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ADVANTAGES REACHED BY REPLACEMENT OF 2D TO 3D PROGRAMMING TO AIMMACHINABILITY OF PRIMARY PARTS

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Abstract

Industrial programming is a tiresome and time-consuming task that requires technical skill. Thus, new and more intuitive ways for people to interact with CNC machines are required to make programming easier. The goal is to present two methods of programming that helps users to program a machine in an intuitive way, providing a high-level of abstraction from the machine language. Therefore, this paper presents a CAD-based system to program from a 3D CAD environment, allowing users with essential CAD skills to generate programs off-line in order to facilitate and accelerate these related tasks. This is feasible due to a relatively low cost and commercially available CAD packages that enable the user to generate machining programs. The method used to get data from CAD and techniques to manipulate, simulate and convert it into CNC machine commands are presented herein. Finally, the effectiveness of the two methods is showed when the time and wastes saved in 3D programming is compared to 2D programming to perform the same task. This presented method can also contribute to improve the quality of work, increase productivity, standardize work routines, and strive for excellence in adding value. A case study is showed to evidence the benefits reached.

Keywords: CAD, CAM, Off-Line Programming, Machining

1. INTRODUCTION

The competitive nature of a globalized aerospace industry requires aircraft manufacturers to remain current and push the boundaries of aircraft design in all development phases. Continuous progress in affordable computing power is enabling the use of more precise aircraft analysis codes in the conceptual design phase. Consequently, within a specified timeframe, more analysis loops with higher fidelity can be accomplished, which allows more optimized designs of an already-mature product (Banerjee *et al*, 2013).

Advances in CAD/CAM (Computer Aided Design and Manufacturing) and the advent of CNC/DNC (Computer and Direct Numerical Control) made off-line programming a realistic proposition for groups of more complex machines indirectly communicating with each other through shop floor computer systems (Chan *et al*, 1988). These are intended to be used for programming machining process in order to establish the contact between engineering and production environments.

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Industrial programming is a task for specialists. Although off-line programming can drastically reduce the machines to stop time to maintenance, with the use of object oriented design patterns, it is possible to minimize the time spent in programming (Bottazzi *et* Fonseca, 2005).

The programmer determines an appropriate choice of machines, tools, acessories, fixtures and the related parameters of the whole process. Without computer assistance in this procedure, it is highly likely that it will only be possible to find optimal solutions for the simplest of manufacturing tasks.

Based on these trends and needs, a specific methodology has been proposed to enable the programming in 3D environment to processing in CNC machining centre. Hence, the method is built on the CATIA V5 platform, which is widely used in the aviation industry.

In this paper, a proper use of 3D programming method is used to support the manufacturing of parts. Definition of parameters, trajectories, reduction of cycle and control

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of steps related to process are discussed. It also aims to provide a comparison between 2D and 3D programming methods and their technical features.

Finally, results are presented to certify the advantages reached when 3D programming is applied to machining of composites parts on CNC processing centre. Moreover, this proposed methodology can contribute to the business' competitiveness in terms of savings as it will be presented in the study case.

2. LITERATURE REVIEW

2.1 Offline programming

In order to avoid idle times of capital intensive installations, the programming of the industrial robots must be performed off-line in a virtual world. Nowadays, robot simulation is often applied for designing work cells with industrial robots (Worn *et al*, 1998).

Figure 1 illustrates the offline programming application for a cooperative robots situation on aircraft industry.

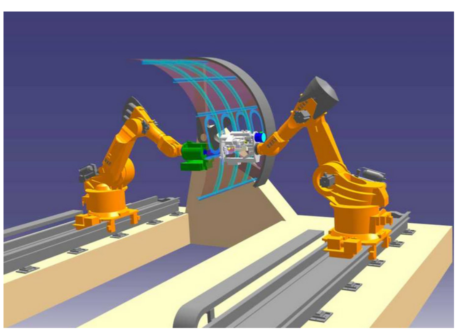

Figure 1. Offline programming simulation
source: Cenit, 2014

Off-line programming system developed includes graphical simulation of the robot and its workcell, kinematic model of the robot, motion planning and creation of the NC code for manufacturing processes (Mitsi *et al*, 2005).

Figure 2 shows a graphical simulation of a routing process application.

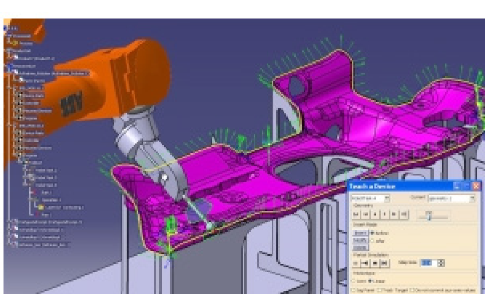

Figure 2. 3D contour machining
source: Cenit, 2014

Offline programming has been gradually implemented on manufacturing processes to supporting aircraft manufacturers compete against future aircraft builders.

This solution contains essential benefits due to many reasons as described below (Cenit, 2014):

- Continuous process chain from modeling to offline programming using native V5 data;
- Time saving through automatic fixture creation;
- Time saving through less required prototypes;
- Increased robot cell availability through obsolete teaching activities;
- Robot simulation and collision-checking before execution;
- Flexible adaption to boundary conditions through macro editor;
- Continuous process chain through integration in V5.

Offline programming integrates robotic simulation and code generation with CAD/CAM software, delivering quick, error-free robot programs.

2.2 CNC machining centre

High speed, high quality, repeatability and flexibility are the typical requirements of any kind of production. Faced to these needs, CNC processing centers can satisfy many demands with efficiency and good performance.

CNC machining center can be defined as a sophisticated machine that can perform milling, drilling, tapping, and boring operations at the same location with a variety of tools (Tooling U-SME, 2014).

Figure 3 shows a kind of state-of-art CNC machining center used for several applications in industry.

Figure 3. Flexible CNC technology for the woodworking industry

source: Hamuel Reichenbacher, 2014)

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Short setup times, a variety of machining options and ease of operation are requirements for high productivity of the businesses. Machines of this nature consistently have high output and reliability.

Wood factories have been widely using several types of these machines in their manufacturing shops due to being high performance equipments that contribute to provide good quality for end products.

2.3 Composite Materials

Aerospace composite businesses are increasingly sought after as acquisition targets. Many component makers are seeking to acquire composite capabilities and few acquisition targets of scale are available (Defense Industry Daily staff, 2009).

Composite materials in airplane components have been used for decades. Prior to the mid-1980s, airplane manufacturers used composite materials in transport category airplanes in secondary structures (E.g., wing edges) and control surfaces. In 1988, Airbus introduced the A320, the first airplane in production with an all-composite tail section; and, in 1995, Boeing Company introduced the Boeing 777, also with a composite tail section. Composite materials used in commercial airplanes are typically produced by combining layers of carbon or glass fibers with epoxy. In recent years, manufacturers have expanded the use of composites to the fuselage and wings because these materials are typically lighter and more resistant to corrosion than are the metallic materials that have traditionally been used in airplanes (Freissinet, 2011).

Figure 4 presents the percentage of composites applied to aircraft structures.

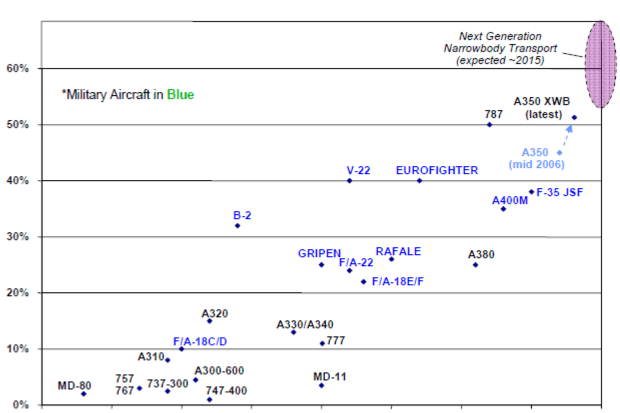

Figure 4. Aircraft Composite Content to Select Airframes % of structural weight

source: National Institute for Aviation Research, 2014

The Boeing 787 is the first mostly composite large transport airplane in commercial service. The Boeing 787 is about 50 percent composed by weight (excluding the engines). It will be followed soon by the Airbus A350, having composite material roughly in the same proportion as its Boeing competitor (Freissinet, 2011).

The importance of composite materials for aerospace structures has increased in recent years due to their key properties such as low weight, high performance, high stiffness and the ability for it to be tailored specifically for different structural uses (Frulla, 2013).

2.4 CNC Nesting conception

Nesting programming consists of optimally fit many different manufacturing parts into a single sheet of raw material. It means that you get the parts you want in exact quantities at the lowest possible cost, including material and machine efficiency, schedule adherence, order completion and all other cost considerations. In general terms, nesting automatically and efficiently arranges the required quantities of individual parts to be produced on sheets or plates of stock material. It does this by using part geometry from CAD files to output CNC code that controls a cutting machine (Optimation, 2014).

It has been also used to minimize the amount of scrap raw material produced during manufacturing. Using algorithms, it then determines how to lay these parts out in such a way as to produce the required quantities of parts, while minimizing the amount of raw material wasted. Nesting programming provides solutions to all of your profile cutting needs (Torchmate, 2014; Hypertherm, 2014).

Figure 5 shows an example of nesting programming used for manufacturing primary parts.

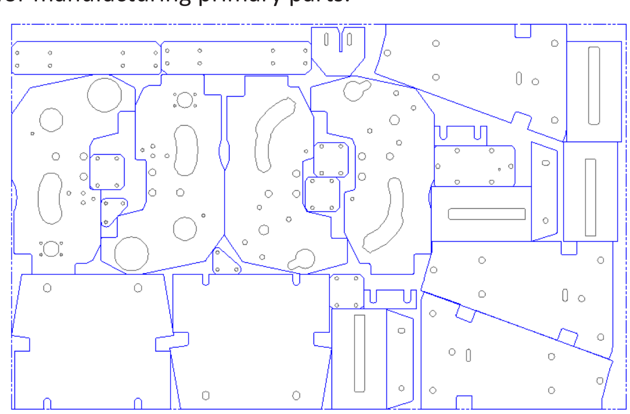

Figure 5. Nesting example

source: ExactCAM, 2014

According to the increase of composite materials used in aerospace industry, nesting conception for manufacturing has been usually applied. Composite primary parts can be processed by robots or CNC machining center depending on related strategies.

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Thereby, improvements regarding the programming have been performed to make the business more competitive.

3. NESTING PROGRAMMING FOR COMPOSITE PARTS

Programming methods applied to any manufacturing enterprise can significantly influence product lead times, final cost and its competitiveness. This method used to a given application reflects all conditions of the programming cycles from the programmers' tasks based on their specific routines until the production begins on shop floor.

In the aerospace context, the programming includes files downloading, manipulation, simulation of the process and manufacturing control on CNC centres. Thus, the objective of this work is to quantify the advantages that 3D programming provides to CNC machining shops in relation to 2D method.

3.1 Motivation and novelty of this paper

This work presents two programming methods used for CNC machines. The novelty of this paper is to present a real comparison between 2D and 3D methods applied to machinability of composite parts computer-based on a nesting concept. The motivation of this work is to present the benefits and cost savings identified and quantified in a specific case study regarding the programming of aircraft parts.

3.2 Programming needs and trends

The machining and routing of composites is not a new topic. CNC machining centers have been successfully machining composites for a while and are able to operate under ideal conditions. Routing equipments allow production operatives to machine composite material using simple templates (Richards *et* Turnbull, 2012).

Moreover, industrial robots represent another solution for both productivity and flexibility. Nevertheless, the programming of industrial systems for this specific application is still very difficult, time-consuming, and expensive.

Therefore, different programming processes have been used to provide condition to manufacture parts in machines. It depends on the needs of the business and its conditions. In this practical composite parts manufacturing, there are two main methods of programming used, which are, 2D and 3D offline programming (OLP).

Faced to the globalisation, the high costs of skilled workers, long learnship curve needed, number of labor, amount of MH (man hours) and the difficulties involved will define which method is more interesting for the business. The next topic will show the comparison between the two methods used for this specific application.

3.3 Comparison between 2D and 3D methods

Regarding the two nesting programming methods used for this specific machining of composite parts, these industrial applications are offline programming (OLP) used to provide the best arrangement of parts along the composite plate.

Although the concept is simple, the quality of programming is limited by the skills of the operator and once the program is generated, it is very difficult to make further amendments.

The whole process for both programming methods (2D and 3D) comprises three phases: design, process and manufacturing, wherein the phase of process requires more detailed and careful works. The following flowcharts (Figures 6 and 7) represent the tasks needed for each programming method.

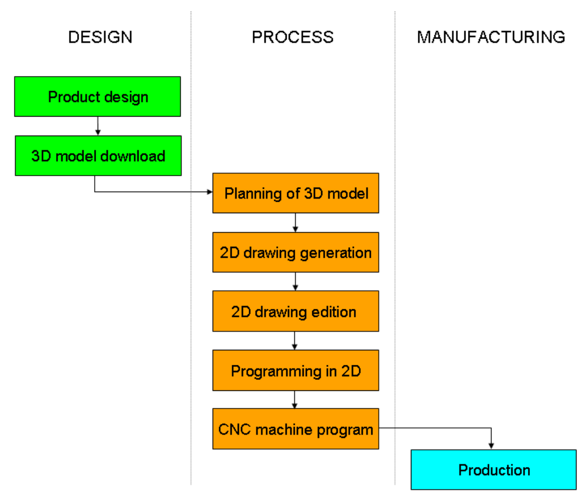

Figure 6. Nesting 2D programming

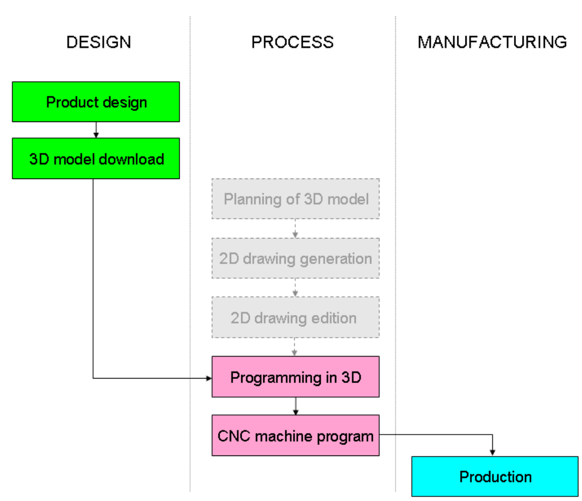

Figure 7. Nesting 3D programming

Design phase tasks are the same for both methods and it comprises getting the 3D models by downloading them from the models database.

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Concerning the process phase of programming, this step requires a lot of work when 2D method is applied. After the models are downloaded, they have to plan to create the 2D drawing. It requires a powerful hardware to perform that and it has difficulties for complex drawing, also, it takes a long time. When 2D drawings are generated, the lines, radius and edges are usually discontinued and they need to be reworked to provide conditions for processing. This edition is needed due to the extraction from 2D geometry of the 3D model. 2D programming requires much more careful and experienced technicians than the 3D method. It includes difficulties, time-consuming and it is also generally responsible for many mistakes. There is no interaction or automation involved in this process that demands measurements on 3D file to enter these pieces of information in 2D programming.

Regarding the 3D programming, tasks represented in the dashed gray boxes are not necessary for this method. After the 3D models are downloaded, the programming is directly done in 3D environment, which minimizes the steps and simplifies the programming process. Benefits of 3D programming will be presented in case study section.

After the programming process is completed, a CNC machine program is performed to simulate the whole process, resources and a previous route of each machining process in order to minimize cycle times, reduce errors and eliminate future reworks.

Then, the post processed programming is sent to the CNC machining centers used to manufacture products and orient towards improvements in economy, quality and effectiveness of cutting processes.

4. CASE STUDY

4.1 Introduction

As a proof and attestant of the 3D programming efficiency faced to 2D method presented in this paper, a case study is exposed in this chapter.

The case study method was applied to allow a comprehensive analysis of the situation and comprehension of both methods related to each other. Data were collected by a real example of nesting processed by CNC machining center on the shop floor. It reports the comparison between the 2D and 3D methods to evidence the advantages and disadvantage of each method and their involvement to the business.

The process comprises the CAD models downloading and its programming tasks, regarding the best arrangement of parts along the plate, CNC machine program and production.

Figure 8 illustrates some parts that compose the product and will be manufacturing by CNC programming.

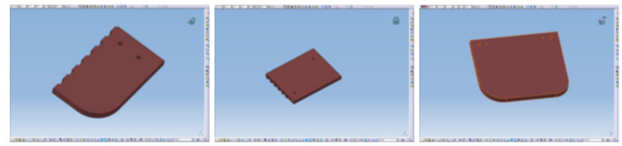

Figure 8. CAD models of parts

4.2 Production assisted by 2D programming method

This programming method requires some steps to be fulfilled before the program is sent to CNC machine. The main reason for it is to convert the 3D model in 2D drawing.

Figure 9 demonstrates the steps of this process related to the 2D programming method only.

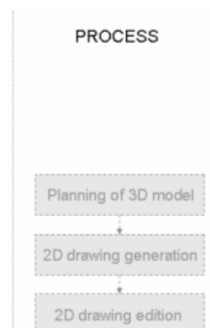

Figure 9. 2D drawing creation

These three steps, showed above in Figure 9, are necessary because the most common softwares widely used in the industry do not comprise the postprocessor. Postprocessors are files that act upon generation of NC code. It means that they act as converters of graphic language into numerical language (CN).

Figure 10 shows the 2D programming after execution of CAD models downloading, preparation and edition.

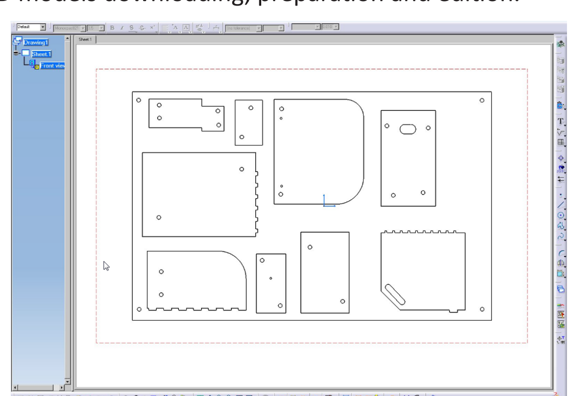

Figure 10. 2D programming method

3D files convertion process spends a high cycle time due to the preparation of the nesting until it is ready for manufacturing. It means a loss of productivity in terms of time that will represent more money involved.

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Furthermore, other significant troubles regarding to this method are cited below:

- Loss of the information input by the draftsman in the 3D design;
- Difficulties in interpreting the offline simulation;
- Programming errors concerning to the operator distractions;
- No floating licenses;
- Difficulties of communication between design and manufacturing environments.

4.3 Production assisted by 3D programming method

The 3D method simplifies the programming process and reduces some steps until sending the program to the CNC machine. This happens because the edition process is not necessary for this kind of method. All CAD models can be directly used because the postprocessor is present in this solution.

Figure 11 illustrates the 3D programming after execution of CAD models downloading and preparation.

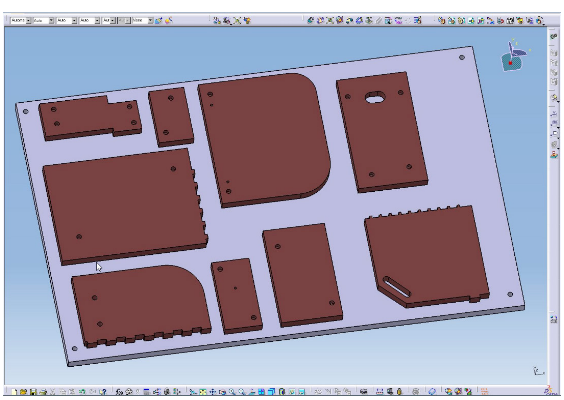

Figure 11. 3D programming method

Some advantages of 3D method can be listed below:

- Time saving to programming;
- Program based on 3D, making the process more interactive, simpler and easier;
- The visualization facilitates the detection of design errors and interferences between tools and workpiece;
- Elimination of needs to create geometries;
- Greater exploration of the machine resources;
- Easeness to training other programmers;
- Floating licenses.

4.4 Savings by commutation of 2D to 3D programming

A comparison between the two methods presented above can show the progress when 3D programming is applied.

This application regarding the nesting concept for composite parts can contribute to the company's competitiveness when 3D programming method presented in this paper is applied to the production environment.

The amount of hours needed to perform the programming on both situations (2D and 3D) is presented in Table 1 below:

Table 1. Cycle time in hours

	Cycle time (hours)	
Step	2D	3D
Product design	-	-
3D model download	0,50	0,50
Planning of 3D model	0,58	0,00
2D drawing generation	0,42	0,00
2D drawing edition	0,33	0,00
Programming	7,00	5,00
Production	0,42	0,42
Total	**9,25**	**5,92**

Cycles of product design are not described in the table because it is done by product department and it does not affect the analysis.

A comparison between the two methods presented above can show the progress when 3D method is used. It reflects a gain of productivity that contributes for the competitiveness of the business as expressed in Figure 12 below.

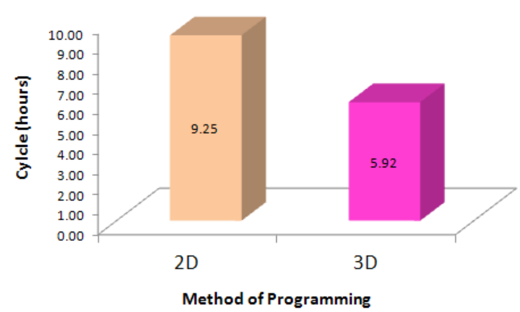

Figure 12. Cycles of programming

In order to make valid and to certify the tangible gains obtained with the method application, the hours were valued according to the tax ($) related to the manpower's cost.

Table 2 shows the values and its related savings according to the reduction of hours when 3D programming method is performed to programming of nesting.

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Table 2. Annual savings (US$)

Δ of hours	Tax (manpower)	# of nesting per month	Annual Saving
3.33	$60.00	35	$84,000.00

It is important to emphasize that these measurable savings add to the competitive advantages described in topic 4.3 (page 5) of this paper.

5. CONCLUSION

The evidences and results presented in this paper assure that the use of 3D programming is more advantageous than 2D method. In addition, it contributes to innovation on the CAD / CAM process in order to make the company more competitive faced to challenges on the market.

Discussing the results of this paper, it is important to emphasize a practical application of composite parts based on nesting concept and its related advantages that make the programming faster, when 3D method is used.

3D method also cooperates significantly to increasing productivity, quality and flexibility due to providing updated data directly to machines, reducing wastes with editions, reworks, adjustments and minimizing errors during files preparation.

Therefore, the evidences demonstrated in the case study certify that the application of 3D method faced to 2D for programming in nesting concept contributes significantly to adding value in terms of technology, productivity and strategic matters. It increases the level of the company's competitiveness in terms of profit.

Furthermore, it could be said that the quality of files obtained immediately from the design's database provides a quick response to the production needs. It is important to say that the 3D method also provides a better integration between the design and manufacturing environments.

Finally, it can be concluded that the application of 3D method presented in this paper meets the most important needs required by the aerospace competitive market. It guides the production's support team for sustaining a manufacturing system with focus on gains in productivity, flexibility and innovation.

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