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HIGH ALTITUDE LAUNCH
OF
ASW SONOBUOYS

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This effort was funded by NAVAIR (AIR-370) under AIRTASK A035-370A/001B/0F11-100-000. The objective of this study was to investigate the critical technology for the improvement of the sonobuoy launch capability of ASW aircraft. In particular, the purpose of this effort was to define the placement accuracy of high altitude launch of sonobuoys and the extent to which that accuracy could be improved.

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EXECUTIVE SUMMARY

To achieve the objectives of target localization, Navy ASW sonobuoys must be placed in the ocean from an air platform with an accuracy consistent with the capabilities of the sonobuoy acoustic performance. Sonobuoy placement is usually accomplished by low altitude launch, where errors arising from wind drift are minimized. High altitude launch of sonobuoys can be feasible only if a measure of placement accuracy can be achieved.

To prevent excessive shock to the sonobuoy on water entry, a decelerator or retardation device, usually a parachute, is deployed directly after launch. Rotochutes, once widely used, have been replaced largely by parachutes and are not addressed. The parachute slows the descent of the buoy to an acceptable terminal velocity, and it assures that the sonobuoy impacts the water surface end-on with a small angle between the sonobuoy axis and vertical. The one deleterious effect of the parachute is to allow the sonobuoy to drift horizontally with the wind during air descent. The magnitude of this drift is dependent upon the altitude of launch as well as the wind speed; drift being greater the longer the sonobuoy is airborne. Since the profile of wind speed and direction varies with the altitude is not normally known, the wind drift of the buoy results in an error in its location.

The purpose of this investigation was to determine what errors can be expected to occur in high altitude sonobuoys launched under various wind conditions, to what degree these errors can be reduced through the modification of the decelerator system, and what impact such measures would have upon the sonobuoy. It was also considered appropriate to assess the value of measuring the wind profile within specific limits of error as a means of reducing the sonobuoy drop error. To perform this investigation, a computer program, designated DRIFT, which predicts flight trajectories of parachute retarded stores, was used.

RESULTS

The presence of wind which may vary in magnitude and direction with altitude is a source of significant error in placement of sonobuoys launched from high altitude. When buoys are launched from 1,000 ft, the wind is not an important factor, but as the launch altitude is increased, the effect of the wind becomes more dominant and uncertainty in sonobuoy placement increases because the wind profile is not known. Using a "typical" wind profile and computer simulation of sonobuoy trajectories, it was determined that standard sonobuoys launched at high altitude (e.g., 10,000 to 30,000 ft) have large placement errors (1,500 to 7,500 yd).

Placement errors are reduced by allowing the sonobuoy to "freefall," essentially eliminating the decelerator system (Parachute), the drag of which is the principal cause of the buoy being misplaced by the wind. However, eliminating the decelerator would result in the buoy impacting the ocean with a velocity (250-550 ft/s) far in excess of present sonobuoy structural design, undoubtedly damaging the sonobuoy structure and internal components. Without redesigning the mechanical structure and components, a reasonable compromise is to delay the decelerator deployment until an altitude of 1,000 ft is attained. The water entry velocity is reduced to an acceptable level (95 to 140 ft/s) and wind drift is considerably reduced. This procedure does reduce the placement error from 10,000 ft to fairly small values (300-600 yd) and reduce the error for a 30,000-ft altitude launch to moderate values (1,100 to 2,100 yd).

Placement errors may be further reduced if the wind profile is defined by an aircraft-launched instrument to measure wind (as by a wind dropsponde) and the trajectory of the sonobuoy computed in the aircraft. In this case, the placement error is a function of the accuracy of measurement, the accuracy of the computer program used to generate the trajectory, and the variability of the wind between the time of measurement and the actual sonobuoy drop. If the errors listed above are, for example, within ± 15% and ±15 deg, improvements in placement accuracy can be achieved, even from 30,000-ft altitudes, especially if the measurement/computation is combined with a delay in decelerator deployment.

CONCLUSIONS

1. High altitude launch of ASW sonobuoys can be achieved with placement errors of 300 to 600 yd from approximately 10,000 ft above sea level if decelerator deployment is delayed until the buoy reaches an altitude of 1,000 ft.

2. High altitude launch of sonobuoys from altitudes up to 30,000 ft with small placement errors are achievable only if the wind profile is measured, the sonobuoy trajectory is calculated, and the decelerator deployment is delayed until the sonobuoy reaches a low altitude (e.g., 1,000 ft).

RECOMMENDATIONS

1. The aeromechanical requirements and the cost of delaying decelerator deployment to approximately 1,000 ft altitude for a high altitude launch sonobuoy should be determined. This would include consideration of a staging device, a stabilizing streamer, strengthened parachute design for increased shock load, and helicopter launch compatibility.

2. The delayed decelerator approach should be compared with the concept of a freefall sonobuoy, which would not require a staging device or strengthened parachute, but would require structural redesign of the sonobuoy, shock protection for internal components, and a built-in stabilizer.

3. A wind dropsonde compatible with ASW aircraft should be considered as an aid to the TACCO, permitting update of the aircraft computer in determining placement of sonobuoys launched from high altitudes.

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DISCUSSION

The trajectory a sonobuoy describes when launched from an ASW aircraft is dependent upon a number of parameters, and to determine the location of the splash point of the sonobuoy with respect to the launch point, requires knowledge of the following:

- aircraft speed and heading,
- launch altitude,
- sonobuoy weight and drag area,
- decelerator drag area,
- time or altitude of decelerator deployment,
- launcher ejection energy and direction, and
- wind speed and direction as a function of altitude.

The computer program DRIFT is capable of utilizing this information to calculate the trajectory and splash point of the sonobuoy and has been used in the past [1,2] in the design of decelerator systems for sonobuoys.

In USN ASW fixed-wing aircraft, A-size sonobuoys are launched typically from the external launch tubes on the underside of the airplane. These launch tubes are oriented to launch the sonobuoys at an angle aft of vertically downward, as shown in figure 1. The P-3 A/B aircraft have pneumatic and freefall tubes at 45 deg, the P-3C has Cartridge Activated Device (CAD) and freefall tubes at 45 deg, and the S-3A has CAD launch tubes at 40 deg from vertical. The difference between the two angles of launch as they affect the horizontal launch velocity is shown in figure 2. The launch energy imparted by the CAD is 800 ft-lb. The kinetic energy resulting is found from

$$1/2\ \frac{W}{g}\ V^2 = E$$

where W is the weight of the sonobuoy, g is the gravitational acceleration, V is the velocity of launch, and E is the CAD-imparted potential energy. The horizontal component of the velocity is subtracted, in effect, from the aircraft speed in determining the initial horizontal velocity of the sonobuoy at launch. Because of the small difference (approximately 2 kn) between the launch velocities from the two different launch angles, the 45 deg launch from P-3 aircraft was used throughout the analysis. Helicopter launch was not addressed because of limitations upon helicopter operation at high altitude, i.e., no pressurization capability, limited avionics, fuel consumption, etc.

Once launched from the aircraft, a typical sonobuoy describes a trajectory as shown in figure 3. The down range, or distance from the launch point to the splash point in the direction of the aircraft heading, and the cross range, or distance from the launch point to the splash point in the direction orthogonal to the aircraft heading, are calculated by the computer program. In straight and level flight and in the absence of wind, there is no cross range component to the trajectory; this case will be considered first.

The vertical descent of the sonobuoy is determined by the gravity and fluid (air) drag forces acting upon it. Initially, the sonobuoy is ejected from the aircraft with a vertical component of velocity. Gravity acts to accelerate the descent while the drag resulting from air resistance acts to oppose acceleration. Once in the airstream, a wind flap initiates decelerator deployment. After a brief time, nominally 1 second, the parachute is fully deployed and increased drag causes the buoy descent to slow. A balance between the gravitational and drag forces is attained:

$$W = \rho/2\ C_D A\ V^2$$

where W is the weight of the sonobuoy, ρ is the density of air, C_D is the drag coefficient of the parachute system, A is the area of the parachute exposed to the air flow, and V is the velocity of descent. The descent velocity is found to be:

$$V = \sqrt{\frac{2\ W}{\rho\ C_D A}}\ .$$

It is customary to define the ballistic coefficient as:

$$\beta = \frac{W}{C_D A}$$

$$V = \sqrt{\frac{2\beta}{\rho}}\ .$$

If the sonobuoy is launched at high enough altitude for an equilibrium condition to be reached, this terminal velocity is the water entry velocity, as shown in figure 4. During descent, the velocity of the buoy typically increases to a maximum and then decreases slowly and becomes nearly constant. The results, shown in figure 4, indicate that when the buoy is launched from 1000 ft altitude, it is still accelerating when it impacts the water surface, except for low values of β where the drag area is sufficient to slow the descent rapidly.

The time of descent as a function of β and altitude is shown in figure 5. Low values of β significantly increase the time for the buoy to descend from high altitude, but they do not have an appreciable effect upon a low altitude descent. Sonobuoys presently have ballistic coefficients between 10 and 20 with cross parachute decelerators, as shown in table I. If no decelerator were used, much larger ballistic coefficients, shown in table II, would result and descent time would decrease. Figure 6 shows the effect of delaying the decelerator deployment on water entry velocity for high and low altitude launch of the AN/SSQ-53A sonobuoy, as a typical case. The descent time can be minimized and reasonable values of water entry velocity can be retained for high altitude launch of sonobuoys if the parachute is deployed at an altitude between 500 and 1000 ft above the water surface. This could be accomplished with an aneroid barometer device actuating the parachute deployment; however, a small stabilizing parachute or streamer to orient the sonobuoy prior to deploying the main parachute and a strengthened parachute design to sustain higher opening shock loads would be required.

THE EFFECT OF WIND

Without the presence of wind, the splash point of a sonobuoy could be calculated with small errors independent of the launch altitude. However, an unknown wind causes an increase in the possible error; the higher the altitude of launch, the larger the error. In order to assess the magnitude of this error, a typical wind profile[2], shown as the winter-spring profile in figure 7, was used. The profile is a two-dimensional profile with all wind vectors acting in one plane. To separate the effect of the sonobuoy ballistics from aircraft launch in calm air from the effect of the wind, the wind in figure 7 was applied as a crosswind, i.e., at 90 deg to the aircraft heading.

Down range, for the crosswind situation, is dependent upon the ballistic coefficient of the sonobuoy and decelerator, the aircraft launch speed, and the altitude, as shown in figure 8. In all cases, there was a 1-second delay in decelerator deployment. A small range variation (approximately 1 percent does occur for different weight buoys with the same ballistic coefficient and launch conditions because of the vertical component of the ejection velocity.

The cross range resulting from the wind profile acting at 90 deg to the aircraft heading is shown in figure 9. Small range variations (less than 3 percent) occur for different weight buoys with the same ballistic coefficient and for different aircraft speeds at the time of launch. The uncertainties in splash points for a sonobuoy launched at various altitudes for a typical wind profile, the direction of which is not known, are shown in figure 10. This demonstrates the dramatic increase in uncertainty associated with high altitude launch compared with low altitude (1000 ft) launch as a result of exposing a relatively large drag area (C_DA) to the wind for a relatively long time (see figure 5). The exposure time, or descent time, can be decreased by increasing β. The ballistic coefficient ($\beta = \frac{W}{C_DA}$) can be increased by increased weight or decreased C_DA; however, since the sonobuoy is weight limited, the only viable way to increase β is to decrease the size of the decelerator. Unfortunately, a larger β also results in an increased water entry velocity, (see figure 4) which may require a structural redesign of the sonobuoy to survive the impact of water entry.

An alternative to decreasing the size of the decelerator is to delay the deployment until the sonobuoy is at a lower altitude. Acceptable water entry velocities can be obtained (see figure 6) and the wind drift can be reduced. Figure 11 shows the AN/SSQ-53A sonobuoy (β = 15.5) with a delayed decelerator deployment in the typical crosswind profile. The cross range due to wind drift is reduced if the decelerator deployment is delayed until the sonobuoy is at a lower altitude. Figure 12 shows the reduction of the uncertainty area of 113 kyd^2 for a 30,000-ft altitude launch of the sonobuoy with immediate decelerator deployment to an uncertainty area of 9 kyd^2 for the same sonobuoy launch, but with a delay in decelerator deployment until the buoy is at 1000 ft. Table III compares the splash point uncertainties for three types of sonobuoys launched from various altitudes when the decelerator is deployed immediately or delayed until 1000-ft altitude. The AN/SSQ-41B and AN/SSQ-53A have similar characteristics, and the deployed decelerator deployment reduces the range uncertainty by 70 percent to 72 percent of the undelayed deployment range, and the area uncertainty by 90 percent to 92 percent of the corresponding undeployed deployment are uncertainty. The AN/SSQ-62 with a higher ballistic coefficient table II) shows an even more significant reduction in splash error.

Because of the sparcity of open ocean three-dimensional wind profiles, the two-dimensional typical profile has been used as a standard throughout this analysis. However, it is instructive to consider the three-dimensional wind profile from the perspective of a real world example. For this purpose, a three-dimensional wind profile obtained at Wallops Island, as shown in figure 13, is used. The sonobuoy is now subjected to a wind which varies in both speed and direction with altitude and the effect of the wind is determined by varying the aircraft heading, as in figure 14. The AN/SSQ-41B launched at 30,000 ft from a 290-kn aircraft in the Wallops profile has an uncertainty radius of approximately 1767 yd, or an area of uncertainty of 9.8 kyd^2. In the typical wind profile, the same sonobuoy would have a splash point uncertainty of 7400 yd radius, or 172 kyd^2 area (as in table III). Since the wind profile is not known when the sonobuoy is launched, no assessment of splash point accuracy can be made in the aircraft at high altitude except in the broadest terms available, such as a rule of thumb based on the typical wind profile.

If the instrumentation to measure the wind as a function of altitude (e.g., a wind dropsonde) were available, a reduction of uncertainty would result in a significantly enhanced capability to make high altitude sonobuoy launches for localization. Presently, meteorological wind dropsondes are not compatible with ASW aircraft, and dropsondes usable by ASW aircraft do not measure wind. A development would be required to provide ASW aircraft with such a wind measuring device.

Using the Wallops profile as representing a true wind profile, the splash point for an AN/SSQ-41B sonobuoy launched from a 290-kn aircraft at various altitudes was calculated using the DRIFT program. Splash points were also calculated assuming a measured profile which was allowed to vary by ±15 percent in magnitude and by ±15 deg in direction to simulate measurement system inaccuracies and short term variations in the wind itself. Figure 15 shows the maximum splash error (radius) from the DRIFT-calculated point of water entry as a function of launch altitude for the best possible case (without a decelerator) and the worst case (with the decelerator deployed immediately upon launch). The reduction in error obtained by delaying the decelerator deployment in the typical wind profile is also observed in the Wallops profile. Table IV summarizes the various uncertainties for an AN/SSQ-41B sonobuoy launched at 290 kn at 30,000 ft for both the typical wind profile and the Wallops profile. In either case, the use of a wind measuring device, which could provide wind speed and direction with altitude to the aircraft's onboard computer, would significantly reduce the uncertainty in sonobuoy location.

The radius of uncertainty for the AN/SSQ-41B sonbuoy launched in a typical wind profile from a 290-kn aircraft at various altitudes is shown in figure 16, where comparison is made among a standard sonobuoy with decelerator, one in which the decelerator deployment is delayed, one with the standard decelerator where the wind is known to ±15 percent, and one with delayed decelerator deployment with the wind known to ±15 percent. The requirements for accuracy of placement for sonobuoys are determined by various factors, depending upon the scenario under consideration and the quantity of buoys available. If a particular radius of uncertainty were required, a sonobuoy could be launched from low altitude without modification or at a higher altitude if the decelerator deployment is delayed until the buoy has descended to 1,000 ft. If the wind were measured, these launch altitudes might be increased even higher.

TABLE I. Typical Sonobuoy Ballistic Coefficients

Sonobuoy	Weight (lb)	Decelerator C_DA (ft^2)	$\beta = \frac{W}{C_DA}$
AN/SSQ-41B	16.1	1.37	10.74
AN/SSQ-53A	23.25	1.37	15.50
AN/SSQ-62	39.0	2.37	15.64

TABLE II. Freefall Sonobuoy Ballistic Coefficients

Sonobuoy	Weight (lb)	Decelerator C_DA (ft^2)	$\beta = \frac{W}{C_DA}$ without Decelerator
AN/SSQ-41B	16.1	0.1296	124.2
AN/SSQ-53A	23.25	0.1296	179.4
AN/SSQ-62	39.0	0.1296	300.9

TABLE III. Comparison of Sonobuoy Splash Point Uncertainty in the Typical Wind Profile

Sonobuoy	Launch Altitude (ft)	Decelerator Deployment At Launch Altitude Uncertainty Radius (yd)	Decelerator Deployment At Launch Altitude Uncertainty Area (kyd^2)	Decelerator Deployment At 1000-ft altitude Uncertainty Radius (yd)	Decelerator Deployment At 1000-ft altitude Uncertainty Area (kyd^2)
AN/SSQ-41B	1,000	110	0.038	110	0.038
	10,000	1867	10.951	576	1.042
	30,000	7400	172.03	2100	13.85
AN/SSQ-53A	1,000	94	0.028	94	0.028
	10,000	1563	7.679	450	0.636
	30,000	6054	115.14	1700	9.08
AN/SSQ-62	1,000	96	0.029	96	0.029
	10,000	1559	7.636	312	0.306
	30,000	6033	114.34	1133	4.03

TABLE IV. Splash Point Uncertainty for the AN/SSQ-41B Sonobuoy Launched at 30,000 ft Altitude in Two Wind Profiles

	Typical Wind Profile Uncertainty		Wallop Profile Uncertainty	
	Radius (yd)	Area (kyd^2)	Radius (yds)	Area (kyd^2)
Normal launch with decelerator	7400	172.03	1767	9.81
Decelerator deployment delayed until low altitude	2100	13.85	504	0.80
Normal launch with decelerator-wind known ±15% ±15°	1099	3.79	533	0.89
Decelerator deployment delayed until low altitude wind known ±15%, ±15	324	0.330	143	0.064

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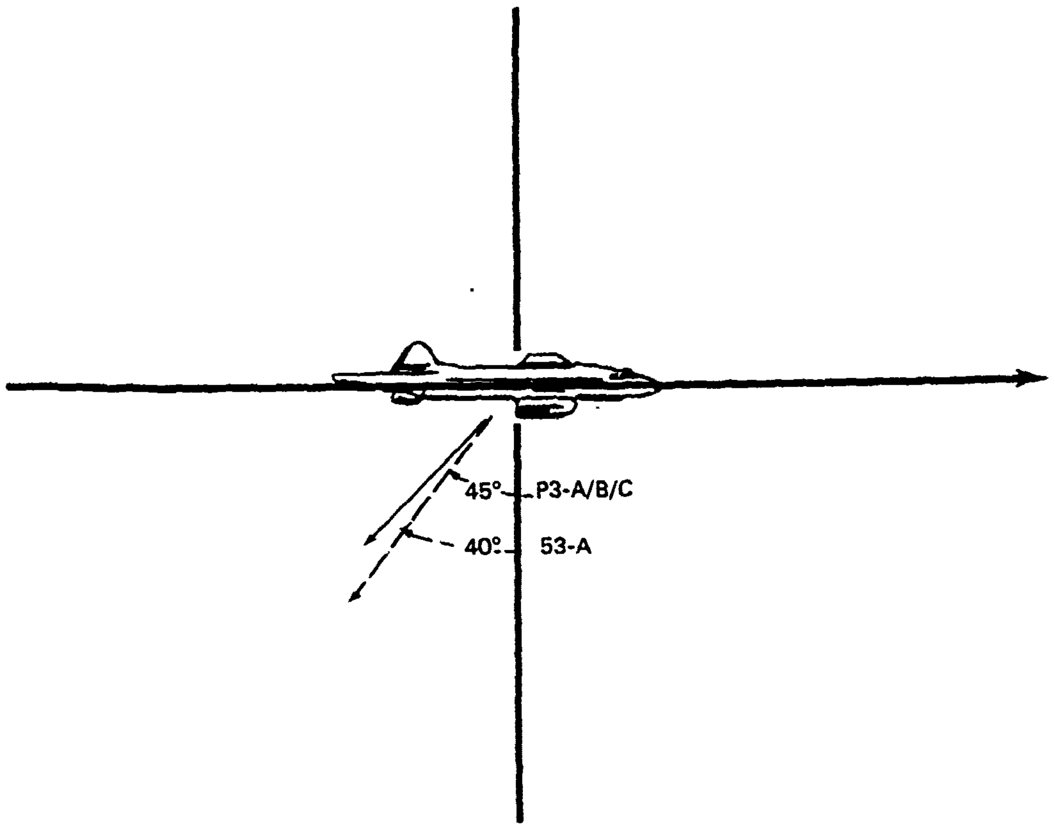

Figure 1 - Sonobuoy Launch from ASW Aircraft
Directed as Angles of 40 and 45 deg Aft of Vertical

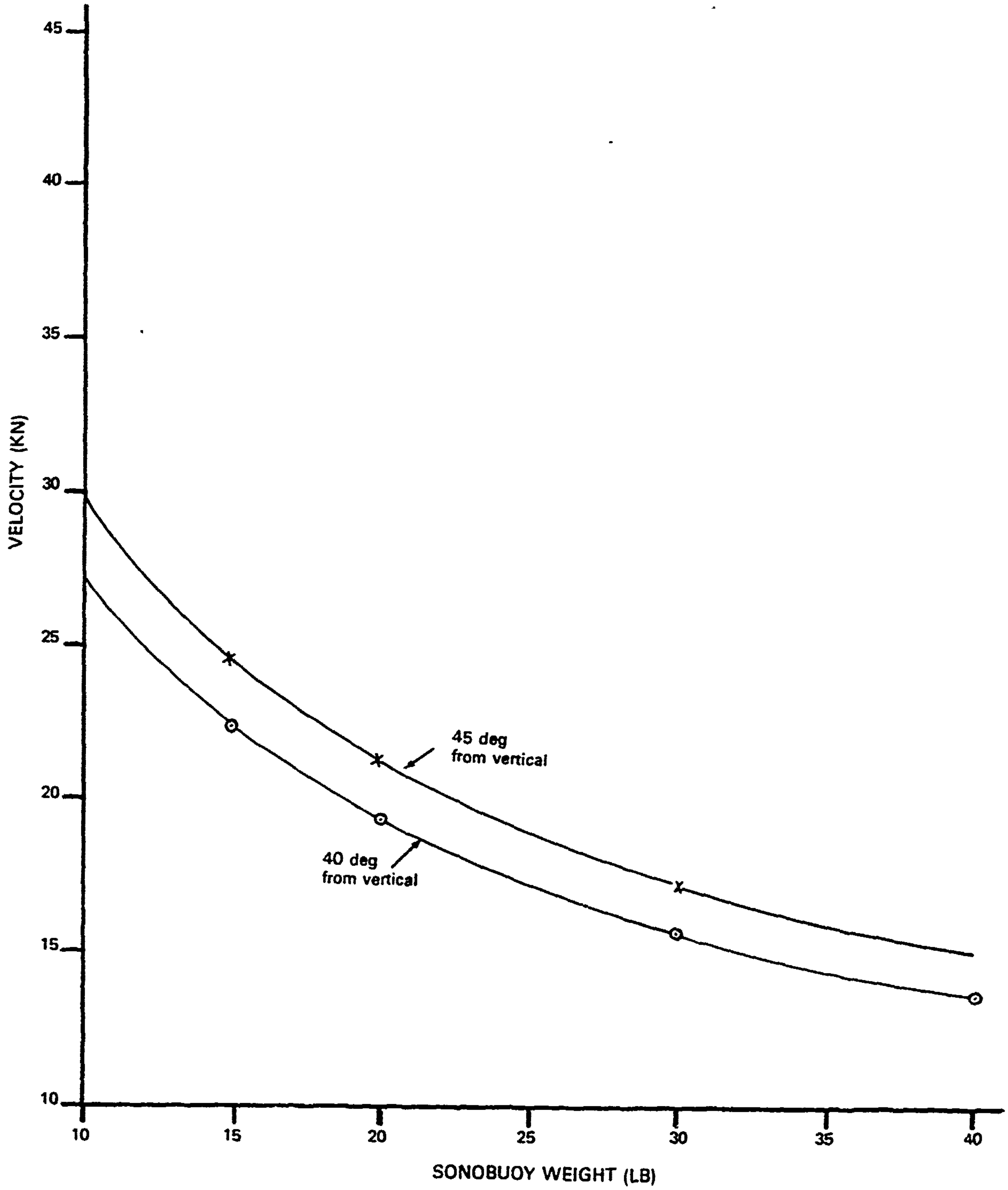

Figure 2 - Horizontal Velocities Directed Aft by the Aircraft CAD Launchers

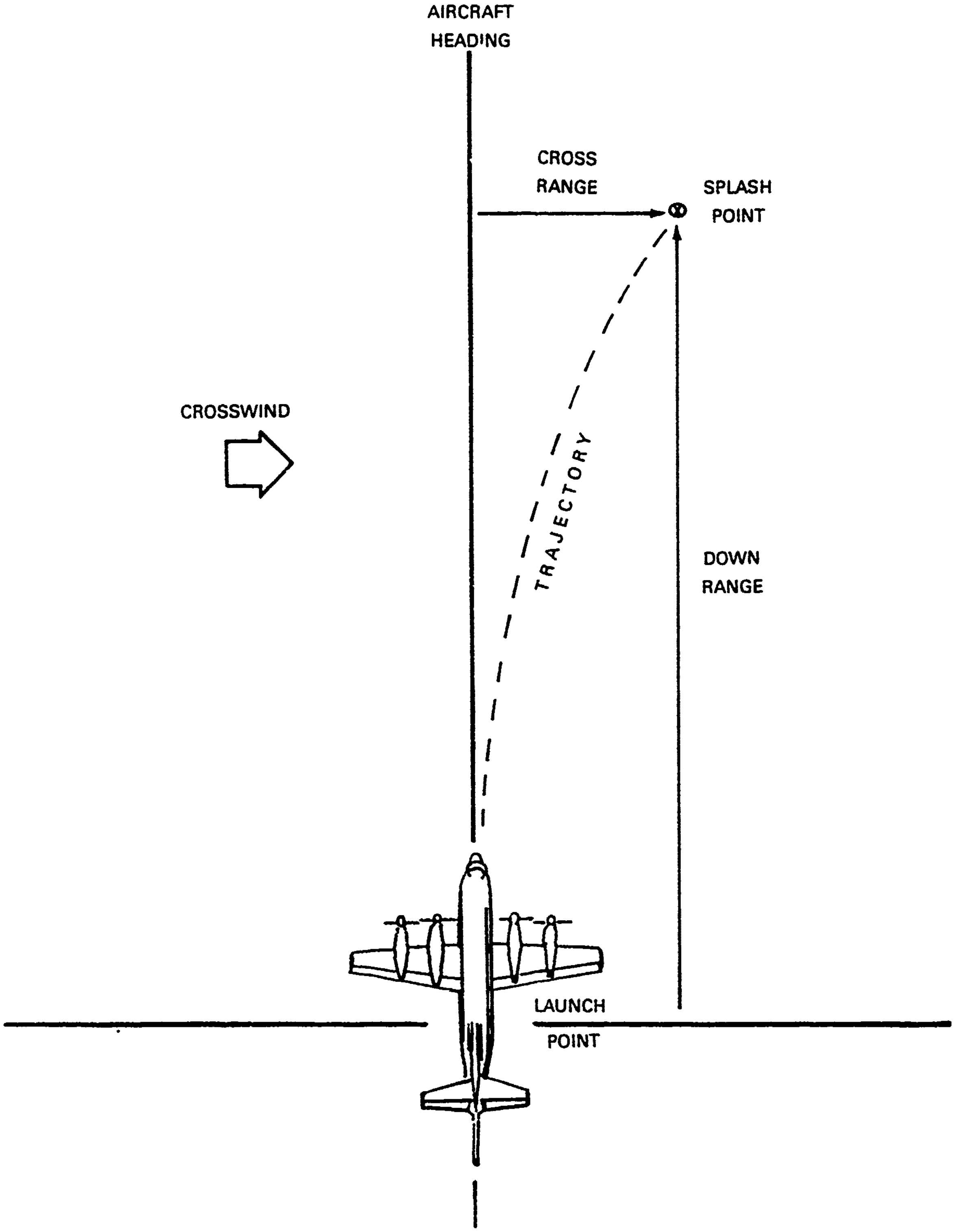

Figure 3 - Splash Point Relative to Point of Launch from Aircraft in a Crosswind

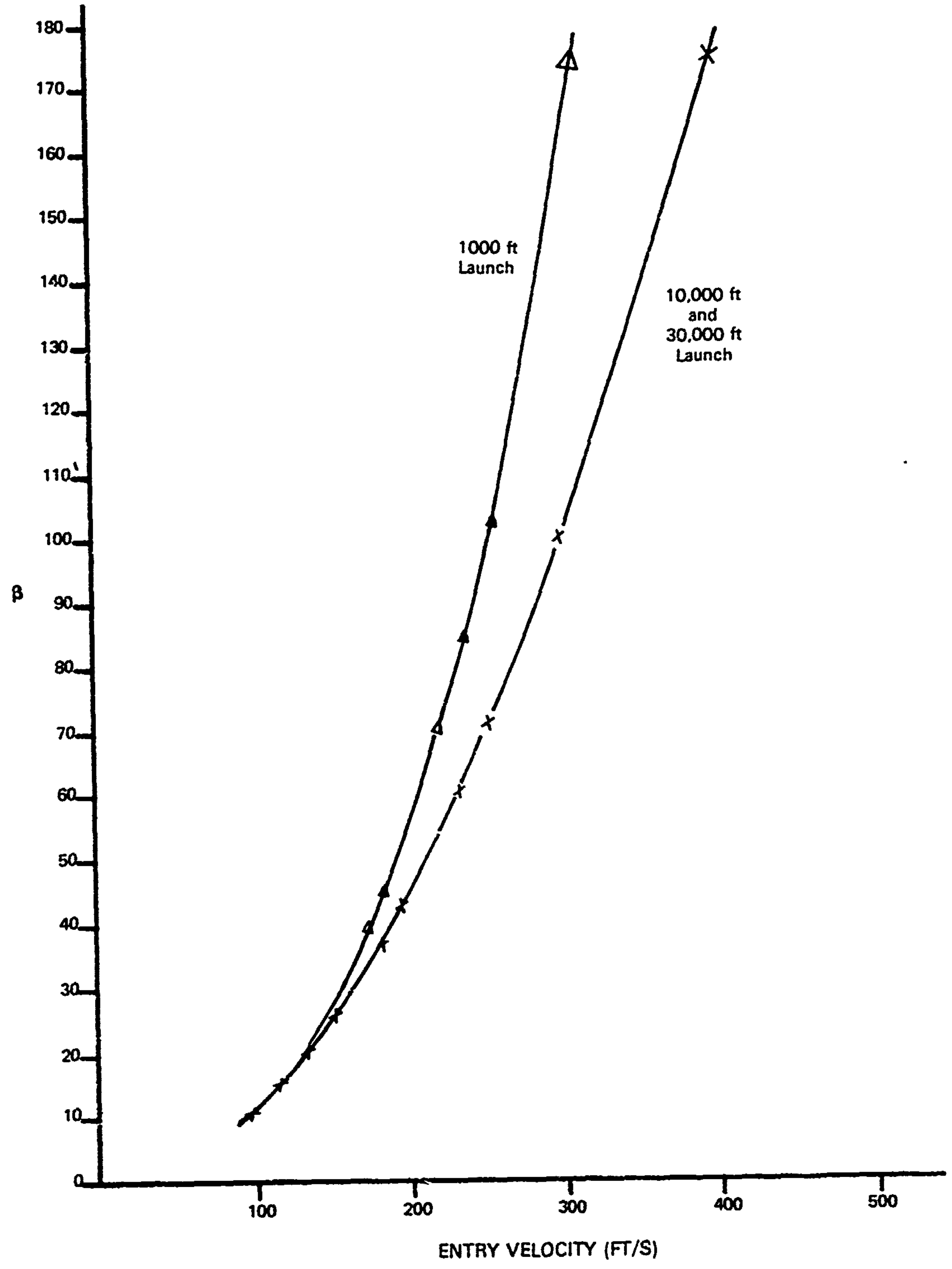

Figure 4 - Water Entry Velocity as a Function of β for One Second Delay of Decelerator Deployment and 200 kn Aircraft Speed at Launch

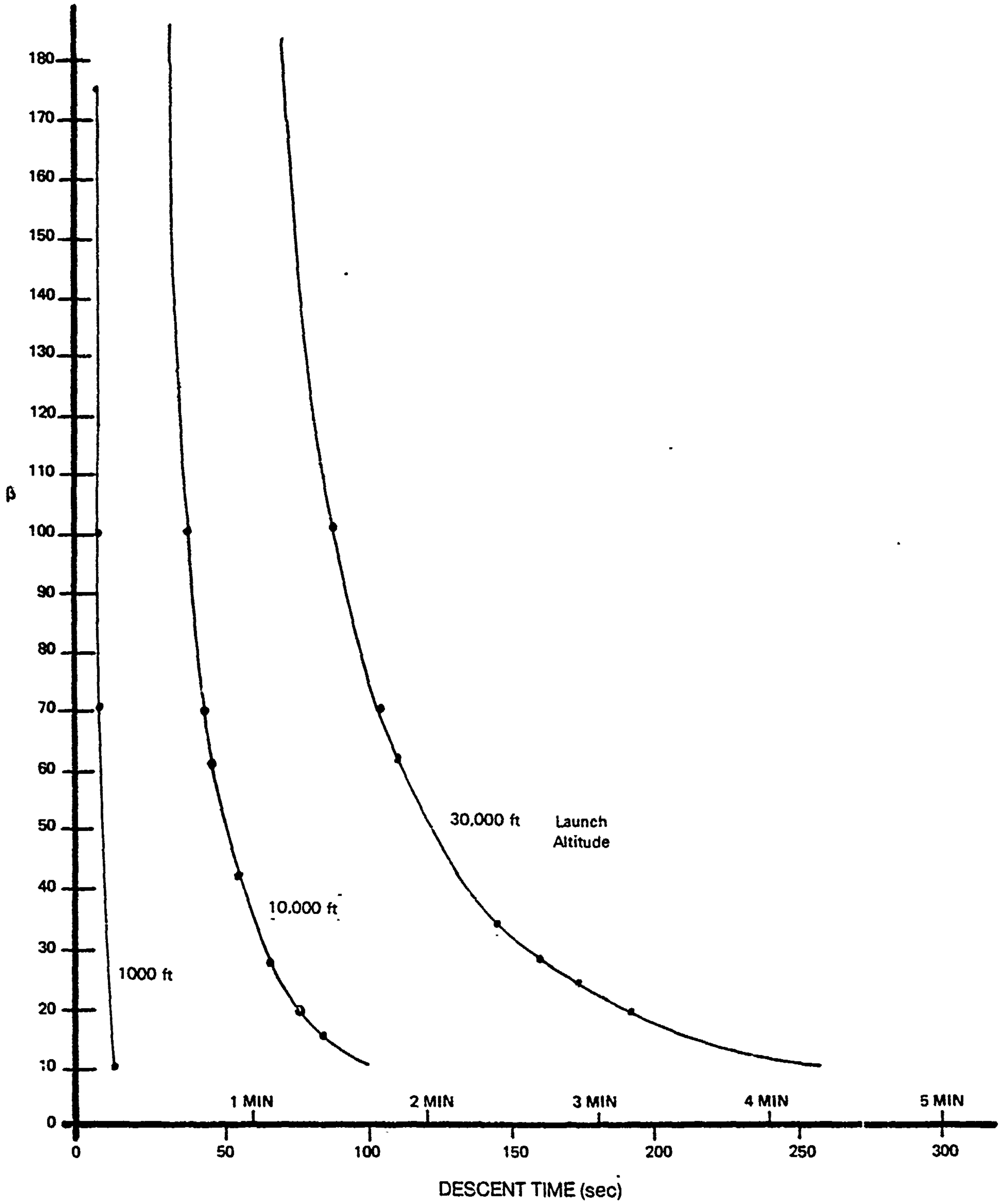

Figure 5 - Descent Time as a Function of $\hat{\beta}$ for One Second Delay of Decelerator Deployment for 290 kn Aircraft Speed at Launch

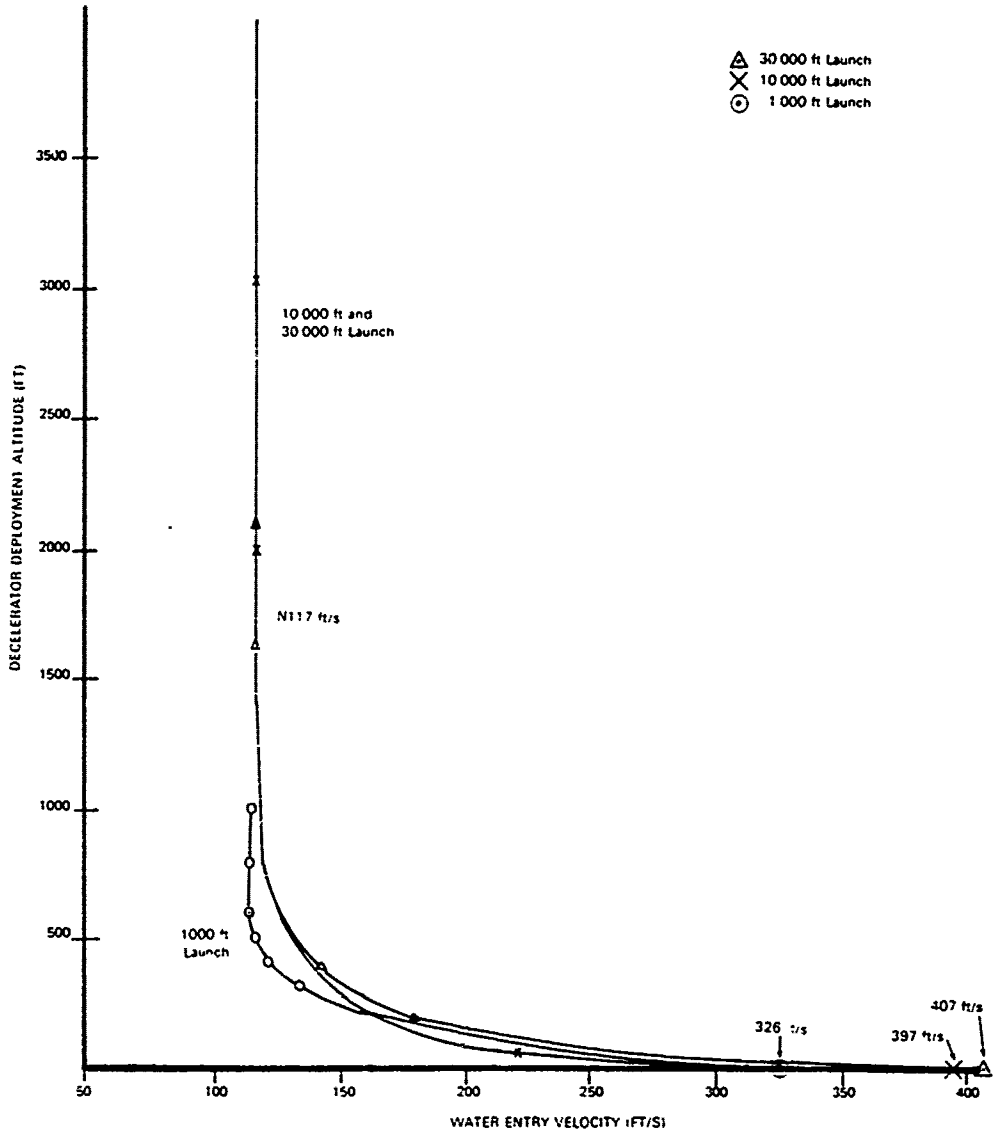

Figure 6 - Water Entry Velocity as a Function of Decelerator Deployment Altitude for the AN/SSQ-53A Sonobuoy Launched from 290 kn Aircraft

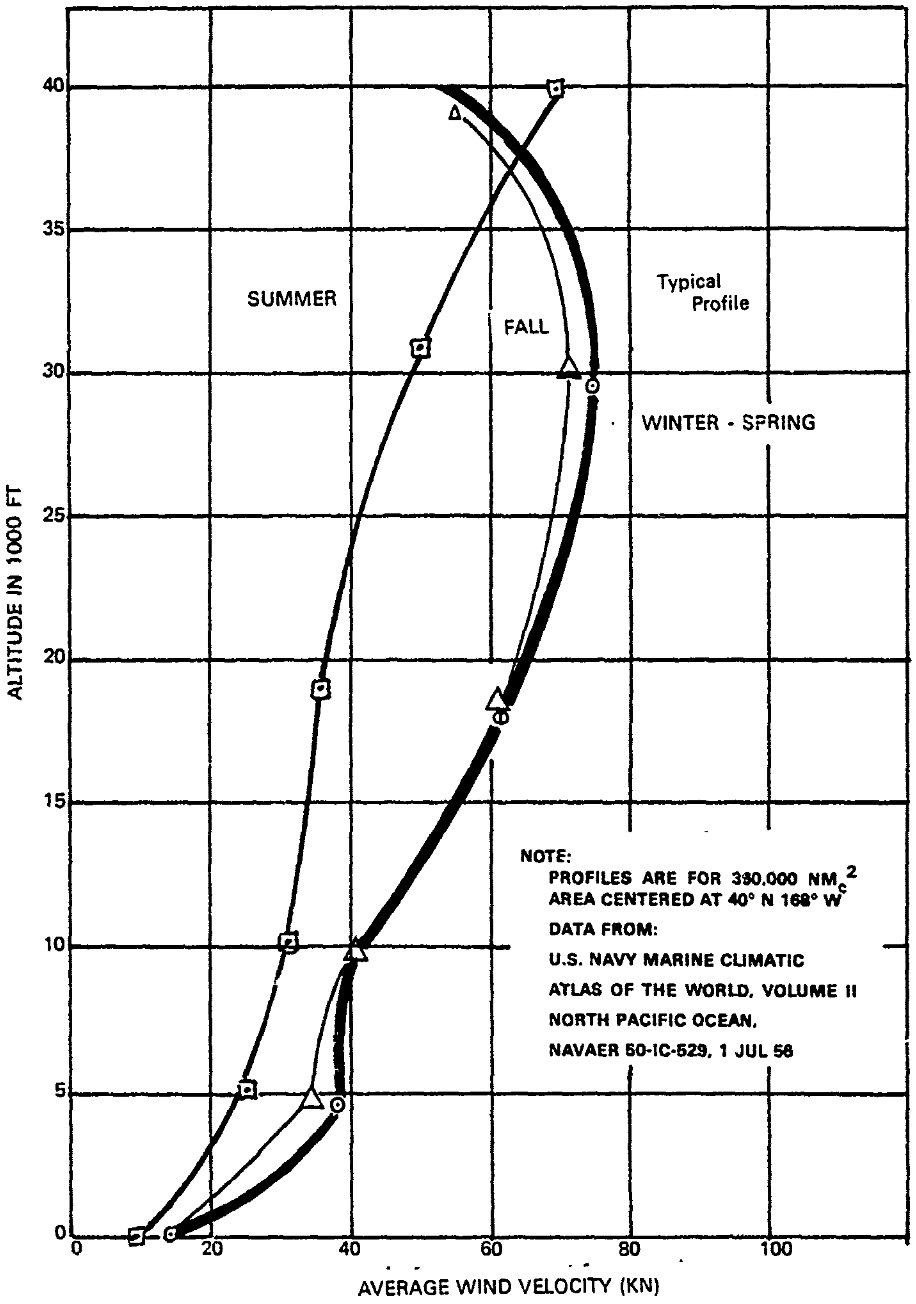

Figure 7 - Wind Profiles

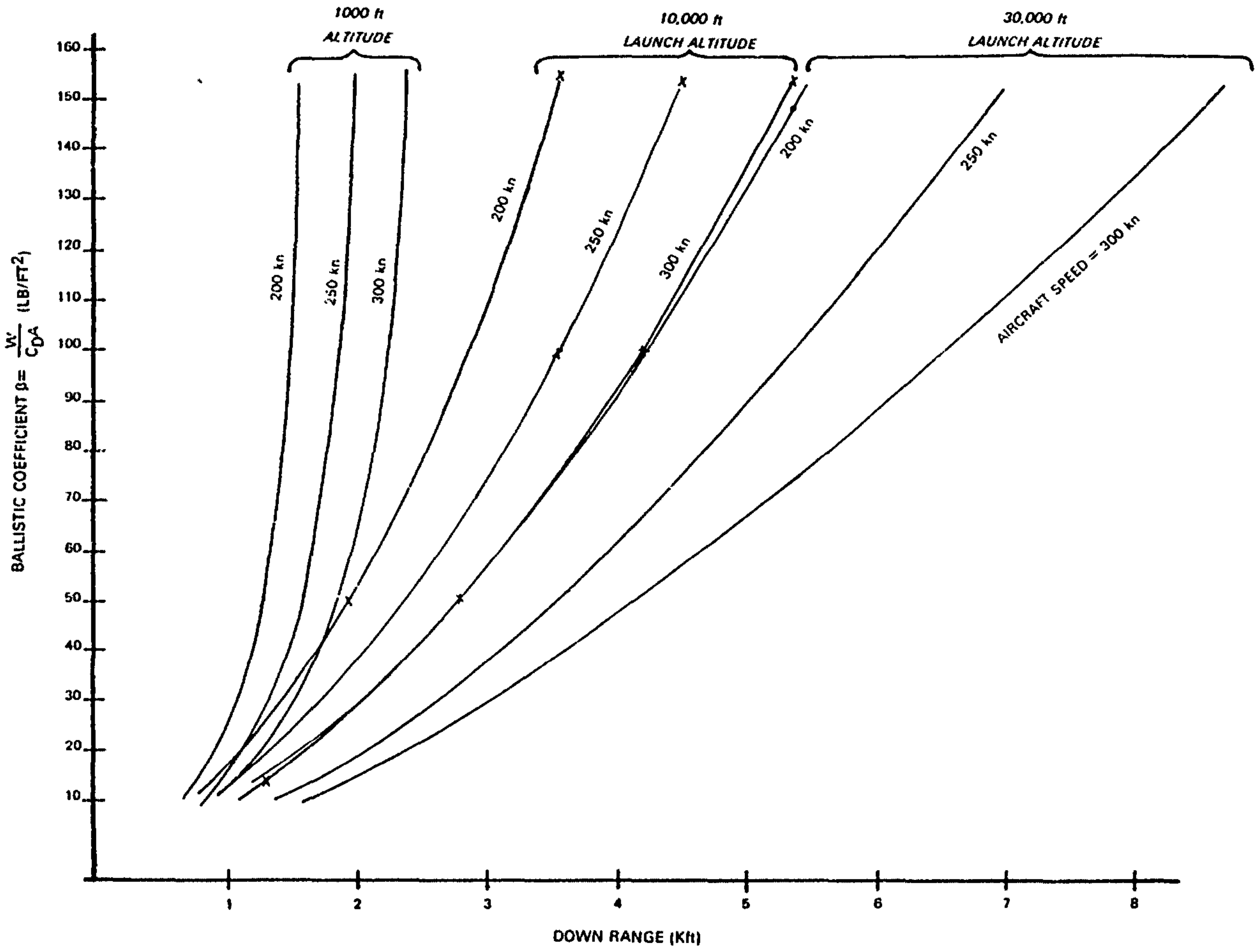

Figure 8 - Down Range as a Function of Ballistic Coefficient, Aircraft Speed, and Launch Altitude, for One Second Delay of Decelerator Deployment

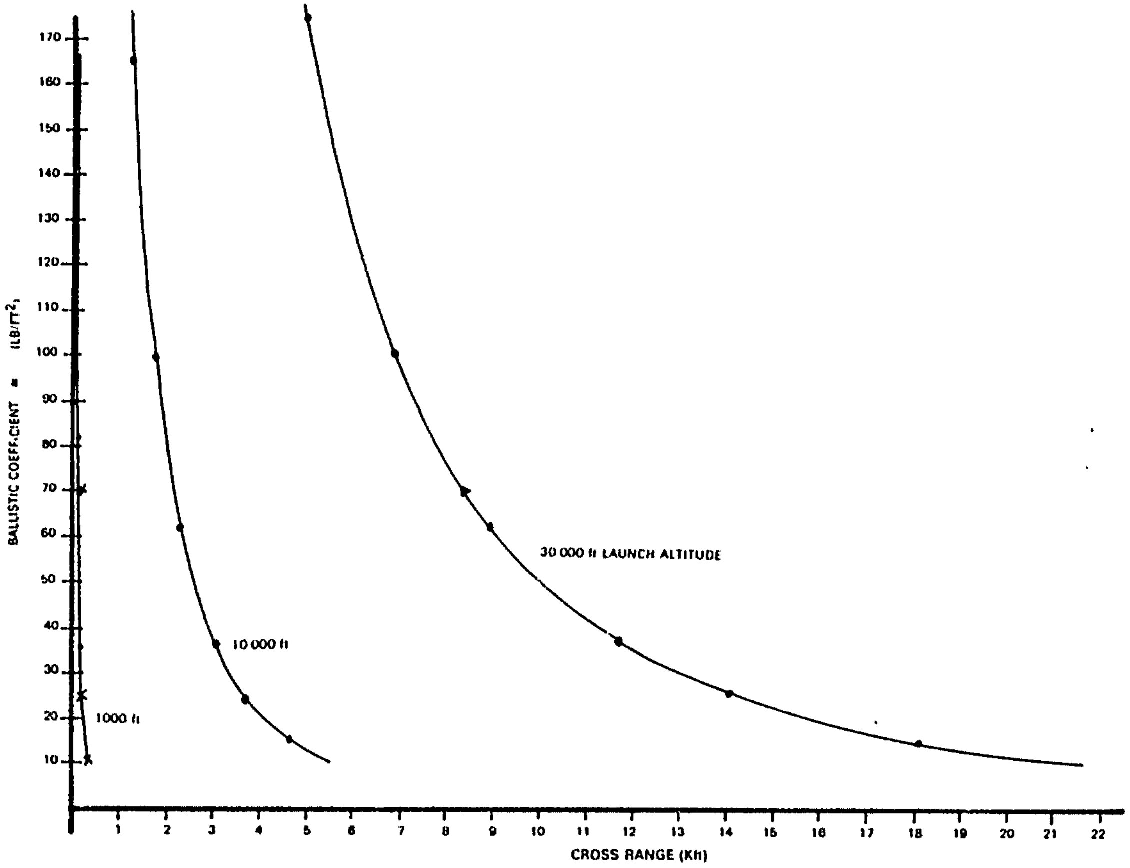

Figure 9 - Cross Range as a Function of Ballistic Coefficient in a Typical Wind Profile Orthogonal to Aircraft Heading, with Aircraft Speed 290 kn and 1 sec Time Delay of Decelerator Deployment

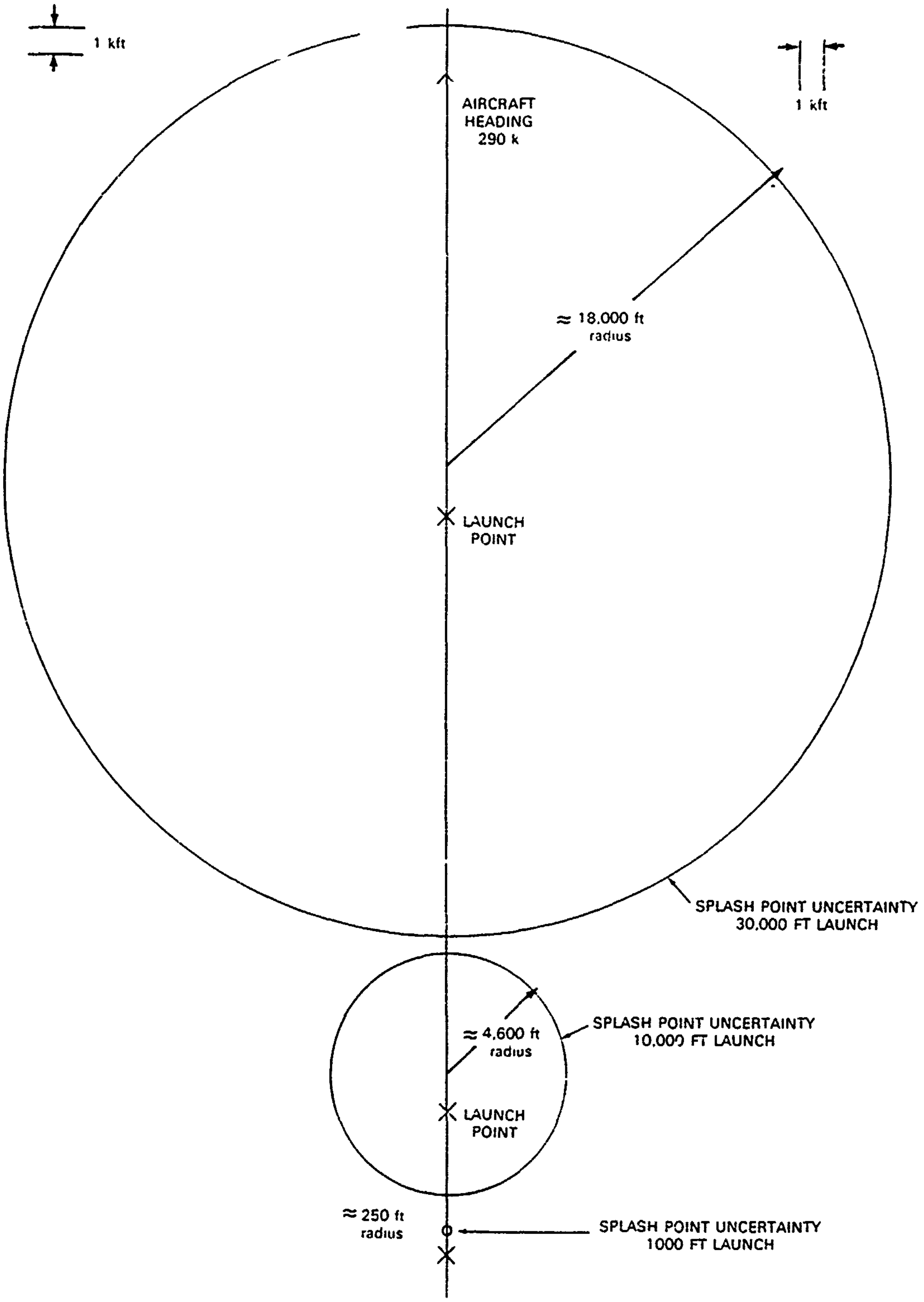

Figure 10 - Comparison of Splash Point Uncertainty for Launch of the AN/SSQ-53A Sonobuoy from a 290 kn Aircraft at Different Altitudes in a Typical Wind Profile

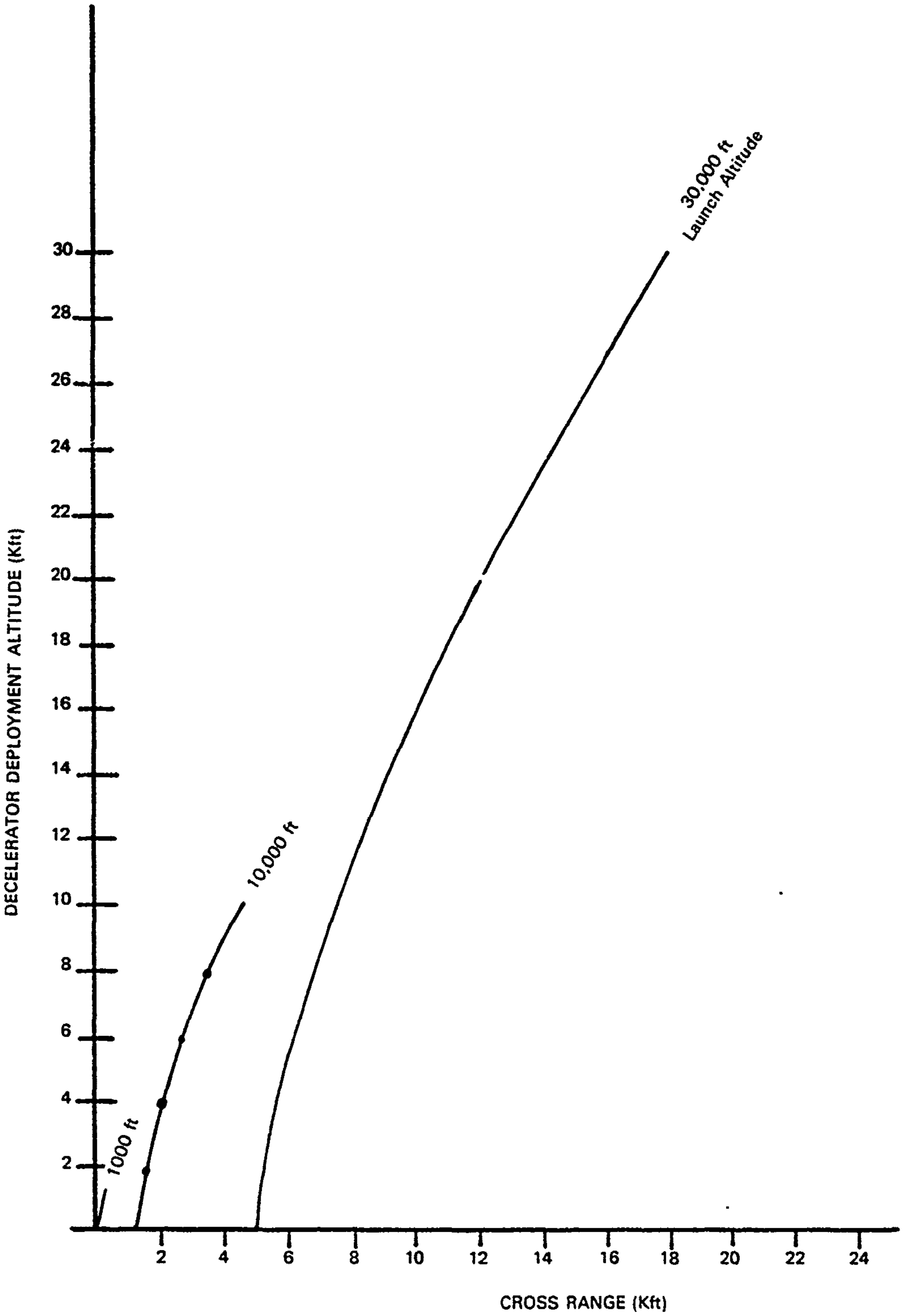

Figure 11 - Cross Range for Various Decelerator Deployment Altitudes for the AN/SSQ-53A Sonobuoy in a Typical Crosswind Profile

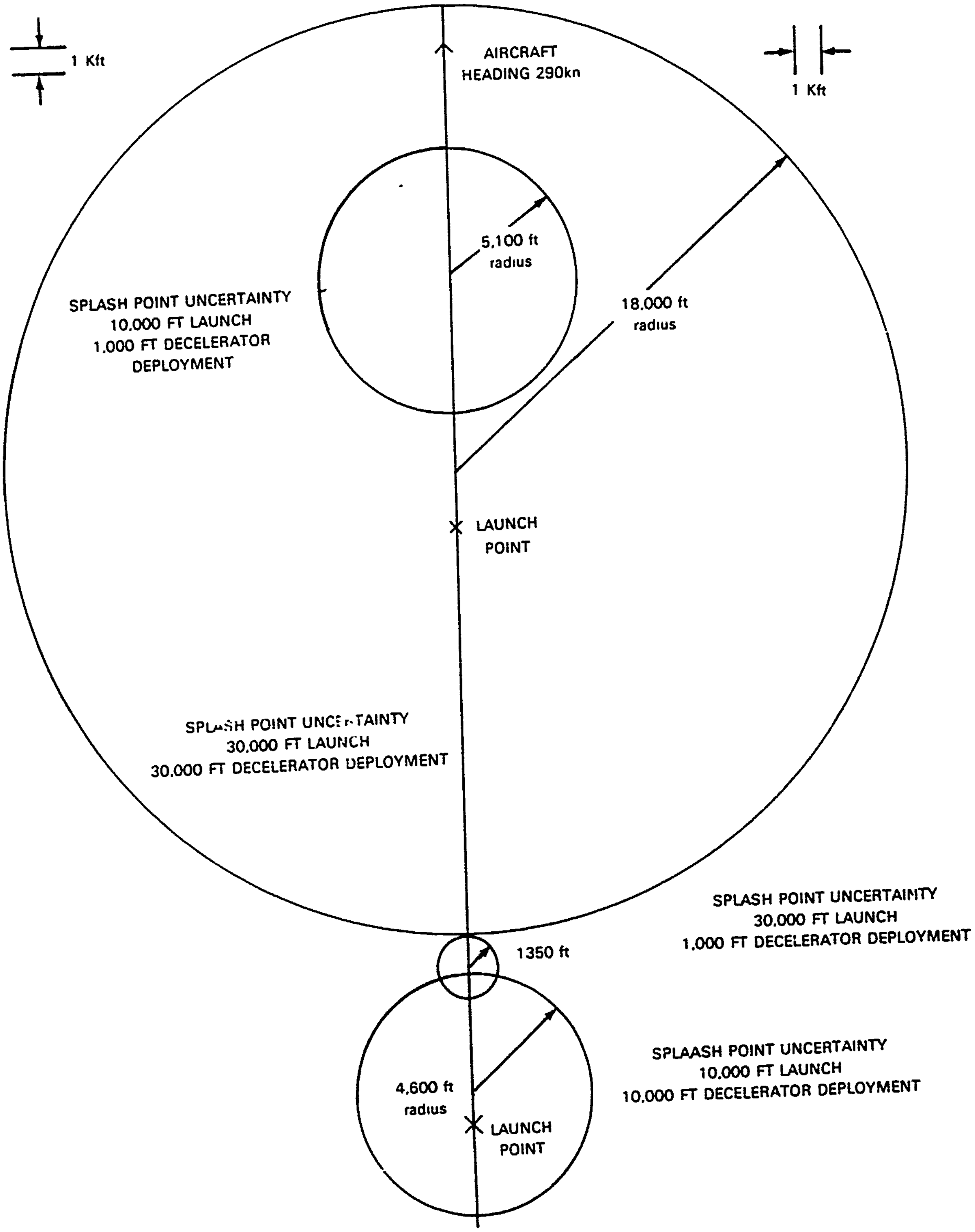

Figure 12 - Comparison of Splash Point Uncertainty for Launch of the AN/SSQ-53A Sonobuoy from a 290 kn Aircraft at Different Altitudes in a Typical Wind Profile with Decelerator Deployment at Launch or at 1000 ft

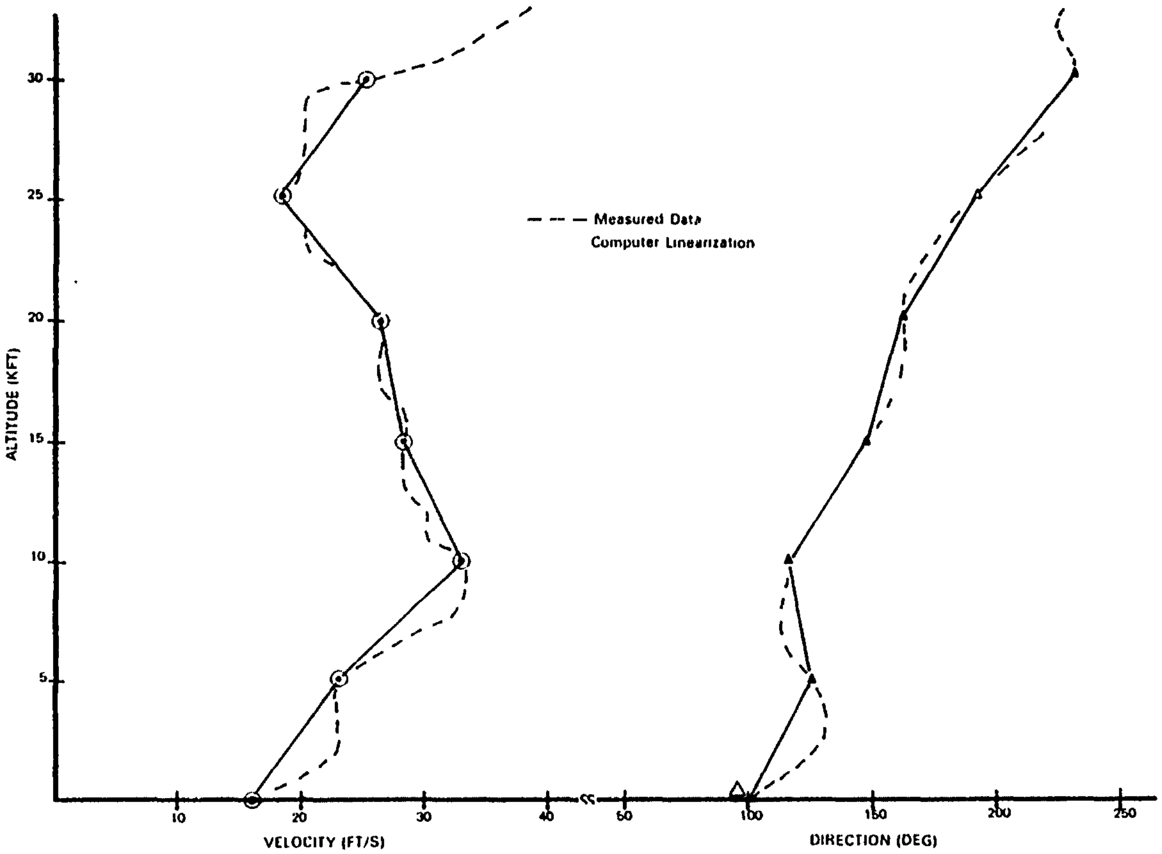

Figure 13 - Three Dimensional Wind Profile Measured at Wallops Island, VA (July 1972)

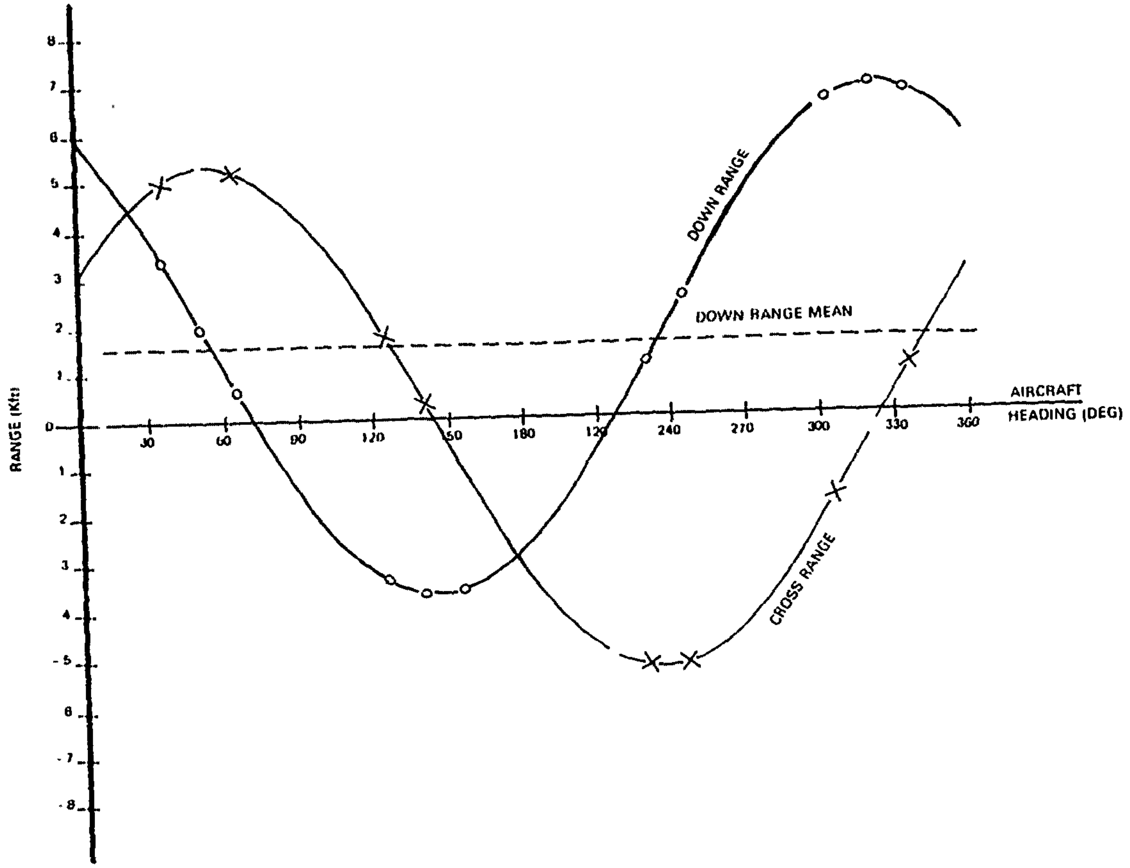

Figure 14 - Cross-range and Down-range for an AN/SSQ-41B Sonobuoy Launched at 30,000 ft Altitude with Immediate Deployment of Decelerator in the Wallops Island Profile

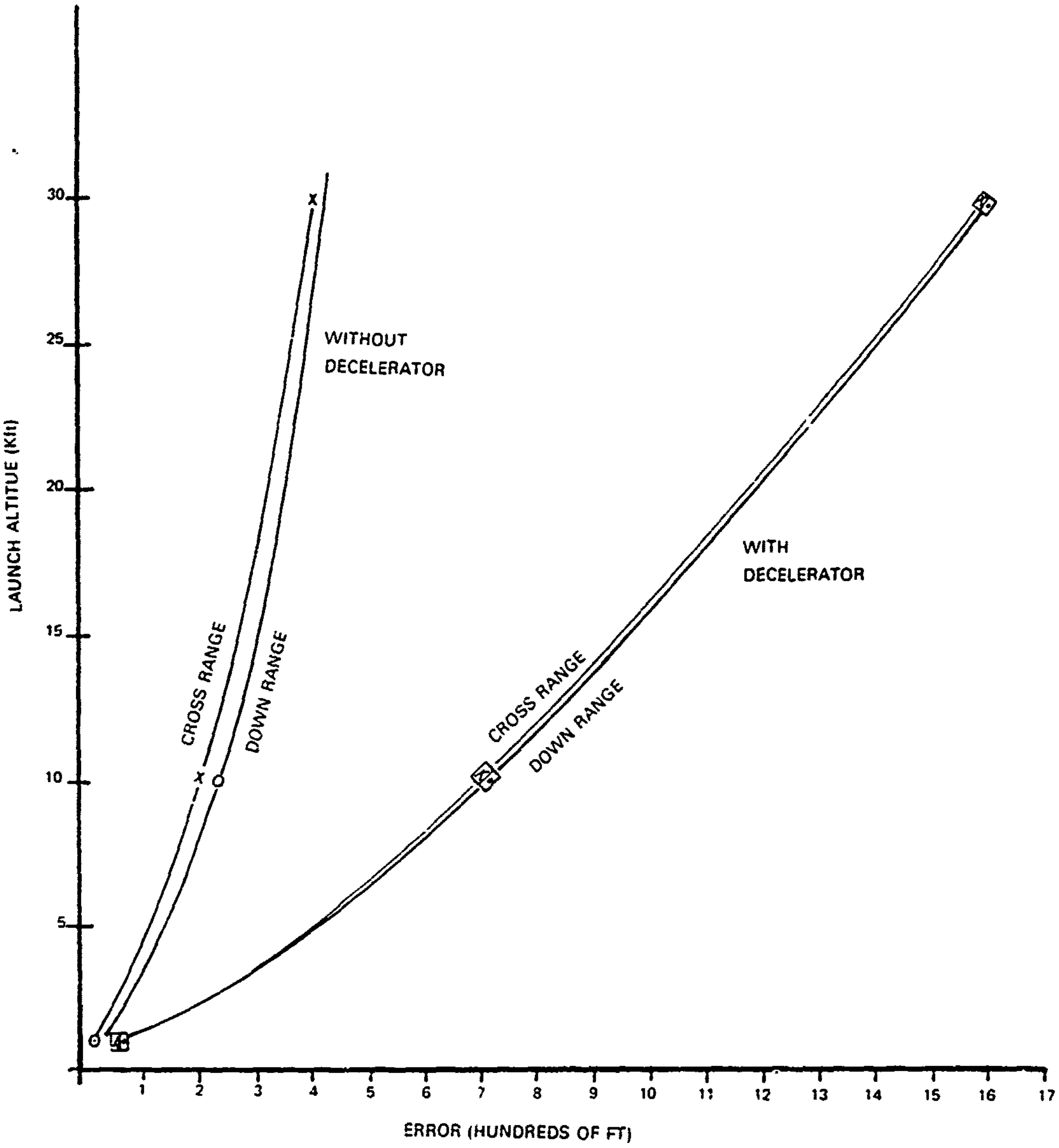

Figure 15 - Maximum Splash Error with Reference to DRITT-computed Splash Points in the Wallops Profile for Wind Velocity Measurement ±15 Percent and Wind Direction Measurement ±15 deg for the AN/SSQ-41B Sonobuoy with and without a Decelerator from Various Launch Altitudes

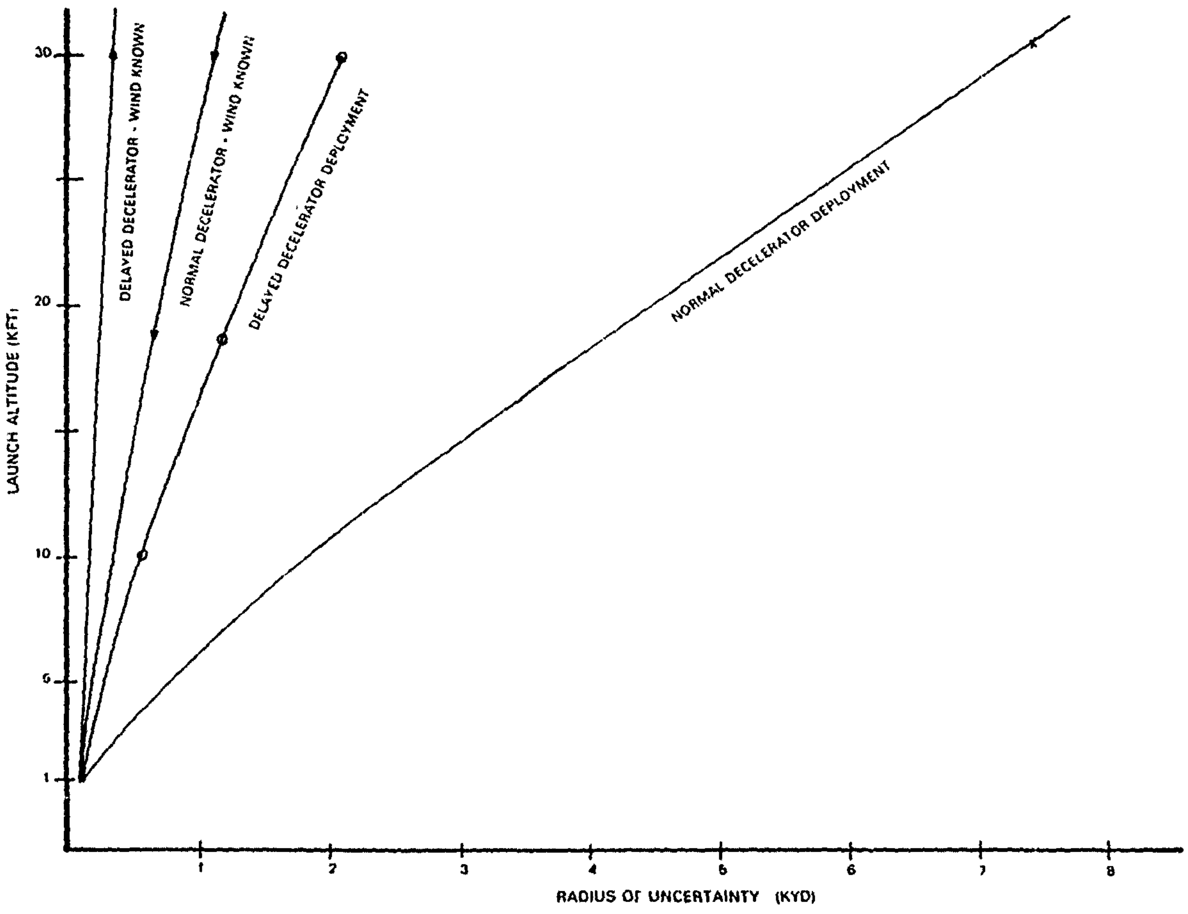

Figure 16 - Splash Point Uncertainty for AN/SSQ-41B Sonobuoy Launched at 290 kn at Various Wind Altitudes in the Typical Wind Profile