N94- 28136

Pgs 66

BST SYSTEMS INC.

Advanced Silver Zinc Battery Development for the SRB and ET Range Safety Subsystems

- Presented by: BST Systems, Plainfield, CT
- Presented for: 1993 NASA Aerospace Battery Workshop
- November 16-18, 1993
- US Space and Rocket Center, Huntsville, Al

This work was conducted in support of USBI Purchase Order 44420

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Introduction

- Design and develop AgZn batteries for the SRB and ET Range Safety Subsystems
  - AgZn new to the RSS battery--current chemistry is lithium
- Various engineering techniques were used to meet difficult requirements
  - » Composite separator systems
  - » New electrode processing techniques
  - » New restrainment techniques

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OFI and RSS Requirements

- OFI   Overall Requirements
  - Capacity: 50 AH
  - Temperature: 30 F to 105 F
  - Wet Stand: 120 days
  - Weight: 45 lbs max
  - Relief Valve and Pressurizing capability
  - Thermistor circuit
  - Power and monitoring connector harnesses
    - » Monitoring circuit fused

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OFI and RSS Electrical Requirements

- **OFI BATTERY**
  - OCV 40 VDC max
  - Static Loads
    - » 26.00 VDC to 32.00 VDC within 200 ms of application of 0.16 A to 30 A loads
  - Transient Loads
    - » 10.00 VDC to 32.00 VDC during application of pulses up to 30.00 A followed by transition within 100 ms to static load levels

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OFI and RSS Requirements

- RSS Overall Requirements
  - Capacity: 14 AH
  - Temperature: 30 F to 118 F
  - Wet Stand: 120 days
  - Weight: 14 lbs max
  - Orientation insensitive--leakproof
  - Relief valve and Pressurizing capability
  - Thermistor circuit
  - Power and monitoring connector harnesses
    - » Monitoring circuit fused

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OFI and RSS Electrical Requirements

- **RSS BATTERY**
  - OCV 44 VDC max
  - Static loads
    - » 30.50 VDC to 35.00 VDC within 100 ms of application of 0.10 A to 1.00 A loads
  - Pulse loads
    - » 27.00 VDC to 35.00 VDC during a 250 ms 3.65 A pulse
  - Transient loads
    - » 10.00 VDC to 35.00 VDC during a 2 ms 8 A pulse followed by transition within 100 ms to static load levels

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Dynamic Environmental Conditions OFI/RSS

- Random vibration levels
  - » Most damaging low frequency levels high throughout flight
- Ordnance shock
- Water impact shock
- Must remain intact following splashdown (RSS)
- Must function after splashdown (OFI)
- Testing conducted up front during development

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Design Considerations

- Rapid voltage transitions at turn on
- Temperature insensitivity (no heater blankets)
- Reliable 120 day wet stand
  - Temperatures up to 118 F
- Capacity retention
- Orientation insensitivity
- Dynamic conditions

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Design Considerations Deperoxidation

- Extensive experimentation conducted to optimize method
- Both thermal and electrical methods considered
- Thermal technique found to provide the best results
- Processing optimized

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Design Considerations

Temperature Insensitivity and 120 day wet stand

- Prototype testing conducted to simulate worst case conditions
- Pack design modified as required
- Incorporated separator system based on data obtained from in-house development testing

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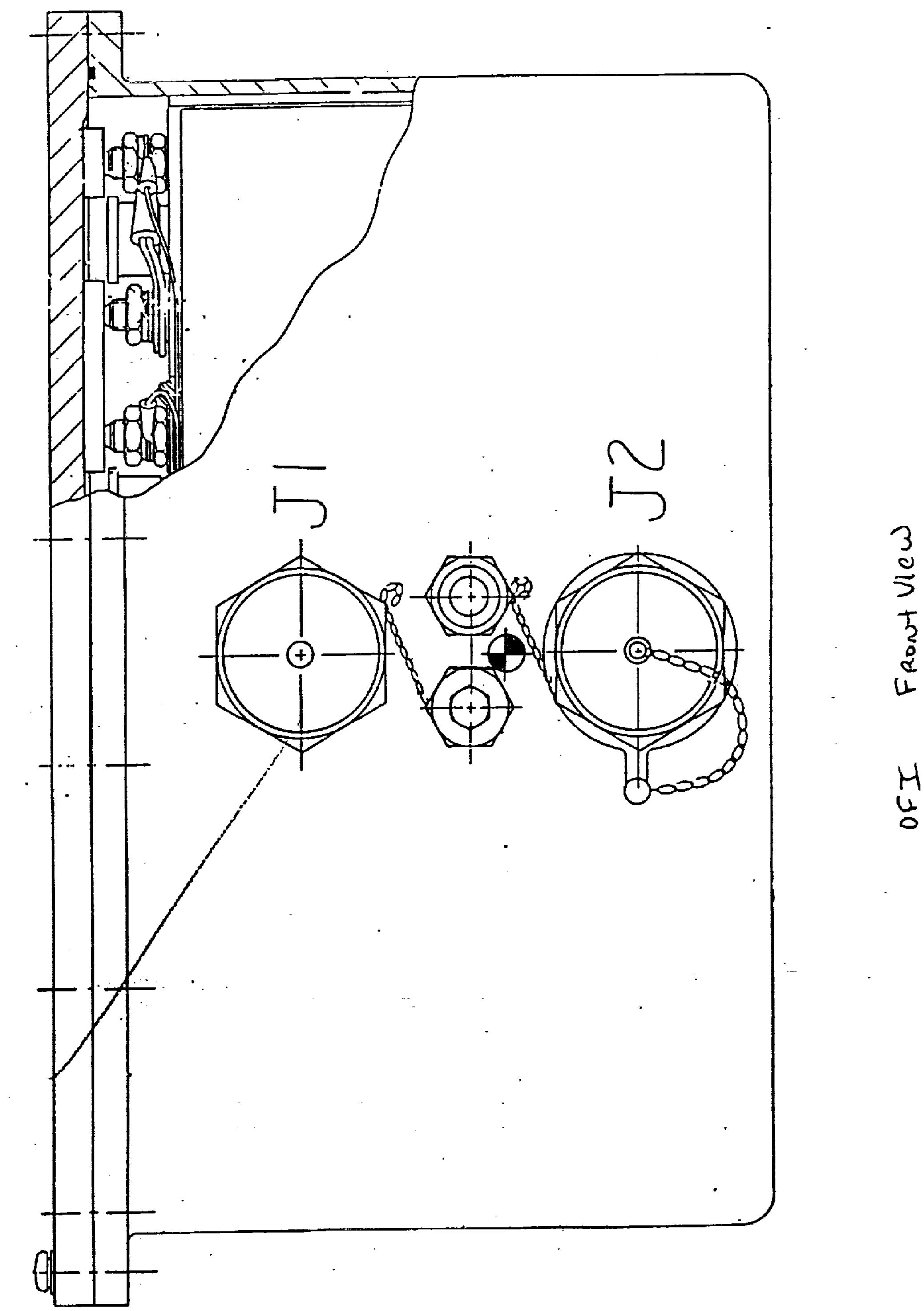
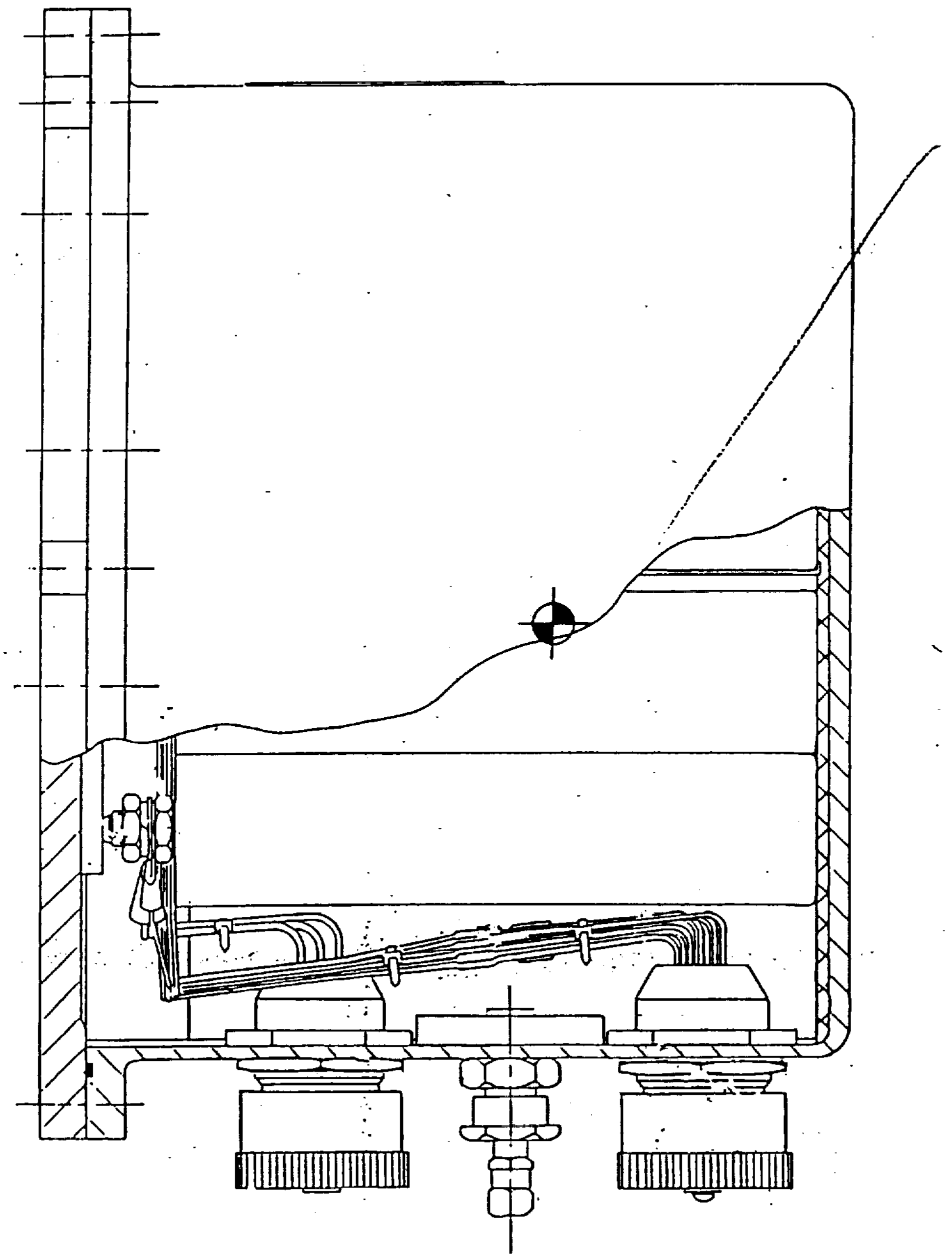
Design Considerations
Orientation Insensitivity

- RSS battery oriented connector end up (or down)
- The following techniques were incorporated:
  - Reliable redundant terminal to cover seals
  - Reliable, redundant case to cover seals
  - Electrolyte starvation (RSS only)
  - High pressure cell relief valves
  - Absorbent barriers

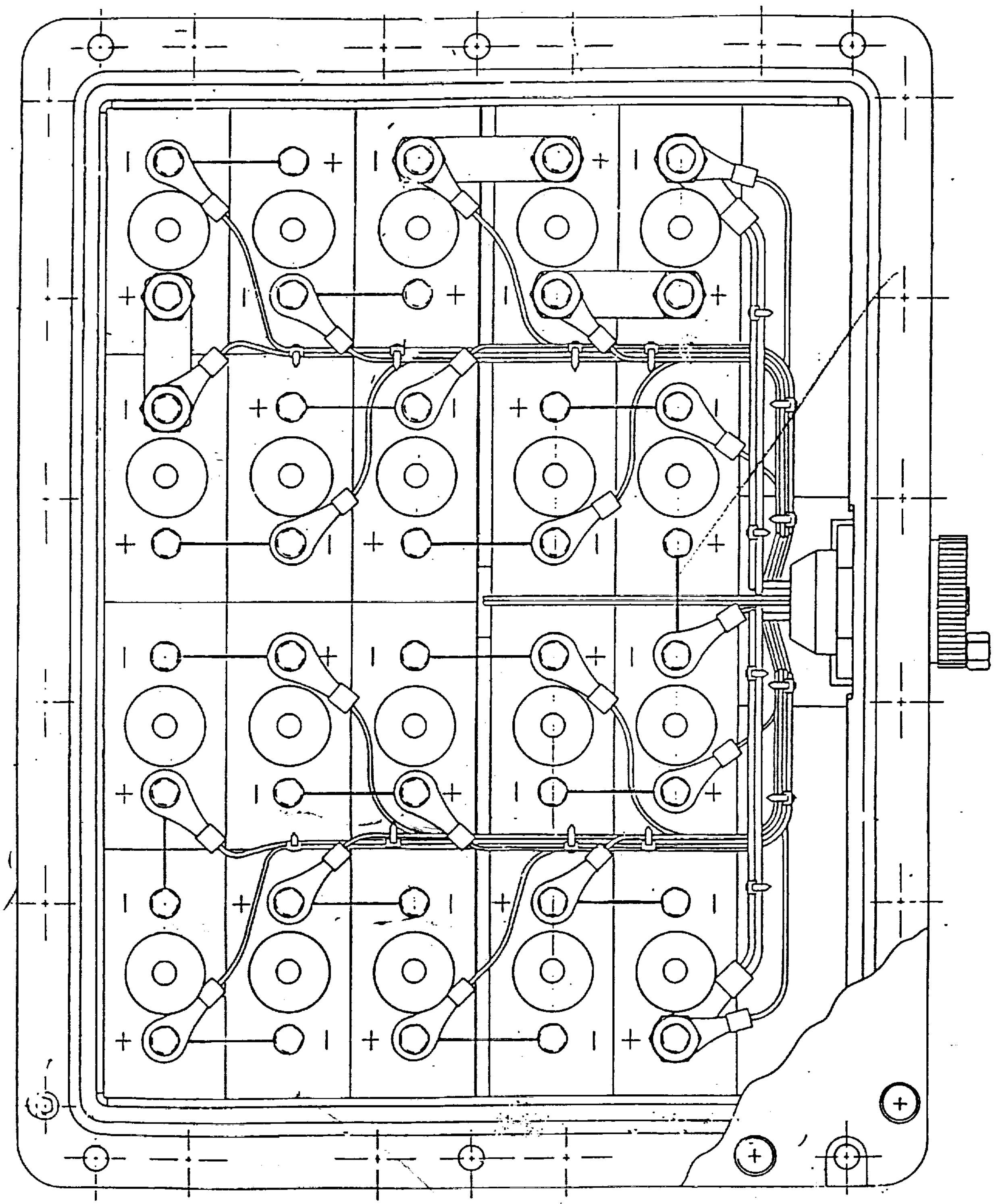
Design Considerations
Dynamic Conditions

- **Technical approach to engineer unpotted units for both applications**
- **Advantages to this approach include**
  - Ease of manufacturing
  - Improved inspectability
  - Strapping variability
  - Mechanically simple
- **Several restraint techniques utilized**
  - Internal cell hold down features
  - Spacers and shims to prevent lateral movement
  - Cushioning material on underside of cover to prevent up and down movement

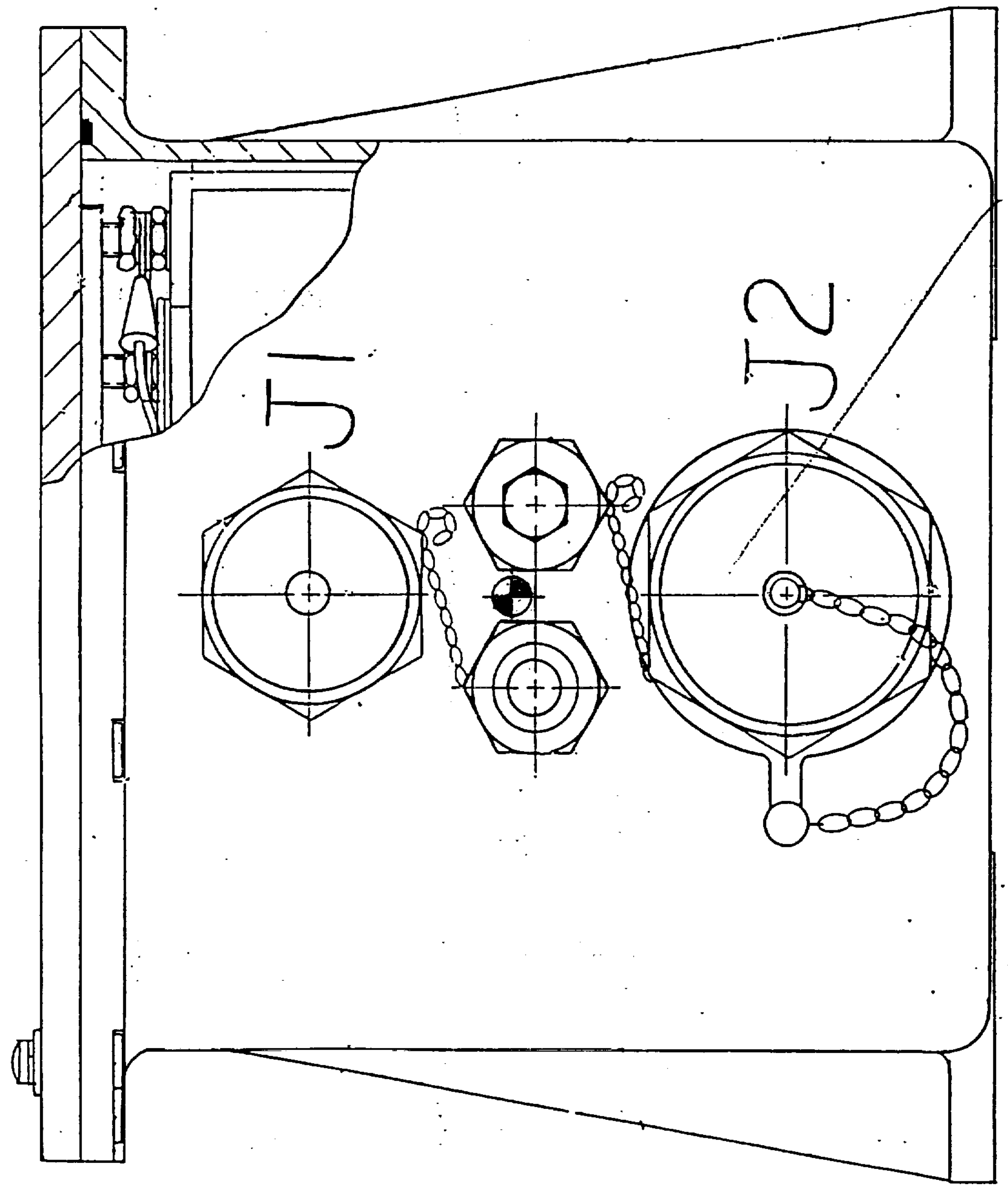

J1
J2
Front View



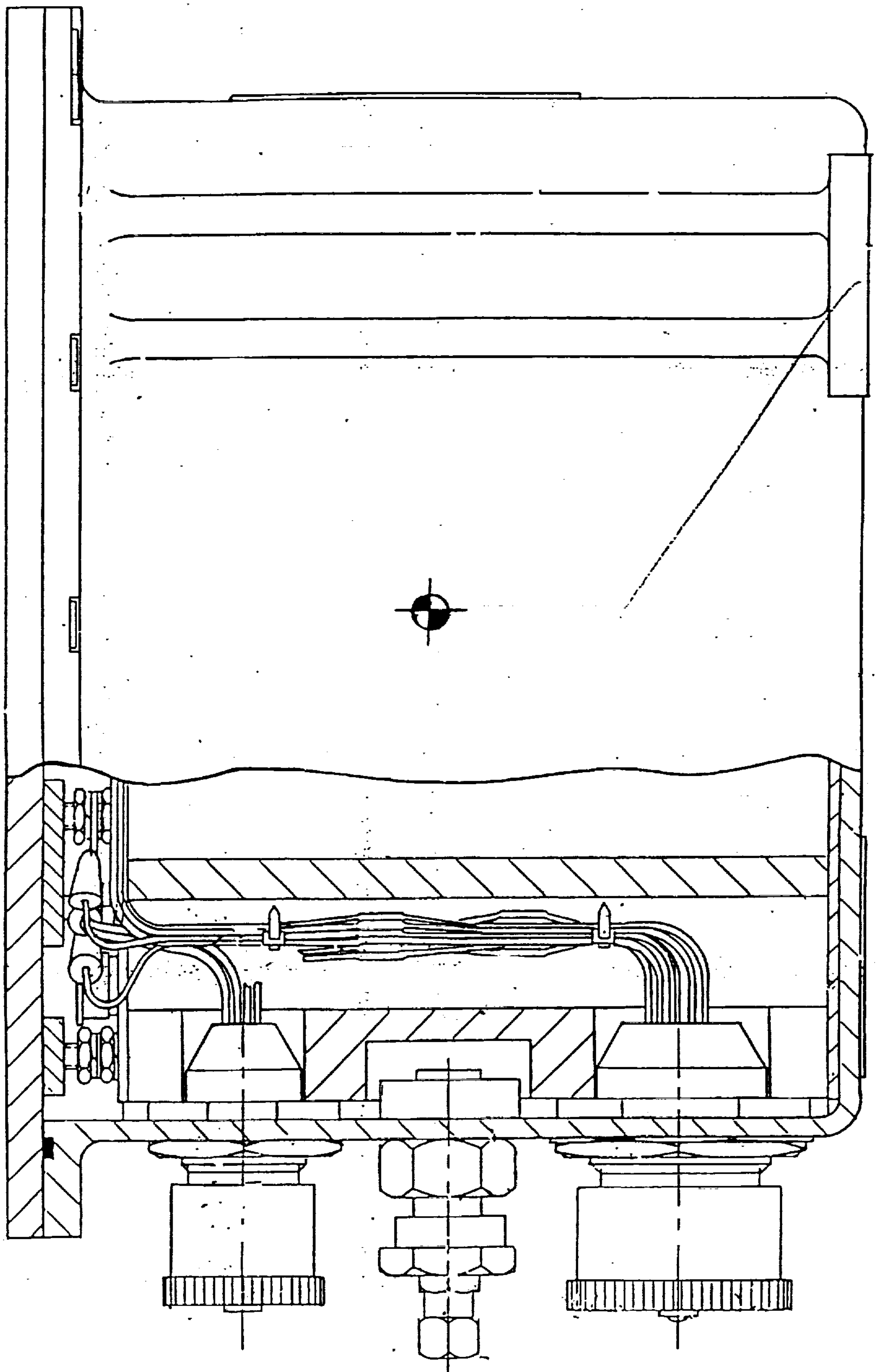
OFI Side View



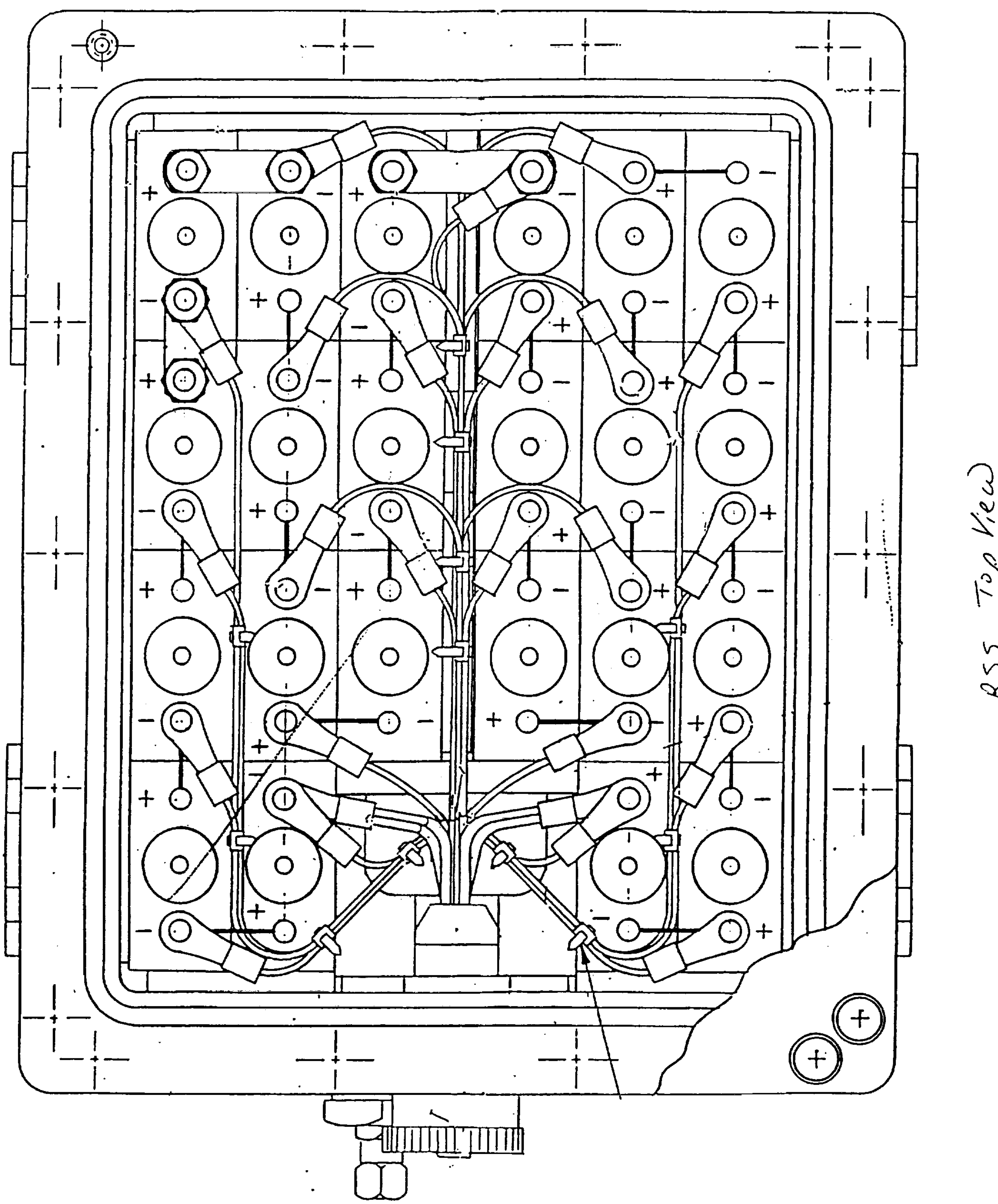
OFI Top View



RSS Front View



RSS Side View


RSS Top View

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Testing Approach

- Conducted on 75 development cells and (at least) 8 batteries of each type to verify design and approach
- Transient load profiles to simulate actual usage
- Samples held at room temperature, hot and cold conditions

OFI Cell Test Matrix

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OFI Cell Test Matrix (75 Cells)

TEMPERATURE PROFILE	ACTION PERFORMED	GROUP NO.				
		DAY 6	DAY 30	DAY 60	DAY 90	DAY 120
HOT	100% DISCHARGE	1			2	3
	TRANSIENT♦ DISCHARGE	2,3	2,3	2,3	3	
ROOM	100% DISCHARGE	4			5	6
	TRANSIENT DISCHARGE	5,6	5,6	5,6	6	
COLD	100% DISCHARGE	7			8	9
	TRANSIENT' DISCHARGE	8,9	8,9	8,9	9	

Note 1: ♦ means transient discharge will be performed during 105°F section of hot temperature profile.

Note 2: ' means transient discharge will be performed during 30°F section of cold temperature profile.

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OFI Cell Transient Load Profile

III. C. CELL DEVELOPMENT TESTING

TRANSIENT PROFILE

Load	Duration		AH Consumption
0.16A	10	Minutes	0.0267 AH
0.5A	20	Minutes	0.1667 AH
3.5A	250	Milliseconds	0.0002 AH
0.5A	15	Minutes	0.1250 AH
3.5A	250	Milliseconds	0.0002 AH
0.7A	15	Minutes	0.1750 AH
1.0A	5	Minutes	0.0833 AH
2.5A	5	Minutes	0.2083 AH
5.0A	5	Minutes	0.4167 AH
8.0A	2	Millisecond	0.0000 AH
10.0A	3	Minutes	0.5000 AH
15.0A	3	Minutes	0.7500 AH
30.0A	3	Minutes	1.5000 AH
	===============		=========
Totals	84	Minutes	3.9521 AH

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OFI Results
Capacity, Wet Life & Performance

- All cells met 50 AH capacity requirement after 120 days
- No shorting
- Charge retention good
  - Approx 97% capacity retention at room temperature and cold temperature after 120 days
  - Approx 90% capacity retention at high temperature after 120 days
- Deperoxidation successful
- Load conditions at various temperatures met

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OFI Results
Physical

- No case to cover leakage
- No terminal leakage
- No leakage through valve

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RSS Cell Test Matrix

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RSS Cell Test Matrix

TEMPERATURE PROFILE	ACTION PERFORMED	GROUP NUMBER				
		DAY 6	DAY 30	DAY 60	DAY 90	DAY 120
HOT	100% DISCHARGE	1			2	3
	TRANSIENT♦ DISCHARGE	2,3	2,3	2,3	3	
ROOM	100% DISCHARGE	4			5	6
	TRANSIENT DISCHARGE	5,6	5,6	5,6	6	
COLD	100% DISCHARGE	7			8	9
	TRANSIENT' DISCHARGE	8,9	8,9	8,9	9	

Note 1: ♦ means transient discharge will be performed during 118°F section of hot temperature profile.

Note 2: ' means transient discharge will be performed during 30°F section of cold temperature profile.

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RSS Cell Transient Load Profile

I. C. CELL DEVELOPMENT TESTING

TRANSIENT PROFILE

Load	Duration	AH
0.10A	10 Minutes	0.0166
3.65A	250 Milliseconds	0.0002
0.10A	10 Minutes	0.0166
8.00A	2 Milliseconds	0.0000
0.10A	10 Minutes	0.0166
0.50A	8 Minutes	0.0666
3.65A	250 Milliseconds	0.0002
0.50A	8 Minutes	0.0666
8.00A	2 Milliseconds	0.0000
0.50A	8 Minutes	0.0666
1.00A	5 Minutes	0.0833
3.65A	250 Milliseconds	0.0002
1.00A	5 Minutes	0.0833
8.00A	2 Milliseconds	0.0000
1.00A	5 Minutes	0.0833
	=================	=========
	69 Minutes	0.500 AH

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RSS Results
Capacity and Wet Life

- All cells met the 14 AH capacity requirement
- Charge retention good
  - Approx 90% capacity retention at room temperature and cold temperature after 120 days
  - Approx 84% charge retention at high temperature after 120 days
- No performance variations with respect to orientation
- Deperoxidation successful
- Load conditions at various temperatures met

I. C. RSS CELL DEVELOPMENT TESTING

CAPACITIES vs. TIME

HOT TEMPERATURE CHARGED STAND

DAY OF DISCHARGE	ORIENTATION			
	UPRIGHT	-UP	+UP	AVERAGE
INITIAL	22.9	22.6	22.2	22.6 ± 1.1
DAY 90	18.4	18.7	19.6	
	18.2	14.4*	20.4	
	19.0	17.7	20.0	
	18.5			
AVERAGE	18.5	18.2*	20.0	18.5 ± 4.9
				18.9 ± 2.6*
DAY 120	19.3	18.6	18.4	
	19.0	19.2	18.9	
	18.4	17.6	18.1	
	19.6	18.1	19.6	
	18.5	18.7	19.3	
		18.3	19.3	
Average	19.0	18.4	18.9	18.8 ± 1.7

I. C. RSS CELL DEVELOPMENT TESTING

CAPACITIES vs. TIME

COLD TEMPERATURE CHARGED STAND

DAY OF DISCHARGE	ORIENTATION			
	UPRIGHT	-UP	+POS	
INITIAL	20.8	20.8	21.8	21.2 ± 1.7
DAY 90	19.5	20.9	20.9	
	20.6		21.2	
	20.2	21.0	20.9	
	19.9			
AVERAGE	20.1	20.8	21.0	20.6 ± 1.6
DAY 120	21.0	22.4	20.0	
	21.0	22.0	22.3	
	21.5	22.1	22.3	
	21.5	21.7	22.1	
	22.0	21.9	21.5	
			21.2	
AVERAGE	21.4	22.0	21.6	21.7 ± 1.9

I. C. RSS CELL DEVELOPMENT TESTING

CAPACITIES vs TIME

ROOM TEMPERATURE CHARGED STAND

DAY OF DISCHARGE	ORIENTATION			
	UPRIGHT	-UP	+UP	
INITIAL	23.0	22.3	22.3	22.5 ± 1.2
DAY 90	21.9	22.5	21.4	
	21.4			
AVERAGE	21.7	22.5	21.4	21.8 ± 1.5
DAY 120	19.7	20.0	19.4	
	20.2	19.7	20.1	
		20.5	20.4	
AVERAGE	20.0	20.1	20.0	20.0 ± 1.1

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RSS Results
Physical

- No case to cover leakage
- No leakage through valve

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RSS Battery Testing

- Eight development batteries built and tested
  - Six units to demonstrate wet life and capacity performance
  - Two units to demonstrate performance during shock and vibration
- Batteries oriented on mounting feet or connector end up
- Discharge profile and matrix similar to cell matrices
- The six wet life batteries tested out to 150 days

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RSS Results
Capacity and Wet Life

- All six wet life batteries met the 14.00 AH capacity requirement
- Units were kept on stand from 147 to 161 days at cold, room and high temperatures
- Capacities ranged from 16.95 AH (hot) to 21.0 AH (cold)
- Units were orientation insensitive

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Capacity

Battery #	Temp	Capacity	Days	Orientation
SDB2	Hot	16.96AH	147	Upended
SDB3	Hot	16.95AH	161	Upright
SDB4	Room	19.92AH	152	Upended
SDB5	Room	19.47AH	152	Upright
SDB7	Cold	20.62AH	151	Upended
SDB8	Cold	21.0AH	151	Upright

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RSS Results

- No cell case to cover leakage
- No leakage through valve
- No terminal leakage
- One battery also inverted fully for 48 hours
  - No leakage

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OFI Battery Testing

- Eight development batteries built and tested
  - Six units to demonstrate wet life and capacity performance
  - Two units to demonstrate performance during shock and vibration
- Discharge profile and matrix similar to cell matrix

BST SYSTEMS INC.

OFI Results
Capacity and Wet Life

- All six wet life batteries met the 50 AH capacity requirement
- Units were kept on stand from 123 days to 155 days at cold, room and hot temperatures
- Capacities ranged from 61.3 AH (hot) to 74.5 AH (cold)

Capacity

Battery #	Temp	Capacity	Days
FDB102	Hot	61.60AH	155
FDB103	Hot	61.30AH	133
FDB104	Room	71.40AH	131
FDB105	Room	70.60AH	128
FDB107	Cold	74.50AH	147
FDB108	Cold	74.60AH	121

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OFI Results

- No cell case to cover leakage
- No leakage through valve
- No terminal leakage

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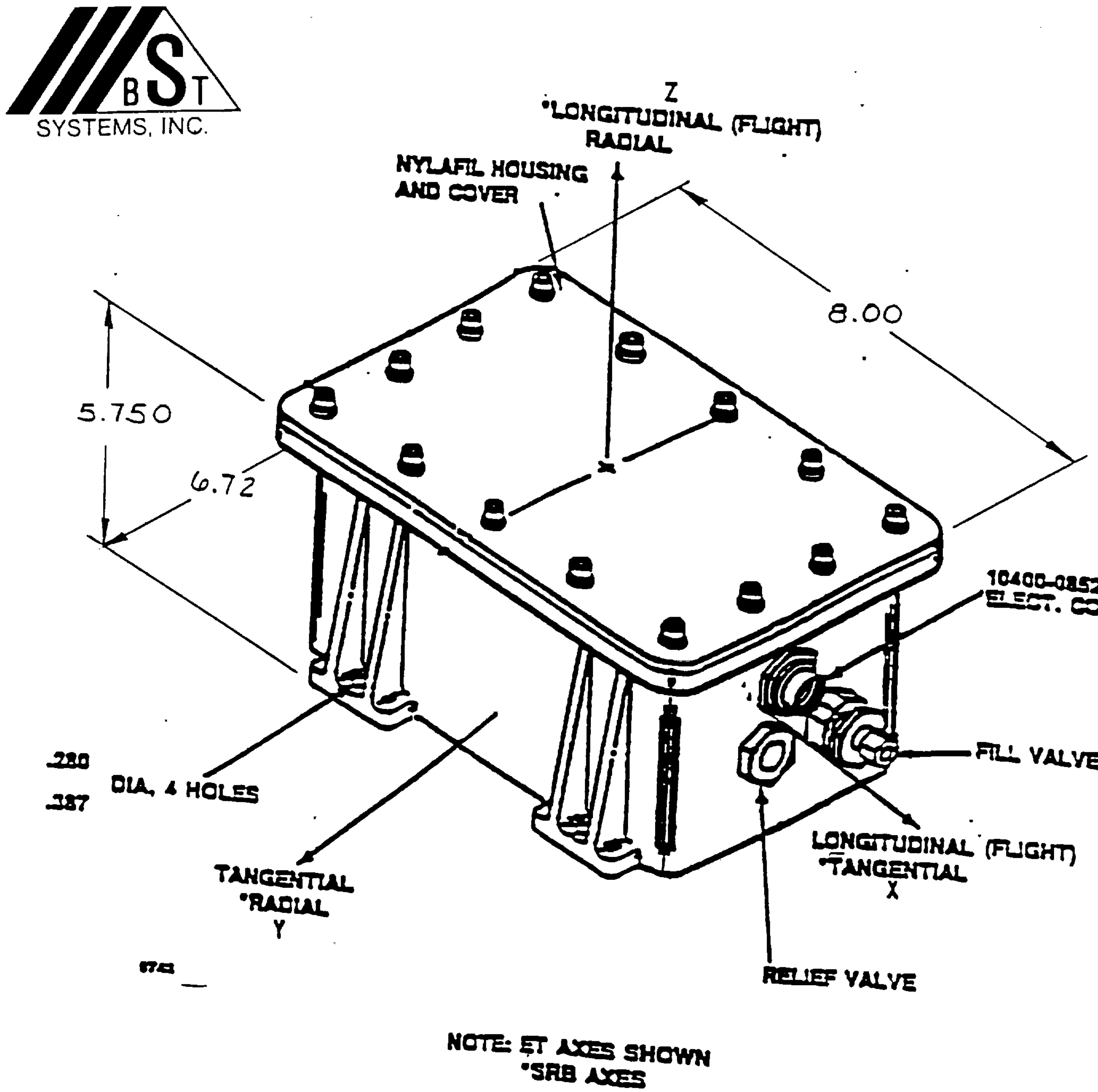
Dynamic Testing

- Testing conducted during development to minimize risk
- One battery of each type tested at SRB levels
  - Reentry vibration
  - Ordnance shock
  - Water impact
- One battery of each type tested at ASRB levels
  - Reentry vibration
  - Ordnance shock
  - Water impact



SRB/ET RSS BATTERY ORIENTATION AXIS

NOTE: X, Y, Z Axis orientation is shown for environmental testing.

FIGURE 1

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RSS VIBRATION

The order of testing shall be Y Axis, then X Axis, followed by the Z Axis.

The Cold Profile is to be vibrated at the following levels:

RANDOM VIBRATION CRITERIA (90 seconds in each axis)

RADIAL AXIS (Y Axis)

20-200 Hz @ 0.02 g^2/Hz
200-250 Hz @ +9.4 dB/oct
250-800 Hz @ 0.04 g^2/Hz
800-2000 Hz @ -7.6 dB/oct
2000 Hz @ 0.004 g^2/Hz

Composite = 6.6 grms

LONG. AND TANG. AXES (Z and X respectively)

20 Hz @ 0.02 g^2/Hz
20-100 Hz @ +5 dB/oct
100-800 Hz @ 0.3 g^2/Hz
800-2000 Hz @ -11 dB/oct
2000 Hz @ 0.01 g^2/Hz

Composite = 17.4 grms

The Hot Profile Unit is to be vibrated at the following levels:

Reentry Random Vibration (90 seconds in each axis)

RADIAL AXIS (Y Axis)

20 - 100 Hz @ 0.05 g^2/Hz
100 - 200 Hz @ +6.0 dB/oct
200 - 500 Hz @ 0.2 g^2/Hz
500 - 2,000 Hz @ -5.0 dB/oct
2,000 Hz @ 0.02 g^2/Hz

Composite = 12.9 g_{rms}

LONG. AND TANG. AXES (Z and X respectively)

20 Hz @ 0.01 g^2/Hz
20 - 100 Hz @ +8.2 dB/oct
100 - 400 Hz @ 0.8 g^2/Hz
400 - 2,000 Hz @ -6.1 dB/oct
2,000 Hz @ 0.03 g^2/Hz

Composite = 22.6 g_{rms}

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RSS ORDNANCE SHOCK Ref. Doc. 10SPC-0225 Para. 3.2.7.2.2.1

The order of testing shall be X+, X-, Y+, Y-, Z+, Z-.

50 Hz	@	12 G's peak
50-100 Hz	@	+12 dB/oct
100 Hz	@	47 G's peak
100-4000 Hz	@	+6 dB/oct
4000-10000 Hz	@	1,875 G's peak

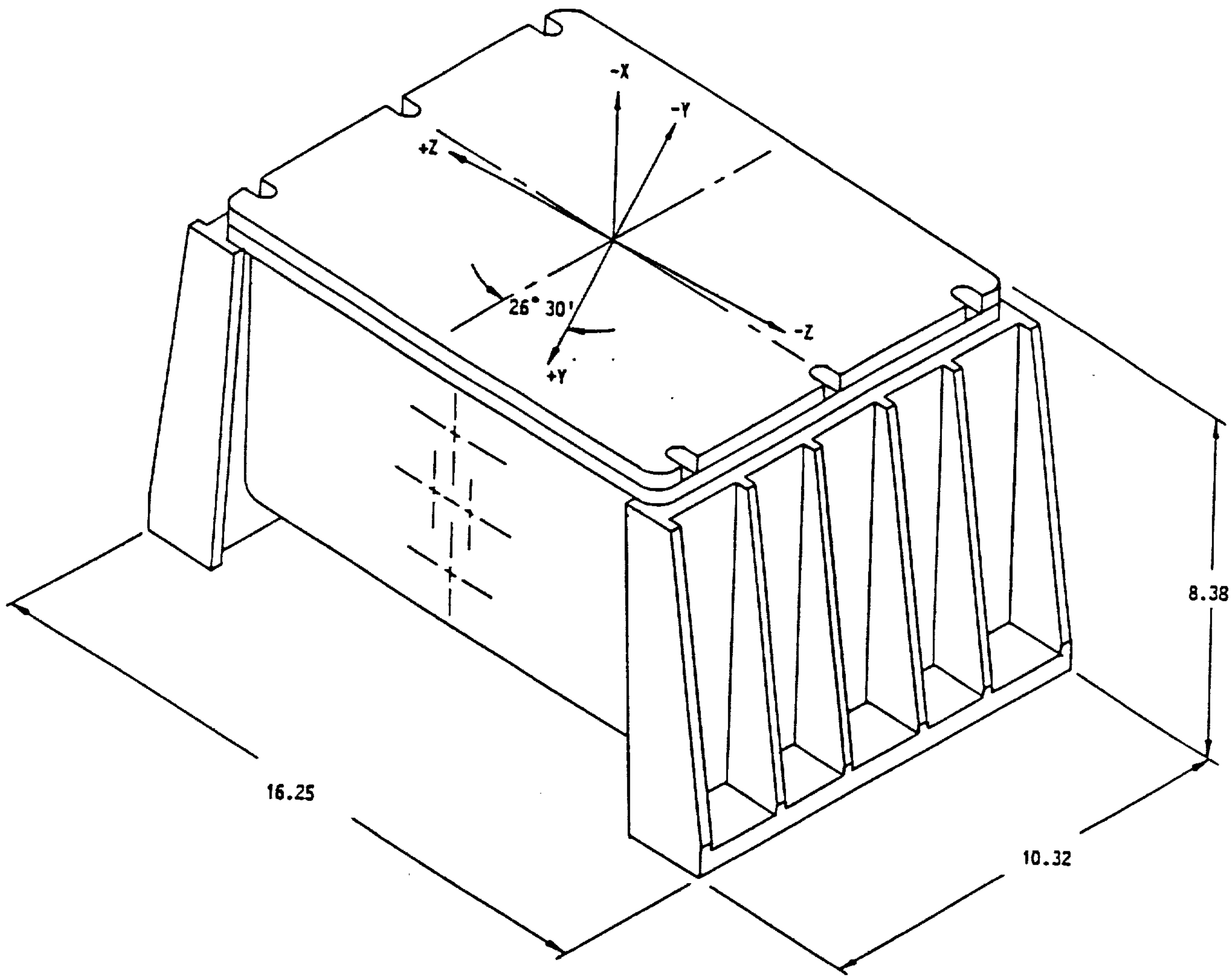
RSS WATER IMPACT SHOCK Ref. Doc. 10SPC-0225 Para. 3.2.7.2.2.2

The order of testing shall be X+, X-, Y+, Y-, Z+, Z-.

Water Impact (1 shock per axis per mission for all axes)

Longitudinal Axis and Lateral Axes

20 Hz	@	50 G's peak
20-70 Hz	@	+8 dB/oct
70-5000 Hz	@	250 G's peak



OFI Battery

FIGURE 1

SYSTEMS, INC.

OFI VIBRATION

The order of testing shall be Z Axis, then Y Axis, followed by the X Axis.

The Cold Profile Unit is to be vibrated at the following levels:

RANDOM VIBRATION CRITERIA (90 seconds in each axis)

RADIAL AXIS (Z Axis) - 120 seconds

20 Hz	@ 0.050 g^2/Hz
20-48 Hz	@ +3 dB/oct
48-750 Hz	@ 0.12 g^2/Hz
750-2000 Hz	@ -9 dB/oct
2000 Hz	@ 0.0064 g^2/Hz

Composite = 11.2 grms

LONG. AND TANG. AXES (X and Y respectively) - 90 seconds

20 Hz	@ 0.02 g^2/Hz
20-100 Hz	@ +5 dB/oct
100-800 Hz	@ 0.3 g^2/Hz
800-2000 Hz	@ -11 dB/oct
2000 Hz	@ 0.01 g^2/Hz

Composite = 17.4 grms

The Hot Profile Unit (Paragraph 4) is to be vibrated at the following levels:

Reentry Random Vibration (90 seconds in each axis)

RADIAL AXIS (Z Axis)

20 - 100 Hz	@ 0.05 g^2/Hz
100 - 200 Hz	@ +6.0 dB/oct
200 - 500 Hz	@ 0.2 g^2/Hz
500 - 2,000 Hz	@ -5.0 dB/oct
2,000 Hz	@ 0.02 g^2/Hz

Composite = 12.9 g_{rms}

LONG. AND TANG. AXES (X and Y respectively)

20 Hz	@ 0.01 g^2/Hz
20 - 100 Hz	@ +8.2 dB/oct
100 - 400 Hz	@ 0.8 g^2/Hz
400 - 2,000 Hz	@ -6.1 dB/oct
2,000 Hz	@ 0.03 g^2/Hz

Composite = 22.6 g_{rms}

The order of testing shall be Z+, Z-, Y+, Y-, X+, X-.

OFI ORDNANCE SHOCK Ref. Doc. 10SPC-0226 Para. 3.2.7.2.2.1

50 Hz	@	12 G's peak
50-100 Hz	@	+12 dB/oct
100 Hz	@	47 G's peak
100-4000 Hz	@	+6 dB/oct
4000-10000 Hz	@	1,875 G's peak

OFI Water Impact (1 shock per axis per mission for all axes)

20 Hz	@	50 G's peak
20-70 Hz	@	+8 dB/oct
70-5000 Hz	@	250 G's peak

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OFI Dynamic Testing

- Battery tested to SRB levels exhibited no performance anomalies
- Output capacity 77.9 AH
-
- Battery tested to ASRB levels exhibited no performance anomalies
- Output capacity 77.6 AH
- Upon teardown, one cell found to have 1 wire on 1 electrode broken

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RSS Dynamic Testing

- Battery tested to SRB levels exhibited no performance anomalies
- Output capacity 21.8 AH
- Battery tested to ASRB levels failed approx 1 minute into vibration
- Upon teardown, all cells found to have sustained some form of wire breakage

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Dynamic Testing Grooming Modification

- Dynamic stress relief incorporated
- Two types proposed
  - Full loops
  - S-turns
- One battery of each type built with cells having both types of loops evenly distributed throughout case

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Dynamic Testing with Stress Relief

- Each battery subjected to full flight levels at SRB conditions
- OFI exhibited no performance anomalies
  - Output capacity 71 AH
- RSS suffered breakage in one cell with S-turn
- Full loops chosen as stress relief method

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Dynamic Testing

- Shims and spacers restrained cells
- Hold down cushions on cover functioned as designed
- Internal cell hold down restrained cell pack

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Summary

- **Requirements were met with silver-zinc as a result of certain engineering approaches:**
  - Innovative composite separator system
  - Carefully controlled deperoxidation resulting in excellent voltage regulation given the wide current range and excellent charge retention
  - Unpotted battery restrainment system
  - Dynamic stress relief and electrode hold-down structures

SYSTEMS INC.

Acknowledgment

- BST Systems would like to thank both USBI and MSFC for their technical support and for the use of the dynamic test facilities at MSFC which helped to assist the conclusion of this development program

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The subjects covered included nickel-cadmium, nickel-hydrogen, nickel-metal hydride, and lithium based technologies, as well as advanced technologies including various bipolar designs.

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