A Self-Opening Diaphragm for Expansion Tubes and Expansion Tunnels

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IN expansion tube and expansion tunnel operations,[1,2] the secondary and ternary diaphragms (Fig. 1) are burst by normal shock waves which travel downstream. These diaphragms are usually made of a thin, light-weight material such as mylar. Experimental investigations have shown that using these shock waves to burst the mylar diaphragms can seriously affect the efficiency of the facility as well as the quality of the test gas.

A possible solution to this problem would be to provide a means of opening these diaphragms a short time prior to the arrival of the shock. Such a device would have to open the secondary diaphragm to the full tube area in as short a time as possible. For use as a ternary diaphragm, it was estimated that an opening time of 500 μsec would not seriously disrupt the flow. Also, the device must be capable of supporting a pressure differential as great as 100-mm Hg. This Note will discuss a device which utilizes electromagnetic forces to meet these criteria.

Figure 2 shows cross-sectional views of the configuration for the self-opening diaphragm and its retainer rings. The diaphragm is made of 0.0038-mm or 0.006-mm mylar. The opening mechanism is constructed of No. 15 magnet wire which has an insulating coating. The mechanism is of a one piece, tri-spoke construction with electrical connections at the end of one of the spokes.

The wire is bent to the desired shape, and then bonded to the diaphragm with DuPont cement No. 46950, a mylar bonding material, which is applied under heat and pressure. The mylar diaphragm material must be preshrunk by heating for one hour at 150°C before bonding.

The retainer rings are constructed of micarta. The o ring in the face of each ring provides a vacuum seal across the diaphragm. The other two surfaces have o ring finishes to seal with the rest of the system. The electrical feedthroughs are sealed in place with epoxy. The retainer ring assembly provides a cavity into which the wire and mylar can retract. The two hooks are used as restraints for two of the spokes.

The force generated by passing opposing currents through parallel conductors was used to open the diaphragm. The repulsive force between the pairs of each spoke moves the wire in its plane to a near-circular loop as shown in Fig. 3.

The capacitor energy storage system used with the self-opening diaphragm can provide maximum of 5.0 kjoule at 5.0 kv. The system has a discharge time constant of 240 μsec, and a ringing frequency of approximately 5.3 kHz with

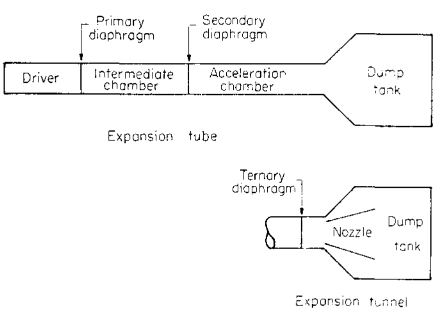

Fig. 1 Diaphragm placement for expansion tube and expansion tunnel operations.

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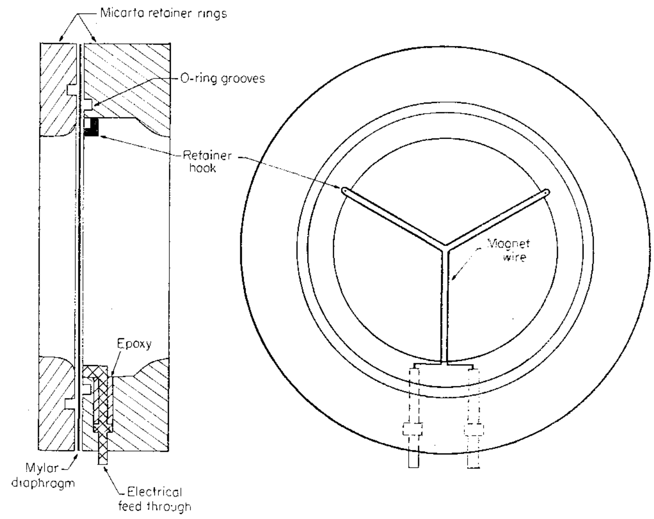

Fig. 2 Cross section of retainer ring assembly and wire configuration.

the load. The discharge unit is designed to accept a triggering pulse so that the diaphragm opening can be synchronized with the flow.

Figure 4 gives the opening times of the diaphragm as a function of the capacitor energy. For this case, the total area to be opened was 76.0 cm² and the diaphragm material was 0.006-

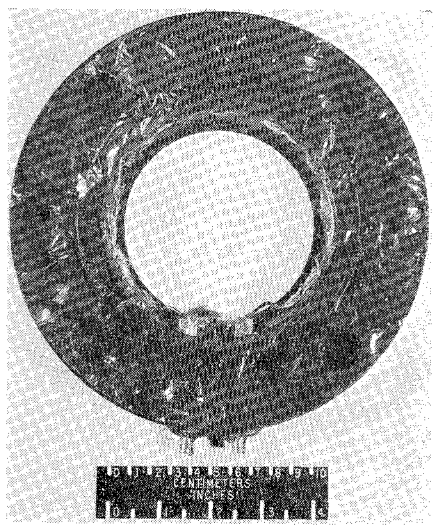

Fig. 3 Diaphragm configuration after opening.

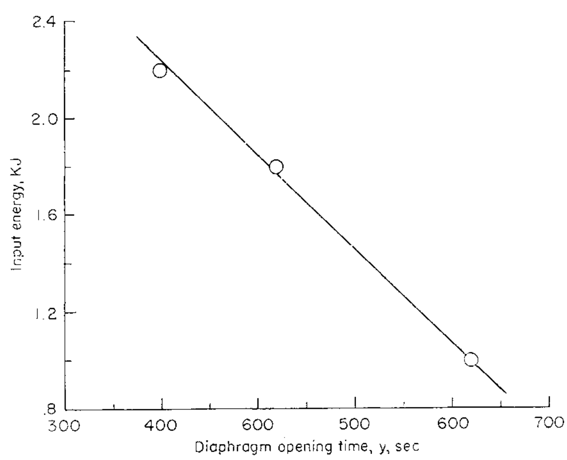

Fig. 4 Diaphragm opening time as a function of input energy.

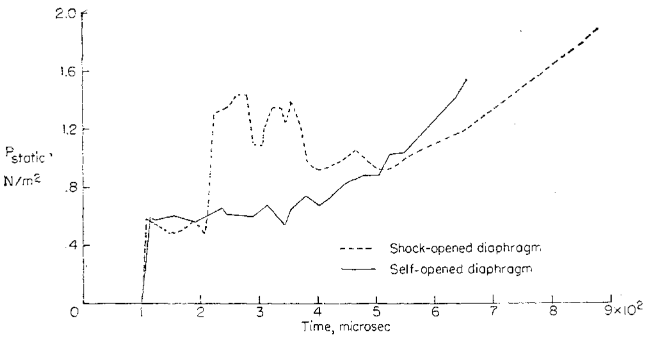

Fig. 5 Comparison of static pressure upstream of the ternary diaphragm for a shock-opened and self-opened diaphragm. Incident shock Mach number = 3.9. Static pressure port located 94.5 mm upstream of diaphragm.

mm mylar. The usable upper limit for the energy is 2.2 kjoule as greater energies break the wire. Tests showed that the cavity in the retainer ring assembly needs to be lined with a deformable, energy absorbing material to keep the wire from rebounding off of the cavity surface.

Experimental results have shown that when used a ternary diaphragm, this device has eliminated the reflected shocks observed when the diaphragm was opened by the incident shock. See Fig. 5 for a comparison of upstream static pressures. Also, flow downstream of the diaphragm is comparable to the case for which no ternary diaphragm was used, e.g., the straight expansion tube. This device may have further application as a high-speed optical shutter or as an opening device on ballistic ranges.

References

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[2] Trimpi, R. L. and Callis, L. B., "A Perfect-Gas Analysis of the Expansion Tunnel, A Modification to the Expansion Tube," TR R-223, 1965, NASA.

Thermal Boundary-Layer Similarity at Limiting Prandtl Numbers

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Introduction

THE study of thermal boundary layers is greatly simplified by consideration of very small[1–3] or very large[3–6] Prandtl numbers. The solution is then written as a series expansion in terms of a small parameter[2,3] (the Prandtl number or its inverse, depending on the case). The principles involved in evaluating each term of the expansion are essentially the same.[2,3] For simplicity only the first term of the expansion is considered here. The case of a large Prandtl number is of particular importance since it is well known that results derived under such an assumption are still numerically adequate even for Prandtl numbers of order one (case of gases).[4]

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For instance, for $Pr \gg 1$ an incomplete gamma function[3,6] is obtained as a fundamental similar solution† when the temperature at the wall is a step function and for the most general flowfield. The problem being linear, the solution for an arbitrary wall temperature can then be written by integral superposition.[3,6] Although straightforward in principle, an integral superposition can be cumbersome to handle numerically. Furthermore since the fundamental solution has such a simple form,[3,6] it is natural to try to obtain the most general similar solution, not limited to a step function for the wall temperature.

Indeed, there exists a general class of boundary conditions at the wall (among which the earlier step function[3,6] is but a particular case) which yields a corresponding class of simple solutions. Besides its intrinsic interest the existence of a general class of similar solutions allows for the consideration of an arbitrary temperature distribution at the wall by a series expansion. If only a few terms in the series are necessary to represent the wall temperature adequately then it is advantageous to use the more explicit series solution rather than the earlier integral representation.[3,6] Furthermore the method applies equally well for temperature or heat flux prescribed at the wall, in contrast to the earlier approach[2,3,6] which can be applied in general only if the wall temperature is known.‡

Thermal Similarity

The thermal boundary layer, for both planar and axisymmetric flows is governed by,

$$u\partial T/\partial x + v\partial T/\partial y = \nu Pr^{-1}\partial^2 T/\partial y^2 \tag{1}$$

where Pr is the Prandtl number, ν the kinematic viscosity, T the temperature, u and v the components of the velocity along the wall (x direction) and normal to the wall (y direction), the fluid is incompressible and its properties constant. Call

$$\bar{x} = xU/\nu, \quad \bar{y} = yU/\nu \tag{2}$$

two dimensionless coordinates. U is an arbitrary constant with the dimensions of a velocity; for instance U could be the velocity at infinity upstream if the flow there is uniform. For $Pr \ll 1$ the thermal boundary layer is much thicker than the viscous layer and (u,v) in Eq. (1) can be replaced by the velocity at the wall of the potential flow.[1–3] For $Pr \gg 1$ the thermal boundary layer is much thinner than the viscous layer and (u,v) can be replaced by the velocity in the viscous boundary layer near the wall.[3–6] In both cases the velocity field can be represented in general by

$$u = U\beta(\bar{x})\bar{y}^m,\ v = -U[r(\bar{x})\beta(\bar{x})]'\bar{y}^{m+1}/r(m+1) \tag{3}$$

$\beta(\bar{x})$ is an arbitrary function of $\bar{x}$, $r(\bar{x})$ is equal to one for a planar flow and to the distance of a point at the wall to the axis for an axisymmetric flow. Normally m is equal to zero[2,3,6] if $Pr \ll 1$ and to one or two[3,6] if $Pr \gg 1$. The following treatment is not limited to those values of m but applies to any arbitrary m (notice that if $Pr \gg 1$ then $m \geq 1$ for the stress to be finite at the wall). It is clearly possible to construct pathological flows not included in Eq. (3), but all the flows of interest are represented if m is kept arbitrary.

When the temperature at the wall is a step function then $(T - T_\infty)/T_\infty = h(\eta)$ where T_∞ is the constant freestream temperature and η is the similarity variable which can be

† Usually,[3] similarity refers to the viscous boundary layer and imposes constraints on the outside flow. In the present context on the contrary, similarity involves only the thermal boundary layer and the outside flow remains arbitrary.

‡ In numerous problems of practical importance the temperature at the wall is unknown a priori, while some knowledge of the heat flux is available. This is the case, for instance, whenever solar radiation is the primary heating source of the wall (which could be anything from a low speed aircraft to the leaves of a plant).