ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

ROCKET-GRENADE EXPERIMENT FOR UPPER-ATMOSPHERE TEMPERATURE AND WINDS

<u>Quarterly Report</u>

for the period

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Submitted for the Project

by

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Department of Aeronautical Engineering

Project 2387

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ABSTRACT

A subcontract was let to National Northern for conducting blast-damage and other tests. A preliminary layout of the single-grenade structure was made. Models to be used in the damage tests were constructed. Instrumentation for the tests was designed and constructed. The literature was consulted for blast-damage data. Refinements to the finite-amplitude-propagation calculations were made. Work was started on programming data reduction for computers. Investigation of spin errors was continued.

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1. INTRODUCTION

This is the second in a series of quarterly reports on Contract No. DA-36-039 SC-64659 describing a research program, the primary purpose of which is to adapt the rocket-grenade experiment for use in the Arctic during the International Geophysical Year. The experiment was developed by the Signal Corps and used successfully in a series of flights at White Sands Proving Ground. For background material the reader is referred to the first Progress Report of the series.

A second purpose of the contract is a general investigation of problems relating to upper-air research.

2. SINGLE-GRENADE METHOD

The necessity for developing the grenade method into an all-weather experiment and three possible solutions to the problem were discussed in the previous report. Since the single-grenade-near-the-rocket method has the advantage of simplicity over the other two, and since its engineering feasibility is the least predictable, it was decided to place the major emphasis on establishing this feasibility. It is thought that if either the two-grenade or single-grenade-at-a-distance method is finally selected, the engineering problems may be solved with less preliminary experimental work.

2.1 GRENADE TESTS

Several commercial organizations and Picatinny Arsenal were approached with the problem of conducting tests to determine the explosive to be used in the grenades and the distance from the rocket at which the grenade can be detonated without damage. A subcontract was let to National Northern Technical Division of National Fireworks Ordnance Corporation, West Hanover, Massachusetts. Technical consultation service will be provided by Picatinny Arsenal, Dover, New Jersey. The subcontract covers experimental work only.

Production of the grenade design resulting from the tests will be handled separately. The work statement of the subcontract follows:

EXHIBIT A - STATEMENT OF WORK

Subcontractor shall, during the period commencing on 1 November 1955 and ending on 31 December 1955, conduct rocket-damage tests with explosive charges and develop a complete flash-and-sound unit as outlined below, and supply reproducible production drawings with specifications for complete construction and assembly of flash-and-sound units.

Scope of Tests:

The sequence of tests shall be as follows:

(1) Determine by use of Signal Corps Sound-Ranging Microphones (equipment and operators furnished by Contractor) and by blast-pressure gauges the relative effectiveness of 4-pound charges on Comp. A3 (with 20 per cent aluminum), MOX, and any other likely explosive in uncased charges relative to Comp. A3 (with 20 per cent aluminum) in a cased charge similar to that used in previous Grenade Experiment (specifications of previous cased charges to be supplied by Michigan).

(For an adequate comparison there should be three samples of each explosive used in this test. If A, B, and C represent three different compositions, the charges should be exploded in a sequence like A, B, C - A, B, C - A, B, C. The charges should be exploded at the same point in space, and the interval between successive explosions should be kept to a minimum (say 1 minute) - to minimize effects of variations in meteorological parameters.)

(2) Determine from simulated 90,000-foot altitude tests at temperatures from +30 to -40°C the relative effectiveness of MOX, RDX, and any of the other common explosives relative to Comp. A3 (with 20 per cent aluminum) for the flash-and-sound units.

(3) After evaluation of tests (1) and (2), with Michigan's consultation, determine the closest distance that a 4-pound charge may be exploded without appreciable damage to rocket structures supplied, also without detonation of simulated flash-and-sound units in the structure. For this test, the explosive selected from (1) and (2) above, (or Comp. A3) shall be used, bare or thinly cased, the experiment to be conducted at atmospheric pressure.

(4) If the distance in (3) above is found to exceed 15 feet, recommendations shall be made by the Subcontractor to Michigan as to what changes will be necessary in the rocket structure to permit exploding the 4-pound charges within 15 feet of the forward end of the rocket. (The preferred location of exploding the flash-and-sound unit is within 10 feet of the forward end of the rocket.)

(5) Assuming the successful completion of the above feasibility tests, Subcontractor shall develop a flash-and-sound unit of the following general specifications:

(a) Each complete package shall consist of two electric squibs (for igniting propulsion charge), propulsion charge, lanyard-operated ignition device (consisting of two firing pins, two igniters, and single booster), the explosive charge, and an emergency self-destructive feature. It is proposed that the ignition device be located near the center of the explosive charge to minimize formation of shrapnel.

(b) Each complete package shall be encased in a waterproof cylindrical container (such as the ejectable flare container), hermetically sealed to retain approximately 1 atmosphere. It is understood that the main charge which is ejected before detonation will not have a metal case and that the number and mass of parts for lanyard triggering will be kept to the minimum consistent with reliable operation.

(c) Each unit shall fit into the rocket structure and be retained there. The final design of this structure and retention mechanism will result from a mutual design effort of Michigan, Picatinny Arsenal, and Subcontractor. The propulsion charge shall eject the explosive charge at a speed of 50 to 200 feet per second and such that the charge will be detonated when the lanyard is taut and the charge is at a distance of $x \pm 1$ feet (x maximum = 15).

(d) Simulated ground tests of each component shall be made to ensure reliable operation of the units over a temperature range -40 to +30°C, and altitude of 90,000 feet.

(e) The flash-and-sound units shall be capable of withstanding the following tests:

(i) 40-Foot Safe Drop Test - MIL-STD-302.
(ii) Jolt Test - MIL-STD-300.
(iii) Transportation Vibration Test - MIL-STD-303.
(iv) Cyclic Temperature and Humidity Test - MIL-STD-304.
(v) Appropriate vibration tests at a temperature -20°F, or colder, to ensure that the explosive charge will

not be chipped or fractured during normal handling in the Arctic and by the vibration of the rocket during launching.

(f) The operation of the unit must not be impaired by being stored at temperatures as low as -50°F for periods of two weeks.

(g) The complete flash-and-sound unit shall have a maximum diameter of 3 inches and a maximum length of 24 inches. Optimum O.D. is 2-1/2 inches.

(h) In the event that the explosive charge is not detonated for any reason, means must be provided for the destruction of this charge within 10 days of rocket launching.

(6) Subcontractor shall advise Michigan one week prior to conducting the major tests so that Michigan and/or representatives of the Government may witness the tests.

In the tests, it is desired to test a structure as much like the final structure as possible. Some consideration was therefore given to the design of the single-grenade rocket. It appears that a group of long, slender grenades arranged with their axes parallel to the rocket axis will give the best volume efficiency while presenting the least area to the grenade blast, which will occur forward of the rocket. A tentative layout of this arrangement is seen in Fig. 1. Twelve or more grenades will be located in individual firing tubes. During the high-drag, high-heating part of the ascent, the grenades will be covered by a cone which will be ejected when the drag becomes small. The grenades will then be ejected by propulsive charges, detonated in sequence by a timer. It is planned to ignite the explosive charges by pins actuated by lanyards attached to the rocket. As in previous grenade rockets, the time of the grenade burst will be detected by a photocell. In this case, the single-channel DOVAP telemeter will transmit the photocell signals.

Having decided on the general layout of the instrumentation, a model was constructed to be used in the blast-damage tests. A grenade section, an instrument section, and a section simulating the tank section of the Aerobee were constructed. These are shown in Figs. 2 and 3. Part A is a section 15 inches in diameter and 42 inches long, which will be filled with sand to simulate the Aerobee tank section. Part B will be the forward end of the rocket for the initial blast-damage tests. Parts A and B will be joined together and raised to about 15 feet above the ground. Successive 4-pound charges will be exploded at decreasing distances until damage occurs. Part C will replace B for similar tests. Part D will then replace B and C, and final tests will be made during which light intensities and accelerations of components will be measured.

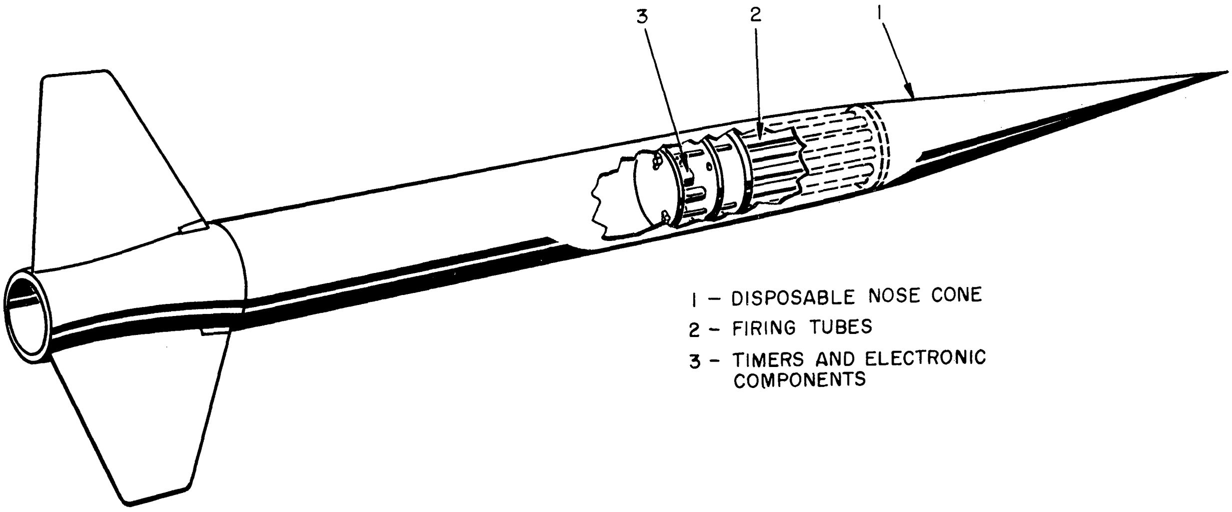

Fig. 1. Proposed layout of single-grenade Aerobee.

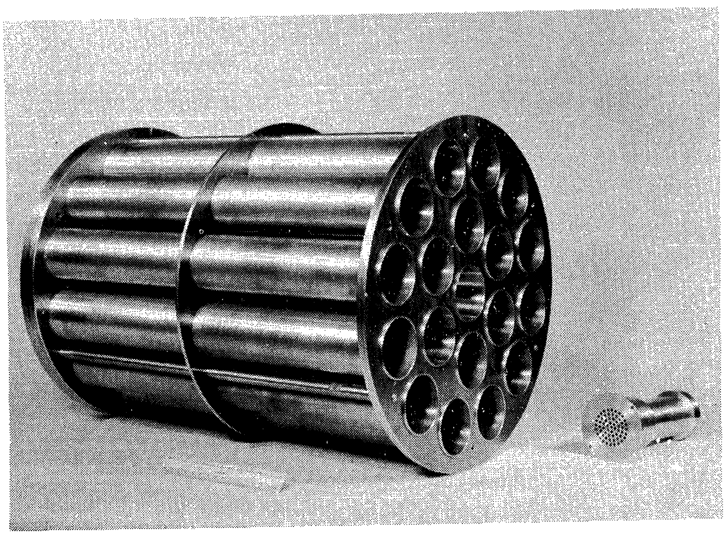

Fig. 2. Grenade tube structure.

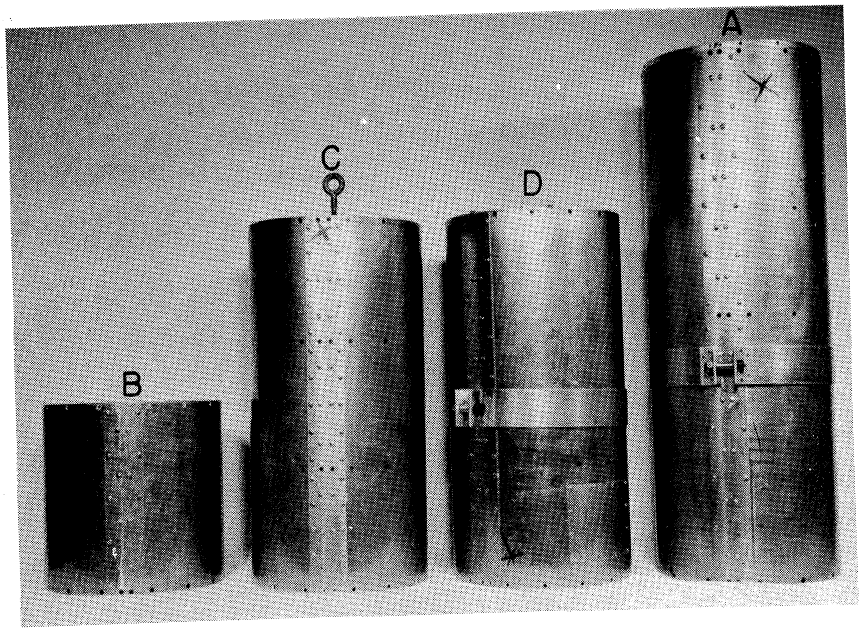

Fig. 3. Rocket test sections.

2.2 GRENADE TEST INSTRUMENTATION

Detonation of grenades in relatively close proximity to the rocket may result in electronic equipment failures even in the absence of objectionable rocket damage. Two methods of checking the probability of such a failure are in preparation.

The first method involves the quantitative determination of the vibration accelerations imparted to the electronic-instrumentation mounting plate by the grenade detonation. The second method consists of qualitatively observing the damage and change of operating characteristics, if any, which occur in representative electronic instrumentation mounted in place during the tests.

Measurement of the accelerations experienced by the mounting plate will provide valuable data upon which laboratory preflight tests can be based.

Since the phenomenon is transient in nature, high frequency response is necessary, while response to steady-state conditions is neither necessary nor desirable. A self-generating crystal-type gage most closely fulfills these requirements, and the Massa Model No. M-191 was selected (Fig. 4). Pertinent specifications of this unit are as follows:

Sensitivity - 0.026 volts/g (preamplifier output),
Range - 1000 g,
Frequency range - 10-30,000 cycles, and
Sensitivity at perpendicular axis - down 50 db minimum.

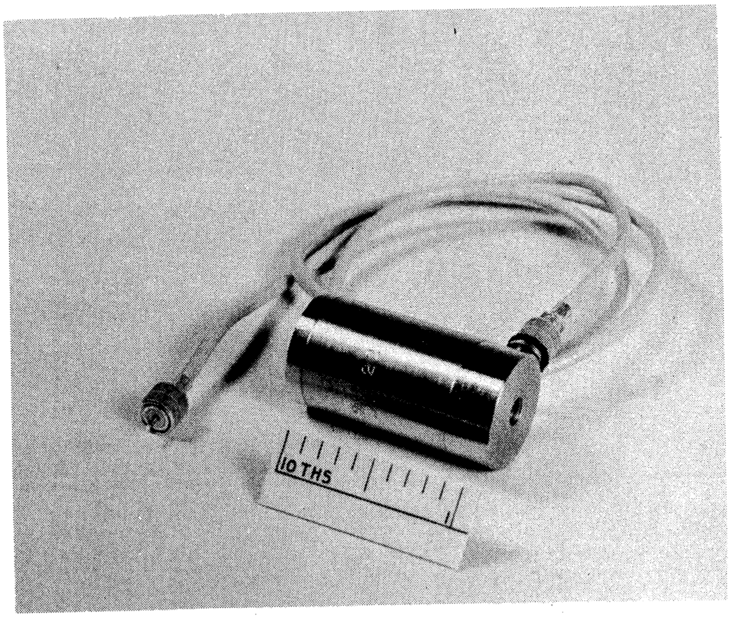

Fig. 4. Accelerometer

Recording and observation of the accelerometer information must be at a remote point, due to the nature of the test. To maintain its sensitivity, the accelerometer must be uncoupled from its long signal cable. Accordingly, the cathode-follower preamplifier circuit of Fig. 5, patterned after a Massa design, is under construction. Calculated performance characteristics are as follows:

Input resistance - 135 megohms,
Output resistance - 480 ohms, and
Voltage gain - 0.92.

Assuming a cable length of 200 feet, response will be down 3 db at approximately 55 kc.

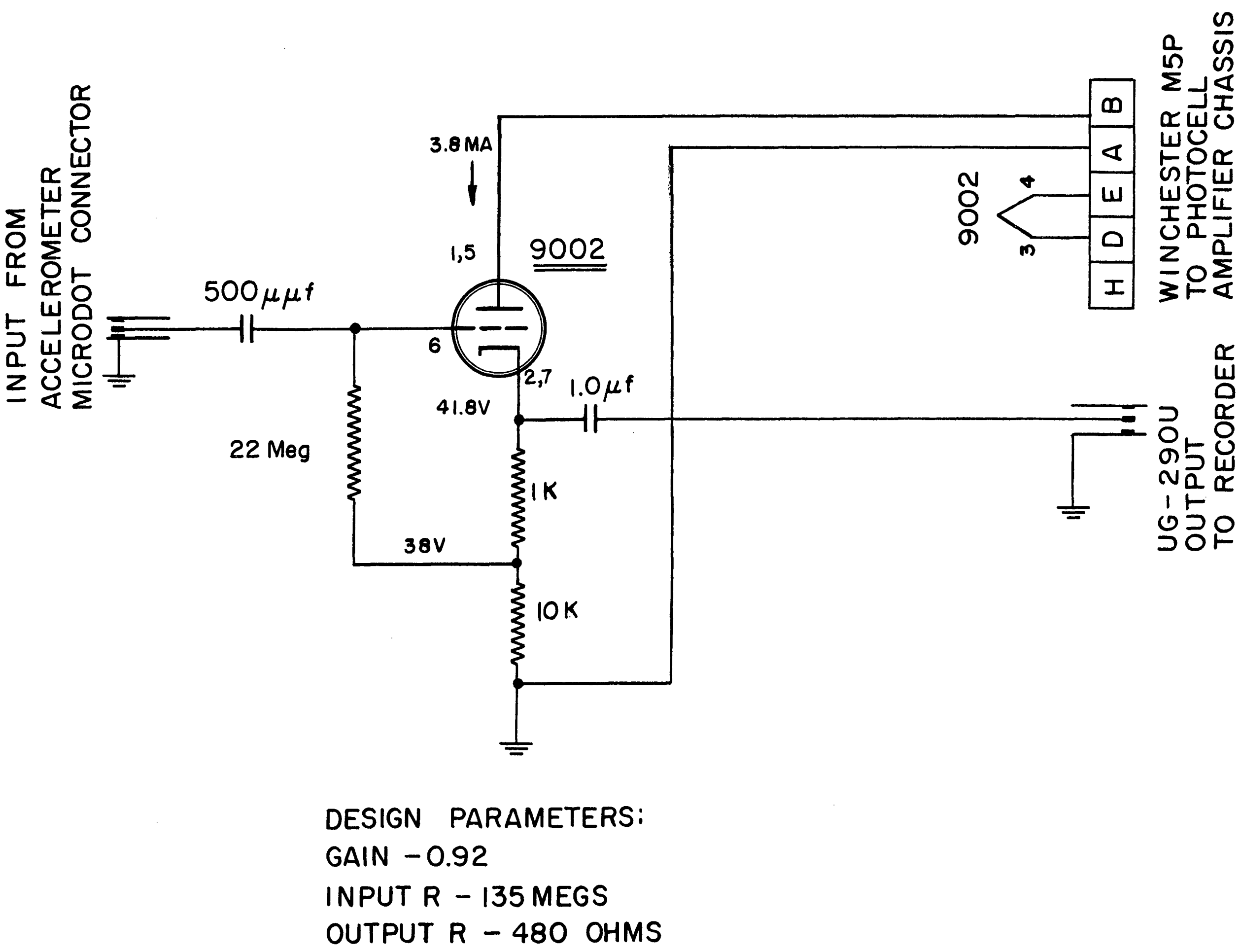

Fig. 5. Preamplifier circuit diagram.

Microphonic outputs from this unit would appear superimposed on the acceleration information. Shock mounting will be employed to eliminate this source of error.

To match the frequency response of the accelerometer, a single-sweep oscilloscope display and camera recording will be utilized. Accelerations of the order of 0.5 g or less should be easily detectable.

Perhaps the most vulnerable piece of electronic equipment aboard the rocket will be the phototube flash detector. A unit, similar to the anticipated final design, will be included in these tests. Operation of this unit during the test will provide information on the flash signals as a valuable by-product.

Because of its small size, end-type sensitivity, and spectral response, the 1P42 vacuum phototube was selected. In addition to the increased mechanical strength which generally accompanies reduction in size, a small phototube is less likely to be damaged because of the smaller target it presents. A high-vacuum photocell was selected because of its higher frequency response and better ability to withstand overloads as compared to a gas-type phototube.

The amplifier of Fig. 6, currently under construction, will perform the dual function of converting the small, high-impedance photocell signals to a useful level at a recording oscilloscope 200 feet away and give qualitative information on the survival of electronic equipment subjected to the grenade detonation. This can be accomplished because of the time lag between the flash information and the arrival of the shock wave.

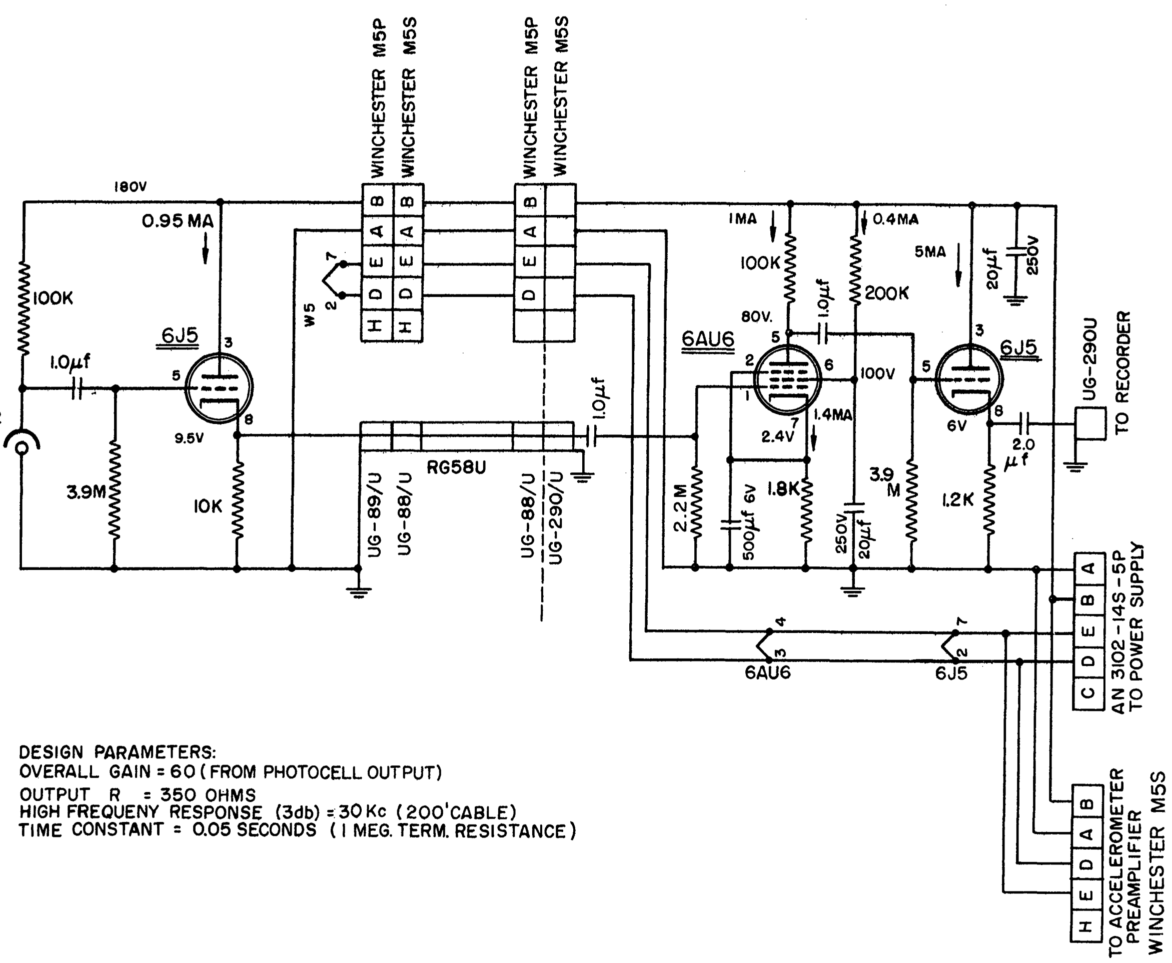

Fig. 6. Photocell-flash-detector test circuit.

Based on the published phototube sensitivity and a peak grenade flash intensity of 1.3×10^6 candlepower reported in SCEL Engineering Report E-1140, a peak phototube current of nearly 1 microampere is expected from a grenade flash 50 feet distant when the photocell is located behind its protective shield. Thus a signal of 0.1 volt will be developed across the 100-k load resistor. To maintain frequency response to 50 kc, the first cathode-follower stage is mounted directly behind the photocell (Fig. 7), and the remainder of the amplifier is mounted on the electronic-instrumentation plate. No attempt at ruggedization or shock mounting is made anywhere, so the unit will be subjected to conditions at least as severe as can be expected in flight.

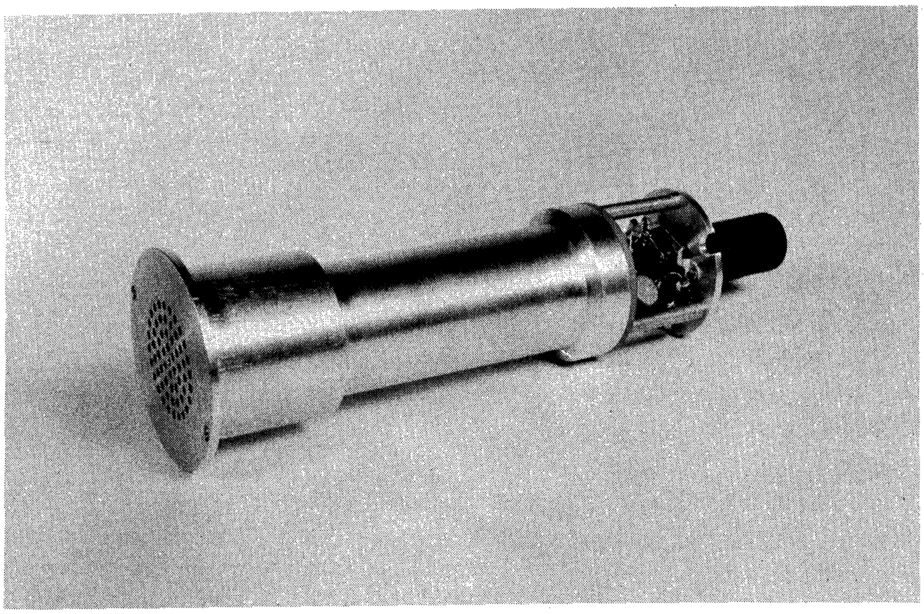

Fig. 7. Photocell holder and preamplifier.

A low output impedance of about 350 ohms is provided by the cathode follower so that overall frequency response to about 30 kc with a 200-foot cable will be realized. A long time constant of about 0.05 second is used to obtain information on the burning of the aluminum metal as well as the initial flash. An overall gain of about 60 will provide a peak signal of 6 volts at the recording instrument when the detonation is 50 feet distant. Attenuation of signal as the detonation is brought closer will be accomplished by masking an appropriate number of holes in the photocell shield with opaque photographic paper.

As in the case of the accelerometer, recording will be accomplished by means of an oscilloscope and camera. A single unit may be utilized to gather light information at the larger detonation distances, and acceleration information when the grenade is brought in closer. Qualitative operation of the photocell circuit will be checked following each test.

2.3 EVALUATION

Continuing the evaluation of the single-grenade method prior to the experiments to be undertaken by National Northern, data were sought in the technical literature about the effects of exploding 4 pounds of high explosives at various small distances from the rocket.

It is expected that at 15 feet from the explosion, the peak excess pressure for free-propagation conditions will be approximately 0.5 atm and the positive-pressure impulse approximately 0.5 millisecond atm (the duration of positive pressure will be 3 milliseconds). This applies to an explosion of TNT, while for some more powerful explosives (such as compositions TNT: RDX: Al) the corresponding values might be 1.2 atm and 1.2 milliseconds atm.

The face of the rocket with the grenade tubes represents a rigid wall approximately perpendicular to the path of propagation of the shock wave. The reflection that will occur at this surface will increase the peak overpressure by a factor of from 2 to 3.

At the distance of 10-15 feet for the 4-pound explosion, the pressure wave falls definitely outside Taylor's strong-blast solution[1] according to which the peak pressure is independent of the ambient pressure. The excess pressure and the impulse will thus be considerably smaller if the explosion takes place at high altitude, at densities lower than the ground atmosphere. This can be seen from the experimental curves shown in Fig. 8 reproduced from Schardin.[2] Because of this fact, if the rocket is not damaged in the experiments at ground level, there is a considerable safety margin in exploding the grenade at the same distance at high altitudes. No calculations were made of the probable damage effect of the estimated pressures. However, it is felt that the estimated pressures are small enough so that there is a good chance that the structure and grenades will survive the tests.

References were also found in the literature relating to the use of uncased cast explosive charges. Their use apparently is common. Grime and Sheard[3] report relative pressures created by uncased and steel-cased charges

[1]G. I. Taylor, "The Formation of a Blast Wave by a Very Intense Explosion," Proc. Roy. Soc. (London), A201, 159 (1950).

[2]Hubert Schardin, "Measurement of Spherical Shock Waves," Comm. on Pure and Appl. Math., Vol. VII, No. 1, pp. 223-243 (Feb. 1954).

[3]G. Grime and H. Sheard, "The Experimental Study of the Blast from Bombs and Bare Charges," Proc. Roy. Soc. (London), A187, 357-380 (Nov. 1946).

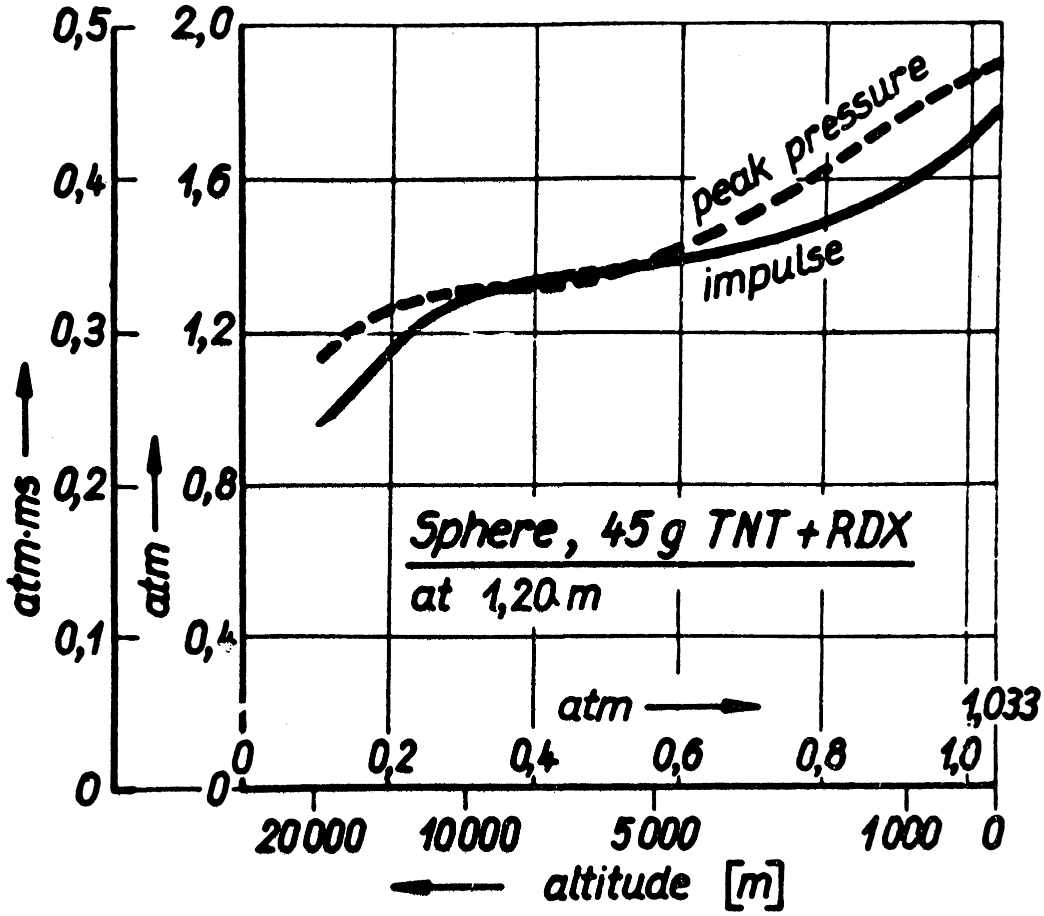

Fig. 8. Peak pressure and impulse vs outside air pressure (Schardin).

ranging in weight from 3 to 2000 pounds. Their experiments showed that uncased charges yield higher pressure impulses than charges of equal weight in steel cases. Figure 9 from Reference 3 shows positive impulses obtained from a series of 8-1/2-pound charges of 60/40 RDX and TNT, cased and uncased.

3. FINITE PROPAGATION

The effect of finite propagation on the systematic accuracy of the grenade experiment has been further investigated. In the calculations of the previous report, the energy density at the front of the shock wave was assumed to vary as $1/R^2$. The energy density of the shock wave can be expressed as

$$\epsilon = \frac{P^2}{\rho_0 C^2} = \left(\frac{P}{P_0}\right)^2 \frac{P_0^{\ 2}}{\rho_0 C^2} = \frac{\pi^2 P_0}{\gamma} ,$$

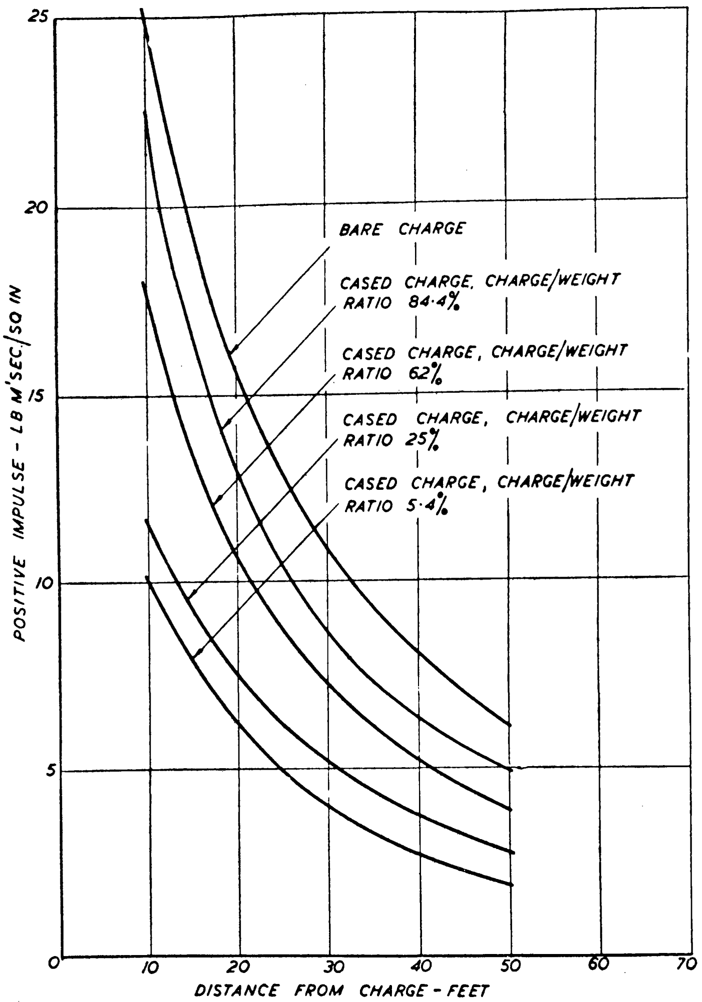

Fig. 9. Positive impulses from 60/40 RDX/TNT charges of various charge/weight ratios (Grime and Sheard).

where P is the excess pressure, P_o is the ambient pressure, $\pi = P/P_o$, the relative overpressure, ρ_o is the ambient density, and C is the ambient velocity of sound. Thus, at equal distances from an explosion, the relative overpressure is inversely proportional to the square root of the pressure.[4]

$$\pi = \left(\frac{\gamma\varepsilon}{P_o}\right)^{1/2} .$$

In the present calculations, the dissipation of the energy in the regions close to the explosion and the spreading out of the wave throughout its downward travel, neglected previously, have been taken into consideration

[4]This approach to the problem of propagation through the atmosphere at large distances from the explosion was first suggested by E. Wiechert in "Bemerkungen über die anormale Schallausbreitung in der Luft," Nachrichten der Gesellschaft der Wissenschaften zu Göttingen, 49-69 (1925).

in computing the amplitudes. As anticipated, these more exact computations resulted in a considerably smaller maximum possible error.

The calculations are largely based on a dimensionless solution of spherical blast waves by H. L. Brode.[5] A particular wave form, shown in Fig. 10, has been used as the starting point of the calculations. This wave form occurs at the distance $R_0 = 3.63(E/P_0)^{1/3}$ and at the time $T_0 = (3/C)(E/P_0)^{1/3}$, where E is the energy of the detonation. The finite-amplitude-propagation effect (the distance from the center of the explosion minus the distance that a sound wave would cover in the same interval of time) at this stage amounts to $R_0 - T_0C = (3.63 - 3)(E/P_0)^{1/3} = .63(E/P_0)^{1/3}$.

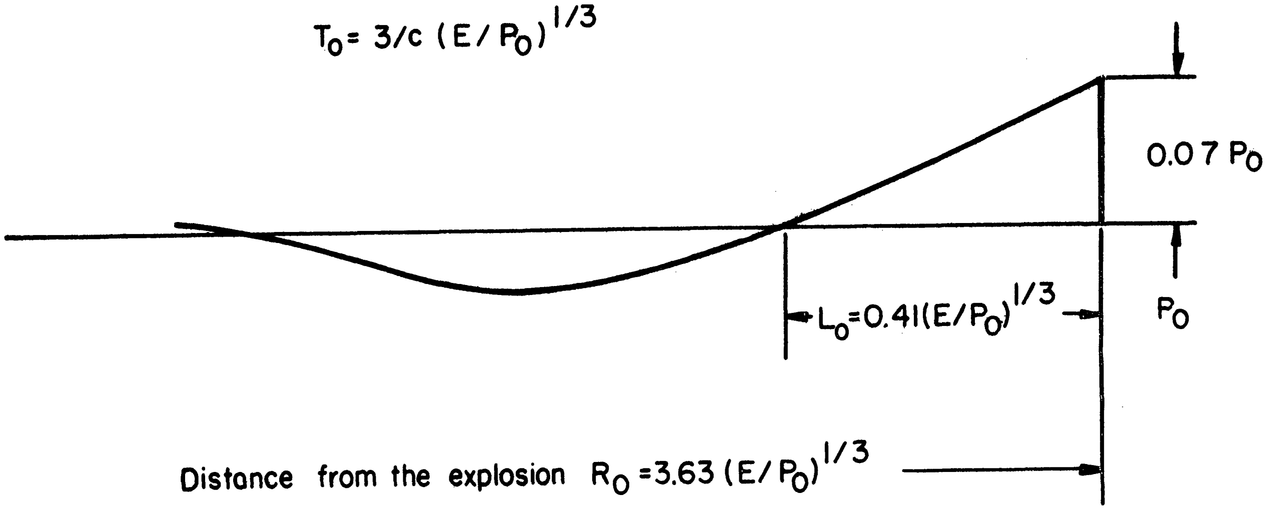

Fig. 10. Pressure wave form.

The energy of the explosion of the grenade was taken as 1.25×10^6 kgm, corresponding to the assumed specific energy of 1650 cal/g for the explosive. The actual value of R_0 is thus 915 m for an explosion at the altitude of 83 km ($P_0 = 8.3$ microbars); the length L of the positive overpressure region is 103 m; and the finite-amplitude-propagation effect is 157 m.

Brode's solution takes into account the viscosity of the air. Thus up to the distance R_0, the attenuation of energy is not neglected.

For the propagation from R_0 on, the total energy of the wave is assumed constant and equal to

[5] H. L. Brode, "Numerical Solutions of Spherical Blast Waves," J. Appl. Phys., 26, 766 (June 1955).

$$E_W = \frac{\pi R^2 \pi^2 L\ P_o}{\gamma},$$

where R is the distance of the explosion, L the length of positive overpressure region, γ the ratio of the specific heats.[6] The atmosphere was assumed isothermic with P_o, therefore, changing exponentially with altitude.

The finite-amplitude-propagation effect (the lengthening in L) is computed, as previously, by means of the equation for the shock velocity

$$V = C\left(1 + \frac{\gamma + 1}{2\gamma}\pi\right)^{1/2} = C\left(1 + \frac{\gamma + 1}{4\gamma}\pi\right)$$

which is based on the Hugeniot-Rankine equations and the equation of state of the perfect gas. It is actually rather doubtful whether this equation for the velocity of propagation is valid under the conditions of extreme attenuation of high frequencies,[7] but it ought to provide a reasonable estimate of the maximum possible finite-propagation effect.

The difference in finite-amplitude-propagation effects between an explosion at 83 km and at 77 km is approximately 48 m. Thus, the determination of sound velocity based on this experiment over the 6-km vertical distance between 77 km and 83 km would be 48/6000 = 0.008 too high. The average temperature in the layer, computed from the formula $T = C^2/R$ (where R is the gas constant for air), would be 1.6 percent, or approximately 3.5° too high. This compares with the maximum expected error of 12° in the previous calculations.

4. DATA REDUCTION

It is planned to reduce as much of the grenade-experiment data by computer and routine methods as may be done without loss of accuracy. Trajectories from Michigan sphere flights which carried DOVAP will be used as models to check various techniques because complete DOVAP cycle counts, spin corrections, and trajectories exist for these flights.

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[6]H. A. Bethe, et al., "Shock Hydrodynamics and Blast Waves," AECD-2860, 59, Eq. 367, (Oct. 1944).

[7]E. Schrödinger, "Zur Akustik der Atmosphäre," Physikalishe Zeit., 18, 445, (1917).

The calculation of trajectories from corrected DOVAP cycle counts has already been programmed for digital computers, both at BRL (ORDVAC and ENIAC) and at Michigan (MIDAC). The trajectory for SC-31 was computed on both ORDVAC and MIDAC, and excellent agreement was obtained. Recent changes in the MIDAC necessitated reprogramming the DOVAP computation, which was done.

SC-31 was also used in some work on spin correction. The BRL technique for spin correction is as follows: take one-half the difference between the cycle counts from the receiver with the left-hand polarized antenna and the counts from the receiver with the right-hand polarized antenna, and either subtract it from the lower of the two counts or add to the higher of the two counts consistent with:

(a) the direction of spin at the time,
(b) the geometry of the trajectory, and
(c) the smoothness of the result.

Step (c), smoothing, is accomplished by adjusting the counts so that second-order differences vary smoothly while keeping the total count nearly the same as the total raw count. An alternate method was used at Michigan on SC-31 as follows: the one-half difference in cycle counts was added or subtracted so as to produce the smoothest accelerations. This is consistent with the physical situation. The differences in the two methods are being compared on SC-31.

It appears that the Michigan method, which affected less than 10 percent of the points, was quicker, resulted in the same average accelerations and velocities (and densities), but caused minor changes in some individual velocities and accelerations as well as a maximum error of 200 feet in position. Because of the last effect, the BRL method will be used on the grenade data since positional accuracy is of primary importance.

It is planned to purchase a cycle-counting device for counting DOVAP cycles at Michigan on the grenade shoots. A visit was made to Ballistic Research Laboratories to examine a new synchronous motor or "Putnam" device. In this counter, the DOVAP cycles are played back at a variable speed such as to generate a signal which drives a synchronous motor at its synchronous speed. The shaft position of the motor is measured to give cycle counts. An earlier instrument is the "stroboscopic" film reader. In this device, a slotted wheel projects an optical line image on the moving image of the Doppler cycles. The operator keeps the line images moving in synchronism with the cycle images. A counter then counts shaft position of the slotted wheel as a function of uniform time signals on the film. It appears that either of these devices would serve our purposes. An evaluation will be made on the basis of cost and operation, and one of the counters will be purchased.

5. LABORATORIES VISITED

The following places were visited during the course of the work:

Ballistic Research Laboratories
Evans Signal Laboratory
Hercules Powder Company
National Fireworks Ordnance Corporation
Picatinny Arsenal.

6. FUTURE PROGRAM

The tests at National Northern will be carried out. Further consideration will be given to the mechanical designs of both one- and two-grenade rockets. The work on finite propagation will be terminated until high-fidelity sound-ranging records are obtained. Work will start on programming the sound-ranging data on rocket-trajectory data for reduction to temperature and winds on MIDAC.

7. ACKNOWLEDGEMENT

Thanks are due the Meteorological Branch, Evans Signal Laboratory, for cooperation and financial support.