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How does supergravity affect combustion?

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It is well known that gravity may have a profound impact on the combustion process under certain conditions [1]. The densities of the gaseous combustion products are typically 5-12 times lower than those of reactants. Under normal gravity conditions, the density difference generates buoyant forces that drive the flow, which affects the combustion process through flow-transport-chemistry interaction. For example, the buoyant convection in normal gravity causes the candle flame to be shaped like a teardrop while spherical candle flame is observed in microgravity. Recently, microgravity combustion has drawn great attention. A series of combustion experiments have been and will be conducted in the International Space Station and Chinese Space Station. In fact, significant progress has been made in microgravity combustion. For example, the discovery of steadily burning cool flames [2] in microgravity experiments was regarded as one of the "20 Breakthroughs from 20 Years of Science aboard the International Space Station".

On the other hand, supergravity may have a much stronger effect on the combustion process than normal gravity. Supergravity, which refers to a state of gravitational force significantly greater than the Earth's normal gravity, may occur in the context of space exploration. For example, Jupiter, the largest planet in our solar system, has a gravitational force about 2.5 times stronger than Earth's. Besides, supergravity also appears during the sudden acceleration or deceleration when a spacecraft exits or enters the atmosphere of a gas giant. However, in literature, there is little work on supergravity combustion. There is an urgent need to study supergravity combustion due to its potential to enhance our understanding of fundamental physical processes and contribute to advancements in propulsion systems.

Liang and Law [3] assessed the effects of supergravity on the propagation and structure of premixed hydrogen/air flames. They conducted transient simulations considering detailed chemistry and transport for the one-dimensional planar and spherical flames. Employing such simple flame configurations can avoid flame instabilities and thereby help to identify the supergravity influence on flow, flame propagation, and flame structure. Moreover, the use of simple flame configurations can serve as a starting point for more complex simulations. Liang and Law [3] found that the direction of gravity relative to the flame propagation has a profound impact on the flame's behavior. When gravity acts in the same direction as the flame propagation, it causes the flame to accelerate, whereas it decelerates the flame when acting in the opposite direction. This effect becomes particularly pronounced at high gravity levels, leading to substantial modifications in the flame propagation and structure. They observed that the flame's absolute propagation speed, which is influenced by the local induced flow field, is more significantly affected by gravity than the relative flame speeds.

In order to explain this observation, Liang and Law [3] further examined the gravity effects on the flame's thermal and chemical structures at different equivalence ratios, pressures, and flame stretches. They found that supergravity induces intensive flow which compresses or expands the flame structure and thereby affects the reactivity and temperature at the flame front. The temperature profiles under negative gravity levels are similar to those for stratified flames in which there is extra heat flux from the products to the reaction zone, resulting in combustion enhancement [4].

In the literature, there are only a few studies [5-7] on flame behavior at elevated gravity (higher than Earth's gravity). Liang and Law [3] showed that a very high gravity level exerts a profound influence on flame behavior. Despite its limitations, such as the use of simplified flame configurations, the study of Liang and Law [3] offers valuable insights into the complex interplay between supergravity and flame dynamics. It serves as the first step for further exploration of the various effects of supergravity on flame dynamics and combustion chemistry. In future works, it would be interesting to take into account more practical flame configures

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and near-limit combustion processes such as ignition and extinction. Additional studies would be also of great interest on the influence of supergravity on cool flames which are much weaker than hot flames. In the long term, it would be interesting to assess the supergravity effects on turbulent combustion under engine-relevant conditions.

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