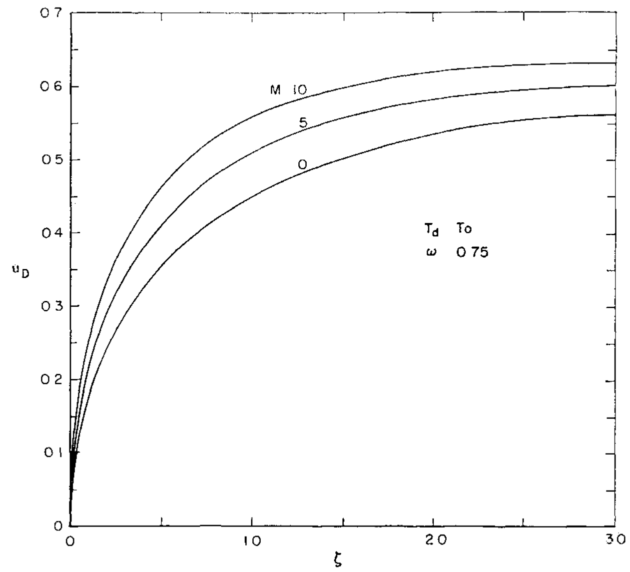

Fig 1 The velocity at the dividing streamline for different boundary conditions inside the base region

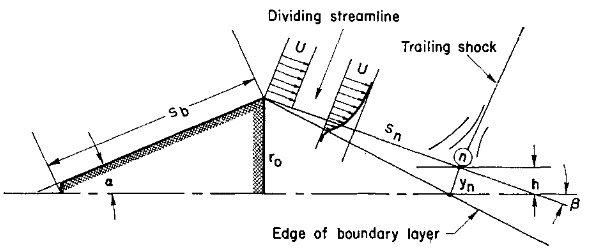

Fig 2 Schematic diagram of base flow

Assuming that all of the mass contained in the boundary layer over the body goes through the neck, we set

$$h/r_0 = 40(Ur_0/\nu)^{1/2} \tag{10}$$

The factor 40 is fixed by the experiments of Ref 3 Setting the position of the neck λ radii back of the base, Eq (9) yields, after some trigonometry,

$$\zeta_n = 20\ u_D/(\lambda\ \cos\beta)^{1/2} \tag{11}$$

From this equation, it appears that the value of u_D is again directly independent of the Reynolds number Since the angle β is of the order of 10°, so that $\cos\beta \approx 1$, and since from experiments λ is of order one, the assumption $\zeta_n \to \infty$ is still reasonable The proof of this last statement lies in the fact that Eq (11) yields a value of $\zeta_n = 12$ when $u_D \approx 0\ 6$, $\lambda \approx 1$, and $\cos\beta \sim 1$; then, Fig 1 indicates that our choice for u_D is consistent with the fact that at $\zeta_n = 12$ the asymptotic value for u_D has been reached In fact, it is reached roughly when $\zeta_n > 3\ 0$ One needs a neck length of the order of 10 radii in order to make a correction in u_D for finite base radius

References

[1] Chapman, D R , Laminar mixing of a compressible fluid," NACA Rept 958 (1950)

[2] Denison, M R and Baum, E , Compressible free shear layer with finite initial thickness," AIAA J 1, 342–349 (1963)

[3] Chapman, D R , Kuehn, D M , and Larson, H K , "Investigation of separated flows in supersonic and subsonic streams with emphasis on the effect of transition," NACA Rept 1356 (1958)

[4] Dewey, C F , Jr , "Measurements in highly dissipative regions of hypersonic flows, Part II: The near wake of a blunt body at hypersonic speeds," Ph D Thesis, Calif Inst Tech (1963)

Acoustic Absorption Coefficients of Combustion Gases

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Nomenclature

c = speed of sound, cm sec^{-1}
C_p = specific heat at constant pressure, cal g^{-1} °K^{-1}
C_v = specific heat at constant volume, cal g^{-1} °K^{-1}
f = frequency, sec^{-1}
f_n = frequency of the nth harmonic, sec^{-1}
l = length of resonance tube, cm
n = harmonic index, integer
P = pressure, dyne cm^{-2}
P_r = Prandtl number, dimensionless
R = tube radius, cm
γ = ratio of specific heats
δ = frequency width of a resonance peak, sec^{-1}
λ = thermal conductivity, cal cm^{-1} sec^{-1} °K^{-1}
μ = dynamic viscosity, poise
σ = wall acoustic damping coefficient, cm^{-1}

WORK on the problem of combustion instability in solid propellant rocket motors has focused interest upon the various acoustic losses and gains that are present in these motors

Acoustic damping in the combustion gas phase is one of the acoustic energy sinks that is present in any rocket motor, and it is the purpose of this note to present some initial results from an experimental investigation of the acoustic damping constant of solid propellant combustion gases The data of this note apply to combustion gases that have been cooled to room temperature

Experimental Apparatus

The experiments were carried out in an acoustic resonance tube patterned after the one used by Parker [1] A Goodman's VR-II electromagnetic shaker driver was used to drive a rigid flat-topped piston that closed one end of a 50 mm diam steel tube The other end of the tube was closed by a rigid brass plate which carried a flush-mounted condenser microphone at its center The tube length between the closures was 683 mm

During an experiment, the tube was filled with the test gas at 1 atm pressure and room temperature, and the apparatus was set to drive the piston at a constant velocity amplitude The driving frequency was varied from the fundamental of the tube up through the 12th harmonic, which represented the high-frequency limit of the driving apparatus All frequencies were determined to ±0 1 cps by an electronic counter

The resonant frequencies of the tube were given by

$$f_n = n(c/2l) \tag{1}$$

and the acoustic damping coefficient (wall damping was the only significant gas phase damping mechanism involved) was obtained from the relation[1, 2]

$$\sigma = \pi\delta/c \tag{2}$$

The frequency width of a resonant peak, δ, was determined as the difference in frequencies on a given peak at the points

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where the signal amplitude had fallen to $1/2^{1/2}$ of its maximum value

Combustion gases were obtained by burning 8 g of solid propellant in a Peters combustion bomb, which contained approximately 0 4 mg of air The gases were allowed to cool to room temperature in the bomb The resonance tube was pumped down to approximately 8 mm Hg absolute and then filled to slightly over 1 atm pressure with combustion gases from the bomb It was then re-evacuated and refilled with combustion gases to 1 atm pressure The apparatus was allowed to equilibrate to room temperature before the experiment was started

Results

Figure 1 shows the results obtained from tests on room air and compares them with values calculated from the expression[1, 3]

$$\sigma = \left[\frac{(\pi\mu)^{1/2}}{R}\right]\left[\left(\frac{1}{\gamma}\right)^{1/2} + \left(\frac{\lambda}{\mu C}\right)^{1/2}\left(\frac{\gamma - 1}{\gamma}\right)\right]\left[\frac{f}{P}\right]^{1/2} \quad (3)$$

The physical properties of dry air at 1 atm and 23°C were taken as[4, 5] $\mu = 1\ 86 \times 10^{-4}$ poise, $\gamma = 1\ 40$, and $P = (C_p\mu/\lambda) = 0\ 73$

The calculated and experimental curves are in reasonable agreement at the lower frequencies with the experimental values somewhat in excess of the theoretical values, as has been noted by other investigators [1] The experimental results show an expected departure from a linear function of $f^{1/2}$ at the higher frequencies [1]

Figure 2 shows the results for combustion gases from a typical nonmetalized double-base propellant It must be remembered that these gases were expanded into the tube from a room temperature container at pressures from 18 to 2 atm Therefore, they were relatively dry, and their composition was not that of flame-temperature gases from the same propellant A comparison will show that the absorption coefficient from these gases is almost identical with that obtained for air

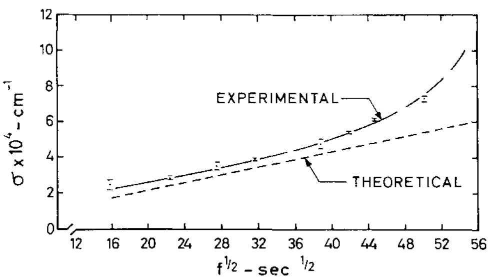

Fig 1 Acoustic damping constant for air as a function of $f^{1/2}$ Temperatuie range is 22°–26 C Pressure is 1 atm The theoretical curve was calculated foi 23 C Horizontal lines above and below each average point mark the two values that were used to compute the average

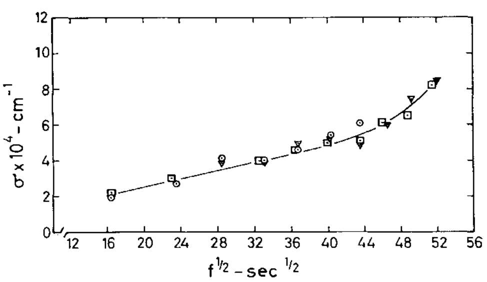

Fig 2 Acoustic damping constant for combustion gases from a typical double-base solid propellant as a function of $f^{1/2}$ Temperature range is 21°–23°C Pressure is 1 atm Γhe diffeient point symbols represent three separate sets of data for a single type of propellant

By assuming $P \propto T^0$, $\mu \propto T^{1/2}$, and $\gamma \propto T^0$, one sees that $\sigma \propto T^{1/4}$, and these results may be roughly extrapolated to higher temperatures

Future Work

It is intended to extend this preliminary low-temperature work to the case where the test gas contains suspended particles of Al_2O_3 Also, apparatus that will directly determine σ for combustion gases at the flame temperature is presently being manufactured This apparatus will be used with both nonmetalized and metalized propellants

Finally, it is hoped in the future to arrange a method that will permit hot tests to be run in the 10–20 kc frequency range

References

[1] Parker, J G , "Effect of several light molecules on the vibrational relaxational time of oxygen,' J Acoust Soc Am **34**, 1763–1772 (1961)

[2] Blair, D W , "Acoustic wave burning zone interaction in solid propellants," AeroChem Res Labs TP-49 (1962)

[3] Rayleigh, J W S , *The Theory of Sound* (Dover Publications Inc , New York, 1945), 2nd ed , Vol II, pp 325–326

[4] Hodgman, C D (ed), *Handbook of Chemistry and Physics* (Chemical Rubber Publishing Co , Cleveland, Ohio, 1963), 50th ed , pp 2264–2382

[5] Bird, R B , Stewart, W E , and Lightfoot, E N., *Transport Phenomena* (John Wiley and Sons, Inc , New York, 1960), Table 8 3-1, p 256

Tracer-Spark Technique for Velocity Mapping of Hypersonic Flow Fields

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IN the experimental study of the aerodynamic structure of hypersonic wakes at Stanford University, a technique for measuring density was desired It appeared that the density could be deduced from measurements of Pitot pressure and flow velocity according to the relation

$$\rho = p_t/k(\rho, T, V)V^2 \quad (1)$$

where ρ is the stream density, p_t the Pitot pressure, T the stream temperature, and V the flow velocity It can be readily shown that $k(\rho, T, V)$ is essentially a constant over a wide range of flow conditions Although Pitot-pressure measurements could be made with "conventional" instrumentation techniques, this was not the case for velocity measurements Thus, it was necessary to develop a technique for the direct measurement of flow velocity

Bomelburg[1] was successful in using a series of electric sparks to measure velocity at lower speeds An extension of this method has therefore been attempted for the measurement of velocity in hypersonic wakes The large differences between the freestream velocities and densities encountered in hypersonic wakes and those of Bomelburg's work made it necessary to use a different method of producing the sparks With the present system, a set of electrodes is positioned in the flow field to be studied The electrodes, which can be seen in Fig 1, are cylindrical rods about 6 in apart, aligned with the flow Two pairs of electrodes are used, a pair of initiator or tip electrodes and a pair of main

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