FCR-0047

HIGH POWER DENSITY FUEL CELL FOR AIRCRAFT HIGH POWER

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Power Systems Division has conducted a two-month program to investigate the effect of increased operating pressure on the performance of lightweight high power density fuel cells. A lightweight cell had been operated during previous investigations at 60 psia to power densities as high as 2320 watts/ft^2. In this program the capability was evaluated at pressures of 60, 90, 120, 150, and 180 psia. Increasing operating pressure to 180 psia increased cell power density to 3890 watts/ft^2. Endurance tests verified stable cell operation at the increased power density levels. These tests show that operation of high power density fuel cells at higher than current baseline pressure levels can significantly improve cell performance and reduce powerplant and power system weight and volume.

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I. INTRODUCTION

During the period 1 April 1972 through 31 March 1975, Pratt & Whitney Aircraft and Power Systems Division* conducted an analytical and experimental program which demonstrated the feasibility of an ultra-lightweight fuel cell powerplant with a specific weight of less than 0.5 lb/kw. This powerplant is a candidate for the supply of electrical power in advanced aircraft applications. Full-scale single cells and 12-cell development units, the basic modular repeating subsection of which a complete powerplant is assembled, were constructed and successfully tested. The development unit tests demonstrated a power density of 2260 watts/ft^2 and single cell tests demonstated higher power densities. Single cell tests also demonstrated an operating capability in excess of 600 baseline missions. Several complete Reference Power Systems based on the as-demonstrated performance were defined. These systems included all equipment required for a flight operational installation; i.e., powerplants, a reactant supply system, and a cooling water system. Each of the designs was based on fuel cell operation at 250°F, 60 psia and a power density of 2150 watts/ft^2.

Toward the end of the program the effect of increasing operating pressure from 60 psia to 90 psia was determined experimentally. Power densities as high as 3000 watts/ft^2 were demonstrated, almost 50 percent higher than Reference System design power densities. Operation at higher pressure could therefore significantly reduce powerplant and power system weight. As a result the program was extended for a period of two months with the objective of determining the effect on fuel cell performance of increasing operating pressure to levels as high as 200 psia.

The program extension called for testing of four single cells each to be of the lightest configuration developed to date, Configuration 4, and to be capable of operation for periods equivalent to 30 seconds in the no-water removal mode at 2000 watts/ft^2 and to be capable of operation in a water-removal mode at up to 4000 watts/ft^2. Tests of two kinds were to be conducted: (1) Performance tests, to determine the cell's peak power density as a function of increased pressure and (2) Endurance tests, to demonstrate stable operation could be maintained at peak power densities.

*NOTE — On January 1, 1975, the fuel cell operations of Pratt & Whitney Aircraft Division, United Aircraft Corporation became part of the newly formed Power Utility Division, United Aircraft Corporation. On May 1, 1975, the name of Power Utility Division, United Aircraft Corporation was changed to Power Systems Division, United Technologies Corporation.

II. SUMMARY

Four single cells of Configuration 4 were performance and endurance tested at pressures to 180 psia. The results and conclusions of the investigation are as follows:

(1) A maximum power density of 3890 watts/ft^2 was demonstrated at an operating pressure of 180 psia.

(2) At an operating pressure of 200 psia the cells peak power density capability is 4000 watts/ft^2.

(3) The equivalent powerplant specific weight based on the weight of the test cells when operated at 4000 watts/ft^2 is 0.40 lb/kw.

(4) Increasing system operating pressure from 60 psia to 200 psia has the potential to reduce equivalent powerplant specific weight by 20 percent from 0.5 lb/kw to 0.40 lb/kw.

(5) Development of a Configuration 5 cell, based on the Configuration 4 cell but tailored to take full advantage of operation at elevated pressure, has the potential to reduce equivalent powerplant specific weight to 0.33 lb/kw.

(6) Cell performance was stable throughout endurance tests equivalent in duration to 120 30-second 4-MW missions.

The maximum cell power densities demonstrated are presented as a function of operating pressure in Figure 1.

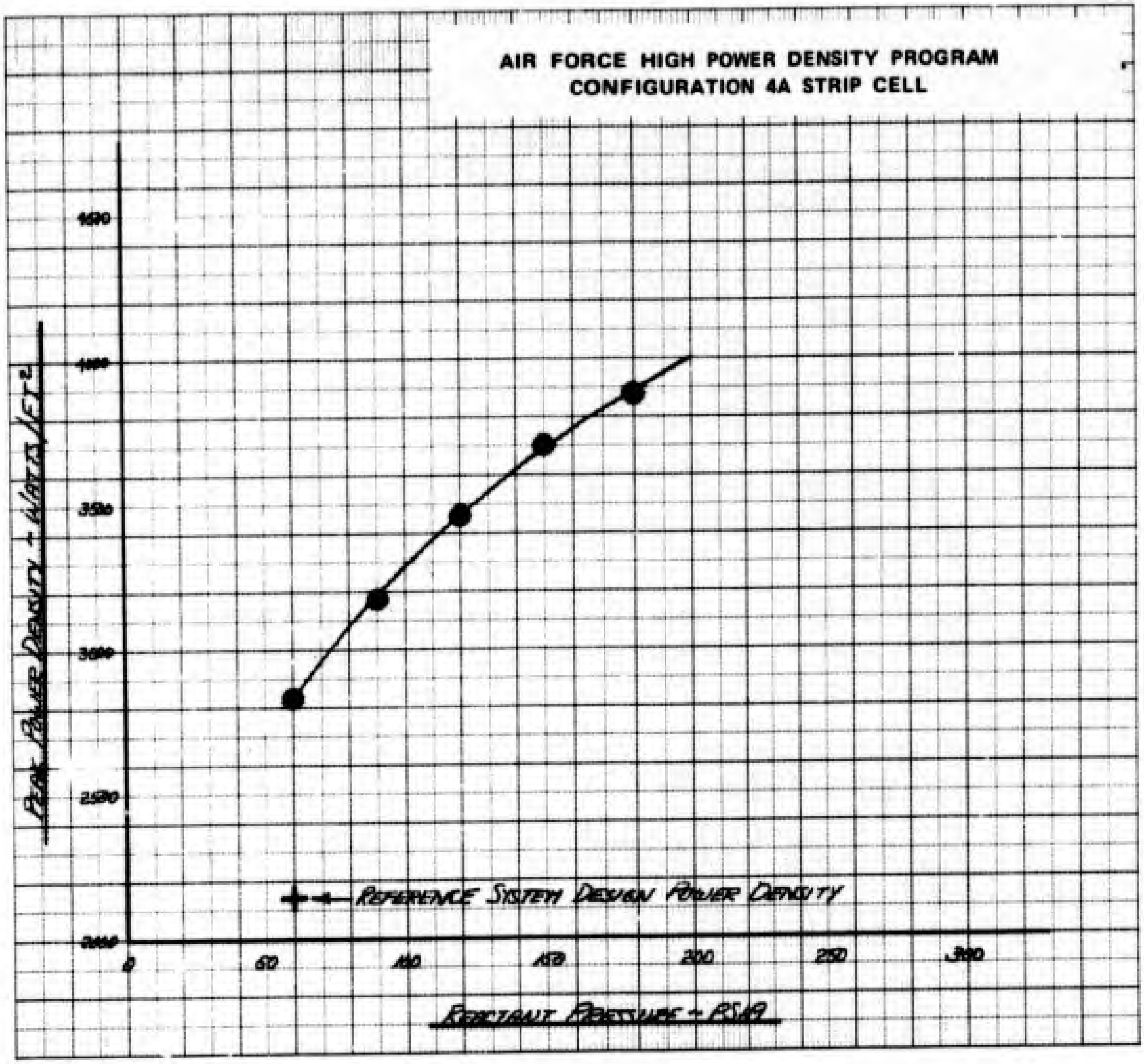

Figure 1 — Peak Power Density vs. Operating Pressure

III. ELEVATED PRESSURE OPERATION

A. Test Article Description

The design of the four single cells tested in this program was based on the Configuration 4 cell design developed in the previous three-year program. This cell design was the lightest weight cell developed and has an equivalent powerplant specific weight of 0.55 lb/kw at an operating power density of 2150 watts/ft^2. It is designed for an operating pressure of 60 psia. A cross section of the cell is shown in Figure 2. Two modifications were made to this

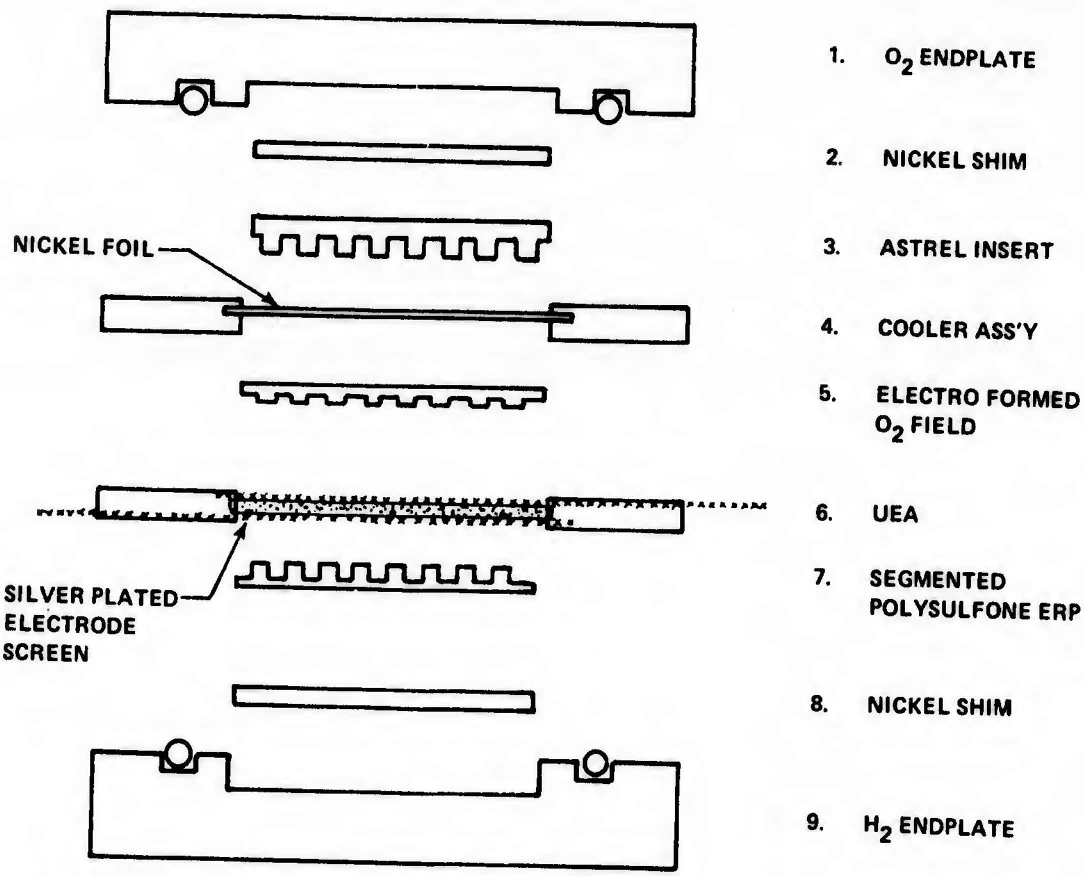

Figure 2 – Configuration 4 Cell Cross Section

design to permit elevated pressure and higher power density operation: (1) The nickel foil of the cooler assembly (Item 4) was increased in thickness to 3 mils from 1.5 mils, and, (2) the silver plating of the electrode screens in the UEA (Item 5) was increased from 0.5 mils to 0.7 mils in the active cell area and from 1.0 mil to 1.5 mils in the frame area. The nickel foil thickness was increased to withstand increased oxidant to coolant crosspressure which could reach as much as 185 psi when operating pressure is raised to 200 psia. When the cell is operated at 60 psia this cross pressure is approximately 45 psi. The silver plating of the electrode screens was increased in thickness to minimize I^2R heating of the electrodes and frame under the higher operating current densities which were anticipated to and did approach 10,000 amperes/ft^2 during this investigation. The effect of these two modifications was to increase the equivalent powerplant specific weight of the cell from 0.55 to 0.66 lb/kw at the nominal power density of 2150 watts/ft^2. However the objective was to reach for higher power densities and this markedly reduced equivalent powerplant weight, as shown in Table I. This modified design was designated Configuration 4A.

TABLE I

EFFECT OF INCREASED POWER DENSITY ON SPECIFIC WEIGHT

	Power Density Watts/ft^2	Equiv. Powerplant Specific Weight Conf. 4A lb/kw
(1)	2150*	0.66
(2)	2500	0.58
(3)	3000	0.50
(4)	3500	0.44
(5)	4000	0.40

*(Reference System Power Density)

The equivalent powerplant specific weights are probably conservative for the increase in cooler assembly nickel foil thickness and the increase in plating thickness is considered greater than necessary. In a Configuration 4 cell specifically developed for elevated pressure operation these items would be lightened further reducing equivalent powerplant specific weight.

B. Test Program

1. Summary

The test plan for this program was to first performance calibrate each cell at 60 psia and to conduct cell diagnostic tests including Tafel slope and IR evaluation if necessary.*

The cell was then performance calibrated at 90, 120, 150, and 180 psia using a duty cycle of 3 seconds on load followed by 6 seconds at open circuit. Following the performance calibration the cells were to be placed on endurance test, if the performance calibrations were satisfactory. The test program is summarized in Table II.

- Cell No. 16, the first in the series, performed well but did not deliver power densities as high as predicted, see Figure 3, and was not placed on endurance.
- Cell No. 17 performed poorly due to a manufacturing problem which resulted in internal shorting.
- Cell No. 18, like Cell No. 16, did not deliver as high a power density as predicted but was placed on endurance to begin evaluating long term operating effects. It performed stably for 60 minutes of power delivery at 5000 ASF or higher.
- Cell No. 19 performed slightly higher than predicted, see Figure 3, and delivered 3890 watts/ft^2 at 180 psia. Extrapolation to 200 psia indicates the cell would deliver 4000 watts/ft^2. During 60 minutes on endurance at over 5000 ASF cell operation was stable.

The results of each cell test are presented in greater detail in the following section.

*These diagnostic tests and others are described in detail in the Final Report, "High Power Density Fuel Cell for Aircraft High Power" by A. P. Meyer and W. F. Bell, FCR-0003 AFAPL-TR-75-43, Power Systems Division, United Technologies Corporation.

TABLE II

HIGH POWER DENSITY STRIP CELL ELEVATED PRESSURE TEST SUMMARY

Cell No.	Configuration	Powerplant Equivalent Specific Weight: @ 2150 WSF lb/Kw	Powerplant Equivalent Specific Weight: Max. Power Density Over 2150 WSF lb/Kw	Max. Demon. Power Density WSF	No. Starts	Total Load Time (Hrs)	Load Time 3000 ASF or Higher (Hrs)
16†	4A	0.66	0.45	3400	2	8.4	0.07
17	4A	0.66	DNA	1627	1	4.6	0
18	4A	0.66	0.48	3180	2	6.4	1.02
19	4A	0.66	0.41	3890	2	4.5	1.04

† Cells are numbered consecutively beginning in the initial 3-year development program.

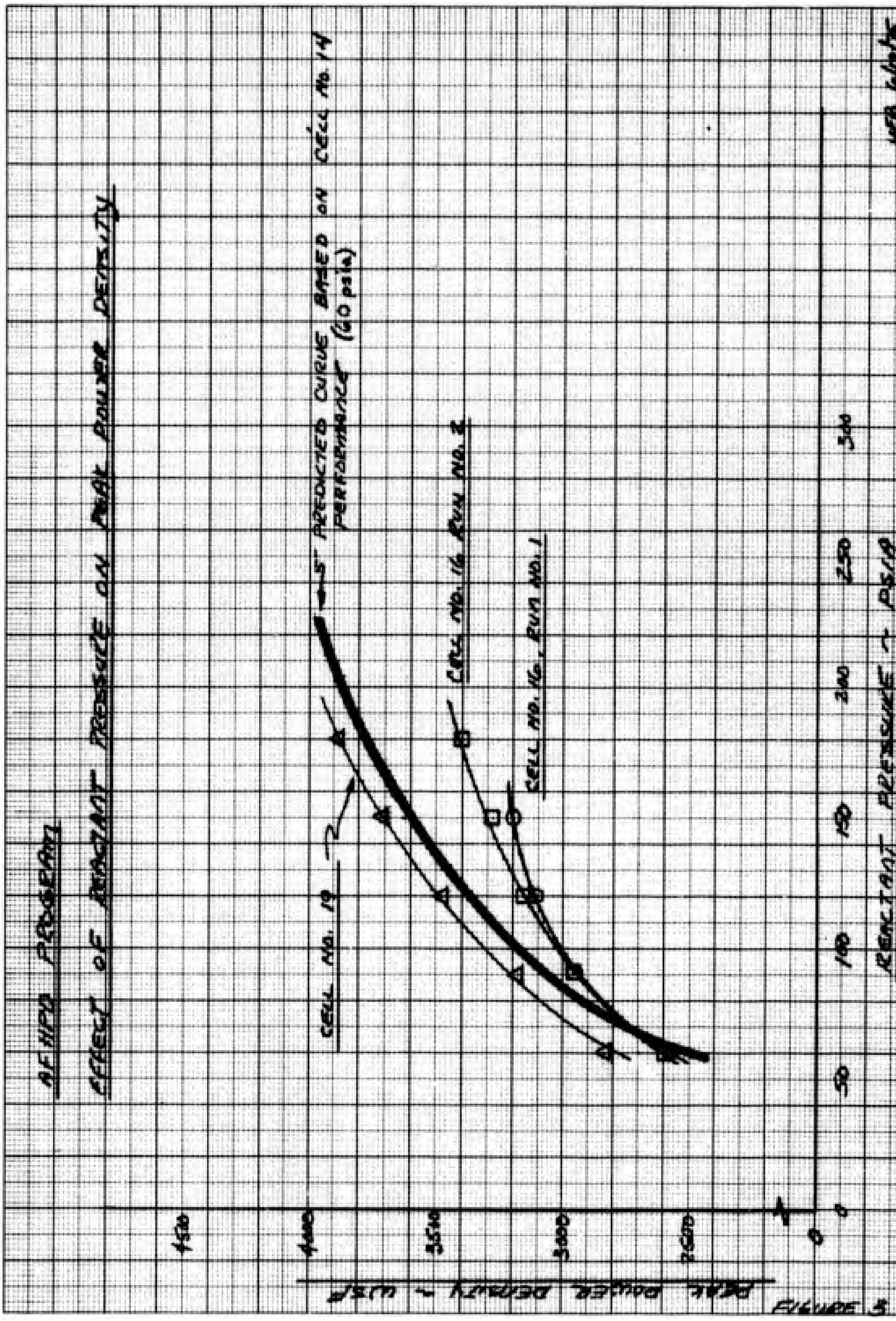

Figure 3 — Peak Power Density Summary

2. Test Results

Cell No. 16

Cell No. 16 was the first cell in the elevated pressure test program. Initial diagnostics at 60 psia reactant pressure showed the cell to be operating normally although the cell IR was higher than expected. The cell voltage at 100 ASF was 0.986 v which compares favorably with previous Configuration 4 single cells. Following diagnostics, performance calibrations to peak power density were run at 60, 90, 120, 150, and 160 psia, see Figure 4. The power density at 3500 ASF, 60 psia was 2150 WSF which is the Reference System design power density at these conditions. The maximum power densities increased with pressure from 2570 WSF at 60 psia to a peak of 3220 WSF at 160 psia and 7400 ASF, see Figure 5. The maximum current density during this run was 9100 ASF. The cell was then shut down in order to increase matrix compression and refill with electrolyte. The objective was to reduce cell IR to bring the cell performance closer to the predicted levels as shown in Figure 3. Following the refill, the cell was returned to test. Diagnostics showed the activation level to be essentially unchanged, and there was a slight improvement in IR. The cell performance was improved over the first run, see Figures 6 and 7, reaching a maximum power density of 3400 WSF at 7800 ASF, 180 psia. This completed the testing on Cell No. 16. During the test no cell or stand problems were noted. Endurance was not run because predicted performance had not been achieved.

Inspection of the cell after disassembly disclosed some leaching of the epoxy frame in the coolant cavity. Ohterwise all cell components were in excellent condition. Total load time on the cell was 8.4 hours. A total of 3.7 minutes were accumulated at or above 3000 ASF.

Cell No. 17

In an effort to further reduce the cell IR this cell was filled at an electrolyte concentration lower than that of Cell No. 16. Fill concentration was reduced to 32 percent KOH from 40 percent KOH. This reduces nominal operating electrolyte concentration from 52 percent KOH to 44 percent KOH and increases electrolyte conductivity to 2.08 ohm^{-1} cm^{-1} from 1.78 ohm^{-1} cm^{-1}. Cell voltage was erratic on startup and it was shut down to inspect for a possible short. Shorting was found and was traced to contact between cathode substrate wires and an endplate at one of the tie-bolt holes. After removing the cause of the short, the cell was refilled and returned to test. Diagnostics after restart showed a good IR value, however, the activity level of the cell was low. A crosspressure check indicated reactant crossover and the test was terminated. No evidence of a problem could be found after disassembly, however, it was concluded that handling the cell in order to remove the short probably led to the crossover condition. Laboratory analysis of the electrodes confirmed cathode activity was low.

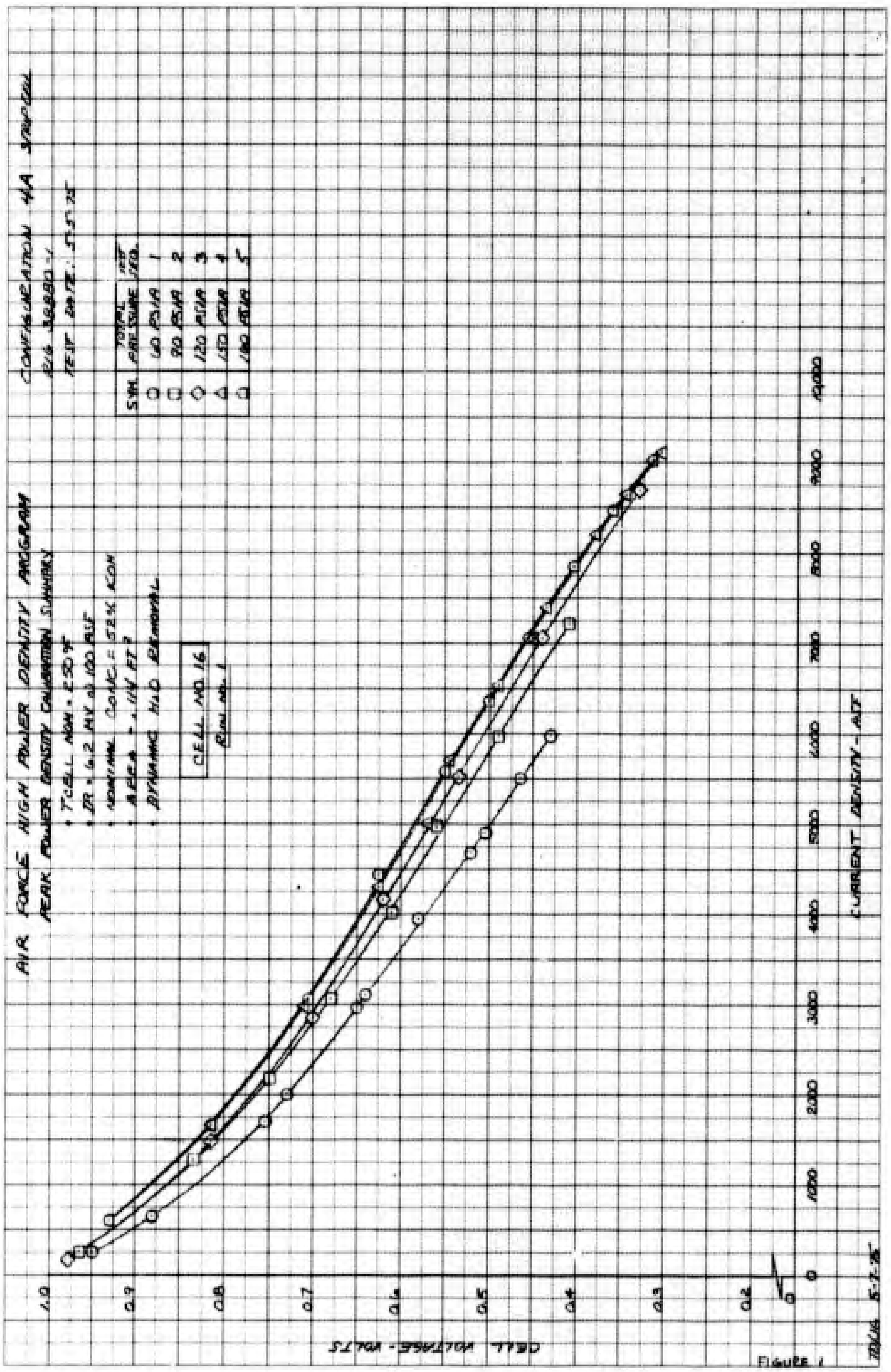

Figure 4 — Performance Calibrations to 160 psia, Cell No. 16

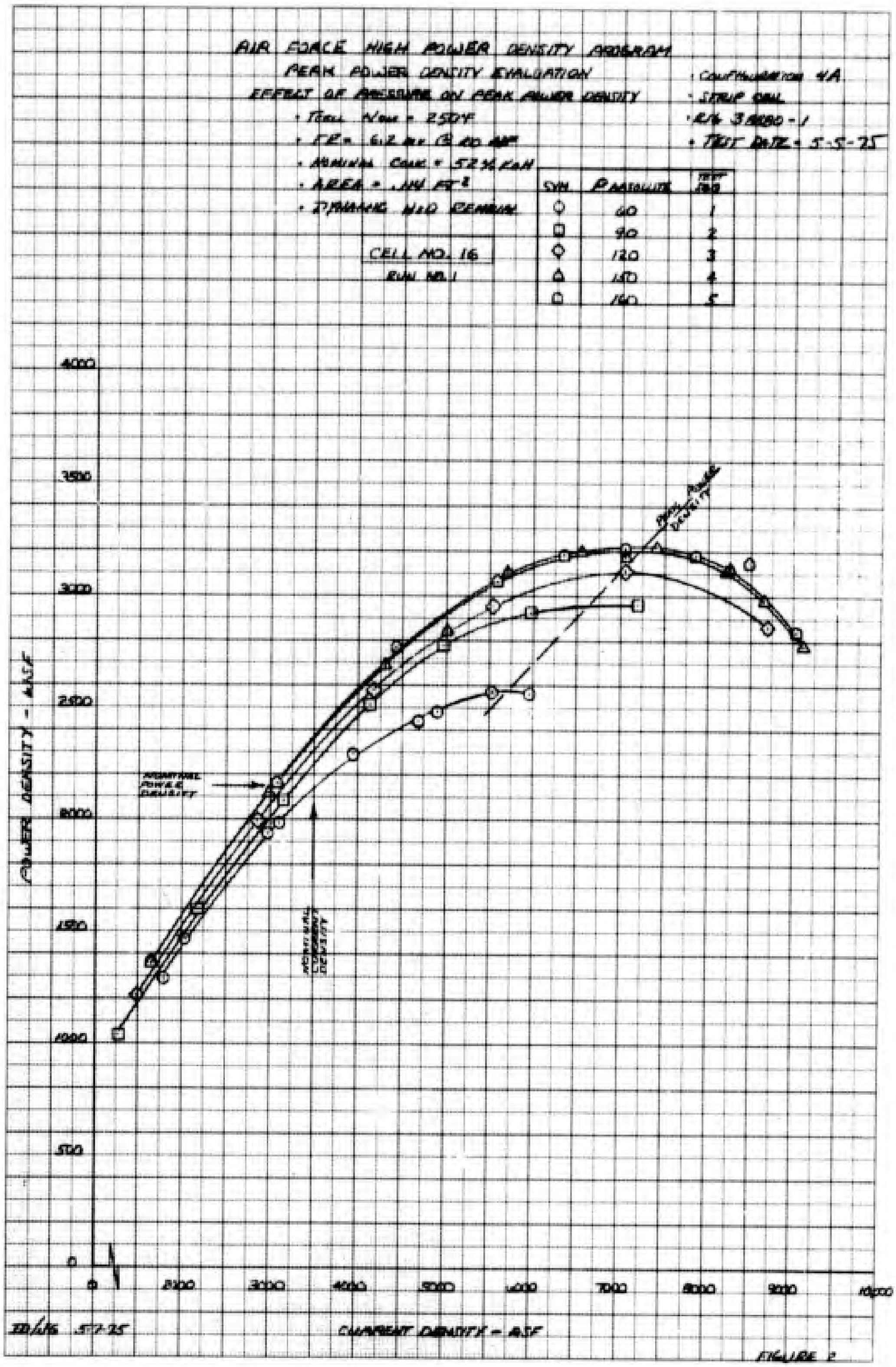

Figure 5 – Peak Power Densities to 160 psia, Cell No. 16

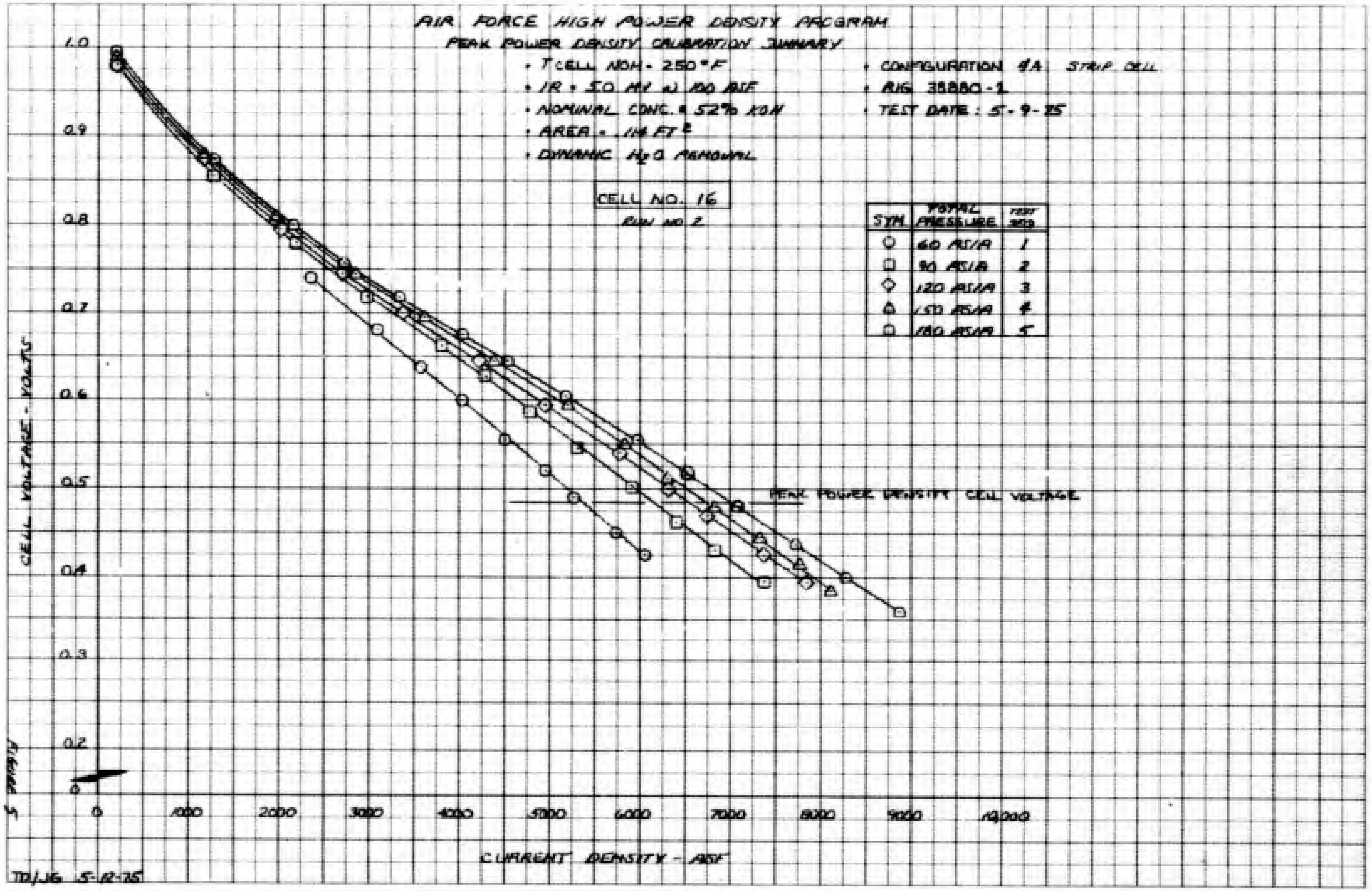

Figure 6 — Performance Calibrations to 180 psia, Cell No. 16

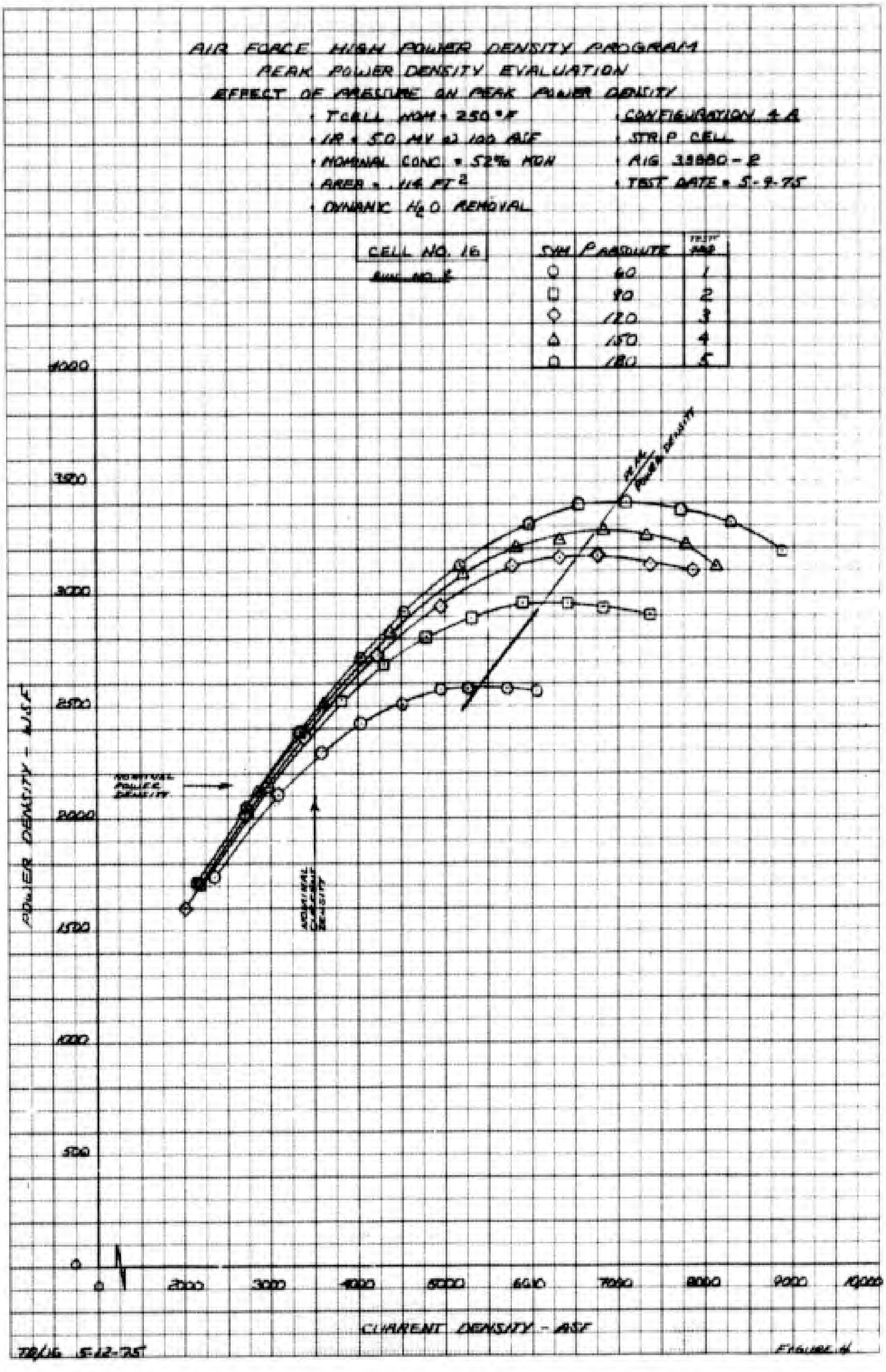

Figure 7 – Peak Power Densities to 180 psia, Cell No. 16

Cell No. 18

Cell No. 18 was filled with the same concentration electrolyte as Cell No. 17. This cell also had a low initial activation level and a similar voltage at 100 ASF. Calibrations to peak power were run at 60, 90, and 120 psia. Figure 8 shows the resulting performance was poor at all pressures and there was little response to increasing pressure. The maximum power density obtained was 2340 WSF at 120 psia. Consequently efforts were made to diagnose the problem.

Dewpoint of the reactant gases was varied to cause electrolyte volume variations, performance changes were normal and indicated no tolerance response problems. The test stand was inspected and instrumentation was checked without finding any cause for poor performance. The 60 and 90 psia calibrations were then repeated, because performance was gradually improving during the diagnostics. Performance had substantially improved, see Figure 8, at 60 and 90 psia. Based on past experience, it was concluded the electrodes might not have been filled sufficiently and were approaching an optimum fill as they were wetting up with time. The fact that this cell was filled with electrolyte of lower than usual concentration supported this hypothesis because the wettability of the electrolyte decreases with decreasing KOH concentration. Therefore it was decided to refill the cell in order to further wet the electrodes before proceeding further. The electrolyte concentration was kept the same as in the first fill in an effort to minimize cell IR.

The performance after refill at 150 ASF was slightly improved while the IR remained the same. Peak power calibrations were then run at 60, 90, and 120 psia, see Figure 9. There was little gain in performance in going from 60 to 90 psia, however the 60 psia performance was superior to that of Cell No. 16 and at 120 psia it was equal to that of Cell No. 16. The reasons for this result could not be determined. However, a possible cause is leakage of nitrogen into the reactant gas lines from the pressure regulator nitrogen biasing system during the change to 90 psia, thus depressing the cell performance. Following the 120 psia calibration the cell was set on endurance. Initial current density was 5000 ASF, and performance was stable but a gradual degradation was observed. As a result load current was reduced to 4500 ASF at about 50 minutes into the test. The cell was shutdown after 60 minutes of endurance. An endurance log is presented in Figure 10. The variation of individual voltage points during the test are a result of changes in reactant gas dew point and the length of on periods imposed on the cell in an attempt to find a set of optimum operating conditions which would eliminate the gradual degradation. A final IR check showed an increase in IR of 1.5 mV at 100 ASF from the initial value. This increase and the increase in diffusion losses both indicated electrolyte loss may have occurred, however, it was not possible to confirm this.

Cell No. 19

This cell was filled at the higher electrolyte concentration (40 percent KOH) of Cell No. 16. The initial IR and activation level were both good. Peak power curves were generated at 60, 90, 120, 150, and 180 psia, see Figures 11 and 12. At each pressure level the maximum power density exceeded the analytically predicted levels shown in Figure 3. A maximum power density of 3890 WSF at 8000 ASF was obtained at 180 psia. Following this

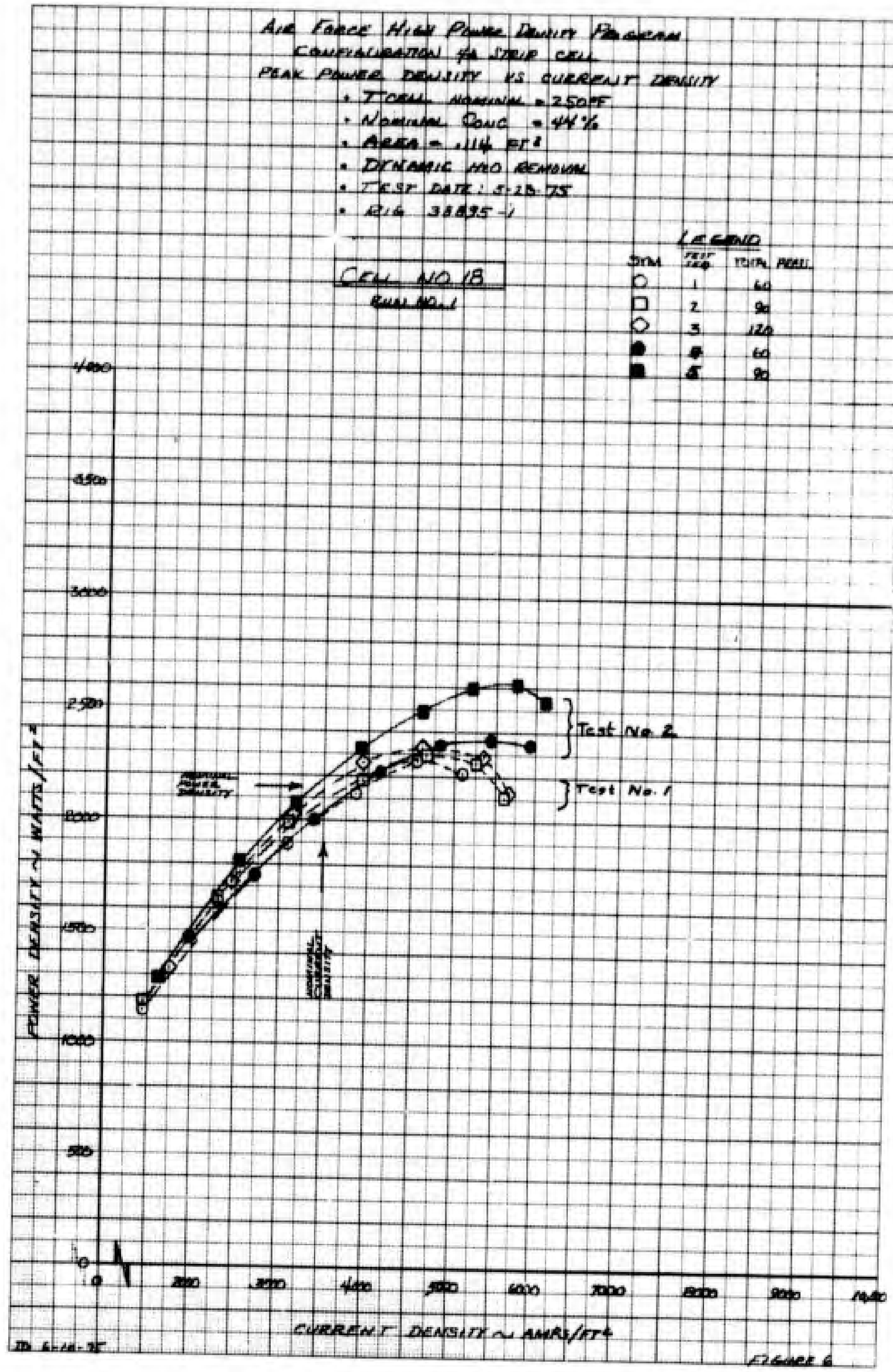

Figure 8 – Peak Power Density Test Nos. 1 and 2, Cell No. 18

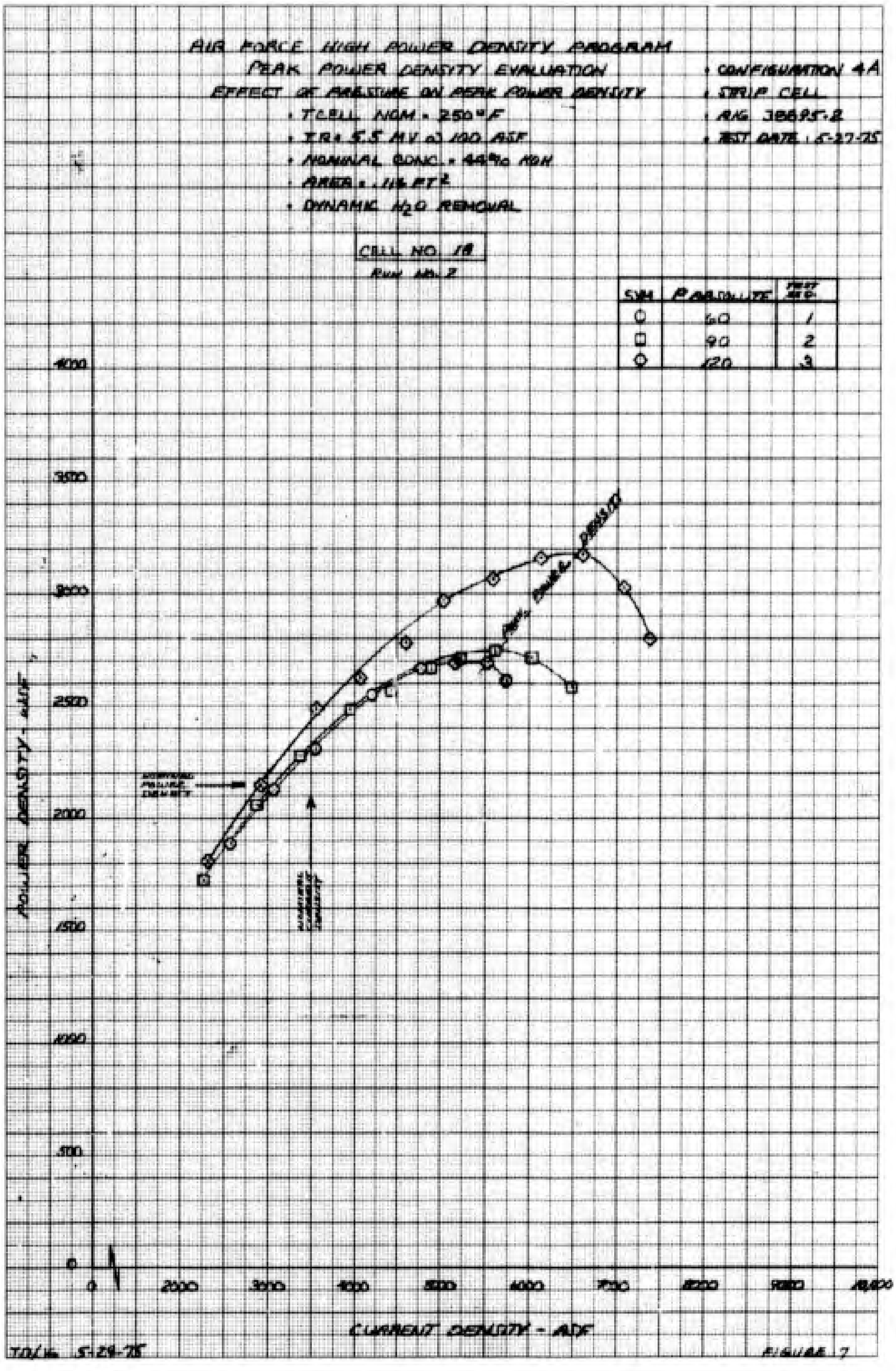

Figure 9 – Peak Power Density Test No. 3, Cell No. 18

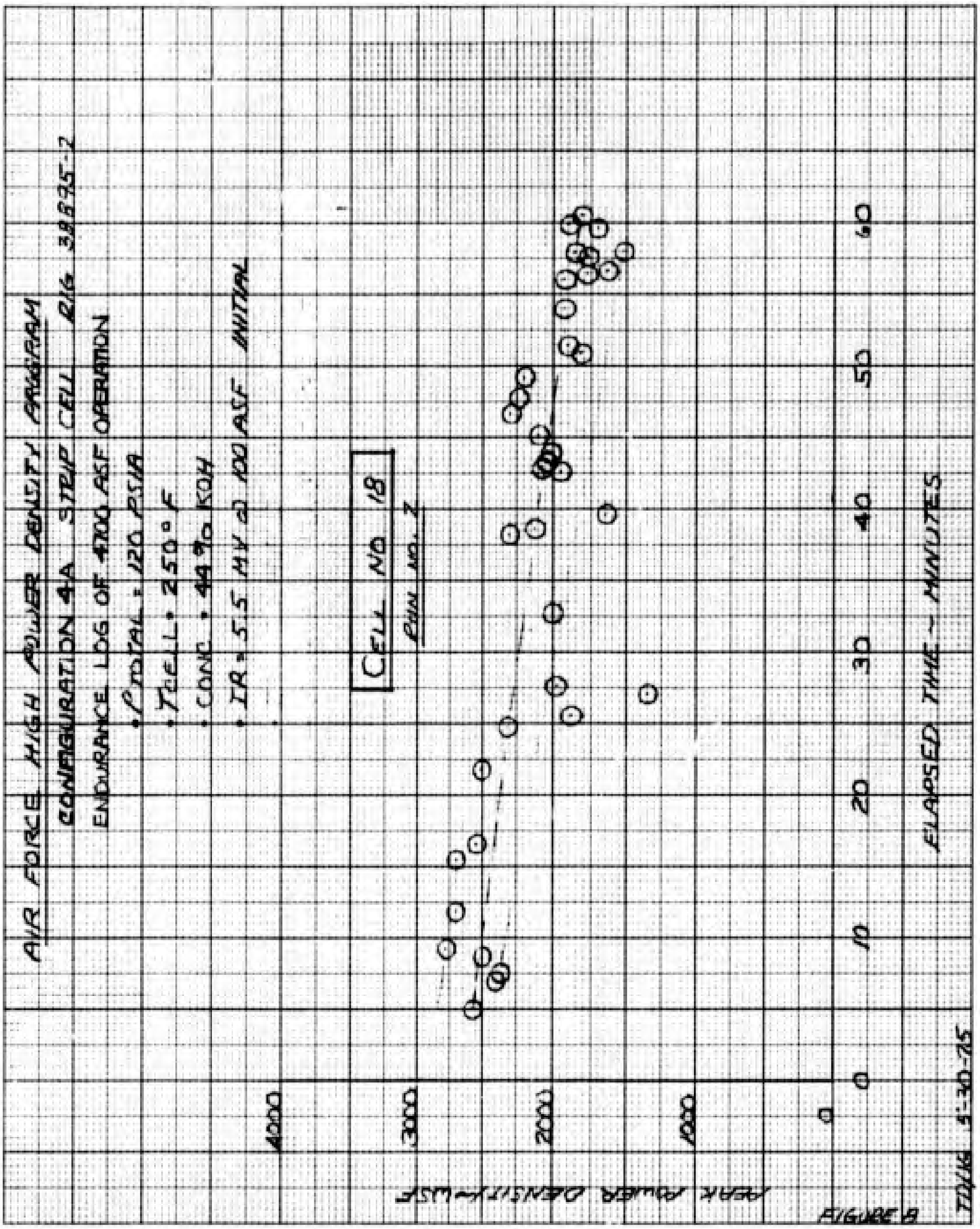

Figure 10 – Endurance Log, Cell No. 18

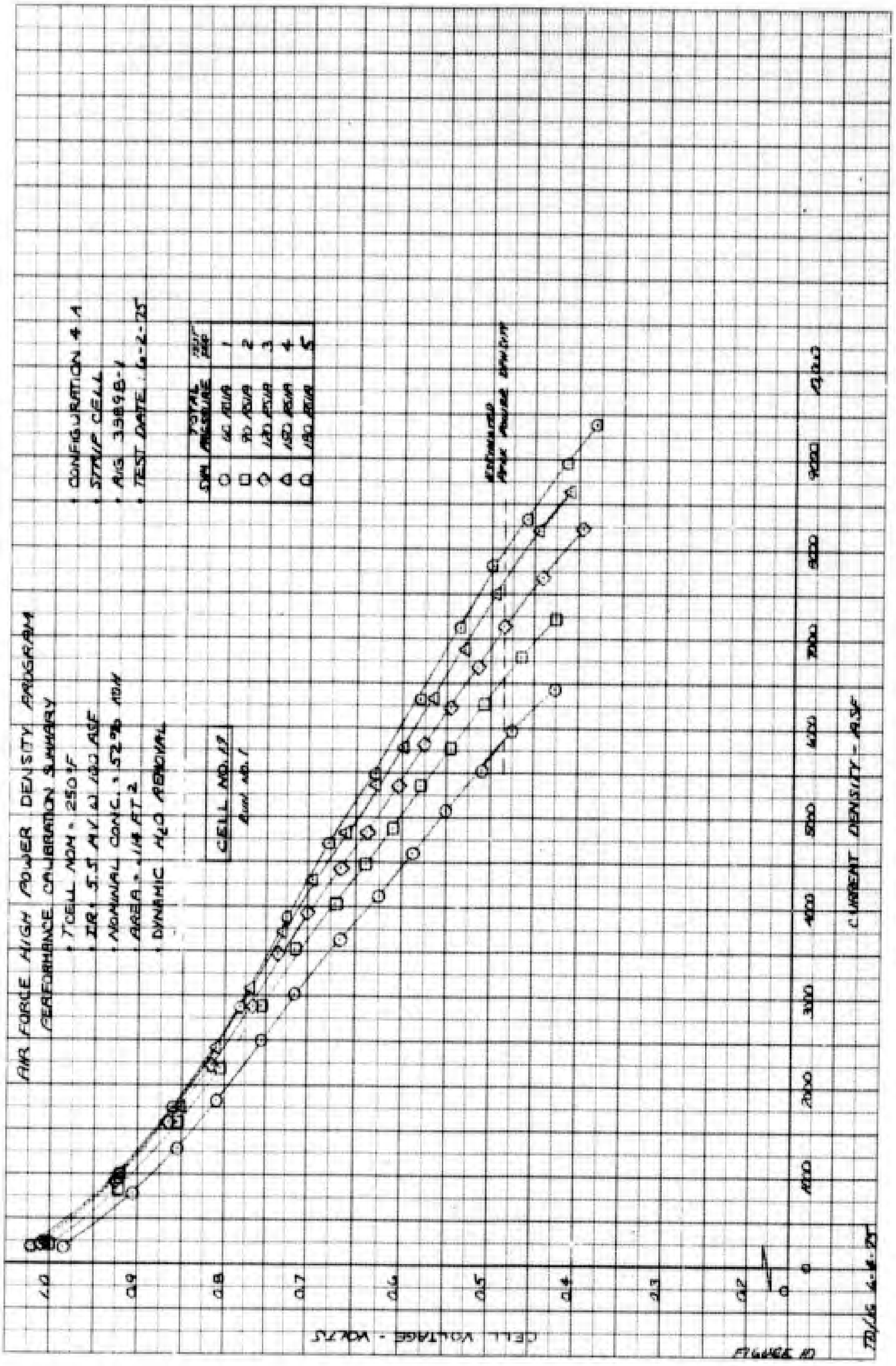

Figure 11 — Performance Calibrations to 180 psia, Cell No. 19

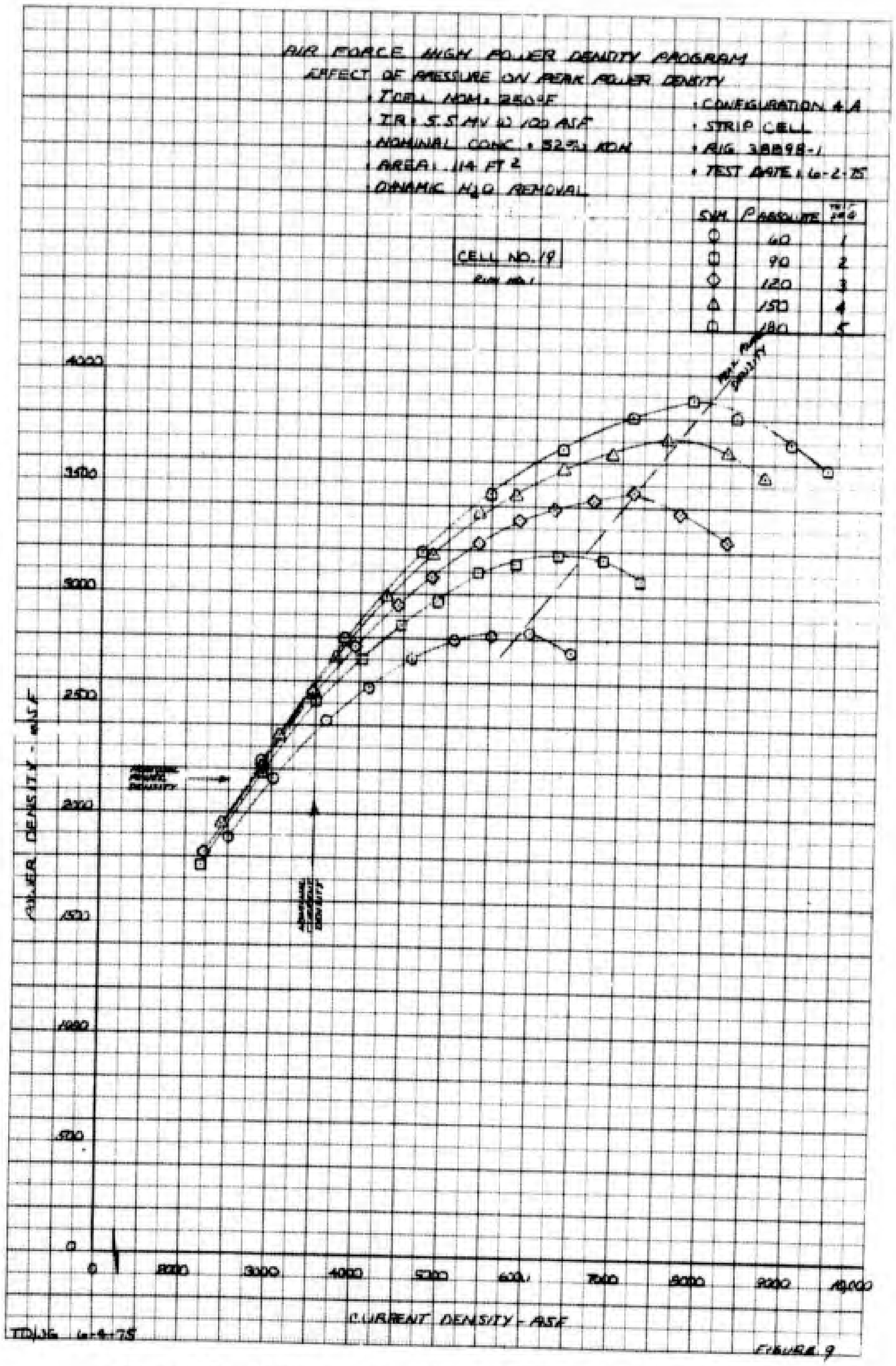

Figure 12 – Peak Power Densities to 180 psia, Cell No. 19

test the cell was run for 30 seconds at 3000 ASF in the no-water-removal mode. It was then placed on endurance at 150 psia. The initial endurance conditions were 6000 ASF with a duty cycle of 2 seconds on load followed by 2 seconds at open circuit. The initial power density was 3400 WSF, however, the cell voltage began to degrade and the current density was lowered after approximately 8.5 minutes of load time. For the remainder of the test, the duty cycle ranged from 2 seconds on and 3 seconds off to 3 seconds on and 7 seconds off in an effort, again, to find an optimum set of operating conditons. The current density was also varied between 3000 ASF and 5000 ASF with most of the testing at 4500 ASF. The cell performance did not degrade noticeably at current densities up to 4000 ASF but did degrade above that level. In addition the voltage response became less stable over the length of the burst above 4000 ASF. After 42 minutes of load time the cell was put on open circuit and the IR level checked. The IR had risen from 5.5 mV at 100 ASF to over 10 mV. It was theorized this increase could be due to electrolyte loss and the reactant gas dewpoint was raised in order to increase the electrolyte volume. After stabilizing at the new condition the IR value had decreased to less than 7 mV. This resulted in improved cell performance and the voltage response for each burst again was stable. The cell performance continued to degrade with additional running and as more electrolyte may have been lost. The test was terminated when 60 minutes of load time were accumulated. The endurance log for this test is shown in Figure 13.

Post test examination showed all components to be in good condition. Laboratory analysis of the electrodes showed the cathode to be susceptible to electrolyte pumping (electrolyte loss) at current densities that were lower than usual for occurance of this phenomenon. The anode appeared to be in good condition.

To further investigate the electrolyte loss problem an unused cathode from the same manufacturing batch was tested in the laboratory. This electrode also showed pumping tendencies at lower than usual current densities. Consequently it was concluded that the primary cause of the possible electrolyte loss during endurance testing was characteristic of this batch of electrodes rather than the effect of the high current density or elevated pressure operation. The tendency for electrode pumping is a function of electrode structure. By changing the electrode structure, i.e. changing catalyst to binder ratios, blending methods. or sintering temperatures, a structure can be obtained that does not pump. The suspected electrolyte loss indicates that if exploration of the benefits of elevated pressure operation is continued alternate electrode structures should be investigated to preclude this problem in the future.

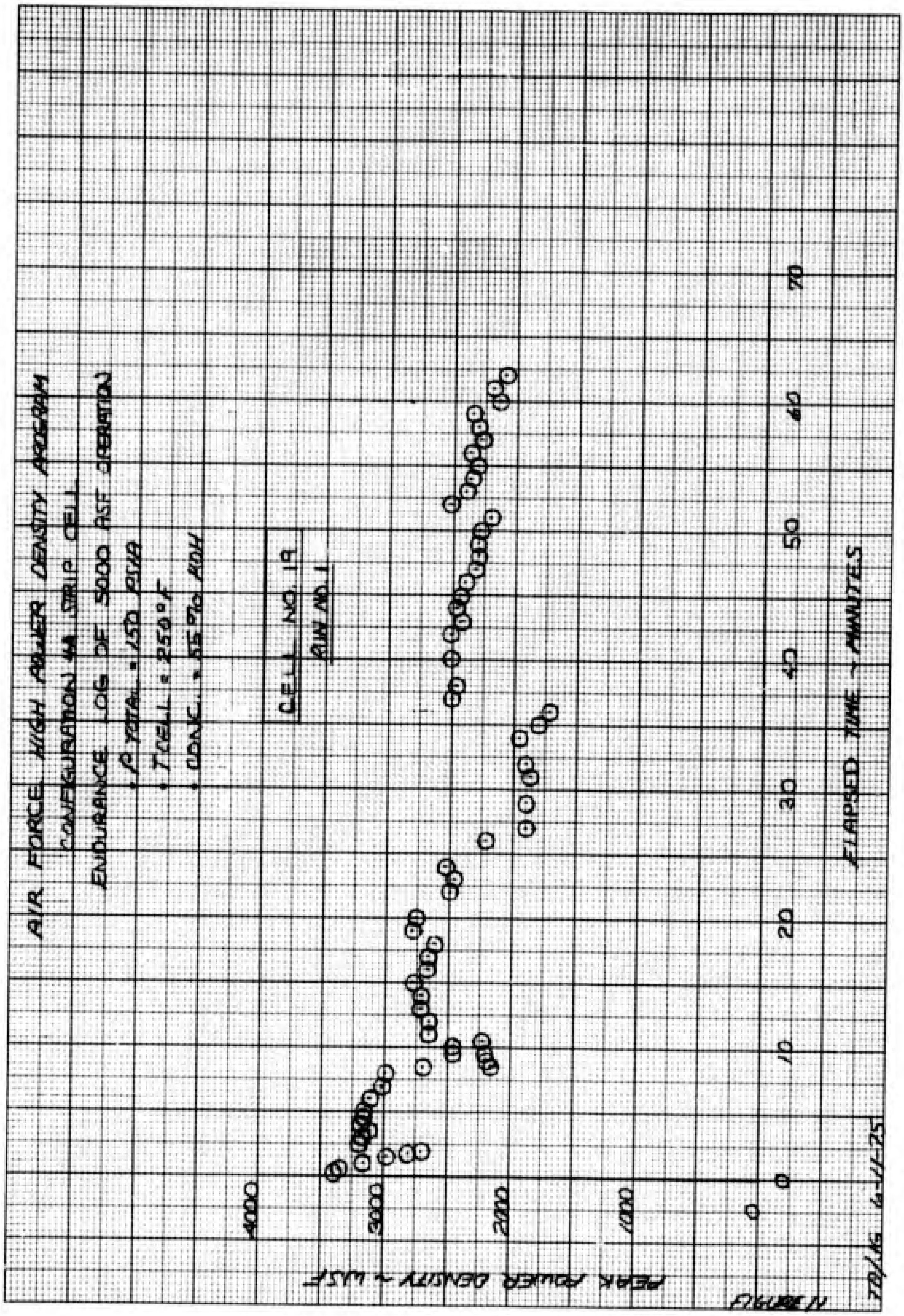

Figure 13 — Endurance Log, Cell No. 19

IV CONCLUSIONS

The conclusions of the investigation are as follows:

(1) The equivalent powerplant specific weight based on the weight of the test cells when operated at 4000 watts/ft^2 is 0.40 lb/kw.

(2) Increasing system operating pressure from 60 psia to 200 psia has the potential to reduce equivalent powerplant specific weight by 20 percent from 0.5 lb/kw to 0.40 lb/kw.

(3) Development of a Configuration 5 cell, based on the Configuration 4 cell but tailored to take full advantage of operation at elevated pressure, has the potential to reduce equivalent powerplant specific weight to 0.33 lb/kw.