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A SCREENING AND SELECTION METHOD FOR NICKEL-CADMIUM CELL PLATES

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ABSTRACT

A procedure has been developed for selection and screening of nickel cadmium cell materials to improve cell uniformity and reliability. It will be proven that selection and screening by weight has been found to be a successful method for improving uniformity of plate capacity. A statistical analysis of the test results provides high weight-to-capacity correlations and a means of predicting plate capacity of every plate in a batch from weight alone.

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INTRODUCTION

Means for the selection and screening of nickel-cadmium cell materials are being investigated at GSFC. The primary aim of this work is the improvement of cell uniformity and reliability. The results reported here show that selection and screening through the use of single-plate weights within a batch has been found to be a successful method for improving uniformity of plate capacity. A statistical analysis of the test results provided high weight-to-capacity correlations and thus gave a reliable means of predicting the capacity of a plate from its weight alone.

This effort has been directed mainly toward the 20-ampere-hour (A-h) cells used in the Orbiting Astronomical Observatory (OAO), but the technique also merits consideration by users involved with other projects.

Plates from a batch manufactured by the SAFT Corporation of America and assembled by Gulton Industries for the OAO Flight III (batteries 32 and 33) were considered in the evaluation. Also included in the investigation were 20-A-h cell plates from the General Electric Company, considered as a backup source for OAO, the 20-A-h cell plates manufactured by Gulton Industries for aircraft use, and some 20-A-h aircraft-grade plates from batches manufactured by Texas Instruments, although this company no longer produces nickel-cadmium cells.

DISCUSSION

The selection and screening evaluation is centered on the relationship between plate weight and plate capacity. The basis for this relationship is tied to the composition of the positive and negative plates. The plates of a nickel-cadmium cell are produced in the following manner:

(1) Nickel powder is sintered onto a screen or perforated sheet substrate to produce an 80% porous plaque structure.

(2) The plaque structure is then impregnated with the active material to produce a plate—nickel hydroxide as the active material for a positive plate and cadmium hydroxide as that for a negative plate.

The weight of a plate is therefore dependent on the weight of the substrate, the weight of porous nickel deposited to produce the plaque, and the weight of the active material in the plaque. The weight of the substrate for each plate is relatively constant within a batch because the dimensions are essentially the same for each plate. The plaque length and width are also the same for each plate, and thus only the thickness, density, and therefore the quantity of nickel can vary.

If the manufacturing process is well controlled and the nickel quantity is constant, then the final plate weight will vary only as a function of the quantity of active material added to the plaque. Because the capacity (ampere hours) of a plate is a strong function of the quantity of active material, the weight of a plate can be related to the plate capacity. Variation in plaque weight would have an added, complicating effect on the weight-to-capacity relationship.

PLAQUE WEIGHT VARIATION AND MEASUREMENTS

Table 1 presents the results of a comparative evaluation of the plaque material for aircraft-grade plates manufactured by Gulton Industries and Texas Instruments.

Table 1

Group	Plaques for Positive Plates	Plaques for Negative Plates
Gulton Industries	Average weight (96 plaques): 15.37 g 94 plaques: ±0.1 g All plaques: ±0.3 g	Average weight (96 plaques): 17.15g 83 plaques: ±0.5 g All plaques: ±1.0 g
Texas Instruments	Average weight (70 plaques, without tabs): 13.39 g All plaques: ±0.1 g	Average weight (70 plaques, without tabs): 11.80 g All plaques: ±0.2 g

The weight variation of positive plaques is quite small, that of the negative plaque is slightly larger. Gulton Industries' plaques were screened by visual inspection for mechanical faults from a lot of 500; the Texas-Instruments plaques were similarly screened from a lot of 100. (Texas Instruments' plaques were included for comparative purposes only.)

PLATE WEIGHT VARIATION AND MEASUREMENTS

Batch averages and variation for the SAFT (OAO batteries 32 and 33), General Electric (OAO backup), and Gulton Industries and Texas Instruments (aircraft-grade) plates are given in Table 2.

The following items in Table 2 should be noted:

(1) The negative plates exhibit wider variations than do the positive plates.

(2) Three of the 67 negative plates from the SAFT plates (OAO batteries 32 and 33) were considerably different in weight from the others in the batch.

(3) Except for the three widely varying negative plates from the SAFT group, the SAFT negative plates otherwise exhibited smaller variations than did most of the others.

(4) With regard to the positive plates, the G. E. plates exhibited the least variation of the four.

In order to set an acceptable tolerance limit and to utilize plate weight as a method of screening and selection, the relationship between weight and capacity had to be determined. Ten positive and ten negative plates selected at random from each manufacturer (other than T. I.) were given a few charge and discharge cycles while submerged in 31% potassium hydroxide electrolyte solution. The operating procedure utilized appears below. No stand time was allowed between the end of a charge cycle and the beginning of the subsequent discharge cycle.

Table 2

Type	No. of Plates	Within Tolerance (g)	± %	Type	No. of Plates	Within Tolerance (g)	± %
SAFT positives	46	±0.5	1.8	SAFT negatives	39	±0.5	1.8
Average weight	61	±1.0	3.5	Average weight	56	±1.0	3.5
28.86 g	66	±1.5	5.2	28.21 g	64	±1.5	5.3
	67	±2.0	7.0		67	±3.0	10.6
G.E. positives	72	±0.5	2.0	G.E. negatives	41	±0.5	1.8
Average weight	86	±1.0	4.0	Average weight	61	±1.0	5.2
24.83 g				28.62 g	77	±1.5	5.2
					±84	±2.0	7.0
					±86	±2.5	8.7
Gulton aircraft positives	37	±0.5	1.9	Gulton aircraft negatives	47	±0.5	1.6
Average weight	61	±1.0	3.7	Average weight	56	±1.0	3.1
26.76 g	63	±1.5	5.6	31.83 g	60	±1.5	4.7
					63	±2.0	6.3
Texas Inst. positives	89	±0.5	2.2	Texas Inst. negatives	81	±0.5	1.8
Average weight	99	±1.0	4.4	Average weight	96	±1.0	3.6
22.80 g				27.99 g	98	±1.5	5.4
(with tabs)				(with tabs)			

Cycling Procedure

Cycle	Charge	Current	Discharge	Current
1	24 hr	250 mA	to 0.5 V	1.0 A
2	24 hr	250 mA	to 0.5 V	1.0 A
3	24 hr	250 mA	to 0.5 V	1.0 A
4	8 hr	700 mA	to 0.5 V	0.7 A
5	8 hr	700 mA	to 0.5 V	0.7 A
6	8 hr	700 mA	to 0.5 V	0.7 A

Each plate was placed between two plates of opposite polarity. The plates were held by means of spacers at the edges. An interposed polyethylene net was used to protect against shorting.

When the plates were tested in the above regimes, it became obvious that those plates that exhibited the highest ampere-hour capacity also weighed the most and that those with the lower weights exhibited correspondingly lower capacities. These data were compiled and appear in Table 3 below.

In five out of six groups the lowest weight had the lowest of 10 capacities. In three of six groups, the highest weight plate had the highest capacity; in the remaining groups the highest weight plates ranked second, third and fourth in capacity. This result indicates that the substrate and plaque weights are satisfactorily uniform and shows that the observed capacity differences were therefore dependent on the quantity of active material in the plaque.

Table 3 – Upper and lower limits of plate weight and capacity

Plate Type	Average Weight (g)	10 plate Average Capacity (A-h)	Standard Deviation (10 plate test)	High or Low	Plate Identification	Weight (g)	% from Average	Capacity (A-h)	Rank of 10
SAFT - Gulton (OAO)									
Positive	28.86 (60 plates)	3.08	0.22	high	J	29.30	+1.5%	3.48	1
				low	G	28.08	–2.7%	3.05	6
Negative	28.21 (60 plates)	3.47	0.23	high	F	29.19	+3.5%	3.67	1
				low	B	25.14	–10.9%	2.84	10
G.E. (OAO backup)									
Positive	24.83 (50 plates)	3.46	0.13	high	I	25.87	+4.2%	3.52	3
				low	A	24.19	–2.6%	3.16	10
Negative	28.62 (50 plates)	3.67	0.36	high	G	29.34	+2.5%	3.85	4
				low	B	26.04	–9.0%	3.00	10
Gulton (aircraft grade)									
Positive	26.76 (60 plates)	2.84	0.07	high	G	26.94	+0.6%	2.93	2
				low	D	25.50	–4.7%	2.83	10
Negative	31.83 (60 plates)	4.10	0.28	high	E	33.11	+4.0%	4.23	1
				low	A	31.30	–1.7%	3.98	10

STATISTICAL RELATIONSHIP BETWEEN PLATE WEIGHT AND CAPACITY

To determine whether statistically sound weight-to-capacity relationships exist, a computer program (CUPCRRG)* was modified and utilized in the data evaluation. Some of the results appear in Table 4. The table indicates what happens when the weight tolerance level is changed in step to a minimum of ±2% by successive elimination of the less uniform plates. As an example, in the case of the group of SAFT positive plates, the tolerance level is changed from ±3% to ±2% by omission of those outside the 2% weight tolerance limits.

Weight and standard deviation of weight are given and the average capacity and its standard deviation are also given for those plates within the ±3% tolerance. Then, data for the worst plate(s) were removed and the program rerun.

The penultimate column is the correlation coefficient, which indicates the relationship between weight and capacity. A coefficient of 1.0 is a perfect relationship, 0.0 indicates no relationship, and -1.0 is a perfect inverse relationship.

The very high correlation coefficient for the SAFT negatives and the Gulton aircraft-grade positives and negatives is noticeable. The General Electric Co. plates exhibited a somewhat poorer relationship and the SAFT positive correlation coefficient was quite poor. A high correlation coefficient can only exist when the plaques are produced in a uniform manner, in which case the capacity is a function of the active material quantity, which is, in turn, directly related

*University of Pennsylvania computer program, July 10, 1964; available from SHARE Program Library, SDA. No. 3205, D. Segal.

Table 4

Plate Manufacturer	Plate Type	Average Weight (g) (all plates)	Plates Removed	Weight Tolerance	Number of Plates	Average Weight (g)	Standard Deviation σ	Average Capacity (A-h)	Standard Deviation σ	Correlation Coefficient	Negative-to-Positve Capacity Ratio (assuming ±3% weight tolerance)
SAFT	Positive	28.86		3%	10	28.76	0.39	3.08	0.21	-0.17	1.25
			G, H	2%	8	28.92	0.24	3.04	0.20	0.29	
	Negative	28.21		11%	10	28.19	1.09	3.47	0.22	0.98	
			B	3.5%	9	28.53	0.42	3.54	0.06	0.81	
			B.H	3%	8	28.46	0.39	3.52	0.05	0.77	
			B, F.H.I	2%	6	28.56	0.12	3.53	0.04	0.88	
G.E.	Positive	24.83		4.5%	10	24.97	0.53	3.46	0.12	0.65	1.22
			I	4%	9	24.87	0.46	3.45	0.13	0.69	
			D, I	3%	8	24.75	0.33	3.45	0.13	0.84	
			A, D, I	2%	7	24.83	0.28	3.49	0.08	0.72	
	Negative	28.62		10%	10	28.29	0.97	3.67	0.34	0.84	
			B	6%	9	28.54	0.65	3.75	0.27	0.70	
			B, I	3%	8	28.71	0.46	3.83	0.12	0.06	
			B, F, G, I	2%	6	28.50	0.34	3.82	0.13	-0.07	
Gulton (aircraft)	Positive	26.76		5%	10	26.34	0.54	2.84	0.07	0.95	1.59
			D	3%	9	26.43	0.48	2.85	0.06	0.94	
			A, B, C, D, E, J	2%	4	26.59	0.32	2.86	0.06	0.99	
	Negative	31.83		5%	10	32.24	0.64	4.10	0.12	0.96	
			E	3.5%	9	32.15	0.60	4.08	0.11	0.95	
			E, G	3%	8	32.06	0.57	4.06	0.11	0.95	
			B, E, G, H, J	2%	5	31.66	0.32	3.98	0.05	0.80	

to plate weight. This was shown to be true for the Gulton aircraft-grade plates, for which the plaque variations were measured directly. It was also shown, although more indirectly, that SAFT negatives exhibited satisfactory plaque and substrate uniformity. With regard to the SAFT positive plates, however, it must be concluded that there were significant variations in the substrate or, more probably, the plaque weights, so that the plate weights, when within the ±3% tolerance, were not necessarily very indicative of capacity.

Also included in this table is an indication of the negative-to-positive capacity ratios that may be expected for these plates.

The overall effect of setting a weight tolerance limitation of ±3% is given in Figures 1, 2, and 3. The distributions are given in terms of standard deviations (σ) for each of the six groups of 10 plates tested and then for the plates remaining after the ±3% weight tolerance limit is imposed. In the case of the SAFT positive plates used in the OAO batteries (Figure 1a), all plates in the test were within the ±3% tolerance limit and consequently only a single distribution is given. The distribution of plate capacities is also given in terms of the standard deviation for all 10 plates in each of the tests and then for those remaining after the tolerance limit is imposed. The relatively sharp distribution of capacities for the SAFT negative plates (Figure 1b) and for the Gulton positive and negative plates (Figures 2a and 2b) is noticeable. The narrow distribution is related to the high correlation coefficients for the weight-to-capacity relationships given for each group.

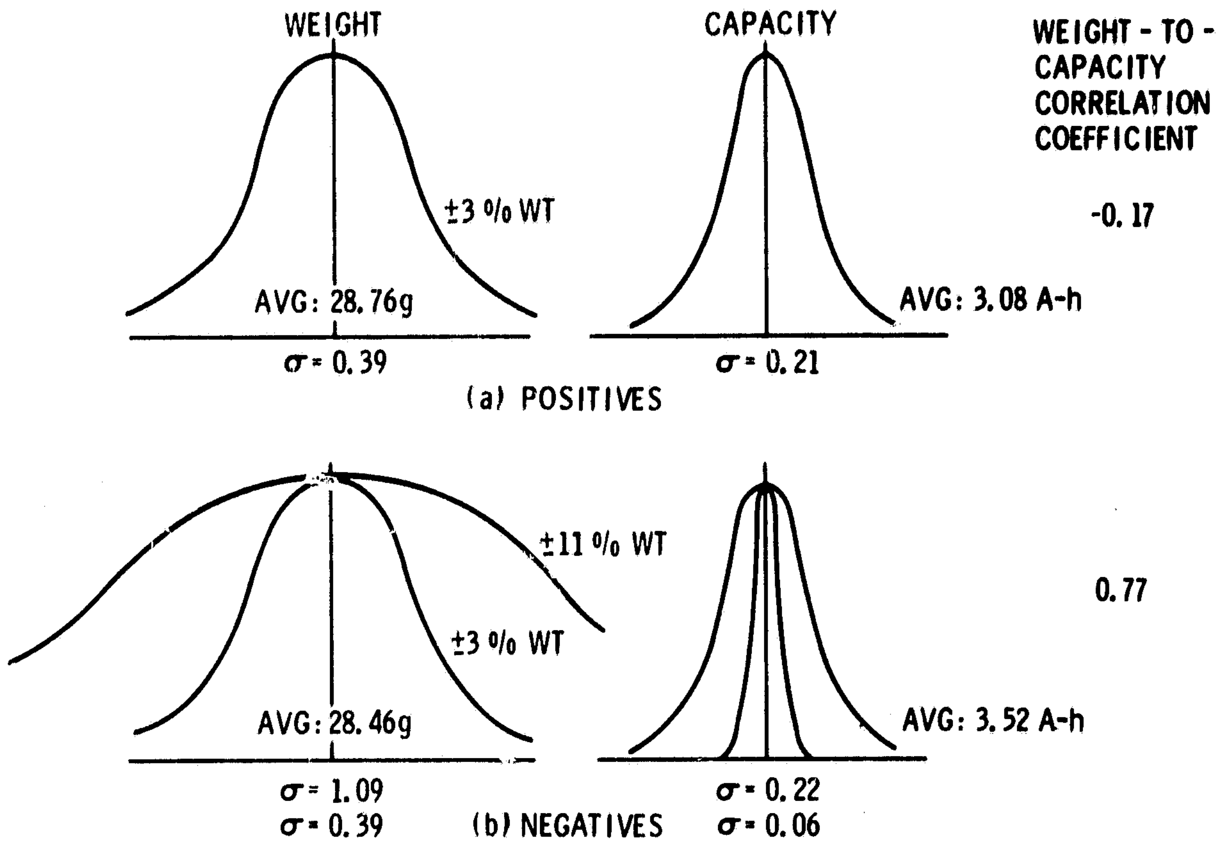

Figure 1–SAFT-Gulton OAO plates.

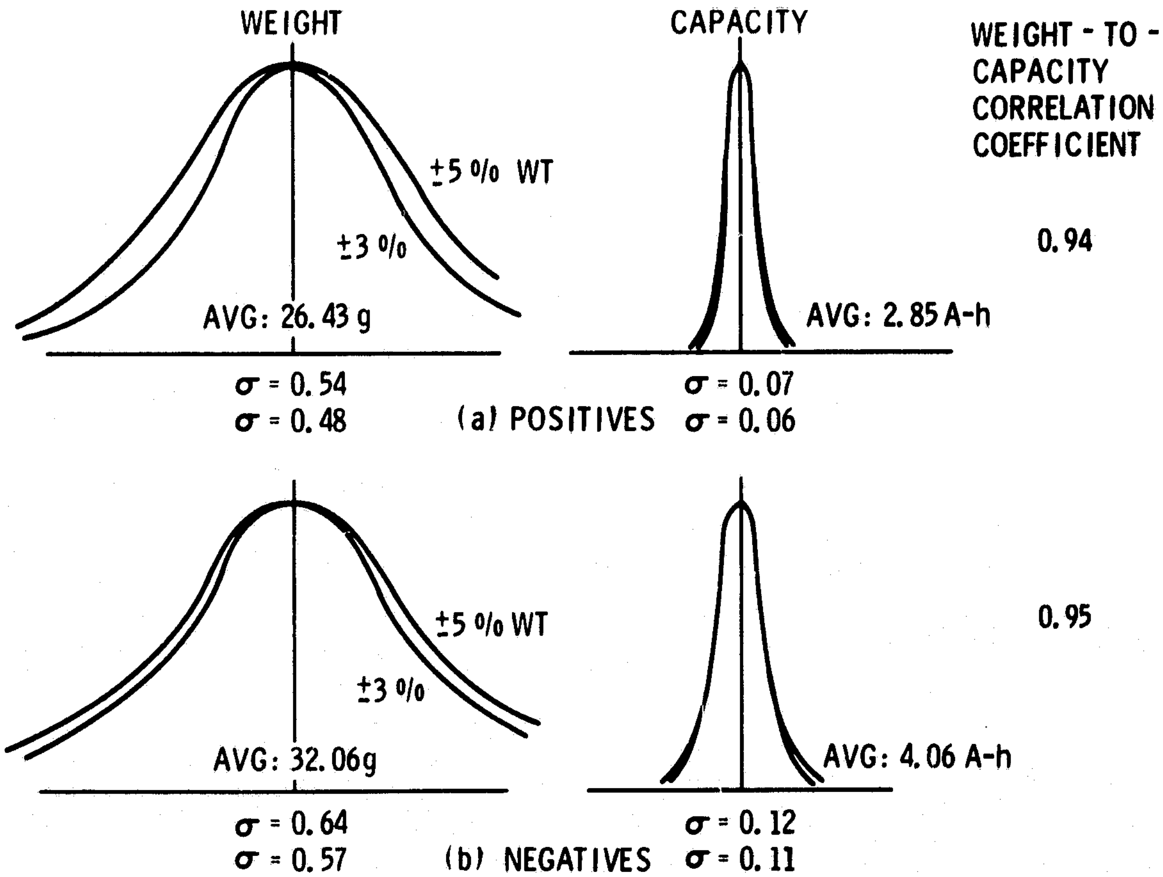

Figure 2–Gulton aircraft-grade plates.

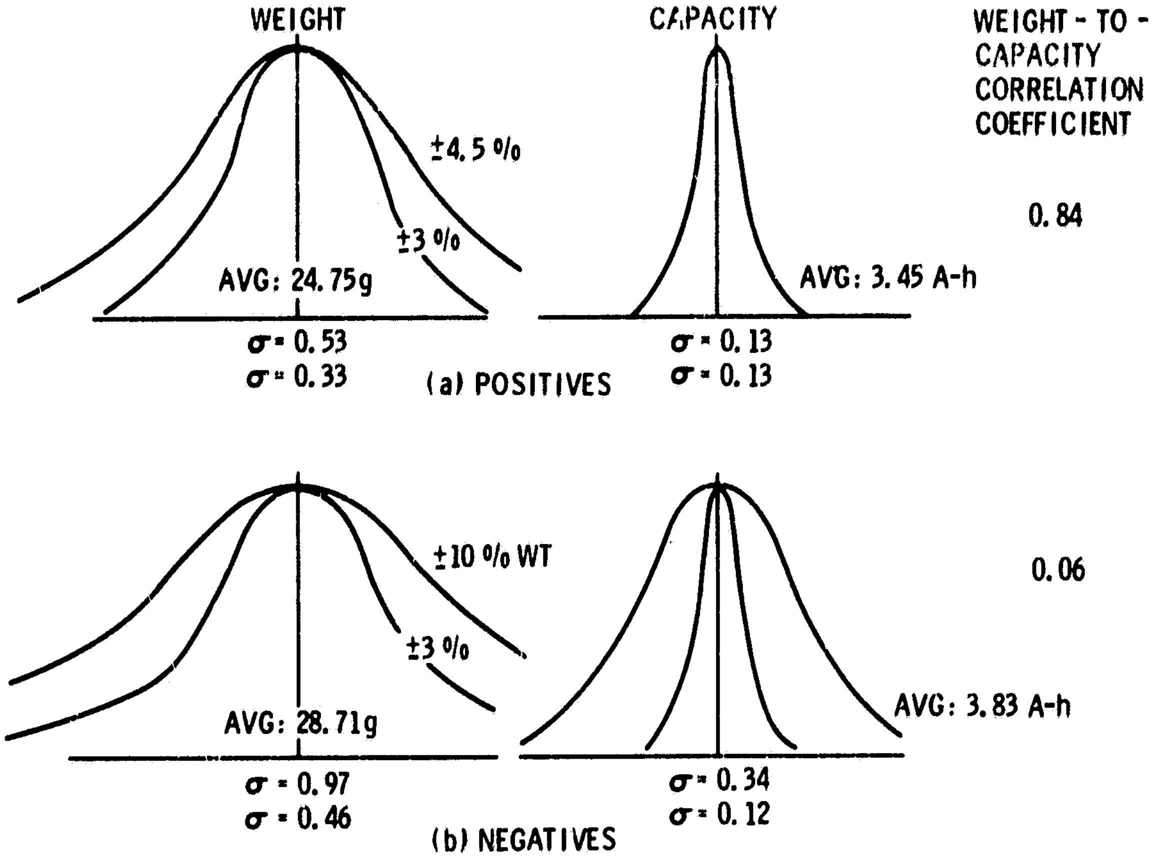

Figure 3–G.E. OAO backup plates.

The data shown in Figures 1, 2, and 3 were included in the modified statistical analysis computer program (CUPCRRG) mentioned above. The program includes a means of mathematically relating weight and capacity by the regression analysis technique. The equations given in Table 5 for each group take the form

$$y = ax + b,$$

where y is the capacity in ampere hours, x is the plate weight in g, and a and b are, respectively, the coefficient and constant given in Table 5. Again the relationship between weight and capacity is verified for all cases. The greatest deviation cited in the table is in the case of the SAFT positive plates, in which 67% of the plates fall within a ±0.22-A-h (±7%) range. The closest relationship between weight and capacity is given for the three groups cited above, and in

Table 5. Plate capacity prediction based on plate weight.

Manufacturer	Correlation Coefficient	Average Weight	Regression Equation Terms y (A-h) $= a\ (x) \pm b$ (g)	Average Capacity (A-h)	Standard Error of y
SAFT (OAO)	0.29	28.86	Positive plate capacity = 0.24 (weight) -3.94	3.08	0.22
	0.98	28.21	Negative plate capacity = 0.09 (weight) +0.90	3.47	0.04
GE (OAO Backup)	0.69	24.83	Positive plate capacity = 0.34 (weight) -4.97	3.45	0.10
	0.84	28.62	Negative plate capacity = 0.02 (weight) +3.36	3.67	0.22
Gulton (Aircraft-Grade)	0.95	26.76	Positive plate capacity = 0.12 (weight) -0.32	2.84	0.02
	0.96	31.83	Negative plate capacity = 0.18 (weight) -1.80	4.10	0.04

Figure 1, with the highest correlation coefficients. These are the SAFT negative plates and the Gulton aircraft-grade positive and negative plates. For these groups, given a plate weight, the standard deviation in the predicted capacity would be 0.04, 0.02, and 0.04 A-h, respectively.

These data indicate that the weight of single plates is a reliable measure of plate capacity. A recommended practical procedure for screening by weight is the following:

(1) Perform a visual inspection of each plate in the batch. Reject plates with obvious defects or abnormalities.

(2) Weigh a statistically sound sample of more than 100 randomly selected plates from the remaining acceptable plates to determine the average weight of each plate in the entire batch.

(3) Select only those plates within ±3% of the average weight.

(4) Select ten plates and perform a charge-discharge cycling test as described in the procedure listed in this report.

(5) Perform a statistical analysis of the weight and capacity data. If the correlation coefficient is greater than 0.85, an acceptably close relationship exists between capacity and weight.

(6) Perform a regression analysis that will provide a mathematical relationship between weight and capacity. This can then be used to predict individual plate capacity and negative-to-positive capacity ratios for the entire batch of plates.

In summary, the use of weight as a selection and screening method for nickel-cadmium cell plates has been shown to be reliable. There exists a strong relationship between the capacity and weight of plates for 20-A-h nickel-cadmium cells of the type used on the OAO and other satellites. This is not unexpected, considering the details of a typical plate assembly, if the basic structure of a plate, namely the substrate and plaque, is made uniformly and reproducibly. With a uniform and reproducible structure the plate weight is a linear function of the weight of active material incorporated in the plate, and this is directly related to the capacity.

CONCLUSIONS

The following can be concluded from this effort:

(1) The capacity of plates from nickel-cadmium cells of the OAO 20-A-h type is highly correlated with weight.

(2) Plate weight is an effective means of screening for abnormal plates, and it can also be used to select plates for a narrow capacity distribution, thereby improving uniformity.

(3) A ±3% tolerance on weight is recommended* as a working limit in the selection and acceptance of plates for nickel-cadmium cells.

(4) Mathematical relationships are derived which, for a given manufacturer, will predict plate capacity from plate weight with a standard error in capacity given below:

*Grumman Corp. has requested that a ±3.5% tolerance limit be imposed on weight in the OAO program. For the plates studied here, data show that the ±3.5% tolerance would be acceptable.

SAFT OAO	positive ±0.22 A-h,	
	negative ±0.04 A-h.	
G.E. OAO backup	positive ±0.10 A-h,	
	negative ±0.22 A-h.	
Gulton aircraft	positive ±0.02 A-h,	
	negative ±0.04 A-h.	

(5) With plate capacity known, the critical negative-to-positive capacity ratio can be determined prior to cell assembly.

(6) A procedure is recommended for the screening of plates within a batch weight.

These procedures are being incorporated in the Interim Model Specification for High Reliability Nickel-Cadmium Spacecraft Cells (Specification No. S-716-P-23), prepared by the Joint NASA/GSFC-Aerospace Industry Battery Committee.

Additional testing of plates and battery materials is continuing in order to develop further screening methods and control techniques to improve uniformity and reliability of satellite- and spacecraft-grade batteries.