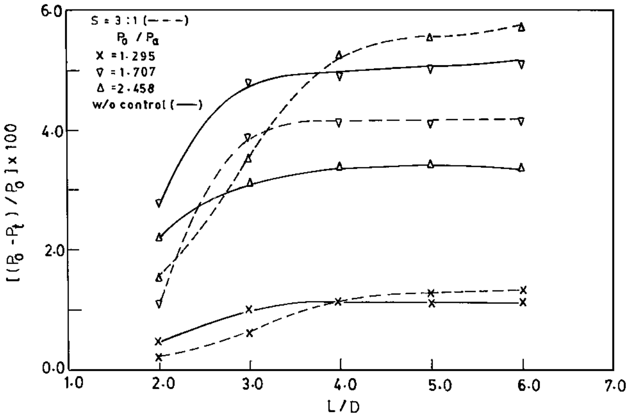

Fig. 4 Pressure loss vs duct *L/D*.

pressure reaches nearly atmospheric pressure is strongly influenced by the rib height. A decrease in the rib height makes this point shift downstream. Another important fact from these results is that, even though the rib aspect ratios 3:3 and 3:2 introduce mild oscillations to the pressure field in the enlarged duct, the aspect ratio 3:1 results in a considerable decrease in base pressure and does not introduce any appreciable oscillations in the pressure field.

The results of measured pressure loss are presented in Fig. 4 for the plain duct and duct with rib aspect ratio 3:1 for three values of primary pressure ratio. It is interesting to note that the increase in pressure loss due to the passive control is always less than 6% in the present range of parameters. The pressure loss results presented here suggest that the losses due to the introduction of the ribs are not great.

Conclusions

For suddenly expanded axisymmetric flows, passive controls in the form of annular ribs have been found to reduce the base pressure significantly, compared to a plain passage. Annular ribs with aspect ratio 3:1, compared to 3:2 and 3:3, prove to be efficient in reducing the base pressure. Further, ribs of aspect ratio 3:1 do not introduce any significant oscillations in the wall pressure field of the duct. At the same time, the increase in pressure loss compared to plain duct is less than 6%. Even for the case with passive control, ducts with L/D in the range 3–5 experience the minimum base pressure, as in the case of plain ducts. Rib aspect ratios 3:2 and 3:3 result in an increase of base pressure beyond $L/D = 3$, and they also introduce mild oscillations to the duct pressure field. This implies that there is a threshold of the control rib aspect ratio that is necessary for obtaining maximum suction at the base along with minimum pressure loss.

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Functional Dependence of Flame Flicker on Gravitational Level

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Introduction

LAMINAR diffusion flames burning in quiescent oxidizing environments oscillate, or flicker, as a result of hydrodynamic instability, and the frequency of oscillation under normal-gravity condition is in the 10–18-Hz range.[1–3] However, for a wide range of gaseous fuels and Reynolds numbers, the flicker frequency is

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around 12 Hz. It is also shown[4,5] that the flicker frequency is inversely proportional to the square root of the burner diameter. A linear instability analysis has been used[1] to obtain the flicker frequency. Later, this analysis was modified[2] by separating the outer structures from the inner jet, showing that buoyancy is the cause of flame flicker. Subsequently, extensive numerical and experimental work (e.g., Refs. 3–8) has been conducted on flame oscillation and instability. In one of these studies,[6,7] the development and growth of the shear-driven, inner (small-scale) and buoyancy-driven, outer (large-scale) structures was predicted in a H_2–N_2 diffusion flame burning in air. Using a simplified analysis, a relationship in the form $f \propto (g/g_0)^{0.5}$ was obtained,[6,7] which agrees well with numerical results.[7] According to this analysis,[6]

$$f = U(x)/L = [2(\rho_0/\rho - 1)xg_0]^{0.5}(g/g_0)^{0.5}\Big/L \qquad (1)$$

where f is the flicker frequency, U is the axial velocity, L is the length scale of the vortices, ρ and ρ_0 are the densities of the hot and cold gas, x is the axial distance, g is the acceleration of gravity, and g_0 is the normal gravity. The assumptions were straight flame surface, uniform temperature in the flame outer layer, no radial convection, and negligible initial axial velocity at the flame base. The relation $f = 13.0(g/g_0)^{0.5}$ Hz was obtained, which was in agreement with numerical computations[6,7] for gravity levels up to $10g_0$.

Data on flame flicker as a function of gravity (except for the normal-gravity case) are difficult to obtain. High-gravity levels ($g > g_0$) require a centrifuge,[8] where increased flicker frequency and reduction in flame height with increasing g level has been reported.[8] By reducing the pressure, the influences of buoyancy on flicker can be reduced.[9,10] However, no data on flame flicker have been available for reduced-gravity levels except for the microgravity case, where no flicker was observed because of the negligible effects of buoyancy.[11] Therefore, the objective of this study was to obtain the flicker frequency of laminar jet diffusion flames under partial-gravity conditions and to find a relationship between the measured frequency and the gravitational level.

Experimental

The experiments were conducted onboard the KC-135 Research Aircraft of the NASA Johnson Space Center. A typical flight lasts 2–3 h and provides approximately 40 low-gravity parabolic trajectories of up to 20 s each. The beginning altitude is about 7 km above sea level, where the plane climbs rapidly at a 45-deg angle, traces a parabola, and then descends at a 45-deg angle. The gravity levels experienced are $1.5g_0$–$2.0g_0$ during both the climb and descent phases. During the parabolic portion of the maneuver, gravity levels on the order of $1 \times 10^{-2}g_0$ (if the experiment is attached to the aircraft) or $1 \times 10^{-3}g_0$ (for free-float experiments) are normally obtained. However, for this work additional flames at $0.1g_0$ and $0.3g_0$ (which are close to Lunar and Martian gravities) were studied during specially executed alternate trajectories. Also, flames at $1.5g_0$ from the climb and descent segments of the flight were investigated. Baseline tests in normal-gravity condition (on the ground) and microgravity condition[11] (in the NASA John H. Glenn Research Center drop facilities) were conducted to complement the preceding test points.

The experiment chamber was a cylindrical vessel of 80 liters in volume with a length of about 50 cm. The chamber was attached to the aircraft floor. A stainless-steel nozzle with a diameter of 1.65 mm was used to burn methane at a flow rate of 1.8 mg/s in quiescent air under atmospheric pressure. The nozzle tip was located approximately 10 cm above the chamber base plate. A retracting hot-wire igniter was used to ignite the flame. The laminar flames were generally ignited at the beginning of the low-gravity period, and the fuel flow was stopped at the end of the period. Orthogonal side view of the flame was imaged by a video camera at 30 frames/s with each frame consisting of two interlaced fields spaced 1/60 s apart. The fuel flow rate, chamber pressure, and three components of acceleration were also measured.

Results and Discussion

The video images provided the flicker range, flicker frequency, and average luminous flame height. It was not possible to measure the flicker range (if any) for the $0.01g_0$ case because, for the most part, the measured g jitter and the gravity level were of the same order ($\sim 0.01g_0$). Aircraft-induced g jitter was not found to be a problem for gravity levels of $0.1g_0$ and higher because the buoyant force dominates the effect of jitter. Therefore, the oscillatory data presented here are for the $0.1g_0$ level and higher. The microgravity flames tested in the drop facilities did not exhibit any flicker.

Figure 1 shows the frequency spectra obtained from flame height oscillation for different gravitational levels. The flame height oscillation for a normal-gravity and a $0.1g_0$ flame over a period of 3 s is shown in the inset in Fig. 1. Application of fast Fourier transform to the flame height oscillations provides the frequency spectra. As seen in Fig. 1, the dominant frequency can be obtained by analyzing the time-dependent behavior of the flame height. The spectra show sharp peaks for each case, indicating that the camera imaging rate was sufficient for this purpose. The frequencies for the peaks are plotted in Fig. 2 as a function of gravitational level. The best fit to these data (including normal-gravity and microgravity test points) results in the relationship

$$f = 11.4(g/g_0)^{0.5} \qquad (2)$$

This is in satisfactory agreement with $f = 13.0(g/g_0)^{0.5}$ obtained in Refs. 6 and 7 using a simplified analysis, where the results agree well with predictions for gravity levels up to $10g_0$. The error bars in Fig. 2 indicate uncertainties in both frequency measurement and gravitational level. The agreement between the current result (which is for methane flames) and that from Refs. 6 and 7 (for a H_2–N_2 flame

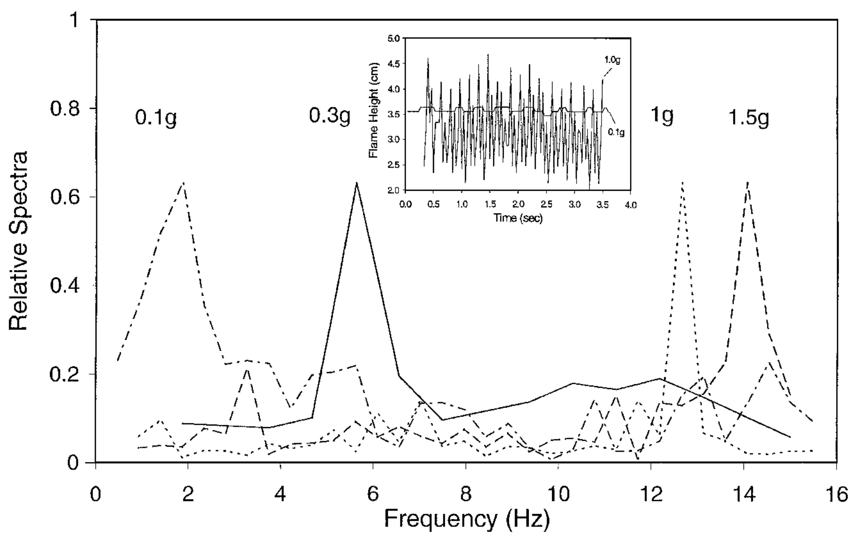

Fig. 1 Frequency spectra of the oscillating flames under different gravitational levels. The flame height oscillation as a function of time in $1g_0$ and $0.1g_0$ is shown in the inset.

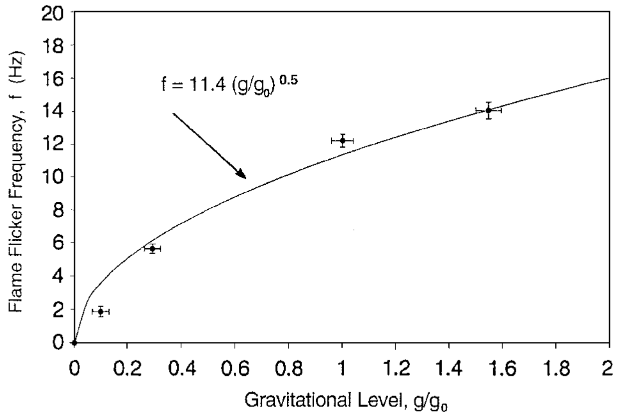

Fig. 2 Flame flicker frequency as a function of relative gravitational level.

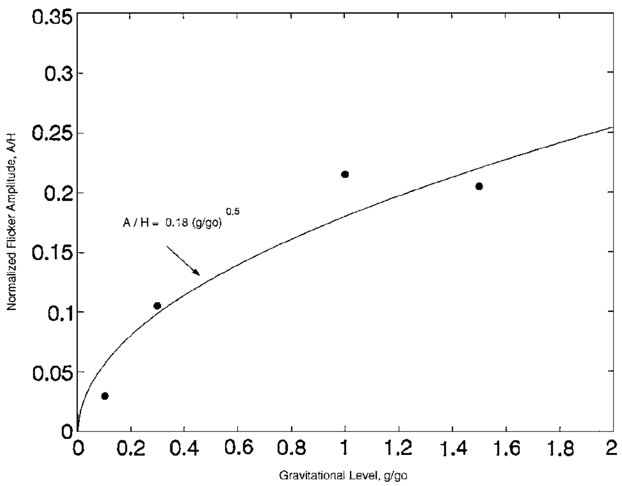

Fig. 3 Nondimensional flicker amplitude (with respect to the corresponding measured average flame height) as a function of gravitational level.

burning in air) supports the observation in the literature (e.g., Ref. 2) that flicker frequency may not be sensitive to fuel type.

Figure 3 shows the amplitude A of the flame height oscillation (nondimensionalized with respect to the corresponding measured average flame height H) as a function of gravity. The amplitude is found to scale approximately as

$$A/H = 0.18(g/g_0)^{0.5} \tag{3}$$

which shows a $g^{0.5}$ dependence for flicker amplitude as well.

Conclusions

An experimental study of diffusion flame flicker under different gravitational levels has provided a correlation between the flicker frequency and gravitational level in the form $f = 11.4(g/g_0)^{0.5}$, which agrees with one obtained from previous theoretical results.[6,7] It is shown that flicker is buoyancy-dominated and that flicker frequency increases with increasing gravitational level. In addition, it is shown that the nondimensional flicker amplitude increases with increasing gravitational level and has a $(g)^{0.5}$ dependence.

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Static and Modal Analysis of Twin-Cell Box Girder Structures

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Nomenclature

D = plate flexure rigidity $Et^3/[12(1-\nu^2)]$
E = modulus of elasticity
M_w = warping moment
$\boldsymbol{S}'_n$ = vector of stress resultants in local coordinate system
$\boldsymbol{T}^T$ = transpose of transformation matrix
t = plate thickness
$u_{,y}$ = derivative with respect to y coordinate
$w^{(4)}$ = fourth derivative of transverse displacement with respect to longitudinal coordinate x
α = cross-section aspect ratio
$\bar{\alpha}$ = square root of the ratio of primary to secondary rigidities
β = ratio of web thickness to flange thickness
$\boldsymbol{\Delta}'_n$ = vector of nodal displacements in local coordinate system
ν = Poisson's ratio

Introduction

FOR reasons of economy, efficiency, and practicality, the use of thin-walled box-type structures is considered an ingenious

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