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A STUDY OF WIRE–DEPLOYING DEVICES DESIGNED TO TRIGGER LIGHTNING

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SUMMARY

Methods were explored for deploying wire from rotating gun-launched bobbins and from nonrotating rocket-launched bobbins as a research tool in the study of atmospheric electricity and as a possible means for reducing lightning hazard to tall rockets during fueling and during ascent from the launch pad through storm clouds that may be in the area. The objective of the program was to develop a device that would deploy approximately 1 mile of steel wire (0.005 to 0.008 in. diameter) in one piece along a trajectory through the atmosphere at a velocity of 500 ft/sec or greater. Possible trajectories should include those from the vertical to one with an apogee of about 1000 ft. It should be possible to control the beginning of wire deployment so that it would start at the launch site or about 1/2 mile from the launch site. No consideration was given to features that would soften the impact of the remains of the round on the ground, e.g., deployment of a parachute or dispersal of the debris. Since the required length of wire would have a large drag if drawn through the air at the velocities desired, it was felt to be necessary to deploy the wire from the projectile so that it was nearly stationary relative to the air.

In brief, the gun-launched devices were made to function satisfactorily so that they met most of the objectives; however, only partial success was achieved in one case on the rocket-launched devices. The following article summarizes the development program on the wire-deploying projectiles that were studied.

INTRODUCTION

A brief review of both the means and reasons for deploying long lengths of fine wire will be given in this section. Since past efforts to dispense wire or rope over distances of the order of 1 mile are quite limited, that aspect will be covered first.

Line-throwing devices have been used by the U.S. Coast Guard for some time for rescue and salvage of vessels and on occasion to assist in setting up communication systems. In one design, a sporting rifle is used to fire a 13 or 15 ounce weight which tows a nylon line from a cannister under the barrel over distances up to 600 yards. They still on occasion also use their historic line-throwing shore cannon to propel a 3-lb weight and large line 600 to 1000 yards. The 50-lb cannon recoils 25 to 30 ft. Somewhat similar to these devices is a line-throwing mortar [*Harvey et al.*, 1967] used by Dr. E. A. Lewis and his group at the Upper Atmosphere Physics Laboratory at AFCRL, Bedford, Mass. The mortar shell serves as propulsion and weight to pull an 0.008 in. diam. steel wire aloft (~85°) to altitudes up to 6000 ft from a cannister on the ground with a 3 in. diam. bakelite core. Attempts were made to trigger lightning with the device but conditions over the launch site were never intense enough for initiation of a stroke by the vertically deployed wire.

Another technique for deploying wire vertically to draw lightning to a desired test site was developed by the Lightning and Transients Research Institute [*Newman et al.*, 1967*a*, *b*]. A small Coast Guard rocket is used to tow a steel wire aloft from a cannister on board a metal ship off the Florida coast. About 600 to 1000 ft of fine wire are deployed toward a cloud in about 1 second. The lightning follows the spiral shape of the wire back to the ship [*Newman et al.*, 1967*a*] so that measurements can be made of the characteristics of the stroke. These experiments demonstrated the feasibility and practicality for drawing lightning strokes from electrified clouds to a desired location. The deployed wire serves only as a trigger to initiate a lightning stroke. The discharge process begins with an initial surge of current along the wire which vaporizes and ionizes the metal wire and some of the surrounding air. The substantial current path thus provided conducts the remainder and largest part of the electric charge in the discharge. When the current falls, the ionized channel cools and the charge transfer process is completed.

Resistance of the air on long lengths of wire being towed from a container on the ground (see, e.g., *Payne*, 1970) prompted consideration of means for deploying the wire from the towing vehicle. This permits longer lengths of wire and higher speeds because the dispensed wire is then nearly stationary relative to the air and the only force it experiences is that required to take it off the bobbin and bring it to rest relative to the air (i.e., the so-called deployment force). The effectiveness of this concept is demonstrated by a device developed by Avco Space Systems Division at Wilmington, Mass., for deploying long lengths of metalized nylon as radar chaff. Although the breaking strength of the filament is very low, it is dispensed in one piece at speeds around 50 ft/sec by blowing the line off the end of a bobbin with a Freon jet. In another design, M. B. Associates of San Ramon, California, deploy about 200 ft of 0.002 in. diam. aluminum wire from the outside of a rotating projectile fired from a 45 caliber gun. The wire is spun off fast enough so that there is negligible deployment force on the projectile and wire.

Since the drag on a wire being pulled through water is even higher than through air, Vitro Laboratories of Silver Spring, Maryland, deploy wire from both a ship and a torpedo to guide the weapon to target. The wire is deployed from the inside of nonrotating bobbins. Several rocket-propelled missiles that use wires to transmit guiding signals have also been developed. Probably the highest performance of the wire-deploying devices used with these craft is the one for the TOW missile developed by Hughes Aircraft Co. at Tucson, Arizona. It deploys 0.005 in. diam. steel wires from two nonrotating slightly tapered bobbins at speeds up to 1350 ft/sec over horizontal distances up to about 2 miles. Much of the information and technology used by the Ames Research Center in the tests described in this article were given to us by David S. Fox and his group at Hughes, saving considerable time and false trials on our part. The effort at Ames was directed at extending the Hughes technology to a low-cost device adaptable to existing propulsion equipment and capable of launching from vertical to nearly horizontal directions. These requirements were placed on the device because the intent was to use it to study atmospheric electricity, thereby making it necessary to be able to launch in any direction and at modest cost. Our work was initially motivated by a study of the possibility that atmospheric vortices such as waterspouts and tornadoes might be identified, controlled, or modified by electricity in the parent cloud. Since measurements made from aircraft indicated that this could occur at most only on a random basis [*Rossow*, 1970], the wire-deploying study was directed at obtaining a device to trigger lightning for research and protective purposes.

Since the purpose of the deployed wire is to initiate lightning, design consideration should be given to the nature of lightning and to various methods for generating strokes. Although natural lightning has been observed and studied for some time, a systematic investigation of it with sophisticated instruments is relatively recent. A nice historical account from the layman point of view is given in a book by *Viemeister* [1961]. Books published of the papers presented at conferences on atmospheric electricity [*Smith*, 1958; *Coroniti*, 1965; *Coroniti and Hughes*, 1969; *Staff of Air Force Avionics Laboratory and SAE*, 1969] provide an excellent survey of the more technical aspects. Included there and elsewhere are descriptions of strikes to tall objects such as trees [e.g., *Orville*, 1968], buildings, towers, etc. [*Viemeister*, 1961]. Strokes to such objects are quite common even though they are stationary, but the probability of a strike to a single tall object in one year is remote so that something must be done to enhance the drawing power of the object if research is to be carried out at a reasonable rate. It has been found that the likelihood of a strike is increased considerably by thrusting a wire or a long conductor rapidly into an electrified region. The reasons for this are pointed out in a clearly written article by *Brook et al.* [1961]. They point out that slow moving wires (as from a kite or balloon) permit a slow discharge by conduction through the wire to occur and thereby reduce the intensity of the field near the wire, tending to make a breakdown less likely. If, however, a grounded conductor is thrust rapidly into the electrified region, an avalanche of charge movement occurs, tending to intensify the field leading to breakdown and a lightning bolt. This has been observed to occur with water plumes from underwater explosions [*Brook et al.*, 1961], with aircraft flying in and through clouds [*Fitzgerald*, 1967; *Cobb and Holitza*, 1968], and with long rockets taking off when electrified clouds are nearby [*Staffs of Marshall Space Flight Center, Kennedy Space Center, and Manned Spacecraft Center*, 1968]. The incident with Apollo 12 added motivation to the development of a wire-deploying device to protect launch operations by discharging the electrified clouds in a harmless fashion when a launch must be made in unfavorable weather.

Although neither the breakdown process for ordinary lightning nor the role of the wire in triggered lightning is fully understood, *Viemeister* [1961], *Smith* [1958], *Coroniti* [1965], *Coroniti and Hughes* [1969], *Staff of Air Force Avionics Laboratory and SAE* [1969], *Orville* [1968], *Brook et al.* [1961], *Fitzgerald* [1967], *Cobb and Holitza* [1968], *and Staffs of Marshall Space Flight Center, Kennedy Space Center, and Manned Spacecraft Center* [1970] present information on the sequence of events that appear to occur. Of interest here is the observation that a slowly deployed wire transfers by conduction along the solid wire only a fraction of a coulomb over a period of minutes, whereas a breakdown such as those achieved by Newman and his associates [1967*a*, *b*] vaporizes the wire, forming a large ionized path so that from 1 to many coulombs are transferred in less than a second. Since the cloud would be more strongly modified by a stroke than by the slow current through the wire, it is important to be able to deploy the wire rapidly enough to be assured of a strong bolt. From laboratory experiments, an acceptable velocity was found [*Brook et al.*, 1961] to be about 20 m/sec (65 ft/sec). Since the volume over which the charge is distributed is much larger in the atmosphere, this minimum velocity should probably be scaled up by 1 to 2 orders of magnitude. The success achieved by LTRI from shipboard with a rocket moving at several hundred feet per second [*Newman et al.*, 1967*a*, *b*] indicates that a towing velocity of around 1000 ft/sec or larger should be adequate for most situations.

Another approach was used by *Kasemir and Weickmann* [1965] to dissipate a large amount of charge separation in a cloud. They reasoned that a large number of short wires dispersed in the electrified region would serve as corona points, thereby enhancing the conductivity of the air so that the strong electric fields would be dissipated. Their method did not get general acceptance because the test results were not positive and because the problems associated with distributing the wires properly are not small.

It is not surprising that long fine wires came to be used to trigger lightning because they have been used in the laboratory for some time to establish electric arcs along desired paths for research purposes, to channel the energetic blast from the discharge, and to guide the arc path in such devices as arc jets and electrically driven shock tubes [*Dannenberg and Silva*, 1969]. Since the wire virtually explodes from the solid state through the melting, vaporizing and ionizing stages as the current pulse passes through it, the laboratory study is carried out under the term, exploding wires. A history of these studies is given by *Chace* [1964] and research on the subject is gathered in published proceedings in *Chace and Moore* [1959, 1962, 1964, 1968]. These laboratory studies have identified the steps in the discharge process and have found that such factors as the metal from which the wire is made governs the type of discharge achieved [e.g., *Dannenberg and Silva*, 1969]. These laboratory studies serve as an aid to understanding the atmospheric discharge, but since the conditions under which lightning occurs may differ greatly from the laboratory set up, direct transfer of the technology should be done carefully. For example, steel wires have been used successfully by LTRI [*Newman et al.*, 1967*a*, *b*] for triggering lightning but were found to give difficulty in laboratory discharges [*Dannenberg and Silva*, 1969]. (Steel wire was originally chosen because of its high strength and low cost.) Better results may or may not be achieved under certain circumstances with a different material.

Dannenberg and Silva [1969], *Chase* [1964], *Chase and Moore* [1959, 1962, 1964, 1968] show that more effort has gone into the study of the discharge than into the methods used to deploy the wire. In a laboratory experiment, the wire is usually put in place by hand and the discharge initiated by either pulling the wire a short distance with an insulating thread such as cotton to bring the circuit to breakdown conditions or by closing the circuit with a switching device. Only a limited amount of effort appears to have been directed at towing long wires (see, e.g., *Sheetz and Krumins*, 1970].

The foregoing served as background material for the study reported here on the development of wire-deploying devices. Included in the following sections are descriptions of the devices built and tested whether the resulting performance was felt to be satisfactory or unsatisfactory. The purpose of this paper is to present our experiences on wire-deploying devices so that other groups who may be working on such items may use or extend the findings presented here.

ROTATING GUN-LAUNCHED BOBBINS

When the Ames Research Center first considered development of a wire-deploying device, the survey, described in the Introduction, was made of methods used in the past to deploy wire or rope. It was concluded that the least expensive and most quickly available means for dispensing about 1 mile of wire was by a gun-launched spinning projectile. This decision was influenced by the fact that the authors had considerable experience with firing projectiles of various configurations from guns and had access to a 500-ft enclosed range. Initial tests were conducted with a rifled 37 mm cannon (standard field weapon modified for laboratory use) because the size of the projectile was such that a mile of 0.008 in. wire (approximately 1 lb in weight) could be easily wound onto a recess on the body of the projectile without coming in contact with the barrel and because the gun size did not exceed the capacity of the range. In later tests, a 40 mm gun was used because some Coast Guard cutters still carried them, which is where the device was planned to be used. Since the Coast Guard removed the 40 mm guns from their cutters in the Key West, Florida, area, the final design was applied to the 3 in./50 caliber slow-fire gun carried by all the cutters. The development of these devices began in December 1966 and continued through the summer of 1967. Over 40 rounds of the 40 mm design were fired in the enclosed range and 11 were fired in the Gabilan Range at Hunter-Liggett Military Reservation near King City, Calif. Thirty-five rounds of the 3-in./50 caliber design were fired to test the performance of the larger gun-fired rotating bobbin.

Method of Construction

The three different projectile sizes had a number of features in common (see Figures 1 and 2). Each had a blunt nose with a recessed hole for the tailstock center-rest to facilitate machining of the body and the winding of the wire on the recessed area. As suggested by David Fox (Hughes Aircraft Co., Tucson), a shallow thread is machined on the recessed section to help hold the first layer of wire in place during winding. One-hundred-twenty threads per inch were used for 0.008 in. wire. It was later found that an experienced machine operator could wind the bobbins without first machining the threads in the bobbin. This first layer and each added layer is then held in place with a clear acrylic spray (also suggested by Hughes) that is allowed to thoroughly dry, with the aid of a heat lamp, before the next layer is applied. About 1-lb tensile force is used on the wire during winding. In this way, a combination of wire and acrylic plastic is built up in the center of the projectile to form a durable projectile so that the wire is held securely in place until it is torn out of its position by the deployed wire. This technique closely parallels that used by Hughes to construct the TOW bobbins. Their method has the ends of the wire layers standing free, differing from the gun-fired bobbins which have the

Figs. 1&2

ends of the layers resting on the shoulders. The TOW bobbins have a 4 to 6 wire stepback at both ends of each layer to give the bobbin structural strength. Since proper matching of the wire space and the shoulder on adjacent layers is not possible with the gun-launched bobbins, imperfections in the wire arrangement develop at the ends unless a compromise is made as to contact of the wire with the shoulder. This required considerable time and care on the part of the winder, so most projectiles had some flaws in the wire bobbins. However, it was found that this did not have an effect on the deployment of wire from spinning bobbins, so most of the rounds were made using the earlier and less exacting technique. The stepback procedure used by Hughes at the ends of the wire layers did not work for the gun-launched bobbins because the high acceleration during firing caused the wire pack to slip backward and become tangled so that deployment of wire could not be completed.

The larger diameter section at the rear of the projectile is designed to completely engage the rifling in order to establish a good seal against the powder gas pressure and to spin the projectile for stability and to aid in the wire deployment. The diagonal cut across this ring is to provide a recessed area in which to lay the free end of the wire during loading and firing. Once the projectile leaves the gun barrel, centrifugal and air forces pull this loose end of wire off the bobbin to begin deployment.

Tests in Hypervelocity Ballistic Range at Ames Research Center

The Hypervelocity Ballistic Range was chosen for these tests because it permitted an enclosed trajectory of up to 500 ft and could accommodate guns up to 40 mm bore diameter. Over 40 rounds were made and fired in this range to test various designs in 37 mm and 40 mm bore size. A typical test round (Figures 1 and 3) weighed from 0.7 to 1.1 lb and consisted of a projectile bobbin with wire wound onto it as described in the previous section. The round would then be loaded with gun powder (about 200 grams) estimated to propel the bobbin at the desired velocity (1500 to 3300 ft/sec). On loading, the free end of the wire was laid in the groove on the borrelet ring and held lightly in place with a small piece of plastic adhesive tape. On some rounds, a small lead shot was fastened to the wire end to add weight and thereby centrifugal force to assist the beginning of deployment. At no time, with or without the lead shot, did there appear to be difficulty with the beginning of deployment. On exit from the gun barrel, the spin of the bobbin throws off wire (Figure 4). The deployed wire coasts with the projectile downrange but is decelerated by air drag so that it would eventually come nearly to rest compared with the velocity of the projectile. At 150 to 500 ft downrange, depending on the type of test being made, the bobbin would impact into a catcher made of styrofoam and cotton wadding. Photographs taken during flight and the imprint made by the wire on the catcher face (Figure 5) showed that the deployed wire was thrown off at the start as planned. As more wire was spun off, it formed a long spiral behind and centered on the projectile that was about bore size at the base of the projectile and enlarged continuously to about 3 ft at the free end of the wire. A smaller set of waves or spirals was also found in the wire due to it being wrapped on the bobbin core. The spiral formed by the wire was easily identified as the wire is pulled from the face of the

<Fig. 3

<Fig. 4

<Fig. 5

catcher even though the spiral is not too clearly defined in Figure 5. After the round was fired, the deployed wire was examined and measured. During this early part of the trajectory it was found that the length of the wire was about one-third of the flight path. On some rounds the recovered bobbin could simply be cleaned and fired again since the remaining wire layers were held in place by the acrylic spray even at the approximately 100,000 g load experienced during launch in the gun barrel and during deceleration in the catcher. At no time was a launch failure encountered and no wear or abrasion was ever noted on the gun barrels.

Tests at Hunter-Liggett Military Reservation

These tests were conducted to determine if the wire deployment would proceed throughout the whole bobbin as it did for the first 100 to 200 ft as demonstrated in the enclosed-range tests. The Gabilan Range at the Hunter-Liggett Military Reservation provided more than 1 mile of open grassland over which the rounds could be fired to try various designs found to work well over short distances. Eleven wire-deploying rounds were fired. Of these, three worked as planned and the rest worked incompletely for one reason or another. The main reason for most of the failures was the breakage of the bobbin on launch so that two or three sections came out of the gun held together by the wire in the bobbin. As these pieces came apart, the wire loops on the bobbin became so tangled that further deployment was impossible. It was soon deduced that the bobbins failed because the solvent in the acrylic spray caused large cracks to form in the zelux bobbin after several days storage. This was not observed during the enclosed-range tests because those rounds were fired within a day or two after construction. These results forced the use of aluminum as the bobbin material. An aluminum model was then checked out in the Hypervelocity Ballistic Range at a speed of 2700 ft/sec and found to work as planned (see Figure 6). Fig. 6

The successful rounds at Hunter-Liggett showed nicely deployed wire whose free end, or beginning, came to rest 500 to 750 yards from the gun and the projectile at 1000 to 1500 yards from the gun. The deployment force required to pull the wire off the projectile increased greatly as the amount of dispensed wire increased (i.e., as the deployment velocity increased) and thereby decelerated the bobbin so that the flight path was shortened considerably. Since the rounds were fired at only 10° elevation, the wire pulled the bobbin down to the ground in about one-half the normal trajectory.

3-Inch/50 Caliber Wire-Deploying Projectile

As mentioned previously, the 3 in. gun was the only one available on Coast Guard cutters capable of being used to deploy long lengths of wire. Therefore, the technology found with the 37 mm and 40 mm guns was applied to the design of the 3 in./50 caliber device (see Figure 2). Since the Coast Guard obtains all of their guns and ammunition from the Navy, they require that all ammunition be issued or approved by the Naval Ordnance Systems Command. Arrangements were then made for the Naval Ordnance Systems Command to examine and test the design for limited experimental use by the Coast Guard for NASA tests on waterspouts [*Rossow*, 1970]. Briefly, the projectile bases (see Figure 2) were loaded into standard 3 in./50 caliber slow-fire cases at the Naval Ammunition Depot at Crane, Indiana. Then, 50 wire-wound spools (the forward part of the projectile) were made at Ames for the tests. When both parts were completed, they were shipped to the Naval Weapons Laboratory at Dahlgren, Virginia, for tests to prove that the device would not damage the gun. The final weight of the projectile was a little over 9 lb (depending on the amount of wire wound on the body of the spool), which was less than the 13 lb weight of standard ammunition. Hence, the breech pressures for our projectile were lower than standard. The music wire was held in place during gun launch by a plastic sprayed on during winding. On July 21, 1967, 20 rounds were fired. No wear or abrasion could be detected on the gun barrel. Since the rounds impacted into water it was not possible to determine whether or in what manner the wire was deployed. However, considerable dispersion (10°-15° spread) was noted in the impact location, suggesting that the wire did cause variation in the line of flight. One round was fired into the water about 1/4 mile from the muzzle to see if the projectile was in one piece. The first impact indicated one piece, but two splashes noted shortly afterward, further downrange, suggested that the projectile base broke off when it first hit the water. These test results permitted the ammunition to be safety certified for the intended limited use. Several additional rounds were fired from the Coast Guard cutters Active and Ariadne to familiarize the crews with procedures used to handle, load, and fire the rounds; no difficulties were encountered.

On August 3, 1967, three rounds were fired from C.G.C. Active over North Arguilla Island in the Caribbean, with the permission of the Bahamian government, to see if the 3 in. projectiles did deploy wire. Wire from only one round was found. It was not possible to determine whether the other two rounds deployed wire since the heavy underbrush

(6-15 ft high) made it nearly impossible to locate deployed wire. The round known to have worked deployed over 2000 ft of wire before it hit a tree about 3500 ft from the muzzle and ricocheted. A fourth round was fired to see if the wire could be detected by the radar but no signal was seen. Although further shots were made, a test to see if these rounds would trigger lightning was not made because a satisfactory situation did not present itself.

NONROTATING ROCKET-LAUNCHED BOBBINS

Development of a rocket-launched bobbin was undertaken to provide a device more mobile than the mortar- or gun-launched equipment and capable of deploying about a mile of wire in any direction at modest cost. The 2.75 in. Folding-Fin-Aircraft Rocket (FFAR) was chosen because it was readily available, inexpensive, and could be fired from the vertical to horizontal direction both from the ground and from an aircraft. Also, it had a detachable head that could be removed and substituted with a wire-deploying head. Work began in January 1968 and was terminated in July 1970 on the design of a head that would deploy at least a mile of wire in one piece. The diagrams of the device presented in Figures 7 and 8 show the sizes of the various parts and the method of construction. Figs. 7&8 The following paragraphs present the results of tests conducted at Ames and some details of construction not given on the drawings. Note that the wire-deploying head does not contain any material that is explosive or hazardous to personnel handling the device. All parts can be safely stored at any temperature under about 200° F.

Technical Description of 2.75-Inch FFAR Wire-Deploying Head

As mentioned previously, the wire-deploying head was designed to deploy about 1 mile of fine steel wire (0.005 to 0.008 in. diam.) along the trajectory of the 2.75-in. FFA rocket beginning at the launcher or 800-1000 ft from the launch sight. The wire is stored in coil form in a cavity in the forward part of the head as shown in Figure 7. The drawing was prepared as if an air launch were being made, so that process will first be described. When the ram pressure of the air on the nose exceeds about 17 $lb/in.^2$ the diaphragm breaks, releasing the bead tied to the end of the wire. At about that time the trap door is also released by the Hamilton Watch Co. Safety and Arming 427 device which is actuated by acceleration brought about by the burning of the rocket motor. Air flowing from the stagnation point at the nose through the diagonal channel blows the plastic bead out into the airstream, pulling the beginning of the wire with it. The wire exits through the port near the rear of the head and then passes along the side of the rocket motor between two of the fins. Air drag on the bead and on the deployed wire pull more wire from the inside of the coil with an increasing speed which eventually approaches the velocity of the rocket through the air so that the deployed wire is nearly stationary relative to the air. Bench tests show that the force required to deploy the wire from the inside of the head is small (estimated at below 1 ounce). The head is screwed rigidly into the rocket motor casing so that it moves and rotates only if the motor does. Shims at the base of the head are used to align the deployment port with the space between two fins.

Characteristics of the wire-deploying head on a 2.75-in. rocket motor are:

Weight of complete head: 10.7 ± 0.2 lb

Length of steel wire: 5000 ft if 0.008 in. wire is used; 8000 ft if 0.005 in. wire is used

Length of head outside motor: 14.0 in.

Total length of head: 16.5 in.

Center of gravity location at: 7.75 ± 0.20 in. from nose; 0.02 in. off axis in direction away from deployment port

Estimated final velocity: 1800 ft/sec
(Based on Mark IV motors; weight = 11.4 lb, thrust = 720 lb, burning time = 1.69 sec)

Acceleration: 32.4 g = 1045 ft/sec^2

Diaphragm

Material: polyethylene type plastic 0.0015 in. thick

Breaking pressure: 17 ± 0.5 lb/in.^{2} = (Ram pressure - static pressure)

Breaking velocity: 1300 ft/sec at 2000 ft altitude (T = 80° F) (Mach No. = 1.14)

Time to diaphragm break: 1.24 sec

Trajectory distance to diaphragm break: 800 ft

Safety and Arming Device: Hamilton Watch Co. S and A 427

Time to trap door release: 1.11-1.16 sec

Trajectory distance to trap door release: 650-700 ft

Drogue used to start deployment is 0.385 in. diam. plastic bead

Weight: 0.001 lb

Acceleration force of bead on diaphragm at 32.4 g = 0.03 lb $\simeq$ 1% gas pressure force

The critical item pertaining to the safety of launch from an aircraft appears to be that wire deployment begin at a distance from the launch point great enough to allow the aircraft to change course before overtaking the deployed wire. For this reason, two rather than one deployment delay devices (i.e., both the diaphragm and the trap door (to be released by the S and A 427)) are incorporated in the head. Estimates made of the distance to wire deployment in the foregoing table indicate that an aircraft flying at 150 knots would have over 3 sec in which to turn onto a new course and avoid the deployed wire. Furthermore, experience with gun-launched wire-deploying projectiles in a firing range at Ames and on the outdoor range has shown that the wire coasts downrange with the projectile for at least several hundred feet. Hence, it is our belief that the wire will not come to rest until it is beyond 1000 ft from the launch point providing the aircraft an even longer time in which to change course.

The wire-deploying spool or bobbin is made by winding the high-strength steel wire on a mandrel as shown in Figure 8. The wire is wound on the mandrel carefully under about 1 lb tension so that each layer is not mixed or intertwined with any other layer. Before the winding begins, the mandrel is coated with a low melting point (155° F) lead-bismuth alloy so that the tension of the wire loops on the mandrel can be released by melting the alloy. Once the layer of metal is melted the mandrel can be easily withdrawn. The innermost layer of wire is then pulled out to remove any residue remaining from the lead-bismuth alloy. Prior to removal of the mandrel, the entire assembly is placed into the threaded-coupling/coil-retainer unit and the cavity remaining around the outside of the coil is filled with a lead-bismuth alloy that melts at 255° F. This metal holds the outside of the coil rigidly enough that the wire loops remain orderly during and after the removal of the mandrel.

If deployment of wire is planned to begin at the launcher (say from a ground- or ship-based site), the diaphragm and S and A 427 are left out of the head. Sufficient wire is then simply pulled out of the head and the free end tied to the desired test location (preferably well grounded and away from personnel) that is aligned with the deployment port.

In order to check as many aspects of the wire-deploying head as possible, various tests were made at Ames. The first group of tests included bench tests made on the components that make up the various parts of the head. For example, the wire from prepared coil samples was pulled out to see how the wire laid inside the coil and how it left. The present design was chosen because it held the loops of wire in place so that no flaws were found in coil structure and so that the wire was deployed flawlessly (from a bow and arrow at speeds of about 250 ft/sec) with a force estimated at less than 1 ounce. Diaphragm tests were conducted to find the correct material and the repeatability in breaking pressure. By use of a turbine-driven reel, wire was pulled from two sample heads by Hughes Aircraft Co., Tucson, Arizona. It was found that the wire was dispensed easily at low speeds but a kink-type break appeared when the pulling speed exceeded about 250 ft/sec. These results are consistent with those tests described in the following paragraphs. All of the subsequent changes made in the head and bobbin design did not correct the kinking tendency of the wire when pulled out of the bobbin center at a velocity greater than some critical amount. Before beginning the tests, other tests were made on the various components to determine which materials and construction procedures would result in the best operation. Estimates were also made of the trajectories to be anticipated with various configurations through a standard atmosphere using the thrust data on the rocket motor and the drag data for typical head shapes for the motor as given in *Stengel et al.* [1965]; *Bureau of Naval Weapons* [1966]; *Bureau of Ordnance, Dept. of Navy* [1952].

Open-Jet Tests

The second group of tests was made by mounting a complete wire-deploying head on an empty rocket motor casing with fins attached and placing the assembly in front of a free jet that emerged from a high-pressure wind tunnel at Ames (i.e., the 12-ft pressure tunnel; see Figure 9). Air in the tunnel at 55 lb/in.^{2} gauge was allowed to exhaust downward through an orifice of 6-in. diam. and about 12 ft above a concrete pad. It is estimated that the Mach number was about 1.5 and the air velocity about 1800 ft/sec. The flow was quite unsteady, however, and the jet deteriorated about 4-6 ft from the orifice. It was reasoned that these tests could only simulate such items as the beginning of wire deployment, breakage of the diaphragm, drag of the bead on the wire to start deployment, and the passage of the wire down the side of the rocket motor and between the fins. Of the ten runs that were made, the diaphragm and plastic bead worked in every case as planned in the design. Varying lengths from 100 ft to a complete spool of wire were deployed on the runs, but breakage usually occurred due to the development of

Fig. 9

kinks in the wire while it passed along the bobbin core into the deployment channel. Test conditions were varied and several simple modifications tried on several runs to isolate the cause of the development of the kinks. It was first thought that they were a result of the irregular pulling of the airstream from the jet on the deployed wire; that is, if the wire is first pulled rapidly and then slowly, a backlash-type condition can develop inside the wire-deploying head. Such a backlash condition need only involve one or more loops for a destructive kink to occur when the wire is again pulled rapidly during the next surge of speed in the jet. Later tests with rocket motors showed that this is probably not the case. The smallness of the wire and the short duration (or high speed) of the event made it impossible to analyze the problem more thoroughly by visual techniques.

The tests also showed that the wire never hung up on the fins even when the deployment port was aligned with a fin. No wear was caused by the wire on any part of the head or motor although scratches were noted in the soft paint sprayed on the model in the vicinity of the deploying port and on the leading edge of a fin nearly aligned with the port.

Tests of Wire-Deploying Head at Naval Weapons Center, China Lake, California, on May 20 and 21, 1968

Two days were spent on Range G2 of the Naval Weapons Center, China Lake, California. Of the twelve rounds fired, six had the wire end tied directly to the launch tube and six were equipped to release the end of the wire for deployment at about 1000 ft from launch. All the results were consistent and showed the same type of failure for all the wire and head arrangements tried. That is, the wire that was deployed and

Fig. 10

recovered, and the broken end that remained with the head, was in each case permanently deformed into a sequence of curls that tightened into a kink near the break location as sketched in Figure 10. Of the 30 to 50 ft of wire deployed, only the last 4-6 ft had this character. The rest was deployed smoothly as planned. The rocket velocity at break was estimated at 250-300 ft/sec. The recovered heads showed that the diaphragm (actuated by ram pressure) and the trap door (actuated by the acceleration of the rocket) both functioned as planned but that only a small amount of wire was deployed.

Test conditions were such that it was not possible to identify with certainty the reason for the waves in the wire and its breakage. A high wind (20-45 knots) persisted the entire time and it is possible that abrupt yaw of the rocket on exit of the launch tube may have affected the test results. Discussions within our group and by telephone with personnel of Hughes Aircraft at Tucson, Arizona, who developed the TOW missile, led to the conclusion that the present design does not restrain the wire enough in the bobbin. It was the objective of this design to reduce the deployment force as much as possible to increase the upper limit on deployment velocity. Now, it is felt that the force was reduced too far (i.e., less than 1 ounce) so that disturbances propagating up the wire to the bobbin cause wire to be thrown off the bobbin in amounts greater than needed so that an unstable whipping sequence occurs. As more energy is fed into the instability, larger overlap or looping occurs and destructive kinks develop as the wire is drawn taut on the next oscillation. The deformation caused to the hardened steel wire consisted of a series of waves with an increasingly tighter loop at its crest which finally becomes a cusp (or kink) as indicated in Figure 10. After several kinks form, the wire breaks. This same type of failure occurred in all the tests that followed where a break could be identified.

Tests at White Sands Missile Range

Following the tests at the Naval Weapons Center, it was decided that a possible remedy for the kinking of the wire was to embed the bobbin wires in a stronger or more viscous substance than the brittle clear acrylic spray used previously. Arrangements were made with the NASA MSC White Sands Test Facility near Las Cruces, New Mexico, to have samples of various bobbins tested on one of the firing ranges at WSMR. Bobbins were made with an adhesive spray (Scotch Grip, Spray Adhesive 77-N), adhesive transfer (Scotch Brand No. 465), combinations of these two with Ambroid cement and clear plastic tape with adhesive on both sides (Scotch Pressure Sensitive Double Coated Tape No. 666). Two coils were also made by Hughes Aircraft Co. using epoxy, but these were not used because the deployment force was not increased with these materials. Each of these coils was the same as shown in the previous sketch and differed only in the binder used to hold the wires in place.

After the rounds were constructed, they were mounted on 2.75-in. FFAR motors at WSMR Range 37, pad B (see Figure 11). The free end of the wire from each head was tied to the launcher before firing. Afterward, the deployed wire was measured and examined to see the type of break that occurred, and an attempt was made to recover the expended motor and head. Of the twenty-two rounds fired, none were recovered because of the

Fig. 11

presence of a large number of soft sand mounds covered with low brush (boondocks) in the impact area.

The tests of the bobbins with the stickier materials as binder (March 13-19, 1970) increased the amount of deployed wire by only a small amount, i.e., from 30-50 ft to 90-200 ft. It was felt that the corrective measure was probably partially effective but not to the degree necessary. Discussions with Richard Souder and George Ortiz of MSC-WSTF led to a concept that a damping material inside the bobbin core of the deployment channel might be more effective in damping out undesirable waves. A number of substances such as paste wax, heavy and light oils, and grease were then stuffed into the channel of seven rounds. Several of these rounds also had a pipe placed beside the rocket motor to guide the wire from the exit port past the fins and several had the bobbin axis centered so that it was aligned with the deployment channel. These rounds performed no better than the previous rounds and the wire broke in the same fashion experienced in the other tests. It was concluded, therefore, that the deployment of wire from the inside of a bobbin as carried out with this device will not work at speeds in excess of about 250 ft/sec. An attempt to show this theoretically or to associate this speed with the bending strength of the wire in the bobbin was not successful.

FFAR HEAD WITH TOW BOBBIN

The presence of the folding fins on the 2.75-in. FFAR and the necessity of a launch tube made it impossible to mount bobbins near the rear of the rocket motor. The design shown in Figure 12 was made to Fig. 12

determine at what speed a canted TOW bobbin would deploy wire in that position. Only one head was built because Hughes personnel were certain that the wire would break as it is pulled off the outside of the bobbin at speeds much in excess of 1300 ft/sec. Therefore, the design would never work at the burnout velocity of the FFAR. An unmodified TOW bobbin was used just as given to Ames by Hughes. It differed from the other bobbins in that only the ends of the wire layers are sprayed with Krylon. Since the wire is very hard and is deployed from the outside, its spring tension makes the wire deploy whenever the loose end is not held. A few of the Krylon wound bobbins that paid out from the inside would self-deploy but most did not.

The one head available was launched at WSMR (Range 37, pad B) on March 17, 1970. The deployment force unfortunately tore the wire end off the launcher so that no wire was found at the launch site. The recovery team later found 6000 ft of wire that was deployed along the trajectory from this bobbin. However, the wire was in three pieces and it had the same wave-type deformation noted on the other rounds. Since the TOW bobbin is self-deploying, it was reasoned that after the rocket left the pad it continued to deploy wire but at a speed much less than its ground speed. As more wire was paid out, the air drag forced the deployment speed up beyond the critical speed, causing the wire to break. After the break, probably on or near the bobbin, the wire began to self-deploy again and the process repeated itself.

Wire can be dispensed in this manner but it is not believed to be a satisfactory method if lightning is to be triggered. An improvement in this design would be to have the bobbin aligned with the deployment direction and to leave ample room around and behind the bobbin for the wire to loop and swing as is done on the TOW vehicle and on the gun-fired bobbins. The impact of the wire on a solid surface at deployment speeds in excess of 1000 ft/sec will probably cause the wire to break because of the large amount of energy involved. Since the bobbin design developed by Hughes Aircraft for the TOW vehicle is both reliable (at speeds below 1350 ft/sec), inexpensive, and readily available, various schemes were considered for mounting one of these bobbins on the rear of some rocket and using it for the wire-deploying scheme. Since no satisfactory rocket was found, the foregoing attempts were made.

CONCLUDING REMARKS

It was concluded that the best available source for bobbins was that made for the TOW missile by Hughes Aircraft Co. or one that was wound on their wire-winding machine. The gun-launched rotating bobbins appear to work satisfactorily at speeds up to about 2800 ft/sec. They have the disadvantage that the free end of the wire cannot be fastened to a desired point near the launch site. It must be left free because the projectile must go through the close-fitting gun barrel during the first part of its trajectory. Although a satisfactory test was not conducted, these devices should be capable of triggering within-cloud or cloud-to-cloud lightning.

The nonrotating rocket-launched bobbins that deploy from the inside could not be made to deploy wire over 200 ft long and the wire usually broke at about 50 ft (250 to 300 ft/sec). The deployment force for the bobbins deploying from the inside is less than 1 ounce at speeds up to about 200 ft/sec as determined by bow and arrow tests. A means for eliminating the kinking of the wire as it is deployed must be found before this device can be made to function satisfactorily.

These results suggest that a tractor rocket whose performance matches that of the TOW missile might serve as a suitable vehicle for wire deployment from a ground station so that cloud-to-ground lightning can be triggered.

REFERENCES

Brook, M., G. Armstrong, R. P. H. Winder, B. Vonnegut, and C. B. Moore, Artificial initiation of lightning discharges, *J. Geophys. Res., 66*, 3967-3969, 1961.

Bureau of Naval Weapons, Aircraft rockets, *NAVWEPS Op 2210 (Vol. 1)*, First Revision, Sept. 1966.

Bureau of Ordnance, Department of Navy, Trajectory tables for 2.75-inch aircraft rocket, *OP 1998*, Nov. 1952.

Chace, William G., Exploding wires, *Phys. Today, 17*, 19-24, 1964.

Chace, William G., and Howard K. Moore, eds., *Exploding Wires*, Plenum Press, New York, Vol. 1, Proceedings of the First Conference on the Exploding Wire Phenomenon, 1959; Vol. 2, Proceedings of the Second Conference on the Exploding Wire Phenomenon, 1962; Vol. 3, Proceedings of the Third Conference on the Exploding Wire Phenomenon, 1964; Vol. 4, Proceedings of the Fourth Conference on the Exploding Wire Phenomenon, 1968.

Cobb, William E., and F. James Holitza, A note on lightning strikes to aircraft, *Monthly Weather Rev., 96*, 807-808, 1968.

Coroniti, Samuel C., ed., Problems of atmospheric and space electricity, Proceedings of the Third International Conference on Atmospheric and Space Electricity, Montreux, Switzerland, 1963, Elsevier Publishing Co., New York, 1965.

Coroniti, Samuel C., and James Hughes, eds., Planetary electrodynamics, Proceedings of the Fourth International Conference on the Universal Aspects of Atmospheric Electricity, Vol. I, Sections I-IV, Vol. II, Sections V-VIII, Gordon and Breach Science Publishers, New York, 1969.

Dannenberg, Robert E., and Anthony F. Silva, Exploding wire initiation and electrical operation of a 40-kV system for arc-heated drivers up to 10 feet long, *NASA TN D-5126*, April 1969.

Fitzgerald, Donald R., Probable aircraft "triggering" of lightning in certain thunderstorms, *Monthly Weather Rev.*, *95*, 835-842, 1967.

Harvey, R. B., J. L. Heckscher, and E. A. Lewis, Transient atmospheric electric effects caused by a wire carried aloft by a mortar shell, *J. Geophys. Res.*, *72*, 5752-5753, 1967.

Kasemir, Heinz W., and Helmut K. Weickmann, Modification of the electric field of thunderstorms, Proceedings of the International Conference on Cloud Physics, May 24-June 1, 1965, Tokyo and Sapporo, Japan, Meteorological Society of Japan, pp. 519-523.

Newman, M. M., J. R. Stahmann, and J. D. Robb, Experimental study of triggered natural lightning discharges, *FAA Rept. DS-67-3, Final Rept. Project 520-002-03X, Contract FA66NF-156*, March 1967*a*.

Newman, M. M., J. R. Stahmann, J. D. Robb, E. A. Lewis, S. G. Martin, and S. V. Zinn, Triggered lightning strokes at very close range, *J. Geophys. Res.*, *72*, 4761-4764, 1967*b*.

Orville, Richard E., Photograph of a close lightning flash, *Science, 162*, 666-667, 1968.

Payne, P. R., The terminal forces acting on a light trailing wire, *Aeron. J. Roy. Aeron. Soc., 74*, 759-761, 1970.

Rossow, Vernon J., Observations of waterspouts and their parent clouds, *NASA TN D-5854*, 1970.

Sheetz, Norman W., Jr., and Maigonis V. Krumins, An investigation of the effect of flexible trailing wire on a hypervelocity cone, *NOLTR 70-49*, March 1970.

Smith, L. G., ed., Recent advances in atmospheric electricity, Proceedings of the Second Conference on Atmospheric Electricity, Portsmouth, N.H., Pergamon Press, New York, 1958.

Staff of Air Force Avionics Laboratory and SAE, Lightning and Static Electricity Conference, 3-5 December 1968, Miami Beach, Part II, compiled by C. R. Austin, *AFAL-TR-68-290, Part II*, May 1969.

Staffs of Marshall Space Flight Center, Kennedy Space Center, and Manned Spacecraft Center, Analysis of Apollo 12 lightning incident, *MSC-01540*, Feb. 1970.

Stengel, Robert F., William L. Lord, and Cary F. Milliner, The 2.75-inch folding fin aircraft rocket, Final Rept., NASA Wallops Station, August 1965.

Viemeister, Peter E., *The Lightning Book*, Doubleday and Co., Inc., Garden City, New York, 1961.

FIGURE LEGENDS

Figure 1. Diagram of gun-launched bobbin for 40 mm gun designed to deploy 0.008 in. diam. steel wire.

Figure 2. Diagram of structure of gun-launched bobbin for 3-in./50 caliber gun designed to deploy 1 mile of 0.008 in. diam. steel wire.

Figure 3. Photographs of 40 mm bobbin being loaded into standard case.

Figure 4. Photograph of plastic bobbin for 40 mm gun in flight as wire is deployed.

Figure 5. Photograph of impact of deployed wire on styrofoam catcher face and of hole made by bobbin.

Figure 6. Photograph of aluminum bobbin in flight showing wire being deployed as planned.

Figure 7. Diagram of wire-deploying head for 2.75-inch Folding-Fin-Aircraft Rocket; wire is deployed from inside the nonrotating bobbin.

Figure 8. Sketch of bobbin to be built into wire-deploying head for 2.75-inch FFAR shown in Figure 7.

Figure 9. Set-up used for open-jet tests.

Figure 10. Sketch of deformed wire near break.

Figure 11. Photographs of typical launch sequence of 2.75-inch FFAR wire-deploying heads from WSMR Range 37, pad B. (a) Launch tube before loading rocket, (b) Technician loading round, (c) Final check of alignment of launch tube, (d) Arrangement just before firing, (e) Round leaving launch tube just after firing.

Figure 12. Diagram of wire-deploying head for 2.75-inch FFAR that uses the TOW bobbin.

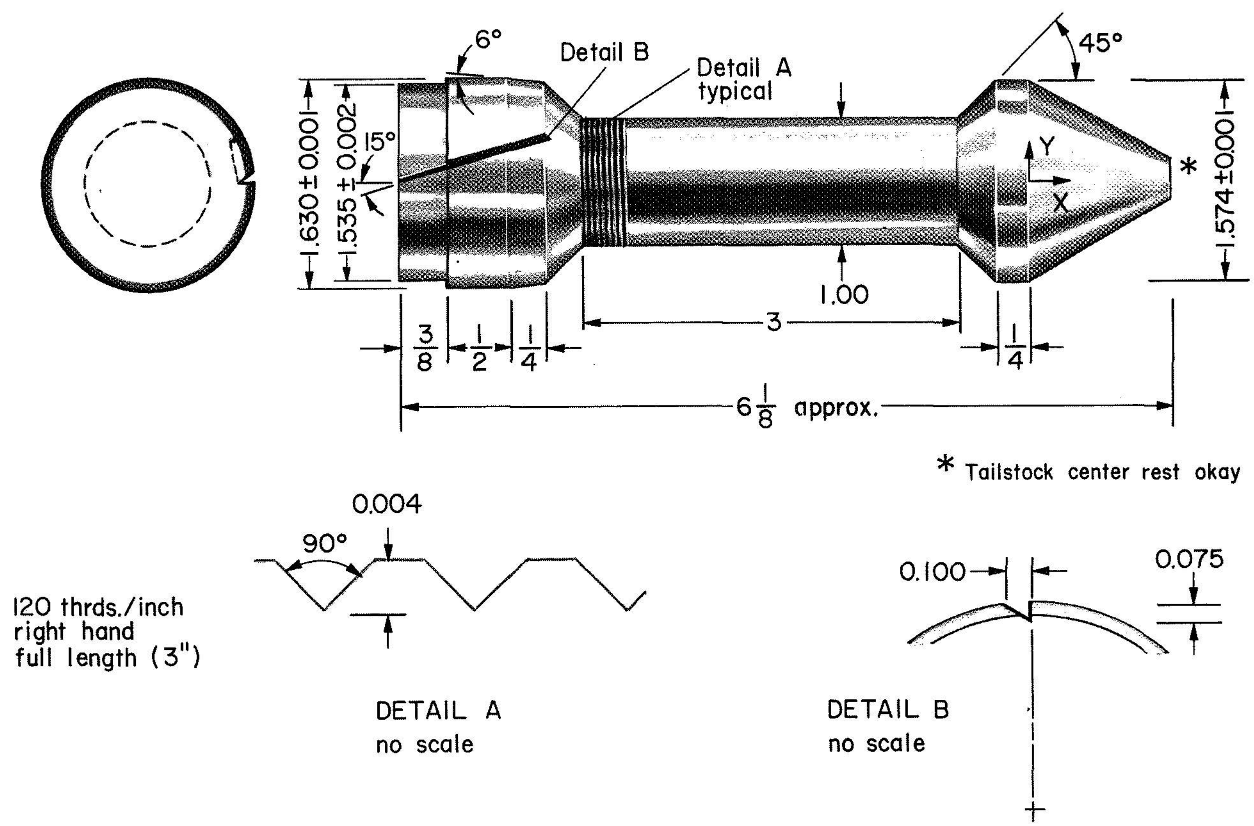

6°
Detail B
Detail A
typical
45°
15°
1.630 ± 0.001
1.535 ± 0.002
Y
X
*
1.574±0.001
1.00
3/8
1/2
1/4
3
1/4
6 1/8 approx.
* Tailstock center rest okay
0.004
90°
120 thrds./inch
right hand
full length (3")
DETAIL A
no scale
0.100
0.075
DETAIL B
no scale

Figure 1.

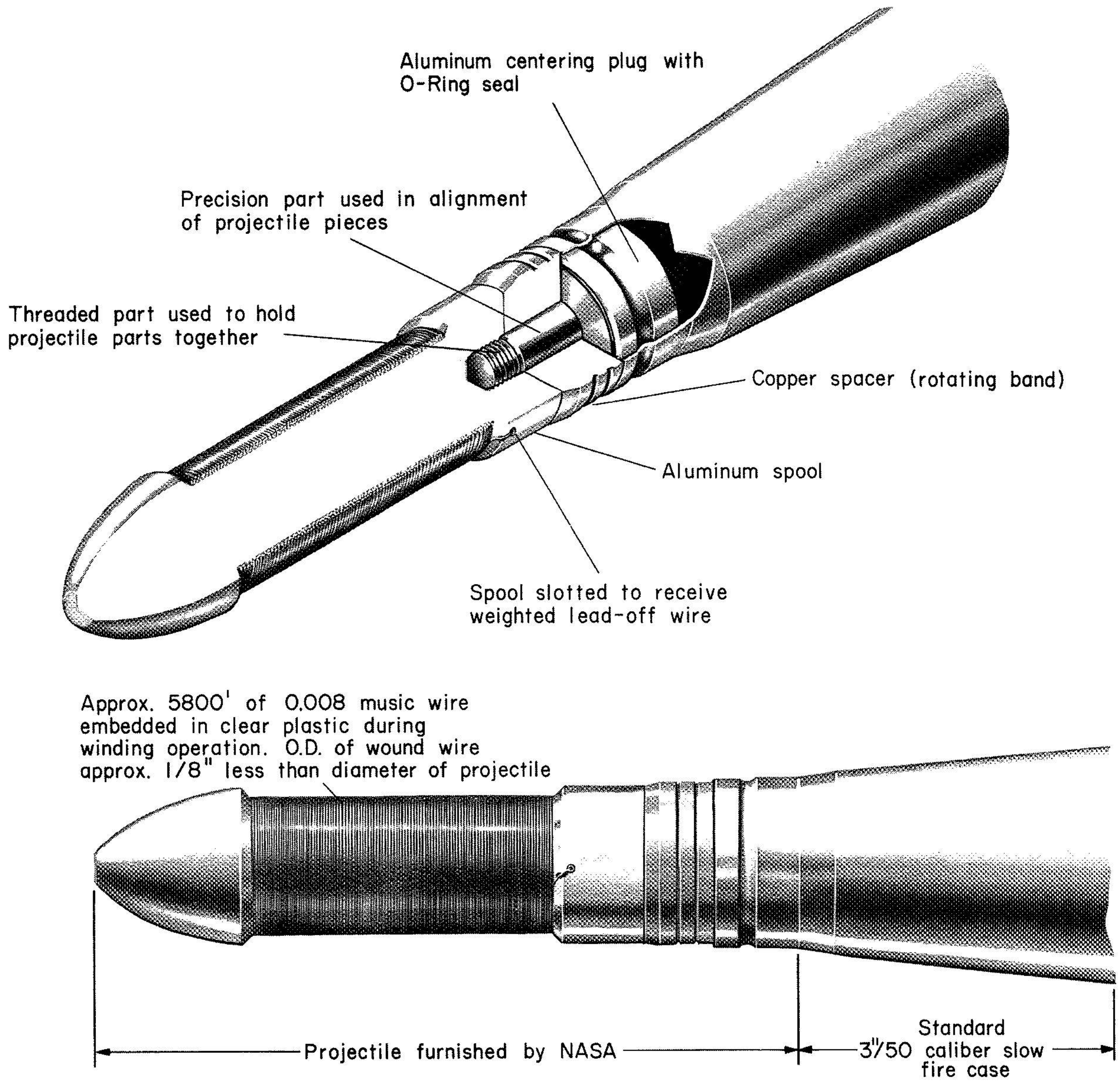

Aluminum centering plug with O-Ring seal
Precision part used in alignment of projectile pieces
Threaded part used to hold projectile parts together
Copper spacer (rotating band)
Aluminum spool
Spool slotted to receive weighted lead-off wire
Approx. 5800' of 0.008 music wire embedded in clear plastic during winding operation. O.D. of wound wire approx. 1/8" less than diameter of projectile
Projectile furnished by NASA
Standard 3"/50 caliber slow fire case

Figure 2.

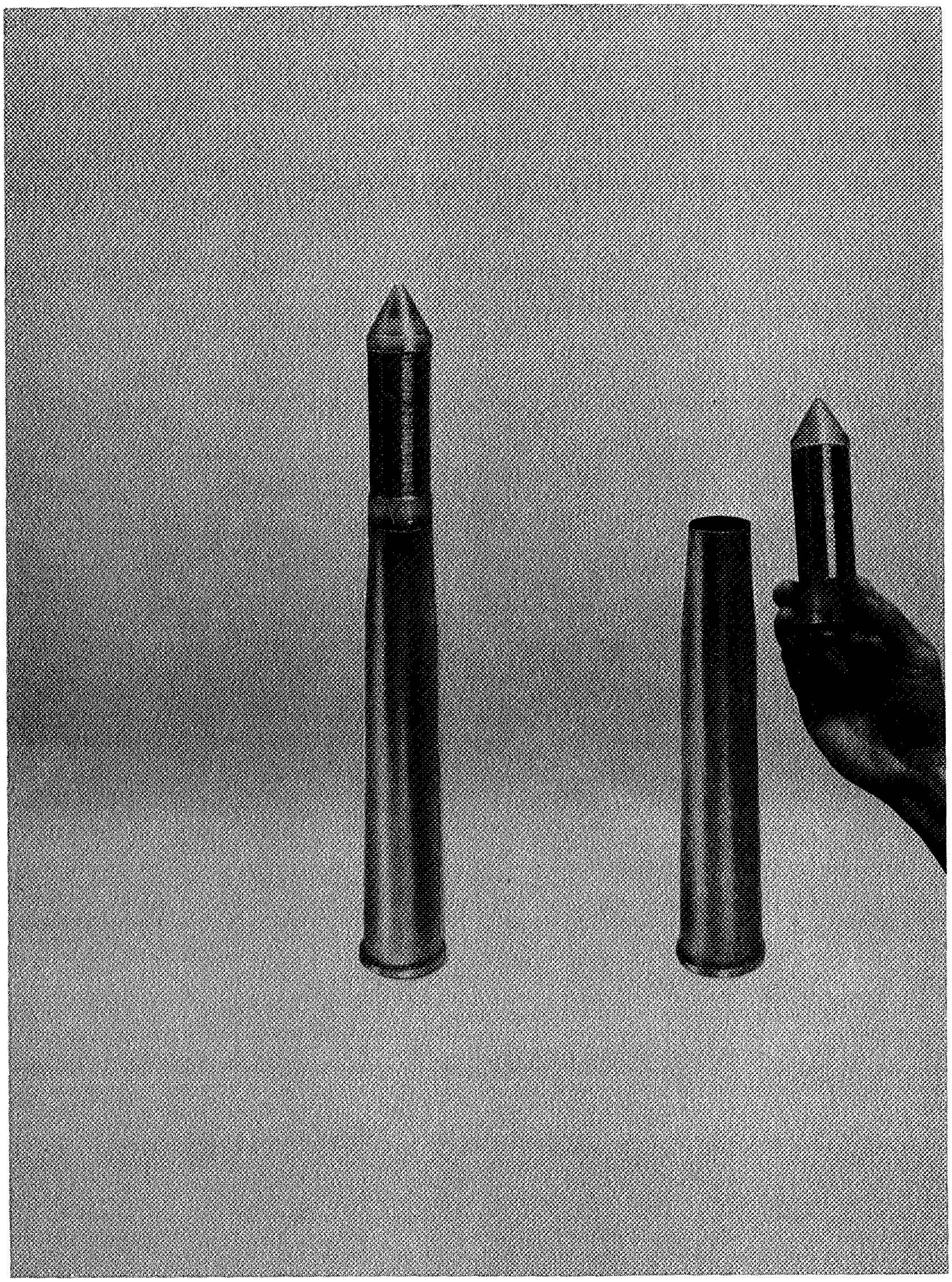
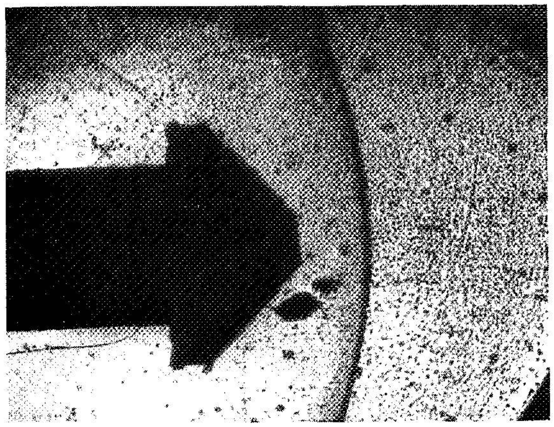
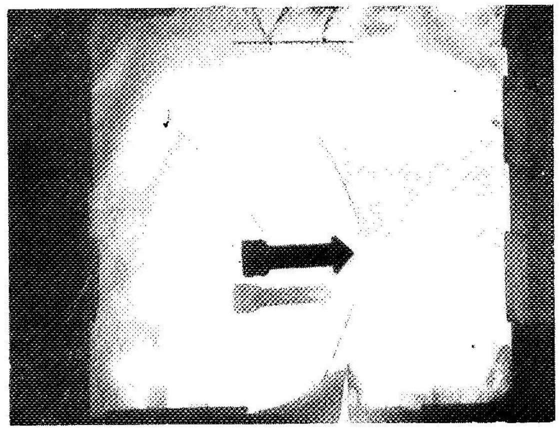


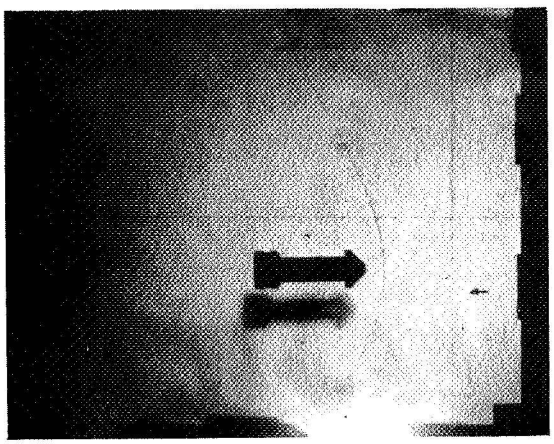
Figure 3.



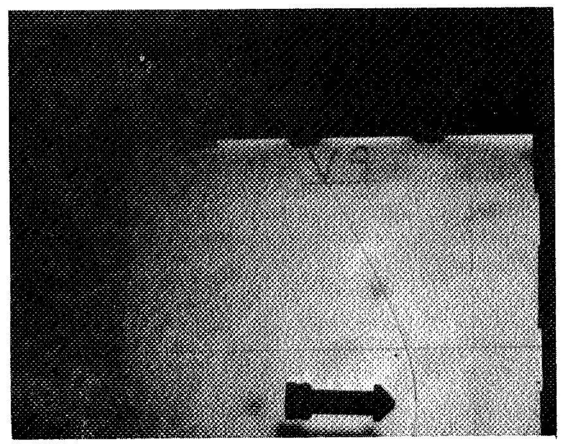
Distance from muzzle = 20 ft



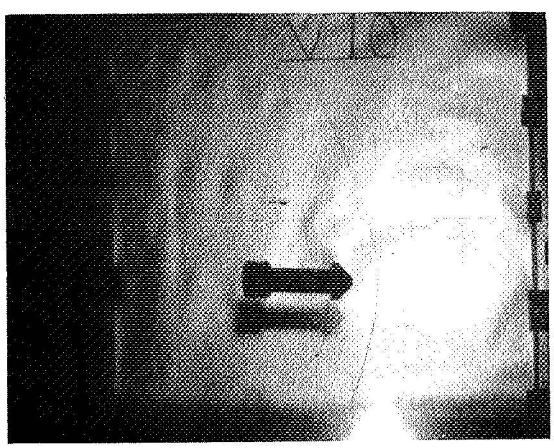
50 ft



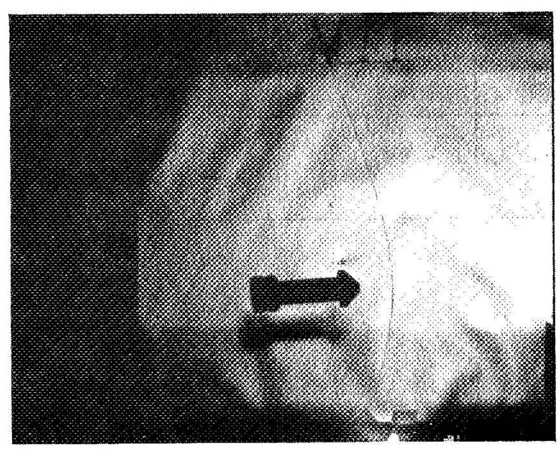
58 ft



66 ft



76 ft



86 ft

Figure 4.

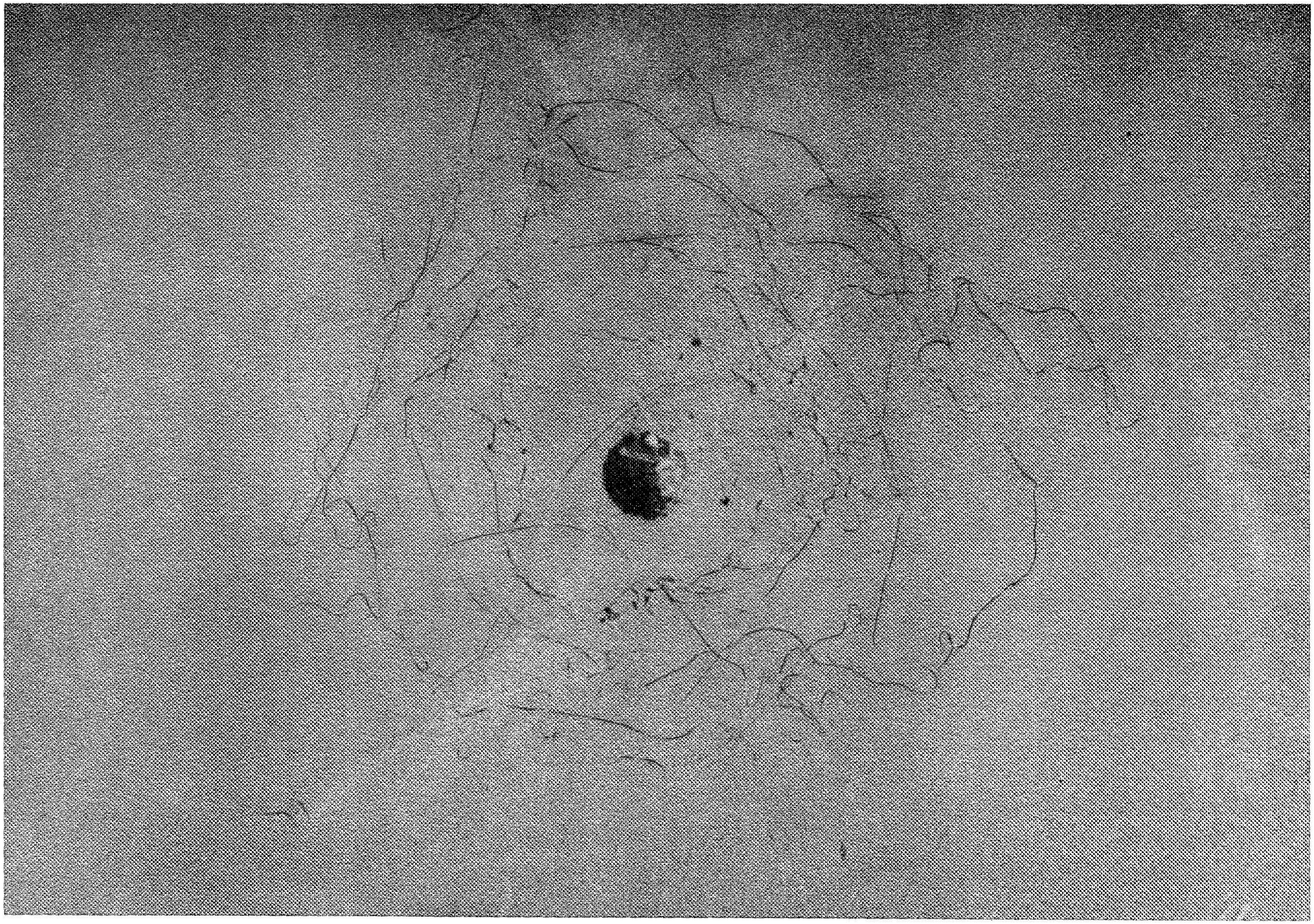


Figure 5.

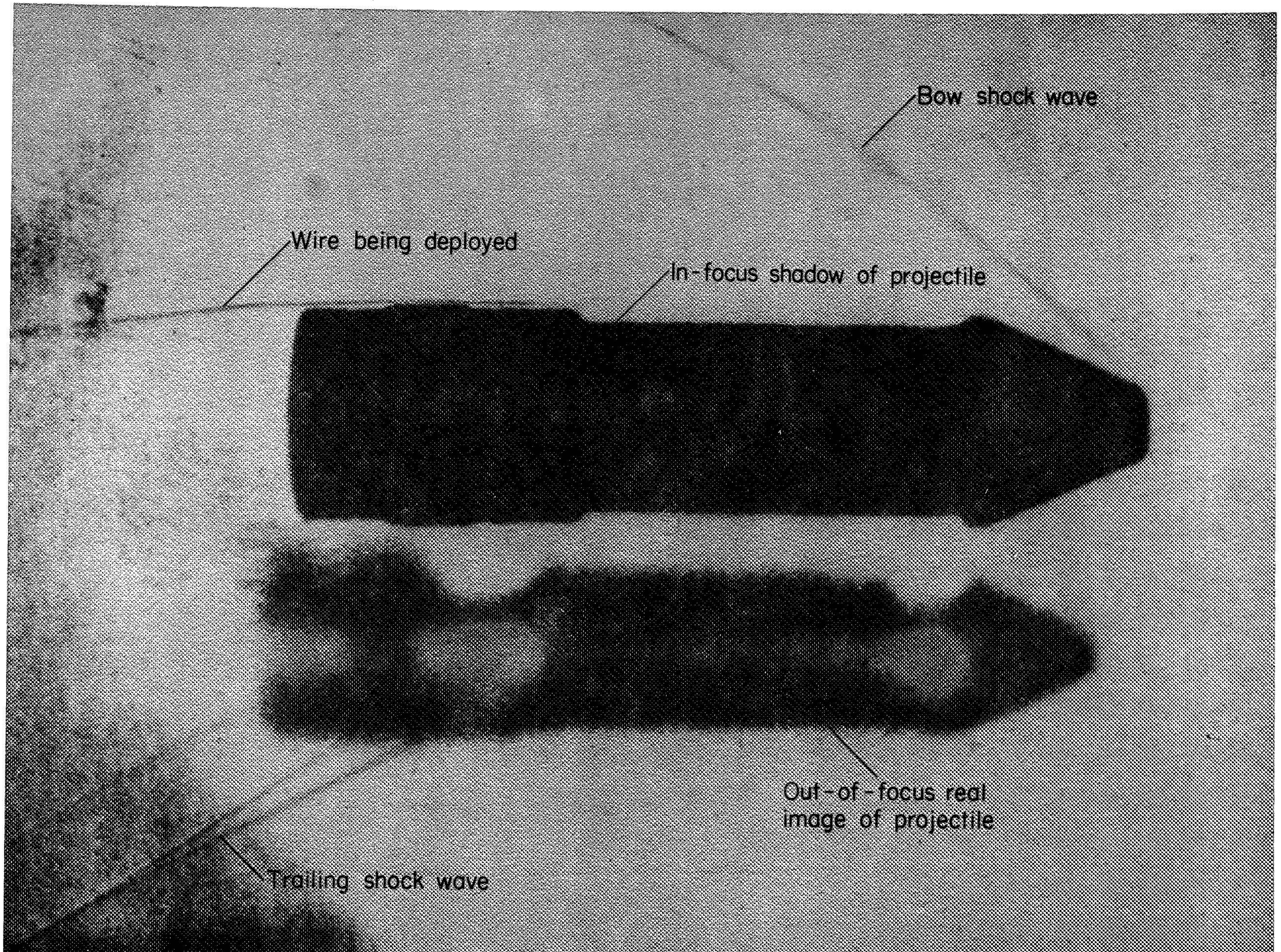

Bow shock wave
Wire being deployed
In-focus shadow of projectile
Out-of-focus real
image of projectile
Trailing shock wave

Figure 6.

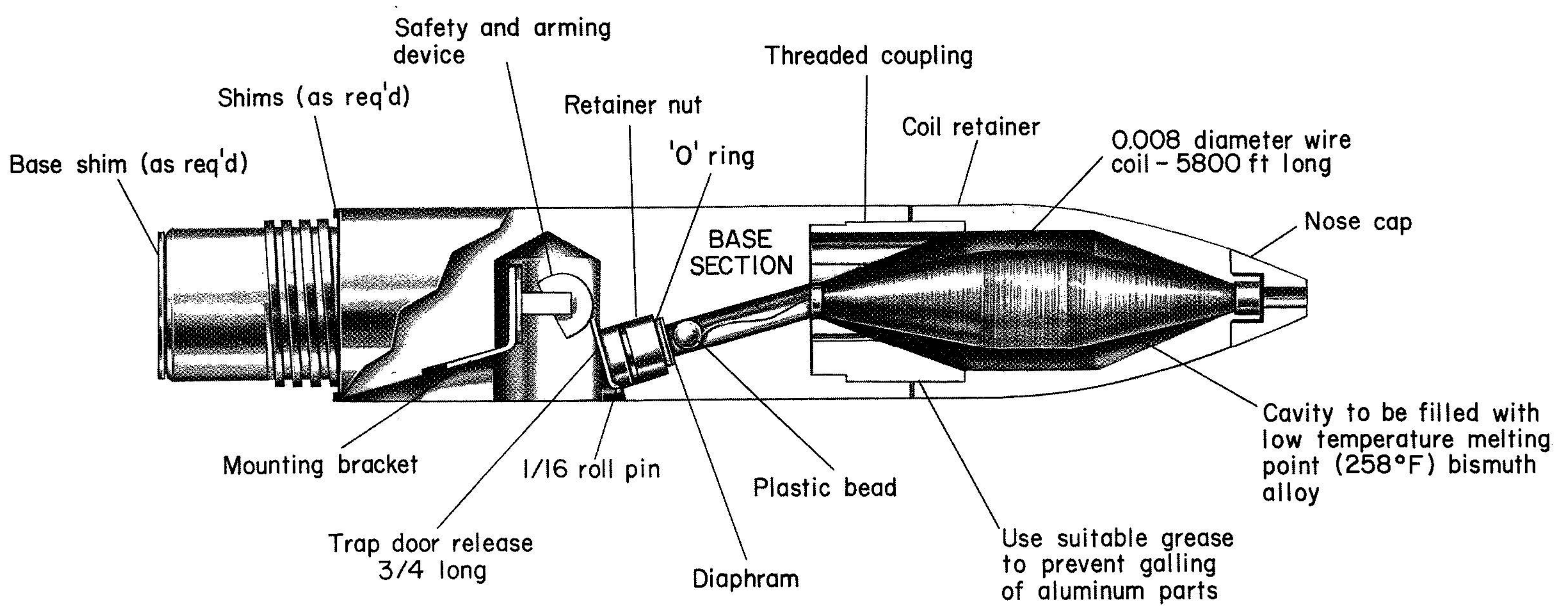
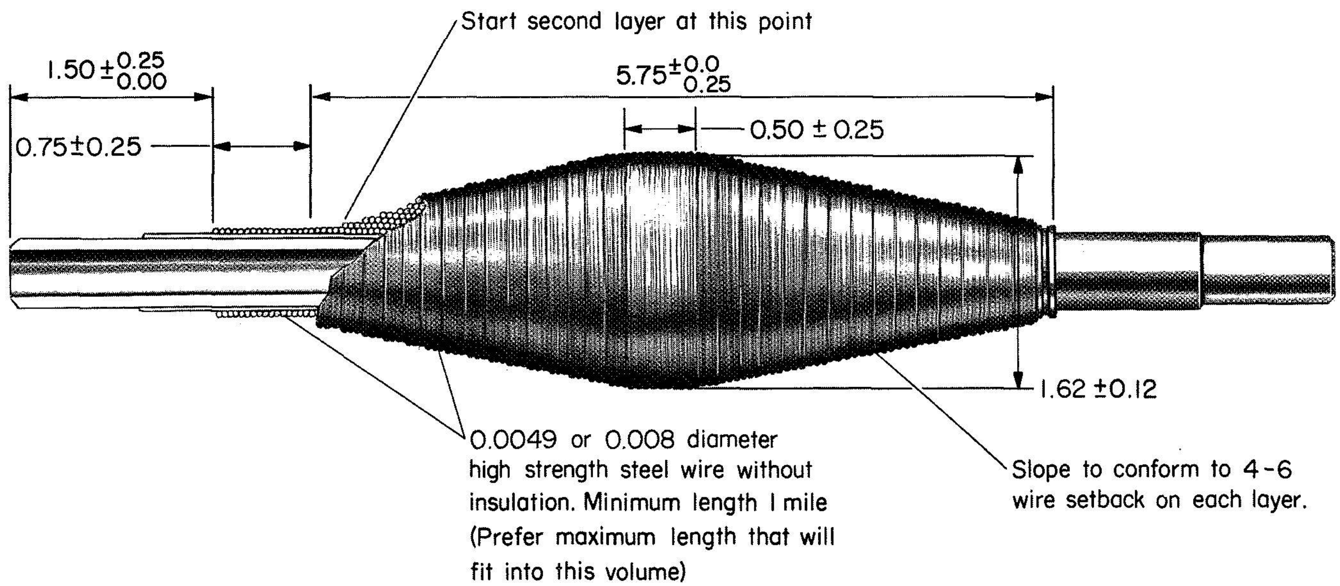

Safety and arming device
Threaded coupling
Shims (as req'd)
Retainer nut
Coil retainer
0.008 diameter wire coil - 5800 ft long
'O' ring
Base shim (as req'd)
BASE SECTION
Nose cap
Cavity to be filled with low temperature melting point (258°F) bismuth alloy
Mounting bracket
1/16 roll pin
Plastic bead
Use suitable grease to prevent galling of aluminum parts
Trap door release 3/4 long
Diaphram

Figure 7.



1. Spray each layer of wire with clear lacquer in setback region. Spray entire layer if drying time is not excessive.
2. Ends of wire may either be tucked under neighboring loops of wire or held in place with plastic tape.

Figure 8.

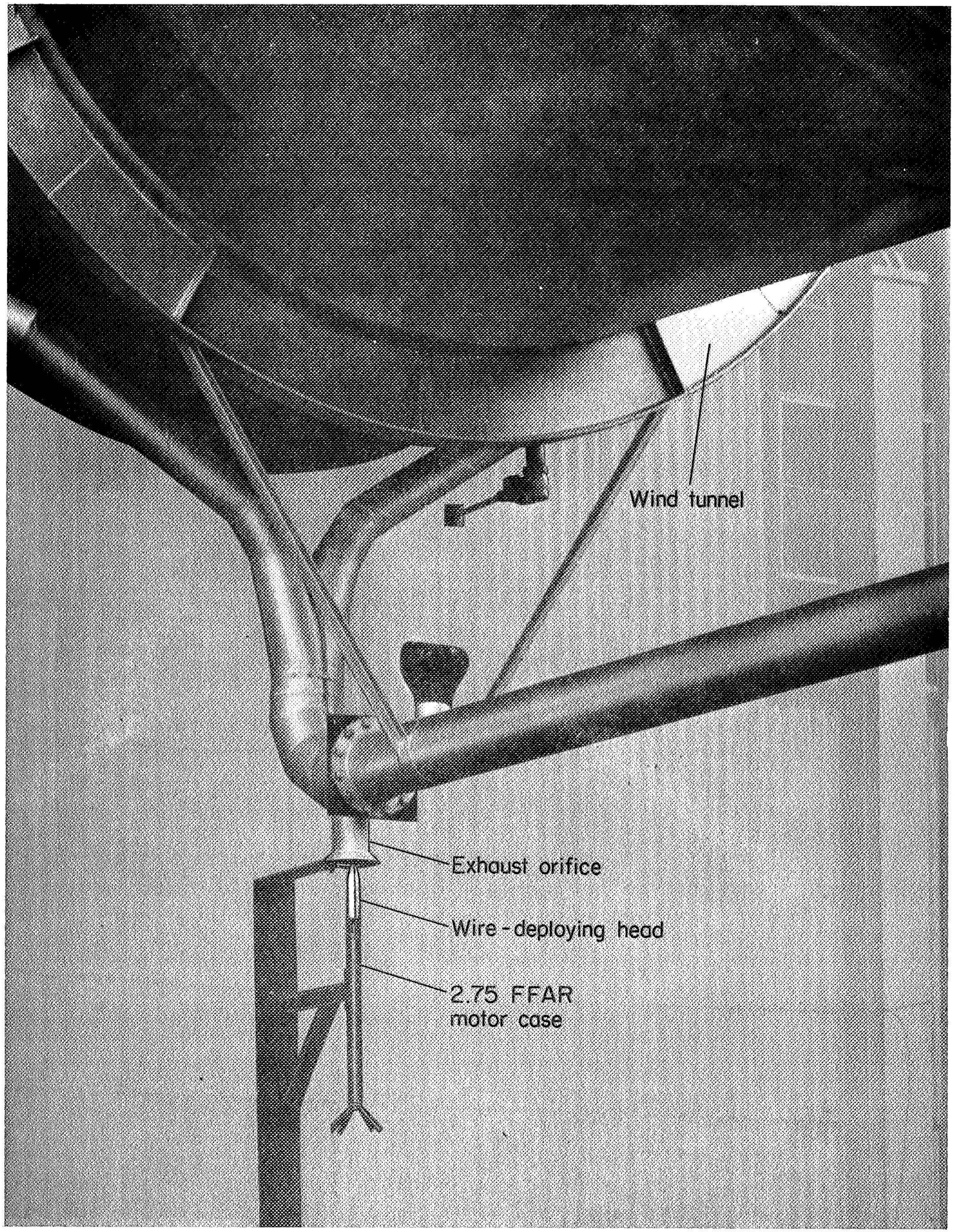

Wind tunnel
Exhaust orifice
Wire - deploying head
2.75 FFAR
motor case

Figure 9.

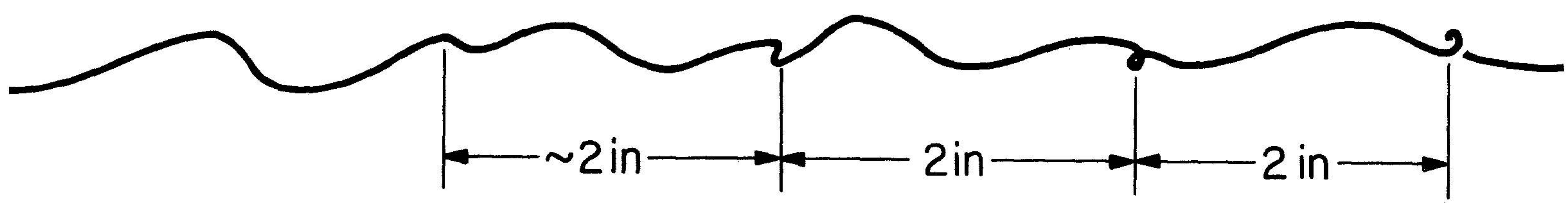


Figure 10.

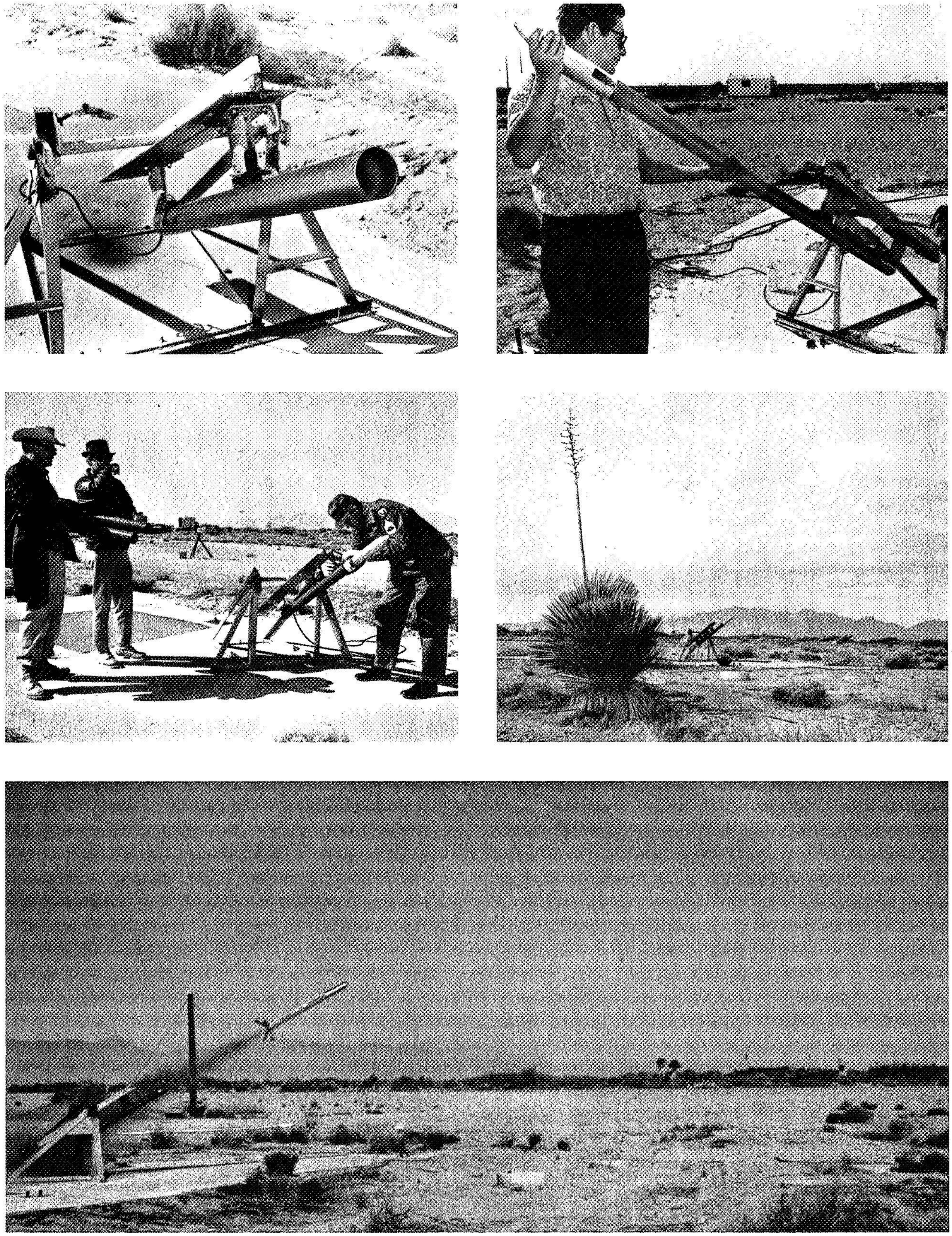


Figure 11.

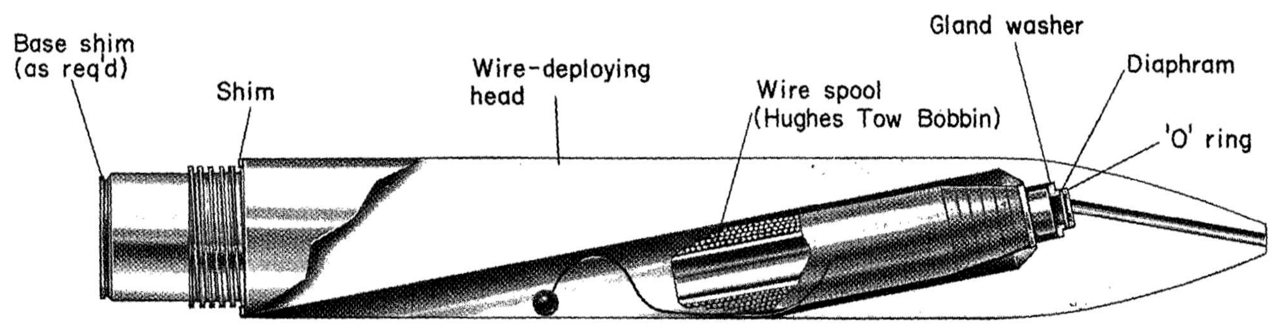

Base shim
(as req'd)
Shim
Wire-deploying
head
Wire spool
(Hughes Tow Bobbin)
Gland washer
Diaphram
'O' ring

Figure 12.