[redacted] Serial No. [redacted]

Navy Department - Office of Research and Inventions

DECLASSIFIED

NAVAL RESEARCH LABORATORY
Washington, D. C.

* * *

MECHANICS & ELECTRICITY DIVISION

THERMODYNAMICS SECTION

24 September 1945

DECLASSIFIED by NRL Contract
Declassification Team
Date: 26 SEP 2014
Reviewer's name(s): A. THOMPSON, P. HANNA
Declassification authority: NAVY DECLASS MANUAL 11 DEC 2012, 03 SERIES

DECLASSIFIED: By authority of DOD DIR 5200.9
Cite Authority Date
Entered by NRL Code 1570

PARTIAL REPORT ON GAS PULSATOR

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

- Report 0-2650

[redacted]

FR-2650

* * *

DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by UNLIMITED only.

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

Dr. Ross Gunn, Superintendent
Mechanics & Electricity Division

Rear Adm. A. H. Van Keuren, USN (Ret.)
Director, Naval Research Laboratory

Preliminary Pages .... a-d
Numbered Pages 12
Plates 44
Distribution List ... e

NRL Problem 0-56

DECLASSIFIED

[redacted] [redacted]

Navy Department - Office of Research and Inventions

NAVAL RESEARCH LABORATORY
Washington, D. C.

* * *

MECHANICS & ELECTRICITY DIVISION

THERMODYNAMICS SECTION

24 September 1945

PARTIAL REPORT ON GAS PULSATOR

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

\- Report 0-2650

[redacted]

* * *

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

Dr. Ross Gunn, Superintendent
Mechanics & Electricity Division

Rear Adm. A. H. Van Keuren, USN (Ret.)
Director, Naval Research Laboratory

Preliminary Pages ... a-d
Numbered Pages 12
Plates 44
Distribution List ... e

NRL Problem 0-56

DECLASSIFIED

ABSTRACT

This is a partial report of experimental work conducted on a 13-inch gas pulsator in order to obtain operating characteristics and in an effort to extend valve life. There are included descriptions and photographs of test stand for thrust and air flow, of fuel system, and of damaged valve assemblies. Previous investigations of Eichelberg valves found that 0.010" steel vanes lasted 32 minutes and 0.006" vanes lasted 6 minutes. This work finds that 0.008" vanes lasted 65 minutes, 0.012" vanes ground to 0.008" for portion of length lasted 45 minutes, and doubled 0.006" vanes lasted 24 minutes. Initial investigations indicate encouraging possibilities of using plastic-impregnated glass-cloth protectors to extend valve life. External fuel feed cools vanes by evaporation, provides good mixing of fuel with air, and promises success for a simplified, low-pressure fuel system with gravity feed. Investigation of air capacity shows more vanes may be added in special grid assemblies to permit higher fuel consumption and increased thrust. Plans for future work include determination of operating characteristics of 0.008" vanes, investigation of ceramic protectors, development of external fuel feed, and measurements of air capacity.

DECLASSIFIED

[redacted]

DECLASSIFIED

TABLE OF CONTENTS

[redacted]

DECLASSIFIED

TABLE OF CONTENTS (Cont'd)

Plate No.

I. INTRODUCTION

A. Authorization

1. 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.

B. Previous Development

2. Reference (6) describes previous developmental work on 13-inch gas pulsator. Operating characteristics, such as thrust, specific fuel rate, air flow, and air-fuel ratio were obtained for 0.010" and 0.006" Eichelberg valves. The 0.010" valves lasted about 30 minutes. Although the 0.006" valves lasted only 6 minutes, they produced higher thrust, lower specific fuel, and higher air flow than the 0.010" valves. Starting was simplified by the substitution of a torpedo igniter fuse for spark ignition. Fuse ignition provided smooth starting and eliminated auxiliary starting air as well as electrical equipment.

C. Purpose

3. Recommendations were made in Encl. (A) of Ref. (4) that the principal problem of this project is to extend the life of the Eichelberg valve. Longer life would facilitate the use of the gas pulsator for landing craft type boats as suggested in Ref. (2) as well as for similar applications requiring long life. These tests have been conducted in an effort to extend valve life and to further study the operating characteristics of the gas pulsator as recommended in Ref. (1).

II. TEST METHODS

4. <u>Pulsator Tube.</u> The general specifications for the 13-inch gas pulsators used in this experimental work are given in the blueprint enclosures (B), (C), and (D) of Ref. (1). An additional 38" length of 7" tubing has been added onto the exhaust end. The final dimensions are as follows: combustion chamber, 13" diameter, 20" long; cone, 13" to 7" diameter, 30" long; and exhaust, 7" diameter, 88" long. Special bosses have been welded onto the pulsator tube to facilitate mounting and to permit the use of spark plugs, torpedo igniter fuses, and pressure pickups. Pipes with drilled holes for spraying cooling water onto the tube have been mounted along the top of the motor as illustrated by Plates 34, 35, and 36. This cooling permits continuous operation of the pulsator for runs of any desired time as limited by the fuel supply or valve deterioration. Steam produced from the cooling water is occasionally blown around the motor grid where it may be drawn into the combustion chamber. When excessive, this steam has sometimes stopped the pulsator. Prevailing winds generally blow the steam toward the exhaust end but compressed air has been necessary upon a few occasions to sweep steam away from the intake grid.

5. <u>Stationary Stand.</u> One of the 13-inch gas pulsators has been mounted on a stationary stand rigidly fixed to the concrete apron. This motor is ued for life testing of valves, for experimentation in

grid design, and for investigation of modified fuel systems. This motor is permanently attached to the water line for cooling. A skid-mounted blower is placed several feet in front of the stationary stand so as to blow objectionable steam away from the grid on windy days.

6. Thrust Stand. A second 13-inch pulsator is mounted in a horizontal thrust stand depicted in Plates 34, 35, and 36. This tube is suspended similarly to a ballistic pendulum by means of airplane cable and turnbuckles from roller-bearing trolleys which run on I beams. This method of suspension serves to minimize friction and to aid accurate thrust measurements. Motor thrust is balanced by air pressure against the pistons of two small cylinders mounted onto the stationary air box on either side of the motor. One of these cylinders is shown in the closeup of Plate 36. This photograph also shows the mounting for the microswitches which indicate the limit positions of the motor. A large angle-bracket welded onto the side of the motor transmits motor thrust to the air piston and also actuates the switches. These limit switches are located in pairs on either side of the motor and control panel lamps which indicate whether the motor is floating freely or is at either end of its motion. This movement is limited to one-half inch by the switch housings. The panel lamps, air pressure regulator, and pressure gage are shown in Plate 37. A linear relationship between thrust and air pressure is shown by the air piston calibration of Plate 41. This thrust stand is more convenient than the vertical stand discussed in Ref. (6) and permits simultaneous data taking.

7. Air Flow. A decided advantage of the horizontal thrust stand derives from the construction as an integral part of the air box discussed in Ref. (6). This design permits simultaneous measurements of thrust and air flow as suggested in Encl. (A) of Ref. (4). The large volume of the air box and the use of flexible diaphragms damp oscillations caused by pulsating flow sufficiently to permit accurate computation of air flow rate from the measured pressure drop across a flat-plate orifice. This pressure drop is measured by a water manometer. Normal operation of the air box necessitates that it be sealed to the motor grid by means of a flexible diaphragm, not included in Plate 37. This sealing diaphragm causes all intake air to pass through the orifice plate and is flexible so as to permit the limited motion required by the air pistons.

8. Fuel System. The fuel control system shown in Plates 38 and 39 consists of a pressurized fuel tank suspended from a precision spring scale, regulator for air pressure, filter, rotometer, and three Lunkenheimer valves for control of filling, venting, testing, and running. Rotometer readings are checked against weight readings taken at one-minute intervals while running at constant fuel rate. Steady-flow calibration of jets is made by volume and by weight. Fuel spray is caught in a graduated cylinder and timed by means of a stop-watch. This is checked against rotometer readings and weight readings made at one-half minute intervals for five-minute periods. Calibration curves for fuel jets are shown in Plates 40 and 26. The fuel admission system, fuel manifold,

[redacted]

and fuel pressure gage are shown in Plates 6 and 18. Primary fuel jets used to spray fuel directly into the combustion chamber are shown in Plates 7, 18, and 21. Secondary fuel jets used for external fuel feed are shown in Plate 24 and discussed in paragraph 18. All runs have been made with 62 octane unleaded gasoline.

9. Starting. Two methods of starting have been used in this experimental work. As described in Ref. (5) and (6), a torpedo igniter fuse may be used for ignition without the necessity of auxiliary air except for scavenging between runs. Starting by this method consists of inserting the fuse, striking a pin with a hammer, and turning on the fuel. However, in order to conserve the supply of torpedo fuses, the majority of experimental tests have been made with high voltage spark and auxiliary air. Both are turned off after successful starting has been assured. Numerous practice starts have been made to gain technique in smooth starting.

10. Frequency Measurements. Following the recommendations in Encl. (A) of Ref. (4), the frequency of motor operation at various fuel rates was investigated by means of several different instruments. Measurements indicate an approximately linear decrease of frequency with increase of fuel rate as illustrated in Plate 44. Although not indicated on the graph, the frequency at a given fuel rate is not constant but seems to vary continuously around an average value with an amplitude of several cycles per second. Vibrational frequencies were checked by means of a Westinghouse Vibrometer held in direct contact with the motor mounting and also by means of a General Radio Vibration Analyzer and Vibration Meter using a crystal pickup clamped to the motor mounting. Sound frequencies were measured by means of microphone pickups fed through amplifiers to the various frequency meters. Electronic frequency meters manufactured by Hewlett-Packard and General Radio respond so readily to high frequency harmonics that a low-pass filter was constructed in order to use them for measuring fundamental frequency. Analysis of the sound wave by means of a General Radio Sound Analyzer and Sound Level Meter indicated that the third harmonic is as intense as the fundamental with higher harmonics of appreciable intensity. The most satisfactory instrument for frequency measurements was a Biddle-Frahm-type vibrating-reed Frequency Indicator. This can be used as a direct-contact mechanical-response instrument or as an electrical meter fed by microphone pickup and amplifier. The data given in Plate 42 and the graph of Plate 44 were obtained with this instrument.

11. Typical Data. Although the fundamental problem of the current experimental work has been to increase valve life, sometime has been devoted to the development of methods of determining all operating characteristics. Measurements of fuel flow, thrust, air flow, and frequency have been made for various physical set-ups and data taken at different operating conditions as exemplified in Plate 42 by typical data taken for 48 of the standard 0.010" vanes. From these data computations are made for specific fuel rate and air-fuel ratio. Typical curves for thrust, specific fuel rate, air flow, and air-fuel ratio versus fuel flow are shown in Plate 43. The corresponding curve of frequency against

[redacted]

fuel rate is shown in Plate 44. Assembled grid and vane damage are shown in Plates 31, 32, and 33. Because of the importance of extending valve life, little work has been done in the fields of temperature and pressure measurements. Such data will be taken as soon as convenient in order to secure a more complete picture of all operating characteristics of gas pulsator as suggested in Ref. (7).

III. VANE LIFE

12. Damage Reports. The primary purpose of the current experimentation, as expressed in Encl. (A) of Ref. (4) and in Ref. (7), 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. (2). Present work has been confined to Eichelberg valves with modifications and redesigning towards extending life expectancy. Previous tests reported in Ref. (5) showed it advisable to make vanes with the grain running longitudinally so this practice was observed by the shop. Many of the tests consisted of running a set of vanes for 15 minutes, removing them for observation, running for another 15 minutes, observation, and this process continued until the motor was stopped spontaneously or because of noticeable damage. After vanes had been removed and inspected, care was taken to replace each in its original position so that successive runs might show if one particular spot of the grid received more severe treatment than any other spot. Damage reports were made for various short runs. Vanes were numbered for convenience from left to right starting at the top and viewing the vanes from the combustion side of the grid. Typical damage reports are included in Plates, 1, 2, 3, 4, 5, 11, 12, 14, 15, and 16 with discussions in paragraphs 14, 15, and 22.

13. 0.008" Vanes. Operating characteristics for both 0.006" and 0.010" vanes have been reported in Ref. (6). The 0.006" vanes produced higher maximum thrust with lower specific fuel but lasted only six minutes. The 0.010" vanes gave lower maximum thrust with higher specific fuel but lasted thirty minutes. The next step was to try 0.008" thick vanes of similar blued Swedish spring steel. A set of 48 of these vanes was run for several short tests until stopped by the operator. No vanes were replaced but at the end of a total of 64 minutes and 56 seconds enough of the vanes were considered to be damaged to warrant taking that time as the practical life of the 0.008" vanes although they were still operable. These 0.008" Eichelberg valves have shown the most desirable results to date. Their life was checked by subsequent tests so as to eliminate the possibilities of a particularly good run of steel or of special test conditions.

14. Damage to 0.008" Vanes. The damage record of this set of 0.008" vanes is depicted in Plates 1 to 5 inclusive and shows that once vanes begin to fail they continue rather rapidly. Plate 1 shows six out of 48 vanes slightly damaged after 10 min. 27 sec. running, with vane #38 worst of all. Plate 2 shows 12 of 48 damaged after 13 min. 9 sec. additional time, or 23 min. 36 sec. total time, with #38 still the worst. Plate 3 shows 12 of 48 damaged after 9 min. 30 sec. additional time or 33 min. 6 sec. total time, with #38 progressively worse. Plate 4 shows

[redacted]

17 of 48 damaged with #12, 13, 38, and 48 most damaged and #10, 15, 18, 27, and 31 appearing on the damage report for the first time after 16 min. 10 sec. additional time or 49 min. 16 sec. total. Plate 5 shows 22 of 48 damaged with #12, 13, 19, 20, 38, 41, and 44 most damaged after additional 15 min. 40 sec. for total of 64 min. 56 sec. Plate 6 shows the external view of the grid assembly together with the fuel admission system and the fuel gage at the fuel block. Plate 7 is a photograph from the combustion side of the grid when removed after 64 min. 56 sec. total running time and clearly shows the condition of the vanes and the location of the fuel jets. Plate 8 shows the vanes removed from the grid assembly, mounted onto a sheet of masonite, and numbered in the standard manner. Plate 9 is a closeup of the vanes from the upper half of the grid. Plate 10 is a closeup of the vanes from the lower half of the grid and clearly shows the damage to vane #38. A 65 minute life is a vast improvement over 6 minutes or 30 minutes and serves as a yardstick for comparisons. Further experimentation should be carried out to secure the required two-hour life.

15. Dual Thickness Vanes. The increased life of the 0.008" vanes over that of the 0.006" and 0.010" vanes led to an investigation to see if longer valve life could be secured by designing special vanes with reinforced tips for strength and flexible bodies for ease of operation. One of the easiest mechanical solutions seemed to be to start with thick vanes which could be ground down along a portion of their length for flexibility. Vanes of 0.012" blued Swedish spring steel were ground to about 0.008" for about 5/8-inch at the base, or just slightly beyond the point of bending. Plate 13 is an exaggerated drawing of these vanes. Grinding was performed on a surface grinder with subsequent honing to remove surface marks which might have been left from the grinding operation. Only 16 of these special dual-thickness vanes were made but these were mounted in the grid so as to receive the most severe treatment. Three fifteen-minute runs were made at high fuel rates. After 15 minutes at 398 lbs/hr, 4 of 16 dual vanes were slightly damaged as shown in Plate 14. After another 15 minutes at 398 lbs/hr, 10 of 16 dual vanes were damaged as shown in Plate 15 although not seriously enough to affect motor operation. At the end of the third 15-minute run, 12 of the 16 dual vanes were damaged as shown in Plate 16. One vane, #18, had broken off at the bend. This was attributed to a slight thinning of the metal in the honing operation. Although this grid assembly had been subjected to 45 minutes of high power running, only #18 and #34 presented serious leakage conditions. Although the motor was still operable, no further tests were made since the dual vanes had not performed as well as the standard 0.008" vanes. Future investigations will be made of other methods of reinforcing the sealing edge of the vanes. Plate 17 shows these vanes mounted on a panel with pertinent data. Interestingly, sixteen of the 0.008" vanes used in this test had enough previous running time to accumulate 62 minutes total time and were still in perfect condition. Thi substantiates the life test reported in paragraph 9 and further indicates the superiority of the 0.008" vanes. Plate 18 shows the combustion side of the grid after removal from motor. Plates 19 and 20 are additional photographs of the vanes after 45 minutes of running.

16. Double 0.006" Vanes. Another investigation in an attempt to prolong valve life was the use of two vanes of 0.006" thickness to make a total of 0.012" for each valve. It was hoped that if the first vane started to chip at the tips, the second would seal against hot combustion gases and so prevent rapid deterioration of the valves. A grid was assembled with 48 of the double 0.006" valves and run for 24 minutes at 344 lbs/hr. At about 12 minutes, flame appeared through the front of the grid and increased until the motor was stopped by the operator. The doubled 0.006" vanes lasted three times as long as single 0.006" ones but did not nearly equal the 65-minute life of the single 0.008" vanes. Plate 21 shows the grid as removed from the motor after 24 minutes running. Plates 22 and 23 are views of the vanes in the double assembly. Leakage is apparent at vanes 17, 18, and 31. The vane receiving the greater impact on tips and reed supports usually failed before its mate. There were two exceptions where the vane receiving lesser impact failed first but damage was slight in each case. The decreased flexibility caused by doubling tended to make starting difficult. However, by springing the vanes slightly open, as shown in Plate 21, starting and running were facilitated. This same procedure had previously been found necessary with the 0.010" vanes, whose initial tension had been too great. Although better than single o.006" vanes, the doubled 0.006" did not surpass single 0.008" vanes. Doubled 0.008" valves have not been tried because of the extreme stiffness.

17. Ceramic Protection. Still another method of extending the life of the vanes is to protect each vane with a ceramic cover. This protector should insulate against the heat of combustion and might also act as a buffer against impact shock. Trials have been made with a fiberglass cloth impregnated with plastic. Each protector was cut slightly narrower than the vane but twice as long, folded over the combustion or vibrating end of 0.006" steel vanes, and riveted to the standard vane plate. A single set of four vanes was run for 15 minutes at a fuel rate of 329 lbs/hr with no apparent damage. Markings on the ceramic caused by supporting ribs of the grid proved that the protectors were successfully cushioning against shock as well as insulating against heat. A further test was conducted on a set of eight of these special valves which were placed in the grid in such a position that they would be subjected to the most severe treatment. The motor was then run for 30 minutes at a fuel rate of 350 lbs/hr. This was the longest continuous run on the 13-inch gas pulsator. Again the ceramic had protected the steel from impact as well as from heat. The glass cloth was still integral although some of the plastic impregnating material has melted or burned. The Plastics Section at NRL is now working on a more applicable impregnator for this ceramic protector. Glass cloth is being bonded with a plastic material possessing better heat resistance. Nevertheless, results of these tests clearly show that it is possible to protect the steel vanes against impact shock and against heat. Work should be continued along this life in an effort to provide valves of long life.

IV. EXTERNAL FUEL FEED

18. Evaporative Cooling. Another method of protecting the

Eichelberg valve from extreme heating is by means of evaporative cooling. If fuel is sprayed directly onto the vanes, the latent heat of evaporation may be utilized for cooling the steel. For 62 octane gasoline this amounts to approximately 150 btu/lb. In order to test this effect experimentally, a sheet metal hood shown in Plate 24 was fitted over the front of the motor grid with a special fuel manifold placed in this hood to accomodate one, two or three external fuel jets. Plate 25 shows that the internal, or primary, jets were left within the combustion chamber for starting purposes. A flexible fuel supply was provided by the use of a separate pressurized fuel tank for the external fuel jets. Hence, the amount of fuel sprayed onto the vanes and through the grid from outside the motor was independent of the internal fuel supply. Jets #2, 3, and 4 were used for the secondary, or external fuel. Calibration curves are given in Plate 26 for the external fuel.jets and in Plate 40 for the internal jets. Tests were conducted to make sure that the fuel from these external jets was properly drawn into the motor through the valves and grid assembly.

20. Tests. The first test run was made with the motor in normal operation on internal jets for five minutes and then on both internal and external jets for another five minutes. Internal fuel rate was 240 lbs/hr, external fuel rate was 85 lbs/hr, and total fuel rate for the last five minutes was 325 lbs/hr. The motor operated satisfactorily with external fuel and all the fuel from the external jets was drawn into the motor. The second test run was made with 235 lbs/hr internal fuel, 120 lbs/hr external fuel, and 355 lbs/hr total fuel. The third test was made to determine if the pulsator would operate with all fuel supplied by the external jets. The motor was started on internal fuel. This was then gradually decreased as the external fuel was increased. The run was of 8 min. 40 sec. duration with the last 3 min. 40 sec. at a fuel rate of 360 lbs/hr supplied entirely by the external fuel system. The motor functioned very well on external fuel and sounded more regular than with internal fuel.

21. Gravity Fuel System. Successful operation of the gas pulsator with all fuel supplied by external jets resulted in an investigation of the practicality of another type of external fuel system. A gravity fuel system feeding a venturi placed in the air intake might furnish sufficient fuel for motor operation. This would mean starting the motor with the internal fuel jets which could be cut off as soon as the external gravity system operated. No results are available at present but experiments are being conducted using an airfoil section for combined venturi and fuel manifold. A venturi would provide good mixing with a sacrifice of evaporation cooling. The initial investigation of evaporative cooling has developed into a study of gravity fuel feed, a desirable feature for the propulsion unit of a landing-craft type boat as suggested in Ref. (2). A low pressure fuel system in keeping with recommendations of Ref. (7) would be a definite simplification with obvious advantages.

V. SPECIAL GRID ASSEMBLIES

22. Air Capacity. Another investigation related to a study of

[redacted]

operating characteristics of the gas pulsator is that of fundamental air capacity. The amount of air that can be drawn into the combustion chamber is limited by the grid dimensions and the number of Eichelberg valves. However, there has been some question as to whether the gas pulsator could use more air; i.e., if more fuel could be burned and more thrust produced. The possibility of securing increased air capacity by increasing the number of vanes has been suggested in Ref. (6) and in Ref. (7). There will be a limit to motor operation which is probably determined by the physical dimensions of the combustion chamber, cone and tail pipe. Therefore, it was deemed advantageous to determine if this limit had been reached or if the 13-inch pulsator could use more vanes, draw more air, burn more fuel, and produce more thrust. Special grid assemblies have been built in an attempt to experimentally investigate air capacity. These special grid assemblies include any setup different from the standard 48-vane frontal grid.

23. Expanded Grid. In order to investigate the fundamental capacity of the 13-inch gas pulsator a special adaptor was constructed so as to take two extra grid sections. This required 64 Eichelberg valves instead of the 48 of the standard grid assembly. A trial run of 1½ minutes was made to determine the maximum fuel rate. The fuel rate was kept constant for 10 sec. intervals for values of 200, 250, 300, 350, 400, 450, 500, 550, and 575 lbs/hr. The motor stopped at this last fuel rate. A similar test was then run for 9 min. 51 sec. with fuel rates maintained constant for 1 minute intervals. Spontaneous stoppage caused by flooding the motor occured at 560 lbs/hr. Plate 11 shows slight vane damage after the total of 12 min. 21 sec. running. Finally, a third run was made for 10 min. at a constant fuel rate of 500 lbs/hr. The damage report of Plate 12 shows the 64 vanes after a total running time of 22 min. 21 sec. Buckling of one grid section deformed vanes #10 and 14. This buckling was caused by a special supporting bracket which was installed to take care of the added weight of the expanded grid adapter. This did not allow for free expansion of the grid during heating but has been corrected. It is interesting to note that the 0.008" vanes were only slightly damaged after 22 min. 21 sec. running. This special 64-vane grid assembly started and operated very satisfactorily with a noticeable increase in sound level over the standard 48-vane grid.

24. Side-entry Grid. Still another method of increasing the air capacity of the gas pulsator is to add grid sections and vanes to the sides of the main grid. The principle of side-entry was suggested in Ref. (3). One set has been tried combining 24 vanes in the side with the standard 48-vane grid. Plate 27 illustrates this special grid assembly as attached to the motor. Plate 28 shows the grid removed and is taken from the combustion side with two of the side-entry vanes plates removed. Plate 29 shows the aft sections of the vanes and Plate 30, the forward sections. A test run was made with continuously increasing fuel rate, stopping at 620 lbs/hr. The frontal section contained 0.010" vanes with six minutes previous running for a total of 15 minutes. The side-entry section contained new 0.008" vanes. All valves functioned successfully with increased fuel. The fuel rate of 620 lbs/hr is the

[redacted]

DECLASSIFIED

highest ever measured for the 13-inch pulsator. Considerable flame from the exhaust indicated a rich mixture and suggested that the true maximum fuel capacity was near.

25. Results. Interesting comparisons may be made between the results of experiments on these special grid sections and the data taken during normal operation of the gas pulsator with the standard 48-vane grid. If an increase in vanes causes a corresponding increase in air capacity and permits a proportional increase in fuel capacity, the ratio of the number of vanes should be equivalent to the ratio of the maximum fuel capacities. Normal operation with 48-vane grid permitted a maximum fuel rate of 415 lbs/hr as reported in Ref. (5). The 64-vane expanded grid permitted a maximum fuel rate of 560 lbs/hr as reported in paragraph 23.

$$64 : 48 = 1.33$$

$$560 : 415 = 1.35$$

The 72-vane side-entry grid permitted a maximum fuel rate of 620 lbs/hr as reported in paragraph 24.

$$72 : 48 = 1.50$$

$$620 : 415 = 1.49$$

The fact that the ratios of the number of vanes and of the maximum fuel capacity are so close to each other seems to indicate that both the air capacity and the fuel capacity of the gas pulsator increase directly with an increase in the number of vanes. This may be expressed numerically as the maximum fuel rate per vane. Thus 48 vanes permitted 8.65 lbs/hr per vane, 64 vanes permitted 8.77 lbs/hr per vane, and 72 vanes permitted 8.62 lbs/hr per vane. The close agreement between these values substantiates the theory that the fuel capacity is directly proportional to the number of vanes up to some limit determined by the fundamental dimensions.

26. Future Work. The increased air capacity and fuel capacity which result from an increase in the number of vanes probably cause an increase in thrust. Mechanical problems have prevented the measurement of thrust and air flow with these special grid assemblies until special adaptors and sealing gaskets can be prepared. This further investigation seems advisable because of the apparent advantages of increased fuel capacity. Therefore, necessary equipment is being constructed to permit the determination of thrust and air flow for these special grids. Values of specific fuel rate and air-fuel ratio will then be computed in order to better compare these assemblies with the standard grid. Other suggested arrangements will be (1) 48 vanes on the sides to supplement 48 on the front for a total of 96 and (2) 48 vanes on the side with a solid plate on the front. The side-entry grids may serve to increase vane life since the solid plate will take the motor thrust. The vanes will still be subjected to heat and impact but the latter may be less for the side-entry vanes. Still another advantage of the extra vanes might be that at

[redacted]

DECLASSIFIED

moderate fuel rates the added air capacity would result in easier wearing of the vanes as they would tend to spread the work and each would be required to lift only a fraction of its total travel. The possibility of increasing valve life by increasing the number of vanes has been suggested in Ref. (8). This is similar to engineering practice in compressor design where extra valves are included in order to distribute the load and so to assure longer life.

VI. CONCLUSIONS

27. Conclusions. Test equipment has been set up and test methods developed to facilitate investgation of operating characteristics and valve life for a 13-inch gas pulsator. Valve life has been extended to over one hour by using 0.008" instead of 0.010" or 0.006" steel stock for the Eichelberg valves. Although plain 0.006" vanes lasted but 6 minutes, these same vanes lasted over 30 minutes when protected by ceramic sleeves which cushioned against shock and insulated against heat. Evaporative cooling by means of external fuel feed extended vane life, provided good mixing of fuel and air, and may permit the use of a gravity or low pressure fuel system to replace the high pressure fuel system now in use with atomizing jets. The use of special grid assemblies which added more vanes has increased air capacity, fuel capacity, and, presumably, thrust with a unit fuel capacity of 8.65 lbs/hr per vane. Furthermore, these special grids may indirectly result in increased valve life by easing the load impressed on each vane. Hence valve life is being extended by ceramic protectors, by evaporative cooling, and by special grid assemblies.

VII. RECOMMENDATIONS.

28. Experimental work should be continued on an investigation of operating characteristics of the 13-inch gas pulsator and in an attempt to further extend valve life. Operating characteristics are required for the 0.008" vanes and an attempt will be made to try 0.007" and 0.009" spring material as soon as such can be secured. Further studies should be made on vanes with reinforced edges, paragraph 15. New plastics should be investigated for ceramic protection of the steel vanes, paragraph 17. External fuel feed should be developed for high pressure jets and for a gravity fuel system, paragraph 21. Extra vanes should be tried in special grid assemblies for added air capacity and extended vane life, paragraph 25. Measurements should be made of temperature and pressure, paragraph 11. In short, every effort should be made to continue work on the gas pulsator in order to obtain higher motor efficiency and to secure longer motor life.

VIII. ACKNOWLEDGMENTS

29. This report has been prepared by L. F. Campbell and T. O. Meyer. The experimental group also included Gustave C. Milak, Sp(X) 3/c; Ens. George A. Brundrett; Ens. Fred Kingsley Elder, Jr.; Lt. Robert M. Jordan; and Lt. (jg) Charles J. Baader.

30. Appreciation is expressed for the cooperation of a group from the Chemistry Division of the Naval Research Laboratory whose experiments with a 6-inch gas pulsator provided valuable information concerning valve life.

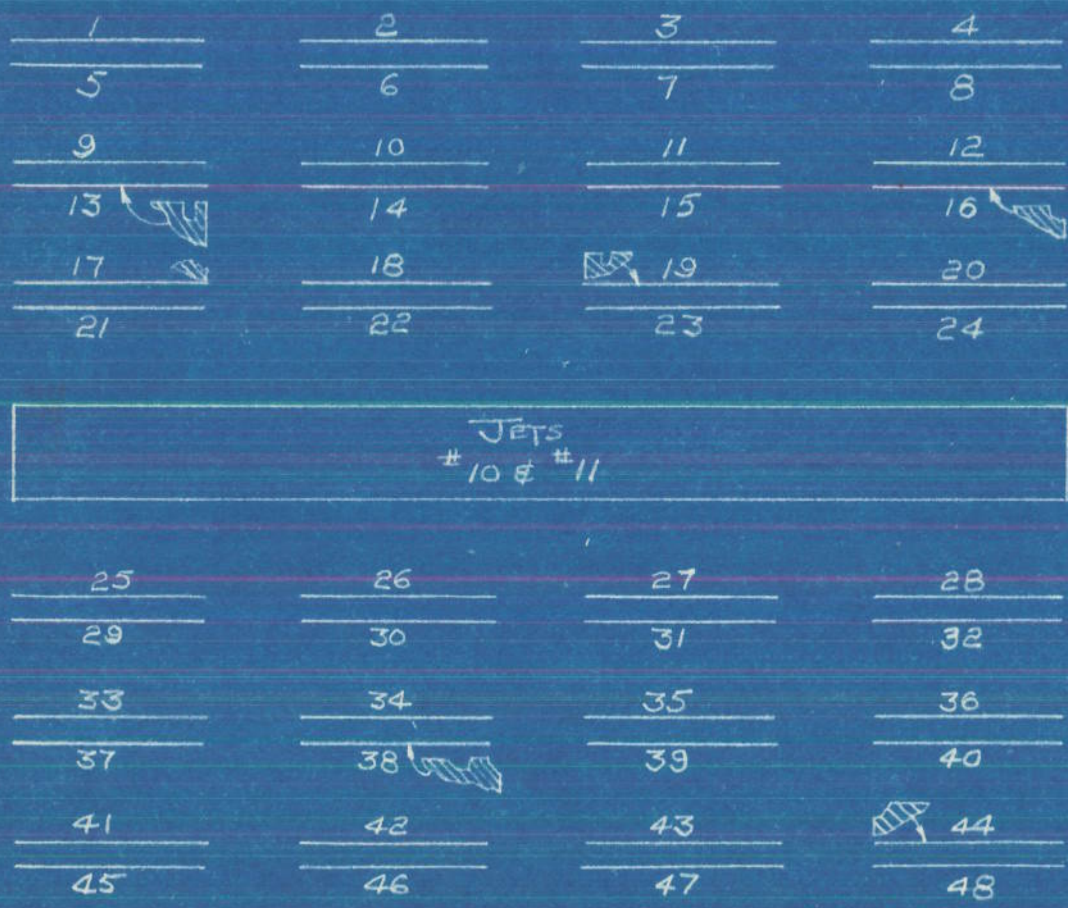
REFERENCES

Reference (1) BuShips ltr. C-S41-1 (643-330) of 8 August 1944.
Reference (2) BuShips ltr. C-S41-7 (643)of 6 October 1944.
Reference (3) BuShips ltr. C-S41-7 (643-330) of 30 December 1944.
Reference (4) BuShips ltr. C-S41-7 (643c) of 20 January 1945.
Reference (5) NRL ltr. C-S41-8 (447) of 26 January 1945.
Reference (6) NRL ltr. C-S41-8 (447) of 21 February 1945.
Reference (7) BuShips ltr. C-S41-7 (643c) of 6 March 1945.
Reference (8) BuShips ltr. C-S41-8 (643c) of 9 March 1945.

Original data recorded in NRL Log Book 5453.

RECORD OF DAMAGE

TOP OF GRID



DATA ON RUN 15 JUNE 1945

TIME OF RUN	9 MIN - 54 SEC.	FUEL PRESSURE	35 #/IN²
PREVIOUS TIME	0 MIN - 33 SEC.	FUEL RATE (FROM CURVE)	310 #/HR.
TOTAL RUNNING TIME	10 MIN - 27 SEC.	JETS USED	#10 & #11

COMMENTS

VANE	FAILURE
#13	CRACK 1/32" WIDE, 1/16" DEEP 3/32" FROM EDGE ONLY SLIGHT DAMAGE
#16	CRACK 1/8" WIDE, 1/16" DEEP AT CORNER - ONLY SLIGHT DAMAGE
#17	CRACK 3/32" WIDE, 1/16" DEEP AT CORNER - ONLY SLIGHT DAMAGE
#19	CRACK 1/32 WIDE, 1/32 DEEP 3/64" FROM EDGE - ONLY SLIGHT DAMAGE
#38	CRACK 1/4" WIDE, 3/32" DEEP CRACK 5/32" WIDE, 3/32" DEEP 1/8" FROM FIRST CRACK FAILURE ALLOWED LEAKAGE
#44	CRACK 1/8" WIDE, 3/32" DEEP AT CORNER — WOULD ALLOW SLIGHT LEAKAGE

VANE #38 DAMAGED MOST
ALL VANES .008" THICK

RECORD OF DAMAGE

TOP OF GRID

DATA ON RUN 29 JUNE 1945

TIME OF RUN	13 MIN - 09 SEC	FUEL PRESSURE	40 #/IN²
PREVIOUS TIME	10 MIN - 27 SEC	FUEL RATE (BY WEIGHT)	327 #/H
TOTAL RUNNING TIME	23 MIN - 36 SEC	JETS USED	#10 & #11

COMMENTS

VANE	FAILURE
#11	SMALL CORNER NICK 3/32 x 3/32
#12	SMALL CORNER NICK 1/64 x 1/64
#13	NICKED FOR 5/8" DISTANCE DEEPEST 1/8 - SOME LEAKAGE
#16	NICKED FOR 7/16" FROM CORNER - DEEPEST 5/32
#17	NICKED ALONG ENTIRE EDGE 3/32 DEEP AT RIGHT - 1/16 DEEP AT LEFT
#19	CORNER CHIP 9/32 x 7/32
#20	SLIGHT NICK LEFT CORNER 1/32 x 5/32
#35	SLIGHT NICK - 1/32 x 1/32
#38	9/32 x 1 1/16 - RIGHT CORNER
#40	1/16 x 1/16 NICK - 3/32 FROM RIGHT CORNER
#41	1/32 x 1/64 DEEP - 1/16" FROM RIGHT CORNER
#44	1/4 x 3/16 - LEFT CORNER

VANE #38 DAMAGED MOST

ALL VANES .008 THICK

PLATE 2

RECORD OF DAMAGE

TOP OF GRID

DATA ON RUN 10 JULY 1945

TIME OF RUN	9 MIN – 30 SEC.	FUEL PRESSURE	20 #/IN²
PREVIOUS TIME	23 MIN – 36 SEC.	FUEL RATE (BY WEIGHT)	221 #/HR.
TOTAL RUNNING TIME	33 MIN – 06 SEC.	JETS USED	#10 & #11

COMMENTS

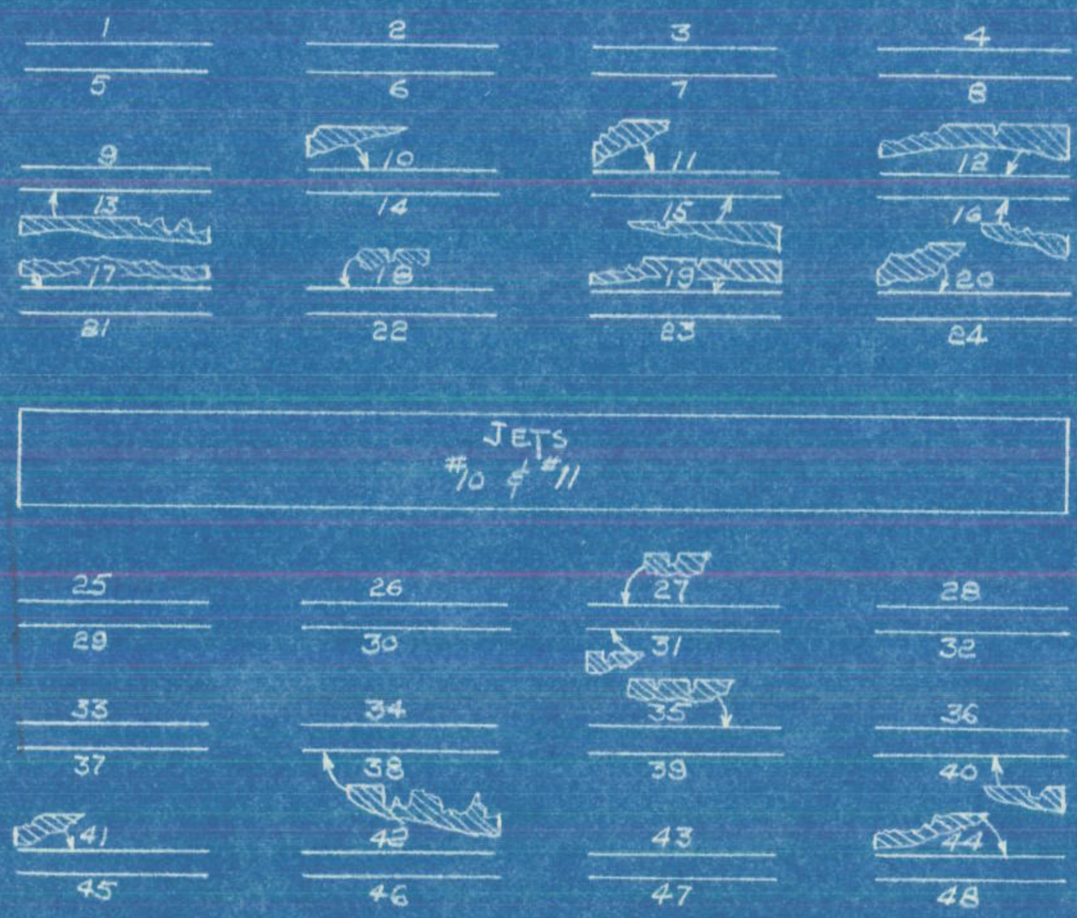
VANE	FAILURE
#11	CORNER NICK 3/32" x 3/32"
#12	CORNER NICK 1/64" x 1/64"
#13	NICKED 5/8" FROM CORNER DEEPEST – 1/8"
#16	NICKED 7/16 FROM CORNER DEEPEST 1/4" AT CORNER.
#17	NICKED ALONG ENTIRE EDGE DEEPEST 3/32" AT CORNERS
#19	CORNER NICK 5/16 x 5/16"
#20	CORNER NICK 1/8 x 1/4 DEEP
#35	EDGE NICK 1/32" x 1/32"
#38	EDGE NICK 1" x 1/2" DEEP AT CORNER
#40	EDGE NICK 1/8" x 3/32"
#41	EDGE NICK 1/32" x 1/32"
#44	CORNER NICK 1/4 x 3/16 DEEP

VANE #38 DAMAGED MOST

ALL VANES .008" THICK.

RECORD OF DAMAGE

TOP OF GRID



COMMENTS

VANE	FAILURE
#10	CORNER NICK 1/64 x 1/32 WID
#11	CORNER NICK 1/8 x 3/16 WID
#12	NICKED FOR 3/4" OF EDGE
	3/16" DEEPEST AT CORNER
#13	NICKED FOR 5/8" OF EDGE
	3/16 DEEPEST NICK
#15	EDGE NICK 1/64 x 1/64 – CORNER
	NICKED SLIGHTLY
#16	TRIANGULAR CHIP 1/2 x 1/4 DEE
#17	ENTIRE EDGE CHIPPED – 1/4" DEE
#18	EDGE CHIP 1/8 x 1/16 DEEP
#19	TRIANGULAR CHIP 5/8 x 1/4 DEE
#20	TRIANGULAR CHIP 1/2 x 1/2
#27	EDGE CHIP – 1/64 x 1/64
#31	EDGE CHIP – 1/64 x 1/64
#35	TWO EDGE NICKS – 1/64 x 1/64
#38	EDGE CHIPPED FOR 1"
	DEEPEST NICKS 1/2"
#40	EDGE NICK 1/8 x 3/32
#41	EDGE NICK 3/16 x 1/16 DEEP
#44	TRIANGULAR CHIP 3/4 x 1/4

VANES 12, 13, 38, & 44 DAMAGED MOST

ALL VANES, .008 THICK

DATA ON RUN 20 JULY 1945

TIME OF RUN	16 MIN. – 10 SEC.	FUEL PRESSURE	27 1/2 #/IN²
PREVIOUS TIME	33 MIN. – 06 SEC.	FUEL RATE	410 #/HR
TOTAL RUNNING TIME	49 MIN – 16 SEC.	JETS USED	#10 & #11

PLATE 4

RECORD OF DAMAGE

TOP OF GRID

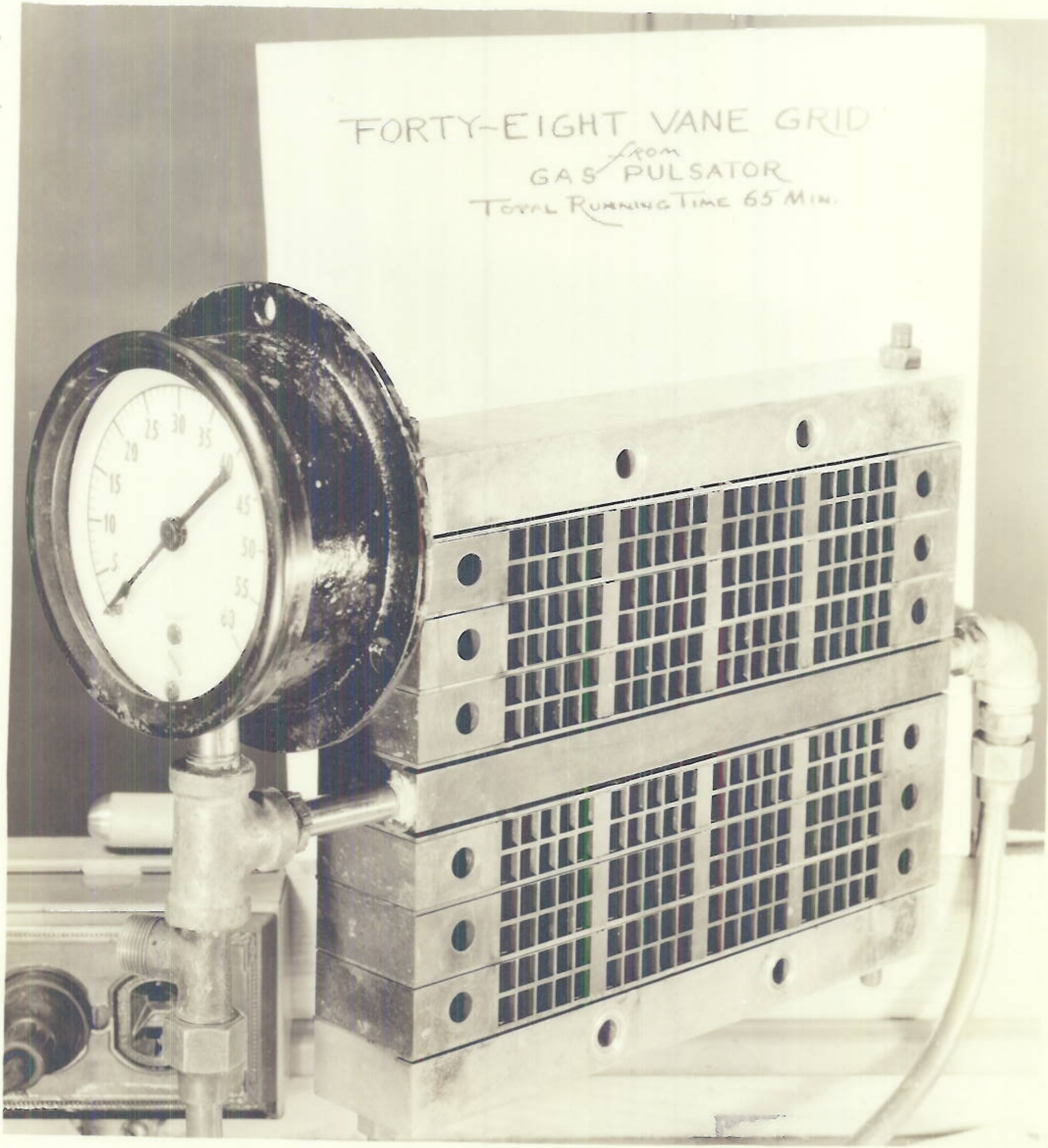
DATA ON RUN 23 JULY 1945

TIME OF RUN	15 MIN - 40 SEC.	FUEL PRESSURE	27½ #/IN²
PREVIOUS TIME	49 MIN - 16 SEC.	FUEL RATE (BY ROT.)	410 #/HR.
TOTAL RUNNING TIME	64 MIN - 56 SEC.	JETS USED	#10, #11, & #12

COMMENTS

VANE	FAILURE
#4	¼" CRACK NEAR RIGHT EDGE
#9	CORNER CHIP - ¼" x 3/16 DEEP
#10	CORNER CHIP - ⅛ x ¼ DEEP
#11	EDGE CHIPPED 1" - DEEPEST ¼"
#12	EDGE CHIPPED ¾" - DEEPEST ¼"
#13	EDGE CHIPPED ⅞" - DEEPEST ⅜"
#15	EDGE CHIP - 1/32 x 1/32
#16	TRIANGULAR CHIP - ½ x ⅜
#17	ENTIRE EDGE CHIPPED - ¼ DEEP
#18	EDGE CHIP - ¼ x 3/16
#19	CORNER CHIP - ¾ x ⅜
#20	CORNER CHIP - ½ x ⅝
#27	EDGE CHIP - 1/64 x 1/64
#28	CORNER CHIP - ¼ x ⅛
#30	CORNER CHIP - ¼ x 3/16
#31	EDGE CHIP - 1/64 x 1/64
#34	EDGE CHIP - 1/64 x 1/64
#35	THREE EDGE CHIPS - 1/64 x 1/64
#38	EDGE CHIP - 1¼ x ⅝
#40	CORNER CHIP - ¼ x 3/16
	EDGE CHIP - ⅛ x 1/32
#41	ENTIRE EDGE CHIPPED - ⅛" DEEP
#44	EDGE CHIP - ¾ x ¼

ALL VANES .008" THICK



DECLASSIFIED

PLATE 6

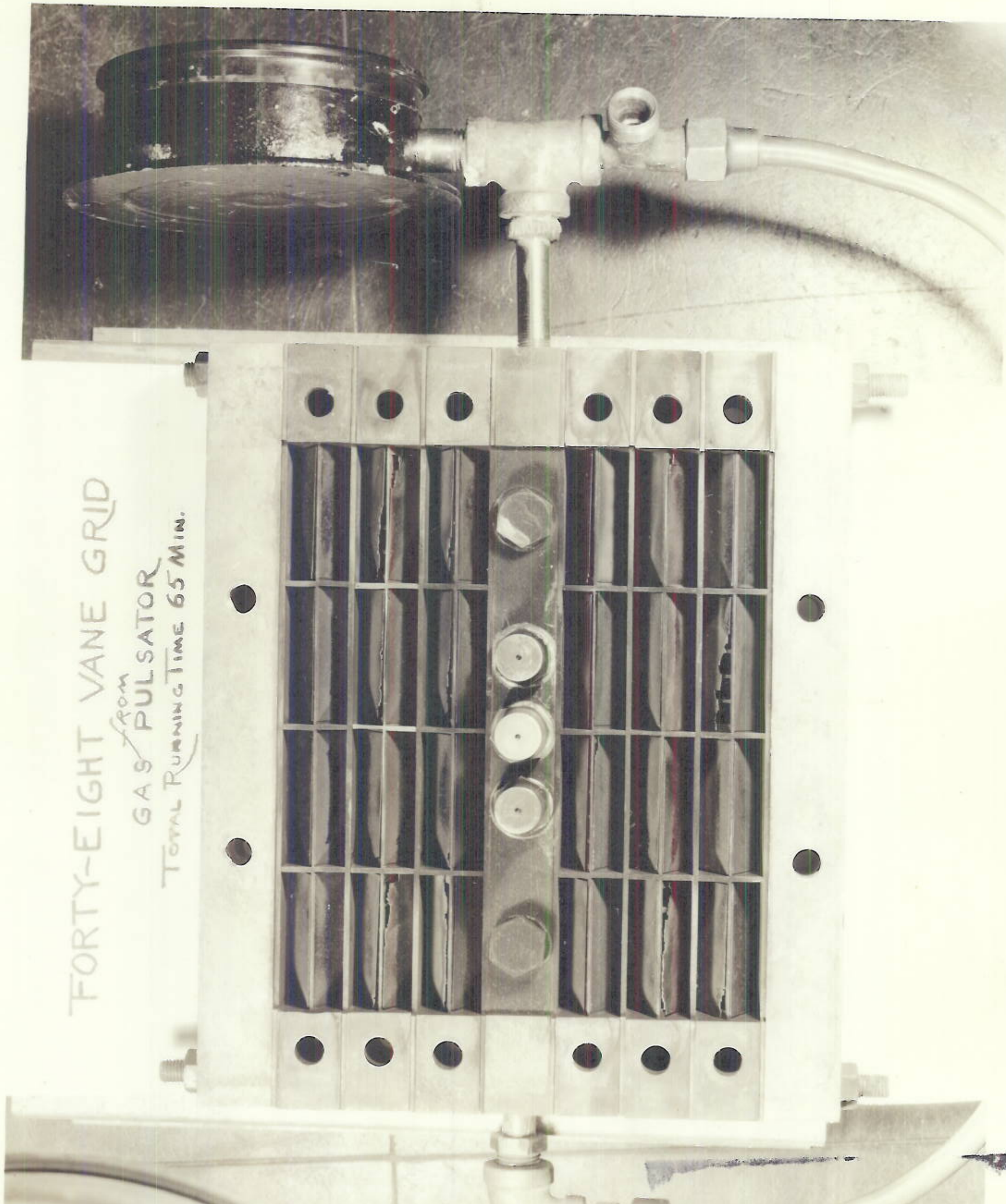
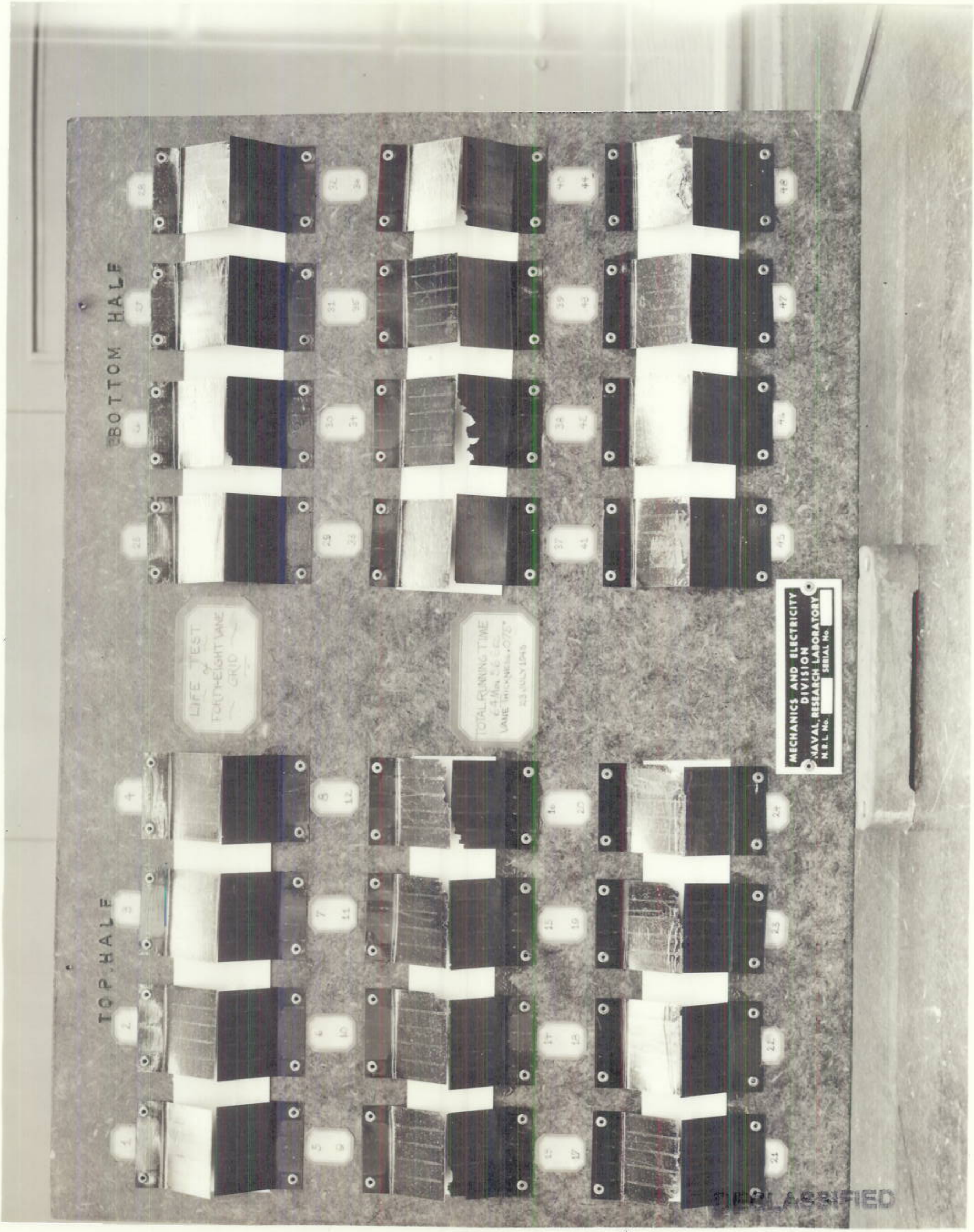

FORTY-EIGHT VANE GRID
GAS FROM PULSATOR
TOTAL RUNNING TIME 65 MIN.
DECLASSIFIED

PLATE 7

DECLASSIFIED



CONFIDENTIAL

PLATE 8

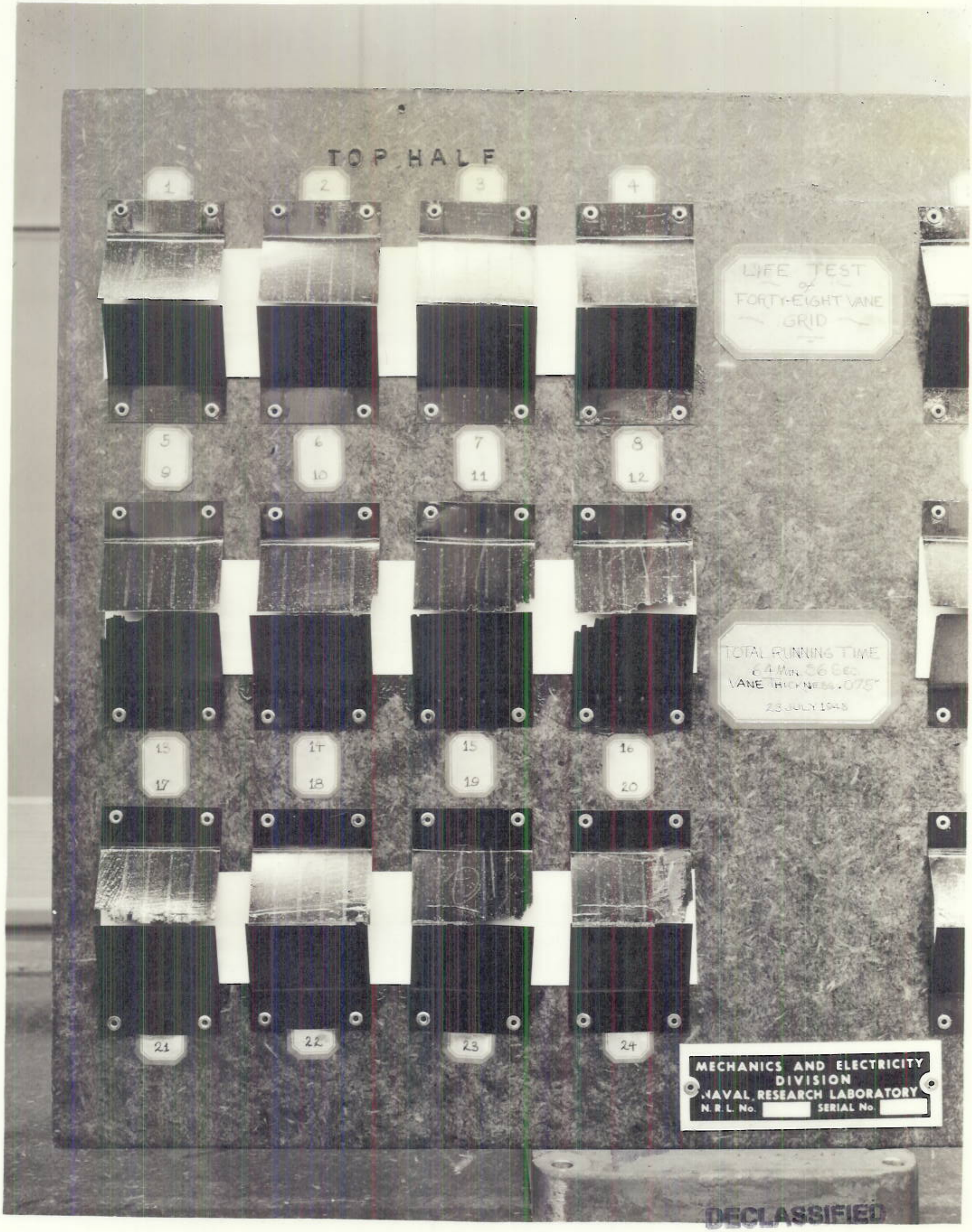
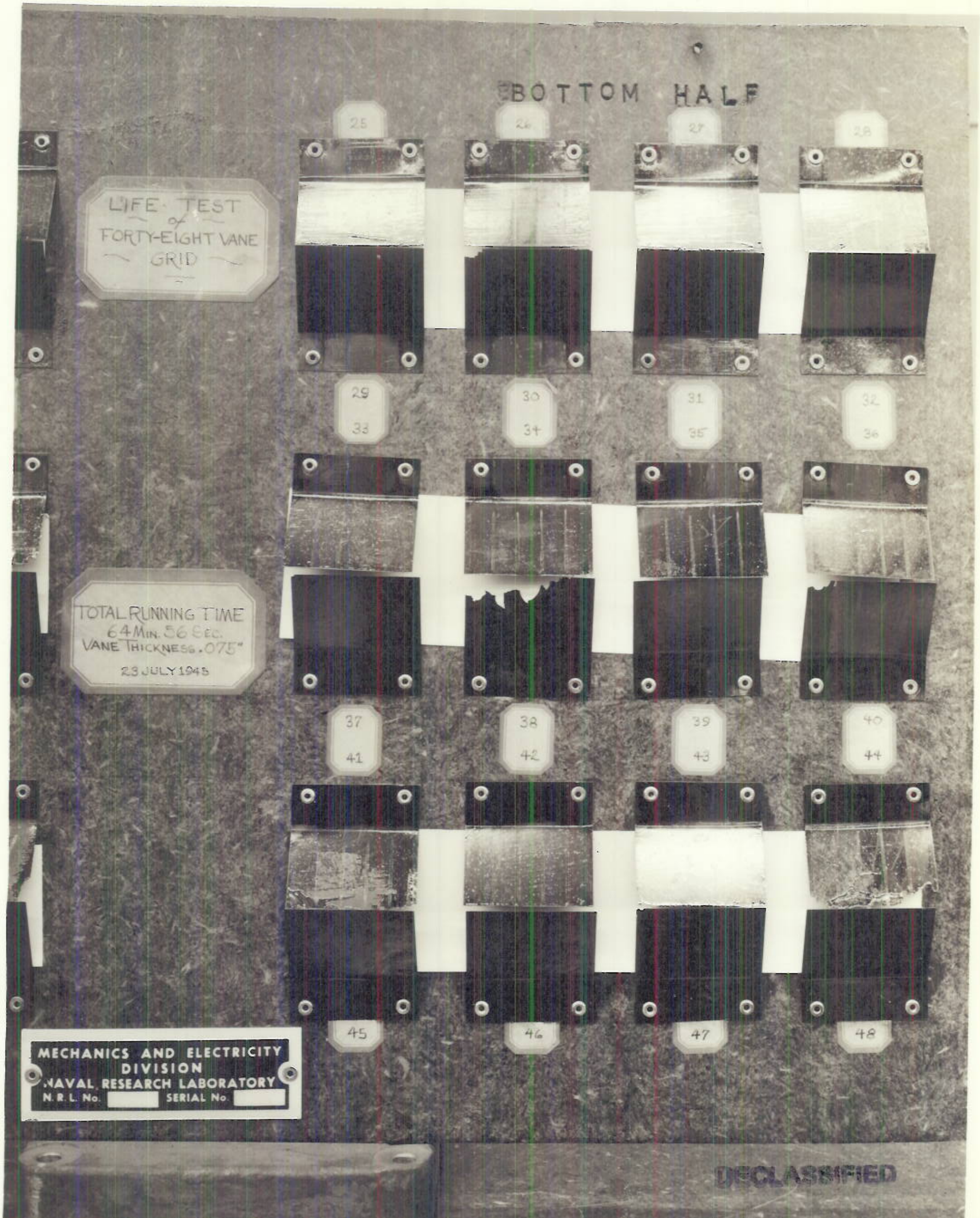

TOP HALF
1
2
3
4
LIFE TEST of FORTY-EIGHT VANE GRID
5
9
6
10
7
11
8
12
TOTAL RUNNING TIME
64 MIN. 56 SEC.
VANE THICKNESS .075"
23 JULY 1948
13
17
14
18
15
19
16
20
21
22
23
24
MECHANICS AND ELECTRICITY DIVISION
NAVAL RESEARCH LABORATORY
N. R. L. No.
SERIAL No.
DECLASSIFIED

PLATE 9

DECLASSIFIED



CONFIDENTIAL

PLATE 10

RECORD OF DAMAGE

TOP OF GRID

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32

JETS
#10, #11, & #12

33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64

COMMENTS

VANE	FAILURE
27	ENTIRE EDGE CHIPPED TO DEPTH OF 1/32"
38	CORNER CHIPPED 3/32 x 3/32

DATA ON RUN 20 JULY 1945

TIME OF RUN	9 MIN. 51 SEC	FUEL PRESSURE	
PREVIOUS TIME	2 MIN. 30 SEC	FUEL RATE	560#/HR (MAX)
TOTAL RUNNING TIME	12 MIN. 21 SEC	JETS USED	#10, #11, & #12

Encl. A to NRL Ltr. C-S41-8(447:LFC)
Ser. No. C-440-36/45

[redacted]

PLATE 11

RECORD OF DAMAGE

TOP OF GRID

[redacted]

DATA ON RUN	20 JULY 1945		
TIME OF RUN	10 MIN. 00 SEC.	FUEL PRESSURE	47 #/IN.^{2}
PREVIOUS TIME	12 MIN. 21 SEC.	FUEL RATE	500 #/HR.
TOTAL RUNNING TIME	22 MIN. 21 SEC.	JETS USED	#13 & #14

COMMENTS

VANE	FAILURE
13	CORNER CHIPPED 3/8 x 1/8 - TWO CRACKS
14	CORNER CHIPPED 1/4 x 1/16
27	EDGE FRAYED 1" LENGTH - 1/32 TO 1/16 DEEP
38	CORNER CHIPPED 1/8 x 1/16
41	3/16 CRACK - 1/2" FROM END
56	CORNER CHIPPED 1/8 x 1/16

VANES #10 & #14 WERE BENT PERMANENTLY BY GRID. GRID BUCKLED CAUSING A CURVED SEAT

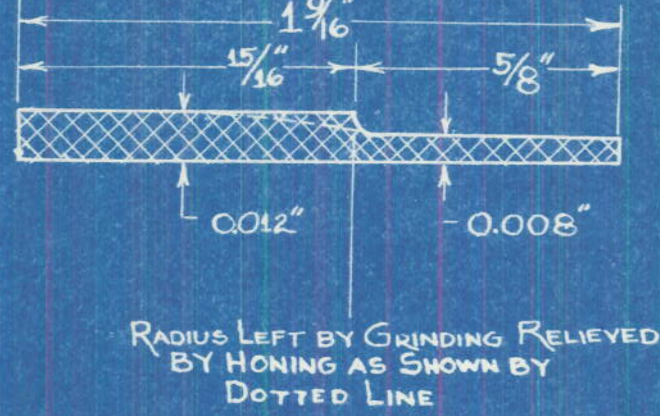
VANE #27 DAMAGED MOST.

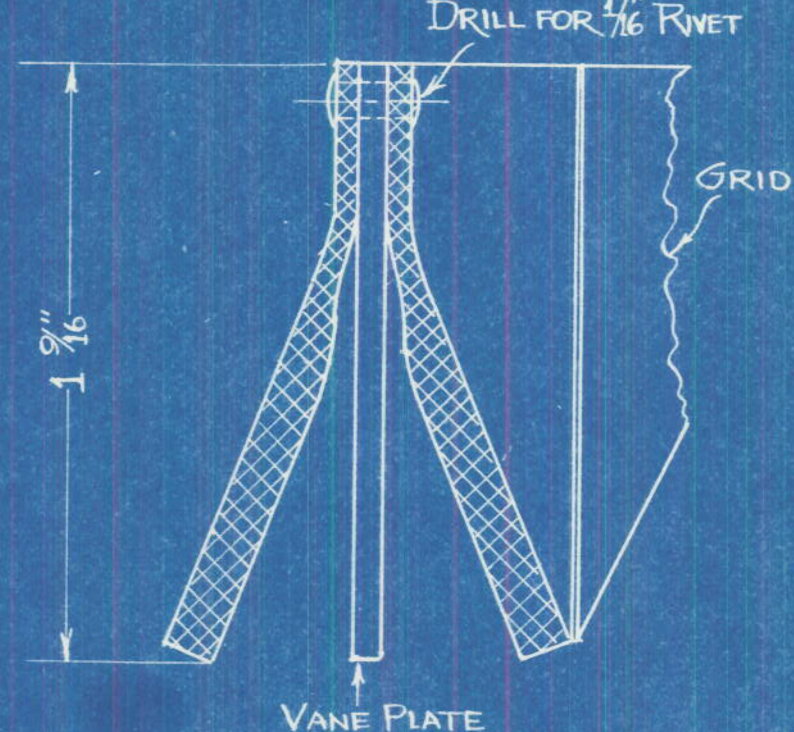
DECLASSIFIED

Encl (A) to NRL Ltr. C-S41-8(447:LFC)
Ser. No. C-440-36/45

PLATE 12

PLATE #

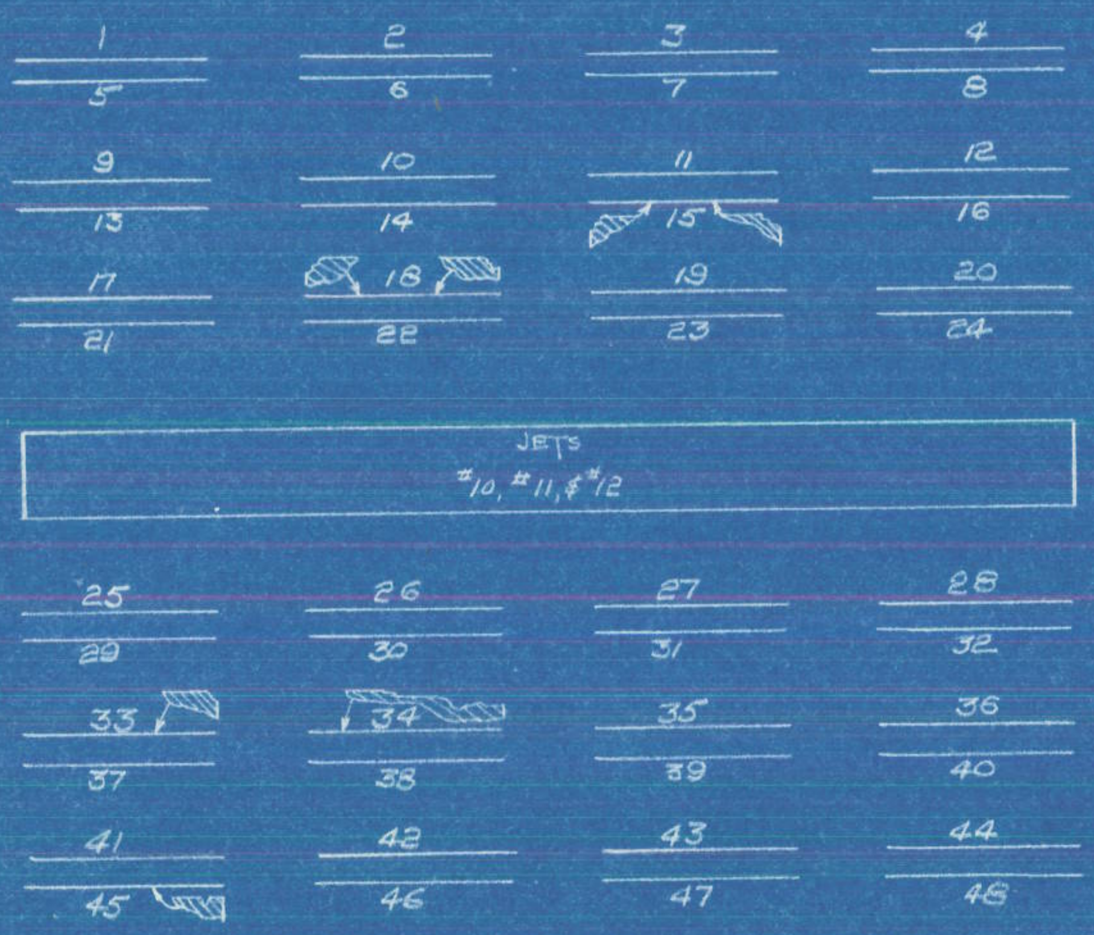




0.012" SPRING STEEL VANE GROUND TO 0.008" FOR FLEXIBILITY

RECORD OF DAMAGE

TOP OF GRID



DATA ON RUN	7 AUGUST 1945	FUEL PRESSURE	27 #/IN²
TIME OF RUN	15 MIN. 00SEC.	FUEL RATE (BY ROT)	398 #/HR.
PREVIOUS TIME	NONE	JETS USED	#10, #11, & #12
TOTAL RUNNING TIME	15 MIN 00SEC		

COMMENTS

VANE	FAILURE
15	TRIANGULAR CHIP FROM ENDS – 1/16 × 3/32
18	TRIANGULAR CHIP FROM ENDS – LEFT, 1/32 × 1/16 RIGHT, 3/32 × 1/4
33	TRIANGULAR CHIP – 1/32 × 1/32
34	EDGE CHIPPED 1/8 TO 1/16 ALONG 1" OF LENGTH
45	CRACK STARTING AT EDGE

VANES #13–#20 & #29–#36 ARE DUAL-THICKNESS – SEE PLATE 13

[redacted]

RECORD OF DAMAGE

TOP OF GRID

COMMENTS

VANE	FAILURE
14	CORNER CHIP - 1/8 x 1/16 EDGE CHIPS - 1/16 x 1/32
15	EDGE CHIP 1/16 x 3/4, CORNER CHIP 1/8 x 1/8
16	TRIANGULAR CHIP 1/16 x 1/16
18	REED BROKEN AT BEND
19	TRIANGULAR CHIP - 1/4 x 1/16
20	TRIANGULAR CHIP - 1/8 x 3/16
21	CORNER CHIP - 1/16 x 1/8
23	3 - 1/16 x 1/64 EDGE CHIPS
29	TRIANGULAR CHIP 1/16 x 1/16
32	TRIANGULAR CHIP - 1/8 x 1/16
33	TRIANGULAR CHIP - 1/16 x 1/16
34	EDGE CHIP 1/4" x 1 1/4, REMAINDER CHIPPED 1/16
35	TRIANGULAR CHIPS - 1/16 x 1/8
36	TRIANGULAR CHIP - 1/8 x 1/8
45	TRIANGULAR CHIP - 1/16 x 1/32 RT CORNER 1/8 x 3/16
47	TRIANGULAR CHIP - 1/4 x 5/16

SEQUENCE TO PLATES 14 & 15

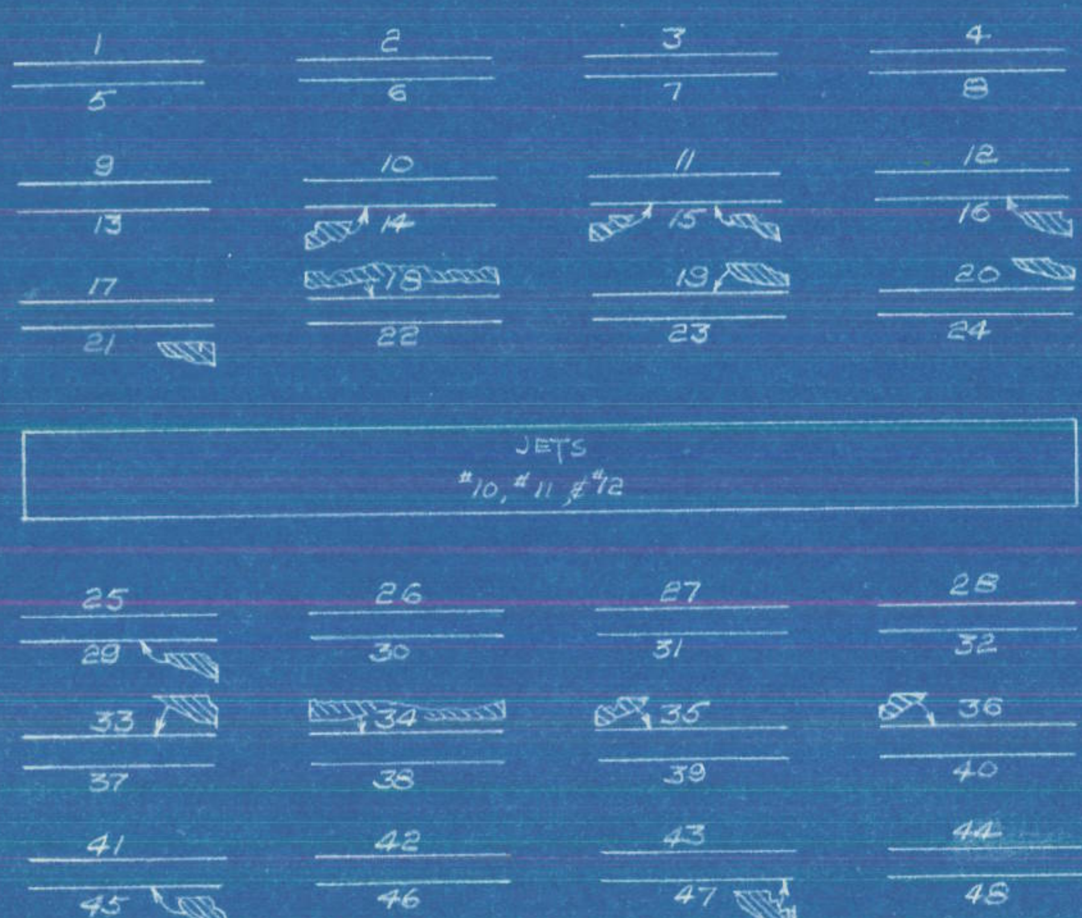
DATA ON RUN	7 AUGUST 1945		
TIME OF RUN	15 MIN. 00 SEC.	FUEL PRESSURE	27 #/IN²
PREVIOUS TIME	30 MIN. 00 SEC.	FUEL RATE	402 #/HR.
TOTAL RUNNING TIME	45 MIN. 00 SEC.	JETS USED	#10, #11, & #12

Encl. (A) to NRL Ltr. C-S41-8(447:LFC)
Ser. No. C-440-36/45

PLATE 15

RECORD OF DAMAGE

TOP OF GRID



DATA ON RUN	7 AUGUST 1945		
TIME OF RUN	15 MIN. 00 SEC.	FUEL PRESSURE	27 #/IN.²
PREVIOUS TIME	15 MIN. 00 SEC.	FUEL RATE (BY ROT)	398 #/HR.
TOTAL RUNNING TIME	30 MIN. 00 SEC.	JETS USED	#10, #11 & #12

COMMENTS

VANE	FAILURE
14	CORNER CHIP - 1/16 x 1/16
15	CORNERS CHIPPED - 3/16 x 1/4
16	TRIANGULAR CHIP - 1/16 x 1/16
18	ENTIRE EDGE CHIPPED 5/16
19	TRIANGULAR CHIP - 1/8 x 1/4
20	TRIANGULAR CHIP - 1/8 x 3/16
21	TARE 1/8" LONG
29	TRIANGULAR CHIP - 1/16 x 1/16
33	TRIANGULAR CHIP - 1/16 x 1/16
34	ENTIRE EDGE CHIPPED 1/16 - 1/8
35	CORNER CHIP - 1/8 x 3/16
36	TRIANGULAR CHIP - 1/8 x 1/8
45	CORNER CHIP - 1/8 x 1/8
47	CORNER CHIP - 3/16 x 1/8

SEQUENCE TO PLATE 14

Encl. (A) to NRL Ltr. C-S41-8 (447:LFC)
Ser. No. C-440-36/45

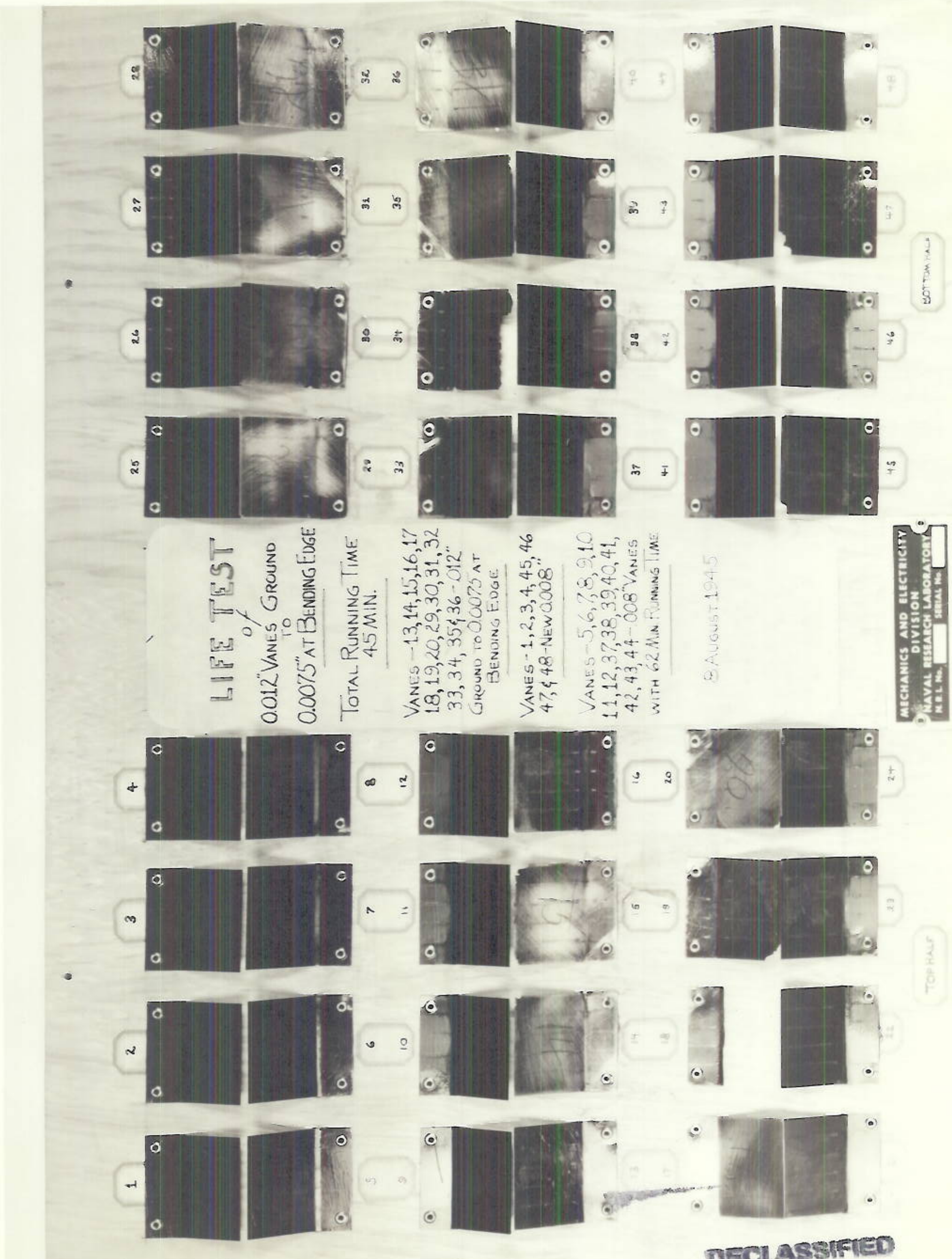
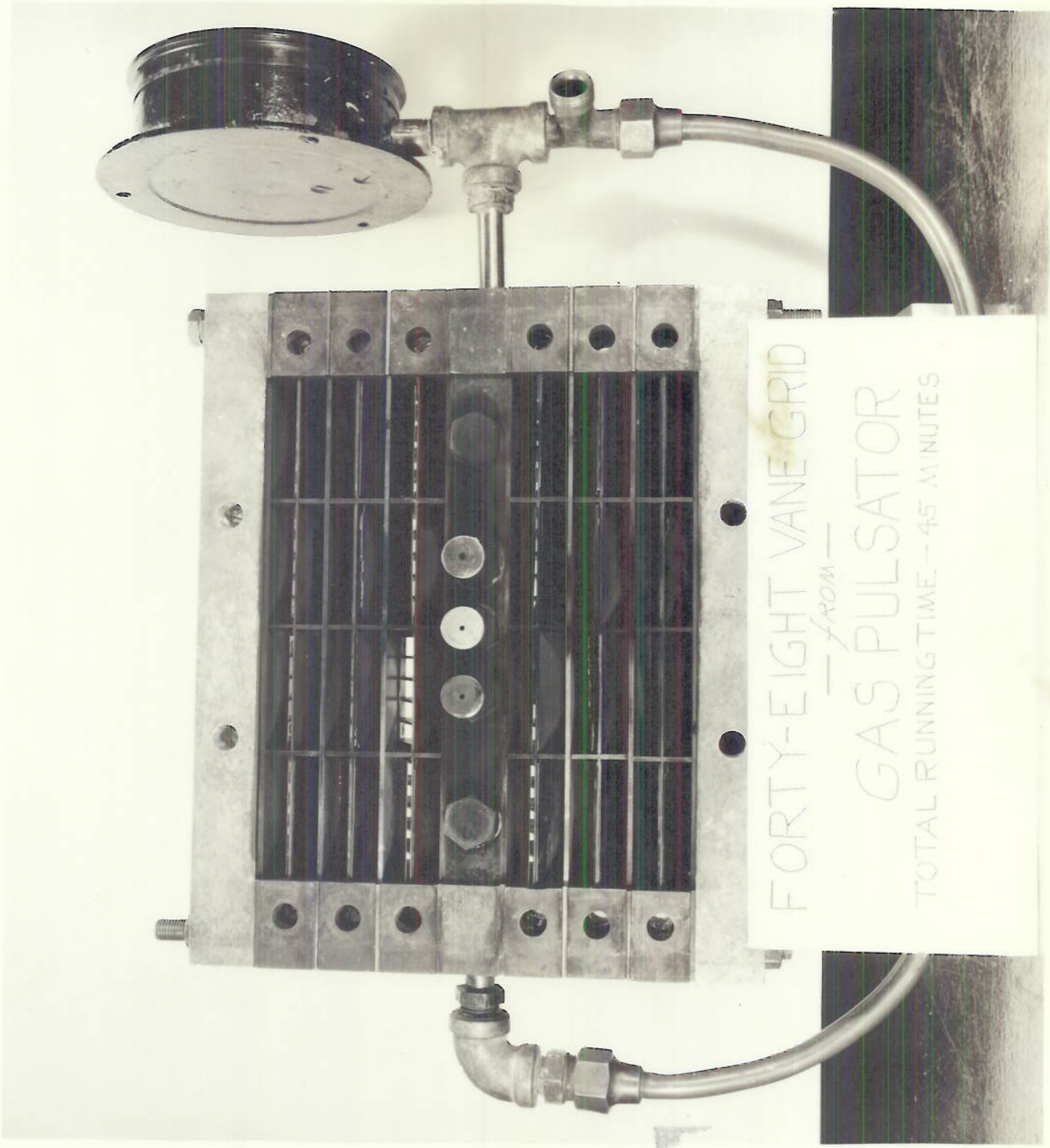
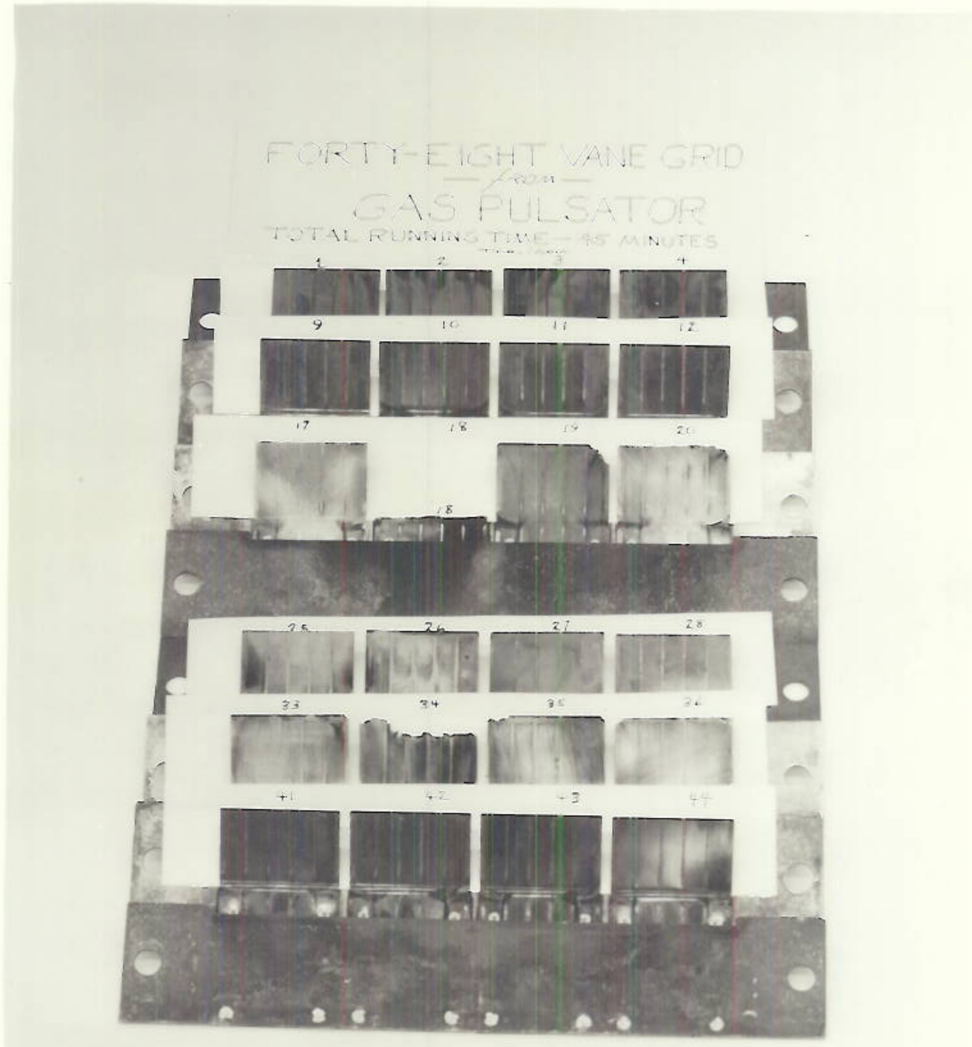

LIFE TEST
of
0.012" VANES GROUND
TO
0.0075" AT BENDING EDGE
TOTAL RUNNING TIME
45 MIN.
VANES - 13,14,15,16,17
18,19,20,29,30,31,32
33,34,35 & 36 - .012"
GROUND TO 0.0075 AT
BENDING EDGE
VANES - 1,2,3,4,45,46
47 & 48 - NEW 0.008"
VANES - 5,6,7,8,9,10
11,12,37,38,39,40,41,
42,43,44 - .008" VANES
WITH 62 MIN RUNNING TIME
8 AUGUST 1945
MECHANICS AND ELECTRICITY
DIVISION
NAVAL RESEARCH LABORATORY
BOTTOM HALF
TOP HALF

PLATE 17

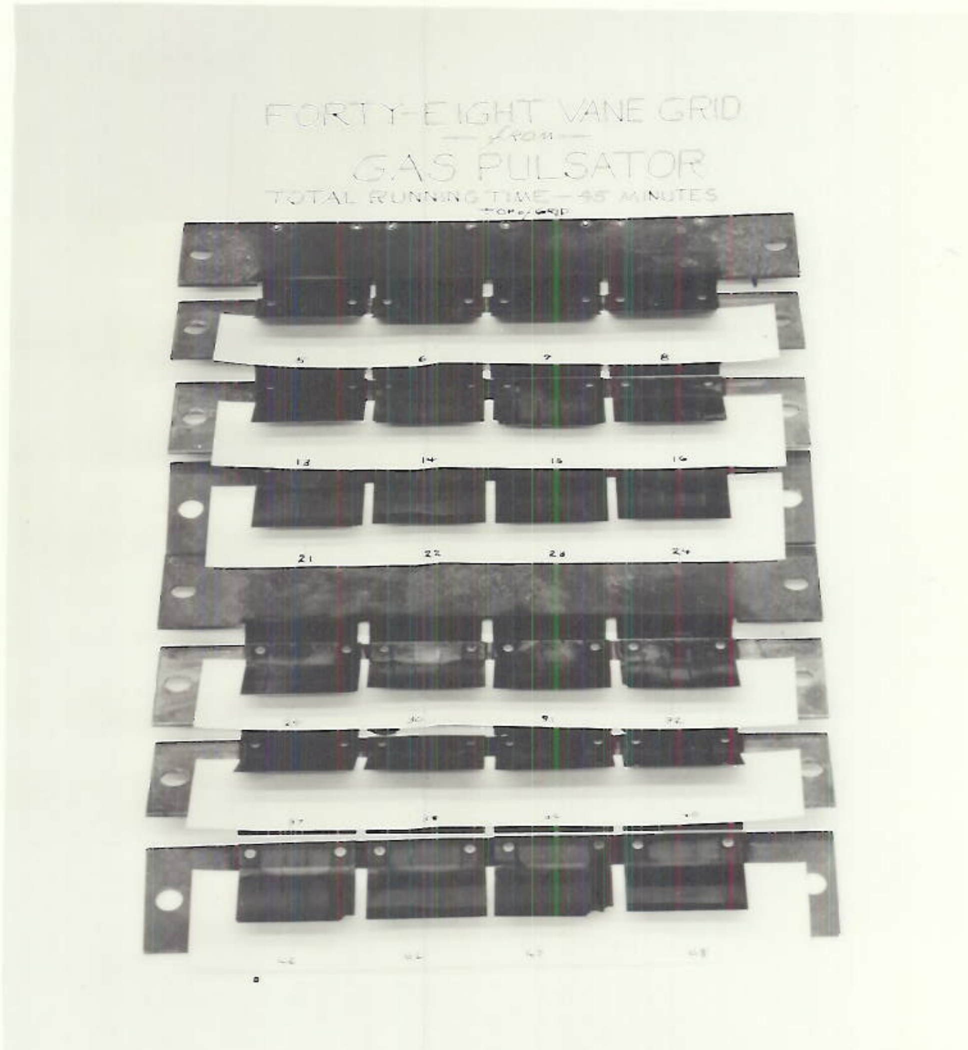


DECLASSIFIED



CONFIDENTIAL

PLATE 19


FORTY-EIGHT VANE GRID
from
GAS PULSATOR
TOTAL RUNNING TIME - 45 MINUTES

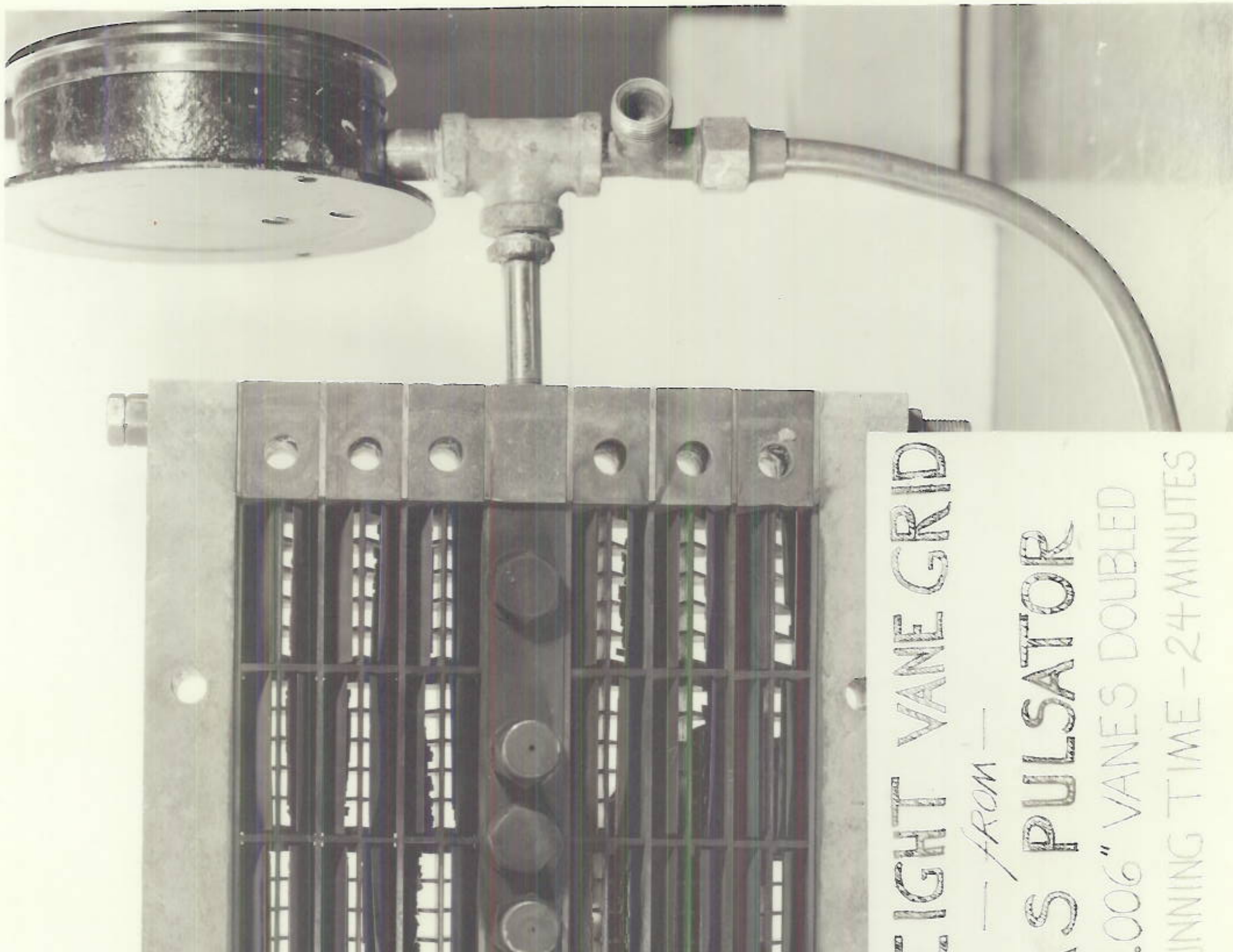

FORTY-EIGHT VANE GRID
— from —
GAS PULSATOR
USING 0.006" VANES DOUBLED
TOTAL RUNNING TIME - 24 MINUTES

PLATE 21

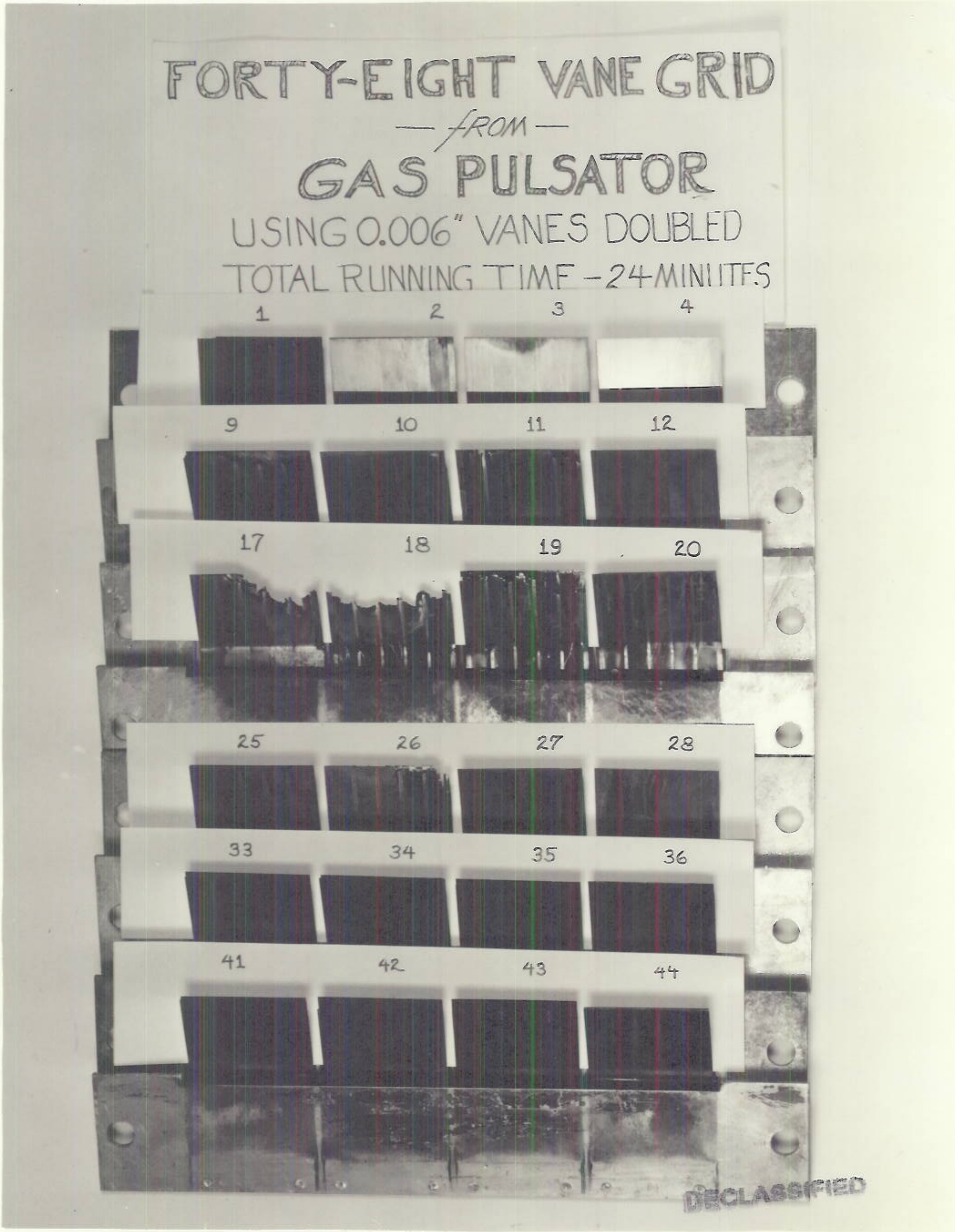

FORTY-EIGHT VANE GRID
— FROM —
GAS PULSATOR
USING 0.006" VANES DOUBLED
TOTAL RUNNING TIME - 24 MINUTES
1
2
3
4
9
10
11
12
17
18
19
20
25
26
27
28
33
34
35
36
41
42
43
44
DECLASSIFIED

PLATE 22

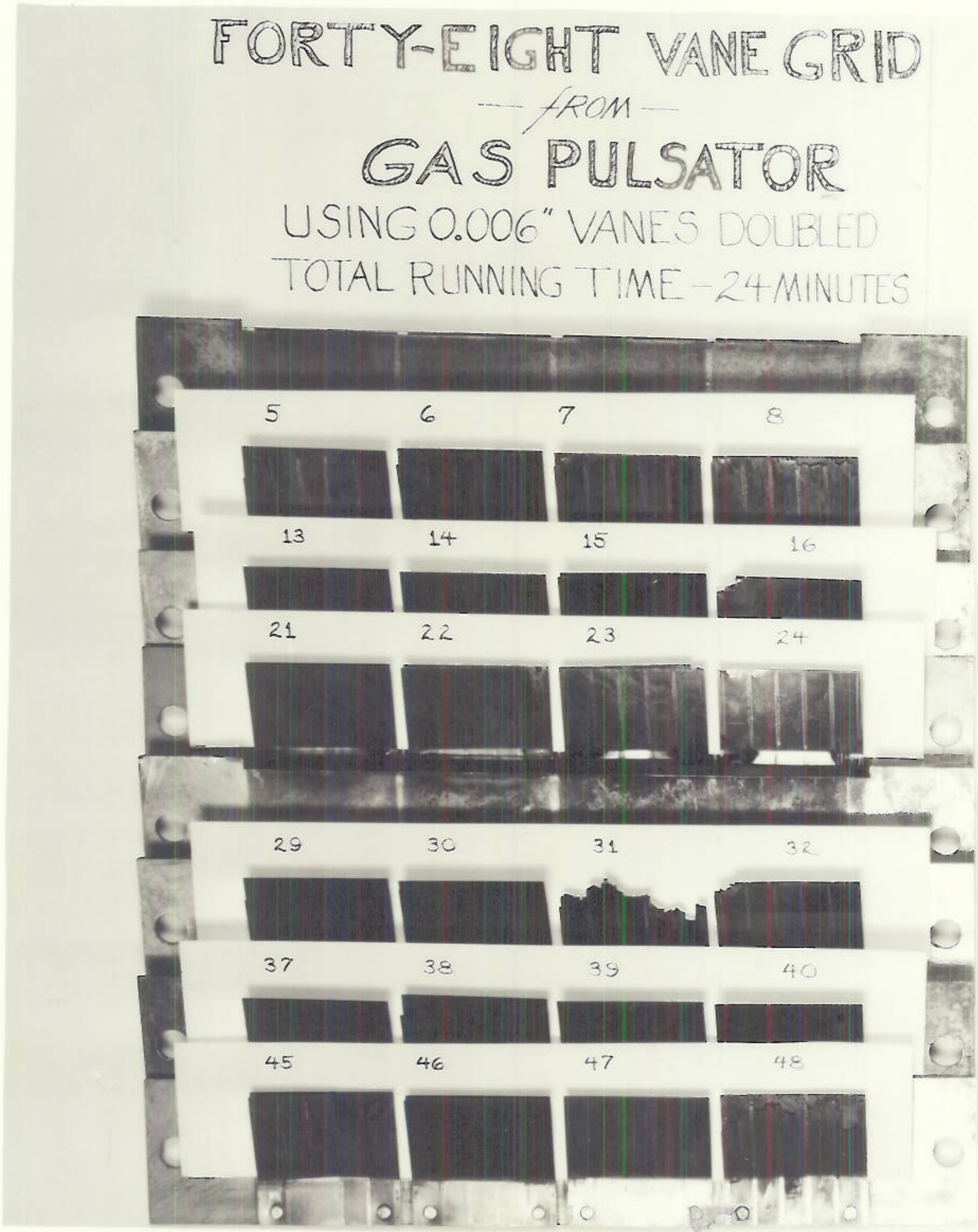
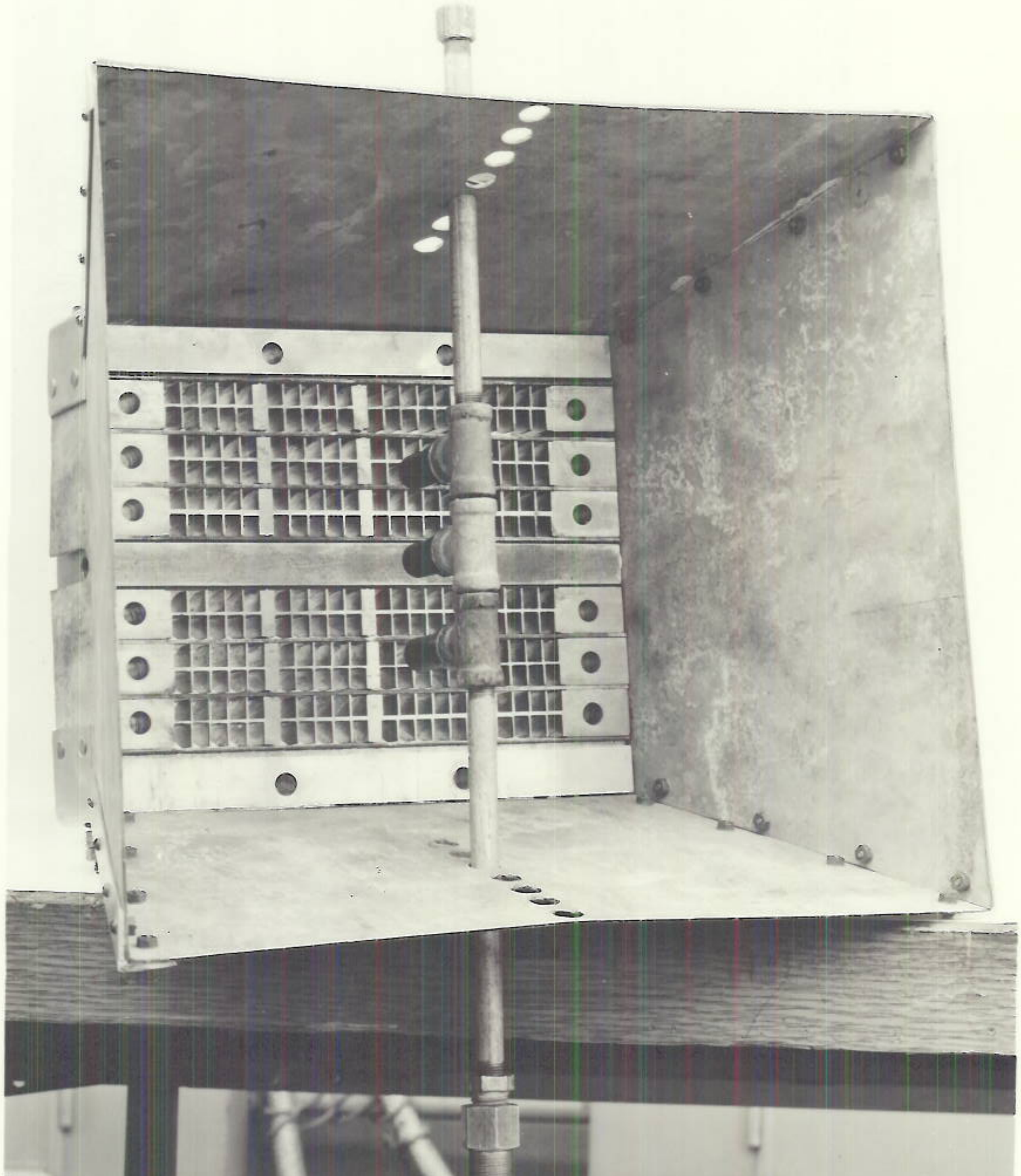
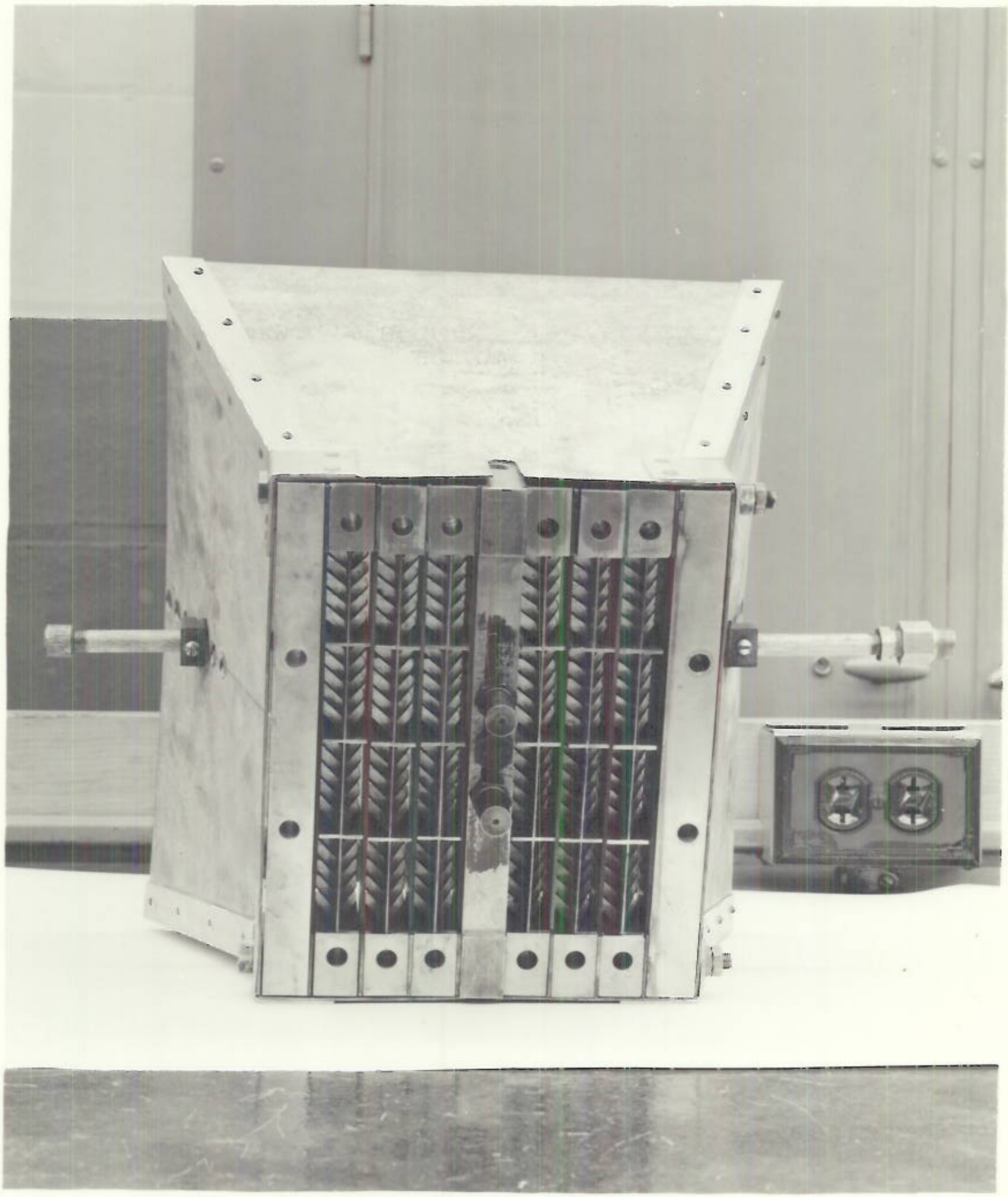

FORTY-EIGHT VANE GRID
— FROM —
GAS PULSATOR
USING 0.006" VANES DOUBLED
TOTAL RUNNING TIME - 24 MINUTES
5
6
7
8
13
14
15
16
21
22
23
24
29
30
31
32
37
38
39
40
45
46
47
48

PLATE 23



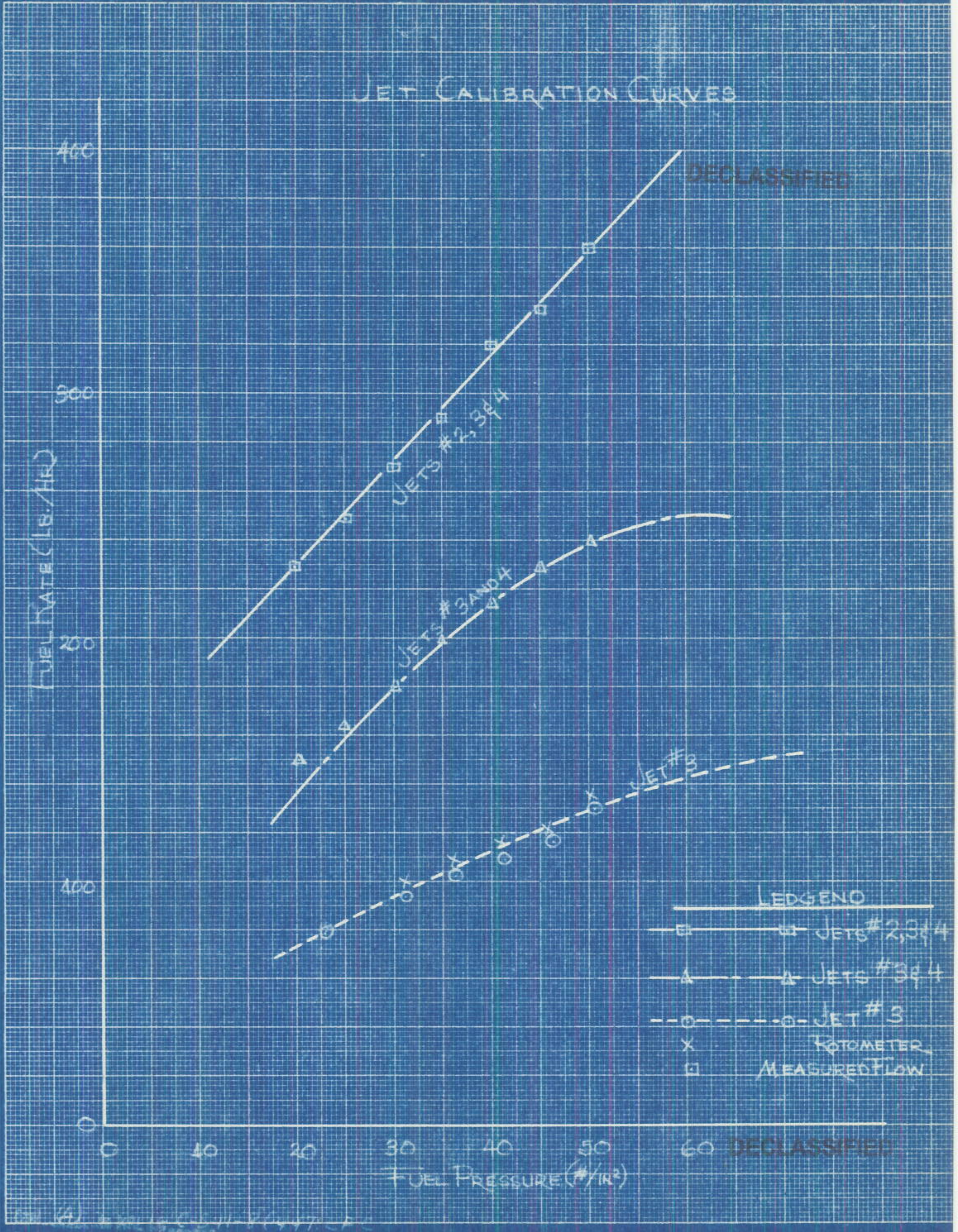
DECLASSIFIED



DECLASSIFIED

CONFIDENTIAL

PLATE 25



[redacted]

PLATE 26

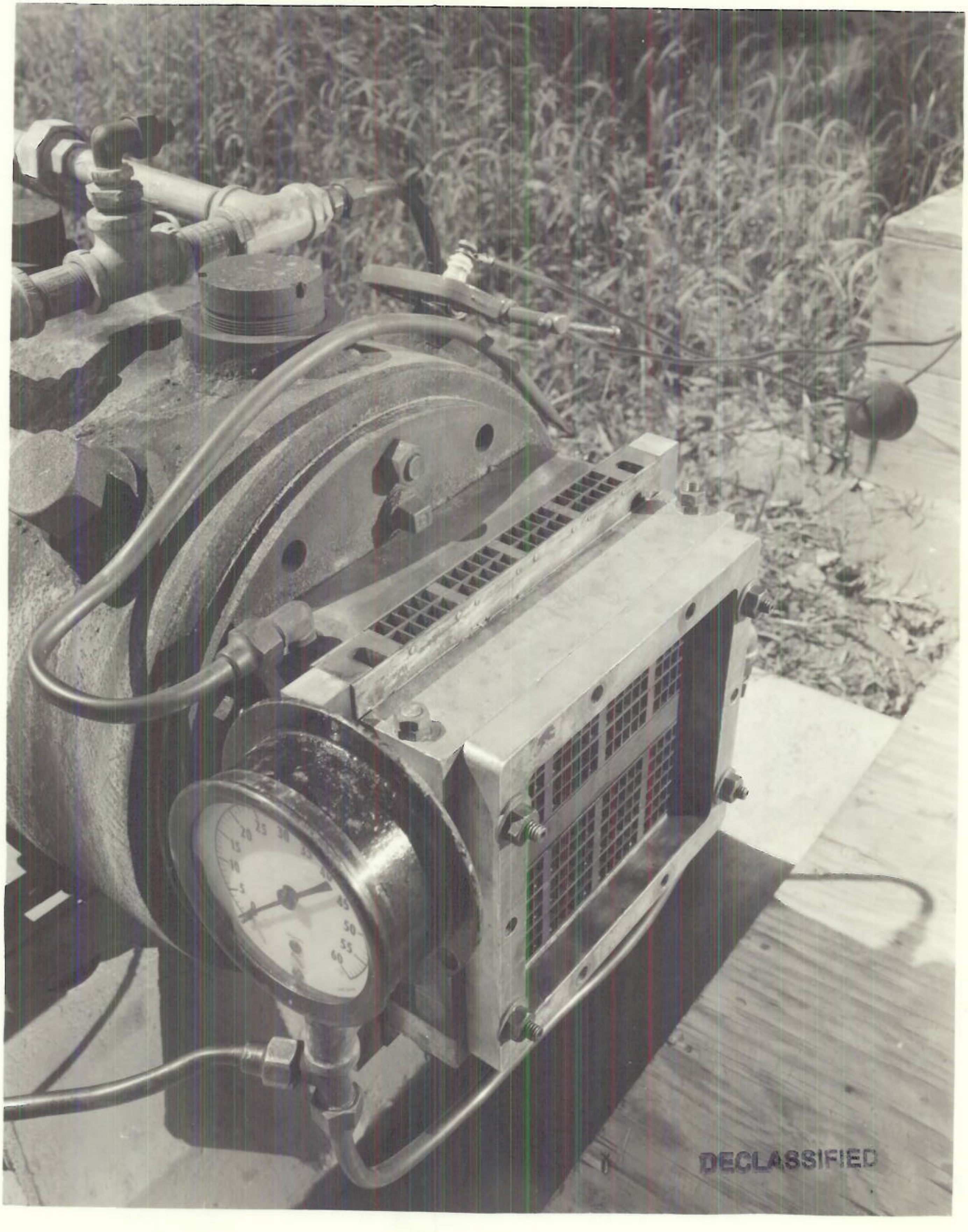
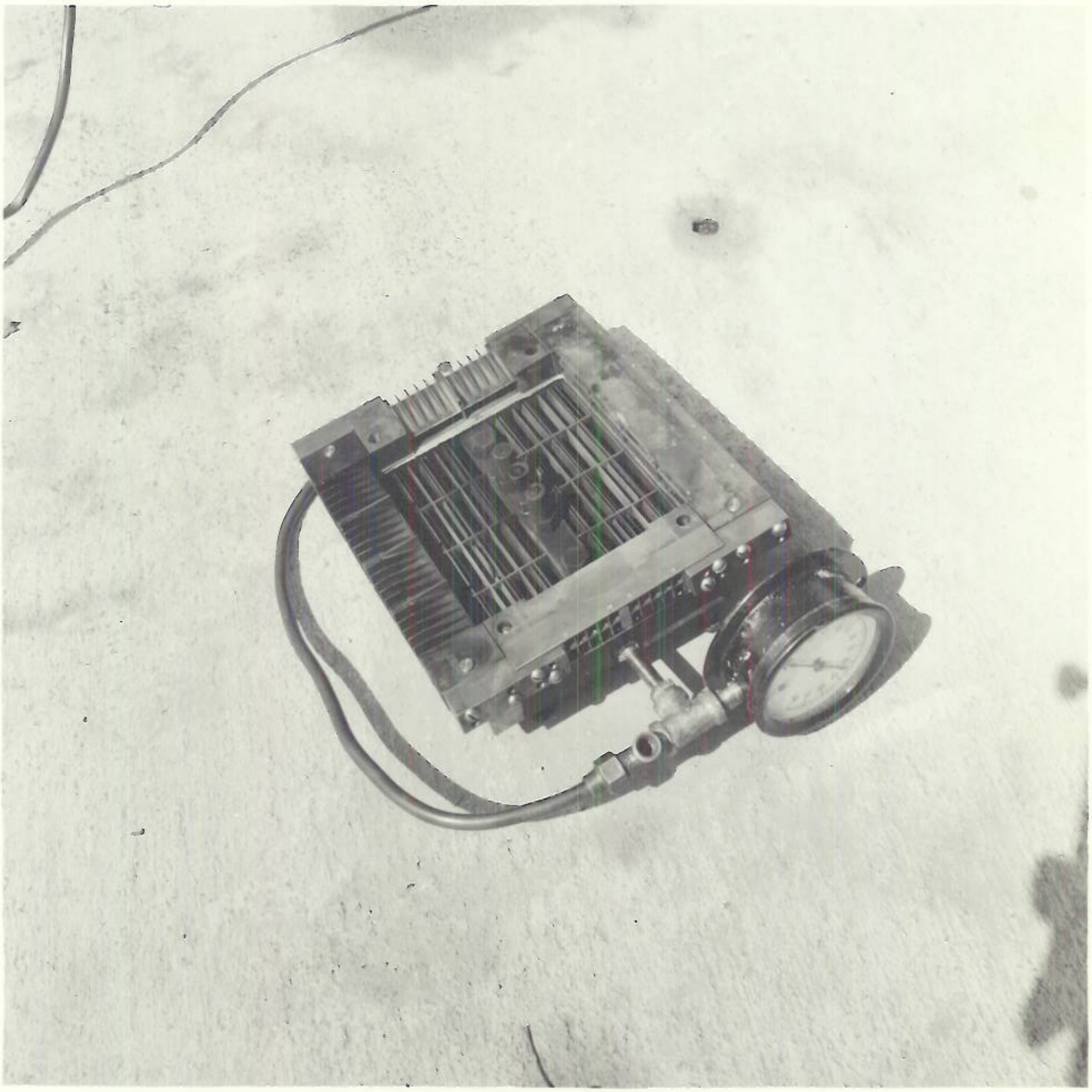


PLATE 27

DECLASSIFIED



DECLASSIFIED

CONFIDENTIAL

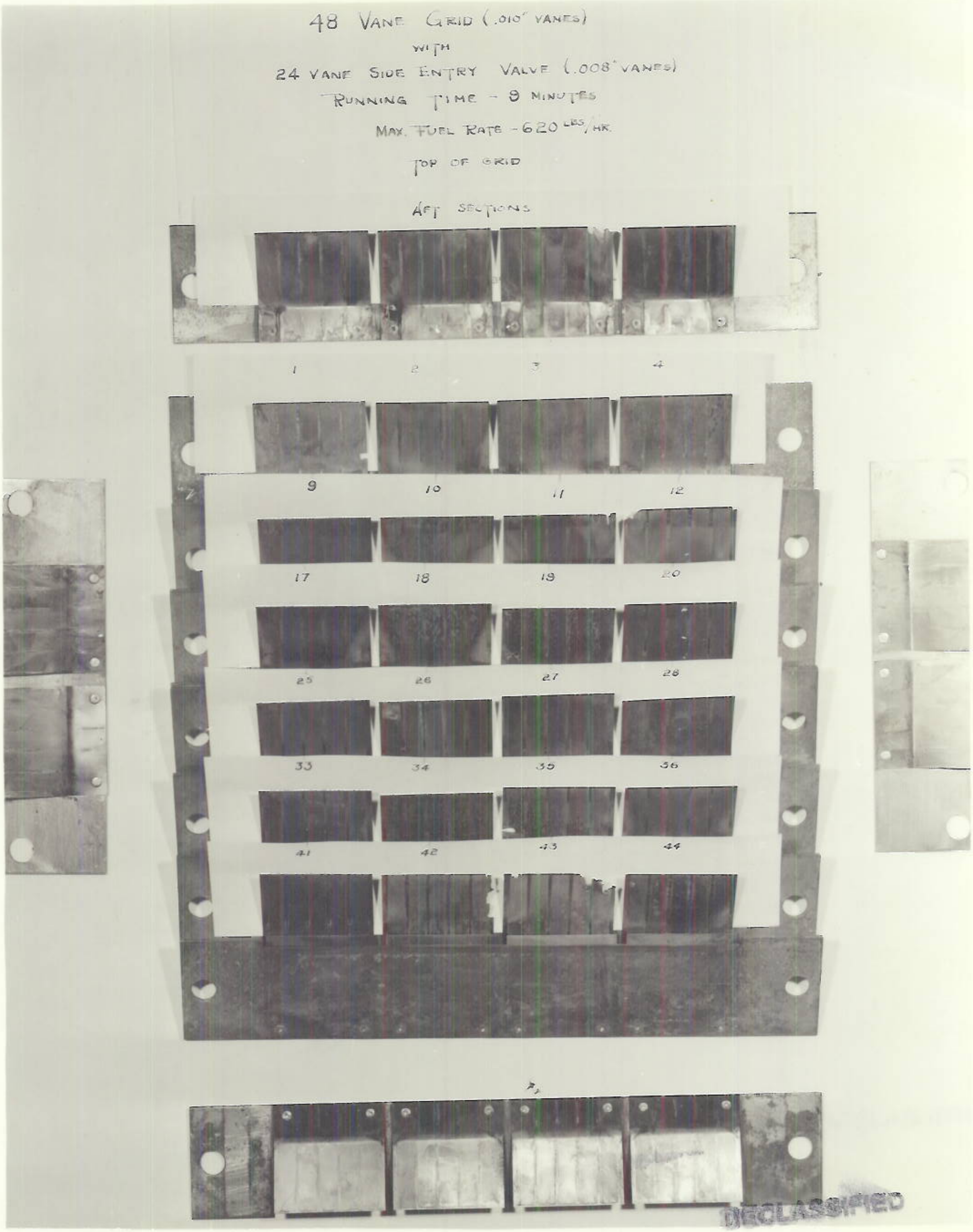

48 VANE GRID (.010" VANES)
WITH
24 VANE SIDE ENTRY VALVE (.008" VANES)
RUNNING TIME - 9 MINUTES
MAX. FUEL RATE - 620 LBS/HR.
TOP OF GRID
AFT SECTIONS
1
2
3
4
9
10
11
12
17
18
19
20
25
26
27
28
33
34
35
36
41
42
43
44

PLATE 29

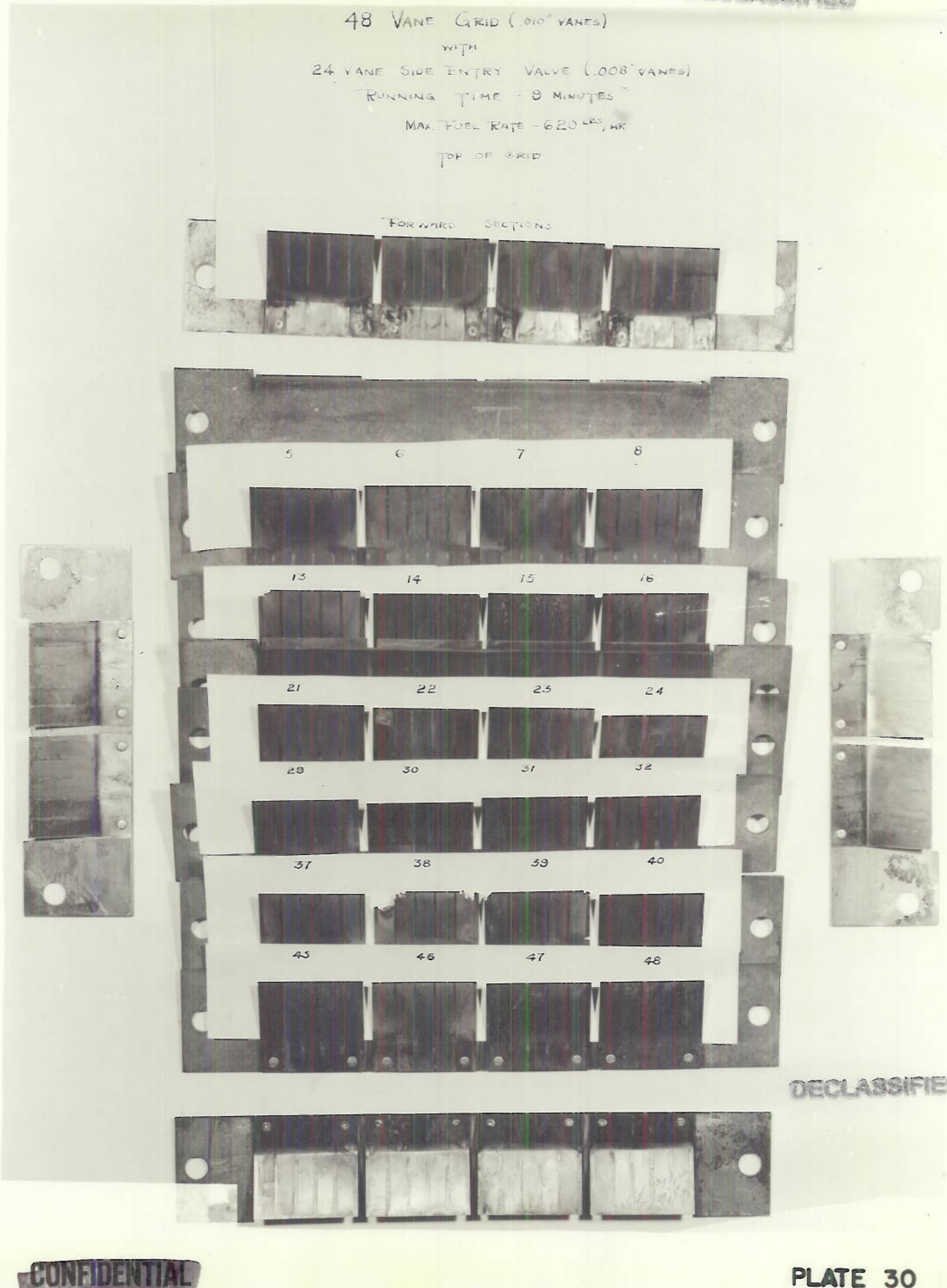
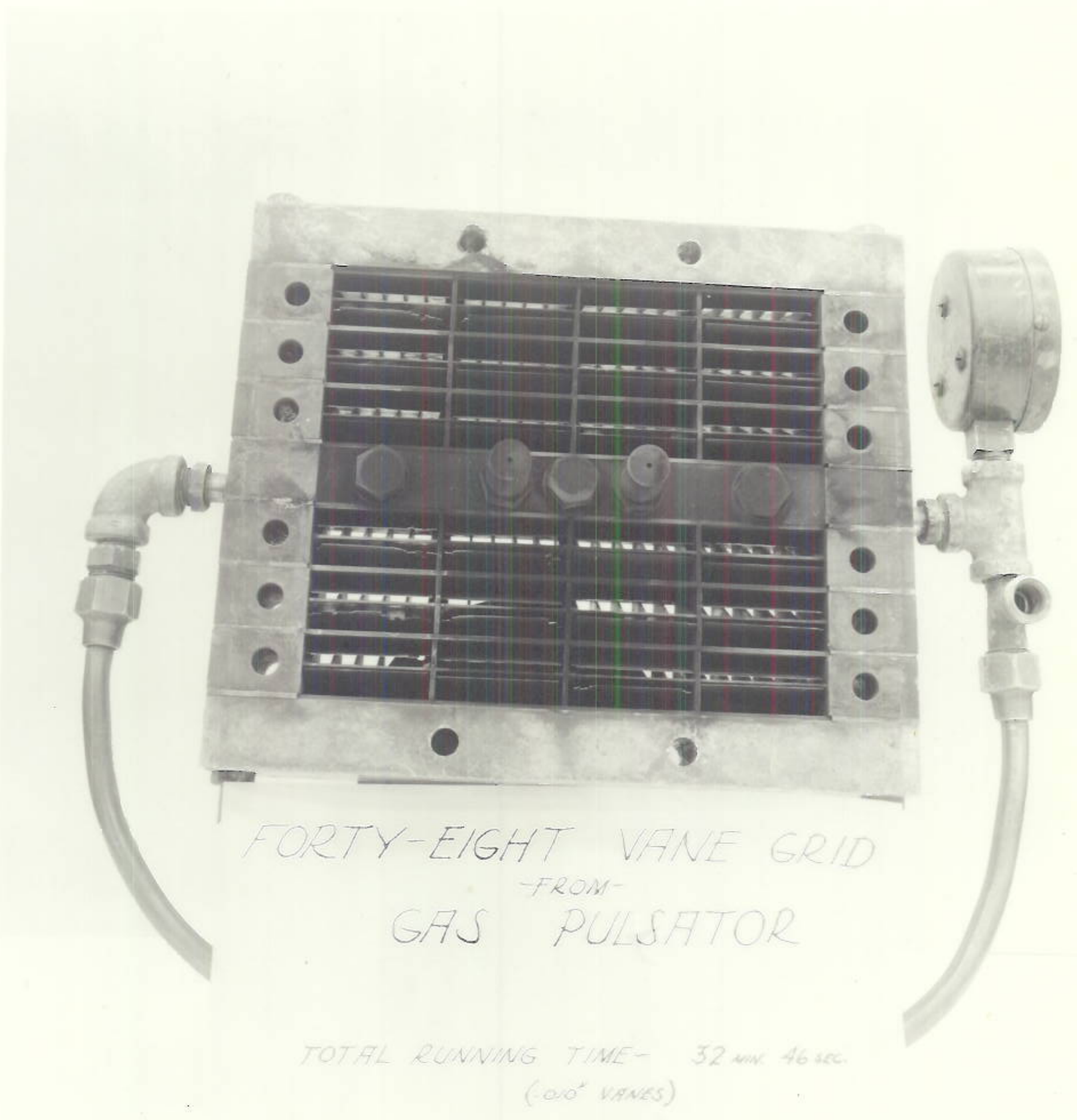

48 VANE GRID (.010" VANES)
WITH
24 VANE SIDE ENTRY VALVE (.008" VANES)
RUNNING TIME - 8 MINUTES
MAX. FUEL RATE - 620 LBS/HR
TOP OF GRID
FORWARD SECTIONS
5
6
7
8
13
14
15
16
21
22
23
24
29
30
31
32
37
38
39
40
45
46
47
48

PLATE 30


FORTY-EIGHT VANE GRID
-FROM-
GAS PULSATOR
TOTAL RUNNING TIME- 32 MIN. 46 SEC.
(.010" VANES)


FORTY-EIGHT VANE GRID
FROM
GAS PULSATOR
TOTAL RUNNING TIME - 32 min. 46 sec.
(.010" VANES)

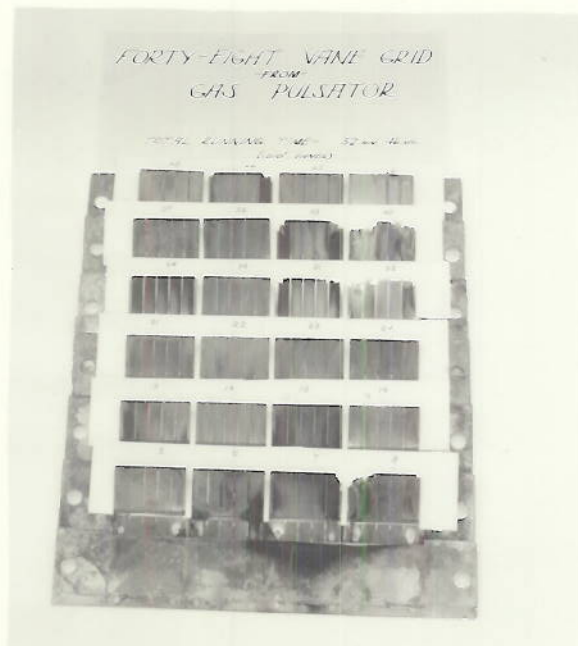


PLATE 33

DECLASSIFIED

PLATE 34

PLATE 35

PLATE 36

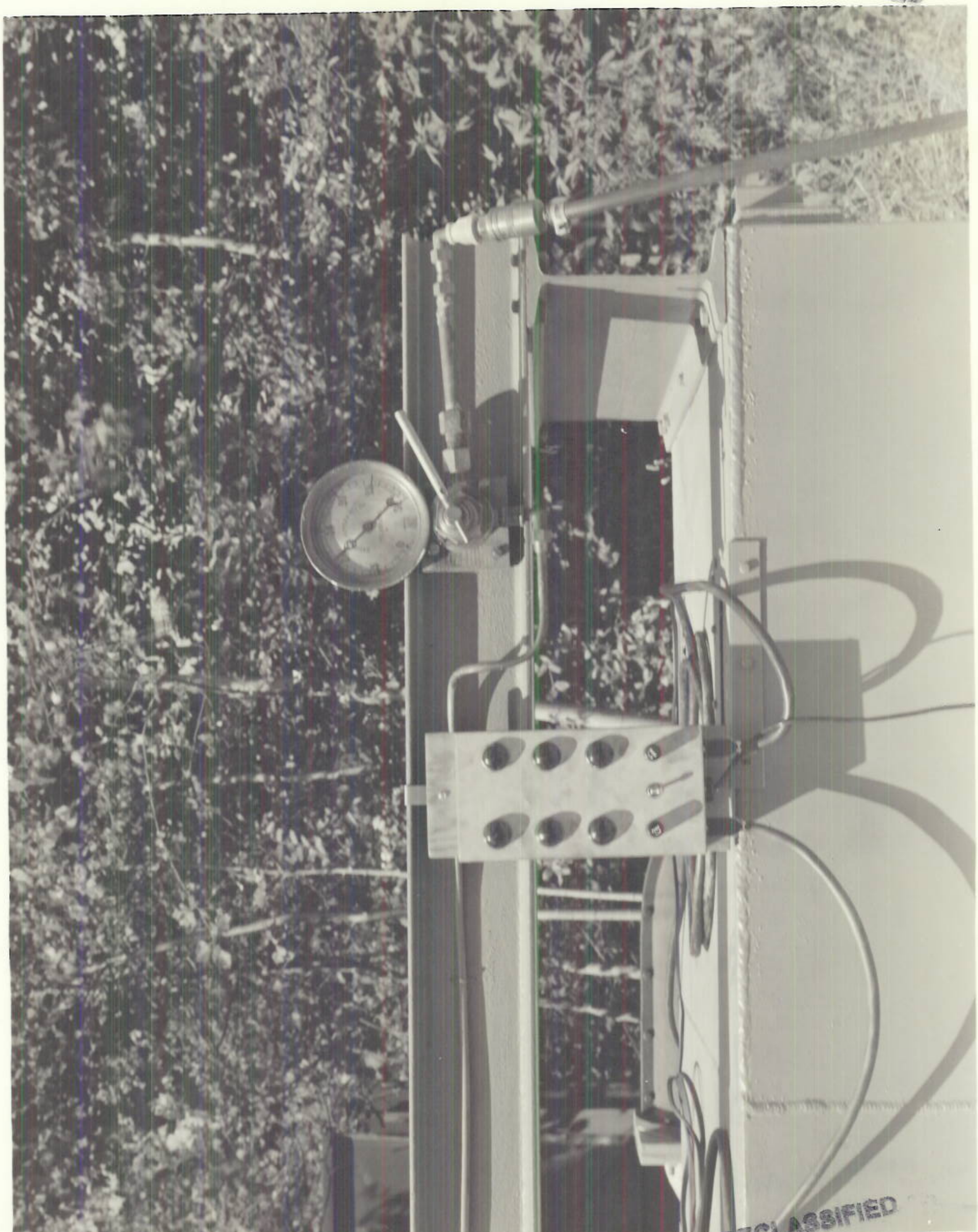


PLATE 37

PLATE 38

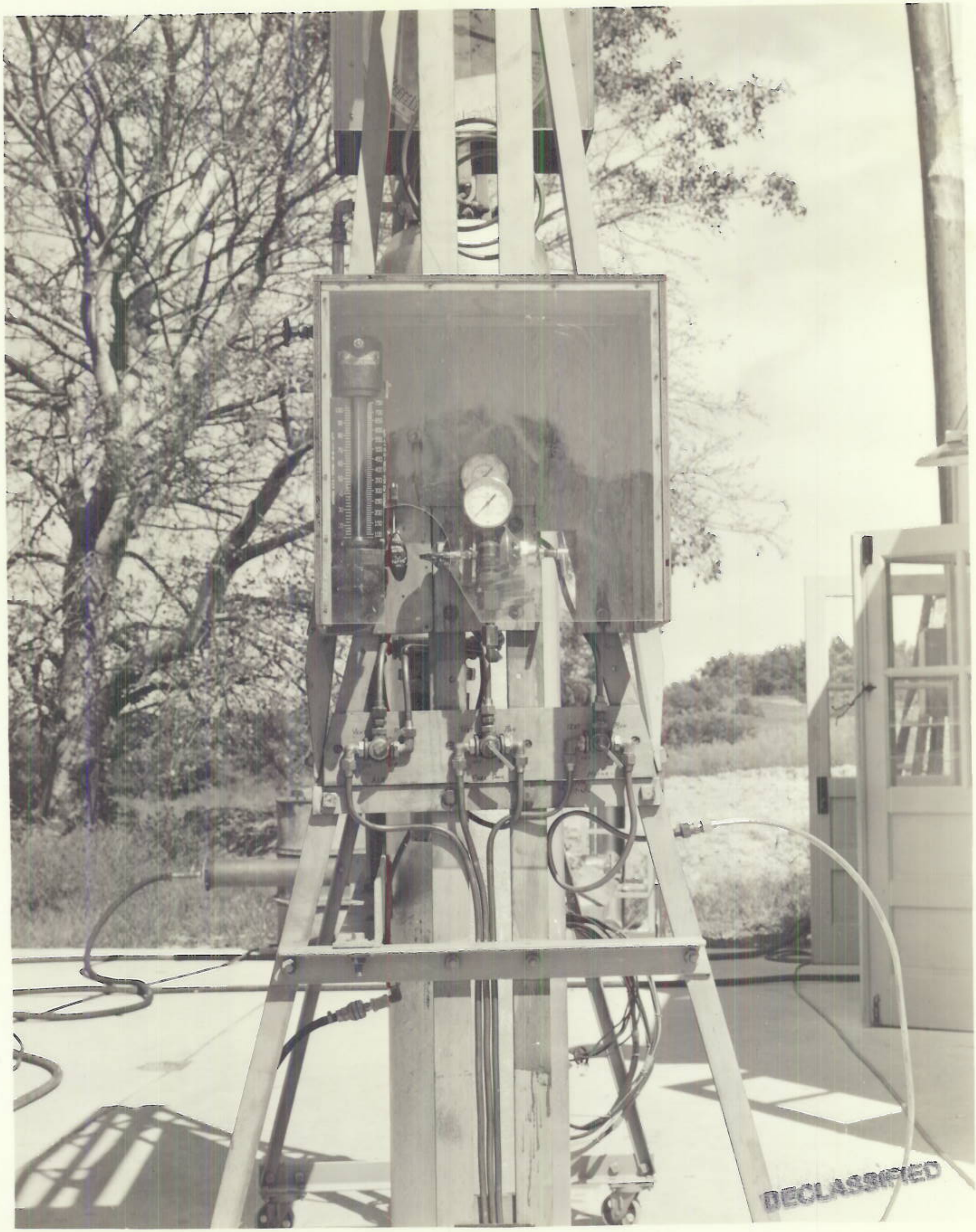
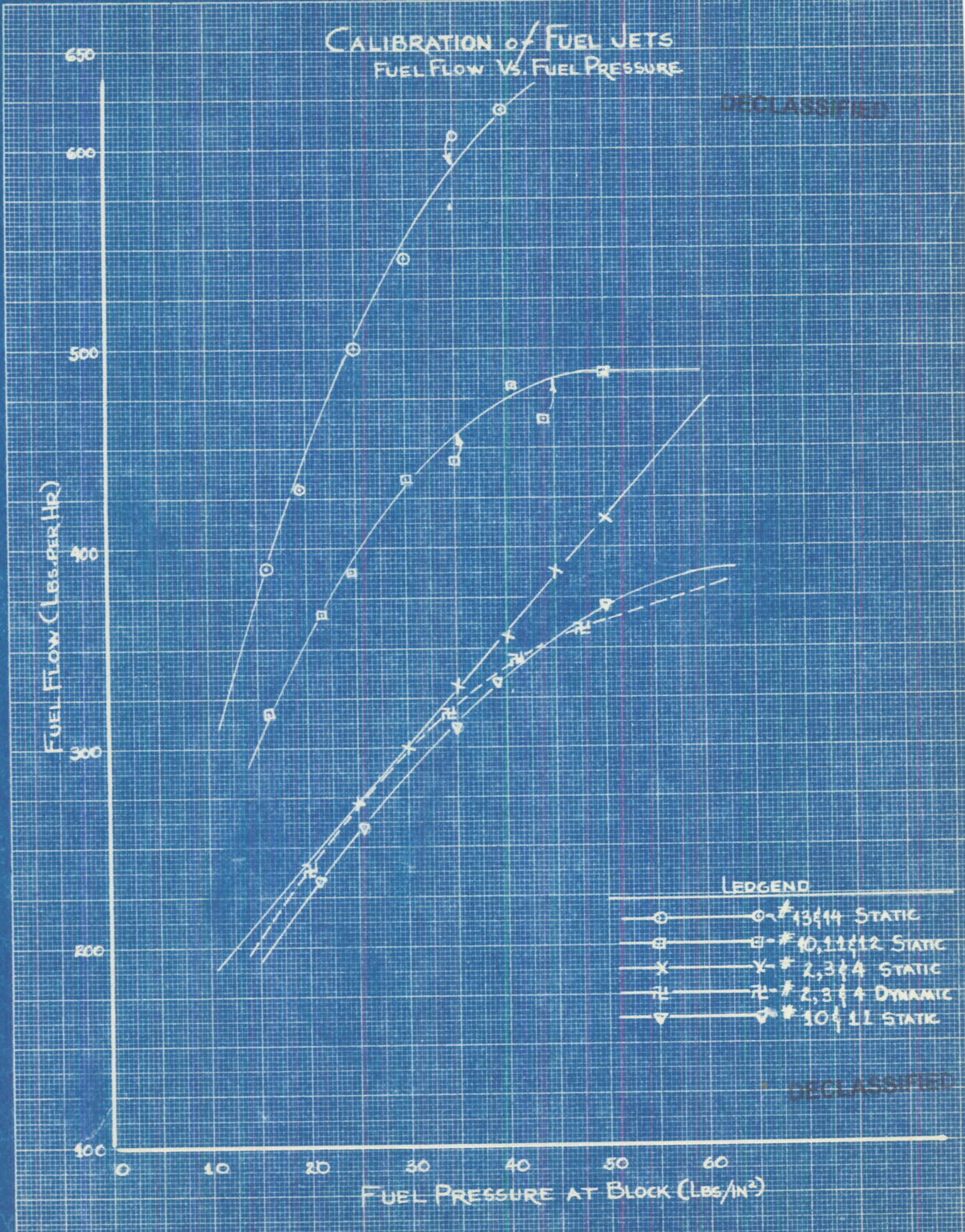


PLATE 39


CALIBRATION OF FUEL JETS
FUEL FLOW VS. FUEL PRESSURE
650
600
500
400
300
200
100
FUEL FLOW (LBS. PER HR.)
0
10
20
30
40
50
60
FUEL PRESSURE AT BLOCK (LBS/IN²)
LEDGEND
#13&14 STATIC
#10,11&12 STATIC
#2,3&4 STATIC
#2,3&4 DYNAMIC
#10&11 STATIC
DECLASSIFIED
DECLASSIFIED

[redacted]

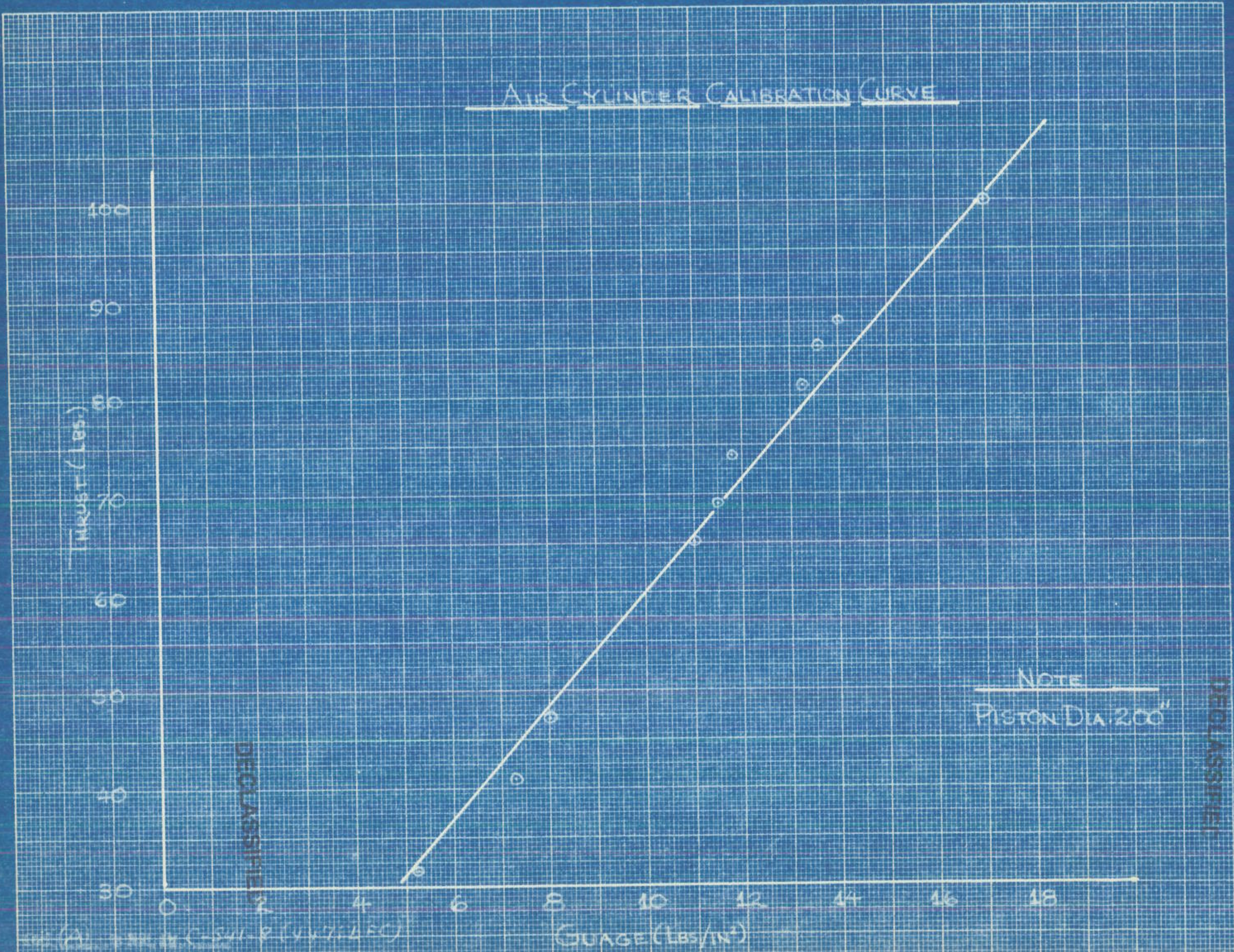

AIR CYLINDER CALIBRATION CURVE
THRUST (LBS.)
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
GUAGE (LBS/IN²)
NOTE
PISTON DIA. 2.00"

PLATE 41

GAS MOTOR

Typical Data for Large Tube Mounted in Thrust Stand with Air-Flow Box

Vanes: Thickness - 0.010", Number - 48, Condition - Opened

Jets: #10 and #11, Internal

Ignition: Spark plug, 2½" from front of tube

FUEL RATE	THRUST		SPECIFIC FUEL	AIR FLOW		AIR:FUEL RATIO	FREQUENCY
lb/hr	psig	lb	lb/hr / lb	in. H_2O	lb/hr		vib/sec
250	10.5	64	3.91	4.0	4060	16.2	44.0
300	13.4	81	3.71	4.3	4200	14.0	42.5
350	15.6	93.6	3.74	4.7	4400	12.6	42.0
400	17.0	102	3.92	4.8	4450	11.1	40.5

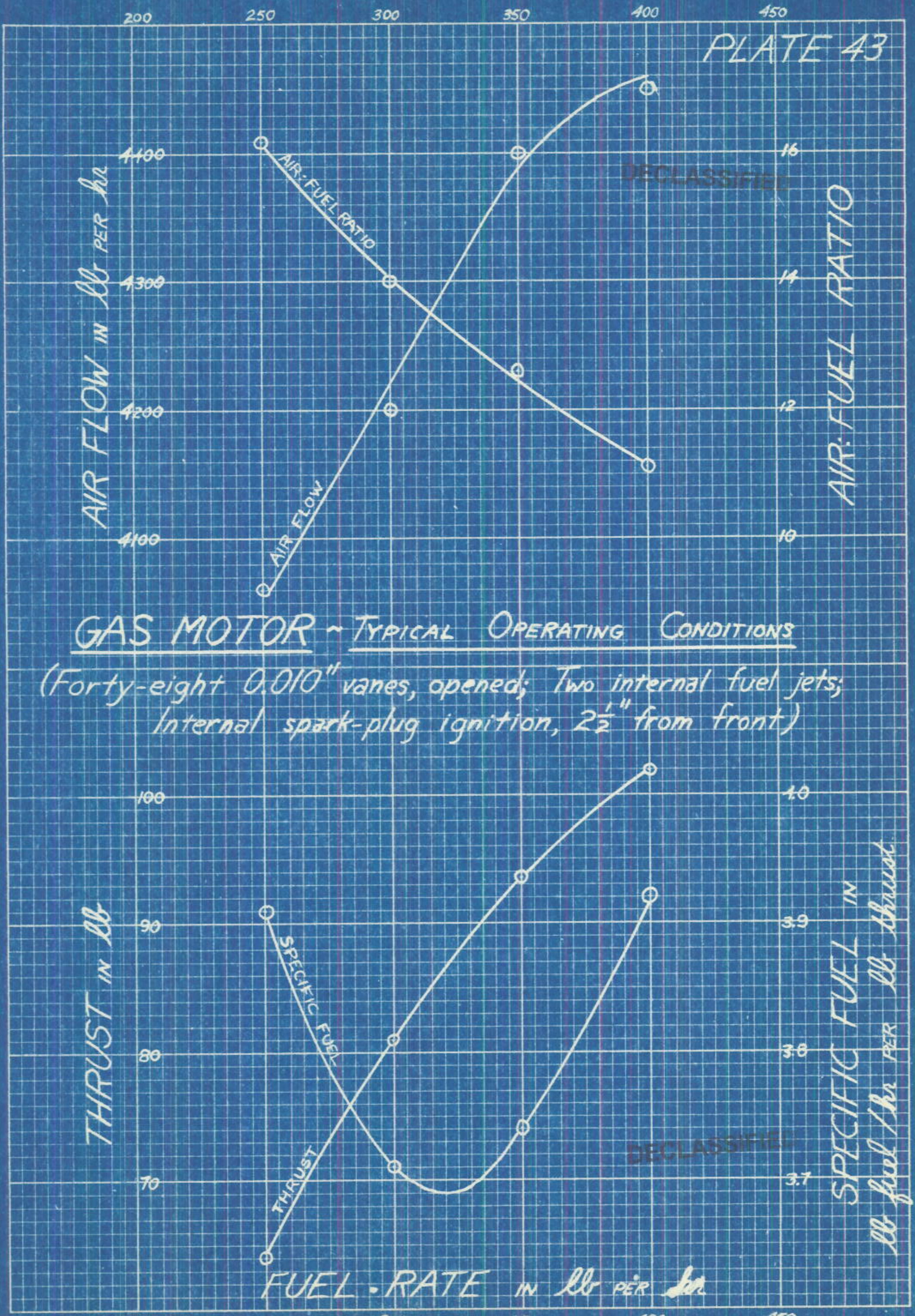
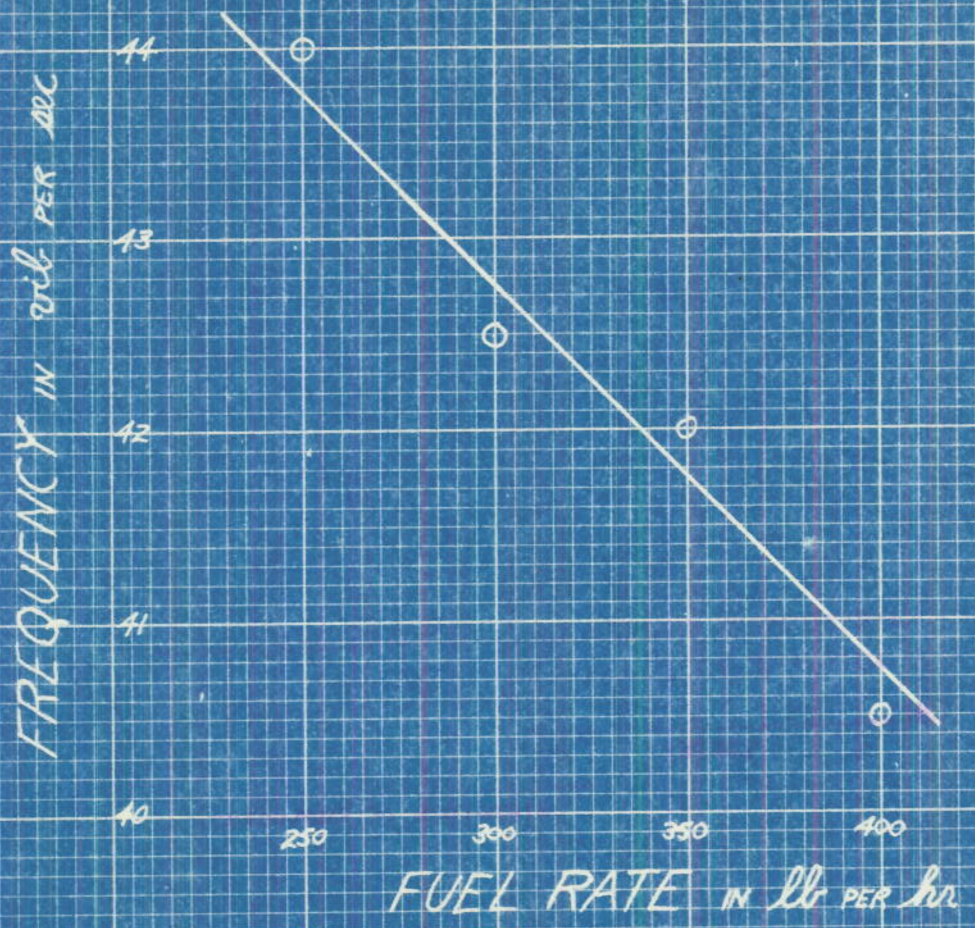


PLATE 43
GAS MOTOR ~ TYPICAL OPERATING CONDITIONS
(Forty-eight 0.010" vanes, opened; Two internal fuel jets; Internal spark-plug ignition, 2½" from front)
AIR FLOW IN lb PER hr
AIR:FUEL RATIO
AIR-FUEL RATIO
AIR FLOW
THRUST IN lb
SPECIFIC FUEL IN lb fuel / hr PER lb thrust
SPECIFIC FUEL
THRUST
FUEL - RATE IN lb PER hr
200
250
300
350
400
450
4400
4300
4200
4100
16
14
12
10
100
90
80
70
4.0
3.9
3.8
3.7



GAS MOTOR ~ FREQUENCY VARIATION WITH FUEL RATE

(Forty-eight 0.010" vanes, opened; Two internal fuel jets; Internal spark-plug ignition, $2\frac{1}{2}$" from front)