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The structure, sustenance and stability of gaseous detonations are believed to be the result of complex interactions between chemical kinetics and gas dynamics. Recent studies on two-dimensional detonations further show the initiation and the sustenance of a transverse wave structure through such interactions. In channels of large widths (in terms of characteristic reaction lengths), transverse waves d develop rapidly in initially planar detonations undergoing longitudinal oscillations. For very narrow channels, however, only longitudinal waves are observed, because transverse waves of short wave lengths or high frequencies are attenuated. Analysis of the observed low-frequency instability in dump combustors shows that the oscillations are triggered and sustained by interactions between non-uniform entropy zones and pressure waves. Rarefaction waves incident on the flame zone of low entropy. The non-uniform entropy zones then generate compression and rarefaction waves, as they are convected with the flow through the choked nozzle. Development of instability in a shear flow has been examined. Exothermic reaction tends to augment the growth rate of the accompanying Tollmien-Schlichting Waves.

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Basic Instability Mechanisms in Chemically Reacting Subsonic and Supersonic Flows

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Massachusetts Institute of Technology

Summary of Progress

The structure, sustenance and stability of gaseous detonations are believed to be the result of complex interactions between chemical kinetics and gas dynamics. Recent studies on two-dimensional detonations further show the initiation and the sustenance of a transverse wave structure through such interactions. In channels of large widths (in terms of characteristic reaction lengths), transverse waves develop rapidly in initially planar detonations undergoing longitudinal oscillations. For very narrow channels, however, only longitudinal waves are observed, because transverse waves of short wave lengths or high frequencies are attenuated.

Analysis of the observed low-frequency instability in dump combustors shows that the oscillations are triggered and sustained by interactions between non-uniform entropy zones and pressure waves. Rarefaction waves incident on the flame zone cause the flame to stretch and separate, forming

a zone of low entropy. The non-uniform entropy zones then generate compression and rarefaction waves, as they are convected with the flow through the choked nozzle.

Development of instability in a shear flow has been examined. Exothermic reaction tends to augment the growth rate of the accompanying Tollmien-Schlichting waves.

One paper is published, two in press and one in preparation.

I. Objective and Scope of the Work

The main objectives of this work are to determine the major mechanisms governing the efficiency, power output and pollutant emission of propulsion devices as well as safety against explosions. Three problems have been studied during the past grant period. They are: (1) Initiation and and Sustenance of Gaseous Detonations, (2) Triggering and Sustenance of Low-Frequency Instability in Dump Combustors, and (3) Temporal Development of Turbulence-Combustion Interactions. The following section summarizes briefly the results obtained.

II. Results and Discussion

(1) Initiation and Sustenance of Gaseous Detonations

The structure, sustenance and stability of gaseous detonations are believed to be the result of complex interactions between chemical kinetics and gas dynamics. These interactions also govern the requirements for their initiation, in terms of the power density, energy density and energy-deposition duration or volume (cf. Ref. 13 in Enclosure I). The mechanism which sustains the longitudinal instability of a shock-reaction zone complex also involves such interactions (Ref. 14). Recent studies on the genesis of transverse waves in two-dimensional detonations further show the importance of these chemicokinetic-gasdynamic interactions (Ref. 15).

Results of a linearized theory developed for the case of high activation-energy reactions show that the mechanism responsible for the one-dimensional oscillations is also responsible for the two-dimensional instability. Figure 1 shows the amplification rates ω_i versus the wave numbers k_η of the transverse disturbances at different degrees of overdrive f. The degree of instability increases as the wave number decreases or as the wave length increases for a given degree of overdrive. For very short wave lengths or very high frequencies, the flow is stable and the transverse wave structure disappears. This is in agreement with the experimental observations that transverse wave structures do not appear in narrow channels.

Figure 1 also shows that, at a given wave number, the flow is more stable as the degree of overdrive increases. Again, this seems to agree with the experimental observation that the transverse structure disappears at high f.

Numerical simulations of two-dimensional detonations in channels of different widths have also been conducted. In channels of large widths, the initially planar detonations develop a transverse structure. Figure 2 shows the presence of two transverse waves, propagating in opposite directions toward the detonation tube walls as a non-planar detonation front moves downward. As the channel width is reduced, the transverse wave strengths become weaker. Below a certain critical width, the flow becomes stable with respect to two-dimensional disturbances and only longitudinal oscillations appear. Figure 3 shows the presence of a planar detonation front for such a case. Again, these observations are in agreement with Fig. 1 and with experiments.

(2) Triggering and Sustenance of Low-Frequency Instability in Dump Combustors

One major problem related to the use of dump combustors in propulsion devices is to eliminate the low-frequency oscillations. Figure 4 shows typical low- and high-frequency pressure oscillations observed in a combustor, in which the flame is stabilized by the use of a flame holder or simply a recirculation zone.

The low-frequency mode is believed to be triggered and sustained by the interactions between non-uniform entropy zones and pressure waves. Figure 5 illustrates the mechanism. Rarefaction waves incident on the flame zone (Fig. 5a) cause the flame to stretch (b) and to separate (c), forming a zone of low entropy. The non-uniform entropy zones then generate compression (d) and rarefaction waves (e), as they are convected with the flow through the choked nozzle. Thus, the cycle repeats itself.

Figure 6 shows that the predicted frequencies agree quite well with the observed values.

(3) Temporal Development of Turbulence-Combustions Interactions

Despite the importance of turbulence in enhancing combustion efficiency and reducing NO_x and hydrocarbon emissions, the exact nature of its role is still not completely understood, thus making full utilization of its effects difficult. One promising way to achieve in-depth physical understanding of the turbulence-combustion interactions involved is to study the temporal development of the turbulence characteristics from laminar combustion. Figure 7 shows the development of instability in a shear flow, where vortices are formed due to the growth of Tollmien-Schlichting disturbance waves.

Figure 8 shows the growth rates of the disturbance waves versus their wave numbers. The lowest curve is for the case with no chemical reaction. In the presence of exothermic reaction, the growth rate increases for a given wave number, thus suggesting an amplification of the disturbances due to chemical reaction.

III. Publications and Reports

See attached Enclosure I.

IV. Professional Personnel

Professors T. Y. Toong and G. E. Abouseif.

CAPTION TO FIGURES

Fig. 1 Amplification rates versus wave numbers of transverse disturbances at different degrees of overdrive.

Fig. 2 Two transverse waves, propagating in opposite directions toward detonation tube walls as a non-planar detonation front moves downward. Channel width = 20 reaction lengths.

Fig. 3 A planar detonation front with no transverse wave structure in a narrow channel of 1.9 reaction lengths in width.

Fig. 4 Typical low- and high-frequency pressure oscillations in a dump combustor.

Fig. 5 Illustrating low-frequency instability mechanism.

Fig. 6 Comparison of predicted and observed frequencies for low-frequency instability.

Fig. 7 Development of instability in a shear flow, showing the formation of vortices due to the growth of Tollmien-Schlichting disturbance waves.

Fig. 8 Growth rates of disturbance waves versus wave numbers with and without chemical reaction. The parameter $\alpha\Gamma\beta M^2$ indicates the degree of importance of chemical effect.

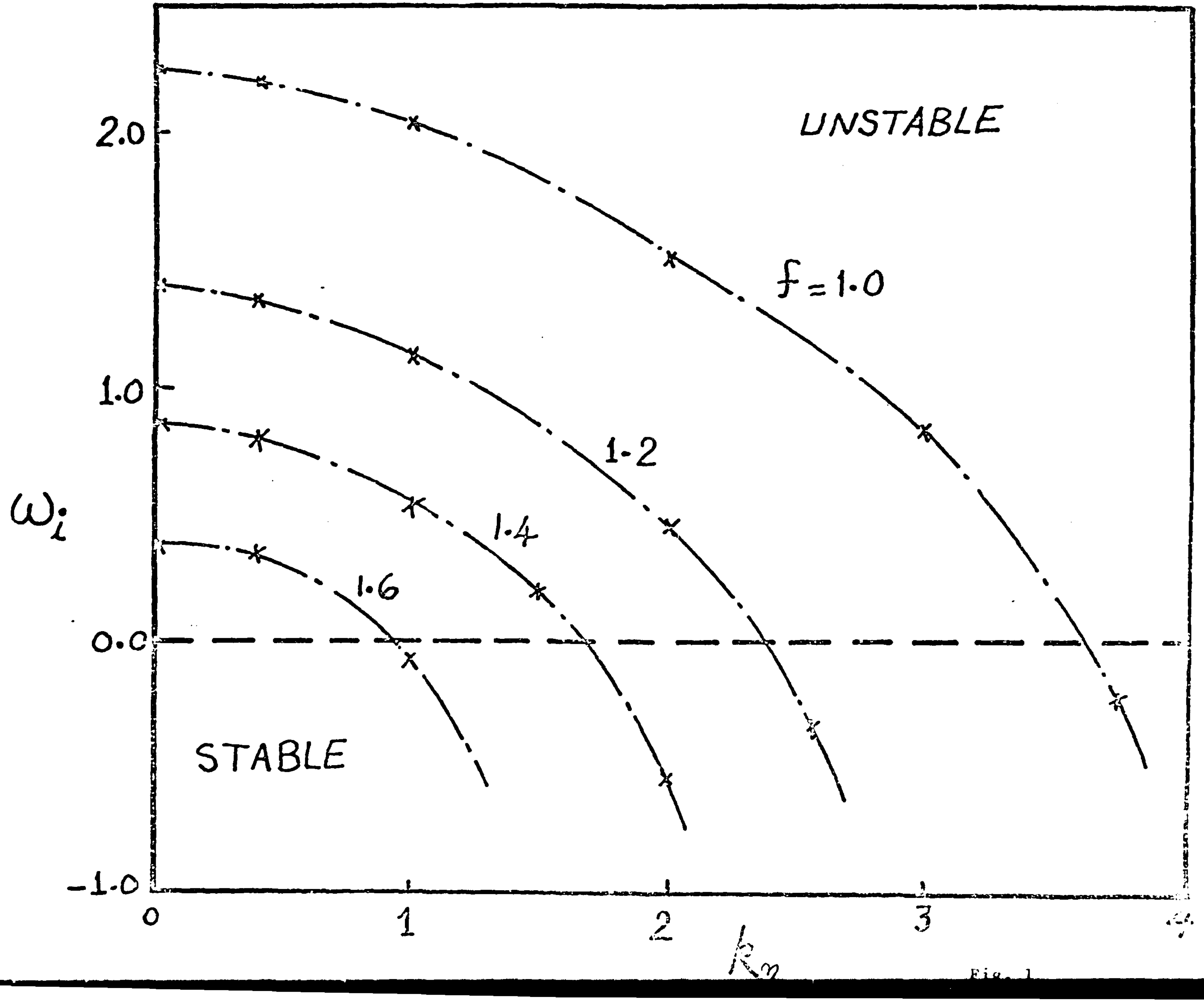
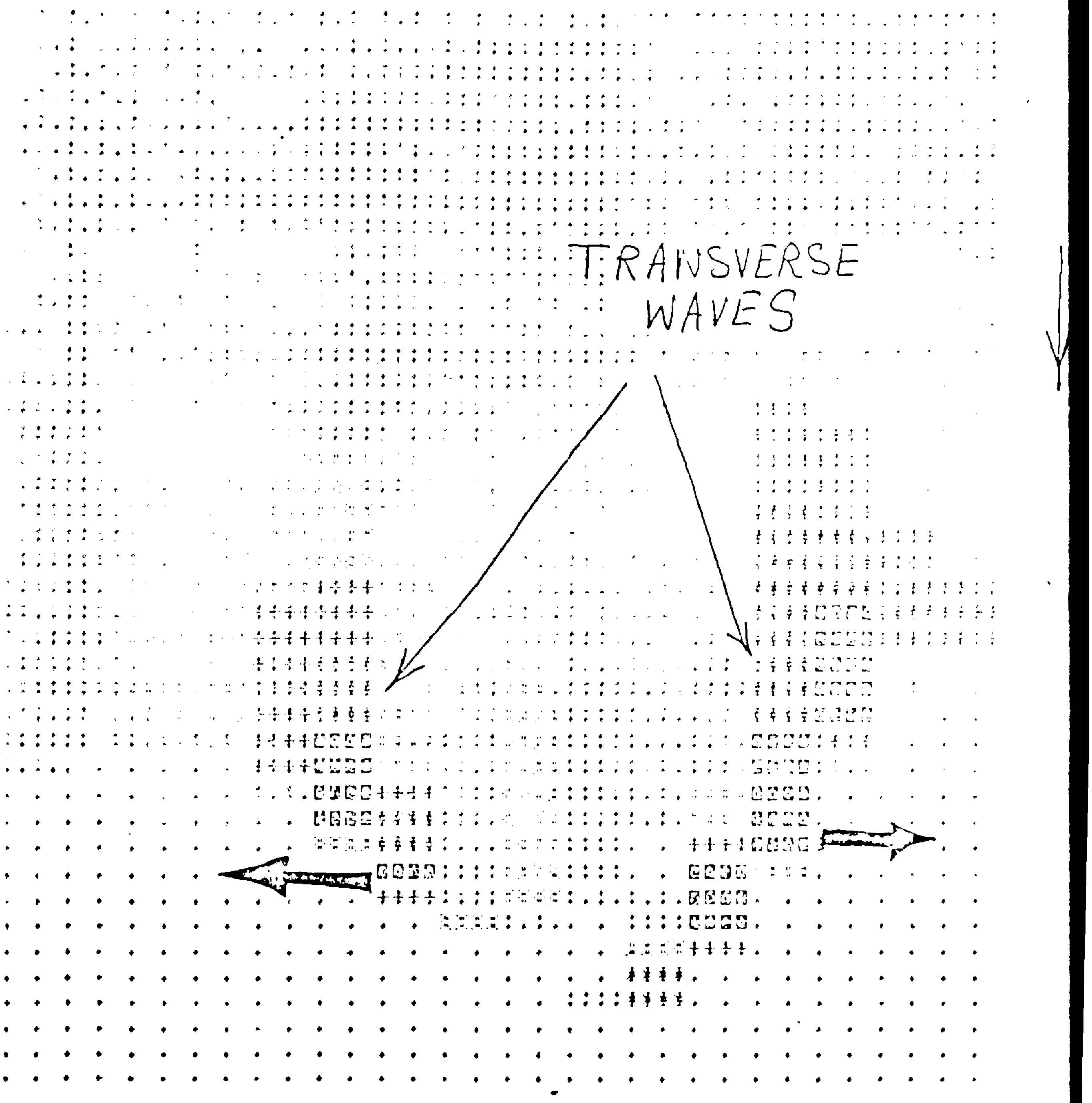


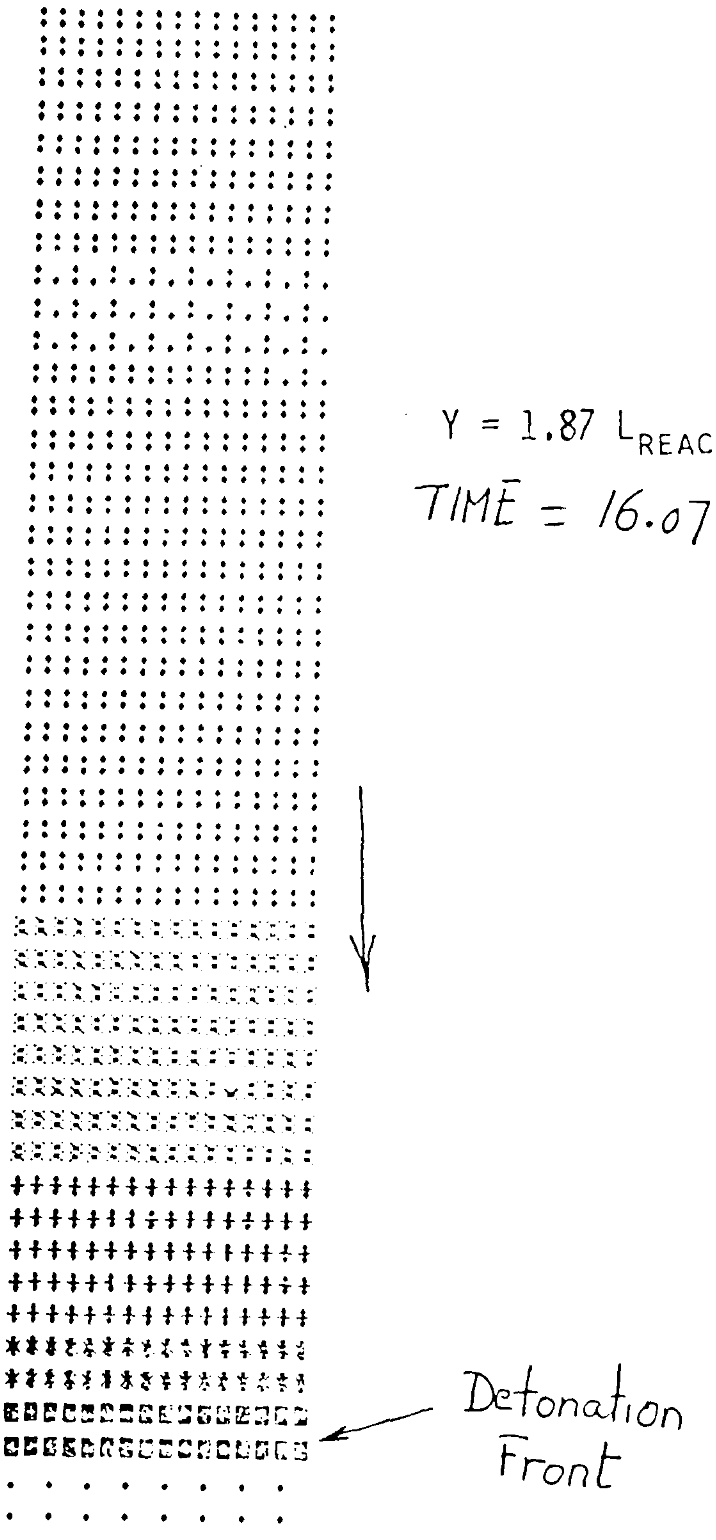
Fig. 1



Y = 20 $L_{REACTION}$

TIME = 15.68

Fig. 2



Y = 1.87 $L_{REACTION}$

TIME = 16.07

Fig. 3

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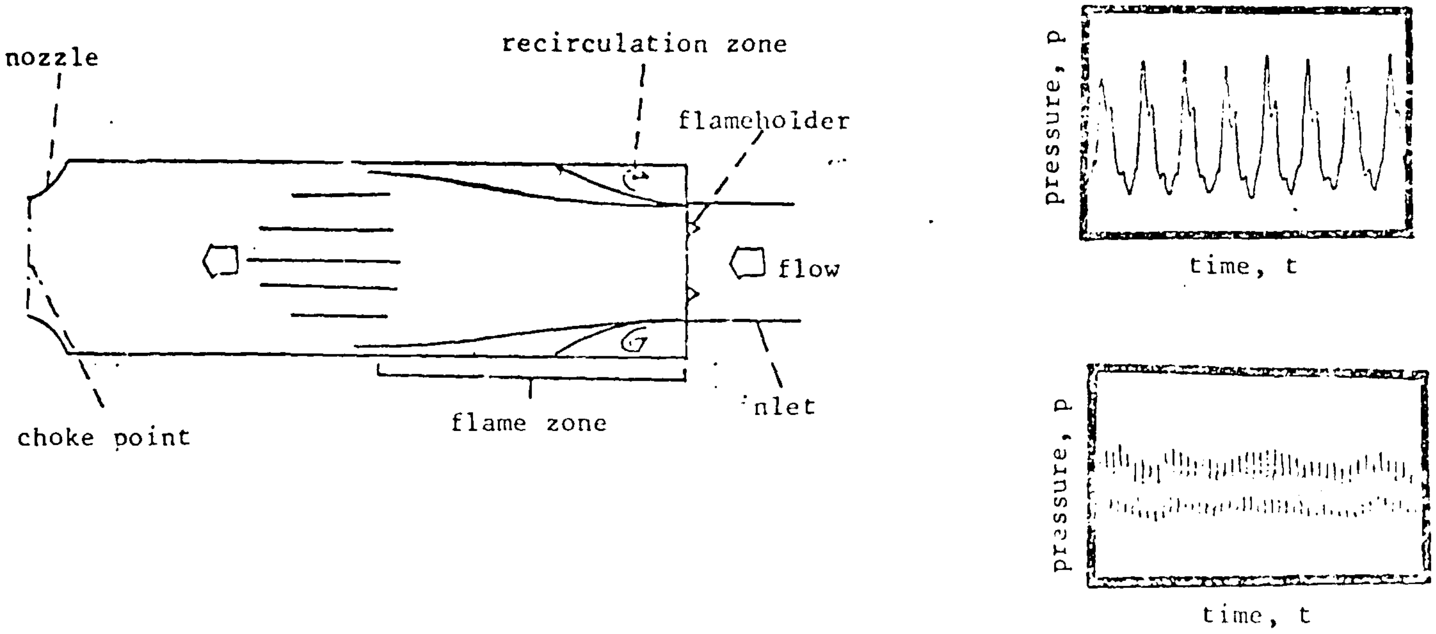
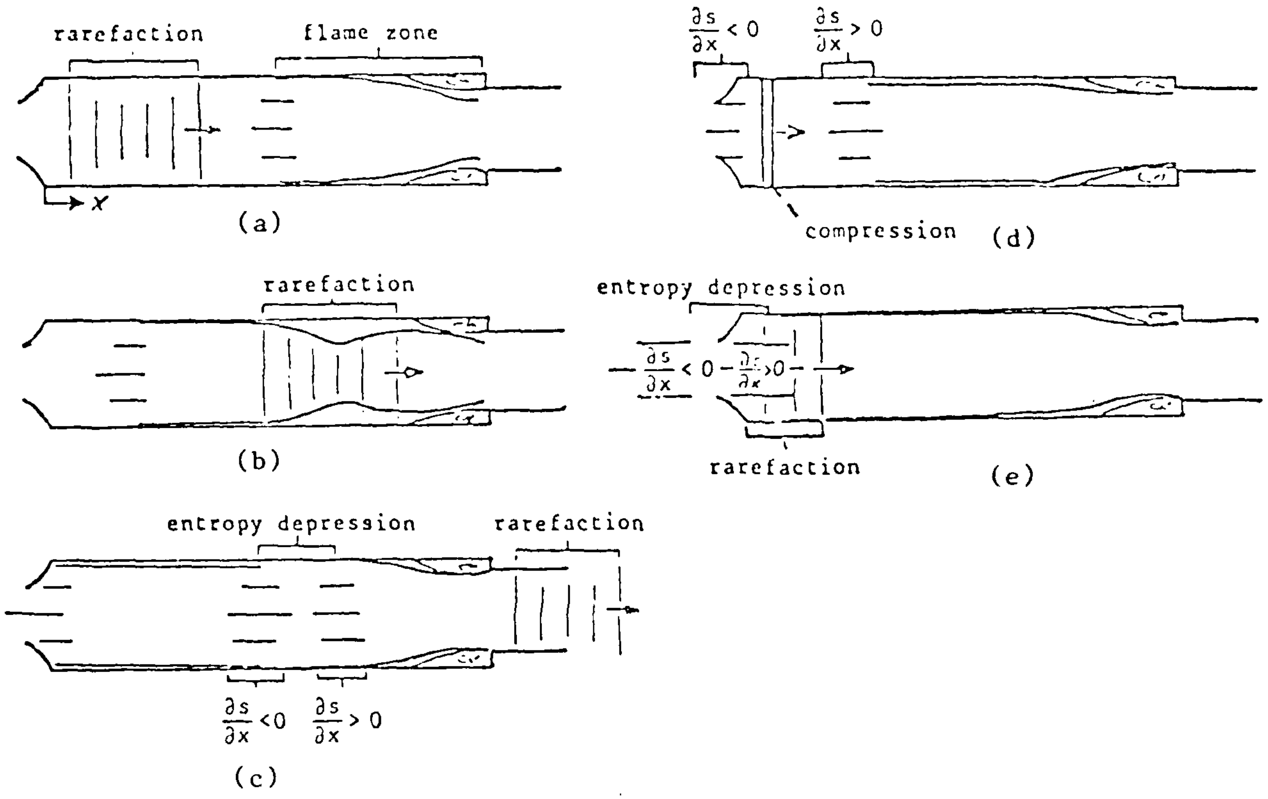
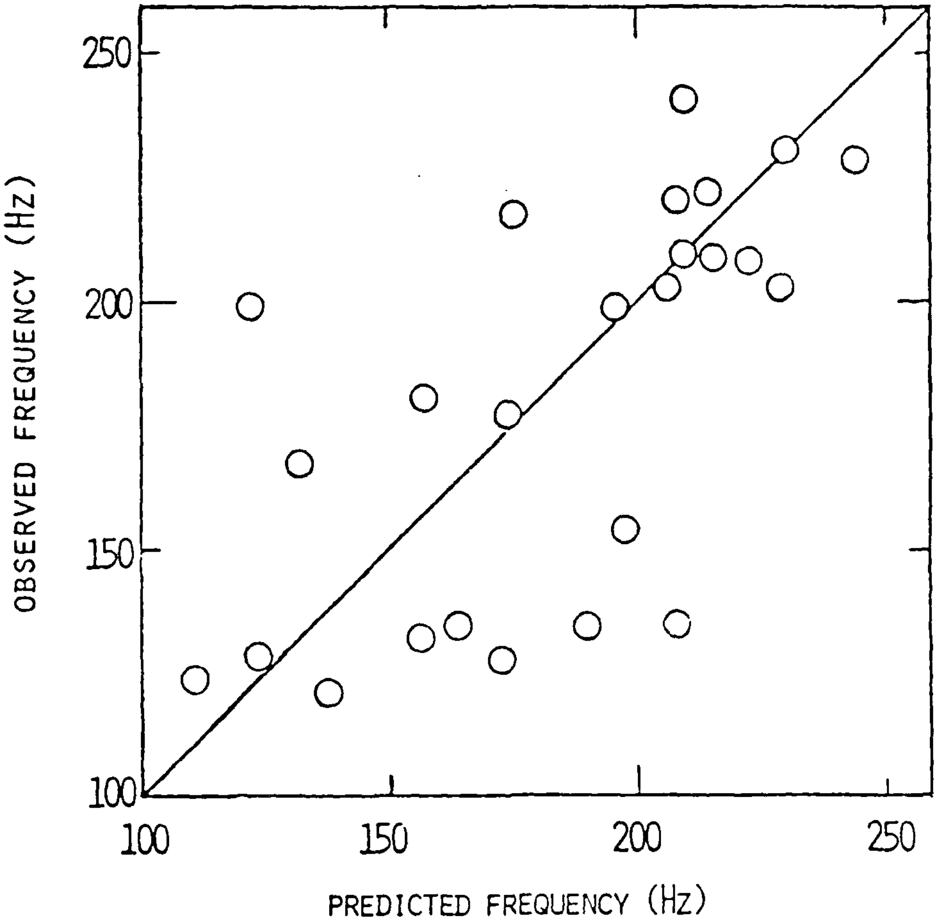

nozzle
recirculation zone
flameholder
flow
choke point
flame zone
inlet
pressure, p
time, t
pressure, p
time, t

Fig. 4



ILLUSTRATING THE LOW-FREQUENCY INSTABILITY MECHANISM

Fig. 5



$$f_{predicted} = \frac{(\bar{a}-\bar{v})\bar{v}}{2(1-\hat{x}_s)L_c\bar{a}}$$

COMPARISON BETWEEN PREDICTED AND OBSERVED VALUES OF THE FREQUENCIES OF THE LOW-FREQUENCY INSTABILITY

Fig. 6

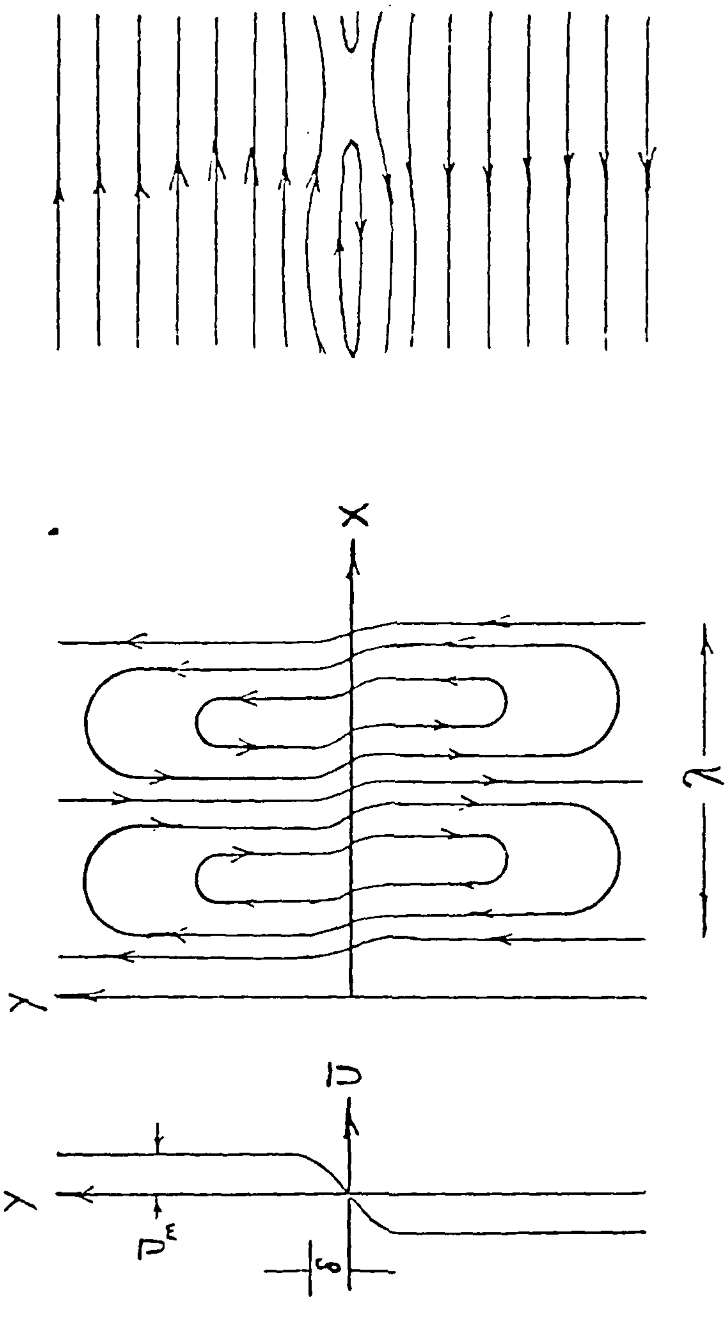


Fig. 7

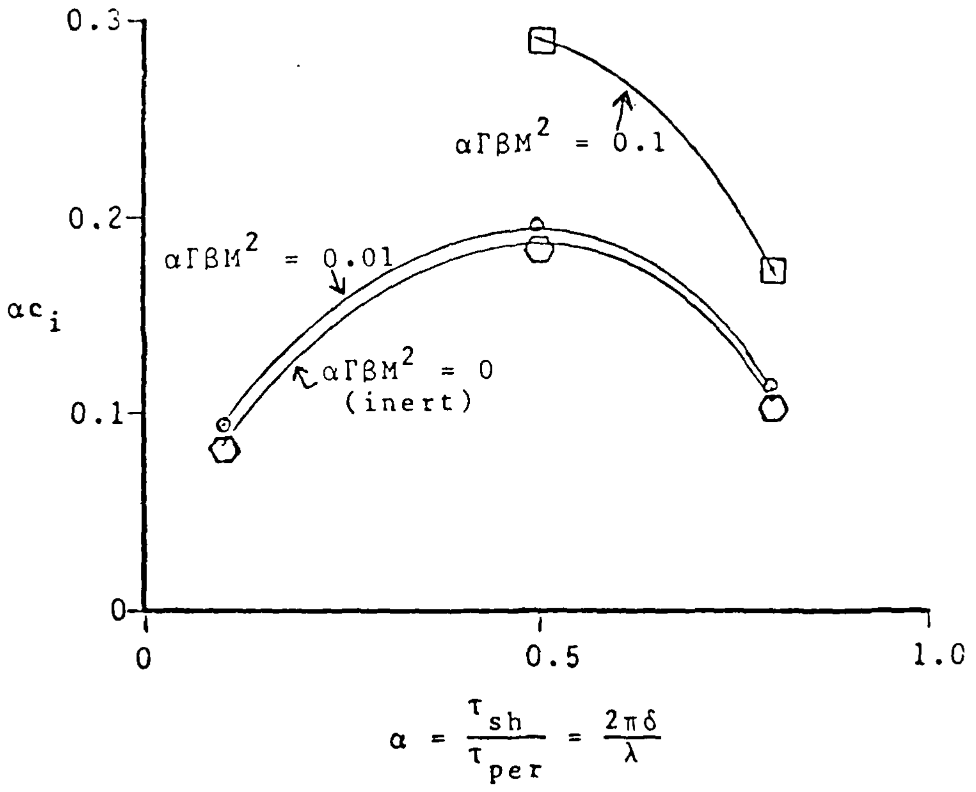

0.3
0.2
0.1
0
αc_i
$\alpha\Gamma\beta M^2 = 0.1$
$\alpha\Gamma\beta M^2 = 0.01$
$\alpha\Gamma\beta M^2 = 0$
(inert)
0
0.5
1.0
$\alpha = \frac{\tau_{sh}}{\tau_{per}} = \frac{2\pi\delta}{\lambda}$

Fig. 8

ENCLOSURE I

Basic Instability Mechanisms in Chemically Reacting Subsonic and Supersonic Flows

Publications and Reports

(Grants AFOSR-74-2619 and AFOSR-78-3662)

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