TECHNICAL REPORT RK-76-8

STINGER LAUNCH AND FLIGHT MOTOR SQUIB ELECTRICAL SAFETY AND FUNCTIONAL PERFORMANCE EVALUATION

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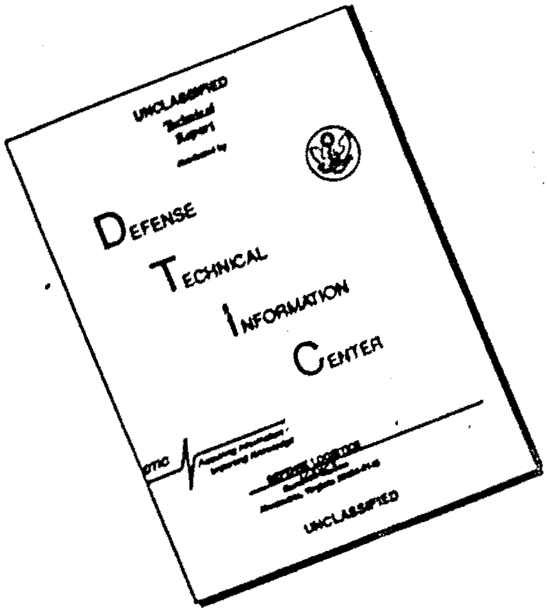

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides the measured electrostatic sensitivity, resistance, no-fire current, all-fire current, ramp current, step current, and the Bruceton firing current estimated standard deviation values for the STINGER launch and flight motor squibs. The tests included one lot of 250 launch motor squibs and two lots of flight motor squibs (one contained 145 and the other 346).

ABSTRACT (Continued)

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ABSTRACT (Concluded)

The values obtained from these evaluation tests exceed the Atlantic Research Corporation's specification requirements. One exception was the above tolerance pin-to-pin resistance value of 33% of the first lot of flight motor squibs. The high resistance did not adversely affect the functional performance. Another exception was the firing of one squib from the first lot of flight motor squibs near the end of the 1-ampere, 1-watt, 5-minute no-fire test.

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Recognition is given to Gary Christian and Kenny Renner for initial circuit design work.

1. Introduction

The STINGER missile is a shoulder-fired, air defense weapon system which requires man-rating of the propulsion subsystem.

Safety requirements were established for electrical initiators (squibs) by Atlantic Research Corporation's (ARC) Engineering Order SP10071B to preclude accidental or unexpected initiation. These requirements include the application of an energy input of 1 ampere, 1 watt through the bridgewire and a man-rated electrostatic charge from case-to-leads without functioning.

Functional requirements were established for the squibs by the ARC specification to insure performance and reliability. These requirements include pin-to-pin resistance, maximum functioning time, all-fire current, and the Bruceton minimum-maximum firing current limits.

This project was conducted to experimentally evaluate the STINGER launch and flight motor squibs by determining the electrical safety characteristics with simulated environments and functional performance to specified energy.

2. Test Conditions — Required and Additional

a. Technical Requirements

The following safety and functional requirements were established by ARC (Propulsion Division's Engineering Order SP10071B) for the STINGER Project 1-ampere, 1-watt, twin leadwire squib [1].

(1) Nonfunctional. The squibs must not fire when subjected to any of the following electrical conditions:

a) Electrostatic Sensitivity — The squib shall withstand an electrostatic charge of 25 kilovolts from a 500-picofarad capacitor with a 5-kilohm resistor in series. The test shall be conducted within a temperature range of 14 to 28°C (This is the man-equivalent test, case-to-leads mode).

b) No-Fire Current — The squib shall not fire when a minimum direct current of 1.0 ampere is applied to the squib circuit for a minimum of 5 minutes at a temperature of 14 to 28°C and a minimum power level of 1.0 watt.

(2) Functional. The squibs must meet the following electrical conditions:

a) All-Fire Current — The squib shall fire when a minimum direct current of 3.0 amperes is applied to the squib circuit.

b) Functioning Time — The squib shall fire within 4.5 milliseconds when a direct current of 3.30 plus 0.20 minus 0.00 amperes is applied to the squib.

c) Bruceton Firing Standard Deviation — For each group of Bruceton firing test samples, the mean value minus three estimated standard deviations (-3s) shall be greater than 1.00 amperes and the mean value plus three estimated standard deviations (+3s) shall be less than 3.00 amperes.

d) Pin-to-Pin Resistance — The squib with a lead-wire length of 5.00 ± 0.25 inches shall have a continuous circuit with a resistance of 0.85 to 1.10 ohms.

e) Pin-to-Case Resistance — The squib shall have a minimum resistance of 100 kilohms measured between the shorted lead-wires and the metal case.

b. <u>Additional Tests</u>

The following safety and functional tests were performed by the Propulsion Directorate in addition to the required tests [2].

(1) <u>Nonfunctional</u>. The squibs were checked for sensitivity to the following electrical conditions.

a) Electrostatic Sensitivity —

1) Three squibs were checked for their helicopter equivalent electrostatic sensitivity. The circuit is a 3 nanofarad capacitor charged to 30 kilovolts with no resistor in series and then discharged through the squib, case-to-leads mode.

2) Forty-seven squibs were checked for their electrostatic sensitivity at 45 kilovolts using the man-equivalent circuit.

b) No-Fire Current, 1 ampere, 1 watt — These tests also met the no-fire 5-minute required test.

1) Two squibs were checked for 1 hour each to determine the bridgewire resistance equilibrium point.

2) Thirty-two squibs were checked for 10 minutes each to insure that they passed the no-fire test.

3) One squib was checked for 20 minutes to determine the case temperature during a 1-ampere, 1-watt environment when mounted in a sealed, insulated chamber.

(2) Functional. The squibs were fired to determine their performance characteristics.

a) Ramp Current Firing — Seventy-two squibs were fired using a 1.0 ampere/millisecond ramp current rate [3, 4].

b) Step Current Firing — Ten squibs were fired using a 2.0-ampere step current. The functioning time was obtained.

The required and additional tests were conducted in the sequences indicated in Figures 1, 2, and 3 using the circuits depicted in Figures 4, 5, and 6.

3. Resistance Tests

a. Bridgewire Resistance (Lead-to-Lead)

Tests were conducted on all squibs from the three groups using a Hewlett-Packard 3450B Multi-Function Meter which utilizes the four wire resistance method. The results were given in Tables 1 through 10.

The 105B Lot A group resistance mean* is at the 1.10-ohm upper tolerance limit, and 48 of the 145 squibs are above the upper limit. The highest value is 1.27 ohms and the lowest is 0.84 ohm. One should note that only two squibs had a resistance of less than 1.00 ohm. The results are given in Tables 1, 2, and 3.

The 105B Lot B group resistance mean is slightly below 1 ohm with only 10 of the 346 squibs above the 1.10-ohm upper tolerance limit. The highest value is 1.158 ohms. No squibs were below the 0.85-ohm lower tolerance limit. The results are given in Tables 4, 5, 6, and 7.

The 105C group resistance mean is slightly below 1 ohm with only three of the 250 squibs above the 1.10-ohm upper tolerance limit. The highest value is 1.130 ohms. No squibs were below the 0.85-ohm lower tolerance limit. The results are given in Tables 8, 9, and 10.

b. Resistance (Case-to-Shorted Lead)

Tests were conducted on the 105B Lot A group using a Hewlett-Packard 3450B Multi-Function Meter which utilizes the four-wire resistance method. The results are given in Tables 1, 2, and 3.

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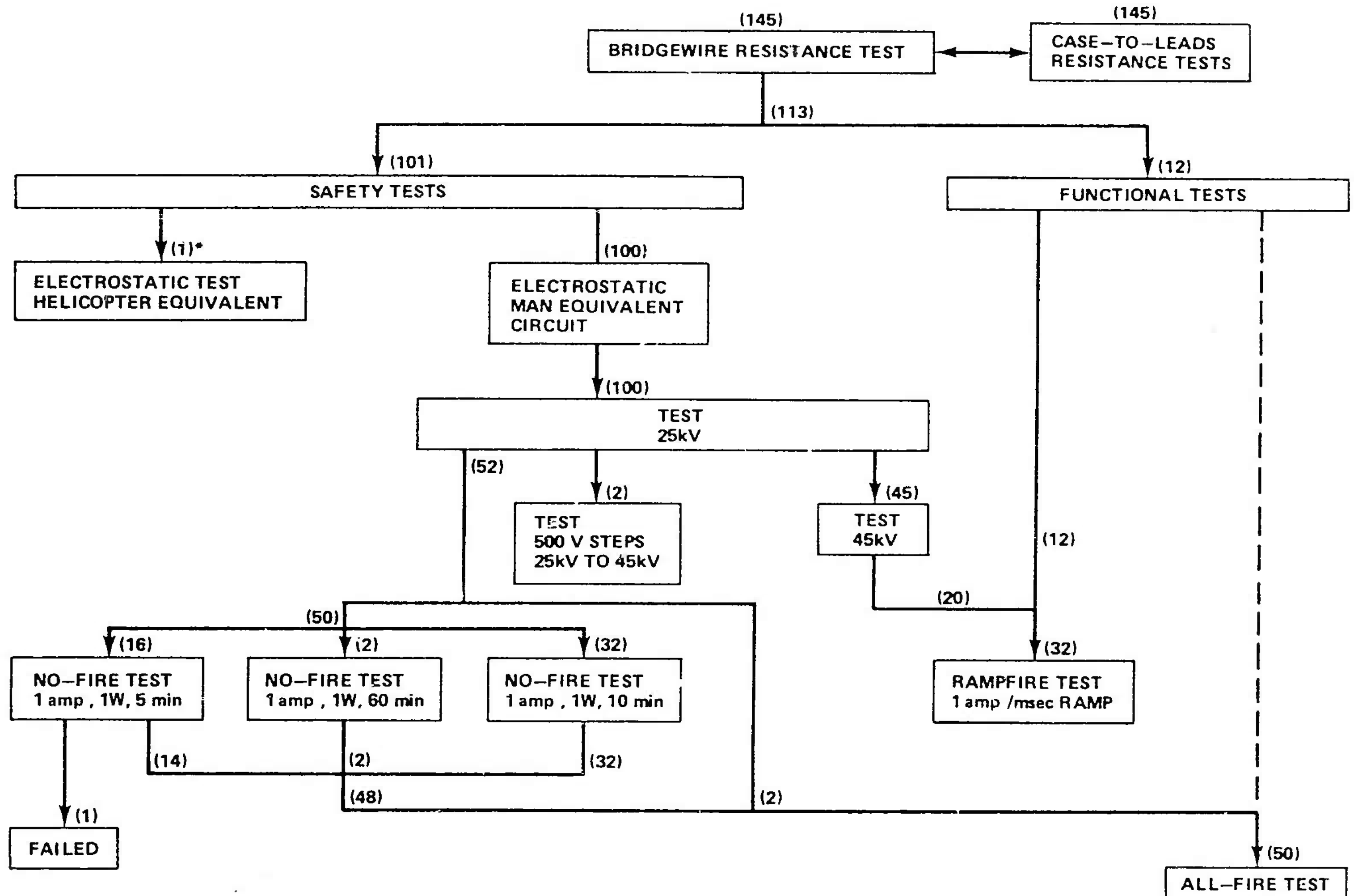
* All values of means and standard deviations in this report are for samples, not the population.



*NOT A SAFETY REQUIREMENT, FOR INFORMATION ONLY.

Figure 1. STINGER 105 squib evaluation tests conducted on the 105B Lot A group. (Flight motor squibs, 80 milligram pyrotechnic charge).

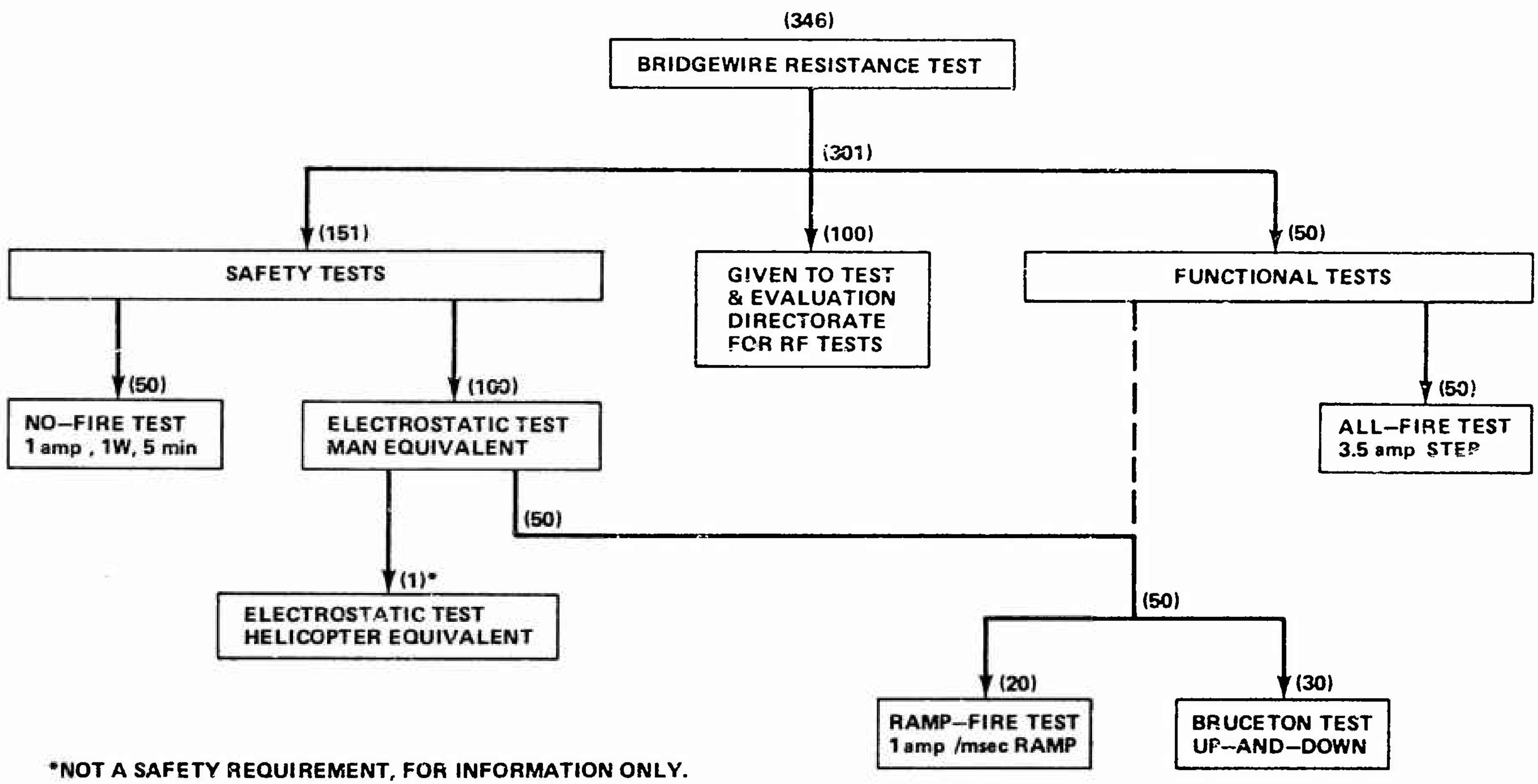


Figure 2. STINGER 105 squib evaluation tests conducted on the 105B Lot B group. (Flight motor squibs, 80 milligram pyrotechnic charge).

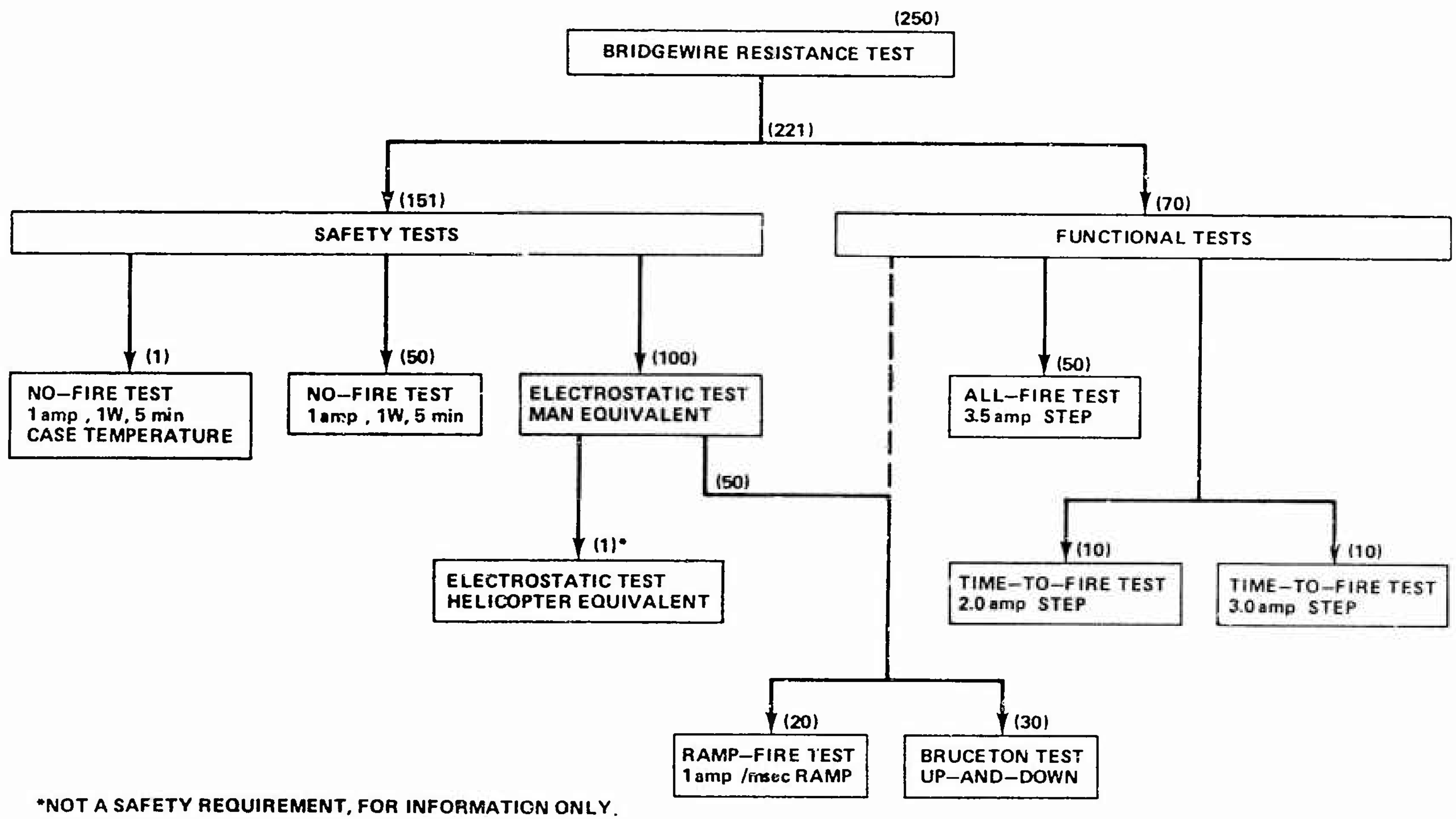


Figure 3. STINGER 105 squib evaluation conducted on the 105C group. (Launch motor squibs, 40 milligram pyrotechnic charge).

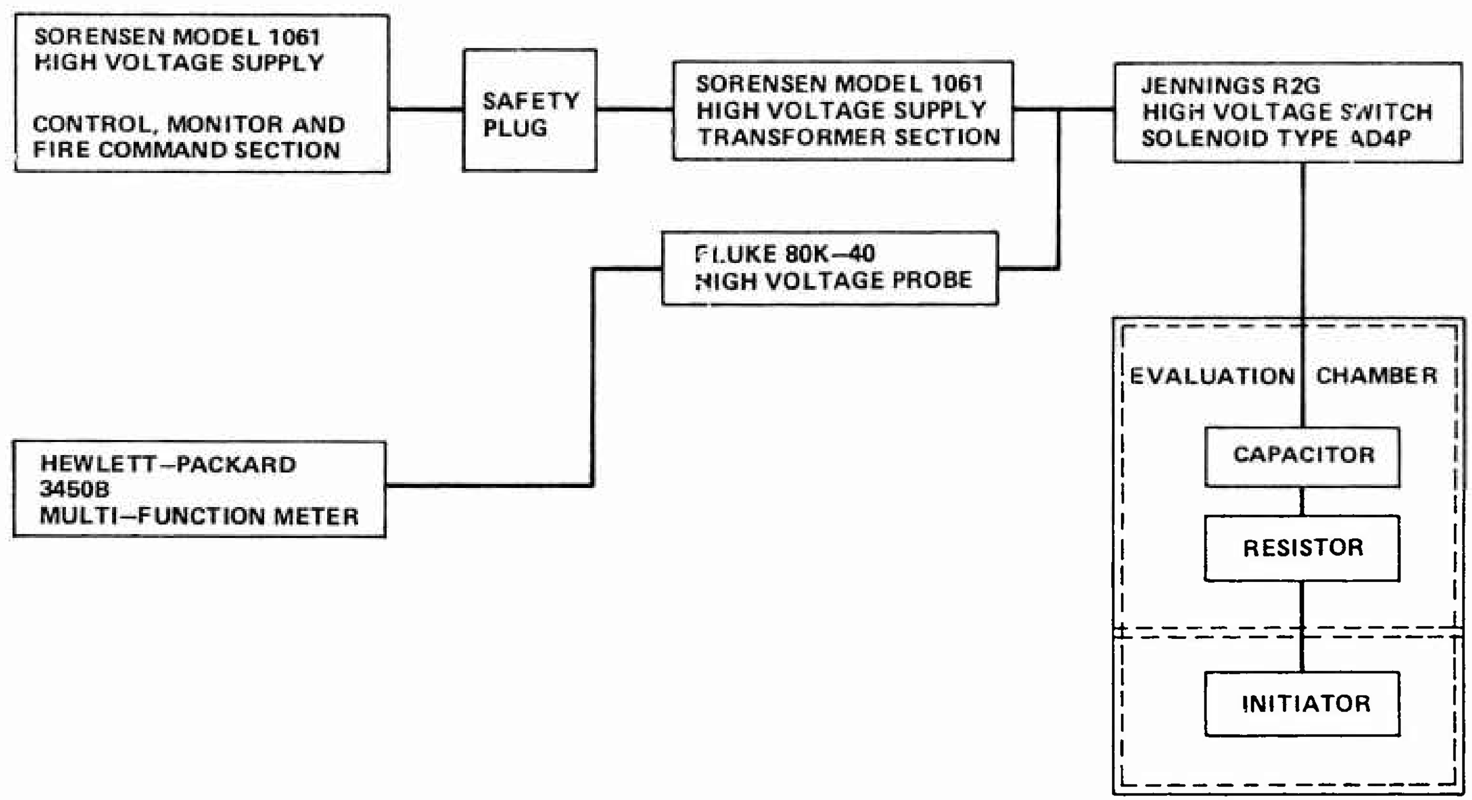


Figure 4. Electrostatic initiator evaluation system.

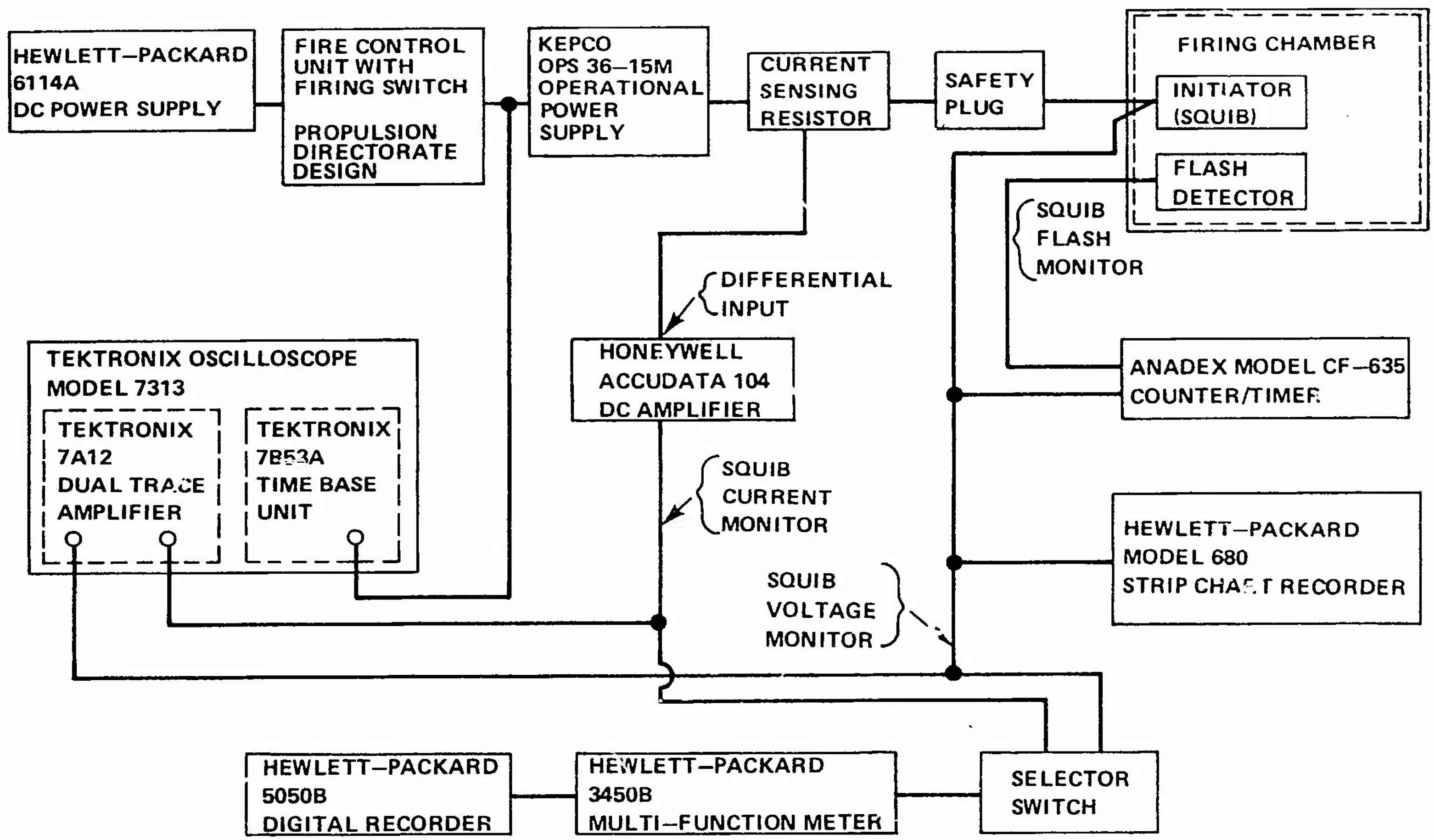


Figure 5. Step current initiator evaluation system used for 1-ampere, 1-watt evaluation of STINGER 105B Lot A squibs, Nos. 1 through 50.

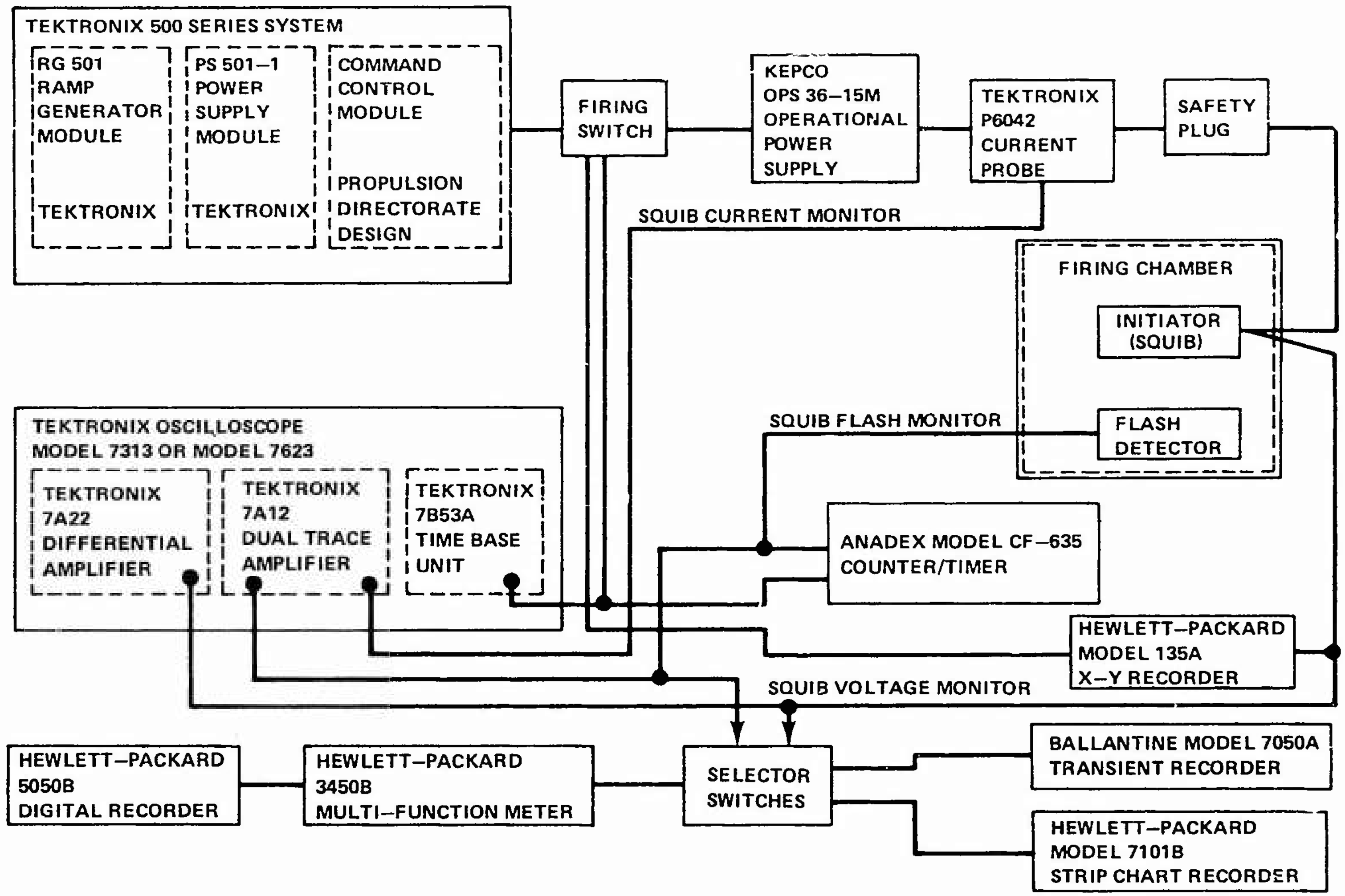


Figure 6. Ramp/step current initiator evaluation system used for all squib current evaluation except the 1-ampere, 1-watt evaluation of STINGER 105B Lot A squibs, Nos. 1 through 50.

TABLE 1. TEST DATA FOR STINGER 105B LOT A SQUIBS, NOS. 1 THROUGH 52

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Case-to-Lead Resistance (MΩ)	Man Equivalent Electrostatic 25 kV	No-Fire 1 amp, 1 W 5 Minutes	All-Fire 3.5 amp Step Function Time (msec)
1	1.09	> 12	No-Fire	No-Fire	1.42
2	1.14	> 12	No-Fire	No-Fire	1.90
3	1.03	> 12	No-Fire	No-Fire	1.73
4	1.13	> 12	No-Fire	No-Fire	1.40
5	1.09	> 12	No-Fire	No-Fire	1.33
6	1.13	> 12	No-Fire	No-Fire	1.49
7	1.09	> 12	No-Fire	No-Fire	1.39
8	1.08	> 12	No-Fire	No-Fire	1.45
9	1.16	> 12	No-Fire	No-Fire	——
10	1.11	> 12	No-Fire	No-Fire	1.57
11	1.16	> 12	No-Fire	No-Fire	1.48
12	1.08	> 12	No-Fire	No-Fire	1.48
13	1.07	> 12	No-Fire	No-Fire	1.28
14	1.08	> 12	No-Fire	No-Fire	1.45
15	1.07	> 12	No-Fire	No-Fire	——
16	1.04	> 12	No-Fire	Fired	——
17	1.07	> 12	No-Fire	No-Fire*	1.96
18	1.12	> 12	No-Fire	No-Fire*	1.99
19	1.15	> 12	No-Fire	No-Fire†	1.52
20	0.87	> 12	No-Fire	No-Fire†	1.44
21	1.06	> 12	No-Fire	No-Fire†	1.40
22	1.09	> 12	No-Fire	No-Fire†	1.47
23	1.10	> 12	No-Fire	No-Fire†	1.47
24	1.16	> 12	No-Fire	No-Fire†	1.47
25	1.14	> 12	No-Fire	No-Fire†	1.38
26	1.06	> 12	No-Fire	No-Fire†	1.31
27	1.05	> 12	No-Fire	No-Fire†	1.66
28	1.09	> 12	No-Fire	No-Fire†	1.66
29	1.09	> 12	No-Fire	No-Fire†	1.31
30	1.10	> 12	No-Fire	No-Fire†	1.42
31	1.07	> 12	No-Fire	No-Fire†	1.47
32	1.09	> 12	No-Fire	No-Fire†	1.47
33	1.06	> 12	No-Fire	No-Fire†	1.35
34	1.10	> 12	No-Fire	No-Fire†	1.46
35	1.12	> 12	No-Fire	No-Fire†	1.55
36	1.10	> 12	No-Fire	No-Fire†	1.59
37	1.10	> 12	No-Fire	No-Fire†	1.54
38	1.15	> 12	No-Fire	No-Fire†	1.39
39	1.02	> 12	No-Fire	No-Fire†	1.33
40	1.12	> 12	No-Fire	No-Fire†	1.79
41	1.06	> 12	No-Fire	No-Fire†	1.57
42	1.06	> 12	No-Fire	No-Fire†	1.41
43	1.01	> 12	No-Fire	No-Fire†	1.79
44	1.15	> 12	No-Fire	No-Fire†	1.42
45	1.09	> 12	No-Fire	No-Fire†	1.44
46	1.09	> 12	No-Fire	No-Fire†	1.36
47	1.10	> 12	No-Fire	No-Fire†	——
48	1.09	> 12	No-Fire	No-Fire†	1.52
49	1.08	> 12	No-Fire	No-Fire†	1.62
50	1.06	> 12	No-Fire	No-Fire†	1.57
51	1.10	> 12	No-Fire	——	1.53
52	1.07	> 12	No-Fire	——	1.22
$\bar{x}$	1.09	> 12			1.50
s	0.05	——			0.17
Lowest	0.87	——			1.22
Highest	1.16	> 12			1.99

* 60 Minutes
† 10 Minutes

TABLE 2. TEST DATA FOR STINGER 105B LOT A SQUIBS, NOS. 53 THROUGH 100

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Case-to-Leads Resistance (MΩ)	Man Equivalent Electrostatic 25 kV	Man Equivalent Electrostatic Circuit Voltage (45kV) Limit Breakdown	1 amp/msec Rate Ramp Firing Values		
					Current (amp)	Voltage Across Squib (V)	Time to Flash (msec)
53	1.13	> 12	No-Fire	No-Fire 500V	Fired, Helicopter Equivalent		
54	1.14	> 12	No-Fire	No-Fire step			
55	1.02	> 12	No-Fire	No-Fire			
56	1.10	> 12	No-Fire	No-Fire			
57	1.10	> 12	No-Fire	No-Fire			
58	1.13	> 12	No-Fire	No-Fire			
59	1.06	> 12	No-Fire	No-Fire			
60	1.08	> 12	No-Fire	No-Fire			
61	1.06	> 12	No-Fire	No-Fire			
62	1.07	> 12	No-Fire	No-Fire			
63	1.08	> 12	No-Fire	No-Fire			
64	1.08	> 12	No-Fire	No-Fire			
65	1.08	> 12	No-Fire	No-Fire			
66	1.08	> 12	No-Fire	No-Fire			
67	1.12	> 12	No-Fire	No-Fire			
68	1.11	> 12	No-Fire	No-Fire			
69	1.15	> 12	No-Fire	No-Fire			
70	1.07	> 12	No-Fire	No-Fire			
71	1.13	> 12	No-Fire	No-Fire			
72	1.05	> 12	No-Fire	No-Fire			
73	1.08	> 12	No-Fire	No-Fire			
74	1.09	> 12	No-Fire	No-Fire			
75	1.07	> 12	No-Fire	No-Fire			
76	1.08	> 12	No-Fire	No-Fire			
77	1.11	> 12	No-Fire	No-Fire			
78	1.13	> 12	No-Fire	No-Fire			
79	1.15	> 12	No-Fire	No-Fire			
80	1.11	> 12	No-Fire	No-Fire			
81	1.15	> 12	No-Fire	No-Fire	3.86	4.6	3.863
82	1.14	> 12	No-Fire	No-Fire	3.72	4.6	3.717
83	1.15	> 12	No-Fire	No-Fire	3.73	4.1	3.728
84	1.05	> 12	No-Fire	No-Fire	3.81	4.2	3.809
85	1.09	> 12	No-Fire	No-Fire	3.70	4.3	3.697
86	1.05	> 12	No-Fire	No-Fire	3.83	4.1	3.834
87	1.05	> 12	No-Fire	No-Fire	3.76	4.4	3.764
88	1.07	> 12	No-Fire	No-Fire	3.82	4.4	3.824
89	1.10	> 12	No-Fire	No-Fire	3.73	4.3	3.732
90	1.09	> 12	No-Fire	No-Fire	3.77	4.3	3.774

TABLE 2. (CONCLUDED)

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Case-to-Leads Resistance (MΩ)	Man Equivalent Electrostatic 25 kV	Man Equivalent Electrostatic Circuit Voltage (45kV) Limit Breakdown	1 amp/msec Rate Ramp Firing Values		
					Current (amp)	Voltage Across Squib (V)	Time to Flash (msec)
91	1.03	> 12	No-Fire	No-Fire	3.81	4.2	3.812
92	1.08	> 12	No-Fire	No-Fire	3.76	4.4	3.760
93	1.17	> 12	No-Fire	No-Fire	3.62	4.4	3.616
94	1.05	> 12	No-Fire	No-Fire	3.79	4.4	3.788
95	1.13	> 12	No-Fire	No-Fire	3.71	4.3	3.713
96	1.10	> 12	No-Fire	No-Fire	3.75	4.6	3.748
97	1.13	> 12	No-Fire	No-Fire	3.78	4.4	3.775
98	1.12	> 12	No-Fire	No-Fire	3.83	4.7	3.833
99	1.12	> 12	No-Fire	No-Fire	3.64	4.5	3.643
100	1.10	> 12	No-Fire	No-Fire	3.80	4.4	3.801
$\bar{x}$	1.10	> 12	—	—	3.76	4.4	3.762
s	0.04	—	—	—	0.06	0.2	0.064
Lowest	1.02	—	—	—	3.62	4.1	3.616
Highest	1.17	> 12	—	—	3.86	4.7	3.863

TABLE 3. TEST DATA FOR STINGER 105B LOT A SQUIBS NOS. 101 THROUGH 145

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Case-to-Leads Resistance (MΩ)	1 amp/msec Rate Ramp Firing Values		
			Current (amp)	Voltage Across Squib (V)	Time to Flash (msec)
101	1.06	> 12	3.52	4.3	3.516
102	1.14	> 12	3.51	4.7	3.505
103	1.10	> 12	*		
104	1.09	> 12	*		
105	1.06	> 12	3.65	4.4	3.649
106	1.13	> 12	3.54	4.4	3.544
107	1.04	> 12	*		
108	1.12	> 12	3.66	4.7	3.66
109	1.12	> 12	*		
110	1.09	> 12	3.70	4.7	3.695
111	1.10	> 12	3.59	4.5	3.586
112	0.84	> 12	3.63	3.5	3.626
113	1.03	> 12	3.67	4.3	3.670
114	1.11	> 12	3.50	4.4	3.499
115	1.07	> 12	*		
116	1.07	> 12	3.67	4.6	3.672
117	1.08	> 12	*		
118	1.08	> 12	3.63	4.3	3.627
119	1.04	> 12	*		
120	1.10	> 12	*		
121	1.19	> 12	*		
122	1.07	> 12	*		
123	1.27	> 12	*		
124	1.14	> 12	*		
125	1.13	> 12	*		
126	1.11	> 12	*		
127	1.15	> 12	*		
128	1.09	> 12	*		
129	1.14	> 12	*		
130	1.13	> 12	*		
131	1.03	> 12	*		
132	1.16	> 12	*		
133	1.07	> 12	*		
134	1.13	> 12	*		
135	1.10	> 12	*		
136	1.05	> 12	*		
137	1.05	> 12	*		
138	1.10	> 12	*		
139	1.07	> 12	*		
140	1.08	> 12	*		
141	1.10	> 12	*		
142	1.05	> 12	*		
143	1.12	> 12	*		
144	1.06	> 12	*		
145	1.14	> 12	*		
$\bar{x}$	1.09	> 12	3.61	4.4	3.629
s	0.06	—	0.10	0.3	0.083
Lowest	0.84	—	3.50	4.3	3.499
Highest	1.27	> 12	3.70	4.7	3.695

* Use for other tests

TABLE 4. TEST DATA FOR STINGER 105B LOT B SQUIBS NOS. B-1 THROUGH B-100

Squib No.	Lead-to-Lead Initial Resistance (Ω)	All-Fire 3.5 amp Step Function Time (msec)	Squib No.	Lead-to-Lead Initial Resistance (Ω)	No-Fire 1 amp, 1W 5 minutes
B-1	1.030	*1.35	B-51	0.971	No-Fire
B-2	0.955	1.480	B-52	0.994	No-Fire
B-3	0.971	1.675	B-53	0.950	No-Fire
B-4	1.054	1.341	B-54	1.044	No-Fire
B-5	0.948	1.293	B-55	0.933	No-Fire
B-6	1.053	1.453	B-56	0.928	No-Fire
B-7	0.977	1.769	B-57	1.024	No-Fire
B-8	1.034	1.436	B-58	0.990	No-Fire
B-9	0.930	1.523	B-59	0.989	No-Fire
B-10	1.060	1.417	B-60	1.024	No-Fire
B-11	1.043	1.670	B-61	0.928	No-Fire
B-12	1.063	*1.40	B-62	0.967	No-Fire
B-13	0.873	1.955	B-63	0.850	No-Fire
B-14	0.999	1.469	B-64	0.972	No-Fire
B-15	0.988	1.568	B-65	0.970	No-Fire
B-16	0.968	1.874	B-66	0.912	No-Fire
B-17	0.942	1.540	B-67	0.930	No-Fire
B-18	1.029	1.783	B-68	0.960	No-Fire
B-19	0.919	1.582	B-69	0.972	No-Fire
B-20	1.083	1.348	B-70	1.001	No-Fire
B-21	0.990	1.522	B-71	0.918	No-Fire
B-22	1.076	1.258	B-72	0.947	No-Fire
B-23	0.964	1.790	B-73	0.904	No-Fire
B-24	1.127	1.339	B-74	0.925	No-Fire
B-25	1.094	1.358	B-75	0.984	No-Fire
B-26	1.022	1.460	B-76	0.929	No-Fire
B-27	0.982	1.473	B-77	0.985	No-Fire
B-28	0.991	1.630	B-78	0.997	No-Fire
B-29	0.993	1.321	B-79	0.973	No-Fire
B-30	1.047	1.380	B-80	1.005	No-Fire
B-31	0.978	1.611	B-81	0.904	No-Fire
B-32	1.096	1.010	B-82	0.968	No-Fire
B-33	0.986	1.630	B-83	0.910	No-Fire
B-34	0.900	2.431	B-84	0.935	No-Fire
B-35	1.056	1.358	B-85	0.920	No-Fire
B-36	0.936	1.337	B-86	0.944	No-Fire
B-37	0.976	1.807	B-87	0.937	No-Fire
B-38	0.916	1.424	B-88	0.971	No-Fire
B-39	0.952	1.705	B-89	0.990	No-Fire
B-40	0.981	1.550	B-90	0.946	No-Fire
B-41	1.019	1.636	B-91	0.942	No-Fire
B-42	0.948	1.525	B-92	0.988	No-Fire
B-43	1.048	1.498	B-93	0.912	No-Fire
B-44	1.021	1.329	B-94	0.991	No-Fire
B-45	0.975	1.642	B-95	0.972	No-Fire
B-46	1.066	1.438	B-96	0.931	No-Fire
B-47	1.033	1.218	B-97	0.915	No-Fire
B-48	0.991	1.310	B-98	0.913	No-Fire
B-49	1.012	1.543	B-99	0.935	No-Fire
B-50	0.977	1.352	B-100	0.969	No-Fire
$\bar{x}$	1.000	1.516	$\bar{x}$	0.955	
s	0.057	0.225	s	0.038	
Lowest	0.873	1.010	Lowest	0.850	
Highest	1.127	2.431	Highest	1.044	

* From scope oscillogram

TABLE 5. TEST DATA FOR STINGER 105B LOT B SQUIBS, NOS. B-101 THROUGH B-200

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Squib No.	Lead-to-Lead Initial Resistance (Ω)
B-101	1.060	B-151	1.053
B-102	1.089	B-152	1.037
B-103	1.070	B-153	1.002
B-104	1.105	B-154	0.923
B-105	1.065	B-155	0.991
B-106	1.061	B-156	0.986
B-107	1.086	B-157	0.952
B-108	1.158	B-158	0.977
B-109	0.992	B-159	1.037
B-110	0.851	B-160	1.037
B-111	1.157	B-161	1.066
B-112	1.129	B-162	0.937
B-113	1.074	B-163	0.941
B-114	1.128	B-164	1.022
B-115	1.026	B-165	0.997
B-116	0.989	B-166	1.005
B-117	1.035	B-167	0.992
B-118	1.126	B-168	0.954
B-119	1.048	B-169	0.987
B-120	1.017	B-170	0.943
B-121	1.104	B-171	1.061
B-122	1.083	B-172	1.053
B-123	0.965	B-173	1.002
B-124	1.048	B-174	1.019
B-125	1.057	B-175	1.025
B-126	1.086	B-176	0.943
B-127	0.975	B-177	1.083
B-128	1.095	B-178	0.951
B-129	1.084	B-179	1.017
B-130	1.137	B-180	1.062
B-131	1.043	B-181	1.089
B-132	1.109	B-182	0.974
B-133	1.081	B-183	1.013
B-134	1.082	B-184	1.046
B-135	1.066	B-185	0.983
B-136	1.104	B-186	1.040
B-137	1.135	B-187	1.077
B-138	1.081	B-188	1.013
B-139	1.085	B-189	0.945
B-140	1.081	B-190	1.065
B-141	1.115	B-191	0.942
B-142	1.027	B-192	1.043

TABLE 5. (CONCLUDED)

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Squib No.	Lead-to-Lead Initial Resistance (Ω)
B-143	1.010	B-193	0.947
B-144	0.993	B-194	0.939
B-145	1.022	B-195	1.054
B-146	1.039	B-196	1.017
B-147	1.036	B-197	1.082
B-148	1.009	B-198	1.005
B-149	1.062	B-199	1.071
B-150	1.115	B-200	1.042
$\bar{x}$	1.064	$\bar{x}$	1.009
s	0.056	s	0.047
Lowest	0.851	Lowest	0.923
Highest	1.158	Highest	1.089

This group of 100 squibs was given to the Test and Evaluation Directorate for RF tests.

TABLE 6. TEST DATA FOR STINGER 103B LOT B SQUIBS, NOS. B-201 THROUGH B-250

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Man Equivalent Electrostatic 25kV	1 amp/msec Rate Ramp Firing Values: Current (amp)	Voltage Across Squib (V)	Time to Flash (msec)	Bruceton Data Up-And-Down No-Fires Tested For 5 seconds: Current (amp)	Result	Time (msec)
B-201	0.927	No-Fire	4.19	4.2	4.190			
B-202	0.977	No-Fire	4.16	4.2	4.161			
B-203	0.857	No-Fire	4.33	3.9	4.328			
B-204	0.949	No-Fire	4.09	4.2	4.087			
B-205	0.918	No-Fire	4.20	4.1	4.202			
B-206	1.047	No-Fire	3.94	4.2	3.937			
B-207	1.038	No-Fire	3.92	4.5	3.917			
B-208	0.878	No-Fire	4.12	4.0	4.118			
B-209	0.974	No-Fire	4.14	4.4	4.139			
B-210	0.966	No-Fire	4.00	4.2	4.001			
B-211	0.981	No-Fire	3.86	4.1	3.863			
B-212	0.885	No-Fire	4.31	4.0	4.311			
B-213	0.889	No-Fire	4.26	3.9	4.261			
B-214	0.941	No-Fire	3.86	3.9	3.864			
B-215	0.952	No-Fire	4.12	4.1	4.116			
B-216	0.893	No-Fire	4.06	3.9	4.060			
B-217	0.960	No-Fire	3.94	4.3	3.935			
B-218	0.967	No-Fire	4.13	4.3	4.128			
B-219	1.011	No-Fire	4.07	4.4	4.068			
B-220	0.888	No-Fire	4.18	4.0	4.179			
B-221	0.935	No-Fire				2.6	Fire	4.8
B-222	0.940	No-Fire				1.8	Fire	87.0
B-223	0.994	No-Fire				1.4	No-Fire	—
B-224	1.004	No-Fire				1.6	No-Fire	—
B-225	1.034	No-Fire				1.750	Fire	72.8
B-226	0.923	No-Fire				1.700	No-Fire	—
B-227	0.900	No-Fire				1.750	Fire	80.5
B-228	0.941	No-Fire				1.725	Fire	46.8
B-229	0.918	No-Fire				1.700	No-Fire	—
B-230	0.890	No-Fire				1.725	No-Fire	—
B-231	1.014	No-Fire				1.750	Fire	59.9
B-232	1.028	No-Fire				1.725	Fire	63.1
B-233	0.944	No-Fire				1.700	No-Fire	—
B-234	0.905	No-Fire				1.725	No-Fire	—
B-235	1.013	No-Fire				1.750	Fire	41.0
B-236	1.030	No-Fire				1.725	Fire	70.7
B-237	0.927	No-Fire				1.700	No-Fire	—
B-238	1.011	No-Fire				1.725	Fire	36.4
B-239	0.880	No-Fire				1.700	Fire	161.6
B-240	0.935	No-Fire				1.675	Fire	189.0
B-241	0.944	No-Fire				1.650	No-Fire	—
B-242	0.915	No-Fire				1.675	No-Fire	—
B-243	0.916	No-Fire				1.700	No-Fire	—
B-244	0.933	No-Fire				1.725	Fire	122.1
B-245	0.990	No-Fire				1.700	Fire	131.7
B-246	0.946	No-Fire				1.675	Fire	51.9
B-247	0.972	No-Fire				1.650	Fire	95.1
B-248	0.915	No-Fire				1.625	No-Fire	—
B-249	0.908	No-Fire				1.650	No-Fire	—
B-250	0.966	No-Fire				1.675	Fire	104.0
$\bar{x}$	0.949	—	4.09	4.1	4.093	—	—	—
s	0.048	—	0.14	0.2	0.139	—	—	—
Lowest	0.857	—	3.86	3.9	3.863	—	—	—
Highest	1.047	—	4.33	4.5	4.328	—	—	—

TABLE 7. TEST DATA FOR STINGER 105B LOT B SQUIBS, NOS. B-251 THROUGH B-346

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Man Equivalent Electrostatic 25kV	Squib No.	Lead-to-Lead Initial Resistance (Ω)
B-251	0.964	*No-Fire	B-301	0.875
B-252	1.036	No-Fire	B-302	1.002
B-253	1.002	No-Fire	B-303	0.989
B-254	0.945	No-Fire	B-304	0.874
B-255	0.965	No-Fire	B-305	0.921
B-256	0.893	No-Fire	B-306	0.970
B-257	0.980	No-Fire	B-307	0.925
B-258	0.988	No-Fire	B-308	1.035
B-259	0.933	No-Fire	B-309	0.999
B-260	0.964	No-Fire	B-310	0.891
B-261	0.988	No-Fire	B-311	0.937
B-262	0.914	No-Fire	B-312	0.993
B-263	0.972	No-Fire	B-313	0.978
B-264	0.969	No-Fire	B-314	0.909
B-265	0.923	No-Fire	B-315	0.972
B-266	0.938	No-Fire	B-316	0.913
B-267	0.971	No-Fire	B-317	0.896
B-268	0.914	No-Fire	B-318	0.922
B-269	0.879	No-Fire	B-319	0.995
B-270	0.991	No-Fire	B-320	0.980
B-271	0.933	No-Fire	B-321	0.941
B-272	0.933	No-Fire	B-322	0.938
B-273	0.893	No-Fire	B-323	0.975
B-274	0.918	No-Fire	B-324	0.965
B-275	0.955	No-Fire	B-325	0.989
B-276	0.886	No-Fire	B-326	1.078
B-277	1.062	No-Fire	B-327	0.874
B-278	0.975	No-Fire	B-328	0.975
B-279	1.009	No-Fire	B-329	0.970
B-280	1.005	No-Fire	B-330	0.907
B-281	0.932	No-Fire	B-331	0.960
B-282	0.902	No-Fire	B-332	0.944
B-283	0.939	No-Fire	B-333	0.953
B-284	0.905	No-Fire	B-334	0.905
B-285	0.956	No-Fire	B-335	0.956
B-286	0.909	No-Fire	B-336	1.027
B-287	0.924	No-Fire	B-337	0.916
B-288	0.873	No-Fire	B-338	0.808
B-289	0.976	No-Fire	B-339	0.873
B-290	0.957	No-Fire	B-340	0.977
B-291	0.970	No-Fire	B-341	0.870
B-292	0.878	No-Fire	B-342	0.896
B-293	0.875	No-Fire	B-343	0.884
B-294	1.034	No-Fire	B-344	1.030
B-295	0.932	No-Fire	B-345	0.945
B-296	1.020	No-Fire	B-346	0.945
B-297	0.991	No-Fire		
B-298	0.911	No-Fire		
B-299	0.932	No-Fire		
B-300	0.950	No-Fire		
$\bar{x}$	0.949	———	———	0.945
s	0.045	———	———	0.053
Lowest	0.873	———	———	0.874
Highest	1.062	———	———	1.078

* Fired Helicopter Equivalent Test

TABLE 8. TEST DATA FOR STINGER 105C SQUIBS, NOS. C-1 THROUGH C-100

Squib No.	Lead-to-Lead Initial Resistance (Ω)	All-Fire 3.5 amp Step Function Time (msec)	Squib No.	Lead-to-Lead Initial Resistance (Ω)	No-Fire 1 amp, 1W 5 minutes
C- 1	0.990	1.674	C- 51	1.068	No-Fire
C- 2	1.060	1.301	C- 52	0.962	No-Fire
C- 3	1.017	1.584	C- 53	1.000	No-Fire
C- 4	1.037	1.423	C- 54	1.019	No-Fire
C- 5	1.015	1.441	C- 55	0.956	No-Fire
C- 6	1.034	1.407	C- 56	1.025	No-Fire
C- 7	0.935	1.360	C- 57	0.982	No-Fire
C- 8	0.92[illegible]	1.462	C- 58	0.931	No-Fire
C- 9	0.947	1.545	C- 59	0.938	No-Fire
C-10	1.018	1.385	C- 60	0.909	No-Fire
C-11	0.954	1.613	C- 61	0.993	No-Fire
C-12	1.042	1.446	C- 62	1.092	No-Fire
C-13	1.090	1.405	C- 63	0.961	No-Fire
C-14	0.957	1.451	C- 64	0.951	No-Fire
C-15	1.019	1.374	C- 65	1.023	No-Fire
C-16	0.879	1.457	C- 66	1.016	No-Fire
C-17	0.945	1.616	C- 67	0.943	No-Fire
C-18	0.974	1.454	C- 68	1.036	No-Fire
C-19	0.977	1.399	C- 69	0.994	No-Fire
C-20	0.979	1.626	C- 70	1.077	No-Fire
C-21	1.000	1.405	C- 71	0.986	No-Fire
C-22	0.952	1.370	C- 72	0.934	No-Fire
C-23	0.944	1.497	C- 73	0.961	No-Fire
C-24	1.088	1.702	C- 74	0.982	No-Fire
C-25	0.976	1.387	C- 75	1.003	No-Fire
C-26	0.910	1.454	C- 76	1.126	No-Fire
C-27	0.994	1.553	C- 77	0.986	No-Fire
C-28	1.046	1.499	C- 78	0.995	No-Fire
C-29	0.980	1.547	C- 79	1.026	No-Fire
C-30	0.948	1.605	C- 80	0.992	No-Fire
C-31	0.964	1.695	C- 81	1.022	No-Fire
C-32	0.982	1.599	C- 82	0.977	No-Fire
C-33	1.071	1.282	C- 83	1.068	No-Fire
C-34	0.953	1.491	C- 84	0.957	No-Fire
C-35	0.962	1.362	C- 85	1.097	No-Fire
C-36	0.983	1.532	C- 86	0.982	No-Fire
C-37	1.103	1.276	C- 87	1.050	No-Fire
C-38	0.940	1.594	C- 88	0.983	No-Fire
C-39	1.086	1.516	C- 89	0.926	No-Fire
C-40	0.935	1.634	C- 90	0.902	No-Fire
C-41	1.010	1.433	C- 91	1.010	No-Fire
C-42	0.944	1.[illegible]	C- 92	1.005	No-Fire
C-43	1.112	1.2[illegible]	C- 93	0.983	No-Fire
C-44	0.950	1.6[illegible]	C- 94	0.957	No-Fire
C-45	0.980	1.[illegible]	C- 95	1.005	No-Fire
C-46	1.009	1.346	C- 96	0.946	No-Fire
C-47	1.054	1.368	C- 97	1.016	No-Fire
C-48	1.032	1.448	C- 98	1.063	No-Fire
C-49	1.034	1.448	C- 99	0.966	No-Fire
C-50	0.891	1.39[illegible]	C-100	1.030	No-Fire
$\bar{x}$	0.993	1.473		0.996	
s	0.055	0.115		0.049	
Lowest	0.879	1.276		0.902	
Highest	1.112	1.702		1.126	

TABLE 9. TEST DATA FOR STINGER 105C SQUIBS, NOS. C-101 THROUGH C-200

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Man Equivalent Electrostatic 25kV	1 amp/1 msec Rate Ramp Firing Values			Bruceton Data Up and-Down No-Fires Tested For 5 seconds			Squib No.	Lead-to-Lead Initial Resistance (Ω)	Man Equivalent Electrostatic 25kV
			Current (amp)	Voltage Across Squib (V)	Time to Flash (msec)	Current (amp)	Result	Time (msec)			
C-101	0.979	No-Fire	3.89	4.0	3.885				C-151	0.970	*No-Fire
C-102	1.014	No-Fire	3.93	4.2	3.925				C-152	1.097	No-Fire
C-103	1.052	No-Fire	3.94	4.3	3.942				C-153	0.978	No-Fire
C-104	1.044	No-Fire	3.89	4.2	3.887				C-154	0.978	No-Fire
C-105	1.004	No-Fire	4.03	4.3	4.029				C-155	1.030	No-Fire
C-106	1.016	No-Fire	3.86	4.3	3.863				C-156	1.005	No-Fire
C-107	0.970	No-Fire	4.14	4.1	4.140				C-157	0.962	No-Fire
C-108	0.908	No-Fire	4.12	3.9	4.115				C-158	1.076	No-Fire
C-109	0.915	No-Fire	3.75	3.6	3.746				C-159	0.925	No-Fire
C-110	0.973	No-Fire	3.89	4.0	3.893				C-160	0.952	No-Fire
C-111	1.002	No-Fire	3.96	4.2	3.956				C-161	0.980	No-Fire
C-112	0.922	No-Fire	4.13	3.9	4.134				C-162	0.990	No-Fire
C-113	1.047	No-Fire	4.02	4.3	4.023				C-163	1.041	No-Fire
C-114	0.966	No-Fire	3.77	4.0	3.765				C-164	0.982	No-Fire
C-115	0.913	No-Fire	4.12	4.2	4.120				C-165	1.007	No-Fire
C-116	1.009	No-Fire	3.82	4.1	3.822				C-166	1.060	No-Fire
C-117	1.031	No-Fire	3.85	4.0	3.851				C-167	1.095	No-Fire
C-118	0.956	No-Fire	4.03	4.2	4.034				C-168	0.987	No-Fire
C-119	0.984	No-Fire	3.97	4.0	3.970				C-169	1.043	No-Fire
C-120	1.061	No-Fire	3.87	4.6	3.874				C-170	1.107	No-Fire
C-121	0.887	No-Fire				1.750	Fire	38.9	C-171	1.015	No-Fire
C-122	1.071	No-Fire				1.725	Fire	42.8	C-172	1.018	No-Fire
C-123	0.961	No-Fire				1.700	Fire	136.5	C-173	1.029	No-Fire
C-124	0.945	No-Fire				1.675	Fire	303.6	C-174	1.026	No-Fire
C-125	0.992	No-Fire				1.650	Fire	47.0	C-175	1.055	No-Fire
C-126	1.026	No-Fire				1.625	Fire	87.5	C-176	0.997	No-Fire
C-127	1.004	No-Fire				1.600	No-Fire	—	C-177	1.008	No-Fire
C-128	1.052	No-Fire				1.625	Fire	13.0	C-178	1.013	No-Fire
C-129	0.958	No-Fire				1.600	No-Fire	—	C-179	0.947	No-Fire
C-130	0.992	No-Fire				1.625	No-Fire	—	C-180	1.028	No-Fire
C-131	0.943	No-Fire				1.650	No-Fire	—	C-181	1.125	No-Fire
C-132	0.940	No-Fire				1.675	Fire	235.2	C-182	1.030	No-Fire
C-133	1.023	No-Fire				1.650	No-Fire	—	C-183	1.008	No-Fire
C-134	0.930	No-Fire				1.675	No-Fire	—	C-184	0.915	No-Fire
C-135	0.992	No-Fire				1.700	Fire	87.8	C-185	1.070	No-Fire
C-136	1.007	No-Fire				1.675	Fire	299.4	C-186	1.130	No-Fire
C-137	0.952	No-Fire				1.650	No-Fire	—	C-187	1.001	No-Fire
C-138	0.954	No-Fire				1.675	No-Fire	—	C-188	1.008	No-Fire
C-139	0.972	No-Fire				1.700	Fire	89.0	C-189	0.947	No-Fire
C-140	0.989	No-Fire				1.675	Fire	244.5	C-190	1.070	No-Fire

TABLE 9. (CONCLUDED)

Squib No.	Lead-to-Lead Initial Resistance (Ω)	Man Equivalent Electrostatic 25kV	1 amp/1 msec Rate Ramp Firing Values			Bruceton Data Up-and-Down No-Fires Tested For 5 seconds			Squib No.	Lead-to-Lead Initial Resistance (Ω)	Man Equivalent Electrostatic 25kV
			Current (amp)	Voltage Across Squib (V)	Time to Flash (msec)	Current (amp)	Result	Time (msec)			
C-141	1.020	No-Fire				1.650	No-Fire	—	C-191	0.944	No-Fire
C-142	0.948	No-Fire				1.675	Fire	127.4	C-192	1.047	No-Fire
C-143	1.037	No-Fire				1.650	Fire	50.8	C-193	0.987	No-Fire
C-144	0.999	No-Fire				1.625	Fire	146.1	C-194	0.973	No-Fire
C-145	1.024	No-Fire				1.600	Fire	74.7	C-195	1.099	No-Fire
C-146	1.033	No-Fire				1.575	Fire	161.2	C-196	1.032	No-Fire
C-147	0.940	No-Fire				1.550	No-Fire	—	C-197	1.028	No-Fire
C-148	0.991	No-Fire				1.575	No-Fire	—	C-198	1.046	No-Fire
C-149	1.018	No-Fire				1.600	Fire	122.8	C-199	0.994	No-Fire
C-150	1.043	No-Fire				1.575	No-Fire	—	C-200	0.943	No-Fire
$\bar{x}$	0.988	—	3.95	4.1	3.949	—	—	—	$\bar{x}$	1.016	—
s	0.045	—	0.12	0.2	0.120	—	—	—	s	0.051	—
Lowest	0.887	—	3.75	3.6	3.746	—	—	—	Lowest	0.915	—
Highest	1.071	—	4.14	4.6	4.140	—	—	—	Highest	1.130	—

* Fired Helicopter Equivalent Test

TABLE 10. TEST DATA FOR STINGER 105C SQUIBS, NOS. C-201 THROUGH C-250

				Step Current Time-to-Fire Data			
Squib No.	Lead-to-Lead Initial Resistance (Ω)	Step Current (amp)	Voltage at Bridgewire Break (V)	Time to Flash (msec)	Step Current (amp)	Voltage at Bridgewire Break (V)	Time to Flash (msec)
C-201	0.990						
C-202	0.981		1 amp, 1W Temperature Tested				
C-203	0.958						
C-204	0.981						
C-205	1.010						
C-206	0.983						
C-207	1.013						
C-208	0.964						
C-209	0.955						
C-210	0.960						
C-211	0.943						
C-212	0.983						
C-213	0.945						
C-214	1.023						
C-215	0.957						
C-216	0.970						
C-217	0.950						
C-218	0.935						
C-219	0.933						
C-220	0.969						
C-221	0.980						
C-222	0.960						
C-223	0.951						
C-224	0.923						
C-225	1.002						
C-226	0.989						
C-227	1.027						
C-228	1.001						
C-229	1.012						
C-230	0.997						
C-231	0.976	1.92	2.0	28.636			
C-232	1.007	2.00	2.2	17.334			
C-233	1.082	2.00	2.3	18.815			
C-234	0.971	2.00	2.1	25.498			
C-235	1.016	2.00	2.18	13.326			
C-236	0.935	2.00	2.02	26.674			
C-237	0.990	2.00	2.15	16.789			
C-238	1.045	2.00	2.20	20.502			
C-239	0.997	2.00	2.20	15.347			
C-240	1.012	2.00	2.15	22.122			
C-241	0.943				3.0	3.1	3.162
C-242	0.990				3.0	3.3	2.223
C-243	0.979				3.0	3.2	3.003
C-244	0.947				3.0	3.2	2.208
C-245	0.958				3.0	3.2	3.055
C-246	0.939				3.0	3.2	3.170
C-247	1.005				3.0	3.4	2.164
C-248	0.987				3.0	3.3	*2.58
C-249	0.931				3.0	3.3	2.899
C-250	1.060				3.0	3.5	2.773
$\bar{x}$	0.981	—	2.15	20.504	—	3.3	2.724
s	0.034	—	0.1	5.127	—	0.1	0.403
Lowest	0.923	—	2.0	13.326	—	3.1	2.208
Highest	1.082	—	2.3	28.636	—	3.5	3.170

* From Scope Oscillogram

All resistance values are greater than 12 megohms which is much greater than the minimum allowed value. The test was not attempted for the other two groups since they are very similar squibs.

4. Safety Tests

a. Electrostatic Sensitivity (Case-to-Shorted Leads)

(1) Man-Equivalent Circuit. Tests were conducted on 300 squibs (100 each group) with the man-equivalent circuit which is a 500-picofarad capacitor, charged to 25 kilovolts with a current limiting 5-kilohm resistor in series with the capacitor and squib. The circuit for these tests is depicted in Figure 4. The results are tabulated in Tables 1, 2, 6, 7, and 9. No squibs fired, which indicates for each group of 100 that there is at least 97% reliability with 95% confidence [5] that a similar lot will not fire, or for the three groups (300 squibs) there is at least 99% reliability with 95% confidence that similar Celesco STINGER 105 squibs will not fire.

Attempts were made to obtain Bruceton electrostatic threshold fire point data [6] from the 105B Lot A squib group. From 25 to 45 kilovolts, two squibs were tested in 500-volt steps. To further prove the high level of electrostatic insensitivity, 45 squibs were tested at 45 kilovolts with all no-fires. For the 47 squibs, there is at least 93.6% reliability with 95% confidence that a similar lot will not fire. The test was not attempted for the other two groups since they had passed the 25-kilovolts test and are very similar squibs.

(2) Helicopter Equivalent Circuit. Three squibs, one from each group, were tested for helicopter electrostatic sensitivity. The circuit is a 3-nanofarad capacitor charged to 30 kilovolts (with no resistor in series) and discharged through the squib case-to-leads mode. All three fired. This test was for information only and is not to be construed as a safety requirement test. The circuit for this test is depicted in Figure 4.

b. Direct Current (1-Ampere, 1-Watt No-Fire)

Tests were conducted for the no-fire requirements on 50 squibs from each of three groups. The circuits for the tests are depicted in Figures 5 and 6. The results are tabulated in Tables 1, 4, and 8. There was one failure out of 150 tests, which occurred at 47 seconds before the end of the 5-minute test. This indicates at least 96.8% reliability with 95% confidence that similar Celesco STINGER 105 squibs will pass the test. A recheck of the instrumentation indicated the test application to be correct. From the data obtained, the 105B Lot A squibs did not pass the specification requirement; however, the squib failure is believed to be a "maverick." Since the failure time approaches the spec limit for acceptance, it is believed that Lot A type squibs could be safely used in STINGER without compromising realistic safety.

The 105B Lot A squibs were previously subjected to the man-rated electrostatic equivalent safety test at 25 kilovolts. These squibs were subjected to different current durations because the sixteenth squib test at 1 ampere, 1 watt for 5 minutes fired at 253 seconds. The next two squibs were checked for 1 hour to determine at what time the bridgewire resistance reach equilibrium. Neither squib fired and equilibrium resistance was reached in approximately 5 minutes. The next 32 squibs were checked for 10 minutes each with none firing. (See the preceding discussion of this failure.) This failure indicates at least 90.6% reliability with 95% confidence that a similar lot of 105B Lot A squibs will pass the 5-minute test.

The 105B Lot B and 105C squibs (50 each group) were subjected to the 1-ampere, 1-watt, 5-minute test. They had previously been checked only for initial bridgewire resistance. None of either group fired, thus the two groups passed the test. For each of the two groups, the tests indicate at least 94% reliability with 95% confidence.

c. Direct Current (1-Ampere, 1-Watt Case Temperature)

Case temperature tests were conducted on one squib from the 105C group. These tests were deemed necessary because the squib cases had been hot to the touch after the 1-ampere, 1-watt 5-minute test discussed in the preceding Paragraph. There was some concern about the squib cases reaching the auto-ignition temperature of the STINGER ignitor material in a sealed insulated environment. The test was conducted by placing a copper-constantan thermocouple referenced to a 0°C ice bath on an untested 105C squib case and encasing the squib in ground charcoal. The squib case temperature rose steadily for 15 minutes and remained constant for 5 more minutes. The 1-ampere, 1-watt current was terminated after 20 minutes. The temperature curve was recorded during the current application and the 10-minute cool down period. The following data were recorded:

	Current Application Period					Cool Down Period	
Time (min)	0	5	10	15	20	25	30
Temperature (°C)	20	50	58	60.5	60.5	33	24

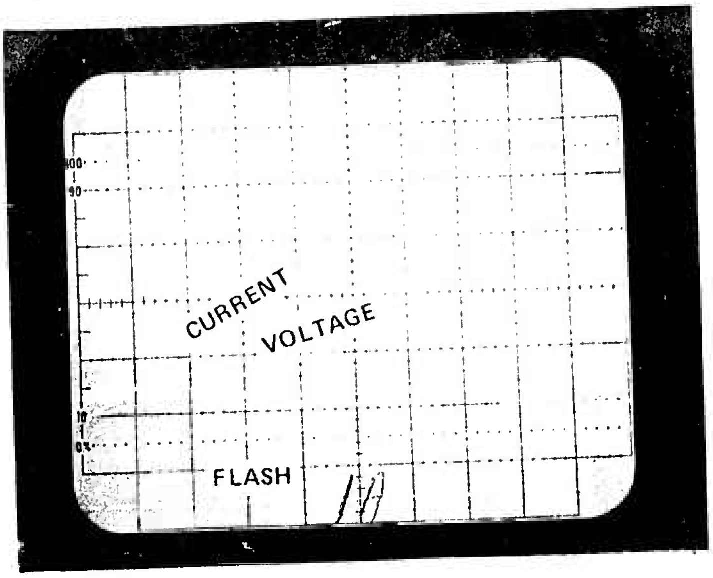
Ambient Temperature = 22°C

The maximum temperature reached was 60.5°C. This is well below the auto-ignition temperature of $B\text{-}KNO_3$ (288°C) and below the planned aging program temperature (71°C). It is also below the temperature (177°C) at which the squib must not ignite. This test indicates STINGER ignitor materials to be safe from auto-ignition due to squib case temperature if a 1-ampere, 1-watt source is applied to the bridgewire.

5. Functional Tests

a. Direct Current (1-Ampere/Millisecond Ramp Rate Firing)

Tests were conducted on 72 squibs with the circuit depicted in Figure 6. The results are tabulated in Tables 2, 3, 6, and 9. The ramp current firing technique* demonstrated that all three groups have good uniform functional performance. Figure 7 is a typical oscillogram of a ramp firing. The mean and estimated standard deviation for the 105B Lot B group and 105C group are 4.09 amperes, 3.95 amperes and 0.14 ampere, 0.12 ampere, respectively. These data show that the two groups fired at essentially the same current level. However, the 105B Lot A group fired at a slightly lower mean current of 3.70 amperes, with an estimated standard deviation of 0.1 ampere. The mean of the firing currents of the three groups decreases as the mean of the initial bridge-wire resistance increases. The relative closeness of the three estimated standard deviations supports the statement concerning uniform functioning.



UNITS = I = 1 amp/div
V = 2 V/div
TIME = 500 μ sec/div

Figure 7. Oscillogram of 1-ampere/millisecond ramp rate squib firing, depicting the squib current, voltage, and flash traces.

Two distinct groups were chosen from the 105B Lot A group to determine if the electrostatic tests had altered the electrical firing characteristics. A group which had been electrostatically checked and

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* The ramp firing technique and system will be detailed completely in a future report by D. R. Drietzler and W. A. Williams. Also see References 3 and 4.

a group which had not been electrostatically checked were ramp fired. There was no essential difference in the means of the firing currents, voltages, or times. This result may be observed in the 105B Lot A tables.

b. Direct Current (3.5-Ampere Step)

This test provided the all-fire functioning time data. Tests were conducted on 150 squibs, 50 from each group using the circuit in Figure 6. The results are tabulated in Tables 1, 4, and 8. All three squib groups had essentially the same mean functioning time of 1.50 milliseconds which is well below the required maximum allowable time of 4.5 milliseconds. The highest function time for any of the 150 squibs was 2.431 milliseconds.

c. Direct Current (Functioning Probability, Bruceton Up-and-Down Method)

A statistical evaluation of the threshold current firing characteristics of two groups of Celesco's STINGER 105 squibs was performed. The Bruceton up-and-down method of sensitivity testing [6] was used to collect data and compute values for defining the "all-fire", "no-fire," and "50% fire-point," current characteristics, as well as the current values of plus and minus three standard deviations from the current mean of the squibs.

A total of 60 squibs which had been previously tested electrostatically with a man-equivalent circuit were tested to establish the current firing limits of single squibs subjected to a step-current for 5 seconds using the circuit depicted in Figure 6. The firing current for the tests was varied in increments of 0.025 ampere. The procedure followed was to search first by trial and error for the current which gave marginal firings (four squibs used); second, determined the current interval for the tests (two squibs used); and third to increase or decrease the stimulus (current) depending on the results of the previous test. If a squib fired at a certain current level, the next squib was tested at a current decreased by 0.025 ampere or vice versa. Each squib had only one opportunity to fire. For the tabulated results see Tables 6, 9, 11, and 12. If a squib fired, its time-to-fire is included in the tables. Note that increasing or decreasing the current level does not necessarily increase or decrease the time-to-fire.

The calculated data for 95% confidence of the 95, 50, and 5% firing probabilities for the 105B Lot B squib group, are as follows:

95% = 1.823 ± 0.176 amperes, 50% = 1.698 ± 0.045 amperes, and 5% = 1.573 ± 0.176 amperes.

The data for the 105C squib group are as follows:

95% = 1.827 ± 0.299 amperes, 50% = 1.635 ± 0.062 amperes, and 5% = 1.443 ± 0.299 amperes.

TABLE 11. BRUCETON UP-AND-DOWN TEST DATA FOR STINGER 105B LOT B SQUIBS, NOS. B-221 THROUGH B-250

Squib No.	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	Counts	
Time-to-Fire (msec)	4.8	87.0	—	—	72.8	—	80.5	46.8	—	—	59.9	63.1	—	—	41.0	70.7	—	36.4	161.6	189.0	—	—	—	122.1	131.7	51.9	95.1	—	—	104.0		
Step Current (amp)																															Fire	No-fire
1.4			0																												—	—
1.6				0																											—	—
1.625																												0			0	1
1.650																					0						X		0		1	-
1.675																				X		0				X				X	3	1
1.700						0			0				0				0		X				0		X						2	-
1.725								X		0		X		0		X		X						X							5	-
1.750					X		X				X				X																3	0
1.800		X																													—	—
2.6	X																														14	10

6 Squibs

→ Bruceton Data

N = 10

Firing Probability at 95% Confidence
95% = 1.823 ± 0.176 amp
50% = 1.698 ± 0.045
5% = 1.573 ± 0.176

24 Squibs

TABLE 12. BRUCETON UP-AND-DOWN TEST DATA FOR STINGER 105C SQUIBS, NOS. C-121 THROUGH C-150

Squib No.	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	Counts	
Time-to-Fire (msec)	38.9	42.8	136.5	303.6	47.0	87.5	–	13.0	–	–	–	225.2	–	–	87.8	299.4	–	–	89.0	244.5	–	127.4	50.8	146.1	74.7	161.2	–	–	122.8	–		
Step Current (amp)																															Fire	No-fire
1.550																											0				0	1
1.575																										X		0		0	1	2
1.600							0		0																X				X		2	2
1.625						X		X		0														X							3	1
1.650					X						0		0				0				0		X								2	4
1.675				X								X		0		X		0		X		X									5	2
1.700			X												X				X												3	0
1.725		X																													1	0
1.750	X																														1	0
																															18	12

N = 12

Firing Probability at 95% Confidence
95% = 1.827 ± 0.299 amp
50% = 1.635 ± 0.062
5% = 1.443 ± 0.299

30 Squibs

The calculations used to obtain the data in the preceding Paragraph and the data plotted in Figure 8 are outlined in this Section [6, 7, 8, 9, and 10].

Current values were obtained from Figures 8 and 9 to check against the firing standard deviation requirement. For the 105B Lot B group, the +3s value is 1.93 amperes and the -3s value is 1.47 amperes. For the 105C group, the +3s value is 1.99 amperes and the -3s value is 1.29 amperes. The ±3s values for both groups are well within the required minimum of 1.0 ampere and maximum of 3.00 amperes.

(1) Calculation Outline. The following data listing depicts 14 "X's" and 10 "0's". The column with the smallest total (0's in this case) is used for calculations.

Test Current	X	0	i	n_j	in_j	i^2n_j
1.625	0	1	0	1	0	0
1.650	1	2	1	2	2	2
1.675	3	1	2	1	2	4
1.700	2	4	3	4	12	36
1.725	5	2	4	2	8	32
1.750	3	0	5	0	0	0
Totals	14	10		N = 10	A = 24	B = 74

(2) Symbols. The definitions of the terms used in the preceding data listing and the following calculations are as follows:

X = Fired.

0 = No-fire.

$(\overline{y})$ = The average firing current for the sample lot.

(s) = The standard deviation of firing current for the sample lot.

i = Adjusted current (used to simplify calculations).

n_j = Number of "fires" or "no-fires" occurring at each current level (depending on choice made).

d = Current interval which is recommended to be equal to the standard deviation.

Z_p = A variable determined from student's t-distribution mathematical tables for N-1 degrees of freedom for the assumed normal distribution.

N = The number of data points corresponding to the less frequent attribute total.

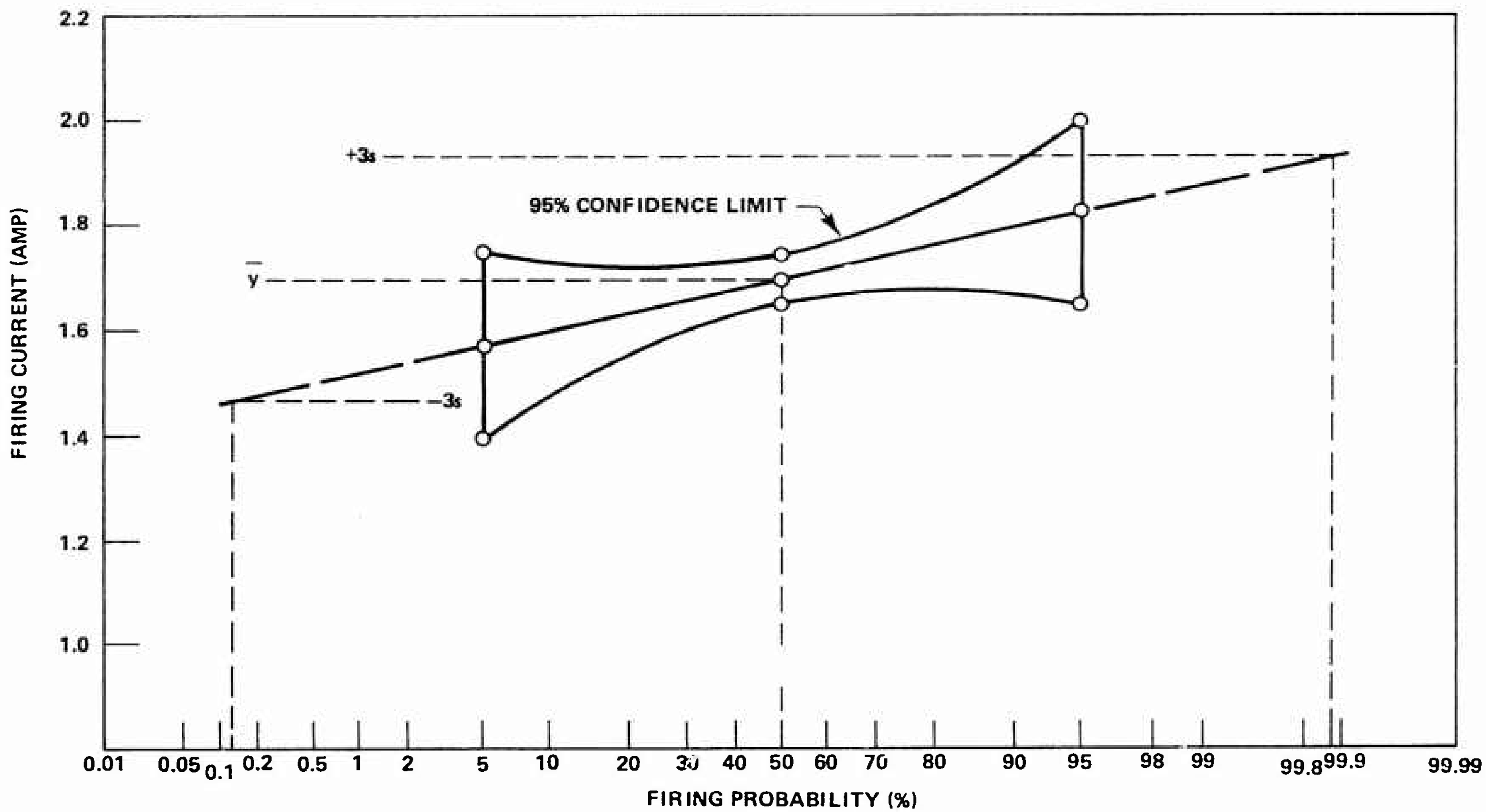

Figure 8. Firing current versus firing probability for STINGER 105B Lot B squibs using Bruceton data.

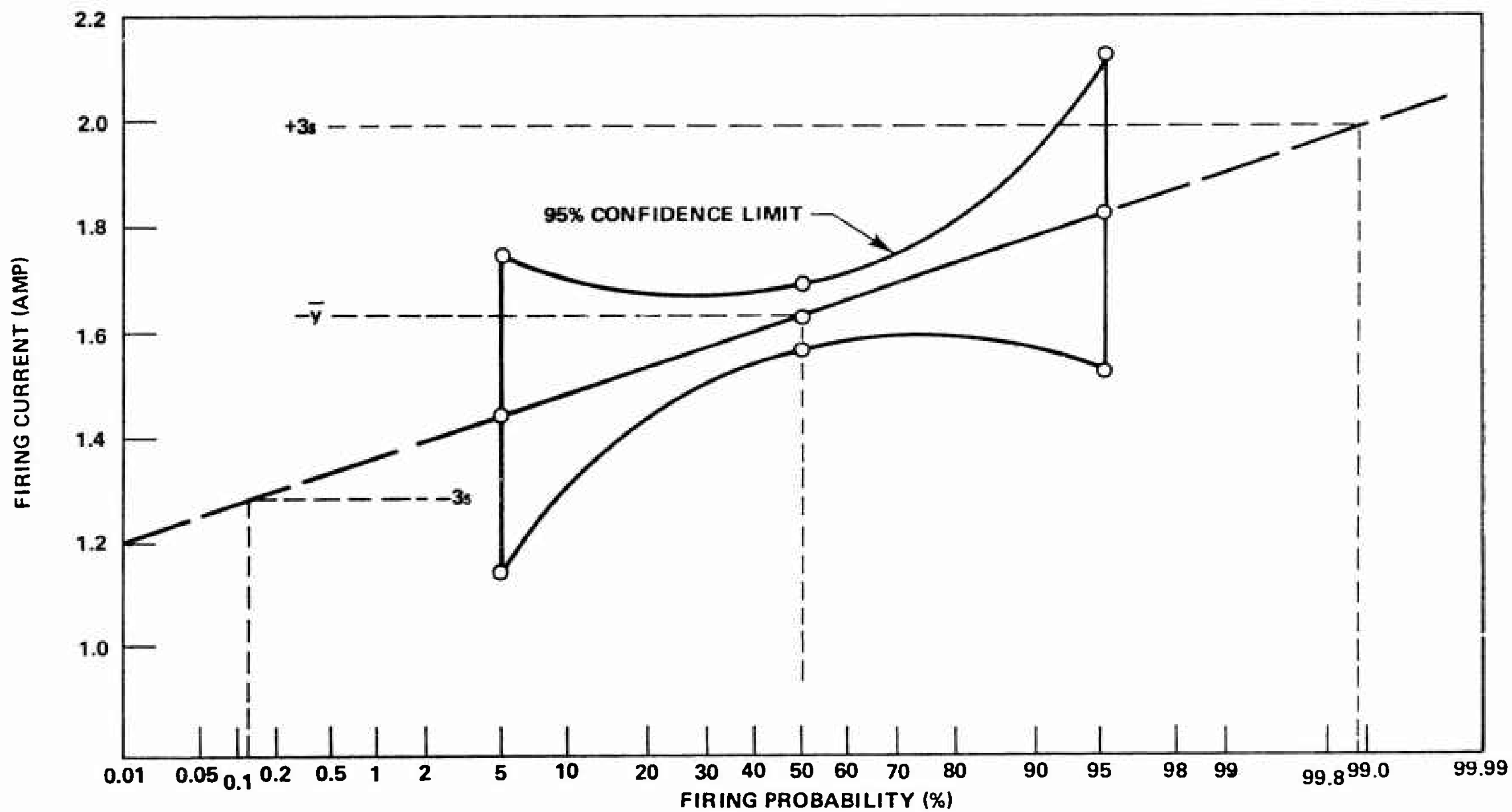

Figure 9. Firing current versus firing probability for STINGER 105C squibs using Bruceton data.

α = Level of significance (the probability that a true hypothesis will be rejected).

Y_0 = Lowest level of test current.

$$A = \sum_{i=0}^{k} in_j$$

where

i = 0, 1, 2, ..., k

0 = Lowest level of less frequent attribute

k = Highest level of less frequent attribute.

$$B = \sum_{i=0}^{k} i^2 n_j$$

where

$n_0, n_1, n_2, \ldots, n_k$ denote frequencies of the less frequent attributes in total.

(3) Equations. The estimate of $\mu = \overline{y} = Y_0 + d(\frac{A}{N} \pm 1/2)$ with "+1/2" used for data from 0's and "-1/2" used if X's are used.

Therefore

$$\overline{y} = 1.625 + 0.025\ (\frac{24}{10} + 1/2)$$

$$\overline{y} = 1.698 \text{ amperes.}$$

The estimate of $\sigma = s = 1.620\ d(\frac{NB - A^2}{N^2} + 0.029)$.

Therefore

$$s = 1.620\ (0.025)\ \frac{(10)\ (74) - (24)^2}{10^2} + 0.029$$

$$s = 0.068 \text{ ampere.}$$

The estimate of firing probability $\mu + Z_p\sigma = \overline{y} \pm Z_p s$ with $Z_p s(\alpha, N-1) = Z_p\ (0.05, 9) = 1.8331$ from mathematical tables.

Therefore

95% firing probability = 1.698 + (1.8331) (0.068) = 1.823 amperes
50% firing probability = 1.698 + (1.8331) (0) = 1.698 amperes
5% firing probability = 1.698 (1.8331) (0.068) = 1.573 amperes.

The estimate of the standard deviation of $\bar{y} = s_{\bar{y}} = \frac{6s+d}{7\sqrt{N}}$.

Therefore

$$s_{\bar{y}} = \frac{6\,(0.068) + 0.025}{7\sqrt{10}}$$

$$s_{\bar{y}} = 0.020.$$

The estimate of the standard deviation $s = s_s$

where

$$s_s = \frac{1.1 + (0.3)\left(\frac{S^2}{d}\right)}{\sqrt{N}} .$$

Therefore

$$s_s = \frac{1.1\ (0.068) + 0.3\ \frac{(0.068)^2}{0.025}}{\sqrt{10}}$$

$$s_s = 0.041.$$

The estimate of the standard deviation of $\bar{y} + Z_p s = s_{(\bar{y} + Z_p s)}$

where

$$s_{(\bar{y} + Z_p s)} = \sqrt{s_{\bar{y}}^2 + Z_p^2\ s_s^2} .$$

For the 95 and 5% point,

$$s_{(\bar{y} + Z_p s)} = \sqrt{(0.020)^2 + (1.8331)^2\ (0.041)^2} = 0.078,$$

and for the 50% point

$$s_{(\bar{y} + Z_p s)} = \sqrt{(0.020)^2 + (1.8331)^2 (0)^2} = 0.020.$$

The 95% confidence intervals of the 95, 50, and 5% firing probabilities are given by the relation

$$\bar{y} + Z_p s \pm (t_{(\alpha/2, N-1)}) (s_{\bar{y}} + Z_p s),$$

where $t_{(\alpha/2, N-1)}$ is given in mathematical tables as the "upper percentage points of the t distribution." Therefore for the STINGER 105B Lot B squib group,

95% point = 1.823 ± (2.2622) (0.078) = 1.823 ± 0.176 amperes
50% point = 1.698 ± (2.2622) (0.020) = 1.698 ± 0.045 amperes
5% point = 1.573 ± (2.2622) (0.078) = 1.573 ± 0.176 amperes.

Similarly, one may calculate data points for Figure 9 (STINGER 105C squib group); i.e.,

95% point = 1.827 ± 0.299 amperes
50% point = 1.635 ± 0.062 amperes
5% point = 1.443 ± 0.299 amperes.

d. Direct Current (Time-to-Fire)

Tests were conducted on 20 squibs from the 105C group with the circuit depicted in Figure 6. The results are tabulated in Table 10. They were tested in two groups, 10 each, for their time required to function after application of a 2.0 and 3.0-ampere step current.

The 3.0-ampere step current test resulted in a time-to-squib flash mean of 2.724 milliseconds and a standard deviation of 0.403 millisecond. The 2.0-ampere step current test resulted in a time-to-squib-flash mean of 20.504 milliseconds and a standard deviation of 5.127 milliseconds. These tests show the squib meets the all-fire current requirement, and that the squib functions more consistently with a 3.0-ampere or greater firing current.

6. Conclusions

The STINGER launch and flight motor squibs that were tested successfully passed the functional and safety requirements of the ARC SP10071B specification. Therefore, both types of squibs are considered qualified for use in the STINGER missile system.

The ramp current functional tests revealed that the three lots of squibs had almost identical mean firing current values with very small standard deviations. This indicates that the squibs were very uniformly manufactured.

These evaluation tests show that both types of squibs are safe for man-handling, thus they may be considered for use in other shoulder-fired systems such as I-LAW and ROLAND.

The functional tests evaluated the electrical performance only. Any system using the squibs must have an igniter designed for both squibs' brisance and ignition potential.

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APPENDIX: Correlation of Squib Numbers and Package Information

The squibs used for the evaluation discussed in this report were loaded at different times. The following information correlates the individual squib numbers to the Celesco packaging label information.

SQUIB NUMBERS	CELESCO LABEL
STINGER Flight Motor Squibs	
105B Lot A, Nos. 1 through 145	Model 105, Lot No. FND 1-2 Date Loaded 5-73, Mfg. P/N A0079051 Rev. A
STINGER Flight Motor Squibs	
105B Lot B, Nos. B-1 through B-100	Model 105, Lot No. FND 1-3 Date Loaded 9-73, Spec 200131-4 FND Job 6110
105B Lot B, Nos. B-201 through B-346	Model 105 B-4, Lot No. FND 1-6 Date Loaded 2-74, Spec ARC SP10071B, FND Job 5014
STINGER LAUNCH Motor Squibs	
105C, Nos. C-1 through C-200	Model 105-7, Lot No. FND 2-1 Date Loaded 3-74, Spec SP10071 Rev. C, FND Job 6426
105C, Nos. C-201 through C-250	Model 105B-7, Lot No. FND 2-1 Date Loaded 3-74, Spec ARC SP10071B FND Job 5014

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-MW	1
-PE-X	1
-PM	1
-PME	2
-RK	1
-RK4	1
-SHO	1
-TO	1
AMSMI-FR, Mr. Strickland	1
-R, Dr. McDaniel	1
Mr. Fagan	1
Dr. Kobler	1
-RBD	3
-RC	1
-RD	1
-RE	1
-RF	1
-RG	1
-RH	1
-RK	1
-RKC	10
-RKK	1
-RL	1
-RN	1
-RR	1
-RT	1
-RTE	1
-RTR	1
-TM	1
-U	1
-Q	1
-QE	1
-QL	1
-QR	1
-QT	1
-Y	1
-YP	1
-RPR (Record Set)	1
(Reference Copy)	1
-LP, Mr. Voigt	1