TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 728

AERODYNAMIC FORCES AND MOMENTS OF A SEAPLANE ON THE WATER

By M. Kohler

Washington
November 1933

E R R A T A

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# AERODYNAMIC FORCES AND MOMENTS OF A SEAPLANE ON THE WATER*

By M. Kohler

## I. INTRODUCTION

The designers and pilots of seaplanes should have a thorough knowledge of the action of air and water on floating objects. This is possible only when adequate hydrodynamic and aerodynamic data are at their disposal. The problems involved are so complex that they cannot be solved by theory alone. It is necessary to find the right combination of theory and experimental data. Full-scale tests are not expedient or necessary for a comprehensive systematic investigation. Laboratory research is more suitable. The problem has already been tackled from the experimental hydrodynamic side (reference 1). This report gives the results of wind-tunnel tests with a seaplane model as a contribution to the solution of the aerodynamic problems.

## II. TESTS

In the tests it was assumed that the seaplane rested motionless on the water and was exposed, in various positions with respect to the supposedly flat surface of the water, to a uniform air current at $0^\circ$ to $360^\circ$.

1) Model.- The tests were made with the model of a twin-engine seaplane from the Heinkel works in Warnemünde. The biplane cellule had a straight upper wing and a lower wing with a slight dihedral. The two lateral engine nacelles were between the wings. The fuselage and tail surfaces were of the conventional type. The twin floats had the usual form and arrangement (figs. 1 and 2). The principal dimensions of the model were:   span  b  of both

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wings, 1.296 m (51.02 in.); maximum chord  t  of both
wings, 0.187 m (7.36 in.); total wing area  F,  0.4752 m²
(5.12 sq.ft.).  Other dimensions can be obtained approxi-
mately from figure 2.

2) Experimental arrangement.- The tests were made in
the large Göttingen wind tunnel with the aid of the large
6-component balance (reference 2).  Since, with the usual
method of suspending the model, the balance stand can be
turned laterally only ±18°, a special arrangement of the
model had to be adopted in this case, in order to obtain
the desired lateral range of 0° to 360° exposure to the
air stream.  This was accomplished by suspending the model
in the wind tunnel with the wings vertical, thus necessi-
tating the vertical installation of the plate represent-
ing the surface of the water (fig. 2). In order to be
able to bring the model into any desired position with
reference to the plate, it was supported on a ball, so
that the center of the ball coincided with the center of
gravity of the model.  The ball with the clamping device
was mounted on a rod which in turn formed a part of the
model support (figs. 2 and 3).  The lateral adjustment
was effected by means of a rotatable disk in the plate,
in which the float models were embedded to the proper
depth.  The plate was hollow, so that the parts of the
clamping device could be kept out of the air stream.

3) Testing.- The tests were for the purpose of deter-
mining three force components and three moment components,
i.e., the six components requisite in a continuous process
for the definite determination of the aerodynamic result-
ants in space.  These six components were first determined
for the system of axes fixed with respect to the wind tun-
nel and at an air velocity of about 30 m (98.4 ft.) per
second.  In order, however, to be able to consider the
phenomena as presented to the seaplane pilot, the measured
quantities were mathematically transformed so as to corre-
spond to axes fixed with respect to the seaplane.  The
latter axes form a rectangular right-hand system, whose
origin coincides with the center of gravity of the airplane
and whose positive x-axis is parallel to the propeller axis
and extends forward from the pilot.  The quantities evaluat-
ed are the tangential force  T,  the lateral force  S,  the
normal force  N,  the rolling moment  $M_{q_0}$,  the pitching
moment  $M_{h_0}$,  and the yawing moment  $M_{s_0}$.  (The subscript

o indicates that the reference axes pass through the center of gravity.) The position of the model with reference to the plate was designated by the lateral angle $\tau$, the pitching angle $\vartheta$, and the banking angle $\varphi$. These forces, moments, and angles are shown in figure 4. Insofar as possible, the rules of the FALU for the standardization of aircraft notation were followed (reference 3). The tests include measurements at pitching angles $\vartheta$ of $-1.5^\circ$, $3^\circ$, and $8^\circ$ and at lateral angles $\tau$ of 0 to $180^\circ$ or $360^\circ$. Moreover, a test was made in order to determine the velocity course near the plate without model (fig. 5). The test point is on the horizontal middle line of the plate at 28.5 percent of the plate length L (= 2.4 m = 7.87 ft.) from the leading edge. The vertical distance of the c.g. from the plate is $h_0$ = 125 mm (4.92 in.).

## III. RESULTS

The test results are represented nondimensionally. The force coefficients refer to the dynamic pressure q of the flow velocity and to the wing area F; the moment coefficients, also to the maximum wing chord t. (See table and figures 6, 7, and 8.) The abscissas represent the lateral angles $\tau$ = 0 to $360^\circ$; the ordinates, the force, or moment coefficients. The plain curves correspond to the banking angle $\varphi$ = $0^\circ$; the dash curves to $\varphi$ = $5^\circ$. The effect of the suspension on the force and moment values was determined by a special test with the suspension alone, in which the model served as a "screen." Zero-point errors, due to imperfections in the model or in its adjustment during the tests, were not corrected. Figure 6 shows the course of the forces for the conditions investigated. The results of the moment measurements, as given in figures 7 and 8, contain much information for judging the behavior on the water. In a lateral current at an angle of about $60^\circ$, the rolling moment $M_{qo}$ in the horizontal position of the model has approximately the same minimum value at all three of the pitching angles investigated. According to the definition there is a moment which tends to depress the starboard wing into the water so as to endanger the seaplane. For the smallest pitching angles tested, a second minimum of smaller value occurs in a lateral current at an angle of about $150^\circ$. The

conditions are similar at lateral angles of $\tau > 180^\circ$.*
If the seaplane already has a lateral inclination in the
direction of a right-hand or negative moment, then the
dangerous moment increases about 37 percent for the maxi-
mum longitudinal inclination in a lateral wind of about
$60^\circ$. The peak values recur at lateral angles above $180^\circ$.
They are no longer very dangerous, however, because the
depressed half of the wing is on the windward side. A
current from the rear may become dangerous for the pitch-
ing moment $M_{h_0}$, especially at large positive longitudi-
nal inclinations. The horizontal tail surfaces and the
wing are then struck negatively above their trailing edges
by the air current, so as to produce a tail-heavy pitch-
ing moment. In this case the floats offer but little re-
sistance since, for technical reasons, they taper aft into
slender tips. Herein lies another danger which, though
it seldom eventuates, must always be considered in design-
ing the floats. The yawing moment $M_{s_0}$, due to the lat-
eral angle, is important for judging the operating char-
acteristics of the seaplane on the water. The model in-
vestigated exhibited directional instability in all lat-
eral air currents. The longitudinal and lateral inclina-
tions had but little effect on the lateral moment.

## IV. SUMMARY

The results of the 6-component tests of a seaplane
model over a plate representing the surface of the water
are reported and discussed. The tests were made at vari-
ous longitudinal and lateral inclinations of the model in
a lateral air current at 0 to $360^\circ$. The data can be use-
ful to seaplane designers and pilots for judging the be-
havior of full-scale seaplanes on the water. This, how-
ever, represents only a modest beginning in obtaining ex-
perimental data for solving the problem of the mutual re-
actions of the water and air on the one hand and of the
seaplane on the other hand. The experiments should be
continued with seaplanes of other types. It would also
be desirable to supplement the experiments under consider-
ation by tests with various rudder deflections with the
propeller running.

*For the sake of clearness in the positions without lateral
inclination, only the values for $\tau = 0$ to $180^\circ$ are given.
These values can be symmetrically supplemented for the re-
gion between 180 and $360^\circ$.

Translation by Drwight M. Miner,
National Advisory Committee for Aeronautics.

TABLE

| $\vartheta°$ | $\varphi°$ | 0&360 | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $c_t$ values | | | | | | | |
| -1.5 | 0 | 0.0345 | 0.0310 | -0.0020 | -0.0370 | -0.0180 | -0.0450 | -0.0525 | | | | | |
| -1.5 | +5 | 0.0375 | 0.0330 | 0.0130 | -0.0250 | -0.0040 | -0.0380 | -0.0535 | -0.0585 | -0.0255 | -0.0395 | -0.0015 | 0.0390 |
| +3.0 | 0 | 0.0295 | 0.0220 | -0.0140 | -0.0400 | -0.0280 | -0.0590 | -0.0590 | | | | | |
| +3.0 | +5 | 0.0305 | 0.0090 | -0.0125 | -0.0295 | -0.0225 | -0.0195 | -0.0595 | -0.0550 | -0.0460 | -0.0320 | -0.0075 | 0.0295 |
| +8.0 | 0 | -0.0120 | -0.0220 | -0.0110 | -0.0380 | -0.0330 | -0.0465 | -0.0490 | | | | | |
| +8.0 | +5 | -0.0190 | -0.0360 | -0.0125 | -0.0185 | -0.0175 | -0.0525 | -0.0520 | -0.0425 | -0.0300 | -0.0245 | -0.0160 | -0.0055 |
| | | | | | | | $c_s$ values | | | | | | |
| -1.5 | 0 | -0.0045 | -0.181 | -0.289 | -0.384 | -0.273 | -0.175 | 0 | | | | | |
| -1.5 | +5 | -0.0135 | -0.226 | -0.298 | -0.292 | -0.305 | -0.230 | -0.0160 | 0.199 | 0.279 | 0.301 | 0.308 | 0.188 |
| +3.0 | 0 | 0 | -0.173 | -0.295 | -0.294 | -0.276 | -0.189 | 0.0010 | | | | | |
| +3.0 | +5 | -0.0660 | -0.250 | -0.303 | -0.288 | -0.298 | -0.227 | 0.0565 | 0.229 | 0.278 | 0.302 | 0.306 | 0.163 |
| +8.0 | 0 | 0 | -0.170 | -0.269 | -0.288 | -0.264 | -0.183 | 0.0110 | | | | | |
| +8.0 | +5 | -0.104 | -0.271 | -0.305 | -0.288 | -0.287 | -0.136 | 0.115 | 0.247 | 0.287 | 0.298 | 0.262 | 0.104 |
| | | | | | | | $c_n$ values | | | | | | |
| -1.5 | 0 | 0.099 | 0.148 | 0.0895 | 0.0655 | 0.174 | 0.162 | 0.167 | | | | | |
| -1.5 | +5 | 0.0880 | 0.238 | 0.137 | 0.0400 | 0.229 | 0.300 | 0.182 | 0.0670 | 0.101 | 0.0515 | 0.0020 | 0.037 |
| +3.0 | 0 | 0.444 | 0.433 | 0.250 | 0.0805 | 0.0840 | -0.149 | -0.350 | | | | | |
| +3.0 | +5 | 0.389 | 0.482 | 0.208 | 0.0425 | 0.167 | 0.0070 | -0.276 | -0.210 | 0.0250 | 0.0530 | 0.0730 | 0.250 |
| +8.0 | 0 | 0.691 | 0.634 | 0.248 | 0.0700 | -0.0075 | -0.431 | -0.694 | | | | | |
| +8.0 | +5 | 0.712 | 0.676 | 0.288 | 0.0220 | 0.0510 | -0.355 | -0.694 | -0.492 | -0.0880 | 0.0460 | 0.193 | 0.557 |
| | | | | | | | $c_{m_{qo}}$ values | | | | | | |
| -1.5 | 0 | -0.0375 | -0.161 | -0.215 | -0.126 | -0.176 | -0.205 | 0.074 | | | | | |
| -1.5 | +5 | -0.0440 | -0.170 | -0.240 | -0.242 | -0.269 | -0.179 | 0.0885 | 0.196 | 0.0940 | 0.0650 | 0.115 | 0.0660 |
| +3.0 | 0 | -0.0460 | -0.156 | -0.322 | -0.121 | -0.128 | -0.105 | 0.0380 | | | | | |
| +3.0 | +5 | -0.0055 | -0.149 | -0.264 | -0.240 | -0.241 | -0.157 | -0.0350 | 0.0590 | 0.0195 | 0.0610 | 0.157 | 0.115 |
| +8.0 | 0 | -0.0580 | -0.176 | -0.240 | -0.128 | -0.0615 | -0.0290 | 0.0215 | | | | | |
| +8.0 | +5 | -0.0560 | -0.213 | -0.330 | -0.209 | -0.143 | -0.0895 | -0.0310 | -0.0880 | -0.0185 | 0.0700 | 0.160 | 0.0945 |
| | | | | | | | $c_{m_{ho}}$ values | | | | | | |
| -1.5 | 0 | -0.0345 | 0.0210 | -0.0215 | -0.0070 | 0.0885 | 0.0780 | 0.160 | | | | | |
| -1.5 | +5 | -0.0415 | 0.0425 | 0.0125 | 0.0390 | 0.186 | 0.201 | 0.160 | 0.0105 | 0.0080 | -0.0285 | -0.0630 | -0.0120 |
| +3.0 | 0 | 0.0490 | 0.0930 | 0.0025 | -0.0095 | 0.0375 | -0.138 | -0.302 | | | | | |
| +3.0 | +5 | 0.0265 | 0.0890 | 0.0140 | 0.0265 | 0.141 | 0.0005 | – | -0.207 | -0.0575 | -0.0335 | -0.0665 | 0.0255 |
| +8.0 | 0 | 0.131 | 0.116 | -0.0065 | -0.0315 | -0.0305 | -0.368 | -0.578 | | | | | |
| +8.0 | +5 | 0.139 | 0.140 | 0.0640 | -0.0035 | 0.0430 | -0.277 | -0.585 | -0.455 | -0.147 | -0.0360 | -0.0155 | 0.0830 |
| | | | | | | | $c_{m_{so}}$ values | | | | | | |
| -1.5 | 0 | 0.0085 | 0.113 | 0.141 | 0.270 | 0.335 | 0.247 | -0.0085 | | | | | |
| -1.5 | +5 | 0.0105 | 0.112 | 0.164 | 0.264 | 0.318 | 0.237 | -0.0165 | -0.284 | -0.361 | -0.278 | -0.185 | -0.118 |
| +3.0 | 0 | -0.0015 | 0.0915 | 0.135 | 0.257 | 0.339 | 0.244 | -0.0030 | | | | | |
| +3.0 | +5 | 0.0025 | 0.0910 | 0.148 | 0.246 | 0.326 | – | -0.0080 | -0.256 | -0.348 | -0.265 | -0.169 | -0.109 |
| +8.0 | 0 | 0.0035 | 0.0575 | 0.128 | 0.221 | 0.292 | 0.223 | -0.0100 | | | | | |
| +8.0 | +5 | -0.0055 | 0.0705 | 0.130 | 0.250 | 0.320 | 0.271 | 0.0105 | -0.228 | -0.337 | -0.250 | -0.172 | -0.0885 |

Figure 1.- Model suspended in wind tunnel over plate representing surface of water.
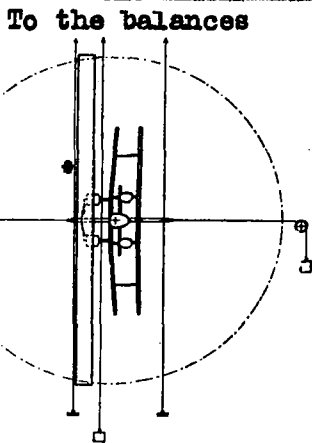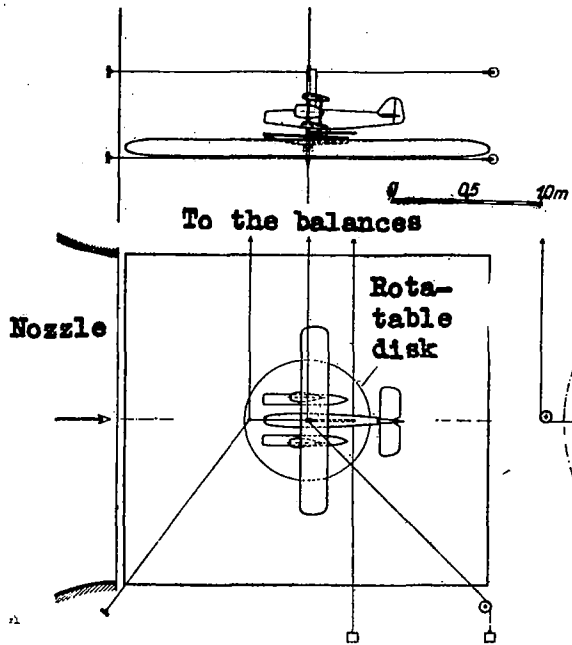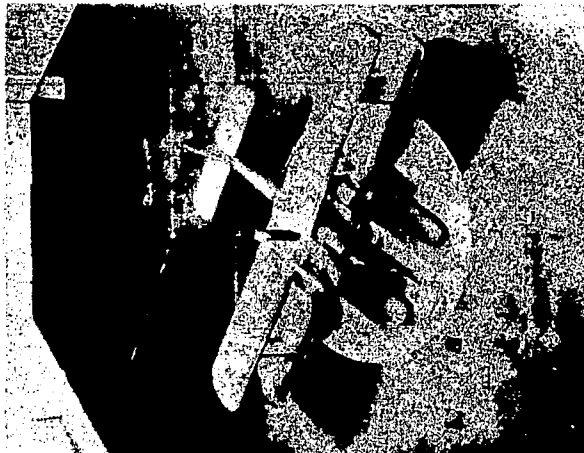
To the balances

Nozzle

Rotatable disk

To the balances

Figure 2.-

Experimental arrangement.

Propeller axis

Parallels to propeller axis.

$R_2$

Plate

Section B-B

Plastilin

rd.5

$R_1$

Section A-A
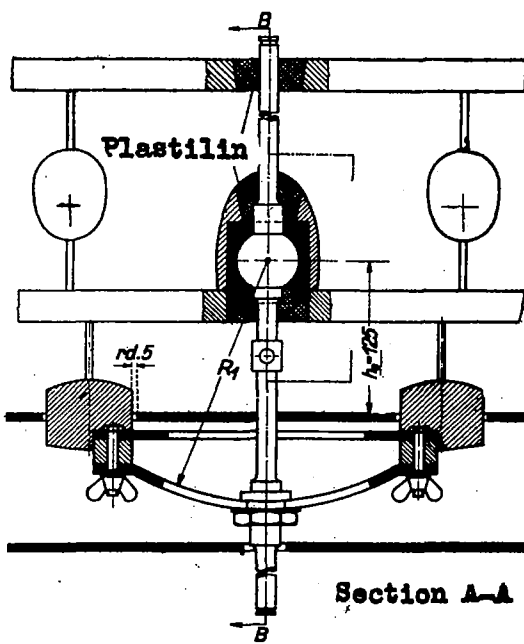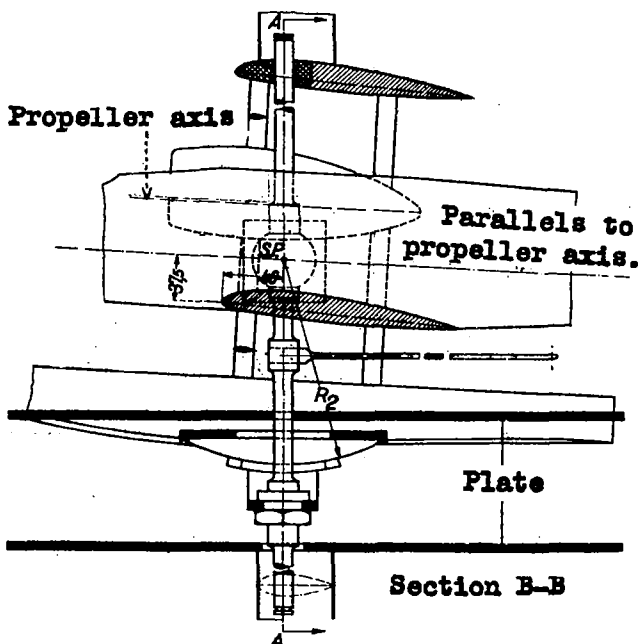
Figure 3.- Device for securing model to suspension rod.

Figure 5.- Velocity curve in vicinity of plate, without model.

Figure 4.- Definition diagrams for system of axes fixed with reference to airplane; forces, moments and angles.

$\vartheta = -1.5^{\circ}$ } $\varphi = 0^{\circ}$ } o ———

$+5^{\circ}$   x - - - - -

$\vartheta = +3.0^{\circ}$ } $\varphi = 0^{\circ}$ } △ ———

$+5^{\circ}$   ▽ - - - - -

$\vartheta = +8.0^{\circ}$ } $\varphi = 0^{\circ}$ } □ ———

$+5^{\circ}$   + - - - - -
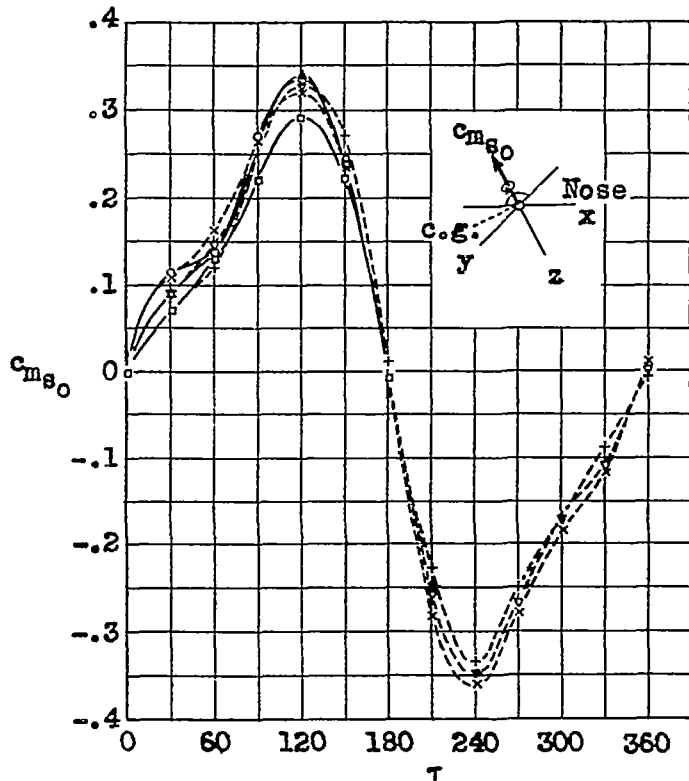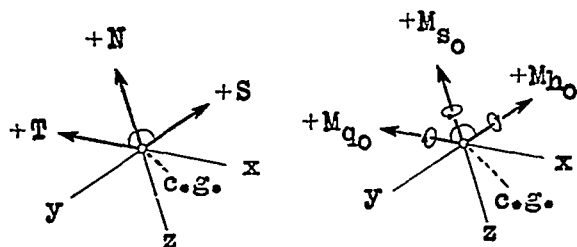
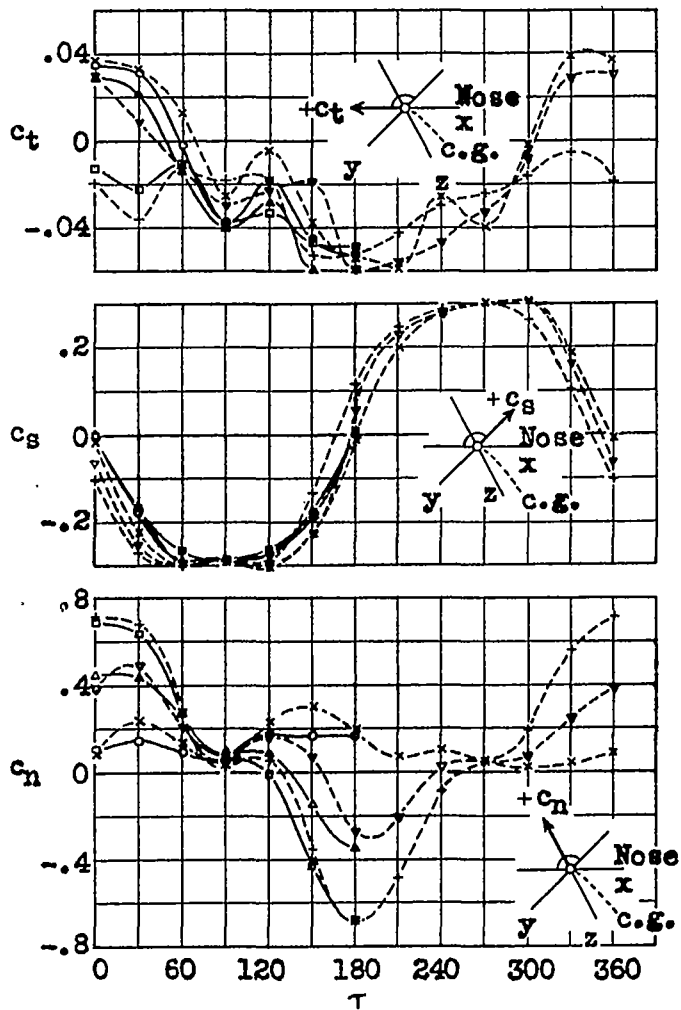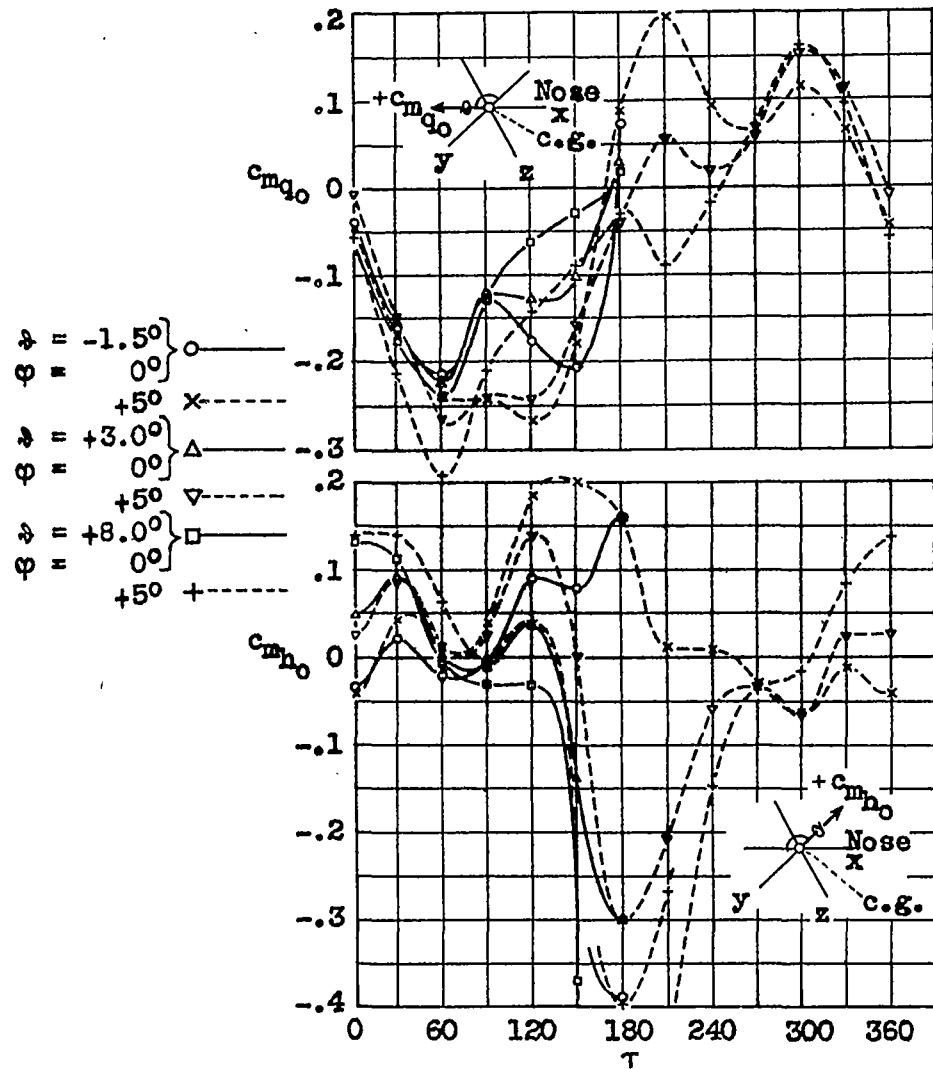

Figure 8.- Yawing-moment coefficients.

Figure 6.- Force coefficients.

Figure 7.- Coefficients of rolling and pitching moments.