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Development of a Light Aircraft Flight Test Equipment

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INTRODUCTION

In the last decades the use of flight tests in the aeronautical industries have been increasing, mainly because the parameters identification technics have been used in the flight mechanics field, including control systems and flight simulation as well.

In the light airplane industries the flight tests are useful to develop new solutions and technologies. The work made by Johnson (2005) is an example of how light airplane tests can improve the future developments. Outside of the industry, in the academic field, the experimentation are essential to add pratical and realistic experience to the students, helping the industry future development, since the engineers will be more prepared to the work. Universities of all the world are including flight tests in the scope of the engineering course. The Technical Universities of Germany and the master course of the Cranfield University, in the United Kingdom, are examples of how the flight tests can be applied in the academic field.

Recently some Universities have been using light airplanes and UAVs in flight tests, providing data to the research, development and didatic issues. The work made by Dr. Domenico Coiro from the University of Naples, Italy, shows that the utilization of light airplanes for this purpose is promissing, because the data acquisition, maintenance and operational costs are low (Coiro, 2002).

This system was developed to provide a data acquisition system that can be used with the airplanes developed in the CEA – UFMG. This data acquisition system is applicable to the new scope of the Aeronautical Engineering Course, that includes a flight test discipline, and to others research and development tasks as well. The requirements and constraints of the system were made 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 peripherics are explained. In future papers the sensors development for flight data acquisition will be presented.

REQUIREMENTS OF A LIGHT AIRPLANE DATA ACQUISITION SYSTEM

Some specific requirements applied to light airplanes must be considered. The main requirements applied to this system are (Iscold et all, 2004):

- Portability – light airplanes have a limited space and payload weight
- Operation – the operation of the system must be automatic, because light airplanes are mainly monoplaces or biplaces
- Cost – light airplanes production are limited to a few number or units, so, to avoid an increase in the product price 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 performed

Based on the requirements described above, the basic architecture for the system was made, figure 1.

Figure 1 – Basic configuration adopted.

Some advantages of this basic configuration related with the system requirements are:

- Microcontroller utilization – provides reduced cost with some built-in capabilities: A/D converter, serial comunication, high speed;
- Serial communication – provides an easy and flexible way to connect a lot of computer or data storage devices: PCs, PDAs, scientific calculators, wireless modems for telemetry, data links;

- Computer device – provide permanent memory storage for acquired data, control of the data acquisiton board, and must satisfy the portability requirements as well;

Based on the assumptions above, the system obtained will be suitable for light airplanes and for the specified requirements.

3. Microcontrollers

Microcontrollers are a new concept of integrated circuits based on a multifunctional architecture (Zelenovski, 2003). The majority of microprocessors requires a lot of discrete components and CI´s to execute a relative simple function, resulting in large and complex hardware. This is based on a fact that the microprocessors must be flexible, in the application viewpoint. This architecture is often dificult to update, and requires a lot of electronics knowledge and low level programming.

Incorporating some basic functions inside of a microcontroller, the hardware can be quite simple and with low cost as well. Some of these basic functions are: A/D converter, comparator, PWM, serial communication, internal clock, RAM/EPROM memory, flash memory and programable I/O. Some microcontrollers incorporate all of these functions in a single chip, the additional discrete components are minimal (Zelenovski, 2003).

Another advantage of the recent microcontrollers is the programming process and the language used (Zelenovski, 2003). The software can be made with high level languages, C++, Basic, or low level language (assembler). To upload the software into the microcontroller, just a PC and an external board is required.

3.1. PIC Microcontrollers

Actualy, a large number of different microcontrollers are available for different applications and from different manufacturers: Zilog, National, Motorola and Microchip. Microchip developed the PIC microcontroller family, very popular nowadays.

PIC microcontrollers uses the RISC (reduced instruction set computer) technology, that comprises a reduced set of simple instructions (Microchip, 2005). 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 (Microchip, 2005), 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 a 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 – Número de bits do microprocessador.

(2) MIPS – Millions of instructions per second.

Another important aspect is the memory used by the microcontroller. The PIC family 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 have 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 support the following technologies: USART, I^2C, USB, SPI e CAN. Actualy, the communication standard more often used is the USART, but gradually the USB have been used instead of USART.

3.2. Microcontroller Model Selection

To choose a suitable 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 considerated, preserving the adaptability requirements.

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

- Easy to buy in the local market;
- Cheap firmware recorder device;
- Bibliography available (Microchip, 2005).

The microcontroller technical specs is shown in table 2.

Tabela 2 – Microcontroller technical specifications (Microchip, 2005).

Model		**PIC16F877A**
Memory (bytes)	FLASH	14336
	EEPROM	256
	RAM	368
I/O Pins		33
A/D		8 x 10bit
Serial I/O		AUSART, MI^2C/SPI
Max. Clock		20MHz

4. The Data Acquisition System

The first tests were made using an HP48G scientific calculator as a computer device, to control the data acquisition and for data storage. The block diagram of the system is shown in figure 2. The processing speed and memory storage capacity of the HP48G are limitating 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.

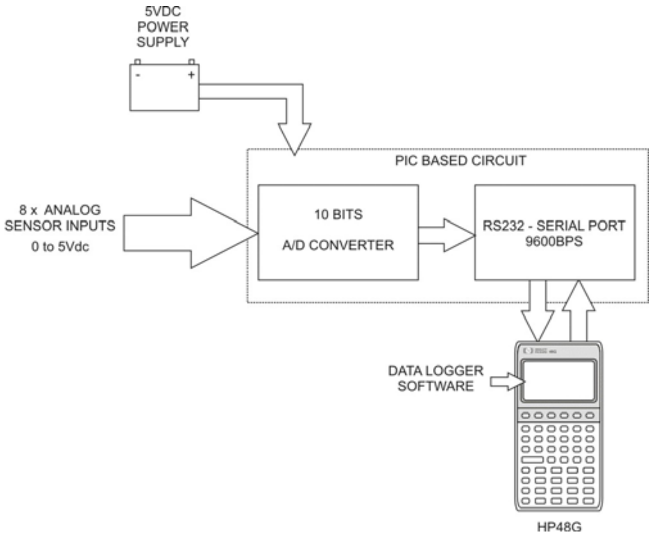

Figure 2 – Data acquisition system using an scientific calculator.

For the flight tests an 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 uses the NMEA0183 protocol, therefore no specific GPS unit is required.

In the development phase an GPS Garmin model GPSIII was used. The GPS send data through serial port at each 2 seconds (0.5Hz) at a baud rate of 4800bps. The GPS was used to syncronize 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 limitating 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 storage capacity. The block diagram is shown in figure 3.

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

THE MICROCONTROLLER FIRMWARE

The development and design of the firmware is the key of 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.

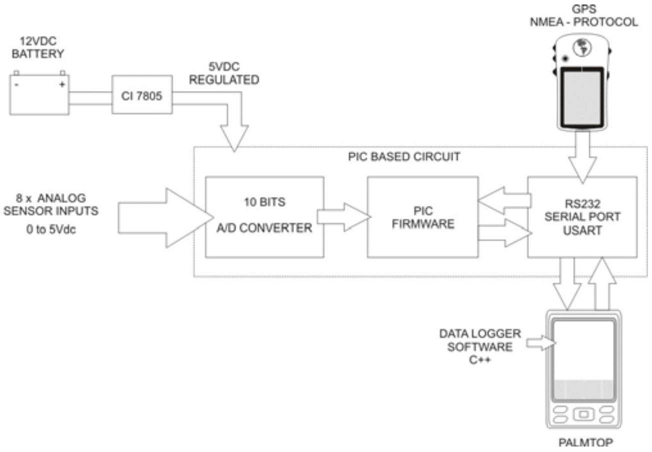

Figure 3 – Functional block diagram.

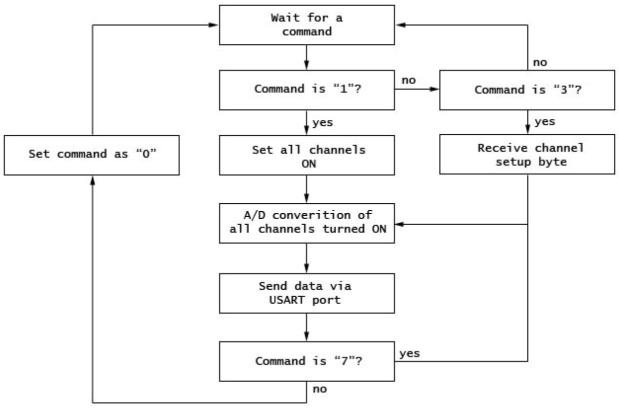

Figure 4 – PIC firmware flowchart – without GPS.

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

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

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

ADDING GPS DATA

With GPS the acquisition synchronization device is the GPS instead of the computer 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 as 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. Actually, the GPS data sent frequency is 5Hz and the data acquisition rate is 30Hz. At each GPS data read 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 (NMEA, 2005). The firmware must locate a string “GPGAA” in the GPS data packet and detach the necessary information. The algorithm developed to decode have 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. 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 loss, the information acquired by the analog ports can be identified.

COMPARISON WITH ANOTHERS SYSTEMS

Another 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 (SIMTEC, 2005);
- PODS System – developed by the English company Flight Dynamics (PODS, 2005);
- DPA System – developed by Prof. Domenico Coiro from the University of Naples, Italy (Coiro, 2002).

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

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	yes/outside	4	10Hz	na	no	Int. Drive	38kUS$
PODS	yes	inside	33	25Hz	1kHz	yes	PDA	20kUS$
DPA	yes	yes/outside	32	10Hz	na	no	Flash Card	28kUS$
CEA/FDAS	yes	yes/outside	32	30Hz	6kHz	yes	PDA	na

The performance of the four systems is very similar, and in some itens 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.

SENSORS DEVELOPMENT

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

Three axial accelerometer

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

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 conditioning circuits in order to fit the measurement range to 200kph for airspeed and 1150m for altitude.

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

Normally this pitot tube was installed on aircrafts in 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 modifying anything on the airplane’s wing,.

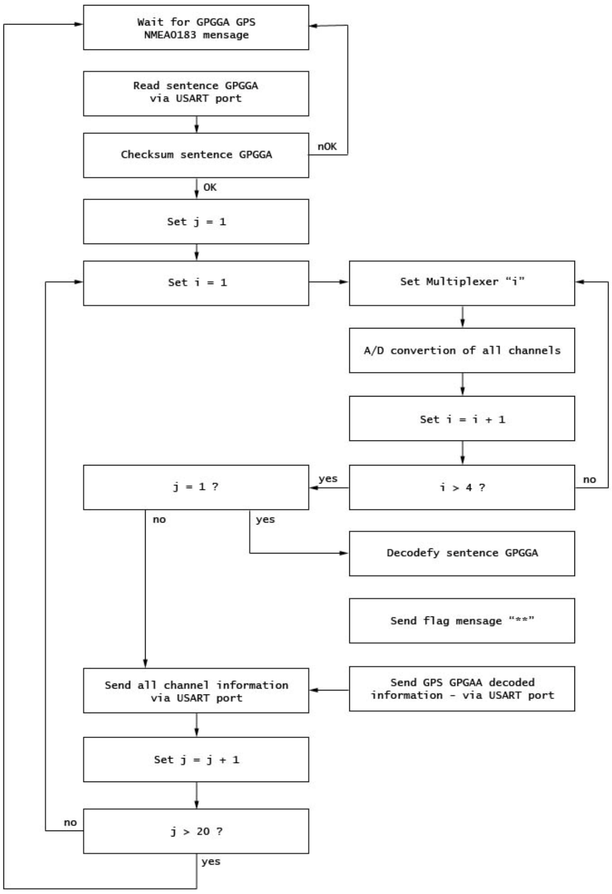

Figure 5 – PIC firmware flowchart – with GPS.

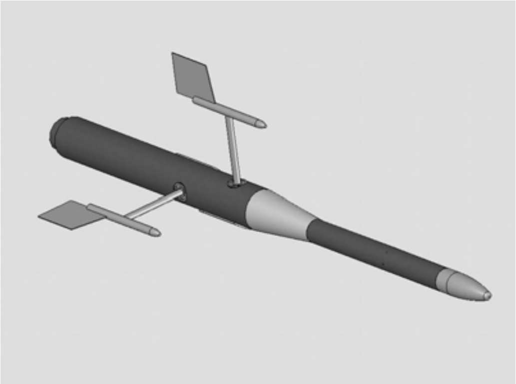

Figure 6. Pitot Probe and Angle Indicators

Attack 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 that output a voltage signal proportional to a magnetic field intensity produced by a Ne-Fe-Bo magnetic that was installed at the end of flag axel.

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

Command position indicators

In order to know the position of the command surfaces and throttle, linear potentiometers had been installed on the command system cables and tubes.

GEFRAN’s PZ12 series potentiometers were used 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.

Propeller tachometer

In order to measure the propeller rotation speed LDR (light dependent resistor) was used. This sensor was used with a frequency to voltage converter to generate an analog signal proportional to the light intensity changes produced by the propeller.

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 provide analog signal from 0 to 5Vcc. Therefore, using the entire range of the data acquisition A/D converter.

APPLICATIONS

The CEA/FDAS system have been used extensively for light airplane flight tests in the Centre for Aeronautical Studies (CEA) of UFMG. Until the publication of this paper, three tests campaign were made successfully with this system. These tests involved three airplanes, a training sailplane SZD 50-3 Puchacz (Figure 7), a very light airplane designed and built at CEA CB-9 Curumim and an UAV for the SAE AeroDesign competition.

Two applications related with others areas of science have been performed with this system: i) automotive dynamic tests data acquisition; ii) physiotherapy muscle force measurement. The applications listed above shows the versatility and adaptability of this system.

10. Conclusions

The PIC microcontroller used was considerated suitable 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 succesfully for applications where portability is not a requirement.

The use of HP48G scientific calculator was considered acceptable for applications that requires 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 succesfully 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 provide an easy solution to upgrade the system for better performance and to add new capabilities as well.

Figure 7 – Puchacz sailplane prepared to perform flight tests.

Figure 8 – Curumim ultralight prepared to perform flight tests.

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