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Expansion Tunnel Performance with and without an Electromagnetically Opened Tertiary Diaphragm

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Introduction

PREDICTIONS[1] for expansion tunnel flow demonstrate that substantial losses in available test time occur when the nozzle is not evacuated to a much lower initial pressure than the quiescent acceleration gas. To obtain a lower initial nozzle pressure, a diaphragm must be used to separate the acceleration section and nozzle. This diaphragm, referred to as the tertiary diaphragm,[2] must be self-opened, since experiment has shown a flow-ruptured diaphragm results in a degradation in nozzle entrance flow quality.[2] Naturally, such a diaphragm cannot open instantaneously as assumed in prediction,[1] and because of the finite opening time, the opening must be synchronized with the flow arrival at the diaphragm. Upon opening the tertiary diaphragm, an expansion wave propagates into the quiescent acceleration gas at the ambient speed of sound. If the diaphragm is opened too soon in the flow sequence, the flow will experience a density gradient in the acceleration gas in the vicinity of the nozzle entrance. The time available for the spreading of this density gradient is reduced if the opening is initiated at the proper time. If the flow arrives prior to removal of the diaphragm from the nozzle entrance, a reflected shock will be produced,[3] resulting in a degradation of nozzle flow quality.

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The purposes of the present study are to 1) examine the effect of synchronization of an electromagnetically opened tertiary diaphragm with flow arrival at the diaphragm on the pitot pressure measured at the test section of the Langley expansion tunnel and 2) determine the effect of tertiary diaphragm pressure ratio (ratio of initial nozzle pressure to quiescent acceleration section pressure) on the pitot pressure time history. As a point of interest, the present study revealed the inadequacy of a pressure transducer protection arrangement used in previous expansion tube and expansion tunnel tests.[3] This inadequacy, in terms of response time, is demonstrated herein for the short test time of the expansion tunnel and low magnitude of pitot pressure.

Apparatus and Tests

The Langley expansion tube[4] is basically a 15.24-cm-diam tube divided into three sections by two diaphragms; thus, this facility may be viewed as a shock tube with a constant diameter tube section added to the downstream end. The driver gas is introduced into the upstream, high-pressure section and the intermediate section is filled with the desired test gas. The downstream section is referred to as the expansion or acceleration section and is filled with the acceleration gas. Thick steel diaphragms separate the driver and intermediate sections, whereas a thin Mylar diaphragm separates the intermediate and acceleration sections. The expansion tunnel[3] is simply an expansion tube with a nozzle installed at the exit of the acceleration section. A third or tertiary diaphragm separates the acceleration section and nozzle so that the initial nozzle pressure may be lower than the quiescent acceleration gas pressure.

The idealized operating sequence of the expansion tube is shown schematically in Fig. 1. Upon rupture of the primary diaphragm, an incident shock propagates through the test gas and encounters and ruptures the low-pressure secondary diaphragm. A secondary incident shock propagates into the acceleration gas and the shock-heated test gas undergoes an isentropic, unsteady expansion as it passes through the upstream expansion wave generated upon rupture of the secondary diaphragm. This expansion process generates hypersonic and hypervelocity flow at the acceleration section exit from the low Mach number shock-tube flow which encounters the secondary diaphragm. For the expansion tunnel, the test gas undergoes an isentropic steady expansion in the nozzle following removal of the tertiary diaphragm at the acceleration section exit.

An electromagnetically opened tertiary diaphragm[2] was employed. The concept is to use electromagnetic repulsive forces in a wire to rip open a Mylar diaphragm and rapidly withdraw the Mylar from the flow path. In this study, the copper wire was 13 AWG (American Wire Gage), the Mylar was 12.7 μm thick, and the energy storage system (which consisted of two capacitors, each rated at 5 kV and 100 μf) was charged to 3.2 kV. This voltage produced opening times[2] of 700 to 900 μsec without wire breakage. The tertiary

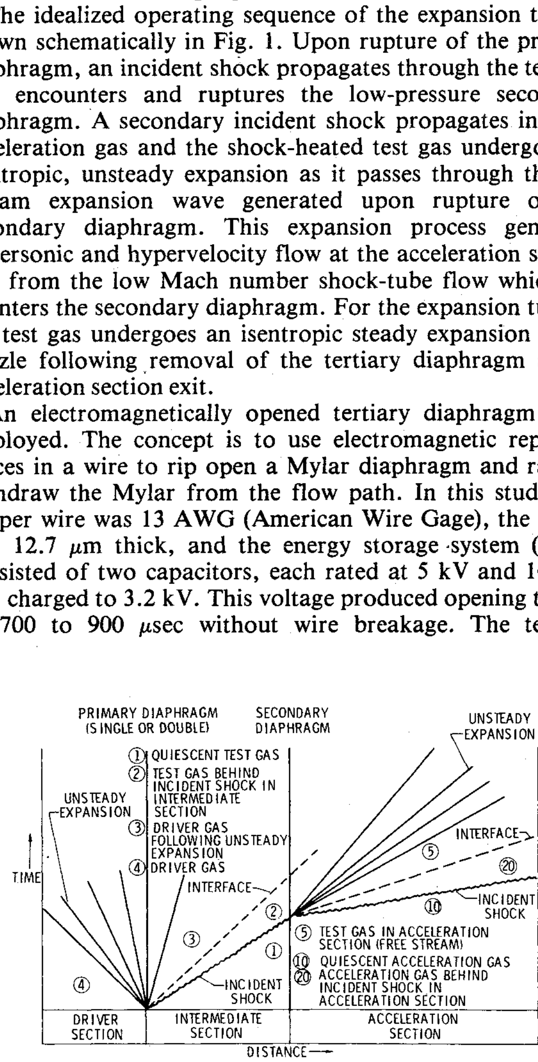

Fig. 1 Schematic diagram of expansion tube flow sequence.

diaphragm was positioned 1.3-cm upstream of the nozzle entrance.

The present tests were performed with an unheated helium driver pressure of approximately 33 MN/m^2, air test gas at a quiescent pressure of 3.45 kN/m^2, and air acceleration gas at a quiescent pressure of only 3.2 N/m^2. For tests with the tertiary diaphragm, the ratio of initial nozzle pressure to quiescent acceleration air pressure was less than 0.05. Entrance and exit diameters for the 10° half-angle conical nozzle were 8.9 cm and 63.5 cm. The output signal from a thin-film resistance gage located 9.255-m upstream of the tertiary diaphragm was supplied to a time-delay generator connected to the energy storage system of the self-opened diaphragm. This arrangement permitted the time interval between initiation of the diaphragm opening and arrival of the flow at the diaphragm station $\Delta\tau$ to be varied. Values of $\Delta\tau$ were inferred using a nominal value of the time required for the incident shock in the acceleration gas to travel the distance between the location of the resistance gage and diaphragm location. (Electrical disturbances generated by the discharge of the energy storage system created disturbances on the output of time-of-arrival instrumentation[3] and on microwave measurements,[3] thereby prohibiting measurement of the incident shock velocity in the vicinity of the acceleration section exit. A nominal value of 1695 μsec was obtained from five tests without the tertiary diaphragm.)

Pitot pressures at the nozzle exit were measured using commercially available, miniature quartz pressure transducers. The transducers were mounted in probes having an outside diameter at the sensing surface of 7.9 mm.[3] Two methods of mounting the pressure transducers in the pitot pressure probes were used. One was simply to install the sensing surface of the transducer flush with the end of the probe; this method is referred to herein as flush mount. The second was to place a perforated disk ahead of the transducer to protect the transducer from particle contamination in the post-test flow.[3] This arrangement for protecting the transducer is illustrated in Ref. 3 and referred to herein as protector disk. To minimize the chance of destroying the flush-mounted transducer, the probe was positioned 6.9 cm off the nozzle centerline and out of the bore of the nozzle entrance. Results presented for the protected transducer were obtained from an adjacent probe, 4.6 cm from the nozzle centerline.

Results and Discussion

Pitot pressure time histories with no tertiary diaphragm (initial nozzle pressure equal to the quiescent acceleration gas pressure) and with the self-opening tertiary diaphragm are shown in Fig. 2. These pitot pressure time histories were obtained with the pressure transducer mounted flush with the end of the pitot pressure probe. For tests with the tertiary diaphragm, the only variable in Fig. 2 is the time difference between initiation of the diaphragm opening and arrival of the flow at the diaphragm, $\Delta\tau$. The pitot pressure time history measured at the nozzle exit for the case of no tertiary diaphragm reveals the existence of initial peaks in pitot pressure, which are followed by a quasisteady pitot pressure period of approximately 400 μsec. For the two largest time intervals presented in Fig. 2, an initial peak in pitot pressure such as observed for the case of no tertiary diaphragm is absent; however, a quasisteady pitot pressure period of 300 to 350 μsec exists and the magnitude of this pitot pressure is essentially equal to that measured for the no-diaphragm test. This indicates that the nozzle flow is fully started for the case of no tertiary diaphragm, despite the higher initial nozzle pressure and usage of the tertiary diaphragm diminishes the magnitude of the starting shock. Also, the useful quasisteady flow period for the case of no tertiary diaphragm appears to exceed that obtained with the tertiary diaphragm. These findings contradict the predictions of Ref. 1, which indicated that excessively long nozzle starting times would be required if

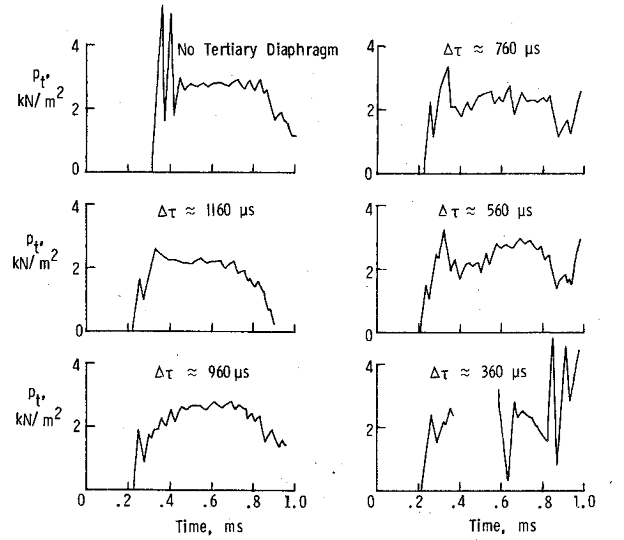

Fig. 2 Pitot pressure time history for the case of no tertiary diaphragm and for various time intervals between initiation of tertiary diaphragm opening and flow arrival at the diaphragm.

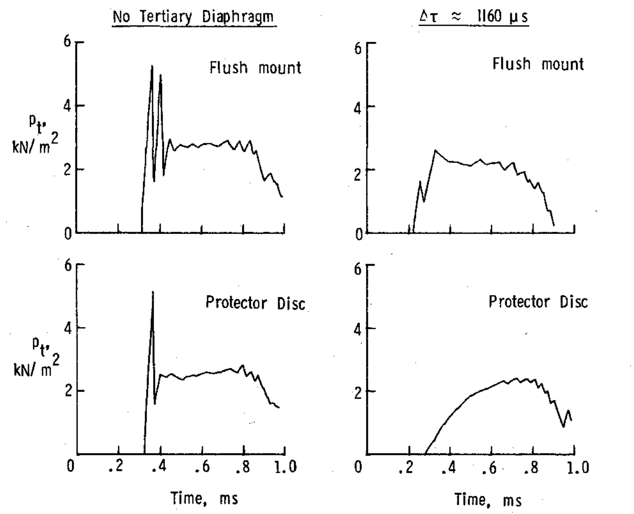

Fig. 3 Pitot pressure time histories for flush-mounted pressure transducer and a transducer having a protector disk.

the nozzle were not evacuated initially to a pressure much lower than the acceleration gas pressure. A possible explanation for the discrepancies between experiment and prediction is that in Ref. 1, the tertiary diaphragm was assumed to open instantaneously, whereas the actual opening time was approximately 700 to 900 μsec, and the nozzle flow is not one dimensional as assumed in Ref. 1.

The two largest time intervals exceed the diaphragm opening time determined from bench tests, implying that the diaphragm is removed completely from the tube prior to flow arrival. When the time interval is approximately equal to the diaphragm opening time ($\Delta\tau \approx 760$ μsec), the pitot pressure experiences a more pronounced initial pressure increase. This is expected, since the time available for the spreading of the density gradient in the quiescent acceleration gas is reduced. Following this initial increase for $\Delta\tau \approx 760$ μsec, the pitot pressure is nearly constant for approximately 450 μsec; however, the magnitude of the fluctuations in pitot pressure is greater than those observed for the two largest time intervals and for no tertiary diaphragm. For time intervals less than 760 μsec, thus, less than the diaphragm opening time, a degradation in pitot pressure time history occurs. For the smallest time interval, which is considerably less than the diaphragm opening time, the pitot pressure time histories resemble that of a flow-opened tertiary diaphragm, indicating that the diaphragm was not removed sufficiently at the time of flow arrival to avoid producing a disturbance at the nozzle entrance. That reasonably good quality pitot pressure time histories were measured for time intervals nearly equal to or somewhat less than the opening time is attributed to the close positioning of the nozzle entrance to the diaphragm. This permits the diaphragm to open cleanly to approximately the entrance diameter of 8.9 cm, instead of the tube diameter of 15.4 cm, to avoid significantly disturbing the nozzle-entrance flow. (Pitot pressure magnitudes, during the period of nearly constant pitot pressure, were within 10% of the mean value for no tertiary diaphragm and time intervals equal to 1160, 960, 760, and 560 μsec. This implies that nozzle flow started for no diaphragm and for time intervals less than the diaphragm opening time.)

The present tests demonstrated that a significant pressure lag effect exists for pitot pressure probes in which the pressure transducer is protected from particle contamination in the post-test flow by a perforated disk arrangement.[3] This effect is illustrated in Fig. 3, where pitot pressure time histories for a flush-mounted pressure transducer and a protected pressure transducer are shown for tests with no tertiary diaphragm and the self-opening diaphragm for $\Delta\tau \approx 1160$ μsec. The protective arrangement used in this study did not produce a pressure lag effect in expansion tube tests, where the pitot pressure was approximately 100 times that measured at the tunnel exit,[3] nor in calibration shock-tube tests for pitot pressures as low as 8 to 10 kN/m^2. Also, the preliminary expansion tunnel pitot pressure measurements presented in Ref. 3, which did not employ a tertiary diaphragm, gave no indication of the existence of a pressure lag effect as demonstrated in Fig. 3. However, by reducing the magnitude of the starting nozzle shock, the self-opening diaphragm data reveal that erroneous conclusions may be drawn from pitot pressure time histories if the protector arrangement is used. For example, the present protector arrangement and quasisteady pitot pressure magnitude of about 2.5 kN/m^2 yields a pressure lag time roughly 300 to 400 μsec, or nearly equal to the quasisteady flow duration.

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Response of Cantilever Columns under Transient Follower Forces

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Introduction

THERE has been an increasing interest in the problem of dynamic stability of columns subjected to transient axial loads. Holzer and Eubanks[1] and Holzer,[2] employing Liapunov's method, explicitly obtained a bound on the transverse motion of elastic columns subjected to a transient compressive force. McIvor and Bernard[3] studied the dynamic response of a simply supported column subjected to short duration axial loads including the effects of axial inertia. These works consider the transient loads to act axially. The present paper deals with the elastic response of a cantilever column to a transient compressive follower load. Material dissipation is included by means of a Kelvin model for the material behavior. The amplification of the lateral response of the column is obtained assuming a set of initial perturbations. The effect of pulse duration, internal damping, and different initial perturbations are investigated. The present study is applicable to the analysis of the response of a severed pipeline conveying fluids under high pressure. The objective would be, to determine whether the pipe deforms enough to damage adjacent equipment and structure

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Formulation and Solution

The equation of motion for the small lateral vibration of a column of length ℓ and flexural rigidity EI loaded axially by a follower force $P_0(\tau)$ can be written in nondimensional form as

$$\frac{\partial^4 w}{\partial \xi^4} + \gamma \frac{\partial^5 w}{\partial \xi^4 \partial \tau} + P(\tau) \frac{\partial^2 w}{\partial \xi^2} + \frac{\partial^2 w}{\partial \tau^2} = 0 \tag{1}$$

where

w = transverse deflection

$\gamma = \dfrac{\mu}{\ell^2}\left[\dfrac{I}{Em}\right]^{1/2}$ = dimensionless dissipation parameter

μ = internal damping coefficient

$\tau = \left[\dfrac{EI}{m}\right]^{1/2} \dfrac{t}{\ell^2}$ = dimensionless time

m = mass per unit length

$P(\tau) = \dfrac{P_0(\tau)\ell^2}{EI} \geq 0$ in $(0,\tau)$ and $P(\tau) = 0$ when $\tau > \tau^*$.

Assumption of a solution in the form

$$w(\xi,\tau) = \Sigma Y_n(\xi) q_n(\tau) \qquad n = 1,2,... \tag{2}$$

where $Y_n(\xi)$ are the normal modes of the freely vibrating column, and application of Galerkin's techique leads to

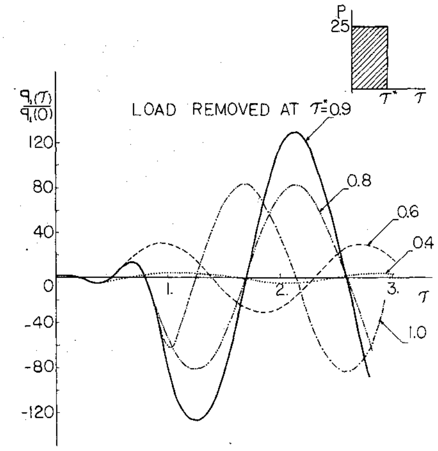

Fig. 1 Variation of q_1 with τ for various pulse duration τ^*.