Initial Flow Model in Shock Tubes

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Introduction

AMONG the perturbational phenomena of the flow generated by the incident shock wave in a shock tube, one of the most important comes from the noninstantaneous opening of the diaphragm. The flow has a three-dimensional behavior in the first instants of the rupture and compression waves continually arise next to the diaphragm during the opening, generate first a shock wave, accelerate and strengthen this wave. Many experiments, both old and new, have shown the importance of these effects.[1-4]

The formation process of a plane shock wave is confined in a small length of the tube,[3] but the acceleration process may require a large tube length, depending on initial conditions, diaphragm material and shape, and the tube itself.

White's model[2] is an approximation of the formation process; in the x,t diagram, compression waves are assumed to coalesce in a single point where the shock possesses its final and constant value, but the acceleration process is not taken into account. More recently, the "multistage" model[5] may be considered as an improvement of White's model but it is still a discontinuous model.

In the present model, the flow regime is related to the opening process itself. Boundary-layer effects are neglected, although it would not be too difficult to include them.[6] In the same way, the formation phase itself will not be taken into account, but a numerical method of determination of the flow variables is developed in order to describe the acceleration phase.

Model Analysis

The opening process itself is assumed known and determined only by the initial conditions. In fact, among the previous models tested experimentally,[7-10] this process[9] has been chosen in spite of its limitations; this model, however, gives the time-dependent ratio of the aperture area to the tube area.

Next to the diaphragm, practically at $x=0$, a steady flow is assumed (see Fig. 1). The driver gas is isentropically expanded (3a-3b) through the variable orifice of the breaking diaphragm and recompressed by a standing shock[11] (3c). Thus at each instant, the driver gas variables are related to the aperture area, assuming a simple wave regime in the high-pressure chamber. This scheme has already been suggested,[12] and it is qualitatively analogous to experimental observations.[13] The flow variables, determined along the $x=0$ line, are used as boundary conditions for the computation briefly described subsequently.

The computation of the entire flowfield is carried out using constant temporal steps, assuming perfect gases, and implicitly taking into account the compression waves arising at the diaphragm during the opening. The flow is assumed to remain one-dimensional, neglecting the initial three-dimensional effects.

The numerical procedure needs an initial scheme at $t=t_i$ (called "initial" instant). At t_i, the flow is assumed to have the same character as at the further instants, i.e., it is one-dimensional and includes a moving shock wave and an interface (Fig. 1). The problem is to determine the corresponding aperture so that, at t_i, the flow in 3c is compatible with this one generated by a moving shock wave. This

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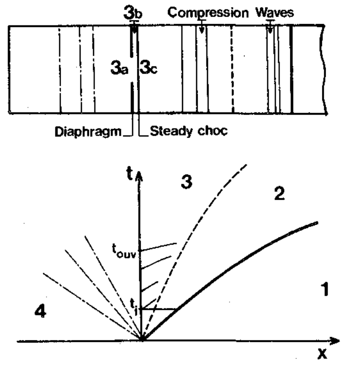

Fig. 1 Flow model in the x,t diagram.

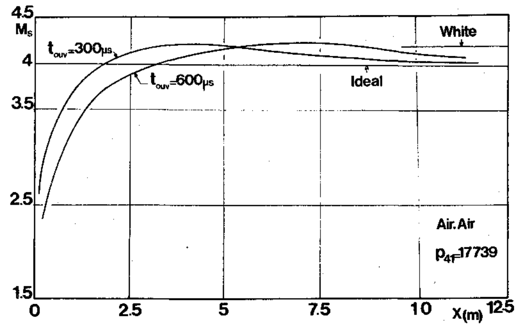

Fig. 2 Example of shock-wave evolutions.

problem has a unique solution.[14] Thus, knowing the opening process, the gas combination, the initial pressure ratio p_{41}, and the total opening time t_{ouv}, t_i can be determined as well as the initial shock Mach number M_{si} and the corresponding "initial" flow properties.

Numerical results show that, for a given combination, M_{si} depends very little on p_{41}, but t_i decreases when the ideal shock Mach number M_{sth} (or p_{41}) increases. For example, with air/air, $t_{ouv}=300$ μsec and $M_{sth}=4$ and 5 we have, respectively, $M_{si}=1.226$ and 1.225, $t_i=27$ and 8 μsec. Thus, the major part of the acceleration phase can be determined by the model. However, for light driver gases, t_i and M_{si} have higher values.

Results and Discussion

With the present hypotheses, the behavior of the flow, and in particular the evolution of the shock wave, are uniquely determined if the initial pressure ratio p_{41} (or M_{sth}) and t_{ouv} are known. The absolute pressure of the low- and high-pressure chambers, the tube diameter, and the characteristics of the diaphragm determine t_{ouv}[8].

Figure 2 shows characteristic shock-wave evolutions along the tube. As expected, the shock Mach number rapidly increases next to the diaphragm. After it reaches a maximum of nearly the same value as in White's model, it slowly decreases to the ideal shock Mach number. This behavior has been found for different gas combinations, and experimental results[2-5] confirm the existence of a maximum greater than the ideal value when the boundary-layer effects are small.

Such an evolution may be interpreted with simple considerations since, when $t/t_{ouv}\rightarrow\infty$, the regime corresponds to the ideal case, and the velocity decrease may be attributed to the reflections of the compression waves at the shock and at the contact surface. The existence of a maximum depends on the relative acoustical impedances of the driver and driven gases. An example of temporal temperature variations between the diaphragm and the shock wave is represented in Fig. 3.

The influence of t_{ouv} has been analyzed and obviously the shock-wave evolution is more rapid when t_{ouv} is small. Moreover, the abscissa of the maximum is proportional to

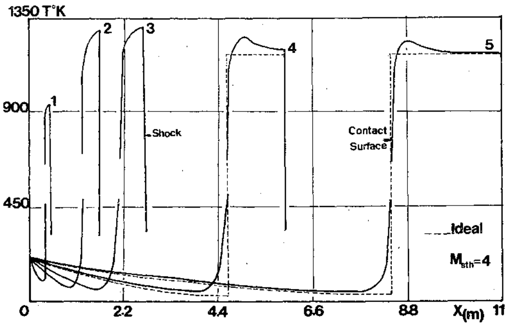

Fig. 3 Example of temperature profiles. 1. $t=550$; 2. $t=1350$; 3. $t=2100$; 4. $t=4350$; 5. $t=800$ μsec.

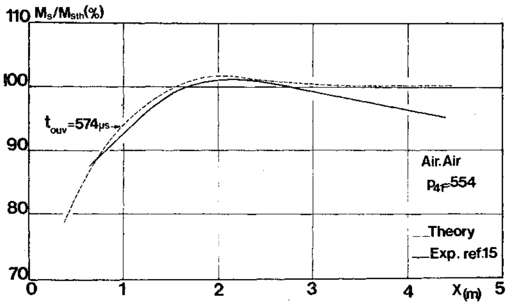

Fig. 4 Comparison of theory and experiments (Ref. 15).

t_{ouv}, but the value of this maximum M_{sm} is not affected. These results are in agreement with experimental data.[3] The influence of p_{41} has also been studied, and it has been shown that the initial acceleration and the abscissa of the maximum increase when p_{41} increases,[2] but the ratio M_{sm}/M_{sth} is only slightly modified. Finally, the lighter the driver gas is (high sound velocity), the more rapidly the ideal value is attained and the smaller the maximum is.

A comparison has been made with the experimental data of Ref. 15, for which viscous effects are small (Fig. 4). Keeping in mind the relative inaccuracy observed for t_{ouv}, which has not been given by the authors, the agreement may be considered as good in the acceleration phase.

Conclusion

The model may be improved by taking into account the following points: Temporal variation of the pressure on either side of the diaphragm, real gas effects, initial three-dimensional dissipative effects, noncentered expansion waves in the high pressure chamber, and turbulent transport phenomena at the contact surface. This model must also take into account boundary-layer effects,[6] so that comparisons with experimental data will be more significant.

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Effect of Electric Field on Composite Solid Propellants

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Introduction

COMPOSITE-SOLID propellants generally contain an oxidizer like ammonium perchlorate (AP). It has been shown recently by this school that the thermal decomposition of the propellant itself and the oxidizer contained in it play a significant role during the combustion.[1,2] The oxidizer (AP) decomposition, as shown by Maycock and Pai Verneker, seems to be controlled by the ionic diffusion process in the low-temperature region.[3] The ionic diffusion process, on the other hand, may further depend upon the nature of the charge-carrying species. For example, in AP it has been shown by conductivity measurements and electric field effects that the perchlorate ion is the charge-carrying species which controls the diffusion process during thermal decomposition.[3-5] Since the oxidizer decomposition seems to be the controlling process during the propellant decomposition, it is worthwhile to examine the effect of the electric field on the propellant decomposition and its subsequent ballistic behavior. The objective of the present Note, therefore, is to examine the effect of prior electric field on the thermal decomposition and burning behavior of the propellant. It may be mentioned here that no studies on the effect of prior electric field treatment on propellant behavior have been reported in the open literature.

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