WINGS CONSTRUCTION USING A FOAM CNC CUTTER

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Abstract. *This paper shows the development of a CNC system for the cutting of foam wings. The need for carrying out this project was originated by the difficulty and uncertainty found in the manual processes for the manufacture of wings, made by the CEFAST team, who is participating in the SAE Aerodesign Competition, representing CEFET-MG. The main objectives are the development of an electronic interface, a control software and a cutting electromechanical system. The following were developed: an interface via parallel port for the control of step motors, using PIC16F84 microcontrollers; a mechanical system of independent carriages that enables moving the axes horizontally and vertically; an arc for thermal cutting of foam; a power supply. The system was controlled by the CENECE v1.6.10 software. The system also allows the control of the arc temperature through software and the use of an end sensor. After the development and construction of the entire system, various cuttings of wings, profiles and of different configurations were made with success. For the SAE Aerodesign competition of 2004 three wings were constructed using the Selig 1223 profile. The results obtained show that the CNC cutter meets the requirements of the team and provides higher construction speed and a precision higher that that of the manual techniques.*

Keywords: CNC, Experimental Aviation, Aerodesign, Rapid Prototyping

1. Introduction

An important study of small Reynolds aerodynamic profiles (bellow 500.000) has being made by Michael Selig, since 1995, at University of Illinois. His staff has tested more than 180 profiles at wind tunnel and the results were compiled in the work of Selig, 1995. For these wind tunnel tests is important to assure the dimensional accuracy of test models. Selig used automatic process of manufacture to reach the dimensional accuracy required. Figure 1, shows one template, worked by CNC, used by Selig to cut profiles models from expanded polystyrene plates.

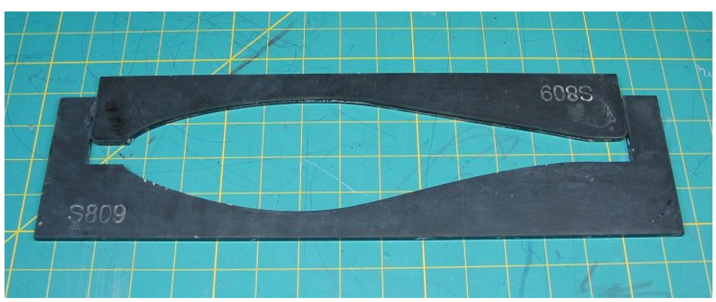

Figure 1 – Templates for airfoil cuts.

Following the Selig recommendations for profiles construction, Javier Lopez started in 2002 to develop a computer aided cutter of expanded polystyrene (EPS). Over the years the system was improved to became the most advance cutter available, with the advantage of being an open project.

This work was developed to optimize the process of wings construction of the CEFAST group who is participating in the SAE Aerodesign contest, representing CEFET-MG. This competition calls students to design and construct a high efficiency cargo radio controlled airplane which should conform with the regulations and the team specifications. With the increase of the technical level of the groups it was necessary to search new techniques which would be the differential among the crews. With this objective it was proposed the development of a Computer Numerical Control (CNC) Foam Cutter, for the cutting of foam wings, as the manual processes previously used had an uncertainty of millimeters, which directly influenced the performance of the aircrafts designed by the team.

2. Development

First it was carried out a process of research on the already existing systems. The components of each system were studied for the analysis of the characteristics of each one of the components. Upon the completion of the study, it was started a process of definition of the components to be used. In Figures 1 and 2 are shown some examples of the systems used.

Figure 2. Spanish System

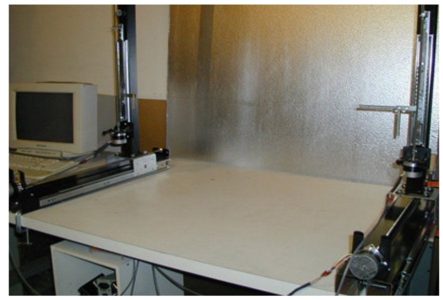

Figure 3. American System

The Spanish system (Figure 2) has an interface based on the PIC16F84 microcontroller, produced by Microchip. This interface incorporates several functions which, together with proper software, enable a higher control of the various parameters of the system; however, its movement system is more complex, with linear pivots and bearings (López, 2005).

The American system (Figure 3) presents a simple interface based on the UCN5804 microcontroller, produced by Allegro. The carriage's movement system is made with telescopic sliders. It was decided to use, in the developed system, an interface of the Spanish system to enable a higher control of the parameters, and the system of sliders of the American system due to its simplicity and easiness of construction (8linx, 2004). Below we provide details of the system developed.

2.1. Interface

The interface has the function of receiving the control data through the parallel port, of controlling the position of the engines and the start of the cutting arc. The interface used was based on the C4 model (López, 2005) which uses the PIC16F84 microcontrollers. Figure 4 shows a constructed and tested interface board.

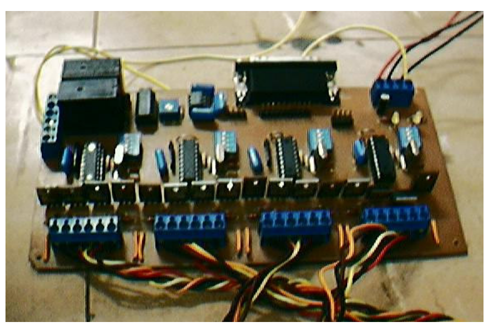

Figure 4. CNC Foam Cutter Control Interface

The interface is composed of: a logical part of control of the engines, a starter of the cutting arc, an oscillator for the frequency control of the motors power stage circuit. The fabrication of the board was made through the process of thermal transfer.

2.1.1. Digital Control

For the control of the engines it was used the PIC16F84 microcontroller which interpret the data sent by the software through the parallel port of an IBM-PC type computer, which control the engines. The microcontroller was programmed for the control of step motors, unipolar type, which can operate in the modes: simple pitch or semi-pitch and double or regular bias of the coils.

2.1.2. Motors and the cutting arc drivers

For the control of the driving of the cutting arc and of the engines, were used G2R-14 power relays produced by OMRON, which work with voltages of 6V/220V and the 7438N integrated circuit produced by Texas Instruments.

2.1.3. Frequency control

For the motors frequency control, it was used an oscillator based on the NE555 controller, produced by Texas Instruments. This control enables a fine adjustment of the motors displacement speed, which can also be controlled through software.

2.1.4. Power Driver

For the power stage were used IRF540 transistors, produced by Phillips, and zenner diodes of 15v/1W. This circuit can feed engines with total current of up to 5A.

2.1.5. Electromechanical System

The system was developed using 23BB-H252-32P step motors, produced by Minibea, which operates in a 12V tension and that consumes 0,34A. For the movement of the carriages (Figure 6) were used tapped bars with 6mm diameter and a pitch of 1mm for the vertical axis; and with 8mm diameter and a pitch of 1,25mm for the horizontal axis. The carriages move on telescopic sliders that have a low cost and easiness of construction. To use few tools for work with metal, the base material was chosen as MDF plywood of 10mm, due to its easy handling and has a low cost.

Figures 6 and 7 present the designed and the assembled cutting system. Differences can be noticed such as the use of bearings for the sliding of the tapped bars and modifications in the structures to reduce the quantity of material used.

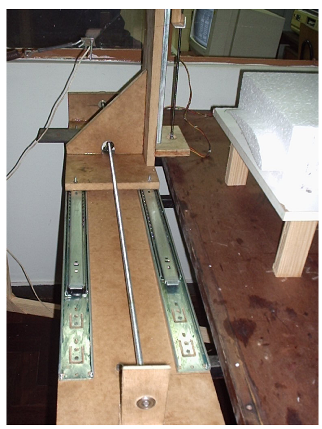

Figure 5. System for the movement of the carriages.

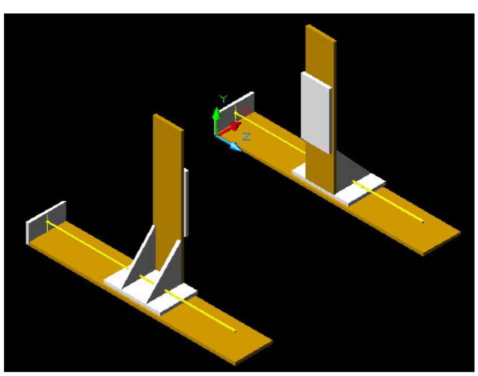

Figure 6. Project made using CAD.

Figure 7. Assembled CNC Cutter.

2.2. Thermal cutting arc

It was designed a variable power supply to feed a resistive filament which, when heated, performs the cutting of the material as it is thermoplastic. The filament is sustained by an arc built in wood, which rolls freely on the cutting table (Figure 7). To keep the mechanical tension in the filament were used springs and cable stretchers. The system can work with various materials such as: expanded polystyrene (EPS), expanded polypropylene (EPP), among other thermoplastic foams.

2.3. Control Software

With the need to obtain a software that would control the entire designed project, we have opted to use the CENECE V1.6.10 software (Figure 8) developed by López, 2005. The software was chosen as it is compatible with the control interface and for its being developed specifically for cutting wings. The software functionality's are the following:

- Cutting of wings of rectangular or trapezium plant, with or without sweepback, with or without washout;
- It works with all profiles defined with the **.DAT* format, many of them available at the UIUCC data base (more than 1,300 different ones);
- To connect/disconnect the cutting arc both in manual and automatic manner, as well to control its temperature;
- To connect/disconnect the engines both in manual and automatic manner;
- Adjustable heating time of the cutting arc;
- Preparation of the foam block, with cutting in parameter angle, so as to facilitate and adjust its size to the wing;
- Cutting of plates, adjustable quantity and thickness;
- Manual positioning of the arc with/without temperature in the cutting edge;
- Engines advance speed: adjustable both in the cutting and in the positioning;
- Cutting stop: emergency stop;
- Choice of the address of the control parallel port;
- Adjustable compensation of the thickness of the cutting edge;
- Simulation of the cutting to be made, through generated control file;
- Allows different mechanical advances, as well as different resolution of the motors, in the horizontal and vertical axes;
- Cutting with dihedral angle;
- Separate types of trailing edge;
- Leading edge with parameter;
- Inverted cutting direction;
- Rotation of the leading edge;
- Guillotine-cutter;
- Cutting of shapes created through AutoCAD ®. (using the Creadat software developed by F. Pantano for the CENECÉ);
- Cutting holes for wing spars, reinforcements, wire passer, weight reliever, square and round holes;
- Materials data base (Immediate and independent adjustment of cutting speed, temperature and edge thickness);
- Simulation of the machine size;
- Selection of profiles and their visualization;
- Manual adjustment of the edge, through control keys;
- Positioning of the arc in a pre-determined starting point. Control of end of course;
- To modify the relative thickness of the selected profile.

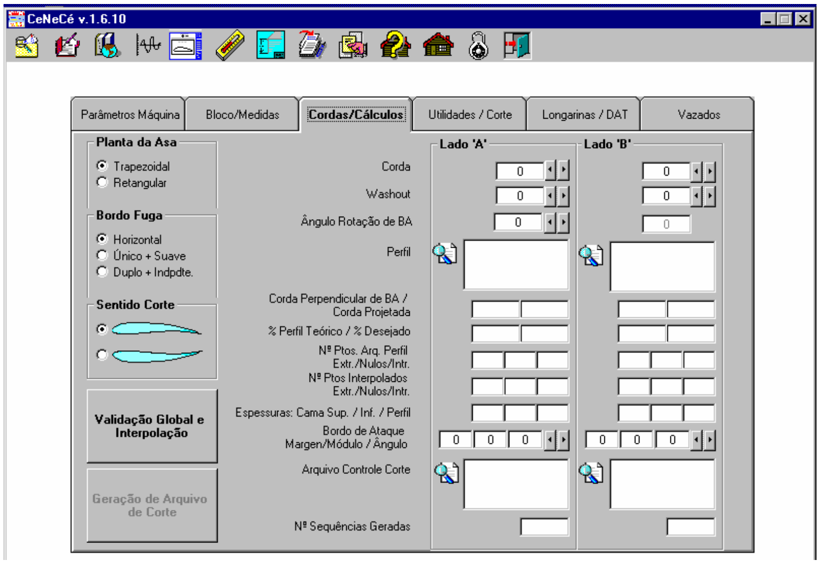

Figure 8. Software screen of CeNeCé V1.6.10

2.4. Hardware

It was used an IBM-PC computer dedicated to the control of the system, with the following configuration:

- Processor: AMD 586 DX5 133MHz;
- 32 Mb of RAM memory;
- Windows 98 operational system – Second Edition.

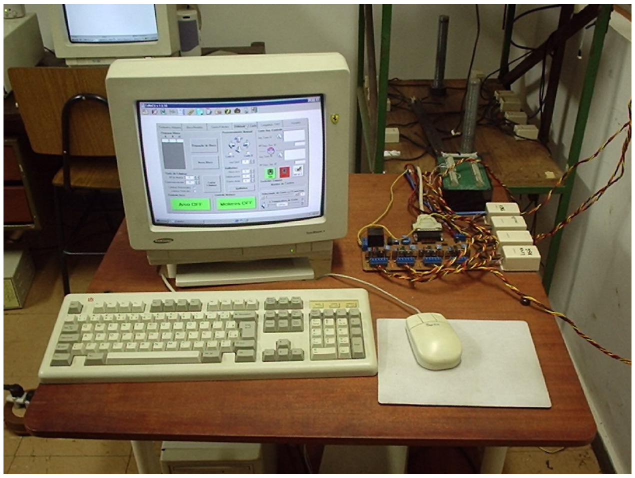

Figure 9. Computer used for control of the cutter.

3. Assembly and tests

During the assembly process were found problems of alignment of the tapped bars due to the uncertainty of the tools used in the construction of the system. For this reason bearings were used in the edges, what corrected the problem. In a way that the carriages could slide smoothly, it was necessary to lubricate the entire system. A test was made to determine the uncertainty of the system constructed. The test consists of the cutting of a profile with a stair format, with increasing steps, through the comparison between the designed dimensions and the actual dimensions of the piece (Table 1).

Table 1. Data from the cut test.

Designed dimensions mm	Actual dimensions mm	Deviation	Designed dimensions mm	Actual dimensions mm	Deviation mm
Vertical			Horizontal		
50	50.90	0.45	50	49.85	0.07
40	40.90	0.45	40	40.10	0.05
30	30.95	0.48	30	30.15	0.07
20	20.95	0.48	20	20.10	0.05
10	10.90	0.45	10	10.10	0.05

The analysis of the test data shows that the uncertainty is 0.06 mm for the cutting in the vertical direction and of 0.46mm in the horizontal direction. The Figure 10 was made with the designed dimensions and the actual dimensions of the piece. In the graphic it can be seen a higher deviation in the last step, which is the result of the accumulation of cutting errors since the first step. This type of cutting profile was chosen to emphasize the equipment errors.

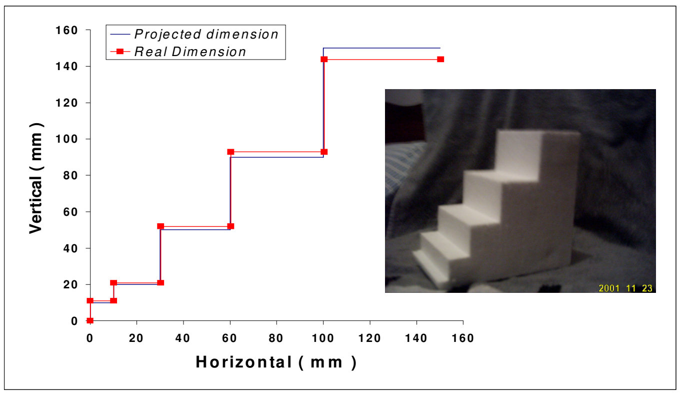

Figure 10. Chart created with data from cutting test.

In order to evaluate the uncertainty of aerodynamic profiles cutting, an optical measuring method was developed by authors. The dimensional contact meter were inappropriate because foam deformation. The test consist of cutting a Eppler 423 profile with 200 mm of cord and to scan the foam plate outer part. The scanning resolution was 1200 dots per inch at vertical and horizontal, which means a 0.02 mm resolution. The image was put over the original profile drawing, as could be seen at figure 11. The maximum deviation was of 0.65 mm that could be a result of the low foam homogeneity.

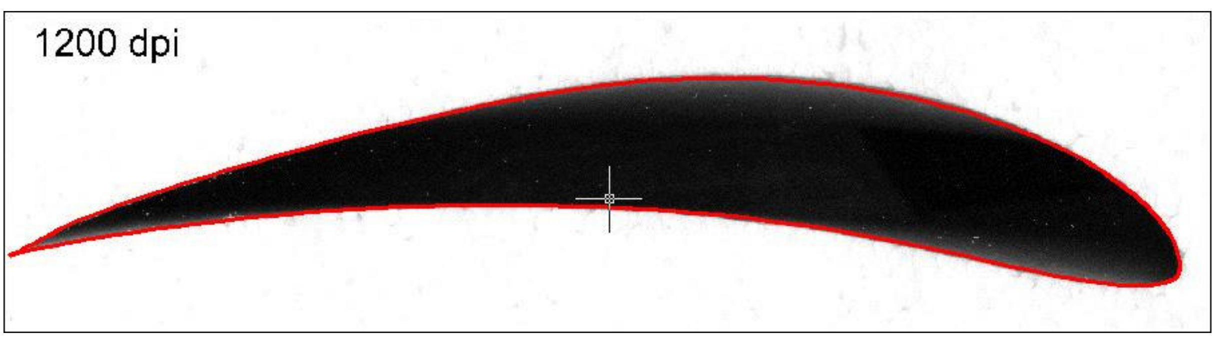

Figure 11 – E423 Profile, original and external foam plate cut.

4. Results and Conclusions

After the successful completion of the entire assembly and of the testing of the system, cuttings of the wings were made with different configurations and profiles. It was verified that the system meets the needs of the group, as the cut wings reproduce the design with more accuracy. Besides, it was found out that there was a reduction in the time of cutting of the wings from 12 hours, for the manual method, to 2 hours using the CNC method.

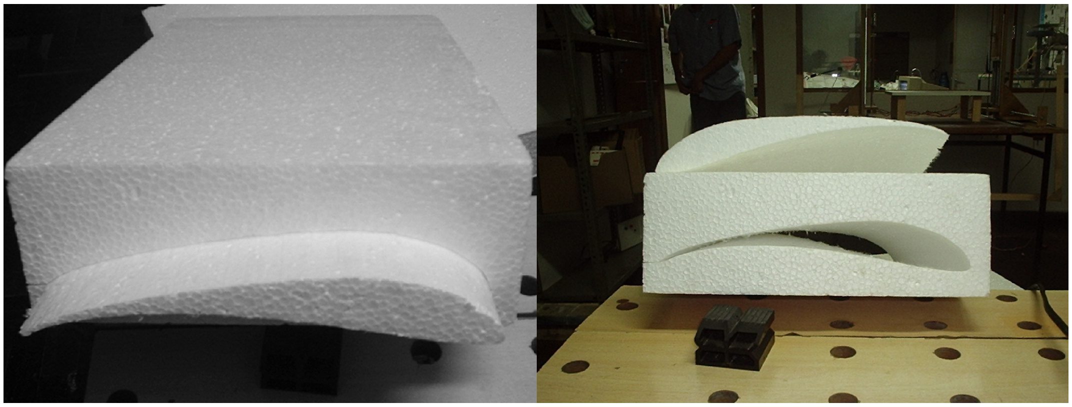

Figure 12. Sample of cuts using the S1223 profile.

For the SAE Aerodesign Brazil 2004 were built three wings with 1,83m of span, with a double tapered format, using the 1223 Selig profile (Figure 12). Several flight tests were carried out with the aircraft and it was verified a significant increase in its performance.

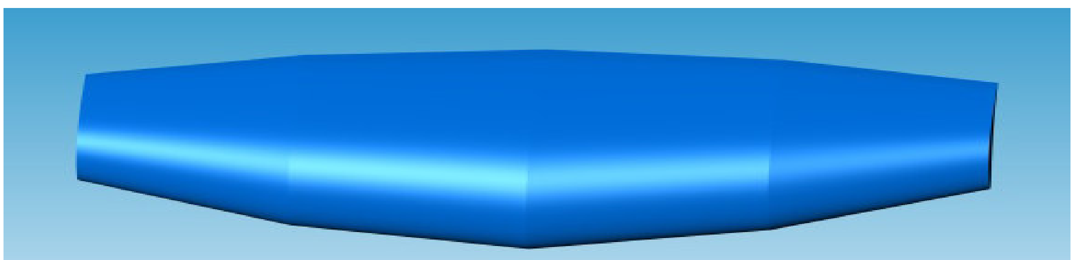

Figure 13. Projected wing for SAE Aerodesign 2004

Figure 14. Constructed wing for SAE Aerodesign 2004

In Figure 13 is show the wing designed for the SAE Aerodesign 2004 Brazil. The design was executed using the SolidWorks ® 2005 software. In Figure 14 is shown the built wing that was used in the 2004 competition. By observing the figures one can notice the accuracy of the wing built as compared to the design. With the construction of the system, the group gained freedom to perform designs of more complex wings that could not be executed before. The cutting system can also be used for the construction of models of wings and even for fuselages for tests in wind tunnel. Thus, this equipment can be defined as a system of rapid prototyping, applicable in the field of aerodynamics.

5. Cost

It was analyzed the total cost of construction of the system developed and compared to the total cost of acquisition of a similar equipment (Table 2) not including importing taxes and transportation. It was then evidenced the feasibility of construction of the system, which has a cost 30% lower than that of the imported one.

Table 2. Total system cost

Developed system		Imported system	
Item	**Cost**	**Item**	**Cost**
IBM - Pc Computer	$605.00	IBM - Pc Computer	$605.00
Digital Driver	$120.00	Digital Driver	$196.00
Software	$70.00	Software	$70.00
Stepper motors	$160.00	Cutter CRT - 100	$999.00
Workmanship	$240.00		
Materials	$160.00		
Total	$1,355.00	Total	$1,870.00

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