# EXHAUSTIVE SIMULATION

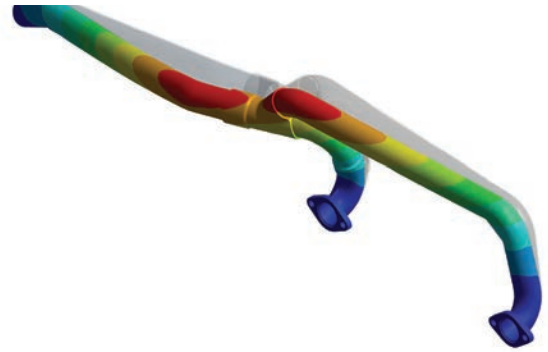
**An exhaust system designer uses multiphysics simulation to reduce costly iterations by validating designs before testing.**

**By Matt Butson**, Engineering Services Manager, and **Ning Cao**, Product Design Engineer, Active Exhaust Corp., Toronto, Canada

Designing exhaust systems is complicated by the number of different physical phenomena involved. Designers must consider airflow inside the exhaust system and its impact on back pressure experienced by the engine. The flow of gas through the exhaust manifold produces vibrations and noise that the design must mitigate. The system's temperature must be maintained to maximize exhaust after-treatment performance and to minimize impact on both the environment and adjacent vehicle components. Active Exhaust uses multiphysics simulation to reduce costly iterations by validating designs before testing.

Active Exhaust is a world-class provider of exhaust management systems for industrial engine and vehicle applications. The company specializes in sound, emissions and thermal management solutions for mobile and stationary engine applications ranging from 5 HP to 700 HP.

The company's headquarters in Toronto, Canada, houses R&D, product engineering and customer support, as well as its North American manufacturing center, all under one roof. It has a staff of approximately 275 employees along with two off-shore joint ventures in China and India, and warehouse locations in the United States. Active Exhaust caters its technologies to markets that include consumer and commercial lawn care equipment, construction and farming machinery, welders and generators, in addition to all-terrain, recreation and utility vehicles.



▲ FEA results show deformation of a manifold headerpipe.

## DESIGN VALIDATION BY TESTING

In the past, the company utilized two-dimensional design tools that were developed internally based on existing tube and muffler elements. The design engineer approximated the design performance using these tools. The accuracy, documentation and scope of design-ready geometries were limited. Engine manufacturers must adhere to stringent regulations including those set forth by the U.S. Environmental Protection Agency and Department of Agriculture. As a value-added service, Active Exhaust directly collaborates with various approving bodies to simplify the process for its customer base. As a result of uncertainty in design performance, all new exhaust systems have to undergo lab validation of criteria such as pressure drop, horsepower, torque, thermals, vibrations, acoustics, emissions, cleanliness, particulate and leak testing.

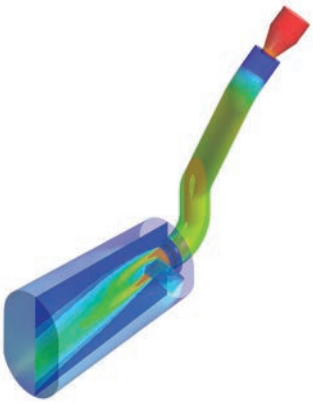
This process relied heavily on physical testing to validate design performance. Active Exhaust's extensive test facility has provided the final validation before products are shipped to customers. The million-dollar test facility includes five eddy current dynamometers with capacity of up to 10,000 rpm, 400 Nm and 160 kW. When the engines are instrumented, these state-of-the-art data acquisition systems collect flow, pressure, noise, acceleration, temperature and other measurements at frequencies to distinguish exhaust pulsations with high resolution. Recently, however, the company entered markets with engines so large that they exceed the capacity of internal dynamometers. Third-party testing would have been required, driving costs to uncompetitive levels. The additional costs related to building prototypes and the outside manpower required to perform analyses made it too expensive to continue designing these larger systems employing the physical testing method.

Active Exhaust recognized several other limitations in their test-based design process. Whenever a design did not meet requirements, the team had to react quickly to redesign, rebuild the prototype, and repeat the tests at considerable expense. Additional design iterations took substantial amounts of time, running the risk of delaying product introduction. The measurements that were captured by physical testing were constrained by the physical limitations of sensor technology: Information generated by the tests was often insufficient to diagnose the root cause of a problem. For example, physical testing is unable to detect flow recirculation, which can significantly increase exhaust pressure drop. Further, the high cost of testing meant that the team had only limited opportunities to evaluate design alternatives that might optimize performance and cost.

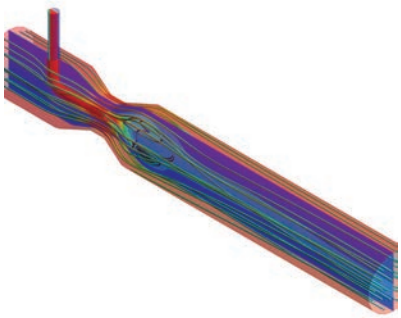
## SIMULATION-BASED DESIGN PROCESS

Active Exhaust considered a number of different simulation options. With fluid flow crucial to the design, the company first focused on computational fluid dynamics (CFD) solutions. Engineers found several software packages that met the company's needs, but ANSYS software was distinguished by its ability to solve the additional physics involved in the design, including mechanical, thermal and acoustics. Active Exhaust selected ANSYS CFD-Flo for fluids simulation along with ANSYS Mechanical, which provides structural, thermal and acoustics capabilities. These and other ANSYS tools reside within the ANSYS Workbench environment, providing bidirectional data transfer with CAD systems, a common user interface, integration between the different physics, and many other capabilities.

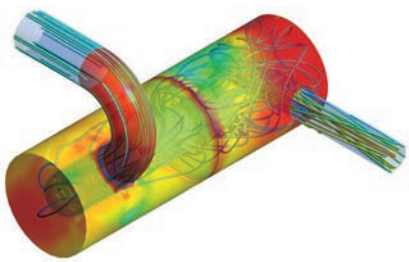
Simulation now is at the heart of the design process at Active Exhaust. The first step typically is to open a file containing the CAD geometry that has been created in Creo® software. Active Exhaust then extracts the fluid volume from the solid model and adds boundary conditions to it, such as the mass flow rate at the exhaust inlet, exhaust outlet pressure, and other



▲ Temperature distribution of exhaust gas inside exhaust diffuser



▲ Flow field streamlines and temperature distribution inside venturi-type aspirator



▲ Flow field streamlines and temperature distribution inside muffler displaying fluid streamlines and temperature contours

# Active Exhaust's customers benefit from higher performance and shorter lead times.

parameters arising from the engine operating conditions. ANSYS CFD is then used to perform a flow simulation through the exhaust system. This simulation calculates the exhaust system pressure drop and resulting back pressure at the inlet. Since the flow is now being simulated in the actual exhaust geometry, the results usually correlate quite closely with physical measurements.

The CFD software provides diagnostic capabilities far beyond what is obtainable from test results, including velocity and pressure at every point in the flow path. For example, an engineer running a flow simulation of a new exhaust system might see a recirculation zone in the flow path. Aware that recirculation generally increases the system pressure drop, he would then make changes to the geometry of the CFD model, such as reducing any obstruction or excess curvature in the main flow path. The engineer would then rerun the simulation to see if the change eliminated the recirculation zone. If not, the engineer would continue modifying the model geometry until the recirculation zone was eliminated. This process often leads to a significant reduction in back pressure. The benefit of using ANSYS Workbench is that as the geometry changes, the mesh, setup and solution are automatically updated, saving time in the development process.

In conjunction with using CFD simulation, Active Exhaust engineers apply ANSYS Mechanical to analyze the exhaust system from thermal, structural and acoustics perspectives. The integration between ANSYS CFD and ANSYS structural mechanics software makes it easy to transfer the internal temperatures calculated using CFD to ANSYS Mechanical, where they become inputs for a thermal analysis that determines the temperatures on the exterior of the exhaust system and identifies the stresses generated by thermal expansion. ANSYS Mechanical is also used to validate the structural integrity of the exhaust system by inputting power spectral density data from the vehicle. Using these inputs to drive a random vibration simulation determines frequency response and stress distribution. The dynamic analysis also determines modal frequencies of the exhaust system. If the modal frequencies have the potential to be activated by the engine, engineers make design changes.

The next step in simulation at Active Exhaust is to predict the acoustic performance of exhaust systems prior to the prototype phase. This is determined using ANSYS structural mechanics features that utilize the output from modal analysis data to calculate attenuation and absorption of pressure waves (sound) by the muffler. Based on this data, the software simulates the transmission loss across the frequency spectrum and calculates noise emission levels. Active Exhaust has been able to utilize its library of raw engine acoustics as a source impedance to help characterize insertion loss values, a widely compared value in the industry.

The most important advantage in moving to a design process based on simulation is that Active Exhaust now almost always gets the design right the first time. Every new design is still exhaustively tested, but upfront simulation ensures that the first prototype meets the customer's requirements in nearly every case. Simulation also provides much more diagnostic information, making it possible for engineers to quickly identify the root cause of problems and to make substantial improvements in performance. The company's customers benefit from higher performance and shorter lead times. Active Exhaust absorbs most design costs with the intent of earning them back when the exhaust system moves into production. Active Exhaust has won several major contracts that can be directly attributed to the new design methods.

**AUTOMOTIVE FLUID-STRUCTURE INTERACTION (FSI) CONCEPTS, SOLUTIONS AND APPLICATIONS**
ansys.com/82exhaustive