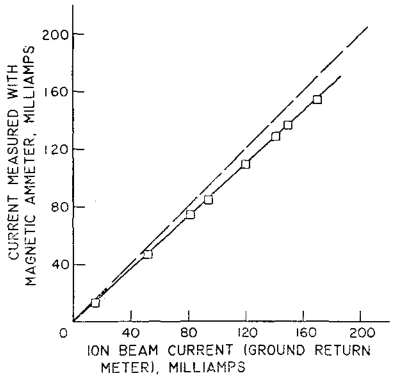

Fig. 3 Measurement of beam current without neutralizer

source of heat is present, either radiative or from ion impingement, cooling is required.

Bench tests of the ammeter with a current carrying wire simulating the ion beam show that the instrument reads correctly within ordinary meter accuracy (3%). Movement of the current-carrying wire within the ring did not affect the readings. The device also is sensitive to any stray magnetic fields and must be nulled before a run.

Application to Ion Engine Studies

Figure 2 shows the ammeter set up inside a vacuum tank for preliminary tests with an electron bombardment-type ion engine. Details of the engine and vacuum facility can be found in Refs. 2 and 3.

In order to compare the magnetic ammeter with a ground return meter, the ion engine was operated without current neutralization. The result is shown in Fig. 3. The current through the ring is about 9% lower due to a loss of ions from charge exchange and excessive beam spreading. It should be noted that electrons coming upstream through the ring are reflected at the engine and are not counted as current since they return through the ring again.

As shown in Fig. 4, the ammeter was used to measure the degree of beam current neutralization with an immersion-type neutralizer in operation. The neutralizer was a 0.020-in. tungsten wire stretched across the beam 3 in. from the engine. Ideally, one might expect zero current through the ring when the neutralizer current is equal to the beam current (space application). However, there is an electron loss current to the valve and tank walls due to the thermal motion of the electrons.

It is concluded that the magnetic ammeter is a practical device for measuring net beam current and has the important advantage that no physical object is placed in the beam, so that the beam itself is not affected.

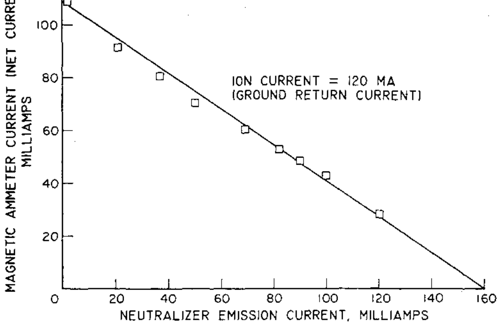

Fig. 4 Current through magnetic ammeter as a function of neutralizer emission current for constant ion current of 120 ma

References

[1] Whitlock, W. S. and Hilsum, C., "Measurement of ion beam current using a Hall effect magnetometer," Nature **185**, no. 4709, 302 (1960).

[2] Kaufman, H. R., "An ion rocket with an electron bombardment ion source," NASA TN D-585 (1961).

[3] Keller, T. A., "NASA electric rocket test facilities," Paper R-25, National Vacuum Symposium (1960).

[4] Reitz, J. R. and Milford, F. J., *Foundations of Electromagnetic Theory* (Addison Wesley Publishing Co., Reading, Mass., 1960), p. 205.

Effect of Radiation on Flow Properties behind Strong Shock Waves in Air

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Many of the problems associated with superorbital re-entry can be studied in high-performance shock tubes. Shock Mach numbers between 25 and 40 are required to simulate the stagnation enthalpies encountered by vehicles returning to earth on hyperbolic trajectories. (The equivalent flight velocity, in thousands of feet per second, is approximately 1.5 times the incident shock Mach number.) The temperature behind the shock at these Mach numbers is so high that thermal radiation has a significant effect on the flow properties behind the shock.

A low-pressure, arc-driven shock tube with a 12-in.-i.d. driven section currently is under construction at Lockheed Missiles and Space Company. In this facility, it will be possible to study equilibrium and nonequilibrium radiation as well as convective heating at total enthalpies corresponding to superorbital re-entry. In this note, the results of a preliminary investigation of the effects of thermal radiation on driven-gas properties are presented for the case of air. The initial conditions and Mach numbers selected in the numerical examples are typical of those expected in the LMSC low-pressure, arc-driven shock tube.

It can be shown that the effect of energy loss due to radiation is to reduce the speed of the shock wave and increase the speed of the contact surface. Conditions behind the shock wave therefore will change throughout its passage from the diaphragm station to the working section. However, a study of the effects of radiation cooling on shock waves traveling with constant speed provides valuable information about the ranges of shock Mach number and initial pressure over which the radiation loss will have an appreciable effect on shock-tube performance.

The equations governing the flow through a constant-speed shock wave are, in a coordinate system fixed in the wave,

$$\rho_2 v_2 = \rho_1 v_1 \quad (1)$$

$$p_2 + \rho_2 v_2^2 = p_1 + \rho_1 v_1^2 \quad (2)$$

$$h_2 + \tfrac{1}{2} v_2^2 = h_1 + \tfrac{1}{2} v_1^2 - q \quad (3)$$

where ρ is density, v velocity, p pressure, and h enthalpy. Subscript 1 refers to conditions ahead of the wave and subscript 2 to any point behind the wave; q is the total amount of energy lost per unit mass up to station 2. For $q = 0$, the

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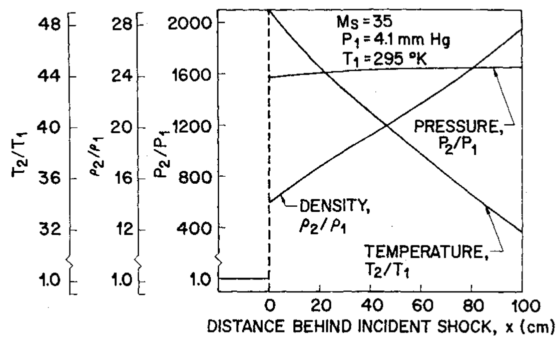

Fig. 1 Driven-gas profiles with radiation loss

equations reduce to the usual shock-wave equations and give the conditions immediately behind the shock.

In addition to Eqs. (1–3), the equation of state is required. This was used in the form of the large-scale Mollier diagram by Korobkin and Hastings.[1] All calculations were carried out for an initial temperature $T_1 = 295°K$.

The presently available information about the radiation properties of air has been summarized by Thomas,[2] who presents a curve fit for the emissivity which covers the ranges of temperature and density of interest here. This was used together with the assumption that all energy radiated is lost to the walls. The resulting expression is

$$dq/dt = 1.57 \times 10^4(\rho/\rho_0)^{1.28}(T/10^4)^{10.54} \text{ w-cm}^{-3} \quad (4)$$

where ρ/ρ_0 is the density in Amagat and T is in degrees Kelvin.

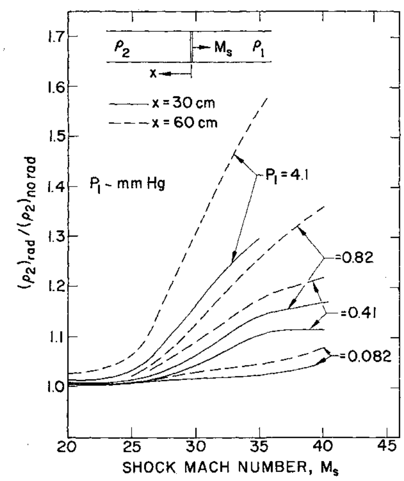

Fig. 2 Effect of thermal radiation from the driven gas on driven-gas density

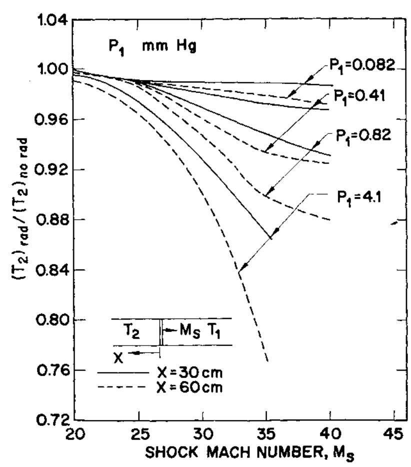

Fig. 3 Effect of thermal radiation from the driven gas on driven-gas temperature

The equations now can be solved for any choice of ρ_1 and M_s (i.e., v_1). A point behind the shock wave is found by choosing a value of ρ_2 and finding v_2 aud p_2 from (1) and (2) and h_2 and T_2 from the Mollier diagram. Equation (3) then gives q. All variables behind the shock therefore can be plotted as functions of q. To transform to the x coordinate, integrate

$$\Delta x = v\Delta t = v\Delta q/(dq/dt) \quad (5)$$

As an example, Fig. 1 shows the variations of pressure density, and temperature behind a Mach number 35 shock wave traveling into air at a pressure of 4.1 mm Hg. This is an extreme case in which the effects on density and temperature are very large while the pressure remains essentially constant. Figures 2 and 3 show the effect on density and temperature, respectively, over the Mach number and pressure ranges covered in the calculations and at two stations, 30 and 60 cm behind the shock. It is apparent that calculations based on the presently available information about radiation from air suggest that, for high Mach number operation, the initial pressure shock be about 100 μ in order to limit nonuniformities in the test gas.

References

[1] Korobkin, I. and Hastings, S. M., "Mollier chart for air in dissociated equilibrium at temperatures of 2000°K to 15,000°K," U. S. Naval Ordnance Test Station, NAVORD Rept. 368 (1957).

[2] Thomas, P. D., "Air emissivity and shock-layer radiation," J. Aerospace Sci. 29, 477–478 (1962).

Instability of Arc Columns

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Nomenclature

I = arc current, amp
$\bar{I}$ = mean arc current, amp
L = photo-diode output/output at reference temperature T
$\dot{m}$ = gas mass flow rate, lb/min
T = Temperature, °K
T_r = reference temperature, °K
V = arc voltage
$\bar{V}$ = mean arc voltage

In a recent note,[1] the characteristics of a Gerdien-type plasma generator were described and an hypothesis proposed to explain the arc column's instability. Work of a similar nature has been carried out at Imperial College, some results of which are thought to be of current interest.

The tests to be described were performed using a Giannini vortex-stabilized arc-heater, equipped with a "constrictor" type of anode, shown schematically in Fig. 1. The arc chamber pressures range between 0.1 and 1 atm. Measurements were made of the instantaneous arc voltage, current, and the intensity of visible radiation of the plasma after it had been expanded to a supersonic velocity. The optical measurements were confined to a narrow plane normal to the

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