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MEMORANDUM

A LIMITED STUDY OF A HYPOTHETICAL WINGED ANTI-ICBM POINT-DEFENSE MISSILE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A LIMITED STUDY OF A HYPOTHETICAL WINGED ANTI-ICBM POINT-DEFENSE MISSILE*

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SUMMARY

A preliminary investigation was conducted to determine whether a warhead stage of an antimissile missile could be placed within an arbitrary 2-nautical-mile-radius maneuver cylinder around an intercontinental-ballistic-missile (ICBM) flight path above an altitude of 140,000 feet, a horizontal range of 40 nautical miles, at a flight-path angle of approximately 20°, and within 50 seconds after take-off using only aerodynamic forces to turn the antimissile missile.

The preliminary investigation indicated that an antimissile missile using aerodynamic forces for turning was capable of intercepting the ICBM for the stated conditions of this study although the turning must be completed below an altitude of approximately 70,000 feet to insure that the antimissile missile will be at the desired flight-path angle.

Trim lift coefficients on the order of 2 to 3 and a maximum normal-acceleration force of from 25g to 35g were necessary to place the warhead stage in intercept position.

The preliminary investigation indicated that for the two boosters investigated the booster having a burning time of 10 seconds gave greater range up the ICBM flight path than did the booster having a burning time of 15 seconds for the same trim lift coefficient and required the least trim lift coefficient for the same range.

INTRODUCTION

Recent advancements in the development of an intercontinental ballistic missile (ICBM) has led to investigations of a missile to be

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used for defense against the ICBM. Little work in the past has been performed to determine the aerodynamic requirements, size, and weights of an antimissile missile to be used for the defense against the ICBM.

Many problems exist concerning the design of an antimissile missile, hereinafter referred to as AMM. The size and velocity of an intercontinental ballistic missile (ICBM) will make interception a most difficult task and destroying it will require a very accurate system. Radar information concerning the ICBM's flight path and velocity must be known accurately. Acquisition of the oncoming ICBM will be needed well in advance of the launch time of the AMM. The forewarning, supplied by the acquisition radar, will not only establish the ICBM's trajectory but will also determine the maximum time available to the AMM before intercept as well as the range and altitude of the ICBM when intercept occurs. This advance warning will also determine the amount of time the launching crew will have to ready the AMM for flight.

Another of the problems that must be solved by the radars will be that of distinguishing the ICBM from surrounding foreign bodies or decoys. After the ICBM has been identified from these foreign bodies, interception can be attempted. One of the ways to accomplish this interception is to program an AMM so that interception occurs before the ICBM reenters the atmosphere. If interception can be accomplished at this point, evasive actions by the ICBM will be held to a minimum.

In this paper an attempt is made to show some of the aerodynamic requirements of a hypothetical antimissile missile capable of placing a warhead in flight for a point defense against an ICBM in the altitude region from 100,000 to 200,000 feet. Placing the warhead stage within the warhead maneuver capability ranges consisted of four phases. These phases are: (1) a nonguided boost phase, (2) a turning phase (utilizing aerodynamic forces only to perform the turning maneuver), (3) a thrusting phase, and (4) a ballistic coast. At the end of 50 seconds of flight time it was desired to have the warhead stage of the configuration within an assumed 2-nautical-mile-radius maneuver cylinder around the ICBM traveling on a 20° flight path, at a minimum altitude of 140,000 feet, and a horizontal range of 10 nautical miles from the point of launching. Various combinations of launch angle, booster burning time, and trim lift coefficient during turning maneuver were utilized to determine the effect of each on the overall performance of the AMM. No considerations have been given to azimuth correction in this investigation. The effects of aerodynamic heating have been neglected although some consideration was given to this in the selection of the maximum velocity during boost phase.

Since this hypothetical missile will utilize aerodynamic forces to complete its mission, a configuration with low-aspect [redacted] wings was chosen because this configuration [redacted] over that for a body alone. Ref[redacted]s, at a Mach n[redacted]ber of 3.3,

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that a wing-body combination similar to the hypothetical missile chosen for this paper will have an increase in lift of approximately 60 percent over that for a body alone at an angle of attack of approximately 10°.

Another approach to the interception of an ICBM has been undertaken with a flared-body configuration and is presented in reference 2. This AMM (ref. 2) uses aerodynamic lift forces as well as a small component due to rocket thrust to maneuver the AMM but the controlling forces are applied by a reaction jet.

SYMBOLS

A	maximum cross-sectional area of fuselage, 7.544 sq ft
a_n	normal acceleration, g units
C_D	drag coefficient, D/qA
C_L	lift coefficient, L/qA
$C_{L,T}$	trim lift coefficient, L/qA
D	drag, lb
F	thrust, lb
g	acceleration due to gravity, ft/sec^2
h	altitude of missile, ft
I_{sp}	specific impulse of propellant, lb-sec/lb
L	lift, lb
M	Mach number
q	dynamic pressure, lb/sq ft
R	horizontal range, naut. miles
T	time from launch, sec
t	time, sec

V velocity of missile, ft/sec

W weight, lb

$\ddot{X}$ acceleration along X-axis

x_{cg} center-of-gravity location, measured from missile nose, ft

x_{cp} center-of-pressure location, measured from missile nose, ft

α angle of attack, deg

γ flight-path angle, angle between horizontal reference and velocity vector, deg

$\Delta\gamma$ change in flight-path angle, deg

Subscripts:

b burning of rocket motor

f conditions at end of 35 seconds from launch

MODEL DESCRIPTION

A sketch of the steerable stage of the hypothetical missile considered for this preliminary investigation is shown in figure 1. A sketch of the missile and booster arrangement is shown in figure 2, along with tabulated quantities of weights and center-of-gravity locations.

The hypothetical missile configuration used for this investigation was scaled from the models tested in references 3, 4, and 5. The body of the missile had a fineness ratio of 10 and consisted of a forebody of fineness ratio 5 followed by a tapered section that fairs into a cylindrical afterbody with a fineness ratio of 5.

The wings of the missile had an 85° delta cruciform plan form with an aspect ratio of 0.35 and were mounted on the cylindrical portion of the body.

MISSION CONSIDERATIONS

The maneuver characteristics of the warhead stage are presented in reference 2 and results show that the warhead stage with the approximate weight and size of that shown in reference 2 will be capable of correcting the orientation a distance of 2 nautical miles perpendicular to the ICBM flight path in 10 seconds; therefore, the problem of concern in this paper is to place the warhead stage within a 2-nautical-mile-radius maneuver cylinder around the ICBM flight path.

The hypothetical missile used in this investigation was decided upon only after the region in which to place the warhead stage was determined. The following conditions were assumed for the position of the AMM warhead:

(1) Minimum altitude, 140,000 feet

(2) Minimum horizontal range from launching site, 40 nautical miles

(3) Minimum time from missile take-off to 140,000-foot altitude and 40-nautical-mile horizontal range, 50 seconds

(4) Flight-path angle at the end of 50 seconds to be near 20° and within the maneuver capability of the warhead stage (a 2-nautical-mile-radius cylinder about the ICBM flight path)

(5) Warhead stage must have 10 seconds of maneuver time after separation from steerable stage; therefore, total time from missile take-off to intercept will be 60 seconds

(6) No azimuth corrections or aerodynamic heating were considered

CONFIGURATION

The assumed requirements of the weights and sizes of the component parts of the hypothetical missile (warhead stage and aerodynamic steerable stages) and booster stage are as follows:

Warhead stage:

(a) Warhead - diameter, 15 inches; length, 55 inches; weight, 1,000 pounds

(b) Guidance - weight, 200 pounds; density, 62.4 pounds per cubic foot

(c) Control system - weight, 200 pounds; density, 62.4 pounds per cubic foot

(d) Spherical rocket motor - I_{sp} of propellant, 220 pound-second per pound of propellant; diameter, 30 inches; loaded weight, 930 pounds; empty weight, 54 pounds; propellant weight, 876 pounds; propellant density, 95 pounds per cubic foot

Aerodynamic steerable stage:

(a) Guidance - weight, 300 pounds; control-system weight, 375 pounds; density, 62.4 pounds per cubic foot

(b) Body - skin weight, 5 pounds per square foot of wetted area

(c) Wings - weight, 5 pounds per square foot of wetted area

(d) Rocket motor - I_{sp} of propellant, 220 pound-second per pound of propellant; propellant density, 100 pounds per cubic foot

Booster stage:

(a) Rocket motor - structural weight, 15 percent of booster total weight

(b) Fin and fin attachment - weight, 5 percent of booster total weight

(c) Rocket motor - I_{sp} of propellant, 220 pound-second per pound of propellant; propellant density, 100 pounds per cubic foot

Thrust requirements:

(a) 10-second booster, 681,120 pounds for 10 seconds; total impulse, 6,811,200 pound-second

(b) 15-second booster, 460,600 pounds for 15 seconds; total impulse, 6,909,000 pound-second

(c) Sustainer rocket, 308,000 pounds for 5 seconds; total impulse, 1,540,000 pound-second

TRAJECTORY PROGRAMING

The trajectories of the AMM were divided into four phases. The first of these was the boost stage. Two different boosters were used in the investigation with the burning times different for each of the boost periods. One of the boosters had a burning time t_b of 10 seconds with a mass ratio (weight of booster loaded to weight of booster empty) of the booster alone of 5.0, and the second booster had a burning time t_b of 15 seconds with a mass ratio of the booster alone of 5.0. At the end of the boost period, 10 and 15 seconds, respectively, the booster separated from the missile.

The second phase of the trajectory was the aerodynamic turning portion. During this portion of the trajectory the missile decelerated and trim lift was applied until the missile reached a flight-path angle necessary to satisfy the conditions of reasonable tangency to the ICBM flight path at 50 seconds from launch time.

The third phase of the trajectory consisted of the thrusting portion and was supplied by the sustainer motor in the aerodynamic steerable stage. The mass ratio of the steerable stage was approximately 2.2. The thrust of the sustainer motor propelled the missile to the maximum Mach number reached during the flight. During this phase the missile flew a zero-lift trajectory.

The fourth phase of the trajectory consisted of a ballistic type of trajectory and terminated when the total time from missile launch reached 50 seconds and the missile was near tangency to the incoming ICBM path near an altitude of 140,000 feet and a horizontal range of 40 nautical miles.

DISCUSSION AND REMARKS

Aerodynamic Data

A model of the configuration used in this investigation has been previously tested in wind tunnels and the data have been presented in references 3 to 6. Static stability derivatives are given in these reports for a Mach number range from 2.0 to 6.8. Some of the data used in this paper are presented in figures 3 and 4 in the form of plots of lift coefficient (based on maximum cross-sectional area of fuselage) as a function of angle of attack and drag coefficient as a function of Mach number. Center-of-pressure locations were calculated for the steerable stage by use of these data and are given in table I for the Mach number range of the investigation.

Figure 4 presents the drag coefficient (based on maximum cross-sectional area of fuselage) as a function of Mach number for various trim lift coefficients. These data have been modified from those presented in references 3, 4, and 5 because it was necessary to add base drag during that period when the sustainer was not thrusting.

As shown in reference 6 the trailing-edge flaps were incapable of producing the trim lift coefficients covered in this investigation. However, reference 7 shows that triangular controls interdigitated to a triangular wing having an aspect ratio of 3/8 and mounted on a body similar to the one used in this study would produce trim lift coefficients on the order of 4.5 to 5 for a Mach number of 3 with a static stability of 0.2 body diameter. It is felt (in consideration of unpublished data) that, considering the size and plan form of the controls, center-of-gravity location of the missile, and position of the controls with respect to the wing and body, trim lift coefficients on the order of 3 can be obtained at a Mach number of 6 with the configuration used in the investigation of reference 7. Because of the limited amount of control data at the high Mach numbers covered in this investigation ($M = 4.0$ to 6.0), it appears that, before a satisfactory control can be obtained, more research on controls is necessary at the higher Mach numbers.

Configuration Layout

After the configuration was decided upon for the investigation, a layout of the AMM was made to determine the size necessary to carry the equipment and accomplish the mission. By use of the data presented in the section entitled "Configuration" and in figure 2, the sizes of the various stages were determined. The mass ratio of the vernier stage was 1.5 and included a warhead payload of 1,000 pounds. The aerodynamic or steerable stage which included the warhead stage had a mass ratio of 2.2.

With the size and weight of the AMM selected, trajectories were then calculated to determine the turning capability of the missile.

Trajectories

Equations used to compute the trajectories are presented in the appendix. Presented in figures 5 to 8 are plots of the trajectories for various trim lift coefficients, normal accelerations, dynamic pressures, and velocities as a function of time for the two boosters at various flight-path angles (at the end of boost). In each case the launch angles were such as to give flight-path angles of 90°, 80°, and 70° at the end of boost. For clarity, hereinafter these three flight-path angles are referred to as the launch angles since there is very little difference between these angles and the true launch angles (approximately 3.7° for the 10-second booster and 70° flight-path angle at the end of boost).

In figures 5(a), 6(a), 7(a), and 8(a) are shown trajectories for each of the boosters at various values of $C_{L,T}$. The two boosters differed in that the 10-second booster had 5 seconds more time for turning than did the 15-second booster since all aerodynamic turning was terminated at $T = 35$ seconds. Little change in flight-path angle could be obtained after $T = 35$ seconds because the missile had reached such an altitude and velocity that insufficient dynamic pressure was available for efficient aerodynamic turning. It was also necessary to leave sufficient time for the sustainer rocket motor to increase the velocity to that required to cover the altitude and range.

As mentioned in the section entitled "Trajectory Programing," the third and fourth phases of the trajectory were zero-lift or ballistic trajectory; therefore, for the last two phases it was assumed that no forces were present to change the flight path except that due to gravity. Calculations for zero-drag conditions show that, in order to have a flight-path angle of approximately 20° at the end of $T = 50$ seconds, an angle of approximately 26° or less was needed before $T = 35$ seconds. In each of the trajectories the turning phase was terminated at $T = 35$ seconds or at such time as the flight-path angle reached 26°. Examination of figures 5(a), 6(a), 7(a), and 8(a) indicated that a number of the trajectories shown did not have sufficient power to turn the AMM to 26° or less at $T = 35$ seconds. In table II are given the various times that each of the aerodynamic phases were terminated in order that the requirements of $T = 35$ seconds or a flight-path angle of 26° may be fulfilled.

Steerable-Stage Requirements

As may be seen in figure 5(a), for a launch angle of 90° and 10-second boost, a value of $C_{L,T}$ greater than 3 during the burning phase is necessary to produce the final angle of approximately 20° at $T = 50$ seconds. Figures 6(a) and 7(a) indicate that for launch angles of 80° and 70° a lower value of $C_{L,T}$ is necessary to turn the vehicle to a flight-path angle of approximately 20°. For a launch angle of 80° a value of $C_{L,T}$ of approximately 2.5 or greater will be required and for a launch angle of 70° a value of $C_{L,T}$ of approximately 1.75 or greater will be required.

Figures 5(b), 6(b), and 7(b) show the normal acceleration for values of $C_{L,T}$ that are capable of producing enough change in flight-path angle to position the AMM near the desired 20° flight-path angle at the end of the 50-second flight time. Since the total change in flight-path angle may be expressed as

$$\Delta\gamma = 1844 \int \frac{a_n}{V}\,dt$$

the area under the normal-acceleration—time curve is indicative of the turning capability of the missile.

It should be noted that the maximum normal acceleration for any value of $C_{L,T}$ did not exceed 50g for any of the flight paths shown. Maximum trim normal accelerations as low as 25g were experienced in several of the flight paths for launch angles of 70° and 80° with the 10-second booster. Examination of figures 5 to 8 indicates that, in order to place the warhead stage within the warhead-stage maneuver capability zone, trim lift coefficients on the order of 2 to 3 and maximum normal-acceleration forces of from 25g to 35g were necessary. Figures 5(b), 6(b), and 7(b) show that the trim normal acceleration (or turning rates) of the missile was quite small (approximately 4g) after an altitude of approximately 70,000 feet was reached. This would indicate that, in order to turn a missile by use of aerodynamic forces only, turning must be completed in the atmosphere below 70,000 feet.

In a practicable flight application, it may be advantageous at first to decrease $C_{L,T}$ for the first part of the aerodynamic turn and then to increase $C_{L,T}$ for the last part of the flight. This can be done by pulling larger angles of attack through a programed control setting or a g-sensing device. This will reduce the maximum g-load of the missile and a weight saving can be realized. Increasing $C_{L,T}$ for the last part of the flight will still give the same area under the normal-acceleration—time curve (turning capability) as for some of the trajectories with a constant value of $C_{L,T}$.

Some Effects of Booster Burning Time on Steering Requirements

In order to determine the turning capability of the aerodynamic steerable stage, some consideration was given to the thrusting period of the booster. No detailed analysis was made but an attempt to determine some of the effects of burning time of the booster was made. Two boosters were chosen; one had a burning time of 10 seconds and the other had a burning time of 15 seconds. The selection of the velocity at the end of boost was made after consideration of several important factors. First, it was realized that a large average velocity (5,800 feet per second) must be maintained throughout the flight of the AMM to cover the required distance. Second, it was essential to keep the velocity low in the dense air to minimize aerodynamic heating and, third, it was necessary for the AMM to remain in the atmosphere so that the dynamic pressure would be high enough to provide efficient turning during the second phase of the trajectory. After consideration of these factors, the velocity which was chosen and was thought to satisfy the conditions was 6,000 feet per second. This terminal boost velocity would allow the missile to get through the dense air as slow as possible for maximum turn capability and still be high enough to enable the missile to cover the required distance. Some of the advantages of the booster having a shorter burning time can be seen in a comparison of figures 7 and 8. In these figures it can be seen that much higher values of $C_{L,T}$ are required for the 15-second booster to turn the missile to the desired flight-path angle because of the higher initial altitude of the booster at missile-booster separation. An example of this may be seen by a comparison of the values of $C_{L,T}$ required to obtain a flight-path angle of approximately 17° for the two boosters. For the 10-second booster a value of $C_{L,T}$ of only 2 is required, whereas a value of $C_{L,T}$ of 3.5 is required for the 15-second booster. Also, for the 15-second booster a greater loss in velocity from deceleration was evident. It can be seen from this comparison that it is more desirable for aerodynamic turning to use the 10-second booster instead of the 15-second booster.

Presented in figure 9 is a typical trajectory for one of the launch conditions from take-off to T = 50 seconds. The trajectory presented is for the 10-second booster, a 70° launch angle, and a value of $C_{L,T}$ of 2 for 16 seconds. As may be noted in figure 9, the aerodynamic steerable stage is within the warhead-stage maneuver capability zone at the end of 50 seconds. Other flight paths are likewise capable of placing the aerodynamic steerable stage within the warhead-stage maneuver capability zone.

The amount of time available after the completion of the aerodynamic turn will vary with launch angle and type of booster. This was dependent, as mentioned previously, upon the amount of time needed to turn the aerodynamic steerable stage to the correct flight-path angle. In table II are given the times, velocities, flight-path angles, horizontal ranges, and altitudes for four points along the trajectory. These four points were end of boost, end of aerodynamic turn, end of sustainer burning, and end of coast (T = 50 seconds). Examination of table II will also show the times at which the aerodynamic turn was started and was completed for each of the trajectories computed.

Horizontal Range and Altitude Considerations

Presented in figure 10 are the end points of the trajectories for those launch conditions capable of placing the aerodynamic steerable stage within the maneuver capability zone of the warhead stage (2-nautical-mile-radius maneuv[redacted]inder) along with others that did not make the required range. Figure 10 shows the variation of altitude with horizontal range for various launch angles and trim lift coefficients $C_{L,T}$ for the two boosters. Figure 10 shows that with the 10-second booster and launch angles of 70° and 80° the missile was capable of entering the warhead-stage maneuver capability zone, whereas with a 90° launch angle a trim lift coefficient of 4 was required. Figure 10 also indicates that with the 15-second booster the AMM would not be capable of entering the warhead-stage maneuver capability zone unless trim lift coefficients of 4 and greater were obtained, whereas the 10-second booster with a 70° launch angle would need a trim lift coefficient of only slightly greater than 1.75 to meet the requirement. This could be an advantage in that the structural strength of the missile would not have to be as great; therefore, a saving in the total take-off weight may be realized. No attempt was made to increase the ranges each of the flight paths would obtain during the flight although it is believed that only small gains would be experienced by different selections of flight-path angles at the end of the aerodynamic turn. Some gain in range could be obtained by (1) decreasing the boosting time, (2) decreasing the launch angle, and (3) thrusting the sustainer rocket motor during the turning phase. Thrusting the rocket motor during the turning phase of the trajectory would add a component of thrust of the rocket motor due to the angle of attack of the missile. This would give additional lift to turn the missile to the desired flight-path angle.

Applications for Area Defense

Another important means of increasing the range of the AMM for area defense is to increase the amount of time the missile will have in flight. Some of the effects of increased time on horizontal range and altitude can be seen in figure 11. Another booster exactly like the 10-second booster was added to the configuration and programed as indicated in the figure. Table III presents the time, velocity, altitude, horizontal range, and flight-path angle for several points along the trajectory. It can be seen that the longer flight resulted in an altitude of 280 nautical miles and horizontal range of approximately 400 nautical miles at a time from take-off of 305 seconds. Also shown in figure 11 is a flight path of an intercontinental ballistic missile having a 5,500-nautical-mile range. It can be seen in figure 11 that the longer flight time resulted in the AMM being within the warhead-stage maneuver capability zone for approximately 80 seconds and allowed intercept to take place at altitudes from 236 to 280 nautical miles and at horizontal ranges from 296 to 400 nautical miles. Most of the time, the AMM shown in figure 11 would be on a ballistic trajectory. A trim lift coefficient on the order of only 2 applied for 3.4 seconds was necessary to turn the steerable stage to intersect the ICMB flight path. This lift resulted in a change in flight-path angle of approximately 13°. By flying a ballistic trajectory it is quite possible to eliminate the aerodynamic turning phase completely provided that the [redacted] of the AMM is correct, the range of the target is great enough, and enough time is available to permit gravity to act as a means of turning the AMM to intersect the ICBM flight path. This would mean that the AMM would be dependent on interception at great distances to allow the AMM to turn to the flight path of the oncoming ICBM and no control would be available during the early part of the trajectory to correct launch-angle and radar errors.

CONCLUSIONS

Preliminary calculations concerning placement of the warhead stage of an antimissile missile within a 2-nautical-mile-radius maneuver cylinder around an intercontinental-ballistic-missile (ICBM) flight path above an altitude of 140,000 feet, a horizontal range of 40 nautical miles, at a flight-path angle of approximately 20°, and within a total flight time of 50 seconds after take-off indicate the following conclusions:

1. Aerodynamic turning can be used to complete the interception of an ICBM for the stated conditions of this investigation.

2. Turning of a missile by the use of aerodynamic forces only must be completed in the atmosphere below approximately 70,000 feet.

3. Trim lift coefficients on the order of 2 to 3 and maximum normal-acceleration forces of from 25g to 35g were necessary to place the warhead stage in intercept position.

4. Of two boosters investigated, the booster having a burning time of 10 seconds gave greater range up the ICBM flight path than did the booster having a burning time of 15 seconds for the same trim lift coefficient and required the least trim lift coefficient for the same range.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 18, 1958.

APPENDIX

EQUATIONS FOR TRAJECTORY CALCULATIONS

The following equations were used in the calculation of the various flight paths presented in this report and refer to a flat earth coordinate system:

$$R = \iint \ddot{X} \cos \gamma \, dT^2$$

$$h = \iint \ddot{X} \sin \gamma \, dT^2$$

where

$$\gamma = \int \dot{\gamma} \, dT$$

and

$$\dot{\gamma} = \left(\frac{C_{L,T} qA}{WV} - \frac{W \cos \gamma}{WV} + \frac{F \sin \alpha}{WV} \right) (57.3)(32.2)$$

In the equation for the rate of change of flight-path angle the first term represents the contribution of the wing-body lift and the second term is the turning due to gravity. The third term represents the contribution due to the rocket thrust.

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The axis system with forces and angles used for trajectory calculations is presented in the following sketch:

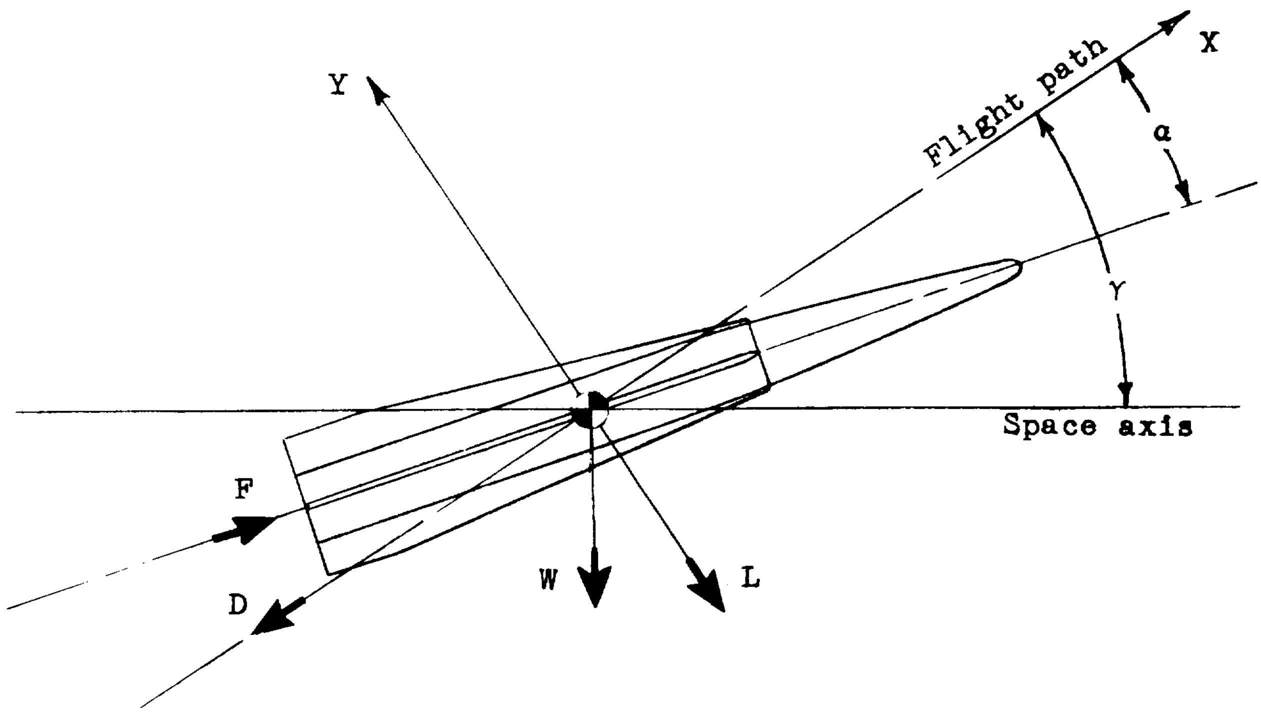

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TABLE I

ESTIMATED CENTER-OF-GRAVITY AND CENTER-OF-PRESSURE

LOCATIONS FOR STEERABLE STAGE

Mach number	Loaded rocket motor		Empty rocket motor	
	x_{cg}, ft	x_{cp}, ft	x_{cg}, ft	x_{cp}, ft
4.0	17.2	18.9	----	----
6.0	17.2	17.7	----	----
8.0	----	----	14.8	16.6
10.0	----	----	14.8	15.5

TABLE II

SUMMARY OF TRAJECTORIES[1]

$C_{L,T}$	End of boost					End of aerodynamic turn					End of sustainer-rocket burning					End of coast				
	T	V	γ	R	h	T	V	γ	R	h	T	V	γ	R	h	T	V	γ	R	h
Launch angle, 70°; 10-second booster																				
1.75	10	6,000	70	8,699	23,903	35	4,387	24.76	101,568	97,600	40	9,576	23.48	131,976	111,129	50	9,439	21.68	219,740	147,623
2.0	10	6,000	70	8,699	23,903	26	4,383	24.95	66,535	73,855	31.0	9,587	23.68	97,019	87,530	50	9,316	20.24	263,332	154,686
3.0	10	6,000	70	8,699	23,903	15.9	4,300	26.00	28,000	44,000	20.9	9,397	24.72	57,557	57,912	50	8,892	19.20	302,714	157,235
4.0	10	6,000	70	8,699	23,903	14.3	4,050	26.00	23,000	38,300	19.3	9,220	24.66	51,764	51,506	50	8,881	18.88	310,963	155,553
Launch angle, 80°; 10-second booster																				
2.5	10	6,000	80	4,417	25,050	30	3,952	24.88	67,059	84,059	35	9,133	23.51	95,488	96,911	50	8,924	20.66	220,875	147,804
3.0	10	6,000	80	4,417	25,050	21	3,950	26.48	37,755	60,697	26	8,900	25.17	60,433	73,992	50	8,495	20.47	252,096	155,476
4.0	10	6,000	80	4,417	25,050	16.6	3,520	26.00	22,200	46,200	21.6	8,634	24.51	48,307	58,402	50	8,123	18.57	268,020	145,718
Launch angle, 90°; 10-second booster																				
3.0	10	6,000	90	0	25,437	38.0	3,500	24.0	78,000	100,200	45.0	8,691	22.49	104,465	111,502	50	8,595	21.09	160,652	133,958
3.5	10	6,000	90	0	25,437	27.0	3,433	24.83	44,871	75,085	32.0	8,609	23.31	73,855	87,479	50	8,347	19.66	215,609	143,357
4.0	10	6,000	90	0	25,437	21.0	3,400	26.0	27,800	59,000	26.0	8,549	24.48	52,440	70,970	50	8,155	19.55	237,508	146,008
Launch angle, 70°; 15-second booster																				
3.0	15	6,000	70	12,920	35,502	36.0	4,150	25.20	86,000	96,200	41.0	9,337	23.89	115,259	109,009	50	9,209	22.28	192,019	141,725
3.5	15	6,000	70	12,920	35,502	28.0	4,060	25.0	57,700	74,600	33.0	9,232	23.64	86,572	87,544	50	8,985	20.44	229,902	145,640
4.0	15	6,000	70	12,920	35,502	24.8	4,040	26.0	45,500	66,500	29.8	9,197	24.66	74,039	79,952	50	8,896	20.91	242,163	150,578

[1] Thrust for 10-second booster = 681,120 pounds for 10 seconds; thrust for 15-second booster = 460,600 pounds for 15 seconds; thrust for sustainer rocket = 308,000 pounds for 5 seconds.

[redacted]

TABLE III

SUMMARY OF TRAJECTORY OF LONG-RANGE MISSILE

Condition	Time from launch, T, sec	Velocity, V, ft/sec	Flight-path angle, γ, deg	Horizontal range, R, ft	Altitude, h, ft
Take-off	0	0	70	0	0
First-stage burnout	10	2,600	60.5	5,700	10,750
Second-stage burnout	20	8,450	58.7	31,711	54,490
End of lifting phase $(C_{L,T} = 2)$	23.4	11,320	45.1	52,370	80,340
End of sustainer rocket burning	25.0	13,500	45	66,360	94,300
Ballistic coast	65.0	12,550	41.4	444,970	448,550
Ballistic coast	105.0	11,760	37.9	818,744	758,970
Ballistic coast	145.0	11,050	34.0	1,187,320	1,027,240
Ballistic coast	185.0	10,410	29.70	1,550,720	1,254,070
Ballistic coast	245.0	9,610	22.0	2,089,210	1,517,480
Ballistic coast	285.0	9,190	16.5	2,443,550	1,641,820
Ballistic coast	305.0	9,020	13.6	2,618,900	1,684,190

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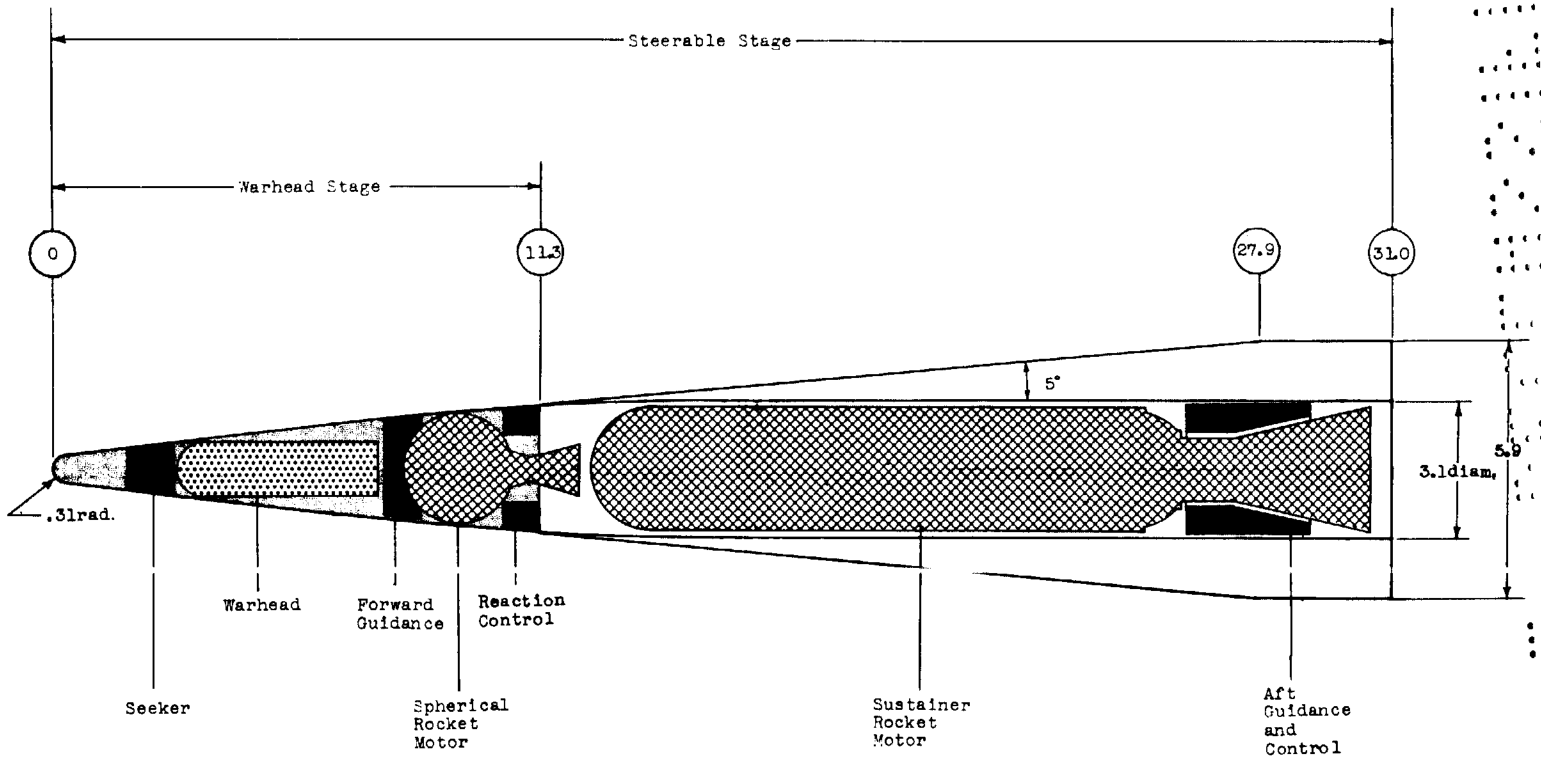

Figure 1.- Sketch of steerable stage of hypothetical model considered in investigation. All dimensions are in feet.

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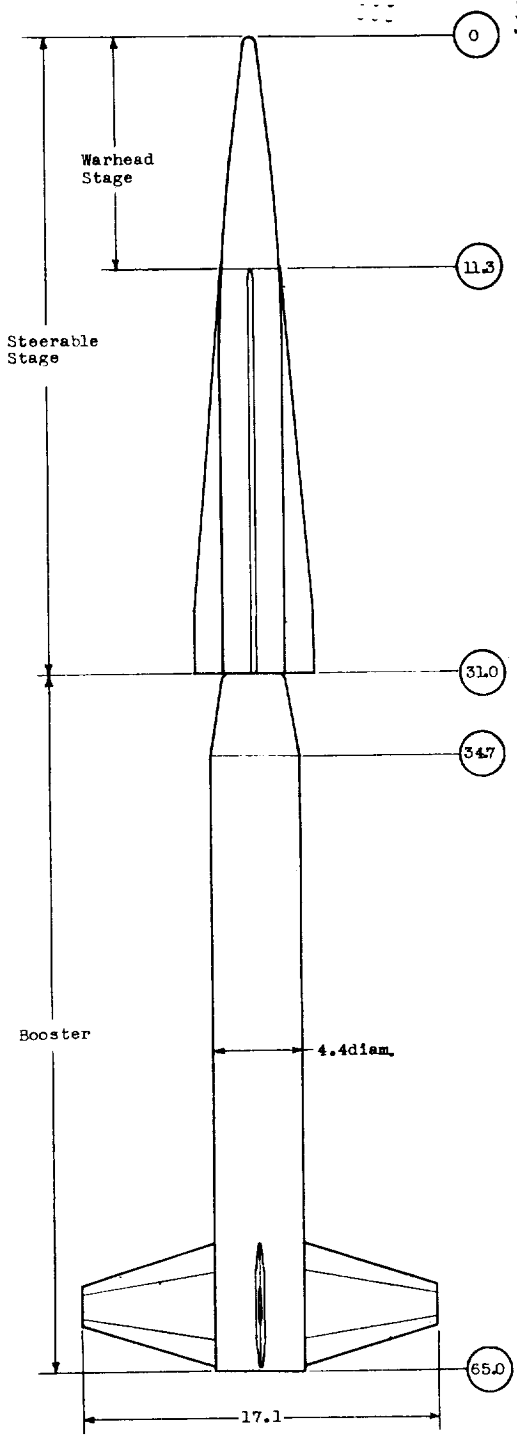

MISSILE WEIGHT SUMMARY

ITEM	W	x_{cg}
Warhead Stage		
Structure (station 0 - 11.3)	270	7.80
Seeker	40	2.30
Forward guidance & power	160	7.40
Warhead	1,000	4.70
Spherical rocket motor	54	9.70
Reaction control	200	10.70
Empty weight	1,724	6.24
Propellant	876	9.33
Gross weight	2,600	7.28
*Heat shield	376	1.80
Steerable Stage Minus Warhead Stage		
Structure (station 11.3 - 31)	965	21.13
Wings	412	22.30
Control surfaces	172	29.40
Aft guidance & power	300	26.50
Aft controls	375	26.50
Sustainer rocket motor	800	21.10
Empty weight	3,024	
Propellant	7,000	19.32
Gross weight	10,024	
Total Configuration		
Steerable Stage minus Sustainer Rocket Motor Propellant	6,000	14.83
Steerable Stage gross weight	13,000	17.24
Booster empty weight	7,740	51.96
Propellant	30,960	46.45
Booster gross weight	38,700	47.55
Overall gross weight	51,700	39.93

*Disposed of at separation of Warhead Stage

Figure 2.- Sketch of hypothetical model and booster and tabulated weight summary. All dimensions are in feet and all weights are in pounds.

[redacted]

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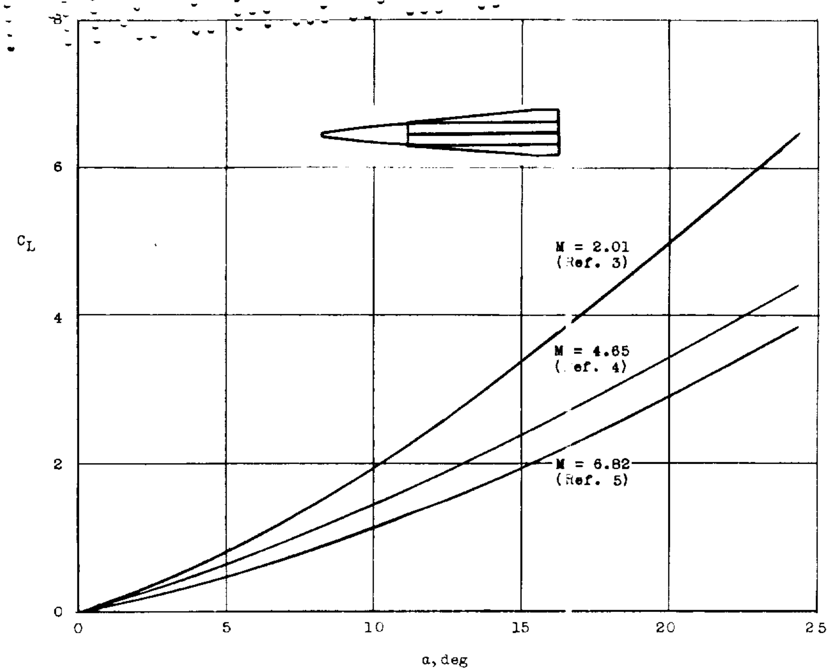

Figure 3.- Variation of lift coefficient C_L (based on maximum cross-sectional area of fuselage) with angle of attack for various Mach numbers for aerodynamic steerable stage.

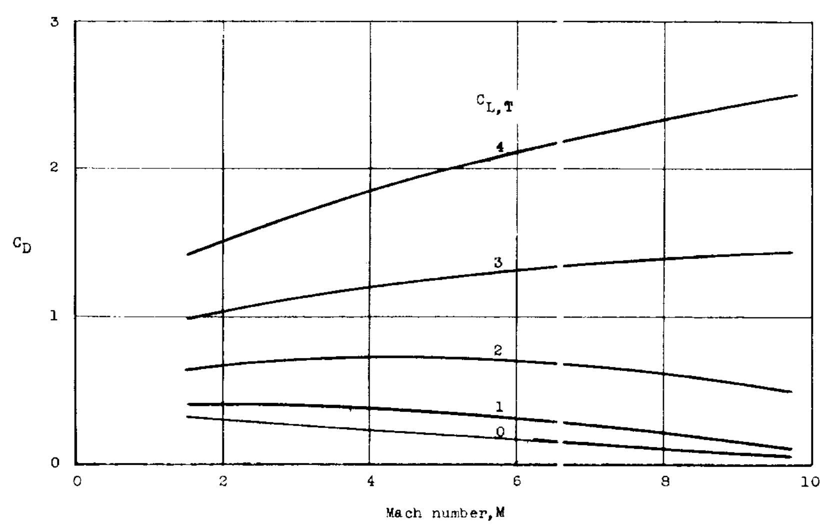

Figure 4.- Variation of drag coefficient C_D (based on maximum cross-sectional area of fuselage) with Mach number for various values of $C_{L,T}$ for aerodynamic steerable stage only and with base drag included.

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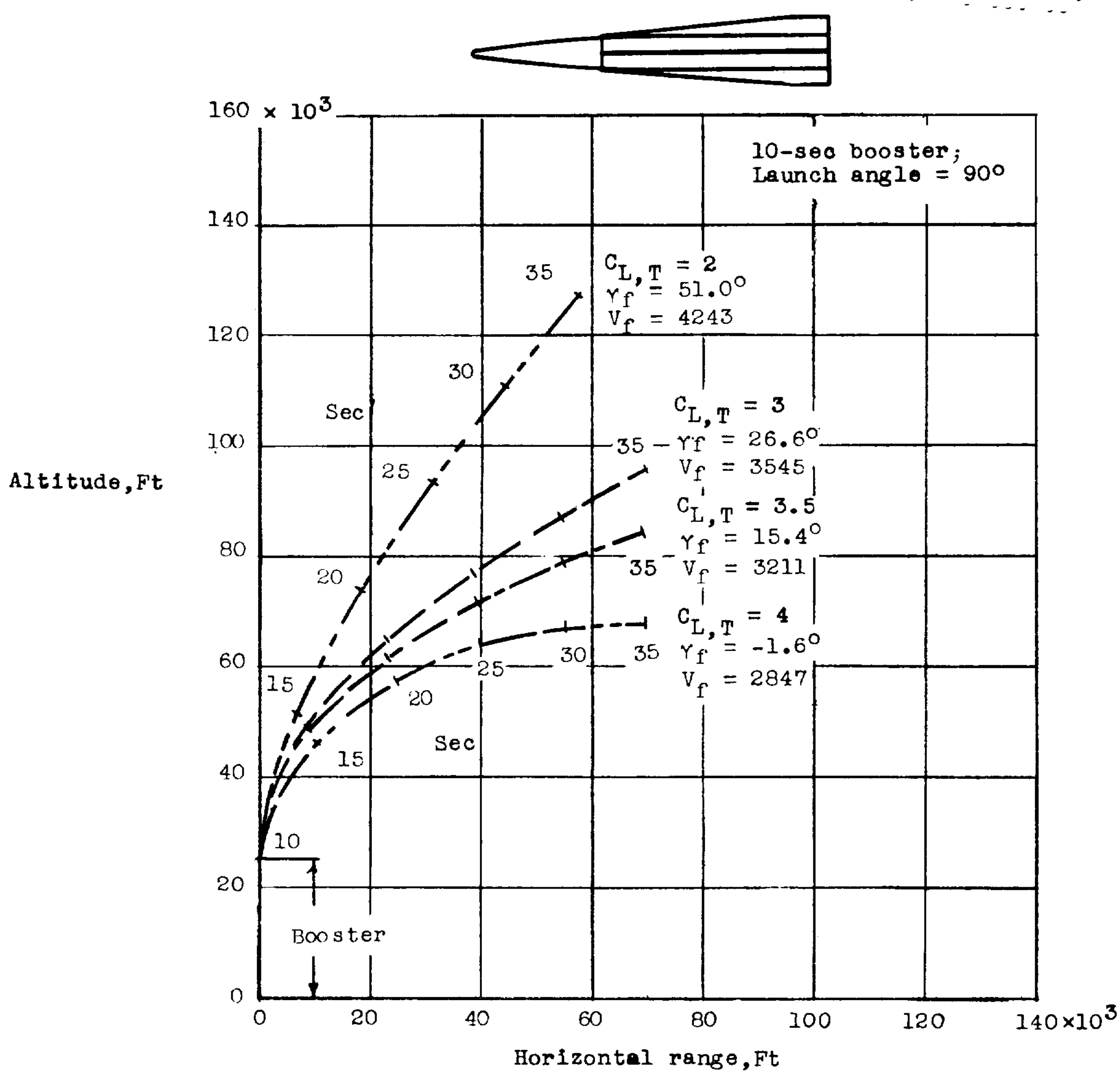

(a) Trajectories.

Figure 5.- Flight conditions during turning phase for various values of $C_{L,T}$. Launch angle, 90°; 10-second booster.

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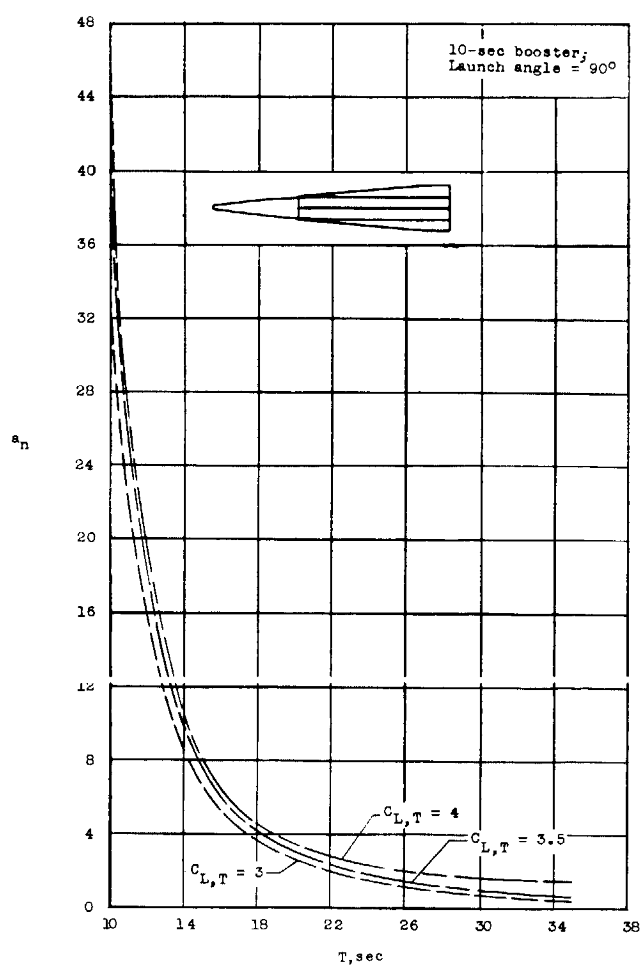
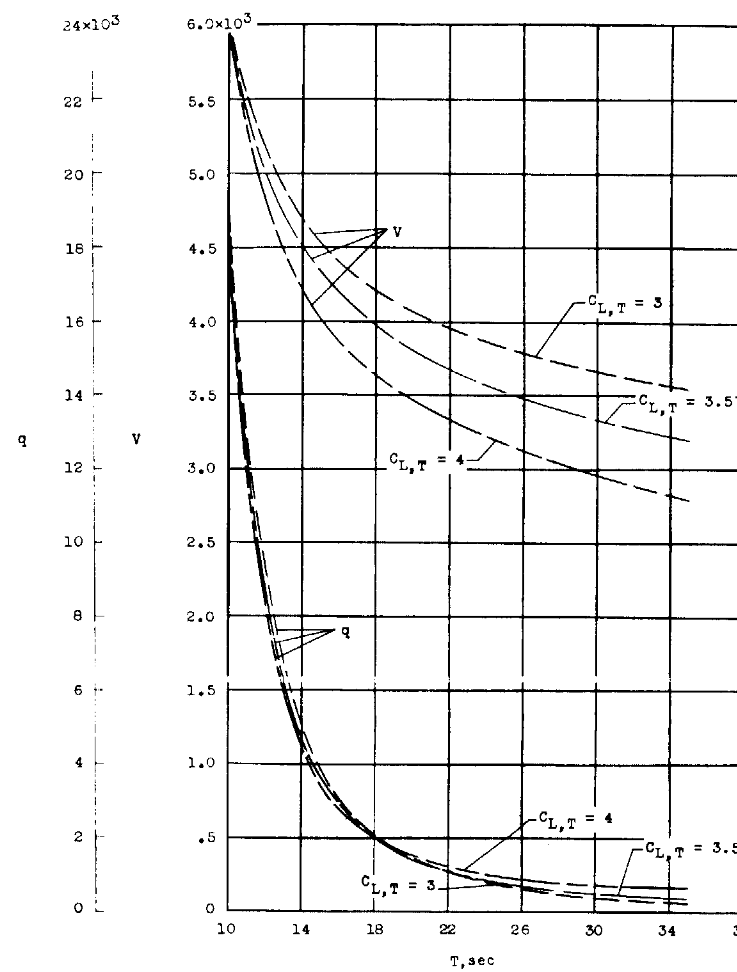


(b) Variation of normal acceleration with time.



(c) Variation of dynamic pressure and velocity with time.

Figure 5.- Concluded.

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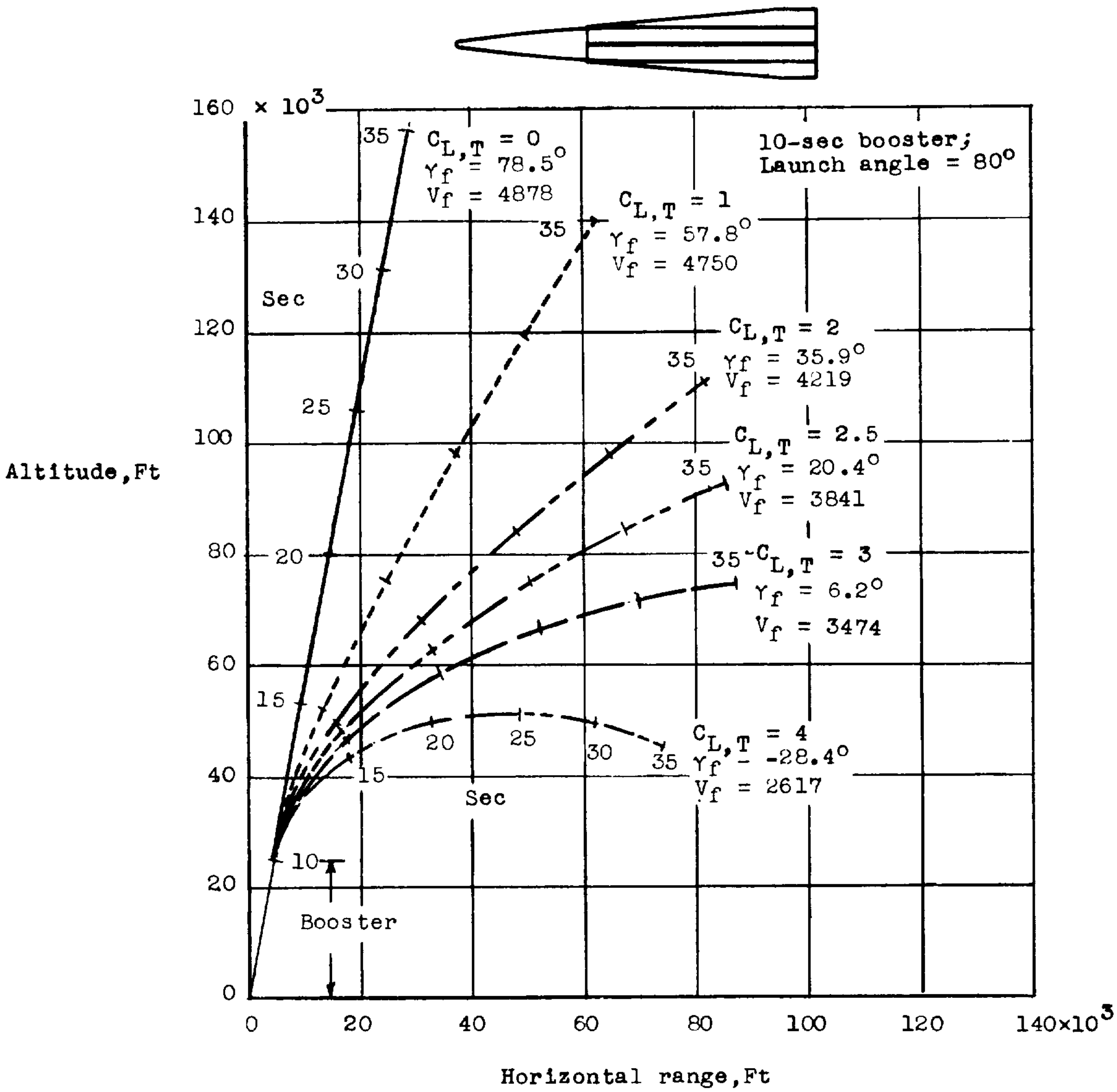

(a) Trajectories.

Figure 6.- Flight conditions during turning phase for various values of $C_{L,T}$. Launch angle, 80°; 10-second booster.

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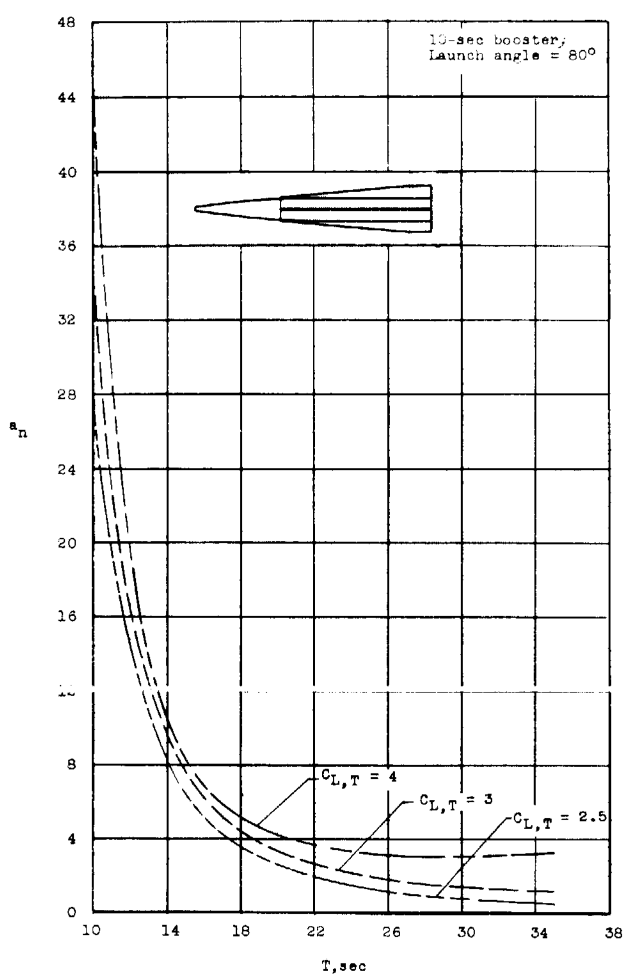
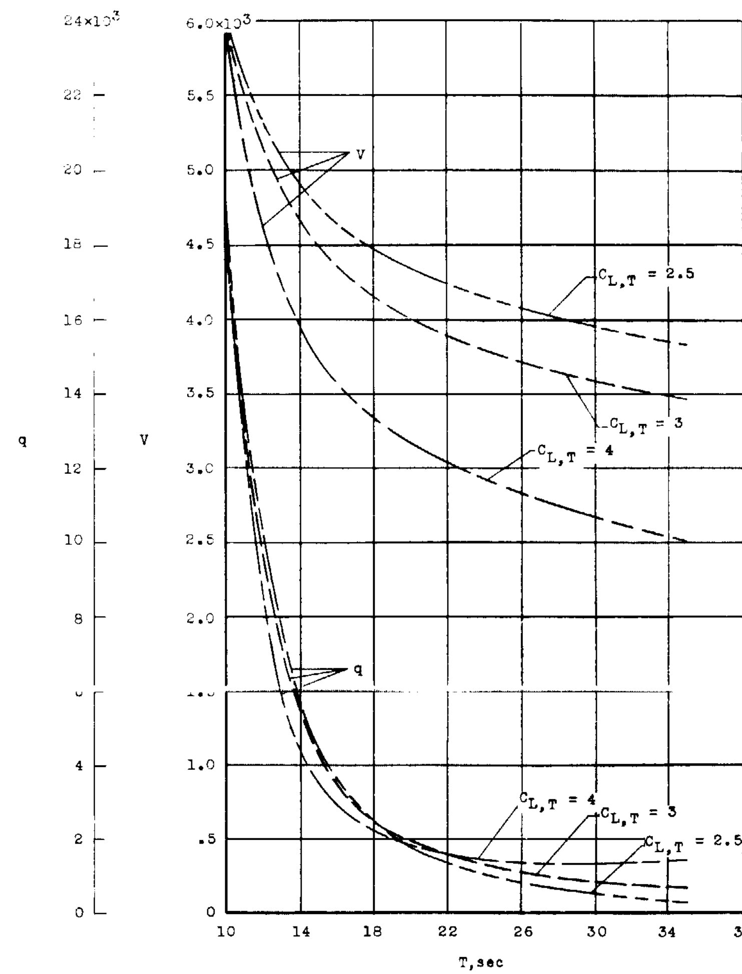


(b) Variation of normal acceleration with time.



(c) Variation of dynamic pressure and velocity with time.

Figure 6.- Concluded.

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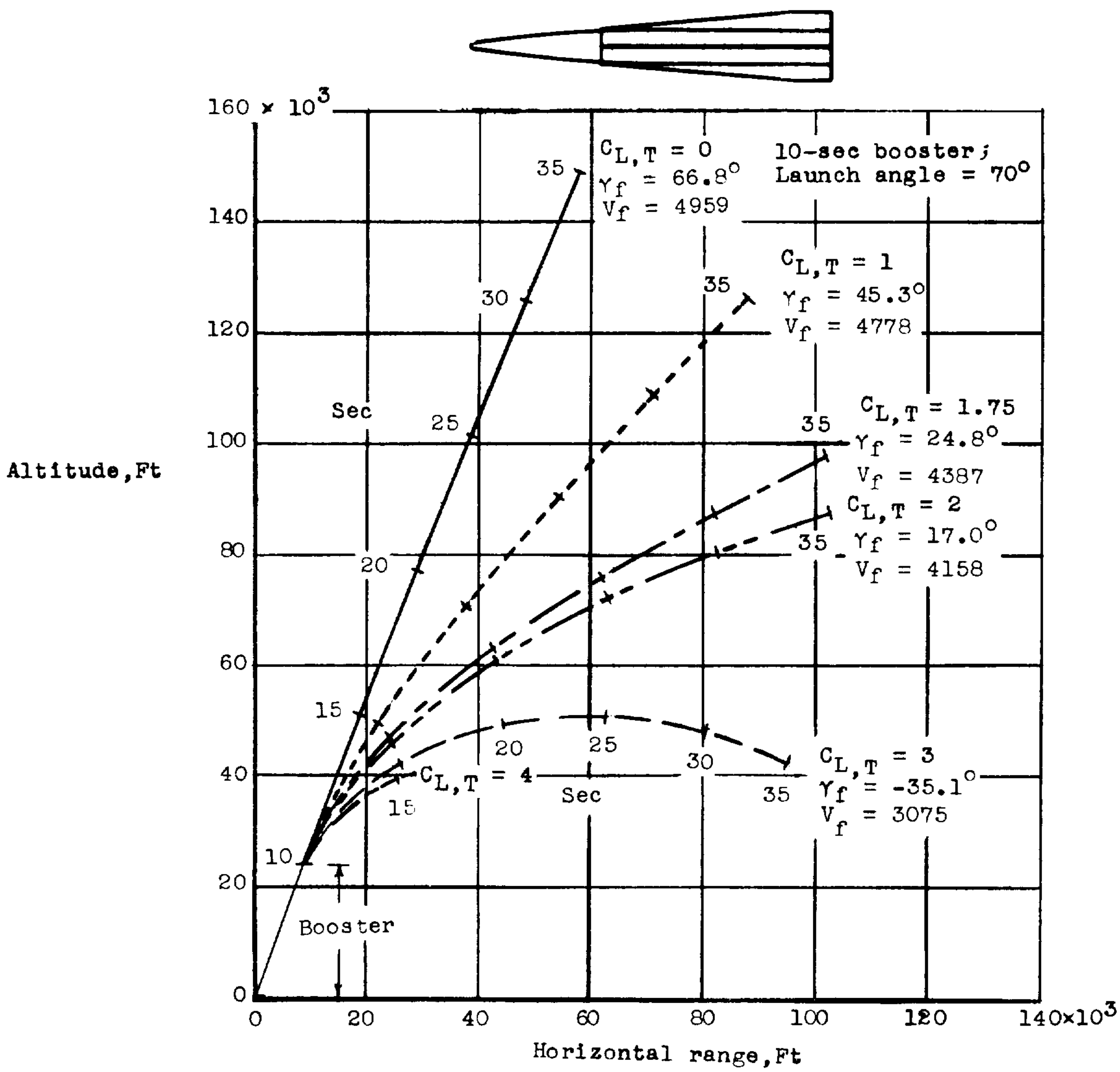

(a) Trajectories.

Figure 7.- Flight conditions during turning phase for various values of $C_{L,T}$. Launch angle, 70°; 10-second booster.

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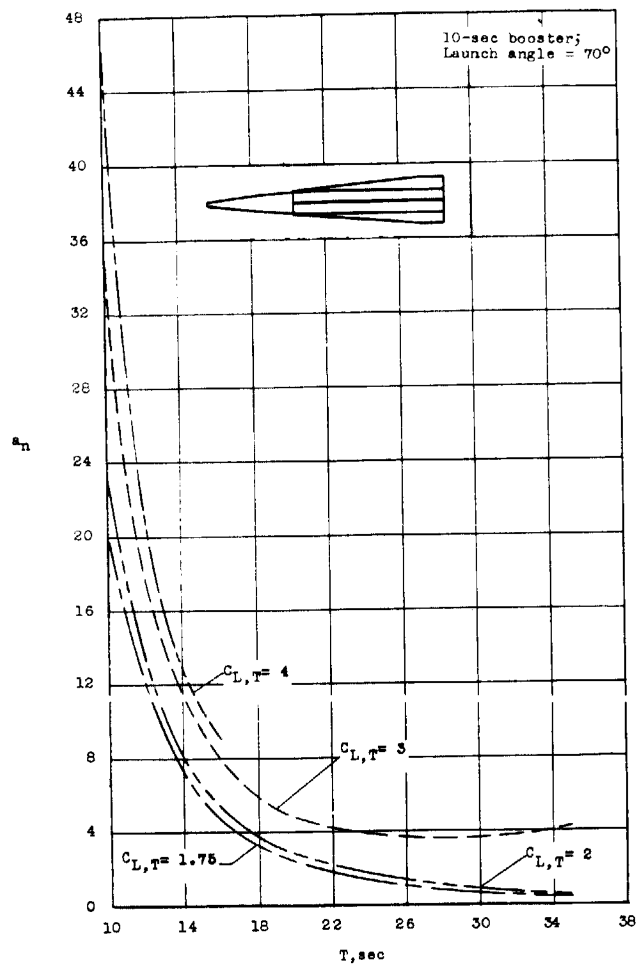
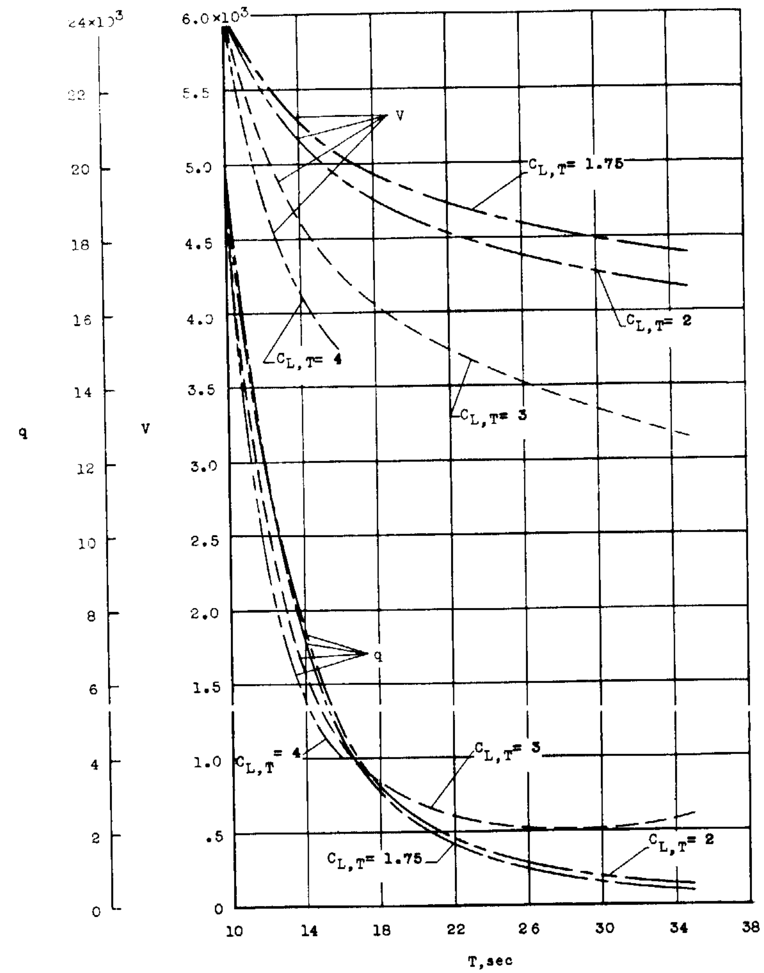


(b) Variation of normal acceleration with time.



(c) Variation of dynamic pressure and velocity with time.

Figure 7.- Concluded.

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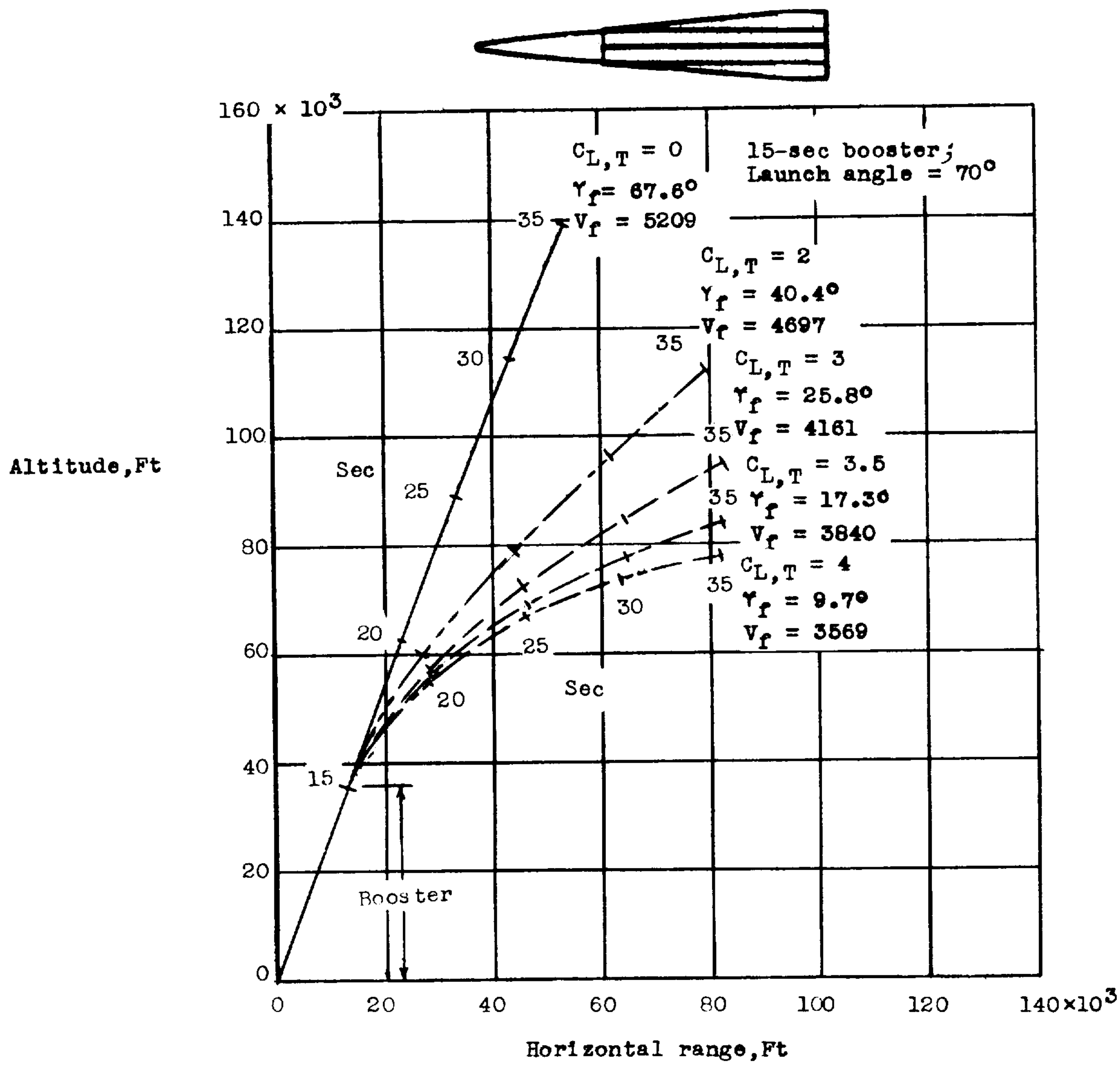

(a) Trajectories.

Figure 8.- Flight conditions during turning phase for various values of $C_{L,T}$. Launch angle, 70°; 15-second booster.

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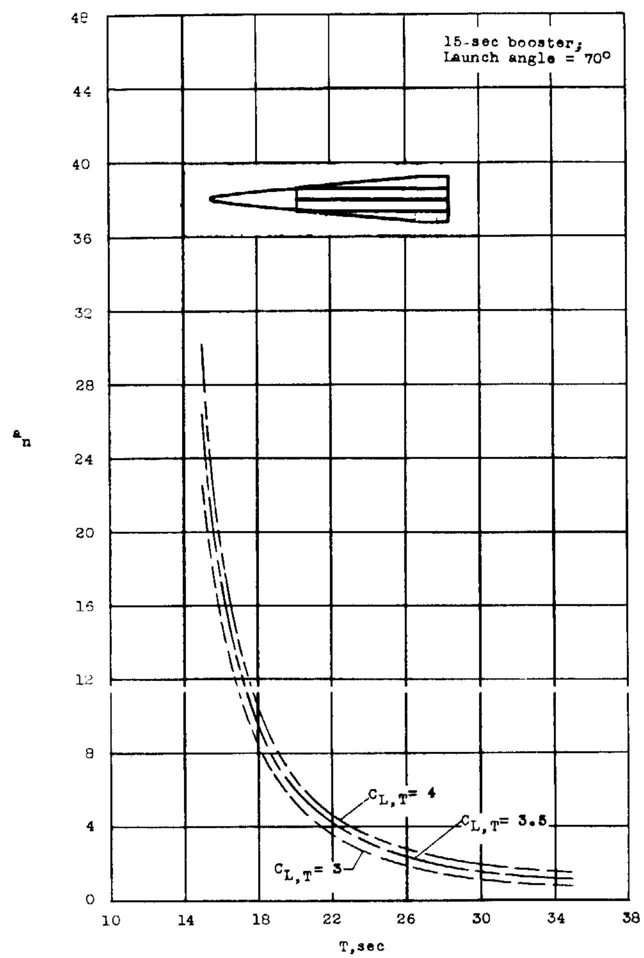
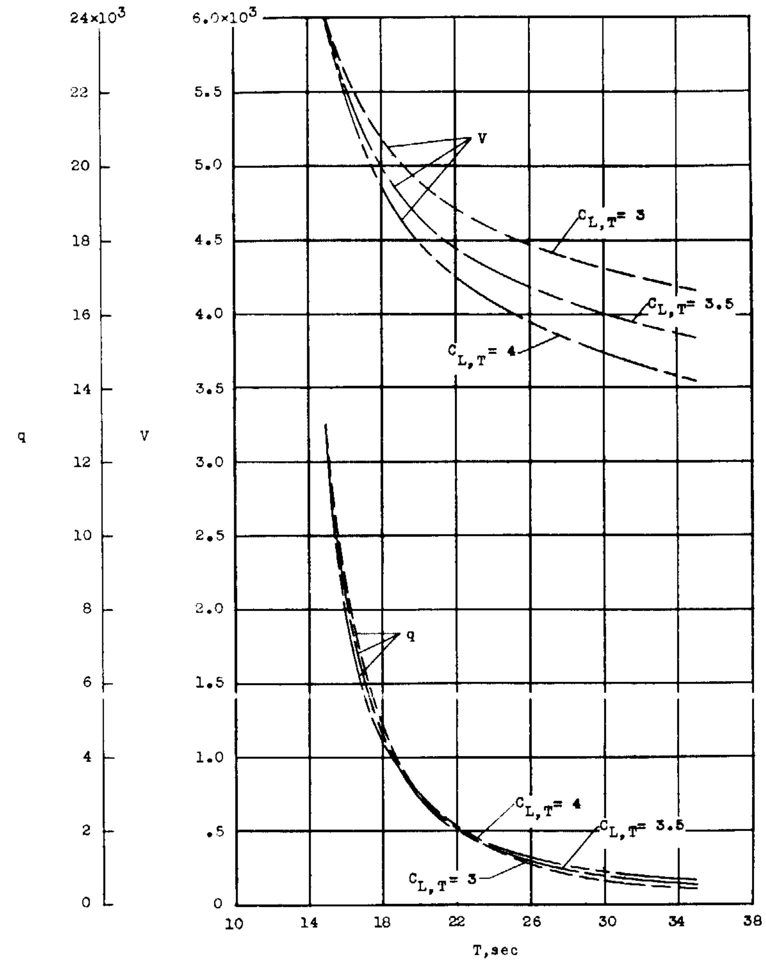


(b) Variation of normal acceleration with time.



(c) Variation of dynamic pressure and velocity with time.

Figure 8.- Concluded.

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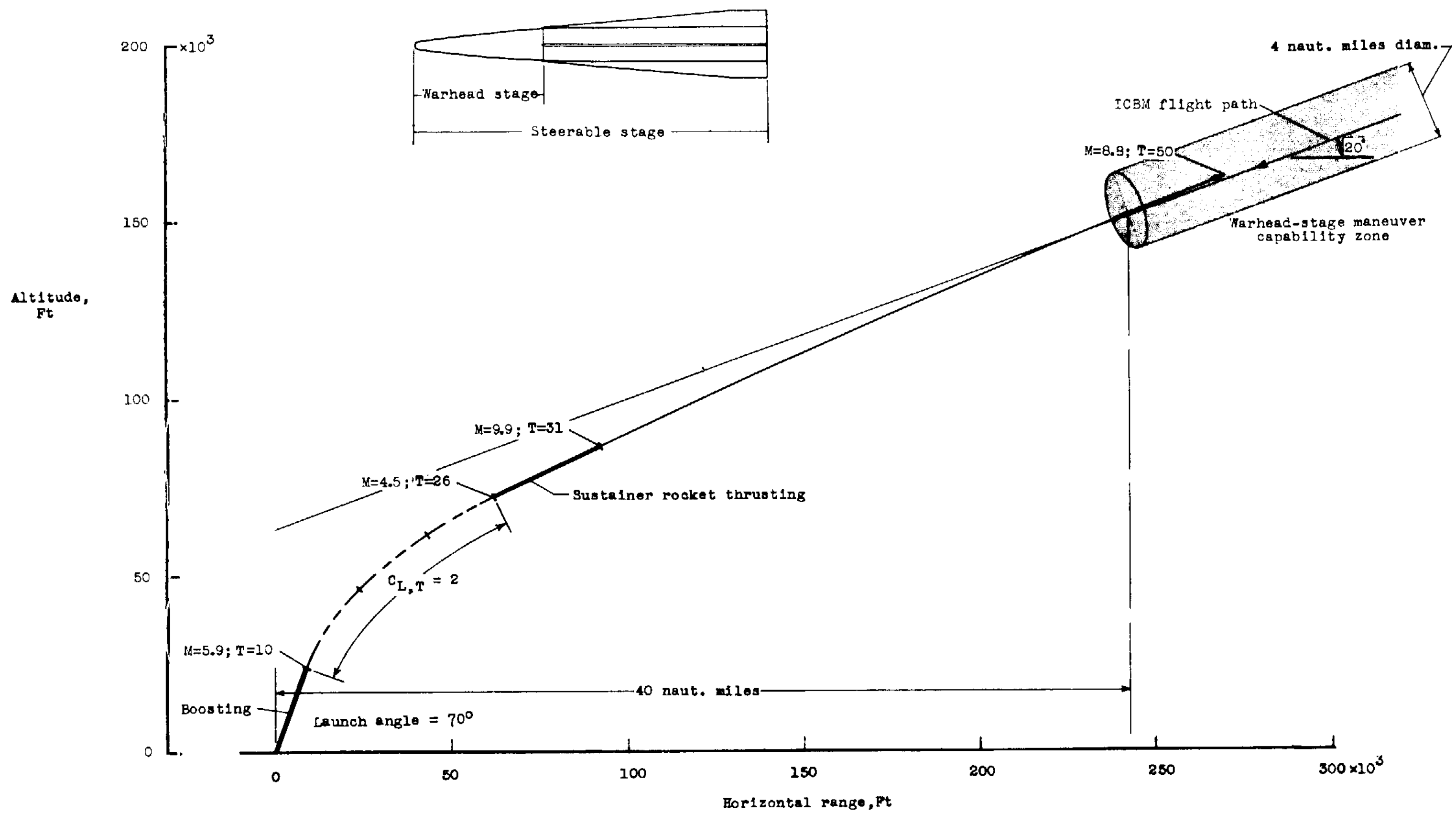

Figure 9.- Typical trajectory showing altitude, range, and time capability of antimissile missile.

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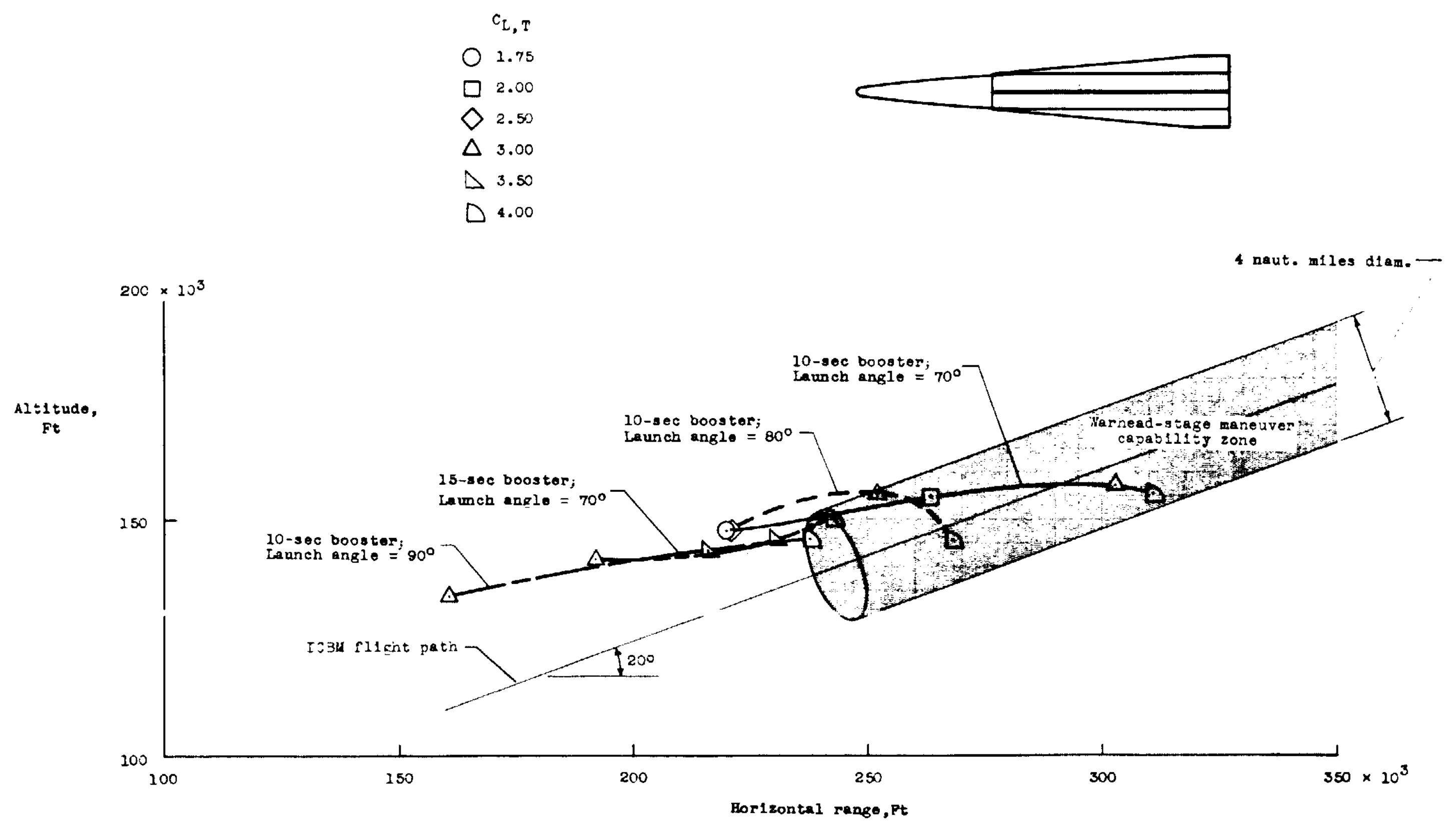

Figure 10.- Position of warhead stage of AMM relative to ICBM flight path at 50 seconds from launch. Flight-path angle, approximately 20°.

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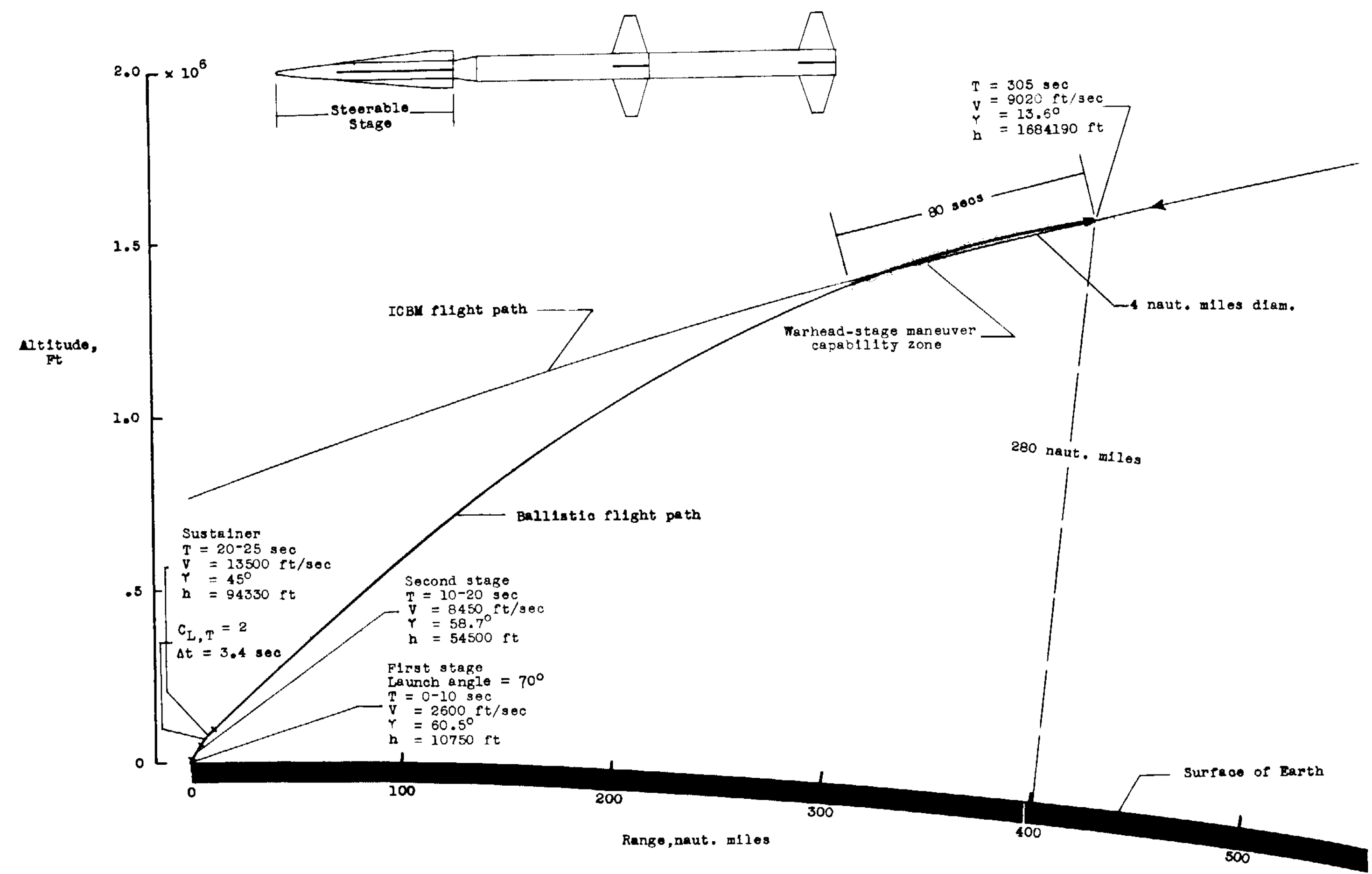

Figure 11.- Trajectory of an AMM for use in area defense of an ICBM.

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