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SANDIA SYSTEMATIC DECLASSIFICATION REVIEW	
1st Review Date: 10-17-96	Determination (Circle Numbers):
Authority: ☐ ADC ☒ ADD	1. Classification Retained
Name: W. Layne	2. Classification Changed to: U
	3. Contains No DOE Classified Information
2nd Review Date: 11/19/96	4. Coordinate With
Authority: ADD	5. Contains UCAI?
Name: R B Craner	6. Comments: OK for Open Lit

SCTM 278-56-51

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RESULTS OF KAMAN AIRCRAFT CORPORATION ROTOCHUTE TEST NO. 2 CONDUCTED ON OCTOBER 8-12, 1956

DECLASSIFICATION REVIEW	
Emilda Selph 11-25-96 U	R. B. Craner
W C Layne 11-26-96	97SN075
	DATED: 11/19/96

W. B. Pepper - 5141

ABSTRACT

Preliminary results of the second Kaman Aircraft Corporation wind-tunnel test under the rotochute contract with Sandia Corporation are presented. The tests cover the effects of solidity, blade mass, blade center-of-gravity location, and spring constant on rotor speed and rotor drag over the low speed range of 0 to 300 feet per second. Pressure distributions, strain measurements, and static stability tests were made on some configurations, but the data are not yet available for examination.

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Case No. 699.02 January 11, 1957

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RESULTS OF KAMAN AIRCRAFT CORPORATION ROTOCHUTE TEST NO. 2 CONDUCTED ON OCTOBER 8-12, 1956

SUMMARY

During the week of October 8-12, 1956 Kaman Aircraft Corporation performed the second in a series of three tests under their rotochute contract to Sandia Corporation. The United Aircraft Corporation 18-foot diameter low-speed wind tunnel was used to obtain performance data on a 4-foot diameter rotor. Tests were made wherein the blade mass, rotor solidity, governor spring constant, and blade location on the hub were varied.

The results of the second Kaman test have led to the following conclusions:

1. Rotor performance in the 18-foot tunnel agreed well with the performance observed in the 8-foot tunnel indicating no wall interference for the rotor test in the 8-foot section for Mach numbers on the order of 0.2.
2. A rotochute should be structurally designed to withstand the highest possible rotational speeds, since the rotor drag coefficient can be increased significantly by increasing rotor speed.
3. Locating the blade center of gravity close to the feathering axis will permit the attainment of higher rotational speeds and rotor drag with a given spring.

INTRODUCTION

Kaman Aircraft Corporation, Bloomfield, Connecticut, has a Sandia Corporation contract to develop a governing rotochute capable of low altitude, high-speed delivery of a 3000-pound pay load store. The contract specifies wind-tunnel tests to determine the operating characteristics of a governing rotochute.

Reference 1 describes the results of the first of three tests. The first test was conducted to determine the high-speed performance of the governing rotochute over a Mach number range of 0.2 to 0.7.

This report will describe the results of the second test in the series which involved low-speed tests over a speed range of 20 to 300 feet per second in the United Aircraft 18-foot diameter low-speed wind tunnel.

Models and Tests -- The same model support sting and instrumentation was used in the present test as was used in Test No. 1 (Reference 1). The sting was supported at the center of the 18-foot diameter test section by two struts as shown in Figure 1. All rotor configurations tested were 4 feet in diameter and the blades were zero twist untapered with NACA 0012 airfoil sections. Kaman's detailed outline of the intended tests is given in Appendix A. Rotor configurations tested were:

1) 2 blades 4" chord σ = 0.106
2) 2 blades 6" chord σ = 0.159
3) 4 blades 4" chord σ = 0.2[illegible]
4) 4 blades 6" chord σ = 0.318

The two-bladed rotor with 4-inch chord was first tested with pressure measurements being recorded at five spanwise stations. Blades with strain gages were then installed to verify the use of strain gages instead of pressure instrumentation in determining blade bending loads. The pressure and strain-gage data would complete data over the Mach number range of 0 to 0.7 for the two-bladed rotochute. Four blades with 4-inch and 6-inch chords were then tested to determine the effects of solidity on rotochute performance through the low speed range. The four blades with 4-inch chord were then mounted in a forward position on the blade grip so that the centrifugal moment effecting the spring was reduced. Static stability tests were made with the four-bladed 4-inch chord configuration. Angles of 0, -10, -20, and -30 degrees were tested.

During all of the tests the governor preload was varied to obtain performance of the governor mechanism. Figure 2 is a detailed view of the four-bladed hub and governor mechanism. Reference 1 contains a detailed description of the operation of the governor.

RESULTS

The sting tare drag shown in Figure 3 was substracted from the tunnel balance readings to obtain the rotor drag coefficients. All drag coefficients are based on the maximum rotor area (4 feet in diameter). The sting tare drag measured in the first Kaman wind-tunnel test is shown for comparison. The tare drag was greater for the sting mounted in the 18-foot test section than in the 8-foot test section, since two tie rods spanning the tunnel were attached to the forward vertical sting support strut and to the balance.

Figures 4(a) to 4(f) show the variation of rotor drag coefficient with tunnel velocity with four values of preload. The variations of rotor speed with velocity for the same models are shown in Figures 5(a) to 5(f).

In general, it can be seen that increasing the preload increases the rotor drag coefficient and speed for velocities above the peak drag coefficient or step condition. This is caused by the higher spring force resulting from the higher preload causing the blades to seek a lower angle of attack where the section lift to drag ratio is higher. The preload does not have a large effect on drag coefficient for the step condition (velocities between 30 and 90 feet per second in Figure 4(a)). Increasing the preload extends the step operation to higher velocities, which is desirable. Comparing Figures 4(f) and 4(a) shows the desirable effect of increasing the drag coefficients caused by moving the blades forward on the grip so that the blade inertia moments are reduced and the spring is more effective. In running the test shown in Figures 4(f) and 5(f) one blade was lost at a test velocity of 120 feet per second and a preload of 1.0. All four of the blade attachment fittings were permanently deformed. The failure point was the coning hinge shaft at the universal joint (see Figure 2). The 0.4 preload test had indicated that the rotor was off the step, and from previous experience, the higher preload was also expected to be off the step. However, the rotor speed picked up rapidly and went into the step condition with the peak speed being 2600 rpm. The rotor was designed for 2200 rpm so the failure indicates the ultimate stress was 1.4 times the design stress. The blades did not show any indication of failure. It can be concluded that Kaman's structural design methods are conservative. Figure 4(f) when compared with Figures 4(a) through 4(e) indicates that higher drag coefficients can be obtained by designing the rotor for as high speeds as are practicable. Figures 4(d) and 5(d) show the drag coefficient and rotor speed for the two-bladed rotor with 4-inch chord that was tested in the 8-foot diameter test section during the first Kaman test. The results from the two test sections agree reasonably well indicating that there is no large wall interference effect for the rotor in the 8-foot tunnel at the velocity of 220 feet per second. The existing difference in data points may be due to different calibration of the preload transducer resulting in different magnitudes of preload.

The effect of solidity on rotor drag coefficient is shown in Figure 6 for a velocity of 200 feet per second. The drag coefficient increases approximately as 2.34 times the solidity.

The stability data will require detailed mass data reduction to reach any definite conclusions, since the forces measured were small and tunnel balance interaction is probable. Large differences in wind-off readings were evident before and after the runs. However, some runs may be usable.

The pressure distribution measurements and strain-gage data on the rotating blades will be reduced by the United Aircraft Corporation data reduction facilities and will be published by Kaman in their summary reports.

CONCLUSIONS

Results of the second Kaman wind-tunnel test have led to the following conclusions:

1. Rotor performance in the 18-foot tunnel agreed well with the performance observed in the 8-foot tunnel, indicating no wall interference for the rotor test in the 8-foot section.
2. A rotochute should be structurally designed to withstand the highest rotational speeds practicable since the rotor drag coefficient can be increased significantly by increasing rotor speed.
3. Locating the blade center of gravity close to the feathering axis will permit the attainment of higher rotational speeds and rotor drag with a given spring.

W. B. PEPPER - 5141

Case No. 669.02
January 11, 1957

SYMBOLS

C_D = Rotor drag coefficient based on maximum disk area (body drag has been subtracted).

σ = Rotor solidity (area of blades exposed to free air stream divided by maximum rotor disk area less portion covered by body).

REFERENCES

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

2. Pepper, W. B., Theoretical Rotochute Trajectories, Sandia Corporation Technical Memorandum 238-56-51, November 16, 1956.

APPENDIX A

Outline of Low-Speed Wind-Tunnel Investigation
of Sandia Model Rotochute

1. Phase I of this wind-tunnel investigation will be devoted to a study of the low-speed performance characteristics of the 4-foot-diameter model rotochute. The initial tests in this phase will consist of a continuation of the spanwise and chordwise pressure distribution survey on the rotor blade under various conditions of rotor speed and tunnel velocity. For this study, the rotor system previously used in the recent high-speed wind-tunnel tests will be utilized. Strain gage measurements on one blade will be recorded during this series of runs for correlation with blade airloads determined by pressure distribution. Data reduction methods similar to those employed in the high-speed tests will be utilized to determine induced velocity distributions and governor operating characteristics. Governor spring preload will be varied at each velocity in increments of 20, 40, 60, 80 and 100 per cent of the allowable spring preload deflection. The maximum spring rate governor spring (-23 spring) will be used during this pressure distribution survey. Data will be recorded at the following tunnel velocities:

1) 20 ft/sec	6) 70 ft/sec	11) 150 ft/sec
2) 30 ft/sec	7) 80 ft/sec	12) 200 ft/sec
3) 40 ft/sec	8) 90 ft/sec	13) 250 ft/sec
4) 50 ft/sec	9) 100 ft/sec	14) 300 ft/sec
5) 60 ft/sec	10) 120 ft/sec	

It is estimated that two hours will be required for each run to cover the ranges of velocity and spring preload prescribed above. Thus for the five pressure distribution runs and the one strain-gaged run this will amount to 12 hours' operating time for this portion of the program.

The second part of the performance study will be devoted to the investigation of the effects of rotor solidity and numbers of blades. A four-bladed hub will be installed on the model allowing either two-bladed or four-bladed operation. Rotor blades of 4-inch and 6-inch chords of approximately equal mass will be utilized giving the following combination and solidities:

1) 2 blades	4" chord	$\sigma = 0.106$
2) 2 blades	6" chord	$\sigma = 0.159$
3) 4 blades	4" chord	$\sigma = 0.212$
4) 4 blades	6" chord	$\sigma = 0.318$

Rotor blade undersling from the coning hinge will be reduced during these tests to approximately 50 per cent of that previously used. Each of the blade combinations will be tested at the tunnel velocities and the spring preload settings noted above. In addition, the four-bladed 4-inch chord rotor will be re-evaluated with two additional governor spring rates. Based on 2 hours per run, it is estimated that this portion of the program will require 12 hours of tunnel operating time.

2. Phase II of this low-speed wind-tunnel investigation will be directed toward determining the effects on the spring governor operation of the following changes: the amount of blade undersling; the chordwise position of blade center of gravity and aerodynamic center relative to the blade feathering axis and the total blade mass. Performance data will be acquired during these tests along with the governor operating characteristics. The four-bladed 4-inch chord rotor will be used for this investigation at the same tunnel velocities and spring preload settings previously employed.

The initial variation to be considered in this part of the test program will be the blade chordwise position relative to the feathering axis. Provisions will be made to shift the blade location on the blade grip fore and aft of the standard position as tested in the second part of Phase I by an amount equivalent to approximately 16 per cent of the blade chord. This shift will simultaneously move the blade a.c. and c.g. from 27 per cent to 173 per cent of the normal position of 0.90 inch aft of the feathering axis with the blades at zero cone angle.

In addition to the above study of chordwise c.g. and a.c. position relative to the feathering axis, a special set of 4-inch chord mass balanced blades will be tested incorporating a forward c.g. shift of approximately 16 per cent of the blade chord for the same total mass of the blade. These blades will be tested in a similar manner as above, thereby allowing independent evaluation of either chordwise c.g. or a.c. shift relative to the feathering axis. It is estimated that these two parts of Phase II will require 8 hours of tunnel operation.

The remaining items to be studied in regard to governor operations are blade mass and blade undersling relative to the coning hinge. The standard blades for the four-bladed hub have a mass increase of approximately 50 per cent as compared with the pressure-tapped blades utilized in Phase I. This mass increase resulted from the desire to maintain equivalent mass in the 4-inch and 6-inch chord blades. The light blades (approximately 1.3 lb/blade for blade above) will therefore be tested on the low undersling grips for comparison with the heavier blades previously tested with these grips. Following this test, the light and the heavy blades will be tested with the blade grips having a 50 per cent increase in blade undersling. It is estimated that 6 hours of tunnel operation will be required to accomplish this study.

3. Phase III of this wind-tunnel investigation will be used to determine the stability derivatives of the operating rotochute in the low-speed regime. The four-bladed 4-inch chord rotor will be utilized with combinations of both the heavy and the light blades on the low and the high undersling grips. The model will be pitched to angles of 5, 10, 15, 20 and 30 degrees for each configuration and data recorded at tunnel velocities of 20, 40, 60, 80, 100, 150 and 300 ft/sec at preload settings of 20, 60 and 100 per cent of the allowable spring preload deflection. Lift, drag, side force, yawing moment and pitching moment will be recorded from the tunnel balance system. It is estimated that 3 hours per run will be required for this portion of the program giving a total operating time of 12 hours required for Phase III.

4. From the time estimations of the individual portions of this low-speed wind-tunnel program, it is expected that a total of 50 hours of operating time will be required to complete the program as outlined here.

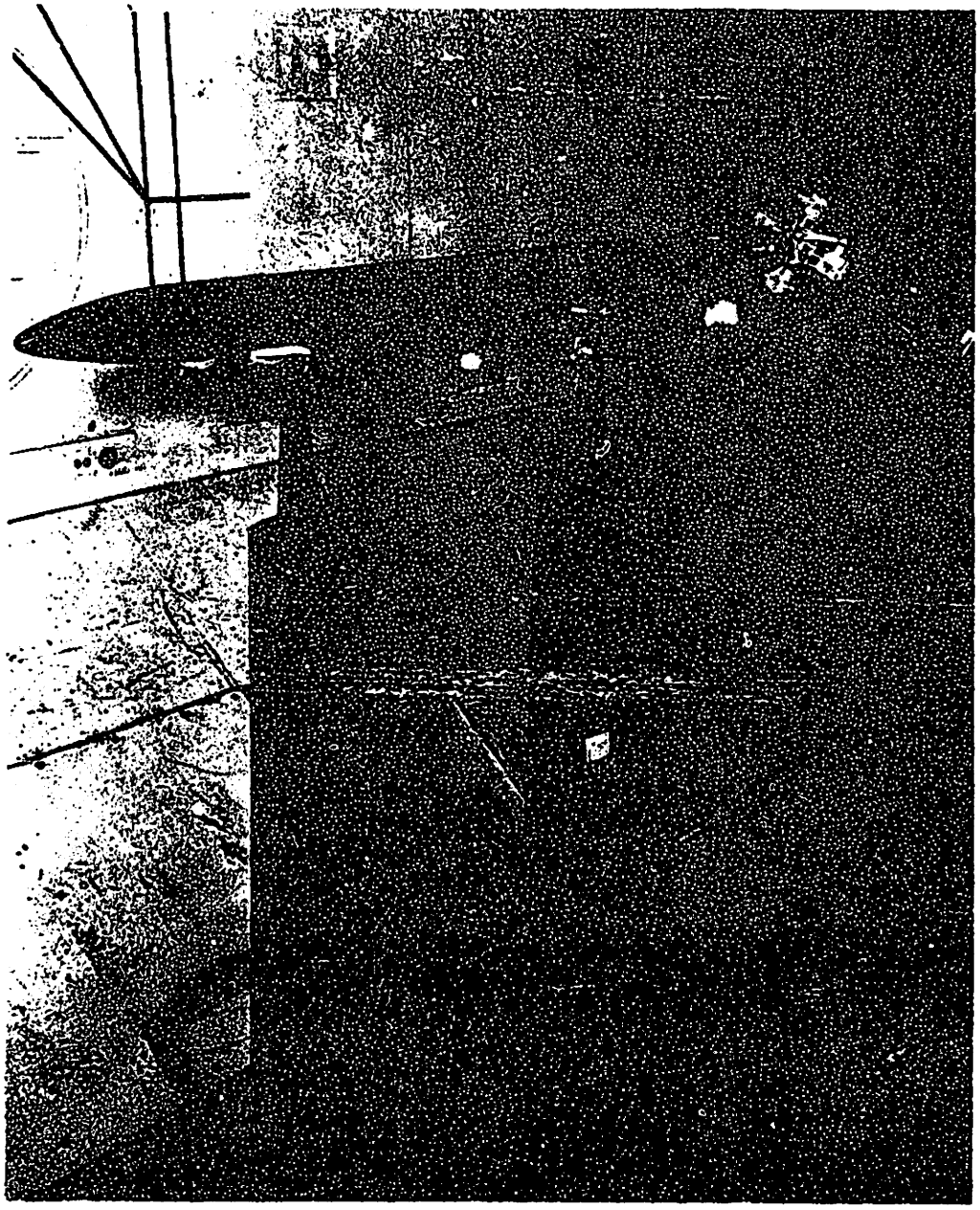

FIGURE - 1. VIEW LOOKING UP - STREAM OF KAMAN FOUR - BLADED GOVERNING ROTOCHUTE IN UNITED AIRCRAFT CORPORATION 18 FT. DIAMETER LOW SPEED WIND TUNNEL.

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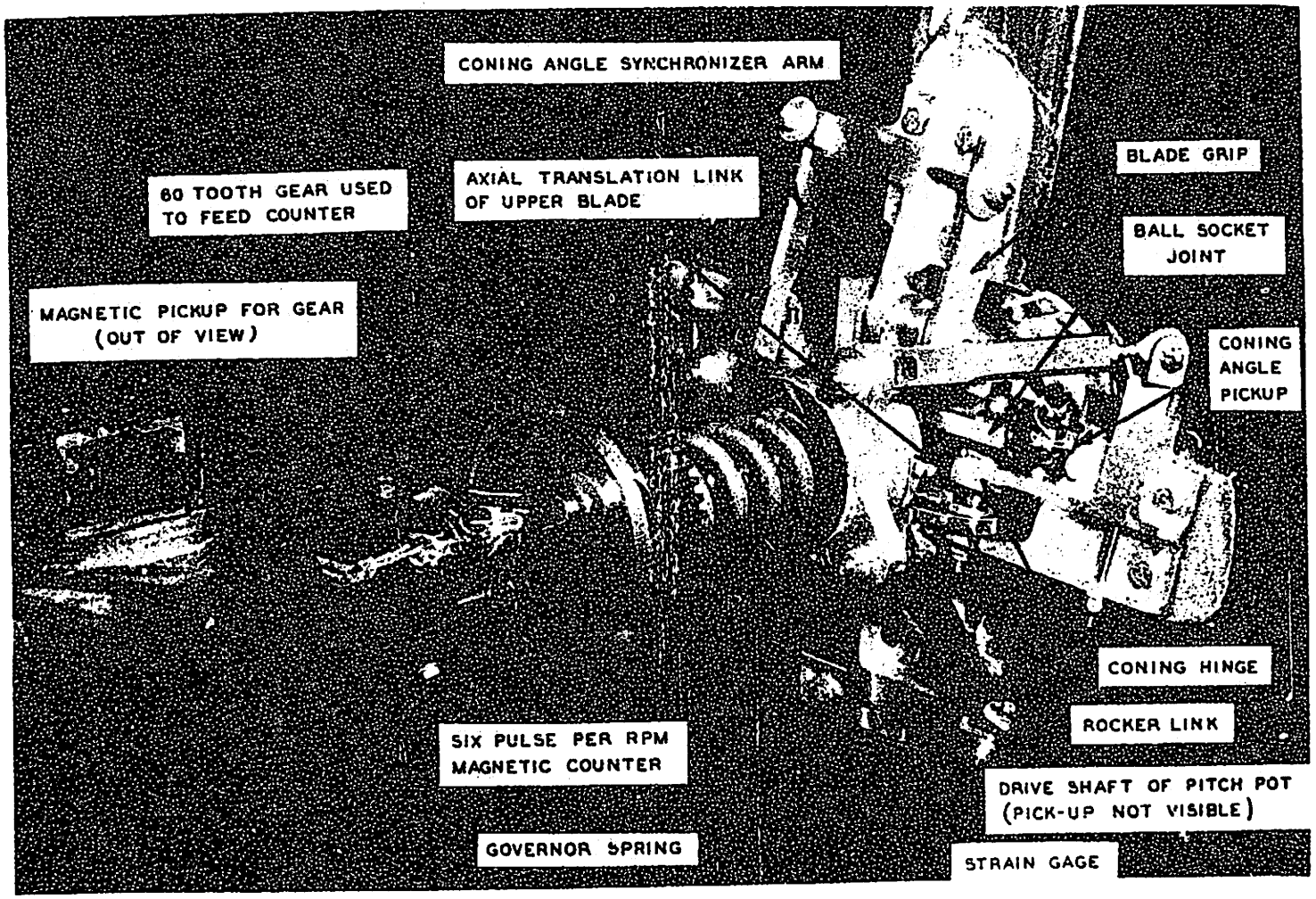

FIGURE - 2. DETAILED VIEW OF KAMAN FOUR - BLADED ROTOCHUTE GOVERNOR

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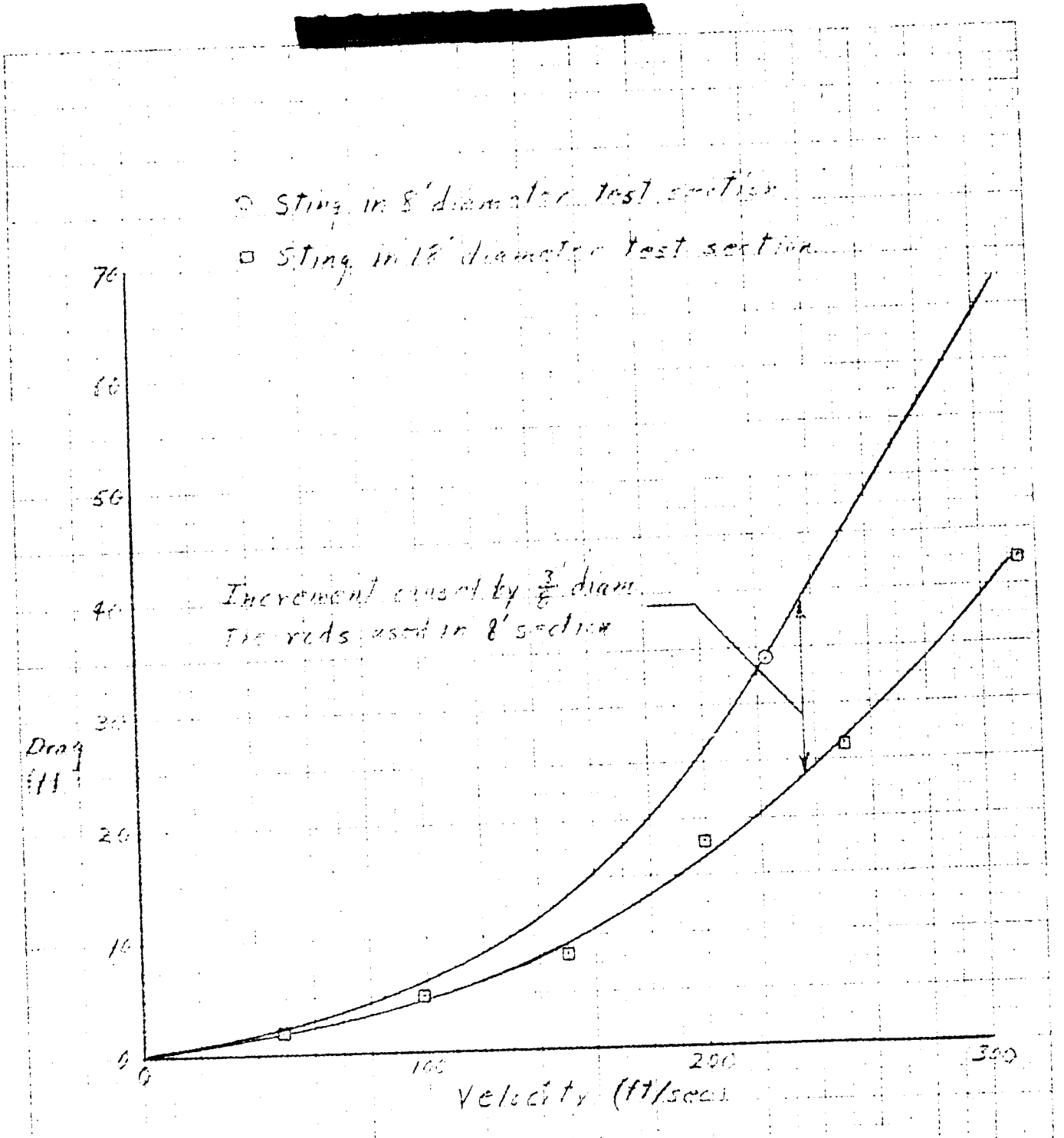

Figure 3. Tare Drag Force of Kaman Rotochute Sting in United Aircraft Corporation 8-foot and 16-foot Test Sections.

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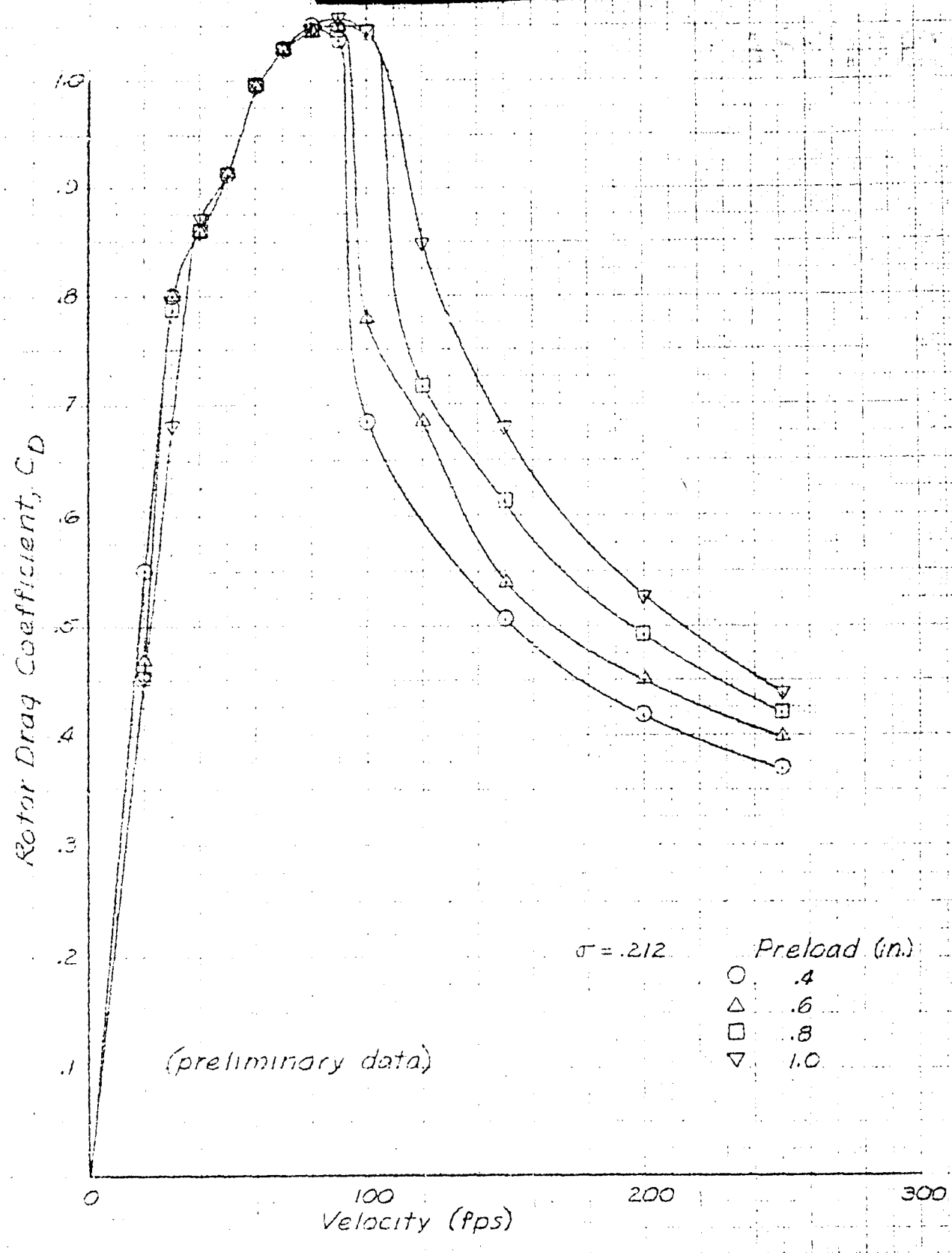

(a) 4 Blades, 4" Chord, Steel Core, -17 Spring (Runs 3-16)

Figure 4 Rotor Drag Coefficient Variation with Velocity

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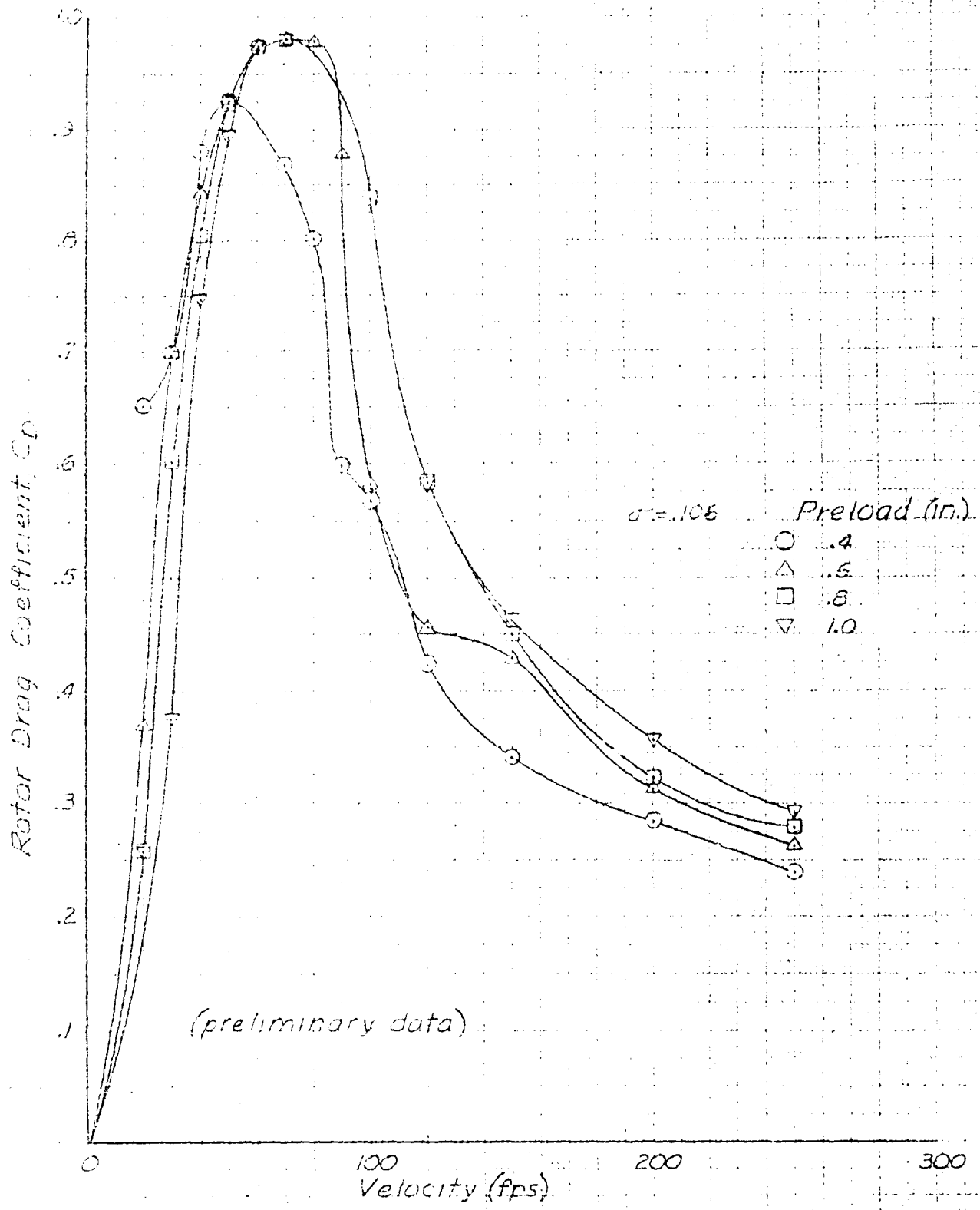

(b) 2 Blades, 4" Chord, Steel Core, -17 Spring (Runs 21-34)

Figure 4 Continued.

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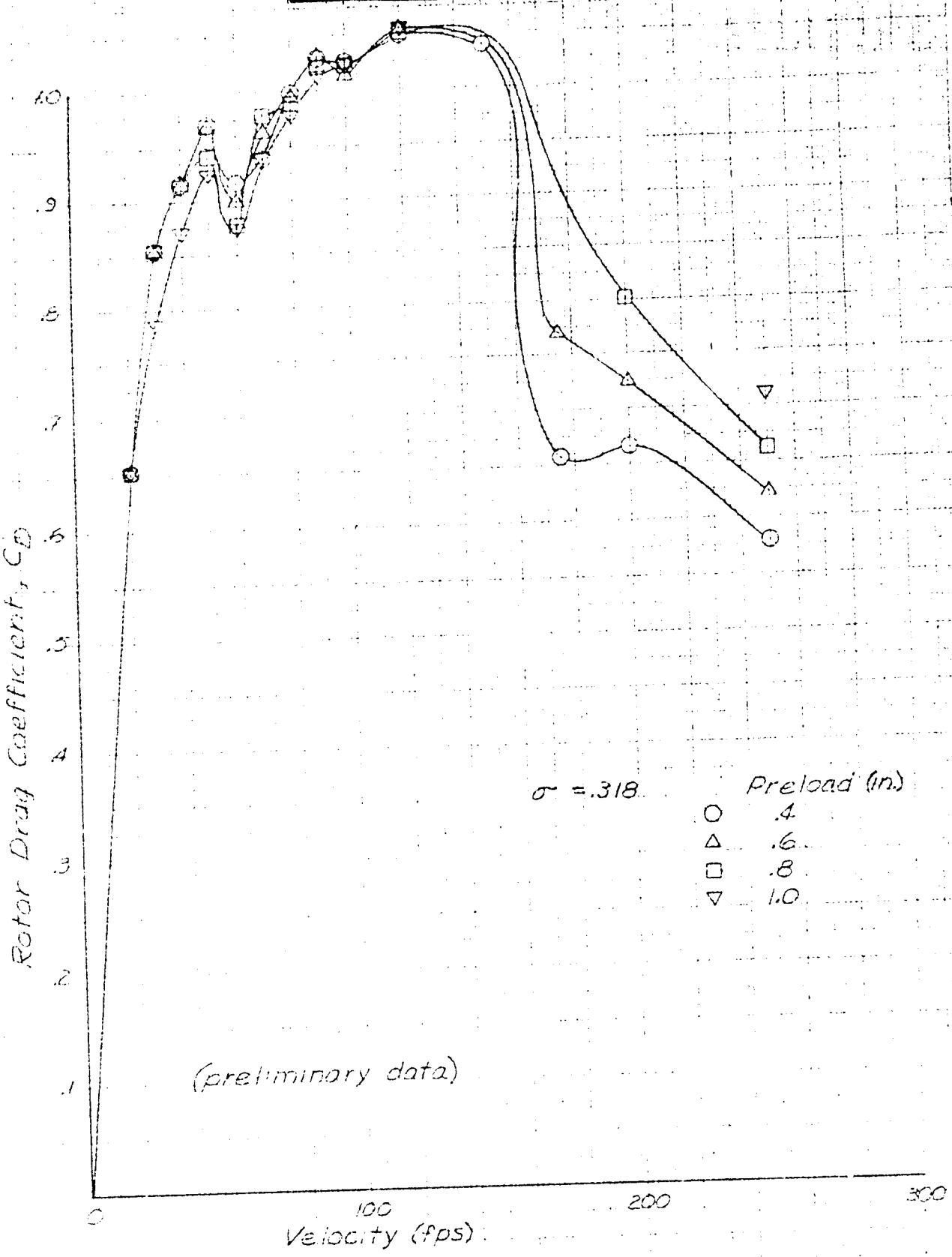
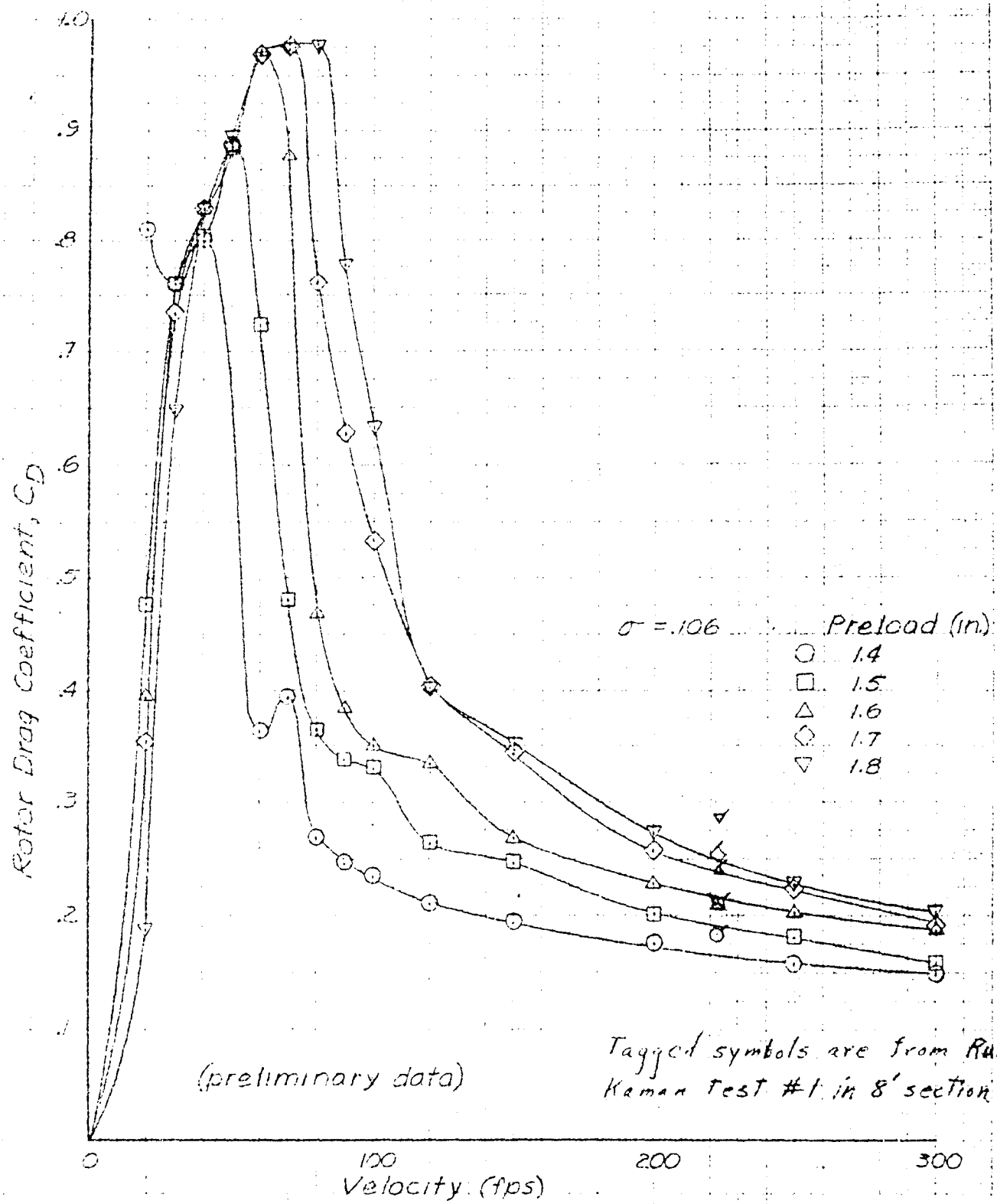


(c) 4 Blades, 6" Chord, Wood Core, -17 Spring (Runs 40-53)

Figure 4 Continued



(d) 2 Blades, 4" Chord, Aluminum Core, -23 Spring (Runs 54-68)

Figure 4 Continued

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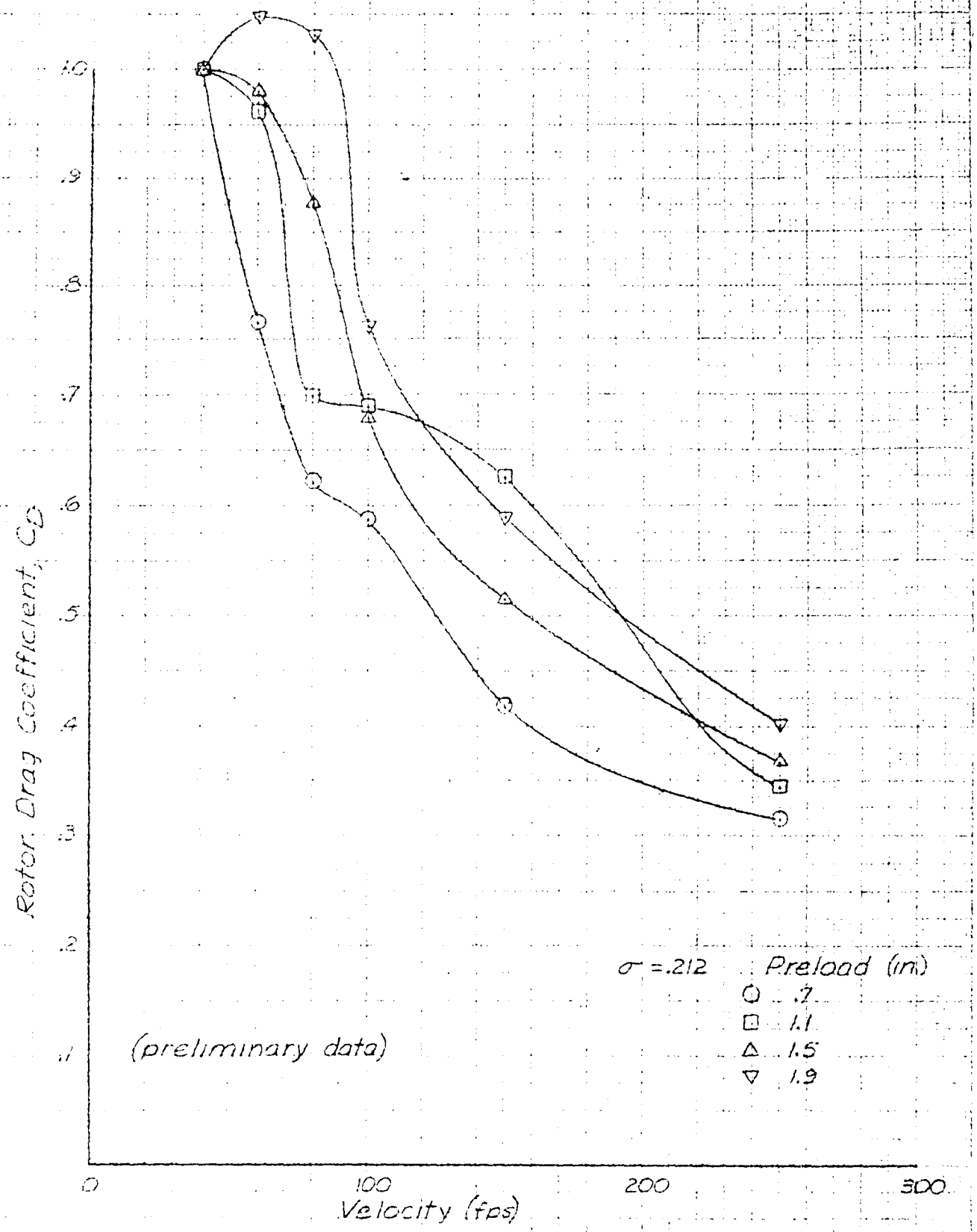

(e) 4 Blades, 4" Chord, Steel Core, -11 Soft Spring (Runs 100-105)

Figure 4 Continued

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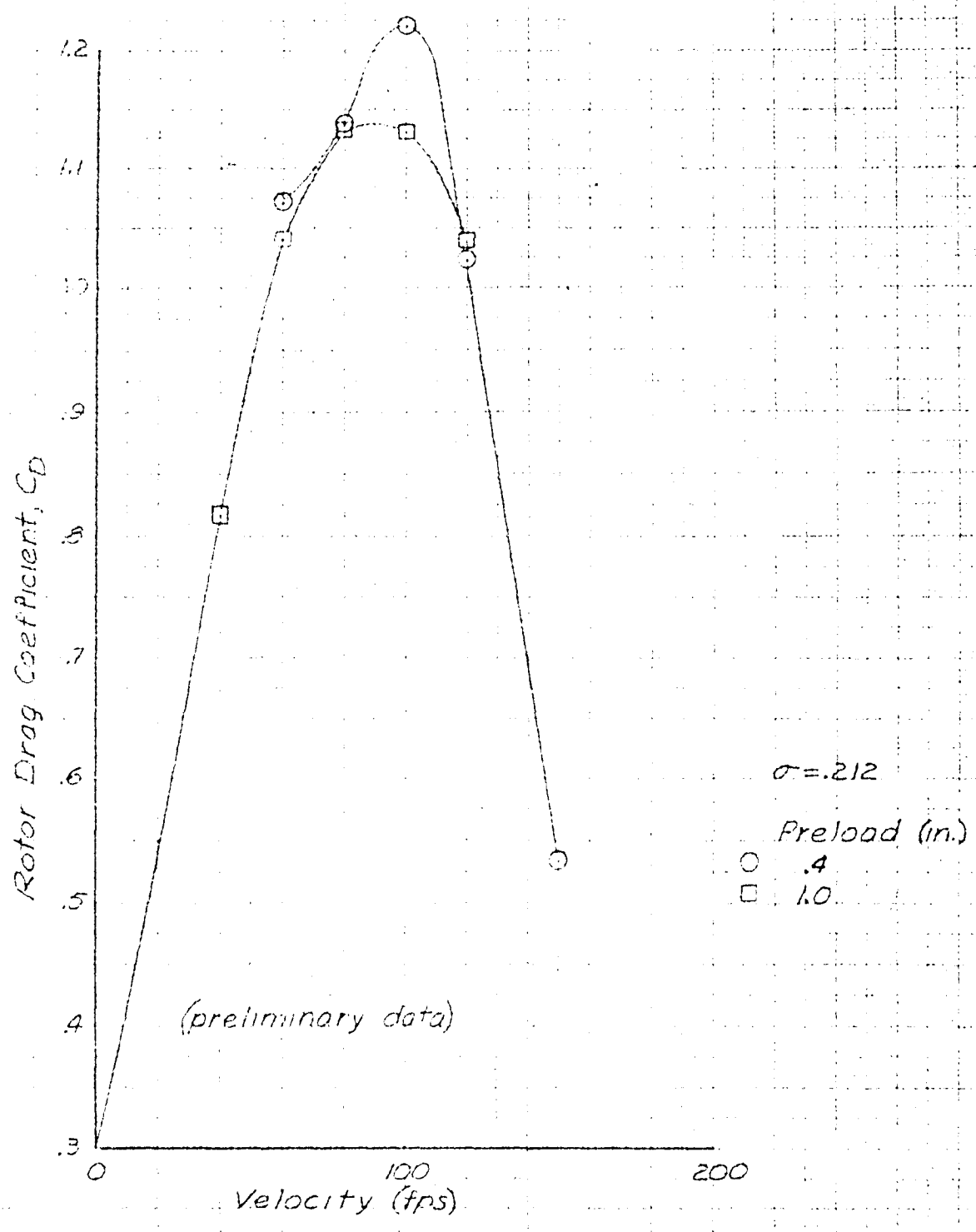

(f) 4 Blades, 4." Chord, Steel Core, Blades forward on Grip, -17 Spring

(Runs 119-124)

Figure 4 Continued

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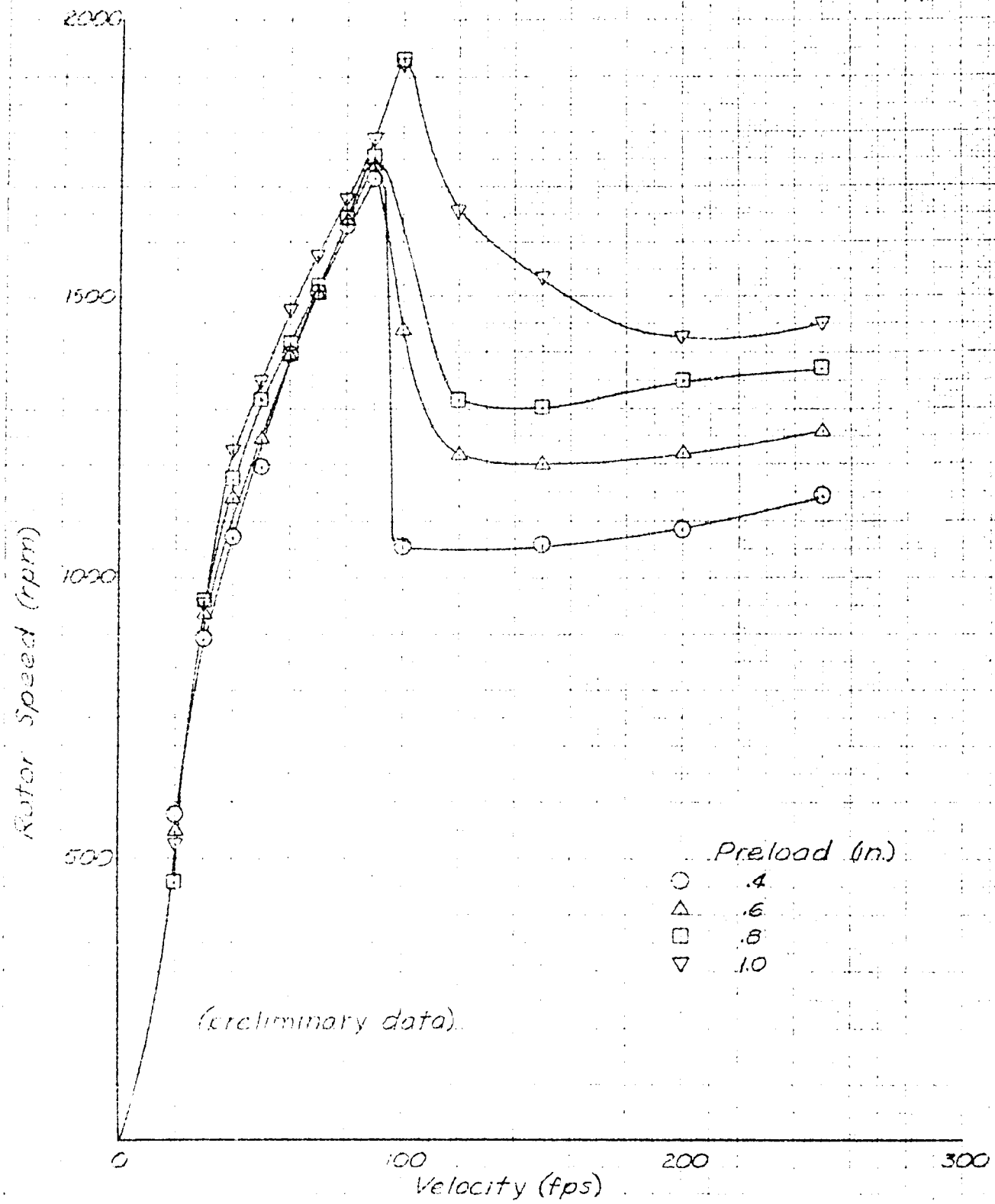

(a) 4 Blades, 4" Chord, Steel Core, -17 Spring (Runs 3-16)

Figure 5 Variation of Rotor Speed with Velocity

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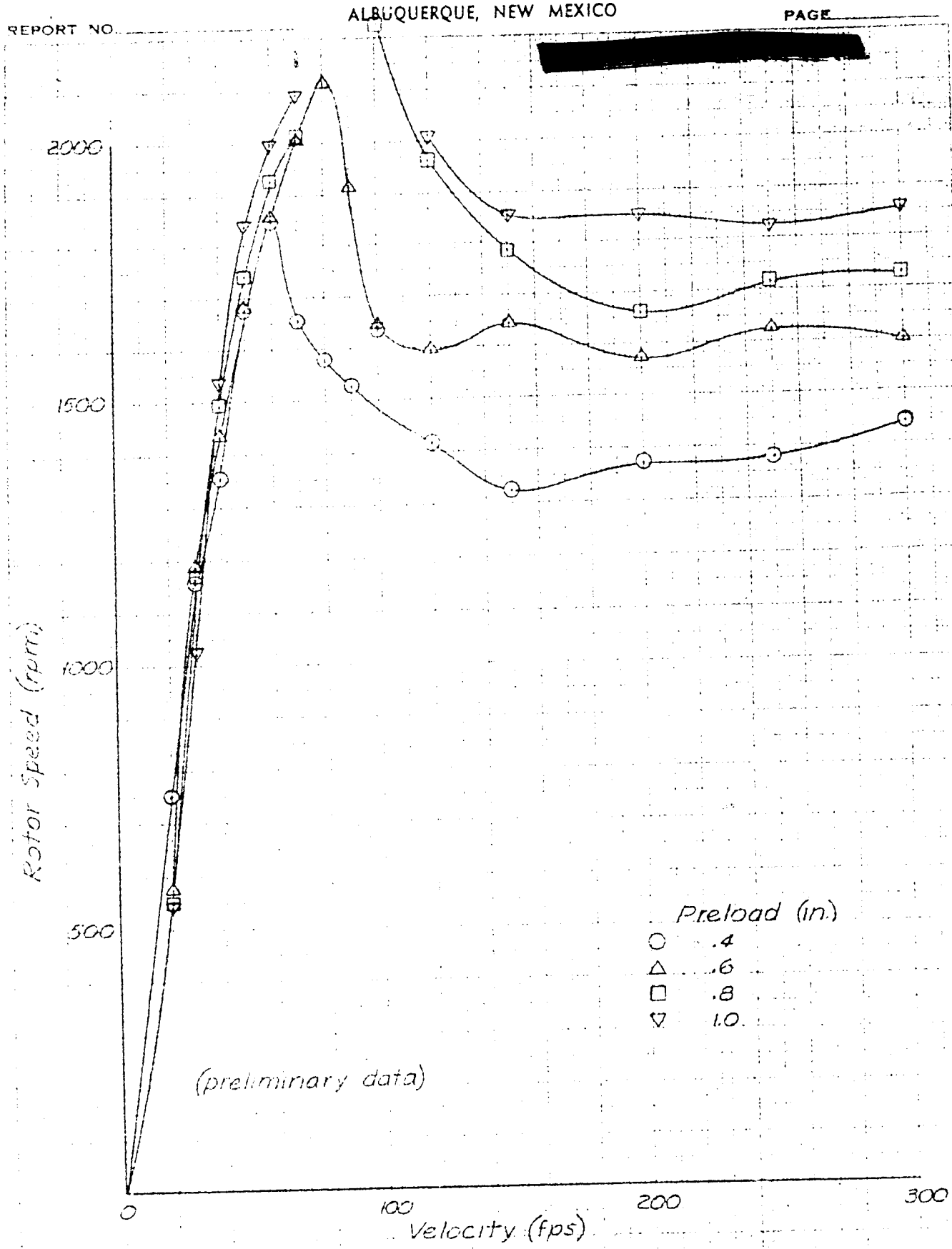

(b) 2 Blades, 4" Chord, Steel Core, -17 Spring (Runs 21-34)

Figure 5 Continued

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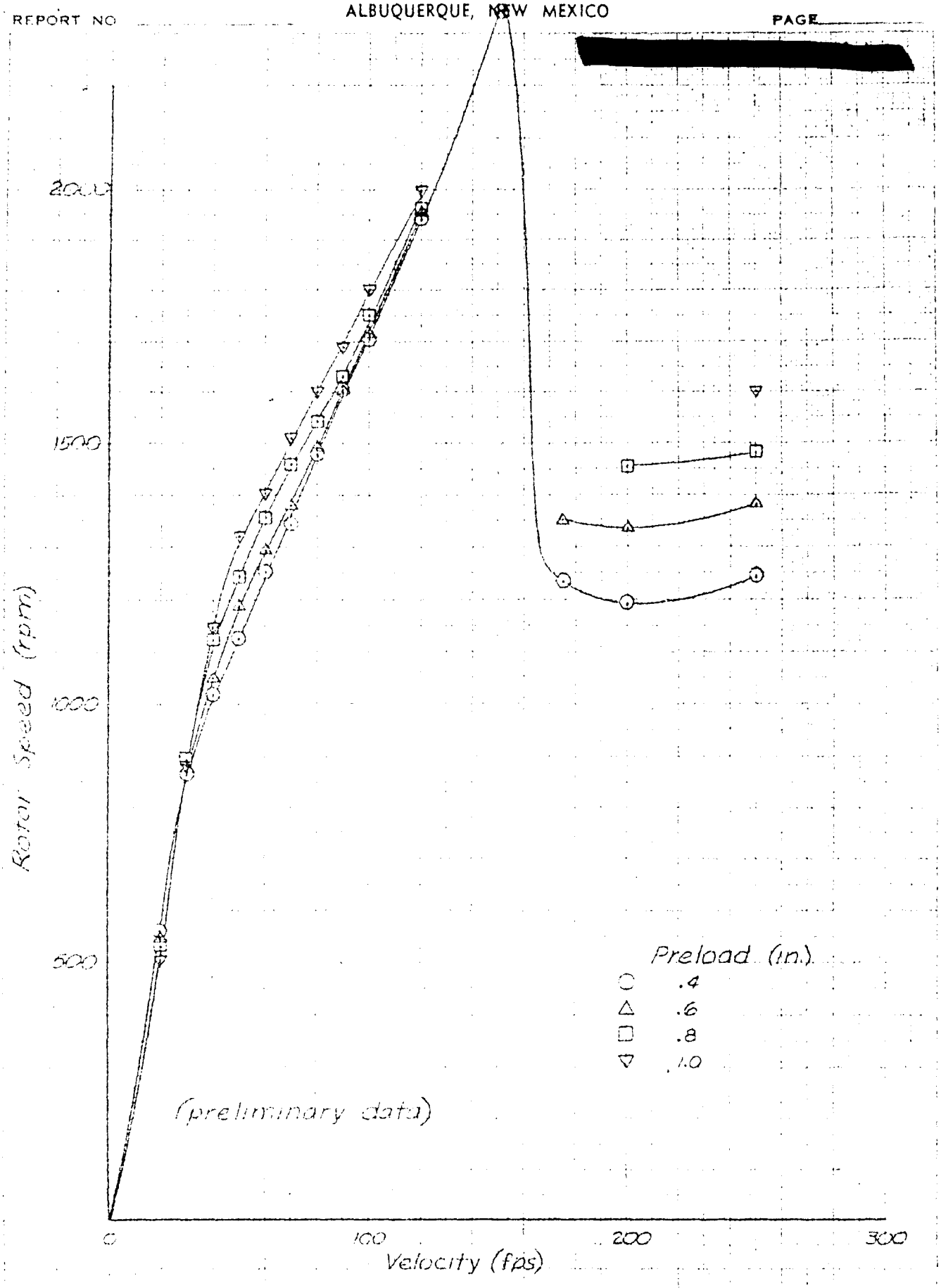

(c) 4 Blades, 6" Chord, Wood Core, -17 Spring (Runs 40-53)
Figure 5 Continued

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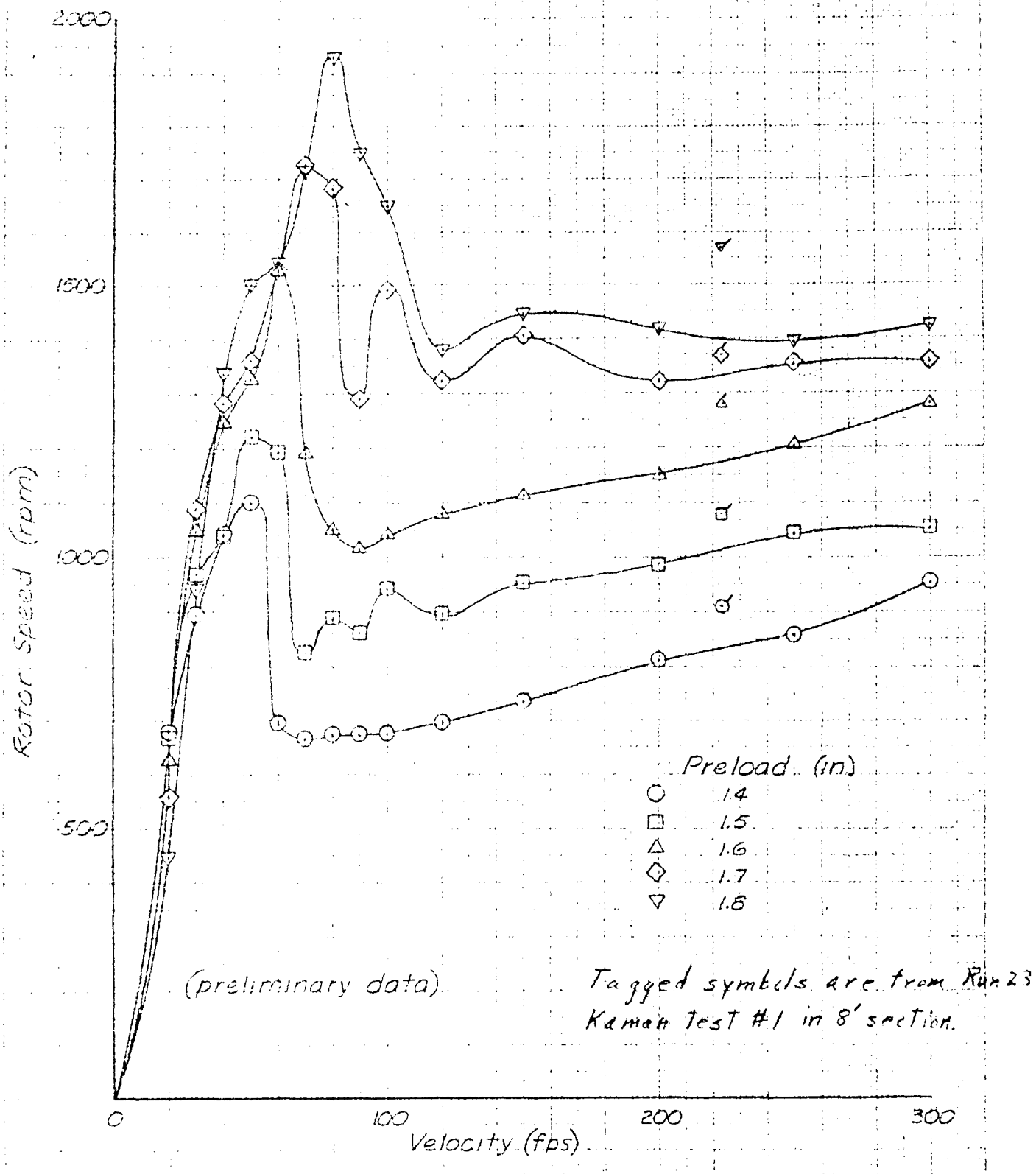

(d) 2 Blades, 4" Chord, Aluminum Core, -23 Spring (Runs 54-68)

Figure 5 Continued

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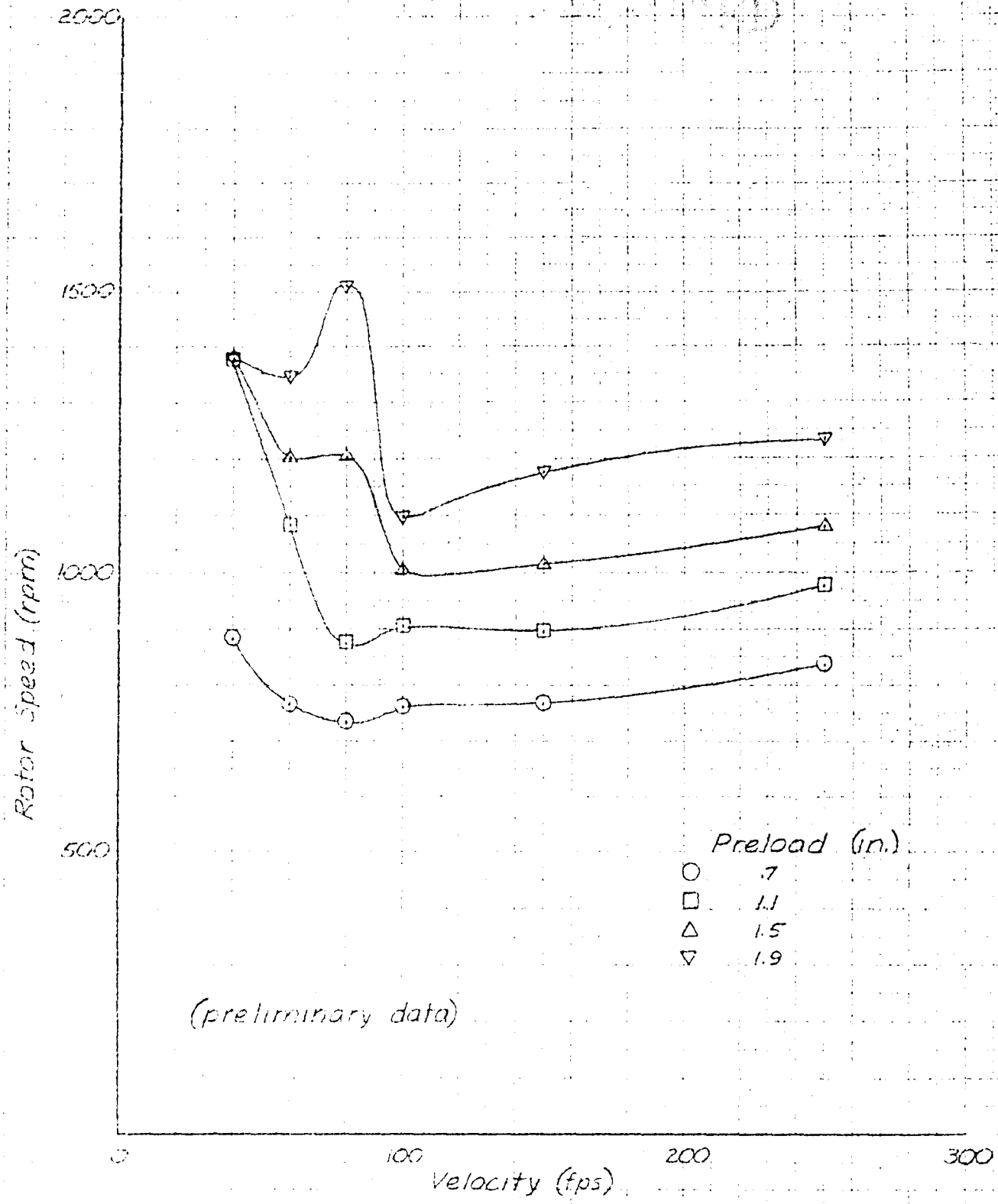

(e) 4 Blades, 4" Chord, Steel Core, -11 Soft Spring (Runs 100-105)

Figure 5 Continued

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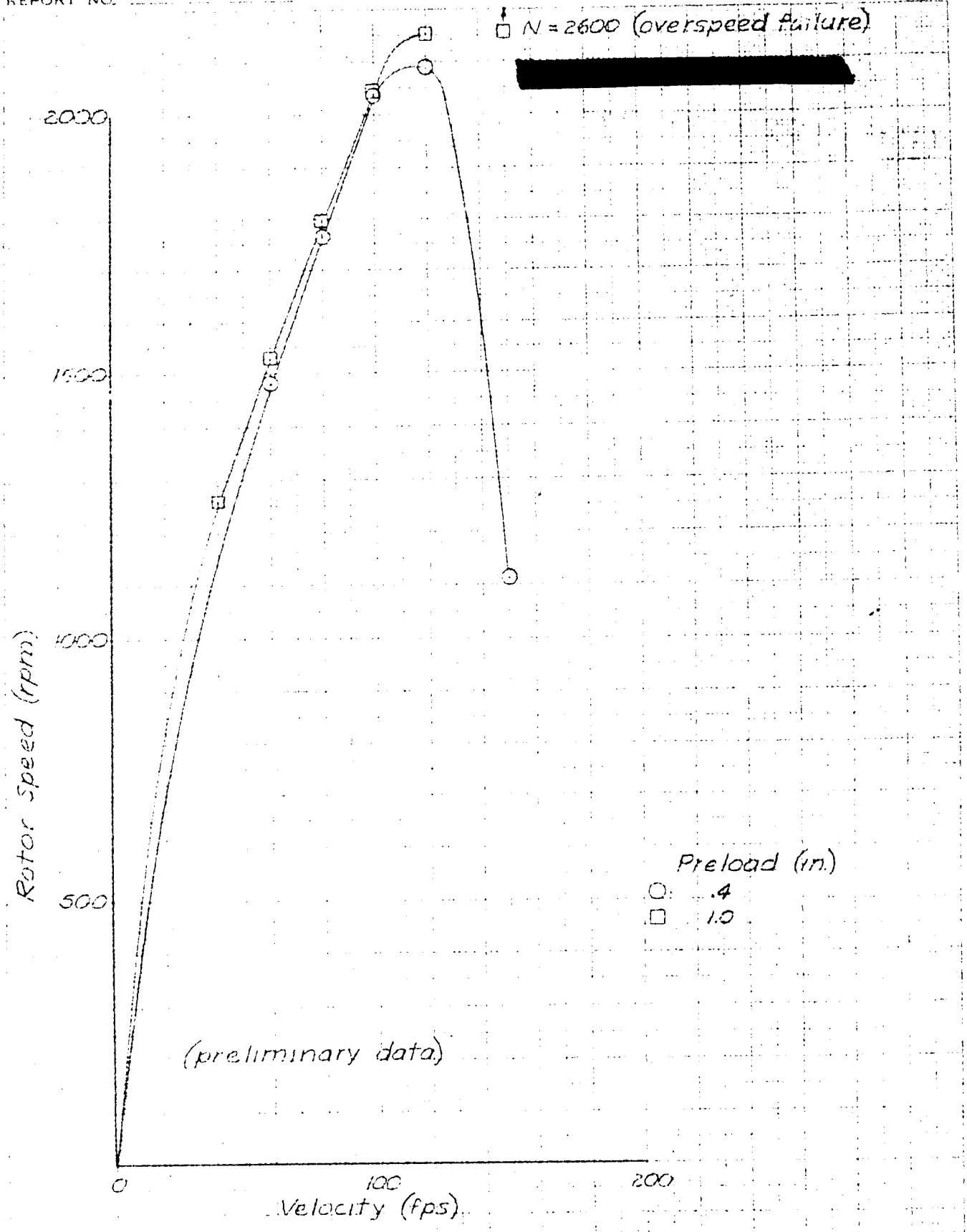

(f) 4 Blades, 4" Chord, Steel Core, Blades forward on Grip (Runs 119-124)

Figure 5 Continued

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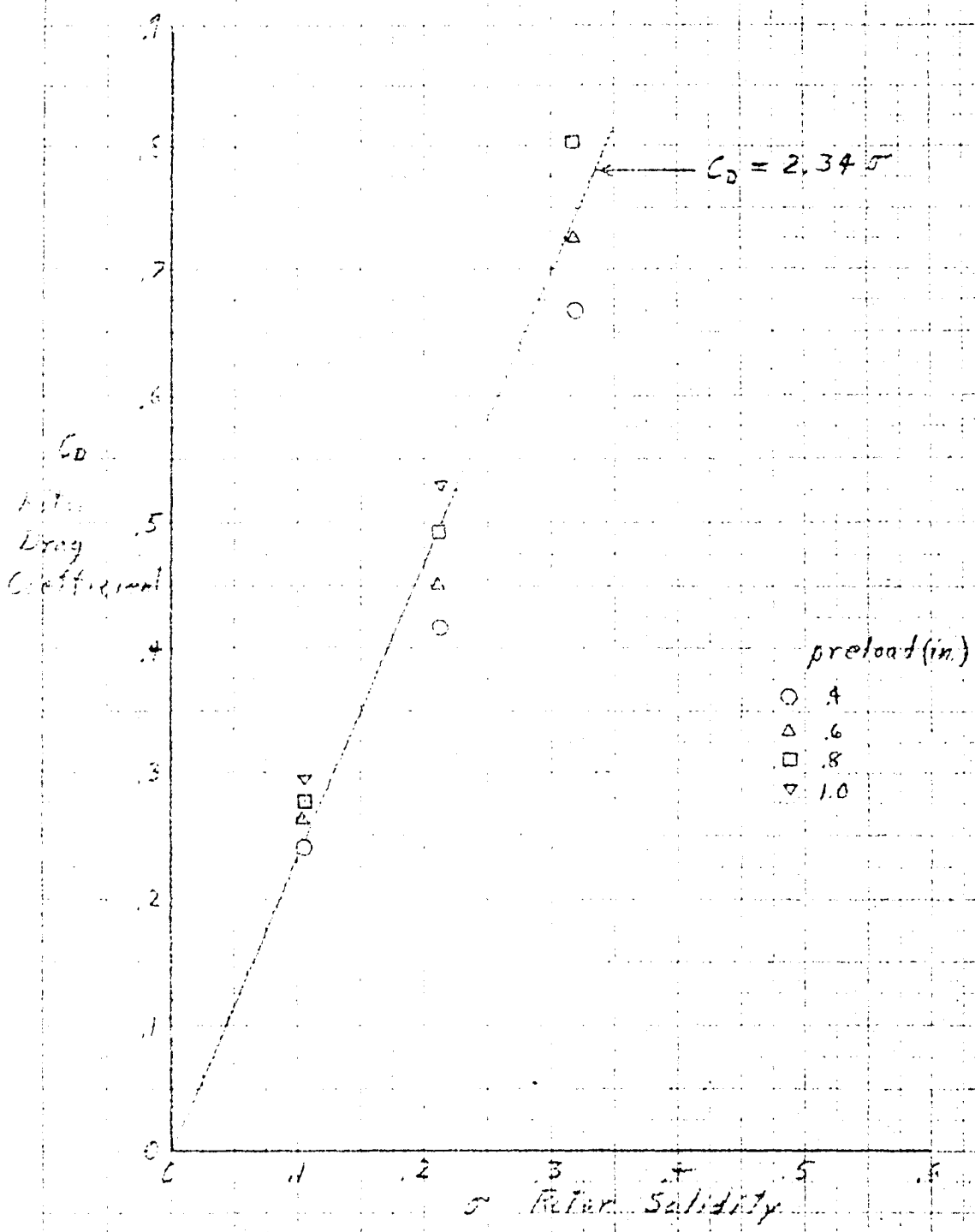

Figure-6. Variation of Rotor Drag Coefficient with Solidity for Governing Rotochutes at a Velocity of 200 f.p.s.

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