Acoustic Comparison of Welding- and Cutting-Torch Jets/Flames

S. L. HALL

School of Mechanical Engineering NSW, Institute of Technology, Sydney.

ABSTRACT

Stoichiometric (5:1) and rich (4:1) mixtures of oxygen and LPG were used in commercial welding and cutting torches. Exit velocities and diameters were similar, giving a 10^4 Reynolds Number similarity. High-speed Schlieren films have confirmed that the flames are transitional (initially laminar) and the jets are fully turbulent at the exit planes.

Acoustic data were obtained in one-third octave bands, over azimuth angles of 30 to 150 degrees from the flow axis, at a radius of 0.5 metre. The mixture jets always had their maximum overall sound-pressure-level (SPL) at 30 degrees from the flow axis; the flames always had their maximum overall SPL at 75 degrees from the flow axis. The frequency spectra illustrated that the directivity was not significant until the peak frequency was reached. The polar plots for the welding-torch flames were larger (higher in level) than those for the cutting-torch flames; data from both types produced cardoid shapes. All jet polar plots were essentially the same. In the low frequency region, all jets and all flames each have similar spectral shapes.

INTRODUCTION

The major difference between an oxy cutting torch and an oxy welding torch is that the former is a multiple-flame device and the latter is a single-flame device. In order to compare the acoustic properties of the different torches, a series of experiments using the 16-slot cutting torch and the single-hole welding torch were undertaken. Identical gas mixture ratios, gas flowrates and equivalent diameters gave Reynolds Number similarity between the jets/flames produced by the two torches.

The cutting torch was tested without using the centre oxygen stream; therefore, the premixed gases exhausted through 16 annular slots having an equivalent hydraulic diameter of 3.2 millimetres. The welding torch had a convergent nozzle leading to a single exit hole of 3.2 mm diameter. Thus, the resultant mixture jets and flames each had Reynolds Number similarity. The cold-flow Reynolds Number of 10^4 produced transitional flames, although the mixture jets were fully turbulent. The flame Reynolds Number would be about 1/20th of the cold-flow value.

The background noise in the testing facility was coincident with the jet and the flame data at 20-31.5 Hertz (Hz). The background noise had no effect on flame data above 40 Hz for the welding torch and above 63 Hz for the cutting torch. At low frequencies, the jet data was close to the background noise up to 400 Hz.

All jet data below 400 Hz were disregarded, due to being "swamped" by the background noise.

Directivity of the mixture jets and flames

Both jet and flame noise were essentially omni-directional up to the peak frequency in the respective spectrum. Above the peak frequency, data for the various angles diverged as frequency increased. Data obtained with the welding torch were more scattered than that of the cutting torch.

The overall or linear SPL values (measured over 20 Hz to 40 kHz) were misleading with respect to directivity. As mentioned above, directivity was negligible up to the peak frequency value. Since all spectral peaks were in the kilohertz range, only the high-frequency components show directivity.

The peak frequency obtained for the cutting-torch flame occurred at 2 kHz; there was no directivity at the peak. At 8 kHz, the SPL data have a 12 dB spread. Overall SPLs (calculated over the 200 Hz - 1.6 kHz range) were essentially the same; those calculated over the 2-40 kHz range differed by up to 5 dB. Similarly, jet overall SPLs (calculated over 2-40 kHz) differed by up to 5 dB.

All welding-torch flames peaked at 8-10 kHz; there was insignificant directivity at the peak. At 25 kHz, data were scattered by 18 dB. Overall SPLs (calculated over the 400 Hz - 3.15 kHz range) were essentially the same; those calculated over the 4-40 kHz range differed by up to 9 dB. Similarly jet overall SPLs (calculated over 4-40 kHz) differed by up to 4 dB.

The higher frequencies of a noise spectrum suffer considerable refraction and possible scattering (Powell, 1977). LPG flames, using air as the oxidant, have a 6.7:1 temperature ratio between the flame front and the ambient air. This causes the refraction-based directivity to maximise at approximately 45-60 degrees from the azimuth angle. The LPG flames, which use oxygen, have a 10:1 temperature ratio. Oxy flames are 50% hotter than flames using air; thus, the maximum directivity angle of 75 degrees (obtained in these experiments) is roughly 50% larger than that of flames using air.

Jet noise data all peaked at 30 degrees azimuth, which was the smallest angle at which measurements were taken. This peak jet angle is identical to that reported from several sources (Powell, 1977). Maximum SPLs have been measured at 15 degrees azimuth (Lush, 1971); however, a nose cone was fitted on the microphone. The noise field is Doppler-shifted in the downstream direction due to flow convection; there is no convection effect at 90 degrees azimuth angle (Lighthill, 1952 and 1963).

The convection-shifted jet sound field is further distorted by refraction when combustion occurs. The overall-SPL polar plots for flames are all cardioid in shape, with the maximum point always at 75 degrees azimuth. The welding-torch data are 8 dB larger (gain of 2.5) than that of the cutting torch over the 75-150 degrees azimuth range. The difference narrows to the welding-torch data being 3 dB larger (gain of 1.4) than the cutting-torch data at 30 degrees azimuth.

Thus, significant flame directivity occurs only at frequencies greater than the spectrum peak ($\geqslant$ 2 kHz) and at large angles (60° - 150°) from the flow axis. These results indicate that the directivity is produced by high-frequency noise near the torch exit plane (Powell, 1977). For combustion roar from premixed flames, the "peak frequency is related directly

to the fuel/air mixture" (Faulkner and Putnam, 1983).
There is no shift in peak frequency between the
stoichiometric (5:1) mixtures and the recommended
slightly rich (4:1) mixtures, using either torch.
Welding-torch data obtained with a richer (2.7:1)
mixture produced a flat-top spectrum over the 800-2,000
Hz range, but still produced a maximum SPL at 75 degrees
from the flow axis.

High-speed Schlieren films showed that, although exit
flow velocities had been varied from 20-80 m/s, the
apex of the flame cone angle was always 8-10 degrees.
The flame front is the outer surface of the flame cone.
The unburnt mixture is inside the flame cone. The
flame temperature is 3,000 degrees Kelvin from the
outer surface of the cone to the edge of the flame.
The ambient air is 300 degrees Kelvin. Assuming perfect
gas laws were valid, the following relation was used
for 100% refraction (no reflection) across an acoustic
impedance layer:

$$[\cos\theta]_{flame} = \frac{[\rho c]_{flame}}{[\rho c]_{amb.air}} [\cos\theta_{amb.air}],$$

where θ = azimuth angle relative to vertical flow
direction;
ρ = gas density; and
c = speed of sound.

Substituting $\theta_{amb.air}$ = 75 degrees and the correct
values for density and sound speed, gave θ_{flame} = 85
degrees. The 85 degrees from vertical gave a cone half-
angle of 5 degrees, which corresponds to an apex angle
of 10 degrees for the flame cone. Thus, the maximum
SPL directivity of 75 degrees azimuth is constant
across a range of fuel/oxidant mixtures of 2.7:1 to 5:1
since the flame cone angle was essentially constant.

Shape of frequency spectra

Both jet-noise and flame-noise (or roar) spectra are
ideally broadband and symmetrical, with the flame
spectra higher in level ($\geq$ 20 dB) and broader in shape
than the jet spectra. Data for premixed fuel/air
mixtures used in tubular burners produced a 20 dB band-
width in about 10 octaves for the flames and in 6.5
octaves for the jets (Smith and Kilham, 1963). The
spectra of the 50% hotter flames from the oxy torches
rose more quickly with a 20 dB bandwidth obtained in 3
octaves. The LPG/oxygen jets reached a 20 dB bandwidth
in 2 octaves. The ratio of 3:2, for the number of flame
: jet octaves, is the same for both the flames using
air and the flames using oxygen.

Jet noise spectra are symmetrical with both sides of
the spectra having slopes of f^2 and f^{-2} for sound
power, or slopes of f^1 and f^{-1} for SPL, versus frequency
(Powell, 1977). The jet spectra from both torches had
the same slopes. The welding-torch flames had a slope
of f^1 for angles $\geq$ 60 degrees azimuth on the low-
frequency side of the spectra. Data for 30 and 45
degrees diverge from the main spectra 2-2.5 octaves
before the main peak frequency. On the high-frequency
side, only the 75 and 90 degree (no convection effect)
data decay as f^{-1}. All other angles decay faster. The
cutting-torch flames had an f^1 low-frequency slope for
all azimuth angles, since all data for all angles
reached the peak frequency before decaying. The high-
frequency side had slopes from $f^{-.33}$ for 75 degree
data to $f^{-0.38}$ for 90 degree (no convection effect)
data to $f^{-1.0}$ for the 30 degree data.

Valve or flow-restriction noise appeared as extraneous
high-frequency (20 k - 31.5 kHz) peaks on the cutting-
torch flame spectra and on the jet spectra from both
torches. There is no evidence of extraneous peaks on
the welding-torch flame spectra. The welding-torch
flames appear to be large amplifications of the jet
noise spectra, with negligible shift of peak frequency.
The peak frequency of the cutting-torch flames shifts
to 10% of the jet peak frequency, or to 3 octaves lower

frequency. This peak-frequency shift and the broader
shape of the flame spectra indicate that the cutting-
torch data behave like flames from most single- and
multiple-hole burners. The welding-torch flames are
single jet flames and behave like amplified jets.

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