The author's interpretation of significance of results is questionable with regard to smoke point, which is actually an empirical test of burning quality and could be considered only as related to deposit-forming tendency in combination with other factors. The index of deposit-formation referred to when discussing smoke point and volatility corresponds precisely to the smoke volatility index developed in the United States by the Coordinating Research Council and incorporated in specifications of the American Society for Testing and Materials (ASTM), although the author makes no reference to either organization in this connection.

Another notable omission in the discussion of burning quality and radiation is the development by the Coordinating Research Council of the luminometer method to determine flame temperature. Results by this method are now incorporated in ASTM specifications for commercial aviation turbine fuels.

There is an ambiguity in the statement that bicyclic aromatics are determined by the chromatographic method. Although chromatographic methods for the determination have been reported, the referenced method does not provide for such determination, and preferred spectroscopic methods usually are used.

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AUGUST 1963 AIAA JOURNAL VOL. 1, NO. 8

Transition of Burning into Detonation in Gases

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Transition of burning into detonation may take place in a number of different ways,[1] depending on the particular condition of gas flow. The initiation of detonation is associated with the acceleration of the burning region, which gradually changes the shape of the convex laminar flame. The increase of the surface area of the flame leads to the progressive increase in burning rate of the gas, which in turn causes an increase in pressure, flow speed, and temperature of the unburned mixture in a compression wave in front of the flame. The detonation wave is generated as a result of an explosive auto-ignition by adiabatic heating of the mixture in the burning region or ahead of it.

The burning region, as it accelerates, may overtake the compression wave-front without forming a detonation. In such case, after a little while, the flame and the compression wave may be propagated in the form of a single complex.[2] Thereafter, the process culminates also in an explosion in the body of the gas. If the compression wave is reflected from the closed end of the tube, explosive ignition may take place in the compressed gas behind the reflected wave. If the temperature of the gas behind the reflected wave is below the auto-ignition temperature of the mixture, the reflected wave induces some additional deformation of the flame, increasing the burning rate.

Currently known methods of predicting the formation of the detonation wave (see, for example, Refs. 1, 2, and 3) are based on consideration of the condition for simultaneous existence of two discontinuities, the shock wave and the flame front, which are in the process of interaction and coalescence. It can be seen from experiments described in this paper that the pressure change in the shock front of the compression wave that propagates ahead of the flame is much smaller than the pressure increase in the region where the compression is continuous and adiabatic. Under such circumstances, it is convenient to limit the analysis to the approximate model involving an adiabatic wave and a flame, quite different from actual observations but permitting an easy evaluation of the thermodynamic state of the compressed gas.

1. Computation of the State of the Gas

We consider the flow generated in a long tube of constant cross section on ignition of the mixture at the closed end. A compression wave is propagated ahead of the flame front, bounded in the general case by a shock wave of small amplitude at its forward end. We will assume as an approximation that, in this wave, the two families of characteristics are subject to the condition of conservation of the Riemann invariant

$$u_2 - \frac{2}{\gamma - 1} c_2 = - \frac{2}{\gamma - 1} c_1$$

The speed with which the burning region is translated relative to the walls of the tube is found as the sum of the speed of the gas flowing ahead of the flame and the burning speed. For a laminar flame, the relative translation speed is therefore

$$U = u_2 + S = u_2 + S_n \frac{\Sigma}{\sigma}$$

Here Σ is the surface area of the flame, σ the area of the tube cross section, and S_n the normal burning speed of the mixture. If we assume that the burned gas is at rest with respect to the tube wall, it is possible to describe the motion of the flame by the following relations:

$$\rho_2 S = \rho_3(S - u_3) \qquad S^2 = \frac{\rho_3}{\rho_2}\left(\frac{p_3 - p_2}{\rho_3 - \rho_2}\right)$$

$$u_3 + u_2 = 0 \qquad \frac{p_3}{\rho_3}\frac{\rho_2}{p_2} = a\,\frac{T_1}{T_2}$$

The latter expression is a close approximation to the experimental data presented in Ref. 3.

For the mixture $C_2H_2 + O_2$ the value of a may be taken equal to 24.3. The degree of approximation in this relation, and also the absence of any consideration of the dependence of specific heat on temperature, limits the accuracy of the computation of the state of the gas to about 10%.

Translated from Zhurnal Prikladnoi Mekhaniki i Technicheskoi Fiziki (Journal of Applied Mechanics and Technical Physics), no. 4, 128–132 (1961). Translated by David T. Williams, University of Florida.

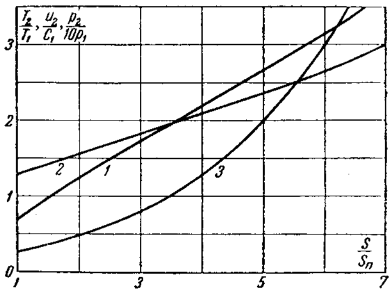


Fig. 1 Computed curve of the state of the gas in front of the flame front: 1) temperature; 2) speed of the gas; 3) pressure.

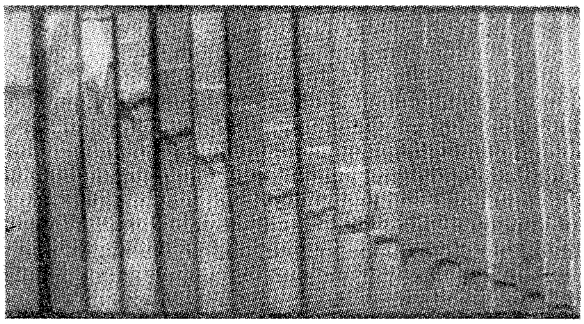
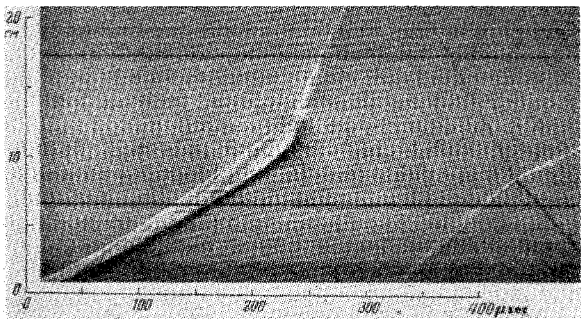


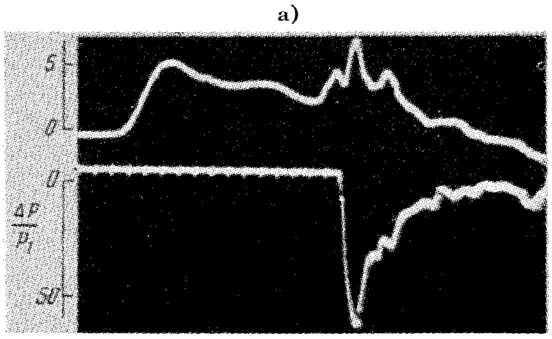
Fig. 2.

Figure 1 shows the computed value of the flow speed u_2/c_1 (curve 1), the temperature T_2/T_1 (curve 2), and the pressure $p_2/10p_1$ (curve 3) of the gas ahead of the flame front as they depend on the ratio of the speed S to the normal speed S_n which is assumed equal to 1300 cm/sec. The profile of pressure, density, and gas velocity in the compression wave may be determined by the use of the ordinary gasdynamic methods if the change in the burning rate is known as a function of time.

The computed prediction would not be accurate as a description of the phenomenon if the initial compression wave were a strong shock discontinuity. The formation of such a discontinuity plays a special role in the analysis of the transition from burning to detonation, in that the coalescence of the flame with that discontinuity is considered a necessary condition for the formation of detonation. Actually, detonation ordinarily arises as the result of the explosive self-ignition in the body of the adiabatically heated mixture, as described in Ref. 4. In the following, the results of experiments are described, illustrating the peculiarities of the dynamics of the formation of detonation in relation to the indicated theory of the process.

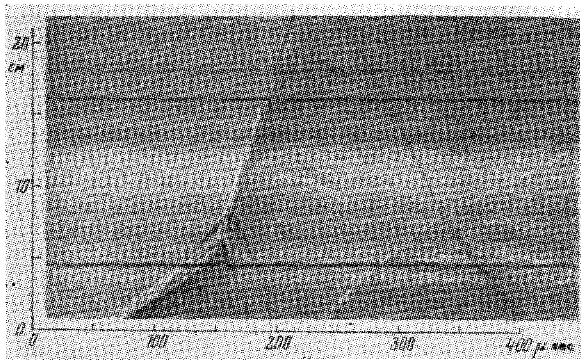


a)

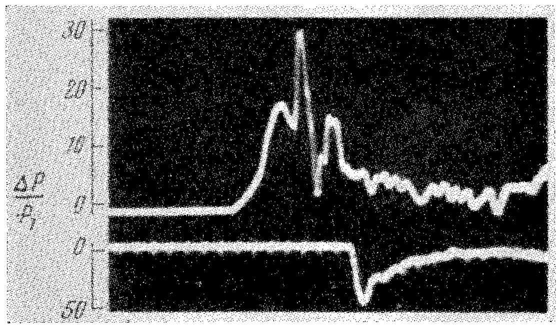


b)

Figs. 3a, b (Ordinate of 3a, cm.; abscissa of 3a, μsec.)



a)



b)

Figs. 4a, b (Dimensions as in 3a.)

2. Initiation of Detonation

For clarification of the details of the formation of a detonation wave, simultaneously with the shaded photograph of the process, a pressure record was obtained on the wall of the channel by two piezoelectric elements, each with a diameter of 13 mm. The mixture investigated was composed of equal volumes of acetylene and oxygen at an initial pressure of 50–200 mm Hg. The dimensions of the explosion chamber were 4 × 25 × 400 mm. Successive frames of a motion picture of the developing detonation are reproduced in Fig. 2. Figures 3 and 4 present the development, showing position of pressure discontinuity as a function of time and also an oscillograph record of the pressure accompanying the formation of the detonation. (The time scale is the same; the marks on the oscillogram are at 10-μsec intervals.)

The positions at which the pressure records were obtained are marked by dark lines parallel to the time axis on the schlieren streak photographs.

As is evident from the successive motion picture frames (Fig. 2) there are only small changes in the shape of the flame front at the initial stages of the process. Its speed of propagation is approximately equal to the

$$u + (\pi/2)S_n = 365 \text{ (m/sec)}$$

theoretical value, obtained by representing the shape of the flame in the plane of the channel by a half circle.

In accordance with known observations, the distance traversed by the flame from the point of its initiation without a significant change in shape is determined to a considerable degree by the nature of the inner surface of the tube wall; it is sharply reduced by roughened walls. Furthermore, the extent of the predetonative acceleration of the flame is increased when the initial density of the mixture is decreased.

The rise in pressure recorded by the pressure pickup ahead of the flame front reflects the predistortion change in the

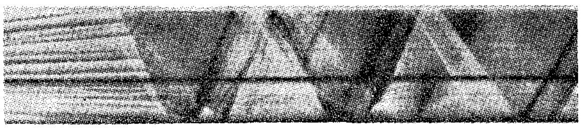


Fig. 5.

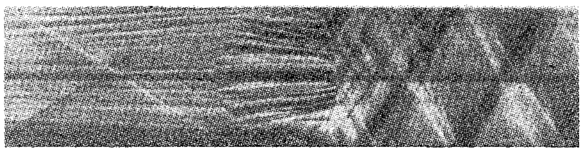


Fig. 6.

burning rate. The position of maximum pressure in the compression wave coincides with the beginning of the burning region. Since the burning region has a finite size, a sharp fall in pressure, corresponding to transition through the flame front, is not observed. The absolute value of the maximum pressure in the compression wave corresponds to that predicted for the approximate theoretical model of the process.

The maximum temperature of the mixture in the compression wave is somewhat less than the self-ignition temperature, so that, as a rule, formation of the detonation wave does not take place outside of the burning zone, unless there is some possibility for a supplementary frictional heating of the compressed gas.

From the photographs, it becomes clear that the detonation wave is generated as the result of an explosive inflammation of one or several volumes of the mixture in the burning region (the detonation wave ordinarily consists of several disturbances). The origin of these explosions may be explained by the following mechanism. As the result of the pronounced change of the shape of the flame, different volumes of the unburned mixture become partially or completely surrounded by the flame. Supplementary heating of the gas as a consequence of local compressions may lead to explosive local self-ignitions. An oscillogram of the explosion in the burning region behind the compression wave is shown in Fig. 4.

The generation of local explosions and of the detonation may be observed both up to the moment when the burning region overtakes the front of the compression wave and after their coalescence. In our experiments, the existence of the "complex" shock-flame wave system is observed ordinarily when the initial pressure of the mixture is low. The speed of such a wave is about 1000 m/sec, and the estimated value of the temperature of the compressed gas is less than 750°K.

3. Determination of the Point of Origin of the Explosion

In order to observe the initial stage of explosion that occurs in the course of transition from slow burning to detonation, as well as the motion of the flame across the tube, a photograph was taken of the density field in the tube cross section. In these experiments, a circular tube was used with an internal diameter of 10 cm and a length of 110 cm, with the wall at the end made of optical glass. The tube was illuminated along the axis by a parallel beam of light in a schlieren apparatus. The variation of the schlieren picture with time was observed through a narrow slit across the center of the circular cross section. The mixture was ignited near the glass window at the end, in the center of the tube. Experiments showed that the explosion started near the tube wall or at several points simultaneously. Figure 5 demonstrates the schlieren record of the propagation of the explosion (the density field) from a single point on the wall of the tube when detonation forms in the acceleration region of burning up to the reflection of the compression wave from the closed end. Figure 6 presents the time variation of the inflammation after the reflection of the shock wave from the closed end of the tube. The figure clearly shows the moment of reflection (converging and diverging radial waves), the propagation of the shock wave through the convex uneven surface of the flame, and the moment of explosion, propagated from the wall toward the center. After the explosion, the intense radial oscillations of the burning gas are clearly recorded; these oscillations play an important part in the explanation of detonation spin.

—*Submitted May 16, 1961*

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Reviewer's Comment

The paper is evidently the result of work done by the author when he was associated with the laboratory of Professor Predvoditelev at the Krzizyanovsky Institute of Energetics in Moscow. It is concerned exclusively with experimental records and their purely qualitative interpretation. Although some mention is made of quantitative predictions, as is usual, they are not specifically reported. All the photographic and pressure records, with exception of the last two figures, are a duplication of those published by Salamandra et al. (the author's Ref. 1). The technique of observing the progress of the process from the butt end of the detonation tube that yielded the last two photographs seems to be novel and provides a significant proof that the point of onset of the retonation wave is indeed located close to the wall.

As usual, no mention is made of western literature, notably the pioneering work of Schmidt et al.[1], and subsequent interpretation of such observations which have been provided by Oppenheim and Stern,[2] Oppenheim, Stern, and Urtiew,[3] and by Brinkley and Lewis.[4]

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