ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

PROGRESS REPORT NO. 3

BY

R. B. MORRISON

J. W. LUECHT

Project M898

AIR MATERIEL COMMAND, U. S. AIR FORCE
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SUMMARY

I Detonation

The work on detonation during this quarter concentrated largely on obtaining detonation velocities for various fuel-oxygen and fuel-air mixtures. A spark schlieren system with the necessary delay circuit, was designed, fabricated, and used for photographing hydrogen-oxygen detonations.

II Instrumentation

Assembly of interferometer continued.

A focusing schlieren system was set up and tested on optical bench.

PROGRESS REPORT NO. 3

DETONATION

A spark schlieren system utilizing a pair of achromatic lenses was set up and used to photograph various hydrogen-oxygen detonations. A schematic

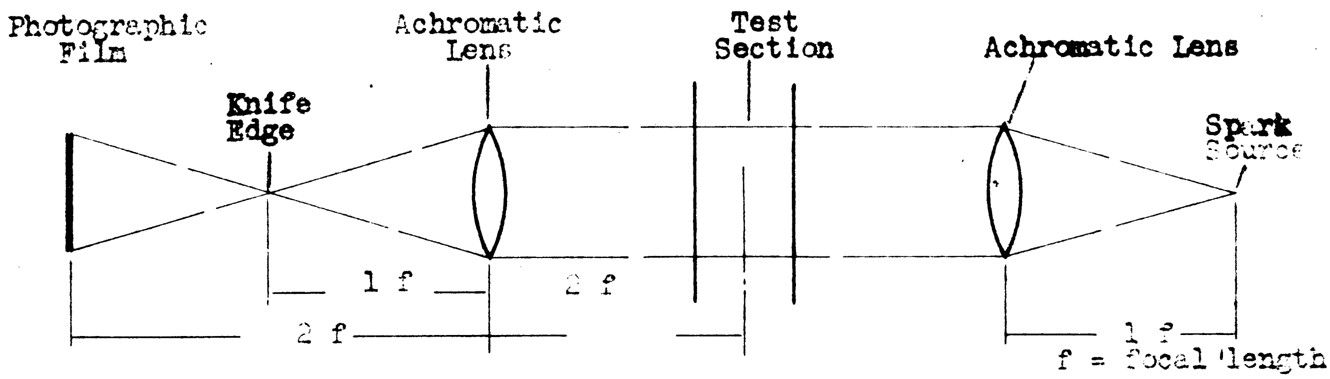
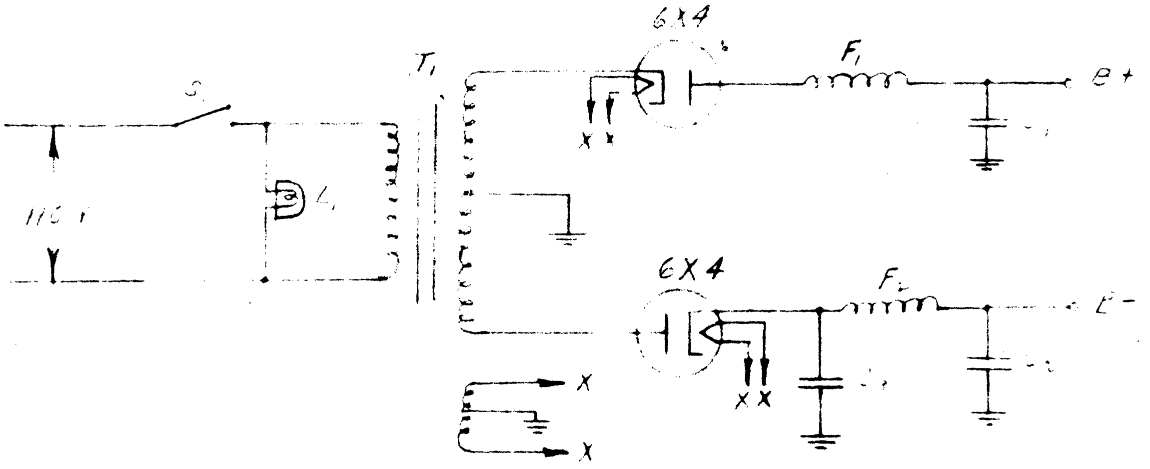


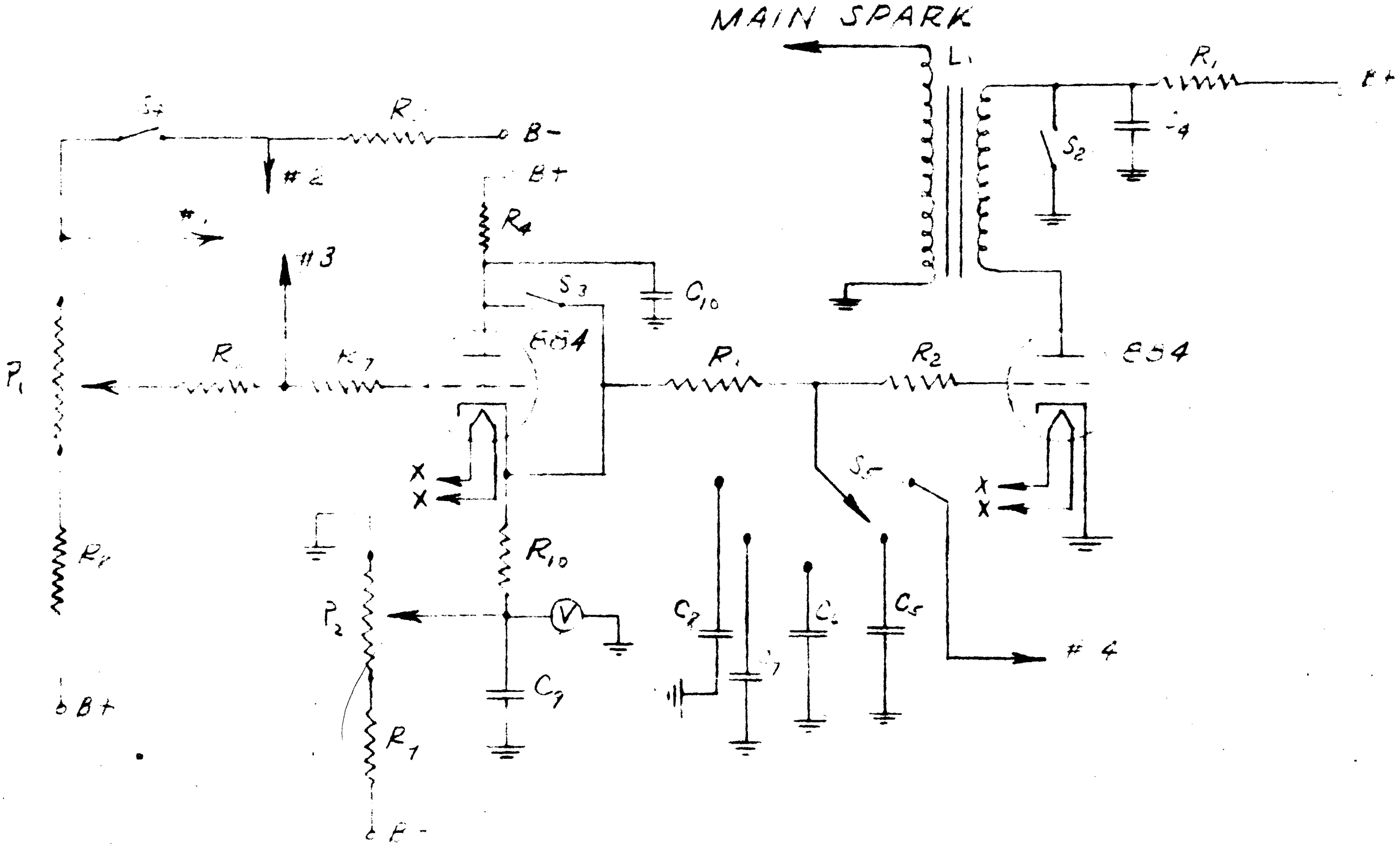
Fig. 1

diagram of the experimental set up is shown in Fig. 1.

In order to photograph the detonation wave at various stations in the test chamber, a time delay circuit was designed and fabricated.

TIME DELAY





X-X – 6.3 VOLTS
#1, 2, 3, 4 – JACKS
L_1 – PILOT LIGHT
F_1, F_2 – FILTER CHOKE
S_1, S_2, S_3, S_4 – SPST SWITCH
S_5 – FIVE POSITION SWITCH
C_1 – 20 μfd 450 V
C_2 – 20 μfd 450 V
C_3 – 1 μfd 400 V
C_4 – 1 μfd [illegible] V

C_5 – .0001 μfd
C_6 – .001 μfd 600 V
C_7 – .01 μfd 600 V
C_8 – .1 μfd 600 V
C_9 – 20 μfd 450 V
C_{10} – 20 μfd 450 V
V – VOLTMETER
L_1 – AUTOMOTIVE [illegible]

R_1 – 23,000 Ω
R_2 – 25,000 Ω
R_3 – 100,000 Ω
R_4 – 390 Ω
R_5 – 25,000 Ω
R_6 – 10 meg Ω
R_7 – 25,000 Ω
R_8 – [illegible] Ω
R_9 – 25,000 Ω
R_{10} – 10,000 Ω
P – 10,000 Ω

FIG. 2

The principle of operation of the time-delay circuit is as follows: (See Fig. 2)

1. A pulse is received from the ionization probe (see reference in Progress Report No. 2) on the grid of the first thyratron. (No. 3 Jack)

2. The firing of the first thyratron from the above pulse starts a charge on a condenser (C_5, C_6, C_7, or C_8) through the resistor R_3.

By means of the potentiometer, P_2, the voltage on the latter condenser was previously set at some negative bias in excess of that required to hold the second thyratron from firing.

3. When the voltage on condenser C_5, C_6, C_7, or C_8 drops to the critical bias voltage for the second thyratron, the tube fires, sending a pulse through the primary of an automotive-type spark coil.

4. The pulse from the secondary of the spark coil triggers the spark of the main spark gap. (Progress Report No. 1)

S_5 serves as a decade switch for selection of various time intervals. Voltmeter, V, indicates the bias on the second thyratron. S_2 and S_3 are restoring switches for the thyratrons.

Photographs of the shock tube and the experimental setup for the timing and photographing of the detonation waves are shown in Figs. 21, 22, 23, and 24.

INSTRUMENTATION

Besides the spark schlieren apparatus described above, a sharp-focusing schlieren system has been set, and initial studies of such a system have been made. A sharp-focusing shclieren system permits making an image confined to a narrow depth of field of the investigated region and eliminates the integrated effects of density changes over a large region, including wall effects, and effects of regions outside the area of investigation. The narrow depth of field is accomplished by

1. large size of light source
2. multiple light sources
3. corresponding multiple knife-edges

The diagram of the system is shown below:

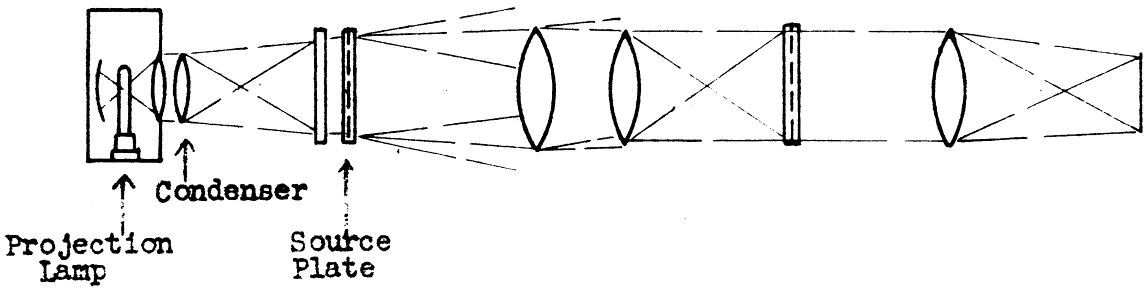


Fig. 3

This system will be used for photographing combustion phenomena, and should help in isolating undesired disturbances.

The equipment is on loan, and work with it has been described in Report No. WTM-186, "A Study of Sharp Focus Schlieren Systems," by E. Turner.

The interferometer assembly is continuing, although at a rather slow pace due to priority requirements on manpower. The instrument is totally assembled, except for the control system and photographic setup. The main interferometer plates were sent back to the manufacturer for final surface coating. A proposal for utilizing the interferometer in flame studies has been completed and submitted.

EXPERIMENTAL RESULTS

The same experimental equipment and methods as were reported in Progress Reports No. 1 and No. 2 were used to obtain detonation velocities for various fuel-oxygen and fuel-air mixtures. These velocities for oxygen mixtures of methane, ethane, propane, butane, and hexane are plotted in Figs. 4, 5, 6, 7, and 8, respectively. It is interesting to note that these graphs of detonation velocities for this hydrocarbon series tend to normalize when plotted vs. actual fuel-oxygen mixture ratio divided by the fuel-oxygen mixture ratio at stoichiometric conditions (see Figs. 9 and 10). Graphs of detonation velocities for hydrogen-oxygen, hydrogen-air, and ether-oxygen mixtures appear in Figs. 11, 12, and 13. Detonation velocities for acetylene-oxygen mixtures are shown in Fig. 14. Figs. 15 and 16 illustrate the effect of ambient pressure on acetylene-oxygen detonation velocities.

Detonation velocities as a function of distance in a 21-ft shock tube are shown in Fig. 17. A 51 per cent mixture of hydrogen and oxygen was used in these tests. The dispersion in data can be attributed to photo-cell probes that were used for these runs. The response times for these cells were unequal and could not be readily reproduced. To eliminate the unequal response times the probes were reversed after each run and the run duplicated. An average of the times in the two runs was used. It is apparent that within the accuracy of these experiments the detonation velocity remains substantially unchanged as a function of distance.

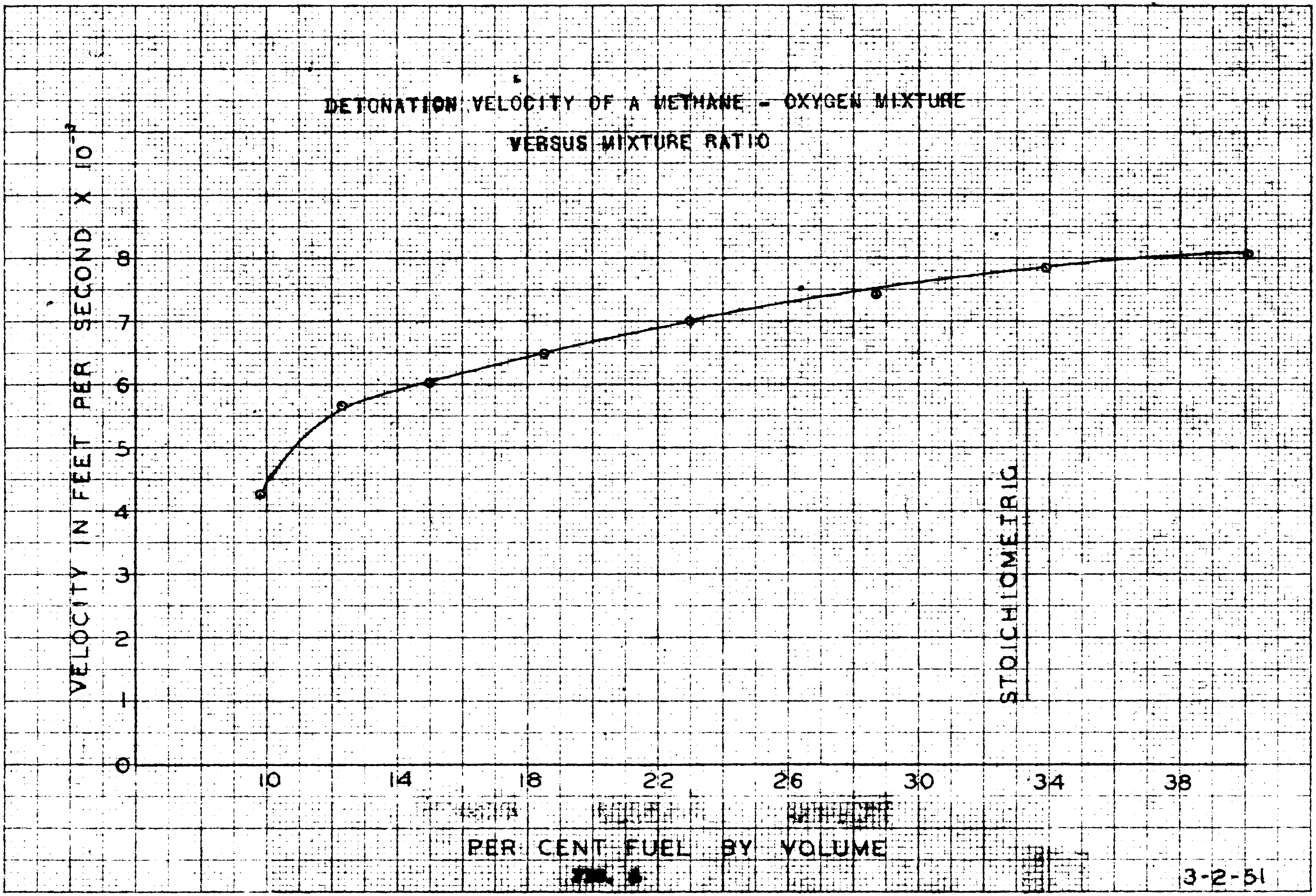
A series of spark schlieren detonation photographs for hydrogen-oxygen mixtures are shown in Figs. 18, 19, and 20. At approximately 40 per cent mixtures (by volume) of hydrogen and oxygen the clean detonation front normally encountered is changed into an interacting and ~~more~~ non-homogeneous region of shocks and combustion. From the small amount of evidence that the photographs give it is felt that the combustion behind the shocks of these lean detonations is quite unstable, continually lagging, and catching up to the shock. By the same reasoning the shocks would also be unstable. Further investigation of this phenomenon is being made.

Fig. 18 shows a sequence of spark schlieren photographs for a detonation wave of hydrogen and oxygen as the wave approaches and breaks over a wedge inserted in the test section of the shock tube.

Fig. 19 is included to show the intermingling and nonhomogeneity of the shock and combustion areas for lean hydrogen-oxygen mixtures. It is evident from these photographs that the combustion zones can lag the shock fronts by an appreciable distance.

Fig. 20 illustrates the effect of knife-edge orientation in the schlieren photographs of detonation waves. The light area in the upper photograph of this series indicates that a strong, adverse density gradient is present after the front.

For a matter of reference the top-to-bottom dimensions of all these photographs is 1/2 inch. The waves in all cases are moving from left to right.


DETONATION VELOCITY OF A METHANE - OXYGEN MIXTURE
VERSUS MIXTURE RATIO
VELOCITY IN FEET PER SECOND X 10^-3
0
1
2
3
4
5
6
7
8
10
14
18
22
26
30
34
38
STOICHIOMETRIC
PER CENT FUEL BY VOLUME
3-2-51

DETONATION VELOCITY OF AN ETHANE - OXYGEN MIXTURE VERSUS MIXTURE RATIO

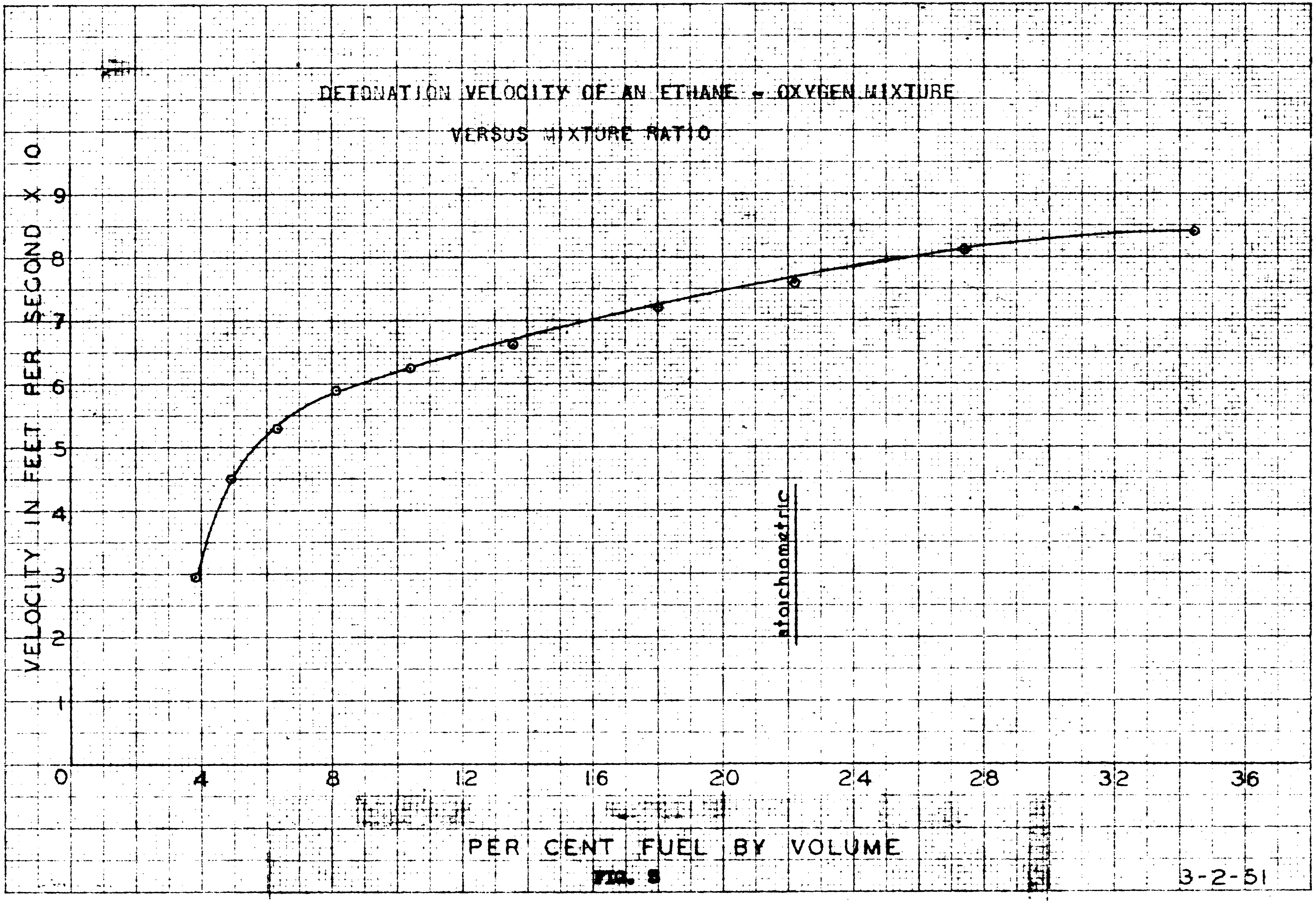
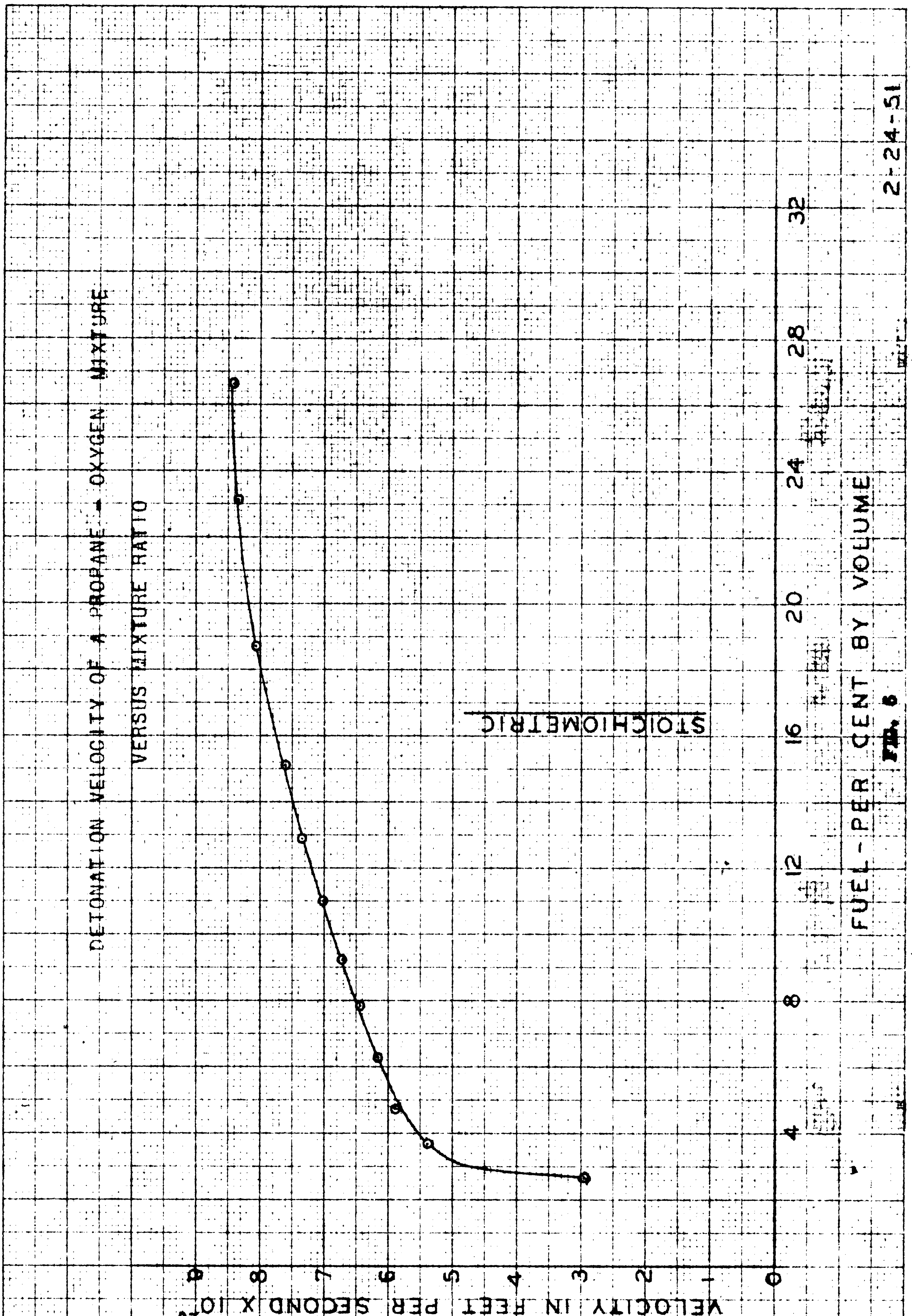


FIG. 5


DETONATION VELOCITY OF A PROPANE - OXYGEN MIXTURE
VERSUS MIXTURE RATIO
STOICHIOMETRIC
VELOCITY IN FEET PER SECOND X 10³
0
1
2
3
4
5
6
7
8
9
4
8
12
16
20
24
28
32
FUEL-PER CENT BY VOLUME
2-24-51

DETONATION VELOCITY OF A BUTANE - OXYGEN MIXTURE
VERSUS MIXTURE RATIO

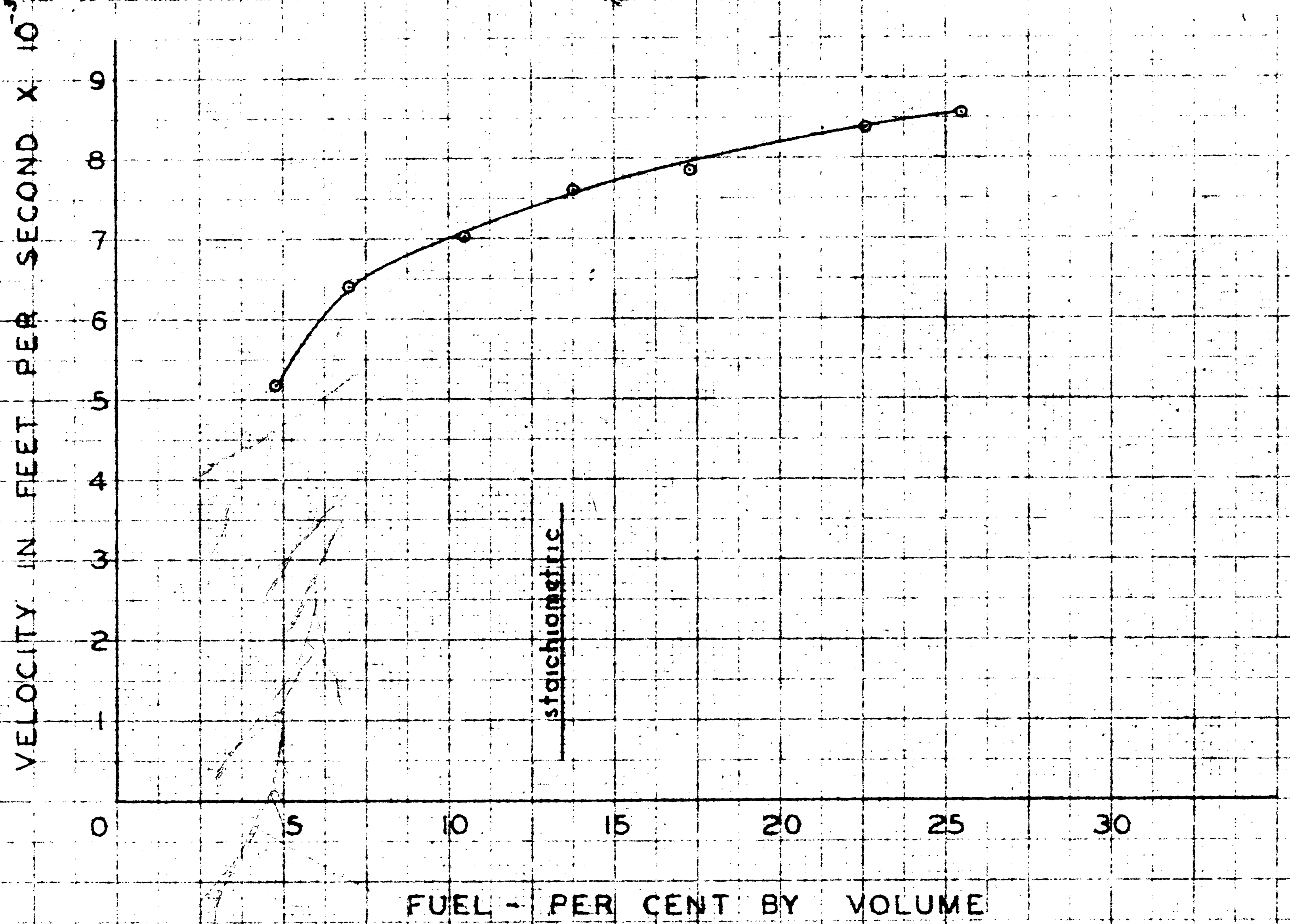


FIG. 7

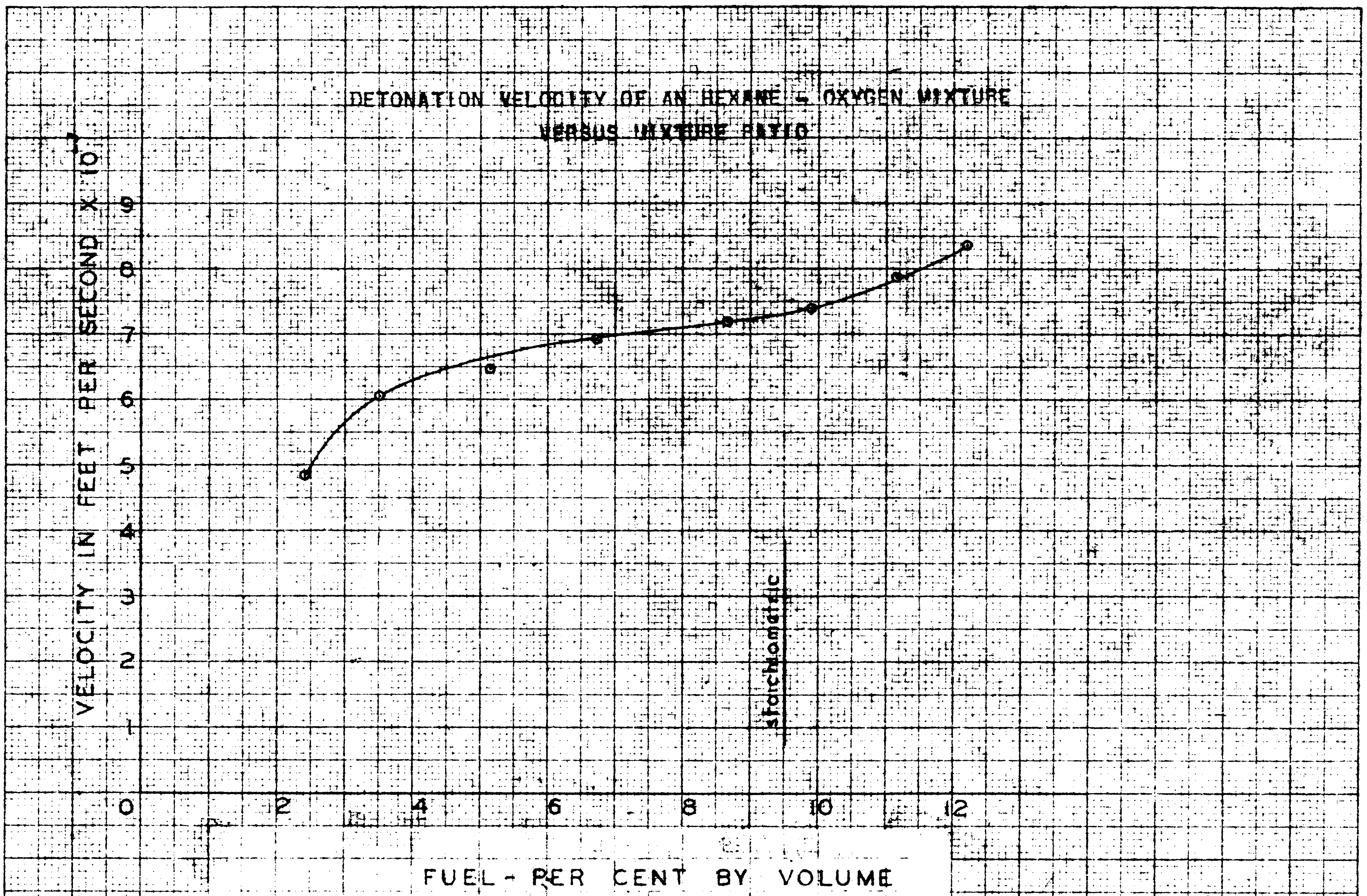

DETONATION VELOCITY OF AN HEXANE - OXYGEN MIXTURE
VERSUS MIXTURE RATIO
VELOCITY IN FEET PER SECOND X 10^3
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12
stoichiometric
FUEL - PER CENT BY VOLUME

FIG. 8

DETONATION VELOCITY OF HYDROCARBON GASES
VERSUS MIXTURE RATIO

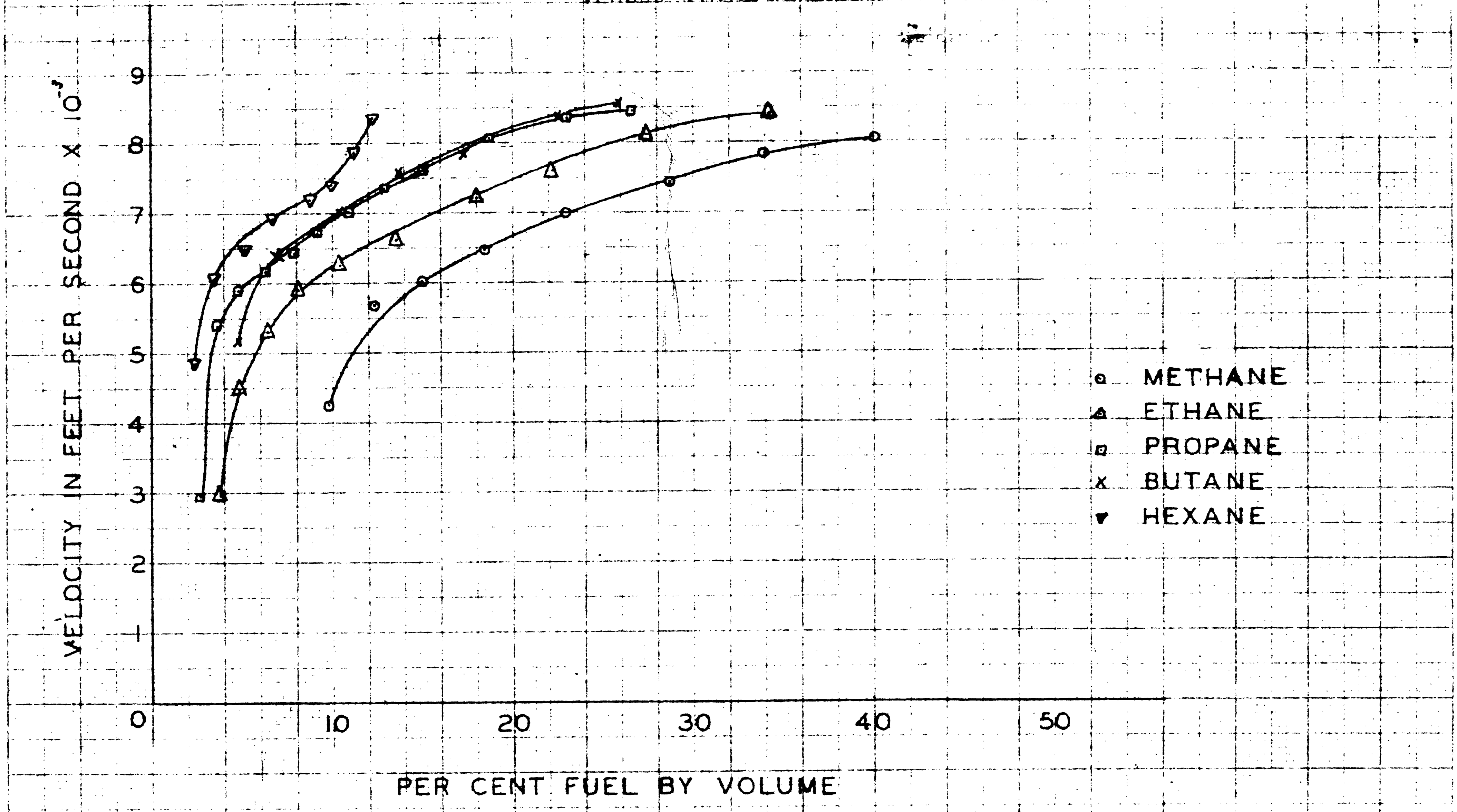


FIG. 9

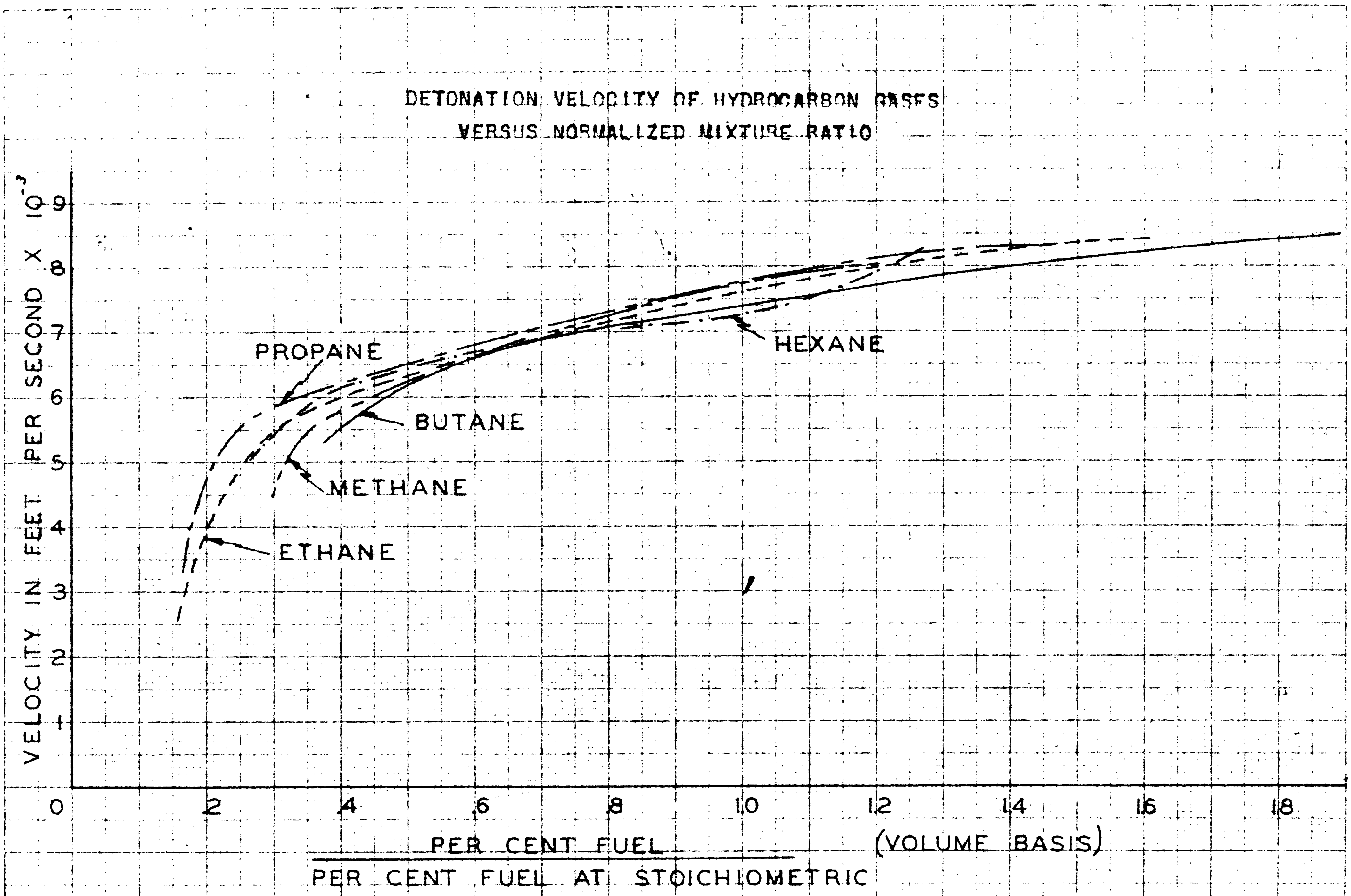

DETONATION VELOCITY OF HYDROCARBON GASES
VERSUS NORMALIZED MIXTURE RATIO
VELOCITY IN FEET PER SECOND X 10⁻³
9
8
7
6
5
4
3
2
1
0
2
4
6
8
10
12
14
16
18
PROPANE
BUTANE
METHANE
ETHANE
HEXANE
PER CENT FUEL / PER CENT FUEL AT STOICHIOMETRIC
(VOLUME BASIS)

FIG. 10

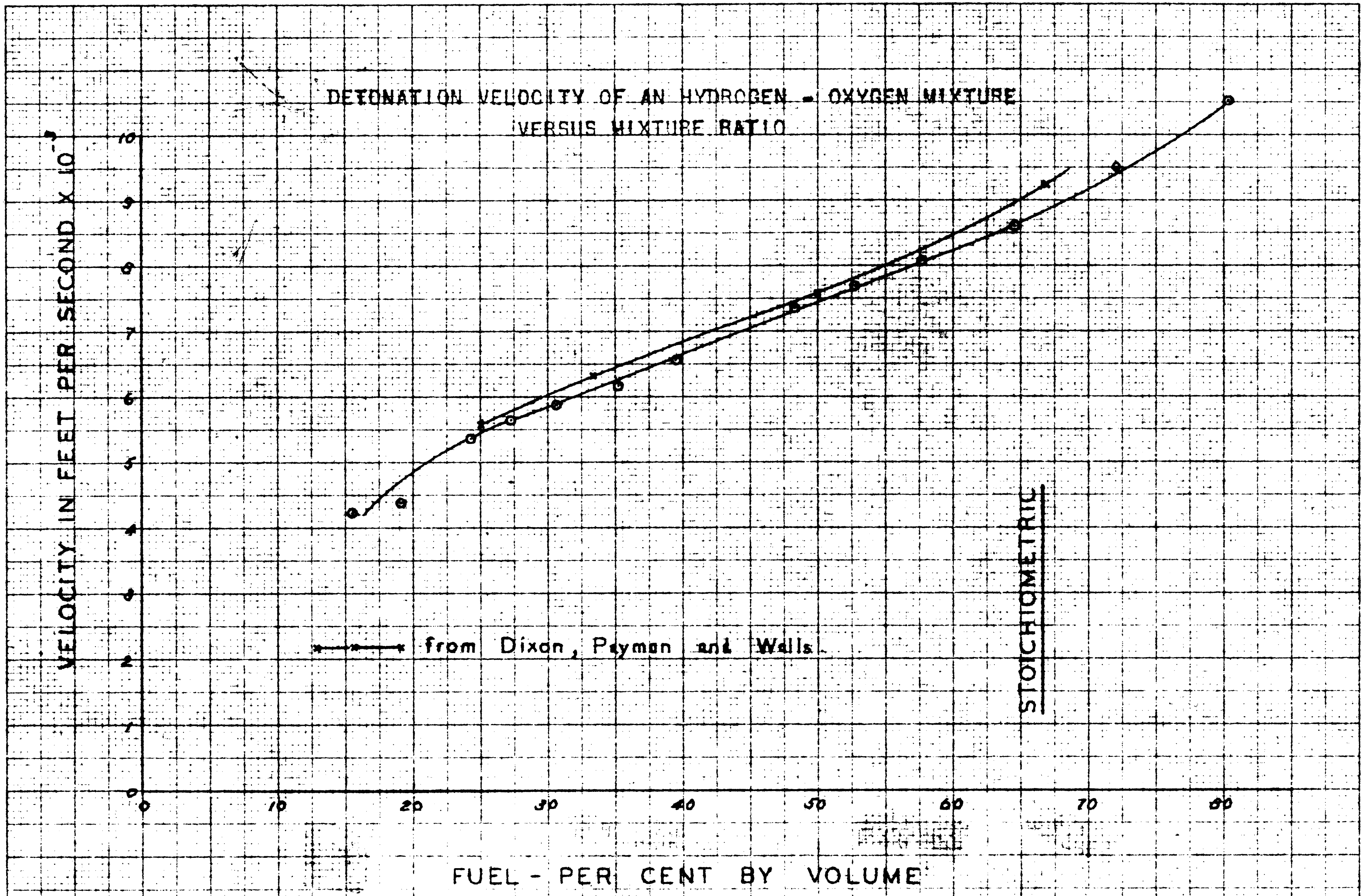

DETONATION VELOCITY OF AN HYDROGEN - OXYGEN MIXTURE
VERSUS MIXTURE RATIO
VELOCITY IN FEET PER SECOND X 10^-3
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80
from Dixon, Payman and Walls
STOICHIOMETRIC
FUEL - PER CENT BY VOLUME
2-26-51

FIG. 11

DETONATION VELOCITY OF AN HYDROGEN - AIR MIXTURE
VERSUS MIXTURE RATIO

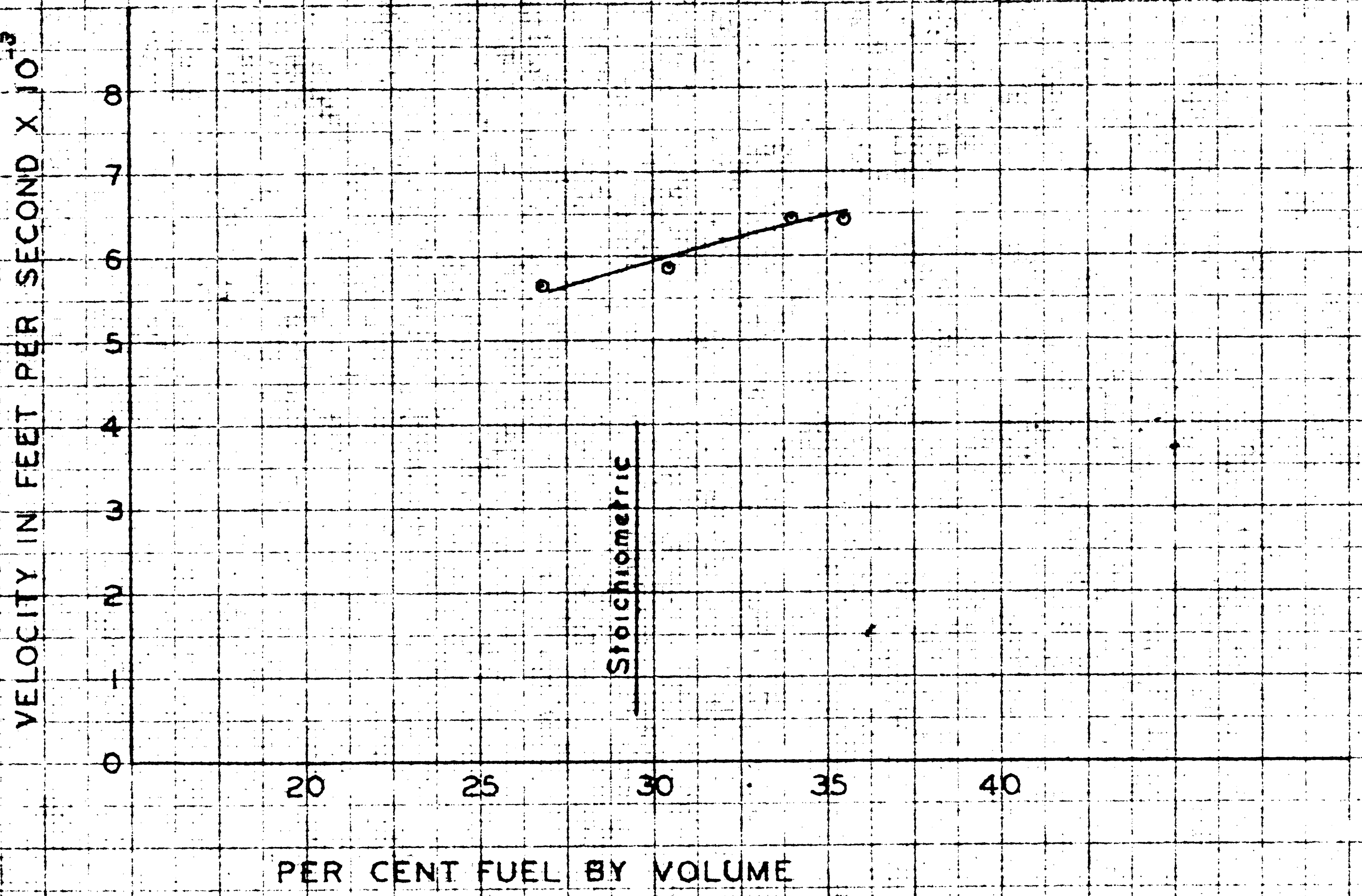


FIG. 18

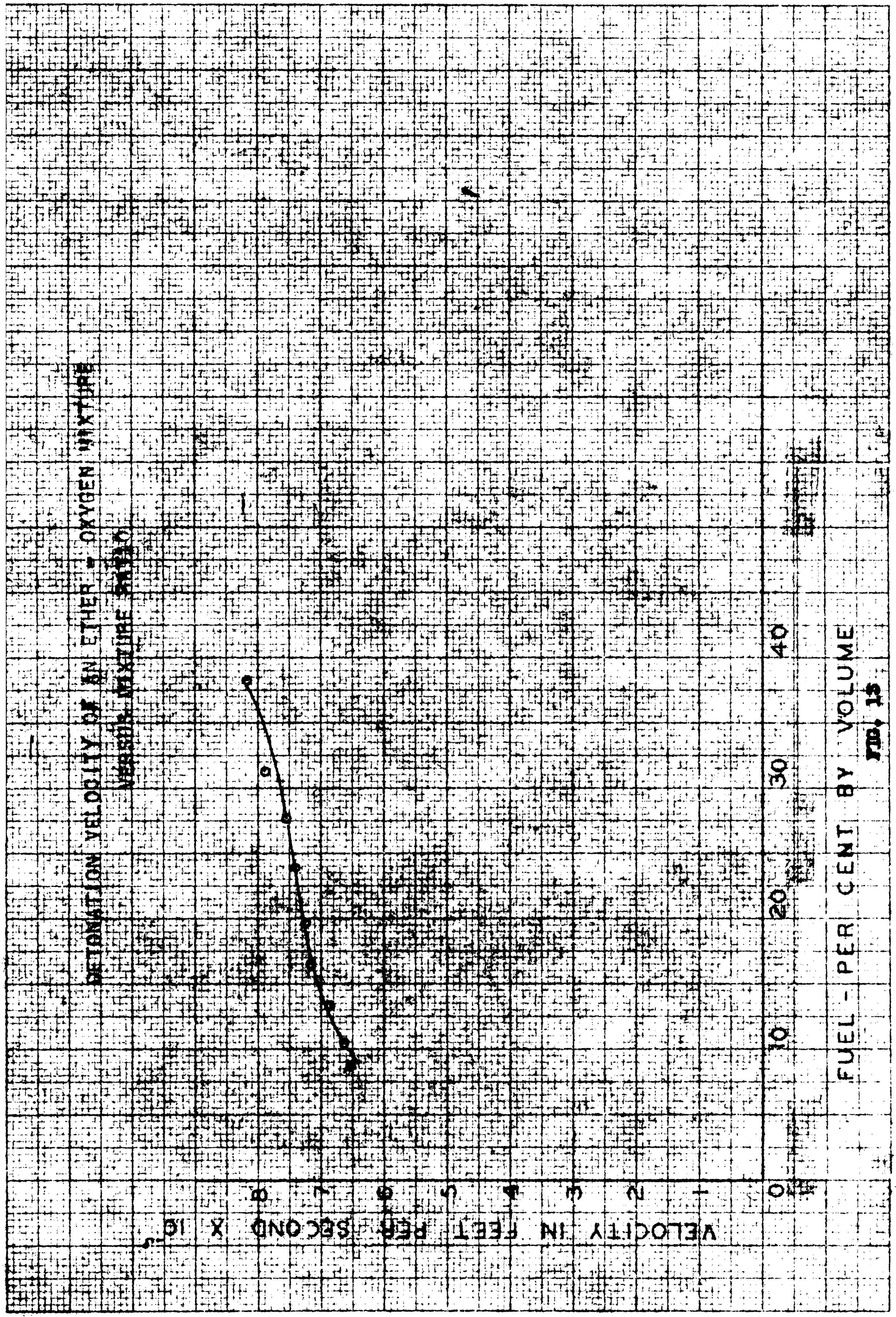

DETONATION VELOCITY OF AN ETHER - OXYGEN MIXTURE
VERSUS MIXTURE RATIO
VELOCITY IN FEET PER SECOND X 10
0
1
2
3
4
5
6
7
8
0
10
20
30
40
FUEL - PER CENT BY VOLUME

FIG. 15

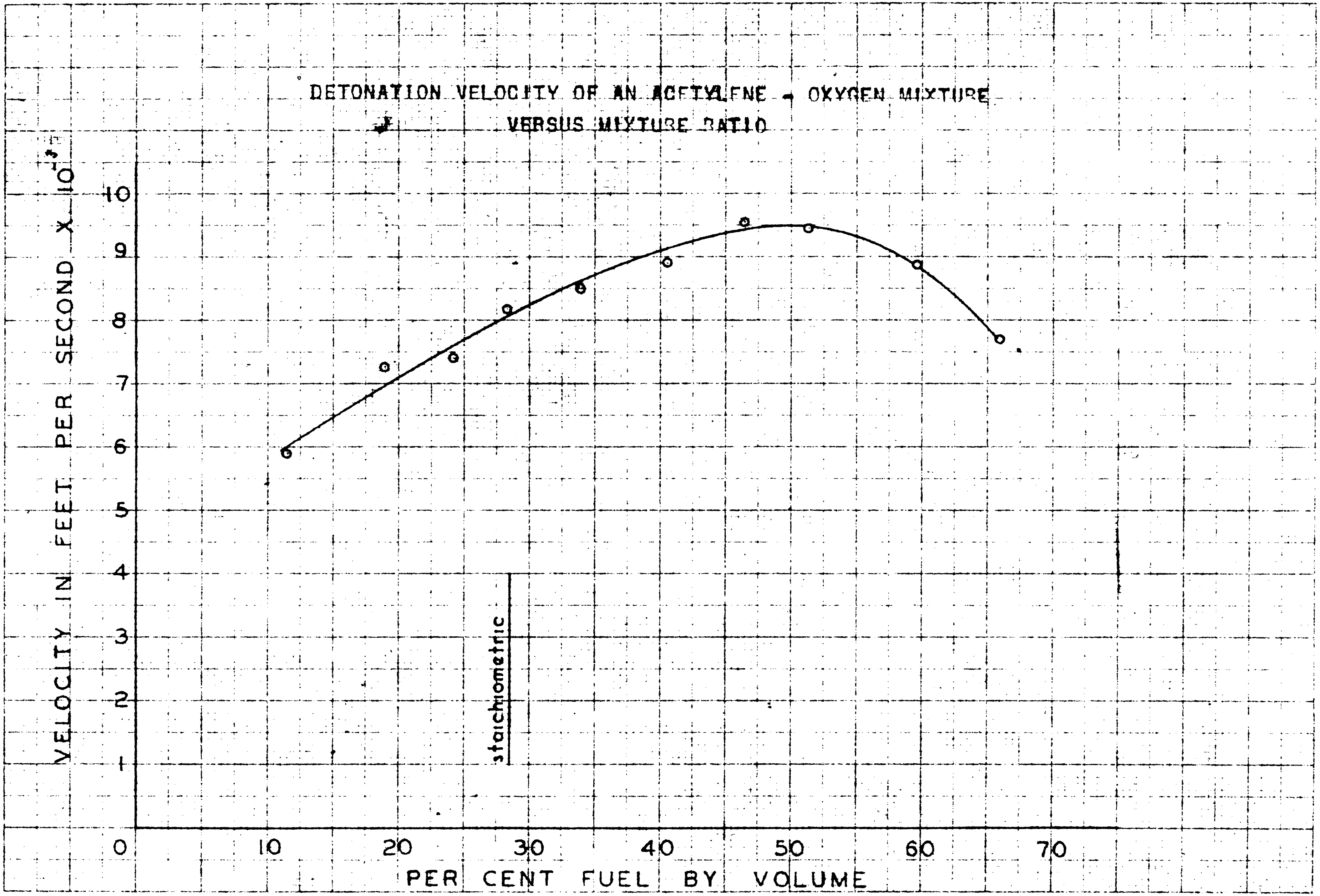

DETONATION VELOCITY OF AN ACETYLENE - OXYGEN MIXTURE
VERSUS MIXTURE RATIO
VELOCITY IN FEET PER SECOND X 10^-3
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
stoichiometric
PER CENT FUEL BY VOLUME

FIG. 14

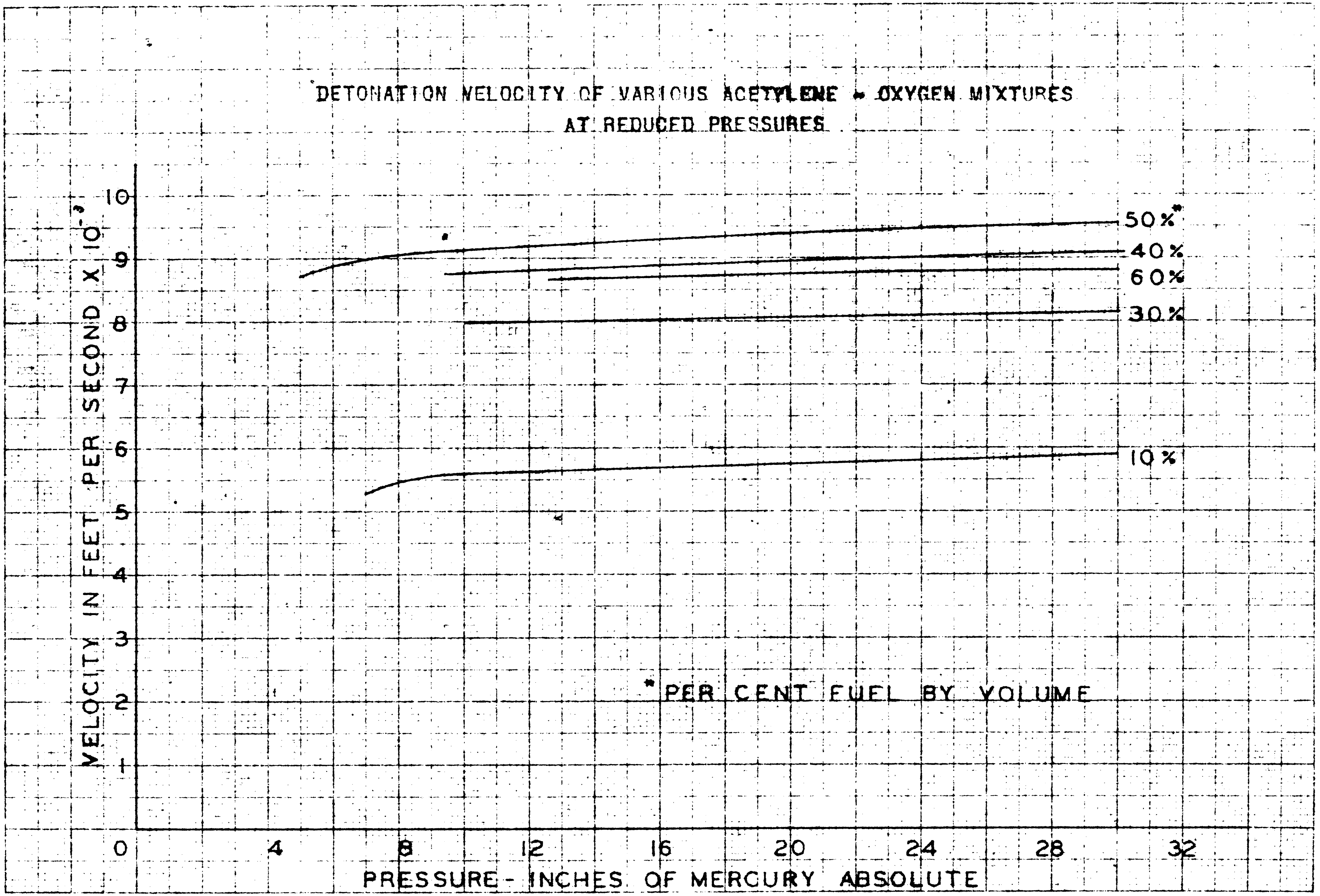

DETONATION VELOCITY OF VARIOUS ACETYLENE - OXYGEN MIXTURES
AT REDUCED PRESSURES
VELOCITY IN FEET PER SECOND X 10^-3
10
9
8
7
6
5
4
3
2
1
0
4
8
12
16
20
24
28
32
PRESSURE - INCHES OF MERCURY ABSOLUTE
50%*
40%
60%
30%
10%
* PER CENT FUEL BY VOLUME

FIG. 15

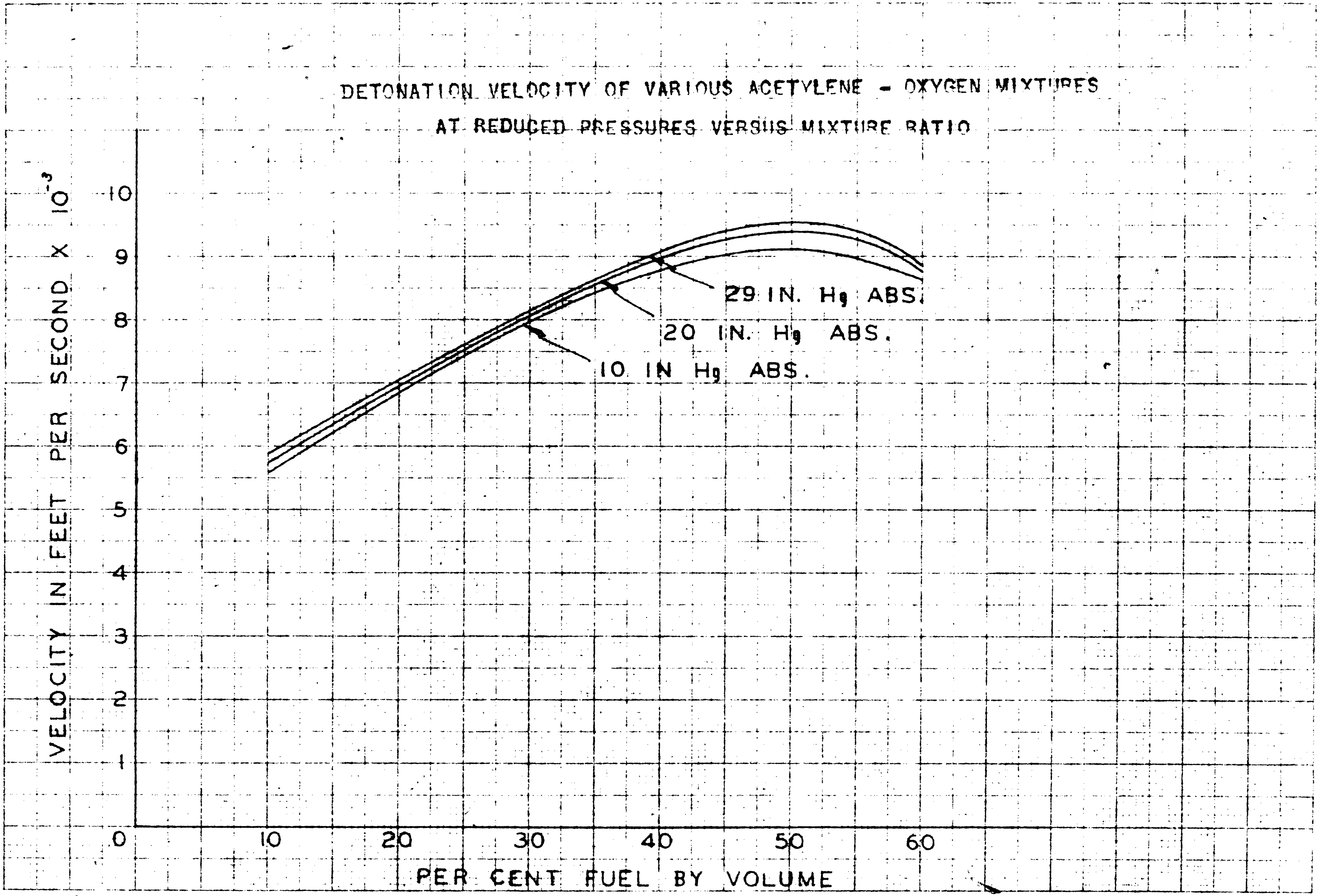

DETONATION VELOCITY OF VARIOUS ACETYLENE - OXYGEN MIXTURES
AT REDUCED PRESSURES VERSUS MIXTURE RATIO
29 IN. Hg ABS.
20 IN. Hg ABS.
10 IN Hg ABS.
VELOCITY IN FEET PER SECOND X 10^-3
PER CENT FUEL BY VOLUME
0
1
2
3
4
5
6
7
8
9
10
10
20
30
40
50
60

FIG. 16

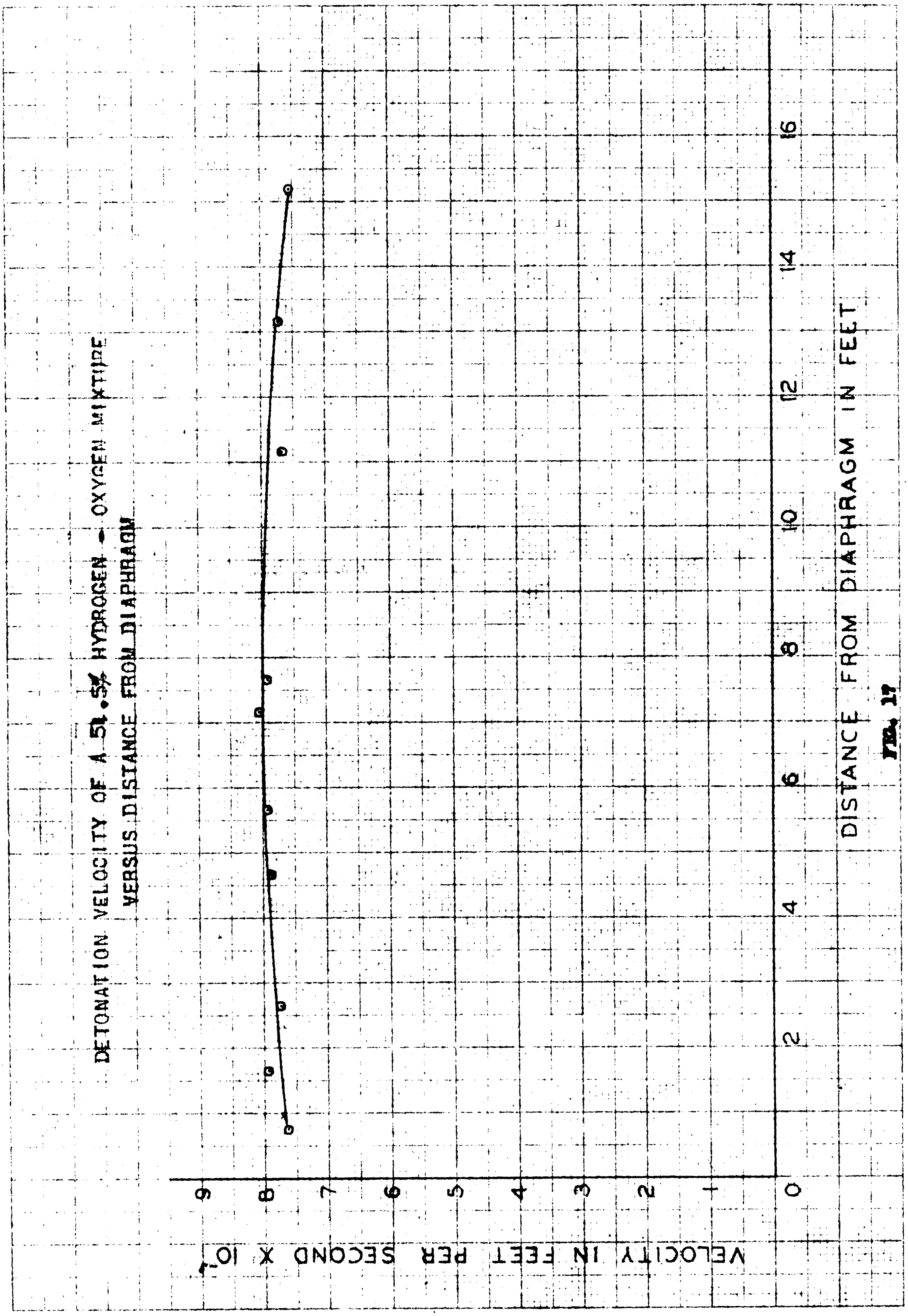

DETONATION VELOCITY OF A 51.5% HYDROGEN - OXYGEN MIXTURE
VERSUS DISTANCE FROM DIAPHRAGM
DISTANCE FROM DIAPHRAGM IN FEET
0
2
4
6
8
10
12
14
16
VELOCITY IN FEET PER SECOND X 10
1
2
3
4
5
6
7
8
9

FIG. 17

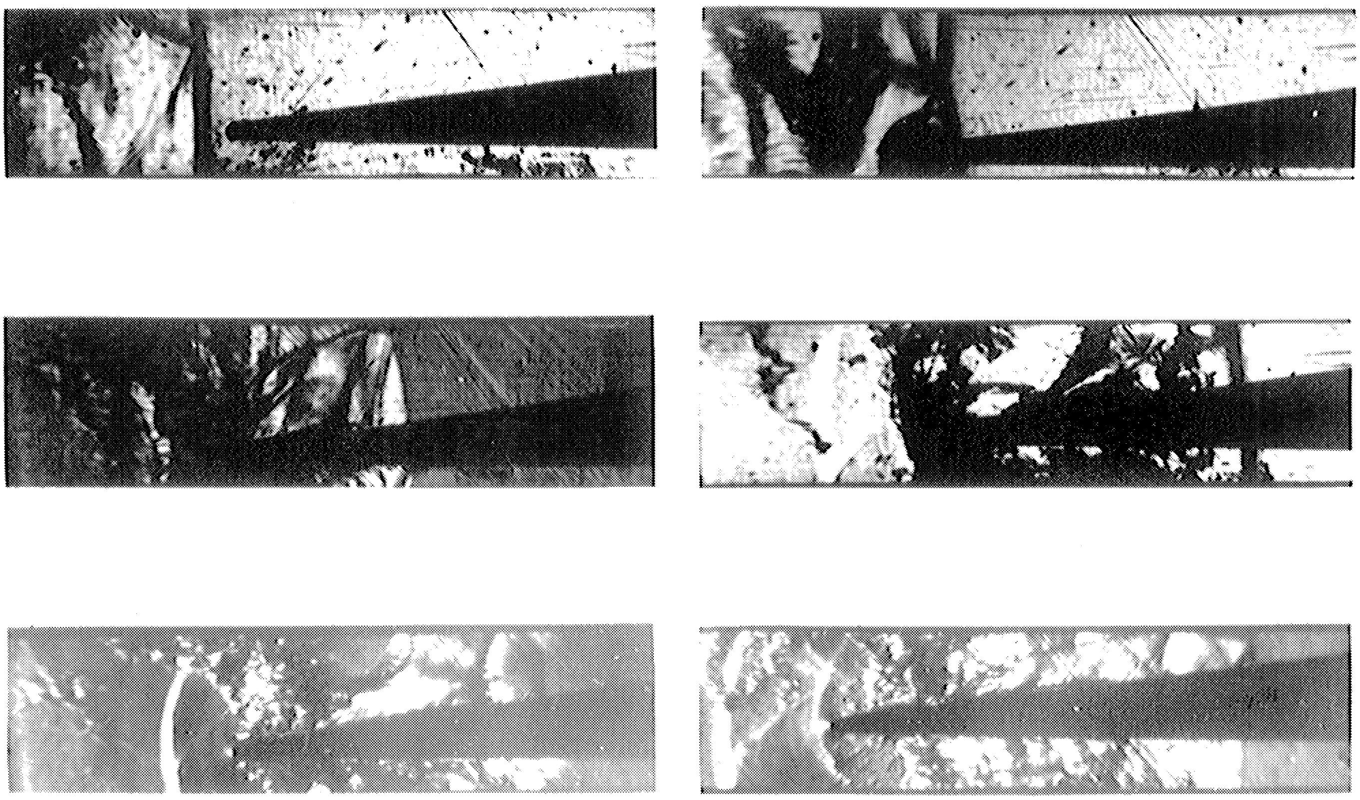
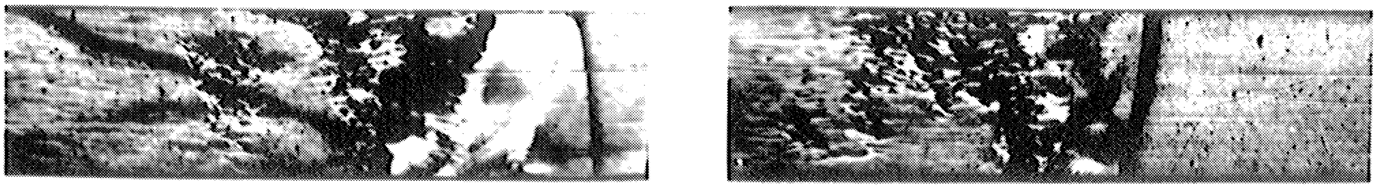
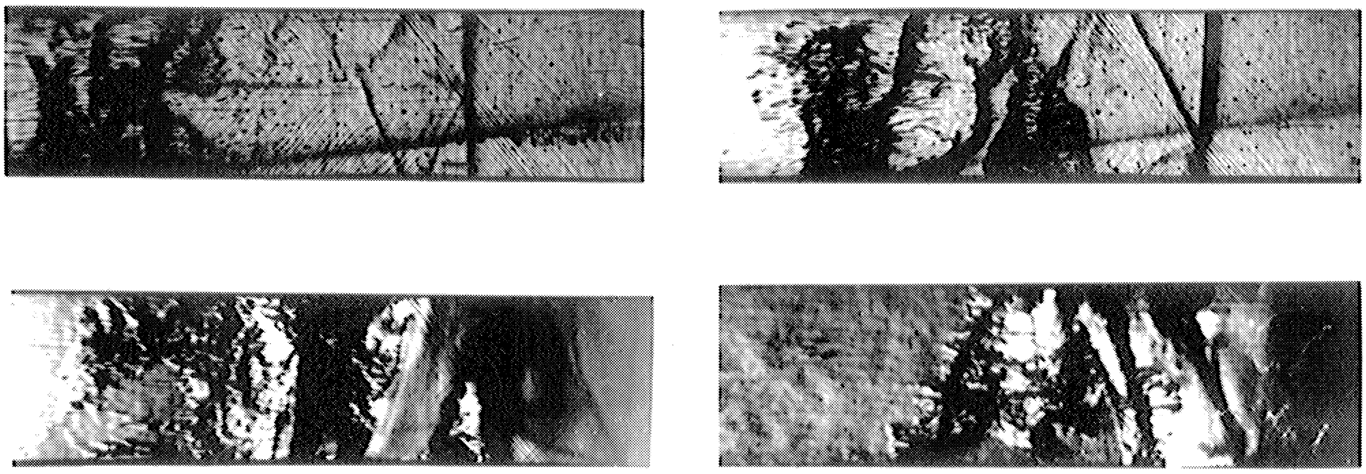


FIG. 18 - 25% H_2-O_2 DETONATION WAVE - SPARK SCHLIEREN



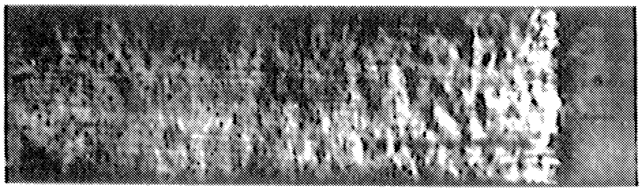
HORIZONTAL KNIFE EDGE



VERTICAL KNIFE EDGE

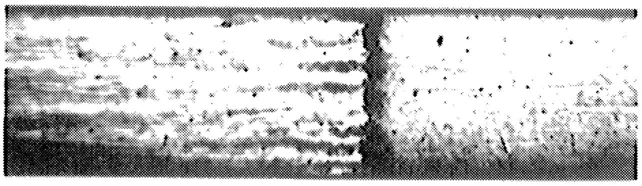
FIG. 19 - SPARK SCHLIEREN PHOTOGRAPHS

25 % H_2 - O_2 DETONATIONS



41 % H_2-O_2

VERTICAL KNIFE EDGE



50 % H_2-O_2

HORIZONTAL KNIFE EDGE

FIG. 20 - SCHLIEREN PHOTOGRAPH OF A DETONATION WAVE

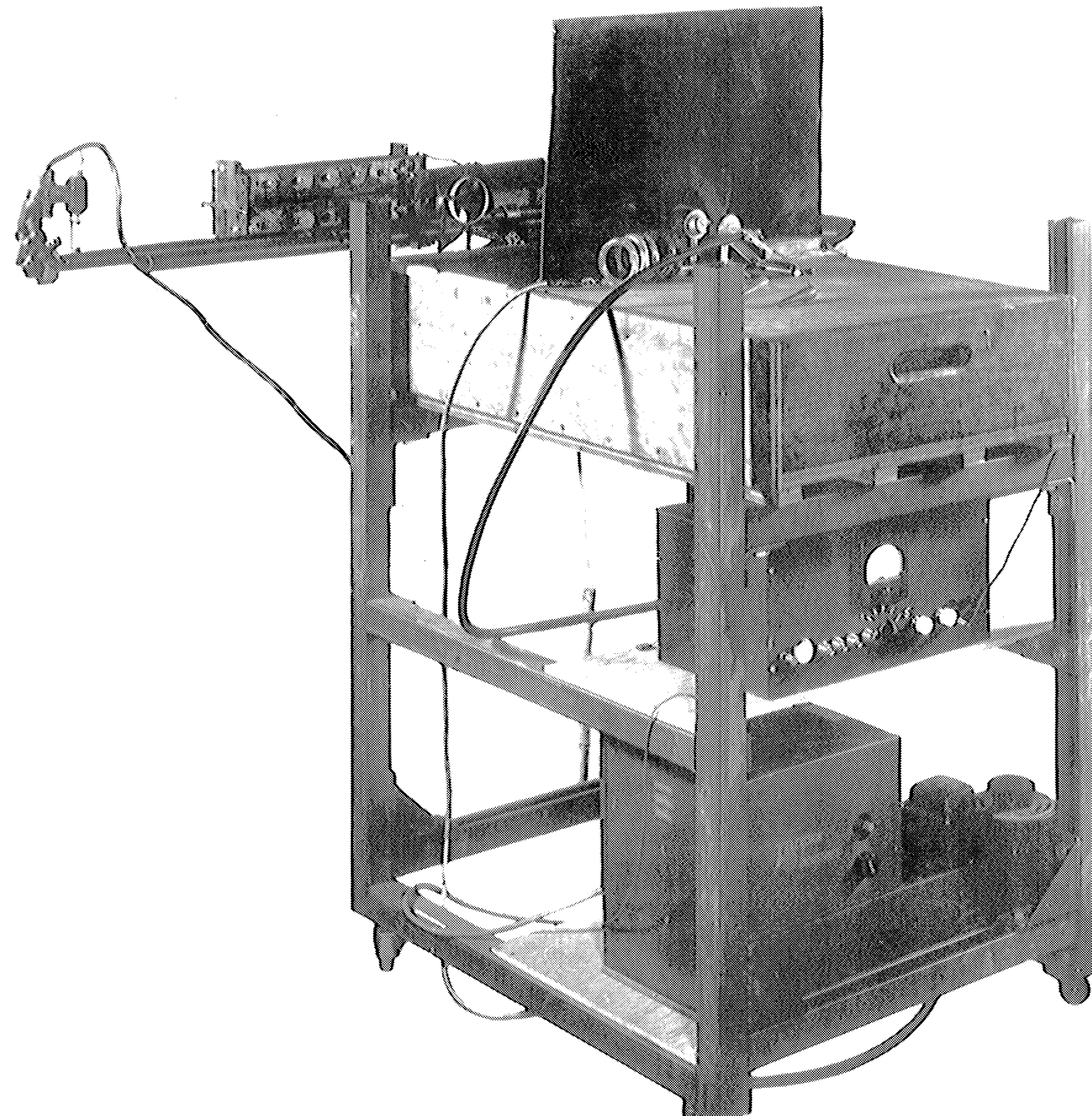
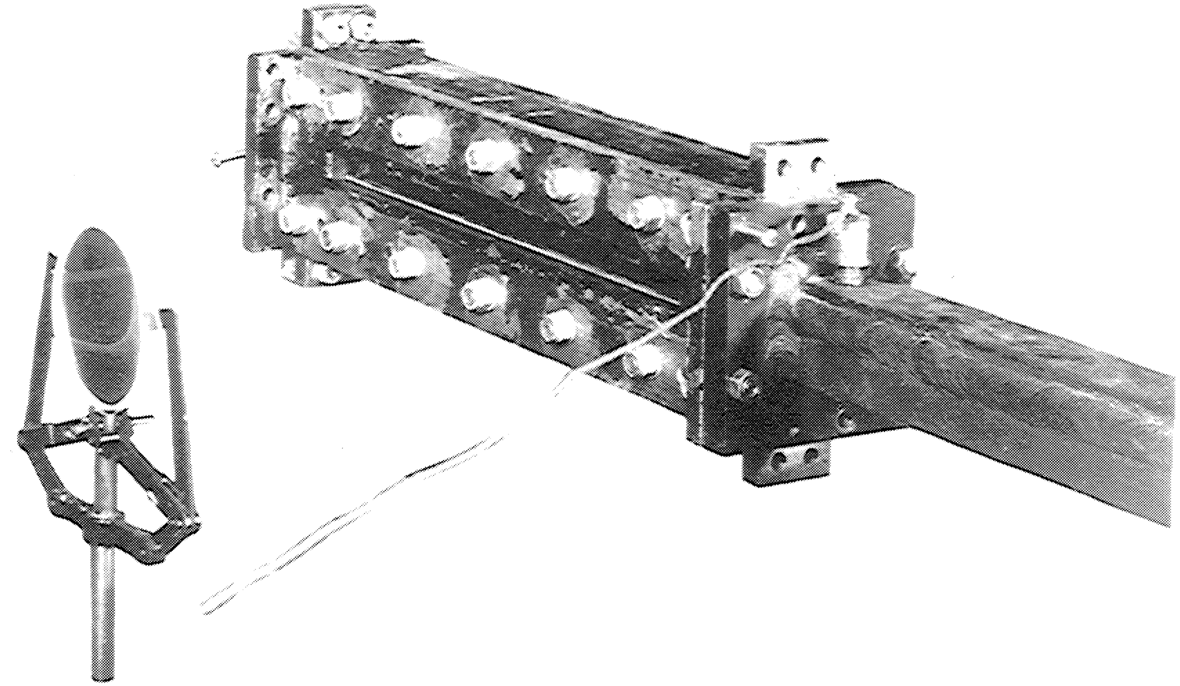


FIG. 21 -- HIGH VOLTAGE SPARK GAP WITH TIME DELAY

FIG. 22 -- TEST SECTION AND IONIZING PROBE



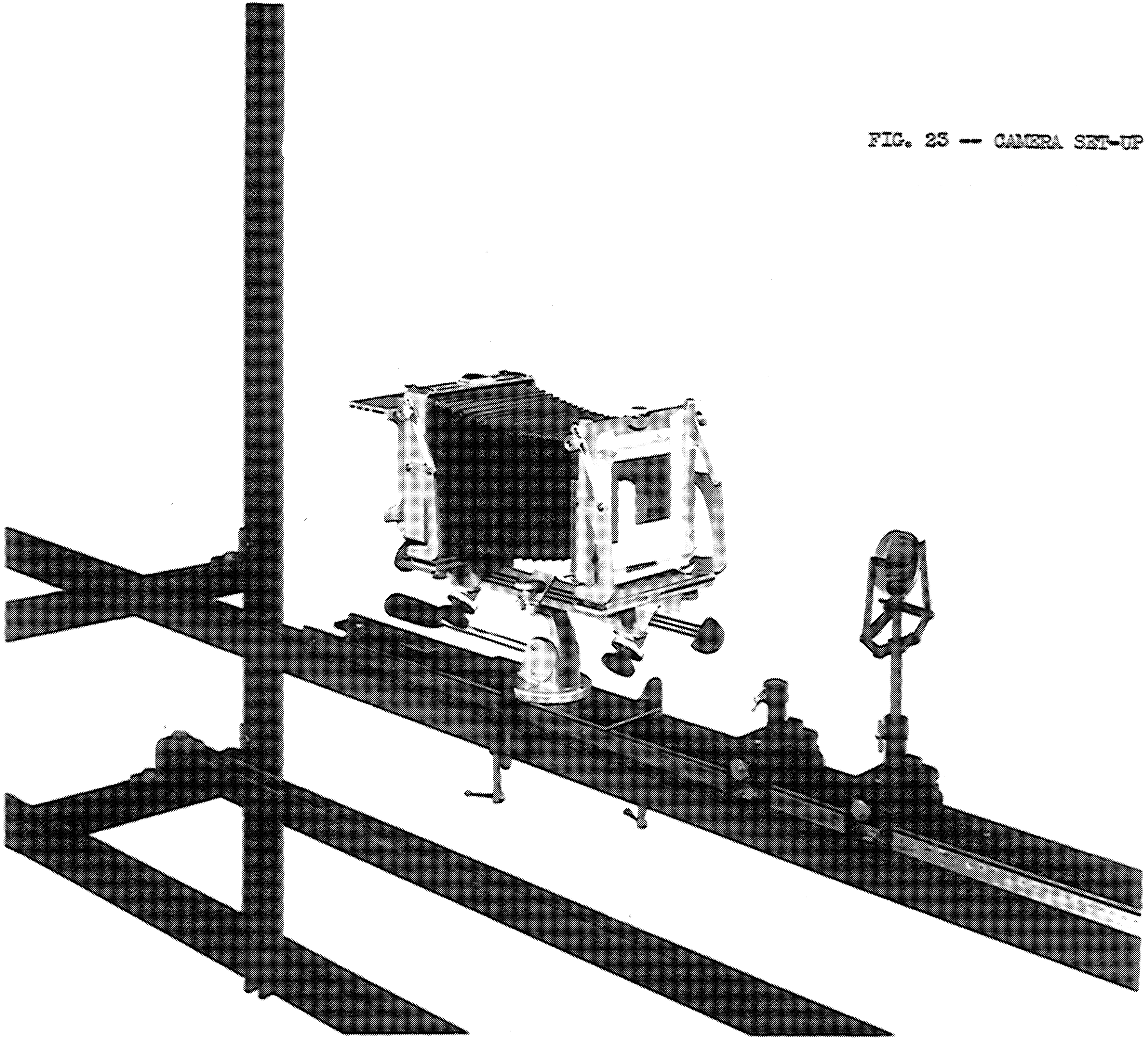


FIG. 23 — CAMERA SET-UP

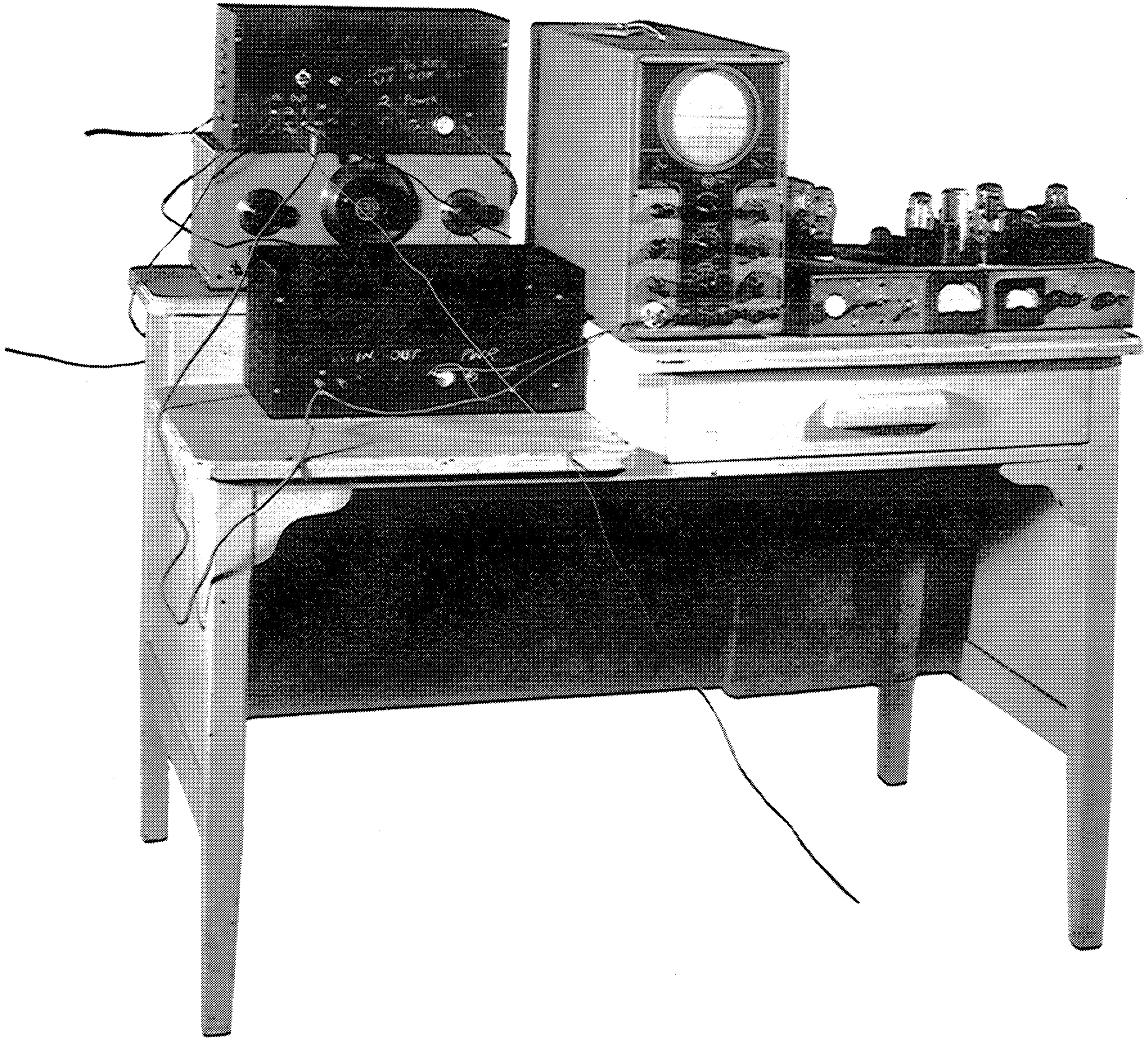


FIG. 24 — TIMING CIRCUIT (on right) WITH ASSOCIATED CALIBRATION EQUIPMENT