SC 1004-A (2-54)

[redacted]

[redacted]

UNCLASSIFIED

[redacted]

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW	
1st Review Date: 4-15-97 Authority: ☐ADC ☒ADD Name: W. Layne	Determination (Circle Numbers): 1. Classification Retained 2. Classified Info Changed to: U 3. Contains No DOE Classified Information 4. Coordinate With: 5. Contains UCNI? 6. Comments: OK for Opennet
2nd Review Date: 4/15/97 Authority: ADD Name: R B Craner	

239-56-51

RESULTS OF SANDIA CORPORATION ROTOCHUTE TESTS AND KAMAN AIRCRAFT CORPORATION ROTOCHUTE TEST NO. 1 CONDUCTED DURING AUGUST 1956

W. B. Pepper - 5141

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW DOWNGRADING OR DECLASSIFICATION STAMP	
CLASSIFICATION CHANGED TO: U Emelda Selph 4-17-97 PERSON CHANGING MARKING & DATE Carmela M Gallegos 5/5/97 PERSON VERIFYING MARKING & DATE	AUTHORITY: R B. Craner RECORD ID: 97SN1312 DATED: 4-15-97

ABSTRACT

The performance of the Sandia Corporation 12-bladed fixed-pitch rotochute as determined by wind-tunnel tests is presented.

The wind-tunnel results of a two-bladed governing rotochute test performed by Kaman Aircraft Corporation are also presented.

[redacted]

Case No. 669.02 UNCLASSIFIED November 16, 1956

[redacted]

[redacted]

UNCLASSIFIED

DISTRIBUTION:

W. F. O'Niell, Kaman Aircraft Corporation, Bloomfield, Conn.
Thru: Mr. R. A. Strieby, Attn: D. V. Robinson
R. W. Henderson, 1200
S. C. Hight, 5100
K. W. Erickson, 5130
G. E. Hansche, 5140
R. N. Browne, 1222
R. S. Claassen, 5133
G. W. McClure, 5133
R. K. Smeltzer, 7221-3
A. D. Pepmueller, 7223 (6)

[redacted]

UNCLASSIFIED

SUMMARY

Sandia Corporation is designing and having built under contract a rotochute drop-test vehicle with a 12-bladed rotor 7.5 feet in diameter. Wind-tunnel tests were made of this rotor in the United Aircraft 18-foot-diameter, low-speed tunnel during August 6-10 to determine the proper blade setting, drag coefficient, and stability.

Kaman Aircraft Corporation has a Sandia Corporation contract to develop a governed rotochute for low-level delivery of a 3000-pound store. During the week of August 13-18, the first Kaman test was conducted in the United Aircraft Corporation 8-foot-diameter, high-speed tunnel.

This memorandum presents the preliminary results of the two tests.

It was concluded that satisfactory performance parameters were obtained for the Sandia Corporation rotochute. A suitable blade angle setting was found to be 98 degrees. For this blade setting, the drag coefficient was 0.85. The Kaman tests showed that the rotor governor was performing as desired over the test Mach range of 0.2 to 0.7. The oscillograph records looked good so that considerable detailed data on rotochute operation should be obtained from the records.

[redacted]

 UNCLASSIFIED

INTRODUCTION

The Sandia Corporation 12-bladed rotochute was tested in the United Aircraft 18-foot-diameter, low-speed wind tunnel during the week of August 6-10. The purpose of this test was to determine a blade angle setting for the fixed-pitch blades which would give maximum drag coefficient without overspeeding the blades and to determine a stable position of the blade hub relative to the gimbal axes. The rotor tested was a full-scale replica of the rotor that will be used on 15 drop-test vehicles.

Kaman Aircraft Corporation conducted their first rotochute test under the rotochute development contract with Sandia Corporation during the following week of August 13-18. The purpose of their test was to measure pressures and stresses over a two-bladed governing rotochute. The 4-foot-diameter rotor was tested in the 8-foot-diameter, high-speed wind tunnel of United Aircraft Corporation.

This memorandum will describe the two tests and give preliminary results.

UNCLASSIFIED

[redacted]

[redacted]

UNCLASSIFIED

RESULTS OF SANDIA CORPORATION ROTOCHUTE TESTS AND KAMAN AIRCRAFT CORPORATION ROTOCHUTE TEST NO. 1 CONDUCTED DURING AUGUST 1956

CH I -- TEST OF SANDIA ROTOCHUTE

Model Description

The rotor consisted of 12 fiber glass-lockfoam blades having a maximum diameter of 7.5 feet. Each blade had 24 degrees of twist and a chord of 5.5 inches. The rotor was mounted on the aft end of a body of revolution having a maximum diameter of 17 inches and a length of approximately 100 inches. The body was supported by a side strut in the 18-foot-diameter test section, as shown in Figure 1. A complete description of the model and test method may be found in Reference 1.

Sandia Test Outline

The blade angle (β) was varied in the following successive steps: 105°, 103°, 101°, 100°, 99°, 98°, 97.5°, 97.0°, 96.5°, 96°. The body was locked during these tests to prevent pitch or yaw. The rotor speed and body-plus-rotor drag was measured at successive constant values of dynamic pressure of 15, 25, 40, and 45 pounds per square foot.

The second phase was concerned with rotochute stability. The longitudinal location of the blade-hub system was varied relative to the gimbal axes. The gimbal stop was generally set to allow 6° of rotor freedom in pitch and yaw relative to the body. The body brake was opened up to allow 8° or 10° of body freedom.

Results of Sandia Tests

Figure 3 shows the variation of body-plus-rotor drag with dynamic pressure for the various blade pitch settings. The linear nature of these curves indicates a constant drag coefficient for each blade angle over the range of dynamic pressures tested. The drag coefficients that are obtained from Figure 3 are plotted in Figure 4. The curve shows a maximum drag coefficient of 0.87 below the step condition. There is a large

UNCLASSIFIED

[redacted]

step increase in drag coefficient between a blade angle of 96.5 and 97.0. On the step the drag coefficient is 1.48. This value is higher than the drag coefficient of a flat solid disk which is 1.17. The rotor is operating in the "vortex ring" state on the step and in the "windmill brake" state for blade angles greater than 97 degrees.

Figure 5 shows the variation of rotor speed with dynamic pressure for the various blade angle settings. The data points appear to be linear on log-log paper indicating that the following formula may be used,

$$N = \frac{b}{q^x}$$

The value of the exponent (x) is the slope of the curves in Figure 5 which is 0.46 and the rotor speed constant (b) is the value of N where each curve intersects the vertical axis at q = 1. A large step increase in rotor speed is noted when the blade angle is decreased from 97.5° to 96.5°. This rotor speed increase corresponds with the drag coefficient increase observed when the rotor goes onto the step condition. The rotor speed never exceeded the 2300-rpm limit to which the blades were tested during the spin tests at WADC. The test values of dynamic pressure on the step condition were limited to a maximum value of (q = 30) because at this speed the drag reached the 2000-pound limit of the tunnel drag balance as may be seen in Figure 3.

The variation of rotor speed constant with blade angle setting is shown in Figure 6. The rotor speed for any dynamic pressure can be calculated by selecting the value of (b) for the desired (β) and using the formula,

$$N = b\, q^{0.46}$$

Figure 7 is a plot of the variation in (b) with (C_D) for the 12-bladed rotor having 24 degrees of twist.

The stability tests were more qualitative then quantitative since the restriction due to sting support makes the wind-tunnel and free-flight test conditions dissimilar because of the gyroscopic effects and the effect of gravity on the gimbaled rotor. When the blade plane of rotation (zero cone angle) coincided longitudinally with the gimbal axes or was downstream of the axes the model was violently unstable dynamically. As the plane of rotation was moved upstream of the gimbal axes, the dynamic stability

improved. The largest separation distance was 3-5/8 inches. Probably even greater separation would be desirable. It would appear that stability is achieved by balancing the centrifugal inertia moment of the rotating blades and hub against the resultant aerodynamic moment of the blades. The gimbal pitch and yaw frequency remained fairly constant at about 0.7 cycle/sec regardless of the position of the rotor plane relative to the gimbal axes.

Discussion of Sandia Rotochute Results

The release conditions for a high-speed low-altitude release will be assumed to be,

Release altitude 1000 ft above sea level,
Release speed $M = 0.9$.

The static pressure at 1000 feet altitude is,

$$p = 2041 \text{ lb/ft}^2.$$

The dynamic pressure is,

$$q = .7\, p\, M^2 = .7(2041)(.9)^2,$$

$$q = 1160 \text{ lb/ft}^2.$$

The Sandia rotochute drop-test vehicle will have blades that are designed for a maximum speed of 2500 rpm. Therefore the allowable rotor speed constant can be calculated,

$$b = \frac{N}{q^{.46}} = \frac{2500}{(1160)^{.46}} = \frac{2500}{25.5} = 98$$

Figure 6 shows that the blade angle must be at least 98° or larger. Values of (β) much larger than 98° would be undesirable since Figure 4 shows that the drag coefficient would be less. Using a blade angle setting of 98° will result in a drag coefficient of 0.85.

The stability tests showed that with the plane of rotation 3-5/8 inches ahead of the gimbal axes, the model was stable but oscillated approximately $\pm 4^\circ$. The gimbal stop was set for 6° so that the hub was not hitting the stop. This configuration will probably be even more stable in free flight.

UNCLASSIFIED

CH II -- KAMAN ROTOCHUTE TESTS

Model Description

The Kaman rotor tested was two-bladed with no twist. The rotor diameter was 4 feet and two blade chords of 4 and 6 inches were tested. The blade airfoil was NACA 0012. The rotor was mounted at the forward end of a sting which was supported in the 8-foot test section by two struts as shown in Figure 2. The purpose and method of the tests is described in detail in Reference 2.

The mechanical operation of the governing mechanism is illustrated in Figure 8. The governor serves the purpose of regulating the blade pitch angle to achieve the highest possible rotor drag consistent with the design speed limitations of a rotor system. In the case of a fixed-pitch rotochute discussed previously, the blade pitch angle must be set high enough to prevent the rotor going onto the step because the much higher rotational speeds of step operation may cause failure under certain conditions such as high dynamic pressure and large diameter. The governor used by Kaman will allow the pitch to change so that the rotor operates on the step when the dynamic pressure has decreased to a value that will result in a rotor speed less than the desired design speed. Step operation, when the dynamic pressure is low enough for the structural design to withstand the speed, allows the attainment of much higher drag coefficients than would be possible with a fixed-pitch rotochute of the same configuration.

The driving force used for governing as shown in Figure 8 is a heavy spring of about 1200 pounds per inch of deflection. At zero forward velocity the spring force causes the blades to assume a full negative pitch position which is limited by a stop to about -6°. As the rotor gains speed the centrifugal force causes the blade to sweep forward as shown in the top view of Figure 8. The linkage system causes the pitch angle to increase when the blade sweeps forward. The degree of positive pitch is limited by the spring force and aerodynamic moment which act against the centrifugal moment. If the spring is compressed by applying preload, the rotor will have to reach a higher rotational speed in order for the centrifugal force to balance the larger spring moment.

Figure 9 diagrammatically describes the operation of the Kaman governing rotochute. In the Mach number range of 0 to 0.2 the rotor is operating on the step condition 1. The governor spring force is causing the blade angle to be negative so that the blade angle of attack

is less than 15°. The blade therefore is operating in the attached flow region where the lift increases linearly with angle of attack and the drag is low. The high lift force and low drag force result in high rotor drag coefficient. As the flow Mach number increases, the rotor speed increases to the point where the blade angle of attack is 15° and the blade stalls since the flow can no longer remain attached. The rotor then seeks a new equilibrium condition which is called the windmill-brake state and is shown in Figure 9 as condition 2.

Kaman Test Outline

The sting support was first tested without the blades to determine tare drag. The 4-inch chord blades were then installed and runs were made at Mach numbers of .2, .3, .4, .5, .6, and .7. The rotor blocking effect limited the tunnel maximum speed to M = 0.7. A series of governor spring settings was tested at each Mach number by remotely setting the spring collar location. All but one of five spanwise pressure stations were covered by scotch tape and each span station was successively tested over the Mach number range mentioned above. During the tests an oscillograph was used to record rotor drag, rotor speed, blade pitch, coning angle, and differential pressures at five chordwise stations. Pitch, drag, and side force were measured on the tunnel balance.

Considerable difficulty was experienced in getting the slip ring system to operate properly. No yawed flight conditions were tested because of time lost in overhaul. The oscillograph data will not be available for analysis until United Aircraft Corporation processes the data but a preliminary analysis indicated that the instrumentation was performing satisfactorily. The 6-inch chord blades were tested next using strain gages to record blade bending moment at five spanwish stations corresponding to the pressure stations investigated previously.

Opening cycle tests were run at the end of the test series. The highest Mach number tested was 0.4. The 6-inch chord blades with strain gages were used. Fastax movies of the opening cycle were taken.

Results of Kaman Tests

The preliminary drag coefficients and rotor speeds shown in Figure 8 show the general performance characteristics of the 2-bladed rotor having 4-inch chord blades. The drag coefficients are low, as would be expected for two blades. Reliable data could not be obtained below a

Mach number of 0.2 because of difficulty in setting tunnel speed. However a rough idea of the variation in rpm from M = 0.2 to M = 0 was obtained by observation. The dotted portion of Figure 8 was therefore estimated. The peaks in rpm and C_D are caused by the rotor operating on the step. The portion of the rpm curve between M = 0.05 and 0.15 is similar to $\beta = 96^{\circ}$ in Figure 5 and the portion between M = 0.2 and 0.6 is similar to $\beta > 97.5^{\circ}$. The second phase Kaman test scheduled for October 8-12 will cover this range by testing the same rotor in the 18-foot-diameter test section at UAC. Figure 10 shows that the governed speed and rotor drag can be varied by adjusting the spring preload. A drag increase is associated with higher speeds and is more pronounced at the lower Mach numbers. The speed can also be controlled by changing the initial blade angle at zero cone (β_o). This change did not affect the drag coefficient curve.

The effect of increasing the blade chord by 50 per cent to 6 inches is shown in Figure 11. The drag coefficient at low Mach numbers is not changed materially. At 0.6 Mach number, the drag coefficient is increased about 30 per cent. The higher solidity 6-inch chord blades results in considerably lower rotor speeds throughout the test Mach number range.

Discussion of Kaman Tests

The effectiveness of the governing action in tending to produce a flat curve of rpm with increasing dynamic pressure is shown in Figure 12. The curve for the Sandia Corporation fixed-pitch rotor is extrapolated up to M = 0.9 from the low-speed data presented in this memorandum using the equation,

$$N = b\, q^{.46}.$$

The curve for the Kaman-governed rotor was obtained by assuming the same design rotor speed as the fixed-pitch rotor and using the same rate of speed variation with Mach number as Figure 10. Figure 12 shows that the governor is working as desired. The step operation afforded by governing will make possible higher drag coefficients than could be obtained with a fixed-pitch rotochute of the same configuration.

CONCLUSIONS

1. Satisfactory performance parameters were obtained for the Sandia Corporation rotochute. A suitable blade setting was determined to

be 98° which results in a constant drag coefficient of 0.85. To preclude the possibility of the rotor going into step operation and overspeeding, a blade angle setting of 99° would be more conservative.

2. The Kaman tests showed that the rotor governor was performing as desired over the Mach number range tested. The oscillograph records looked good so that considerable detailed data on rotochute operation should be obtained from the records. The drag coefficients for a 2-bladed rotor were low, the maximum value being 0.29, indicating that higher solidity, such as four blades, will be necessary.

SYMBOLS

q = Dynamic pressure (lb/ft^2)

β = Blade pitch angle (degrees)

(Considering a rotor fully extended with zero cone angle, the notation generally used by Sandia Corporation has been to say the blade pitch angle is 90° when the blade chord line at 75-per cent radius out from the axis of rotation lies in the plane of rotation. As the airfoil leading edge moves downstream, the blade angle increases.

The notation used by Kaman Aircraft Corporation uses $\beta = 0°$ when we have $\beta = 90°$ and $\beta = +10°$ when we have $\beta = 100°$.)

β_o = Blade pitch angle at zero cone angle (degrees)

C_D = Drag coefficient = $\frac{D}{q\,S}$

S = Maximum disk area covered by rotor at zero cone angle (ft^2) 44.1 sq ft for Sandia tests and 12.58 sq ft for Kaman tests.

D = Drag force (lb)

(In this memorandum the drag force is for body-plus-rotor in the Sandia tests and only for the rotor in the Kaman tests.)

N = Rotor speed (rpm)

b = Rotor speed constant

M = Mach number

W. B. PEPPER - 5141

Case No. 669.02
November 16, 1956

[redacted]

REFERENCES

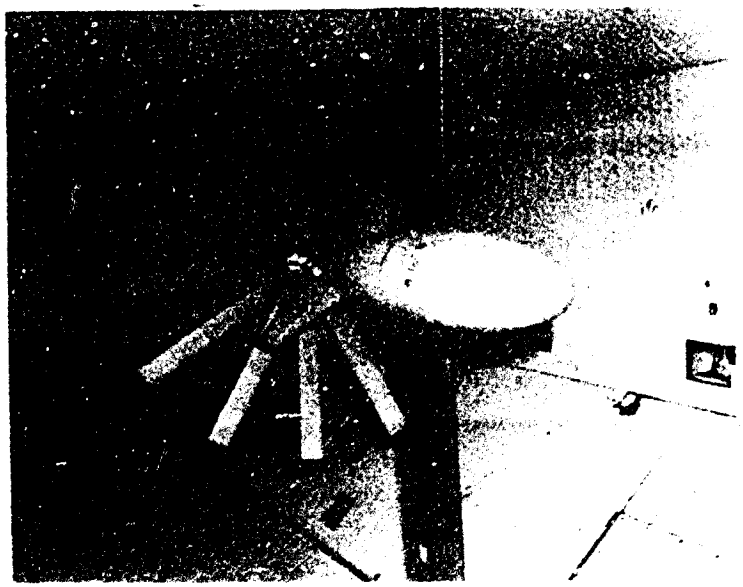
1. E. J. Meyer, Pretest Information Report No. 96 for United Aircraft Corporation, "Low-Speed Wind-Tunnel Test of a Rotochute Drag Device", Sandia Corporation PTI No. 96, June 1956.

2. Letter to G. E. Hansche, "June 19 Trip Report to Kaman Aircraft Corporation (Survey of Contract Status)", by W. B. Pepper, 5141 and G. W. McClure, 5133.

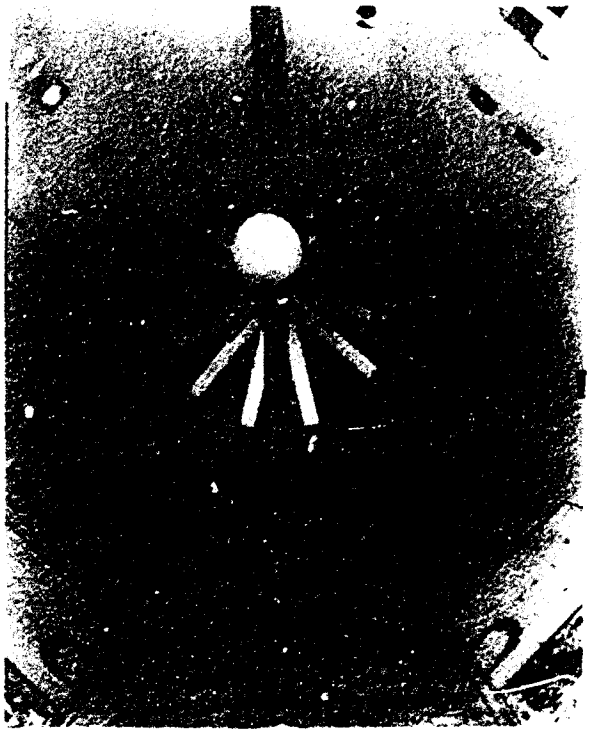
[redacted]

[redacted]

UNCLASSIFIED



b FRONT THREE-QUARTER VIEW



a. FRONT VIEW LOOKING DOWN-WIND

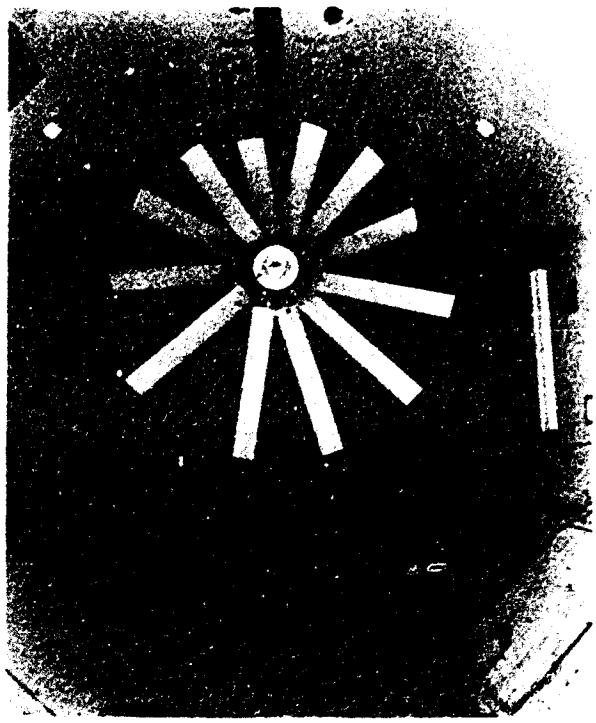
FIGURE I. SANDIA CORPORATION FULL-SCALE ROTOCHUTE IN UNITED AIRCRAFT CORP. 18' DIAMETER WIND TUNNEL.

[redacted]

UNCLASSIFIED

[redacted]

UNCLASSIFIED



c. REAR VIEW LOOKING UP-WIND

FIGURE 1. Continued

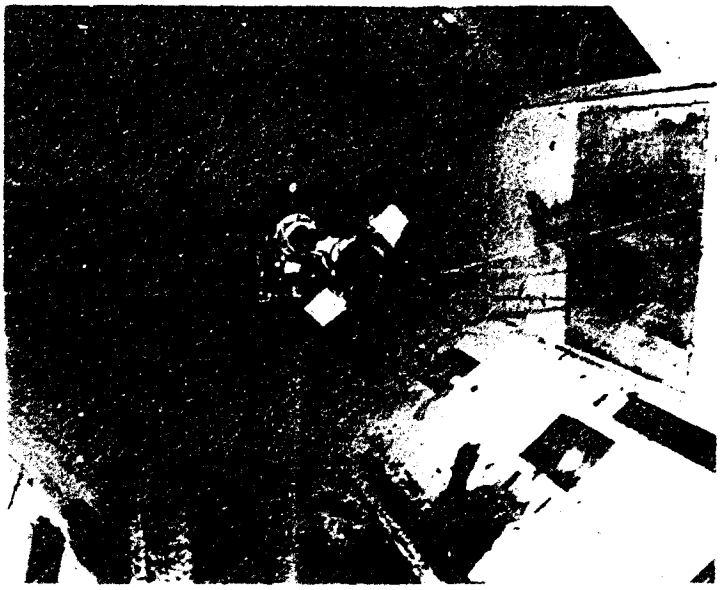
UNCLASSIFIED

[redacted]

[redacted]

UNCLASSIFIED

b. VIEW SHOWING GOVERNOR AND INSTRUMENTATION



a. VIEW LOOKING DOWN-WIND

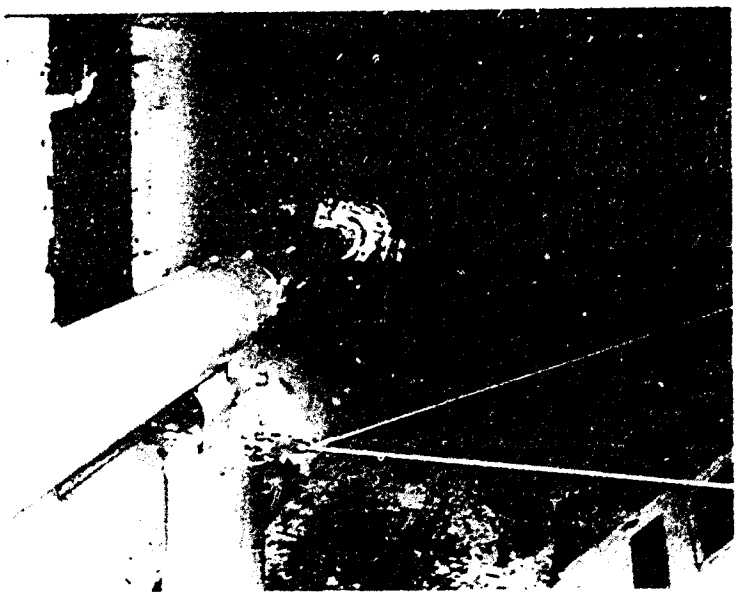
FIGURE 2. KAMAN EXPERIMENTAL TEST ROTOR IN UNITED AIRCRAFT CORP. 8' DIAMETER WIND TUNNEL.

UNCLASSIFIED

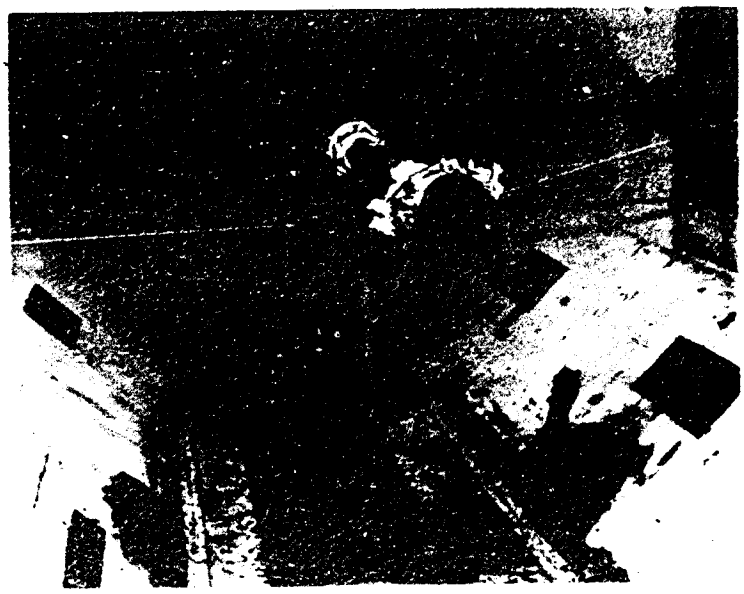
[redacted]

[redacted]

UNCLASSIFIED



d. VIEW LOOKING UP-WIND WITH BLADES FOLDED



c. VIEW LOOKING DOWN-WIND WITH BLADES FOLDED

FIGURE 2. Continued

UNCLASSIFIED

[redacted]

UNCLASSIFIED

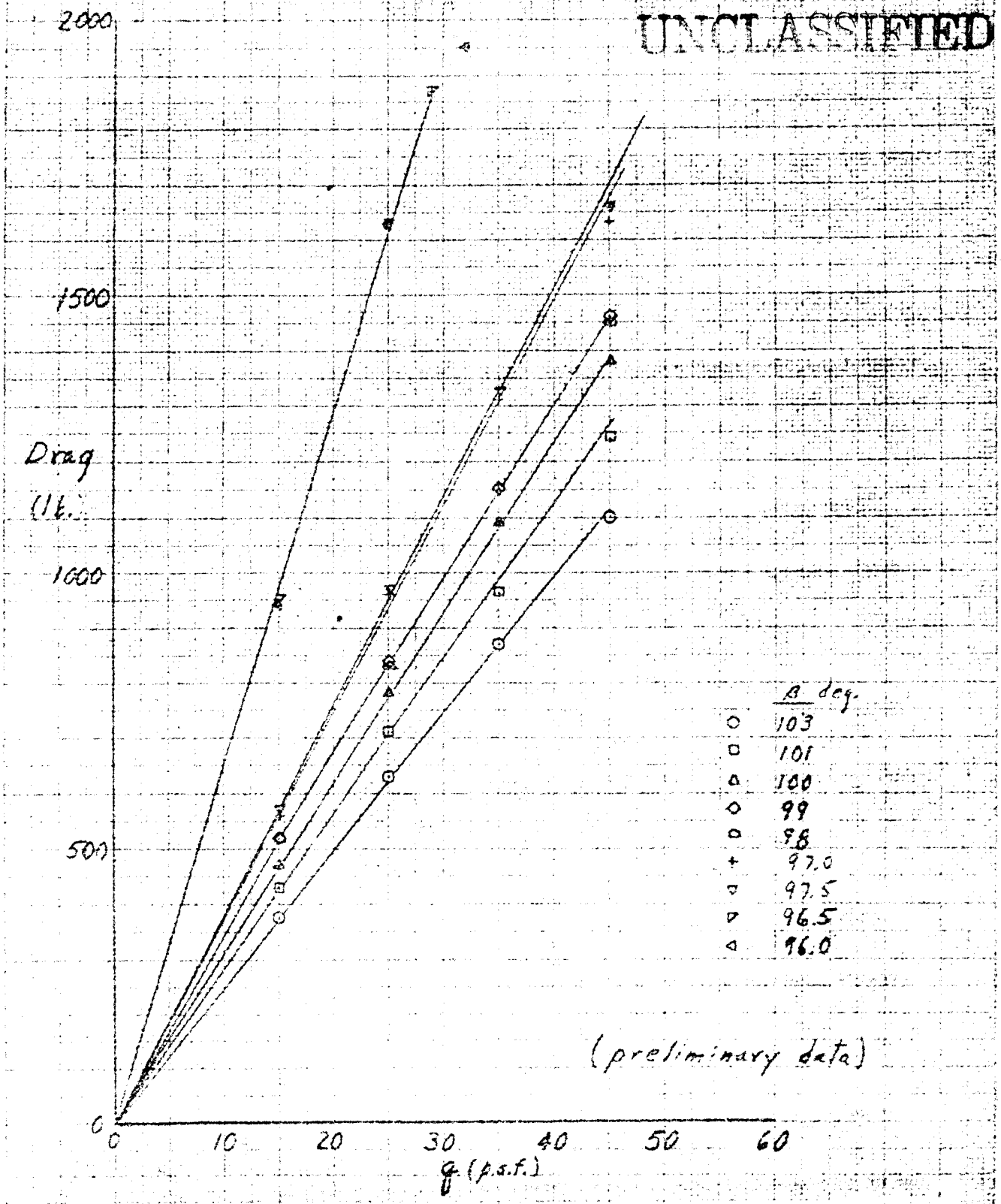


Figure-3. Variation of Drag with Dynamic Pressure for Various Blade Pitch Settings of Sandia Corporation 12-bladed Ringsail Parachute.

UNCLASSIFIED

UNCLASSIFIED

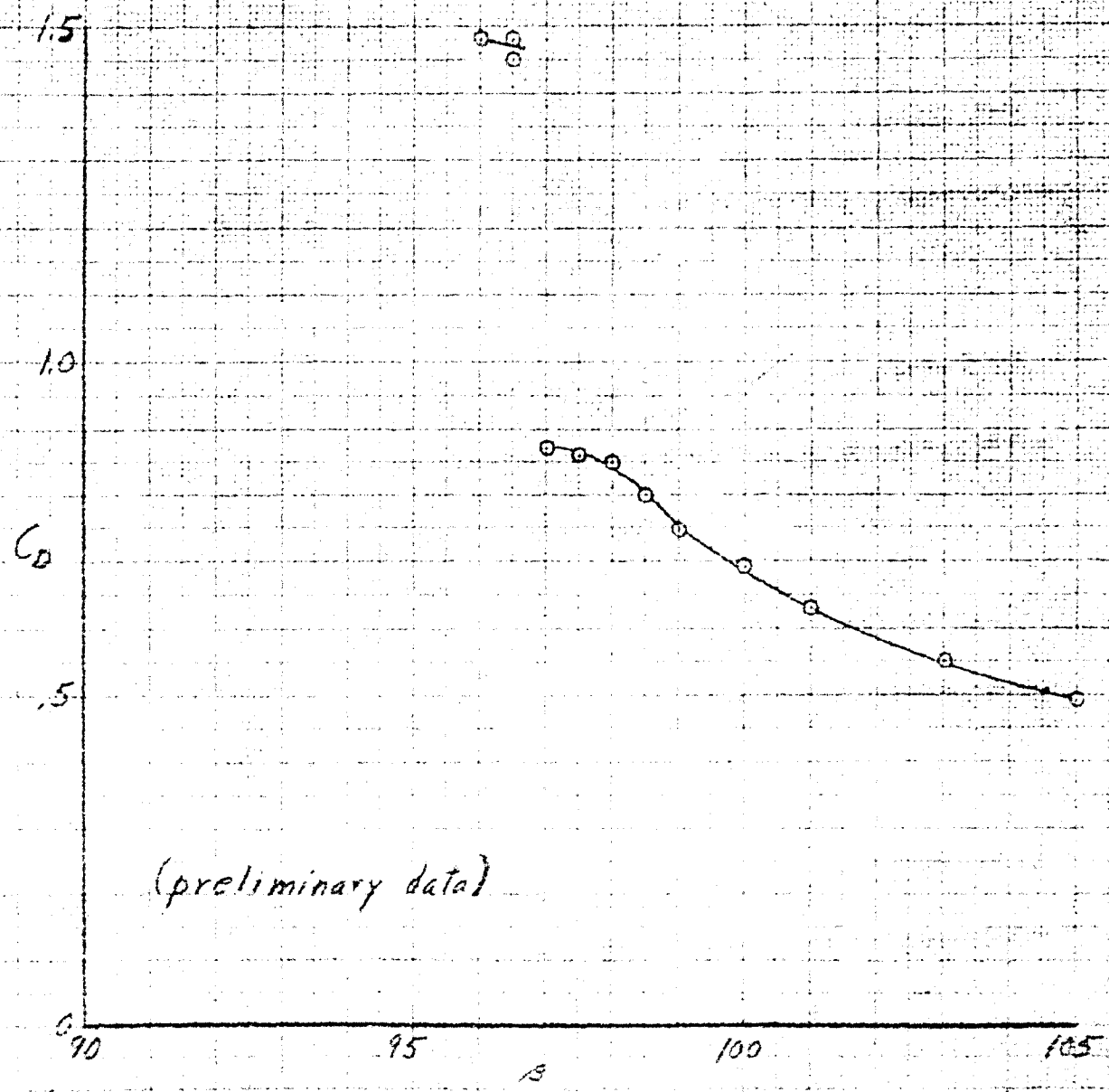
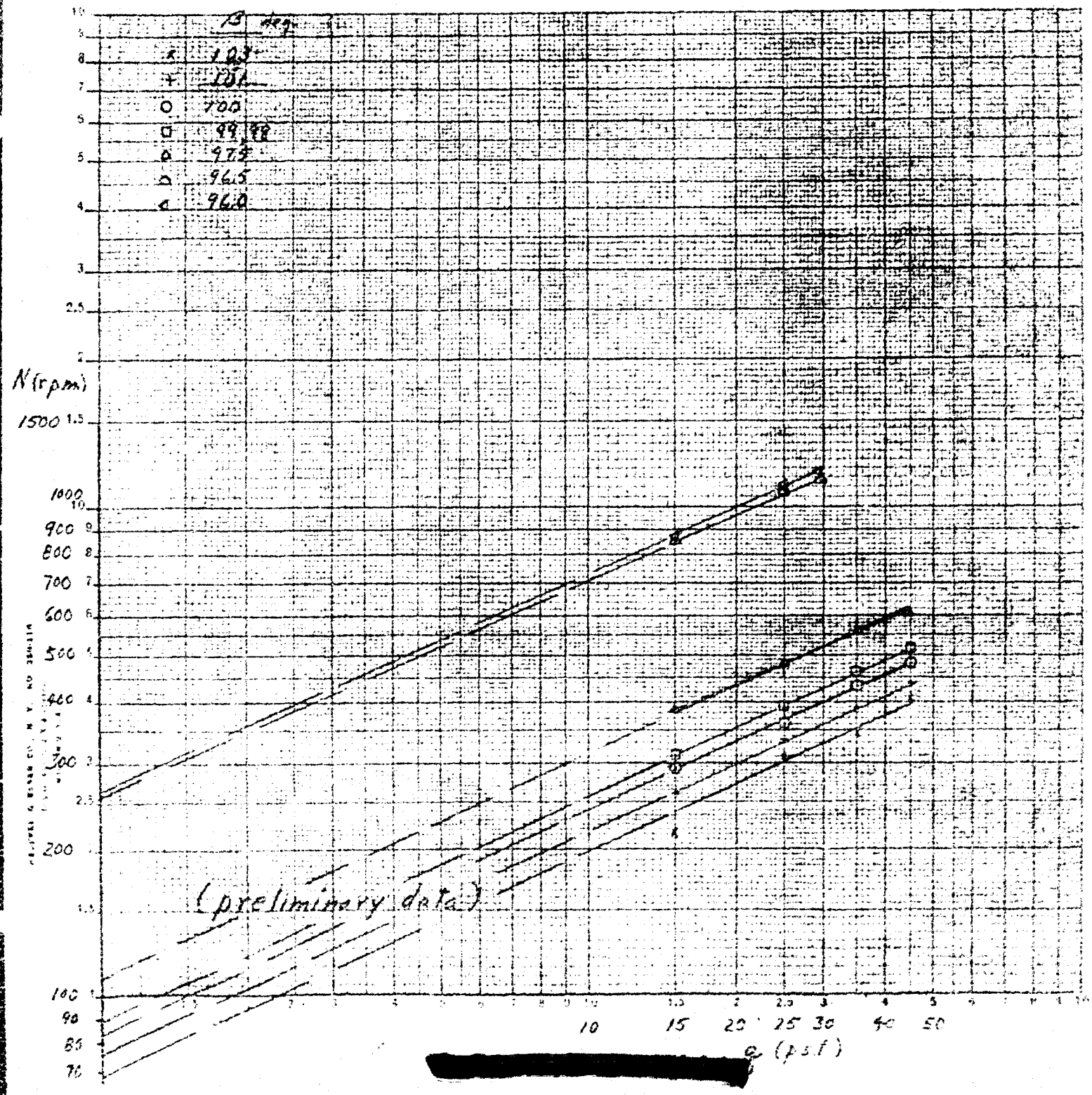


Figure- 4. Variation of Drag Coefficient with Blade Angle Setting for Sandia Corporation 12-bladed Parachute

UNCLASSIFIED

UNCLASSIFIED

[redacted]



[redacted]

Figure-5. Variation of Rotor Speed with Dynamic Pressure for Various Constant Blade Pitch Settings of the 12-bladed Sandia Convertiplane Rotor.

[redacted]

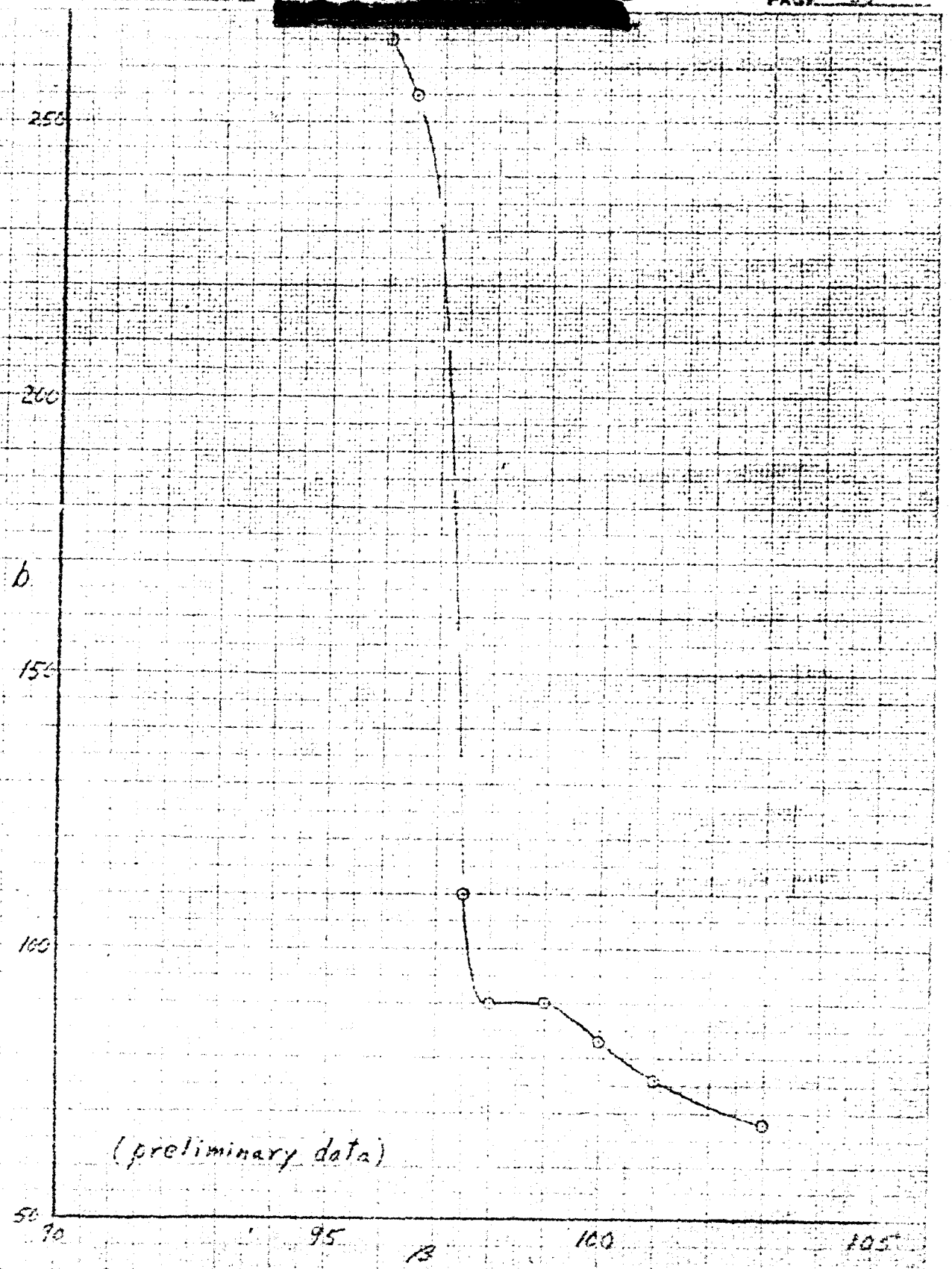


Figure - 6 Variation of Rotor Speed Constant with Blade Angle for Sandia Corporation Bladed Rotor

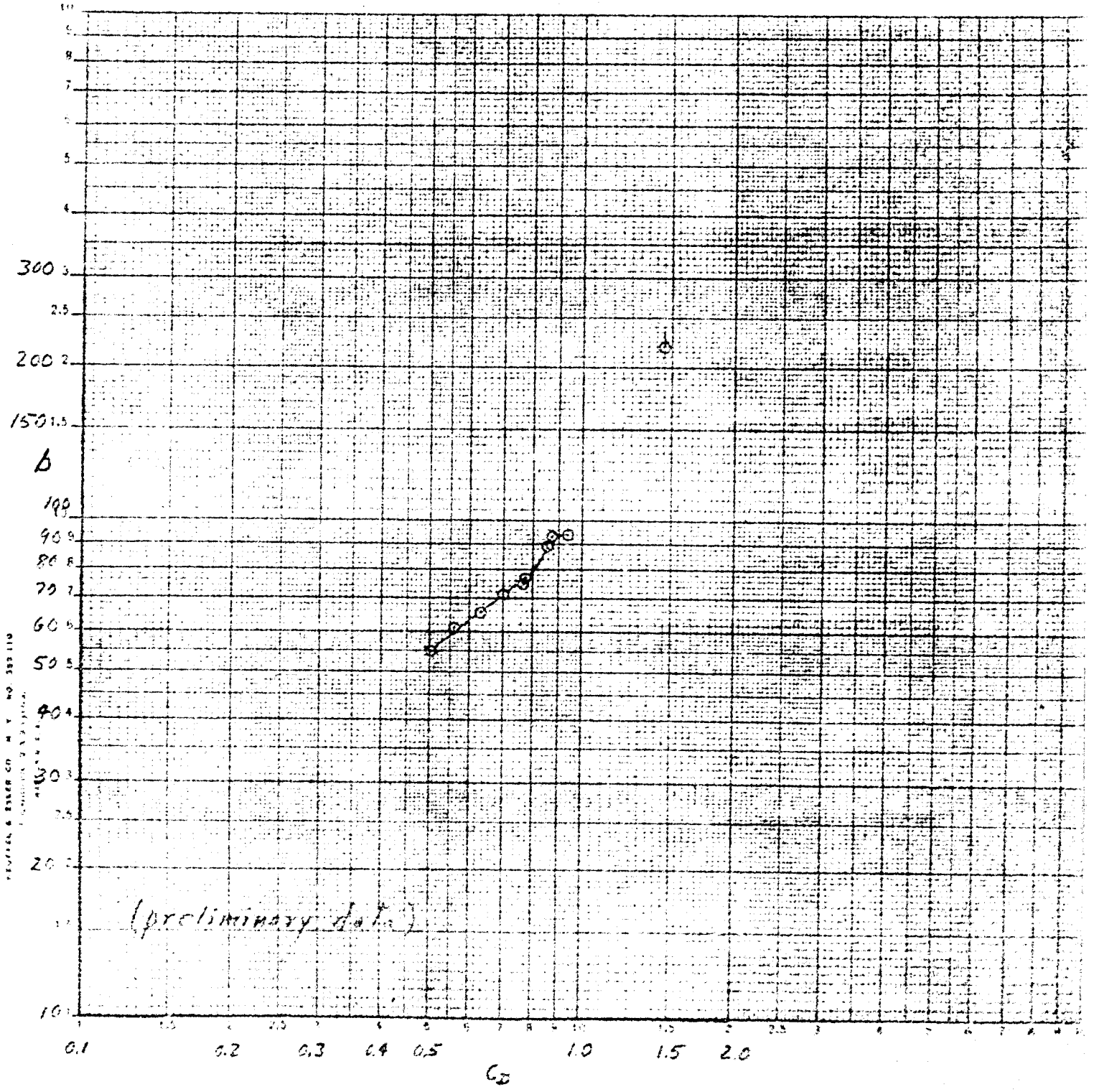


Figure-7. Variation of Drag Coefficient with Rotor Speed Constant for 12-bladed Sandia Corporation Rotochute.

1. Universal ball-socket attaching coning hinge to hub.
2. Blade grip attachment.
3. Governor spring.
4. Hub (rotates with blades).
5. Blades.
6. Spring collar.

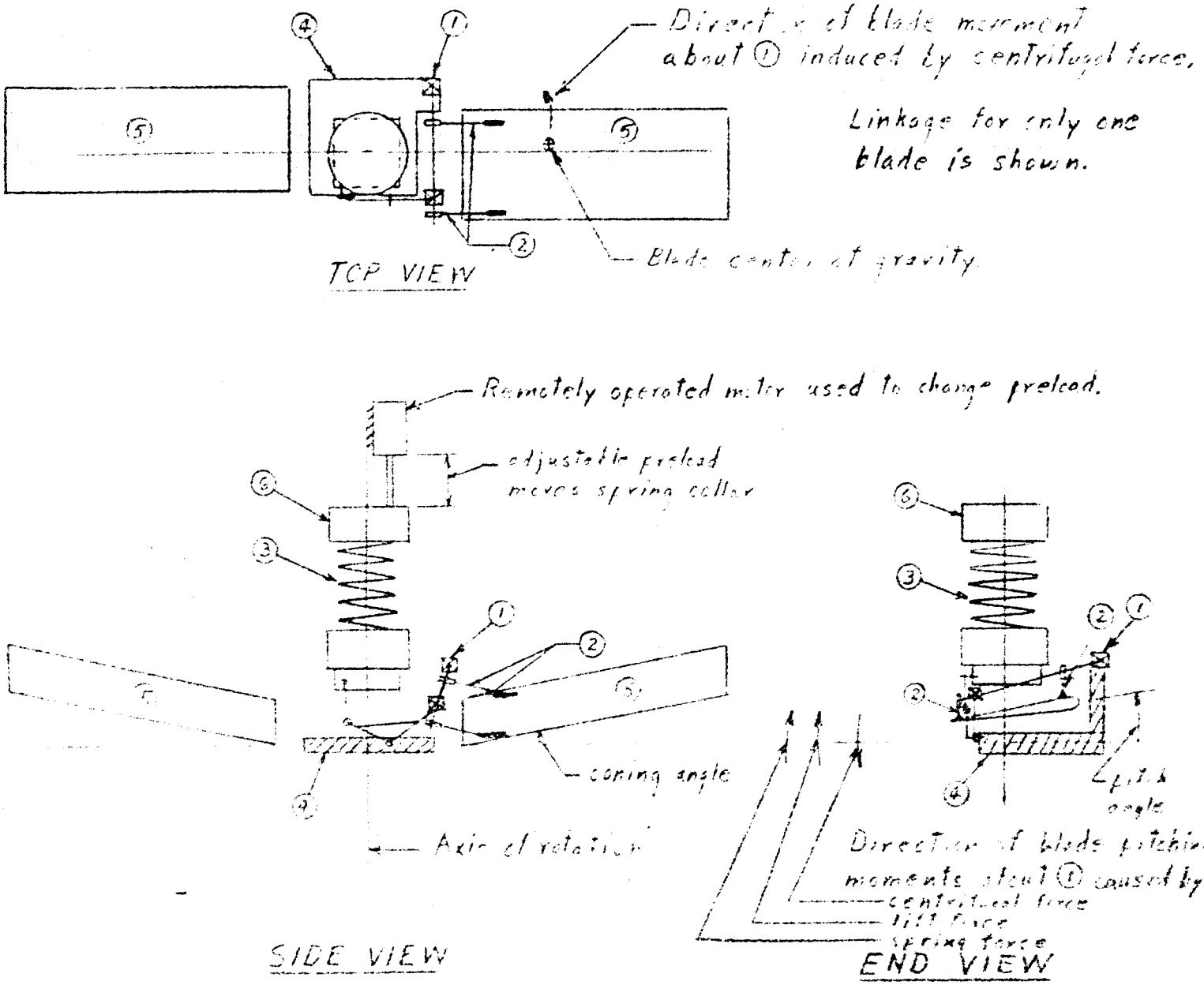
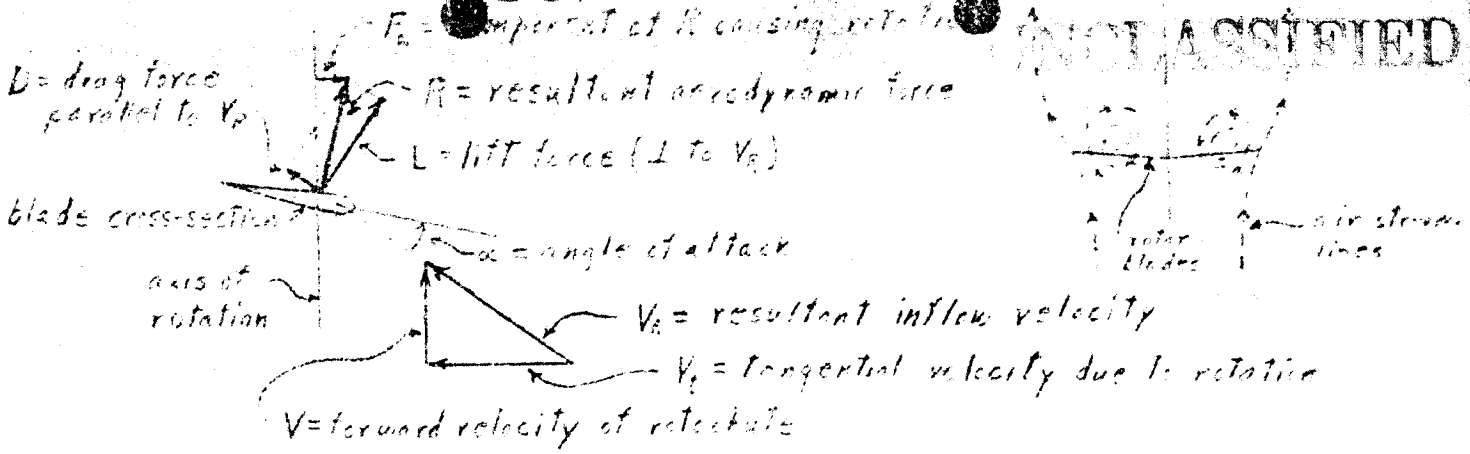


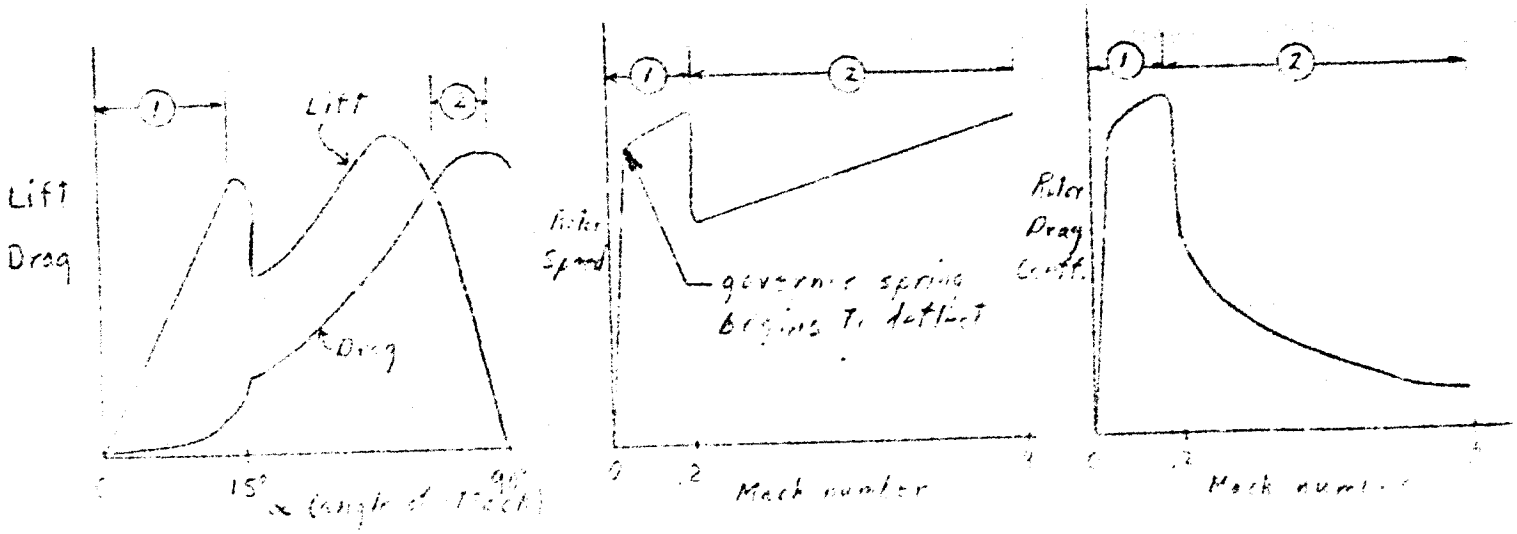
Figure-8. Schematic Illustration of Kaman Rotochute Governor Mechanism.

[redacted]

UNCLASSIFIED



Condition ①, On-Step (Turbulent Windmill Brake State)



Condition ②, Off-Step (Windmill Brake State)

Figure-9. Description of Operation of Kaman Governing Rotorcraft.

UNCLASSIFIED

[redacted]

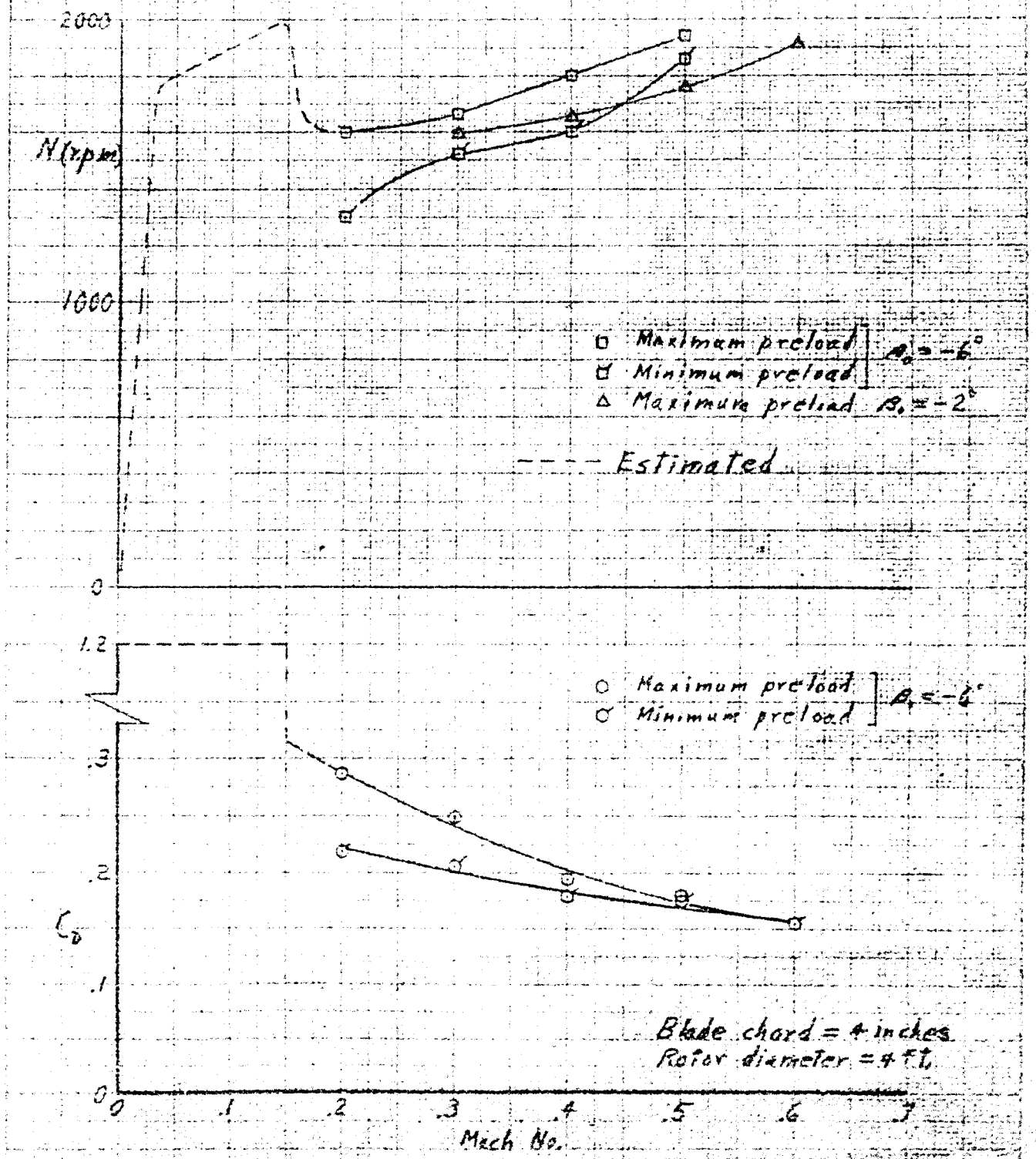


Figure-10. Variation of Rotor Speed and Drag Coefficient with Mach Number for Various Governor Settings of Rotor Two-bladed Rotochute During August 1954 Wind Tunnel Test

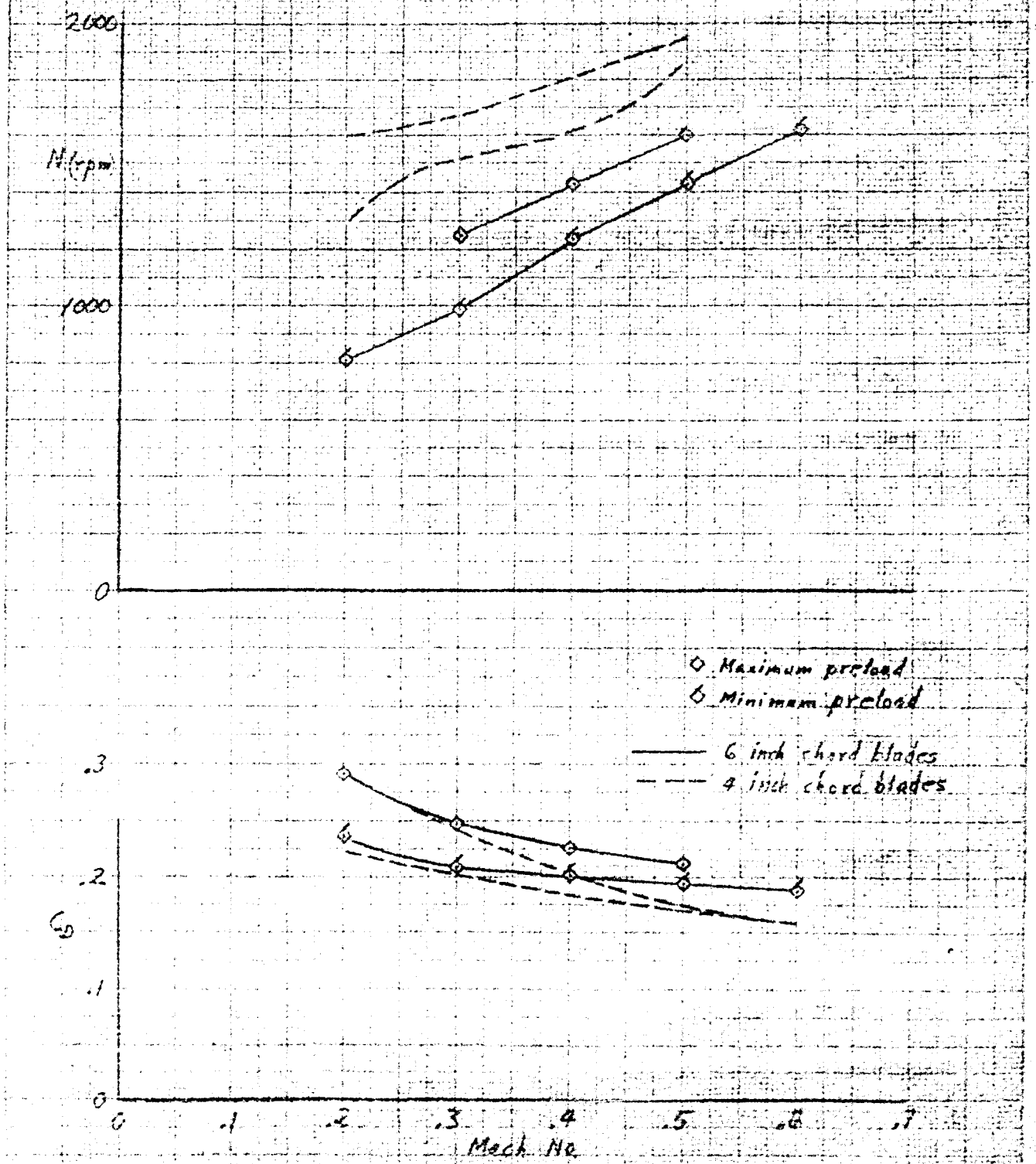


Figure-11 Comparison of 4-inch and 6-inch Blades for 4 Foot Diameter Roman Rotor

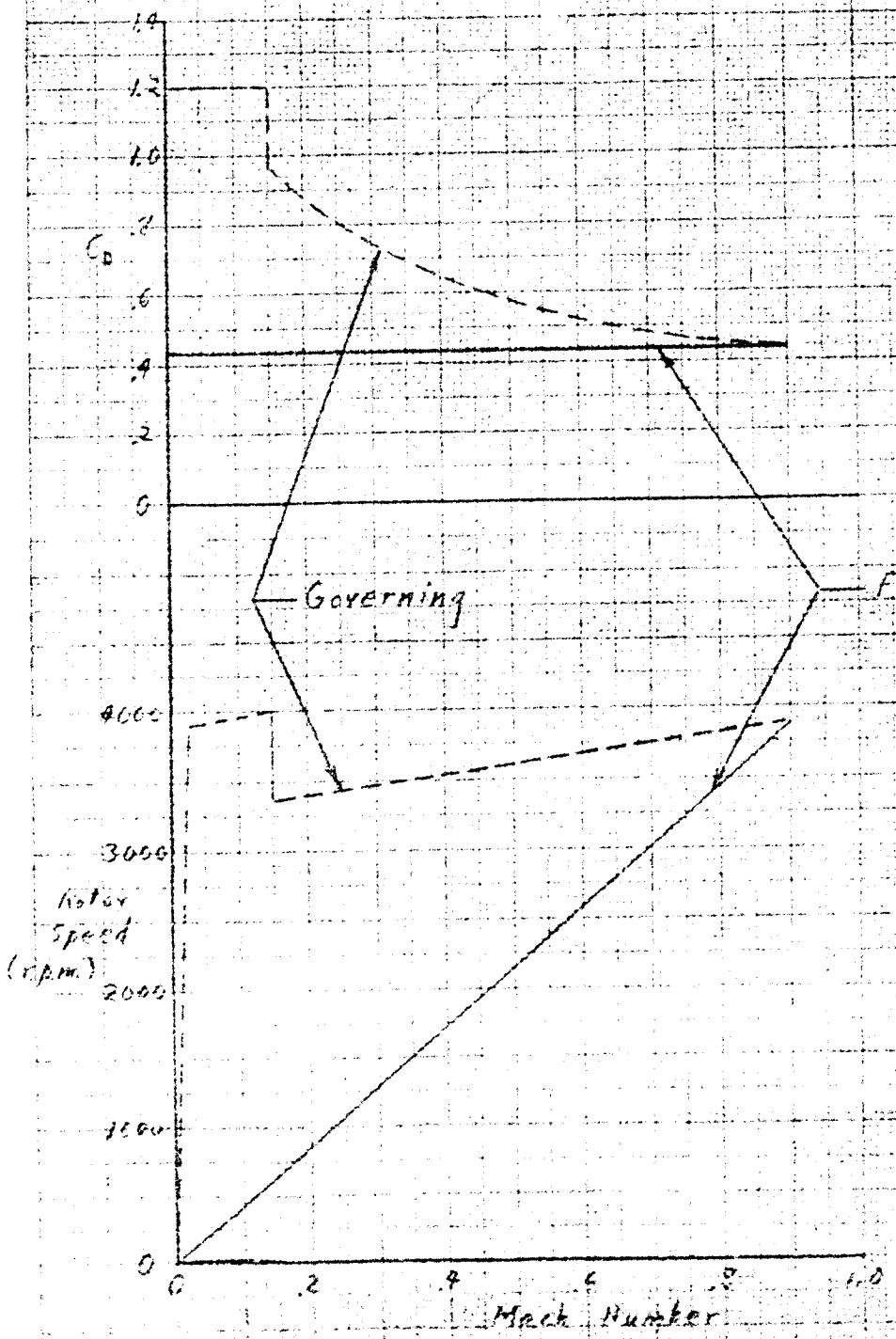


Figure-12 Estimated Performance Comparison of Fixed Pitch and Governed Rotochoters with 4 foot Rotor Diameter