# FLIGHT TESTS FOR PARAMETER INDENTIFICATION IN LIGHT AIRPLANES

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***Abstract.*** *This paper presets the instrumentation procedure used in order to perform parameter identification on light airplanes. Particulary, two instrumentation procedures were shown, one on SZD 50-3 Puchaz sailplane and the other one on CEA-205 CB-9 Curumim ultralight. The instrumentation used consists in: 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 Aeronautical Technological Institute (ITA), intends to assembly a system in order to perform low cost flight tests on light aircrafts.*

***Keywords****: Flight Test, Data Acquisition System, Light Airplanes*

## 1. Introduction

Commercial aircraft industry expends great efforts and costs in flight tests when developing new aircrafts (Coiro, 2002; Coiro 2003). The experimental aviation field has never sought a solution in order to permit the execution of flight tests at low costs.

In the past few years, Brazil has observed a continuous growth in production of this kind of airplane; however, investments in the development of flight test equipment have not kept up. This way, new aircraft developments have been limited due to lack of knowledge, mainly in aerodynamic, stability and control characteristics.

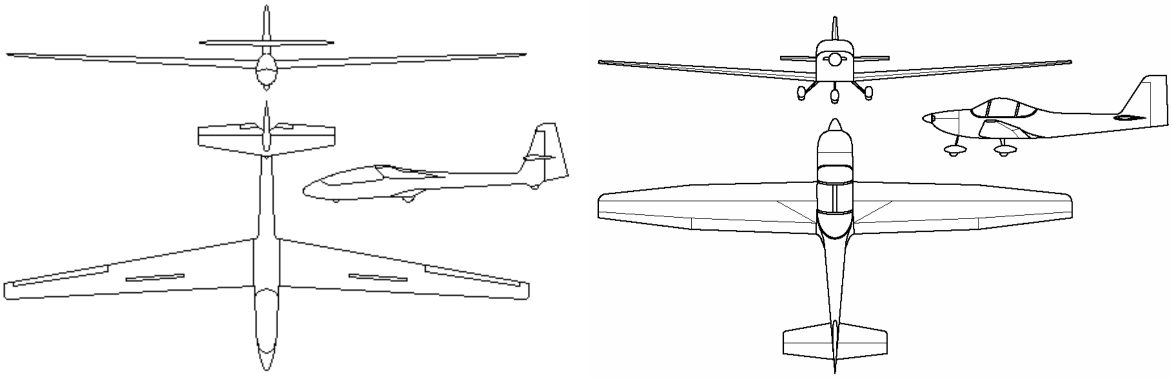
The Center for Aeronautical Studies of UFMG designed and built light airplanes during the last forty years and now is engaged in the development of flight test equipments, focusing on the needs of Brazilian experimental aviation.

In order to continue this task, a partnership with ITA was established to share technical knowledge in flight test procedures and parameter identification techniques. The visit of two researchers from ITA with their own parameter identification code has permitted the execution of some preliminary flight tests on SZD 50-3 Puchaz sailplane and CEA-205 CB-9 Curumim ultralight. The procedures used in the instrumentation of this aircraft will be described in this paper.

## 2. Aircrafts

Two different aircrafts were used for the two different flight test campaigns described in this paper. The sailplane SZD-50-3 Puchaz is a Polish commercial two-seat sailplane with characteristics as a trainer for intermediary and aerobatic flights. Puchaz is all fiber glass, tandem configuration, medium wing and has a convetional tail assembly. The exemplar used is these flight tests belongs to the Minas Gerais Sailplane Club (Aeroclube Mineiro de Planadores), based on Pará de Minas Airport, Minas Gerais (seventy kilometers from Belo Horizonte, where UFMG has its campus), and has almost 600 flight hours. The second aircraft is the CEA-205 CB-9 Curumim, an ultralight aircraft designed and built by the Center for Aeronautical Studies of Federal University in the early 90's being the fourth aircraft developed by UFMG (Barros, 1989). Curumim is an all-wood, bi-place, single engine, low wing airplane. It is powered by a

Limbach L2000B 80HP engine and has already flown over 200 hours. Nowadays Curumim is based in Divinópolis Airport, Minas Gerais (a hundred twenty kilometers from Belo Horizonte, where the University has its campus), and is used as a training aircraft and also as a platform for research made by CEA/UFMG.



(a) (b)

Figure 1. SZD 50-3 Puchaz (a) and CEA-205 CB-9 Curumim (b)

## 4. Equipment Description

The equipment used in the SZD-50-3 Puchaz and CEA-205 CB-9 Curumim flight tests consists 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.

In the Puchaz flight campaign, the data from the inertial platform was collected by a laptop computer and the synchronization with the other sensors was performed using the information of a three axial accelerometer.

In the Curumim flight campaign the data from inertial platform was collected by a second acquisition system (ICASIM) and the synchronization with other sensors was also performed using the information of a three axial accelerometer.

### 4.1. Acquisition System

The acquisition system is the core of any flight test equipment. There are, basically, two problems regarding the acquisition systems used for experimental aircraft flight tests: i) price and ii) size.

Acquisition systems developed for commercial aeronautical industry must be certificated to be installed in airplanes and this makes it very expensive when compared with the financial capacities of experimental aircraft industries. Furthermore, these kinds of acquisition systems are big and heavy and difficult to install inside light airplanes. It must also be that single place aircrafts are very common in experimental aviation, where the pilot must control the airplane and control all the 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.

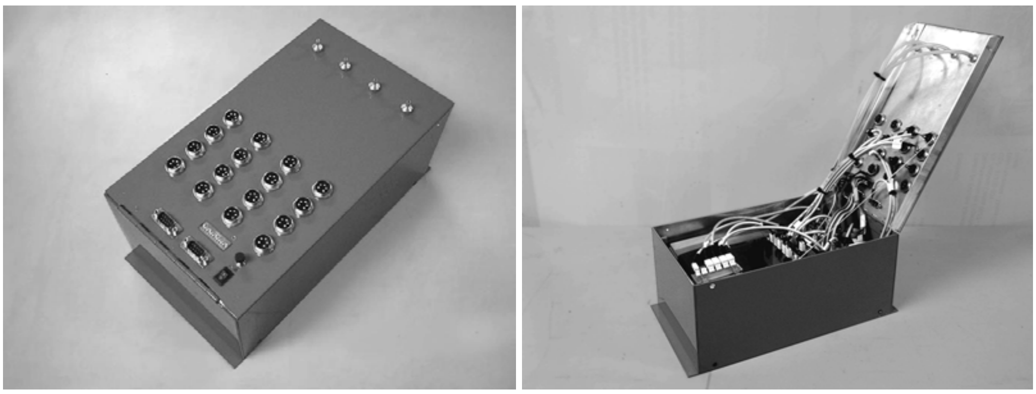


Figure 2. Data acquisition box

CEA UFMG is developing an autonomous acquisition system to be used in unmanned air vehicles and in light aircraft flight tests called CEA/FDAS (Flight Data Acquisition System). This system was developed over a microcontroller system, and uses PDAs to control and store all data acquisition. The microcontroller is a PIC 16F877, able to acquire 8 analog inputs simultaneously (Microchip, 2005a). These analog inputs are converted to digital signal by a 10 bits built-in A/D converter that can perform this conversion in sample rates up to 100 kHz. All the information is recorded a PDA that also is able to control all the acquisition procedure. A four time multiplexer is used to expand inputs from 8 to 32 channels. This system is also able to manage a serial I/O channel that is used to acquire the GPS.

The firmware of the processor is written in PIC assembler (Microchip, 2005b) that gives the system a good computational performance, adequate for integration with PDA unit. The sample rate of the acquisition for this system was set to 10Hz.

A very important characteristic of this system is the synchronization of the GPS signal with the data acquired from the analog inputs. In this system the firmware installed on the PIC microcontroller is responsible for synchronizing this data, detailed presentation of this is out of the scope of this paper.

### 4.2. Inertial Platform

An 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 angular velocities of the airplane, and using this information, an inertial platform must be able to determine the attitude (Euler angles) of the aircraft.

(a) (b)

Figure 3. Puchaz (a) and Curumim (b) inertial platform and three axial accelerometer installation

In the Puchaz flight campaign a MicroStrain GMX-300 (Microstrain, 2005) inertial platform connected to a laptop computer that controls and stores acquisition of this sensor was used. The information of non-stabilized normal acceleration and stabilized angular velocities and Euler angles was acquired in a sample rate of approximately 30Hz. The concept of stabilized and non-stabilized signals is connected to the use or not of a special filter to post-process the information.

In the Curumim flight campaign a Crossbow AHRS400 (Crossbow, 2005) solid state inertial platform was used and acquired by a commercial data acquisition system (ICASIM).

An important observation in the installation of the platform in the airplane is its position in relation to the aircraft gravity center. In both cases the platform was installed exactly over the aircraft gravity center.

### 4.3. Three axial accelerometer

A three axial accelerometer was developed by CEA/UFMG using solid state, MEMS technology, produced by Analog Devices Co. This accelerometer is able to measure acceleration in three orthogonal directions between -10 to +10 g's (-98.1 $m/s^2$ to +98.1 $m/s^2$).

This accelerometer, in both flight campaigns, was installed over the inertial platforms in order to measure exactly the same accelerations (Figure 3) that will be the synchronization information between analog inputs acquired by CEA FDAS and Inertial Platform data, acquired by other devices.

### 4.4. Pitot probe

A calibrated pitot probe was installed on the aircraft for more accurate measurements than those using the airplane's original pitot tube. This pitot tube was built by CEA/UFMG using the technology developed by Prof. Domenico Coiro of Naples University.

The pressure sensor used in this system consisted in two piezoelectric pressure sensors, one with 4kPa range for dynamic pressure and another with 100kPa range for static pressure. These sensors have amplifiers and signal conditions circuits in order to fit it range to 200kph for airspeed and 1150m for altitude.

All calibration is performed in test bench and a detailed explanation on this is out of the scope of this paper.

On Puchaz this pitot was installed in the fuselage nose and on Curumim this pitot was installed near the wing tip. To install this pitot, in both cases, a fiber glass “glove” was made and fixed to the aircraft, 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 4.

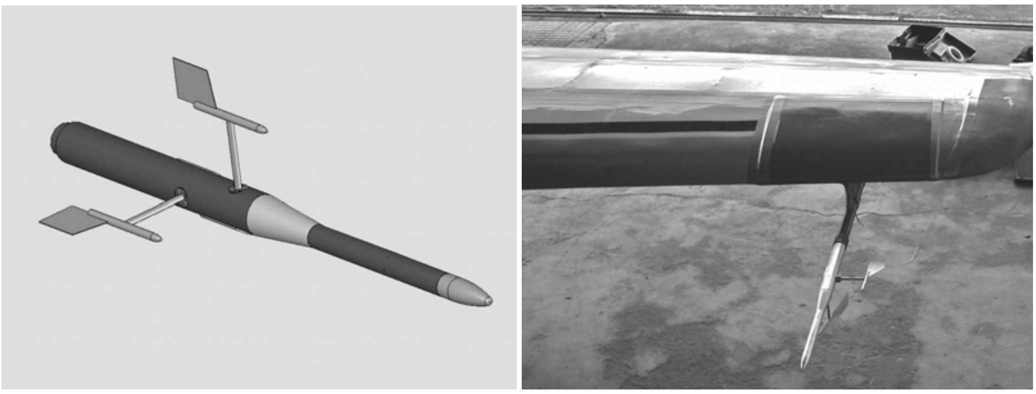


Figure 4. Pitot Probe and Angle Indicators

**4.5. Atack and sideslip angle indicator**

The pitot tube also has 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 the University of Naples and uses Hall Effect sensors to generate the electrical signal. The Hall effects sensor used is a Honeyweel LOHET II (Honeywell, 2004) that outputs a voltage signal proportional to a magnetic field intensity produced by a Ne-Fe-Bo magnetic that was installed at the end of the flag axel.

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.

**4.6. 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.

GEFRAN’s PZ12 (Geffran, 2004) series potentiometers with different sizes with typical linearity of 0.05% were used. 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 no modification to the airplane’s command system are necessary.

**4.7. Propeler tachometer**

In order to measure the propeller rotation speed, a LDR based light intensity measure device was used in connection to a frequency-voltage converter that is able to generate a voltage signal proportional to the light intensity changes produce by the propeller.

**4.8. 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.

**4.9. GPS**

A GARMIN III 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.

**6. Flight tests**

The flight tests performed in SZD 50-3 Puchaz consisted basically of dynamic stability flight maneuvers, used to perform Flight Path Reconstruction and Parameter Indentification procedures. These flights were performed in order to acquire information about some rigid body movements, such as: i) phugoid; ii) short period and iii) dutch-roll. The typical maneuvers performed are: i)elevator doublet; ii) elevator double-doublet; iii) elevator 2-1-1 maneuver; iv) elevator 3-2-1-1 maneuver; v) rudder doublet; vi) first type aileron and rudder coordination. All the flights were performed in early morning or at the end of the afternoon in order to minimize the effects of turbulence.

The main difficulty of these flights was to stop the phugoid movement of the sailplane. As know, sailplanes are very susceptible to this kind of motion and the time spent between maneuvers is not enough to stop this motion. Also, there was a problem in attack angle flag indicator, due high friction between the flag and the pitot tube body, impeding correct measurements of this value. After a change in the flag size, observing the dynamic balance of the entire flag, this problem was solved.

The flight tests performed in CEA-205 CB-9 Curumim have the intention of determining the optimality of some kind of maneuvers during parameter identification procedures of longitudinal (short-period linear) movements. The typical maneuvers performed are: i)elevator doublet; ii) elevator 2-1-1 maneuver and iii) elevator 3-2-1-1 maneuver. The optimized maneuvers performed were: i) elevator X-X-X-X-X and ii) X-X-X-X-X.

Besides some problems with data lost between, GPS, Data Acqsuition System and PDA, these flights was performed with no further problems.

For both flights, risk analysis was performed and defined in order to minimize probability of accidents during these campaigns. This analysis consisted in determining probable hazards, its causes and effects, that will be used to determine procedures for minimizing their occurrence probability and emergency procedures that must be done in each case. Table 1 presents a compilation of a typical risk analysis adopted in these flight campaigns.

Table 1 – Typical Flight Test Campaign Risk Analysis

| |
|---|
| **Hazard:**<br>• Aircraft impact ground;<br>• Aircraft overstress. |
| **Cause:**<br>• Loss of control;<br>• Over control;<br>• Abnormal attitude situation. |
| **Effect:**<br>Loss of aircraft/crew |
| **Minimizing Procedures:**<br>• Input development concerning AOA, AOS, roll angle and load factor constraints;<br>• No dynamic flight testing below 2000 ft AGL;<br>• Knock off flight testing if aircraft reach 45 degrees bank angle or 20 degrees pitch angle. |
| **Emergency Procedures:**<br>• If aircraft depart controlled flight, immediately reduce throttle to idle and neutralize flight controls;<br>• If aircraft enters a spin, accomplish spin recover procedures. |
| **Risk Level After Minimizing Procedures Taken Into Account:** |

| **HIGH** | **MEDIUM** | **LOW** |
|---|---|---|
| | | **X** |

## 7. Results

The results presented in this section were obtained with the software SYSID, developed by ITA in partnership with EMBRAER with financial support of FAPESP. SYSID is developed for parameter identification of dynamic systems, especially aircrafts.

For the estimation procedure, an Output-Error Method with Maximum Likelihood criteria was adopted using Gauss-Newton optimization method and a fourth-order Runge-Kutta numerical integrator. More detailed information about this procedure can be found in Góes et al. (2004).

### 7.1 Puchaz Results

These results refer to a longitudinal dynamic model, defined as (Jategaonkar, 2001):

$$
\begin{aligned}
&\dot{q} = \frac{1}{I_y}\left[\overline{q}Sl_\mu C_m^{CG} + M_{tw} - I_{xz}\left(p^2 - r^2\right) + \left(I_z - I_x\right)pr\right] \\
&\dot{\theta} = q\cos\phi - r\sin\phi \\
&\dot{u} = -qw + rv - g\sin\theta + \frac{\overline{q}S}{m}C_x + \frac{1}{m}X_{tw} \\
&\dot{w} = -pv + qu + g\cos\theta\cos\phi + \frac{\overline{q}S}{m}C_Z + \frac{1}{m}Z_{tw} \\
&\dot{h} = u\sin\theta - v\cos\theta\sin\phi - w\cos\theta\cos\phi
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
a_{x\_m} &= a_x^{CG} - x_{bscg}(q^2 + r^2) + y_{bscg}(pq - \dot{r}) + z_{bscg}(pr - \dot{q}) + \Delta a_x \\
a_{z\_m} &= a_z^{CG} + x_{bscg}(pr - \dot{q}) + y_{bscg}(qr + \dot{p}) - z_{bscg}(p^2 + q^2) + \Delta a_z \\
\alpha_{aoa\_m} &= F_\alpha \tan^{-1}\left(\frac{w_{aoa}}{u_{aoa}}\right) + \Delta\alpha_{aoa} \\
q_m &= q + \Delta q \\
\theta_m &= \theta + \Delta\theta \\
h_m &= h \\
V_{tas\_m} &= \sqrt{u_{tas}^2 + v_{tas}^2 + w_{tas}^2} \\
\dot{q}_m &= \dot{q}
\end{aligned}
\tag{2}
$$

Typical flight data acquired and fitted data obtained after parameter estimation of a doublet maneuver in SZD-50-3 Puchaz is shown in Figure 5.

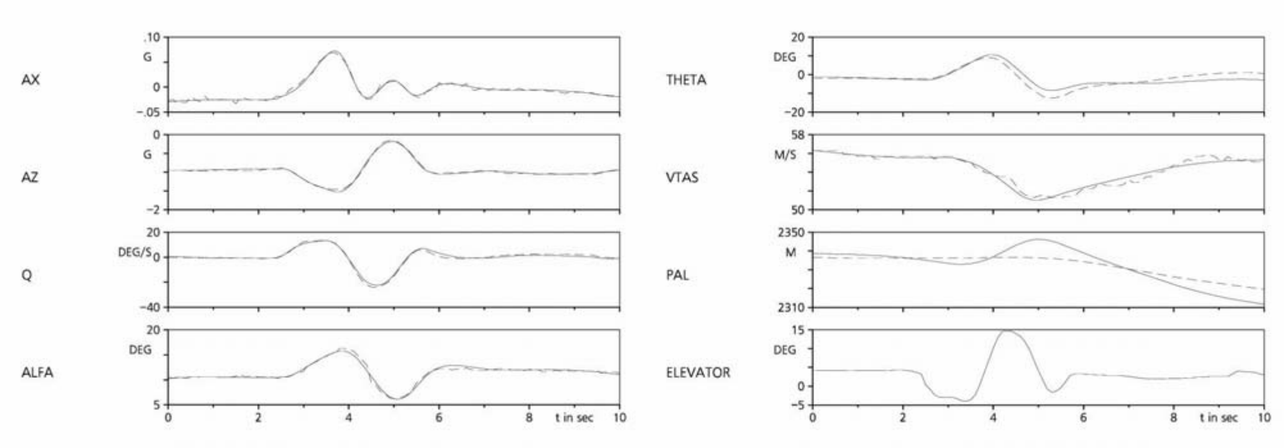



Figure 5. Typical results of SZD 50-3 Puchaz doublet maneuver

In Figure 5, the dashed line represents measured values and solid lines represent estimated values. Longitudinal acceleration is denoted by AX, vertical acceleration by AZ, pitch velocity by Q, attack angle by ALFA, pitch angle by THETA, true airspeed by VTAS, pressure altitude by PAL, and elevator deflection by ELEVATOR. As can be seen, the difference between measured and predicted values are very small except for pressure altitude curves. This difference can be explained by a supposed problem of pressure leg in barometric pressure transducer due a long pressure line between static ports and the transducer.

Figure 6 presents the convergence plot of estimated variables of this result. As can be seen, all variables have good convergence characteristics.

### 7.1 Curumim Results

These results refer to a short-period dynamic model, defined as (Jategaonkar, 2001):

$$\begin{aligned}\dot{\alpha} &= Z_\alpha \alpha + \left(1 + Z_q\right) q + Z_{\delta e}\delta e \\ \dot{q} &= M_\alpha q + M_q q + M_{\delta e}\delta e\end{aligned} \tag{3}$$

$$\begin{aligned}\alpha_m &= \alpha \\ q_m &= q \\ a_z &= Z_\alpha \frac{V_0}{g}\alpha + Z_q \frac{V_0}{g} q + Z_{\delta e}\frac{V_0}{g}\delta e\end{aligned} \tag{4}$$

Typical flight data acquired and fitted data obtained after parameter estimation of a 3-2-1-1 maneuver in CEA-205 CB-9 Curumim is shown in Figure 7.

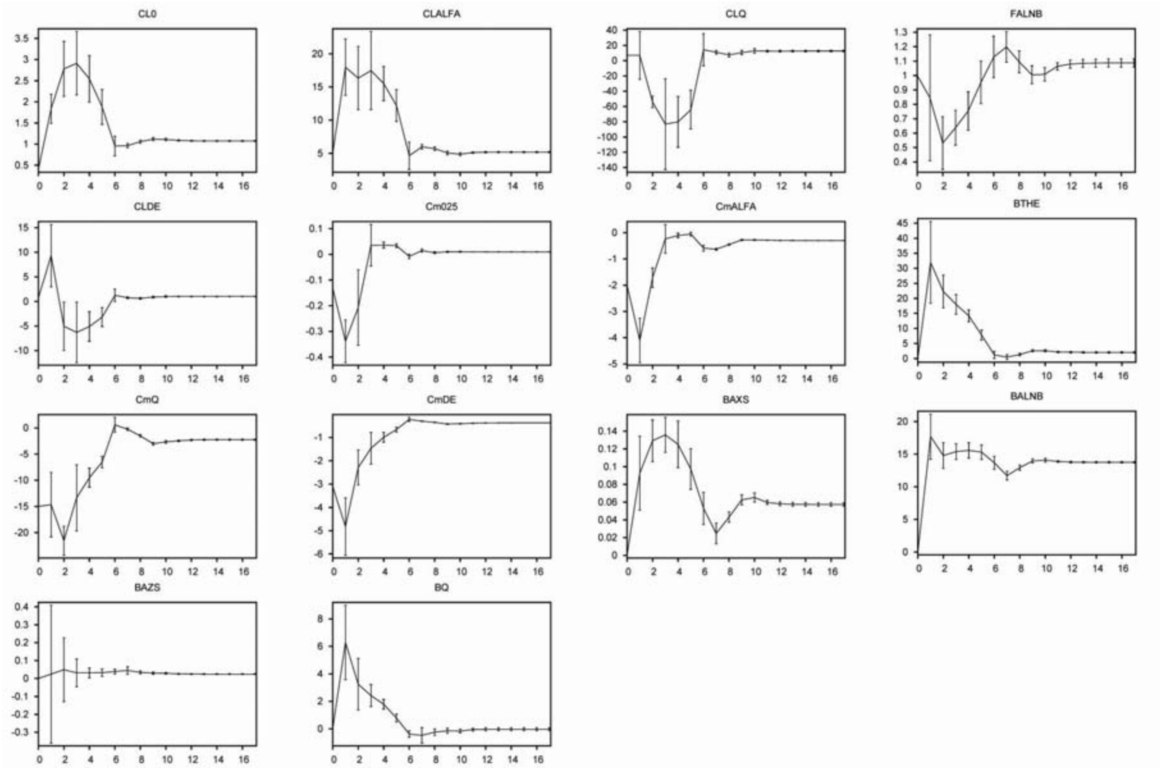



Figure 6. Convergence plots of SZD 50-3 Puchaz doublet maneuver estimation process

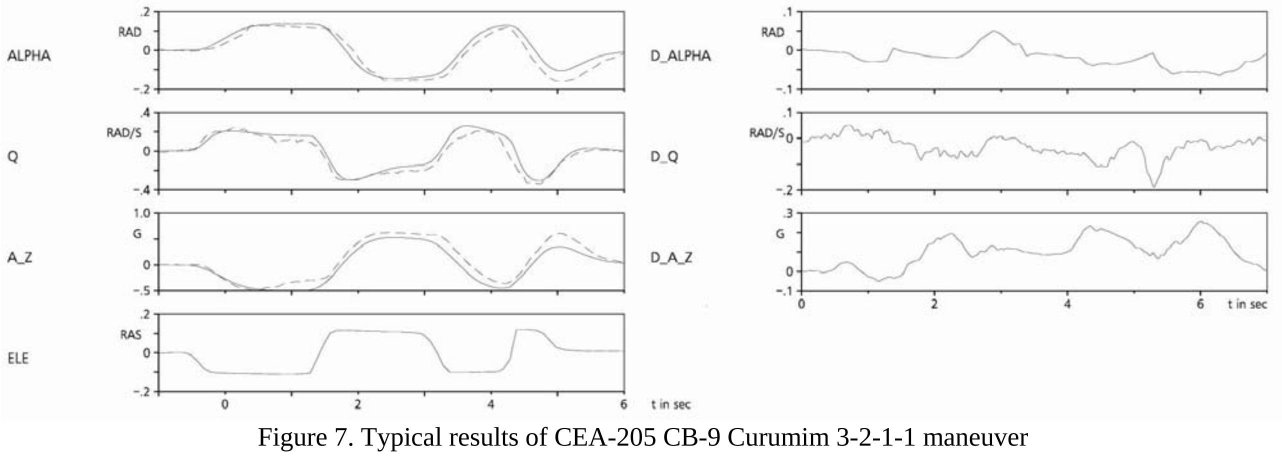



Figure 7. Typical results of CEA-205 CB-9 Curumim 3-2-1-1 maneuver

In Figure 7, dashed lines represent measured values and solid lines represent estimated values. Attack angle is denoted by ALPHA, pitch velocity by Q, vertical acceleration by A_Z, elevator deflection by ELE, and attack angle, pitch velocity and vertical acceleration perturbation in relation to equilibrium value by D_ALFA, D_Q and D_A_Z respectively. As can be seen, the difference between measured and predicted values is very small.

As presented in Puchaz estimation results, figure 8 shows the convergence plot of estimated variables of this result. As can be seen, all variables have good convergence characteristics.

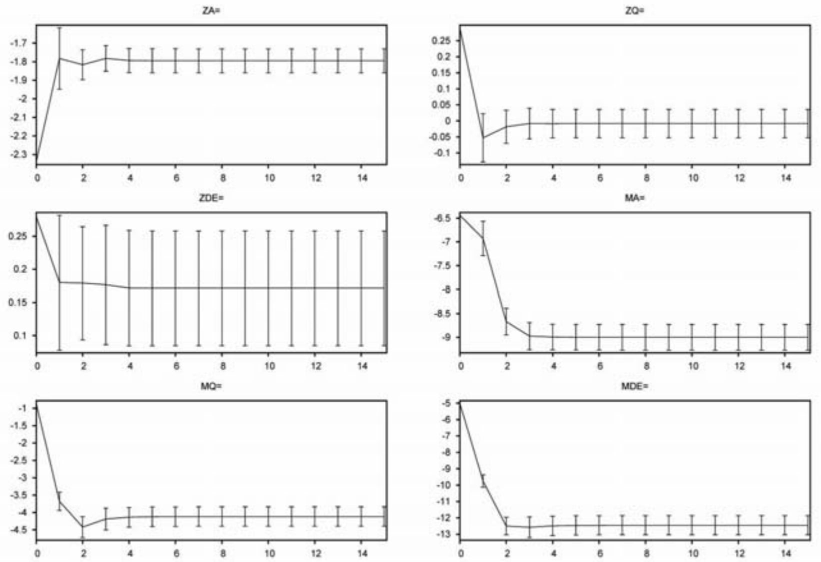



Figure 8. Convergence plots of CEA-205 CB-9 Curumim 3-2-1-1 maneuver estimation process

## 8. Conclusion

The instrumentation equipment and procedures used on the two flight tests campaigns in light aircrafts, SZD-50-3 Puchacz sailplane and CEA-205 CB-9 Curumim ultralight, were described in this paper. Details about the assembly and calibration procedures were presented, explaining important details for its repetition. The equipments used for this flight tests, developed by CEA/UFMG were very simple and low cost, making its use possible in experimental airplane flight tests in Brazil. Procedures and maneuvers adopted in these flight campaigns were also described, including a short description of a risk analysis adopted in order to increase operation safety.

The data acquired in these flight tests was used as input for a parameter estimation computational procedure developed by ITA in partnership with EMBRAER with financial support of FAPESP. Results and analysis are briefly presented showing the consistency of acquired data specially due to the convergence stability of parameter identification procedure.

This paper, in all, presents the viability of performing flight test campaigns in light airplanes in Brazil, using, intensively, in-house technology of hardware and software. Based on the good results seen on these flight campaigns, the authors hope that the development of light aircrafts in Brazil, specially light jet airplanes, would make use of this technology, augmenting the growth of Brazilian capabilities in this field of aeronautical sciences.

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