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A COMPARISON BETWEEN EXPERIMENTAL DATA AND HELICOPTER AIRLOADS CALCULATED USING A LIFTING SURFACE THEORY

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Results of the calculation of helicopter airloads using a lifting surface theory solution are presented and compared with experimental data. These results indicate that a very accurate wake geometry model will be required in order to make full use of the accuracy of the lifting surface theory solution. It is observed that the experimental vortex induced loads decrease as the vortex moves inboard along the blade; this phenomenon in the behavior of the vortex wake of a rotor requires more investigation.

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Results of the calculation of helicopter airloads using a lifting surface theory solution are presented and compared with experimental data. These results indicate that a very accurate wake geometry model will be required in order to make full use of the accuracy of the lifting surface theory solution. It is observed that the experimental vortex induced loads decrease as the vortex moves inboard along the blade; this phenomenon in the behavior of the vortex wake of a rotor requires more investigation.

NOMENCLATURE

C_T	Rotor thrust coefficient: $\dfrac{\text{thrust}}{\rho(\Omega R)^2 \pi R^2}$
r	Rotor radial coordinate
R	Blade radius
$\theta°$	Root collective pitch
μ	Advance ratio: forward speed divided by rotor tip speed
ρ	Air density
σ	Solidity ratio: $\dfrac{\text{total blade area}}{\pi R^2}$
ψ	Rotor azimuth coordinate
Ω	Rotor rotational speed

INTRODUCTION

A lifting surface theory solution has been developed for a model problem for vortex induced airloads (reference 1). The model consists of an infinite aspect ratio wing in a subsonic, compressible free stream, and a straight, infinite vortex at an arbitrary angle with the wing (figure 1). Using the exact numerical results from linear lifting surface theory, an approximate, closed form solution for the vortex induced loads was obtained. The solution in this form is suitable for application to the calculation of rotary wing airloads; procedures for this application were developed in reference 1. This report presents results of calculations using the lifting surface theory solution for the vortex induced loads, and compares the theoretical calculations with available experimental data.

THE CALCULATION OF HELICOPTER AIRLOADS

Experimental data is available (references 2 and 3) from flight tests of a four-blade rotor of a Sikorsky H-34 helicopter; a description of this rotor and its instrumentation may be found in reference 2. Five cases were chosen for study (flights number 7, 12, 17, and 25 from reference 2, and the $\mu = 0.18$ case of reference 3); these cases were chosen because they show vortex induced loads at $r = .95$.

Figures 2 through 6 present a comparison of calculated and experimental section lift, for radial stations $r = .95$, .85, .75, .55, and .25, respectively. The experimental data is from flight number 7 of reference 2; this case has an advance ratio of $\mu = 0.15$. The calculations used the lifting surface theory solution; a rigid wake geometry was used and the values of the wake inflow and the first harmonic flapping were adjusted to give agreement of the loads at the $r = .95$ station. The inboard loads tend to be low; the calculated thrust gives $C_T/\sigma = 0.082$, while the experimental value is about $C_T/\sigma = 0.089$. The greatest discrepancies in the prediction of the inboard loads arise because of the use of a rigid wake geometry. Figures 2 and 6 also include the results of a calculation using a nonrigid wake geometry, with a large vortex core radius to account for local distortion due to the vortex/blade interaction. The non-rigid wake geometry was supplied by M.P. Scully, using a development of his method described in reference 4 for the calculation of the self-induced distortion of the tip vortices in the rotor wake. The prediction of the inboard loads is substantially improved by the use of the nonrigid wake geometry. Figures 7 through 9 present polar diagrams of the section lift, for the experimental data, the rigid wake calculation, and the nonrigid wake calculation, respectively. It is seen that a good wake geometry model is necessary in order to predict the rotor loads. While the lifting surface solution allows an accurate calculation of the loads, its use requires the distribution of the downwash over the rotor disk, and the downwash must be calculated from the vortex wake of the rotor. Moreover, a verv high degree of accuracy is reouired in order to correctly predict the closeness of the vortex to the blade, to which the downwash is most sensitive.

Figures 10 through 12 present a comparison of calculated and experimental section lift, for radial stations $r = .95$, $.85$, and $.75$, respectively. The experimental data is from the $\mu = 0.18$ case of reference 3. The calculations used the lifting surface theory solution; a rigid wake geometry was used and the value of the wake inflow adjusted to give a correct level of the peak-to-peak vortex induced loads at $r = .95$. Flapping was calculated theoretically (rather than adjusted to give agreement of the loads at $r = .95$), producing some discrepancy in the loads. In order that the theoretical peak-to-peak vortex loads on the advancing side of the disk (which are due to the tip vortex from the preceding blade) decrease as the experimental data show, it was necessary to arbitrarily push the vortex farther from the blade as the blade passed over it.

The use of the lifting surface theory solution does require more calculation than the use of lifting line theory, but still the airloads calculation remains small compared with the downwash calculation. The times to calculate the downwash at one point on the rotor disk due to one line element in the wake, to locate the point of nearest approach of a tip vortex to the blade, and to calculate the load at one point on the disk due to one vortex using the lifting surface solution are in the ratio 1:28:22. In a typical case, for one cycle of the blade around the disk the total times to calculate the downwash, to locate the points of nearest approach of the vortices, and to calculate the loads using the lifting surface solution were in the ratio 25:1:3.

The feature of the airloads referred to above as local distortion due to vortex/blade interaction, requiring either a large core size or pushing the vortex away to obtain correct inboard loads due to the vortex, is actually much more involved. Figures 13 through 17 compare the experimental section loads for the five cases studied. It is seen that for every case the effect of the vortex is greatly reduced as it moves inboard along the blade. Current wake geometry models indicate that on the advancing side of the disk the tip vortex of a blade remains very close to the plane of the rotor, and is pushed downward after the passage of the following blade. The vortex/blade separation is small and varies little as the blade moves over the vortex. At the advance ratios of the cases considered here the vortex moves inboard at least to the r = .70 station. With this geometry the vortex induced loads should remain about the same as the vortex moves inboard; instead the loads are observed to decrease substantially. The present calculation procedure might account for this effect by having the blade push the vortex away as it passes over it, or by using a large viscous core size. While these two features are undoubtedly a part of the phenomenon, the calculations above indicate that the vortex would have to be pushed too far away, or too large a core size would have to be used for either of these to be the entire cause. Other possible causes are vortex bursting due to the presence of the blade, or the interference of the vortex with the wake vorticity it generates behind the blade propagating up the vortex. For a very close vortex the viscous core will be in contact with the boundary layer of the blade; moreover, large radial velocities will be induced on the blade by the vortex; these are likely important features of the vortex behavior. The nature of this phenomenon and its causes are at present unknown. It is evident, however, that it is not sufficient to consider the rotor wake simply as composed of well-behaved vortex lines and sheets. There is yet a great deal to be learned about the nature of the wake of a rotary wing.

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3. Scheiman, J., and Ludi, L.H., "Qualitative Evaluation of Effect of Helicopter Rotor-Blade Tip Vortex on Blade Airloads," NASA TN D-1637, May 1963.

4. Scully, M.P., "A Method of Computing Helicopter Vortex Wake Distortion," Massachusetts Institute of Technology, Aeroelastic and Structures Research Laboratory, TR 138-1, June 1967.

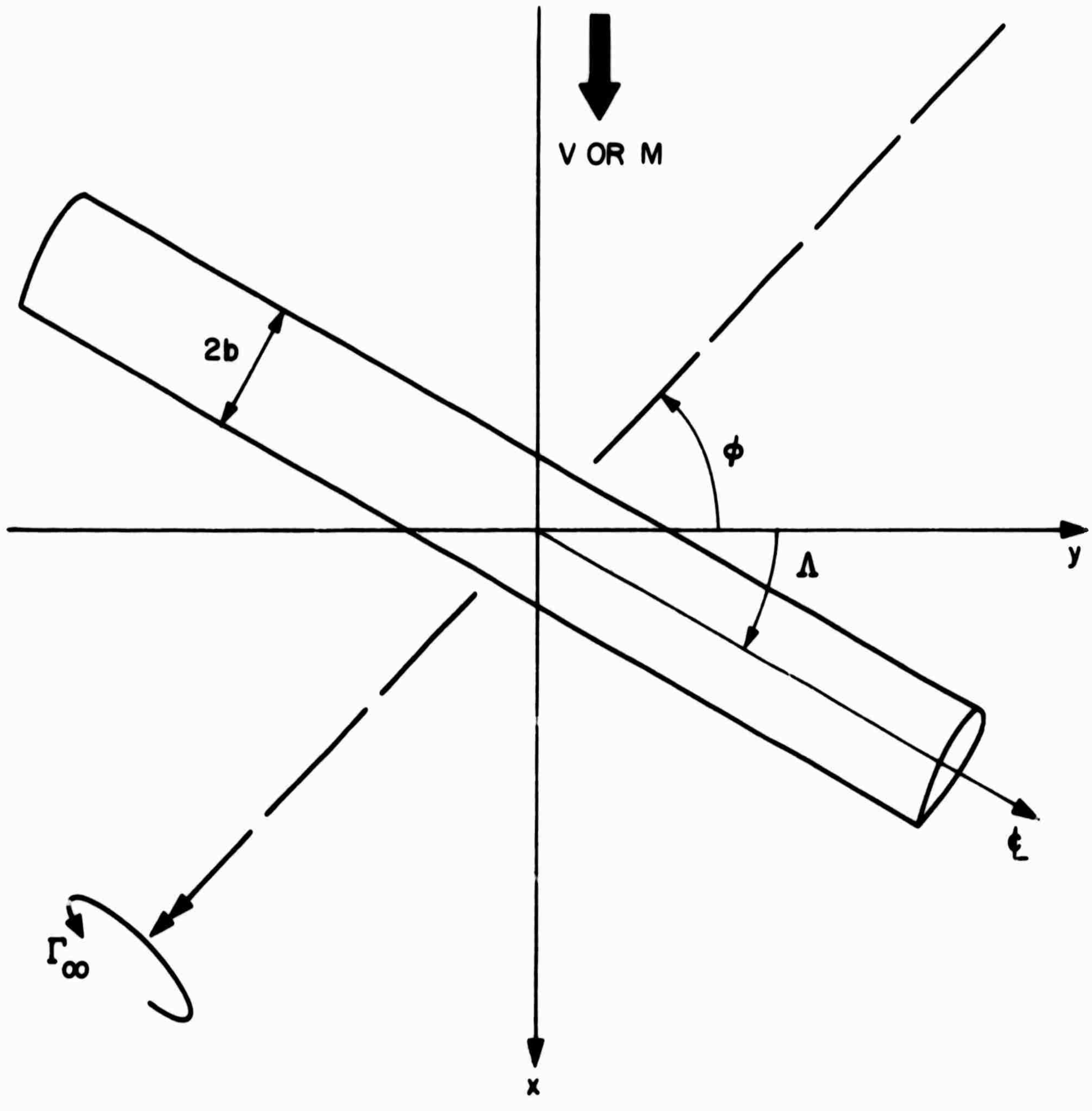


FIGURE 1 MODEL PROBLEM FOR VORTEX INDUCED AIRLOADS

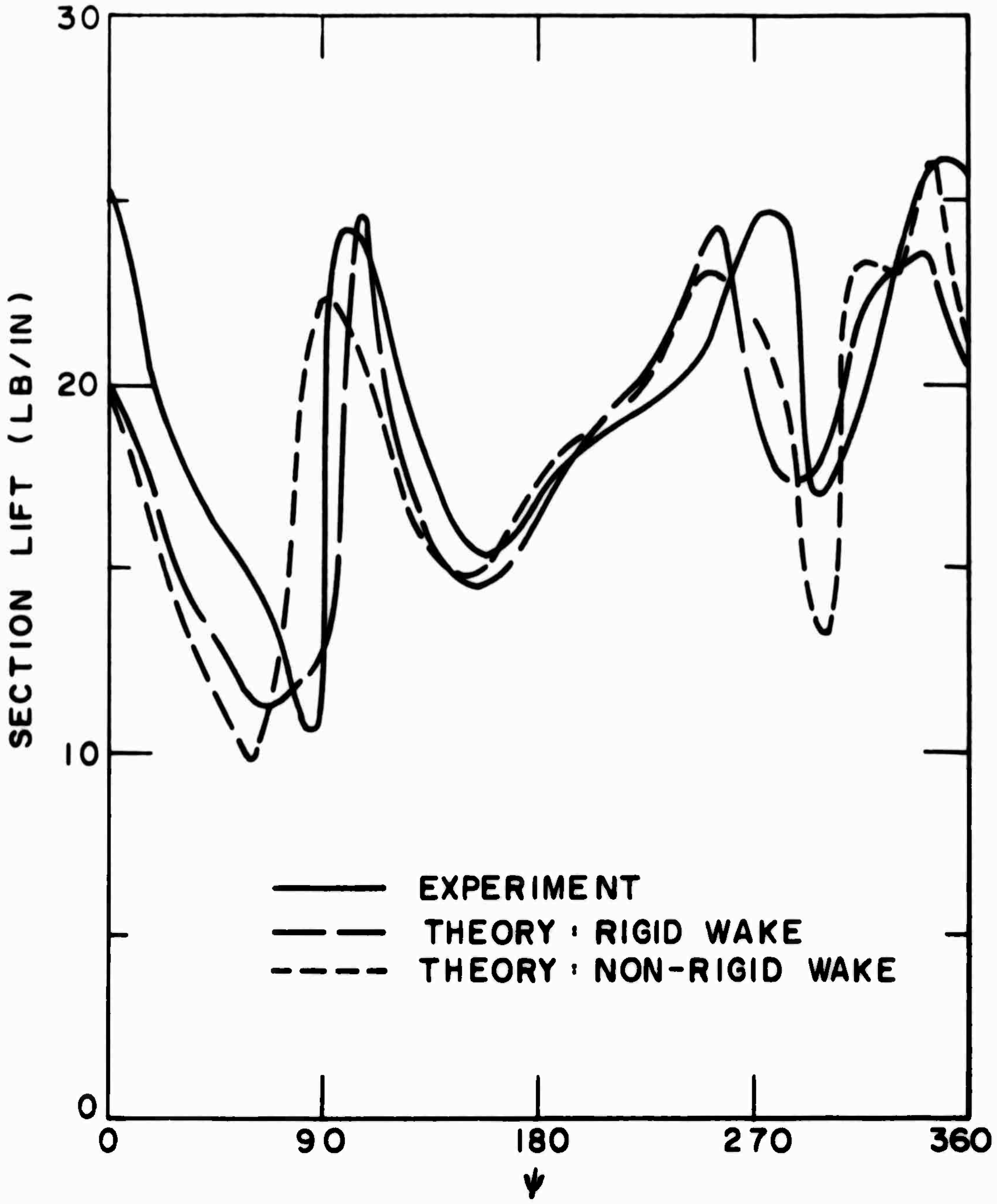


FIGURE 2 COMPARISON OF SECTION LIFT CALCULATED USING LIFTING SURFACE THEORY WITH EXPERIMENTAL RESULTS (FLIGHT No. 7 OF REF. 2): $\mu = 0.15$, $\theta^\circ = 12.5^\circ$, $r = .95$

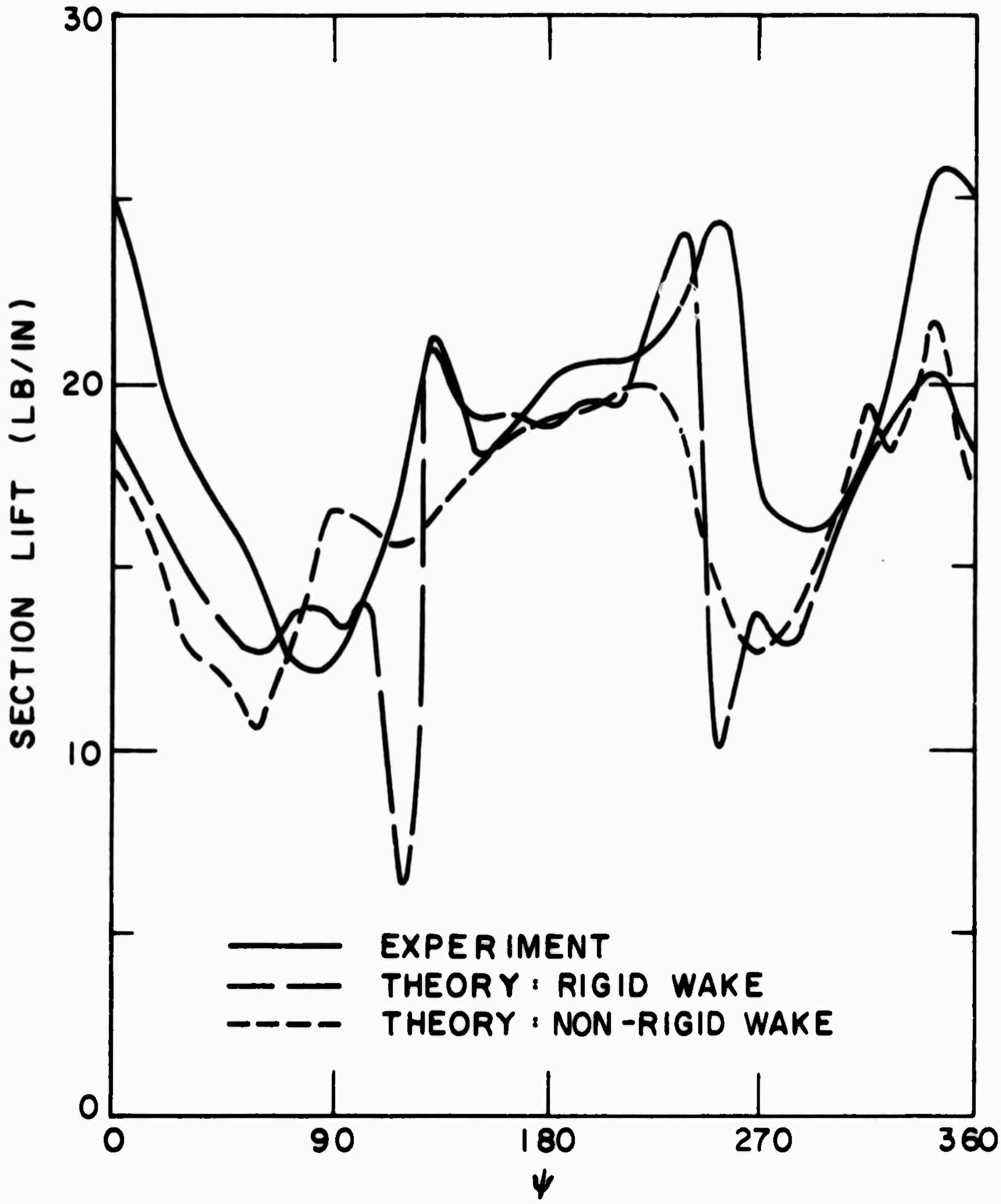
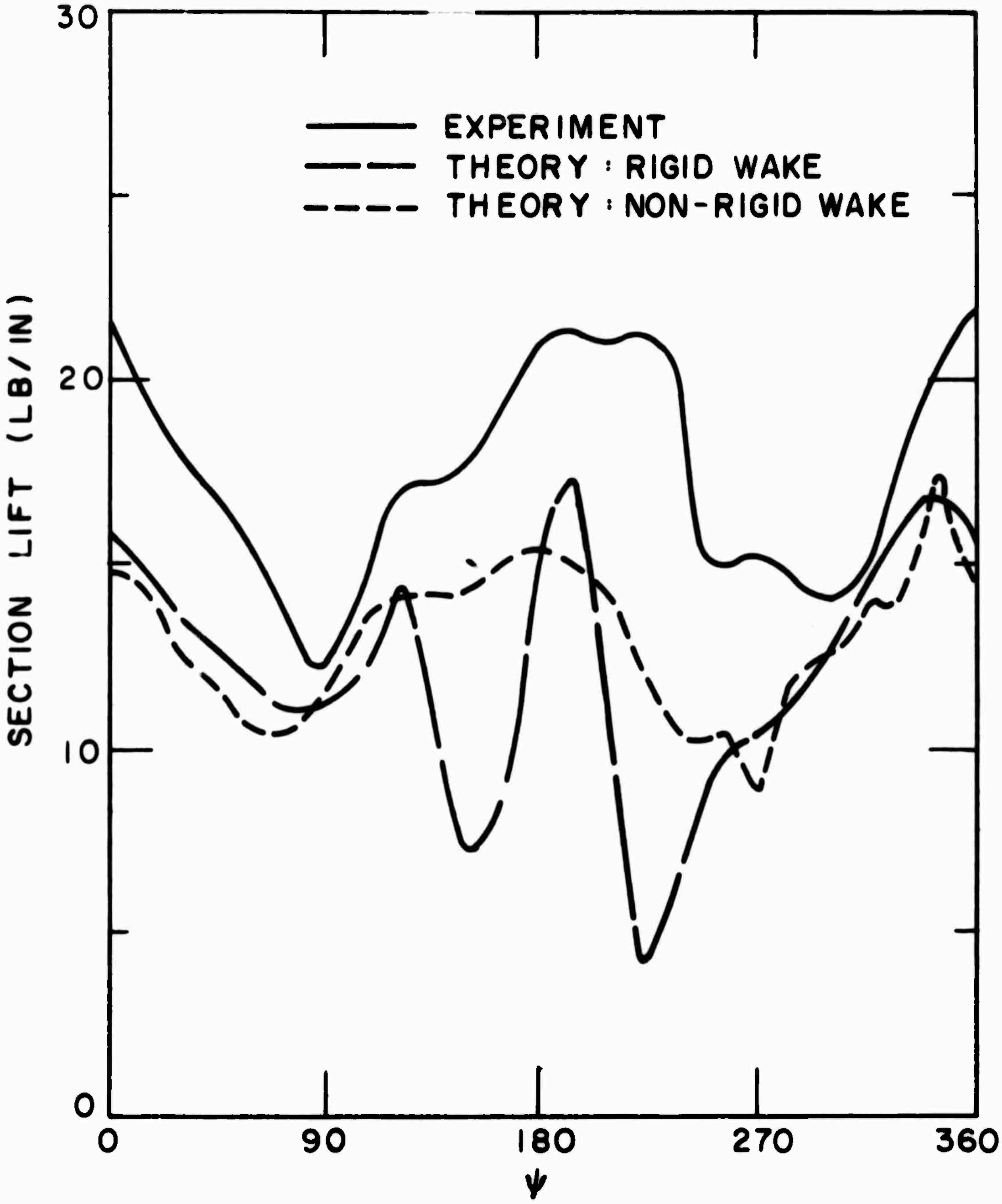

30
20
10
0
SECTION LIFT (LB/IN)
0
90
180
270
360
ψ
EXPERIMENT
THEORY : RIGID WAKE
THEORY : NON-RIGID WAKE

FIGURE 3 r = .85



EXPERIMENT
THEORY : RIGID WAKE
THEORY : NON-RIGID WAKE
SECTION LIFT (LB/IN)
30
20
10
0
0
90
180
270
360
ψ

FIGURE 4 r = .75

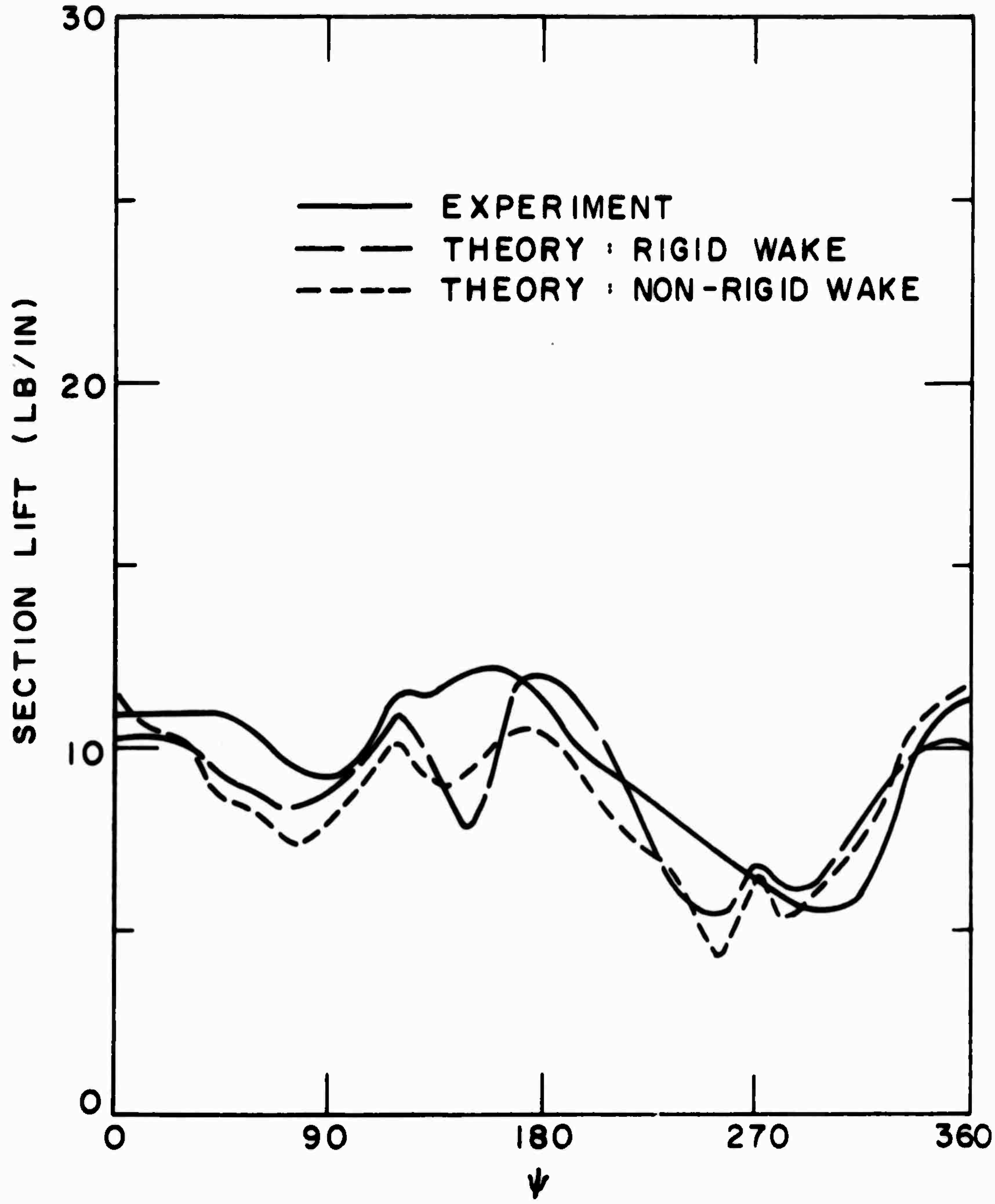
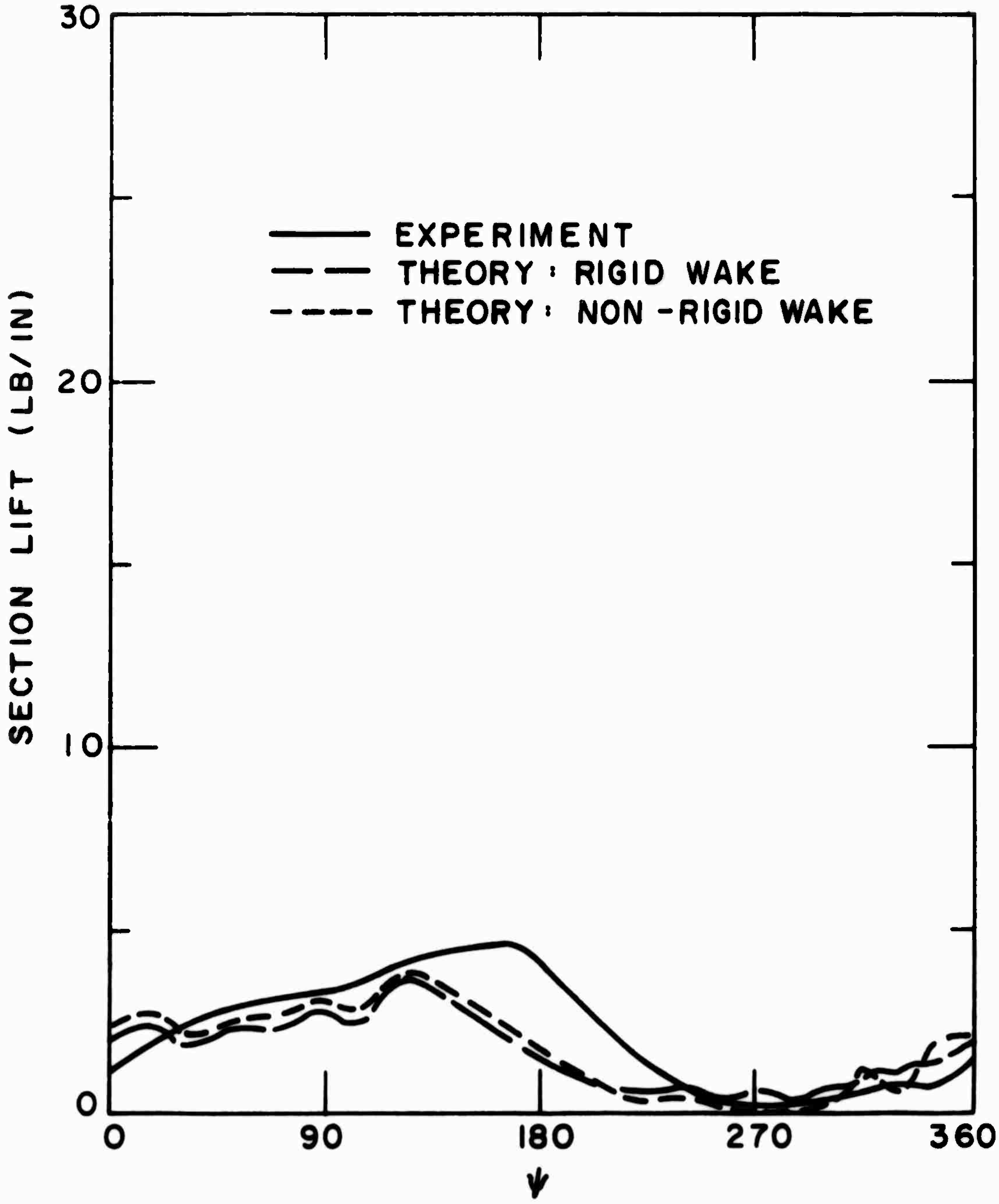

EXPERIMENT
THEORY : RIGID WAKE
THEORY : NON-RIGID WAKE
SECTION LIFT (LB/IN)
30
20
10
0
0
90
180
270
360
ψ

FIGURE 5 r = .55



30
20
10
0
SECTION LIFT (LB/IN)
EXPERIMENT
THEORY : RIGID WAKE
THEORY : NON-RIGID WAKE
0
90
180
270
360
ψ

FIGURE 6 r = .25

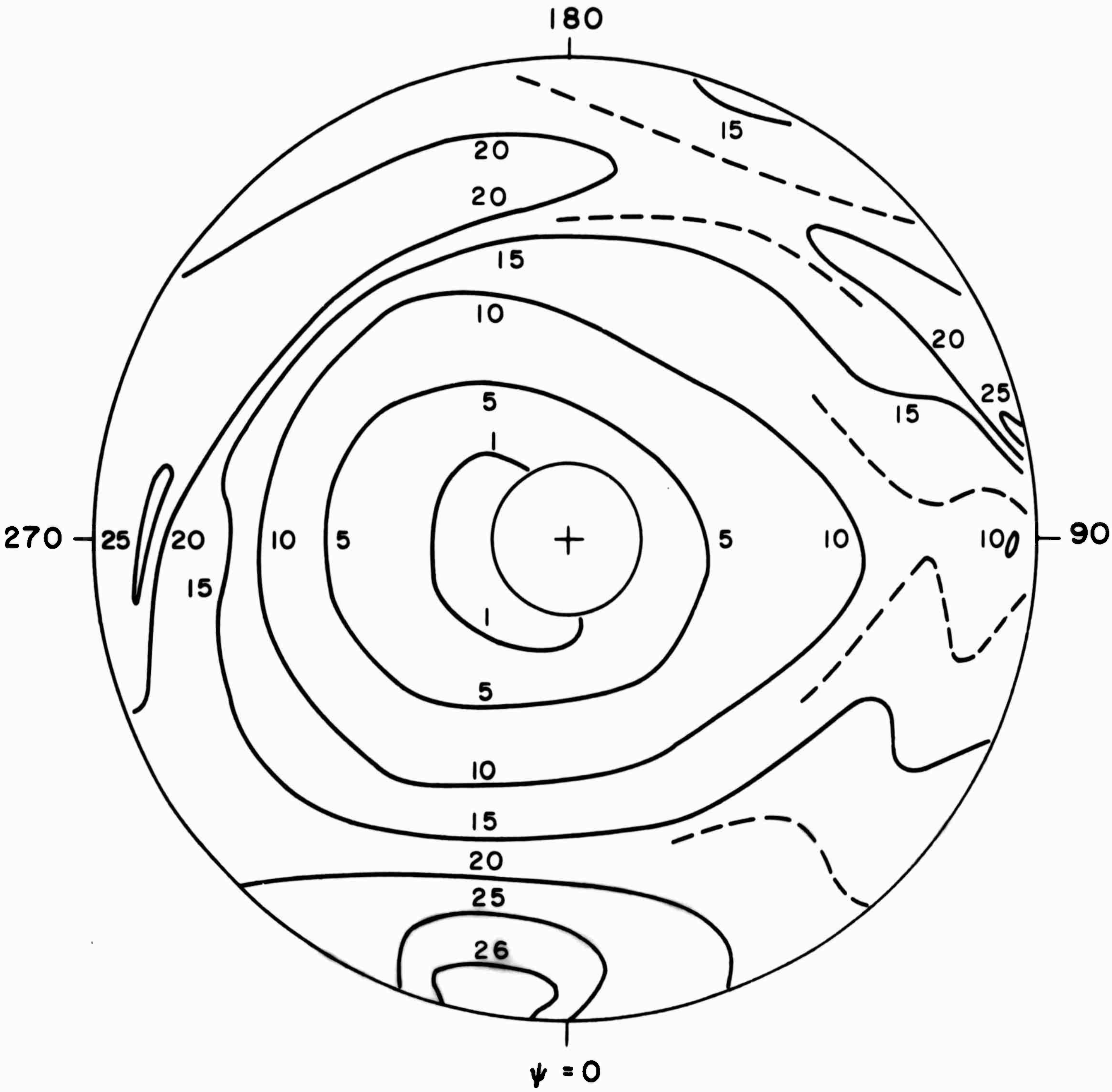


FIGURE 7 POLAR PLOT OF SECTION LIFT FOR FLIGHT No. 7 OF REF. 2 : EXPERIMENTAL RESULTS (LB/ IN)

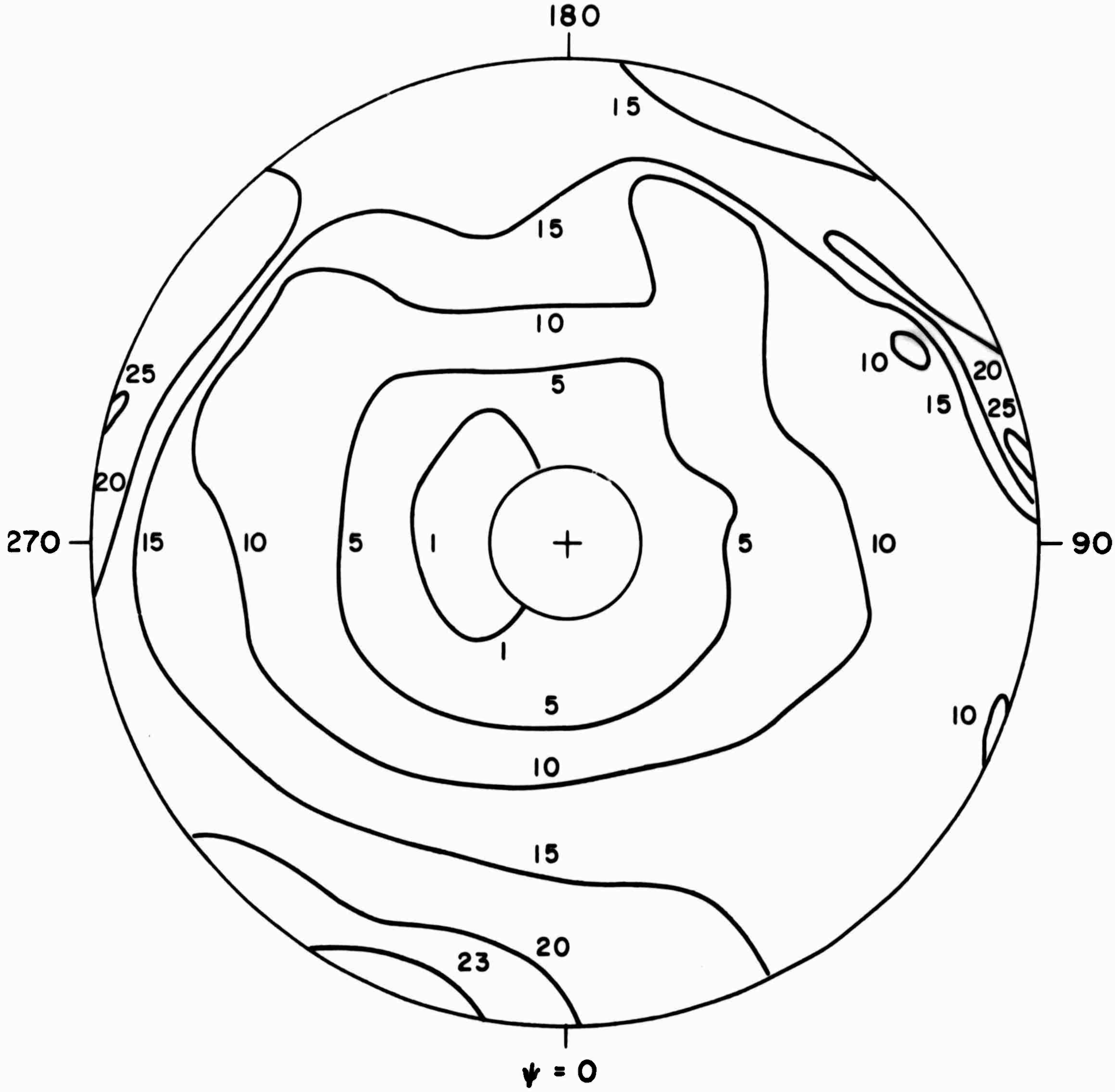


FIGURE 8 LIFTING SURFACE THEORY RESULTS WITH RIGID WAKE (LB/IN)

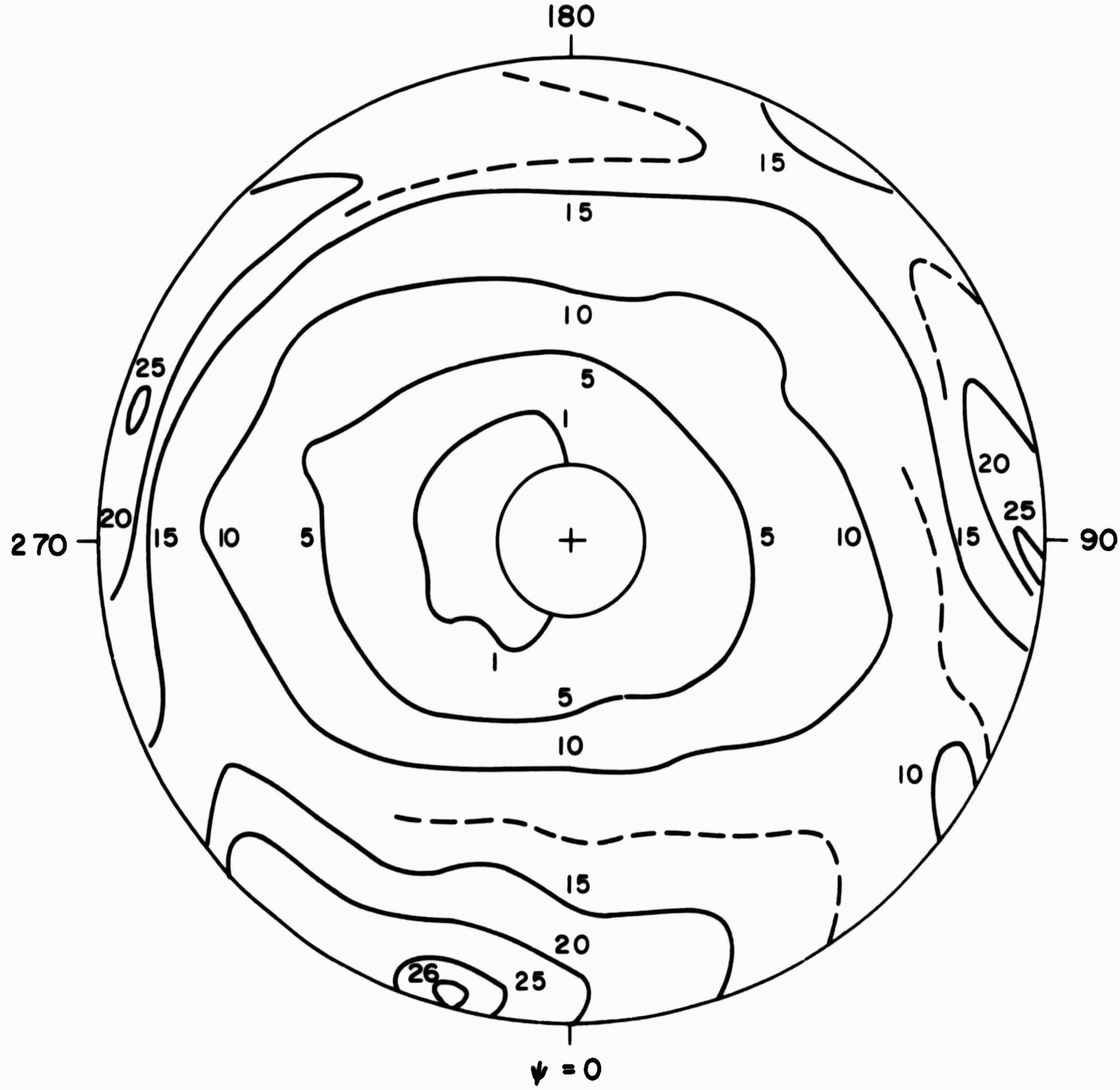


FIGURE 9 LIFTING SURFACE THEORY RESULTS WITH NON-RIGID WAKE (LB/IN)

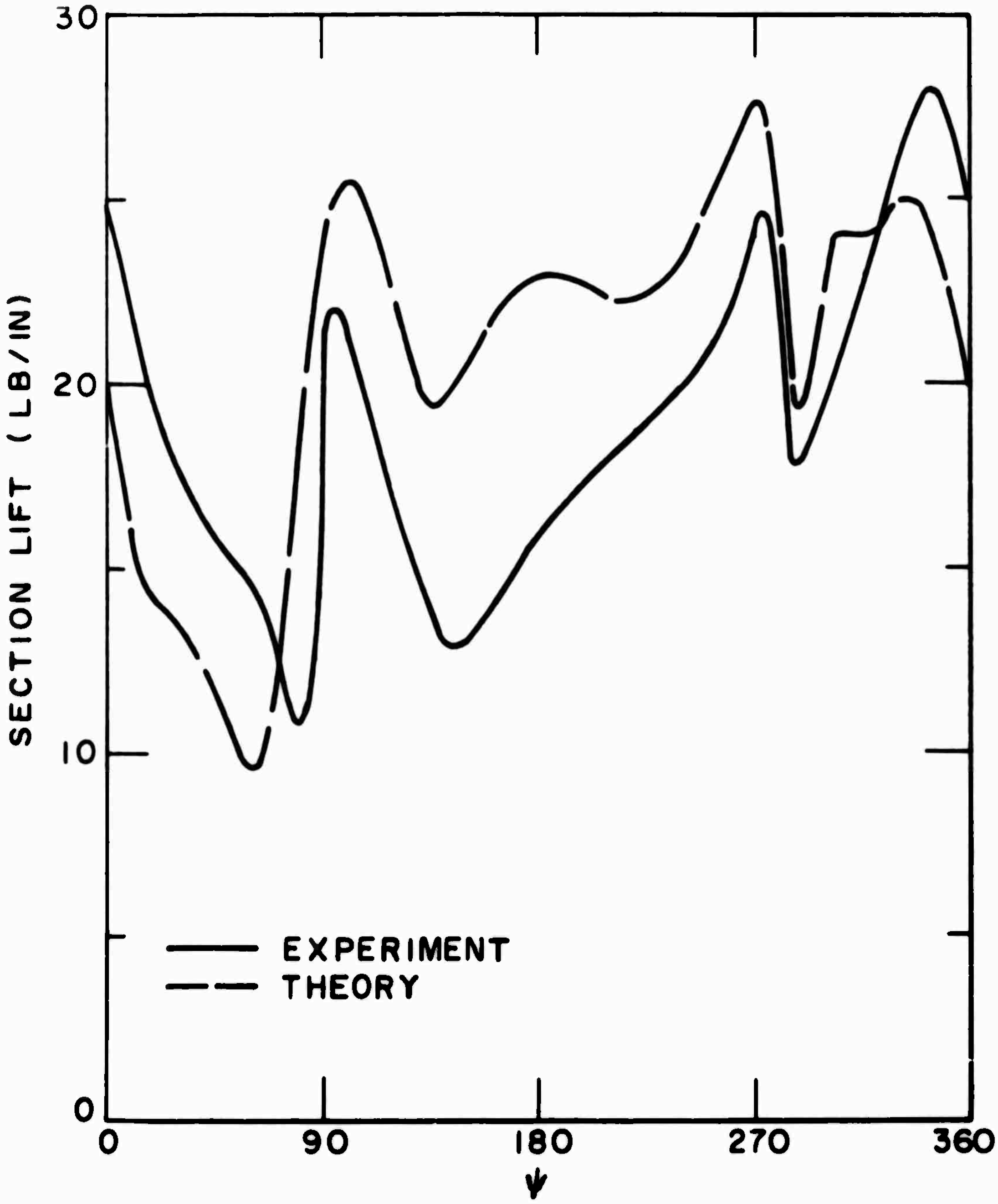


FIGURE 10 COMPARISON OF SECTION LIFT CALCULATED USING LIFTING SURFACE THEORY WITH EXPERIMENTAL RESULTS (FROM REF. 3): $\mu = 0.18$, $\theta° = 13.7°$, $r = .95$

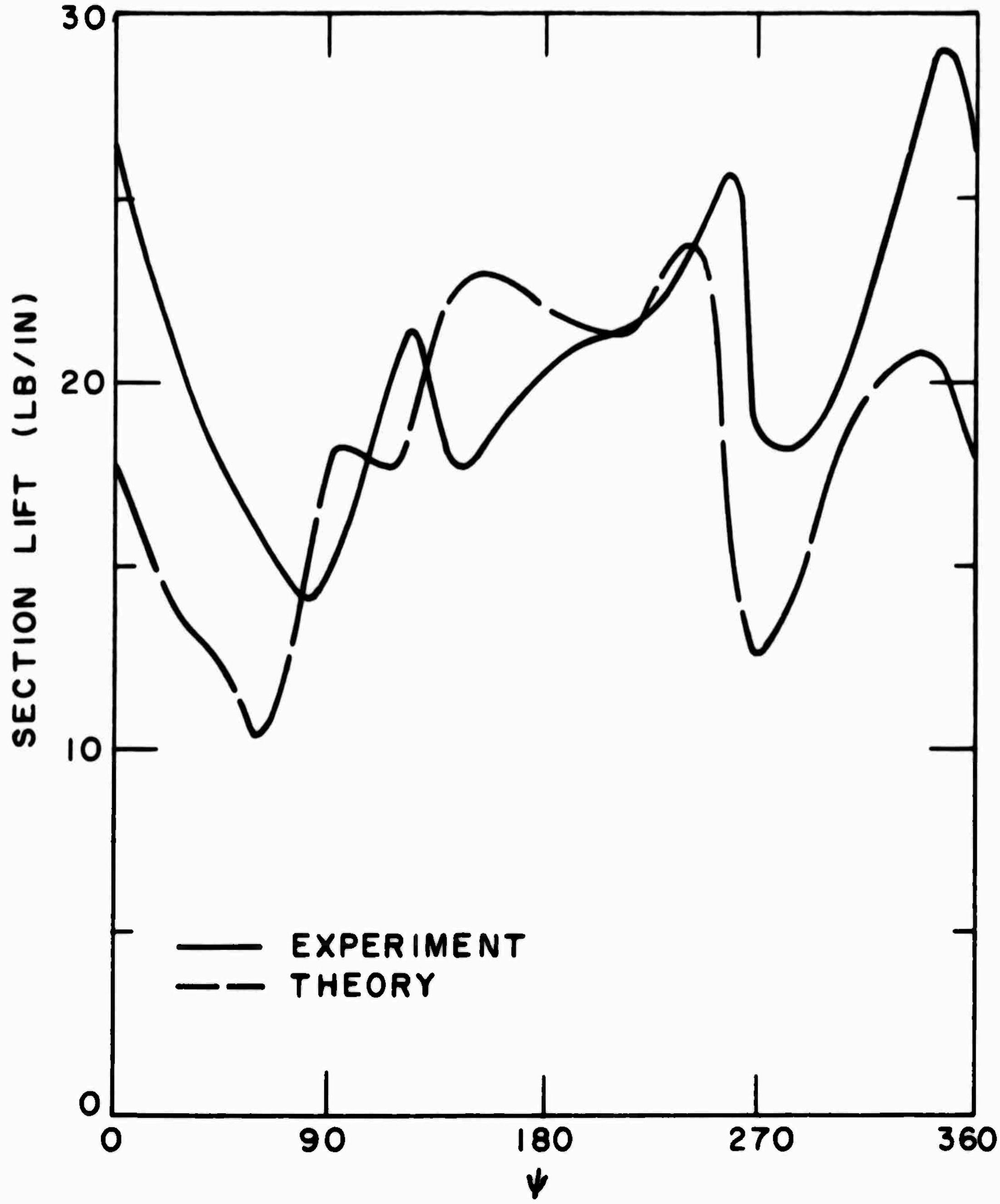


FIGURE 11: r = .85

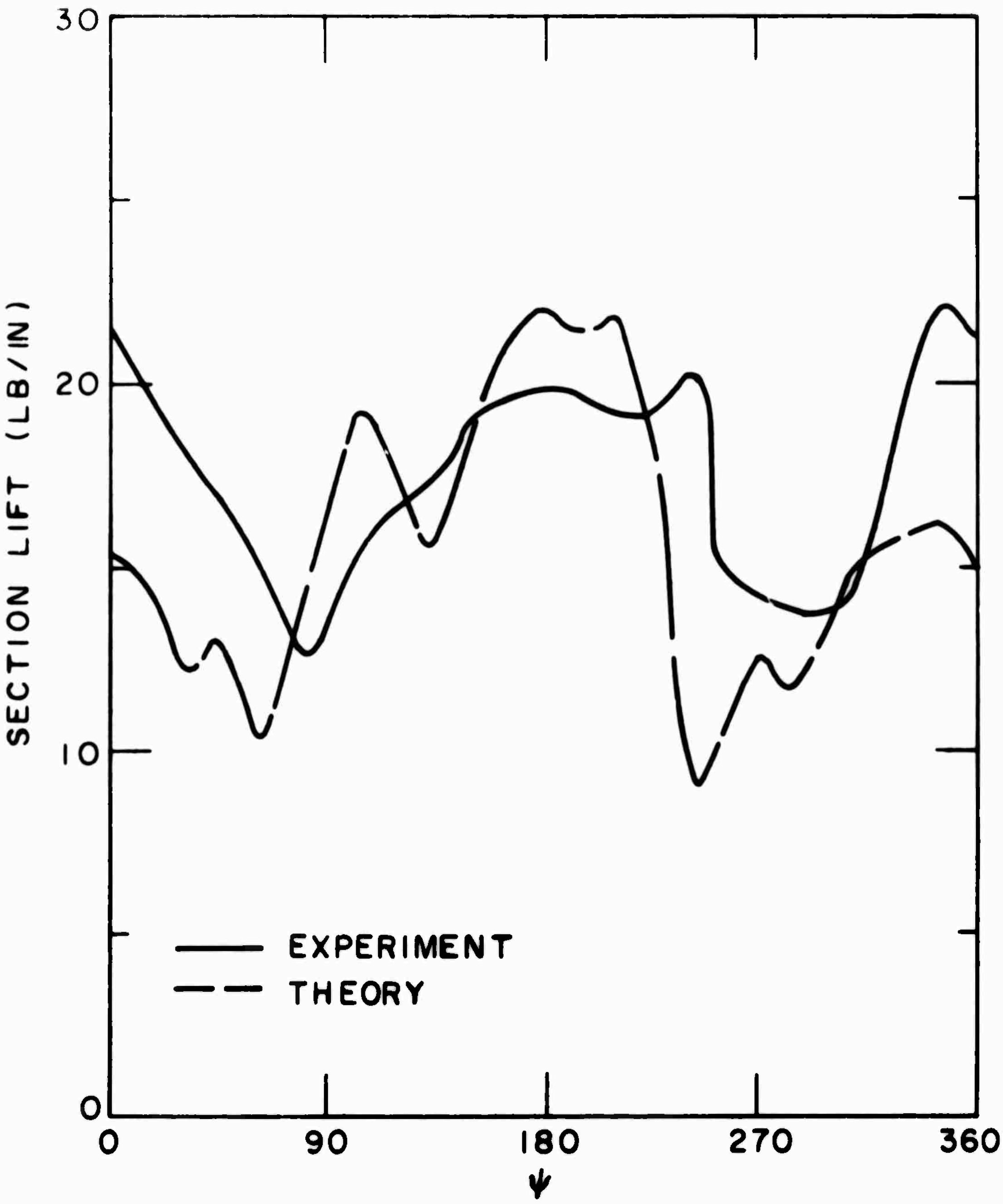


FIGURE 12: r = .75

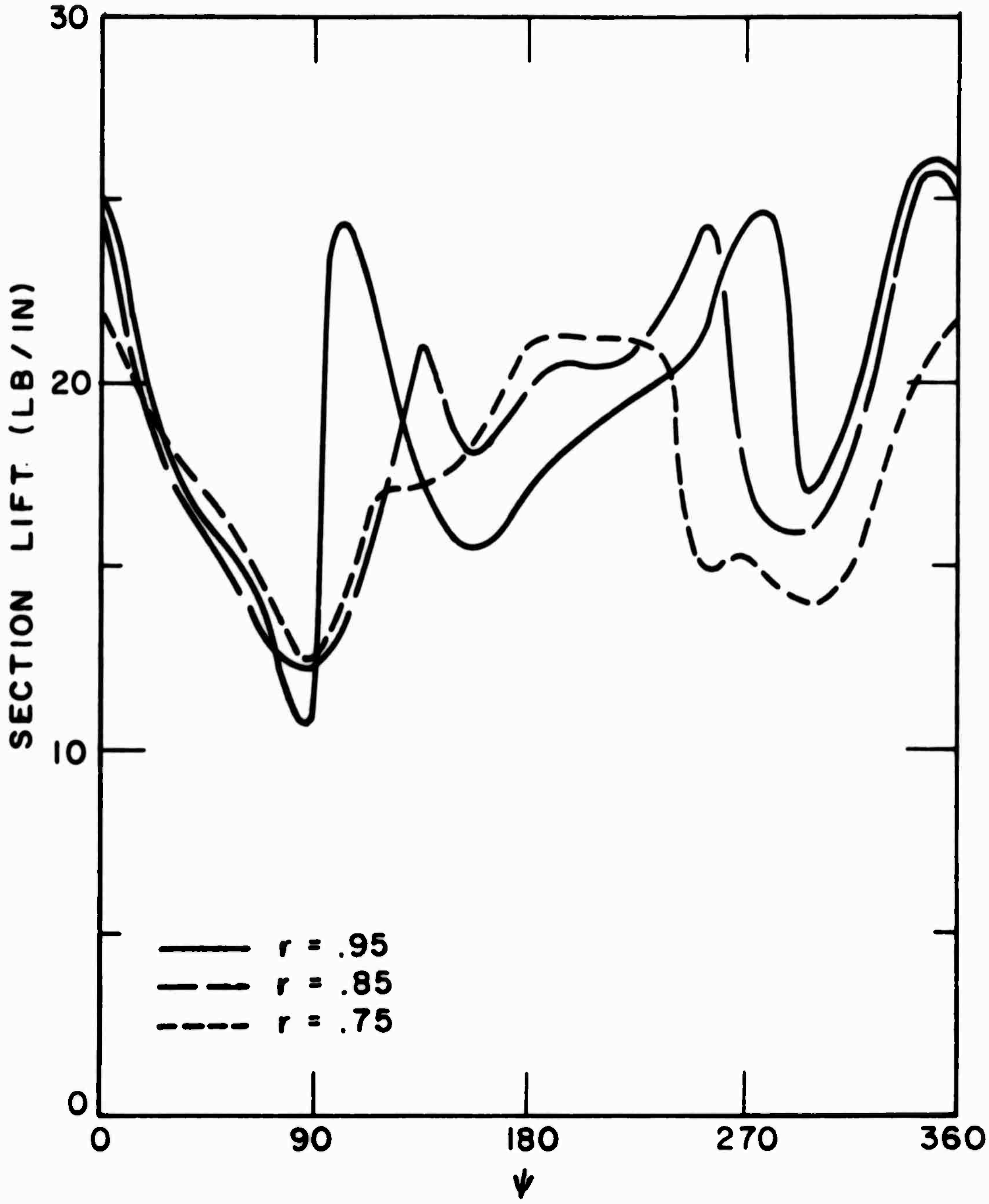


FIGURE 13 EXPERIMENTAL SECTION LIFT (FLIGHT No. 7 OF REF. 2) :
μ = 0.15, $\theta°$ = 12.5°, C_T/σ = 0.089

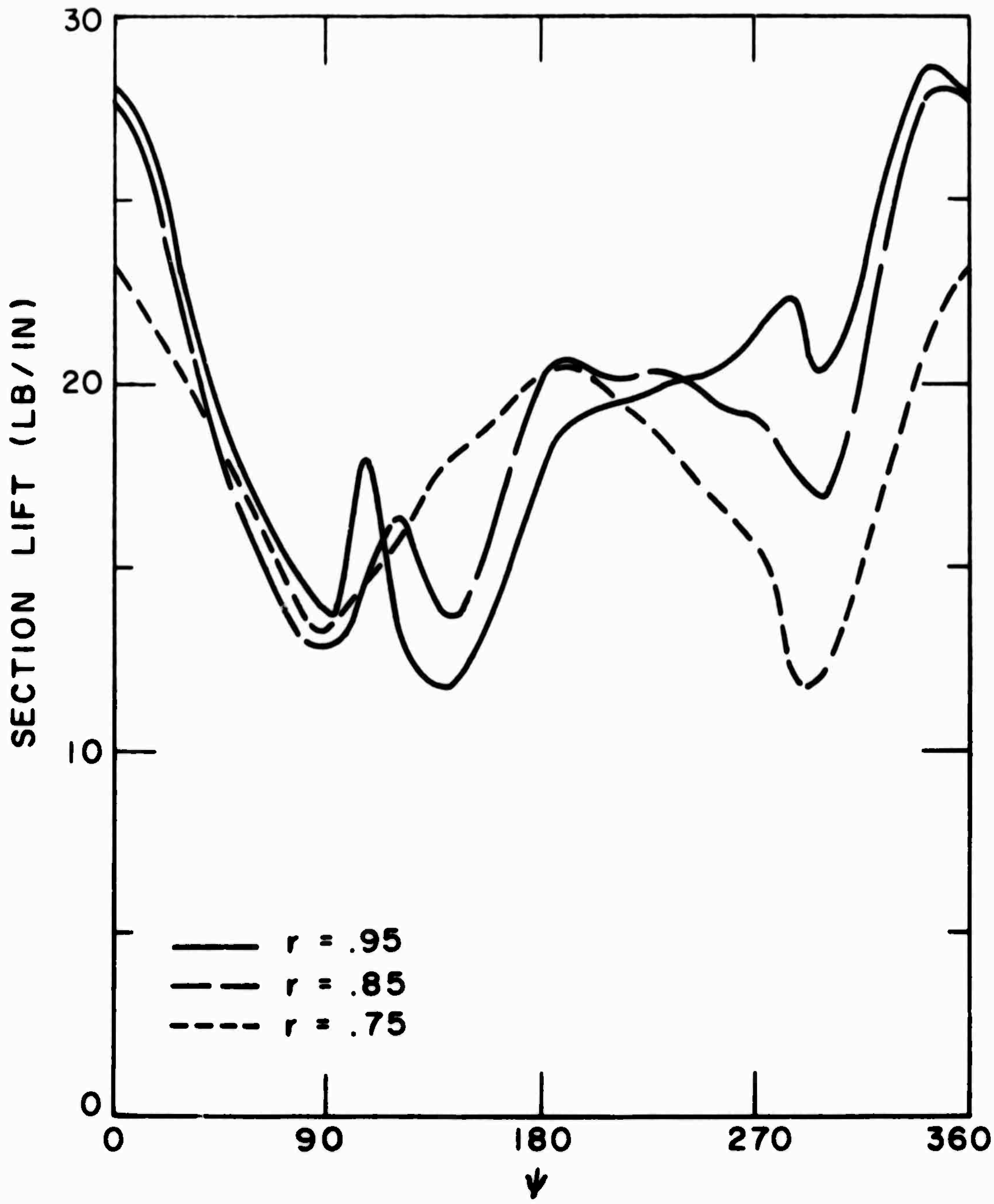


FIGURE 14 EXPERIMENTAL SECTION LIFT (FLIGHT No. 12 OF REF 2): $\mu = 0.25$, $\theta^{\circ} = 13.4^{\circ}$, $C_T/\sigma = 0.091$

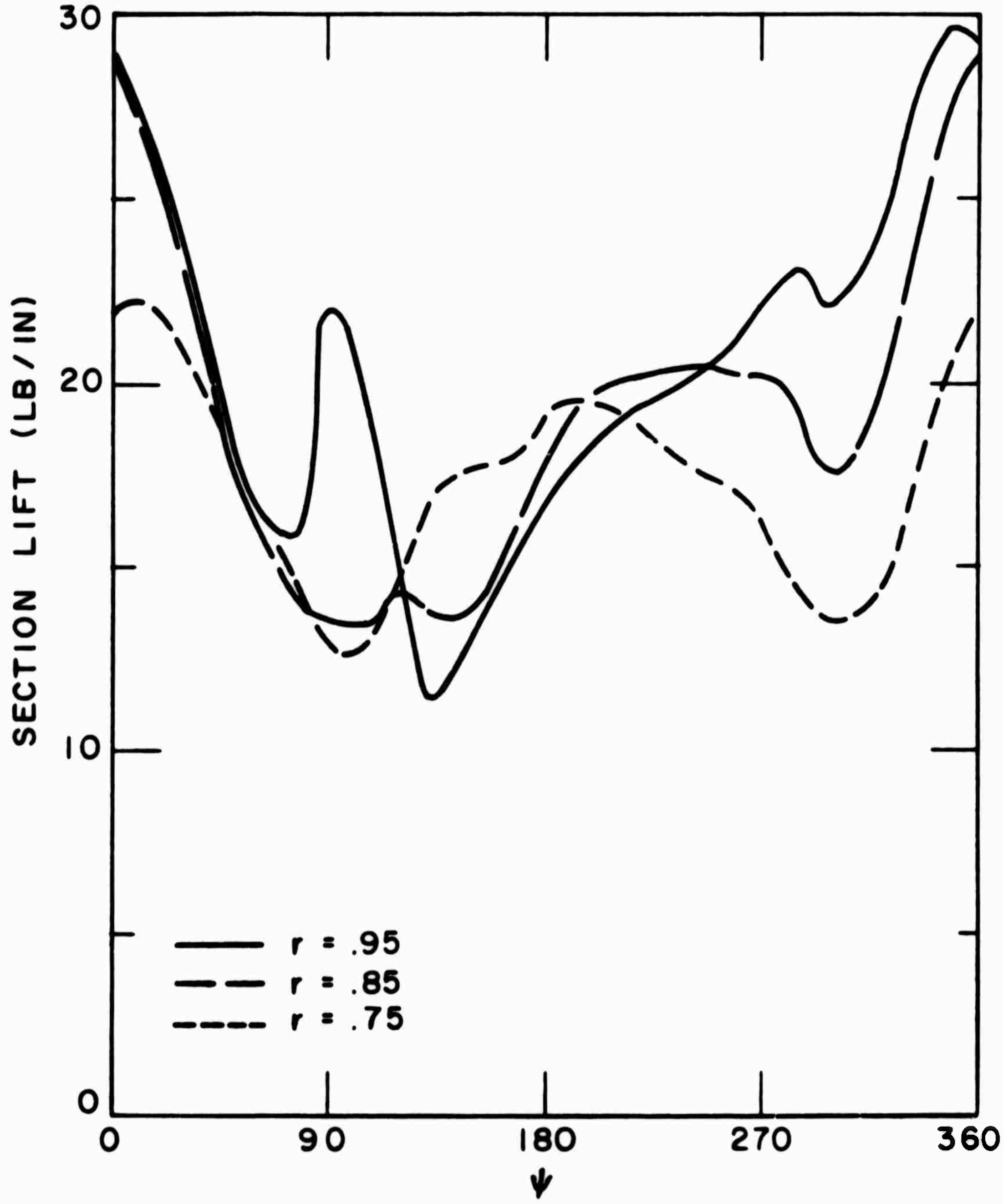


FIGURE 15 EXPERIMENTAL SECTION LIFT (FLIGHT No. 17 OF REF. 2) : $\mu = 0.26$, $\theta° = 12.7°$, $C_T/\sigma = 0.068$

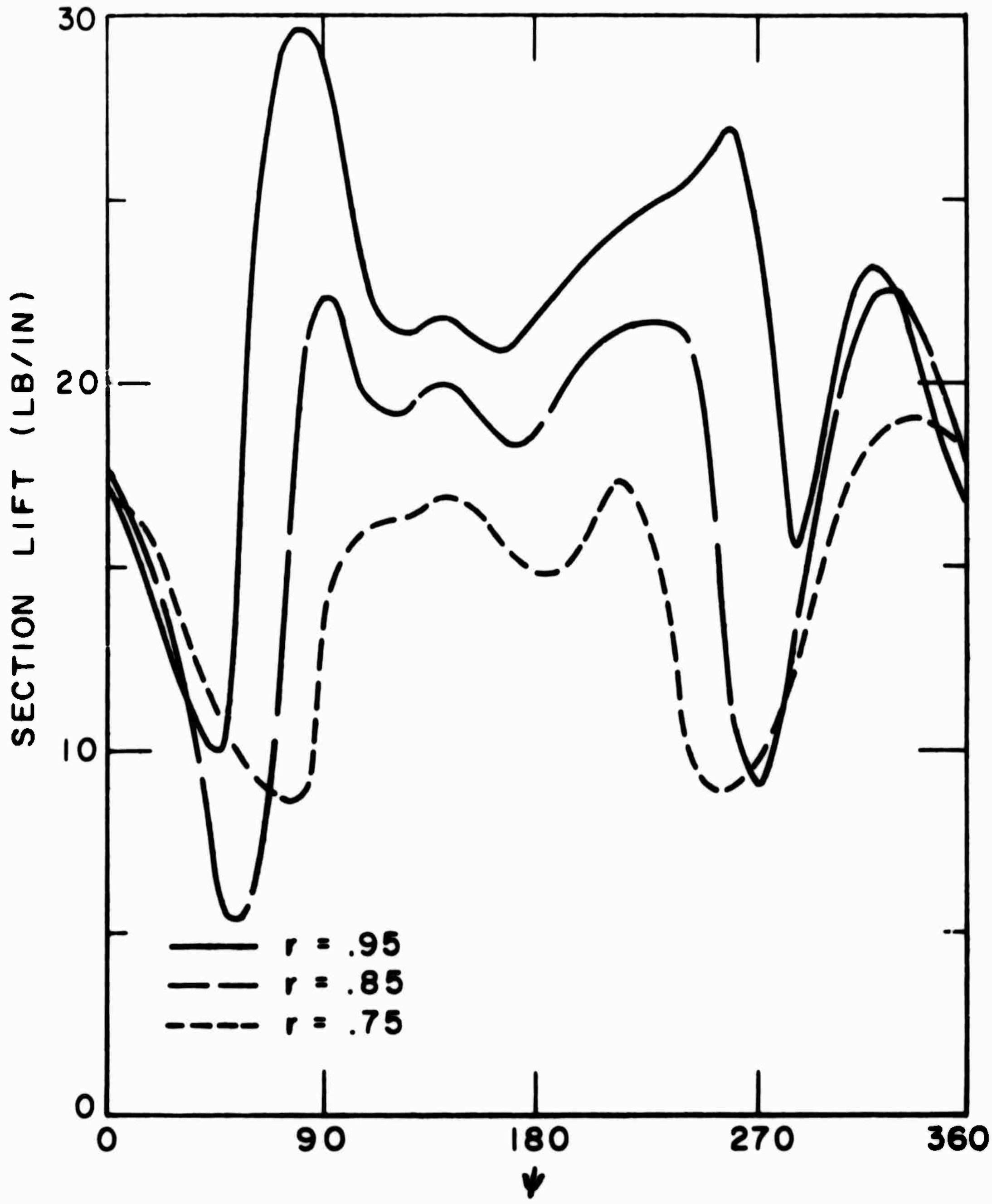


FIGURE 16 EXPERIMENTAL SECTION LIFT (FLIGHT No. 25 OF REF. 2): $\mu = 0.08$, $\theta° = 12.7°$, $C_T/\sigma = 0.072$

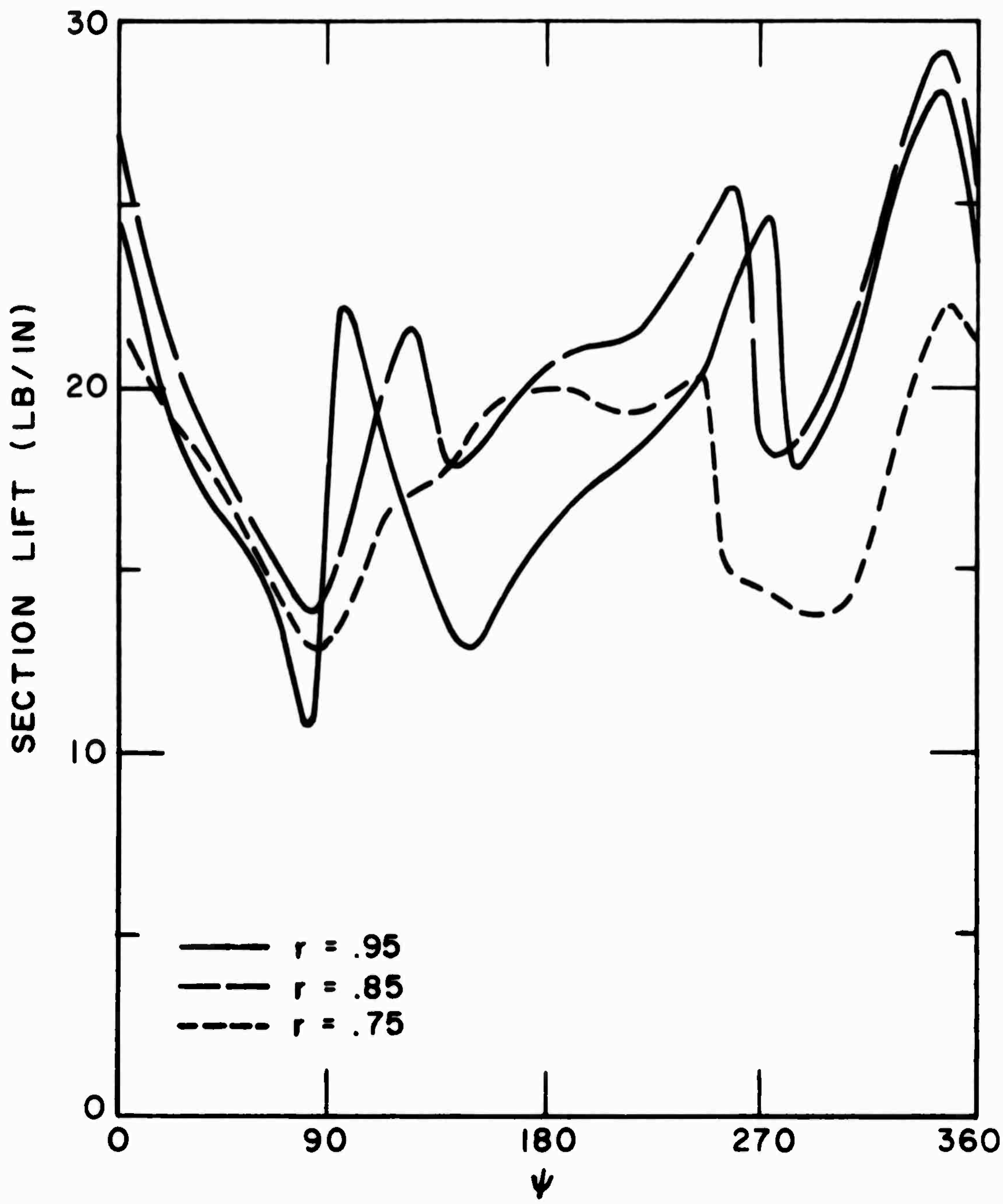


FIGURE 17 EXPERIMENTAL SECTION LIFT (FROM REF. 3): $\mu = 0.18$, $\theta^{\circ} = 13.7^{\circ}$, $C_T/\sigma = 0.089$