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Detonation Initiators for Propulsion Systems

K. Kailasanath and C. Li
Laboratory for Computational Physics and Fluid Dynamics

Introduction: Detonations are an extremely efficient means of burning a fuel-air mixture and converting its chemical energy content into mechanical energy. Air-breathing and rocket engines based on pulsed detonations have the potential to provide the Navy with increased range and speed while reducing fuel consumption and system costs.[1] Over the past few years, we have conducted computational studies of the pulsed detonation engine concept. The results of these simulations have been invaluable in assessing the performance of these engines and isolating factors that may hinder the realization of their full potential. Reliable and repeated low-energy initiation of detonations in the high-speed flow of fuel-air mixtures is one of the challenging problems hindering the practical development of these engines.

Methods to Initiate Detonations: One of the approaches currently adopted is to use a more detonable fuel-oxygen mixture to initiate a detonation wave and then transition the detonation wave into the desired fuel-air mixture. However, for this approach to be practically feasible, additional oxygen must be carried or generated onboard, thereby increasing the weight and complexity of the propulsion system. Other techniques involving hot turbulent jets and radical species; physical obstacles to generate flow turbulence and enhance the transition from a flame to a detonation; and the use of geometrical devices to focus shock waves have also been investigated.[1] We have used our fundamental studies of detonation initiation to develop an innovative initiator concept that does not require any additional oxygen or geometrical obstacles for initiating detonations in fuel-air mixtures.[2] In this concept, shown schematically in Fig. 4, air is introduced along the circumference of a tube in the form of an annular jet. The high temperatures and pressures generated by the implosion of the shock waves generated by these impulsive jets are sufficient to ignite most fuel-air mixtures of practical interest.

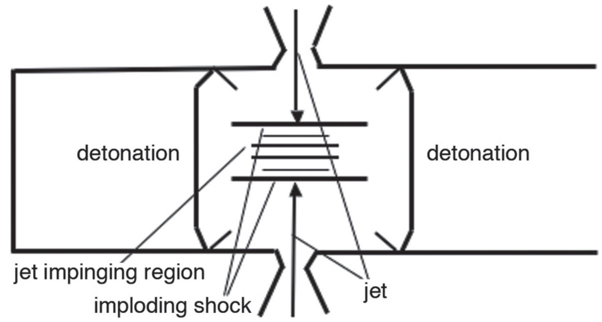

FIGURE 4
Schematic of the new detonation initiation concept involving jet-induced imploding shocks.

Concept Validation using Numerical Simulations: We have extensively validated the detonation initiation concept using multidimensional, time-accurate numerical simulations based on the Flux-Corrected Transport (FCT) algorithm and the Virtual-Cell Embedding (VCE) technique developed at NRL. Figure 5 shows results from a typical simulation. Both pressure and water concentration (typical product of combustion) are shown at a sequence of times. The jet impinges onto itself near the tube centerline around 112 μs and a high-temperature-pressure kernel begins to form. However, there is no water production until 140 μs. At 140 μs, a high-temperature-pressure kernel of elliptical shape is observed. At the edge of the kernel, the pressure is very high and a detonation front begins to form. At 160 μs, the kernel expands and the pressure at the edge of the kernel reduces somewhat to a level corresponding to a slightly overdriven detonation in the chosen mixture. At 178 μs, the kernel further expands. However, at this time, the detonation is observed only at either end of the kernel, and two detonation fronts propagate mainly along the longitudinal direction of the tube toward the tube ends. The part of the detonation front on the side of the kernel is quenched by the air brought in by the jet and becomes a nonreactive shock. Beyond 178 μs, the jet air is entrained and mixed with the combustion products from the detonation process, reducing the water concentration level around the side of the kernel. At 195 μs, the detonation fronts at the two ends of the kernel reach the sidewall of the tube. From this time on, the two detonation fronts further propagate in opposite directions, consuming the combustible material along their way to the tube ends. At 229 μs, reflected shocks from the sidewall can be observed, which further raise the pressure. These reflected shocks might serve as an additional initiation source at marginal conditions where the original annular jet-induced cylindrically imploding shock is not strong enough to initiate detonation directly. After about 230 μs, both detonation fronts are fully established.

Further simulations show that the concept is robust. Depending on the jet parameters, detonation

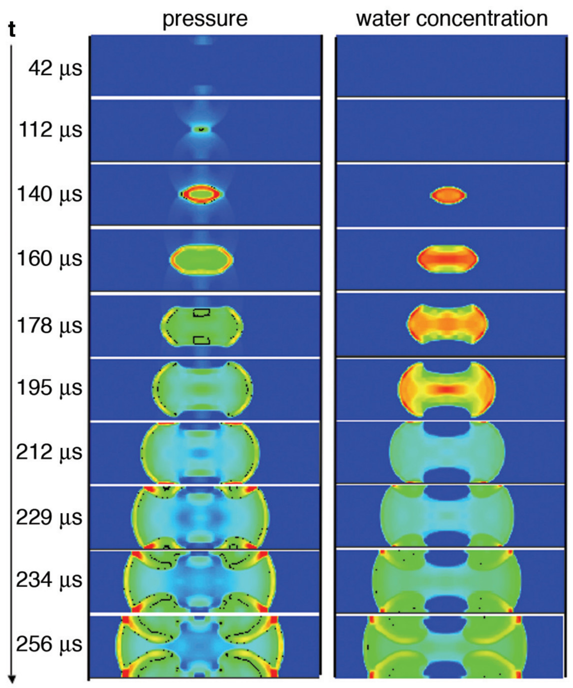

FIGURE 5
Series of snapshots showing the time evolution of the pressure and water concentration distributions during the detonation initiation process.

initiation may occur from the implosion of the initial shocks or after subsequent reflections of these shocks from the walls of the confining chamber.

Conclusions: We have developed a method for initiating detonations using annular jet-induced cylindrically imploding shocks. Our numerical simulations have shown that detonation can be initiated by a single, annular jet at modest jet pressures and temperatures that can be readily provided by practical engineering means. The jet material can be the same fuel used in the engine or air, which is particularly beneficial for air-breathing propulsion applications.

[Sponsored by ONR]

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[1] K. Kailasanath, "Recent Developments in the Research on Pulse Detonation Engines," *AIAA J.* **41**, 1698-1708 (2003).
[2] C. Li and K. Kailasanath, "Detonation Initiation by Annular Jet-Induced Imploding Shocks," accepted for publication, *J. Propul. Power*, September 2004.