

SUPPRESSION OF LOW STRAIN RATE NONPREMIXED FLAMES BY AN AGENT*

A. Hamins, M. Bundy, C.B. Oh, and J. Park
The National Institute of Standards and Technology
Building and Fire Research Laboratory
Gaithersburg, MD 20899-8663

I.K. Puri
Department of Mechanical Engineering
University of Illinois at Chicago
Chicago, IL 60607-7022

The extinction and structure of non-premixed methane/air flames were investigated in normal gravity and microgravity through the comparison of experiments and calculations using a counterflow configuration. From a fire safety perspective, low strain rate conditions are important for several reasons. In normal gravity, many fires start from small ignition sources where the convective flow and strain rates are weak. Fires in microgravity conditions, such as a manned spacecraft, may also occur in near quiescent conditions where strain rates are very low. When designing a fire suppression system, worst-case conditions should be considered. Most diffusion flames become more robust as the strain rate is decreased. The goal of this project is to investigate the extinction limits of non-premixed flames using various agents and to compare reduced gravity and normal gravity conditions.

Experiments at the NASA Glenn Research Center's 2.2-second drop tower were conducted to attain extinction and temperature measurements in low-strain non-premixed flames. Extinction measurements using nitrogen added to the fuel stream were performed for global strain rates from 7 s^{-1} to 50 s^{-1} . The results confirmed the "turning point" behavior observed previously by Maruta et al. in a 10 s drop tower. The maximum nitrogen volume fraction in the fuel stream needed to assure extinction for all strain rates was measured to be 0.855 ± 0.016 , associated with the turning point determined to occur at a strain rate of 15 s^{-1} . The critical nitrogen volume fraction in the fuel stream needed for extinction of 0-g flames was measured to be higher than that of 1-g flames.

Flame temperature measurements were attained in the high temperature region of the flame ($T > 1200 \text{ K}$) using visible emission from a $(12.5 \pm 0.5) \mu\text{m}$ filament positioned axially along the burner centerline. This method was used to obtain the time varying temperatures as the flame transitioned to microgravity conditions and as the flame extinguished. Temperature measurements showed that a peak flame temperature of approximately $1400 (\pm 100) \text{ K}$ for a global strain rate of 20 s^{-1} for conditions when the flame was very near extinction (99% of the required nitrogen volume fraction for extinction in microgravity). The measured flame temperature profiles were a function of the strain rate, the concentration of N_2 and the presence of buoyancy forces. The lower the global strain rate, the greater the changes in the flame as it transitioned from 1-G to μ -G.

A two-dimensional flame simulation using a three step chemical mechanism was developed here and compared favorably to the extinction and temperature measurements in both normal and microgravity. One-dimensional flame computations using OPDIFF could not predict the flame shape or the extinction limits accurately at *low strain rates* in 0-G or 1-G due to multi-dimensional heat loss and the effects of buoyancy. The two-dimensional model (see Figure below) showed that at low strain rates, the 1-G flame extinguishes from the outer flame edge inwards towards the central axis, whereas the 0-G flame

extinguishes from the centerline out. Differences in the details of 0-G and 1-G flame structure are important in interpreting the results of the microgravity extinction experiments.

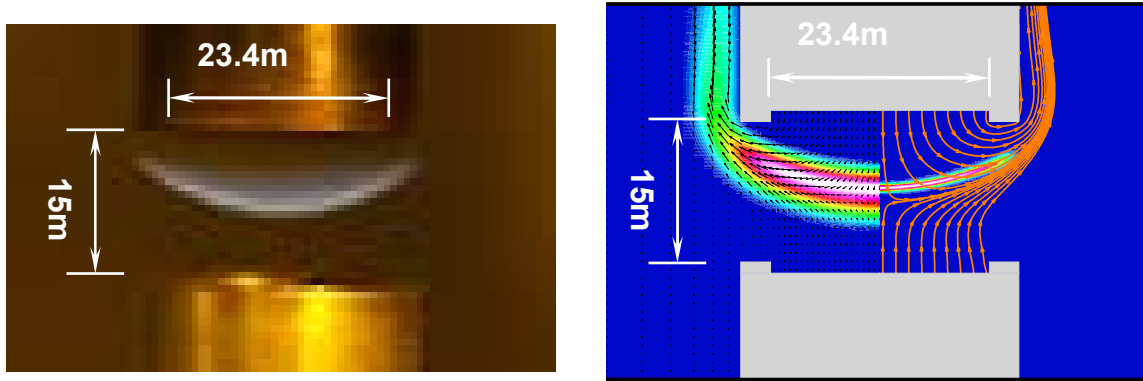


Figure 1. Comparison of photograph and simulation of a near-extinction counterflow diffusion flame at a strain rate of 20 s^{-1} in 1-G with the fuel stream composed of 79 % N_2 and 21 % CH_4 flowing from the bottom duct. The right hand side of the simulation shows the calculated heat release rate and streamlines and the left hand side shows the calculated temperature and velocity contours.

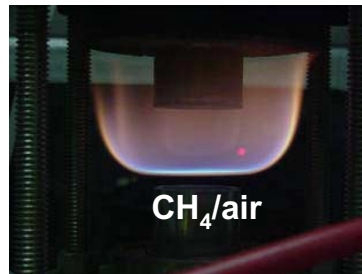
Suppression of Low Strain Rate Nonpremixed Flames by an Agent

A.Hamins, M.Bundy, C.B. Oh, J.Park

National Institute of Standards and Technology, Gaithersburg, MD

I.K. Puri

Dept. Mechanical Engineering, University of Illinois at Chicago, Chicago, IL



Supported by the NASA Microgravity Combustion Research Program;
Dr. Sandra L. Olson, Technical Monitor.

NIST

National Institute of Standards and Technology

Technology Administration, U.S. Department of Commerce



Motivation

- unwanted fires are typically non-premixed
- low strain rate flame conditions prevail for a fire on a space platform

Objective

Investigate the structure and suppression limits of low strain rate non-premixed flames.

Experimental Variables

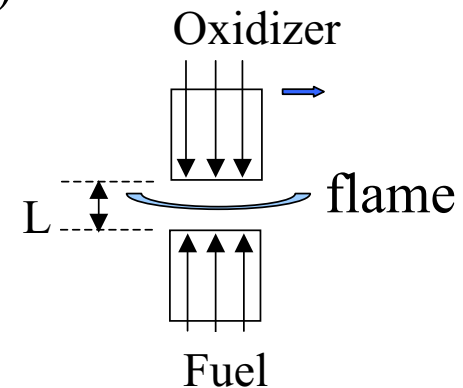
suppressant type: N_2 , CO_2 , CF_3Br

configuration (suppressant in fuel or air stream)

buoyancy (1-g and μ -g)

global strain rate

air/fuel velocity ratio



counterflow configuration

Approach: numerical

- 1D *Oppdif* simulations of 0-g flame structure and suppression
- 2D simulations of 0-g and 1-g flame structure and suppression

1D Model: Oppdif

detailed chemistry & transport

no buoyancy term

optically thin radiation model

predicts extinction

2D Model *

3 step global reaction

buoyancy term

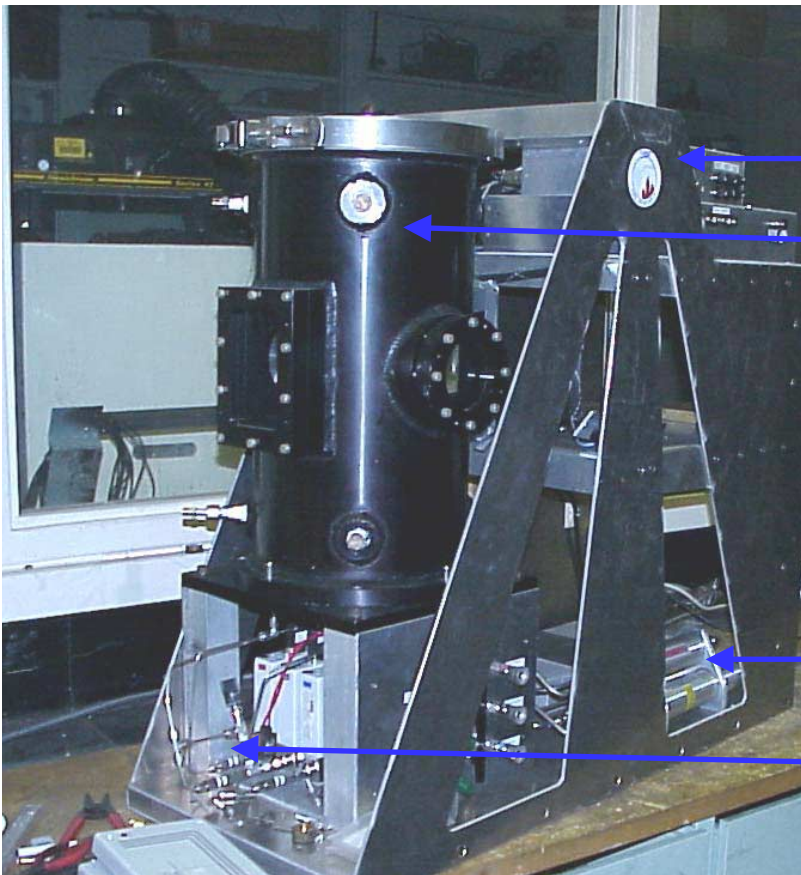
optically thin radiation

predicts extinction

* C.B. Oh, C.E. Lee and J. Park, “Numerical Investigation of Extinction in a Counterflow Nonpremixed Flame Perturbed by a Vortex”, *Combust. Flame*, 2004, to appear.

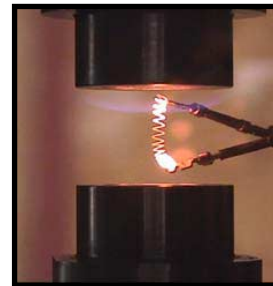
Approach: experimental

- 2.2 s drop tower experiments
- measurements of flame temperature & critical agent requirements
- comparison of simulations and measurements



electronics/on-board computer

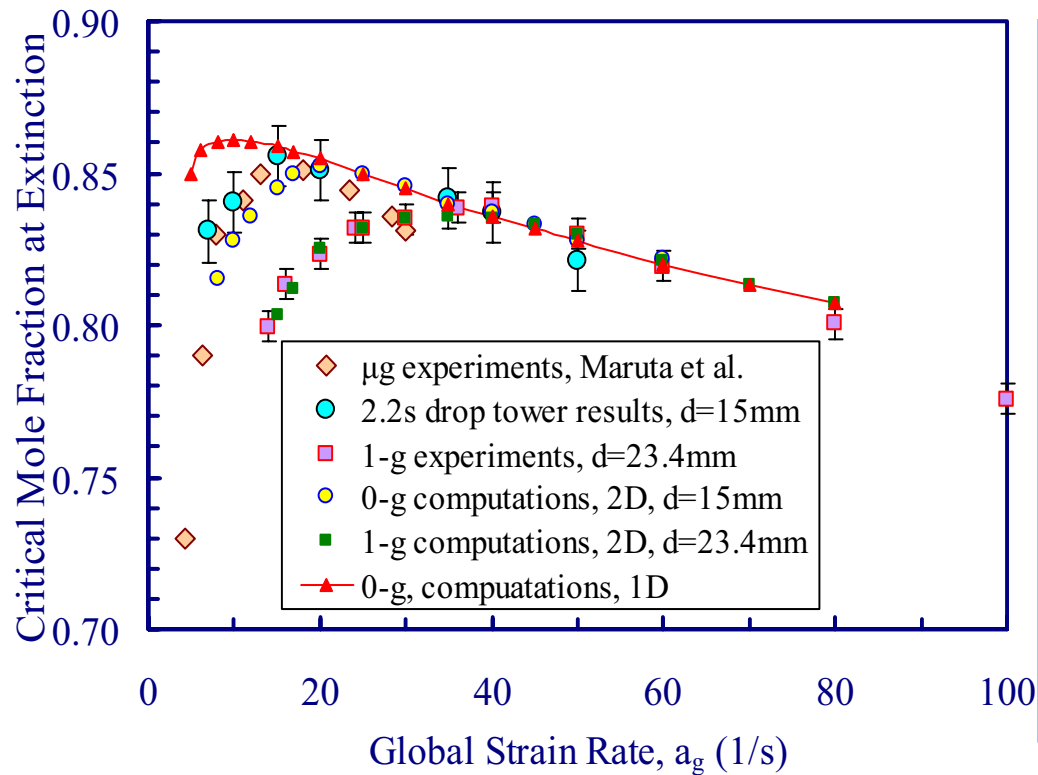
combustion chamber



burner & retractable igniter

gas cylinders
pressure flow controllers/
critical flow orifices

Flame Extinction Limits in 0-g and 1-g Agent (N₂) added to Fuel (CH₄) Stream

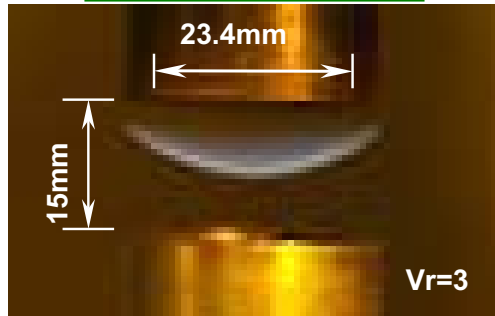


- New extinction measurements agree with Maruta et al, 1998.
- 2D model results agree with 0-g and 1-g measurements.
- 0-g flames are more robust than 1g flames at low strain.
- Multi-dimensional effects exist at low strain rate, which effects extinction limit.

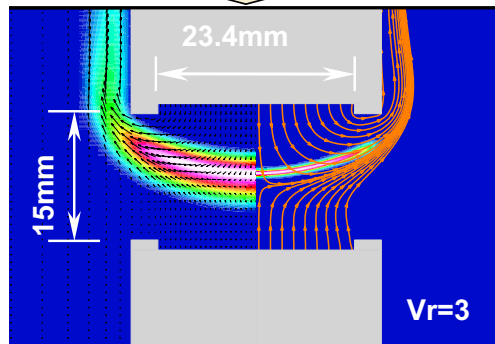
$$a_g = \frac{2|u_O|}{L} \left(1 + \frac{|u_F| \sqrt{\rho_F}}{|u_O| \sqrt{\rho_O}} \right)$$

1-g Flame Shape and Temperature Profile

Experiment

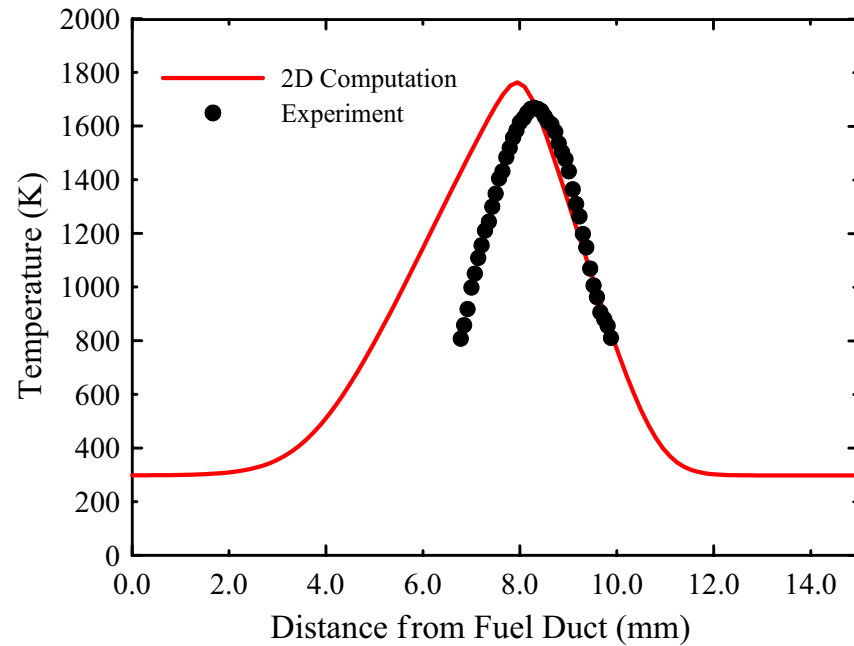


$a_g = 20$ (1/s)



Computation

Fuel \rightarrow CH₄:N₂ = 21:79 by volume
 $a_g = 20$ (1/s), $V_r = 3$

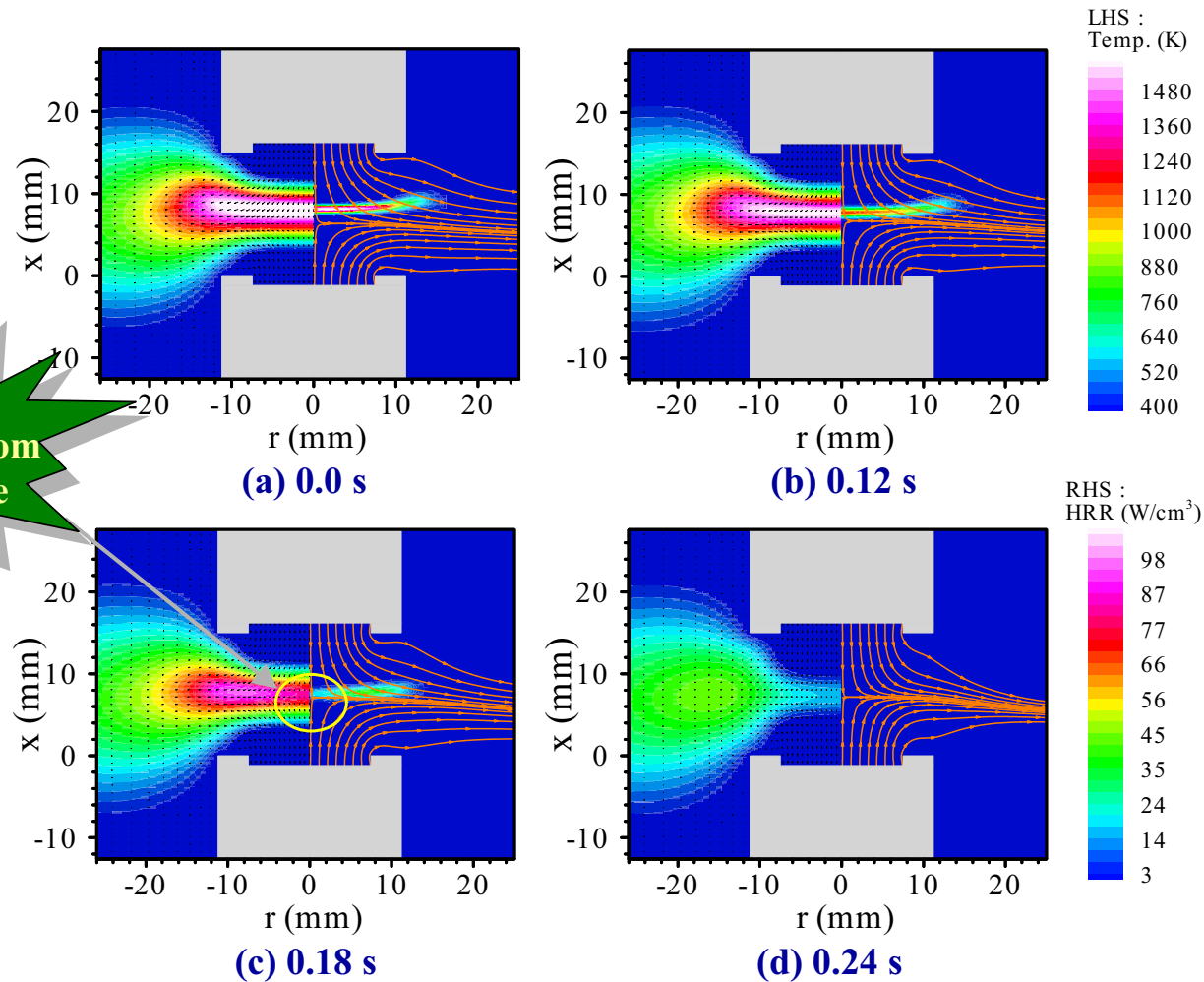


Comparison of Centerline Temperature

LHS : Temperature and Velocity Vector
 RHS : Heat Release Rate and Stream Line

Extinction Process in 0-g Flame; $a_g=20$ (1/s)

Nitrogen fuel stream volume fraction increasing from 0.79 \rightarrow 0.855

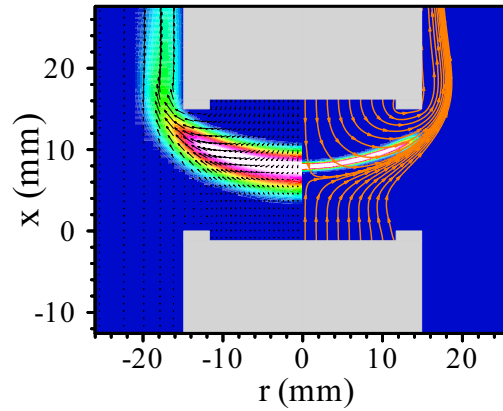
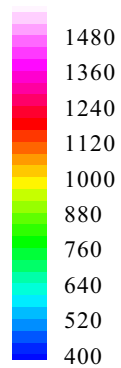


Extinguishes from
the Centerline

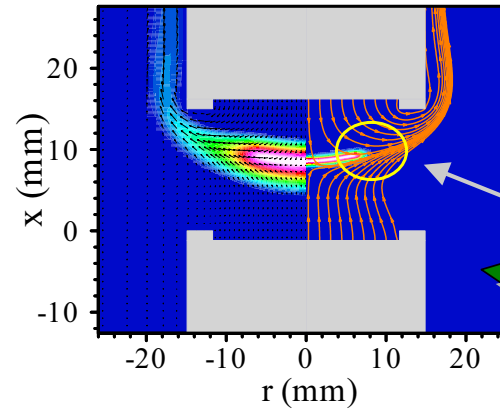
Extinction Process in 1-g Flame; $a_g=20$ (1/s)

Nitrogen fuel stream volume fraction increasing from 0.79 \rightarrow 0.825

LHS :
Temp. (K)



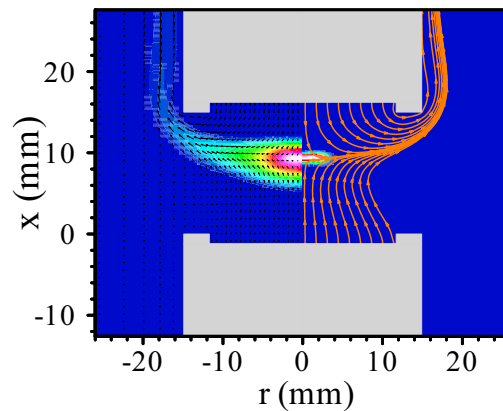
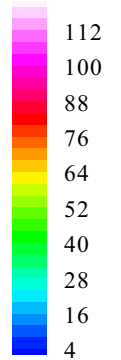
(a) 0.0 s



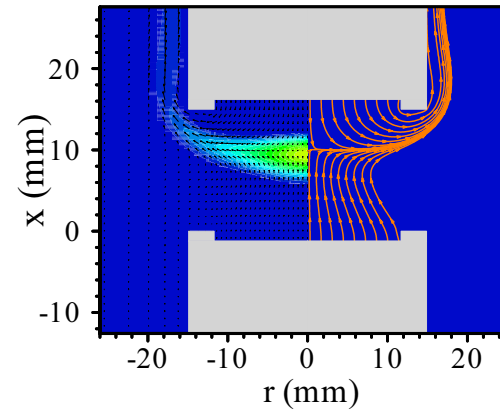
(b) 0.30 s

**Extinguishes from
the Outer
Edge**

RHS :
HRR (W/cm^3)



(c) 0.34 s



(d) 0.35 s

Conclusions

- 2D computations of 0-g and 1-g flames are in good agreement with experimental results.
- At low strain rate, 1g flame extinguishes from the outer flame edge, while 0g flame extinguishes from the centerline.
- 1D computations cannot predict the flame shape and extinction limit reasonably at low strain rates due to multi-dimensional heat loss.
- New extinction measurements in 2.2 s reported here are in good agreement with 10 s JAMIC results (Maruta et al, 1998).
- Critical nitrogen volume fraction in the fuel stream needed for extinction of 0-g flames is higher than that of 1-g flames.