

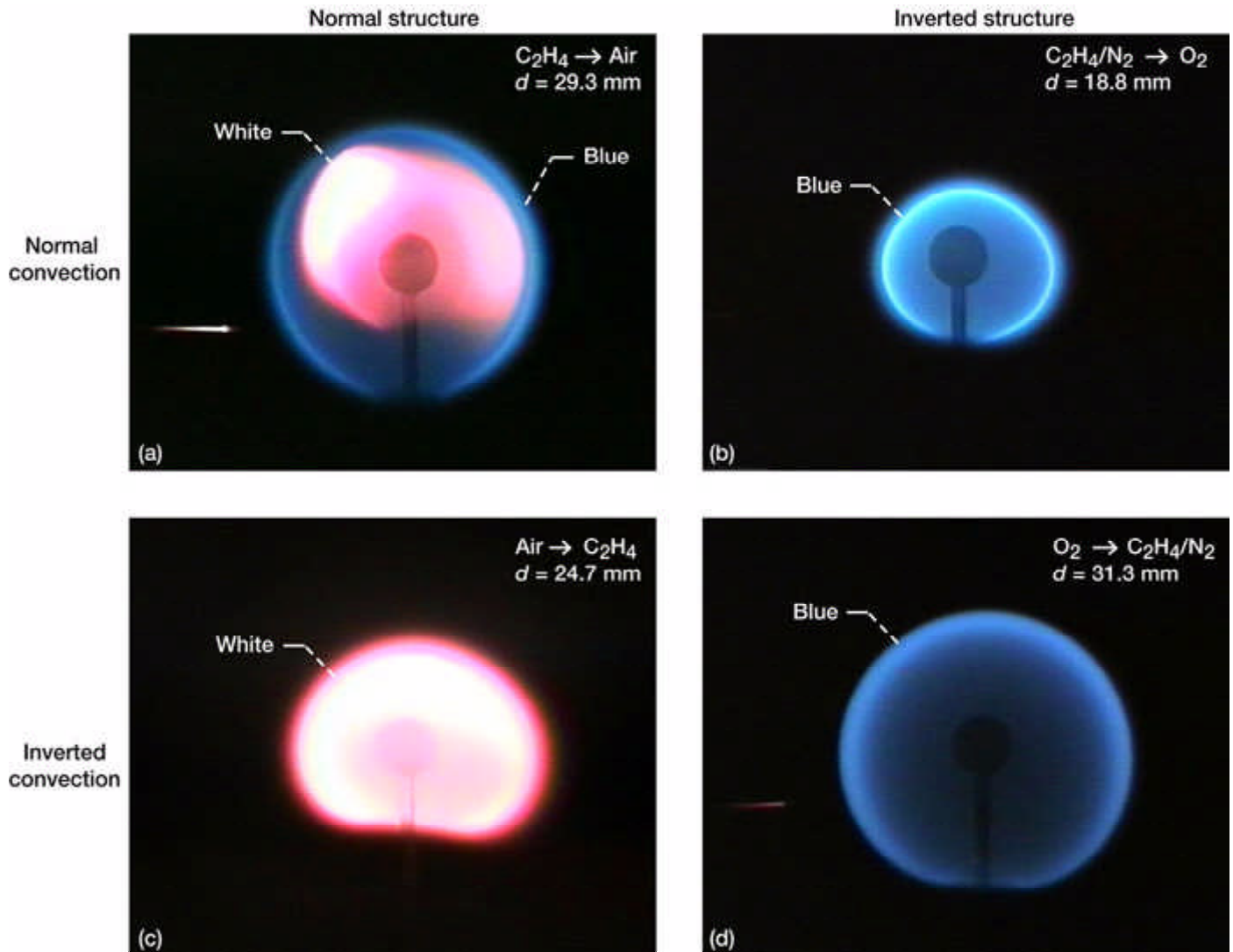
Flame Design—A Novel Approach Developed to Produce Clean, Efficient Diffusion Flames

Soot formation and flame extinction are vital concerns in the combustion of fossil fuels. In particular, soot is responsible for pollutant emissions, and extinction can cause inefficient or unstable burning. Normal-gravity experiments have demonstrated that flames can be designed to improve both characteristics by redirecting some or all of the nitrogen from the oxidizer into the fuel. Such nitrogen exchange can produce permanently blue flames, which are soot free under all possible flame conditions. Furthermore, this approach can lead to stronger, extinction-resistant flames.

Past investigations of nitrogen exchange were unable to identify the physical mechanisms responsible for its benefits because these mechanisms cannot be isolated when normal-gravity flames are studied. In contrast, the Diffusion Flame Extinction and Soot Inception (DESI) experiment considers spherical flames, where nearly perfect spherical symmetry affords new levels of control. Because of buoyancy, spherical flames cannot be created in Earth's gravity.

DESI was conceived by principal investigator Professor R.L. Axelbaum of Washington University in St. Louis. Tests to date have utilized the 2.2-Second Drop Tower at the NASA Glenn Research Center at Lewis Field. The experiment is slated for testing aboard the International Space Station in a few years.

Two mechanisms have been proposed to explain the connection between nitrogen exchange and permanently blue flames. These are the structure (chemical effects) and hydrodynamics (flow direction and speed). In normal-gravity flames, the structure and hydrodynamics are coupled, since nitrogen exchange simultaneously modifies both. Spherical microgravity flames, on the other hand, allow independent control of these factors. Specifically, structure can be modified via nitrogen exchange, and flow direction can be reversed by swapping the ambient and burner-feed gases. In DESI, these variations can be accomplished without changing the theoretical flame temperature.



Images of four representative flames. (a) Ethylene (C_2H_4) burning in air; diameter 29.3 mm. (b) Diluted ethylene (C_2H_4/N_2) burning in oxygen; diameter, 18.8 mm. (c) Air issuing into ethylene (C_2H_4); diameter, 24.7 mm. (d) Oxygen issuing into diluted ethylene (C_2H_4/N_2); diameter, 31.3 mm. The scale is revealed by the 6.4-mm spherical burner.

Images of four flames observed in the 2.2-Second Drop Tower are shown here. The flames surround the burner (barely visible), which is a 6-mm porous steel sphere to which gas is supplied through a 2-mm tube. As is typical for hydrocarbon-fueled flames, yellow regions indicate the presence of glowing soot, and the reaction zones are bright blue. These four flames burn ethylene (C_2H_4) at a rate of 1.5 mg/sec in a still ambient at a pressure of 1 atm. Several salient features of these flames are summarized in the table. In these flames, structure has a defining influence on soot production, with soot suppressed entirely when nitrogen is supplied with the fuel. Convection direction has a smaller influence, suppressing soot when convection is directed toward the oxidizer. These observations contribute significantly to the understanding of permanently blue diffusion flames.

SUMMARY OF THE FOUR REPRESENTATIVE FLAMES			
Flame	Structure	Flow direction	Soot
(a)	Normal	Normal	Present
(b)	Inverted	Normal	Absent
(c)	Normal	Inverted	Present
(d)	Inverted	Inverted	Absent

Because of the inherent transient nature of 2-sec tests, preparations are underway to repeat these tests in Glenn's 5-sec facility. Nevertheless, burn times of 2 min will ultimately be required to obtain steady flames and limit conditions. Thus, if approved, DESI will be conducted aboard the International Space Station. We envision that such tests will yield fully steady flames and will measure sooting and extinction limits, temperatures, soot concentrations and morphology, and radiative emissions. The tests will continue to exploit a class of flames that cannot be observed in Earth's gravity.

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