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REPORT No. B-5350-AS(b)

DATE 18 NOV 1944

SUBJECT

"DESIGN, CONSTRUCTION, AND TESTING OF
A 6" VALVELESS-RESOJET"



BY

**U. S. NAVAL ENGINEERING EXPERIMENT STATION
ANNAPOLIS, MARYLAND**

E.E.S. REPORT No. B-5350-AS(b)

U.S.N.A.-2-12-43-5000

X-43725

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Serial No. EES-B-5350-AS(b)

NAVY DEPARTMENT

BUREAU OF AERONAUTICS

REPORT ON

"DESIGN, CONSTRUCTION, AND TESTING OF
A 6" VALVELESS-RESOJET"

By

U. S. NAVAL ENGINEERING EXPERIMENT STATION
ANNAPOLIS, MARYLAND

NUMBER OF PAGES - Text 4; Plates 12.

AUTHORIZATION - BuAero. Conf. ltr. Aer-E-350-SL, F13-4(1) dated
21 May 1941.

DATE OF TEST - February to June, 1944

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Serial No. EES-B-5350-AS(b)

TABLE OF CONTENTS

	<u>Page</u>
AUTHORIZATION FOR TEST.....	1
OBJECT OF TEST.....	1
SUMMARY.....	1
DESCRIPTION OF EQUIPMENT.....	2
METHOD OF TEST.....	2
RESULTS OF TEST.....	3
CONCLUSIONS.....	3
RECOMMENDATIONS.....	4

	<u>Plate</u>
Drawing of 6" Valveless-Resojet.....	1
Summary of Test Data.....	2 to 7
Photograph of Complete Motor.....	8
Photograph of Head Plate, Propane Injector, and an air-intake duct.....	9
Photograph of Head Plate Assembly.....	10
Curves of Frequency and Efficiency Against Length of Air-intake Duct...	11
Photograph of Test Set-up.....	12

X-43725

CONFIDENTIAL

Serial No. EES-B-5350-AS(b)

AUTHORIZATION FOR TEST

1. This test was authorized by the Bureau of Aeronautics, letter Aer-E-350-S1-F-13-4(1) of 21 May 1941.

OBJECT OF TEST

2. The object of this work was to design, construct, and test a practical Valveless-Resojet motor operating on the principle of the intermittent firing of an atmospheric air-fuel mixture in a chamber to produce a high-velocity jet of the exhaust gases, which produces forward thrust on the motor by direct jet reaction.

SUMMARY

3. A 6" Valveless-Resojet motor was designed, constructed, and tested by this Station. This motor operates on the principle of the intermittent firing of an atmospheric air-fuel mixture in a chamber to produce a high-velocity jet of the exhaust gases which produces forward thrust on the motor.

4. The Valveless-Resojet (see Plate 1) consists of a combustion chamber, a nozzle pipe through which the exhaust gases leave the motor, an air-entrance duct in the front of the chamber, a means for injecting fuel and a means for igniting the fuel-air mixture in the combustion chamber.

5. In an earlier report by this Station entitled "Design, Construction and Testing of a 6" Resojet Motor", Serial No. EES-B-5350-AS(a), tests on a motor similar to the present motor were described. That motor operates on much the same principle, but employs mechanical, reed-type valves in the chamber head-plate to prevent loss of explosive energy in the forward direction. The present motor is, therefore, termed a "Valveless-Resojet" since its "valving" is accomplished acoustically, rather than mechanically.

6. The results of tests on the best motor shape tried are as follows (see Plates 2 to 7):

Approx. Air speed MPH	Net thrust LBS	Specific thrust lbs/lbs/sec.
340	10.5	954
420	13.5	835
480	Would not resonate properly.	

The fuel used in these tests was gaseous propane.

7. It is believed that Valveless-Resojets, in larger sizes, of course,

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Serial No. EES-B-5350-AS(b)

would prove to be of great use in many applications which require a light-weight expendable jet propulsion unit or a light-weight, compact gas generator for driving turbines, etc.

DESCRIPTION OF EQUIPMENT

8. Plate 1 is a drawing of the best Valveless-Resojet tested. Plate 8 is a photograph of the motor completely assembled. The air intake pipe is made of 1-1/2" standard steel pipe, the annular head plate of 1/8" thick mild steel sheet, the combustion chamber of 6" standard steel pipe, the nozzle cone of 1/8" thick mild steel sheet, the nozzle pipe of 4" standard steel pipe, and the fuel supply tube (shown in Plates 8 to 10, protruding from the side of the air intake pipe) is of 3/8" copper tubing. Gaseous propane, the fuel in these tests, is delivered to the motor through this 3/8" tube and enters the air stream through 23 holes, No. 53 drill size, directed along radii of the air-intake pipe at its junction with the combustion chamber (see Plates 1, 9 and 10). The materials from which this motor was made would, of course, not be used if the motor were built as light-weight as possible. The motor described herein is, instead, a test stand model built for long operating life without cooling, and frequent and easy disassembly and modification. The propane used in these tests is purchased by the Navy in the slightly impure form known as "Pyrofax".

9. This type of jet propulsion device has been termed a "Resojet" by this Station since its operation depends upon the excitation of the natural fundamental frequency of the gas column in the tube by the intermittent force of the explosions therein. Referring to Plate 1, it can be seen that air travelling at high speed relative to the motor (as would be the case in operation on a fast-moving airplane) will enter the air-intake pipe and mix with gaseous propane as it enters the chamber. As the explosive mixture reaches the spark-plug, it is ignited, creating a high pressure within the chamber. This pressure surge moves both out the nozzle pipe and forward toward the air-intake pipe. First, this forward moving high pressure wave impedes the flow of propane which is delivered at constant pressure to the injection holes, and then enters the air-intake tube, stopping the air flow. As this pressure wave is dissipated, air and propane are again allowed to mix and ignite, thus repeating the cycle. In the motor shown in Plate 8, the explosion frequency is about 90 cycles per second. Other intake, chamber, and nozzle pipe sizes would cause this frequency to change. Plate 11 shows the dependence of the explosion frequency on the length of the air-intake pipe. Plates 2 to 7 show the effect on frequency of different chamber and nozzle-pipe sizes in various combinations.

METHOD OF TEST

10. Plate 12 shows the 6" Valveless-Resojet on its test stand. The motor is mounted on a rolling carriage which is allowed to move against an oil-filled thrust bellows, which, in turn, is connected to a pressure gauge. This oil pressure system is calibrated to allow direct reading of thrust while the Resojet is in operation.

CONFIDENTIAL

Serial No. EES-B-5350-AS(b)

11. Fuel (gaseous propane) is supplied to the Resojet from a pressure tank into which gaseous propane has been bled from its shipping container. From the gaseous propane tank, the fuel enters a manually-controlled fuel valve which is used to regulate the amount of fuel delivered to the motor. A spark plug, installed in the side of the motor, is connected in an electrical circuit with a Ford coil, and provides the initial ignition of the explosive charge.

12. When it is desired to make an efficiency run, the pressure and temperature of the gaseous propane in its tank are measured. An air blast from compressed air tanks is directed at the air intake pipe of the motor, its speed being measured by a pitot tube mounted between the air source and the motor. The ignition system is turned on and the fuel valve opened, allowing gaseous propane to be fed into the chamber by its own pressure in the supply tank. Combustion begins immediately at about 90 explosions per second. The fuel flow is increased until the thrust reaches a maximum. Any increase in fuel flow beyond this point will cause the motor to stop running. The thrust, as measured by the thrust system pressure gauge, is found to remain quite steady, since the high frequency of operation produces effectively a constant thrust. The total time of the run is measured by a stop watch. When the test run is ended, the pressure and temperature of the gaseous propane in the supply tank are measured. Reference to a Mollier diagram for superheated propane gas yields the total weight of propane consumed during the run.

RESULTS OF TEST

13. Plates 2 to 7 show the results of all tests run on this type of motor. Plate 1 describes the best (from the standpoint of efficiency) form tested. Results of tests on this particular motor are as follows:

Approx. Air speed MPH	Net thrust LBS	Specific thrust lbs/lbs/sec.
340	10.5	954
420	13.5	835
480	Would not resonate properly.	

14. It must be realized that no attempt was made in these tests to measure the external aerodynamic drag occasioned by the high air speeds, since air was supplied from a small duct and there was very little "spillover" from the air intake pipe of the motor. The net thrusts mentioned above and in Plates 2 to 7 do, however, include the detrimental effect of internal air drag.

CONCLUSIONS

15. It is concluded, on the basis of the foregoing test results, that the Valveless-Resojet designed, constructed, and tested at this Station is capable of delivering a maximum net thrust of 13.5 lbs. at a specific thrust of 835, using gaseous propane as fuel. Conclusions, as to the effect of the external air drag on this motor's thrust and efficiency, cannot be

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Serial No. EES-B-5350-AS(b)

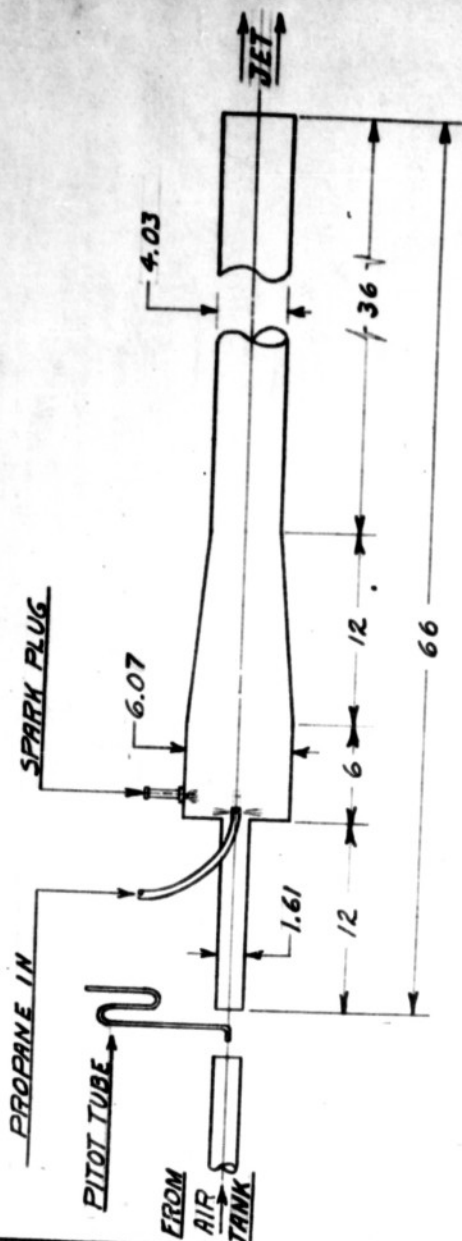
drawn, since no wind tunnel equipment was available for these tests. It is believed that the Valveless-Resojet in larger sizes, of course, could be useful in many applications which require a light-weight, expendable jet propulsion unit or a light-weight, compact gas generator for driving turbines, etc. Air pressure, of course, is required for this motor's operation, but would be readily available in applications to aircraft already travelling at high speeds.

RECOMMENDATIONS

16. It is recommended that work be continued on the Valveless-Resojet to improve its performance and usefulness.

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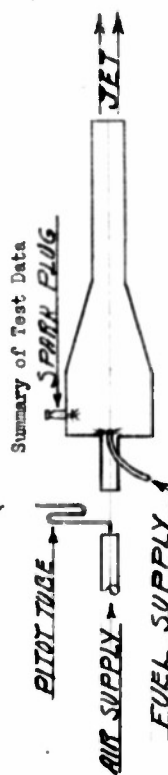


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MATERIAL		STOCK	QUAN.	DATE	BY	USED IN ASSEMBLY
MAT. ± 0.10, 1/4 OR NOTED				9/28/44	UB	
SCALE - 3/4 SIZE				9/28/44	UB	
TOL. ± 0.10, 1/4 OR NOTED				9/28/44	UB	
SUPERSEDES DWG. NO.				9/28/44	UB	
SUPERSEDED BY DWG. NO.				9/28/44	UB	
BUAER PROJECT		TEST SERIES-B5350				
TED EES.3401		CHANGE LETTERS				
U.S.N.E.E. STA						
ANNAPOLIS, MD.						
SCHEMATIC DIAGRAM						
6" DIR. VALVELESS RESOJET						
NAME		DRAWING NO.				
		100953				

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Serial No. EES B-5350 - AS(b)



air intake pipe	Motor		Fuel injection	Air speed mph	Net thrust lbs	Time of run secs	Fuel flow lbs/sec	Specific thrust lbs I	Freq. cyc/sec
	combustion chamber	nozzle cone l=6"							
d=2.5", l=12"	d=6", l=12"	l=6"	d=4" l=36"	240	8.5	-	-	-	-
"	"	"	"	340	13.5	-	-	-	-
"	"	"	"	420	16.5	-	-	-	-
"	"	"	"	340	12.5	127	.0206	610	-
"	"	"	"	"	"	95	.0159	787	-
"	"	"	"	"	13	56	.0187	697	-
"	"	"	"	"	13	155	.0195	655	-
"	"	"	"	200	9	131	.0124	725	-
"	"	"	"	340	14	73	.0193	703	-
"	"	"	"	420	17.5	93.5	.022	795	-
"	"	"	"	540	19	150	.0225	800	-
"	d=6", l=60	none	"	420	-	-	-	-	100
"	"	d=4 l=0	"	would not resonate	-	-	-	-	-
"	"	"	"	340	5.5	90	.0243	222	-
"	"	"	"	420	12.5	60	.0309	405	-
"	d=6, l=12	l=6	"	240	7.5	124	.0122	615	-
"	d=10, l=12	"	"	"	6.5	-	-	-	-
"	"	"	"	340	7.5	-	-	-	-
"	"	"	"	420	12	-	-	-	-

PLATE 2

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Serial No. EES D-5350 - 42(4)

Summary of Test Data (cont'd)

Motor			Fuel injection	Air speed mph	Net Thrust lbs	Time of run secs	Fuel flow lbs/sec	Specific Thrust lbs T lbs/sec	Freq. cyc/sec
air intake pipe	combustion chamber	nozzle cone							
d=2.5", l=12"	d=10, l=12	1-6	at head end of chamber (see sketch)	240	5.5	-	-	-	-
"	"	"	"	340	9	-	-	-	-
"	d=6, l=12	"	mid-point air in-take pipe	240	2	20.7	.0834	59.3	-
"	"	"	at head end of chamber	240	0.5	13	.0169	562	-
"	"	"	"	240	12.5	114	.0144	369	92
"	"	"	"	420	10	26	.0265	713	98.5
"	"	"	"	240	9	127.7	.0150	535	-
"	"	"	"	"	8	95	.01555	495	92
"	"	"	"	340	12.5	36.6	.0252	495	95
"	"	"	"	"	12	22.7	.0239	505	-
"	"	"	"	420	16	35.2	.0401	399	97.5
"	"	"	"	"	16.5	28.3	.0374	441	-
"	"	"	"	420	12.5	12.7	.0335	273	100
"	"	"	"	"	12.5	28	.0404	450	98
"	"	"	"	240	0	21.2	.01415	565	-
"	"	"	"	340	12	70.3	.032	565	-
"	"	"	"	420	17	70.3	.0319	535	-
"	"	"	"	420	17.5	32.4	.0207	597	-
d=2, l=12	"	"	"	240	6.5	15.3	.01255	932	-
"	"	"	"	340	12.5	47.4	.0126	873	-
"	"	"	"	420	17.5	57.4	.0270	627	-
"	"	"	"	420	21	32.7	.0133	594	-
d=1.5, l=12	"	"	"	240	6	14.7	.01025	585	-
"	"	"	"	420	15	30.5	.017	940	-

PLATE 3

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Serial No. EES B-5350-A3(b)

Summary of Test Data (cont'd)

air intake pipe	Motor			Fuel injection	Air speed mph	Net thrust lbs	Time of run secs	Fuel flow lbs/sec	Specific thrust lbs T lbs/sec	Freq. cyc/sec
	combustion chamber	nozzle cone	nozzle pipe							
d=1.5 l=12	d=6, l=12	1=6	d=4 l=36	at head end of chamber	480	15.5	39.8	.0249	663	-
"	"	"	"	"	240	7	62.2	.0084	835	83.4
"	"	"	"	"	340	12.5	53.7	.0134	935	-
"	"	"	"	"	420	15.5	57.8	.0173	955	-
d=1 l=12	"	"	"	"	340	6	35.2	.00764	786	85.7
d=2.5 l=12	"	"	"	"	420	7	95.4	.00943	743	-
"	"	"	"	"	340	12.5	47.4	.0266	470	-
d=1.5 l=12	"	"	"	"	420	15.5	27.1	.0306	506	-
"	"	"	"	"	240	6.5	94.9	.0075	967	-
"	"	"	"	"	340	11	61.7	.0128	860	-
"	"	"	"	"	420	16	53.6	.0159	1001	-
"	"	"	"	"	420	13	68.2	.0142	915	-
"	"	"	"	"	"	13	61.3	.0166	786	-
"	"	"	"	"	480	15.7	54.3	.0194	810	-
"	"	"	"	"	"	15.7	56.5	.0183	858	-
d=1.5 l=18	"	"	"	"	540	would not resonate properly				
"	"	"	"	"	340	10	58.1	.00925	1210	-
"	"	"	"	"	420	13	54.7	.0174	746	-
d=1.5 l=7	"	"	"	"	480	18	very erratic operation			
"	"	"	"	"	340	5.25	117.7	.00953	551	-
"	"	"	"	"	"	5.25	46.3	.0110	477	-
"	"	"	"	"	"	8.25	62.5	.0189	436	-
"	"	"	"	"	"	8.25	58.2	.0191	432	-
"	"	"	"	"	540	13.5	43.7	.0322	420	-
"	"	"	"	"	340	7	60.9	.01596	439	98.4

PLATE 4

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Serial No. EEC B-5350-A3(b)

Summary of Test Data (cont'd)

Motor air intake pipe	combustion chamber	nozzle cone	nozzle pipe	Fuel injection	Air speed mph	Net thrust lbs	Time of run secs	Fuel flow lbs/sec	Specific thrust lbs $\frac{1}{\text{lb}}$	Freq. cyc/sec
d=1.5 l=7	d=6, l=12	l=6	d=4 l=56	at head end of chamber	340	7.7	52.4	.01830	421	-
"	"	"	"	"	420	10.25	52.9	.02330	440	-
d=1.5 l=9	"	"	"	"	480	13.5	55.8	.0299	452	-
d=1.5 l=10	"	"	"	"	340	8.0	58.3	.0163	491	92
d=1.5 l=11	"	"	"	"	"	8.5	56.8	.0167	509	-
d=1.5 l=12	"	"	"	"	"	9	55.0	.014	644	90
d=1.5 l=13	"	"	"	"	"	8.5	62.2	.0143	595	-
d=1.5 l=14	"	"	"	"	"	9.5	62.4	.0125	690	88.5
d=1.5 l=15	"	"	"	"	"	3.5	61.8	.01248	692	-
d=1.5 l=16	"	"	"	"	"	8.7	62.0	.0111	785	87.5
d=1.5 l=17	"	"	"	"	"	9	61.7	.0110	817	-
d=1.5 l=18	"	"	"	"	"	9.9	61.6	.014	953	87
d=1.5 l=19	"	"	"	"	"	8.5	62.0	.00852	900	-
d=1.5 l=20	"	"	"	"	"	9.5	62.4	.00995	955	85
d=1.5 l=21	"	"	"	"	"	9.0	63.1	.0101	892	-
d=1.5 l=22	"	"	"	"	"	9.5	62.2	.0108	880	86.5
d=1.5 l=23	"	"	"	"	"	9.0	62.2	.0103	975	-
d=1.5 l=24	"	"	"	"	"	9.5	62.1	.0111	855	87
d=1.5 l=25	"	"	"	"	"	9.2	64.9	.0117	785	-
d=1.5 l=26	"	"	"	"	"	9.5	61.8	.011	865	-
d=1.5 l=27	"	"	"	"	"	10	63	.0128	780	-
d=1.5 l=28	"	"	"	mid-point air intake pipe	"	9.0	63.2	.0133	553	85

PLATE 5

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Serial No. 235 B-3350 -43 (F)

Summary of Test Data (cont'd)

air intake pipe	Motor		Fuel injection	Air speed mph	Net thrust lbs	Time of run secs	Fuel flow lbs/sec	Specific thrust lbs T lbs/sec	Freq. cyc/sec
	combustion chamber	nozzle cone							
d=1.6 l=12	d=6, l=12	l=6	d=4 l=36	340	9.0	62.2	.0163	553	-
"	"	"	"	"	9.5	63.9	.0102	930	97.5
"	"	"	"	"	10.0	60.9	.0125	800	-
"	"	"	"	"	10.2	60.7	.0113	856	-
"	"	"	"	"	9.5	66.3	.0112	950	-
"	"	"	"	"	9.2	63.3	.0106	853	-
"	d=6, l=11	"	"	"	8.5	62.7	.0108	790	-
"	"	"	"	"	8.5	62.5	.0110	773	-
"	d=6, l=6	"	"	"	8.0	62.1	.00883	933	100
"	"	"	"	"	9.3	62.0	.0106	890	-
"	"	"	"	"	would not resonate properly, intermittent explosions at about 15/sec.				
"	"	l=12	d=4 l=13	240	10	62.7	.0112	properly 855	105
"	"	"	"	"	10	62.3	.0110	862	-
"	"	"	"	"	10.5	62.3	.0103	855	90
"	"	"	"	"	10.3	60.9	.01075	830	-
"	"	"	"	400	13.5	51.0	.0170	795	-
"	"	l=0.5 l=26	"	340	10.5	60.3	.0161	854	-
"	"	"	"	400	8.7	61.7	.0192	402	-
"	"	"	"	340	10.5	62.6	.0022	474	-
"	"	"	"	100	would not resonate properly	not resonate properly	not resonate properly	not resonate properly	-
"	"	"	"	400	11.3	would not take properly	would not take properly	would not take properly	-
"	"	l=0 l=26	d=4.5 l=19	340	10.0	71.5	.0107	1000	-

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Serial No. NES B-5360-AS(b)

Summary of Test Data (cont'd)

air inlet no.	Motor		Fuel injection	Air speed mph	Net thrust lbs	Time of run secs	Fuel flow lbs/sec	Specific thrust lbs/lb fuel/sec	Freq. cyc/sec
	combustion chamber	nozzle case pipe							
1-12	1-12	1-12	at head end of chamber	340	10.3	62.5	.0101	1020	-
"	"	"	"	"	10	63.3	.0107	935	98.5
"	"	"	"	"	10	65.3	.0118	350	-
"	"	"	"	"	9.7	61.7	.0141	617	117
"	"	"	"	"	would not resonate properly				
"	"	"	"	340	9.7	62.5	.01185	820	81
"	"	"	"	"	10	62	.01225	815	-
"	"	"	"	"	10	62.2	.014	714	81
"	"	"	"	"	10	62.1	.0143	700	-
"	"	"	"	"	10.5	62	.01145	915	88.5
"	"	"	"	420	13.5	61.9	.0154	873	88.5
"	"	"	"	430	would not resonate properly				
"	"	"	"	340	19	48	.0198	960	65.6
"	"	"	"	420	25	53.1	.0278	900	65.6
"	"	"	"	340	19	44.5	.020	950	75
"	"	"	"	"	16	61.5	.0244	556	97
"	"	"	"	"	19.5	62	.0192	965	75

PLATE 7

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SERIAL NO. EES-B-5350-AS(b)



PLATE 8

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SERIAL NO. EES-B-5350-AS(b)

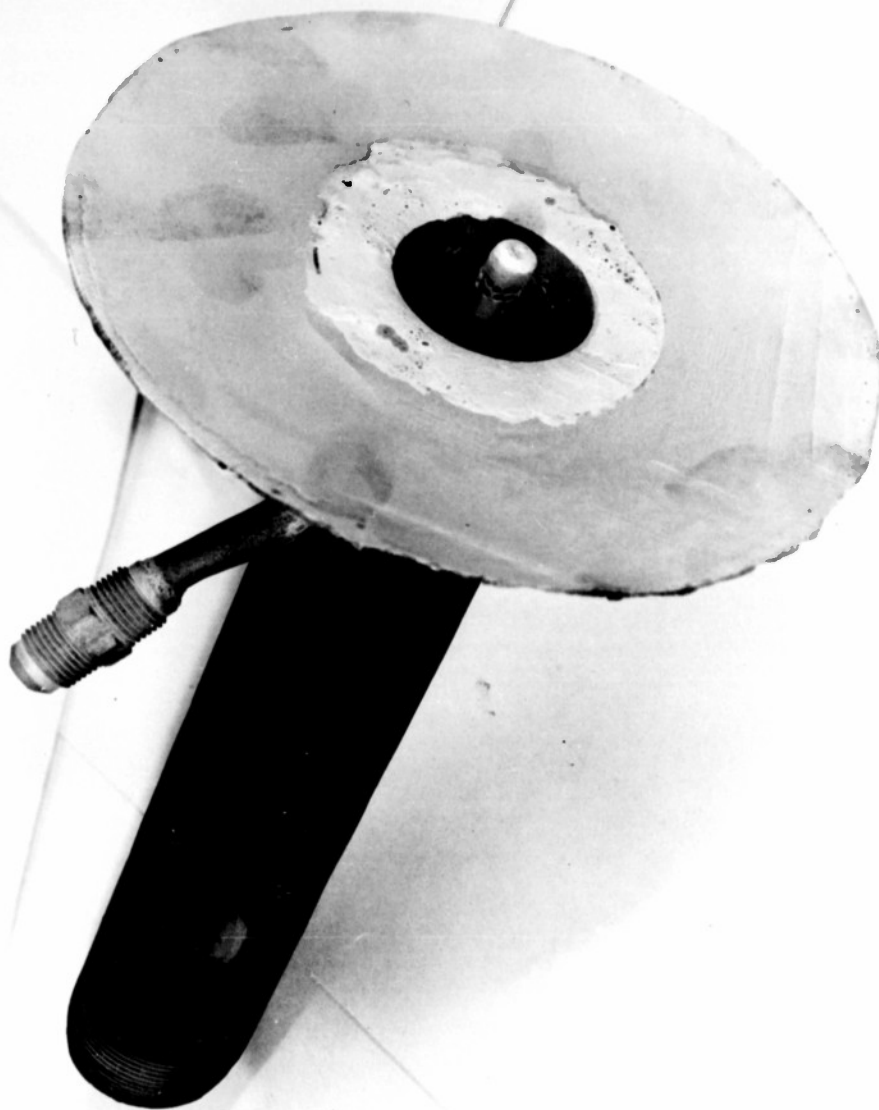


PLATE 9

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SERIAL NO. EES-B-5350-AS(b)

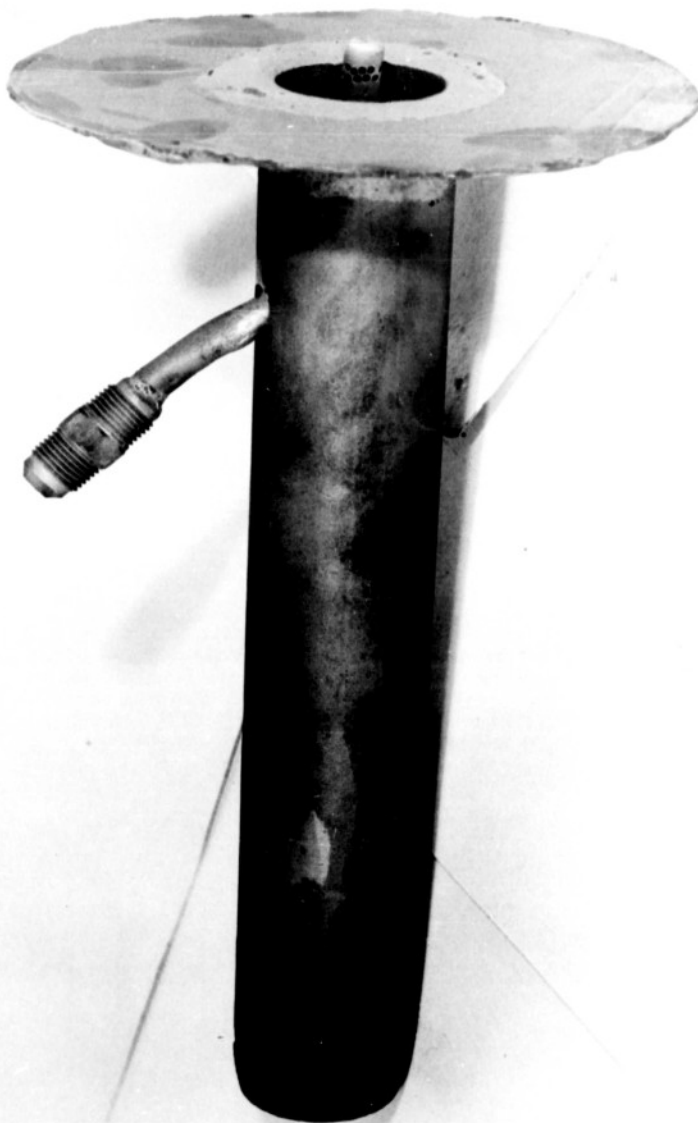


PLATE 10

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SERIAL NO. EES-B-5350-AS(b)

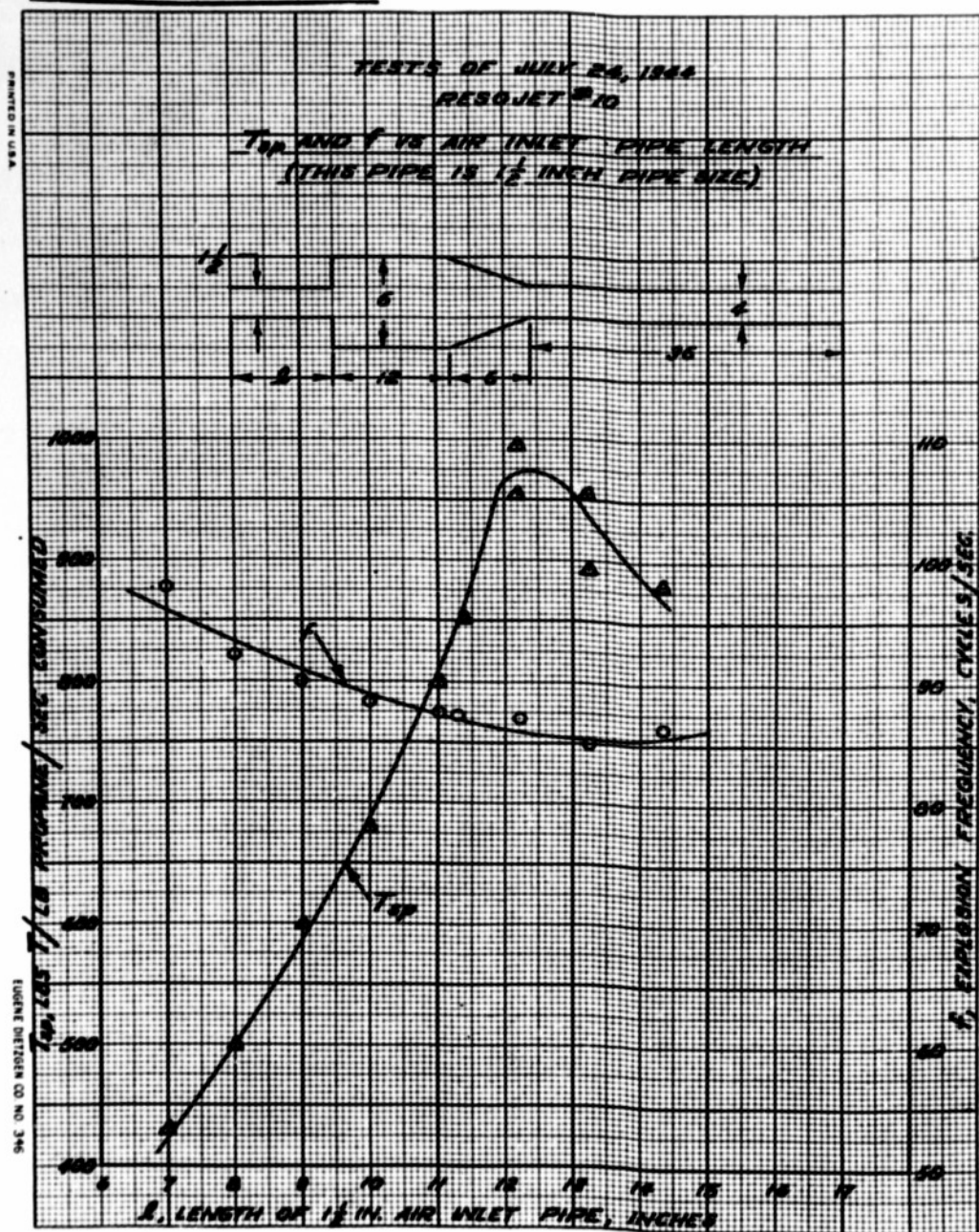


PLATE 11

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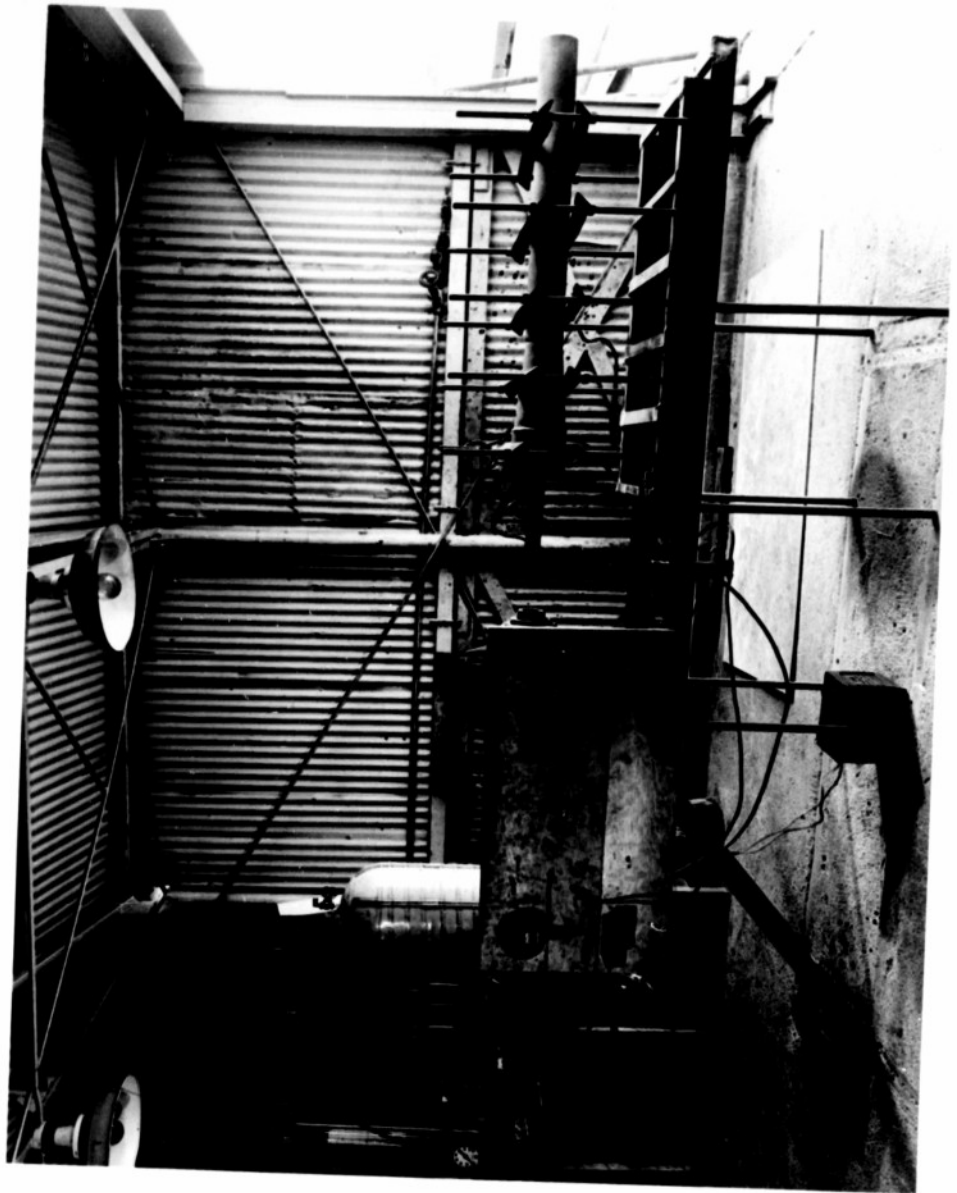


PLATE 12

REEL - C

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1 2 5 4 8

EDITION FORM 10 (20 MAR 67)

Schuber, William

DIVISION: Power Plants, Jet and Turbine (5)

SECTION: Testing (17)

CROSS REFERENCES: Engines, Jet propulsion - Pulse jet (33400); Engines - Design (32864); Generators, Gas (45475)

C-5-17-3

IATI- 12548
ORIS AGENCY NUMBER

EES-B-5350-AS(b)

REVISION

AUTHOR(S)

AMER. TITLE: Design, construction, and testing of a 6" valveless-resojet

FORG'N. TITLE:

P215 Pulse Jet Engines

ORIGINATING AGENCY: Navy Dept., Bureau of Aeronautics, Annapolis, Md.

TRANSLATION:

(OVER)

COUNTRY	LANGUAGE	FORG'N. CLASS	U. S. CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		CONFIDENTIAL	Jun '44	18	7	photos, tables, graph, drwgs

ABSTRACT

Six in. valveless-resojet engine was designed, constructed, and tested. Power plant consists of combustion chamber, nozzle pipe, air intake duct, and a means of injecting and igniting fuel. Valving is accomplished acoustically rather than mechanically. Gaseous propane was used as fuel. This power plant is capable of delivering a maximum net thrust of 13.5 lb at specific thrust of 835 lb/lb/sec. Engine could be used in applications which require a light-weight, jet-propelled unit or as gas generator for driving turbines.

NTIS Auth: USNMSSC Hc, 20 Sep 82

AD-A800 194

NICAL INDEX

WRIGHT FIELD, OHIO, USAAF

WFO-21 MAR 67 1321

U auth: DOD DIR 5200.9, 27 Sep 58
(RBr. 114)