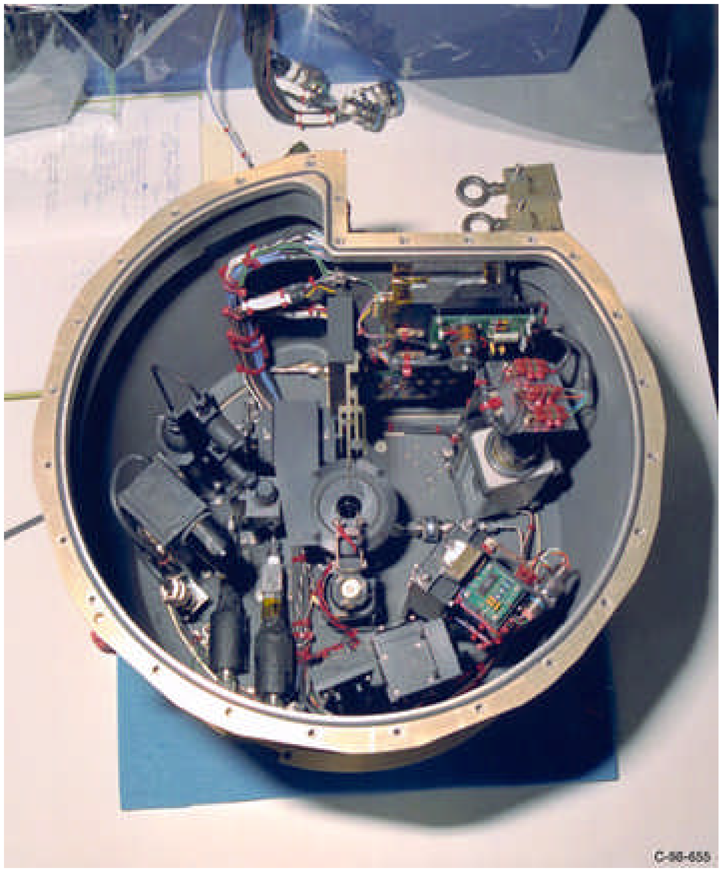
Unlocking the Keys to Vortex/Flame Interactions in Turbulent Gas-Jet Diffusion Flames--Dynamic Behavior Explored on the Space Shuttle

Most combustion processes in industrial applications (e.g., furnaces and engines) and in nature (e.g., forest fires) are turbulent. A better understanding of turbulent combustion could lead to improved combustor design, with enhanced efficiency and reduced emissions. Despite its importance, turbulent combustion is poorly understood because of its complexity. The rapidly changing and random behavior of such flames currently prevents detailed analysis, whether experimentally or computationally. However, it is possible to learn about the fundamental behavior of turbulent flames by exploring the controlled interaction of steady laminar flames and artificially induced flow vortices. These interactions are an inherent part of turbulent flames, and understanding them is essential to the characterization of turbulent combustion. Well-controlled and defined experiments of vortex interaction with laminar flames are not possible in normal gravity because of the interference of buoyancy- (i.e., gravity) induced vortices. Therefore, a joint microgravity study was established by researchers from the Science and Technology Development Corp. and the NASA Lewis Research Center. The experimental study culminated in the conduct of the Turbulent Gas-Jet Diffusion Flames (TGDF) Experiment on the STS-87 space shuttle mission in November 1997. The fully automated hardware, shown in photo, was designed and built at Lewis. During the mission, the experiment was housed in a Get Away Special (GAS) canister in the cargo bay.



Interior of the TGDF combustion chamber, with the innovative vortex generation mechanism visible in the center.

In the TGDF experiment, toroidal flow vortices were generated by sinusoidally varying the open diameter of an iris around the base of a propane flame, thereby causing large-scale fluctuations in the entrained airflow. The iris frequency, which was varied to be 1.5, 3.0, and 5.0 Hz, was the experiment’s key variable. TGDF's primary objective was to gain an understanding of the dynamic behavior of the vortex/flame interaction, including possible vortex breakup or merging, and the interaction’s effect on the time-averaged values of flame temperature, radiation, and shape. In addition, the experiment has provided insights into the development and extinction of microgravity flames. The experimental results were compared with a comprehensive numerical model of the pulsed flame to validate the accuracy of the model and verify our understanding of the flame behavior.

Analysis of the results revealed that the microgravity flame possesses three axially spaced zones of vortex interaction. In the lower portion of the flame, there is a significant transfer of energy from the mean field to the oscillations. In the numerical simulation, the vortex dissipation rate and the kinetic energy of the oscillations both peak in the lower part of the flame. In the central region, the energy transfer is from the primary oscillation to its harmonic and/or the mean field. In the upper portion of the flame, the oscillations decay, and there is no significant transfer of energy between the oscillations and the mean flow, or between oscillations. In contrast, the oscillations grow in the upper portion of buoyant normal-gravity flames. Radiation measurements also indicate that the core of the upper zone receives energy from the flame and the mean flow at the flame base. Thus, the temperature (and combustion) in the upper zone is enhanced by the vortex interaction. This has been confirmed by numerical computation and is in agreement with observations of pulsation-induced flame-tip closure in supporting ground-based studies of microgravity flames. Further analysis is underway, and a TGDF reflight proposal, based on the successful STS-87 results, will be submitted.

Find out more about the Turbulent Gas-Jet Diffusion Flames (TGDF) Experiment.
http://exploration.grc.nasa.gov/expr2/gjdfe.htm

Lewis contact: Dennis P. Stocker, (216) 433-2166, Dennis.P.Stocker@grc.nasa.gov
Author: Dennis P. Stocker
Headquarters program office: OLMSA
Programs/Projects: HEDS, Microgravity Science, STS-87, GAS, TGDF