WIND TUNNEL TESTING

FORTUS
3D PRODUCTION SYSTEMS

Time Required ■□□ Cost ■□□ Skill Level ■□□

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OVERVIEW

Wind tunnel testing is an integral part of the design process in many industries. Whether an object is stationary or mobile, wind tunnels provide insight into the effects of air as it moves over or around the test model.

Since the physics of flight depend on the proper flow of air to produce lift and reduce drag, wind tunnel evaluations are essential in the aerospace industry. Even in an age of advanced computer simulation, aerospace engineers still rely on the testing of physical models to verify the computer data and establish baseline aerodynamic information.

In the never-ending quest for more efficient automobiles, aerodynamics play a very important part in vehicle design. Routinely, the large automotive companies employ wind tunnels to analyze their latest models. While these companies may test an entire vehicle, they will also evaluate the aerodynamics of individual components, such as grilles, side view mirrors, air dams, rear-deck spoilers and roof racks.

If aerodynamics is important for passenger cars, consider how vital it is in the race car industry. In a high speed event, even a slight advantage can be the difference between the checkered flag and "the agony of defeat." Race teams routinely subject scale models to wind tunnel testing as well as full-size cars or individual parts (figure 1).

Figure 1: NASCAR teams rely on rolling-floor wind tunnels to analyze aerodynamics of their race cars.

To make the models for the wind tunnel, automotive and aerospace companies have relied on traditional manufacturing operations. They have used milling, turning and fabrication to convert metal and plastic into test models. These operations require programming, set up and operator supervision, which adds to lead time and cost. Considering the amount of material that ends up as chips on the floor, the material costs can be high.

Cars and planes are not the only beneficiaries of wind tunnel testing. This analysis is just as important for stationary structures. In the architectural industry, much consideration is given to the effects of wind on high-rise buildings, bridges and stadiums, especially when they are located in areas prone to extreme weather. A scale model of the structure is attached to a test rig that has surrounding terrain and ground features. The test rig is placed in the tunnel, and measurements are collected. These results are combined with historical data on wind speeds to predict the total load on the structure and the possible effects.

In the case of architectural models, a skilled model maker will spend days building these structures by hand. Crafted from foam board, acrylic and other materials, the scale models are representative of the design but rarely true to every detail.

FDM AND WIND TUNNEL MODELS

FDM (fused deposition modeling) has rapidly gained acceptance as an alternative process for constructing wind tunnel test models. When compared to machining and model making, FDM is a faster, less expensive and more efficient method for making detailed and accurate test models. Distinguished by its durable and functional materials, FDM is well suited for this application.

FDM materials are some of the strongest available in the additive fabrication market. The mechanical properties of ABS-M30, polycarbonate (PC), PC-ABS and polyphenolsulfone (PPSF) can withstand the forces and stresses induced as the air flow strikes the model's surface.

As wind speeds rise, the mechanical stresses on the model increase. For aircraft applications, there are three categories of mechanical loading: non-structurally loaded (<20 ksi), lightly loaded (~50 ksi), and highly loaded (>125 ksi). The latter two categories demand material properties found in aluminum or steel. However, non-structurally loaded models, which have historically been machined from aluminum, can benefit from the advantages of the FDM process.

A technical representative from a major automotive manufacturer states, "We have been conducting wind tunnel testing with FDM parts for several years with tremendous success. We have not experienced any ‘in tunnel’ failures to date. We utilize this process for scale and full-size components whenever possible.”

Few will question FDM’s suitability for wind tunnel applications based on material characteristics. However, it is common for those not familiar with the technology to be skeptical of this FDM application because of a perceived limitation. They assume that FDM’s surfaces are too coarse, and that it is too difficult to sand them, to yield good wind tunnel test data. This perception is understandable but inaccurate.

When testing at very high wind speeds, it is true that surfaces must be very smooth. However, at lower speeds, companies are using FDM models directly from the system. For those instances where parts must be finished before going into the wind tunnel, there are options. Although FDM materials are durable and somewhat abrasion resistant, and therefore somewhat resistant to sanding, there are a number of finishing techniques that are simple and fast (contact Stratasys’ Application Engineering department for details on finishing processes).

Another surface finish consideration is that slight roughness can be beneficial for some applications. For example, when creating architectural models, it is often important to simulate a texture on a building’s exterior. In these applications, the FDM parts have just enough texture to provide a reasonable approximation of the structure’s surface.

FDM will also preserve small, inaccessible features that are difficult, or impossible, to make with traditional methods. Using soluble supports, which simply dissolve away, engineers and architects can incorporate every detail in the wind tunnel model. Internal passages, baffles and pressure tap locations can be built directly in the object. This level of detail, and the dimensional accuracy of the FDM process, ensures the highest quality of data from wind tunnel testing.

Once the perceived limitation of surface finish is set aside, companies in industries that range from aerospace to architecture can leverage the strength, detail and accuracy of FDM for wind tunnel models. In doing so, they will reduce cost, time and effort.

DESIGN TIPS

Build Orientation

The orientation of the model in the FDM build chamber will affect time, feature detail and surface smoothness. For wind tunnel applications, it is best to orient the part for optimum surface quality.

An ideal part orientation positions the critical contours in the X-Y plane to prevent stepping between layers. With this orientation, the contours are ”drawn” as smooth, continuous curves as the FDM extrusion head deposits material. For example, the airfoil in figure 2 is not in an optimal orientation. In this position, the leading edge will have pronounced steps between layers that could adversely affect the air flow. To improve the surface quality, the airfoil is stood on end (figure 3), which yields smooth contours and layers that are in the same plane as the air flow. Building the airfoil in the vertical orientation will increase build time, but this is offset by the improvement in test data and the minimization, or elimination, of manual part finishing.

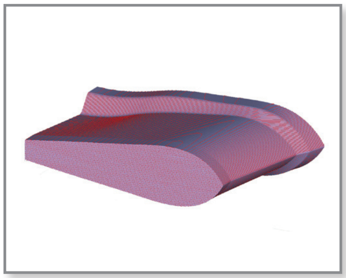

Figure 2: In this orientation, the airfoil’s leading edge would have stepping that may alter wind tunnel results.

Build Style

If the wind tunnel model has a large volume of material, the Sparse-fill build style may be used to reduce build time, material use and part cost. Sparse fill creates an internal honeycomb-like structure that is skinned with solid contours of material. The result is up to a 75 percent reduction in the amount of material used with only minimal effect on the strength of the model.

Sparse- or Sparse Double Dense-fill options are easy to apply in the Insight build preparation software. Optionally, the default shell thickness can be adjusted to add more material for increased strength. Note that this fill style should not be used on walls or features measuring less than 0.25 inch (6.4 mm).

Material Selection

Each FDM material can be used for wind tunnel models. Selection will be based on the strength needed to resist the wind forces in the tunnel. For complex models with difficult to remove support structures, it is advisable to select a model material that uses WaterWorks soluble supports.

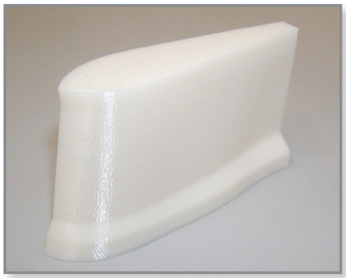

Figure 3: The vertical build orientation of this airfoil produces smoother surfaces that many not need finishing.

Surface Finishing

As noted previously, companies are using FDM models that go directly from the system to the wind tunnel. For many applications, surface finish, when the part is oriented properly, will not be an issue until tunnel speeds reach elevated levels. However, when surface finish is imperative, there is a fast and efficient smoothing process.

The Finishing Touch™ Smoothing Station provides an automated process that produces models with fine surface finishes in under two hours. In the Smoothing Station, parts are cooled for 5 to 15 minutes and then transferred to the smoothing chamber for a 15- to 30-second exposure cycle. This process is repeated two to three times, and the part is allowed to cure for a minimum of one hour. The resulting finish is smooth enough for paint.

Finishing Touch Smoothing Station by Stratasys.

APPLICATIONS AND VALUE

Aerospace Manufacturer

A leading aircraft manufacturer has had great success with a hybrid approach to wind tunnel model construction. The company attaches FDM "skins" made from polycarbonate onto a metal sub-frame. This technique has helped it realize a 75 percent cost savings when compared to its previous method of making skins with CNC-machined foam that is covered with fiberglass. Due to high wind speeds, the FDM models require some surface finishing before testing is performed, but a company representative states, "This is minor compared to the benefits."

NASCAR Team

Joe Gibbs Racing (JGR), a premier NASCAR race team, regularly tests scale models (40 percent scale) in a full-span, rolling-floor wind tunnel. The scale models are articulated through a series of ride heights, yaw angles and roll angles to evaluate various design configurations. The test results are used to improve performance characteristics, such as down force, side force and drag.

In the tunnel, JGR simulates the aerodynamic loads on its race cars at conditions equivalent to 200 mph. Mark Bringle, technical sponsor manager at JGR, says, "The strength of the materials allows the FDM parts to be tested at high wind speeds without the risk of failure." JGR, which makes many of its scale models with FDM's PC-ABS material, often uses the Sparse-fill build style to reduce build time and material consumption. According to Bringle, most of these models are put into the wind tunnels without any secondary finishing work.

Bringle notes that when it used other methods to create wind tunnel models, JGR was limited to approximately 75 to 100 models annually due to the time and labor involved. In contrast, over the previous 12 months, JGR produced 750 parts with its Fortus system. With little direct labor needed and around-the-clock operation, models that would take a week or more to produce with machining or sheet metal fabrication are being completed in a few days with FDM.

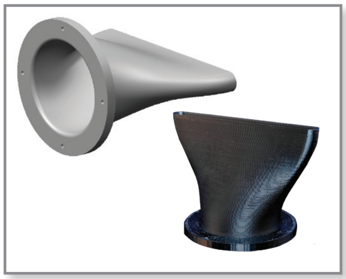

Figure 4: Rear tire blower nozzle for a Joe Gibbs Racing car. CAD model (left), FDM model (right).

Demonstrating both the time and cost savings achieved through FDM, JGR compared conventional methods to FDM for the construction of a rear tire blower nozzle (figure 4). After studying the part, JGR determined that the best comparison would be between a hand-fabricated sheet metal nozzle and an FDM nozzle. Although it has extensive CNC machining capabilities, this option was not competitive, in terms of cost or time, with sheet metal fabrication. However, the trade-off was that the sheet metal part would only hold a tolerance of 0.070 inch (1.8 mm).

In the head-to-head comparison with the sheet metal fabrication process, JGR found that FDM reduced cost by 89 percent and lead time by 66 percent (table 1). The company estimated nine hours of labor to fabricate two halves of the nozzle, weld them together and join them with a machined flange, which would take an additional hour of labor. Conversely, it determined that the FDM process could be completed in three hours with only 30 minutes of direct labor. An added benefit was that the FDM model was significantly more accurate than the sheet metal nozzle (0.005 inch/0.13 mm versus 0.070 inch/1.8mm).

"Producing this part for wind tunnel testing would best be accomplished using a Fortus system. The tolerance, time, and cost could be kept extremely low, and there are no man-hours spent creating the part," says Scott Temple, an aerodynamics engineer JGR.

Process	Lead Time	Detailed Drawing	Fabrication/Build Time	Machining Time	Finishing Time	Labor Cost	Material Cost	Machine Cost
Traditional Fabrication	3 days	2 hours	8 hours	1 hour	--	$720	$30	Included
FDM	1 day	--	3 hours	--	0.5 hours	$40	Included	$45
SAVINGS	**TIME REDUCTION WITH FDM:** **55.5 hours (66%)**					**COST REDUCTION WITH FDM:** **$665 (89%)**		

Table 1: Time and cost comparison of sheet metal fabrication and FDM for a wind tunnel model of a rear tire blower nozzle.

Architectural Design Lab

The Boundary Layer Wind Tunnel Laboratory (BLWTL) on the campus of the University of Western Ontario (London, Ontario, Canada) has been performing various types of architectural testing with FDM models since the purchase of its first system in 1999. As the laboratory continued to devise methods to improve quality and reduce build times, it began using FDM technology more frequently. Among the advantages of using FDM parts, Peter King, wind tunnel research director at BLWTL, is quick to cite the compatibility of the materials with acrylics. This allows lab technicians to bond machined parts to the FDM models when there is a need for added strength or stiffness. King also notes the ability to easily produce highly intricate and dimensionally accurate models as another FDM advantage.

Yet, as with all companies, time and cost are key factors in the decision to use FDM. When BLWTL builds architectural models with pressure taps (figure 5), it no longer has to drill them manually. On large models there can be up to 1,000 pressure tap locations, which are time consuming and tedious to drill. BLWTL eliminates this step by incorporating the pressure tap holes directly into the CAD model and building them in the FDM model. Since it uses WaterWorks, the support material is simply washed out of each pressure tap hole. This technique has resulted in up to a 66 percent reduction in the time and labor required to create their wind tunnel models. Overall, BLWTL has seen an average cost savings of approximately 30 percent over their previous methods. With this savings on its wind tunnel models, the laboratory estimates that it has recovered the cost of each of its Fortus systems in only three to five years.

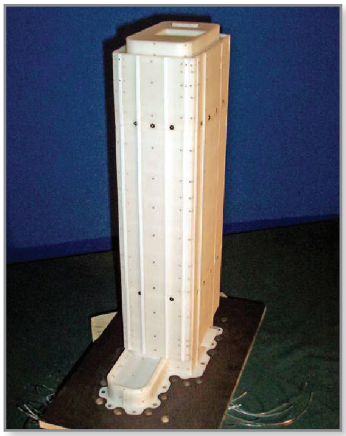

Figure 5: Architectural wind tunnel models are constructed with pressure tap holes to eliminate the time and expense of manual drilling.

CONCLUSION

By simply substituting conventionally made parts with FDM models, these companies have realized cost reductions of 30 to 90 percent while cutting lead times by 66 percent. These companies also benefit from a dramatic reduction of the direct labor needed to make wind tunnel test models since FDM is an automated, unattended manufacturing process. Also, as JGR discovered, this operational efficiency will increase the number of wind tunnel test models that can be made in a year.

These results are attainable by companies in any industry of any size. A major corporation making aircraft or automobiles can apply FDM to its wind tunnel testing applications. Likewise, a smaller organization that optimizes race cars or designs skyscrapers can turn to FDM to get the wind tunnel test data needed to refine the design for performance and endurance.

FDM PROCESS DESCRIPTION

Fortus 3D Production Systems are based on patented Stratasys FDM (Fused Deposition Modeling) technology. FDM is the industry's leading Additive Fabrication technology, and the only one that uses production grade thermoplastic materials to build the most durable parts direct from 3D data. Fortus systems use the widest range of advanced materials and mechanical properties so your parts can endure high heat, caustic chemicals, sterilization, high impact applications.

The FDM process dispenses two materials—one material to build the part and another material for a disposable support structure. The material is supplied from a roll of plastic filament on a spool. To produce a part, the filament is fed into an extrusion head and heated to a semi-liquid state. The head then extrudes the material and deposits it in layers as fine as 0.005 inch (0.127 mm) thick.

Unlike some Additive Fabrication processes, Fortus systems with FDM technology require no special facilities or ventilation and involve no harmful chemicals and by-products.

For more information about Fortus systems, materials and applications, call **888.480.3548** or visit **www.fortus.com**

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