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Serial No. 14

Navy Department - Office of Research and Inventions

NAVAL RESEARCH LABORATORY
Washington, D. C.

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MECHANICS & ELECTRICITY DIVISION

THERMODYNAMICS SECTION

2 January 1946

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PARTIAL REPORT ON GAS PULSATOR

By L. F. Campbell and T. O. Meyer

Report O-2730

[redacted]

FR-2730

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UNCLASSIFIED

Approved by:
W. H. Sanders - Head, Thermodynamics Section

Dr. Ross Gunn, Superintendent
Mechanics & Electricity Division

Commodore Henry A. Schade, U.S.N.
Director, Naval Research Laboratory

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MECHANICS & ELECTRICITY DIVISION

THERMODYNAMICS SECTION

2 January 1946

2d PARTIAL REPORT
ON
GAS PULSATOR

2752

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By L. F. Campbell and T. O. Meyer

Report 0-2730

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ABSTRACT

This is a partial report of experimental work conducted on a 13-inch gas pulsator in order to investigate various methods of extending valve life. Previous investigations of Eichelberg valves found that 0.010-inch steel vanes lasted 32 minutes, 0.006-inch steel vanes lasted 6 minutes, 0.008-inch steel vanes lasted 65 minutes, 0.012-inch steel vanes ground to 0.008-inch for portion of length lasted 45 minutes, and doubled 0.006-inch steel vanes lasted 24 minutes. This work found that 48 special "sandwich" valves of plastic-impregnated glass-cloth between spring steel lasted for a total running time of 6 hours and 25 minutes. This laminated valve consisted of an 0.008-inch spring-steel vane on the striking side, a 0.006-inch spring-steel vane on the combustion side, and an insert of ethyl-cellulose-coated glass-cloth between the two steel vanes. This insert cushioned impact shock and insulated the striking vane from the heat of the combustion chamber. Other methods of extending vane life are discussed. Plans for future work include measurements of pressure, temperature, and frequency in addition to studies of methods to improve thermal efficiency.

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TABLE OF PLATES

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I. INTRODUCTION

1. Authorization. This work was authorized by BuShips Project Order No. 422/45 dated 3 January 1945 and by BuShips Project Order No. 390/46 dated 1 July 1945.

2. Previous Development. Reference (4) describes previous developmental work on a 13-inch gas pulsator and includes photographs as well as discussions of the test stand for thrust and air flow, of the fuel control system, and of damaged valve assemblies. Tests of 0.008-inch spring-steel vanes showed that they lasted 65 minutes, dual-thickness vanes designed with an 0.008-inch section at point of flexure and a 0.012-inch section at the striking edge lasted 45 minutes, and double 0.006-inch vanes lasted 24 minutes. Initial investigations were made on the use of plastic-impregnated glass-cloth to protect steel vanes against impact shock as well as against combustion-chamber heat. A system of external fuel feed was tried in order to study the effect of evaporative cooling of the vanes. Although the standard grid assembly of the 13-inch pulsator includes 48 vanes, additional air capacity was secured by means of an expanded grid of 64 vanes and also by a combination of 24 side-entry vanes in addition to the standard 48-vane assembly. The fuel-burning capacity of the pulsator was found to vary directly as the number of vanes used to control intake air.

3. Purpose. Recommendations were made in Ref. (4) that further experimentation be carried out in an effort to produce a more durable valve system. Early tests indicated that ceramic material in combination with steel vanes would increase valve life. These tests are a continuation of that early work and are directed toward investigations of various combinations of spring steel and ceramics.

II. TEST METHODS

4. Pulsator Tube. The dimensions of the pulsator used in these experiments are as follows: combustion chamber, 13 inches in diameter, 20 inches long; cone, 13 inches to 7 inches in diameter, 30 inches long; and exhaust, 7 inches in diameter, 88 inches long. In order to permit continuous operation of the motor, pipes having drilled holes are mounted along the top of the motor so as to provide cooling of the entire tube by means of water spray.

5. Stationary Stand. A stationary stand rigidly fixed to the concrete apron mounts the gas pulsator for valve testing. Water cooling is provided for the motor tube and for the grid assembly. A skid-mounted blower is placed several feet in front of the motor for air circulation so as to prevent steam from entering the valve grid.

6. Thrust Stand. The horizontal thrust stand used in some of these tests is described in detail in Ref. (4). The motor is suspended as a pendulum from roller-bearing trolleys. Thrust is balanced by air pressure acting against the pistons of a pair of cylinders symmetrically mounted on either side of the motor.

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7. Fuel System. Fuel is supplied to the gas pulsator from a pressurized fuel tank suspended from a precision spring scale. Regulation of the air pressure provides control of fuel flow. Instantaneous fuel flow rates are indicated by a Rotameter. Average fuel-flow rates are computed from readings of spring scale and stop watch. A pressure gage at the grid assembly indicates pressure at the fuel jets. All runs have been made with 62-octane unleaded gasoline. The fuel capacity of the tank limits runs to approximately 30 minutes.

8. Starting. The motor is started by turning on the ignition current to the spark plug, injecting a short blast of compressed air through the valve grid, and opening the fuel valve. This method conserves the torpedo igniters used in the simplified starting system described in Refs. (2), (3), and (4).

9. Frequency Measurements. Frequency of motor operation was measured during running by means of a Westinghouse Vibrometer held in direct contact with the motor mounting.

10. Typical Data. The fundamental problem of the current experimental work has been to increase valve life. Tests have been grouped into a series of runs for each particular valve assembly. Generally, each run is of 30-minute duration, as limited by the capacity of the fuel tank. Typical data are shown in Plates 1, 2, and 3. These data include duration of the individual runs, fuel rate by Rotameter, and fuel rate by weight. Values of thrust and specific fuel have also been included in Plate 1. Specific fuel has been calculated as the fuel rate in pounds per hour for each pound of thrust.

III. VANE IDENTIFICATION

11. Position Numbering. The primary purpose of the experimental work covered by this report has been to develop a valve which would permit operation of the gas pulsator for at least two to four hours as recommended in Ref. (1). This investigation has been confined to Eichelberg valves with modifications and redesign towards extending life expectancy. Most tests consisted of running a set of vanes for 30 minutes, removing them for observation while the fuel tank was refilled, running for another 30 minutes, observing, and continuing this process until excessive vane damage occurred. After vanes had been removed and inspected, care was taken to replace each in its original position so that successive runs might indicate if any particular position of the grid received more severe treatment than other positions. For convenience, vanes were numbered from left to right starting at the top of the vane assembly as viewed from the combustion side of the grid. This system of numbering is indicated on Plate 4.

12. Material Coding. The use of ceramics and laminated vanes has resulted in a need for some simple method of identifying special vane assemblies. Numbers have been used to designate the thickness of spring-steel vanes. Letters have been used to indicate the type of ceramic. Capital letters signify that the ceramic is of the same length and breadth as the steel vane. Small letters signify that the ceramic merely covers the tip of the steel vane. Laminated vanes are specified by a combination of numbers and letters with dashes between symbols. The first symbol indicates the material

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on the striking side of the vane and the last symbol indicates the material on the combustion side. Symbol designations are given on Plate 5. For example, #8-F-6 denotes a laminated valve having an 0.008-inch spring-steel vane on the striking side, a 0.006-inch spring-steel vane on the combustion side, and a full-size filler of flak cloth.

IV. WRAP-AROUND PROTECTORS

13. #F-6-F (30 minutes). The protection of spring-steel Eichelberg valves by means of ceramic covers has been suggested in Ref. (4) where initial investigations are reported. This type of protector would insulate against the heat of combustion and might also serve as a buffer against impact shock. First trials were made with a fiberglass cloth impregnated with ethyl-cellulose. This particular ceramic is commonly known as "Flak" cloth. Each protector was cut slightly narrower than the steel vane but twice as long; folded over the combustion, or vibrating, end of the 0.006-inch steel vane; and riveted to the standard vane plate. This assembly is illustrated in Plate 6. In this case, the ethyl-cellulose coat was placed on the outside. A 30-minute run demonstrated that the ceramic covers successfully protected the steel vane. Plain 0.006-inch spring-steel vanes last about 6 minutes. Protectors of flak cloth extended this life to over 30 minutes. However, the ethyl-cellulose coating was not sufficiently heat-resistant, but burned off the combustion side. This resulted in a program to test other types of ceramics and other methods of protecting steel vanes.

14. #G-6-G (32 minutes). Because the ethyl-cellulose coating of the flak cloth burned off during running, a trial was made of plain fiberglass cloth as ceramic protectors for 0.006-inch spring-steel vanes. This glass cloth had no impregnated plastic and was loosely woven in a square pattern. The wrap-around assembly was similar to that shown in Plate 6. A run was made of 32-minutes duration and stopped only because of an empty fuel tank. The glass cloth was completely disintegrated as had been expected, for the loose weave had made assembly very difficult. However, the steel vanes were still intact, thus indicating that the fiberglass had furnished adequate protection during the run.

15. #P-6-P (30 minutes). Another ceramic which was suggested for use as a wrap-around protector was Poly-F 116, a high-temperature plastic. Some 0.011-inch thick Poly-F 116 was therefore assembled with 0.006-inch spring steel in a valve similar to that sketched in Plate 6. A 30-minute run indicated that this plastic did not furnish adequate protection but curled up from the heat and split out at the edges as shown in Plates 7 and 8.

16. #AR-6-RA (30 minutes). Rubber-coated asbestos tape was also tried as wrap-around protection for steel vanes. The asbestos side of the rubber-coated tape was put on the outside and the valves assembled similar to Plate 6. A 30-minute run demonstrated that this material did not withstand the repeated stress imposed by the ribs of the grid pieces. Hence, this material was also judged undesirable.

V. REINFORCED TIPS

17. #a-6 (30 minutes). Because Eichelberg valves seemed to fail at the

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tip, or vibrating end, an attempt was made to protect the tip from shock by means of reinforcements. Plate 9 shows an arrangement whereby a strip of asbestos material one-sixteenth inch thick and three-eighths inch wide was riveted to the tip of each 0.006-inch steel vane on the striking side. It should be noted that this would be poor aerodynamic design since the raised obstruction of asbestos and rivets would interfere with smooth air flow. However, this reinforcement was tried in order to determine if tip breakage could be prevented. A 30-minute test demonstrated that the asbestos strips failed to stay on the tips of the vanes. Despite the reinforcing strips, vanes chipped at the ends. Moreover, vane seats were roughened by the severe action of these valves.

18. #n-F-6-F-n (30 minutes). Another special valve assembly featured reinforcement of the tip of a steel Eichelberg valve which was also covered by a wrap-around protector. A standard 0.006-inch spring-steel vane was covered with flak cloth and a protecting shoe of 0.006-inch nickel was riveted onto the tip, as depicted in Plate 10. A 30-minute test demonstrated that this assembly was unsatisfactory. The nickel shoe broke under impact, the vane chipped at the tip, and the vane seat became roughened because of the pounding.

VI. SANDWICH VANES

19. Laminations. Experimental investigations of wrap-around protectors clearly demonstrated the value of ceramic covers on steel Eichelberg valves. Although in themselves not sufficiently heat-resistant, these protectors absorbed shock impact and provided a degree of insulation against combustion-chamber heat. Therefore, another laminated design was adopted to combine ceramics with steel in a "sandwich" which consisted of a ceramic between two steel vanes. The vane on the combustion side would shield the ceramic from the intense heat and the ceramic would cushion the vane against impact. Thus the severe conditions would be distributed among the components in a "division of labor". One vane would absorb most of the impact shock and the other, most of the heat. The cushioning effect of the ceramic is similar to engineering practice of using a rawhide hammer when it is necessary to strike a delicately-machined part. There is an additional advantage in this construction in that if the striking vane should chip at the edges, the ceramic and the other vane would still provide a seal to close off explosion pressure and to prevent leakage of hot gases. This is important because the slightest leak permits the passage of hot gasses, excessive heating of the valves, and rapid deterioration of the valves.

20. #6-F-6 (30 minutes). The first trial of laminated vanes was made with ethyl-cellulose-coated glass-cloth sandwiched between 0.006-inch spring-steel vanes as illustrated by Plate 11. A 30-minute run demonstrated that the striking vane tended to chip, whereas the combustion-side vane remained intact. Hence, a complete seal was maintained and the valve assembly prevented leakage of combustion gases. This arrangement was satisfactory for short runs but was subsequently improved.

21. #6-S-6 (30 minutes). Another ceramic was tried in lamination with steel vanes in order to compare it with flak cloth. A glass fabric coated with silicone rubber was sandwiched between 0.006-inch spring-steel vanes in an arrangement similar to that shown in Plate 11. This ceramic proved to be

entirely satisfactory as a buffer and insulator. However, it had no specific advantage over flak cloth and was available only when made by the Plastics Section on special order. Therefore, this silicone rubber and glass cloth combination was abandoned in favor of flak cloth which was more easily available.

22. Multiple Testing. Some of the special laminated vanes were rather tedious to assemble. Therefore, many of the special combinations were given screening tests in small numbers. A few special vanes would be made and then tested in a grid assembly containing a majority of plain vanes. Sometimes only a single vane would be tried. Other times a set of eight would be put into the grid. Generally the special vanes were tested in conjunction with #8 vanes of plain 0.008-inch spring steel. One of the most important tests of a combination of vanes consisted of sixteen #8 vanes in positions #1, 2, 3, 4, 21, 22, 23, 24, 25, 26, 27, 28, 45, 46, 47, and 48 and thirty-two of the #8-F-6 vanes in positions #5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, and 44. Vane positions are indicated in Plate 4. These sandwich vanes lasted four hours and are more fully discussed in the next paragraph.

23. #8-F-6 and #8 (240 minutes). Because of the chipping of the 0.006-inch steel vanes on the striking side during first trials of sandwich vanes, 0.008-inch steel vanes were tried in this position. Tests reported in Ref. (4) demostrated that plain 0.008-inch steel vanes lasted longer than either 0.006-inch or 0.010-inch ones. The sandwich vane then consisted of an 0.008-inch spring-steel vane on the striking side, a 0.006-inch spring-steel vane on the combustion side, and a piece of flak cloth sandwiched between, as illustrated in Plate 12. The motor grid was assembled with a combination of thirty-two #8-F-6 sandwich vanes and sixteen #8 vanes as discussed in paragraph 22. Tests were run at a Rotameter fuel rate of 350 lbs/hr or an average rate of 334 lbs/hr calculated from weight readings. This latter value for a 48-vane grid is approximately 7 lbs/hr of fuel per vane. All runs were of 30 minutes duration except for Runs 3 and 9 which were only 15 minutes long. Thrust was measured from Run 4 through Run 9. During Run 4, 102.5 pound thrust was produced at a specific fuel rate of 3.25 pound of fuel per hour for each pound of thrust. In Run 5 the thrust had dropped to 99 pounds and specific fuel rate had risen to 3.42. In Run 6 the thrust dropped to 89 pounds for a specific fuel rate of 3.76. The cause of this drop in thrust was found to be the deterioration of the #8 vanes in single vane positions #1, 4, 45, 46, and 48. Chipping and tearing of the edges of these plain vanes permitted leakage of combustion gases, loss of pressure, and decrease in thrust. Plate 13 shows the condition of the plain vanes at the end of Run 6 with a total running time of 2 hours and 45 minutes. On the other hand, the special laminated vanes in positions of more severe heating were still intact. As a result of the replacement of eight plain #8 vanes, the thrust in Run 7 was 103 pounds for a specific fuel rate of 3.24. The plain #8 vanes in grid positions of only moderate treatment ran 165 minutes before replacement. Runs were continued for a total running time of 4 hours with the condition of the vanes after that time shown in Plates 14 and 15. The sandwich vanes were still in good running condition since all 0.006-inch steel vanes were perfect. Some chipping had occurred in the 0.008-inch steel vanes on the striking side of the laminated assemblies. However, intact 0.006-inch vanes on the combustion side prevented leakage of

[redacted]

combustion gases through the grid assembly. This test furnished a reliable comparison between #8-F-6 sandwich vanes and plain #8 vanes. The fact that it was possible to operate these vanes for four hours clearly demonstrated that the flak cloth was effective as a shock absorber and as a heat insulator.

24. #8 -F-6 (385 minutes). Because of the good showing of the sandwich vanes when used in combination with plain vanes, another series of tests was made on a complete set of forty-eight of these vanes. Each valve consisted of an 0.008-inch spring-steel vane on the striking side, a 0.006-inch spring-steel vane on the combustion side, and a piece of flak cloth sandwiched in between. The assembly is illustrated in Plate 12. Data in Plate 2 show that thirteen runs were made with this set of vanes. Each run was for thirty minutes except for the last which was only twenty-five minutes long. The total running time was six hours and twenty-five minutes. Fuel rate was set at 350 lbs/hr by Rotameter. Weighed readings gave a computed fuel rate of 334.6 lbs/hr. This was approximately seven pounds of fuel per hour for each vane in the forty-eight vane grid. Frequency measurements by Vibrometer indicated 41.5 to 43.0 cycles per second. Plates 16 and 17 show the vanes after removal from the motor at the end of Run 13. One of the head gaskets blew out during this run and probably allowed excessive leakage of combustion gases on the side. Deterioration was rapid during this run although all vanes had been in good shape at the end of Run 12. Perhaps the deterioration of vanes during Run 13 could be attributed to gasket failure. Leakage through the valves had been negligible during Runs 1 to 12. Therefore, at least six hours running time could be safely expected from an assembly of #8-F-6 sandwich vanes on the 13-inch gas pulsator. Plate 16 shows that vanes 1 and 42 were chipped badly enough to allow excessive leakage. Plate 17 shows that vanes 8, 16, 24, 31, 32, 38, and 40 were also badly chipped. Thus 9 vanes out of 48, or about 18.7 percent, were in bad condition. This series of runs confirmed the tests reported in paragraph 23 whereby four hours running time was accumulated for #8-F-6 laminated vanes placed only in those positions where vane failure had been most noticeable in previous tests. The #8-F-6 vanes were still in usable condition at the end of this 4-hour test. These two sets of runs clearly demonstrated the value of sandwich vanes combining ceramics with spring steel.

25. #8-F-F-6 (150 minutes). Another test of laminated vanes was made to see if a double thickness of flak cloth might be better than a single thickness. Therefore, sandwich-type Eichelberg valves were assembled as illustrated in Plate 18. An 0.008-inch spring-steel vane was placed on the striking side, a 0.006-inch spring-steel vane on the combustion side, and a double thickness of flak cloth was sandwiched between with the ethyl-cellulose coating facing the steel vanes. The pulsator was run at a Rotameter fuel rate of 350 lbs/hr and a weighed rate of 334 lbs/hr. After five runs of thirty minutes each, five of the vanes were damaged sufficiently to permit serious leakage of combustion gases. Plates 19 and 20 show the condition of the vanes after two and one-half hours running. The double thickness of flak cloth did not prove to be as satisfactory as the single thickness reported in paragraph 23. However, this may have been due to the mechanical stresses caused by the extra size. Difficulty was experienced during assembly because of the additional bulk of the double thickness of cloth which caused mechanical distortion of the entire grid assembly. Some redesign or machining of the grid pieces may be necessary in order to test this type of sandwich vane more fairly.

[redacted]

26. Results. The tests discussed in this report demonstrate that the life of Eichelberg valves may be extended by combining ceramics with spring steel. In particular, fiberglass cloth coated with ethyl-cellulose or impregnated with silicone resin has greatly prolonged the useful life of steel vanes. Wrap-around protectors extended the life of #6 vanes from six to thirty minutes. Reinforced tips extended the life of vanes about the same amount but at the end of thirty minutes the spring steel vanes were badly deteriorated and the grid seats were roughened. Sandwich valves with ceramic between steel vanes proved to be the most satisfactory type of intake valve yet tried on the 13-inch gas pulsator. A set of forty-eight #8-F-6 valves lasted six hours and twenty-five minutes at a fuel rate of approximately 334 pounds per hour, a thrust of 103 pounds, and a specific fuel rate of 3.25 lbs/hr per lb of thrust. This special valve consisted of an 0.008-inch spring-steel vane on the striking side, a 0.006-inch spring-steel vane on the combustion side, and a sandwich of flak cloth or ethyl-cellulose-coated glass-cloth. This laminated Eichelberg valve is illustrated in Plate 12. Thus the effective life of the 13-inch gas pulsator has been extended from about thirty minutes to over six hours.

VII. CONCLUSIONS

27. This experimental work has resulted in a type of laminated Eichelberg valve which successfully operates to control intake air to a 13-inch gas pulsator for over six hours, paragraph 24. The importance of maintaining valve life has been shown to lie not only in the matter of the total time of motor operation but also in the effect of valve deterioration on thrust. As shown in Plate 1 and discussed in paragraph 23, vane deterioration permits gas leakage with a decrease in thrust. Ceramics have been used in conjunction with spring steel to insulate against heat of combustion and to absorb impact shock. The extended length of motor operation should permit uniform conditions for motor testing requiring a great deal of time and would also permit continuous operation for the production of useful power for an extended time.

VIII. RECOMMENDATIONS

28. Experimental work should be continued in order to secure measurements of pressure, temperature, and frequency. Other ceramics should be tried for valve protection. Suggestions include silicone-resins and mica. Laminated Eichelberg valves should be tried on gas pulsators of different sizes. Special methods of improving thermal efficiency should be investigated in order to make this type of motor more useful and more economical. In short, instrumentation and motor efficiency appear to be the important problems for future work.

[redacted]

REFERENCES

Reference (1) BuShips ltr. C-S41-7 (643) of 6 October 1944.

Reference (2) NRL ltr. C-S41-8 (447) of 26 January 1945.

Reference (3) NRL ltr. C-S41-8 (447) of 21 February 1945.

Reference (4) NRL report O-2650 of 24 September 1945.

Original data recorded in NRL Log Book 5453.

[redacted]

DATA FOR 240-MINUTE VALVE ENDURANCE TEST

(See paragraph 23, and Plates 12, 13, 14, and 15.)

Vanes: Sixteen #8 and thirty-two #8-F-6.
(Locations specified in paragraph 22.)

Jets: No. 10 and No. 11, internal.

Ignition: Spark plug, 2.5-inches from front.

RUN NO.	DURATION (min)	FUEL RATE (lb/hr) by Rotameter	FUEL RATE (lb/hr) by Weight	THRUST (lb)	SPECIFIC FUEL $(\frac{lb/hr}{lb})$
1	30	350	336		
2	30	350	330		
3	15	350	334		
4	30	350	334	102.5	3.25
5	30	350	338	99.0	3.42
6	30	350	334	89.0	3.76
7	30	350	334	103.0•	3.24
8	30	350	332	101.0	3.29
9	15	350	333	102.0	3.28

• After 165 minutes running time, the #8 vanes in positions No. 1, 2, 3, 4, 45, 46, 47, and 48 were replaced. See paragraph 23 and Plate 4.

[redacted]

DATA FOR 385-MINUTE VALVE ENDURANCE TEST

(See paragraph 24, and Plates 12, 16, and 17.)

Vanes: Forty-eight #8-F-6.

Jets: No. 10 and No. 11, internal.

Ignition: Spark plug, 2.5-inches from front.

RUN NO.	DURATION (min)	FUEL RATE (lbs/hr) by Rotameter	FUEL RATE (lbs/hr) by Weight
1	30	350	336
2	30	350	332
3	30	350	333
4	30	350	336
5	30	350	333
6	30	350	334
7	30	350	338
8	30	350	332
9	30	350	340
10	30	350	334
11	30	350	334
12	30	350	336
13	25	350	334

[redacted]

DATA FOR 150-MINUTE VALVE ENDURANCE TEST

(See paragraph 25, and Plates 18, 19, and 20.)

Vanes: Forty-eight #8-F-F-6.

Jets: No. 10 and No. 11, internal.

Ignition: Spark plug, 2.5-inches from front.

RUN NO.	DURATION (min)	FUEL RATE (lbs/hr)	
		by Rotameter	by Weight
1	30	350	334
2	30	350	334
3	30	350	332
4	30	350	334
5	30	350	334

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VANE LOCATION DIAGRAM

PLATE 4

— NOTE —

ALL VANE NUMBERING IN THIS REPORT IS ACCORDING TO THIS DIAGRAM

U. S. NAVAL RESEARCH LABORATORY WASHINGTON 20, D. C.		SCALE DR'WN.	
B'LD'G.	PHONE	CH'K'D.	
ROOM	DATE	APPR'V'D.	UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±

SHEET OF

MATERIAL CODING

SYMBOL	DESCRIPTION
6	spring steel, 0.006-inch thick
8	spring steel, 0.008-inch thick
10	spring steel, 0.010-inch thick
a	asbestos tip
A	asbestos
F	flak cloth°
G	glass cloth, plain
n	nickel tip
P	poly-F 116, plastic
R	rubber
S	silicone rubber on glass cloth

Capital letters signify that the ceramic is of the same length and breadth as the steel vane.

Small letters signify that the ceramic merely covers the tip of the steel vane.

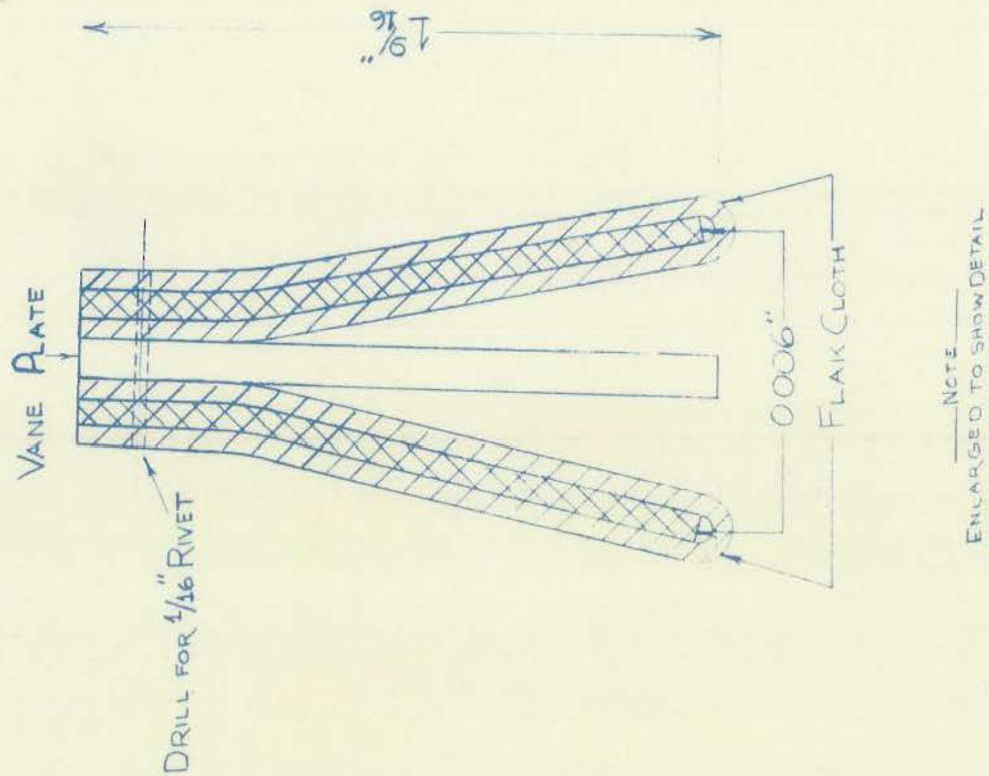
°Flak cloth is fiberglass coated with ethyl cellulose.

[redacted]

PLATE 5

PLATE 6

DIAGRAM OF CUSHIONED VANE



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U. S. NAVAL RESEARCH LABORATORY WASHINGTON 20, D. C.		SCALE	
		DR'WN.	
B'LD'G.	PHONE	CH'K'D.	
ROOM	DATE	APPR'V'D.	UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±

SHEET OF

[redacted]

SAMPLES OF VANES PROTECTED WITH POLY-F PLASTIC
TIME OF RUN 31 MIN.
(.006" VANES)

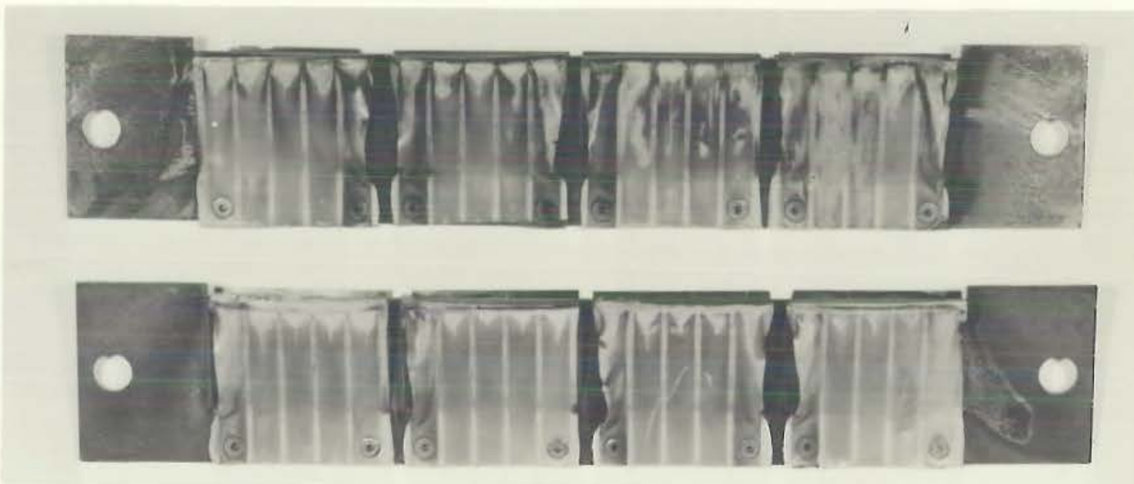


PLATE 7

[redacted]

SAMPLES OF VANES PROTECTED WITH POLY-F PLASTIC
TIME OF RUN 31 MIN.
(.006" VANES)

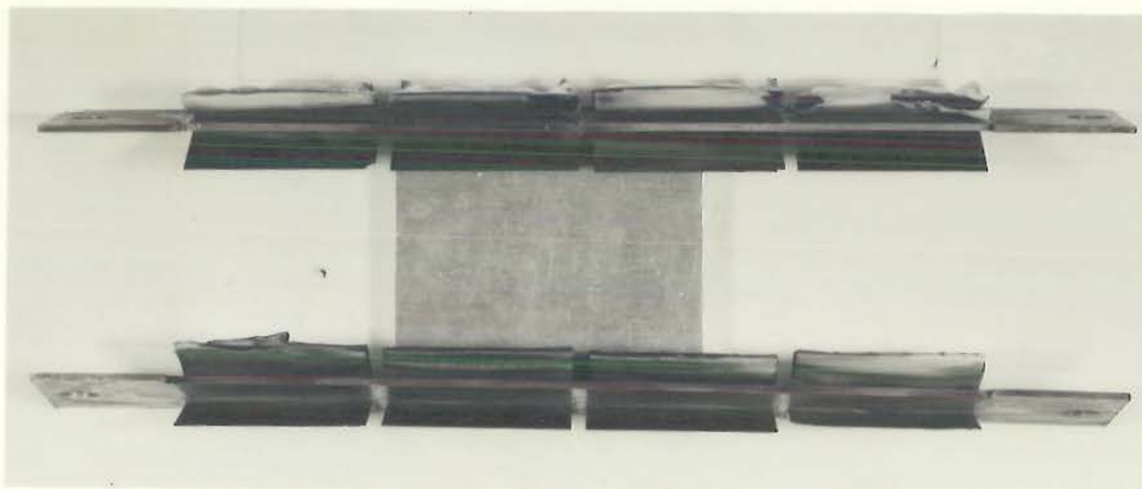
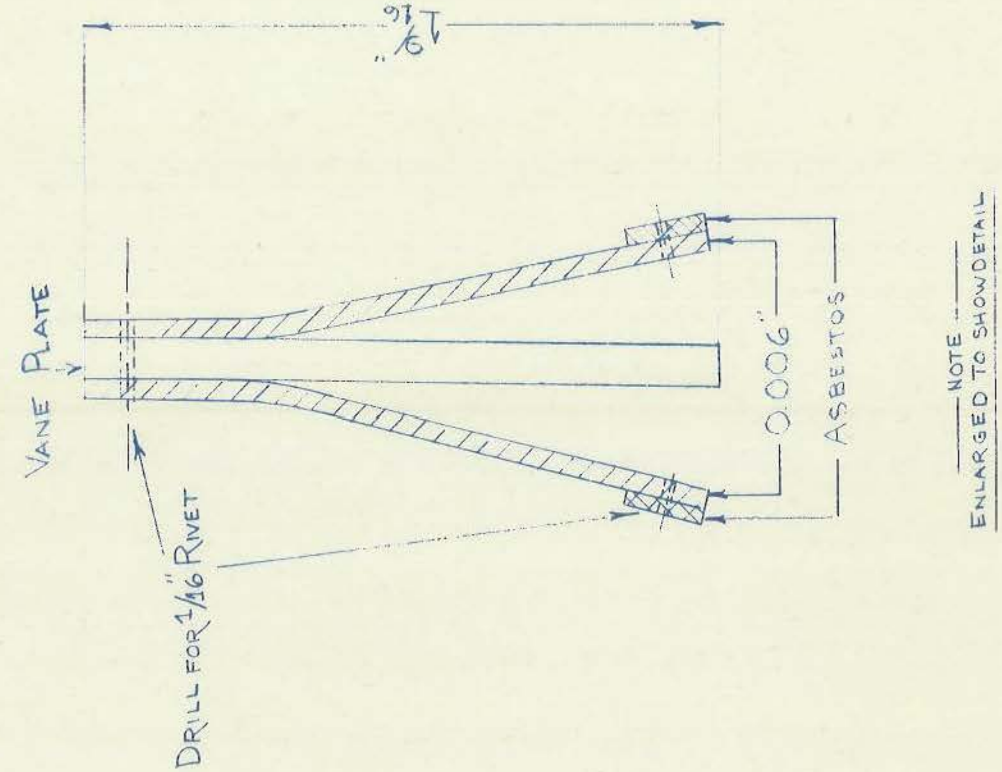


PLATE 8

PLATE 9

DIAGRAM OF CUSHIONED VANE



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ROOM	DATE	APPR'V'D.	UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±

SHEET OF

DIAGRAM OF CUSHIONED VANE

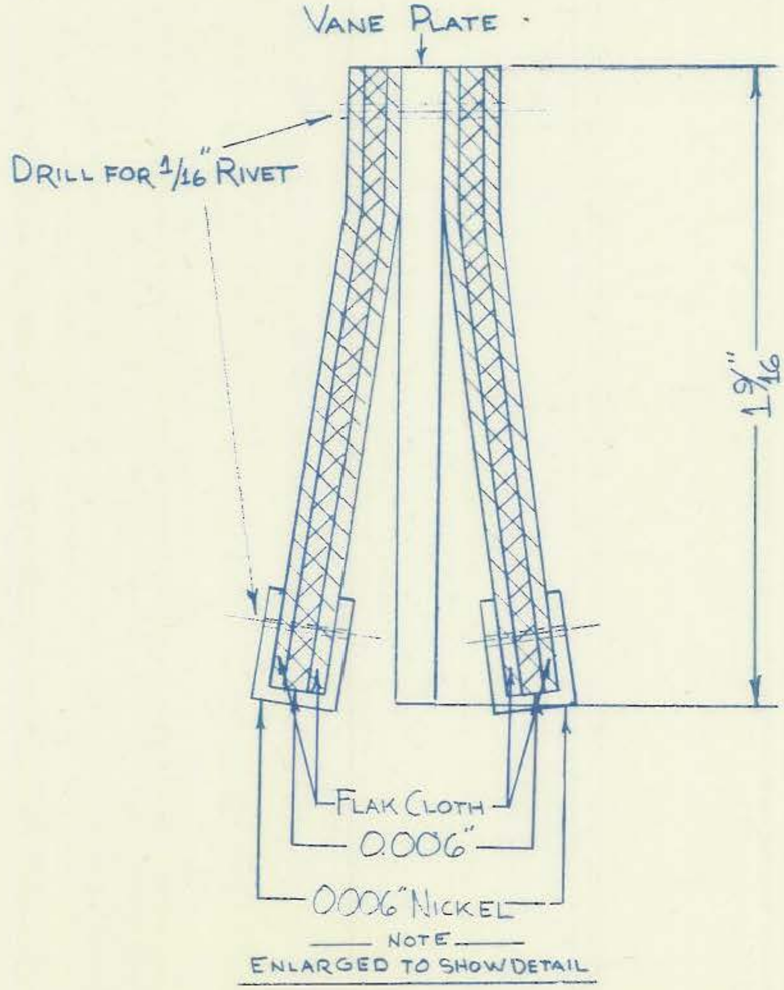


PLATE 10

U. S. NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

B'LD'G.	PHONE	SCALE	
ROOM	DATE	DR'WN.	
		CH'K'D.	
		APPR'V'D.	

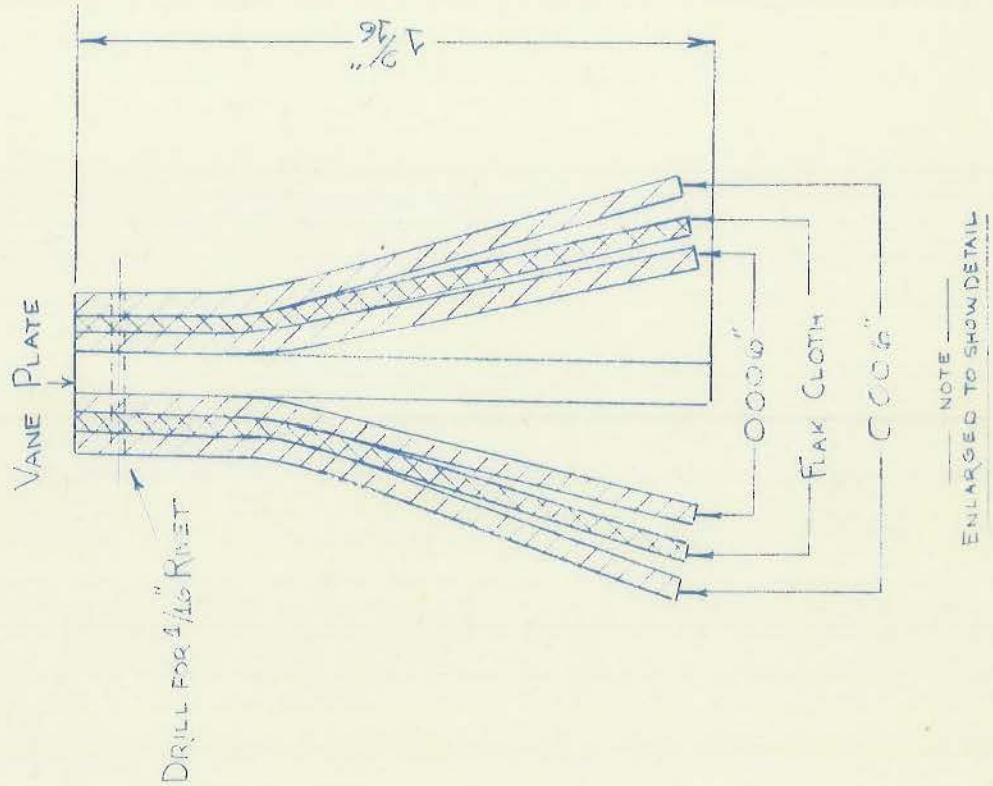
UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±

SHEET OF

DECLASSIFIED

PLATE 11

DIAGRAM OF CUSHIONED VANE



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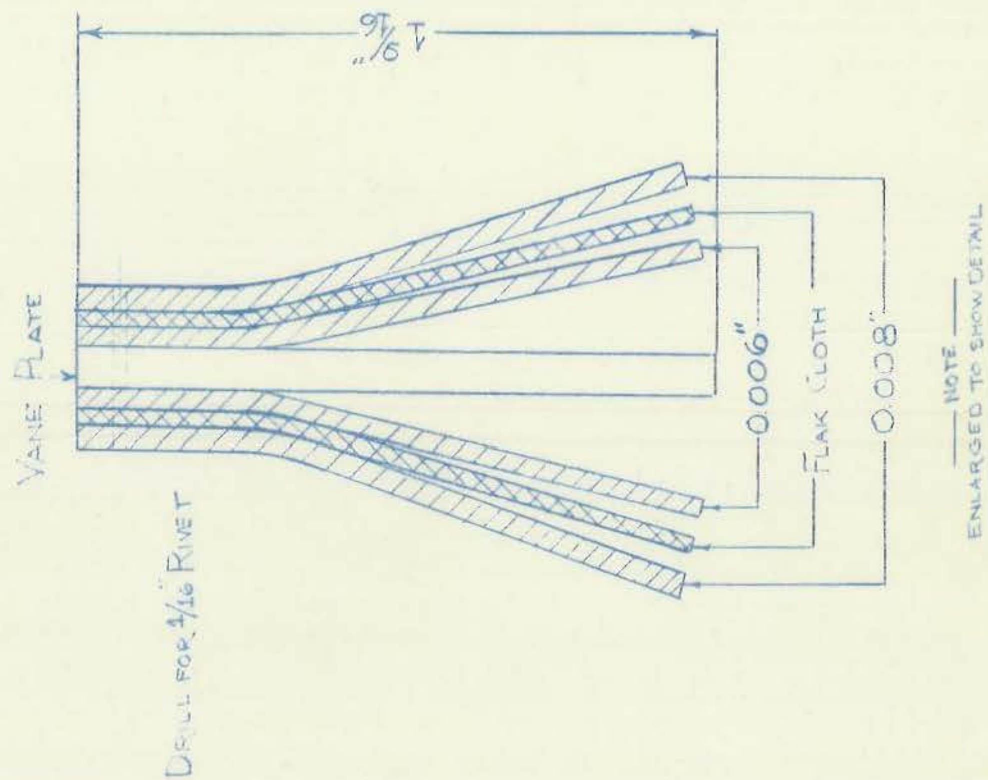
U. S. NAVAL RESEARCH LABORATORY WASHINGTON 20, D. C.		SCALE		
		DR'WN.		
B'LD'G.	PHONE	CH'K'D.		
ROOM	DATE	APPR'V'D.	UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±	

SHEET OF

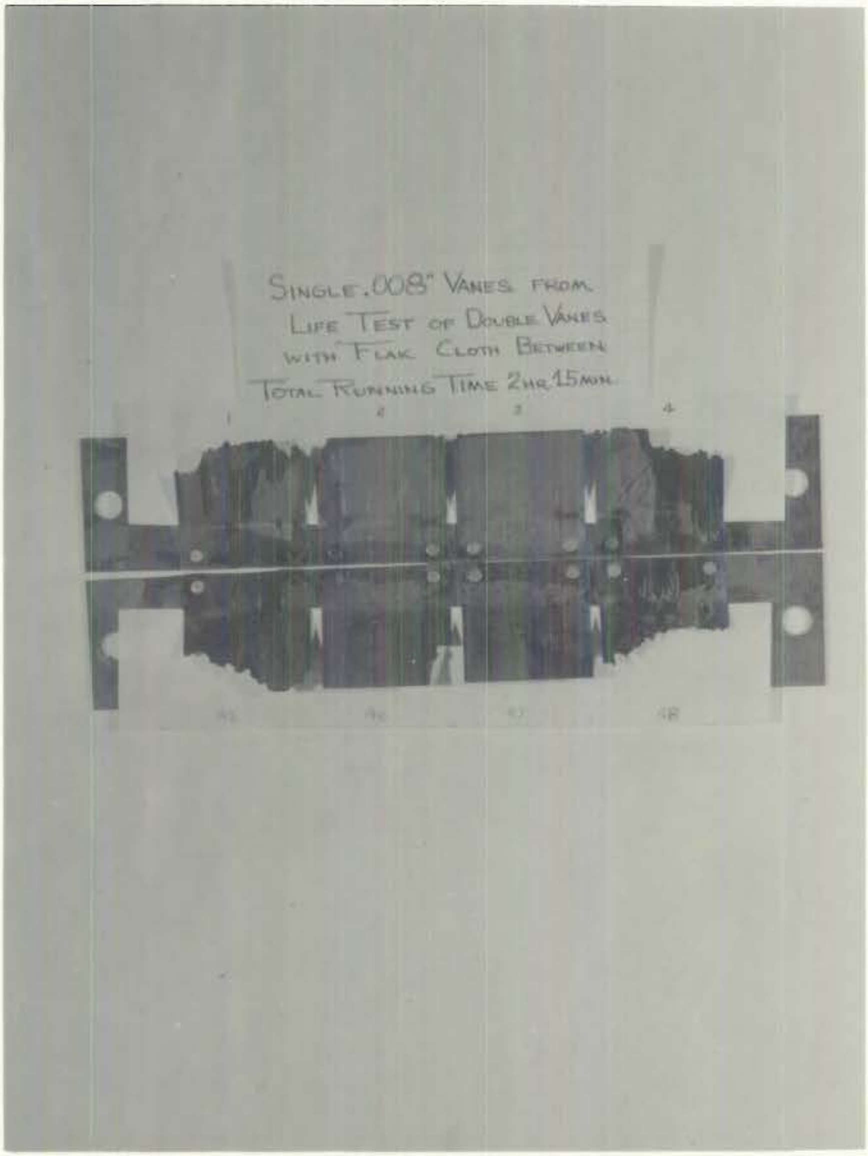
PLATE 12

DIAGRAM OF CUSHIONED VANE



U. S. NAVAL RESEARCH LABORATORY WASHINGTON 20, D. C.		SCALE	
		DR'WN.	
B'LD'G.	PHONE	CH'K'D.	
ROOM	DATE	APPR'V'D.	UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±

SHEET OF



DECLASSIFIED

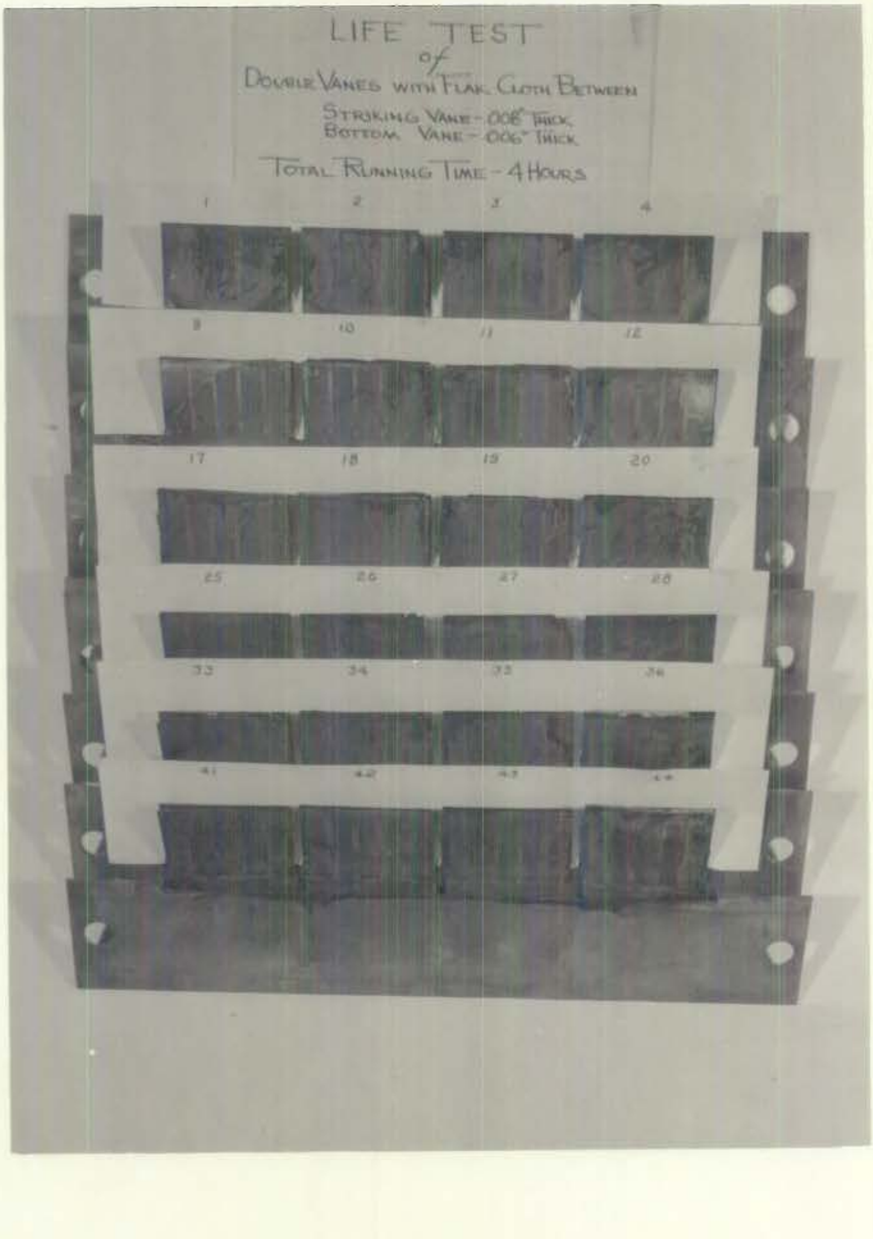

LIFE TEST
of
DOUBLE VANES WITH FLAK CLOTH BETWEEN
STRIKING VANE - .008" THICK
BOTTOM VANE - .006" THICK
TOTAL RUNNING TIME - 4 HOURS
1
2
3
4

PLATE 14

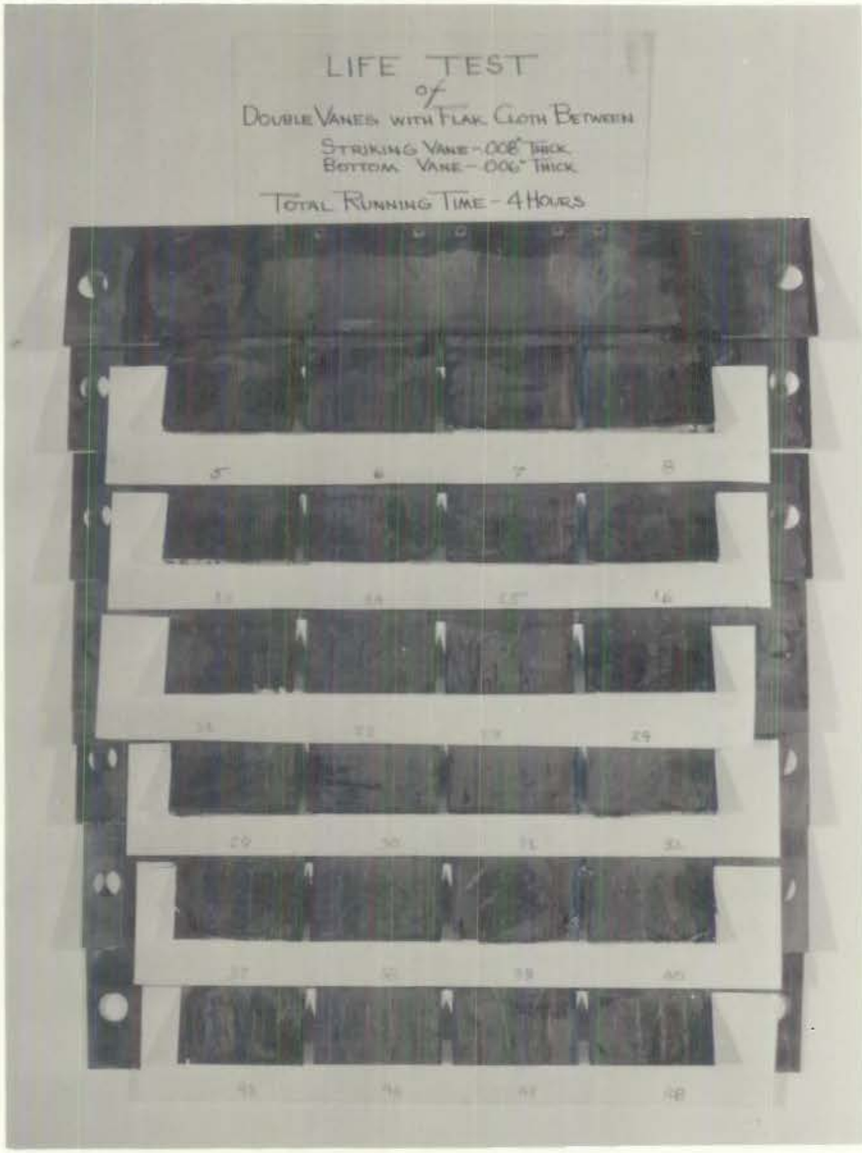

LIFE TEST
of
DOUBLE VANES WITH FLAK CLOTH BETWEEN
STRIKING VANE - .008" THICK
BOTTOM VANE - .006" THICK
TOTAL RUNNING TIME - 4 HOURS

PLATE 15

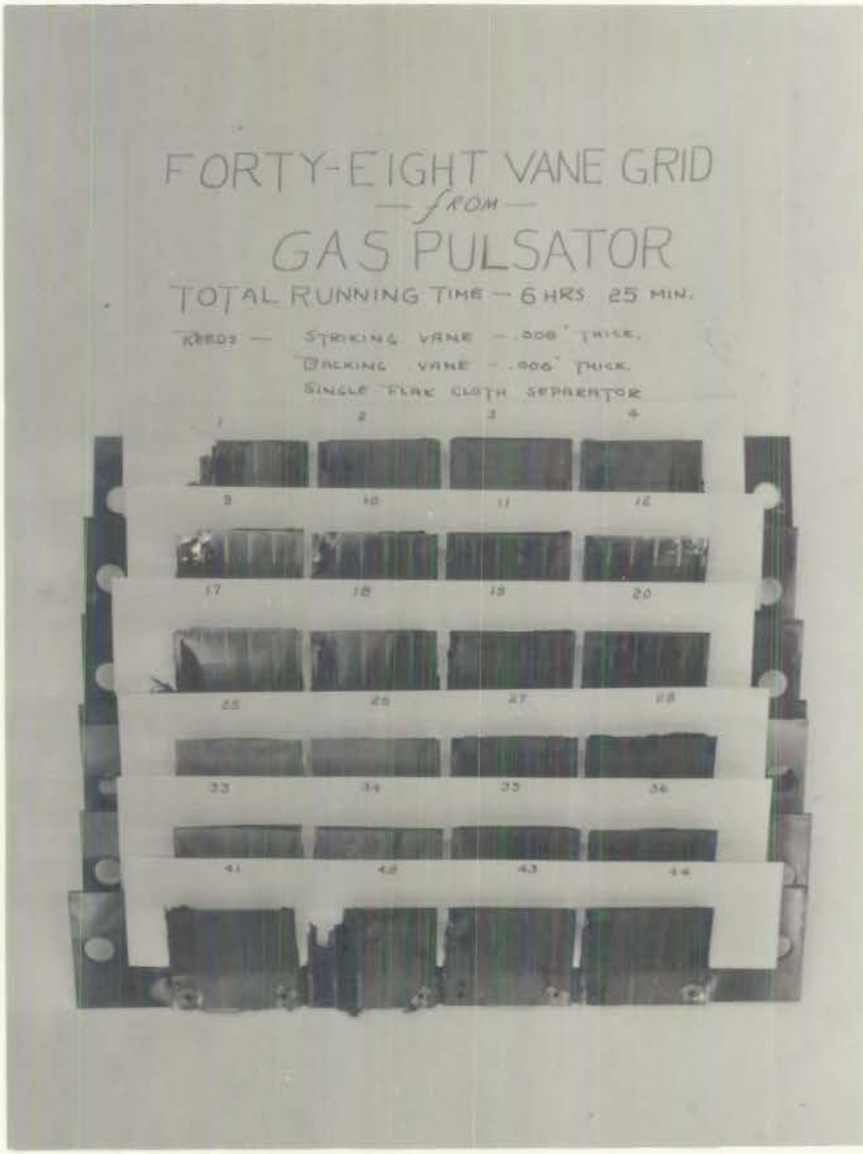
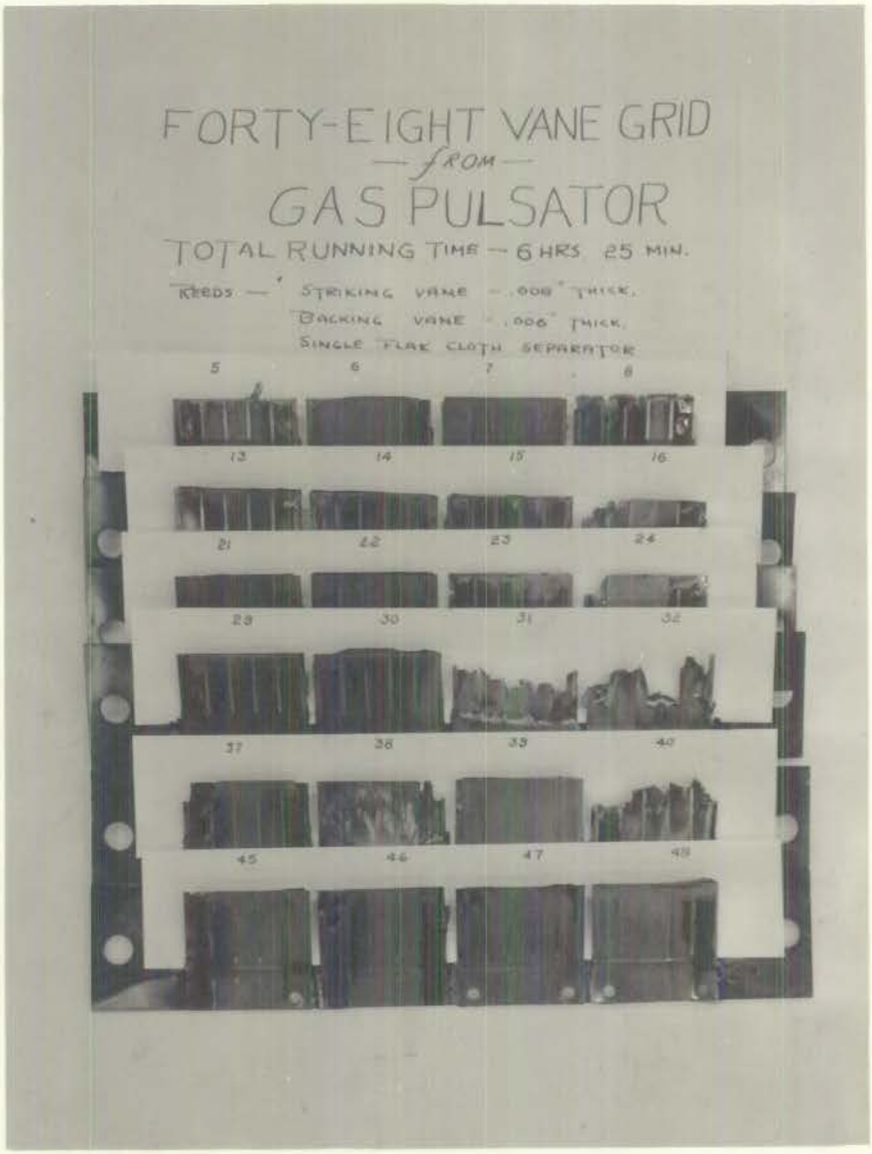

FORTY-EIGHT VANE GRID
— from —
GAS PULSATOR
TOTAL RUNNING TIME — 6 HRS 25 MIN.
REEDS — STRIKING VANE — .008" THICK.
BACKING VANE — .006" THICK.
SINGLE FLAX CLOTH SEPARATOR

PLATE 16



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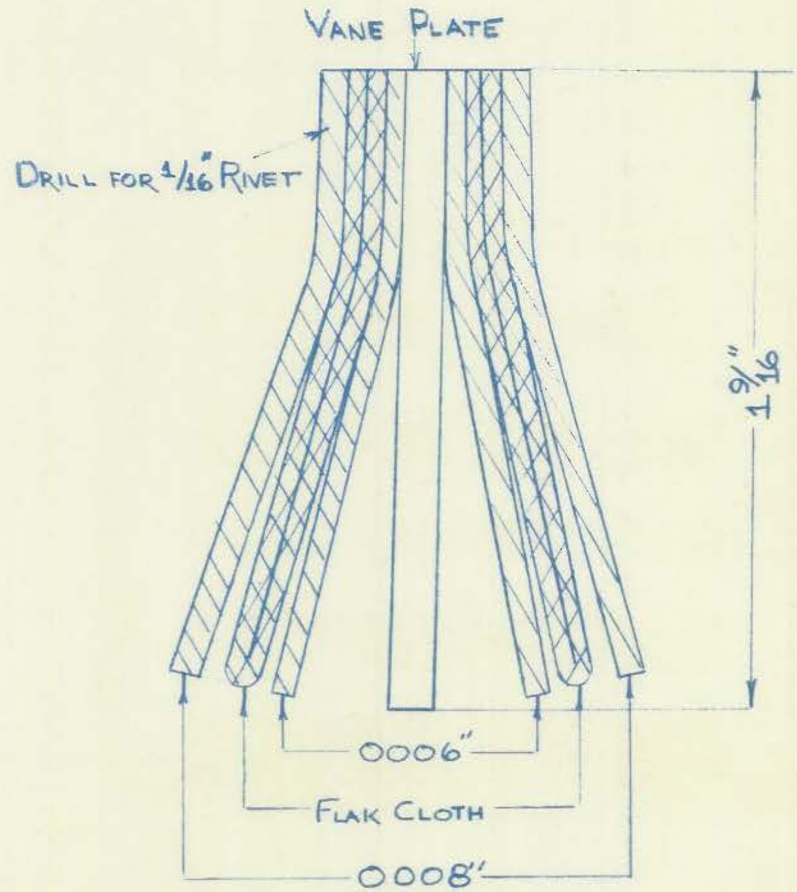
WASHINGTON 20, D. C.

B'LD'G.	PHONE	SCALE	
ROOM	DATE	DR'WN.	
		CH'K'D.	
		APPR'V'D.	

UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±

SHEET OF

DIAGRAM OF CUSHIONED VANE



NOTE
ENLARGED TO SHOW DETAIL

PLATE 18

DECLASSIFIED

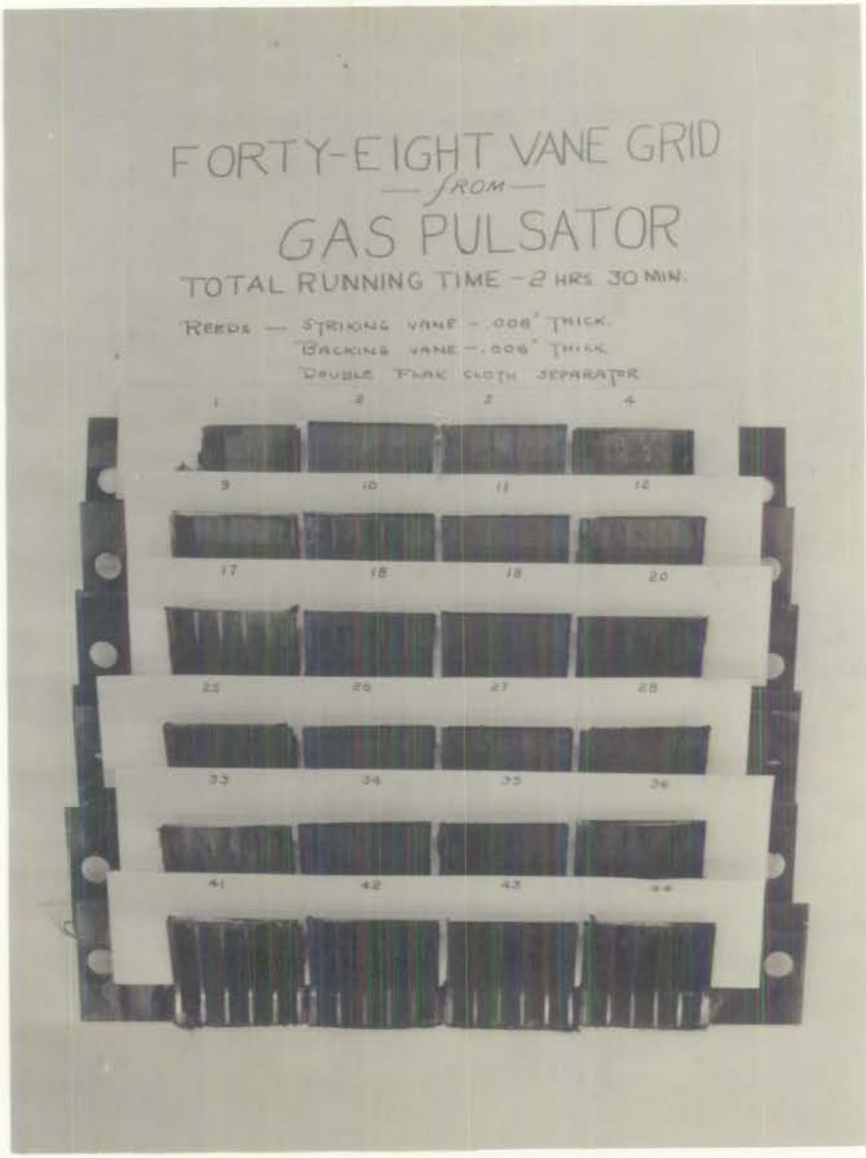


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PLATE 19

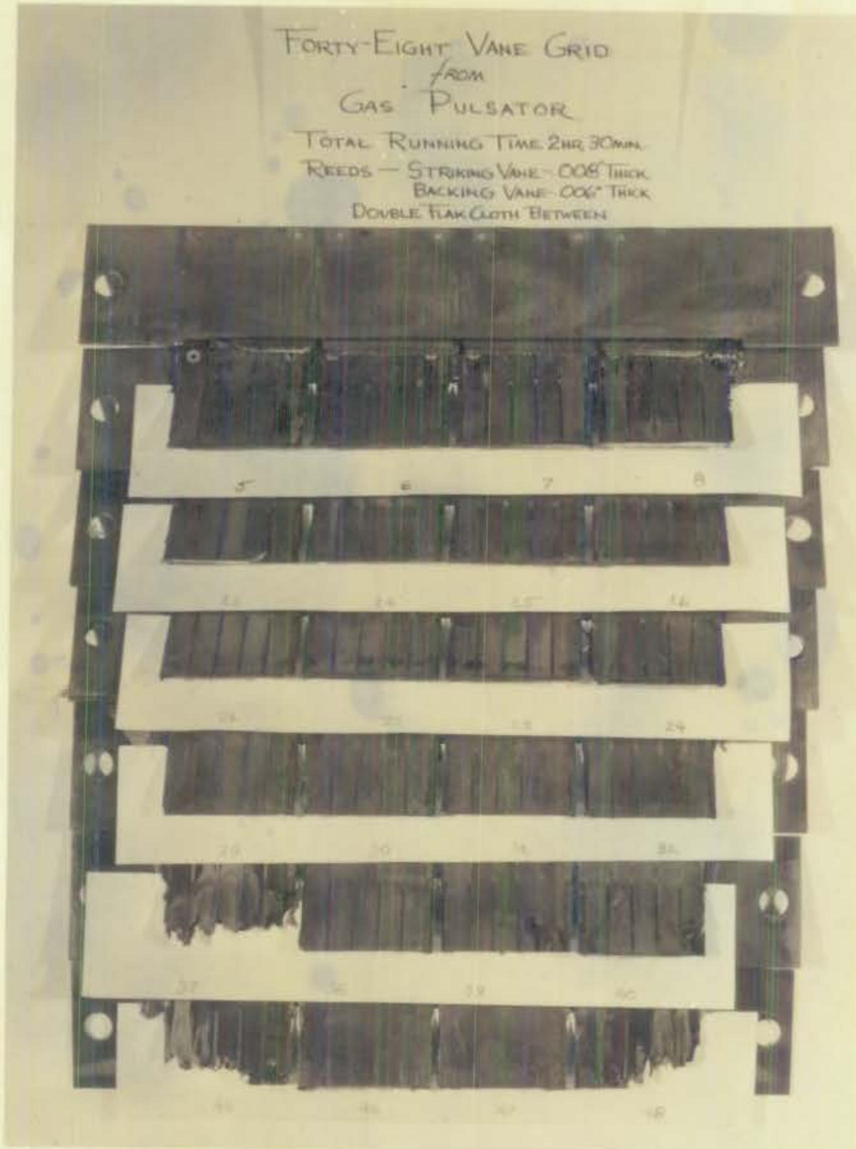
FORTY-EIGHT VANE GRID
FROM
GAS PULSATOR
TOTAL RUNNING TIME 2HR 30MIN.
REEDS — STRIKING VANE - .008" THICK
BACKING VANE - .006" THICK
DOUBLE FLAK CLOTH BETWEEN
5
6
7
8

PLATE 20

Distribution:

BuShips	5
BuAer	2
EES	1
BAGR Wright Field	1