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Fluidic Generator to Power Rocket Proximity Fuze

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

A fluidic generator has been designed to satisfy the power requirements of a rocket proximity fuze. The design was based on the generator used with the XM445 time fuze for the Multiple Launch Rocket System (MLRS). Power output was increased to approximately 5 W at pressure above 10 psig by increasing the diameter of the coil wire (No. 30 versus 36 AWG), reducing the number of turns (550 versus 1500), and increasing the value of the coupling capacitor (0.4 versus 0.022 μF) to achieve optimum matching into a 120-Ω load. The product was evaluated in a configuration where open space within the fuze nose cone was reduced to accommodate a fuze antenna. The ability of the generator to survive pressure extremes normally encountered in an

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20. ABSTRACT (Cont'd)

MLRS flight and to provide sustaining power to a complementary metal-oxide-semiconductor timer at flight apogee was successfully demonstrated. The fluidic generator retains its ability to provide a second independent environmental signature to the safety and arming device.

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1. INTRODUCTION

1.1 *Background*

A power supply that can also provide an independent environmental safing signature is needed for a proximity fuze being developed for the Multiple Launch Rocket System (MLRS). The fuze employes a low-voltage, low-current, high-impedance complementary metal-oxide-semiconductor (CMOS) timer circuit that must be powered throughout the entire flight and a high-power proximity sensor that must function during the last few seconds of flight. The timing circuit delays turning on the proximity sensor until 5 to 7 s before impact. At that time a maximum power output in the range of 3 to 5 W at 0.2 A is required to power the proximity sensor and function the fuze. The independent environmental safety is needed because MIL-STD-1316A/B requires two independent environmental sensors. Because the rocket is nonspin, spin is precluded as a second signature. The first signature is launch setback.

The MLRS rocket already has a time fuze, the XM445, that is powered throughout the trajectory by a fluidic generator, which is an air-driven power supply. The fluidic generator, developed especially for this application, is a vibrating-armature device that produces an ac voltage at a relatively uniform frequency. This output is rectified and provides 0.5 W to operate the timing circuit. At launch the frequency of the ac voltage is counted by the arming system to provide a safe separation distance.

The fluidic generator must survive the severe extremes of pressure and temperature experienced in the flight. During the burning phase, the MLRS rocket attains a velocity of greater than 3000 ft/s with attendant stagnation pressures of 150 psia,* and stagnation temperatures of 1000 F. This is a very harsh environment for the generator to withstand. The rocket when fired for maximum range reaches altitudes above 60,000 ft, where the stagnation pressure decreases to 1 psia, and the air energy needed to power the fluidic generator even at the 0.5-W level is marginal.

pounds per square inch (absolute): (psi) 6.895 × 10^3 = (pascals).

Several design features enabled the generator to withstand these environments and to operate the XM445 time fuze throughout the flight. The vibrating components were strengthened by using two diaphragms and two reeds. Air holes were included along the generator rim so as to equalize the air pressure from front to back and thus help to support the diaphragm during the initial high-velocity portion of the flight. The nozzle and resonator geometry were optimized for supersonic flow conditions where the inlet supply pressure and flow are minimal. The fluidic generator developed in the MLRS time fuze program[1,2] has been extensively tested and has proven to be highly reliable in the laboratory and aboard Zuni, Zap, Honest John, and MLRS rockets. The XM445 fuze is presently in limited production. Therefore, the fluidic generator used in the XM445 fuze is a promising baseline in terms of ruggedness and producibility for the desired proximity fuze power supply.

The main objective of this proximity fuze power supply developmental effort is to increase the power output of the XM445 fluidic generator tenfold without reducing its ruggedness. Advantage can be taken of the requirements that (1) the high output is required only during the last stage of descent where air energy is plentiful, and (2) the electrical energy required in the first part of the flight, including apex, is much less than that required for the original time fuze.

A further objective is to evaluate the effect on the power supply output of placing an antenna for the proximity fuze inside the ogive where it occupies space that was formerly a part of the fluidic generator's interaction region.

The fluidic generator already developed for the MLRS time fuze is a promising candidate for this proximity fuze application because the rocket and trajectories are the same and the electrical power requirements are less during the high-altitude por-

[1] *Richard L. Goodyear and Henry Lee, Performance of the Fluidic Power Supply for the XM445 Fuze in Supersonic Wind Tunnels, Harry Diamond Laboratories, HDL-TM-81-4 (February 1981).*

[2] *Jonathan E. Fine, Performance of Ram Air Driven Power Supply for Proposed High Altitude Rocket in Naval Surface Weapons Center Supersonic Wind Tunnel, Harry Diamond Laboratories, HDL-TM-80-31 (November 1980).*

tions of flight, where only the timer operates. The major development considerations were to modify the coil to match the proximity fuze load and to find a suitable space within the ogive for the antenna.

1.2 *Description of Fluidic Generator Operation*

The fluidic generator converts pneumatic energy (ram air), available along the flight trajectory, into electrical energy.[3] The transformation in energy takes place in three distinct steps: pneumatic to acoustical, acoustical to mechanical, and mechanical to electrical. A schematic of the device is shown in figure 1. As can be seen, ram air passes through an annular nozzle into a cone-shaped cavity whose opening is concentric with the annular orifice. The annular jet stream issuing from the orifice impinges on the leading edge of the cavity, creating an acoustic perturbation which triggers air inside the cavity into resonant oscillation. The pulsation of the air within the cavity in turn drives a metal diaphragm, clamped along its circumference at the end of the cavity, into vibration. The vibratory motion of the diaphragm is transmitted to a reed via a connecting rod. The reed is in the airgap between the poles of a magnetic circuit consisting of a pair of permanent magnets between a pair of magnetic keepers. The reed, made of magnetic material, oscillates in the airgap at the system mechanical resonant frequency, so that the magnetic flux passing through the reed alternates in direction as the reed approaches and recedes from the opposite poles in the airgap. The resulting alternating flux induces an electromotive force in a conducting coil around the reed. The power generated is mainly a function of the rate of change of the magnetic flux density, and the amplitude of the reed excursion in the airgap.

1.3 *Program Objectives*

The objectives of this program were (1) to modify the MLRS generator such that it would provide 24 V into a 120-Ω load without deteriorating its other performance characteristics (i.e., survival at high pressures and temperatures), and (2) to position a simulated rf antenna around the generator

[3]*Carl J. Campagnuolo and Henry C. Lee, Development of a High-Power Fluidic Generator for Hard-Structure Munition (HSM) Bomb, Harry Diamond Laboratories, HDL-TR-1988 (May 1982).*

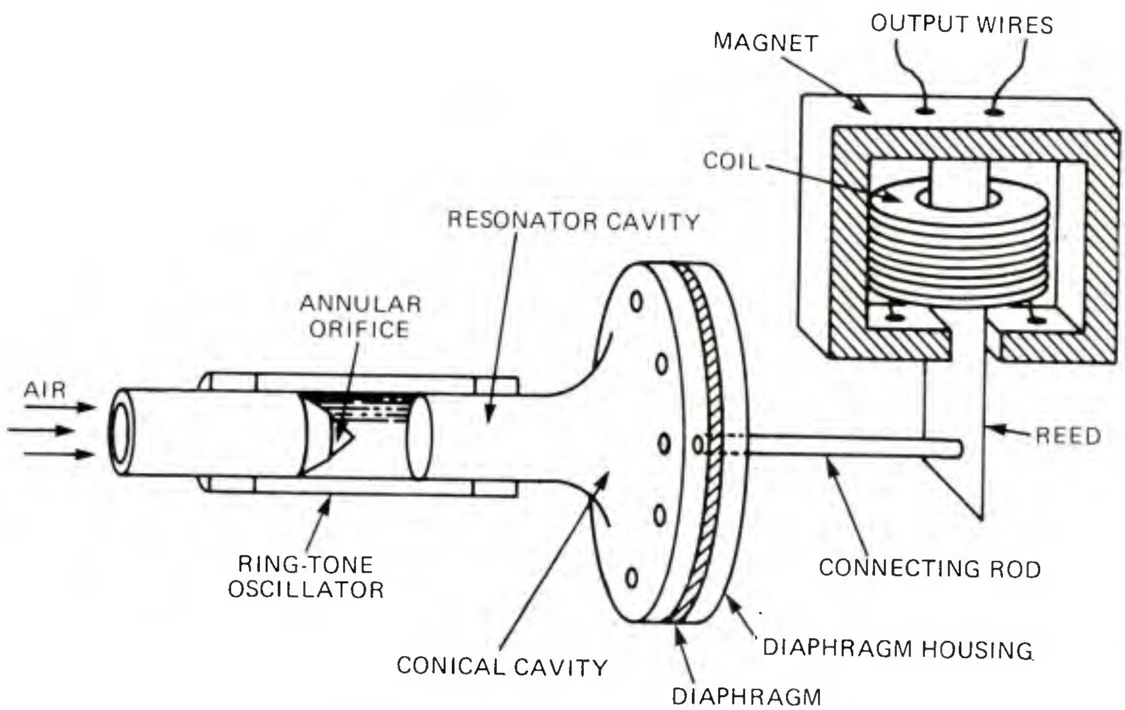

Figure 1. Operational sketch of a fluidic generator.

within the fuze ogive and determine its effects on the generator's performance.

2. EXPERIMENTAL METHODS

The fluidic generator currently used in the XM445 fuze was designed to produce maximum power into a 2000-Ω resistor which was connected to the generator in series with a 0.022-μF capacitor. The coil had 2500 turns of No. 36 gauge wire. To change the generator so that it would produce 24 Vdc across a 120-Ω load, the internal impedance of the generator was reduced so that it better matched the 120-Ω load. To accomplish this the coil was modified so that it could pass higher current (0.2 A) at lower voltage (24 V). This was done by increasing the diameter of the wire, which reduced the coil's internal resistance and permitted higher currents. When the wire size was increased the number of turns had to be reduced (since the volume of the coil bobbin is fixed) and as a consequence the induced voltage was also lower. To attain 24 Vdc across 120 Ω requires 0.200 A. The coil for the MLRS generator uses No. 36 gauge copper wire, which is rated at 0.035 A, clearly inadequate for the proximity fuze application. Higher current ratings can be obtained by using larger diameter wire. However, as the wire diameter is increased, the number of turns that can be accommodated on the bobbin is reduced. As a reasonable trade-off, No. 30 gauge wire (rated at 0.144 A continuous duty) was selected. This permitted up to a maximum of 550 turns. To determine the optimum number of turns when using number 30 wire, three different coils were wound: one with 450 turns, a second with 500 turns, and a third with 550 turns; 550 was the maximum number of turns the existing bobbin could hold.

To determine the optimum configuration each coil was subjected to the two-part test procedure described below. The test setup is illustrated in figure 2. First, for each coil configuration, the fluidic generator internal resistance and optimum matching capacitance were measured by setting the input air pressure at 5 psig* and selecting the load resistance and capacitance values that produced a maximum indication of output power. The external matching capacitance and internal resistance for each coil were thus determined. The rms voltage across the resistor was read and the power was calculated using the formula $P = V^2/R$. It was assumed that this voltage would be numerically equal to the rectified average dc voltage attainable with an equivalent fuze load.

In the second part of the test procedure the generator output power was measured at 5, 10, 15, and 20 psig across a 128-Ω load. This value was the available wattmeter setting nearest to the required 120 Ω and therefore was used for an indication of generator performance. In general, an increase in pressure yields an increase in voltage, and the range from 10 to 20 psig corresponds to the pressure expected in flight where proximity sensor operation is required.

The first coil tested had 550 turns of No. 30 gauge wire. For maximum power output, the voltage output across a 128-Ω resistor when con-

*psi (guage) — differential pressure above ambient atmospheric pressure of 14.7 psia.

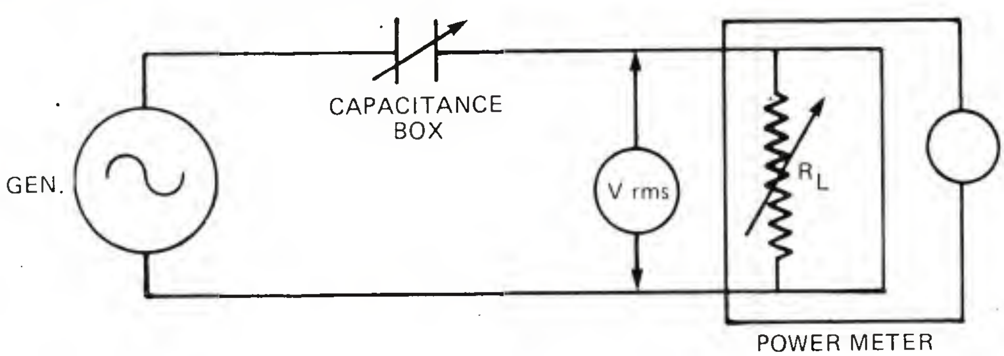

Figure 2. Test circuit used.

nected to the generator in series with 0.4-μF capacitance was 27.5 Vrms at 10 psig. Values obtained at 5, 10, 15, and 20 psig are shown in figure 3.

The same test procedure as above was repeated with the 450- and 500-turn coils. The capacitance was varied while the resistance was kept at 128 Ω. The coil with 450 turns required a 0.6-μF capacitance for maximum power output, and the coil with 500 turns required a 0.5-μF capacitance. The voltage output for either of these coils was lower than the one with 550 turns (see fig. 3).

From the above results the coil with 550 turns and No. 30 wire was selected for the generator to meet the required performance.

Although the high-power output is required from the fluidic generator only during rocket descent, a low-power output into a high-impedance load is needed during the entire flight to operate an electronic logic/timer circuit. To determine the generator power when operating into high-impedance loads, the voltage output was monitored over a 5- to 20-psig pressure range for a 10- and 100-kΩ load each in series with a 0.4-μF capacitor. The results are shown in figure 4. The voltage output for either load varies from 31 V at 5 psig to 59 V at 20 psig. The fluidic generator provides to the 10-kΩ load 93 mW at 5 psig, and 349 mW at 20 psig. It provides less power to the 100-kΩ load: 9.6 mW at 5 psig and 34.9 mW at 20 psig.

2.1 *Effect on Generator Output When Ogive Internal Volume is Reduced*

It has been proposed that, when this power supply is used with a proximity fuze, the fuze oscillator antenna and associated electronic circuits be located in the unoccupied space within the ogive around the generator resonator cavity. To determine what effect this can have on generator performance, an aluminum insert that simulates the volume to be occupied by the antenna electronics was made to fit around the resonator, thereby reducing the internal volume of the ogive. Figure 5 (p 10) shows the ogive inserts that were tested.

To compare performance with and without the aluminum inserts, data were taken first with an unchanged ogive referred to as "normal ogive," and then the same data were repeated using an aluminum insert within the ogive. This ogive is referred to as "ogive with reduced volume."

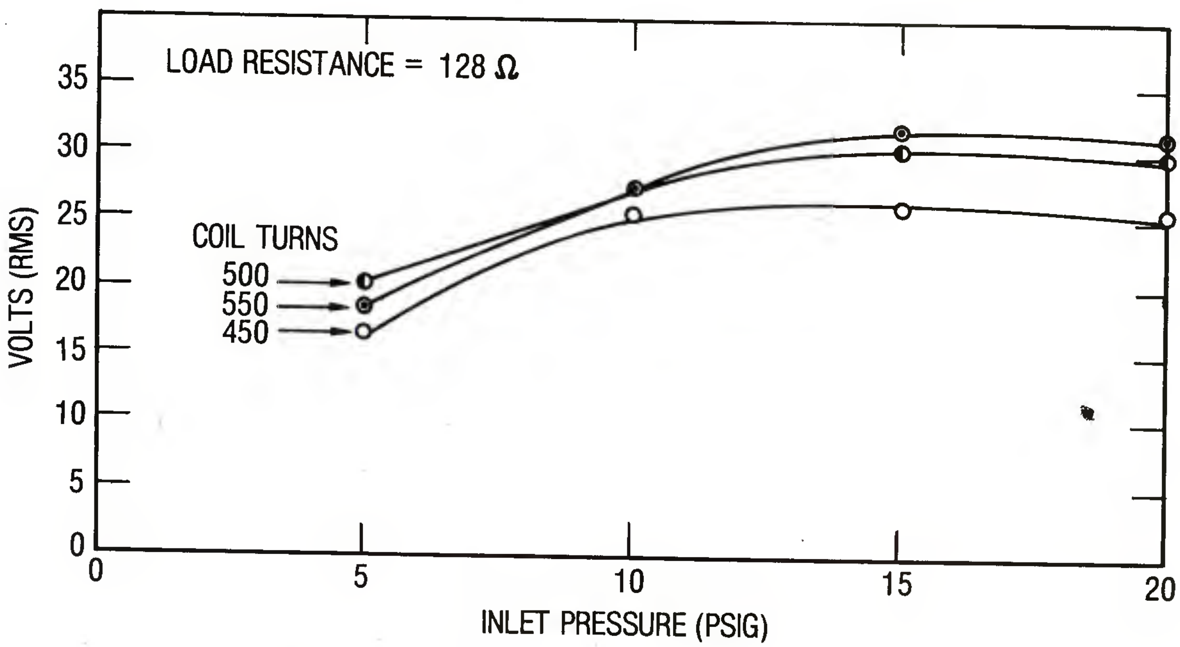

Figure 3. Effect of number of turns in coil on load voltage.

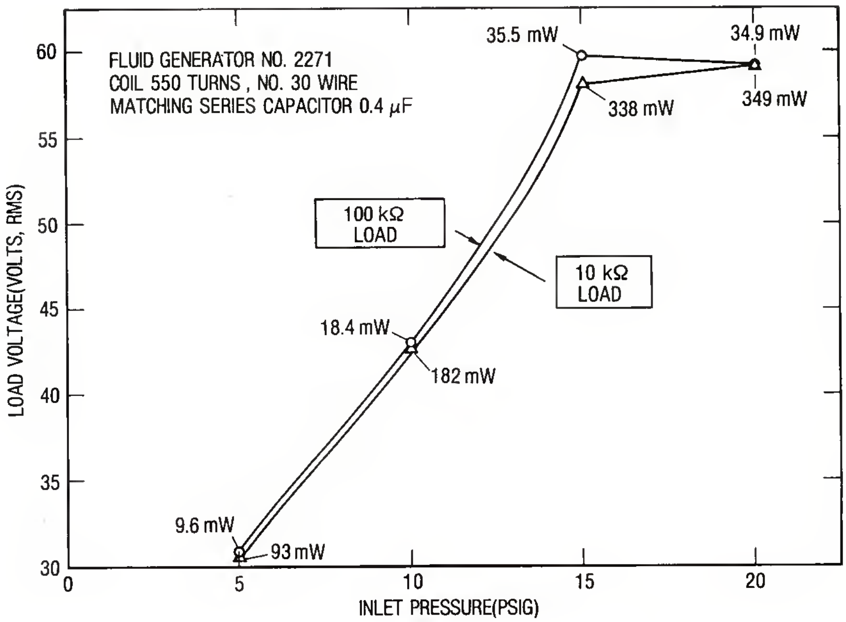

Figure 4. Fluidic generator performance at high load impedance.

The generator used with the normal ogive testing had a load circuit consisting of a 128-Ω resistor and 0.4-μF capacitor. When testing with the ogive with reduced volume, the load resistor was kept at 128 Ω but the capacitance was adjusted to achieve maximum generator output. A test of the normal ogive was made before each insert configuration was tested to insure that the generator performance had not changed.

Insert A of figure 5 caused a reduction of more than 50 percent in output voltage at all pressures (see fig. 6, p 11). It was found that by reducing the insert height and by increasing the inside diameter the loss of output voltage was reduced (see fig. 6). Finally the dimensions of insert B of figure 5 were selected because this configuration produced the least loss of output voltage for that configuration shape. (See the second curve from the top of fig. 6.)

Insert C of figure 5 was made to simulate an antenna along the outer perimeter of the ogive. Table 1 compares voltages obtained with the normal ogive volume to those obtained with the volume with the inserts B and C of figure 5. Note that the two inserts cause a reduction in voltage output of 11 to 12 percent at 10 psig. However, the output voltage at and above 10 psig does satisfy the required objective.

Table 1. Laboratory Performance of Generator

Pressure (psig)	Output voltage (Vac rms)		
	Normal ogive	Ogive with insert B	Ogive with insert C
5	19.5	18.0	17.3
10	30.0	26.4	26.6
15	33.9	33.4	33.0
20	32.6	34.0	32.4

2.2 *High-Pressure Test*

When this power supply is used in a rocket fuze it must operate at maximum inlet pressures of 125 psig (3000 ft/s burn-out velocity). The configuration with the normal ogive was tested to 125 psig and yielded at that pressure 27 Vrms across a 128-Ω load. A test with insert B of figure 5 yielded a voltage of 30.3 Vrms at 125-psig inlet pressure. A post-high-pressure test of the generator in the range from 5 to 20 psig assured

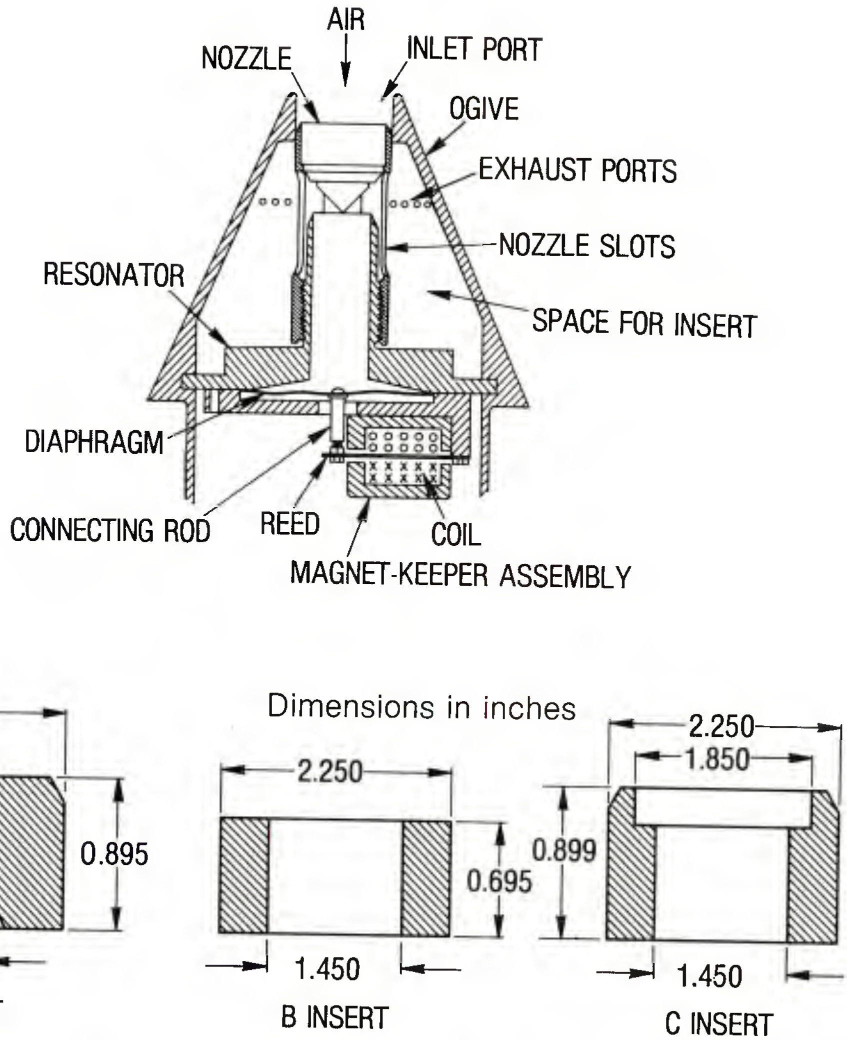

Figure 5. Ogive volume-reducing inserts.

that the generator was still operational and that its performance had not been affected by exposure to the high-pressure environment.

2.3 *Flight Profile High-Pressure Test*

Although the fluidic generator when used with a proximity fuze is required to operate at full power only during the last few seconds of flight, it must survive the pressures encountered throughout the flight. To evaluate its survivability in this environment, a test was devised to simulate the highest pressures likely to be experienced by the fluidic generator in a most severe trajectory flight. The pressure-time profile selected to simulate the severe flight conditions is shown in table 2.

The generator was tested in the ogive having insert C (fig. 5), and its output across a 128-Ω load (the power meter) in series with a 0.4-μF capacitor was monitored while the inlet pressures were adjusted manually to correspond to the profile in table 2. The output voltage was monitored throughout the simulated flight and it was at least 27 V (rms) above 12 psig. After the test the generator was inspected to assure that no damage was sustained by the reed, the connector, or the diaphragm. In conclusion, the generator experi-

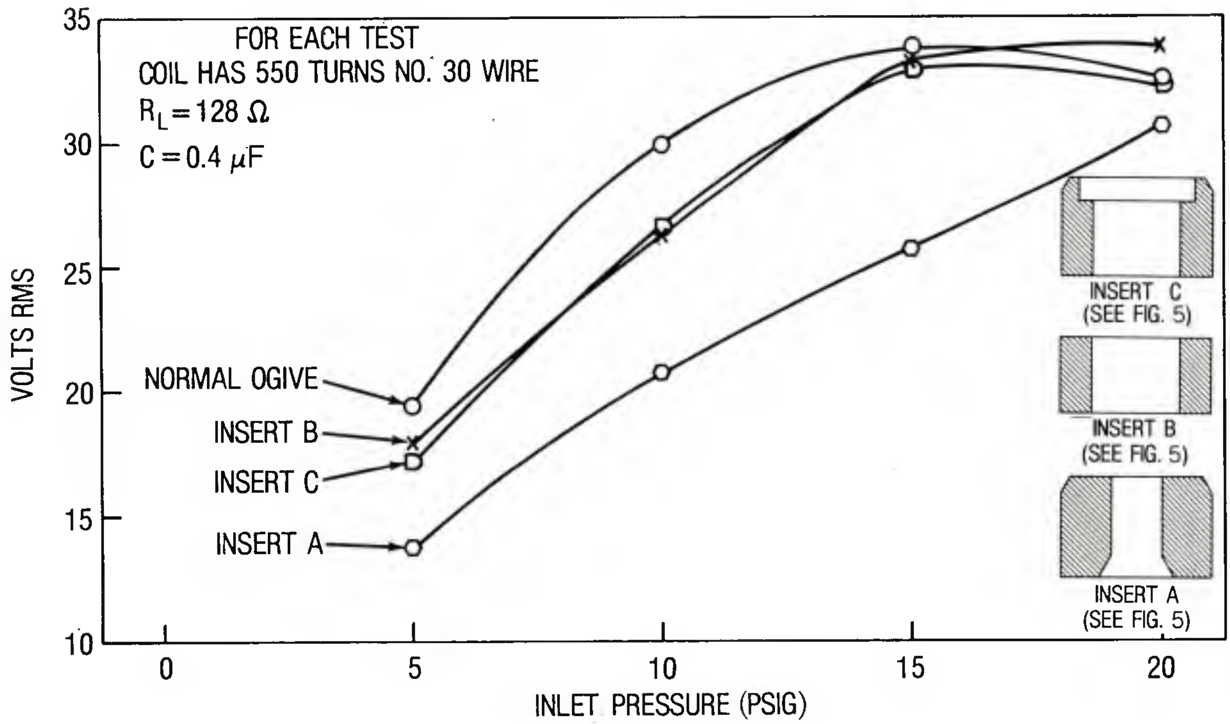

Figure 6. Comparison of normal ogive volume to ogive volume reduced by several inserts.

enced no loss in performance when tested in a pressure time profile that simulates the most severe flight environment.

The use of the 128-Ω load during the 38-s test was an overtest of the current-carrying capacity of the coil, since an actual rocket mission would require the 0.200-A level to be maintained only for the last 5 to 10 s of flight.

Table 2. Simulated Flight Profile

Time (s)	Inlet pressure (psig)
0	0
3	125
8	100
13	70
18	50
23	35
28	30
33	25
38	0

2.4 *High-Altitude Performance Simulation Test*

Although the fuze requires maximum power only just before arrival at the target, the generator is required to remain operational throughout the flight, including the apex, so that it can provide a charging voltage to capacitors that power a timer within the fuze. The apex portion of the trajectory is considered to be most severe on generator performance, in that air energy available for the generator is at a minimum. Three apex points from several possible flight trajectories were simulated in a high-altitude chamber. The chamber is evacuated to the ambient pressures at the specified altitude, and at that point an adjustable valve is used to control the air supplied to the fluidic generator. The air velocity and density are similar to values that occur in actual flight. Table 3 shows the fluidic generator output frequency and voltage obtained at the Mach numbers and altitudes that correspond to the selected trajectory points.

Table 3. High-Altitude Performance of Generator

Altitude (1000 ft)	Mach	Vrms	Frequency (Hz)
52	1.24	6.76	1823
65	1.3	3.96	1802
69	1.3	3.31	1796

From the table it can be seen that the generator is operational at the selected altitudes and Mach numbers. At least 3 V (rms) is obtained at Mach 1.3 and 69,000 ft (a worst-case trajectory point) with a 128-Ω load. This corresponds to a power level of 85 mW, which is sufficient to operate the CMOS timer/logic circuitry which requires less than 10 mW.

3. CONCLUSION

A fluidic generator that can generate sufficient power for a proximity fuze has been developed. The generator, a modification of the one used for the MLRS, produces 5 W at an inlet pressure of 10 psig and 7 W at 20 psig into a 120-Ω lead. To achieve the required design performance, a coil containing 550 turns of No. 30 wire was used. In addition, the volume around the resonator was filled with an aluminum insert to simulate the fuze transmitting antenna. It was determined that the insert reduced the voltage output by 11 to 12 percent at 10 psig. The reduced voltage still met the design objective.

The optimum generator design was tested at pressures of 125 psig and at expected high altitudes (50,000- and 69,000-ft flight conditions). In addition, laboratory simulated flight tests were conducted along a trajectory deemed worst case for this particular generator design. In all the above tests, the generator output performance met the required objectives.

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