A Rapid Prototyping Application in Wind Tunnel Testing – A Student Project

Robert Edwards, David Forsman
The Pennsylvania State University at Erie

Abstract:

3D printing is a rapid prototyping process which creates a part layer by layer by spraying a binder into a bed of powder. This process is used in industry to produce concept models for marketing, fit, form and function models, as well as patterns for molds. A team of Mechanical Engineering Technology students at Penn State Erie, working on a senior project to test the down force on a late model dirt stock car, has integrated the use of rapid prototyping into their project in an innovative way. The project called for the students to build a model of the car, and to conduct wind tunnel tests to determine the down force that is generated. This student team decided to use the 3D printed prototype directly in a wind tunnel, since it appeared to be a quick, relatively inexpensive method for providing test results. Several problems arose during the design and manufacture of the model. One of the main concerns was the strength of the part, since the model contains several thin sections which would have to both survive the build process and withstand the force of the wind. Other issues included the amount of detail needed in the model, model size, and design of the model to allow for simple, economic changes. This paper reports on these issues, and how they were resolved.

I. Introduction:

At Penn State Erie, Mechanical Engineering Technology Students are required to complete a project during their senior year. This project is typically sponsored by a local industry, and is designed to teach the students how the design and development process works. Typically, the students are required to manage the entire project from the planning and scheduling stage through design, analysis, and final report.

Occasionally, a project comes along which is not sponsored by a local industry, but by an individual who has an interest in helping the school and the students. One such project was proposed by a former student who races late model dirt track stock cars as a hobby. These cars race on small oval dirt tracks at fairly high speed. One of the important factors in being able to maintain a high speed on the curves is the amount of down force on the car. It is very difficult for a hobbyist to compete with a heavily sponsored vehicle, and so this project gave the students an opportunity to provide some valuable information to the sponsor, and to learn a little about rapid prototyping and wind tunnels in the process.

The specific goal of this project was to devise a method for evaluating the effects of design changes to the car on down force. It was not critical to determine accurate force magnitude information, but was more important to be able to assess whether a design change would have a positive affect. The primary focus of the project was to obtain a baseline for the existing design. Possible design changes were to be evaluated if time permitted.

II. Rules and Specifications

The design of the car is governed by the STARS racing rules and specifications.

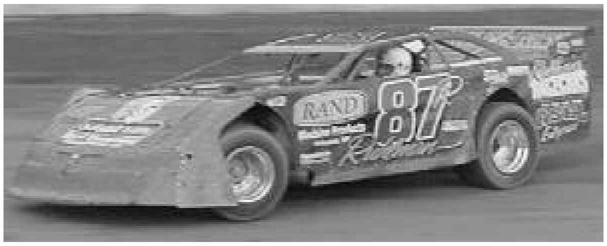

Figure 1

Figure 1 shows a side view of the car. There are no windows, so the drivers compartment is open. The roof is made of sheetmetal, and both the top and bottom of the roof affect the aerodynamics of the car. Many of the features which affect the aerodynamic characteristics of the car are controlled by the rules and specifications of STARS racing. The areas of interest for this project were the roof, the front end, and the spoiler.

The roof is constrained by several dimensions. The rules give the maximum overall height of the car, minimum and maximum dimensions from the ground to the front and back edges of the roof, rake (or slope) dimensions on the front and rear of the roof, and an envelope on the length and width. For the spoiler, the rules give maximum size dimensions, and a location, as well as other specifications regarding the construction of the spoiler.

The first inclination of the design team was to try not only to develop a method to evaluate the effects of design changes on the down force, but also to try to propose possible changes based on their tests. It was decided that this was too ambitious a plan for a senior project, so the students decided to limit the scope to developing a method for analyzing design changes proposed by the project sponsor.

III. Planning the Project

Figure 2

Early in the planning of the project, the students looked into two options for the evaluation. One was the wind tunnel test approach and the other was to use a computational fluid dynamics (cfd) program available at the school. The cfd program was relatively old, and had a very difficult user interface. The students were not familiar with either the program or cfd, so they decided to use wind tunnel testing as their approach to the problem.

The students also had no experience in using a wind tunnel, and so they had to learn the basics quickly. They were instructed on the operation of the wind tunnel, on some of the capabilities of the tunnel, and on general principles to consider in the design of their test model. The key thing they learned was that the frontal area of the model should not exceed 5% of the cross-sectional area of the wind tunnel. Since the unit that was available is a small, educational unit, shown in Figure 2, with a cross-section of only 24"x 24", this dramatically limited the size of the model. They had to limit the frontal area of the model to approximately 29 in^2. By using a scale factor of 12.3 the frontal area was modeled within a rectangle of approximately 7 ¼ " x 4".

Once the size of the model was determined, the next issue for the students was to determine how the model would be made. Some of the students on the project were concurrently taking a course in rapid prototyping, and so it was decided to use that process to make the model.

IV. Designing the Model

The heart of the project was the design and manufacturing phase. The objective of the team was to model the existing car as closely as possible. Measurements were taken from the actual car, and a full scale solid model was made in Pro/Engineer (Pro-E). The full scale model was then scaled down for the wind tunnel. Several questions arose at this point concerning the amount of detail that was needed to get meaningful results from the wind tunnel testing. The questions centered on making the tests as realistic as possible. Some of the issues were:

- One of the main concerns of the team was whether the rapid prototyping process would produce a model which would be strong enough to hold up in the wind tunnel.
- How much detail was needed under the car? The students considered the need for a simulated road surface for the car to sit on. If a road surface was to be used, should the wheels be fixed or rotating, and how would they make the model with the wheels turning?
- After the model was scaled down, many of the features were too small to manufacture. The two areas of most concern were the roof and the spoiler, since those features are made of sheet metal.
- Many of the body contours were very difficult to measure accurately, so the students were concerned about those contours on the model.
- Finally, the model needed to be mounted in the wind tunnel, so a bracket had to be designed which was strong enough to hold the model solidly in place but would have minimum effects on the results.

The students decided to keep the model as simple as possible. Nothing was done to simulate the wheels turning. The road was simulated by slightly flattening the tires and placing a sheet of Plexiglas under the car. Finally, the very small parts such as roll bars and other brackets were eliminated from the model.

The students used a Z-Corporation Z402 3d printer to produce the prototype. This process placed limits on the design of the roof. Thickness limitations will be discussed in the next section. This has the potential to cause the most error in the results, and more testing will be conducted by a future senior project team.

Due to the size of the model and the limits of the Z402 printer, the students decided to make the model out of three separate sections. Figure 3 shows the original design. The car was designed with a front section, mid section, and rear section. The parts were made and evaluated. During the manufacture and evaluation of the model a flaw in the design was discovered. The mid section used a large amount of build material, and took a long time to produce. This is

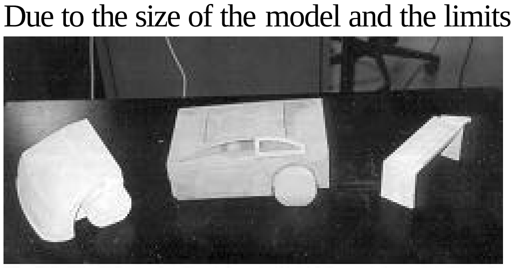

Figure 3

discussed in the manufacturing section of this paper. Many of the anticipated design changes that might be considered would affect this section, causing high cost and manufacturing times for every change.

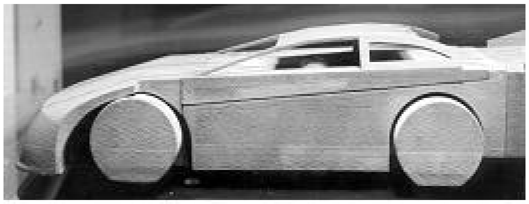

Figure 4

Figure 4 shows the redesigned assembly. Notice that the front end, the roof, the spoiler section and the main body were all manufactured as separate sections. This design eliminated the need for a large main body section, and isolated each of the areas where design changes to the car might be made. If the sponsor were to propose a change in any of these areas they could be easily modeled and tested. The students decided to make this the final design of the model for this project.

V. Manufacturing the Model

The Z-Corporation Z402 printer (Figure 5) builds models from either starch or plaster by using a layering technique common to most additive prototyping systems. A cross section of the geometry is "printed" using a water based binder on a layer of powder, and the build area is covered with a new powder layer and the process repeated. This raw part can then be infiltrated with wax, resin or epoxy depending on the material properties required. One of the advantages of the Z402 printer is that no support structure is required to produce overhanging geometry, as unbound powder is used for support. This makes fairly complex geometry easier to build because there is no need to clean up supporting structure. Excess powder is simply vacuumed and blown from the model in the de-powdering unit as shown in Figure 6. One of the disadvantages of the process is the fact that there is a lower limit to the wall thickness of parts due to the inherent weakness of the raw (un-infiltrated) parts.

Figure 5

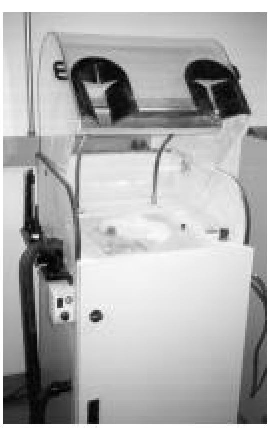

Figure 6

It was decided to build the model using plaster as this material produces a model with the greatest accuracy and green strength. Using plaster, sections can be built with a layer thickness of .0035 inches. Even using plaster, the roof had to be thickened to a point where it could survive being extracted from the build chamber of the machine and infiltrated before being subject to forces from the wind tunnel. In other words, while it is possible to build geometry one layer thick, it would be impossible to extract or move such a part, given the unsupported region of the roof of the model.

The model was built in three pieces. This was a function of the build region of the printer which is 10" x 8" x 6" for plaster. The main portion of the body (Figure 7), including the roof was produced in one build. This

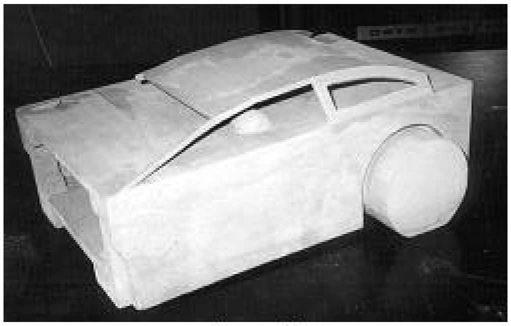

Figure 7

turned out to be a problem for the following reasons: First, building in plaster is relatively slow. The machine takes about one hour to build about ½" in the vertical direction. Second, building in plaster costs about $1.00 per cubic inch of volume and finally, after the part is built, it must be infiltrated. This is a somewhat time consuming process depending on the geometry. After building this part, it became obvious how fragile the roof structure was. If somebody bumped this part the wrong way before it was infiltrated, or handled it too roughly during the infiltration phase, the roof would break and the part need to be rebuilt. That possible problem coupled with the fact that multiple roof modifications was expected to be made and tested brought us to the conclusion that the roof proper should be built as a separate piece and assembled to the rest of the vehicle. This would enable faster turn around times if problems arose either in the design or handling of this somewhat delicate structure.

While this seemed to be a good solution, there of course were problems with this approach. Since the roof structure was sliced from the CAD model, this would require essentially a line fit as far as build tolerances were concerned. Anytime you build a part on an additive machine that uses a binder to adhere material, there is some bleed of the binder into adjacent material. A hole will become slightly smaller in diameter, and a cylinder becomes slightly larger in diameter. The material will also swell slightly upon infiltration. This required that the roof section be sanded to reduce the overall length of the part before assembly. Not doing this would prevent the part from fitting into the notch in the body. Trimming off a few thousands from the CAD models would fix this problem.

These parts were successfully infiltrated with a thin epoxy resin to make them strong enough to withstand the force of the air in the wind tunnel.

VI. Results and Recommendations

The goals of this project were to devise a method for evaluating the effects of changes in design of the car on down force and to evaluate various changes using this method. The results were mixed. The students spent their time developing the rapid prototype model of the car, designing a method for mounting the model, and running preliminary tests on the model. There was very little time available for evaluation of alternate car designs, however one variation was tested.

Figure 8

In some races the drivers are permitted to remove the roof entirely. The sponsor of this project had never tried this, and wanted the students to see what would happen in the wind tunnel. Figure 8 shows the model that was used to test this configuration. The testing showed a dramatic increase in down force with the roof removed, so the sponsor to try it in a race. He reported better control on curves during that race, and was very encouraged by the students work. Removing the roof is a very significant change in the car design. While the results gave the students confidence that the combination of rapid prototype modeling and wind tunnel testing held promise for further studies, there were questions left open about how sensitive the tests would be in evaluating minor design changes.

It is unlikely that the magnitudes of the down force generated by this testing are accurate when compared to actual down force magnitudes on the race car, but the purpose of this project is to evaluate if a proposed change has promise, not necessarily to determine accurate down force magnitudes. The sponsor was very pleased with the results to date, and has decided to return for a second year to continue the study. The wind tunnel tests will continue, along with other methods, to find an economical way to evaluate the down force before actual changes are made to the car.

ROBERT EDWARDS
Robert Edwards is currently a Lecturer in Engineering at The Pennsylvania State University at Erie where he teaches Statics, Dynamics, and Fluid and Thermal Science courses. He earned a BS degree in Mechanical Engineering from Rochester Institute of Technology and an MS degree in Mechanical Engineering from Gannon University.

DAVID FORSMAN
David R. Forsman is an Instructor of Engineering at Penn State Erie. He received his B.S. in Engineering Technology from the Pennsylvania State University and his M.E. in Manufacturing Systems Engineering from SUNY, Buffalo. He has been involved with engineering computer analysis since 1974. He has experience in teaching Computer-Graphics, Programming, CAD and Rapid Prototyping for the last 19 years.