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Report No. T-93
Date: 22 January 1957

THE KAMAN AIRCRAFT CORPORATION

BLOOMFIELD, CONNECTICUT [redacted]

ROTOCHUTE MODEL KRC-2

CONTRACT NO. Nonr 901(00)

TITLE

Low Speed Wind Tunnel Test of 12 Ft. and 14 Ft. Diameter Rotochutes

Prepared by James S. Hodsdon

Checked by [illegible]

Approved by D. W. Robinson Jr.
DM.

This document has been reviewed in accordance with OPNAVINST 5510.17, paragraph 5. The security classification assigned [illegible] is correct.
Date: 7/12/57 Cdr. C. J. Latimer, U.M.
By direction of Chief of Naval Research (Code 46)

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INTRODUCTION

In order to gain additional data on the performance of the Kaman Rotochute, being developed under Contract Nonr 901(00), tests were conducted on full-scale 12 foot and 14 foot diameter Rotochutes in the United Aircraft Corporation General Purpose Wind-Tunnel during the period of 29 February through 3 March 1956.

This report describes the tests and discusses the test results.

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SUMMARY AND CONCLUSIONS

Fixed blade pitch angle operation to determine governor characteristics requires special precautions to avoid rotor overspeeding in the critical angle range.

A governor spring with a spring rate of 1100 pounds per inch and a preload of 650 pounds provides satisfactory governing action with the 12-foot SK22242-11 blades.

Shifts in the location of the chordwise center of gravity of the blades affects the governor action in the same manner as changes in the governor spring constants. A forward shift in the center of gravity corresponds to an increase in preload on the governor spring.

The blade stresses during the test runs were considerably less than the ultimate strength of the blades and were directly proportional to rotor speed.

During these tests, yawed operation with angles of yaw up to 10° had no appreciable effect upon blade vibratory stresses. Clearances in the synchronizer linkages allowed the coning angle to compensate for the angle of yaw.

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12. Abstract:
A presentation of results of low-speed wind-tunnel testing of a full-scale Rotochute assembly to determine the effect of governor spring and blade mass parameters on rotochute speed governor characteristics and performance.

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DESCRIPTION OF TEST

A. Test Model

The test model consisted of a standard KRC-2 Rotor Head Assembly (KAC No. SK22347-1) and a standard Fin Assembly (KAC No. SK22330-1) mounted on a hinged tube which provided a convenient means of changing the yawed attitude of the rotor head. Figures 1 and 2 show the test unit installed in the wind tunnel. The blades used were as follows:

Serial Nos.	KAC No.	Weight	Chord	Chordwise C.G.	NACA Airfoil	Rotor Diameter
1A & 1B	SK22242-13	63#	14.5"	47%	0020	14 ft.
3A & 3B	SK22242-11	42#	14.0"	44.5%	0016	12 ft. 3 in.
5A & 5B	SK22242-11 (modified)	63.5#	14.0"	33.3% 44.5% 49.8%	0016	12 ft. 3 in.

Blades 1A and 1B had extra layers of fiberglas on the up-wind side in order to provide greater resistance to compressive buckling.

Blades 5A and 5B were modified by the addition of three cavities made up of aluminum tubes imbedded in the leading edge, middle, and trailing edge cell of each blade. The chordwise center of gravity was shifted by the insertion of a lead rod into the appropriate cavity.

B. Test Set-Up

The test model was centered in the test section of the United Aircraft General Purpose Subsonic Wind-Tunnel. This test section is of octagonal cross-section, 18 feet between diametrically opposite sides. Three 3/8 inch diameter rod comprised the forward mounting structures, o [redacted]

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plane and one rod to the center of each of the lower 45° panels; all rods being 30° from the longitudinal axis of the tunnel and upstream from the test model. These rods were attached to a common thrust link on the nose end of the test model and to individual panel mounting brackets on the test section walls. Individual calibrated links and turnbuckles were incorporated at the mounting brackets. The rear mounting structure was similar to the forward structure with the rear mounting rods being attached forward of the body hinge in a plane perpendicular to the tunnel wall. The entire system was subjected to a down-stream preload of 1500 pounds through a cable stretched between the rotochute fin shaft and a damped walking beam with a weight pan attached. The cable can be seen in Figure 1 where it passes over a suspended pulley and down through an opening in the floor of the tunnel to the walking beam.

C. Instrumentation

The following quantities were measured:

1. Load in fixed pitch links
2. Coning angle
3. Blade pitch angle
4. Blade strain - root station, downwind side
5. Blade strain - root station, upwind side
6. Blade strain - 1/3 span station, downwind side
7. Blade strain - 1/3 span station, upwind side
8. Blade strain - 2/3 span station, downwind side
9. Blade strain - 2/3 span station, upwind side
10. Mounting link strains
11. Thrust
12. Rotor speed
13. Airspeed

A block diagram of the basic instr [redacted]

Figure 4.

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D. Test Procedure

After the desired test model configuration was obtained, air flow in the tunnel was started while rotation of the blades was initiated manually. The airflow was then increased to the point where autorotation was maintained. Data were recorded at various airspeeds up to the maximum tunnel speed obtainable or until the rotor reached 700 RPM, whichever occurred first. Tunnel operation was performed by United Aircraft personnel. Model configuration changes and oscillographic recording of data was performed by Kaman personnel. Data were recorded at steady state conditions of airflow and rotor speed and also at various vibration modes and during unusual rotor speed surging.

E. Test Program

The test program consisted of four parts:

1. Fixed blade pitch operation to determine blade pitching forces.
2. Spring governor operation to determine spring rate and spring preload required for desired governing action.
3. Operation with various chordwise center of gravity locations to determine effect of center of gravity location upon governing action.
4. Yawed attitude operation to determine effect upon vibratory blade stresses.

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RESULTS OF TEST

The test results may be divided into two categories, operational data and stress data. Each of these will be described separately.

1. Operational Data

a. Fixed Pitch Operation

The rotochute was operated with fixed blade pitch angle in the first part of the test program. The data obtained from this mode of operation were expected to provide a basis for selecting the spring constants for the spring governor. However, in order to avoid excessive rotor speed, it was necessary to restrict operation to the negative pitch angle region.

The 14-foot diameter rotochute (blades 1A and 1B) was operated with the blade pitch angle fixed at -9°, -7°, -5°, and -3°. An attempt to operate the rotochute with the pitch angle fixed at -1° resulted in an abrupt build-up of rotor speed to a point where a blade failure occurred. The airspeed required to initiate auto-rotation proved to be too high for safe operation. Figure 4 contains plots of governor link load, thrust, and rotor speed versus airspeed for each of the fixed blade pitch angles.

The 12-foot diameter rotochute (blades 3A and 3B) was operated with the blade pitch angle fixed at -9°, -7°, and -5°. Figure 5 contains plots of governor link load, thrust, and rotor speed versus airspeed.

b. Spring Governor Operation

For the second part of the test pro[redacted]

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rotochute was operated with a spring governor in place of the fixed link used in the first part of the program. The purpose of this part of the program was to determine the spring rate and spring preload required for governed rotor speed.

Figure 6 contains plots of thrust, rotor speed, coning angle, and blade pitch angle versus airspeed for three spring configurations with blades 3A and 3B. The spring rates and the corresponding preloads used were as follows:

1250 pounds per inch - 1260 pounds
1220 pounds per inch - 1100 pounds
1100 pounds per inch - 550 pounds

The combination of 1100 pounds per inch spring rate with 550 pounds preload was the only one which gave governed operation with these blades without exceeding the established limit RPM.

The effect of change in preload upon thrust, rotor speed, coning angle, and blade pitch angle as a function of airspeed is shown in Figure 7, for blades 5A and 5B.

The effectiveness of string spoilers as a means of governing the rotor speed is shown in Figure 8. Blades 3A and 3B were operated with a spring governor configuration which did not provide governing at airspeeds below 85 f.p.s. (1220 pounds per inch spring rate with 1100 pounds preload) and string spoilers were added to the leading edges of the blades. The rotor speed was limited as shown in the plot of rotor speed versus airspeed in Figure 8, however the thrust developed was much less than that developed by a spring-governed rotochute (Figure 6).

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c. Operation with Various Chordwise Centers of Gravity Locations.

In order to investigate the effect of blade chordwise center of gravity location upon governor operation, the 12-foot rotochute was operated with blades 5A and 5B in part four of the test program. These blades have provisions for locating the center of gravity at 33.3%, 44.5%, and 49.8% of the chord from the leading edge. Figure 9 shows the effects of these center of gravity locations upon thrust, rotor speed, coning angle, and blade pitch angle as a function of airspeed.

2. Stress Data

Stress data were obtained for two types of blades:

a. SK22242-13 blades

Figure 10 shows the blade stresses in blades 1A and 1B. Only one series of fixed pitch runs was made before these blades failed.

b. SK22242-11 blades

Figures 11 and 12 show the blade stress versus rotor speed for the downwind and the upwind sides, respectively, of blades 3A and 3B. These data were accumulated from both fixed pitch operation and spring governor operation with various blade pitch angles, coning angles, airspeeds and yaw angles. The only parameter showing a direct relationship to blade stress was rotor speed.

The bending stresses for blades 3A and 3B are shown in Figure 13. These data were obtained by combining that from Figures 11 and 12.

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Blade vibratory stresses were measured during yawed attitude operation with yaw angles of 5° and 10°. These measurements showed no increase in stress levels for yawed operation over normal operation. During these runs, however, the coning angle fluctuated at a one-per-revolution rate with an amplitude approximately equal to the angle of yaw. The clearances in the synchronizer linkages were found to be great enough to allow sufficient variation in the coning angle to cancel the effects of the yaw angles used in these tests.

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DISCUSSION OF RESULTS

A. Operational Data

Satisfactory governing action was obtained with a governor spring with a spring rate of 1100 pounds per inch and a preload of 550 pounds. Operation with this configuration is shown in Figure 6. A plot of rotor speed, blade pitch angle, and section angle of attack at the blade tip versus airspeed is given in Figure 14. From this plot it can be seen that the characteristic break in the rotor speed curve occurs at an angle of attack of 14 to 18 degrees. This angle of attack is approximately equal to the stall point for the airfoil used. Therefore it follows that the blades are operating in the stalled region of their characteristics during the relatively constant rotor speed portion of the rotor speed versus airspeed curve for spring governor operation.

As shown in Figure 7, the level of the rotor speed curve can be changed by changing the amount of preload applied to the governor spring. Hence, the maximum rotor speed and resultant thrust at any velocity is determined by the governor spring preload.

The addition of string spoilers to the leading edges of the blades resulted in governed operation, as shown in Figure 8. This also indicates that the blades are stalled over the flat portion of the rotor speed versus airspeed curve. However, this constitutes an inefficient method of governing as evidenced by the much lower thrust shown in Figure 8 compared to that shown in Figure 6.

The effect of the location of the chordwise center of gravity upon governor operation is shown in Figure [redacted]

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center of gravity towards the leading edge has the effect of increasing the preload on the governor spring. A shift in the center of gravity location towards the trailing edge has the effect of either decreasing the governor spring preload or decreasing the spring rate of the spring.

Fixed pitch operation at positive blade pitch angles could not be obtained because of the difficulty of initiating autorotation at low enough airspeeds to avoid excessive rotor speed.

B. Stress Data

The stress data obtained (Figures 11 and 12) indicate that the blade stresses are due primarily to centrifugal forces, since they are proportional to rotor speed and are relatively insensitive to variations in other parameters.

The bending in the blades is shown in Figure 13. This shows that the blades bend upwind at the root station and downwind at the outboard stations.

Previous tests on samples of fiberglas similar to that used in these blades have shown the ultimate strength to be approximately 60,000 to 70,000 psi in tension. The maximum tension stress measured in these tests (26,600 for the 14-foot diameter blades, Figure 10, and 22,800 for the 12-foot diameter blades, Figure 12) are well below the ultimate strength.

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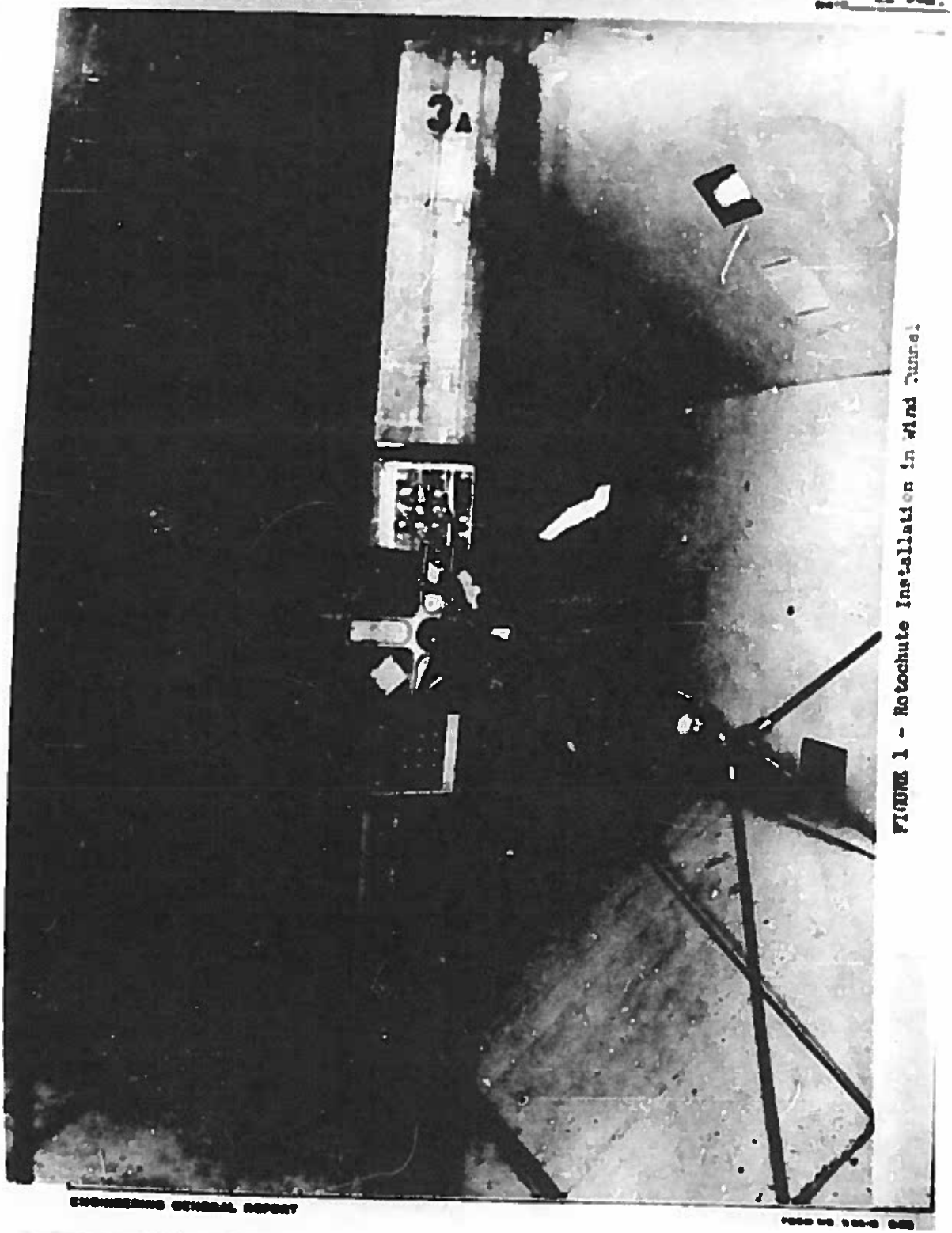

FIGURE 1 - Rotochute Installation in Wind Tunnel

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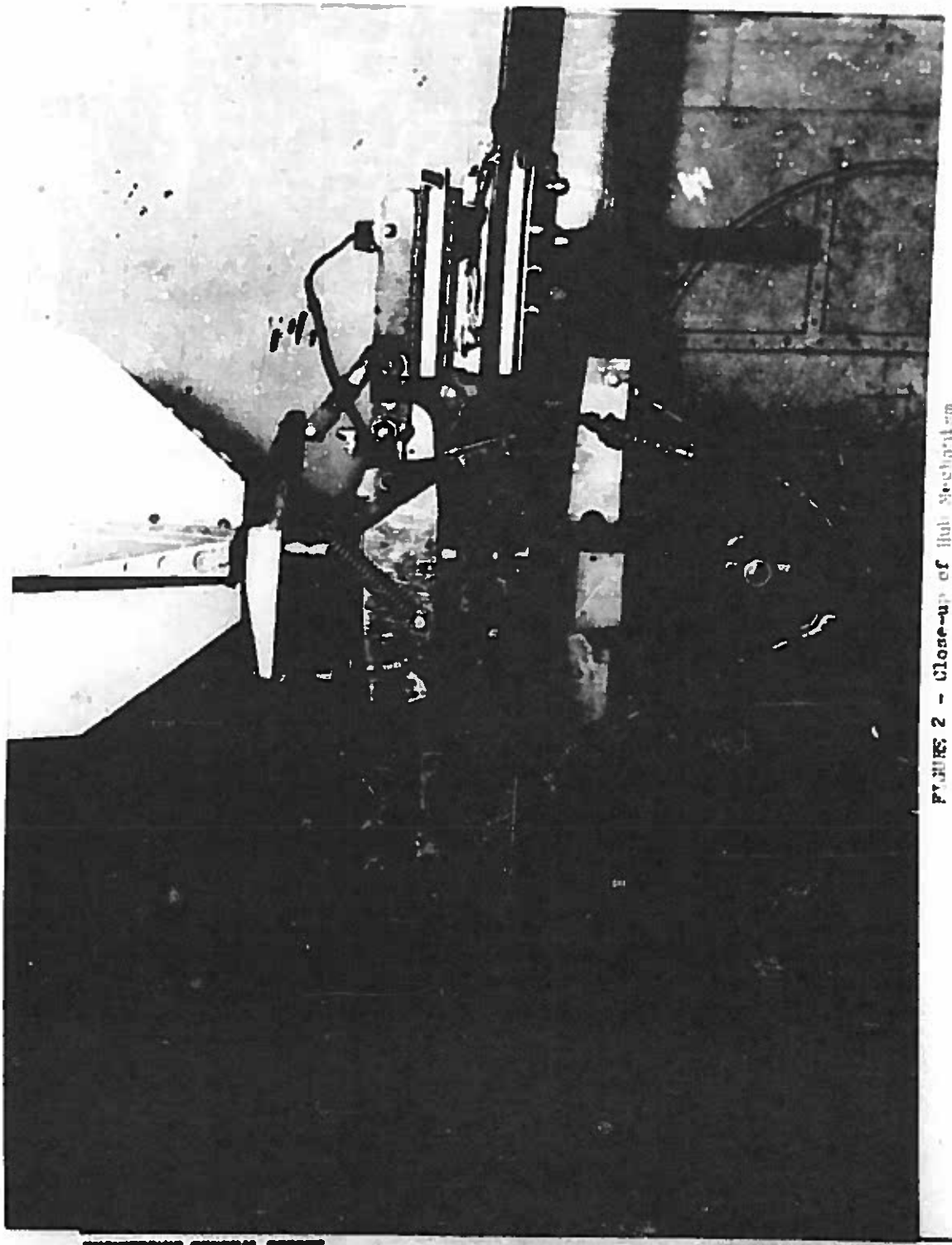

FIGURE 2 - Close-up of Hub Mechanism

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FIGURE 3

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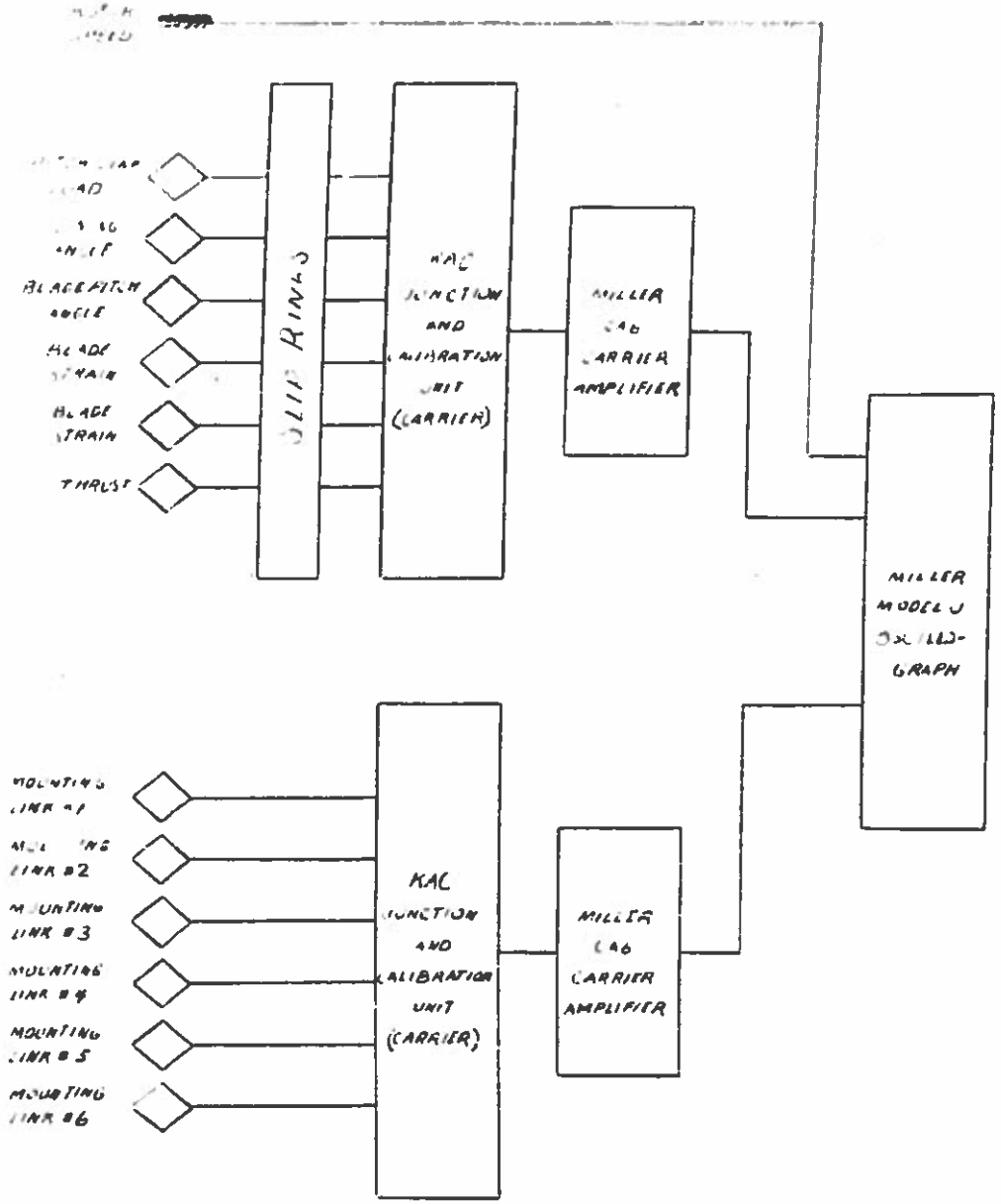

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FIGURE 4

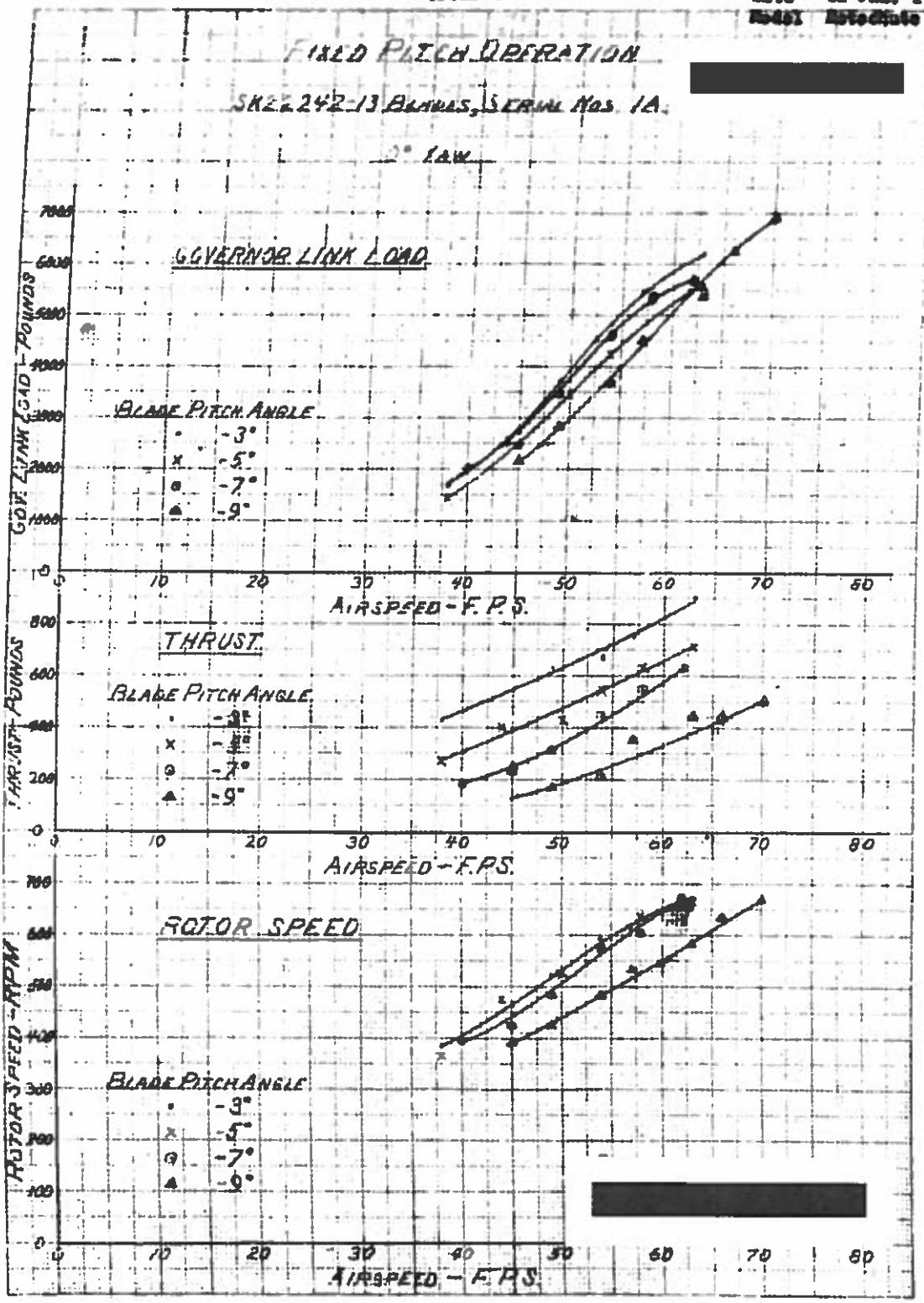

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FIGURE 5

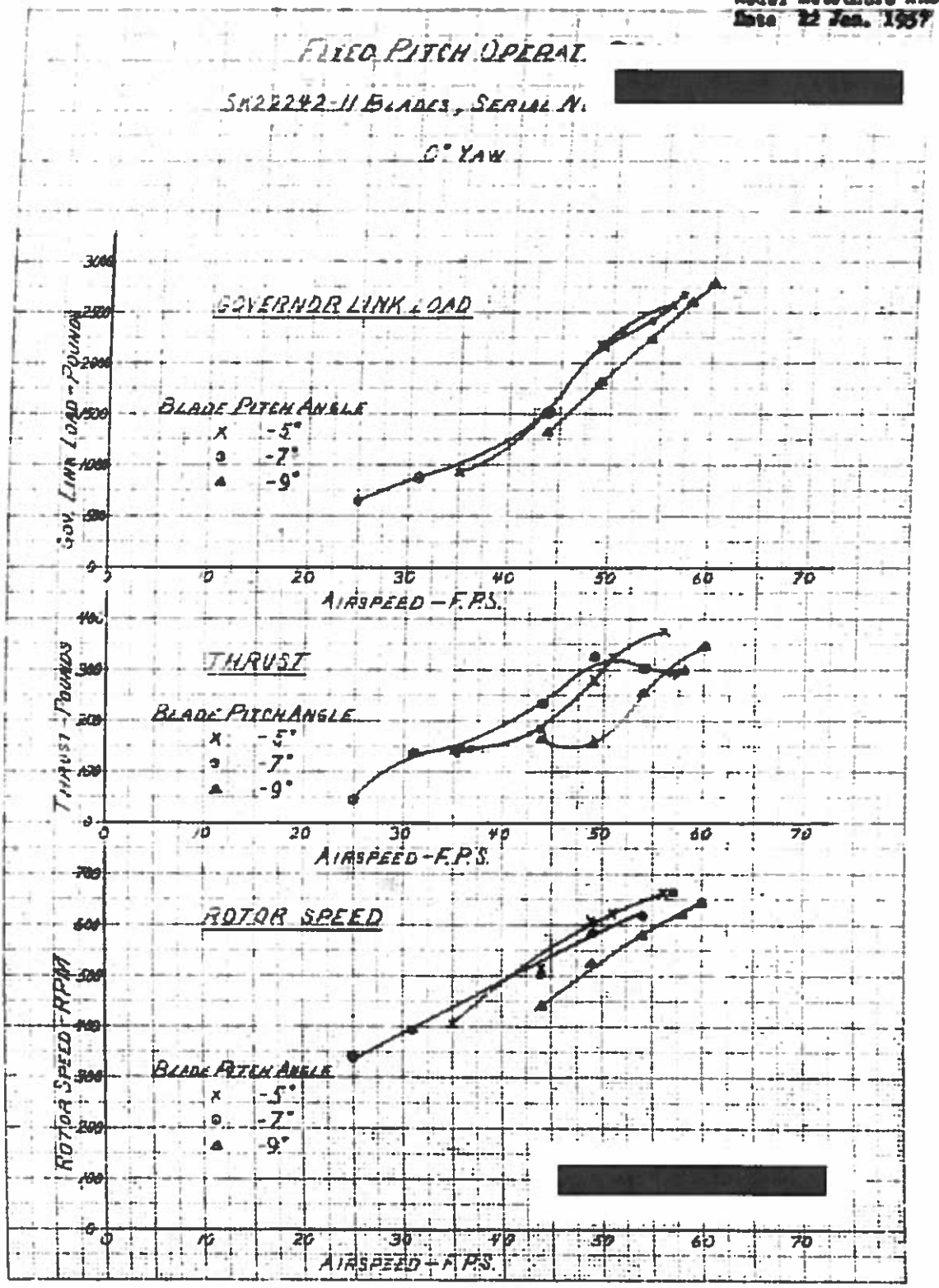

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FIGURE 6

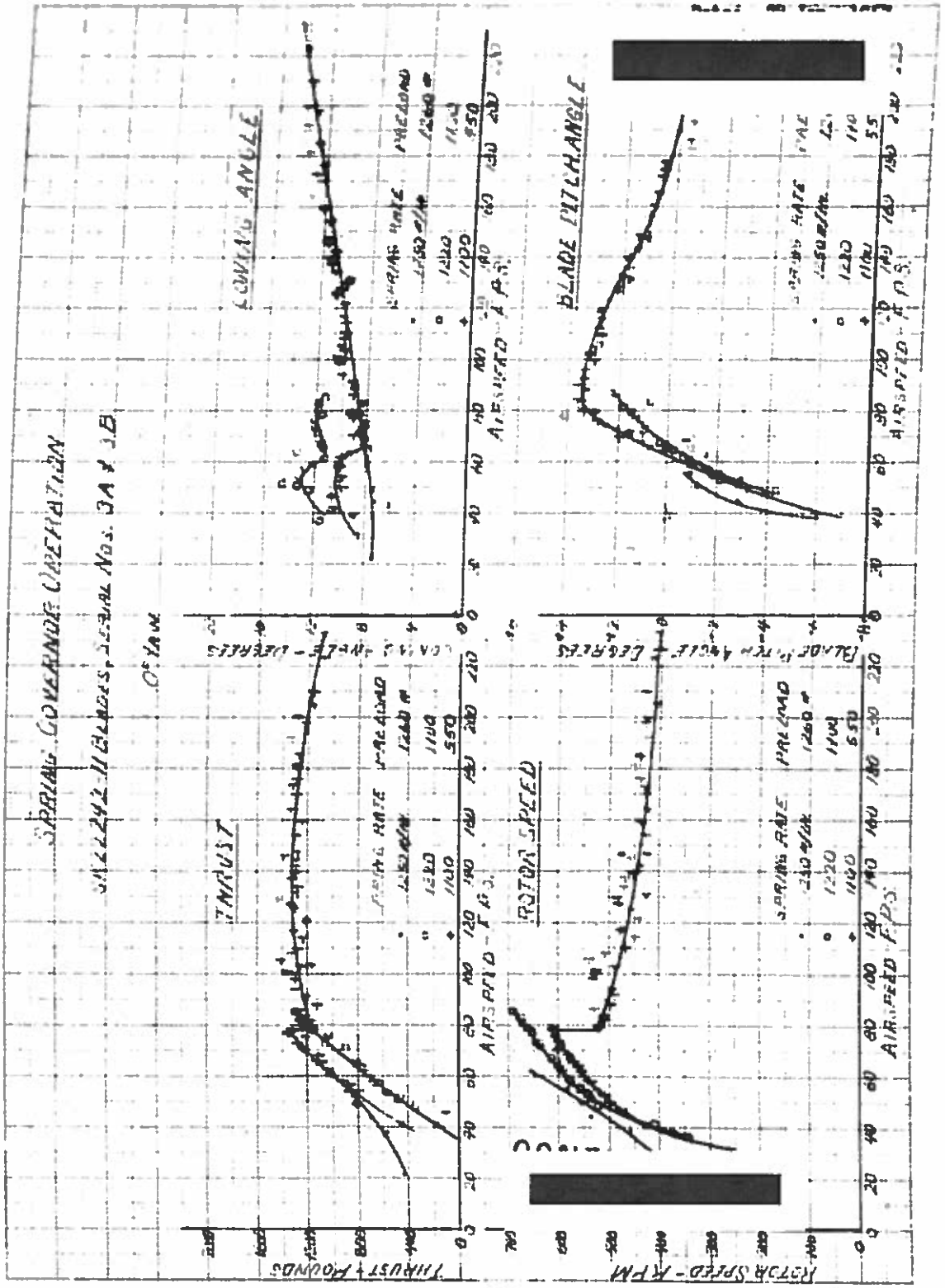

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FIGURE 7

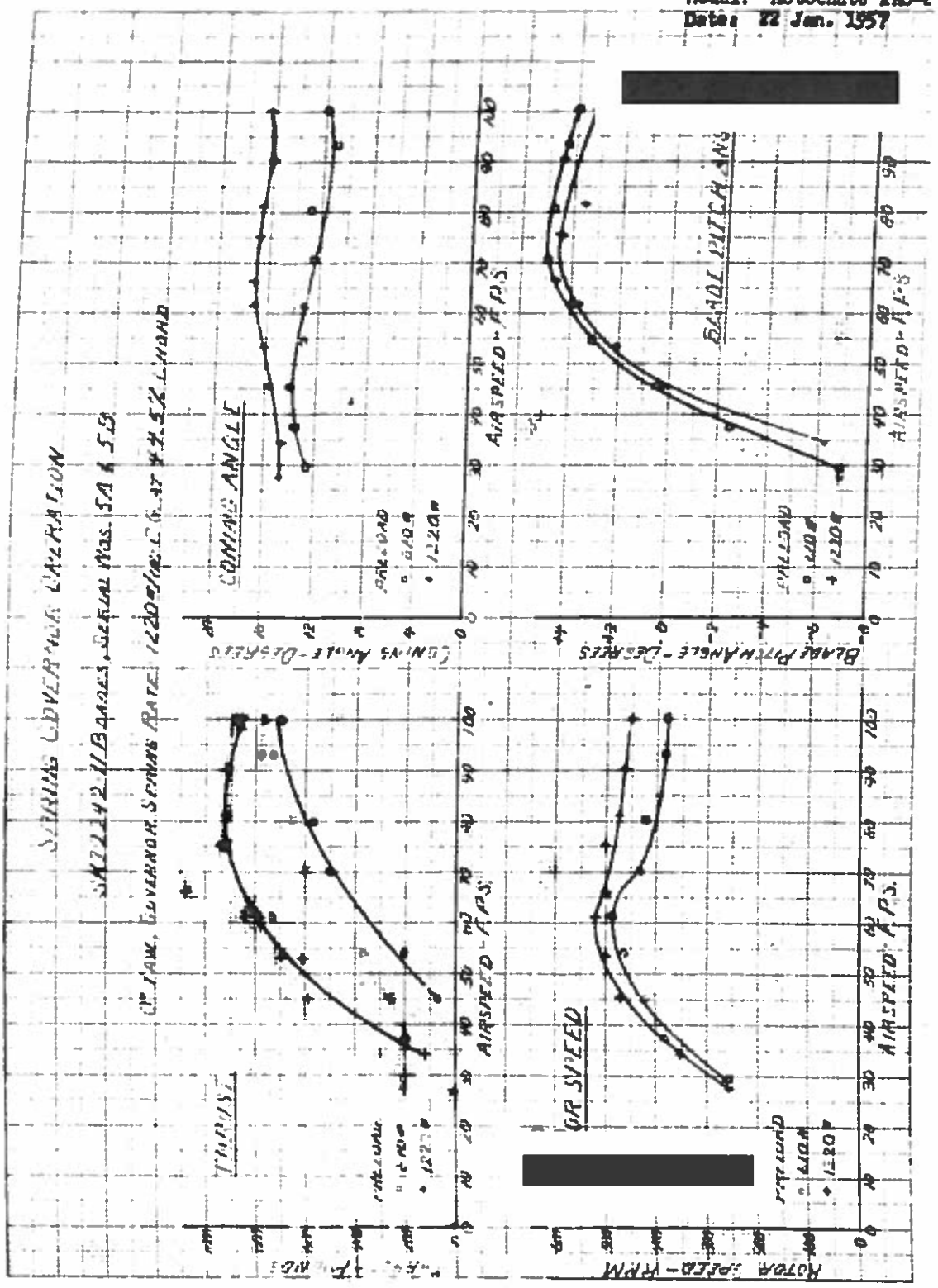

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FIGURE 8

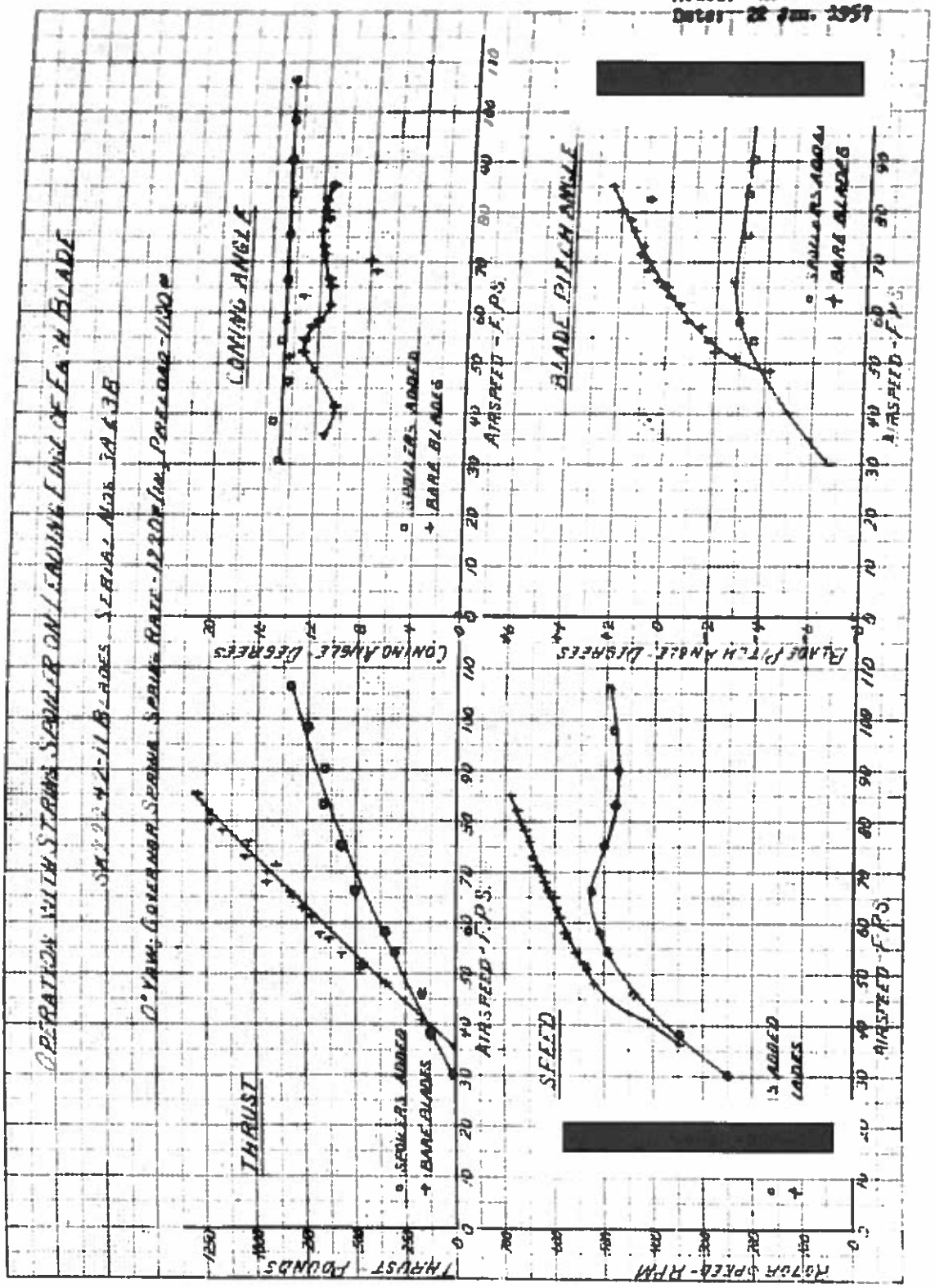

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FIGURE 9

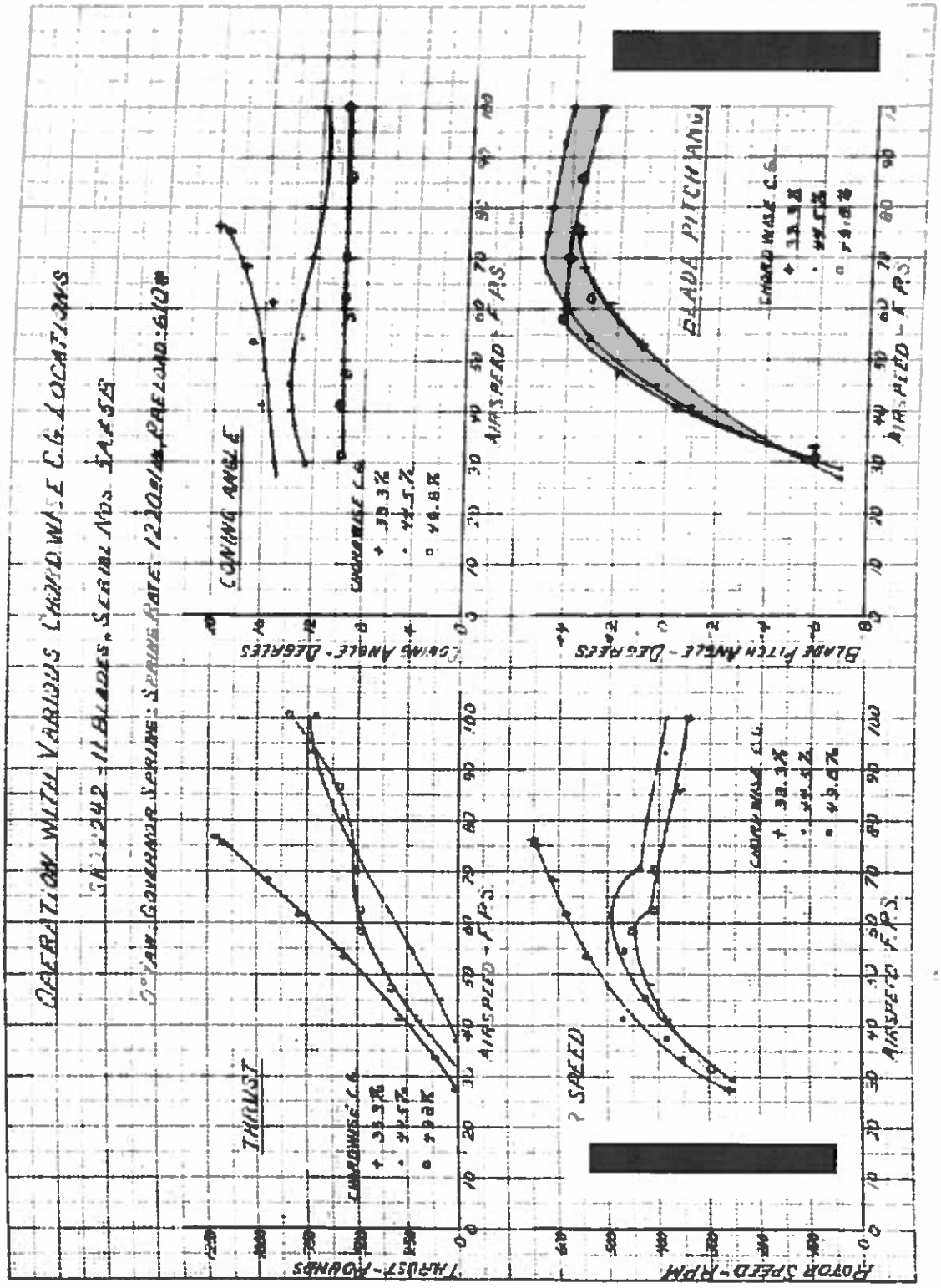

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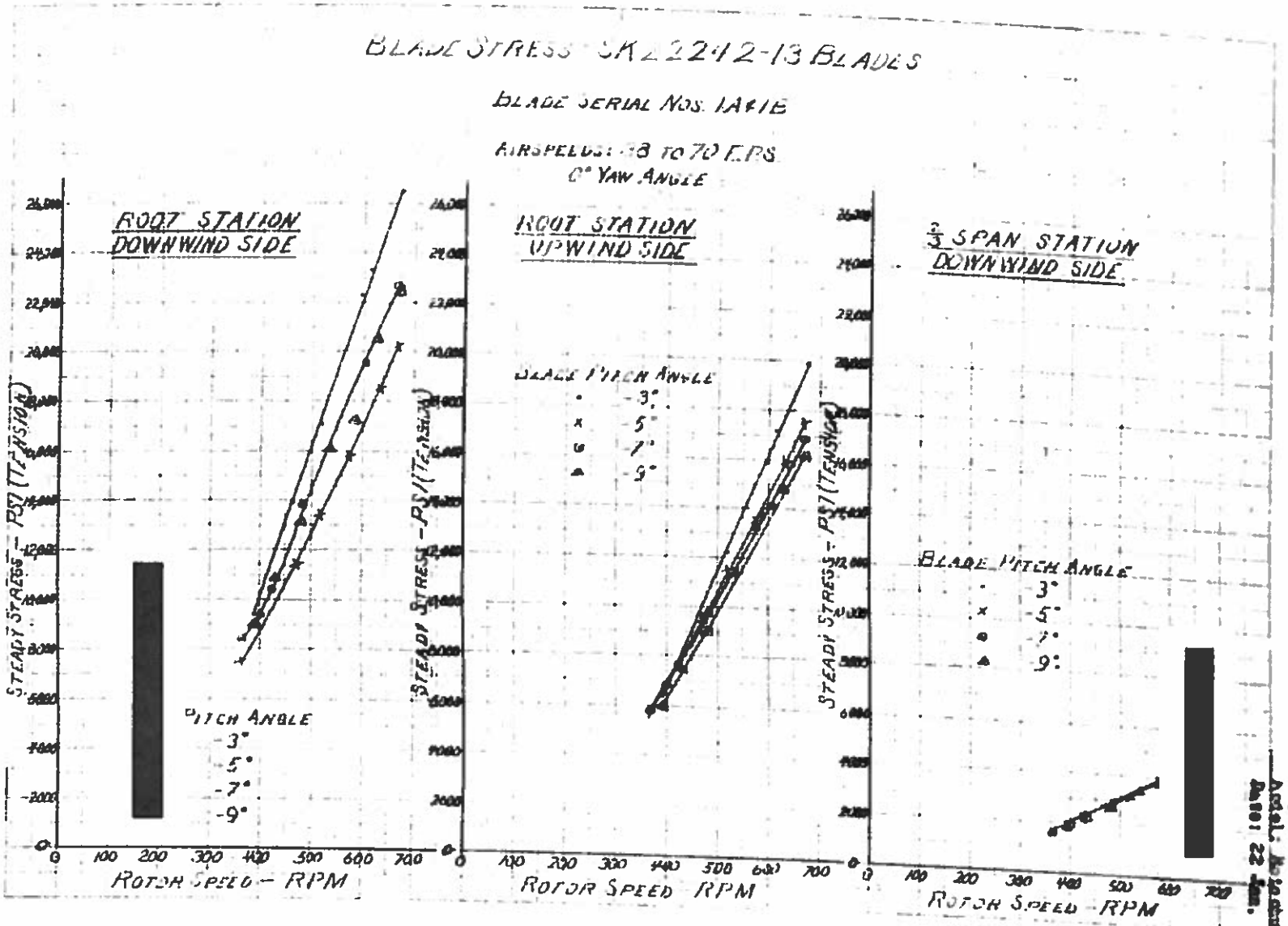
FIGURE 10



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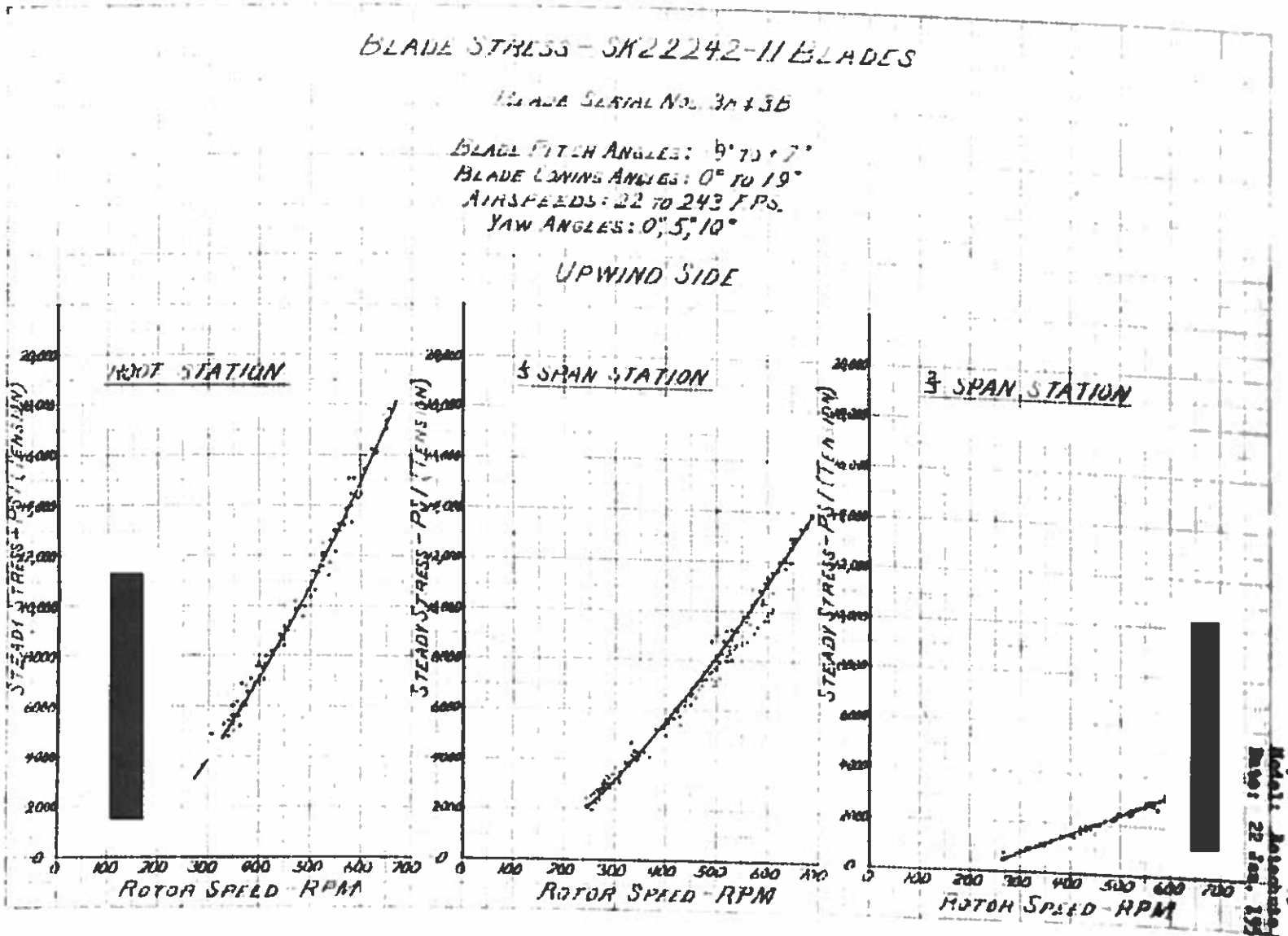

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FIGURE 12

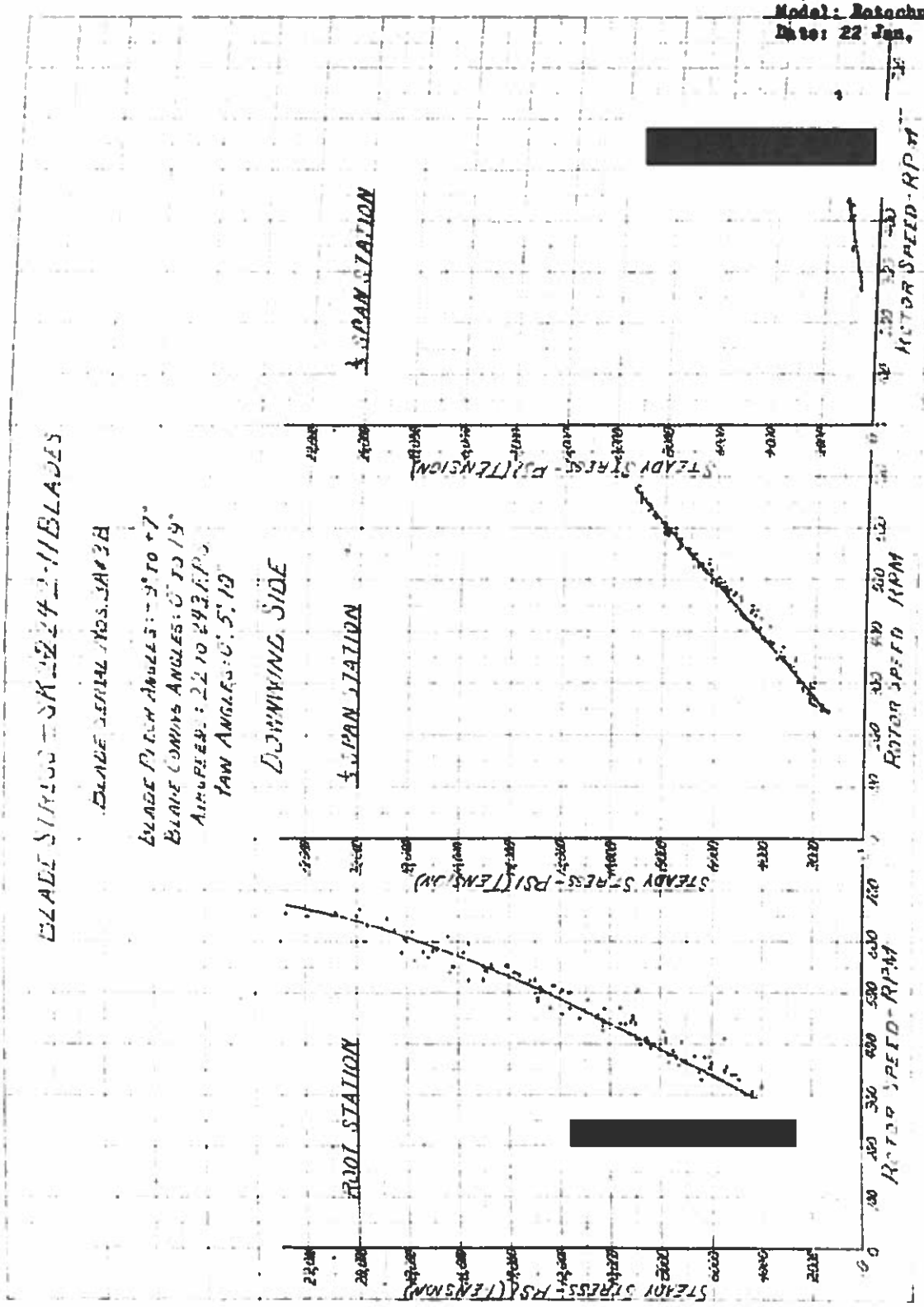

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FIGURE 13

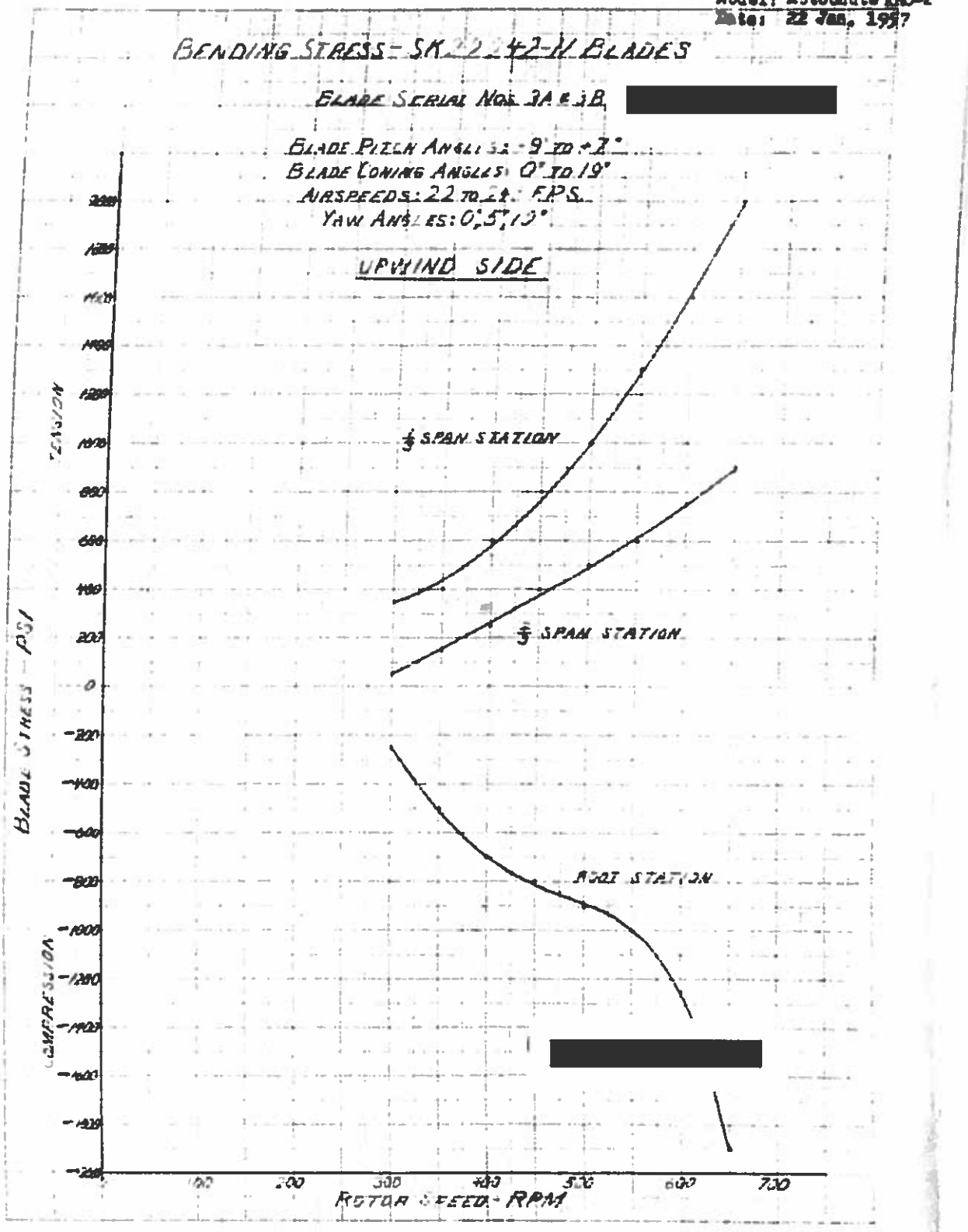

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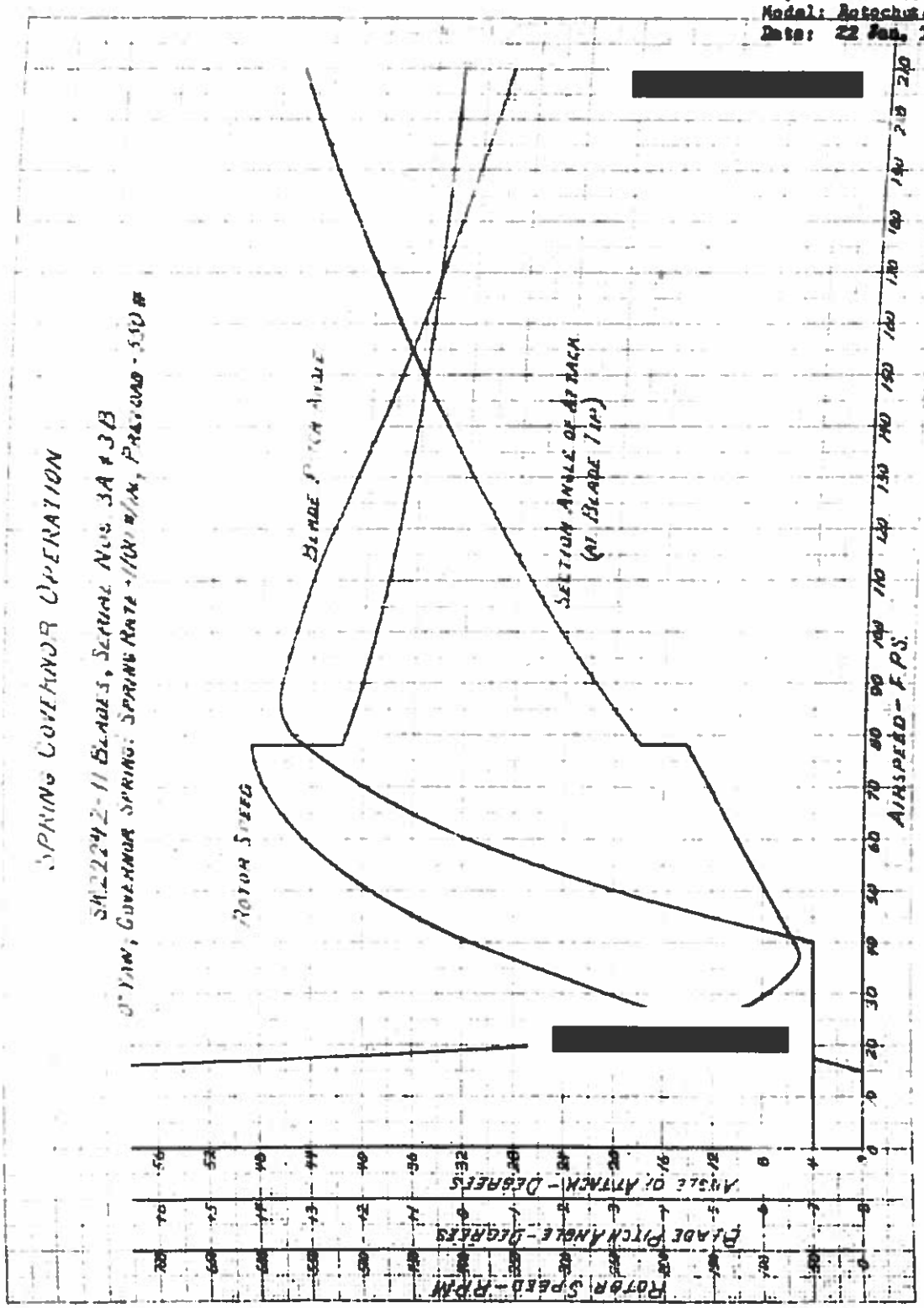
FIGURE 18



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