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TITLE

A WINGED ROCKET BOOSTED TARGET \(ROBOT-X\)

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SUFFIELD MEMORANDUM

NO. 1062

A WINGED ROCKET BOOSTED TARGET (ROBOT-X) (U)

by

K. Schilling

PCN 21V10

September, 1981

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD : RALSTON : ALBERTA

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RALSTON, ALBERTA

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A WINGED ROCKET

BOOSTED TARGET (ROBOT-X) (U)

by K. Schilling

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ABSTRACT

A winged rocket boosted target (ROBOT-X) is proposed as an inexpensive alternative to turbine engine driven drones for low level/high speed target simulation missions.

The basic configuration of a ROBOT-X using 19 CRV7 rocket motors for propulsion is described, results of performance estimates are presented, and the feasibilty of ROBOT-X for the target missions mentioned above is demonstrated. (R)

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1.0 INTRODUCTION

Simulation of a high speed/low altitude aircraft or cruise missile is a typical target mission. So far these missions are flown by expensive turbine engine driven targets. This paper proposes an inexpensive alternative: a winged rocket-boosted target (ROBOT-X). The major cost saving is in making use of a propulsion system based on a stage fired CRV7/rocket cluster. This system is less expensive than a jet engine and needs no maintenance or highly skilled personnel to be operated.

1.1 System Requirements

Performance requirements for a low altitude mission are as follows:

- Range: exceeding 20 nm(radar horizon of a ship)
- Flight-time: exceeding 2 min (minimum acquisition/interception time for Air-Force look-down shoot-down training)
- Speed: high subsonic

Additionally, the target should be able to simulate a cruise-missile pop-up maneuver at the radar horizon, and have (limited) maneuvering capabilites.

Figure 1 illustrates this scenario.

These requirements have to be fulfilled maintaining as many as possible of the low-cost features of the 5 CRV7/BATS and ROBOT-9 targets:

- inexpensive production
- no maintenance
- low skill operation

2. BOOST-GLIDE CONCEPT

Basically there are two rocket motor propulsion concepts for a long range/long endurance mission:

- Launch with booster motors and maintain speed with a sustainer of proper thrust level and burn time.
- Replace the sustainer by more boosters that are ignited sequentially within the flight yielding a boost-glide trajectory.

The sustainer solution will result in a constant velocity, as well as constant ranges and flight-times. The boost-glide solution will permit variablity in speed, range and flight-time, as all these parameters depend on the duration of the glide intervals between booster stage firings. Figure 2a compares velocity-time histories of the propulsion alternatives described above. Figure 2b illustrates the effect of variable glide intervals on velocity, range and flight-time for a ROBOT-X vehicle.

Aside from the advantage of its versatility, the boost-glide propulsion system will be considerably cheaper than an adequate sustainer motor, as it uses many mass produced motors. For a Canadian ROBOT-X development, the obvious choice is the CRV7 rocket motor, due to its high reliability and cost effectiveness. Performance estimates (see Section 4 to follow) show that 19 CRV7-motors are needed to accomplish the range requirement of exceeding 20 nm (37 km).

Launch:	5 or 7 CRV7 motors
Boost-glide:	7 or 6 stages of 2 CRV7 motors
total	19 CRV7 motors

Total cost of the motor cluster will be C$6000. This is extremely inexpensive compared to the cost of jet engines or high performance sustainer motors.

Figure 3 shows how the required mission will be accomplished by ROBOT-X. The vehicle will be boosted off a launcher rail similar to the BATS-rail by 5 or 7 CRV7 motors and will initially follow a ballistic trajectory. Depending on the launch elevation angle, ROBOT-X can simulate a pop-up maneuver. At the end of the ballistic curve the vehicle will climb out to a constant altitude flightpath, as controlled by an autopilot. This level part will consist of 6 or 7 boost-glide segments, each one employing a 2 CRV7 motor inflight boost and a glide phase. The flight will be terminated by a pitch-up maneuver and parachute recovery.

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3. ROBOT-X CONFIGURATION

Compared to a normal drone design, ROBOT-X has to fulfill some additonal requirements imposed by the special propulsion system. These are:

a) The resulting thrust vector of launch boost as well as any inflight stage ignition must pass through the centre of gravity (c.g.), and should be aligned with the vehicle's longitudinal axis in order to avoid thrust asymmetries. This condition requires a vertically balanced configuration (c.g. on the longitudinal axis) and a motor cluster that is symmetrical to the vehicle's axis in two planes.

b) Solid propellant weight will be a major part of the vehicle's gross weight (35 to 45%). To avoid inflight trim problems, the rocket motors have to be mounted close to the empty vehicle's longitudinal center of gravity position.

c) Interference between rocket motor exhaust gas and lifting surfaces, especially the stabilizers, has to be avoided.

Figure 4 shows a proposed ROBOT-X configuration. The vehicle consists of 3 main components:

- the main structure, i.e. wings, stabilizers, and the tube to house the motor pod,
- the front part, i.e. nose cone and avionics compartment,
- the motor pod (loaded with rocket motors), that may be inserted into the housing tube from behind.

It is a midwing configuration, the stabilizers being mounted to extension booms. The special stabilizer configuration was chosen to keep them out of the exhaust gas interference zone. The CRV7 rocket motors are mounted in a pod occupying the body's central part. The vehicle nose cone can accommodate radar augmentation; the avionics compartment is located behind it. The drive motors for control surfaces are housed in the front and aft hoods of the stabilizer extension beams permitting convenient access. The 4 motors are used for ailerons (front pair), elevator, and rudder (aft pair).

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Some preliminary ROBOT-X data are summarized below.

mass:	(launch)	250 .... 300 kg
	(after burnout)	150 .... 200 kg
length:		3 m
span:		2 m
wing area:		1 m
wing aspect ratio:		4
wing sweep back angle:		35 deg
wing loading		1500....3000 N/m^2

The velocity domain within which ROBOT-X has to operate ranges from 100 m/s to 275 m/s (equivalent Ma=0.8). Therefore the aerodynamics design has to be a compromise between good high speed performance and low speed maneuverability.

4. PERFORMANCE ESTIMATES

The following estimates are based on a rough prediction of the ROBOT-X drag polar.

$$C_D = 0.03 + 0.01\ A_{wing}/1m^2 + 0.1\ C_L$$

C_D = drag coefficient
A_{wing} = wing area
C_L = lift coefficient

The basic element of the ROBOT-X trajectory is a boost-glide segment consisting of an initial boost phase (2 CRV7 motors),and a subsequent glide phase, both at constant altitude. Basic parameters to describe such a segment are:

- velocity profile (minimum - maximum velocity)
- range
- flight-time

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Figure 5 shows a typical velocity-time history including the velocity limits set by the system. Each segment is obviously characterized by 3 velocities:

V_i = initial velocity (final velocity of previous segment).

V_m= maximum velocity reached at burnout of the rocket motors.

V_f= final velocity reached at the end of the glide phase.

Depending on the velocity history the segments can be categorized as follows (compare with Fig. 6):

a) Stationary segments, $V_i = V_f$. The speed increase during the boost phase is used to trade speed for range in the glidephase.

b) Accelerated segments, $V_f > V_i$. Some of the boost phase speed increase is used to raise the general speed level rather than to win range.

c) Decelerated segments, $V_f < V_i$. A general drop of speed allows additional range.

Velocity limits are set by:

- Safety against stall at low speed. This limit will be characterized by:

  $C_{L\ max} = 0.5$

- avoidance of supercritical Mach numbers, the limit being set to $Ma_{max} = 0.8$

Figure 7 shows how these limits reduce the variablility of a ROBOT-X boost-glide segment. Conditions a) and b) are the low-velocity limits.

a) Initial velocity V_i has to be above the stall limit $V_i \geq V_{safe,stall}$.

b) Final velocity V_f has to stay above this limit $V_f \geq V_{safe,stall}$

Case a) is valid for accelerated segments, case b) for decelerated segments. For stationary segments both cases coincide. Conditions c) and d) include the high speed limitations.

c) The vehicle cannot be accelerated beyond Ma=0.8 during the boost phase. At a given velocity increment ΔV during the boost phase this condition yields an upper limit for the initial velocity V_i.

$$V_i \leq V_{Ma=0.8} - \Delta V$$

d) As the final velocity V_f will be the initial velocity V_i of the next boost-glide segment,it has to fulfill condition c) as well, in order to avoid exceeding the maximum velocity limit within the following segment.

$$V_f = V_{Ma=0.8} - \Delta V_{next}$$

In some cases (high vehicle mass), the velocity increment ΔV is so small compared to the margin between the upper and lower velocity limits that condition d) is fulfilled even without any decelerating glide phase between two boosts. This means that a double kick by 2 pairs of CRV7 motors is allowed. Condition c) limits decelerated segments, d) puts a constraint on accelerated segments. For stationery segments and constant mass, both conditions coincide.

Performance of a ROBOT-X can be characterized as a velocity-range trade off. Thus, an adequate way to describe it is through a plot of range vs. average velocity of one boost-glide segment (see Fig. 8). Flight-time, being a simple function of the two coordinates, is automatically included.

The domain of permissible range/velocity combinations is limited by the 4 boundary conditions discussed above.

The main diagonal describes stationary segments ($V_i = V_f$), the upper part of the domain contains decelerated segments (additonal range is obtained by a velocity drop), the lower part contains accelerated segments. Note that even stationary segments alone allow a considerable flexibility in trading range for average velocity. The limits are:

range	5400	to	3800	(m)
flight-time	42	to	16	(sec)
average velocity	125	to	240	(m/sec)

In order to obtain a feeling for the amount of average velocity change $V_i - V_f$ connected with additional range increase in decelerated segments, the line representing segments with a velocity loss of

$$V_i - V_f = 50 \text{ m/sec}$$

is included in the upper part of the domain. One can see that this velocity drop yields a range increase of 2500 to 3000 m, compared to stationary segments with the same average velocity. As this range-velocity trade-off proves to be approximately linear and symmetrical, one would have to sacrifice the same amount of range in order to increase speed to the initial level again at a following accelerated segment. Therefore, accelerating or decelerating segments are not useful to obtain a general performance increase over stationary segments, but rather to change the velocity level within a trajectory and thus decouple the actual target velocity at a planned intercept point from any range or flight-time requirement.

Figure 8. shows performance characteristics of a 300 kg vehicle. Influence of mass change from 150 kg to 300 kg is described in Figure 9. The results look paradoxical, but their interpretation is simple:

a) For stationary shots (main diagonal), the mass change has almost no influence on performance. The reason for this unexpected result is that the parasite drag is extremely high and dominates induced drag by orders of magnitude within the regime of lift coefficients ($C_L \leq 0.5$) considered here.

b) The size of the performance domain increases with mass, as the negative effect of mass on the safe stall limit is overcome by the positive effect on the maximum speed limit. This may be explained as follows: The total impulse, delivered by the 2 CRV7 motors, can be stored at lower velocity increases ΔV if the vehicle mass increases. This mass increase allows a greater flexibility in shifting the overall velocity level within the given speed limits. Note that this effect is a function of mass alone, and not of wing loading.

The extension of the left hand side of the main diagonal describes the performance increase obtained by shifting the safe stall limit from $C_{L,max}=0.5$ to $C_{L,max} = 0.7$, i.e. by improving the target's low speed characteristics. Note that the effect on range can even become negative at high masses. Generally, one can say that the gain in performance is too small to justify major efforts to improve low speed performance.

Figure 10 compares performance domains for wing areas varied from 0.5 m^2 to 2 m^2. For reasons of simplicity, only the 300 kg domains are plotted. Obviously the choice of wing area is a compromise between good high speed performace, requiring a small wing to reduce drag, and the ability to obtain maximum range at low average speeds, requiring a large wing. The chosen wing area of 1 m^2 yields maximum range at stationary segments and still offers reasonable high speed performance.

The envelopes were calculated for sea-level/non-maneuvering conditions. An altitude increase or any maneuvering would limit low wing area performance even more than Figure 10 indicates.

The complete ROBOT-X flight includes 6 or 7 of the boost-glide segments described above, and an initial ballistic part. This first part is described in Figure 11. It includes the launch (by 5 or 7 CRV7 rocket motors), a ballistic trajectory, a climbout maneuver, and a final glide phase at constant altitude.

Figure 12 gives the maximum altitude obtainable at different launch angles, vehicle masses, and number of CRV7-motors used for launch.

Figure 13 describes the range-velocity trade-off obtainable from the initial phase. This trade-off can be achieved by varying the length of the final glide phase between climbout velocity (max. velocity/min. range) and safe stall speed (min. velocity/max. range). None of the trajectories included in Figure 13 exceeds the set speed limits (stall and Mach limit) so all parts of the range-velocity curves are realistic.

The range/velocity trade-off for the initial portion of the trajectory is basically the same as for the following boost-glide segments. Therefore it is of no use to increase range for the initial portion by decelerating down to low speeds if a higher velocity level is desired for the following segments. The necessary acceleration in these must be paid for by a range decrease equalling the range increase obtained on the initial

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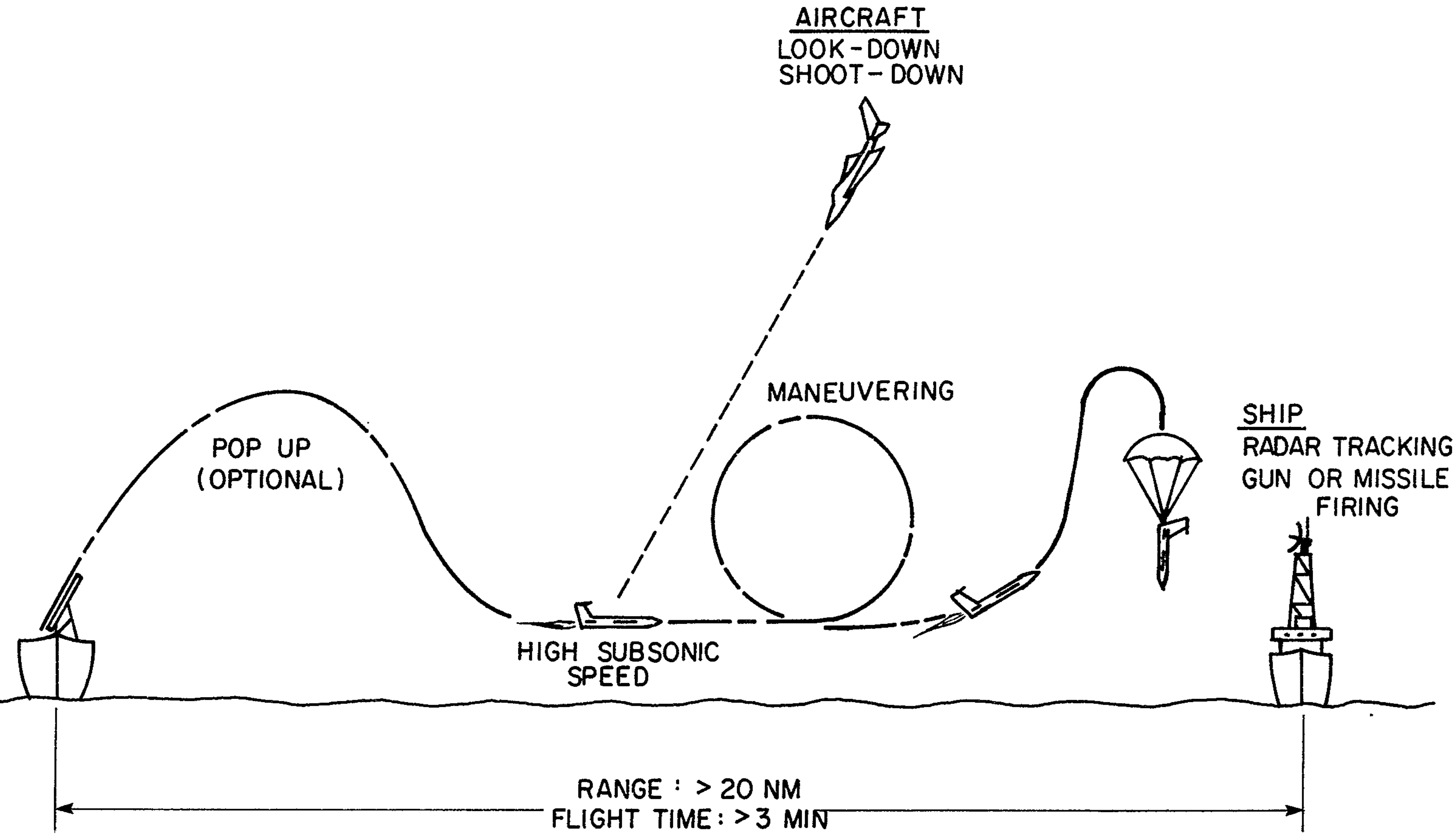

FIGURE 1: LOW ALTITUDE / HIGH SPEED TARGET REQUIREMENTS

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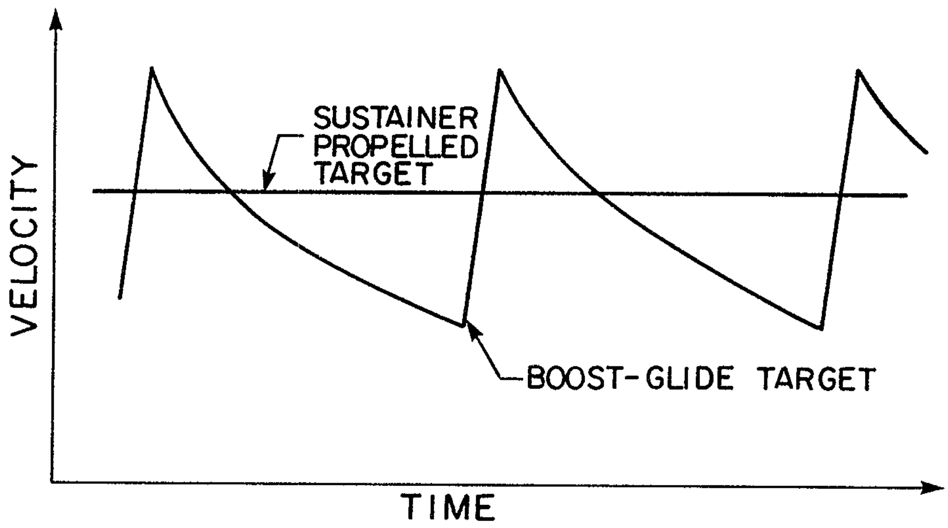

Fig. 2 (a) COMPARISON OF VELOCITY-TIME HISTORIES FOR SUSTAINER PROPELLED AND BOOST-GLIDE TARGET

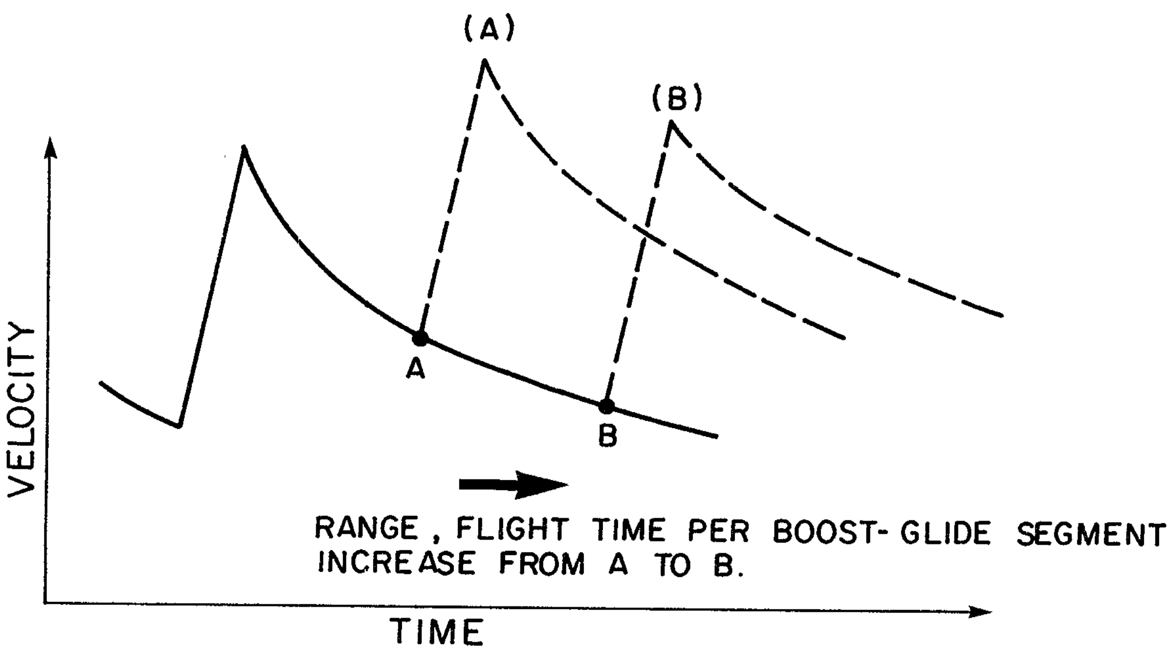

Fig. 2 (b) INFLUENCE OF BOOST STAGE IGNITION ON PERFORMANCE PARAMETERS

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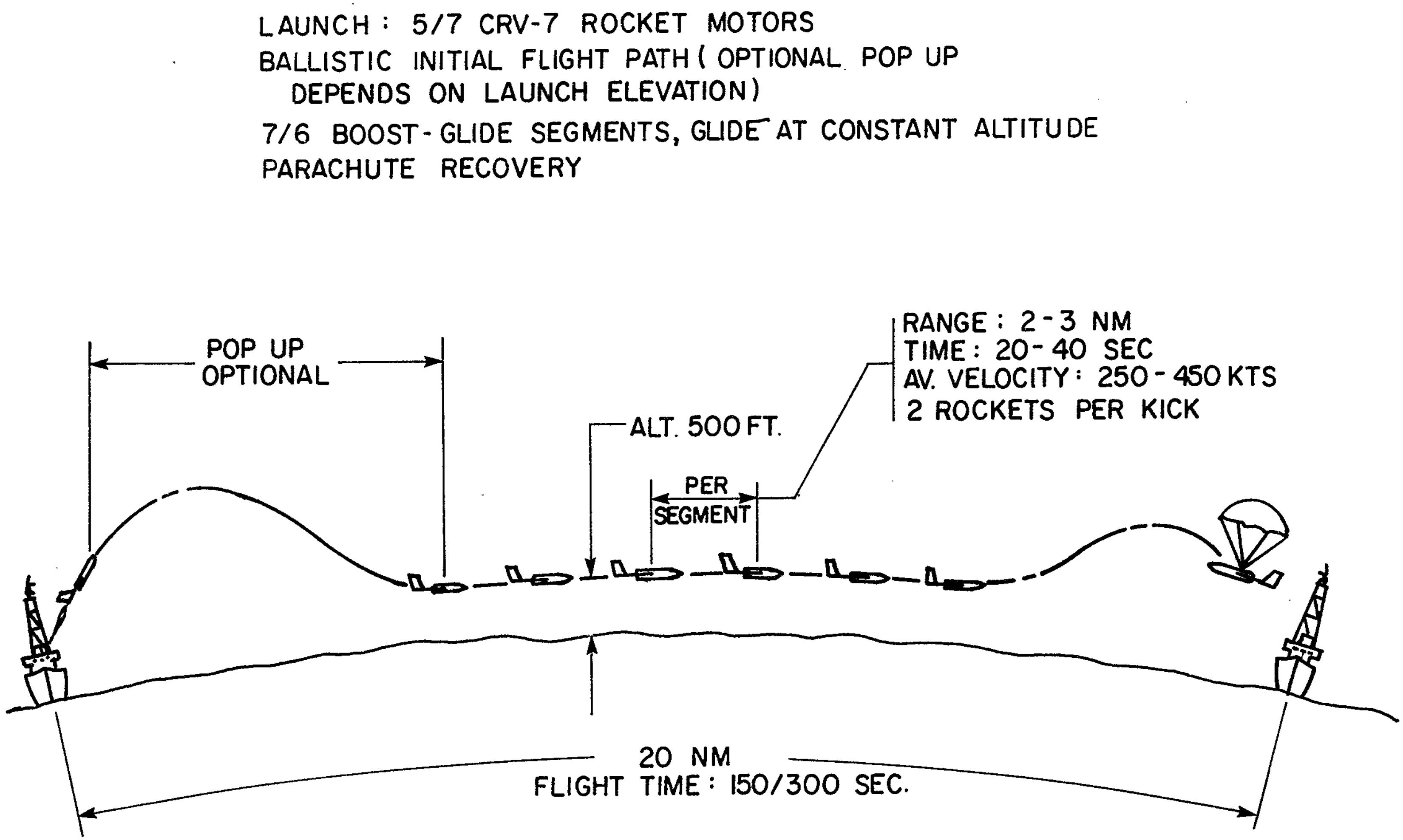

Fig. 3 ROBOT-X TRAJECTORY

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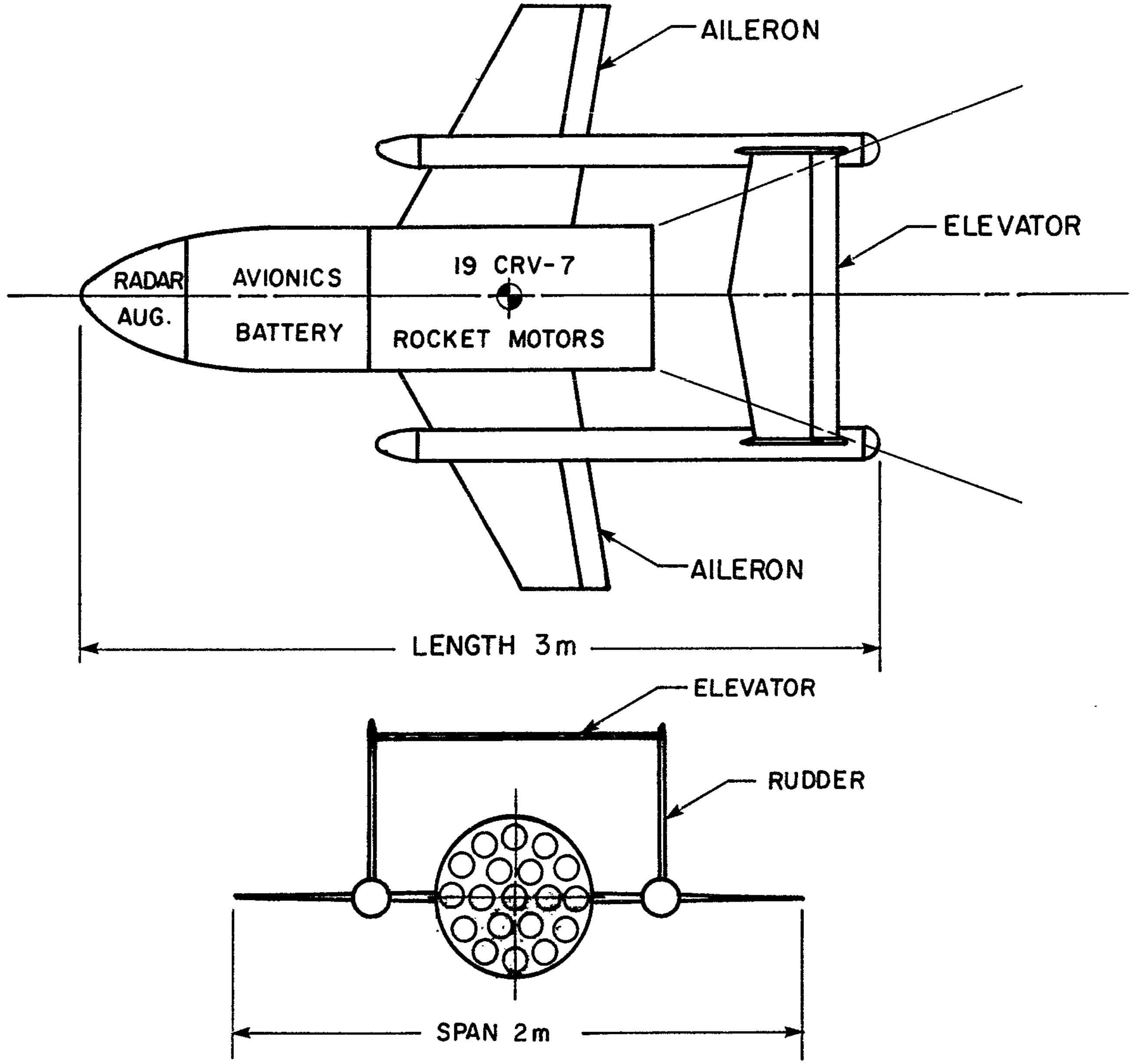

Fig. 4 ROBOT-X CONFIGURATION

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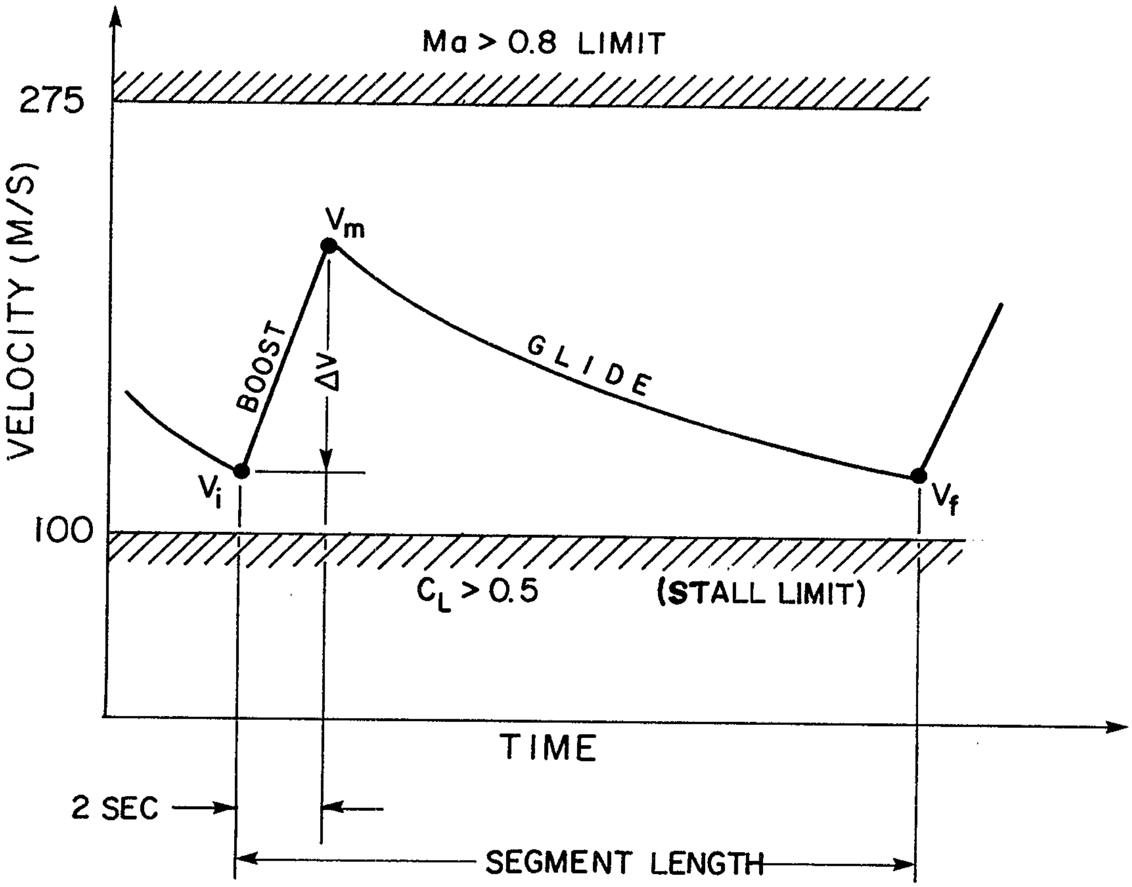

Fig. 5 ROBOT-X, TYPICAL VELOCITY-TIME HISTORY OF BOOST-GLIDE SEGMENT

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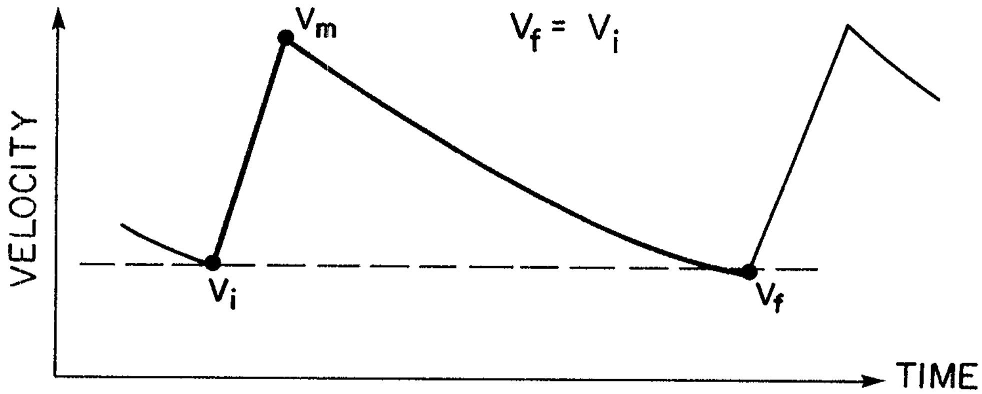
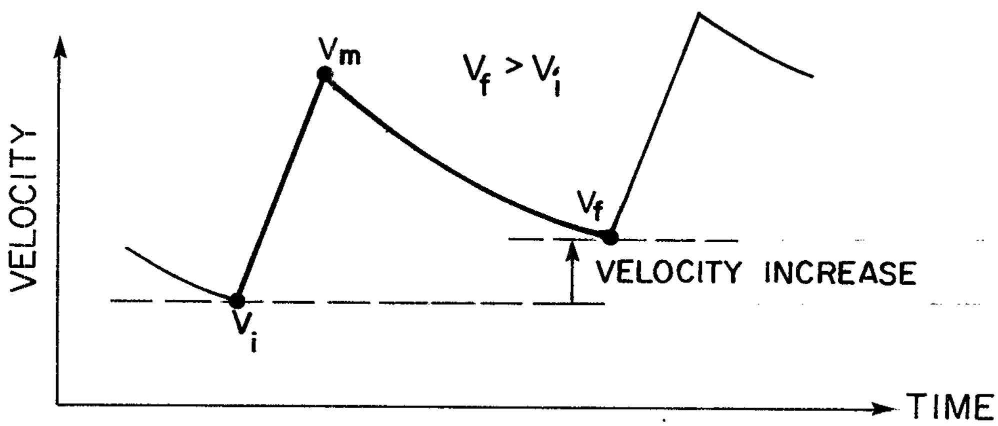
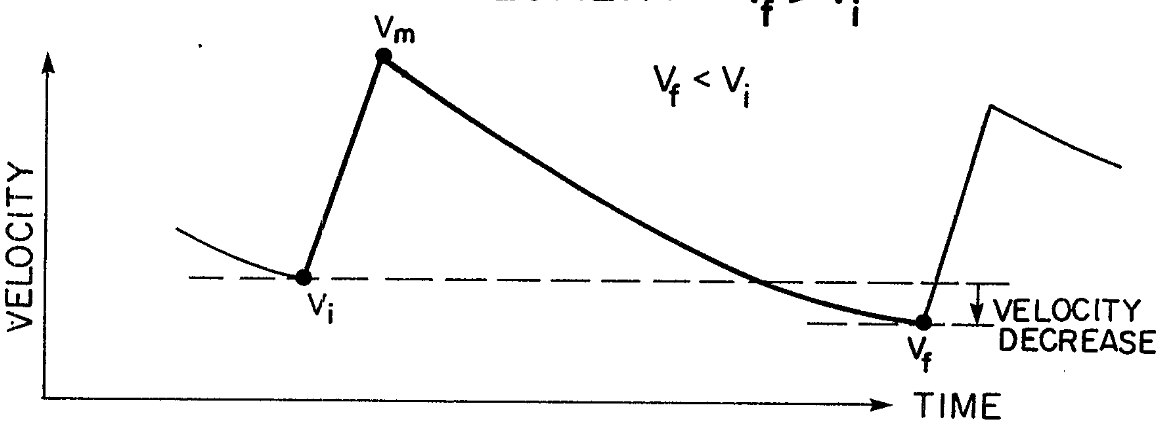


6a : STATIONARY SEGMENT $V_f = V_i$



6b : ACCELERATED SEGMENT $V_f > V_i$



6c : DECELERATED SEGMENT $V_f < V_i$

Fig. 6 SEGMENT CLASSIFICATION

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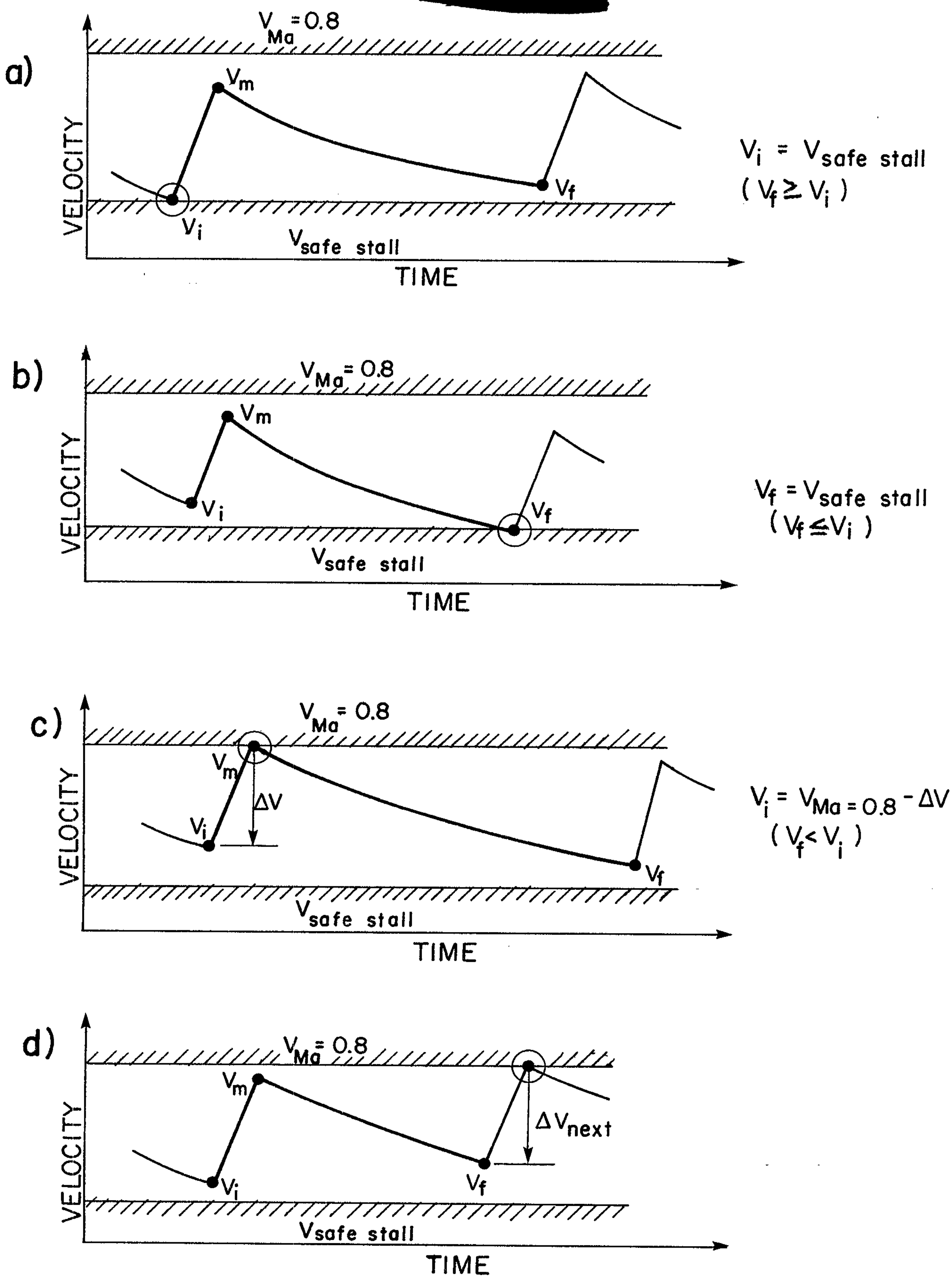

FIGURE 7: VELOCITY LIMITS

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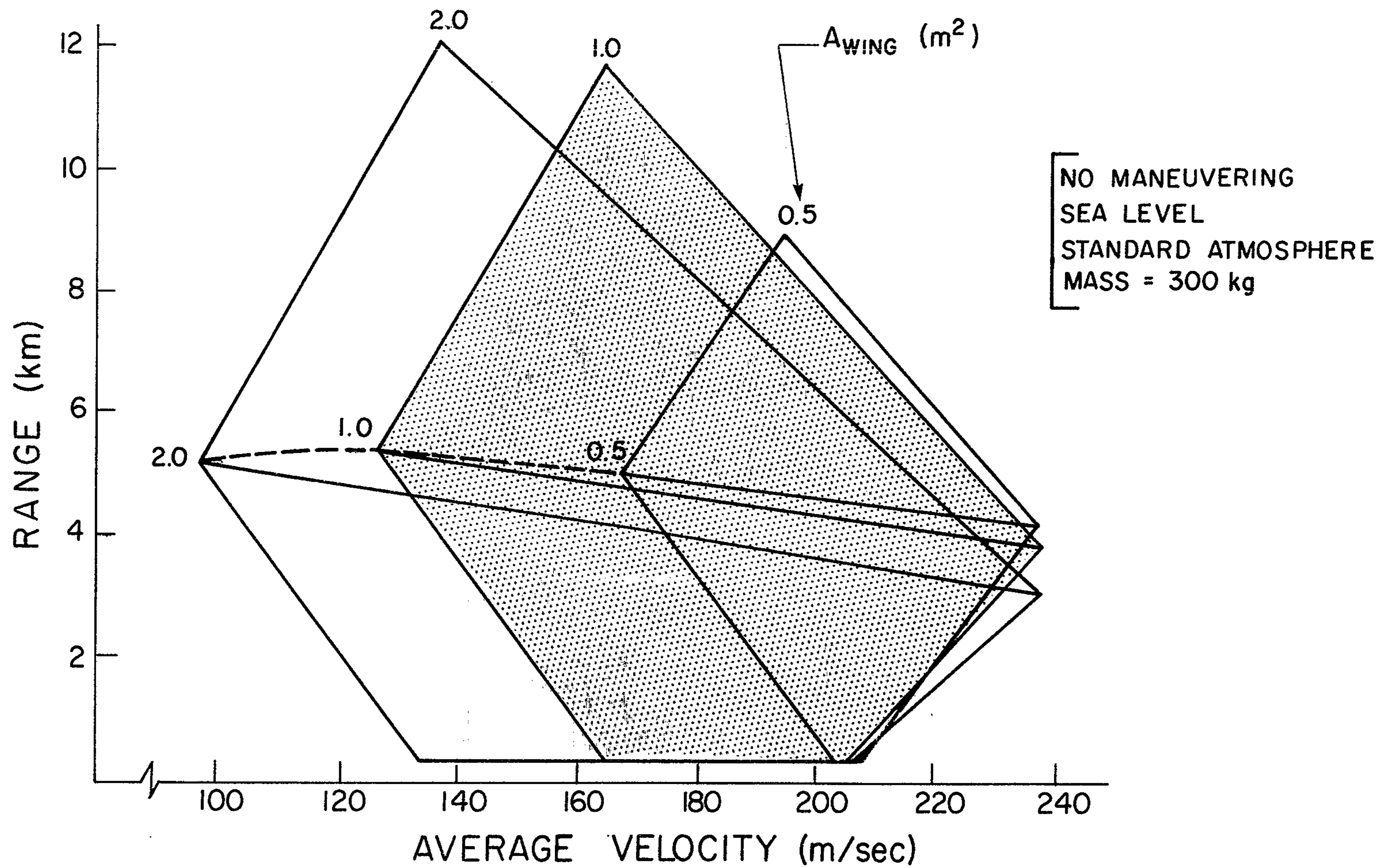

FIGURE 10: BOOST-GLIDE SEGMENT PERFORMANCE DOMAINS
INFLUENCE OF WING AREA

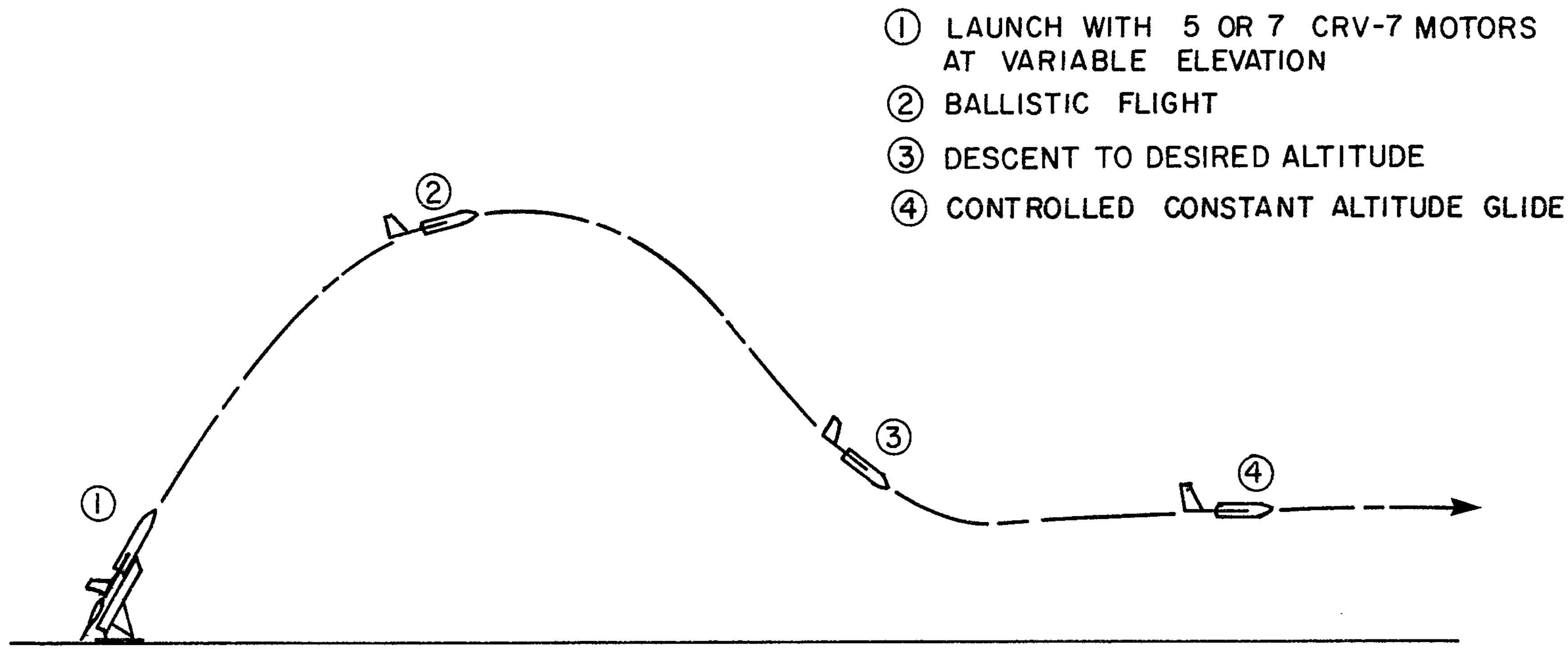

Fig. 11 INITIAL PART OF ROBOT-X FLIGHT

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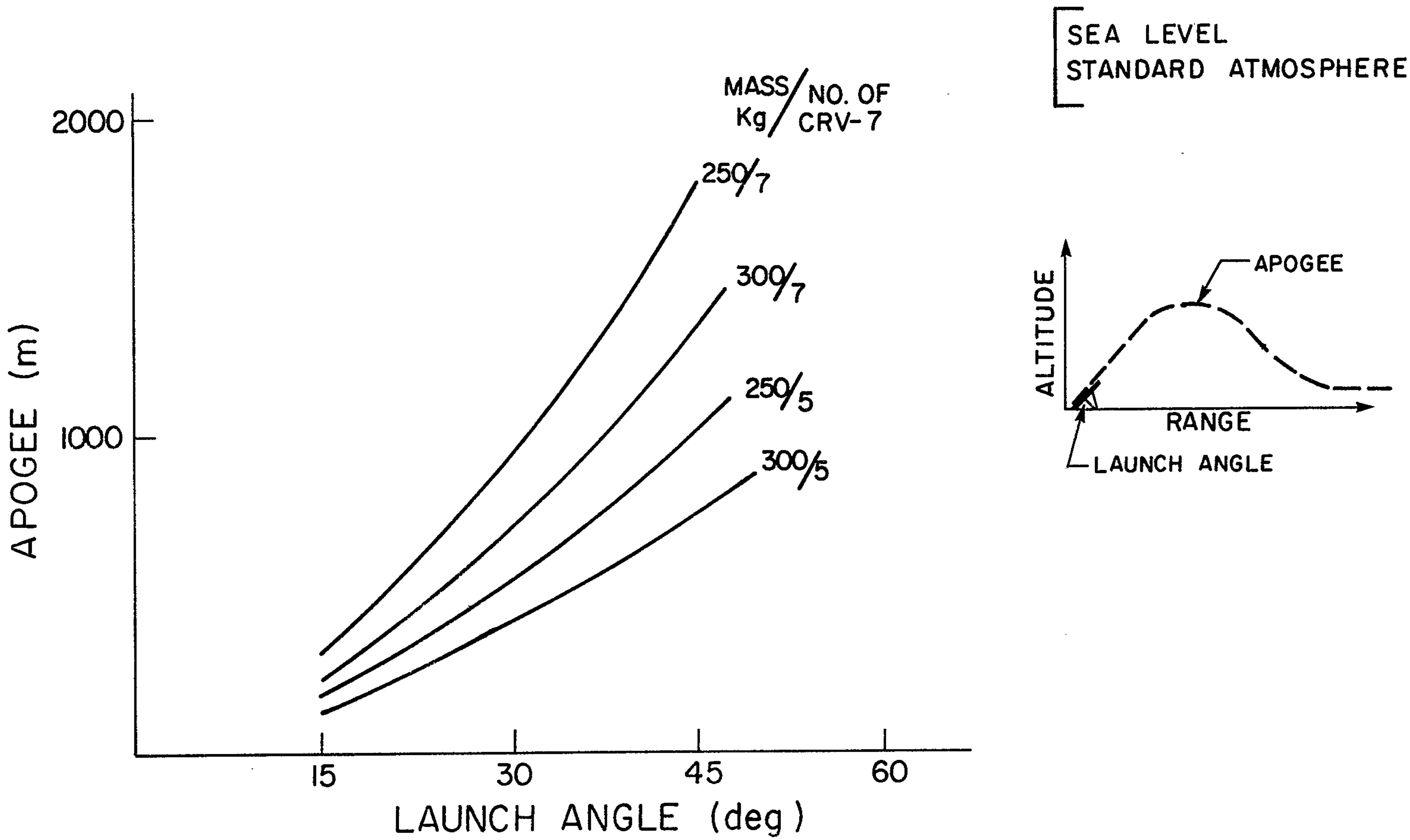

Fig. 12 **ROBOT-X INITIAL PART OF FLIGHT MAXIMUM ALTITUDE AT VARIABLE LAUNCH ANGLES**

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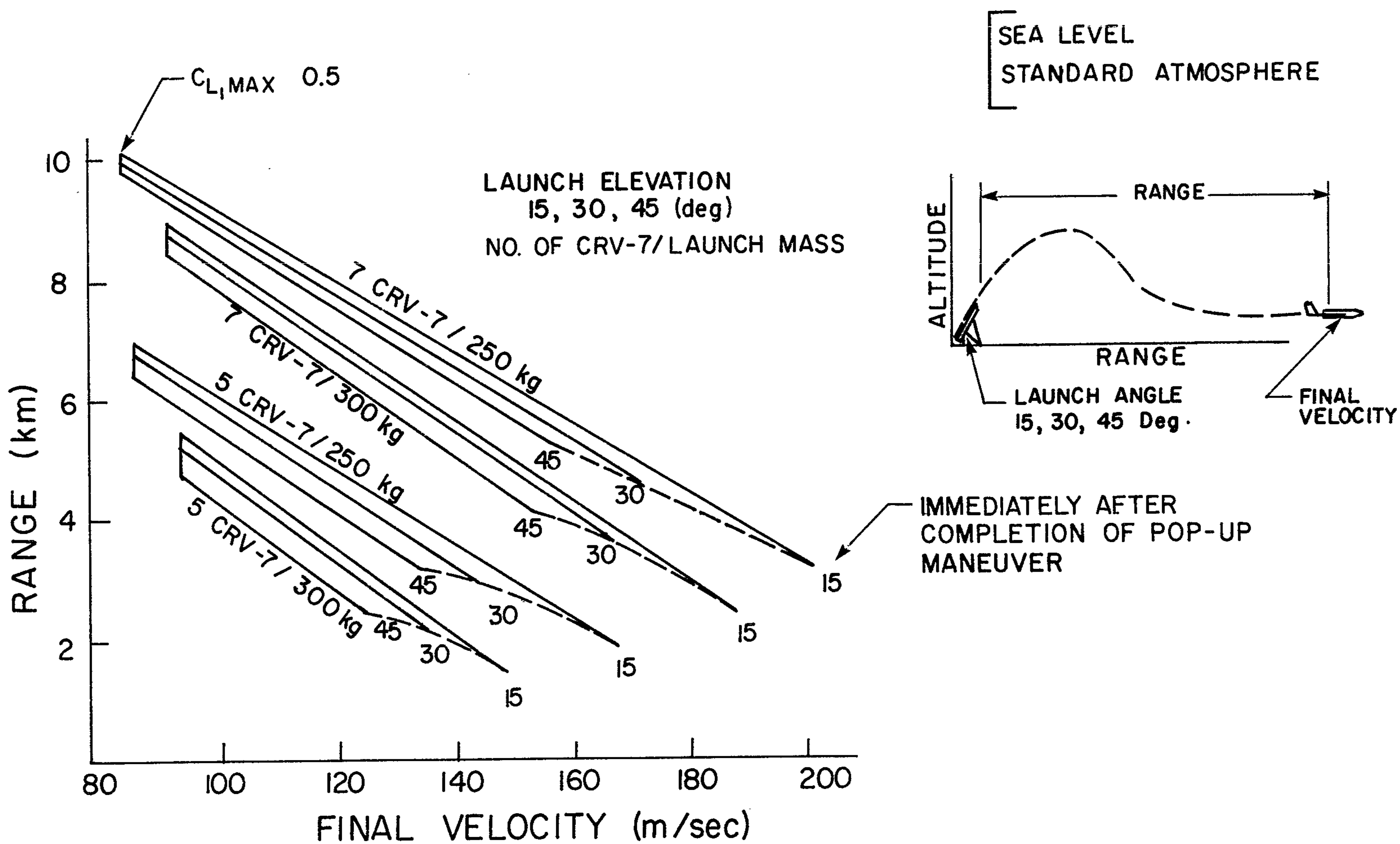

Fig. 13 ROBOT-X INITIAL PART OF FLIGHT, RANGE VS VELOCITY AT VARIOUS LAUNCH CONDITIONS

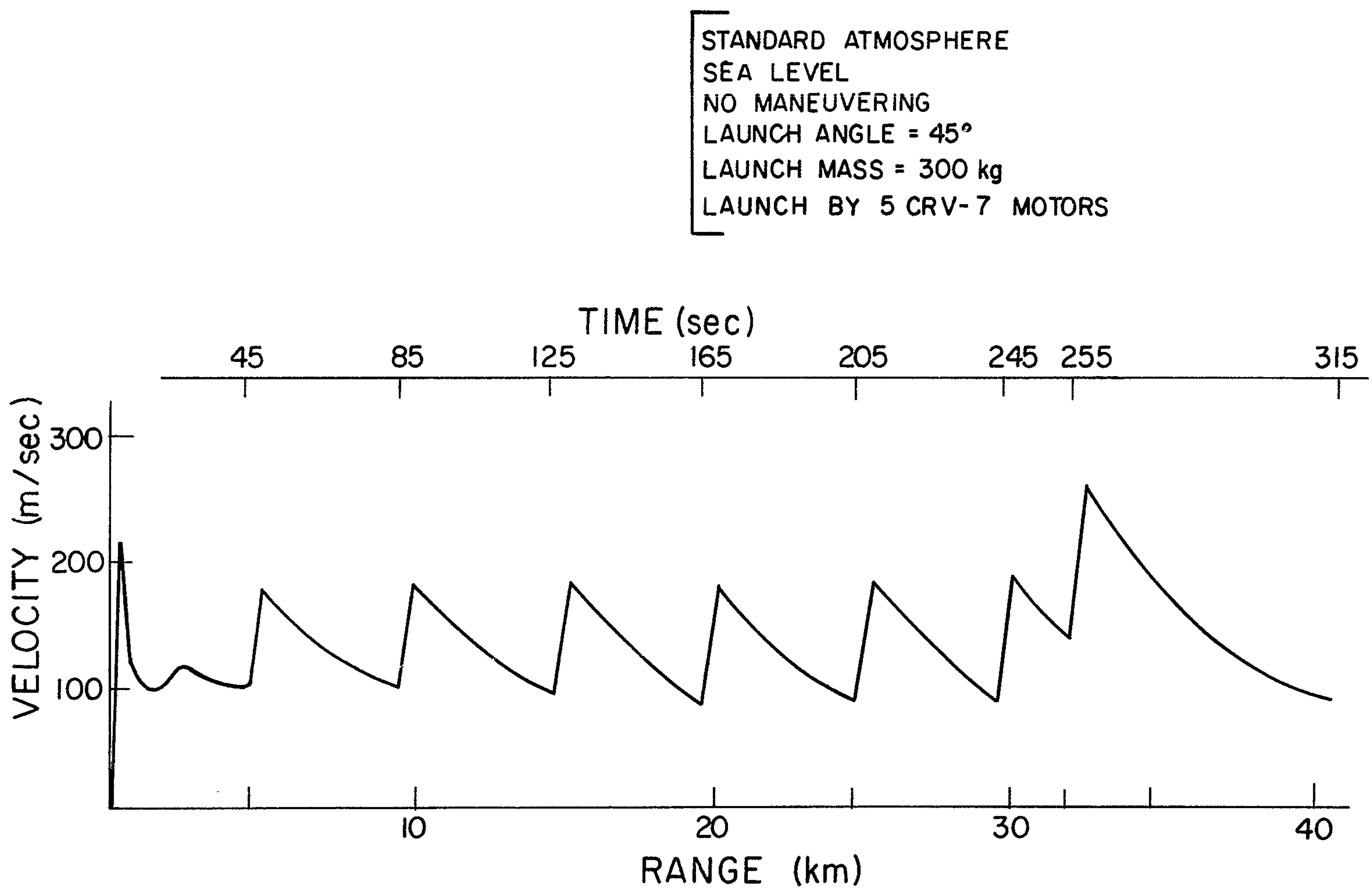

Fig. 15 ROBOT-X SAMPLE TRAJECTORY, VELOCITY-TIME HISTORY

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