

**AC 2007-991: INTRODUCING SHEET METAL DESIGN AND MANUFACTURING
USING CATIA V5 AND CNC EQUIPMENT IN AN AIRCRAFT MATERIALS
COURSE**

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Introducing Sheet Metal Design and Manufacturing Using CATIA V5 and CNC Equipment in an Aircraft Materials Course

Abstract

Students of the Aviation Department at Purdue University enroll in a computer graphics course (CGT 162) during their freshmen year, and in this course they learn how to use the CATIA V5 Solid modeling software. CATIA V5 solid modeling software is used extensively in the aerospace industry to design aircraft and aircraft parts. The authors of this paper have incorporated a new project in the AT166 Aircraft Materials II course to reinforce the knowledge gained in the introductory course and to apply this new skill set to design, and manufacture an aluminum alloy formed wing rib using CNC equipment and conventional sheet metal equipment. For this project students select a wing airfoil using commercial available software based on assigned parameters like gross weight, cruise speed and stall speed. An airfoil for a small piston powered experimental aircraft is selected with a maximum gross weight of 500 pounds, cruise speed of 150 mph, and a stall speed of 50 mph. Airfoil optimizer software is used to download the drawings of the selected airfoil. The CATIA V5 part design workbench is used to model the wing rib form blocks, and the sheet metal design workbench is used to model the formed wing rib. A complete set of engineering drawings is generated to manufacture the parts. The flat pattern layout of the wing rib is cut with a CNC mill, and the wing rib is formed by using form blocks, and a press brake. The authors have noticed that students quickly lose the knowledge acquired during the introductory CGT course, if they don't use it. By introducing new coursework that builds on existing knowledge, they hope to improve the student's knowledge of design software and CNC machining. The students are introduced to a complete manufacturing cycle from conceptual design to the actual manufacture of the part.

The importance of using CATIA V5 software for technology students

CATIA V5 solid modeling software is used extensively in the aerospace industry to design aircraft and aircraft parts, and it is important that technology students learn this new software early on and expand their knowledge during subsequent course work. The program is too large and complicated to master in one course, and if you don't use the program regularly the knowledge will disappear soon. Our students are required to take an introductory computer graphics course during their freshmen year. CATIA V5 is the program used in the course, but this course is focused on learning how to use the program¹. There is not an output application besides creating engineering drawings. There is only enough time in this course to teach students the parts design, assembly, and drafting work benches. Specialized workbenches like sheet metal design or prismatic machining are not covered. We feel that the introductory course is only the first step, and the knowledge needs to be reinforced and expanded in specific aviation courses where CATIA V5 will be used to fabricate parts with CNC equipment. We also encourage students to pursue a minor in computer graphics to further polish their CATIA skills, if they are interested in aerospace manufacturing careers.

Many of the freshmen students who are required to take the introductory computer graphics course have indicated that they don't like it; they don't like to sit behind a computer and would rather be involved in a more practical application. They don't feel that they produce something

that is real, something they can touch. It is important to emphasize the capabilities of the software early on or they will give up. Technology students are typically more interested in the end product than in the preliminary design phase. Designs made in the CATIA V5 work benches can be exported to CNC operated equipment directly or through an interface like SurfCam or MasterCam². Students need to be able to see what the end product is and how it is made. As soon as they realize that the initial sketch, model, and drawing can be imported into a CNC mill and that they can make parts using the drawings they created, they become motivated. Technology students have to realize that CATIA V5 and other solid modeling software are as much tools as a drill, lathe, or mill, and not fancy tools used by engineering students.

In the past, many hours were devoted to manual machining, and it took a lot of skill to master the equipment. New CNC equipment has made it much easier to machine parts, and the operator does not need as much skill, but they need to learn how to use CATIA V5 or similar software to make the design and run the CNC equipment. The focus has shifted from manual machine operations to using software and CNC equipment.

Many students who choose Purdue University are attracted by the hands-on practical orientated curriculum and because they love airplanes. About 50% of our incoming students are transfer students from engineering. They tried engineering for one or two semesters and decided to transfer either, because they couldn't handle the mathematics and science requirements or they didn't want to write computer code and work in an office environment. They wanted to be closer to the end product: the aircraft.

Many of our graduates find employment in the manufacturing industry. Multinational companies like Bell, Pratt & Whitney, and Boeing are hiring Purdue University students for job functions like manufacturing engineer and liaison engineer. These job functions don't require the design of complicated aircraft parts, but knowledge of CATIA and automated machining is strongly preferred or required to design or modify parts or to design structural repairs to aircraft structures. Industry representatives working in the aerospace and aviation industry have indicated students need to have a solid knowledge of CNC operations and processes, and should be able to sketch and model parts using solid modeling software like CATIA. It is still important to have a good knowledge of manual machining operations, but a sound knowledge of CATIA V5 and CNC machining operations has become fundamental.

The wing rib project

The authors of this paper decided to incorporate a new project in the AT166 Aircraft Materials II course to reinforce the knowledge gained in the introductory course, and to apply this new skill set to design and manufacture an aluminum alloy formed wing rib using CNC equipment and conventional sheet metal equipment. The wing rib was chosen as a project because on modern aircraft these parts are modeled and CNC machined (Figure 1). For this project students designed a basic wing shape using commercial available software based on assigned parameters like gross weight, cruise speed, and stall speed. Students will select an airfoil for a small piston powered Ultra Light aircraft with a maximum gross weight of 500 pounds, cruise speed of 150 mph, and a stall speed of 50 mph.

There are plenty of commercial off the shelf aircraft design software packages available. Airplane PDQ was chosen because it is basic and students can quickly manipulate a number of inputs to establish a baseline design.



Figure 1: Machined aircraft ribs (bulkheads).

The parameters for the Ultra Light Aircraft are illustrated in Table 1.

Weight	500 lbs
Payload	100 lbs
Cruise speed	150 mph
Landing speed	50 mph

Table 1: Input parameters for Ultra Light Aircraft.

Wetted Wing area	6.904 m ² - 74.32 ft ²
Span	4.866 m - 15.97 ft
Mean Aerodynamic Chord	0.6803 m - 2.232 ft
Aspect Ratio	7
Root Airfoil Section	2412
Root Airfoil Thickness	12
Tip Airfoil Section	2412
Tip Airfoil Thickness	12
Root Chord	0.7945 m - 2.607 ft
Tip Chord	0.5959 m - 1.955 ft
Taper Ratio	0.75

Table 2: Output parameters for Ultra Light Aircraft.

Students used these inputs to size the aircraft, the wing area, and to select an airfoil. With the airfoil selected the rib design process can begin. Students started to model the wing rib in CATIA V5 sheetmetal design workbench (Appendix A). After the wing rib was modeled, the

form blocks for the wing rib fabrication were modeled in the part design workbench. The form blocks were needed because the top flange is curved and can't be formed with a sheet metal brake.

Sheet metal workbench

For students that have a basic understanding of CATIA V5 part design workbench, it was a small step to master the sheet metal workbench. The sheet metal workbench is easy to use and the formed wing rib was modeled quickly using a few commands. The Advanced CATIA V 5 Workbook³ was used by the students to prepare them for this task. Having practical sheet metal fabricating experience is very helpful when you use this work bench because information like the type of bend relief, metal thickness, and bend radius needed to be entered. After the part was modeled, a complete set of engineering drawings was prepared using the drafting workbench. A great tool in the sheet metal work bench is the ability to unfold the bends of the part to generate the flat pattern layout. This saved time and improved accuracy because no bend allowance calculations were necessary. The flat pattern layout was saved as a DXF file, which is used to cut the flat layout using a CNC mill, or the flat pattern layout could be made using manual sheet metal tools and equipment like shears, rotary punches, and files.



Figure 2: CNC vertical mill used for cutting flat layout.

Modeling of form blocks

The parts design workbench was used to make the form blocks that were used to create the curved top flange of the wing rib. The basic shape of the wing rib was sketched in the parts design workbench and extruded to a thickness of 0.75 inch; the edges were slightly chamfered to allow for material spring back. A set of engineering drawings was prepared in the drafting workbench (Appendix B), and the DXF file was imported in SurfCam software, which ran the CNC vertical mill to fabricate the form blocks. The CATIA drawing was downloaded on disk and imported in the SurfCam program, and the students needed to write a simple CNC milling program to operate the CNC mill.

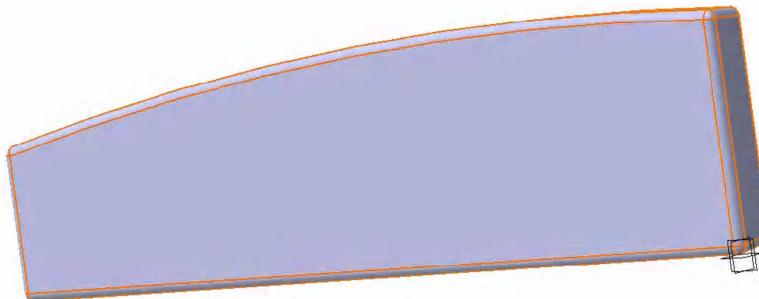


Figure 3: Solid model of wing rib form block.

Sheet metal forming

The next step in the process, after the flat pattern layout was cut and the form blocks were made was to form the wing rib. Form blocks were necessary because the wing rib had a curved top flange. The front, bottom, and rear flanges were formed with a sheet metal brake. Heat treated 2024 T3 aluminum alloy was too hard to form using form blocks and mallets, and it needed to be annealed to soften the material. The material was placed in an oven for a soak time of two hours at a temperature of 775°F. After the soak time the oven was turned off, and the part was allowed to cool at a maximum rate of 50°F to room temperature. This took about 15 hours. The annealed parts were placed in the form blocks and hammer formed. After the forming process, the top flange was worked with a shrinker for a final finish. An arbor press and punch and die set was used to form the lightening hole flanges. The part was solution heat treated to 2024 T4 after the forming process was completed. The part was placed in the oven for a soak time of 30 minutes at a temperature of 900°F, and the part was quenched in cold water. The material aged within four days to its required strength. An optional paint system was applied.



Figure 4: Formed wing rib.

Advanced project

This project could be followed up by a complete wind tunnel model made from multiple rib sections, spars, and skin in an advanced materials class. The airfoils could be tested in a wind tunnel to see if the wing shape will perform aerodynamically as expected. This would enable

students to experience the complete design cycle from design conception to wing testing. It would be interesting to assign different design parameters to student groups, so that they can evaluate how the different airfoils perform.

Faculty training

One of the major challenges for faculty members who are not familiar with CATIA V5 or other solid modeling software is to master these types of software, especially if you were in school before computers were invented. These programs are too complicated to just try to figure it out by clicking on icons. Prior knowledge of AutoCAD or drafting doesn't help. One option to master the knowledge is to purchase CATIA workbooks, which are available from several publishers. The advantage of buying several manuals from different authors is that they all have a slightly different approach. This is especially useful when you get stuck in one workbook and can use a different one to see if this works better for you. The main advantage is that you can work from your office whenever you have some spare time. The disadvantage is that if you get stuck or have questions it can take a while to solve the problem, which can be frustrating. The second option is to enroll in a solid modeling course at your institution. The advantage is that you can ask questions which will speed up the learning process. The disadvantage is that you need to be able to fit the course schedule into your teaching schedule. The third option is to attend a training session off campus provided by a training institute or vendor of the software. The advantage of this option is that you can schedule the course when you don't have classes; for instance during the summer, and you can learn a lot in a short period of time. We have found that you need to use the program regularly or you will lose the acquired knowledge.

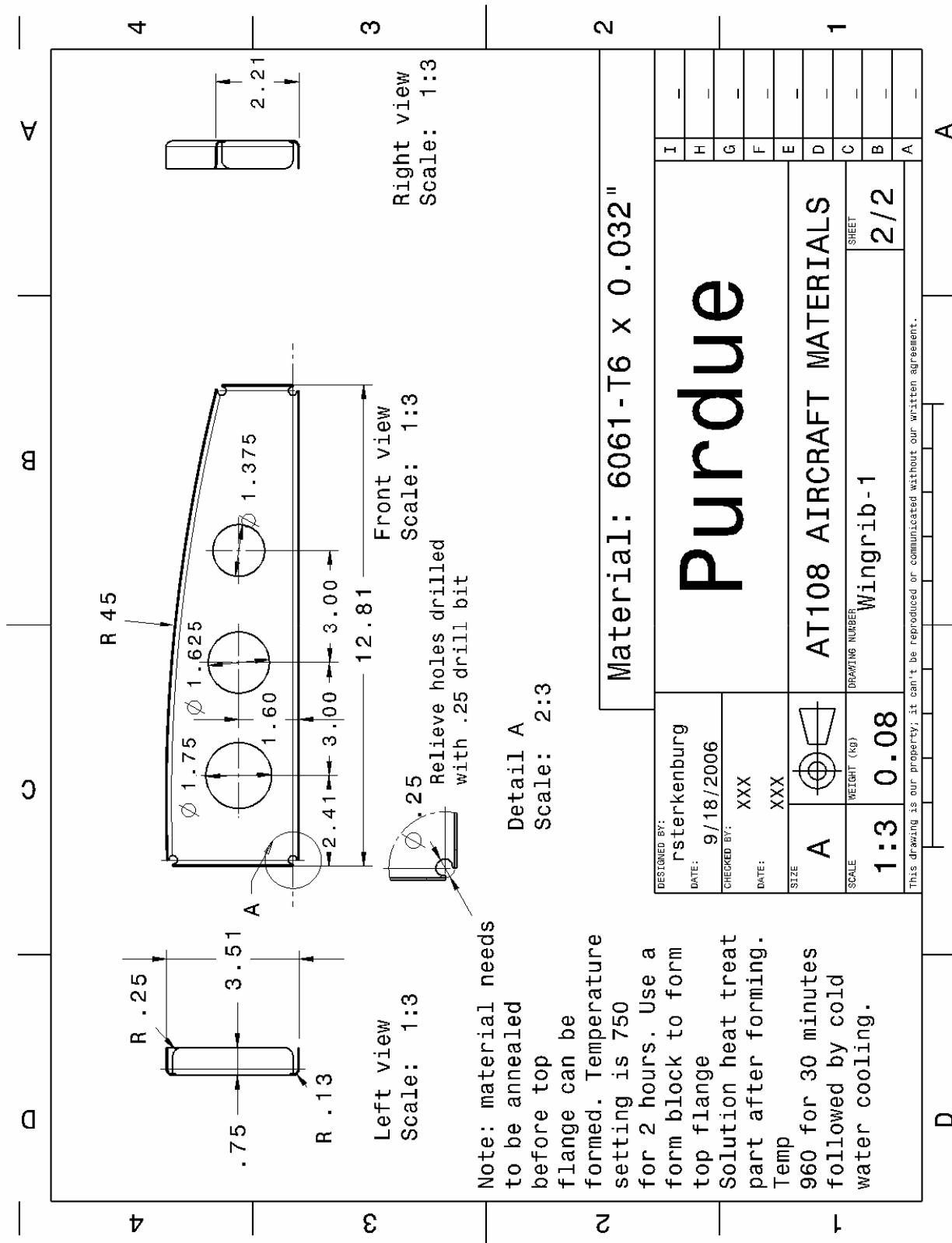
Conclusion

Aviation Technology students need to learn how to use CATIA V5 solid modeling software to be prepared for jobs in the aerospace manufacturing industry. One course during the freshmen year is not enough to master all the workbenches available in the CATIA program, and the initial course needs to be followed up by more practical oriented coursework. We have introduced CATIA V5 and CNC machining into an aircraft materials course so that students understand the potential of solid modeling software. We believe that CATIA could and should be introduced in all technical classes so that students eventually master all workbenches in CATIA V5. Faculty members have a challenge to learn and stay current with CATIA software as well.

References

1. Plantenberg, K. (2006). Introduction to CATIA V5 release 16. Schroff Development Corporation.
2. Cozzens, R. (2006). CATIA V5 workbook release 16. Schroff Development Corporation.
3. Cozzens, R. (2006). Advanced CATIA V5 workbook release 16. Schroff Development Corporation.

Appendix A



Appendix B

