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AERODYNAMIC FORCE AND MOMENT CHARACTERISTICS OF A FOUR-BLADED PROPELLER YAWED THROUGH 120 DEGREES

BY

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Subject: AERODYNAMIC FORCE AND MOMENT CHARACTERISTICS OF A FOUR-BLADED PROPELLER YAWED THROUGH 120 DEGREES

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Director

SUMMARY

This Report presents the results of six-component force and moment measurements on a propeller that was yawed through 120 degrees, for various conditions of blade pitch setting and advance ratio.

Force coefficients C_y and C_z, normal to the propeller axis, were found to vary significantly with yaw angle, and had magnitudes that ranged from 1/10 to 1/4 of thrust coefficient C_x.

All of the moments, (torque, pitching moment, and yawing moment) were of comparable maximum magnitude. The pitching and yawing moments were directed "nose up" and "nose right" respectively, for clockwise propeller rotation, and positive (nose right) yaw.

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LIST OF SYMBOLS

Symbol	Definitions
A, B	Geometric constants for moment transfer (ft.) (Fig. 3)
c	Blade local chord, ft.
C_x, C_y, C_z	Force coefficients $\frac{x,y,z}{\rho N^2 D^4}$
$-C_\ell$, C_m, C_n	Moment coefficients $\frac{-\ell,m,n}{\rho N^2 D^5}$
C_L	Propeller blade section design lift coefficient
D	Propeller diameter, ft.
J	V/ND
ℓ	Torque
m	Pitching moment ft. lb. - referred to propeller centre
N	Propeller rotation speed, rev./sec.
n	Yawing moment
q	Tunnel dynamic pressure lb./ft.^{2}
R	Propeller radius, ft.
t	Blade local thickness, ft.
V	Tunnel velocity, ft./sec.
x, y, z	Forces in body axis system, referred to propeller centre, lb.

LIST OF SYMBOLS (Cont'd)

Symbol	Definition
β	Blade pitch setting, referred to chord line at 0.75R - degrees
ψ	Yaw angle - degrees
ρ	Air density slug /ft.^{3}

AERODYNAMIC FORCE AND MOMENT CHARACTERISTICS OF A FOUR-BLADED PROPELLER YAWED THROUGH 120 DEGREES

1.0 INTRODUCTION

The aerodynamic characteristics of propellers used in the conventional sense (high advance ratios with axis parallel to free stream direction) are well understood, and their performance can, under most conditions, be predicted with satisfactory accuracy. Generally speaking, estimates can be extended to small angles of incidence, under the assumption that the flow through the propeller is nearly uniform, and that the resulting forces and moments due to any flow misalignment are small.

During the transition of a VTOL aircraft, however, or the normal operating regime of a helicopter, the propeller or rotor axis may be inclined at large angles to the relative wind, and may be operating at advance ratios very much different from those of conventional flight. Investigations of the fluid flow field under these conditions have shown that the propeller behaves somewhat like a wing, with an asymetric distribution of induced velocity and, hence, loading, and with large concentrations of vorticity in the wake.

A great deal of experimental data have been gathered for a large variety of propellers and helicopter rotors, but these were concerned mainly with their thrust and torque characteristics.

The aim of the present investigation was to measure the six components (forces and moments) acting at the propeller centre for a wide range of advance ratio, propeller attitude, and blade pitch settings. The experiment was performed in the NAE 6-ft. x 9-ft. low speed wind tunnel, where the propeller was free to yaw about its centre.

The propeller was two feet in diameter, and had four blades. It was constructed for the NAE by Canadair Limited, and is a scale model of the propellers currently in use on the Canadair CL-84 tilt-wing aircraft.

2.0 EXPERIMENTAL EQUIPMENT

2.1 Propeller

The propeller geometric characteristics may be listed as follows:

Diam. 2,000-ft.

No. of blades - 4

$$\text{Solidity} = \frac{\text{Blade area}}{\text{disc area}} = 0.127$$

Blade section at 0.75R - 65 series (design $C_L = 0.7$)

Figure 2 shows distributions of twist, thickness t/c, and chord c/R along the radius.

The pitch setting on all four blades was adjustable simultaneously by means of a mechanism built into the propeller hub.

2.2 Model Installation

The propeller-nacelle model is shown in Figure 1a mounted on its supporting strut in the 6-ft. x 9-ft. wind tunnel. The centre of the propeller was located on the tunnel

centreline, and also at the axis of rotation in yaw. All services to the model and balance, such as power, cooling water, etc. were accessible from the rear of the nacelle, and were led down the supporting strut.

2.3 Balance

The balance used to measure the propeller characteristics was a six-component internal strain-gauge balance. The means of attachment of the balance to the motor, and also to the external supporting strut, are illustrated in Figure 1, which shows the model partially disassembled. The external or "dead" part of the balance rests in a clamping fixture and is restrained in all degrees of freedom. A protective sheath or nacelle, made from fibreglass, is firmly attached to the clamping fixture, but is mechanically free from any other part of the model. The balance supports and motor casing are thus shielded from the oncoming wind, and only those aerodynamic forces acting on the propeller and its hub are transmitted to the balance.

2.4 Data Handling

All data from the model were received in the form of electrical signals that were brought to the main tunnel data system, finally appearing in a digital form from the output devices available (typewriter and punched tape).

Rotational speed was measured by means of a tachometer located at the rear of the motor.

3.0 CONTROLLED PARAMETERS AND DATA REDUCTION

3.1 Controlled Parameters

The controlled parameters in the experiment were propeller advance ratio V/ND, propeller inclination (yaw) and blade angle setting. Nominal values of these quantities are listed in the following Table.

V/ND	0.3, 0.4, 0.6, 0.8, 1.0, 1.4
ψ	0, 10, 20, 30.....120 degrees
β	8.7, 11.7, 14.7, 20.7, 26.7, degrees

A tunnel run consisted of rotating the nacelle in yaw through 120 degrees at a preselected blade pitch setting, while keeping the tunnel speed V and the propeller r.p.m. at a constant value.

The propeller r.p.m. was held fixed at 3,000 throughout the entire test, while the tunnel speed was varied in order to provide the required value of V/ND for each run.

3.2 Reduction of Data

The raw data, as received from the typed or punch tape output, was reduced for forces and moments acting at the centre of resolution of the balance (Fig. 3) by use of the appropriate calibration constants.

To transfer these to the centre of the propeller, the following equations were used

$$x = x_b \tag{1}$$

$$y = y_b \tag{2}$$

$$z = z_b \tag{3}$$

$$\ell = \ell_b - Ay_b \tag{4}$$

$$m = m_b + Ax_b + Bz_b \tag{5}$$

$$n = n_b - By_b \tag{6}$$

Subscript b refers to quantities measured at the centre of the balance. The quantities A and B are dimensions, shown in Figure 3.

A further transformation to a wind axis system was found useful for calculations of the wind tunnel interference corrections

i.e. $x_w = x \cos \psi - y \sin \psi$

$y_w = x \sin \psi + y \cos \psi$

$m_w = m \cos \psi + \ell \sin \psi$

Calculations of the forces, moments, and their respective coefficients, were performed on the IBM 1620 digital computer. Output was in the form of typewritten data and punched cards.

3.3 Accuracy

Tunnel dynamic pressure and propeller r.p.m., hence V/ND, were set to preselected values by the tunnel operator. The variation of V/ND throughout the yaw angle range did not exceed 1% at high tunnel speeds, and was much smaller for the lower speeds. Each value of V/ND was repeated in turn for each new blade angle, to approximately the same accuracy.

The repeatability of the balance output varied from less than 1% to 3%. The turntable yaw angle was known to 0.1 degree, and the blade pitch angle could be set to 0.5 degree.

3.4 Wall and Strut Interference

The data as presented contain no corrections due to the effects of the wind tunnel walls, or due to the proximity of the nacelle and strut. An attempt was made, however, to assess the magnitude of the wall-interference velocities for some specific runs, using the theoretical method of Heyson (Ref. 1).

The behaviour of the in-plane forces and moments near zero yaw indicated the possibility of an interference from the nacelle and supporting strut; however, a dummy system was not available at the time of the test.

4.0 RESULTS AND DISCUSSION

The basic data, i.e. C_x, C_y, C_z, C_ℓ, C_m, C_n, are presented in Figures 4 to 9. In addition, some wind axis coefficients (e.g. C_{x_w}, C_{y_w}) are presented for selected runs.

The computed data in tabular form are recorded in NAE 6 x 9/0081 Wind Tunnel Data Report (Ref. 2), and can be made available on request.

4.1 Propeller Forces, C_x, C_y, C_z

Figure 4 shows curves of the propeller thrust coefficient C_x against yaw angle ψ, for values of advance ratio J and β. These curves indicate that C_x increases with ψ, rapidly for high advance ratios, and more slowly as J decreases. The effect of increasing blade angle is to increase C_x, but to decrease its rate of change with ψ, particularly at the higher advance ratios.

The side force coefficient C_y is shown in Figure 5. This force at first increases with increasing yaw angle, but usually reaches a maximum at a value between 60 and 70 degrees. The effect of both advance ratio J and blade angle β is to increase its magnitude.

The normal force C_z is by far the smallest force acting on the propeller; its maximum values reach 0.02, compared with 0.16 for C_y and 0.36 for C_x. These represent forces of 2, 16, and 36 lb. on the balance, respectively. These measurements presented in Figure 6 are therefore probably the least reliable, but possess, nevertheless, certain trends that are worth noting. In general, an increase in ψ produces an increase in C_z, at least initially. The effect of an increase in J evidently increases the mean value of C_z, but also produces marked changes in its behaviour with ψ. Figures 6d and 6e, β = 20.7, 26.7 degrees, illustrate most clearly the behaviour of C_z with ψ and J. The curves are erratic at the advance ratio J = 1.46.

A surprising lack of coalescence of the individual curves at zero yaw angle was noted (see, for example, Fig. 5). This may be due to some form of flow misaligment resulting from the interference of the external supporting members. There is no experimental evidence to support this view, however, and the data must, for the present, remain as measured.

4.2 Propeller Moments C_ℓ, C_m, C_n

The body axis system adopted in the data reduction defines C_ℓ, a rolling moment, to be positive in the direction of propeller rotation. It has been plotted negatively in this Report, however, in order to correspond to the more usual torque sense, and is referred to as propeller torque. Values of $-C_\ell$ are plotted in Figure 7. Their shape and behaviour with yaw angle and advance ratio is generally similar to thrust. The effect of increasing blade angle β increases torque and also increases its rate of change with ψ for any given advance ratio.

The pitching moment C_m arises from a difference in loading between those blades occupying the advancing and retreating sides of the propeller disc. The resulting couple is "nose up", in the present frame of reference. This quantity is shown in Figure 8. It reaches a maximum value close to $\psi = 80$ degrees, and increases in magnitude with J and blade angle β.

The yawing moment C_n also arises from a lack of symmetry of the loading on the propeller disc and, in this case, is a "nose right" couple. Values of C_n are plotted in Figure 9,

and while it is seen that its behaviour with yaw angle ψ is similar to C_m, the effect of both advance ratio and blade angle is small. The magnitude of C_n is typically 1/2 to 1/5 of C_m.

Both of these moments exhibit, to a certain extent, the same lack of coalescence at zero yaw as did C_y and C_z.

4.3 Location of the Thrust Vector C_x in the Propeller Plane

The centre of pressure in the y-z or propeller plane has been inferred from the measured data as follows

$$\frac{\delta_z}{D} = \frac{C_m}{C_x} \tag{7}$$

$$\frac{\delta_y}{D} = \frac{C_n}{C_x} \tag{8}$$

These quantities have been plotted against yaw angle ψ for a blade angle β = 26.7 degrees, and for various advance ratios, in Figure 10. The curves indicate that, for most advance ratios, the centre of pressure of thrust lies up-wind of the propeller axis. When J reaches 1.46, values of δ_z and δ_y lie outside the swept area of the blades, and in fact tend to infinity at a yaw angle between 20 and 30 degrees, when the thrust component C_x approaches zero.

4.4 Wind Axis Quantities

The presentation of wind axis data is in the form of force polars, as seen in Figure 11. In these curves C_{y_w} is plotted versus C_{x_w} for each value of J, and for all of the blade angles.

The direction of the resultant force in body axis can be inferred from these Figures by drawing a radius vector from the origin to any of the curves. In Figure 11e, for example, β = 26.7 degrees, the force vector follows an almost circular path (constant total force) for the lowest advance ratio. As V/ND increases, the total force decreases at first as the blades are unloaded near ψ = 0, and then increases again with increasing incidence. The polars become correspondingly more distorted as V/ND is increased.

It is clear that, at a low yaw angle and advance ratio, the predominant force produced by the propeller is a thrust, and the propeller wake is essentially cylindrical, with a total head higher than that of the surrounding flow.

It may be noted that the quantities C_{y_w} and $-C_{x_w}$ could be termed "lift", and "drag", in an aircraft frame of reference. It can also be seen from the force polars that "lift" increases with yaw angle, while "drag", $(-C_{x_w})$, is negative (i.e. directed up-wind), and diminishes in magnitude with increasing ψ, until at some point it vanishes. A further increase of ψ produces a drag force that is directed downwind. It is at this point that the propeller has taken on characteristics somewhat similar to a lifting wing, and, as observation (3) has shown, possesses a trailing vortex wake.

Figure 12 shows how the coefficient C_{x_w} changes from thrust to drag as incidence is increased beyond about 60 to 80 degrees. It is presumably in this regime that the propeller flow field becomes somewhat similar to that of a lifting wing.

4.5 Propeller Characteristics at Zero Yaw

Values of thrust coefficient C_x and torque coefficient $-C_\ell$ are plotted in Figure 13 against advance ratio V/ND for a model yaw angle $\psi = 0$ degrees, and various blade angle settings. Propeller efficiency η has been determined from these results, and is plotted in Figure 13c. The envelope efficiency curve approaches a value of 0.84 at propeller blade angles of 27 degrees and greater.

4.6 Variation of Propeller Characteristics with Blade Angle (Fixed V/ND)

Propeller forces C_x, C_y, and C_z are plotted against pitch angle β, for a fixed advance ratio (V/ND = 1.02) and several values of yaw angle ψ, in Figure 14. The normal force C_z seems independent of both ψ and β, except in the region $+ 9° < \beta < 15°$ where a maximum value is indicated.

Thrust varies almost linearly with β, for propeller yaw angle ψ close to zero; as ψ increases, however, C_x becomes nearly independent of β, except in the range $+ 9° < \beta < 15°$.

Propeller moments $-C_\ell$, C_n, and C_m are presented in Figure 15.

5.0 ESTIMATION OF WIND TUNNEL INTERFERENCE EFFECTS

When the propeller is yawed to angles in the range 80 degrees to 120 degrees the resulting lift and drag coefficients can become high compared with a conventional wing, and the slipstream may, in some cases, impinge on the walls of the working section in the vicinity of the model.

It is usual, in wind tunnel tests, to apply corrections that can account for the presence of solid walls. These corrections are based on the assumption that the flow disturbances are small at the model, and, hence, corrections to incidence and speed are also small.

In the present situation this is obviously not the case; the magnitudes of model lift coefficient and flow curvature are far outside the range of conventional practice. To accommodate this, a method has been devised by H. Heyson (Ref. 1) that accounts for any combination of lift and drag, and for a large slipstream deflection.

Calculations of the corrections $\Delta\psi$ and ΔV have been made for two different advance ratios, throughout the range of yaw angle. The blade setting for these runs was 26.7 degrees.

Figure 16 shows the correction to yaw angle $\Delta\psi$ for advance ratios of 0.29 and 1.02 respectively. The magnitude of this quantity is small; $\Delta\psi$ reaches a value of 3 degrees at ψ = 80 degrees. The corresponding corrections to speed were found to be negligible.

6.0 CONCLUSIONS

The following conclusions can be made about the six-component measurements on the yawed propeller.

1. Thrust and torque increase with an increase of ψ and with blade angle, but decrease with V/ND. A calculation of propulsive efficiency at zero yaw gives a maximum value of 0.84.

2. Side force coefficient C_y in the yaw plane reaches a maximum value at a yaw angle of between 60 and 70 degrees, and increases with both blade angle and advance ratio. Its magnitude was approximately $\frac{1}{4}$ C_x.

3. Normal force coefficient C_z was very small (approx. 1/10 C_x) and increased with ψ; it was the least accurate of all measurements. For low values of V/ND, and high blade angles, the data were regular, but as V/ND increased, the results became less consistent.

4. The moments C_m and C_n were of comparable magnitude, and exhibited maxima, at $70° < \psi < 90°$. The direction of these moments was "nose up", and "nose right" respectively, in a body axis frame of reference, for clockwise propeller rotation, and for "nose right" yaw.

5. Computation of jet-boundary interference effects, using Heyson's method, indicated a maximum correction $\Delta\psi$ of + 3 degrees at ψ = 80 degrees. The correction to V or J was negligible.

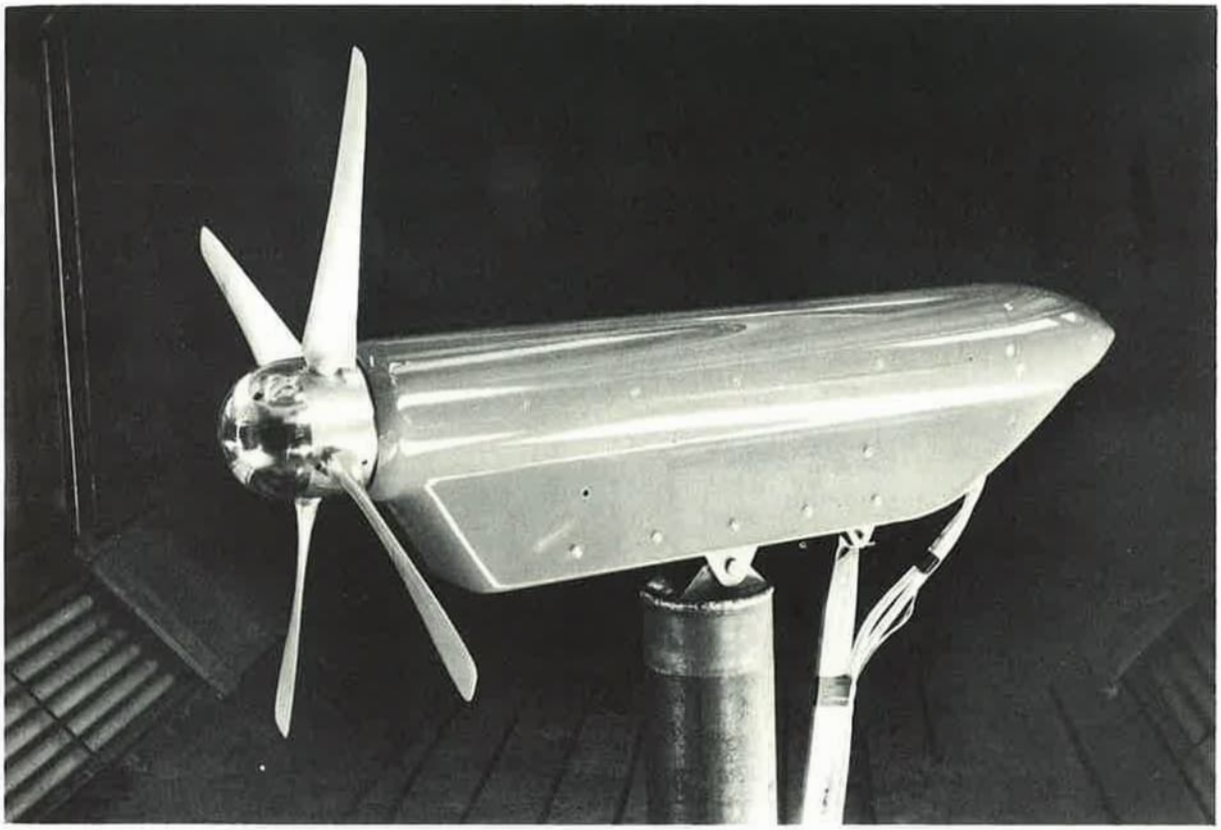
7.0 REFERENCES

1. Heyson, H.H. — Linearized Theory of Wind-Tunnel Jet-Boundary Corrections and Ground Effect for VTOL/STOL Aircraft. NASA TR R-124, 1962.

2. Wickens, R.H. — Four-Bladed Propeller Yaw Tests with Internal Balance. NAE 6x9/0081 Data Report, Oct. 1965.

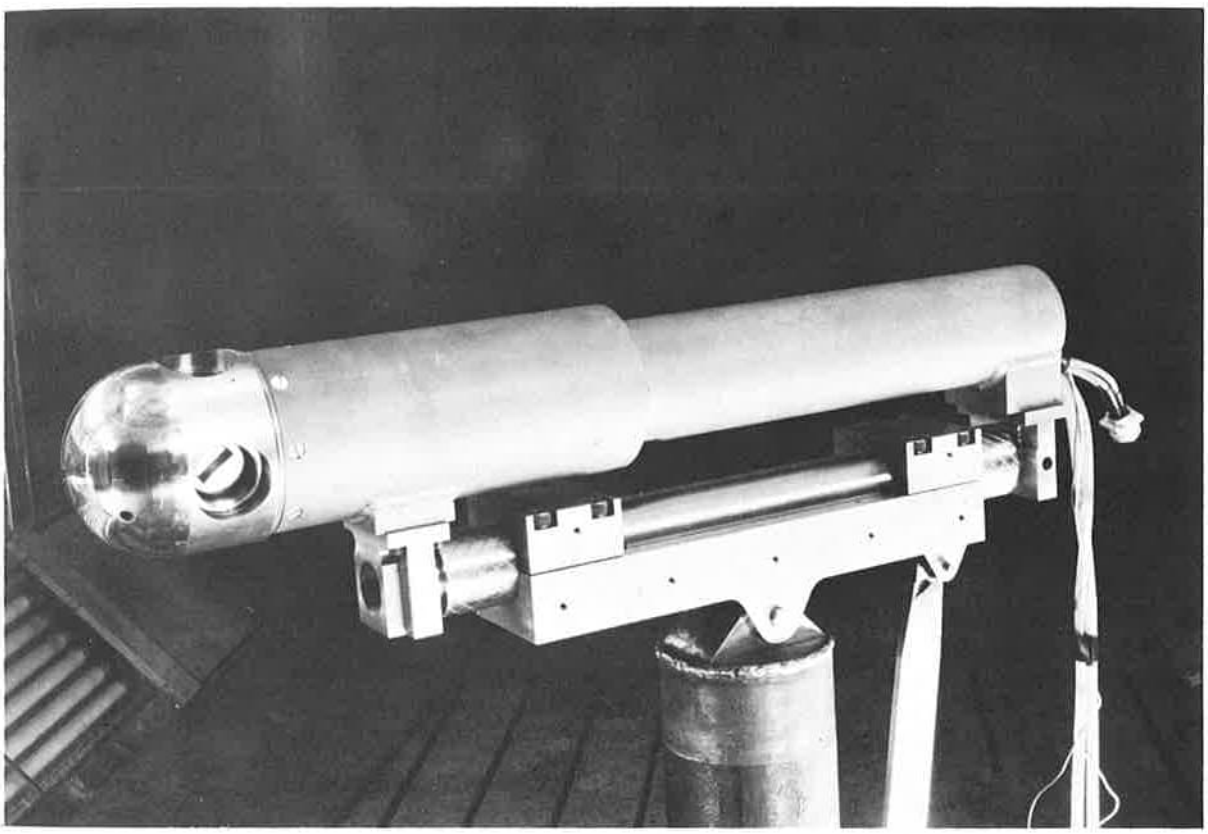
3. Wickens, R.H. Gartshore, I.S. — Observations on the Flow Near a Lifting Propeller. NRC, NAE Aero.Report LR-325, Dec. 1961.

FIG. 1a
LR – 454

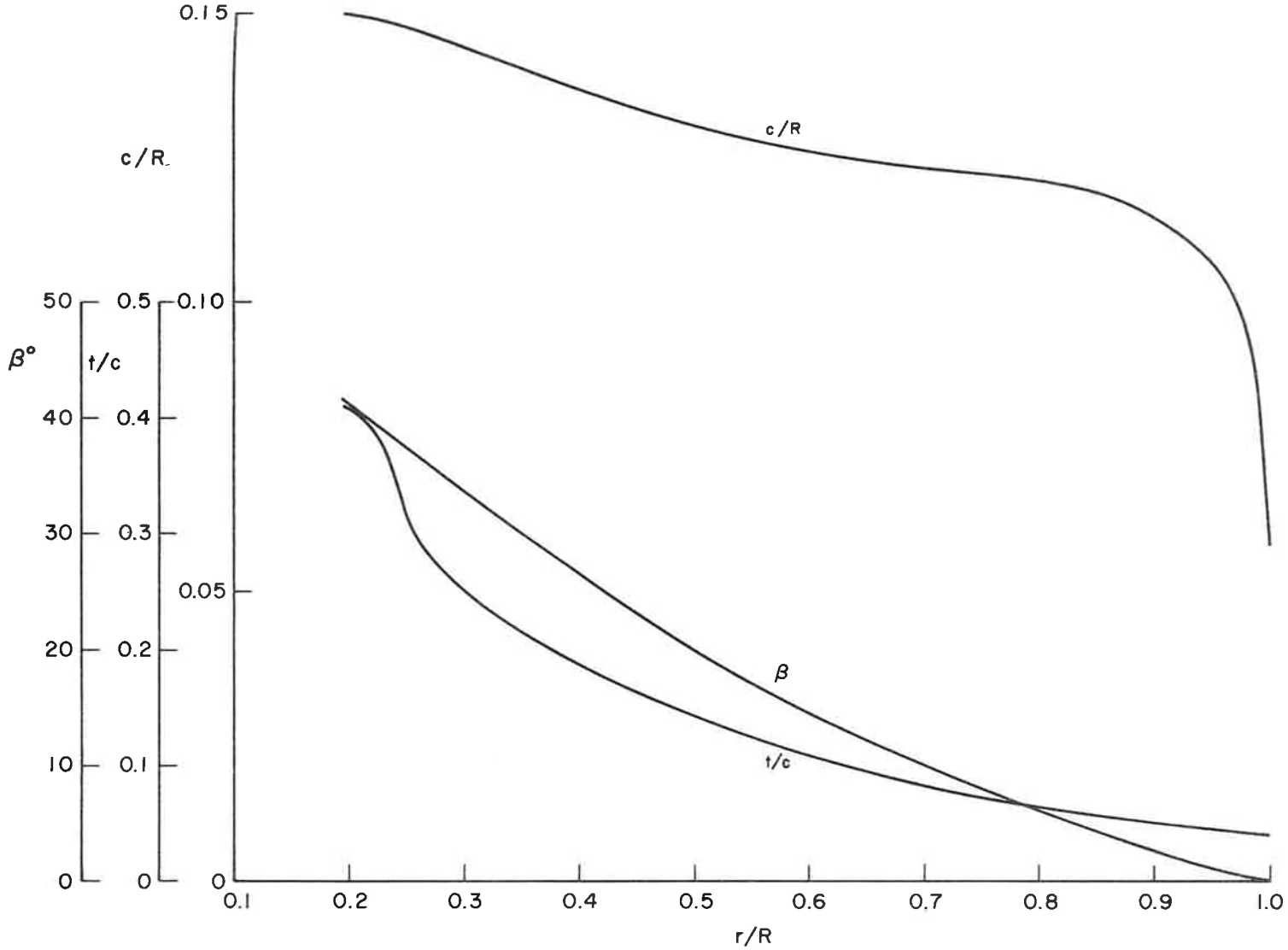


PROPELLER NACELLE MODEL

FIG. 1b
LR – 454

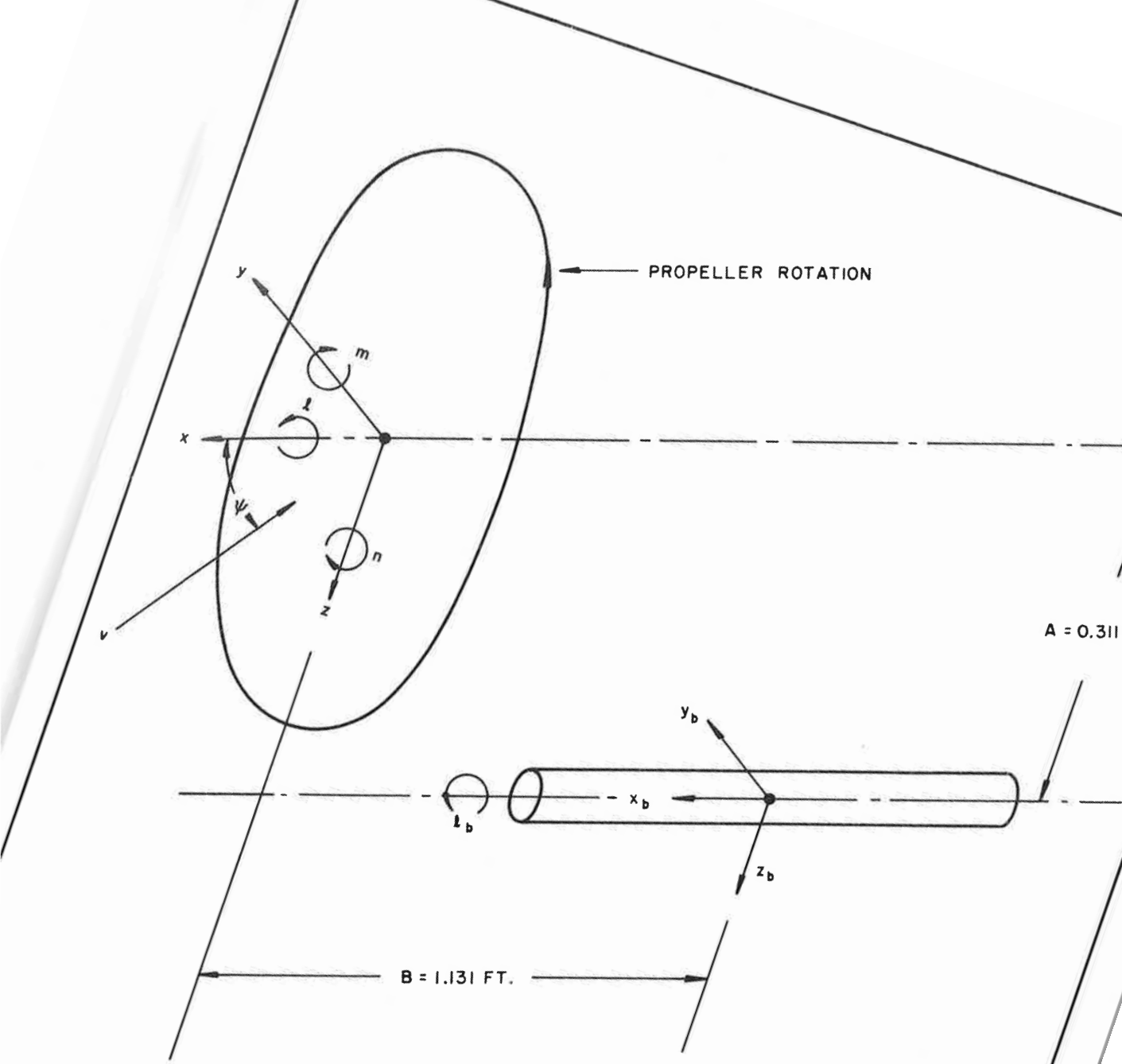


BALANCE MOUNTING ARRANGEMENT



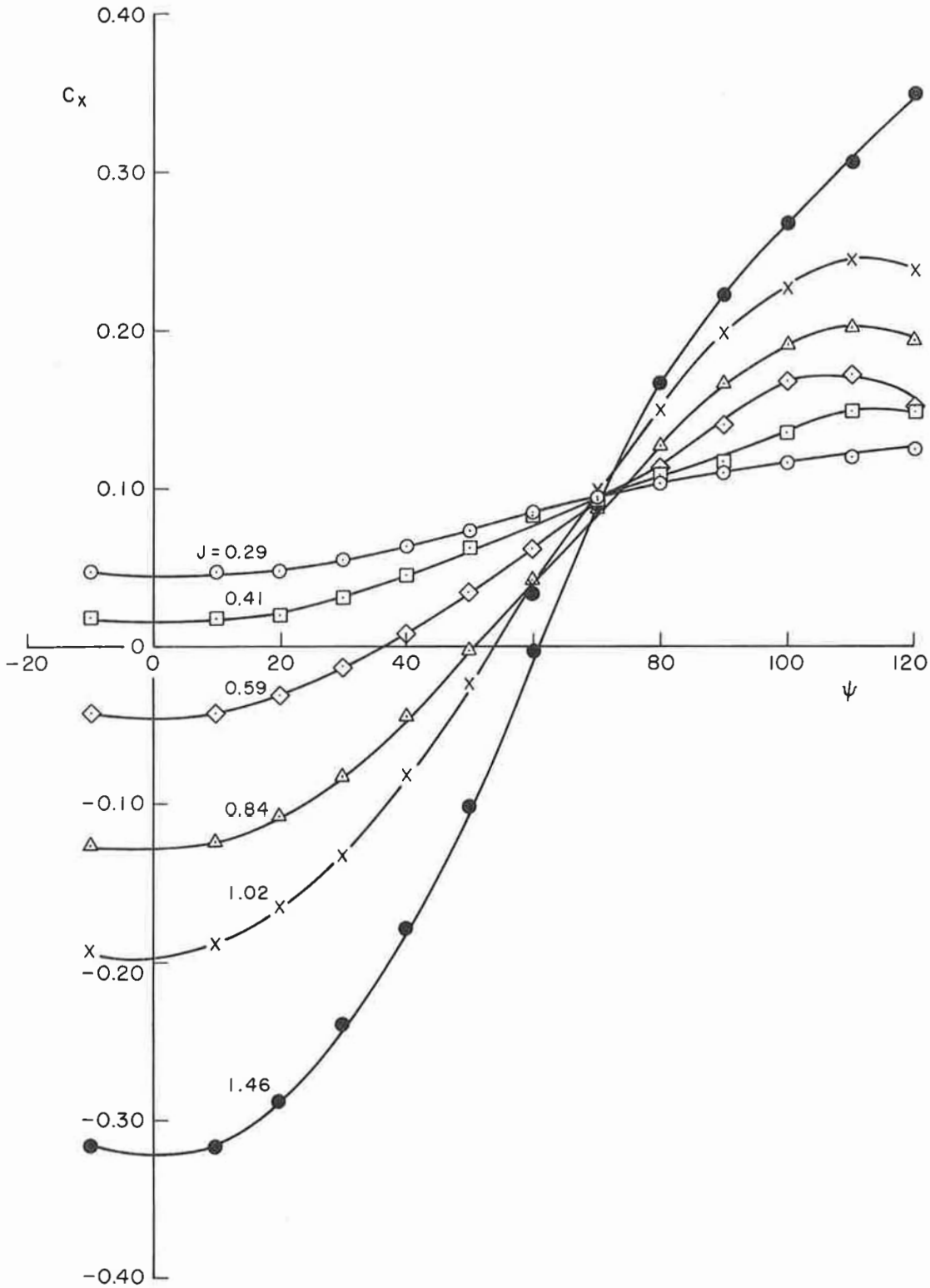
PROPELLER BLADE GEOMETRIC CHARACTERISTICS

FIG. 2
LR-454



PROPELLER BODY AXIS SYSTEM AND BALANCE LOCATION

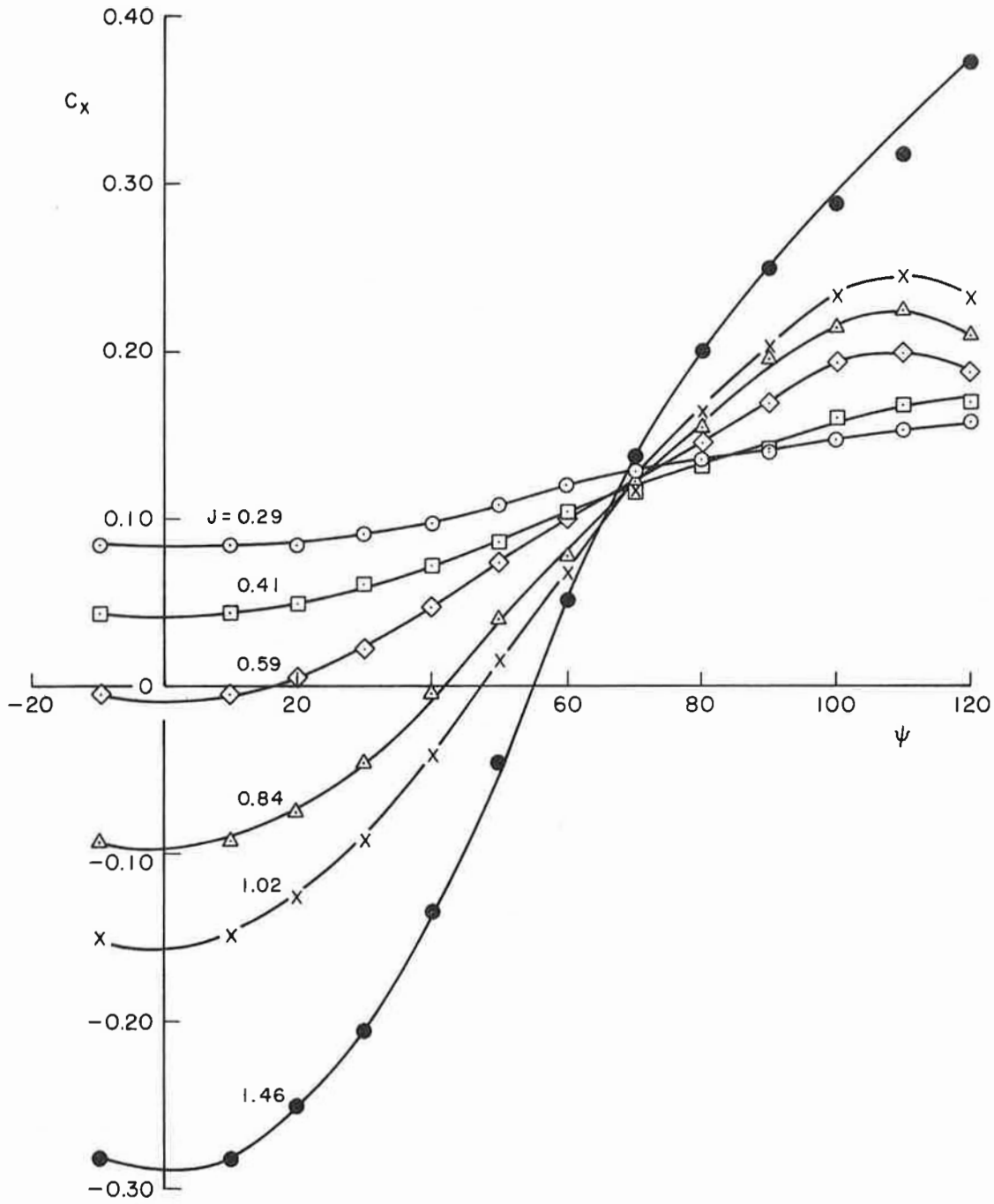
FIG. 4a
LR-454



THRUST COEFFICIENT, C_x VS. ψ

$\beta = 8.7°$

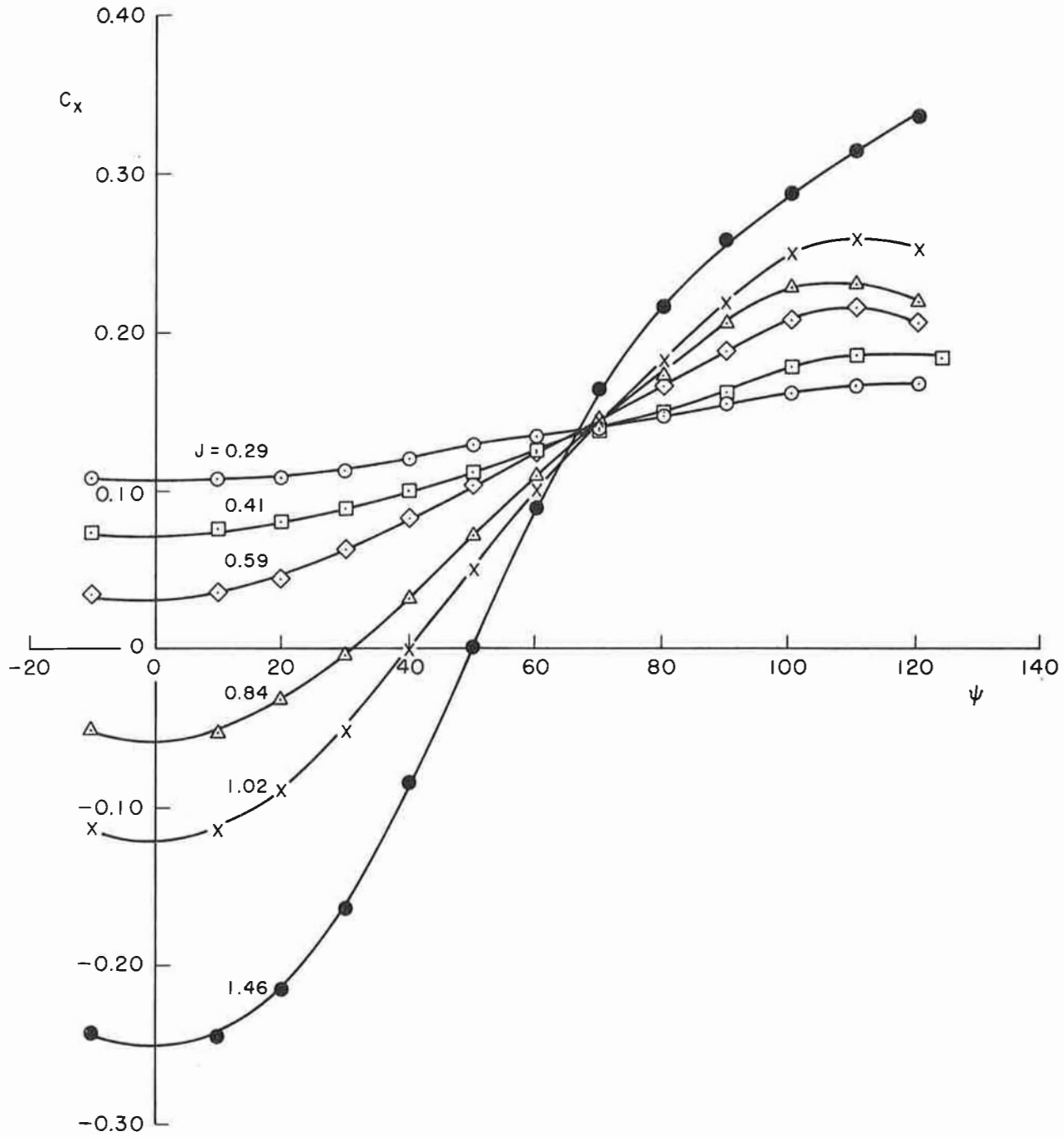
FIG. 4b
LR-454



THRUST COEFFICIENT, C_X VS. ψ

$\beta = 11.7°$

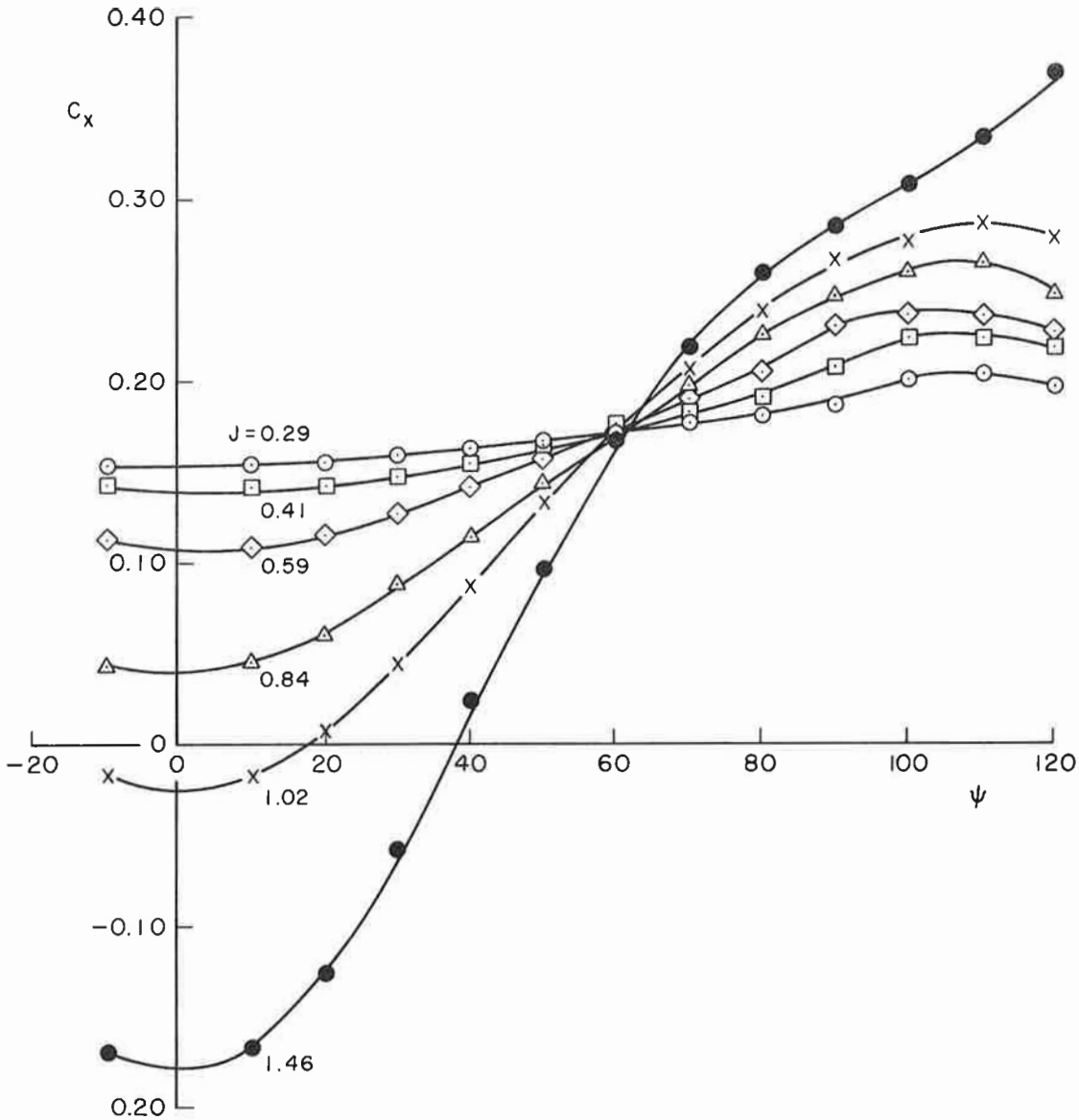
FIG. 4c
LR-454



THRUST COEFFICIENT, C_x VS. ψ

$\beta = 14.7°$

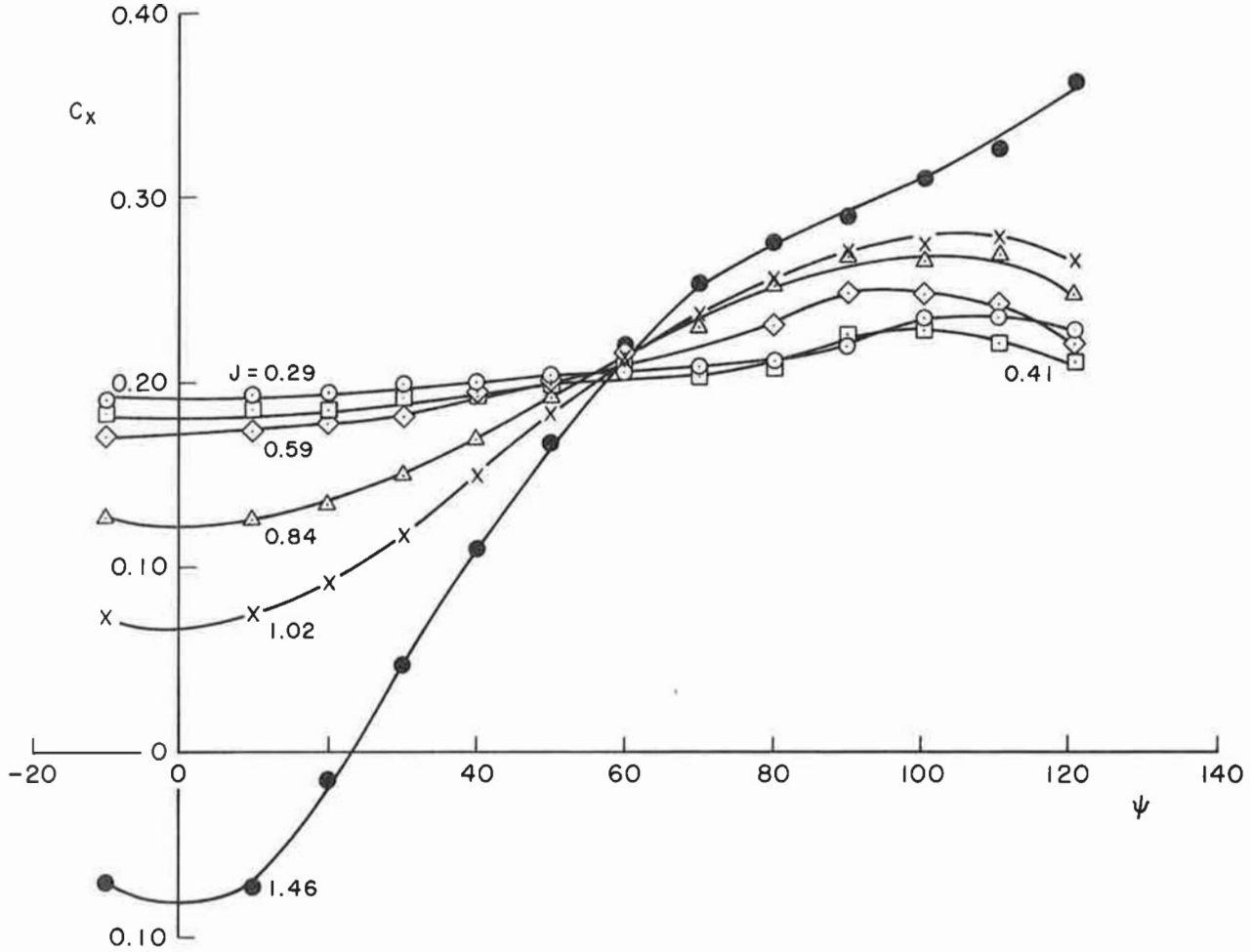
FIG. 4d
LR-454



THRUST COEFFICIENT, C_x VS. ψ

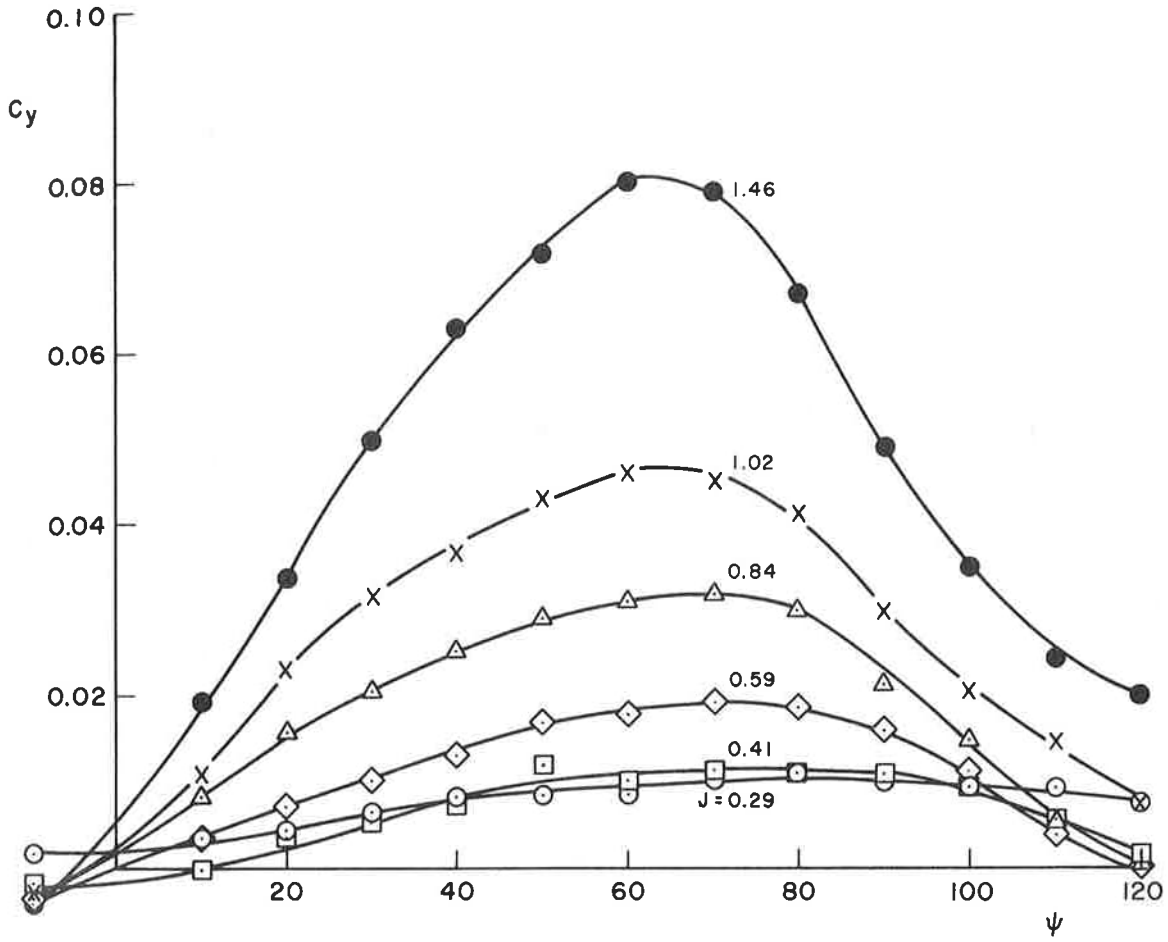
$\beta = 20.7°$

FIG. 4e
LR-454



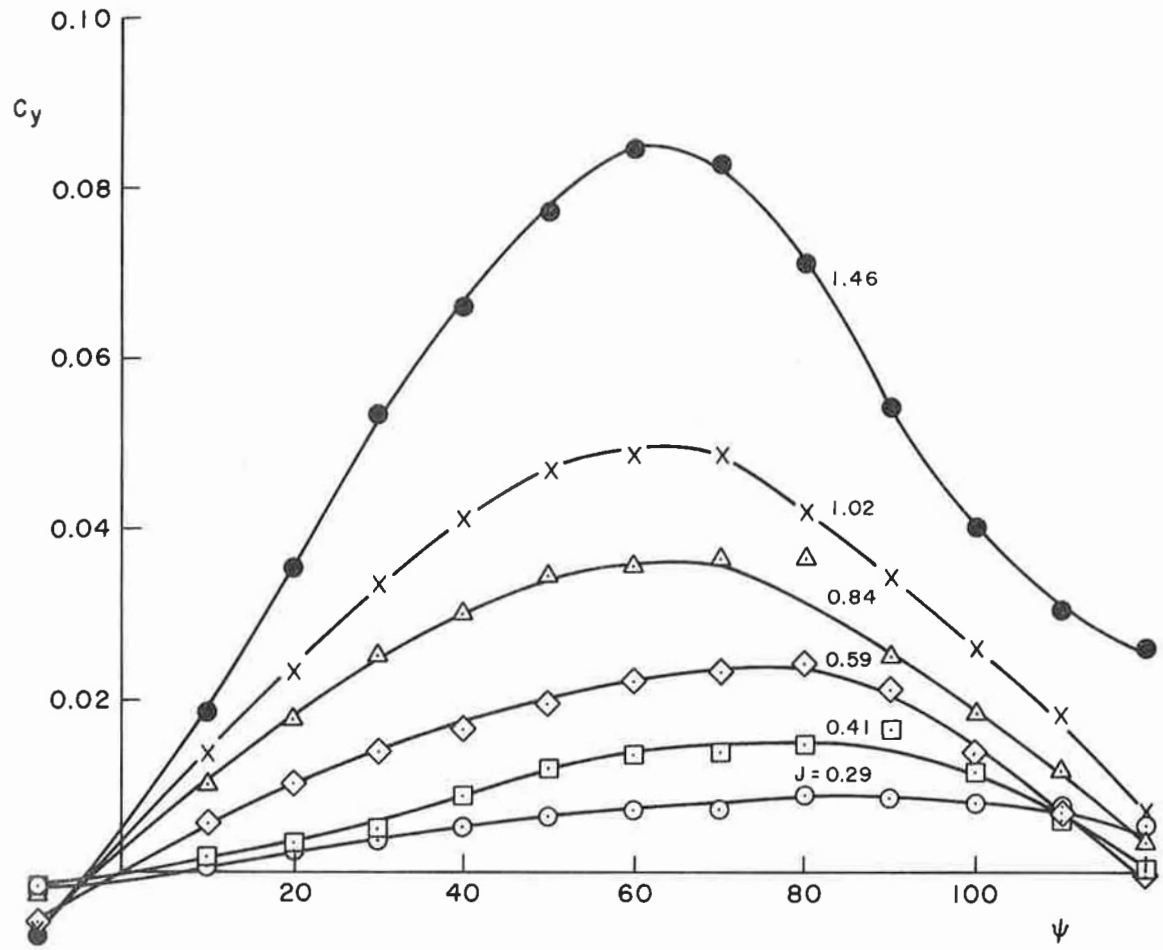
THRUST COEFFICIENT, C_x VS. ψ

$\beta = 26.7°$



SIDE FORCE COEFFICIENT, C_y VS. ψ

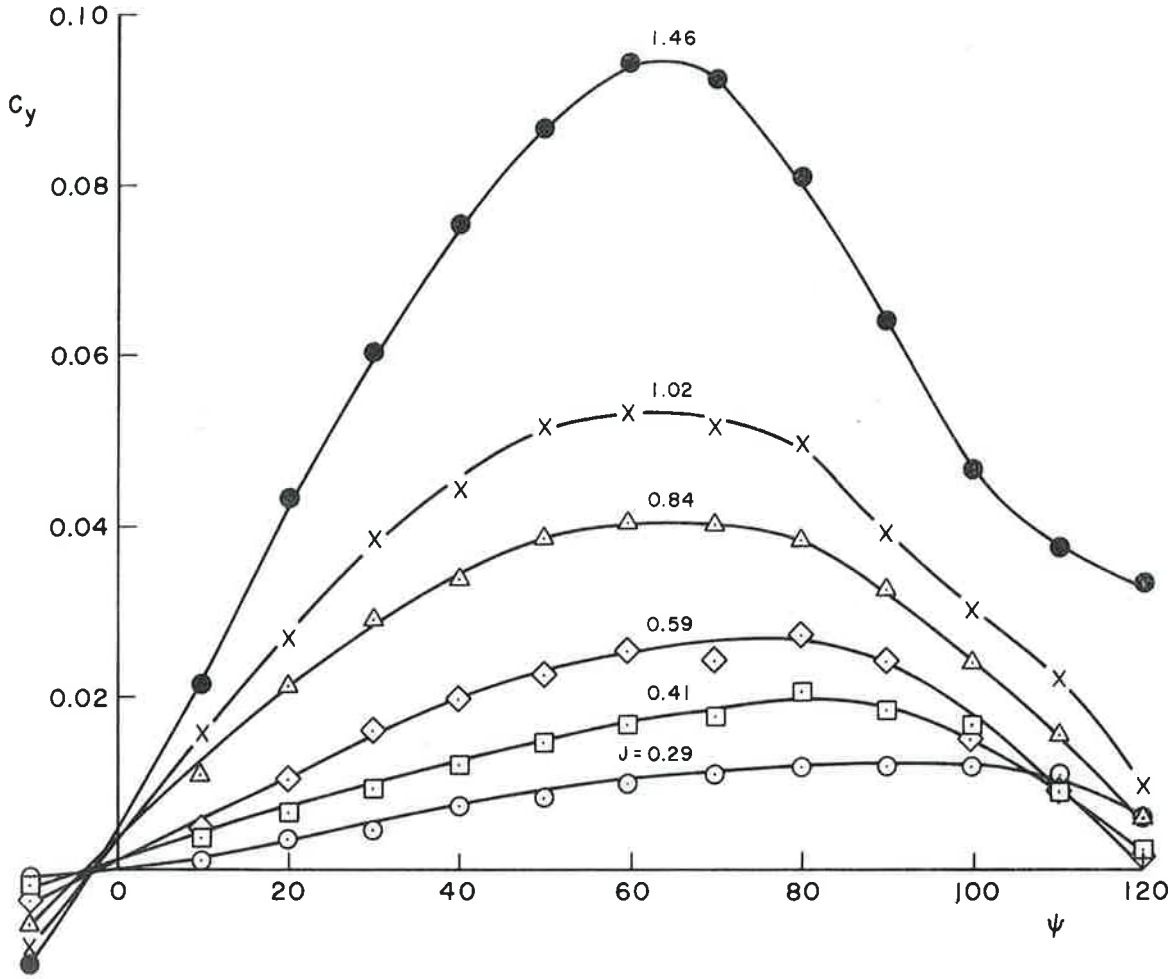
$\beta = 8.7°$



SIDE FORCE COEFFICIENT, C_y VS. ψ

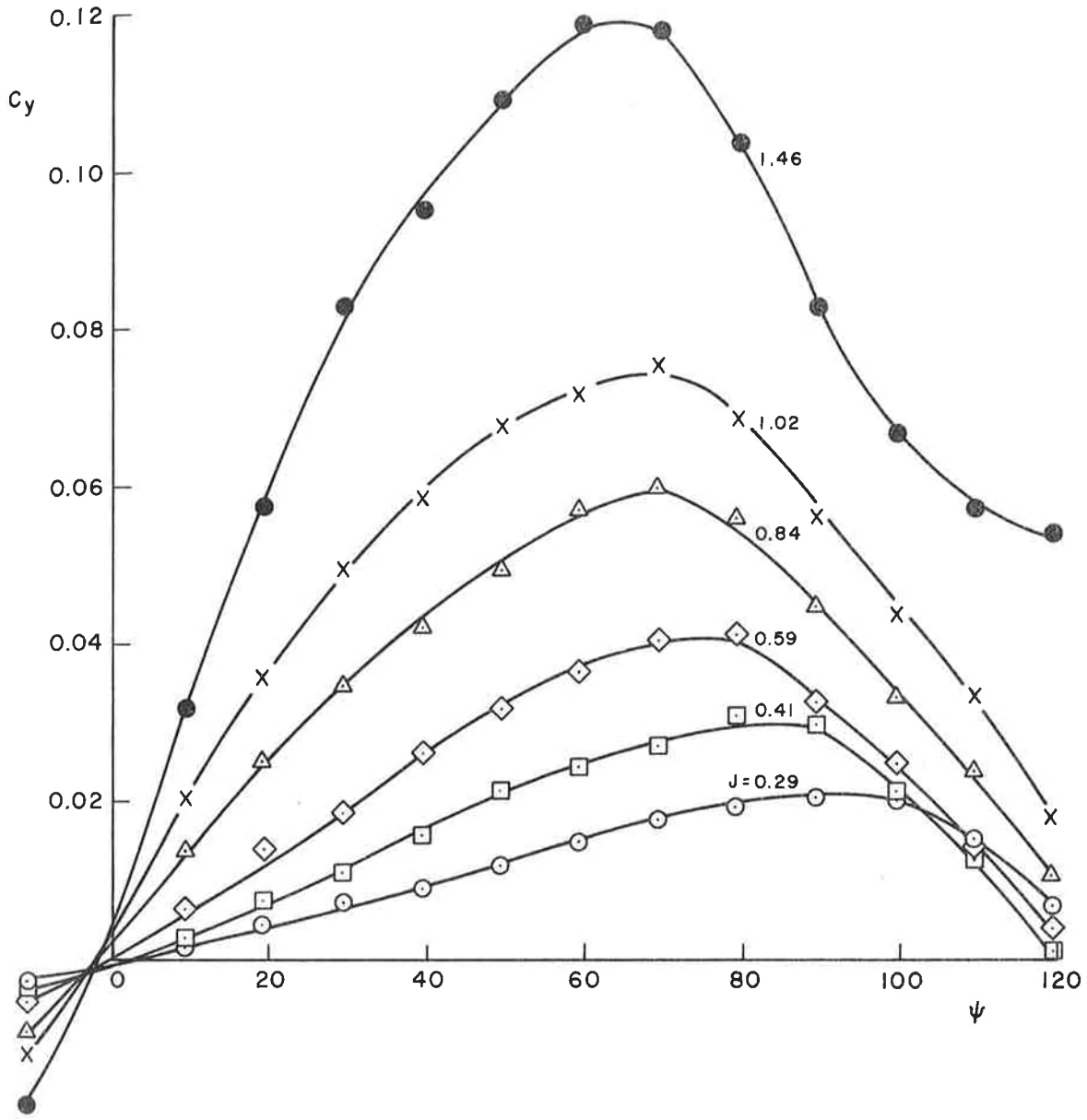
$\beta = 11.7°$

FIG. 5c
LR-454



SIDE FORCE COEFFICIENT, C_y VS. ψ

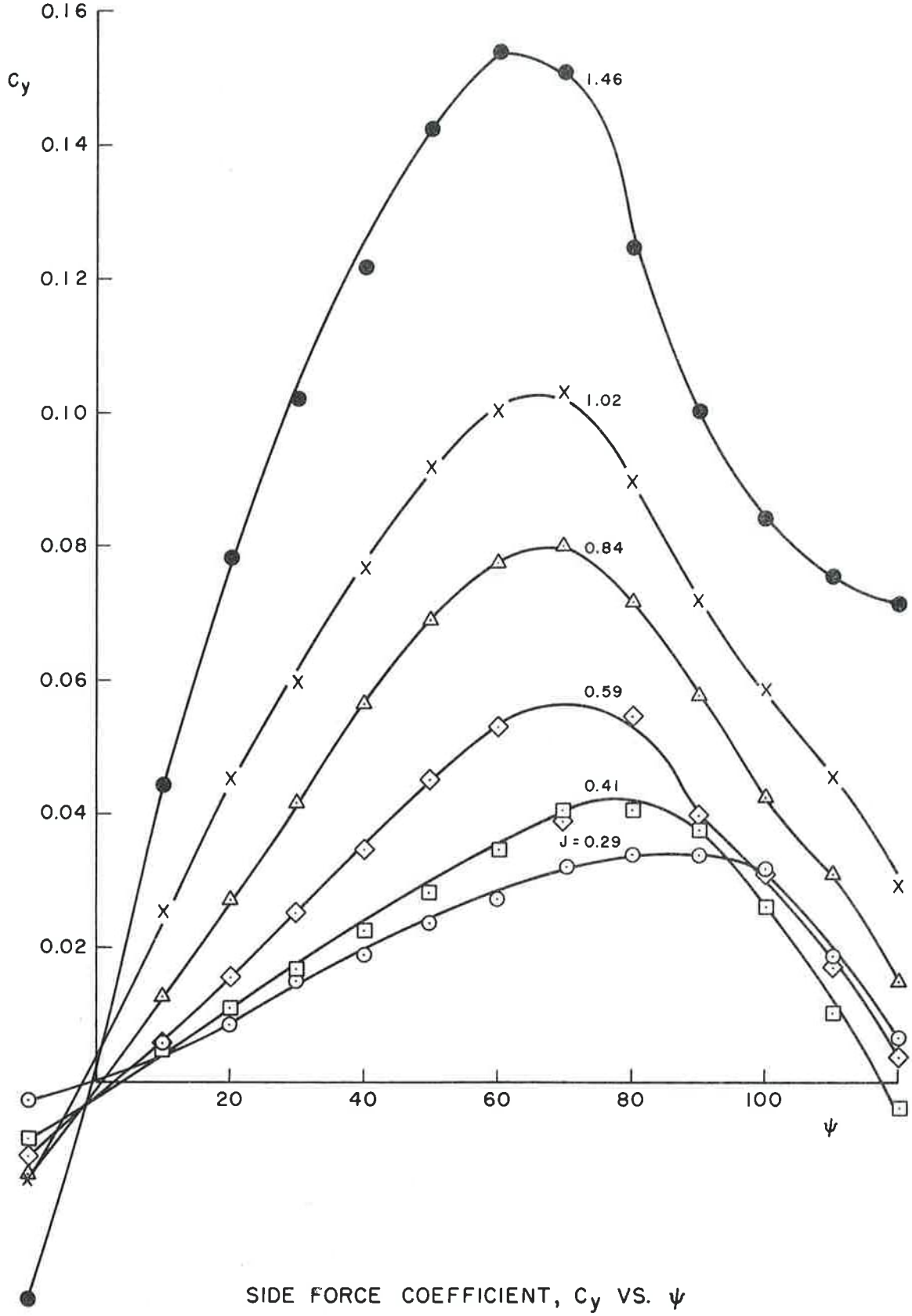
$\beta = 14.7°$



SIDE FORCE COEFFICIENT, C_y VS. ψ

$\beta = 20.7°$

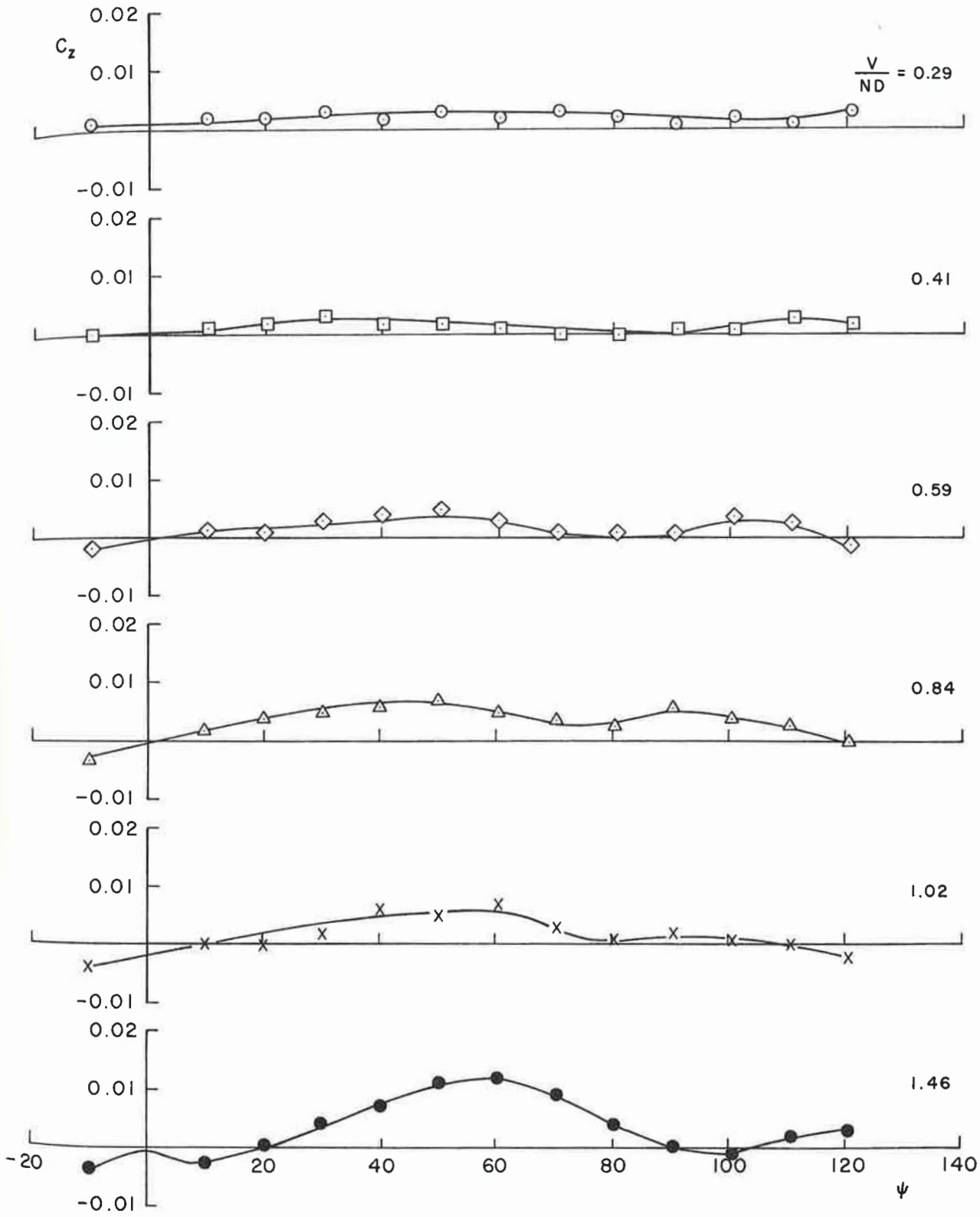
FIG. 5e
LR-454



SIDE FORCE COEFFICIENT, C_y VS. ψ

$\beta = 26.7°$

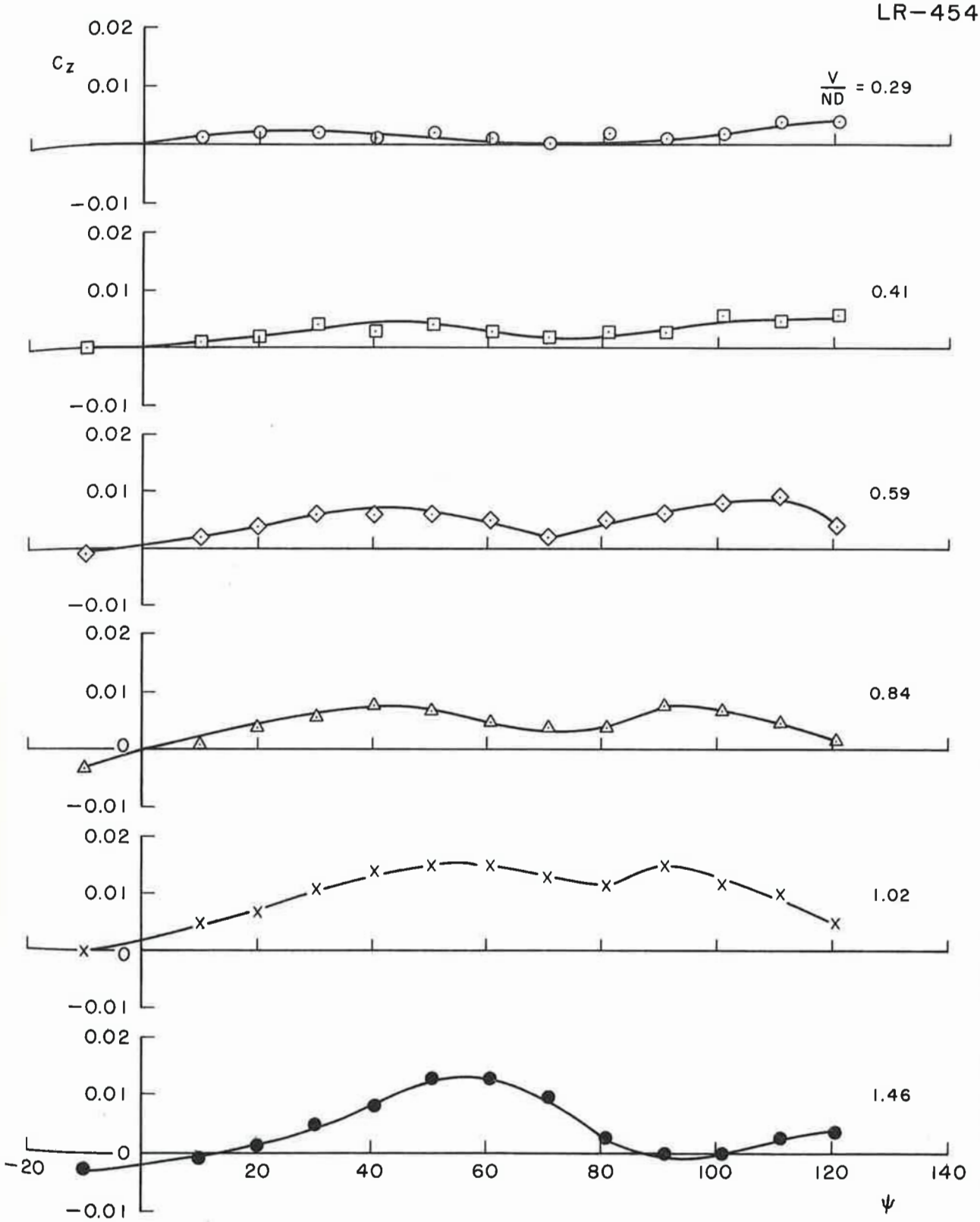
FIG. 6a
LR—454



NORMAL FORCE COEFFICIENT, C_z VS. ψ

β = 8.7°

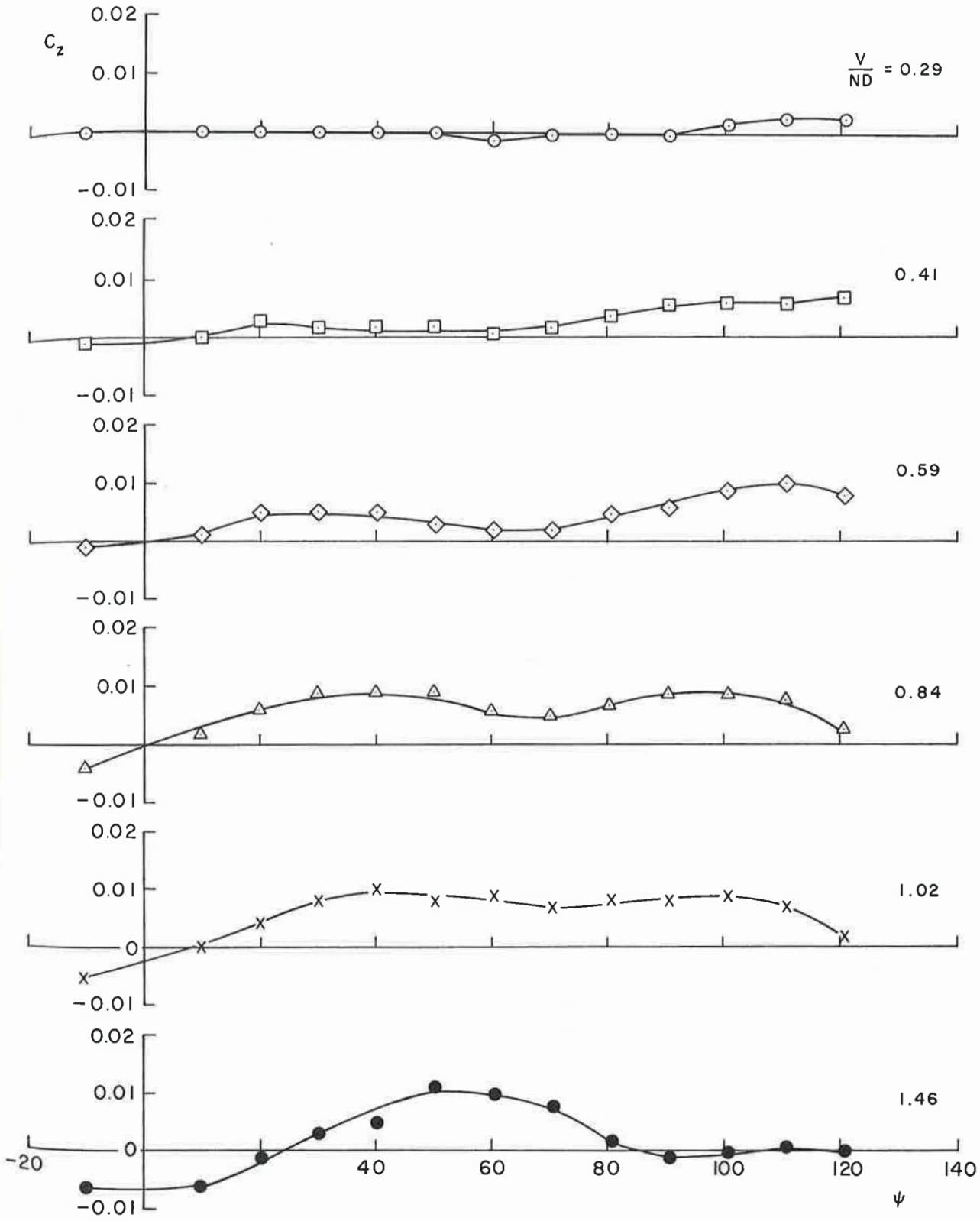
FIG. 6b
LR-454



NORMAL FORCE COEFFICIENT, C_z VS. ψ

$\beta = 11.7°$

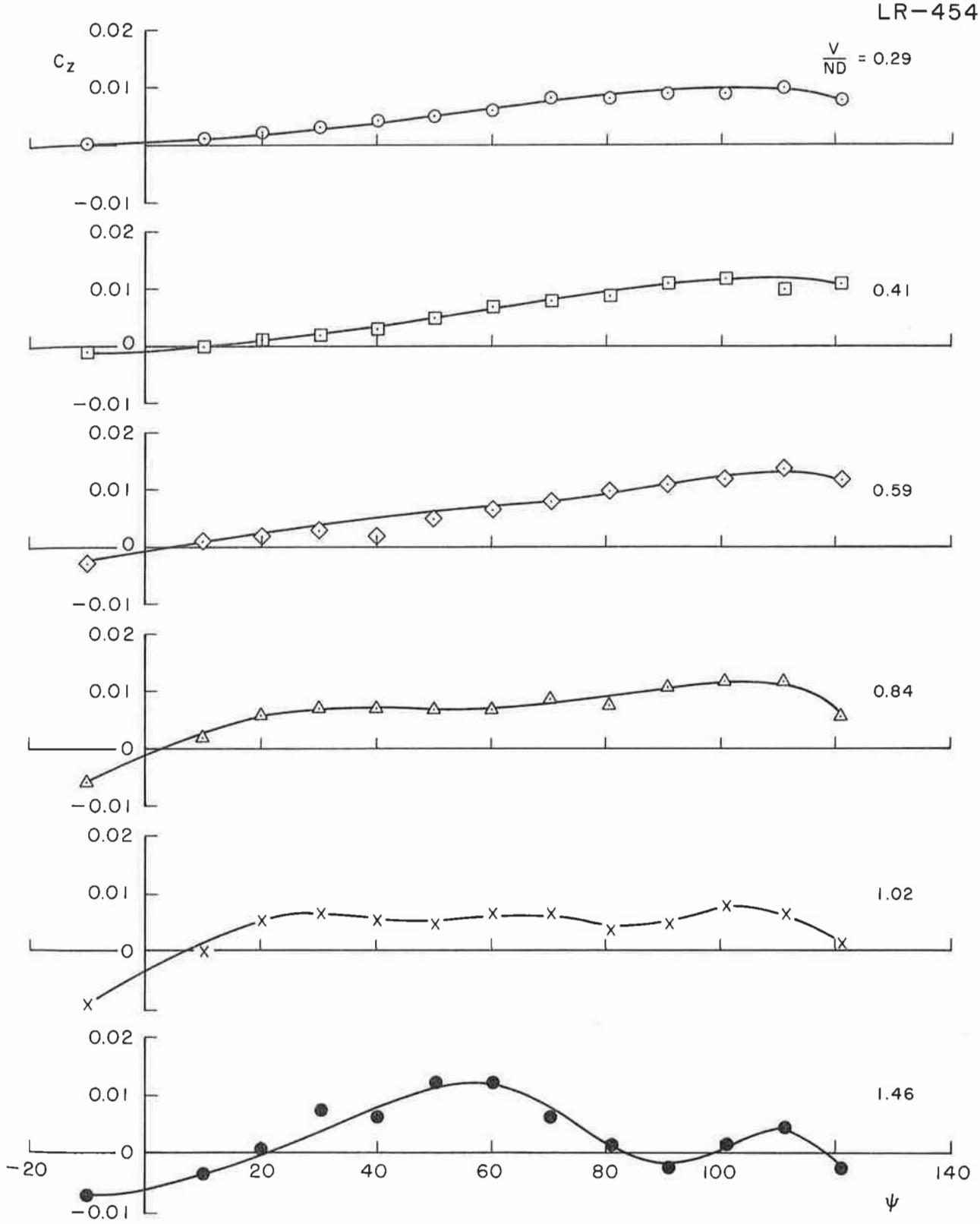
FIG. 6c
LR – 454



NORMAL FORCE COEFFICIENT, C_z VS. ψ

$\beta = 14.7°$

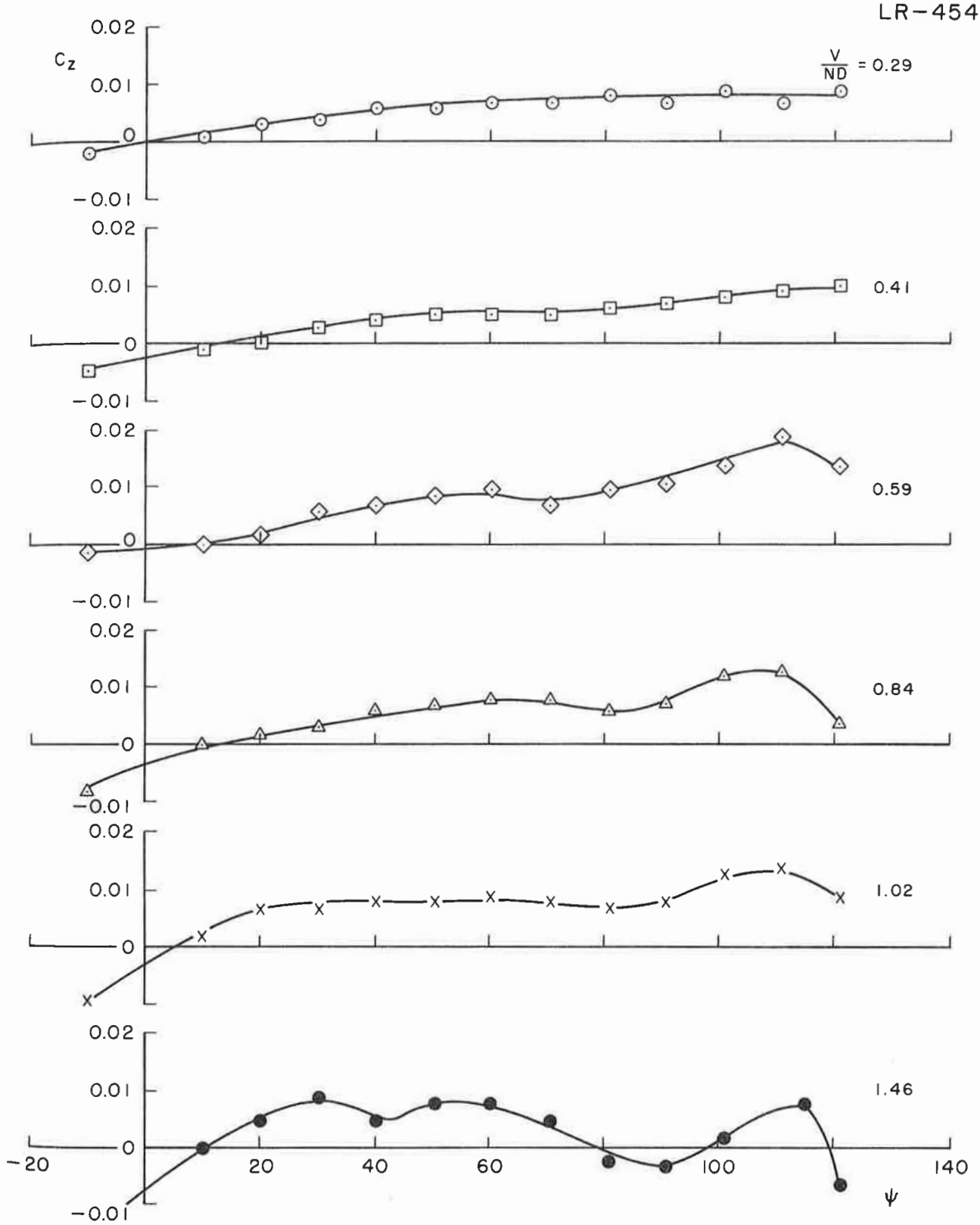
FIG. 6d
LR-454



NORMAL FORCE COEFFICIENT, C_z VS. ψ

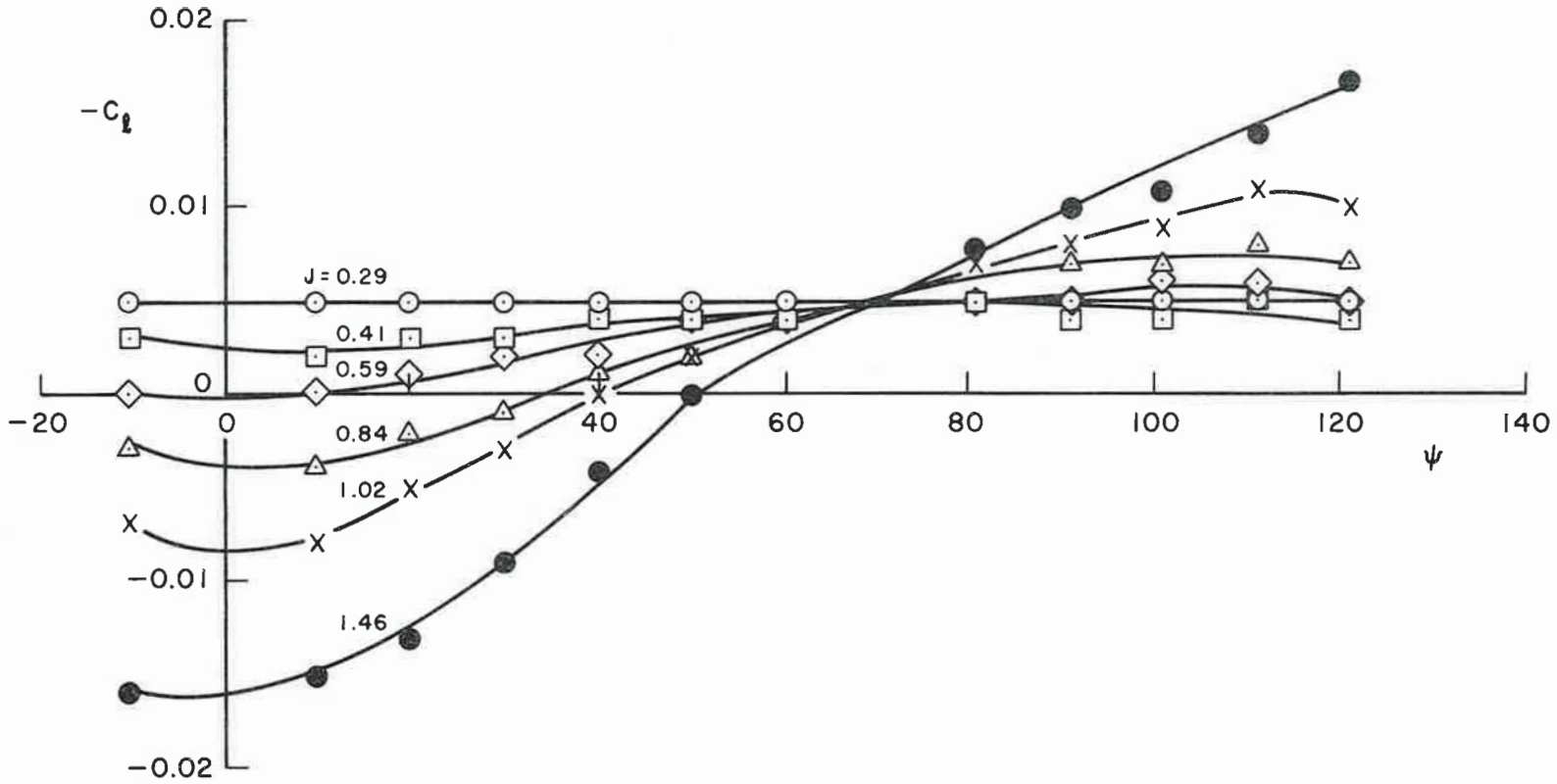
$\beta = 20.7°$

FIG. 6e
LR-454



NORMAL FORCE COEFFICIENT, C_z VS. ψ

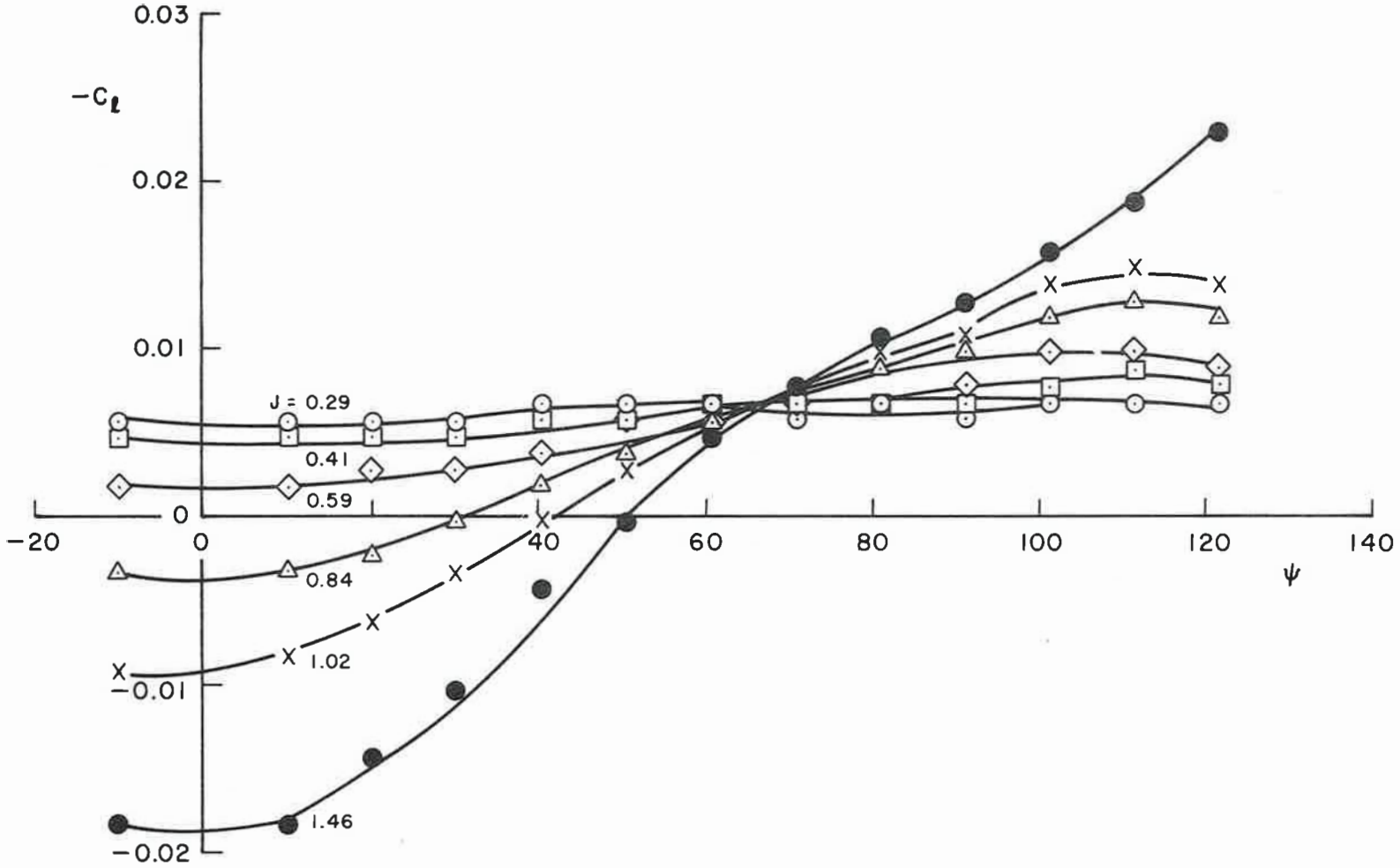
$\beta = 26.7°$



TORQUE COEFFICIENT, $-C_\ell$ VS. ψ

$\beta = 8.7°$

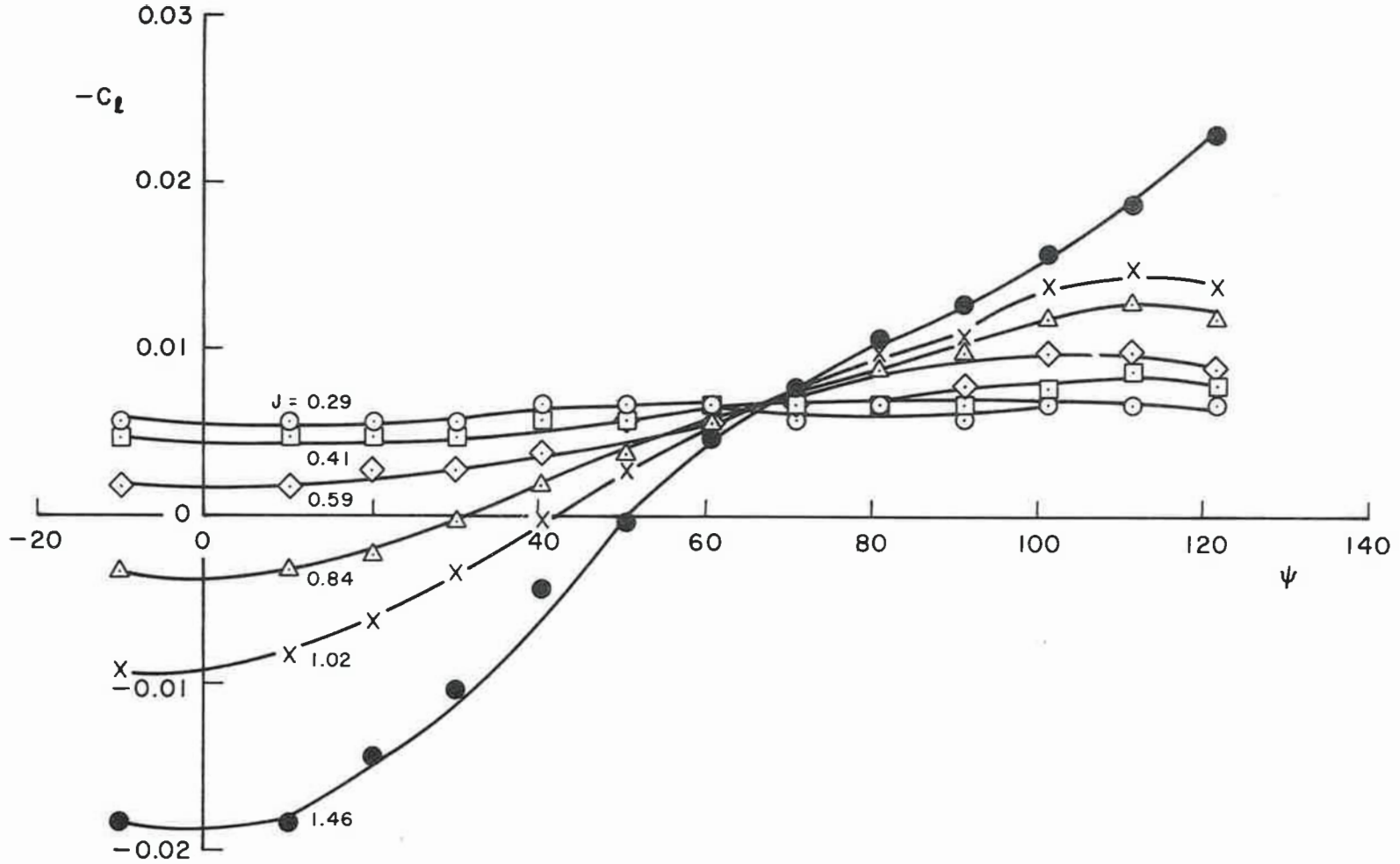
FIG. 7a
LR−454



TORQUE COEFFICIENT, $-C_\ell$ VS. ψ

$\beta = 11.7°$

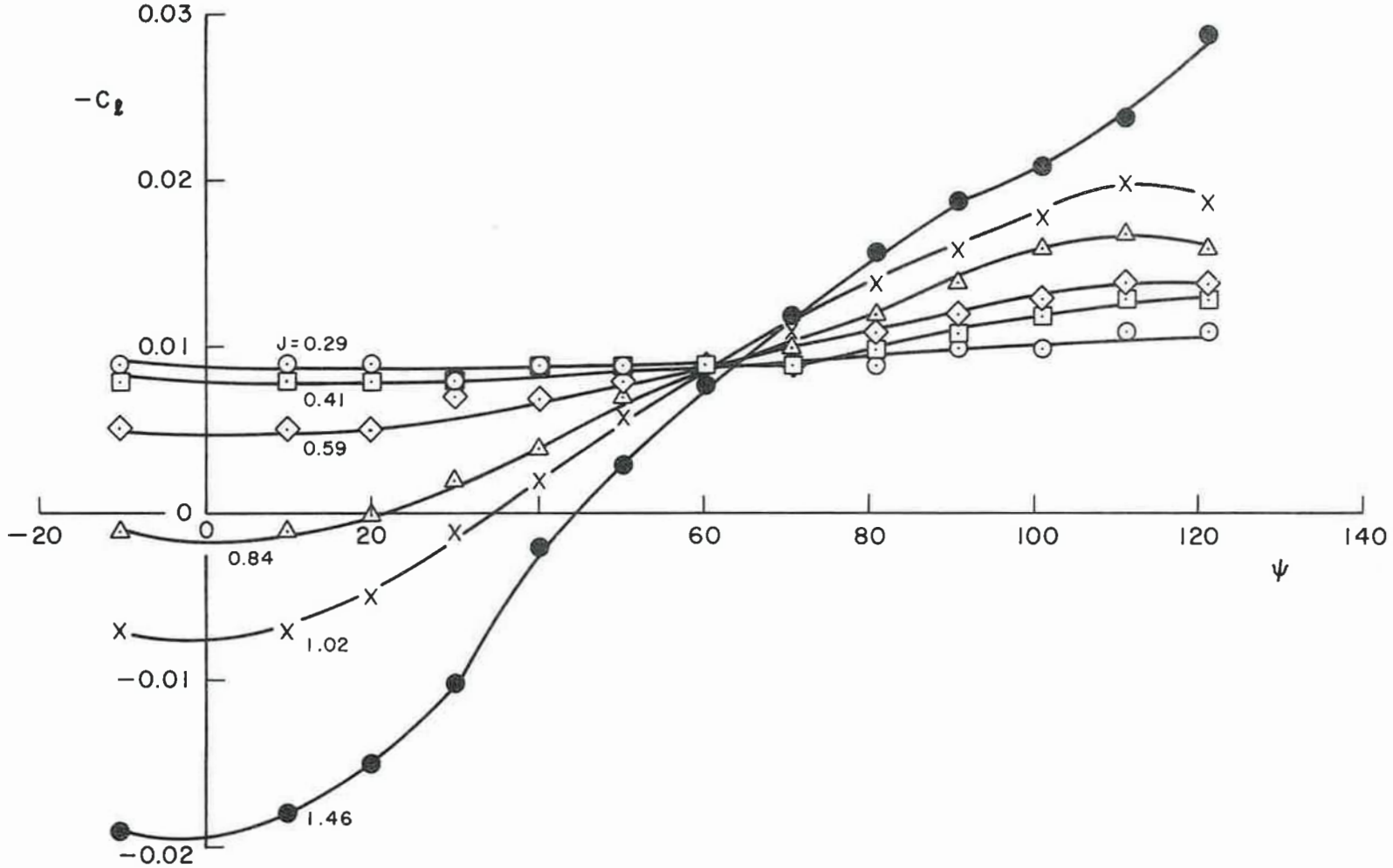
FIG. 7b
LR-454



TORQUE COEFFICIENT, $-C_\ell$ VS. ψ

$\beta = 11.7°$

FIG. 7b
LR-454

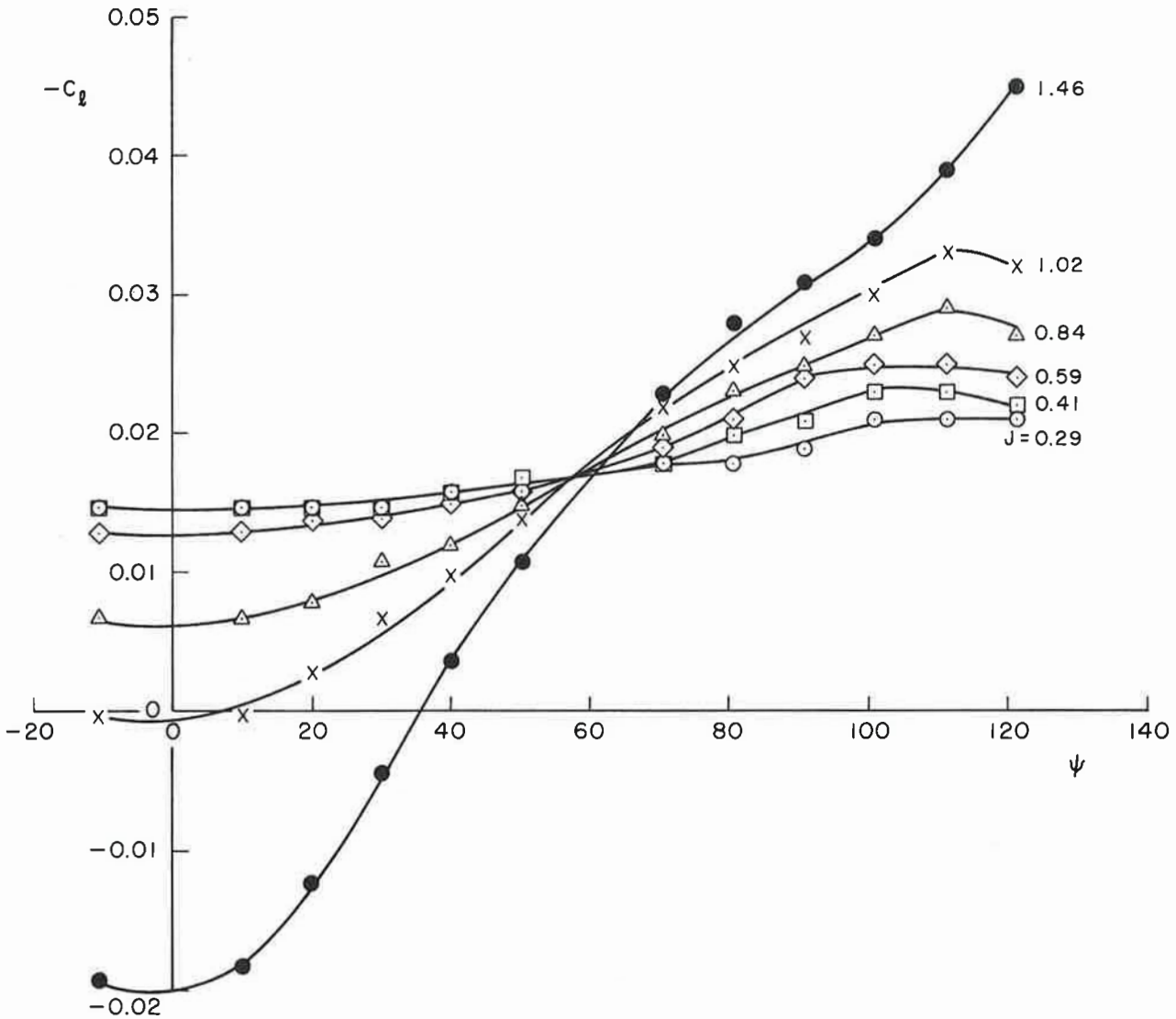


TORQUE COEFFICIENT, $-C_\ell$ VS. ψ

$\beta = 14.7°$

FIG. 7c
LR−454

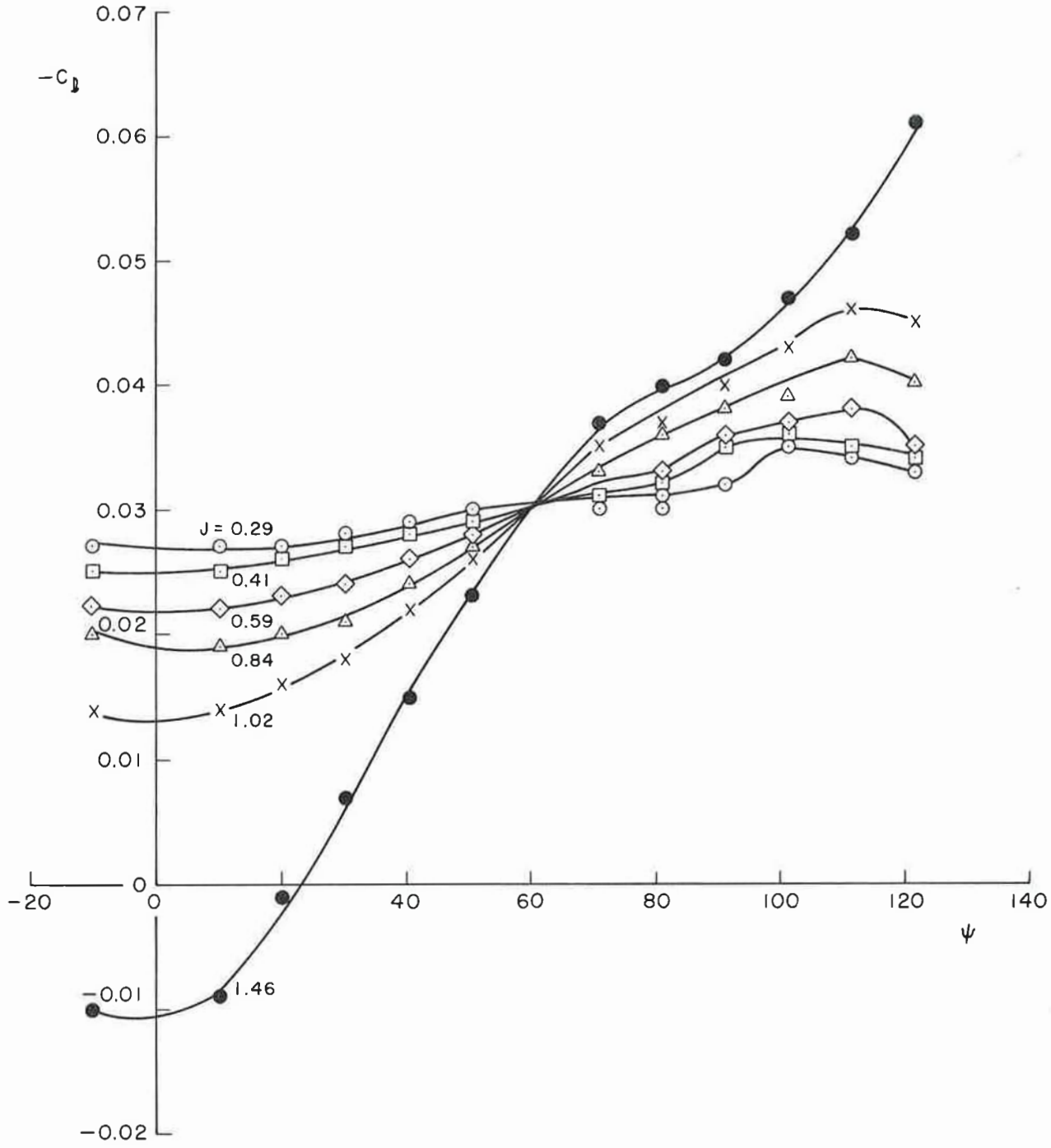
FIG. 7d
LR-454



TORQUE COEFFICIENT, $-C_\ell$ VS. ψ

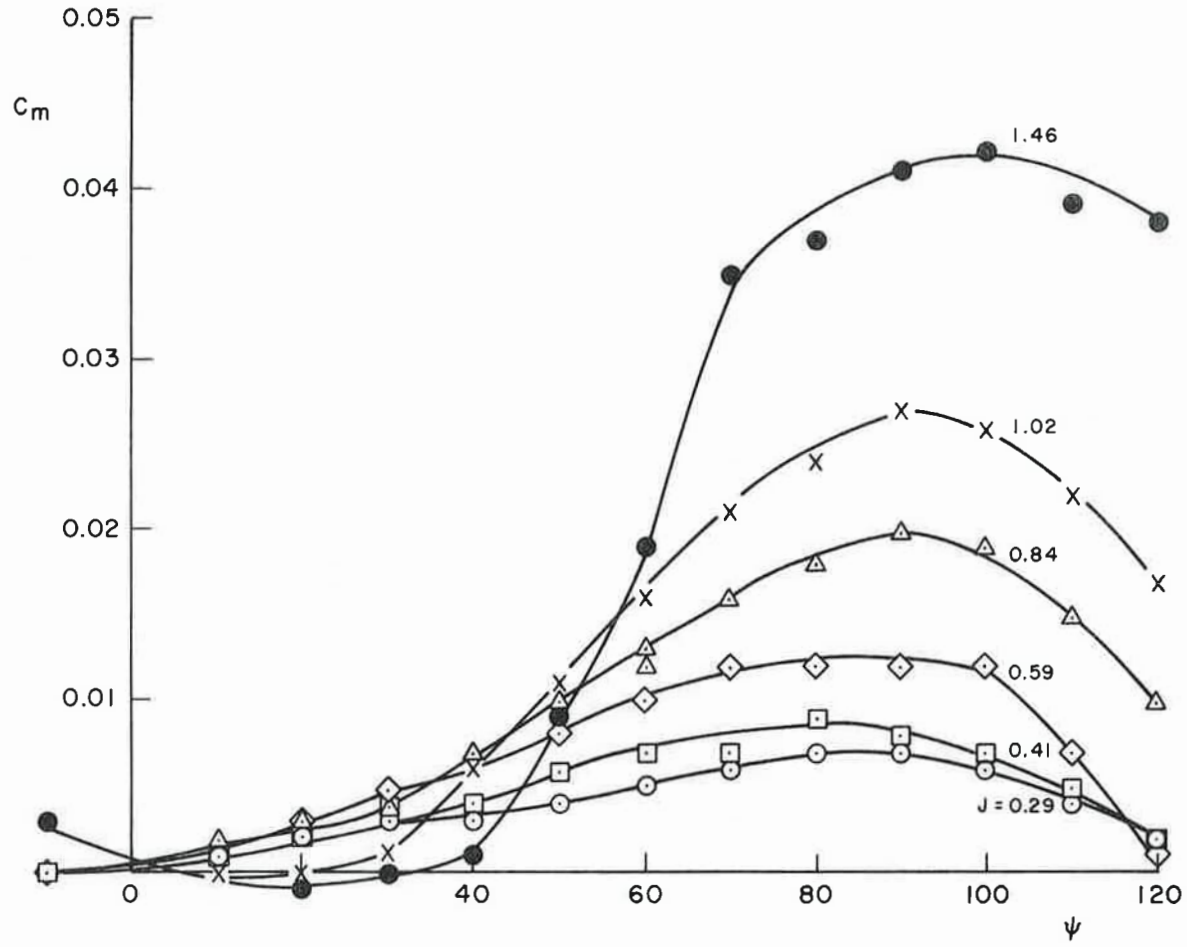
$\beta = 20.7°$

FIG. 7e
LR-454



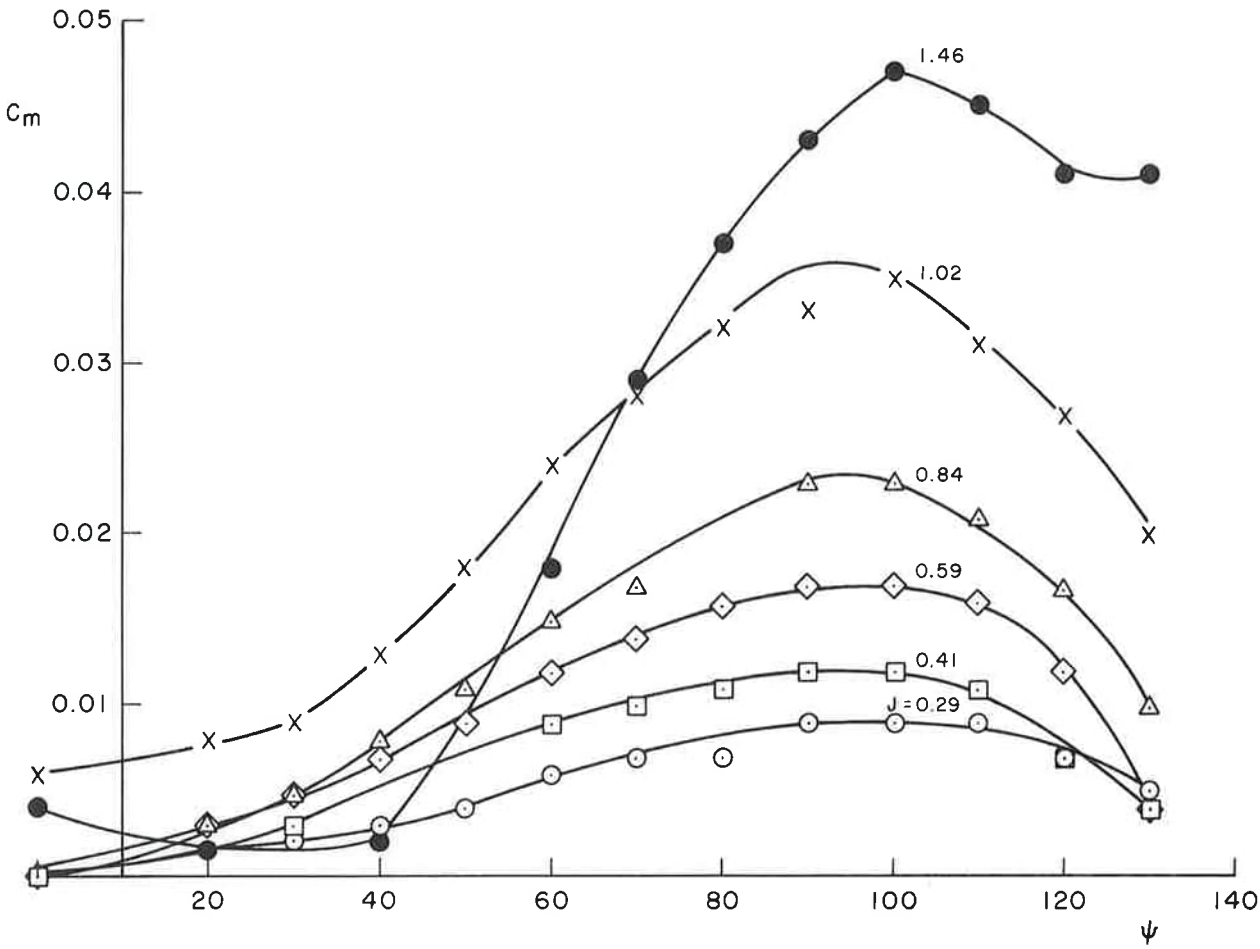
TORQUE COEFFICIENT, $-C_\ell$ VS. ψ

$\beta = 26.7°$



PITCHING MOMENT COEFFICIENT, C_m VS. ψ

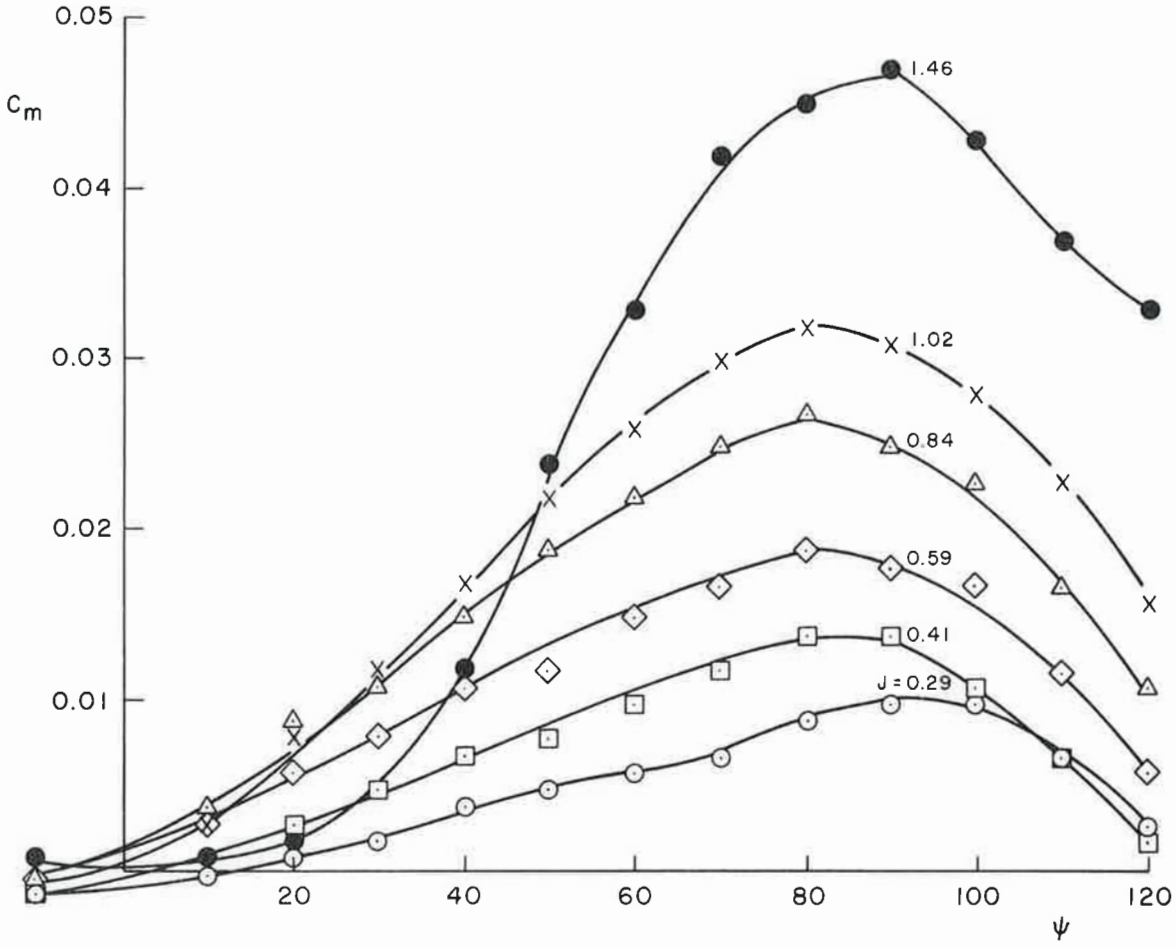
$\beta = 8.7°$



PITCHING MOMENT COEFFICIENT, C_m VS. ψ

$\beta = 11.7°$

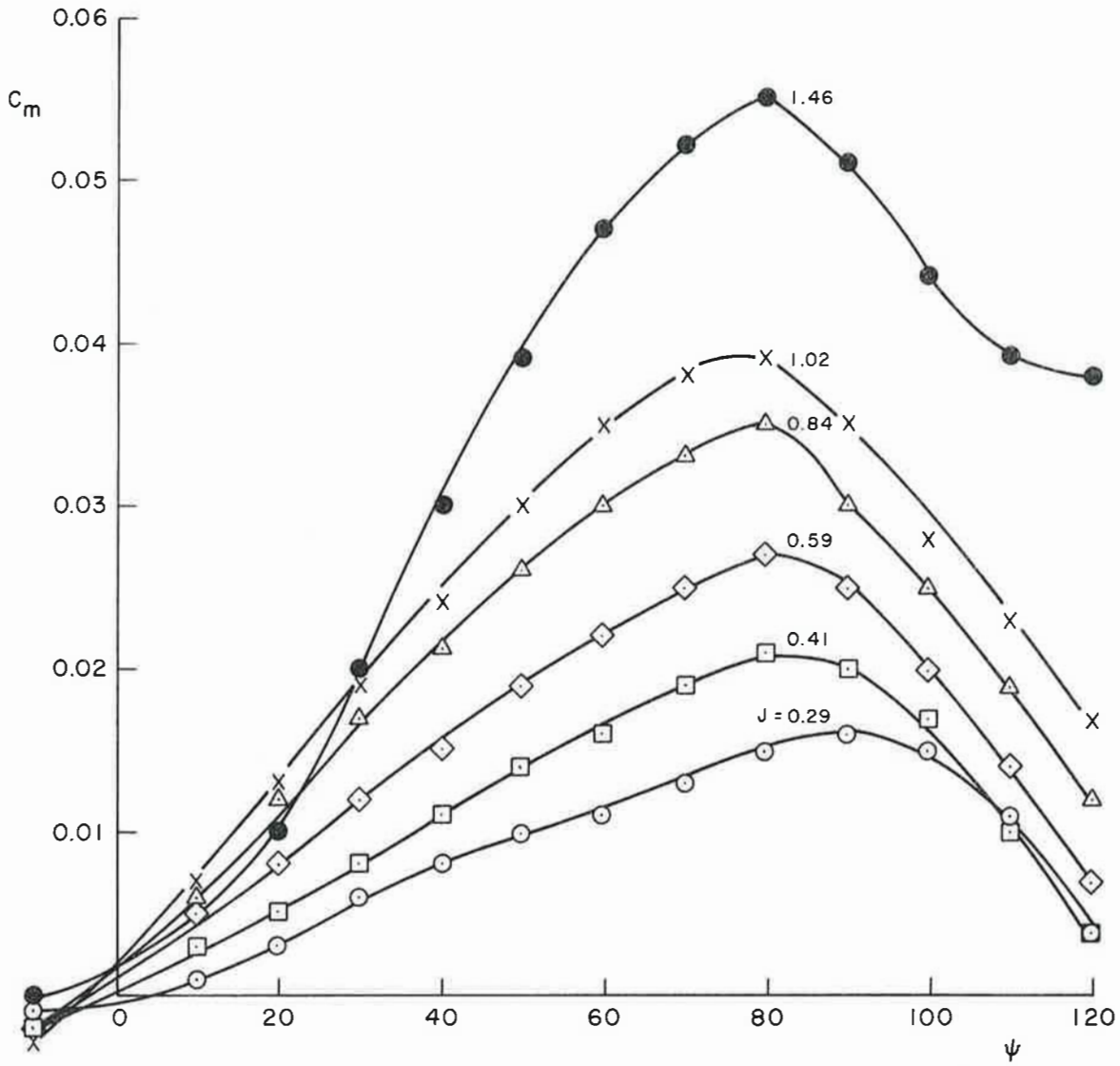
FIG. 8c
LR-454



PITCHING MOMENT COEFFICIENT, C_m VS. ψ

$\beta = 14.7°$

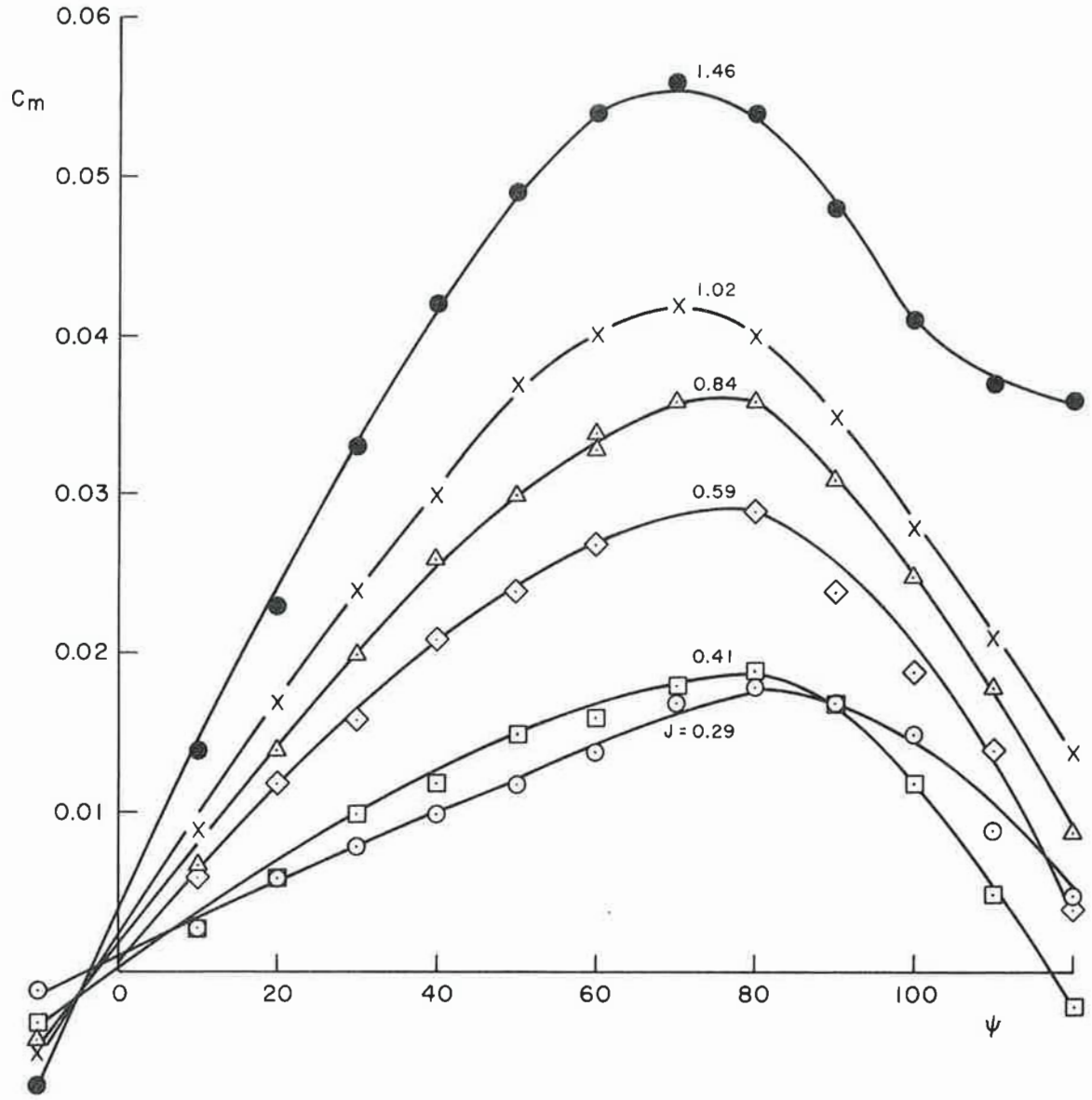
FIG. 8d
LR-454



PITCHING MOMENT COEFFICIENT, C_m VS. ψ

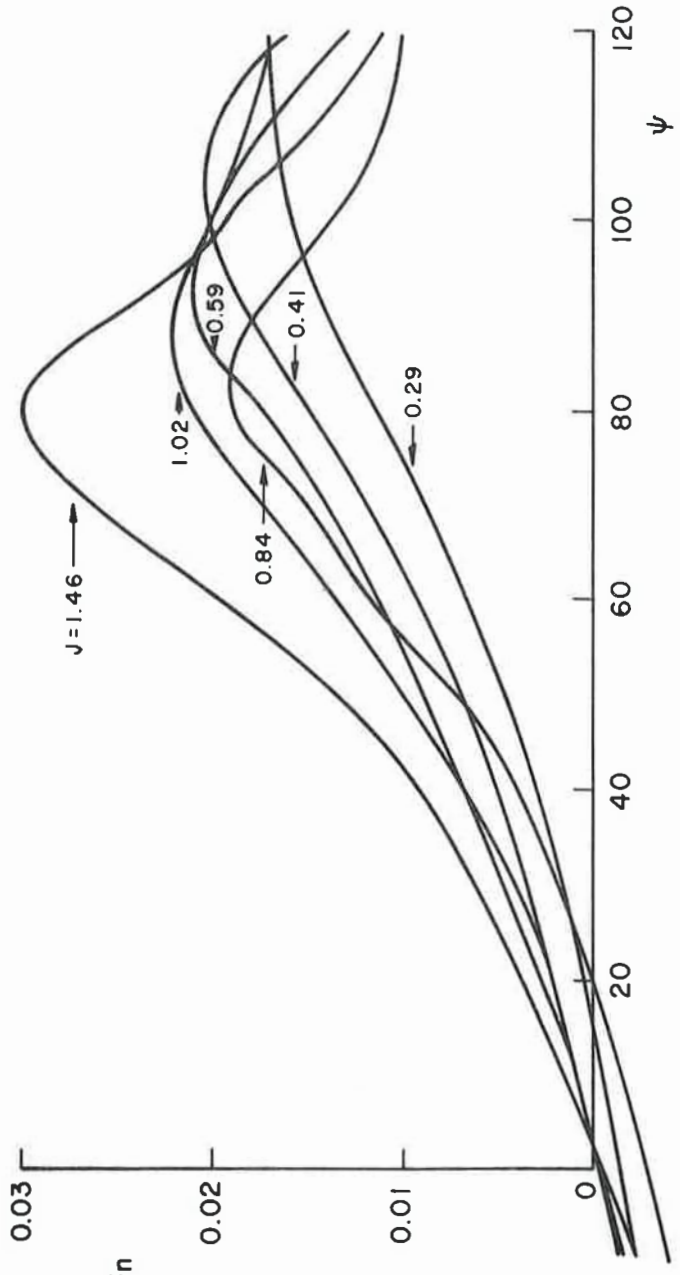
$\beta = 20.7°$

FIG. 8e
LR-454



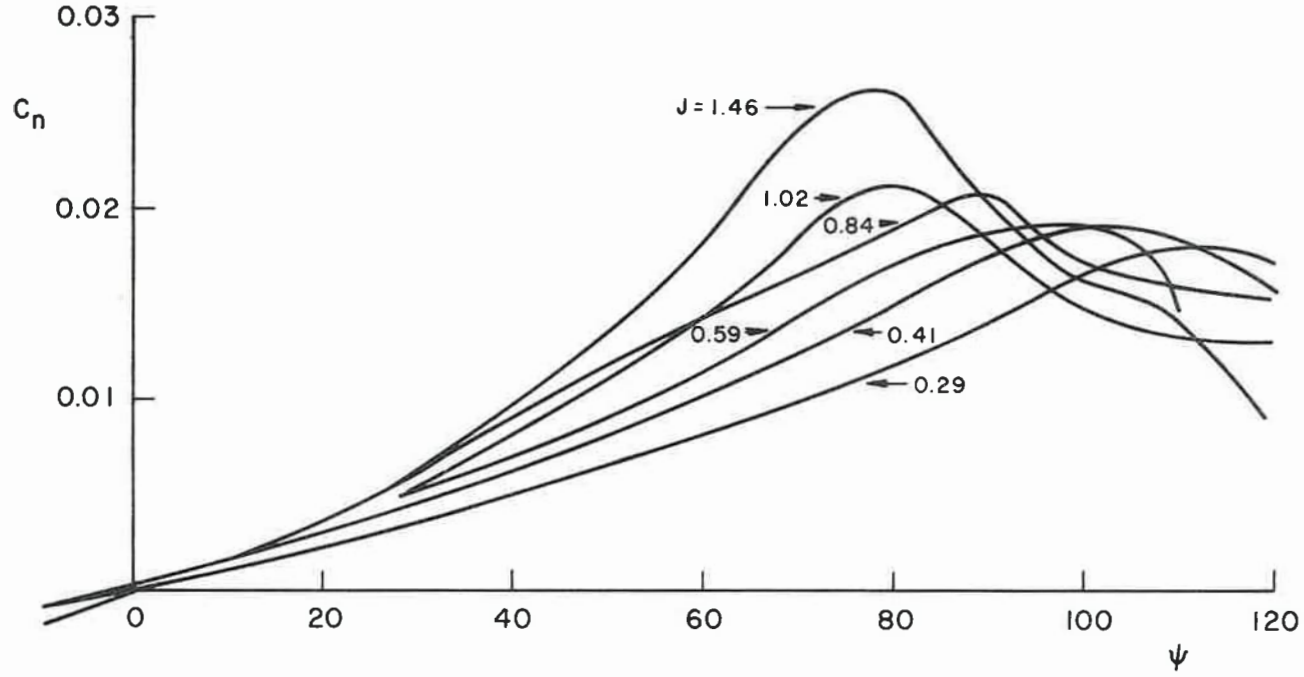
PITCHING MOMENT COEFFICIENT, C_m VS. ψ

$\beta = 26.7°$



YAWING MOMENT COEFFICIENT, C_n VS. ψ

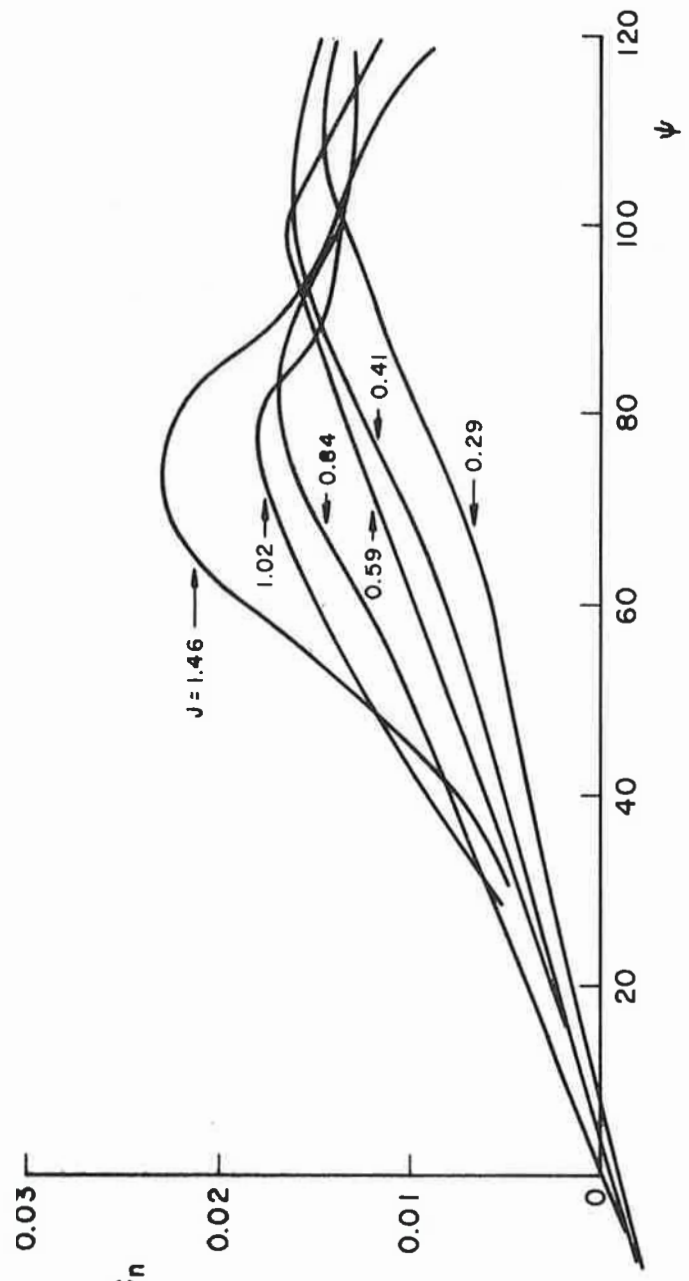
$\beta = 8.7°$



YAWING MOMENT COEFFICIENT, C_n VS. ψ

$\beta = 11.7°$

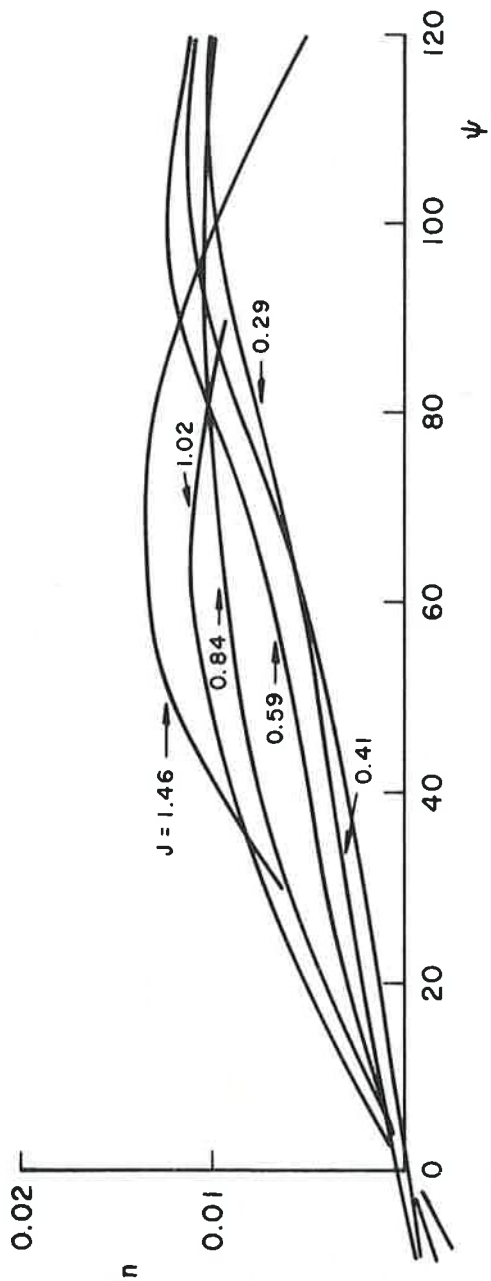
FIG. 9b
LR-454



YAWING MOMENT COEFFICIENT, C_n VS. ψ

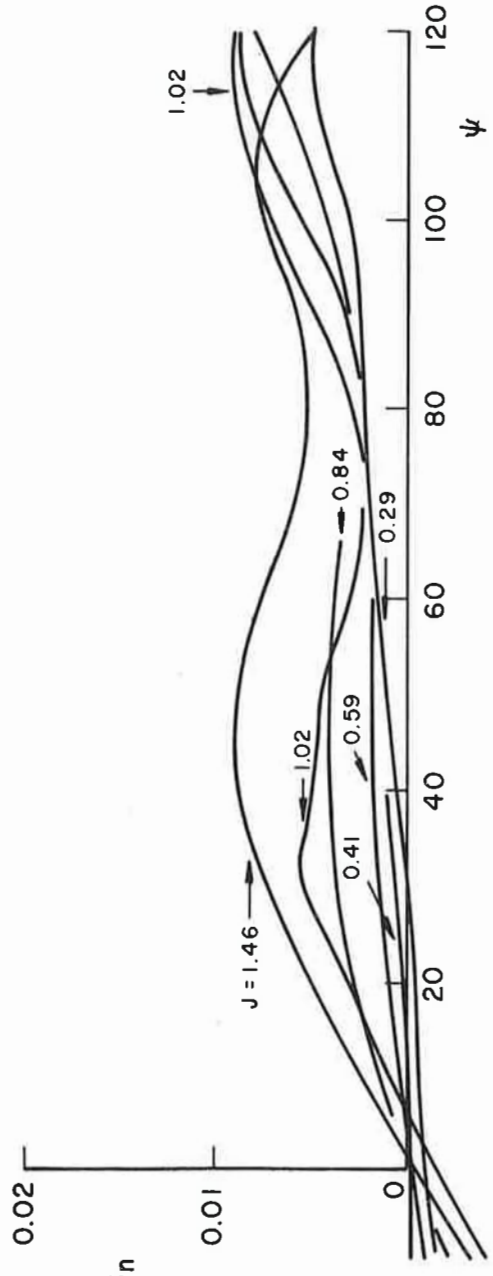
$\beta = 14.7°$

FIG. 9d
LR-454



YAWING MOMENT COEFFICIENT, C_n VS. ψ

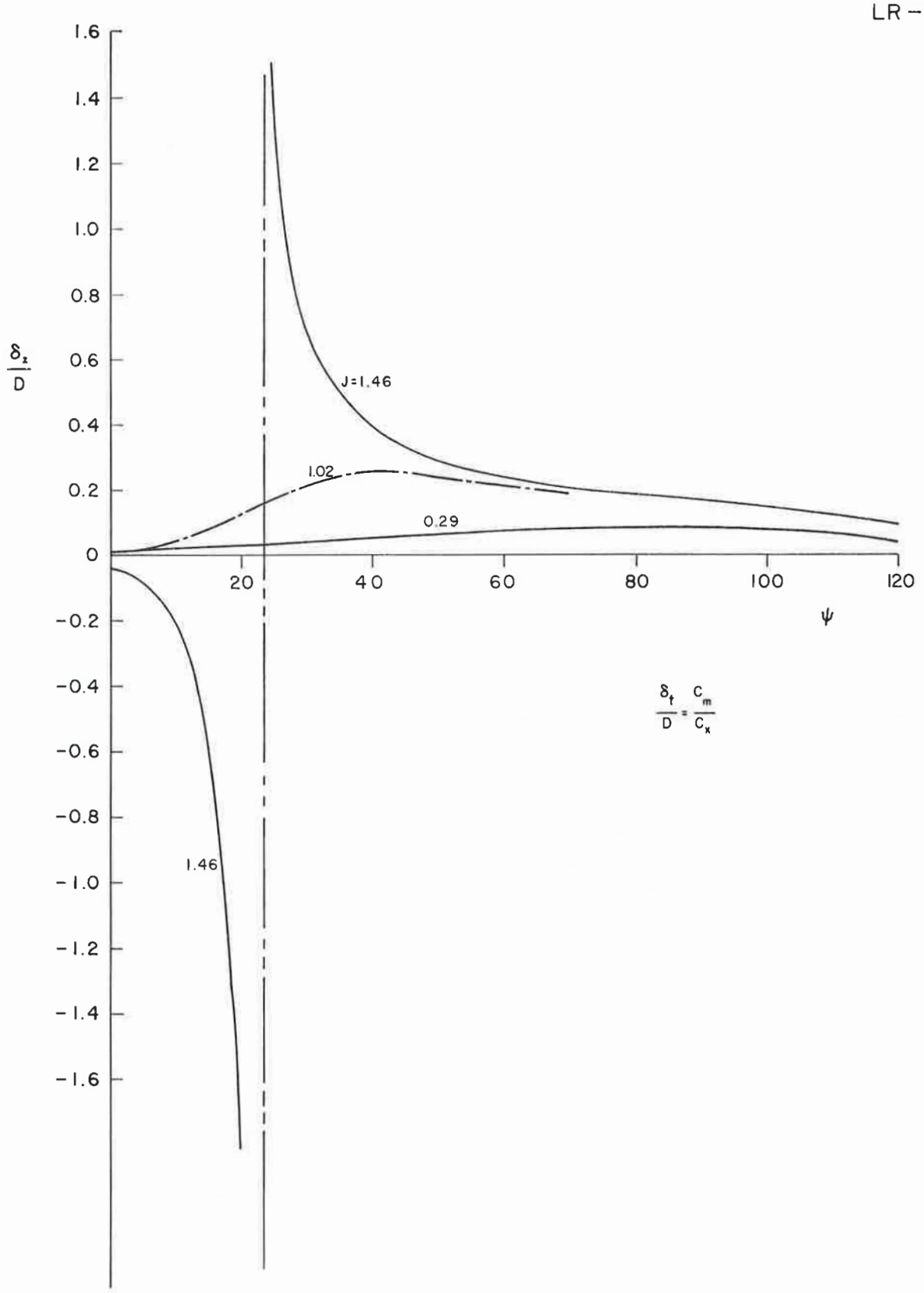
$\beta = 20.7°$



YAWING MOMENT COEFFICIENT, C_n VS. ψ

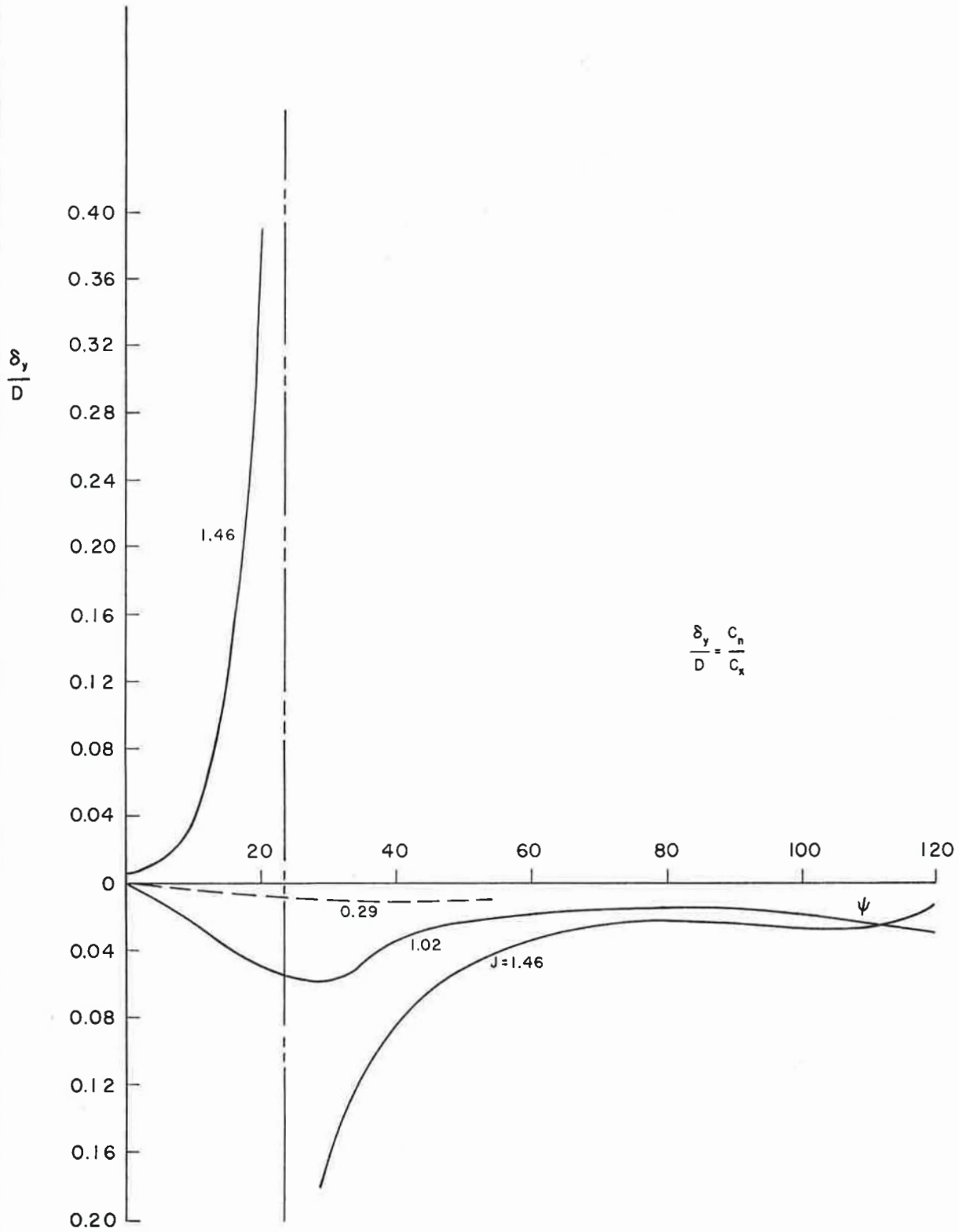
$\beta = 26.7°$

FIG. 10 a
LR – 454

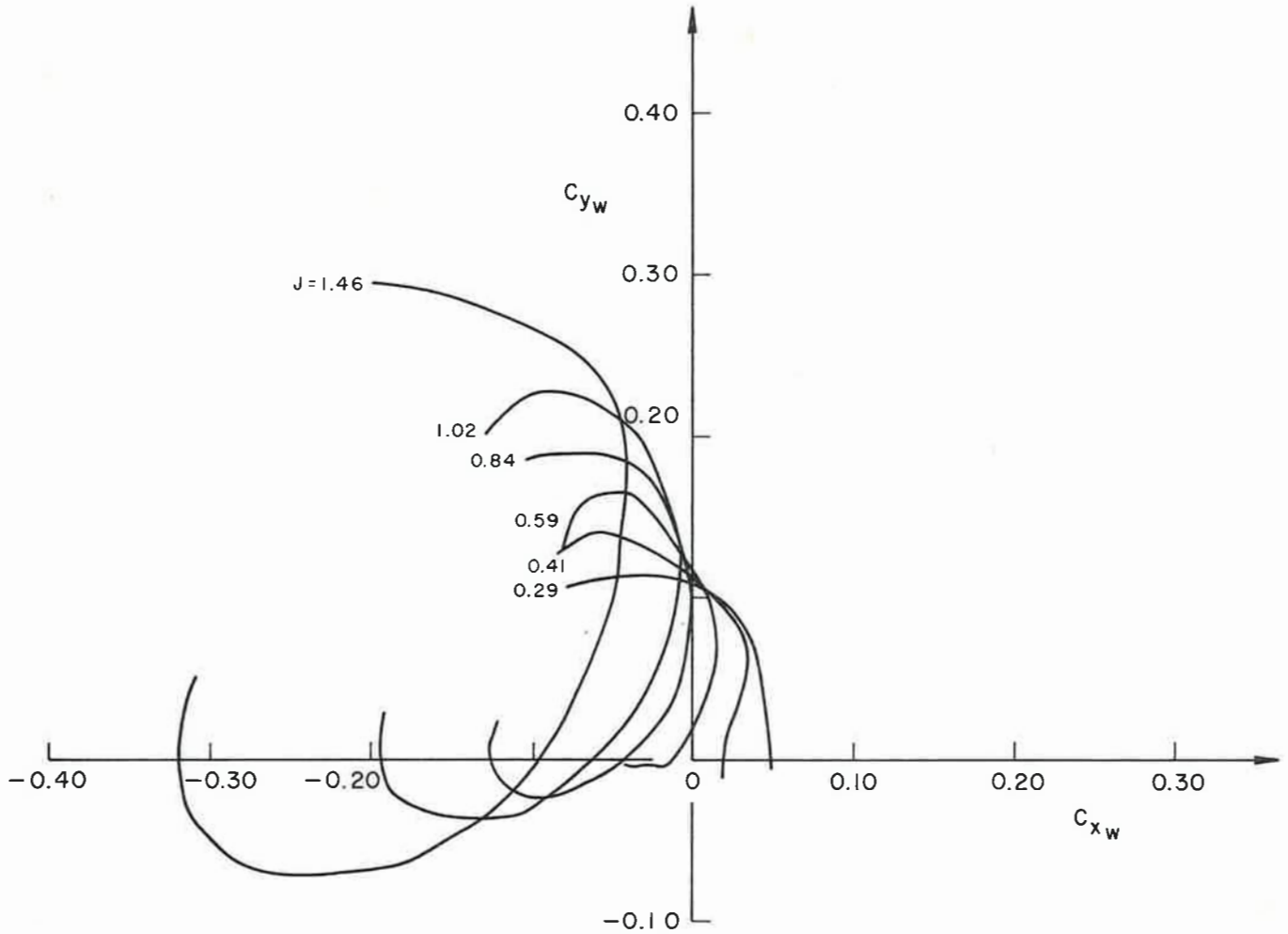


LOCATION OF THRUST VECTOR IN PROPELLER PLANE

FIG. 10b
LR – 454



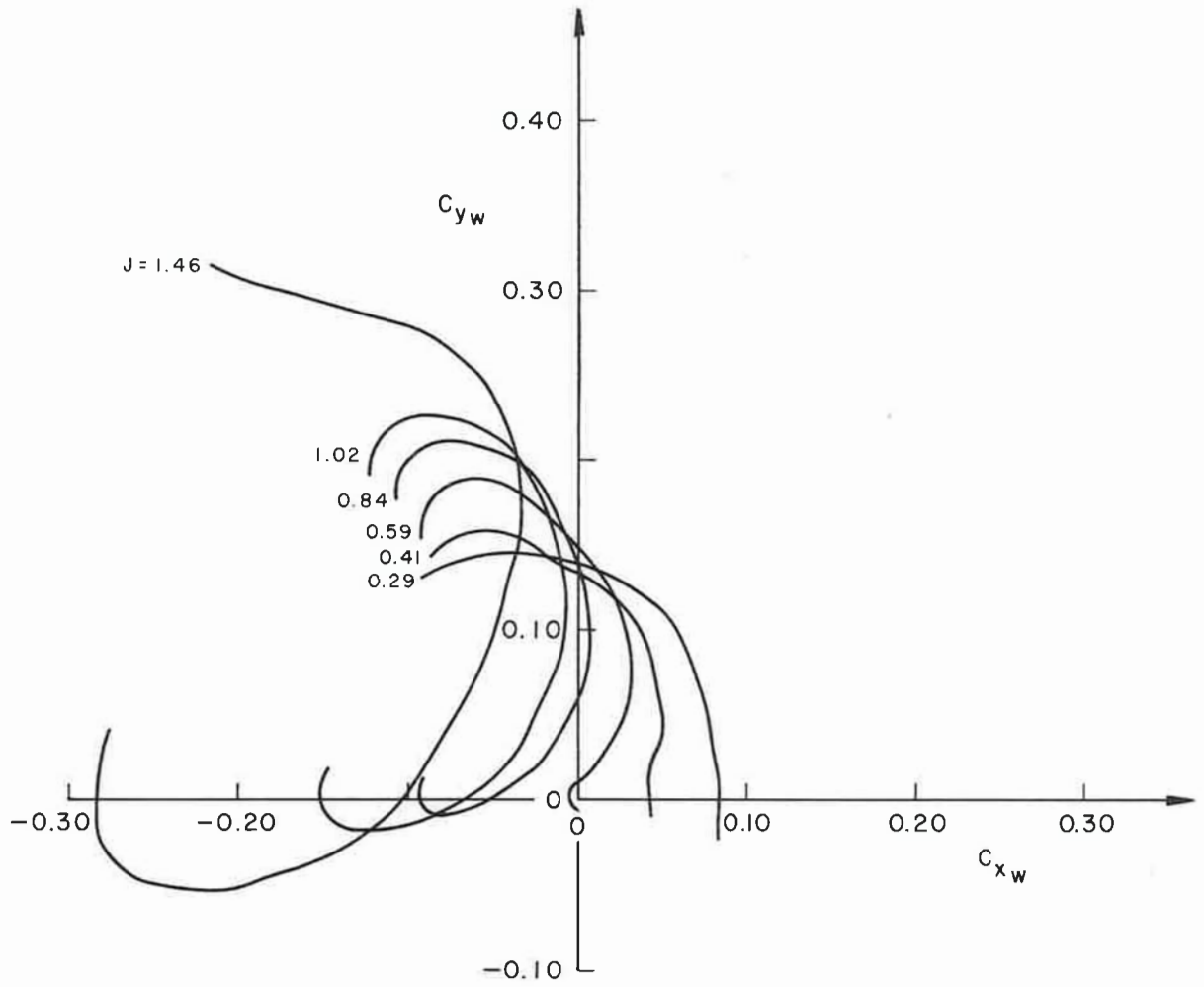
LOCATION OF THRUST VECTOR IN PROPELLER PLANE



WIND AXIS DATA, (C_{y_w}, C_{x_w})

$\beta = 8.7°$

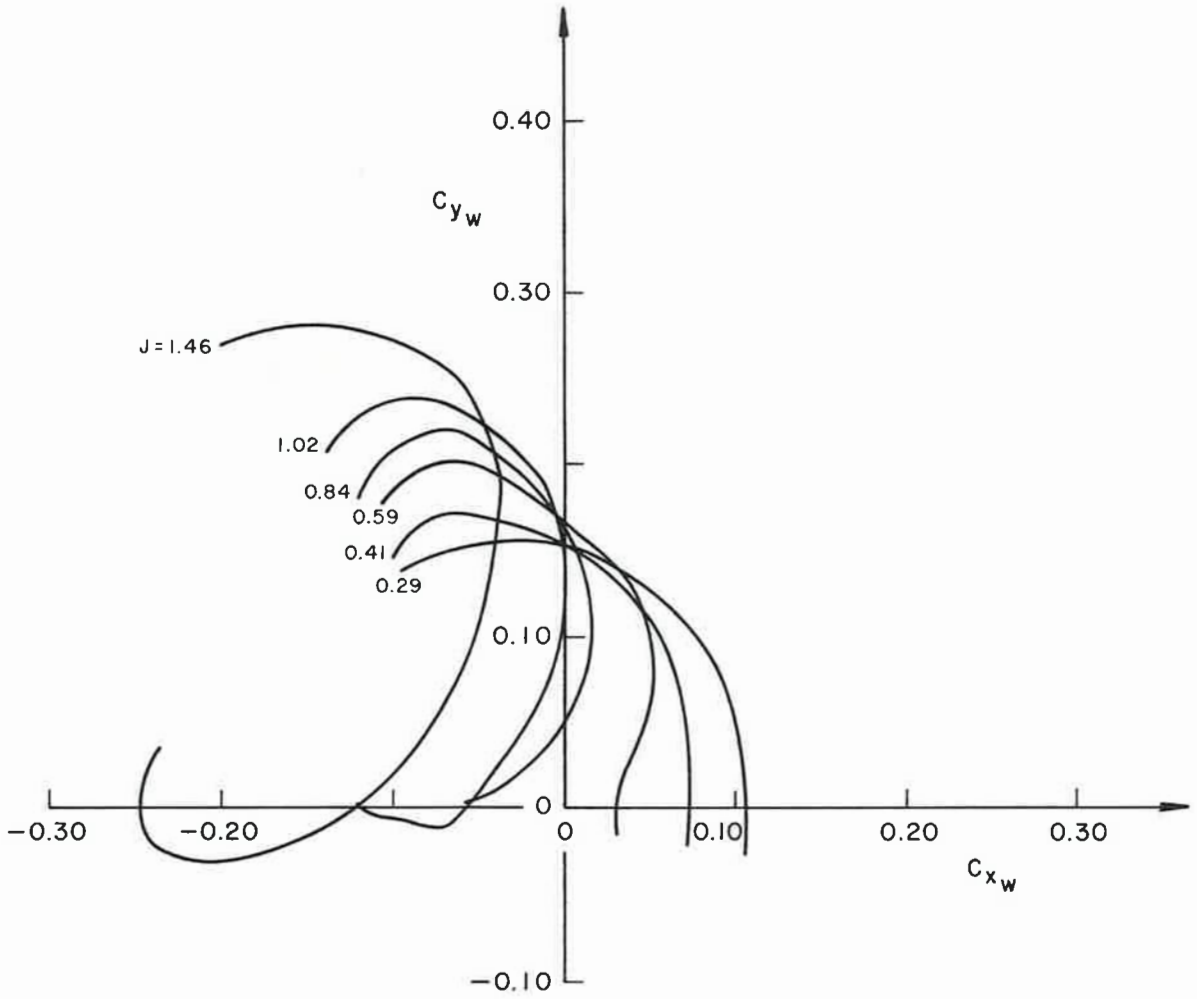
FIG. 11a
LR−454



WIND AXIS DATA, (C_{y_w}, C_{x_w})

β = 11.7°

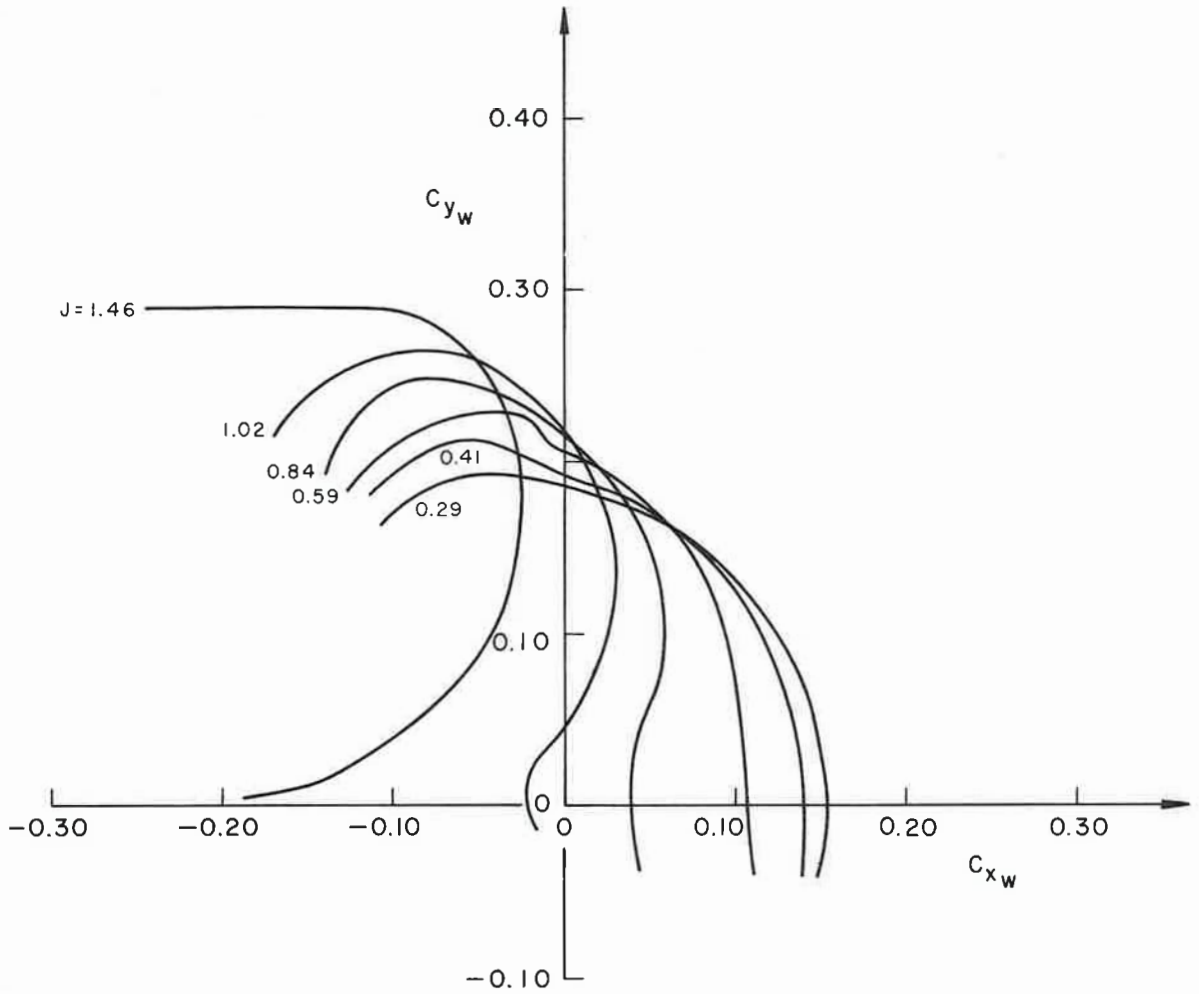
FIG. 11b
LR−454



WIND AXIS DATA, (C_{y_w}, C_{x_w})

$\beta = 14.7°$

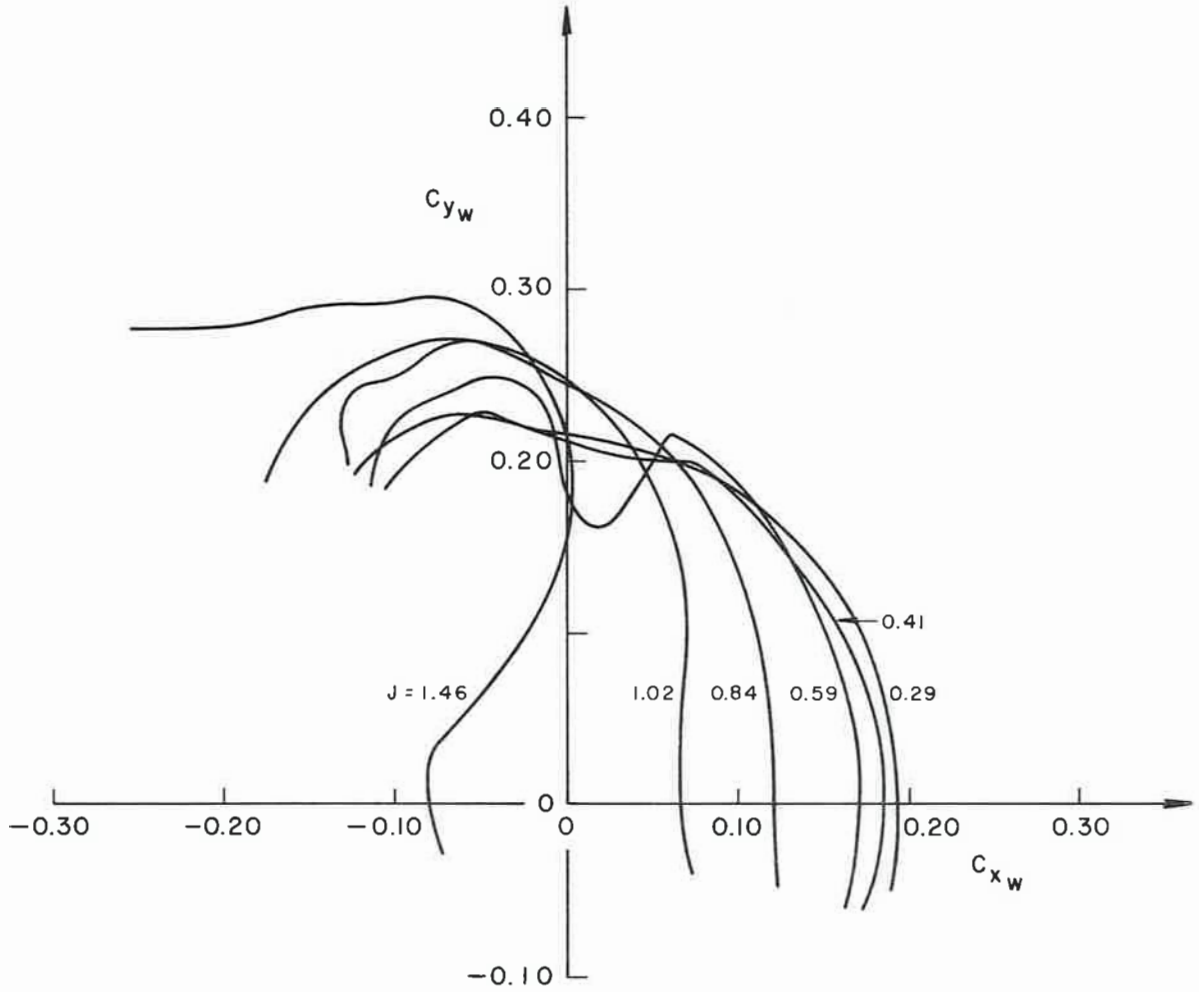
FIG. 11c
LR-454



WIND AXIS DATA, (C_{y_w}, C_{x_w})

$\beta = 20.7°$

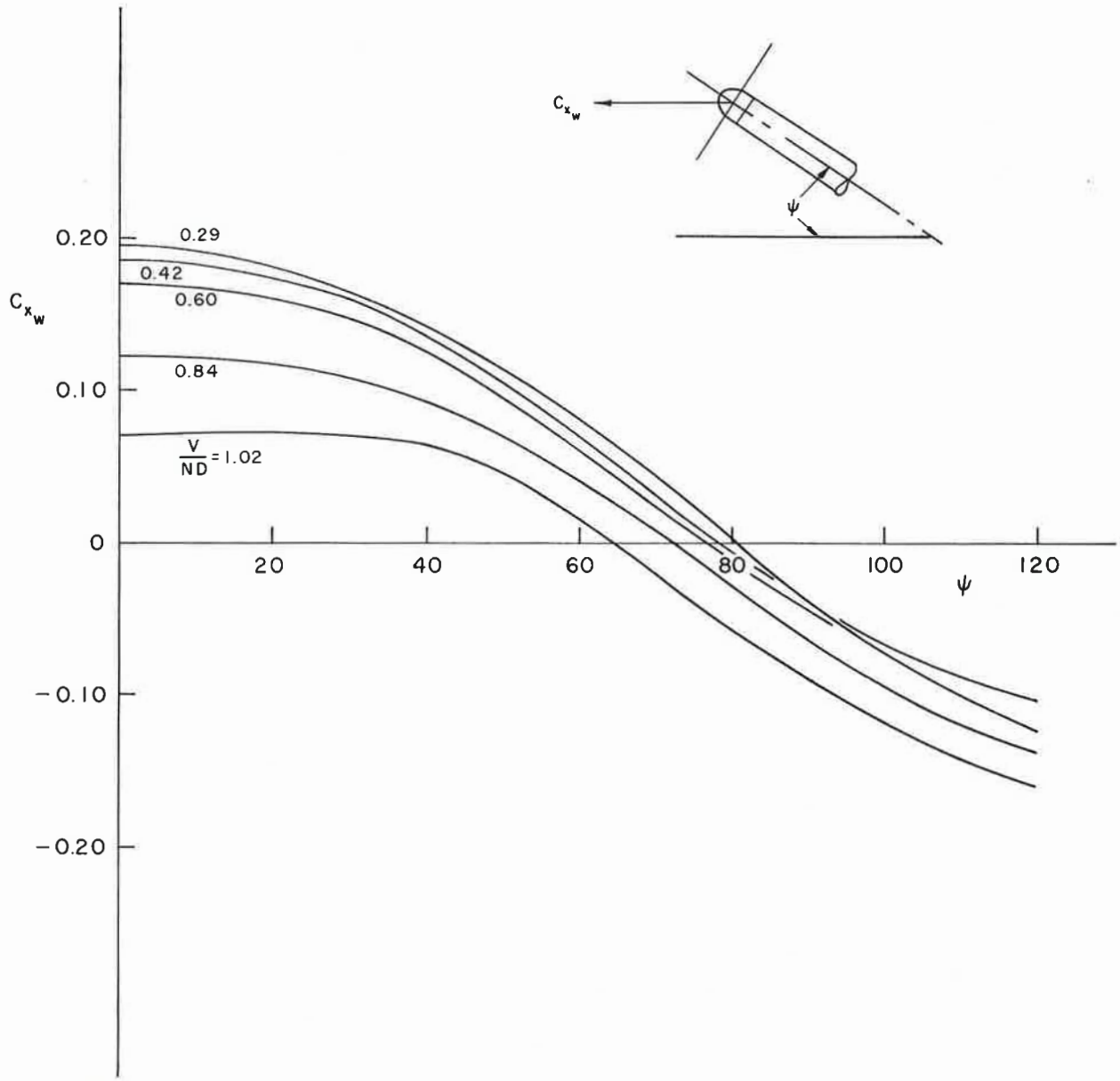
FIG. 11d
LR-454



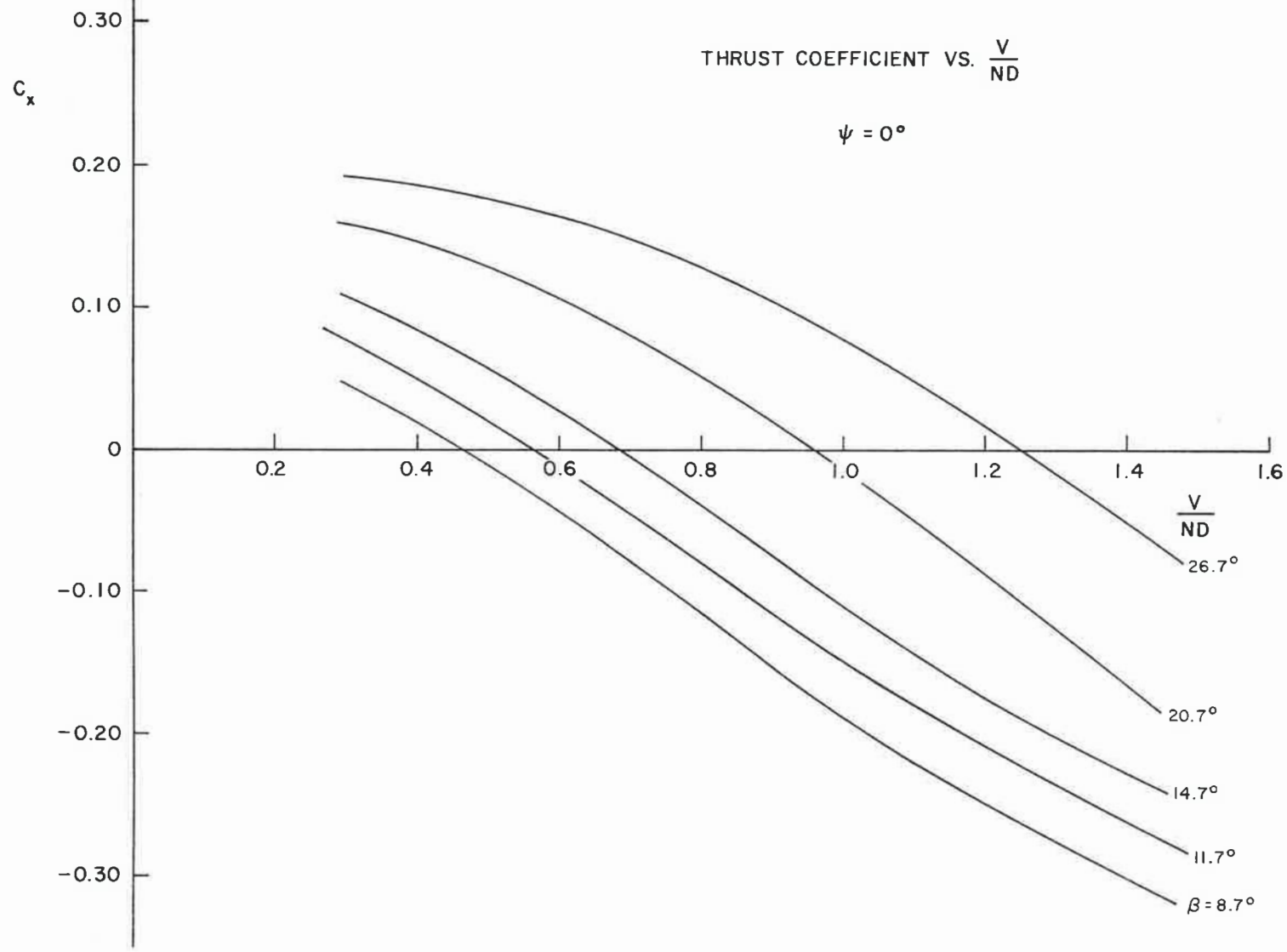
WIND AXIS DATA, (C_{y_w}, C_{x_w})

$\beta = 26.7°$

FIG. 11e
LR−454



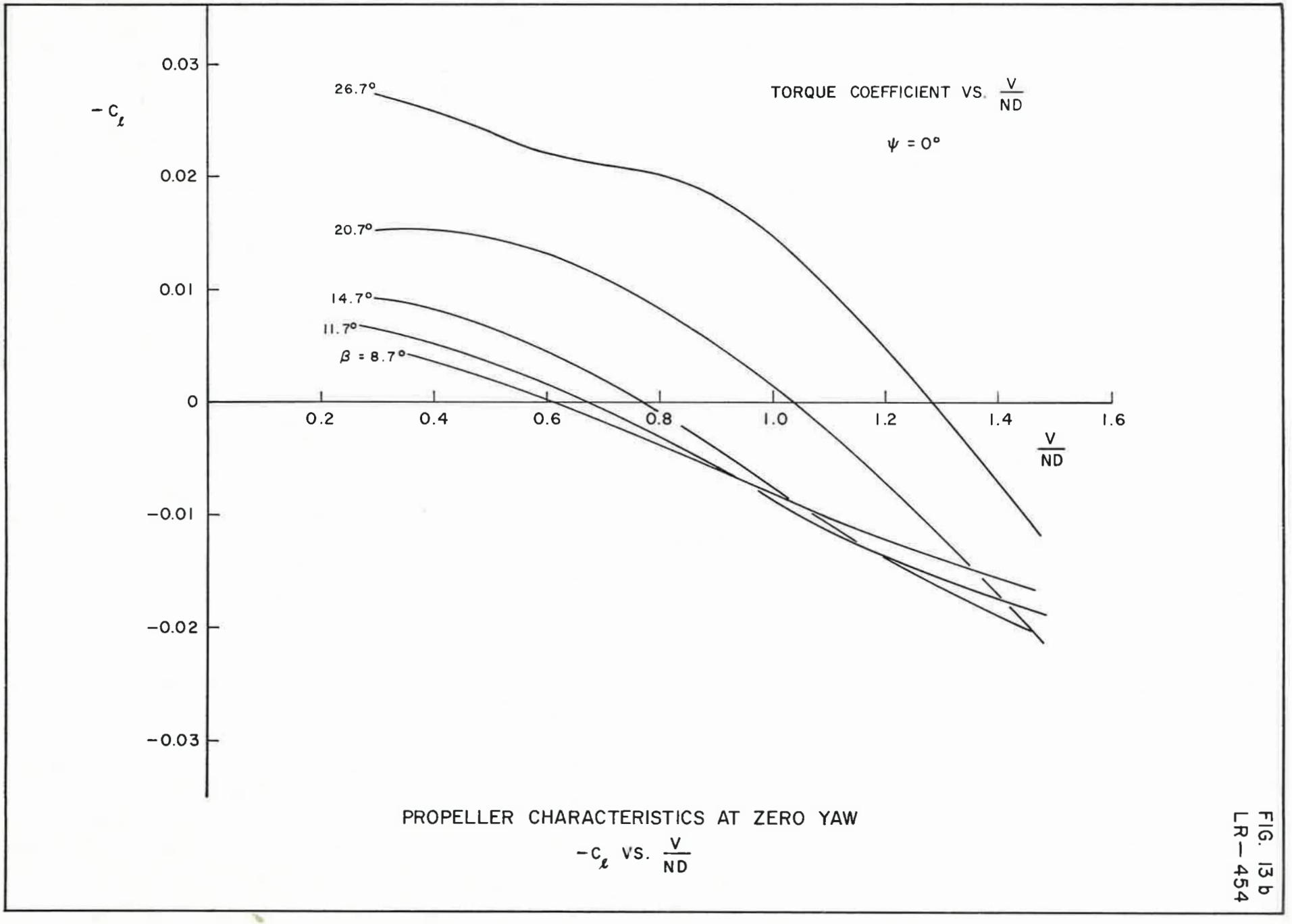
VARIATION OF C_{x_w} WITH YAW ANGLE ψ, β=26.7°



PROPELLER CHARACTERISTICS AT ZERO YAW

C_x VS. $\frac{V}{ND}$

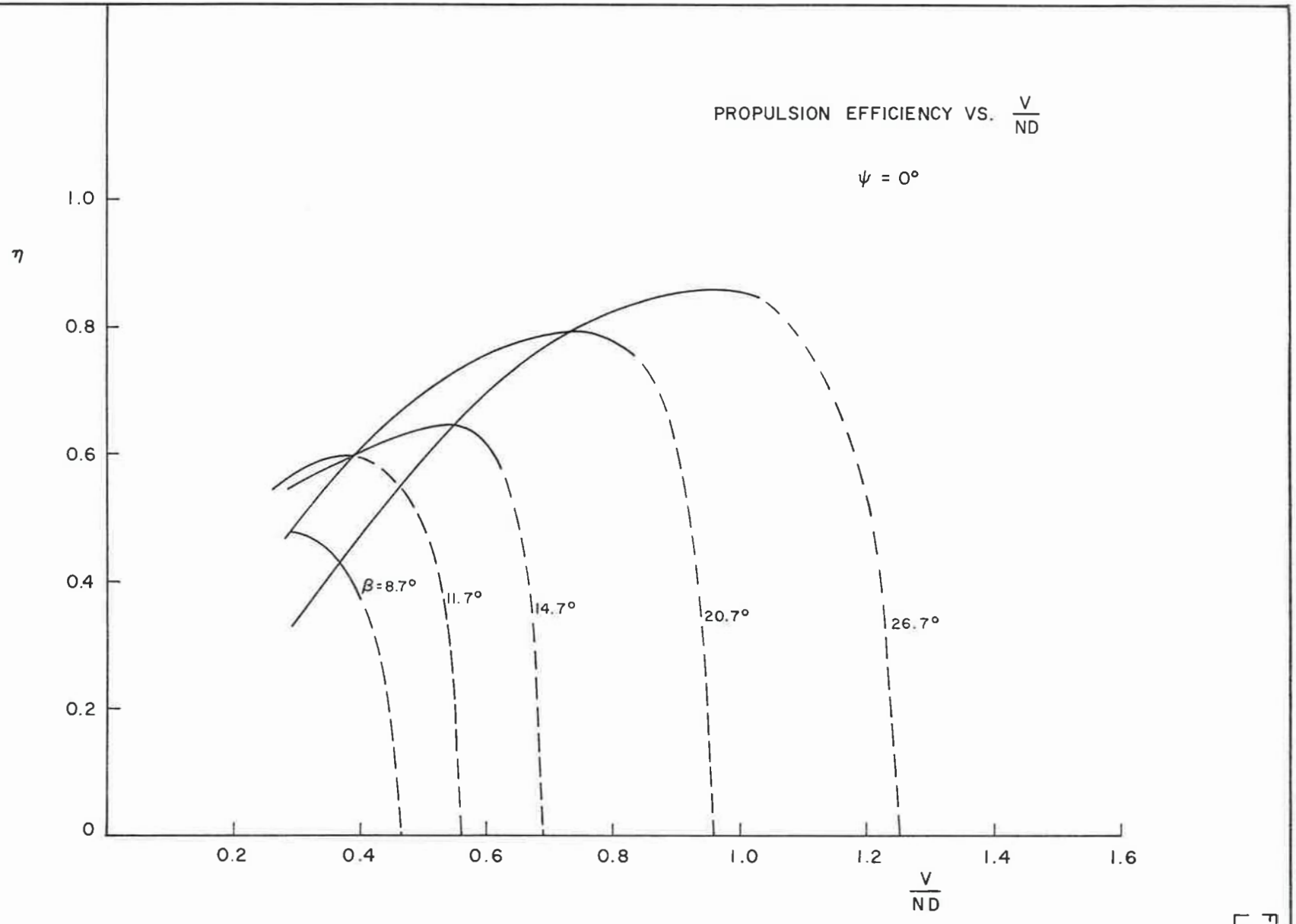
FIG. 13 a
LR-454



PROPELLER CHARACTERISTICS AT ZERO YAW

$-C_\ell$ VS. $\frac{V}{ND}$

FIG. 13 b
LR — 454

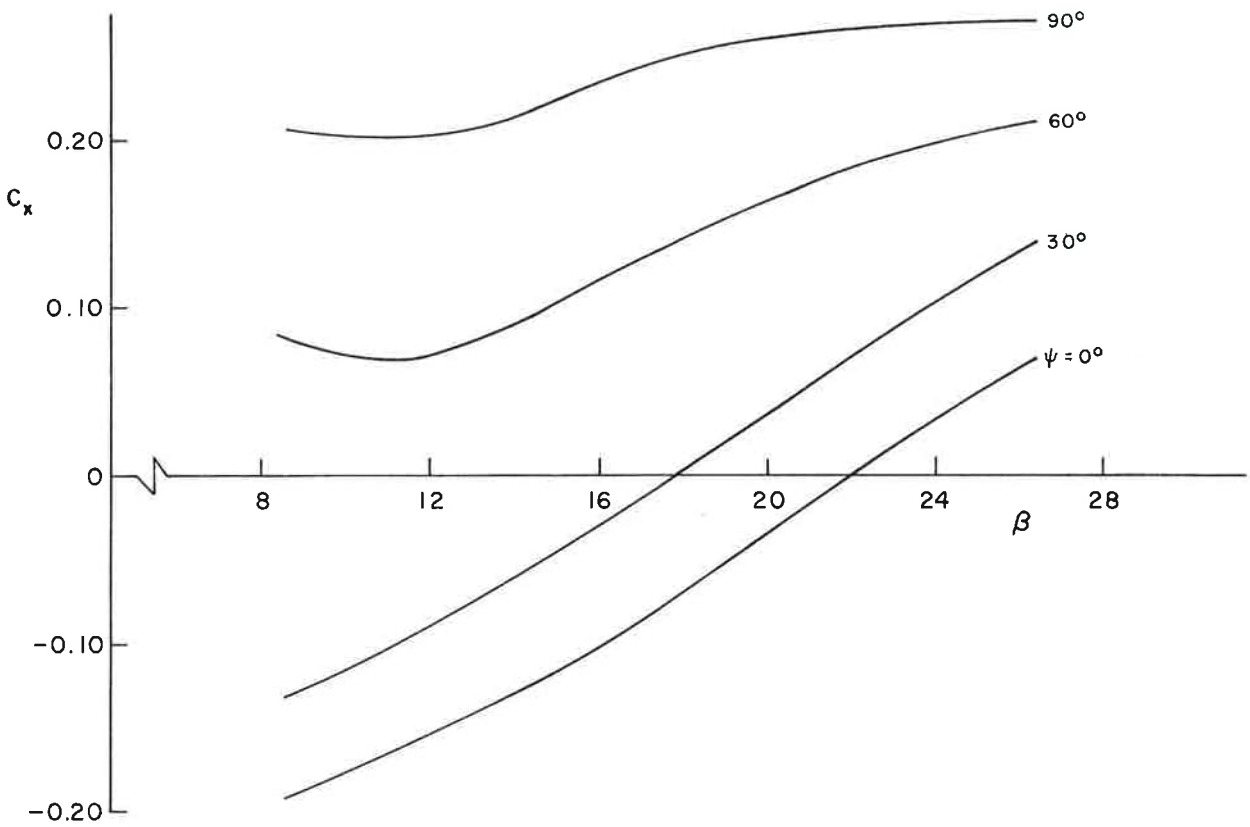


PROPELLER CHARACTERISTICS AT ZERO YAW

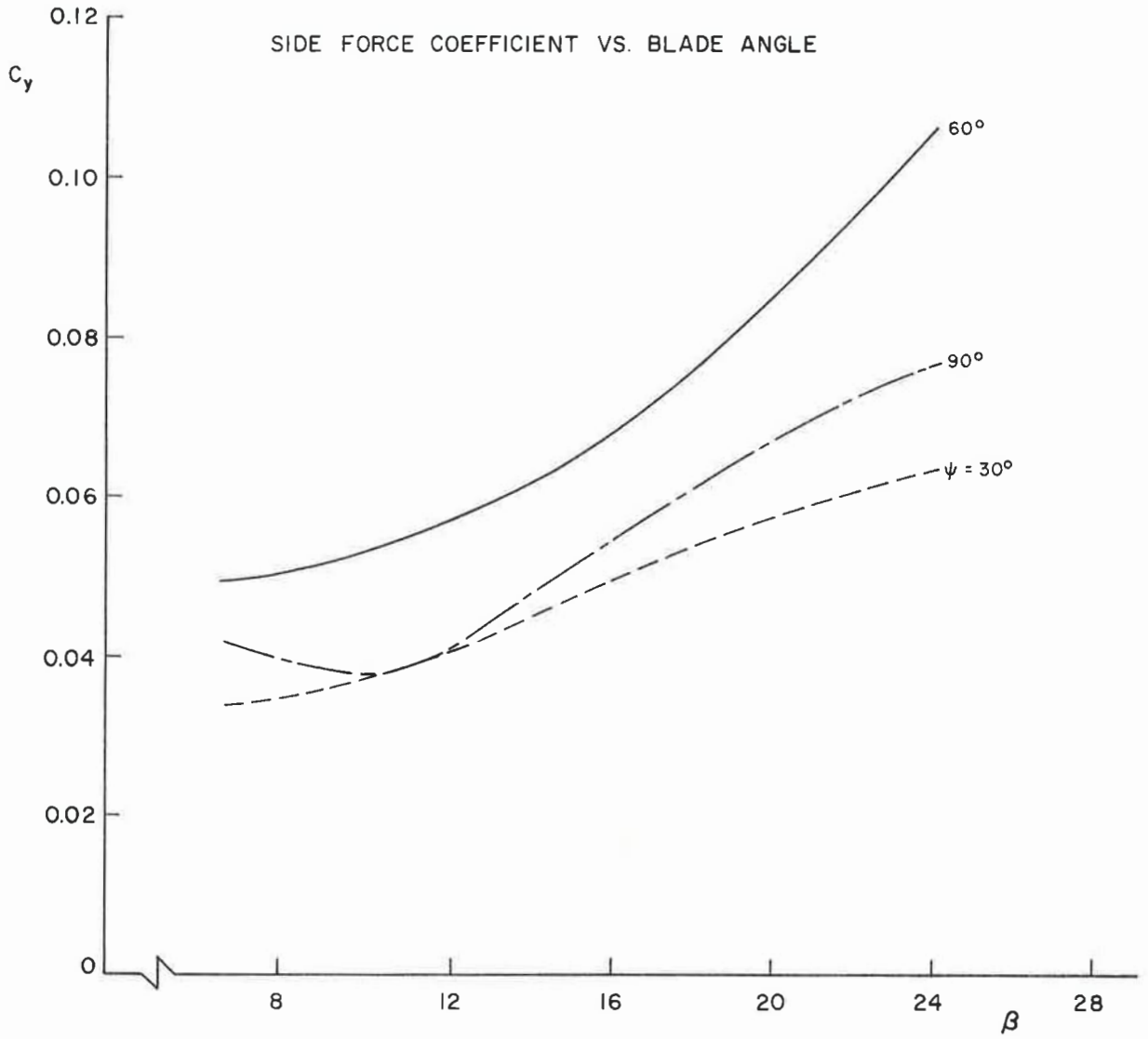
η VS. $\frac{V}{ND}$

FIG. 13c
LR-454

THRUST COEFFICIENT VS. BLADE ANGLE

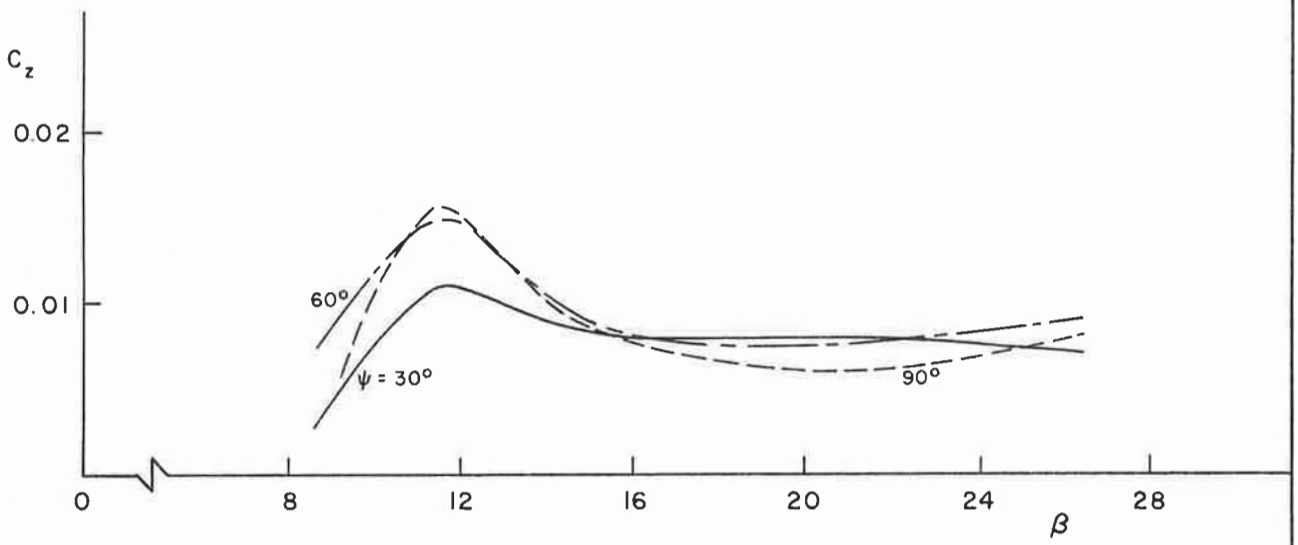


VARIATION OF PROPELLER FORCE COEFFICIENTS C_x , C_y AND C_z WITH BLADE ANGLE β, $\frac{V}{ND} = 1.02$



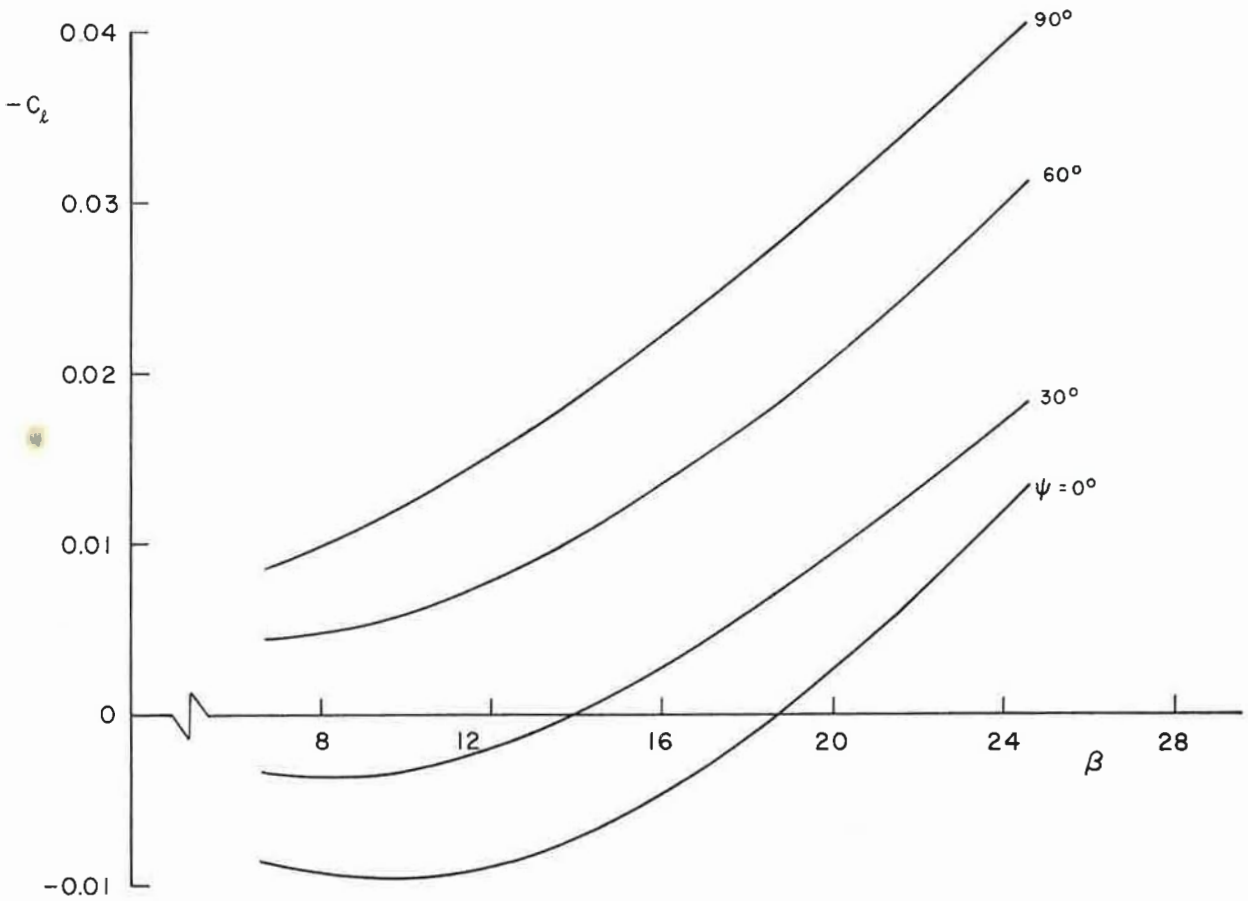
VARIATION OF PROPELLER FORCE COEFFICIENTS C_x, C_y AND C_z WITH BLADE ANGLE β, $\frac{V}{ND} = 1.02$

NORMAL FORCE COEFFICIENT VS. BLADE ANGLE



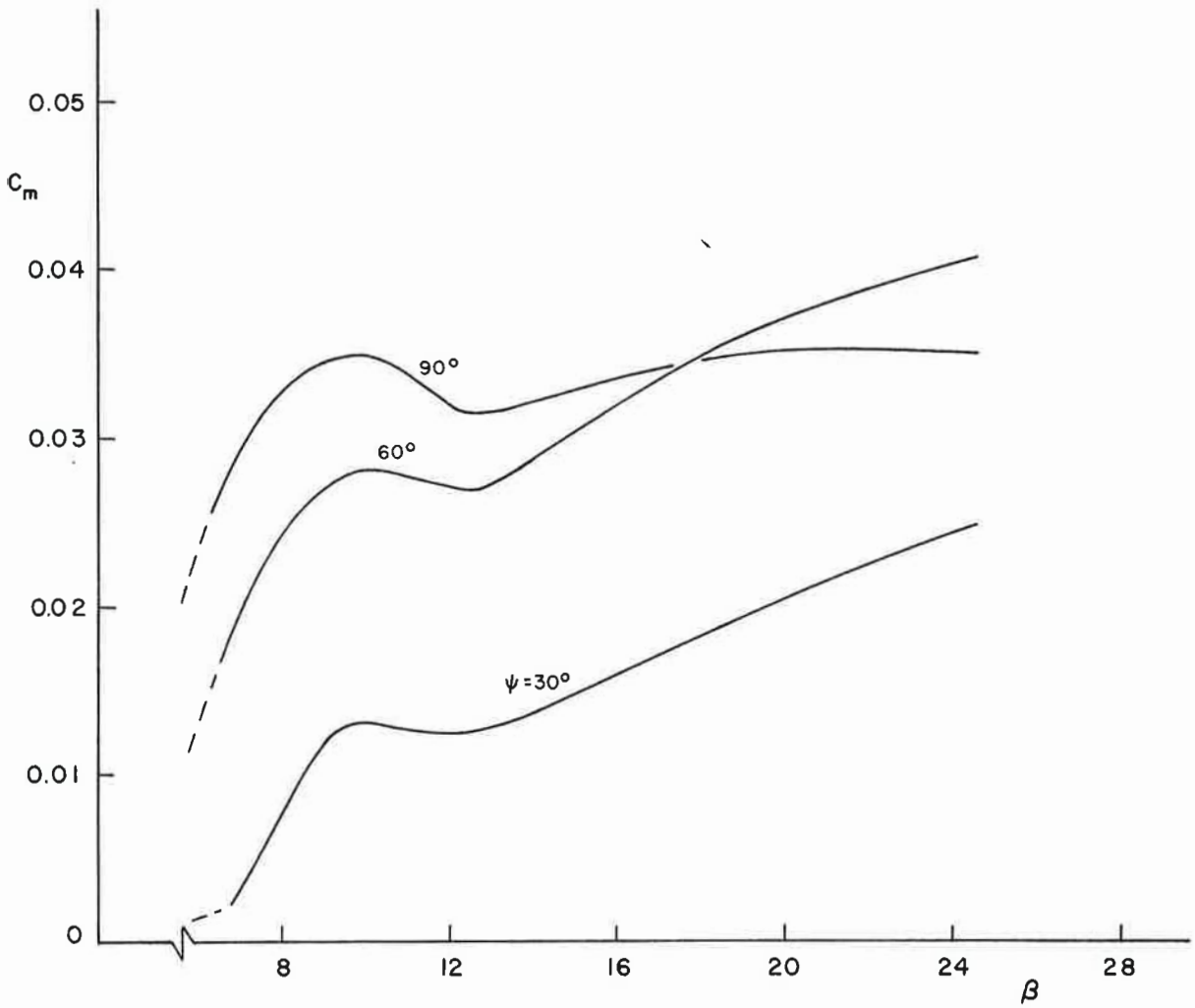
VARIATION OF PROPELLER FORCE COEFFICIENTS C_x, C_y AND C_z WITH BLADE ANGLE β, $\frac{V}{ND} = 1.02$

TORQUE COEFFICIENT VS. BLADE ANGLE



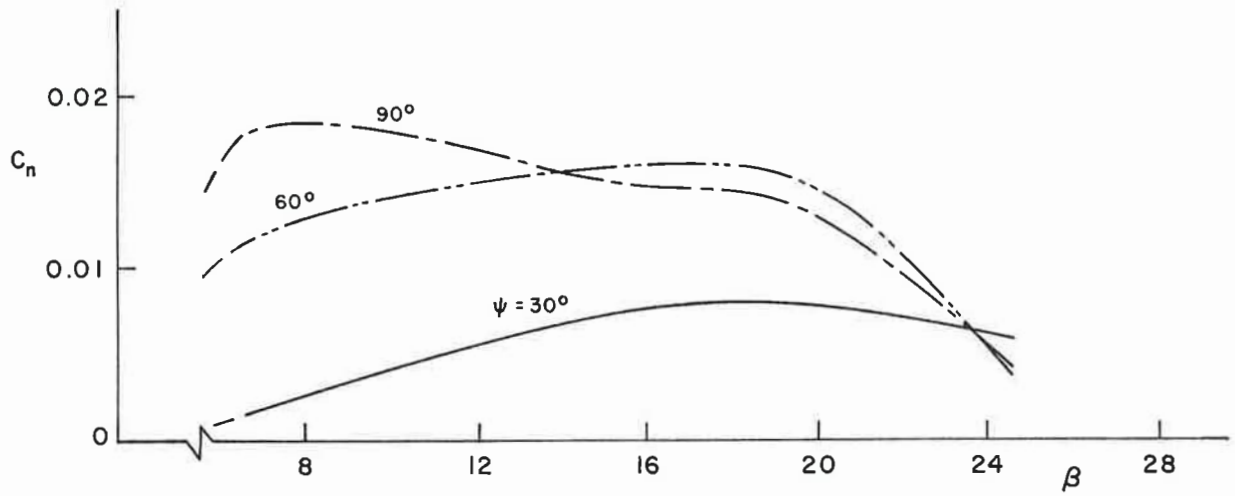
VARIATION OF PROPELLER MOMENT COEFFICIENTS $-C_\ell$, C_m AND C_n WITH BLADE ANGLE β, $\frac{V}{ND} = 1.02$

PITCHING MOMENT COEFFICIENT VS. BLADE ANGLE



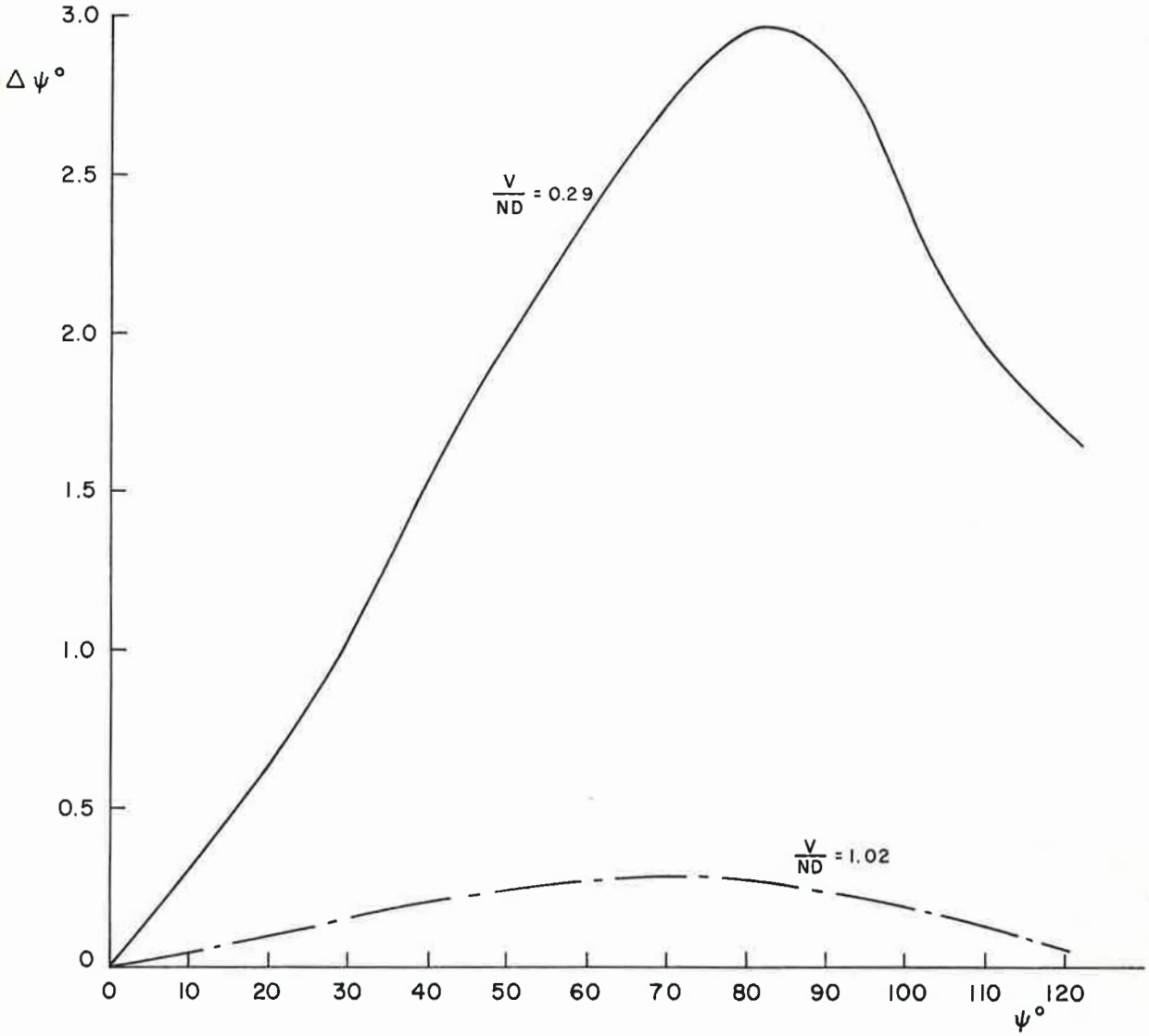
VARIATION OF PROPELLER MOMENT COEFFICIENTS $-C_l$, C_m AND C_n WITH BLADE ANGLE β, $\frac{V}{ND} = 1.02$

YAWING MOMENT COEFFICIENT VS. BLADE ANGLE



VARIATION OF PROPELLER MOMENT COEFFICIENTS $-C_\ell$, C_m AND C_n WITH BLADE ANGLE β, $\frac{V}{ND} = 1.02$

FIG. 16
LR-454



CORRECTIONS TO YAW ANGLE DUE TO WIND TUNNEL
JET-BOUNDARY INTERFERENCE, β=26.72°

NRC, DME LR-454
National Research Council, Canada. National Aeronautical Establishment.

AERODYNAMIC FORCE AND MOMENT CHARACTERISTICS OF A FOUR-BLADED PROPELLER YAWED THROUGH 120 DEGREES. R.H. Wickens. May 1966. 20 pp. + 16 figs.

This Report presents the results of six-component force and moment measurements on a propeller that was yawed through 120 degrees, for various conditions of blade pitch setting and advance ratio. Force coefficients C_y and C_z, normal to the propeller axis, were found to vary significantly with yaw angle, and had magnitudes that ranged from 1/10 to 1/4 of thrust coefficient C_x.
All of the moments (torque, pitching moment, and yawing moment) were of comparable maximum magnitude. The pitching and yawing moments were directed "nose up" and "nose right" respectively, for clockwise propeller rotation, and positive (nose right) yaw.

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1. Propellers - Aerodynamic characteristics

I. Wickens, R.H.
II. NRC, DME LR-454

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AERODYNAMIC FORCE AND MOMENT CHARACTERISTICS OF A FOUR-BLADED PROPELLER YAWED THROUGH 120 DEGREES. R.H. Wickens. May 1966. 20 pp. + 16 figs.

This Report presents the results of six-component force and moment measurements on a propeller that was yawed through 120 degrees, for various conditions of blade pitch setting and advance ratio. Force coefficients C_y and C_z, normal to the propeller axis, were found to vary significantly with yaw angle, and had magnitudes that ranged from 1/10 to 1/4 of thrust coefficient C_x.
All of the moments (torque, pitching moment, and yawing moment) were of comparable maximum magnitude. The pitching and yawing moments were directed "nose up" and "nose right" respectively, for clockwise propeller rotation, and positive (nose right) yaw.

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1. Propellers - Aerodynamic characteristics

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