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STABILIZATION OF PREMIXED COMBUSTORS

by
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In order to attain a sufficiently good insight into the fluid mechanical processes taking place in combustors operating on premixed, prevaporized, and preheated gases, an experimental facility has been developed where the flow field is tractable both experimentally and analytically. The test section is for this purpose of rectangular, 7 in. x 2 in. cross-section, fitted with fused quartz windows to provide an unobstructed view of the combustion chamber across its full 2 in. width, over a length of 9 inches.

The configuration adopted for the initial stage of the study is based on the use of a step to stabilize the combustion zone. Its height is 1 in. -- half the width of the combustor. The flow field created in this manner is considered to be representative of the wake generated by a flame holder.

The primary purpose of the experimental apparatus is to provide a facility for studying the effects of the elementary fluid mechanical processes on the stability of a model combustion system in order to further the understanding of the intrinsic mechanism of non-steady phenomena, rather than to provide criteria for unstable operation of combustors, as expressed by overall performance parameters, such as the blowout and flashback limits. The ultimate objective nonetheless -- one should not forget -- is the acquisition of fundamental information that would be instrumental in extending these limits.

Accordingly the program of study embodied the following phases:

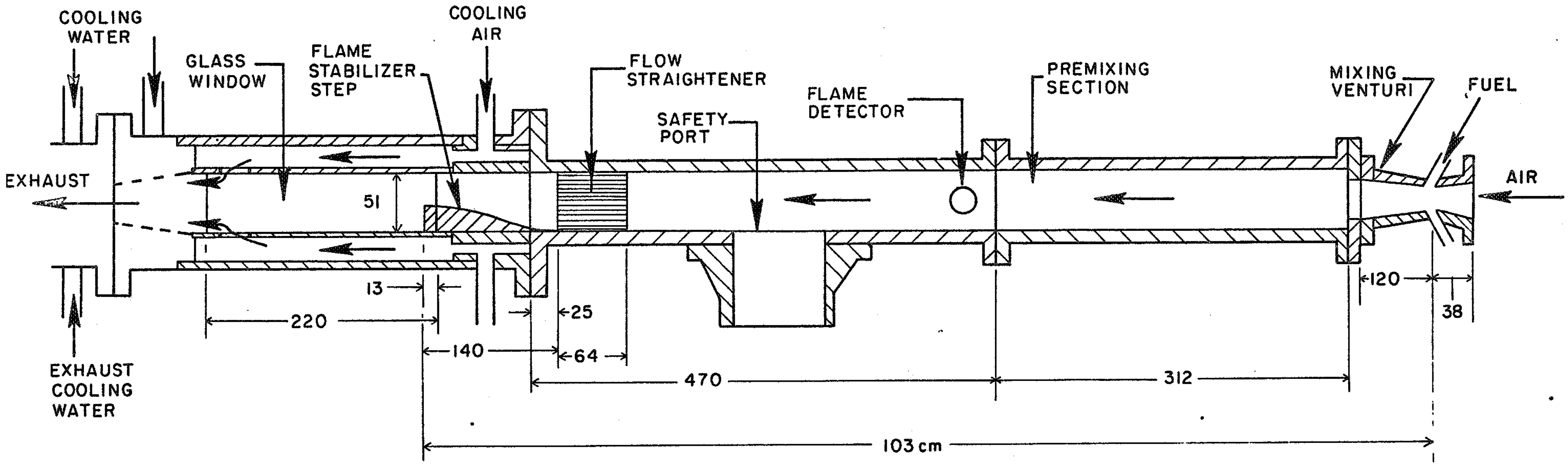
1. Determination of the flow field under steady operating conditions

2. Development of diagnostic point measurement techniques
3. Study of non-steady phenomena with particular emphasis on the mechanism of flashback and auto-ignition.

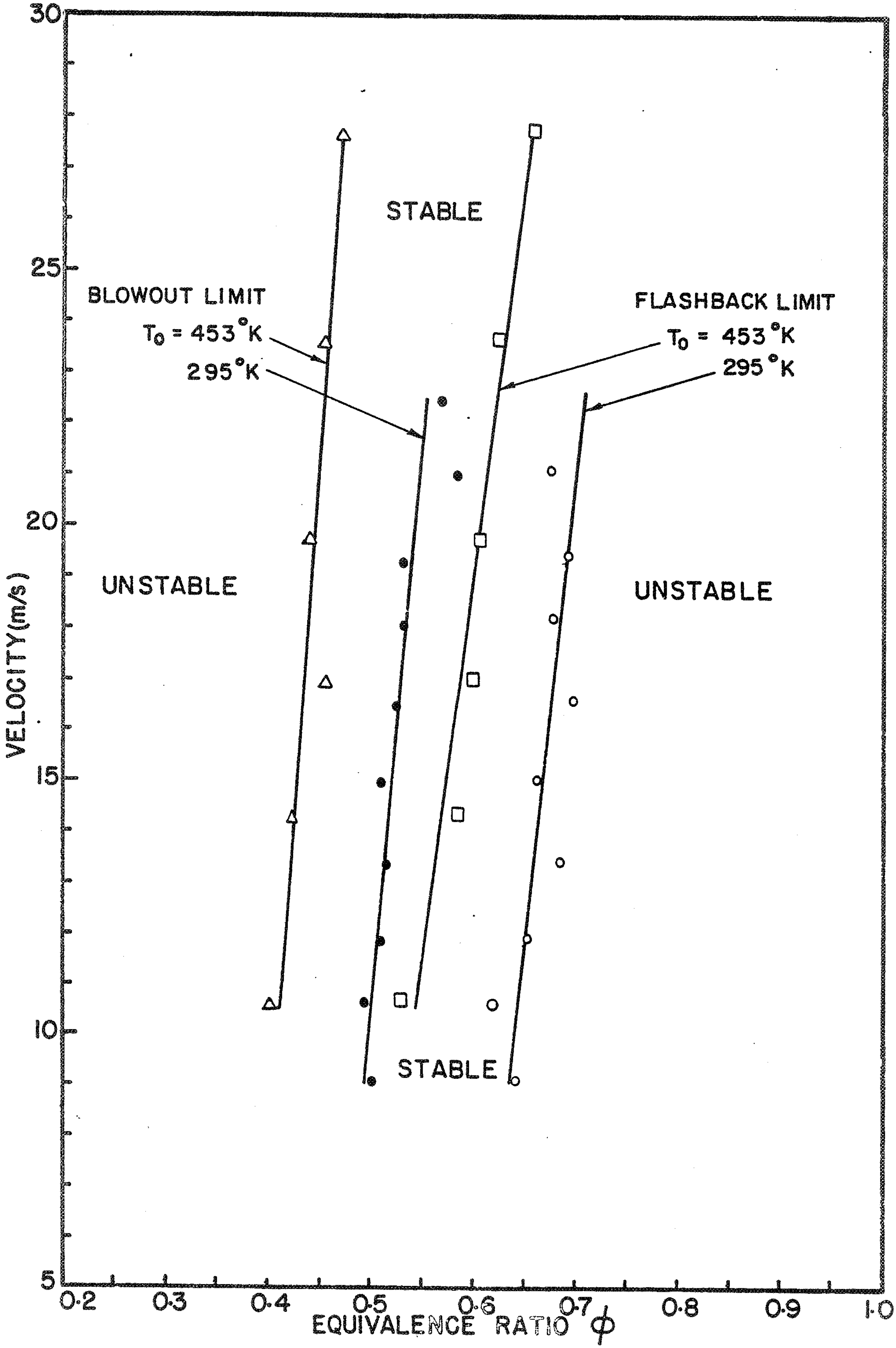
Phase 1 has been essentially completed under the direction of R. F. Sawyer (viz. "An Experimental Study of the Flow Field and Pollutant Formation in a Two-Dimensional Premixed, Turbulent Flame" by A. R. Ganji and R. F. Sawyer, Paper No. 79-0017, A.I.A.A. Seventeenth Aerospace Sciences Meeting, New Orleans, Louisiana, January 15-19, 1979). Phase 2 is nearing completion under the direction of J. W. Daily. Phase 3 is to be conducted under the direction of A. K. Oppenheim. In the enclosed copies of illustrations, the first eight pertain to Phase 1, the following four -- to Phase 2, and the last two -- to Phase 3. The experimental program will be concerned primarily with the observation and measurements of non-steady flow fields associated with transient response of the combustion system to a step change in operating conditions. Of the latter, the particular effect to be studied first will be that of a sudden enrichment of the fuel-air mixture.

FIGURE CAPTIONS

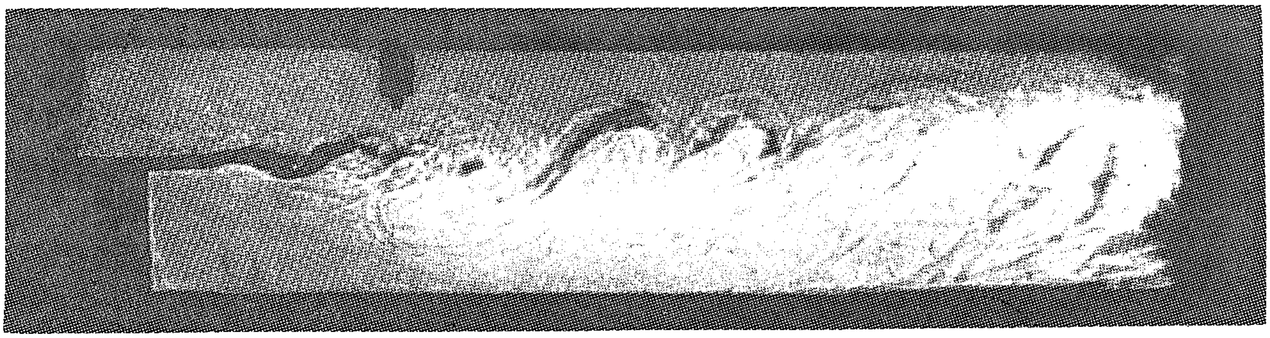
1. Experimental Apparatus
2. Stability Map
3. Schlieren Photographs of Wake Stabilized Combustion Zone at Various Inlet Velocities and Reynolds Numbers (T_0 = 295^{o}K)
4. Two Extracts of Schlieren Movies
   (a) Steady Vortex Sheet
   (b) Vortex Sheet Interacting with Recirculation Zone
   (V_0 = 13.6 m/sec; Re = 8.8 x 10^3/cm; 0 = 0.57: T_0 = 295^{o}K; time interval between frames: 1.22 msec)
5. Extract of Schlieren Movie at High Inlet Temperature (V_0 = 13.3 m/sec; Re = 3.9 x 10^3/cm; 0 = 0.53: T_0 = 454^{o}K; time interval between frames: 0.67 msec)
6. Extract of Schlieren Movie Showing Blowout (V_0 = 9.2 m/sec; Re = 6 x 10^3/cm; 0 = 0.5: T_0 = 295^{o}K; time interval between frames: 24 msec)
7. Extract of Schlieren Movie Showing Flashback (V_0 = 13.2 m/sec: Re = 8.5 x 10^3/cm; 0 = 0.57 switched to 0.68: T_0 = 295^{o}K; time interval between frames 6.6 msec)
8. Pressure Transducer Records Showing the Flashback Mode and Normal Operation
9. Optical System for the Measurement of Density Fluctuations by Rayleigh Scattering
10. Frequency Spectrum of Density Fluctuations along the Center Line Measured by the Rayleigh Scattering Technique
11. Frequency Spectrum of Density Fluctuations Obtained from the Rayleigh Scattering Measurement at two Different Flow Velocities
13. Strategy Adopted for the Development of Numerical Techniques for Modeling Non-Steady Flows in Premixed Combustors
14. Computed Streakline Plots and Vortex Displacement Profiles for Incompressible Flow



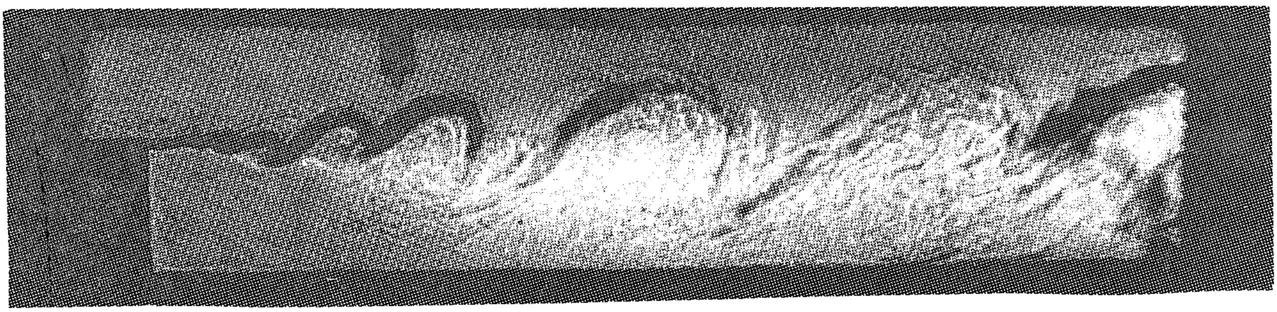
EXPERIMENTAL APPARATUS



STABLE
BLOWOUT LIMIT
T_0 = 453°K
295°K
FLASHBACK LIMIT
T_0 = 453°K
295°K
UNSTABLE
UNSTABLE
STABLE
VELOCITY (m/s)
EQUIVALENCE RATIO ϕ
30
25
20
15
10
5
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0

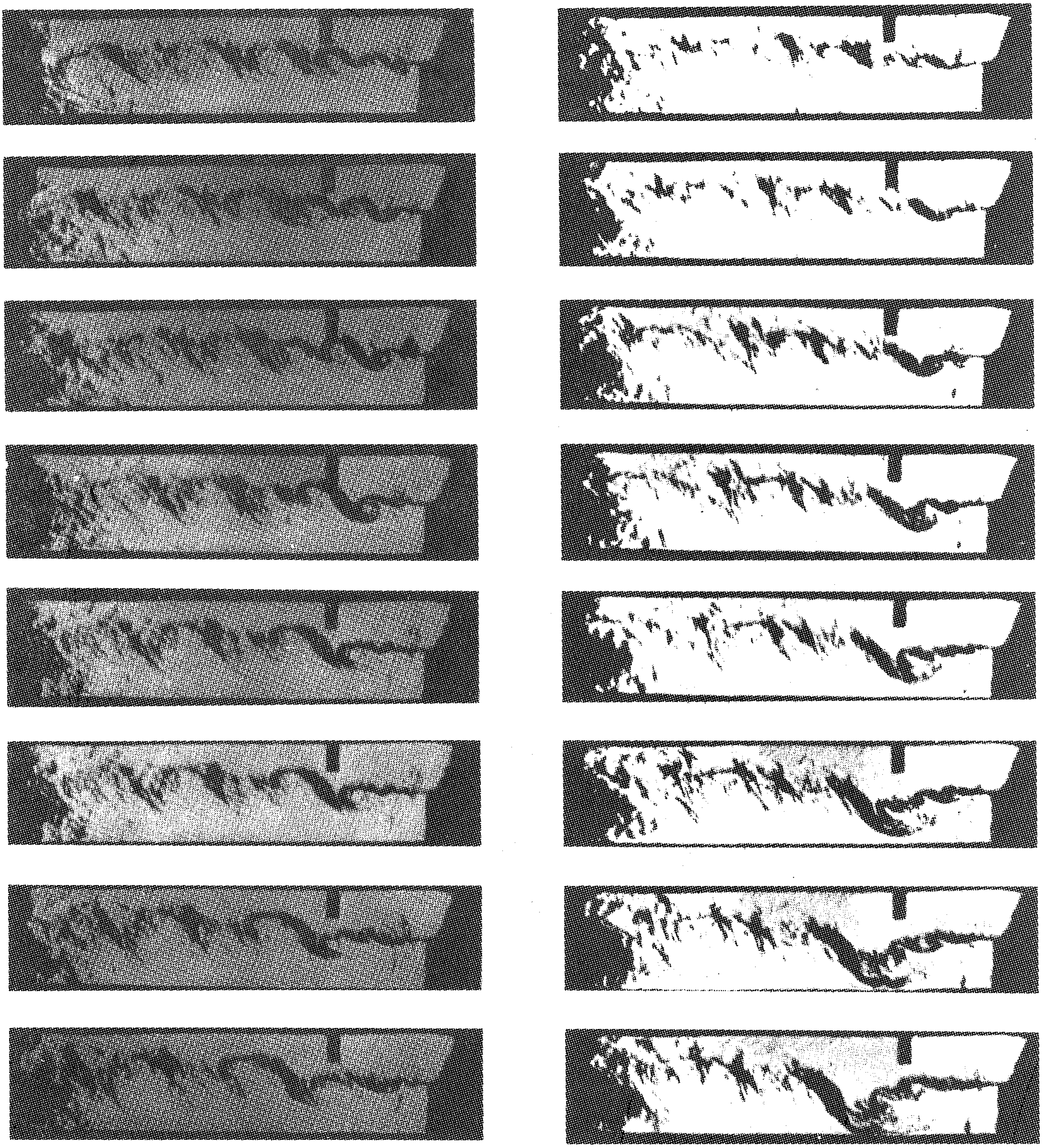


$V = 9.1$ (m/s) $Re = 0.59 \times 10^{4}$/cm $\phi = 0.6$ $t < 10^{-6}$ (s)

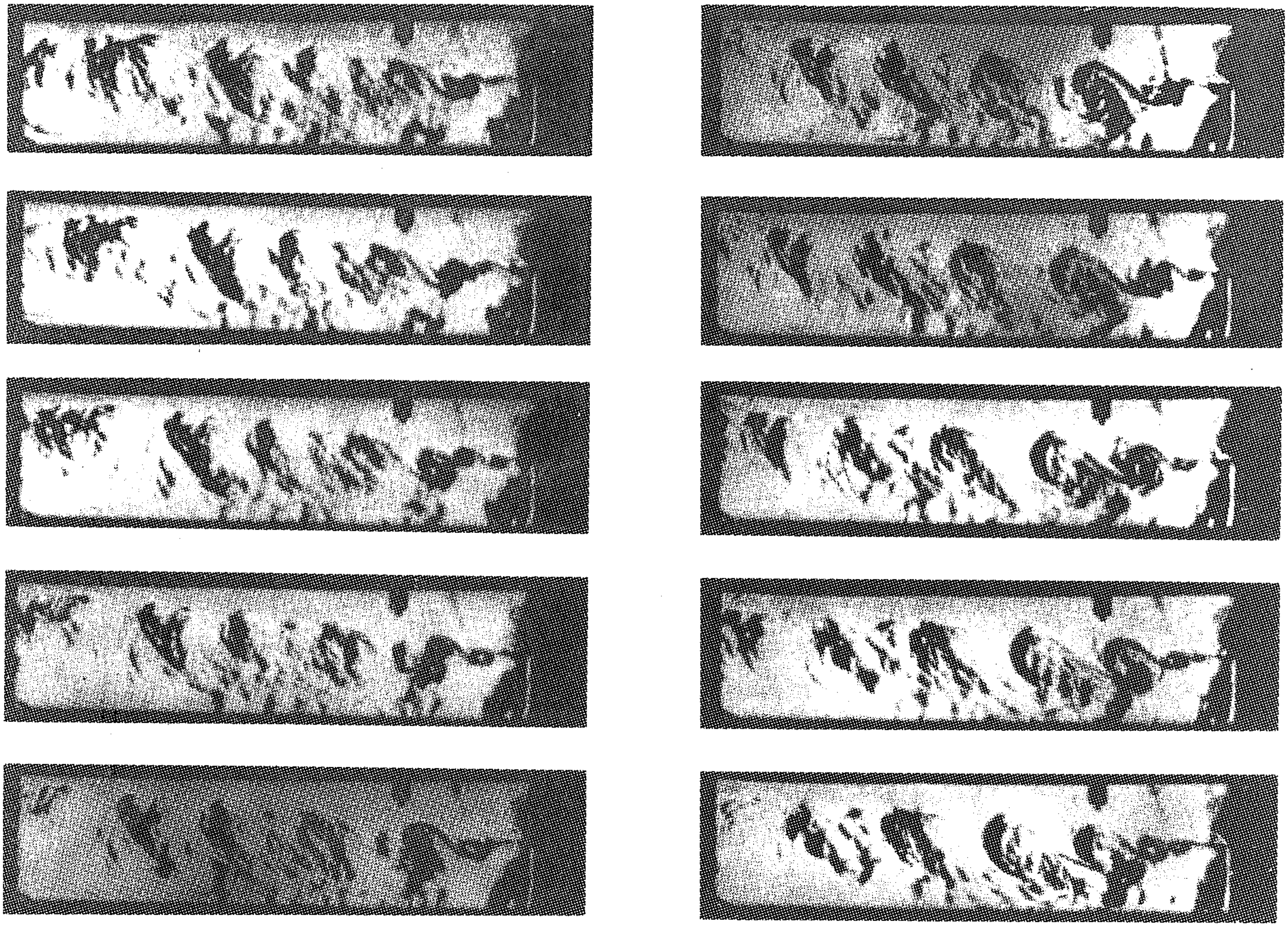


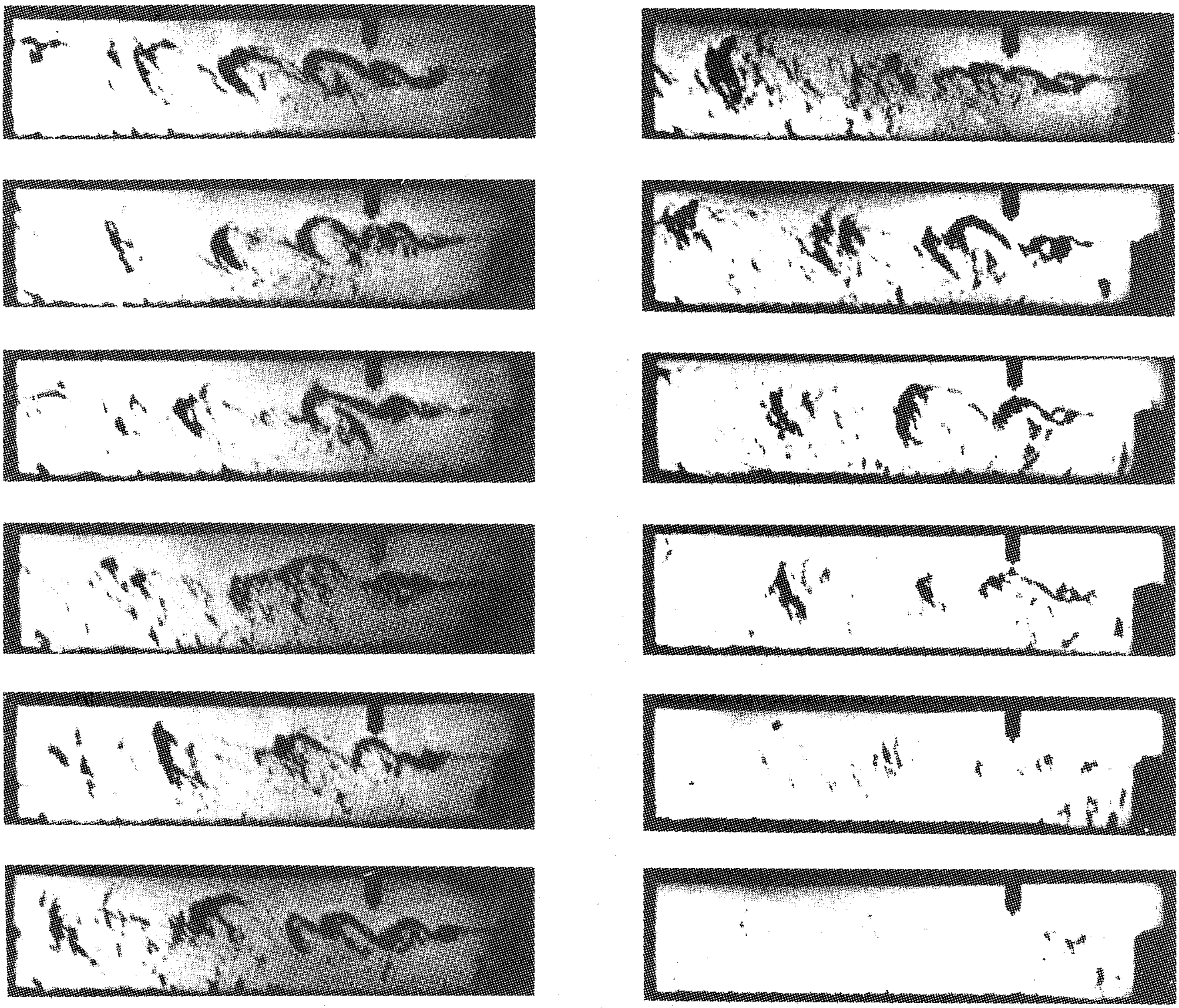
13.3 0.96×10^{4} 0.6 10^{-6}

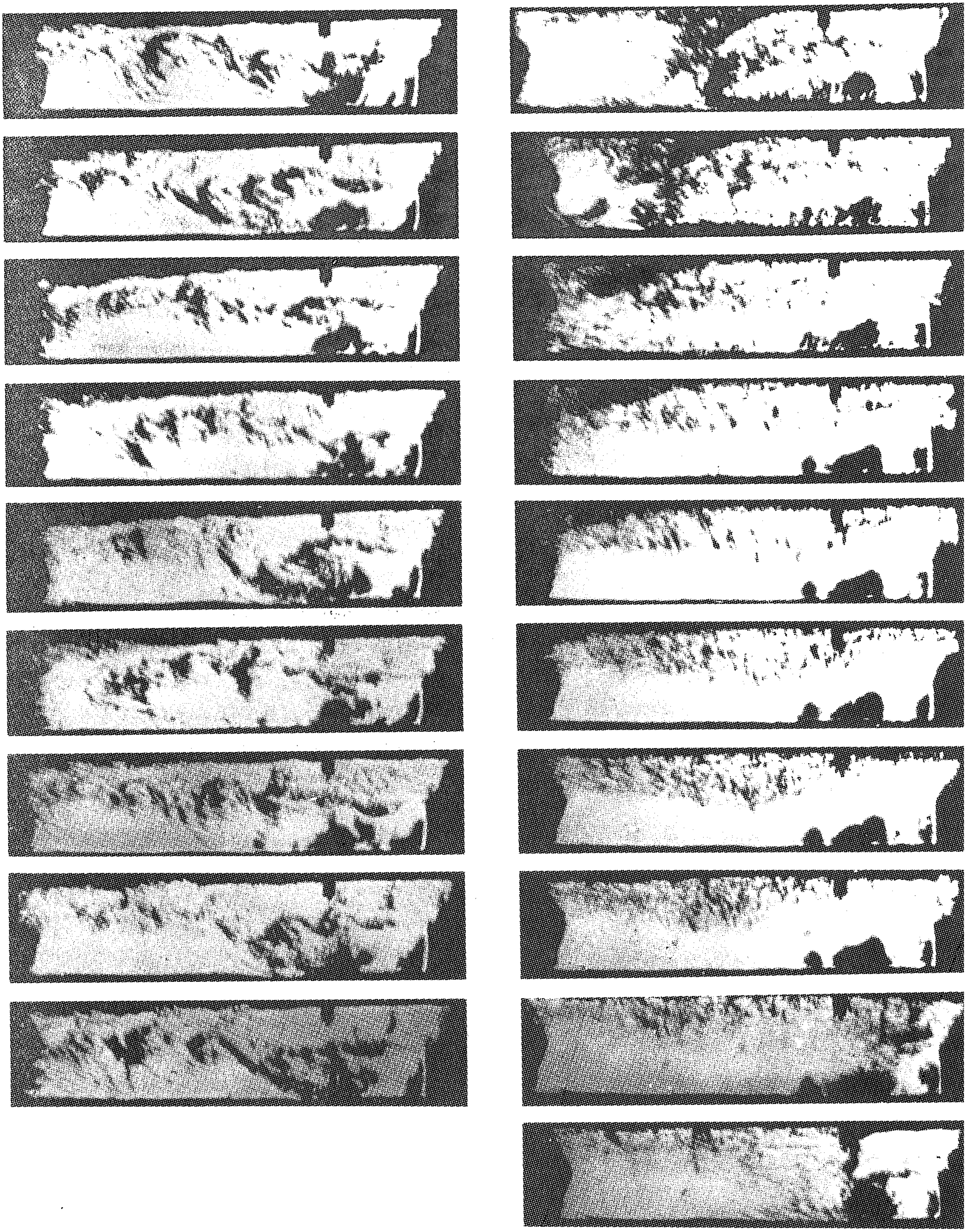
22.2 1.44×10^{4} 0.58 10^{-6}

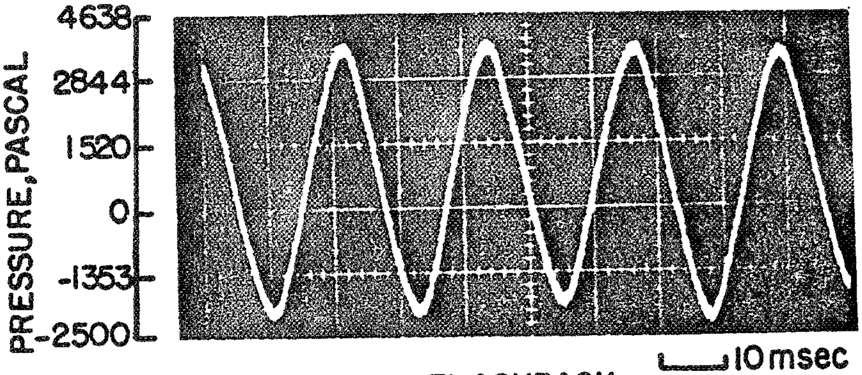


(а) (б)

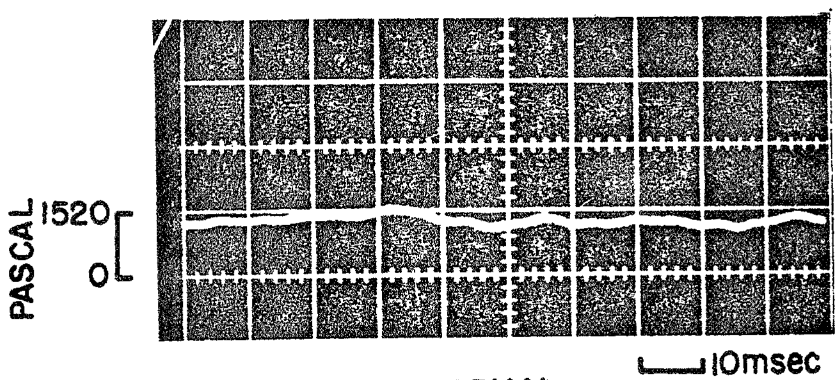




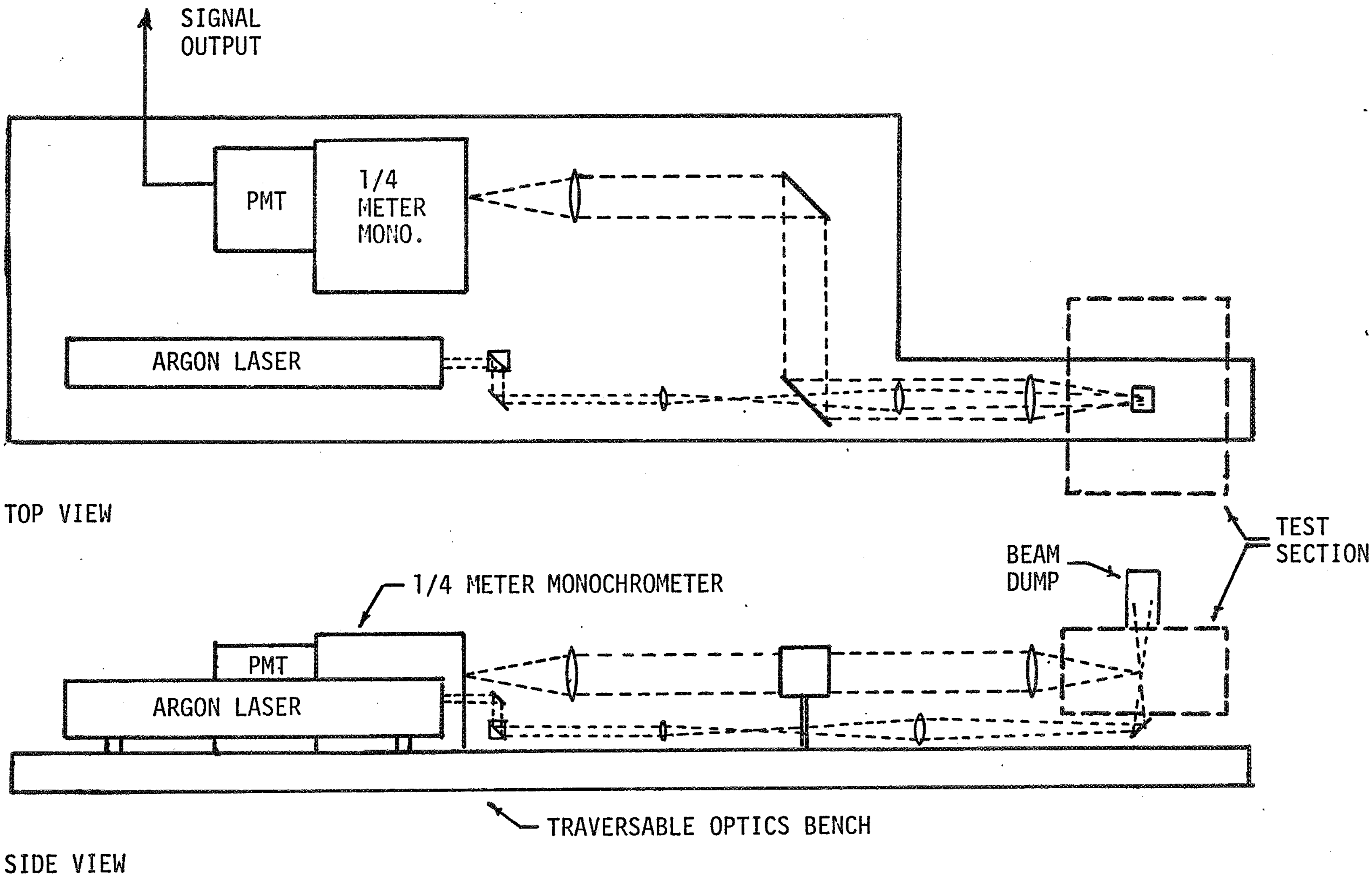




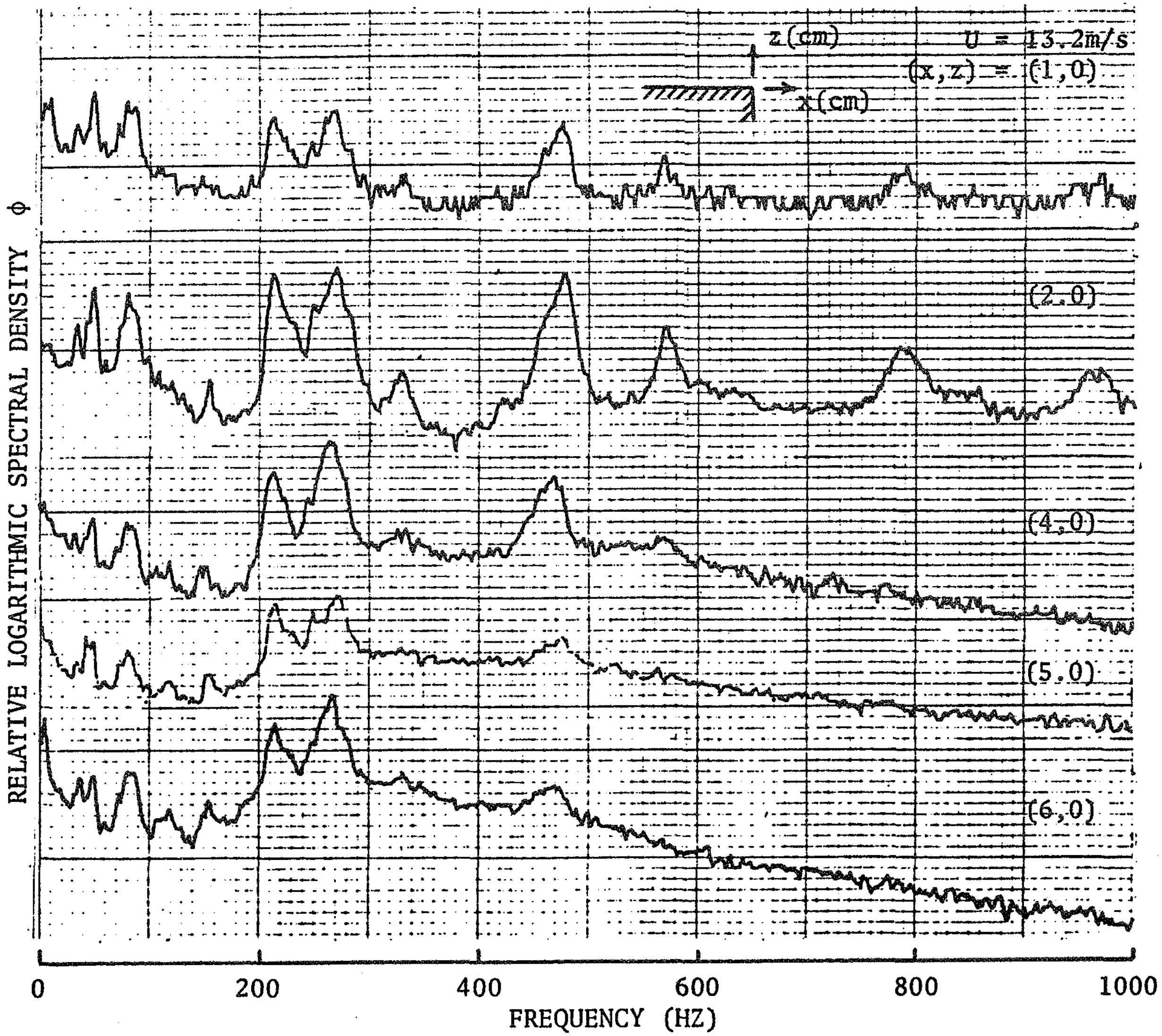
FLASHBACK



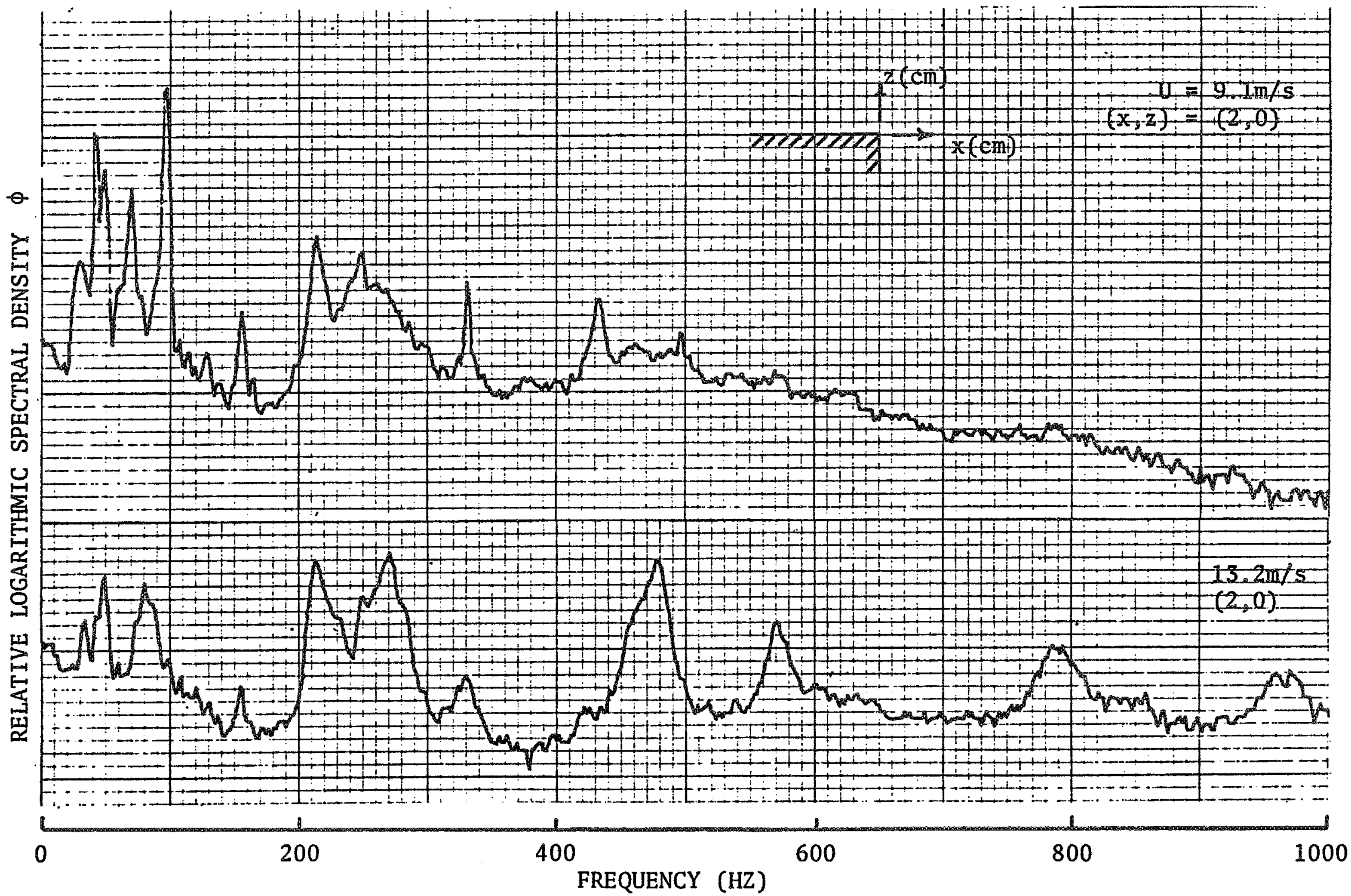
NORMAL

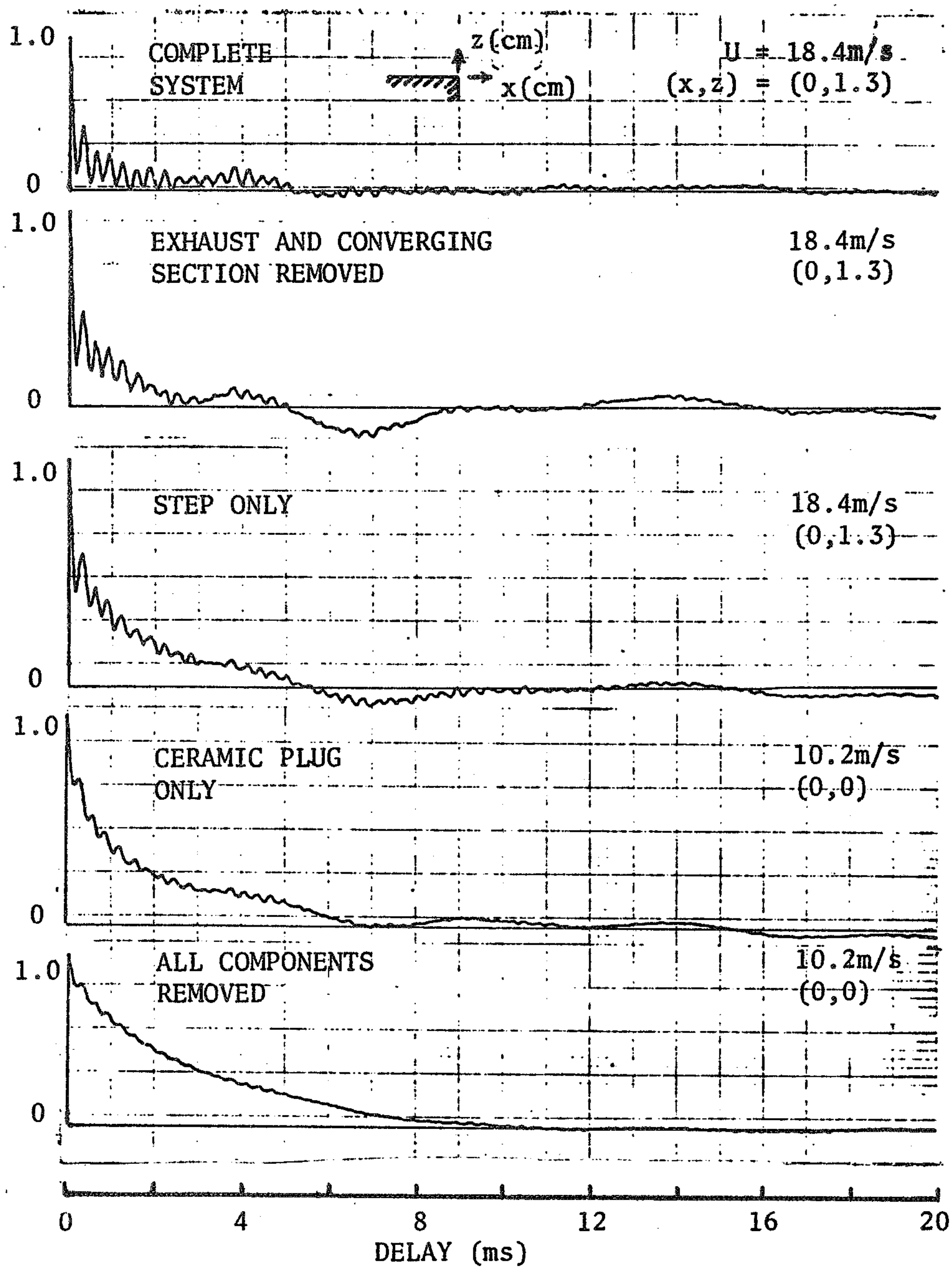


SIGNAL
OUTPUT
PMT
1/4
METER
MONO.
ARGON LASER
TOP VIEW
TEST
SECTION
BEAM
DUMP
1/4 METER MONOCHROMETER
PMT
ARGON LASER
TRAVERSABLE OPTICS BENCH
SIDE VIEW



z(cm)
x(cm)
U = 13.2m/s
(x,z) = (1,0)
(2,0)
(4,0)
(5,0)
(6,0)
RELATIVE LOGARITHMIC SPECTRAL DENSITY Φ
0
200
400
600
800
1000
FREQUENCY (HZ)


z (cm)
x (cm)
U = 9.1m/s
(x,z) = (2,0)
13.2m/s
(2,0)
RELATIVE LOGARITHMIC SPECTRAL DENSITY φ
0
200
400
600
800
1000
FREQUENCY (HZ)


1.0
0
COMPLETE SYSTEM
z (cm)
x (cm)
U = 18.4m/s
(x,z) = (0,1.3)
EXHAUST AND CONVERGING SECTION REMOVED
18.4m/s
(0,1.3)
STEP ONLY
18.4m/s
(0,1.3)
CERAMIC PLUG ONLY
10.2m/s
(0,0)
ALL COMPONENTS REMOVED
10.2m/s
(0,0)
0
4
8
12
16
20
DELAY (ms)

DEVELOPMENT OF NUMERICAL TECHNIQUES

Phase 1 VISCOUS INCOMPRESSIBLE FLOW

TIME DEPENDENT SOLUTION subject to GEOMETRY OF ENCLOSURE at a high Reynolds Number	→	Mechanism of the formation of SHEAR LAYER and RECIRCULATION ZONE

Phase 2 INFLUENCE OF COMPRESSIBILITY

VISCOUS INCOMPRESSIBLE SOLUTION NEAR WALLS matched with INVISCID COMPRESSIBLE SOLUTION FOR CORE FLOW at a low Mach Number	→	Modification of the flow field by VORTICITY STRETCH AND CONVECTION in a compressible medium

Phase 3 INFLUENCE OF COMBUSTION

TIME DEPENDENT SOLUTION subject to DEPOSITION OF ENERGY	→	Flow Phenomena due to COMBUSTION including especially its NON-STEADY EFFECTS