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Computer Assisted Technologies in the Development of Prototypes

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Abstract— **In the industry computer assisted technologies are being implemented very fast. Most companies support the use of the new computer assisted technologies as a fully integrated digital policy. Currently, due to the high number of available alternatives in the market, the integration analysis of the computer assisted conception and production technologies is a critical study, in order to establish the potential for a full implementation of a CIM (Computer Integrated Manufacture) strategy. The technology developments in the area of computer assisted project and production of prototypes is reviewed in this paper. The text is divided in five main topics, namely: i) an introduction to the characteristics of actual markets requirements and demands of clients that lead to the need of new methods and equipments to be used by the production companies, ii) a review about the available capabilities on computer assisted conception and production technologies (computer-aided design / engineering / manufacturing and rapid prototyping); iii) an analysis about product designer standards and requirements (an example concerning the making of working drawings is used to illustrate the actual constraints in the computer assisted technologies); and iv) conclusions regarding the state of the art and future developments preview in the area.**

Index Terms—**CAD, CAE, CAM, CNC, Rapid Prototyping.**

I. INTRODUCTION

Presently, the high stage of competitiveness in the industrial markets leads to the development in the growing of importance of the computer assisted conception and production technologies. In order to achieve the new requirements imposed by the clients, the enterprises have to find better solutions to guaranty faster transformation of the materials, better products quality and lower production costs. In the manufacturing area, the dimensional tolerances and surface finish produced are particularly important in subsequent assembly operations and in the proper operation of machines and instruments. The range of surface finish and dimensional tolerance obtained is influenced by the production processes that are used. In order to obtain finer surface finish and closer tolerances, additional finishing operations, better control of processing parameters, and the use of higher-quality equipment may be required. The closer the dimensional tolerance required, the higher the cost of manufacturing, also the finer the surface finish required, the longer the manufacturing time and the higher the product cost.

Unless it is specifically required otherwise by proper technical and economic justification, parts should be made with as rough a surface finish and as wide a tolerance as will be functionally and aesthetically acceptable. In this regard, the importance of continual interaction and communication between the product designer and the manufacturing engineer becomes a fundamental issue. CAD (computer-aided design), FEA (Finite Element Analysis), CAM (computer-aided manufacturing), CNC (computer numerically controlled) equipments, reverse engineering and rapid prototyping are highlighted in the technical literature as excellent technologies in order to optimize the manufacturing process, necessary to obtain prototypes.

II. COMPUTER-AIDED DESIGN (CAD)

Computer-aided design involves the use of computers to create design drawings and product models and is usually associated with interactive computer graphics (known as a CAD system). Computer-aided design systems are powerful tools and are used in the mechanical design and geometric modelling of products and components.

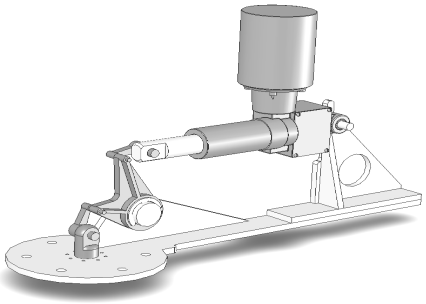

Figure 1: Mechanical Device

Figure 1 show a mechanical device developed to cut metal sheets and used as an example in this paper to illustrate the application of Computer Assisted Technologies in the Development of Prototypes. Most of the analyses will be focused in the mechanical device element that converts the actuator direction in the vertical route, represented in Figure 2.

The CAD system quickly and accurately produces the definition models for products and their components. One of the outputs of this system is the generation of working

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drawings, which generally have higher quality and better consistency than those produced by traditional manual drafting. The drawings can be reproduced any number of times and at different levels of reduction and enlargement.

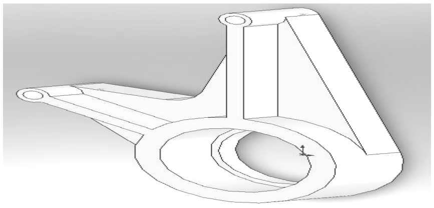


Figure 2: Experimental Part

Figure 3: Database in CAD Software (SolidWorks)

In addition to the design's geometric and dimensional features, other information (such as a list of materials, specifications, and manufacturing instructions) is stored in the CAD database. Namely, CAD systems generally include standard components databases (bearings, bolts and nuts) that can be used to easily apply normalize parts (Figure 3 shows a CAD database example). Using such information, the designer can then analyse the economics of alternative designs.

A. *Exchange Specifications*

Because of the availability of a wide variety of CAD systems with different characteristics supplied by different vendors, proper communication and exchange of data between these systems has become a significant problem. The main concern is due to the risk of information losses during the conversion of CAD files between different CAD software. Currently, the need for a single neutral format for better compatibility is filled mainly by the Initial Graphics Exchange Specification (IGES). Vendors need only provide translators for their own systems, to preprocess the data into the neural format, and to postprocess from the neutral format into their system. IGES is used for translation in two directions (in and out of a system) and is also used widely for translation of 3-D line and surface data.

A more recent development is a solid-model based standard, called Product Data Exchange Specification (PDES), which is based on IGES. Although IGES is adequate for most requirements, PDES requires less memory size and less time for execution, and it is less prone to error. Currently, different standards are used in different countries, but it is expected that these standards will soon be subsumed into the international standard called Standard for the Exchange of Product Model Data (STEP).

B. *Elements of CAD Systems*

The design process in a CAD system consists of three stages:

Geometric Modelling – Product design is a critical activity because it has been estimated that 70% to 80% of the cost of product development and manufacture is determined by the decisions made in the initial design stages.

In geometric modelling, a physical object (or any of its parts) is described mathematically or analytically. The designer first constructs a geometric model by giving commands that create or modify lines, surfaces, solids, dimensions, and text that, together, are an accurate and complete two- or three-dimensional representation of the object.

The models can be presented in three different ways.

i) In line representation (wire frame) all edges of model are visible as solid lines. This image can be ambiguous, particularly for complex shapes, so various colours are generally used for different parts of object, to make the object easier to visualize.
ii) In the surface model, all visible surfaces are shown in the model.
iii) In the solid model, all surfaces are shown, but the data describe the interior volume.

Design Review and Evaluation – An important design stage is review and evaluation, to check for any interference between various components. This stage is done in order to avoid difficulties during assembly or use the part and to determine whether moving members (such as linkages) are going to operate as intended.

Software is available having animation capabilities, to identify potential problems with moving members and other dynamic situations. During the design review and evaluation stage, the part is precisely dimensioned and toleranced, to the full degree required for manufacturing it.

Documentation and Drafting – After the preceding stages have been completed, the design is reproduced by automated drafting machines, for documentation and reference. At this stage detail and working drawings are also developed and printed. The CAD system is also capable of developing and drafting sectional views of the part, scaling the drawings, and performing transformations in order to present various views of the part.

Although much of the design process in CAD systems was formerly carried out on workstations connected to a mainframe computer, the trend has changed rapidly to powerful, high-performance, and much less expensive stand-alone desktop.

C. *Reverse Engineering – Part Digitizing*

Reverse Engineering has become a very useful method to create 3D virtual models of existing physical part. This process usually involves measuring an object and reconstructs it as a 3D model that can be used on CAD, CAM or CAE application. Several techniques have been developed to capture the model shape, CMM's laser scanners, white light digitizers and computer tomography, capture the shape of the object. The measured data alone, usually represented as a point cloud, lacks topological information and is therefore often processed and modeled into a more usable format such as a triangular faced mesh, a set of NURBS surfaces or a CAD model.

III. COMPUTER –AIDED ENGINEERING (CAE)

With the evolution of computers Computer Assisted Engineering (CAE) is becoming an essential tool for product and process development. Nowadays it's possible to create virtual prototypes that enable the designer to test several configurations in order to optimize the design of the product.

Integrated CAD-CAE applications enable fast design analysis loops. The ability to drive parametric and associative product features, trough several CAD-CAE integrated applications, enable fast and automatic evaluation of design changes. In the early stages of product development CAE applications give the mechanical behavior of components in real use situations.

Advanced motion simulation applications enable the designer to create functional virtual prototypes, to simulate mechanical operations of assemblies and obtain the physical forces they generate. Integrated applications enable the designer to automatically transfer critical loads from the motion simulation to linear static analysis, including inertial loads, and therefore to optimize the design.

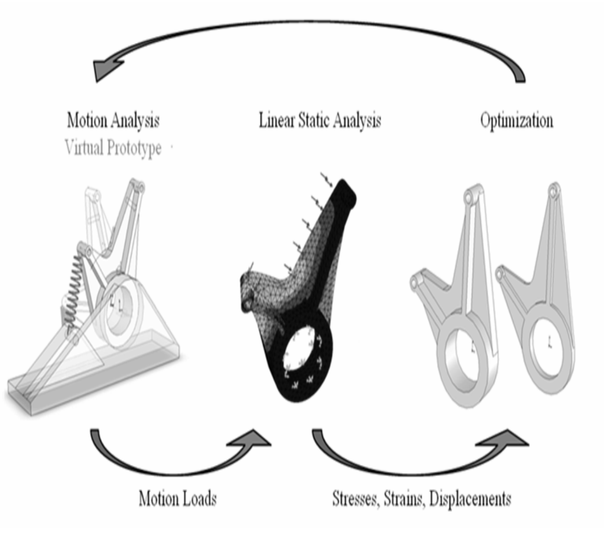


Figure 4: Example of a simple design loop using integrated CAE applications.

Figure 4 shows a simple design cycle that involves three integrated Computer Assisted Engineering (CAE) applications, kinematics analysis, linear static analysis and optimization. In the motion analysis the designer has to define constrains such as joints, couplers, part motion and contacts between parts. Forces can be directly applied by the designer or can be the result of springs and/or dampers, gravity can also be considered. As result, displacements, velocities, accelerations and reaction forces can be obtained, as well as inertial forces, and can be directly exported to a FEA analysis applications.

Optimization of the shape is possible by defining the objective (usually the goal is to minimize mass or volume but other objectives can be defined such as minimization or maximization of natural frequencies.) or goal of the optimization, design variables and constrains. In this case the goal is to minimize the mass, the design variable is the thickness of the part and the constraint is defined in such a way that the maximum Von Mises stress cannot be equal or higher that the yield stress of the material. In a series of "what if" analysis several design sets are obtained and quickly an optimal solution is achieved, resulting on a significant mass reduction.

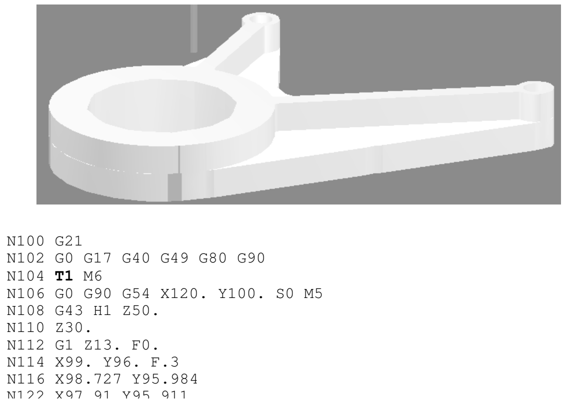
The advantage of using integrated CAE applications is the reduction of necessary steps that are usually needed to create the simulation on a pre-processor. Integrated CAE applications have the ability to recognize automatically constrains from CAD assemblies and even multiple CAE applications can share several information that the designer no longer has to input to the problem, reducing product development cycle loops.

IV. COMPUTER-AIDED MANUFACTURING (CAM)

Computer-aided manufacturing involves the use of computers and computer technology to assist all the phases of manufacturing a product, including process and production planning, machining, scheduling, management, and quality control. Because of the benefits, computer-aided design and computer-aided manufacturing are often combined into CAD/CAM systems.

This combination allows the transfer of information from the design stage into the stage of planning for the manufacture of a product, without the need to re-enter the data on part geometry manually. The data base developed during CAD is stored; then it is processed further, by CAM, into the necessary data and instructions for operating and controlling production machinery, material-handling equipment, and automated testing and inspection for product quality.

In machining operation, an important feature of CAD/CAM is its capability to describe the tool path for various operations, such as NC (numeric control) turning, milling, and drilling. The instructions (programs) are computer generated, and they can be modified by the programmer to optimize the tool path. The engineer or technician can then display and visually check the tool path for possible tool collisions with clamps, fixtures, or others interferences. Figure 5 shows the machining (milling) simulation and a NC code section regarding the experimental part.



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N100 G21
N102 G0 G17 G40 G49 G80 G90
N104 T1 M6
N106 G0 G90 G54 X120. Y100. S0 M5
N108 G43 H1 Z50.
N110 Z30.
N112 G1 Z13. F0.
N114 X99. Y96. F.3
N116 X98.727 Y95.984
N122 X97.91 Y95.911
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Figure 5: Machining (milling) simulation versus NC code

The tool path can be modified at any time, to accommodate other part shapes to be machined. CAD/CAM systems are also capable of coding and classifying parts into groups that have similar shapes, using alphanumeric coding. An example already implemented in CAD/CAM applications is the feature recognition and the automatic tool path generation. These tools are used namely on drilling operations. Prodrill is a module of MasterCam X2 CAD/CAM software and with its use repetitive drilling tasks that previously took hours can be done in a few clicks (see Figure 6). The principal operating stages on Prodrill application are:

- automatically identifies drilling operations independent of the CAD system source;
- functions automatically with surface and Solid models from any CAD system;
- automatically create and insert complex drilling geometry and operations on Solid models and 2D drawings;
- with one click of the mouse, all the holes are identified and the processes from the drilling processes library are automatically applied to the drill forms.

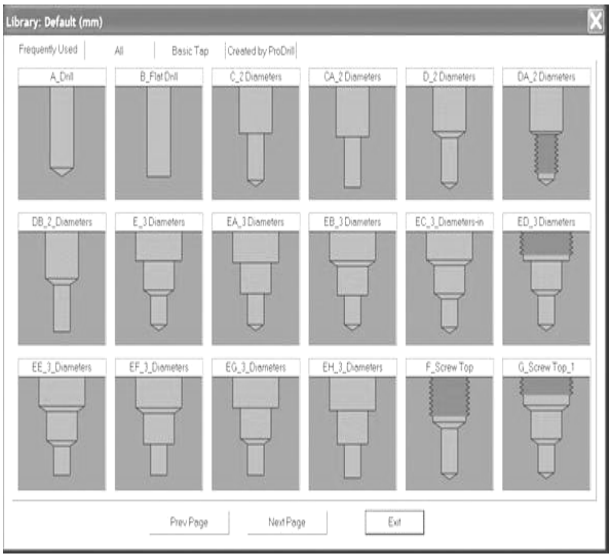

Figure 6: ProDrill Forms Table (ProDrill Aplication - CAD/CAM Software MasterCam X2)

The emergence of CAD/CAM has had a major impact on manufacturing, by standardizing product development and by reducing design effort, tryout, and prototype work; it has made possible significantly reduced costs and improved productivity. Some typical applications of CAD/CAM are as follows:

- programming for NC, CNC, and industrial robots [1, 2];

- design of dies and moulds for casting, in which, for example, shrinkage allowances are pre-programmed;

- dies for metalworking operations, such as complex dies for sheet forming and progressive dies for stamping;

- design of tools and fixtures and EDM (electrical discharge machine) electrodes [3];

- quality control and inspection for instance, coordinate-measuring machines programmed on a CAD/CAM applications.

A. *Engineering versus Working Drawings*

Currently, computer assisted technologies preserve some limitation that compels the human intervention. For instance, at some stage in the making of the working drawings, the use of CAD sometimes can't be fully automated, requiring details from the production sector. Taking in account the machining of the experimental part, Figures 7 to 9 illustrate the necessary change to be inputted in the engineering drawing to convert it in the appropriated working drawing, with a different tolerance specification [4].

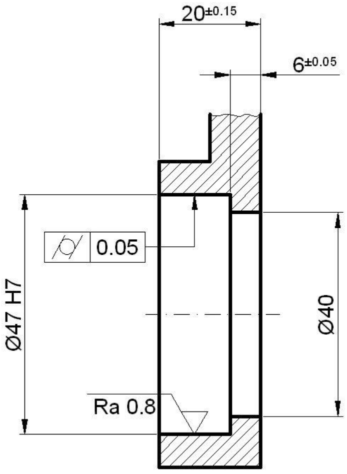

Figure 7: Engineering Drawing

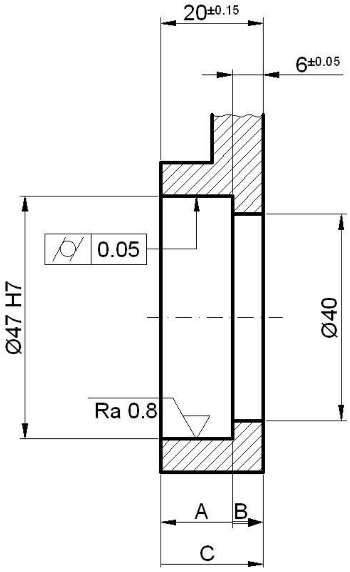

Figure 8: Drawing References

Considering that according to the production process the required dimensions are A and C (instead of B and C presented in the engineering drawing), it is necessary to convert the dimension B to A. Taking into account that now the B is the condition dimension:

$B = C - A$ and Toler. B = Toler. C + Toler. A

Thus

$B_{Máx} = C_{Máx} - A_{min}$ $\quad 6,05 = 20,15 - A_{min}$ $\quad A_{min} = 14,1$

$B_{min} = C_{min} - A_{máx}$ $\quad 5,95 = 19,85 - A_{Máx}$ $\quad A_{Máx} = 13,9$

Since $A_{Máx} > A_{min}$ and the relation between the dimension tolerances is not verified [0,1 = 0,3 + (***- 0,2***)], is necessary to increase the B dimension tolerance (the dimension to convert). This can be done if that change doesn't cause an interference with the functionality of the part.

Considering **$B = 6^{\pm 0,2}$**, this lead to:

$B_{Máx} = C_{Máx} - A_{min}$ $\quad 6,2 = 20,15 - A_{min}$ $\quad A_{min} = 13,95$

$B_{min} = C_{min} - A_{máx}$ $\quad 5,8 = 19,85 - A_{Máx}$ $\quad A_{Máx} = 14,05$

Regarding the tolerances, the new results are:

Toler. B = Toler. C + Toler. A $\Longrightarrow$ **0,4 = 0,3 + 0,1**

The dimension resulting from this converting operation has the following value:

$$\boxed{A = 14^{\pm 0,05}}$$

According to the production requirements, the working drawing is shown in Figure 9

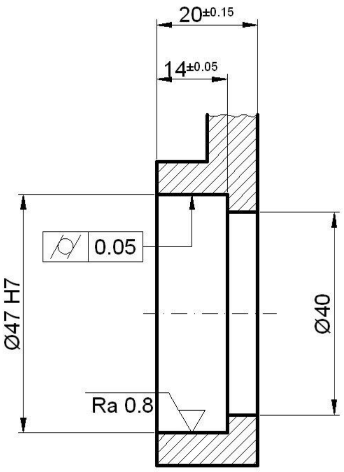

Figure 9: Final Working Drawing

V. RAPID PROTOTYPING (RP)

In the development of a new product, there is invariably a need to produce a single example, or prototype, of a designed part or system, before the allocation of large amounts of capital to new production facilities or assembly lines. The main reason for this need is that the capital cost is so high, and production tooling takes so much time to prepare; consequently, a working prototype is needed for troubleshooting and for design evaluation, before a complicated system is ready to be produced and marketed.

A new technology which considerably speeds the iterative product development process is the concept and practice of rapid prototyping (see Figure 10). The advantages of rapid prototyping include the following:

- physical models of parts produced from CAD data files can be manufactured in a matter of hours, to allow rapid evaluation of manufacturability and design effectiveness. In this way, rapid prototyping serves as an important tool for visualization and for concept verification;

- with suitable materials, the prototype can be used in subsequent manufacturing operations to obtain the final parts. In this way, rapid prototyping serves as an important manufacturing technology;

- rapid prototyping operations can be used in some applications to produce tooling for manufacturing operations. In this way, one can obtain tooling in a matter of a few days.

Rapid-prototyping processes can be classified into three major groups: subtractive, additive, and virtual. As the name imply, subtractive processes involve material removal from a work-piece larger than the final part.

Subtractive processes use computer-based technologies, as computer-numerical-control (CNC) machinery and CAD/CAM software, to speed the process.

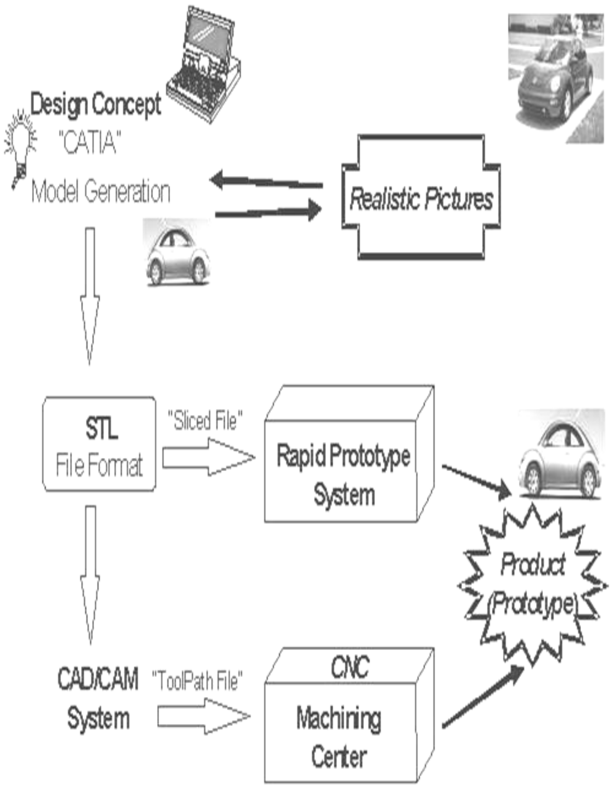

Figure10: Rapid Prototyping Routes

Additive processes built up a part by adding material incrementally, all built parts in layers. The main difference between the various processes lies in the approach taken to produce the individual layers. The first step in the rapid-prototyping based in an additive process is to obtain a CAD file description of the part. There is a standardize format, the STL file (This file is a triangular representation of a 3-dimensional surface geometry. The part surface is tessellated or broken down logically into a series of small triangles “facets”). The computer then constructs slices of the three-dimensional part. Each slice is analyzed separately, and a set of instructions is compiled, in order to provide the rapid-prototyping machine with detailed information regarding the manufacture of the part. Rapid prototyping, in this approach, requires operator input in the setup of the proper computer files and in the initiation of the production process. Following this stage, the machines generally operate unattended and provide a rough part after a few hours. The part is then through a series of finishing manual operations (such as sanding and painting), in order to complete the rapid-prototyping process.

Figure 11 shows the experimental part formatted in a STL file (generated with CAD software – SolidWorks 2007). From the STL file a 3D model (see Figure 12) was produced using a rapid prototyping process, based in the additive processes, a ZCorporation equipment (ZPrinter 450).

Finally, virtual processes use computer-based visualization technologies. The simplest forms of such systems use complex software and three-dimensional graphics routines to allow viewers to change the view of parts on a computer screen. More complicated versions will use virtual-reality headgear and gloves with appropriated sensors, to let the user observe a computer-generated prototype of the desired part in a completely virtual environment.

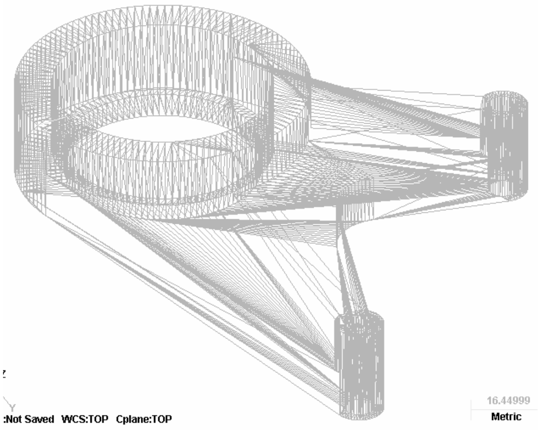

Figure 11: STL file

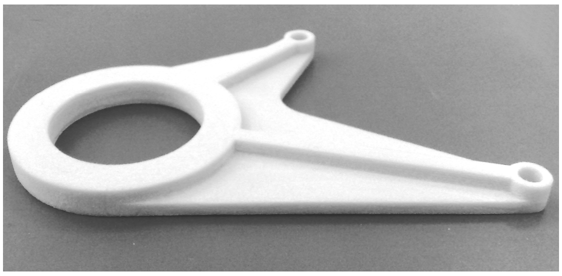

Figure12: RP Part (ZCoorp Process)

VI. CONCLUSIONS AND FUTURE DEVELOPMENTS

Computer-aided design applications maintain several weaknesses that should conduct in the future to new developments in this area. An example can be the incorporation of tolerance or surface roughness data into natural features specification, instead of their traditional detail through a dimensional representation. This type of evolution on CAD characteristics will lead to improvements in other Computer Assisted Technologies for the Development of Prototypes as CAM software that could integrate automatic routines directly using new CAD features recognition.

A good example about the on going research in this field is the STEP-NC program. The main characteristic of the new interface presents higher level of information. Whilst a part program according to ISO 6983 describes movements (G1, G2, G3) and switching instructions (M3, M8), the new language covers manufacturing tasks (so-called "features"). Such a task could be, for example, roughing of a pocket. All operations which are necessary to produce the finished part from the raw piece can be described by a sequence of such manufacturing tasks.

In the future, could be expected to find a deeper integration in the areas of Computer Assisted Technologies that will lead to the integration of actual distinguished operation activities as designer, engineer, CAM programmer, workshop planner.

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