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AERONAUTICAL PLANAR FLANK MILLING AUTOMATION: COMPUTING THE G-ZONES

Ramy HARIK
PhD Student, CRAN
Science and Technology Faculty
BP 239 Henri Poincaré University
54506 Vandoeuvre Cedex – France
ramy.harik@cran.uhp-nancy.fr

Gabriel Ris
Professor, CRAN
Science and Technology Faculty
BP 239 Henri Poincaré University
54506 Vandoeuvre Cedex – France
gabriel.ris@aipl.uhp-nancy.fr

ABSTRACT

Flank milling process is commonly applied in the aeronautical industry. It consists of manufacturing mechanical parts using the side of a machinning tool. This process is relevant to be less time consuming as it delivers better surface quality. However, flank milling can only be applied on ruled surfaces.

In this article, we cover flank milling application on planar surfaces, a particular ruled surface type. In recent works we presented how to extract planar surfaces milling directions by using expertise provided through our industrial application. We take this study further, where we propose a validation for the proposed milling directions. This validation requires at first a translation of the problem from 3D to 2D. Then, by applying several proposed algorithms we extract for each direction its L-Zone. An L-Zone is the term we use to identify the unmachined part area using a particular milling direction. By intersecting the different L-Zones we obtain the G-Zone that consists of the total unmachined area. Computing the G-Zone for each planar surface indicates the ability of this surface to be flank milled.

The proposed study is part of an effort to automate process planning of aeronautical parts. Automating this particular trade can result in a critical reduction of time, effort and costs in aeronautical industries, mainly due to having small production batch.

1. INTRODUCTION

Competitive environments introduced the need to enhance product quality while reducing cost, time and effort. The direct competition results affected the different product lifecycle trades. A product development cycle is generally composed of: need identification, design, realisation, maintenance and management. Particularly in our field of interest, the aeronautical manufactured mechanical parts, the realisation phase consists of the process planning and manufacturing trades. CAD, CAPP and CAM are generally sequenced leading to the finished product. Works are advanced when it comes to the CAD and CAM trades; however efforts are put unto the automation of the process planning trade. Process planning is a function within manufacturing facilities that selects manufacturing processes and parameters to be used to transform a part from its initial stage to the final stage based on a predefined engineering drawing [1]. In fact, the process planner receives from one side the definition of the geometry and from the other the process capabilities of the workshop. He then tries to set up the process plan. Automating the process planning trade in the aeronautical field is justified by small production batch.

[2] has identified the three main functionalities of an automated process planning system. The first being the capability to interpret the part geometry and topology, the second being the capability of the system to build its own process planning from its knowledge base, and the third is

giving the system the ability to update its knowledge by learning through the success of its proposed solutions.

The proposed system architecture can be seen as follows. The first part consists of the bridge between the CAD and CAPP trades. The second consists of generating the process plan or the CAPP trade. The third of the CAM trade application return. Those three parts can be identically found in the USIQUICK project [3].

The USIQUICK project is designed by the French Ministry of Industry to answer the attempts of aircraft industries. The project involves eight partners:

• An aircraft manufacturer (Dassault Aviation) specifies the expected results and proposes its expertise on process planning.

• A leader in PLM software development (Dassault Systèmes) manages the industrialisation perspectives of the project for its future software solutions.

• Five French laboratories (CRAN, L3S, LURPA, LGIPM, and IRCCyN) ensure the scientific consistency of the project and propose innovative solutions to solve strategic locks.

• A French-government institute (CETIM) analyses the possible use in other fields and proposes extra test cases and tool databases.

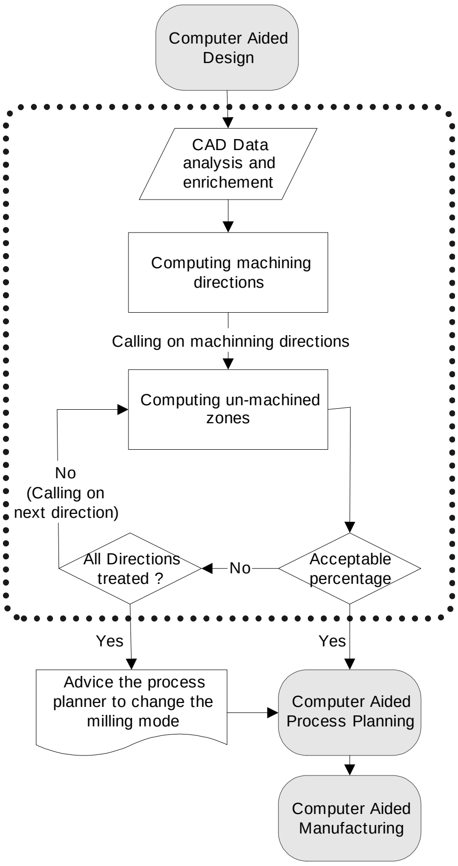

FIGURE 1: Our positioning in the product realisation lifecycle, in grey background the traditional product realisation trades (CAD/CAPP/CAM)

This project focuses on the definition of milling process plans in aircraft manufacturing. The parts to mill have free-form surfaces, and often require 5axis milling machines.

To automate the process planning, one of the main challenges is to fill the semantic gap which lies between the design and the process planning, which is to provide a product definition adapted to the process planning activity. Within the framework of the USIQUICK Project, we try to build a specific product definition adapted to the aeronautic process planning field.

Some previous works on the aeronautical process planning automation shows that each face of the part issued from the design has to be enriched with some technological manufacturing related information. We designed procedures that determine this information thanks to a specific manufacturability analysis which tries to define the possible milling directions and un-machined zones for a given face of the initial design product and a given machining mode (flank-milling, end-milling or ball-milling).

This article presents the planar surfaces flank milling manufacturability analysis. In recent works [4] we proposed an expertise based knowledge management which extracts machining directions for planar surfaces. Now, we put the investigation further by computing the milled zones using these machining directions. This would be seen mutually as a validation for the machining directions and an identification of the accessible part areas using a selected milling mode.

2. STATE OF THE ART

2.1 Flank Milling

Flank milling is a manufacturing process where the realized part is milled by the flank of a tool. Five-axis flank milling of sculptured surfaces shows important advantages in terms of machining time, costs and surface finish compared with point milling. The advantage of point milling is that almost any complex smooth surface can be machined with it. The main disadvantages of it are low material removal rate, poor surface quality and sever cutting tool wear [5]. Flank milling is most commonly applied in the cases of turbine blades, where time and surface quality gives flank milling the priority due to a huge time saving going up to 14 times in comparison with end milling [6] . Time saving is due to the removal of a large amount of material in a single passage. Many techniques have been developed over the last recent years for flank milling with many researchers focusing their attention to develop better methods of tool positioning for flank milling applications. In addition, researchers have centred their works on machining ruled surfaces [7] skipping totally the benefits of using flank milling on planar surfaces. The latter are mainly ignored due to the infinite amount of possible milling directions that can be identified. However it is to mention, that some industrial ventures (where algorithms and research were not communicated) proposed flank milling algorithms within their software solutions. CATIA® offered flank milling possibilities since 1996.

Flank milling a planar surface is completely missing within the research field. In addition, relatively little has been publish in the area of flank milling a ruled surface. Studies showed that flank milling can only be applied on machining ruled surfaces. A ruled surface can be identified as the result of moving a line in space. Ruled surfaces are split into two general types. While general ruled surfaces, the particular cylindrical and conical types are on a side, we find planar surfaces on the other. This separation comes as a natural result for the machining directions extraction. Planar surfaces have an infinite amount of potential machining directions, while general ruled surfaces (as well as cylindrical and conical natures) have a predefined machining direction that is the surface rules.

Studies in the flank milling area focus mainly on the improvement of the tool positioning so to obtain the closest surface to the part modelled in a CAD environment.

Research conducted in the University of Waterloo developed a strategy to roll a cylindrical cutting tool along two guiding rails and later on different optimisation propositions were forwarded. [8 - 10]. These methods are found implemented in CATIA® V4. [11] presented a simulation model for flank milling processes and then analysed the deviation of a machined surface in flank milling due to tool vibration [12]. [13] concerns the evaluation and the deformation of a calculated tool path in 5-axis machining, with the objective of defining a high-performance tool path by generating an accurate and interference free tool path. [14] concentrates on side milling non developable surfaces for almost the same approach of tool positioning improvement in 5-axis ruled surface milling using envelope surface. [5] developed a simple positioning strategy for the cylindrical cutter to minimize the deviation between the designed surface and the actual machined surface. The authors proposed three points offset (TPO) method to calculate the tool positions individually. That method is robust and accurate with a facility to integrate it with current CAD/CAM system.

It is to mention that many flank milling research is subject to confidentiality such as the works of Roland Maranzana and Emanuel Duc.

2.2 Computer Aided Process Planning

Process planning is often described in the literature as the most important task in production preparation. [15] defines CAPP as the most promising technology of enhancing the adaptability and flexibility of manufacturing systems. Many efforts were conducted to develop CAPP systems, such as CAD PPI [16], CAFÉ [17], and the CAD/CAM integration proposed by [18]. The above mentioned approaches vary in their capabilities of part geometry and process. [19] presents an extensive overview of process planning, where it would be interesting to forward the detailed survey of the CAPP systems directions given by [20]:

• In the future, agent based distributed engineering system will provide a basis for the integration of concurrent product development activities.

• There is a need for a universal language for communication among heterogeneous systems of CIM. It is also mentioned that agent-based systems may give solutions for this problem.

• Most of the present CAPP systems are single domain systems such as for machining, sheet metal working, or assembly, but in real-world industrial applications here will be interaction among these domains. So it is suggested that, in future, interaction of these domains should be taken into account when developing CAPP Systems. Further, it is also suggested that manufacturing domains such as joining processes, casting, metal forming, and fabrication of plastics and composites should be considered for process planning. In a standard process plan, the data related to part inspection and statistical process control should be included.

• There is a need to develop user-friendly artificial intelligence (AI) software tools in order to solve some of the problems in CAPP.

• Optimisation techniques should be employed in order to reduce cost during design and manufacturing.

3. COMPUTING THE G-ZONES

3.1 Methodology presentation

In the following, we present the different sections leading to the G-Zones computation. A G-Zone is the term we use to qualify the global unmachined zone. Having opted the planar surfaces study, at first we will elaborate on which machining directions are to be selected for each planar surface's milling. Then, for each machining direction, we compute its L-Zone. The L-Zone would be the local unmachined zone of our surface using a specified machining direction. After computing all L-Zones for each proposed machining direction, we intersect them to obtain the G-Zone in question.

The G-Zone ratio on the total face's area would constitute the indicator if the flank milling mode is advisable for this face or not. Usually ratio's above 80% are acceptable, and the remaining scallop would be removed in a finishing operation.

Figure 2 explains the different previously mentioned sections. We shall investigate each section furthermore in details.

3.2 Milling directions

The first natural step in computing the accessible machining areas (G-Zones) would be to identify the potential milling directions. Since we are dealing with planar surface, a multitude of milling directions is thus possible.

To eliminate and select a discreet set, we base ourselves on knowledge expertise. A process planner would study the face upon its different criterions and surroundings. Then he would propose different machining directions.

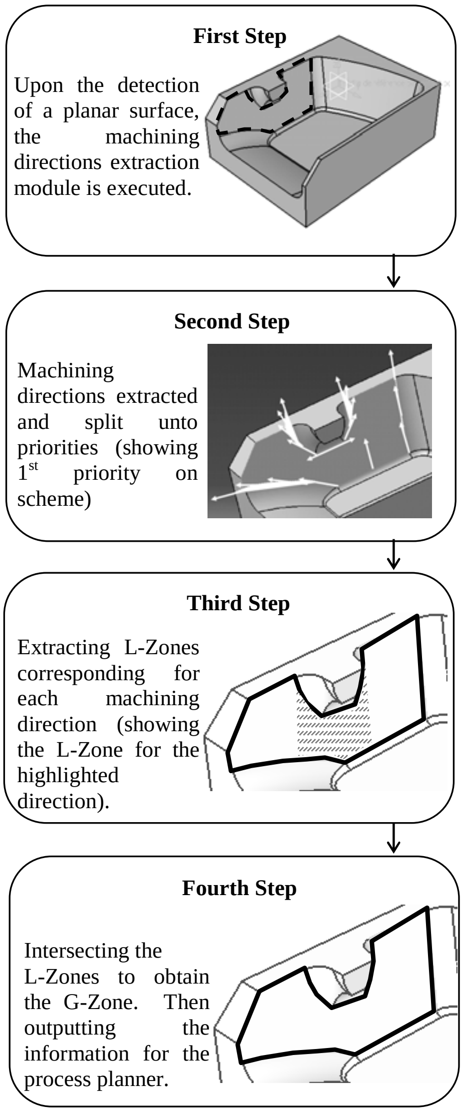

Figure 2. Succession of the different modules that constitutes the G-Zone extraction

Before presenting the rules, we explain the enhanced geometric model (fig. 3). Our part would be transformed to a list of faces, where each face has different attributes such as its type [planar, cylindrical, sweep, ruled, conical and general], nature [closed, open, semi-open] (check fig. 4), area, list of surrounding edges, and list of interior edges. Each edge has different attributes too like its type (linear, circular and general), sharpness [21] [closed, open, tangent, tangent open, tangent close] (check fig. 5), transitions (which edge is before and which is after), border angles (with the previous and next edges) and adjacency (which face is on the other side of the edge). The different values of these attributes would result in extracting our machining directions.

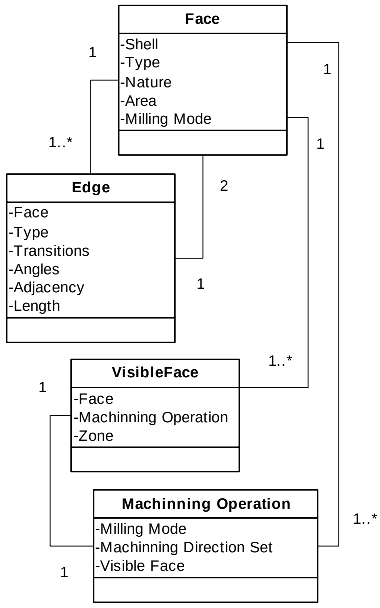

Figure 3. Our data model

At first faces are classified depending on their nature. If the face is totally closed then there would be no need to study its flank milling ability since the face is inaccessible through its borders. If the face is totally open, we would try to find sequenced contouring operations, or open tangent edges that would comprehend the tool cutting length. The third and final possibility, the face would be semi-open and we would study closed edges to extract potential machining directions.

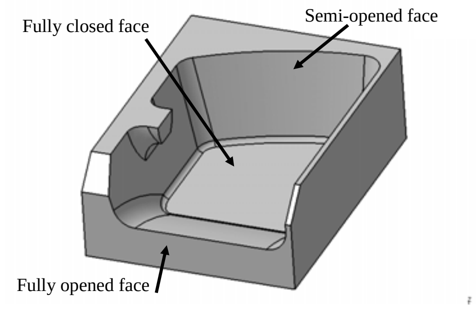

Figure 4. Face Nature types

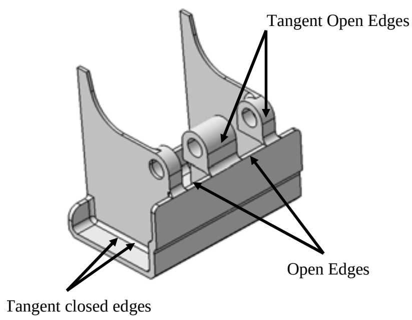

Figure 5. Edge's Sharpness values

By calling on closed and tangent closed edges, we study the output depending on the different values of their attributes: type, sharpness, transitions, angles and adjacency. The different values are modelled in an equation of 5 variables, each having different possible values (per example variable A representing the edge nature would equal 0 for a linear edge, 1 for a circular edge and 2 for a general edge). The equation uses base transformation in a manner that each possible set of attributes values results in one unique value of the equation. Then for each case the output result is based on trade rules. Some of the general trade rules applications are listed next:

• A linear closed edge would result in proposing three machining direction. The main being the direction perpendicular to the edge, the 2^{nd} and 3^{rd} being the direction of the edge in both ways (start point to end point, and end point to start point).

• A circular or general edge would propose a discrete set of machining directions. These are the curve normal directions at different selected points.

• A Fully closed edge direction (having both previous and next edges of closed nature) is privileged on window edges (having one surrounding closed edge and another open).

• A linear edge adjacent to a ruled surface would privilege its natural directions on the perpendicular one, while those adjacent to a fillet would only propose their perpendicular direction completely neglecting its natural direction.

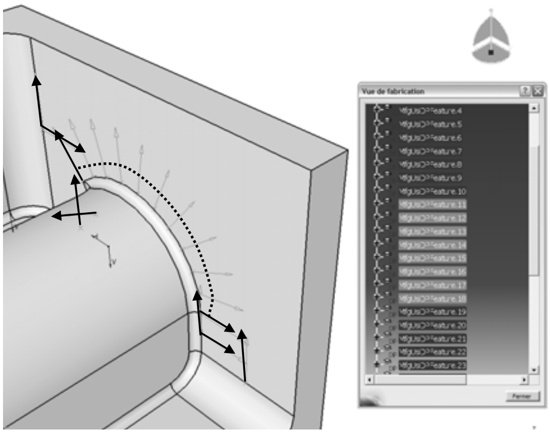

Figure 6. Planar machining directions

The above mentioned list is not comprehensive; it only states some of the trade rules that were used to apply our machining extracting system. 48 different cases are found and treated, which would output the results of figure 6. The arrow simulates the tool inverse direction (the x models the tool's head, and the arrow triangle models the tool's attachment).

Investigating the system in details, we have selected (fig. 7) a sample of three machining directions resulting from the same trade case found on two separate edges. Both of the edges are of linear nature, of tangent closed sharpness, surrounded by closed edges (previous and next), and adjacent to a fillet. However, the edge on the right has its next angle above 1808 giving it an additional potential milling direction.

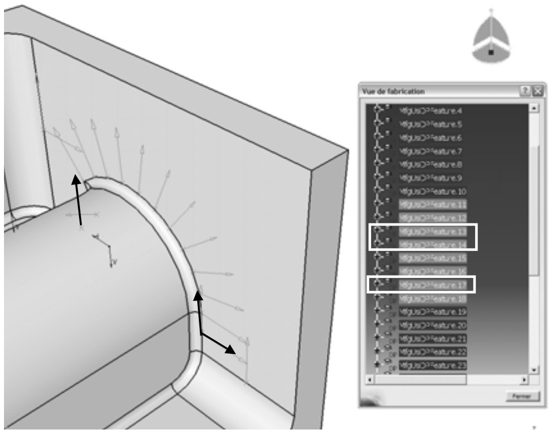

Figure 7. Sample Case Explication

3.3 From 3D to 2D

Before going on further in the G-Zones computation, we generate a 2D equivalent sketch. This transformation leads in a critical time saving and acquires the application a faster computation of inaccessible machining zones (G-Zones and L-Zones). This translation step is split upon two main sections. Following the creation of an empty sketch on the studied face, we project at first the face external edges. Then we should represent on the 2D sketch the part sections that constitute an obstacle to access the face to be milled.

We present the translation scenario in the following; at first an empty 2D sketch is created on the face (figure 8). The sketch origin consists of the first edge's start point. The X axis would be the one constructed by joining the first edge's start and end points. Y axis would be the result of the cross product between the X axis and the face normal vector.

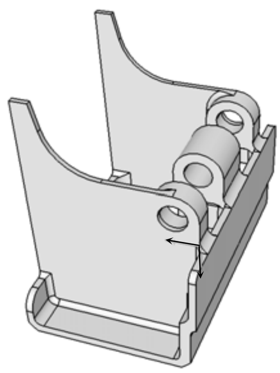
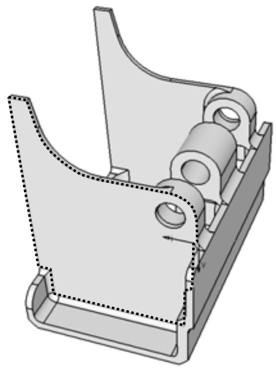

Figure 8 (left). Creating an empty sketch
Figure 9 (right). Projecting the list of outer edges on the created sketch

Follows comes the projection of the list of external edges on the sketch. The projection is done in the same order of the original edges list to preserve the link to the original objects (and thus the link to the model and its attributes).

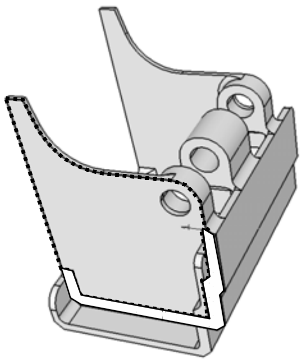

Figure 10. Generating the obstacle and projecting it on the sketch

Next we conduct the projection of the obstacles that prevents accessing the studied face. The obstacles are obtained through creating a mechanical pad having as base a square created on the studied face. The square is then extruded to what corresponds with the machining tool diameter. The bounding boxes of the different obtained shells after intersecting the created pad with the originating part are projected unto the above created sketch. The results are shown in figure 10, for a 1 mm square extruding (presuming a linear cutting tool). The obstacles projection is also regrouped in a list of geometric elements that represent the face accessibility barrier.

3.4 Computing the L-Zones

The next natural step would be to determine the un-machined face zones. We identify an L-Zone (for Local Zone) by the un-machined face zone related to a single milling direction.

The L-Zone is obtained through the following algorithm. At first we compute the bounding rectangle that includes all the projected elements (figure 11, step 1). From the bounding rectangle different points we launch parallel rays to our machining direction (figure 11, step 2). The launched rays intersect the projected element in a set of points. We search for the first barrier point. This point is identified as the closest point in the intersection list that corresponds to a closed edge or to the obstacle projection list. Once this point is identified it is appended to the L-Zones border points list. In the end we join these points constituting the Visible Zone for the tested machining direction.

The L-Zone is then computed through a succession of Boolean operations. At first we intersect the Visible Zone with the studied face area. We obtain the local visible sections. We then subtract the local visible sections from the studied face and obtain our L-Zone.

The given example holds no L-Zone for the selected direction, and thus automatically its G-Zone is empty too. For future test cases we shall use back the test part of figure 6.

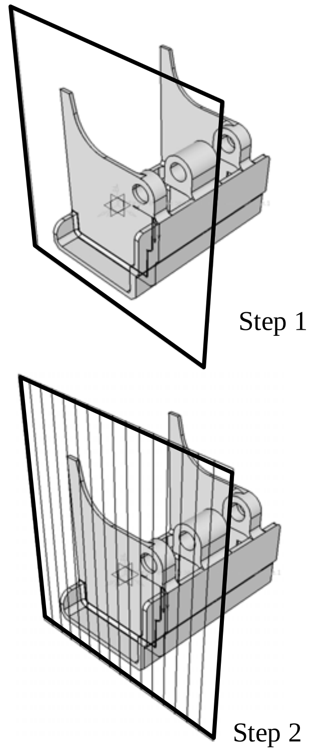

Figure 11. Computing the Visible Zone

3.5 Computing the G-Zones

Computing the G-Zones constitutes of intersecting the different L-Zones. Through selecting test case of figure 6, 9 machining directions were proposed with a certain priority listing. For each direction we compute its L-Zone (figure 12).

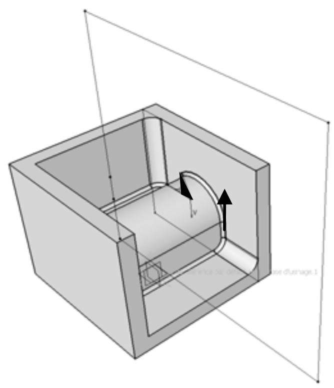

Figure 12. G-Zone after selecting the shown machining direction

We calculate the visibility ratio (Updated G-Zone Area over total Face Area). If the visibility ratio is less then 95%, we call on the next L-Zone corresponding to a same priority level machining direction. We then intersect the second L-Zone with the first and calculate the new G-Zone (the first G-Zone being equal to the first L-Zone) (figure 13). We calculate again and check the visibility ratio. Still under 95% we call on the next machining direction until we reach the desired visibility ratio (generally 95% in the aeronautical field).

In the end if the desired visibility ratio is not reached, the software notifies the process planner of the unsatisfactory results if the surface is to be flank milled.

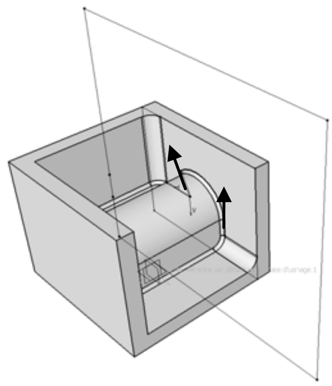

Figure 13. Total visibility after intersecting the last G-Zone with the newly computed L-Zone.

4. APPLICATION

The flank milling approach was developed thanks to the open architecture of the CATIA® V5 PLM software with CAA (Component Application Architecture).

The presented result is the effort (fig 140) conducted within the UsiQuick (French RNTL) project. Four laboratories (besides ours – the CRAN) participated in the effort (IRCCyN – Nantes, LGIPM – Metz, L3S – Grenoble and LURPA – Cachan). Two Industrials took part of the venture too (DASSAULT AVIATION and DASSAULT SYSTÈMES) and an expertise centre (CETIM).

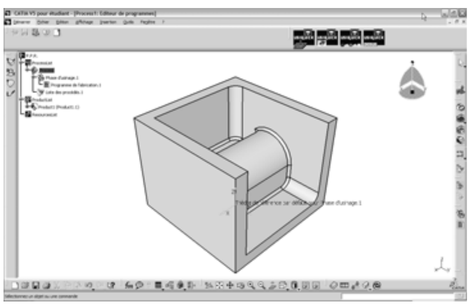

Fig. 14. UsiQuick toolbar within the CATIA® V5 PLM machining module

5. CONCLUSION

In this article we mainly discussed how to test the flank milling ability of a planar surface. At first we presented an enhancement of a previous machining direction extraction proposition. Then, we investigated further the validity of the proposed machining directions by computing their visibility ratio. The obtained value the software would advice the process planner a flank milling mode or no.

This study comes as a part of a Transformation module. The general module studies a CAD Part and then proposes milling operations and different milling modes. The main aim is to enrich the CAD Part with information paving the way for process planning automation.

6. PERSPECTIVES

The different proposed algorithms are to be investigated further. The proposed machining directions could benefit from the 3D to 2D passage, and using the obstacle frontiers as possible machining directions. The L-Zone and G-Zone computation can be generalized to treat the studied face using real milling tools parameters.

In example, the G-Zone resulting for the step 4 in figure 2 would have been the figure 15 if we take into account a tool radius of 10 mm.

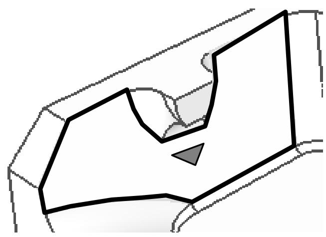

Fig. 15. G-Zone when the tool radius is took into account

On another track, the flank milling mode is not limited to planar faces, and namely complex ruled surfaces should be investigated further.

One last interesting investigation point would be the machining direction testing by comparison with the accessibility of a 5-axis machine tool. The global resulting directions (figure 16) can be compared and tested prior to fixing the machining process.

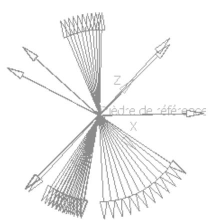

Fig. 16. Machining directions accessibility

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