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ESSO LABORATORIES

STANDARD OIL DEVELOPMENT COMPANY

PROCESS DIVISION

PROGRESS REPORT

ON

STUDY OF COMBUSTORS FOR SUPERSONIC RAM - JET

(ODS PROJECT)

FOR PERIOD NOVEMBER 1, 1945 - JANUARY 31, 1946

REPORT PDN- 4136
FEBRUARY 10, 1946

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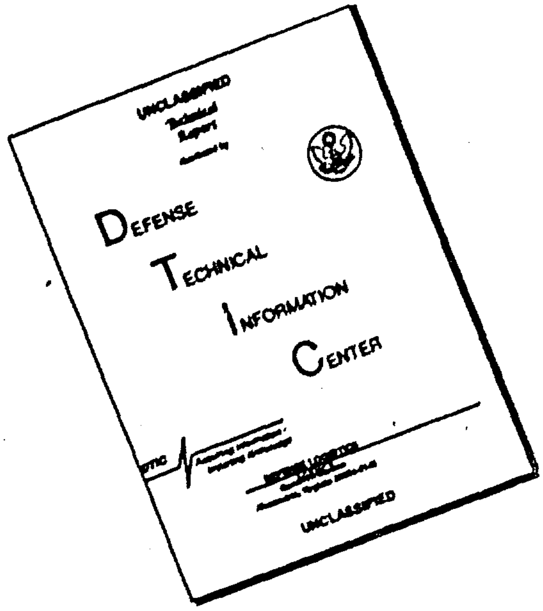

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ON

STUDY OF COMBUSTORS FOR SUPERSONIC RAM-JET (ODS PROJECT)

FOR PERIOD NOVEMBER 1, 1945 - JANUARY 31, 1946

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REPORT PDN-4136

DATE: FEBRUARY 10, 1946

SOD PROJECT: 31888

CONTRACT NORD-9233
(BUMBLEBEE PROJECT)

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TABLE OF CONTENTS

PDN 4136

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SUMMARY

The burner facilities at the Standard Oil Development Company at Bayway, New Jersey, became available for test work in December, 1945. These facilities essentially consist of a compressor and furnace capable of supplying up to 13# air/sec. at a maximum temperature of 600°F., two test cells with a common control room, and a small office building. This equipment is being used to study 6 inch burners.

Previous work on gutter type flame holders carried out at the Forest Grove Station of Johns Hopkins University demonstrated that smooth and fairly efficient burning was obtained, but that ignition was difficult above an air rate of 9 lbs./sec. To burn at higher rates it was necessary to ignite at a low air rate and increase the amount of air after combustion had been previously iniated. In the present work, investigation of the air pressure at various points in these burners before combustion started showed that immediately downstream from the flame holder the pressure was below atmospheric and the velocity above sonic. Since it is known that low pressure makes ignition difficult an effort was made to ignite in a zone of higher pressure. This was accomplished by placing two flame holders in series and igniting at the upstream flame holder where the pressure was higher due to the effect of the downstream flame holder. Using this principle, burners capable of spark ignition over a wide range of air/fuel ratios at an air rate of 11 lbs./sec. have been developed. These burners develop approximately 80% of theoretical thrust at 15:1 air/fuel ratio and 85% of theoretical thrust at 22:1 air/fuel ratio. The air specific impulse is about 150 lbs. per lbs. of air/sec. at an air/fuel ratio of 15:1. The actual thrust under these conditions is about 1000-1100 pounds.

The drag of the atomizing section, the ignition section and the burner walls, as determined from thrust and pressure measurements during burning at 15:1 air/fuel ratio and 11 lbs./sec. of air, amounts to about 11% of the thrust developed or about 4 p.s.i. for one of the burners.

While a spark, tracer or some other source of ignition is necessary to initiate burning, maintenance of combustion does not depend on these ignition sources, and burning, once started, will continue without them.

Investigation of this type of burner is being continued with the immediate objective of developing a model suitable for flight testing. In parallel with this program a study of the influence of changes in geometry of the design is being made in order to arrive at a better understanding of the variables that determine such characteristics as efficiency, ease of ignition and range of air/fuel ratio over which smooth burning can be obtained.

PDN 4136

INTRODUCTION

This report covers the work done by the Standard Oil Development Company on ram-jet burners for the Navy Bureau of Ordnance under Contract NOrd-9233 during November, December, 1945 and January, 1946.

The testing facilities at Bayway, New Jersey, are being constructed under Contract NOrd-(F)1414, were made available for test work in December, 1945. The data given in this report were obtained with these facilities while the data in two previous reports (PDN 3980 dated October 10, 1945 and PDN 4050 dated November 10, 1945) were obtained at the Forest Grove Station of the Johns Hopkins University's Applied Physics Laboratory.

The work on gutter type flame holders reported in PDN 3980 and PDN 4050 demonstrated that this system was capable of giving smooth and efficient burning, but that at high air rates ignition was difficult. Although large oxy-ethylene pilot flames were used and the geometry of the flame holder was varied, ignition could not be obtained at air rates over 9 lbs./sec. However, if combustion was started at an air rate below 9 lbs./sec. the air rate could be increased above this value without losing combustion. It was also shown that once combustion was initiated it could be maintained without the pilot. It was found that the combustion efficiency depended on flame holder design as well as fuel distribution and tail pipe length.

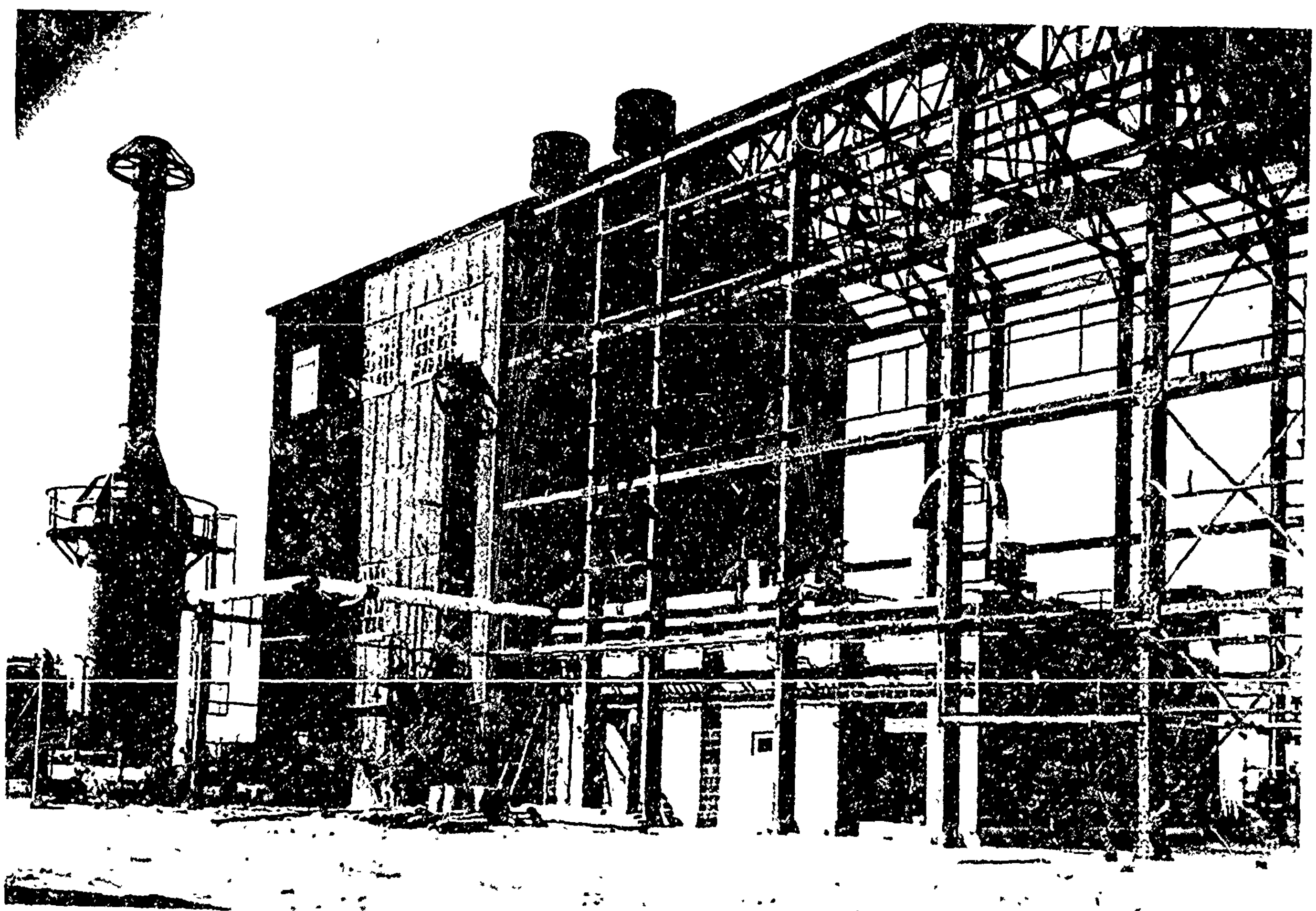
This report describes the results of testing several flame holder and fuel injector designs. These various designs were tested in an effort to improve ignition characteristics and combustion efficiency over that of previous models.

FACILITIES

Air is supplied to the facilities at Bayway by a steam driven turbo-compressor; steam and other utilities being supplied by the Bayway Refinery of the Standard Oil Company of New Jersey. Eleven pounds a second of air is supplied at a pressure of 95 p.s.i. and somewhat larger quantities can be supplied at a lower pressure. The air, leaving the compressor at a temperature of approximately 240°F., can be heated to 600°F. in a gas fired furnace. From the furnace the air passes through a metering orifice and a pneumatically operated control valve into either of two test cells (only one of which is in operation at present). Burners in these cells exhaust directly into the atmosphere through 8 ft. square openings which can be closed when the burner is not in operation. The office building and the control room are of sound resistant construction.

Fuels are stored in two 10,000 gal. and two 1,000 gal. tanks. They are supplied to the burner from three 75 gal. blow cases which can be pressured to 300 p.s.i. with inert gas.

Figure 1 is a photograph of the compressor house, the furnace and the building containing the two test cells and the control room. The air line leading from the furnace to the roof of this building and into the two test cells can be seen. The openings of the test cells in the low laboratory building are visible. The large black building contains the compressor and its auxiliary equipment.



PDN 4136

Figure 2 shows the instrument panel. At the left of the panel the fuel flow is indicated by four armored rotameters in series covering a range from .05 to 1.0 lbs./sec. To the right of the rotameters, air pressure, temperature and rate are recorded and controlled. On the right of the panel is a bank of manometers and several pressure gauges for studying pressures at various points in the burner. Thrust and one pressure are automatically recorded, and temperatures are indicated by an electronic potentiometer.

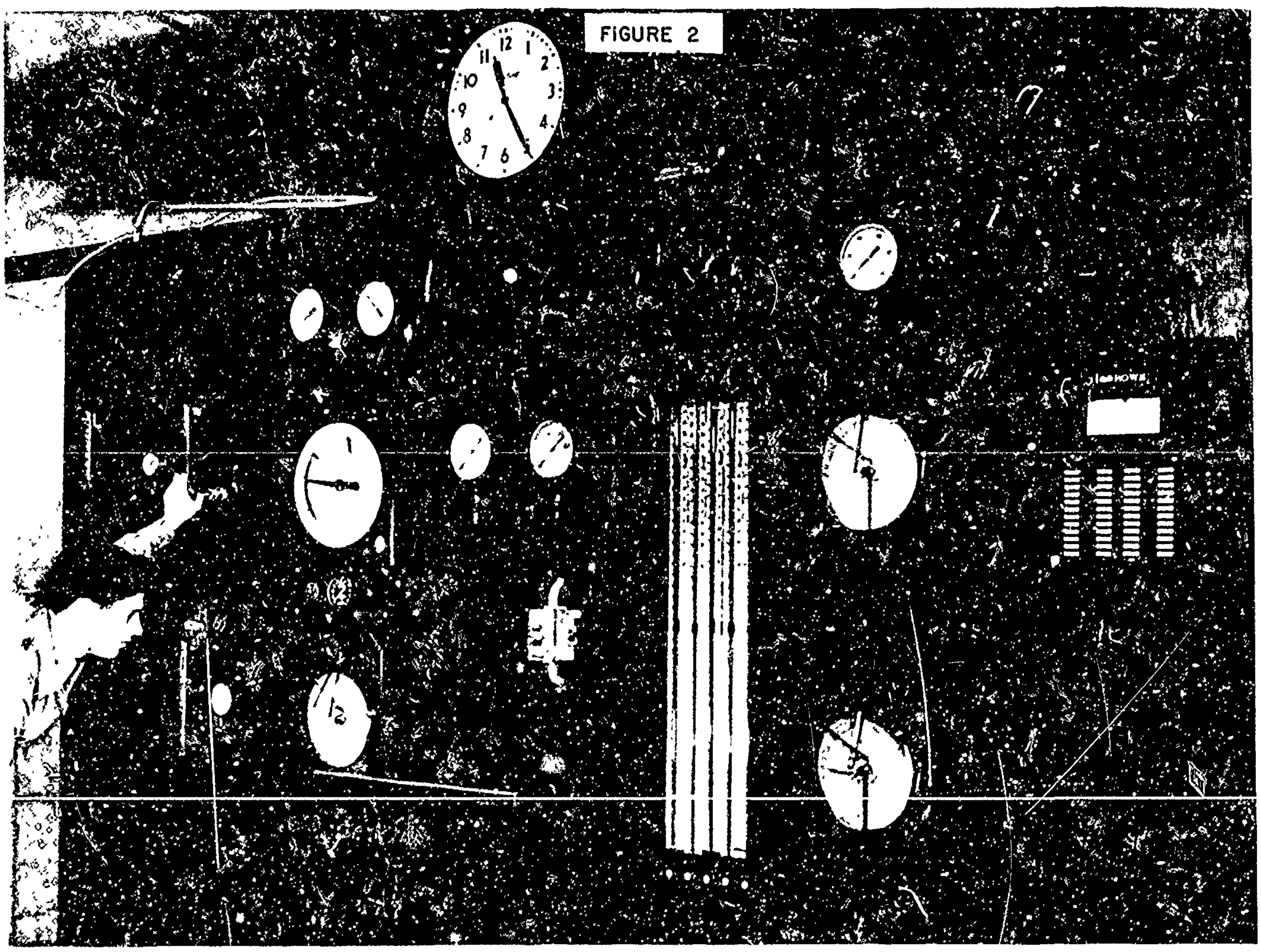
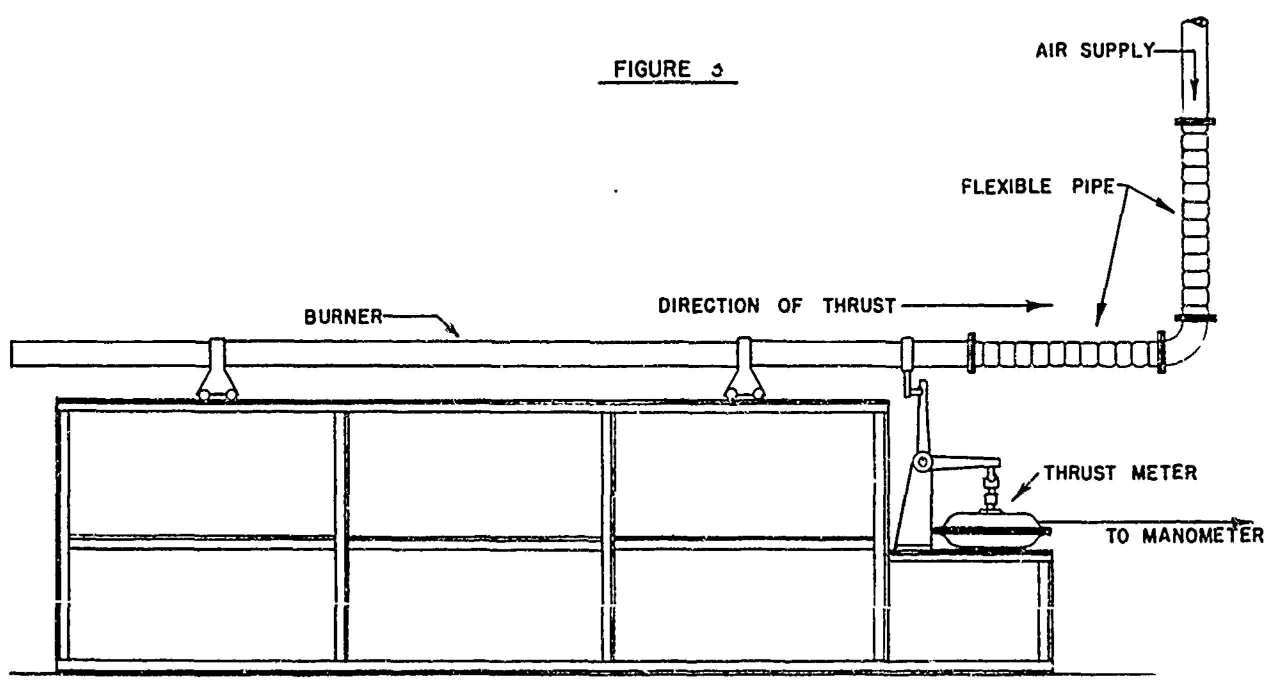


Figure 3 is a diagrammatic sketch showing the technique of measuring thrust. The burner is mounted on rollers and is connected to the air supply by flexible tubing so that it is free to move in a direction parallel to its axis. The thrust of the burner is transmitted to a lever which transmits the force to a commercial position controller. This position controller holds the lever in one position by opposing its force with air pressure behind a diaphragm. This air pressure is recorded on the instrument panel. The instrument is calibrated by means of weights which can be connected to the burner by pulleys. This type of thrust meter gives a measure of the momentum of the gases leaving the tail pipe. The increase of momentum of the gases due to combustion rather than the momentum of the gases leaving the burner is of interest in this study; so the thrusts reported here are the thrust meter reading less the momentum of the air entering the combustion zone. This measurement is not influenced by drag in the equipment. Pressure measurements in addition to the thrust measurement are necessary to determine the internal drag.

FIGURE 3



SCHEMATIC DIAGRAM OF BURNER ARRANGEMENT

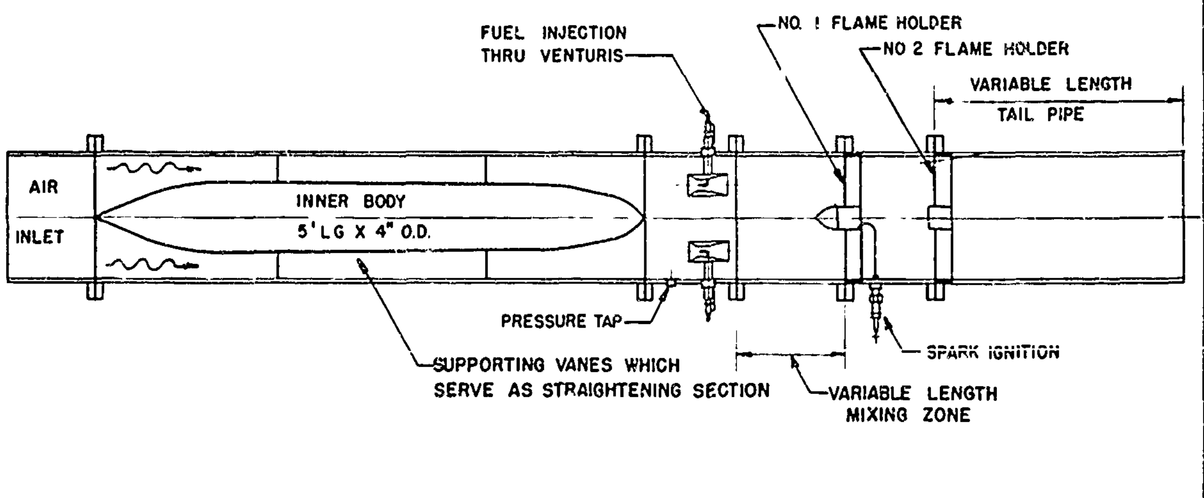
EXPERIMENTAL WORK

A diagrammatic sketch of the burner is shown in Figure 4. The air flows through an inner body diffuser supported by vanes which tend to damp out rotation that might be in the entering air stream. Fuel is injected immediately after the inner body and approximately 20 inches is allowed for mixing of fuel and air. The mixing section is followed by one or more flame holders and a tail pipe - generally four feet in length. Pressure taps are located at various points along the burner. A photograph of a burner mounted for testing is shown in Figure 5. This burner, made of flanged sections of 6 inch pipe, is mounted on rollers and is connected to the air supply by means of a flexible pipe which can be seen in the upper left portion of the photograph. The wires leading to the tail pipe are thermocouples and the copper tubes are pressure taps.

The runs reported here were made with No. 1 solvent naphtha, the inspections of which may be found in the appendix.

Several combinations of diffusers, fuel injection systems and flame holders were used. A number system has been devised to identify the components in the combinations, and a description of this system can be found in the appendix.

FIGURE 4



SCHEMATIC DIAGRAM OF BURNER MODEL

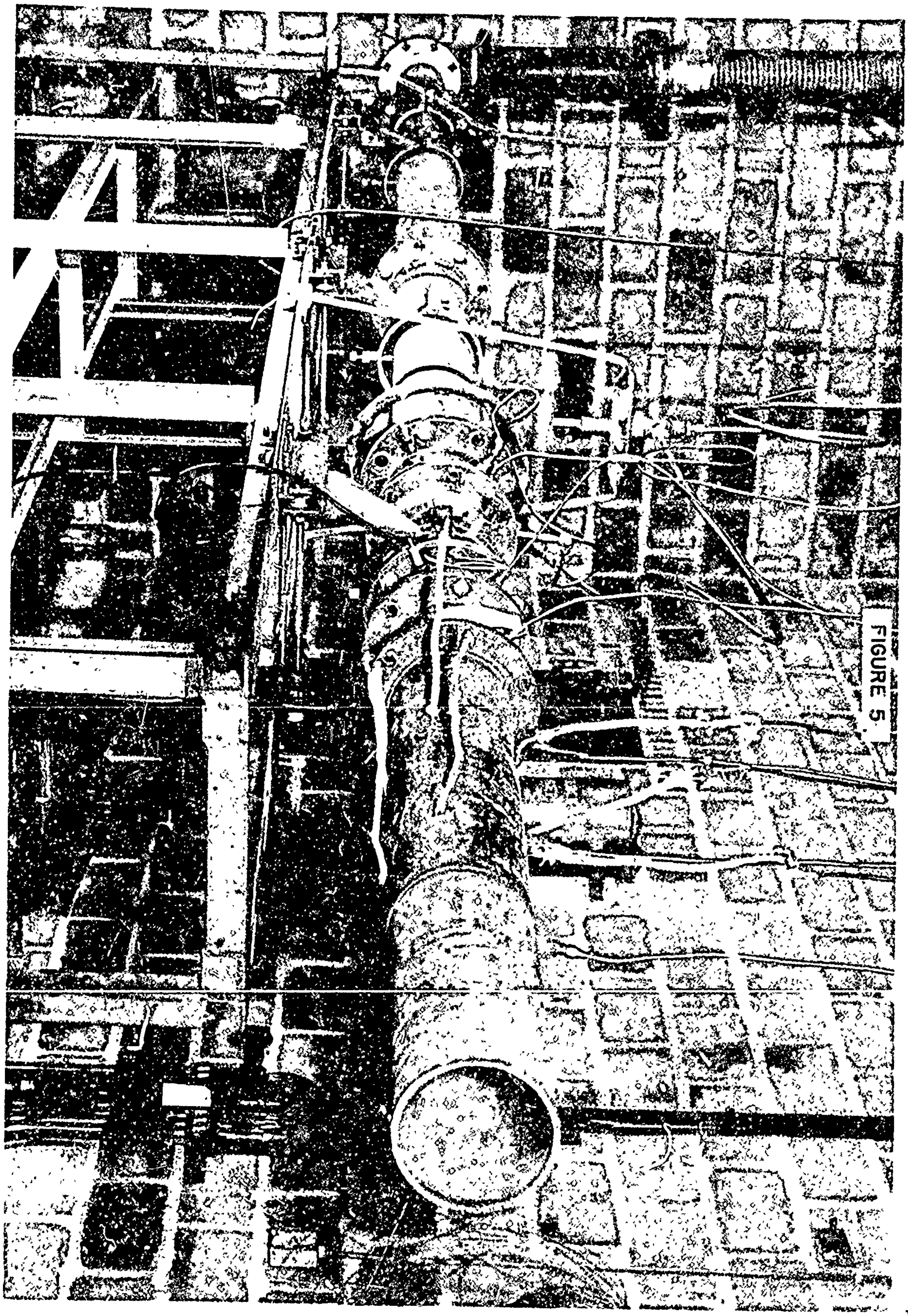


FIGURE 5.

6 INCH BURNER MOUNTED FOR TESTING

PDN 4136

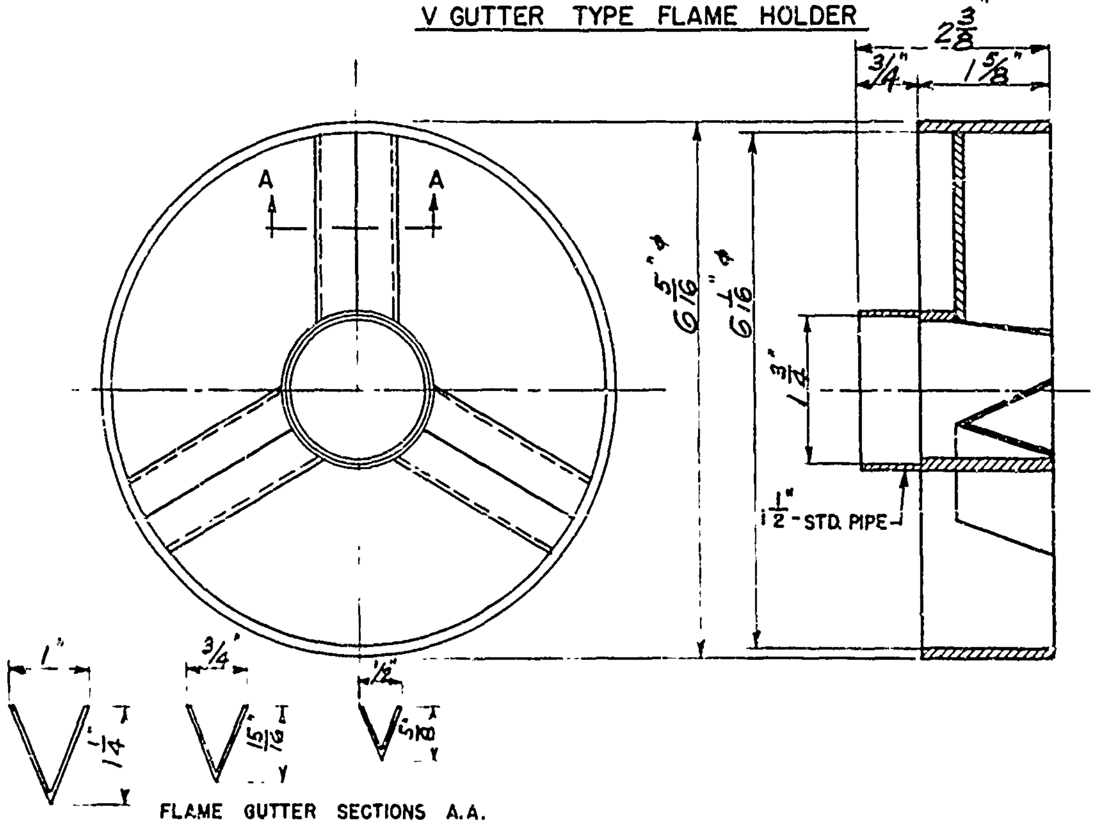
1. Pressure and Ignition Studies

The results given in the previous progress report (PDN 4050, dated November 10, 1945) covering work carried out at the Forest Grove Station at Johns Hopkins University demonstrated that ignition with the single V-gutter flame holder was difficult at high air rates. It was demonstrated that increasing the intensity of the ignition source would increase the air rate at which ignition could be obtained, but that these gains were small with the hydrogen and ethylene-oxygen pilot flames employed.

Measurements of pressures without burning were made using the type flame holder shown in Figure 6 of this report and a typical curve of absolute pressure as a function of distance along the burner is shown in Figure 7. This run, made at 11 lbs./sec. in a 6 in. burner, shows that the pressure is well above atmospheric upstream from the flame holder, but that immediately downstream from it the pressure drops below atmospheric and continues in this condition for some distance along the tail pipe. The conditions existing in this section show that the velocity is above sonic so the flame holder apparently acts as a supersonic nozzle.

FIGURE 6

V GUTTER TYPE FLAME HOLDER



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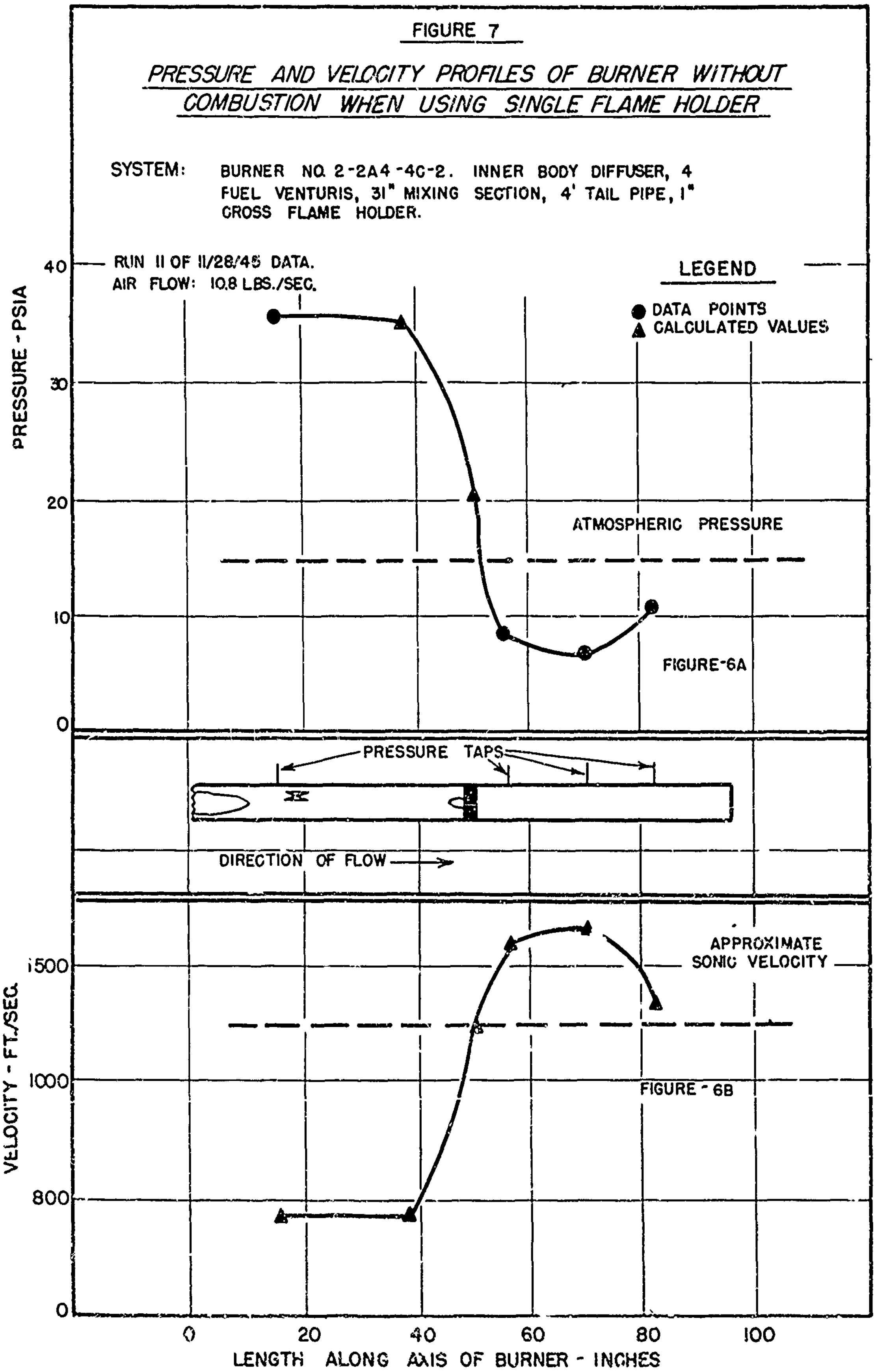

FIGURE 7

PRESSURE AND VELOCITY PROFILES OF BURNER WITHOUT COMBUSTION WHEN USING SINGLE FLAME HOLDER

PDN 4136

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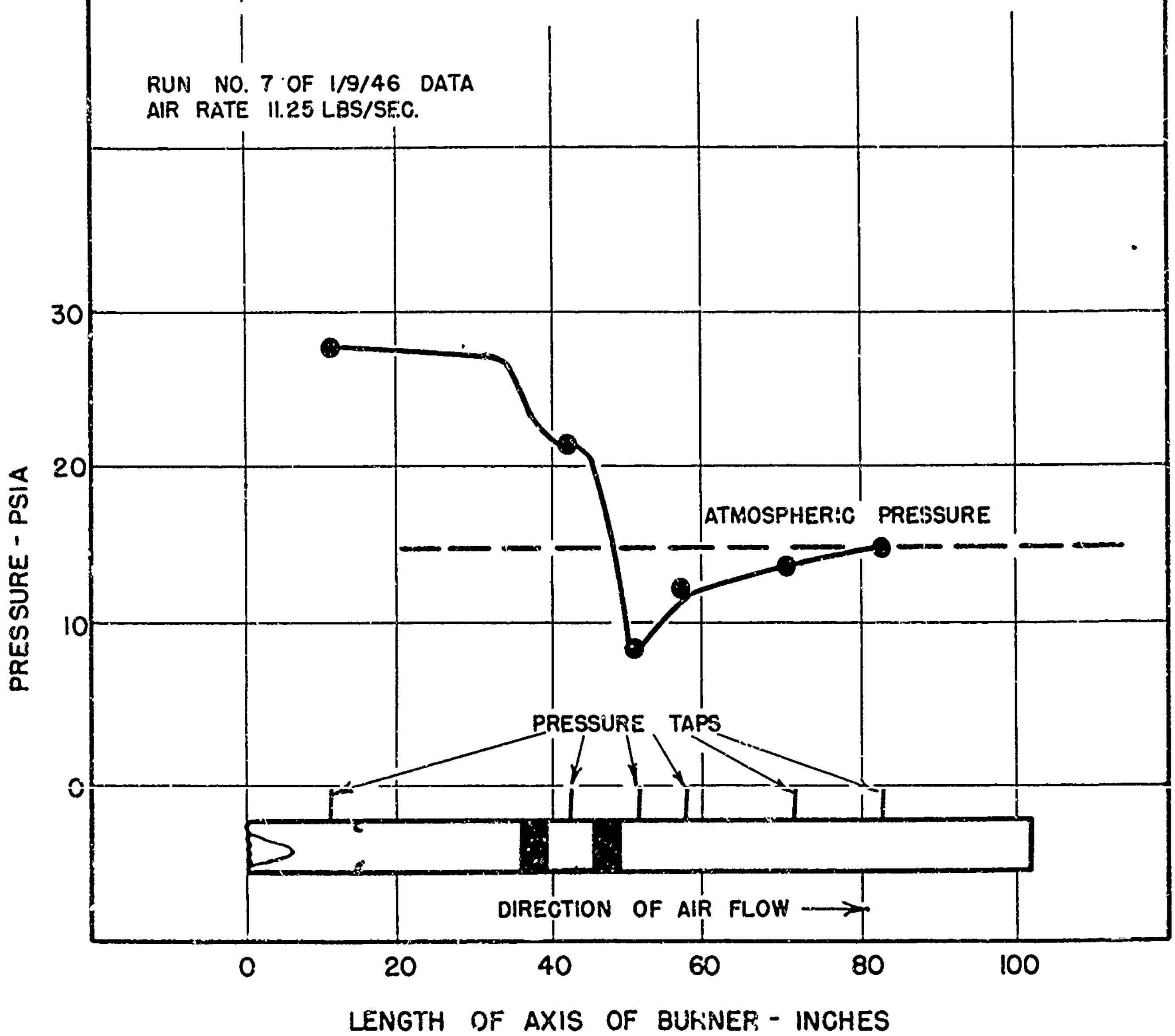
It is known that the spontaneous ignition temperature of this type of fuel increases rapidly as the pressure is decreased below one atmosphere; so it was surmised that low pressure immediately downstream from the flame holder was at least partly responsible for the ignition difficulties.

In an effort to initiate ignition in a zone of higher pressure a burner was tried with two flame holders in series with the point of ignition in the central cavity of the upstream flame holder. Pressure as a function of distance along the burner for such a system is shown in Figure 8. It can be seen that the pressure is above atmospheric between the two flame holders, and that it drops below atmospheric downstream from the downstream flame holder. It was found that a spark placed in the center of the upstream flame holder gave reliable ignition at an air rate of 11 lbs./sec. while with a single flame holder ignition could not be obtained at this air rate even with large heat inputs from a pilot flame. With this type of burner the spark was not needed once combustion was established.

FIGURE 8

PRESSURE PROFILE OF BURNER WITHOUT COMBUSTION WHEN USING TWO FLAME HOLDERS

SYSTEM: BURNER NO. 2-IA3-IOD-4. INNER BODY DIFFUSER, FOUR FUEL INJECTOR NEEDLES, 21" MIXING SECTION, 54" TAIL PIPE, FIRST FLAME HOLDER 3/4" "Y"-GUTTER, SECOND FLAME HOLDER 6" DOWNSTREAM 1" "Y"-GUTTER WITH 1.5" DIA. CENTRAL OPENING.



PDN 4136

Table 1 summarizes the range of air/fuel over which spark ignition and combustion was obtained for several different burners using two flame holders. The range of spark ignition was determined by setting the air and fuel rate before turning on the spark.

The burners described in line A gave burning and spark ignition over a range of A/F from 33 to 14.6. However, burning became rough over the range of 16.5 to 14.6. In an attempt to reduce the pressure drop of the system the width of gutters on both flame holders was reduced by 1/4 in. As shown in line B, ignition was not obtained. These data and data previously reported (progress report PDN 3980, dated October 10, 1945) showing that 1/4 in. gutters did not maintain smooth burning at high air rates indicate that the minimum gutter width for this design may be around 1/2 in.

Line D shows the effect of changing from venturi fuel injection to radial injection needles. The range of smooth operation was increased on both the lean and rich side, but spark ignition was not obtained at mixtures richer than A/F = 22. This difficulty of rich mixture ignition seemed to be characteristic of all burners using injection needles.

Previous 18 in. burner work carried out by the University of Virginia Burner Group at the Lone Star Laboratory indicated that a straightening section mounted upstream from the point of ignition had improved the smoothness of burning. Run G was made with a straightening section mounted upstream from the upstream flame holder. Spark ignition was obtained over the range of 34 - 24 air/fuel ratio and smooth combustion was obtained over a range of 41 - 12.3 air/fuel ratio - the widest range obtained at this air rate.

Line C shows that the burner described in line A which operated quite well would not ignite when the straightening section was installed. Line H describes another burner using a straightening section which would not ignite. The only difference between this burner and the operable burner in line G was that the hole in the center of the downstream flame holder was not plugged. An effort was made to improve the ignition range of the burner in line D by plugging the center of the downstream flame holder. With this arrangement rough burning was obtained at mixtures richer than 23 air/fuel ratio and burning was not sustained at mixtures richer than 20 air/fuel ratio.

The burner described in line F in which the diffuser was removed had the same ignition and combustion ranges as the otherwise similar burner described in line E showing no effect of the diffuser.

In many of the runs where ignition was not obtained but which had an ordinarily inflammable mixture of fuel and air, burning could be observed in the upstream flame holder through a quartz window. However, this burning seemed to cease at the downstream flame holder. It was also noted that this partial combustion would continue after the spark was turned off.

Table 1

RANGE OF IGNITION AND COMBUSTION AS A FUNCTION OF BURNER DESIGN

Conditions - Air Rate 11 lbs./sec., Air Temp. 300°F., Fuel No. 1 Solvent Naphtha

Line No.	Burner Number	Description of Flame Holder: Upstream Flame Holder	Description of Flame Holder: Downstream Flame Holder	Atomization	Range of A/F for Burning	Range of A/F for Smooth Burning	Range of A/F for Spark Ignition
A	2-2A3-10D-4	3/4" gutters	1" gutters-center open	Four	33 - 14.6	32 - 16.5	33 - 14.6
B	2-2A3-12D-4	1/2" gutters	3/4" gutters-center open	Venturis	-	-	No Ignition
C	2-2A3-16D-4	3/4" gutters-13" straightening section upstream	1" gutters-center open		-	-	No Ignition
D	2-1A3-10D-4	3/4" gutters	1" gutters-center open	Four	36 - 13.7	36 - 13.7*	? - 22
E	2-1A3-15D-4	3/4" gutters	1" gutters-center closed	Radial	33 - 20	33 - 23	?
F	--1A3-15D-4**	3/4" gutters	1" gutters-center closed	Injection	35 - 19.3	32 - 23	- 24
G	2-1A3-14D-4	3/4" gutters-12" straightening section upstream	3/4" gutters-center closed	Needles	41 - 12.3	41 - 12.3	34 - 24
H	2-1A3-13D-4	3/4" gutters-12" straightening section upstream	3/4" gutters-center open		-	-	No Ignition

* Some roughness in middle of range - did not seem to reduce thrust.

** No diffuser used.

2. Burner Performance

Information on burner performance based on thrust measurements is available for some of the later runs. The thrust meter used in these runs measured the momentum of the jet leaving the tail pipe. The thrust discussed in this report is the thrust meter reading minus the momentum of the unburned mixture just before initiation of combustion. This momentum is estimated from the flow rate, pressure and temperature of the fuel-air mixture.

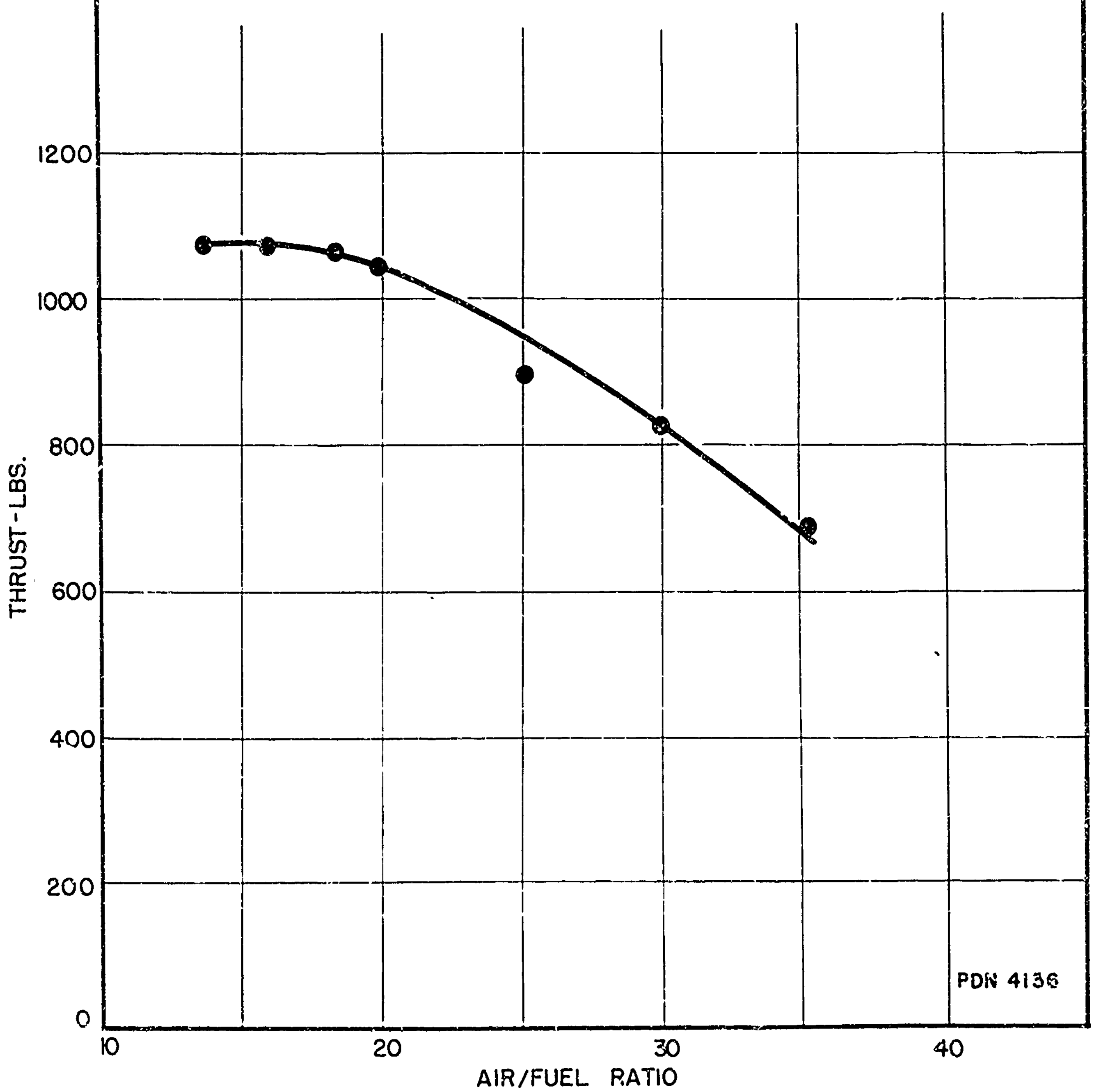
Figure 9 shows this thrust plotted as a function of air/fuel ratio for burner 2-1A3-10D-4 operating at an air rate of approximately 11 lbs./sec. The thrust appears to reach a maximum of 1080 lbs. at around theoretical air/fuel ratio. This thrust decreases as the air/fuel ratio increases until at the lean limit (35 air/fuel ratio) the thrust is 680 lbs.

FIGURE 9

THRUST OF BURNER WITH TWO FLAME HOLDER

SYSTEM: BURNER NO. 2-1A3-10D-4. INNER BODY DIFFUSER, FOUR FUEL INJECTOR NEEDLES, 21" MIXING SECTION, 54" TAIL PIPE, FIRST FLAME HOLDER 3/4" "Y"-GUTTER, SECOND FLAME HOLDER 6" DOWNSTREAM 1" "Y"-GUTTER WITH 1.5" DIA. CENTRAL OPENING.

DATA OF 1/9/46 - AIR FLOWS 10.73-11.19 LBS/SEC.



The maximum thrust obtainable from the air and fuel rate employed has been calculated assuming an equilibrium mixture, no heat losses and adiabatic expansion of the jet to atmospheric pressure. In Figure 10 the ratio of measured thrust to this theoretical thrust is plotted as a function of air/fuel ratio for two burners. This efficiency depends primarily on the completeness of mixing and combustion and on the efficiency of expansion of the jet.

The two burners used to obtain the data in Figure 10 are quite similar except that the burner whose performance is represented by the triangles had a straightening section upstream from the upstream flame holder and its downstream flame holder had 3/4 in. gutters instead of the 1 in. gutters used in the other burner. In the region of rich mixtures it can be seen that the addition of the straightening section and narrowing of the gutters resulted in a lower efficiency although a wider range of operation was obtained and efficiency was better for lean mixtures. It was observed that the burner with the straightening section gave much lower tail pipe temperature than the others. With this burner extended operation at theoretical air/fuel ratio did not seem to harm the tail pipe while with the other burner, operation for a period of much more than a minute was likely to destroy it.

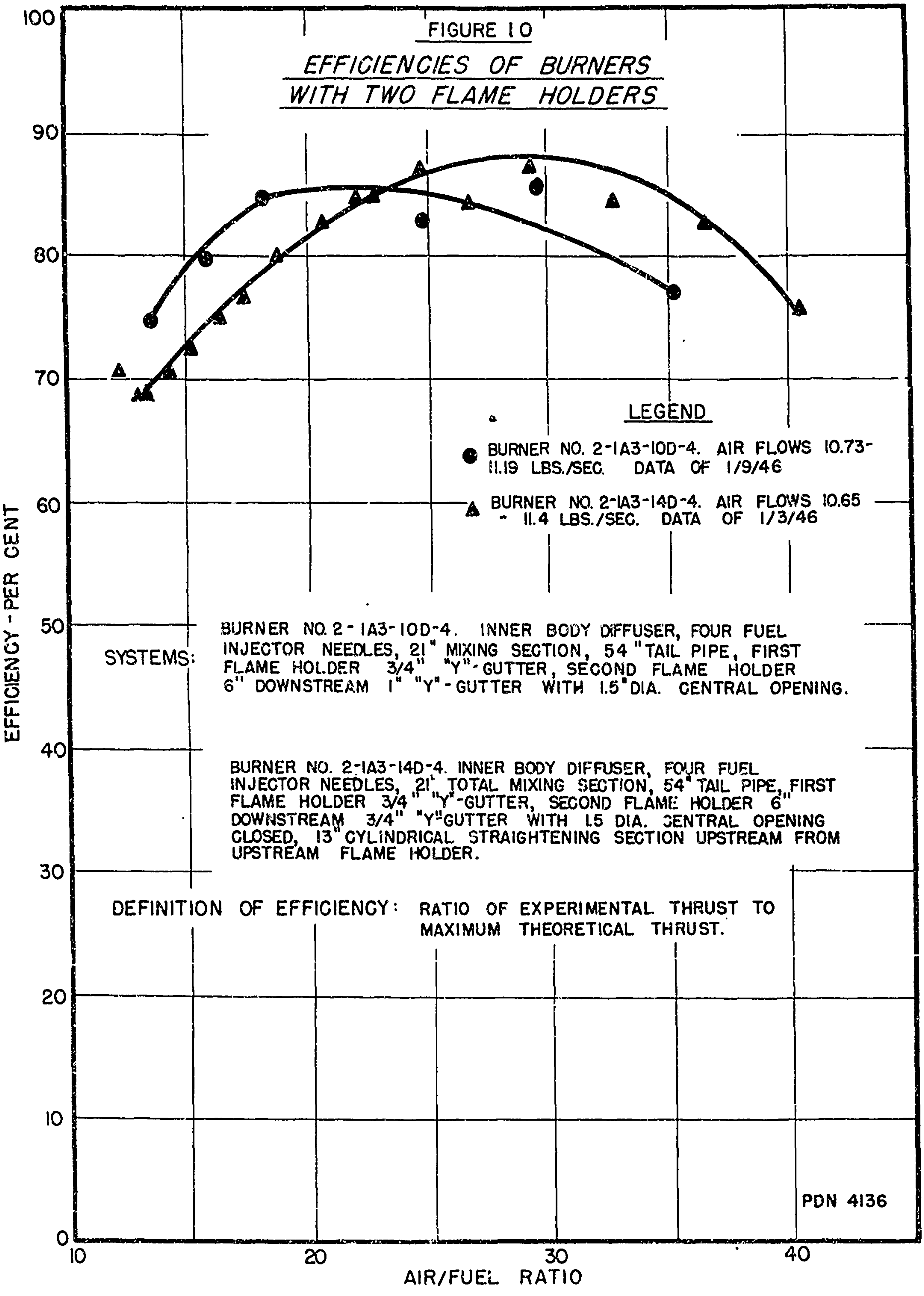


FIGURE 10

EFFICIENCIES OF BURNERS WITH TWO FLAME HOLDERS

In Figure 11 air specific impulse is plotted as a function of air/fuel ratio. Air specific impulse is defined as:

$$\frac{P + \rho V^2}{m} A$$

where P is the absolute pressure of the unburned mixture which is necessary to give the thrust observed if there is no friction in the system.

ρ is the gas density corresponding to the above pressure at the temperature before initiation of combustion.

V is the velocity of the gas under the above conditions.

A is the burner area at the point of the above conditions.

m is the rate of air flow in mass/unit time.

The units used gave the air specific impulse in lbs./lb./sec. The theoretical curve was calculated assuming combustion to equilibrium and adiabatic expansion of the jet with no heat losses in the system.

Air specific impulse, a number related to thrust per lb. of air, is of value in studying the overall performance of a ram-jet and has been adopted by JHU for representing burner data. With this particular burner the maximum air specific impulse was 148 lbs./lb./sec. Another burner (2-2A3-10D-4) gave a maximum value of 151.

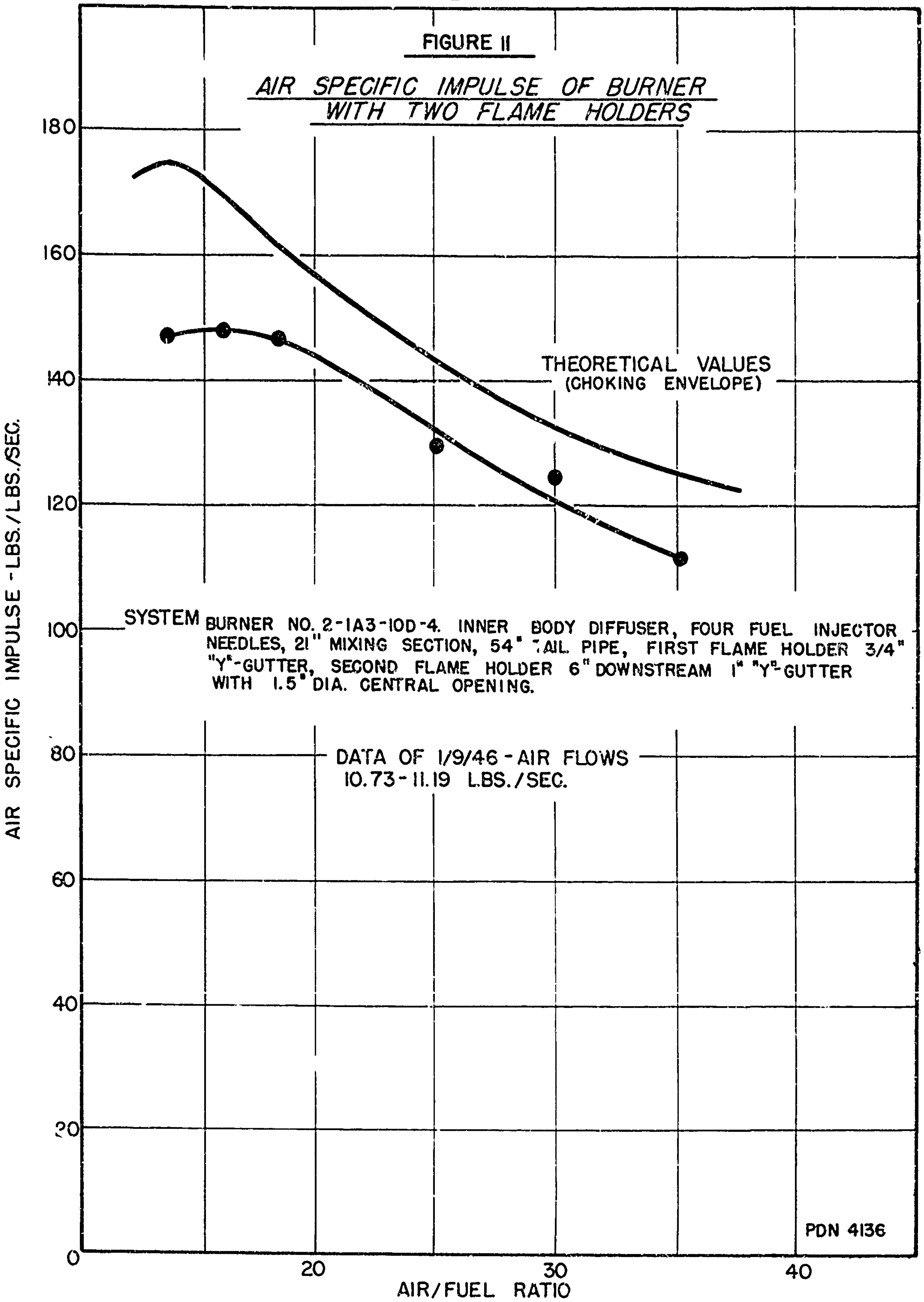


FIGURE II
AIR SPECIFIC IMPULSE OF BURNER WITH TWO FLAME HOLDERS
180
160
140
120
100
80
60
40
20
0
20
30
40
THEORETICAL VALUES (CHOKING ENVELOPE)
SYSTEM BURNER NO. 2-1A3-10D-4. INNER BODY DIFFUSER, FOUR FUEL INJECTOR NEEDLES, 21" MIXING SECTION, 54" TAIL PIPE, FIRST FLAME HOLDER 3/4" "Y"-GUTTER, SECOND FLAME HOLDER 6" DOWNSTREAM 1" "Y"-GUTTER WITH 1.5" DIA. CENTRAL OPENING.
DATA OF 1/9/46 - AIR FLOWS 10.73-11.19 LBS./SEC.
AIR SPECIFIC IMPULSE - LBS./LBS./SEC.
AIR/FUEL RATIO
PDN 4136

3. Drag of the Burner Interior

A pressure measurement upstream from the fuel injection combined with the thrust measurement made possible the calculation of the total drag of the fuel injection system, the ignition and flame holder systems and the burner walls under the conditions existing during burning.

In Figure 12 the drag expressed as pressure drop is plotted as a function of air/fuel ratio for the two burners whose efficiency is plotted in Figure 10. The drag increases as the air/fuel ratio increases. This is probably due to the lower pressure and consequent higher velocity occurring at high air/fuel ratios. For rich mixtures this pressure drop is between 4 and 5 p.s.i.

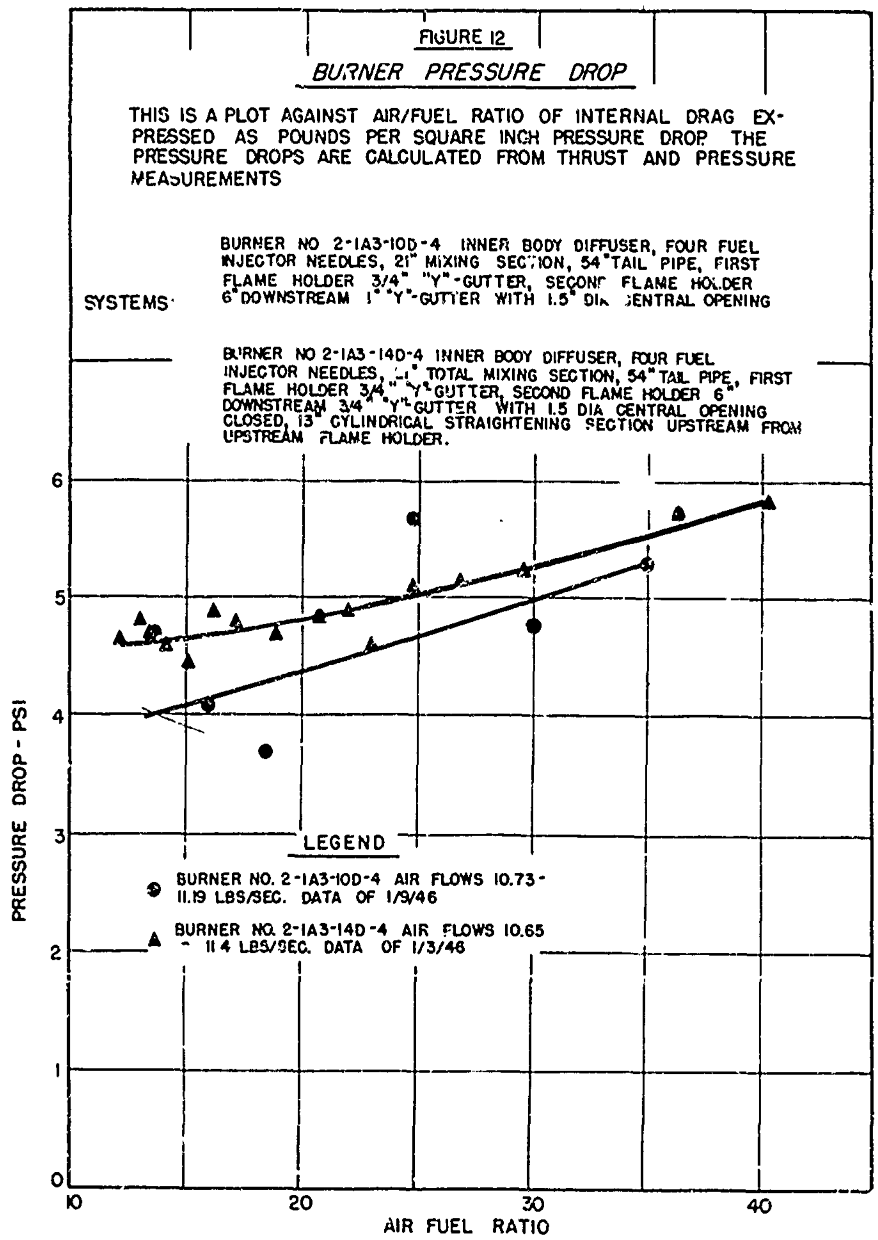


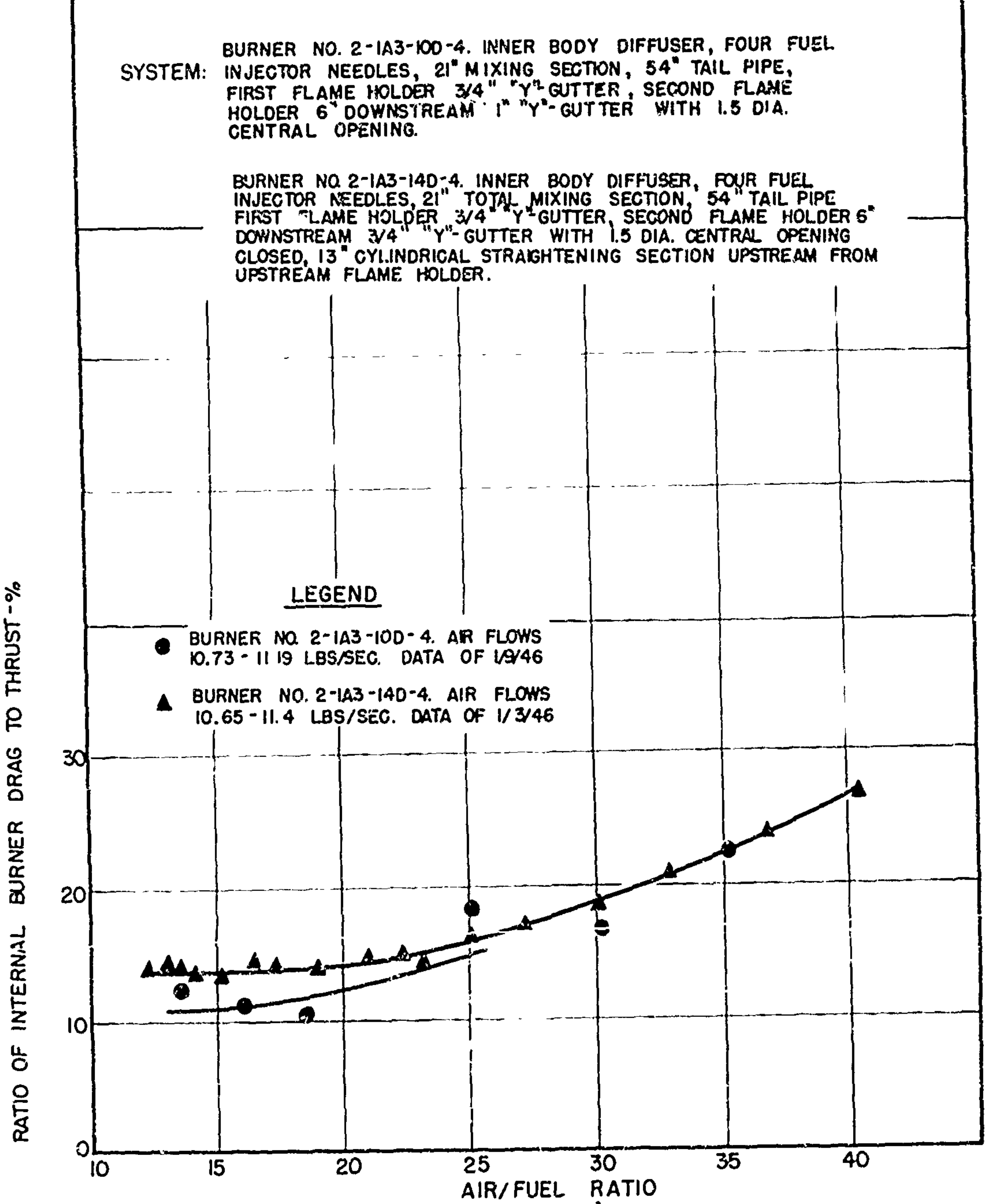
FIGURE 12
BURNER PRESSURE DROP

PDN 4136

Shown on Figure 13 is the fraction of the thrust necessary to overcome the internal drag. This fraction increases as air/fuel ratio increases and for the burner without the straightening section is around 11% for rich mixtures.

FIGURE 13

RATIO OF INTERNAL BURNER DRAG TO THRUST



PDN 4136

FUTURE PROGRAM

The immediate program will be devoted to adapting the gutter type of flame holder to flying model testing. The program will include the study of flare ignition in this type of flame holder, and a study of its performance with the Cobra diffuser. It is planned that some tests of the Cobra ignition system will be made to give comparative results.

The data in the section on pressure and ignition studies emphasize the sensitivity of these burners to changes in the flow pattern of the air. These changes are not sufficiently well understood to enable reliable prediction of the effect of changing the geometry of the burner. Some of the work in the immediate future will be devoted to this aspect of the problem.

APPENDIX

1. System for Numbering Burners

A system which designates each section by a number has been adopted.

The sections designated by separate numbers are:

1. Diffuser section
2. Atomizing and mixing section
3. Flame holder and pilot
4. Tail pipe section

Since these numbers will run into two or more figures they will be separated by dashes. The order of the numbers is that of the preceeding list.

1. Diffuser Section

2. This section consists of a 5'-2" piece of flanged pipe containing a wooden body 4" in diameter and tapered to a point at the ends. (See Figure 5)

2. Atomizing and Mixing Section

2A4. Four 1-1/2" venturis with upstream injection at their throat are mounted with one in the center and the other three arranged on the corners of an equilateral triangle about the center one. The distance between the fuel injection and the flame holder is 31 inches.

2A3. Same as above except that the distance between fuel injection and flame holder is 21 inches.

1A3. Same as above except that radial injection needles were used instead of venturis.

3. Flame Holder Section

Three types of flame holders were used to make up the various combinations reported here.

4. This flame holder, shown in Figure 2 of the October progress report (PDN 3980) has one inch gutters arranged in the shape of a cross.

Figure 6 of this report describes the type known as Y-gutter flame holders; the gutters are arranged in the shape of a "Y".

This type of flame holder was made with 1/2, 3/4 and 1 in. gutters. The opening in the center can be either open or plugged in the downstream flame holder when two are used. When used singly or as the upstream flame holder the opening was always closed. A 3/4 in. Y-gutter flame holder with a straightening section upstream was tested. This straightening section consisted of two concentric cylinders 13 inches long. One was 4-1/2 and the other 1-3/4 inches in diameter.

9. This flame holder is a single 3/4 in. Y-gutter.

The following flame holders were made up by using two of the Y-gutter types in series. The distance between flame holders is 5-3/4 inches.

Flame Holder Number	Description of Flame Holder: Downstream Flame Holder	Description of Flame Holder: Upstream Flame Holder
10	1" gutters - center open	3/4" gutters
11	3/4" gutters - center open	3/4" gutters*
12	3/4" gutters - center open	1/2" gutters
13	3/4" gutters - center open	3/4" gutters with straightening section
14	3/4" gutters - center plugged	3/4" gutters with straightening section
15	1" gutters - center plugged	3/4" gutters
16	1" gutters - center open	3/4" gutters with straightening section

* In this flame holder the gutters were cut so that they extended from the center to within one inch of the outer rim.

The type of ignition source is designated by a letter following the flame holder number.

C. Hydrogen pilot ignited by a spark.

D. Spark only.

4. Tail Pipe Section

2. 4 feet of standard 6 inch pipe.

4. 54-1/2 inches of standard 6 inch pipe.

2. Fuel Inspections

No. 1 Solvent Naphtha

Specific Gravity at 60°F.	.715
Initial Boiling Point	127°F.
5 Volume % Over at	151
10 " " " "	156
50 " " " "	190
90 " " " "	241
Final Boiling Point	286
Refractive Index	1.3980
Bromine No.	0.0

DETAILED BURNER TEST D

Fuel - No. 1 Solvent Nap

Date of Run	Run No.	Model No.	Description of System	Type of Ignition	Air Rate #/sec.	Fuel Rate #/sec.	Air Fuel Ratio	Air Temp. to Burner °F.	Pressure #1 psia	Pressure #2 psia	Pressure #3 psia
11/28/45	1	2-2A4-4C-2	Inner Body Diffuser - 4 fuel venturis - 31" mixing section, 4' tail pipe, 1" cross flame holder, H_2 Pilot, 150# pressure on H_2. Press. #1 - Pressure at upstream end of inner body. Press. #2 - Press. 6" downstream from downstream face of flame holder. Press. #3 - Press. 20" downstream from downstream face of flame holder. Press. #4 - Press. 32" downstream from downstream face of flame holder. Press. #5 - Press. 3½" upstream from downstream face of flame holder.	H_2	5.17	.165	33.2	285	21.00	16.8	16.3
	2			"	5.16	.177	29.2	287	22.55	18.57	17.8
	3			"	5.14	.198	26.0	290	23.60	19.75	18.75
	4			"	5.13	.212	24.2	293	24.55	21.00	19.90
	5			"	5.12	.230	22.3	295	26.10	22.70	21.20
	6			"	5.11	.150	20.4	297	26.45	23.10	21.50
	7			"	5.11	.260	19.7	298	27.60	24.60	22.20
	8			"	5.10	.303	16.9	300	28.85	25.70	22.70
11/28/45	1				2.80			180	15.57	14.72	14.78
	2				4.12			207	16.80	14.64	14.80
	3				5.29			246	13.85	14.51	14.87
	4				6.47			274	22.33	14.12	14.92
	5				7.62			287	26.64	13.27	15.00
	6				8.84			293	30.93	12.17	15.10
	7				9.81			296	36.60	8.08	< 0
	8				10.32			296	36.50	8.08	11.53
	9				10.78			307	38.40	8.48	5.70
	10				10.93			309	39.20	8.70	6.85
	11				10.98			310	39.70	8.81	6.93
11/29/45	1		Same as Model No. 2-2A4-4C-2 except flame holder removed.		3.01			57	15.18	14.78	14.72
	2				4.41			73	16.08	14.80	14.81
	3				5.79			95	17.38	14.88	14.87
	4				7.07			125	20.10	14.99	14.98
	5				8.35			145	23.40	15.19	15.18
	6				9.47			157	26.60	15.42	15.38
	7				10.46			167	30.30	15.78	15.63
	8				10.96			174	32.10	15.98	15.88
	9				11.10			180	32.70	16.09	15.91
	10				Greater Than 11			184	33.10	16.10	15.96
12/24/45	1	2-2A4-9C-2	Inner Body Diffuser - 4 fuel venturis - 31" mixing section, 4' tail pipe, 3/4" "Y"-gutter flame holder, hydrogen pilot. Press. #1 - Pressure at upstream end of inner body. Press. #2 - Press. 6" downstream from downstream face of flame holder. Press. #3 - Press. 21" downstream from downstream face of flame holder. Press. #4 - Press. 33" downstream from downstream face of flame holder. Press. #5 - Press. upstream from venturi injectors.		5.45			233	17.35	14.79	14.79
	2				12.35			282	36.4	7.55	6.25
	3				12.23			296	35.2	7.29	6.36
	4				11.78			312	34.7	7.14	14.10
	5				11.25			298	32.7	14.22	.45
	6				10.71			314	41.3	14.80	15.45
	7				9.94			316	26.7	14.96	15.10
	8				7.63			305	22.80	14.86	14.96
	9				6.55			288	19.69	14.86	14.86
	10			100# H_2	4.63						
	11			"	6.85						
	12			"	8.39						
	13			"	9.58						
	14			"	8.65						
	15			"	9.18						
	17			"	11.59	.378	30.6	295	45.2	38.7	
	18			"	11.70	.440	26.6	293	51.2	45.1	
	19			"	11.48	.533	21.5	292	56.7	51.7	
	21			"	11.30	.716	15.8	271	61.2	56.7	
	22			"	11.37	.716	15.9	280	50.7	46.7	
	24			"	11.37	.716	15.9	280	60.7	55.7	
	25			"	11.01	.367	30.0	276	40.7	35.7	
	26			"	11.50	.433	26.5	282	47.7	42.7	
12/26/45	1	2-2A3-10C-4	Inner Body Diffuser - 4 fuel venturis, 21" mixing section, 54" tail pipe, first flame holder 3/4" "Y"-gutter, second flame holder 6" downstream 1" "Y"-gutter with 1.5" dia. central opening, hydrogen pilot in upstream flame holder. Press. #1 - Press. upstream from venturis. Press. #2 - Press. midway between flame holders. Press. #3 - Press. 10" downstream from downstream flame holder. Press. #4 - Press. 24" downstream from downstream flame holder. Press. #5 - Press. 36" downstream from downstream flame holder.		4.08			305	15.92	14.81	14.79
	2				5.70			309	17.58	15.08	14.83
	3				6.81			314	19.39	15.54	14.97
	4				7.88			321	21.73	16.62	15.01
	5				8.82			326	24.42	18.37	15.05
	6				9.40			327	26.42	19.83	15.26
	7				10.36			325	28.80	21.63	15.51
	8				10.82			325	30.12	22.64	14.80
	9				10.95			325	30.38	22.80	14.51
	10				11.20			325	31.05	23.27	13.87
	11				11.44			324	31.37	23.54	13.42
	12				11.75			323	32.00	23.99	10.77
	13			H_2	7.84			291			
	14			"	8.72			293			
	15			"	9.33			295			
	16			"	10.34			300	25.99		
	17			"	11.40			304			
	18			"	12.00			306			
	19			"	10.94	.333	32.6	313			
	20			"	10.90	.417	26.2	315			
	21			"	10.90	.484	22.6	315			
	22			"	10.90	.584	18.7	315			
	23			"	10.90	.666	16.3	315			
	24	2-2A3-10D-4	Same as Model No. 2-2A3-10C-4 except spark ignition.	Spark Only	10.90	.417	26.2	316			
	25				10.96	.350	31.3	306			
	26			"	10.[illegible]6	.360	29.6	311	44.70	40.70	35.70
	27			"	10.62	.367	29.0	316	46.20	42.20	36.70
	28			"	10.31	.417	24.8	316	49.70	46.20	40.20
	29			"	9.62	.434	19.9	315	52.70	49.20	42.20
	30			"	11.14	.534	20.9	306	57.70	53.70	45.20
	31			"	10.72	.600	17.9	290	58.70	55.20	46.20
	32			"	10.89	.654	16.7	295	60.70	57.20	47.70

CONFIDENTIAL

Table 1, Page 1

CONFIDENTIAL

DETAILED BURNER TEST DATA

Fuel - No. 1 Solvent Naphtha

...ssure ...psia	Pressure #2 psia	Pressure #3 psia	Pressure #4 psia	Pressure #5 psia	Pressure #6 psia	Thrust #	Sp.Thrust #/#/sec.	Efficiency %	Air Sp. Impulse #/#/sec.	Ratio Experimental to Theoretical ical - Air Sp.Impulse %		Notes and Comments
	16.8	16.3	15.65	19.85		60.8	392	26.2				
	18.57	17.8	16.65	21.60		108.8	615	41.8				
	19.75	18.75	17.35	22.70		144.5	730	50.6				
	21.00	19.90	18.10	23.70		177.8	838	58.4				
	22.70	21.20	18.90	25.30		230.3	1002	71.5				
	23.10	21.50	19.15	25.60		242.7	972	70.7				Pipe red
	24.60	22.20	19.25	27.00		296.0	1138	83.6				
	25.70	22.70	19.40	28.20		334.7	1107	84.8				Pipe quite red, pipe very hot for two feet.
	14.72	14.78	14.73	15.28								
	14.64	14.80	14.79	16.10								
	14.51	14.87	14.82	17.63								
	14.12	14.92	14.85	20.44								
	13.27	15.00	14.92	24.32								
	12.17	15.10	15.03	28.22								
	8.08	< 0	< 0	33.05								
	8.08	11.53	14.48	33.7								
	8.48	6.70	12.72	35.2								
	8.70	6.85	10.75	35.7								
	8.81	6.93	6.95	36.4								
	14.78	14.72	14.71	14.88								
	14.80	14.81	14.78	15.12								
	14.38	14.87	14.80	15.80								
	14.99	14.98	14.89	17.12								
	15.19	15.18	14.99	18.91								
	15.42	15.38	15.10	21.20								
	15.78	15.65	15.30	23.62								
	15.98	15.88	15.43	25.10								
	16.09	15.91	15.49	25.70								
	16.10	15.96	15.56	25.74								
	14.79	14.79	14.78	16.29								
	7.55	6.25	7.46	31.55								
	7.29	6.36	14.7	30.20								
	7.14	14.10	15.29	29.53								
	14.22	15.45	15.31	28.79								
	14.80	15.45	15.30	27.70								
	14.96	15.10	15.05	22.80								
	14.86	14.96	14.96	19.87								
	14.86	14.86	14.86	17.72								
												Ignited
												Ignited
												Ignited
												Did not ignite
												Ignited
												Did not ignite
	38.7		30.19	43.7		745	.970	72.6			Values of Thrust, Specific Thrust and Efficiency may be somewhat high. Ignition was initiated at low air rates and burner then brought up to indicated air rate.	
	45.1		34.45	49.7		950	2158	84.0				
	51.7			55.7		1158	2170	92.3				
	56.7			59.7		1339	1868	92.3				Rich Limit
	46.7			54.7		1059	1478	72.7				
	55.7			59.7		1300	1815	89.5				Rich Limit
	35.7			39.7		657	1791	68.4				Lean Limit
	42.7			46.7		879	2027	*78.6				
	14.81	14.79	14.81	14.78								
	15.08	14.88	14.92	14.88								
	15.54	14.97	15.04	14.98								
	16.62	15.01	15.19	15.10								
	18.37	15.05	15.37	15.24								
	19.83	15.26	15.54	15.39								
	21.63	15.51	15.78	15.53								
	22.64	14.80	15.80	15.18								
	22.80	14.51	15.78	15 69								
	23.27	13.87	15.87	15.75								
	23.54	13.42	15.87	15.77								
	23.99	10.77	15.90	15.86								
												Ignited
												Ignited
												Ignited
												Ignited
												Ignited
												Ignited
												Ignited
												Set Rates and Ignited Pilot with Spark.
												" "
												" "
	40.70	35.70	30.18	26.67		691.5	1921	75.0			Thrust, Sp.Thrust and Efficiency figures may be somewhat low since they do not take into account combustion occurring between flame holders.	Intermittent Burning Starts
	42.20	36.70	30 82	26.93		727.9	1990	78.3				Smooth Burning Starts
	46.20	40.20	32.50	28.60		845.0	2030	85.7				
	49.20	42.20		29.64		915.0	1892	89.5				
	53.70	45.20		31.87		1025.0	1924	83.9				
	55.20	46.20		31.78		1067.0	1771	83.6				
	57.20	47.70		33.02		1114.0	1705	82.9				

12

DETAILED

Fuel - No.

Date of Run	Run No.	Model No.	Description of System	Type of Ignition	Air Rate #/sec.	Fuel Rate #/sec.	Air Fuel Ratio	Air Temp. to Burner °F.	Pressure #1 psia	Pressure #2 psia	Pr[illegible] #3
12/27/45	1	2-2A3-11D-4	Inner Body Diffuser - 4 fuel ven-		2.95	-	-	282	15.40	14.78	[illegible]
	2		turis, 21" mixing section, 54"		4.01	-	-	282	16.18	14.82	[illegible]
	3		tail pipe, first flame holder		5.31	-	-	282	17.76	14.97	[illegible]
	4		'4" "Y"-gutter extending to		7.15	-	-	285	21.30	15.34	[illegible]
	5		ithin 1" of pipe wall (gutter		7.93	-	-	287	23.50	15.75	[illegible]
	6		ends open), second flame holder		9.49	-	-	294	27.70	17.07	[illegible]
	7		6" downstream 3/4" "Y"-gutter		11.25	-	-	295	32.60	19.75	[illegible]
	8		with 1.5" dia. central opening, spark ignition.		12.04	-	-	299	25.23	21.43	[illegible]
	9		Press. #1 - Press. upstream from fuel venturis. Press. #2 - Press. midway between flame holders. Press. #3 - Press. 9" downstream from downstream flame holder. Press. #4 - Press.23" downstream from downstream flame holder. Press. #5 - Press.35" downstream from downstream flame holder.	Spark Only	2.5 - 5						
12/27/45	1	2-2A3-12D-4	Inner Body Diffuser - 4 fuel ven-		2.98			263	15.14	14.75	[illegible]
	2		turis, 21" mixing section, 54"		4.16			268	15.66	14.80	[illegible]
	3		tail pipe, first flame holder		5.43			272	16.65	14.92	[illegible]
	4		1/2" "Y"-gutter, second flame		6.74			278	18.26	15.18	[illegible]
	5		holder 6" downstream 3/4" "Y"-		7.82			282	20.07	15.52	[illegible]
	6		gutter with 1.5" dia. central		9.14			286	22.73	16.41	[illegible]
	7		opening, spark ignition.		10.17			290	25.39	17.97	[illegible]
	8		Press. #1 - Press. upstream		10.35			292	27.69	19.61	[illegible]
	9		from fuel venturis.		11.92			295	29.35	20..8	[illegible]
	10		Press. #2 - Press. midway between flame holders.		12.07			296	29.99	21 22	[illegible]
	11		Press. #3 - Press. 9" downstream from downstream flame holder. Press. #4 - Press.23" downstream from downstream flame holder. Press. #5 - Press.35" downstream from downstream flame holder	Spark Only	2.5 - 5						
12/28/45	14	2-2A3-10D-4	Inner Body Diffuser - 4 fuel ven-		3.01			281	15.08	14.79	[illegible]
	15		turis, 21" mixing section, 54"		4.67			281	15.87	14.99	[illegible]
	16		tail pipe, first flame holder		6.61			286	18.32	15.66	[illegible]
	17		3/4" "Y"-gutter, second flame		8.06			293	20.93	16.75	[illegible]
	18		holder 6" downstream 1""Y"		9.50			300	24.36	18.94	[illegible]
	19		gutter with 1.5" dia. central		10.32			305	27.68	21.47	[illegible]
	20		opening. Spark ignition.		11.17			311	30.15	23.36	[illegible]
	21		Press. #1 - Press. upstream from		11.39			315	30.55	23.63	[illegible]
	22		venturis.		11.71			316	31.75	24.60	[illegible]
	23		Press. #2 - Press. midway between		11.86			316	32.37	25.07	[illegible]
	24		flame holders	Spark	11.11	.345	32.2	314	42.7	37.7	[illegible]
	25		Press. #3 - Press. 9 in. downstream	Only	10.93	.367	29.8	315	45.7	41.2	[illegible]
	26		from downstream flame holder.	"	10.81	.417	25.9	315	49.7	45.7	[illegible]
	27		Press. #4 - Press.23" downstream	"	10.73	.467	23.0	315	52.7	49.2	[illegible]
	28		from downstream flame holder.	"	10.62	.5170	20.5	316	54.8	51.7	[illegible]
	29		Press. #5 - Press.35" downstream	"	10.48	.567	18.5	317	55.9	53.2	[illegible]
	30		from downstream flame holder.	"	10.39	.617	16.8	320	57.5	54.7	[illegible]
1/2/46	1	2-2A3-10D-4	See above. Pressure columns are:		2.72			260	14.71	14.66	[illegible]
	2		Press. /1 - Press. midway between		4.23			255	14.75	14.56	[illegible]
	3		flame holders.		5.57			256	14.90	14.38	[illegible]
	4		Press. ?2 - Press. 3" downstream		6.82			265	15.32	14.17	[illegible]
	5		from downstream flame holder.		8.15			267	16.58	13.73	[illegible]
	6		Press. #3 - Press. 9" downstream		9.44			275	18.82	13.03	[illegible]
	7		from downstream flame holder.		10.88			280	21.80	10.18	[illegible]
	8		Press. #4 - Press. 23" downstream		11.28			282	22.70	3.59	[illegible]
	9		from downstream flame holder.		11.85			284	23.88	3.79	[illegible]
	10		Press. #5 - Press. 35" downstream		12.17			284	24.60	3.88	[illegible]
	11		from downstream flame holder.	Spark	11.23	.440	25.5	278	47.7	44.45	
	12		Press. #6 - Press. upstream from	Only	10.42	.483	21.6	285	51.2	47.7	
	13		venturis.	"	11.11	.517	21.5	280	53.7	49.8	
	15			"	10.54	.610	17.3	287	55.2	51.2	

CONFIDENTIAL

Table 1, Page 2

DETAILED BURNER TEST DATA

Fuel - No. 1 Solvent Naphtha

Pressure #1 psia	Pressure #2 psia	Pressure #3 psia	Pressure #4 psia	Pressure #5 psia	Pressure #6 psia	Thrust #	Sp.Thrust #/#/sec.	Efficiency %	Air Sp. Impulse #/#/sec.	Ratio Experimental to Theoretical - Air Sp. Impulse %	Notes and Comments
15.40	14.78	14.72	14.72	14.73	-						These data may be somewhat low due to liquid in the pressure lines.
16.18	14.82	14.76	14.78	14.78	-						
17.76	14.97	15.19	14.85	14.82	-						
21.30	15.34	14.85	15.00	14.96	-						
23.50	15.75	14.90	15.12	15.01	-						
27.70	17.07	14.99	15.38	15.25	-						
32.60	19.75	15.33	15.80	15.59	-						
25.23	21.43	14.70	16.07	15.83	-						
											Smooth burning was obtained at low air rates only (possible from 2-1/2 to 5#/sec. air). At air rates much above 5#/sec. ignition could not be obtained using spark only.
15.14	14.75	14.73	14.72	14.73	-						
15.66	14.80	14.78	14.79	14.77	-						
16.65	14.92	14.85	14.88	14.83	-						
18.26	15.18	14.97	14.99	14.94	-						
20.07	15.52	15.09	15.14	15.05	-						
22.73	16.41	15.20	15.36	15.20							
25.39	17.97	15.33	15.59	15.40							
27.69	19.61	15.58	15.84	15.62							
29 35	20.78	15.18	16.00	15.78							
29.99	21.22	14.65	16.07	15.88							
											Smooth burning over narrow A/F range at air rates of 2-1/2 - 5#/sec. Rough burning at slightly higher air rates. No ignition at high air rates.
15.08	14.79	14.72	14.72	14.72	-						
15.87	14.99	14.78	14.80	14.78	-						
18.32	15.66	14.90	14.97	14.90	-						
20.93	16.75	15.01	15.15	15.05	-						
24.36	18.94	15.14	15.38	15.24	-						
27.68	21.47	15.50	15.69	15.47	-						
30.15	23.36	14.85	15.79	15.64	-						
30.55	23.63	14.29	15.87	15.69	-						
31.75	24.60	11.84	15.88	15.78	-						
32.37	25.07	6.89	15.90	15.80	-						
42.7	37.7	32.7	-	-	-	598	1733	64.30			Thrust, Specific Thrust and Efficiency may be somewhat low since they do not take into account combustion occurring between flame holders.
45.7	41.2	35.2	-	-	-	686	1870	71.87			
49.7	45.7	39.2	-	-	-	824	1978	80.40			
52.7	49.2	41.45	-	-	-	907	1943	82.69			
54.8	51.7	43.2	-	-	-	974	1885	84.25			
55.9	53.2	43.7	-	-	-	1000	1767	8[illegible].95			Sluggish Ignition
57.5	54.7	44.7	-	-	-	1040	1687	80.30			Satisfactory Ignition
14.71	14.66	14.7	14.7	14.7	15.7						
14.78	14.56	14.7	14.7	14.7	16.1						
14.90	14.38	14.7	14.71	14.7	17.0						
15.32	14.17	14.69	14.68	14.7	18.7						
16.58	13.73	14.62	14.68	14.69	22.0						
18.82	13.03	14.60	14.68	14.68	25.4						
21.80	10.18	14.71	14.77	14.68	28.9						
22.70	3.59	16.33	14.7	14.66	30.5						
23.88	3.79	6.01	14.08	14.56	32.1						
24.60	3.88	6.20	7.24	13.61	33.1						
47.7	44.45				50.7	840	[illegible]	[illegible]			
51.2	47.7				53.7	940	1945	86.0			
53.7	49.8				55.9	1106	2140	92.2			
55.2	51.2				57.7	1123	1840	81.3			

Table 1, Page 3

DETAILED BURNER TEST DATA

Fuel - No. 1 Solvent Naphtha

Date of Run	Run No.	Model No.	Description of System	Type of Ignition	Air Rate #/sec.	Fuel Rate #/sec.	Air Fuel Ratio	Air Temp. to Burner °F.	Pressure #1 psia	Pressure #2 psia	Pressure #3 psia	Pressure #4 psia
1/3/46	1	2-1A3-13D-4	Inner Body Diffuser - 4 fuel injector needles, 21" total mixing section, 54" tail pipe, first flame holder 3/4" "Y"-gutter, second flame holder 6" downstream 3/4" "Y"-gutter with 1.5" dia. central opening, 13" cylindrical straightening section upstream from upstream flame holder. Spark ignition. Press. #1 - Press. upstream from injector needles. Press. #2 - Press. midway between flame holders. Press. #3 - Press. 3" downstream from downstream flame holder.	Spark Only	6.67			280				
	4	2-21A3-14D-4	Same as Model No. 2-1A3-13D-4 except central opening in downstream flame holder closed.	"	11.22	.277	40.6	302	41.7	38.2	37.5	
	5			"	11.06	.300	36.8	304	44.45	41.2	38.45	
	6			"	10.98	.333	32.9	305	46.70	44.2	41.2	
	7			"	10.93	.367	29.8	305	48.45	45.7	42.95	
	8			"	10.87	.400	27.2	305	49.95	47.2	44.7	
	9			"	10.83	.433	25.0	305	51.20	48.7	46.2	
	10			"	10.80	.467	23.2	306	51.70	49.2	46.95	
	11			"	10.80	.484	22.3	306	52.20	49.7	47.45	
	12			"	10.81	.517	20.9	306	52.95	50.45	48.20	
	13			"	10.74	.567	19.0	306	53.20	50.95	48.70	
	14			"	10.72	.617	17.4	308	53.70	51.20	49.20	
	15			"	10.70	.650	16.5	308	53.70	51.20	49.20	
	16			"	10.67	.700	15.2	307	53.20	50.95	48.95	
	17			"	10.65	.750	14.2	309	53.20	50.95	48.95	
	18			"	10.65	.784	13.6	309	53.20	50.95	48.95	
	19			"	10.65	.817	13.1	309	53.20	50.70	48.95	
	20			"	10.65	.866	12.3	310	53.20	50.95	48.95	
	21			"	10.65	.900	11.8					
	22			"	10.65	.283	37.6					
	23			"	10.65	.277-.310	34.4-38.4					
	24			"	10.60	.440	24.1	319	49.95	47.20	45.20	
	25			"	11.20	.516	21.7					
	26			"	9.00	.294	30.7	318	39.45	36.95	34.95	
	27			"	[illegible]	.316	28.6	310	40.70	38.45	36.20	
	28			"	[illegible]	.367	24.5	309	42.95	40.20	38.70	
	29			"		.384	23.4	308	43.45	40.70	39.20	
	30			"	[illegible]	.417	21.6	306	44.20	41.70	40.20	
	31			"	9.02	.450	20.5	305	44.70	42.45	40.95	
	32			"	9.03	.484	18.7	305	44.70	42.95	41.20	
	33			"	9.03	[illegible]	16.9	304	45.20	43.20	41.70	
	34			"	9.04	.583	15.5	302	45.20	43.45	41.70	
	35			"	9.02	.634	14.3	301	45.20	43.20	41.70	
	36			"	8.95	.667	13.4	301	44.95	42.95	41.45	
	38			"	9.35	.283	33.0	282		31.7		
	40			"	9.11	.333	27.4	283				
	41			"	9.11	.400	22.8	283				
	42			"	9.11	.433	21.0	283				
	43			"	7.38	.257	28.7	281	23.67	22.55	21.96	
	44			"	7.38	[illegible]	[illegible]	282		20.59	20.1	
	45			"	7.55	.267	28.3	282	24.25	23.18	22.29	
	46			"	7.55	.300	25.2	283				
	47			"	7.55	.300	25.2	283				

e 3

ble 1, Page 3

EST DATA D BURNER TEST DATA

t Naphtha . 1 Solvent Naphtha

Pressure #3 psia	Pressure #4 psia	Pressure #5 psia	Pressure #6 psia	Thrust #	Sp.Thrust #/#/sec.	Efficiency %	Air Sp. Impulse #/#/sec.	Ratio Experimental to Theoretical - Air Sp. Impulse %		Notes and Comments
									Max. Air Rate at which ignition could be obtained. Narrow Air Fuel limits. Ignition was obtained at very low air rates.	
								System Press. Drop Calcd. from Theoretical and Press. Measurements psi		
37.5				618	2230	73.3		5.8		
38.45				698	2530	78.5		5.75		
41.2				774	2325	82.5		5.4		
42.95				832	2265	85.4		5.25		
44.7				876	2190	84.0		5.15		
46.2				916	2115	83.8		5.1		
45.95				935	2000	82.0		4.6	Rates set, then spark thrown on to test ignition.	
47.45				952	1965	81.5		4.9		
48.20				994	1885	80.2		4.85		
48.70				987	1740	77.5		4.70		
49.20				995	1615	75.2		4.8		
49.20				993	1530	73.5		4.9		
48.95				989	1415	71.0		4.55		
48.95				969	1320	69.4		4.6		
48.95				985	1255	68.0		4.7		
48.95				980	1200	69.2		4.8		
48.95				985	1135	71.5		4.65		
										Lost Ignition-Rich Limit No Ignition Lean Ignition obtained at 34.4 and lost at 38.4
45.20				879	2000	84.0			Continuous Burning	
										Sputtered for one minute before taking hold. Small flame started in upstream flame holder when spark was thrown on, but full ignition could not be obtained.
34.95				619	2105	89.2				Lean Ignition obtained at A/F 30.6 and lost at A/F 38.4.
36.20				644	2040	88.0				
38.70				691	1885	85.5				
39.20				699	1820	83.9				
40.20				720	1725	81.8			Continuous Burning	Rough Burning
40.95				742	1650	79.7				
41.20				750	1550	77.5				
41.70				767	1435	75.2				
41.70				771	1320	72.1				
41.70				771	1215	69.6				
41.45				750	1120	66.7				
										Lost Ignition-Rich Limit Thrust, Specific Thrust and Efficiency slightly low since calculated from pressure downstream from downstream flame holder.
									Fuel Rates set, ignited with spark.	Sputtered for about a minute before obtaining full ignition. Sputtered several seconds, then ignited. Small flame in upstream flame holder but no complete ignition. Small flame in upstream flame holder but no complete ignition.
21.95				434	1690	93.7				
20.1				304	1510	81.1				Lean Ignition obtained at A/F 28.7 and lost at A/F 36.5. Thrust, Specific Thrust and Efficiency slightly low since calculated from pressure downstream from downstream flame holder.
22.29				455	1705	83.5				Smooth burning once burning was obtained. Very rough near rich limit. Shutting fuel out of center injection needle did not improve operation.

Table

DETAILED BU

Fuel - No. 1

Date of Run	Run No.	Model No.	Description of System	Type of Ignition	Air Rate #/sec.	Fuel Rate #/sec.	Air Fuel Ratio	Air Temp. to Burner °F.	Pressure #1 psia	Pressure #2 psia
1/4/46	2	2-1A3-14D-4	System is same as above, pressure columns are as follows: Press. #1 - Press. upstream from injection needles. Press. #2 - Press. midway between flame holders. Press. #3 - Press. 3" downstream from flame holder. Press. #4 - Press. 9" downstream from flame holder. Press. #5 - Press. 23" downstream from flame holder. Press. #6 - Press. 35" downstream from flame holder.		2.87			275	15.17	14.73
	3				4.05			273	15.61	14.89
	4				5.35			274	16.33	14.98
	5				6.69			276	17.59	15.28
	6				8.0			282	19.52	16.13
	7				9.18			287	22.06	17.93
	8				10.31			290	24.99	20.24
	9				11.13			290	26.80	21.90
	10				11.32			285	27.20	22.15
	11				11.57			284	27.69	22.61
	12				11.93			284	28.38	23.16
	13				12.05			285	28.62	23.37
1/4/46	2	2-1A3-13D-4	See description of this system above. Pressure columns are as follows: Press. #1 - Press. upstream from injector needles. Press. #2 - Press. midway between flame holders. Press. #3 - Press. 3" downstream from downstream flame holder. Press. #4 - Press. 9" downstream from downstream flame holder. Press. #5 - Press. 23" downstream from downstream flame holder. Press. #6 - Press. 35" downstream from downstream flame holder.		3.08			284	15.1	14.7
	3				5.37			285	16.08	14.72
	4				8.03			290	19.71	14.40
	5				9.40			294	21.20	15.01
	6				10.56			295	23.62	16.51
	7				10.25			295	25.20	17.57
	8				11.82			296	26.40	18.45
	9				12.00			296	26.80	18.82
	12			Spark Only	6.56			300		
1/4/46	1	2-1A3-15D-4	Inner Body Diffuser - 4 fuel injector needles, 21" mixing section, 54" tail pipe, first flame holder 3/4" "Y"-gutter, second flame holder 6" downstream 1" "Y"-gutter with 1.5" dia. central opening closed. Spark ignition. Press. #1 - Press. midway between flame holders. Press. #2 - Press. 3" downstream from downstream flame holder. Press. #3 - Press. 9" downstream from downstream flame holder. Press. #4 - Press. 23" downstream from downstream flame holder. Press. #5 - Press. 35" downstream from downstream flame holder. Press. #6 - Press. upstream from injector needles.		2.80			296	14.72	14.62
	2				3.97			293	14.71	14.56
	3				5.20			293	15.18	14.30
	4				6.63			295	16.07	13.72
	5				7.99			298	18.10	11.81
	6				9.11			300	20.44	11.03
	7				10.11			300	22.72	9.45
	8				10.33			302	23.27	8.75
	9				10.82			304	24.40	6.25
	10				11.85			305	26.57	6.82
	11				11.95			305	27.20	6.96
1/7/46	2	None-1A3-15D-4	Same as Model No. 2-1A3-15D-4 except no diffuser (inner body removed). Pressure columns are also the same as listed for Model No. 2-1A3-15D-4.		3.04			295	14.62	14.73
	3				4.76			292	14.42	14.92
	4				6.17			289	14.03	15.51
	5				7.48			286	12.79	17.08
	6				8.85			286	15.88	4.64
	7				10.11			286	22.47	9.24
	8				10.86			287	24.25	6.79
	9				11.18			290	24.82	6.96
	10				11.55			292	25.57	7.16
	12			Spark Only	10.90	.440	24.8	300	45.50	49.20
	13			"	11.85	.500	23.7	295		
	14			"	11.25	.610	18.5	293		
	15			"	11.08	See Notes		300		
	16			"	11.12	.440	25.3	295		
	17			"	11.12	.500	22.2			
	18			"	11.12	.610	18.2			
	19			"	11.08	See Notes		300		
1/8/46	1	2-1A3-15D-4	See description of Burner No. 2-1A3-15D-4 above.	"	11.10	Not Recorded		297		
	2			"	11.10	Not Recorded		297		
	3			"	11.10	Not Recorded		297		
	4			"	11.05	See Notes		305		
	5			"	11.0[illegible]	.440	25.2	300		

CONFIDENTIAL

Table 1, Page 4

DETAILED BURNER TEST DATA

Fuel - No. 1 Solvent Naphtha

Pressure #1 psia	Pressure #2 psia	Pressure #3 psia	Pressure #4 psia	Pressure #5 psia	Pressure #6 psia	Thrust #	Sp.Thrust #/#/sec.	Efficiency %	Air Sp. Impulse #/#/sec.	Ratio Experimental to Theoretical - Air Sp. Impulse %
15.17	14.73	14.7	14.72	14.71	14.71					
15.61	14.89	14.69	14.72	14.7	14.7					
16.33	14.98	14.66	14.73	14.7	14.7					
17.59	15.28	14.58	14.72	14.7	14.71					
19.52	16.13	14.23	14.73	14.7	14.71					
22.06	17.93	13.15	14.71	14.72	14.73					
24.99	20.24	10.83	14.91	14.77	14.79					
26.80	21.90	4.14	13.16	14.74	14.80					
27.20	22.15	4.24	12.10	14.73	14.81					
27.69	22.61	4.3[illegible]	5.60	14.47	14.73					
28.38	23.16	4.44	5.81	10.28	14.40					
28.62	23.37	4.48	5.86	6.74	14.08					
15.1	14.7	14.7	14.72	14.7	14.7					
16.08	14.72	14.60	14.73	14.7	14.7					
18.71	14.40	14.30	14.74	14.69	14.7					
21.20	15.01	13.81	14.80	14.72	14.72					
23.62	16.51	13.42	14.89	14.80	14.77					
25.20	17.57	12.07	15.07	14.88	14.80					
26.40	18.45	8.45	14.47	14.89	14.84					
26.80	18.82	14.[illegible]4	1[illegible].67	14.89	14.65					
14.72	14.62	14.70	14.7	14.71	15.11					
14.71	1[illegible].50	14.71	14.70	14.71	15.69					
15.18	14.30	14.72	14.70	14.71	16.65					
16.07	13.72	14.70	14.71	14.71	18.54					
18.10	11.81	14.61	14.69	14.72	[illegible]1.52					
20.44	11.03	14.78	14.77	14.77	21.44					
22.72	9.45	14.53	14.70	14.77	26.67					
23.27	8.75	14.23	14.66	14.75	27.93					
24.40	6.25	5.42	14.34	14.69	29.20					
26.57	6.82	5.91	6.40	7.38	31.57					
27.20	6.96	6.06	6.59	7.40	32.39					
14.62	14.73	14.72	14.7	14.7	15.34					
14.42	14.92	14.73	14.7	14.7	16.49					
14.03	15.51	14.73	14.69	14.72	18.00					
12.79	17.08	14.[illegible]	14.69	14.72	20.73					
15.68	4.64	14.75	14.74	14.75	24.13					
22.47	9.24	14.39	14.70	14.74	27.46					
[illegible]4.25	6.79	5.76	11.02	14.36	29.80					
[illegible]4.82	6.96	5.89	6.44	13.31	30.33					
[illegible]5.57	7.16	6.05	6.64	9.83	31.15					
[illegible]5.50	49.20				52.80	864	2175	89.5		

Notes and Comments

Ignition could not be obtained above this air rate, thus confirming observations of 1/3/46 on this burner.

Air and Fuel Rates set, then ignited with spark only.	Ignition after only a few seconds. Smooth flame in upstream flame holder but main portion of fuel did not ignite. No flame in upstream flame holder - no ignition.
Continuous Burning	Full ignition at A/F ratio 19.3 to 35.0. Smooth burning over A/F ratio of 22.9 to 32.3.
Three injection needles used. Air and fuel rates set, then ignited with spark only.	Prompt ignition. Full ignition after about 5 seconds. Very small flame in upstream flame holder-no ignition.
Three injection needles used, 4 in. place - continuous burning.	Full ignition at A/F ratio of 18.2 to 35.0. Smooth burning at A/F ratio of 22.9 to 30.9.
Four injection needles used.	Ignition after only a few seconds.
Air and fuel rates set, then ignited with spark only.	Smooth flame in upstream flame holder but the main portion of the fuel was not ignited. No flame in upstream flame holder - no ignition.
Continuous burning.	Full ignition at A/F ratio of 19.5 to 33.2. Smooth burning over A/F ratios of 22.9 to 32.7.
Three injection needles used, 4 in place.	Prompt ignition.

Table 1, Pa

DETAILED BURNER

Fuel - No. 1 Solve

Date of Run	Run No.	Model No.	Description of System	Type of Ignition	Air Rate #/sec.	Fuel Rate #/sec.	Air Fuel Ratio	Air Temp. to Burner °F.	Pressure #1 psia	Pressure #2 psia	Pressure #3 psi
1/8/46	6	2-1A3-15D-4	See description of Burner No. 2-1A3-15D-4 above.	Spark Only	11.08	.500	22.2	300			
	7			"	11.08	.610	18:1	300			
	8			"	11.10	See Notes		297			
1/9/46	1	2-1A3-10D-4	Inner Body Diffuser - 4 fuel injector needles, 21" mixing section, 54" tail pipe, first flame holder 3/4" "Y"-gutter, second flame holder 6" downstream 1" "Y"-gutter with 1.5" dia. central opening. Spark ignition. Press. #1 - Press. midway between flame holders. Press. #2 - Press. 3" downsteam from downstream flame holder. Press. #3 - Press. 9" downstream from downstream flame holder. Press. #4 - Press. 23" downstream from downstream flame holder. Press. #5 - Press. 35" downstream from downstream flame holder. Press. #6 - Press. upstream from fuel injectors.		2.80			291	14.68	14.64	14.71
	2				4.78			289	14.72	14.50	14.71
	3				6.53			290	14.91	14.17	14.72
	4				7.63			291	15.44	13.78	14.73
	5				9.20			295	17.46	12.94	14.66
	6				10.45			300	19.81	12.56	14.81
	7				11.23			306	21.43	8.44	12.04
	8				11.63			309	22.16	8.75	6.42
	9				12.12			309	22.76	8.98	6.60
	12			Spark Only	11.03	.440	25.2	299	47.7	44.0	
	14			"	11.38	.610	18.7	306			
	15			"	10.46-10.71			308			
	17			"	10.75	.783	13.7	306	54.0	51.20	
	18			"	11.19	.317	35.3	306	39.5	36.4	
	19			"	10.73	.666	16.1	306	53.4	50.7	
	20			"	10.80	.583	16.5	307	52.3	49.8	
	21			"	11.04	.367	30.1	307	44.7	41.5	
	22			"	11.30	.667	16.9	307			
1/10/46	2	2-2A3-10D-4	Inner Body Diffuser - 4 fuel venturis, 21" mixing section, 54" tail pipe, first flame holder 3/4" "Y"-gutter, second flame holder 6" downstream 1" "Y"-gutter with 1.5" dia. central opening. Spark ignition. Press. #1 - Press. midway between flame holders. Press. #2 - Press. 3" downstream from downstream flame holder. Press. #6 - Press. upstream from venturis.	"	10.85	.440	24.7	300	48.4	44.9	
	3			"	10.75	.500	21.5	302	52.0	48.2	
	5			"	10.68	.610	17.5	304	55.2	51.2	
	6			"	10.67	.730	14.6	304			
	8	2-2A3-16D-4	Inner Body Diffuser - 4 fuel venturis, 21" mixing section, 54" tail pipe, first flame holder 3/4" "Y"-gutter, second flame holder 6" downstream 1" "Y"-gutter with 1.5" dia. central opening, 13" cylindrical straightening section upstream from upstream flame holder. Spark ignition.	"	11.08						
1/14/46	3	2-2A3-10D-4	See above. Pressure columns are: Press. #1 - Press. midway between flame holders. Press. #2 - Press. 3" downstream from downstream flame holder. Press. #3 - Press. upstream from venturis.	"	10.99	.440	24.99	297	49.0	45.0	52.6
	4			"	10.90	.500	21.80	297	52.4	48.2	55.3
	5			"	10.65	.610	17.45	297			

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Table 1, Page 5

DETAILED BURNER TEST DATA

1 - No. 1 Solvent Nephtha

Pressure #2 psia	Pressure #3 psia	Pressure #4 psia	Pressure #5 psia	Pressure #6 psia	Thrust #	Sp.Thrust #/#/sec.	Efficiency %	Air Sp. Impulse #/#/sec.	Ratio Experimental to Theoretical - Air Sp. Impulse %	System Press. Drop Calcd. from Theoretical and Press. Measurements psi		Notes and Comments
											Three injection needles used, 4 in place. Air and fuel rates set, then ignited with spark only. Continuous burning.	Full ignition after 15 seconds. No flame in upstream flame holder - no ignition. Full ignition at A/F ratio of 20.2 to 34.1. Smooth burning over A/F ratio of 22.2 to 31.0
14.64	14.71	14.7	14.7	15.08								
14.50	14.71	14.7	14.7	15.93								
14.17	14.72	14.7	14.7	17.35								
13.78	14.73	14.7	14.7	19.18								
12.94	14.66	14.7	14.72	22.29								
12.56	14.81	14.72	14.78	25.40								
8.44	12.04	14.69	14.75	27.41								
8.75	6.42	14.11	14.66	29.07								
8.98	6.60	7.25	16.29	29.13								
44.0				51.2	897	2040	83.0	130	90.2	5.7	Air Fuel Ratio set, then ignited with spark.	Full ignited after a few seconds. Small unsteady flame in upstream flame holder. No full ignition. Full ignition over A/F ratio of 13.3 to 35.0. Smooth burning over A/F ratio of 29.4 to 35.0; 13.3 to 19.3. Resonant over A/F ratio of 19.3 to 27.9 - particularly bad 22.7 to 25.4.
51.20				56.3	1075	1375	75.3	147	84.0	4.7		Smooth burning.
36.4				43.5	684	2160	77.3	111	88.5	5.3		Smooth burning.
50.7				55.7	1075	1610	80.3	148	88.4	4.1		Smooth burning.
49.8				55.0	1063	1825	84.7	146	91.9	3.7		Smooth burning.
41.5				47.8	823	2250	85.7	123	92.0	4.8		Smooth burning.
												Small unsteady flame in upstream flame holder, no full ignition.
44.9				52.0	927	2110	87.1	136	91.4		Air Fuel Rates set, then ignited with spark.	Prompt ignition - smooth burning.
48.2				55.2	1032	2065	90.2	144	93.4			Burning smooth after a few seconds.
51.2				58.1	1089	1785	85.2	151	92.9			Prompt ignition but very rough burning.
												No full ignition. Small flame in upstream flame holder over A/F ratios of 20.1 to 51.1.
45.0	52.6				945	2150	87.7				Air Fuel Rates set, then ignited with spark.	Smooth burning.
48.2	55.3				1020	2040	88.0					Smooth burning.
												Rough burning.

CONFIDENTIAL C-5-12-9 ATI- 181

Standard Oil Development Co.

AUTHOR(S)

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ORIG. AGENCY NUMBER: SODC Rpt PDN 4136

REVISION

AMER. TITLE: Study of combustors for supersonic ram - jet

FORG'N. TITLE:

ORIGINATING AGENCY: Standard Oil Development Co.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U.S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Conf'd'l	Jun'46	33	23	photos, tables, diagrs, graphs

ABSTRACT

Earlier tests had demonstrated that ramjet ignition was difficult above an air rate of 9 lbs/sec. An investigation of air pressure in the burner without combustion revealed that immediately downstream from the flame holder the pressure was below atmospheric and velocity above sonic. Higher pressure for ignition at an air rate of 11 lbs/sec was achieved by installation of two flame holders in series and ignition at the upstream flame holder. Thrust for various fuel-air ratios and the drag of the atomizing section were determined. After initiation of burning, combustion was sustained without further use of ignitors.

NOVEMBER 1946