DIRECT DIGITAL MANUFACTURING

The Birth of the Pit Viper: Handcrafting Paired with Advanced Digital Tools

BY TODD GRIMM

Restoring and customizing cars and trucks is a laborious process that demands skill and attention to detail. Even with weeks of meticulous work, highly skilled individuals are unable to approach perfection. The human hand is incapable of producing customized pieces with perfect symmetry and consistent gap and flush with mating parts. Additionally, when producing multiple vehicles, as done with the Pit Viper, handworking custom parts will inevitably lead to variances from car to car.
This is where digital technology comes in.

PIT VIPER

- 1968 Mustang Fastback
- 427 cid Shelby-tuned aluminum small block, V8, 575 hp
- Tremec TKO 600, 6 speed manual transmission
- Total Control Products power rack and pinion steering
- 31 spline Positraction differential
- Total Control Products front/rear suspension
- HRE Performance Wheels 541 R
- Michelin Pilot Sport tires
- Custom side-mount exhaust ports
- Full roll cage
- Shelby embroidered hi-back bucket seats
- 5-point quick release harness
- Shelby Signature gauges

The Birth of the Pit Viper

The Pit Viper, a GT500E inspired Mustang, started life as a 1968 Fastback. In late 2005, Brook Phillips and his team at TPI Performance began the restoration and customization process. The Pit Viper exhibited at SEMA 2006 will be auctioned in January 2007 by Barrett-Jackson. The future owner will have a ride built with artistry, skill and craftsmanship. He will have a classic American muscle car with fit and finish that is unsurpassed. What he may not realize is that advanced technology played a vital role in bringing the Pit Viper to life.

Figure 1: Finished Pit Viper

The SEMA Pit Viper, and the 24 limited production cars that will follow, pairs the skill and craftsmanship of the TPI crew with advanced digital modeling technology that is widely used in the aerospace industry. Seeking perfection in fit, finish and symmetry, Phillips elected to use 3D scanning and rapid prototyping for nine of the components on the Pit Viper. Along the way, he also discovered that these technologies dramatically reduced labor, project time and cost.

Auto Restoration and Customization

Restoring and customizing cars and trucks is a laborious process that demands skill and attention to detail. Every step in the process, from design to sheet metal fabrication to paint, requires the talents of a craftsman with a deft hand and a good eye.

Weeks are spent recreating or customizing a single part. Starting with clay, foam or sheet metal, the designer crafts the piece by hand; working the material to achieve the design concept while blending and mating the part to those that surround it. If available, kits offer a shortcut and reduce the labor. However, hand fabrication is still required because most kits are not quite bolt-on ready. Some cutting, tweaking and hand modification are often required.

Even with weeks of meticulous work, highly skilled individuals will be unable to approach perfection. The human hand is incapable of producing customized pieces with perfect symmetry and consistent gap and flush with mating parts. Additionally, when producing multiple vehicles, as will be done with the Pit Viper, handworking custom parts will inevitably lead to variances from car to car.

This is where digital technology comes in.

3D Scanning and Direct Digital Manufacturing

To achieve the 1/16th inch precision, perfect symmetry and consistent flush and gap that Brook Phillips wanted for the Pit Viper, he turned to two leading companies in the fields of 3D scanning and direct digital manufacturing, Realadi, Inc. and Stratasys, Inc. Realadi offered TPI reverse engineering and 3D scanning tools that digitally captured the 1968 Mustang and its custom components. Stratasys, the manufacturer of fused deposition modeling (FDM®) systems (Fig. 2), provided rapid prototyping and direct digital manufacturing services. Through its application engineering and RedEye RPM service arms, Stratasys built one-quarter scale and full-size models. The company also manufactured the finished parts for the Pit Viper on display at SEMA 2006.

For his first venture into these new technologies, Phillips opted to use them to craft nine parts on the Pit

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Viper:
- Two pair of side scoops
- Two hood scoops
- Front grill
- Rear bumper
- Center console

The process started with a complete 3D scan of the 1968 Mustang. From this 3D, digital definition of the car, a one-quarter scale model was produced with rapid prototyping. TPI's crew then handcrafted the nine components on the scale model. After several design iterations and visual inspections, TPI used the direct digital manufacturing process to produce full scale parts. These were then used as patterns for splash molds and also prepped and painted for mounting on the SEMA show car.

Upon inspection of the Pit Viper, SEMA attendees will see that Phillips' goals of symmetry and fit were achieved with this new process. What they cannot see is the tremendous savings in man time, the acceleration of the project and the savings in cold, hard cash. Phillips estimates that the 3D scanning, rapid prototyping and direct digital manufacturing tools saved hundreds of man hours and thousands of dollars.

The Process

When the 1968 Mustang rolled in from California, TPI Performance started the build the same as any other (Fig. 3), removing everything from the car and inspecting it for worn, rusted or damaged parts. From there, everything changed, at least for the nine parts that were to be digitally assisted.

Step One: 3D Scanning

Realadi brought its scanning systems to TPI's shop where it captured the 3D, digital definition of the entire Mustang. The scanning process took one and a half days.

The first step in the scanning process was a photogrammetry shoot (Fig. 4). Since 3D scanners capture the car in two foot by two foot sections, the individual scans need to be aligned to each

About 3D Scanning

3D Scanning, which is also called reverse engineering, converts physical objects to 3D, digital definitions. Although there are many technologies, the most common project light onto the surface of an object. The light is reflected back to the scanner and processing software determines the 3D spatial position through triangulation. The information that is gathered produces a dense cloud of points that contains hundreds of thousands of individual measurements. Collectively, these points fully describe the 3D shape of an object.

ABOUT PROTOTYPING AND DIRECT DIGITAL MANUFACTURING

Prototyping is a process that construct physical objects by "growing" them on a layer-by-layer basis. Working directly from digital data (the STL file), the technology eliminates the need for tooling, molding, machining and casting. This allows for the production of parts with unlimited complexity. Direct digital manufacturing uses the same process, and often the same systems, but the application is different. Instead of producing prototypes, direct digital manufacturing makes production parts for end use.

Fused deposition modeling (FDM®) constructs the object by depositing a thin filament of plastic. Starting from the bottom of the part and working upwards, an extrusion nozzles lays down semi-molten plastic one layer at a time. The process creates functional models or production parts directly from any 3D CAD program using ABS, polycarbonate, polyphenolsulfone and blends.

Figure 2: FDM Maxum

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other, and photogrammetry was used as a spatial reference to ensure precise positioning of all scans. Using the TRITOP system from GOM GmbH, Realadi took digital pictures of the Mustang. Software then processed the images, seeing the targets and scale bars, to establish 3D positioning of the car. The resulting 3D points were used as references for the alignment of the 3D scan data.

With photogrammetry data in hand, Realadi proceeded to 3D scanning. It opted to use an ATOS system from GOM, which is a white light scanner. The system projects a series of white and black patterns that are analyzed to calculate the 3D position of millions of points. Working around the car and into the interior, Realadi completed 105 scans for a complete digital representation of the Mustang.

Step Two: Data Processing

Unlike 2D image scanners, 3D scanners require software processing of the data. For the Pit Viper, this process took two weeks.

Realadi technicians refined the raw scan data to create a complete, accurate and smooth representation of the Mustang. The technicians used several specialized software packages for processing the scan data, including PolyWorks®, Geomagic®, rapidform™ and Imageware. For this type of work, the company expects to have data that is accurate to 0.005 inch.
After processing, Realadi generated an STL file, a file format that represents 3D data as a mesh, for the rapid prototyping process and a Catia V5 CAD (computer-aided design) model for design reference (Fig. 5). It also used the data to create photorealistic images in Alias Wavefront.

When the data files were completed, Realadi sent the 3D information to Stratasys.

Step Three: Rapid Prototyping

Directly from the STL file, without machining, molding, forming or casting, the application engineering and RedEye RPM teams at Stratasys created a quarter scale model of the Mustang. The

PROCESS

- 3D scanning of Mustang
- Process scan data
  - o Export CAD/STL files
  - o Scale data (1:4)
- Construct rapid prototype of Mustang
- Handcrafft components on scale model
- 3D scanning of custom parts
  - o Mirror data (left/right) for symmetry
- Construct ¼ scale rapid prototypes of custom parts
- Fit rapid prototypes to ¼ scale model
  - o Adjust fit, styling lines as necessary
  - o 3D scan modified components
- Build full scale components with direct digital manufacturing
  - o Confirm fit and style
  - o Options:

    For one off, prep and paint rapid prototypes and mount to vehicle. For multiples, prep direct digital manufactured parts as pattern for splash mold

Figure 3: Sketch

Figure 4: Photogrammetry

model, with every detail of the car, was delivered in 10 days.

Stratasys technicians prepared the STL file for building by sectioning the model into two halves. For smaller models this is unnecessary, but the quarter scale Mustang exceeded the capacity of the FDM Maxum™, which has an envelope of nearly 24 x 20 x 24 inches. Once prepped, the files were loaded onto two FDM Maxums for simultaneous construction.

Running around the clock without an operator, the FDM Maxum manufactured the scale model in a durable ABS plastic with an overall accuracy better than 1/32nd of an inch.

While the scan data was being prepared and the rapid prototype built, the Mustang remained at TPI's shop. This gave the crew full access to the car so that it could continue work on body restoration (Fig. 6).

Step Four: Design

With the quarter scale model in hand, TPI began the process of sculpting the custom scoops, grill, console and rear bumper. Working from the design sketches, the modeling process took only a few weeks, not months.

Upon receiving the two halves of the Mustang, Phillips joined them together and began the design process. Working directly on the quarter scale prototype model, Phillips handcrafted the custom parts from clay and foam. He found that working on this scale was much faster and easier than working at full scale (Fig. 7). Also, more work was getting done since his crew continued to work on the Mustang instead of waiting for Phillips to complete his custom pieces.

Since Phillips' next step would be to scan his custom parts, he had only to model one-half of the bumper, console and grill and one each of the side and front scoops. With the 3D scan data, he would create a mirror image of each part.

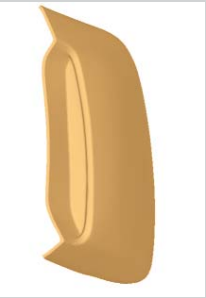

Figure 5: STL

Figure 6: Body restoration

Figure 7: 1/4 scale part built on FDM Maxum

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Working on a smaller scale and modeling only half the parts saved TPI more than six weeks in the design process.

While time savings was valuable to TPI, the most important result was that the Mustang would have perfect symmetry because of the mirroring option. The left half of the bumper would be identical to the right, and the passenger's side scoops would be twins of those on the driver's side.

Step Five: Scanning & Processing
Realadi repeated the 3D scanning and data processing of the custom parts that TPI had handcrafted. This step in the process took only three weeks.

After scanning and processing, Realadi mirrored the files to create a digital representation of the full bumper, grill and console, side scoops and hood scoops. The company also used digital modeling tools to refine mounting points and hollow the parts out to create the desired wall thickness.

Step Six: Rapid Prototyping
Seeking perfection, Phillips chose to have RedEye RPM, a parts building business unit of Stratasys, produce the newly designed parts at quarter scale. From receipt of the files, it took the RedEye team just one week to deliver the nine prototype parts.

Step Seven: Review and Refine
When TPI received the quarter scale prototypes, it mounted them on the quarter scale Mustang for design review and modification. Although TPI wanted to make absolutely sure that the custom parts captured the design vision and had the desired fit and finish, the review and refinement took just a few days.

With his new creations mounted to the quarter scale Mustang, Phillips interrogated each and every piece to confirm that he had achieved the desired look for the Pit Viper and that each part satisfied his demands for precision. Where needed, he made modifications by handworking the rapid prototypes. To capture

Fig. 8: Cherokee restoration

these subtle changes, Realadi repeated the 3D scanning process. This data, when enlarged to full scale, became the digital definition of the parts that would define the Pit Viper.

Step Eight: Full Scale Parts

With the design work completed, Stratasys began manufacturing the nine full scale custom parts. All parts were delivered over a two week period.

The RedEye team used the digital definitions from the scanning process to create exact replicas of the rear bumper, console, front grill, side scoops and hood scoops. For strength and durability, each was made from ABS plastic.

Upon receiving the custom parts, TPI mounted them on the Pit Viper to confirm the fit to the car (Fig. 9-11). Not surprisingly, Phillips found that each was a perfect fit with the Mustang. When places on the car, he saw that all parts exceeded his demands for 1/16th inch precision and that they were flush with a consistent gap.

TPI finished, primed and painted the custom parts. They were then installed on the SEMA 2006 Pit Viper.

Limited Production

The SEMA Pit Viper is the first in a limited production series of 25 cars. While the design is complete, TPI has, and will, continue to use 3D scanning and direct digital manufacturing for rapid prototyped and manufactured parts.

To reproduce, in exacting detail, the custom parts for the limited production run of Pit Vipers, TPI is using the FDM technology to manufacture patterns for splash molds. The patterns will be exact duplicates of the originals, and the parts from the molds will have the same fit and finish as those on the SEMA car.

Should the need arise for a replacement part or a new splash

Figure 9: Hood scoop

Figure 10: Side scoop

Figure 11: Console

mold, TPI will simply pull the digital CAD data from its files to remanufacture an FDM part. TPI views this as a safety net that would not be possible without 3D scanning and direct digital manufacturing. If a Pit Viper is damaged, the replacement parts will be produced quickly, and since it is an exact duplicate, it can be installed with no modification required. If the splash molds wear out, or if demand for the Pit Viper is higher than anticipated, TPI can simply order another pattern from Stratasys' RedEye operations.

The digital data also creates and interesting opportunity for TPI. Having seen the Pit Viper, Mustang owners and customizers are asking how they can get their own kits. While still toying with the idea of selling the custom parts, Phillips knows that he can use the digital data from Realadi's 3D scanning to have production molds made, either through conventional methods or Stratasys' direct digital manufacturing process. He also knows that each of these kits will fit perfectly, since they will be made from the same CAD data that was used to make the first Pit Viper.

Figure 12: Finished Pit Viper

Figure 13: Bumper

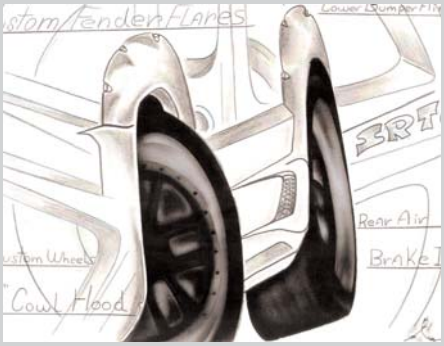

Figure 14: Cherokee sketch

Show Time

Pairing traditional techniques with advanced technology, TPI Performance achieved its primary goal of showing a car with unmatched precision and perfect symmetry. Casual car buffs at SEMA 2006 may not detect this level of craftsmanship, but Phillips knows that his peers will pick up on every detail of the Pit Vipers' design, fit and finish.

With the success of the Pit Viper project, Phillips will apply 3D scanning and direct digital manufacturing to future restoration and customization work. He also plans to partner with Realadi and RedEyeRPM to apply the same process to aftermarket parts for late model vehicles.

LATE MODEL VEHICLES

The scanning and direct digital manufacturing process can also be used for design and production of aftermarket parts for late model vehicles. In fact, it is this application that spurred the investigation

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of 3D scanning and direct digital manufacturing for the Pit Viper. The challenge in manufacturing aftermarket components is to make them available when the vehicle is launched. With the exception of aftermarket companies with ties to the automotive OEMs, there is no access to design data or vehicles prior to them rolling off the assembly line. The delay associated with waiting for a production vehicle means that aftermarket parts cannot be supplied to dealers and retailers until six months to one year after the vehicle hits the dealer lots.

Using the tools that were applied to the Pit Viper, aftermarket companies can have access to prototype or production vehicles well before the product launch. This means that accessories and customization products can be ready for sale the day the vehicle becomes available.

This process is illustrated with a 2006 Jeep Grand Cherokee SRT8 (Fig. 15).

In January 2006, the new Jeep was 3D scanned, by Realadi, at the OEMs facility. The scan data was then processed and exported as 3D CAD files and STL files (Fig, 15), which were sent to Stratasys for rapid prototyping. The STL file was used to create a rapid prototype of a one quarter scale model of the SUV (Fig. 16). Both the CAD data and prototype model were completed six months before the introduction of the vehicle.

With the product design specification offered by the CAD data and rapid prototypes, aftermarket companies can begin the design process well in advance of the vehicle's launch. For perfect fit and finish, companies may also elect to use the scanning and rapid prototyping process of the Pit Viper to yield perfect symmetry, amazing details and high precision (Fig. 17).

Figure 15: Image SRT8 scan

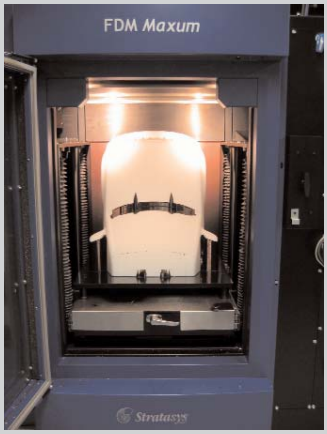

Figure 16: SRT8 scan

Figure 17: Painted Jeep Cherokee

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ABOUT STRATASYS, INC. (www.stratasys.com)
Stratasys Inc, headquartered in Eden Prairie, Minn., makes direct digital manufacturing systems for rapid prototyping and manufacturing. Through its RedEye RPM group, it also offers prototyping and manufacturing services.

Stratasys equipment is used in industries such as aerospace, automotive, defense, medical, and consumer products. In 2005, the company installed 34 percent of all systems sold worldwide, making it the unit market leader for the fourth consecutive year, according to Wohlers Report 2006. Stratasys patented the rapid prototyping process known as fused deposition modeling (FDM®).

ABOUT REDEYE RPM (www.RedEyeRPM.com)
RedEye RPM is a state-of-the-art rapid prototyping and rapid manufacturing facility. It uses high-end rapid prototyping equipment to create physical models of CAD designs using durable high-performance engineering-grade materials. RedEye RPM provides automated, instant quoting and ordering around the clock, seven days a week.

ABOUT REALADI, INC. (www.realadi.com)
Realadi, Inc. enables customers to cost-effectively transform legacy processes to digitally driven enterprises. The company, which has locations in Missouri, Washington, Kansas and Utah, provides 3D CAD definition of physical objects through 3D scanning technology. Founded 2004, the company was created as a spin out of the Boeing Company's internal scanning capabilities.

ABOUT TPI PERORMANCE
(www.tpitotalperformance.com)
TPI Performance, Wichita, Kan., specializes in auto restoration and repairs on classic cars, muscle cars and street rods. With roots in auto racing, the company has been in business for 15 years. The 16 person TPI crew includes nationally recognized fabrication personnel.

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