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VACUUM-TUBE LAUNCHERS AND BOOSTERS

By
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White Sands Missile Range, New Mexico

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NOTICES

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ABSTRACT

Systems are being developed by the Atmospheric Sciences Laboratory to investigate the feasibility of using an evacuated (vacuum) tube as either a launcher or booster for small to medium size projectiles. Two eight-inch diameter tubes are being fabricated to propel a one- to three-pound meteorological probe into the lower atmosphere. A 70-foot long tube can propel this projectile to approximately 7000 feet above ground level, while a 20-foot tube will send the same projectile to an altitude of approximately 3500 feet.

A vacuum tube may be used to impart initial velocities in the range of 300 to 500 ft sec^{-1} to the ARCAS. This increased launch velocity will result in a 10 to 20 percent increase in peak altitude, with a simultaneous reduction in wind effect of 30 to 60 percent.

CONTENTS

INTRODUCTION

The use of a vacuum-tube system to launch low-altitude meteorological probes was proposed by Kumar and Shieh [1] who discussed the potential and feasibility of such a system. Kumar also suggested the employment of a vacuum tube as a method of imparting initial velocities to meteorological rockets such as the ARCAS. This paper will describe systems which are being developed by the Atmospheric Sciences Laboratory to explore this technology.

The vacuum-tube system consists of a partially evacuated tube with a breakable seal at the top and with the lower end sealed by the cup of a missile sabot (Figure 1). The expansion chamber near the top reduces the buildup of pressure ahead of the projectile as it moves up the tube. The principle of operation of such a system is the utilization of atmospheric pressure to impart an initial velocity to the rocket. When the sabot is released, atmospheric pressure accelerates the missile and sabot. The maximum acceleration is obtained at the instant of release and is given in g's by $PAW^{-1}-1$, where W is the weight of the missile and sabot, A is the cross-sectional area of the tube, and P is the difference between atmospheric pressure and the residual pressure within the tube. The exit velocity thus depends upon the length and diameter of the tube, the weight of the missile and sabot, and the residual pressure inside the tube.

THEORETICAL CALCULATIONS OF EXIT VELOCITY

As the projectile moves up the tube, factors such as flow loss, friction, and pressure increase in front of the projectile will result in a decrease in acceleration. The following equation of motion for a projectile moving inside a vertical launch tube was derived by Kumar, Rajan, and Murray [2]:

$$1/2\,(m + \rho A x)\frac{dV^2}{dx} + 1/2\,A\rho V^2 + 1/2\,A\rho f\,\frac{x}{D}V^2 + A\rho x g + mg(1+s) - A\,(P - P_{sx}) = 0 \qquad (1)$$

where

m = mass of projectile
ρ = atmospheric density
A = internal cross-sectional area of tube
D = internal diameter of the tube
f = frictional factor for the tube
mgs = sliding or solid friction between the tube and the projectile
x = distance of the projectile from the breech end
V = velocity of the projectile

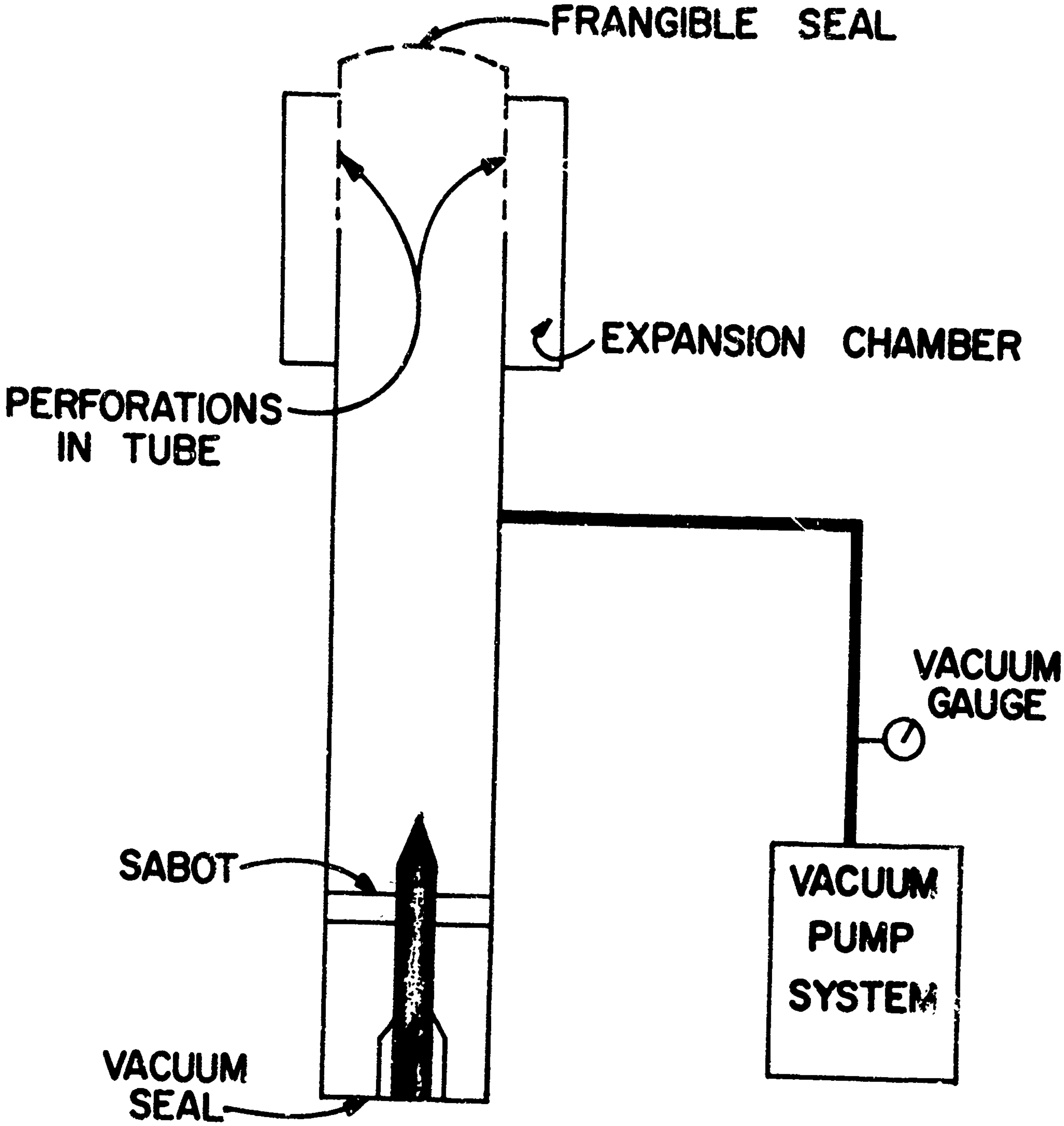

FIGURE 1. VACUUM TUBE LAUNCHER SYSTEM

P = atmospheric pressure

P_{sx} = stagnation pressure in front of the projectile at position x.

A numerical solution and FORTRAN program of the solution were obtained by Lee [3]. The solution assumes adiabatic compressible flow. In this same study Lee presented comparisons of theoretical results with experimental results obtained at Duke University. These comparisons showed close agreement between prediction and observation.

METEOROLOGICAL PROBE LAUNCHERS

In the development of an atmospheric sounding system one must consider the altitude regime to be sounded, the parameters to be measured, reliability, and, of course, cost (both of the original installation and of operation). The vacuum-tube launcher should provide a reliable, low-cost system for wind and temperature measurement in the lower atmosphere.

Two systems, each consisting of a vacuum-tube launcher and a meteorological probe, are being developed for wind and temperature measurements in the lower atmosphere. The launcher tube for each system has been fabricated from 8-inch inside diameter aluminum tubing. The general design for both tubes is the same as shown in Figure 2, except for length. The first system has been designed as a mobile facility with a tube length of 20 feet, while the second will be a fixed installation with a tube length of 70 feet. The probe will be a small, fin-stabilized, reusable, instrumented missile which will eject a parachute at or near apogee. The instrumented missile then descends on the parachute. The instrument will measure and transmit temperature data to a ground station, while wind data will be obtained by radar track of the parachute.

The launch tube for the mobile system is mounted on a frame assembly (see Figure 3) which together with the tube weighs approximately 600 pounds. Since the system can be carried on a small truck, it provides a system for gathering data at remote locations such as those used for either special meteorological studies or military operations. The tube itself may be lowered for transport or during periods when measurements are not required and raised to a desired elevation angle for firing. The elevation angle control allows for placement of the probe near a desired spatial point.

The tube for the fixed installation consists of three sections: A 24-foot section containing the breech and release mechanism; a 22-foot section containing the expansion chamber and muzzle; and a 24-foot center section. This system can be installed as a 46-foot tube by deleting the center section. A rigid structure, such as the side of a building or a telephone pole, is required for support of the tube. The latter will be used for test firings at White Sands Missile Range (WSMR), New Mexico.

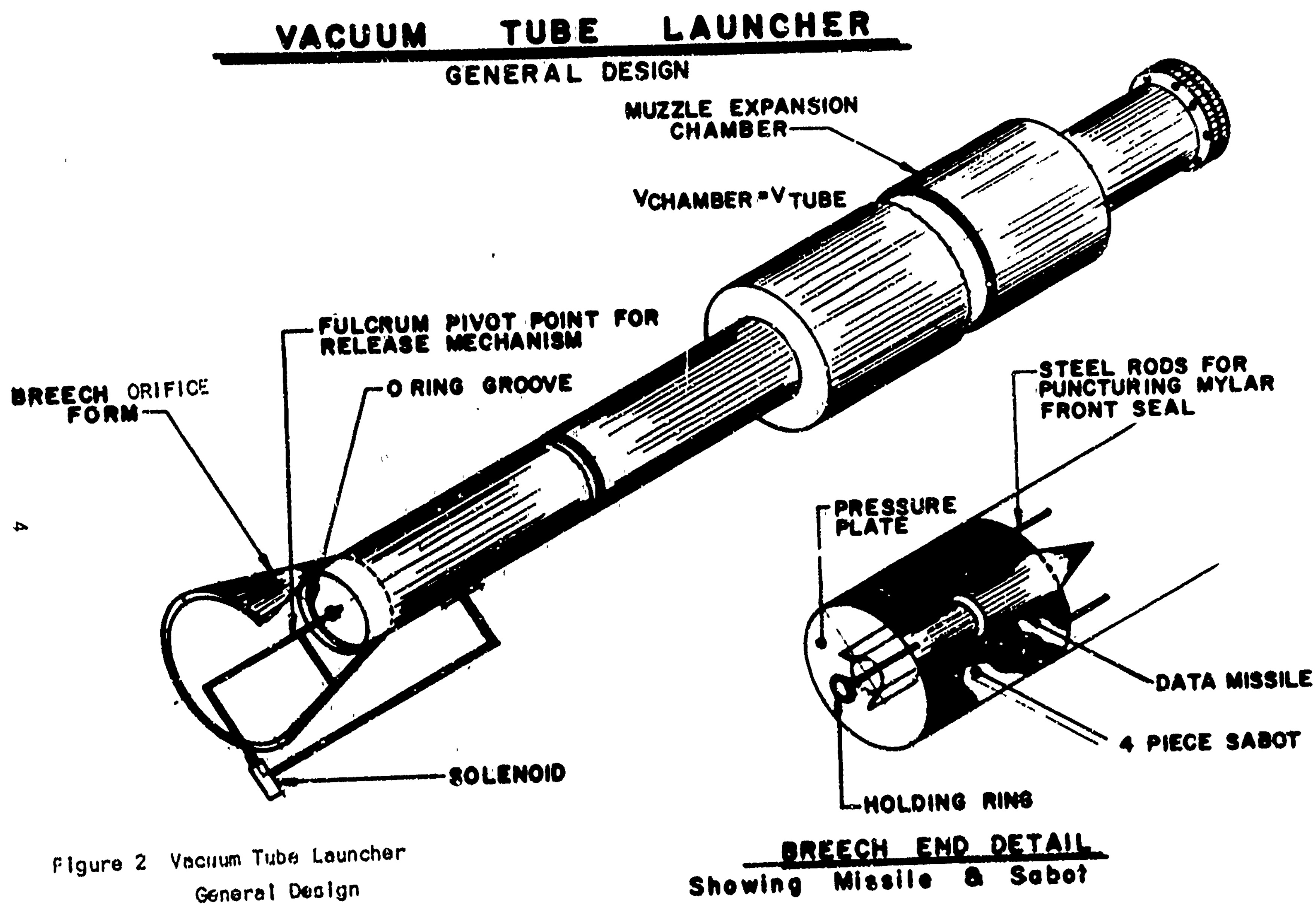

Figure 2 Vacuum Tube Launcher General Design

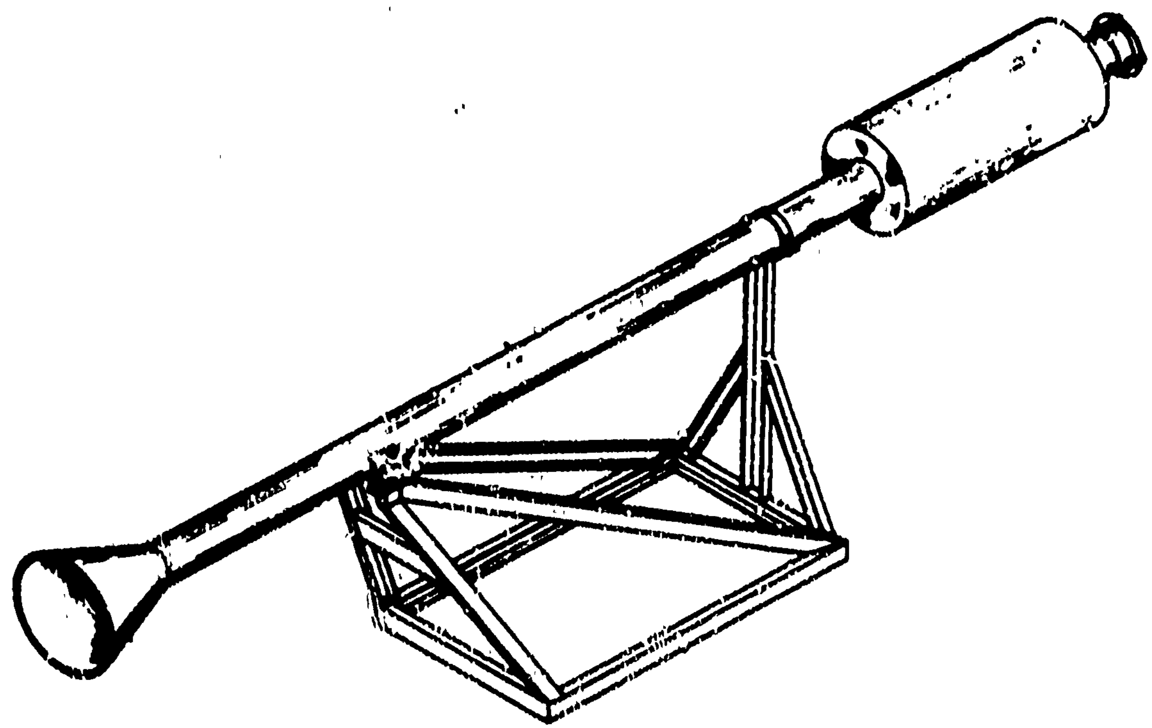

ILLUSTRATION VIEW

Figure 3 Mobile Launcher

The exit velocity of a projectile from a vacuum tube may be obtained from the solution of equation 1. Once the tube has been specified, the exit velocity is a function of the weight of the projectile, the residual pressure inside the tube, and the mean sea level (MSL) altitude of the launcher (since atmospheric pressure decreases with altitude). Theoretical values of exit velocity for projectile weights of 1, 2, and 3 pounds, tube lengths of 20 and 70 feet, and various values of internal pressure are shown in Figure 4 for sea level and WSMR launches.

The primary forces acting on the projectile after it exits the launcher will be those of gravity and aerodynamic drag. The corresponding equation of motion for the projectile is

$$m \frac{dV}{dt} = -(1/2\ C_d \rho V^2 A + mg). \qquad (2)$$

The maximum height obtained by the projectile may be obtained by numerical integration of equation 2, using the exit velocity as an initial condition.

It is easy to see from equation 2 and Figure 4 that the peak altitude depends upon the mass and drag coefficient of the projectile. Thus, to obtain high altitudes, it is important to design a projectile with a suitable shape for low aerodynamic drag. Designs for two prototype missiles are shown in Figure 5. The estimated drag coefficient for each of these projectiles is approximately 0.2. The dependence of peak altitude on mass is not easily analyzed in the absence of calculations since both exit velocity and deceleration due to drag are inversely proportional to mass. Computed values of peak altitude for tube lengths of 20, 46, and 70 feet and projectile weights of 1, 2, and 3 pounds are shown in Table 1. In each case, the exit velocity for an internal pressure of 1" Hg was used since experience has shown that such a residual pressure is readily obtainable. It is clear from Figure 4 that peak altitude will vary with the residual pressure in the tube. A typical plot of this variation is shown in Figure 6. From the data shown in Table 1, it appears that an optimal projectile weight is approximately two pounds.

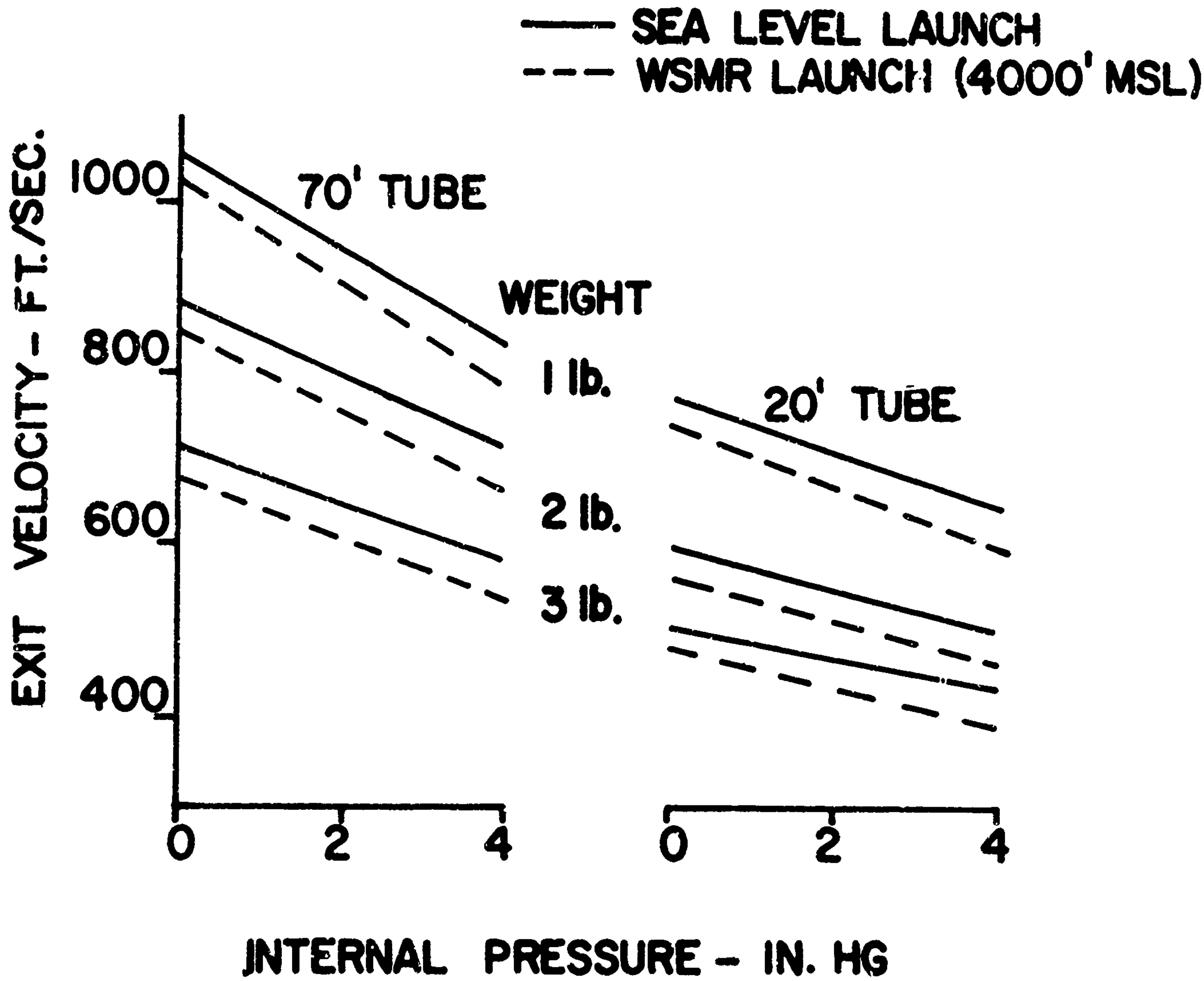

FIGURE 4. THEORETICAL EXIT VELOCITIES FOR METEOROLOGICAL PROBE

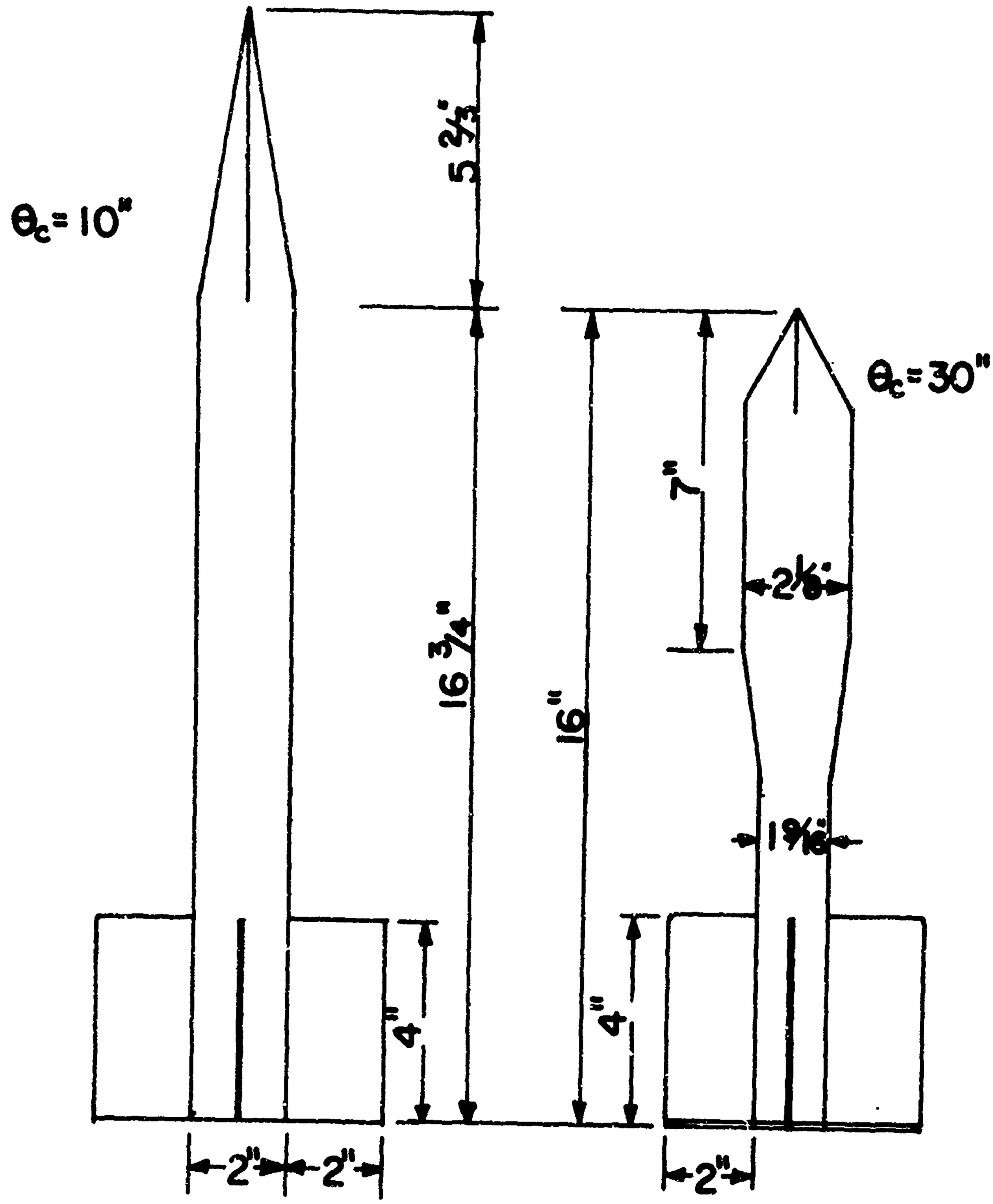

FIGURE 5. PROTOTYPE METEOROLOGICAL PROBES

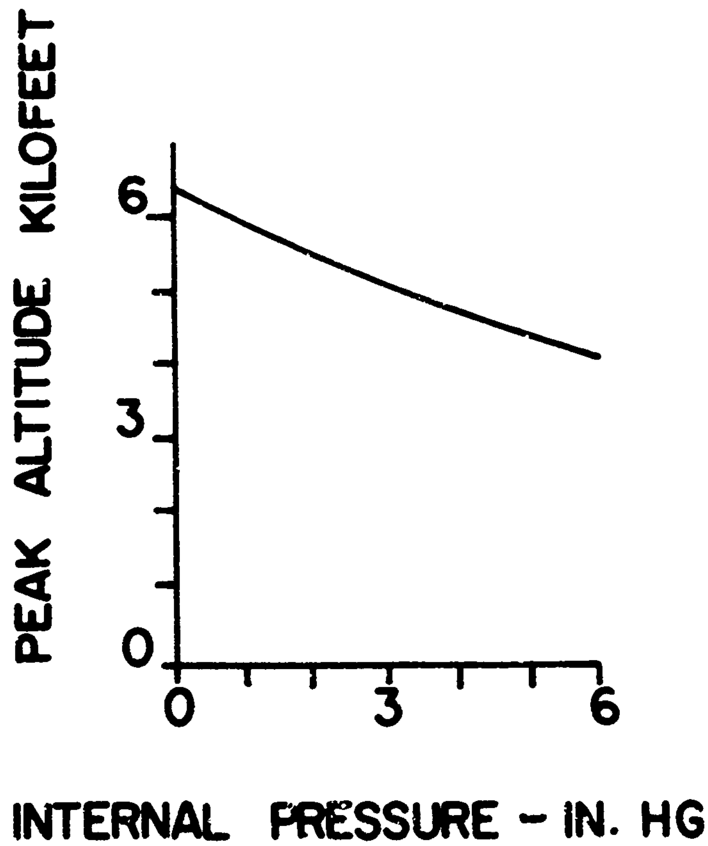

FIGURE 6. PEAK ALTITUDE FOR 2 lb. METEOROLOGICAL PROBE. $C_d = 0.2$, TUBE LENGTH = 70'

TABLE I

PEAK ALTITUDE FOR VARIOUS TUBE LENGTHS AND PROJECTILE WEIGHTS

WEIGHT	LAUNCH ALTITUDE	TUBE LENGTH 20 ft.	46 ft.	70 ft.
1 lb.	Sea Level	3655	4759	4883
2 lb.	Sea Level	3511	5194	5889
3 lb.	Sea Level	3035	4946	5739
1 lb.	4000 ft.	3707	4802	5216
2 lb.	4000 ft.	3361	5132	5806
3 lb.	4000 ft.	2791	4768	5677

VACUUM BOOSTER FOR THE ARCAS

The ARCAS rocket is one of the principal vehicles used by the Meteorological Rocket Network for measurements in the upper atmosphere. It is fired from a closed-breech launcher approximately fifteen feet long. A gas generator is used as a "booster assist". With this system the rocket exits from the launcher at 0.16 second with a velocity of 221 feet sec^{-1}. (These are average figures; there appears to be considerable round-to-round variation.)

The ARCAS is fairly wind sensitive, having a unit wind effect of 2.2 miles/MPH. This necessitates meteorological support for prelaunch impact predictions. Excessive wind speed and/or wind variability sometimes causes cancellation of planned launches.

A vacuum-tube launcher would provide a "booster assist" for the ARCAS, yielding exit velocities well in excess of that provided by the present system. A schematic for a proposed tube design is presented in Figure 7. The muzzle end is partially capped. This cap serves two purposes; it supports the vertical rods and simplifies the problem of sealing the end of the tube since a much smaller area must be sealed. The opening in the cap is, of course, large enough for passage of the missile. This cap, together with the system of vertical rods, allows for a simple sabot or carrier system.

The carrier system (sabot) would consist of the styrofoam packing used with the current ARCAS launcher and the pressure plate shown in Figure 7. The styrofoam would be placed between the rocket and the vertical

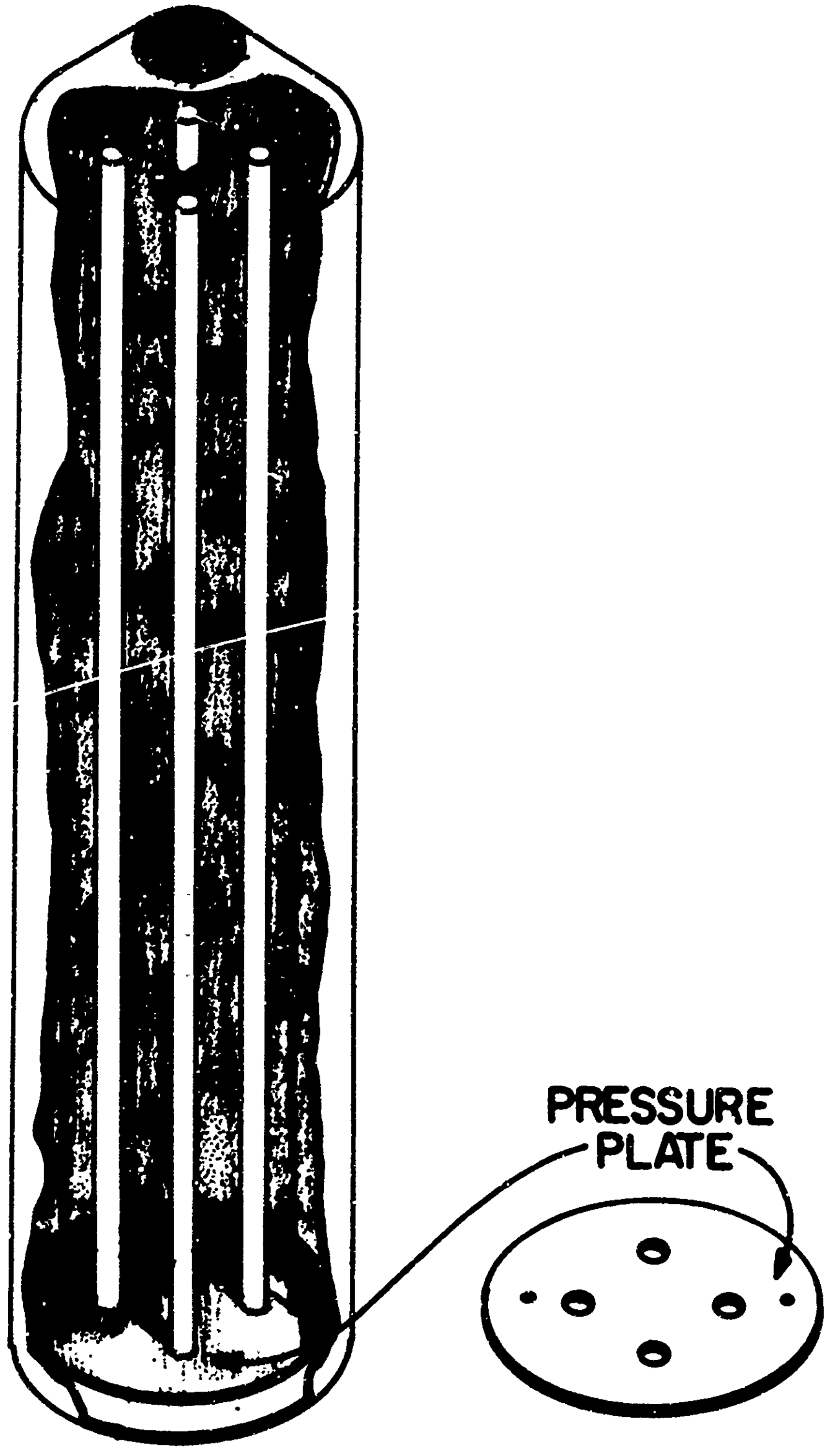

FIGURE 7. PRELIMINARY DESIGN

rods to maintain proper alignment of the rocket prior to and during the launch. Atmospheric pressure would act upon the pressure plate which would push the rocket down the tube. The pressure plate would also serve as the breech-end vacuum seal. An "O" ring seal would be used to seal the pressure plate and the tube itself. Smaller "O" rings would be used to seal the openings for the vertical rods. The styrofoam will exit the tube with the rocket. The pressure plate will be caught by the springs near the breech end and then will fall back down the tube.

The design proposed here will provide a launcher which is easily adaptable to rockets other than the ARCAS (e.g., the RDT&E Met Rocket) with minor changes in the carrier system.

A method for supporting the tube and providing azimuth and elevation angle control has been omitted since it is believed that several techniques employed by conventional launchers could be used with the vacuum tube for this purpose.

Exit velocities obtainable with the vacuum launcher are shown in Figure 8 for missile and sabot weights of 80 and 90 pounds. The nominal launch weight of the rocket including payload is approximately 77 pounds. With the carrier system described above, it should be possible to achieve a gross missile and sabot weight of near 80 pounds. Figure 9 depicts a time history of velocity and acceleration for three different tube diameters. It is easy to see that an exit velocity in the range 300 - 500 feet/second is readily achievable.

The increased altitude and decreased wind effect provided by usage of the vacuum-tube launcher are shown in Figure 10. It can be seen that an increase of 10 to 20 percent in altitude with a simultaneous decrease of 35 to 60 percent in wind effect is obtained.

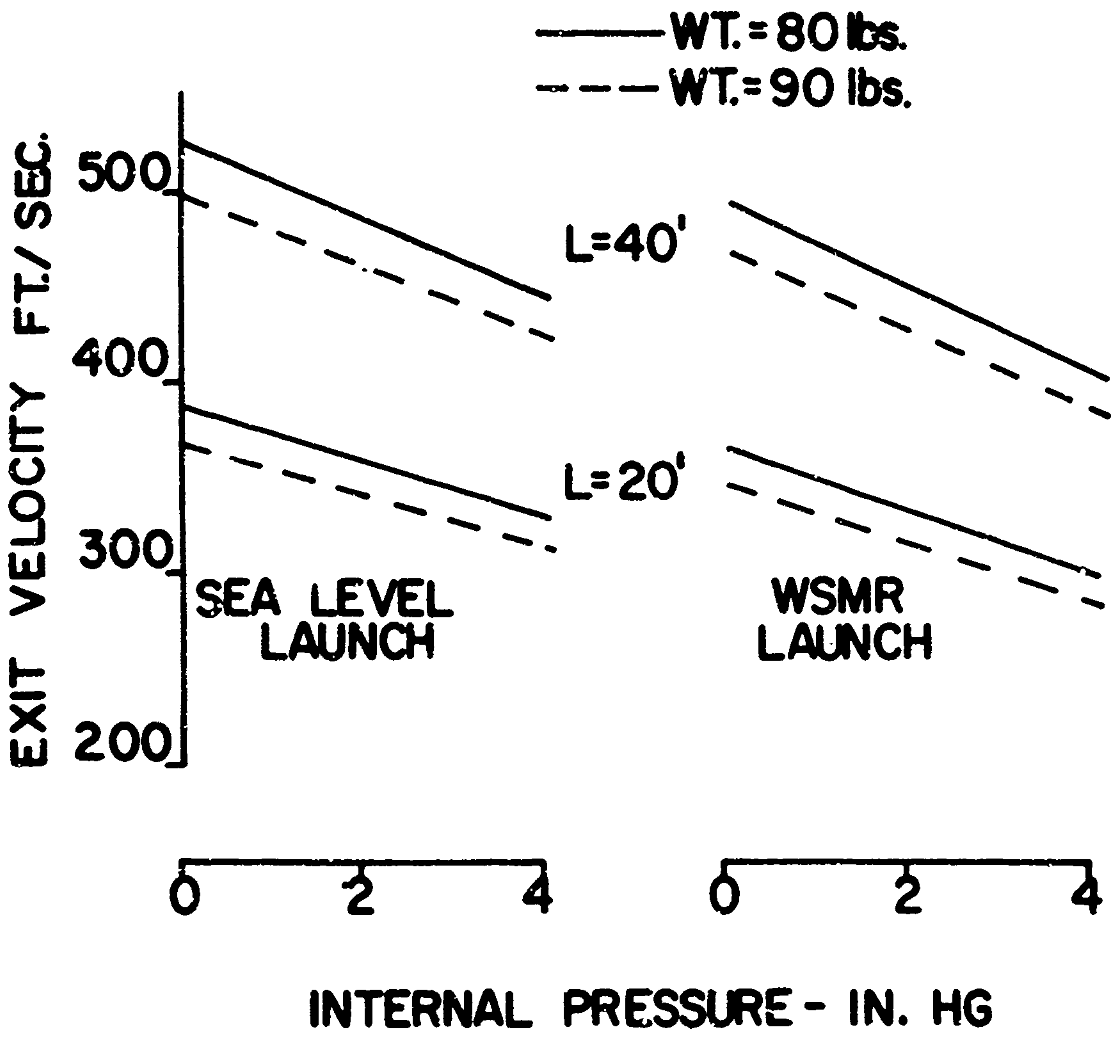

FIGURE 8. ARCAS THEORETICAL EXIT VELOCITIES. TUBE DIAMETER = 30"

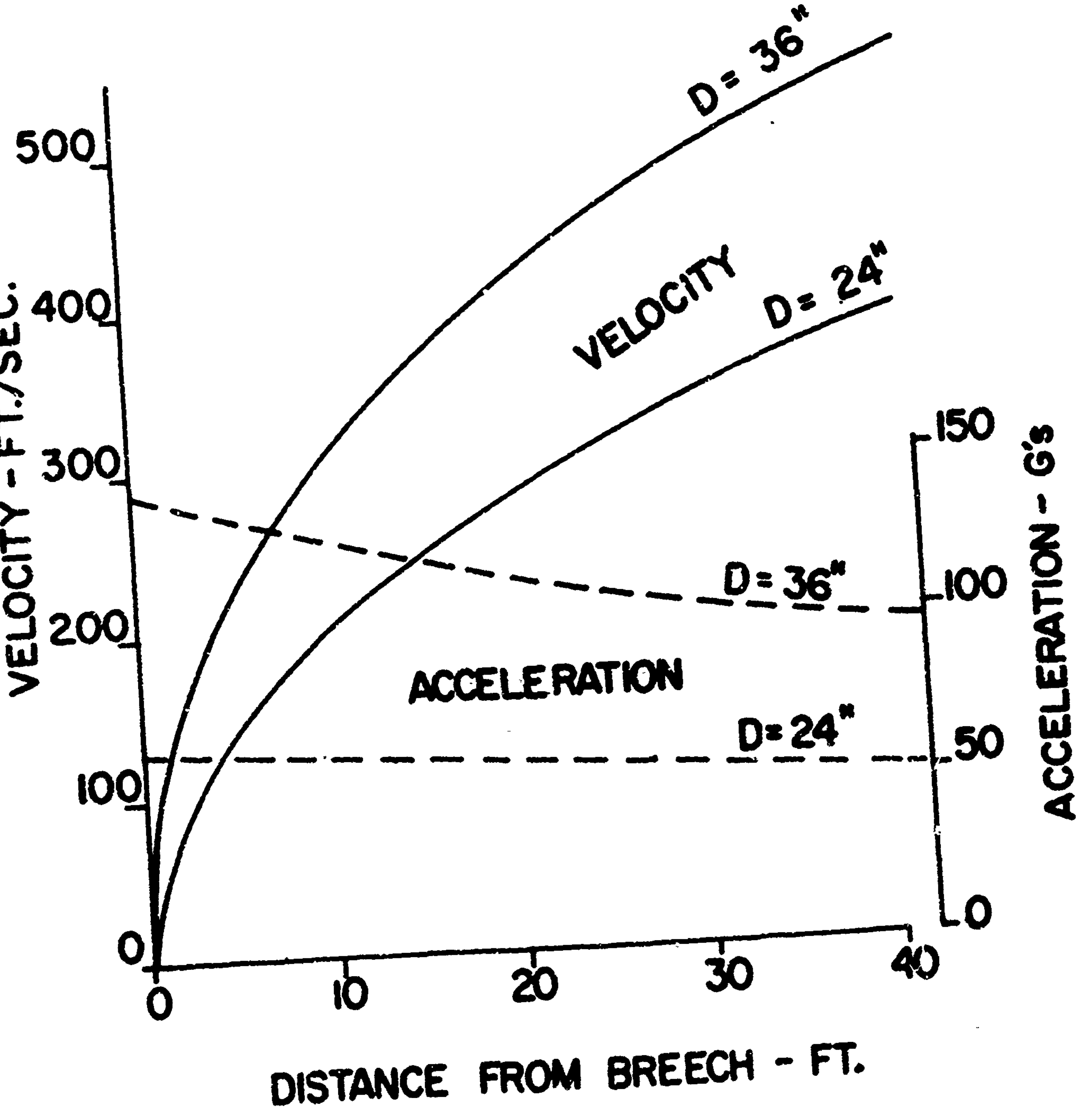

FIGURE 9. ARCAS THEORETICAL VELOCITY AND ACCELERATION TIME HISTORY

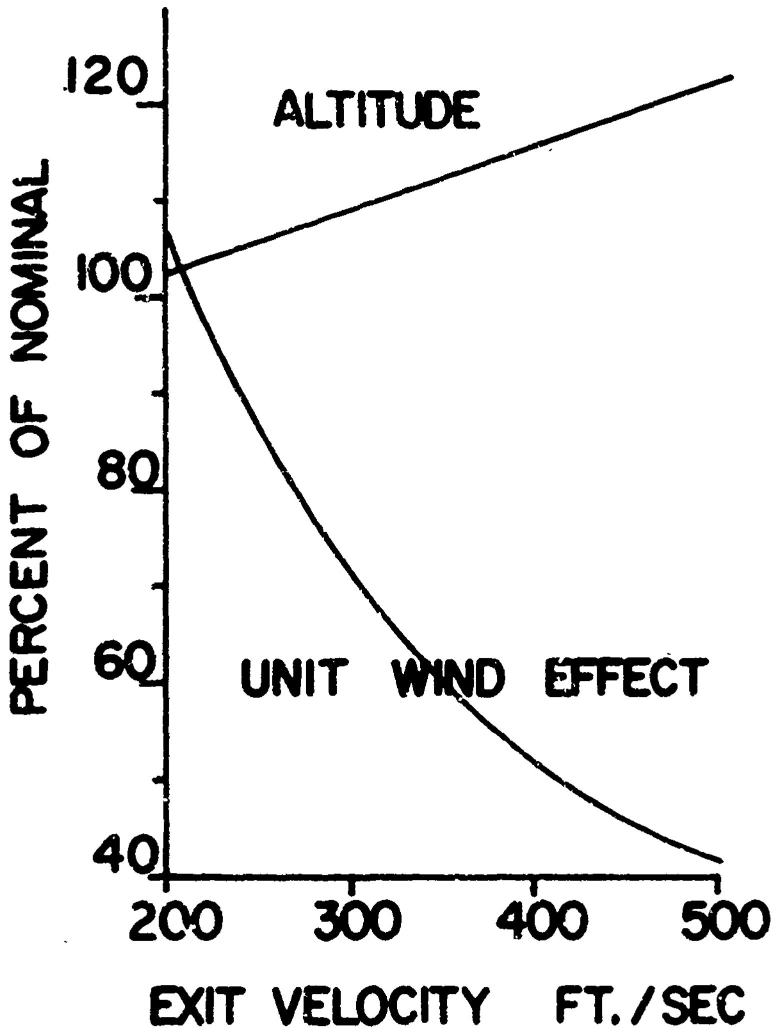

FIGURE 10. ARCAS ALTITUDE AND UNIT WIND EFFECT VS EXIT VELOCITY

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VACUUM-TUBE LAUNCHERS AND BOOSTERS

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13. ABSTRACT

Systems are being developed by the Atmospheric Sciences Laboratory to investigate the feasibility of using an evacuated (vacuum) tube as either a launcher or booster for small to medium size projectiles. Two eight-inch diameter tubes are being fabricated to propel a one- to three-pound meteorological probe into the lower atmosphere. A 70-foot long tube can propel this projectile to approximately 7000 feet above ground level, while a 20-foot tube will send the same projectile to an altitude of approximately 3500 feet.

A vacuum tube may be used to impart initial velocities in the range of 300 to 500 ft sec^{-1} to the ARCAS. This increased launch velocity will result in a 10 to 20 percent increase in peak altitude, with a simultaneous reduction in wind effect of 30 to 60 percent.

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