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SPHERE AT HIGH ALTITUDES

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FREE-FLIGHT TEST OF A TECHNIQUE FOR INFLATING AN NASA 12-FOOT-DIAMETER SPHERE AT HIGH ALTITUDES

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SUMMARY

A free-flight test has been conducted to check a technique for inflating an NASA 12-foot-diameter inflatable sphere at high altitudes. Flight records indicated that the nose section was successfully separated from the booster rocket, that the sphere was ejected, and that the nose section was jettisoned from the fully inflated sphere. On the basis of preflight and flight records, it is believed that the sphere was fully inflated by the time of peak altitude (239,000 feet). Calculations showed that during descent, jettison of the nose section occurred above an altitude of 150,000 feet. The inflatable sphere was estimated to start to deform during descent at an altitude of about 120,000 feet.

INTRODUCTION

Knowledge of characteristics of the upper atmosphere (100,000 to 500,000 feet) is of paramount importance to insure successful reentry of orbiting vehicles and ballistic missiles. The use of balloon-carried instruments has fairly well established a standard atmosphere below 100,000 feet and data from artificial earth satellites have given indications of density at altitudes near 500,000 feet. Determination of atmospheric conditions between balloon and satellite altitudes appears to require special techniques.

One method of measuring density at high altitudes has been suggested through the use of the known drag of spheres at various Reynolds and Mach numbers. In order to insure either radar or camera tracking, a large sphere is desirable. The inflatable sphere is especially useful inasmuch as a large size can be folded into a small package and contained in the nose of a rocket.

The purpose of this paper is to report the results of a free-flight test of a technique for inflating an NASA 12-foot-diameter sphere at high altitudes. The test vehicle was a two-stage rocket with the packaged sphere in a separating nose section. The vehicle was launched by the Langley Pilotless Aircraft Research Division from its testing station at Wallops Island, Va.

SYMBOLS

A	cross-sectional area, sq ft
C_D	drag coefficient, D/qA
D	drag, lb
d	diameter, ft
h	altitude, ft
M	Mach number
q	dynamic pressure, lb/sq ft
R	horizontal range, ft
t	time, sec
V	velocity, ft/sec
W	weight, lb
ρ	density of air, slugs/cu ft

TEST VEHICLE

Nose-Section Description

A sketch of the nose section and second-stage rocket motor is shown in figure 1. The nose section consisted of a blunted fineness-ratio-1.87 ogive nose with a cylindrical afterbody. An explosive band held the nose section to the second-stage adapter section. The overall weight of the nose section, including the 9-pound, 12-foot-diameter sphere, was 53 pounds.

Details of the nose section and of the inflatable-sphere section are shown in figure 2. Photographs of the nose section are shown in figure 3. The ogive nose was fabricated from mild steel and varied in wall thickness from about 0.25 inch near the nose tip to 0.06 inch near the intersection of the ogive-nose—inflatable-sphere section. The inflatable-sphere section was constructed of magnesium alloy and had a constant wall thickness of 0.25 inch. A flare was located at the end of the inflatable-sphere section to protect the explosive charge in the band from aerodynamic heating. Also included in the flare was a switch positioned so as to indicate nose-section separation from the second stage. The ogive nose contained an NASA inertia-starting timer and the telemeter transmitter and batteries. The inflatable-sphere section contained the telemeter antenna, the inflatable sphere, and the sphere-ejection mechanism. The nose-section—second-stage rocket-motor adapter section contained a 70-pound-force spring to separate the nose section from the second stage.

The inflatable sphere was constructed of 0.001-inch-thick Mylar with a 0.00045-inch-thick coating of aluminum on each side of the Mylar. The bellows were constructed of Fairprene No. 5769, a flexible cloth-like material. It should be pointed out that the construction of the 12-foot-diameter inflatable sphere is semirigid; that is, unlike a toy balloon, the size does not materially increase as the internal pressure is increased. Also, once the sphere has been fully inflated and pressurized, the sphere will retain its shape, unless acted upon large forces, even if the internal and external pressures are balanced.

Working Procedure

An explanation of the working procedure is as follows: A dual explosive charge actuates a valve in the front of the pressure bottle. Gas (nitrogen) is fed from the bottle through the valve and into a metal tube that runs inside the bottle to a small orifice at the rear. From the orifice at the rear of the bottle, the gas enters the bellows. During this process, the pressure is decreased from 1,500 pounds per square inch in the bottle to a maximum of about 4 or 5 pounds per square inch in the bellows. The pressure in the bellows ejects the folded 12-foot-diameter sphere. Gas cannot enter the sphere until the sphere package is completely ejected. The gas from the bellows then inflates the sphere. As a result of difference in volumes, there is a pressure drop from the bellows to the sphere; the pressure in the fully inflated and pressurized sphere is about 0.1 pound per square inch. As long as the pressure in the bellows is above a preset value (about 0.7 pound per square inch), the spring attached to the sphere inflating stem is of insufficient strength to overcome the force of the bellows; however, as the pressure in the bellows decreases below the preset value, a disconnect mechanism jettisons the nose section.

Booster Rockets

The three-stage vehicle consisted of an M5 JATO Nike booster solid-propellant rocket motor as the first stage, a 6.25-inch-diameter solid-propellant Cajun rocket motor as the second stage, and the nonsustained nose section as the third stage.

A weight breakdown of the various components is as follows:

Nose section (including 9-pound, 12-foot-diameter sphere, lb	53.0
Cajun rocket motor (second stage), lb	171.0
Second stage fins, lb	30.0
Nozzle extension, lb	5.0
Explosive band, lb	1.5
Nose-section—second-stage adapter, lb	1.5
Spring, lb	1.0
Total weight of nose section and second stage, lb	263.0
Total weight of first-stage Nike, lb	1,300.0
Launching weight, lb	1,563.0

INSTRUMENTATION

An NASA FM/AM single-channel telemeter and an NASA inertia-starting timer were contained in the nose section. The telemeter transmitted a continuous signal to the ground recording stations. A switch was connected to the telemeter to provide an easily detectable shift of subcarrier frequency when the nose section separated from the second-stage booster. The inertia timer mechanism consisted of an inertia switch and a spring-wound clock motor. The inertia switch was designed to start operation of the clock motor at firing of the first stage. The clock motor was preset to close an electrical switch 75 seconds after start. The electrical switch, when closed, completed a circuit which fired the explosive charge in the explosive band and the 4-second-delay charge in the inflatable-sphere pressure bottle.

Ground instrumentation included a CW Doppler velocimeter to provide velocity data and an AFMTC model 2 tracking radar to provide trajectory data. Atmospheric and wind conditions were determined by means of a radiosonde released near the time of the flight and tracked by a Rawin set AN/GMD-1A. In addition to the radar and telemeter recording stations, ground instrumentation also included motion-picture and still cameras as well as visual monitoring of the telemeter and radar signals.

TESTS

Preflight Tests

Prior to flight testing, the ejection and inflation characteristics of the 12-foot-diameter sphere were determined from vacuum tank tests. The tests were conducted in a 41-foot-diameter vacuum sphere at the Langley Research Center. The pressure bottle, bellows, folded 12-foot-diameter sphere, and the nose section used in the vacuum tank test were the same as those described in the section entitled "Test Vehicle." At a simulated altitude of about 150,000 feet, the folded sphere was ejected and was fully inflated in about 30 seconds. Separation of the fully inflated and pressurized sphere from the nose section occurred about 180 seconds after ejection.

Flight Test

The test vehicle was launched at an elevation angle of approximately 80° from the horizontal by means of a launcher as shown in figure 4. A time history of Mach number and velocity as determined from the Doppler velocimeter and from machine calculations is shown in figure 5. The first stage boosted the nose-section—second-stage combination to a Mach number of about 2.9. The nose-section—second-stage combination then coasted for about 20 seconds at which time the second stage fired. At burnout of the second stage, an estimated peak Mach number of about 5 was obtained. Doppler velocimeter data of the nose-section—booster combinations were obtained for 26.7 seconds; attempts to obtain accurate velocity data from tracking radar after 26.7 seconds were unsuccessful. A digital-computer calculation, employing standard atmospheric values, was used to determine velocity and Mach number at times greater than 26.7 seconds.

RESULTS AND ANALYSIS

Results

The results of a free-flight technique for inflating an NASA 12-foot-diameter sphere at high altitudes are presented in figure 6.

From telemeter records it was determined that the nose section separated from the second-stage rocket at 75 seconds, that the sphere was ejected at 79 seconds, and that the nose-section impact time was about 510 seconds.

The nose-section—second-stage combination was tracked with the tracking radar for 57 seconds (at an altitude of 146,000 feet) before the radar signal faded into noise. Two seconds after sphere ejection (81 seconds after launch and at an altitude of 205,000 feet), a strong radar return signal was recorded and the nose-section—sphere combination was tracked until 151 seconds. At this time the radar operator thought he was tracking the second-stage rocket because preflight calculations had predicted a higher altitude for the sphere. The radar operator, therefore, elected to search at higher altitudes but failing to find anything, he returned to the strong signal area and picked up the inflated sphere at 306 seconds at a range and an altitude of 93,000 feet and 150,000 feet, respectively. The sphere was tracked to a low elevation angle for a total time from launch of 1 hour and 3 minutes (slant range of about 300,000 feet) before the signal faded into noise. The unusual change in altitude with range of the inflatable sphere at altitudes less than about 60,000 feet was caused by high winds (jet stream). The velocity of the jet stream caused the sphere to translate horizontally at rates of about 100 miles per hour.

Analysis

The time proximity of sphere ejection (79 seconds) and a strong radar return signal (81 seconds) and the relative cross-sectional area of even a partially inflated sphere (approximately 100 square feet) with respect to the maximum cross-sectional area of the second-stage rocket (approximately 6 square feet) strongly indicate that the nose-section—sphere combination was radar-tracked at times greater than 81 seconds and not the second-stage rocket. Comparisons of machine-calculated second-stage and radar-tracked trajectories (fig. 7) show that the second-stage rocket either in a 0° or 90° angle-of-attack attitude achieved a higher altitude and shorter impact time than the radar-tracked trajectory. Initial conditions of velocity, altitude, and range for the second stage at 75 seconds (nose-section separation time) were estimated from figure 6. Drag coefficients were determined from references 1 and 2.

It is believed that the sphere was fully inflated near peak altitude. The velocity of the nose-section—sphere combination at peak altitude (239,000 feet) was about 500 ft/sec; this velocity would give a stagnation-point pressure of less than 0.001 pound per square inch whereas the pressure in the vacuum tank during preflight tests was about 0.01 pound per square inch. Also, the time between flight sphere ejection and peak altitude was about 50 seconds, whereas in preflight tests the sphere was fully inflated in about 30 seconds.

From telemeter records, it was determined that the nose-section impact time was about 510 seconds; since at this time the sphere was at an altitude of 115,000 feet, it was known that jettison of the nose section occurred above this altitude. In order to determine whether the nose section was attached to the sphere at altitudes of 150,000 feet or less (altitude where radar data were available), calculations were made by using the following equation:

$$W \approx D = \frac{1}{2}\rho V^2 C_D A$$

where ρ was obtained from standard atmospheric tables; C_D, from reference 3; and $V \approx \frac{dh}{dt}$, from figure 6(a). The value of A was determined from the formula $A = \frac{\pi d^2}{4}$, and, since $d = 12$ feet, the cross-sectional area was 113 square feet. The weight was calculated for altitudes of 150,000, 140,000 and 130,000 feet and found to be approximately 9 pounds (the weight of the sphere alone). From these calculations, it was known that the nose section was jettisoned above 150,000 feet. The time for jettison was then estimated to be the same as in the preflight vacuum tank tests, that is, 180 seconds after sphere ejection.

The altitude for sphere deformation was estimated to be that altitude where the stagnation-point pressure was equal to the sphere internal pressure of 0.1 pound per square inch. This altitude is estimated to be about 120,000 feet.

CONCLUDING REMARKS

A free-flight test has been conducted to check a technique for inflating an NASA 12-foot-diameter inflatable sphere at high altitudes. Flight records indicated that the nose section was successfully separated from the booster rocket, that the sphere was ejected, and that the nose section was jettisoned from the fully inflated sphere. On the basis of preflight and flight records, it is believed that the sphere was fully inflated by the time of peak altitude (239,000 feet). Calculations showed that during descent, jettison of the nose section occurred above an altitude of 150,000 feet. The inflatable sphere was estimated to start to deform during descent at an altitude of about 120,000 feet.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., October 29, 1958.

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1. Walchner, O.: Systematic Wind-Tunnel Measurements on Missiles. NACA TM 1122, 1947.

2. Penland, Jim A.: Aerodynamic Characteristics of a Circular Cylinder at Mach Number 6.86 and Angles of Attack Up to 90°. NACA TN 3861, 1957. (Supersedes NACA RM L54A14.)

3. Jones, L. M., and Bartman, F. L.: A Simplified Falling-Sphere Method for Upper-Air Density. Rep. No. AFCRC-TN-56-497, Project 2215 (Contract No. AF 19(604)-999), Eng. Res. Inst., Univ. of Michigan, June 1956. (Available from ASTIA as AD No. 101328.)

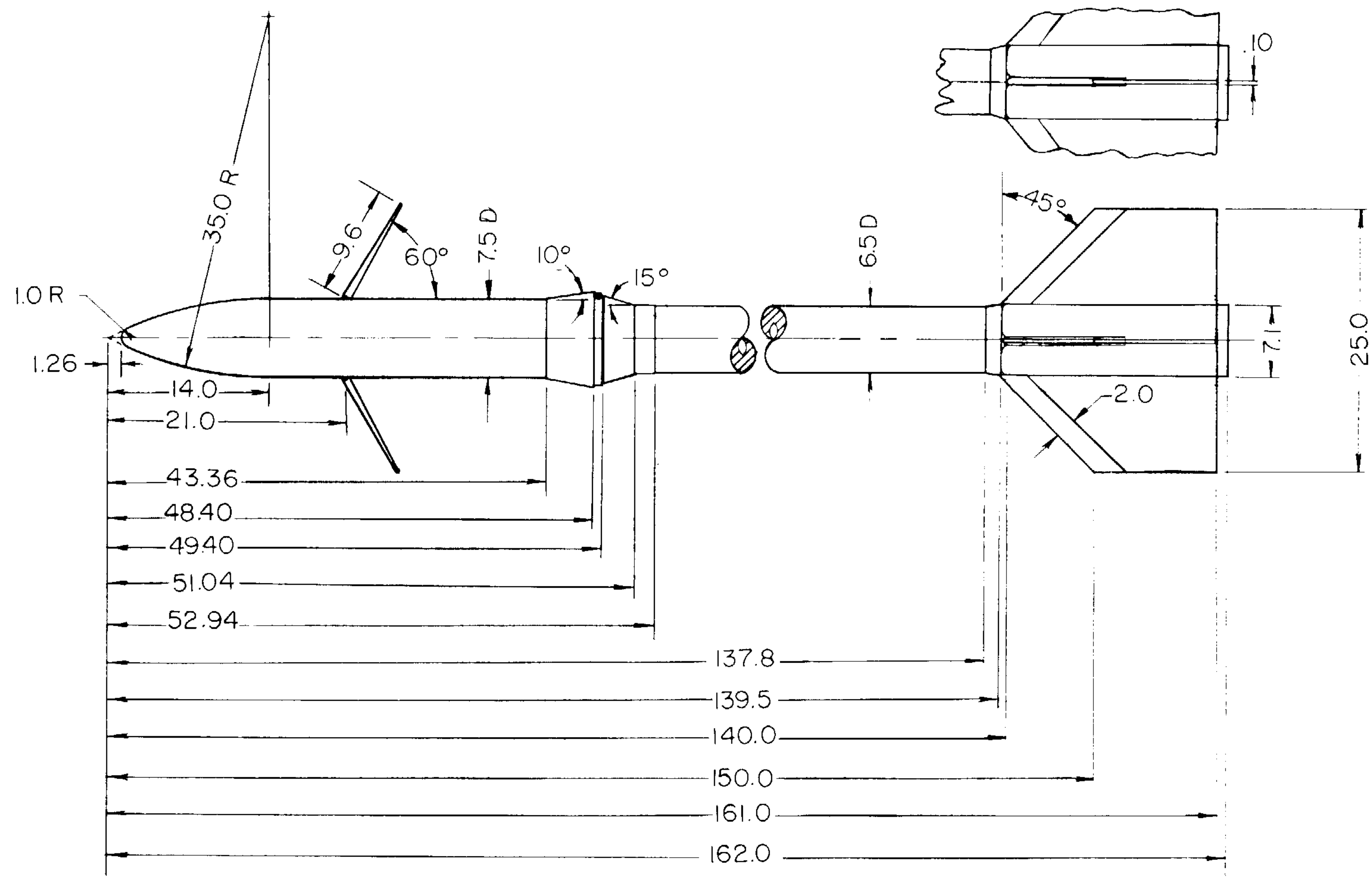
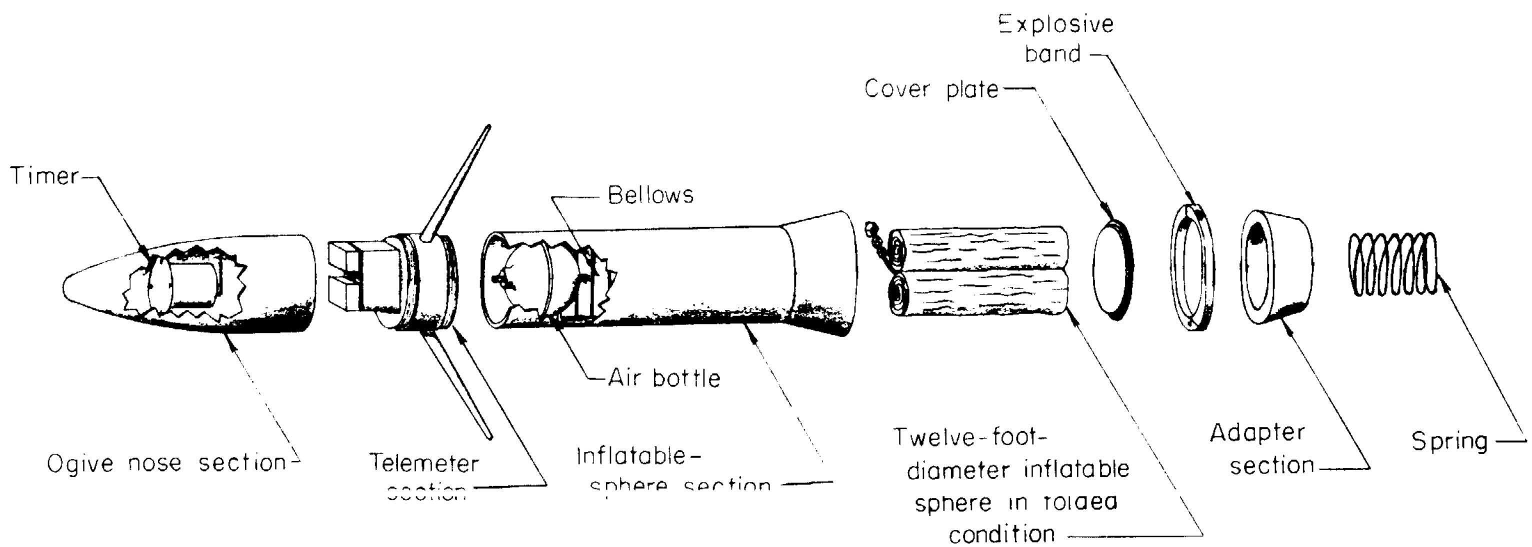
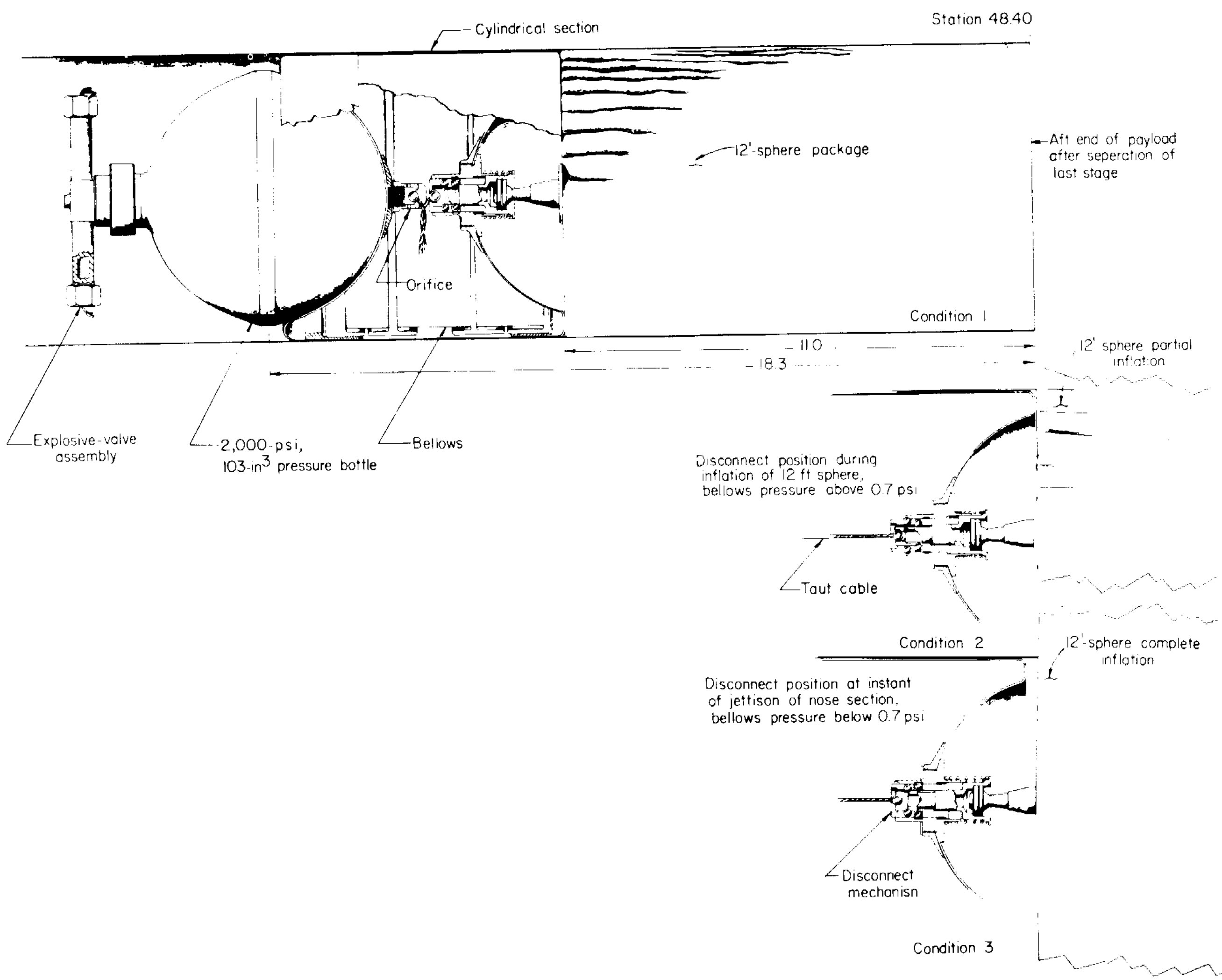


Figure 1.- General arrangement of nose section and second stage. All dimensions in inches.



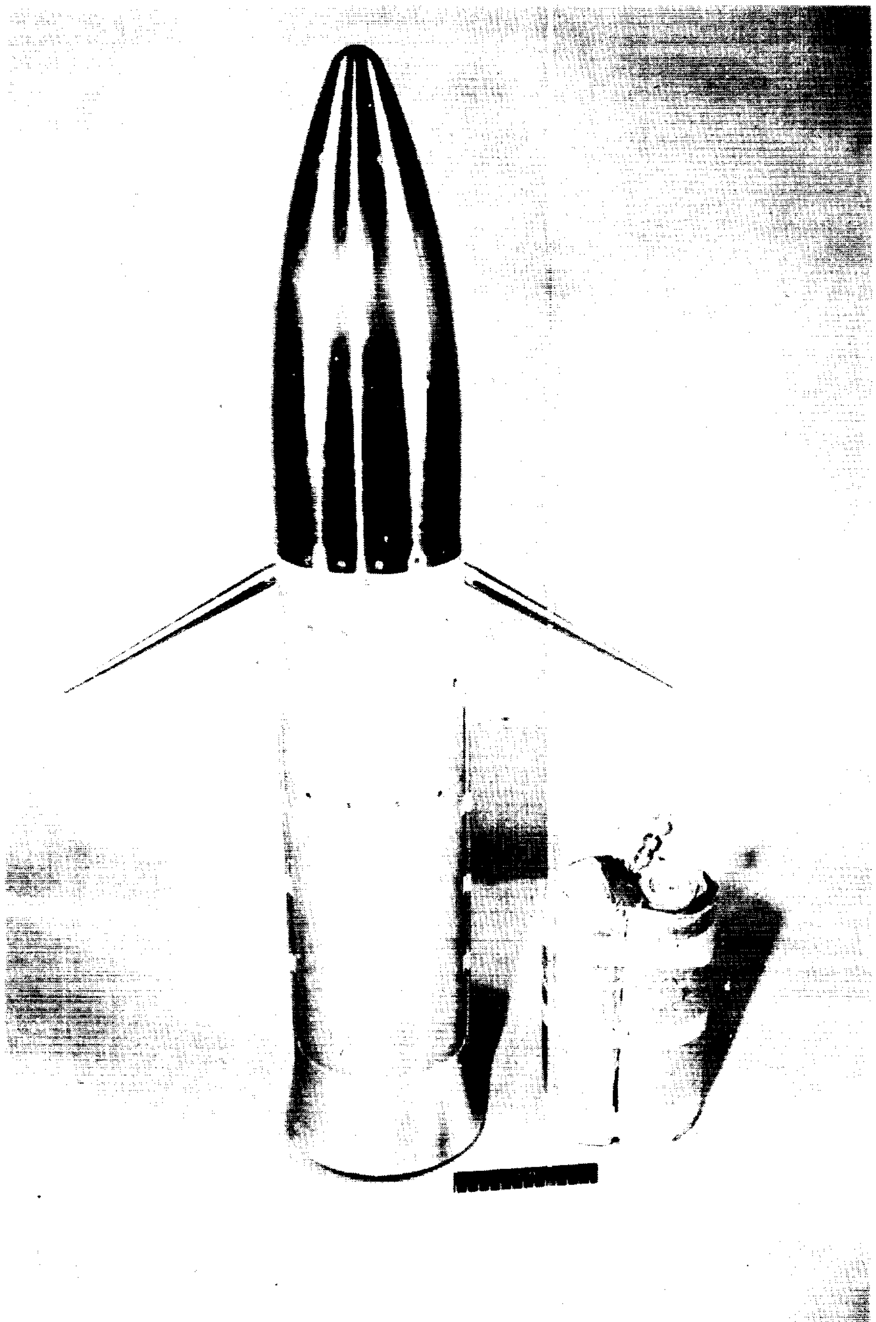
(a) Nose section.

Figure 2.- Details of nose section and of inflatable-sphere section.



(b) Inflatable-sphere section.

Figure 2.- Concluded.



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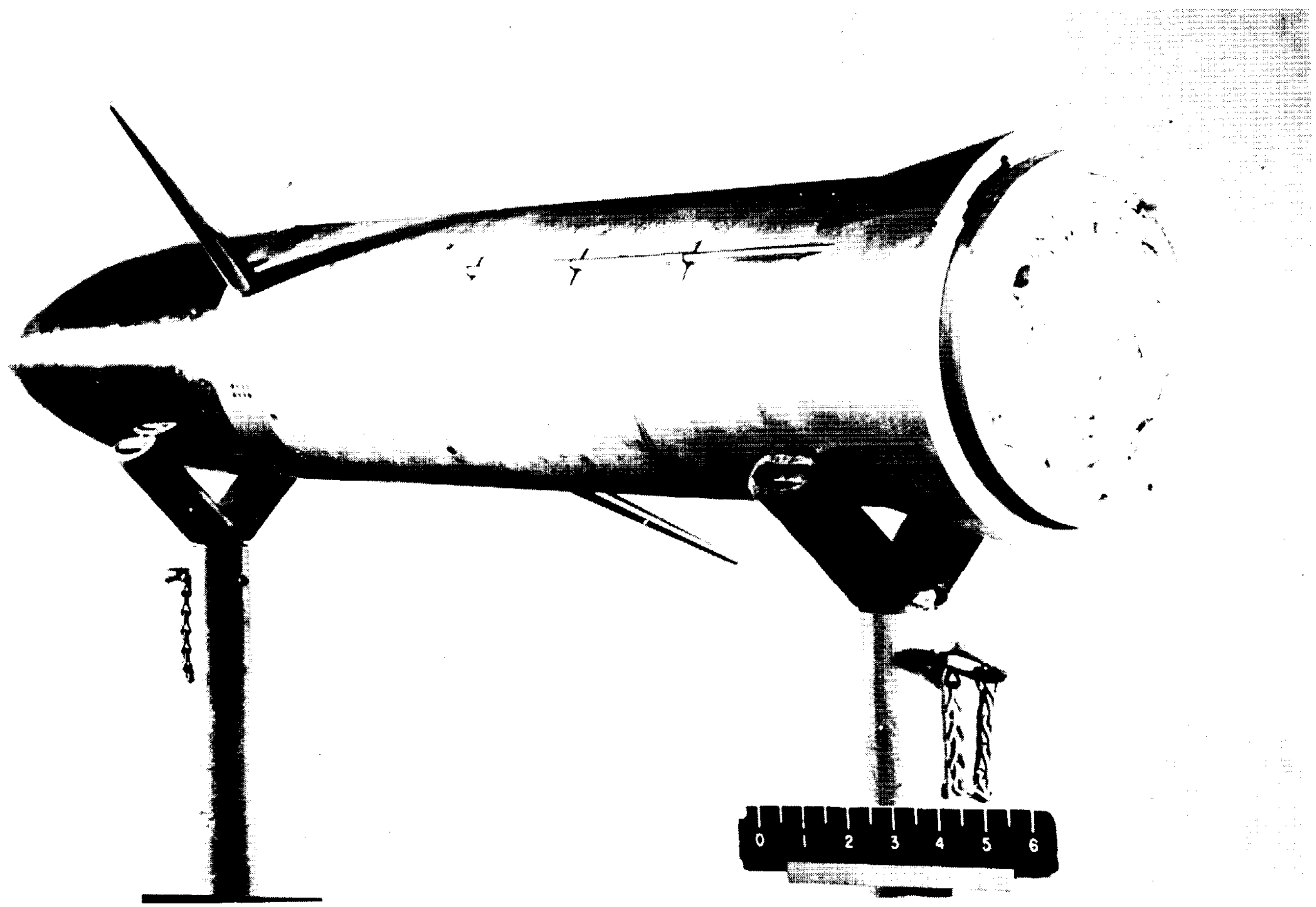
(a) Nose section and inflatable 12-foot-diameter sphere.

Figure 3.- Photographs of nose section.



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(b) Three-quarter rear view of nose section.

Figure 3.- Concluded.

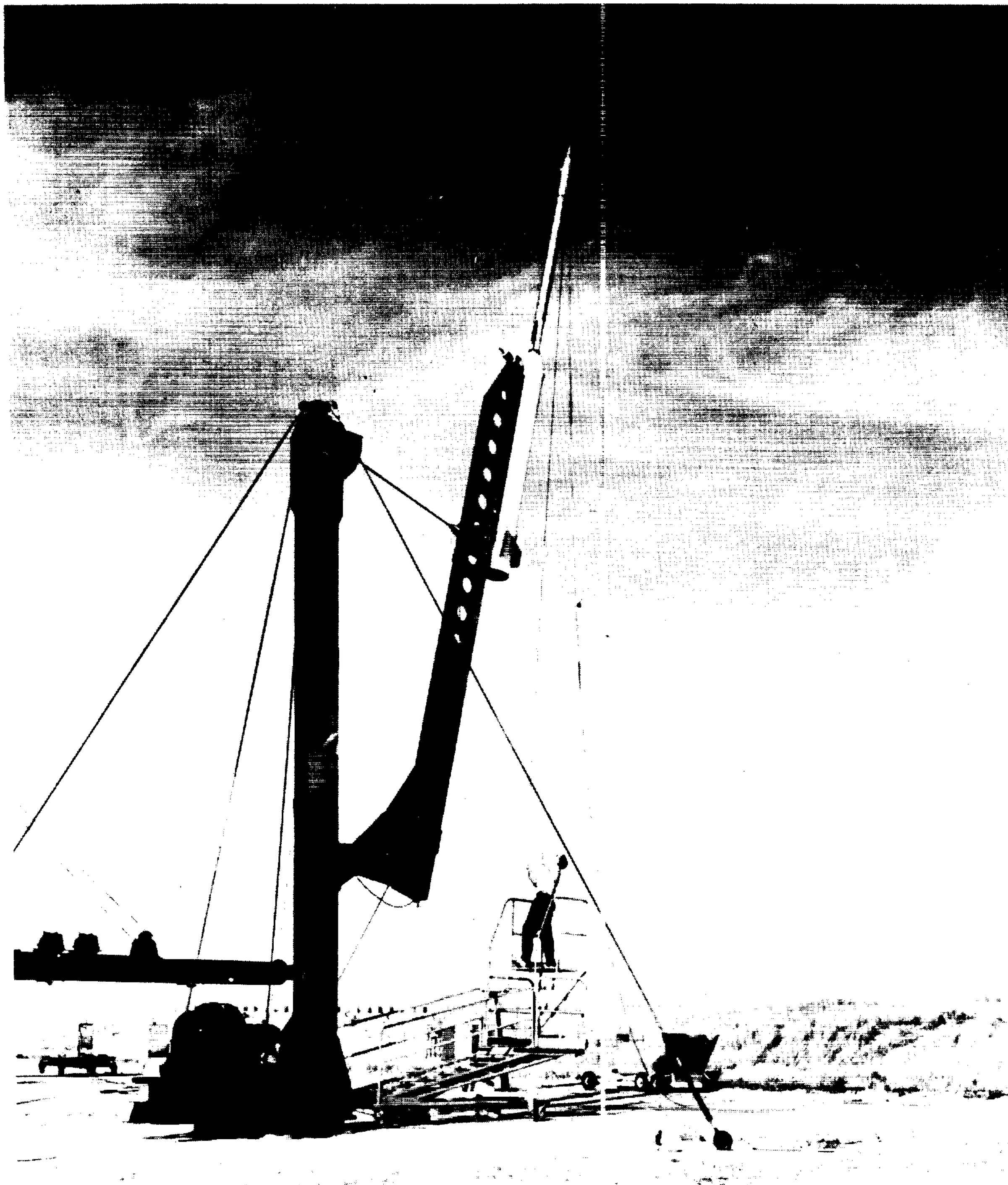

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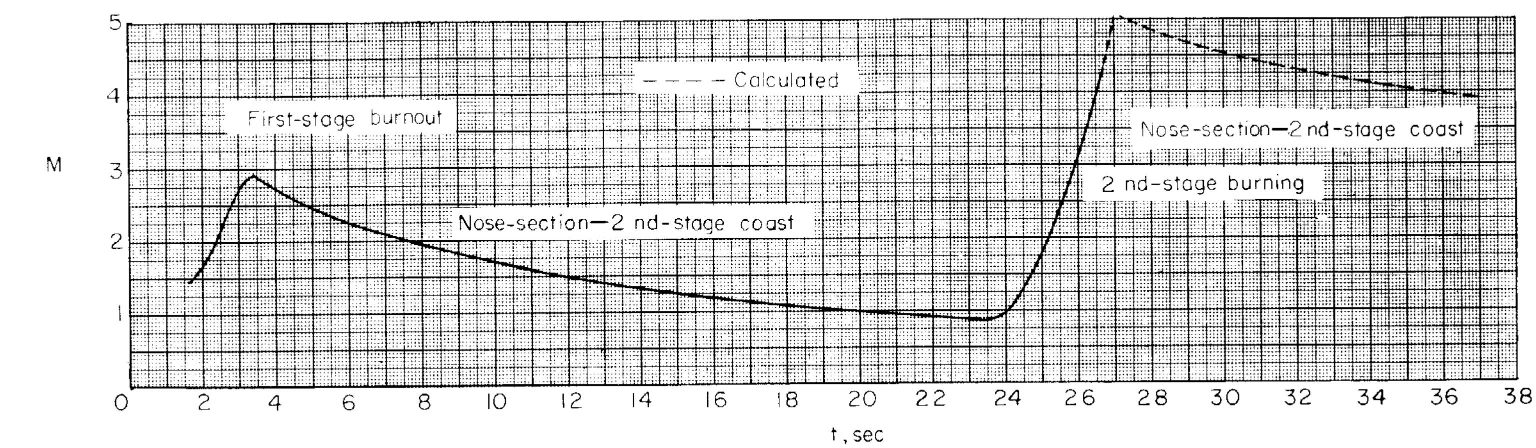
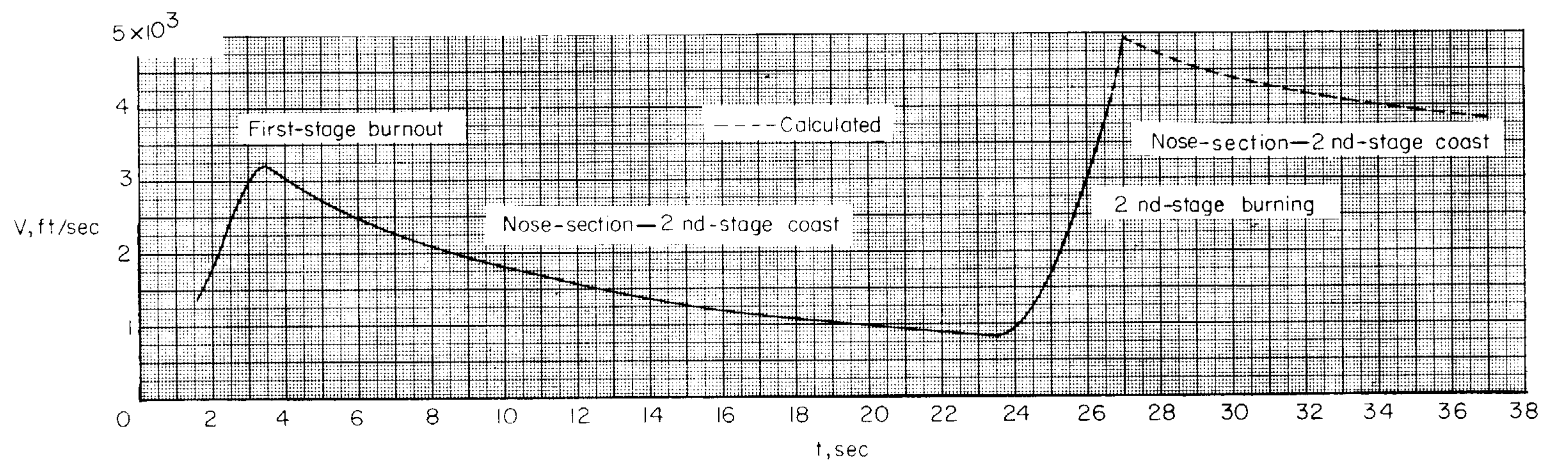
Figure 4.- Nose-section—booster combination on launcher.

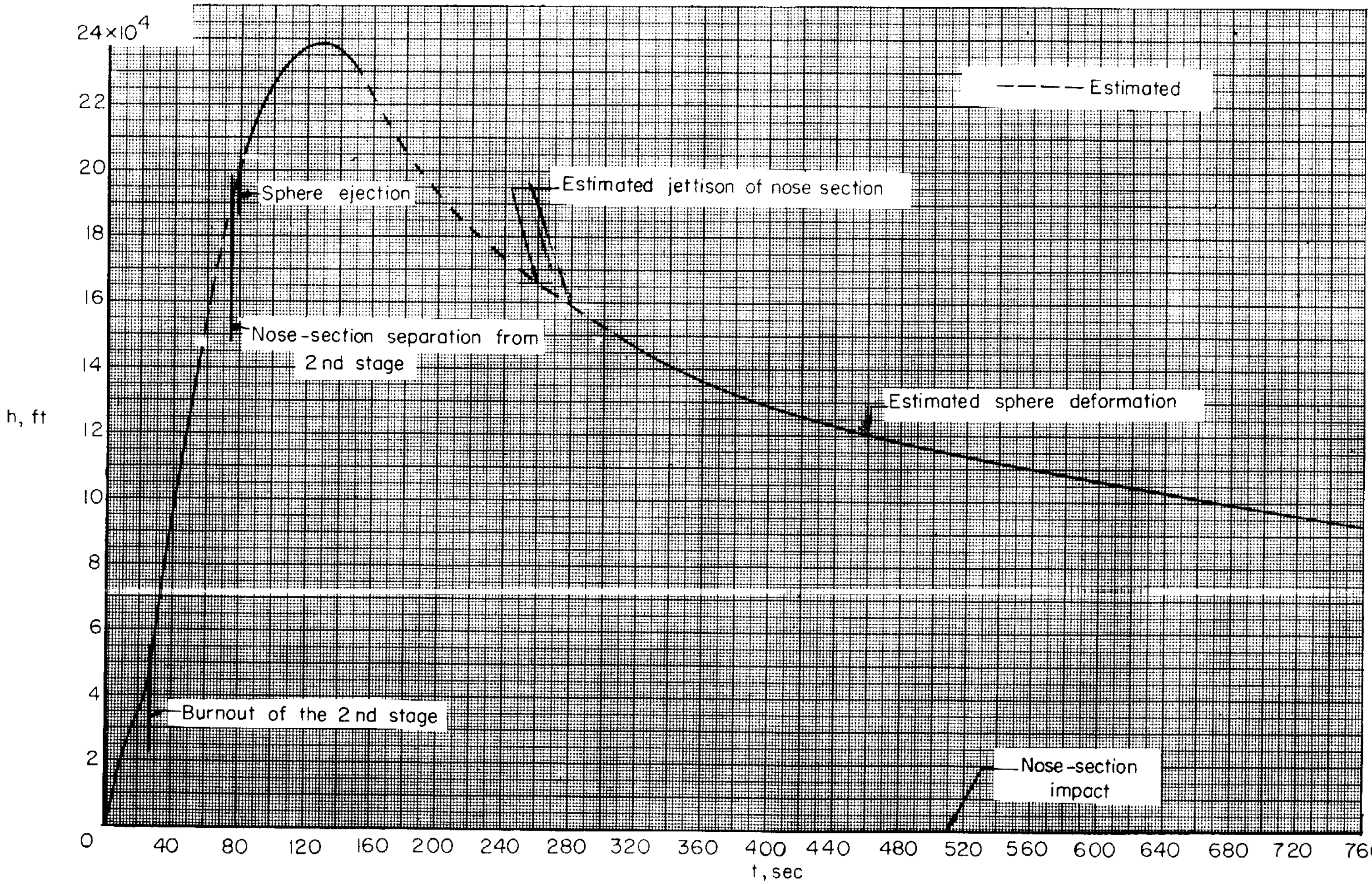


(a) Time history of Mach number.



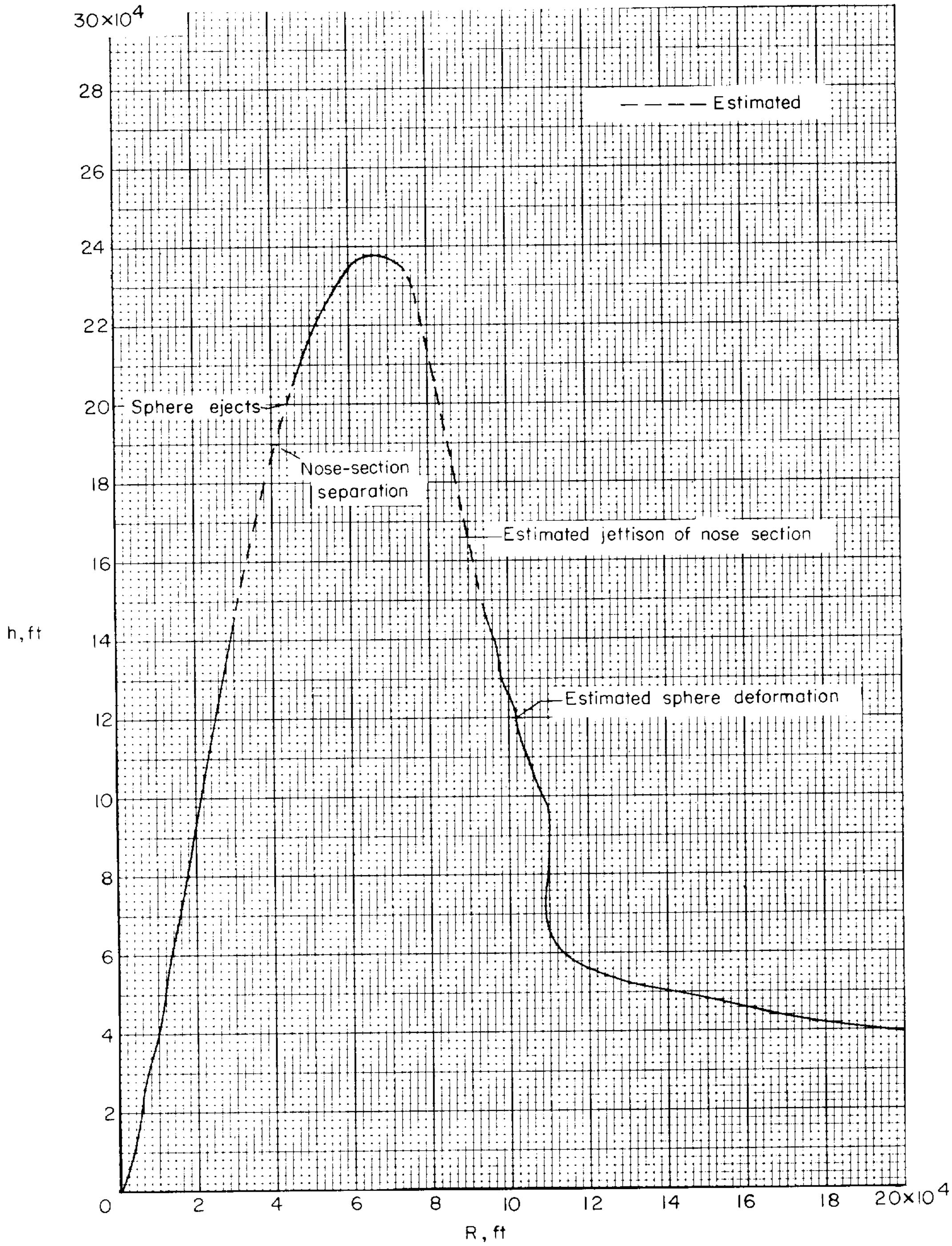
(b) Time history of velocity.

Figure 5.- Partial time history of Mach number and velocity.



(a) Time history of altitude.

Figure 6.- Time history of altitude and variation of altitude with range.



(b) Variation of altitude with range.

Figure 6.- Concluded.

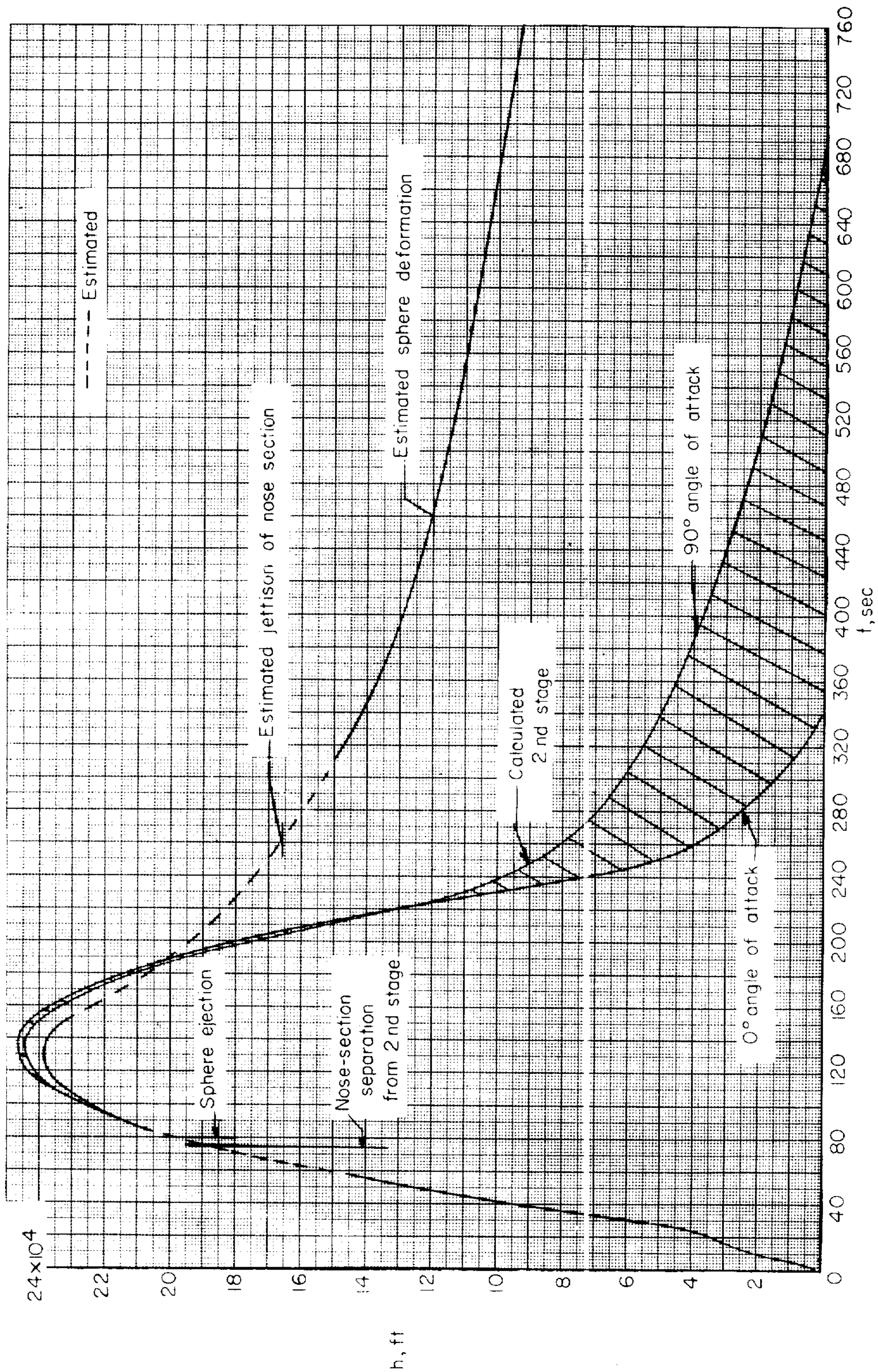


Figure 7.- Time history of altitude for 12-foot-diameter sphere and second stage.