RECENT PASSIVE DENSITY SENSOR EFFORT AT THE NAVAL ORDNANCE LABORATORY

By George J. Sloan

U.S. Naval Ordnance Laboratory

3

The Naval Ordnance Laboratory has developed an atmospheric sounding system known as HASP, or High Altitude Sounding Projectile, capable of shipboard launching from a five-inch 38-caliber slow-fire gun. In this system, which is based upon the Loki antiaircraft rocket system, a three-inch-diameter booster is used to boost a dart vehicle to a velocity of about 5,000 feet per second in 1.9 seconds, at which time the booster separates, and the dart vehicle coasts to an altitude of 65 to 70 kilometers. For such a system to have good altitude capability, the dart must have a high sectional density. The normal HASP dart is therefore $1\frac{3}{8}$ inches in diameter, 40 inches long, and weighs eight to ten pounds, depending on the payload. The space available in such a dart is a compartment one inch in diameter and 20 inches in length, which is a volume of about 16 cubic inches. Efforts to develop a passive density sensor have been directed toward a system compatible with the small payload volume. It is the purpose of this paper to briefly describe the efforts to develop a useful passive density system for the HASP dart.

The first effort was directed toward use of the Robin sphere in the dart vehicle, but the Robin, as configured for the Arcas nose cone, simply would not fit the small dart compartment. It was necessary to reshape the isopentane capsule and remove the internal corner reflector to package the one-meter sphere in the 16-cubic-inch compartment. This configuration, called a Robinette, was constructed of half-mil metalized mylar for radar reflectivity and weighed 95 to 100 grams, or 20 to 25 grams less than the Robin. Flight tests of this configuration resulted in practically no useful data for several years of experimentation. Environmental tests conducted in the Langley Research Center 60-foot-diameter vacuum sphere in March 1964 revealed several important problems. The isopentane capsule, which incorporates an entrapped-air bag to displace the capsule cover similar to the Arcas Robin capsule, was not reliable. It was also discovered that hot particles from the expulsion charge were burning small holes in the sphere. These hot particles were not experienced in static firings at sea level since there is enough atmospheric oxygen to insure complete combustion within the dart. A reduction in the expulsion charge and a redesign of the charge holder eliminated the burning problem. The use of a sealed isopentane capsule, which is pierced by the force of the expulsion charge, proved to be a much more reliable inflation system.

Problems with sphere inflation with isopentane led to the concurrent development of a system of inflation of small spheres by entrapped air. Spheres of 12 to 16 inches in diameter were inserted in the dart compartment, folded along the gore seams with the polar caps at the end of the tube-like compartment. Air was introduced at one end with a hand pump to expand the sphere to the maximum volume of the compartment, and then the inflation tube was sealed. Of course, half-mil mylar will leak any super pressure in several hours, but this method tends to maximize the volume of residual air at atmospheric pressure. Two types of construction of spheres were used, namely, construction with longitudinal gores with polar caps and a draped form construction of one-eighth sections of the sphere. In the gore construction, similar to Robin, the half-mil mylar was metalized for reflectivity. In the draped formed construction laminated half-mil material was used with an internal corner reflector.

Evaluation of sphere performance is usually made with the lambda check in the University of Dayton density program. All of the early Robinette flight tests were evaluated, using the Dayton program at LRC, and were rejected as collapsed at ejection. In order to evaluate the system from other than a go or no-go basis, a computer program was written by the NOL Mathematics Department which incorporated a unique feature for performance evaluation. In this program, the theoretical vertical velocity of the descending device is computed and then plotted, using the weight, dimensions, drag coefficient tables, and the 1962 standard atmosphere values of density and temperature. The vertical velocity, as obtained from the radar tape, is also plotted at the same time so a comparison can be made. Figure 1 is an example of a Robinette-type sphere ejected from a Cajun dart vehicle at an altitude of 308,000 feet. The vertical velocity profile is smooth and follows the theoretical curve down to an altitude of about 100,000 feet, at which time it appears to have collapsed. The density derived from these data is plotted as a ratio to the standard atmosphere density, Figure 2. Temperature is plotted on the same plot as the standard atmosphere values for a quick comparison, Figure 3. This is an example of a good flight with a one-meter Robinette in which data were obtained from 270,000 to 100,000 feet.

The performance of the 16-inch-diameter entrapped-air configurations can be evaluated from the velocity profile, Figure 4. Flight number 2990, flown 10 March 1967, is a good example of the 16-inch sphere of a normal longitudinal gore configuration. The fall-rate curve appears to follow the theoretical curve very well at the top end, but departs from it below 160,000 feet. Density data derived from these data were not satisfactory. Data from the 16-inch draped formed sphere, Figure 5, were completely unsatisfactory. This poor performance was probably due to the rough and inaccurate shape of the draped formed sphere. Some improvement could possibly have been made with further development of this construction technique.

In an effort to eliminate some of the problems of the use of inflatable spheres as passive density sensors, a development effort was started to develop a self-erecting ram-air inflated configuration. As a result of this study, a biconical ram-air inflated balloon evolved, Figure 6. This configuration is comprised of a frustum of a 45° cone with a 28° cone extending the air inlet opening and the attached weight forward of the center of pressure. An octagonal shape of the top was selected, rather than circular, to preclude the generation of one large helical vortex which might generate a coning motion during descent. The aerodynamic characteristics of this device, determined by the University of Minnesota,* are presented in Figure 7 and illustrate why this shape was selected. The moment coefficient curve indicates excellent stability characteristics with no areas of neutral stability. The tangent-force coefficient curve indicates that there is virtually no change in coefficient with angle of attack for the small angles of attack which would be associated with the high degree of stability of the device.

From an aerodynamic standpoint this is an ideal shape; however, construction of such a shape has presented many problems since the shape is not determined entirely by the internal pressure. A construction, using quarter-mil mylar for the conical surfaces and internal supporting ribs with a one-mil roof panel, evolved from environmental testing as the construction which would produce the theoretical shape in free flight. However, free-flight tests showed good fall rate curves, but not with the same drag coefficient values as determined by the University of Minnesota. There was good agreement in performance among units manufactured at the same time, but poor agreement between manufacturing lots. Figure 8 illustrates this discrepancy between the theoretical fall rate and the actual performance. In an effort to improve this condition the configuration was changed to one without sharp corners, a shape that could be determined by the internal pressure. Such a shape is shown in figure 9. The performance of this configuration has been very satisfactory, as illustrated in Figure 10. However, the drag coefficients used for the theoretical fall rate are only estimated. Once a sufficient number of flight tests have been completed to establish reliability and reproducibility of this configuration, the actual drag coefficients will be determined.

Temperature-sensing instrumentation is also undergoing further development with the HASP system. Instrumentation currently under evaluation has a total weight of less than six ounces. It is the ultimate objective to combine the density sensor and instrumentation to derive density from fall rate and measure the temperature. The fall-rate curve in Figure 10 is such a combination. With the lightweight instrumentation the fall rate is approximately half of that of a Robin sphere, which should provide a more sensitive wind and density sensor than the Robin in the upper atmosphere, i.e., above 40 kilometers.

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*U.S. Air Force Contract No. F33615-67-C-1010.

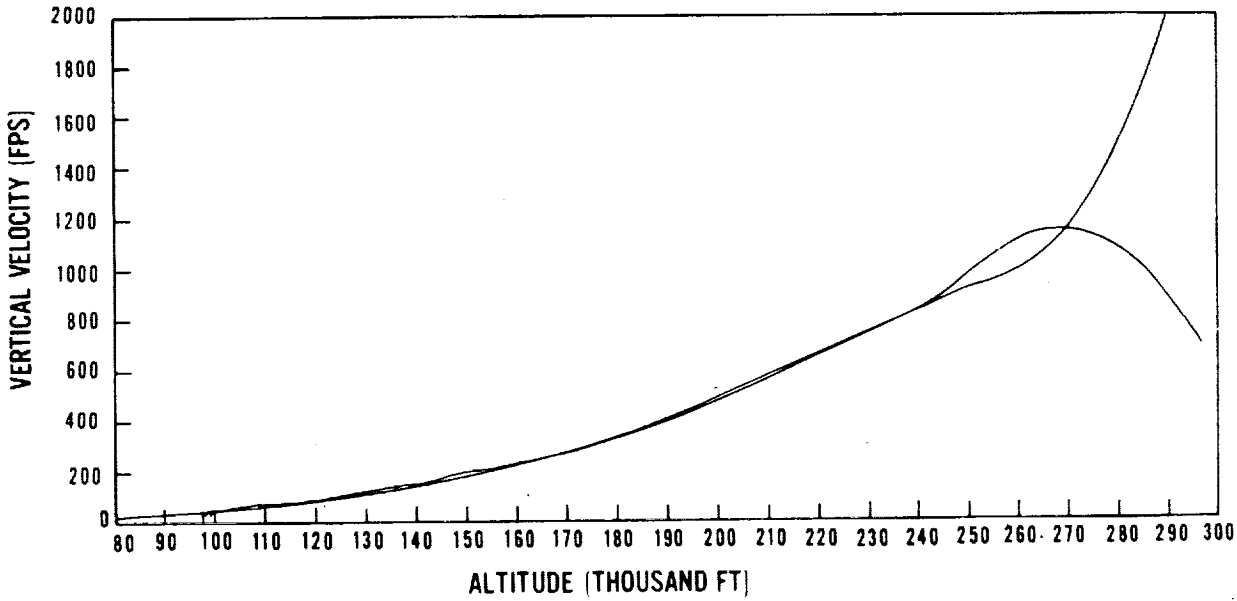

Figure 1.- Experimental and theoretical vertical velocities of 1-meter Robinette sphere (model 2290) ejected from a Cajun dart vehicle at an altitude of 308,000 feet, 5 May 1966.

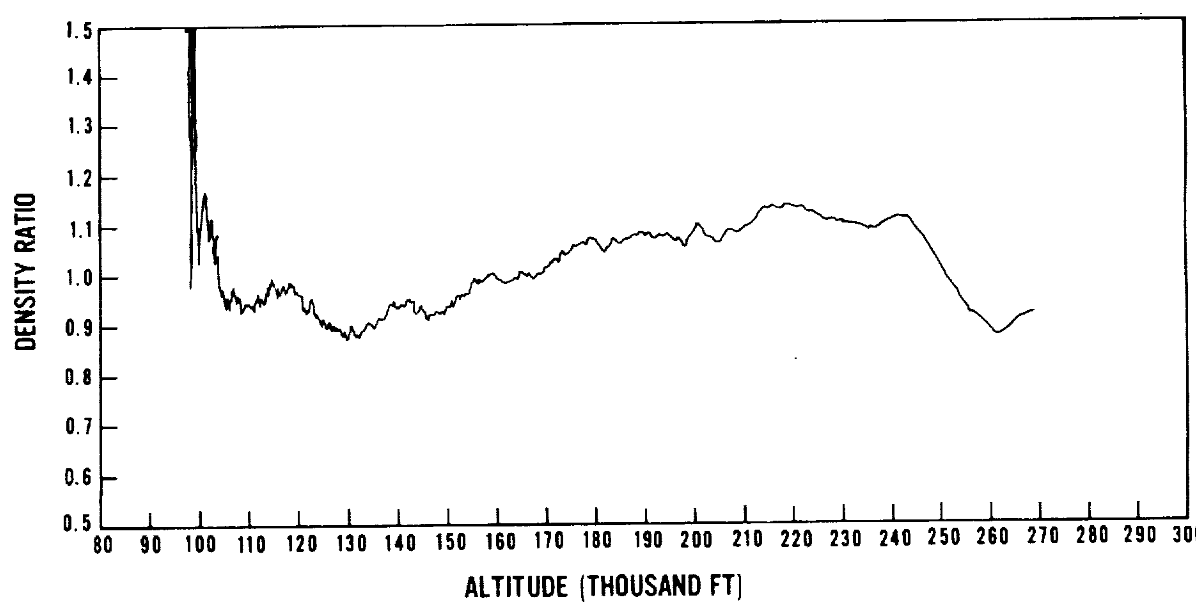

Figure 2.- Ratio of density derived from data of figure 1 to standard-atmosphere density.

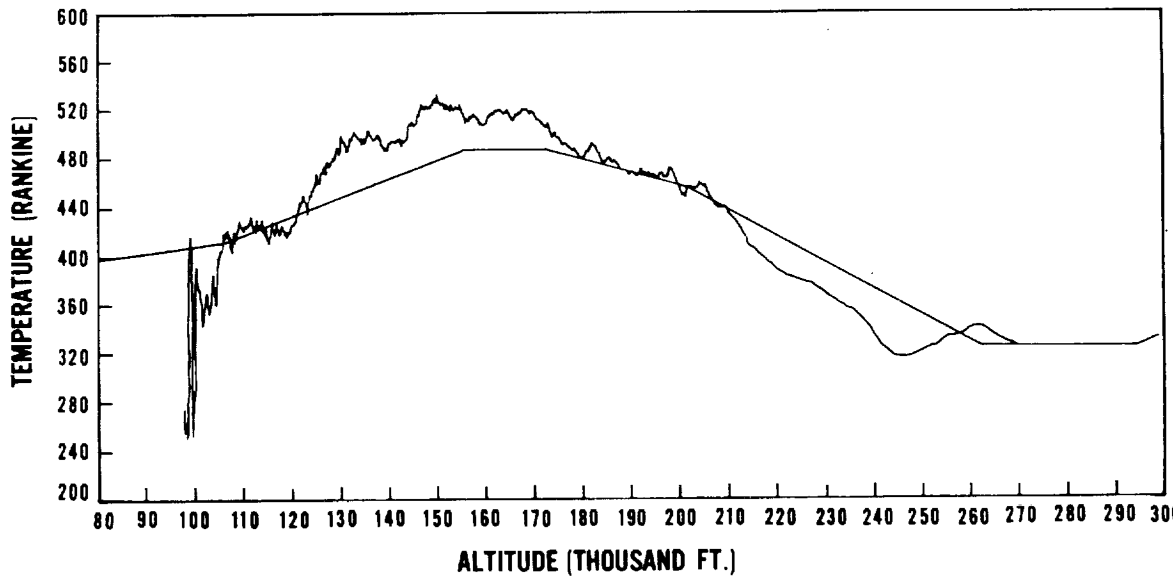

Figure 3.- Experimental and standard-atmosphere temperatures for flight test of figure 1.

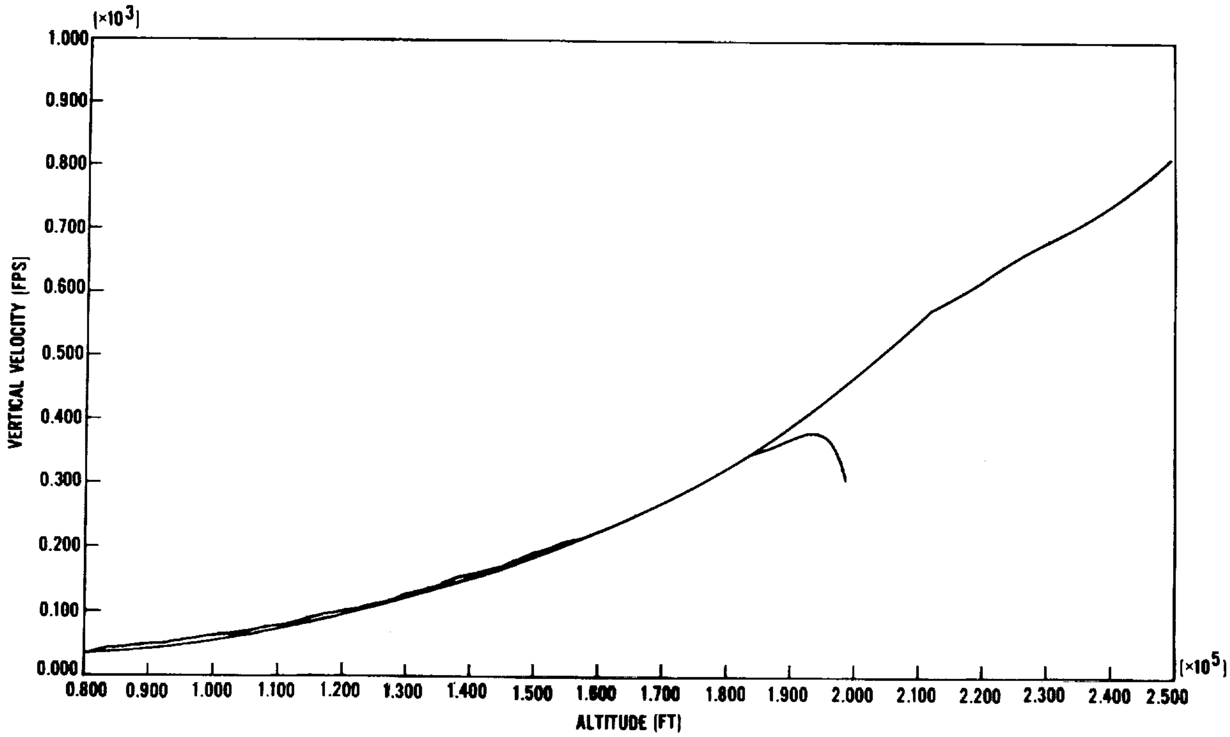

Figure 4.- Experimental and theoretical vertical velocities of 16-inch entrapped-air sphere with longitudinal gores and mass of 16.9 grams (model 2990), 10 March 1967.

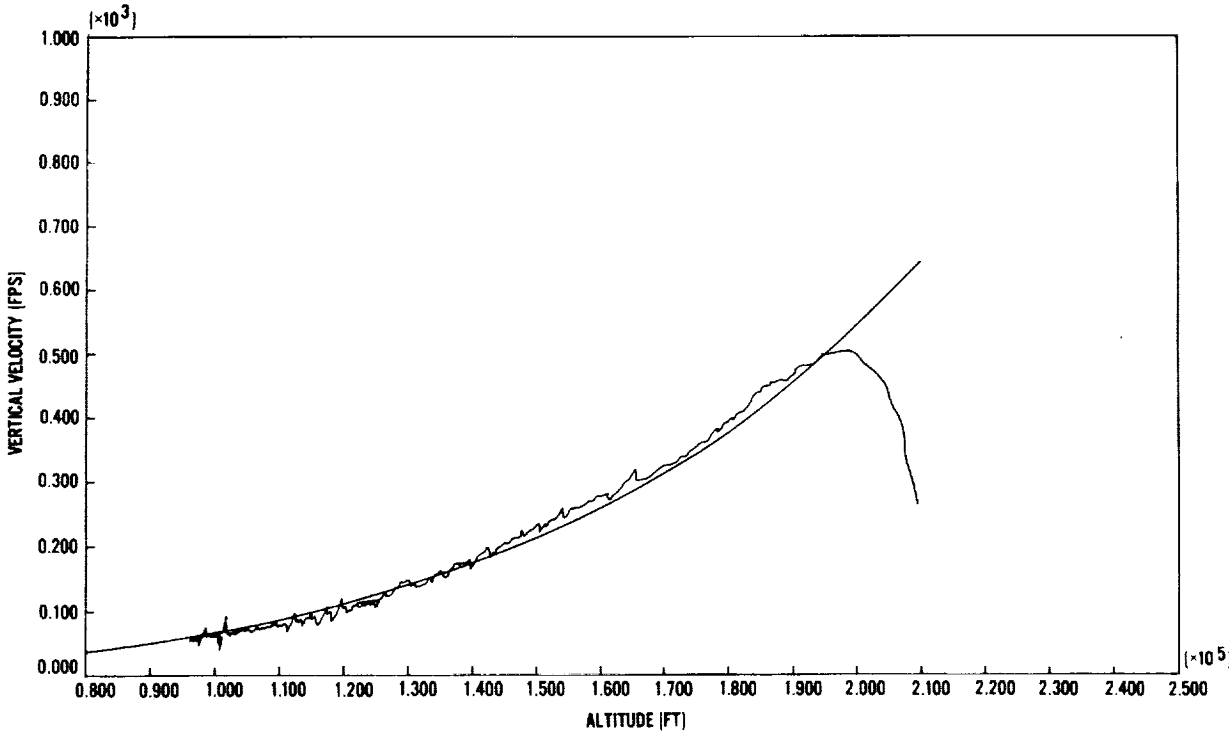

Figure 5.- Experimental and theoretical vertical velocities of 16-inch entrapped-air sphere of draped formed construction with mass of 0.0495 pound (model 2127).

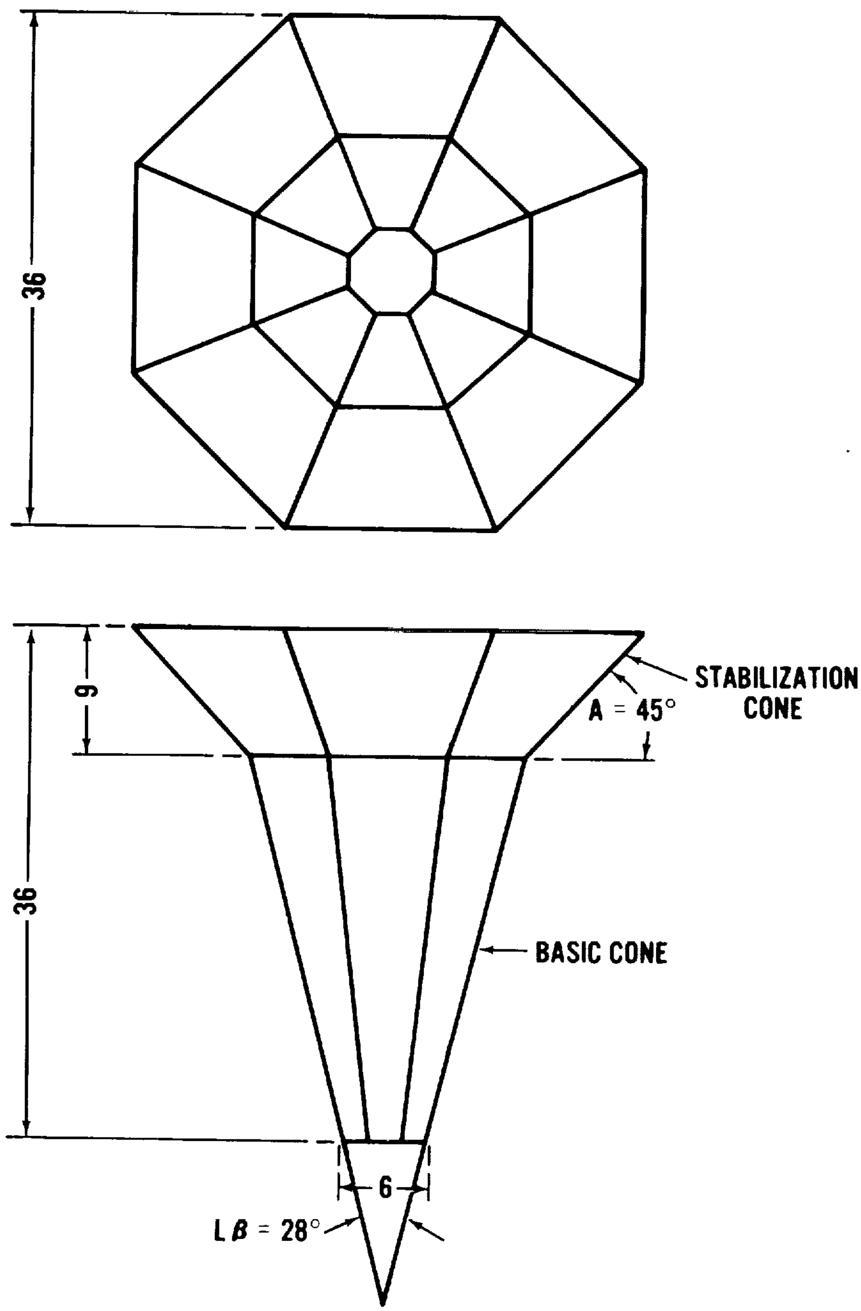

Figure 6.- Self-erecting biconical ram-air-inflated balloon.

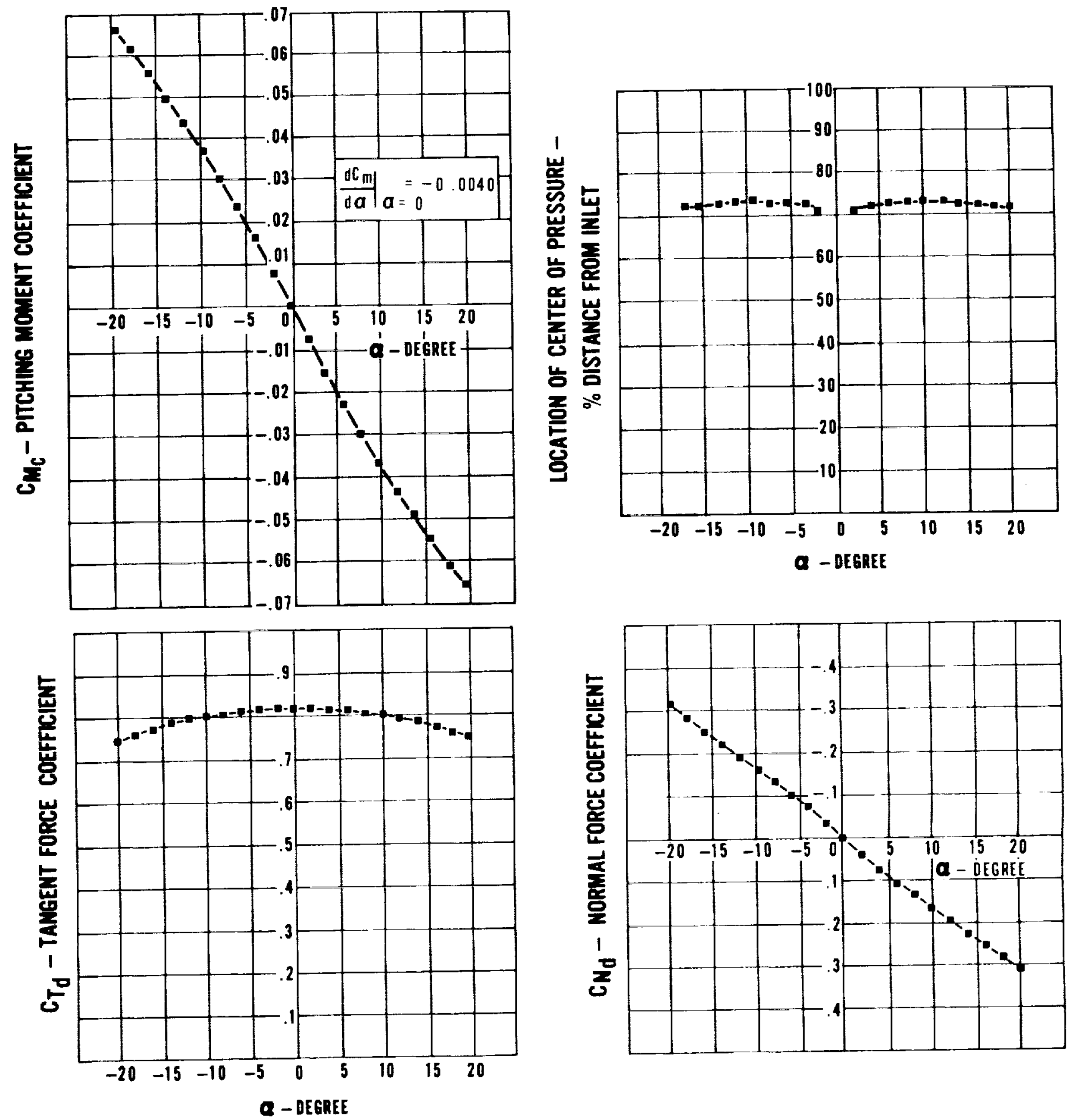

Figure 7.- Aerodynamic characteristics of configuration of figure 6.

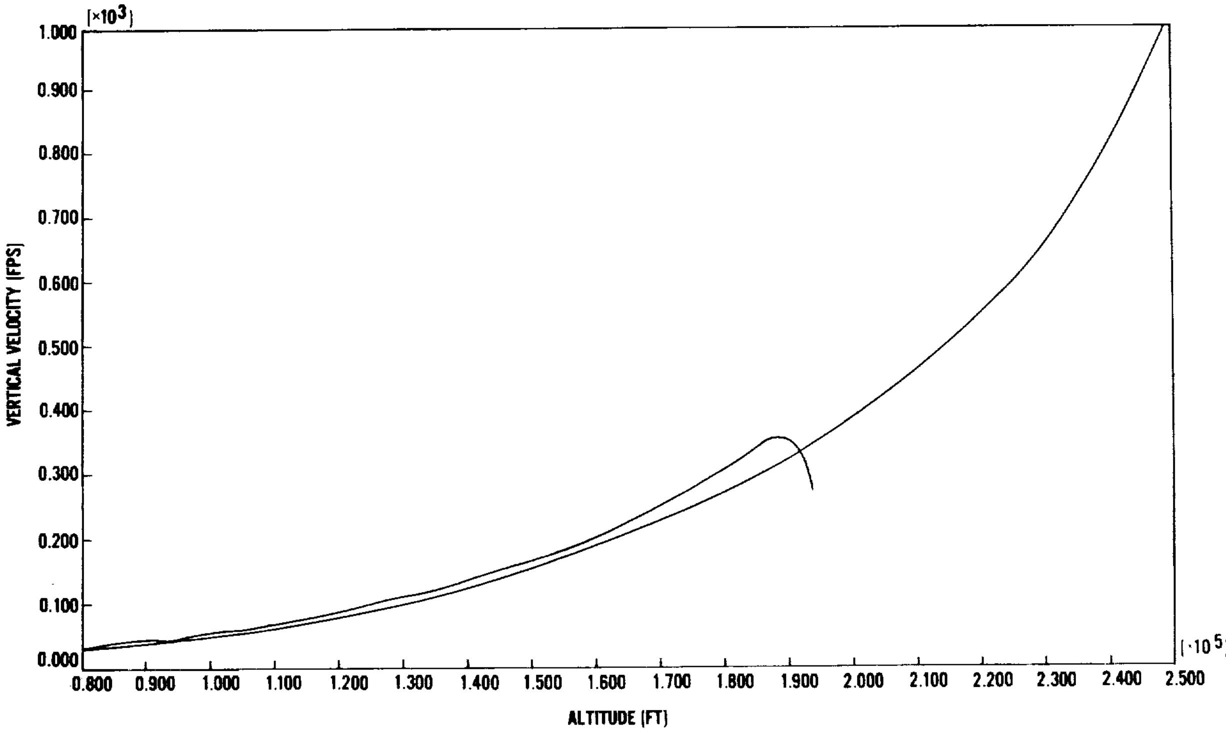

Figure 8.- Experimental and theoretical vertical velocities of configuration of figure 6 with mass of 0.23105 pound (model 3296).

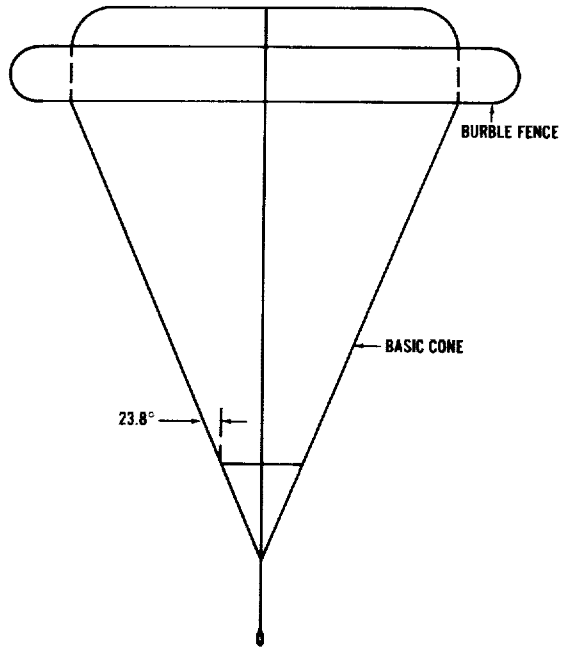

Figure 9.- Revised version of configuration of figure 6.

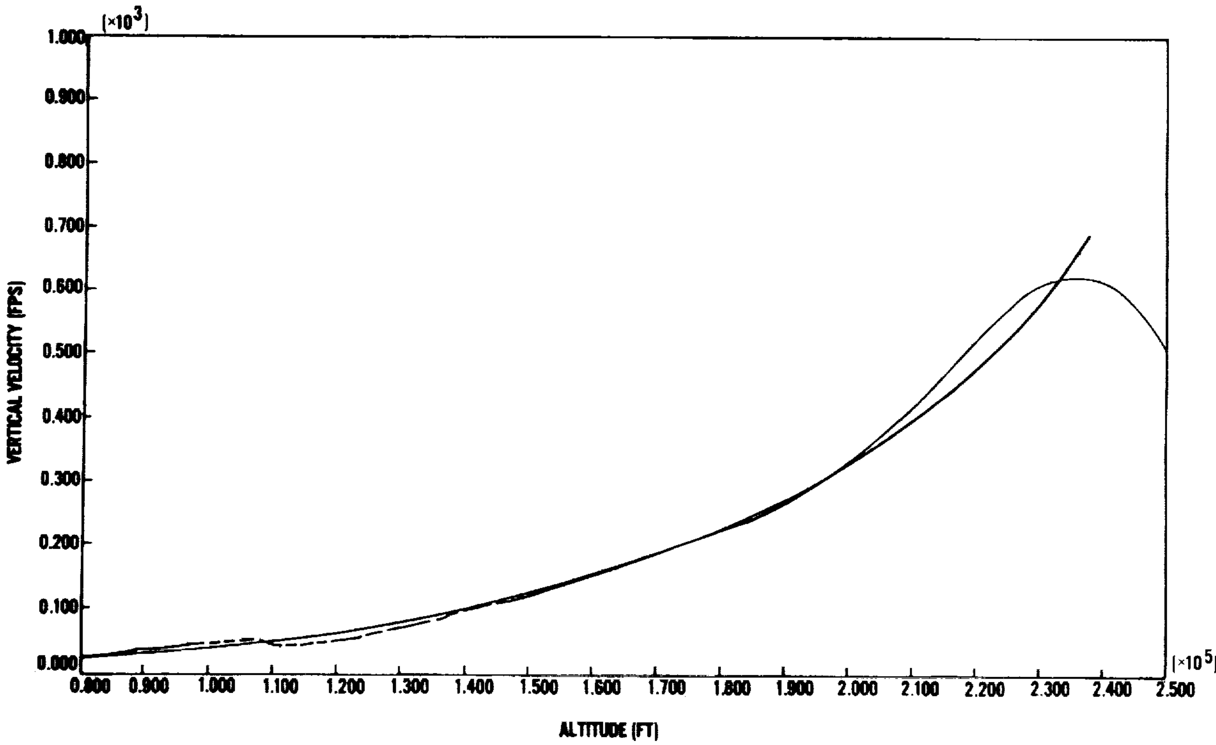

Figure 10.- Experimental and theoretical vertical velocities of configuration of figure 9 (model 4180), 2 May 1969.