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SECONDARY FLOW RATES IN A VERTICAL DIFFUSER OF DECREASING LENGTH USING A ROCKET EXHAUST JET AS THE MOTIVE FLUID

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ABSTRACT

This report presents some experimental results obtained from tests with a diffuser of decreasing length and exit area, in which the exhaust jet of a LOX-RP1 rocket engine was used to entrain water into the jet as a liquid coolant.

Typical values of pressure and temperature in the diffuser and exhaust duct are presented as a function of the diffuser exit area with the mass ratio of exhaust gas to water as a parameter.

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TEST LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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DEFINITION OF SYMBOLS

Symbol	Definition
P_c	chamber pressure of rocket engine measured at the injector face
n	mass ratio of secondary to primary flow rate (water to propellant flow rate)
LL-1	height of liquid above the diffuser inlet during operation
p-1	suction pressure generated at diffuser entrance
TG-4	typical gas temperature in the exhaust duct downstream of the diffuser
DP-1 through DP-6	diffuser pressures
P-2 through P-5	static pressures in the exhaust duct downstream of the diffuser, measured at wall stations

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SUMMARY

In a model sound suppressor, the rocket exhaust jet was used as the motive fluid in an ejector system to entrain a heavy flow of water into the rocket exhaust jet. The original length of the diffuser was reduced in four consecutive steps, and the performance of the system, expressed in terms of the water-to-gas mass ratio, was determined. This ratio decreased by about 50 percent as the divergent section of the diffuser was shortened by 68 percent on one side, and 17 percent on the opposite site, resulting in an oblique exit plane.

INTRODUCTION

In the development of a model sound suppressor for test facilities using a single rocket engine, a jet impingement plate was used downstream of the vertically arranged diffuser to divert the gas flow from the vertical into a horizontal flow direction (Fig. 1). However, existing rocket test facilities are already equipped with a flame deflector for the same purpose. If such a facility is to be provided with a sound suppressor, the already existing flame deflector has to be retained since it is a piece of proven hardware. In such a case, the distance between the engine exit plane and the jet impingement point on the flame deflector may be relatively short and inadequate for the installation of a regular-length diffuser. The actual length of the diffuser which can be installed and still achieve the desired eduction performance can only be determined through tests.

Figure 2 shows the deflector which was to be used in these tests; it also shows the size diffuser which could be accommodated in the existing space between the flame deflector and the engine exit plane.

The performance of such a short diffuser is very questionable. Therefore, it was to be expected that there would not be enough water entrained into the rocket exhaust to sufficiently cool the deflector plate. Thus the decision was to shorten the original diffuser shown in Figure 1 in four successive steps, after which the final configuration as shown in Figure 2 would be obtained. The four steps of shortening the diffuser are shown in Figure 3, and the performance of the system is presented in graphical form and in tabulated values.

Although the initial tests were conducted using a single H-1 rocket engine, the tests with the shortened diffuser were performed using a cluster of five (Vanguard) rocket engines, with a thrust of 28,250 pounds each, or a total thrust of 141,250 pounds. The gas inlet nozzle was modified to reflect the particular cross-section of the four-lobed jet pattern, but the cylindrical cross-section of the diffuser was left unchanged, as it has been used with the single H-1 engine.

Sections were cut from the diffusers in 4 steps of 17 inches each, as indicated by the dotted lines in Figure 3. After the first cut, a small lip was left on each section so that each successive cut was on the bias. The length and exit area were both reduced and the total reduction in pumping rate was 50 percent. However, the results indicate that the effect is a complex function and not straight forward percentage of either length or exit area.

DISCUSSION OF OPERATION

The gas from the five engines together with a small amount of induced air passes through a short convergent duct which is one nozzle diameter below the engine exit plane. The duct itself is 1. 73 nozzle diameters in length. The supersonic gases induce water flow past the liquid level gauge, LL-1, which measured the water height above the diffuser lips. The mixture of exhaust gas and water passes through the diffuser throat, which is 9. 5 times the exit area of one engine, and exits into the mixing chamber where it impinges on the water cooled deflector plate on the floor of the sound suppressor. The hot mixture of exhaust gas, water, and steam moves out of the mixing chamber toward the right into the exhaust duct (Fig. 1). The mixture has been cooled or contains sufficient water to allow the mixture to be ducted with normal construction materials.

RESULTS

The normal engine and diffuser parameters are given in Table 1. The engine actually operated at a chamber pressure of 600 p. s. i. a. (injector pressure which is less than the designed operational pressure). A summary of test data is given in Table 2.

The most important result of decreasing the diffuser length was the reduction in pumping rate of water, expressed here as n, the ratio of water to propellant flow rate (Fig. 4). For a reduction in length of the divergent section on one side of 68 percent the pumping rate was reduced by only 50 percent. At the same time, the static pressure in the water compartment, P-1, increases, and the initial surge and equilibrium pressure are both less negative. The temperature at the back wall and at the height of the diffuser exhaust, TG-4, indicates an increasing temperature of the mixture in general. The reductions shown for test SS-73 and SS-76 are probably due to local distribution of water from the diffuser before complete mixing has occurred. The results of two tests, SS-68 and SS-69, are given for comparison of the original length diffuser with the short diffusers.

The minor effects are given in Figure 5, and consist of diffuser pressures (DP-1, 2, 3, 4, 5, 6) which show an increase in pressure with decreasing diffuser length, and the static pressures at the walls (P-2, 3, 4, 5), which indicate a slight increase for P-2, near the mixing chamber roof. The others show a slight decrease which can be explained as the result of increasing velocity and corresponding reduction in static pressure. A typical graph of diffuser pressure versus height before the diffuser was cut is given in Figure 6. These diffuser pressures are five-second averages of highly fluctuating values which vary with time and may be different at any given time by as much as ± 0. 5 p. s. i.

The area calculated for the shorter diffusers is based on the minimum elliptical cross-section formed and not the irregular shape of the actual diffuser wall, as this is believed to be more nearly the actual flow cross section with water flowing over the diffuser lip. Note that in the case of the fourth cut, the area actually increased and that the minor parameters DP-1, DP-2, P-4 and P-5 seem to be affected; however, this could be coincidental. In Table 2, values are given for static pressures P-20 and P-22 which are located near the exhaust duct exit. Measurement P-10 is located at the duct end and is an indication of velocity change where flow is being redirected.

CONCLUSIONS

The result of these tests indicates that large flow rates of water can be induced by rocket exhaust jets, and that fairly drastic reductions in diffuser length can be tolerated, depending on flow rate requirements. The reduction of the water flow rate, however, is neither directly proportional to the length reduction, nor to the change in exit area, but is the result of the combined effect of both changes.

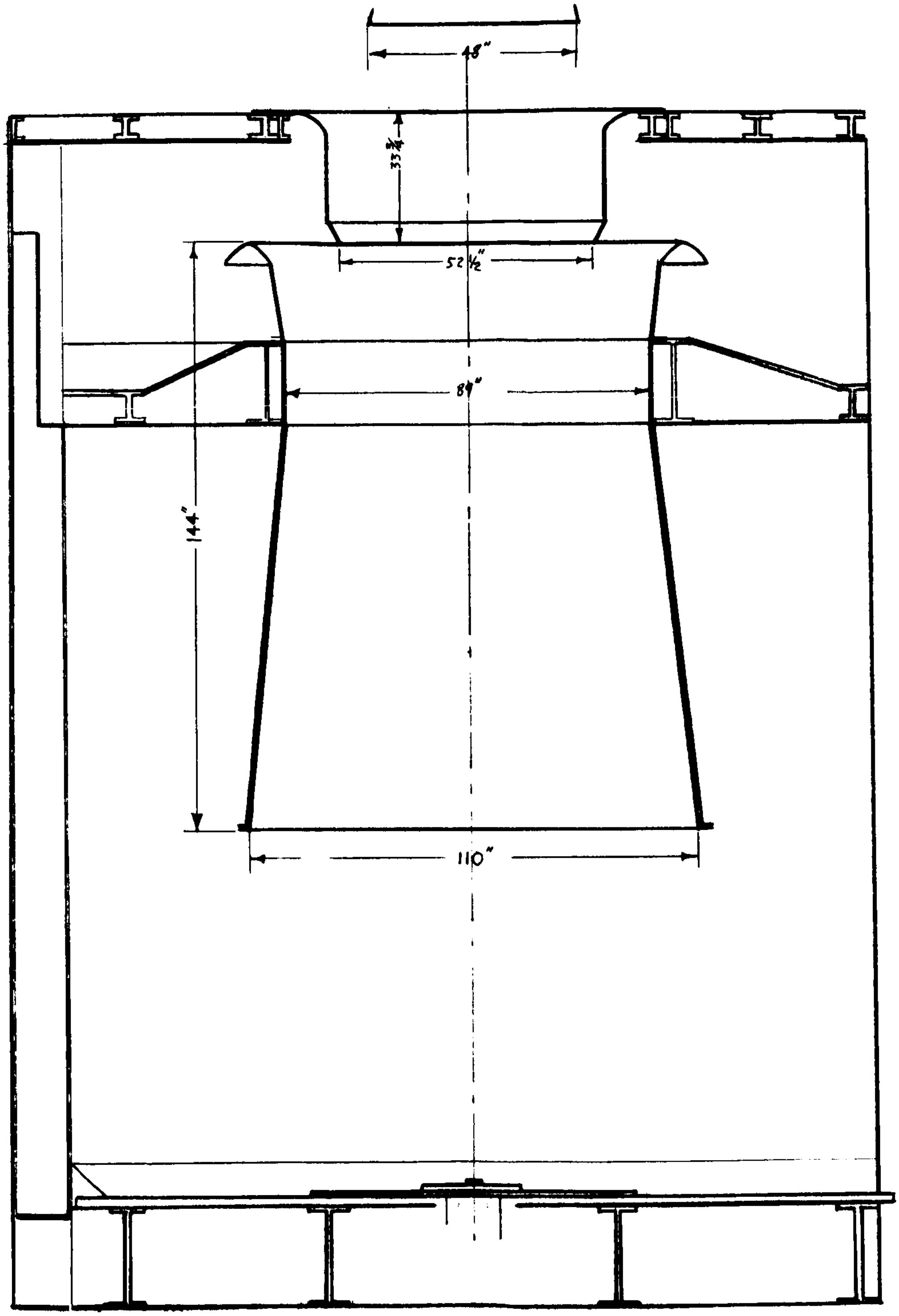

FIGURE 1. ARRANGEMENT AND GEOMETRY OF ORIGINAL DIFFUSER (H-1 ROCKET ENGINE)

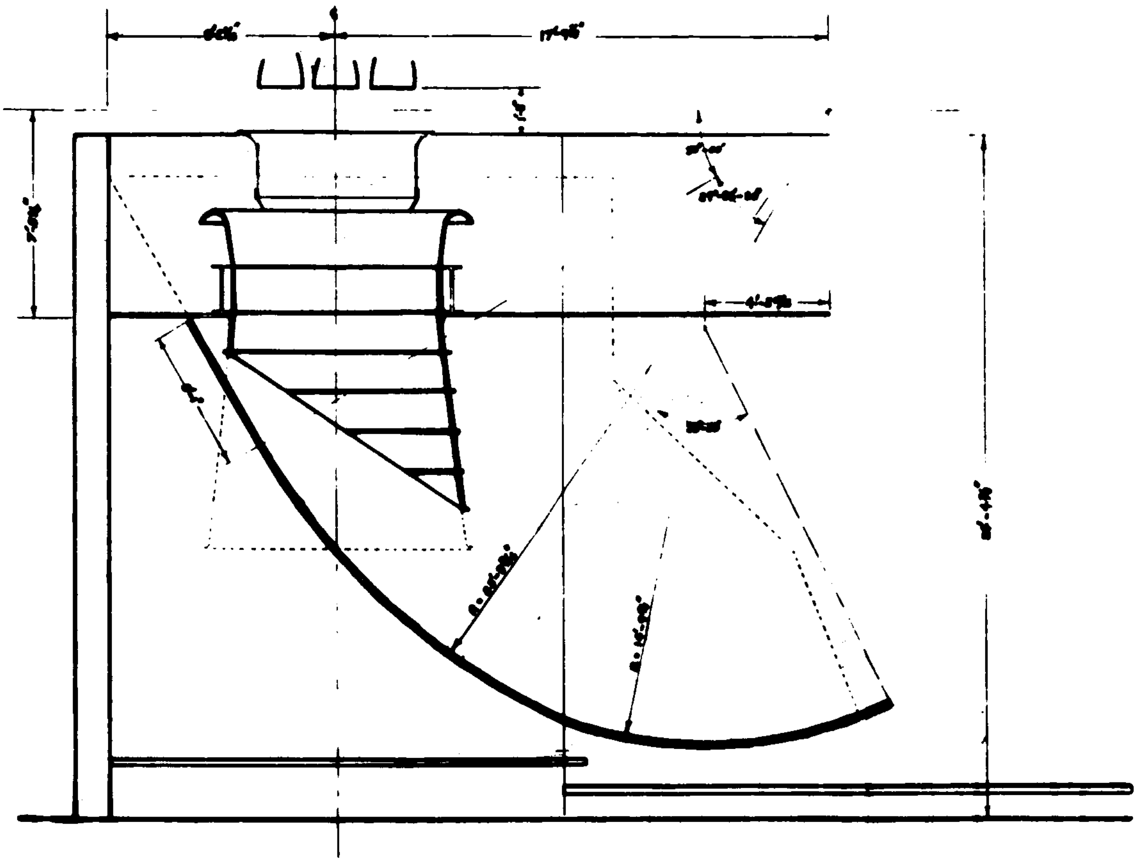

FIGURE 2. FLAME DEFLECTOR SCALE MODEL OF SATURN V TEST FACILITY

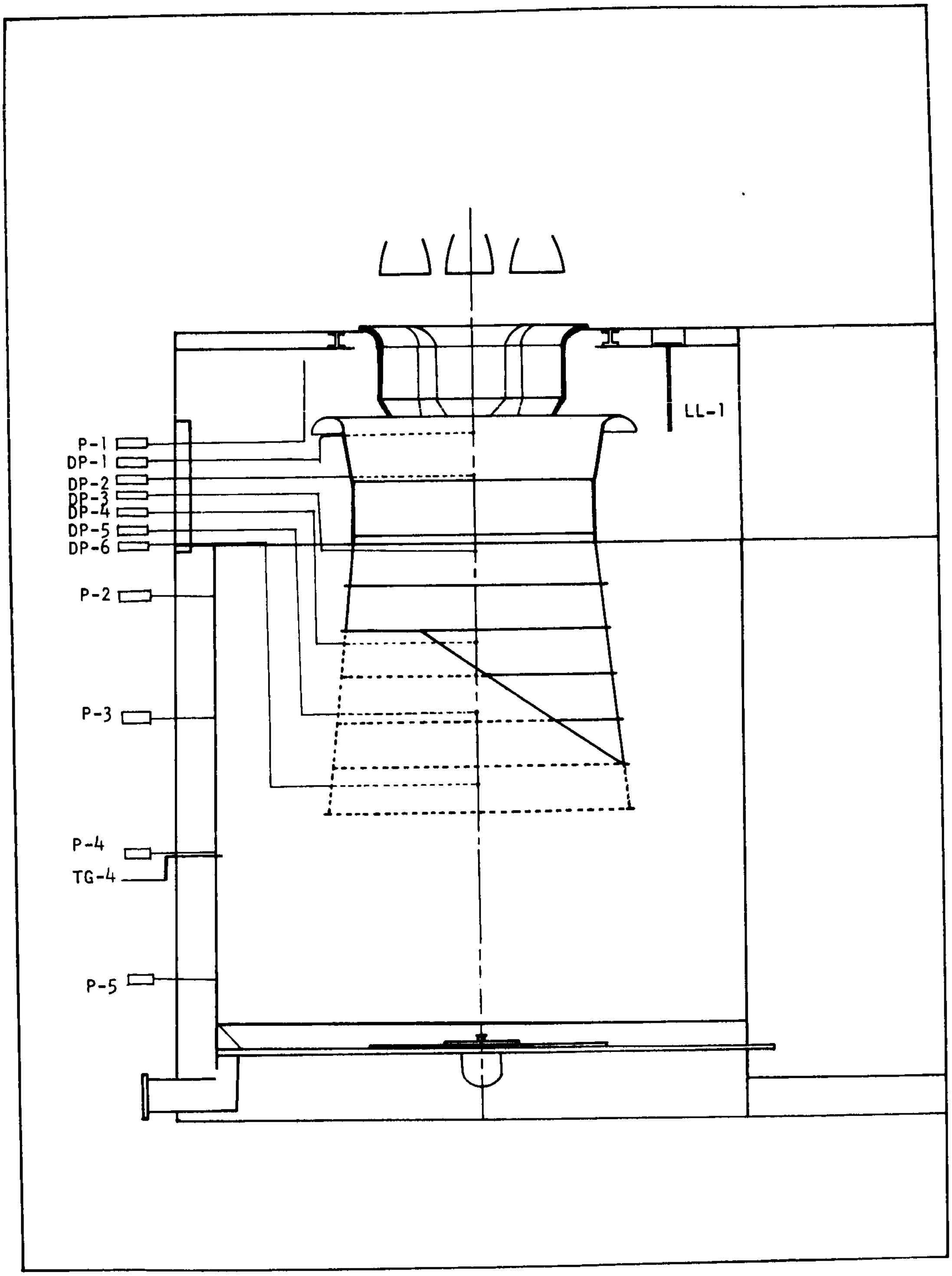

FIGURE 3. STEPWISE REDUCTION OF DIFFUSER LENGTH AND MEASUREMENT LOCATIONS

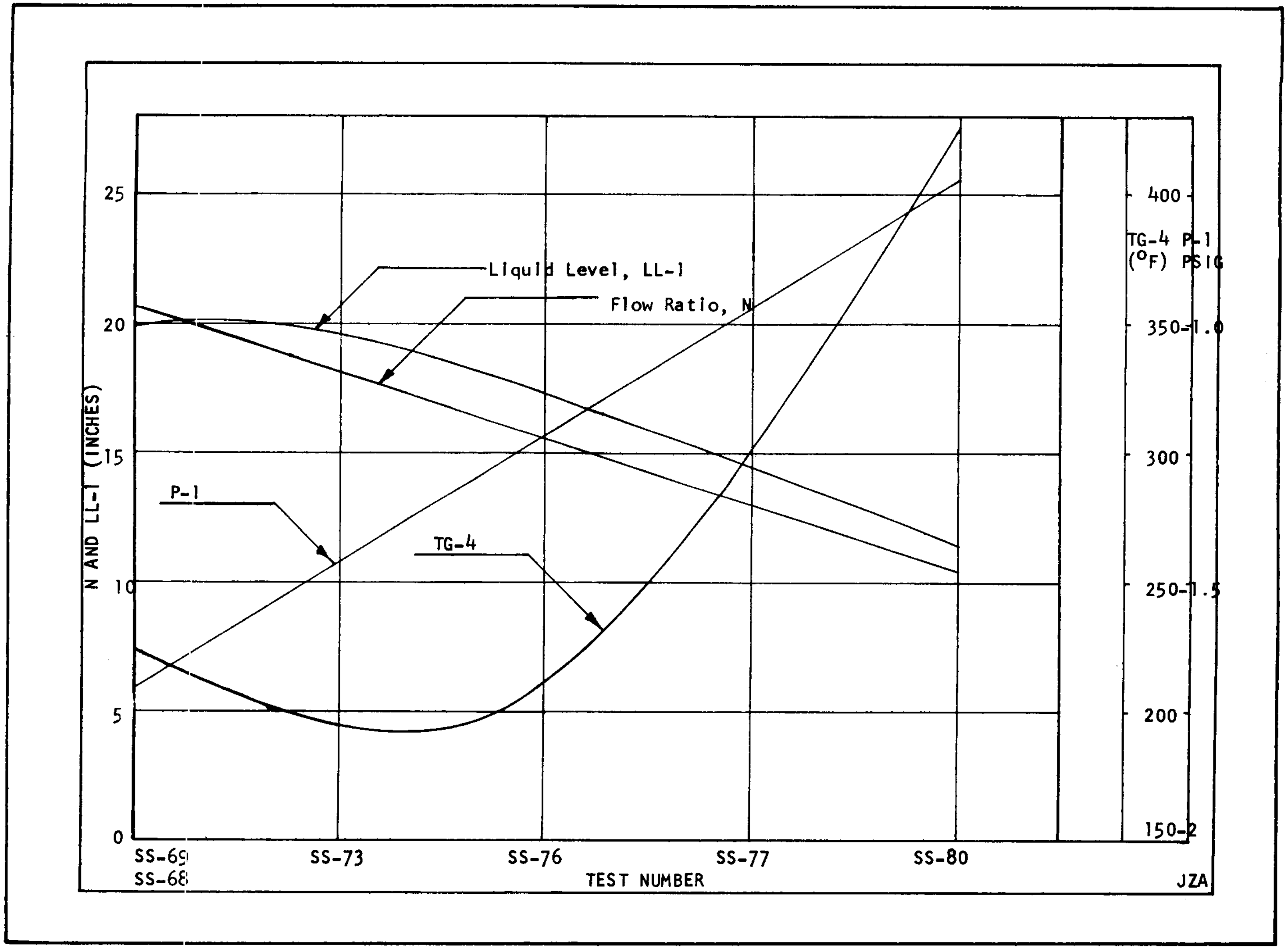

FIGURE 4. MAJOR EFFECTS OF REDUCED DIFFUSER LENGTH

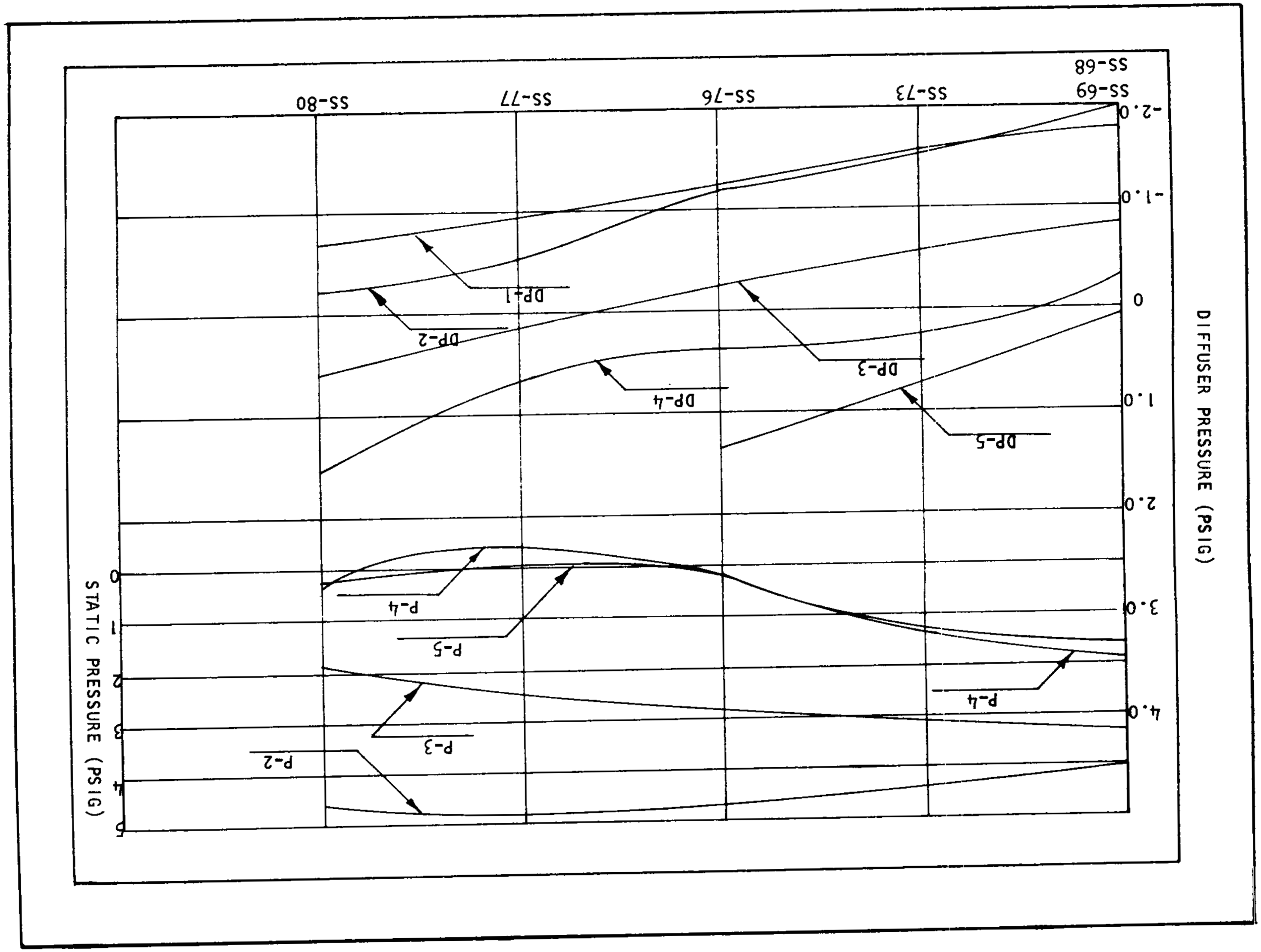

FIGURE 5. MINOR EFFECTS OF REDUCED DIFFUSER LENGTH

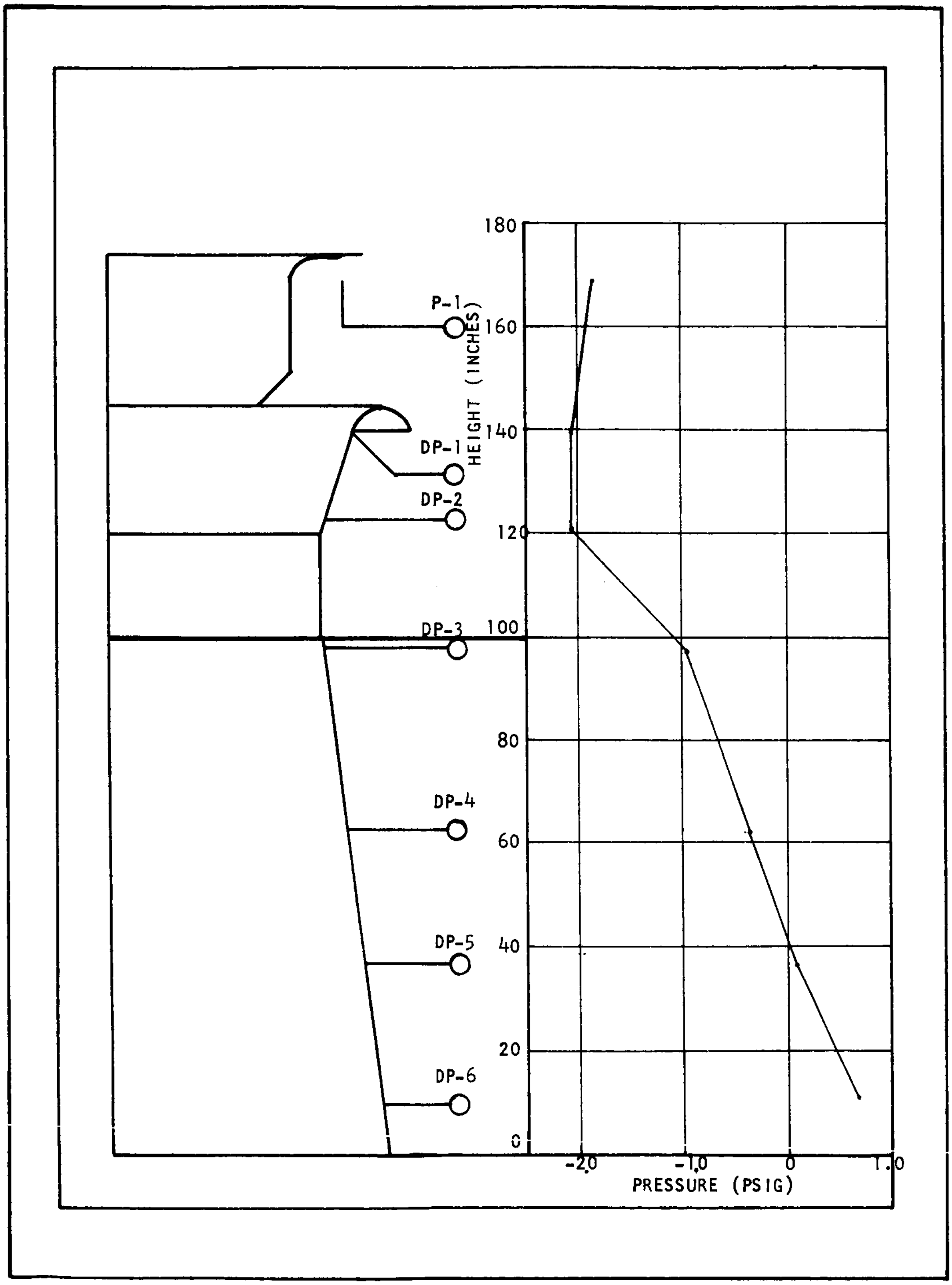

FIGURE 6. TYPICAL DIFFUSER PRESSURE

TABLE 1

ENGINE AND DIFFUSER PARAMETERS

Nominal Chamber Pressure (injector), P_i	650 p. s. i. a.
Nominal Chamber Pressure (Nozzle), P_n	610 p. s. i. a.
Actual Chamber Pressure (injector), P_c	600 p. s. i. a.
O/F Ratio	2.2
Pressure Ratio (P_i/P_n)	1.065
Characteristic Velocity (ft/sec), C^*	5370
Thrust (lb), F.	28,230
Thrust Coefficient (opt. assuming $k = 1.24$), C_f	1.57
Specific Impulse (sec), I_{sp}	260
Area Throat, A_t.	32.2 $in.^2$
Area Exhaust, A_e.	268.8 $in.^2$
5 Engines	1344 $in.^2$
Diameter Exit, D_e	18.5 in.
Expansion Ratio	8.35
Expansion Angle (conical)	15°
Exit Mach Number	3.25
Exit Static Pressure	8.7 p. s. i. a.
Area Diffuser Throat, A'_t	2554 $in.^2$

Diffuser Exit, A'_e	Expansion Ratio (A'_e/A'_t)	Area ($in.^2$)
1st Cut	3.72	9498
2nd Cut	3.51	8954
3rd Cut	3.41	8701
4th Cut	3.34	8538
	3.36	8591

TABLE 2

SUMMARY OF TEST DATA

Test No.	P_c (p. s. i. a.)	N	LL-1	P-1 (p. s. i. g.)	TG-4 (°F)	DP-1 (p. s. i. g.)	DP-2 (p. s. i. g.)	DP-3 (p. s. i. g.)	DP-4 (p. s. i. g.)
SS-68	600	20	20	-1. 8	212	-1. 0	-2. 0	-0. 9	-0. 3
SS-69	594	21. 5	20	-1. 6	232	-1. 8	-2. 0	-0. 8	-
SS-73	599	17. 5	-	-1. 6	195	-1. 6	-1. 5	-0. 5	0. 3
SS-76	606	15. 5	17. 5	-1. 2	210	-1. 2	-1. 2	-0. 2	0. 4
SS-77	604	12. 7	14. 5	-0. 95	300	-0. 85	-0. 5	0. 25	0. 7
SS-80	603	10. 5	11. 3	-0. 75	425	-0. 65	-0. 20	0. 40	1. 60

Test No.	DP-5 (p. s. i. g.)	DP-6 (p. s. i. g.)	P-2 (p. s. i. g.)	P-3 (p. s. i. g.)	P-4 (p. s. i. g.)	P-5 (p. s. i. g.)	P-20 (p. s. i. g.)	P-22 (p. s. i. g.)	P-10 (p. s. i. g.)
SS-68	0. 1	0. 7	4. 2	3. 3	1. 7	0. 95	0. 25	0. 25	3. 2
SS-69	0. 8	1. 1	4. 1	3. 4	1. 9	1. 60	0. 30	0. 10	2. 8
SS-73	0. 75	-	4. 7	3. 1	1. 4	1. 35	0. 35	0. 14	3. 0
SS-76	1. 40	-	4. 5	2. 9	0. 24 -0. 32	0. 25	0. 80	0. 30	3. 0
SS-77	-	-	5. 0	2. 45	-0. 32	0	0. 66	0. 24	1. 7
SS-80	-	-	4. 6	1. 95	0. 40	0. 55	0. 86	0. 15	1. 4

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MEASUREMENT OF LIQUID PUMPING RATES IN VERTICAL DIFFUSERS AND THE EFFECT OF DECREASING LENGTH

By J. Z. Adamson

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Fritz Kramer

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