown on Figure 5.

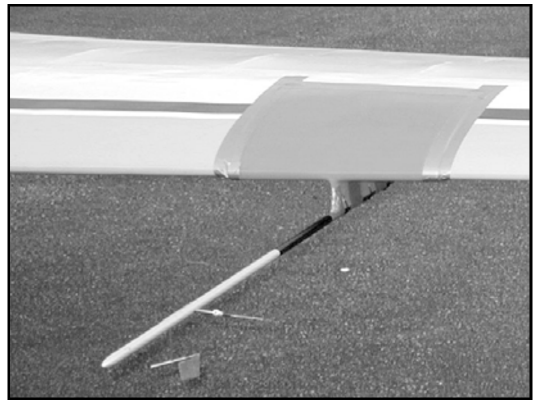

Figure 5. Pitot Probe and Angle Indicators

ATACK AND SIDESLIP ANGLE INDICATOR – The pitot tube has also two built-in flags in order to measure the angles of attack and sideslip. The mechanism of these two flags is also a development of University of Naples and use Hall Effect sensor to generate the electrical signal. The Hall effects sensors used is a Honeyweel LOHET II.

This solution is very cheap, light and precise, especially because there are no parts in contact to generate the signal. Another possible solution should use rotational potentiometers with low friction and high precision that is, normally, very expensive.

COMMAND POSITION INDICATORS – In order o know the position of the command surfaces and throttle linear potentiometers had been installed on the command system cables and tubes.

It was used GEFRAN's PZ12 series potentiometers with different sizes with typical linearity of 0.05%. Those potentiometers have self aligning ball-joints on their ends, so it was possible to fix then on the command system using steel brackets protected by rubber stripes. Again, this solution is very useful because is not necessary any modification on the airplane's command system.

The installation of these potentiometers can be viewed on Figure 6 for the aileron command, on Figure 7 for the elevator command, on Figure 8 for the rudder command and on Figure 9 for the throttle knob.

LOAD CELL ON COMMAND SYSTEM – In order to measure the forces needed to make the maneuvers was used a bending beam load cell.

Figure 6. Aileron Potentiometer

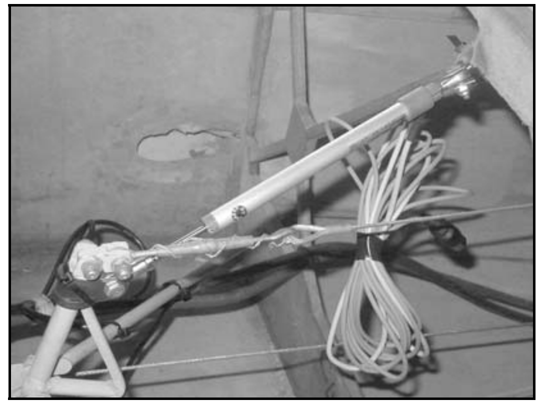

Figure 7. Elevator's Potentiometer

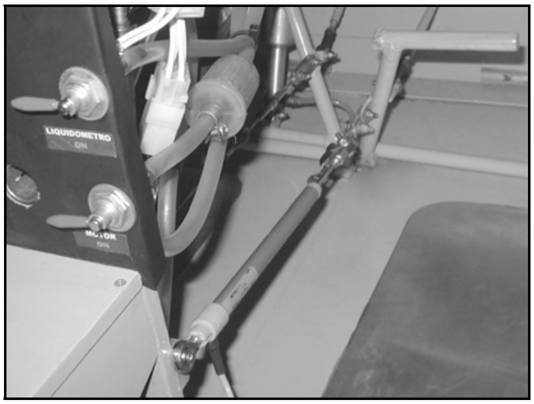

Figure 8. Rudder's Potentiometer

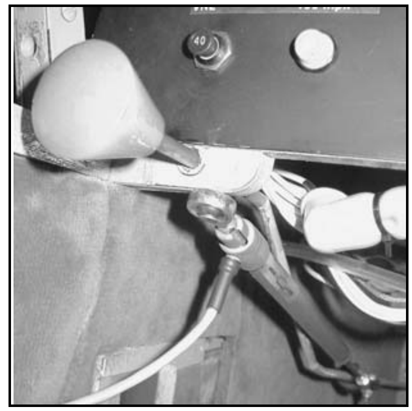

Figure 9. Throttle control knob's potentiometer

This load cell was attached to pilot's stick on one side and, on the other side an additional stick was made for the pilot to fly with it. The pilot would fly using this stick only when the forces on the commands were in interest. Load cell installation is shown on Figure 10.

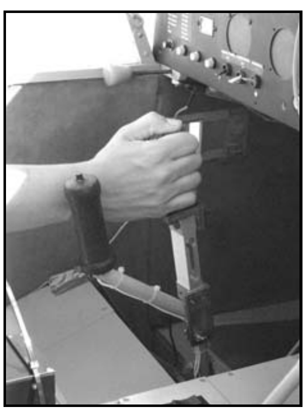

Figure 10. Load cell on command system

PROPELER TACHOMETER – In order to measure the propeller rotation speed a frequency-voltage converter was used to read the frequency signal produced by the engine alternator.

BAROMETER – The airplane altitude was determined by the static pressure measurement from the pitot tube. By this way is possible to reduce sensor quantity decreasing the cost of the equipment.

THERMOMETER – In order to measure the external temperature, a type K thermocouple was used. This thermocouple was installed outside of the cockpit in a place protected from external flow. In this way the temperature measured was the external air temperature without the effect of the airspeed.

GPS – A GARMIN 12 global positioning system was used to record the airplane's position and ground speed. This information is provided one time per second by a serial communication port.

CALIBRATION

A special procedure, using a personal computer as a terminal, connected to one of the serial ports of the acquisition system, was developed in order to read the individual signals of each sensor to perform its calibration.

The inertial platform linear acceleration calibration was performed before its installation at the airplane. This procedure consists to place the platform over a horizontal leveled table (leveled using bubble level) with one of the axis pointed downward. In this position the acceleration signal of this axis is considered to be equal 1g. Placing these axes upward the acceleration signal is considered as 1g. This procedure must be repeated for other two axes. The angular speed calibration is not performed because would need a special device with a precisely known angular speed to rotate the platform. The manufacture calibration information about angular speed, supplied by the Crossbow, was used as standard.

The calibration of all command position sensors was done once this equipment has been completely installed. The control surfaces angular position (aileron, rudder or elevator) was measured with a simple pendulum device as shown on Figure 11. The command position sensor signal is read together with the corresponding surface position measured by this device. Getting at least five points it is possible to determine with precision the calibration curve of this sensor. Must be noted that for the command system consisted by rigid linkages is very common to have non-linear behavior of the sensor signal in relation to the surface command.

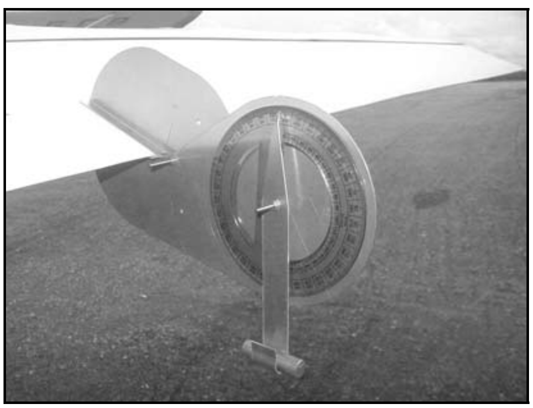

Figure 11. Control surface angle indicator

The pitot tube and temperature sensor were calibrated at Naples University wind tunnel and a detailed description of this procedure is out of the scope of this paper.

The load cell was calibrated using known weights attached to the load cell's stick and than acquired its value.

Propeller tachometer calibration was made reading the propeller's rotation through an optic tachometer and than compared with the sensor signal.

FLIGHT TESTS

The flight tests performed in CEA-205 CB-9 Curumim consisted basically of performance, stability and control flight maneuvers.

The performance flights intent to measure: i) stall speed; ii) cruising speed; iii) maximum speed; iv) climb characteristics; v) glide characteristics; vi) turn speed; vii) roll rate, and; viii) yaw speed.

The stability and control flights were performed in order to acquire information about some rigid body movements as: i) phugoid; ii) short period; iii) dutch-roll and iv) longitudinal acceleration and deceleration.

The typical maneuvers are: i)3-2-1-1 longitudinal maneuver, used to excite longitudinal short period movement; ii) elevator pulse, used to excite longitudinal phugoid movement; iii) aileron bank to bank maneuver, used to measure roll rate and roll acceleration, iv) level turn, used to measure turn speed; v) rudder doublet, used to excite dutch roll movement and vi) thrust variation, used to measure acceleration and deceleration.

The maneuvers used in order to measure other characteristics are very simple, being important only to keep the airplane really at a steady condition. About stalls, it is important to note that the deceleration must be less than $6m/s^2$ (1mph/s).

RESULTS

Typical results of these flight tests can be viewed at Figure 12.

This figure shows only a small number of variables, which is the most interesting for the analysis of a phugoid. This visual presentation is performed by a MATLAB code developed by Naples University.

A detailed study interpretating all data acquired in these tests will be published in future. This interpretation will be done using techniques of parameter estimation that is beyond the scope of this paper.

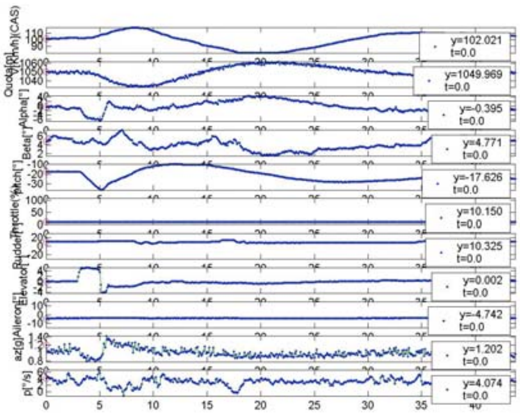

Figure 12 – Typical results – phugoide movement

COST ESTIMATION

An initial cost estimative to build a similar system is showed on Table 1.

Table 1– Cost estimation

DESCRIPTION	QT.	PRICE US$
Garmin GPS 12	1	~ 300,00
Type K Thermocouple	1	~ 10,00
GEFRAN PZ12 Potentiometer	4	~ 220,00
CROSSBOW VG3000GA	1	2000,00
Pitot Probe complete	1	300,00
Bending beam load cell	1	90,00
HOBO Tattletale Model 8v2	1	500,00
Miscellaneous electronic		200,00
TOTAL		4280,00

Can be noted that this cost is compatible with the possibilities of experimental aviation industry.

CONCLUSION

The instrumentation equipment and procedures used on CEA-205 CB-9 Curumim, was described in this paper. Details about the assembly and calibration procedures was presented, explain important details for its repetition.

The equipments used for this flight tests was very simple and low cost, making possible its use in experimental airplanes flight tests in Brazil.

Results and analysis was not presented in this paper will be published in future, but the results visualization show that is consistent and without high noise.

BIBLIOGRAPHY

DPA, 2004, http://www.dpa.unina.it/coiro/ - Aeronautical Design Department – Prof. Domenico Coiro.

Gefran, 2004, http://www.gefran.com/ing/home.html

Onset, 2004, http://www.onsetcomp.com/

CEA, 2004, http://www.demec.ufmg.br/cea

Crossbow, 2004, http://www.xbow.com/

Barros, C.P., 1989, “Projeto da aeronave CEA-205 CB-9 Curumim”, Centro de Estudos Aeronáuticos da UFMG, Belo Horizonte, Brazil.