Computer Simulation Helps Tanks Stay Hidden During Battle

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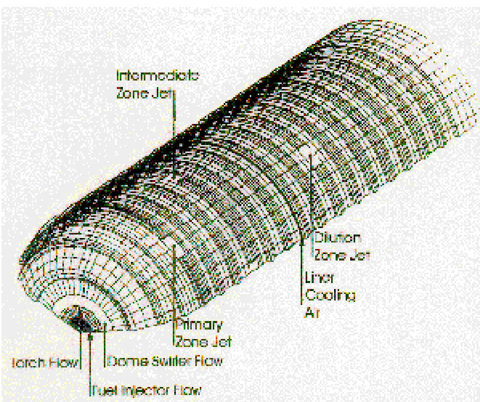


Combustor grid for computational model with illustration of model inlet flows.

Precision Combustion Inc. (PCI) used computer simulations to improve the design of a new combustion method for Army tanks that helps keeps them hidden during battle while reducing harmful pollutant emissions. Analysts used computational fluid dynamics (CFD) to optimize the performance of tank turbine engines operating with a catalytic torch as the ignition source instead of conventional spark plugs.

The analysis showed that the addition of the catalytic torch reduced performance when the engines were operating under the old conditions but that performance could be dramatically improved by adding more air through primary jets. CFD provided this insight for a small fraction of the cost and time that would have been required to build prototypes and test them using traditional approaches. PCI, founded in 1986, is a rapidly growing New Haven, Connecticut-based research and development company with a historical focus on the development and refinement of proprietary catalytic technologies. Over the past several years, the company has won contracts from major U.S. and European corporations and the NSF, NASA, EPA, DOD, and DOE, enabling it to become a world leader in the area of catalytic combustion. One of the company's specialties is designing catalytic combustors for natural gas turbines to reduce nitrogen oxides (NOx) and other harmful emissions. PCI has also developed catalytic glow plugs for diesel engines and an advanced technology automotive catalytic converter that enables the strictest emissions standards to be met at a relatively low cost.

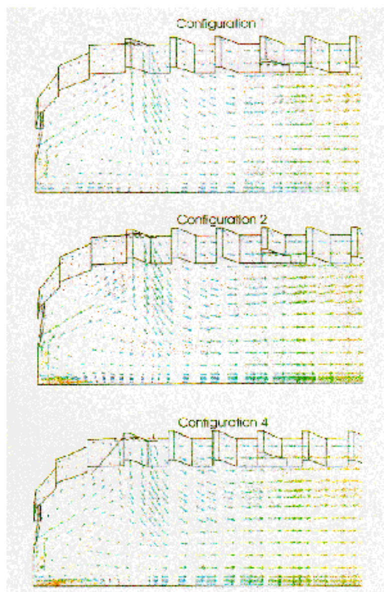
In its work for the military, PCI has been trying to improve the performance of liquid-fueled gas turbine engines such as those used in U.S. Army tanks. In these engines, air-blast atomizers have been the preferred method for injecting fuel into the combustor for the past 30 years. The drawbacks of air- blast designs include inadequate atomization for ignition and difficulty in achieving wide combustor stability limits.

While the optimum location for the spark plug is along the centerline of the combustor in the central recirculation zone, this isn't a practical option. The high gas temperatures and significant fuel concentrations encountered within the central recirculation zone tend to form deposits on the spark plug face and rapidly degrade its performance. For this reason, spark plugs generally are mounted near the dome of the combustor and do not protrude far from the combustor liner. This means a wide spray angle must be provided by a pressure atomizer and this wide angle is required throughout all operating conditions. If the primary zone is fuel rich, a highly luminous and even sooty flame with its associated high liner wall temperatures results during acceleration and power conditions. This makes concealment difficult during wartime and poses environmental problems. Near stoichiometric F/A ratios in the primary zone produce significant amounts of NOx.

To overcome these problems, PCI has been investigating an alternate approach in which a catalytic torch is integrated with an air-blast injector. Although conventional diffusion flame torches have been used along the centerline of ground power gas turbines to provide both ignition and lean flame stability, the substantial size of these torches has limited their benefit in applications where space requirements are tight. Flame diffusion torches also contribute substantially to NOx formation in combustors. Recent advances in catalytic substrates have made it possible to integrate a catalytic torch with air-blast fuel injectors along the injector centerline. The torch not only provides reliable ignition but also enhances combustor stability, so that the primary zone can operate leaner to reduce emissions.

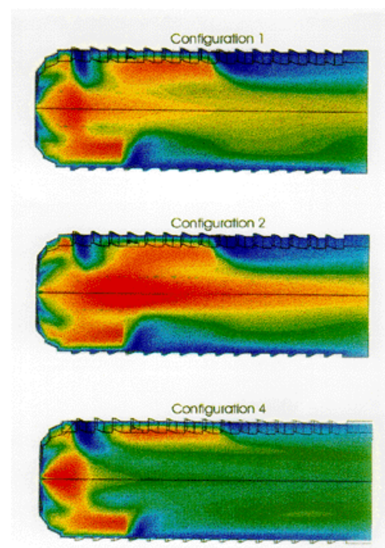
Traditional testing methods are time consuming, expensive, and limited in their ability to provide detailed performance information. CFD software offered engineers on this project an attractive alternative for evaluating options. CFD simulations provide complete flow field and heat transfer predictions. The results of the analysis allow a designer or an engineer to optimize fluid flow patterns or temperature distributions by adjusting critical system parameters. Detailed parametric studies performed using CFD can provide design engineers with critical insights into optimal design configurations while dramatically reducing design cycle times and costs.

For the analysis, researchers chose FLUENT from Fluent, Inc. of Lebanon,New Hampshire. This package was chosen for its robust combustion model and a user interface that makes it easy to define the conditions of a simulation.With most analyses, a user can be initiating an analysis in minutes after importing the analysis model or mesh. PCI engineers modeled an AGT1500 Army gas turbine combustor. The periodic nature of the geometry allowed the model to be reduced to a 72-degree sector of the combustor with cyclical boundary conditions. The domain consisted of 23,000 cells.



Fluent model results of velocity vectors (in m/s) for primary zones of combustor configurations 1, 2&4 on axial plane in-line with center of primary zone jets.

The computational study compared combustor performance with the catalytic torch for four different primary hole jet sizes to a baseline combustor performance that used spark plugs as the ignition source. To insure similar total combustor air flow, the dilution jet holes were reduced by the same amount of area that the primary zone jets were increased. Plots of velocity vectors indicated that the main difference between the spark plug configuration and those using a catalytic torch was occurring near the centerline of the combustor.



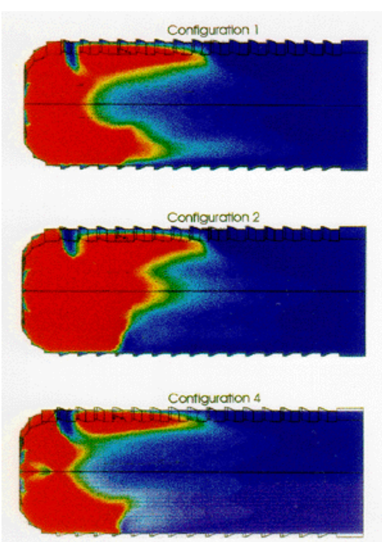
Fluent model results of temperature profiles (in K) for combustor configurations 1, 2&4. (Top halves of plots are along axial plane in line with center of primary zone jets. Bottom halves are along axial plane in line with center of intermediate zone jets.)

The high velocity reactive mixture of the catalytic torch pushed into the central recirculation zone to create a stagnation point midway between the torch exit and the stagnation point further downstream created by the primary zone air jets. This torchinduced stagnation point appeared to be the anchoring point of the flame. The addition of more air through the primary zone jets did not appear to influence the primary zone flow field as much as did the addition of the catalytic torch air. However, the additional air through the primary zone jets did appear to reduce the corner recirculation zones and did increase velocities near the wall in the primary zone.

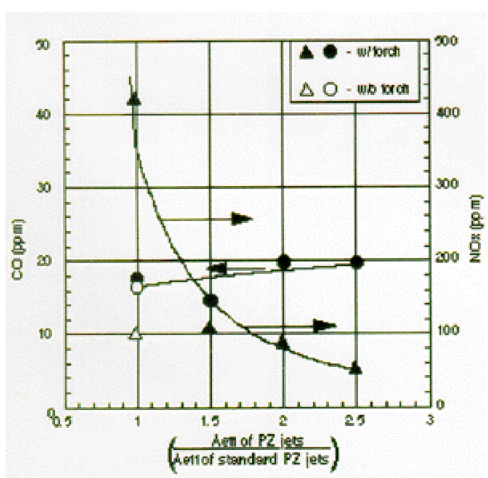
The temperature contour plots provided by the CFD analysis showed that with the addition of more air through the primary jets, the torch provides a tremendous improvement in combustor performance. The computational model showed that the additional air from the enlarged primary jets mixed with hot reactive gases from the torch to substantially increase the heat release rates in the primary zone. The flame zone is anchored by the enlarged stagnation zone where the primary jets impinge on each other and interact with the torch exit flow. Significant improvement in the mixing of hot gases is seen, which results in a dramatic flattening of the combustor exit temperature profile. This phenomenon can be directly attributed to the interaction between the torch and the additional primary zone air; cases run with the additional air and no torch were found to still have the hot core extending down the combustor.

Carbon monoxide (CO) and nitric oxide (NO) mass fraction distributions provided insight into the flame structure and extent of pollutant formation for each of the different combustor designs. The configuration with the catalytic torch and increased primary air flow provides earlier destruction of CO than in any other configuration. The model also predicted that this configuration substantially lowered CO and NOx emissions. The addition of the torch in the primary zone without adding more air increased NOx emissions, but increasing air through the primary zone jets pulled the majority of the heat release back into the primary zone, dropping NOx emissions below baseline combustor values. Tesner's simplified carbon formation model was used to predict the formation of soot/coke in the front end of the combustor. The results showed that the leaner primary zone with the torch is very effective at reducing soot concentrations in the primary zone.

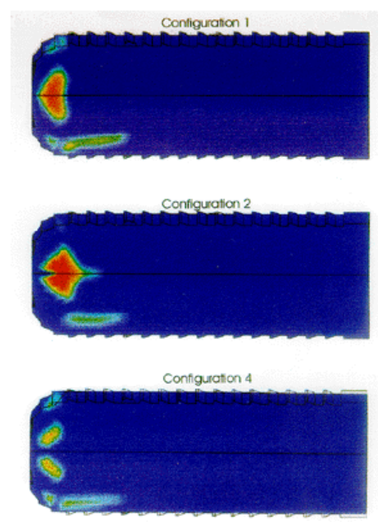
Evaluating the performance of the five different combustor designs using FLUENT took one person approximately one month and had an estimated cost of about $20,000. The cost of testing each of these configurations would have been about ten times as high and would have generated only a fraction of the useful information provided by the analysis. Once the analysis was completed, the design that was predicted to perform best was built and tested.



Fluent model results of CO mass fraction profiles for combustor configurations 1, 2 &4. (Top halves of plots are along axial plane in line with center of primary zone jets. Bottom halves are along axial plane in line with center of intermediate zone jets.)



Predicted mass-averaged CO and NOx emissions at the combustor exit for various primary zone jet areas (1 = standard orconfigurations 1&2) odification).



Fluent model results of soot concentrations (kg/m3) for combustor configurations 1, 2 &4. (Top halves of plots are along axial plane in line with center of primary zone jets. Bottom halves are along axial plane in line with center of intermediate zone jets.)

Experimental results matched the simulation very closely. Soot formation and NO emissions were substantially lower than in current engines. PCI engineers are now working on developing catalytic ignition solutions for a broad range of gas turbine and reciprocating engine applications.