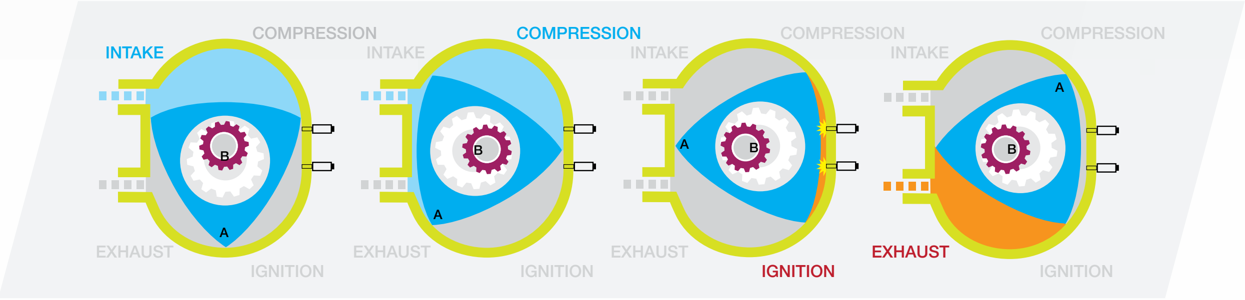
Pouring COLD WATER on It

To design one of the highest power-density rotary engines ever developed, engineers at Orbital Power needed to cool the housing sufficiently to preserve the life of the rotor tips. They accomplished this goal using ANSYS software to optimize the design of the water cooling jacket. This required less than one-third of the time that would have been required using build-and-test methods.

By **Shawn Okun**, President,
and **Wenwei Zeng**,
Combustion Engineer,
Orbital Power Ltd.,
Lakeland, USA

Most of us are familiar with internal combustion engines that have pistons that move back and forth, reversing direction. However, in a rotary engine (or Wankel engine, named after its inventor), the parts rotate and move only in one direction. A four-stroke cycle within a combustion chamber located in a peanut-shaped housing drives a three-lobed rotor. Intake, compression, ignition and exhaust occur within the four chambers defined by the spinning rotor inside the housing. When compared to piston engines, rotary engines are generally simpler, smoother and more compact. Their higher revolutions per minute, and high power-to-weight ratio, make them perfect for applications where high power and light weight are needed, such as for portability purposes.



^ Diagram of the four-stroke cycle of a generic rotary engine. *Courtesy: Y_tambe's file. Permission =GFDL*

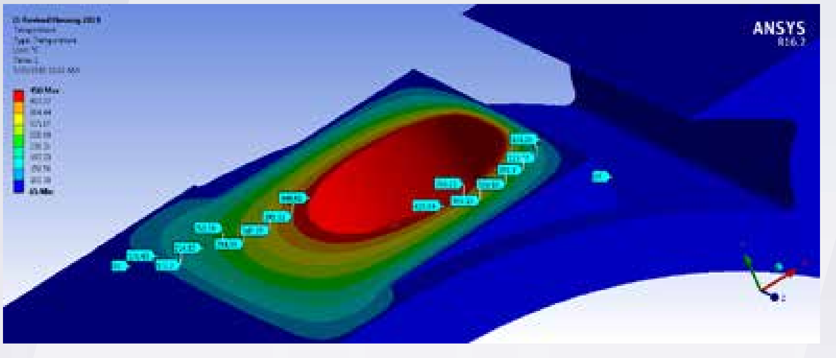
Orbital Power produces rotary engines ranging from 2.5 to 40 horsepower for applications such as generator sets and unmanned aerial vehicles. The company's new ORB-20A rotary engine enables a person to carry a 500-watt generator in a backpack. Its high power-density stems partly from the fact that the new engine burns heavy fuels, such as kerosene, that have higher caloric value than lighter fuels, such as gasoline. Heavy fuels are also less expensive, safer to handle, easier to store and transport, and have better lubricating qualities. Another Orbital Power engine/generator combination delivers 10 KVA with a 40 horsepower engine that weighs 17 pounds, a fifth of the weight of competitors' products.

> "Guided by ANSYS simulation tools, Orbital Power achieved a 93 percent decrease in cost and a 70 percent decrease in design time."

On the other hand, heavy fuels present a major design challenge because they generate more heat, and orbital engines already have a natural tendency to run hot. Combustion occurs near the tips of the rotors where they seal off the housing, and temperatures exceed the limits of all usable rotor tip materials. Orbital Power overcame this obstacle by using ANSYS CFX computational fluid dynamics (CFD) software to develop a unique water cooling system that keeps the temperature of the tips at safe levels.

THERMAL DESIGN CHALLENGE

The original concept design of the ORB-200L used air cooling, but Orbital Power engineers quickly determined that water cooling was needed to maintain safe operating temperatures. They developed an initial design in which water was pumped through internal passages in a water jacket to remove heat generated during combustion. Most of the heat generated in a rotary engine is near the ignition and exhaust chambers, so another goal of the cooling system is to distribute heat over the entire housing as much as possible.



^ Temperature distribution across water jackets on early development design shows hot spot in red.

Orbital Power engineers defined the geometry of the engine in computer-aided design (CAD) software and imported the model into ANSYS Workbench. The geometry contained many imperfections, such as tiny gaps and overlaps, which are not relevant to the flow analysis. Removal of such imperfections often improves the subsequent mesh and reduces the time it takes to generate the solution. Engineers used ANSYS SpaceClaim to remove these unnecessary features, correct the imperfections with automated tools, and directly edit and manipulate faces — in real time without rebuild errors. They used ANSYS meshing to create a mesh with more than 30 million elements and simulated the engine's performance with CFD.

The resulting temperature distribution showed numerous hot spots ranging up to 212 F, which is unacceptable for the materials used in the engine. The simulation showed that the hottest areas corresponded to recirculation zones that prevent cool water from entering. It also showed that the outlet temperature was above 190 F, and that the left side of the engine was much hotter than the right side.

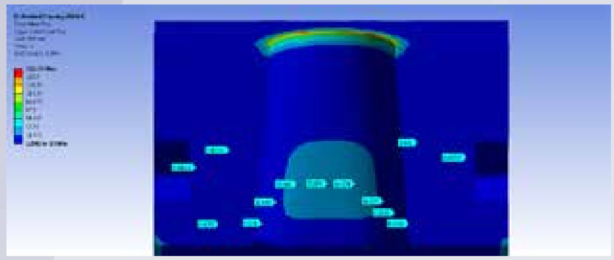
^ Orbital Power ORB-200L rotary engine

ITERATING TO AN OPTIMIZED DESIGN

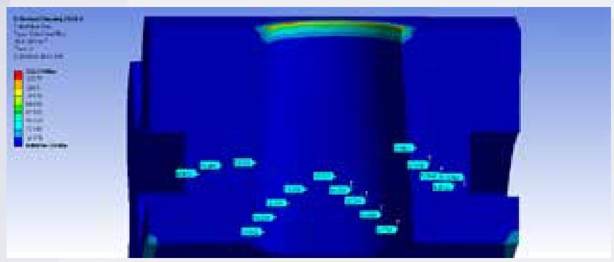
Guided by the simulation results, Orbital Power engineers then created designs using fins and curved walls to alter the direction of flow through the water jacket in an effort to eliminate the hot spots and even out the temperature throughout the jacket. Engineers ran about 40 design iterations while manually adjusting the direction and angle of deflectors, the size and angle of the inlet and exhaust flow, and other variables based on the results of previous design iterations. They also changed the position of oil pipes that pass through the water jacket for oil cooling, which indirectly affect the water jacket by creating obstructions and releasing heat.

The team achieved a final design that yielded a much more even flow distribution across the water jackets. With a low pressure pump, the hottest point in the water jacket on the left side has a maximum temperature of about 190 F, which is an acceptable value. There are no strong temperature gradients in the water jacket, and the outlet temperature is less than 180 F. The spark ignition area is also cooled very well.

With a high-pressure water pump (as is used in heavy duty applications), the new water jacket design runs at even cooler temperatures. The temperature at all points in the water jacket is less than 160 F, with the hottest area being near the left core side. There is also a relatively even temperature distribution across the water jacket, and the spark ignition area is also well-cooled. The heat absorbed by the oil pipes is minimized by the passing of liquid coolant, reducing the oil temperature significantly. After physical testing and review, the optimized structure was validated in a controlled engine dynamometer testing facility with a dynamic pressure water pump. Results showed the highest effective temperature of the liquid cooling system was less than 185 F, and there was relatively even temperature distribution across the entire water jacket.



^ Another view of temperature distribution on early development design shows temperature on left side is higher than right side. The left core is between the intake port and the first spark plug, roughly 20 degrees from the port toward the spark plug.



^ Another view of temperature distribution on final design shows lower temperatures and more even temperature distribution.

SIMULATING TEMPERATURE GRADIENTS IN HOUSING

Orbital Power engineers then used ANSYS CFX and ANSYS Mechanical to address a temperature gradient issue near the exhaust port. The initial concept design showed a gradient from 450 F to 131 F in the cross-section of the housing near the right side of the exhaust port. In this area, the minimum wall thickness between the exhaust port and cooling channel is only 2 mm, resulting in a heat flux exceeding 25 W/mm^2, compared to less than 15 W/mm^2 in the surrounding area. This creates the potential for the coolant to boil and generate bubbles that can hurt the performance of the entire cooling system. Orbital Power engineers used ANSYS Mechanical to evaluate the effect of varying the minimum wall thickness. They ended up with a minimum wall thickness of 5 mm, which reduced the heat flux to 11 W/mm^2 (42 percent of the original value).

"The optimized liquid cooling system provides temperatures that are 35 percent lower than air cooling and 20 percent lower than the original liquid cooling design."

Orbital Power estimates that designing the water jacket through traditional build-and-test methods would have cost about $600,000 and taken about 40 weeks. Guided by ANSYS simulation tools, Orbital Power engineers iterated to an optimized design in about 25 man-weeks of engineering effort over a 12-week period; the company pegs the total cost of the simulation effort at about $40,000 including labor, software and computing expenses. This is a 93 per cent decrease in cost and a 70 percent decrease in design time. The optimized liquid cooling system provides temperatures that are 35 percent lower than air cooling and 20 percent lower than the original liquid cooling design, ensuring a long and reliable engine life.

Thermal Management with ANSYS Multiphysics
ansys.com/thermal101