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WIND TUNNEL INVESTIGATION OF THE AERODYNAMIC  
CHARACTERISTICS OF FIVE FOREBODY MODELS AT HIGH  
ANGLES OF ATTACK AT MACH NUMBERS FROM 0.25 to 2

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Test results show that with increasing Mach number the maximum side forces decrease to zero between Mach numbers of 0.8 and 1.5, depending on the nose angle; the smaller the nose angle the higher the Mach number at which the side force exists. At a Mach number of 0.6 there is some variation of side force with Reynolds number, the variation being the largest for the more slender tangent ogive ( $\ell/d = 5$ ).			
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SUMMARY

Five forebody models of various shapes were tested in the Ames 6- by 6-Foot Wind Tunnel to determine the aerodynamic characteristics at Mach numbers from 0.25 to 2 at a Reynolds number of  $0.8 \times 10^6$  (nominal, based on base diameter). At a Mach number of 0.6 the Reynolds number was varied from 0.4 to  $1.8 \times 10^6$  (nominal). Angle of attack was varied from  $-2^\circ$  to  $88^\circ$  at zero sideslip. The purpose of the investigation was to determine the effect of Mach number on the side force that develops at low speeds and zero sideslip for all of these forebody models when the nose is pointed.

Test results show that with increasing Mach number the maximum side forces decrease to zero between Mach numbers of 0.8 and 1.5 depending on the nose angle; the smaller the nose angle the higher the Mach number at which the side force exists. At a Mach number of 0.6 there is some variation of side force with Reynolds number, the variation being the largest for the more slender tangent ogive ( $\ell/d=5$ ).

INTRODUCTION

When bodies of revolution are pitched to high angles of attack, a side force can occur at zero sideslip angle. This side force results when the separation-induced vortex flow field on the lee side of the body becomes asymmetric. Although occurrence of asymmetric body vortex flow is well known, research on the phenomenon has increased considerably in recent years with the advent of highly maneuverable aircraft because the side force and yawing moment could contribute to the onset of aircraft spin (ref. 1). To date, much of the research on asymmetric forces has centered on studies of forces on long slender bodies. For example, references 2-4 present recent test results obtained at Ames for bodies with various nose shapes and cross sections. Results for forebody models tested at low speed and low Reynolds number (ref. 5) showed that the configuration of the forebody might play an important role in the spin characteristics of the

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aircraft. Accordingly a comprehensive wind tunnel test program was undertaken to obtain static aerodynamic data for forebody-alone models, covering a wide range of forebody shapes and a wide range of Reynolds numbers and Mach numbers. The objective was to determine the effect of forebody on the forces and moments so that design criteria could be established for aircraft and missiles with good high angle-of-attack aerodynamic characteristics. Selected results of tests at low subsonic speeds have been presented in reference 6.

This report presents static aerodynamic data for the same five forebody models of reference 6 at transonic and supersonic Mach numbers. The data obtained from the tests are presented with a minimum of analysis.

#### NOMENCLATURE

The axis system and sign convention are presented in figure 1. Except for lift and drag coefficients, the data are presented in the body axis coordinate system with the moment center located at the base of the forebody models. Because the data were computer plotted, the corresponding plot symbol, where used, is given together with the conventional symbol.

<u>Symbol</u>	<u>Plot Symbol</u>	<u>Definition</u>
b	B	span of elliptic forebody at base (major or minor axis of base depending on the orientation of the model; major or minor axis horizontal)
$C_A$	CA	axial-force coefficient; axial force/ $qS$
$C_{AF}$	CAF	axial-force coefficient adjusted for base pressure equal to free stream static pressure, $[C_A + C_{pb} \text{ (base area/S)}]$
$C_m$	CLM	pitching-moment coefficient, pitching moment/ $qSd$
$C_{m,R}$	CRM	resultant-moment coefficient, $C_n \sin \psi + C_m \cos \psi$
$C_N$	CN	normal-force coefficient, normal force/ $qS$
$ C_N $	ACN	absolute value of $C_N$
$C_n$	CYN	yawing-moment coefficient, yawing moment/ $qSd$

<u>Symbol</u>	<u>Plot Symbol</u>	<u>Definition</u>
$CP_R$	CPR	resultant-force center of pressure location, fraction of length, $\ell$ , from nose tip, $1 - (C_{m,R}/C_R) (d/\ell)$
$C_{p,b}$	CPB	base pressure coefficient, $(p_b - p)/q$
$C_R$	CR	resultant-force coefficient in body axis system, $\sqrt{C_N^2 + C_Y^2}$
$C_Y$	CY	side-force coefficient; side force/ $qS$
$ C_Y $	ACY	absolute value of $C_Y$
d	D	reference base diameter (for elliptic body it is taken to be the span, b, at the base)
$\ell$	L	reference length (length of forebodies with pointed noses, except reference length of paraboloid is with parabolic nose)
M	MACH	free stream Mach number
p		free stream static pressure
$p_b$		base pressure
q		free stream dynamic pressure
R	R	Reynolds number, based on base diameter
$R/d$		unit Reynolds number, $10^6/m$
S	S	area of base (elliptic body: area of an equivalent circular base with a diameter equal to the span of the base)
$\alpha$	ALPHA	angle of attack
$\beta$	BETA	angle of sideslip
$\delta_N$		nose semiapex angle
$\psi$	PSI	angle between the resultant and normal forces, resultant force inclined to the right is positive angle looking upstream, $\tan^{-1}(C_Y/C_N)$

## MODEL CONFIGURATION CODE

<u>Symbol</u>	<u>Definition</u>
FC1	conical forebody with pointed nose
FEH	elliptic tangent ogive forebody with pointed nose; major axis horizontal
FEV	elliptic tangent ogive forebody with pointed nose; major axis vertical
FP	parabolic forebody with pointed nose
FT3.5	tangent ogive forebody with pointed nose; $\ell/d=3.5$
FT5	tangent ogive forebody with pointed nose; $\ell/d=5.0$

## TEST FACILITY

The models were tested in the Ames Research Center 6- by 6-Foot Supersonic Wind Tunnel, which is a variable pressure, continuous flow facility. The nozzle leading to the test section is of the asymmetric sliding-block type which permits a continuous variation of Mach number from 0.6 to 2.3. A Mach number of 0.25 was obtained with special speed control settings; however, this Mach number is not generally used in test programs because of relatively rough air flow. Limited data, therefore, were obtained at this Mach number. The test section has a perforated floor and ceiling with provisions for boundary layer removal.

## MODEL DESCRIPTION

Figure 2 is a sketch of the five forebody models designed to represent forebodies of aircraft fuselages or missiles; Table 1 lists the dimensions. Photographs of one of the models and the wind tunnel installation are shown in figure 3. Four of the forebodies were bodies of revolution: two tangent ogives with fineness ratios of 3.5 and 5.0, a paraboloid, and a cone. Although all of these bodies had removable nose sections of various nose radii, only the pointed nose tips were used in the present investigation. The paraboloid was provided with a pointed nose with an apex angle ( $32.9^\circ$ ) identical to that of the  $\ell/d = 3.5$  tangent ogive (see Table 1 for apex angles of the other bodies). The fifth body was designed with an elliptic cross section that could be tested with either

the major or the minor axis perpendicular to the crossflow velocity. The major and minor axes of the base were selected so that the respective  $\ell/d$  values were 3.5 and 5.0 to coincide with the circular tangent ogive values.

### TESTING AND PROCEDURES

The investigation was conducted over a Mach number range of 0.6 to 2.0 at a unit Reynolds number of  $5 \times 10^6/m$ . At a Mach number of 0.6 the unit Reynolds number was varied from  $2.5 \times 10^6$  to  $12 \times 10^6/m$ . Some limited test data were obtained at  $M = 0.25$ . Three model-support setups were required to cover the angle of attack ranges:  $-2^\circ$  to  $28^\circ$ ,  $28^\circ$  to  $58^\circ$  and  $58^\circ$  to  $88^\circ$ . The model support shown in figures 3(a) and 3(b) is a straight sting with a  $45^\circ$  offset support, resulting in an angle of attack range of  $28^\circ$  to  $58^\circ$ . The lower and higher angle ranges were obtained with a sting-bent joint of  $30^\circ$ , bent down for  $\alpha = -2^\circ$  to  $28^\circ$  (fig. 3(c)) and bent up for  $\alpha = 58^\circ$  to  $88^\circ$ . The angle of sideslip was zero. Aerodynamic forces and moments on the model were measured using an internal six-component strain-gage balance. The model base pressure was measured using one pressure tube attached to the sting and open at the base of the model. The  $\ell/d = 3.5$  tangent ogive forebody was tested over the maximum angle of attack range of  $\alpha = -2^\circ$  to  $88^\circ$ . All other models were tested with the straight sting at  $\alpha = 28^\circ$  to  $58^\circ$ . The elliptic tangent ogive was tested with its major axis both horizontal and vertical.

### PRESENTATION OF RESULTS

Table 2 is an index of the figures in which the data for each of the five forebody models are presented. In figures 4 to 6 the effects of Mach number and Reynolds number are presented for the angle of attack range of  $-2^\circ$  to  $88^\circ$  for the  $\ell/d = 3.5$  tangent ogive. In figures 7 to 15 the effects of Mach number and Reynolds number are presented for  $\alpha = 28^\circ$  to  $58^\circ$  for the  $\ell/d = 5$  tangent ogive, the paraboloid, the 20 degree cone and the elliptic tangent ogive tested with the major axis horizontal and vertical. The following coefficients are plotted and faired as a function of angle of attack using an automatic data plotting system:  $C_y$ ,  $C_N$ ,  $|C_y|/|C_N|$ ,  $(C_R - C_N)$ ,  $C_n$ ,  $C_m$ ,  $C_{AF}$ ,  $C_{PR}$ ,  $\psi$ ,  $C_{m,R}$  and  $C_{p,b}$ . (Note that the results for  $|C_y|/|C_N|$  and  $C_{PR}$  are naturally spurious at angles of attack near zero, because these parameters are undefined at  $\alpha = 0$ ).

### DISCUSSION

The purpose of this investigation was to determine the effect of Mach number on the side force that develops at low speed and zero sideslip for

all of the forebody models when the nose is pointed. Previous tests at subsonic speeds in the Ames 12-Foot Wind Tunnel (ref. 6) showed that the side forces were as large as 1.5 times the normal force and varied considerably with Reynolds number. It was shown in reference 6 that the angle of attack at the onset of side force can be correlated with the nose semiapex angle by a simple formula: onset  $\alpha \approx 2 \delta_N$ . Further, it was found that these side forces can be reduced or eliminated by bluntness or nose strakes.

The present investigation included tests at  $M = 0.25$  and  $R/d = 5 \times 10^6/m$  for both circular tangent ogives and the cone. The results shown in figures 4, 7, and 10 are similar to the results obtained for the same test conditions in the Ames 12-Foot Tunnel (ref. 6), in that large side forces develop at zero sideslip. Test results for all of the pointed forebodies show that with increasing Mach number the maximum side forces decrease to zero between  $M = 0.8$  and  $1.5$ , depending on the nose angle; the smaller the nose angle the higher the Mach number at which the side force exists. Test results at  $M = 0.6$  show some variation of side force with Reynolds number. The variation is the largest for the more slender  $\lambda/d = 5$  tangent ogive.

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National Aeronautics and Space Administration  
Moffett Field, California 94035

November 28, 1975

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1. Chambers, J. R.; Anglin, E. L.; and Bowman, J. S., Jr.: Effects of a Pointed Nose on Spin Characteristics of a Fighter Airplane Model Including Correlation with Theoretical Calculations. NASA TN D-5921, 1970.
2. Jorgensen, Leland H.; and Nelson, Edgar R.: Experimental Aerodynamic Characteristics for a Cylindrical Body of Revolution With Various Noses at Angles of Attack from 0 to  $58^\circ$  and Mach Numbers From 0.6 to 2.0. NASA TM X-3128, 1974.
3. Jorgensen, Leland H.; and Nelson, Edgar R.: Experimental Aerodynamic Characteristics for a Cylindrical Body of Revolution With Side Strakes and Various Noses at Angles of Attack From 0 to  $58^\circ$  and Mach Numbers From 0.6 to 2.0. NASA TM X-3130, 1975.
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5. Coe, P. L., Jr.; Chambers, J. R.; and Letko, W.: Asymmetric Lateral-Directional Characteristics of Pointed Bodies of Revolution at High Angles of Attack. NASA TN D-7095, 1973.
6. Keener, Earl R.; and Chapman, Gary T.: Onset of Aerodynamic Side Forces at Zero Sideslip on Symmetric Forebodies at High Angles of Attack. AIAA Paper 74-770, 1974.

TABLE 1. - MODEL GEOMETRY

Planform	Forebody Shape	Crosssection	$\frac{z}{d}$	$z, \text{cm}$	$d, \text{cm}$	$S, \text{cm}^2$	Sharp nose apex angle, deg
Tangent ogive	Circular		3.5	53.3	15.24	182.4	32.9
Tangent ogive	Circular		5.0	76.2	15.24	182.4	22.8
Tangent ogive Major Axis-Horizontal	Elliptic		3.5	66.0	18.87	279.6	32.9
Major Axis-Vertical			5.0	66.0	13.21	137.0	22.8
Cone	Circular		2.84	53.3	18.82	278.2	20.0
Paraboloid	Circular		3.5	53.3	15.24	182.4	32.9
Reference diameter ( $d$ ) and area ( $S$ ):							

**Circular bodies:** Base diameter and base area

**Elliptic bodies:** Span at the base and area of an equivalent circular base with a diameter equal to base span.

TABLE 2. - INDEX OF DATA FIGURES

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14	L/D=3.5 ellip. tan. ogive, major axis hor., effect of Mach number	71
15	L/D=5 ellip. tan. ogive, major axis vert., effect of Mach number	78

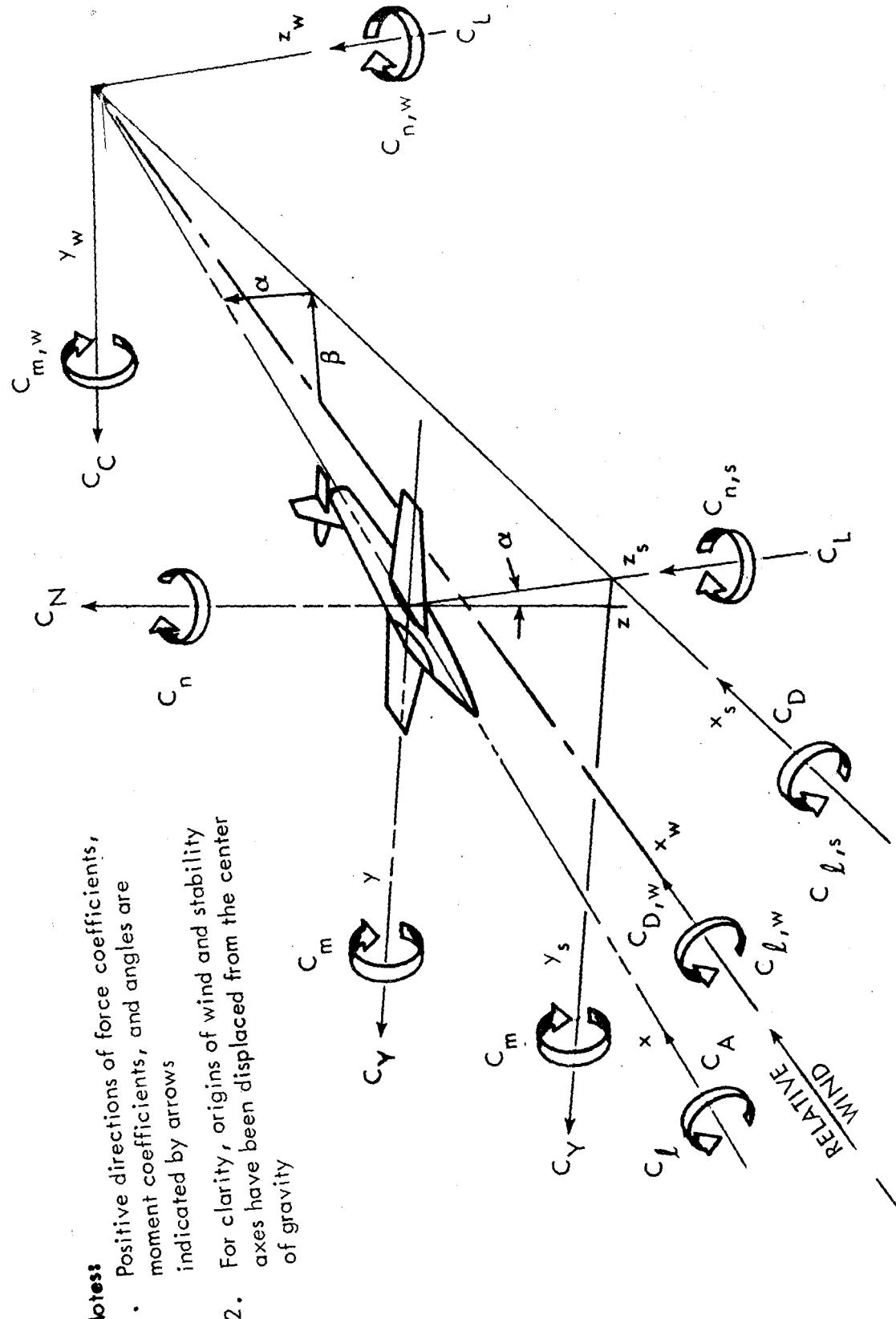


Figure 1. - Axis systems.

(1) TAN. OGIVE

$$z/d = 3.5$$



(2) TANGENT OGIVE

$$z/d = 5.0$$



(3) PARABOLOID

$$z/d = 3.5$$



(4) 20° CONE

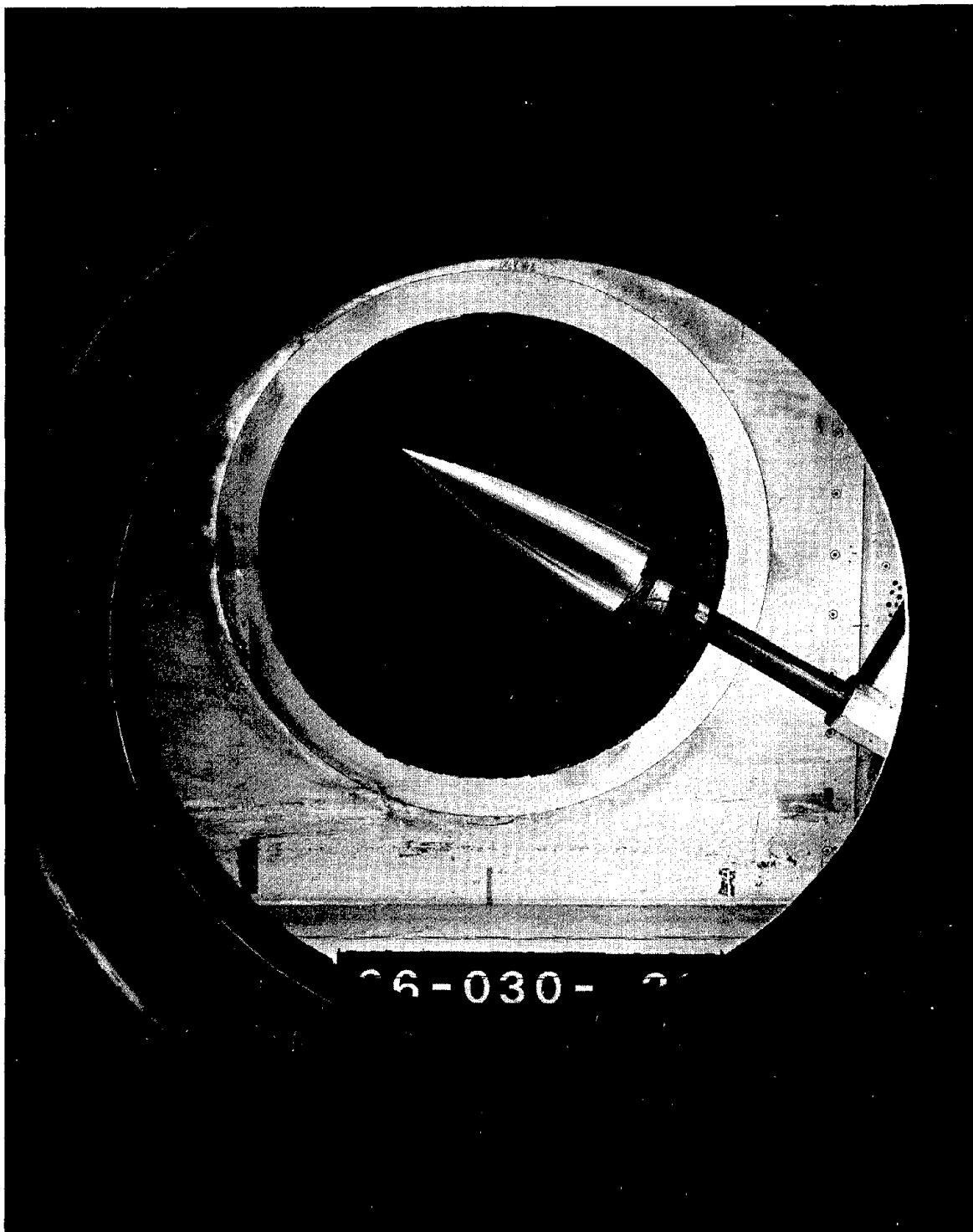


(5) ELIP. TAN. OGIVE

$$z/b = 3.5 \text{ & } 5.0$$



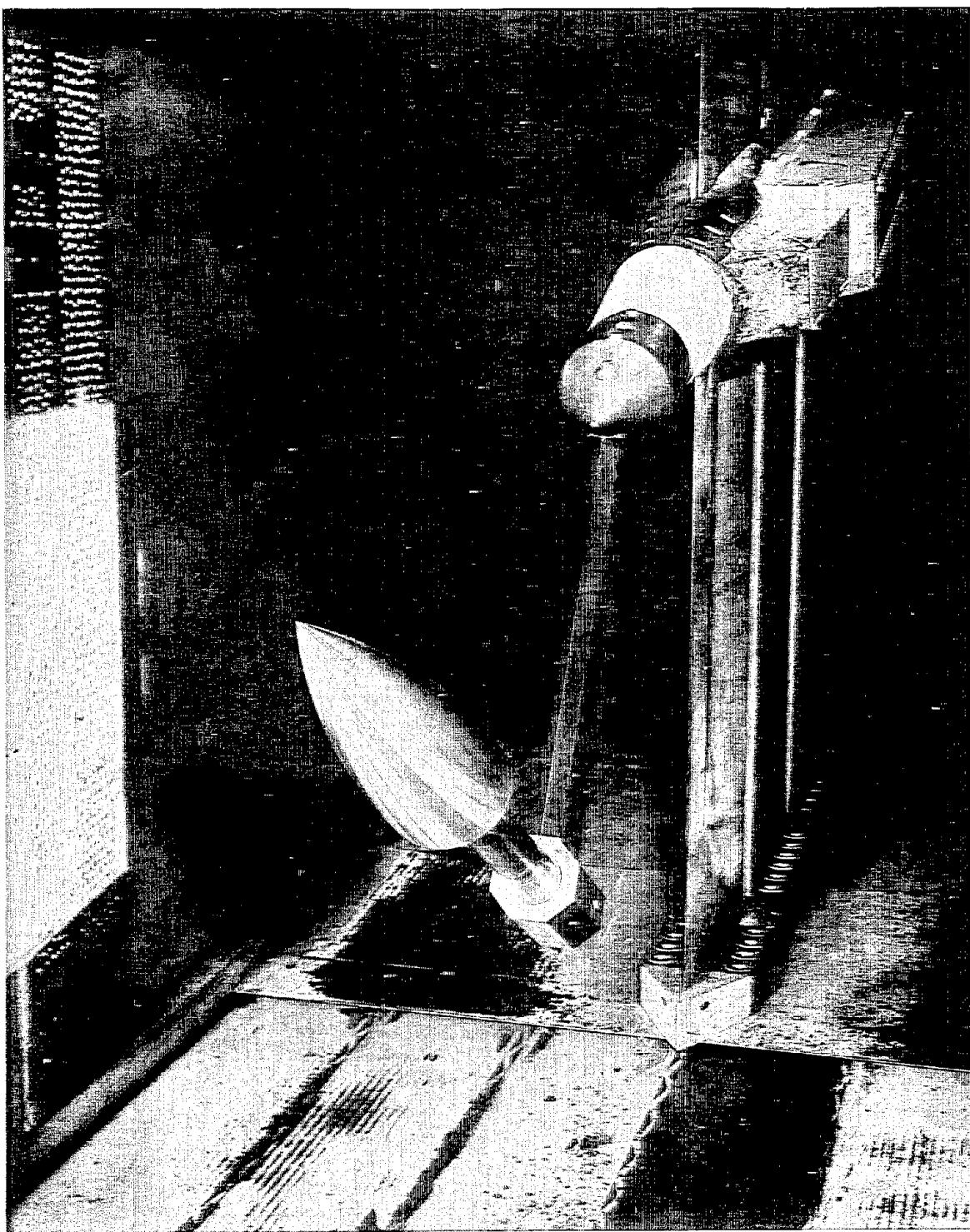
Figure 2. - Sketches of models.



(a) Side View of straight sting support setup for  $\alpha = 28^\circ$  to  $58^\circ$

Figure 3. - Photographs of typical model-support set-ups  
in the Ames 6- by 6-Foot Wind Tunnel

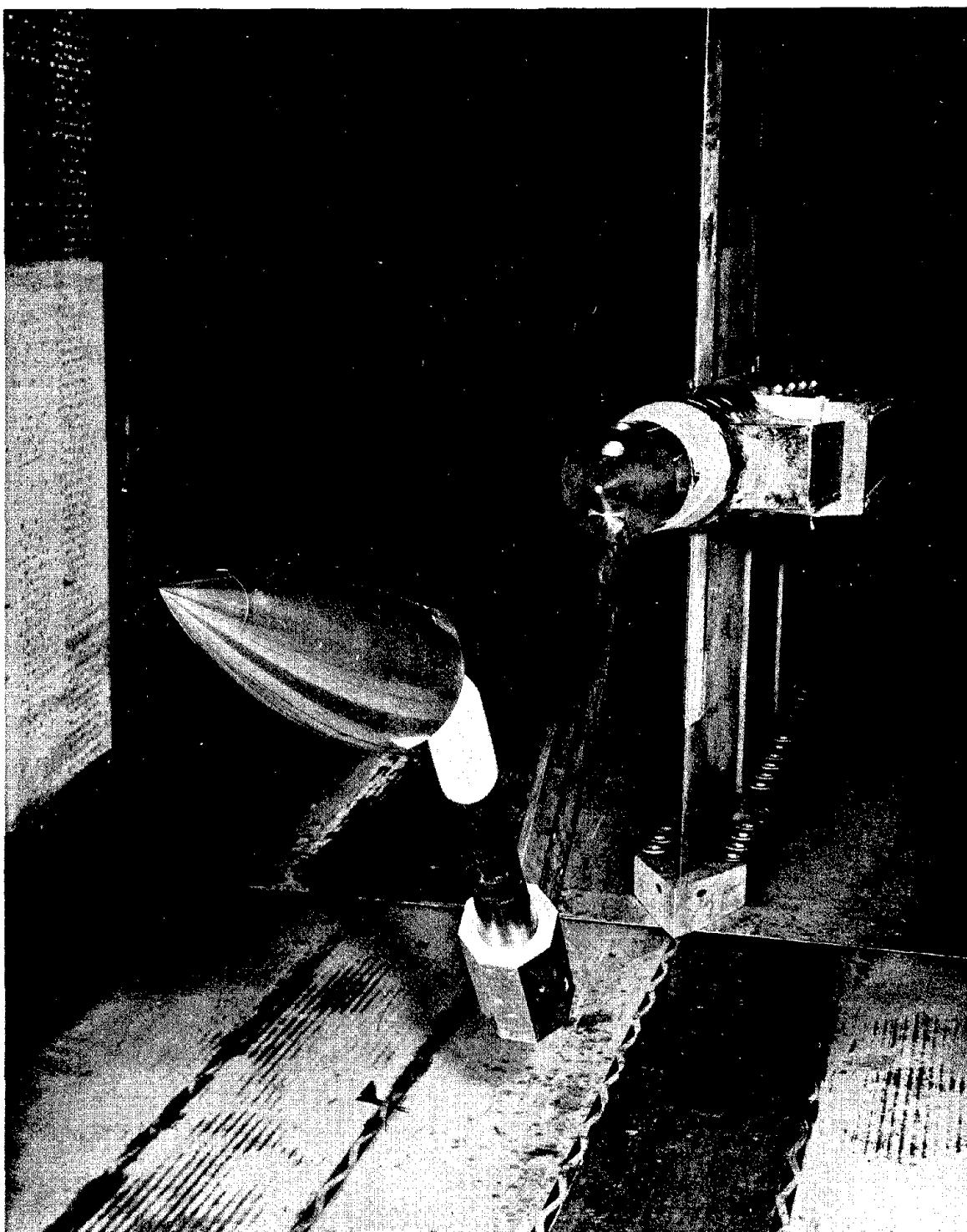
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OF POOR QUALITY



(b) Three-quarter front view of straight sting support  
setup for  $\alpha = 28^\circ$  to  $58^\circ$

Figure 3. - Continued

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OF POOR QUALITY



(c) Three-quarter front view of 30° bent sting support  
setup for  $\alpha = -2^\circ$  to  $28^\circ$

Figure 3. - Concluded

**DATA**

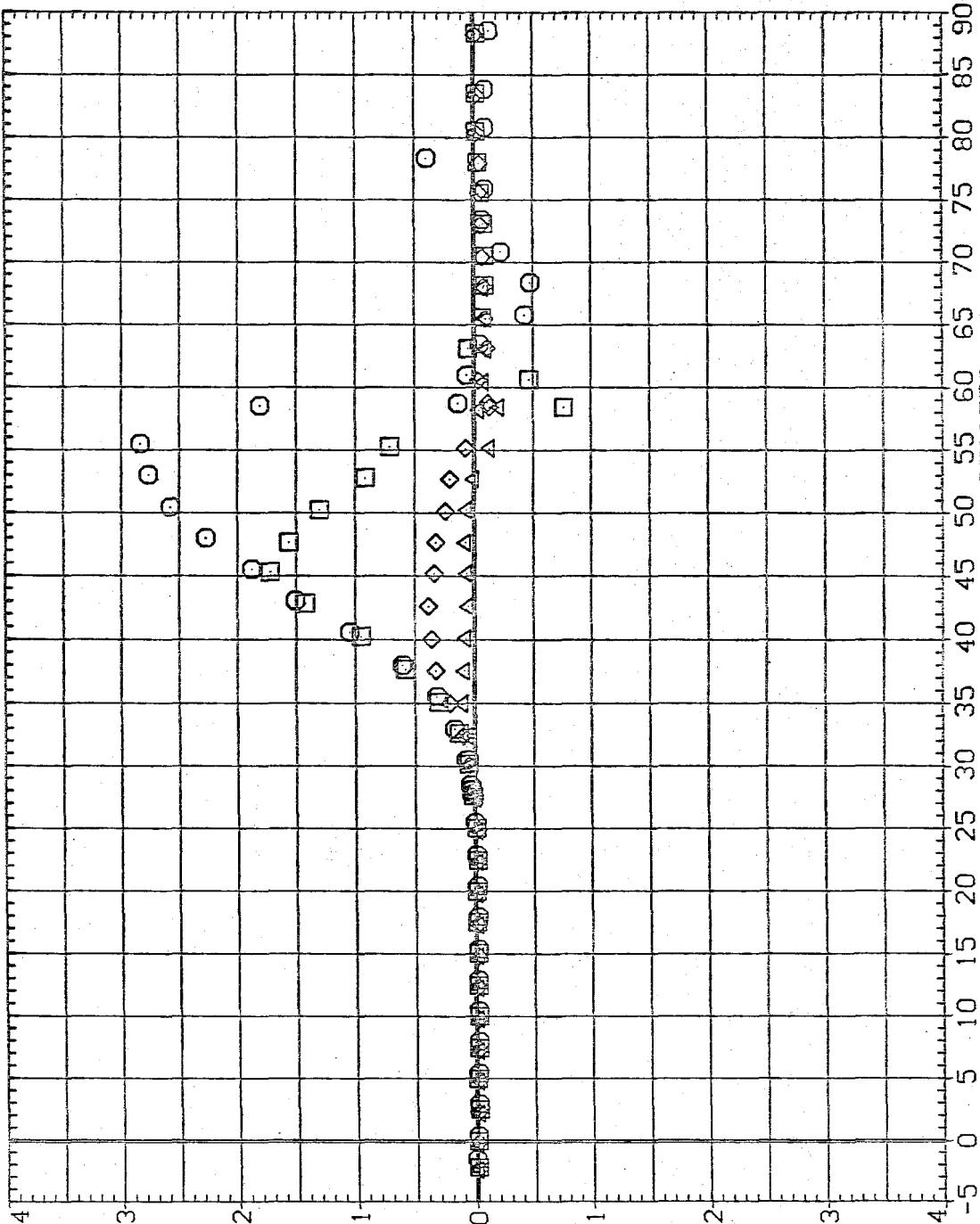


FT3.5

(RJDCC01)

PARAMETRIC VALUES  
MACH .251 R .750  
.602  
.800  
.905

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SIDE FORCE COEFFICIENT,  $C_y$

FIG. 4 L/D=3.5 TAN. 0GIVE, EFFECT OF MACH NUMBER, SUBSONIC

FT3.5  
 .251 R .750  
 .602  
 .800  
 .905

○□◇△

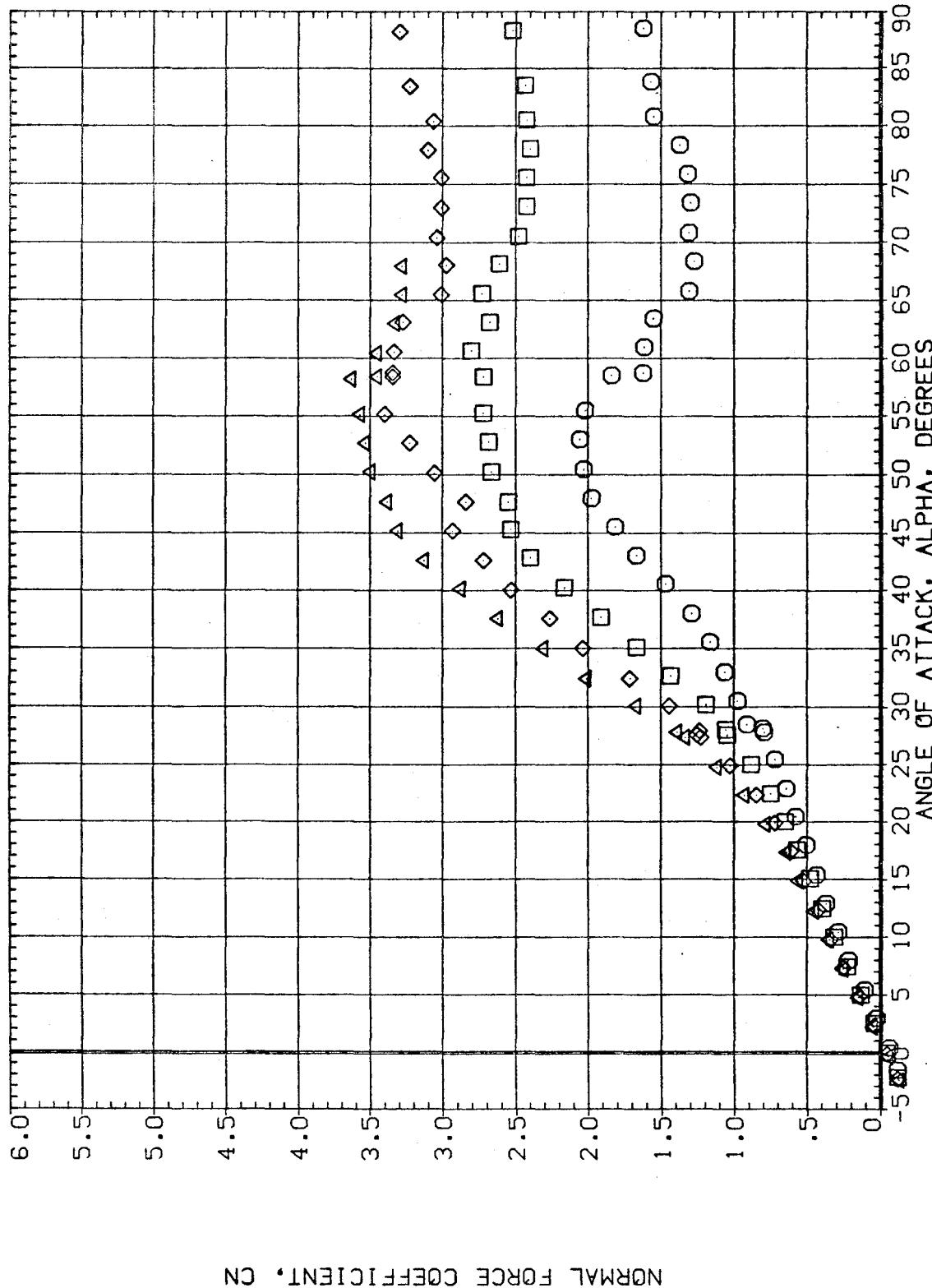
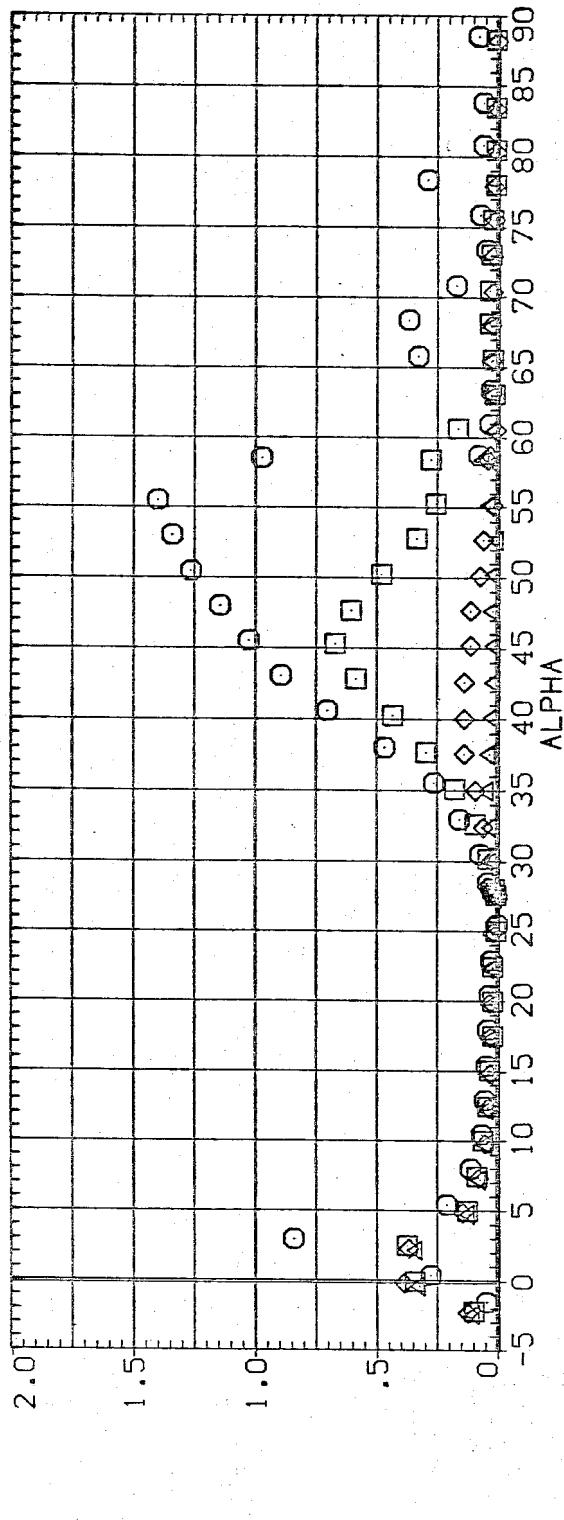


FIG.4 L/D=3.5 TAN. OGIVE, EFFECT OF MACH NUMBER, SUBSONIC

FT3.5

(RJD01)

PARAMETRIC VALUES  
MACH R  
.251 .750  
.602  
.800  
.905



ACY/CN

CR-CN

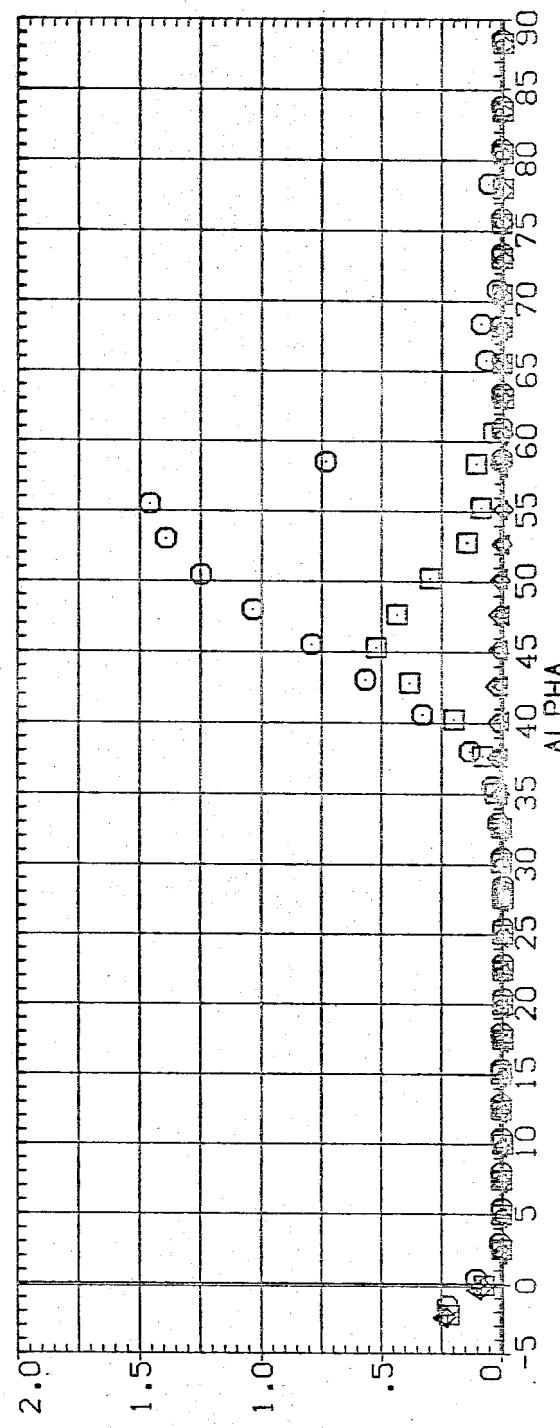
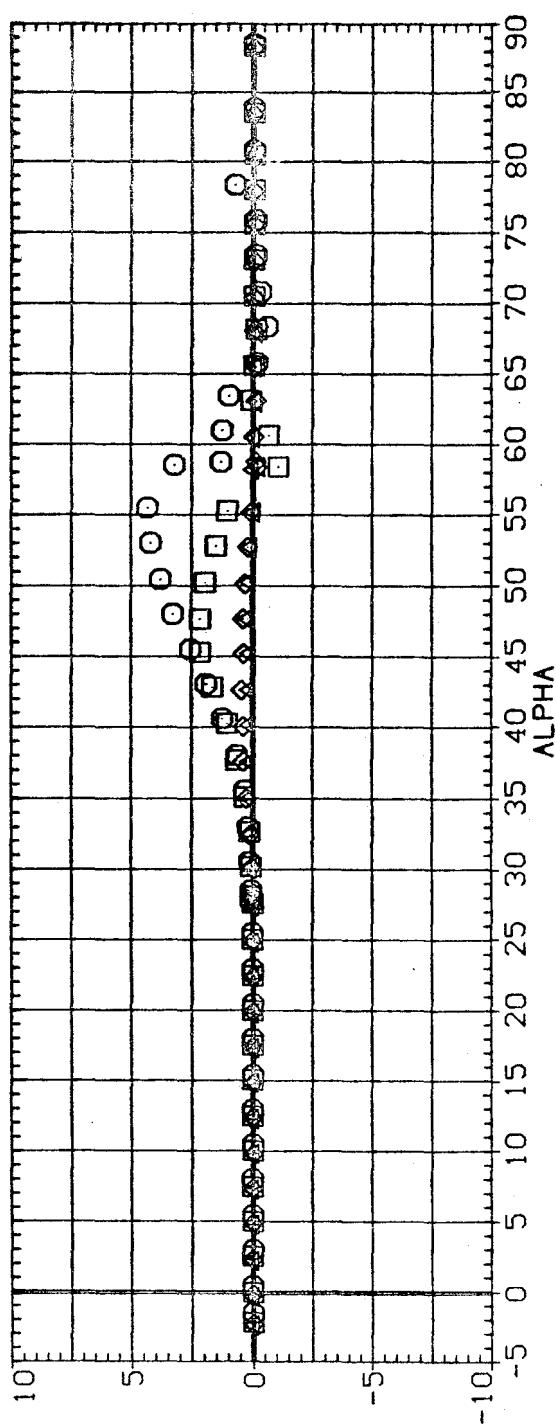


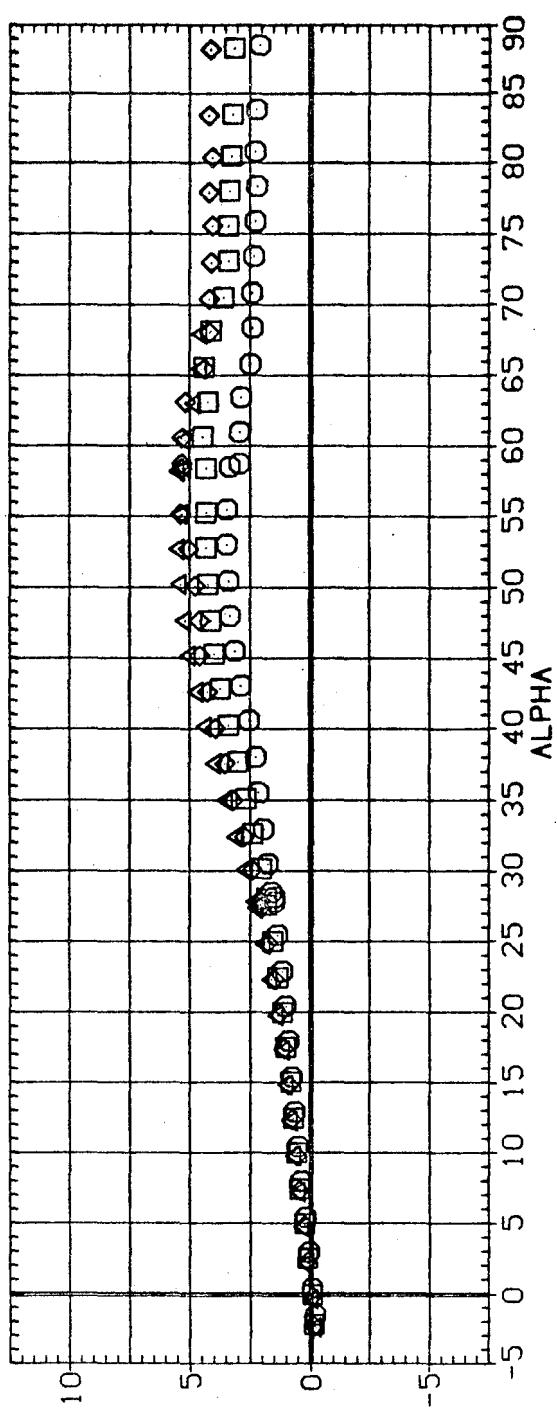
FIG. 4 L/D=3.5 TAN. 0GIVE, EFFECT OF MACH NUMBER, SUBSONIC

FT3.5

.251 R .750  
.602  
.800  
.905  
○□◊△



CLM



CYN

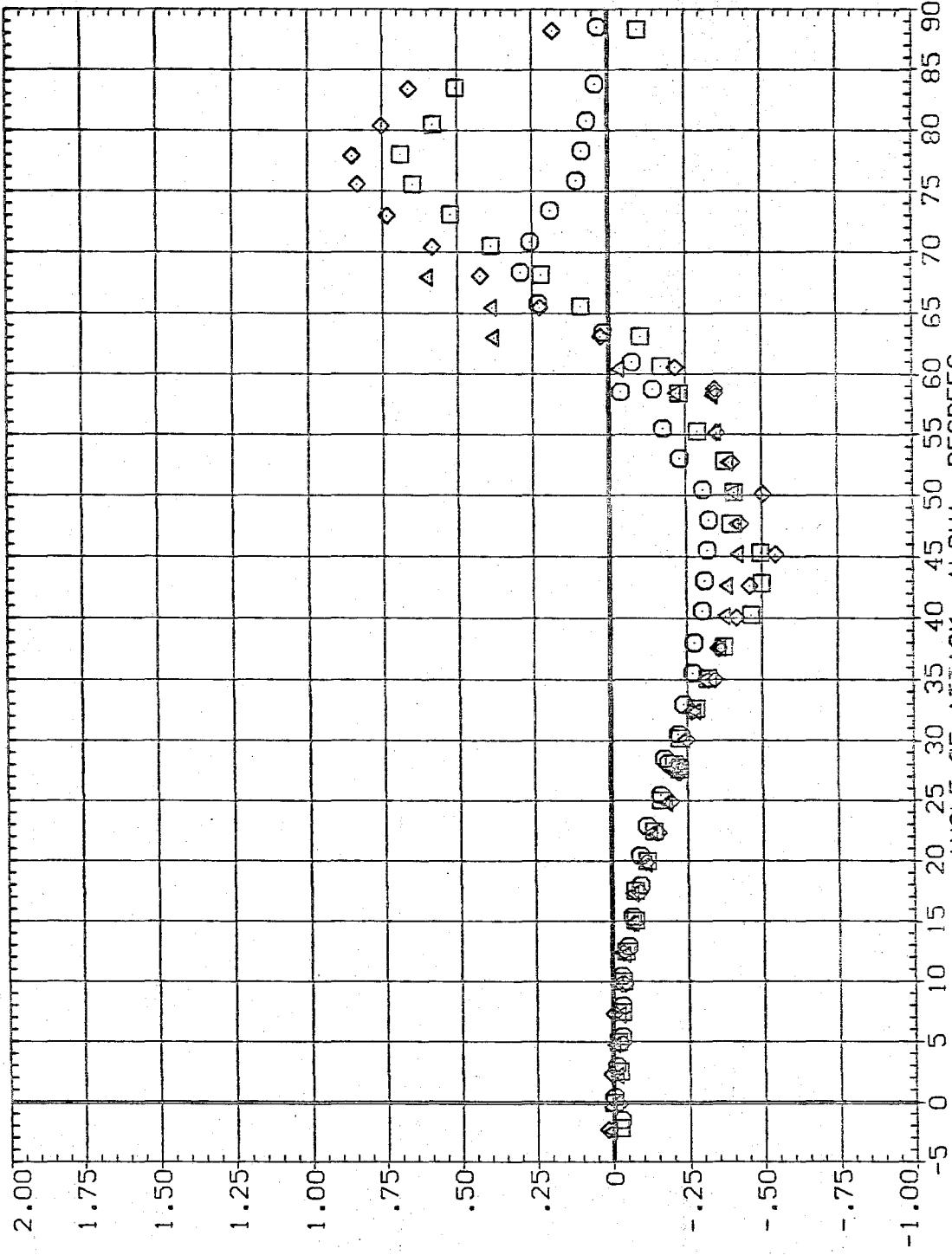
FIG.4 L/D=3.5 TAN. 0GIVE, EFFECT OF MACH NUMBER, SUBSONIC

FT3.5

(RJD/C01)

SYMBOL	MACH	R
○	.251	R
□	.602	
◊	.800	
△	.905	

PARAMETRIC VALUES



FORREBODY AXIAL FORCE COEFFICIENT, CAF

FIG. 4 L/D=3.5 TAN. 06IVE, EFFECT OF MACH NUMBER, SUBSONIC

FT 3.5

[AJDC01]

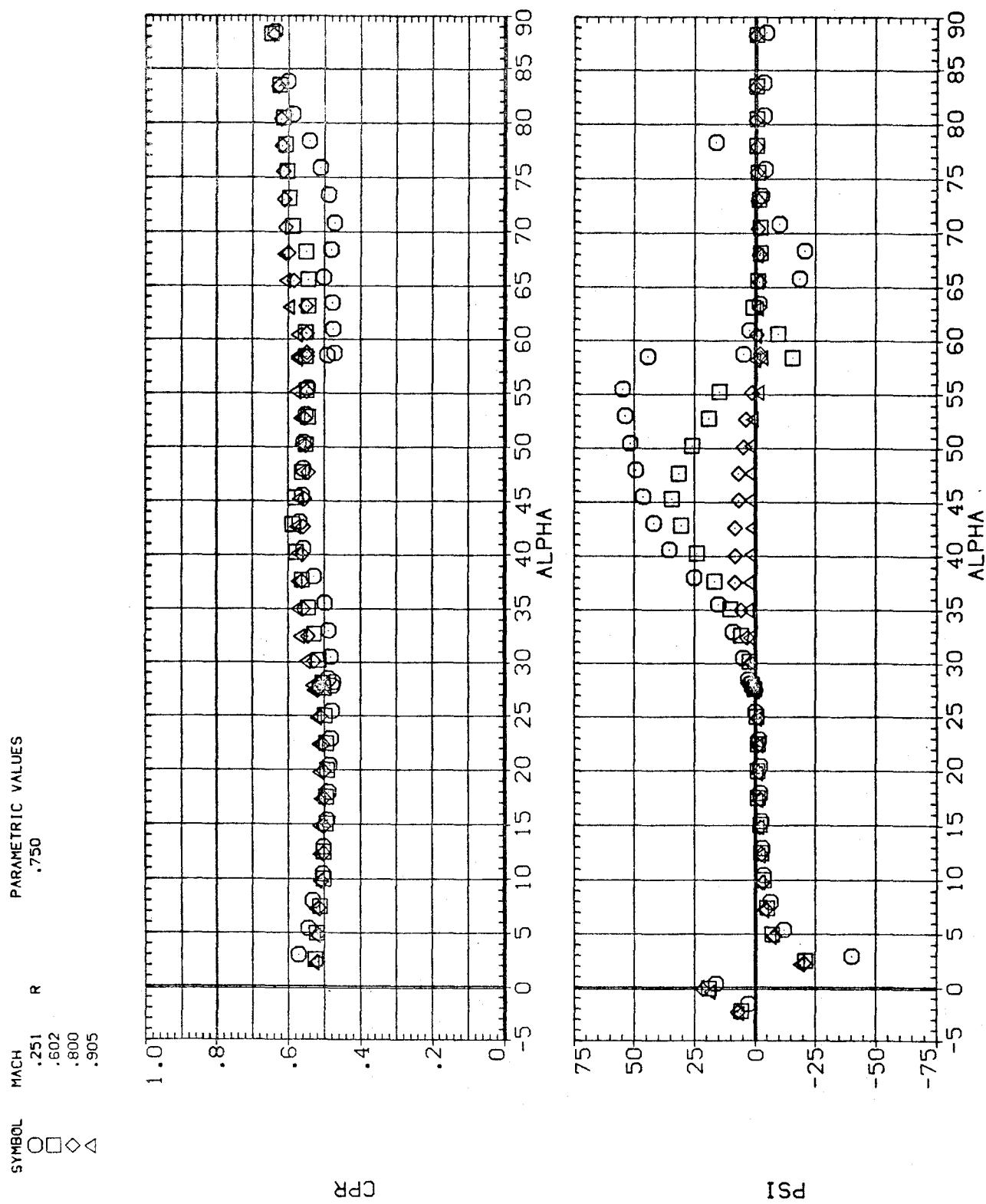
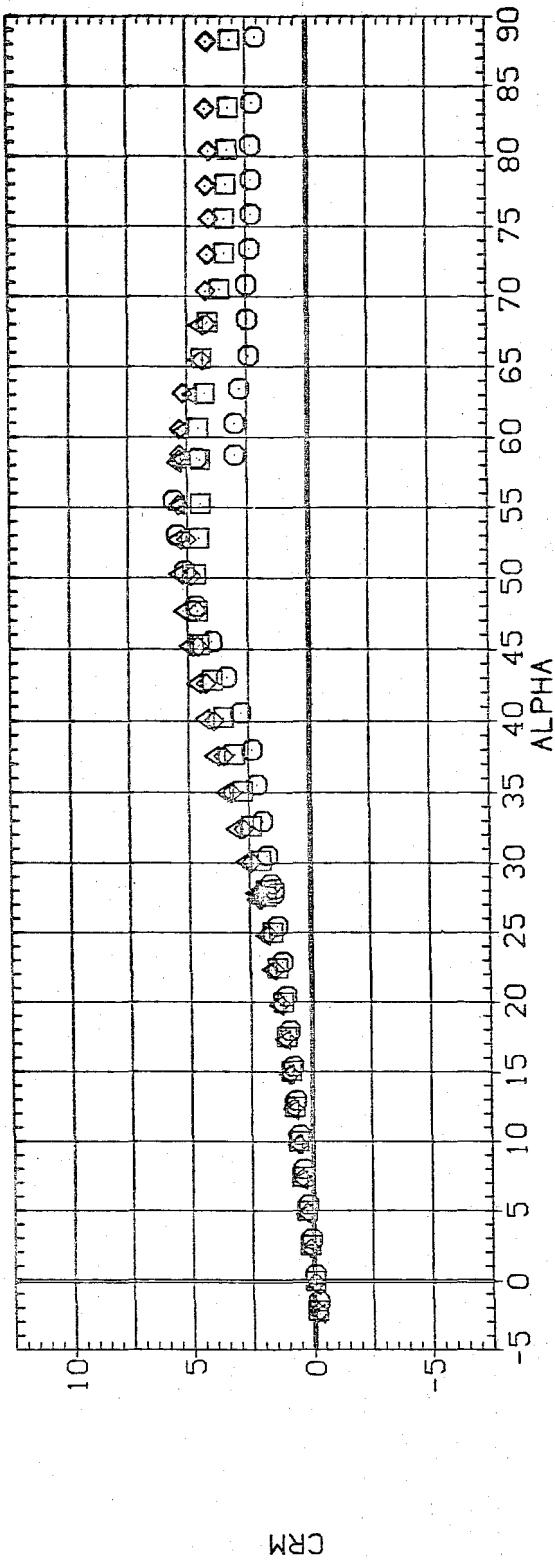


FIG.4 L/D=3.5 TAN. OGIVE, EFFECT OF MACH NUMBER, SUBSONIC

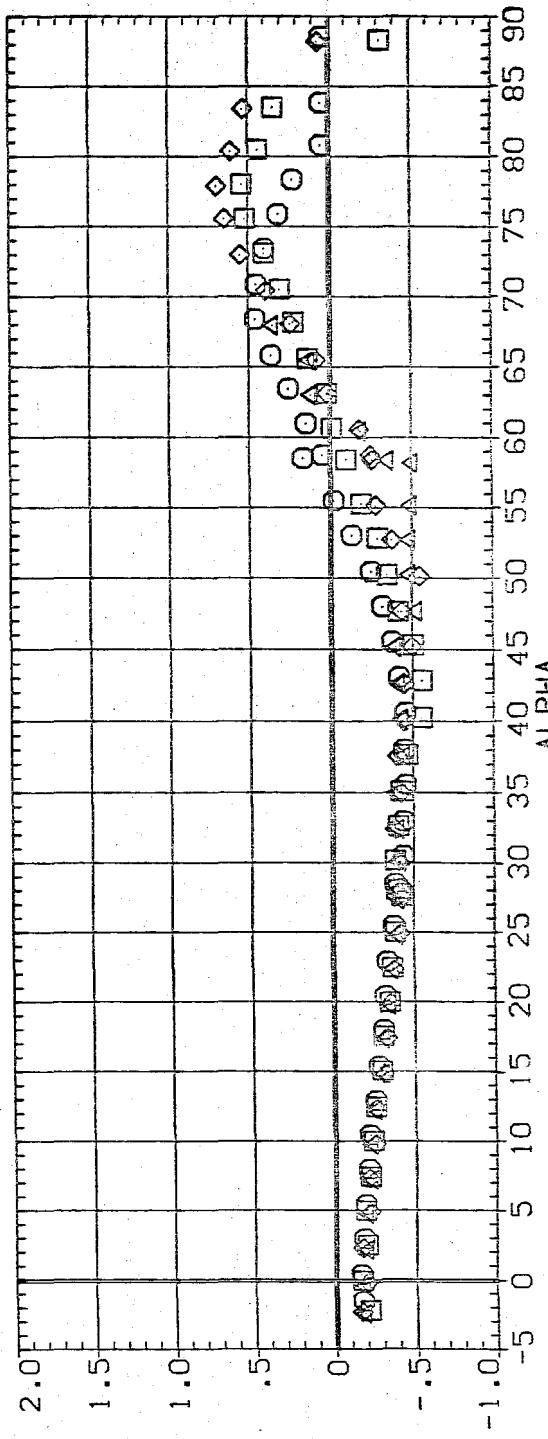
FT3.5

(AJDC01)

SYMBOL	MACH	R	PARAMETRIC VALUES
○	.251	R	.750
□	.602		
◊	.800		
△	.905		



$C_L$



$C_D$

FIG.4  $L/D=3.5$  TAN. OGIVE, EFFECT OF MACH NUMBER, SUBSONIC.

FIG.5

(RJDG01)

PARAMETRIC VALUES  
MACH      R  
1.195    .750  
1.506  
1.993

SIDE FORCE COEFFICIENT, CY

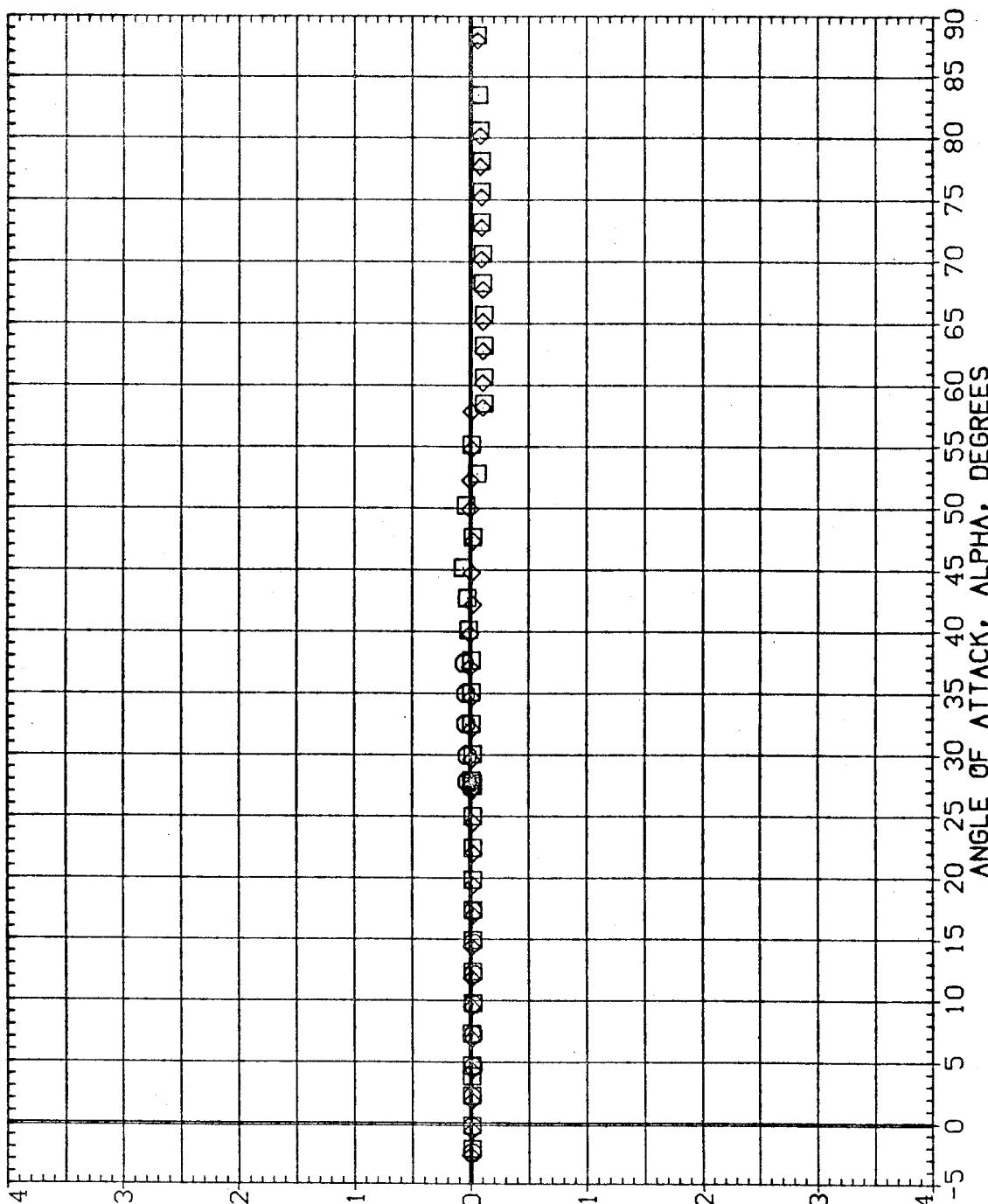


FIG.5 L/D=3.5 TAN. 0611, EFFECT OF MACH NUMBER, SUPERSONIC

FT3.5

(RJOC01)

SYMBOL      MACH      R      PARAMETRIC VALUES  
○      1.195      .750  
□      1.506  
◊      1.993

6.0

5.5

5.0

4.5

4.0

3.5

3.0

2.5

2.0

1.5

1.0

.5

0

-5

NORMAL FORCE COEFFICIENT, CN

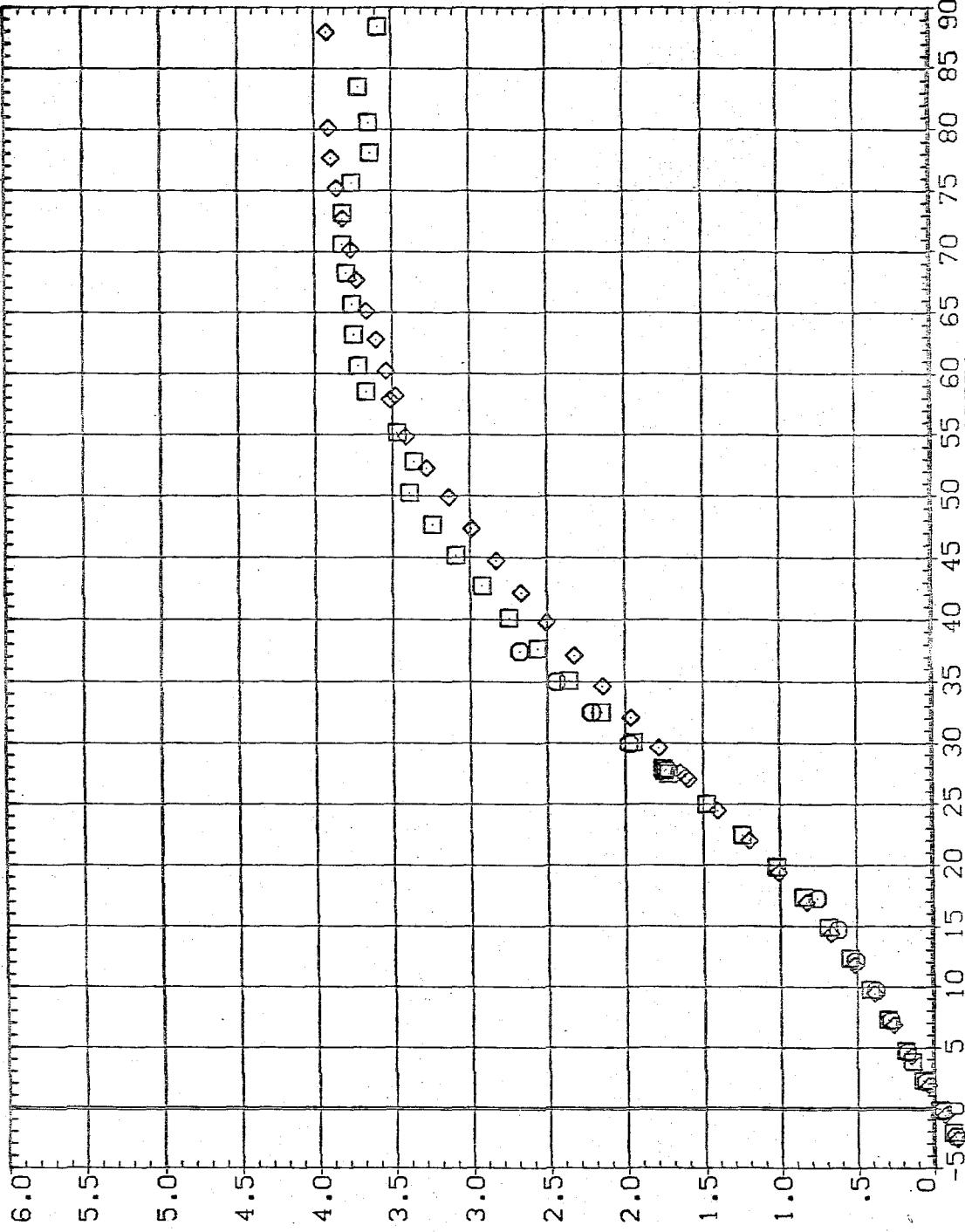


FIG.5 L/D=3.5 TAN ogive, EFFECT OF MACH NUMBER, SUPERSONIC

FIG. 5

SYMBOL	MACH	R
○	1.195	.750
□	1.506	1.993
◊		

FIGURE 5

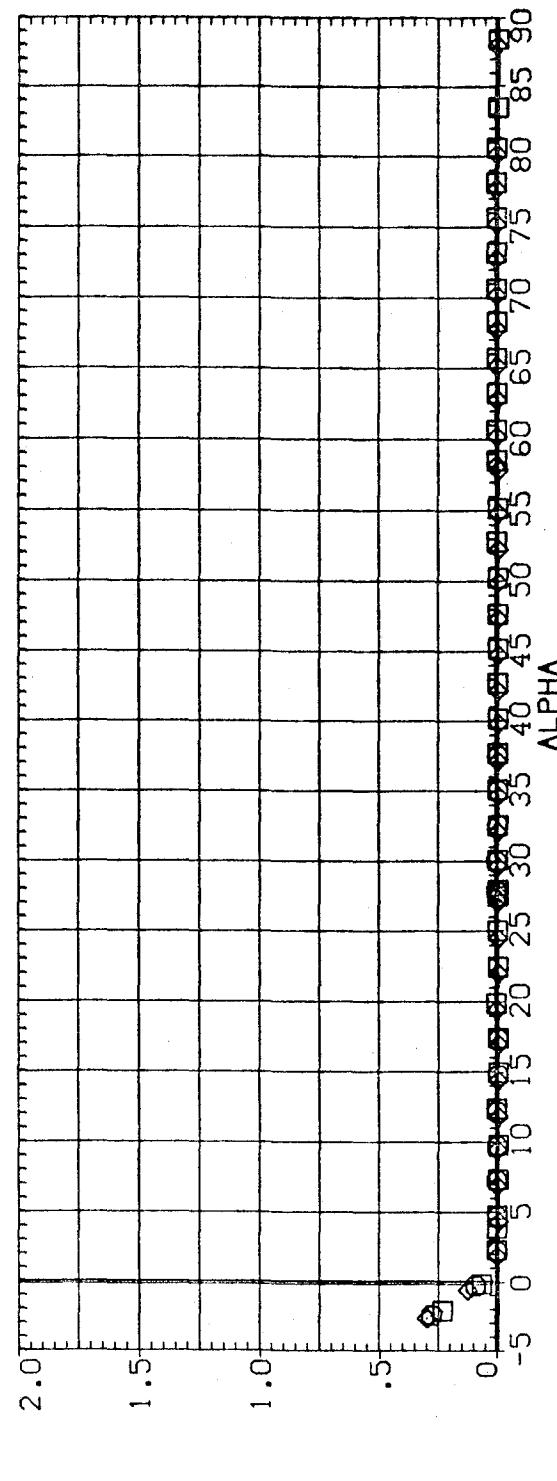
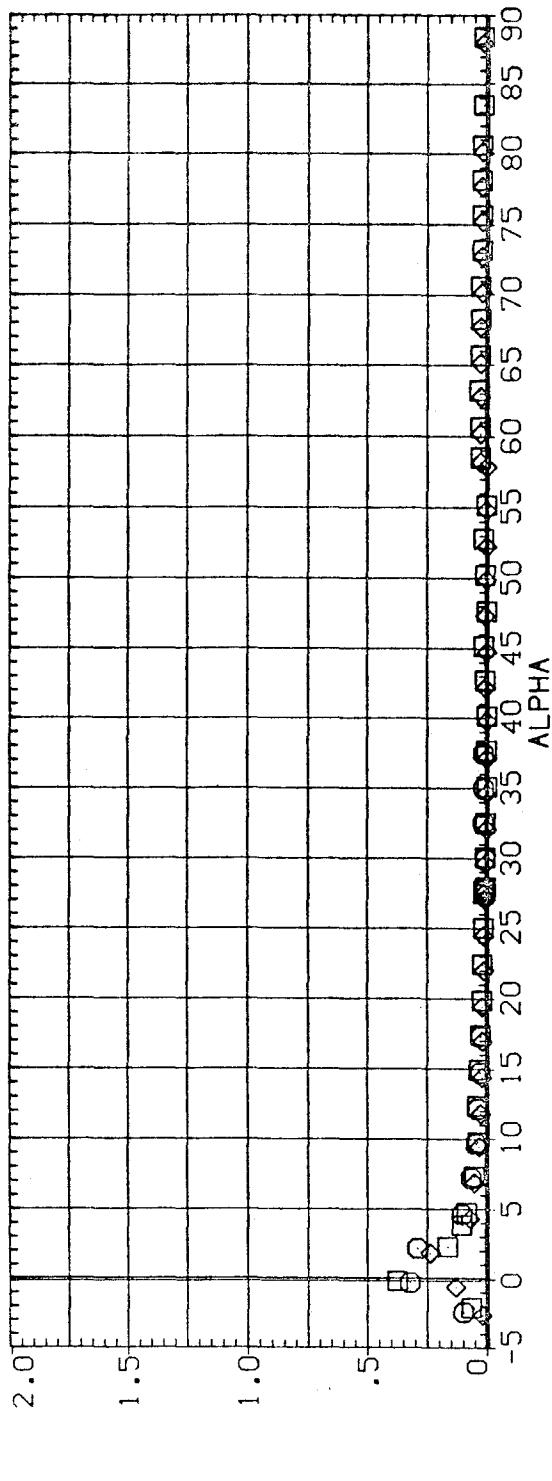


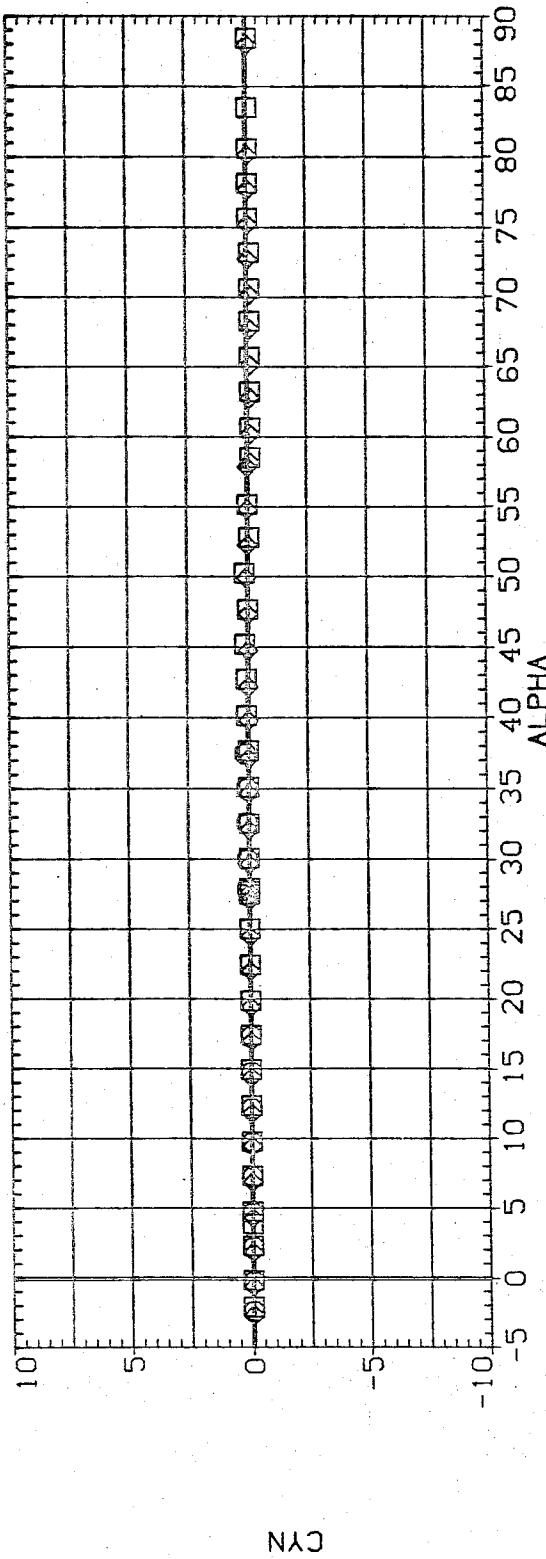
FIG. 5 L/D=3.5 TAN. GIVE, EFFECT OF MACH NUMBER, SUPERSONIC

FT3.5

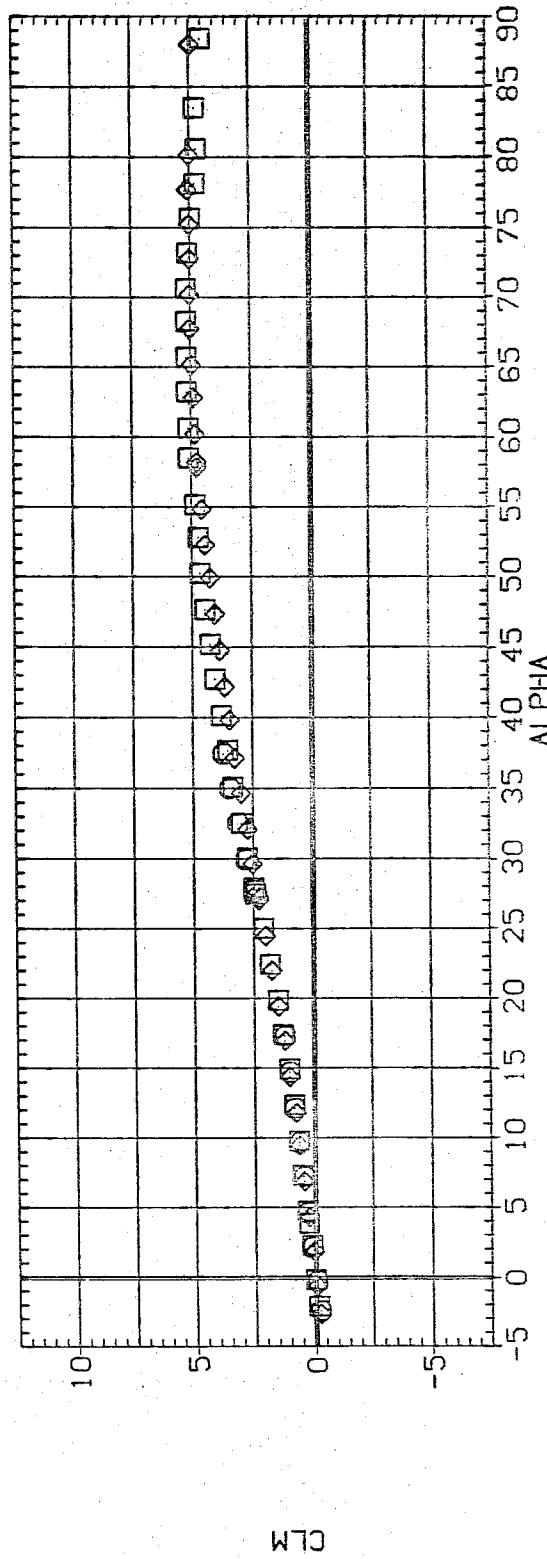
(RJD001)

PARAMETRIC VALUES  
MACH R  
1.195 .750  
1.506  
1.993

SYMBOL  
○ □ ◊



CYN



CL2

FIG.5 L/D=3.5 TAN. GIVE, EFFECT OF MACH NUMBER, SUPERSONIC

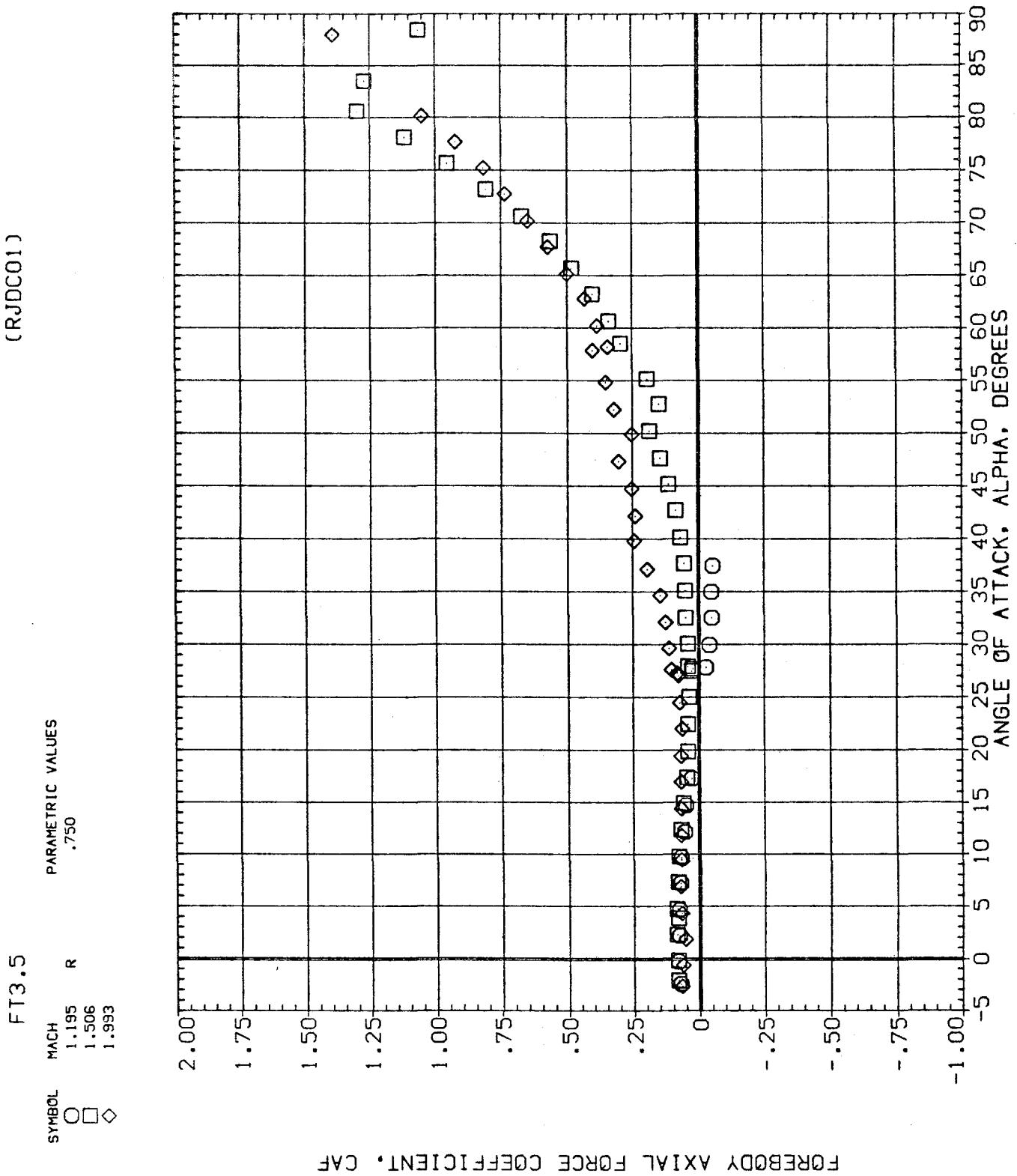


FIG.5 L/D=3.5 TAN. 0GIVE, EFFECT OF MACH NUMBER, SUPERSONIC

(AJDC01)

FT<sub>25</sub>

SYMBOL	MACH	R	PARAMETRIC VALUES
O	1.195	R	.750
□	1.506		
◊	1.993		

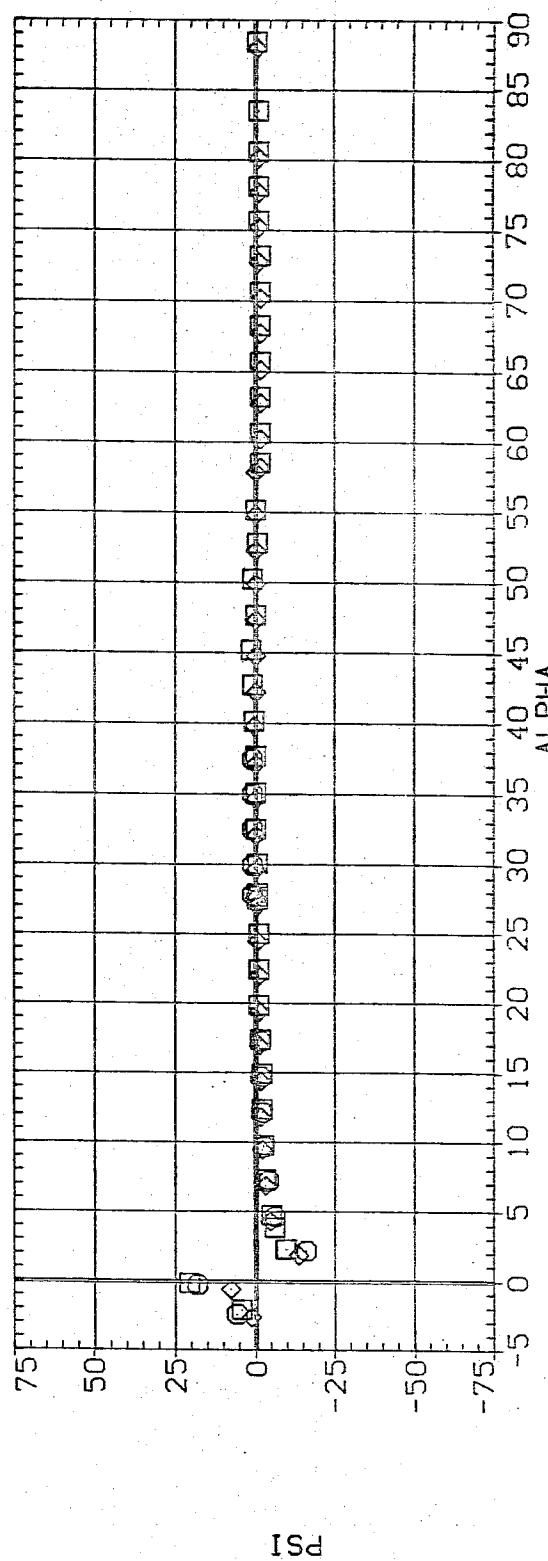
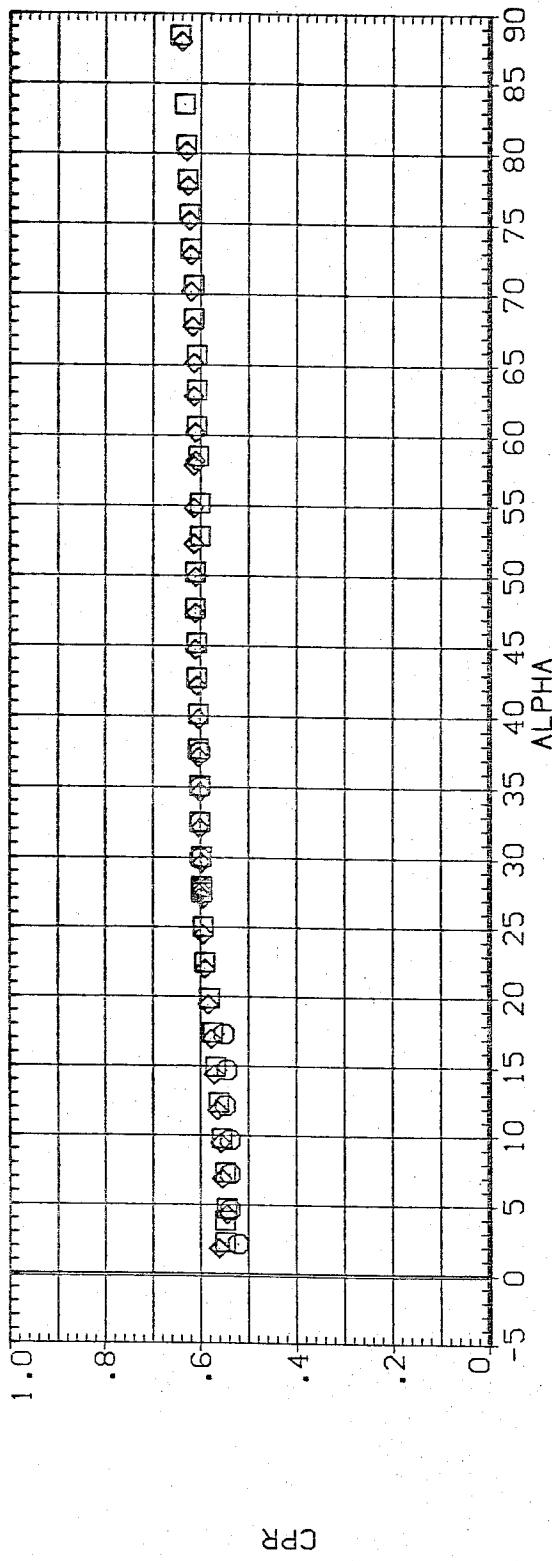


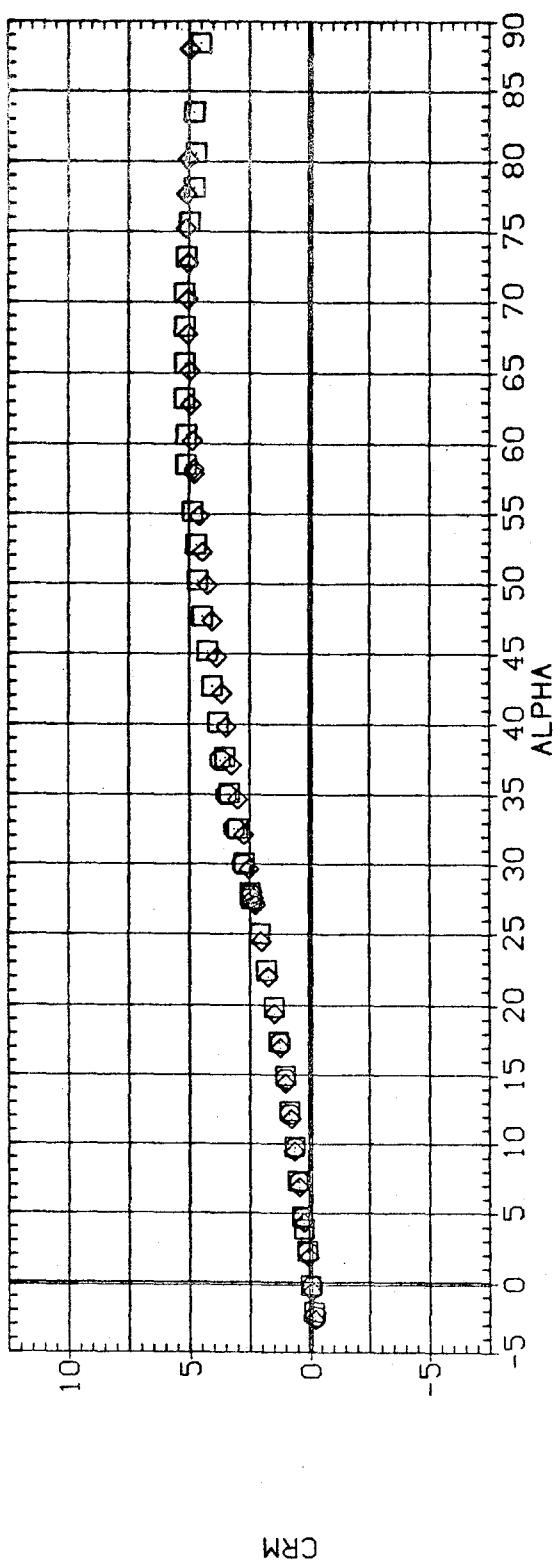
FIG.5 L/D=3.5 TAN. 061VE, EFFECT OF MACH NUMBER, SUPERSONIC

FT3.5

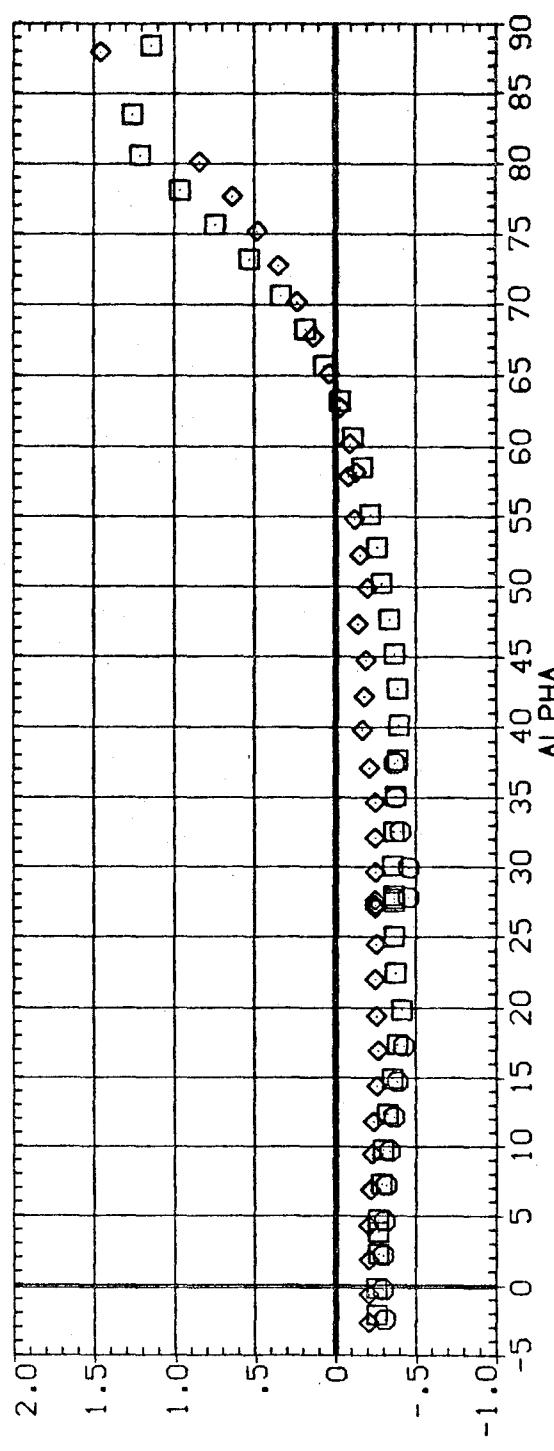
(AJDC01)

SYMBOL	MACH	R
○	1.195	
□	1.506	
◇	1.993	

PARAMETRIC VALUES

R  
.750

CR2

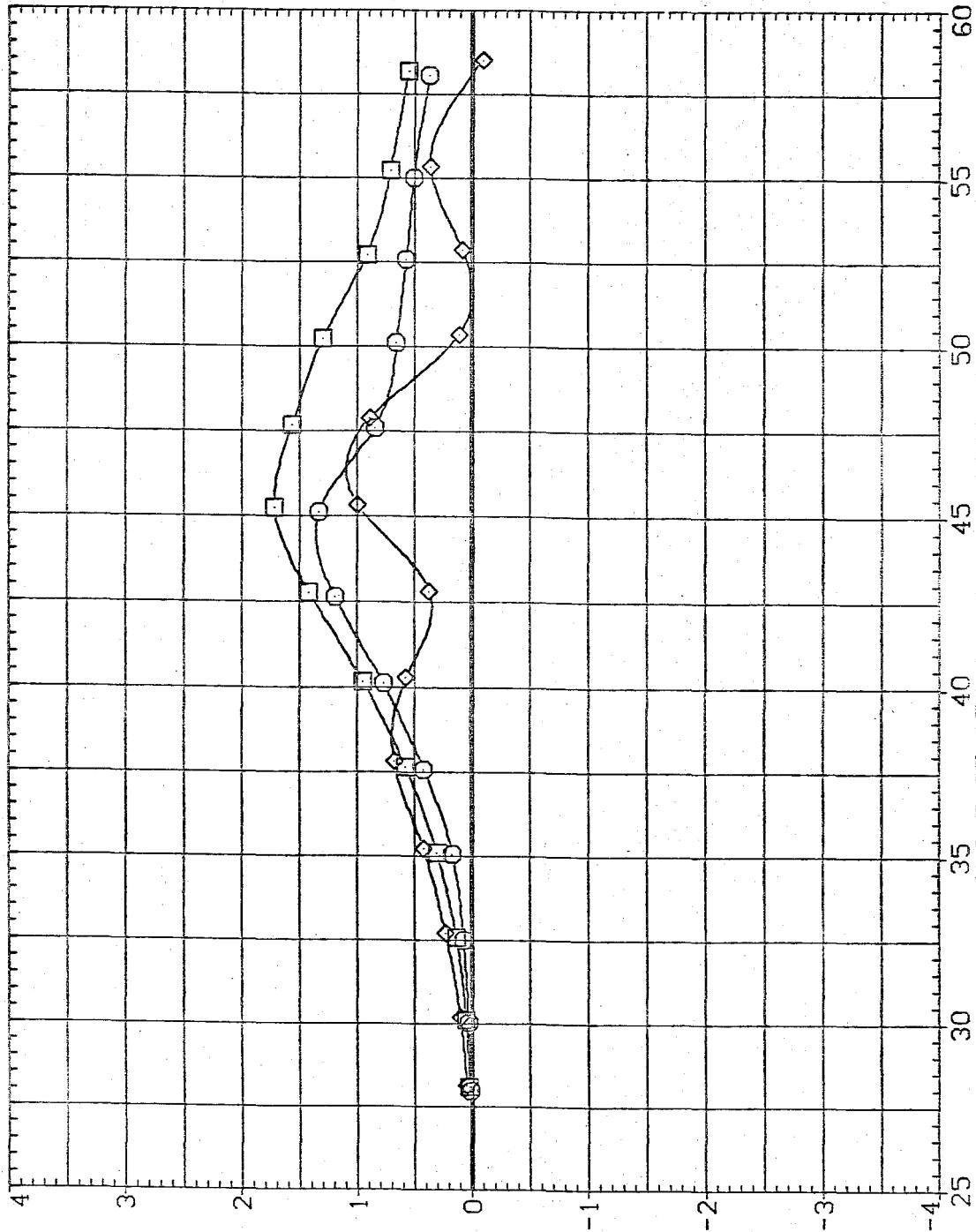


CPB

FIG.5 L/D=3.5 TAN. OGIVE, EFFECT OF MACH NUMBER, SUPERSONIC

DATA SET SYMBOL      CONFIGURATION DESCRIPTION  
 [CRJDA13]      FT3.5  
 [CRJDA14]      FT3.5  
 [CRJDA12]      FT3.5

R      BETA  
 .400      .000  
 .750      .000  
 1.750      .000



SIDE FORCE COEFFICIENT, C<sub>y</sub>

FIG. 6 L/D=3.5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER  
 (A) MACH = .60

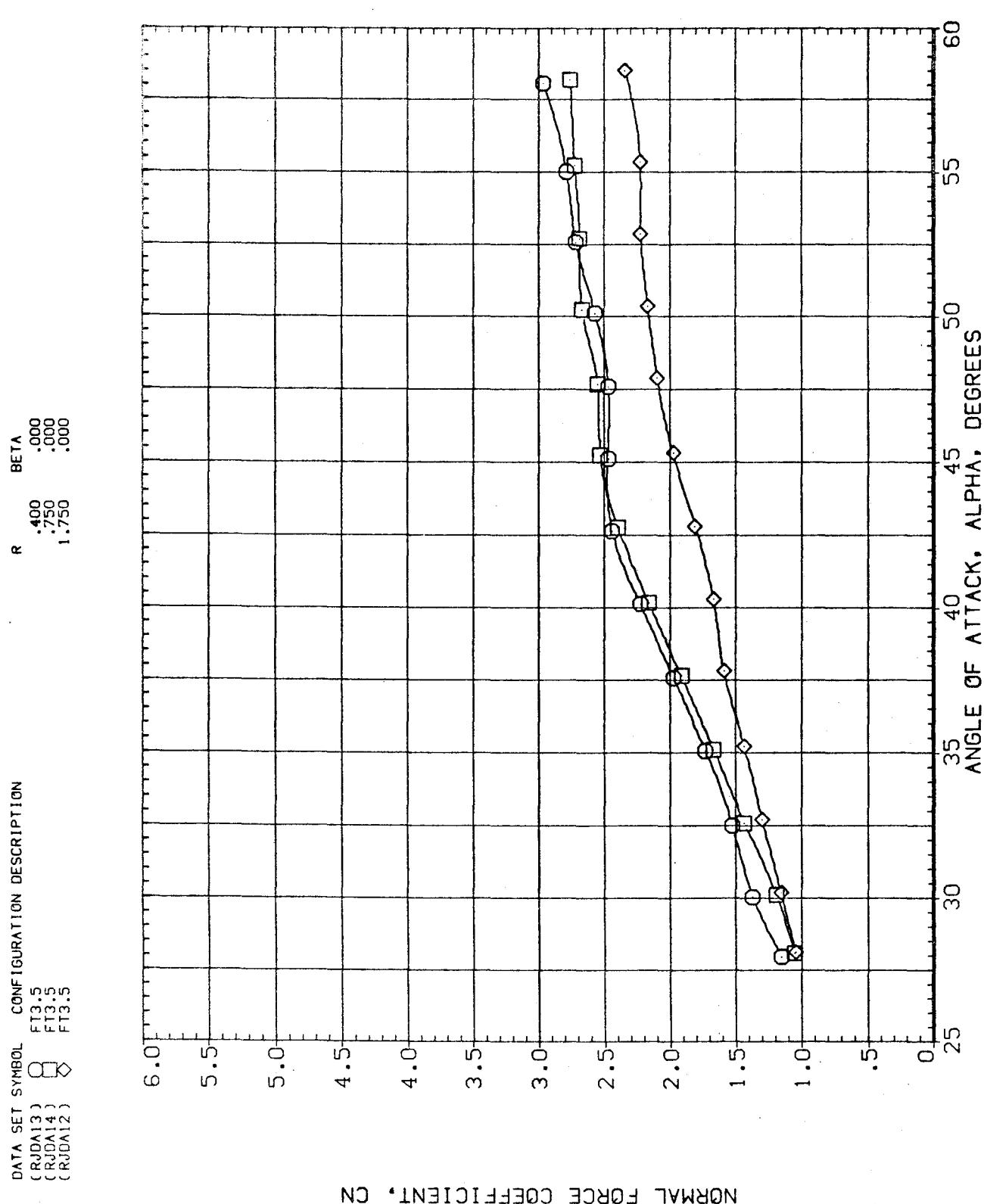


FIG. 6 L/D=3.5 TAN. 0GIVE, EFFECT OF REYNOLDS NUMBER

(A)MACH = .60

DATA SET SYMBOL CONFIGURATION DESCRIPTION

(CRUDA13)	○	FT3.5
(CRUDA14)	□	FT3.5
(CRUDA12)	◇	FT3.5

R      BETA

.400	.000
.750	.000
1.750	.000

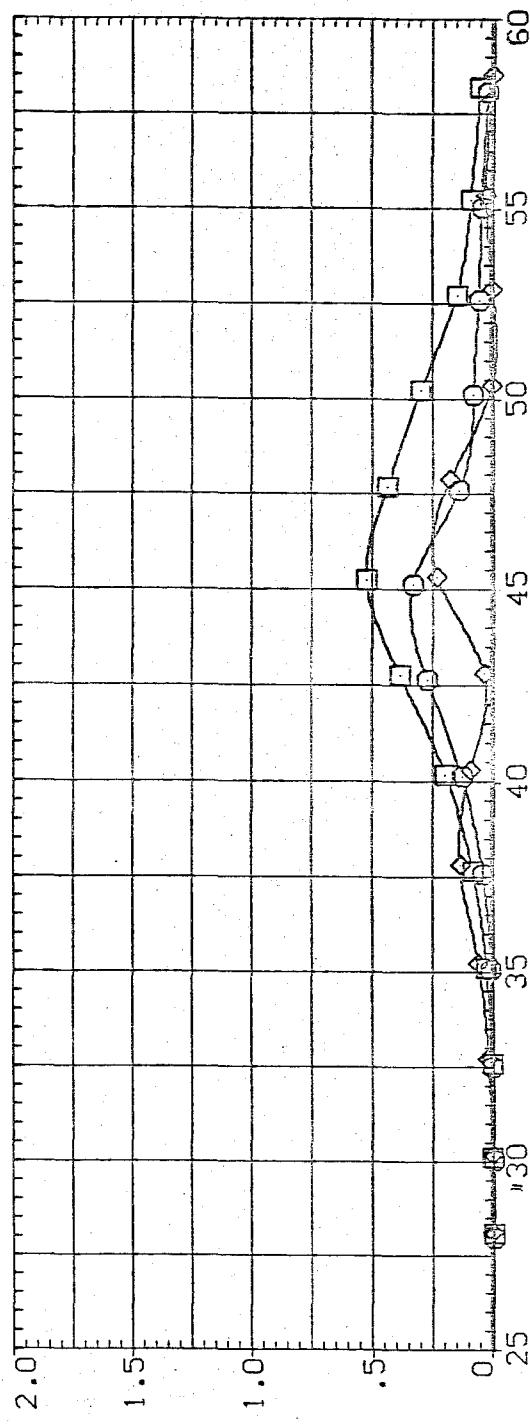
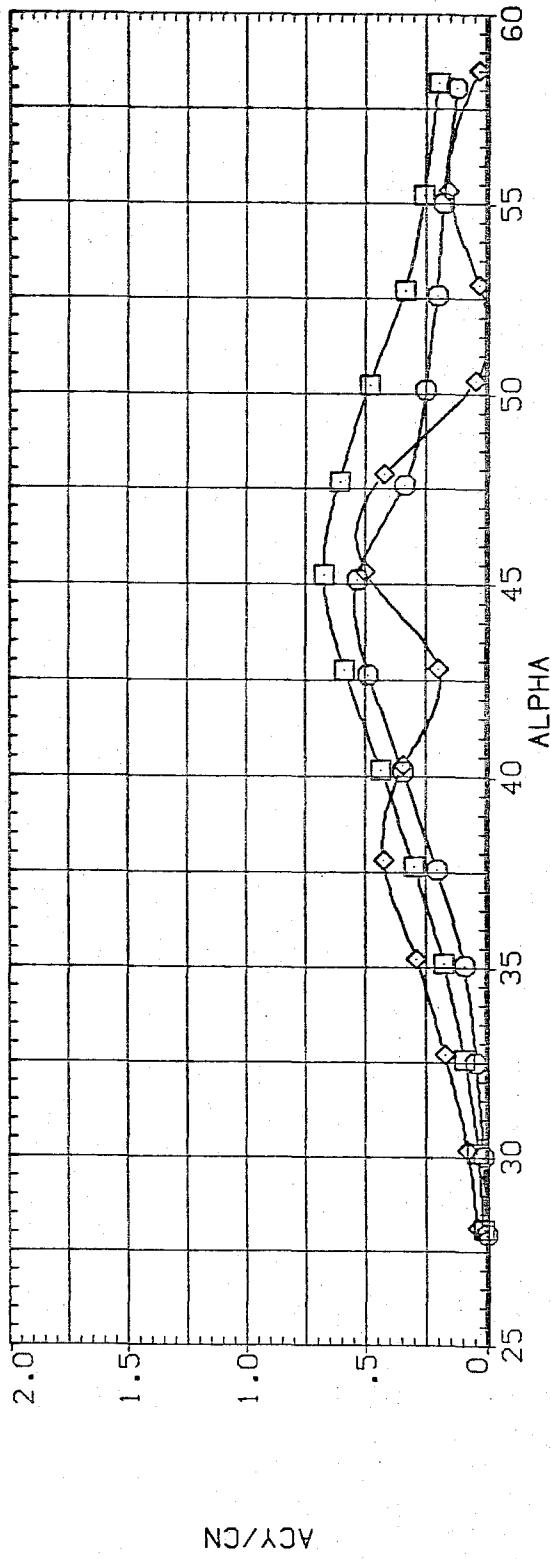
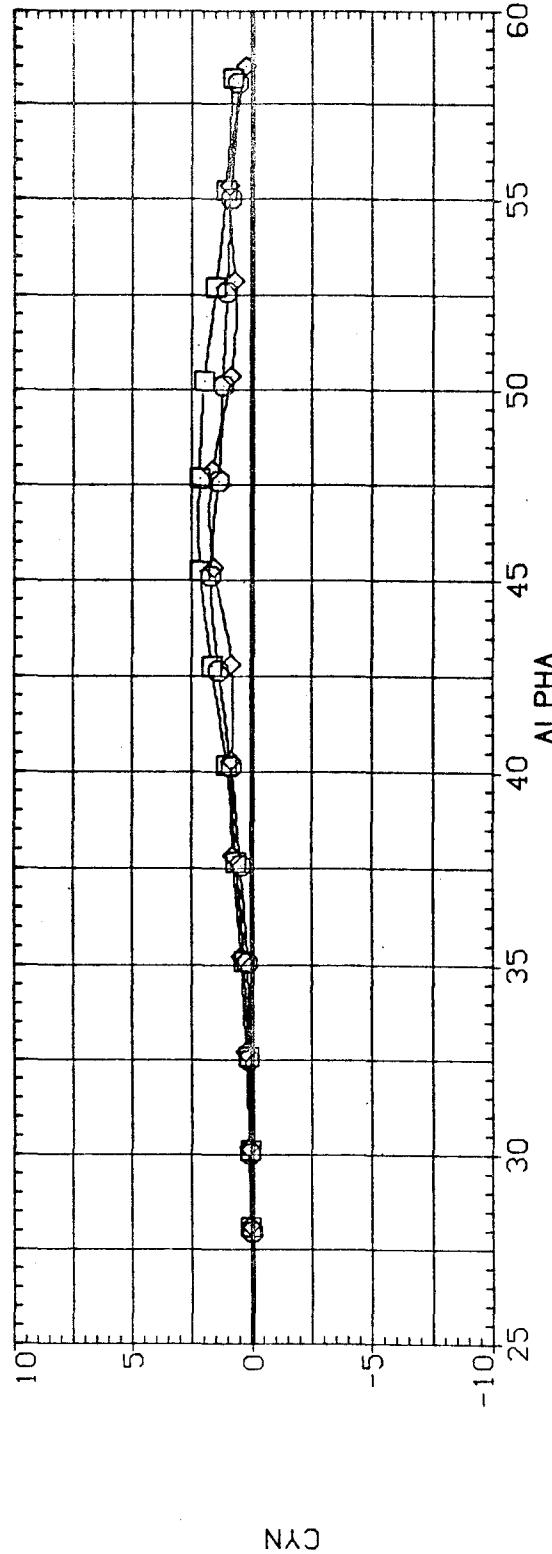


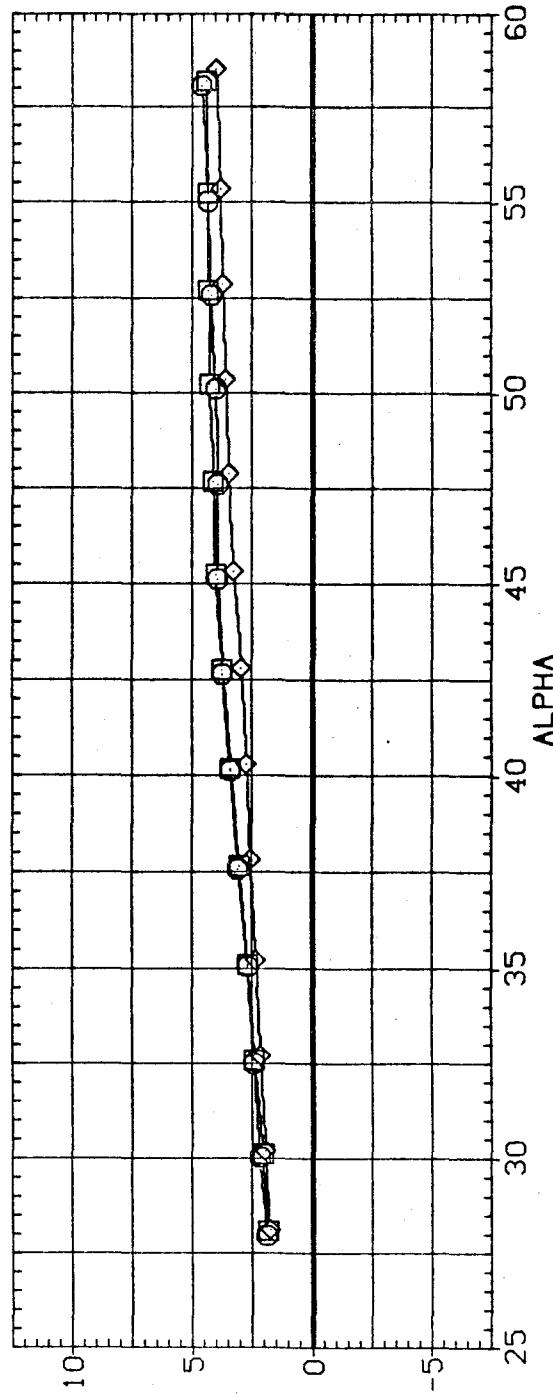
FIG. 6 L/D=3.5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER  
 $(\Delta)_{MACH} = .60$

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
 (RJDAA13) FT3.5  
 (RJDAA14) FT3.5  
 (RJDAA12) FT3.5

R .400 .000  
 .750 .000  
 1.750 .000



CLM



CYN

FIG.6 L/D=3.5 TAN. 06IVE, EFFECT OF REYNOLDS NUMBER

(A)MACH = .60

PAGE 18

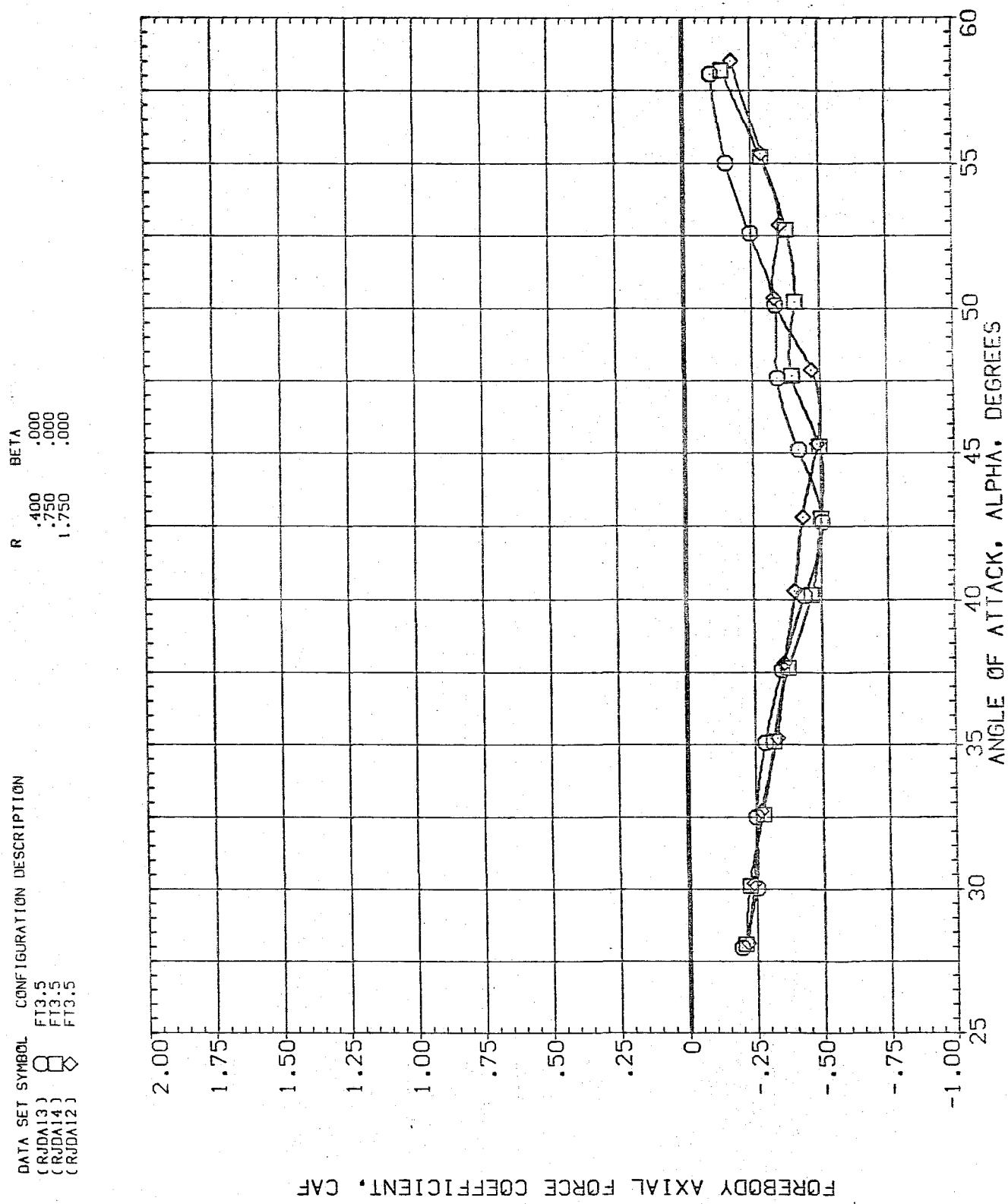


FIG. 6 L/D=3.5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
 ( AJD013 ) FT3.5  
 ( AJD014 ) FT3.5  
 ( AJD012 ) FT3.5

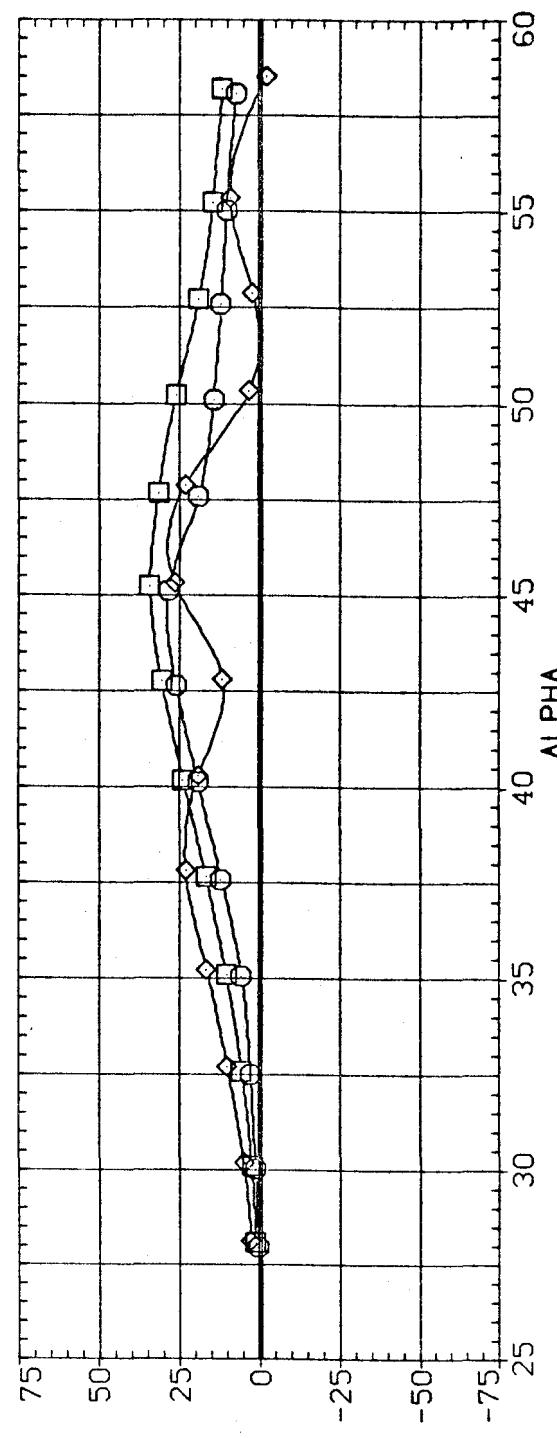
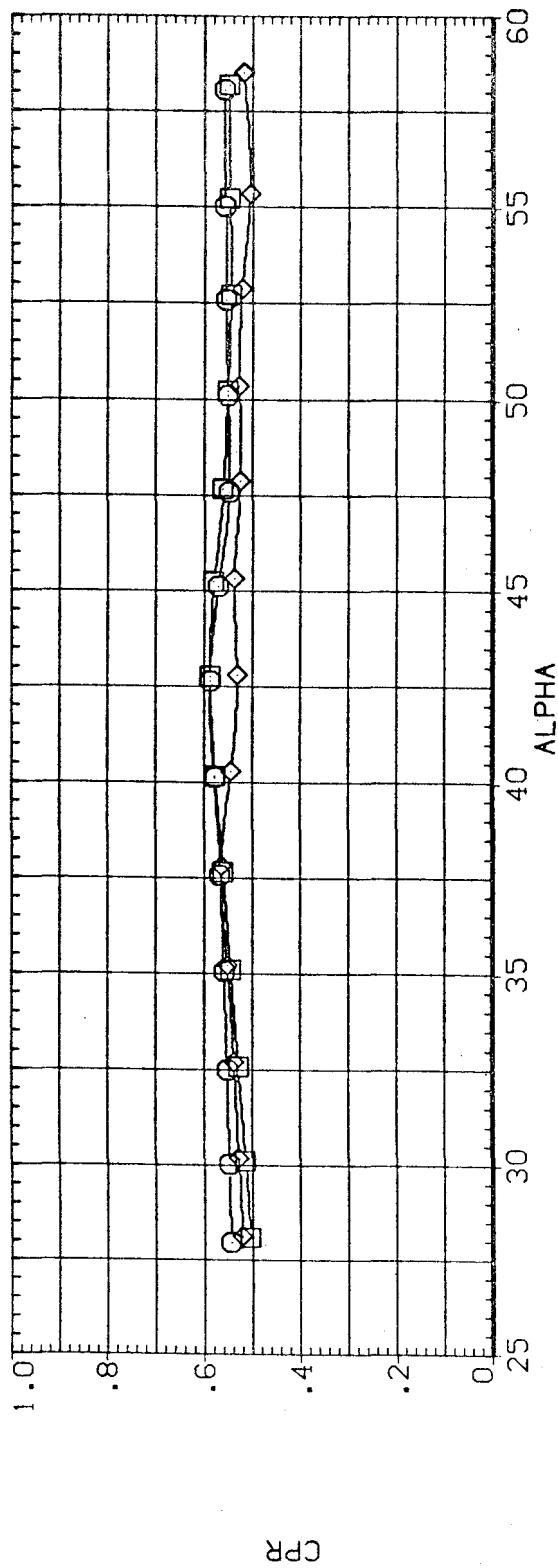
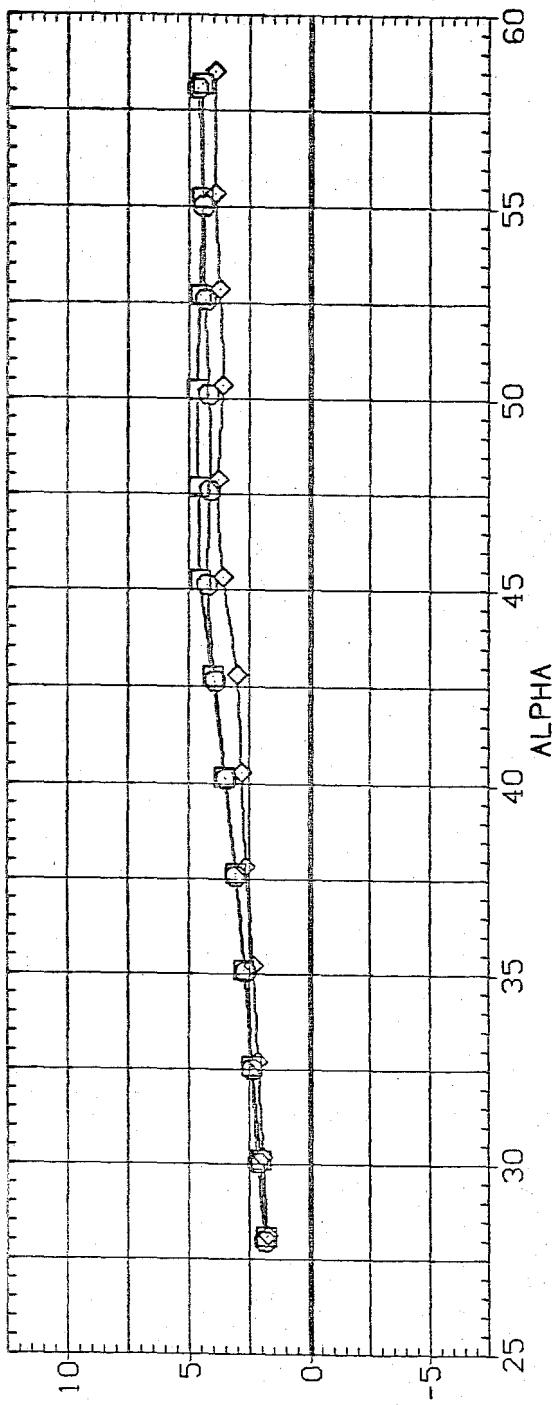


FIG.6 L/D=3.5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER  
 $(\Delta)_{MACH} = .60$

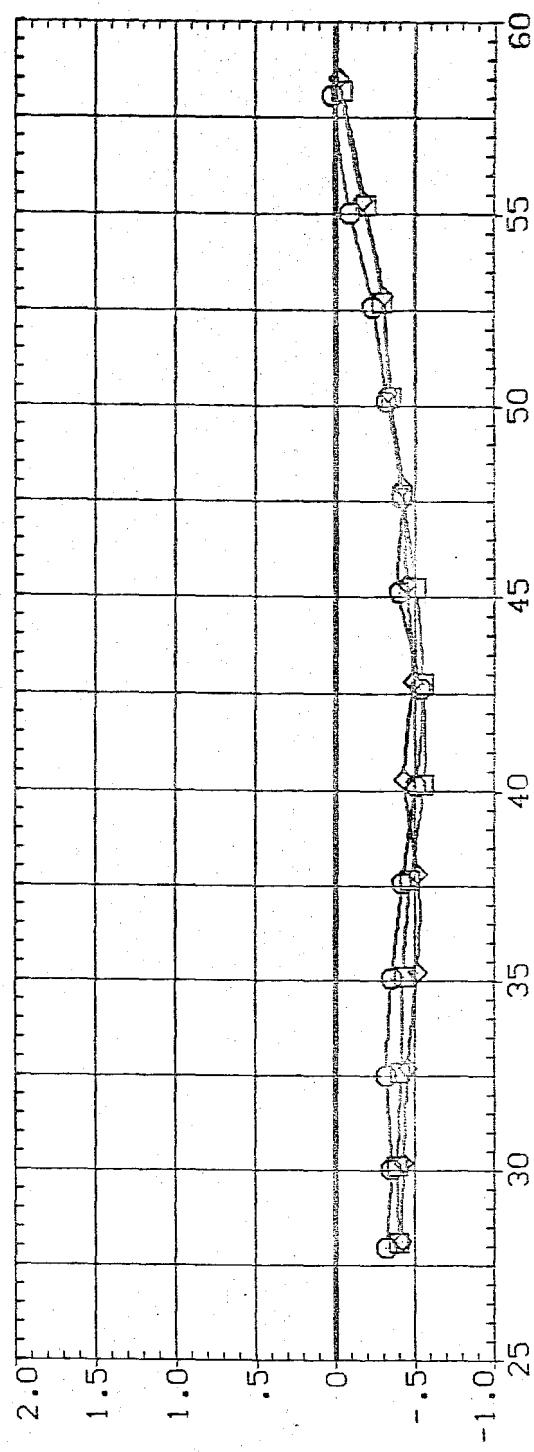
DATA SET SYMBOL CONFIGURATION DESCRIPTION

(AJD013)	FT3.5
(AJD014)	FT3.5
(AJD012)	FT3.5

R .400 .000  
R .750 .000  
R 1.750 .000



CPB



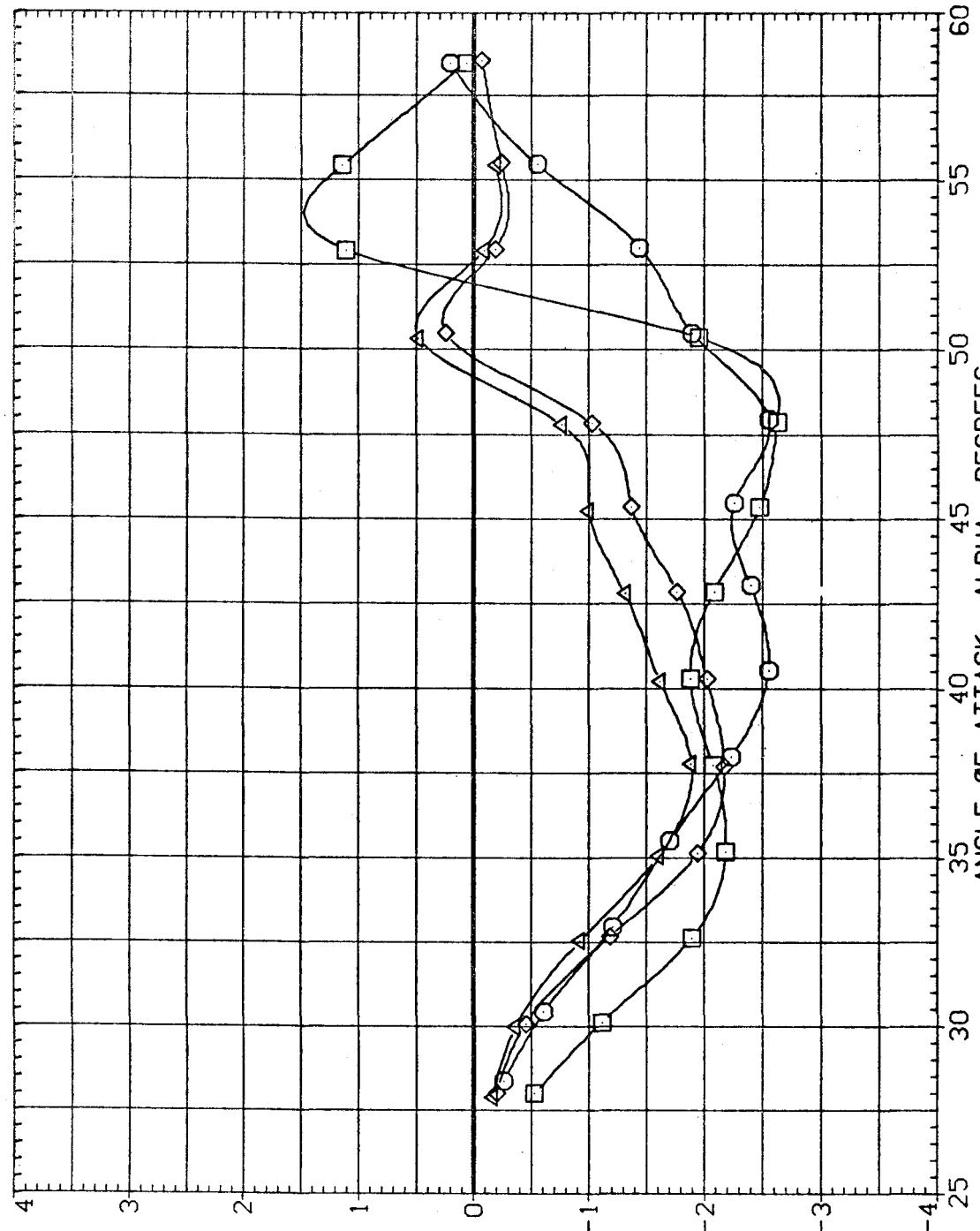
CPB

FIG.6 L/D=3.5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER

REYNOLDS NUMBER

(RJD/C24)

H 15  
PARAMETRIC VALUES  
MACH .253    BETA .000    R .750  
.600    .800    .904  
SYMBOL    ○    □    ◇    △



SIDE FORCE COEFFICIENT,  $C_y$

FIG. 7 L/D=5 TAN. 0611, EFFECT OF MACH NUMBER, SUBSONIC

FT5

(RJDC24)

PARAMETRIC VALUES	MACH	BETA	R
.000	.253	.600	.750
	.600	.800	
	.800	.904	
	.904		

SYMBOL

- 
- 
- ◊
- △

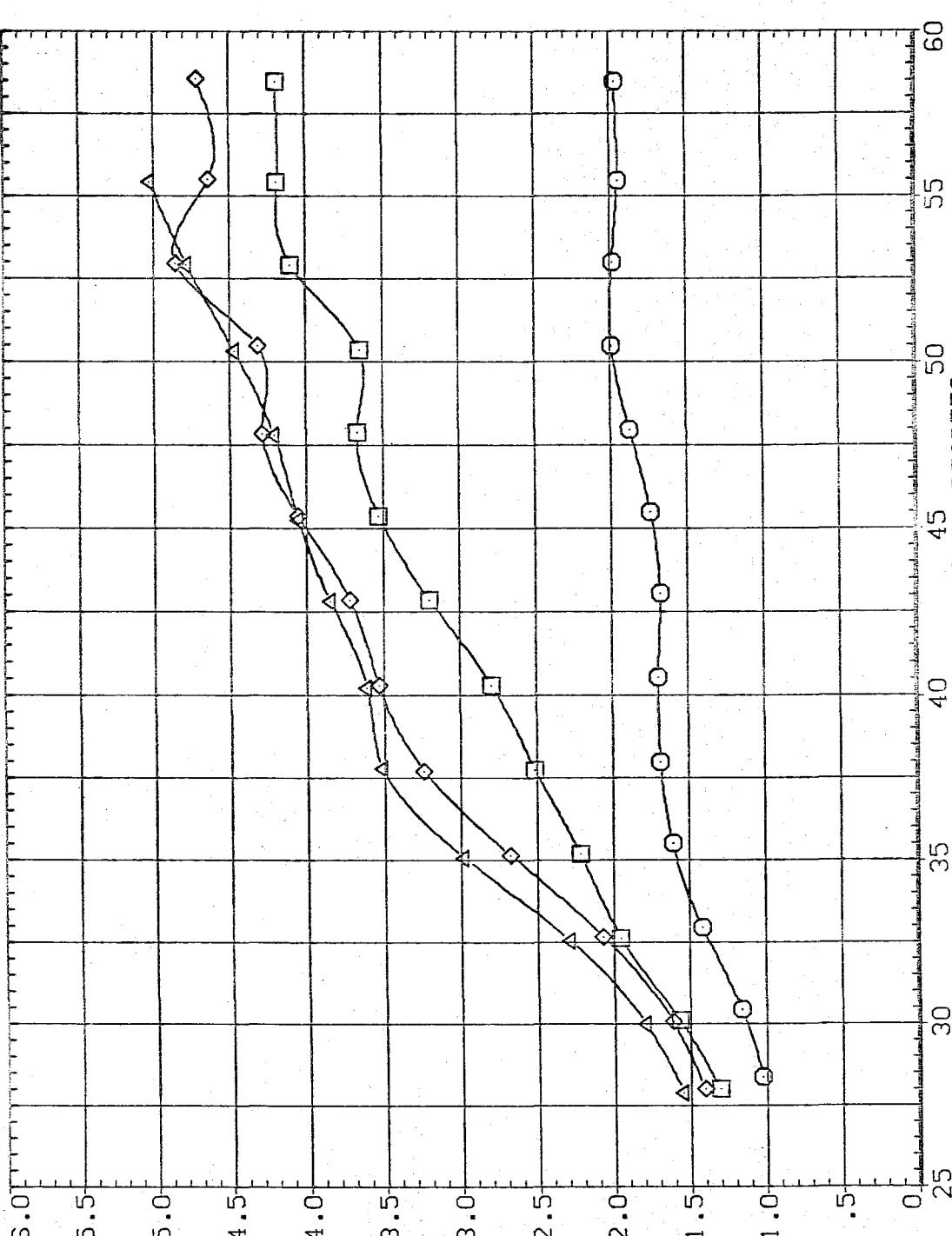
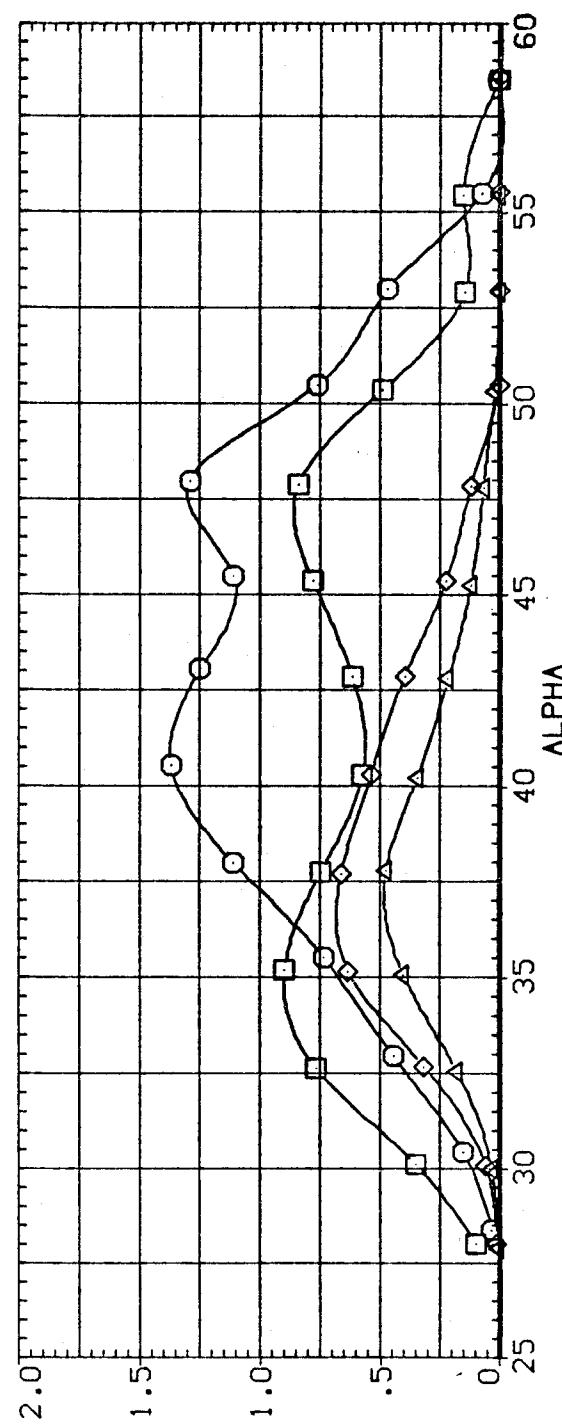
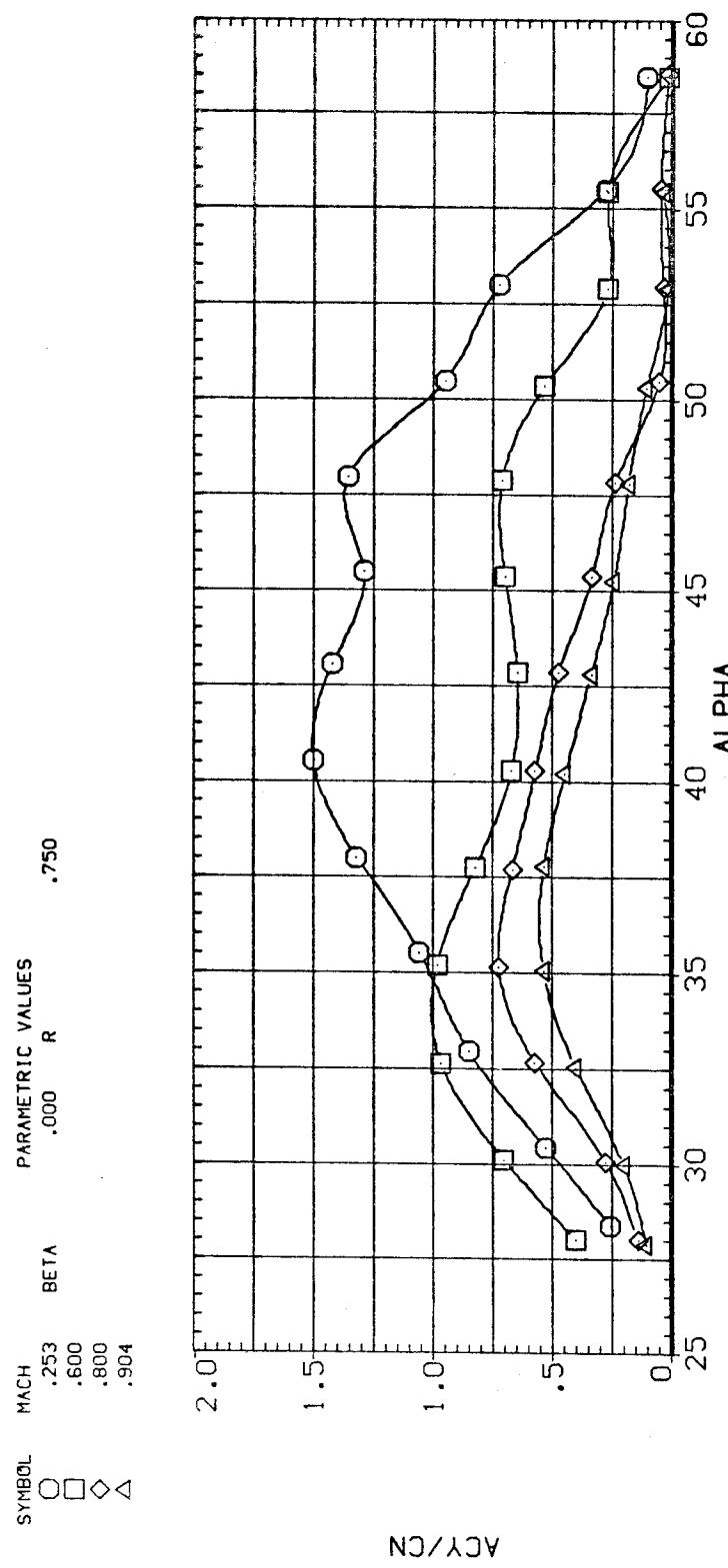
NORMAL FORCE COEFFICIENT,  $C_N$ 

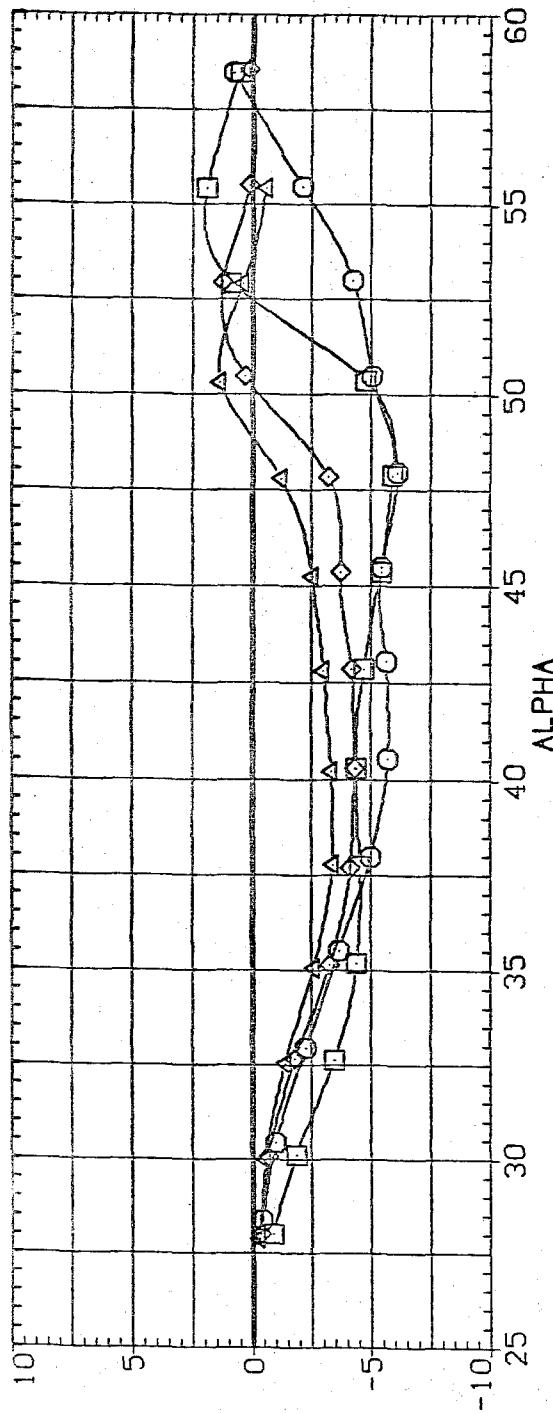
FIG. 7 L/D=5 TAN. OGIVE, EFFECT OF MACH NUMBER, SUBSONIC



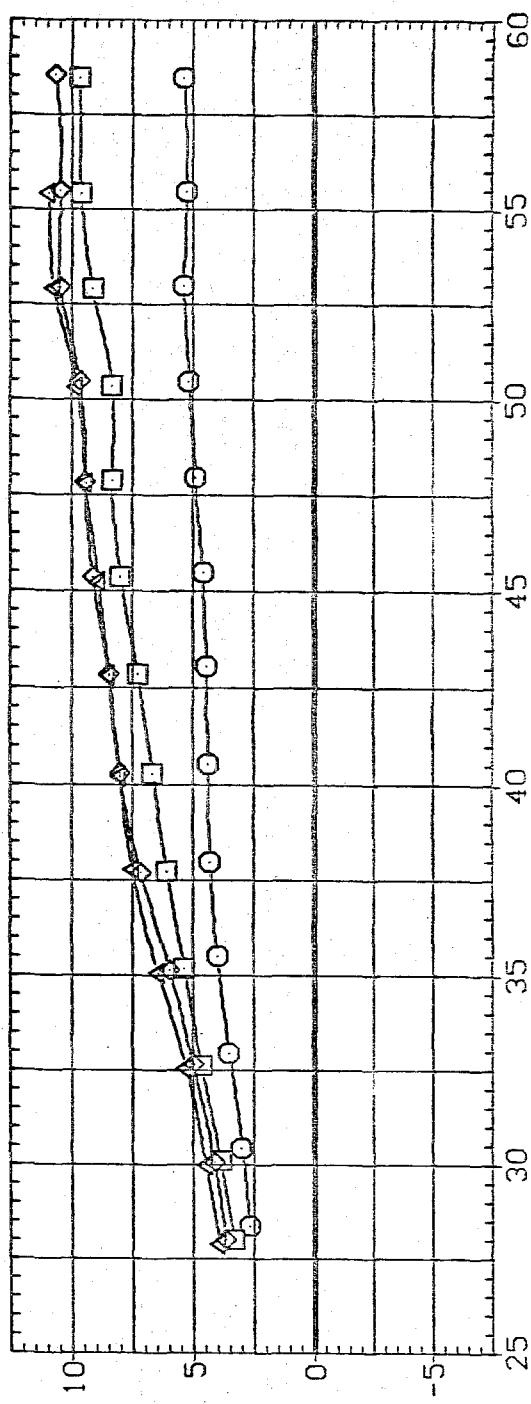
FT5

(RJD/C24)

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	.253	.000	R .750
□	.600		
◊	.800		
△	.904		



CYN



CLM

FIG.7 L/D=5 TAN. 0GIVE, EFFECT OF MACH NUMBER, SUBSONIC

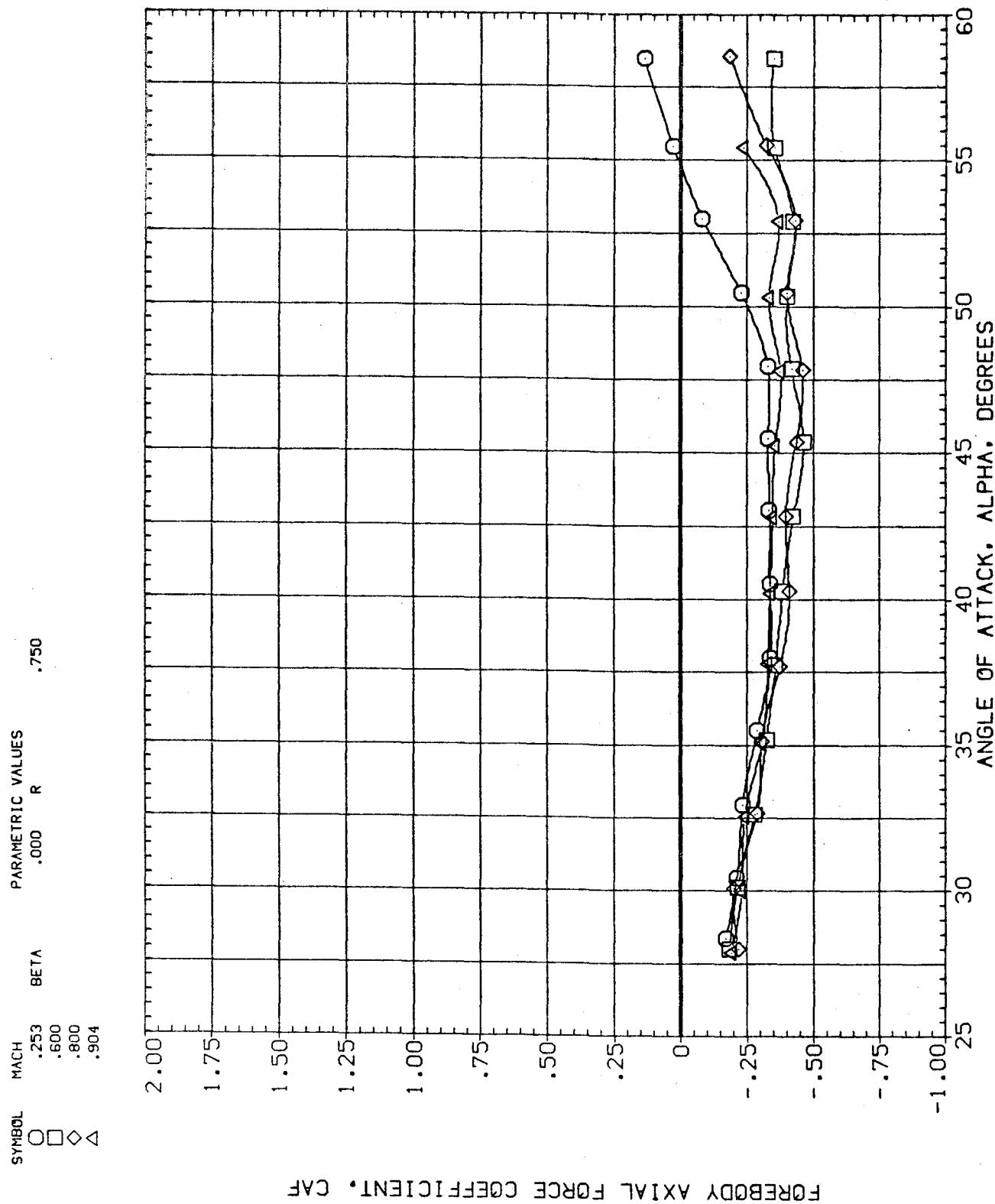
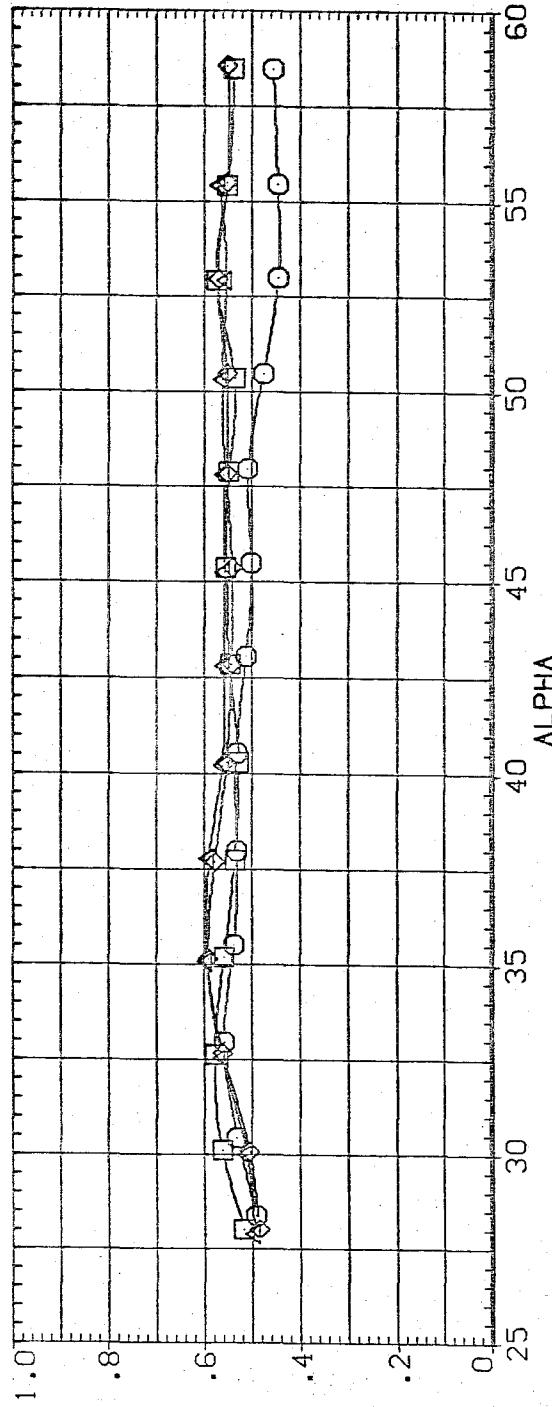


FIG.7 L/D=5 TAN.0GIVE, EFFECT OF MACH NUMBER, SUBSONIC

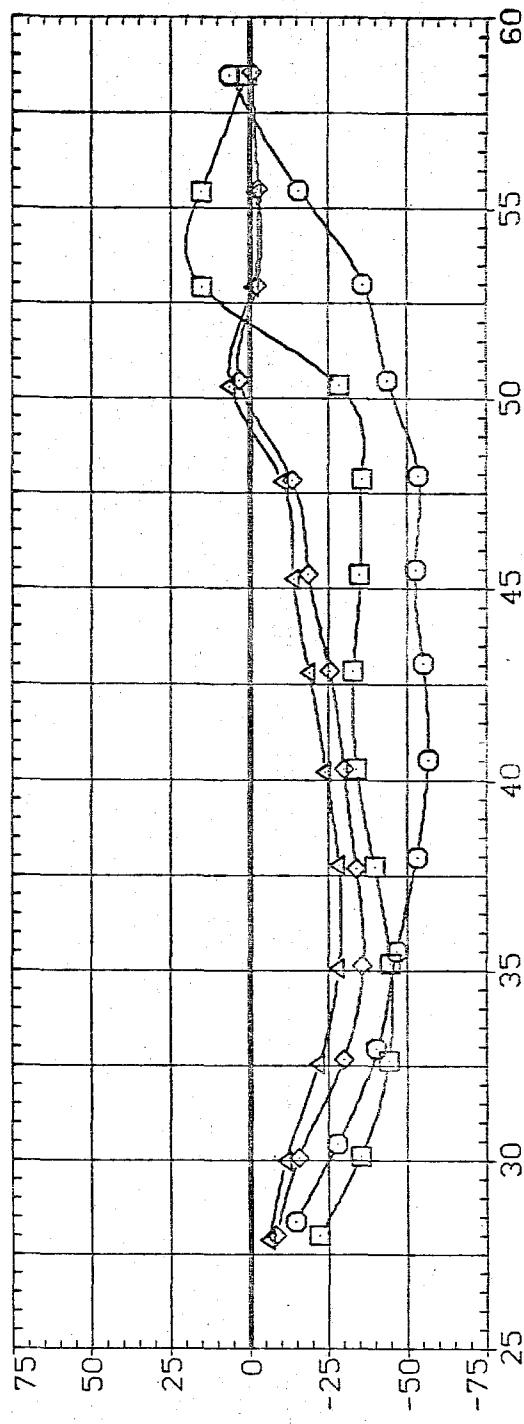
FT5

( AJDC24 )

SYMBOL	MACH	BETA	PARAMETRIC VALUES	
			R	.750
○	.253			
□	.600			
◊	.800			
△	.904			



CL



Cp

FIG.7 L/D=5 TAN. GIVE, EFFECT OF MACH NUMBER, SUBSONIC

(AJDC 24)

SYMBOL	MACH	BETA	PARAMETRIC VALUES	
			.000	R .750
○	.253			
□	.600			
◊	.800			
△	.904			

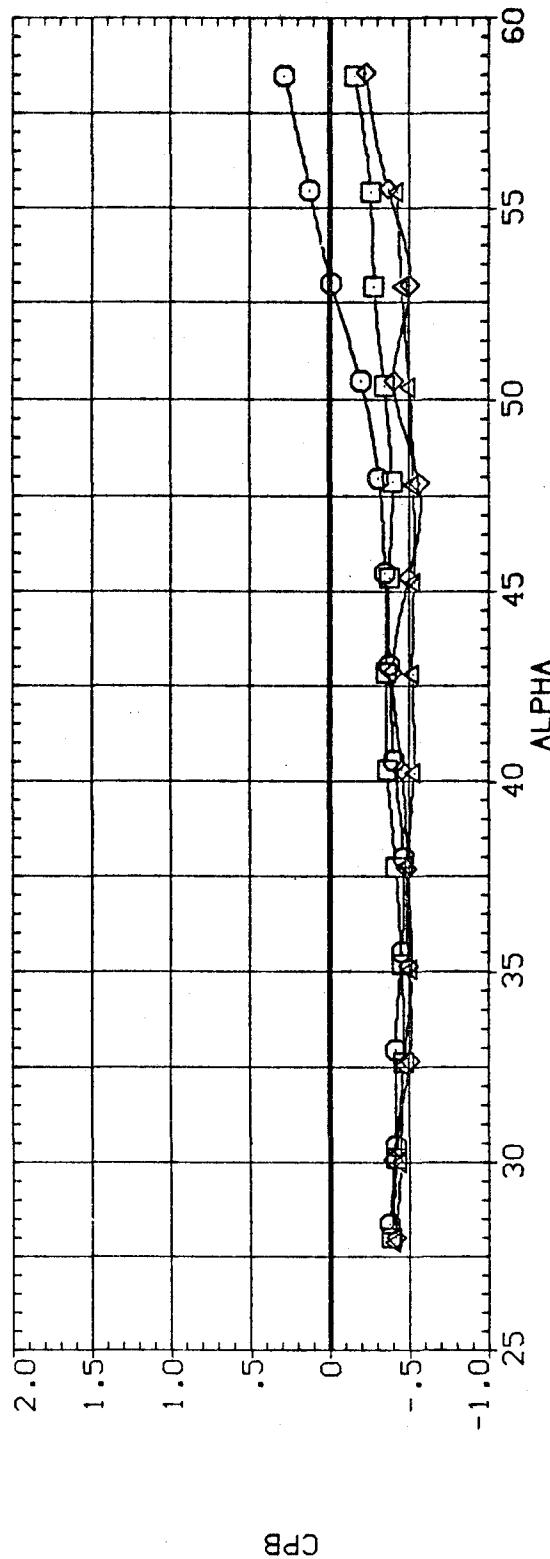
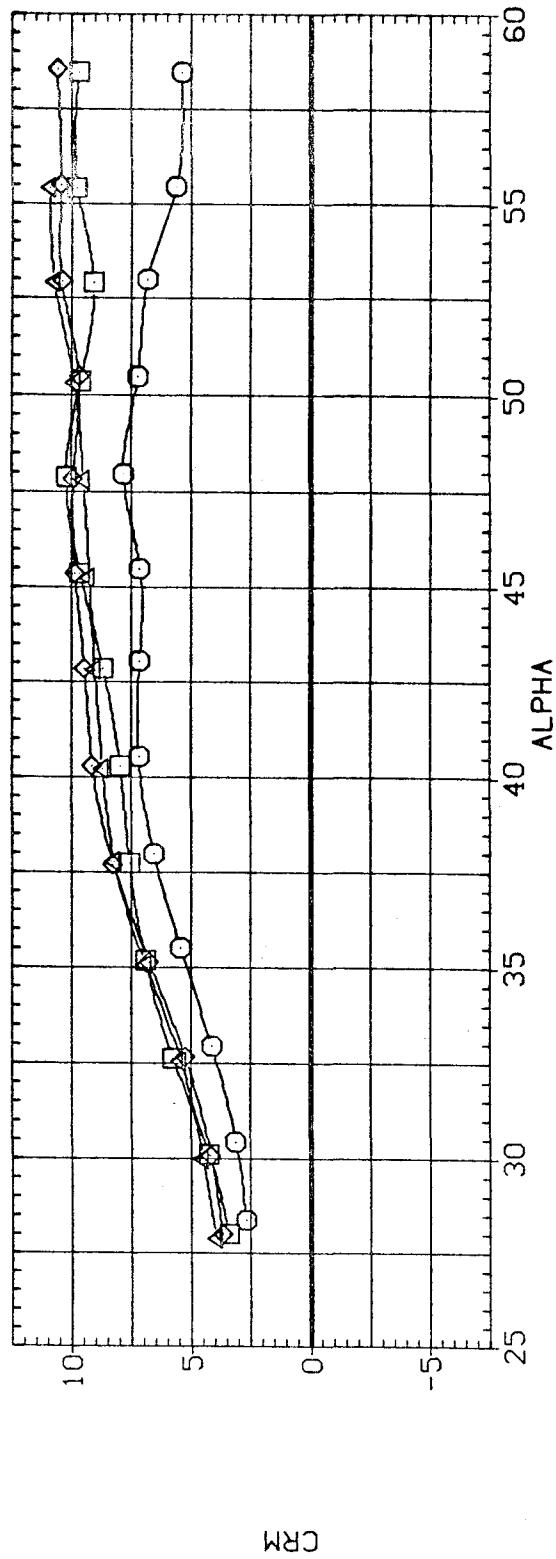
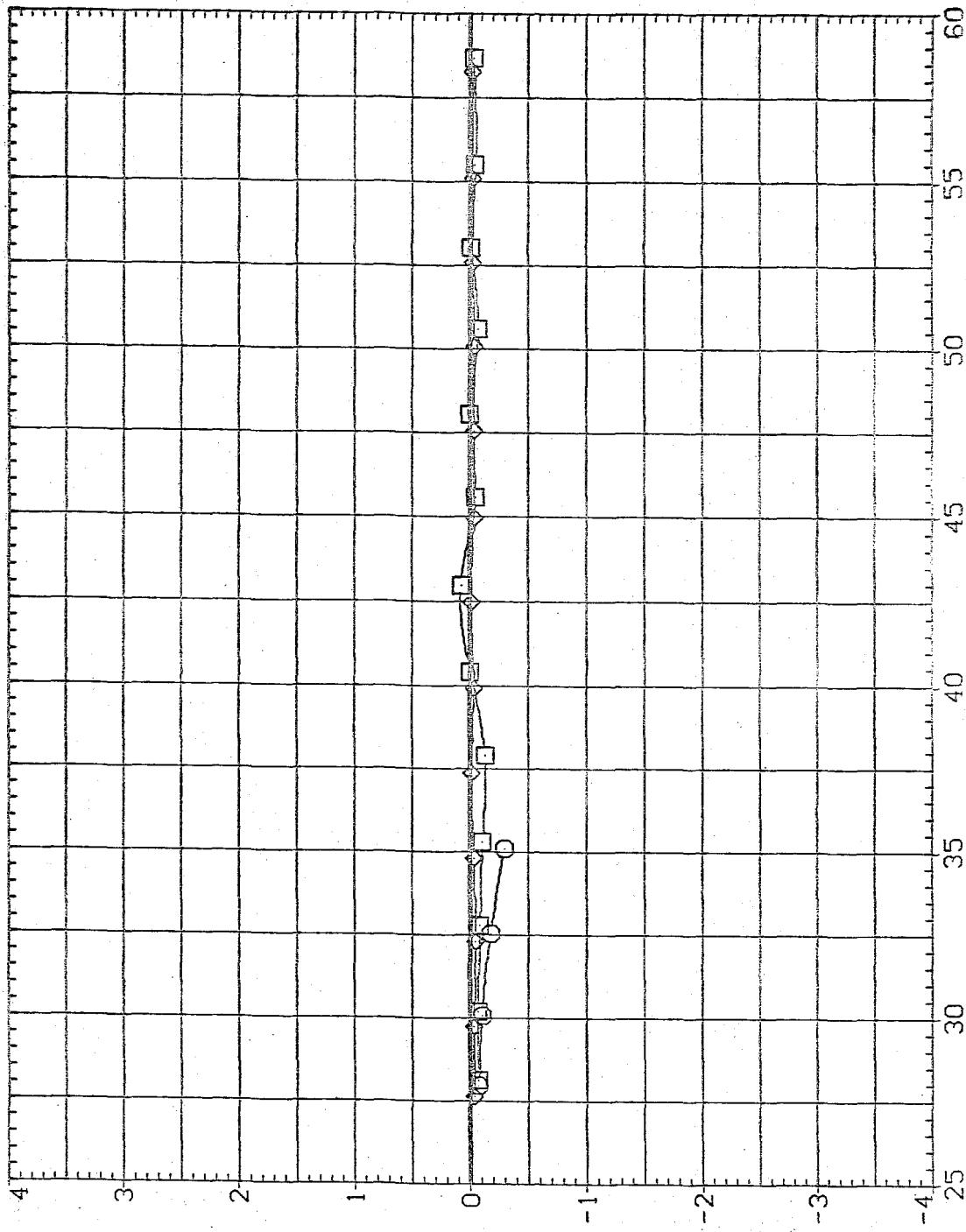


FIG. 7 L/D=5 OGIVE, EFFECT OF MACH NUMBER, SUBSONIC

FT5

(RJD/C24)

PARAMETRIC VALUES  
MACH .1.201    BETA .000    R .750  
1.504  
1.995  
SYMBOL    O    □    ◊



SIDE FORCE COEFFICIENT,  $C_y$

FIG. 8 L/D=5 TAN. 0GIVE, EFFECT OF MACH NUMBER, SUPERSONIC

PARAMETRIC VALUES  
 MACH .000 R .750  
 1.201 BETA  
 1.504  
 1.995

SYMBOL	MACH	BETA	R
○	1.201		.000
□	1.504		.750
◊	1.995		

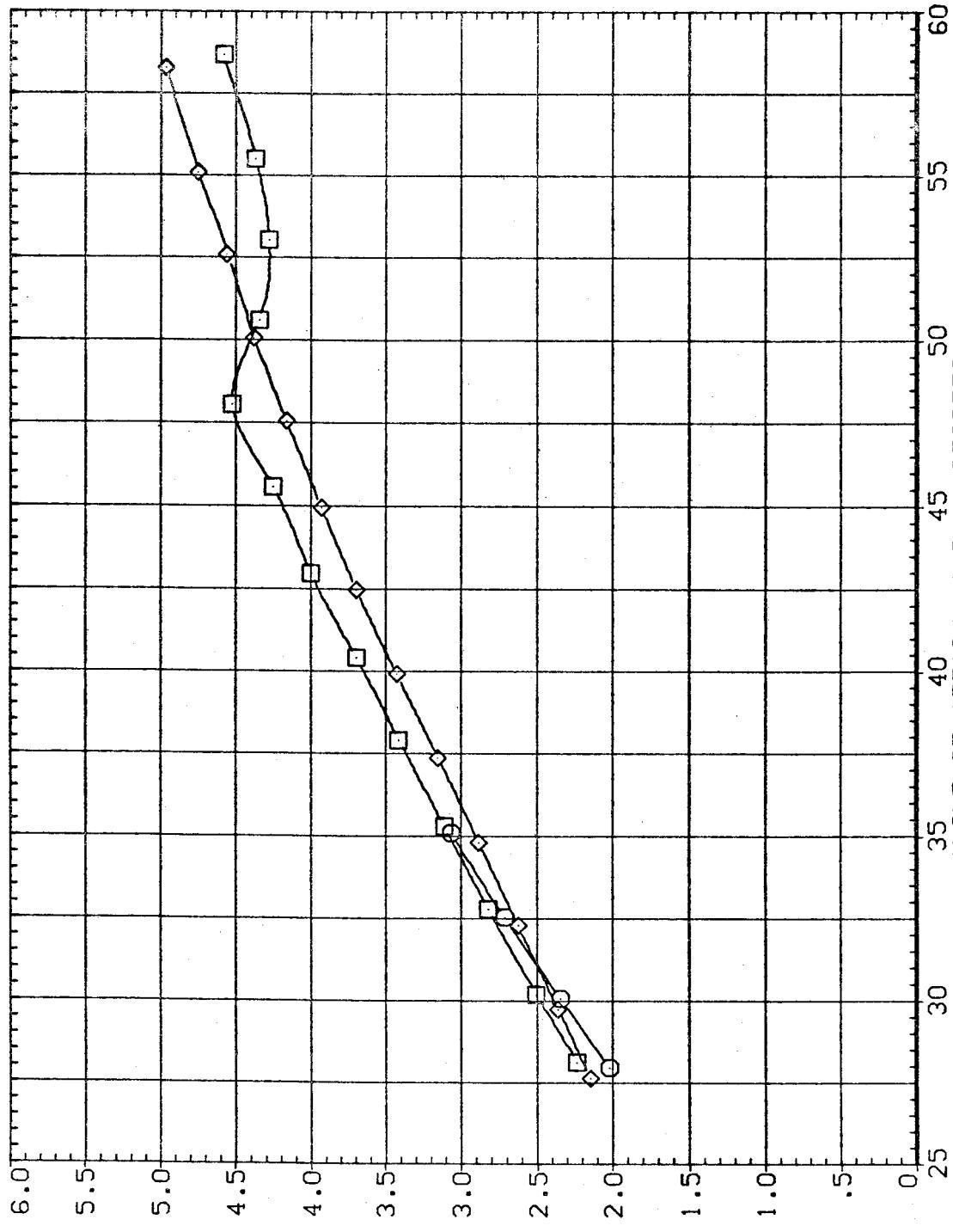
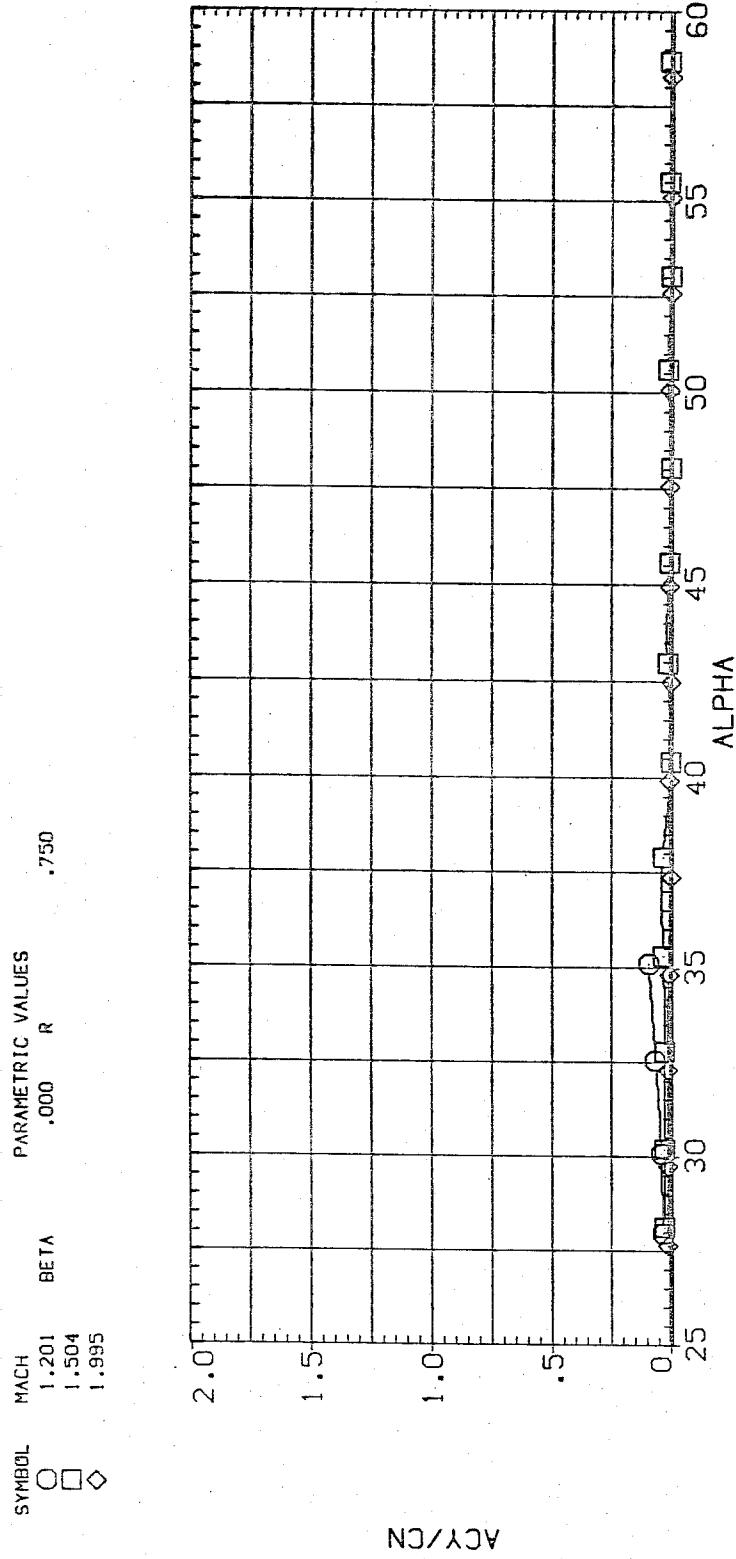
NORMAL FORCE COEFFICIENT,  $C_n$ 

FIG.8 L/D=5 TAN. OGIVE, EFFECT OF MACH NUMBER, SUPERSONIC

(RJD/C24)

FT5

PARAMETRIC VALUES  
MACH .1.201 .000 R .750  
BETA 1.504  
1.995



CR-CN

ACY-CN

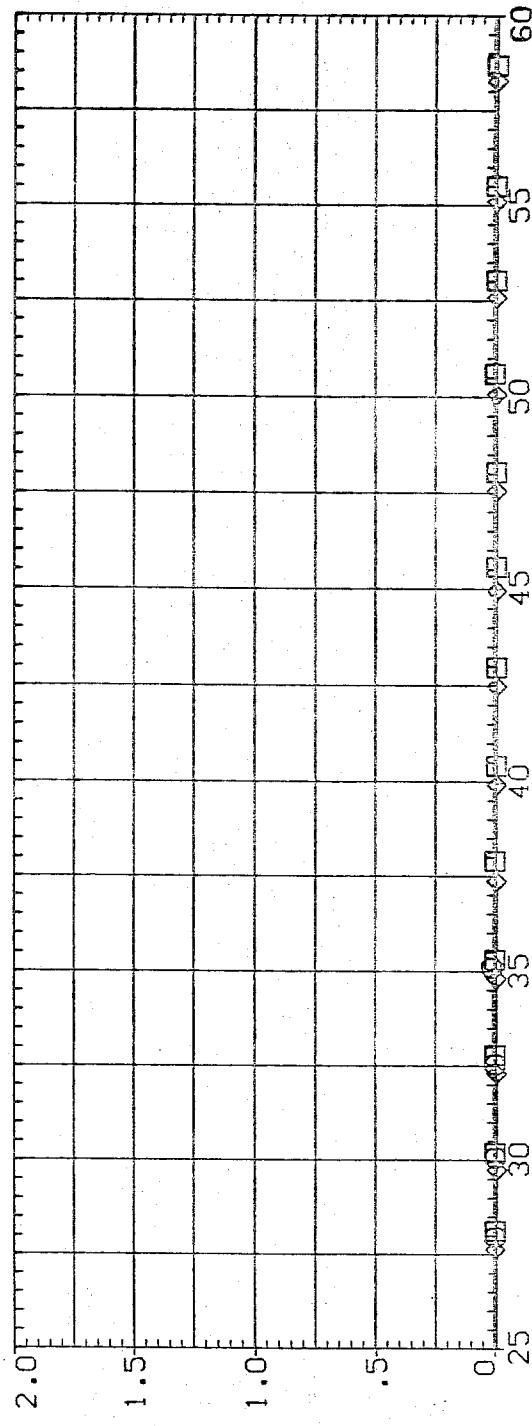
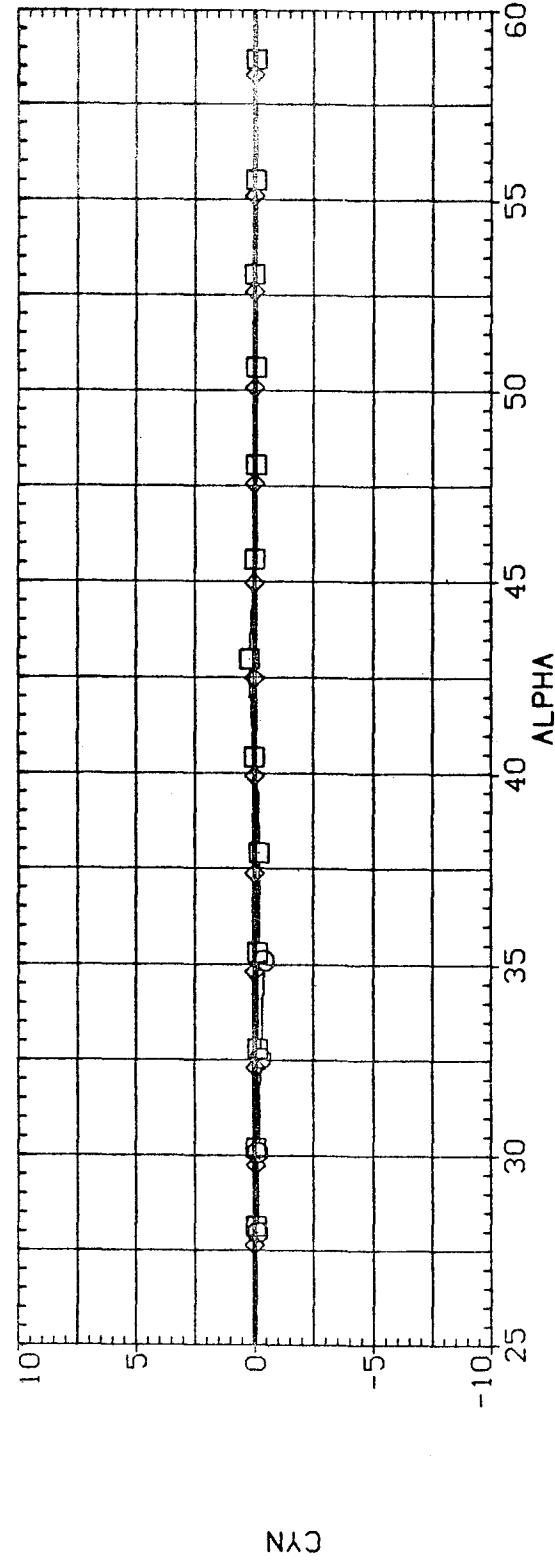


FIG.8 L/D=5 TAN. OGIVE, EFFECT OF MACH NUMBER, SUPERSONIC

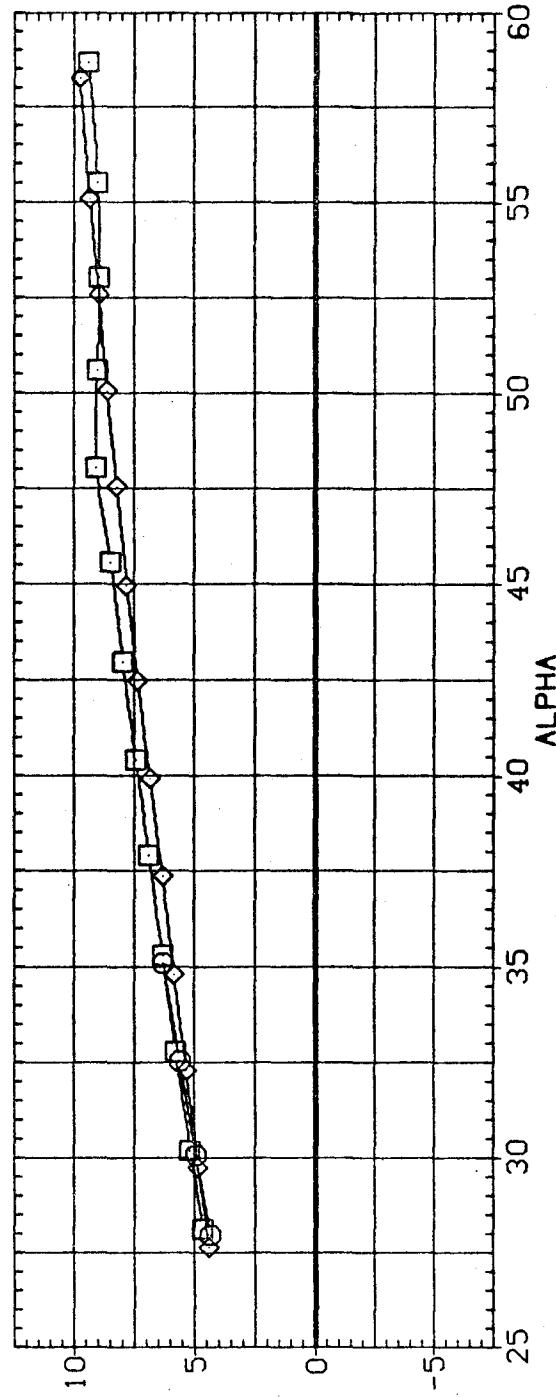
C1

CHORD

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	1.201	.000	.750
□	1.504	.500	
◊	1.995	.995	



CYN



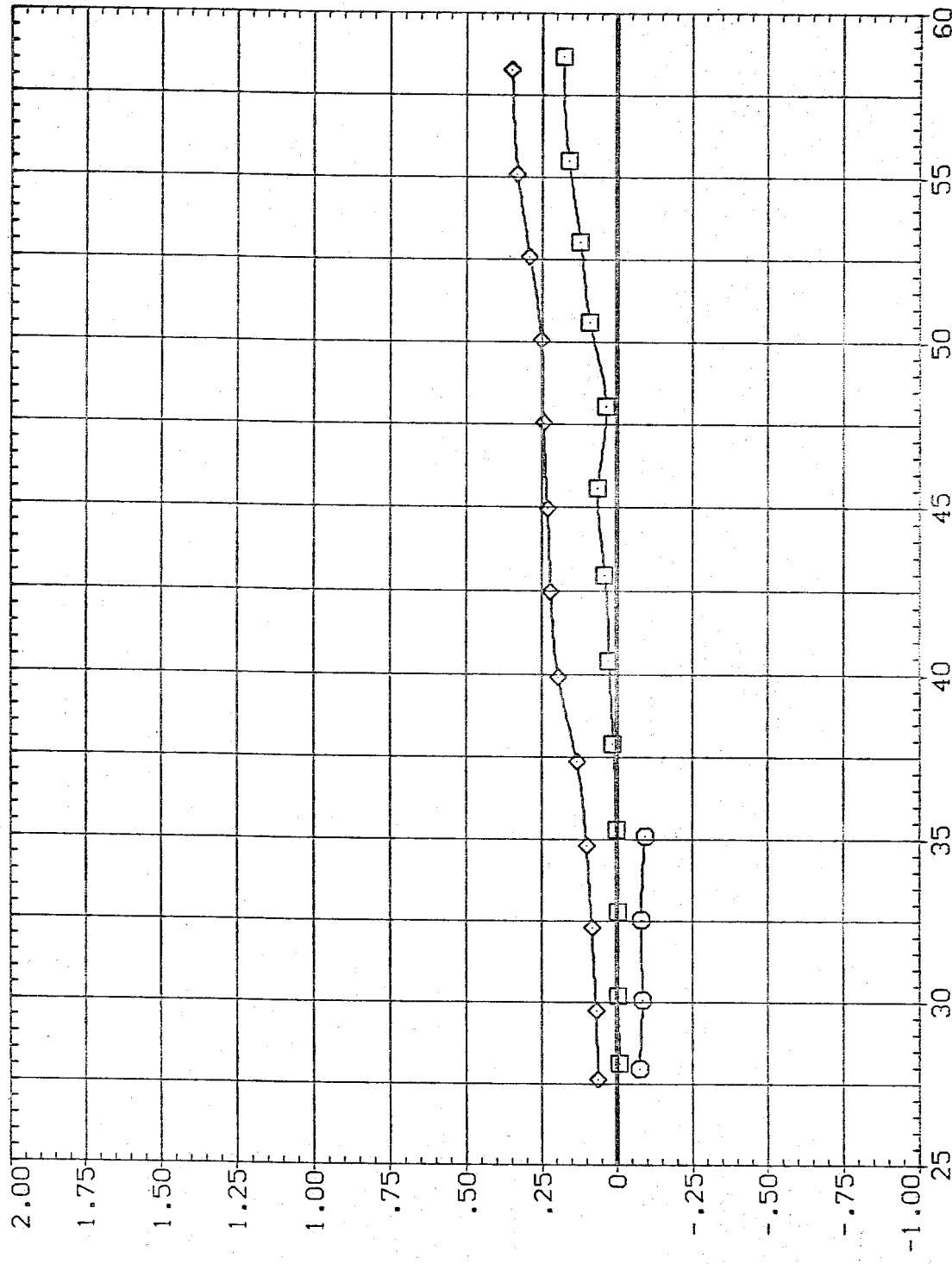
CLM

FIG.8 L/D=5 TAN. 0GIVE, EFFECT OF MACH NUMBER, SUPERSONIC

(RJDCC24)

FT5

PARAMETRIC VALUES  
MACH .201    BETA .000    R .750  
SYMBOL    O    □    ◊  
1.504  
1.995



FOREBODY AXIAL FORCE COEFFICIENT, CAF

FIG.8 L/D=5 TAN. GIVE, EFFECT OF MACH NUMBER, SUPERSONIC

PARAMETRIC VALUES  
 MACH      .1.201      BETA      .000      R      .750  
 SYMBOL      ○      □      ◇  
 MACH      1.201      BETA      1.504  
 1.504      1.995

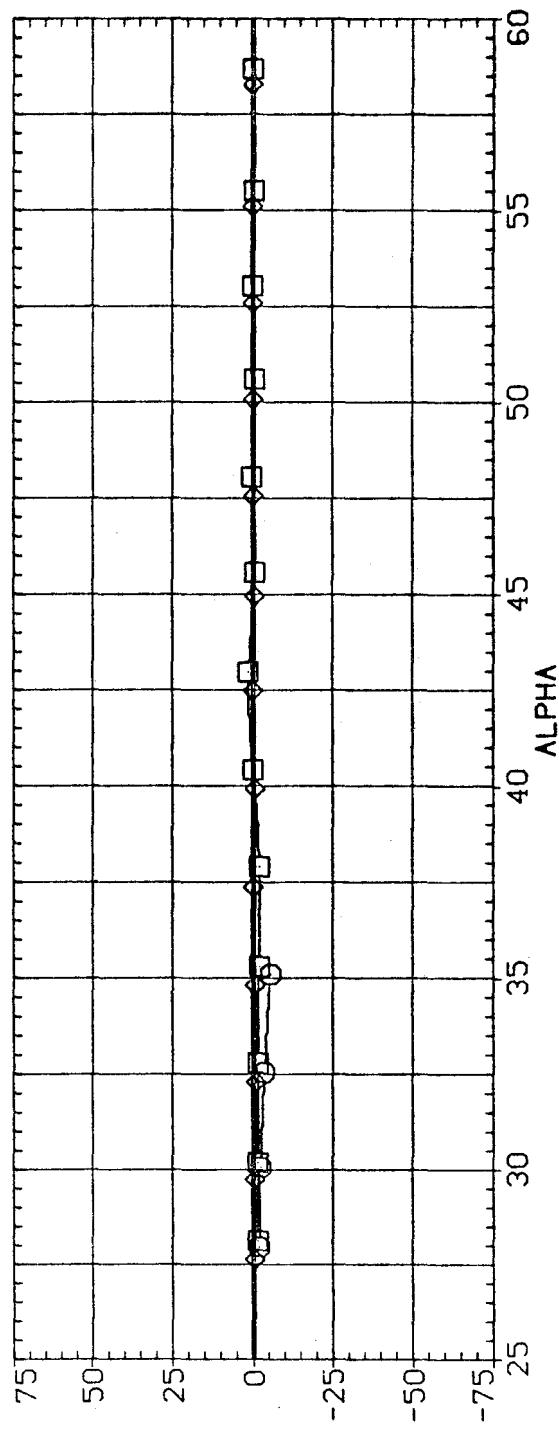
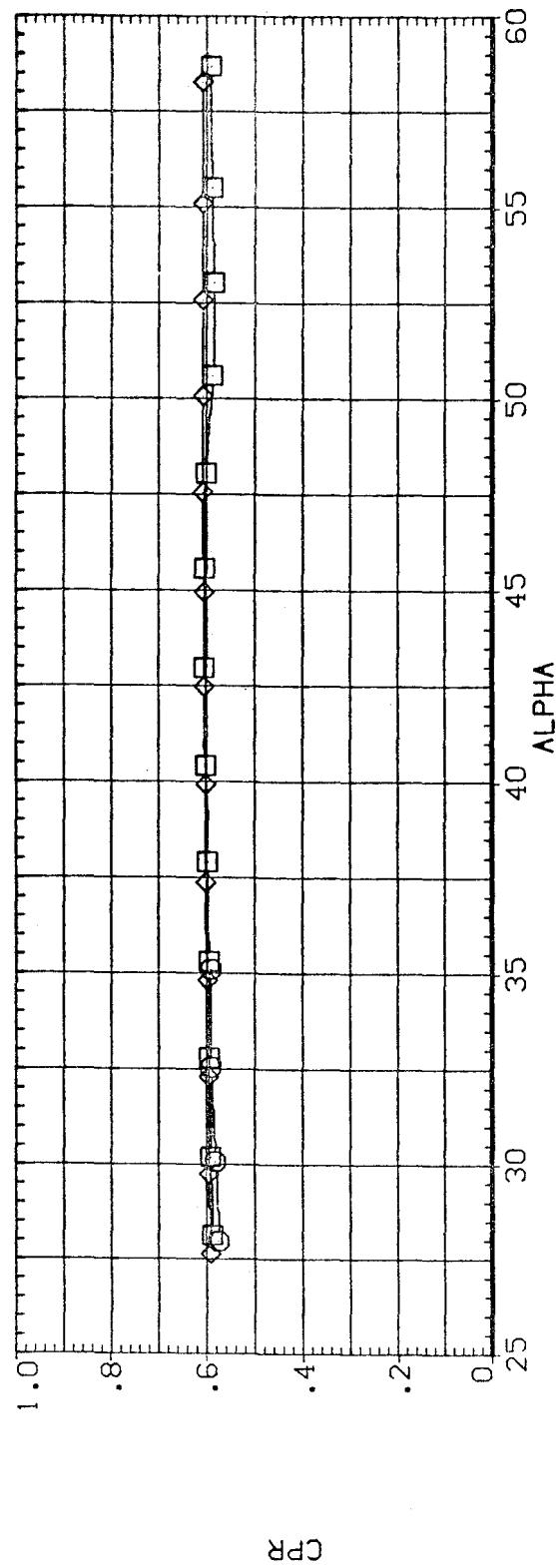


FIG.8 L/D=5 TAN. 0615, EFFECT OF MACH NUMBER, SUPERSONIC

FT5

(AJDC24)

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	1.201	.000	R .750
□	1.504		
◊	1.995		

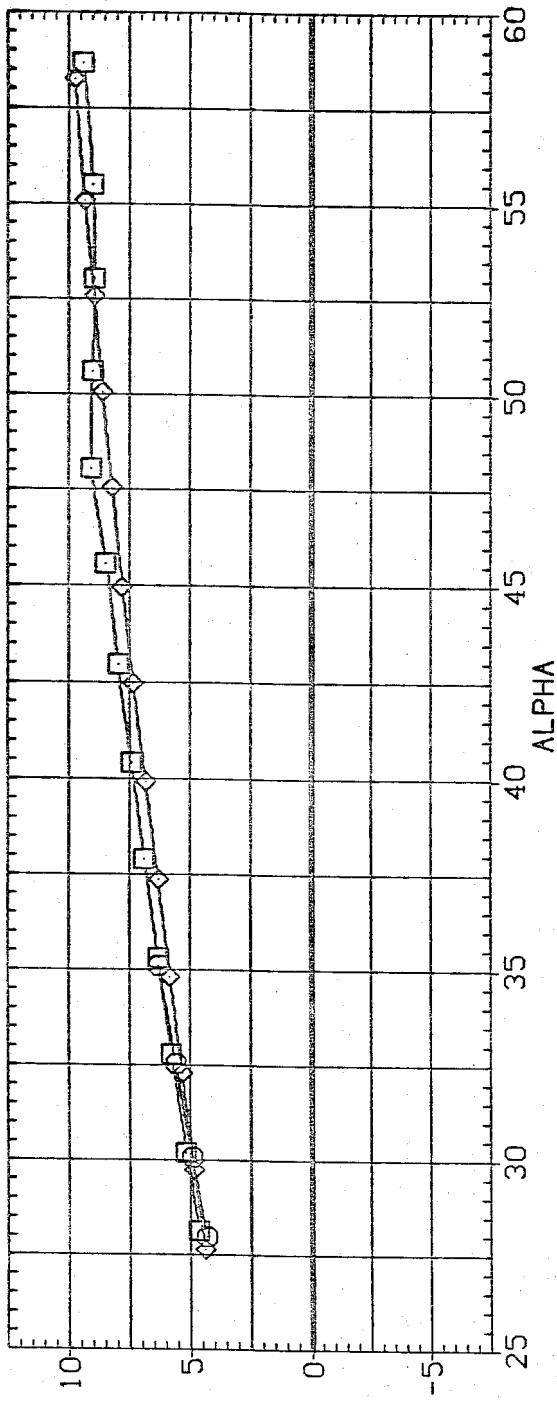
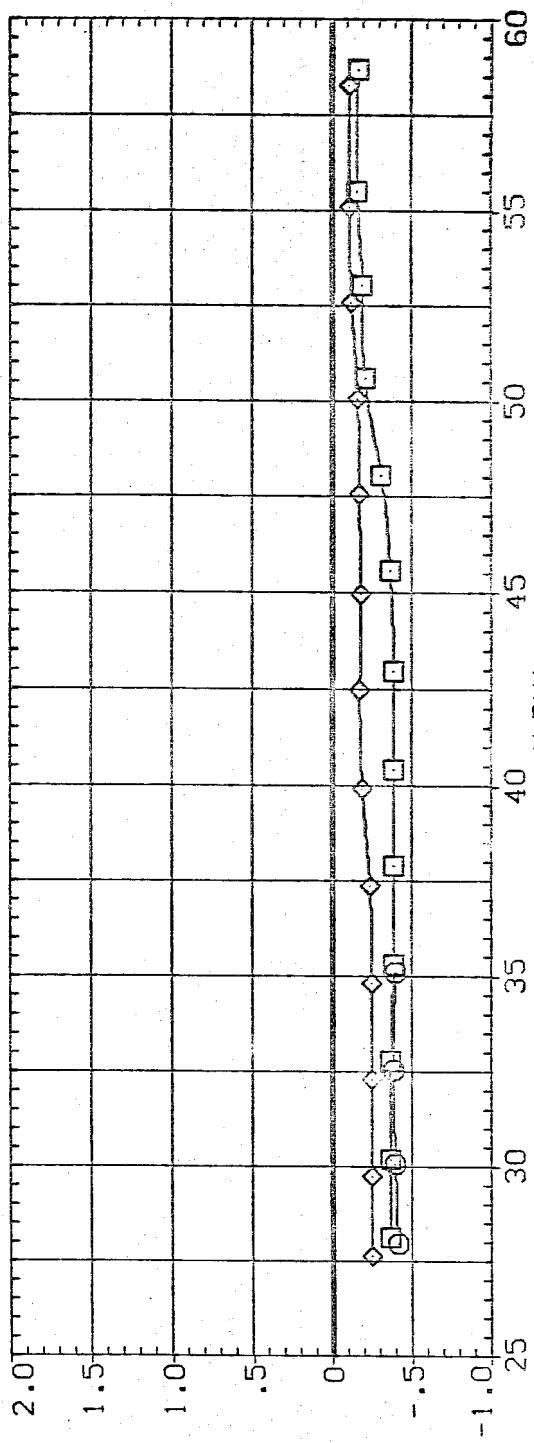
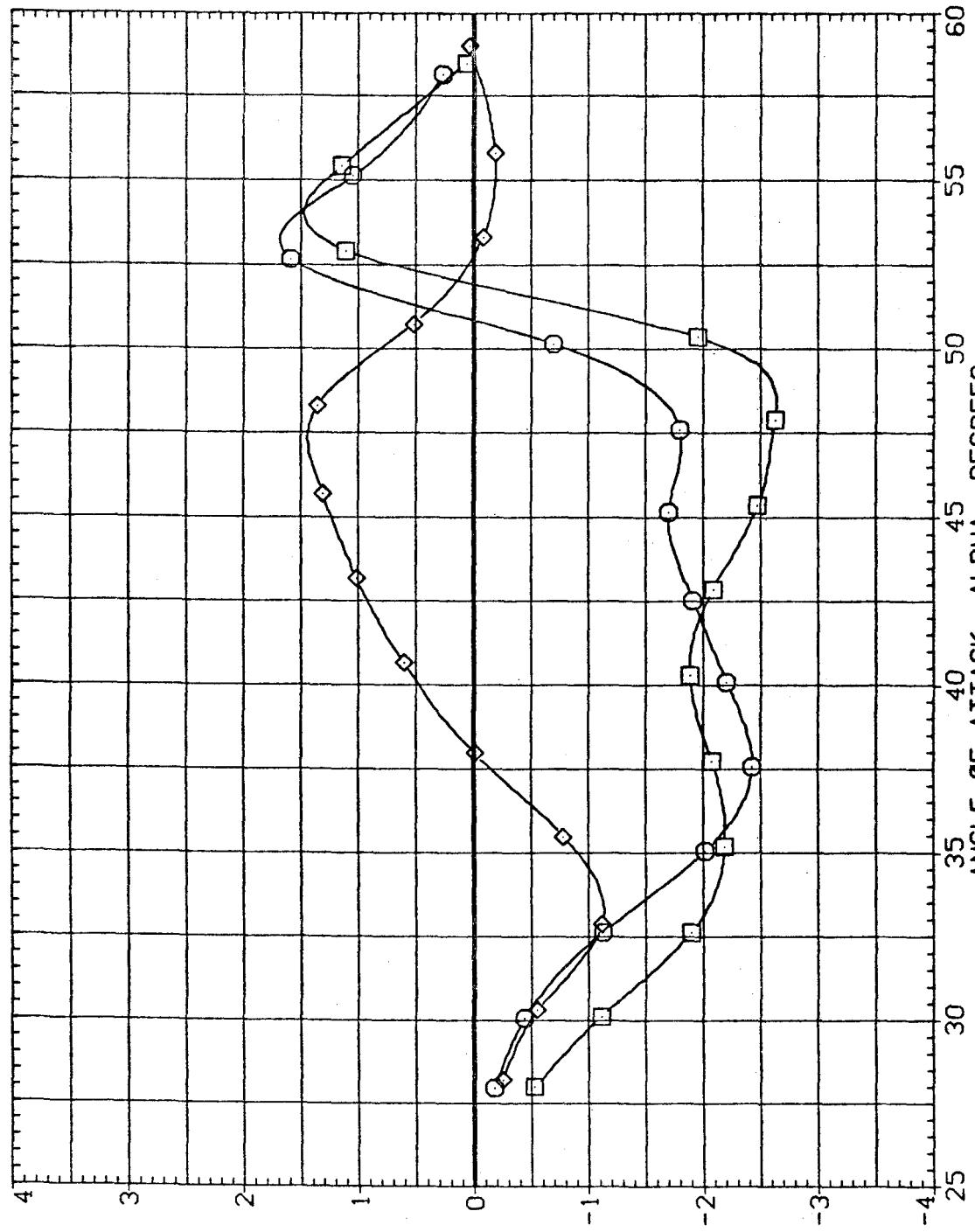
 $C_D$  $C_D$ 

FIG.8 L/D=5 TAN. ACTIVE, EFFECT OF MACH NUMBER, SUPERSONIC

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
 (RJDAA25) FTS  
 (RJDAC24) FTS  
 (RJDAA26) FTS

R       $\beta$   
 .400    .000  
 .750    .000  
 1.750   .000



SIDE FORCE COEFFICIENT,  $C_y$

FIG.9 L/D=5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER  
 $(A)MACH = .60$

DATA SET SYMBOL CONFIGURATION DESCRIPTION

[RJDG25]	FT5
[RNJDC24]	FT5
[RJDAA26]	FT5

R .400 .000  
1.750 .000  
1.750 .000

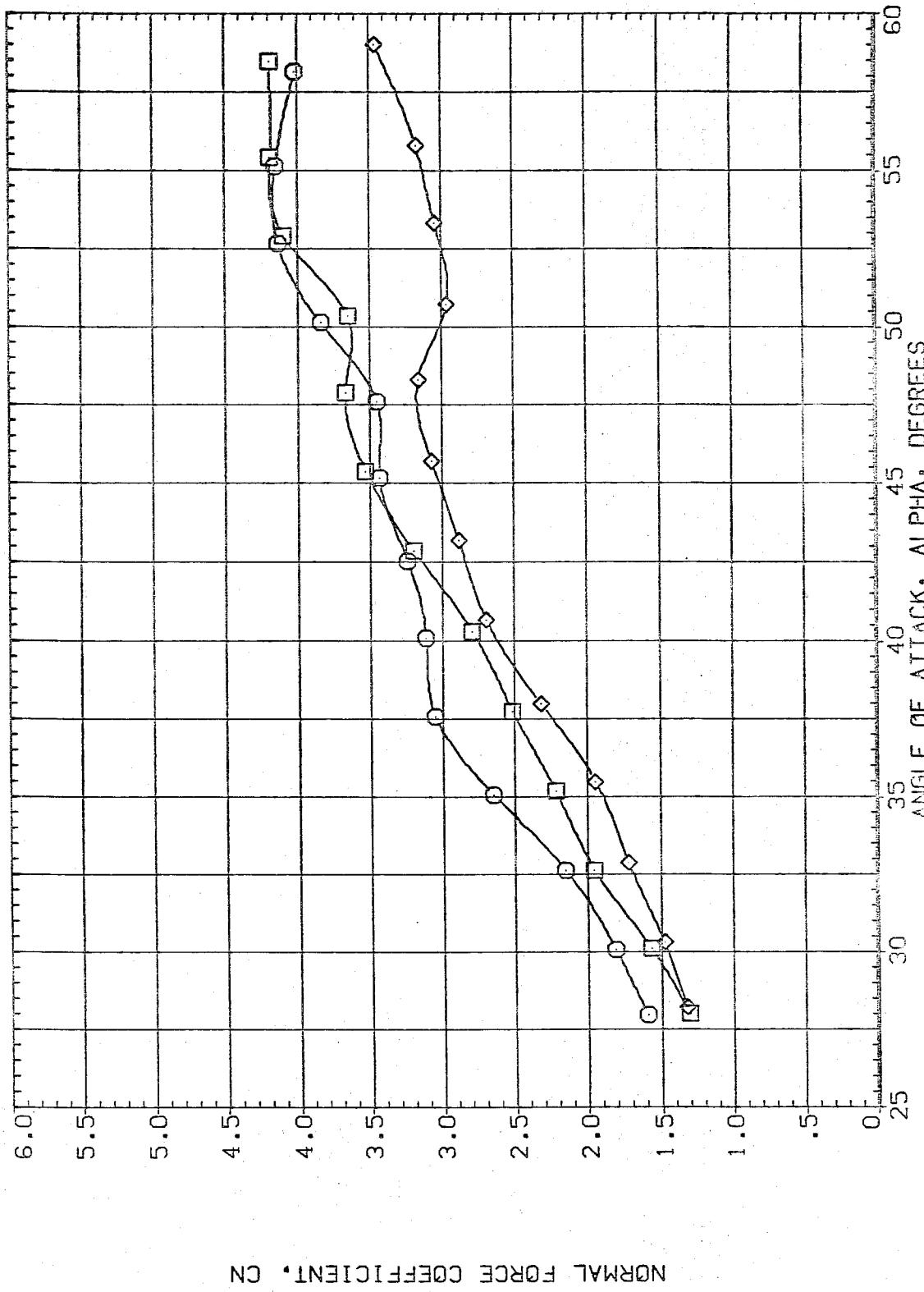
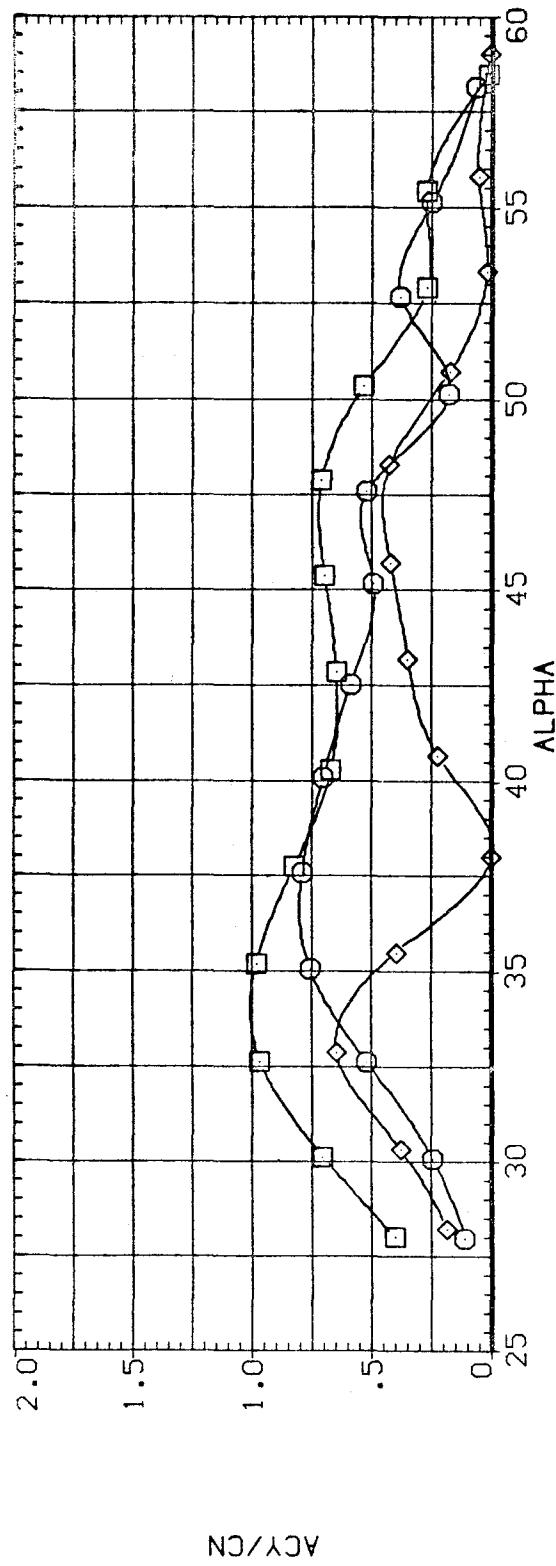


FIG. 9 L/D=5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
 (RJDAC25) FTS  
 (RJDAC24) FTS  
 (RJDAC26) FTS



CR-CN

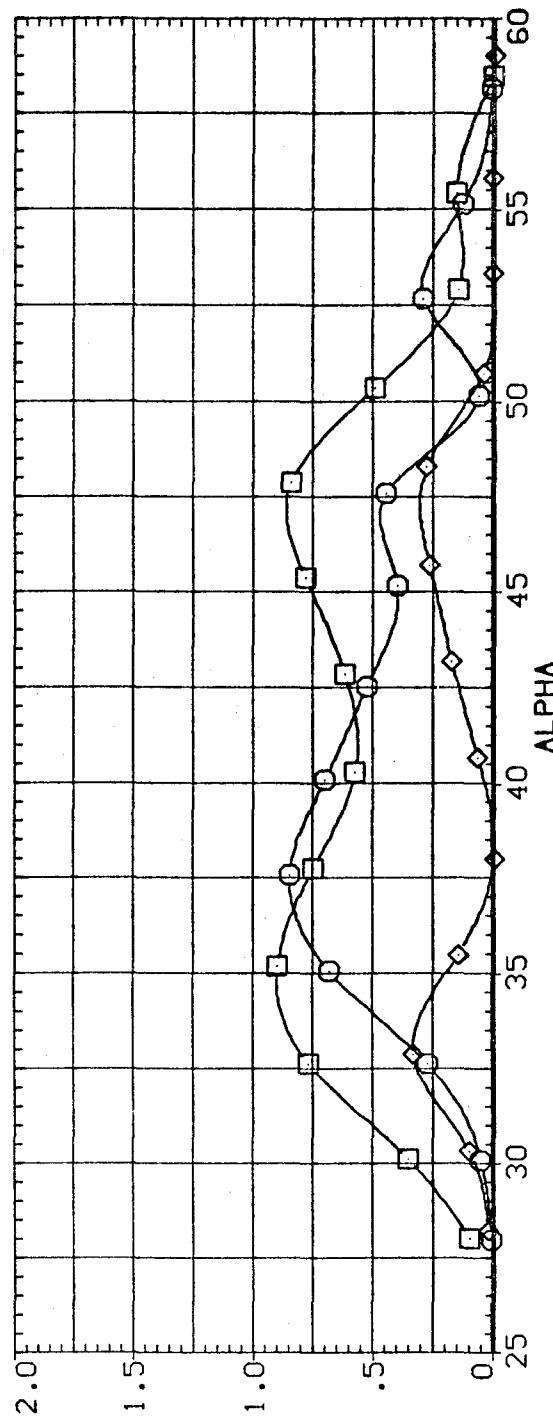
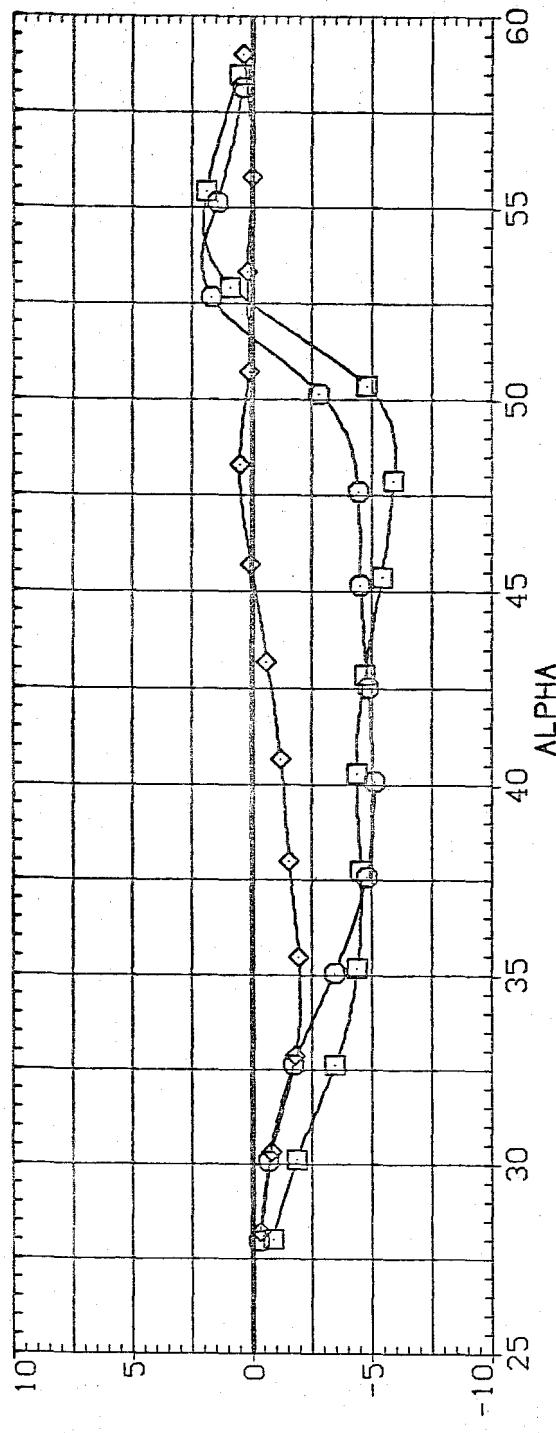


FIG. 9 L/D=5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER  
 $(\Delta) MACH = .60$

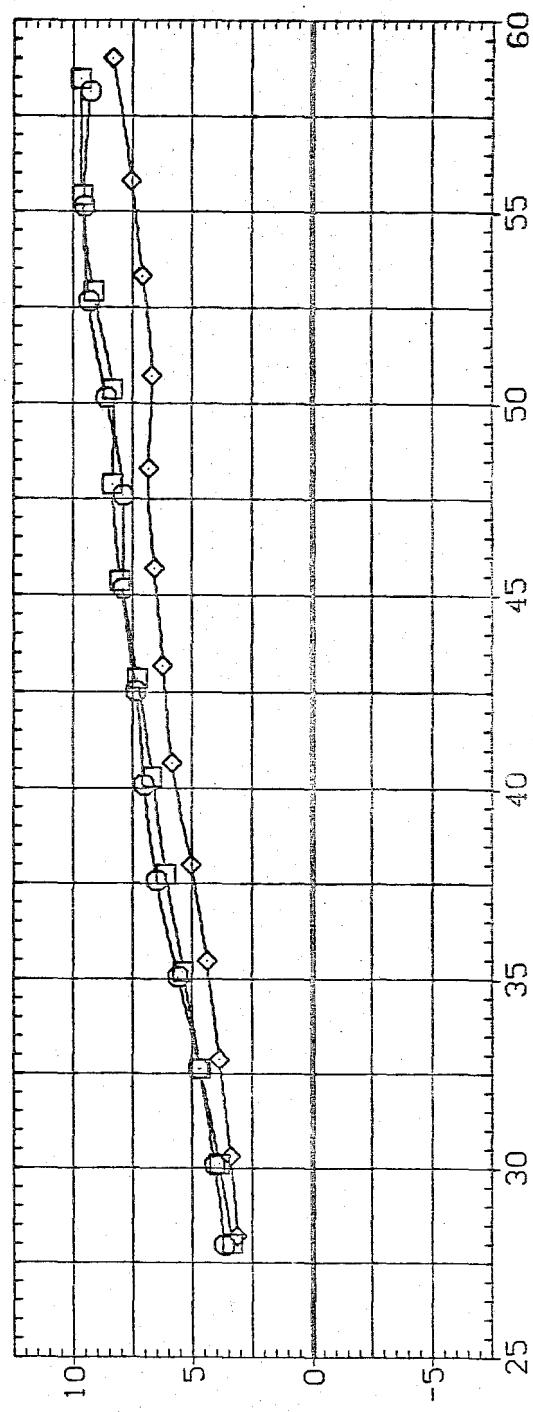
DATA SET SYMBOL CONFIGURATION DESCRIPTION

(RJD25)		F15
(RJDC24)		F15
(RJD26)		F15

R .400 .000  
1.750 .000  
1.750 .000



CY2



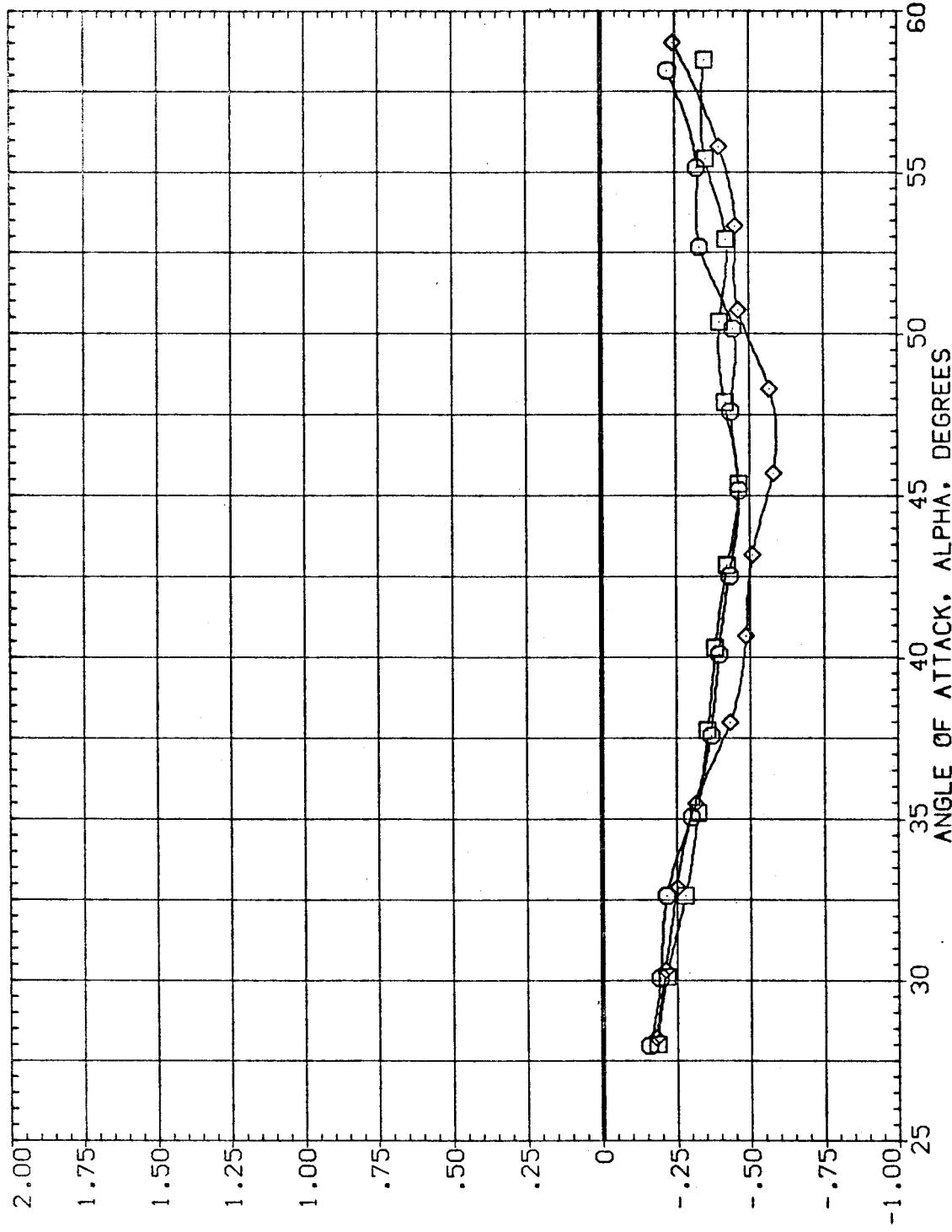
CLM

FIG. 9 L/D=5 TAN. 061VE, EFFECT OF REYNOLDS NUMBER  
[A]MACH = .60

DATA SET 1  
 (RJD25) FTS  
 (RJD24) FTS  
 (RJD26) FTS

CONFIGURATION DESCRIPTION

400 .000  
 .750 .000  
 1.750 .000



FOREBODY AXIAL FORCE COEFFICIENT, CAF

FIG. 9 L/D=5 TAN. 061IVE, EFFECT OF REYNOLDS NUMBER  
 $(\lambda)_{MACH} = .60$

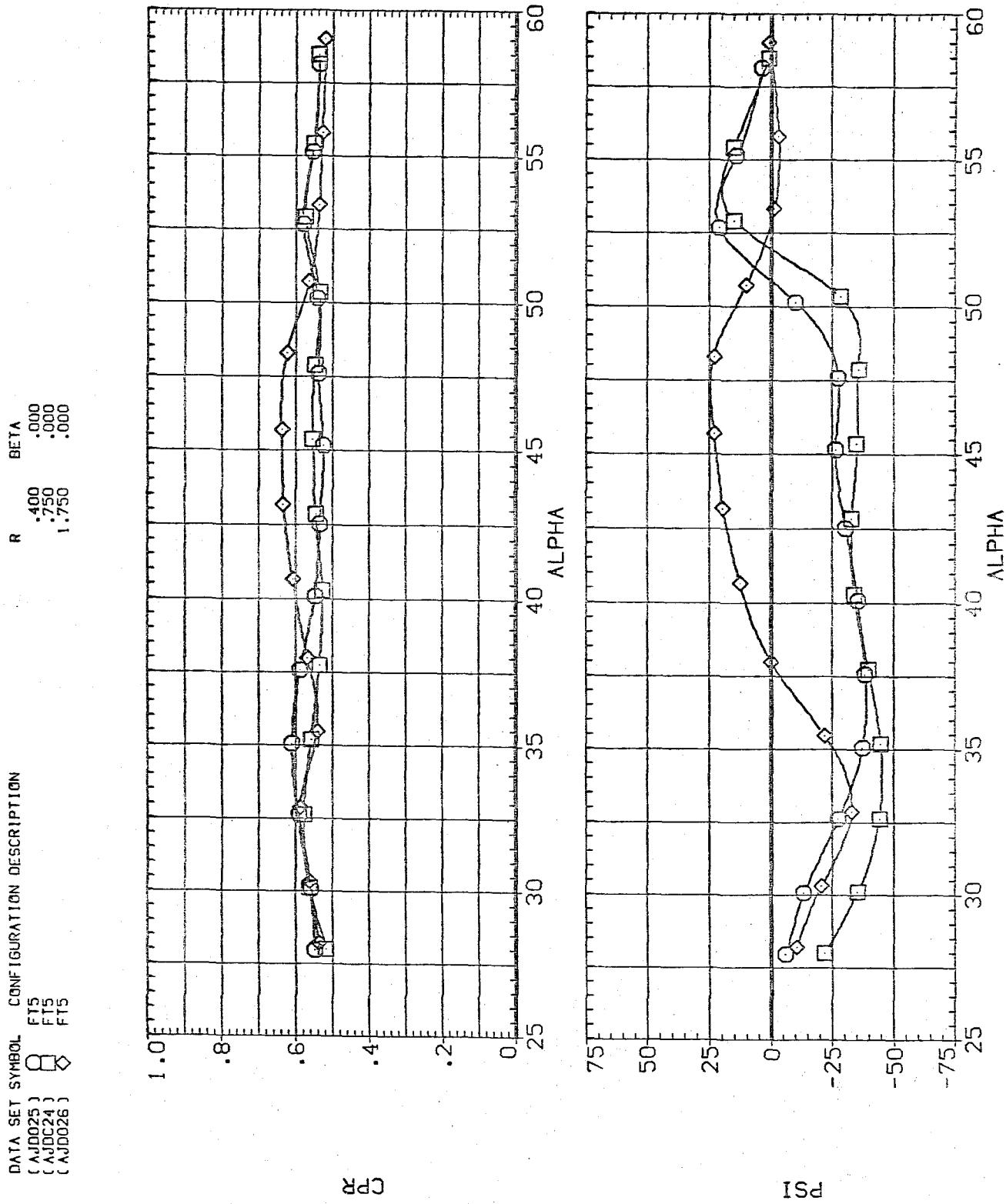
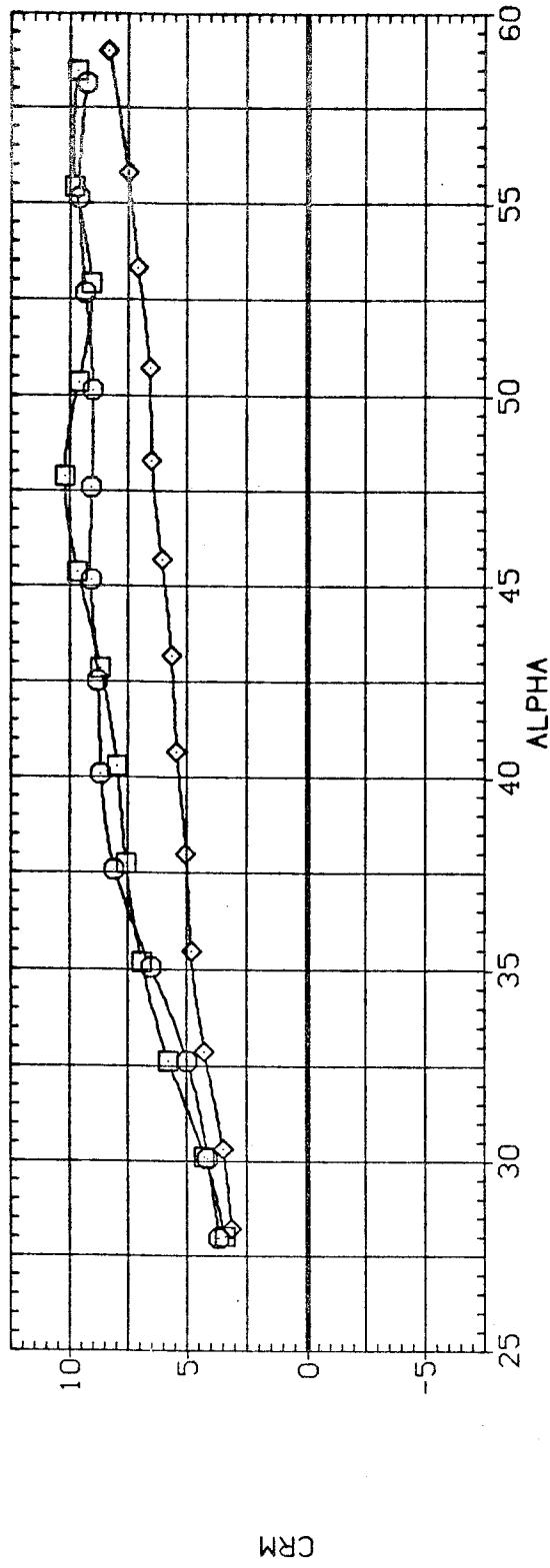


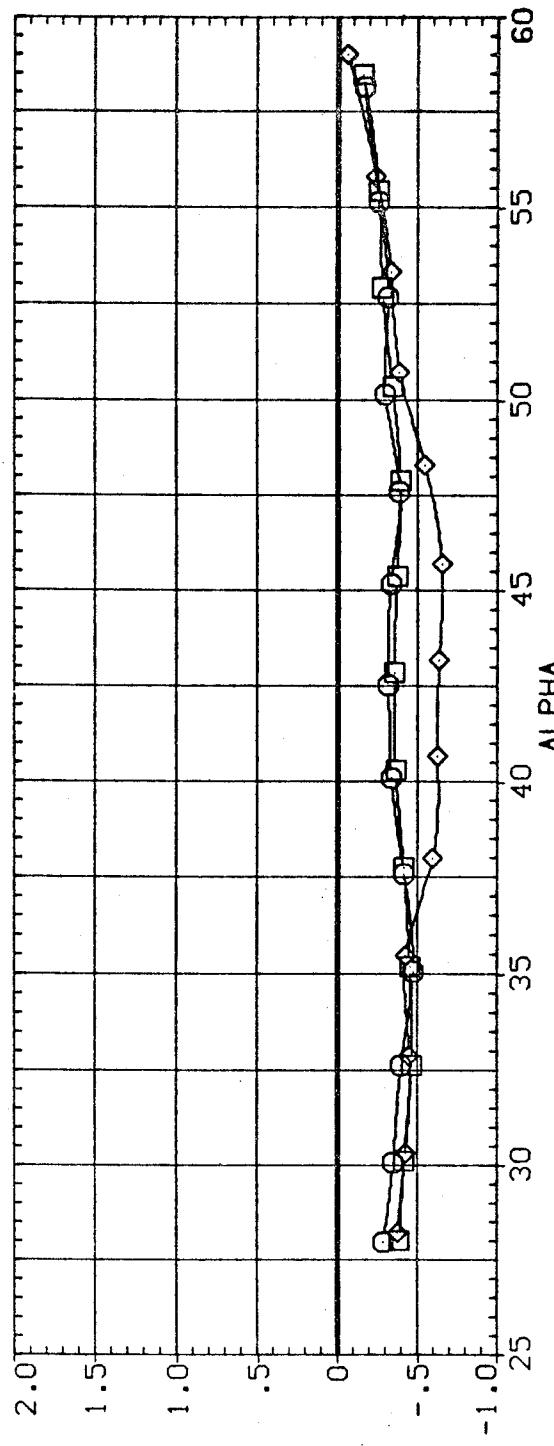
FIG. 9 L/D=5 TAN. OGIVE, EFFECT OF REYNOLDS NUMBER

UNIVERSITY OF TORONTO LIBRARY  
 LIBRARY USE ONLY  
 ADD025 ) FTS  
 ADDC24 ) FTS  
 ADD026 ) FTS

$\alpha$  .400 .000  
 .750 .000  
 1.750 .000



CRM



CPB

FIG. 9 L/D=5 TAN. 0611, EFFECT OF REYNOLDS NUMBER  
 (MACH = .60)

FP

(RJDC46)

SYMBOL	MACH	BETA	R	PARAMETRIC VALUES
○	.600		.000	
□	.795			.750
◊	1.497			
△	1.981			

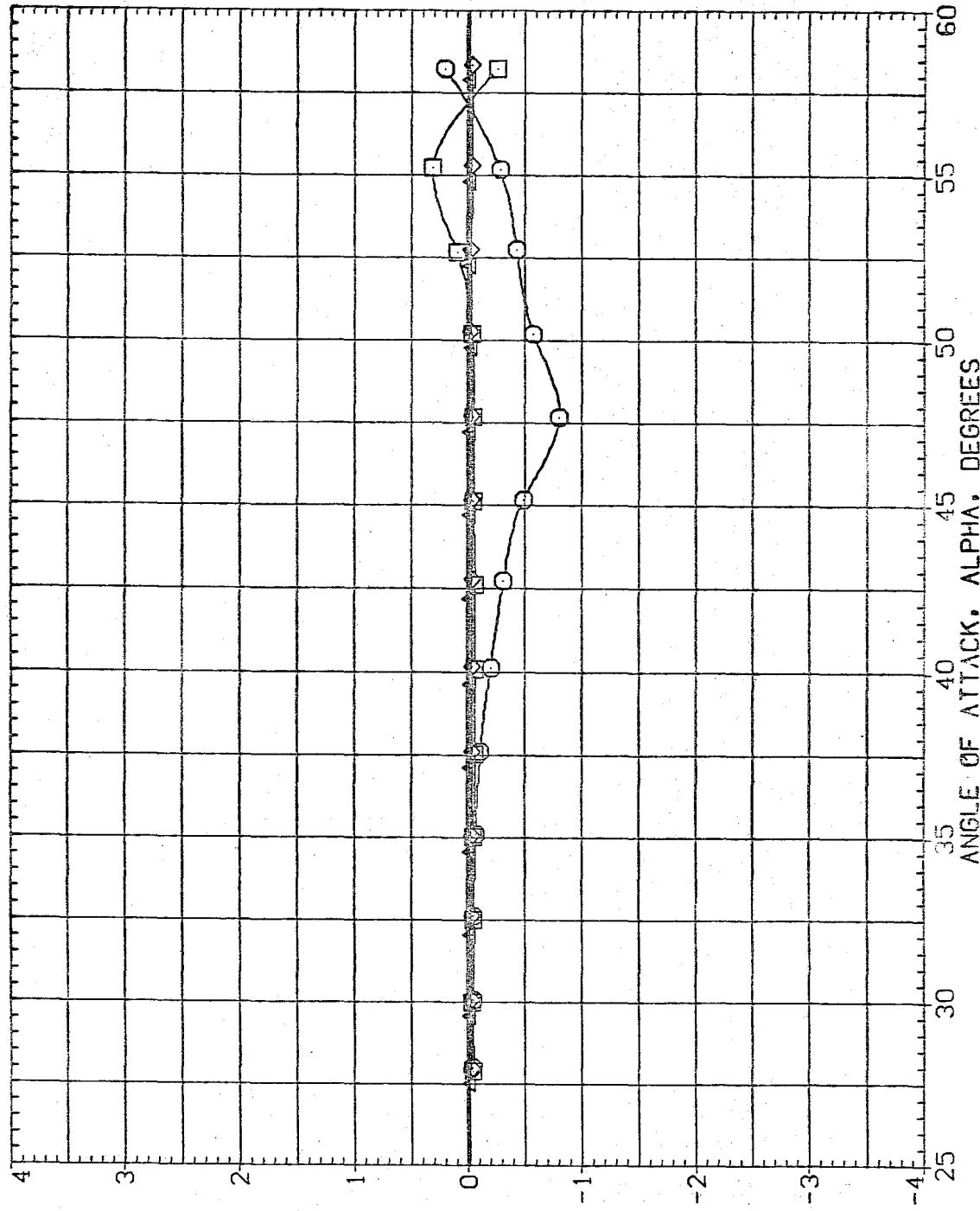
SIDE FORCE COEFFICIENT,  $C_y$ 

FIG.10 L/D=3.5 PARABOLOID, EFFECT OF MACH NUMBER

PARAMETRIC VALUES  
 MACH .600    BETA .000    R .750  
 SYMBOL      ○    □    ◇    △  
 .795    1.497    1.981

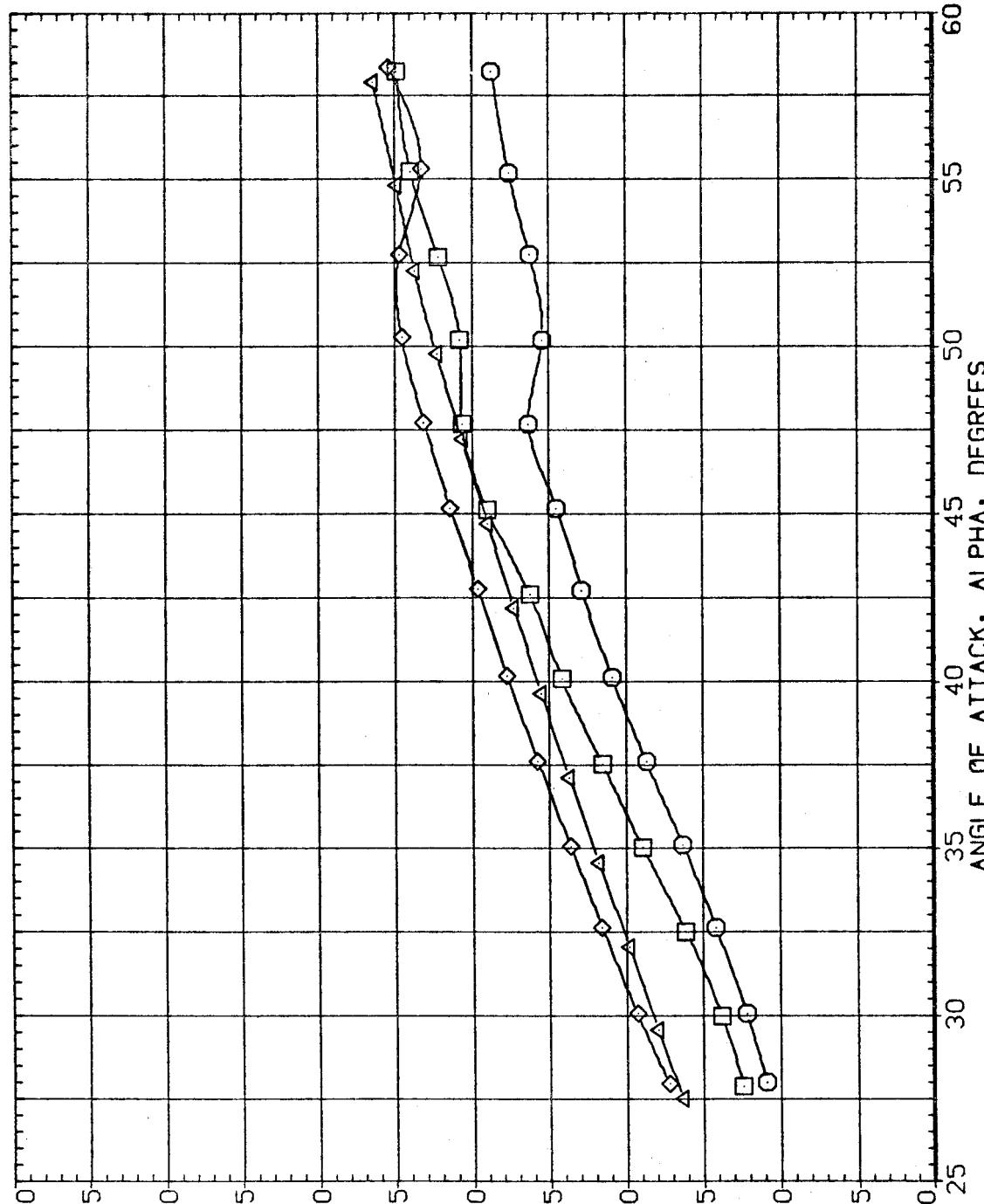
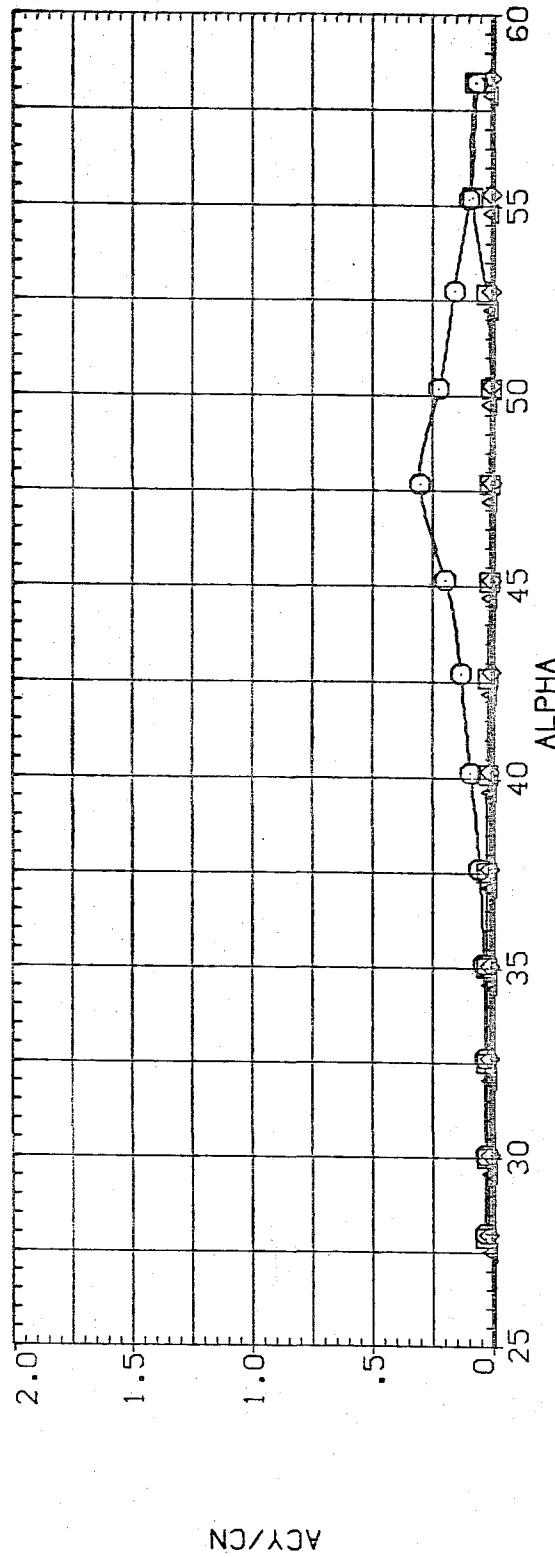
NORMAL FORCE COEFFICIENT,  $C_n$ 

FIG.10 L/D=3.5 PARABOLOID, EFFECT OF MACH NUMBER

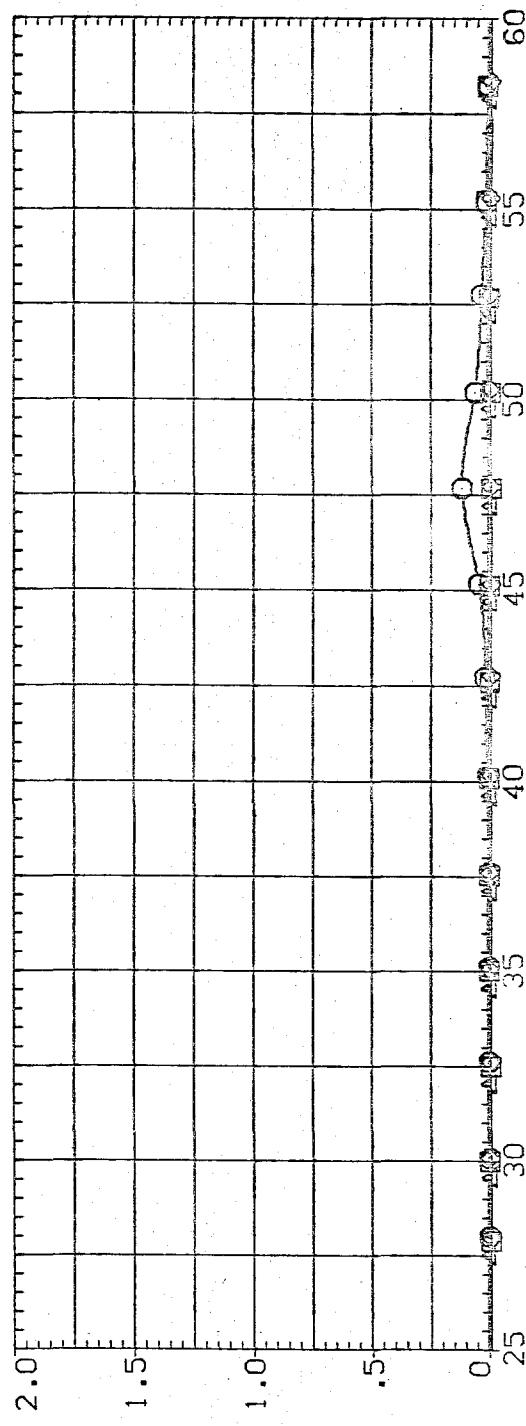
[RJDC 46]

FP

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	.600		.000 R .750
□	.795		
◊	1.497		
△	1.981		



ACY/CN



CR-CN

FIG.10 L/D=3.5 PARABOLOID, EFFECT OF MACH NUMBER

(RJD/C46)

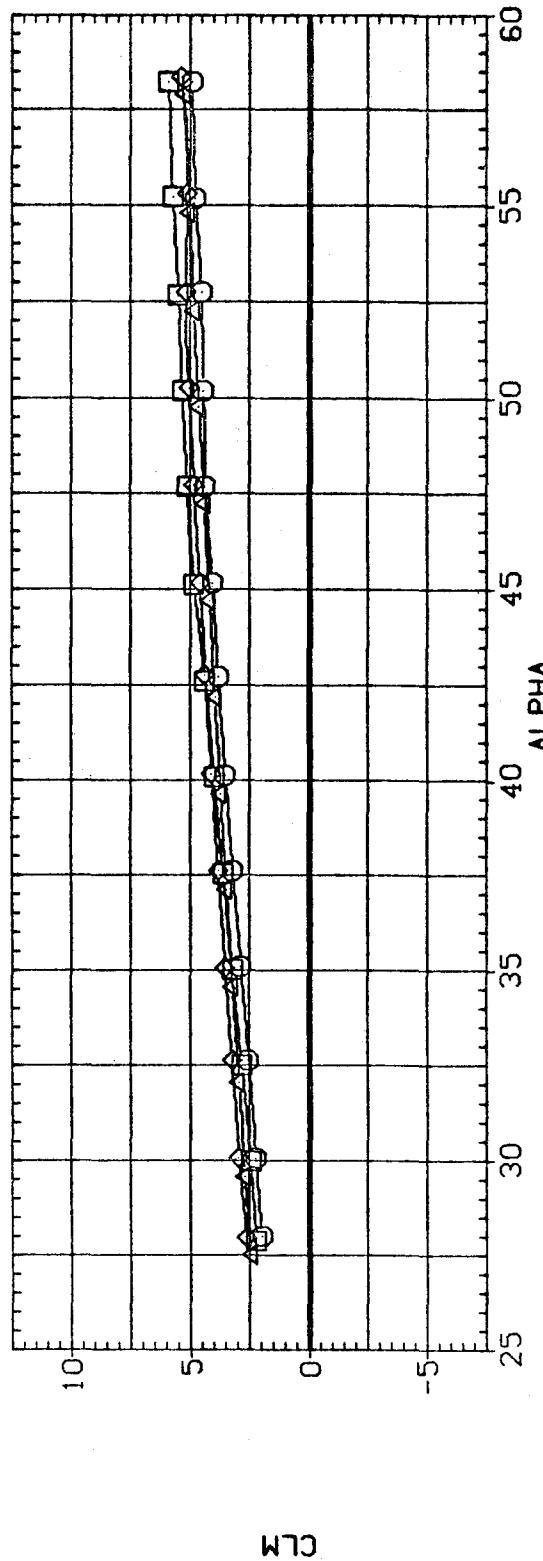
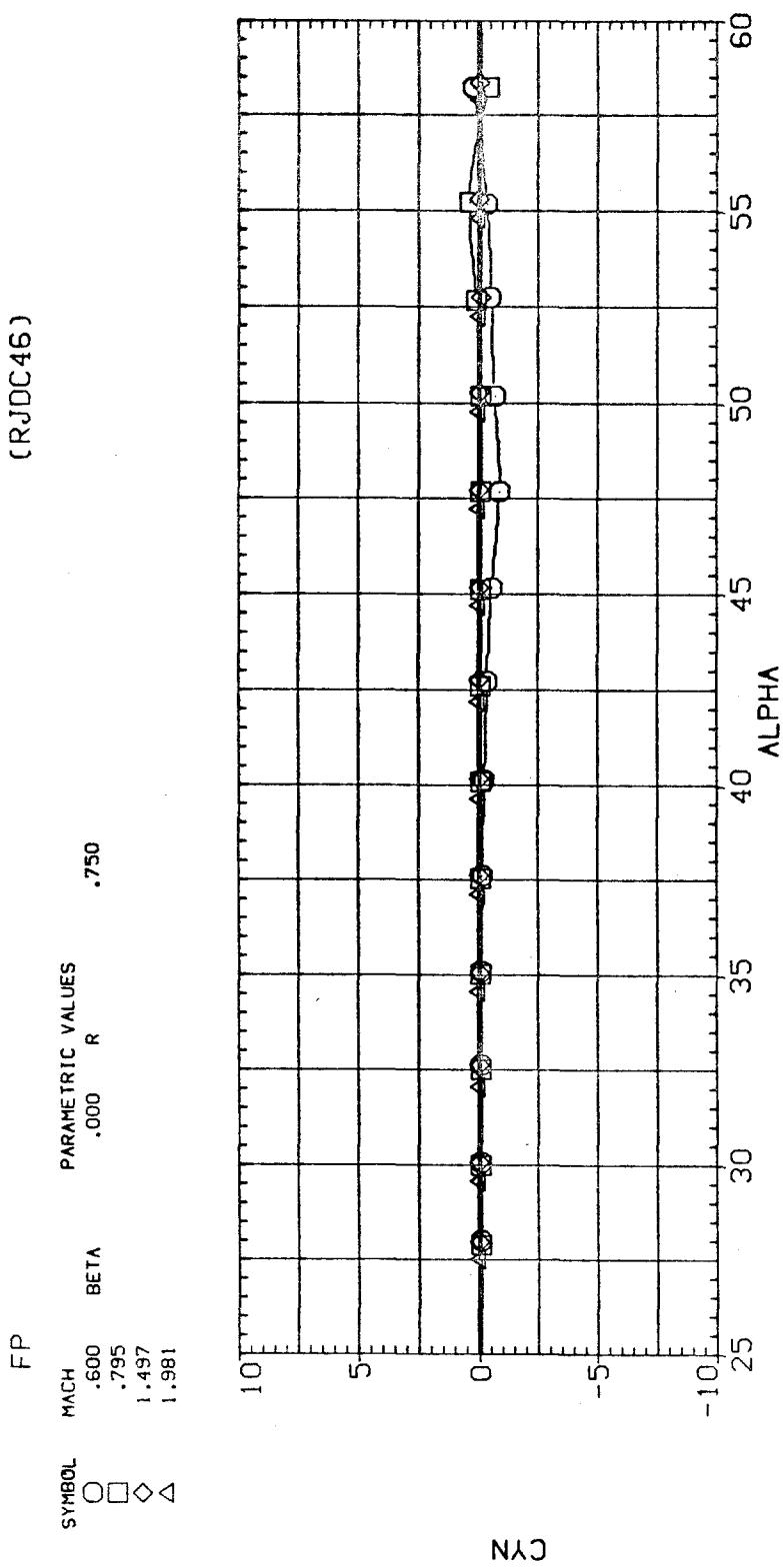
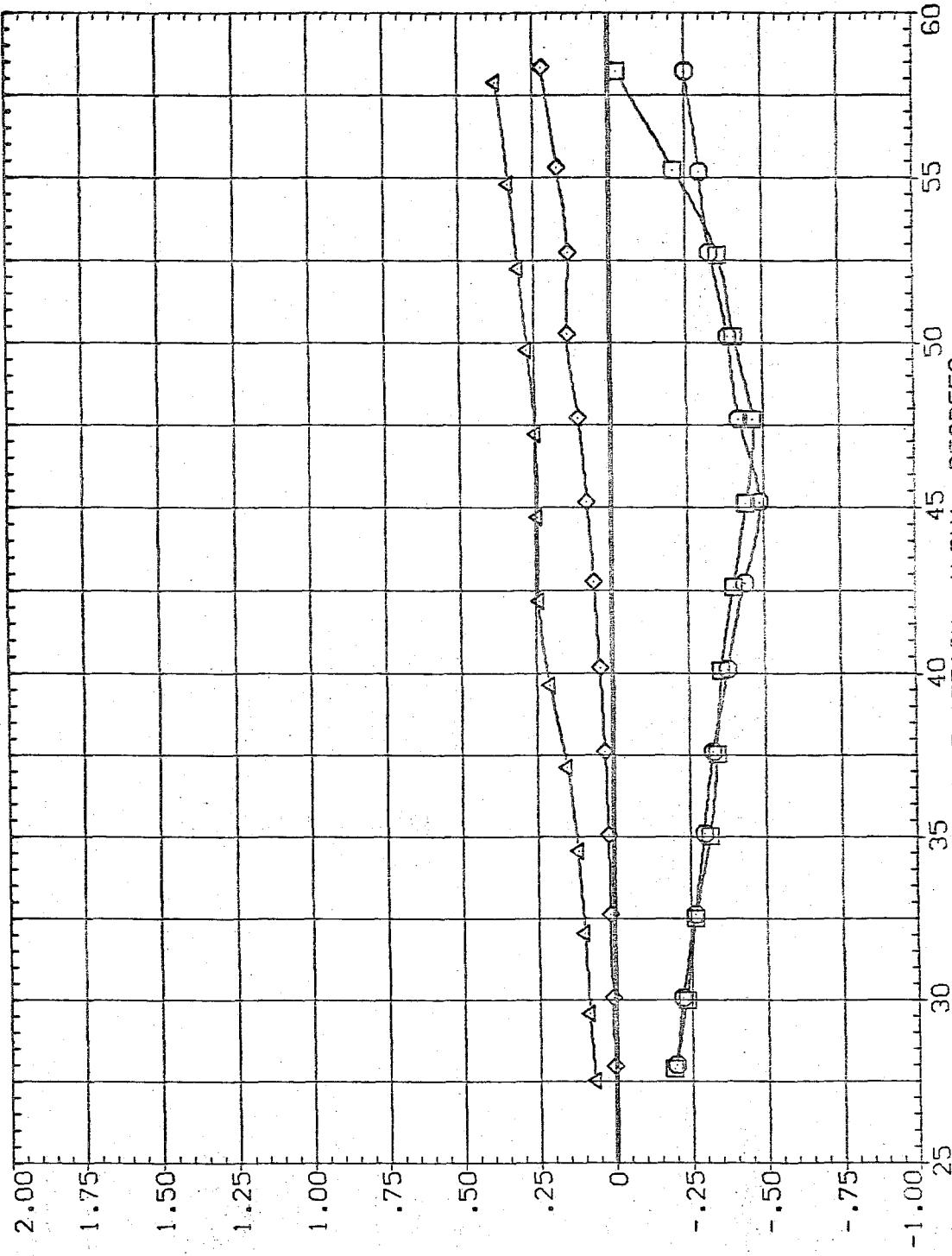


FIG.10 L/D=3.5 PARABOLOID, EFFECT OF MACH NUMBER

(RJDC46)

FP

SYMBOL.	MACH	BETA	PARAMETRIC VALUES
○	.600		.000 R .750
□	.795		
◊	1.497		
△	1.981		



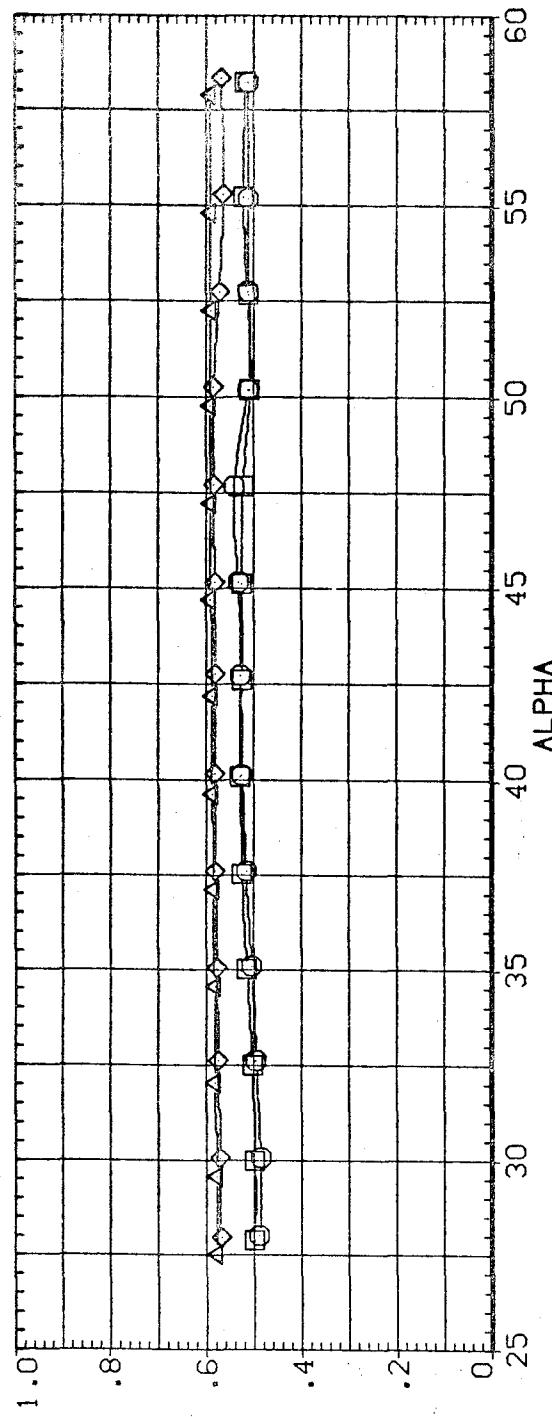
FORREBODY AXIAL FORCE COEFFICIENT, CAF

FIG.10 L/D=3.5 PARABOLOID, EFFECT OF MACH NUMBER

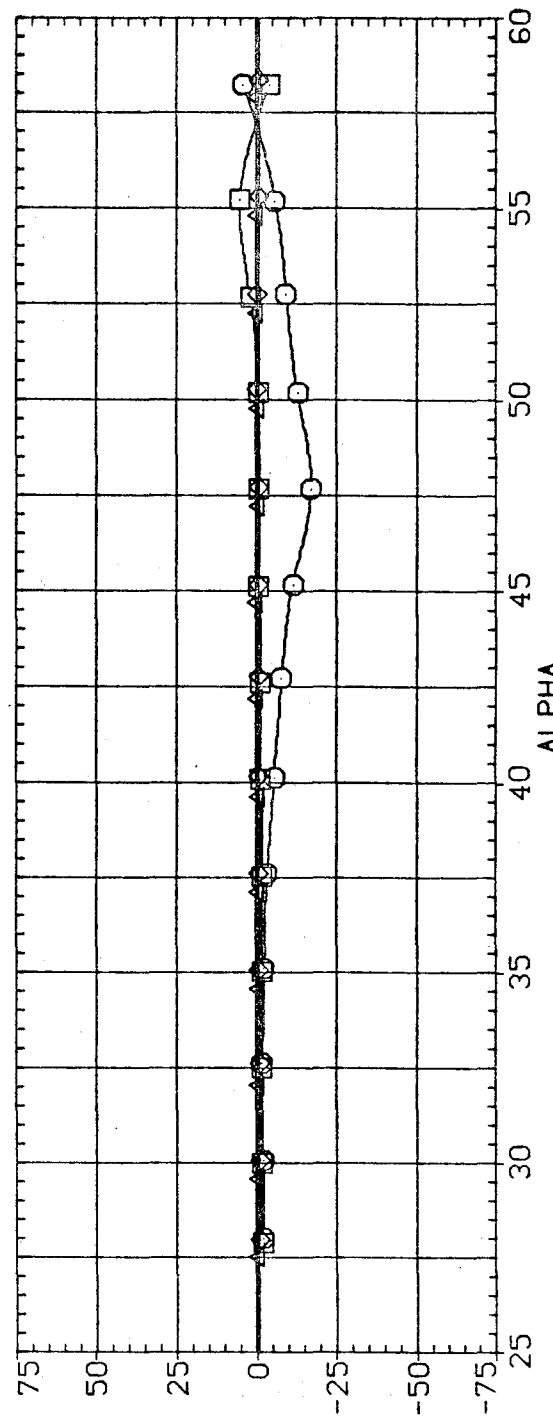
(AJDC46)

FP  
PARAMETRIC VALUES  
MACH .600 BETA .000 R .750  
.795  
1.497  
1.381

SYMBOL  
○ □ ◇ △



CP



PSI

FIG.10 L/D=3.5 PARABOLOID, EFFECT OF MACH NUMBER

FP

(AJDC46)

SYMBOL	MACH	PARAMETRIC VALUES		
		BETA	.000	R
O	.600			.750
□	.795			
◊	1.497			
△	1.981			

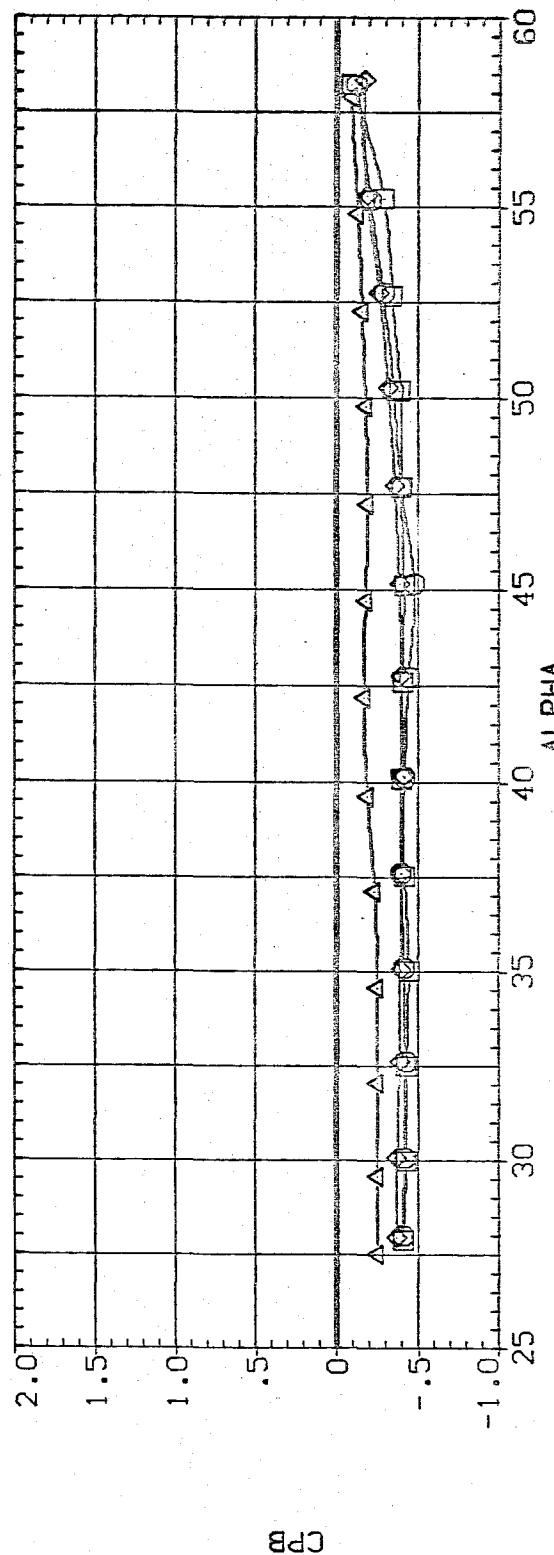
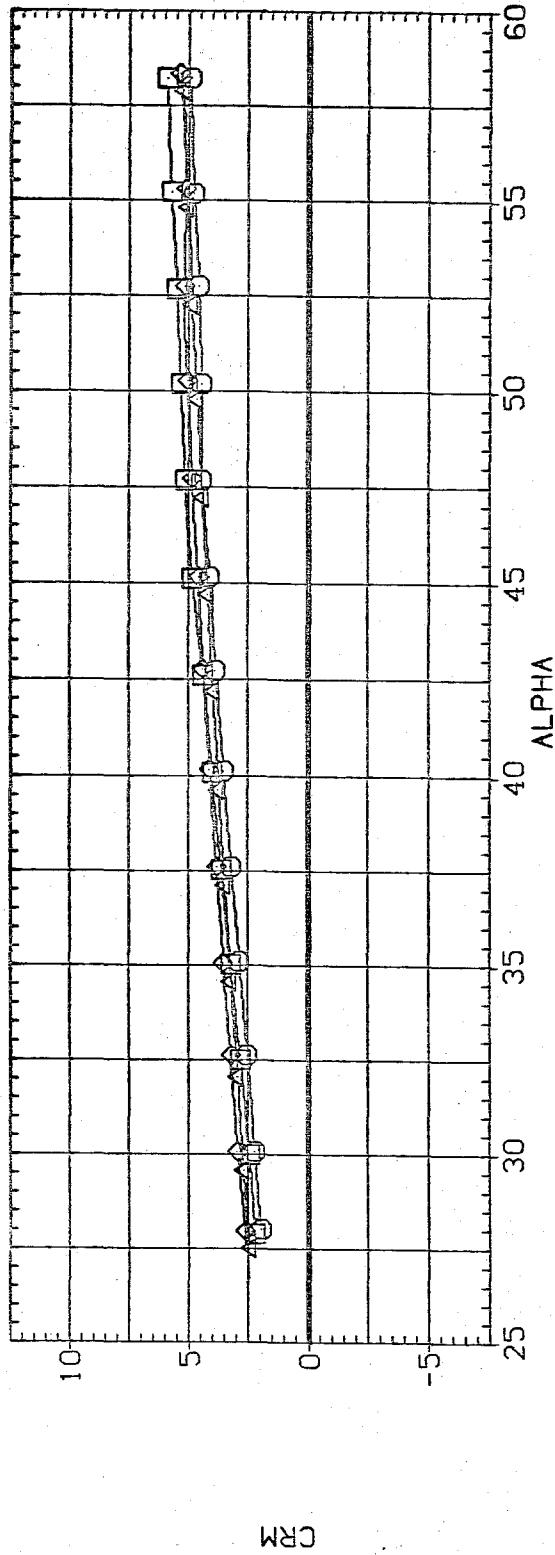


FIG.10 L/D=3.5 PARABOLOID, EFFECT OF MACH NUMBER

PARAMETRIC VALUES  
 MACH .253    BETA .000    R .930  
 SYMBOL      ○    □    ◇  
 MACH .599    .803

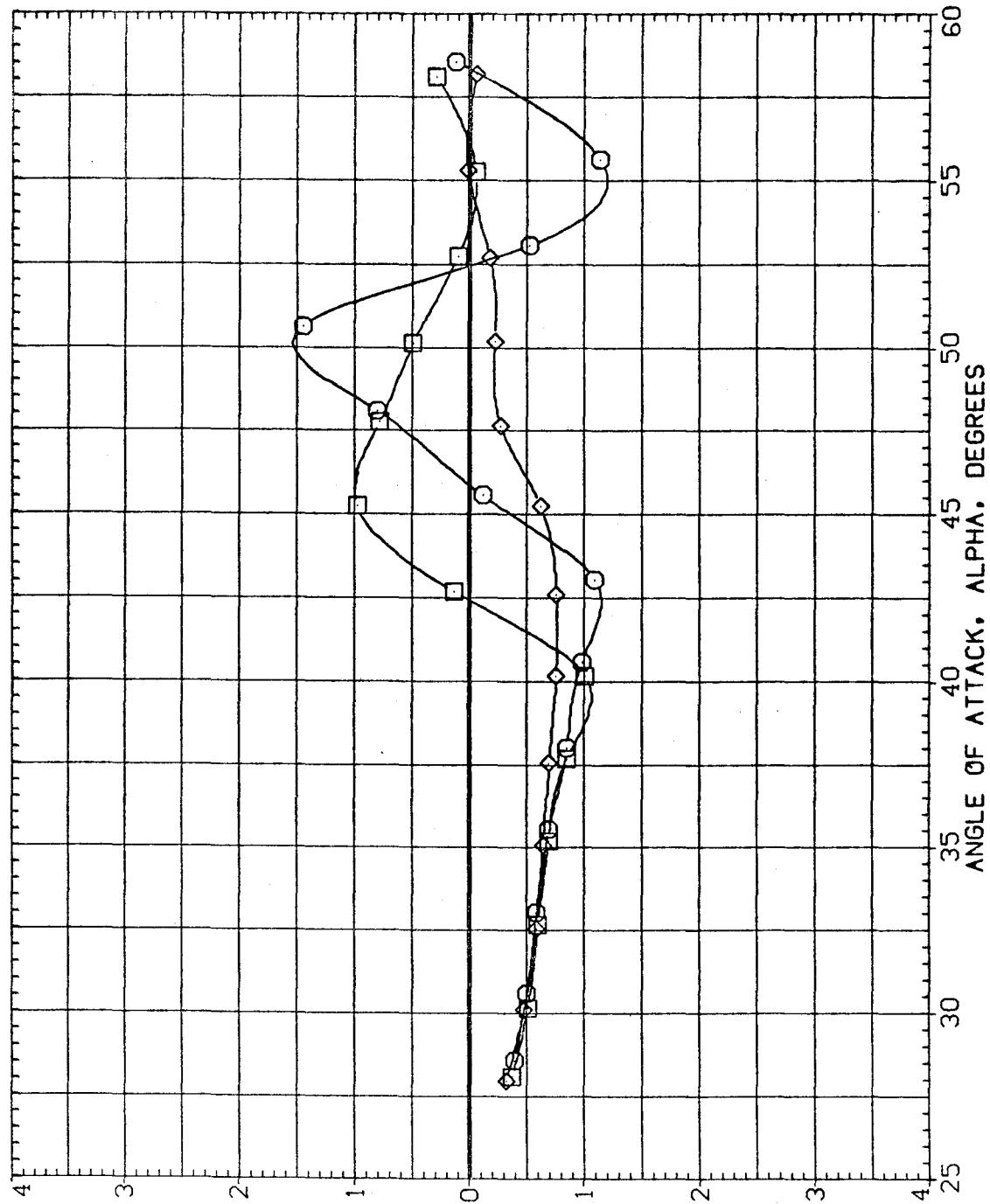
SIDE FORCE COEFFICIENT,  $C_y$ 

FIG.11 20 DEG. CONE, EFFECT OF MACH NUMBER, SUBSONIC

FC1

(RJDC30)

SYMBOL.	MACH	PARAMETRIC VALUES		
		.253	.599	.803
○	,000			
□				
◊				

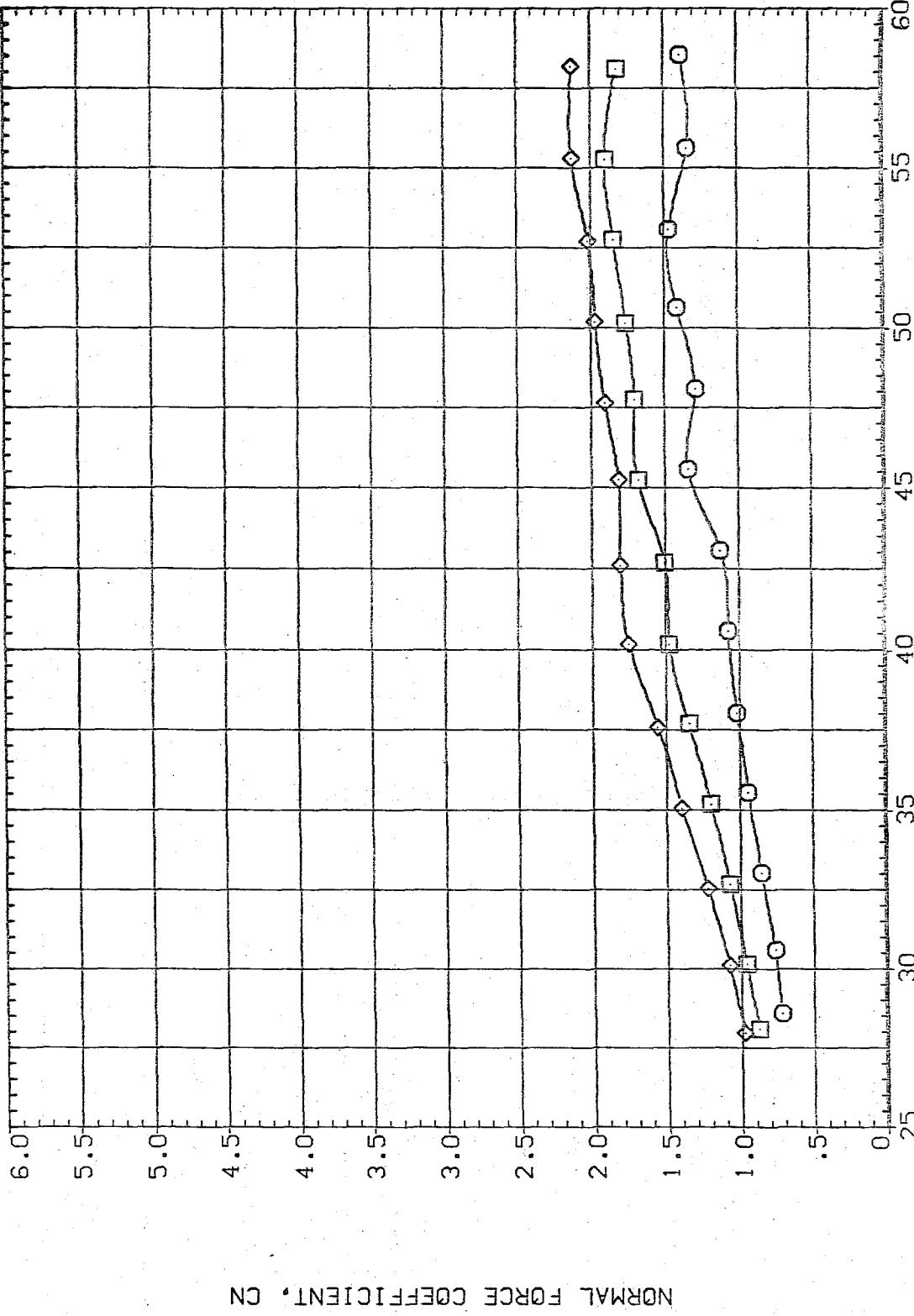
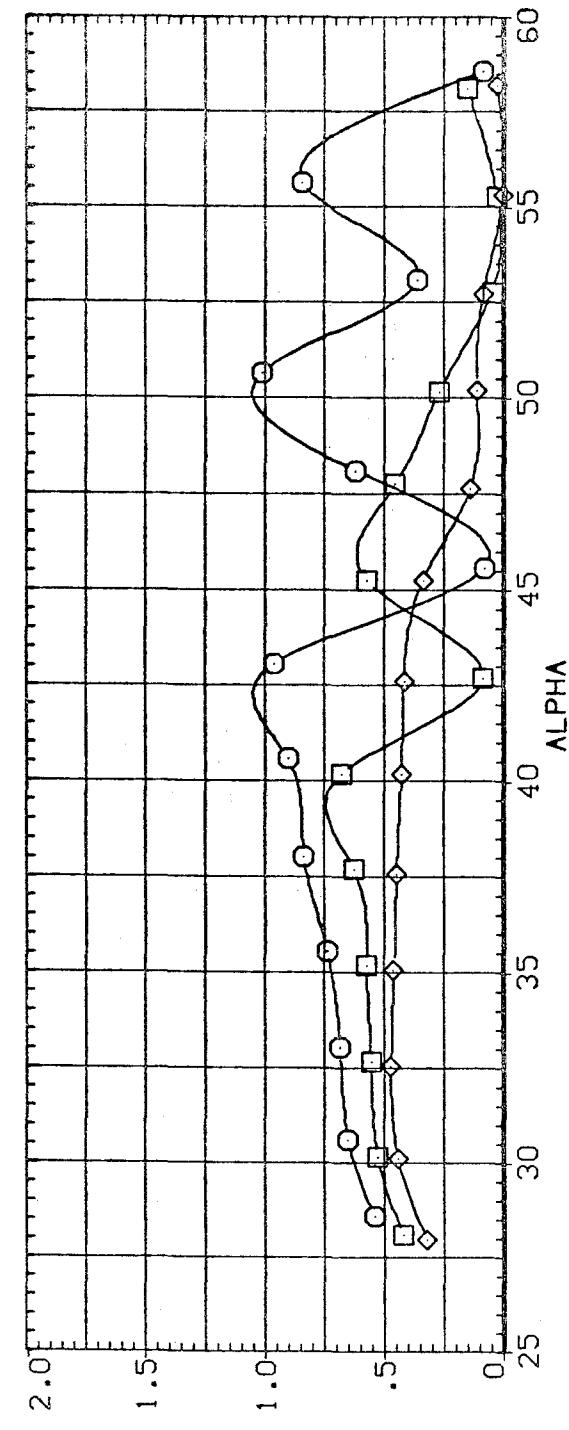


FIG.11 20 DEG. CONE, EFFECT OF MACH NUMBER, SUBSONIC

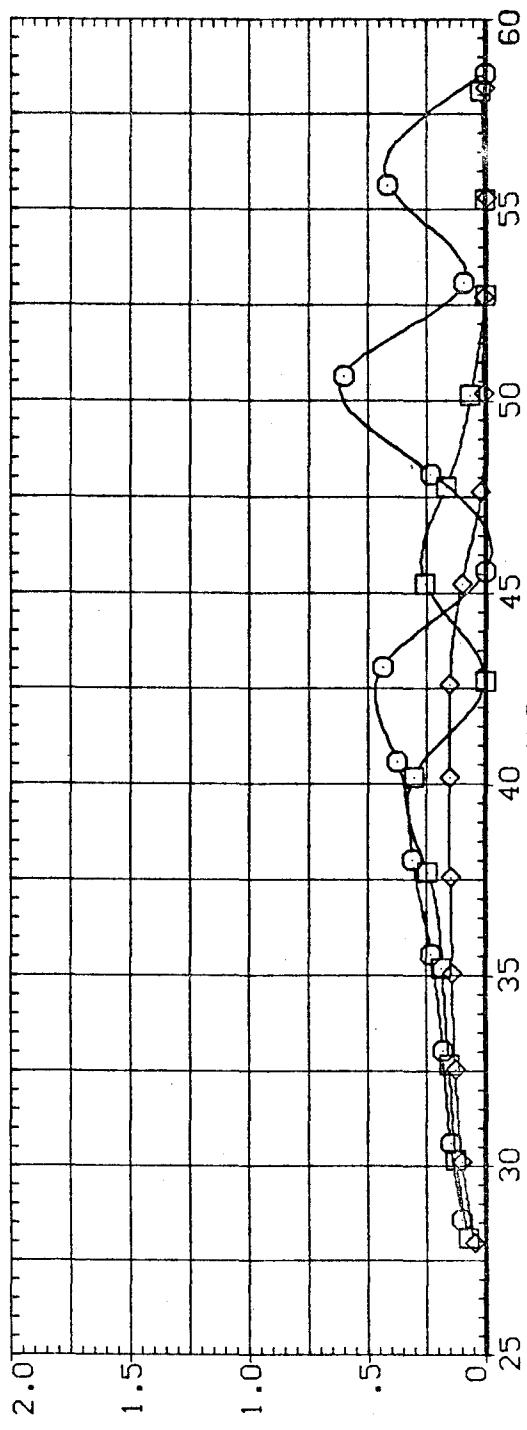
(RJD/C30)

FC1

SYMBOL    MACH    .253    .599    .803  
            .000    R    .930  
            .000    R    .930



ACY/CN



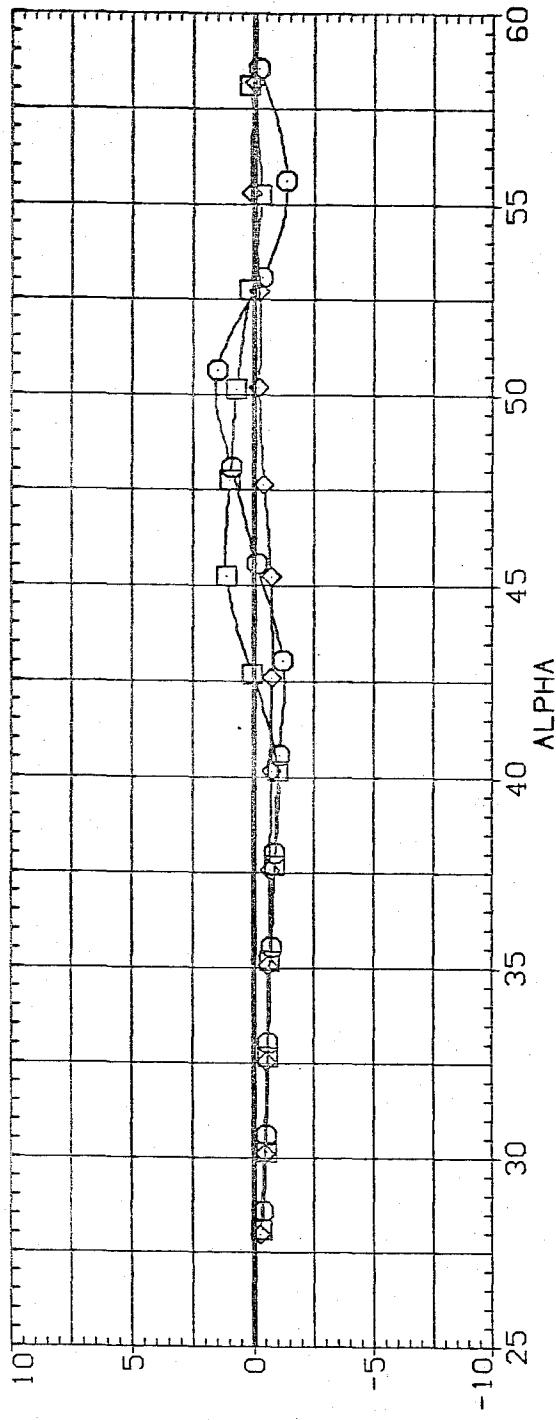
CR-CN

FIG.11 20 DEG. CONE, EFFECT OF MACH NUMBER, SUBSONIC

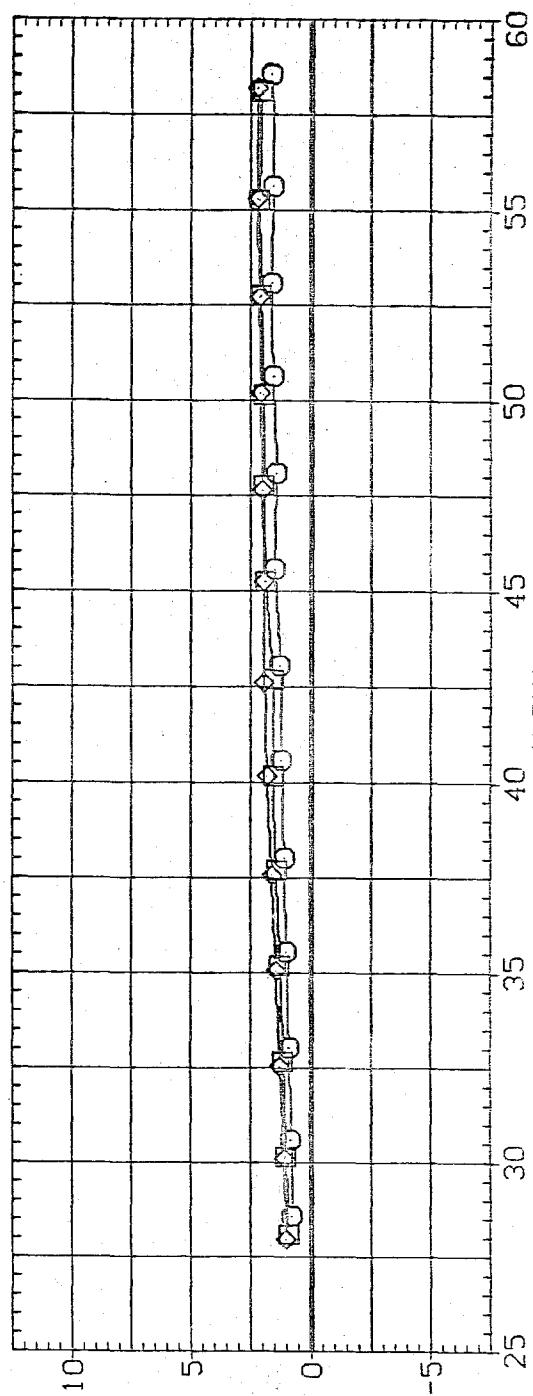
FC1

(RJD/C30)

SYMBOL	MACH	BETA	PARAMETRIC VALUES	R
○	.253		.000	.930
□	.599			
◇	.803			



CYN



CLM

FIG.11 20 DEG. CONE, EFFECT OF MACH NUMBER, SUBSONIC

(RJDC30)

FC1  
FOREBODY AXIAL FORCE COEFFICIENT, CAF  
PARAMETRIC VALUES  
MACH .253    BETA .000    R .930  
SYMBOL    ◎    □    ◆  
.259  
.803

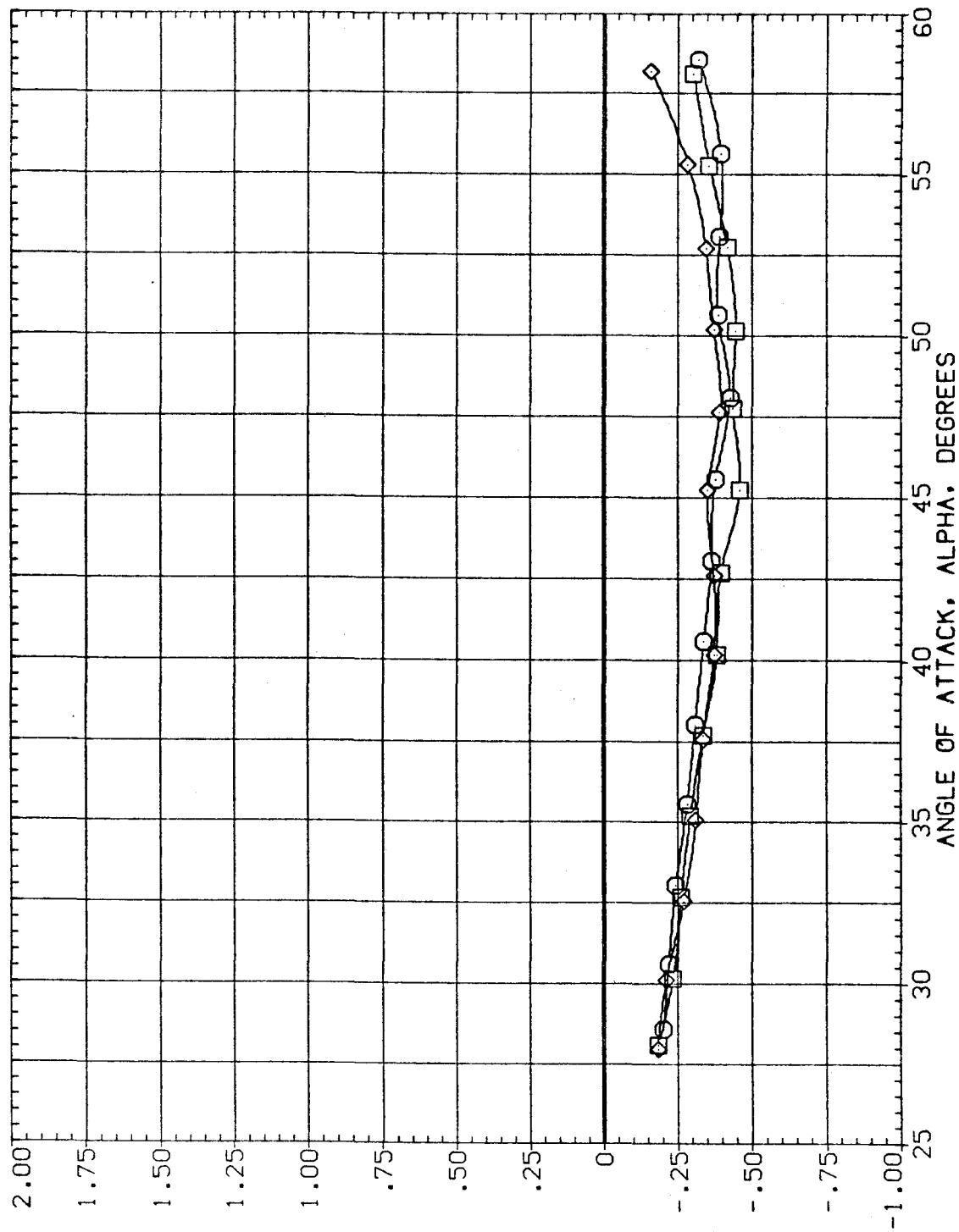
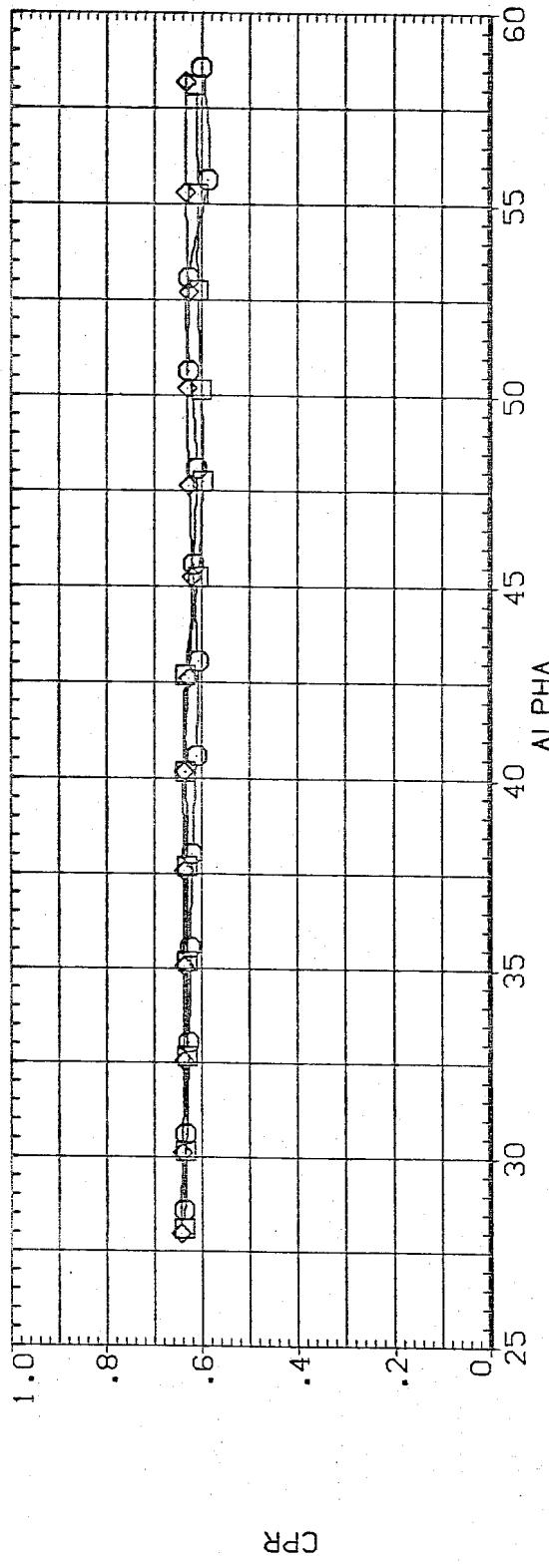


FIG.11 20 DEG. CONE, EFFECT OF MACH NUMBER, SUBSONIC

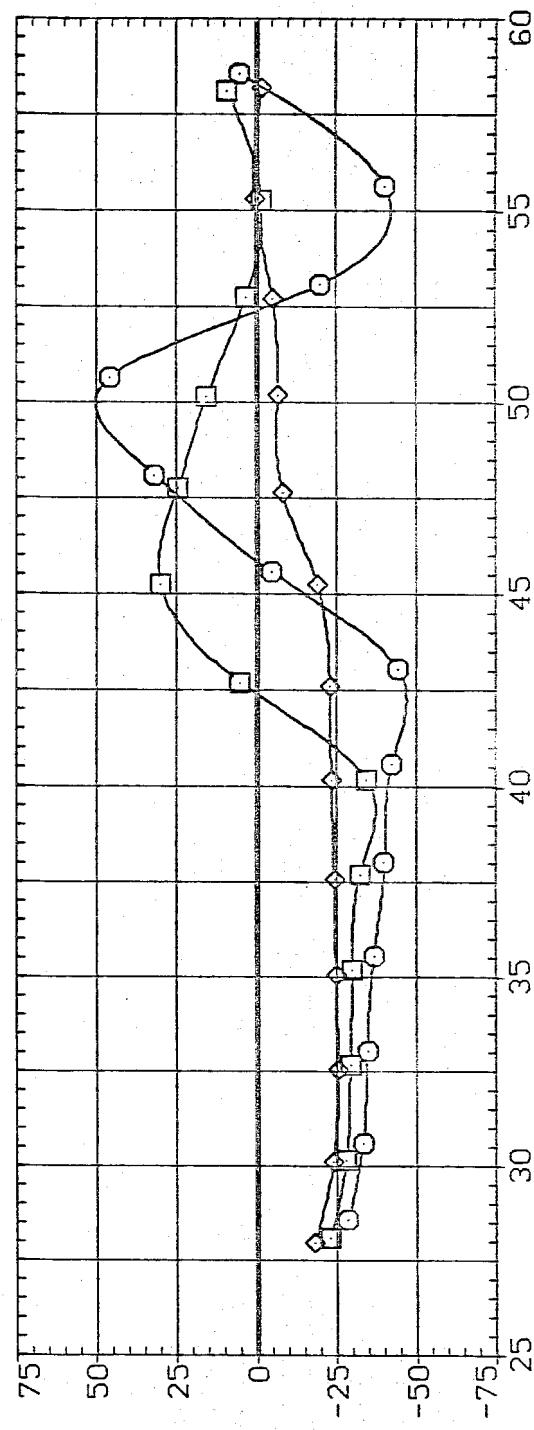
FC1

(AJDC30)

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	.253	.599	R .000
□	.599	.803	
◊			R .930



CL



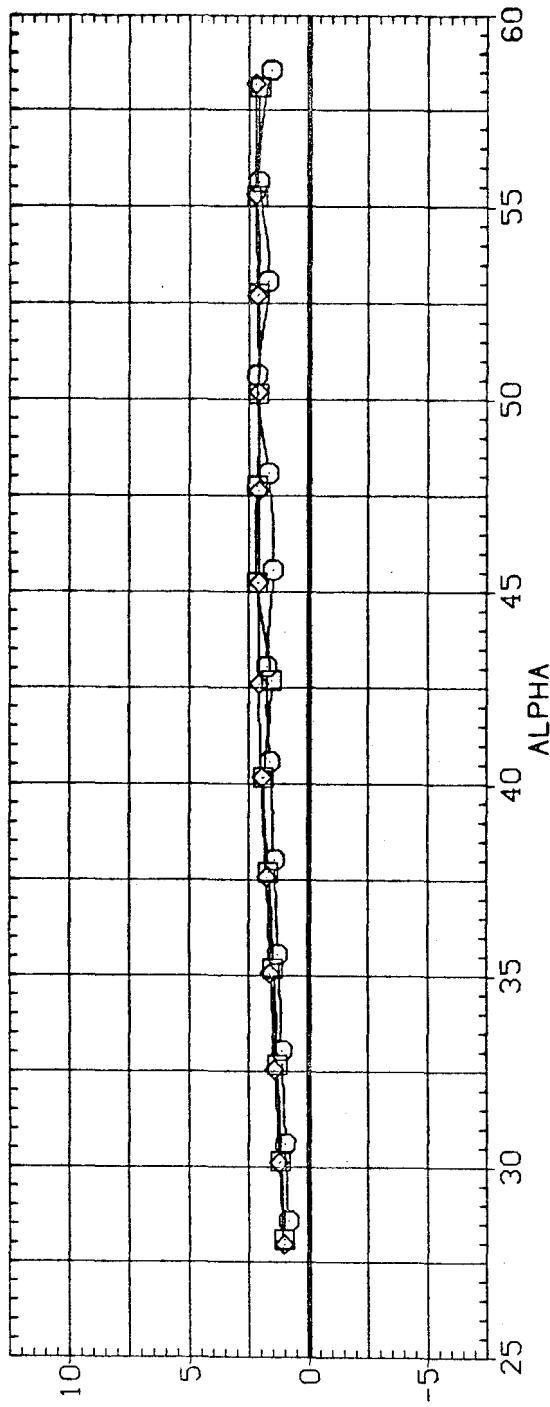
Cp

FIG.11 20 DEG. CONE, EFFECT OF MACH NUMBER, SUBSONIC

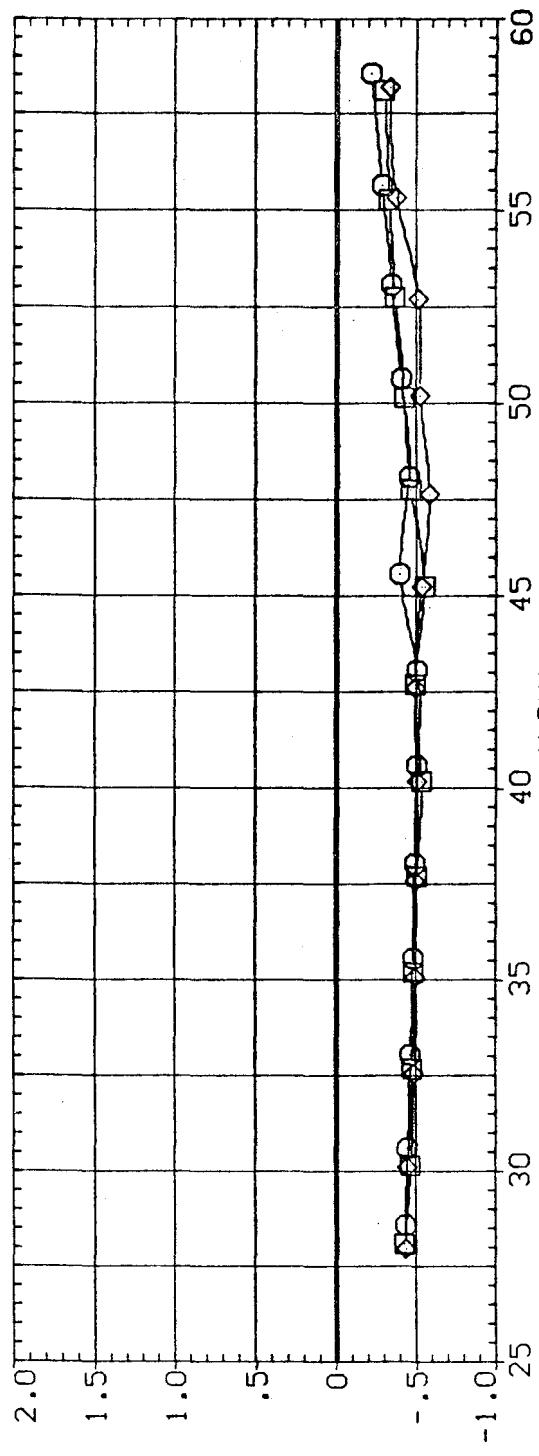
( AJDC30 )

FC1

SYMBOL      MACH      BETA      PARAMETRIC VALUES  
○      .253      .000      R      .930  
□      .599  
◊      .803



CR2



CPB

FIG.11 20 DEG. CONE, EFFECT OF MACH NUMBER, SUBSONIC

FC1

(RJD/C30)

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	1.205	.000	.930
□	1.501		
◇	1.995		

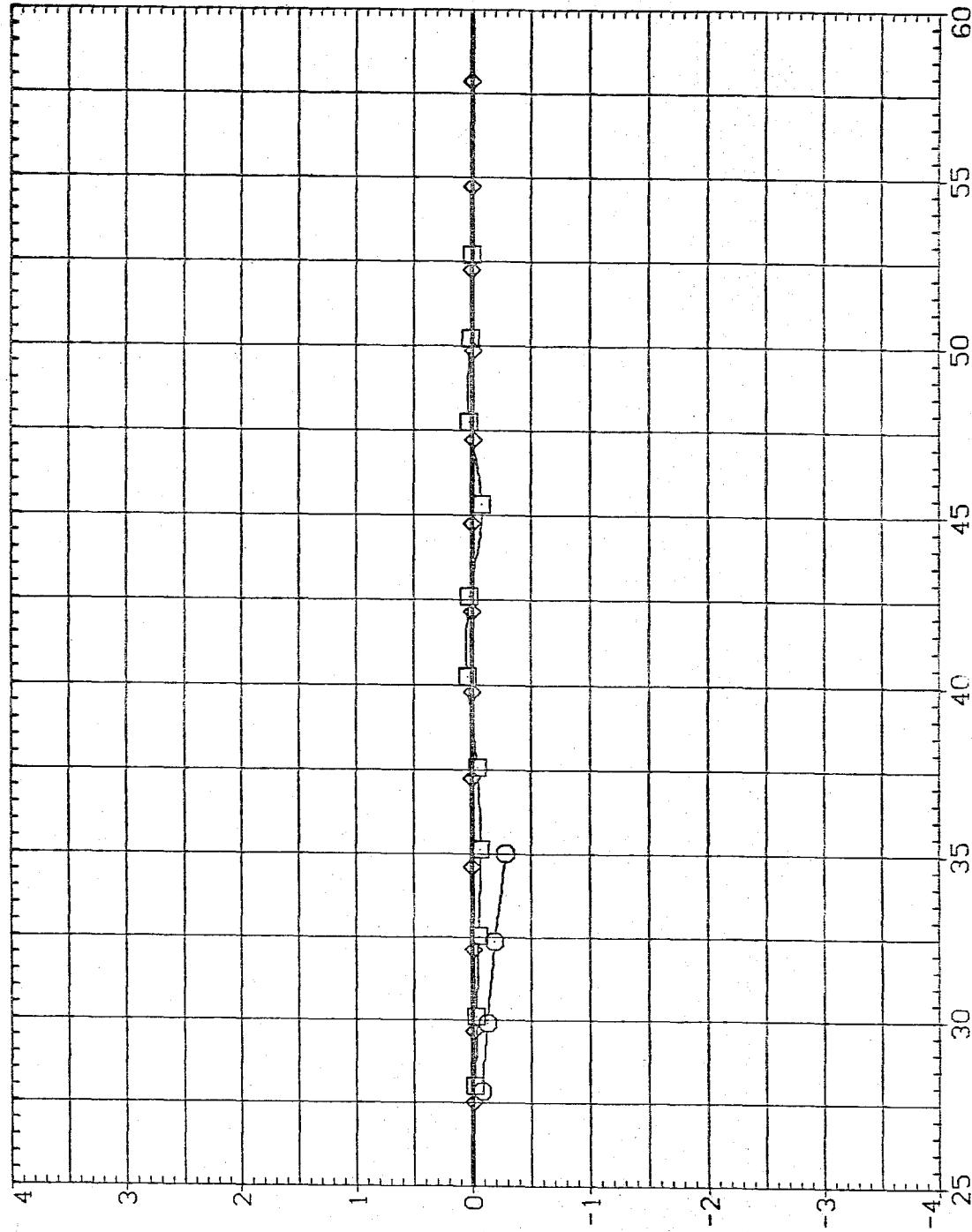
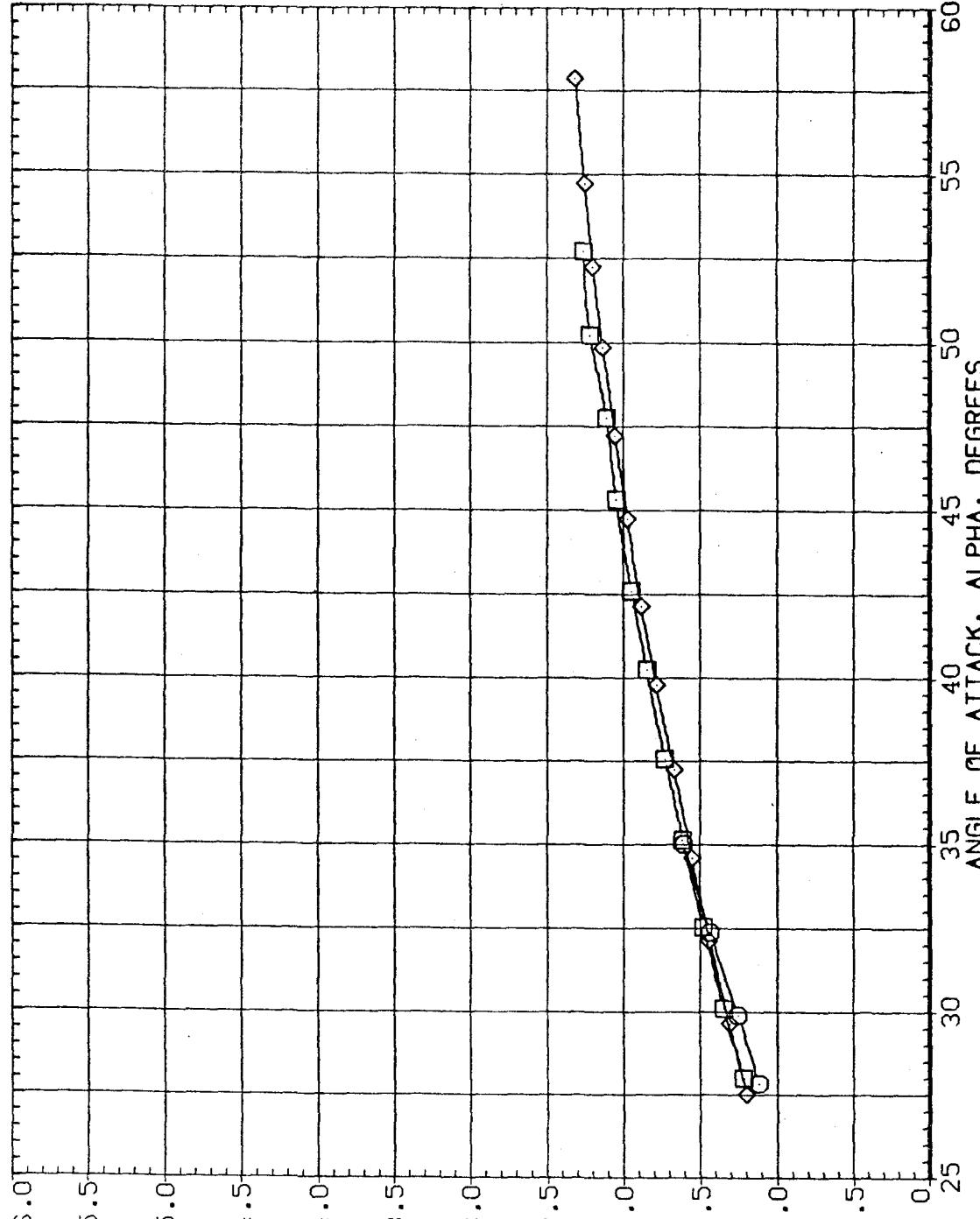
SIDE FORCE COEFFICIENT,  $C_y$ 

FIG.12 20 DEG. CONE, EFFECT OF MACH NUMBER, SUPERSONIC

(RJD/C30)

FCL

PARAMETRIC VALUES  
MACH .1.205    BETA .000    R .930  
SYMBOL O    □    ◊  
1.501  
1.995



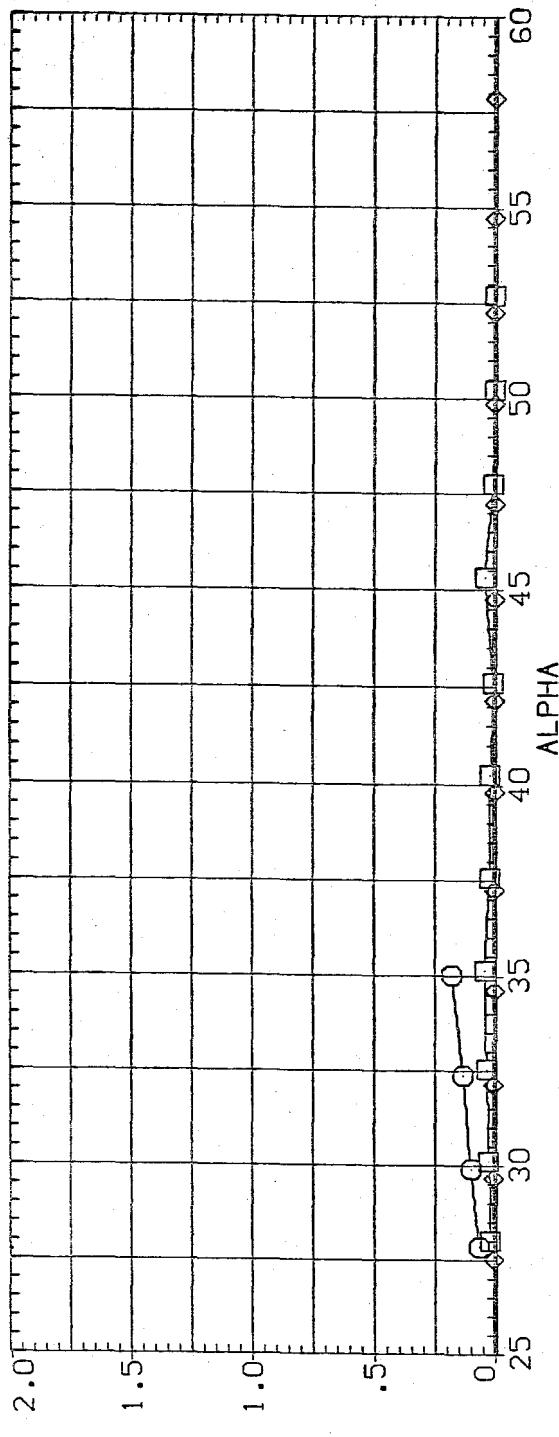
NORMAL FORCE COEFFICIENT, CN

FIG.12 20 DEG. CONE, EFFECT OF MACH NUMBER, SUPERSONIC

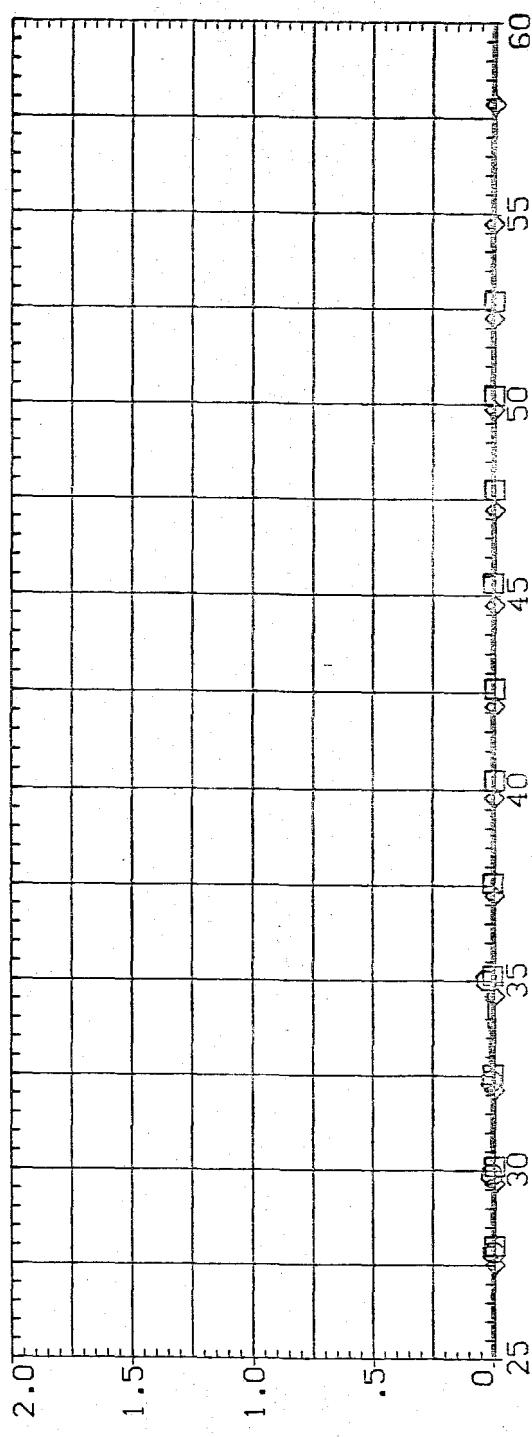
FC1

(RJDC30)

SYMBOL	MACH	BETA	PARAMETRIC VALUES	R
O	1.1205	.000		.930
□	1.1501			
◊	1.1995			



ACY/CN



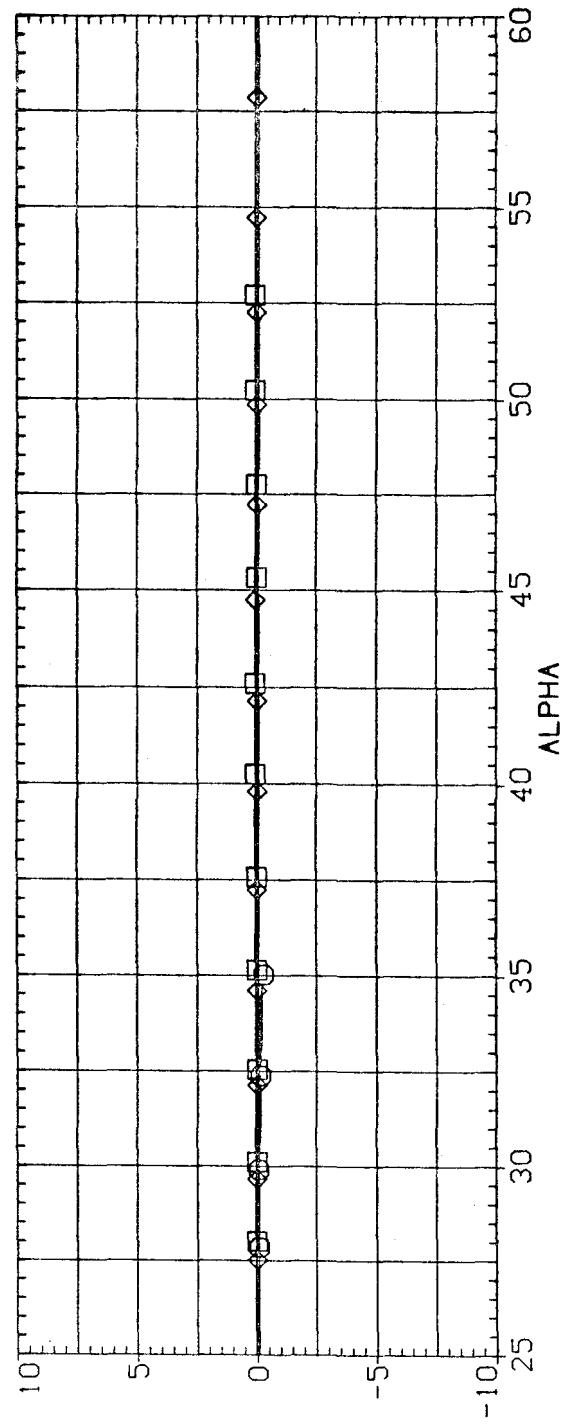
CR-CN

FIG.12 20 DEG. CONE, EFFECT OF MACH NUMBER, SUPERSONIC

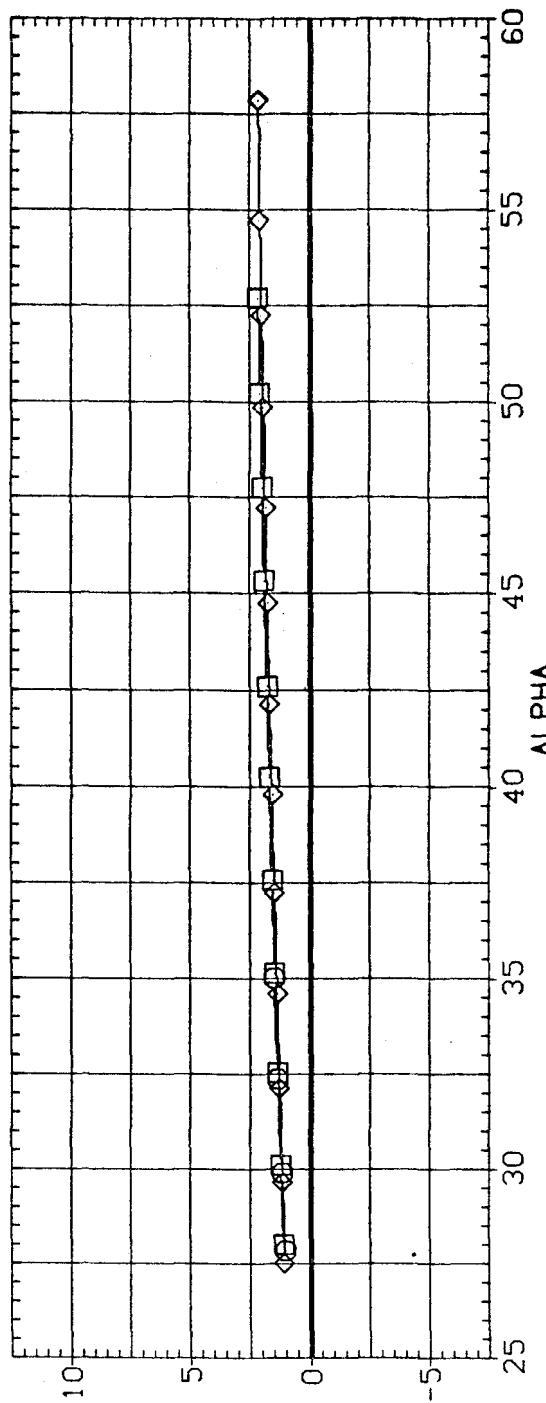
(RJDCC30)

FC1

SYMBOL  
○ □ ◊  
MACH 1.205 1.501 1.395  
BETA .000 .930  
PARAMETRIC VALUES R



CYN



CLM

FIG.12 20 DEG. CONE, EFFECT OF MACH NUMBER, SUPERSONIC

(RJD/C30)

FC1

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	1.205	.000	.930
□	1.501		
◊	1.995		

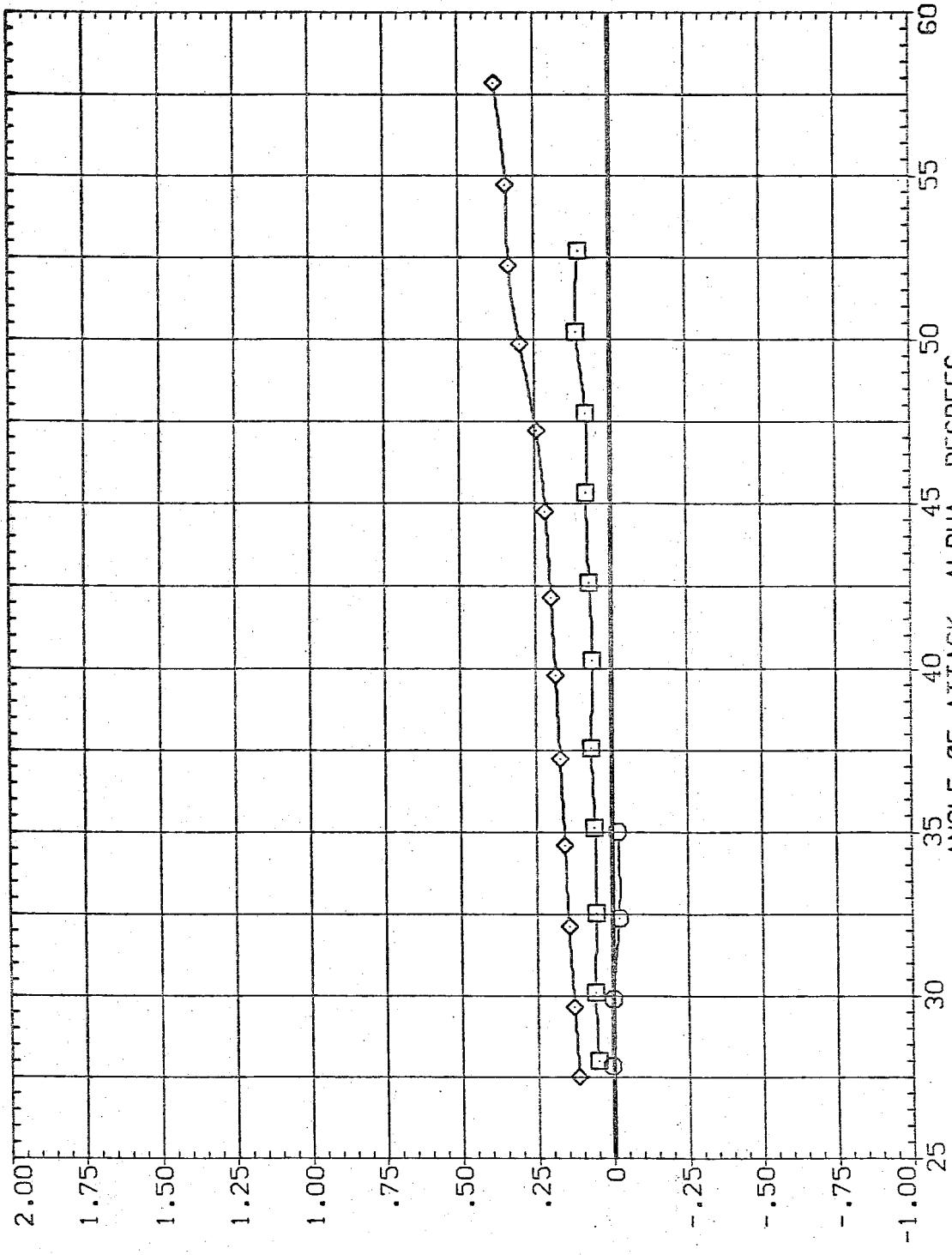
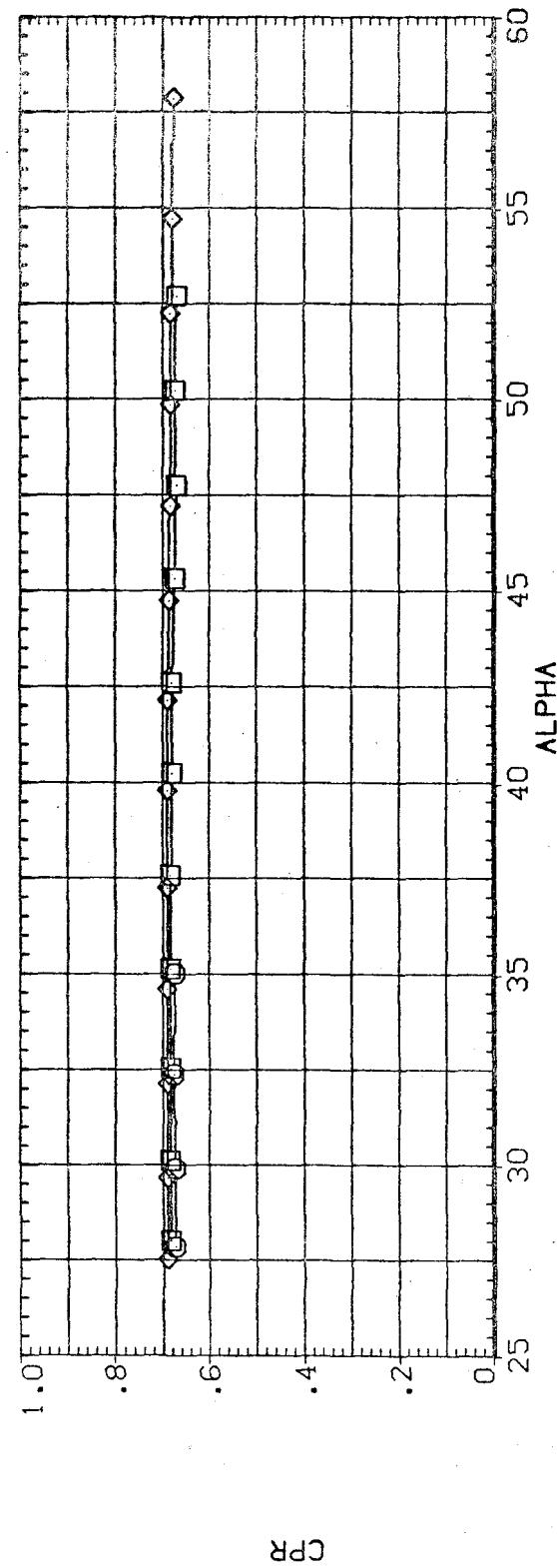


FIG.12 20 DEG. CONE, EFFECT OF MACH NUMBER, SUPERSONIC

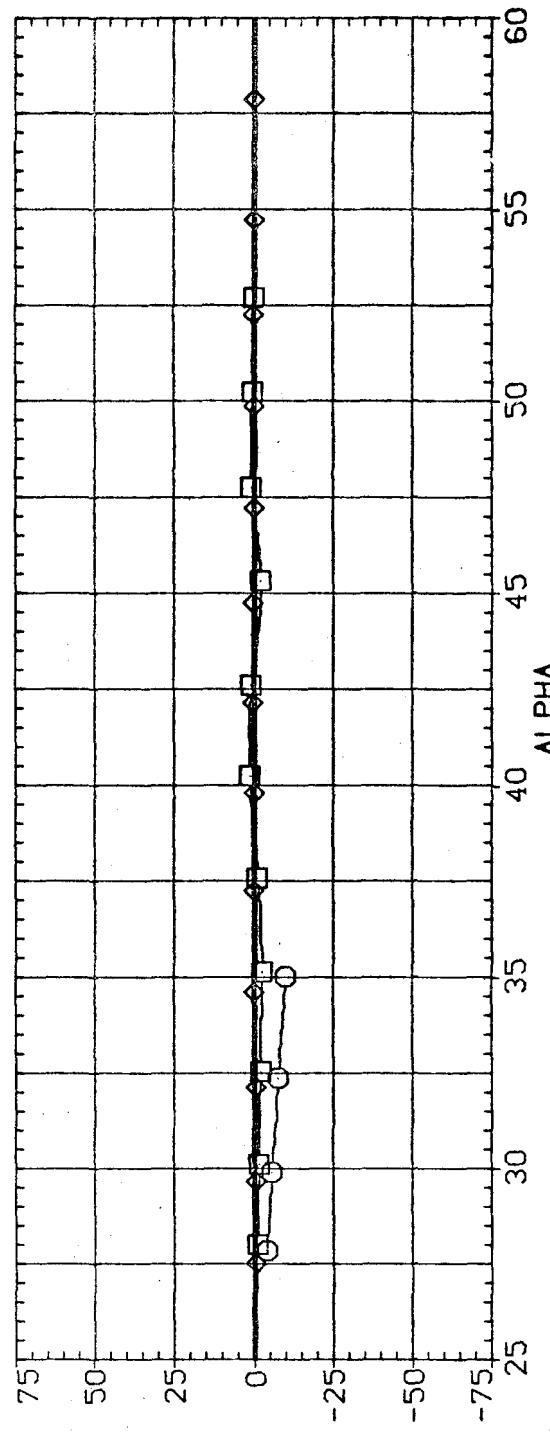
(AJDC30)

FC1

PARAMETRIC VALUES  
MACH      1.205      1.501      1.995  
BETA      .000      R      .930  
SYMBOL      O      □      ◊



CP/R



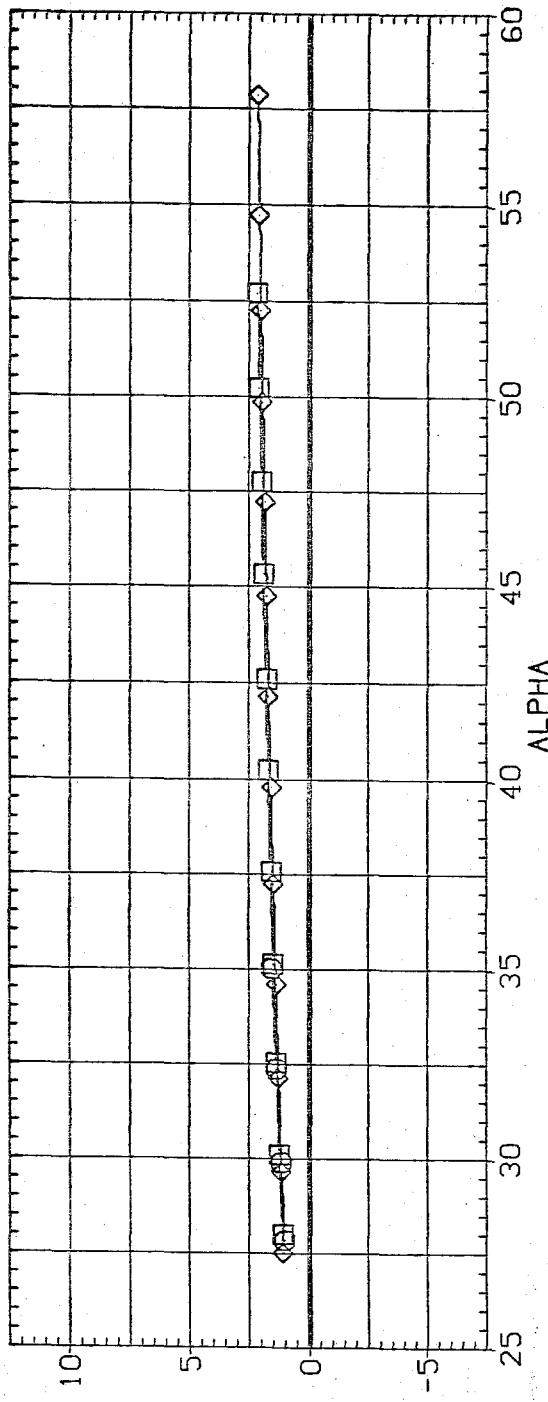
PSI

FIG.12 20 DEG. CONE, EFFECT OF MACH NUMBER, SUPERSONIC

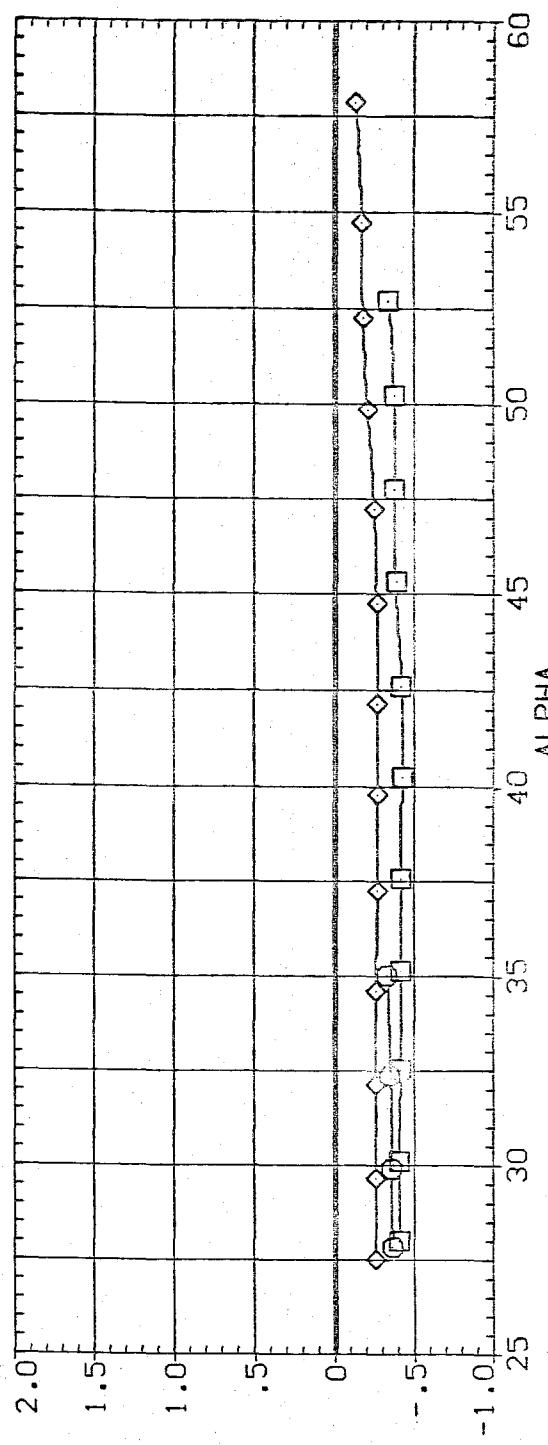
FC1

(AJDC30)

SYMBOL	MACH	BETA	R	PARAMETRIC VALUES
○	1.205	.000	.930	
□	1.501			
◊	1.995			



CRM



CPB

FIG.12 20 DEG. CONE, EFFECT OF MACH NUMBER, SUPERSONIC

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
 (RJDC30) FC1  
 (RJDC31) FC1

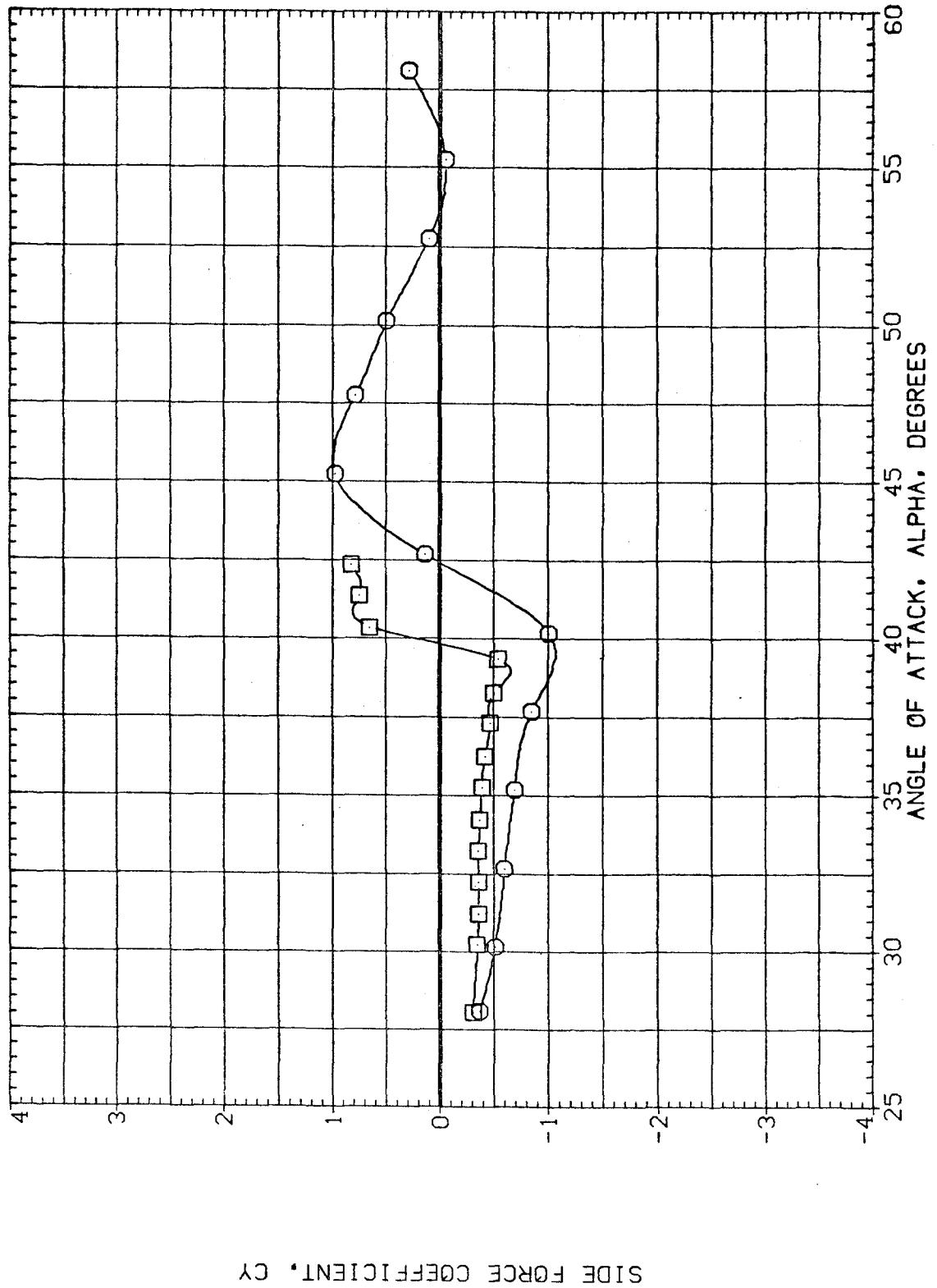


FIG.13 20 DEG. CONE, EFFECT OF REYNOLDS NUMBER  
 $(A)_MACH = .60$

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
(RJD30) FCI  
(RJD31) FCI

R .930 .000  
2.160 .000

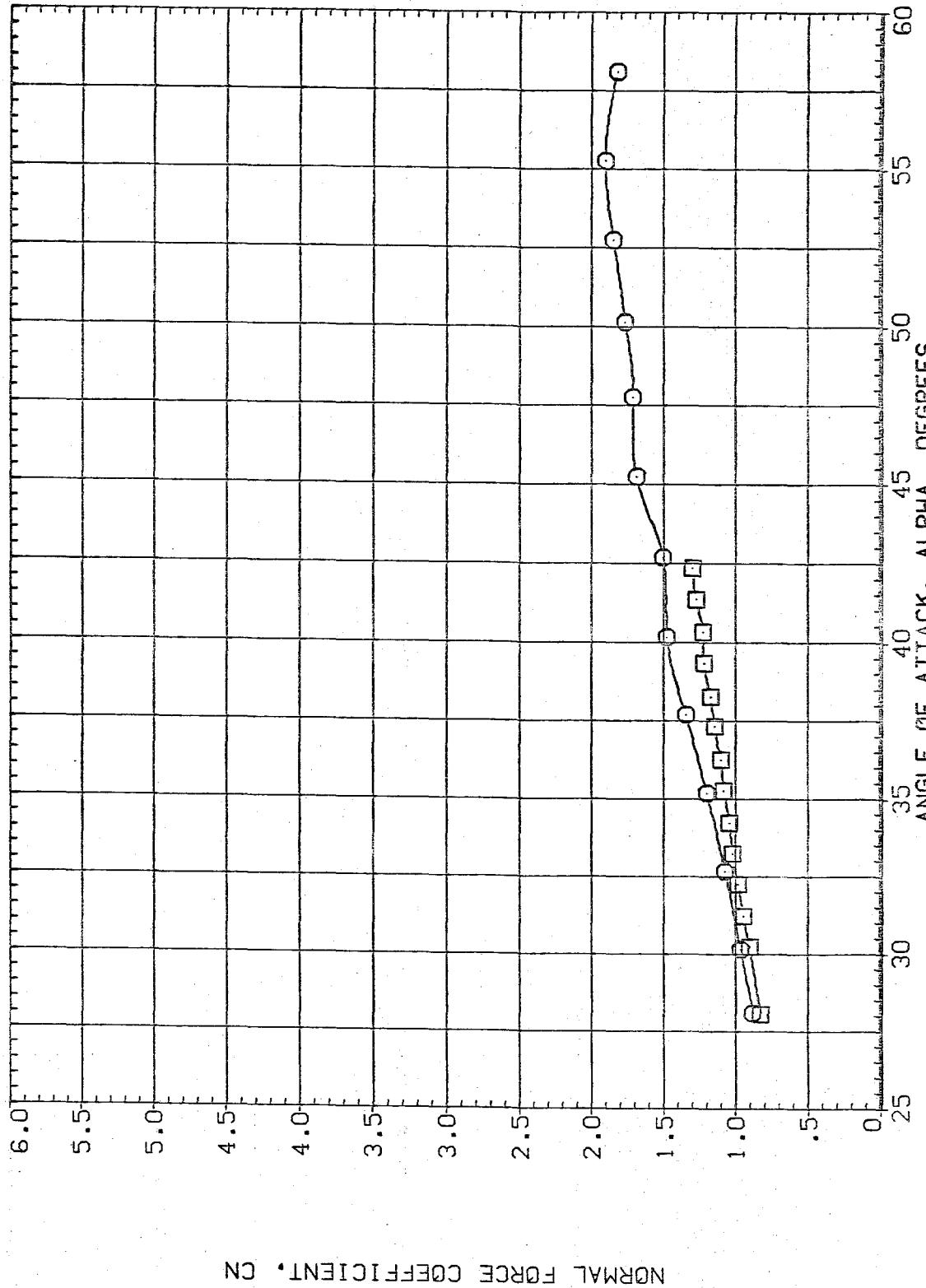


FIG.13 20 DEG. CONE, EFFECT OF REYNOLDS NUMBER  
C<sub>A</sub>MACH = .60

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
 (RJDCC30) FCI  
 (RJDCC31) FCI

R .930 .000  
 2.160 .000

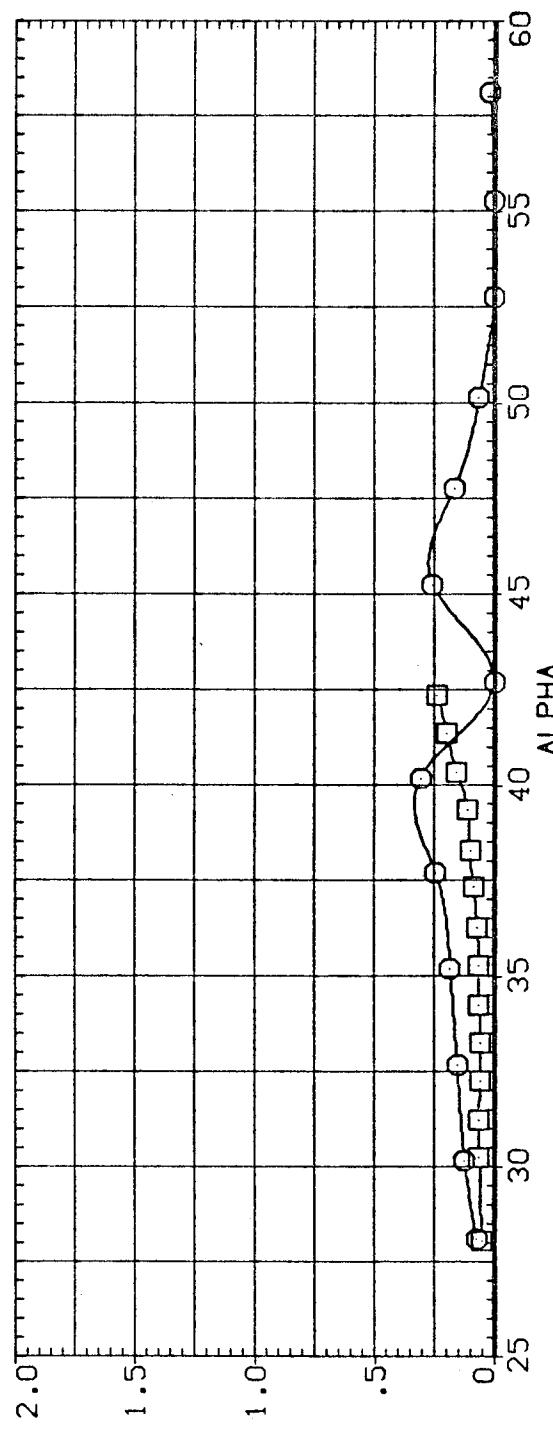
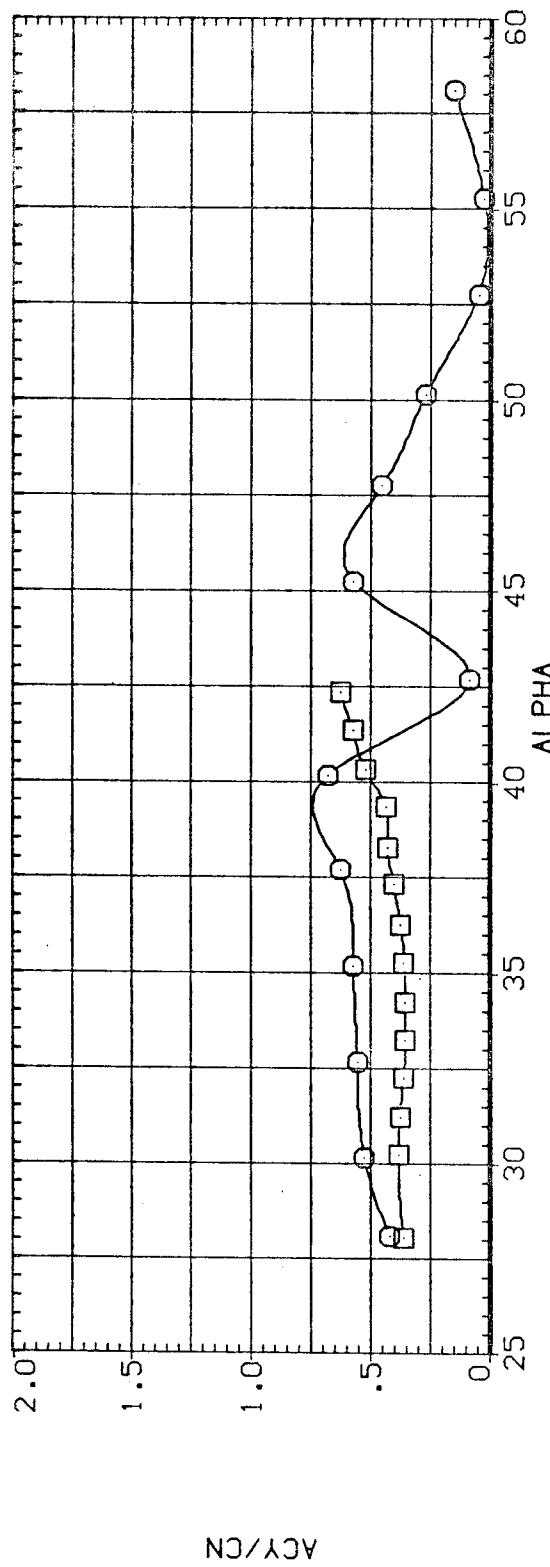


FIG.13 20 DEG. CONE, EFFECT OF REYNOLDS NUMBER

(A)MACH = .60

PAGE 66

DATA SET SYMBOL    CONFIGURATION DESCRIPTION  
(RJD30)            FCI  
(RJD31)            FCI

R .930 .000  
2.160 .000

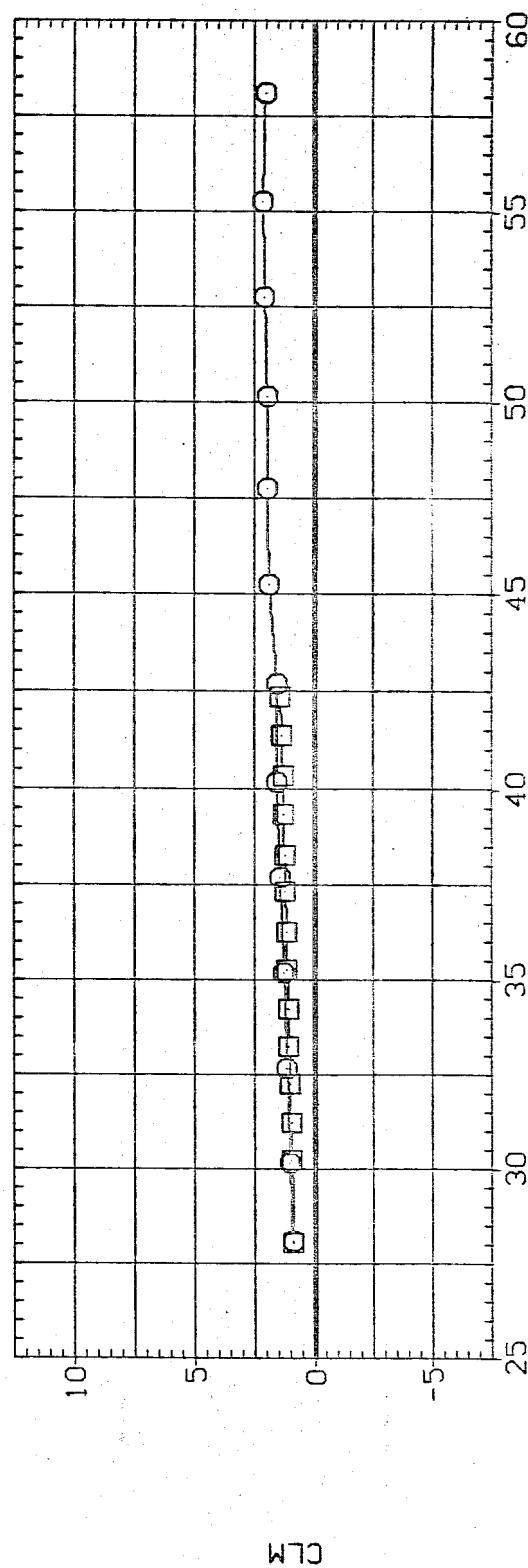
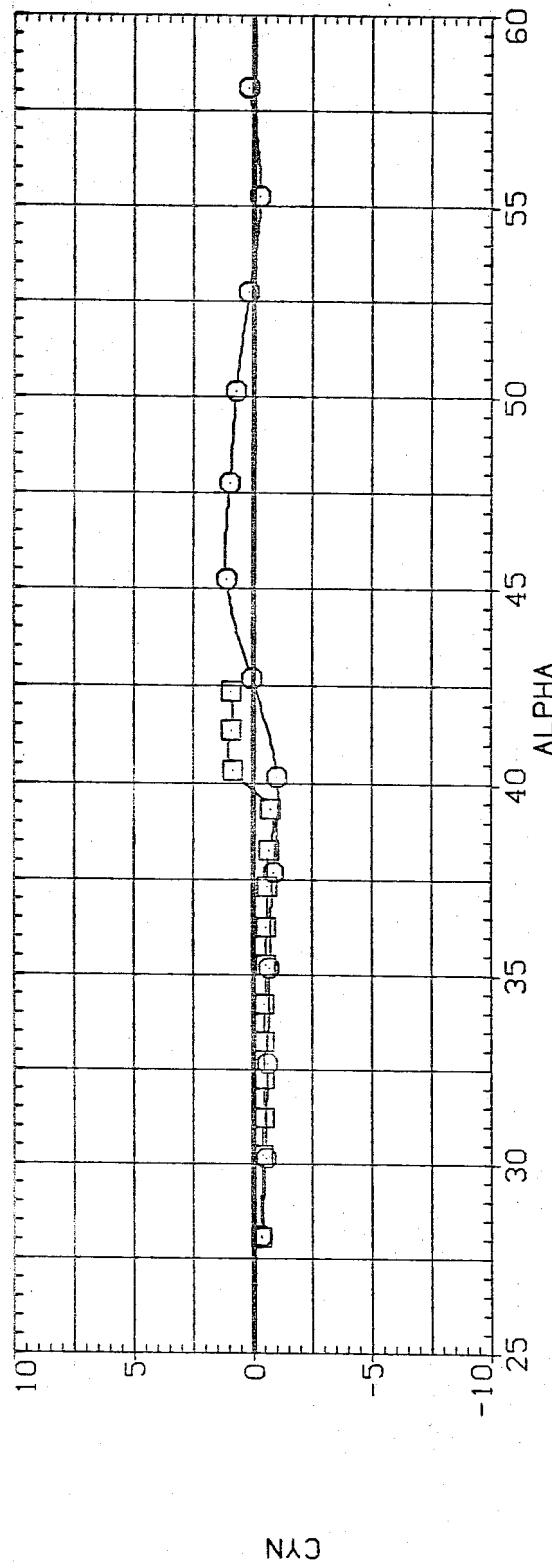
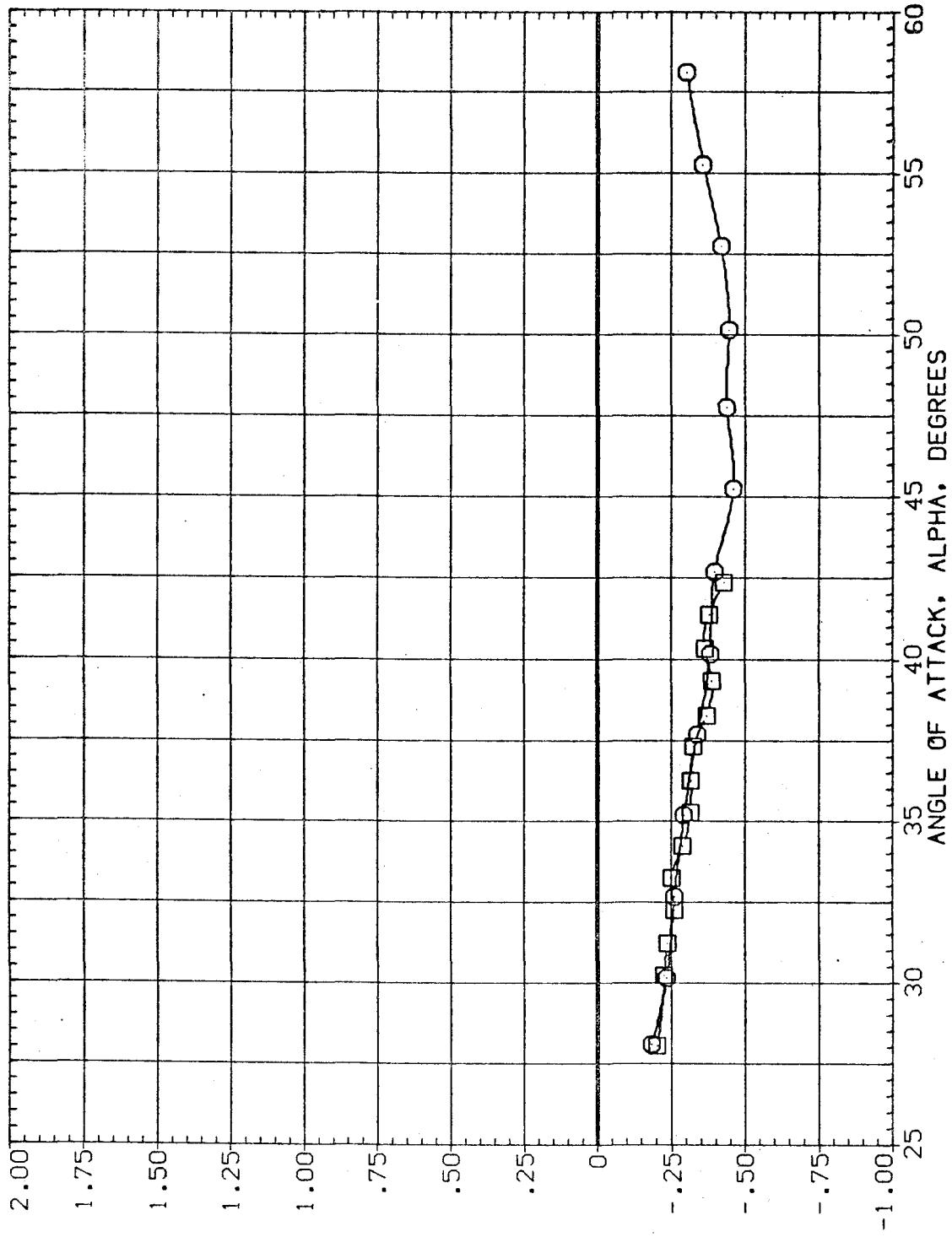


FIG.13 20 DEG. CONE, EFFECT OF REYNOLDS NUMBER  
(A)MACH = .60

DATA SET SYMBOL      LUNI ILLUSTRATION DESCRIPTION  
(RJDCC30)       FC1  
(RJDCC31)       FC1

MACH      .930      .000  
2.160      .000



FOREBODY AXIAL FORCE COEFFICIENT, CAF

FIG.13 20 DEG. CONE, EFFECT OF REYNOLDS NUMBER  
(A)MACH = .60

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
 { ADJC30 } B FCI  
 { ADJC31 } B FCI

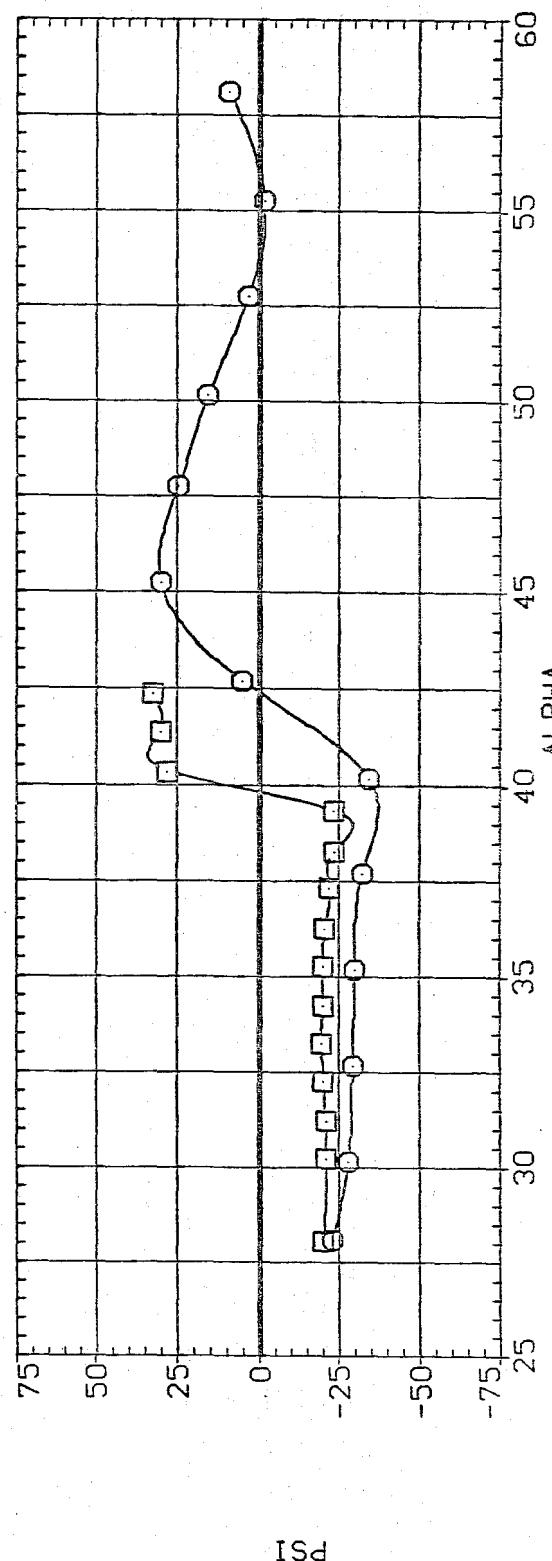
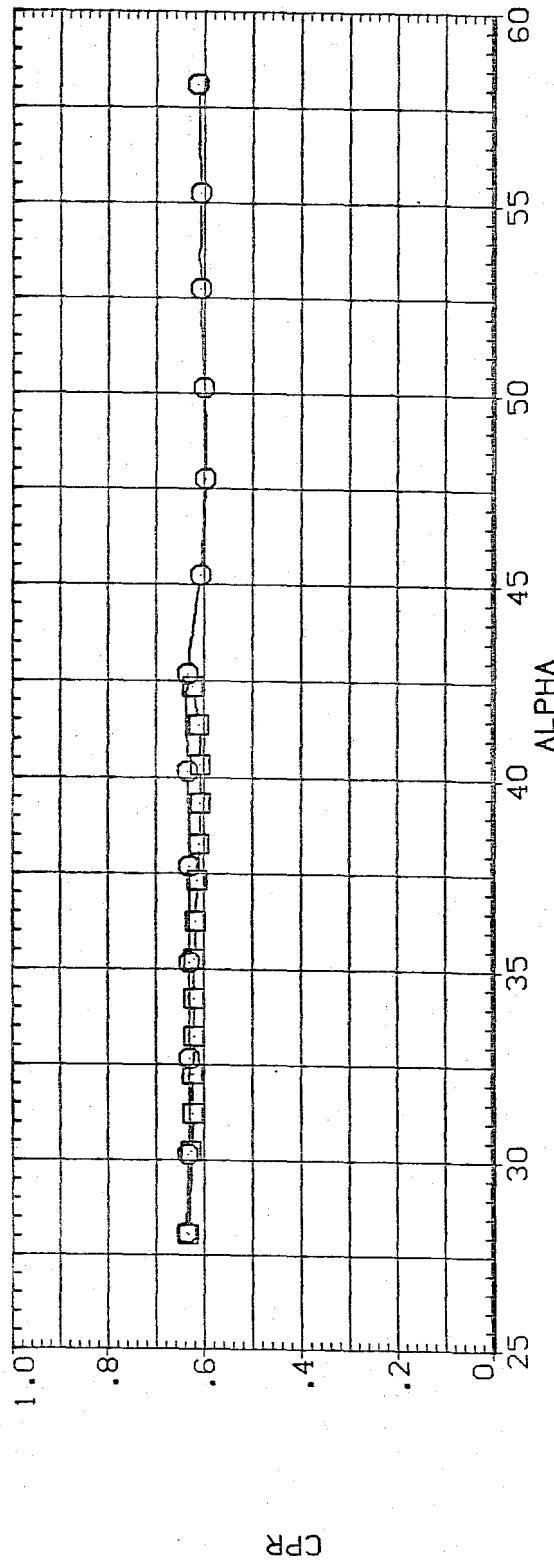


FIG.13 20 DEG. CONE, EFFECT OF REYNOLDS NUMBER  
 $(\text{AJMACH} = .60$

DATA SET SYMBOL CONFIGURATION DESCRIPTION  
 (AJDC30) FCI  
 (AJDC31) FC1

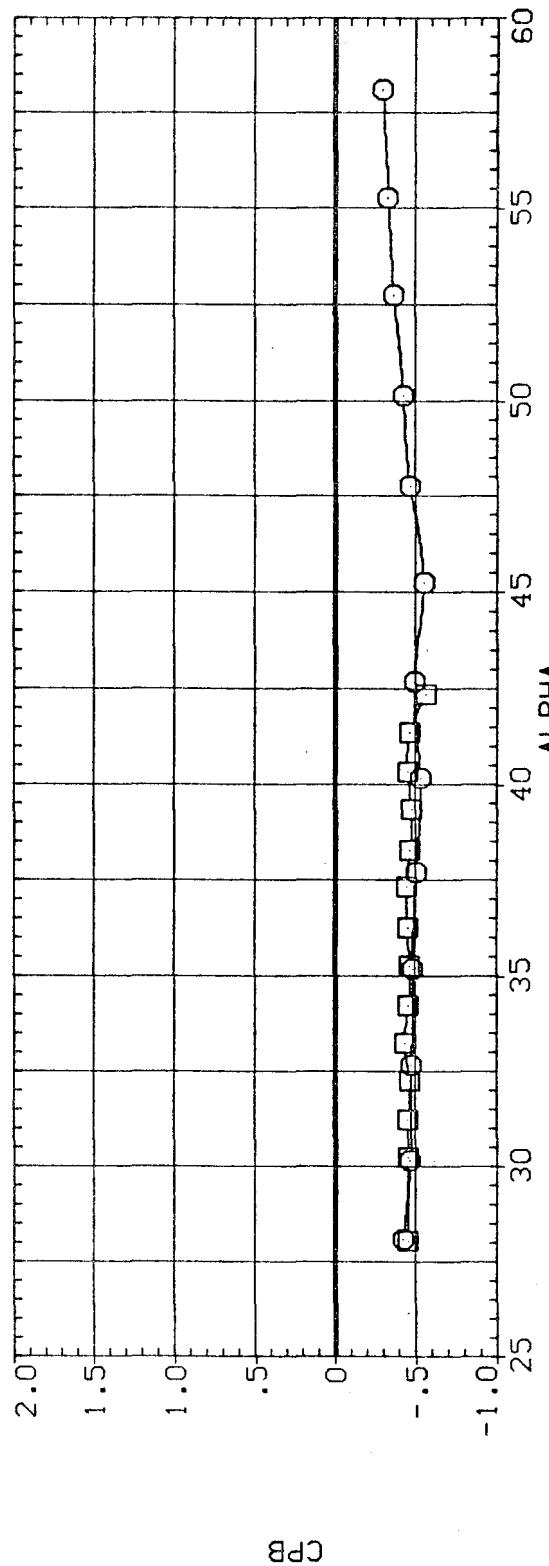
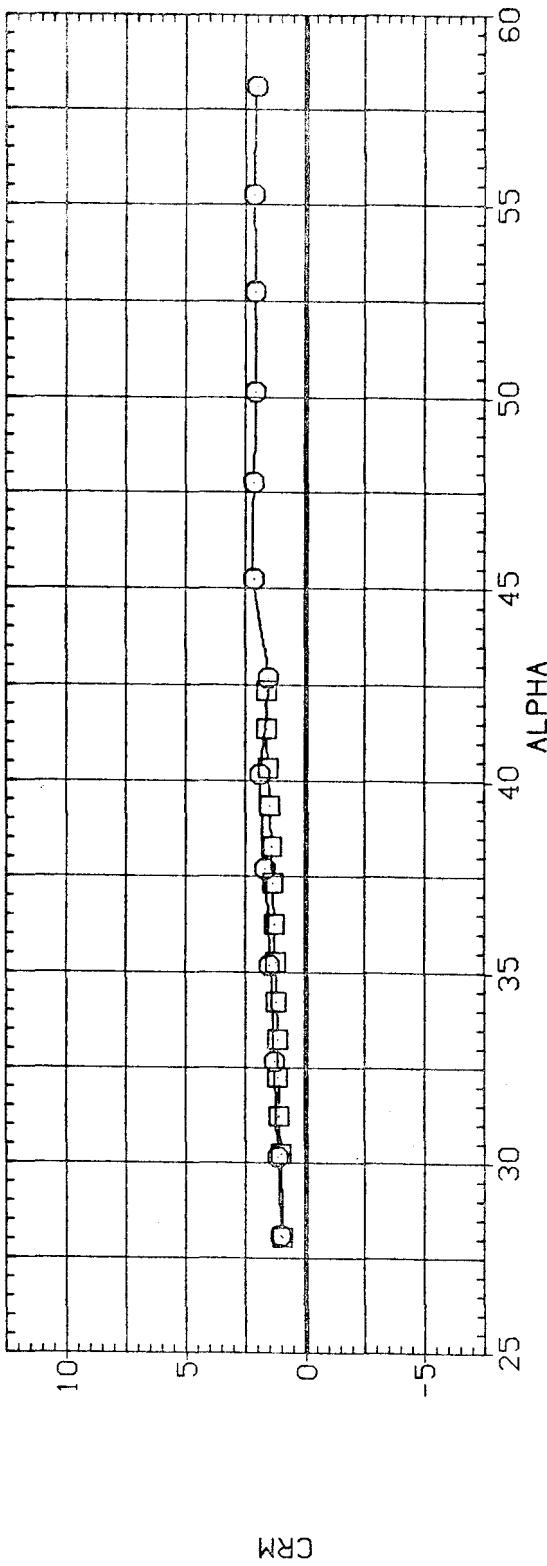
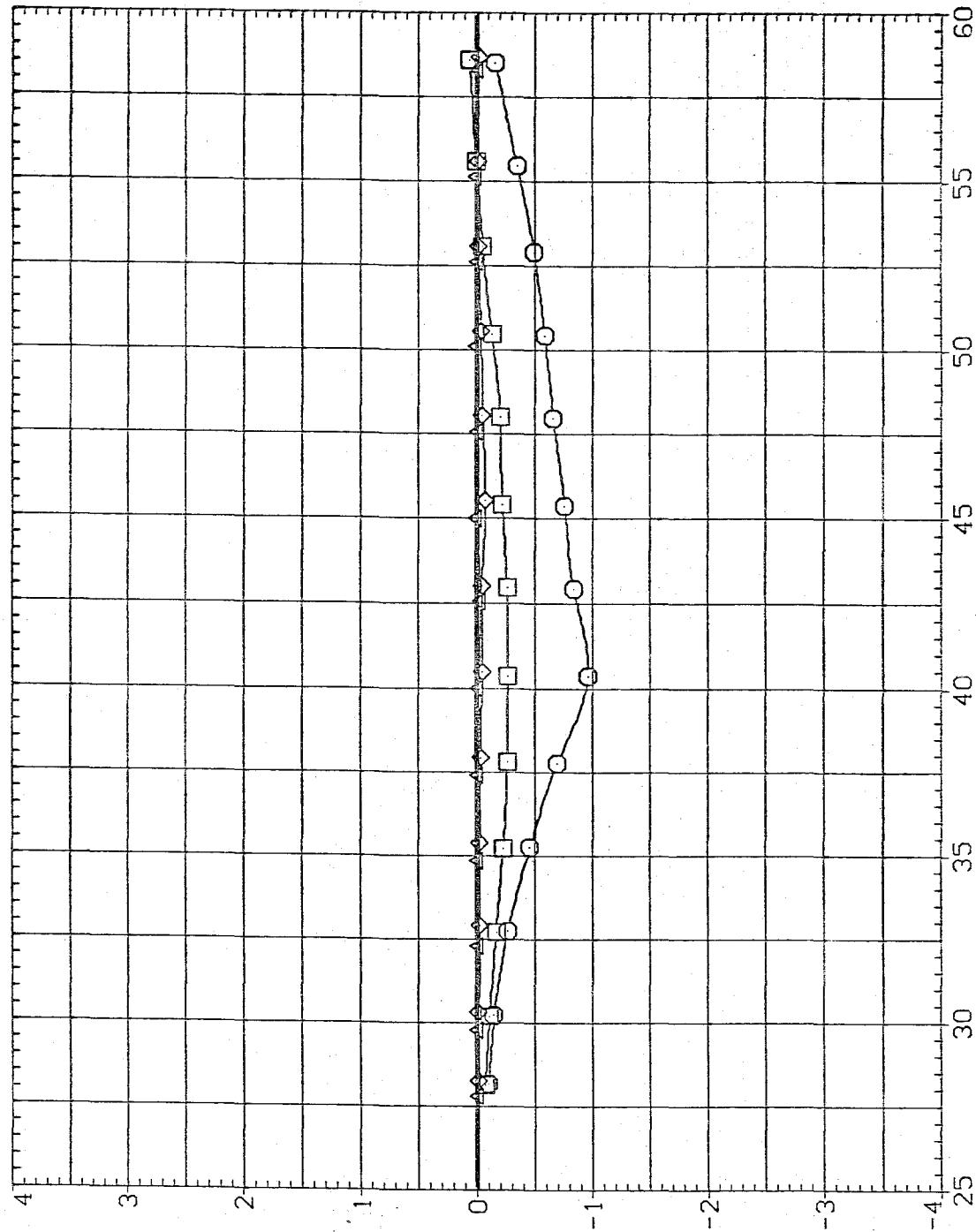


FIG.13 20 DEG. CONE, EFFECT OF REYNOLDS NUMBER  
 $(A)MACH = .60$

FEH

(RJDC36)

PARAMETRIC VALUES  
MACH .600    BETA .000    R .930  
SYMBOL      .800    1.099    1.991  
○            □        ◇        △



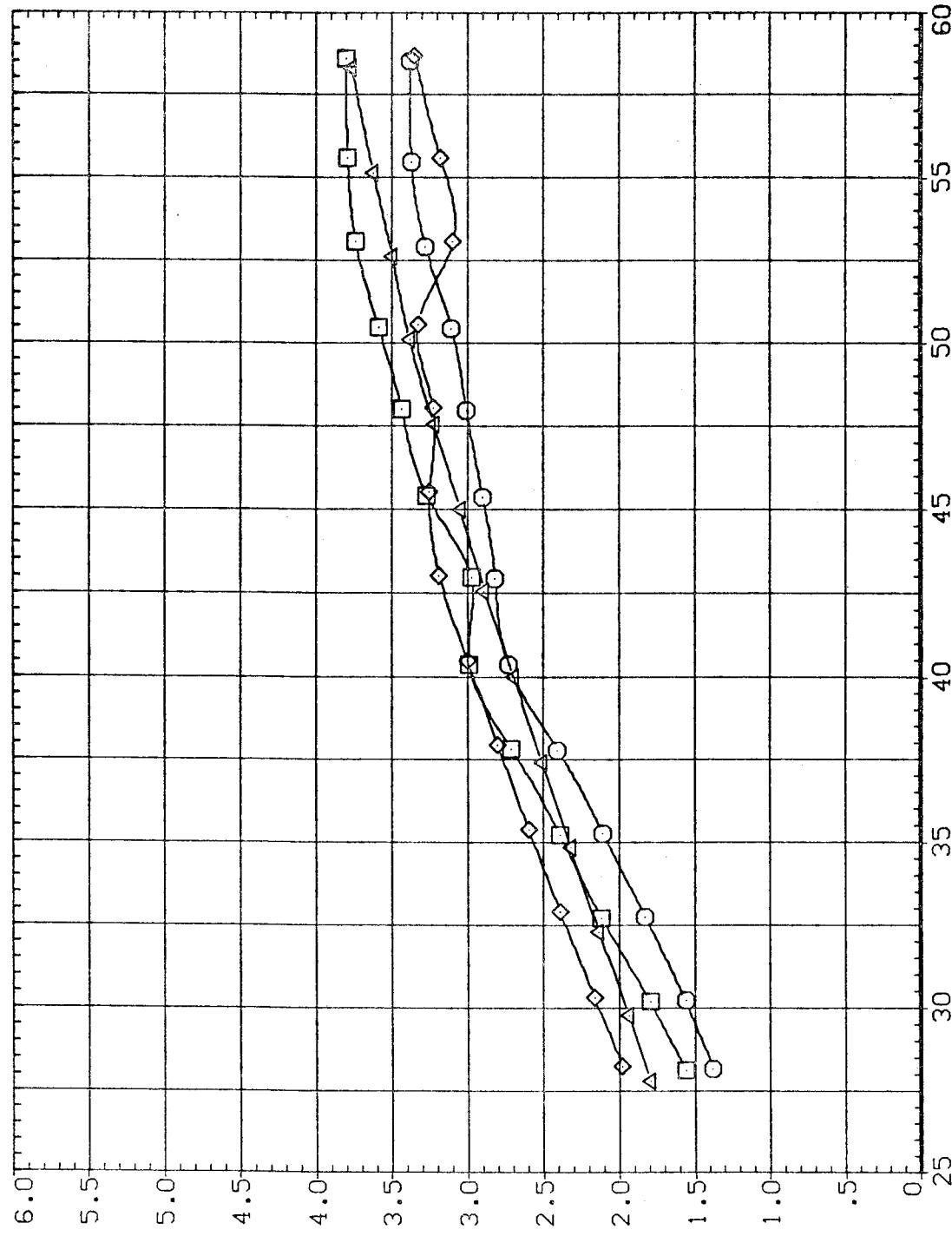
SIDE FORCE COEFFICIENT,  $C_y$

FIG.14 L/D=3.5 ELLIP. TAN. OGIVE, MAJOR AXIS HUR., EFFECT OF MACH NUMBER

(RJD/C36)

F/EH

SYMBOL  
○ □ ◇ △  
MACH .600 .800 1.499 1.991  
BETA .000 .R .930



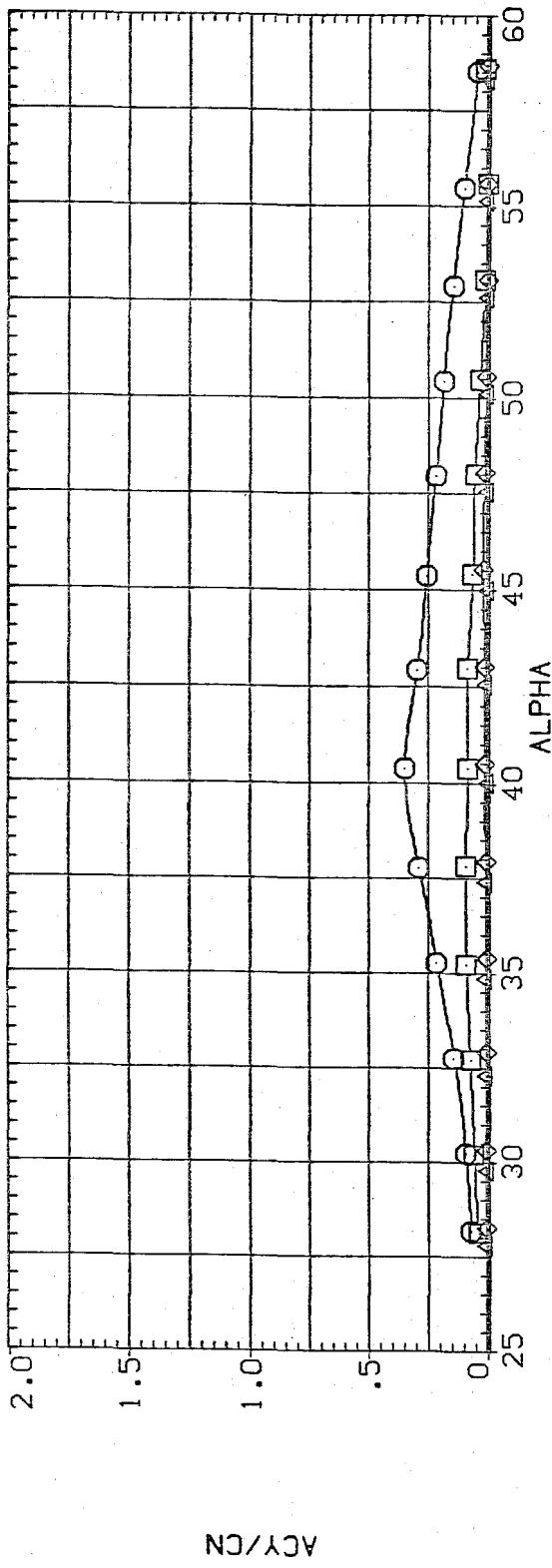
NORMAL FORCE COEFFICIENT,  $C_n$

FIG.14 L/D=3.5 ELLIP. TAN. OGIVE, MAJOR AXIS HOR., EFFECT OF MACH NUMBER

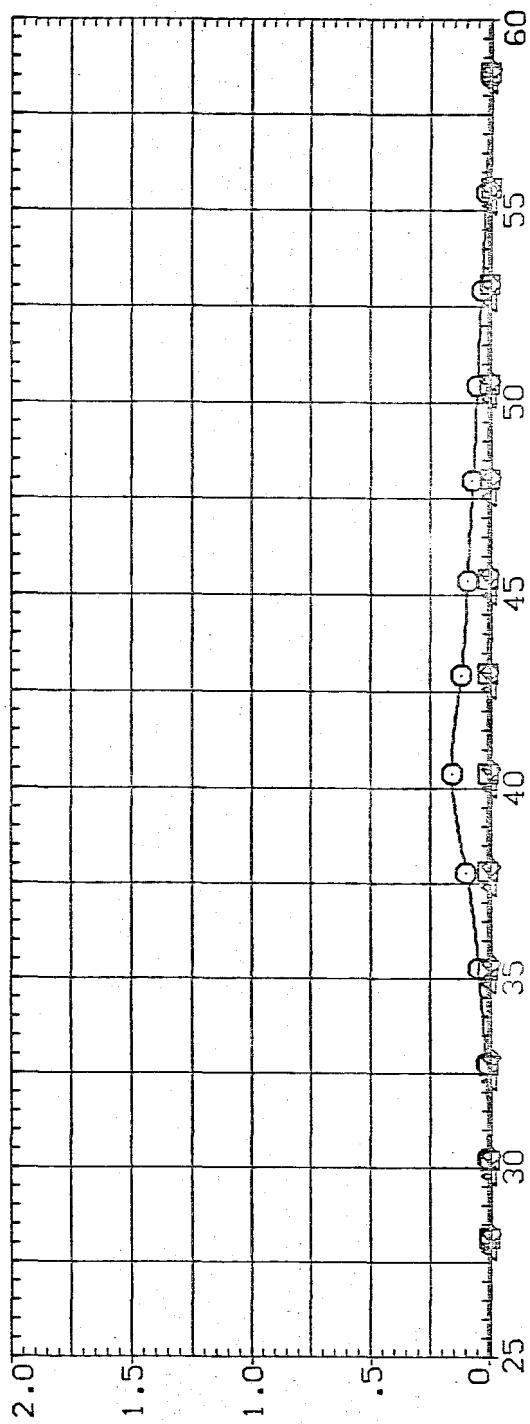
(RJD/C 36)

FEH

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	.600	.000	.930
□	.800		
◊	1.499		
△	1.991		



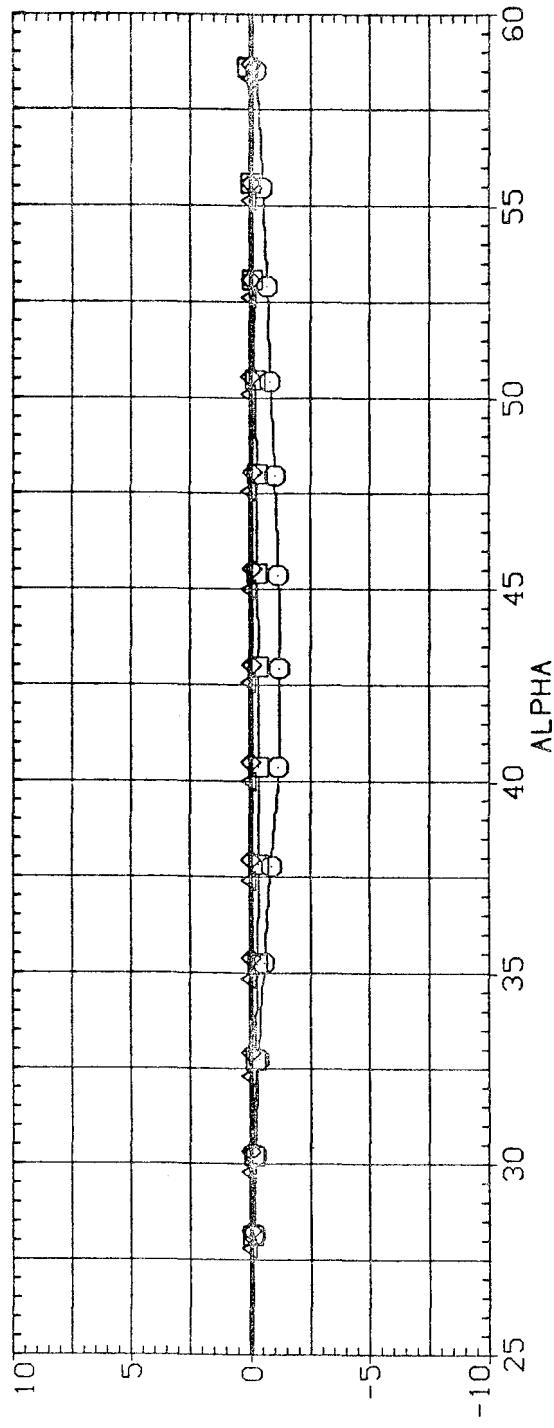
ACY/CN



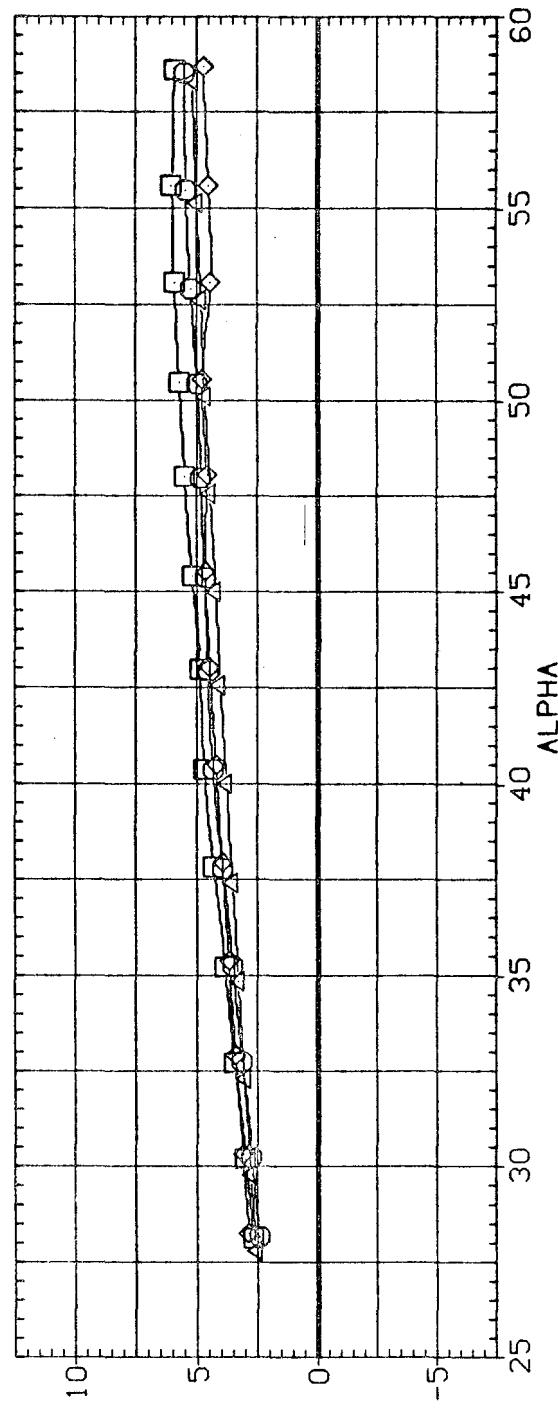
CR-CN

FIG.14 L/D=3.5 ELLIP. TAN. 0GIVE, MAJOR AXIS HOR., EFFECT OF MACH NUMBER

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	.600		.000 R .930
□	.800		
◇	1.499		
△	1.991		



CLM



CYN

FIG.14 L/D=3.5 ELLIP. TAN. OGIVE, MAJOR AXIS HOR., EFFECT OF MACH NUMBER

FEH

(RJDC36)

SYMBOL	MACH	PARAMETRIC VALUES		
		BETA	R	R
○	.600			.930
□	.800			
◊	1.499			
△	1.991			

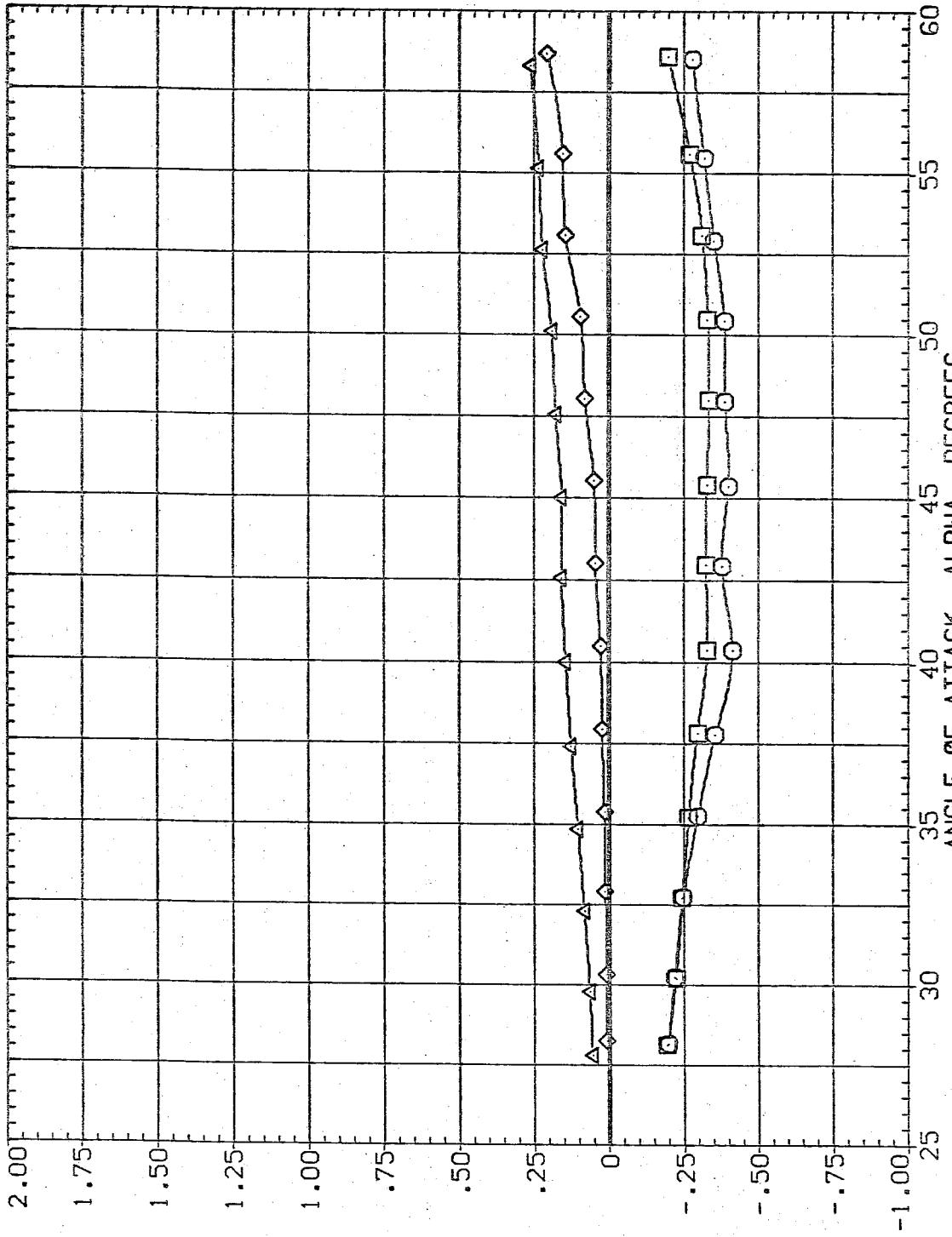


FIGURE 14 L/D=3.5 ELLIP. TAN. OGIVE, MAJOR AXIS HOR., EFFECT OF MACH NUMBER

(AJDC36)

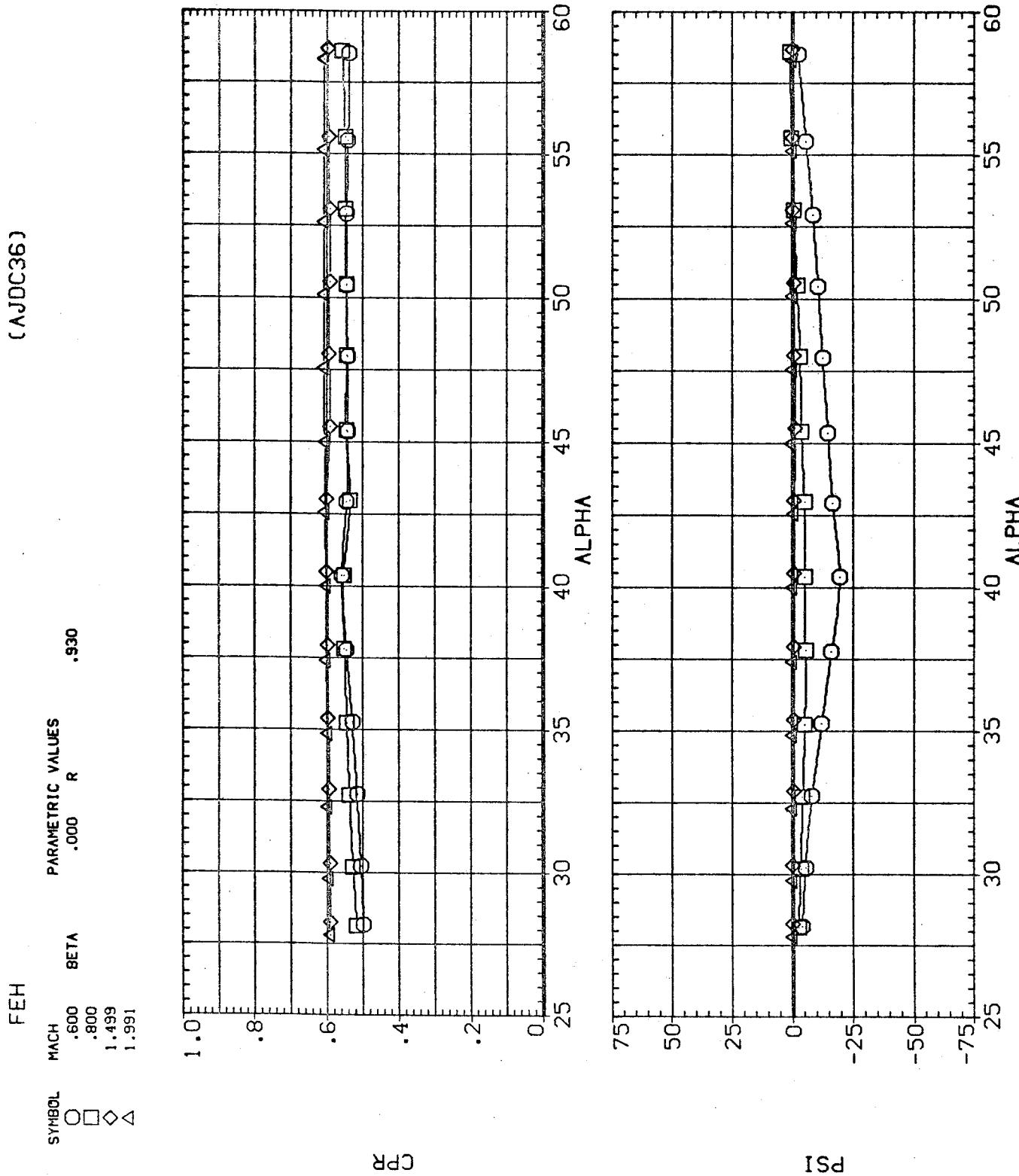


FIG.14 L/D=3.5 ELLIP. TAN. OGIVE, MAJOR AXIS HOR., EFFECT OF MACH NUMBER

FEH

SYMBOL	MACH	BETA	PARAMETRIC VALUES
O	.600	.000	.930
□	.800		
◇	1.499		
△	1.991		

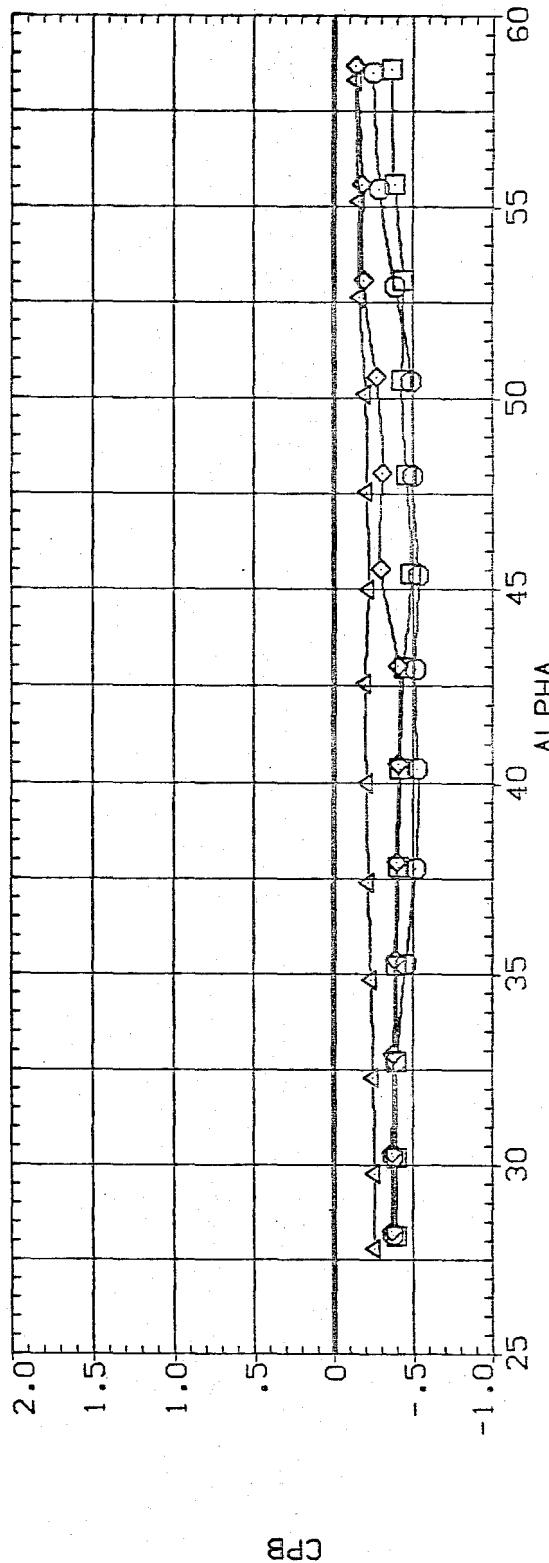
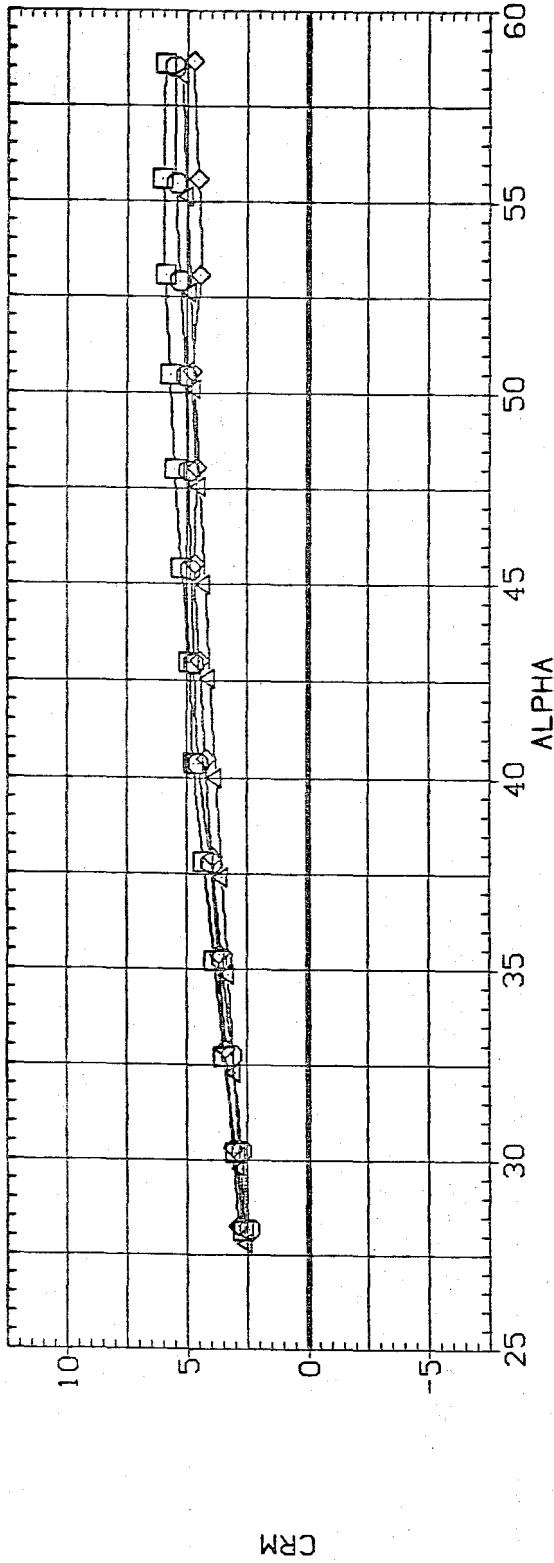


FIG. 14 L/D=3.5 ELLIP. TAN. OGIVE, MAJOR AXIS HOR., EFFECT OF MACH NUMBER

SYMBOL	MACH	BETA	PARAMETRIC VALUES	
			R	.650
○	.604	.801		
□	.801	.604		
◇	1.503	.801		
△	1.996	.604		

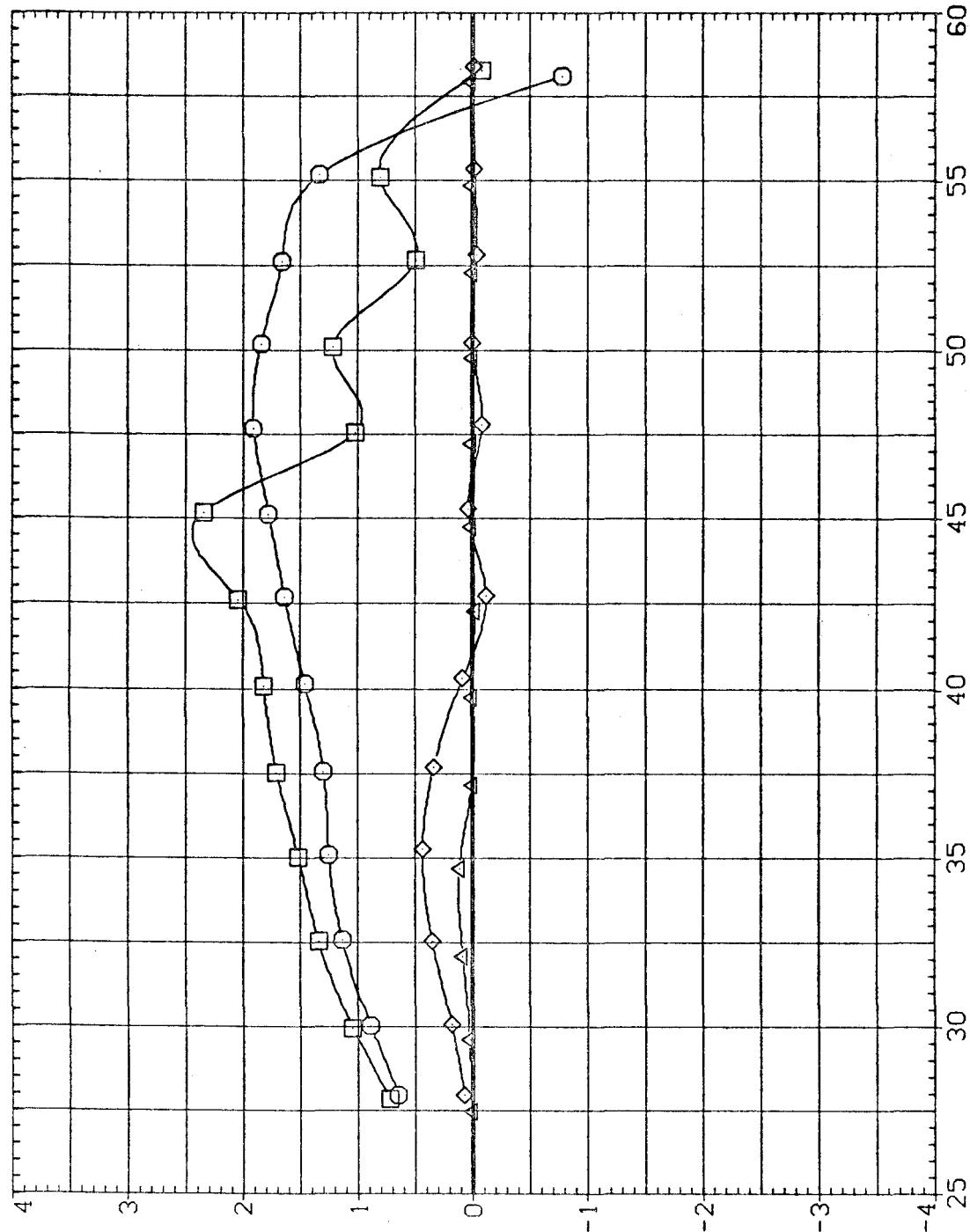
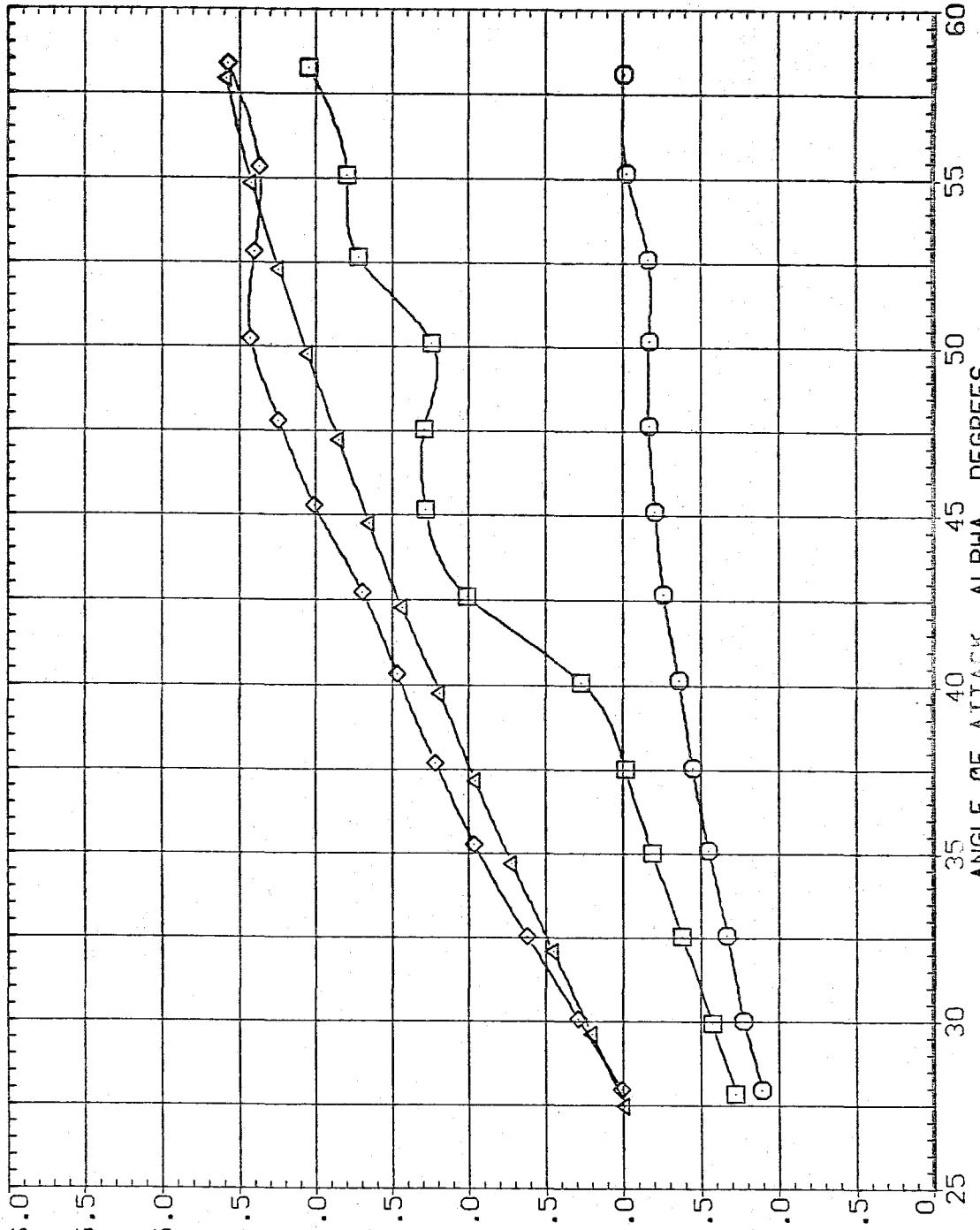
SIDE FORCE COEFFICIENT,  $C_y$ 

FIG.15 L/D=5 ELLIP. TAN. 0GIVE, MAJOR AXIS VERT., EFFECT OF MACH NUMBER

(RJDC38)

FFEV

SYMBOL	MACH	BETA	PARAMETRIC VALUES
○	.604		R .000
□	.801		R .650
◊	1.503		
△	1.996		



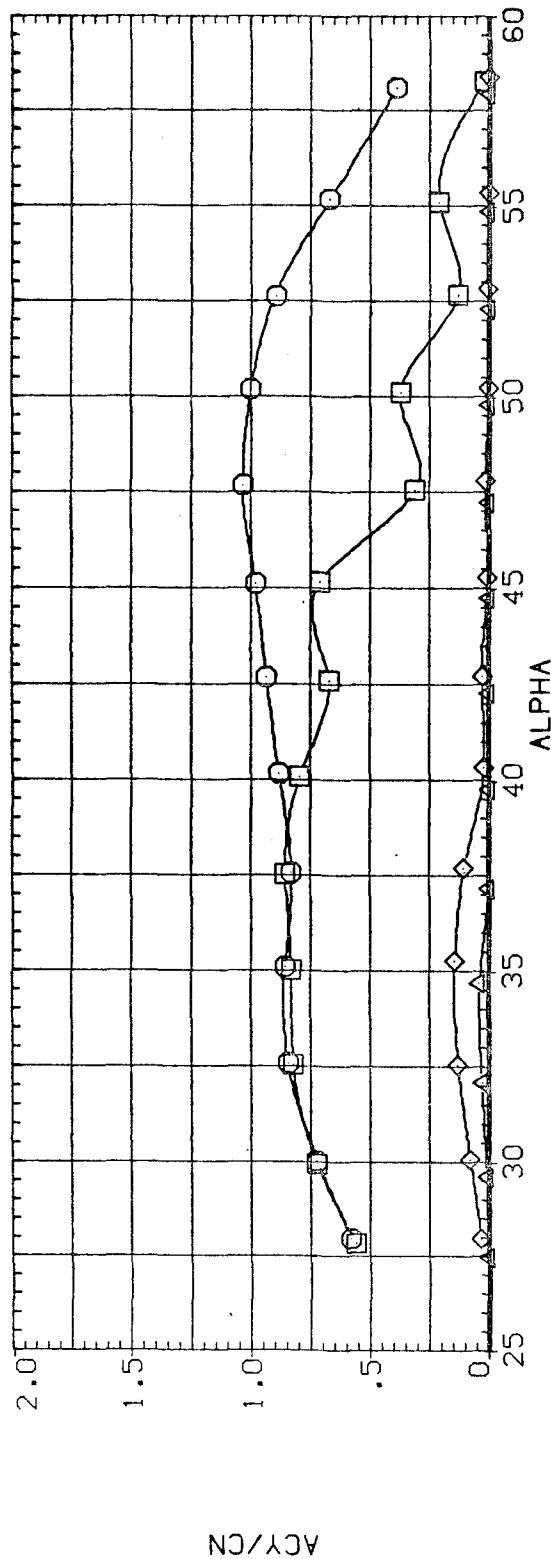
NORMAL FORCE COEFFICIENT, CN

FIG. 15 L/D=5 ELLIP. TAN. OGIVE, MAJOR AXIS VERT., EFFECT OF MACH NUMBER

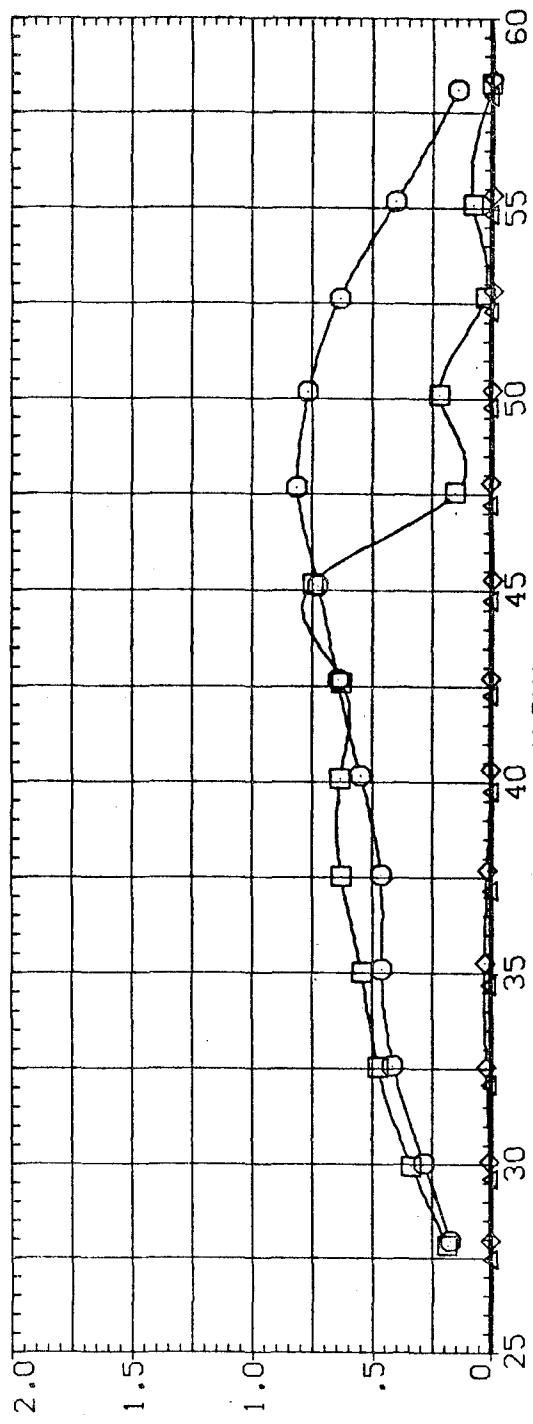
(RJD/C38)

F/EV

PARAMETRIC VALUES  
MACH .604    BETA .000    R .650  
SYMBOL    ○    □    ◇    △  
.801    1.503    1.996



ACY/CN



CR-CN

FIG.15 L/D=5 ELLIP. TAN. 0GIVE, MAJOR AXIS VERT., EFFECT OF MACH NUMBER

(RJD/C38)

SYMBOL	MACH	BETA	PARAMETRIC VALUES	R
○	.604			.650
□	.801			
◊	1.503			
△	1.996			

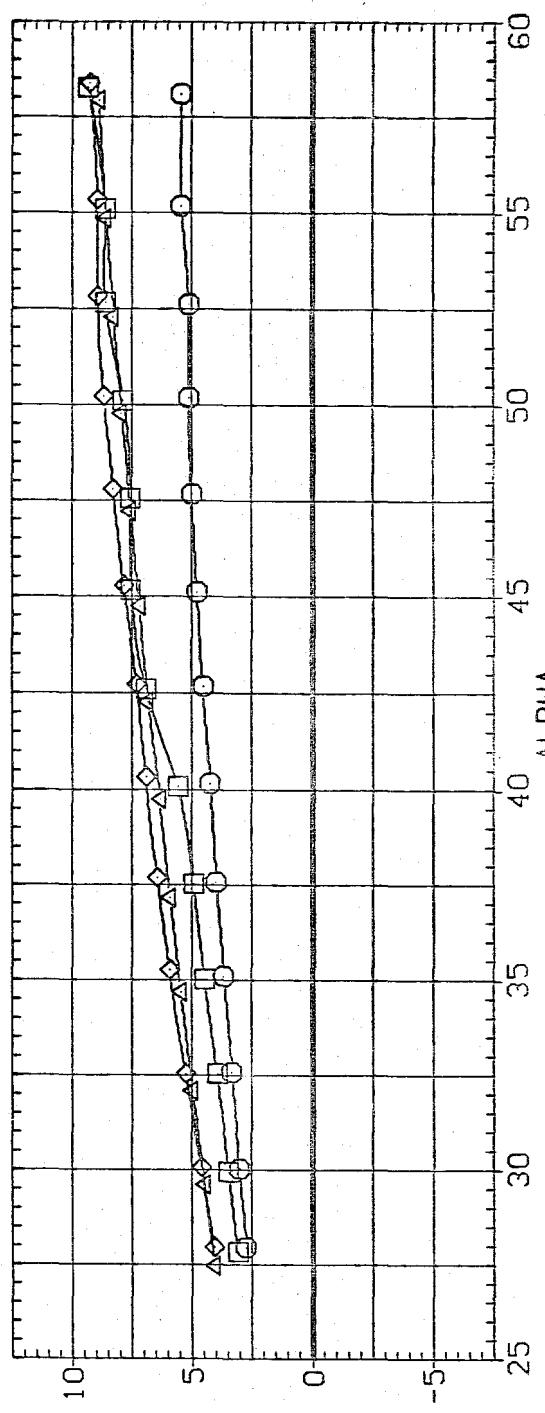
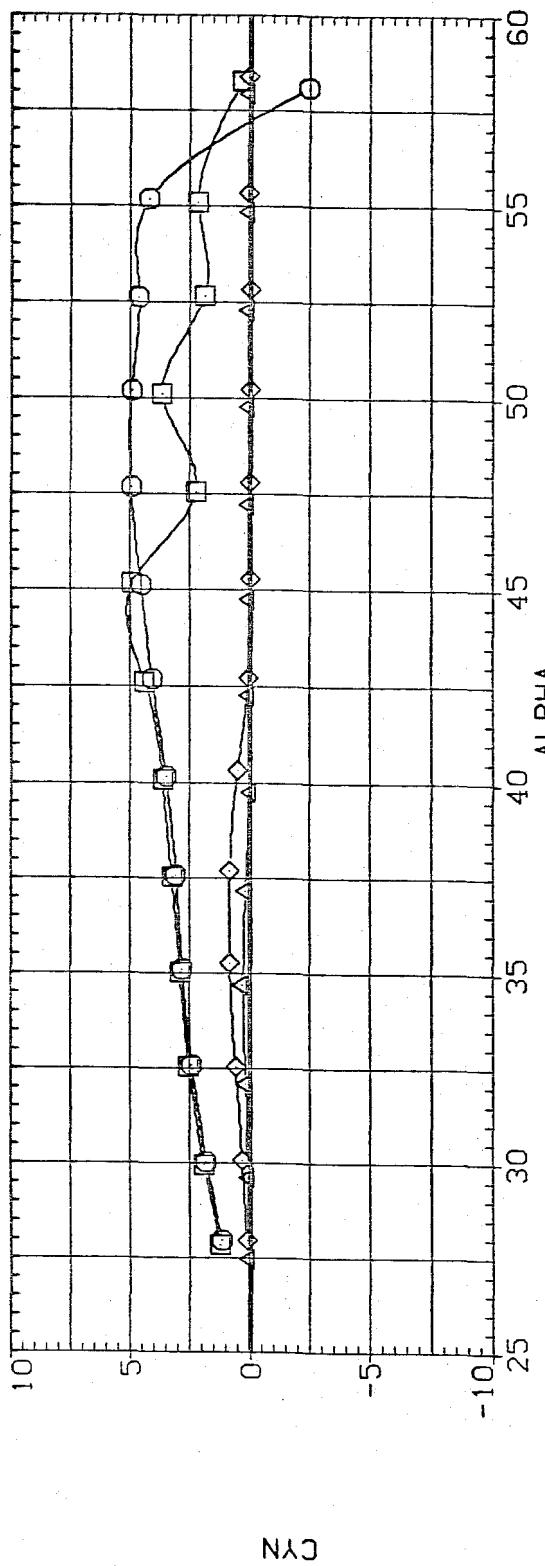
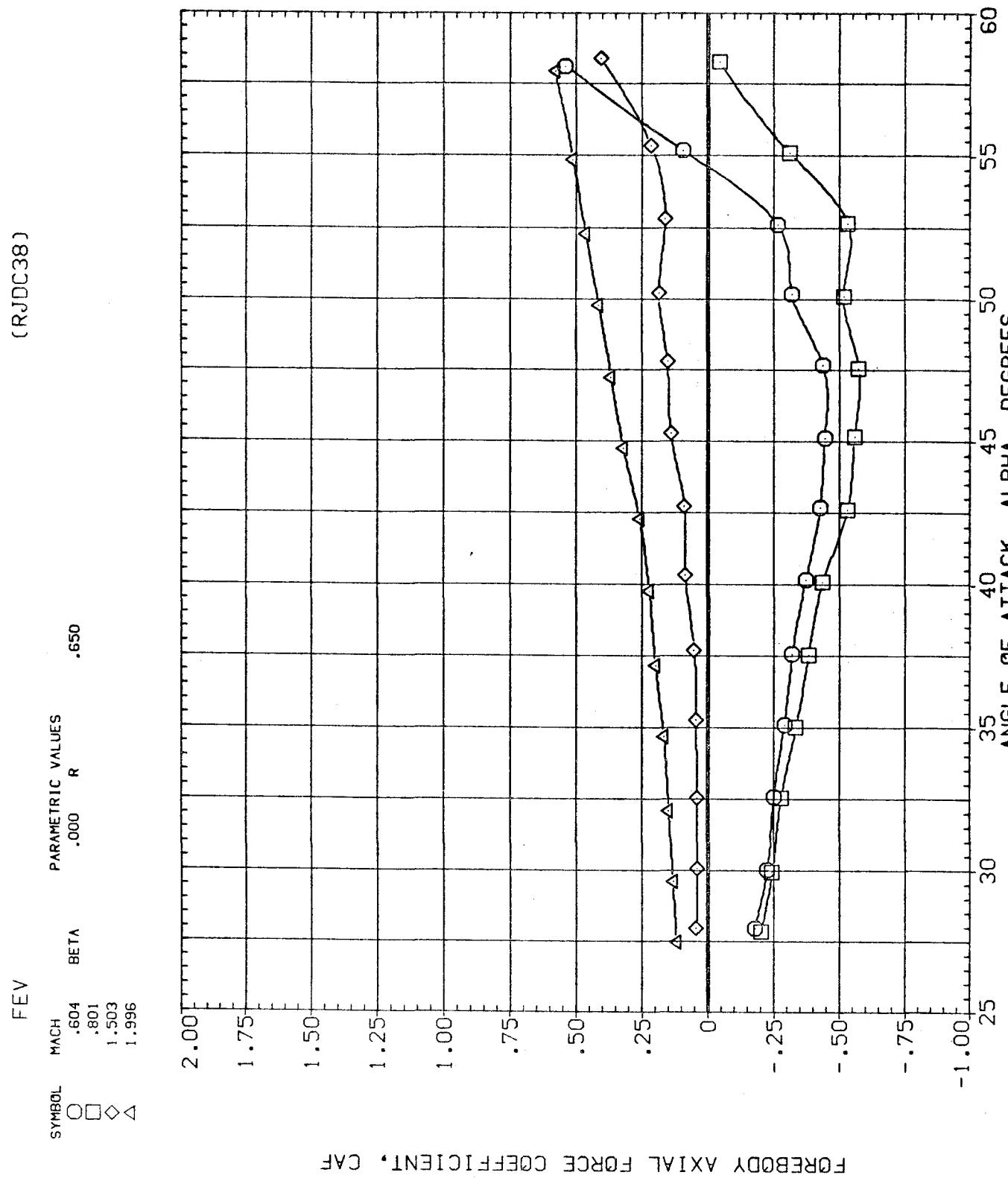


FIG. 15 L/D=5 ELLIP. TAN. GIVE, MAJOR AXIS VERT., EFFECT OF MACH NUMBER

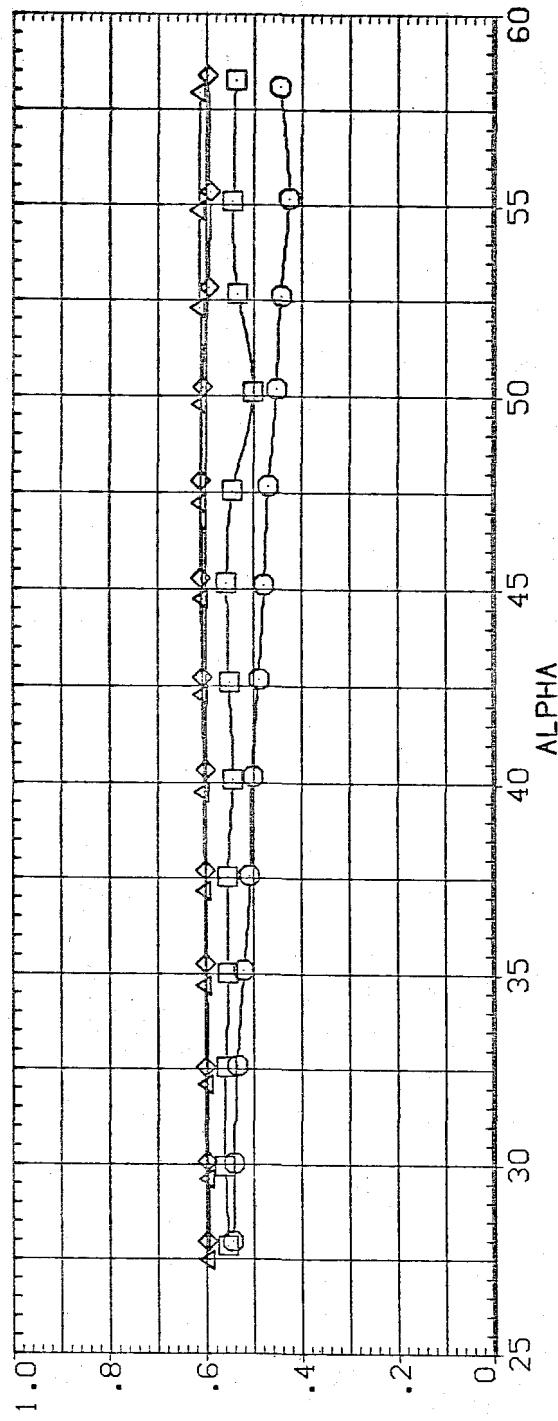
(RJD/C38)



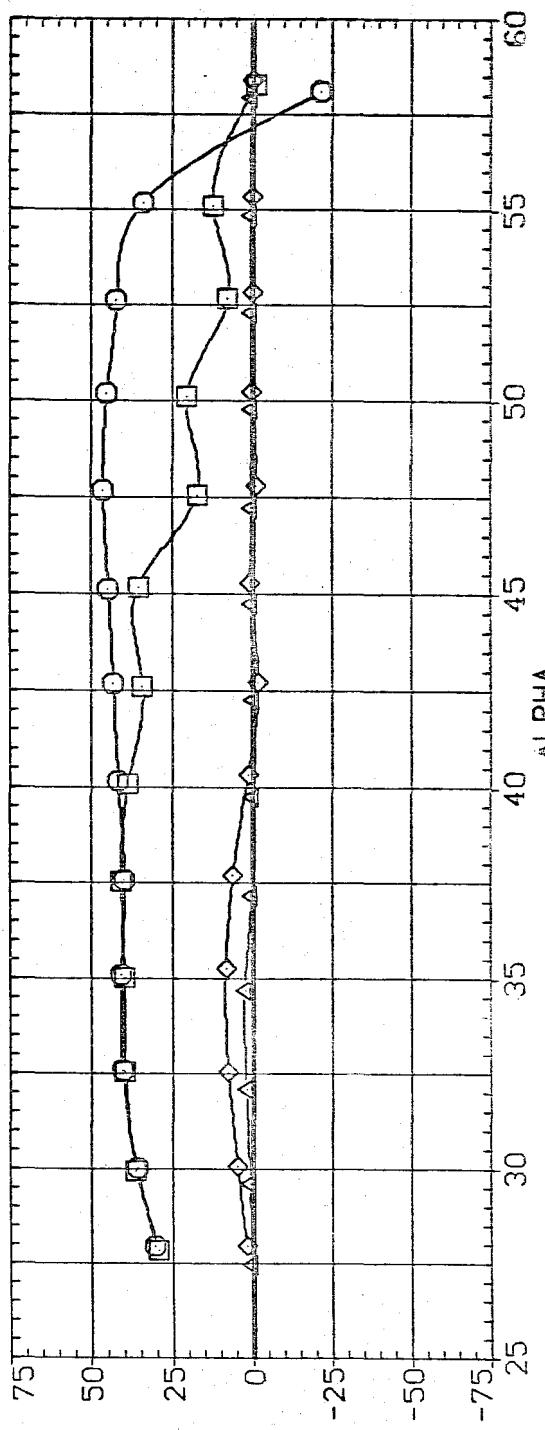
(AJDC38)

FEV

PARAMETRIC VALUES  
MACH .604    BETA .000    R .650  
SYMBOL      .801    1.503    1.996  
○    □    ◇    △



CR



PSI

FIG.15 L/D=5 ELLIP. TAN. OGIVE, MAJOR AXIS VERT., EFFECT OF MACH NUMBER

SYMBOL	PARAMETRIC VALUES		
	MACH	BETA	R
○	.604	.000	.650
□	.801	.801	
◇	1.503	1.503	
△	1.996	1.996	

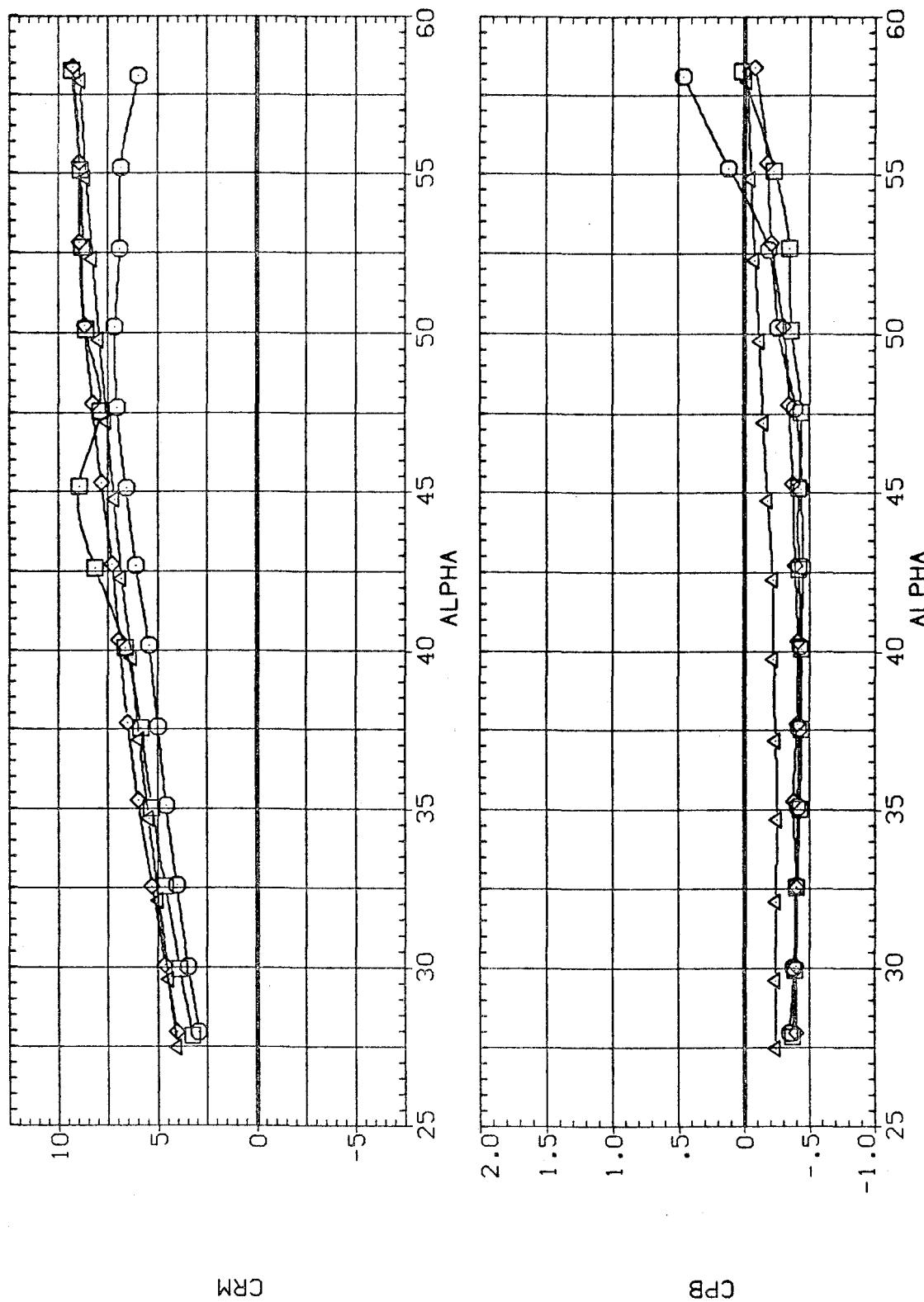


FIG.15 L/D=5 ELLIP. TAN. OGIVE, MAJOR AXIS VERT., EFFECT OF MACH NUMBER