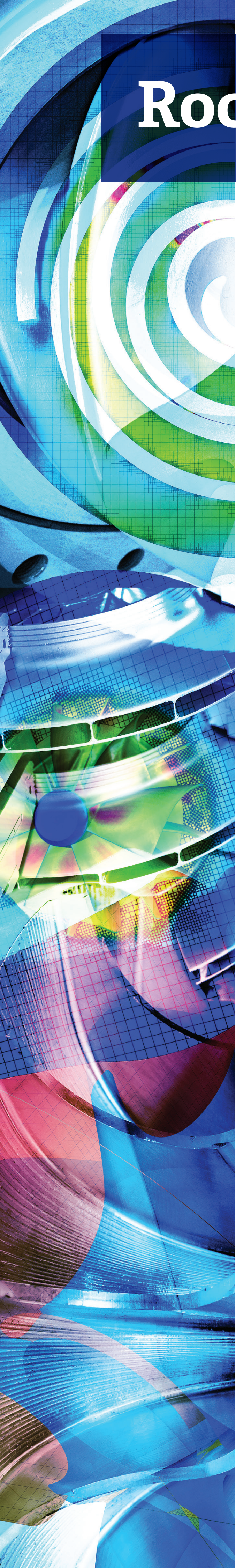


Rockets

Reach for the Stars: Rocket Science Made Simple

Since the mid-twentieth century, the quest to understand and traverse the universe has remained a driving force behind scientific innovation. However, the design and optimization of rockets presents significant challenges, such as the safe storage of the fuel and oxidizer, ignition and combustion control, shock interaction, and more. CONVERGE CFD software offers a suite of powerful tools to address these challenges, providing a virtual sandbox for testing different propulsion systems, optimizing engine designs, and predicting complex fluid dynamics during launch and flight. There are three main categories of rockets—liquid, solid, and hybrid—which differ by how the fuel and oxidizer are stored, transported, and mixed.

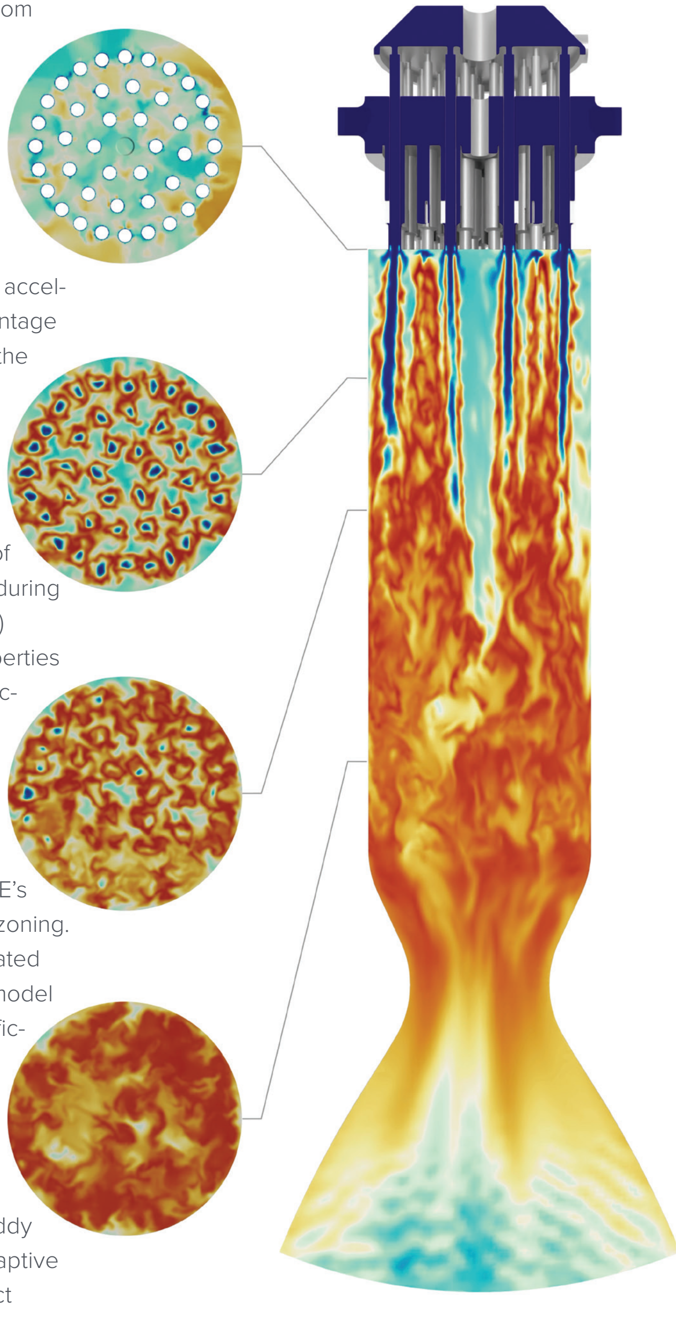
Diving Into Fluid Dynamics: Simulating Liquid Rockets

Liquid rockets supply liquid fuel and oxidizer from cryogenic storage to the combustion chamber where they are mixed and burned. These rockets typically have a higher specific impulse than solid rockets, which means they can generate more thrust per unit of propellant mass, resulting in higher efficiency. Additionally, the thrust of these rockets can be throttled, allowing for precise control of rocket acceleration and deceleration. The biggest disadvantage of liquid rockets is the need to accommodate the additional rocket auxiliary component mass, such as pumps, piping, and separate storage for the fuel and oxidizer.

One challenge of liquid rockets is the need to accurately model the effect of the vast range of temperatures and pressures that are realized during operation. CONVERGE's real-fluid model (RFM) generates a table of these important fluid properties based on real fluid vapor-liquid equilibrium calculations by considering the temperature, pressure, and species mass fractions.

Flame dynamics and the resulting combustion chamber pressures are important characteristics that can be captured through CONVERGE's SAGE detailed chemistry solver with adaptive zoning. CONVERGE also includes the Flamelet Generated Manifold (FGM) combustion model. The FGM model reduces the full chemistry to two scalars, significantly lowering computational cost.

Liquid rocket engines may experience thermoacoustic instabilities caused by dynamic coupling between unsteady heat release and acoustic perturbations. CONVERGE's large eddy simulation (LES) turbulence modeling and Adaptive Mesh Refinement (AMR) can effectively predict these instabilities.

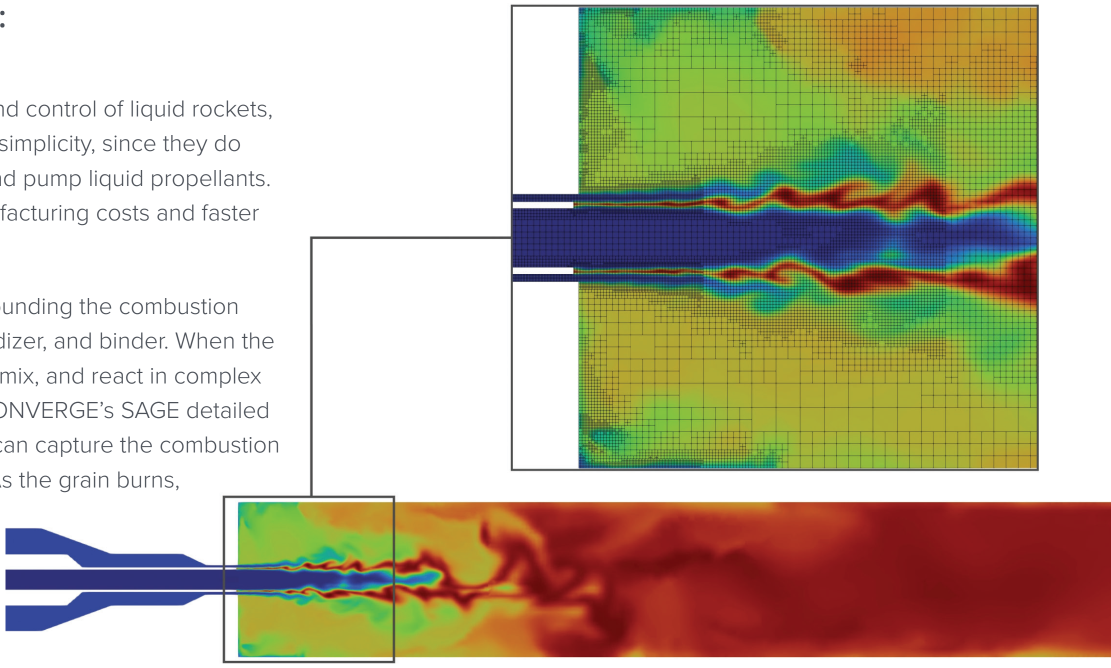


Supercritical H2-O2 BKD rocket combustor

Harnessing Propulsive Power: Simulating Solid Rockets

While solid rockets lack the flexibility and control of liquid rockets, the core asset of these rockets is their simplicity, since they do not require extra equipment to store and pump liquid propellants. This simplicity translates to lower manufacturing costs and faster production times.

Solid rockets feature a solid grain surrounding the combustion chamber made of a mixture of fuel, oxidizer, and binder. When the grain heats, the components vaporize, mix, and react in complex sublimation and ablation processes. CONVERGE's SAGE detailed chemistry solver with adaptive zoning can capture the combustion process and predict the burning rate. As the grain burns, it regresses toward the casing, exposing fresh propellant material for combustion. The moving geometry is accurately captured by CONVERGE's autonomous meshing, which regenerates a cut-cell mesh at each time-step.



Single-element PSU H2-O2 Research Combustor

Blending Power and Control: Simulating Hybrid Rockets

Hybrid rockets combine elements of liquid and solid rockets, featuring a solid fuel grain with a liquid or gaseous oxidizer. As the fuel burns and the grain surface regresses, the oxidizer flows over the fuel, causing a diffusion flame. CONVERGE can model this flame using the SAGE detailed chemistry solver or the FGM model with a diffusion flamelet. These features allow the solver to accurately predict the chamber and throat pressure in hybrid rocket engines.

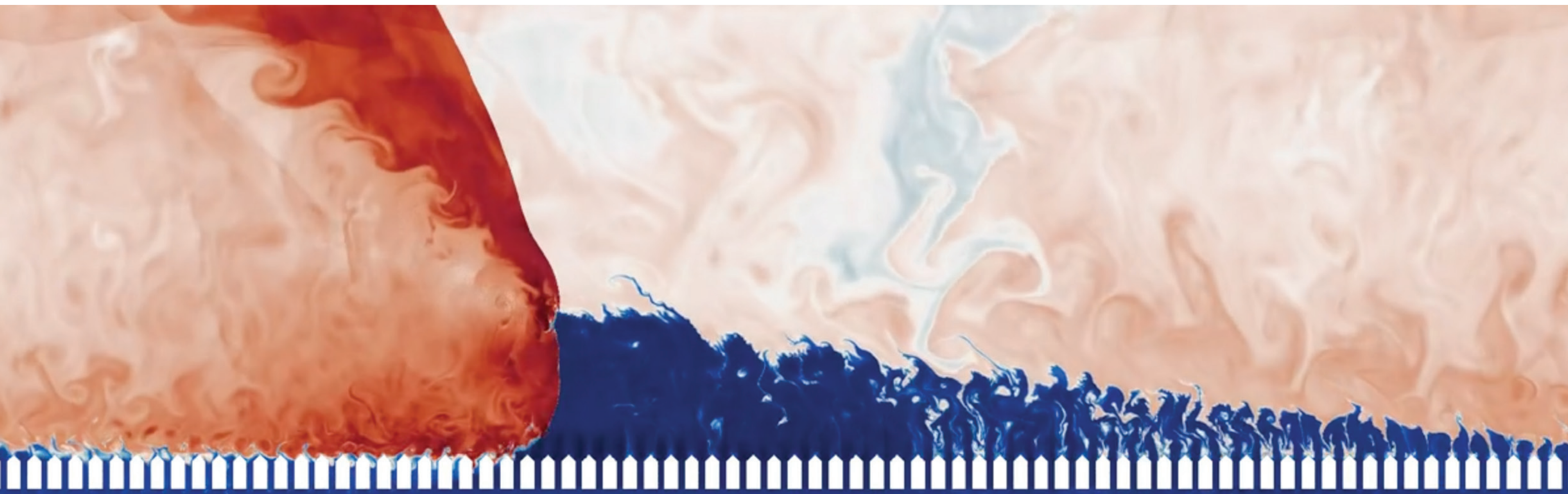
CONVERGE CFD SOFTWARE

Redefining Rocket Propulsion: Simulating Rotating Detonation Engines

Rotating detonation engines (RDEs) generate thrust via a traveling detonation wave, which can offer a substantial increase in efficiency with a decrease in emissions. In an RDE, the shockwave travels around a circular channel within the engine, producing continuous thrust. As such, RDEs are suitable for rocket propulsion since they can provide a steady source of thrust with higher thermal efficiencies than traditional rocket engines.

CONVERGE is a powerful tool when it comes to modeling RDEs, due to its detailed chemistry solver, turbulence models, and AMR, which can effectively capture velocity, temperature, and density gradients. The solver uses this information to predict key RDE parameters, including detonation wave frequency, wave height, oblique shock angle, and pressure.

Supersonic combustion in an unwrapped RDE



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