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SCTM-238-56-51

THEORETICAL ROTOCHUTE TRAJECTORIES

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W. B. Pepper - 5141

ABSTRACT

Theoretical rotochute trajectories are presented for the vehicle recovery application. Design charts permit the selection of rotor diameter and number of blades required to achieve given terminal conditions.

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Case No. 669.02 (22 pages) November 16, 1956

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THEORETICAL ROTOCHUTE TRAJECTORIES

SUMMARY

The results of the first Kaman wind-tunnel drag measurements were used to calculate theoretical rotochute trajectories in an attempt to determine the proper size and number of blades required to satisfy the specifications made in the Sandia Corporation-Kaman rotochute contract. The operational effects of varying release altitudes were investigated by making calculations for 1000- and 5000-foot mean sea level release altitudes. Rotor diameters of 12, 14, 16, and 20 feet were studied.

It was concluded that the Kaman Aircraft Corporation rotochute drop-test vehicle should be four-bladed and have a diameter of 20 feet. All of the contract specifications except the 200-foot drop altitude may be fulfilled by such a rotochute. The theoretical trajectories indicate that for the case of a 3000-pound vehicle released at Mach number 0.9, and an impact 300 feet below the release altitude of 5000 feet, the range will be 2000 feet, the impact velocity will be 90 feet per second, and the impact angle will be 40 degrees from vertical.

The use of higher rotor speeds, which will be investigated in the third series of wind-tunnel tests, may allow a reduction in the 20-foot blade diameter because of higher drag coefficients anticipated.

INTRODUCTION

Rotochutes are being considered by Sandia Corporation as a means of drag retardation for the recoverable vehicle program. Sandia Corporation is developing a 7.5-foot-diameter fixed-pitch rotochute for vehicle weights of the order of 500 to 1000 pounds. Kaman Aircraft Corporation has a contract with Sandia Corporation to study the application of a governing rotochute to be used for recovery of a 3000-pound test vehicle.

The size of rotochute that would be required to satisfy the Kaman contract specifications has not been evident up to the present time. Results from the Phase I wind-tunnel tests made by Kaman are reported in Reference 1. These results provide a basis for theoretical trajectory studies made in this memorandum.

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ANALYSIS

In the Kaman Aircraft Corporation contract (Reference 1), Sandia Corporation had asked them to meet certain specifications for a recoverable vehicle. These were:

1. Vehicle weight 3000 pounds,
2. Release Mach number 0.9,
3. Release altitude 200 feet (above ground),
4. Impact velocity 130 ft/sec or less, and
5. Trajectory range 2000 to 3000 feet.

The initial constant conditions assumed for the trajectory study were:

1. Vehicle weight 3000 pounds,
2. Release Mach number 0.9,
3. Two release altitudes of 1000 feet and 5000 feet above sea level were used for each trajectory (The NACA standard atmosphere was used for air density.), and
4. Trajectory angle at release was horizontal.

The two variable parameters studied were rotor area and drag coefficient curve shape. Rotor diameters used were 12, 14, 16, and 20 feet. The drag coefficient curves are shown in Figure 1. Curve (e) in Figure 1 is the experimental wind-tunnel result from Reference 2 for a two-bladed governing rotor. Curve (d) represents the effects on drag coefficient of a governor setting which would result in lower speeds of the two-bladed rotor. Curve (f) is estimated to be the characteristic curve for a four-bladed rotor and is 50 per cent greater than (e).* Curve (g) would represent an eight-bladed rotor, having drag coefficients of twice the values for (e). Curves (b) and (h) represent the constant drag coefficient curve for the 12-bladed Sandia Corporation fixed-pitch rotochute as obtained in wind-tunnel tests (Reference 2). Two step conditions of (a) and (c) were considered since experimental values were not known. The seven drag conditions used for theoretical trajectory calculations are listed in Figure 1.

* Wind-tunnel data indicate that drag coefficient varies approximately as the square root of the solidity ratio.

The trajectories were computed by Department 5242 on their Electronic Analog Computer. No consideration of vehicle release and opening cycle was made, since these conditions could be considered constant for all conditions investigated. The blades were assumed to be fully open at zero time.

RESULTS

Typical trajectory information for one condition is shown in Figures 2 through 6. Figure 2 shows the variation of range with altitude above mean sea level. Time marks are also shown. Figure 3 shows the decrease in longitudinal velocity (tangential to flight path) with increasing time. The velocity is lowered about 90 ft/sec when the rotochute goes into the high-drag step condition at 4 seconds. The step condition can be seen in Figure 1 from 0.15 Mach number down to zero. Figure 4 shows the variation in trajectory angle with drop time. The impact time can be found from Figure 2 by assuming a drop altitude extent of 500 feet, for instance, and reading the drop time as 7.5 seconds. The angle at impact or 7.5 seconds is 24 degrees from vertical as seen in Figure 4. The variation of deceleration with time is shown in Figure 5.

The results of the trajectory study are shown in Figures 6 through 10 for a drop of 500 feet. The value of 500 feet was first investigated because 200 feet appeared to be a severe limit. A comparison between 500-, 300-, and 200-foot drops is given in Figures 11 through 13 for the parameters of most interest.

The trajectory angle at impact is the most critical parameter in selecting rotor size and drag condition. At present, the angle is desired to be 40 degrees or less.*

Figure 6 shows that drag conditions 1, 2, and 3, which represent two-bladed rotors, result in impact angles greater than 40 degrees even for the largest diameter of 20 feet that was considered. Condition 4 representing a four-bladed rotor is the minimum drag condition that will give impact angles less than 40 degrees. The rotor diameter should be 18 feet or greater. Possibly the smaller drop altitide extent of 300 feet could be considered for such a four-bladed rotor. This possibility can be evaluated in Figures 11 to 13. Using the Sandia Corporation fixed-pitch rotochute would require a rotor diameter of 13 feet to achieve angles less than 40 degrees. However, Figure 7 shows that the fixed-pitch

* Per G. W. McClure, 5133.

rotor would have to be 15 feet in diameter to result in less than 130-fps impact velocity. The 7.5-foot radius of the blades would be difficult to store behind the test vehicle because of aircraft clearance problems. The solid symbols in Figure 7 show the large values of impact velocity that result when the step condition is never reached by the governing rotochutes. Relaxing the vehicle weight specification to 2500 pounds was considered for the 16-foot-diameter rotochute but the impact velocity was still above 130 fps.

The range specification of 3000 feet or less is not as severe a limit as impact velocity or angle, as may be seen from Figure 8. Maximum decelerations shown in Figure 9 are between 5 and 30 g's for all the governing rotochutes as compared to a range of 30 to 100 g's for the fixed-pitch rotochutes. Drop times are shown in Figure 10 for general reference.

The more desirable drops of 300 and 200 feet are considered in Figures 11 through 13 for drag condition 4, which is the four-bladed governing rotochute. Figures 12 and 13 show that a rotor diameter of 20 feet will be required to achieve impact velocities less than 130 fps and impact angles less than 40 degrees from vertical.* For a drop of 200 feet, the impact angle will be greater than 50 degrees even for the 20-foot-diameter rotochute. Therefore, a 300-foot drop would appear to be a reasonable goal.

The curves presented in this memorandum may be used for different vehicle weights and rotor sizes, since trajectories are identical when the ratio,**

$$\frac{W}{C_D S},$$

is the same for two configurations.

As an example, the maximum vehicle weight can be found which will result in an impact velocity of 130 fps in the case of vehicle release at Mach 0.9 at 5000 feet above sea level. The ground level will be assumed to be 4500 feet so that the drop will be 500 feet. It will also be assumed that the 12-bladed fixed-pitch rotochute 7.5 feet in diameter will be used. From Figure 7, it may be seen that for a 3000-pound weight to

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* Designing the blades to withstand higher rotational speeds will result in higher drag curves than those shown in Figure 1 and will allow a reduction in blade diameter.

** W = Vehicle weight (lb), C_D = Rotor drag coefficient based on S, and S = Disk area of blades fully open (ft^2).

result in an impact velocity of 130 feet per second, the rotor diameter must be 14.7 feet. Therefore,

$$\frac{W_1}{C_{D_1} S_1} = \frac{3000}{.85\left(\frac{\pi(14.7)^2}{4}\right)} = \frac{3000}{.85\ (170)} = 20.8.$$

In order to keep identical trajectories,

$$\frac{W_2}{C_{D_2} S_2} = \frac{W_1}{C_{D_1} S_1} = 20.8.$$

Therefore,

$$W_2 = C_{D_2} S_2\ 20.8.$$

The area of the rotor that is desired to be used is,

$$S_2 = \frac{\pi}{4}(7.5)^2 = 44.1\ \text{ft}^2,$$

$$C_{D_1} = C_{D_2} = .85, \text{ and}$$

$$W_2 = .85(44.1)(20.8) = 780 \text{ pounds}.$$

The 12-bladed Sandia Corporation rotochute will deliver a maximum vehicle weight of 780 pounds with an impact velocity of 130 feet per second for the conditions assumed.

CONCLUSIONS

A theoretical rotochute trajectory study using experimental drag coefficients has led to the following conclusions:

1. The Kaman-governing rotochute prototype drop-test vehicle should be four-bladed and have a diameter of 20 feet. Telescoping blades are being considered by Kaman, so the stowed length of the rotochute would be about 6 feet.

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2. All of the Sandia Corporation-Kaman contract specifications except drop altitude extent may be fulfilled by the 20-foot-diameter four-bladed governing rotochute. The theoretical trajectories based on the first Kaman wind-tunnel tests indicate that for a drop of 300 feet with a release altitude of 5000 feet, range will be 2000 feet, the impact velocity will be 90 feet per second, and the impact angle will be 40 degrees from vertical, for the case of a 3000-pound vehicle released at Mach 0.9. The use of higher rotor speeds, which will be investigated in the third series of wind-tunnel tests, may allow a reduction in the 20-foot blade diameter because of higher drag coefficients anticipated.

W. B. PEPPER - 5141

Case No. 669.02
November 16, 1956

REFERENCES

1. Letter, McGovern, J. L. to Strieby, R. A., Contract Specifications, February 17, 1956.

2. Pepper, W. B., Results of Sandia Corporation Rotochute Tests and Kaman Aircraft Corporation Rotochute Test No. 1 Conducted during August 1956, Sandia Corporation Technical Memorandum 239-56-51, November 16, 1956.

Drag Condition	Curve to be Used		Rotochute Config. Represented		
	0<M<.15	.15<M<.9	No. Blades	Solidity	Remarks
1	c	e	2	0.106	high step
2	a	e	2	0.106	low step
3	c	d	2	0.106	low preload
4	c	f	4	0.212	1.5 Times (e)
5	a	f	4	0.212	low step
6	c	g	8	0.424	2.0 times (e)
7	b	h	12	0.464	Sandia Rotochute

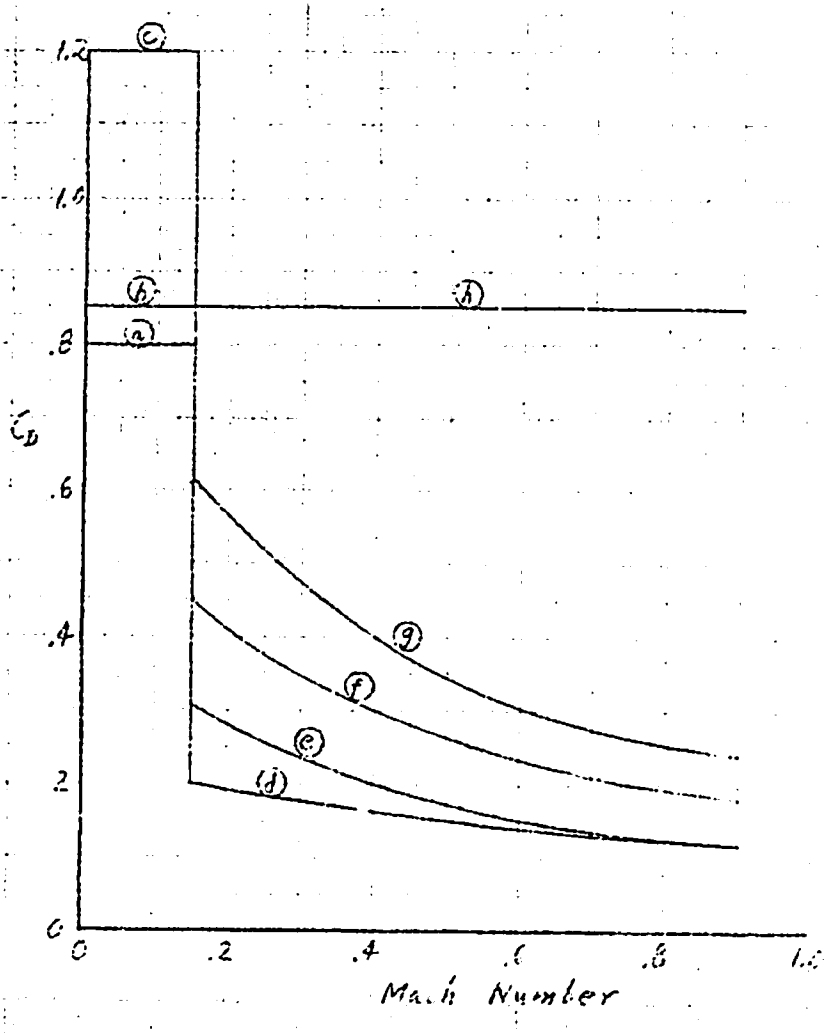

Figure-1. Drag Curve Conditions Used for Trajectory Study.

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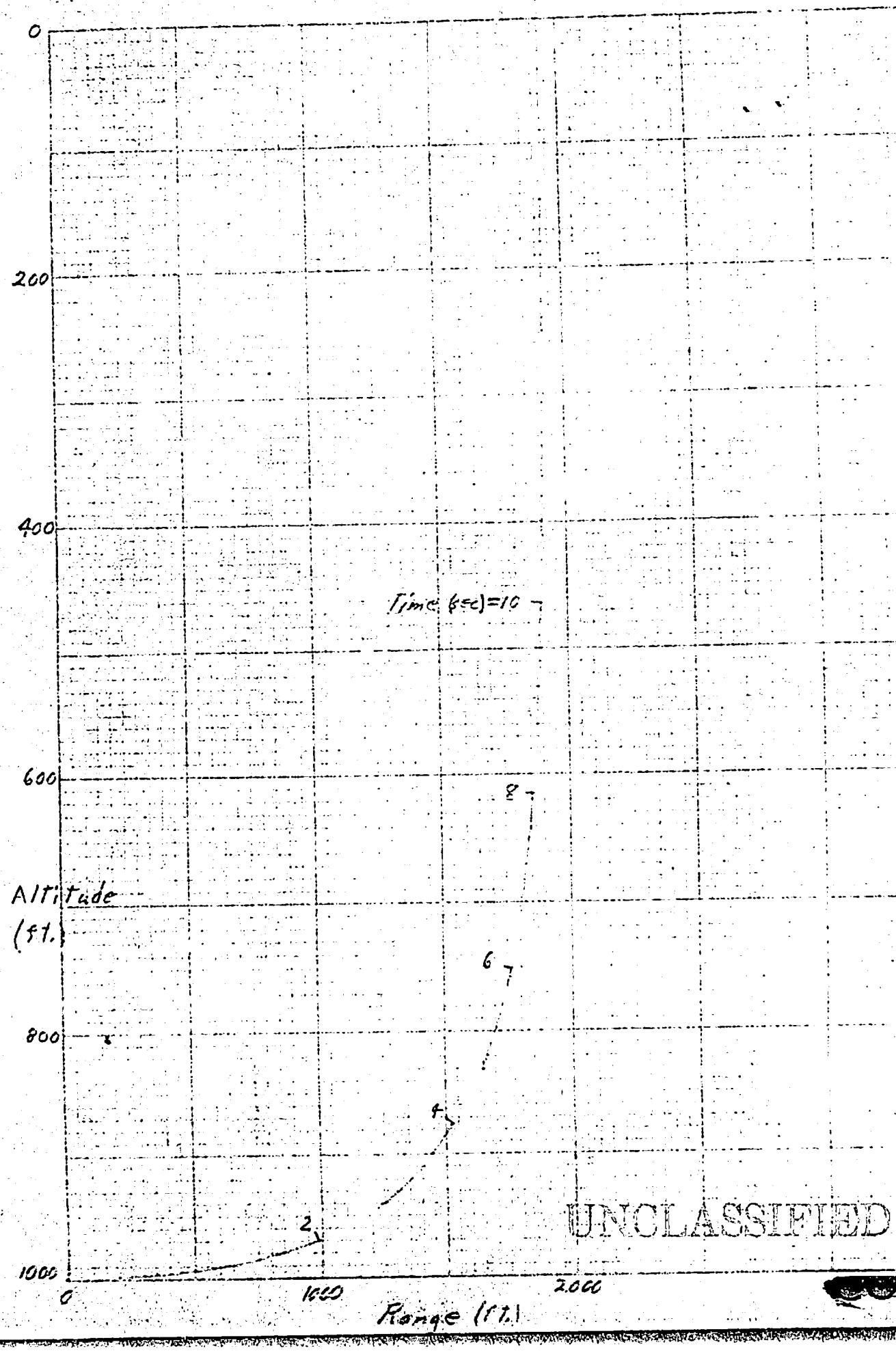

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Figure-2

Altitude vs Range

Theoretical Rotochute

Trajectory

Rotor Diameter 20 ft.

Release Altitude 1000 ft.

Drag Condition # 4

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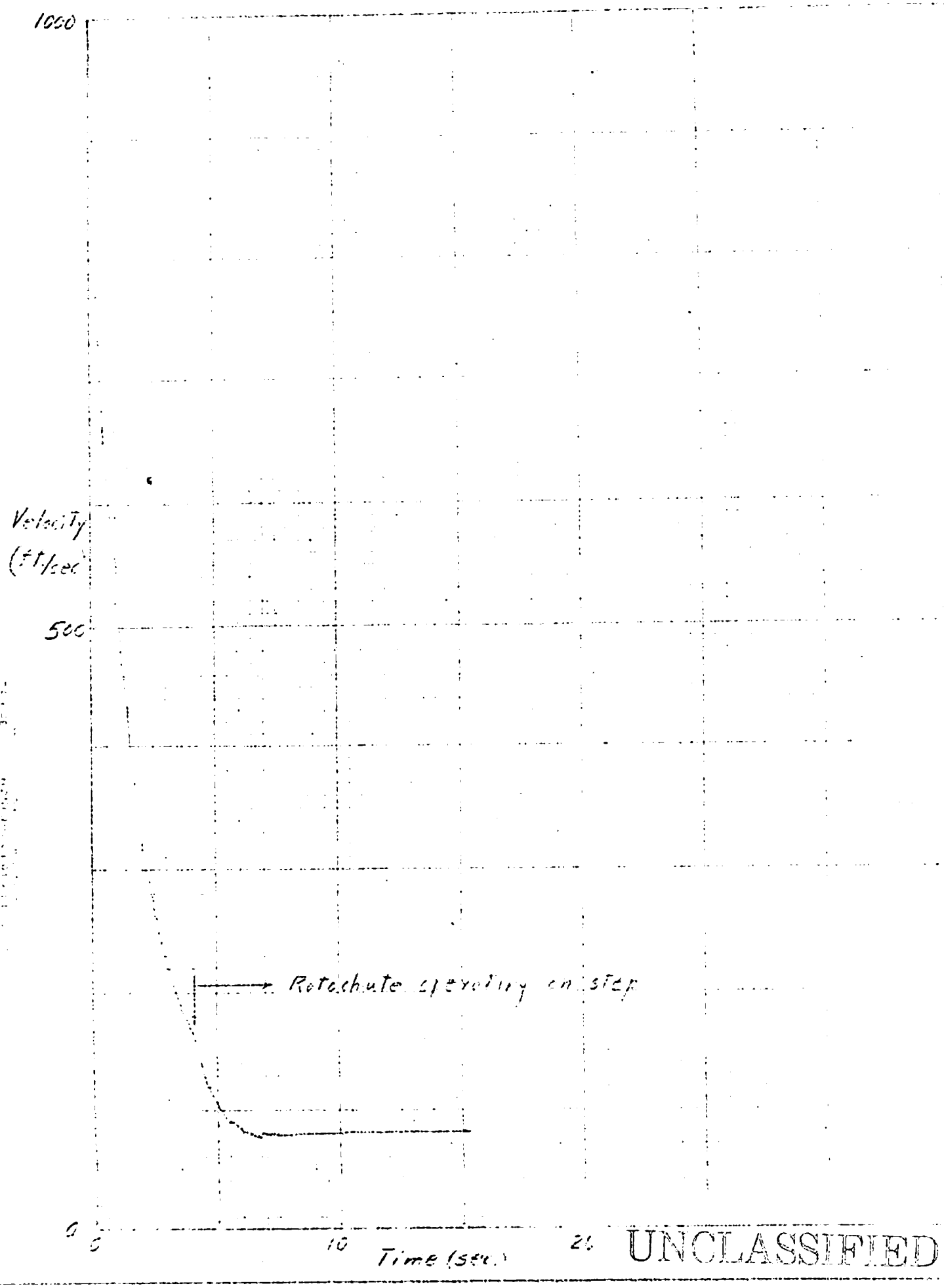

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Figure-3

Velocity vs. Time

Theoretical Rotochute Trajectory

Rotor Diameter 20 ft.
Release Altitude 1000 ft.
Drag Condition #4

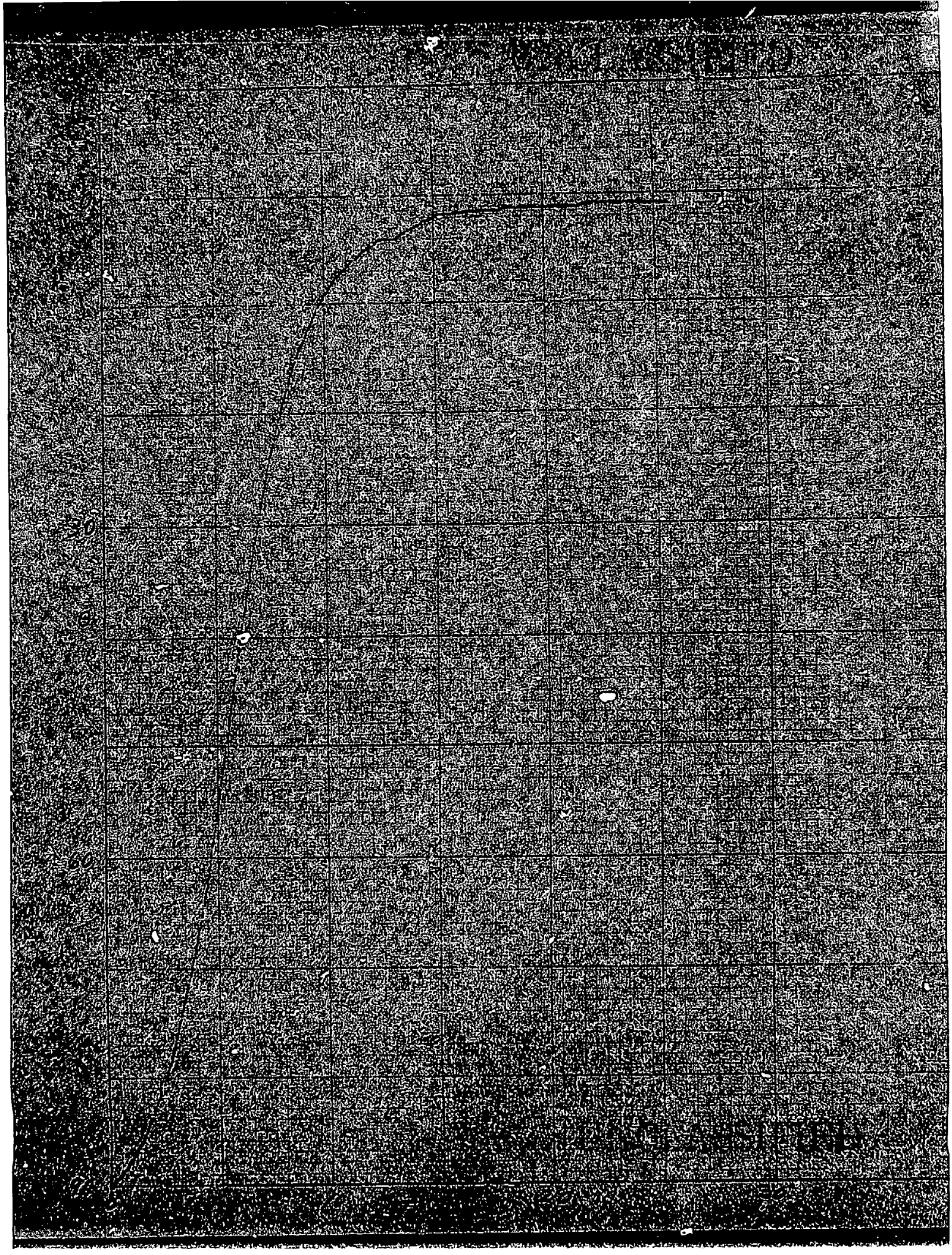
30
60

Figure - 4

Trajectory Angle vs Time

Theoretical Rotochute Trajectory

Rotor Diameter 20 ft.
Release Altitude 1000 ft. m.
Drag Condition #4

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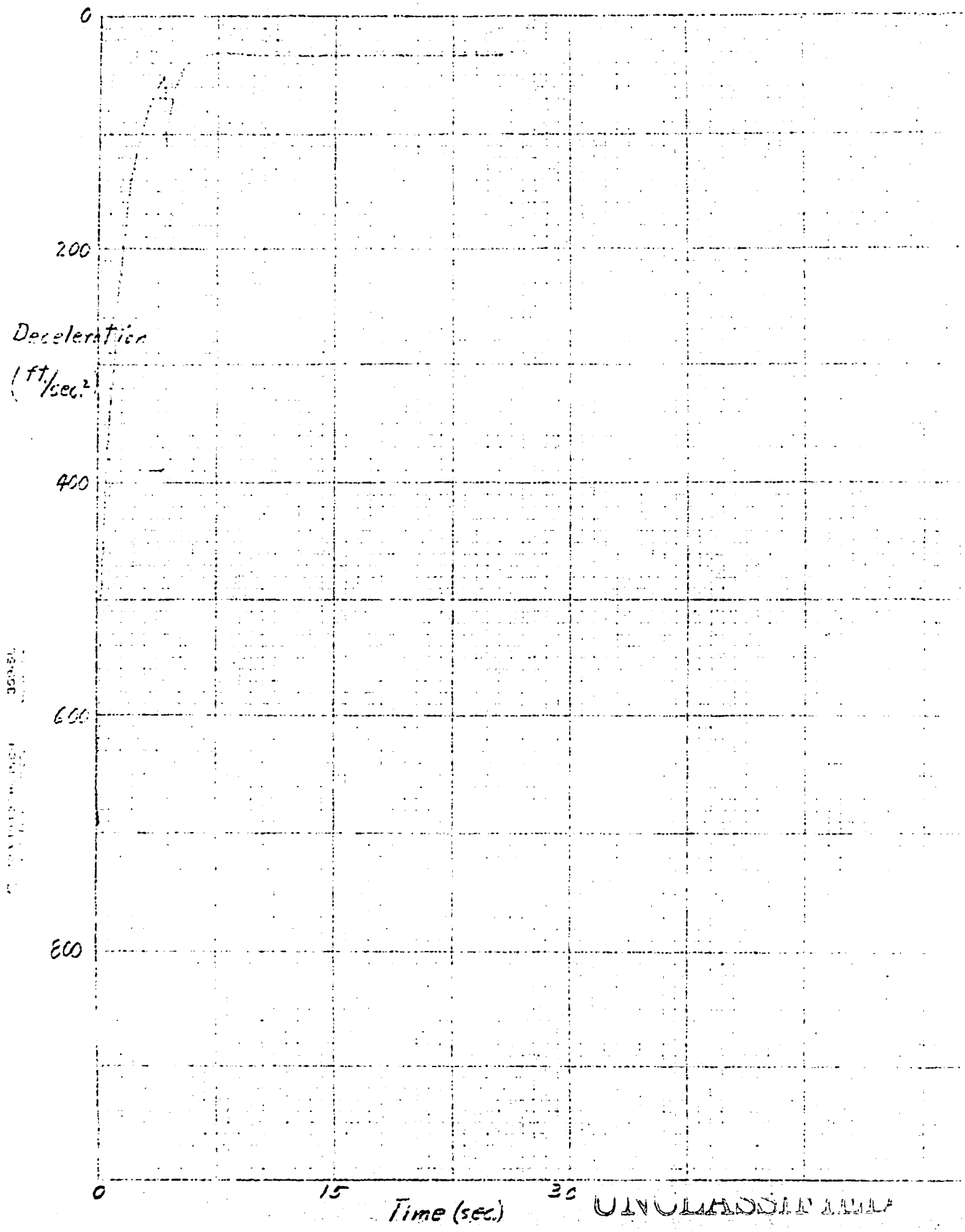

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Figure - 5

Deceleration vs Time
Theoretical Rotochute
Trajectory

Rotor Diameter 20 ft
Release Altitude 1000 ft
Drag Condition #4

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Vehicle Weight = 3000 #			Vehicle Weight 2500 #
Drag Condition	Release Altitude (ft.) m.s.l.		
	1000	5000	
1	△	△	A
2	□	□	
3	▷	▷	
4	▽	▽	
5	⌓	⌓	
6	◇	◇	
7	○	○	

Solid symbols indicate that step condition was not reached.

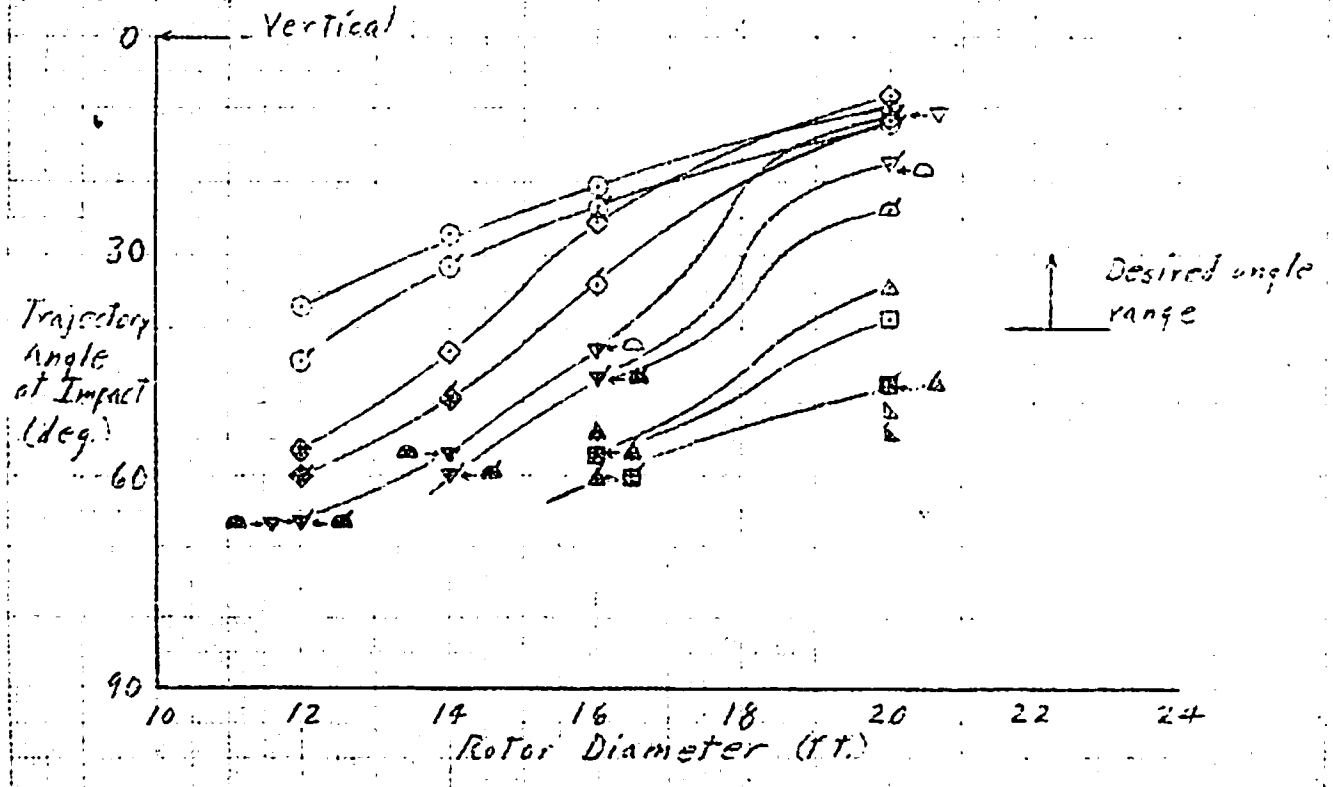

Figure-6. Variation of Trajectory Angle at Impact with Rotor Diameter for Drop Altitude of 500 feet

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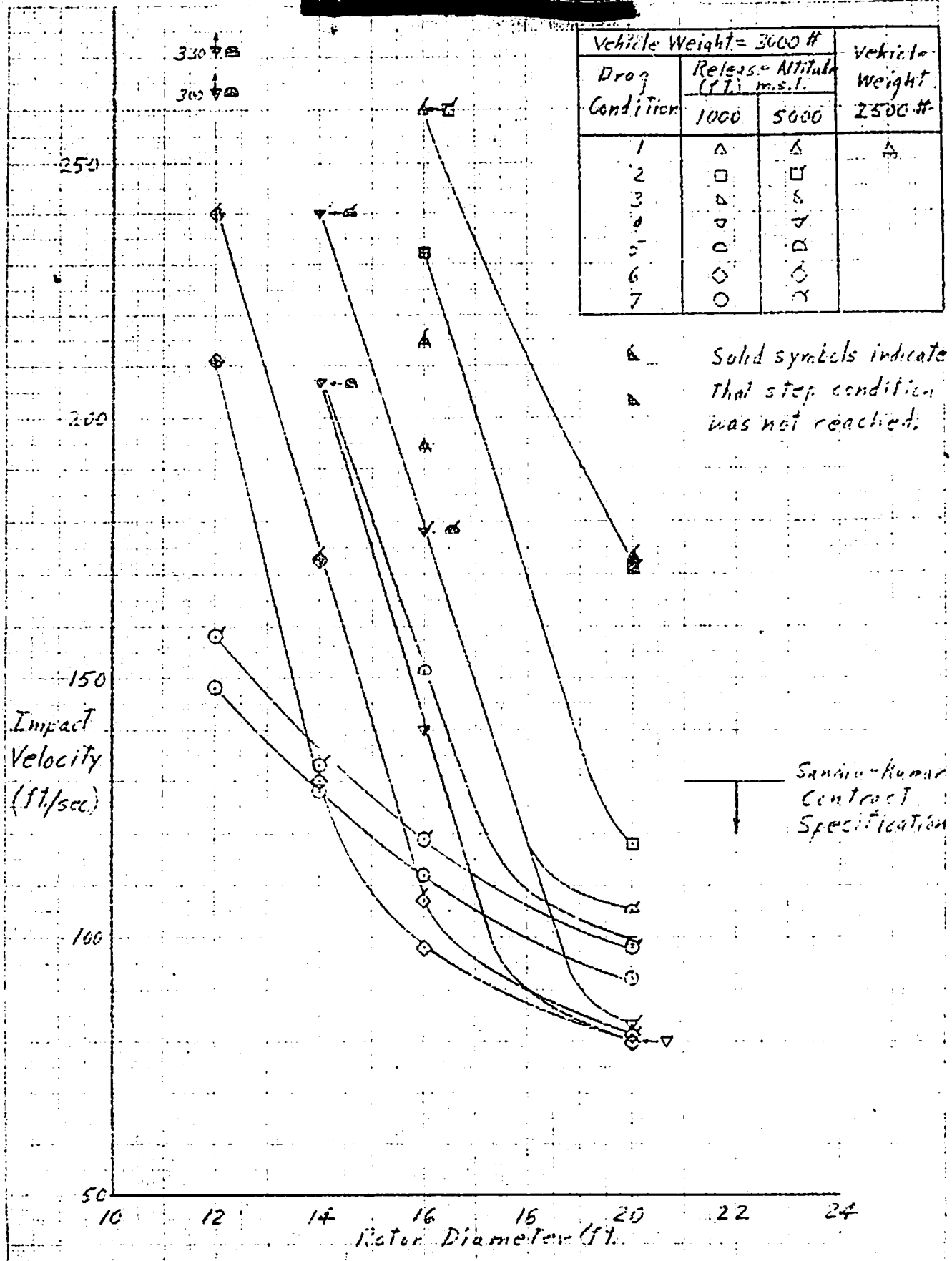

Figure-7. Variation of Impact Velocity with Rotor Diameter for Drop Altitude of 500 feet.

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Drag Condition	Vehicle Weight = 5000# Release Altitude (ft) m.s.l. 1000	5000	Vehicle Weight 25000#
1	△	△	△
2	□	□	
3	◁	◁	
4	▽	▽	
5	▱	▱	
6	◇	◇	
7	○	○	

Solid symbols indicate that step condition was not reached.

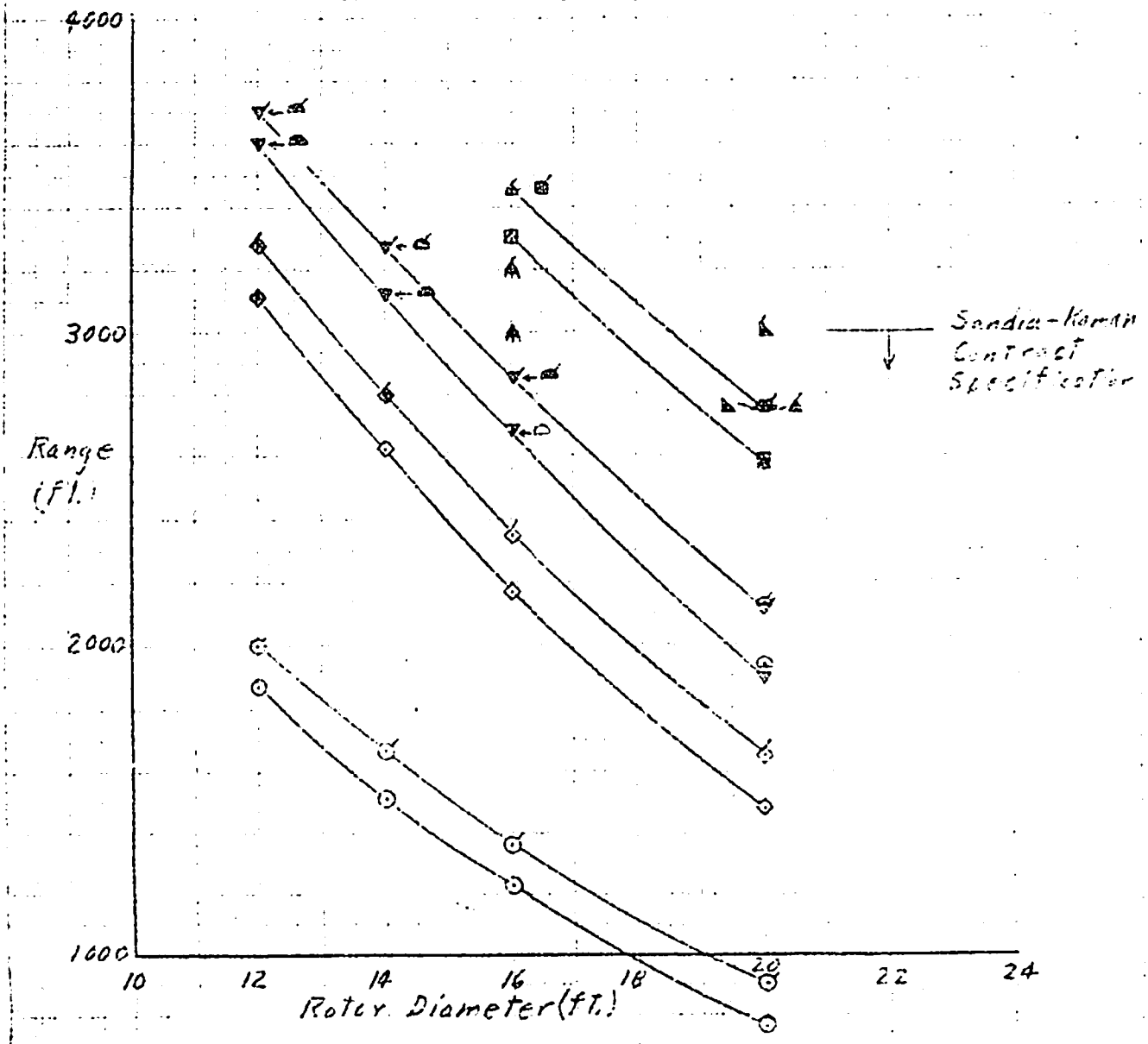

Figure-8. Variation of Range with Rotor Diameter for Drag Altitude of 500 feet

Vehicle Weight = 3000 #			Vehicle Weight 2500 #
Drag Condition	Release Altitude (ft. msl.)		
	1000	5000	
1	△	△	△
2	□	□	
3	◺	◺	
4	▽	▽	
5	⌓	⌓	
6	◇	◇	
7	○	○	

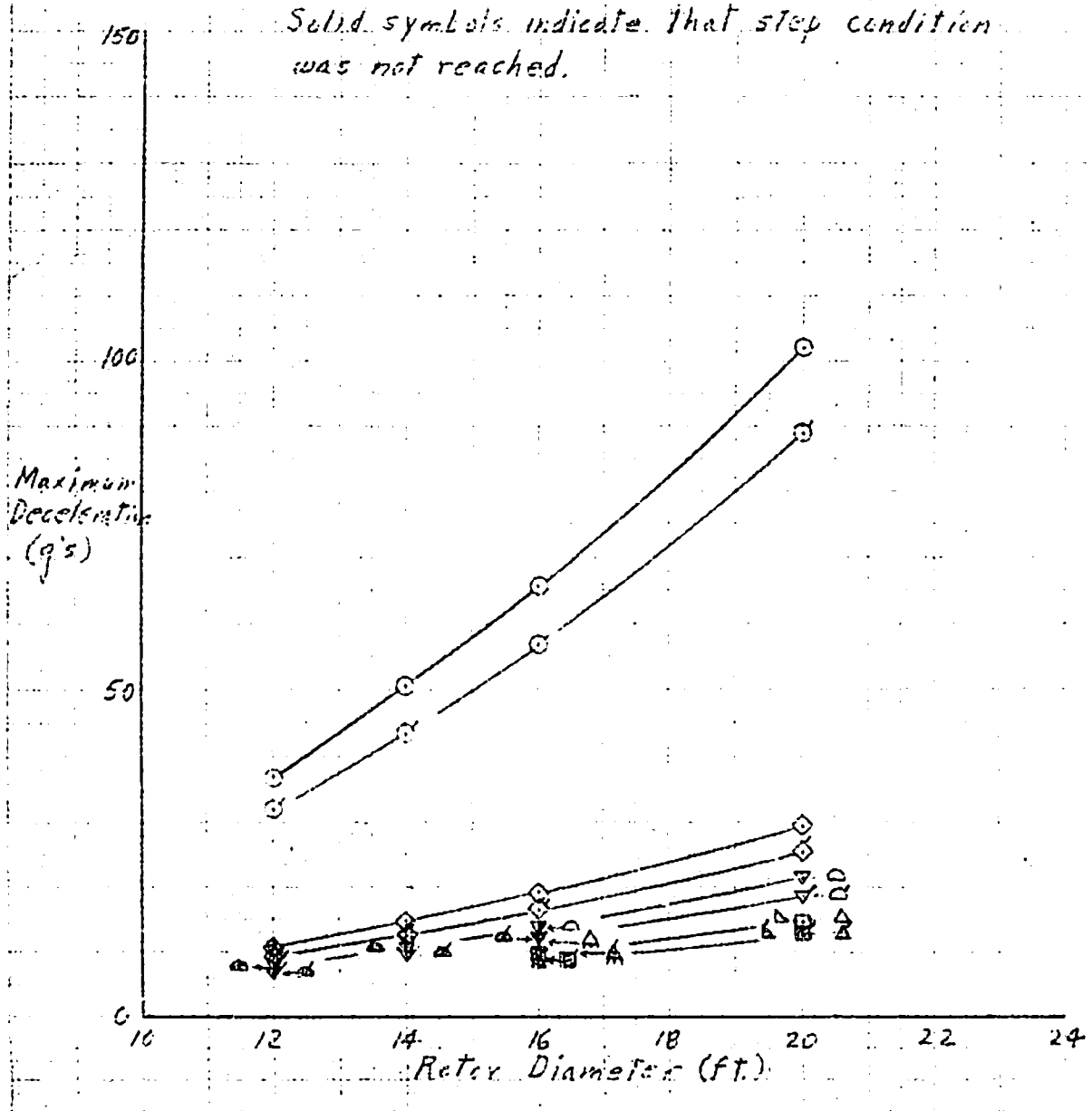

Figure-9. Variation of Maximum Deceleration with Rotor Diameter for Drop Altitude of 500 feet.

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Vehicle Weight = 3000 #			Vehicle Weight 2500#
Drag Condition	Release Altitude (ft.) m.s.l.		
	1000	5000	
1	△	△	⌂
2	□	□	
3	◺	◺	
4	▽	▽	
5	⌓	⌓	
6	◇	◇	
7	○	○	

Solid symbols indicate that step condition was not reached.

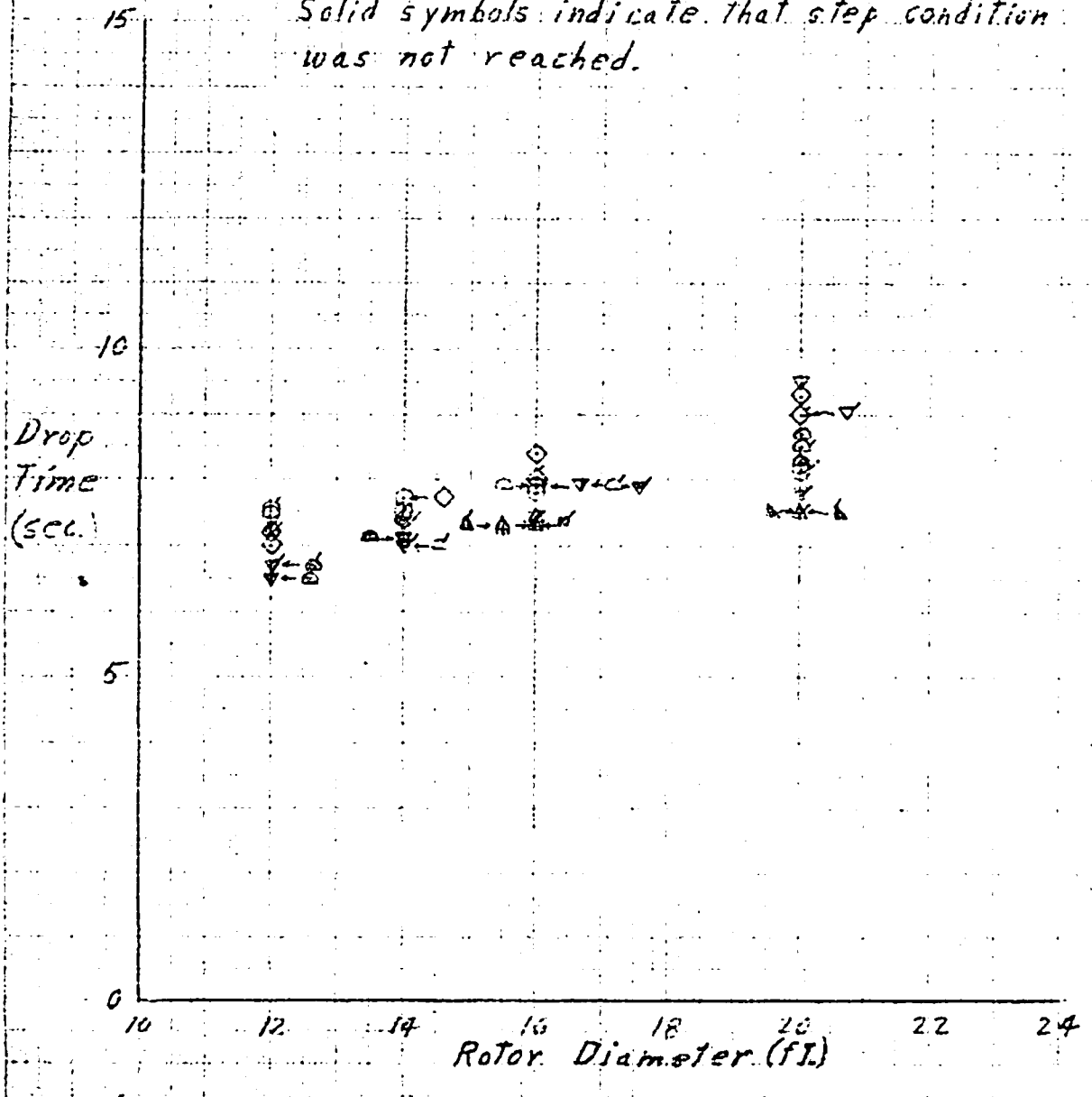

Figure-10. Variation of Drop Time with Rotor Diameter for Drop Altitude of 500 feet.

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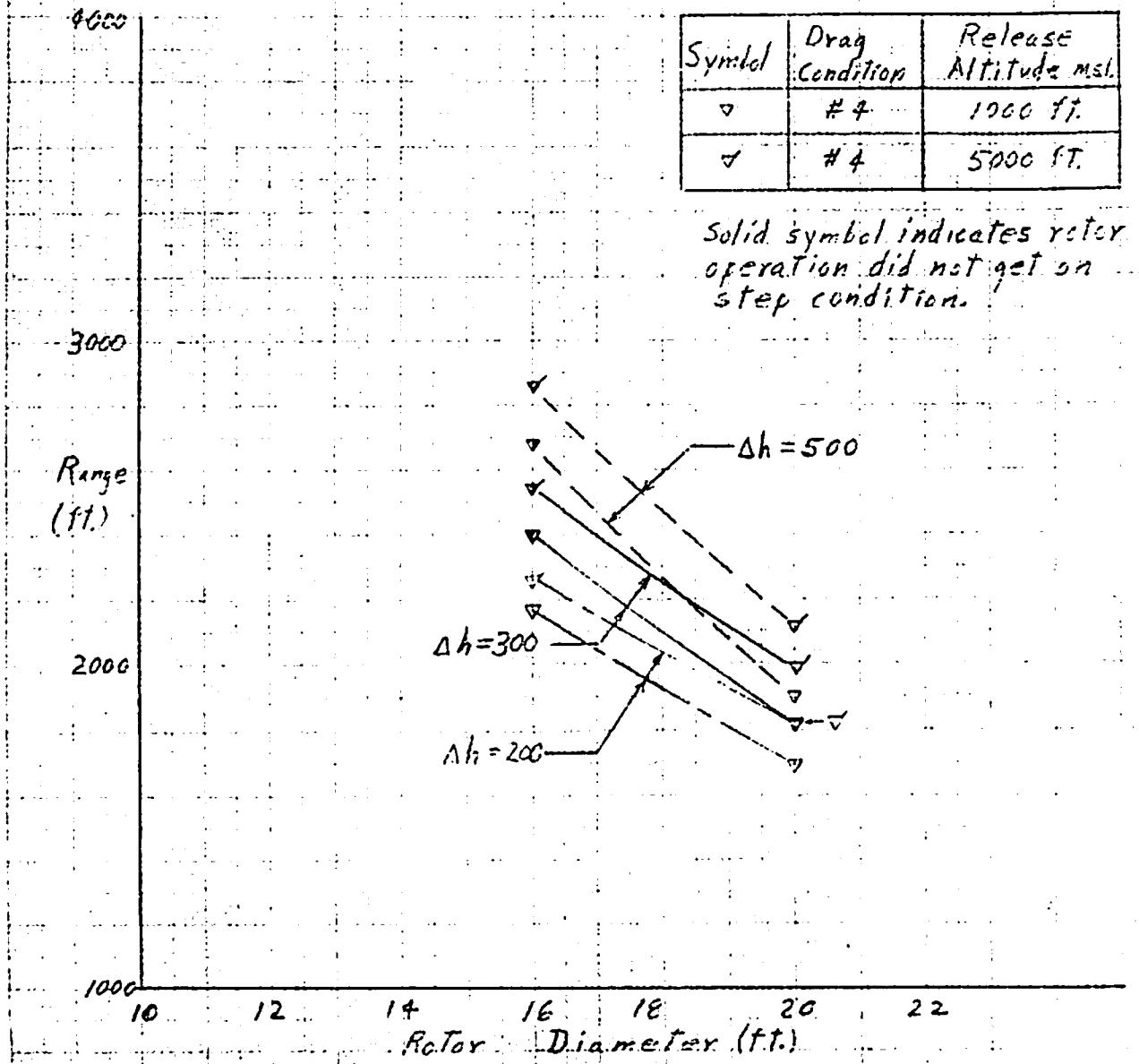
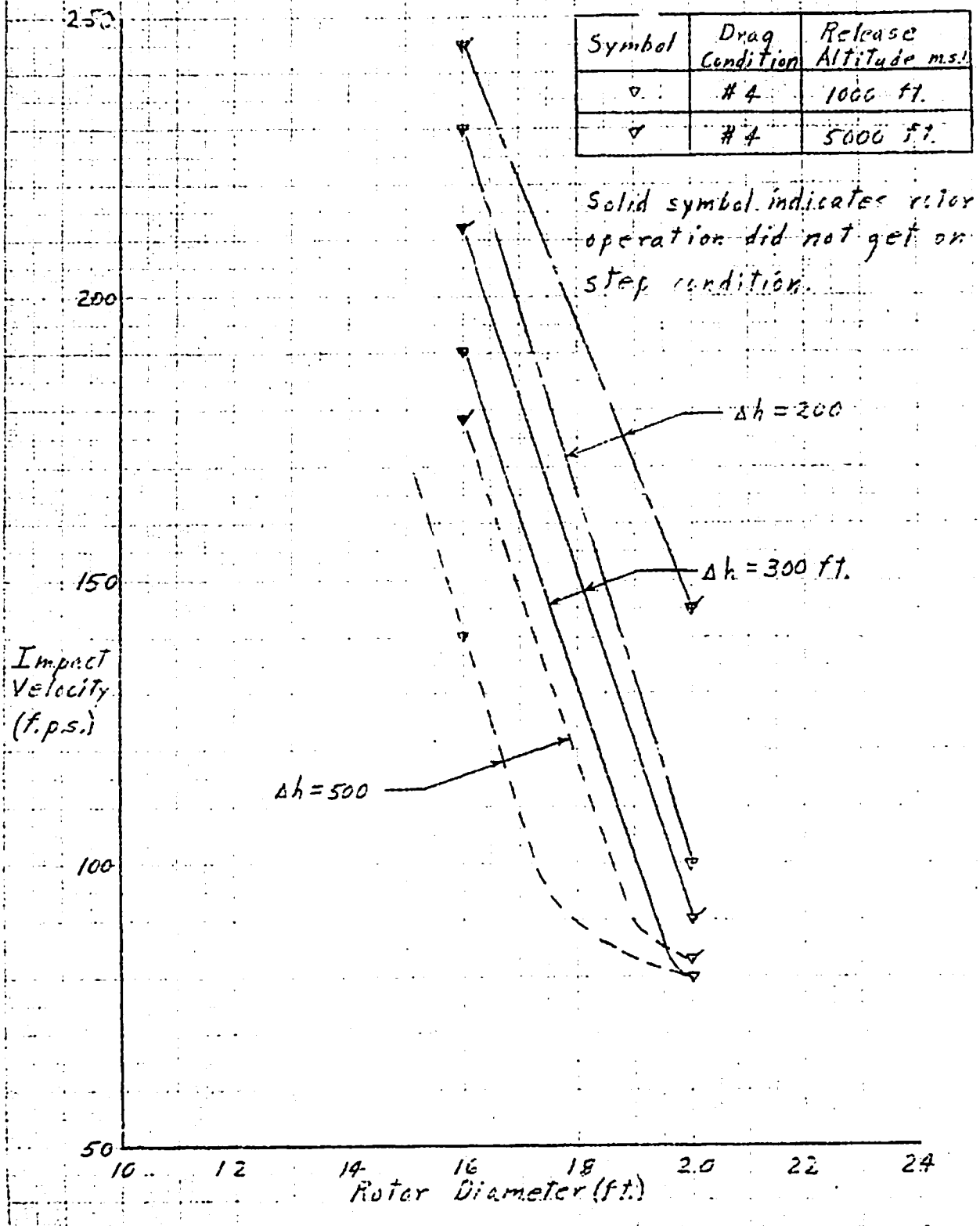


Figure-11. Effect of Drop Altitude Extent on Horizontal Range.



Symbol	Drag Condition	Release Altitude m.s.l.
▽	#4	1000 ft.
▼	#4	5000 ft.

Figure 12. Effect of Drop Altitude Extent (Δh) on Impact Velocity.

Symbol	Drag Condition	Release Altitude msl
▽	#4	1000 ft.
▽	#4	5000 ft.

Solid symbols indicate rotor operation did not get on step condition.

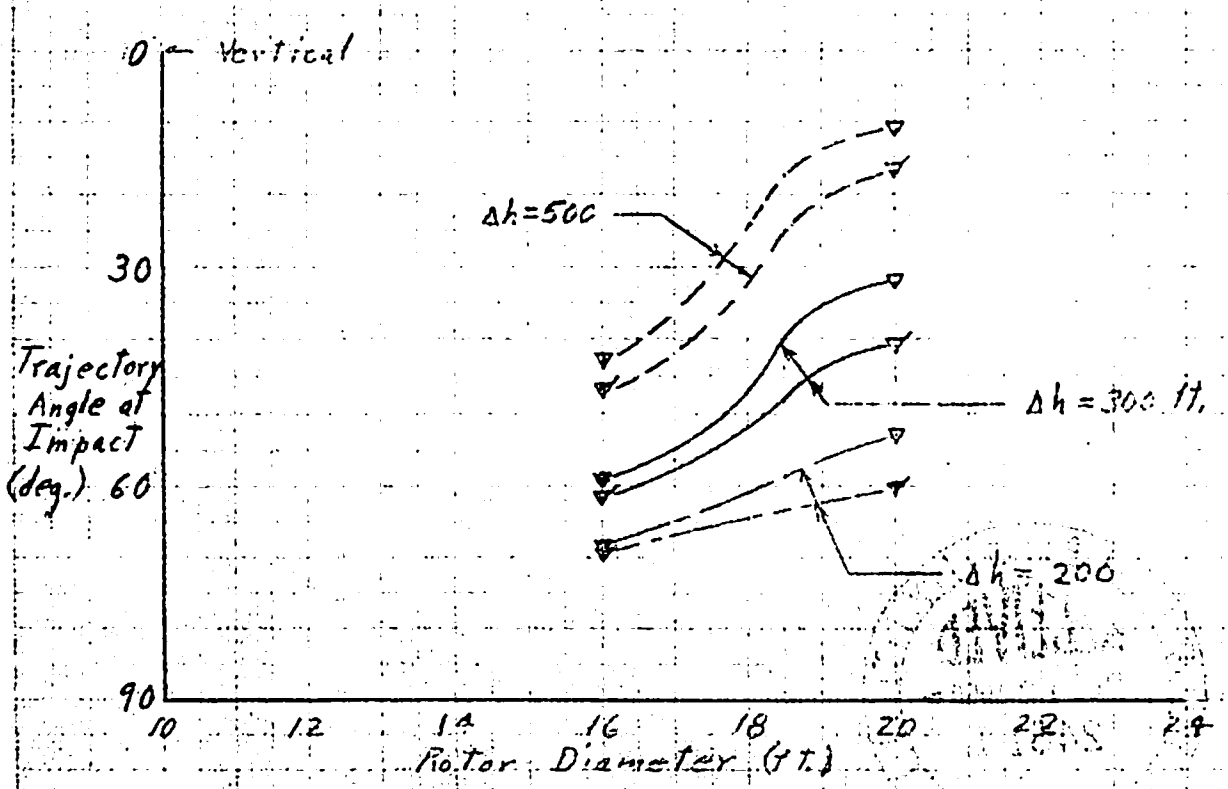


Figure-13. Effect of Drop Altitude Extent (Δh) on Trajectory Angle at Impact.