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# FLIGHT MEASUREMENTS OF COMPRESSIBILITY EFFECTS ON A THREE-BLADE THIN CLARK Y PROPELLER OPERATING AT CONSTANT ADVANCE-DIAMETER RATIO AND BLADE ANGLE

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# ERRATUM

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Please insert the attached table II in your copy of the subject paper.

TABLE II - RESULTS AFTER CONVERSION OF DATA TO $V/nD = 2.37$

[NACA 10-408-03RCY three-blade propeller on Bell
YP-39 airplane; $\beta = 46.8^\circ$]

| Run | $C_T$ | $C_Q$ | Shank thrust loss (percentage low-speed $C_T$) | Tip thrust loss (percentage low-speed $C_T$) | Decrease in torque (percentage low-speed $C_Q$) |
|---|---|---|---|---|---|
| Low-speed average | | | | | |
| | 0.0830 | 0.0340 | ---- | ---- | ---- |
| High speed | | | | | |
| A | 0.0676 | 0.0314 | 9.0 | 6.9 | 7.7 |
| B | .0685 | .0319 | 11.3 | 6.8 | 5.9 |
| C | .0666 | .0311 | 11.1 | 7.9 | 9.7 |
| D | .0672 | .0320 | 11.9 | 6.9 | 5.9 |
| E | .0658 | .0314 | 12.3 | 7.7 | 7.6 |
| F | .0589 | .0296 | 13.6 | 13.5 | 12.9 |

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ADVANCE CONFIDENTIAL REPORT

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# FLIGHT MEASUREMENTS OF COMPRESSIBILITY EFFECTS ON A THREE-BLADE THIN CLARK Y PROPELLER OPERATING AT CONSTANT ADVANCE-DIAMETER RATIO AND BLADE ANGLE

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## SUMMARY

Flight tests were made of a three-blade thin Clark Y propeller (NACA 10-408-03RCY blades) operating at a fixed blade angle of approximately 46.8° at 0.75 radius, at an advance-diameter ratio of 2.37, and at true airplane speeds of approximately 300 and 450 miles per hour.

Comparison of the results obtained at 450 miles per hour with those obtained at 300 miles per hour indicated losses in propeller efficiency from 11 to 18 percent at high speed. It is indicated that a large part of these losses may be due to poor shank sections. A decrease in thrust from the blade tips up to 13 percent was also recorded at high speed. These tip losses were counterbalanced by corresponding reductions in propeller torque.

## INTRODUCTION

As part of a program of flight tests of airplane propellers to determine compressibility effects at high speeds, tests have been made of a three-blade thin Clark Y propeller (NACA 10-408-03RCY) on a Bell YP-39 airplane. In these tests, the propeller blade angle was fixed and the advance-diameter ratio $V/nD$ was maintained essentially constant while runs were made at high and at low forward speeds.

This report presents the data obtained from these tests with an analysis of the results.

## SYMBOLS.

| | |
|---|---|
| $V/nD$ | advance-diameter ratio |
| $V$ | true airspeed |
| $n$ | rotational speed |
| $D$ | propeller diameter |
| $\beta$ | section blade angle |
| $R$ | propeller radius to tip |
| $x$ | ratio of section radius to propeller radius |
| $b$ | blade section chord |
| $h$ | blade section thickness |
| $T$ | propeller thrust |
| $r$ | radial distance from thrust axis to survey point |
| $p$ | static pressure |
| $p_T$ | total pressure |
| $c_p$ | specific heat of air at constant pressure |
| $T$ | absolute temperature (with proper subscripts) |
| $K$ | heat energy per unit mass of air added to slipstream<br>$\left[\frac{550\ \text{bhp}\ (1 - \eta)}{\rho_o V_o \pi R^2}\right]$ |
| $\eta$ | propeller efficiency |
| $\rho$ | density |
| $Q$ | propeller torque |
| $C_T$ | propeller thrust coefficient |
| $C_Q$ | propeller torque coefficient |

| | |
|---|---|
| $\sigma$ | relative density |
| $M$ | airplane Mach number |
| $M_t$ | propeller-tip Mach number |
| $\gamma$ | ratio of specific heat of air at constant pressure to specific heat of air at constant volume |
| $hp_w$ | waste engine power |
| bhp | brake horsepower |

Subscripts:

| | |
|---|---|
| 0 | station 0, plane ahead of propeller (free stream) |
| 1 | station 1, survey plane behind propeller |
| 2 | station 2, plane behind propeller where $p_2 = p_0$ |

## DESCRIPTION OF PROPELLER AND TEST EQUIPMENT

General specifications of the propeller and power plant are as follows:

| | |
|---|---|
| Number of blades | Three |
| Blade design | NACA 10-408-03RCY |
| Blade design lift coefficient | 0.4 |
| Diameter | 10 feet, 5/8 inch |
| Engine | Allison V-1710-35 |
| Propeller gear ratio | 1.8:1.0 |

Tests were made without cuffs and with a spinner covering approximately the inner 18 percent of the propeller diameter. The developed plan form and blade sections of the NACA 10-408-03RCY blade are given in figure 1. In figures 2 and 3 are given the pitch distribution and the blade-width and the thickness distributions of the blades.

The survey equipment used in measuring the total pressure rise behind the propeller and the various other recording instruments were the same as the equipment and instruments described in reference 1. In addition to the instruments listed in reference 1, a propeller-blade-setting indicator was installed and was used by the pilot in locking the propeller to the approximate test setting. A recorder was also installed and was used in obtaining a more precise measurement of the blade setting.

The original intention was to use the hydraulic thrust meter to measure the total propeller thrust and to use the survey rakes to indicate the thrust distribution over the propeller radius. In this regard, the propeller spinner was modified to float on the propeller in such a way that the axial load on the spinner would not be transmitted to the thrust meter; the need for applying large spinner-load corrections to the thrust measurements was thus eliminated. In the early stages of the tests, large differences between thrust-meter values and survey values of thrust were noted and were attributed, in part at least, to the inability of the spinner to float properly on the propeller. After repeated attempts, although the spinner was apparently made to function satisfactorily, differences in the thrust values remained. In order to investigate further, attempts were made to recalibrate the thrust meter on the airplane. The results obtained from repeated calibration runs showed that the thrust meter was inconsistent but indicated that the calibration had changed from the original calibration made on a special bench setup by as much as 180 pounds. The thrust meter was found to function so erratically that the data obtained with it are unreliable and not indicated in the present report.

Failure of the hydraulic thrust meter to provide the desired measurement of total thrust made it necessary to rely entirely on the survey data for the measurement. A question then arose as to whether the survey tubes were giving the correct mean value of the pulsating slipstream impact pressure. The characteristics of the pressure-recording equipment when subjected to pulsating pressures were therefore investigated. Because the nature of the pulsating pressures imposed on the survey rake in flight had not been determined, a wide range of pressure wave forms and amplitudes as well as the approximate range of frequencies was investigated. The range of conditions is believed adequate to cover any flight conditions that may have existed. In no case was the error in measurement of average pressure by the survey tubes found to be greater than ±2 percent.

Because of the similarity in construction and operation of the torque meter and the hydraulic thrust meter, it was also decided to recalibrate the torque meter on the airplane. For this purpose, a dynamometer was devised to accommodate the entire airplane and several calibration runs were made. It was found that the torque-meter calibration had not changed and that its operation was satisfactory.

## TEST PROCEDURE

All tests reported were made at a blade setting of approximately 46.8° at 0.75 radius. This setting is very nearly the highest blade setting obtainable with the use of full power and the maximum allowable airplane speed.

In each test run, it was necessary to dive the airplane in order to maintain the required V/nD. With the propeller set at an angle of approximately 46.8°, the dive for each run was started at about 20,000 feet. During the dive from 20,000 feet to 15,500 feet, the pilot endeavored to reach steady conditions of indicated airspeed and engine speed. The recording instruments were started at 15,500 feet and records were taken until the airplane had passed 14,500 feet.

The pilot attempted to maintain the following conditions:

| | |
|---|---|
| High speed: | |
| Airplane indicated airspeed, mph . . . . . . . . . . | 360 |
| Engine speed, rpm . . . . . . . . . . . . . . . . . . . | 3000 |
| Low speed: | |
| Airplane indicated airspeed, mph . . . . . . . . . . | 240 |
| Engine speed, rpm . . . . . . . . . . . . . . . . . . . | 2000 |

These conditions were so chosen that a V/nD of approximately 2.37 was reached at an altitude of 15,000 feet at both high and low speeds.

## REDUCTION OF DATA

In evaluating the data obtained from the test runs, the actual propeller blade settings were determined from the records of the blade-setting recorder. There was generally some slight disagreement between indicated and recorded blade settings owing to the lower precision of the indicator. The test runs in which the blade settings did not agree within ±0.05° with the required setting of 46.8° were discarded.

All records of each selected run were then worked up as time histories. From these histories, points at which all records were smooth were chosen. These points were finally worked up completely to give values of free-air temperature, free-stream static pressure, true airspeed, propeller rotational speed, engine torque, and the variation of total pressure across the propeller slipstream.

The propeller thrust was evaluated from the measurements of slipstream total pressure by a simplified version of a formula expressing the increase of axial momentum imparted by the propeller to the air in the slipstream. The complete formula, which is derived in the appendix, is as follows:

$$\frac{dT}{\pi d(r^2)} = 7p_1\left[\left(\frac{p_{T_1}}{p_1}\right)^{\frac{2}{7}} - 1\right]\left[\frac{\left(p_{T_1}^{\frac{2}{7}} - p_0^{\frac{2}{7}}\right)^{\frac{1}{2}} - \left(\frac{c_pT_0}{K+c_pT_0}\right)^{\frac{1}{2}}\left(p_{T_c}^{\frac{2}{7}} - p_0^{\frac{2}{7}}\right)^{\frac{1}{2}}}{\left(p_{T_1}^{\frac{2}{7}} - p_1^{\frac{2}{7}}\right)^{\frac{1}{2}}}\right]$$

The factor $\left(\frac{c_pT_0}{K + c_pT_0}\right)^{\frac{1}{2}}$ is a correction for the heat added to the slipstream by the propeller and may usually be neglected as in the present case.

In the present tests $\Delta p_T$ was measured directly, where

$$\Delta p_T = p_{T_1} - p_{T_0}$$

If $\Delta p_T$ is small in comparison with $p_{T_0}$ with the result that second-order terms in $\Delta p_T$ may be neglected and if $p_1$ is assumed equal to $p_0$, the formula for $\frac{dT}{\pi d(r^2)}$ reduces to

$$\frac{dT}{\pi d(r^2)} = \left(\frac{p_0}{p_{T_0}}\right)^{\frac{5}{7}} \Delta p_T$$