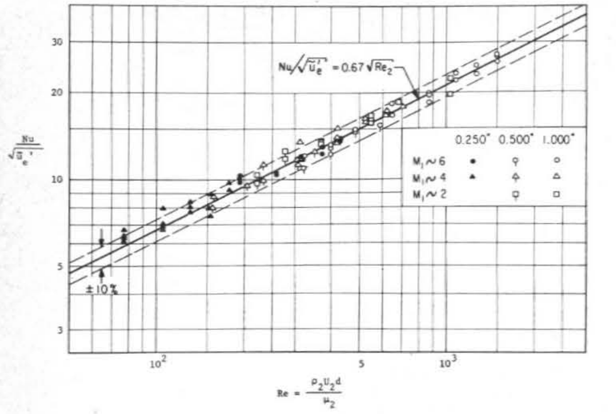

Fig. 2 Comparison of measured stagnation point heat transfer with continuum boundary-layer theory.

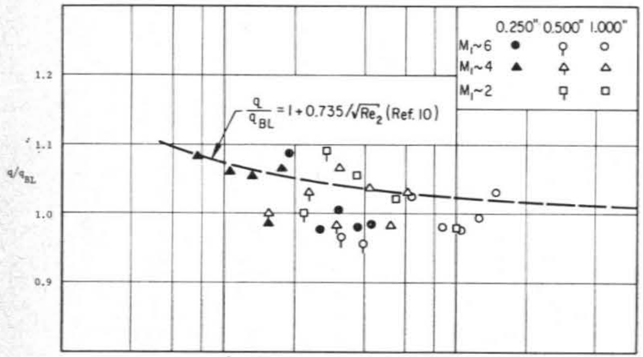

Fig. 3 Ratio of average values of measured stagnation point heat transfer to continuum boundary-layer theory.

The ratios of these average values to continuum boundary-layer theory have been plotted as a function of Re_2 in Fig. 3. The curve representing a least-squares fit of the data reported in Ref. 1 has also been included in this figure. Although the results from this investigation are in agreement with this curve, it should be noted that the data at the lower Reynolds numbers are primarily from the 0.250 in. model tested at $M_1 \sim 4.0$. In view of this and the experimental scatter, a firm conclusion regarding an increase over boundary-layer theory is not considered justified.

The results are therefore considered to be in agreement with boundary-layer theory over the range of Reynolds numbers investigated. However, since the trends predicted by the analyses of Refs. 6–8 lie within the experimental scatter, it is possible that small second-order effects are present. Reference to Fig. 1 shows that the experimental results of Ferri et al.[3, 5] as well as the theories of Ferri[3] and Cheng[4] are significantly higher, and also show a deviation from continuum boundary-layer theory at much higher Reynolds numbers. It is noted that the data of Ferri et al. were obtained at higher stagnation temperatures (~2300° compared to 530°R). This has been advanced as the reason for the differences in the theoretical predictions and experimental results. This explanation is, however, questioned by Van Dyke.[8]

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Measurements of Test Time in the GALCIT 17-Inch Shock Tube

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EXPERIMENTAL measurements of test time were obtained in the GALCIT 17-in. shock tube[1] using both air and argon for driven gases. One series of tests was conducted using a constant driver pressure (pure helium) for various initial pressures of the driven gases. Another series was conducted using air for the driven gas at various initial pressures holding the shock Mach number constant. The data are presented and compared to theoretical predictions computed from the theory in two recent papers by Mirels for the case of a laminar[2] and turbulent[3] wall boundary layer.

Test times were obtained at the centerline of the shock tube using two different contact surface probes to detect arrival of the contact surface (in a manner similar to that described in Ref. 4); these were a stagnation-point heat-transfer gage and a cold-wire gage. The stagnation-point heat-transfer gage consisted of a thin platinum film deposited on a $\frac{1}{8}$-in.-diam quartz rod. The cold-wire probe consisted of a 0.0005-in.-diam platinum wire; because of its low resistance, it was useful at higher Mach numbers for avoiding shorting by the slightly ionized gas (particularly argon). Initially, it was felt that the lifetime of the stagnation-point heat-transfer gage would be longer than that of the cold wire, but this was found not to be the case, and so the cold-wire probe was used to obtain all the data for the series of constant Mach number tests. For the very low initial pressures of the driven gas ($p_1 \leq 100\ \mu$ Hg), it was possible to measure the shock-wave contact-surface separation distance (and thus test time) from a station a few centimeters from the end wall ($x_s = 20.332$ m from the diaphragm). Test times for the higher initial pressures were obtained at a station farther from the end wall ($x_s = 16.668$ m).

In order to determine the time between shock passage and transition (if any) to a turbulent boundary layer, the response of a thin-film resistance gage on the side wall was recorded along with the oscillograph recording of the voltage change of the contact surface probe during each test. Transition Reynolds numbers as defined in Refs. 5 and 6 were found to be between 2×10^6 and 4×10^6.

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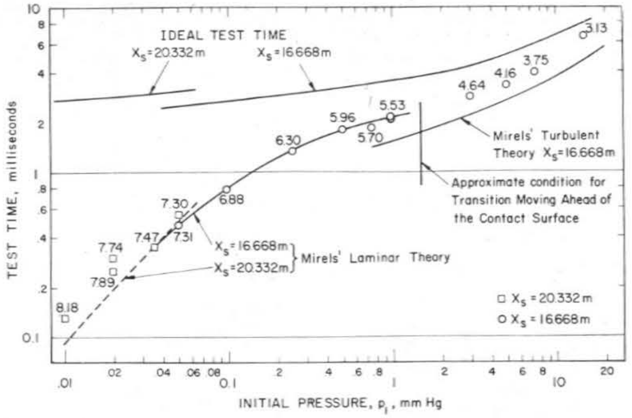

Fig. 1 Test time vs initial pressure p_1, constant driver series, using argon for the driven gas. Shock Mach number indicated for each experimental point.

The results presented in Figs. 1 and 2 were obtained using helium at a constant driver pressure. Initial pressures p_1 of the driven gas ranged from 50 μ Hg to 20 mm Hg ($7.12 \geq M_s \geq 2.81$) for air and from 10 μ Hg to 15 mm Hg ($8.18 \geq M_s \geq 3.13$) for argon. The ideal test time was computed for each test condition and appears as the uppermost curve in both Figs. 1 and 2. The theoretically predicted test times were computed using Mirels' laminar[2] and turbulent[3] theories and are presented with the data in Figs. 1 and 2. The fact that the laminar and turbulent theoretical predictions nearly fair into one another in Fig. 2 is an accidental consequence of the particular driver conditions used.

Agreement between the data and theoretical predictions seems to be slightly better for air than for argon. For the argon data (10 μ Hg $\leq p_1 \leq$ 35 μ Hg), the observed test times are about 30% greater than the values predicted by the laminar theory, whereas for 35 μ Hg $\leq p_1 \leq$ 1 mm Hg they are within 10%. At the lower pressures this discrepancy may occur because the separation distance between the shock and contact surface is then of the order of a tube diameter, and the assumptions of the theory may be somewhat violated. Figure 2 shows that the observed test time in air is within 10% of the value predicted by the laminar theory (50 μ Hg $\leq p_1 \leq$ 1 mm Hg). However, in the region where the turbulent theory is expected to be valid, the observed test times in air are approximately 10% less than those predicted, and in argon the test times are 25% greater than those predicted. The systematic discrepancy between the theory and measurements for argon in the turbulent case is puzzling when compared with the good agreement for air.

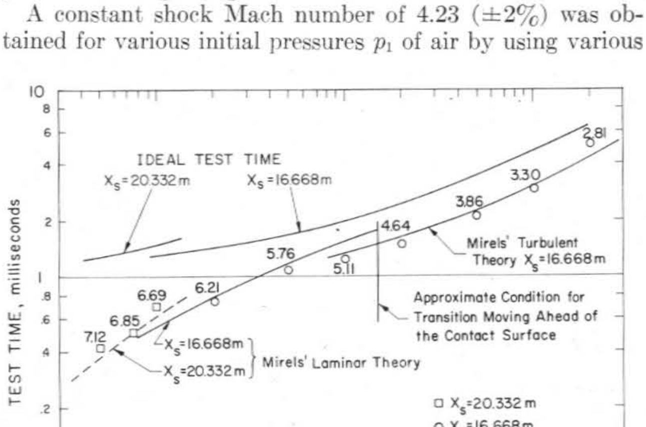

Fig. 2 Test time vs initial pressure p_1, constant driver series, using air for the driven gas. Shock Mach number indicated for each experimental point.

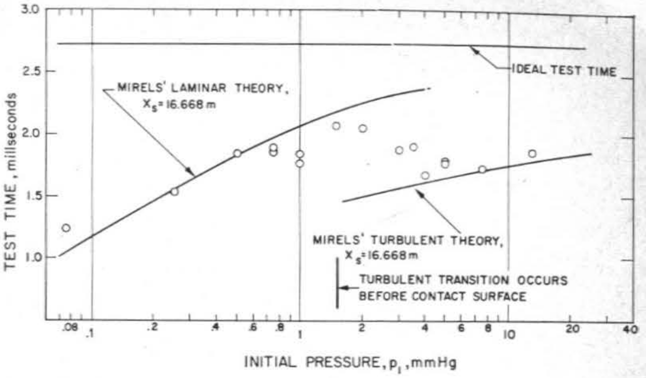

Fig. 3 Test time vs initial pressure p_1, constant shock Mach number series $M_s = 4.2 \pm 0.1$, using air for the driven gas.

A constant shock Mach number of 4.23 ($\pm 2\%$) was obtained for various initial pressures p_1 of air by using various mixtures of helium and nitrogen in the driver. The experimental test time and corresponding theoretical predictions for this series are presented in Fig. 3. At the low initial pressures, the test time increases rapidly with increasing pressure. When transition to a turbulent boundary layer begins to occur ahead of the contact surface, the test time is reduced due to the greater displacement thickness of the turbulent boundary layer (which allows more mass to "leak" past the contact surface). The transition point moves farther ahead of the contact surface as the pressure is increased. The effect of the transition moving farther ahead of the contact surface is to reduce test time further, and for a small range of pressures (1.5 mm Hg $\lesssim p_1 \lesssim$ 4 mm Hg) this effect is greater than the increasing effect on the test time due to the increasing initial pressure, and so the test time continues to decrease as the pressure is raised. Eventually, the effect of increasing initial pressure on test time is greater than the effect of the forward movement of the transition point, and the test time increases again. Here also the agreement between theory and experiment is within 10% where the theory applies.

Mirels states that the limits of application of the laminar theory is $dp_1 \lesssim 0.5$ and the turbulent theory $dp_1 \gtrsim 5$ (d = tube diameter in inches, p_1 = initial pressure in centimeters of mercury). Therefore, in the 17-in. shock tube we would expect to observe a transition region from the case where the boundary layer is entirely laminar ($p_1 \lesssim$ 300 μ Hg) to where it is predominantly turbulent ($p_1 \gtrsim$ 3 mm Hg). In Figs. 1 and 2 this region is disguised due to the changing Mach number along the curves. However, from Fig. 3 it appears that the transition region in our shock tube is somewhat higher in pressure, approximately 1.5 mm Hg $\lesssim p_1 \lesssim$ 5 mm Hg. The higher transition Reynolds number is probably due to the very smooth (honed) surface of this stainless-steel shock tube.

The laminar theory seems to give a very good estimate of test time when the boundary layer between the shock and contact surface is entirely laminar, and the turbulent theory seems to give a reasonable estimate when the boundary layer is at least 50% turbulent.

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