



Challenges of Analyzing Parametric CFD Results

White Paper

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Introduction

As global competition intensifies, companies are under mounting pressure to innovate with increased speed, efficiency and quality. Accordingly, product development has been given a central role within most organizations. Among the methodologies that organizations use to help them optimize product design and analyze performance is parametric computational fluid dynamics (CFD) analysis—or the use of CFD to help determine the influence of various design parameters. As computers become more powerful and CFD technology continues to advance, parametric CFD analysis is becoming both faster and cheaper—and capable of producing better design decisions.

Parametric CFD analysis promises to offer organizations a strong competitive advantage by making it possible to produce higher-quality designs. The goal of this white paper is to help business leaders, engineers and scientists better understand both the promise and challenges of parametric CFD analysis so they can fully prepare for the next wave of this critical methodology.

Parametric CFD Analysis: A Methodology Poised for Growth

Parametric analysis—or the examination of the relationships between different input variables to analyze how they influence the results—dates at least all the way back to the Industrial Revolution, when companies began developing products for mass distribution. Product designers had to balance different parameters to create the best product. Perhaps they wanted to develop a product that was both durable and light-weight, for example, or perhaps one that was both durable and low-cost. To accomplish their goal, they needed to weigh different parameters against each other, physically testing these variables until they came up with the best solution.

While parametric analysis is as old as product development itself, what's changed in recent years is the use of computational fluid dynamics (CFD)—a computational technology that enables engineers to study the details of flow dynamics. Today, CFD is playing an increasingly larger role in parametric analysis. According to Fang, Li and Sudjianto,¹ engineers use simulation-based parametric analysis in three ways:

- *Prediction and optimization.* Once the dependence of output variables on the input parameters is clearly understood, it is possible to predict the behavior of the system and determine the configuration that will give optimal results.
- *Sensitivity analysis.* In many systems, the designer wishes to quantify the leverage of each input variable on the various output variables.
- *Probabilistic analysis.* Engineers are also interested in examining the effect of input uncertainty on the variability of the output variables, and thereby the performance of the system. In particular, this may be used for risk analysis and to evaluate the robustness of a specific design.

Today, as many as 60 percent of engineers who use Tecplot 360 CFD visualization software also have some experience with parametric CFD modeling.² Indeed, the use of parametric CFD analyses spans a broad number of industries including the aeronautics, automotive, chemicals processing, energy, and consumer products sectors.

For example, designers in the consumer products industry frequently rely on parametric CFD analysis for prediction and optimization. To design durable plastic bottles at the lowest cost, for instance, they often use parametric CFD analysis to model different physical shapes of plastic bottles using different grades of plastic that hold varying amounts of liquid.

Likewise, the aeronautics industry often uses parametric CFD analysis for optimization studies—to maximize the performance and fuel-efficiency of aircraft. By performing parametric CFD analyses of a given airplane against varying Mach numbers, angles of attack and flight altitudes, for example, engineers can better understand how an airplane behaves under varying conditions. They can then use this information to maximize performance, while understanding the safety thresholds that shouldn't be exceeded.

¹ Kai-Tai Fang, Runze Li, and Agus Sudjianto, "Design and Modeling for Computing Experiments," Chapman & Hall/CRC, Boca Raton Fla., 2006.

² This figure resulted from a 2010 Tecplot e-mail survey completed by 280 Tecplot customers in the commercial, government and academic sectors.

A More Demanding Design Process

More powerful computers have increased the demand for sophisticated tools to assist with product design. As competition has grown increasingly fierce, the ability to create quality, new products both quickly and inexpensively has become central to almost every organization's economic survival. As a result, more and more companies have made product design the focal point of their strategy. In recent years, businesses have been expanding both their in-house design groups and their reliance on outside design consultants. In addition, a growing number of companies are adopting rigorous design approaches that integrate product design more closely with manufacturing, marketing and other parts of the business. As the demands on product design have increased, parametric CFD analysis has become a fundamental part of the design process in many organizations. Over the next few years, an even larger percentage of engineers are expected to turn to parametric CFD modeling to help them produce better designs both more quickly and cost-effectively.

Advancing Technology

Ever since Intel co-founder Gordon Moore first observed that the number of transistors on a microchip doubles every one to two years, computer power has continued to grow exponentially, while its price has gradually dropped. In recent years, computing power and CFD technology have evolved to the point where engineers have enough confidence in their CFD solutions to use it as a standard tool. As parametric CFD analysis moves further into the mainstream, the available tools are gradually becoming easier to use, reducing the skill level required to perform these analyses. Accordingly, the market for CFD technology has experienced consistent, annual, double-digit growth, and that growth is expected to continue into the next decade as more engineers incorporate CFD analysis into their workflows.

Challenges of Parametric CFD Analysis Today

While the demand for parametric CFD analysis is growing, several obstacles remain to the widespread use of this technology. Among the challenges are managing the massive amount of data generated from multiple runs, and assessing the accuracy of the results. It also remains difficult to compare data from different sources, understand trends and anomalies across the metadata and collaborate effectively with others.

Managing the Data

Today, one of the main challenges of parametric CFD analysis is the difficulty of managing the large amount of CFD data that result from parametric studies. While some engineers use commercial databases to manage this data, most house their CFD runs within internal hierarchical file systems stored on a network server. Without a database to manage the details of CFD simulations, it can be difficult for engineers to find specific projects that they've created in the past. This can result in the loss of valuable data, which prevents them from applying lessons from past projects to current ones.

Assessing the Solution Quality

Although CFD tools are becoming easier to use, expertise is still required to determine the accuracy of the results. While CFD specialists are trained to assess the solution quality, it can be a cumbersome process. As the volume of data generated from parametric analyses increases, CFD specialists increasingly lack the time to examine the results from every simulation. Moreover, as a growing number of generalists incorporate parametric CFD modeling into the design process, they do not have an easy way to judge the quality of the solution generated—for example, whether the computational cell size

they used was sufficient. Without tools to help guide their use of the data, generalists performing parametric CFD analyses risk missing vital information that's critical to the design and performance of their products.

Comparing Data

Comparing data from different sources also remains a laborious process. Oftentimes, engineers need to compare data from CFD runs that were based upon different computational cell sizes. They also need to compare data from multiple CFD software programs, which frequently use different naming conventions for the same variable or parameter. In addition, they need to compare CFD data against data gathered from experiments—such as wind tunnel tests and other physical experiments—to validate their CFD data. Converting data into the similar format needed to make head-to-head comparisons can be extremely time-consuming, requiring engineers to focus a disproportionate amount of their time on formatting the data rather than analyzing it.

Understanding Trends and Anomalies

With parametric CFD analysis, understanding trends in the data is critical to predicting the overall behavior of a product. Likewise, making sense of anomalies in the data—or data that doesn't fit the general pattern—is crucial to designing products that perform optimally. Today, when engineers want to examine the reasons for a trend or anomaly, they need to figure out the exact CFD run associated with a particular point on their metadata plot, search through their file system to find that piece of data and then bring that data into their CFD visualization software to examine it in detail. Or, if they're aware of a problem in advance, they can write scripts that help them collect the data they need and assemble it into a form that allows them to examine it with CFD visualization software. What's needed is a way to instantly retrieve the CFD data that engineers want to examine, and bring this data into a view that will help engineers understand the physical drivers behind trends and anomalies.

Collaborating with Others

Without a database to store data from CFD simulations, it's difficult to share data and collaborate with others. It's also hard for engineers to access past parametric studies created by others, and for engineers in different parts of the company to share data and collaborate on projects. This inability to share data makes it more time-consuming and costly to complete parametric studies. It also prevents business leaders from capitalizing on the full range of organizational talent during the design process.

The Lack of an Integrated Tool

While use of parametric CFD analysis continues to grow, the technology is still evolving. Today, engineers use several tools for parametric CFD analysis. Each of these tools offers an important capability, yet each of these capabilities is not well-integrated, making it difficult for engineers to closely tie the metadata to the underlying physics. Without an easy way to understand the drivers behind trends and anomalies, engineers often lack the full picture required to make savvy design decisions.

In general, today's parametric analysis tools fall within five major categories – design optimization, data management, metadata analysis and visualization, physics visualization and simulation run manager tools.

- *Design Optimization* — Tools that support simulation-driven design with a graphical environment, allowing users to explore the design space and find the optimal designs.
- *Data Management* — The structural database that manages and tags data from CFD simulations so they can be easily mined and filtered.
- *Metadata Analysis and Visualization* — Software that makes it possible to quickly examine relationships among metadata to better understand metadata trends and anomalies.
- *Physics Visualization* — CFD visualization software that enables users to plot and animate their flow field solutions to better understand the physics underlying metadata trends and anomalies.
- *Simulation Run Manager Tools* — Tools designed to help with the management of simulation runs and load balancing of parametric studies.

While each of these technologies offers an important capability, all of them by themselves are limited in some way. For example, today's design optimization tools are aimed at helping product designers find the optimal design point. Yet they fail to provide a view into the entire parametric space, preventing engineers from seeing how the product functions under less optimal conditions. Without this insight, engineers lack the understanding needed to improve the product's performance within the full spectrum of operating conditions.

Other technologies—such as data management, metadata visualization and physics visualizations tools—each play an important role in performing parametric CFD analyses. Yet because these tools are not fully integrated, engineers find it both cumbersome and time-consuming to move back and forth among applications. In some cases, engineers analyze parametric problems by piecing together one or more of the disparate tools available on the market. In other cases, they resort to writing their own scripts and creating their own ad-hoc processes to perform these analyses.

Preparing for the Next Wave of Parametric CFD Analysis

The next wave of parametric CFD analysis promises to conquer the complexity of this important methodology by providing easier-to-use tools than are available today. While improved tools are needed, there are ways in which organizations can prepare now for the next wave of parametric CFD analysis. First, be sure to keep your difficult-to-compute 3D field data so that you can determine the underlying causes of trends and anomalies in the metadata. Second, analyze your design process to better understand which parts are time-consuming, inefficient or risky. Where is your organization losing valuable information? What parts of the process include the most risk? In what areas would greater collaboration be useful?

Once you've pinpointed the areas needing improvement, decide which processes can be immediately addressed. Perhaps your organization can more efficiently store and organize your CFD simulation data. Or perhaps you can begin writing scripts to better process that data. As parametric CFD analysis continues to evolve, it's certain that the volume of data that needs to be managed will grow exponentially. To prepare for the next generation of this important methodology, it's critical that organizations begin to assess how they can best incorporate parametric CFD analysis into their design process.

Conclusion

Ultimately, an engineer who understands the connection between the underlying physics and the metadata makes a better designer. By making it easier for engineers to understand the physical phenomena that underlie trends and anomalies in the metadata, the next wave of parametric CFD analysis tools promises to take product design to a new level. With the ability to produce better designs faster, organizations that embrace this emerging methodology will obtain a key competitive advantage—one that could mean their economic survival.