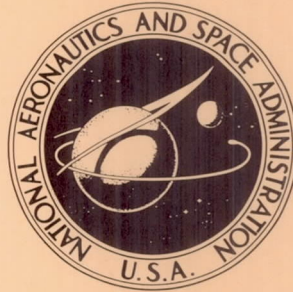


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DEVELOPMENT OF A SMOKE-TRAIL
VEHICLE FOR APPLICATION TO
WIND-SHEAR MEASUREMENTS
UP TO 80,000 FEET

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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DEVELOPMENT OF A SMOKE-TRAIL VEHICLE FOR APPLICATION TO
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SUMMARY

A relatively inexpensive, easily handled vehicle system was developed which is capable of producing a satisfactory smoke trail for determination of horizontal wind profiles to an altitude of approximately 80,000 feet. This vehicle, which produces a smoke trail of desired persistence and light-scattering ability, has a relatively simple, inexpensive payload and an off-the-shelf Nike-Ajax booster which can be assembled for launching by four men. The modified Nike-Ajax military launcher, which has been qualified for this vehicle, is mobile and readily adaptable to any missile range.

This vehicle and other vehicles described herein were used in conjunction with a method of determining the detailed structure of the horizontal wind profile from photographs of successive positions of a smoke trail left by a nearly vertically rising rocket-propelled vehicle.

INTRODUCTION

Systematic acquisition of small-scale or short-wavelength variation in wind velocity as a function of altitude is required for proper vehicle design because of severe stresses and vibrations which may be imposed on launch vehicles as a result of horizontal winds. Until recently, measurements of small-scale variations of wind with altitude were not available.

Rocket-boosted fin-stabilized vehicles were used to produce a grid of smoke trails which were essential to a technique of investigating blast-wave effects by photographically determining the apparent displacement of smoke trails. Subsequently, as is described in reference 1, a program was undertaken to evaluate a smoke-trail technique which could yield wind profiles showing small-scale effects by photographically determining horizontal smoke-trail displacement due to winds. Comparison of wind velocity as a function of altitude obtained by smoke trail with information obtained by balloon soundings taken at approximately the same time (ref. 1) demonstrates that the smoke-trail technique yields data of sufficient detail for determination of small-scale disturbances and of much greater detail than the balloon soundings.

Since the region in which atmospheric winds seem to impose the most severe loads on vehicles is an altitude range of 30,000 to 40,000 feet, it was necessary to design a smoke-generating, fin-stabilized vehicle which would have a minimum altitude capability that included this range. The Nike 36° cone vehicle designed for this purpose produced continuous smoke trails of required light-scattering ability and persistence from an altitude of approximately 6,000 feet to apogees in the range of 40,000 feet to 45,000 feet. Subsequently, wind data above 40,000 feet were required. This report presents chronologically the several approaches and results thereof in the development of a vehicle capable of producing a continuous smoke trail of required light scattering ability and persistence, starting at approximately 6,000 feet and extending to a minimum apogee of 65,000 feet.

SMOKE-TRAIL TECHNIQUE

All vehicles produced smoke trails by expulsion of FS, a solution of sulfur trioxide (SO_3) in chlorosulfonic acid ($ClSO_3H$), along the vehicle trajectory. This technique is in general a very reliable means of producing a smoke trail. However, for a smoke trail to be satisfactory for use in obtaining wind-velocity measurements, there are three important requirements: (1) that it be formed over the proper altitude range, (2) that it have the necessary persistence, and (3) that pictures of it be of "sharp" photographic detail.

For a vehicle with the proper payload-altitude capability, the only condition necessary for formation of a smoke trail over the desired altitude range is sufficient ambient moisture to react with the FS expelled. Available information indicates that there is probably sufficient moisture at all times for proper smoke-trail formation to altitudes in excess of 100,000 feet, which, insofar as is known, is higher than any altitude at which an effort has been made to form a smoke trail with FS.

To obtain good photographic detail of FS trails, all of which have been found to be of good persistence, there must be sufficient brightness contrast between the trail and its background. The brightness contrast is the difference between background brightness (which is dependent on sun position and atmospheric conditions) and trail brightness (which is dependent mainly on trail width and density).

As FS is expelled from a vehicle, it is atomized by the action of the airstream on it. The small particles of FS thus produced then react with and absorb ambient moisture to grow into larger particles which form the smoke trail. The vertical velocity of these particles is low and the response thereof to wind movement is good. Therefore, time averaging of displacements obtained by successive simultaneous photographs taken at suitable time intervals by two cameras correctly dispersed from the smoke-producing vehicle launch site determines wind velocity. Two such photographs taken for determining a wind profile at Wallops Island are shown in figure 1.

DATA ACQUISITION EQUIPMENT

Data necessary to this program were vehicle-performance information and time history of the position of the smoke trail, which is essential to wind-velocity determination. The two cameras, each located at bearings from the launch site approximately 90° apart and at a distance of approximately 10 miles from the launch site, were U.S. Air Force type T-11 precision aerial mapping cameras. Special power pulse circuits were designed and installed at each station to provide the required synchronized operation of the cameras. Special camera mounts provided a rigid platform with fixed elevation and azimuth angles. A more detailed description of this photographic equipment and technique is given in reference 1. Vehicle azimuth, elevation, and slant range as functions of time which were used to compute altitude, horizontal range, and velocity as functions of time were obtained by SCR-584, FPS-16, and SCR-584 Mod II radars. A CW Doppler radar unit provided partial velocity time histories for some vehicles.

DESCRIPTION AND OPERATION OF PAYLOADS AND VEHICLES

Descriptive characteristics including weights, dimensions, FS container material, and type booster for all vehicles included in this report are summarized in table I. The motors designated Nike-Ajax and Arcas in table I denote the Nike-Ajax solid-propellant booster rocket motor (U.S. Army Ordnance M5E1) and the Arcas rocket motor (ref. 2), respectively.

TABLE I.- DESCRIPTIVE CHARACTERISTICS OF PAYLOAD AND BOOSTER

Vehicle designation	Overall length, in.	Type of nose	Fin span, in.	FS container material	Weight of vehicle at launch, lb	Gross payload weight, lb	Weight of FS, lb	Type of propulsion
Nike 36° cone	165	36° cone	43.2	Mild steel	1,521	253	160	Nike-Ajax
Arcas type I	91	10° cone	13	Stainless-steel cylinder; Teflon coated piston	84	19	12	Arcas
Arcas type II	93.7	Ogive	13	Stainless steel	83	18	12	Arcas
Arcas type III	91.7	Ogive	13	Stainless steel	89	24	16	Arcas
Nike-Spear	290		59.5	Stainless steel	1,484	178	87	Nike-Ajax
(Spear)	142	8° cone	25					
Nike 10° cone (no check valve)	235	10° cone	43.2	Mild steel	1,544	267	160	Nike-Ajax
Nike 10° cone (with check valve)	235	10° cone	43.2	Stainless steel	1,555	287	160	Nike-Ajax

The requirement for corrosion resistance dictated selection of stainless steel and Teflon for material in contact with FS. One exception to this requirement was that in some cases Nike type nose cones were made of mild steel instead of stainless steel. This was operationally possible since the vehicle was fired before corrosion could be harmful.

A number of approaches were taken in designs for expelling FS. These approaches generally employed one of two types of pressurization: the impact tube, in which stagnation pressure was used; and the pre-pressurized reservoir type, in which nitrogen gas was used to either push a piston or to pressurize the FS.

Descriptions of the procedure for filling each vehicle with FS and the manner in which each payload functions to expel FS follow.

Nike 36° Cone

The first vehicle considered was the Nike 36° cone. (See fig. 2.) With the center axis horizontal, approximately 10 gallons of FS was added to the Nike 36° cone (see fig. 3) through the fill hole. After filling, the fill hole was plugged and the 36° cone was ready for attaching to the Nike rocket motor.

During acceleration of the Nike 36° cone, FS was in the position as shown in figure 3(a) and no FS flowed from the vehicle. After rocket motor burnout, the FS moved to the position shown in figure 3(b) due to vehicle deceleration caused by drag forces. Stagnation pressure then is utilized to force FS overboard as an aerosol.

Arcas Type I

The Arcas type I configuration may be seen in figures 4 and 5(a). After filling the payload with FS, the space below the piston (nose up) was pressurized to 60 pounds per square inch gage with nitrogen. After vehicle launch, an approximately 10-second delay squib actuated an explosive valve which allowed FS to be forced overboard by movement of the piston caused by the pressurized nitrogen.

Arcas Type II

The Arcas type II payload (figs. 4 and 5(b)) was filled with FS in the outer cylinder and partially filled in the inner cylinder while in a nose-down attitude. The payload was then turned nose up and pressurized with nitrogen to 100 pounds per square inch gage. The nose-up attitude was maintained until the flight to insure that the nitrogen would remain in the end of the cylinder toward the nose. This was done so that FS could be expelled from the inner cylinder while the vehicle was still accelerating. The FS expulsion was started by the initiation of an explosive valve while the vehicle was accelerating. After the Arcas motor burned out, vehicle deceleration forced FS in the inner cylinder to shift toward the nose end of the payload section, displace nitrogen away from the nose end of the inner cylinder, and cause FS to then be exhausted from the outer cylinder.

Arcas Type III

Payloads of Arcas type III (see figs. 4 and 5(c)) were charged in a nose-down attitude with FS. Any FS in excess of the volume of the forward compartment overflowed into the aft compartment which was only partially filled with FS. The remaining volume in the aft compartment served as a reservoir for nitrogen pressurized to 100 pounds per square inch gage.

Although the geometric configuration of this type payload was different from that of the type II payload, this payload functioned in flight in the same manner as the Arcas type II configuration.

Nike Spear

A drawing of the Nike-Spear configuration is shown in figures 6 and 7. FS was poured into the liquid reservoir of the Spear (see fig. 7) after which the pressure cylinder was charged with nitrogen at 150 pounds per square inch gage. At rocket motor burnout, the Nike booster drag separated from the Spear after which an approximately 10-second delay squib, which had been fired simultaneously with the Nike igniter squib, actuated an explosive valve to allow FS to be exhausted overboard. Nitrogen pressure in the FS compartment was maintained at 75 pounds per square inch absolute by means of a pressure regulator.

Nike 10° Cone

The final configuration, Nike 10° cone, is shown in figures 8 and 9. There were two types of 10° cone payloads, both of which were prepared for flight simply by filling the payload compartment with FS and then plugging the fill hole.

The type I payload (see fig. 9(a)) functioned identically to the 36° cone payload. The type II payload (see fig. 9(b)) functioned in a similar manner except that this type was equipped with a check valve in the impact tube which retained high-pressure air accumulated in the space between the 10° nose cone and the FS tank during the flight condition of increasing dynamic pressure. A high-pressure source was thus available when the vehicle was under the condition of low dynamic pressure which would not provide an adequate FS flow rate.

Weights of components of the type II Nike 10° cone, the final vehicle in the development program and the type vehicle which gave the most satisfactory performance, are summarized in the following table:

Component	Weight, lb
10° cone assembly	127
FS	160
Nike-Ajax booster	1,195
Fin assembly	69
Launch fittings	4
Total	1,555

PAYLOAD AND VEHICLE PERFORMANCE

Table II summarizes information relative to the vehicle-payload systems discussed herein. The first vehicle employed in the program to develop a vehicle capable of producing smoke trails to altitudes of 65,000 feet or above, which is appreciably higher than the maximum altitude reached by the Nike 36° cone, was an Arcas fitted with a smoke-producing payload. Since the single-stage Arcas sounding rocket, when used for meteorological applications, had reached altitudes in excess of 200,000 feet, is lightweight, inexpensive, and easy to handle, it was concluded that this motor could very easily be adapted to a smoke-producing payload of such weight that the Arcas rocket motor could boost it to an altitude of at least 100,000 feet. Three designs of smoke-producing payloads boosted by Arcas rocket motors were flown. Flow of FS from each of these vehicles was not started until about 10 seconds after launch to insure that the launcher would not be damaged by FS and to conserve FS during the low-altitude portion of flight when the trail could not be photographed because of camera positions and ground haze. Because burnout altitude of the Arcas is much higher than burnout altitude of the Nike 36° cone and because dynamic pressure in the upper regions of the Arcas trajectory is insufficient for adequate FS flow, the scheme used for expelling FS from the Nike 36° cone, which begins to expel FS at Nike burnout, was not applied to expel FS from Arcas smoke-producing vehicles. Nike burnout occurs very close to the minimum altitude at which wind-shear data can be obtained whereas Arcas burnout occurs at an altitude considerably higher than the minimum altitude for which data are desired.

The first Arcas boosted payload (herein called type I) used a piston to force FS overboard. A series of design problems were experienced with leakage past the piston. A Teflon piston and a Teflon-coated aluminum piston with "O" rings coated with corrosion-resistant flourolube both leaked. The Teflon piston leaked because of its lack of rigidity and the Teflon-coated piston leaked because FS dissolved the "O" rings. This approach was considered unsatisfactory and was abandoned.

This second type Arcas smoke payload (see section "Payload and Vehicle Description") produced a smoke trail, although not of the desired light-scattering ability. Since density of the smoke trail has an effect on light-scattering ability, it was decided to construct three payloads of the third type to produce trails of different density to determine the optimum flow rate required for the desired light-scattering ability. Flight tests of these payloads disclosed that the small width of the trail produced was the main cause of poor photographic detail of these trails and that this inadequacy could not be compensated for by making the trails more dense. It is believed that the width of the smoke trail produced by a vehicle is approximately the same as the width of the turbulent wake produced by a vehicle in flight. The width of the turbulent wake is, in general, dependent upon the widest portion of the vehicle which for most vehicles is the fin span.

Taking into consideration the benefit to be derived from a vehicle using fins of greater span and the previously mentioned desire to extend altitude capability, trajectory computations were made to determine whether a sufficient

TABLE II.- SUMMARY OF VEHICLE OPERATION AND PERFORMANCE

Configuration	Figure	Pressurization method	Altitude range of trail, ft	Remarks
Nike 36° cone	2, 3	Impact tube	6,000 to 45,000	Good trail to apogees of 40,000 to 45,000 feet.
Arcas type I	4, 5(a)	Reservoir pressurized before launch	No flight test	FS forced overboard by piston: This concept abandoned after repeated difficulties.
Arcas type II	4, 5(b)	Reservoir pressurized before launch	5,000 to 65,000	Produced trail to 65,000 feet but of inadequate density; payload limited in orientation prior to launch.
Arcas type III	4, 5(c)	Reservoir pressurized before launch	5,000 to 40,000	Orientation after filling and prior to launch not limited; produced trails of various densities to altitudes between 40,000 and 90,000 feet. No trails were of adequate visibility because of insufficient width.
			5,000 to 65,000	
			5,000 to 90,000	
Nike Spear	6, 7	Reservoir pressurized before launch	15,000 to 85,000	Trail to 85,000 feet but of insufficient visibility because of inadequate width.
Nike 10° cone (conical container)	8, 9(a)	Impact tube	6,000 to 78,000	Conical FS container similar to Nike 36° cone produced trail of sufficient visibility and persistence to 78,000 feet.
Nike 10° cone (check valve)	8, 9(b)	Impact tube with check valve	6,000 to 78,000	Nearly cylindrical (slight taper) FS container; produced trail of good visibility and persistence to 78,000 feet.

altitude could be obtained with a payload stage having fins of substantially greater span than the Arcas. The payload stage would have lower drag than the Nike booster or the aforementioned Nike 36° cone and would separate from the booster approximately at booster burnout. This study showed the altitude capability of such a vehicle to be very promising and, accordingly, a two-stage vehicle, Nike-Spear (see section "Vehicle Description") was designed, constructed, and flown. The 85,000-foot altitude achieved by the Spear was quite satisfactory. However, the light-scattering ability of the trail was found to be inadequate because of its insufficient width.

Realizing that the altitude achievement of the Spear could not be duplicated by a single-stage Nike-Ajax boosted smoke vehicle which, however, could produce a trail of ample width, a study was made to determine what altitude could be expected from a Nike booster with a sharp, nonseparable nose cone which would have considerably lower drag than the Nike 36° cone and consequently attain a higher altitude. A digital computer trajectory program indicated that a Nike vehicle which weighed 1,540 pounds, including 160 pounds of FS and fitted with a 10° nose cone, launched at 80° would reach an altitude of 72,000 feet. Altitude as a function of horizontal range obtained from the flight of the first Nike 10° cone is presented in figure 10 in which the aforementioned digital computer results are also presented for comparison. This vehicle, which weighed 1,544 pounds at launch including 160 pounds of FS, produced a persistent smoke trail (which, although thin in spots, was of good light-scattering ability) to an altitude of 78,000 feet. It was believed that the thin spots in the trail were due to insufficient FS flow which could result from several causes, the most probable of which were insufficient dynamic pressure or lack of contact of FS with the discharge tube in the conical FS container if centrifugal force due to vehicle spin were sufficient to cause FS to lose contact with the discharge orifice by flowing away from the spin axis. A check valve was added to the second Nike 10° cone vehicle to insure adequate air pressure until FS was exhausted and the shape of the FS container was changed to eliminate the possibility of centrifugal force interfering with the discharge of FS. Altitude and velocity of the first Nike 10° cone vehicle are presented in figure 11 as functions of time. These data prior to 14 seconds were not obtained because of delay in radar acquisition of the vehicle.

At the time the first Nike 10° cone was flown from a fixed launcher, the NASA was planning a program of periodic launchings of smoke vehicles at several missile ranges in this country to obtain wind-velocity profiles. At this point it was necessary to establish vehicle reliability and vehicle-launcher compatibility prior to commencing the aforementioned program. Because of their availability, mobility, and adaptability, it was established that standard Nike-Ajax military launchers modified to handle four-fin Nike boosters would best satisfy the launcher requirements at these sites. Therefore, a series of eight firings were made at Wallops Island to complete qualification of the Nike 10° cone vehicle, to qualify the military launcher, and to obtain wind-velocity profiles. A photograph of a Nike 10° cone on a modified Nike-Ajax military launcher is presented in figure 12. These vehicles launched at elevation angles between 70° and 81° produced persistent trails of good light-scattering ability to apogees between 61,000 and 79,300 feet. In addition to the acceptable performance of the payload and vehicle, another desirable feature is that the cost of the vehicle

system is reasonably low (approximately \$3,000.00 in lots of 50 or more) so that numerous firings at various missile ranges are not prohibitively expensive. Modified military launchers which were used subsequent to the initial Nike 10⁰ cone firing functioned satisfactorily.

CONCLUDING REMARKS

All devices tested which utilize a piston to expel FS (a solution of sulfur trioxide chlorosulfonic acid) overboard were found to be unsatisfactory and are considered to be impractical. Up to the altitude where atmospheric moisture becomes insufficient, light-scattering ability of an FS smoke trail is dependent upon the amount of FS dispensed per unit volume of smoke trail and the maximum transverse dimension or fin span of the smoke-trail vehicle. However, there is a limit beyond which light-scattering ability cannot be increased by means of greater FS flow rate but can be enhanced only by increasing the fin span of the vehicle. Of the several types of vehicles flown, only Nike 36⁰ cone and Nike 10⁰ cone vehicles had sufficient fin span to produce a satisfactory trail.

In view of the altitude achieved by the Nike 10⁰ cone vehicle, which produces persistent smoke trails of good light-scattering ability, and the satisfactory operation of the modified Nike-Ajax military launcher, equipment of this type is being employed in a program of systematic determination of wind velocities at several missile ranges in this country.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 10, 1963.

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2. Webster, R. C., Roberts, W. C., Jr., and Donnell, E. P.: Final Report Development of the Arcas Rocketsonde System. Contract NOnr-2477(00), Atlantic Res. Corp. (Alexandria, Va.), Feb. 29, 1960.

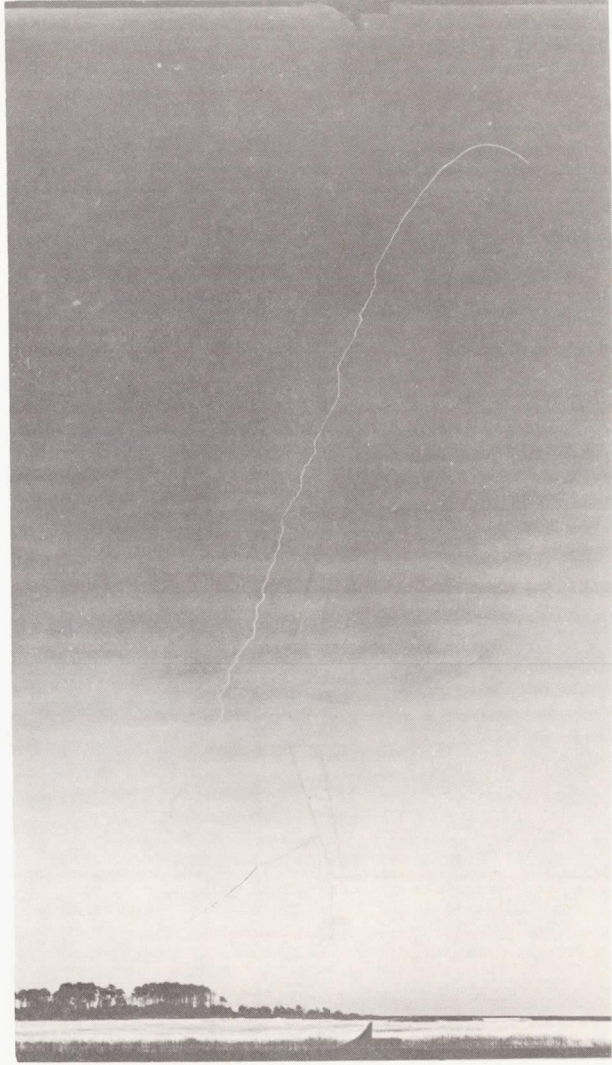
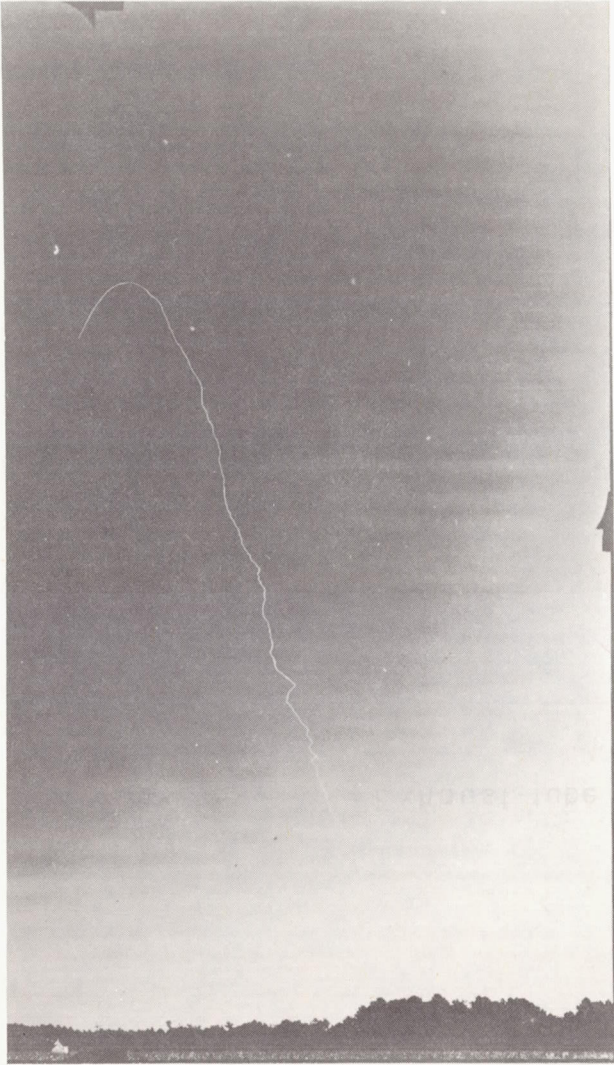


Figure 1.- Smoke trail as simultaneously photographed from two camera sites.

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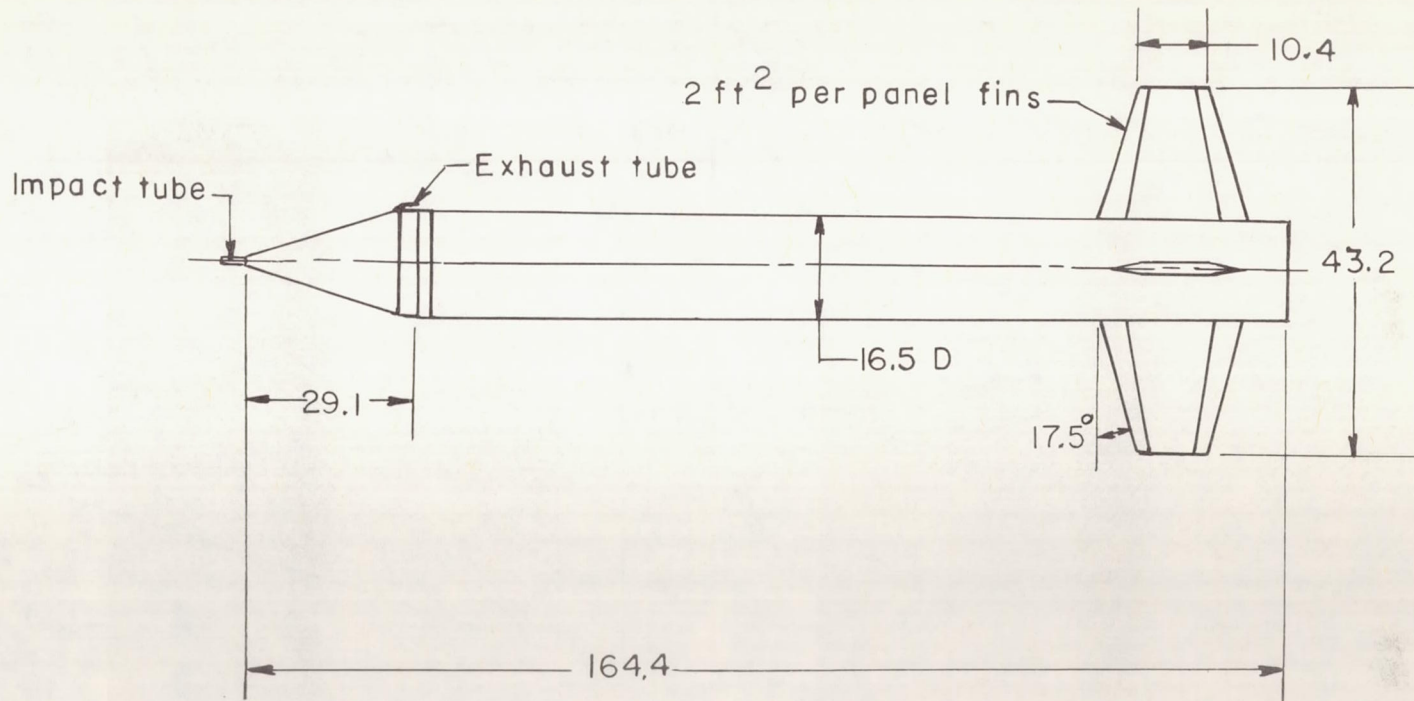
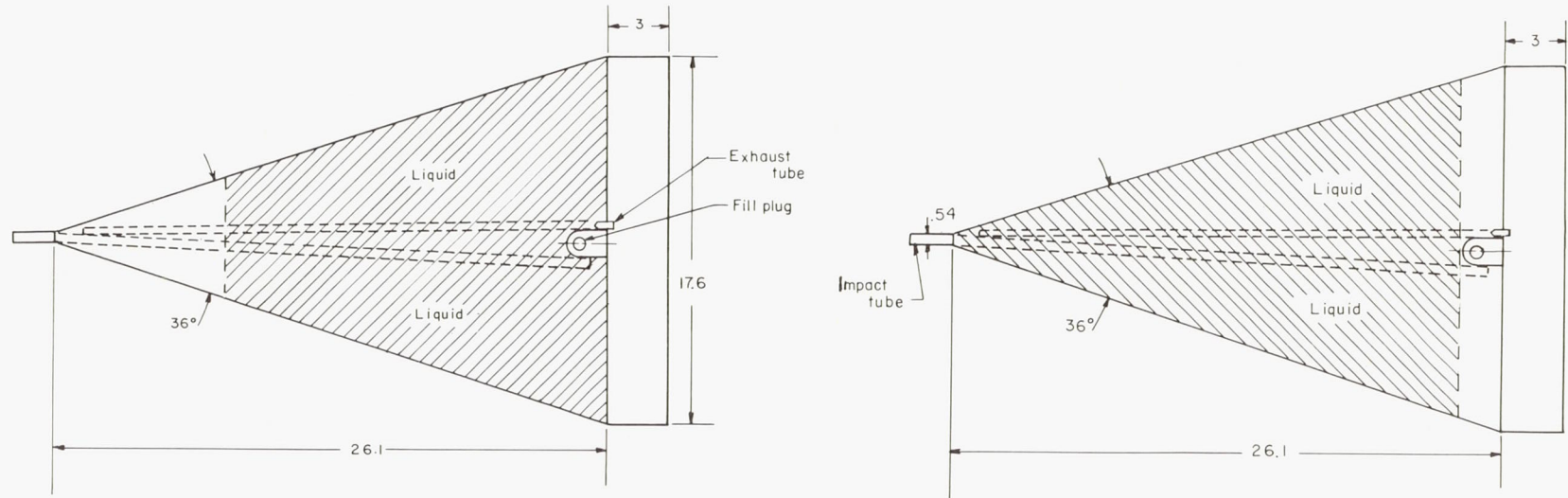


Figure 2.- Assembly drawing of Nike 36⁰ cone vehicle. All dimensions are in inches.



(a) Vehicle accelerating; no discharge of FS.

(b) Vehicle decelerating and discharging FS.

Figure 3.- 36° nose cone smoke generating payload. All dimensions are in inches.

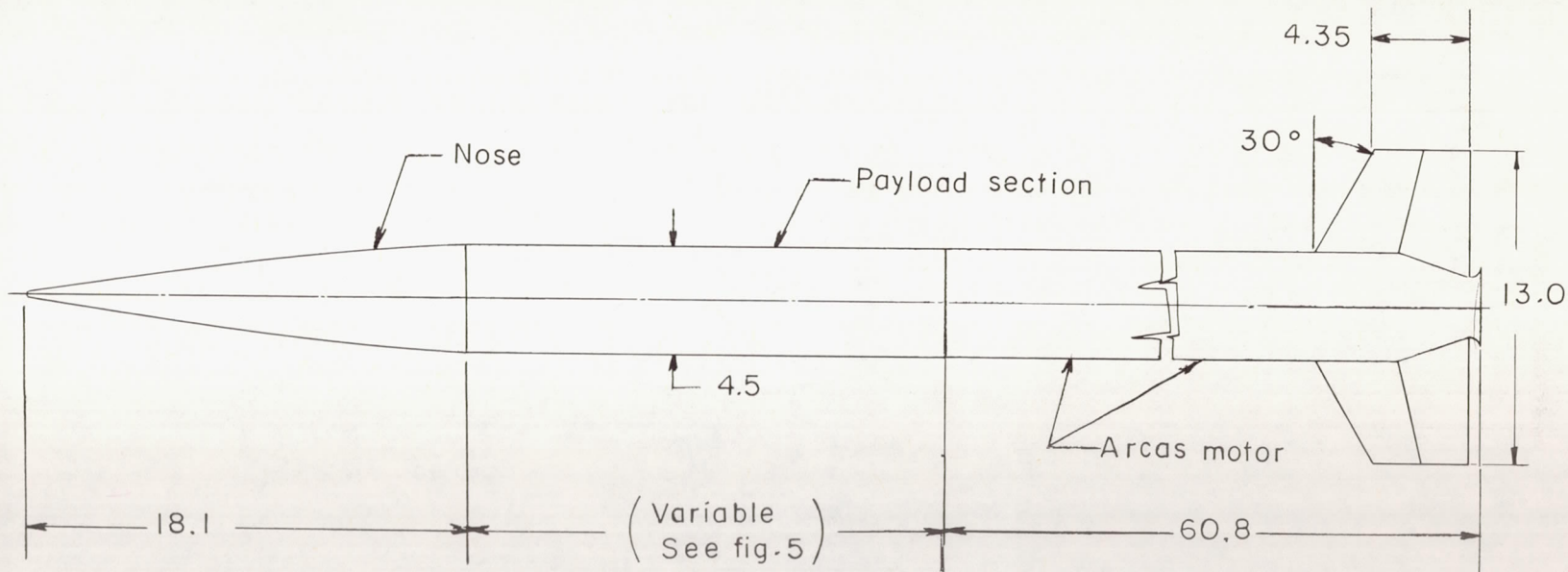
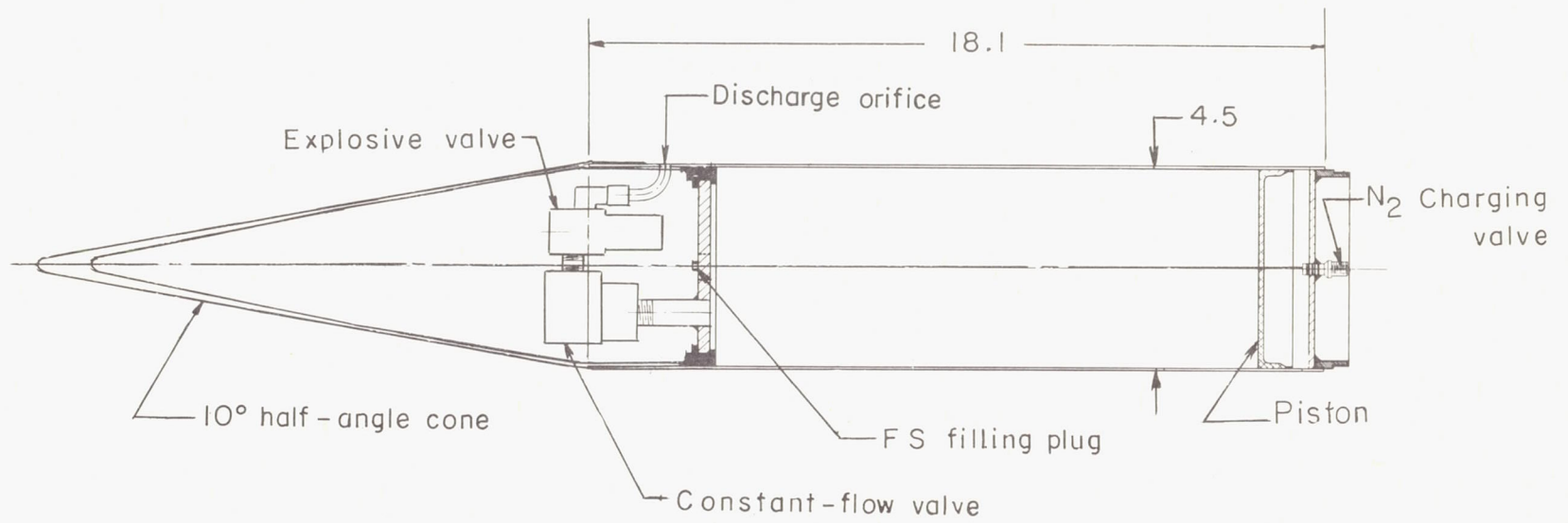
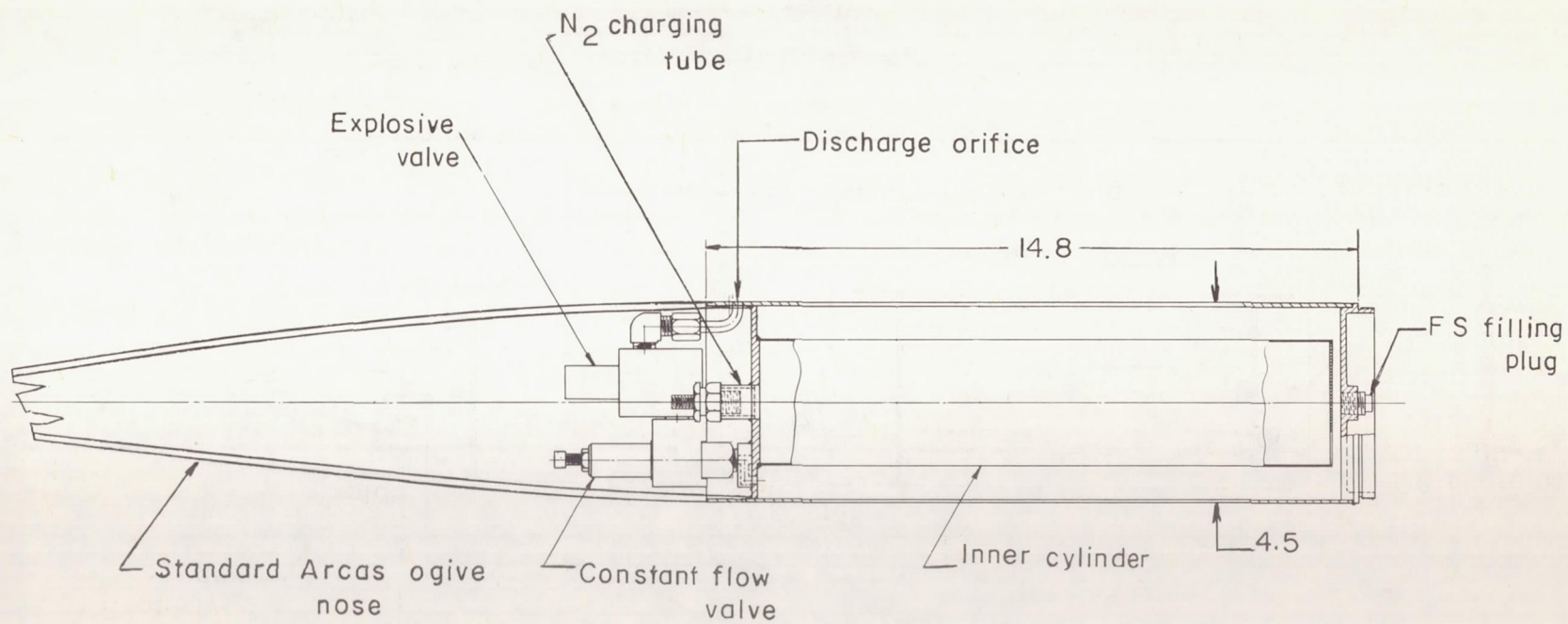


Figure 4.- Assembly drawing of an Arcas smoke-producing vehicle. All dimensions are in inches.



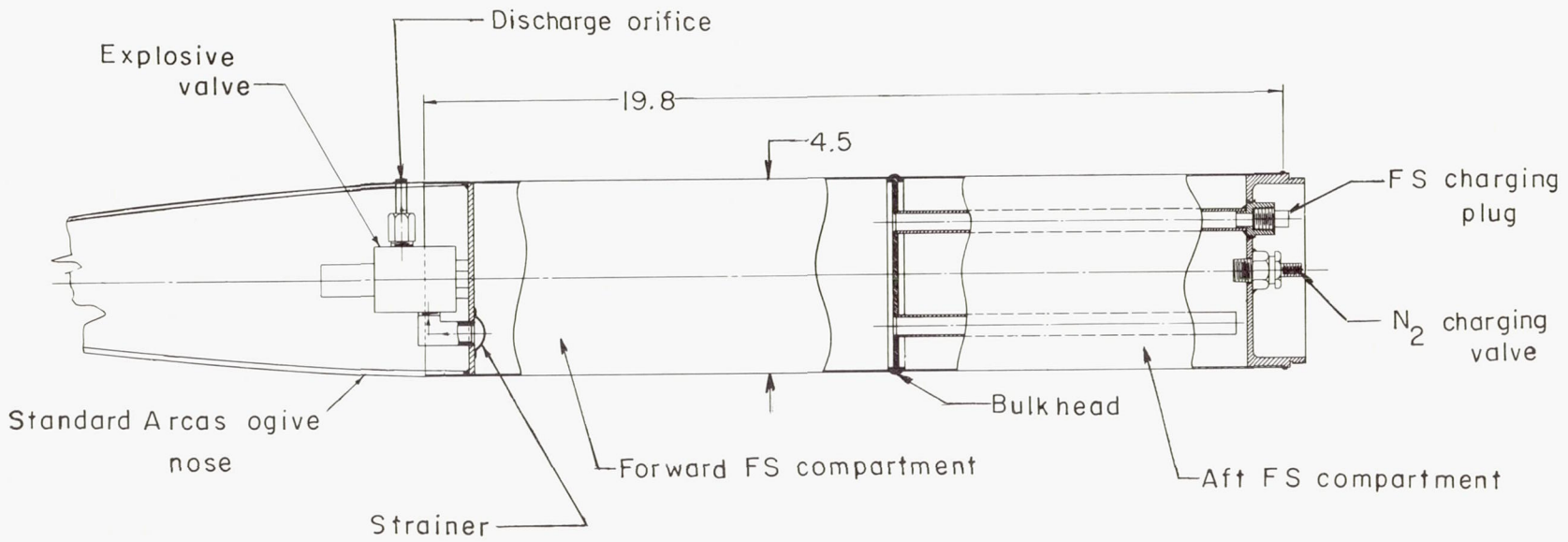
(a) Type I Arcas payload.

Figure 5.- Arcas smoke-producing payloads. All dimensions are in inches.



(b) Type II Arcas payload.

Figure 5.- Continued.



(c) Type III Arcas payload.

Figure 5.- Concluded.

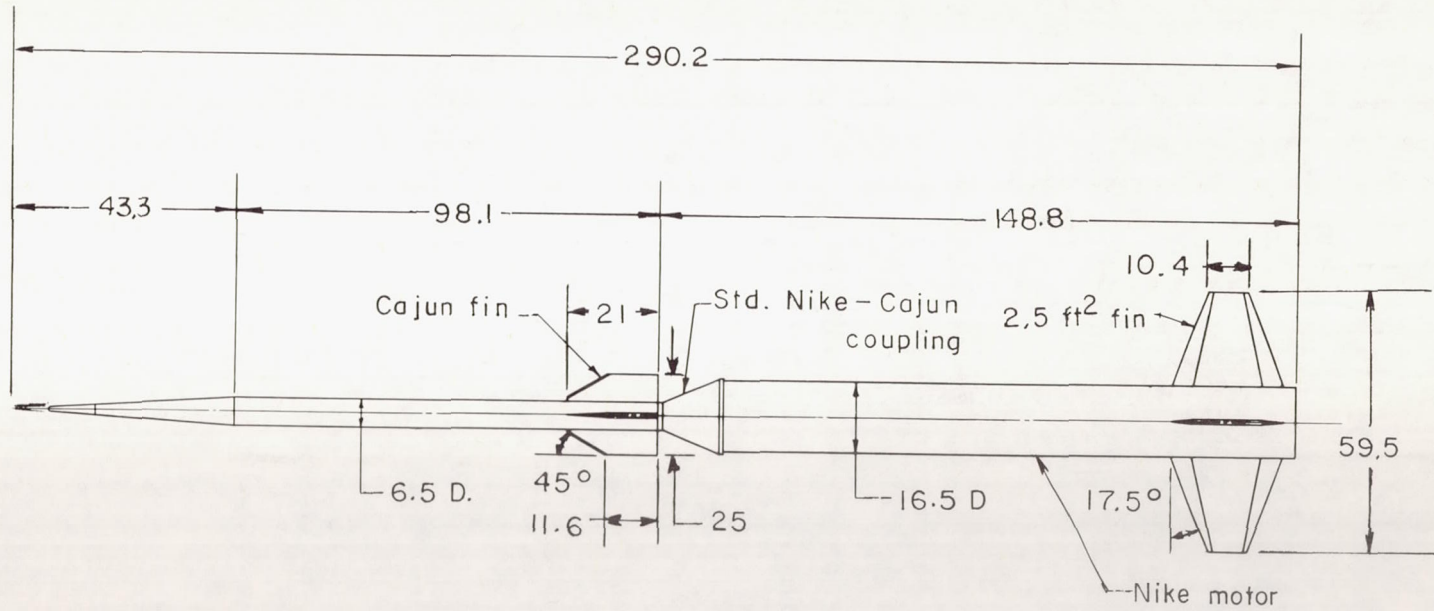


Figure 6.- Assembly drawing of Nike Spear. All dimensions are in inches.

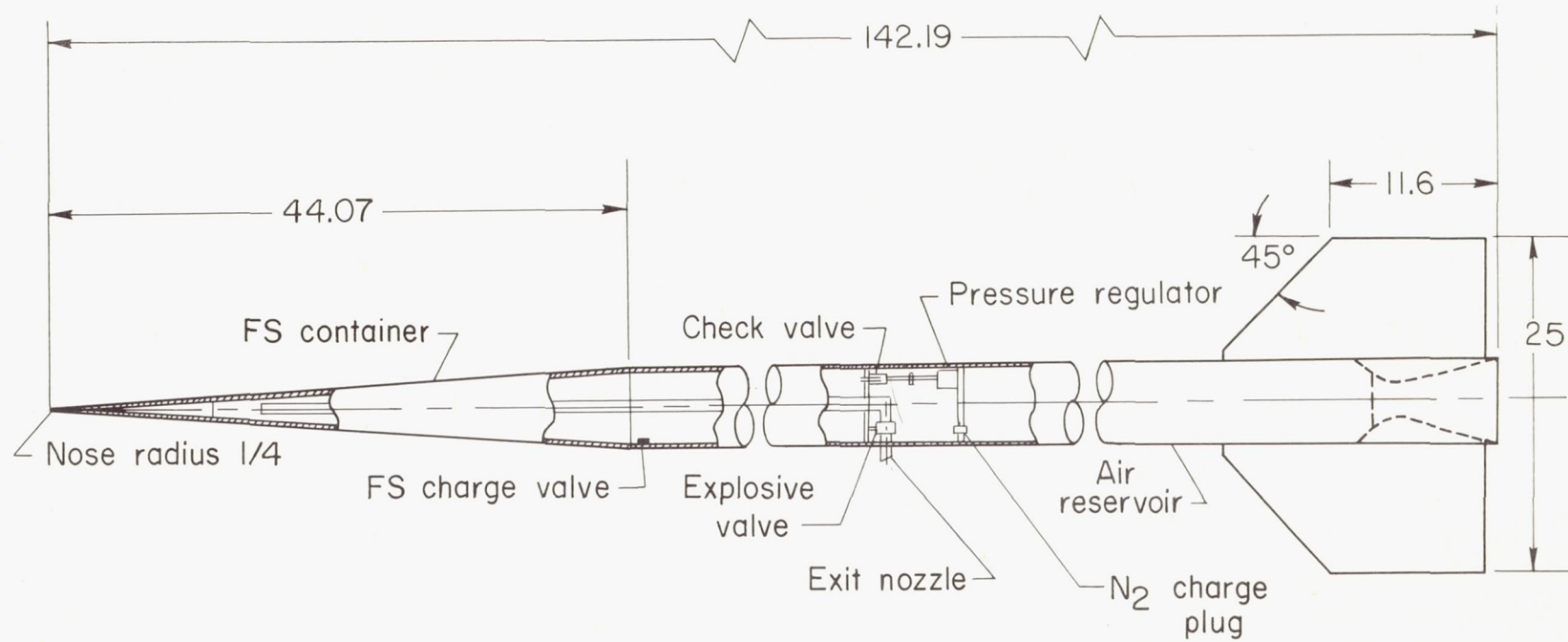


Figure 7.- Nike-Spear payload details. All dimensions are in inches.

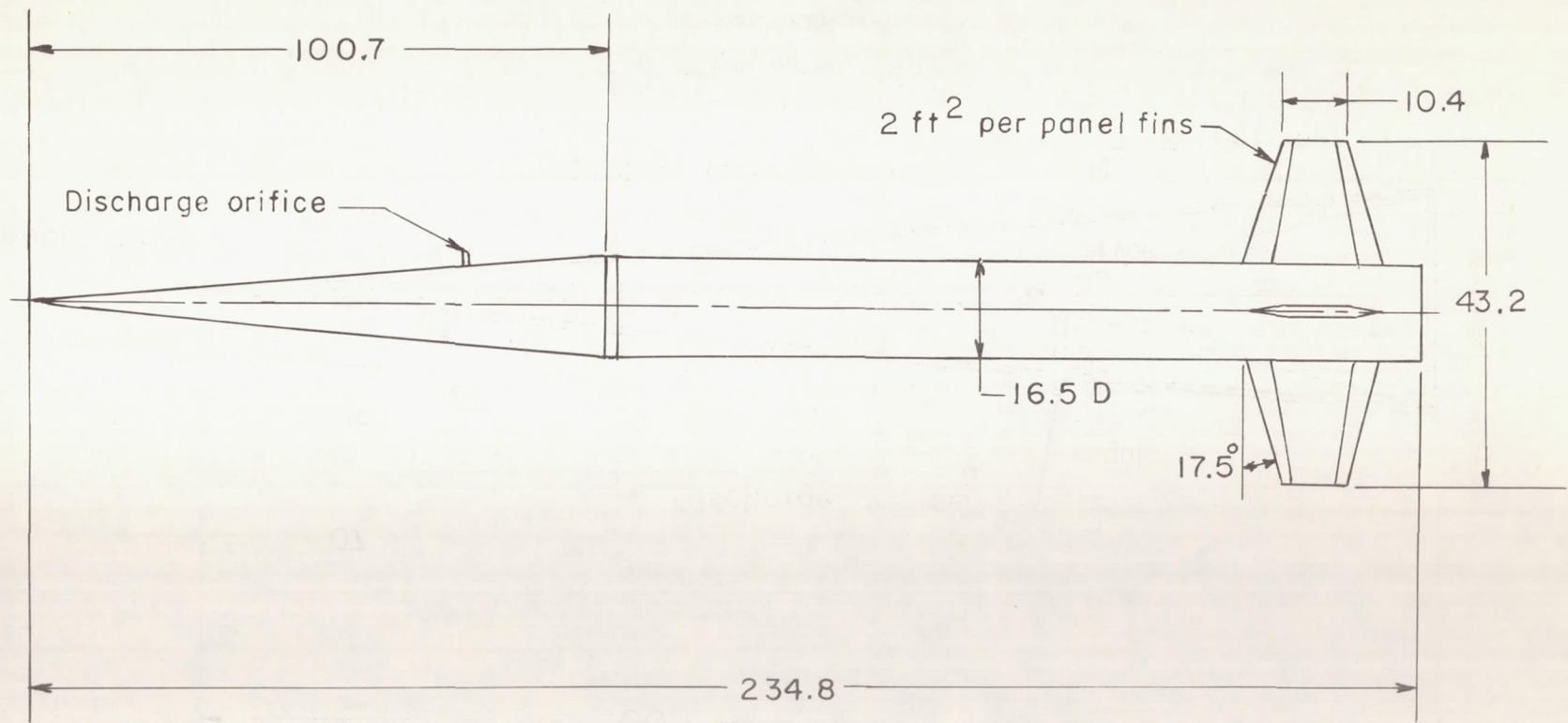
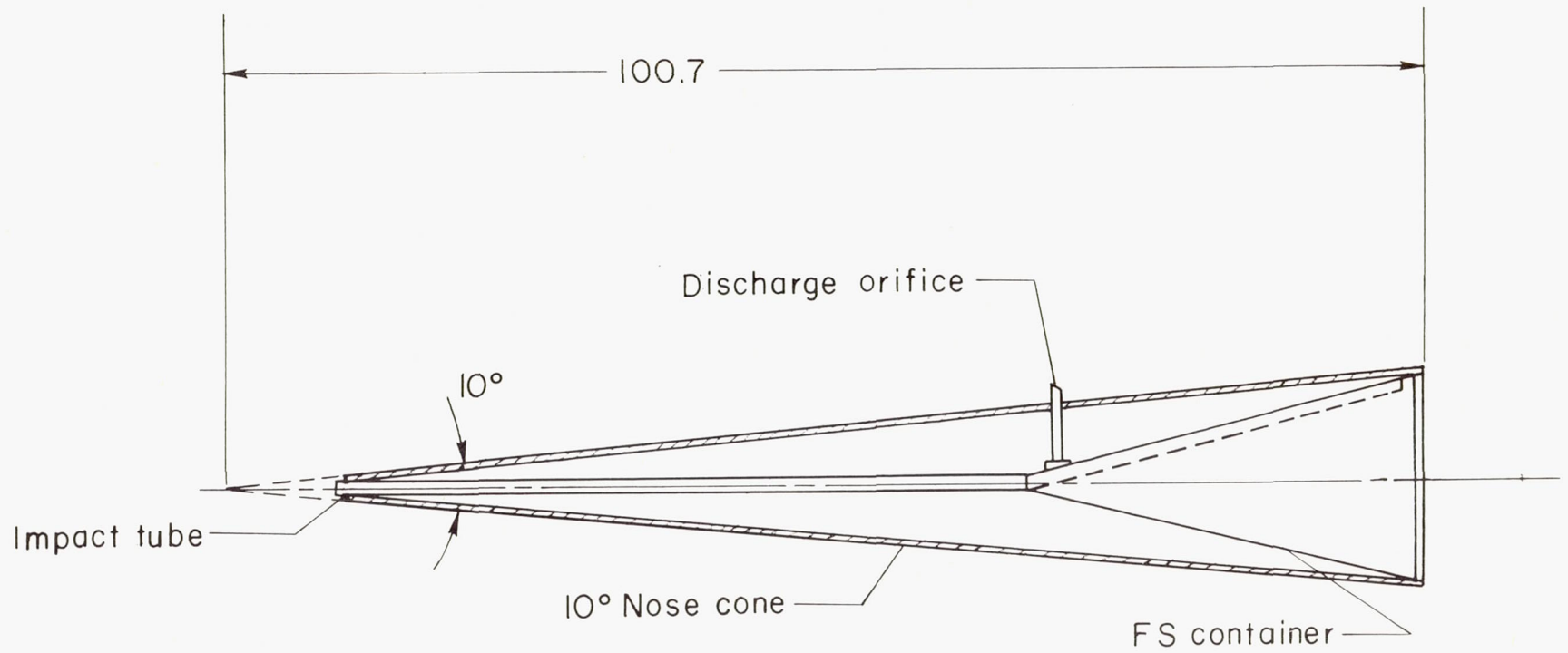
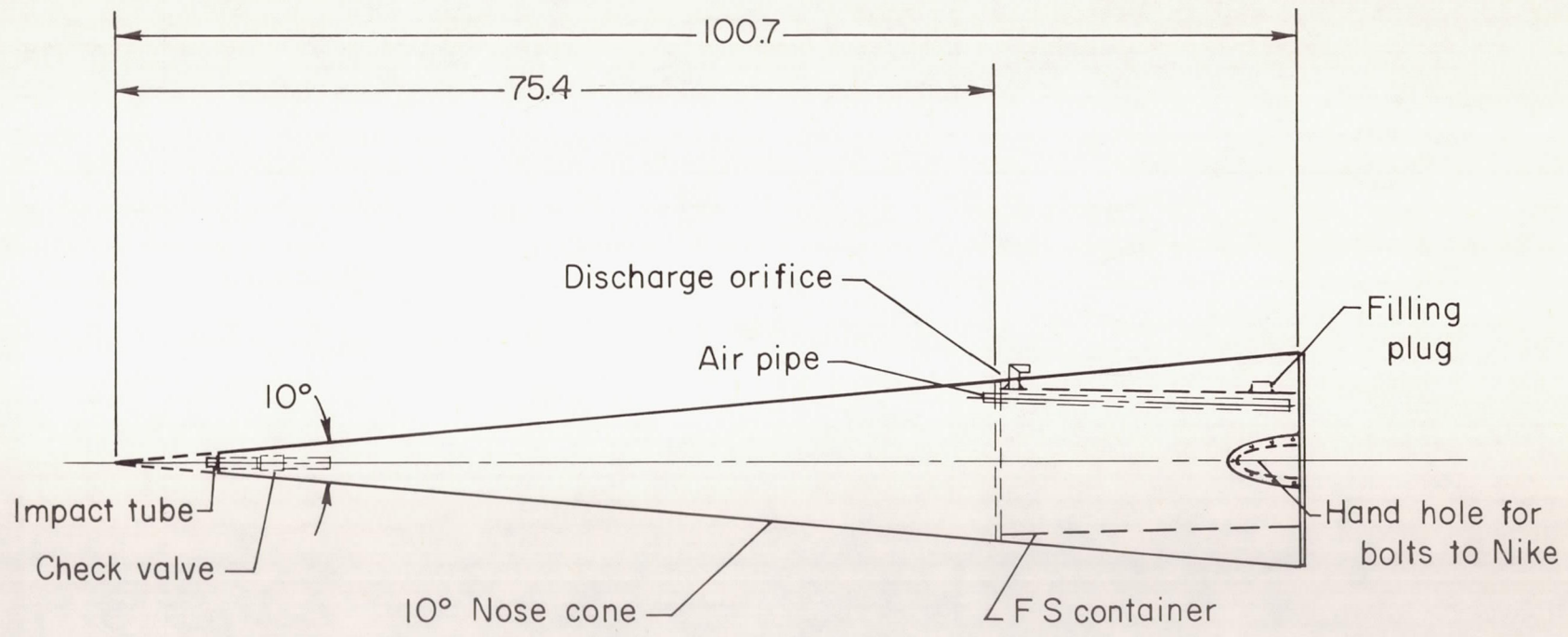


Figure 8.- Assembly drawing of Nike 100 cone vehicle. All dimensions are in inches.



(a) 10° cone payload type I.

Figure 9.- 10° cone payloads. All dimensions are in inches.



(b) 10° cone payload type II.

Figure 9.- Concluded.

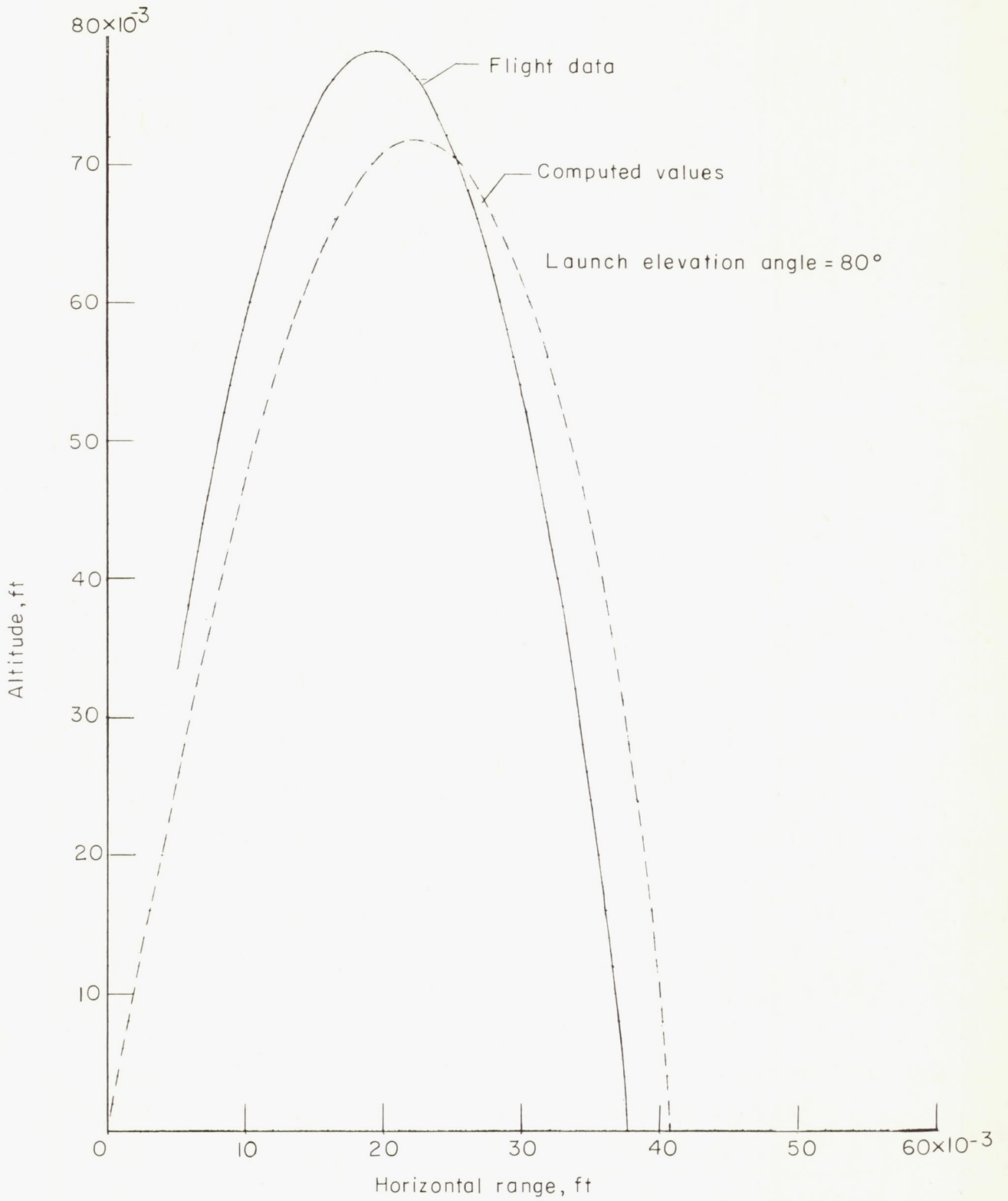


Figure 10.- Altitude as a function of horizontal range for Nike 10^0 cone.

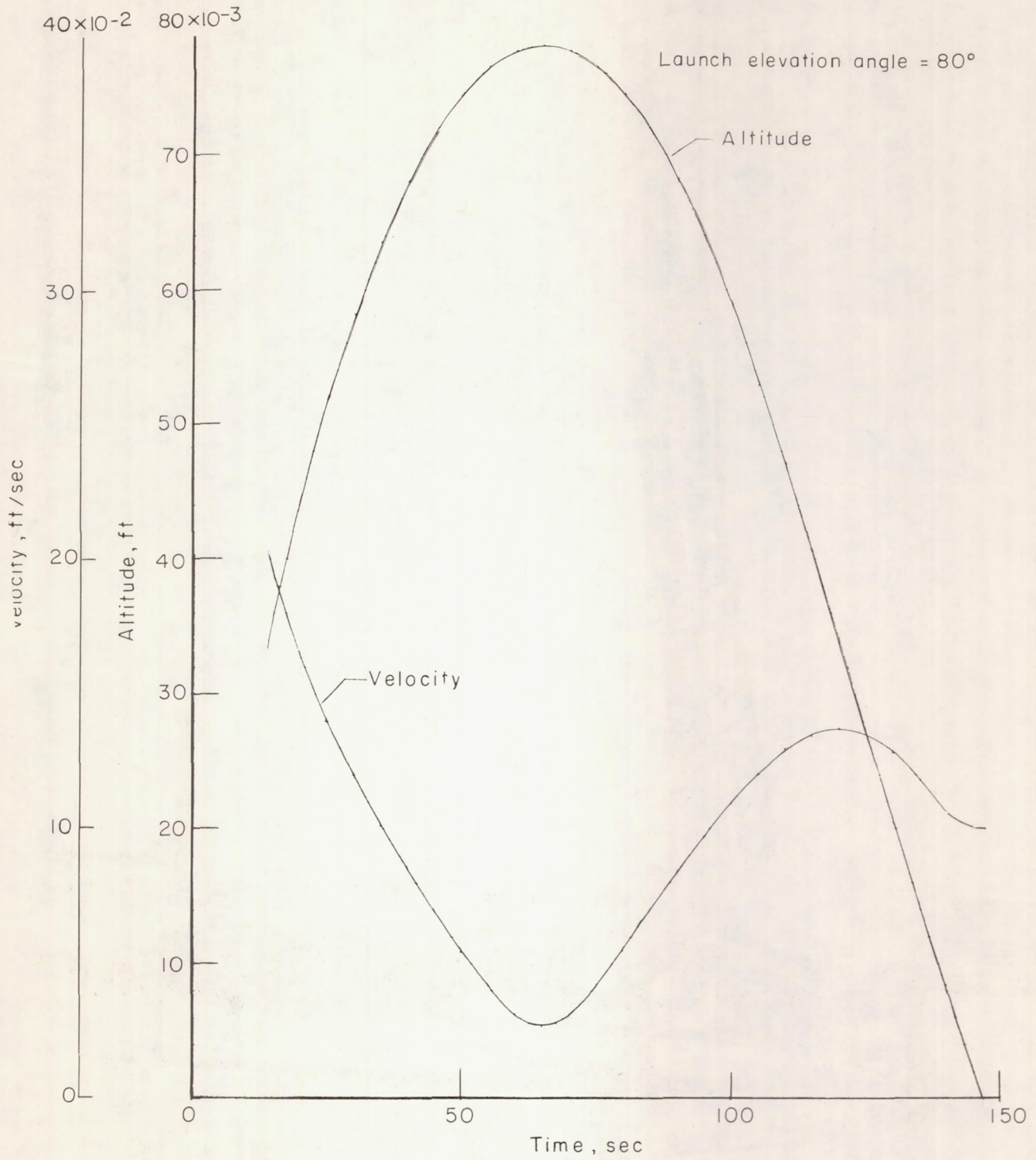


Figure 11.- Altitude and velocity as functions of time for Nike 10⁰ cone.



Figure 12.- Nike 10° cone on modified Nike-Ajax military launcher.

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