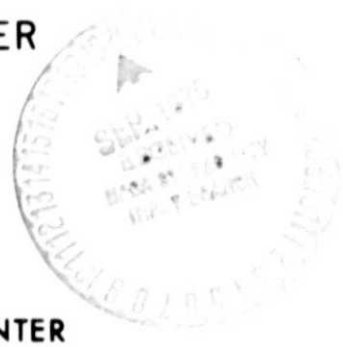
EVALUATION PROGRAM
for
SECONDARY SPACECRAFT CELLS

INITIAL EVALUATION TESTS
OF
GULTON INDUSTRIES, INC.
9.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS
WITH AUXILIARY ELECTRODES
FOR THE
SMALL ASTRONOMY SATELLITE (SAS-C)

prepared for
GODDARD SPACE FLIGHT CENTER

CONTRACT S-53742AG



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29 JUL 1975

From: Commanding Officer, Naval Weapons Support Center, Crane, Indiana
To: National Aeronautics and Space Administration, Goddard Space Flight Center (711.2), Greenbelt, MD 20771

Subj: Report WQEC/C 75-165; Evaluation program for secondary spacecraft cells; initial evaluation tests of 9.0 ampere-hour nickel-cadmium spacecraft cells with auxiliary electrodes for the Small Astronomy Satellite (SAS-C) manufactured by Gulton Industries, Inc.

Ref: (a) NASA Purchase Order S-53742AG

Encl: (1) Report WQEC/C 75-165

1. In compliance with reference (a), enclosure (1) is forwarded for information and retention.

D. G. MILEY
By direction

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NAVAL WEAPONS SUPPORT CENTER
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EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

INITIAL EVALUATION TESTS OF GULTON INDUSTRIES, INC. 9.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS WITH AUXILIARY ELECTRODES FOR THE SMALL ASTRONOMY SATELLITE (SAS-C)

WQEC/C 75-165 2 JULY 1975

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Enclosure (1)

REPORT BRIEF

INITIAL EVALUATION TESTS OF GULTON INDUSTRIES, INC. 9.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS WITH AUXILIARY ELECTRODES FOR THE SMALL ASTRONOMY SATELLITE (SAS-C)

Ref: (a) NASA Purchase Order S-53742AG
(b) Initial Evaluation Test Procedure for Nickel-Cadmium Sealed Space Cells: NAD 3053-TP324, 10 April 1973

I. TEST ASSIGNMENT BRIEF

A. The purpose of this evaluation test program is to insure that all cells put into the life cycle program are of high quality by the screening of cells found to have electrolyte leakage, internal shorts, low capacity, or inability of any cell to recover its open-circuit voltage above 1.150 volts during the internal short test.

B. The 12 cells were provided by the National Aeronautics and Space Administration, Goddard Space Flight Center, to NAD Crane for evaluation on life test. The cells were procured by the Applied Physics Laboratory (APL), to APL Specification 7217-9014-A for the Small Astronomy Satellite (SAS-C), from Gulton Industries, Inc., Metuchen, New Jersey. These cells are from the same lot of cells that are being flown in the satellite which was launched in May 1975. Ten cells had no auxiliary electrode and were identified by the manufacturer's model number V09HS and part number 805051. The remaining two, with auxiliary electrodes, had model number V09HSAD and part number 805052. The auxiliary electrode cells and two of the other cells have pressure gauges. These cells are rated at 9.0 ampere-hours and contain double ceramic seals. The auxiliary electrode is Gulton's standard adhydrode (U-fold). The auxiliary resistor used throughout the test was 47 ohms. Testing was funded in accordance with reference (a).

C. Test limits specify those values in which a cell is to be terminated from a particular charge or discharge. Requirements are referred to as normally expected values based on past performance of aerospace nickel-cadmium cells with demonstrated life characteristics. A requirement does not constitute a limit for discontinuance from test.

II. SUMMARY OF RESULTS

A. The cells exceeded the maximum voltage requirement of 1.480 volts during their charges at 20°C.

B. One cell exceeded the test limit of 1.560 volts for a continuous time period of 2 hours during the 0°C overcharge test. The other cells exceeded 1.560 volts during charge; but did not exceed the time period.

C. Average end-of-charge voltages and capacity output in ampere-hours (ah) were as follows:

Charge	Volts	ah Out
c/20 for 48 hours at 25°C	1.429	12.3
c/10 for 24 hours at 25°C	1.443	12.3
c/10 for 24 hours at 20°C	1.469	12.0
c/10 for 24 hours at 20°C*	1.471	10.8
c/40 for 20 hours at 20°C	1.373	3.0**
c/20 for 60 hours at 0°C	1.553	13.0
c/10 for 24 hours at 35°C	1.403	10.1

*Charge retention test.
**This value represents 66.7 percent of the input capacity (charge efficiency test)

D. The average cell voltage at the end of one week open-circuit, during the charge retention test, was 1.305 volts.

E. The 24-hour average cell voltage, following a 16-hour short period, was 1.221 volts.

F. One of the auxiliary electrode cells reached its pressure limit of 20 psia with 12.8 ampere-hours input, and a voltage of 1.541 volts, during the pressure versus capacity test. The other three cells reached their voltage limit of 1.550 volts with an average input of 13.5 ampere-hours. Three cells exhibited pressure decay of 1 psia during the last 30 minutes of the 1-hour open-circuit stand. Average capacity out was 11.4 ampere-hours.

III. RECOMMENDATIONS

A. It was recommended that these cells be placed on life test simulating that which the spacecraft will require of the flight batteries.

B. On 4 April 1975, one 10-cell pack (Pack 18G) began life test on a 1.48-hours orbit (1.00-hour charge) with a voltage limit control (1.447 V/C) at 20°C and a depth of discharge of 25 percent.

RESULTS OF INITIAL EVALUATION TESTS OF GULTON INDUSTRIES, INC. 9.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS WITH AUXILIARY ELECTRODES FOR THE SMALL ASTRONOMY SATELLITE (SAS-C)

I. TEST CONDITIONS AND PROCEDURE

A. All evaluation tests were performed at room ambient (RA) pressure and temperature (25° ± 2°C), with discharges at the 2-hour rate, and in accordance with reference (b), unless otherwise specified, and consisted of the following:

1. Phenolphthalein leak tests (2).

2. Three capacity tests, third at 20°C; with internal resistance measurements during second charge/discharge.

3. Auxiliary electrode characterization test.

4. Charge retention test, 20°C.

5. Internal short test.

6. Charge efficiency test, 20°C.

7. Overcharge tests, 0° and 35°C.

8. Pressure versus capacity test.

9. Phenolphthalein leak test.

(See Appendix I for summary of test procedure.)

II. CELL IDENTIFICATION AND DESCRIPTION

A. Ten of the twelve cells were manufactured without auxiliary electrodes. The cells were identified by the Applied Physics Laboratory part numbers 7217-9040A and also by the manufacturer as follows:

Model	Part Number	Serial Number
V09HS	805051	2049-2082 (not inclusive)
V09HSAD*	805052	109, 112

*Cells with auxiliary electrodes and pressure gauges. Two cells without auxiliary electrodes also had pressure gauges. The cells were placed in a temporary pack configuration for initial testing.

B. The 9.0 ampere-hour cell is rectangular with average weight and physical dimensions as follows:

Weight (g)*	Overall Height (in)	Length (in)	Width (in)
404.5	3.696	2.967	.877

* Does not include those cells with pressure gauges.

C. The cell containers and covers are made of stainless steel. The positive and negative terminals are insulated from the cell cover by ceramic seals and protrude through the cover as solder-type terminals.

D. The auxiliary electrode in Gulton's standard adhydrode (U-fold).

III. RESULTS--The following was condensed from tables I through VII.

A. The cells exceeded the maximum voltage requirement of 1.480 voltages during their charges at 20°C.

B. One cell, S/N 2069, exceeded the test limit of 1.560 volts for a continuous time period of 2 hours during the 0°C overcharge test. The other cells exceeded 1.560 volts during charge; but did not exceed the time period.

C. Average end-of-charge (EOC) voltages and capacity output in ampere-hours (ah) were as follows:

Charge	Volts	ah Out
c/20 for 48 hours at 25°C	1.429	12.3
c/10 for 24 hours at 25°C	1.443	12.3
c/10 for 24 hours at 20°C	1.469	12.0
c/10 for 24 hours at 20°C*	1.471	10.8
c/40 for 20 hours at 20°C	1.373	3.0**
c/20 for 60 hours at 0°C	1.553	13.0
c/10 for 24 hours at 35°C	1.403	10.1

* Charge retention test.
** This value represents 66.7 percent of the input capacity (charge efficiency test).

D. Average Internal Resistance Measurements (milliohms):

Measurement Taken	Resistance
30 min before end-of-charge (Cycle 1)	4.41
1 Hr after start-of-discharge (Cycle 2)	4.25
2 Hr after start-of-discharge (Cycle 2)	4.42

E. Maximum power was obtained with a 50-ohm resistance; but a 47-ohm resistance was used throughout the tests as instructed by the Goddard Space Flight Centers' Technical Officer.

F. The average cell voltage at the end of one week open-circuit during the charge retention test, was 1.305 volts.

G. The 24-hour average cell voltage, following a 16-hour short period, was 1.221 volts.

H. One of the auxiliary electrode cells reached its pressure limit of 20 psia with 12.8 ampere-hours input, with a voltage of 1.541 volts, during the pressure versus capacity test. The other three cells reached their voltage limit of 1.550 volts with an average input of 13.5 ampere-hours. Three cells exhibited pressure decay of 1 psia during the last 30 minutes of the 1-hour open-circuit stand. Average capacity out was 11.4 ampere-hours.

APPENDIX I

APPENDIX I

I. TEST PROCEDURE

A. Phenolphthalein Leak Tests:

1. This test is a determination of the condition of the welds and ceramic seals on receipt of the cells and following the last discharge of the cells (Cycle #8).

2. The cells were initially checked with a one-half of one percent phenolphthalein solution applied with a cotton swab and then placed in a vacuum chamber and exposed to a vacuum of 40 microns of mercury or less for 24 hours. Upon removal they were rechecked for leaks and then received a final check following test completion. The requirement is no red or pink discoloration which indicates a leak.

B. Capacity Tests:

1. The capacity test is a determination of the cells' capacity at the C/2 discharge rate to 0.75 volt per cell, where C is the manufacturer's rated capacity. This type discharge follows all charges of this evaluation test.

2. The charges for the capacity tests are as follows:

a. C/20, 48 hours, room ambient (RA), Cycle 0, with a test limit of 1.52 volts or pressure of 100 psia.

b. C/10, 24 hours, RA, Cycle 1, with a test limit of 1.52 volts or 100 psia pressure and a requirement of maximum voltage (1.48) or pressure (65 psia).

c. C/10, 24 hours, 20°C, Cycle 2, with the same limits and requirements as the charge of Cycle 1.

C. Special Resistance Characterization Tests for Auxiliary Electrode Cells:

1. The purpose of this test is to determine the resistance to be placed across the cell's auxiliary electrode and negative terminal which will provide maximum signal when the cell is fully charged.

2. The cells are charged at C/10 for 24 hours at the room ambient temperature following their initial charge/discharge cycle. Following this the cells are continued on charge with the current reduced, if necessary, to maintain the cell's voltage below 1.520 volts

and to stabilize the pressure between 10-20 psia. Resistance values, between 10,000 ohms and 0.1 ohm are then placed between the auxiliary electrode and the negative terminal. The cells are allowed a minimum of 5 minutes, at each resistance value, to obtain an equilibrium voltage across this resistance. This voltage value is then recorded and by calculation using the equation $P = E^2/R$ the resistance that produces maximum power is determined.

D. Internal Resistance:

1. Measurements are taken across the cell terminals 1/2 hour before the end-of-charge (EOC) on Cycle 1 and 1 and 2 hours after the start-of-discharge of Cycle 2. These measurements were made with a Hewlett-Packard milliohmmeter (Model 4328A).

E. Special Charge Retention Test, 20°C:

1. This test is to establish the capacity retention of each cell following a 7 day open-circuit-stand in a charge mode.

2. The cells are charged at c/10 for 24 hours with a test limit of 1.52 volts or 100 psia pressure. They then stand on open-circuit for 7 days, with the requirement that the open-circuit voltage of each cell, following this period, is within $\pm$5 millivolts of the average cell voltage. The cells are then discharged and 80 percent capacity out of that obtained in Cycle 3 is required.

F. Internal Short Test:

1. This test is a means of detecting slight shorting conditions which may exist because of impertections in the insulating materials, or damage to element in handling or assembly.

2. Following completion of the third capacity discharge, the cells are shunted with a 0.5-ohm, 3-watt resistor for 16 hours. At the end of 16 hours the resistors are removed and the cells stand on open-circuit-voltage (OCV) for 24 hours. A minimum voltage of 1.15 is required at the end of 24 hours.

G. Charge Efficiency Test, 20°C:

1. This test is a measurement of the cells' charge efficiency when charged at a low current rate.

2. The cells are charged at C/40 for 20 hours with a test limit of 1.52 volts or 100 psia pressure. They are then discharged and the requirement is that the minimum capacity out equals 55 percent of capacity in during the preceding charge.

H. Overcharge Test #1, 0°C:

1. The purpose of this test is to determine the degree to which the cells will maintain a balanced voltage, and to determine the cells' capability to be overcharged without overcharging the negative electrode.

2. The cells are charged at C/20 for 60 hours. The test limits are cell voltages of 1 56 or greater for a continuous time period of ? hours or pressures of 100 psia. T'.e requirement is a voltage of 1.520 or a pressure of 65 psia. The cells are then discharged and 85 percent capacity out of that obtained in Cycle 3 is required.

I. Overcharge Test #2, 35°C:

1. This test is a measurement of the cells' capacity at a higher temperature when compared to its capacity at 20°C. This test also determines the cells' capability of reaching a point of pressure equilibrium; oxygen recombination at the negative plate at the same rate it is being generated at the positive plate.

2. The cells are charged C/10 for 24 hours with a test limit of 1.52 volts or 100 psia pressure and a requirement of 1.45 volts or 65 psia pressure. The cells are then discharged with a requirement that capacity out equals 55 percent capacity out as obtained in Cycle 3.

J. Pressure versus Capacity Test:

1. The purpose of this test is to determine the capacity to a pressure and the pressure decay during charge and open circuit stand respectively.

2. Each cell is charged at C/2 to either a pressure of 20 psia or a voltage of 1.550. Recordings are taken on each cell when it reaches 5, 10, 15 and 20 psia pressure. The cells then stand OCV for 1 hour with 30-minute recordings and then are discharged, shorted out and leak tested.

MEASUREMENT AND LEAK TEST DATA
TABLE I

9ND-NADC (SP 11/73)

SERIAL NUMBER	WEIGHT (Grams)	HEIGHT (Inches)	LENGTH (Inches)	WIDTH (Inches)	PHENOLPHTHALEIN LEAK TESTS											
					Initial				Following Hi Vac				Following Test Completion			
					Terminals		Fill Tube	Other	Terminals		Fill Tube	Other	Terminals		Fill Tube	Other
					+	-			+	-			+	-		
109	798.5	3.706	2.970	.878												
112	794.4	3.696	2.964	.884												
2049	404.0	3.688	2.968	.877												
2052	781.5	3.691	2.968	.872												
2059	404.7	3.696	2.966	.880												
2061	404.9	3.704	2.965	.880		NO	Leaks			NO	Leaks			NO	Leaks	
2063	402.8	3.701	2.967	.879												
2069	406.3	3.701	2.974	.877												
2072	403.3	3.696	2.965	.875												
2073	406.3	3.692	2.965	.877												
2078	403.6	3.690	2.964	.874												
2082	783.7	3.695	2.968	.879												

TABLE II
Capacity Data

SERIAL NUMBER	Capacity Test 1						Capacity Test 2						Capacity Test 3 (20°C)					
	END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE		
	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC-ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)
109	1.431	.466	12	12.1	.042	3	1.443	.578	22	12.2	.036	4	1.462	.698	65	11.5	.472	13
112	1.431	.479	15	12.2	.024	5	1.444	.590	27	12.2	.045	5	1464	.727	75	11.6	.466	19
2049	1.432			12.4			1.446			12.5			1.475			12.2		
2052	1.427		10	12.3		5	1.442		17	12.4		5	1.469		19	11.6		5
2059	1.427			12.3			1.442			12.3			1.469			12.2		
2061	1.427			12.2			1.442			12.2			1.468			11.9		
2063	1.428			12.1			1.441			12.3			1.466			12.0		
2069	1.428			12.4			1.444			12.5			1.472			12.2		
2072	1.426			12.3			1.440			12.4			1.470			12.2		
2073	1.428			12.4			1.443			12.5			1.470			12.2		
2078	1429			12.2			1.443			12.2			1.469			12.1		
2082	1.431		9	12.2		4	1.446		16	12.3		4	1.472		18	12.1		5

TABLE III
INTERNAL RESISTANCE AND SHORT TEST DATA

9ND-NADC (SP 11/73)

SERIAL NUMBER	INTERNAL RESISTANCE (MILLIOHMS)			INTERNAL SHORT TEST		
	END-OF-CHARGE	ONE HOUR AFTER START-OF-DISCHARGE	TWO HOURS AFTER START-OF-DISCHARGE	AFTER 16 HR SHORT	AFTER 24 HOUR OCV STAND	
				CELL	CELL	PRESS
109	4.8	4.4	4.2	.028	1.223	4
112	4.4	4.2	4.5	.027	1.218	6
2049	4.2	4.2	4.2	.012	1.219	
2052	4.4	4.1	4.2	.016	1.222	5
2059	4.3	4.3	4.3	.014	1.223	
2061	4.3	4.1	4.4	.015	1.223	
2063	5.0	4.3	4.6	.013	1.223	
2069	4.3	4.6	4.6	.012	1.220	
2072	4.2	4.1	4.6	.012	1.221	
2073	4.6	4.2	4.4	.014	1.221	
2078	4.3	4.3	4.6	.014	1.222	
2082	4.1	4.2	4.4	.012	1.222	4

TABLE IV
CHARGE RETENTION TEST DATA

SERIAL NUMBER	END-OF-CHARGE			24 HR. OCV			1 WEEK OCV			END-OF-DISCHARGE		
	CELL (VOLTS)	AUX. ELECT. (VOLTS)	PRESS. (PSIA)	CELL (VOLTS)	AUX. ELECT. (VOLTS)	PRESS. (PSIA)	CELL (VOLTS)	AUX. ELECT (VOLTS)	PRESS. (PSIA)	CAPAC-ITY (AH)	AUX. ELECT. (VOLTS)	PRESS. (PSIA)
109	1.474	.682	65	1346	.063	5	1307	.013	3	10.6	-.164	3
112	1.475	.686	71	1349	.060	6	1.307	.008	4	10.7	-.143	4
2049	1.475			1.348			1.305			11.0		
2052	1.470		36	1349		5	1.307		5	11.0		5
2059	1470			1.349			1.306			10.7		
2061	1470			1347			1304			10.7		
2063	1469			1348			1.305			10.7		
2069	1.477			1349			1305			10.9		
2072	1469			1347			1303			10.7		
2073	1466			1349			1306			10.8		
2078	1468			1346			1304			10.8		
2082	1471		33	1347		5	1303		5	10.8		5

TABLE V

Charge Efficiency and Overcharge Data

SERIAL NUMBER	Charge Efficiency (20°C)						Overcharge Test (0°)						Overcharge Test (35°C)					
	END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE		
	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPACITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPACITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPACITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)
109	1.370	.066	3	2.9	-.010	3	1.558	NA	9	13.0	.034	19	1.410	.701	61	11.2	.226	29
112	1.371	.095	4	3.5	-.072	5	1.551	.308	38	13.0	.014	24	1.408	.688	57	11.2	.226	28
2049	1.374			2.8			1.555			13.4			1.403			10.0		
2052	1.373		5	3.5		4	1.553		31	12.8		19	1.401		56	10.1		18
2059	1.373			3.5			1.553			13.2			1.399			9.5		
2061	1.373			2.9			1.556			13.3			1.399			9.4		
2063	1.373			2.9			1.531			12.4			1.405			10.4		
2069	1.373			2.7			1.562			13.5			1.403			9.9		
2072	1.373			2.9			1.558			12.6			1.398			9.3		
2073	1.372			2.9			1.550			12.6			1.403			9.8		
2078	1.373			2.9			1.557			13.2			1.399			9.5		
2082	1.373		4	2.9		4	1.555		22	12.6		11	1.405		53	10.3		21

TABLE VI
PRESSURE VS. CAPACITY TEST DATA

Serial No.	109	112		2052	2082											
Start-of-Charge, Press.	11	13		9	6											
AH in to 5 PSIA	N/A	N/A		N/A	N/A											
Cell (volts)																
Aux (volts)																
AH in to 10 PSIA	N/A	N/A		7.5	13.1											
Cell (volts)				1.441	1.517											
Aux (volts)				N/A	N/A											
AH in to 15 PSIA	13.5	12.8		13.3	13.8											
Cell (volts)	1.515	1.492		1.531	1.550											
Aux (volts)	.075	.044			N/A											
AH in to 20 PSIA		14.2														
Cell (volts)		1.541														
Aux (volts)		.114														
AH in to V/L (1.55V)	14.3	N/A		13.7	13.8											
Aux (volts)	.151			N/A	N/A											
Press (PSIA)	18			19	15											
30 Min OCV, Cell	1.406	1.402		1.400	1.401											
Aux (volts)	.164	.124		N/A	N/A											
Press (PSIA)	20	21		22	17											
1 hour OCV, Cell	1.389	1.389		1.386	1.382											
Aux (volts)	.177	.136		N/A	N/A											
Press (PSIA)	19	20		21	17											
EOD AH out	11.4	11.3		11.5	11.4											
Aux (volts)	.063	.033		N/A	N/A											
Press (PSIA)	14	17		15	12											

N/A - - - NOT APPLICABLE

TABLE VII

SPECIAL RESISTANCE CHARACTERISTIC DATA ON THE AUXILIARY ELECTRODES

SERIAL NO.	109		112								AVERAGE	
OHMS	VOLTS	PRESS	VOLTS	PRESS	VOLTS	PRESS	VOLTS	PRESS	VOLTS	PRESS	VOLTS	MILLIWATTS
10,000	.835	20	.860	20							.847	.072
5,000	.837	20	.855	20							.846	.143
2,000	.837	20	.847	20							.842	.354
1,000	.830	20	.833	20							.831	.691
500	.804	20	.807	19							.805	1.296
200	.683	19	.675	19							.679	2.305
100	.595	19	.572	19							.583	3.399
50	.475	18	.433	19							.454	4.122
20	.298	18	.260	19							.279	3.892
10	.188	18	.165	18							.176	3.097
5	.133	17	.100	18							.116	2.691
2	.057	17	.050	18							.053	1.405
1	.031	17	.028	18							.029	.841
0.5	.016	16	.015	18							.015	.450
0.2	.008	16	.007	18							.007	.245
0.1	.006	16	.005	18							.005	.250

Note: All pressures in PSIA.

$$\text{POWER} = \frac{V^2}{R} \text{ Watts} \quad 10^3 \frac{\text{Milliwatts}}{\text{Watt}} : \text{Milliwatts}$$