Establishing a Computer-Aided Manufacturing System to Extend the Capability of Traditional Aircraft and Spacecraft Design Courses

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The Aerospace Engineering Department at Embry-Riddle Aeronautical University's Daytona Beach, FL, campus has just completed the initial implementation of a Computer Aided Manufacturing (CAM) system within its long established capstone aircraft and spacecraft design course sequences. This paper details the development process which we went through in order to establish that capability.

1. Why do we need it ?

Students in the design sequence began using Computer Aided Design (CAD) in 1983 and by 1993 the CAD system had evolved to the point of having the capability of doing 3-dimensional solid modeling. At that time Dr. Jim Ladesic acquired a National Science Foundation Instrumentation and Laboratory Improvement Grant to acquire a stereolithography rapid prototyping system which could create actual parts from the CAD solid models. Students learned many lessons about the realities of making three-dimensional shapes from this system and took great pride in showing off their designs. But the STL machine is limited to relatively small parts, about 9 inches in the longest dimension. And the polymer material made by this system is both expensive and sufficiently brittle that it cannot be subjected to any significant loads. The new CAM system described in this paper takes a another step closer to actual engineering practice. It incorporates a Computer Numerical Control (CNC) 3-axis milling machine which can work from the same database already established. This system can make much larger parts, up to eight feet long, and can make them from structurally testable materials.

From a design education point of view, the Boolean algebra or intersection of sets approach to building solid models on a computer screen is deceptively easy. Surfaces overlap each other, cut through each other, can be added and subtracted, and can be painlessly rotated to any angle for viewing. Students find a whole new world of unexpected challenges when they are forced to deal with the geometric realities of making actual parts from their CAD models. Typical frustrations occur from addressing cutting tool access to the surface to be cut, accurately defined reference points and planes for turning parts over to cut the other side, cutter type and speeds to get adequate surface finish, and separation of model parts for manufacture so that they have mating portions that can be assembled in a structurally secure manner.

2. How did we get it ?

This effort was made possible in part by the National Science Foundation Division of Undergraduate Education Grant No. DUE-9451355, through the Instrumentation and

Laboratory Improvement (NSF-ILI) Program.

The CNC milling machine we bought is large enough (13 by 14.5 feet) that we had no place to put it in our existing labs. Fortunately, a new engineering building was in the final design stages. But before I could submit the actual NSF proposal I felt ethically obliged to get a floor space commitment from the building design committee. The draft of the proposal served this purpose. After I received the grant the 2 1/2 year grant period proved to be just long enough to then wait for the new building to be built. It contains a Manufacturing Lab, which we did not have previously, of approximately 2000 square feet.

3. How are we using it?

ERAU has a well established 2-semester capstone sequence of aircraft and spacecraft design courses. These courses have been successful (We took 1st place in the NASA/FAA Advanced General Aviation Transport Experiments design competition in 1996.), so we did not want to seriously disable or redirect those courses. More specifically, we did not want the class to become predominantly a CAD/CAM class rather than an aircraft design class.

Directly across the hall from the Manufacturing Lab we have our design lab/classroom with a lecture area, four separate team work areas, and 26 PC's and work stations on a local network with a web site (http://pinky.ent.db.erau.edu).

Photo 1 - Design lab lecture area

Photo 2 - Design team office / work area

In that lab we have a full schedule of student assistants who serve as tutors and troubleshooters for all design course software use including CAD/CAM. Our approach for this CAM incorporation was to create five tutorial exercises typical of the geometries our students are likely to be creating, then put those tutorials on the web site so that they are accessible both from within the design lab and from off campus. Working through those exercises can thus be self-paced and entirely the responsibility of the students. A student assistant is available at all times during class and during evening lab hours to give guidance and track down problems on request. A sub-team of two students is designated as the manufacturing department, and works within the overall design team in a concurrent engineering format. It has been a pleasant surprise that this arrangement works well with little added demand on the faculty, and it broadens the team's perspective without adversely altering the focus of the class. Student workload was initially a problem, however. In Fall '96, the first time we did this, we kept the teams at our traditional size of 6 students and design duties were heavy enough that we did not get as far as I had hoped in the actual manufacturing. Two teams made only their wings, while only one team actually machined a model of nearly the whole airplane. Photos are shown in Section 6. So the Spring '97 semester, we enlarged the teams and made the CAM sub-team responsible for only that part of the design effort.

The actual manufacturing is done by a Graduate Teaching Assistant (the coauthor of this paper) who was factory trained to be the milling machine operator. The machine is sufficiently powerful to damage itself or its operator, so we decided not to attempt to teach the design students to make their own parts. If we were an Industrial Engineering or Manufacturing Engineering program we might have decided otherwise. The design students deliver their CAD/CAM files to the GTA via the local network. The GTA then puts the files through the postprocessor and makes the parts. We most often use blue insulation grade styrofoam because it is cheap and cuts quickly, but we are transitioning to wood for wind tunnel models. We have also done encouraging prototype experiments with hard plastic (high density polyethylene) and aluminum.

4. CNC milling machine specifications

The milling machine is a Komo VR408P 3-axis milling machine with the widely used General Electric Fanuc controller. Its cost is just under $100,000. Add-on hardware is available to convert it to a 4 or 5-axis machine, but we have no immediate plans to do so as we have had good results cutting compound curvatures using ball end cutters. Its work piece size capacity is 4 by 8 feet by 6 inches thick. The 18,000 pound rigid frame gives it a tool positioning accuracy of .0005 inch. It is quite a bit larger than the typical milling machine, but we wanted to be able to make 1/4 or 1/3 scale wing panels and full scale propellers. Parts can be machined from foam, wood, hard plastic, or aluminum. The cutter is turned by a high speed motor which develops 10 HP at 6000-18,000 RPM.

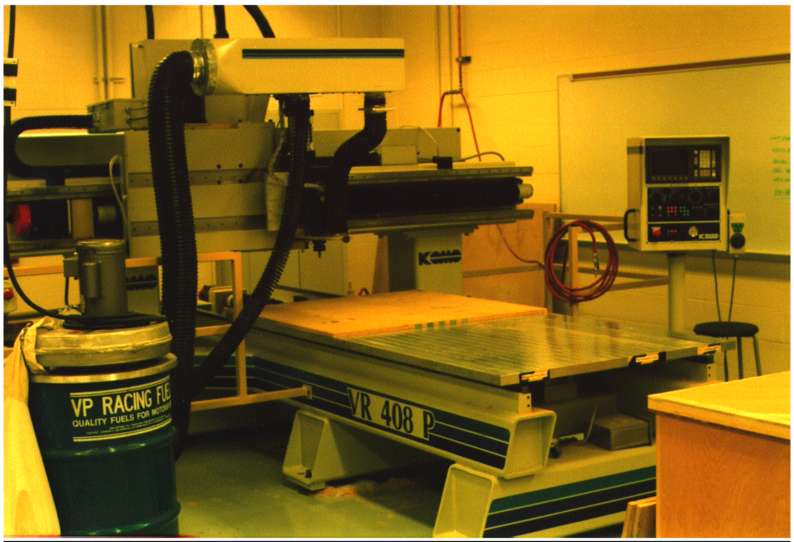

Photo 3 - Komo VR408P milling machine

5. What challenges were involved ?

A CAM module existed in the Varimetrix solid modeling software we had previously set up to drive the stereolithography system, but we had never used it. So making this interface functional became part of the development effort. The output of the CAM module is a machine control program which is somewhat generic in nature and must be put through a post processor in order to actually drive the milling machine. Getting the hardware and software components of the system to function properly was a very frustrating and time-consuming process.. We made many calls all around the country as we searched for the right solution to our various challenges, and I would caution anyone considering developing such a system that CAD/CAM sales literature almost always says that the software will generate tool paths and also the actual machine control program but that those claims are not to be taken literally. A post processor package was required by every machine operator we talked to. But now that the task has been accomplished the milling machine programming is almost automatic, and is managed very effectively by a Graduate Teaching Assistant as described in Section 3.

Another somewhat mundane but nonetheless critical problem was physically getting the machine into the lab. In spite of our best efforts to plan ahead for handling large pieces of equipment, a communication slip occured somewhere. We had to cut out the concrete block doorway of our brand new building to get the machine through the door. The actual cutting involved little time and expense, but the venting of emotions was not insignificant. It would be wise to follow up on such considerations with a degree of fanaticism in future projects.

6. What have we accomplished so far ?

A fortunate change in computer prices allowed us to expand our number of CAD/CAM computers considerably. The October '93 proposal budget included $22,495 for one Silicon Graphics Indy computer to serve as the main operating center for this CAM system. By the time I actually purchased the computers in January '96 that amount covered four Indys, one for each design team work area. In adition,Varimetrix has recently introduced a Linux (shareware version of UNIX) version of their software. This allowed us to acquire two Pentiums at a cost of only $2200 each which run the software at similar speed and which reside in the Manufacturing Lab. This has improved student access to the system significantly.

Initially we are concentrating on making wood wind tunnel models of students' aircraft designs. This had to be preceeded by a number of system familiarization exercises. The first thing we did was to cut dozens of straight and curved channels in sample materials (photo 4) in order to determine what types of cutting tools, cutter RPM, and tool feed rate

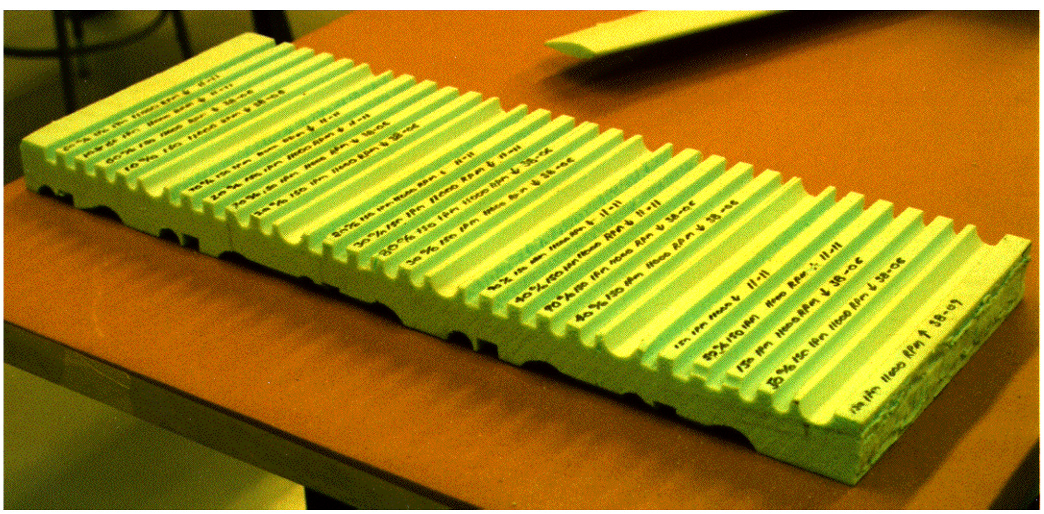

Photo 4 Cutter RPM and feed rate tests

would produce the kind of surface finish we considered adequate. Most of the initial testing was done with blue insulation grade styrofoam, which is inexpensive and available locally. We use this material for tool path verification for everything we do. Then we tested a variety of locally available furniture grade wood. More recently we have used high density polyethylene and aluminum.

This first student-designed part to be made was a wing (photo 5). It does not appear to be

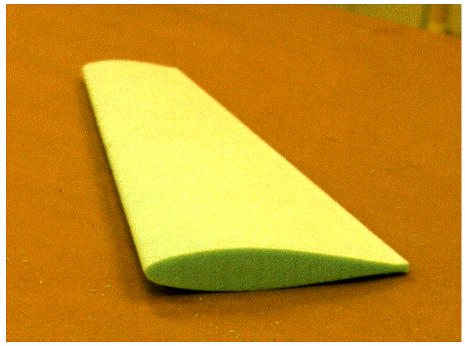

Photo 5 Foam wing model

all that visually exciting, but the ability to cut a fairly precise airfoil shape semi-automatically is actually a major step forward in bringing the design projects closer to practical reality. This was followed closely by a nearly complete aircraft (photo 6)

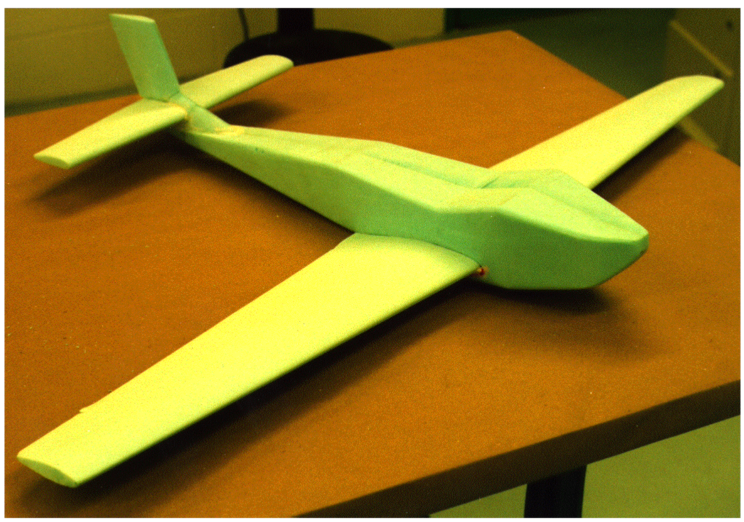

Photo 6 Foam airplane model

produced by one of the design teams in the same class. It is apparent that mastering the lofting of a smooth fuselage shape is not a simple task which is immediately apparent to neophyte users. It is also significant that there is no canopy on the aircraft. This is due to one of the common difficulties in solid modeling, that of getting the computer to correctly interpret the intersection of several surfaces. We were not able to figure out how to get the CAM software to generate tool paths in the canopy/fuselage intersection area.

Another innovative use of the system which a student group figured out almost entirely on their own was cutting of female molds for the composite chassis of their mini-Indy car for SAE competition (photo 7). They went directly from the computer solid model to cutting female molds without having to go through the intermediate process of making a male pattern, which is the most time consuming part of the composite manufacturing process.

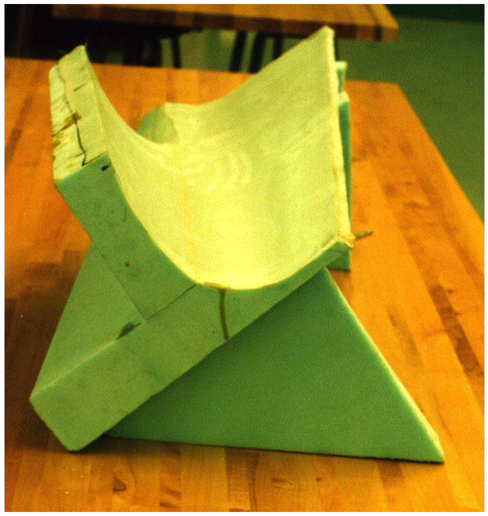

Photo 7 Foam mold for composite mini-Indy car chassis section

Another classic use of this type of system, which was employed in the construction of a radio controlled aircraft to compete this spring in the SAE model cargo airplane competition, was to cut a stack of all the balsa wood wing ribs at one time to precise shape. The airfoil shape is highly curved and cutting identical ribs by hand is tedious if not impossible.

And the current blue ribbon winner for creativity is the HDPE plastic propeller blades (photo 8) designed by a graduate student for his thesis experiment. These blades are

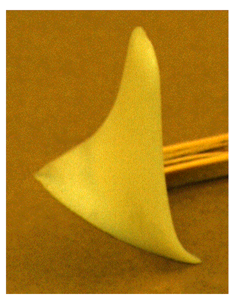

Photo 8 Plastic blade for wingtip turbine

assembled into a six-blade wing tip turbine and are being wind tunnel tested to investigate the potential for reduction of wing drag. These are complex airfoil shapes and are incorporated into a highly twisted planform. Without this new CAM system we would not have been able to manufacture these blades at all.

7. Recommendations

1. Students must work surprisingly hard at learning to separate their design into shapes which the mill can cut and that they then can join together in a structurally sound manner. In spite of the effort, they clearly consider themselves more like real engineers from having had this experience and they take great pride in their products. This makes

the whole development process worthwhile. If you can do such a thing I recommend highly that you do it. The Manufacturing Lab has also become a primary stop on tours of the university, and the good public relations associated with that should not be downplayed.

2. A lot of time and effort went into developing this system from scratch within the Aerospace Engineering department. We had no alternative. Many universities have industrial or manufacturing engineering programs which have this capability or would like to develop it. If you have the option of being the customer/user of an existing system, definitely do that as preferable to doing all the development on your own.

3. Three or four good students can be an effective foundation for the tutoring and operation of this type of system. The students are probably better than many of the faculty at such software oriented activities, and it is great experience for them.

4. Self paced instruction for CAM can work effectively as long as good troubleshooting help is available.

5. Don't bother with tabletop "toy" machines which are designed to cut hard wax or to engrave plastic nametags. Real machines are not that much more expensive within the perspective of the entire development process, and have much greater impact on the feeling of realism imparted to the students.

Biographical information:

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