AD-A011 135

SUBSONIC FORCE CHARACTERISTICS OF A LOW ASPECT RATIO WING INCORPORATING A SPINNING CYLINDER

David G. Lee

Naval Ship Research and Development center

Prepared for:

Naval Material Command

June 1974

DEPARTMENT OF THE NAVY NAVAL SHIP R&D CENTER

SUBSONIC FORCE CHARACTERISTICS OF A LOW ASPECT RATIO WING INCORPORATING A SPINNING CYLINDER

by

David G. Lee

Approved for Public Release:
Distribution Unlimited

AVIATION AND SURFACE EFFECTS DEPARTMENT

Report ASED-329

June 1974

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

BETHESDA
MARYLAND
20034

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ASED-329	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD-A011 135
4. TITLE (and Subtitle) Subsonic Force Characteristics of a Low Aspect Ratio Wing Incorporating a Spinning Cylinder		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) David G. Lee		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ship Research and Development Center Aviation and Surface Effects Department Bethesda, Maryland 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element #62754N Task Area #ZF4343001 Work Unit 1563-001
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Material Command Washington, D. C. 20360		12. REPORT DATE June 1974
		13. NUMBER OF PAGES 27
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release: distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

PRICES SUBJECT TO CHANGE

18. SUPPLEMENTARY NOTES

This work was performed under NSRDC Project "Improved Control for Advanced Submarines." This task area is funded by NAVMAT as part of the "Direct Laboratory Funded Program".

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cylinder Lift
Low Aspect Ratio Wing
Rotating Cylinder

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The effect of a spinning cylinder on the aerodynamics of a low aspect ratio wing was examined in a subsonic wind tunnel program. Results show little effect with the cylinder in the wing leading edge for a velocity parameter of 5 and flow angles relative to the wing up to 16 degrees. However, similar flow conditions with the cylinder relocated to the trailing edge, produce a doubling in the force coefficient. An undeflected flap added to the trailing edge cylinder model nullifies the cylinder's effect. With the flap deflected 30 degrees, large increases in the force coefficient occurred at moderate sideslip angles.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

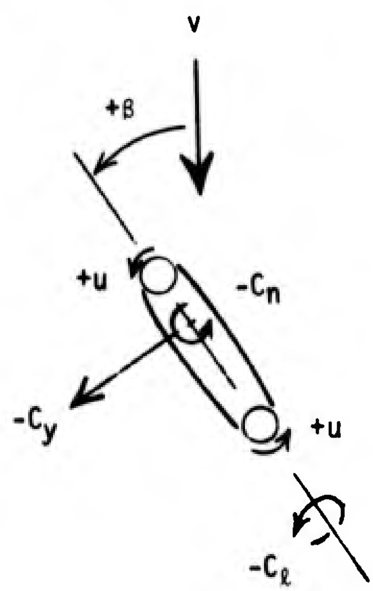
TABLE OF CONTENTS

LIST OF FIGURES

NOMENCLATURE

The results in this report are presented about the stability axes with the origin at 25 percent of the root chord. This point lies on the plane created by the intersection of the wing model with the splitter base plate and is also the moment reference point.

b	Wing span, 3.6 ft
c	Wing chord, 6.0 ft
C_y	Side force coefficient, $\frac{\text{side force}}{qs}$
C_ℓ	Rolling moment coefficient, $\frac{\text{rolling moment}}{qsb}$
C_n	Yawing moment coefficient, $\frac{\text{yawing moment}}{qsb}$
q	Dynamic pressure, lbs/ft^2
s	Wing area, 21.6 ft^2
u	Cylinder peripheral velocity, ft/sec
v	Free stream velocity, ft/sec
β	Angle of sideslip, degrees
δ_f	Flap angle, degrees
u/v	Velocity parameter
CROLLS	Computer plot notation for C_ℓ
CSIDES	Computer plot notation for C_y
CYAWS	Computer plot notation for C_n



SUMMARY

The effect of a spinning cylinder on the subsonic force characteristics of a low aspect ratio wing was examined in an experimental wind tunnel program. The results show little or no effect from the cylinder when mounted in the leading edge of the wing for a velocity parameter of nearly 5 and for flow angles relative to the wing up to 16 degrees. However, for similar flow conditions, with the spinning cylinder relocated to the wing trailing edge position, a doubling of the force coefficient results. The addition of an undeflected flap to the wing trailing edge cylinder configuration largely nullifies the effect of the spinning cylinder. With the flap deflected 30 degrees, significant increases can be produced in the force coefficient at moderate sideslip angles.

INTRODUCTION

A rotating cylinder moving through a fluid such that its body axis of rotation is at an angle to the direction of motion will experience a force perpendicular to the plane created by the flight path and axis of rotation. This effect is the Magnus phenomenon discovered over a hundred years ago. A discussion of the phenomenon and some of the available literature is summarized in Reference 1. The more recent interest in the Magnus effect has been concerned with force argumentation using rotating cylinders in conjunction with lifting surfaces. The resulting high lift device has been proposed as an attractive means of increasing the manuverability of certain ships and aircraft (see References 2, 3, and 4). At the Naval Ship Research and Development Center (NSRDC) interest in the potential increase in control power for both surface and submerged ships with a rotating cylinder - lifting surface device resulted in the establishment of an exploratory wind tunnel program to gather basic design data on the force characteristics of lifting surfaces with a rotating cylinder. A lifting surface, in this case a control surface represented by a low aspect ratio wing, was examined in conjunction with a rotating cylinder mounted at several different locations. This report presents the results of that program.

APPARATUS

The exploratory wind tunnel program was conducted in the North Wind Tunnel of the 8- by 10-foot Subsonic Facilities at NSRDC. This wind tunnel is of the single return, closed circuit type capable of continuous operation at atmospheric pressure. The test section is rectangular in shape and is capable of achieving dynamic pressures up to 80 lbs/ft^2. For this series of investigations, the wind tunnel model was mounted in the test section using strut system #8. This strut system is located beneath the tunnel floor and supports the model using a vertical strut which in turn transfers the air loads to an external Toledo mechanical balance system. The Toledo balance system recorded six component force and moment data for various tunnel conditions and model configurations. The majority of these data were recorded at dynamic pressures of 10 and 20 lbs/ft^2 with some limited data points at 40 and 60 lbs/ft^2. Buoyancy, wall and blockage corrections were applied to the reduced data according to the methods outlined in Reference 5 and presented in the stability axis. During the investigation, the angle of sideslip of the model was varied over the range from -4 to +16 degrees in 2 degree increments. Regardless of configuration, all data reduced to coefficient form used the same reference chord, area and moment point as defined in the Nomenclature.

The wind tunnel model was an existing low aspect ratio wing modified to accept a rotating cylinder in the leading or trailing edge position. The basic wooden model was modified in a manner which allowed for either leading or trailing edge lines and dimensions to be retained when the cylinder was installed in the other of the two positions. This was accomplished by retaining the original portions of the model leading and trailing edge which are removed for installation of the rotating cylinder. Without installation of the cylinder, the model is an untapered, low aspect ratio wing with a symmetrical airfoil section. The airfoil section is modified such that forward of the the maximum thickness it is a standard NACA four digit section while being an elliptical - parabolic - hyperbola section aft of the maximum thickness point. Major dimensions of the airfoil without the cylinder installed is shown in Figure 1. The model has a maximum thickness to chord ratio of 18.34 percent and is located at 34.72 percent of the chord.

Additional details and dimensions of the leading and trailing edge cylinder models are shown in Figure 2.

The cylinder used in the leading and trailing edge position was constructed of solid aluminum with a diameter of 6.38 inches and a length of 42.57 inches. The cylinder is driven by a 13.5 horsepower, variable frequency electric motor. The flap used in conjunction with the trailing edge cylinder has a triangular cross-section. The flap has a sharp trailing edge with a total angle of 18 degrees. Details of the cylinder in the leading and trailing edge positions with the trailing edge flap installed are shown in Figure 3. In the leading edge position, the gap between the cylinder surface and the wing had an average value of 0.02 inches. With the cylinder in the trailing edge position, the average gap was 0.05 inches. When the flap is installed behind the trailing edge cylinder, the gap between the cylinder and the flap had an average value of 0.10 inches. Within the constraints of the program and model, these gap dimensions are considered the most realistic values which can be obtained for this investigation.

DISCUSSION

As the low aspect ratio wing model was mounted in a vertical position in the wind tunnel test section, the effects of the spinning cylinder on the wing were evaluated by examining the lateral force characteristics. Consequently only the side force, rolling moment and yawing moment data are presented in this report.

Figures 4, 5 and 6 present the lateral force coefficients for the model with the cylinder in the leading edge position. The data is presented as a function of sideslip angle for various values of the velocity parameter, U/V (cylinder peripheral to free stream velocity ratio). The rotating cylinder has little or no effect on the moment and force coefficients of the wing. At the higher values of sideslip angles and velocity ratios, there is about a 10 percent increase in the side force due to cylinder rotation. The side force coefficient is presented again in Figure 7; this time as a function of the velocity parameter for various values of dynamic pressure. After initial cylinder start up, a velocity ratio greater than 4 was required before any effect was seen on the side force. Reversing the cylinder's direction of rotation so that the surface of the cylinder advancing into the wind is on the leeward side of the wing with increasing sideslip angle produced the results shown in Figure 8. At the maximum angle of sideslip investigated, 16 degrees, a velocity parameter of 3 or more was needed to initiate stall characteristics on the wing's force coefficient. It is apparent from Figures 6, 7 and 8 that the rotating cylinder in the leading edge position has little influence on the flow over the low aspect ratio wing used in this investigation.

Figures 9, 10 and 11 show the results when the spinning cylinder is located in the trailing edge position of the wing. A definite effect is produced by the cylinder on the lateral characteristics of the wing. An immediate increase results in the side force coefficient which is a direct function of the velocity parameter. Figure 11 shows that with a velocity ratio of 5, the rotating cylinder is capable of doubling the side force of the wing at 16 degrees of sideslip.

The installation of a flap behind the trailing edge cylinder configuration produced the results shown in Figures 12, 13, and 14. The cylinder essentially becomes located in a mid-chord position. With a flap deflection of zero degrees, little or no effect is produced by the rotating cylinder on the force characteristics of the wing - cylinder - flap combination. Increasing the flap deflection to 30 degrees however produced the results shown in Figures 15, 16 and 17. The cylinder's effect on the flow is greatest at the lower angles of sideslip, with a decrease in the cylinder's effectiveness resulting from an increase in the sideslip angle, as can be seen from the side force coefficient shown in Figure 17. For a given sideslip angle, increasing the velocity parameter produced an increase in side force; however, with an increasing velocity parameter the rate of increase in side force decreases noticeably.

The rotating cylinder appears much more effective in keeping the flow attached over the trailing edge of the airfoil and moving the rear stagnation point forward on the bottom of the airfoil (cylinder trailing edge position) as opposed to moving the forward stagnation point rearward on the bottom of the airfoil and energizing the boundary layer over the surface of the airfoil (cylinder leading edge position).

CONCLUSIONS

The location of a spinning cylinder in conjunction with a low aspect ratio wing in subsonic flow produced the following results:

1. There is little or no effect on the force and moment characteristics with a leading edge location.

2. With a trailing edge location and a velocity parameter of 5, the rotating cylinder is capable of doubling the side force normally expected at 16 degrees of sideslip.

3. The installation of a flap behind the cylinder in the trailing edge position (mid-chord cylinder location) results in a configuration which gains little or no benefits from the rotating cylinder. However, with a 30 degree angle flap deflection, significant increases in side force can be obtained at the lower ranges of sideslip angles.

REFERENCES

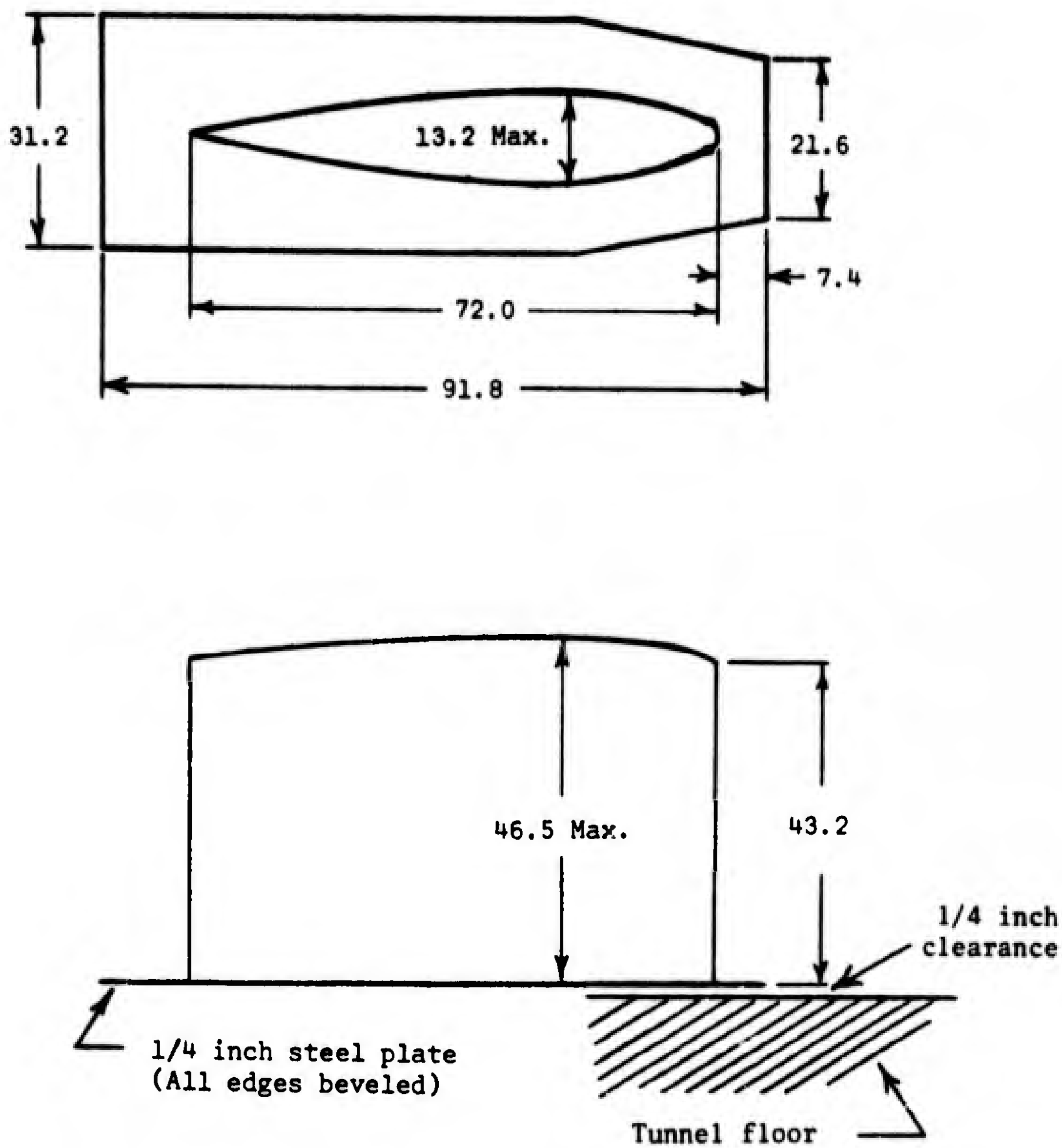
1. Swanson, W. M. The Magnus Effect: A Summary of Investigations to Date. Journal of Basic Engineering, Transactions of the ASME, Sept. 1961. pp. 461-470.

2. Brooks, J. D. The Effect of a Rotating Cylinder at the Leading and Trailing Edges of a Hydrofoil. China Lake, April 1963. (Naval Ordnance Test Station TP-3036)

3. Steele, B. N. and M. H. Harding. The Application of Rotating Cylinders to Ship Maneuvering. London, Dec 1970. (National Physical Laboratory Ship Report 148)

4. Weiberg, J. A. and B. Gamse. Large-Scale Wind-Tunnel Tests of an Airplane Model with Two Propellers and Rotating Cylinders. Wash., March 1968. (NASA TN D-4489)

5. Pope, A. and J. J. Harper. Low-Speed Wind Tunnel Testing. New York, 1966. Wiley and Sons, Inc.



Note: All dimensions in inches

Figure 1 - General Dimensions of the Basic Wind Tunnel Model

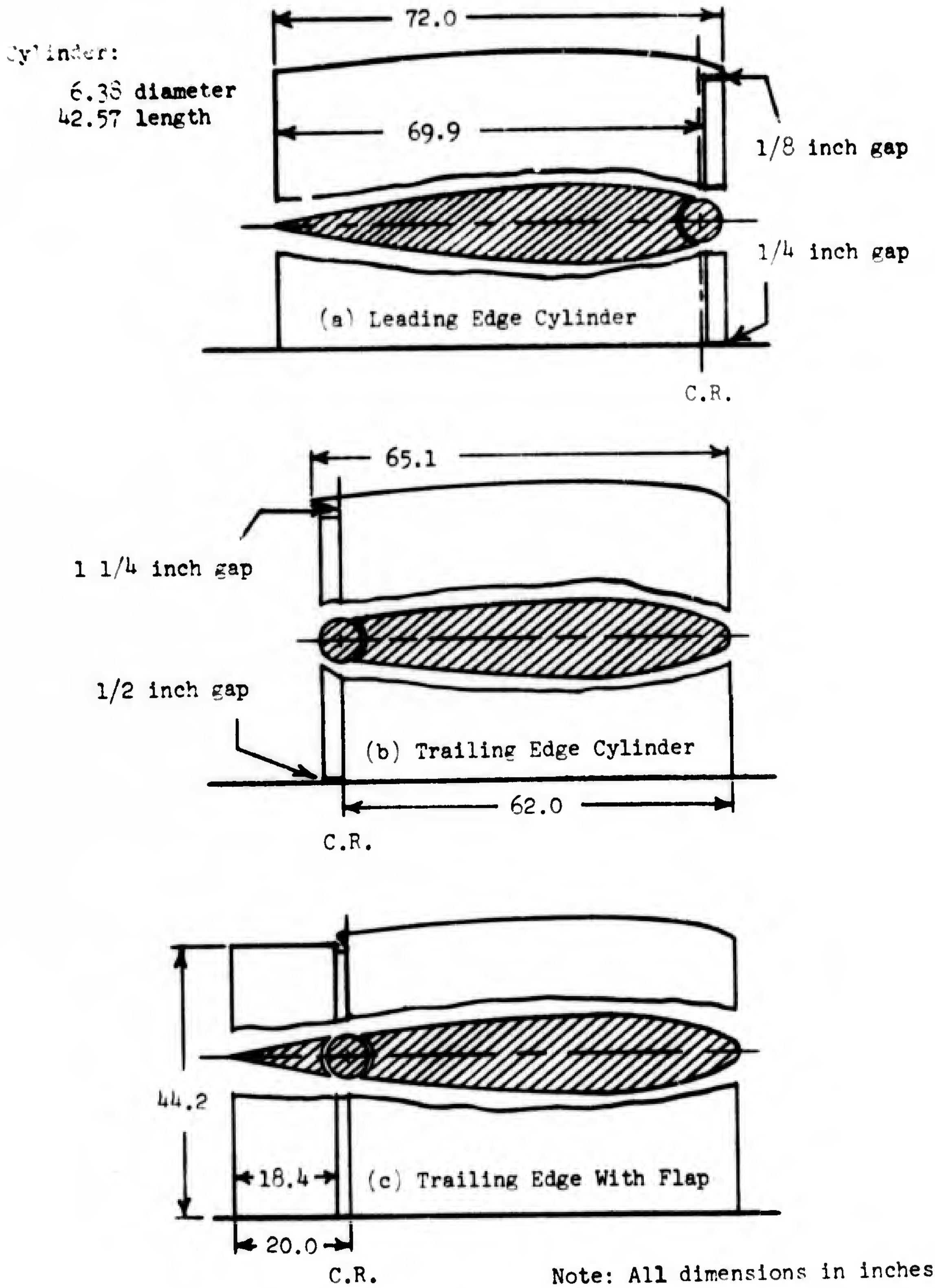
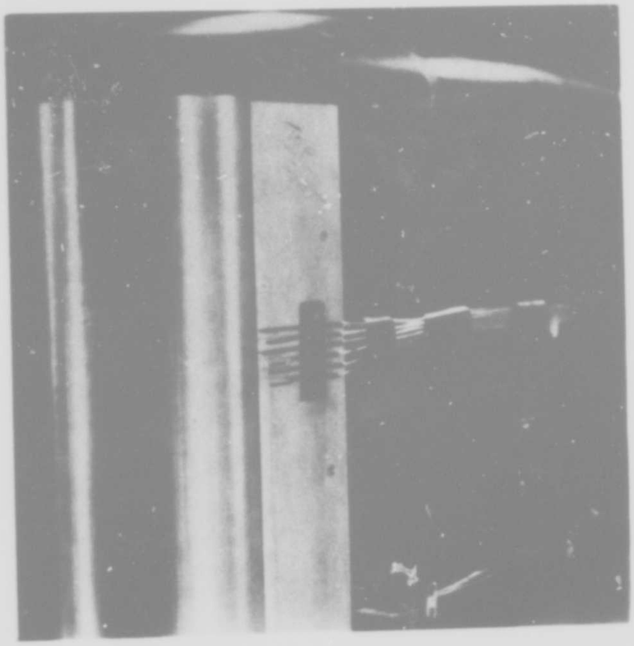
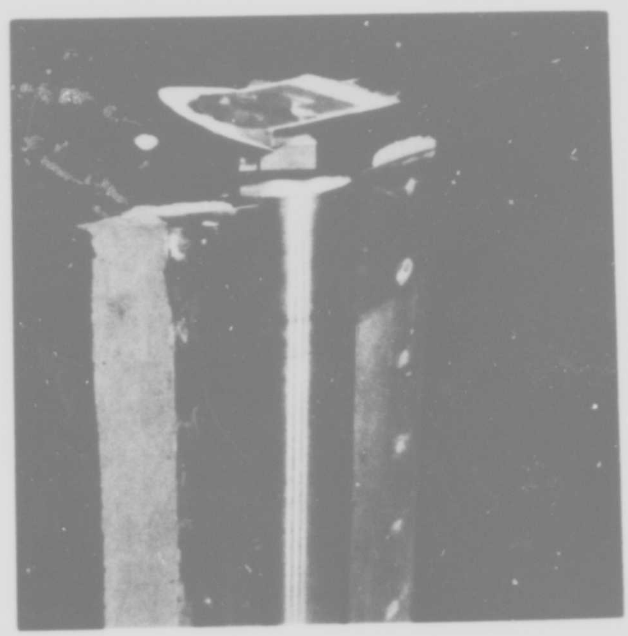


Figure 2 - General Dimensions of Rotating Cylinder Models



Leading Edge Position (Pressure Probe Installed)



Trailing Edge Position (Flap Installed)

Figure 3 - Cylinder Installation Details

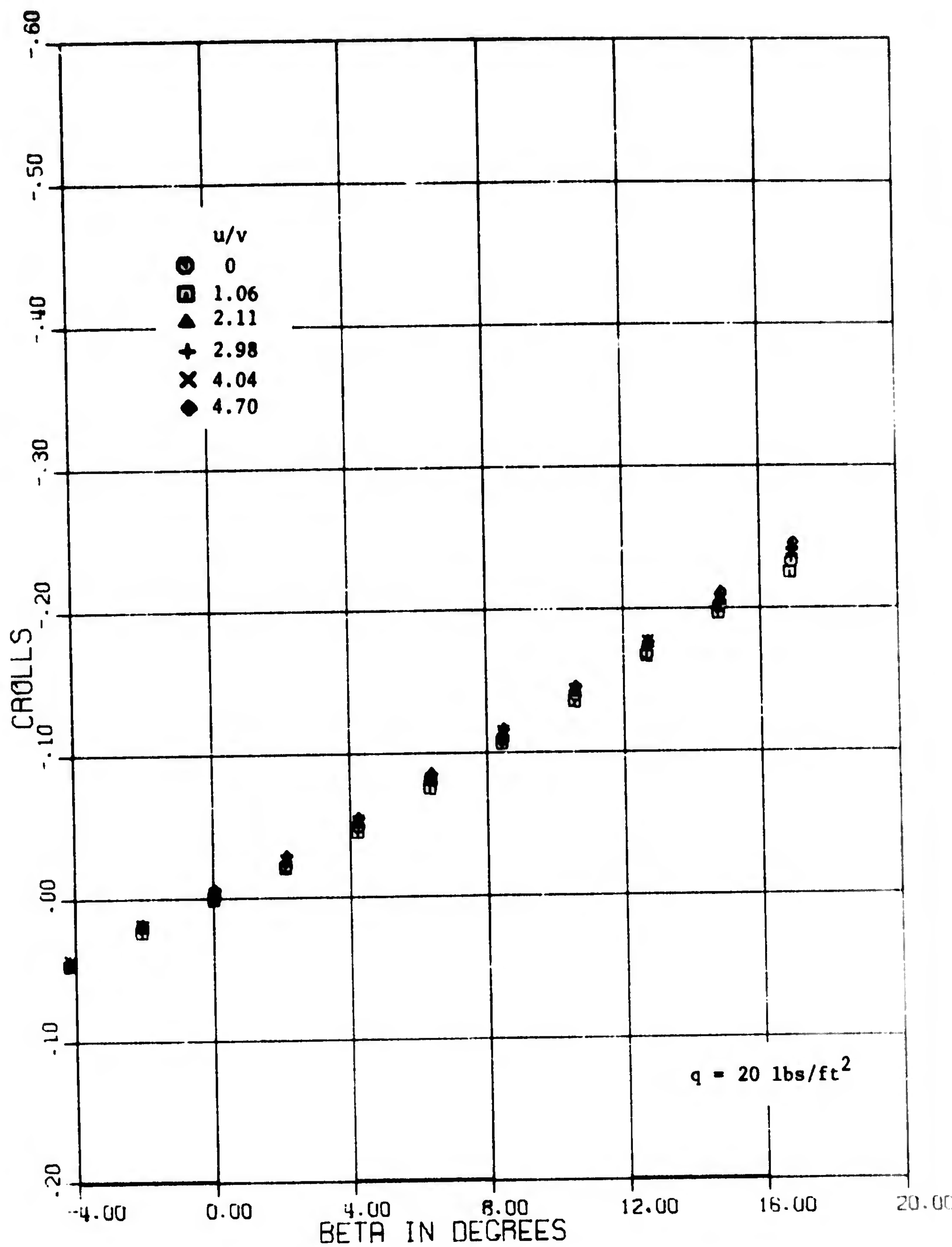


Figure 4 - Rolling Moment for Leading Edge Cylinder Model

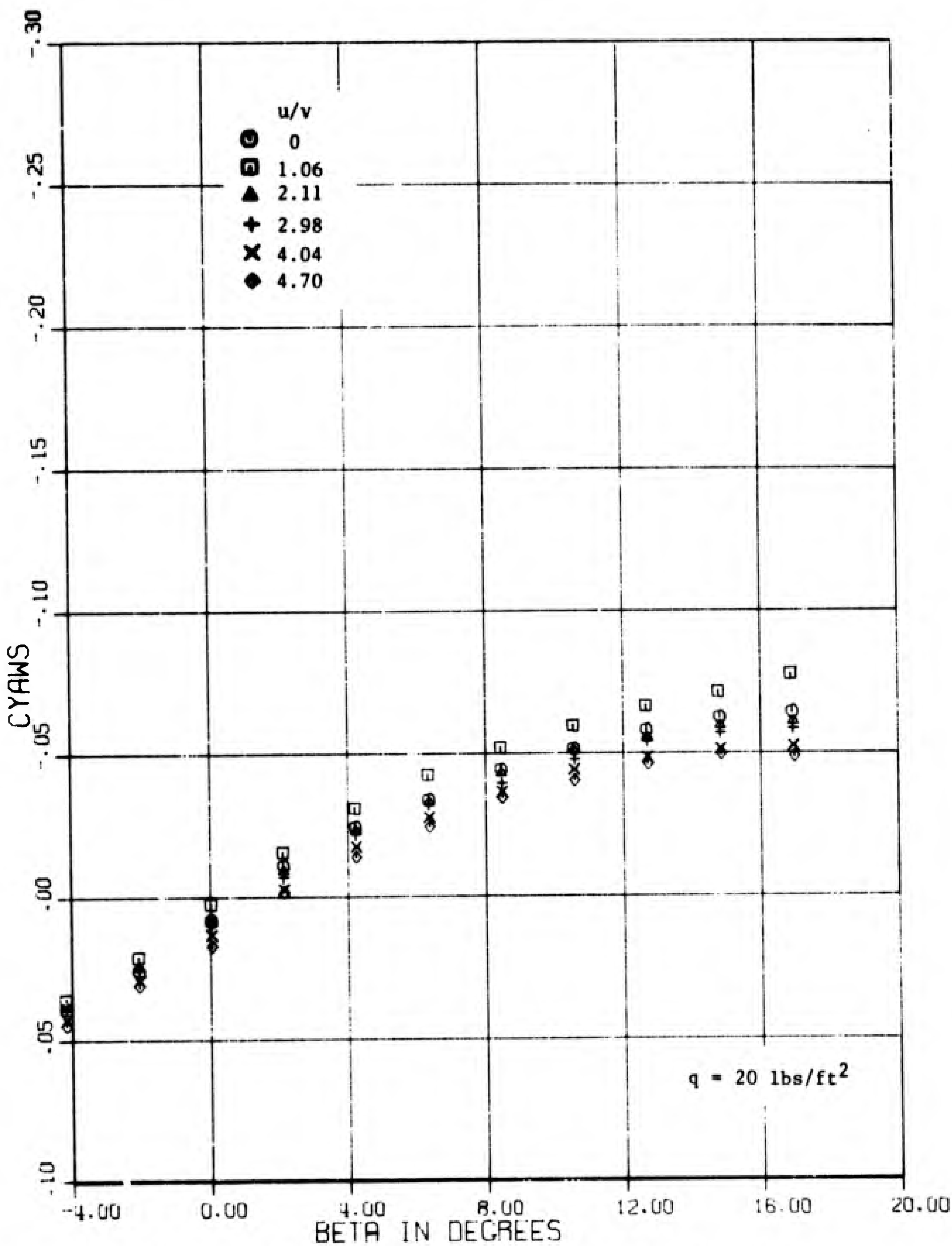


Figure 5 - Yawing Moment for Leading Edge Cylinder Model

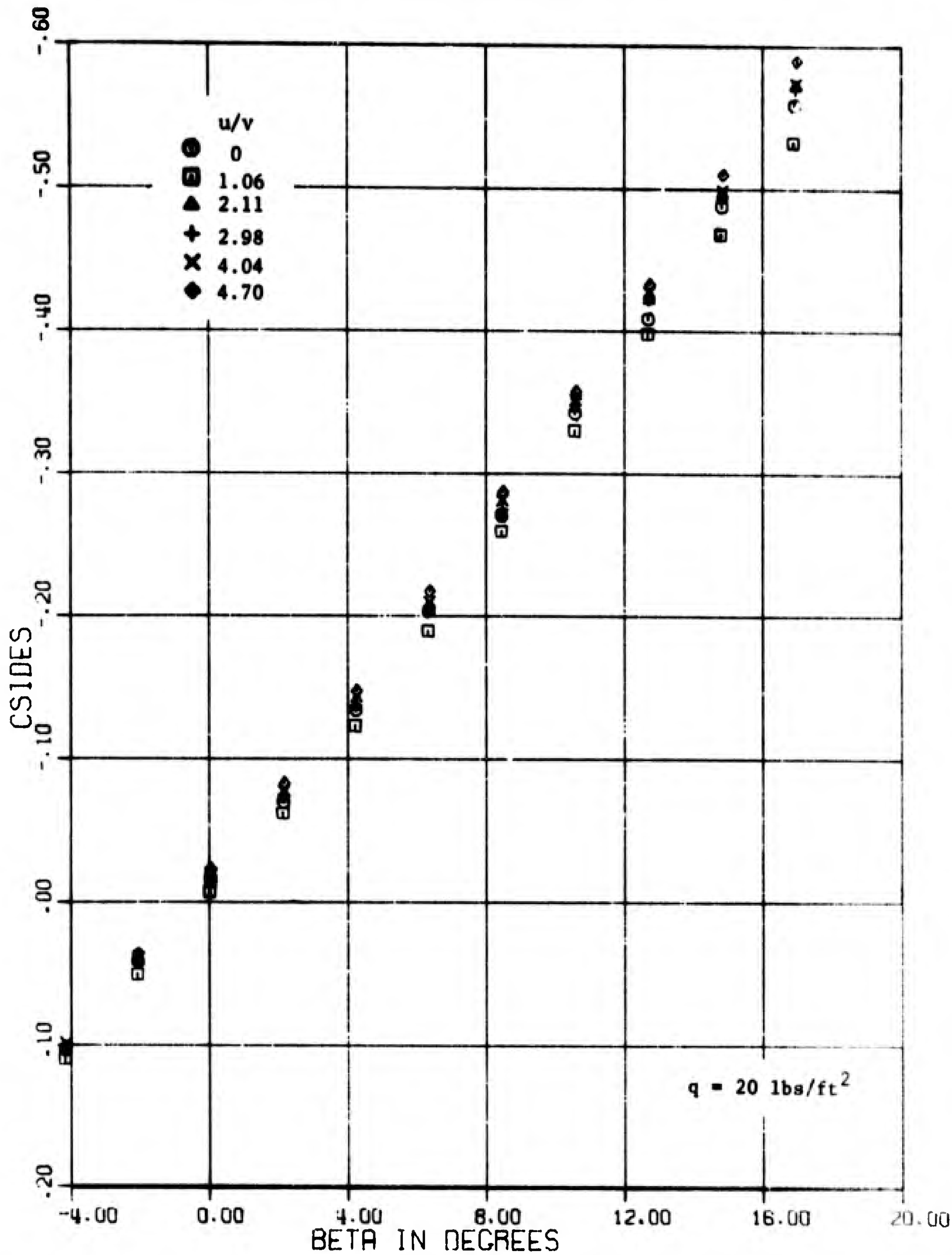


Figure 6 - Side Force for Leading Edge Cylinder Model

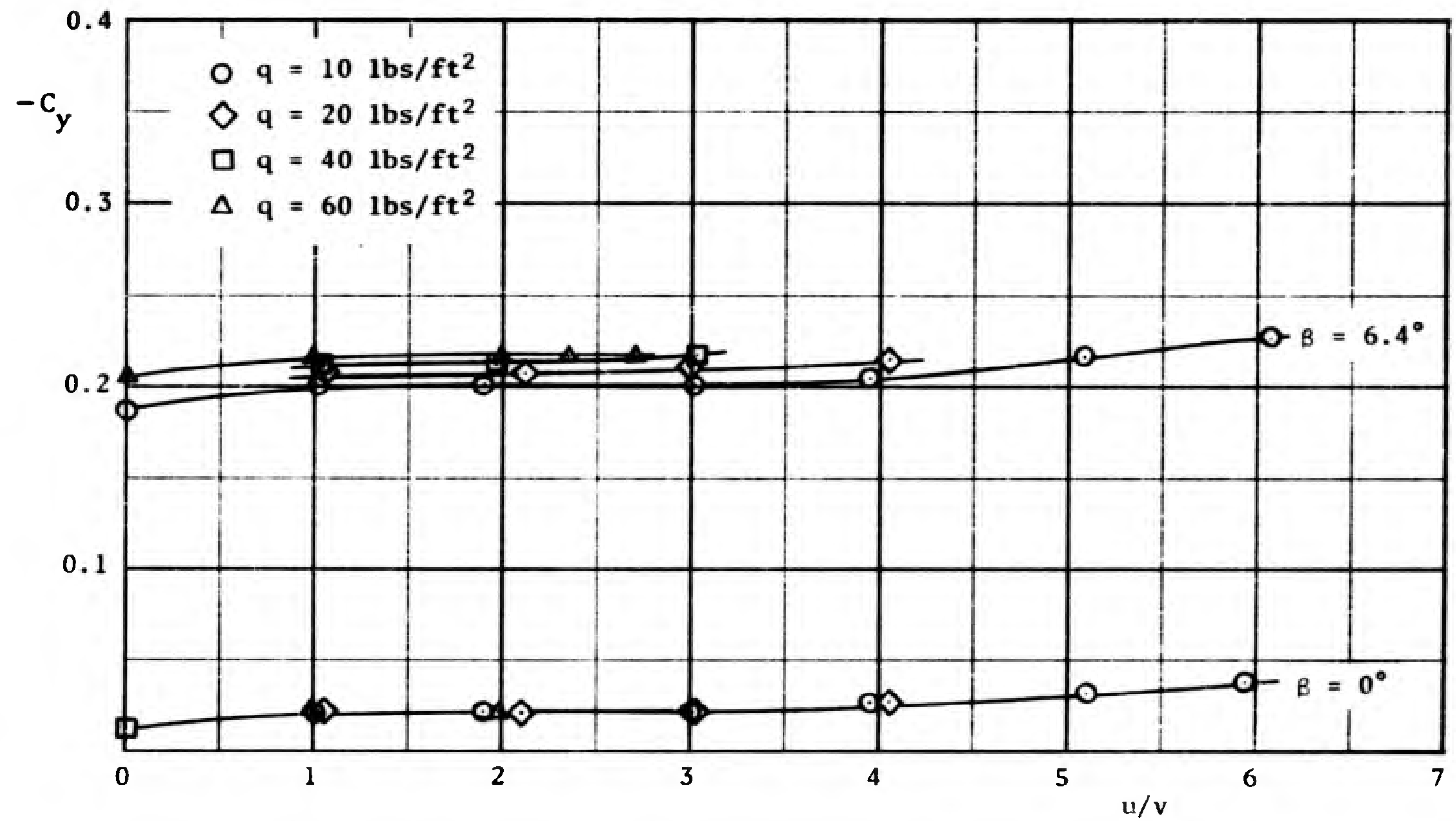


Figure 7 - Variation of Side Force with Velocity Ratio for Leading Edge Cylinder Model

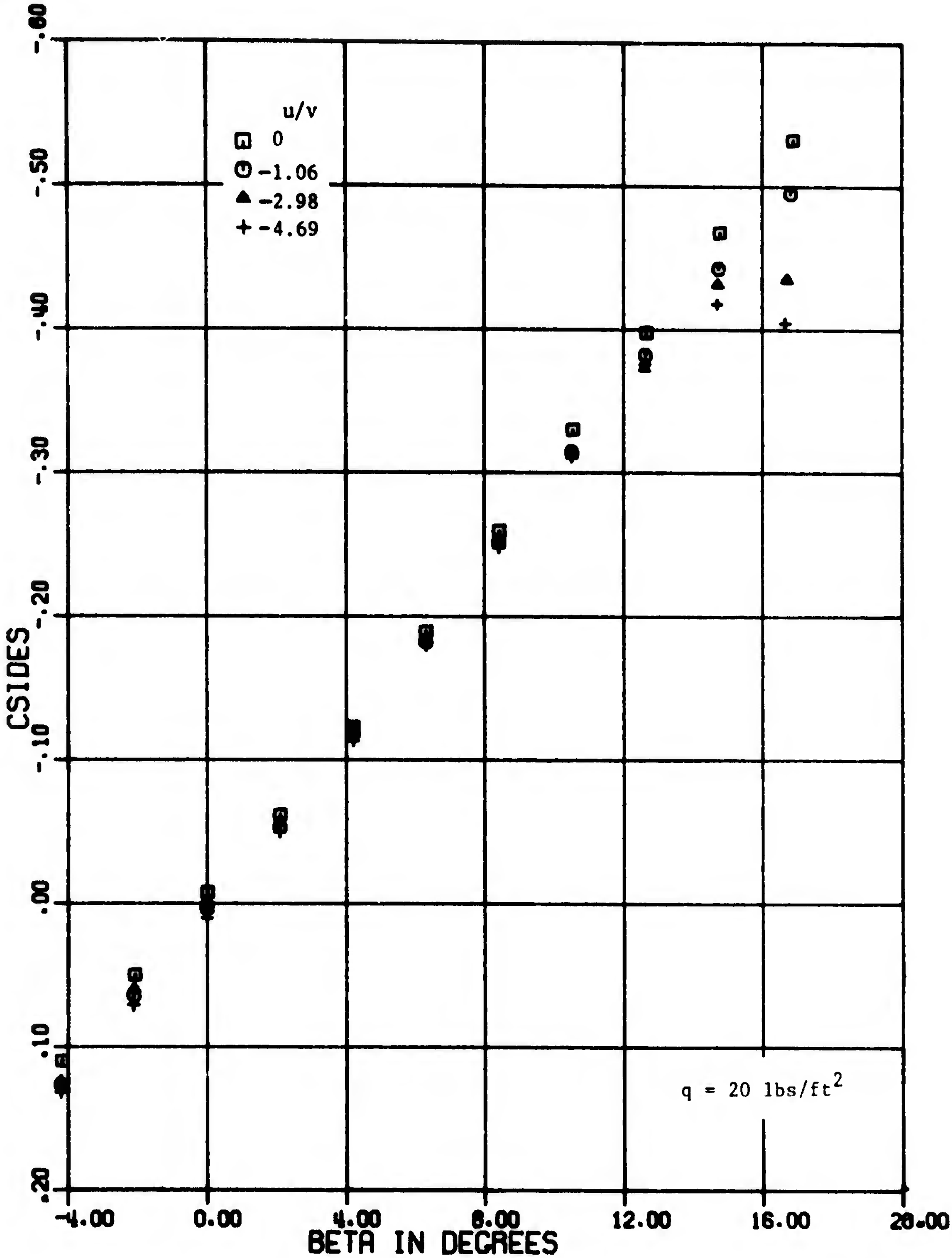


Figure 8 - Spoiling Effect of Leading Edge Cylinder on Side Force With Reversed Cylinder Rotation

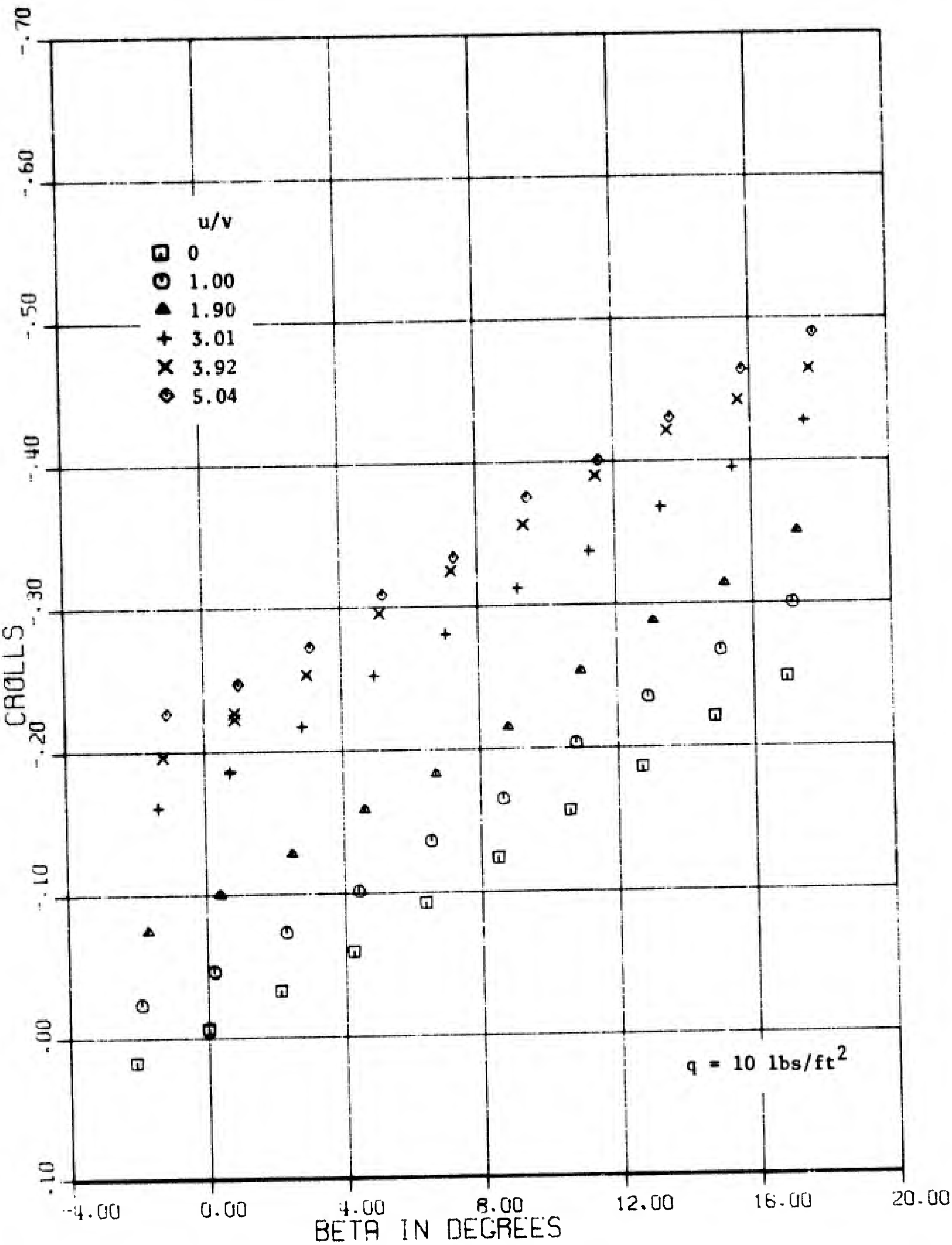


Figure 9 - Rolling Moment for Trailing Edge Cylinder Model

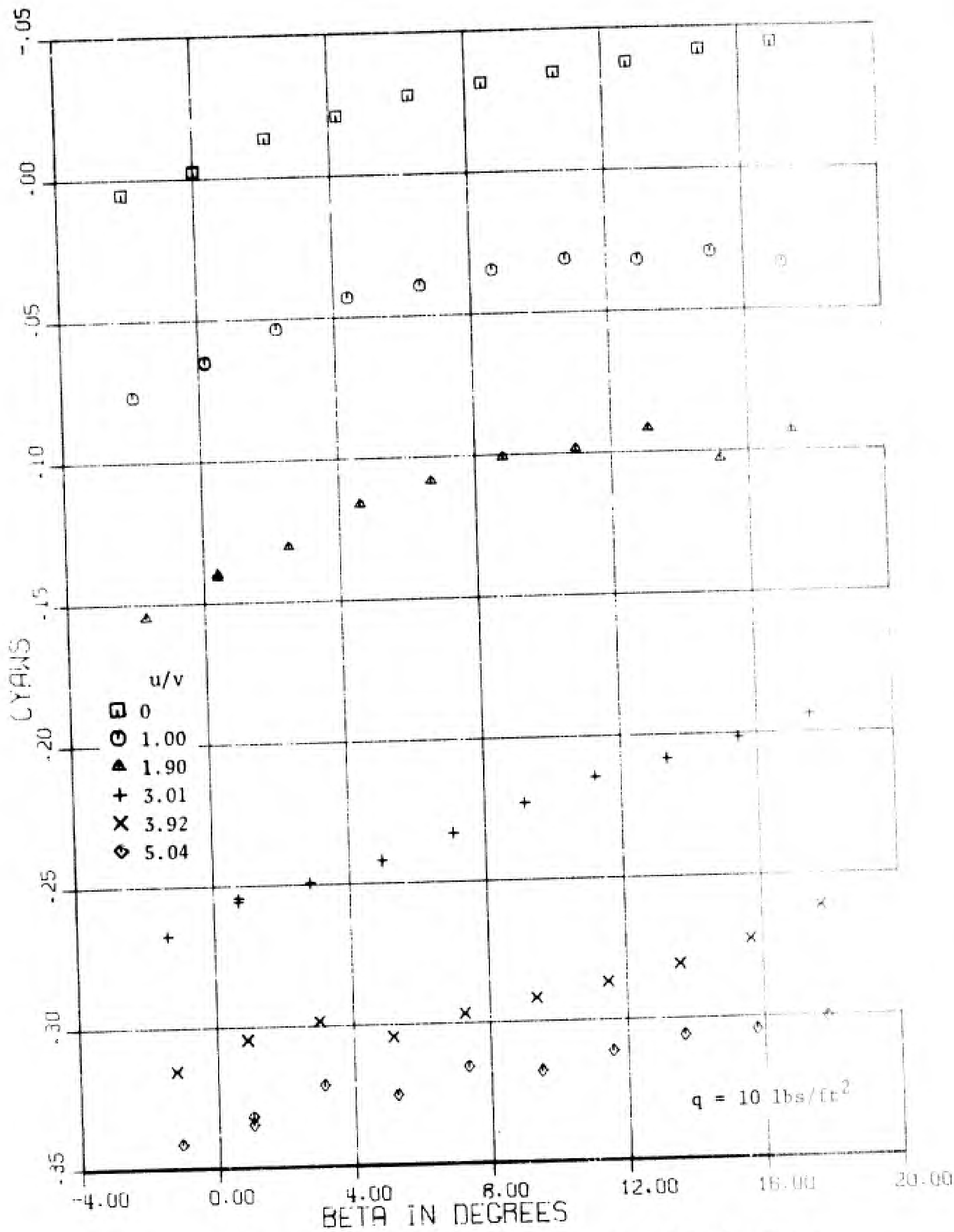


Figure 10 - Yawing Moment for Trailing Edge Cylinder Model

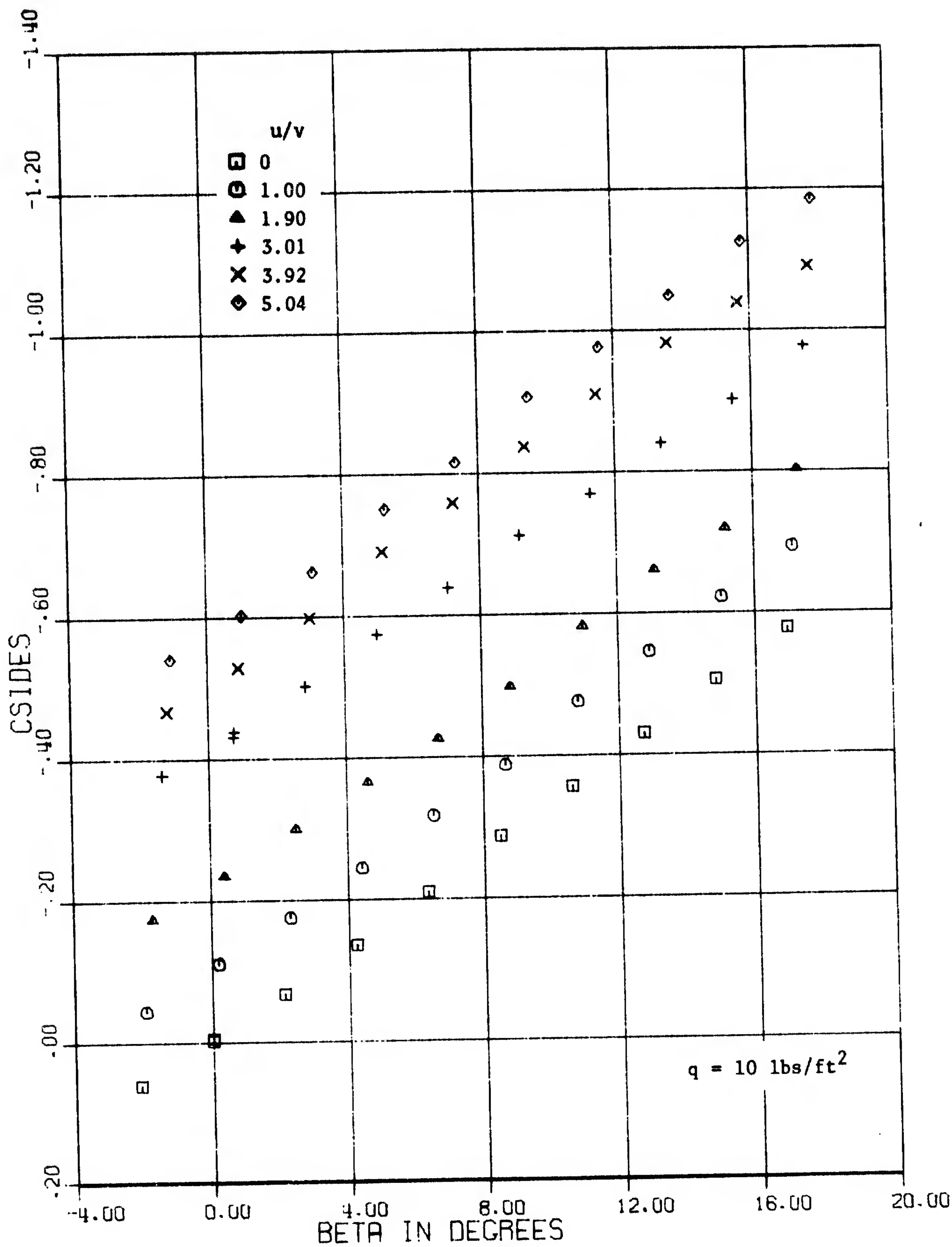


Figure 11 - Side Force for Trailing Edge Cylinder Model

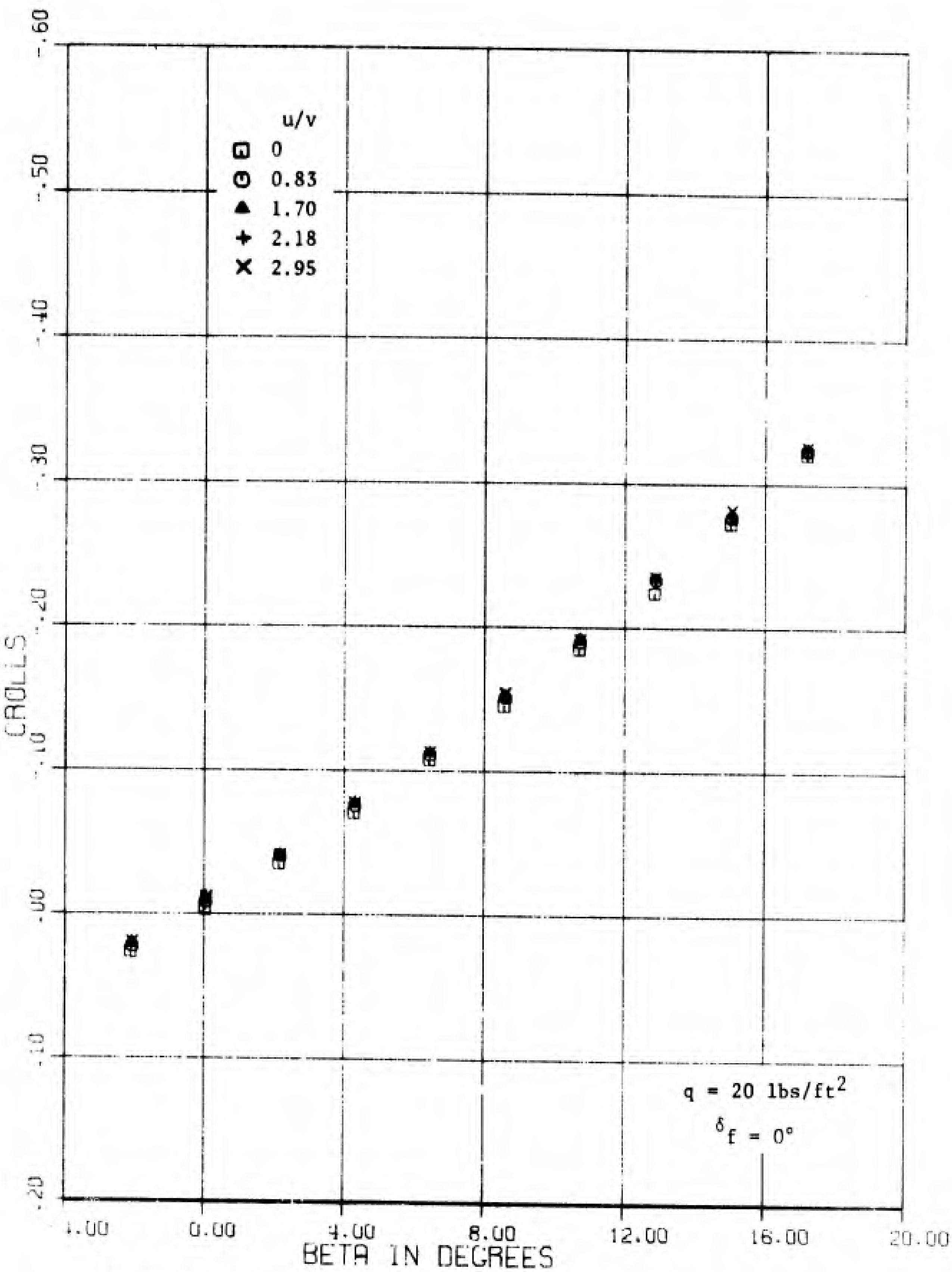


Figure 12 - Rolling Moment for Cylinder Flap Model with Zero Flap Angle

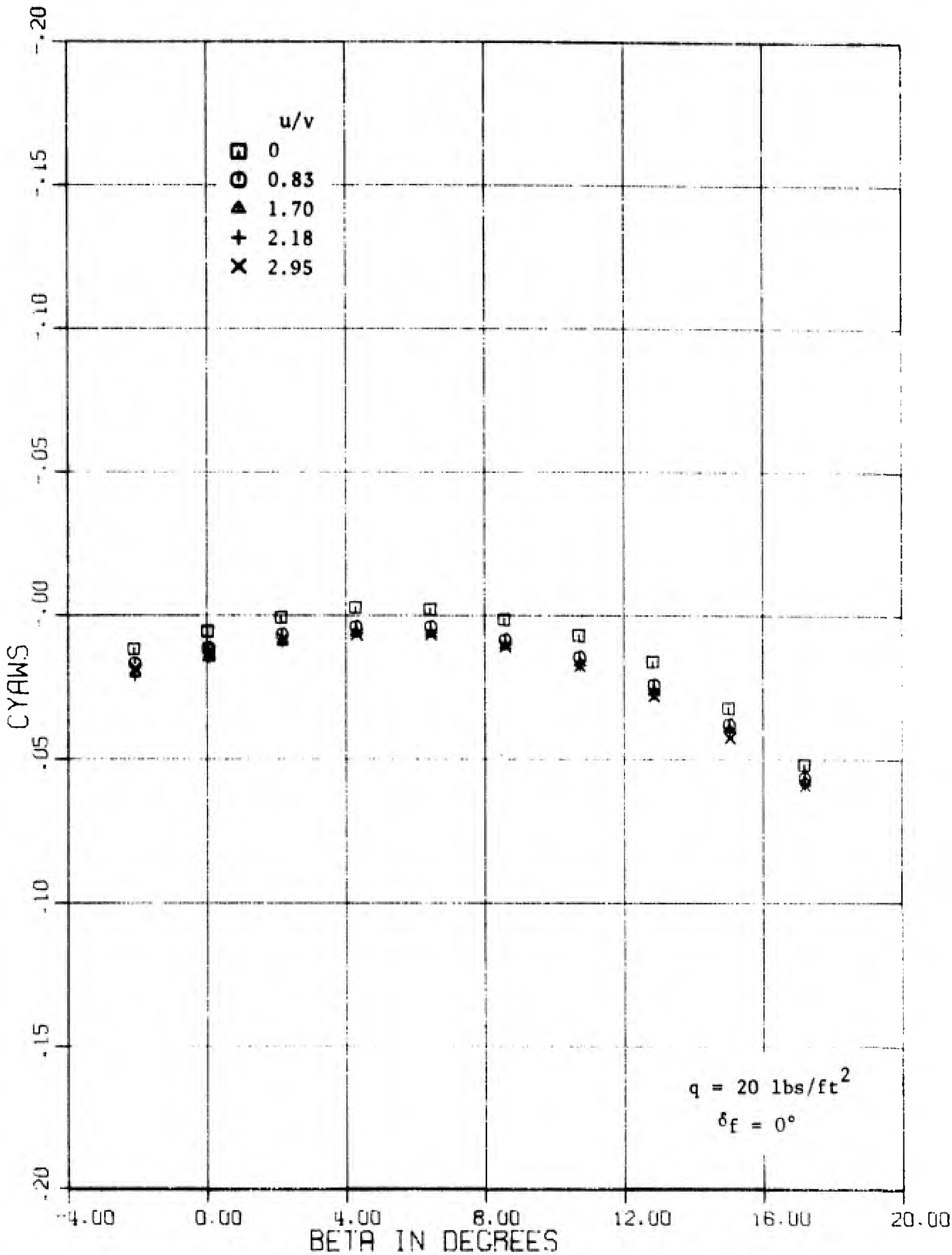


Figure 13 - Yawing Moment for Cylinder Flap Model with Zero Flap Angle

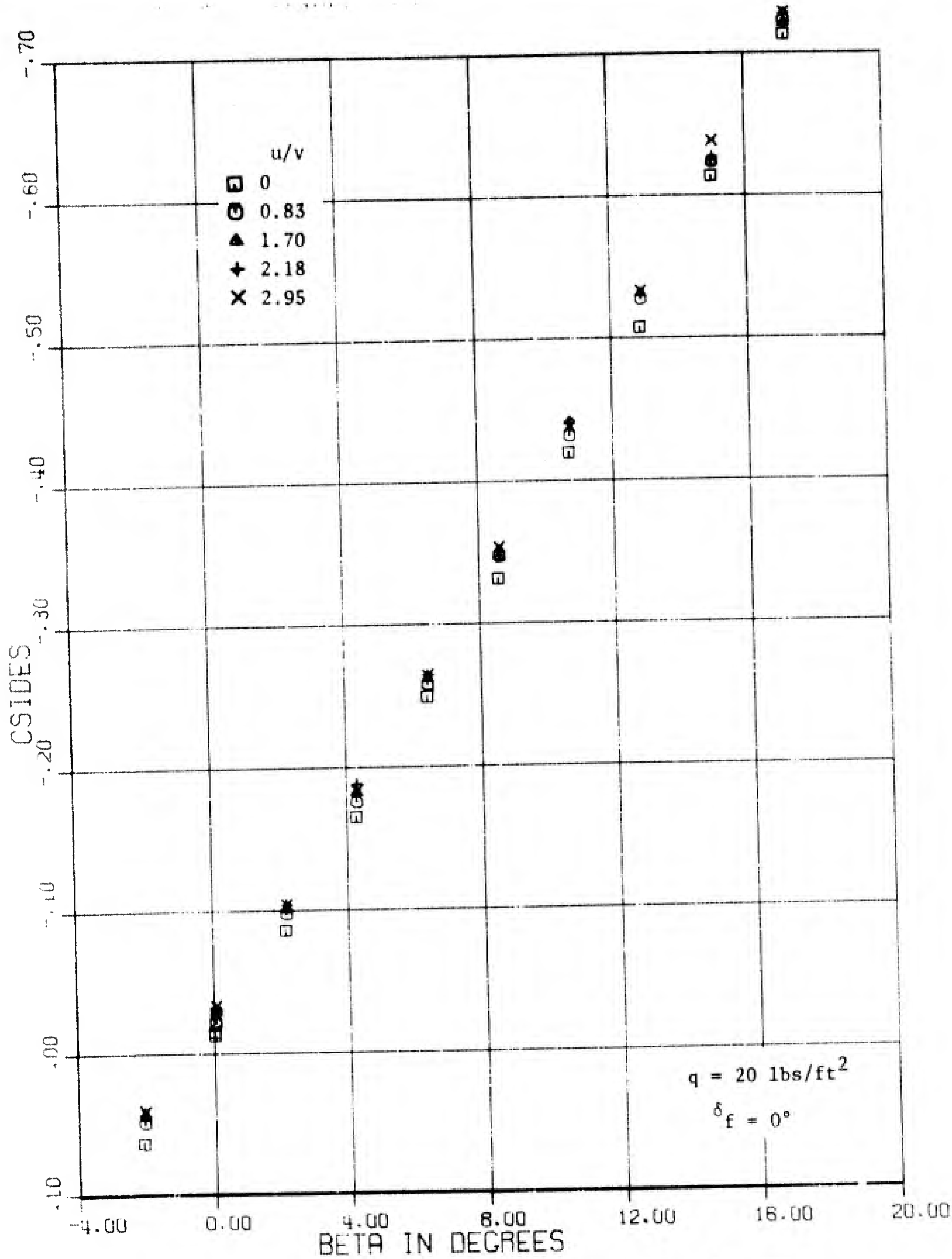


Figure 14 - Side Force for Cylinder Flap Model with Zero Flap Angle

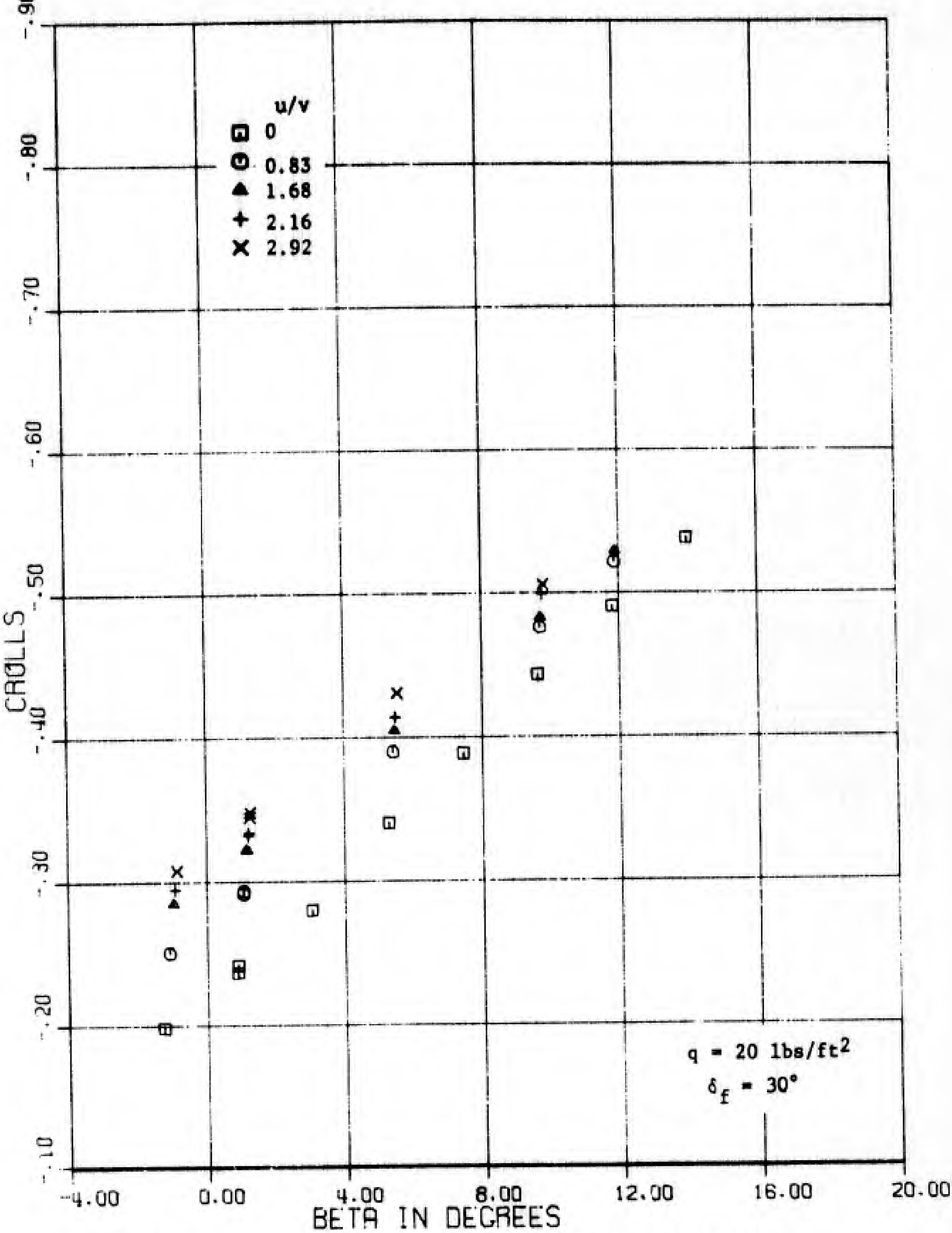


Figure 15 - Rolling Moment for Cylinder Flap Model with 30 Degrees Flap Angle

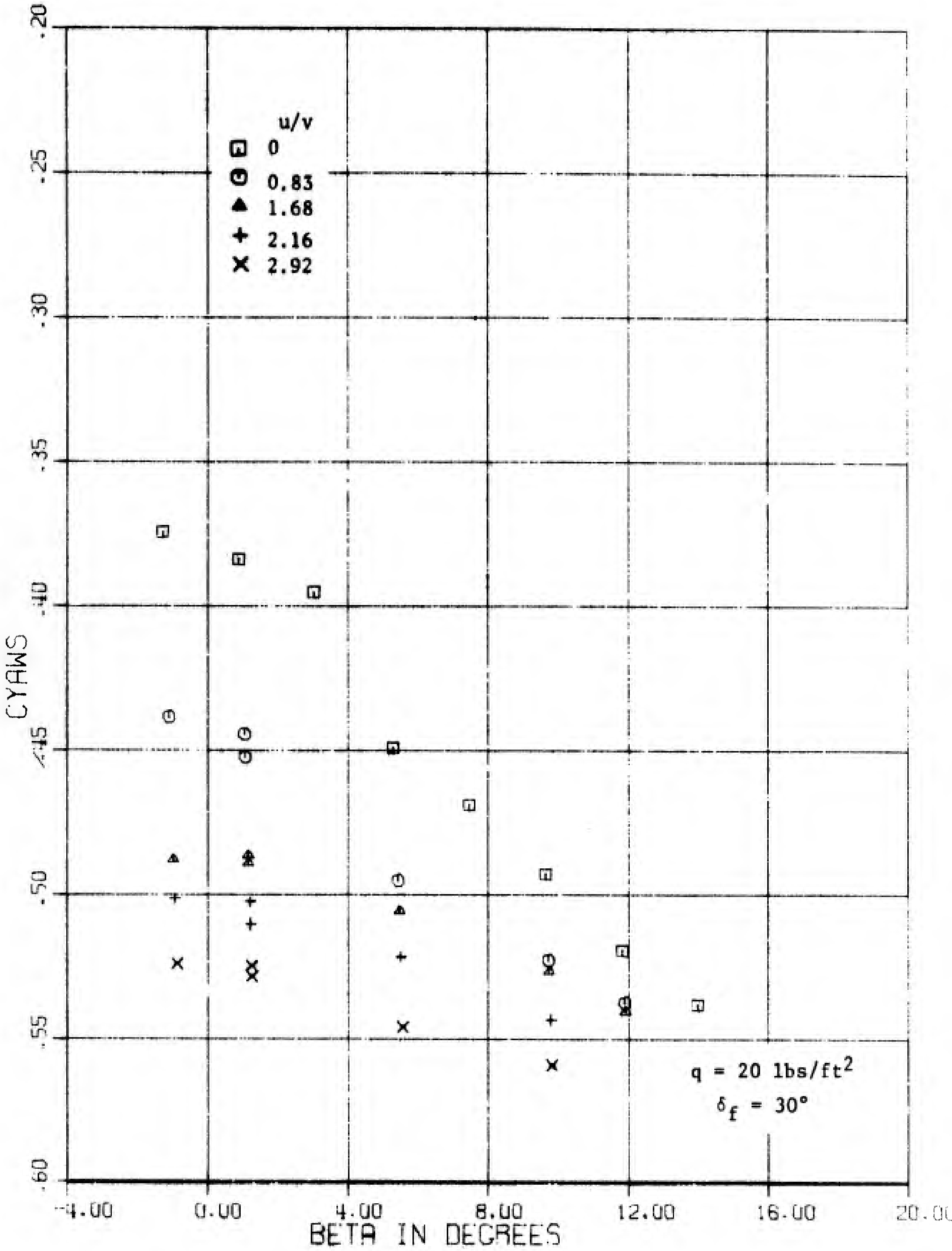


Figure 16 - Yawing Moment for Cylinder Flap Model with 30 Degrees Flap Angle

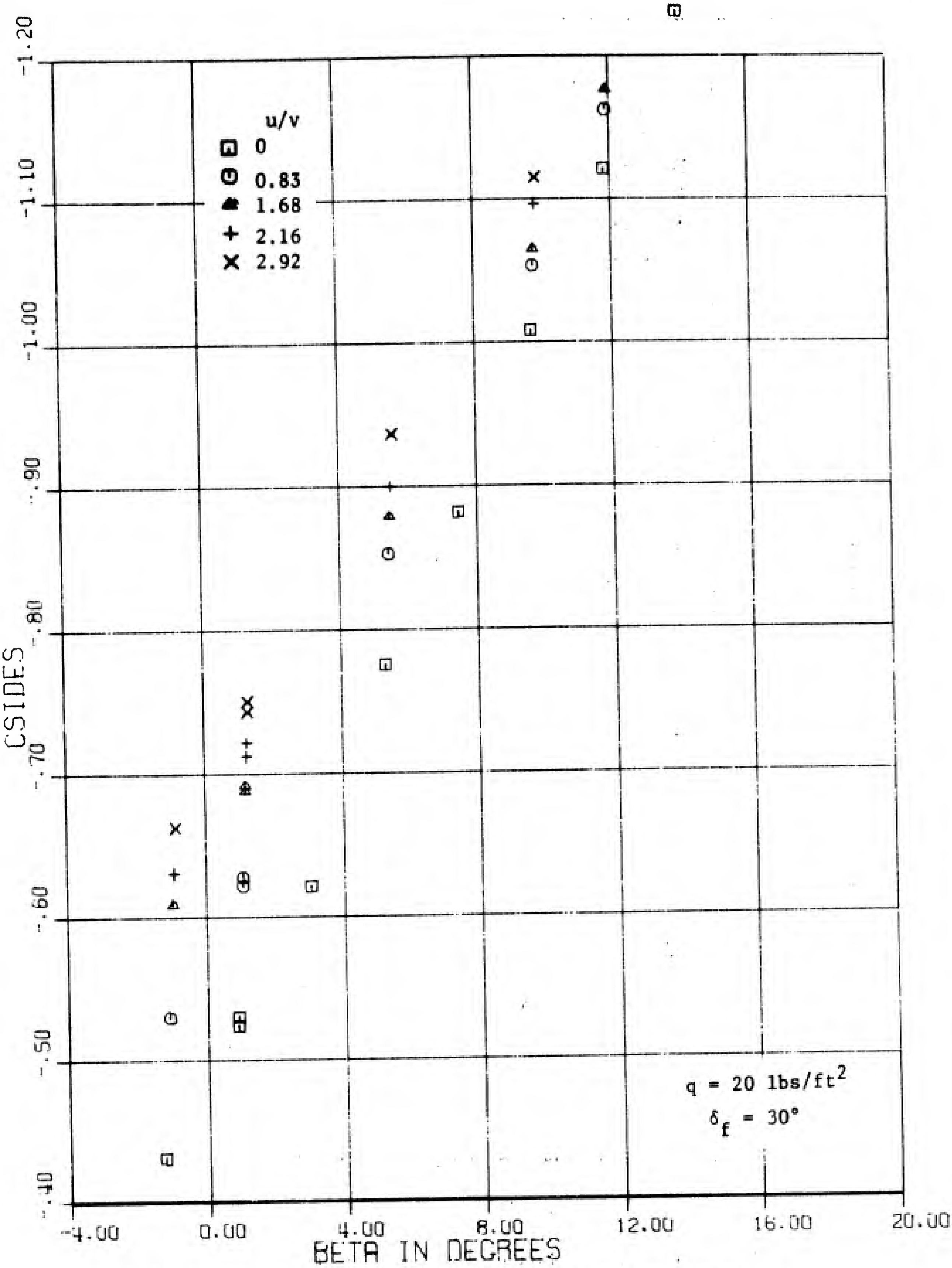


Figure 17 - Side Force for Cylinder Flap Model with 30 Degrees Flap Angle