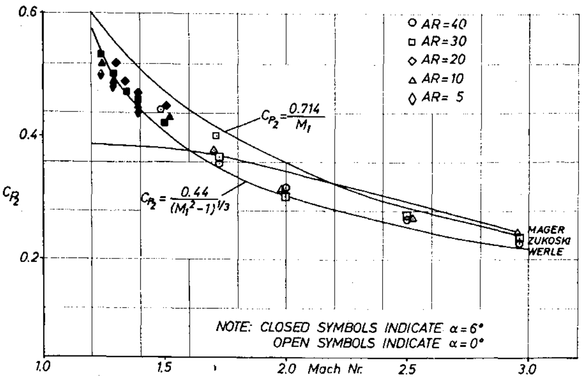

Fig. 2 Effects of Mach number on plateau pressure coefficient.

Figure 1 shows the behavior of the distance $\bar{X}$ as a function of Mach number. All data are for a model with zero angle of attack. The distance $\bar{X}$ is not the usual separation distance x_s measured from the face of the step to the point where separation occurs. It is rather the distance from the face of the step to the point where centerline pressure first begins to rise. This distance was accurately determined from the centerline pressure distributions, whereas the experimental determination of the distance x_s would have required oil-flow pictures of every case studied.

As seen in Fig. 1, at Mach numbers greater than 2, $\bar{X}/h$ is only a weak function of Mach number. However, as Mach number is lowered below $M_1 = 2$, the Mach number dependence becomes increasingly stronger. Separation distance increases with decreasing Mach number. Three different step span-to-height aspect ratios are shown to indicate three-dimensional influences. The point at which the measured separation distance deviates from Zukoski's predicted value is dependent on the degree of three dimensionality. For highly two-dimensional flow where $AR = 40$, the measured separation distance at $M_1 = 2.0$ is already 10% higher than predicted. For the more three-dimensional cases this increase is delayed until lower Mach numbers are reached. Zukoski's simple linear relationship shown in Fig. 1 has been modified to be expressed in terms of $\bar{X}$. In terms of $\bar{X}$, this relationship is

$$(4.2h + 2.25\delta_s) \leqq \bar{X} \leqq (4.2h + 2.75\delta_s)$$

For cases where $M_1 > 2$, this simple relation is reasonably accurate.

The measured plateau pressure coefficients are shown in Fig. 2 as a function of Mach number. Some data obtained with a model angle of attack of 6° is also included. Mager's[3] semi-emperical prediction as well as two empirical predictions of Zukoski and Werle[4] are also shown for comparison. Since Mager's work was based on linearized theory its validity at the lower supersonic Mach numbers is questionable. Indeed, at $M_1 = 1.25$, Mager's predictions are about 20% below the measured values. Werle's correlation best describes the data, but Zukoski's very simple approximation is also reasonably accurate even at the lower Mach numbers.

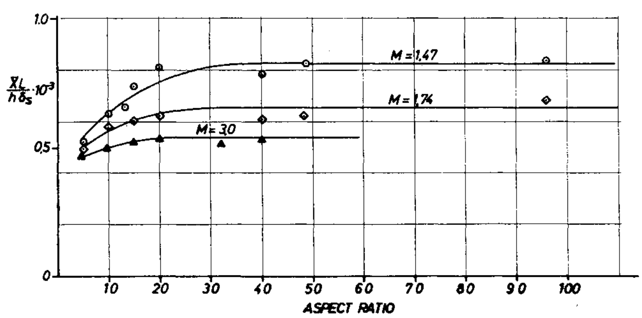

Fig. 3 Effects of step span-to-height aspect ratio on modified separation distance for various Mach numbers.

Figure 3 shows how the chosen separation distance parameter is influenced by three dimensionality at various Mach numbers. In order to eliminate the influence of variation in boundary-layer thickness at the point of separation, the nondimensional separation distance has been multiplied by the quantity L/δ_s. It is seen that the step span-to-height aspect ratio necessary to assure reasonably two-dimensional flow is influenced by the Mach number. As expected, in order to obtain separation distances that are within 10% of the two-dimensional values, a larger aspect ratio is necessary at the lower Mach numbers than at the higher Mach numbers. For flows at $M_1 = 3.0$ an aspect ratio of six or higher produces separation distances that are within 10% of the two-dimensional values, while at $M_1 = 1.47$ an aspect ratio of at least 15 is necessary to produce the same effect.

The wind-tunnel study has shown that: 1) Separation distance becomes an increasingly strong function of Mach number as the Mach number is decreased below 2, increasing with decreasing Mach number. 2) Measured plateau pressure coefficients are most accurately described by a correlation due to Werle but are also quite accurately predicted by the simpler correlation by Zukoski. 3) Three-dimensionality plays an increasingly important role at the lower supersonic Mach numbers. Defining two-dimensional flow solely in terms of step span-to-height aspect ratios is not possible. An aspect ratio that gives nearly two-dimensional flow at $M_1 = 3.0$ may not produce two-dimensional flow at lower Mach numbers.

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A Heated Wire Device for Shock Tube Diaphragm Bursting

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Nomenclature

P_D = ratio of driver section pressure to driven section pressure
P_s = ratio of pressure behind primary shock wave to driven section pressure
R = gas constant for working gas
T_0 = temperature of driven section
u_s = velocity of primary shock wave
γ = ratio of specific heats of working gas

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In the operation of shock tubes, the diaphragm separating the high- and low-pressure sections is commonly burst using either mechanical means, such as a simple pricker, simple fracture along preweakened lines scribed in the diaphragm or by using a double diaphragm method. The bursting of metal diaphragms with scribe marks to locate the fracture and produce a segmented burst has recently been described by Dah Yu Cheng et al.[1] When plastic film materials are used, the result of bursting the diaphragm is usually to release particles of the broken diaphragm into the tube. For experiments in which delicate probes, such as fine wires, are inserted in the tube this is undesirable and the device described has been found to avoid this problem.

A suitably designed ring of insulating material (such as 'Tufnol,' supplied by Tufnol Ltd., Birmingham, England) is inserted on locating bolts between the flanges of the shock tube, the internal bore of the tube being matched to a hole bored in the ring. A sketch of the ring is shown in Fig. 1. Three wires are arranged to be held across the tube axis, being mounted in six steel lined holes in the insulator to avoid burning the insulating material. At the inner end of these mounting holes the wires (made of nichrome wire of approximately 22 gauge) span the shock tube bore close to one face of the insulating ring. The lined holes are inclined away from this end face of the insulating ring so that recessed wire clamps and two bus-bars can be located on the outer surface of the insulating ring. This arrangement ensures that the wires enter the tube bore as close as possible to the flat face of the ring, the diaphragm film material (e.g., Melinex, supplied by Imperial Chemical Industries, Plastics Division) being clamped between this face and the adjacent flange of the shock tube. The diaphragm thus rests against the wires and may stretch them slightly when under load.

The shock tube is fired by passing a heavy current (approximately 10 amps in each wire) through the nichrome wires, after first setting the required pressures on each side of the diaphragm. This produces a clean break of six segments in the diaphragm and, provided the heated wires intersect at a single point, no diaphragm pieces break away. The heavy current is required to increase the temperature of the wires rapidly, as it was found that lower heating currents tended to cause significantly uneven heating rates such that only some of the diaphragm segments opened. A timing circuit was used to switch the heating current on for approximately 0.3 sec only to avoid burning the wires out completely. Good contact could be obtained between the diaphragm material and the wires by initially applying a rather larger differential pressure in order to push the diaphragm firmly on to the wires. Both wires and diaphragm adopted a spherical shape under load and it was necessary to retension the wires when reducing the operating driving pressure significantly.

The performance of the bursting device in an air/air shock tube, with a driven section at atmospheric temperature and pressure, is indicated in Fig. 2. The passage of the shock wave along the tube was timed between two hot wire probes, the first being approximately four feet from the diaphragm. The theoretical time for the shock to move between the measuring position was calculated from the usual shock relations between the shock wave pressure ratio P_s and the shock speed u_s and between the shock and diaphragm (P_D) pressure ratios:

$$1/P_D = (1/P_s)(1 - (\gamma - 1)(P_s - 1)/\{2\gamma[P_s(\gamma + 1) + \gamma - 1]\}^{1/2})^{2\gamma/(\gamma - 1)}$$

and

$$u_s = (\gamma R T_0)^{1/2}(\{[(\gamma + 1)/(\gamma - 1)]P_s + 1\}/[2\gamma/(\gamma - 1)])^{1/2}$$

(see, for example, Liepmann and Roshko[2]). For any given value of P_s, P_D and u_s may be calculated directly. Shown in Fig. 2 are the experimental results which indicate a slightly lower shock velocity than the theoretical value. This effect is caused by the slight blockage introduced by the diaphragm which remains attached to the wall in six segments and is found to cause a larger loss in the resulting shock strength at the lower driving pressure differentials. At low driving pressure differentials, it is also expected that the diaphragm inertia would be proportionately more significant and this would contribute to the deterioration of performance at lower differential pressures. These results were obtained with a 0.0005 in. thickness Melinex diaphragm mounted across a 1.8-in.-diam. shock tube. The diaphragm thickness can be selected to suit the tube diameter and range of pressure differentials, thicker films being required for larger tube diameters and differential pressures. The diaphragm burst due to fracture under load at approximately 50 lb/in.^{2} differential, this being higher than normal for this size of tube due to the supporting effect of the nichrome wires.

Whilst it is seen that the use of this bursting technique has introduced some reduction in the shock velocity below the ideal value, it was found that the wave developed into a steep fronted shock whose strength could be accurately determined from a direct measurement of velocity and the conditions in the driven gas.

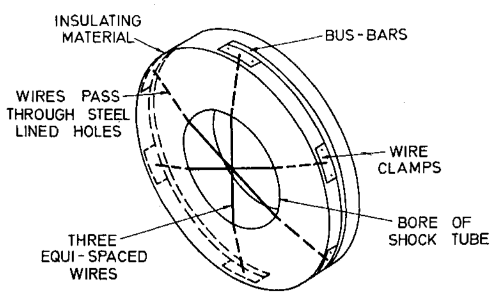

Fig. 1. General arrangement of device.

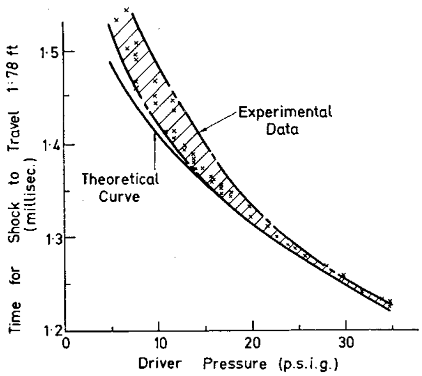

Fig. 2. Reduction of shock strength below ideal.

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