DEVELOPMENT OF LIGHT AIRCRAFT FLIGHT TEST EQUIPMENT

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Abstract

This paper presents the research efforts of the Center of Aeronautical Studies of the Federal University of Minas Gerais – Brazil to develop a flight test data acquisition system for light aircraft and unmanned aerial vehicles. The main topics regard the system architecture and the interesting results presented by the system in applications such as performance evaluation and stability and control derivatives estimation problems. Finally, the most important conclusion is that this system can efficiently support the demands of the aerospace industry for light aircraft and unmanned aerial vehicles development programs as well as the necessities of the research centers and universities developing aeronautical research and didactic programs.

1. Introduction

In the past few decades, the use of flight tests in the aeronautical industries has increased, mainly because of the parameters identification techniques that have been used in the flight mechanics field, including control systems and flight simulation as well [12].

In the light airplane industries, flight tests are useful for development of new solutions and technologies. Johnson’s [3] work is an example of how light airplane tests can improve future developments. In the academic field, these experiments are essential for adding practical and realistic experience for the students, helping the future development of the industry, since the engineers will become more prepared to do such work. Universities in the entire world are including flight tests in the scope of the engineering course. The Technical Universities of Germany and the master course of Cranfield University, in the United Kingdom, are examples of how flight tests can be applied in the academic field.

Recently some Universities have been using light airplanes and UAVs in flight tests, providing data for research, development and didactic issues. The work by Dr. Domenico Coiro from the University of Nápoli, Italy, shows that the utilization of light airplanes for this purpose is promising, because the data acquisition, maintenance and operational costs are low [1],[12],[10].

In order to provide a data acquisition system that can be used in the airplanes developed in the Center of Aeronautical Studies of the Federal University of Minas Gerais – Brazil (see http://www.demec.ufmg.br/cea), a new portable system was developed. This data acquisition system is applicable to a new scope of the Aeronautical Engineering Course at this university, including a flight test class, as well as research and development tasks. The requirements and constraints of the system are based on the airplanes or vehicles involved, cost, maintenance and portability.

In this paper the development of the data acquisition electronic unit and the integration of the peripherals are explained.

2. Requirements of a light airplane data acquisition system

Some specific requirements applied to light airplanes must be taken into consideration. The main requirements applied to this system are [2]:

- Portability – light airplanes have limited space and payload weight;
- Operation – the operation of the system must be automatic, because light airplanes are mainly monoplaces or biplaces and it is difficult for the pilot to operate both the aircraft and the acquisition system;
- Cost – light airplanes production is usually a few numbers or units, so, in order to avoid an increase in the product cost, the system must be cheap;
- Adaptability – the diversity of flight tests that can be made in a light airplane, involving different areas (aerodynamics, flight mechanics, performance etc.), requires that with just a few modifications in the sensors, and no modifications in the general architecture of the system, a large number of tests can be made.

Based on the requirements described above, a basic architecture for the system was adopted. In this architecture, the system was divided into two main subsystems: i) an Acquisition System, for signal conditioning and A/D conversion and ii) a Computer Device, for acquisition control, visualization and data storage. Figure 1 shows a schematic of this architecture.

Fig. 1. Basic configuration adopted.

For the Acquisition System, a Microcontroller was used as the main processor, communicating with the Computer Device by a simple RS-232 serial communication. Some advantages of this architecture, related with the system requirements, are:

- Microcontroller utilization provides reduced cost with some built-in capabilities, like, A/D converter, serial communication and adequate processing speed;
- Serial communication provides an easy and flexible way to connect a lot of computer or data storage devices, like, PCs, PDAs, scientific calculators, wireless modems for telemetry and data links.
- External Computer Device utilization provides permanent memory storage for acquired data, control of the data acquisition board, and must satisfy the portability requirements as well;

Based on the assumptions above, the authors believe that this architecture will be adequate for light airplanes and for the specified requirements.

3. Microcontrollers

Microcontrollers are a concept of integrated circuits based on a multifunctional architecture [9]. The majority of microprocessors require a lot of discrete components and CI´s to execute a relatively simple function, resulting in large and complex hardware. This is based on the fact that the microprocessors must be flexible, in terms of application. This architecture is often difficult to update, and requires much knowledge in electronics and low level programming.

With the incorporation of some basic functions inside of a microcontroller, the hardware can be quite simple as well as low cost. Some of the basic functions that can be included inside a microcontroller, are: A/D converter, comparator, PWM generation, serial communication, internal clock, RAM/EPROM memory, flash memory and programmable I/O. Some microcontrollers incorporate all of these functions in a single chip with minimal additional discrete components [9].

Another advantage of the recent microcontrollers is the programming process and the language used [9]. The software can be made with high level languages, C++, Basic, or low level language (Assembly). To upload the software into the microcontroller, just a PC and an external board are required.

3.1. PIC Microcontrollers

Actually, a large number of different microcontrollers are available for different applications and from different manufacturers: Zilog, National, Motorola and Microchip. Particularly, the Microchip developed the PIC microcontroller family, which is very popular nowadays. PIC microcontrollers use the RISC (Reduced Instruction Set Computer) technology, which comprises a reduced set of simple instructions [4]. The main advantage of this technology is based in the fact that simple instructions are processed faster than complex instructions.

The PIC family are divided in three distinct types[4], with different characteristics, Table 1.

One of the advantages of PIC family adoption refers to the system adaptability requirements. With the RISC technology the system changes required for an expansion or adaptation are quite simple.

Table 1. PIC family subdivision.

Type	**Instructions**	**Bits(1)**	**MIPS(2)**	**Pins**
High Performance	79	16	10	18-80
Mid Range	35	14	5	8-64
Baseline	33	12	5	6-40

(1) Bits – Microprocessor number of bits.

(2) MIPS – Millions of instructions per second.

Another important aspect is the memory used by the microcontroller. The PIC families are available in three types of internal memory: OTP, FLASH and ROM. During the development phase, the utilization of FLASH memory is essential, because this memory has the capability of re-program the firmware almost indefinitely. Therefore, the cost related with the development or expansion of the system is reduced.

For data communication, the PIC supports the following technologies: USART, I2C, USB, SPI e CAN. Actually, the communication standard most often used is the USART, but gradually the USB and CAN have been used instead of USART.

3.2. Microcontroller Model Selection

In order to choose a more appropriate model for this application, all the devices comprised in the Mid-Range with the internal A/D converter were evaluated. Only the devices with FLASH memory were considerate, preserving the adaptability requirements.

Finally the PIC16F877A microcontroller was chosen for the system, based on the following assumptions:

- Easy to buy in the local market;
- Cheap firmware recorder device;
- Bibliography available [4].

The microcontroller technical specs are shown in Table 2.

Table 2. Microcontroller specifications [8]

Model	**Memory (bytes)**			**I/O Pins**	**A/D**	**Serial I/O**	**Max. Clock**
	FLASH	EEPROM	RAM				
PIC16F877A	14336	256	368	33	8x10 bit	AUSART, MI^{2}C/SPI	20MHz

4. The Data Acquisition System

The first tests were made using a HP48G scientific calculator as a computer device, for control of the data acquisition and for data storage. The block diagram of the system is shown in figure 2. The low processing speed and memory capacity of the HP48G are limitation factors for data acquisition; however, the use of the HP48G was essential in the PIC firmware development phase. The use of this calculator for flight tests is justifiable only for didactical application that requires low acquisition data rate.

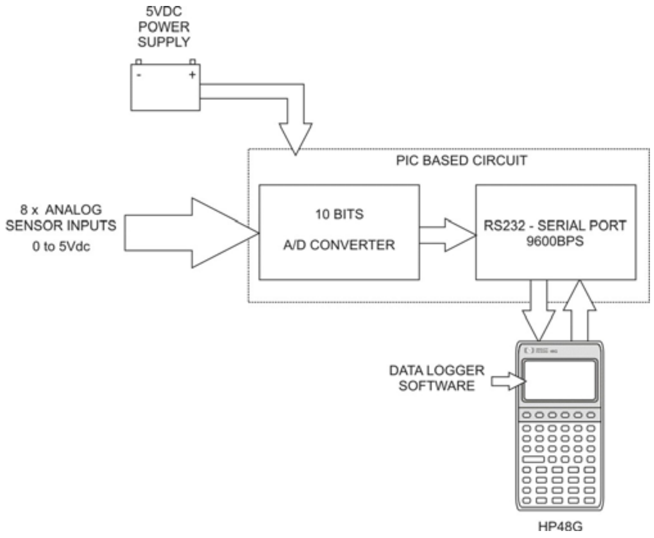

Figure 2 - Data acquisition system using an scientific calculator.

For the flight tests, a GPS system is essential to provide data of ground speed, heading and position of the airplane. In order to include GPS data into the data acquisition system, serial communication was used. The majority of the portable GPS units have the built-in serial port and use the NMEA0183 protocol, so, no specific GPS unit is required.

In the development phase, a GPS Garmin model GPSIII was used. The GPS sends data through serial ports every 2 seconds (0.5Hz) at a baud rate of 4800bps. The GPS was used to synchronize the data acquisition system, when the GPS data is received by the PIC board, the analog data in the sensor inputs are read. Afterwards, the data is sent to the computer device. The gap between each GPS data (less than 2 sec.) is used by the PIC to acquire and send the analog inputs to the computer device, this gap is a limitation factor for the data acquisition rate.

The data transmission for the computer device is made by serial communication. The computer device must comply with the requirements and constraints established for the data acquisition system, mainly portability, performance and cost requirements.

For the computer device a PDA manufactured by PalmOne was used. The advantages of this device are: portability, color display, efficient and stable operational system (PalmOS), and large memory capacity. The block diagram is shown in figure 3.

In order to increase the number of analog input channels to 32, multiplexers were used successfully, maintaining the data acquisition rate acceptable for flight tests.

5. The Microcontroller Firmware

The development and design of the firmware is the key to the system. The firmware programming must be made to maximize the processing speed, maintaining the desired data acquisition rate. To achieve the maximum processing speed the firmware was designed using an assembler algorithm.

In figure 4, the fluxogram of the firmware without GPS capability is shown.

In this case, the communication between the computational device and the microcontroller is bidirectional, and the control and synchronization of the acquisition is made by the computational device. In order to synchronize three basic commands are used:

- 1 (00000001) – sends the data of the 8 input analog channels just once;
- 3 (00000011) – sends just once the data of all ON channels, based on the second byte sent after this one (1 – turned on, 0 – turned off);
- 7 (00000111) – sends continuously all ON channels, based on the second byte sent after this one (1 – turned on, 0 – turned off);

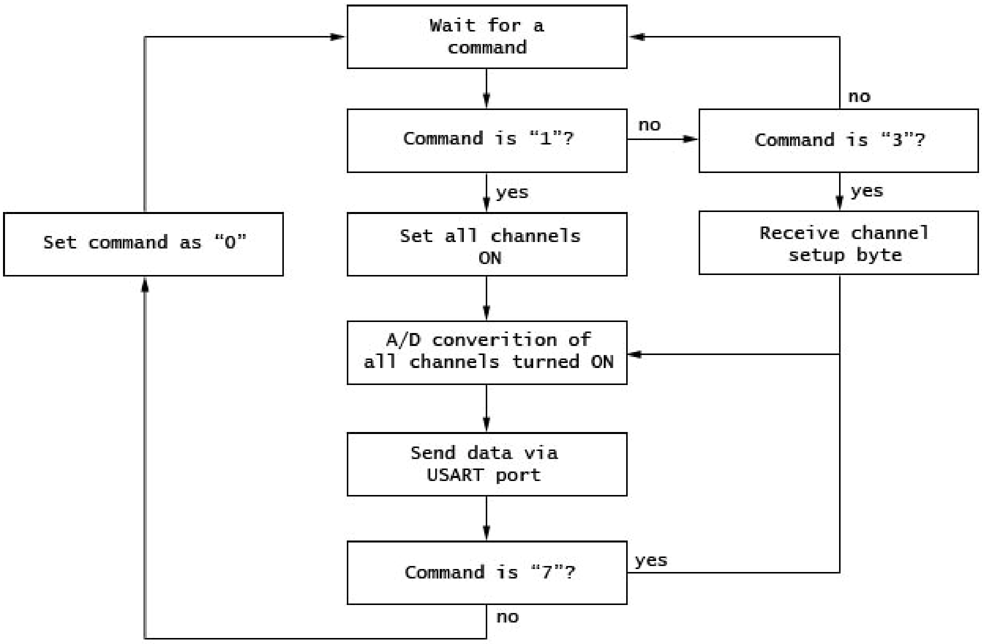

Figure 4 - PIC firmware flowchart – without GPS.

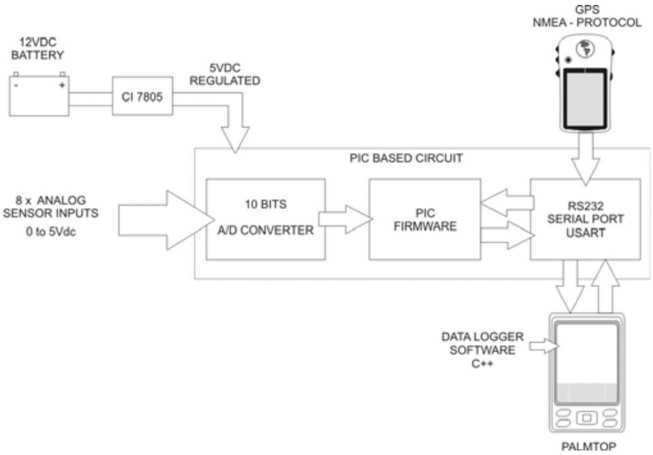

Figure 3 - Functional block diagram.

Using this procedure, the data acquisition rate is controlled by the computational device. If a Personal Computer is used as a computational device, a data acquisition rate of up to 6kHz can be achieved, using the “7” synchronization command.

6. Adding GPS Data

With GPS, the acquisition synchronization device is the GPS instead of the computational device, therefore, the microcontroller firmware with GPS is different from the system without GPS. Initially, at the beginning of the development, the data acquisition rate was defined at 10Hz, and since the GPS data sent frequency is 0.5Hz, the analog channels have to be read and sent 20 times for each GPS data packet. Currently, the GPS data frequency is 5Hz and the data acquisition rate is 30Hz. At each GPS data reading, the channels must be read six times. This synchronization is essential to avoid data loss and firmware locking. Therefore, the firmware must be reliable and stable.

One important task of the firmware is the NMEA0183 protocol decoding [5]. The firmware must locate a string “GPGAA” in the GPS data packet and detach the necessary information. The algorithm developed to do that has a fixed number of instructions, avoiding synchronization problems.

The fluxogram for the firmware with GPS at 0.5Hz and data acquisition rate at 10Hz is shown in figure 5. It must be noted in figure 5 that a flag containing “**” is sent always before the GPS decoded data is sent. This flag is used to indicate the initial part of the data sequence.

In the case of GPS data lost, the information acquired by the analog ports can be identified.

7. Comparison with other systems

Other data acquisition systems for light airplanes have been developed as well. Three systems with the same main characteristics were compared in this section.

- ICASIM System – developed by the Swiss company SIMTEC [7].
- PODS System – developed by the English company Flight Dynamics [6];
- DPA System – developed by Prof. Domenico Coiro from the University of Naples, Italy [1].

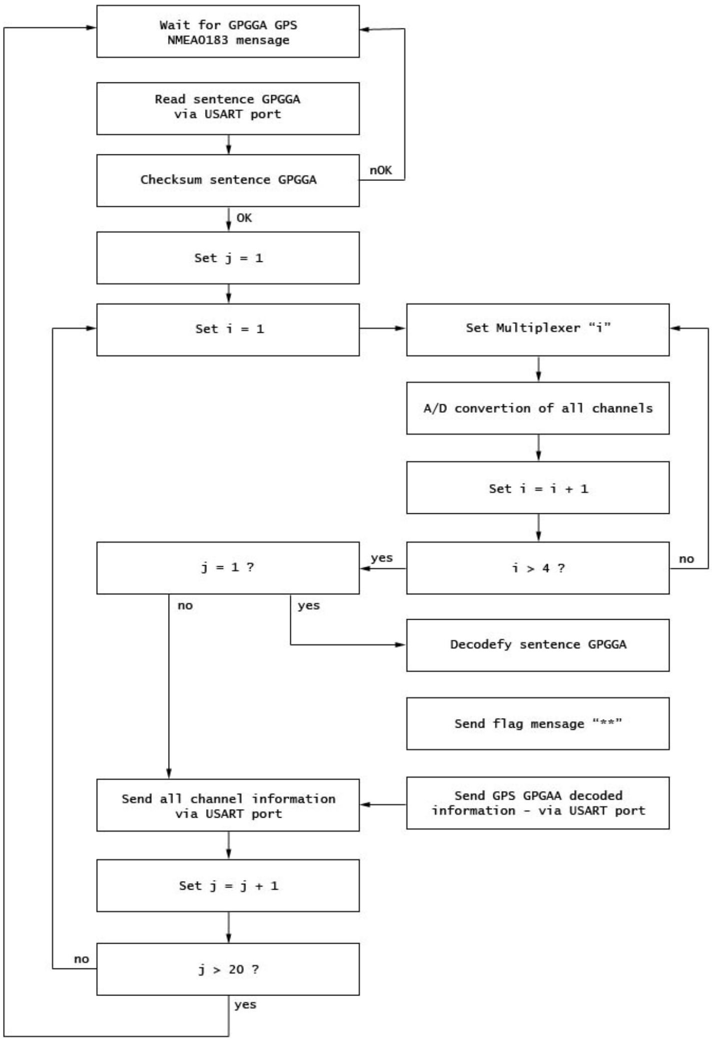

Figure 5 – PIC firmware flowchart – with GPS.

Table 3 - Comparison between some flight data acquisition systems.

	GPS	**Inertial platform**	**Analog Channels**	**Nominal Sample rate**	**Maximum Sample rate**	**On-line Serial output**	**Storage device**	**Price FOB**
ICASIM	yes	outside	4	10Hz	na	no	Int. Drive	38kUS$
PODS	yes	inside	33	25Hz	1kHz	yes	PDA	20kUS$
DPA	yes	outside	32	10Hz	na	no	Flash Card	28kUS$
CEA/FDAS	yes	outside	32	30Hz	6kHz	yes	PDA	na

A comparison between the systems listed above with the CEA/FDAS system is shown in Table 3.

The performance of the four systems is very similar, and in some items the system developed in this paper (CEA/FDAS) is better. Only the DPA and CEA/FDAS have an open code, providing a way to improve the system and to add new sensors as well.

8. Sensor development

In order use the data acquisition system described above in light aircraft flight tests, some sensors especially adapted to this propose were also developed. A brief description of these sensors will be presented in the following sections.

8.1. Inertial Measure Unit

An Inertial Measure Unit (IMU) was developed with a three axial accelerometer and three gyroscopes that use solid state MEMS technology, produced by Analog Devices. This accelerometer is able to measure acceleration in three orthogonal directions between -10 to +10 g's (-98.1 m/s2 to +98.1 m/s2). The gyroscope is able to measure the angular rate in three orthogonal directions between -300 degrees/sec and 300 degrees/sec.

This IMU, in previous flight campaigns, was installed over commercial inertial platforms in order to calibrate it. The results obtained were satisfactory showing that the IMU developed has adequate accuracy to light aircrafts flight tests.

8.2. Pitot probe

A calibrated pitot probe was built by CEA/UFMG using the technology developed by Prof. Domenico Coiro of Naples University (Figure 6).

The pressure sensor used in this system was 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 the calibration is performed in test bench and a detailed explanation about this is beyond the scope of this paper.

Normally, this pitot tube was installed on aircrafts in the fuselage nose or 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 modify anything on the airplane's wing.

8.3. Attack 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 University of Naples and uses Hall Effect sensors to generate the electrical signal. The Hall effects sensors used are Honeyweel LOHET II that output a voltage signal proportional to a magnetic field intensity produce by a Ne-Fe-Bo magnetic that was installed at the end of flag axel.

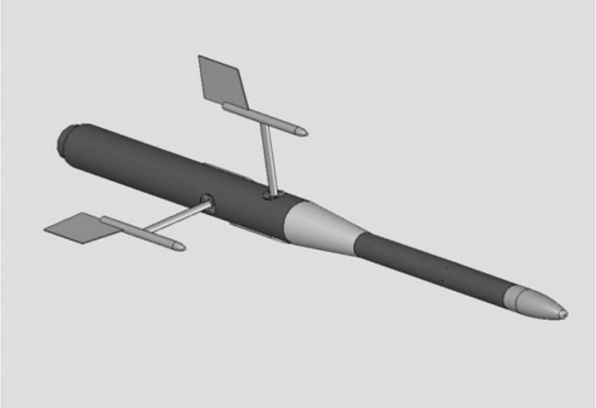

Figure 6 - Pitot Probe and Angle Indicators

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

8.4. Command position indicators

In order o know the position of the command surfaces and throttle linear potentiometers, the command system cables and tubes were installed.

GEFRAN's PZ12 series potentiometers with different sizes with typical linearity of 0.05% were used. These 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 to make any modifications on the airplane's command system.

8.5. Propeller tachometer

In order to measure the propeller rotation speed 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.

8.6. 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.

All of these sensors have signal conditioners in order to convert it voltage output to a TTL level that was represent the full scale of data acquisition A/D conversor.

8.6. Command Forces

In order to measure command forces, three load cells were used. Two were installed on a stick and one installed on rudder cables. The load cells used to measure elevator and aileron forces was installed as a secondary stick that the pilot can use just at the execution of the maneuver. The load cell used to measure the pedal (rudder) force was installed on rudder cable and measure directly the traction force on the cable. These load cells have particular amplifiers and signal conditions circuits.

9. Applications

The CEA/FDAS system has been used extensively for light airplane flight tests in the Center for Aeronautical Studies (CEA) of UFMG. Two tests campaign were made successfully with this system. These tests involved a training sailplane SZD 50-3 Puchacz (Figure 7) and a very light airplane designed and built at CEA, CB-9 Curumim. During these tests, this system was used in order to obtain data for performance certification and parameter estimation. Figure 8 presents the data collected for stall prediction of CEA CB-9 Curumim. This figure shows the accuracy of the data, its good relation with the expected data and the low noise obtained. The determination of this stall speed was performed using the statements of FAR 23 and AC 23.8 for this kind of test. The value of equivalent stall speed determined by fly tests was 18.81m/s or 67.7km/h. The value of stall speed estimated on the design of this aircraft was 19.08m/s or 68.7km/h.

Figure 7 – Puchaz sailplane and Curumim ultralight aircraft prepared for flight tests.

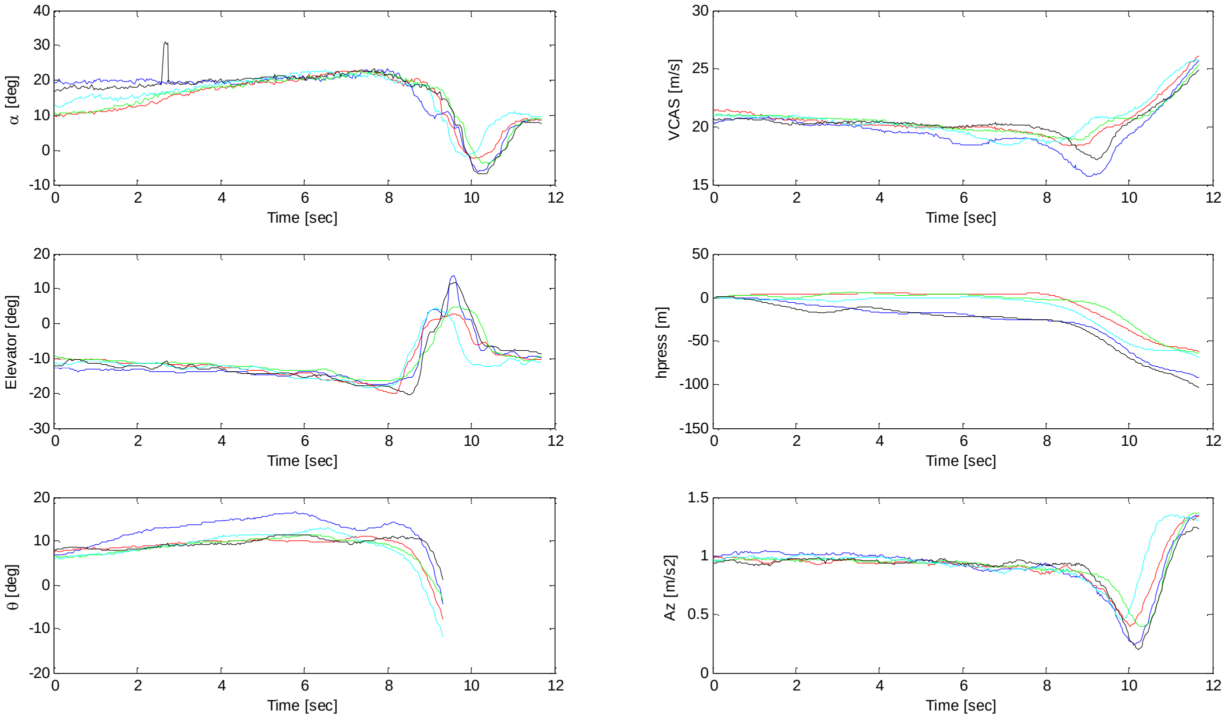

Figure 8 – Stall speed data from CEA 205 CB9 Curumim flight test.

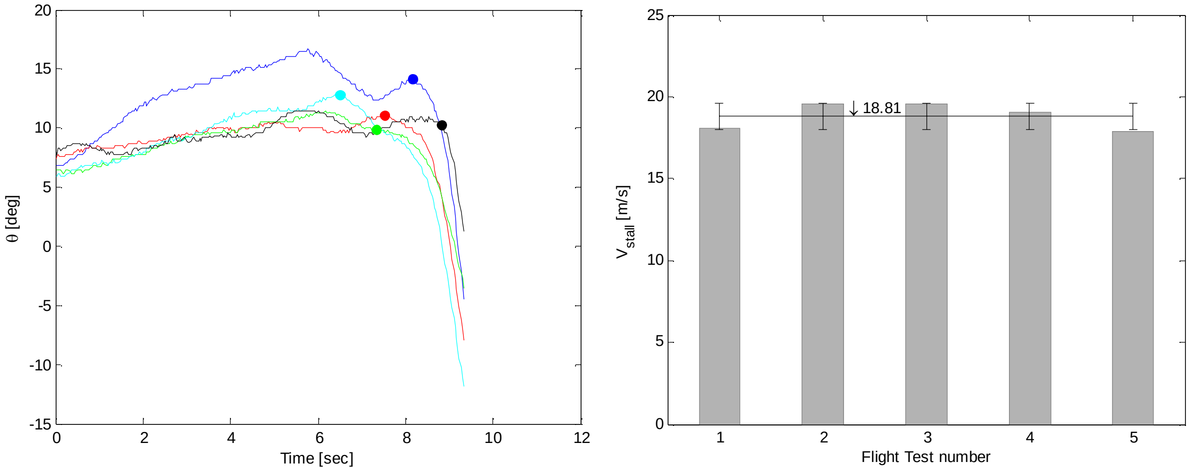

Figure 9 – Stall speed determination (left – stall instant determination; right – stall speed variation).

The difference between these two values (<1.5%) can be explained by the differences between aircraft design and construction and the difficulty in evaluation of the correct stall speed, or maximum lift coefficient, during the design phase.

The figure shows the results of parameter estimation on a Dutch-roll and a rudder-doublet maneuver performed on this aircraft. The process of parameter estimation used in order to obtain these results is based on a usual linear latero-directional model. The estimation process was performed by an Extended Kalman Filter algorithm implemented by Eng. Benedito Carlos de Oliveira Maciel at Technological Institute of Aeronautics (ITA). This data shows that the data collected by the system described in this paper was adequate to perform this kind of analysis.

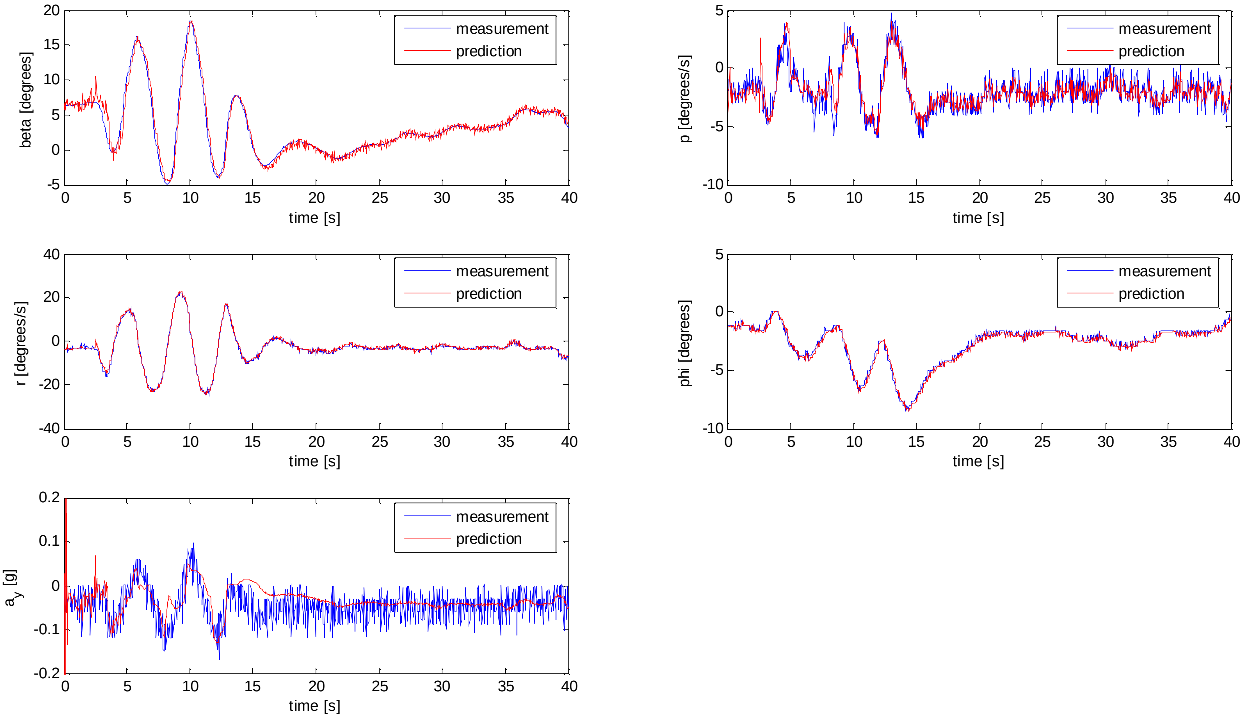

Figure 10 – Maneuver identification – Rudder Doublet.

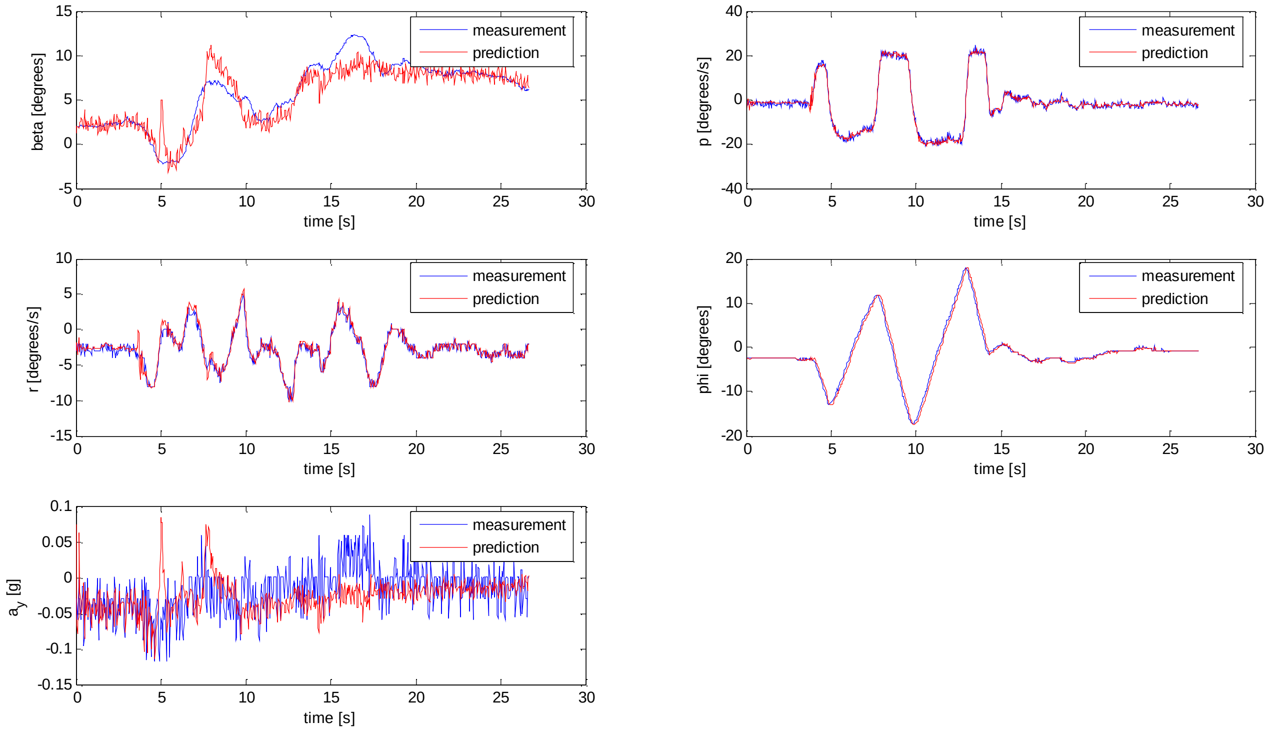

Figure 11 – Maneuver identification – Dutch Roll.

The parameters obtained by this estimation process are show in Table 4. These values show that there is a difference in the values estimated with each maneuver. This difference can be explained by the fact that the maneuvers executed are not very adequate for this process. These differences can be reduced by an adequate flight test campaign planning and by the use of an adequate excitation specification methodology for parametric estimation flight test maneuvers [13] [14].

Table 4 – Parameters Estimated

	Rudder – Doublet	Dutch-Roll
Y_{β}	0.0248	-0.0664
L_{β}'	1.8661	-5.7368
L_{p}'	-11.1917	-9.6339
L_{r}'	2.3229	0.8582
N_{β}'	-0.9697	-0.4675
N_{p}'	-0.7581	-0.3706
N_{r}'	0.3649	0.2620
$Y_{\delta a}$	0.0009	-0.0176
$Y_{\delta r}$	0.0155	-0.0247
$L_{\delta a}'$	8.0642	13.9636
$L_{\delta r}'$	-0.0463	-3.1220
$N_{\delta a}'$	6.7264	0.4901
$N_{\delta r}'$	-1.1563	-0.3012
$\Delta\beta$	0.0980	0.0181

10. Conclusions

The PIC microcontroller used was considerately useful for the data acquisition application. The control and storage of the acquired data can be performed by a lot of devices with serial RS232 port, but the processing speed of the computational device must be evaluated for each application. A PC can be used successfully for applications where portability is not a requirement.

The use of HP48G scientific calculator was considered acceptable for applications that require low data sample rate and low data storage.

For light airplane flight tests at CEA, the use of PDA as a computational device was largely and successfully used. This device provides excellent portability and cost benefit ratio as well. The PDA was considered the best choice for light airplanes flight tests.

The use of open architecture (open code) that was used in this system provides an easy solution for upgrading of the system for better performance and to add new capabilities as well.

12. Acknowledgements

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