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Shock waves might offer the jolt needed to reach Mars

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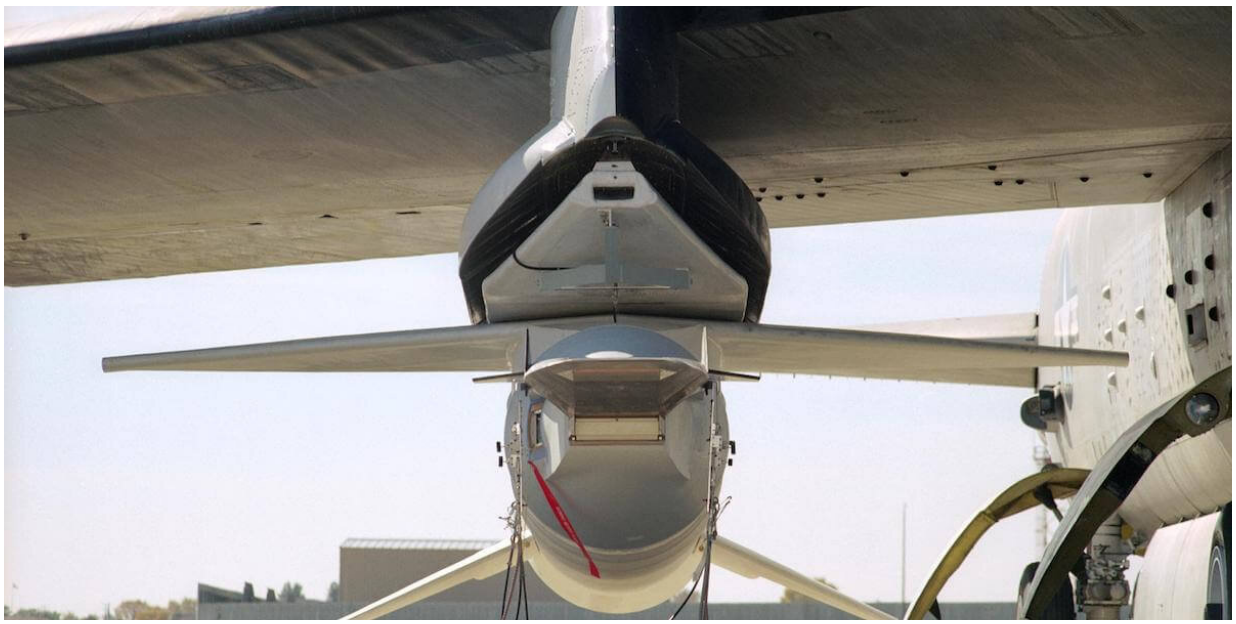

A scramjet–which features an engine that uses an engine's forward motion to compress incoming air, which flows at supersonic speeds. Credit: NASA, Tony Landis.

Applying shockwaves can improve conditions for fluid mixing in supersonic combustion engines, paving the way for flights at speeds five times faster than the speed of sound.

Ivan Bermejo-Moreno likes his coffee with a touch of turbulence. But instead of mixing coffee and cream with a spoon, when it comes to hypersonic jet planes—planes that can fly five times faster than sound—he likes to mix oxygen from the air and jet fuel using something a bit stronger: shock waves.

Similar principles govern fluid mixing in aircraft engines, where oxygen from the air has to mix with fuel to help propel it at a certain speed. USC researchers in the USC Viterbi Department of Aerospace and Mechanical Engineering, including Xiangyu Gao, a USC Viterbi Ph.D. student who recently defended his dissertation, and his doctoral advisor, Assistant Professor Ivan Bermejo-Moreno, are studying how to achieve efficient mixing at high speeds. Better mixing allows supersonic combustion engines—in which airflow is greater than the speed of sound—to remain shorter in length while enabling vehicles to move hypersonically. One approach to achieve this is to use shock waves.

A shockwave is characterized by an abrupt change in pressure, temperature and density of a medium and moves faster than the local speed of sound. "Without applying a shock wave, mixing will occur, as in the example with coffee and cream, but it will take much longer," Bermejo-Moreno said. "Shock waves amplify turbulence—similar to a spoon in the coffee example—and the more turbulence you have, the more rapidly mixing can occur."

The researchers recently published a study in the *Journal of Fluid Mechanics* , which shares conditions in which such rapid mixing—which supports faster, more efficient vehicles—can occur. Once a shock wave—a sudden and strong disturbance in a medium—is produced, the speed of the fluid passing through it will be drastically reduced, also allowing more time for mixing. This puts the fuel and air in a better condition for combustion, and will increase the temperature, making it easier to auto-ignite, the researchers said.

In conditions where mixing can be handled efficiently enough to support hypersonic vehicles, there are numerous implications, including commercial applications for the exploration of space.

Said Bermejo-Moreno: "Imagine instead of a rocket you have something lighter and smaller that could take us all the way to Mars. The combination of scramjets and rotating detonation engines, both based on shock waves and turbulence, may one day do just that."

The research team also includes Johan Larsson, associate professor of mechanical engineering at the University of Maryland. The researchers conducted this study performing massively parallel numerical simulations on the supercomputers at USC's High Performance Computing Center and at Argonne National Laboratory.

Fundamental Building Blocks of Flow

The study isolated the physics the researchers were interested in exploring by using a fundamental geometric set up—essentially a box—and removing variables related to surface friction on the nature of fluid or air flow. In the study, the flow would come in from one side of the box and encounter a shockwave created by carefully controlling the pressure inside of the box. Then it exits through the opposite side of the box, Bermejo-Moreno said.

"In this way, we isolated the interaction between turbulent flows and shockwaves," Bermejo-Moreno said. While people have studied the pure interaction of turbulence and shockwaves in the past, the researchers said only a few studies have focused on mixing in this configuration. Shockwaves are generated by the large (supersonic) speed of the air as it encounters air inlets, Bermejo-Moreno said. Geometric deflections, like corners, are usually enough to produce shock waves.

The researchers studied a greater range of parameters than in prior studies, as well, including variations in incoming speeds of air flow. The researchers also looked at different levels of turbulence.

"To visualize turbulence, consider a faucet," Bermejo-Moreno said. "When the faucet is barely on, the flow is slow, transparent and smooth—known as laminar. But as you keep opening the faucet up, the velocity of the water increases. The water stream becomes blurry and no longer transparent—it's what you would call turbulent. The same thing happens in the air and in mixtures of air and fuel we discuss in hypersonic vehicles."

The researchers said that they are most interested in turbulent flows, because they are most representative of what is actually happening in reality. Just like when you add milk to your coffee and do not stir it up, without a shock wave, which increases turbulence, mixing will occur but it will take much longer. In the study, the researchers found that while some quantities related to mixing levels will saturate after a certain amplification of turbulence, others will keep increasing, suggesting mixing continues to improve as turbulence increases.

Next the researchers hope to look at additional geometries and see how these impact mixing. "In the future, one of the elements we want to investigate is how different shapes of turbulent structures—known as eddies—impact mixing. For instance, how a tube-like structure might impact the transport and mixing of fuel and air differently than a sheet-like structure. "If you know the type of turbulent structures that are dominant in mixing, then you might want to produce more of these structures," Bermejo-Moreno said.

More information: Xiangyu Gao et al. Parametric numerical study of passive scalar mixing in shock turbulence interaction, *Journal of Fluid Mechanics* (2020). DOI: 10.1017/jfm.2020.292

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