NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

October 1945 as
Memorandum Report E5J03

ENDURANCE TESTS OF A 22-INCH-DIAMETER PULSE-JET ENGINE WITH A NEOPRENE-COATED VALVE GRID

By Eugene J. Manganiello, Michael F. Valerino, and John H. Breisch

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

NACA MR No. E5J03

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Services Command, Army Air Forces

and the

Bureau of Aeronautics, Navy Department

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SUMMARY

Thrust-stand tests were conducted at high thrust outputs to determine the operating life of a 22-inch-diameter pulse-jet engine equipped with a neoprene-coated valve grid. The results of the endurance tests show that through the use of the neoprene-coated grid the operating life of the pulse-jet engine, as limited by valve deterioration, was extended to more than 164 minutes, as compared with 30 minutes for the standard uncoated grid. The average jet thrust (not deducting the momentum drag of the entering air) developed by the engine was 855 pounds at a simulated ram pressure of 58 inches of water and a fuel flow of 2800 pounds per hour; no decrease in thrust was obtained during the entire 164 minutes of operation. This jet-thrust value represents a slight reduction in performance from the average 890 pounds of thrust obtained with the standard valve grid under similar operation conditions.

INTRODUCTION

At the request of the Air Technical Service Command, Army Air Forces, and of the Bureau of Aeronautics, Navy Department, an investigation is being conducted at the NACA Cleveland laboratory to improve the performance and extend the operating life of the pulse-jet engine. As a part of this investigation, thrust-stand tests were conducted to determine the sea-level performance of a

22-inch-diameter pulse-jet engine at simulated ram pressures of 0, 18, 40, and 58 inches of water over the entire fuel-flow operating range of the jet engine (reference 1).

The results of reference 1 and of tests conducted at Wright Field (reference 2) indicate that the operating life of the pulse-jet engine, as limited by valve deterioration caused by the repeated impact forces imposed on the valves in closing during operation, is approximately 30 minutes, after which a rapid reduction in engine-thrust output is obtained.

Attempts to increase valve life through change of valve material and thickness have been unsuccessful; oral reports from Wright Field, obtained subsequent to the tests reported herein indicate, however, that the time of satisfactory operation can be increased to about 1 hour by careful selection, honing, and finishing of the valves.

The method of reducing valve deterioration investigated in the present tests consists in diminishing the valve shock forces by cushioning the valves through use of an energy-absorbent material on the valve seats. The entire grid surface of a production flapper-valve assembly was coated with a thin layer of neoprene by means of a process developed by the B. F. Goodrich Company of Akron, Ohio. Thrust-stand endurance tests of this modified valve assembly installed in a pulse-jet engine was conducted at high thrust outputs during July 1945 and the results are presented herein.

APPARATUS AND METHODS

The 22-inch-diameter (maximum) pulse-jet engine used in the tests is described in references 1 and 2. The principal dimensions of the engine shell and the positions of the valve-grid assembly and the venturi are shown in figure 1. The thrust test stand and the method of simulating ram pressure and other installation and instrumentation details are essentially the same as those described in reference 1. In order to obtain a better indication of the valve-grid operating temperatures, the thermocouples previously installed on the upstream face of the grid (see reference 1) were transferred to the downstream face. The process used by the B. F. Goodrich Company to neoprene-coat the valve grid is outlined as follows:

Процесс, используемый компанией B. F. Goodrich Company для покрытия неопреновым покрытием сетки клапана, описан следующим образом:
(a) Секции сетки обезжириваются, окрашиваются грунтовкой, чистятся неопреновым цементом, окунаются в коагулянт, а затем в неопрен, промываются водой и осушаются краем хвостовика вверх.

channels is probably to improve mixing between the combustion air and the fuel. A spark plug installed on the combustion-chamber shell in the position indicated in figure 1 is used for starting the engine.

Figures 2 and 3 are photographs of the downstream and upstream faces of the flapper-valve grid assembly and show the nine centrifugal-spray fuel-injection nozzles, the three compressed-air jets, the fuel-distribution manifold, and the compressed-air lines. The compressed-air jets, which are incorporated for static starting, were not used in the tests.

Resonant operation of the engine is as follows: The flapper valves open and admit air into the combustion chamber. The fuel spray mixes with the incoming air and forms a combustible mixture, which is ignited by the residual exhaust gases of the previous explosion. The pressure rise resulting from the explosive combustion causes the flapper valves to snap shut against the grid and the burned products of combustion are discharged rearwardly through the tail pipe, thus providing a thrust impulse on the engine in a forward direction. The outward rush of gases from the tail pipe reduces the pressure within the combustion chamber, which causes the flapper valves to reopen and admit a new charge of air. The cycle then repeats itself at a frequency governed by the resonant frequency of the engine tube.

Thrust stand and thrust-measuring system. - Figure 4 is a schematic diagram of the test setup showing the mounting frame, the thrust platform and thrust-measuring linkage, and the general ducting system for supplying combustion air to the engine. The shrouds and ducting of the cooling-air system and other details of the test installation may be seen in the photograph of figure 5. The front (upstream) support for the engine consists of an adjustable yoke having flexible rubber-mounted bearings at the two support points for cushioning the violently fluctuating thrust forces obtained during operation. The rear (downstream) support is fixed to the frame with a simple sliding bolt and slot arrangement to provide for the expansion of the shell when heated during normal operation. After initial tests, the extreme end of the tail pipe was clamped to the frame by means of metal straps to prevent it from whipping and sagging during operation. The thrust platform, upon which the mounting frame is bolted, is supported by ball and roller bearing linkages above a bedplate securely anchored to an isolated concrete block set in the ground.

The thrust platform, the support linkages, and the bedplate form the sides of a pin-jointed parallelogram. The rear support linkages and a thrust arm are keyed to a common shaft to form a bell-crank arrangement with a 10:1 leverage ratio. The forces on the engine are transmitted from the thrust platform, through the bell crank, to the piston of a hydraulic piston-cylinder assembly. Kerosene is

F predicted sea-level flight thrust, pounds

V_o free-stream flight velocity corresponding to the simulated ram pressure at which F_j is obtained, feet per second

RESULTS AND DISCUSSION

A summary of the data obtained during the first 43.6 minutes of testing at variable operating conditions is presented in table I. A similar summary of the data subsequently obtained at constant operating conditions (simulated ram pressure, 58 in. water; fuel flow, 2800 lb/hr) is presented in table II. The run numbers listed in the tables indicate periods of continuous operation of the engine. Values of both the jet thrust F_j (see equation (1)) and the corresponding predicted sea-level flight thrust F (see equation (2)) are included in the tables.

The jet thrust and the combustion-air weight flow for the constant operating conditions (data from table II) are plotted against total operating time in figures 2 and 3, respectively. Inspection of these figures indicates that the engine apparetnly operates between a low-power and a high-power level at irregular intervals; during the tests this change in power level was accompanied by a very noticeable change in noise intensity and in the amplitude of the induced vibrations. The explanation for the sporadic variation in power level is not known. The average jet thrust obtained during the constant operating condition (fig. 2) is 855 pounds and the average combustion-air flow (fig. 3) is 10.75 pounds per second. During the tests of reference 1 a standard uncoated valve-grid assembly operating at the same ram pressure and fuel-flow conditions developed an average jet thrust of approximately 890 pounds at a combustion-air flow rate of 11 pounds per second. This result would indicate a slightly adverse effect of the neoprene-coated valve-grid assembly on the performance of the pulse-jet engine, which is attributed to the reduction in free-flow area of the grid caused by the neoprene coating.

The jet thrust and the combustion-air weight flow show no tendency to drop (figs. 2 and 3) even after 163.6 minutes of operation, indicating that the valve deterioration at this point is of insufficient magnitude to affect performance. The condition of the flapper-valve grid assembly after a total operating time of 51.6 minutes and 163.6 minutes is shown in figures 4 and 5, respectively. After 51.6 minutes of operation no deterioration of the valves was visible except for slight discolorations, which apparently were not harmful. After 163.6 minutes of operation, one valve was completely broken off near the rivet holes, evidently due to fatigue in flexure, and three other valves were beginning to split and fray near the trailing edges. Although the valve assembly could possibly have been operated for additional time without appreciable loss in performance, 163.6 minutes is taken as a conservative estimate of the life of the neoprene-coated flapper-valve grid assembly for the operating condition at high thrust output. This value of valve life represents an appreciable increase over the 30-minute life of a standard unit. Observations of the temperature of the downstream face (flame side) of the valve grid during the last part of the tests indicated a maximum grid temperature of 280° F, which is well below the 380° F safe limit specified for the neoprene coating.

Inspection of the grid at intervals during the course of the tests revealed a slightly adhesive or tacky condition of the rubber coating, which caused the valves to stick to the grid. Although this condition apparently did not affect the performance of the engine, it might possibly have an adverse effect on static starting of the engine. Representatives of the B. F. Goodrich Company attribute the tacky condition to the presence of excess quantities of the coagulant used in the coating process and not to the characteristics of the neoprene itself, which tends to harden with prolonged exposure to heat. They believe that careful washing of the coating prior to the drying and curing phases of the process will give the desired results.

SUMMARY OF RESULTS

The results of thrust-stand tests at high thrust outputs of a 22-inch-diameter pulse-jet engine equipped with a neoprene-coated valve-grid indicate that:

1. The operating life of the pulse-jet engine, as limited by valve deterioration, was longer than 164 minutes as compared with 30 minutes for the standard valve assembly.

2. The average jet thrust developed by the engine was 855 pounds at simulated ram pressure of 58 inches of water and fuel flow of 2800 pounds per hour and did not depreciate during the 164 minutes of operation. This value of thrust represents a 4-percent reduction in performance from the average 890 pounds of thrust obtained with the standard valve grid under similar operating conditions.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, October 3, 1945.

REFERENCES

1. Magnaniello, Eugene J., Valerino, Michael F., and Essig, Robert H.: Sea-Level Performance Tests of a 22-Inch-Diameter Pulse-Jet Engine at Various Simulated Ram Pressures. NACA MR No. E5J02, 1945.

2. Bogert, R. C.: Life Test of Ford MX-544 Intermittent Jet Engine. Memo. Rep. Ser. No. TSEPL-5-673-56, Eng. Div., Army Air Forces, Dec. 13, 1944.

TABLE I - SUMMARY OF TEST DATA AT VARIABLE OPERATING TEST CONDITIONS

Run	Total operating time of flapper valve at end of run (min)	Simulated ram pressure (in. water)	Fuel flow (lb/hr)	Fuel-nozzle pressure (lb/sq in. gage)	Combustion-air weight flow (lb/hr)	Combustion-air temperature (°F)	Jet thrust (lb)	Predicted sea-level flight thrust (lb)
1		58.5	3400	58	39,960	80	842	668
		58.7	3200	53	40,320	77	883	707
		59.0	2800	41	37,800	78	866	700
	3.1	58.6	2400	31	36,360	79	805	646
2		59.1	3400	59	39,600	128	753	579
		58.5	3200	53	38,880	128	858	688
		55.5	2800	40	37,440	131	786	627
	6.0	59.3	2400	32	36,000	133	692	533
3		38.4	3000	37	35,640	139	728	602
		36.4	2800	33	32,400	137	699	588
		39.9	2400	24	30,960	138	599	488
	9.0	40.8	2200	20	30,240	137	551	440
4		37.6	3000	46	36,360	88	758	631
		38.0	2800	40	35,280	86	731	607
		40.0	2400	30	32,040	87	699	583
	12.0	40.2	2200	25	31,320	86	652	538
5		58.8	3400	58	40,320	86	867	691
	13.6	58.9	2800	51	37,800	86	847	682
6		38.8	3000	-------	33,840	135	709	589
		37.8	2800	40	35,280	135	738	614
		37.8	2400	31	31,320	136	650	540
	16.4	40.1	2200	27	30,960	136	639	528
7	17.3	19.1	2400	-------	30,960	135	531	454
8		57.4	3200	-------	39,600	85	794	623
	19.9	57.6	2800	-------	37,800	84	843	679
9		59.0	2400	31	36,000	85	743	585
		58.0	3200	51	38,160	130	774	608
		59.1	2800	40	39,960	132	800	624
	22.4	58.7	2400	31	35,640	133	745	589
10		38.7	2800	37	33,480	134	725	606
		38.8	2400	30	34,920	134	661	537
	25.0	38.9	2200	25	30,960	135	640	530
11		37.6	2800	39	35,280	94	761	638
		36.7	2400	30	32,040	93	723	612
	27.5	40.3	2200	25	31,320	93	646	532
12		15.8	2400	25	28,080	79	644	581
		20.4	2000	21	26,640	79	558	490
	30.1	20.5	1600	-------	24,120	79	363	301
13		18.7	2400	25	28,080	126	586	513
		19.3	2000	21	27,360	128	509	440
	32.7	19.8	1600	-------	24,120	128	429	368
14		38.5	3000	43	33,480	134	703	584
		38.7	2800	39	34,200	135	737	616
	35.4	37.6	2400	31	31,680	136	696	585
15		37.5	3000	42	35,640	91	773	649
		37.1	2800	40	34,920	89	764	642
	38.2	37.4	2400	31	32,040	89	702	590
16		57.9	3200	50	39,960	85	781	608
		57.2	2800	41	37,440	84	821	659
	40.9	60.3	2400	-------	36,000	83	749	589
17		58.4	3200	50	38,520	135	788	610
		57.4	2800	41	37,800	136	784	620
	43.6	60.3	2400	31	35,640	137	694	536

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TABLE II - SUMMARY OF TEST DATA AT CONSTANT

OPERATING TEST CONDITIONS

[Nominal simulated ram pressure, 58 in. water; fuel flow, 2800 lb/hr; fuel-nozzle pressure, 41 lb/sq in. gage; combustion-air temperature, 94° F]

Run	Total operating time of flapper valve at end of run (min)	Simulated ram pressure (in. water)	Combustion-air weight flow (lb/hr)	Jet thrust (lb)	Predicted sea-level flight thrust (lb)
18	46.8	58.4	36,720	766	605
19	49.9	59.2	36,720	766	605
20	51.6	59.0	36,360	702	540
21		58.0	39,960	876	702
		56.8	37,800	814	651
	59.1	57.3	37,440	838	676
22		60.0	38,520	867	696
		57.9	38,520	851	683
		57.5	38,160	868	703
		57.6	38,160	837	672
		58.6	38,160	863	696
		57.6	39,600	812	640
		57.8	39,600	794	621
		58.5	37,080	860	698
		57.2	37,800	879	716
		57.8	38,160	897	732
		57.2	37,440	868	706
		56.9	37,800	853	690
		58.1	37,440	820	657
	74.1	58.0	38,520	838	671
23		57.0	37,440	843	682
		57.6	37,800	853	689
		57.2	38,520	875	708
		57.7	39,600	867	696
		58.3	38,160	894	728
		57.9	39,600	944	772
	87.0	58.5	37,800	873	708

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TABLE II - SUMMARY OF TEST DATA AT CONSTANT

OPERATING TEST CONDITIONS - Continued

Run	Total operating time of flapper valve at end of run (min)	Simulated ram pressure (in. water)	Combustion-air weight flow (lb/hr)	Jet thrust (lb)	Predicted sea-level flight thrust (lb)
24		58.2	39,960	841	667
		58.1	37,800	872	707
		58.4	37,800	857	692
		57.4	39,240	910	740
		58.4	37,440	820	657
		57.2	37,800	861	698
		57.3	37,800	840	677
		55.3	37,800	907	746
		58.0	37,440	845	682
		58.0	38,520	843	675
	112.1	56.8	37,440	865	704
25		58.0	39,600	839	667
		59.2	39,960	851	675
		60.1	39,960	859	682
		57.1	39,960	914	741
		59.0	39,960	926	750
		57.3	39,960	788	615
		57.0	38,880	861	693
		56.3	38,880	788	622
		57.6	39,960	872	698
		57.7	38,880	890	721
		57.0	38,520	890	723
		59.0	37,800	862	696
		58.0	39,600	897	725
		58.0	37,440	839	676
		58.0	39,240	886	716
		58.0	39,960	865	691
		58.0	37,800	860	696
	142.1	59.0	39,600	900	727

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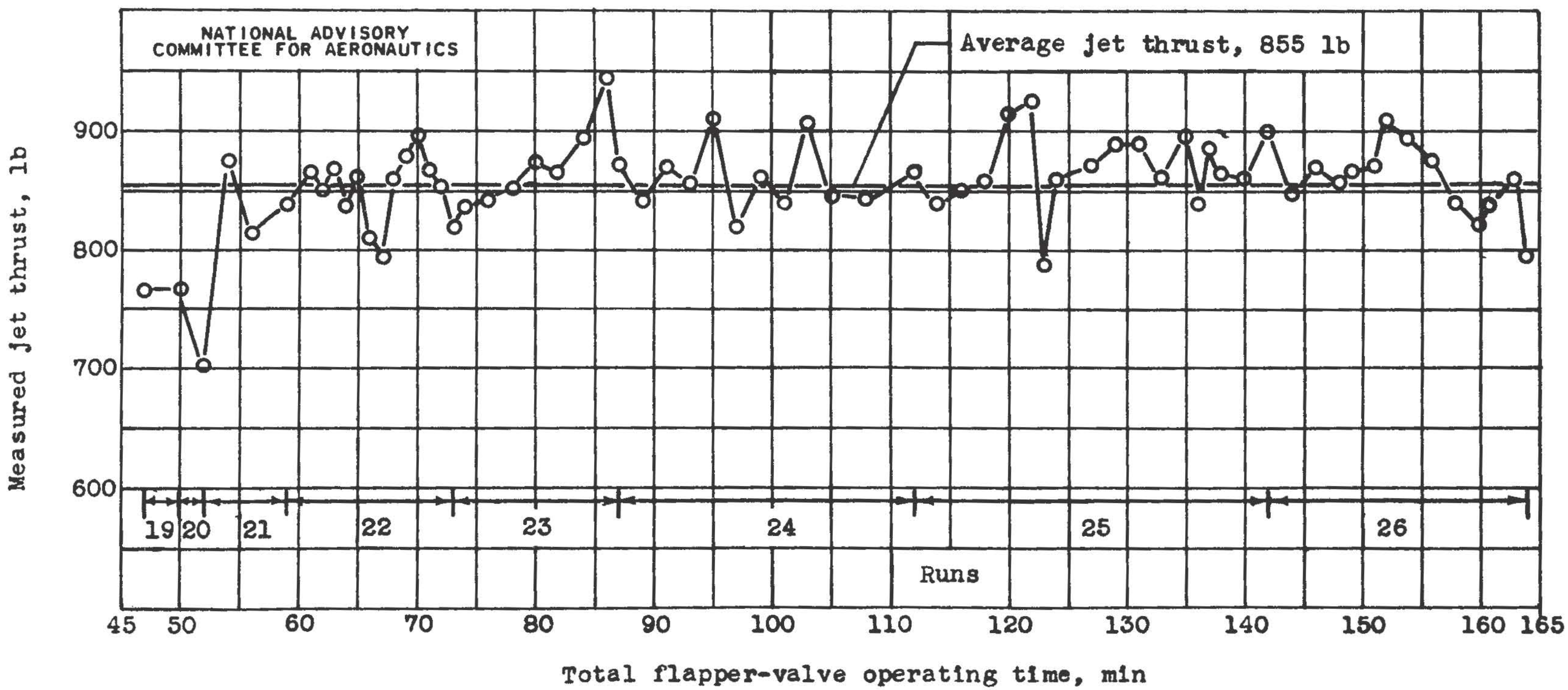

Figure 2.- Variation of measured jet thrust with flapper-valve operating time. Average simulated ram pressure, 58 inches of water; fuel flow, 2800 pounds per hour.

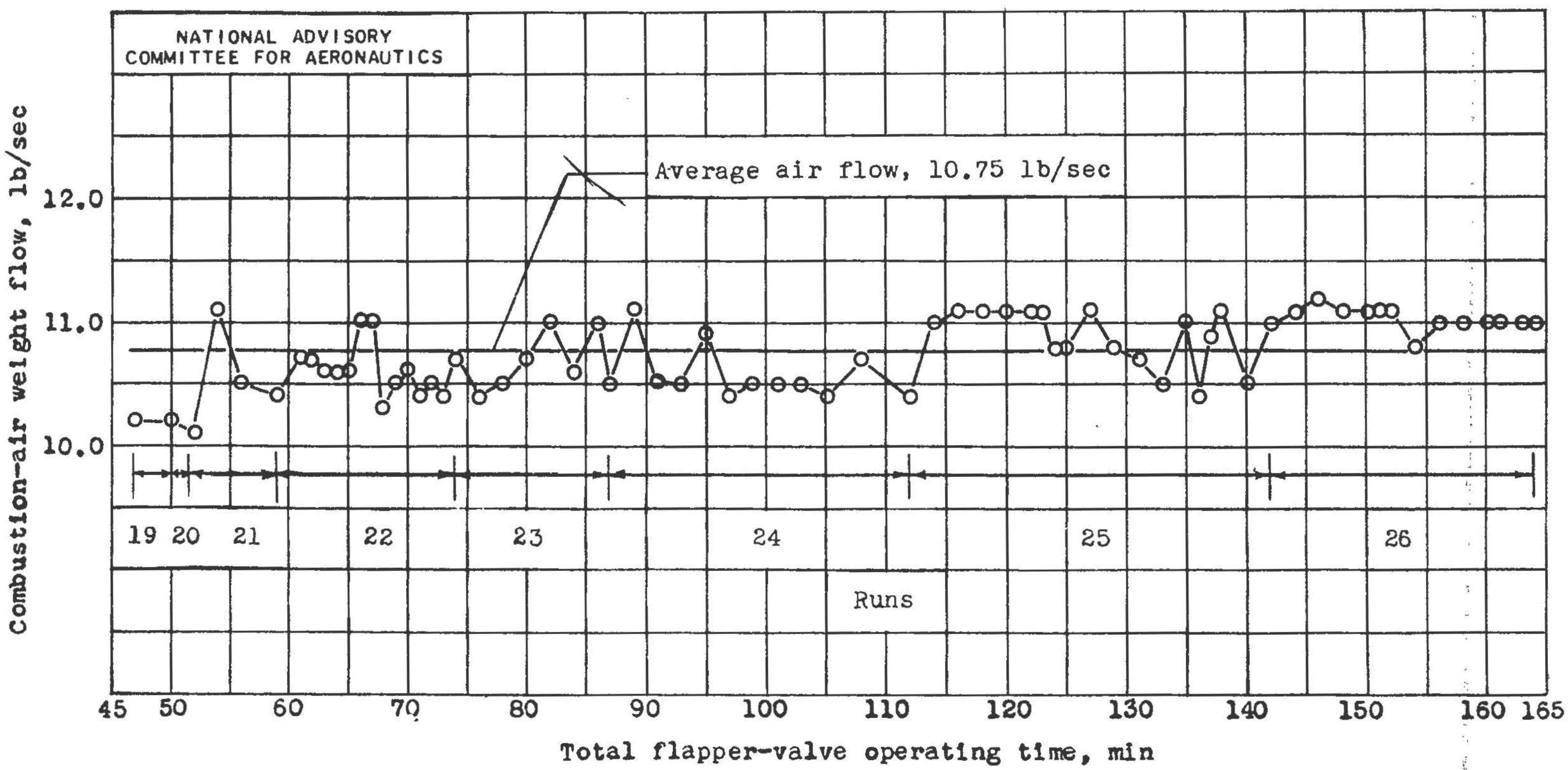

Figure 3.- Variation of combustion-air weight flow with flapper-valve operating time. Average simulated ram pressure, 58 inches of water; fuel flow, 2800 pounds per hour.

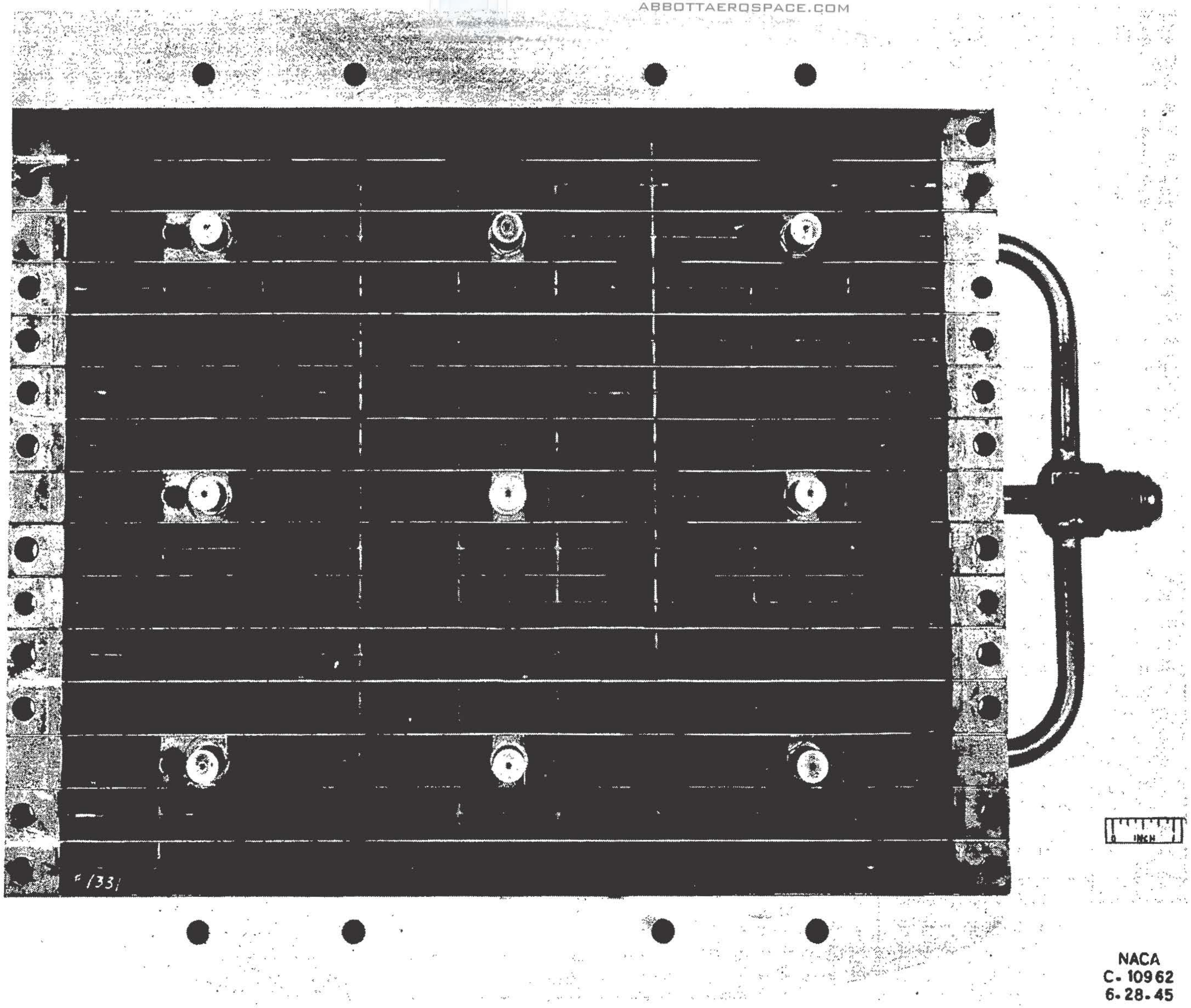

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Figure 4. – Neoprene-coated flapper-valve grid assembly after 51.6 minutes (after run 20) operating time.

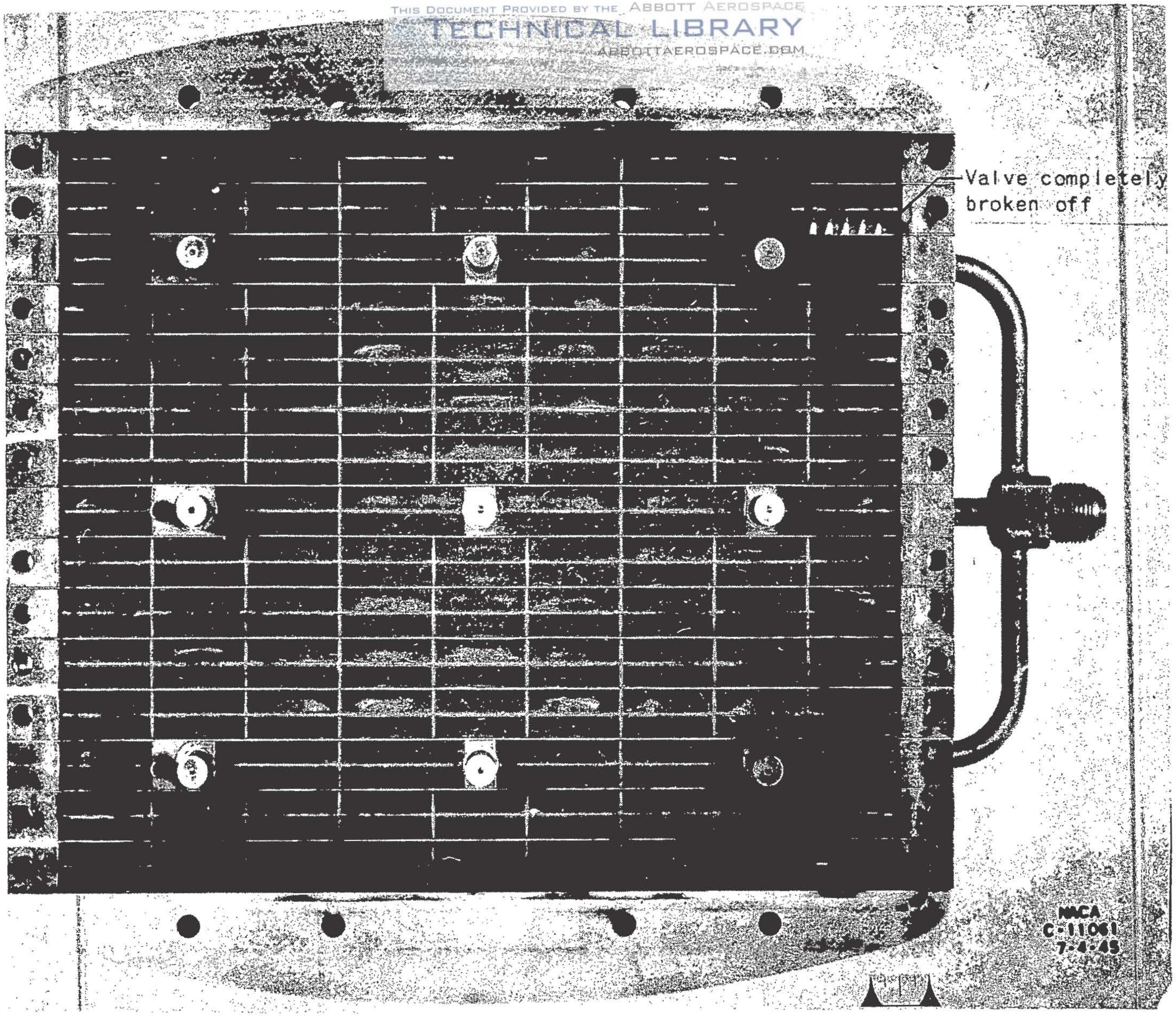

Figure 5. - Neoprene-coated flapper-valve grid assembly after 163.6 minutes operating time.