TITLE

ROBOT-9 PERFORMANCE SCATTER AND SAFETY-ENVELOPE

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ROBOT-9
PERFORMANCE SCATTER AND SAFETY-ENVELOPE (U)

by

A.B. Markov

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ABSTRACT

The performance of a free flight, ballistic, multistaged, rocket-boosted aerial target designated ROBOT-9 is described. This target is the second vehicle in the ROBOT family of targets, and uses a four stage propulsion system based on the Canadian developed CRV-7 rocket motor.

The performance results were obtained using a nonlinear, six degree-of-freedom dynamic model. They include a description of nominal performance under standard conditions, the scattering effects of various environmental conditions, and the specification of a safety-envelope based on a set of worst-case conditions. Performance comparisons are included with the original U.S. Army BATS and with CRV7/BATS.

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1. INTRODUCTION

During the period 1967 to 1970, the U.S. Army Missile Command developed the Ballistic Aerial Target System (BATS) to provide a low-cost, unguided, nonrecoverable target for exercising Army air defence systems. BATS is a versatile target system that can be flown at low and medium altitudes and at speeds ranging from 140 m/s (275 knots) to 260 m/s (500 knots). It is completely troop-operated and can be set-up with minimum effort. The boost phase uses two to five 70 mm (2.75 inch) rocket motors while sustained thrust is derived from the use of two jet engine starter cartridges. All motors are fired at time zero. Using five Mk4 Mod. 10 or Mk 40 rocket motors, the maximum range is 6400 m (21000 feet) with a flight time of 43 seconds.

In 1979, under the auspices of the TTCP, it was agreed that a joint U.S./Canadian feasibility study be undertaken on improving BATS using the greater specific impulse, Canadian developed CRV-7 rocket motor. As part of this program, the U.S. Army contributed 100 BATS airframes and Canada contributed CRV-7 rocket motors. The required development work, including prototype trials, was carried out at DRES.

The TTCP program culminated in a vehicle that is designated CRV7/BATS (Figure 1), now also referred to as ROBOT-5, the acronym ROBOT standing for "**RO**cket **BO**osted **T**arget". This vehicle has not only incorporated the CRV-7 rocket motors, but also has been redesigned to permit multistaging. The latter significantly improves range performance while limiting maximum airspeed, for structural and operational reasons, to Mach 1.5.

The improvement in overall performance of CRV7/BATS over the original BATS vehicle was significant enough (see Section 4) to strongly suggest the possibility of further improvement by using more CRV-7 rocket motor stages. This prompted a DRES initiated development program of an all CRV-7 vehicle. Consideration was given to both 7 and 9 motor configurations, and ultimately a nine motor configuration was chosen and designated ROBOT-9 (Figure 2).

The following sections describe the performance characteristics of the ROBOT-9 vehicle. Section 2 gives a more detailed description of the vehicle and associated systems. Section 3 contains the performance results. These results include a description of nominal performance under standard conditions, the scattering effects of various environmental conditions, and the specification of a safety-envelope based on a set of worst-case conditions. Section 4 compares the performance of ROBOT-9 with that of CRV7/BATS and the U.S. Army BATS.

A more detailed engineering description of the target system, including a DRES developed target firing console incorporating features that permit launches in heavy seas and of sea trial results will be the subject of a future report (Reference 1 gives a general description of the various components of the ROBOT system and of the results of a recent CF(Navy) sea evaluation). Early CRV7/BATS trial results are given in Reference 2. The companion report to this report for CRV7/BATS is Reference 3. The development of the launch window functions used in the microprocessor software of the firing console is given in Reference 4.

2. ROBOT-9 DESCRIPTION

The basic features of the ROBOT-9 vehicle, including component weights, are summarized in Figure 3.

The airframe of the vehicle is based on that of the U.S. Army BATS and incorporates structural changes only as required to facilitate the use of the CRV-7 rocket motors. The fuselage is made of a 0.38 mm (0.015 inch) thick rolled steel tube with interior foam providing the required stiffness. The vehicle's weight less rocket motors is 46 Kg (101 lbs). It is nonrecoverable and totally destroyed on impact (see Figure 4).

ROBOT-9 uses nine CRV-7 rocket motors and no sustainer motor. The motors are fired in four stages as summarized in Table 1. The five CRV-7 motors that are used in the first two stages are those in the rear of the vehicle. The third and fourth stage motors are located in front of the vehicle (see Figure 3). The elimination of the sustainer motor that is used in BATS and CRV7/BATS makes ROBOT-9 a one motor-type vehicle and thus simplifies the training that is required of the target operators. As well, it alleviates the need for keeping the jet engine starter cartridges, on which the sustainer motor is based, in the CF inventory.

The thrust characteristics of the different motor types are summarized in Table 2.

Since the original BATS vehicle fired all motors at time zero, it did not require timing circuitry to fire any later stages. In order to permit multistaging, a DRES designed avionics board was developed that carried out the timing functions and provided the power required to fire the stage motors (see Figure 5). The boards that are used for CRV7/BATS and ROBOT-9 are nearly identical, the only changes being minor alterations for the different number of stages and for the different stage firing timing sequences between the two vehicles. In its current form the board is designed for up to three inflight rocket motor stage firings with the timing between stages being variable in one second increments. All stages must be fired by time T + 39 seconds.

The avionics board does not employ a battery as a power supply. Power to run the circuitry and fire the rocket motors is provided by a large 30000 μF capacitor that is charged just prior to launch of the target. Such a power system has two major advantages:

(a) Long term storage of batteries is not required.

(b) There is no onboard power until just prior to the target launch thereby reducing the probability of inadvertently firing the rocket motors.

The stage firing sequence of Table 1 is the standard sequence used by DRES for ROBOT-9. The avionics board permits variation of the sequence through minor changes on the board. Such changes, however, would require a safety-envelope re-evaluation.

ROBOT-9 has been equipped with a passive radar-augmenting nosecone (see Figure 5). This is required in order to give the target a radar cross-section typical of current threats (see Reference 1 for further details).

An important consideration in developing the ROBOT system was to make it suitable for use at sea by the Canadian navy. The basic scenario consists of the rapid deployment of the system at sea from the helicopter deck of a destroyer referred to as the target launching ship. A second ship, referred to as the training ship, is stationed a safe distance away and would use the targets in radar tracking exercises or engage them with Sea Sparrow missiles or radar-controlled gun firings.

ROBOT-9, being a free-flight target, is quite susceptible to environmental conditions that disturb its flightpath from the nominal. These effects result in a need for relatively large safety-envelopes (as will be discussed in some detail in Section 3). In the naval environment these safety-envelopes would be even larger if there was no means of minimizing the effects of the target launching ship's pitching and rolling motion (Figure 6).

This problem may be solved through the use of a stabilized launch platform, but the cost of such a solution is incompatible with the low cost of the ROBOT family of targets, and thus a less costly alternative has been implemented. In the latter a vertical gyro located at the base of the ROBOT-9 launcher (Figure 7) senses the launch ship's roll and pitch attitude and feeds this information to a microprocessor located in the firing console (Figure 8). The microprocessor then uses an algorithm based on the roll and pitch attitudes and their rates to determine an acceptable launch window (References 1 and 4 discuss, respectively, this target launching technique and the derivation of the associated launch window algorithms).

Because of propellant consumed during the firing of the four ROBOT-9 rocket motor stages, the mass and centre-of-mass of the target will change appreciably during a flight. For the standard stage firing timing of Table 1, these characteristics are summarized in Figure 9. The vehicle has been designed so that even for the worst possible combination of stage failures, the centre-of-mass will always be in front of the aerodynamic centre of the vehicle, and thus the target will always have static aerodynamic stability. The nominal location of the aerodynamic centre of the vehicle (neutral point) is also shown in Figure 9. This location will shift as a function of Mach number, so it is shown as a band rather than as a single point.

3. ROBOT-9 PERFORMANCE CHARACTERISTICS

3.1 Performance Model

The performance characteristics, scatter and safety-envelopes described in the following sections were obtained using a six degree-of-freedom, nonlinear dynamic model with a quasisteady aerodynamic model (Reference 5). Uncertainties in the computational model and in the actual flight conditions have been taken into account in the safety-envelope of the target.

Unless otherwise noted, the predictions are for the ICAO standard atmosphere, no wind, sea level launch, and a stationary launch platform. In reality these conditions are never satisfied, and some scatter from the nominal trajectories should always be anticipated. Since ROBOT-9 is a free-flight target, scatter caused by environmental effects (wind, nonstandard temperature, launch elevation and so forth) can, in fact, be quite significant as will be seen in Section 3.6. In addition to normal scattering effects, a reasonable set of worst-case conditions and limitations must be defined in order to determine a safety-envelope suitable for naval operation, as will be discussed in Sections 3.4 and 3.7.

Appendix B of Reference 3 contains a detailed description of the dynamic characteristics of CRV7/BATS including both qualitative and quantitative descriptions of environmental effects. While the quantitative results are not relevant to ROBOT-9, the qualitative trends are relevant and are an excellent source of insight into the flight characteristics of ROBOT-9.

3.2 Nominal Trajectory Data Basis

Unless otherwise indicated, all performance computations are based on the following:

a) Sea level launch.
b) No wind.
c) Standard atmosphere (see comments in Section 3.1).
d) The standard stage firing sequence in Table 1.
e) Stationary launch platform.
f) A 70° launch elevation.
g) The standard mass characteristics of Figure 9.

The trajectory that results under the above conditions is referred to as the ROBOT-9 standard shot.

The performance descriptions to follow are largely restricted to this standard shot because of the volume of material that would be required to describe all possible flights (different launch elevations, stage timings, and environmental effects). The 70° launch elevation is chosen as the standard elevation as this results in a substantial reduction in the size of the required safety-envelope for a nominal range that is only slightly less than the range that would result at the maximum range launch elevation (see the discussion to follow in Sections 3.5 and 3.7).

3.3 Scatter Assumptions

The scatter results of Section 3.6 were determined using a number of combinations for the following error budget:

a) Effective launch elevation —	2° due to ship motion. 1° due to vehicle asymmetries.
b) Effective launch azimuth —	3.5° due to ship motion. 1.5° due to vehicle asymmetries.
c) Air density variations —	8% relative to standard pressure and temperature.
d) Tail/head wind —	10 m/s (20 knots) at surface increasing to 25 m/s (50 knots) above 1500 m (5000 ft).
e) Crosswind —	10 m/s (20 knots) at surface increasing to 25 m/s (50 knots) above 1500 m (5000 ft).

The scatter assumptions are not worst-case but they are conservative. None of the single error sources is improbable, but their most unfavorable combination is.

3.4 Worst-Case Assumptions

The safety-envelope of Section 3.7 was determined using the following error budget:

a) Effective launch elevation —	+ 10°, – 2°.
b) Effective launch azimuth —	± 15°.
c) Air density variations —	± 10% relative to standard pressure and temperature.
d) Worst-case (skewed) — wind profile	15 m/s (30 knots) cross-wind at surface changing to 50 m/s (100 knot) tailwind above 1500 m (5000 ft).
e) Rocket motor failures —	all possible combinations.
f) Vehicle asymmetries —	centre-of-mass lateral shift of 0.05 ft (equivalent to physical loss of two rocket motors). aerodynamic (equivalent to fin misalignment of 4°).

Because of the low probability of any two or more items in this error budget occurring simultaneously, they were considered separately in the determination of the safety-envelope of ROBOT-9.

3.5 Nominal Performance Description

Figure 10 shows a number of ROBOT-9 trajectories obtained under the conditions described in Section 3.1 with the exception that launch elevation variation is allowed. The maximum 14.4 km range is obtained at a launch elevation of 75°. As has already been indicated, because of safety-envelope considerations the maximum ROBOT-9 launch elevation is restricted to the 70° standard shot. At this elevation the range is 14.1 km (7.6 nm). The flight time for 70° shots is 83 seconds with apogee occurring 41 seconds into the flight at an altitude of 5200 m (17100 ft).

Figure 11 shows the ROBOT-9 standard shot's trajectory with a more detailed breakdown of flight times corresponding to key altitudes and ranges.

Figure 12 shows the ROBOT-9 standard shot's airspeed profiles. The maximum velocity is Mach 1.36 and occurs after the burnout of stage 4. The deceleration after each stage firing is quite rapid and is produced by the aerodynamic drag acting on the vehicle.

Velocity histories for other than the standard shot's launch elevation differ only slightly from that of Figure 12.

Figure 13 shows the ROBOT-9 standard shot's aspect elevation angle presentation to a tracking ship located 18.5 km (10 nm) from the target launch ship. This information is important for establishing engagement windows during live missile firing exercises.

Although the target is a free-flight vehicle and thus has no inherent maneuvering capability, the rapid and continuous changes in both the velocity vector's magnitude and its direction result in pseudomaneuvering profiles that are challenging to radar-guided weapon systems.

3.6 Scatter Envelopes

As has already been indicated, ROBOT-9 is a free-flight vehicle, and thus the vehicle's trajectory may only be controlled by setting launch azimuth, launch elevation and stage timing. This provides limited capability for compensating for environmental effects that will typically result in off-nominal flight characteristics for the vehicle. This section outlines some of these effects and shows that they can be quite significant.

The error budget allocated to scattering effects has been defined in Section 3.3.

Figure 14a shows the effect of an 8% change in temperature and pressure from standard atmospheric conditions. This represents an approximately 23°C (41°F) departure from the standard atmospheric sea level temperature and approximately 8 kPa (2.4 in Hg) departure from standard sea level pressure. The scatter of the standard shot's trajectory is noticeable but not excessive.

Figure 14b shows the effect of the headwind/tailwind profiles defined in Section 3.3. As may be clearly seen from this figure, the effects on the trajectory are very dramatic producing apogee dispersion of more than 1500 m (4900 ft) and range dispersion of more than 2 km (1.1 nm). The wind profile that was used to generate these dispersions is not unusual. Such dispersions are further complicated by the fact that the launch ship's motion will induce an additional wind component that can also have a noticeable effect on the flight characteristics of the target.

Figure 14c shows the dispersion effect of the crosswind profile defined in Section 3.3. Again, the wind produces a significant dispersion of the vehicle's trajectory, the splash point being over 4 km (2.2 nm) off the nominal flight line.

Figure 14d shows the effect of 3° errors in the effective launch elevation. As was indicated in the error budget of Section 3.3, this deviation may arise due to errors in the setting of the launch elevation, due to the launch ship's motion, and due to asymmetries in the ROBOT-9 vehicle equivalent to an error in launch elevation. As may be seen from this figure, the resulting trajectory dispersion is very noticeable, particularly for apogee. For the latter, a 3° change in effective launch elevation produces a nearly 1000 m (3300 ft) change in apogee altitude.

Similar cross-range scatter effects may be shown to occur due to equivalent launch azimuth errors. Combining these scattering effects in a worst-case way, scatter envelopes are defined in Figures 15a through 15d. It is stressed that these envelopes were obtained using a worst-case combination of the scattering effects defined in Section 3.3, a combination that is unlikely to occur in reality. Nevertheless, as has been demonstrated in the previous examples, certain scatter causes, particularly wind effects and launch elevation errors, can also produce significant dispersion on their own.

The scatter envelopes of Figures 15a through to 15d are useful in specifying suitable missile launch windows against ROBOT-9's launched at 70° elevations. It is strongly recommended that the launch windows be established based on the scatter envelopes rather than on the nominal trajectory alone. It should also be noted that the aspect elevation angle envelope (Figure 15b) and the aspect azimuth angle envelope (Figure 15d) are only valid for an 18.5 km (10 nm) standoff distance between the target launching ship and the tracking ship. All of these results must be recomputed if either a different standoff distance or a launch elevation other than 70° are employed.

As more and more flight data is gathered, these scatter envelopes will be refined.

3.7 ROBOT-9 Safety-Envelope

Figure 16 shows the ROBOT-9 safety-envelope that results in applying the worst-case assumptions of Section 3.4. This safety-envelope is recommended on the basis of a number of restrictions. These are as follows:

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a) The maximum launch elevation is less than or equal to 70°.
b) The maximum surface wind speed is 20 knots.
c) The maximum ship's roll angle is 10° and the target firing console is fully operational.
d) The stage timing is as given in Table 1.

Relaxation of any of these restrictions would require a re-evaluation of the safety-envelope.

Figure 16 also indicates that the ROBOT-9 safety-envelope ceiling is 10,700 m (35,000 ft). The latter is based on the remote possibility of an accidental, nearly vertical launch. Nevertheless, great care should be taken to ensure that the training area is clear not only on the surface, but also vertically. In particular this may require coordination with the appropriate authorities for the issuing of Notices to Airmen (NOTAMS) when trials are being conducted.

Reference 4 indicates that there is some uncertainty in the accuracy with which the dynamic model used in this investigation predicts the effects of the target launching ship's forward velocity on the ROBOT-9 vehicle. Therefore, until adequate operational experience has accumulated on this influence, it is recommended that the target launching ship's speed be **restricted to 5 m/s (10 knots) or less.**

The safety-envelope was determined with the important assumption that **there cannot be a fin loss**. The consequences of such a failure are difficult to predict and may result in significant increases in range and lateral scatter (see Reference 3).

Fortunately, such failures are improbable if preflight checkouts include a careful examination of the structural integrity of the fuselage attachment points of the fins.

Extreme caution should be exercised if modifications to the fins are being considered in that fin mass distribution changes may make them susceptible to flutter at the higher target velocities.

The assumptions used to compute the safety-envelope are very conservative but necessary in view of the limited operational experience with ROBOT-9. As this experience accumulates, it may be possible to reduce the size of the envelope. Such a decision must, however, be taken with great care and only after a significant statistical basis exists for making it.

Figure 17 compares the ROBOT-9 and CRV7/BATS safety-envelopes. As might be expected, because of the shorter range and lower launch elevation characteristics of CRV7/BATS, its safety-envelope is substantially smaller than that of ROBOT-9.

4. COMPARISON OF ROBOT-9 PERFORMANCE WITH CRV7/BATS AND WITH THE U.S. ARMY BATS

Figure 18 compares the standard ROBOT-9 shot with those predicted for the original U.S. Army BATS and for CRV7/BATS using both CRV-7 and Mk4 rocket motors. The CRV7/BATS standard shot is identical to that for ROBOT-9 (see Section 3.2) except for the launch elevation, which is 65°, and the stage timing, which is summarized in Table 3. The CRV7/BATS standard shot is a maximum range shot for that vehicle.

The differences in performance between the different targets and target configurations are summarized in Table 4. In terms of range relative to the original U.S. Army BATS, improvement of performance of CRV7/BATS is 64% and of ROBOT-9 is 120%. ROBOT-9 range performance represents a 34% improvement over the standard shot of CRV7/BATS.

As may also be deduced from Table 4, the improvement in maximum Mach number of ROBOT-9 is over 75% relative to that for the U.S. Army BATS and 27% relative to that for CRV7/BATS.

Finally, Figure 19 compares the velocity time history of ROBOT-9 with that for CRV7/BATS for their standard shots.

5. CONCLUSIONS

A six degree-of-freedom dynamic model was used to predict ROBOT-9 nominal performance and scatter from a standard trajectory. In addition, a set of worst-case assumptions were made in order to determine a safety-envelope that is suitable for use in sea trials.

The ROBOT-9 vehicle represents a significant improvement in both range and maximum velocity relative to the original U.S. Army BATS and CRV7/BATS. It is well suited for use by the CF(N) as an interim target while a more sophisticated, over the radar horizon, low altitude target simulating an antiship missile or low flying invader aircraft is developed.

Work is currently in progress on establishing safety-envelopes for a 65° standard shot and verifying predicted characteristics with actual flight characteristics. These results will be the subject of a future report.

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5. Markov, A.B., **A Nonlinear Six Degree-of-Freedom Ballistic Aerial Target Simulation Model (U)**, Suffield Memorandum No. 1081, Volumes 1 and 2, February 1984. UNCLASSIFIED.

Table 1. ROBOT-9 STANDARD SEQUENCE

STAGE	MOTOR	TIME (secs)
1	3 × CRV-7	0 (Launch)
2	2 × CRV-7	12
3	2 × CRV-7	24
4	2 × CRV-7	36

Table 2. THRUST CHARACTERISTICS OF DIFFERENT MOTOR TYPES

MOTOR	MAXIMUM THRUST		AVERAGE THRUST		THRUST DURATION	SPECIFIC IMPULSE
	N	lbs	N	lbs	(secs)	(secs)
CRV-7	6900	1550	4450	1000	2.3	245
MK4	4300	965	2800	630	1.7	180
SUSTAINER	780	175	712	160	17.0	160

Table 3. CRV7/BATS STANDARD STAGE FIRING SEQUENCE

STAGE	MOTOR	TIME (secs)
1	3 × CRV-7	0 (Launch)
2	2 × CRV-7	11
3	SUSTAINER	16

Table 4. COMPARISON OF TARGET PERFORMANCE WITH MK4 AND CRV-7 ROCKET MOTORS

CONFIGURATION	MOTOR TYPE	LAUNCH ELEVATION (deg)	RANGE		APOGEE		FLIGHT TIME (secs)	MAXIMUM MACH NO.
			km	nm	m	ft		
1. ROBOT-9 Standard Shot	9 CRV-7	70	14.1	7.6	5200	17100	83	1.4
2. CRV7/BATS Standard Shot	5 CRV-7 Sustainer	65	10.5	5.7	4415	14500	71	1.1
3. US ARMY BATS All Motors Fired at t = 0	5 MK4	48	6.4	3.5	1900	6200	43	0.8

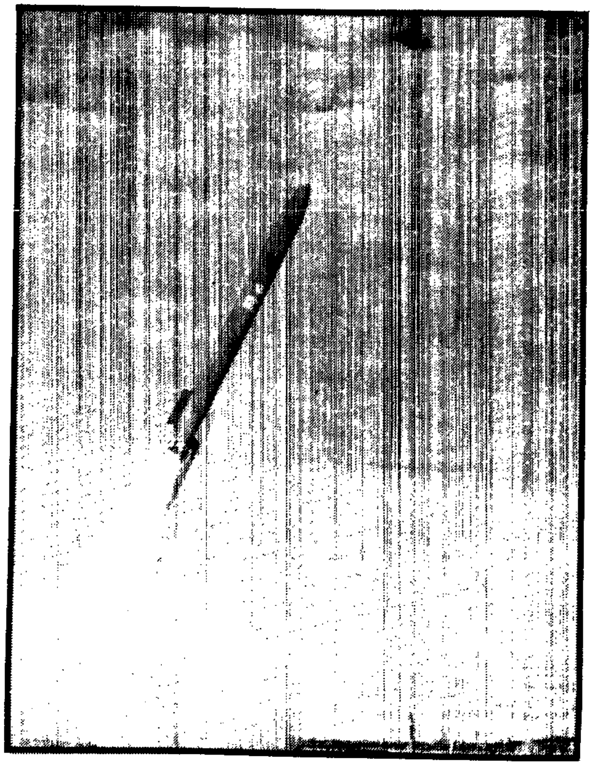


Figure 1

CRV7/BATS (ROBOT-5) AT LAUNCH

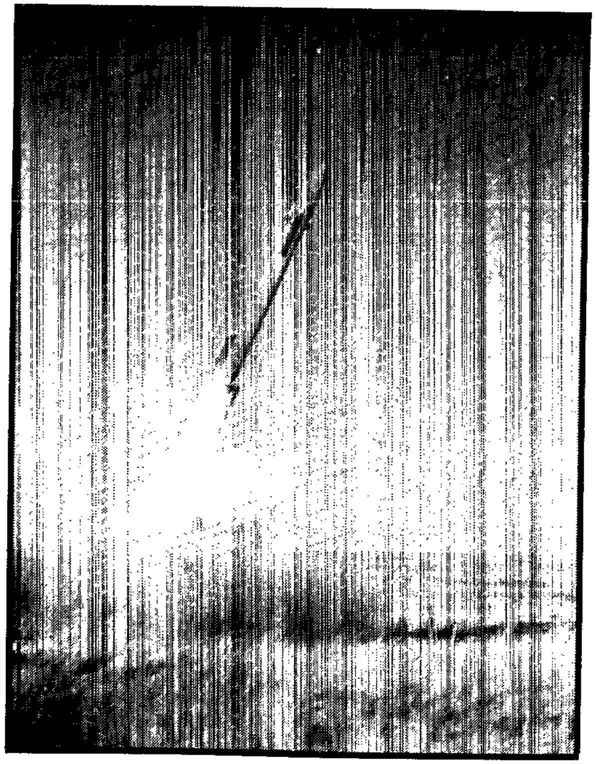


Figure 2

ROBOT-9 AT LAUNCH

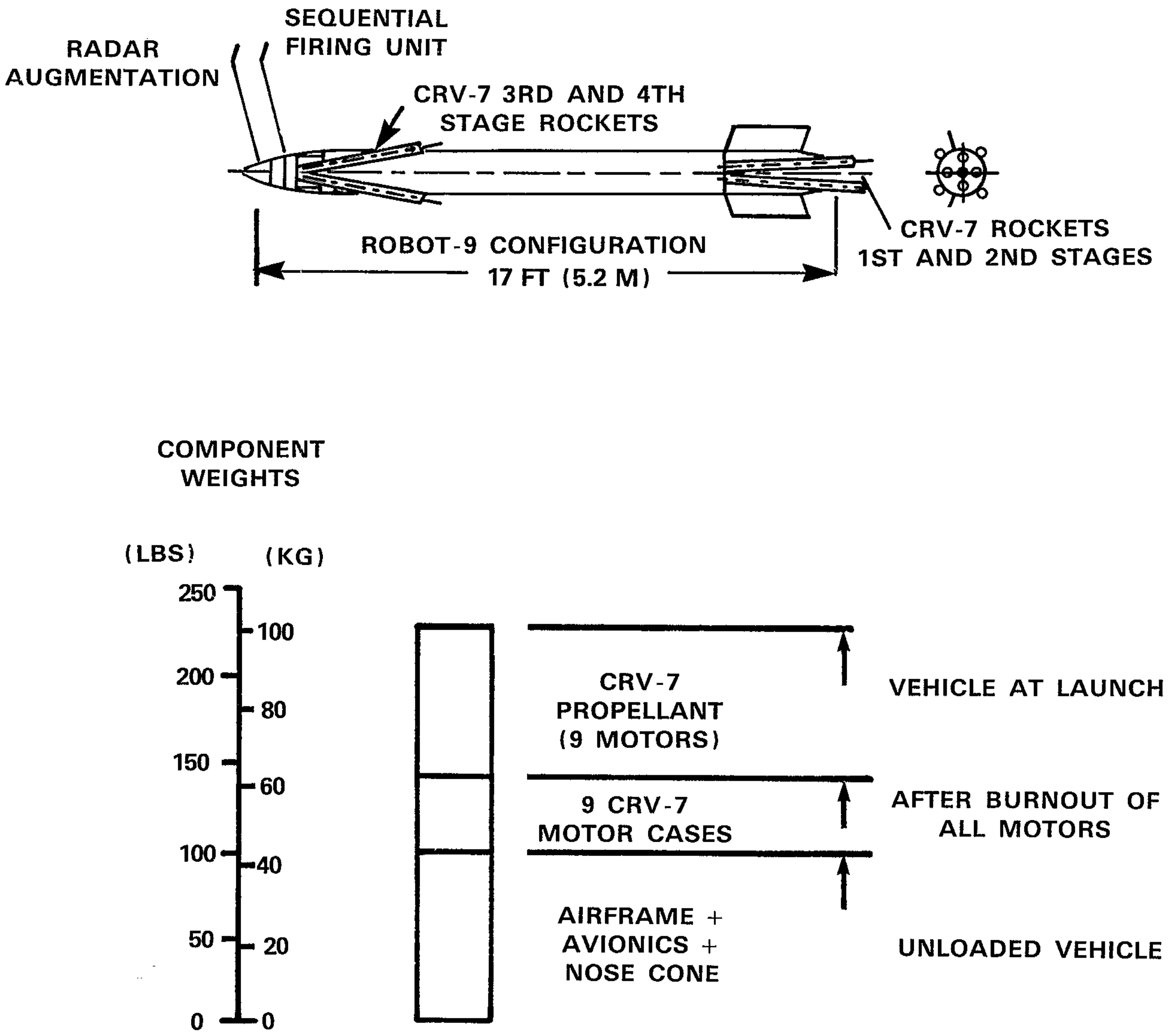


Figure 3

ROBOT-9 CONFIGURATION CHARACTERISTICS

Figure 4

ROBOT-9 AIRFRAME AFTER IMPACT

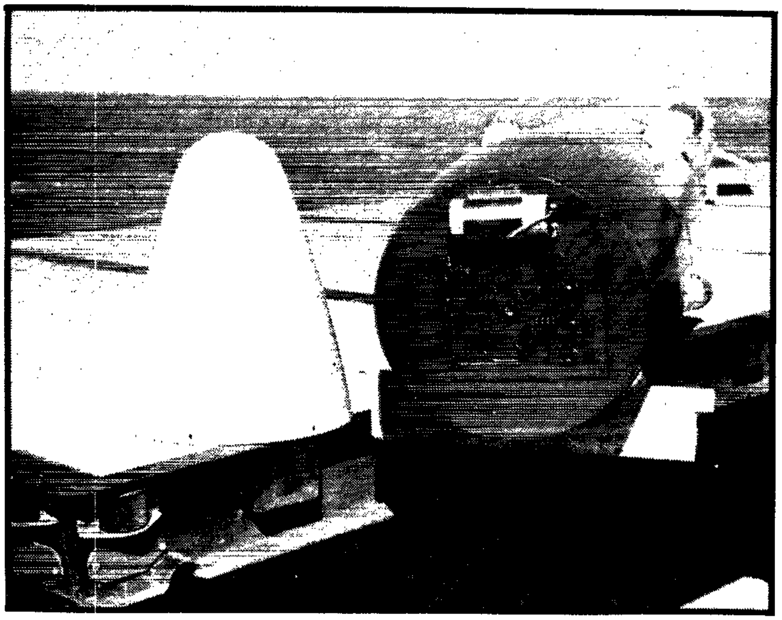


Figure 5

ROBOT-9 AVIONICS BOARD AND NOSE CONE

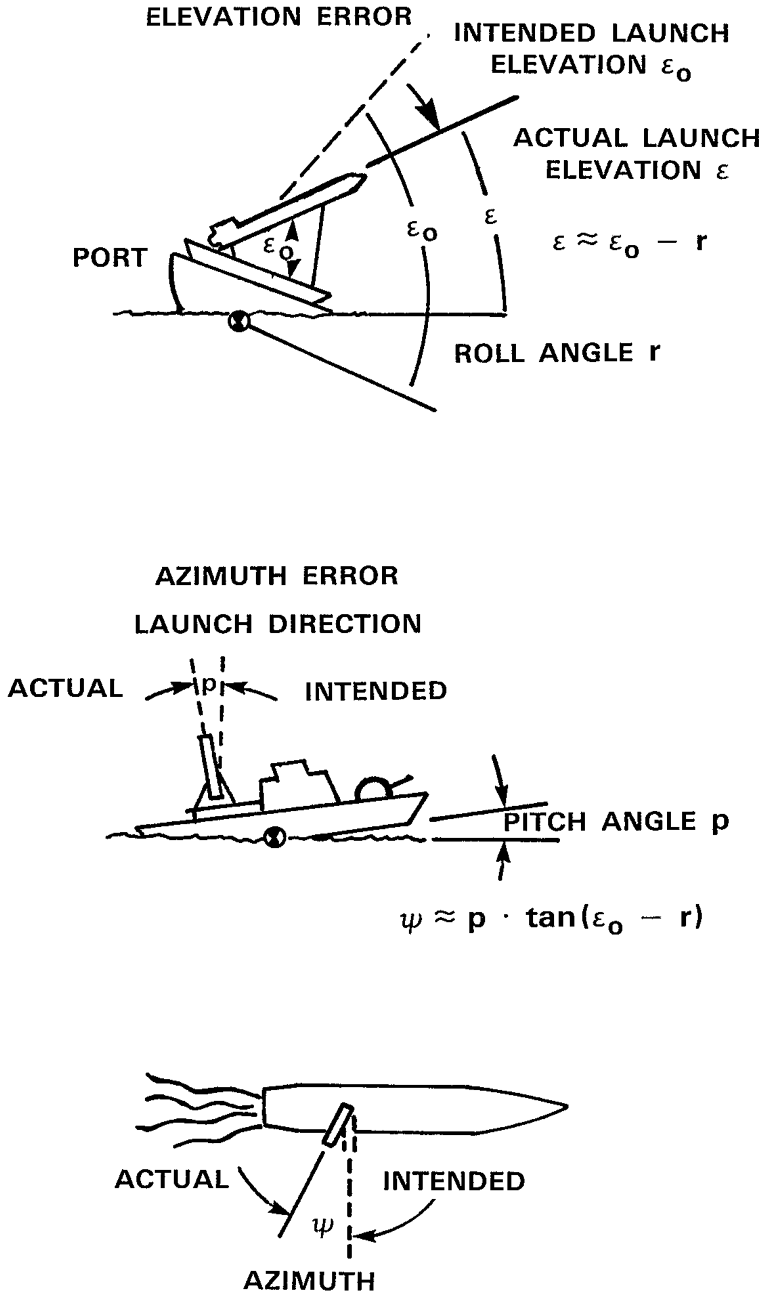


Figure 6

PERTURBATIONS DUE TO LAUNCH SHIP'S PITCHING AND ROLLING

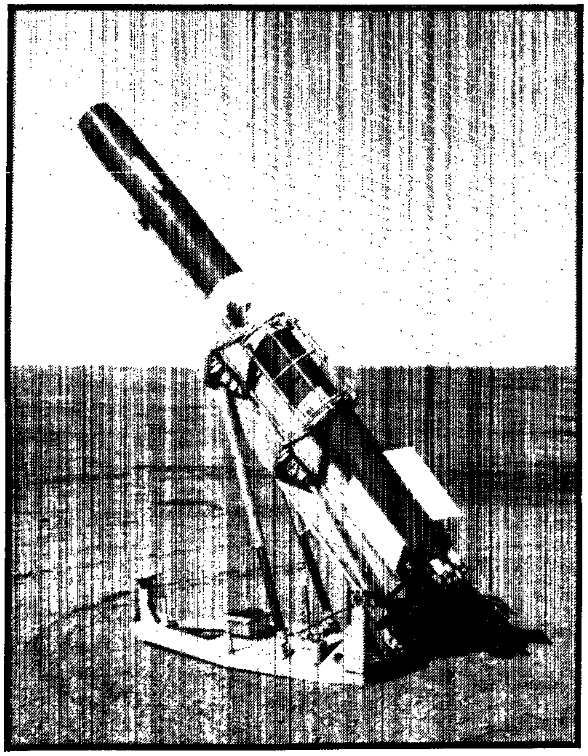


Figure 7

ROBOT-9 VEHICLE ON LAUNCHER
WITH VERTICAL GYRO BOX INSTALLED

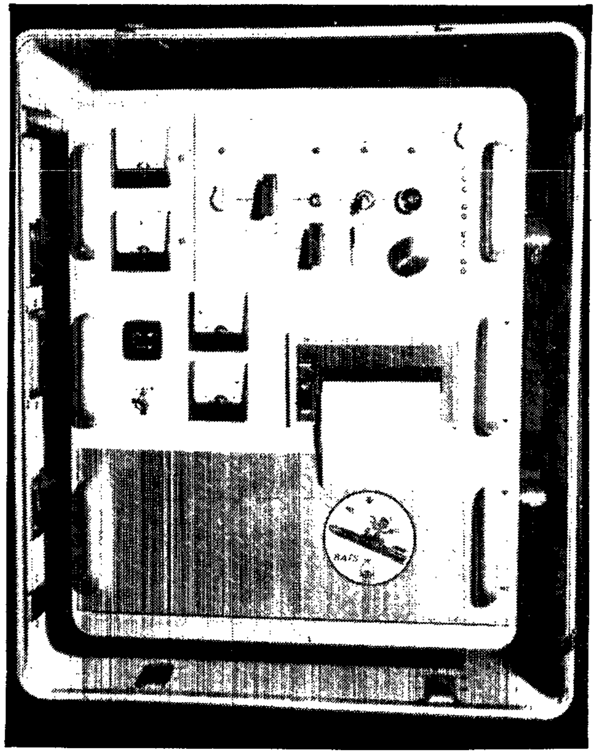


Figure 8

DRES DEVELOPED TARGET FIRING CONSOLE

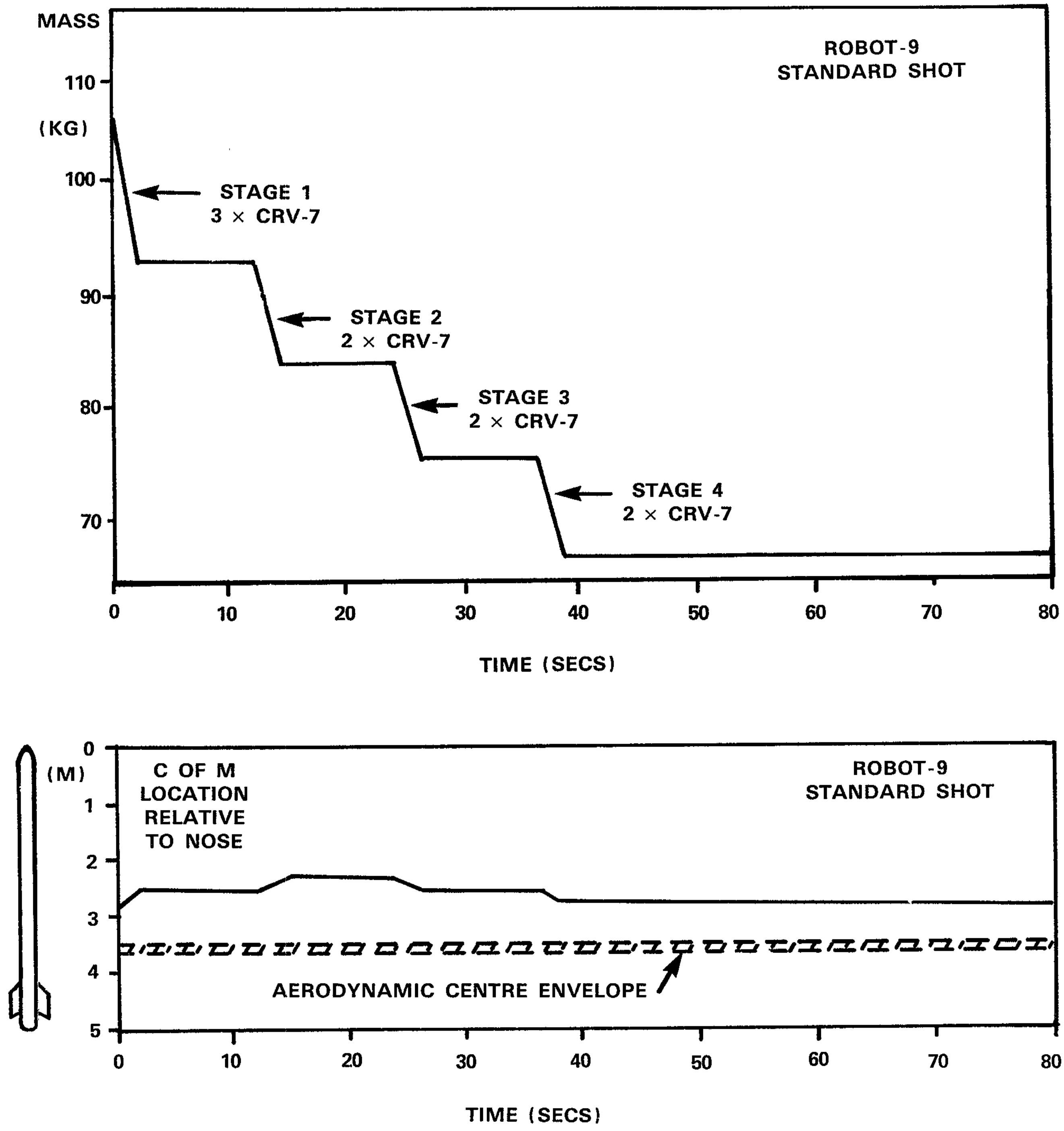


Figure 9

ROBOT-9 MASS AND CENTRE-OF-MASS CHARACTERISTICS

LAUNCH ELEVATION (DEG)	FLIGHT TIME (SEC)
50	44
55	52
60	61
65	71
70	83
75	96
80	111

ROBOT-9
STANDARD CONDITIONS
NO WIND
SEA LEVEL LAUNCH

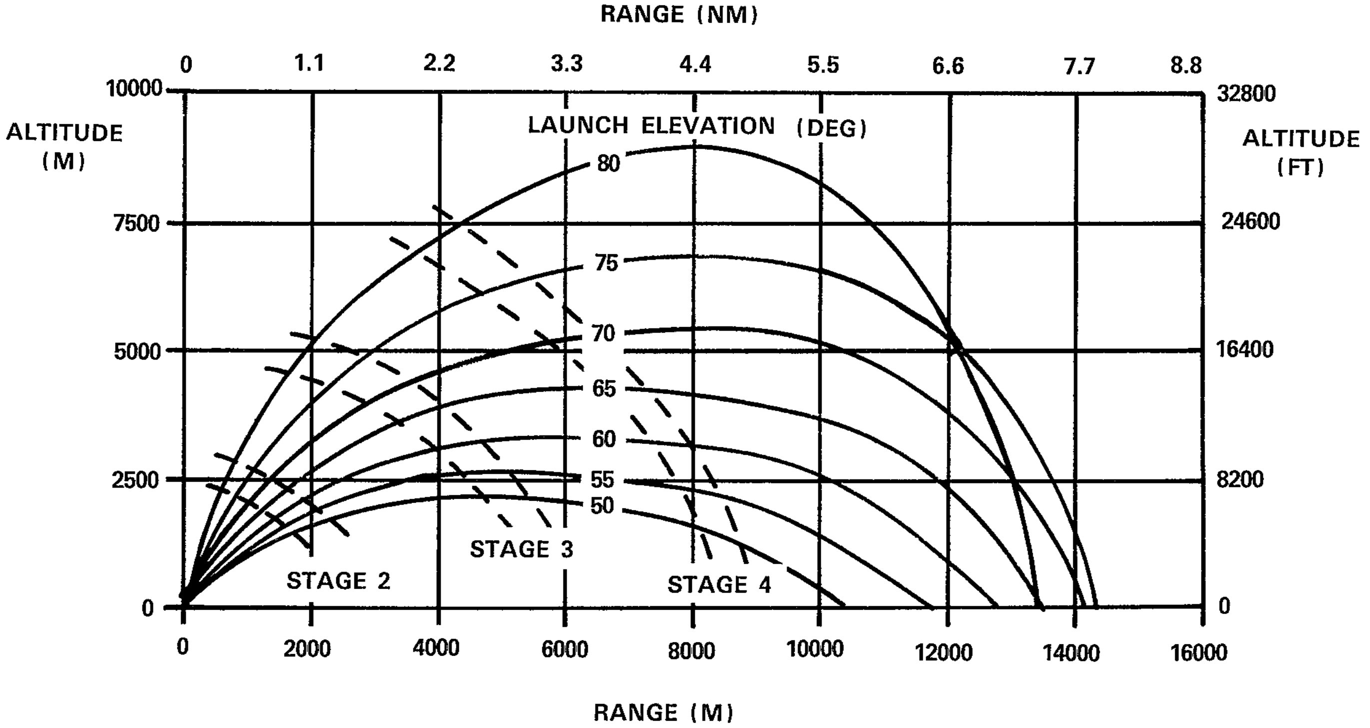


Figure 10

ROBOT-9 NOMINAL TRAJECTORIES

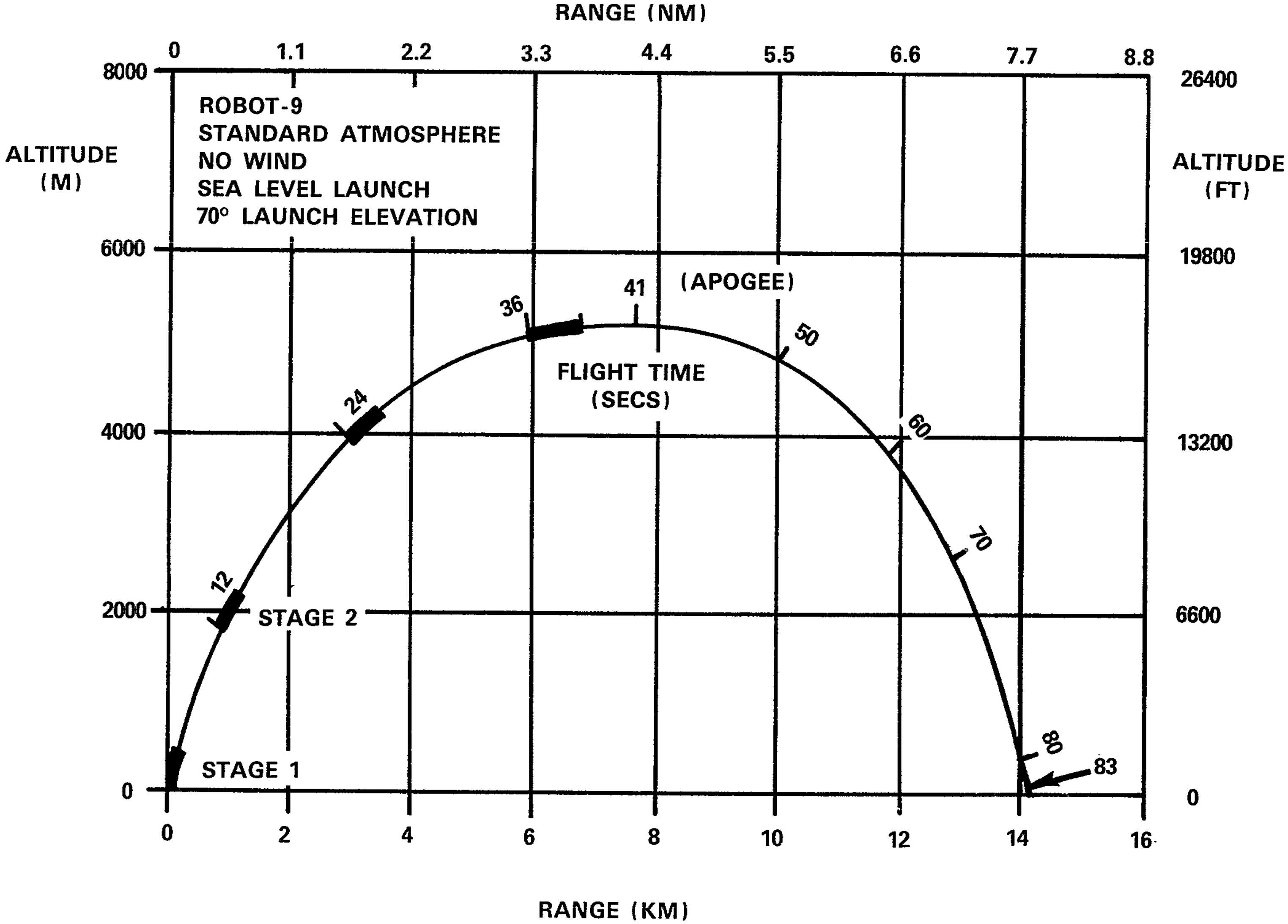


Figure 11

ROBOT-9 70° TRAJECTORY

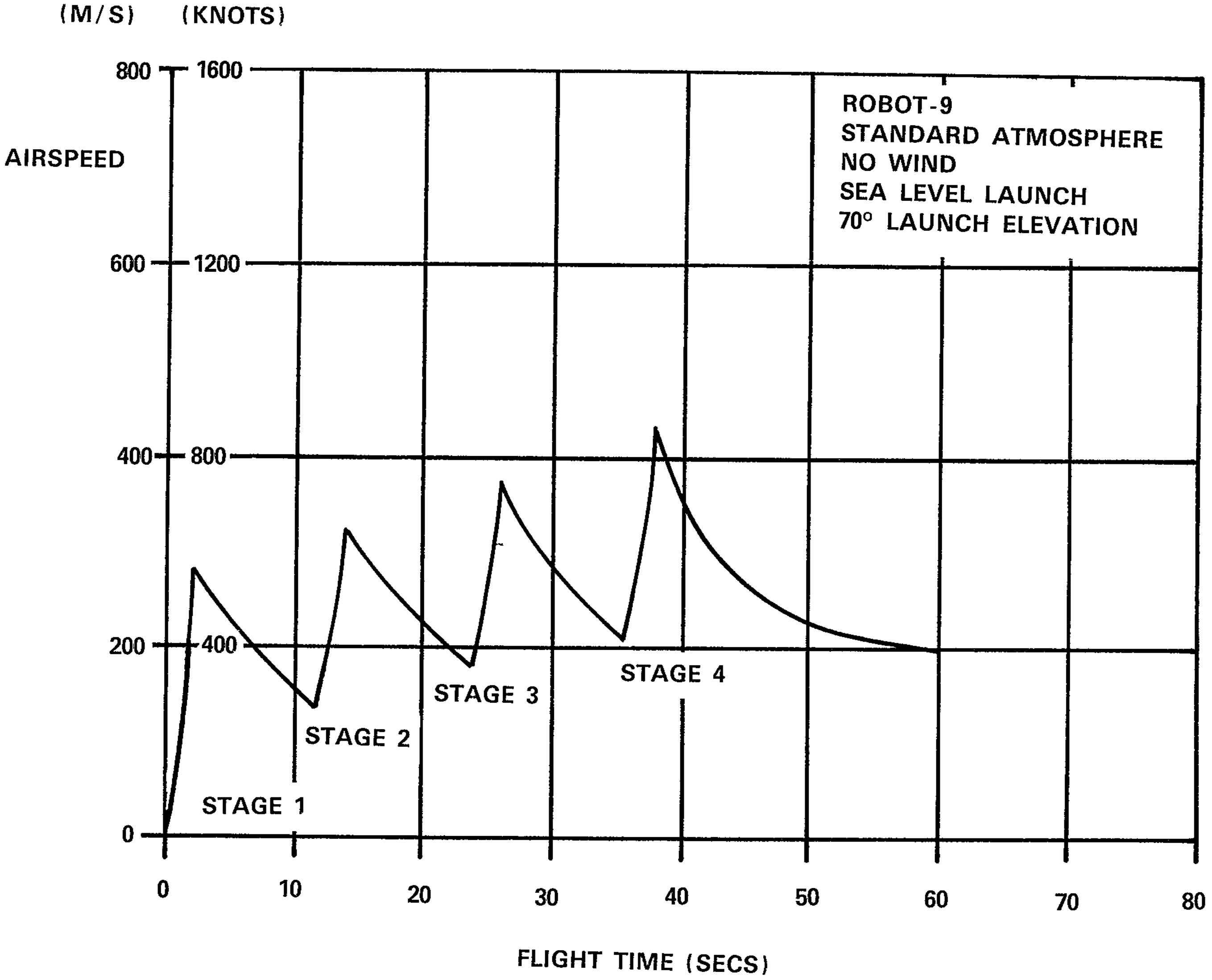


Figure 12

ROBOT-9 70° SHOT AIRSPEED TIME HISTORY

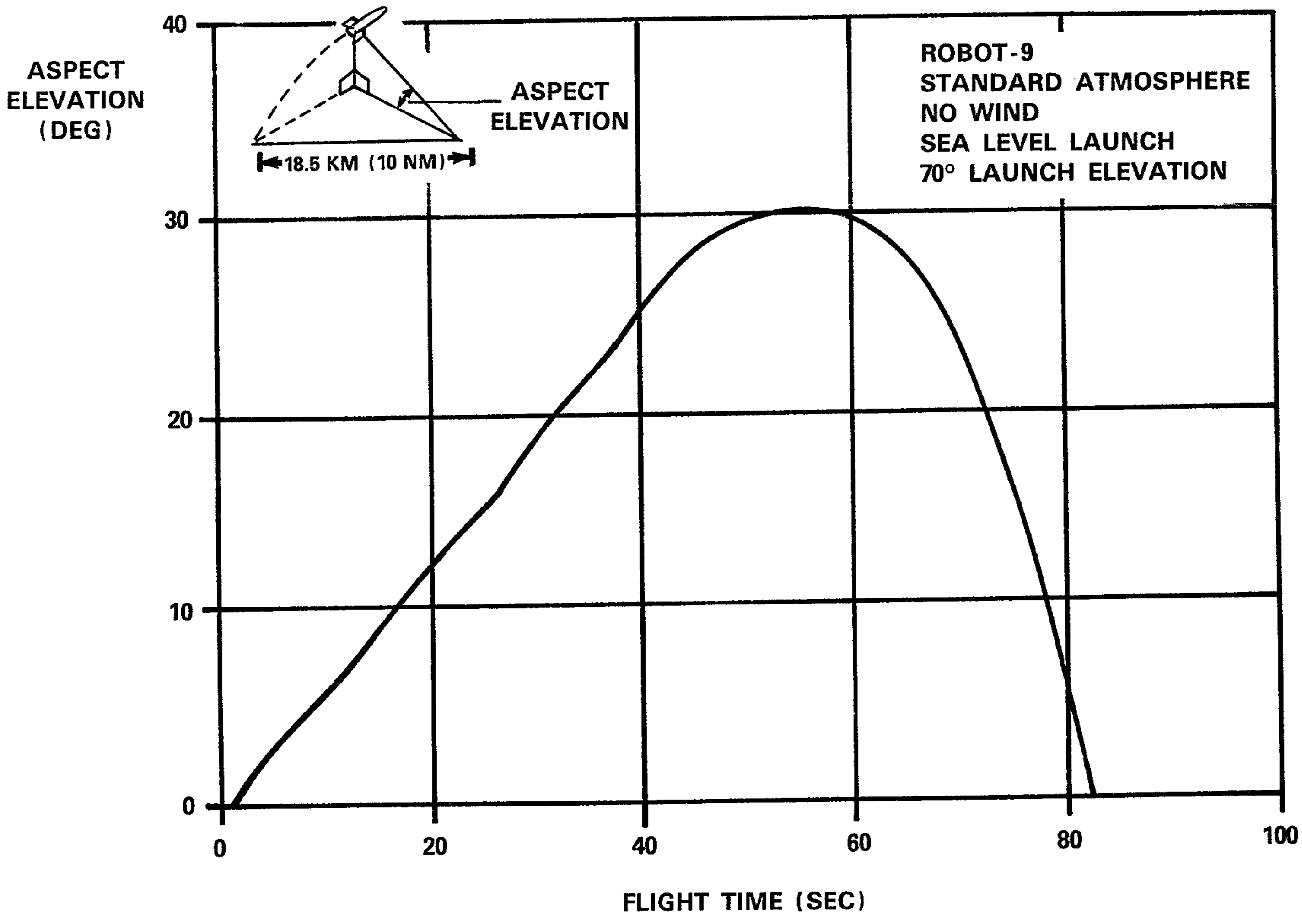


Figure 13

ROBOT-9 70° SHOT ASPECT ELEVATION ANGLE TIME HISTORY
18.5 KM (10 NM) separation, 70° launch elevation

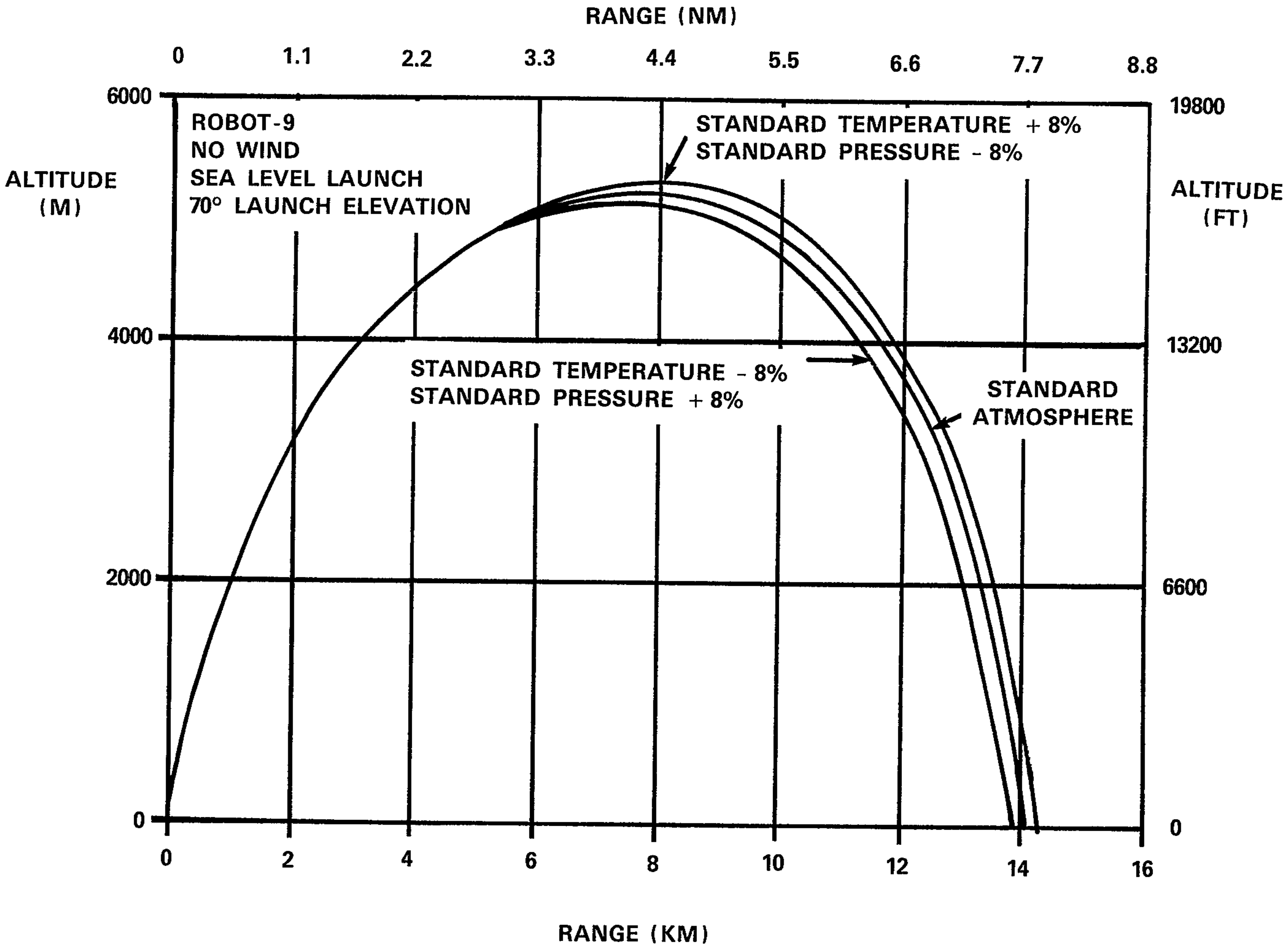


Figure 14a

ROBOT-9 TRAJECTORY SCATTER DUE TO NONSTANDARD TEMPERATURE AND PRESSURE CONDITIONS

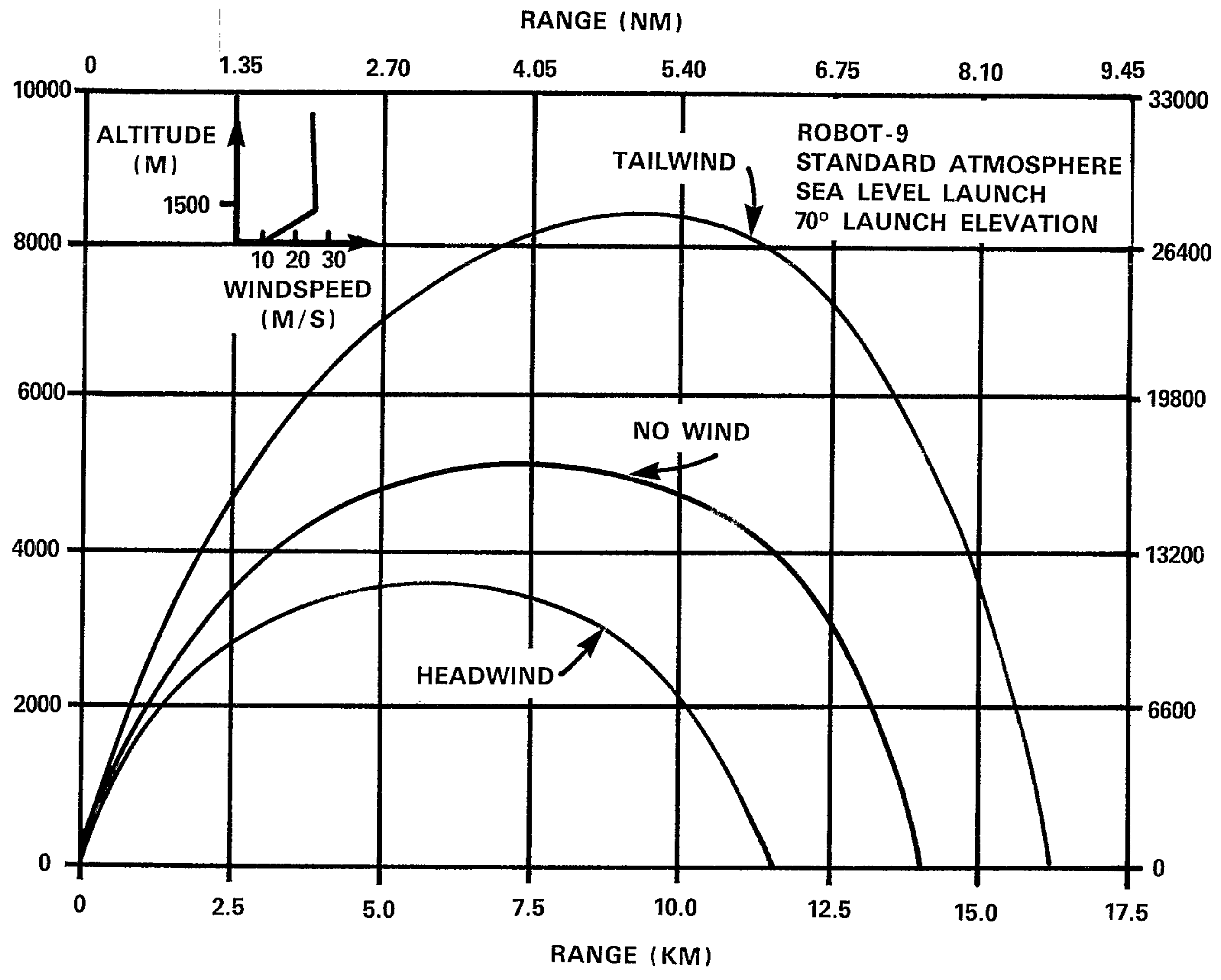


Figure 14b

ROBOT-9 TRAJECTORY SCATTER DUE TO TAILWIND/HEADWIND EFFECTS

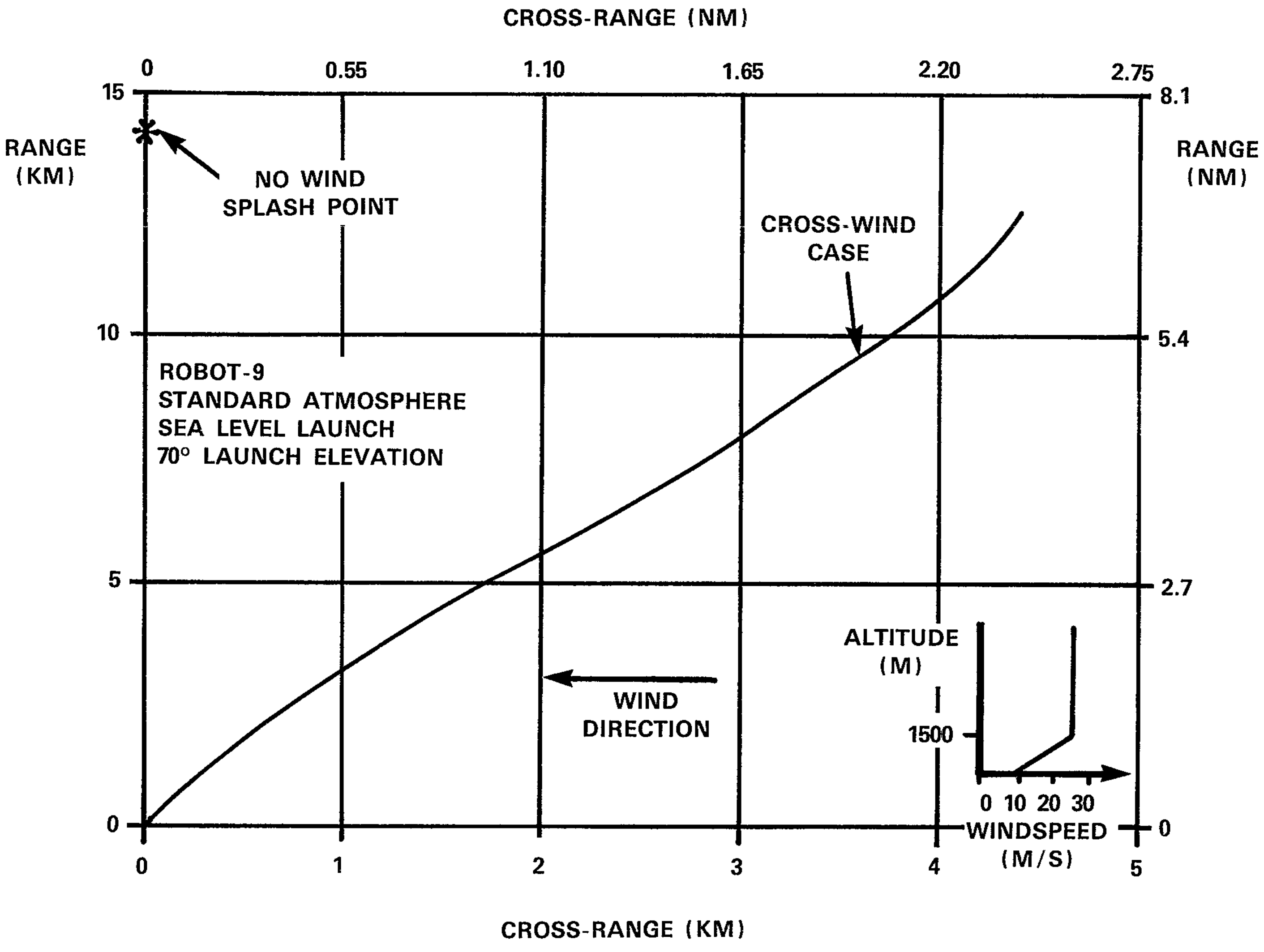


Figure 14c

ROBOT-9 CROSS-RANGE SCATTER DUE TO CROSSWIND EFFECTS

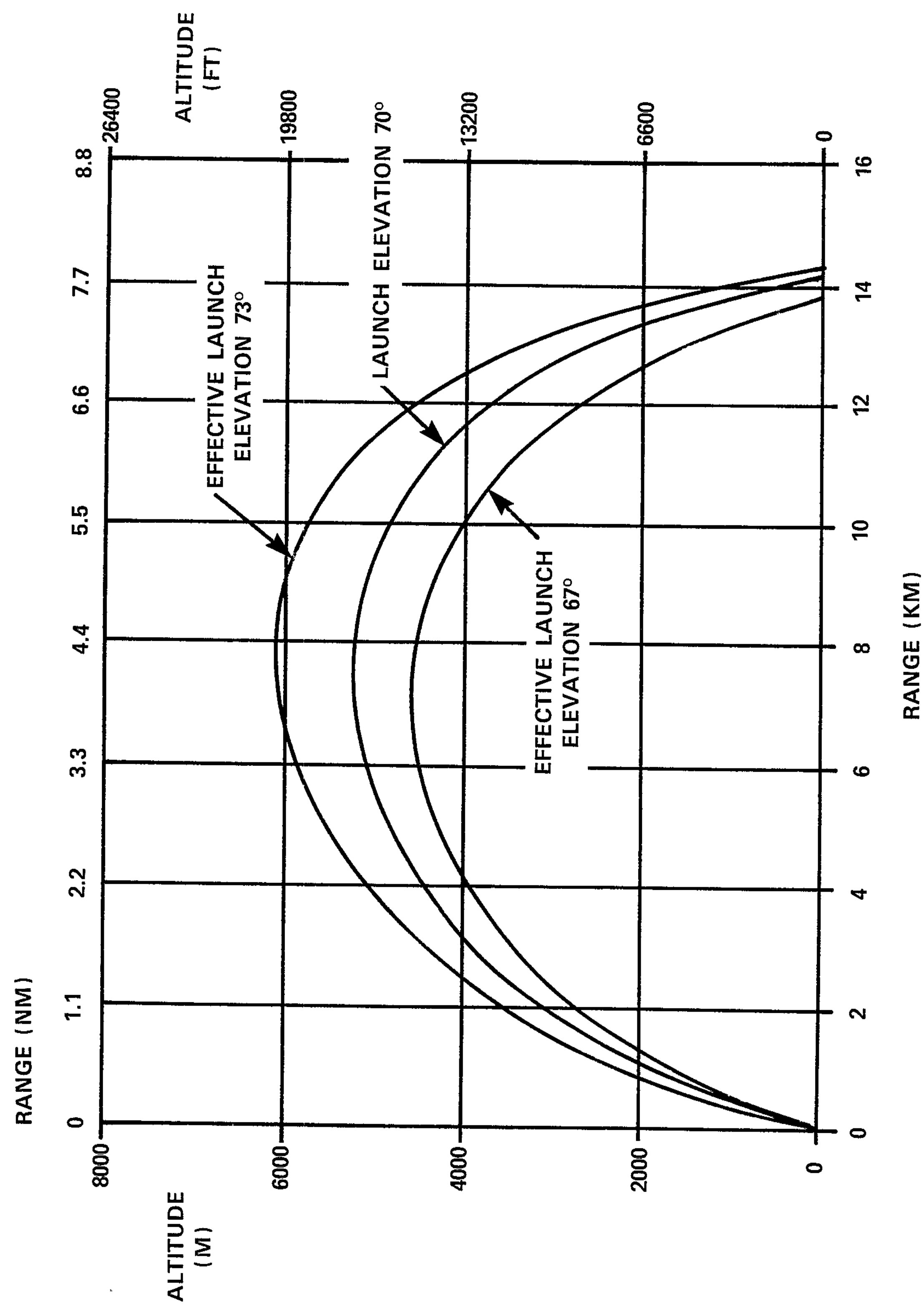


Figure 14d

ROBOT-9 TRAJECTORY SCATTER DUE TO VARIATION IN EFFECTIVE LAUNCH ELEVATION

(Vehicle asymmetry and launch ship's motion effects)

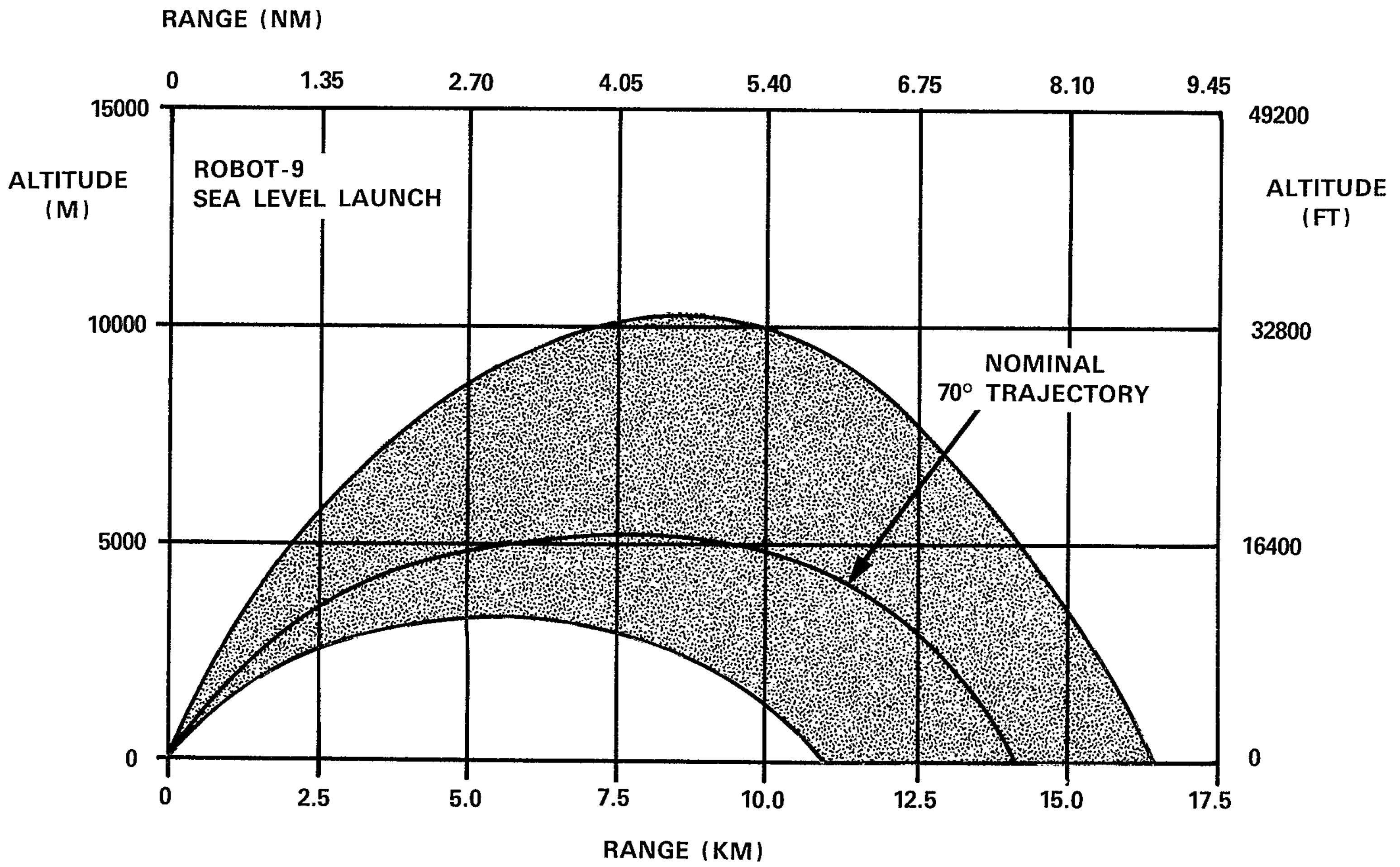


Figure 15a

ROBOT-9 TRAJECTORY SCATTER ENVELOPE BASED ON WORST-CASE COMBINATION OF ERROR BUDGET
(See Section 3.3)

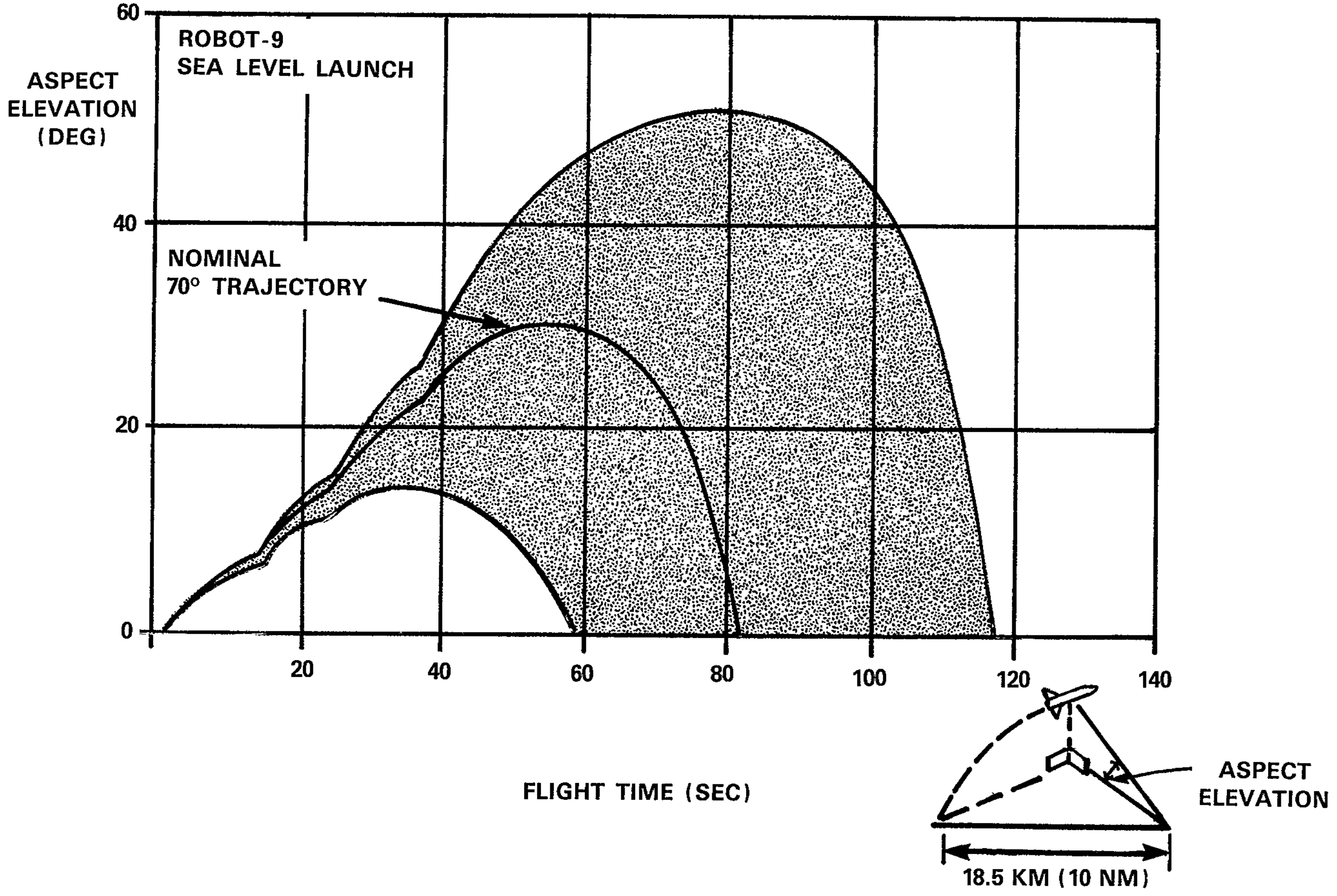


Figure 15b

ROBOT-9 ASPECT ELEVATION ANGLE SCATTER ENVELOPE BASED ON WORST-CASE COMBINATION OF ERROR BUDGET
(See Section 3.3)

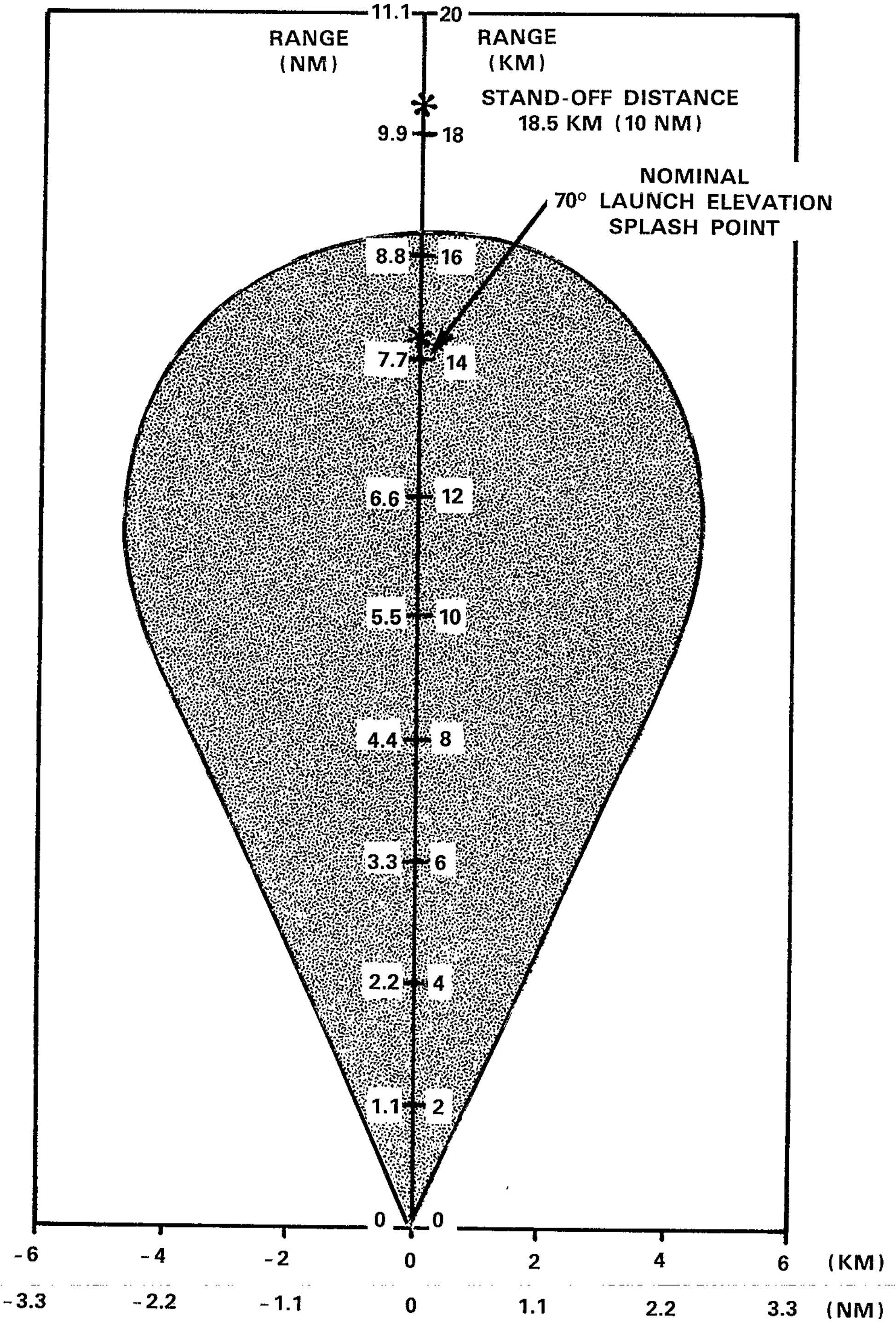
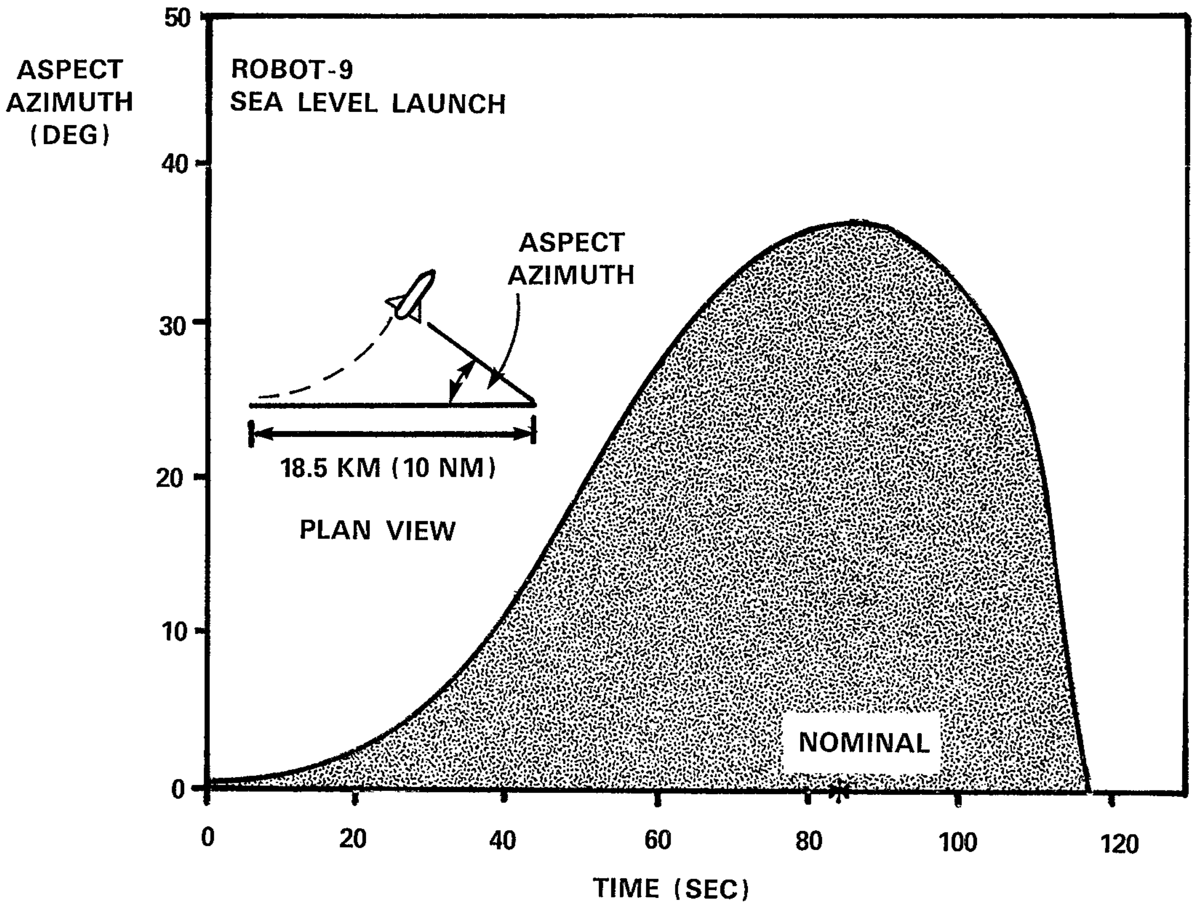


Figure 15c

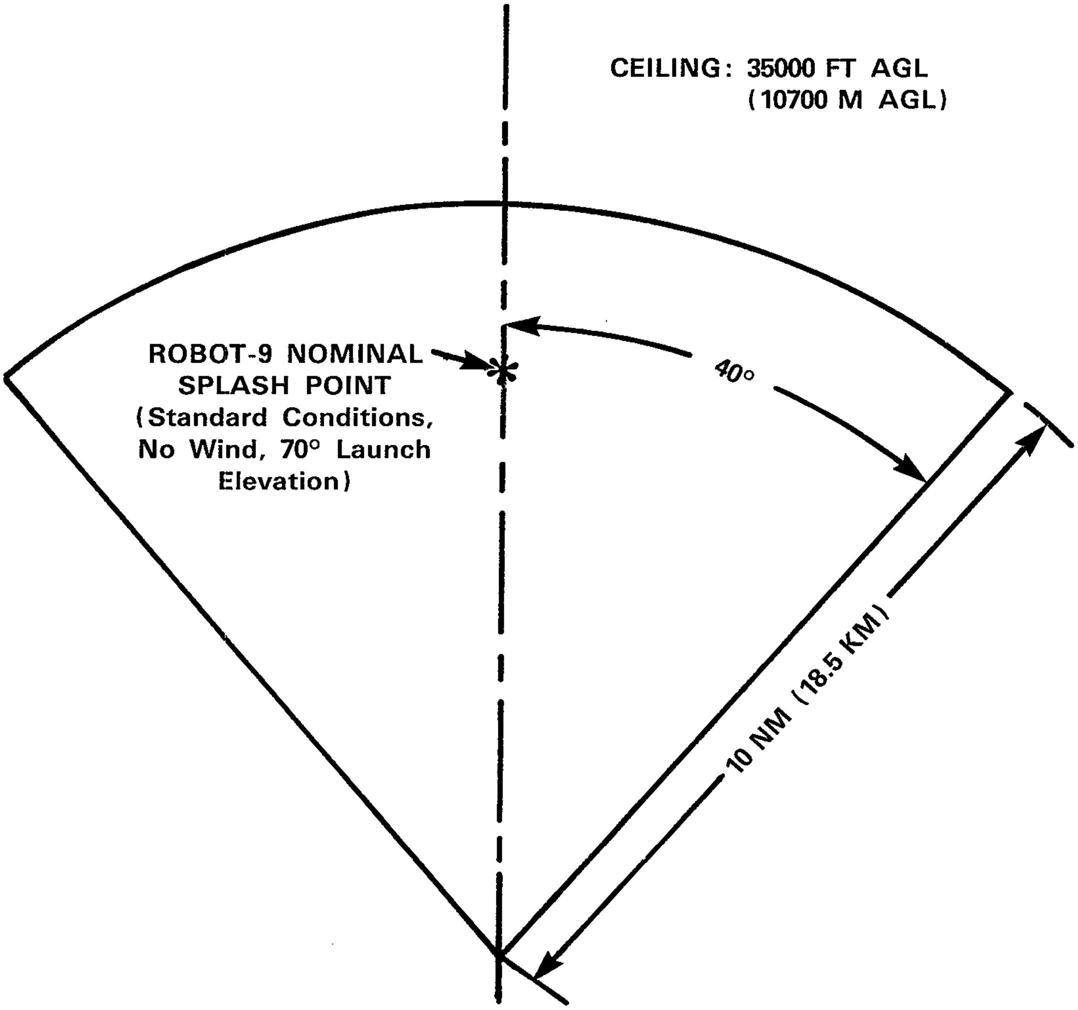
ROBOT-9 CROSS-RANGE SCATTER ENVELOPE BASED ON WORST-CASE COMBINATION OF ERROR BUDGET (See Section 3.3)



CURVE IS SYMMETRICAL ABOUT THE TIME AXIS

Figure 15d

ROBOT-9 ASPECT AZIMUTH ANGLE SCATTER ENVELOPE BASED ON WORST-CASE COMBINATION OF ERROR BUDGET (See Section 3.3)



LIMITING CONDITIONS

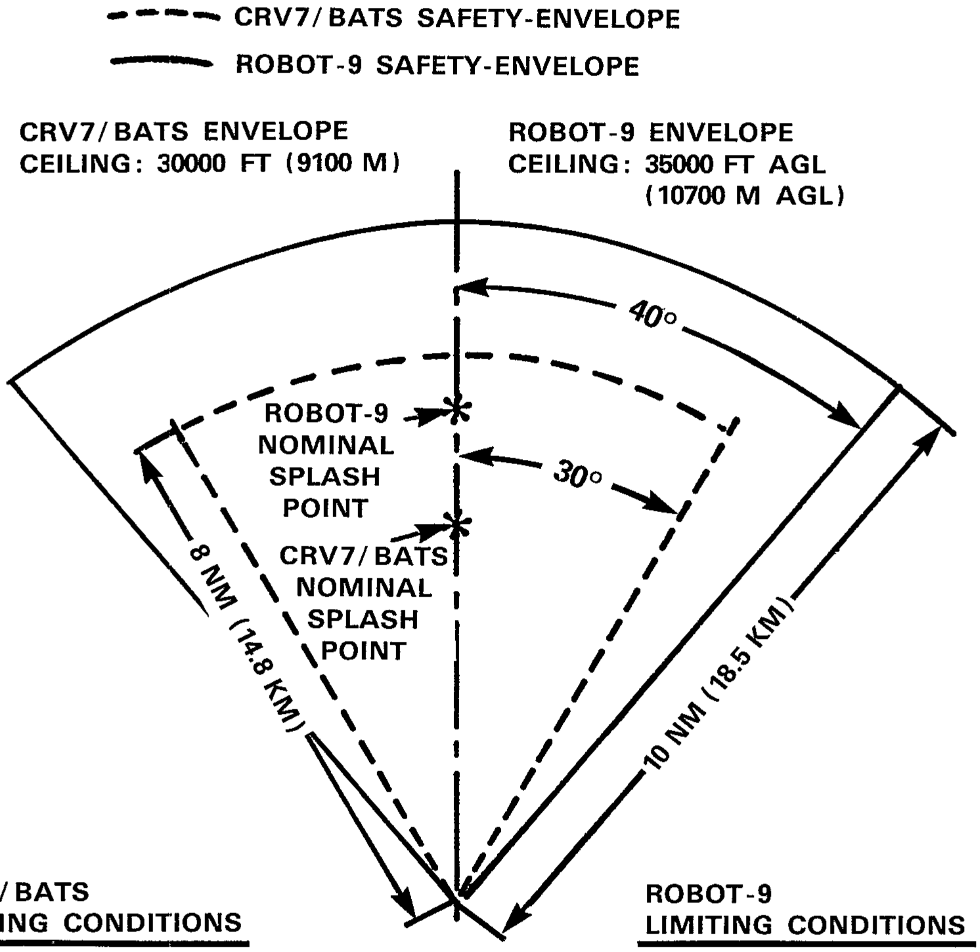
LAUNCH ELEVATION $\leqslant 70°$

SURFACE WIND SPEED $\leqslant$ 20 KNOTS (37 KPH)

MAXIMUM LAUNCH SHIP'S ROLL ANGLE = 10°

Figure 16

ROBOT-9 SAFETY-ENVELOPE
(Sea Launches)



CRV7/BATS
LIMITING CONDITIONS

LAUNCH ELEVATION ⩽ 65°

SURFACE WIND SPEED:
⩽ 30 KNOTS (56 KPH)

MAXIMUM LAUNCH
SHIP'S ROLL ANGLE = 15°

ROBOT-9
LIMITING CONDITIONS

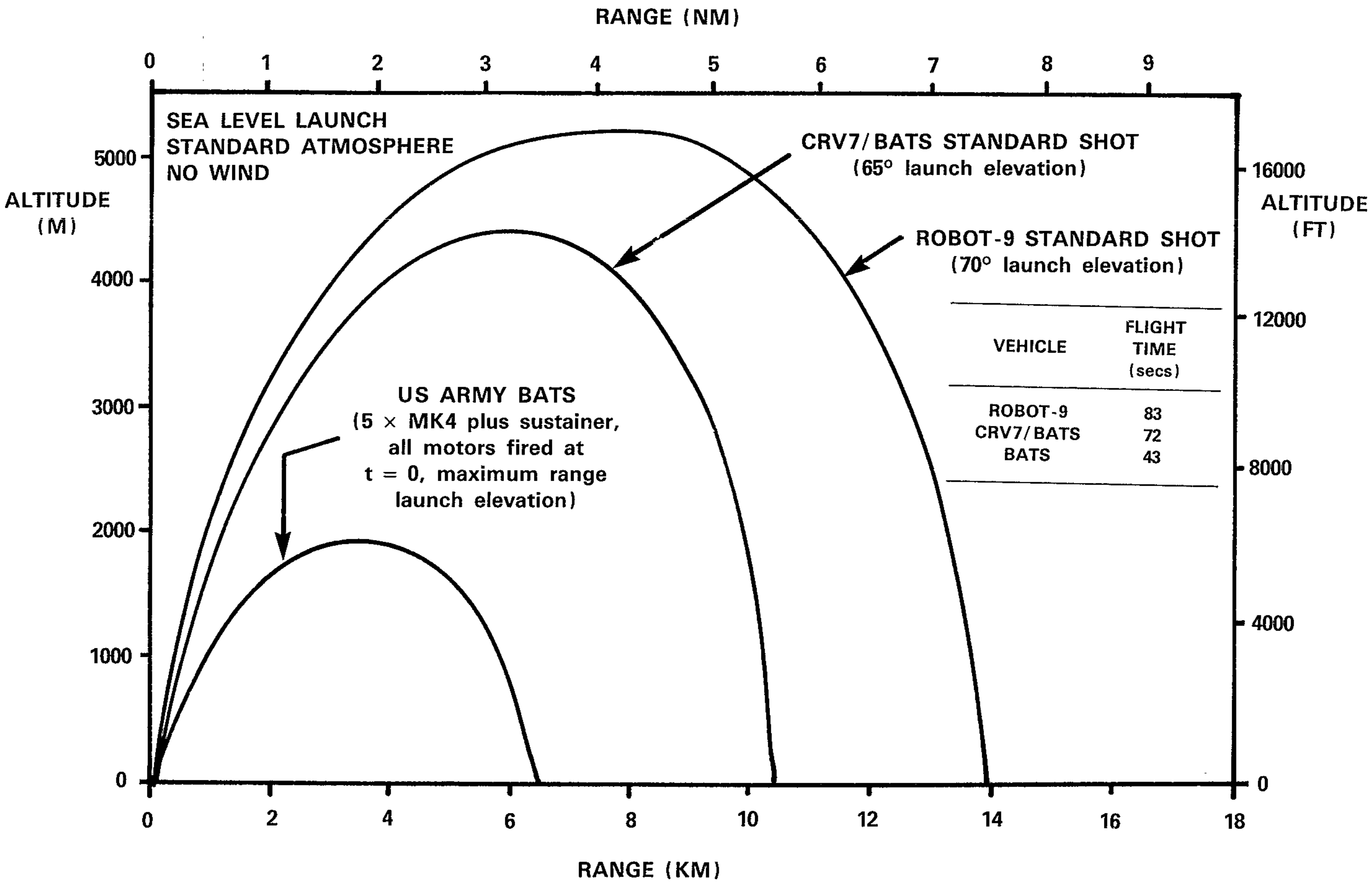
LAUNCH ELEVATION ⩽ 70°

SURFACE WIND SPEED:
⩽ 20 KNOTS (37 KPH)

MAXIMUM LAUNCH
SHIP'S ROLL ANGLE = 10°

Figure 17

COMPARISON OF ROBOT-9 AND CRV7/BATS SAFETY-ENVELOPES



VEHICLE	FLIGHT TIME (secs)
ROBOT-9	83
CRV7/BATS	72
BATS	43

Figure 18

COMPARISON OF US ARMY BATS, CRV7/BATS AND ROBOT-9 TRAJECTORIES

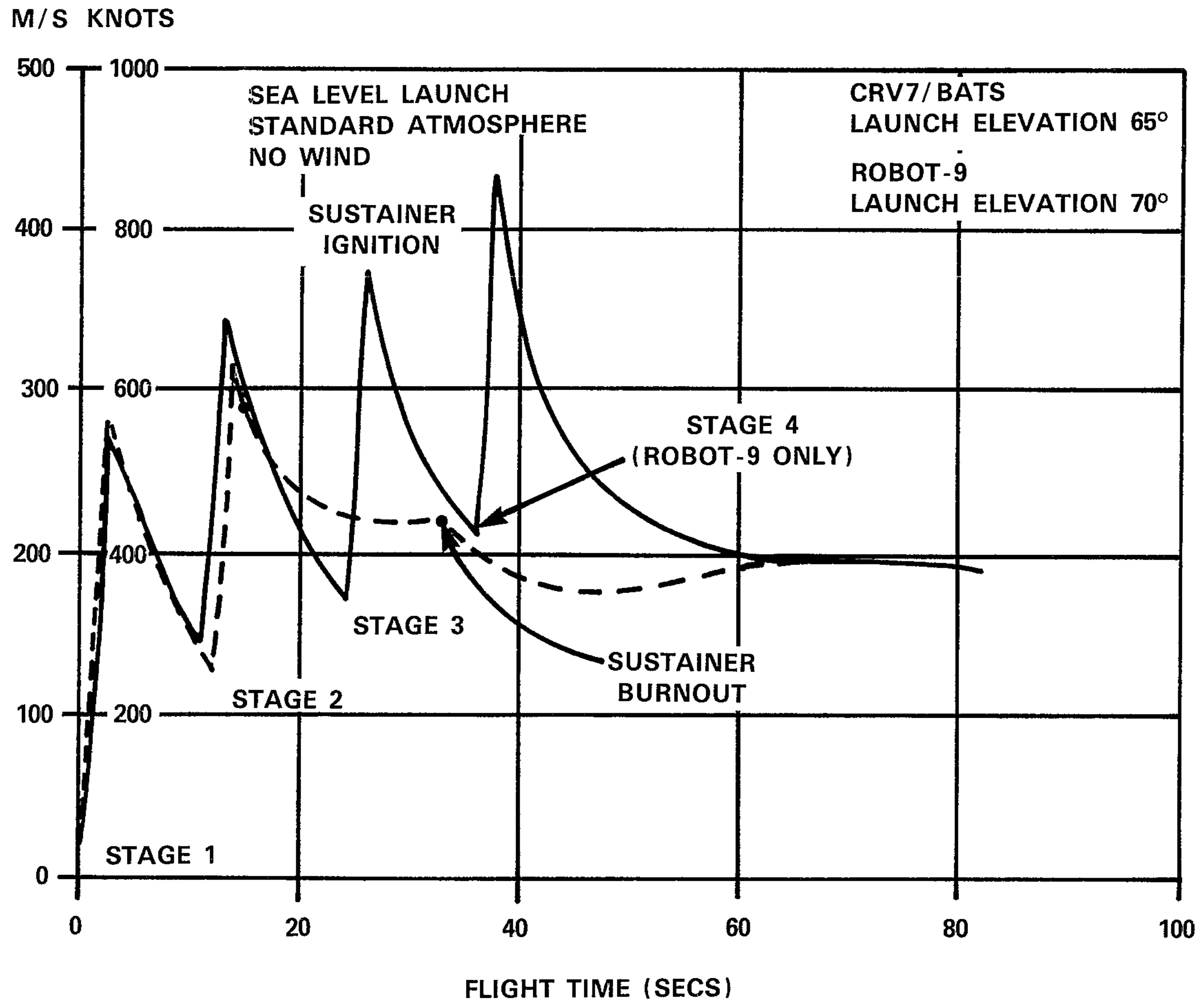


Figure 19

COMPARISON OF THE STANDARD SHOT CRV7/BATS AND ROBOT-9 AIRSPEED TIME HISTORIES

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13. ABSTRACT

The performance of a free flight, ballistic, multistaged, rocket-boosted aerial target designated ROBOT-9 is described. This target is the second vehicle in the ROBOT family of targets, and uses a four stage propulsion system based on the Canadian developed CRV-7 rocket motor.

The performance results were obtained using a nonlinear, six degree-of-freedom dynamic model. They include a description of nominal performance under standard conditions, the scattering effects of various environmental conditions, and the specification of a safety-envelope based on a set of worst case conditions. Performance comparisons are included with the original U.S. Army BATS and with CRV7/BATS. (U)

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This Sheet Security Classification

KEY WORDS

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CRV7/BATS
CRV-7
Flight Dynamics
ROBOT-5
ROBOT-9
Rocket-Boosted Targets
Six-Degree-of-Freedom Simulation

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