NASA TECHNICAL NOTE

NASA TN D-3786

NASA TN D-3786

GPO PRICE $ ______

CFSTI PRICE(S) $ 1.00

Hard copy (HC) ______

Microfiche (MF) .65

ff 653 July 65

N67 15958
(ACCESSION NUMBER) (THRU)
17 (PAGES) 1 (CODE)
(NASA CR OR TMX OR AD NUMBER) 01 (CATEGORY)

FACILITY FORM 602

HOVERING PERFORMANCE CHARACTERISTICS OF A ROTOR WITH AND WITHOUT BLADE-PITCH SERVO-CONTROL FLAPS

by James P. Shivers

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1967

NASA TN D-3786

HOVERING PERFORMANCE CHARACTERISTICS OF A ROTOR WITH AND WITHOUT BLADE-PITCH SERVO-CONTROL FLAPS

By James P. Shivers

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $1.00

HOVERING PERFORMANCE CHARACTERISTICS OF A ROTOR WITH AND WITHOUT BLADE-PITCH SERVO-CONTROL FLAPS

By James P. Shivers
Langley Research Center

SUMMARY

An investigation has been conducted on the Langley helicopter test tower to determine the hovering performance characteristics and efficiency of a rotor system operated with servo flaps to control blade pitch. The rotor was tested with and without the servo flaps, over two different tip speed ranges, to determine the differences in overall performance.

The rotor blade, with its nonlinear geometric twist of approximately -15°, might be viewed as an approximation to "ideal" twist and, in turn, might be expected to have relatively high efficiency. The high pitch inboard, however, exceeded the stall angle and separated flow was experienced over that section of the airfoil. Photographic coverage of the rotor blade with servo flaps removed when operating at 8.5° blade pitch at the three-quarter radius shows that this stalled flow extends to about 0.3 blade radius; operation at higher pitch would be expected to increase rapidly the extent of this stalled flow. Photographs of streamers mounted underneath the rotor indicate a mild upflow through the center of the rotor disk.

A peak rotor efficiency of about 0.68 is reached at a blade mean lift coefficient of 0.5 for the rotor with servo flaps on. With the servo flaps removed, the efficiency is already 0.70 for a blade mean lift coefficient of 0.35 and it appears from extrapolation that it will reach a peak at about 0.74. A comparison of total power for the rotor with servo flaps removed to that with the servo flaps on for a rotor-blade mean lift coefficient of 0.34 indicates that the servo flaps increase the total power required by about 6 percent. Indications are that at higher blade mean lift coefficients, this percentage also becomes greater. When the data for the rotor were compared at different shaft speeds, it was found that the efficiency was not improved by reducing the speed. Experience gained in these tests reemphasizes the importance of construction and maintenance procedures resulting in smooth and faired blade surfaces in order to maintain high rotor efficiency.

INTRODUCTION

This paper presents the results of research relating to the hovering efficiency for a rotor having servo-flap-controlled blade pitch and a relatively large nonlinear geometric twist. Servo-flap controls permit the reduction of control loads and, in addition, have been of interest as one means to permit the designer to adjust both control sensitivity and angular velocity damping. They can also be of interest for special rotor designs where pitch change at the root is difficult or relatively ineffective, as can be the case for retractable blades of a type having little torsional stiffness. The servo flaps, however, can be expected to increase the rotor's power losses to an extent requiring assessment.

Since profile losses can be a sizable and highly variable part of the power required to drive a helicopter rotor system, this test program was oriented toward determining such losses. The profile drag can originate from a number of sources: separated flow, compressibility, dirty or deformed airfoil sections, protuberances, or external control surfaces. For optimum efficiency the profile losses should, of course, be a minimum and for this purpose the airfoil sections should operate near but not beyond stalling angles. (See ref. 1.) Results from previous research (refs. 2 to 5) indicate that the profile losses can be doubled when the blade-tip angle of attack exceeds the angle for either stall or drag divergence by only a few degrees. Observations of tuft patterns for blades from previous tests indicate that initial section stall occurs at different spanwise locations for the blades depending on the blade geometry and twist.

Photographic studies of the present test rotor were made to observe visually the tuft action on the upper surface of the rotor blades and also streamer action under the rotor disk. Torque and thrust were measured over a range of blade pitch angles. Calculations were made to compare the basic blade performance to that predicted by theory. Also, the efficiency of this rotor is compared with that for numerous other rotors tested.

The rotor system was tested on the Langley Research Center helicopter tower at tip speeds of 558 and 628 feet per second (170.08 and 191.41 m/s) with corresponding tip Reynolds number of 5.99×10^6 and 6.73×10^6, respectively.

The rotor was tested with and without servo flaps.

SYMBOLS

a — slope of section-lift-coefficient curve as a function of section angle of attack (radian measure), assumed to be 5.73 per radian for incompressible-flow calculations

b — number of blades

C_Q	rotor torque coefficient, $\frac{Q}{\pi R^2 \rho (\Omega R)^2 R}$
$C_{Q,o}$	rotor profile-drag torque coefficient, $\frac{Q_o}{\pi R^2 \rho (\Omega R)^2 R}$
$C_{Q,i}$	rotor induced-drag torque coefficient, $\frac{Q_i}{\pi R^2 \rho (\Omega R)^2 R}$
C_T	rotor thrust coefficient, $\frac{T}{\pi R^2 \rho (\Omega R)^2}$
c	blade chord at radius r, feet (meter)
$c_{d,o}$	airfoil section profile-drag coefficient
$\bar{c}_l$	rotor-blade mean lift coefficient, $6C_T/\sigma$
Q	rotor torque, pound-foot (newton-meter)
Q_o	rotor profile-drag torque, pound-foot (newton-meter)
Q_i	rotor induced torque, pound-foot (newton-meter)
R	rotor-blade radius, feet (meter)
r	radial distance to a blade element, feet (meter)
T	rotor thrust, pound (newton)
θ	blade-section pitch angle measured from line of zero lift, degrees
α	airfoil-section angle of attack, degrees or radians, as specified
ρ	mass density of air, slugs/cu ft (kg-sec^2/m^4)
σ	rotor solidity, $\frac{bcR}{\pi R^2}$
Ω	rotor angular velocity, radians/sec

The figure of merit is equal to $0.707 \frac{C_T^{3/2}}{C_Q}$.

APPARATUS AND TESTS

Rotor Blades

The rotor used for this investigation was a fully articulated constant-chord four-blade rotor with flapping and drag hinges located at the 3.22-percent radial station. A sketch with dimensions for the rotor blade is presented in figure 1. The rotor radius was 22 feet with a solidity of 0.097 when the servo flaps were not included. The servo flaps added another 0.012 solidity to the basic rotor. The geometric twist distribution from the center line of rotation to station 139 is -1.022° per foot and from station 139 to station 264 (tip) it is -0.294° per foot. The rotor-blade airfoil had a modified section with a NACA 230 series nose section and a NACA $63_{1}012$ aft section. The servo-flap airfoil had a NACA $63_{3}018$ airfoil section. The rotor blade had reasonably good section contour and was kept smooth and clean during testing.

When the servo flaps were removed and the blades operated with the pitch locked at the root, the flap support brackets that attached the servo flaps to the blades were faired into the trailing edge of the airfoil. The hole in the under surface of the blade that the servo-flap control rod passed through was sealed, filled, and faired. Blade root hardware associated with the servo-flap pitch-change mechanism was removed for the flaps-off part of the test program.

Test Procedure and Analysis

The rotor system used was that from a flight vehicle and was adapted to the Langley Research Center helicopter tower. The tower blade control system used only collective pitch with a small increment of cyclic pitch to correct swashplate tilt resulting from inputs due to pitch change. Surface wind velocities for data reported herein were from 0 to 2 statute miles per hour.

The test procedure was similar to other test programs on the tower (refs. 6 and 7). At a selected speed the pitch was varied at about 2° increments from near zero thrust to a thrust limit imposed by torque limitations or by vibrations. Force data and blade position data were recorded for each speed and pitch-angle setting.

The rotor system was tested initially with the servo flaps controlling the collective pitch for the two speed ranges used. Secondly, the servo flaps were removed, the blade contour was checked, and the pitch was preset and locked at the root; repeat runs were made at similar speeds with a series of pitch values to a maximum of 8.5° at 0.75 R. The performance data for servo flaps off are compared with the data for servo flaps on.

A simple strip analysis calculation (ref. 8) using the nonlinear twist of the present rotor blades was made for comparison purposes. A constant lift-curve slope was assumed (a = 5.73). The profile drag polar was adjusted from the standard

$$c_{d,o} = 0.0087 - 0.0216\ \alpha r + 0.400\ \alpha r^2$$

to

$$c_{d,o} = 0.0084 - 0.0454\ \alpha r + 0.400\ \alpha r^2$$

to extropolate the performance curve more accurately. The need for this modification to the drag polar indicates that the rotor blade with servo flaps off had better contour characteristics than the blades considered to represent good quality practical construction rotor blades at the time the standard polar was adopted.

There was a limited operational envelope for the tip speed and thrust range for the present tests which was imposed by the kinematics of the rotor system as operated on the test tower. The performance data were not started at zero thrust because of the suspected possibility of wake flutter.

RESULTS AND DISCUSSION

Basic Performance Polars and Figure of Merit

The performance data presented in figure 2 includes the data obtained from the rotor as tested with and without the blade-pitch servo flaps. The effect of tip speed is found to be small for the range covered, and single faired lines can be used to represent the data for each of the two configurations. Included in the figure is the calculated performance curve obtained from the strip analysis calculation. This curve was used as a guide to permit extrapolation and facilitate comparisons.

Figure 3 presents the faired data of figure 2 converted to figure of merit form. In this form the variation of efficiency with rotor blade mean lift coefficient is easier to follow. Here the rotor with servo flaps on appears to have reached a peak figure of merit of 0.68 for a blade mean lift coefficient near $\bar{c}_l = 0.5$. The efficiency curve for the rotor with servo flaps off, for the same $\bar{c}_l$, appears to reach a peak at a figure of merit of about 0.74 (from extrapolated portion of curve). This result indicates that the rotor without servo flaps will reach about 8- to 10-percent higher efficiency as compared with the rotor with servo flaps on. This relative increase in efficiency would be expected to be more pronounced at higher mean lift coefficients.

Photographic Study of Inboard Flow Phenomena

Because of the high blade twist used, it was suspected that, even in the absence of fuselage interference and at a height almost free of ground effect (nearly one rotor diameter), inboard blade-section stall might occur. In fact, unless the rotors were able to maintain appreciable downflow at the inner ends of the blades, the root-section angle of attack at operating blade-pitch settings would be well above the two-dimensional stall angle. As a preliminary step, for the rotor with the servo flaps removed, a few photographs such as those of figure 4 were taken to give an idea of flow direction near the blade root. The photographs show streamer action suggesting turbulent upflow rather than downward or strong inward flow in the region below the blade root. To obtain more direct evidence relating to stall, tufts were mounted on the upper surface of one blade. Two samples from numerous photographs of these tufts are shown in figure 5. The chordwise and radial extent of tuft disturbance varies with azimuth even though the wind velocity is near zero. Based on examination of all these photographs, for a pitch setting of 8.5° at the three-quarter radius, a tip speed of 558 fps (170.08 m/s) and a thrust coefficient of about 0.006, the extent of flow separation is judged to represent section stall for roughly the inner 2 feet (0.6096 m) of the blades or to about spanwise station 80 (0.3 R). Operation at rotor-blade mean lift coefficients above that for this test condition would be expected to increase the stalled area rapidly.

Effect of Servo Flaps on Hovering Performance

The power loss chargeable to servo flaps, as shown by the difference between the two experimental curves of figure 2, has been plotted directly in figure 6. For a $\bar{c}_l = 0.34$, which is representative of a utility-type helicopter operating at sea-level conditions, the servo flaps absorb about 6 percent of the rotor torque or shaft power. This loss appears to be increasing at higher mean lift coefficients (or thrust coefficients).

Although the data obtained are not self-sufficient in conclusively showing this rise in losses at higher mean lift coefficients, such a rise is compatible with the flap angles required. The flaps are neutral at a blade pitch $\left(\theta_{0.75R}\right)$ near zero, and the flap initially has to be deflected roughly 1° (trailing edge up) for every degree of blade-pitch increase obtained. This relation means that the servo flap drag should increase with increased blade pitch eventually in a faster than linear fashion and possibly reach a condition where the servo flap would stall. It is expected, also, that the servo flap tends to wash out the lift increase between 66 and 82 percent of the blade radius; this lift discontinuity would be expected to contribute a more rapid increase in power loss at higher pitch angles.

Effect of Blade Surface Condition

To ensure comparability of successive tests, surface smoothness was maintained by use of a filler and by frequently cleaning the blades. In one instance where atmospheric conditions (primarily fog) resulted in more rapid accumulation of dirt, rotor torque values were affected sufficiently (perhaps 2 or 3 percent within roughly 25 minutes of continuous operation) to require obviously that the data obtained in that series of runs be discarded.

Effect of Choice of Blade Twist

Two factors relating to twist, the high root angles and the twist distribution, require discussion. The previous discussion of figure 5 brought out the presence of inboard blade-section stall at the high root pitch angles. This condition was at a relatively low rotor-blade mean lift coefficient $\left(\bar{c}_l = 0.34\right)$. As the mean lift coefficient is increased to higher values, it would be expected that the inboard stalling would spread outward and become a significant source of power loss. The inboard stalling would also be expected to be increased by flow interference effects such as can be produced by pylon, fuselage, and ground proximity.

The use of a higher twist rate inboard than outboard (a total of 15° washout) might be expected to provide an approximation to "ideal" twist. Simple strip theory (without blade stall) might in turn be expected to indicate an advantage of the high twist as compared with a lower linear twist rate. A strip analysis comparison of the actual twist rate with that of -10° linear twist, however, showed a small advantage for the latter; thus, even without stall the present twist distribution could easily be improved upon, at least insofar as hovering efficiency is concerned.

Overall Comparison of Rotor With Blade Pitch Servo Flaps and Previously Tested Rotors

Although direct detailed comparisons are awkward because of differences in solidity and other factors, it is noteworthy that examination of results from 16 previously tested rotors, tested at comparable tip Mach numbers, shows only three with as low a maximum figure of merit, and only two which reach their peak figure of merit at as low a blade mean lift coefficient as that for the rotor reported herein. Figures of merit about 10 percent higher are common, and theoretical adjustments for solidity would be expected to increase this difference. Values of mean lift coefficient corresponding to peak figure of merit are often about 50 percent higher; theoretical adjustments for solidity might somewhat reduce this spread.

As previously implied, the servo flaps and (to a lesser extent) the twist distribution are concluded to be the primary contributing factors for the low figure of merit and the early peaking of the efficiency curve.

Effect of Reduction in Operating Speed

It was believed that significant efficiency gains might be attainable for this rotor by reduction of rotor speed during hovering. By reducing the speed, the rotor would be operating at a higher mean lift coefficient. Higher mean lift coefficients are usually associated with higher efficiency. The test results, as already discussed, however, show that the efficiency of this rotor with servo flaps fails to increase much at higher mean lift coefficients. Probable overloads and moderately higher density altitudes will tend to give mean lift coefficients reaching or perhaps exceeding that for maximum efficiency. No direct effect with speed is shown on the C_T, C_Q polar of figure 2 as the scatter in the data points is so little that a single faired line can represent the data for the speed spread. Thus, a reduction in operating speed would not improve efficiency for this rotor.

CONCLUSIONS

The hovering performance characteristics for a full-scale rotor having servo-flap-controlled blade pitch and a relatively high nonlinear twist have been determined for the rotor when operated with and without the servo flaps. Data for this rotor operated with the flaps off are compared with the data obtained when the rotor is operated with the flaps on. Also, the efficiency of this rotor is compared with the efficiency of numerous other rotors tested on the Langley helicopter tower. Examination of the data indicates the following conclusions:

1. The hovering efficiency of this rotor for a mean lift coefficient of 0.34 is considerably less than that for numerous previously tested rotors. Increasing the mean lift coefficient, for example, by increasing thrust or density altitude, would be expected to widen this difference.

2. Reduction in rotor speed was not an effective way to increase the efficiency of this particular rotor.

3. One way to increase the rotor hovering efficiency would be through choice of a more optimum twist distribution, one objective of which would be avoidance of early stall on the inboard sections.

4. At a rotor-blade mean lift coefficient of 0.34, which represents a moderate flight condition for a utility type of helicopter, the servo flaps were found to absorb about 6 percent of the rotor torque or shaft power. These servo-flap losses would be expected to increase with an increase in mean lift coefficient.

5. The current test experience reemphasizes the importance of construction and maintenance procedures that result in smooth and faired blade surfaces in order to maintain high rotor efficiency.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 30, 1966,
721-01-00-02-23.

REFERENCES

1. Gustafson, F. B.: Effect on Helicopter Performance of Modifications in Profile-Drag Characteristics of Rotor-Blade Airfoil Sections. NACA WR L-26, 1944. (Formerly NACA ACR L4H05.)

2. Shivers, James P.; and Carpenter, Paul J.: Experimental Investigation on the Langley Helicopter Test Tower of Compressibility Effects on a Rotor Having NACA 63_2-015 Airfoil Sections. NACA TN 3850, 1956.

3. Powell, Robert D., Jr.: Compressibility Effects on a Hovering Helicopter Rotor Having an NACA 0018 Root Airfoil Tapering to an NACA 0012 Tip Airfoil. NACA RM L57F26, 1957.

4. Powell, Robert D., Jr.; and Carpenter, Paul J.: Low Tip Mach Number Stall Characteristics and High Tip Mach Number Compressibility Effects on a Helicopter Rotor Having an NACA 0009 Tip Airfoil Section. NACA TN 4355, 1958.

5. Carpenter, Paul J.: Lift and Profile-Drag Characteristics of an NACA 0012 Airfoil Section as Derived From Measured Helicopter-Rotor Hovering Performance. NACA TN 4357, 1958.

6. Shivers, James P.; and Monahan, William J.: Hovering Characteristics of a Rotor Having an Airfoil Section Designed for a Utility Type of Helicopter. NASA TN D-1517, 1962.

7. Shivers, James P.: Hovering Characteristics of a Rotor Having an Airfoil Section Designed for Flying-Crane Type of Helicopter. NASA TN D-742, 1961.

8. Gessow, Alfred: Effect of Rotor-Blade Twist and Plan-Form Taper on Helicopter Hovering Performance. NACA TN 1542, 1948.

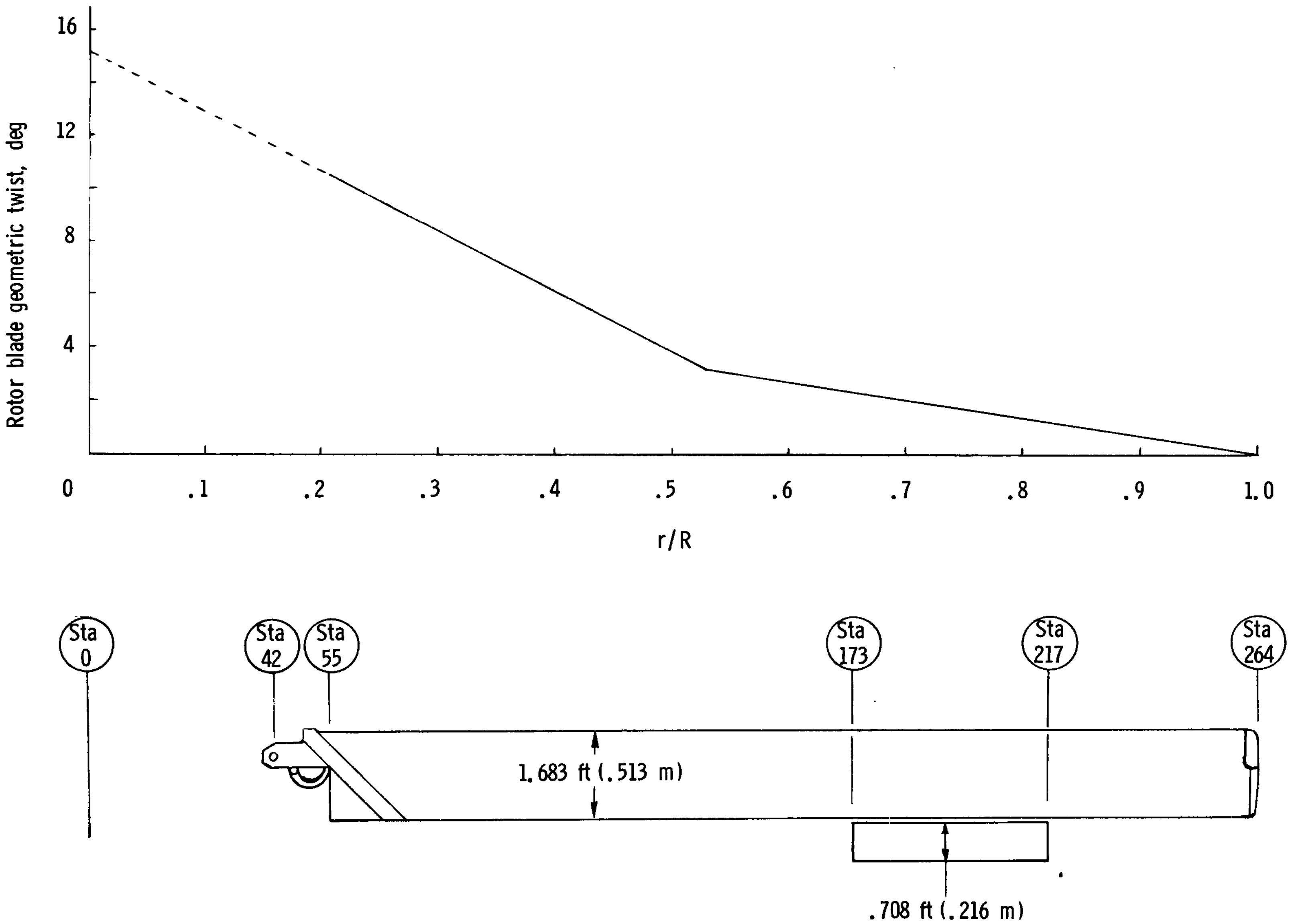


Figure 1.- Sketch of rotor blade having a NACA 23012 modified airfoil section with an externally mounted servo-control flap. Blade chord, 1.683 ft (0.513 m); σ = 0.097 without servo flaps and 0.109 with servo flaps. Servo flap has a NACA 63_3018 airfoil section with an 8.5-inch (21.59-cm) chord.

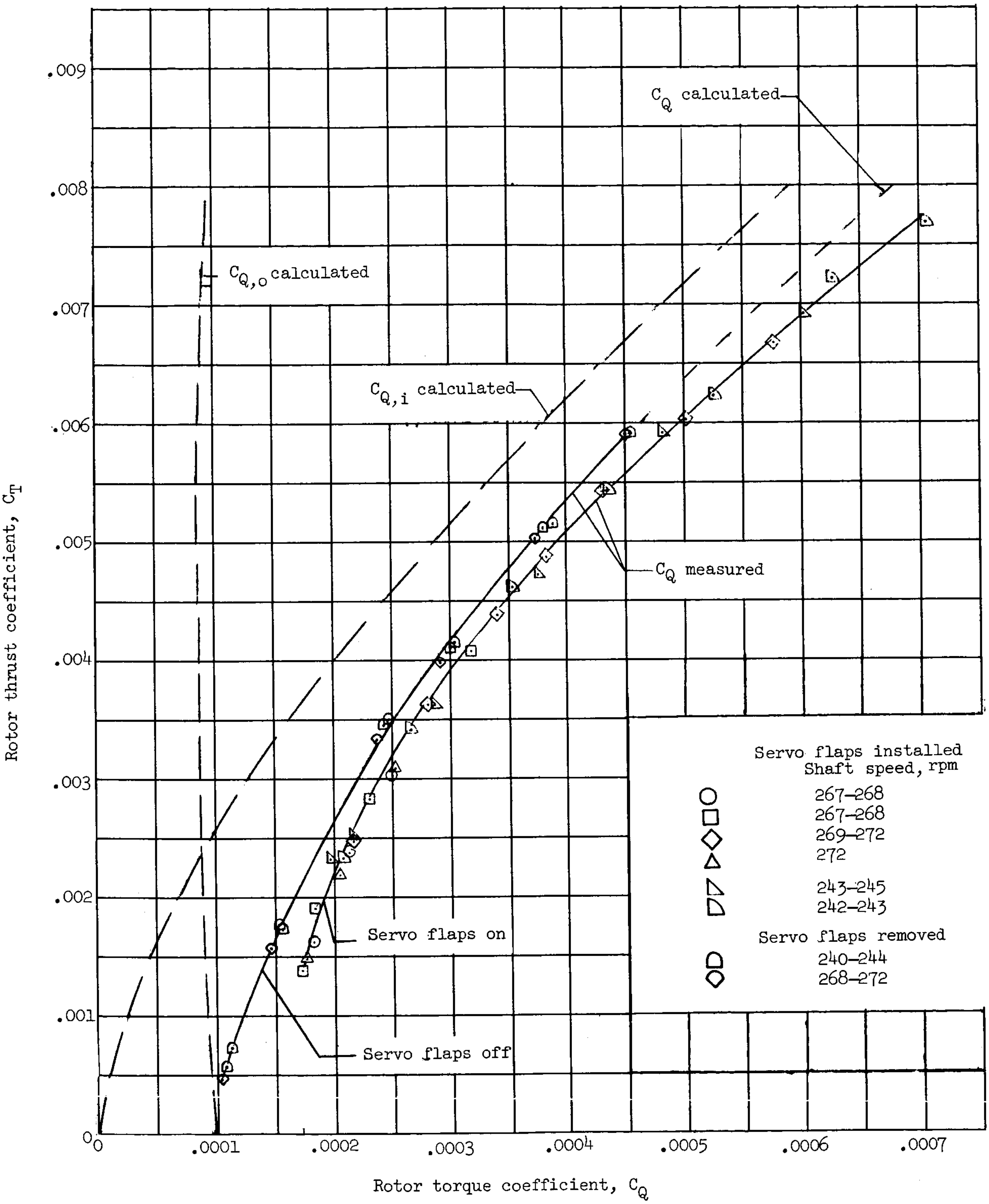


Figure 2.- Hovering performance of rotor blade operating with and without servo-flap-controlled blade pitch.

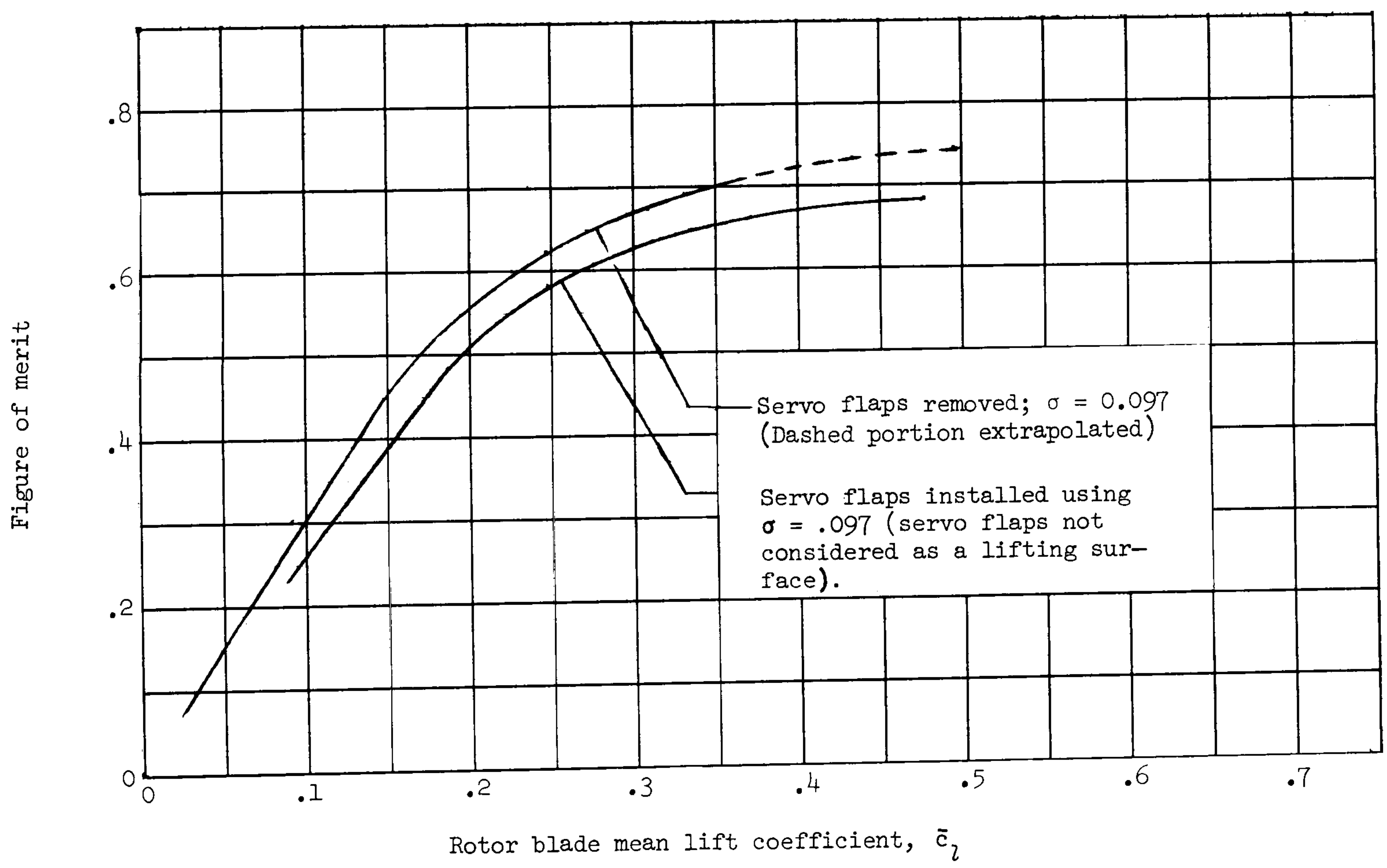


Figure 3.- Effect of servo-flap removal on rotor figure of merit.

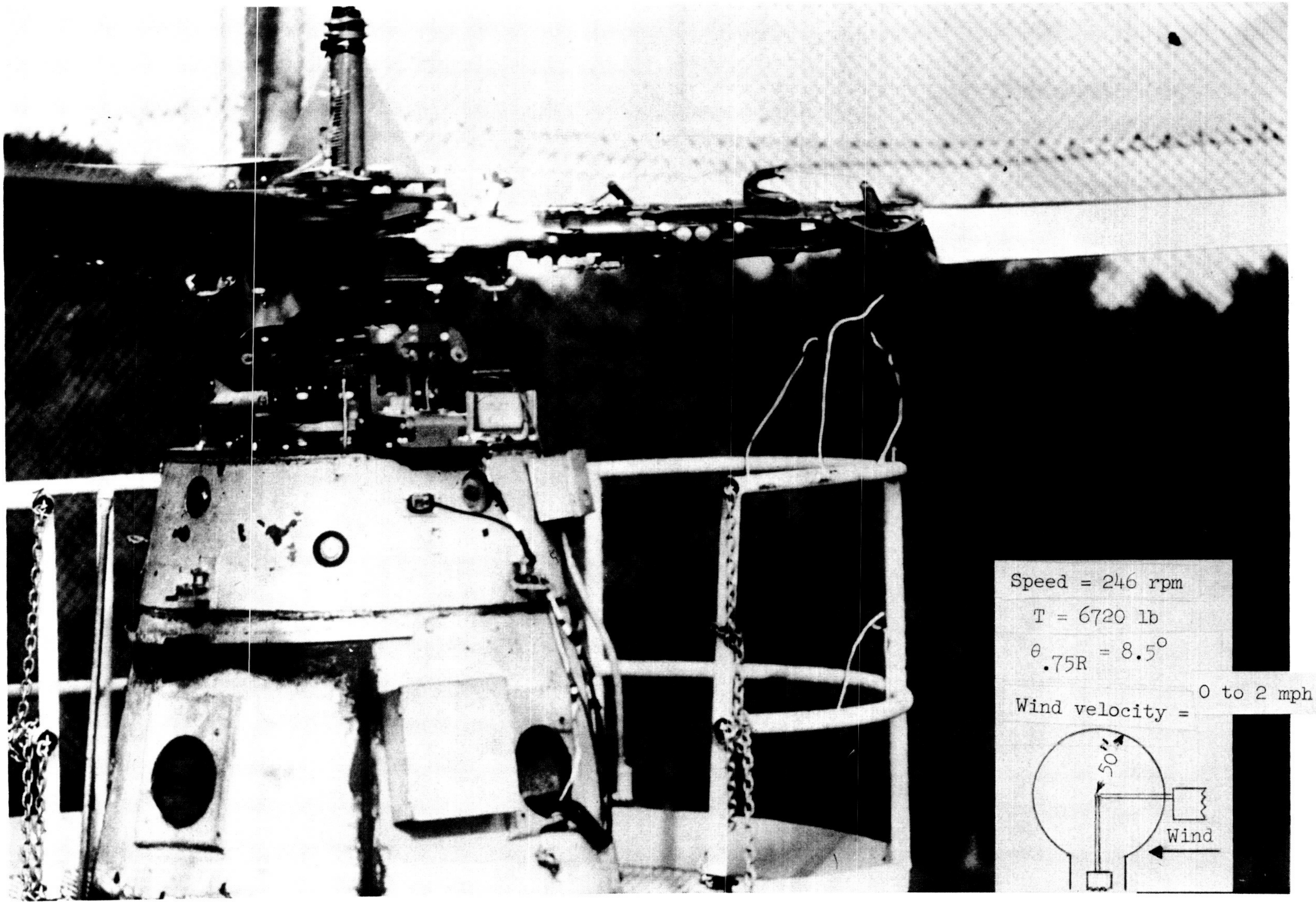
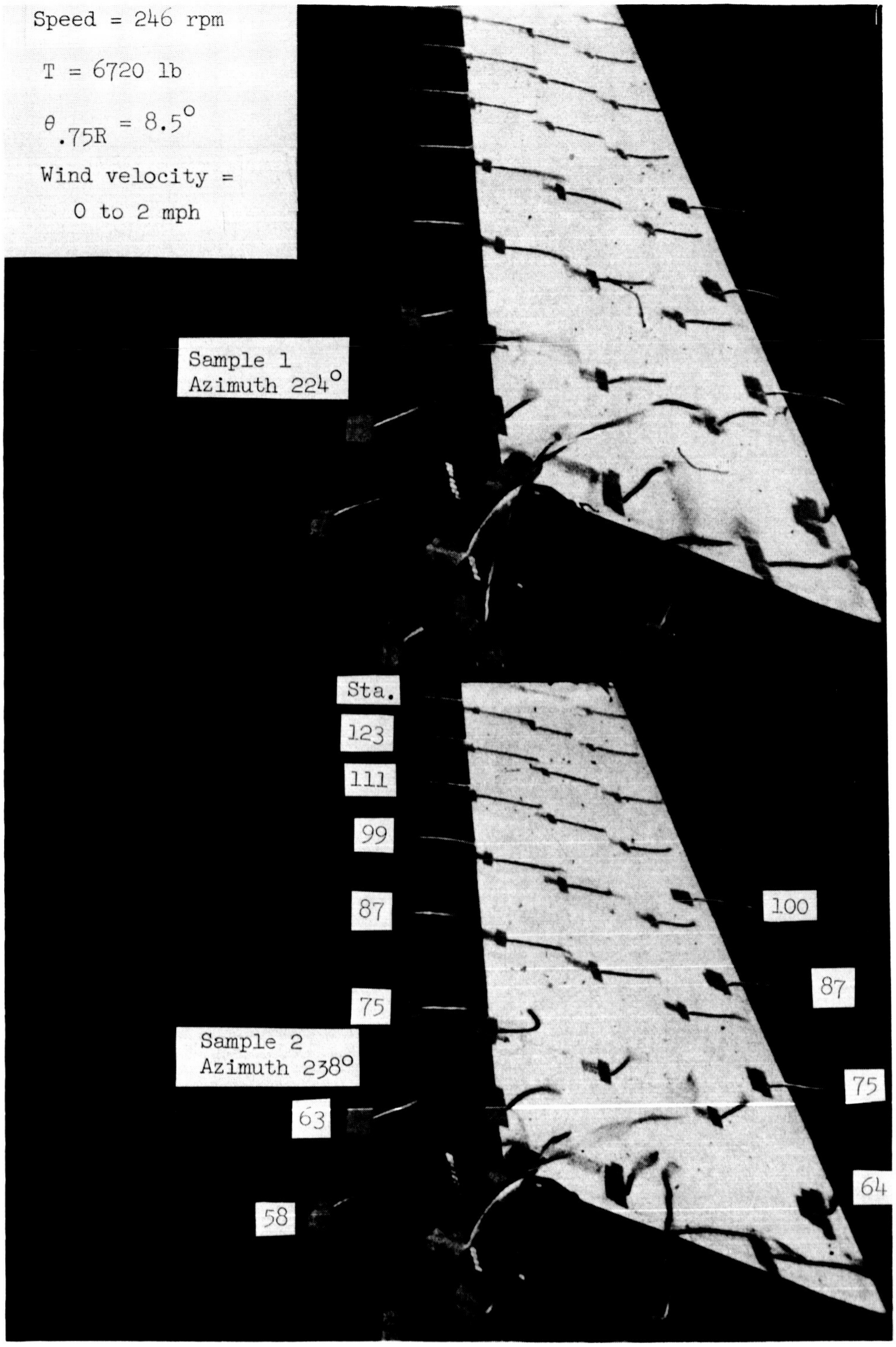


Figure 4.- Streamers mounted on hand rail under rotor to show flow under rotor disk.

L-66-7604



L-66-7605

Figure 5.- Tufts mounted on upper surface of rotor blade. Servo flaps removed, pitch locked at root. (Operating conditions, radial station for tufts, and azimuth position as noted on print.)

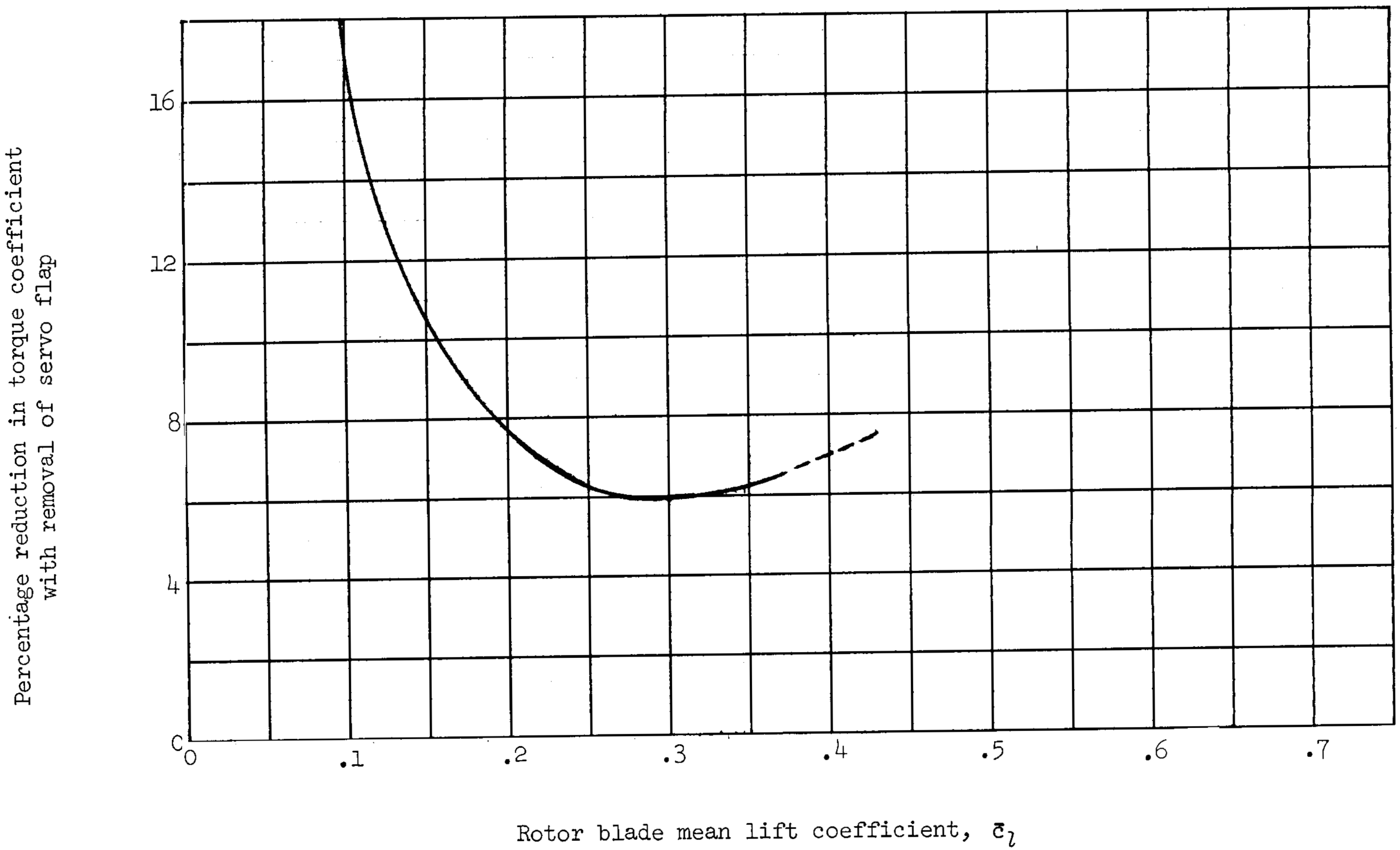


Figure 6.- Effect of servo-flap removal on rotor torque coefficient.

NASA-Langley, 1967 L-5245