Computer Aided Manufacturing with Computer Aided Design: Some Lessons Learned

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ABSTRACT- *The use of Computer Aided Manufacturing (CAM) tools in college environments has increased dramatically over the last ten years. Partnerships between engineering schools and the suppliers of CAM equipment are on the increase. As companies realize the value of having their machines in academic settings, more and more students are exposed to the benefits that CAM brings to the manufacturing world. Most CAM tools can use solid models from a CAD system to provide geometry input. As many students are already familiar with a CAD system, it is reasonable for them to use the CAD system to generate the geometry for their CAM work. This paper investigates the lessons learned in having students with a minimal amount of solid modeling experience using the CAD system to generate CAM models.*

I. INTRODUCTION

All engineering students at Rensselaer Polytechnic Institute are required to take a one credit course in solid modeling. This course, Engineering Graphics and Computer Aided Design (EG&CAD) teaches the skills of using a solid modeling system to create parts, small assemblies, and documentation. The students normally take EG&CAD during their freshman year and then have the opportunity to use solid modeling in their sophomore and senior design projects as well as some special topic electives. One of these electives is an introduction to computer aided manufacturing called "Advanced Manufacturing with CAD/CAM Systems (AMS). In AMS, students take their knowledge of machining and solid modeling and apply that knowledge to create a small assembly using Computer Numerical Control (CNC) lathes and 3 axis milling machines. Students are also asked to research a small problem in AMS and make a presentation to the class. This class is generally populated with sophomores and juniors.

In addition to AMS, prototype sessions of a freshman course in manufacturing are also being taught. In the traditional freshman manufacturing course, the students build a small assembly using traditional shop tools with no CNC. In the prototype sessions, students are introduced to CNC technology and 3D printing. As such, more and more undergraduate students are exposed to and using the CAM tools on campus. This increased usage has presented 3 challenges to the school. The first is the ability to properly schedule the workload to maximize the student use of the tools. The second is to provide the mechanisms necessary for students to submit work and have a timely response to their work requests. The third, and the major focus of this paper, is to adjust the current freshman curriculum to maximize the ability of students to start using the CAM tools.

II. COMPUTER AIDED MANUFACTURING CAPABILITIES

Rensselaer has had computer aided manufacturing for over 20 years with the introduction of Cincinnati mills and lathes. These tools were the property of the school's

machine shop and were not available for student use. If students had projects that required CNC machining, they were sent to the machine shop and their work was created for them. This method of operation changed when the Advanced Manufacturing Laboratory (AML) was created as a secondary capstone experience for seniors. A two semester offering, students work in the first semester designing a small assembly. While fully documenting the assembly as a solid model, students must also project how to manufacture the parts and assembly with the given capabilities of the laboratory. In the second semester, students then create the parts using the facilities on campus and also create a robotic assembly line to manufacture several hundred assemblies. These assemblies are then given to sponsors of the advanced manufacturing laboratory. Initial projects were simple 2 part key chains (with the plastic logo created from an injection molder with molds designed and milled by the students on the AML's CNC mill) to projects today that include more complex assemblies such as pocket flashlights and toy cars. Today, the AML has 50 students that engage in this two semester project.

To allow even more students access to the CNC machining and CAM in general, the HAAS Manufacturing Center was created in 2000. The HAAS Manufacturing Center is a business partnership with HAAS, a major United States manufacturer of CNC equipment. There are 50 of these HAAS Manufacturing Centers in the United States. At present, the HAAS center contains three CNC mills, a mini mill, a tool room mill and a VF-2 mill. All three mills are 3 axis mills. The mini mill and the VF-2 have multiple tool holders. In addition, there are 2 CNC lathes, a full CNC lathe and a combinational CNC/traditional lathe. The CNC machines can either be purchased or loaned on a 2 year basis allowing the school to provide different tools for the students. The HAAS center is available to all students, graduate and undergraduate with a full time technician to aid in the use of the center. Obviously, students must be properly trained and supervised while using the CNC machines.

In discussing the CAM capabilities with CAD, there are two major areas of discussion: additive and subtractive CAM. These two areas do not discuss the full capabilities of the AML or the HAAS Manufacturing Center. Machines such as the plastic injection mold machine, the vacuum form machine and the robotic assembly lines are not directly interfaced with the CAD systems and will not be included in the following discussion. This is not to say that CAD does not play a roll in using these machines, but rather, that there is not a direct link. For example, the molds for the plastic injection molder are often cut from the CNC mill. Likewise, the template for the vacuum mold machine can be cut from the CNC mill. Both of these in turn, can have associated solid models. By discussing the additive and subtractive CAM capabilities, the extension for their use with the other manufacturing tools becomes obvious.

III. ADDITIVE MANUFACTURING TOOLS

Additive manufacturing tools are those that build the part by adding material to a base. The most common types of these tools are three dimensional printers. In Figure 1, there are two 3D printers that students can use to create parts and assemblies. The machine on the left is a Stratasys 3D printer that uses ABS plastic to create the solid geometry. The pieces on the right are the pieces of the Z-Corporation 3D printer that uses either starch or plaster to create the solid geometry. Both of these machines use STL (stereo lithography) files to work the machines. Parts and assemblies created with the 3D printers are not normally used for use in a machine. Rather, these models are used for demonstration as they often do not have the strength to survive under actual

loading. STL file formats are common write formats for CAD packages. STL format reduces the solid model (parts and/or assemblies) to a series of connected triangles that form the geometry that can be reproduced with the 3D printer. Figure 3 shows an example of a simple solid formatted as an STL file.

Figure 1: AML Laboratory Showing 3D Printers

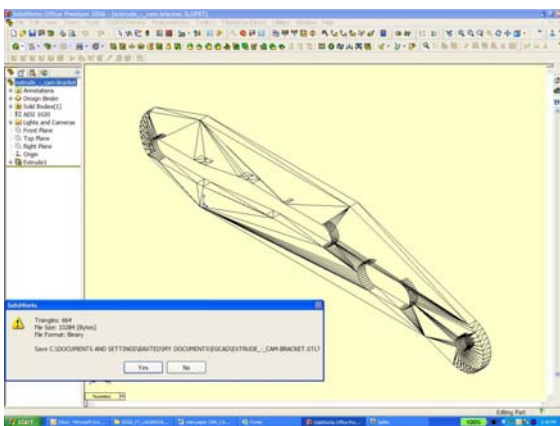**Figure 2: Some Examples of Parts created with Additive Methods**

Figure 3: STL File Format Moving from CAD to STL Files

The creation of the STL file is very simple. As long as the STL format is available, the file can be created with the SAVE AS option. Many solid modeling programs allow the user to set the amount of triangulation by adjusting the average size of the triangle, similar to the control of a finite element mesh. In general, it has been found that no adjustment of the triangulation size has been necessary. The difficulty in creating the solid model with a 3D printer is based on the limitations of the 3D printer. The single most limiting factor is wall thickness. Thickness below 1 mil for the Stratasys machine will produce very unreliable results. Thickness below 2 mils can be difficult for the Z-Corporation machine. As such, it is often necessary to thicken up the walls for 3D printing. Students are given the recommendation to create a configuration for printing that has necessary wall thickness.

This also holds true if the solid model must be shrunk to fit within the limitations of the 3D printer. A second configuration with a scaling factor can be employed to allow the solid model to fit the printer. When this technique is employed, it is vital to ensure that minimum wall thicknesses are maintained. These changes can be difficult to work out and students are urged to use the solid models analysis tools to find minimum lengths in the solid model. If models can not be shrunk, parts and assemblies can be built in multiple pieces as long as a glued joint is acceptable. To help our students with all of these issues and options, the 3D printers are operated by a graduate student who actually runs the print jobs and can offer advice to the students to aid in the part creation.

IV. SUBTRACTIVE MANUFACTURING TOOLS

Subtractive manufacturing tools are those that remove material to create the desired geometry. These tools start with stock material and then with a series of operations, remove material to produce the finished

product. For sheet cutting tools, the process can be very simple, for the mills and lathes, there are dozens of available tools and operations.

V. SHEET CUTTING TOOLS

Sheet cutting tools are used to cut shapes from either metal or plastic sheet stock. The tool reads an engineering drawing that outlines the lines to be cut. Normally, the user removes all format from the drawing so that any line shown is cut. For some tools, depth of cut can be controlled from the tool operator.

Rensselaer has 3 sheet cutting tools, a laser cutter, a water jet cutter and a CNC router. The router is only used to cut wood, the laser jet cutter is used on non chlorine based plastics and the water jet cutter is used on metal and plastic. The water jet is shown in Figure 4.

Figure 4: Water Jet Cutter

All 3 sheet cutters can use AutoCad drawings as the input file. As such, this file type is suggested for use to the students. Fortunately, the CAD students can save their work as AutoCAD drawings very easily. Students are asked to create an engineering "drawing" that only contains a 1:1 scale view of the part to be cut. Students then save the drawing as an AutoCAD DWG file that is read into the machine. If necessary, lines are assigned depth cuts. This option is not available for the water jet cutter which simply cuts the sheet with a given water

pressure (based on the input material and thickness). For the router, a secondary CAM tool, MasterCAM is used to generate the necessary machine code. For the water and laser cutters, software provided by the machine supplier is used.

VI. MOVING FROM CAD TO DWG FILES

Since DWG is a standard drawing format, no additional techniques are necessary to create a DWG file. Students must be taught how not to show a drawing format (usually an option click) and to ensure that only one drawing view is shown. If multiple instances of the part are needed, it is best to use the software with the cutter to add multiple instances. This can be done by the tool operator and it has been found that better tool paths are generated in this fashion. An example of a DWG file with the stripped format is shown in Figure 5.
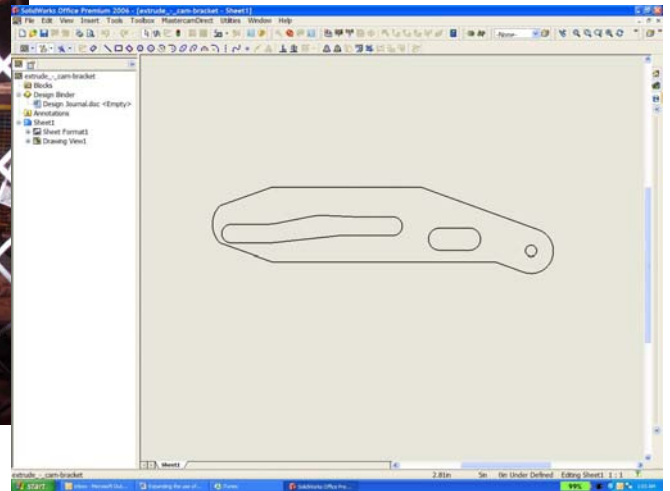

Figure 5: Example of a Drawing for a Laser or Water jet Cutter

VII. CNC MILLS AND LATHES

CNC mills and lathes present the most difficult challenge for the student. Unlike the 2D cutting tools or the 3D Printers, the CAD part needs considerable work in a CAM package (again at Rensselaer, MasterCAM is used). There are a variety of cuts that can be done on a solid. For example, consider the cannon base shown in

Figure 6. Operations are performed on every side of the base. For example, on the front face, the surface is faced, then pocketed to produce the wheel mounting tabs, then the wheel tabs are drilled and taped and the pin hole for the cannon barrel is drilled. The base then must be re-mounted in the mill and a new face is then cut. It is desirable to have six MasterCAM models that generate the six machine codes for the 6 faces for the mill.
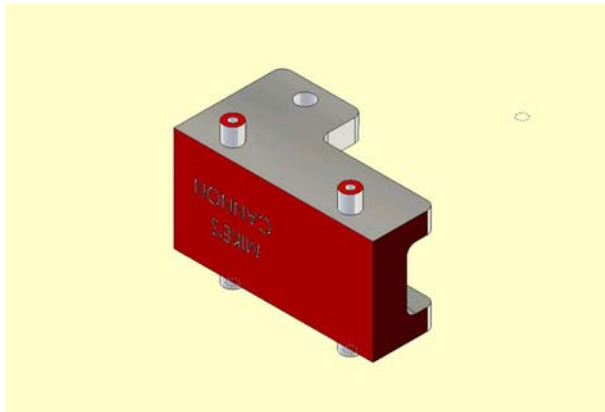

Figure 6: Cannon Base

An example of a part using the CNC lathe is shown in Figure 7. The cannon barrel is simpler in that the barrel is created in only three operations (a cutting operation to create the profile, a drilling operation for the barrel, then a cutting operation to remove the barrel from the stock) but still, multiple operations are required. Although, with this example, only one program from MasterCAM is required to generate the canon barrel.
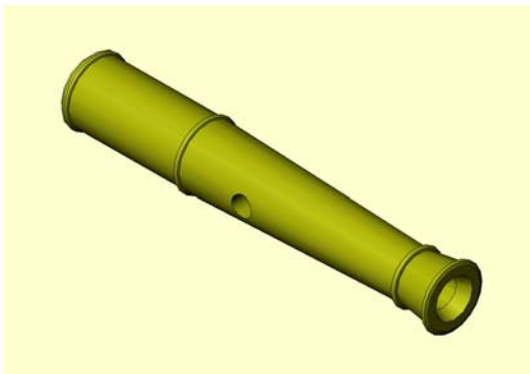

Figure 7: Cannon Barrel

VIII. MOVING FROM CAD TO MASTERCAM FOR MILL AND LATHE WORK

As MasterCAM is a CAD, as well as a CAM system, it is possible to create all the geometry and machine code in MasterCAM. However, the students have already used SolidWorks and unless the geometry is very simple, they tend to use SolidWorks. Also, in an introductory course, considerable time can be saved in only teaching the CAM aspects of MasterCAM and only using the CAD aspects when absolutely necessary.

The major technique that is taught to the students in transferring data from SolidWorks to MasterCAM is to use the configurations ability in the solid modeler to create the necessary orientations of the part. MasterCAM can read configurations from SolidWorks so a single solid model can be used to set up all the necessary operations for machining. For milling, this is done by using a series of translations and rotations of the solid to place the solid such that the solid is entirely in the negative Z space, the cutting surface is in the positive XY with the top of the part at Z=0. This orientation conforms to the defaults found in MasterCAM and ensures that the part is properly oriented without having to use the orientation commands in MasterCAM. In addition, when writing the machine code, the user can look for –Z commands and know the tool is cutting material, +Z means the tool is being moved. Likewise negative X and Y coordinates can be highlighted as possible interferences with fixtures. Similarly for the lathe, the part is oriented such that R=0 is the outer surface and the part is fully contained in negative Z space.

IX. CONCLUSIONS

Computer Aided Manufacturing and Computer Aided Design allow students to see a design from conception to completion in a very short span of time. The steps necessary to take a CAD model to a CAM system are not insurmountable for undergraduate

students. Many of the necessary links are provided by the CAD and CAM software packages. Techniques and modeling skills necessary for the transition from CAD to CAM are logical enough to be taught within the context of an introductory CAM course. As time progresses, work will continue to move the teaching of CAM techniques to as early in the curriculum as possible.

SolidWorks is a registered trademark of the SolidWorks Corporation.

MasterCAM is a registered trademark of CNC Software Inc.

Stratasys is a registered trademark of Stratasys

X. REFERENCES

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Biography

Douglas H. Baxter is the Director of CAD/CAM/CAE for the School of Engineering at Rensselaer Polytechnic Institute. He has been at RPI since 1993 teaching Engineering Graphics and Engineering Design and Introduction to Engineering Design. He is presently finishing his Doctorate in Mechanical Engineering. His research concerns integrating solid modeling tools with design methodologies to produce intelligent design tools. Prior to coming to RPI, Doug worked for International Business Machines Corporation where he worked as a heat transfer engineer and later as an FEA analyst.