HPC MODELING OF SUPERSONIC COMBUSTION **SHRINKS DESIGN CYCLE FOR PROPULSION SYSTEMS**

Using world-class HPC, Argonne researchers conduct high-fidelity simulations of sprays, chemically reacting flows and other physics within supersonic combustion chambers for faster evaluation of new designs at lower development costs.

SCRAMJET ENGINE DESIGN CHALLENGES

There are major challenges in designing scramjet engines for supersonic/hypersonic flight:

- Dynamics of fuel and oxidizer mixing over short time scales are not fully understood.
- Tools for modeling two-phase flows and combustion phenomena have only recently become fully predictive.
- Live testing is expensive, challenging and time-consuming.

THE ARGONNE ADVANTAGE

Argonne's expertise and success in using high-fidelity simulations to optimize design and performance in piston engines is being applied to gas turbine combustion and can be extended to supersonic/hypersonic applications.

Armed with some of the world's most powerful computing resources at the Argonne Leadership Computing Facility, the lab's renowned computational scientists are making breakthroughs that hold the promise of solving key challenges faced by developers in these areas.

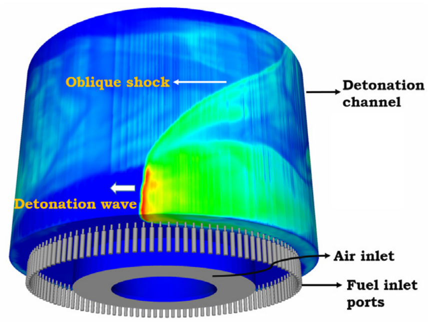
Predictive two-phase flow and combustion models developed at Argonne are used to aid the design process and significantly reduce the number of prototypes required during testing. These models are validated using Argonne's Advanced Photon Source, the brightest hard X-ray synchrotron in the Western Hemisphere, leading to faster and more efficient evaluation of new designs and lower development costs.

HYPERSONICS CAPABILITY

Argonne's role in the development and advancement of high-speed propulsion flight for national security is a world-class combination of **targeted domain expertise** in areas such as complex aerodynamics, propulsion, combustion, material science, modeling and simulation, and the **unique experimental and computational resources** of two DOE Office of Science national scientific user facilities: the Advanced Photon Source and the Argonne Leadership Computing Facility.

CASE STUDIES

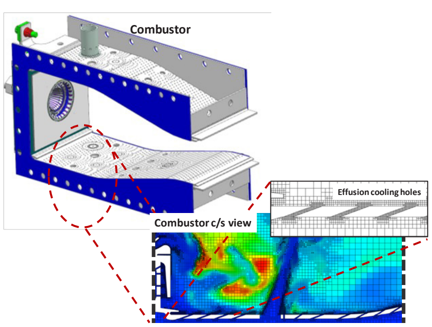
COMBUSTION DYNAMICS IN ROTATING DETONATION ENGINES



Temperature contours showing the detonation wave propagating within the RDE combustor in clockwise direction (when seen from top)

Argonne has simulated Rotating Detonation Engine (RDE) combustion using a realistic 3D geometry obtained from the **Air Force Research Laboratory**. While most of the RDE literature is based on premixed gaseous fuels, Argonne offers simulation capabilities for modeling non-premixed RDE, a technology that holds far more promise. Argonne's advances in turbulent combustion modeling, together with machine learning for design optimization can expedite the maturation of this technology for real-world aerospace applications.

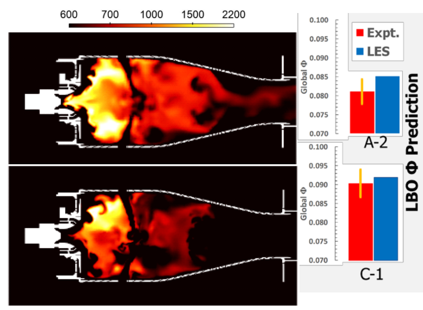
FLOW-SPLIT ANALYSIS OF A GAS TURBINE COMBUSTOR



This image shows a realistic 3D gas turbine combustor that was modeled using a Large Eddy Simulation model and detailed chemistry mechanisms at Argonne National Laboratory. The cross-sectional view shows the mid-plane of the combustor along with adaptive grids that were used to resolve the turbulent flow. The inset shows the grid resolution in the effusion cooling holes of the combustor. The simulations were used to assess the performance of alternative jet fuels in realistic combustors.

As part of the **National Jet Fuel Combustion Program**, Argonne developed an approach to capture complex flow paths, including those produced by effusion-cooling holes, without simplifying assumptions. The procedure is initially validated against standalone, single-hole experiments and then applied to a complex aviation combustor. The modeling approach shows excellent match against experimental data.

FUEL SENSITIVITY TO LEAN BLOWOFF



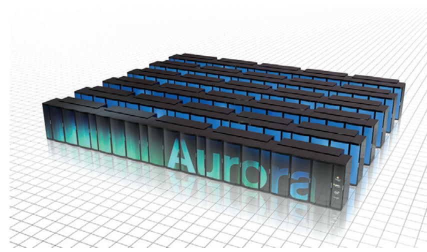
These images show the temperatures (K) predicted along the mid-plane of a realistic gas turbine combustor, during the lean blowout (LBO) process for the A-2 and C-1 jet fuels. The results were obtained from Large Eddy Simulations with a detailed chemistry mechanism. The model is able to closely predict the LBO trends for different fuels as seen in the experiments.

Argonne used experimental data from an **Air Force Research Laboratory** reference combustor to look at the characterization of conventional vs. alternative fuels as it relates to lean blowout and high-altitude relight for a wide range of operating conditions. As determining how to model such data has challenged gas turbine engine developers, Argonne adapted its expertise in internal combustion engines to tackle the problem. An advanced turbulent combustion modeling approach accurately captures the fuel sensitivity to lean blowout trends using different classes of chemical kinetic mechanisms. Researchers use these validated tools to effectively predict trends and optimize combustor designs.

Simulations for all the case studies were performed using the CONVERGE CFD software from Convergent Science Inc.

WORK WITH ARGONNE

With targeted expertise for addressing a wide range of combustion dynamics challenges and the innovative computational, simulation and visualization tools required to solve them, Argonne reduces time and costs in the design of advanced scramjet engines.



The Argonne Leadership Computing Facility offers world-class supercomputing resources and is the future home to Aurora, the nation's first exascale system.

Argonne's Advanced Photon Sources is one of the world's most powerful X-ray sources.

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