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GRAPHS OF OBLIQUE-SHOCK RELATIONSHIPS FOR VARIOUS RATIOS OF SPECIFIC HEATS

W. C. Armstrong and J. C. Latimer

ARO, Inc.

July 1969

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FOREWORD

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This technical report has been reviewed and is approved.

Forrest B. Smith, Jr.
Research Division
Directorate of Plans
and Technology

Harry L. Maynard
Colonel, USAF
Director of Plans
and Technology

ABSTRACT

This report is a presentation of graphs of the oblique-shock relationships for several ratios of specific heats at several Mach numbers. The specific heat ratios vary from 1.10 to 1.66 in increments of 0.02, and a plot is also shown for a specific heat ratio equal to 1.667. The Mach numbers range from 1.5 to 6.0 with increments of 0.5 and from 6.0 to 10.0 with increments of 1.0; Mach number 15.0 is presented separately.

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NOMENCLATURE

M	Mach number
P	Pressure
q	Dynamic pressure (ρV^2)
T	Temperature
V	Velocity
γ	Ratio of specific heats
δ	Flow deflection angle (wedge angle)
θ	Shock angle
ρ	Density

SUBSCRIPTS

1	Upstream of shock
2	Downstream of shock
t	Stagnation condition

SECTION I INTRODUCTION

Oblique shocks occur in supersonic flow when the flow encounters a compression corner (Fig. 1, Appendix). Often quick qualitative solutions to the oblique-shock equations are needed. These have been available for some time at one ratio of specific heat ($\gamma = 1.4$) in NACA Report 1135¹ in graphical form. The graphs in Report 1135 are applicable to air, nitrogen, and other diatomic gases.

The need also exists for similar graphs applicable to nondiatomic gases, for example, argon and engine exhaust gases. The specific heat ratios vary from less than 1.12 for exhaust gases to 1.67 for argon. The purpose of this report is to present graphs to cover specific heat ratios from 1.1 to 1.67 and Mach numbers from 1.5 to 15.

SECTION II METHOD OF SOLUTION

To obtain solutions which do not depend upon stagnation conditions, a perfect gas has been assumed. All the pertinent equations were obtained from NACA Report 1135.

For a given Mach number and ratio of specific heat, the maximum flow deflection angle for an attached shock is obtained from two equations. The first computes the shock angle, and the second the flow deflection angle.

$$\sin^2 \theta_{\delta_{\max}} = \frac{1}{4\gamma M_1^2} \left\{ (\gamma + 1) M_1^2 - 4 + \sqrt{(\gamma + 1) [(\gamma + 1) M_1^4 + 8(\gamma - 1) M_1^2 + 16]} \right\}$$

$$\tan \delta_{\max} = \frac{2 \cot \theta_{\delta_{\max}} (M_1^2 \sin^2 \theta_{\delta_{\max}} - 1)}{2 + M_1^2 (\gamma + 1 - 2 \sin^2 \theta_{\delta_{\max}})}$$

This establishes the upper limit of the flow deflection. For flow deflection angles less than $\delta_{\max}$, the shock angle is obtained by extracting the middle root of the cubic equation in $\sin^2 \theta$:

$$\sin^6 \theta - \left[\frac{M_1^2 + 2}{M_1^2} - \gamma \sin^2 \delta \right] \sin^4 \theta + \left[\frac{2M_1^2 + 1}{M_1^4} + \left\{ \left(\frac{\gamma + 1}{2} \right)^2 + \frac{\gamma - 1}{M_1^2} \right\} \sin^2 \delta \right] \sin^2 \theta - \frac{\cos^2 \delta}{M_1^4} = 0$$

¹Ames Research Staff. "Equations, Tables, and Charts for Compressible Flow." NACA Report 1135, 1953.

The least root corresponds to a decrease in entropy which violates the second law of thermodynamics, and the greatest root corresponds to a strong shock which is not normally obtained.

Once the shock angle is known, the other plotted parameters are obtained from the following equations.

$$\frac{P_2}{P_1} = \frac{2\gamma M_1^2 \sin^2 \theta - (\gamma - 1)}{\gamma + 1}$$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma + 1) M_1^2 \sin^2 \theta}{(\gamma - 1) M_1^2 \sin^2 \theta + 2}$$

$$\frac{T_2}{T_1} = \frac{[2\gamma M_1^2 \sin^2 \theta - (\gamma - 1)] [(\gamma - 1) M_1^2 \sin^2 \theta + 2]}{(\gamma + 1)^2 M_1^2 \sin^2 \theta}$$

$$M_2^2 = \frac{(\gamma + 1)^2 M_1^4 \sin^2 \theta - 4(M_1^2 \sin^2 \theta - 1)(\gamma M_1^2 \sin^2 \theta + 1)}{[2\gamma M_1^2 \sin^2 \theta - (\gamma - 1)] [(\gamma - 1) M_1^2 \sin^2 \theta + 2]}$$

$$P_{t2}/P_{t1} = \left[\frac{(\gamma + 1) M_1^2 \sin^2 \theta}{(\gamma - 1) M_1^2 \sin^2 \theta + 2} \right]^{\frac{\gamma}{\gamma - 1}} \left[\frac{\gamma + 1}{2\gamma M_1^2 \sin^2 \theta - (\gamma - 1)} \right]^{\frac{1}{\gamma - 1}}$$

$$\frac{P_2 - P_1}{q} = \frac{4(M_1^2 \sin^2 \theta - 1)}{(\gamma + 1)M_1^2}$$

SECTION III RESULTS AND DISCUSSION

The results are presented as graphs (Figs. 2 through 31) in the following manner: The abscissa for all plots is the wedge angle (δ). There are seven graphs for each ratio of specific heat (γ). The ordinates are shock angle (θ), Mach number behind the shock (M_2), pressure ratio across the shock (P_2/P_1), density ratio across shock (ρ_2/ρ_1), temperature ratio across shock (T_2/T_1), total pressure ratio across shock (P_{t2}/P_{t1}), and coefficient ($\Delta P/q$).

Each graph contains curves for the following Mach numbers: 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 7.0, 8.0, 9.0, 10.0, and 15.0. The ratios of specific heat presented start at 1.10 and go to 1.66 in 0.02 increments. The last plot is for a specific heat ratio of 1.667, corresponding to a monatomic gas.

**APPENDIX
ILLUSTRATIONS**

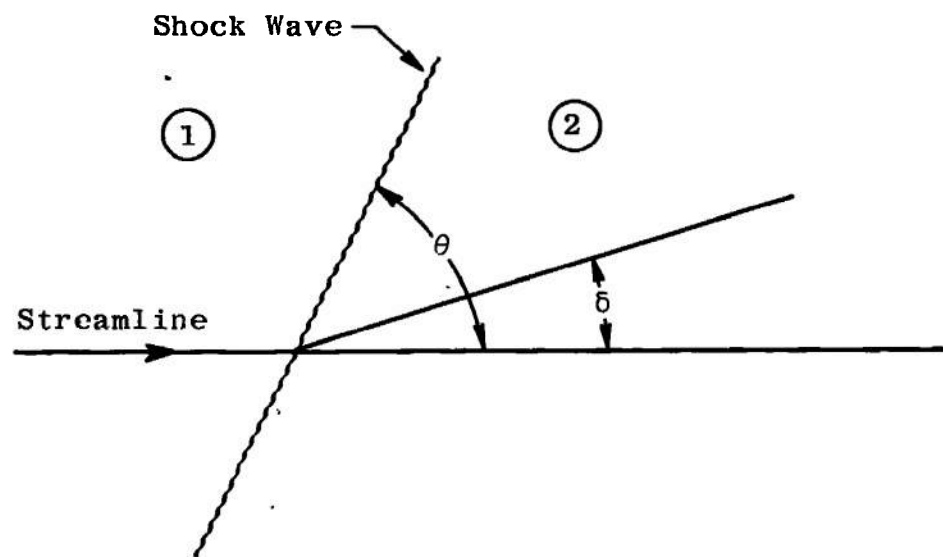


Fig. 1 Notation for Oblique Shock Wave

OBLIQUE SHOCK $\gamma = 1.10$

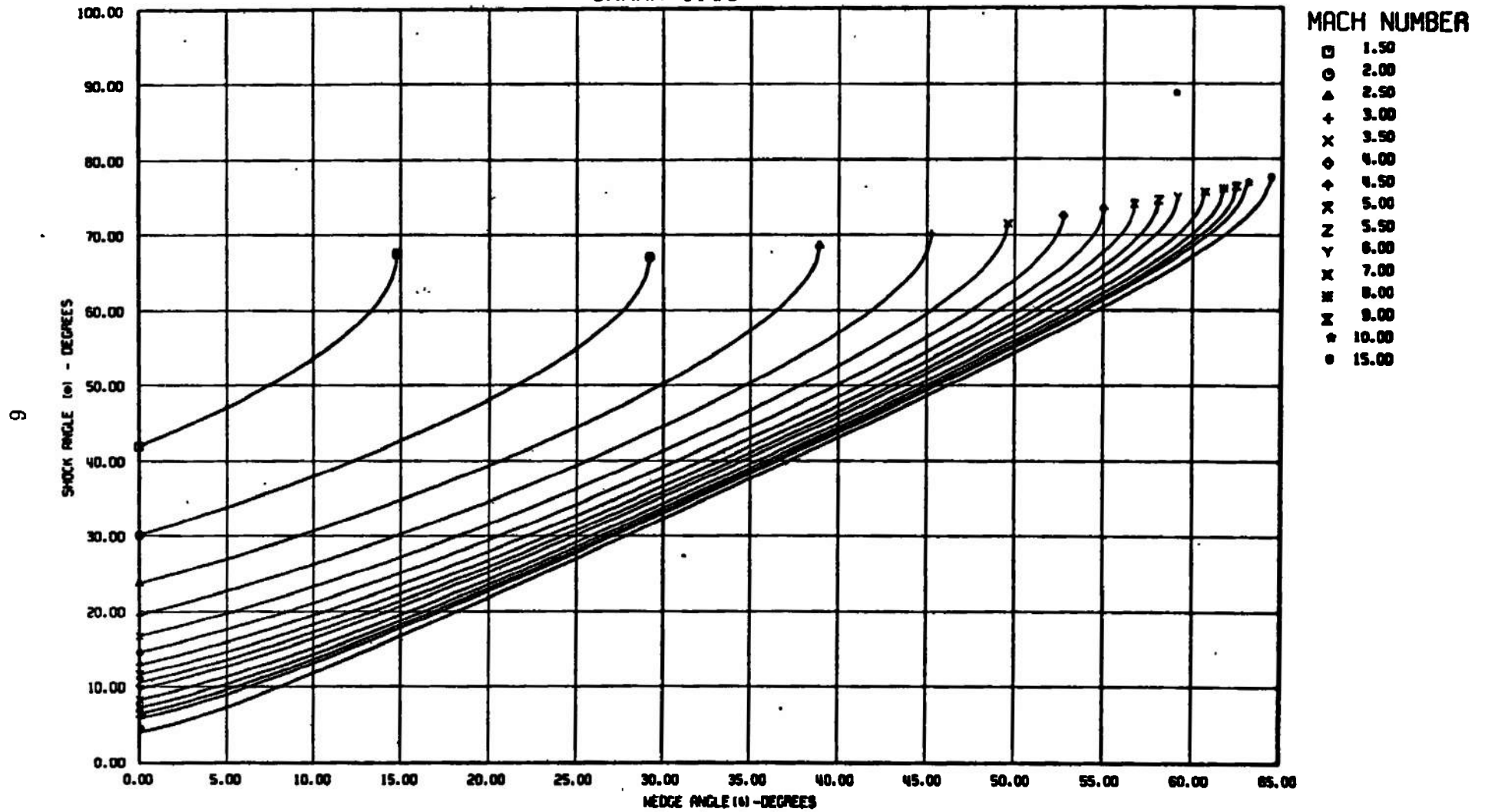


Fig. 2 $\gamma = 1.10$

OBLIQUE SHOCK GAMMA=1.10

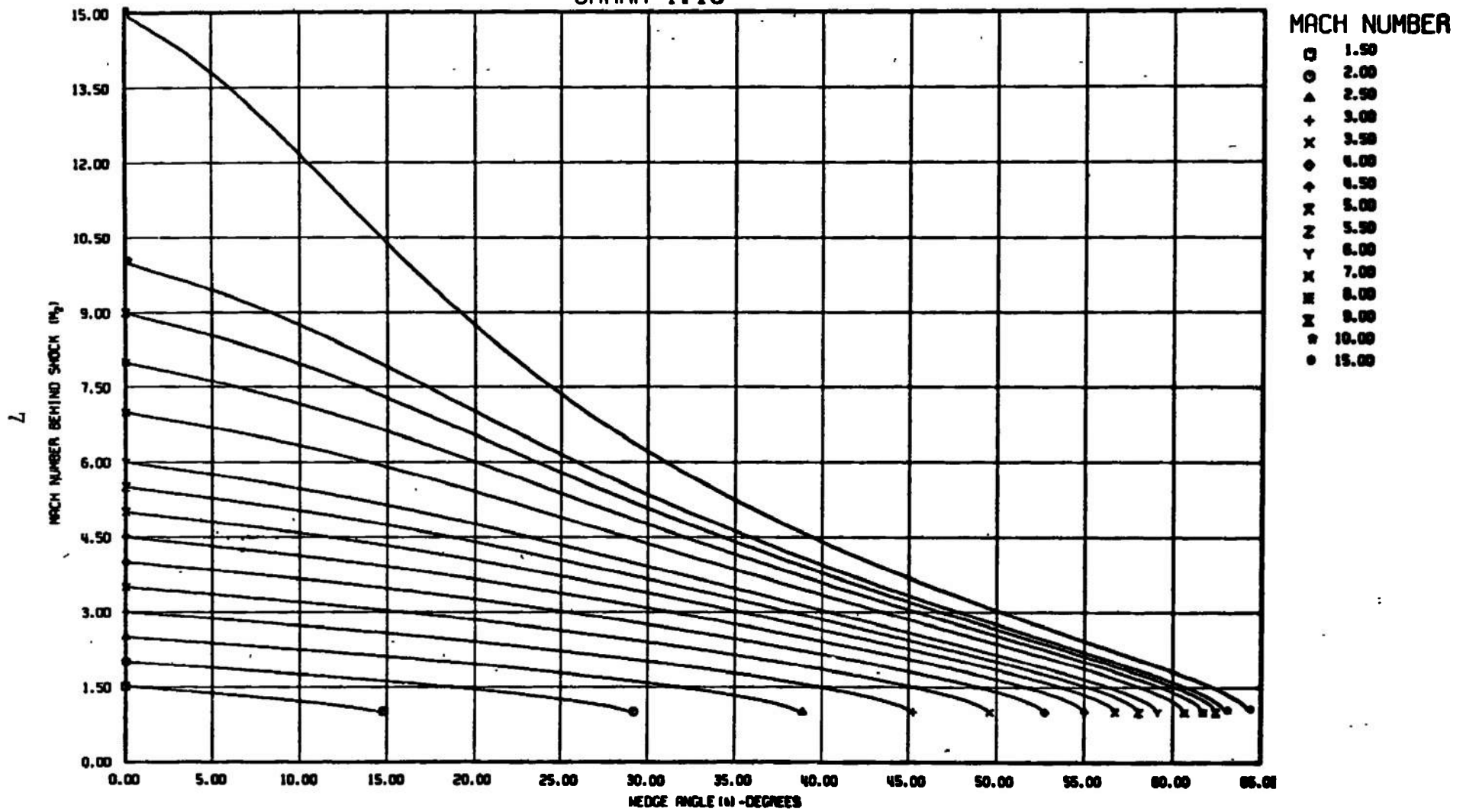


Fig. 2 Continued

OBLIQUE SHOCK GAMMA=1.10

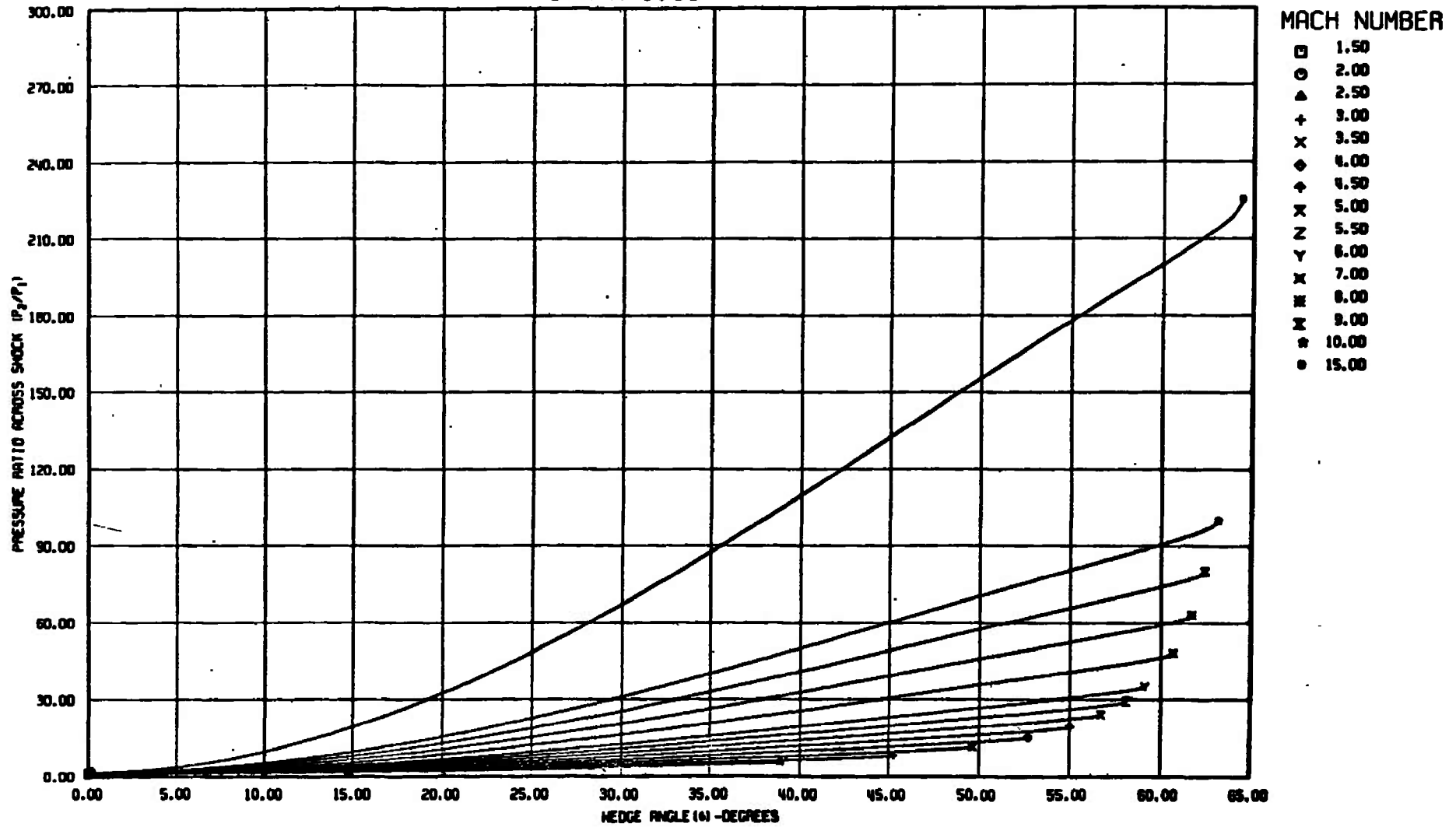


Fig. 2 Continued

OBLIQUE SHOCK
 $\gamma = 1.10$

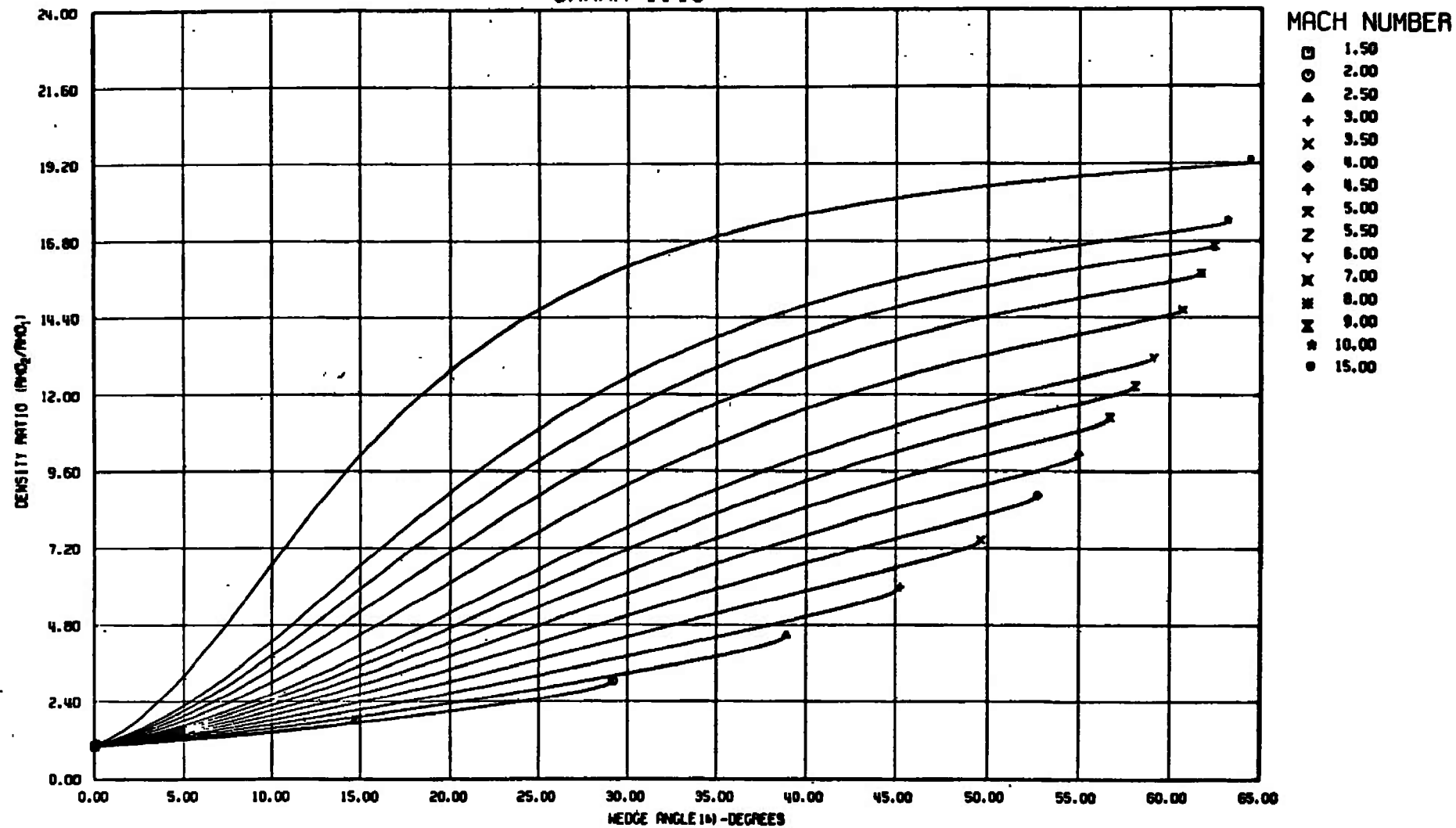


Fig. 2 Continued

OBLIQUE SHOCK GAMMA=1.10

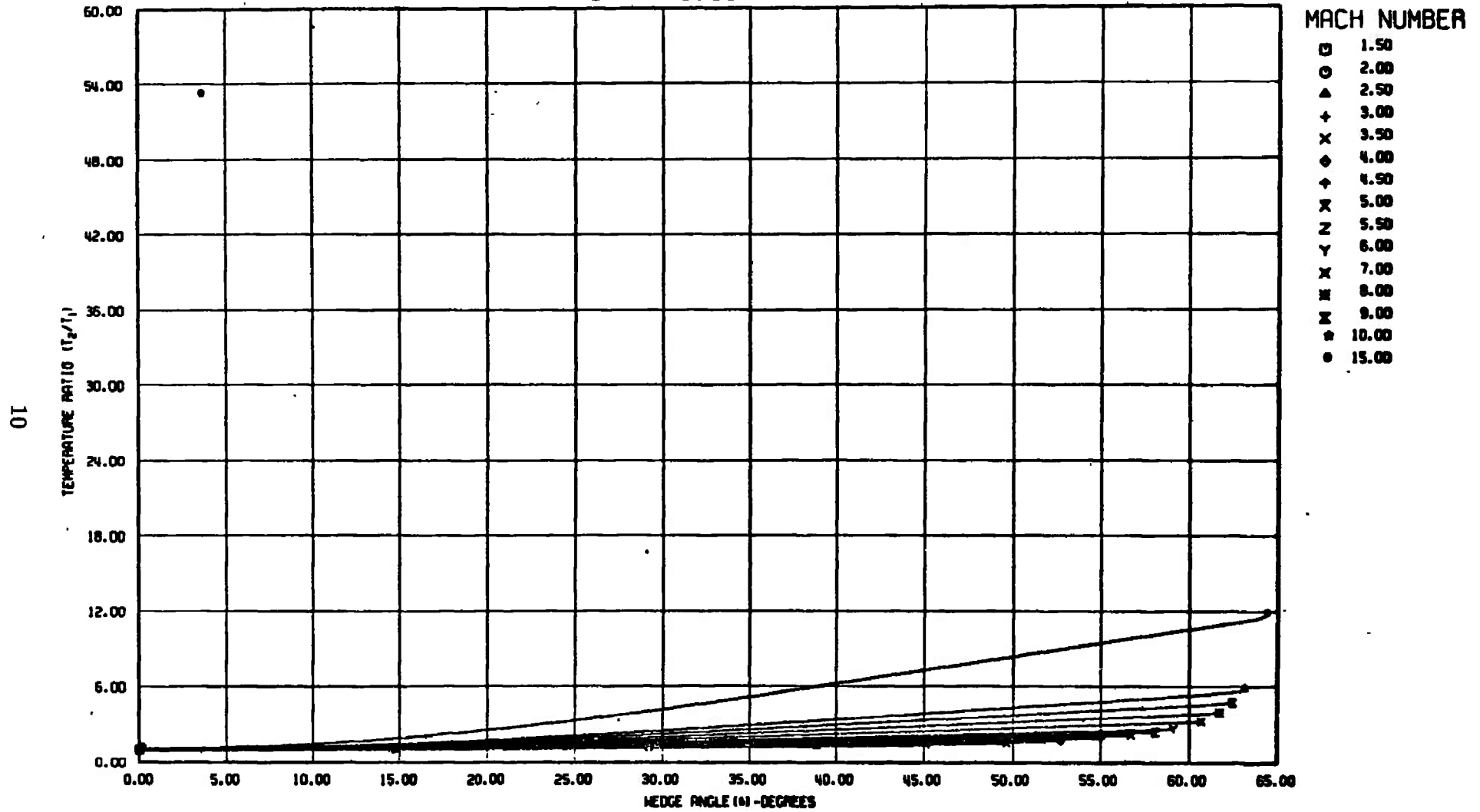


Fig. 2 Continued

OBLIQUE SHOCK GAMMA=1.10

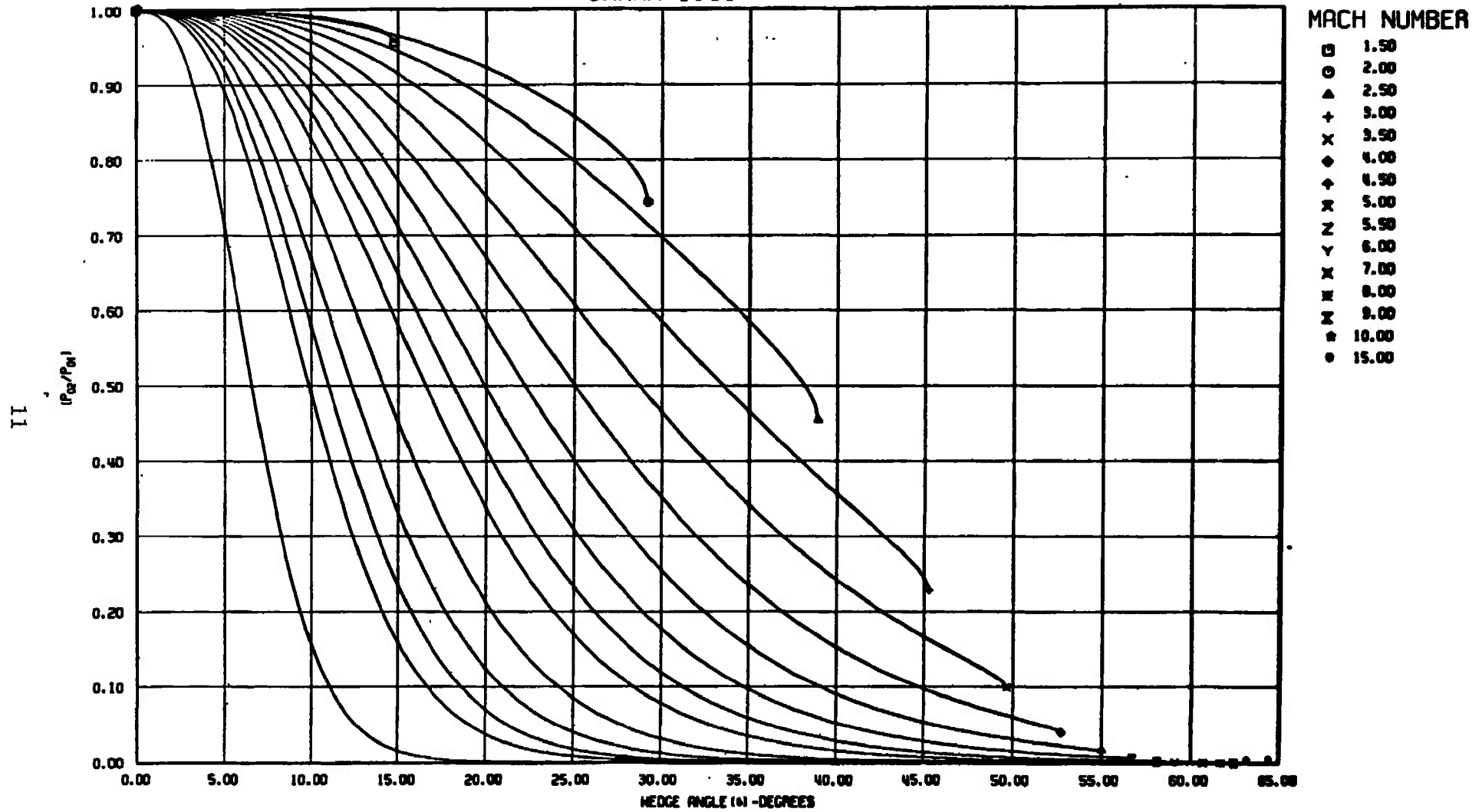


Fig. 2 Continued

OBLIQUE SHOCK GAMMA=1.10

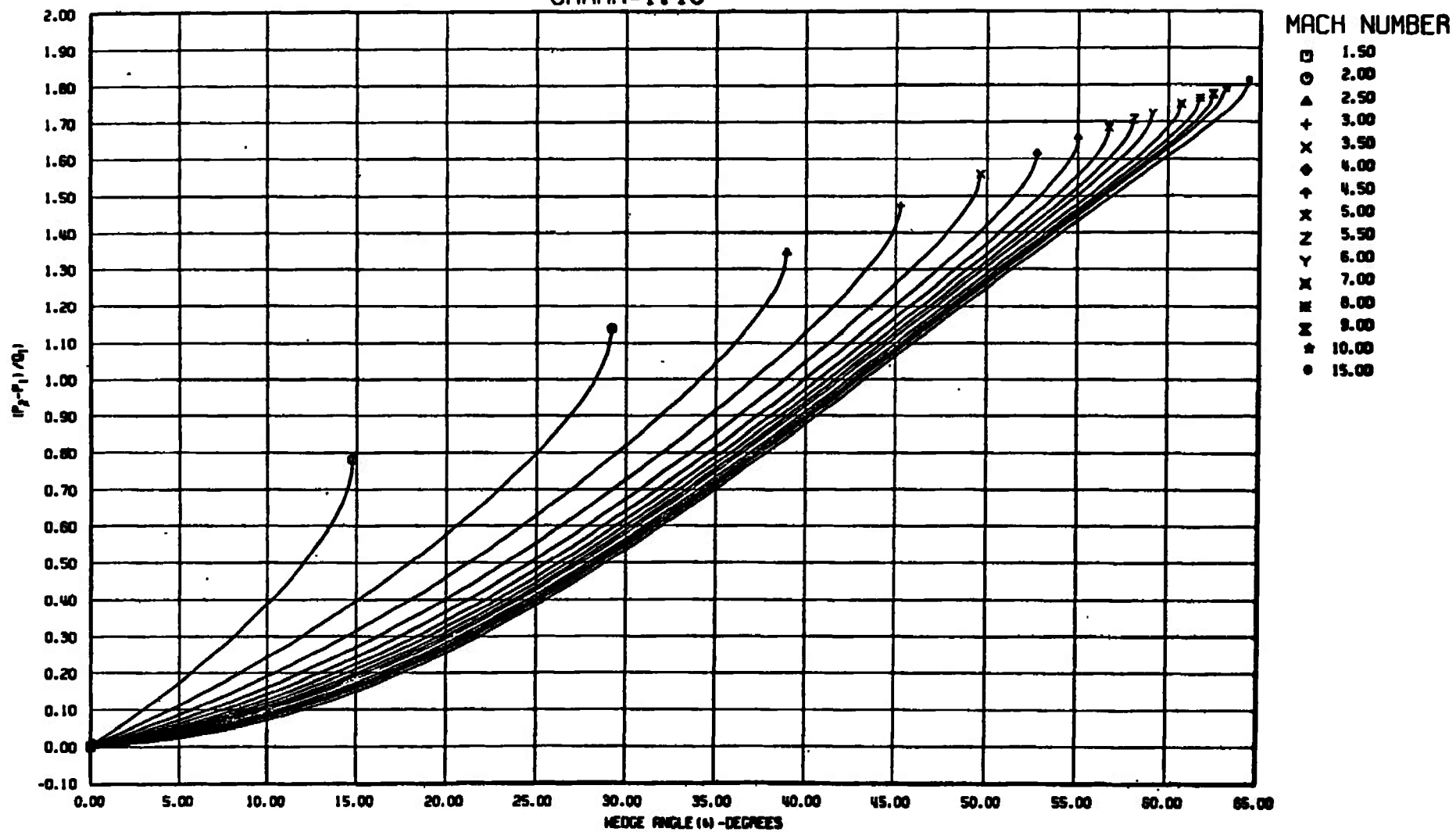


Fig. 2 Concluded

OBLIQUE SHOCK
 $\gamma = 1.12$

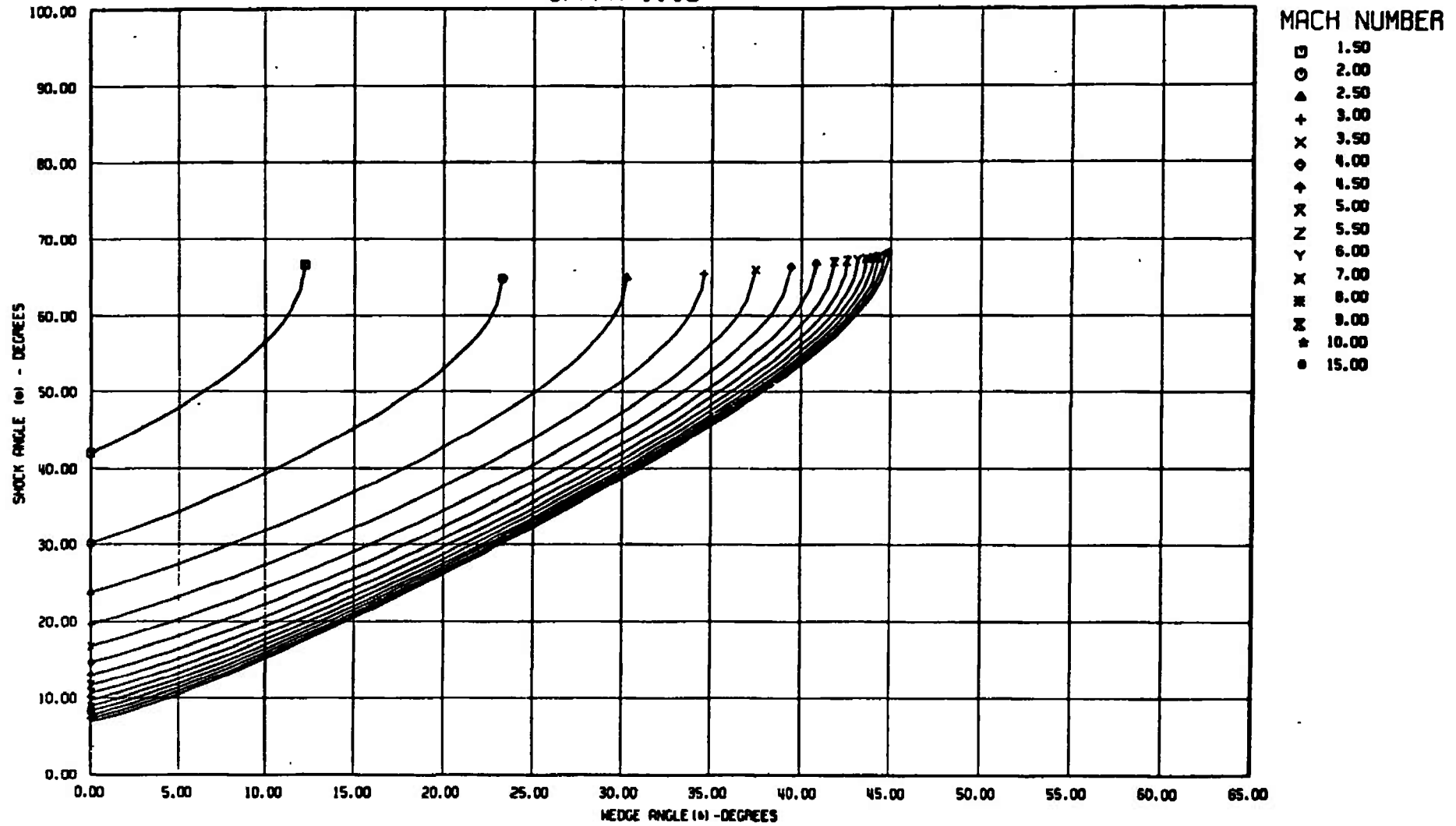


Fig. 3 $\gamma = 1.12$

OBLIQUE SHOCK GAMMA=1.12

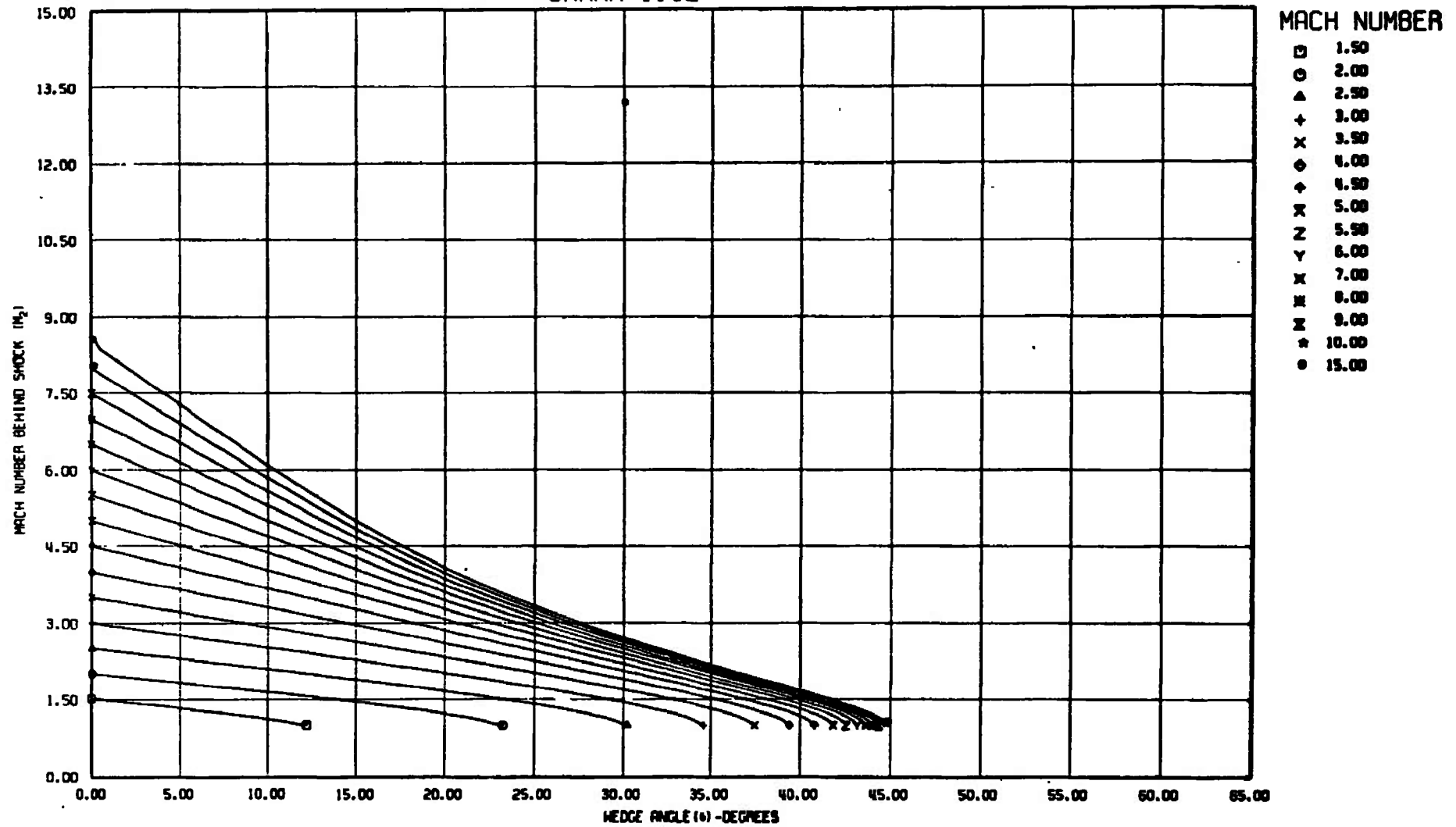


Fig. 3 Continued

OBLIQUE SHOCK GAMMA=1.12

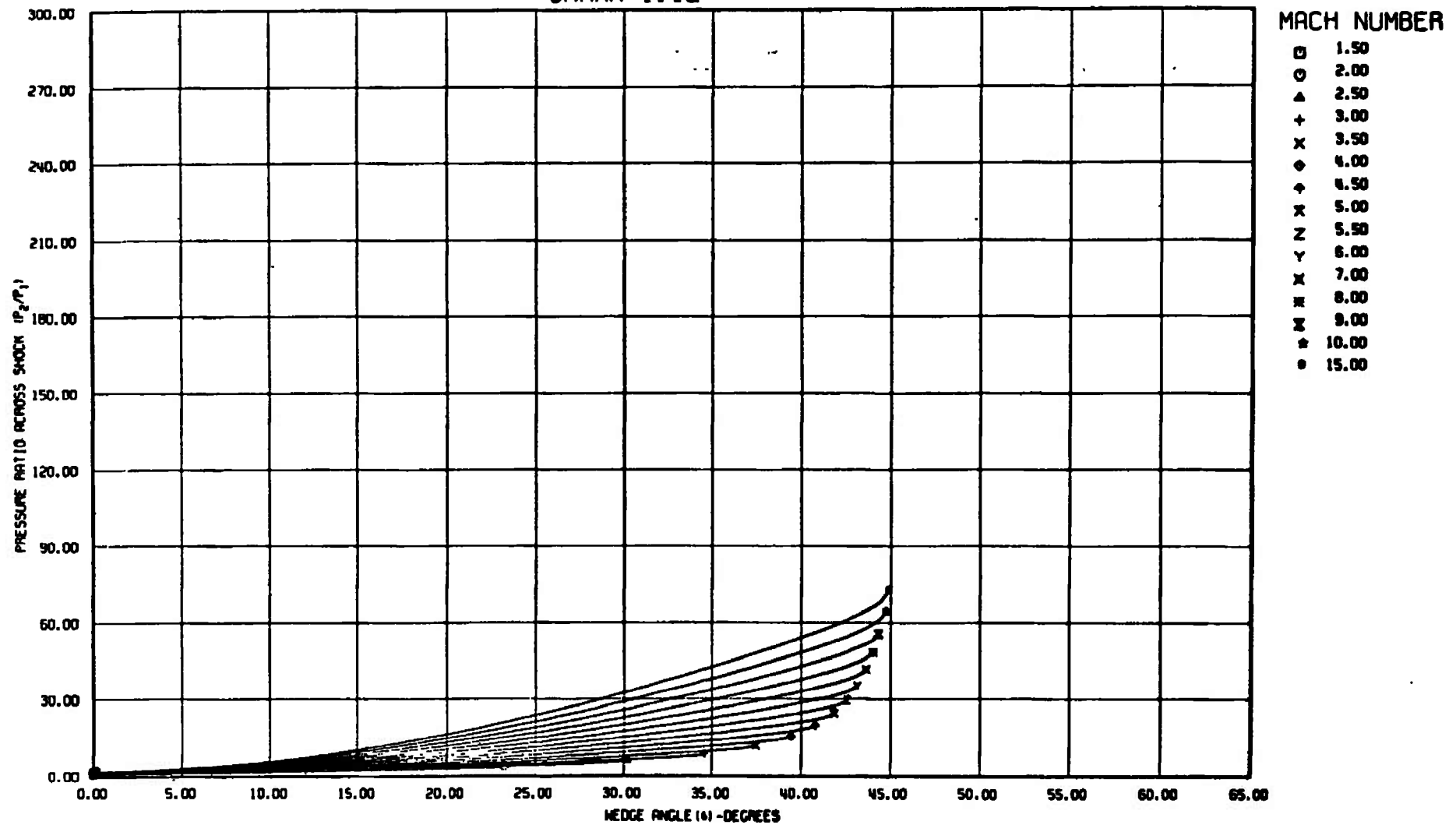


Fig. 3 Continued

OBLIQUE SHOCK
GAMMA=1.12

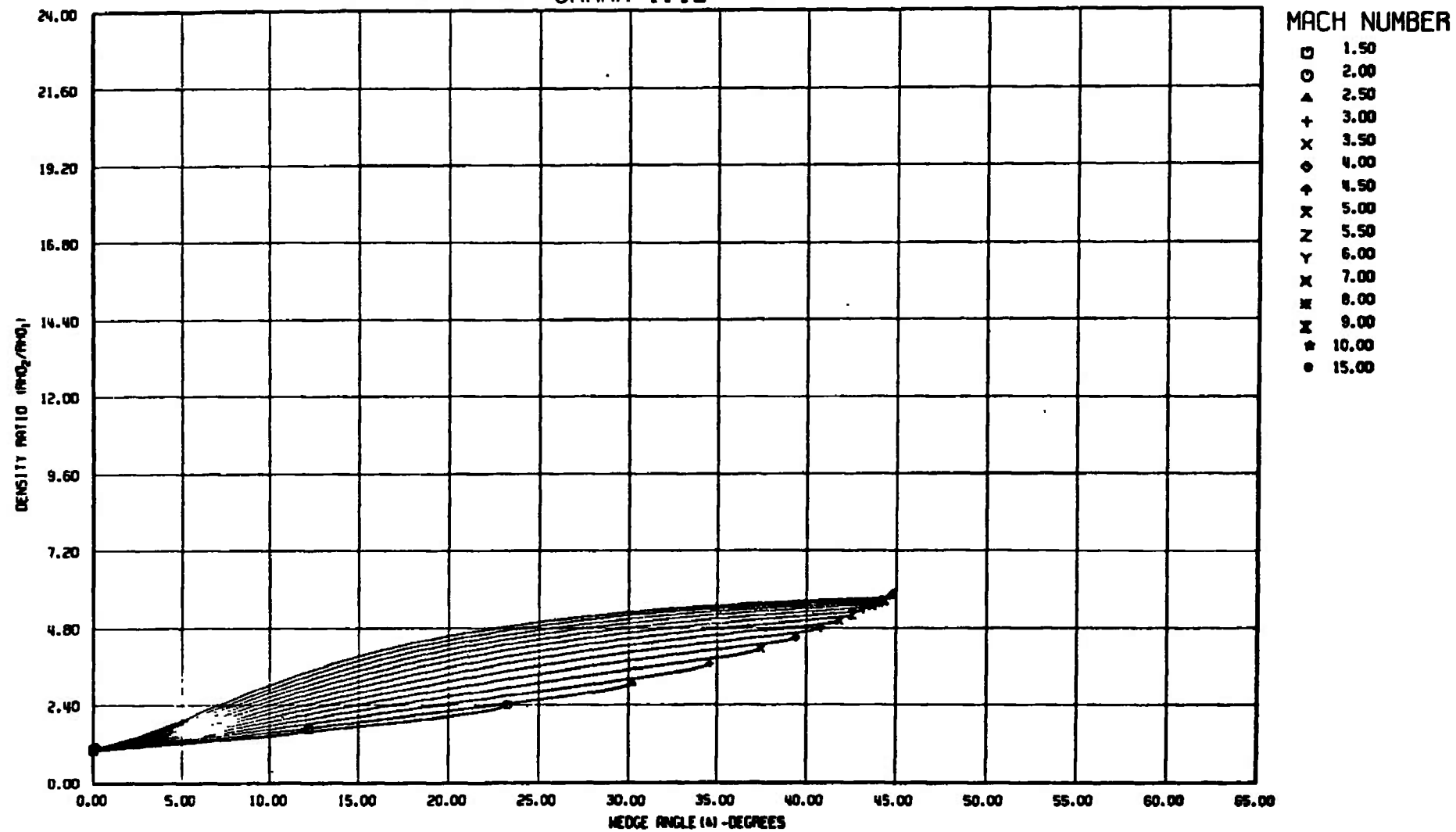


Fig. 3 Continued

OBLIQUE SHOCK GAMMA=1.12

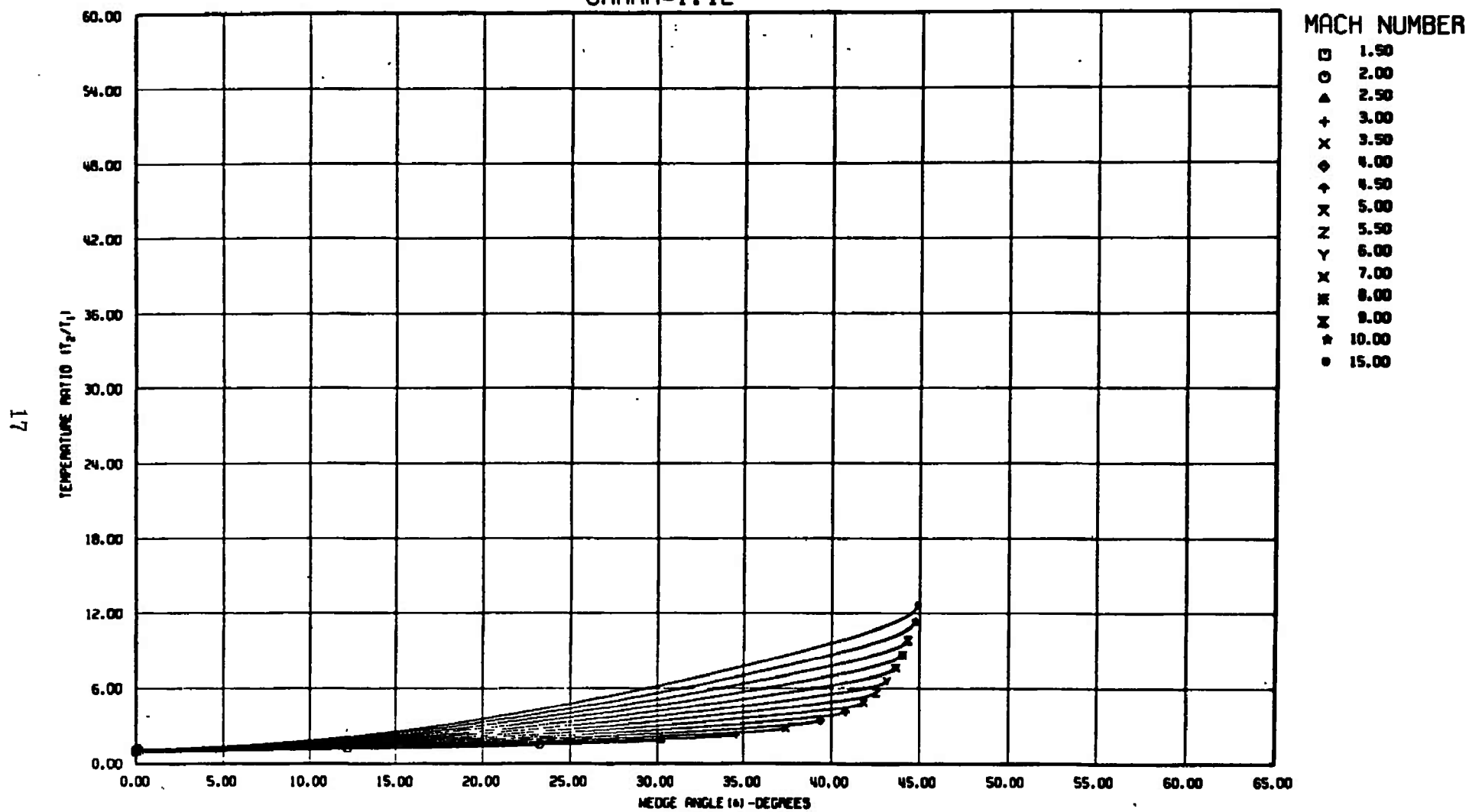
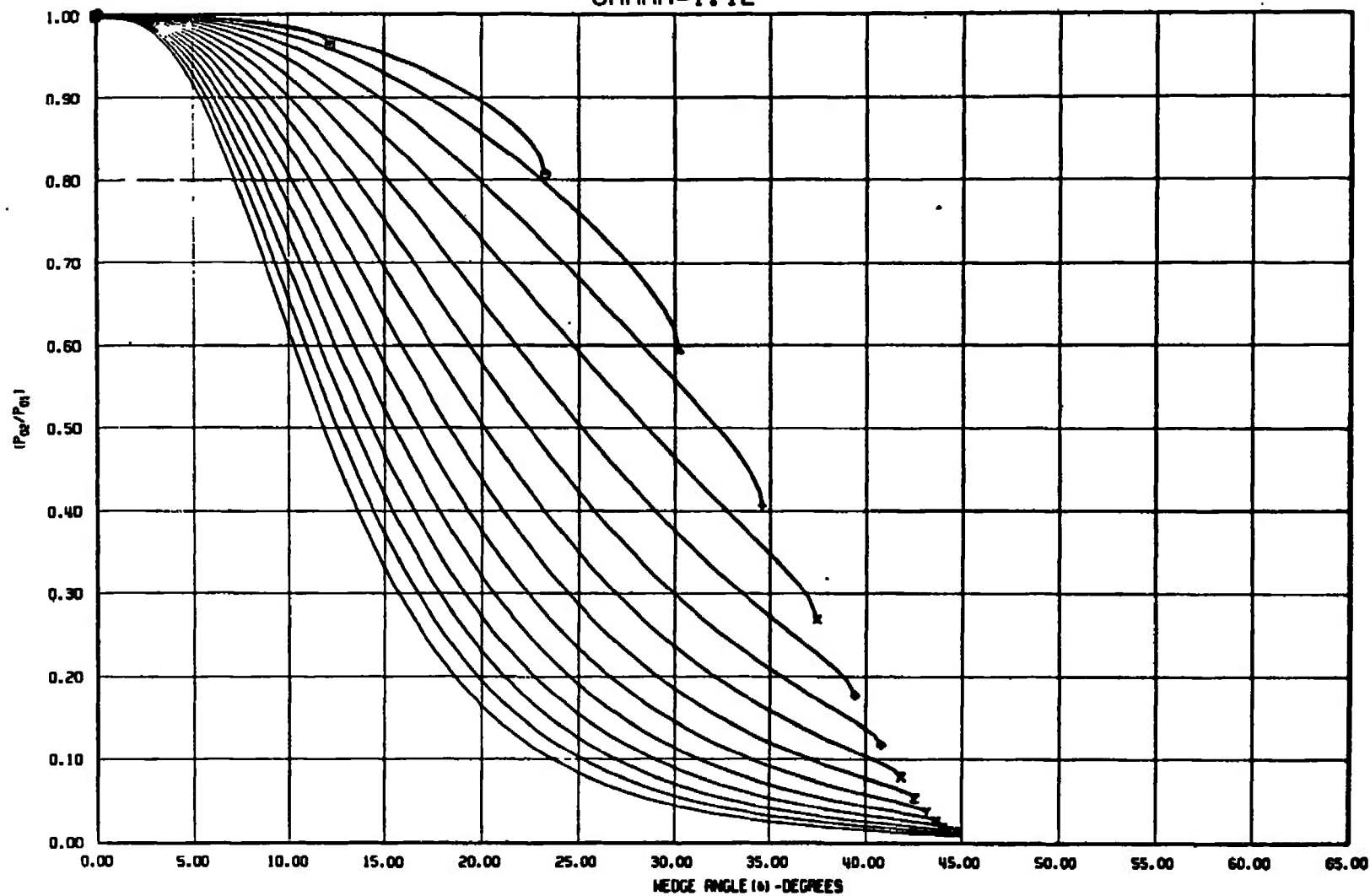


Fig. 3 Continued

OBLIQUE SHOCK
GAMMA=1.12



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- +
- x 3.50
- ◇ 4.00
- ◆ 4.50
- x 5.00
- Z 5.50
- Y 6.00
- x 7.00
- ≡ 8.00
- x 9.00
- ★ 10.00
- 15.00

Fig. 3 Continued

OBLIQUE SHOCK GAMMA=1.12

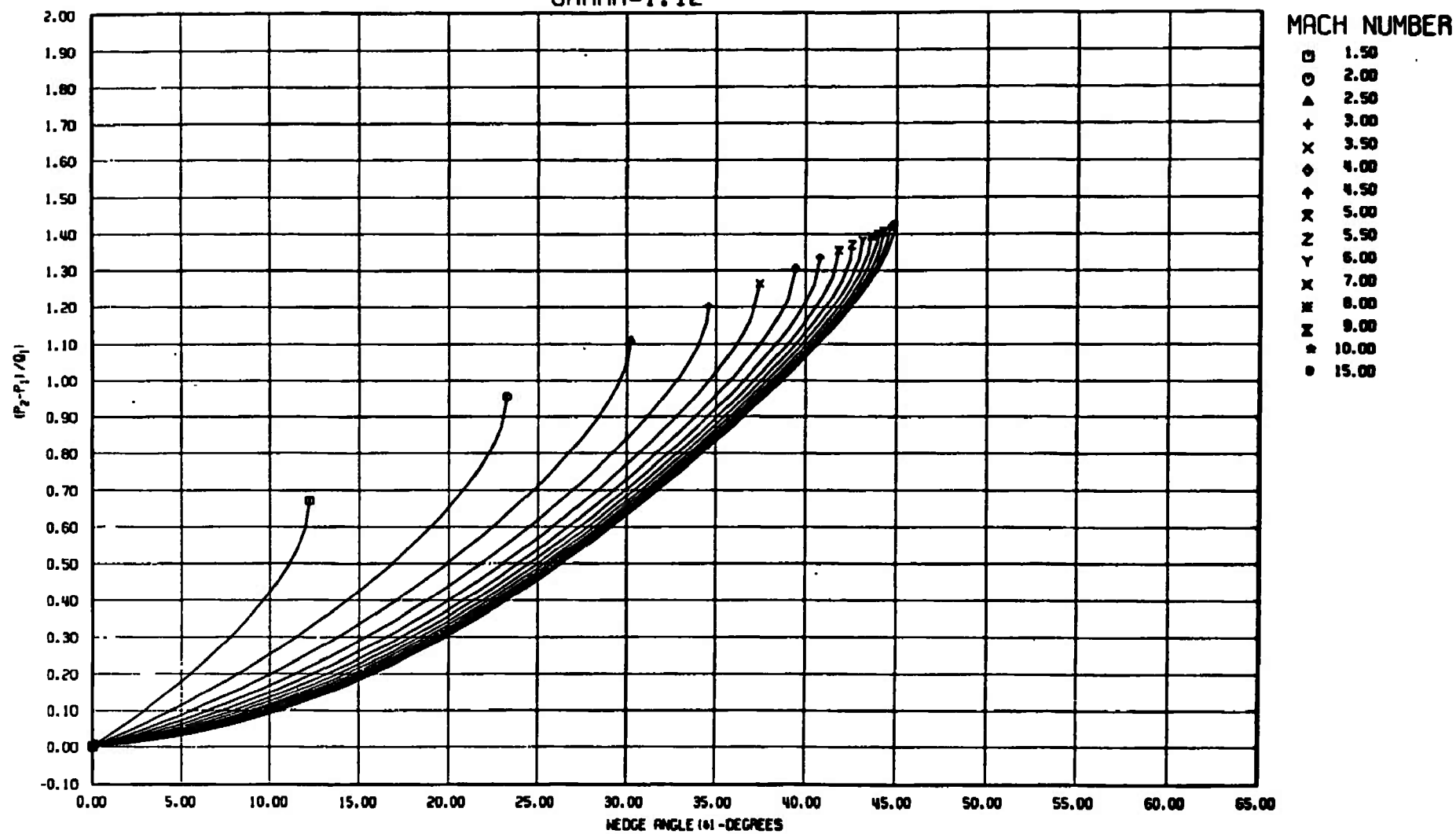
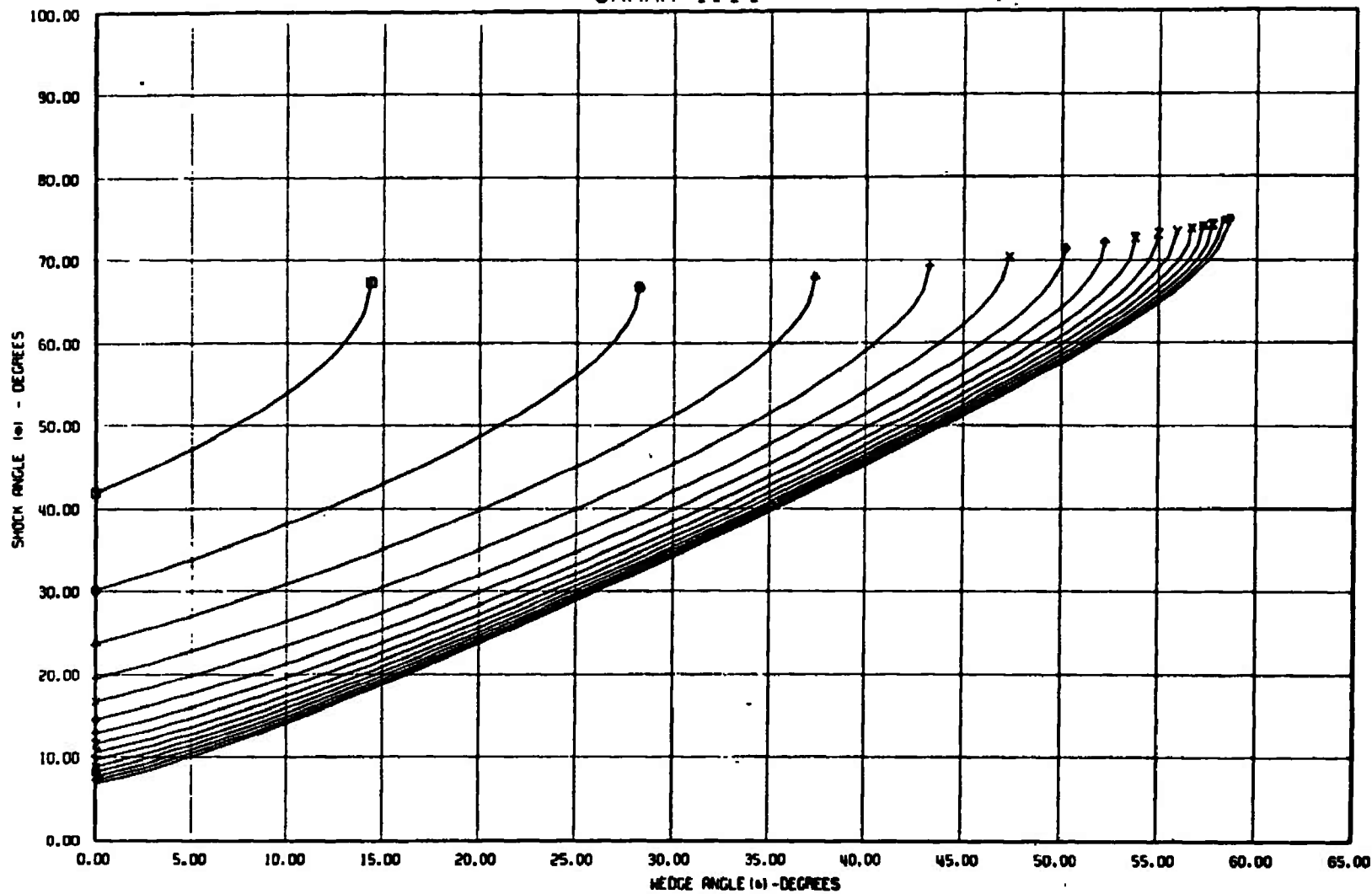


Fig. 3 Concluded

OBLIQUE SHOCK $\text{GAMMA}=1.14$

20



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- +
- x 3.50
- ◇ 4.00
- † 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- # 8.00
- W 9.00
- * 10.00
- 15.00

Fig. 4 $\gamma = 1.14$

OBLIQUE SHOCK
GAMMA=1.14

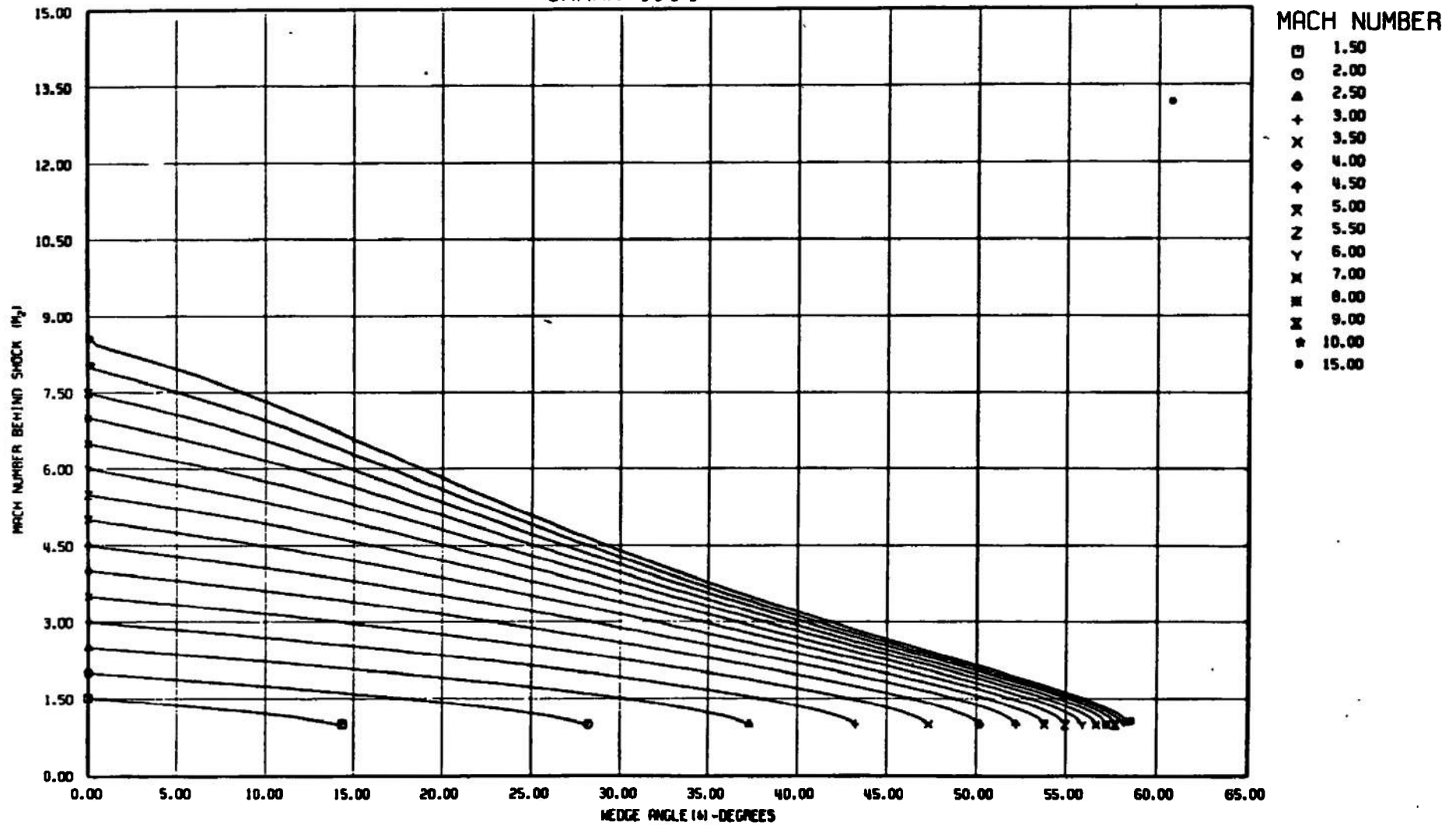


Fig. 4 Continued

OBLIQUE SHOCK GAMMA=1.14

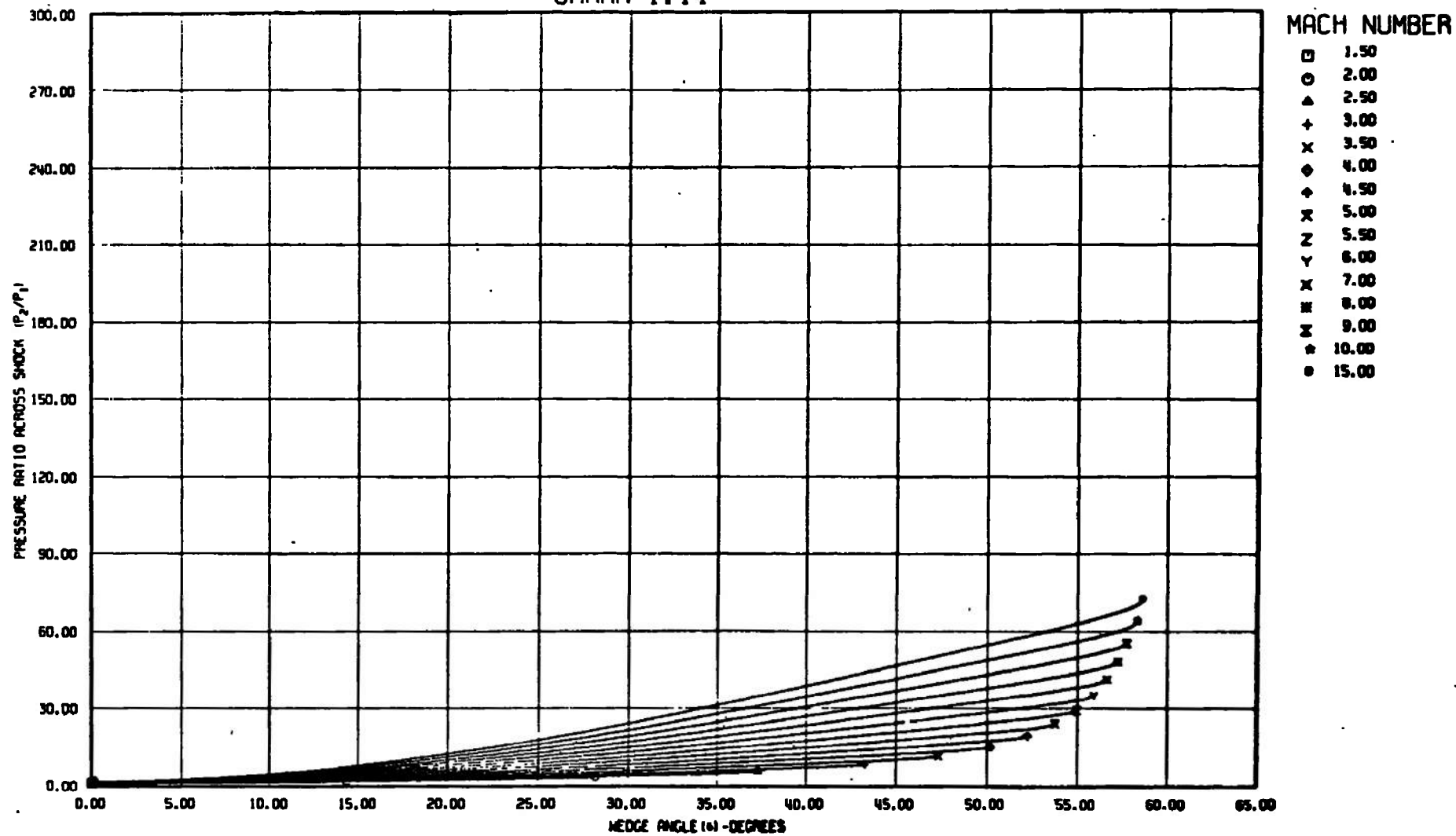


Fig. 4 Continued

OBLIQUE SHOCK GAMMA=1.14

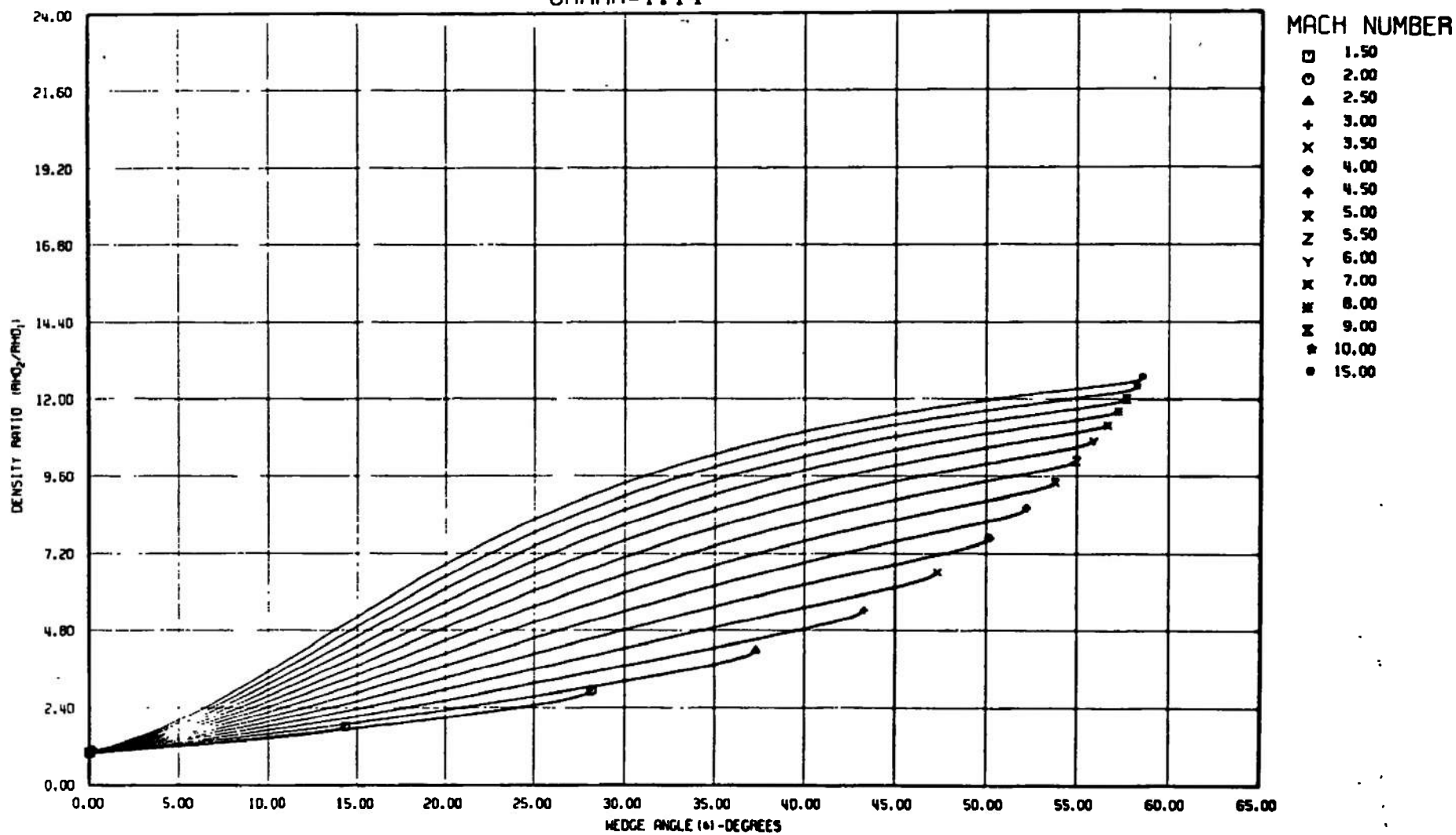


Fig. 4 Continued

OBLIQUE SHOCK GAMMA=1.14

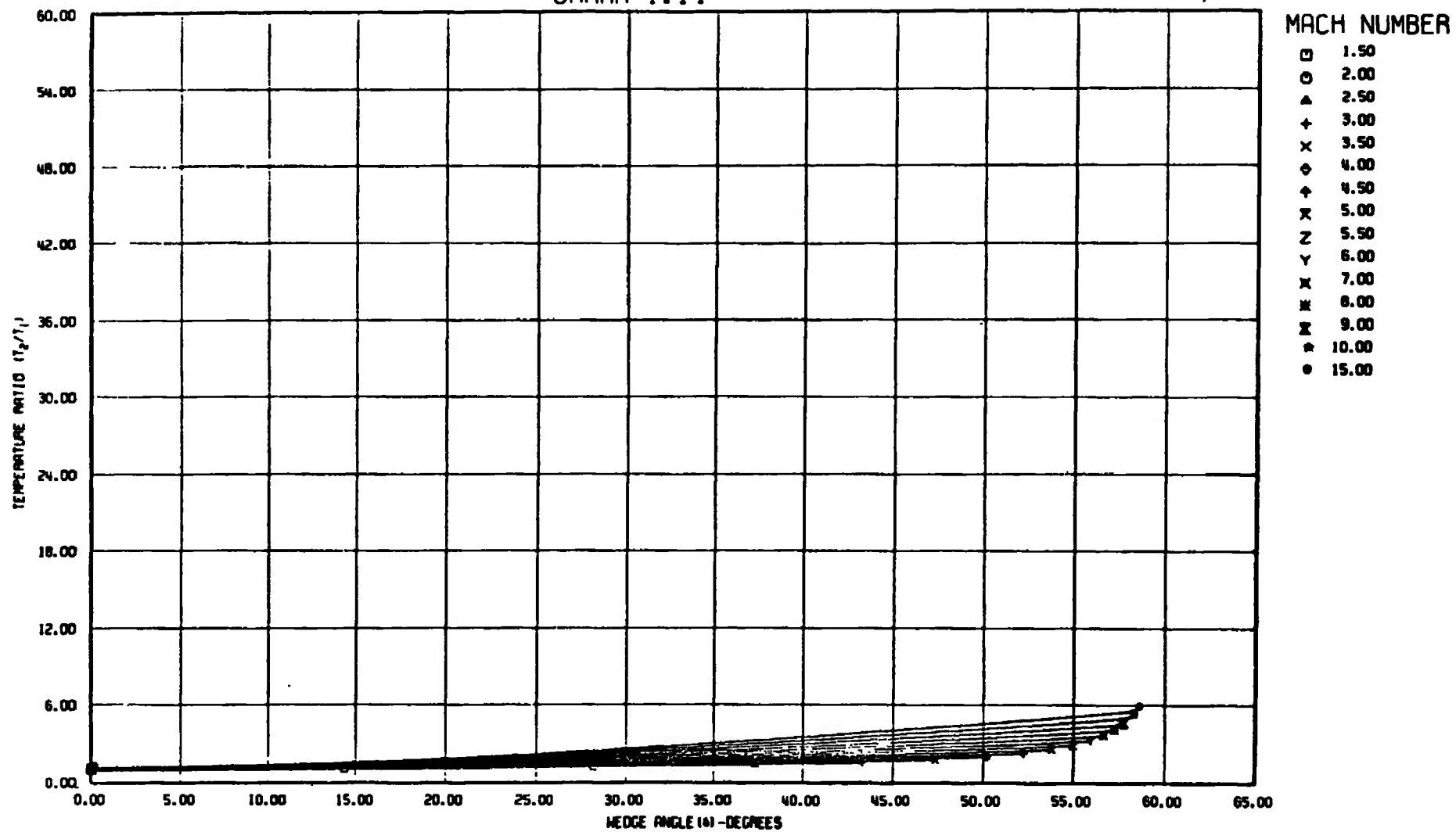


Fig. 4 Continued

OBLIQUE SHOCK
GAMMA=1.14

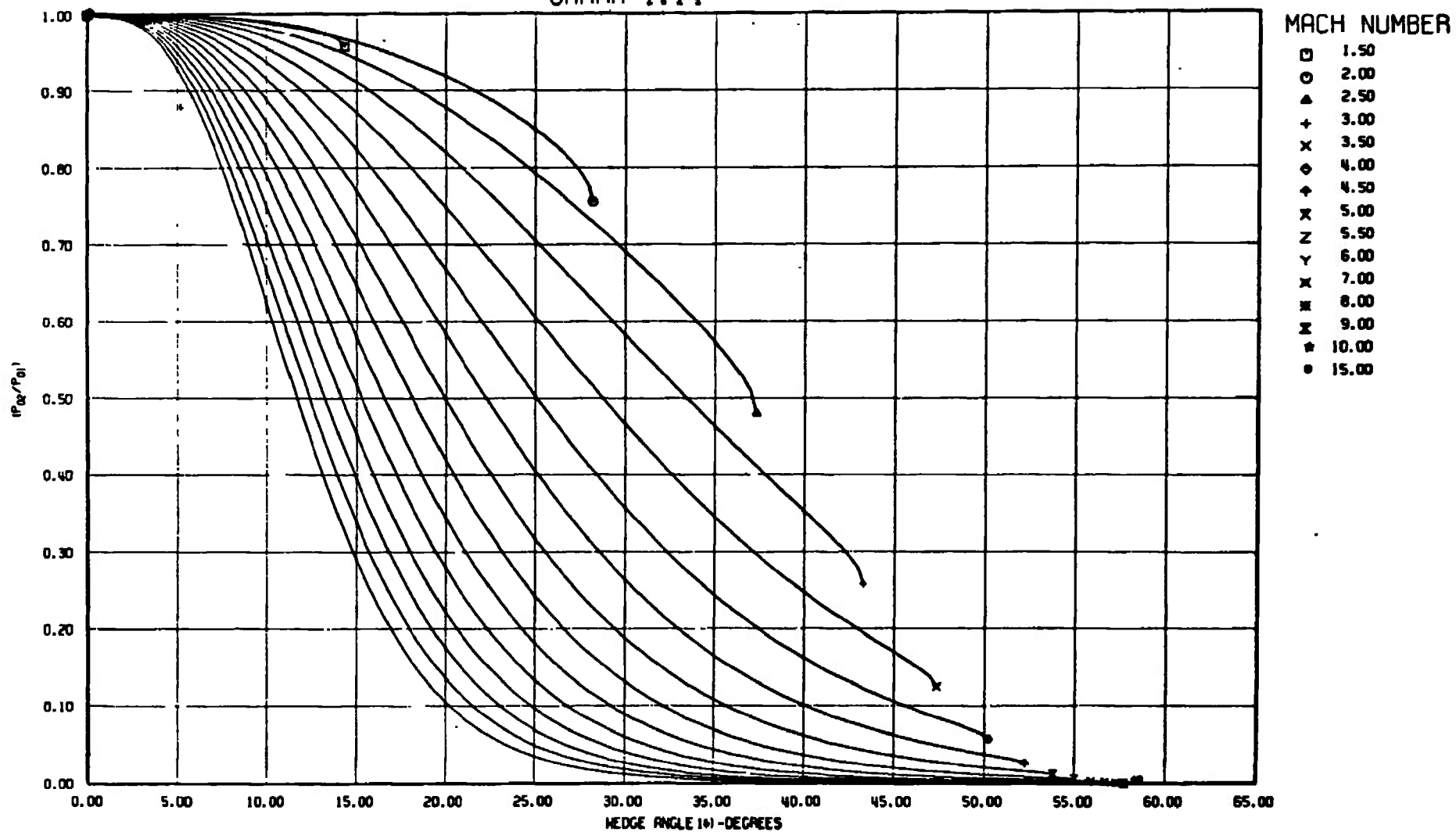


Fig. 4 Continued

OBLIQUE SHOCK
GAMMA=1.14

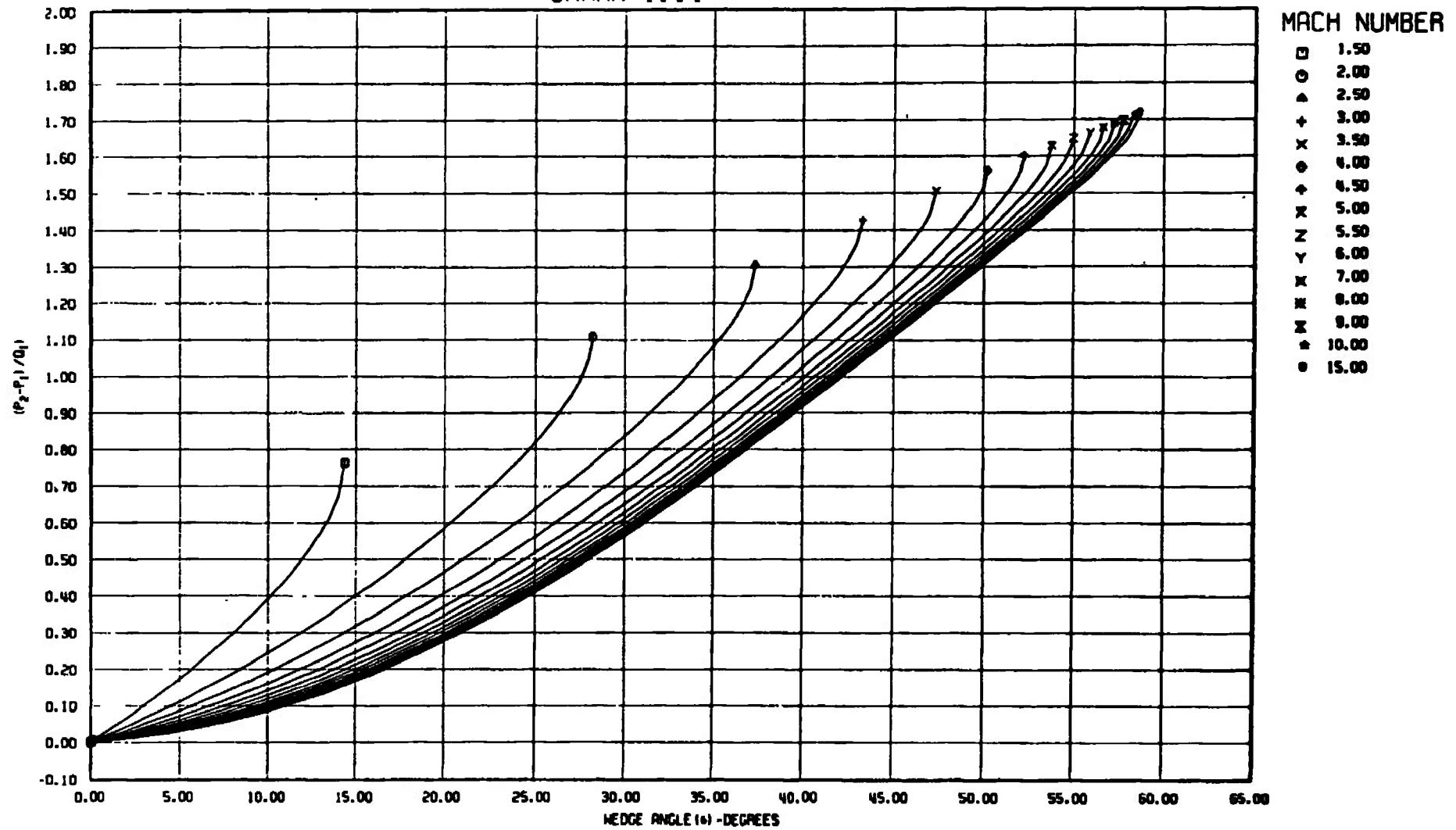
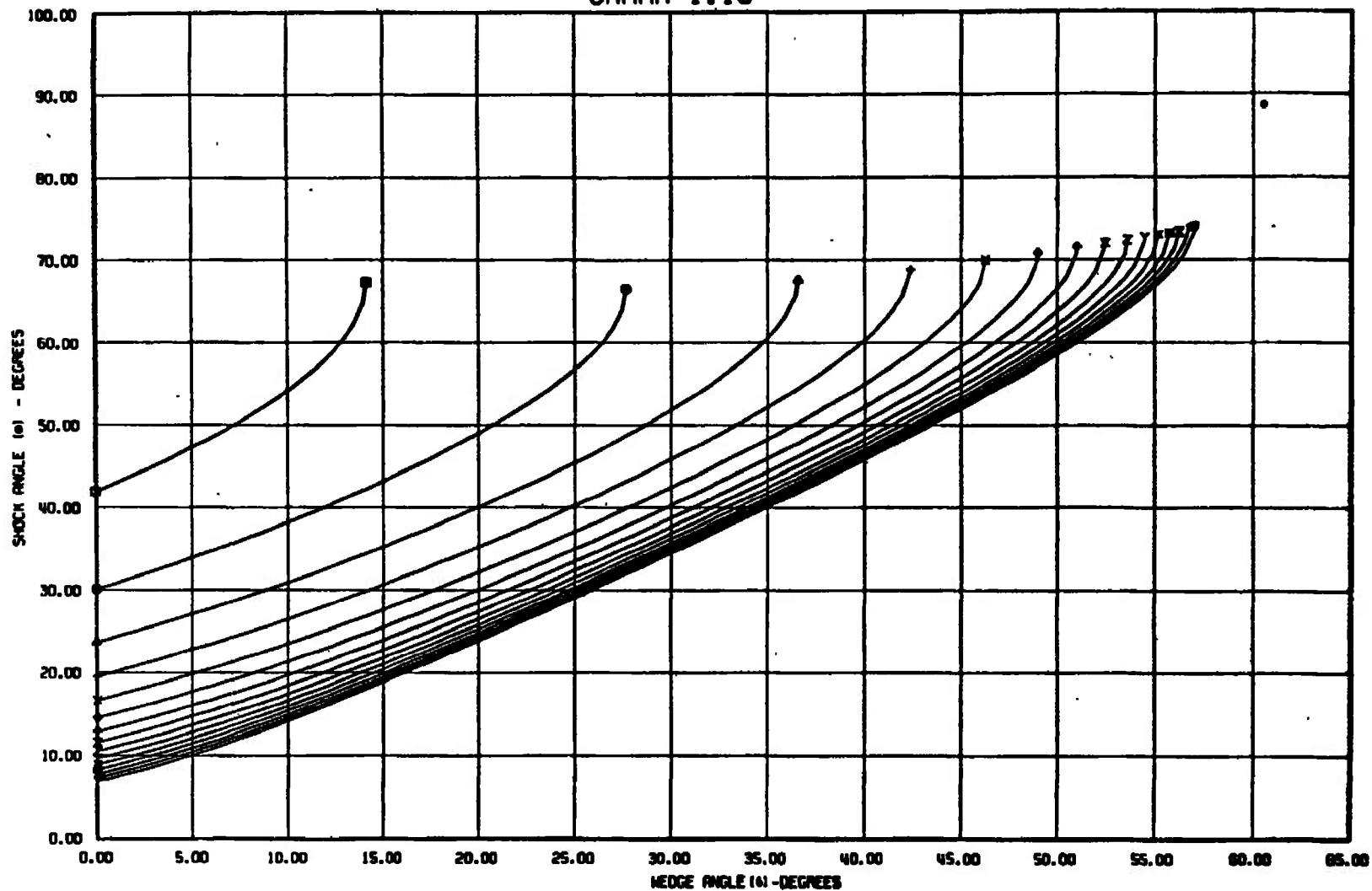


Fig. 4 Concluded

OBLIQUE SHOCK GAMMA=1.16



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◊ 4.00
- ◊ 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- x 8.00
- x 9.00
- * 10.00
- 15.00

Fig. 5 $\gamma = 1.16$

OBLIQUE SHOCK GAMMA=1.16

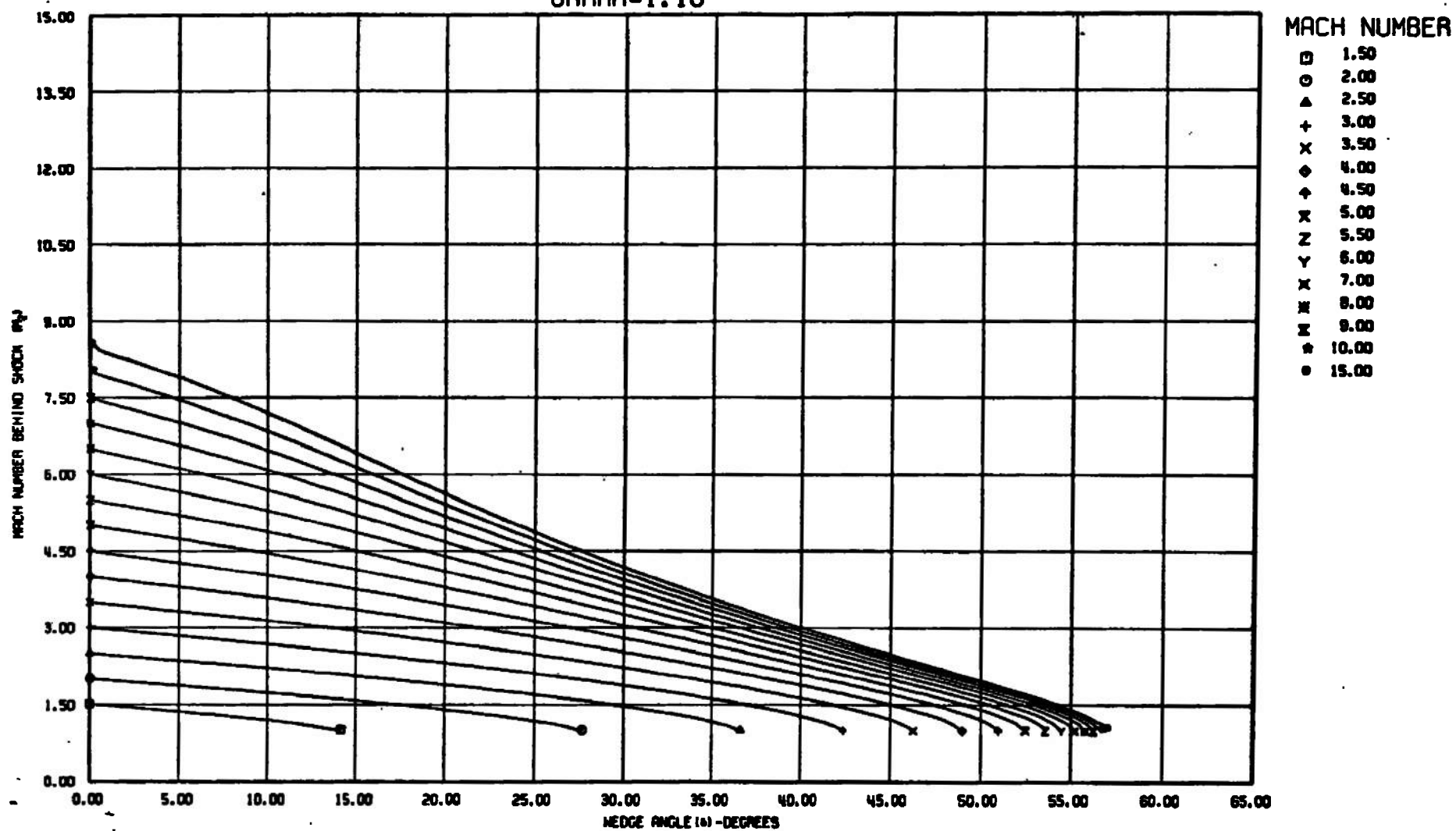


Fig. 5 Continued

OBLIQUE SHOCK GAMMA=1.16

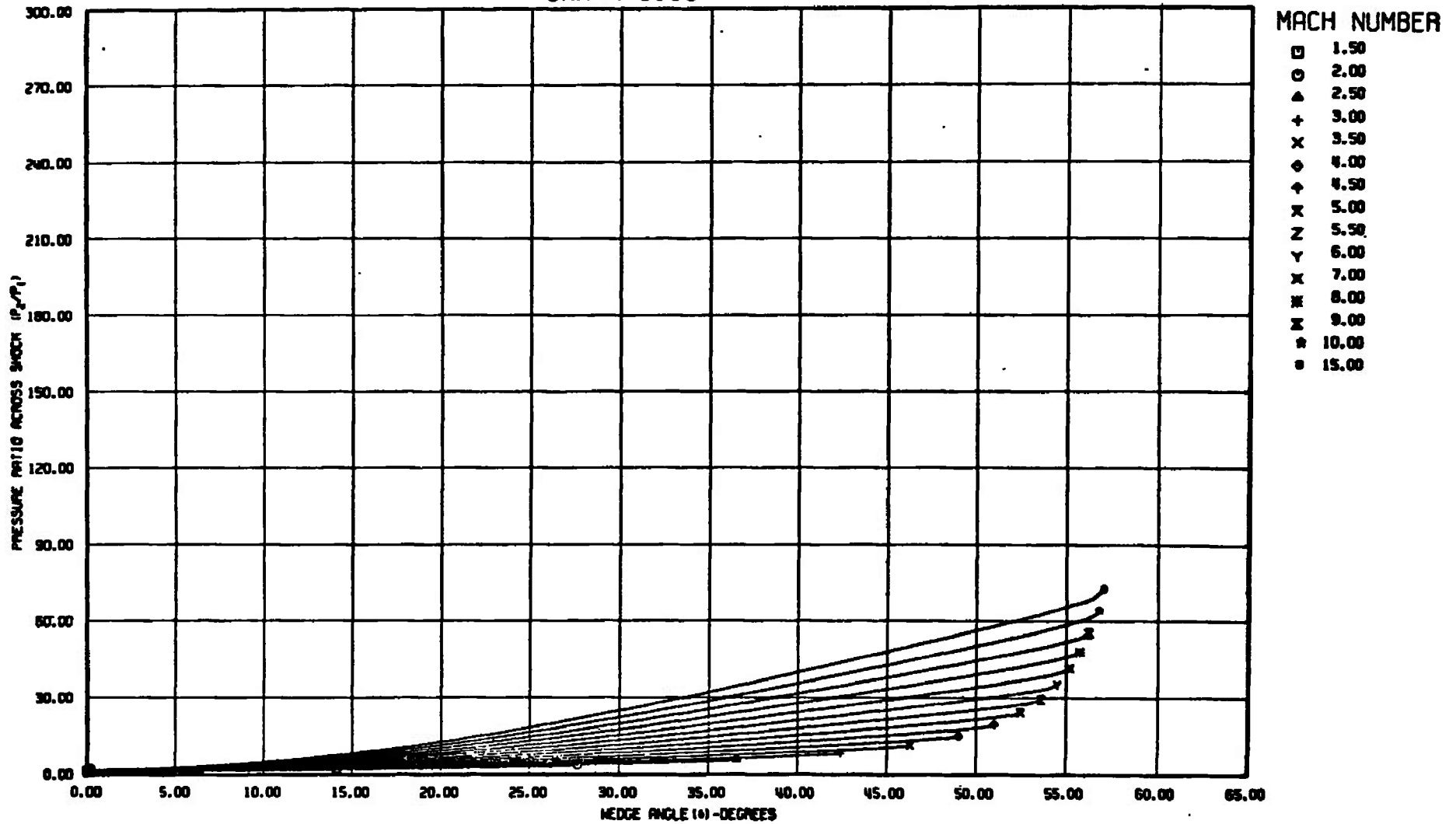


Fig. 5 Continued

OBLIQUE SHOCK
GAMMA=1.16

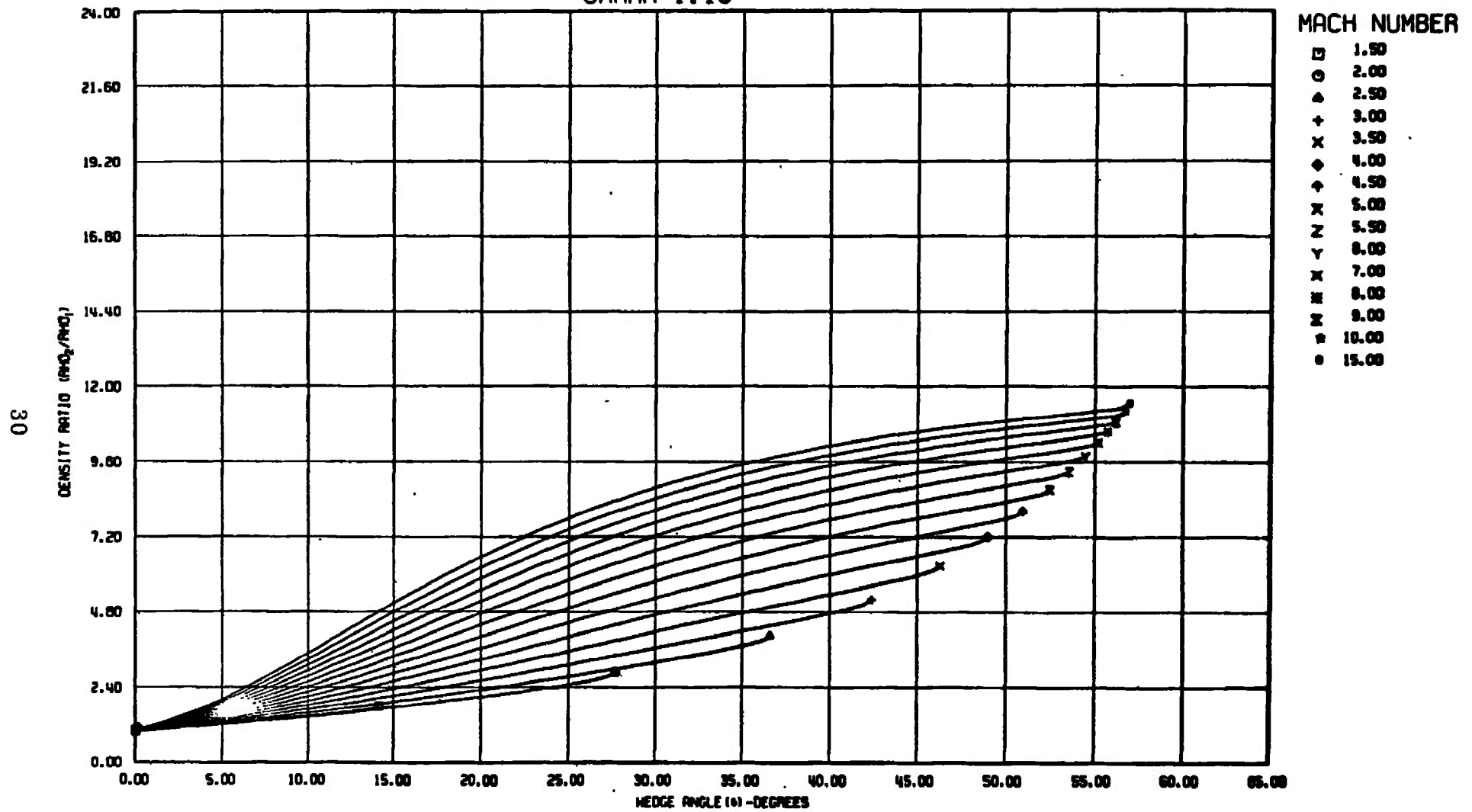


Fig. 5 Continued

OBLIQUE SHOCK GAMMA=1.16

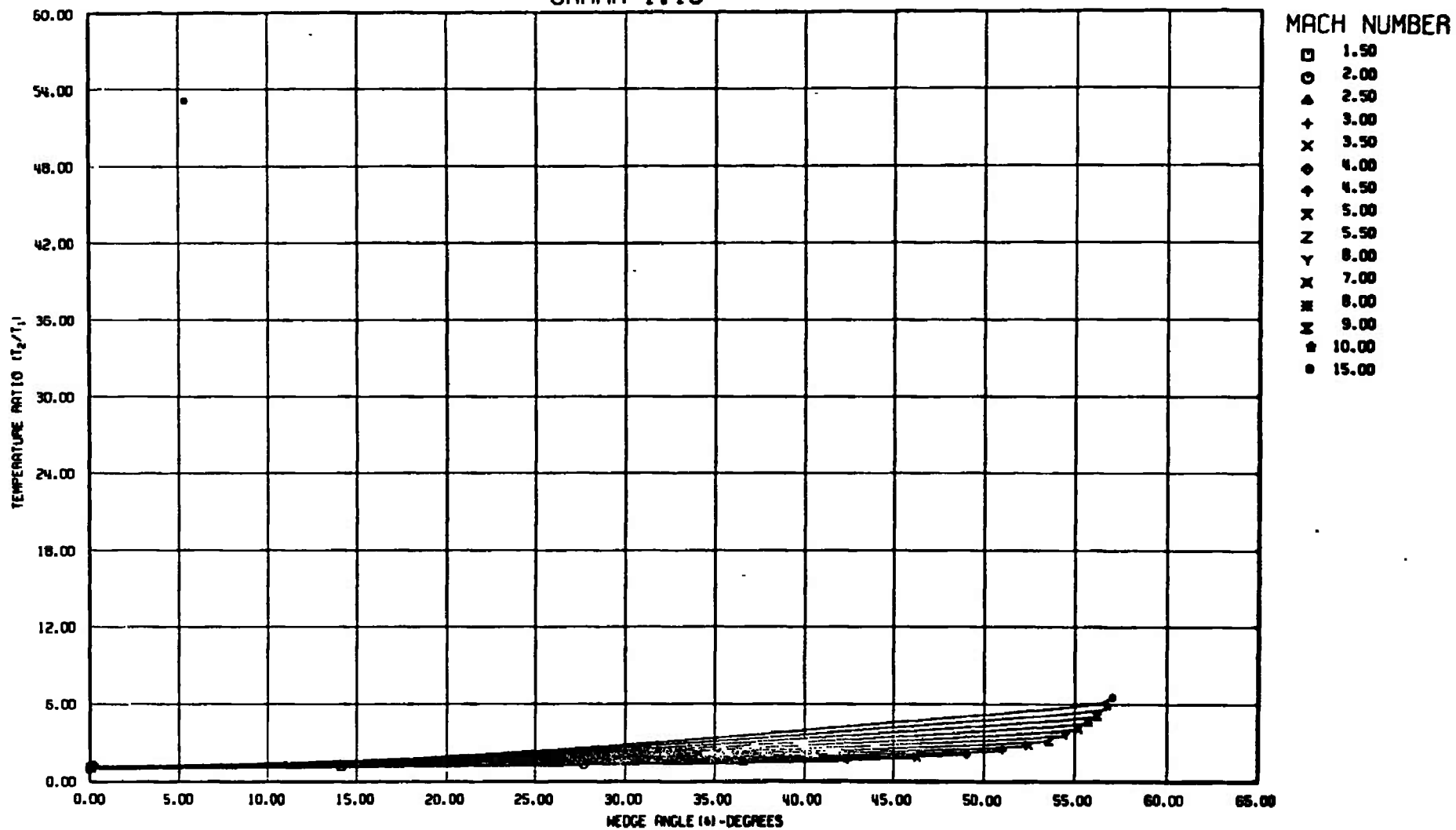


Fig. 5 Continued

OBLIQUE SHOCK
GAMMA=1.16

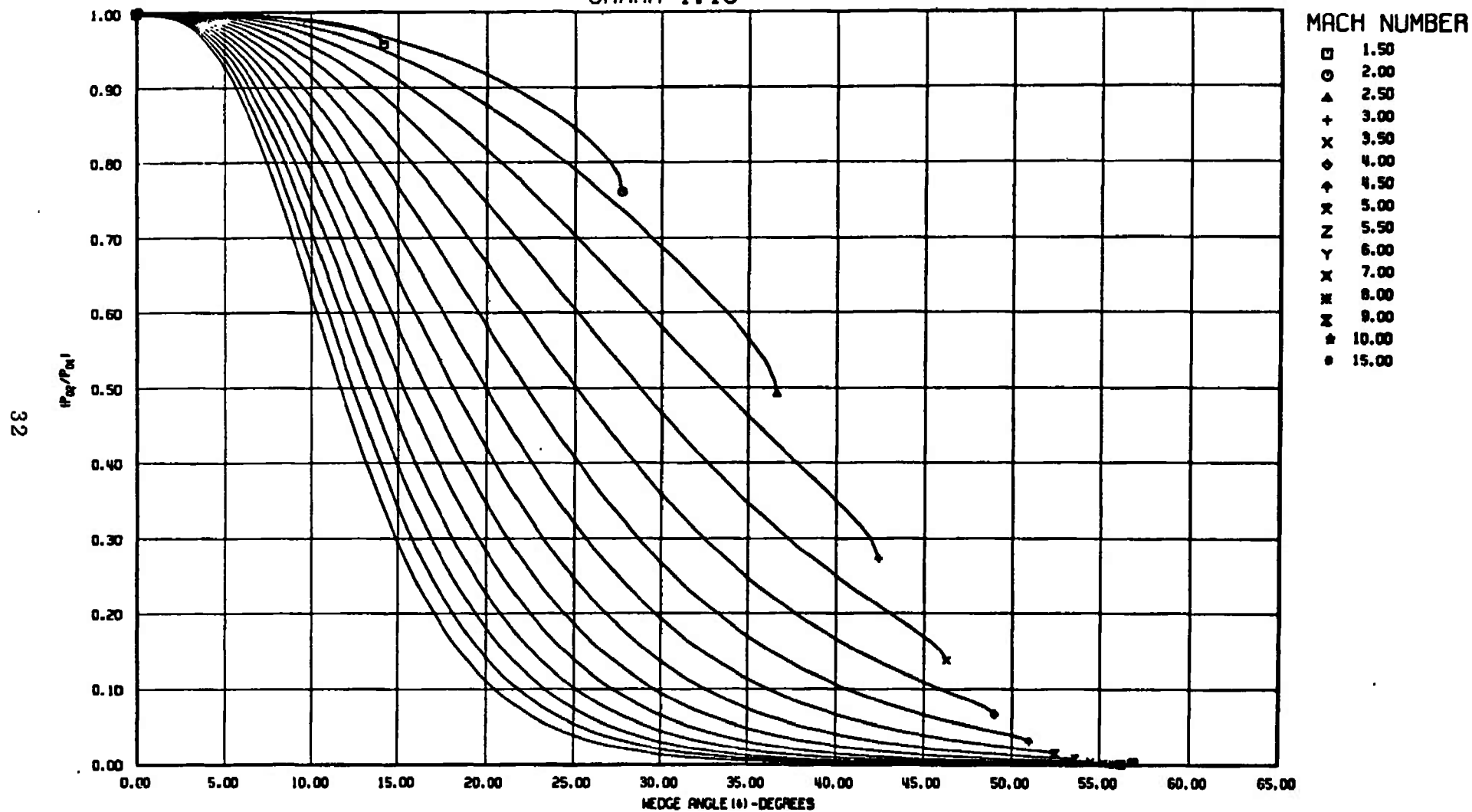


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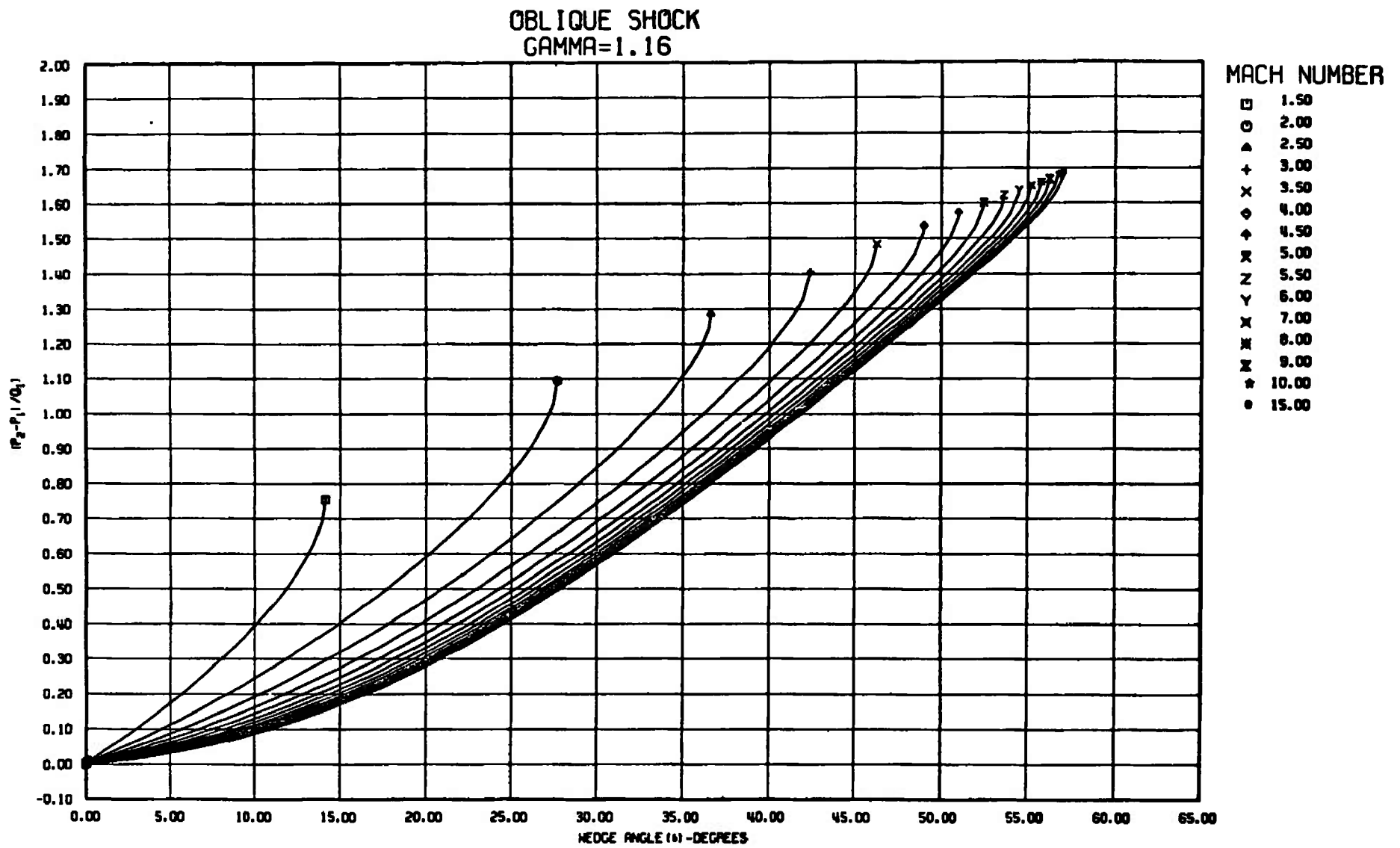


Fig. 5 Concluded

OBLIQUE SHOCK GAMMA=1.18

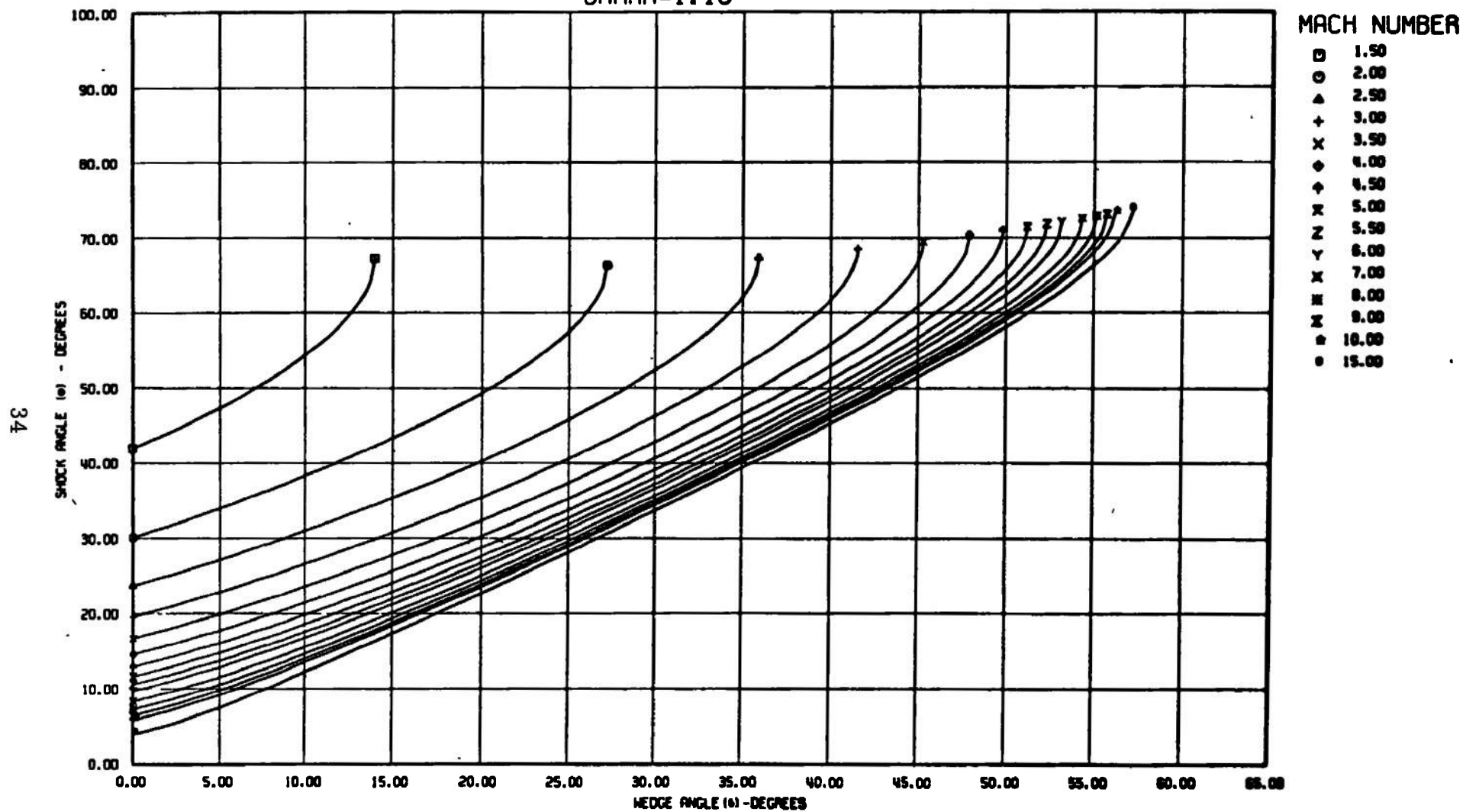


Fig. 6 $\gamma = 1.18$

OBLIQUE SHOCK GAMMA=1.18

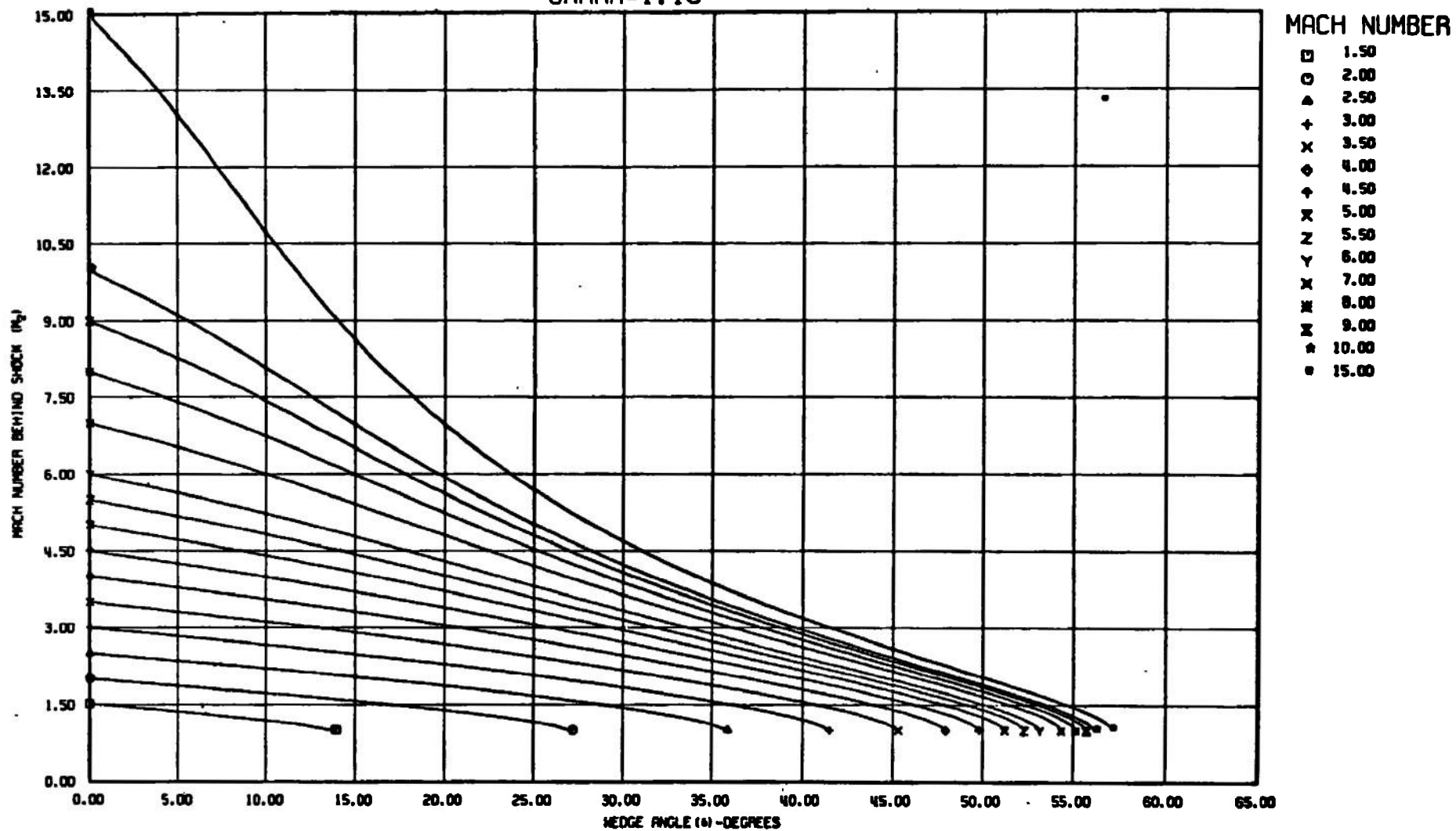


Fig. 6 Continued

OBLIQUE SHOCK
GAMMA=1.18

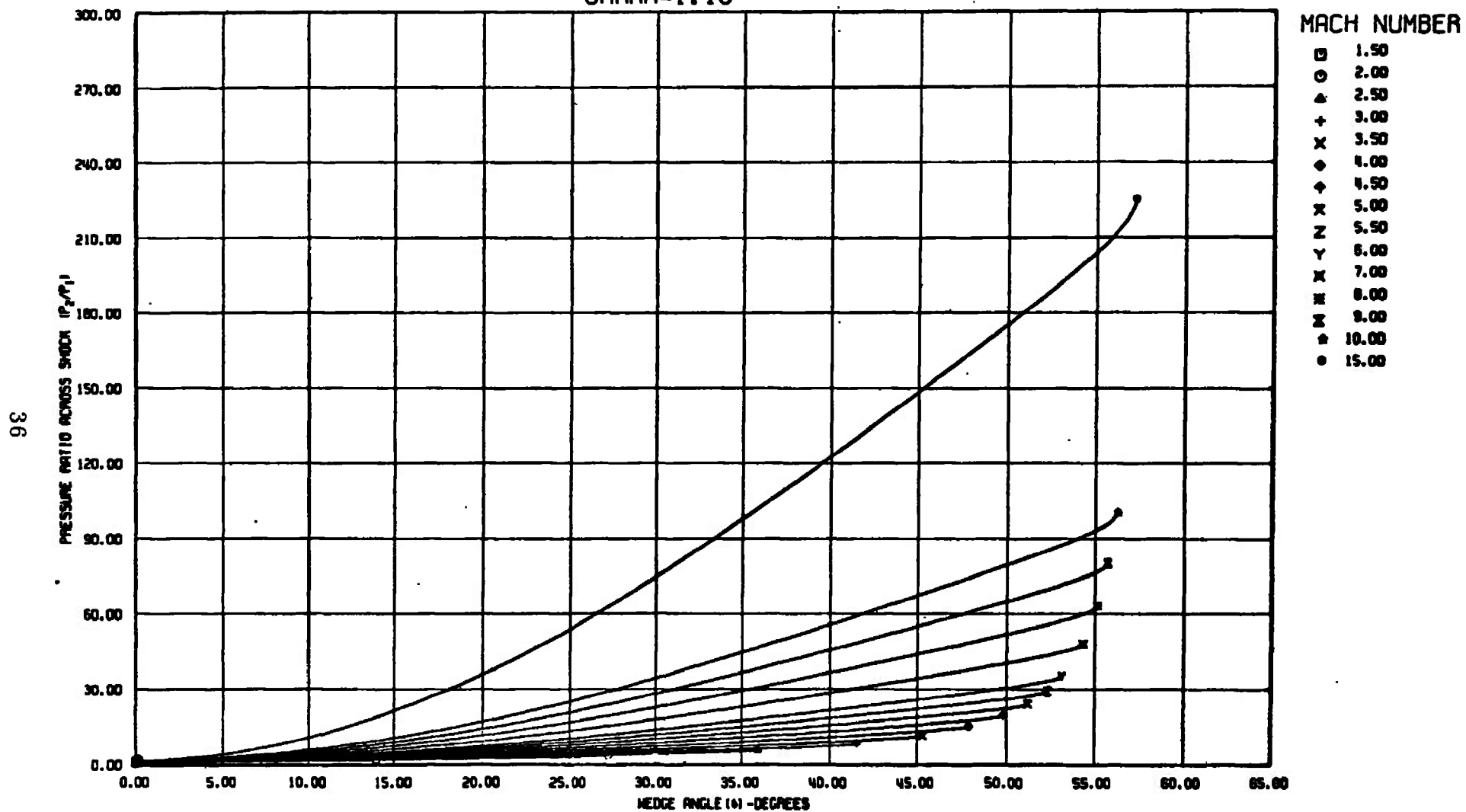


Fig. 6 Continued

OBLIQUE SHOCK GAMMA=1.18

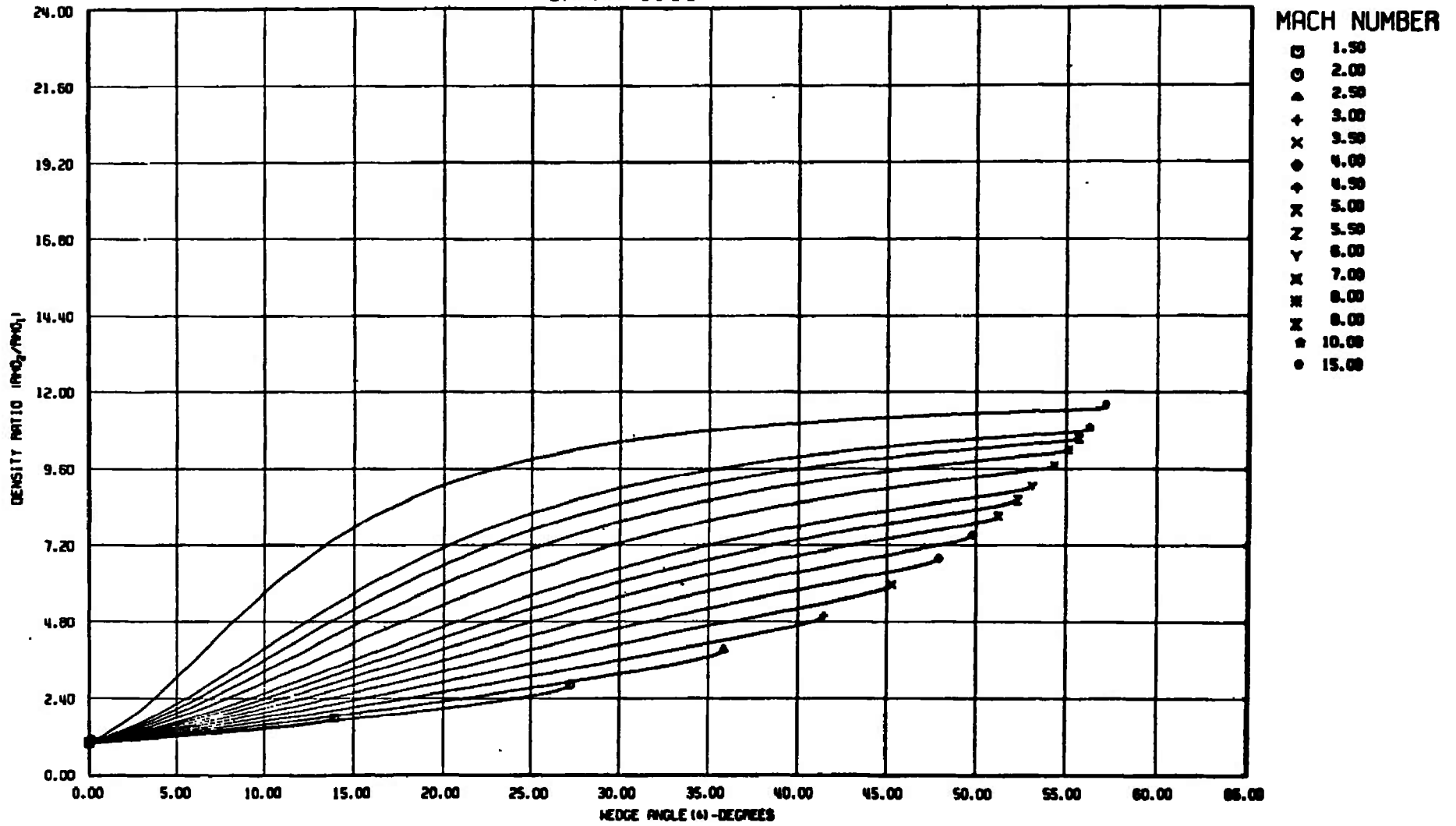


Fig. 6 Continued

OBLIQUE SHOCK GAMMA=1.18

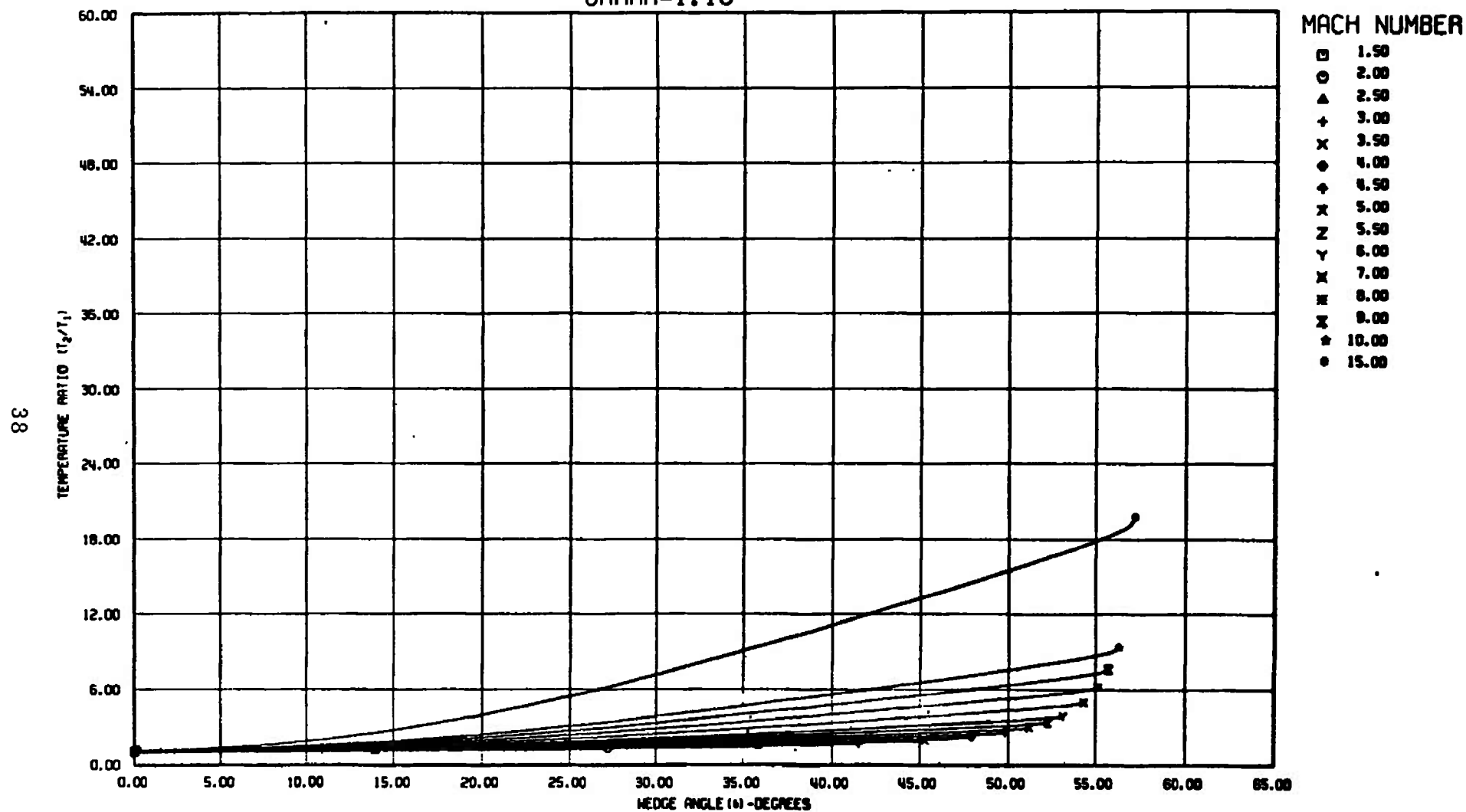


Fig. 6 Continued

OBLIQUE SHOCK GAMMA=1.18

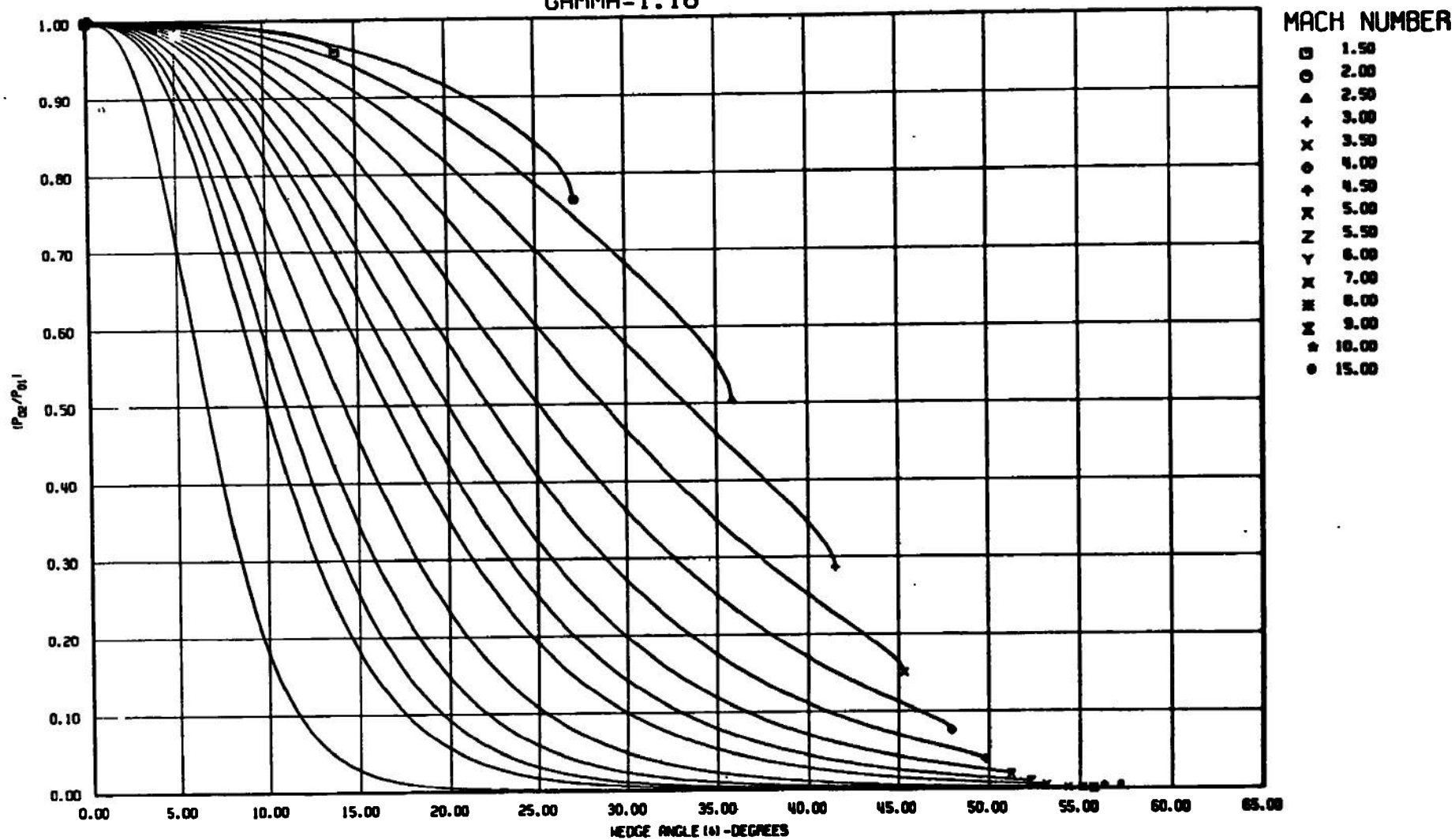


Fig. 6 Continued

OBLIQUE SHOCK GAMMA=1.18

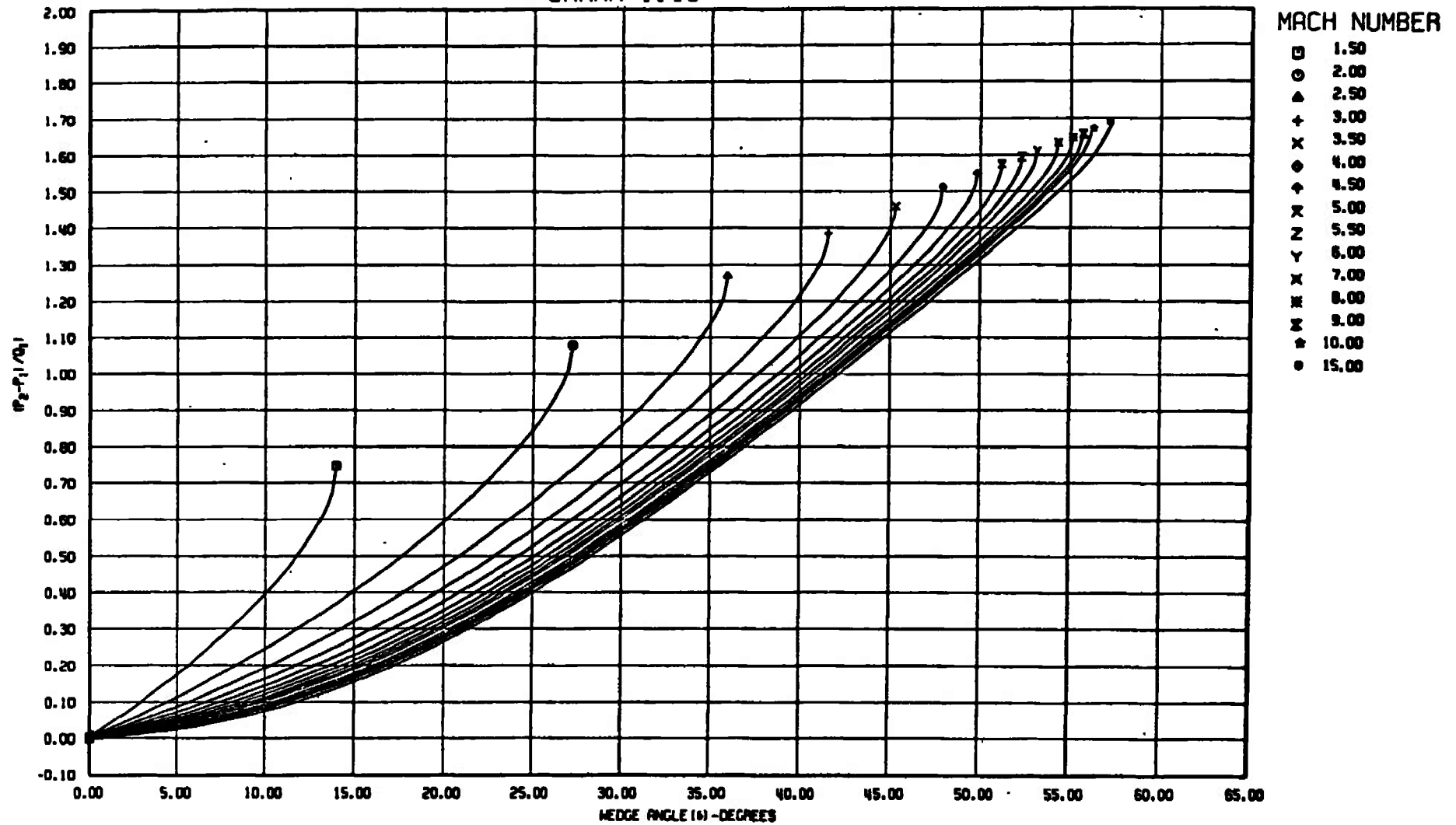
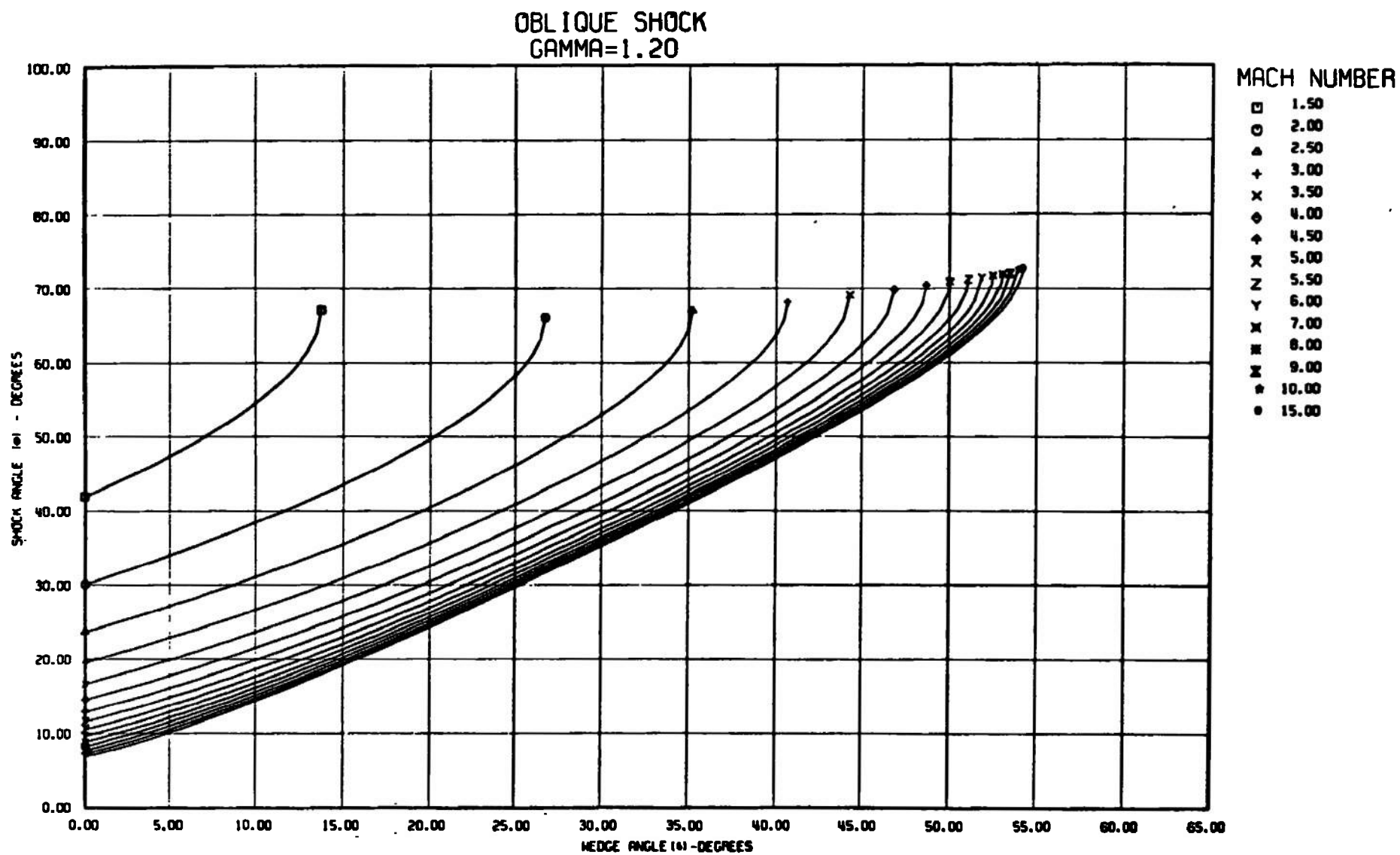
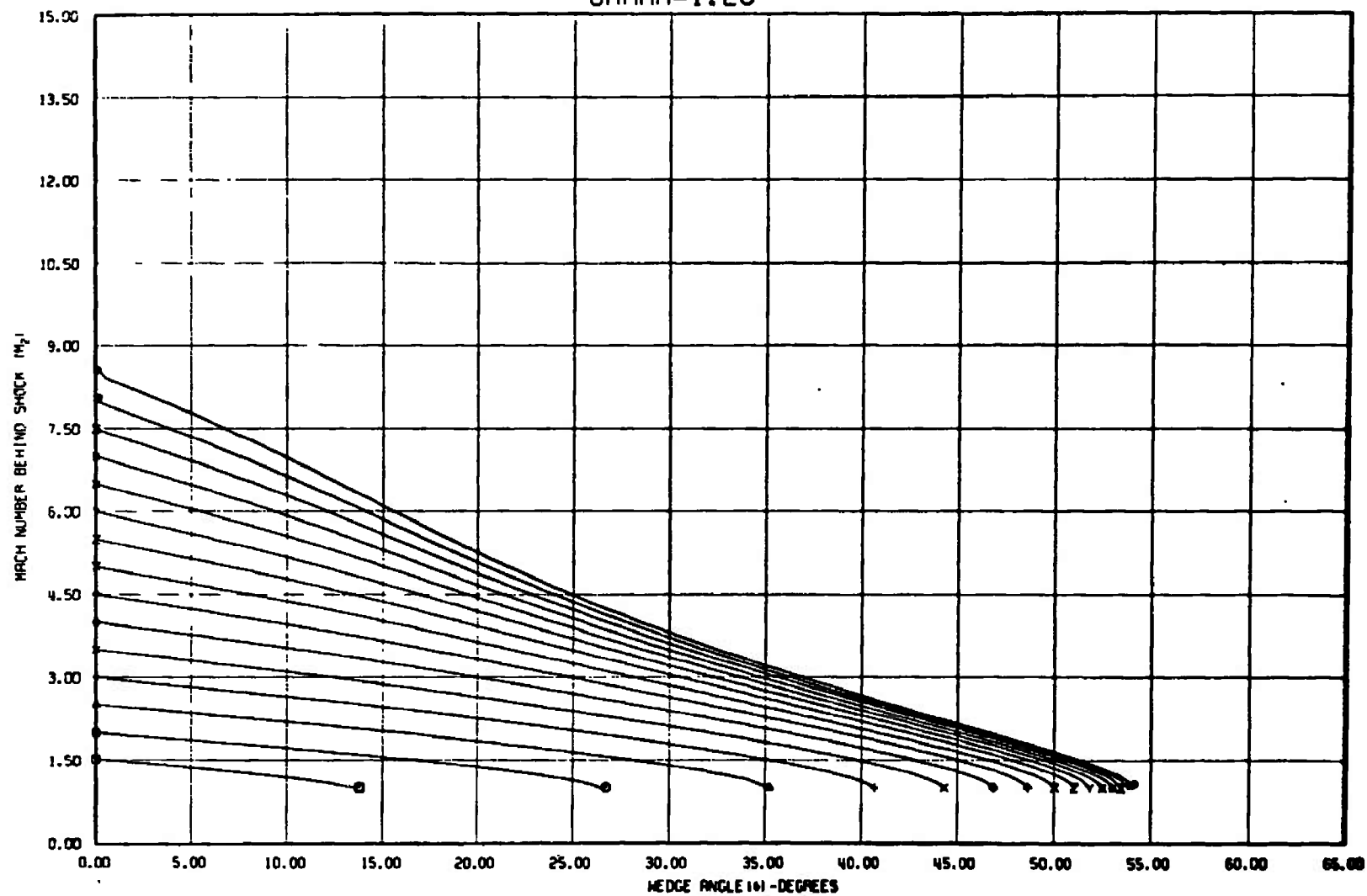


Fig. 6 Concluded

Fig. 7 $\gamma = 1.20$

OBLIQUE SHOCK $\gamma=1.20$

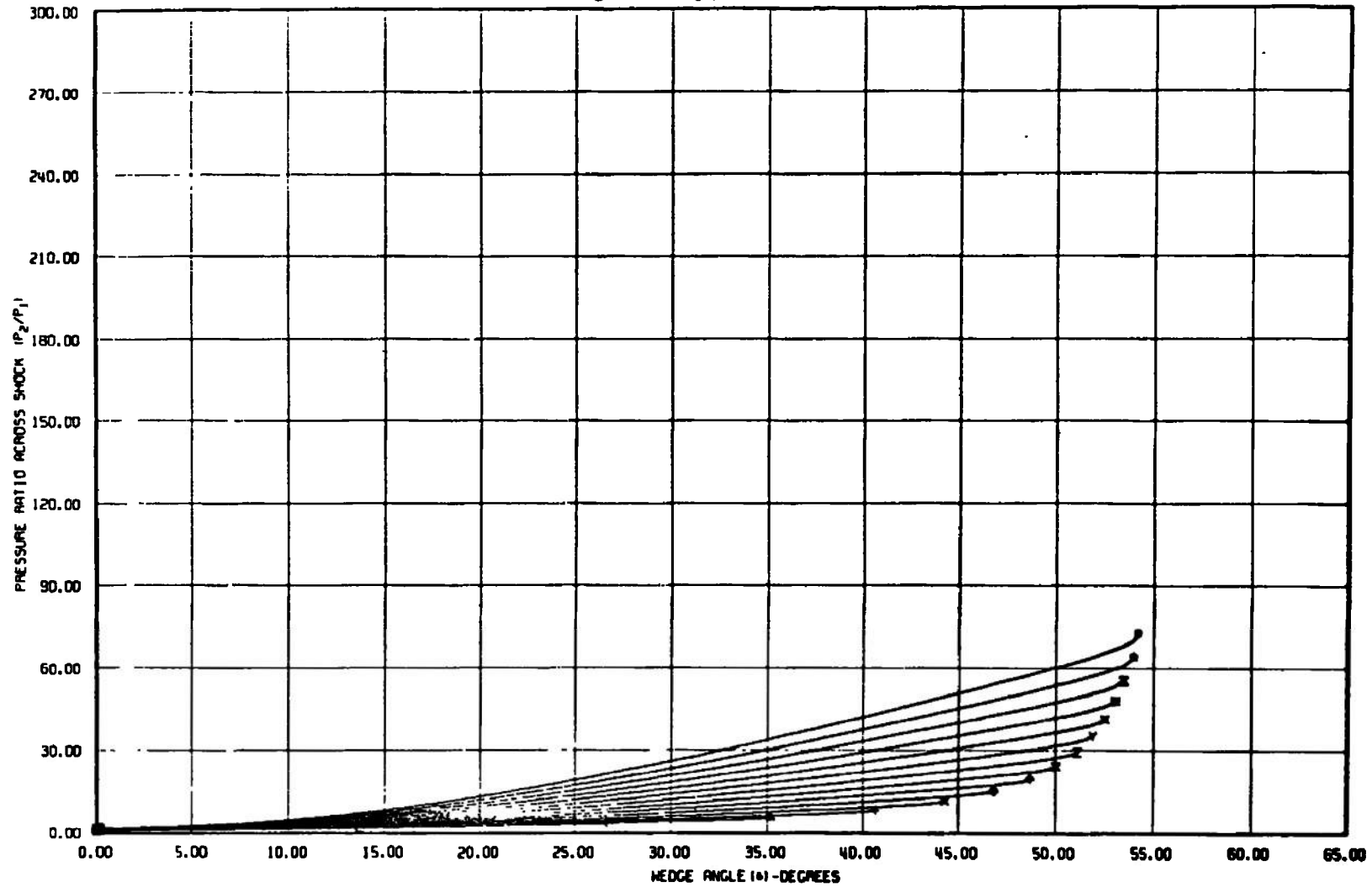


MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- +
- x 3.50
- ◆ 4.00
- ◊ 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- 8.00
- x 9.00
- ★ 10.00
- 15.00

Fig. 7 Continued

OBLIQUE SHOCK
GAMMA=1.20



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- ⋈ 4.50
- x 5.00
- z 5.50
- Y 6.00
- x 7.00
- ⋈ 8.00
- x 9.00
- ⋈ 10.00
- 15.00

Fig. 7 Continued

OBLIQUE SHOCK
GAMMA=1.20

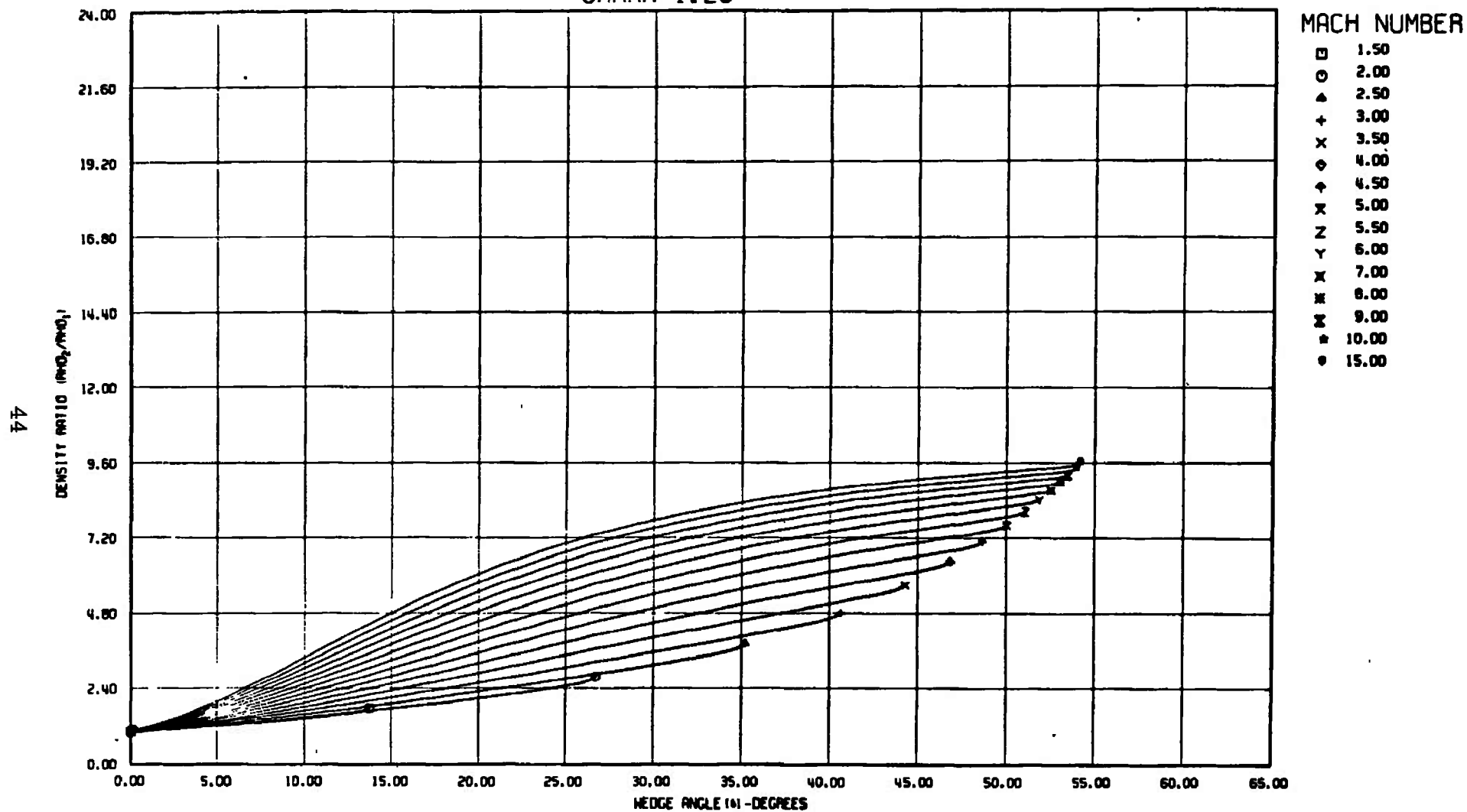


Fig. 7 Continued

OBLIQUE SHOCK
GAMMA=1.20

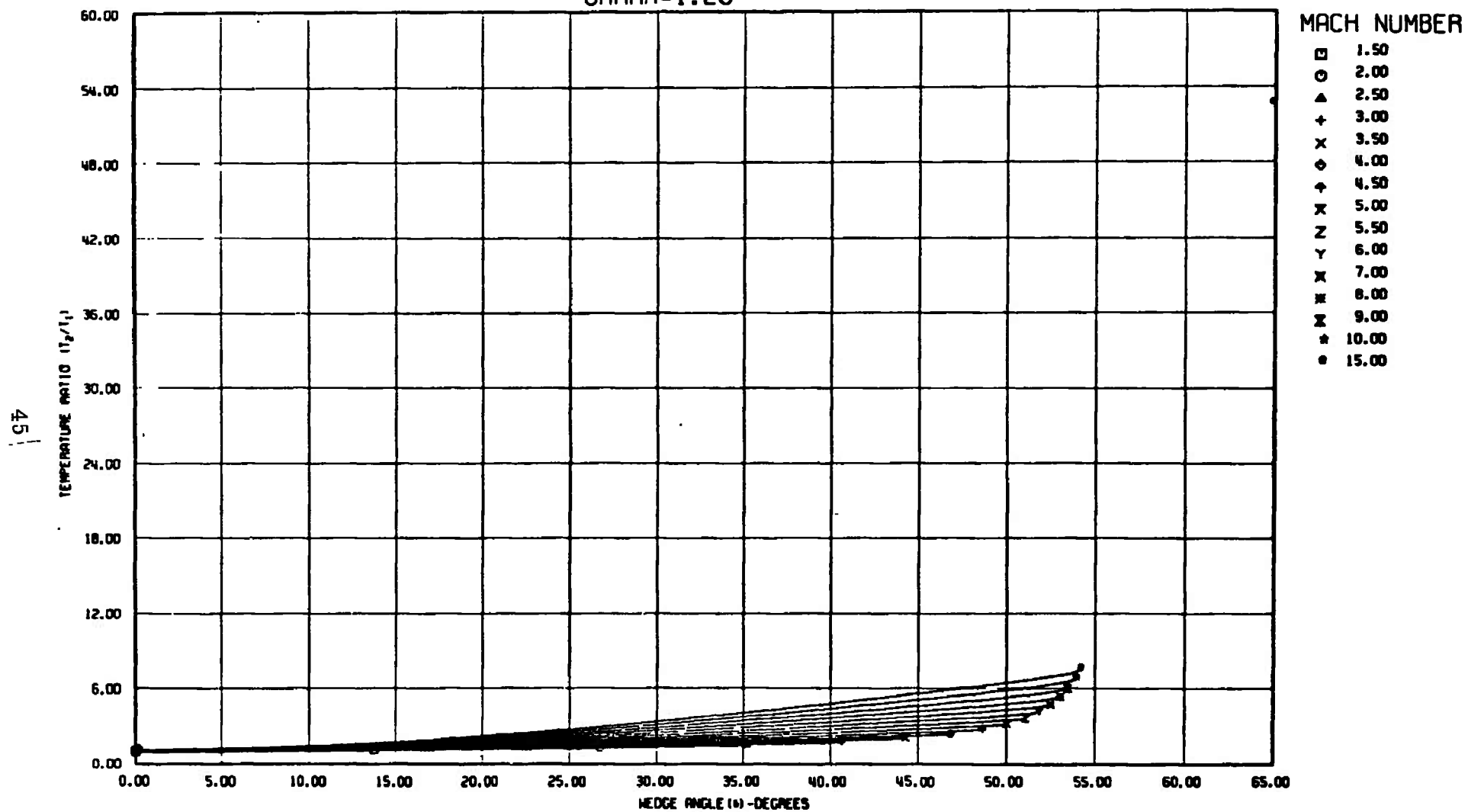


Fig. 7 Continued

OBLIQUE SHOCK
GAMMA=1.20

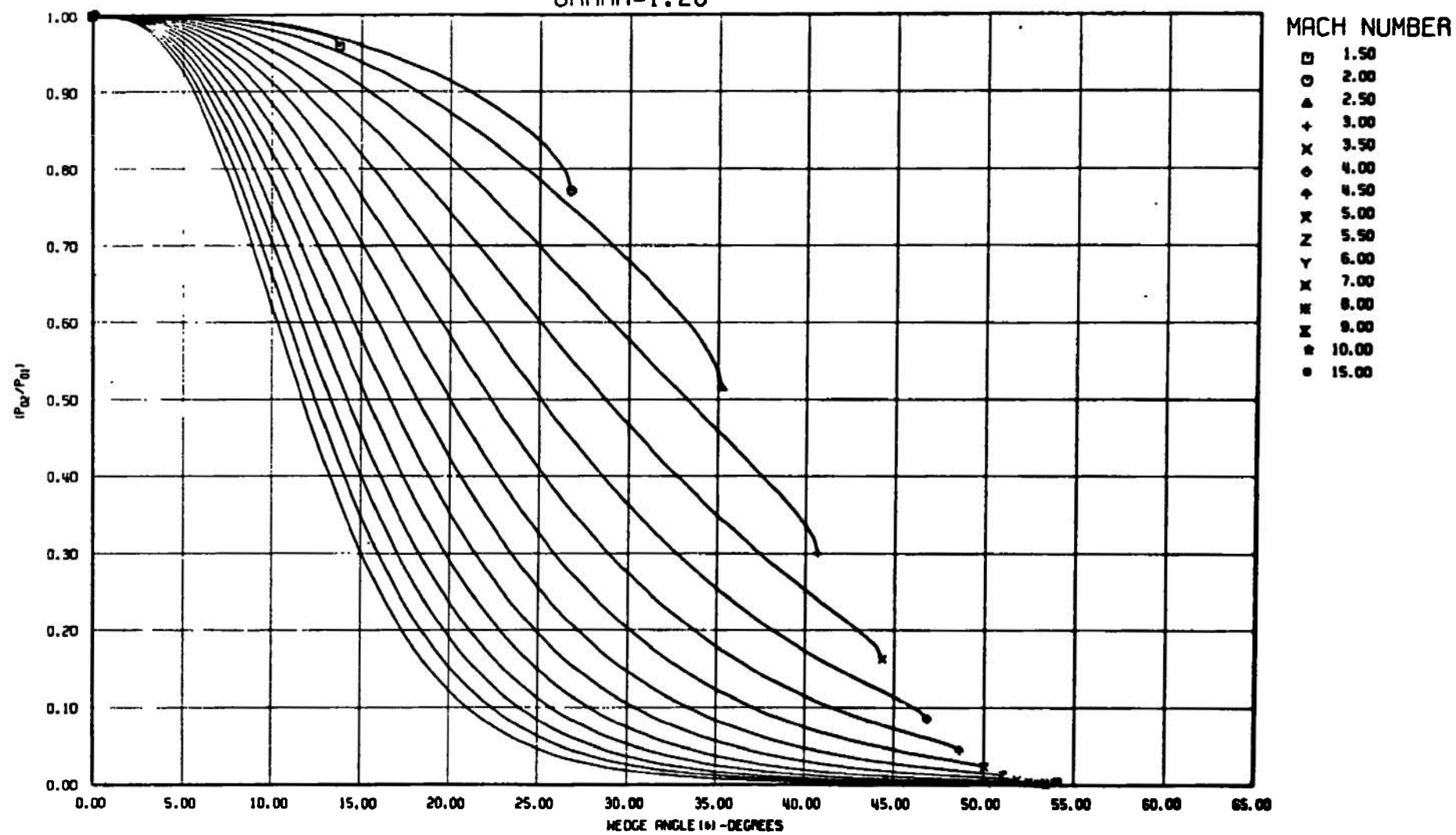
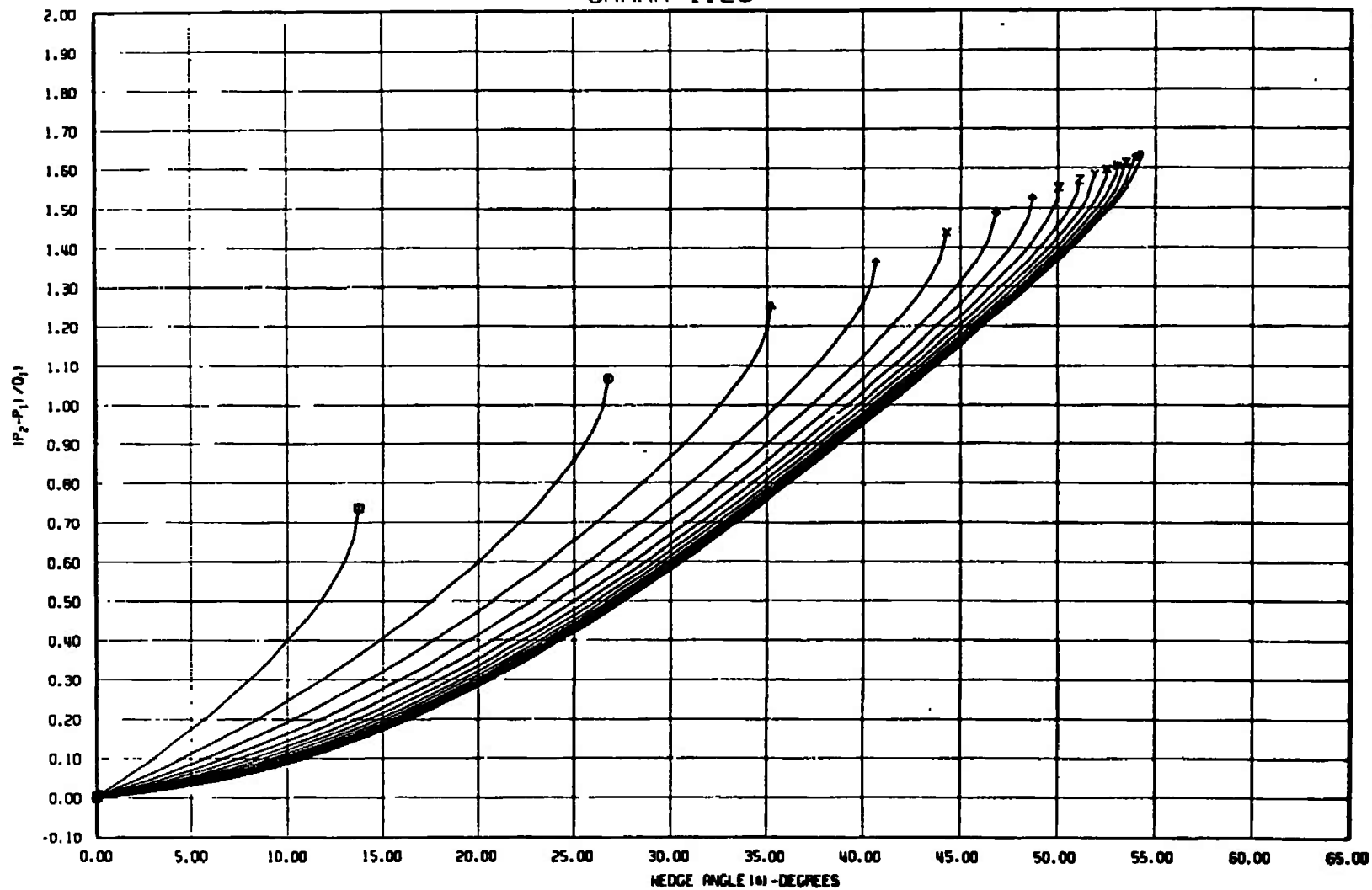


Fig. 7 Continued

OBLIQUE SHOCK GAMMA=1.20



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- ⋈ 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- x 8.00
- x 9.00
- * 10.00
- 15.00

Fig. 7 Concluded

OBLIQUE SHOCK GAMMA=1.22

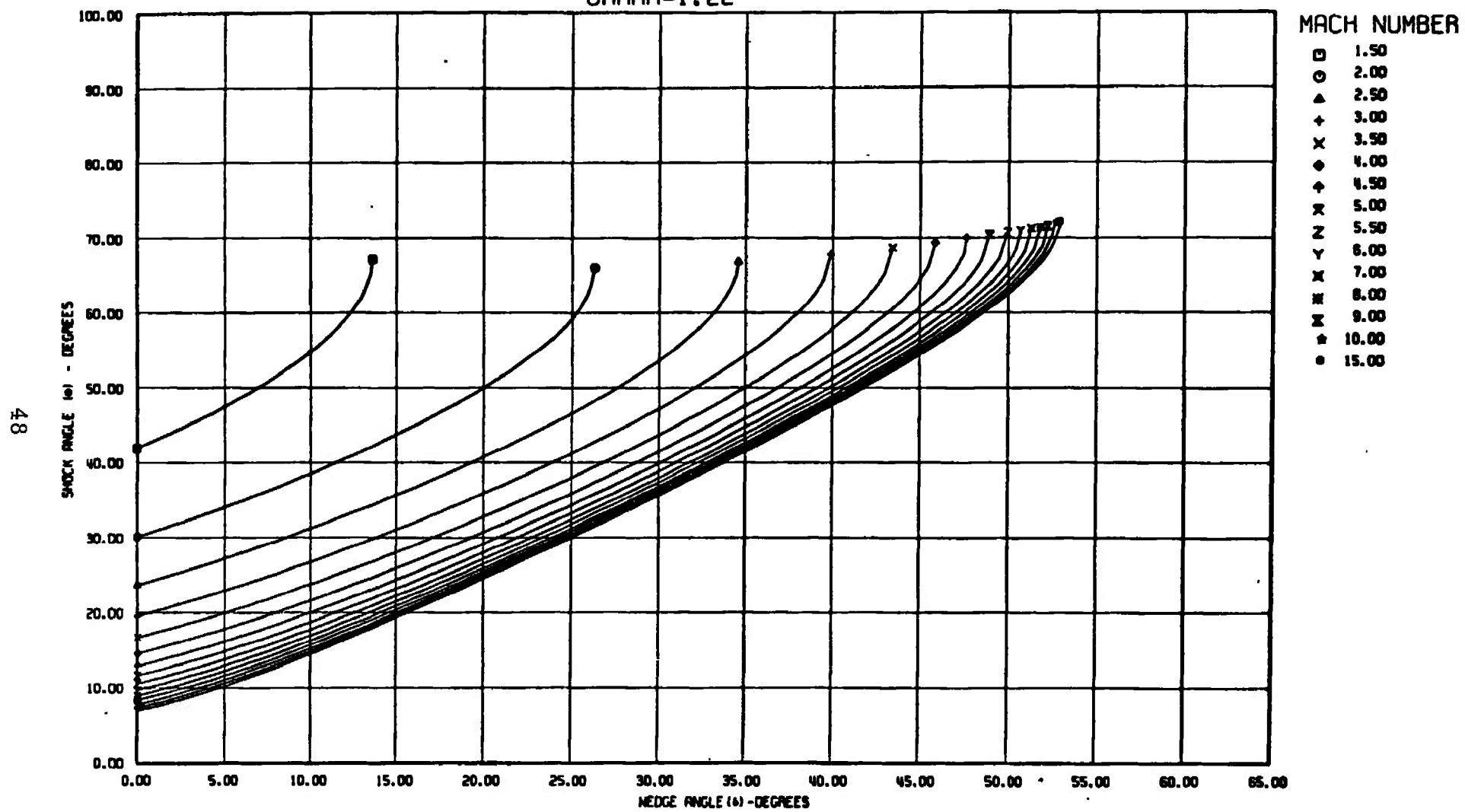


Fig. 8 $\gamma = 1.22$

OBLIQUE SHOCK GAMMA=1.22

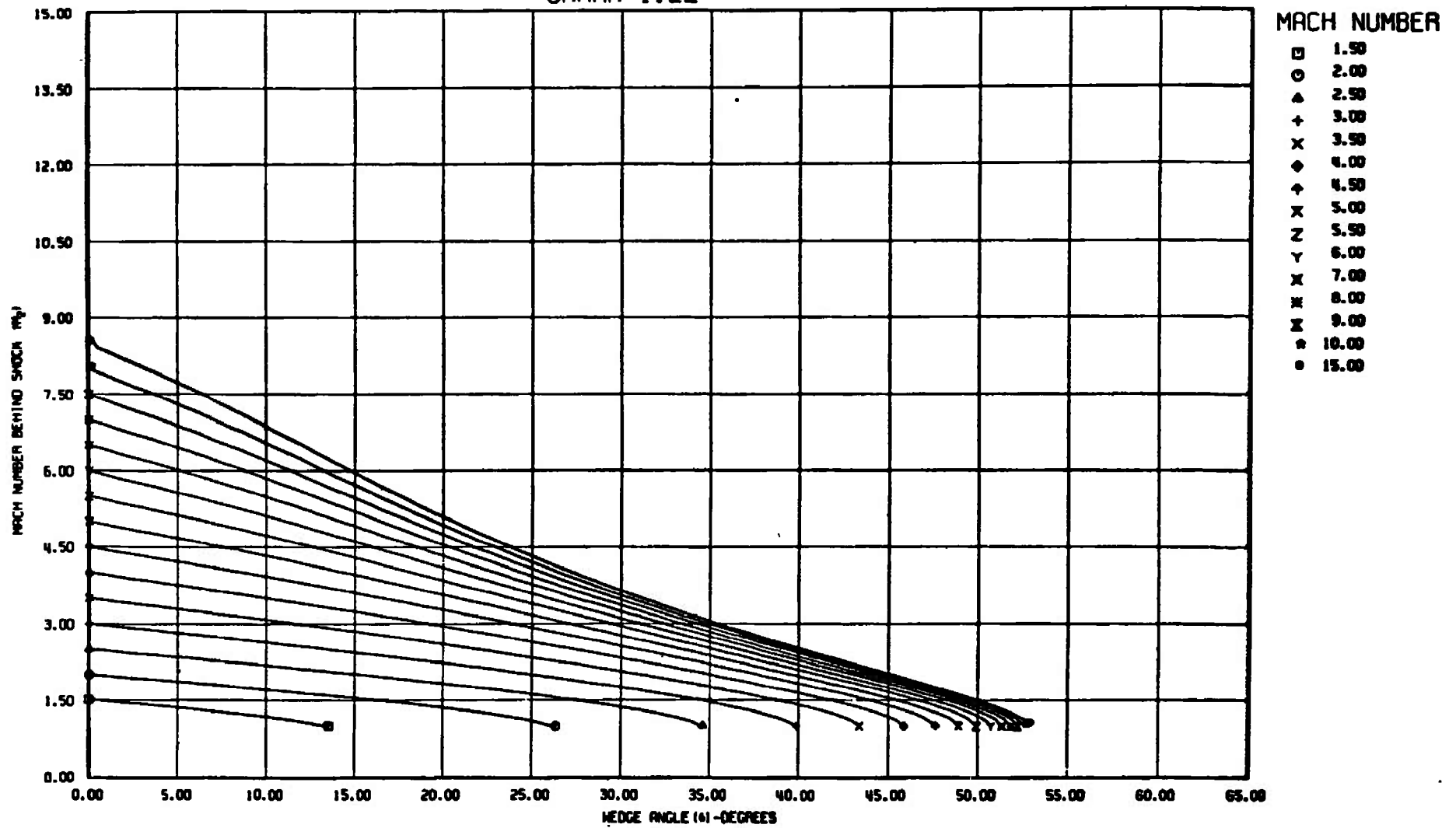


Fig. 8 Continued

OBLIQUE SHOCK
GAMMA=1.22

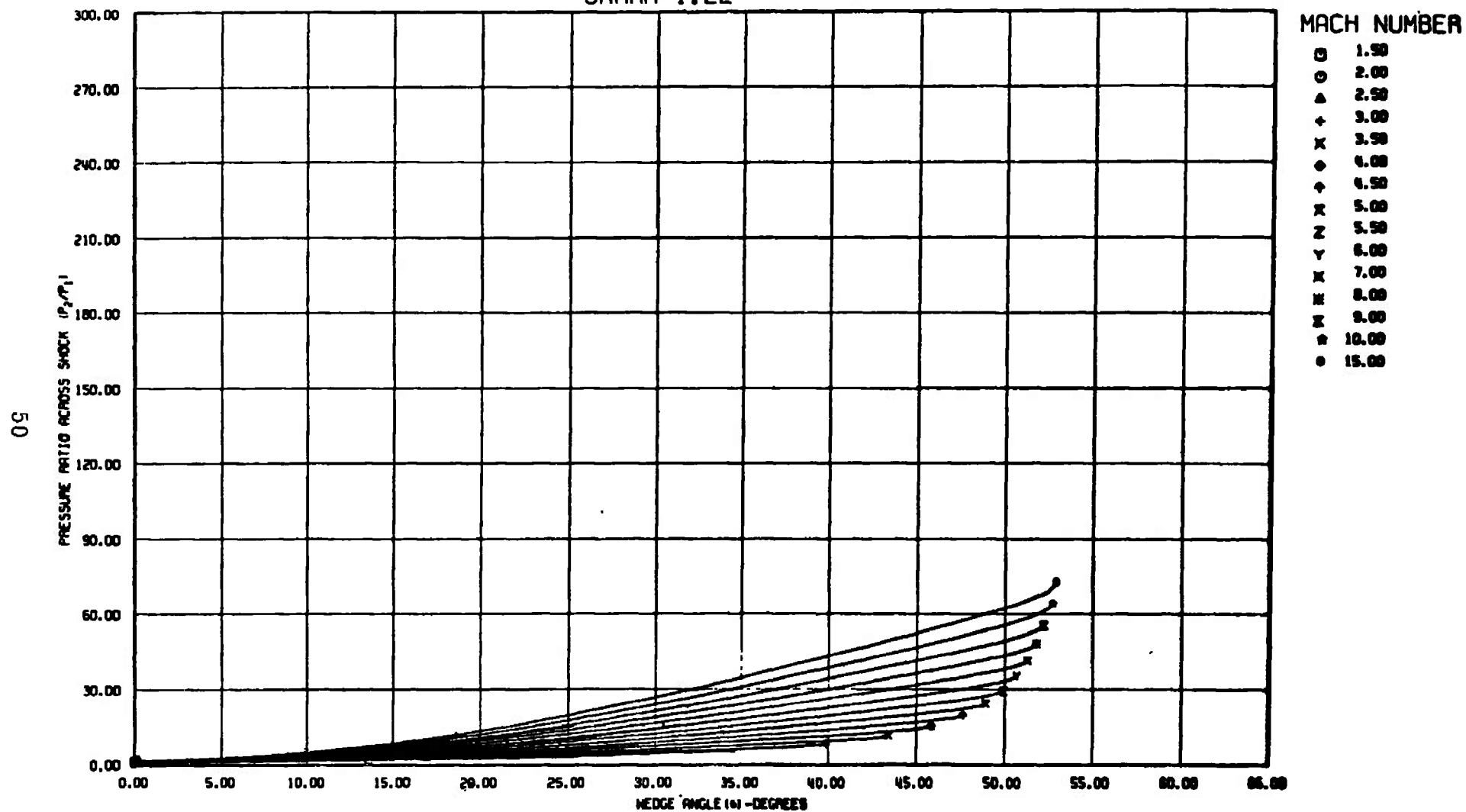
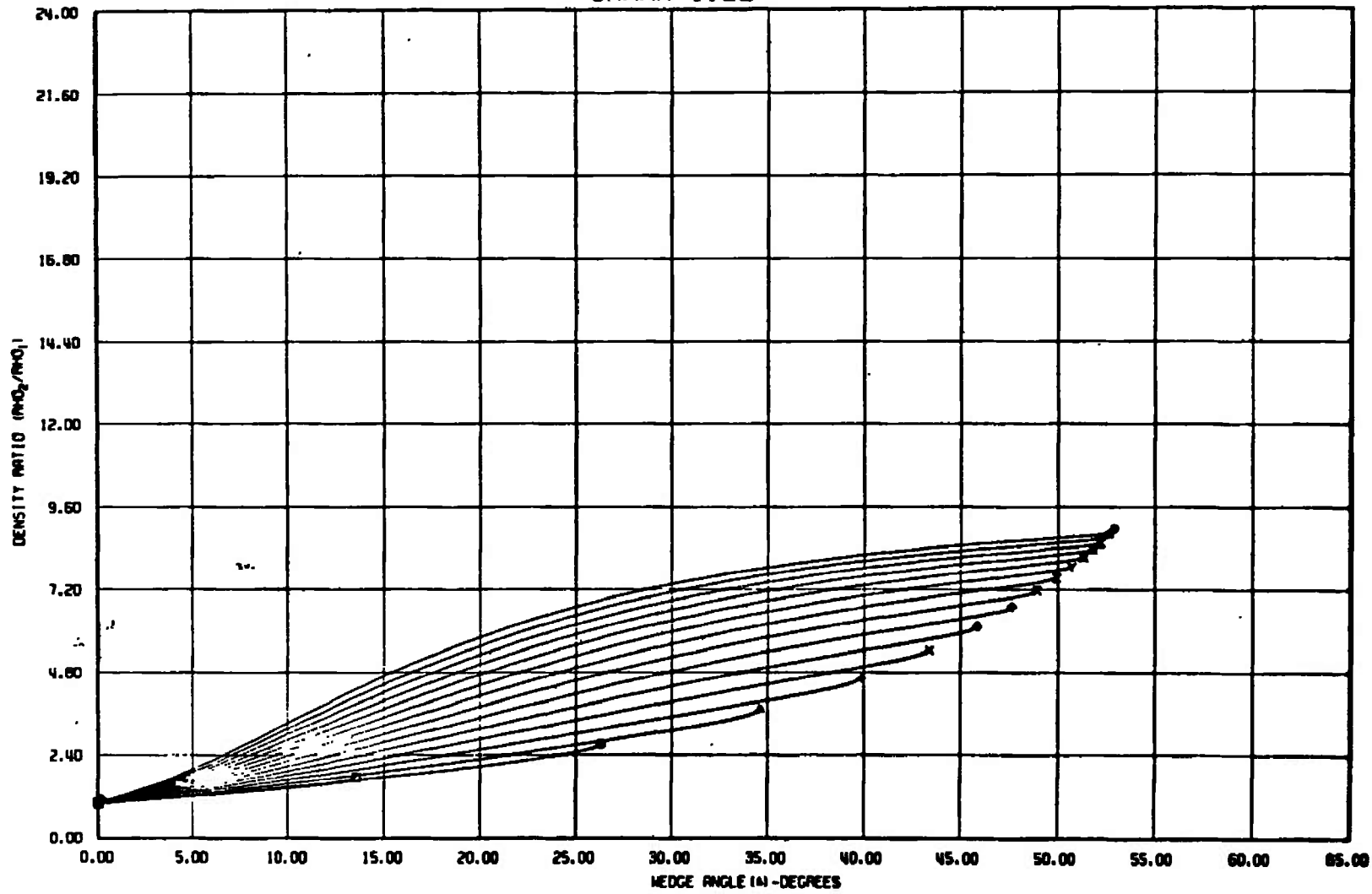


Fig. 8 Continued

OBLIQUE SHOCK GAMMA=1.22



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◆ 4.00
- ⋈ 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- ≡ 8.00
- x 9.00
- 10.00
- 15.00

Fig. 8 Continued

OBLIQUE SHOCK GAMMA=1.22

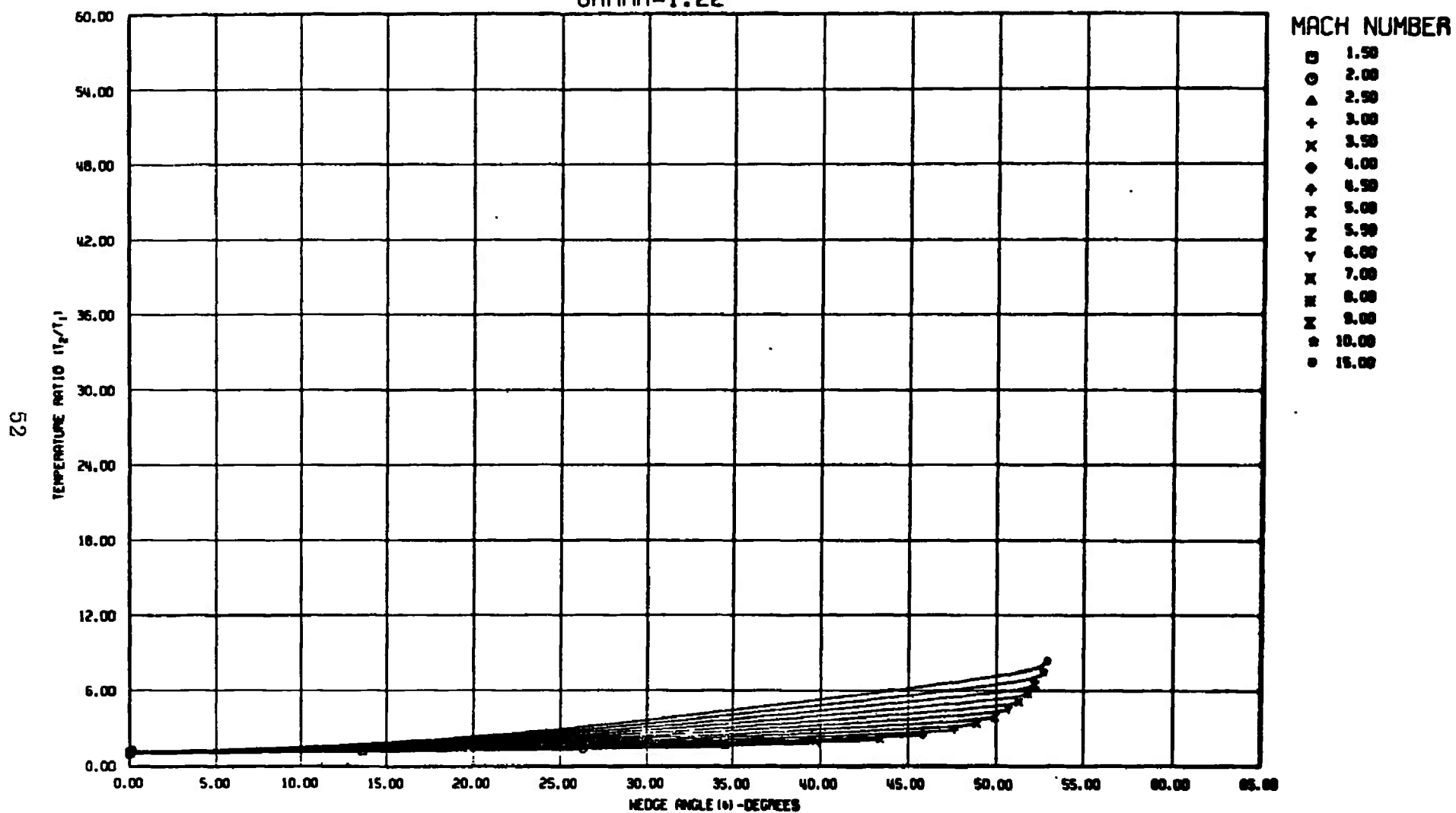


Fig. 8 Continued

OBLIQUE SHOCK
GAMMA=1.22

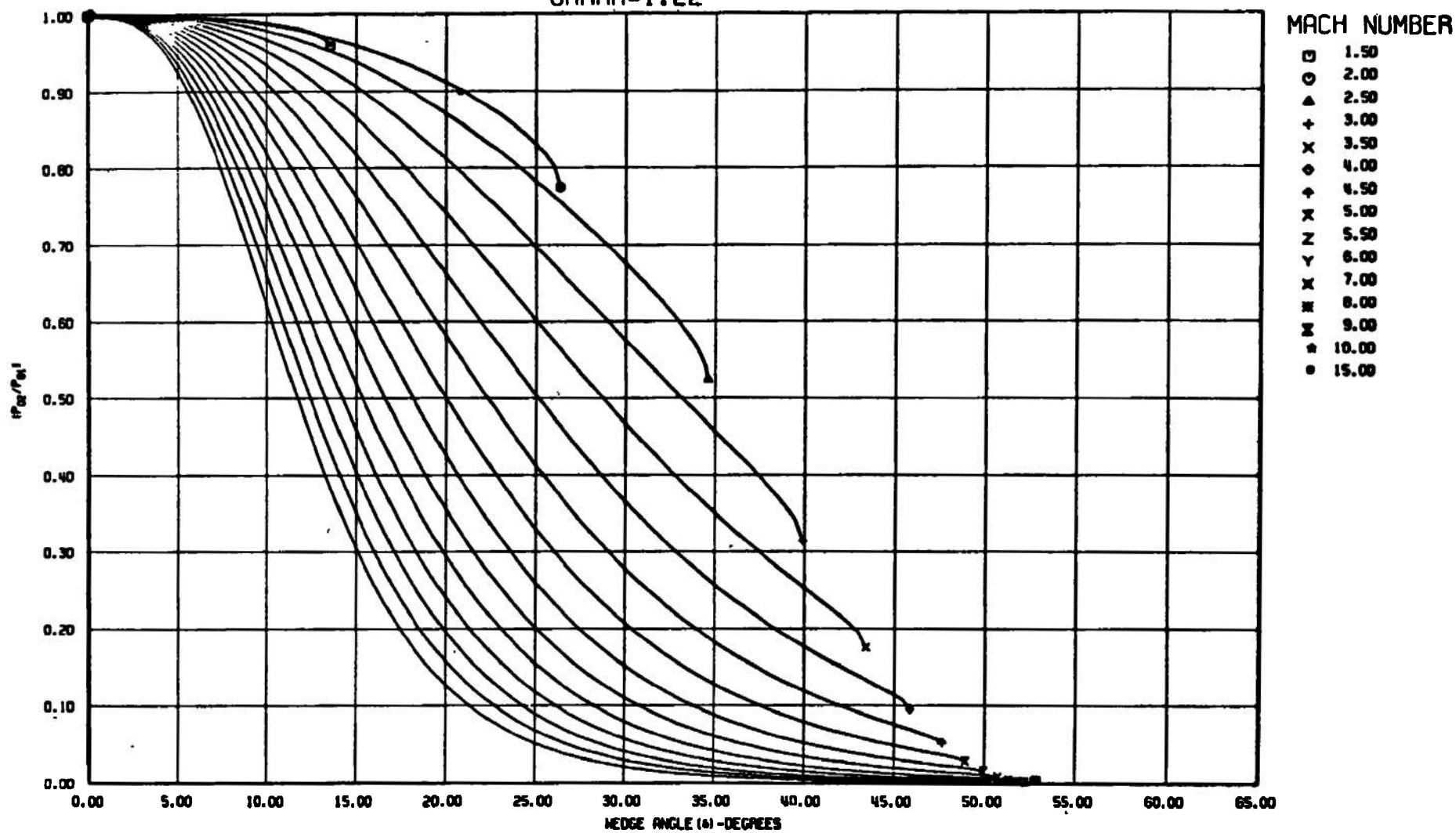


Fig. 8 Continued

OBLIQUE SHOCK GAMMA=1.22

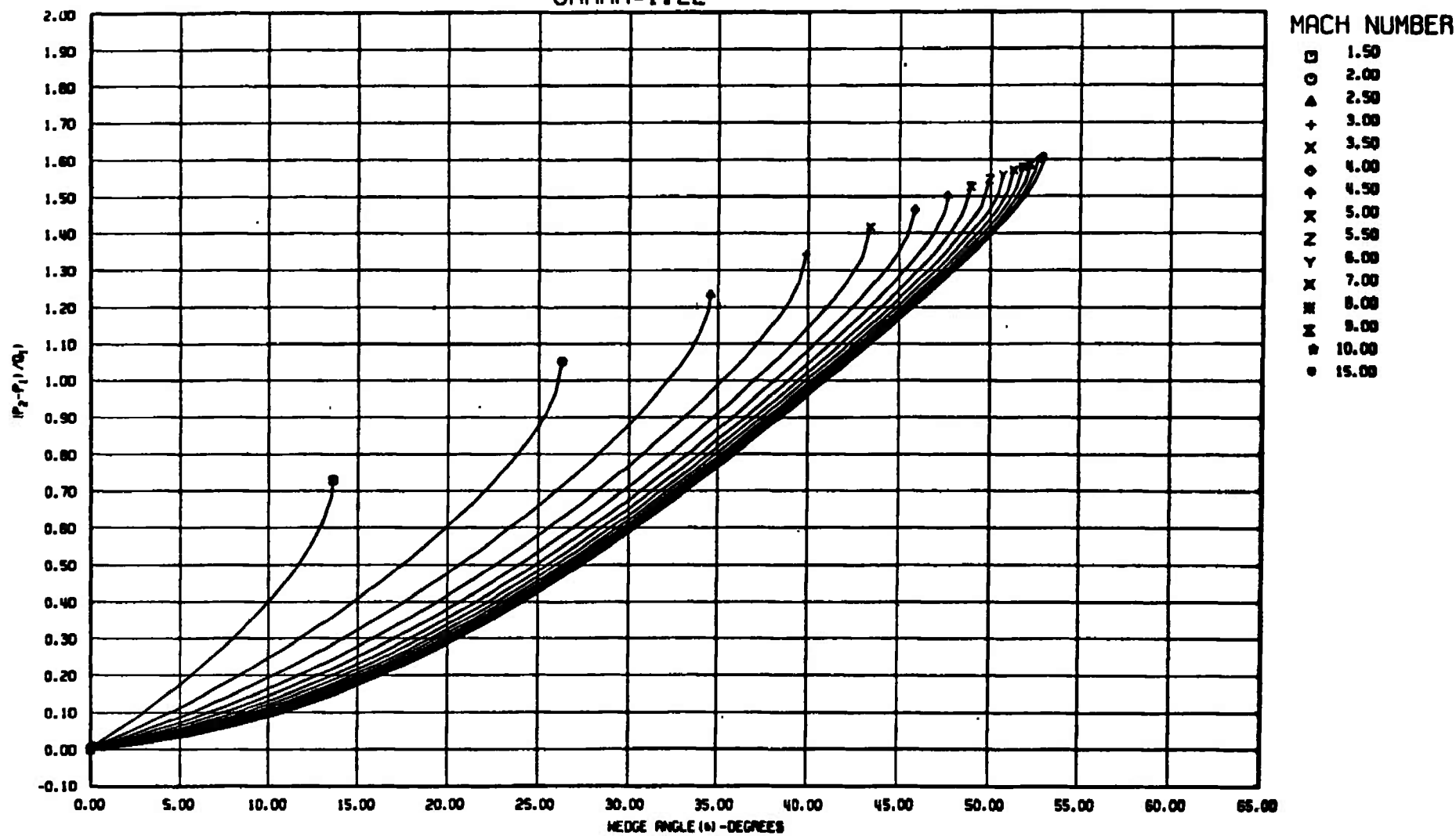


Fig. 8 Concluded

OBLIQUE SHOCK $\gamma = 1.24$

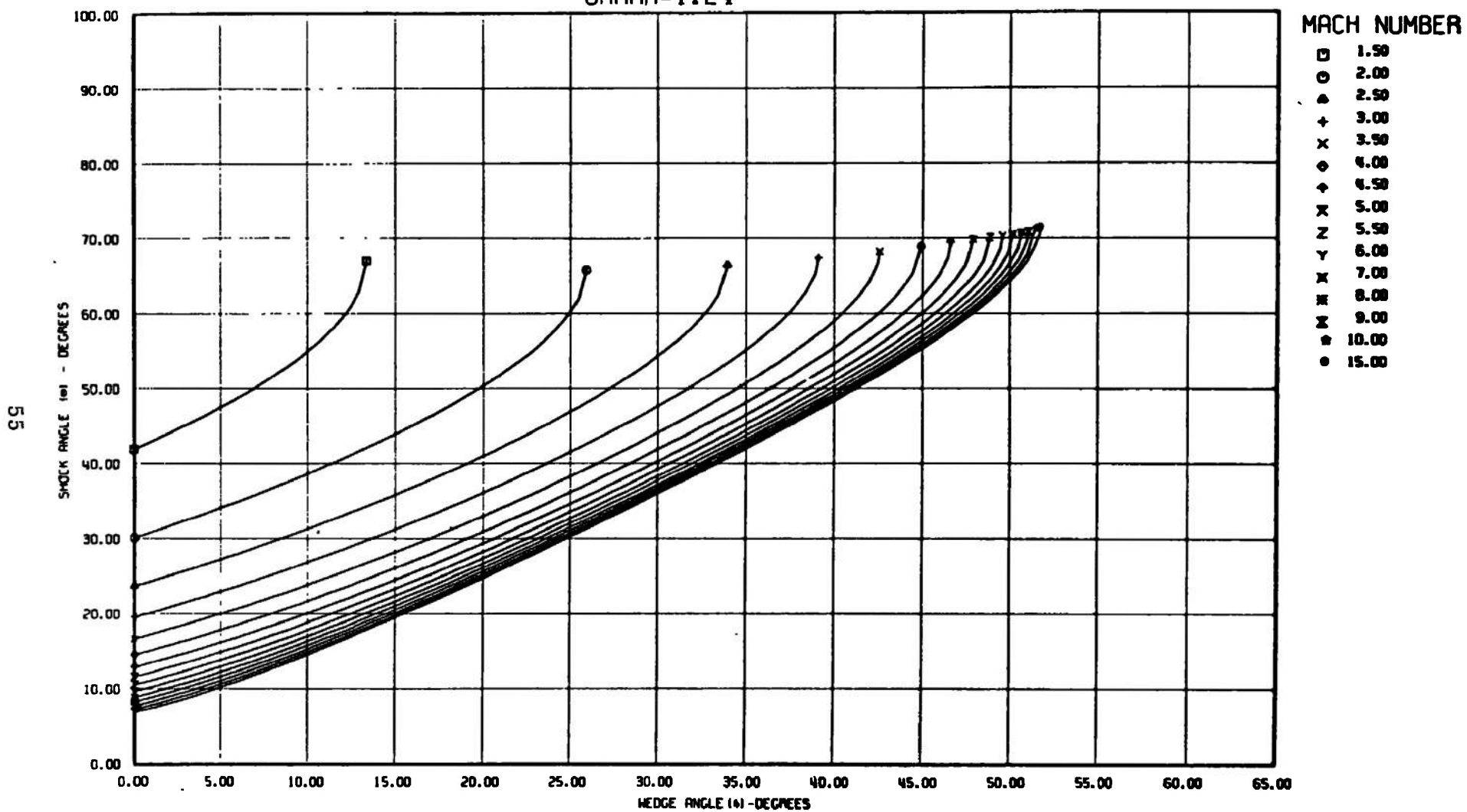


Fig. 9 $\gamma = 1.24$

OBLIQUE SHOCK GAMMA=1.24

56

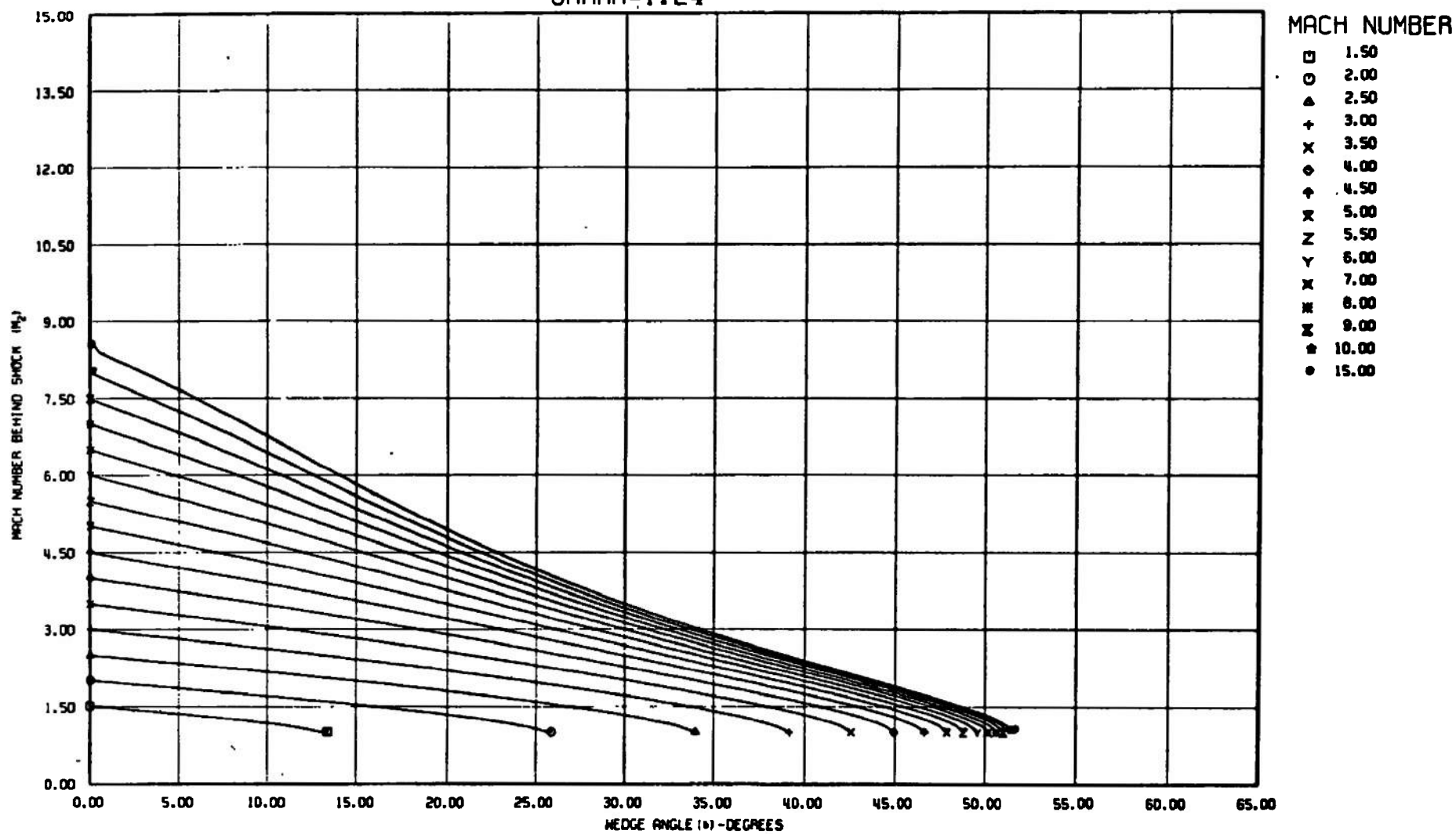


Fig. 9 Continued

OBLIQUE SHOCK GAMMA=1.24

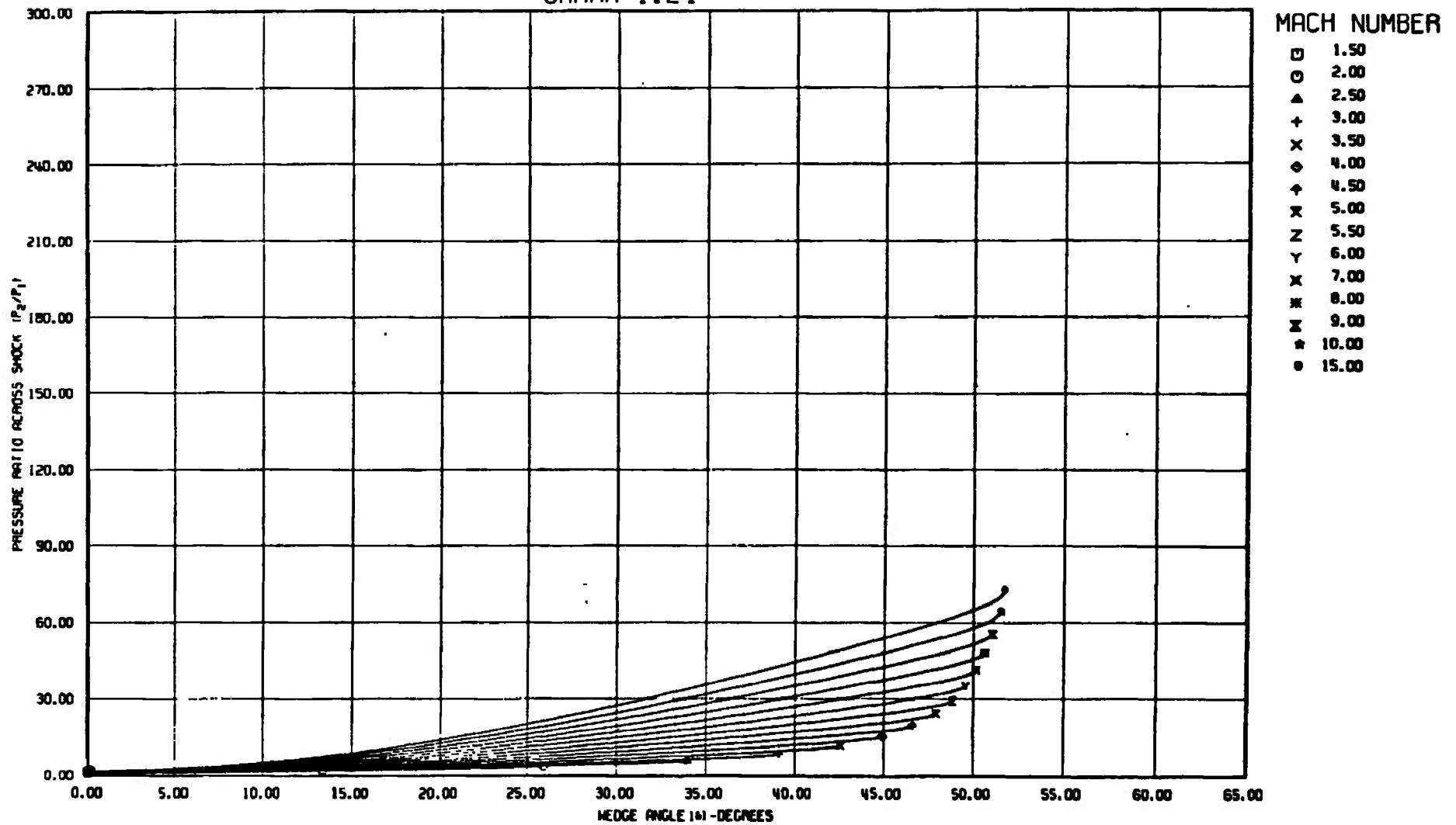


Fig. 9 Continued

OBLIQUE SHOCK
GAMMA=1.24

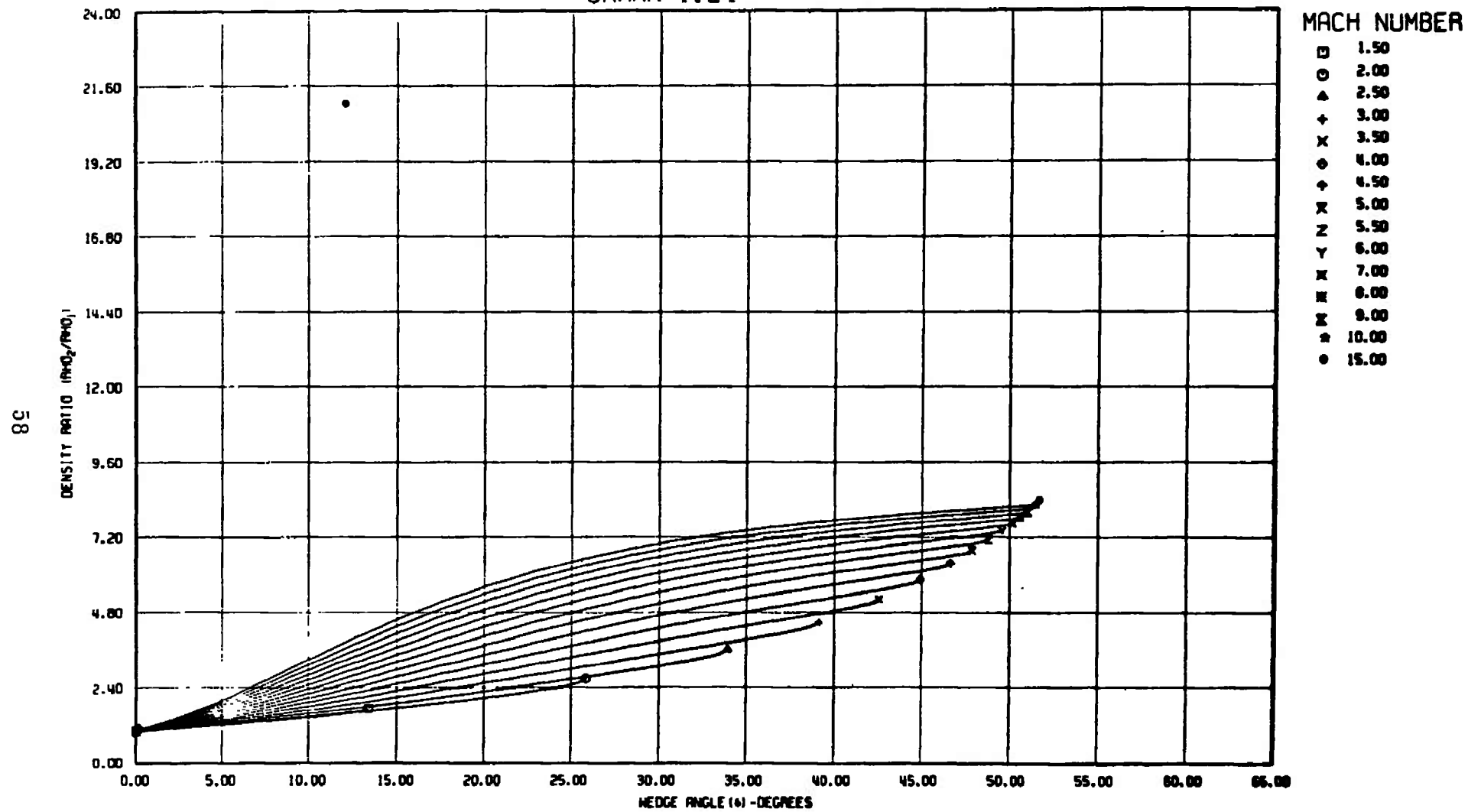


Fig. 9 Continued

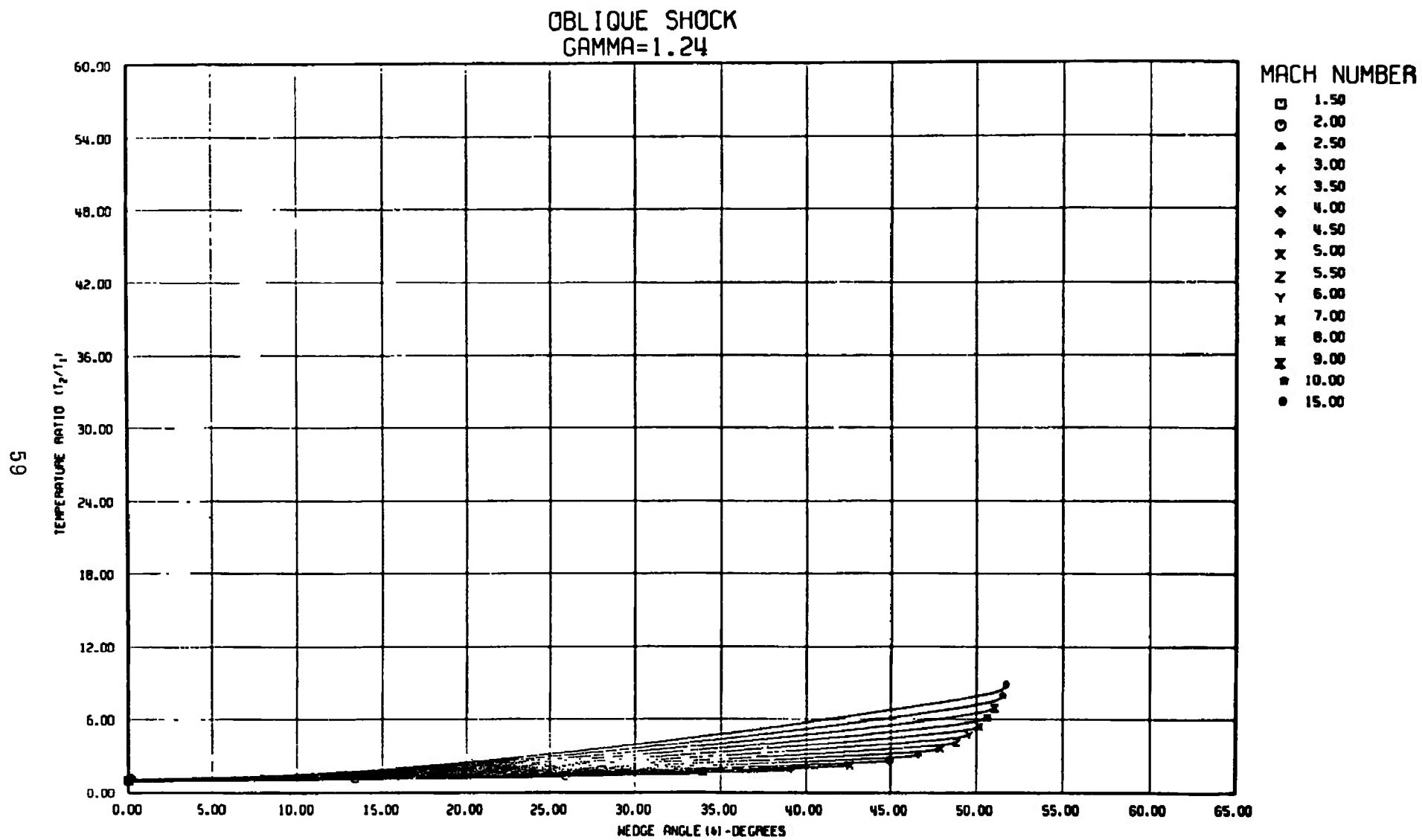


Fig. 9 Continued

OBLIQUE SHOCK GAMMA=1.24

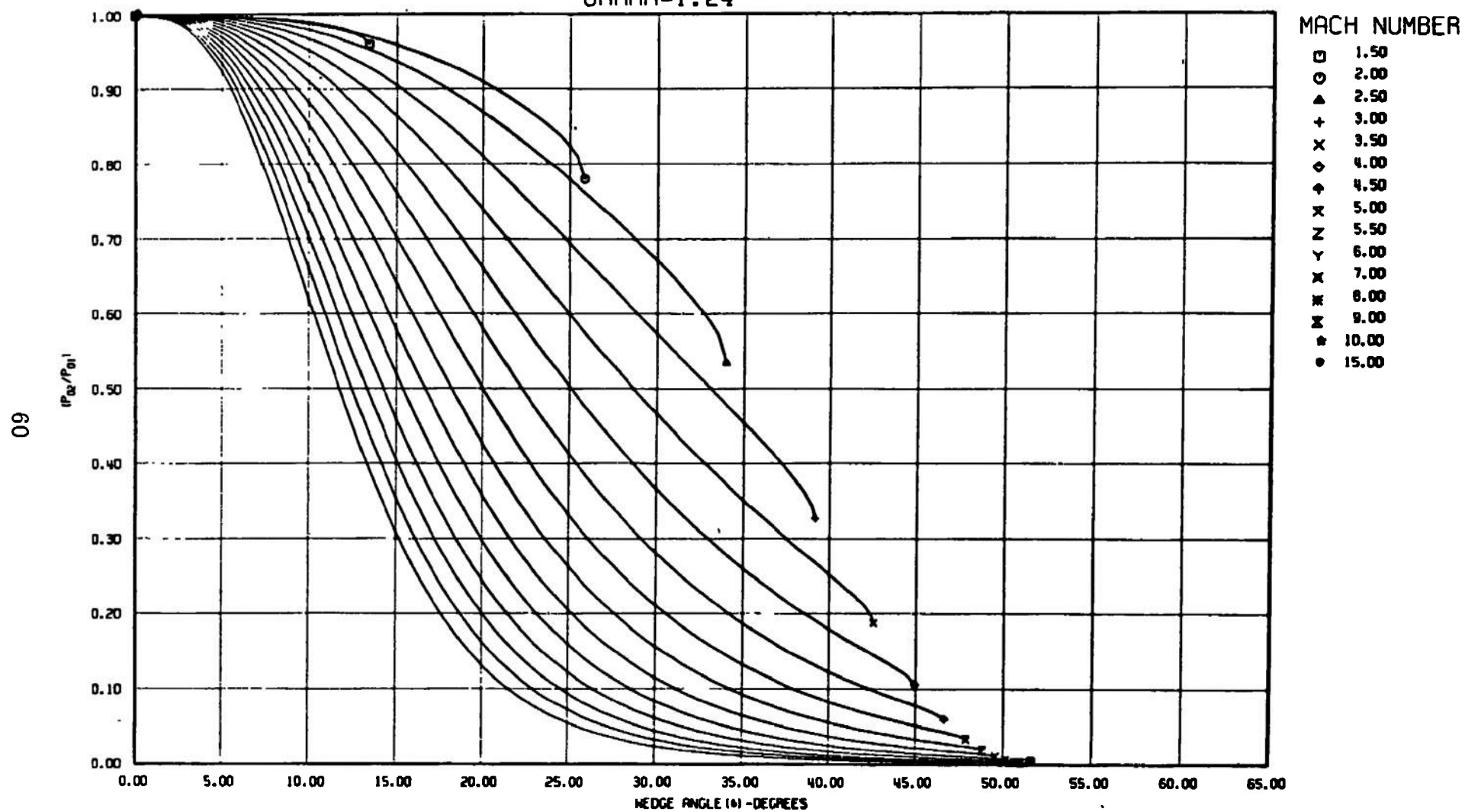


Fig. 9 Continued

OBLIQUE SHOCK GAMMA=1.24

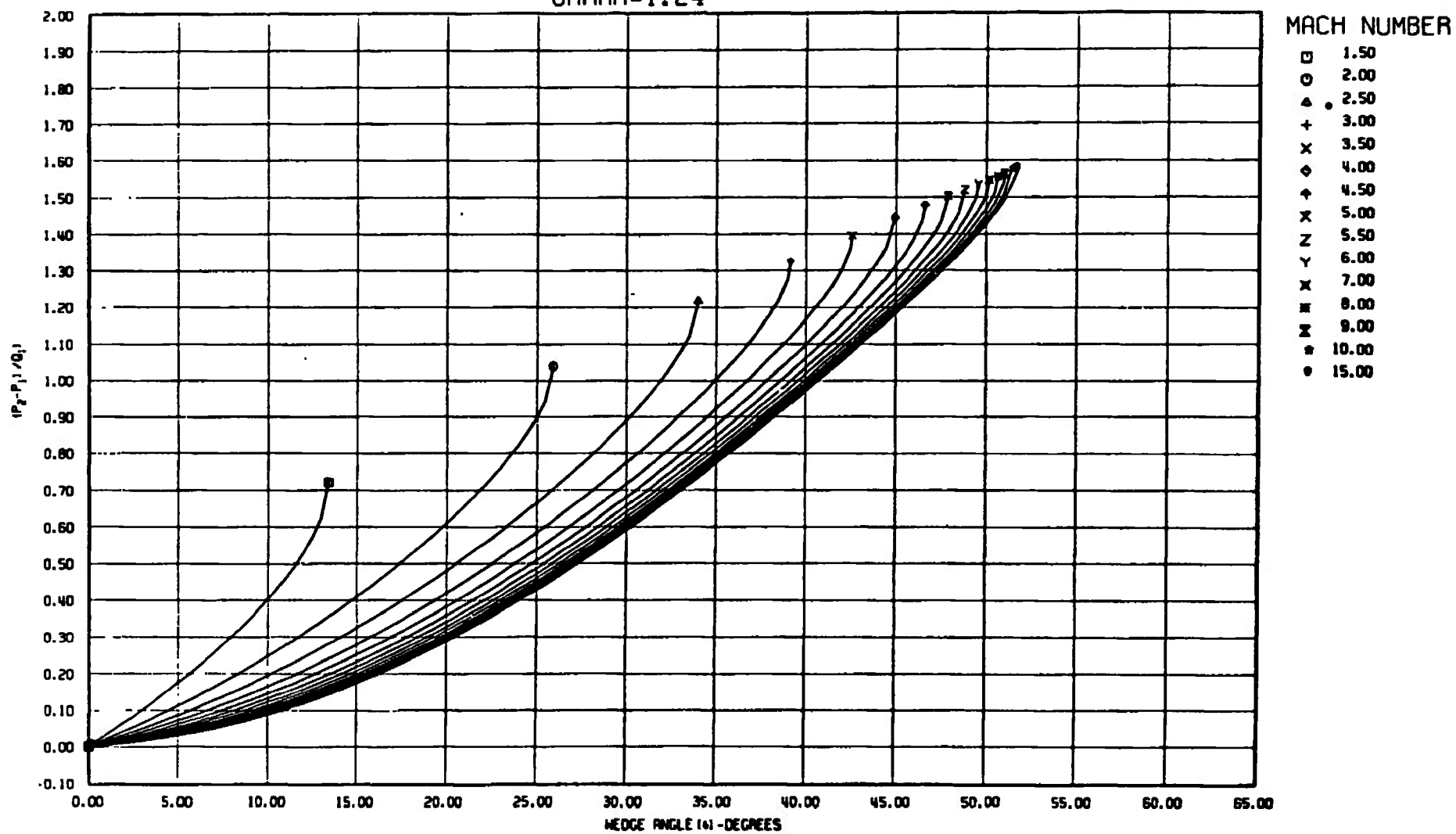


Fig. 9 Concluded

OBLIQUE SHOCK GAMMA=1.26

62

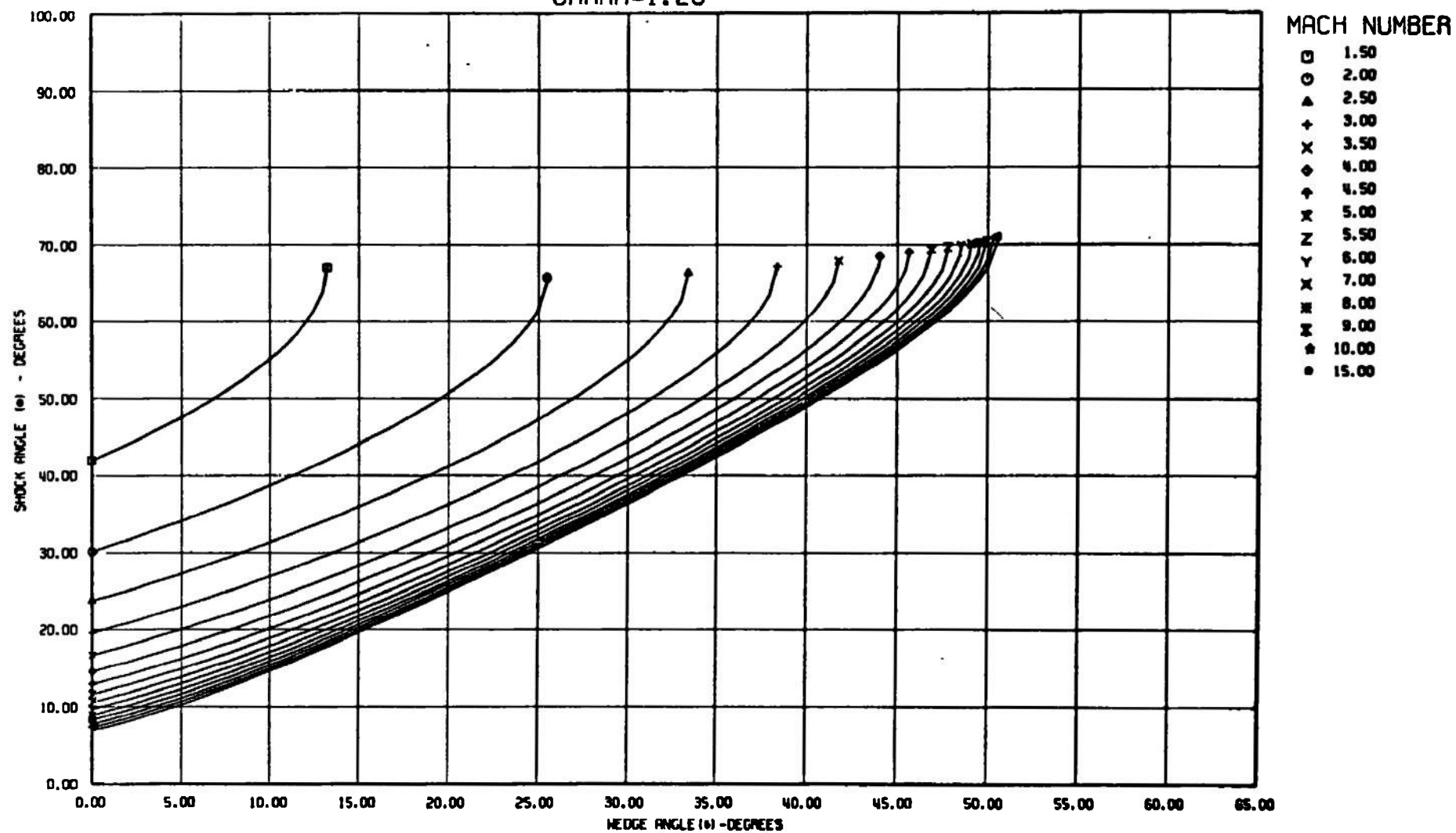


Fig. 10 $\gamma = 1.26$

OBLIQUE SHOCK GAMMA=1.26

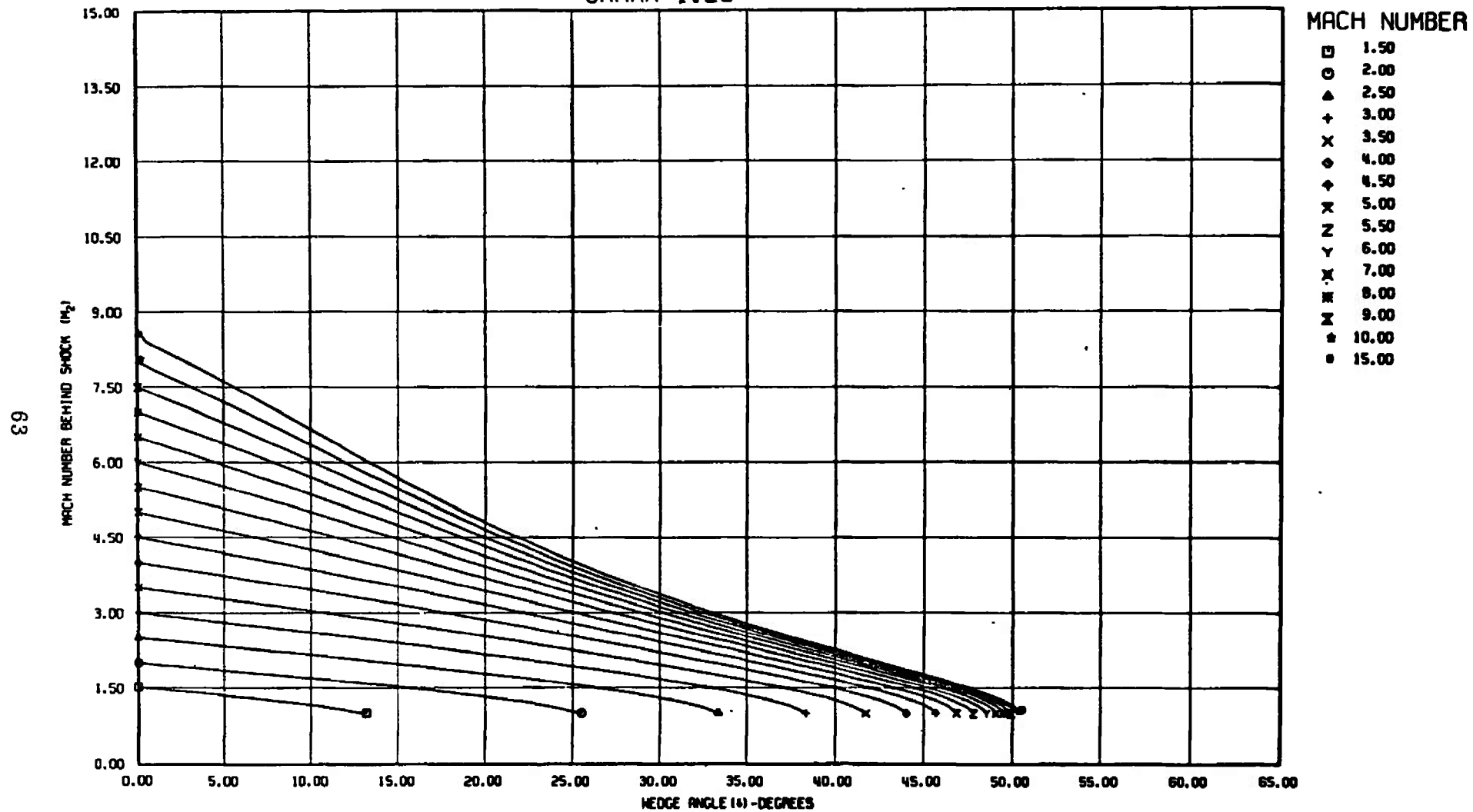


Fig. 10 Continued

OBLIQUE SHOCK GAMMA=1.26

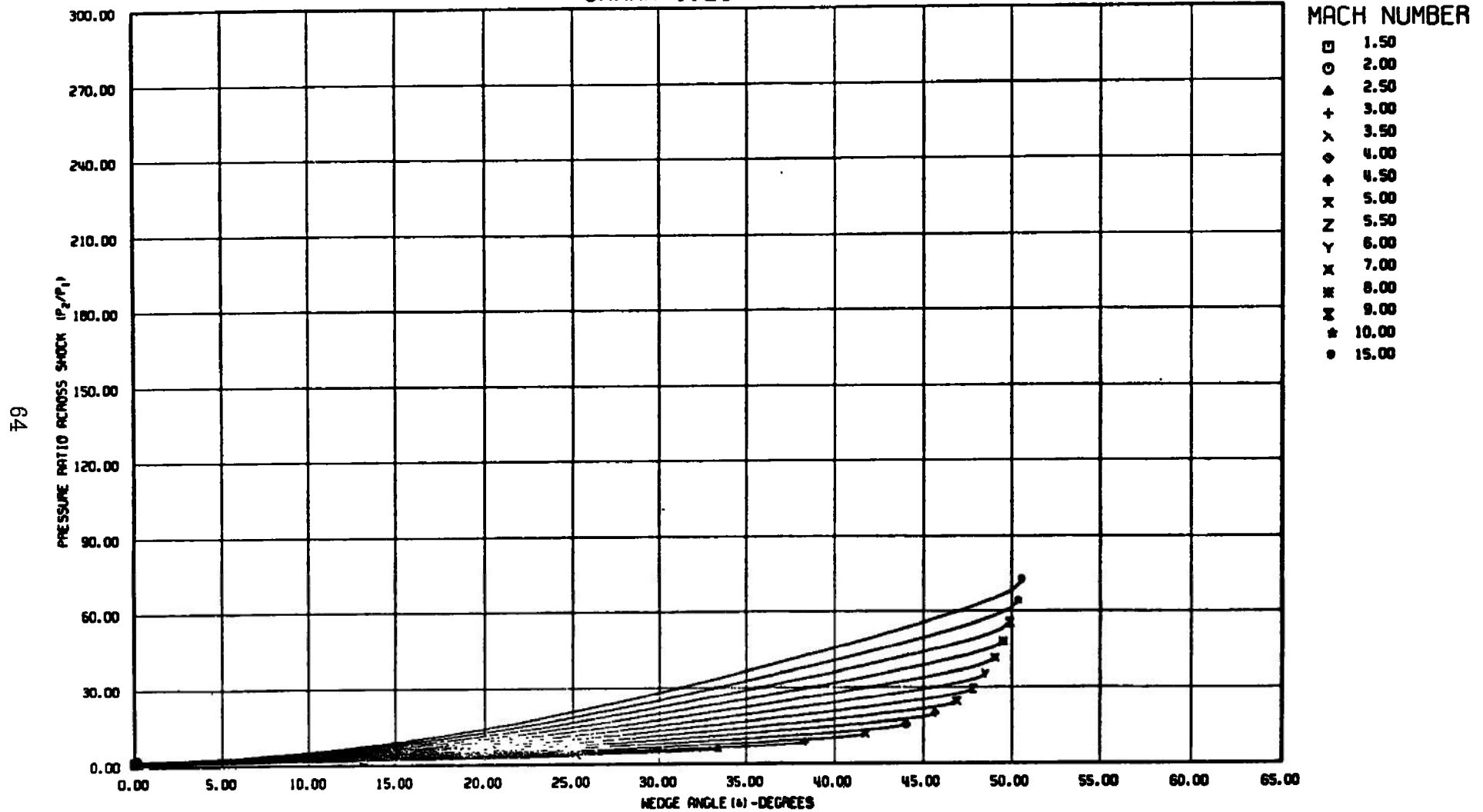


Fig. 10 Continued

OBLIQUE SHOCK
 $\gamma = 1.26$

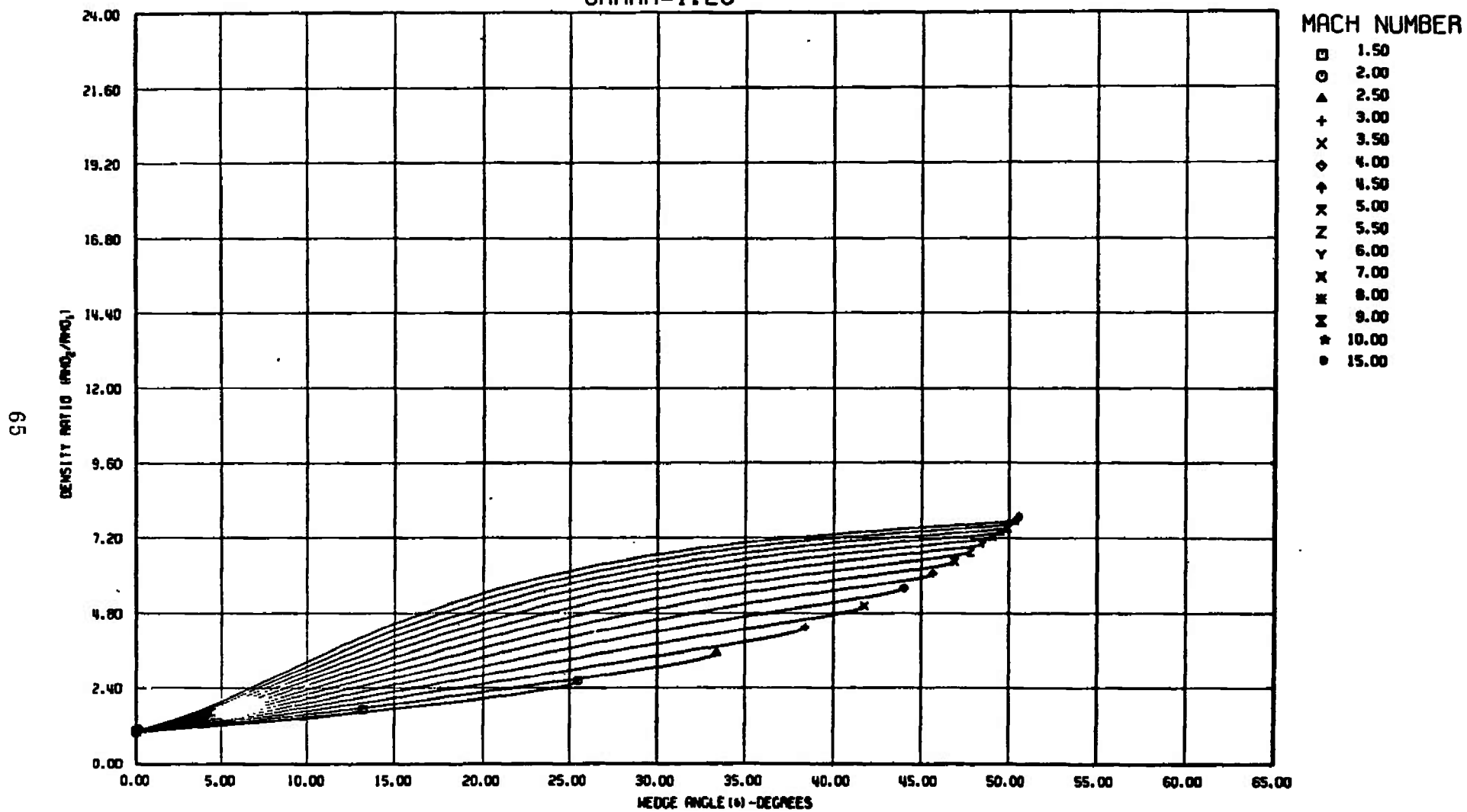


Fig. 10 Continued

OBLIQUE SHOCK
GAMMA=1.26

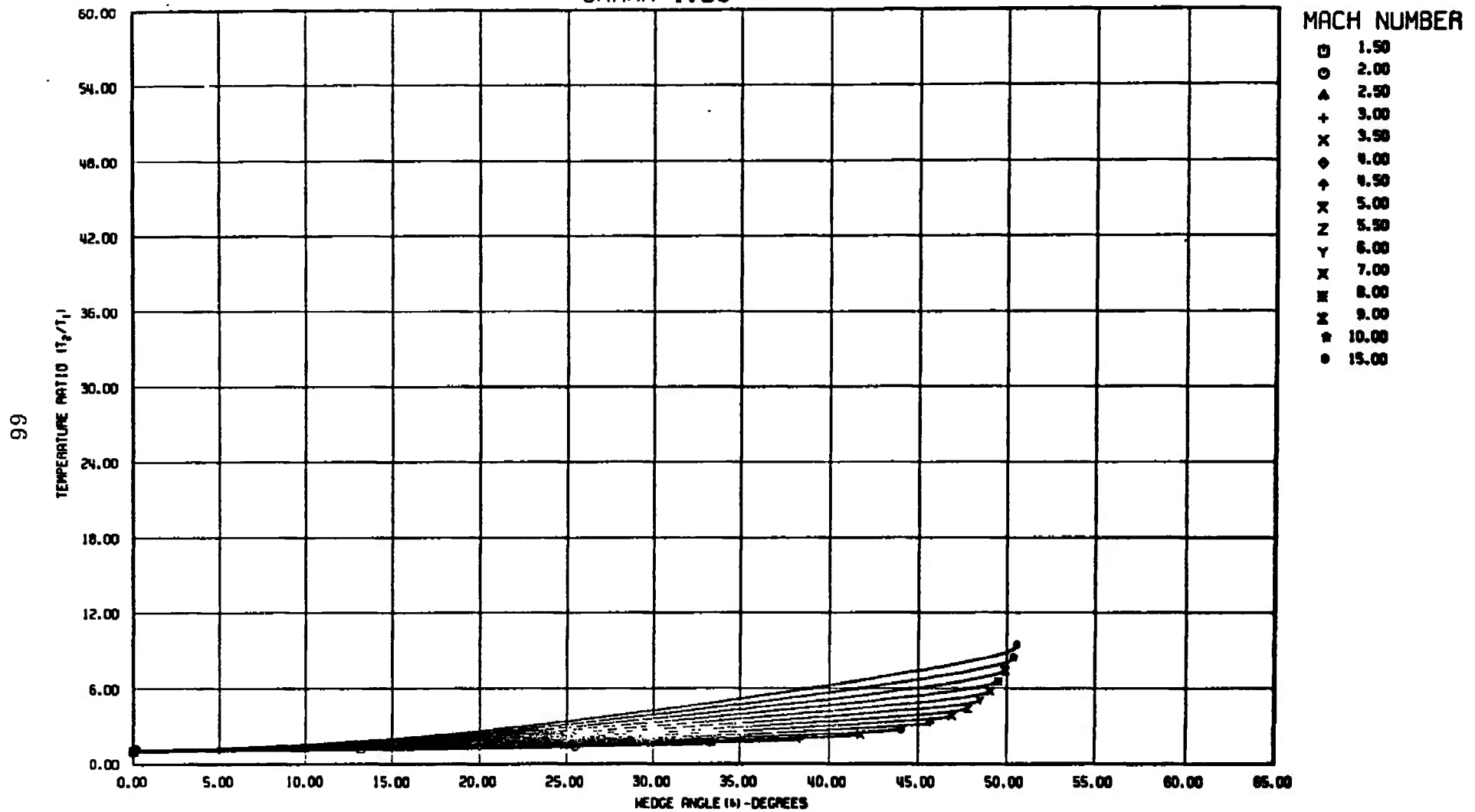
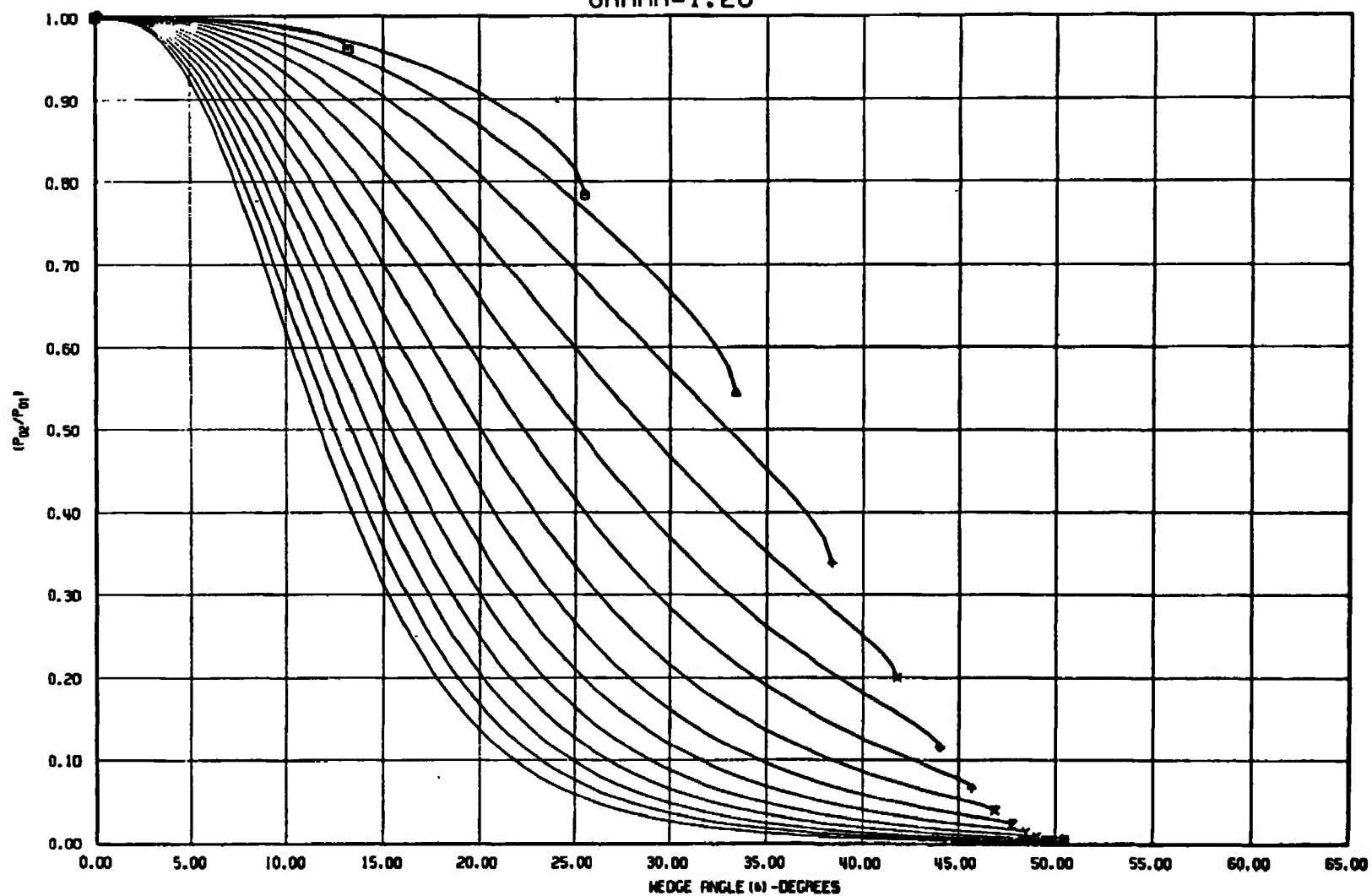


Fig. 10 Continued

OBLIQUE SHOCK
GAMMA=1.26



MACH NUMBER

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- 2.00
- △ 2.50
- +
- x 3.50
- ◊ 4.00
- + 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- ≡ 8.00
- x 9.00
- ★ 10.00
- 15.00

Fig. 10 Continued

OBLIQUE SHOCK GAMMA=1.26

88

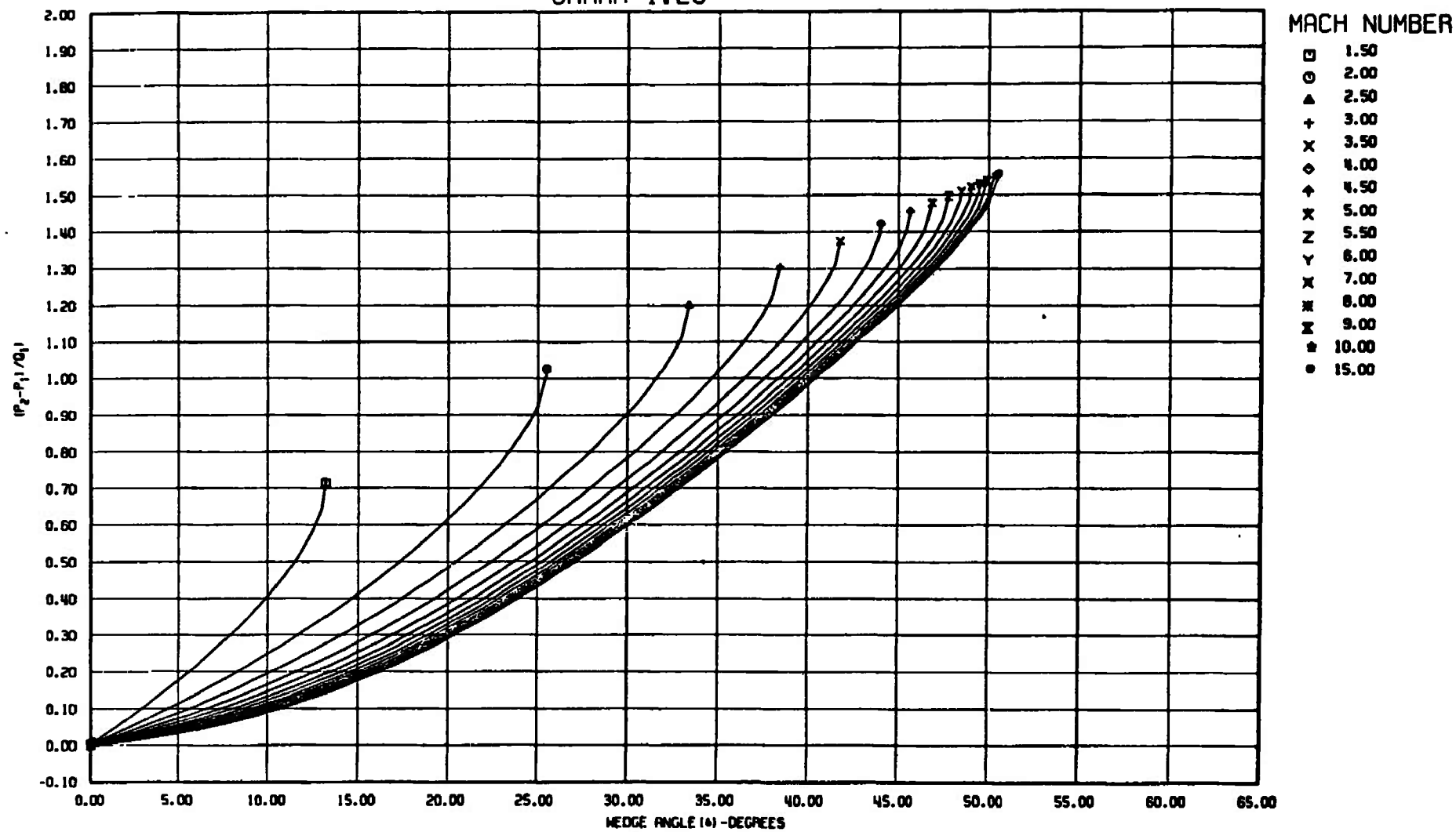


Fig. 10 Concluded

OBLIQUE SHOCK GAMMA=1.28

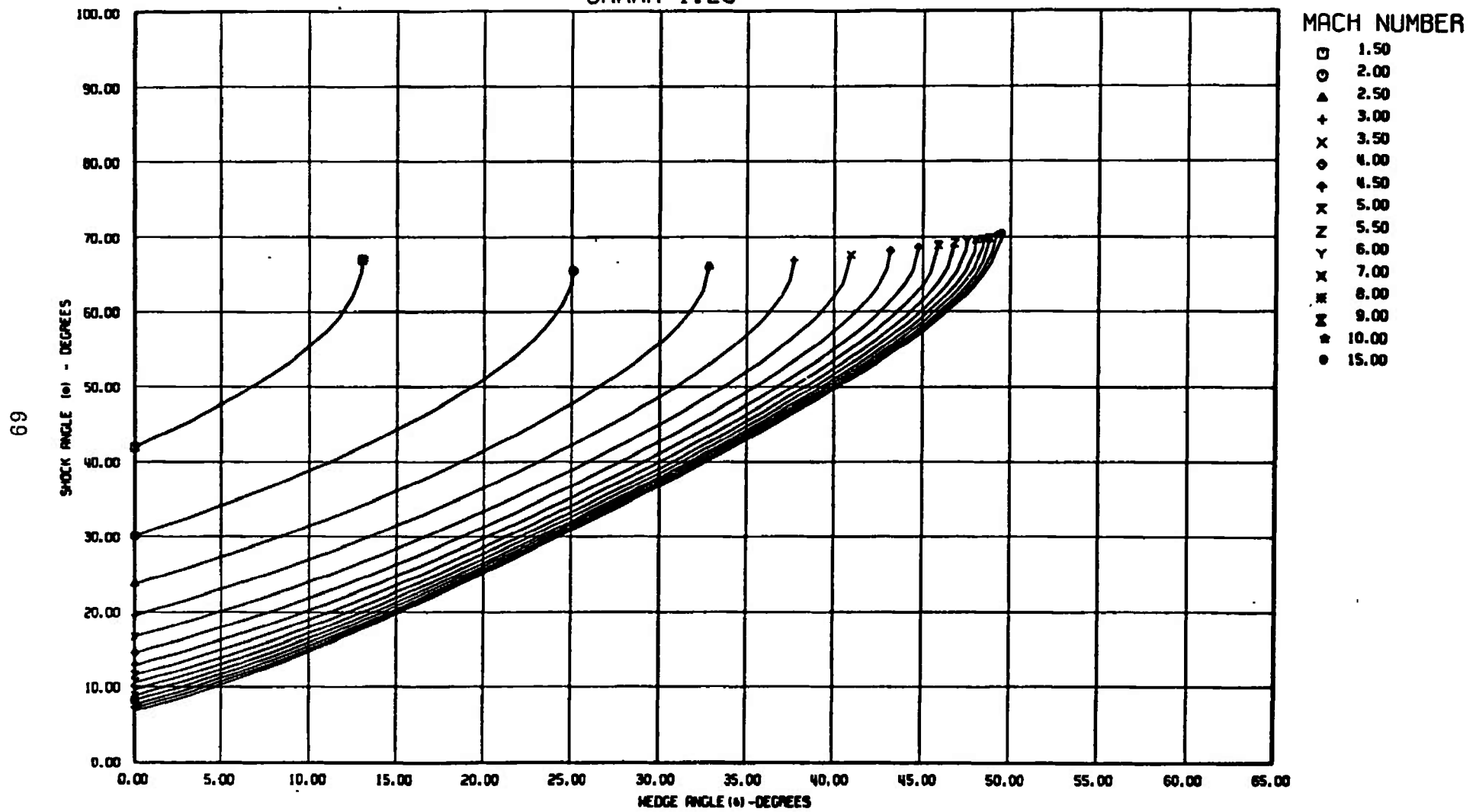


Fig. 11 $\gamma = 1.28$

OBLIQUE SHOCK GAMMA=1.28

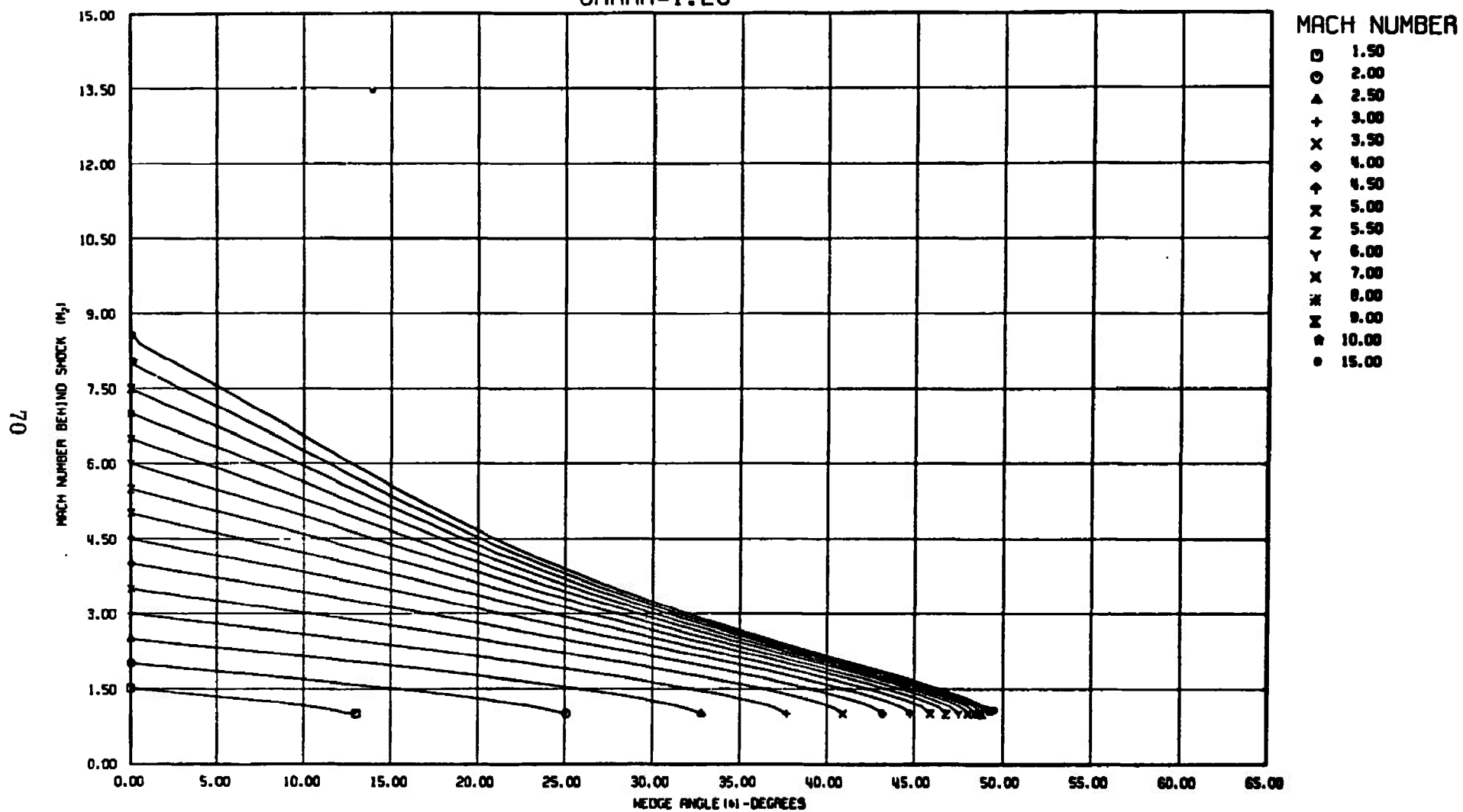


Fig. 11 Continued

OBLIQUE SHOCK
GAMMA=1.28

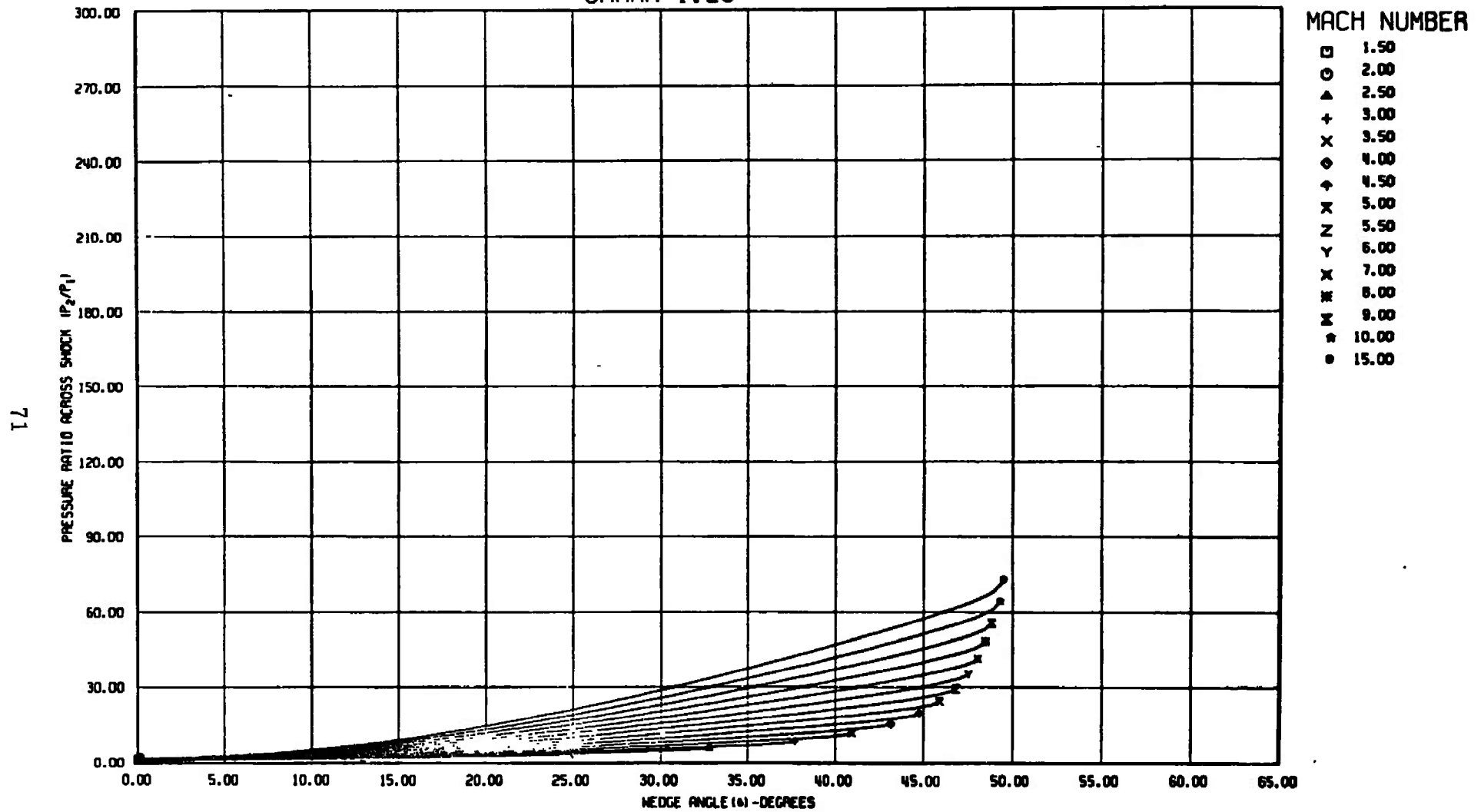


Fig. 11 Continued

OBLIQUE SHOCK GAMMA=1.28

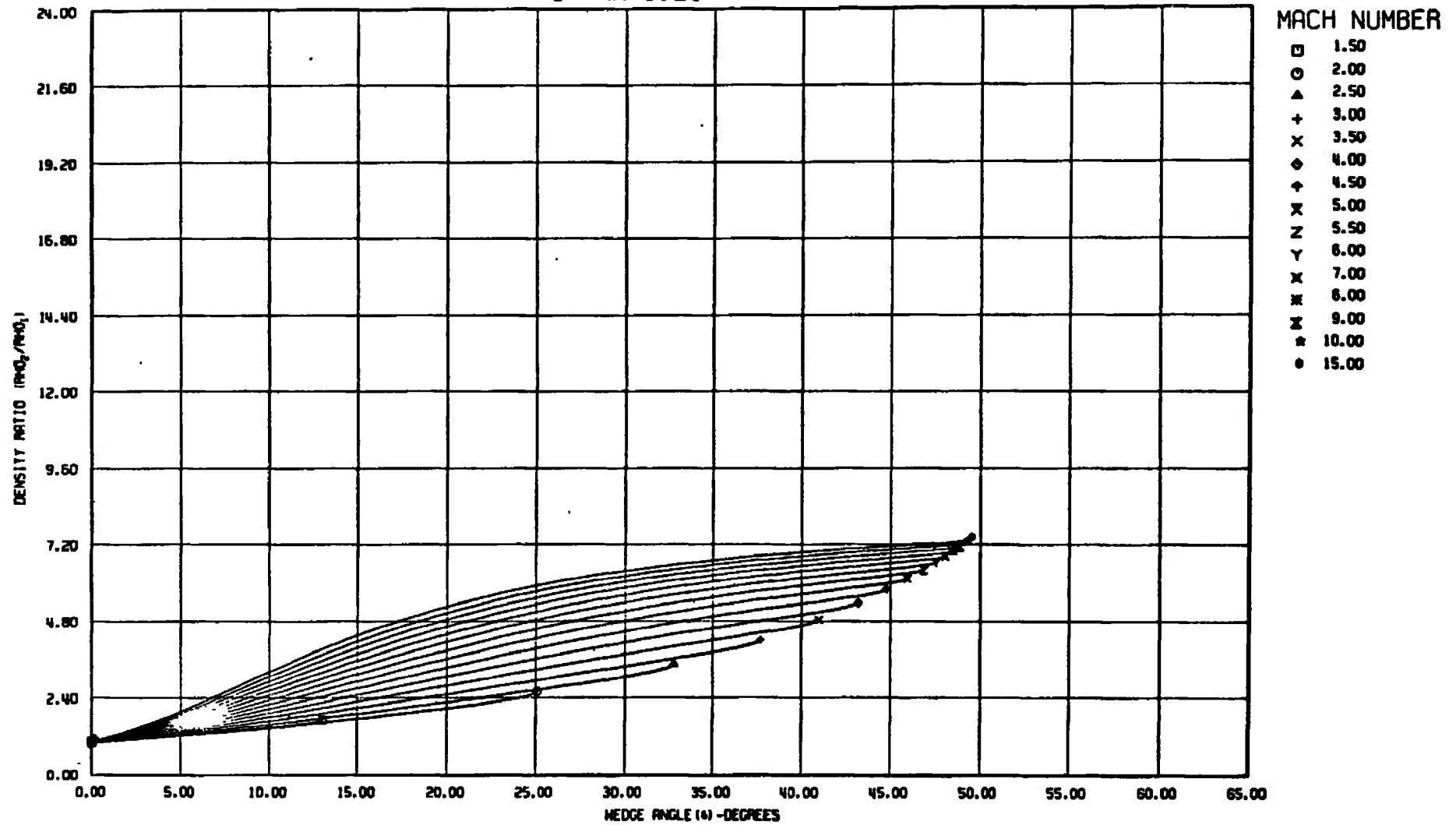


Fig. 11 Continued

OBLIQUE SHOCK
GAMMA=1.28

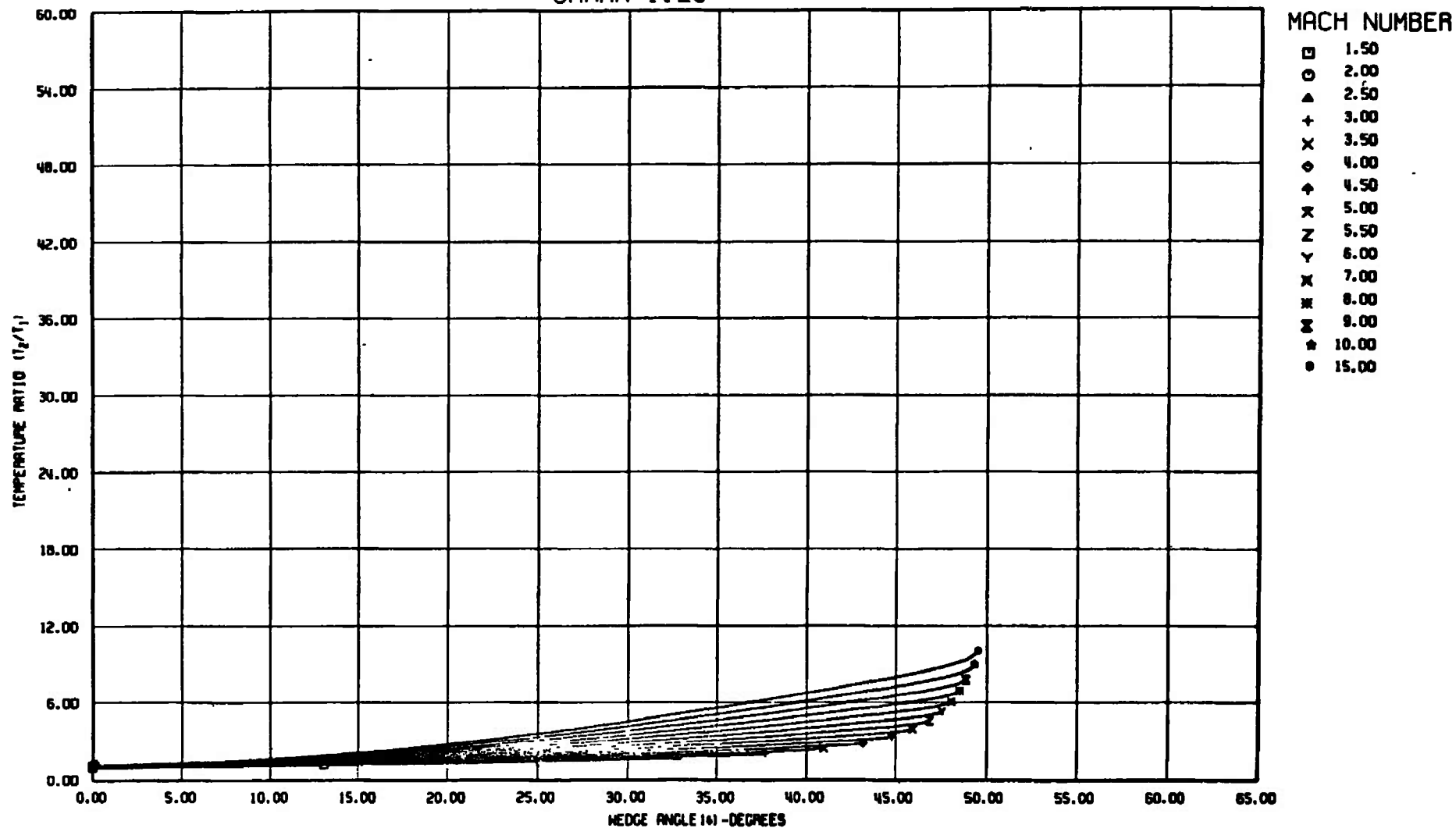


Fig. 11 Continued

OBLIQUE SHOCK
GAMMA=1.28

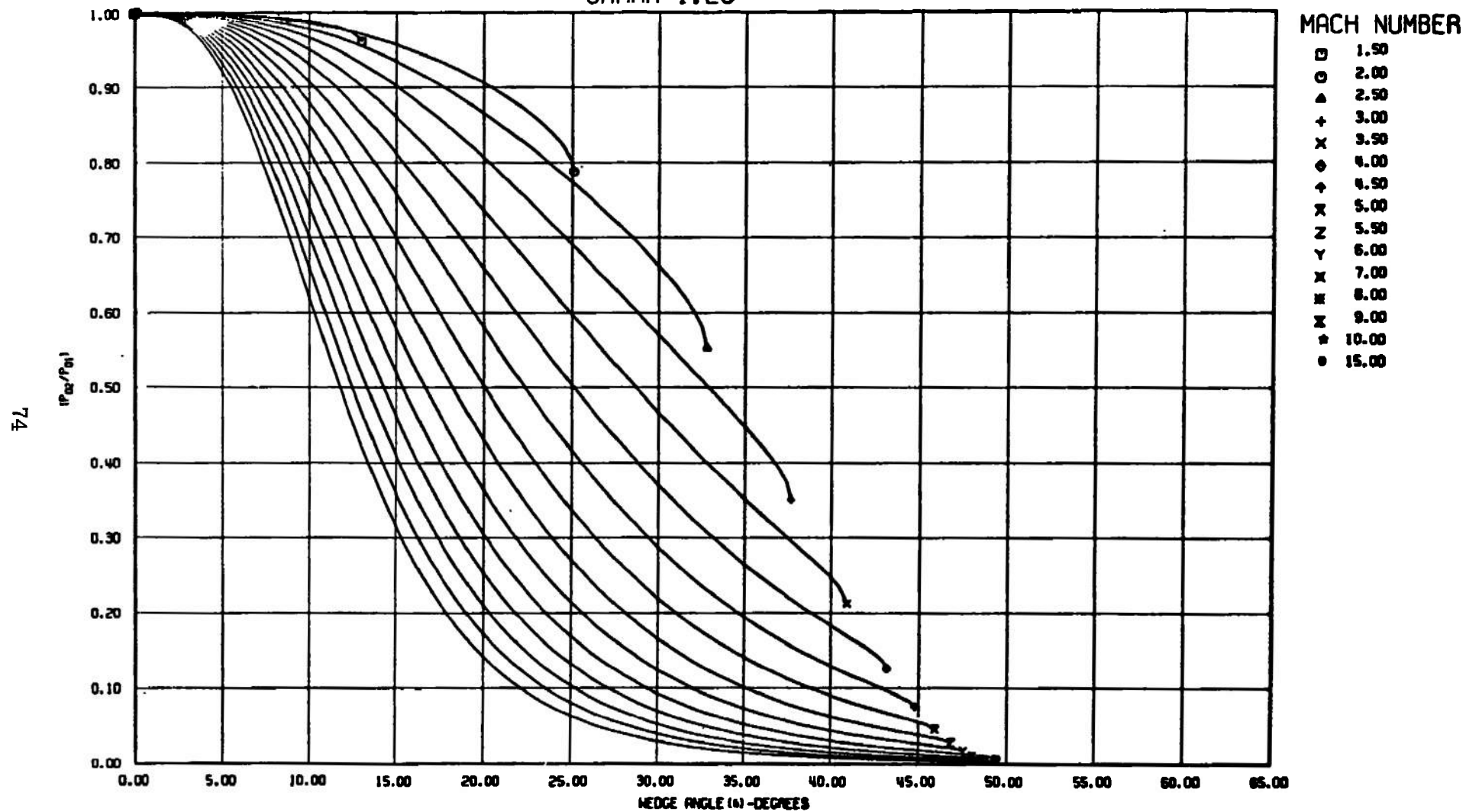


Fig. 11 Continued

OBLIQUE SHOCK
GAMMA=1.28

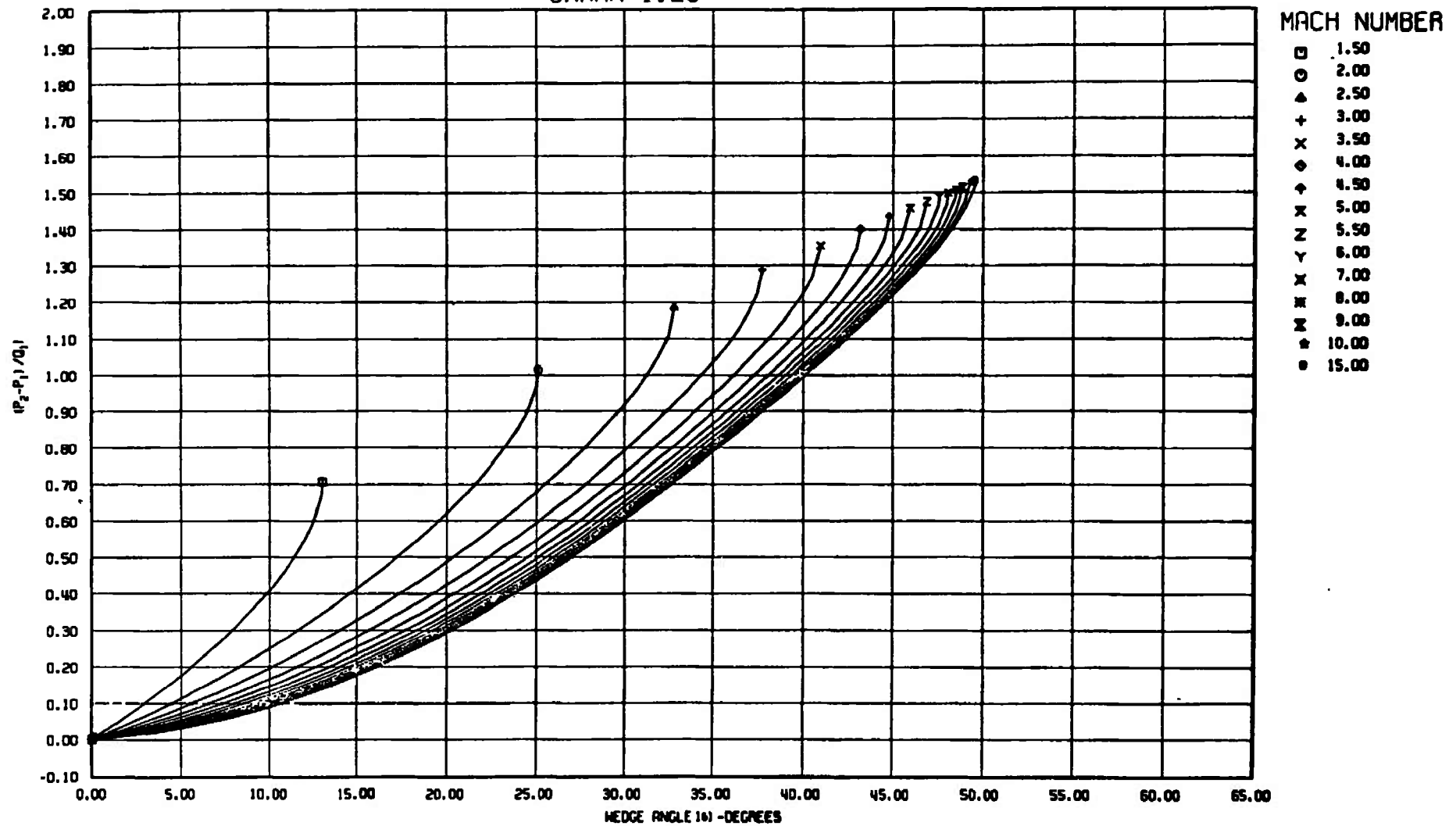


Fig. 11 Concluded

OBLIQUE SHOCK $\gamma = 1.30$

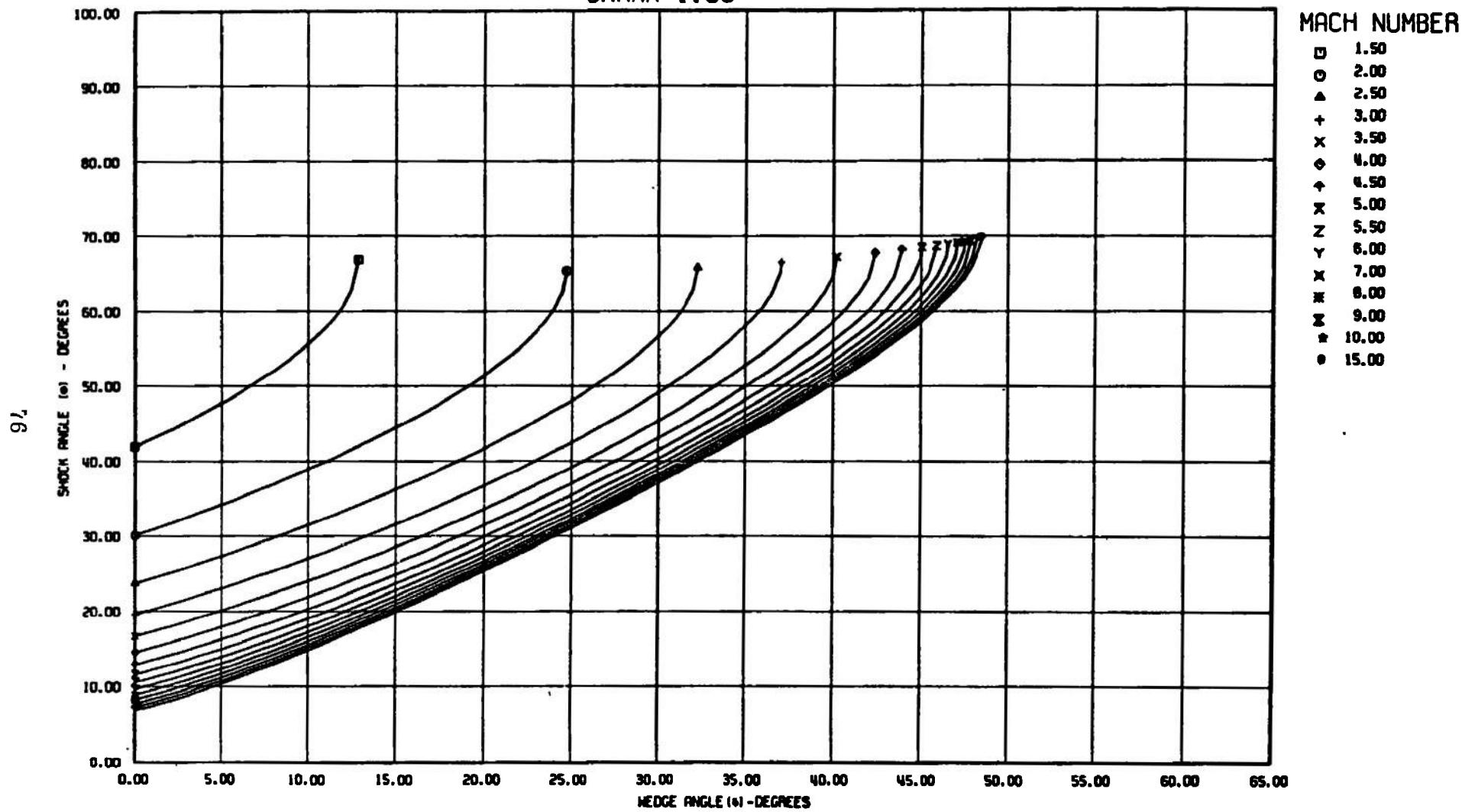


Fig. 12 $\gamma = 1.30$

OBLIQUE SHOCK $\gamma=1.30$

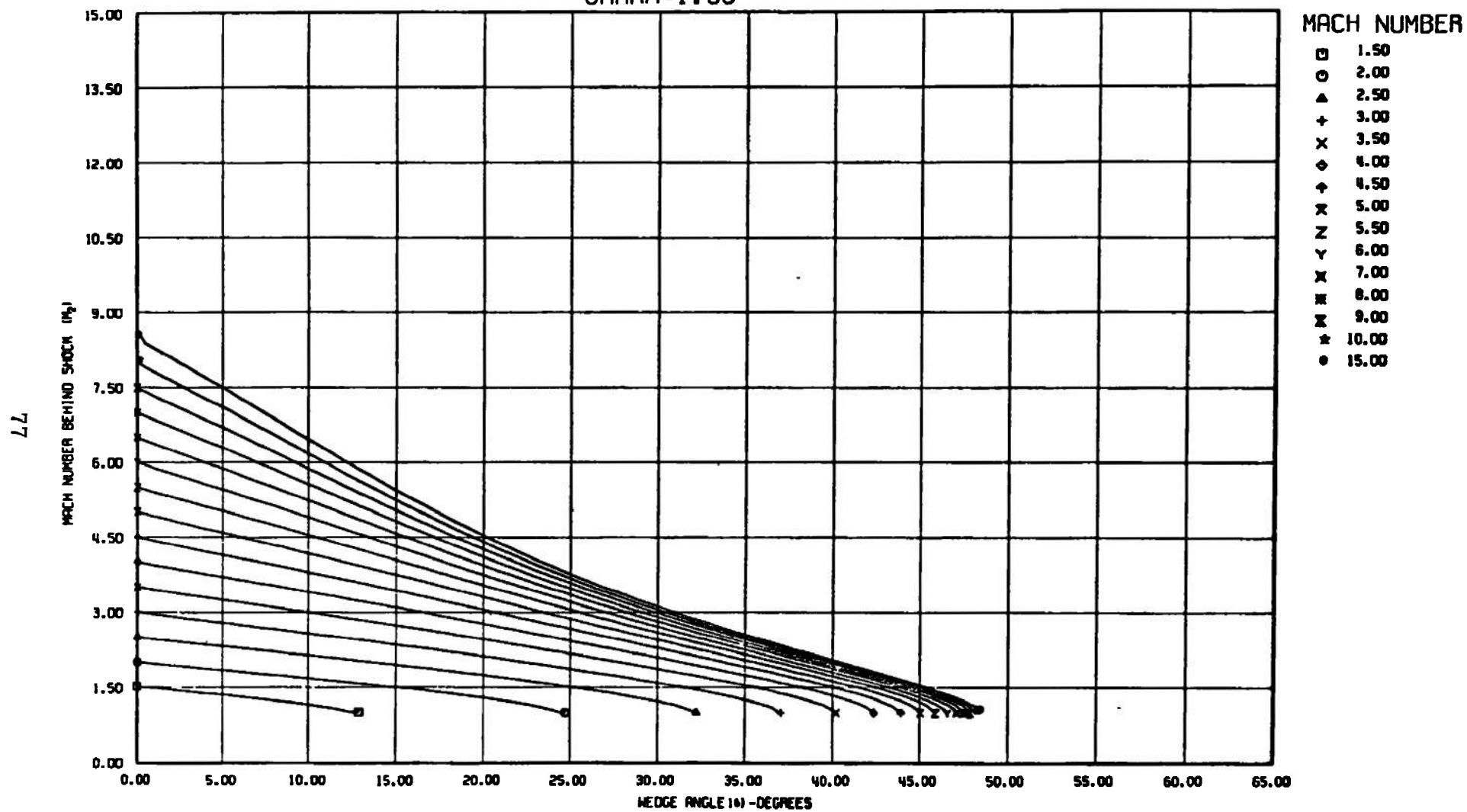
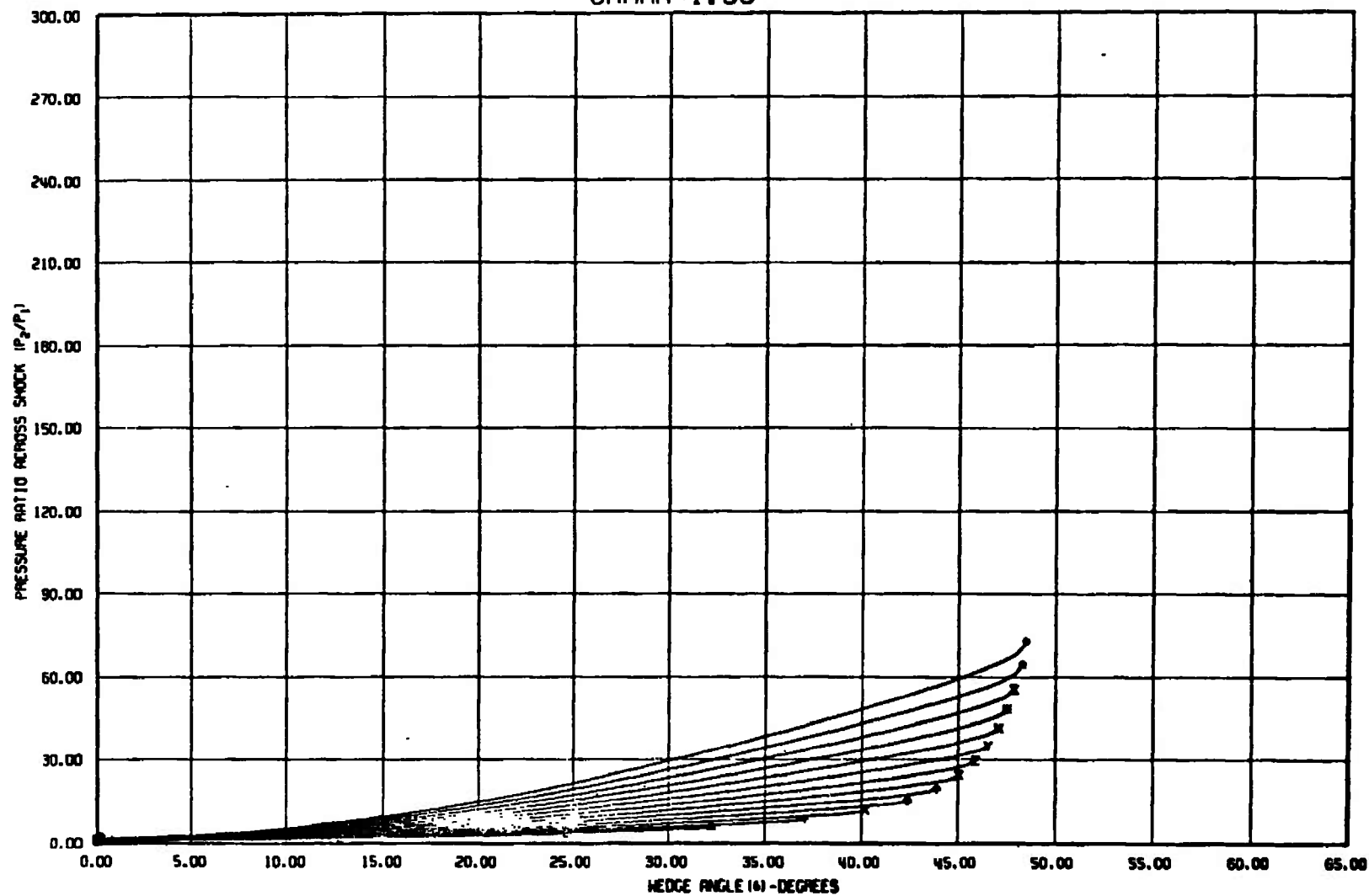


Fig. 12 Continued

OBLIQUE SHOCK
GAMMA=1.30



MACH NUMBER

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- 2.00
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- ◇ 4.00
- † 4.50
- x 5.00
- Z 5.50
- Y 6.00
- x 7.00
- 8.00
- x 9.00
- ★ 10.00
- 15.00

Fig. 12 Continued

OBLIQUE SHOCK
GAMMA=1.30

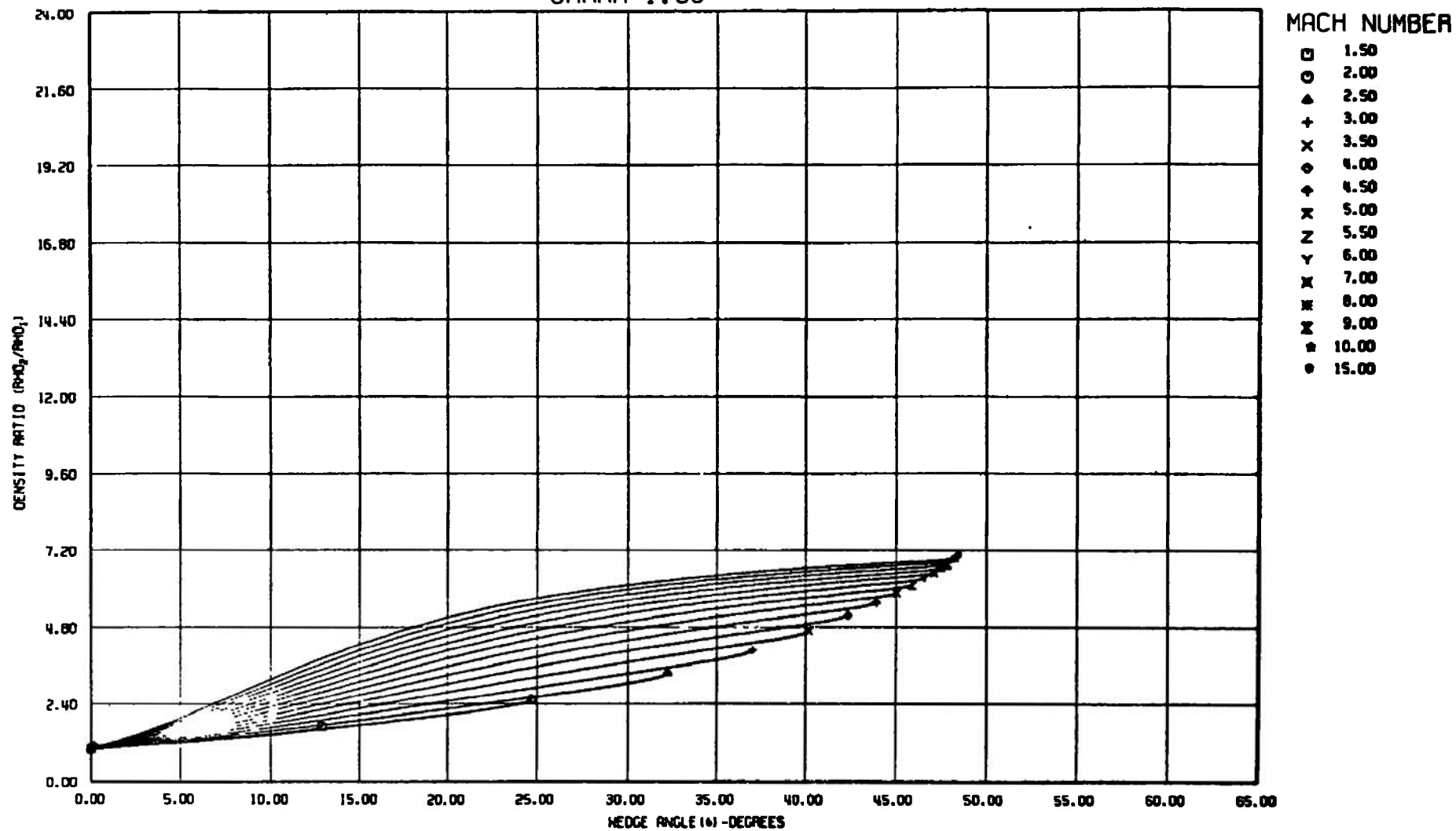
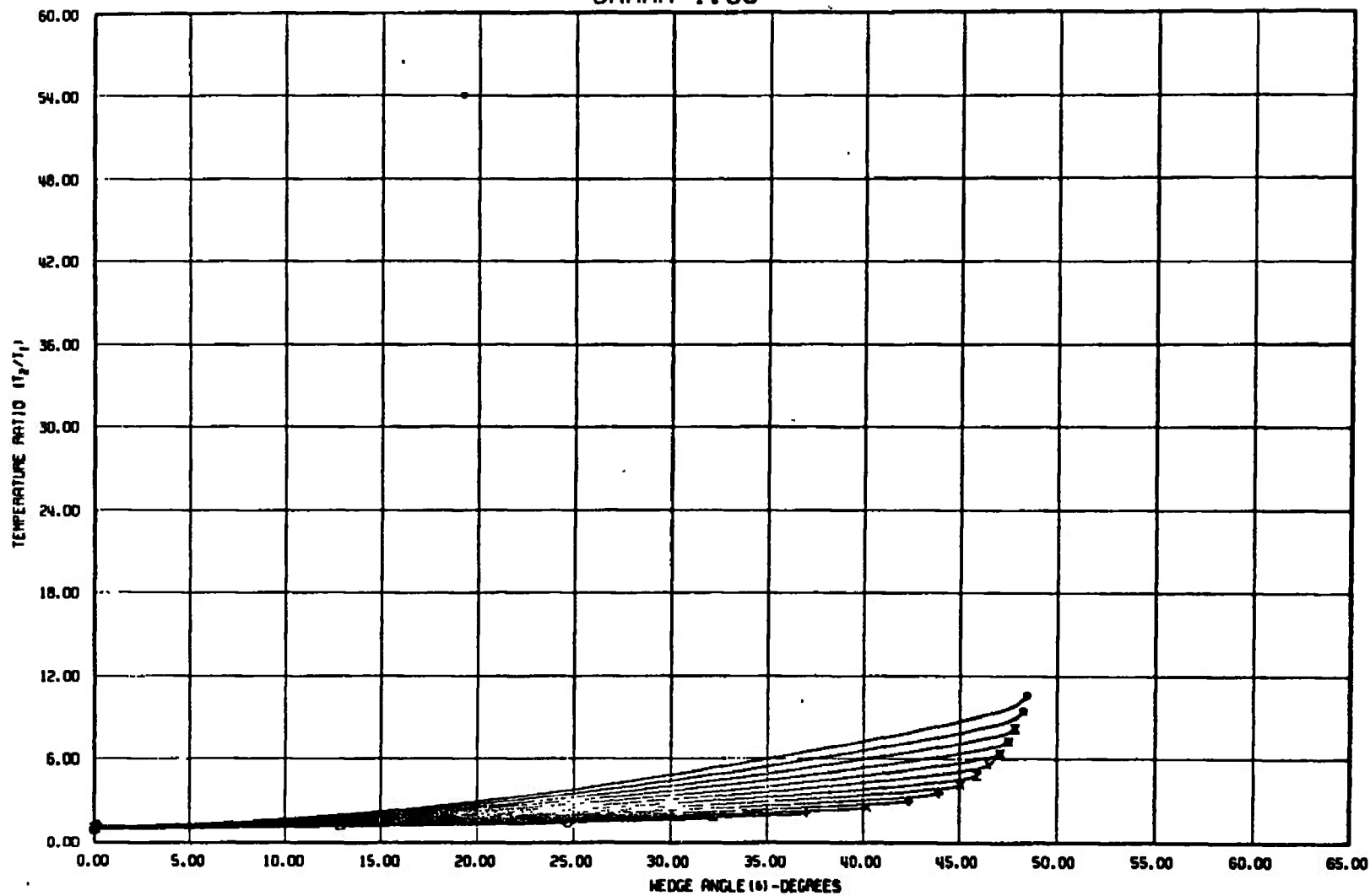


Fig. 12 Continued

OBLIQUE SHOCK $\gamma = 1.30$



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- +
- x 3.50
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- + 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
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- x 9.00
- * 10.00
- 15.00

Fig. 12 Continued

OBLIQUE SHOCK GAMMA=1.30

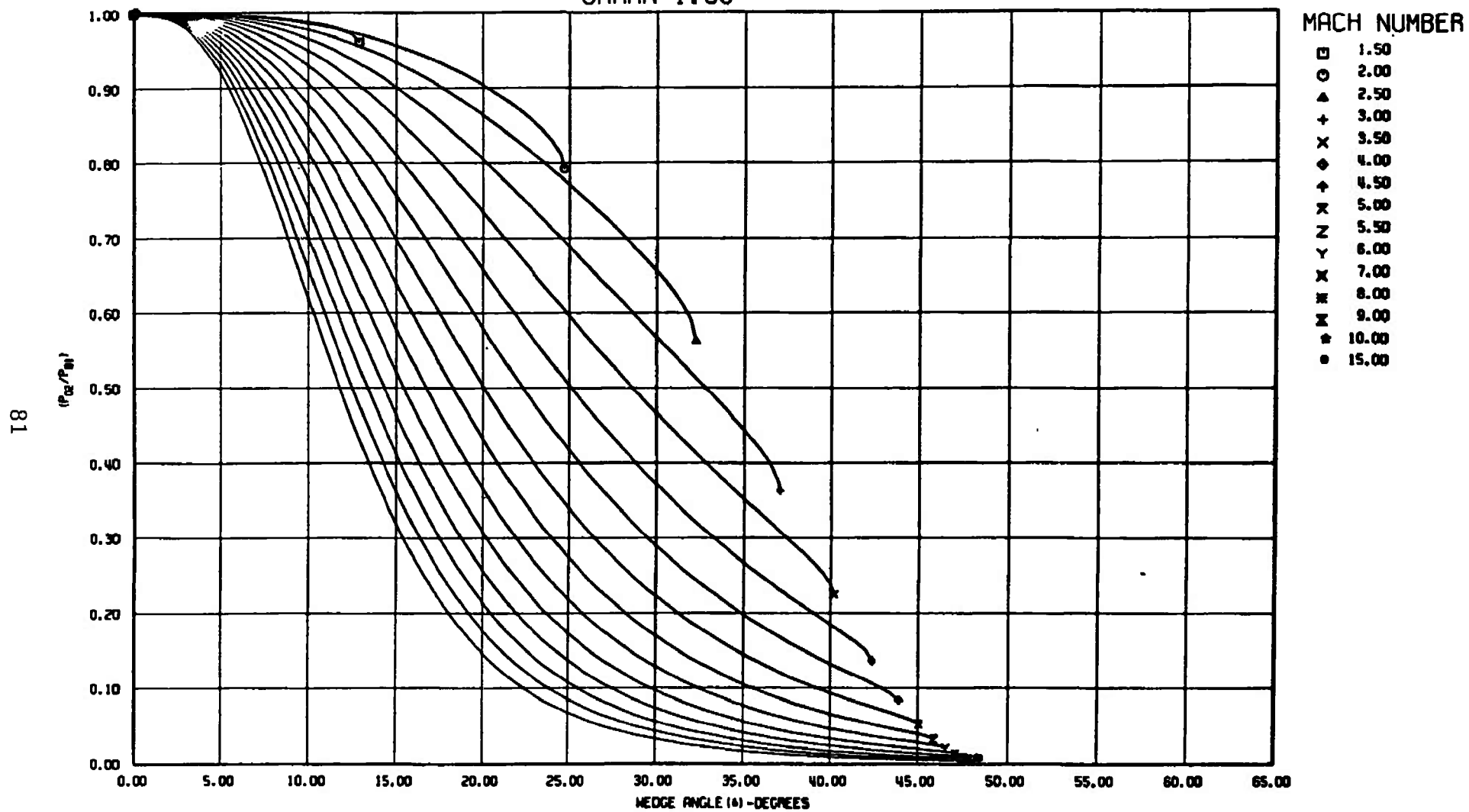


Fig. 12 Continued

OBLIQUE SHOCK GAMMA=1.30

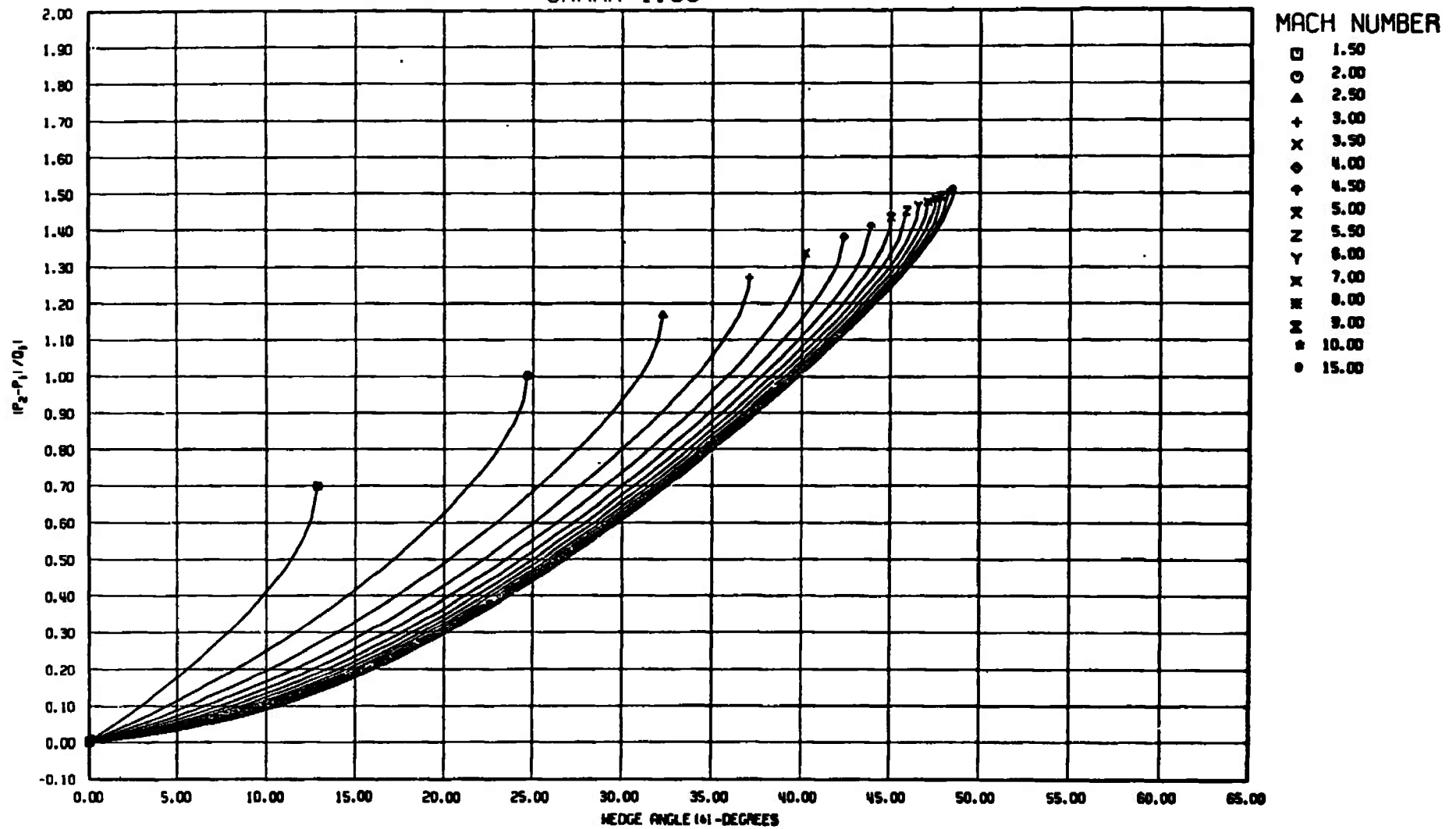


Fig. 12 Concluded

OBLIQUE SHOCK $\gamma = 1.32$

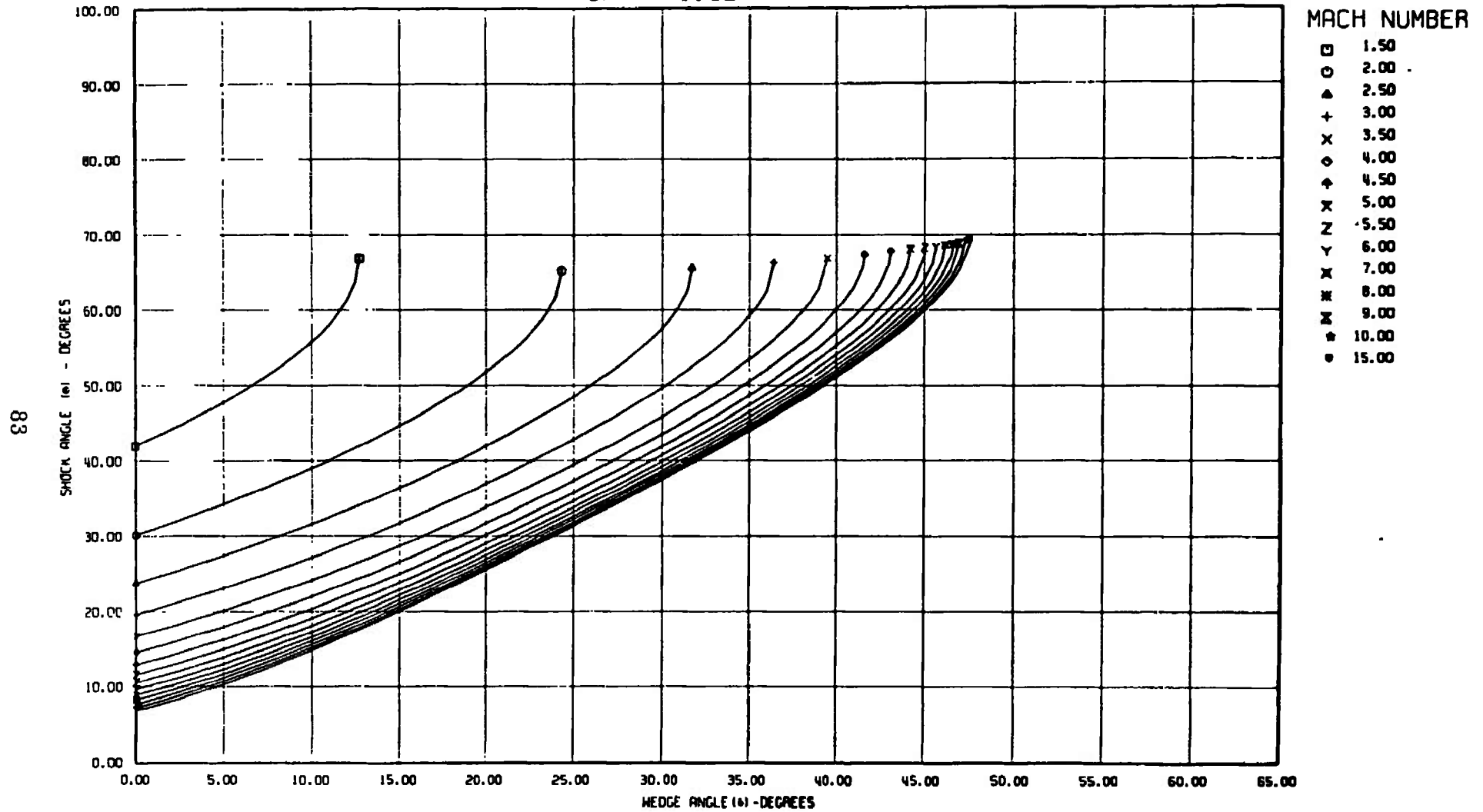


Fig. 13 $\gamma = 1.32$

OBLIQUE SHOCK $\gamma = 1.32$

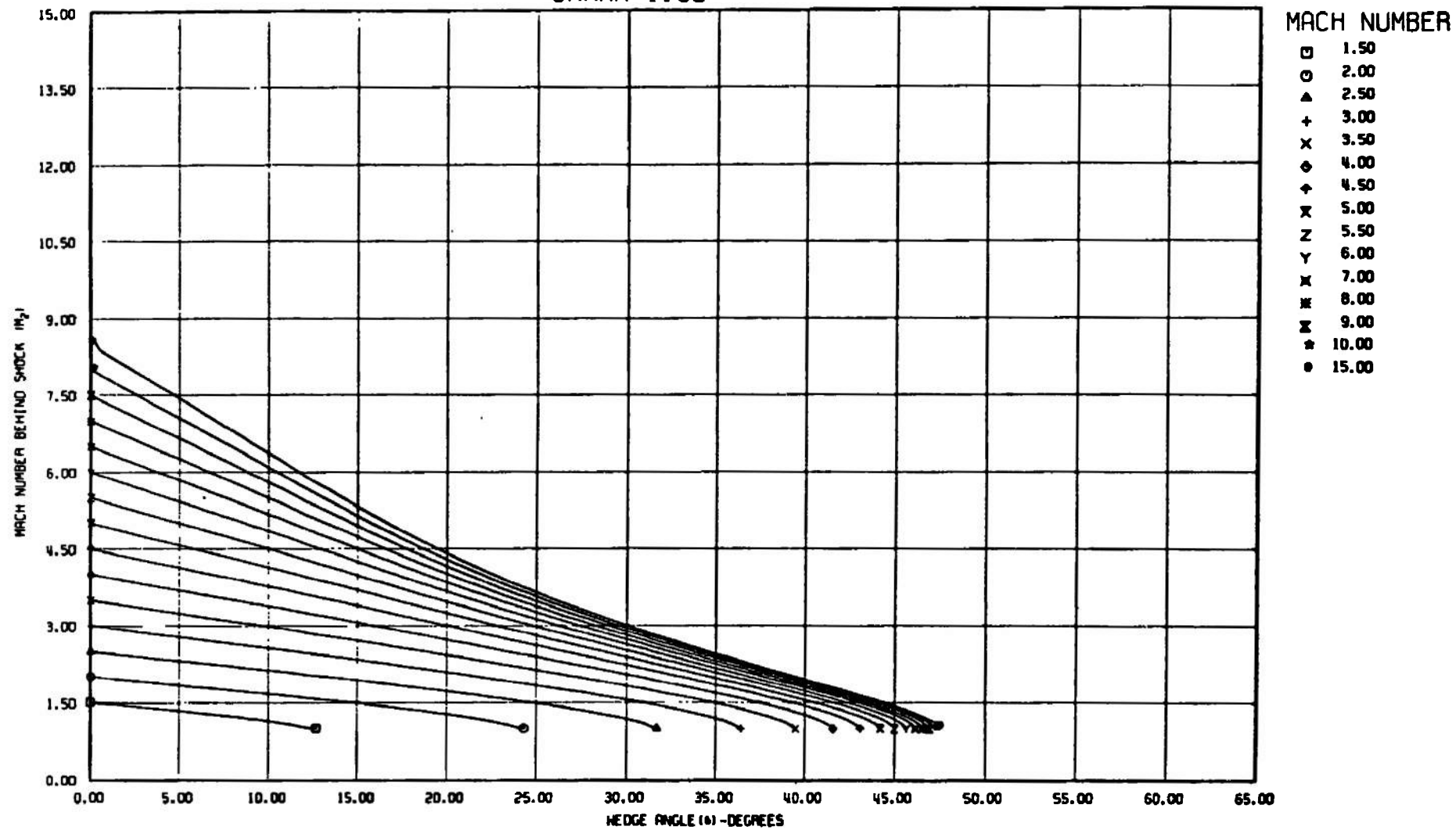


Fig. 13 Continued

OBLIQUE SHOCK GAMMA=1.32

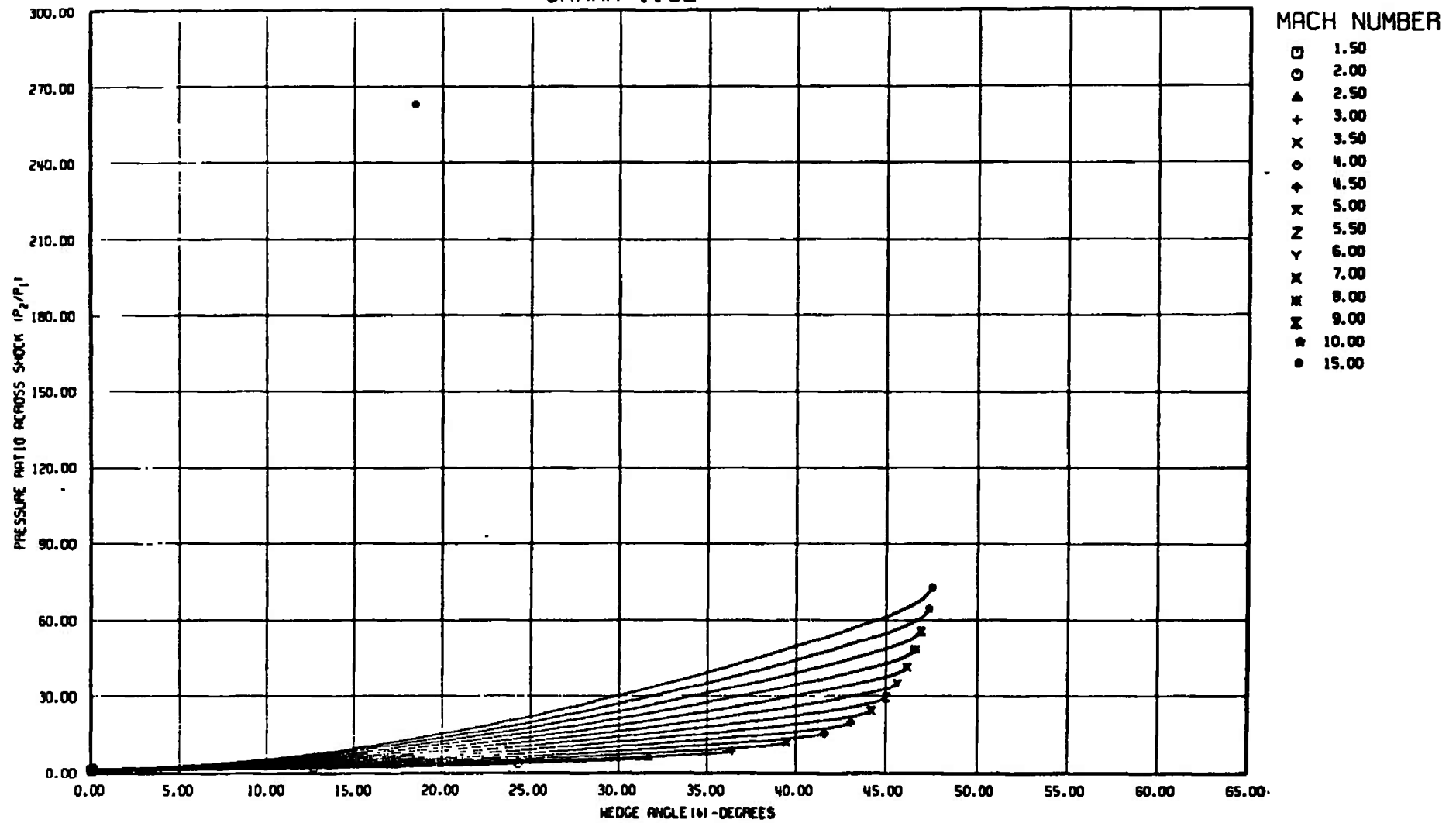


Fig. 13 Continued

OBLIQUE SHOCK
GAMMA=1.32

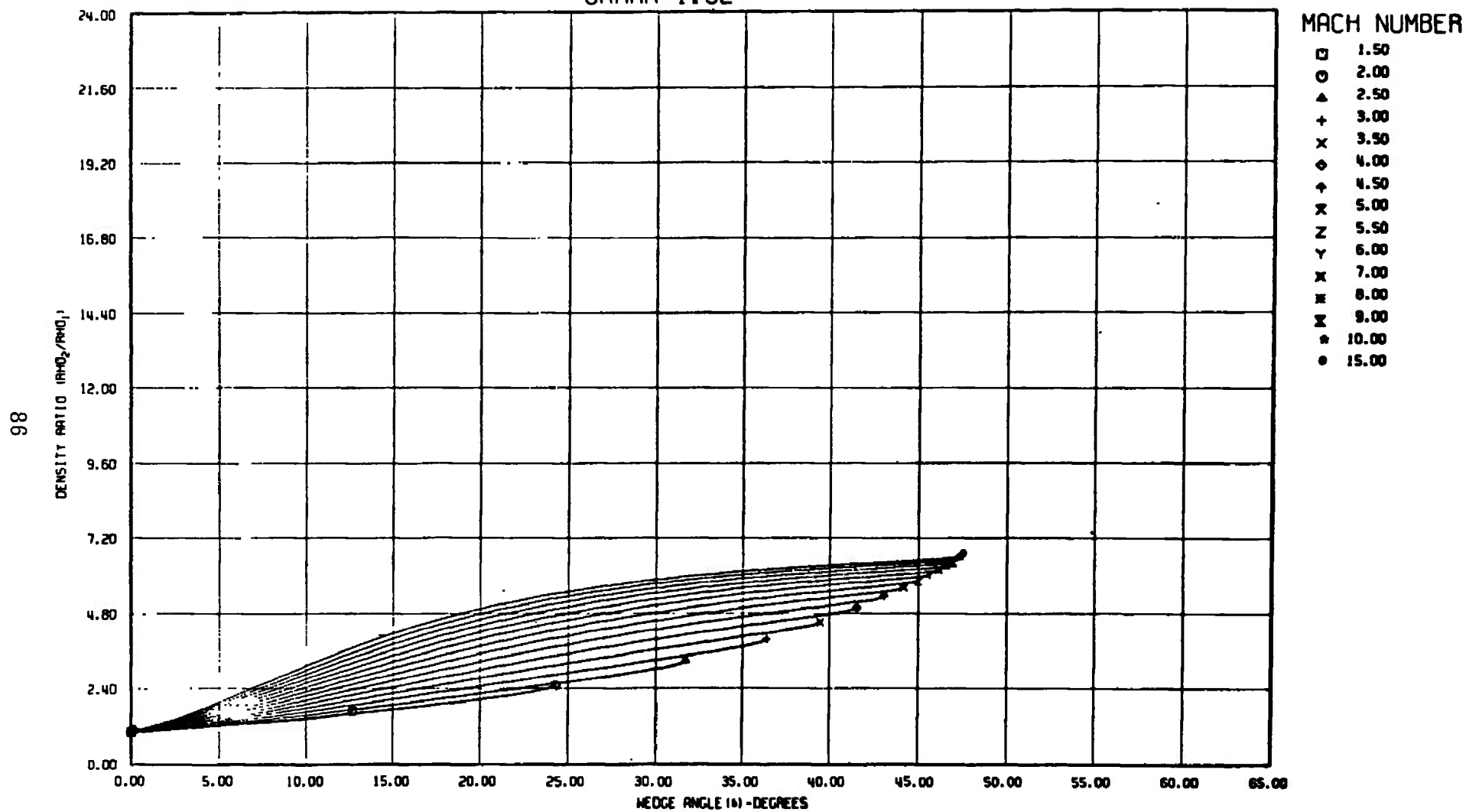


Fig. 13 Continued

OBLIQUE SHOCK GAMMA=1.32

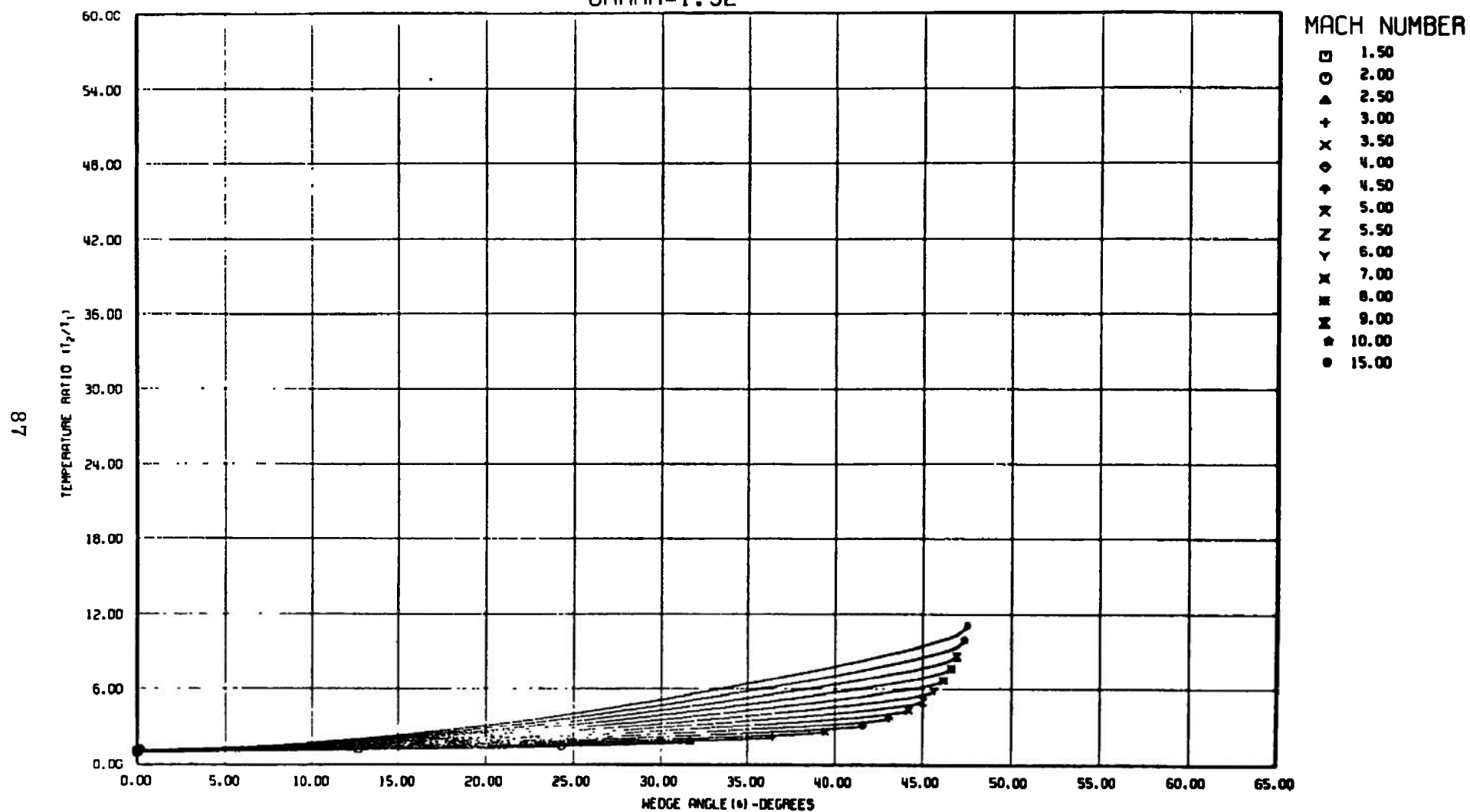


Fig. 13 Continued

OBLIQUE SHOCK GAMMA=1.32

88

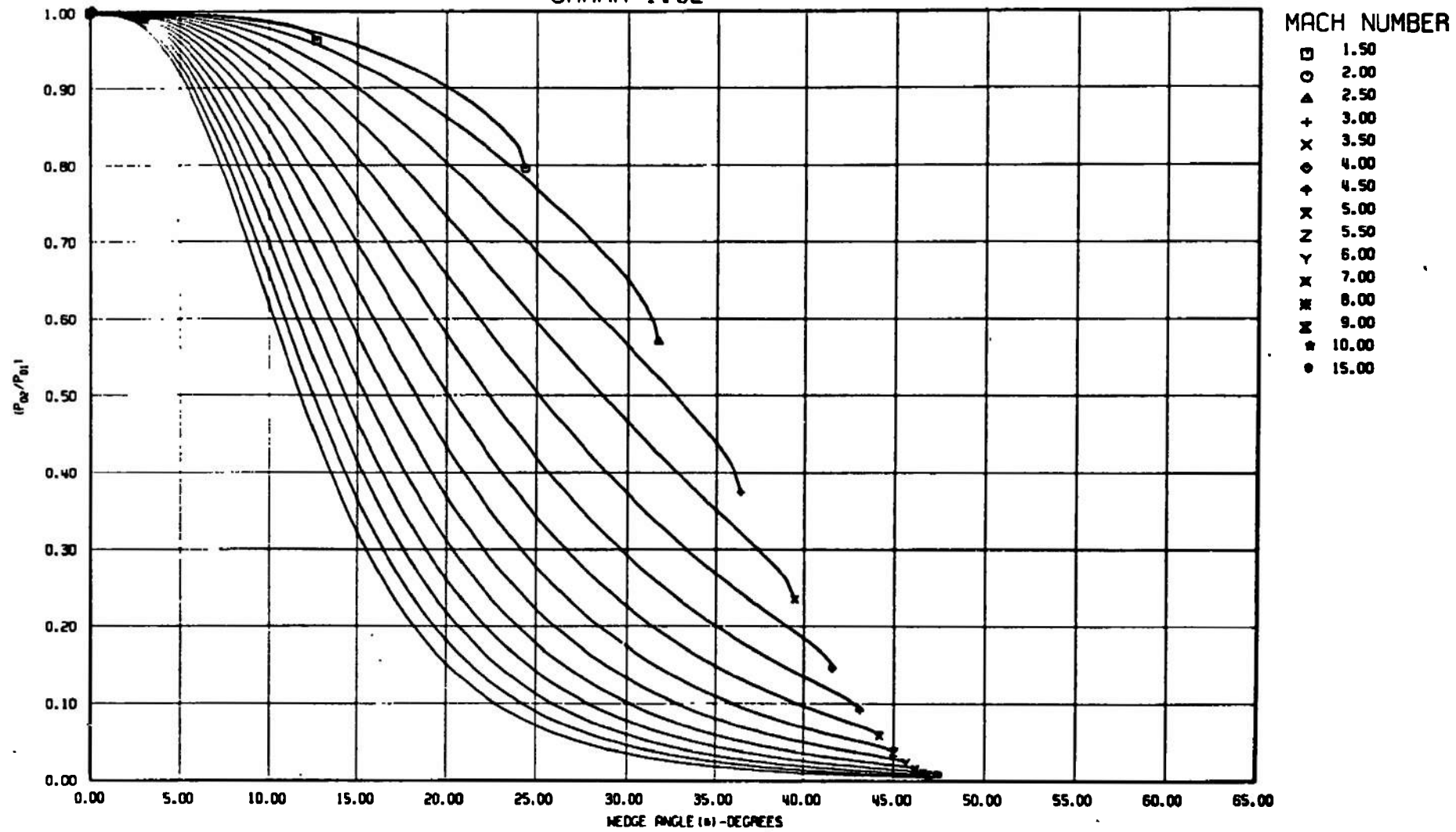
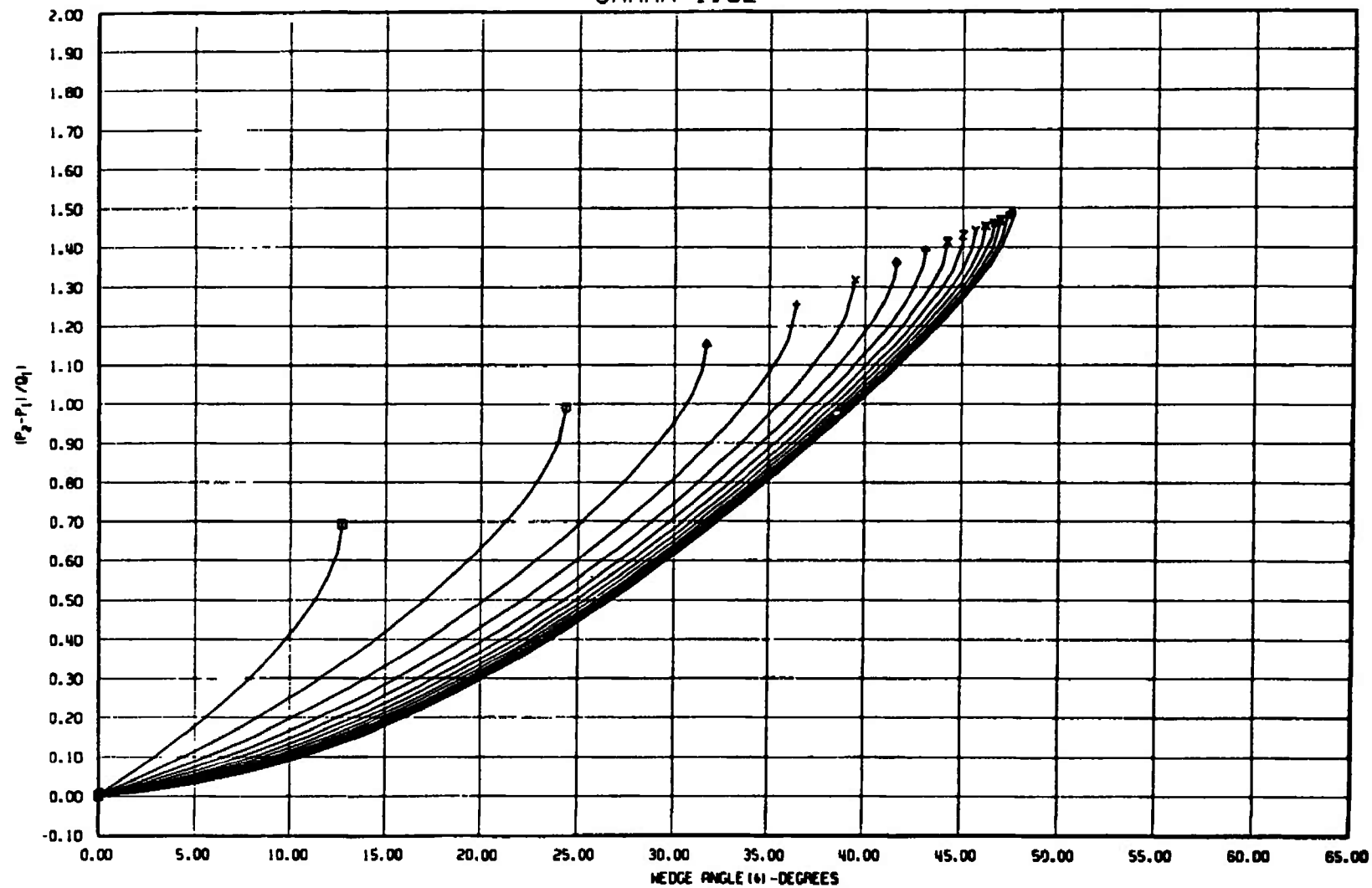


Fig. 13 Continued

OBLIQUE SHOCK GAMMA=1.32



MACH NUMBER

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- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- ⊕ 4.50
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- z 5.50
- y 6.00
- ⊗ 7.00
- ⊞ 8.00
- ⊠ 9.00
- ★ 10.00
- 15.00

Fig. 13 Concluded

OBLIQUE SHOCK
GAMMA=1.34

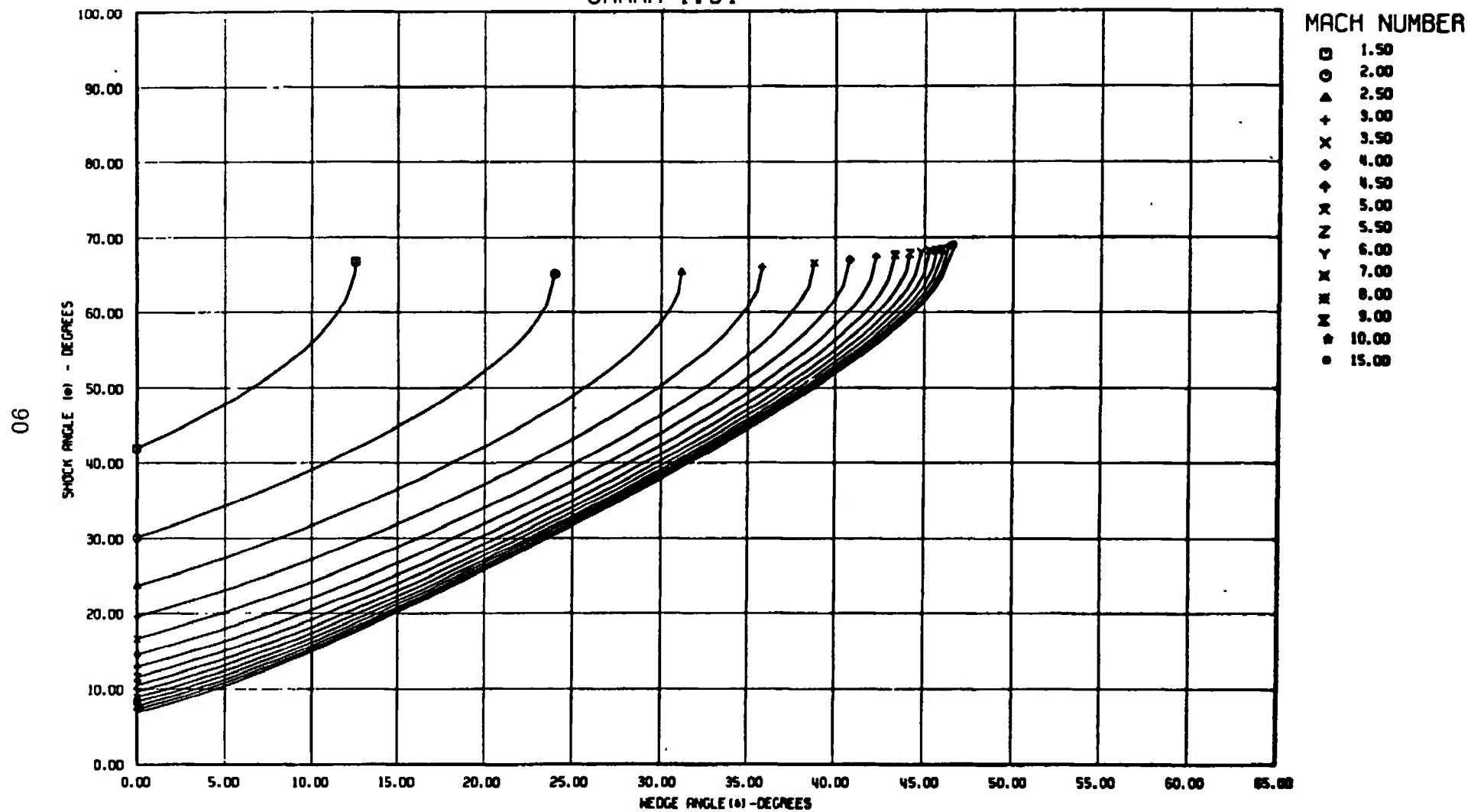


Fig. 14 $\gamma = 1.34$

OBLIQUE SHOCK
GAMMA=1.34

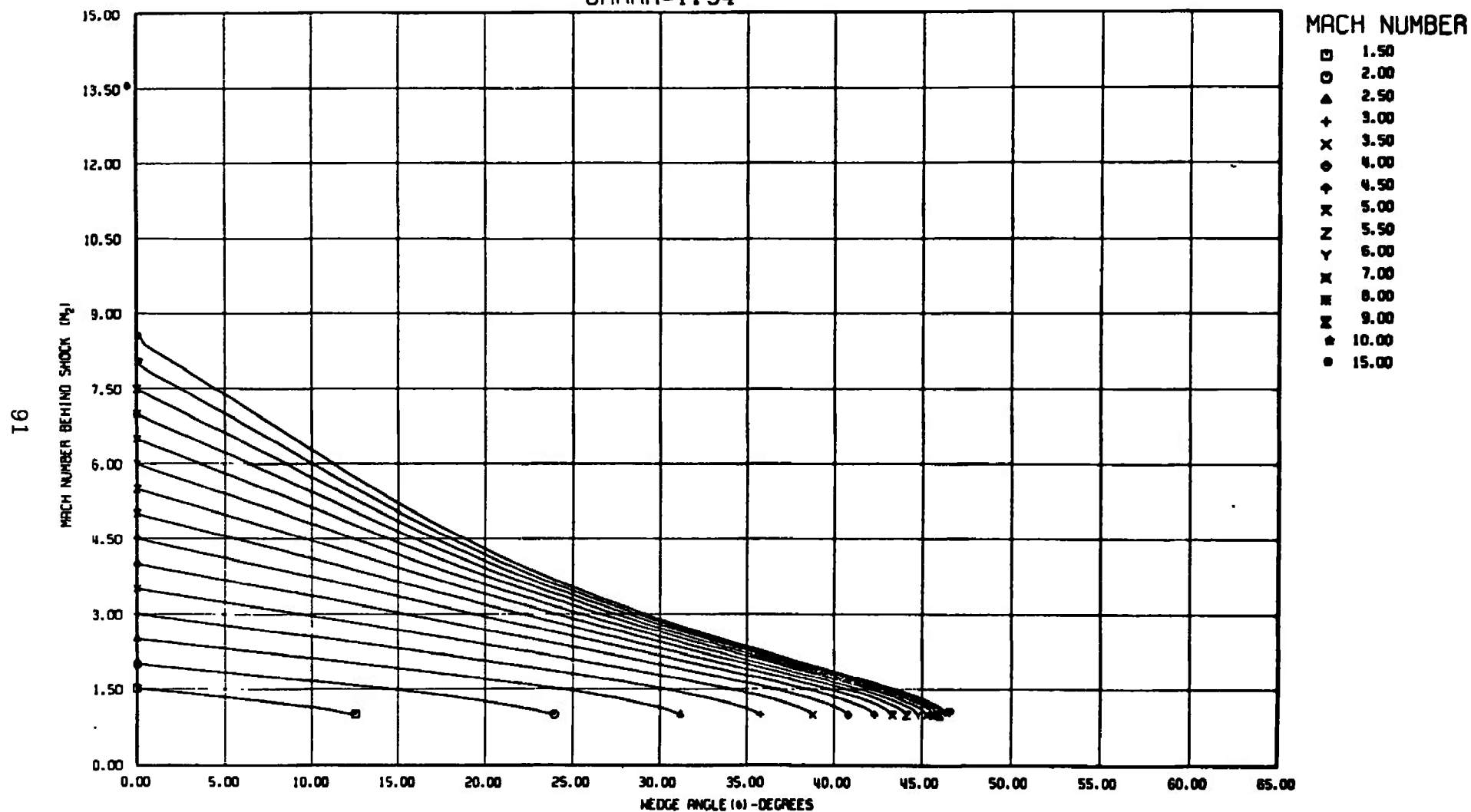


Fig. 14 Continued

OBLIQUE SHOCK GAMMA=1.34

92

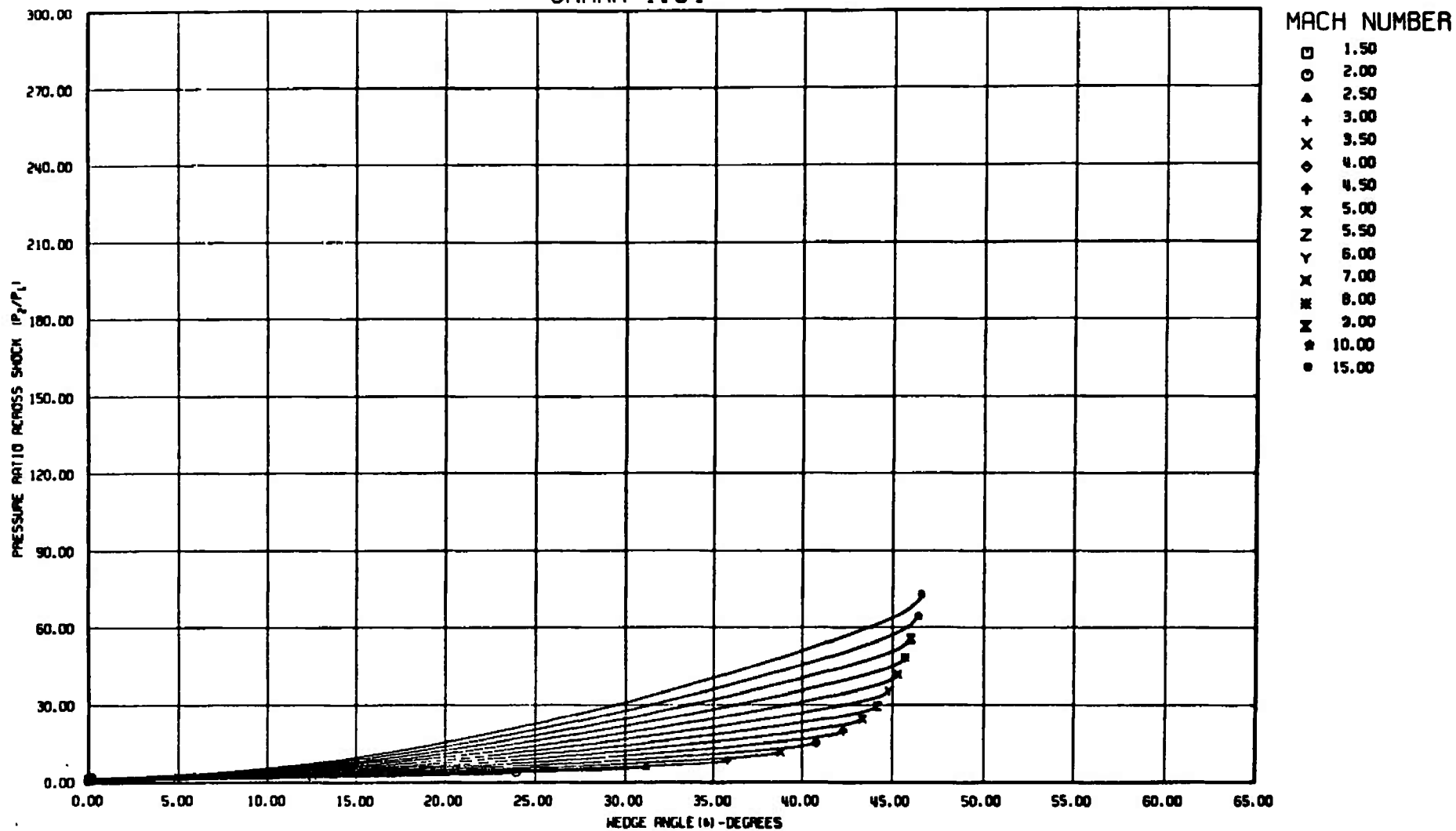
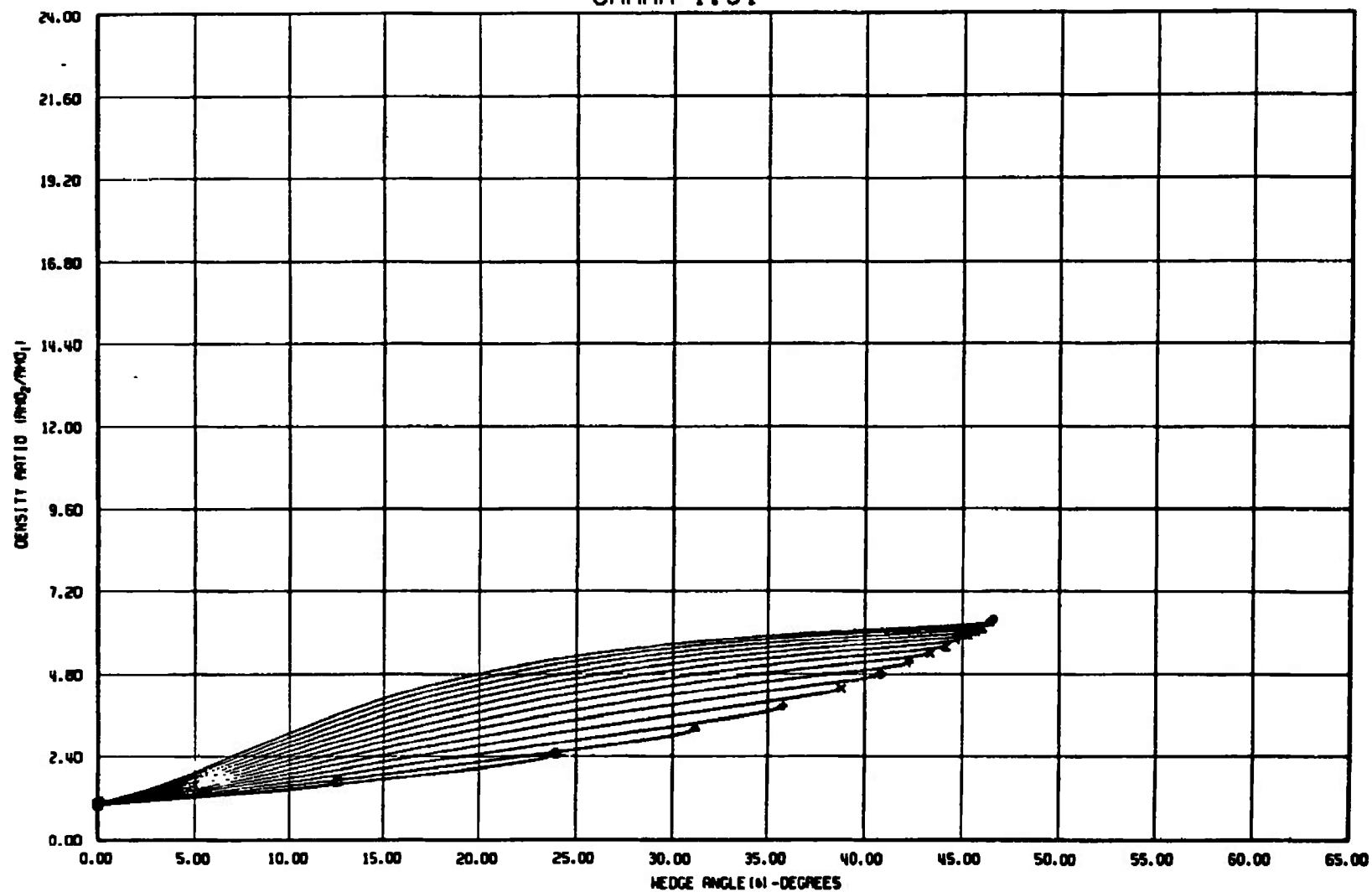


Fig. 14 Continued

OBLIQUE SHOCK
GAMMA=1.34



MACH NUMBER

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- 2.00
- △ 2.50
- +
- x 3.50
- ◆ 4.00
- ⋈ 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- ≡ 8.00
- x 9.00
- ★ 10.00
- 15.00

Fig. 14 Continued

OBLIQUE SHOCK
GAMMA=1.34

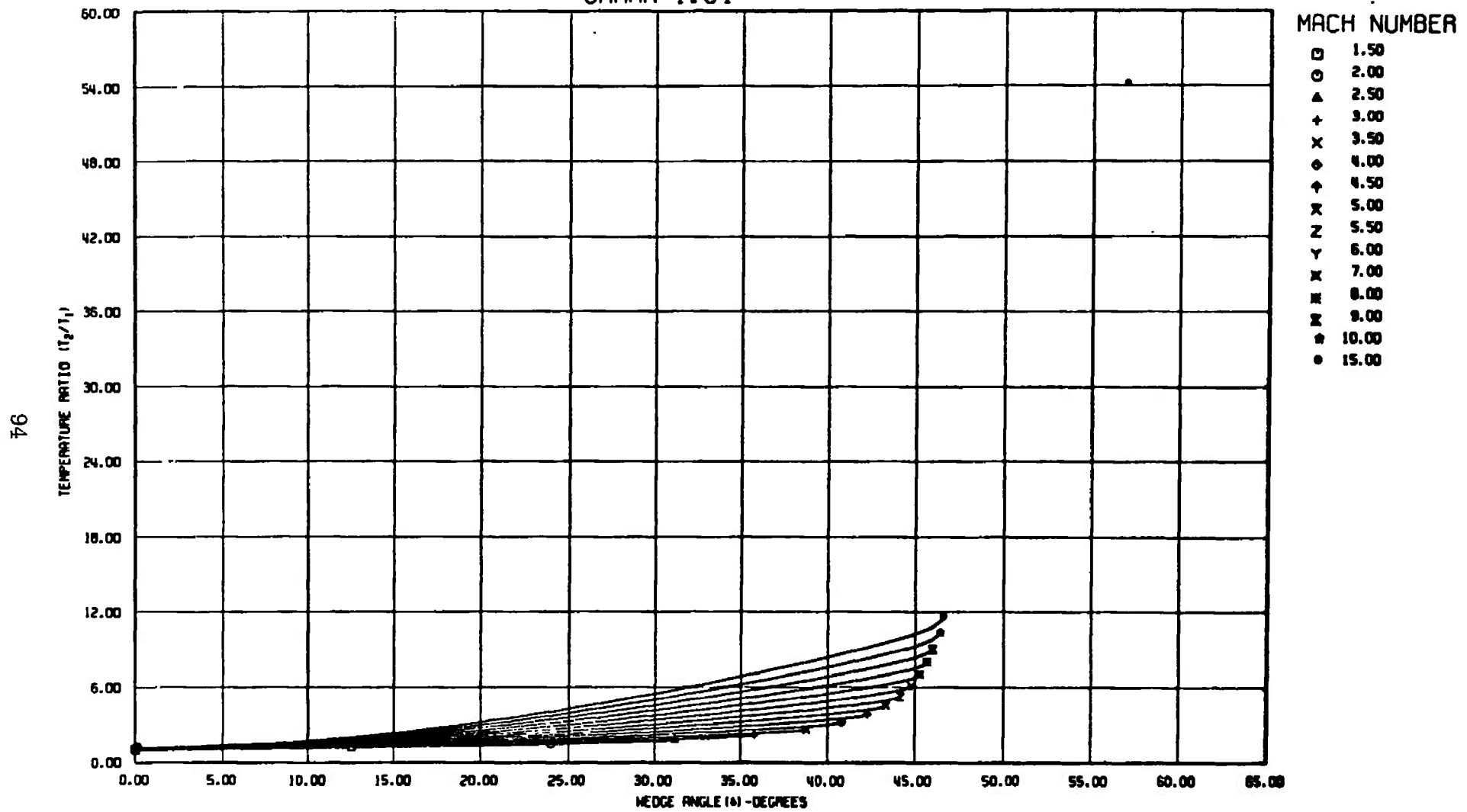


Fig. 14 Continued

OBLIQUE SHOCK
GAMMA=1.34

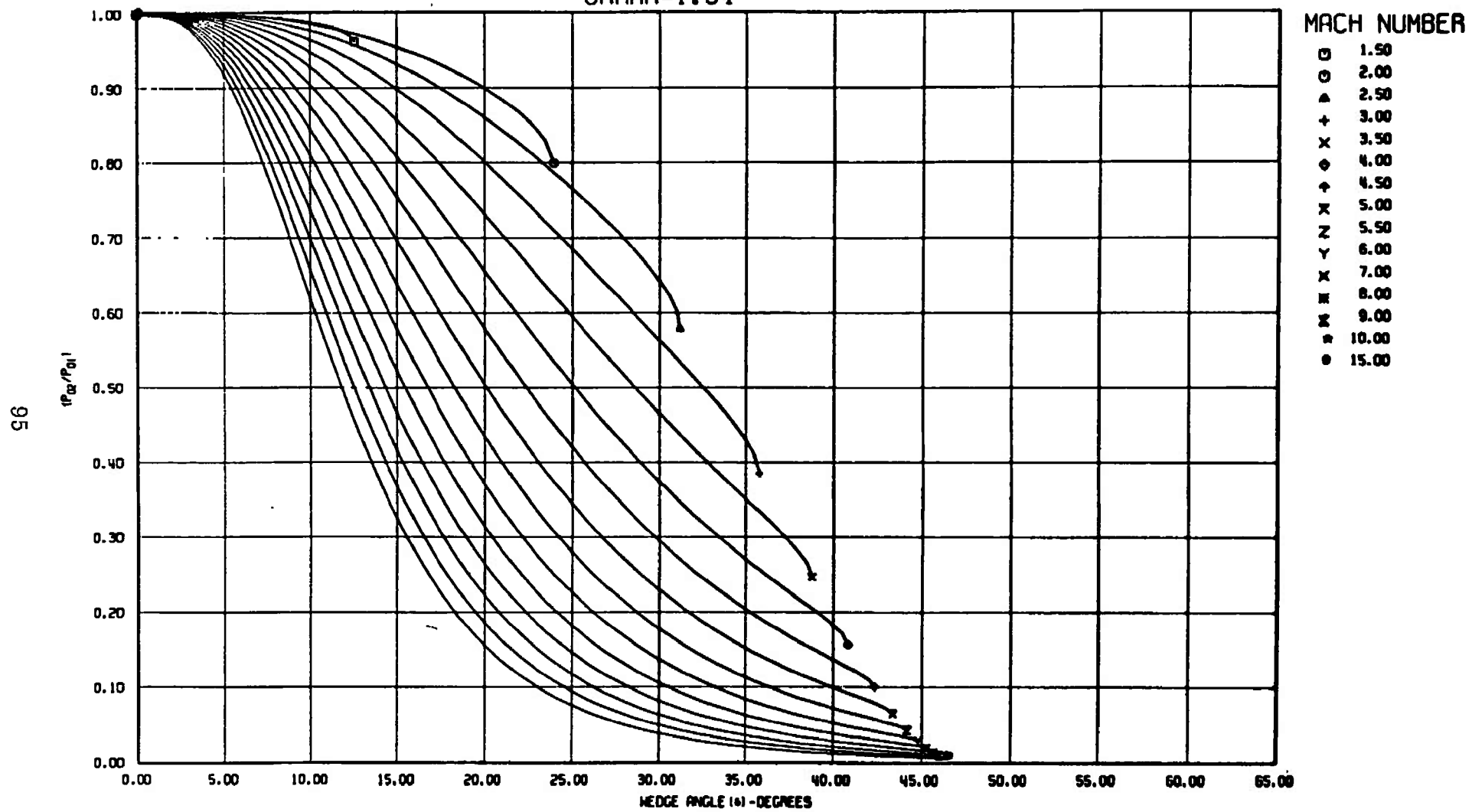
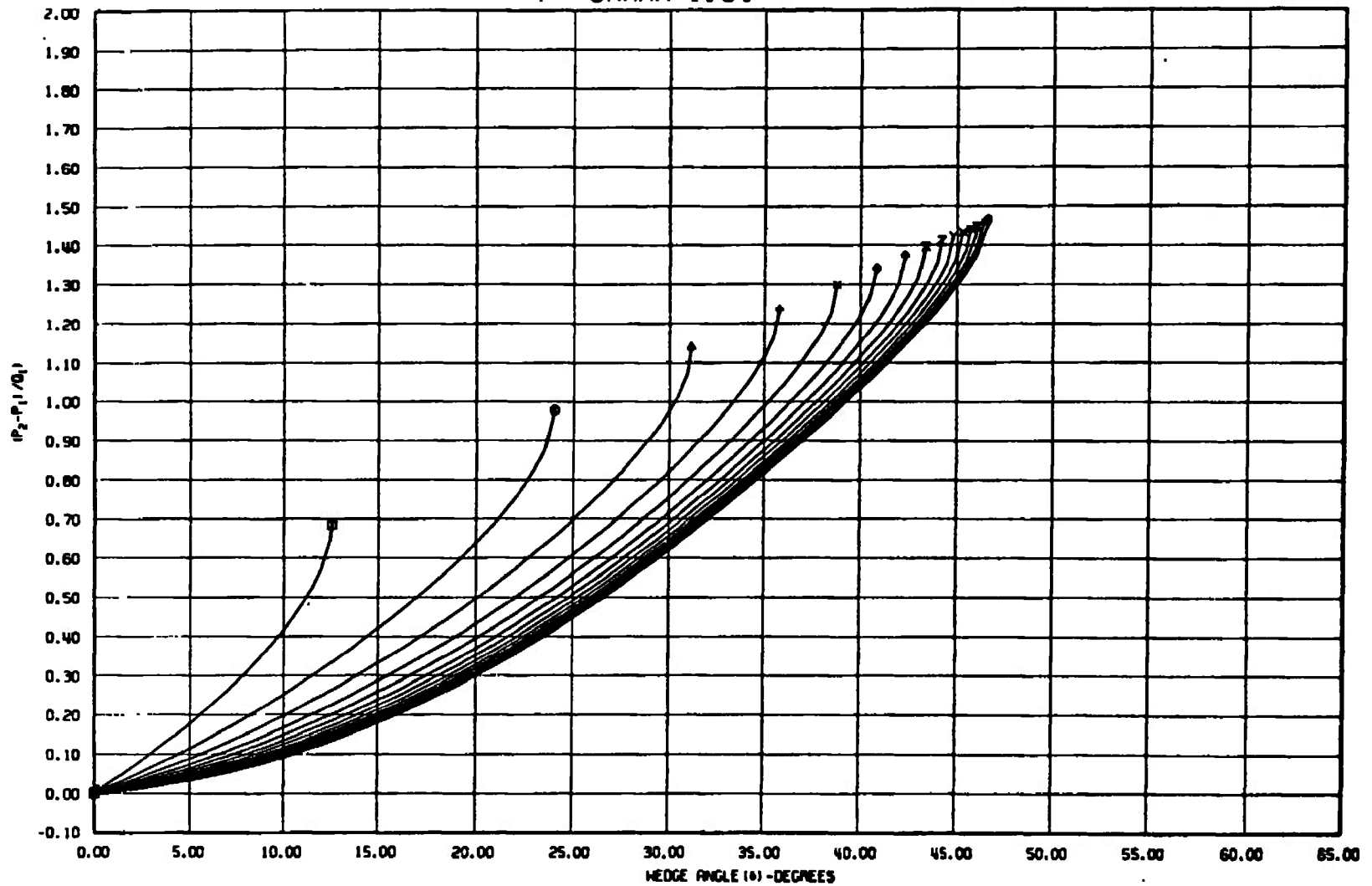


Fig. 14 Continued

OBLIQUE SHOCK GAMMA=1.34

96



MACH NUMBER

Fig. 14 Concluded

OBLIQUE SHOCK $\gamma = 1.36$

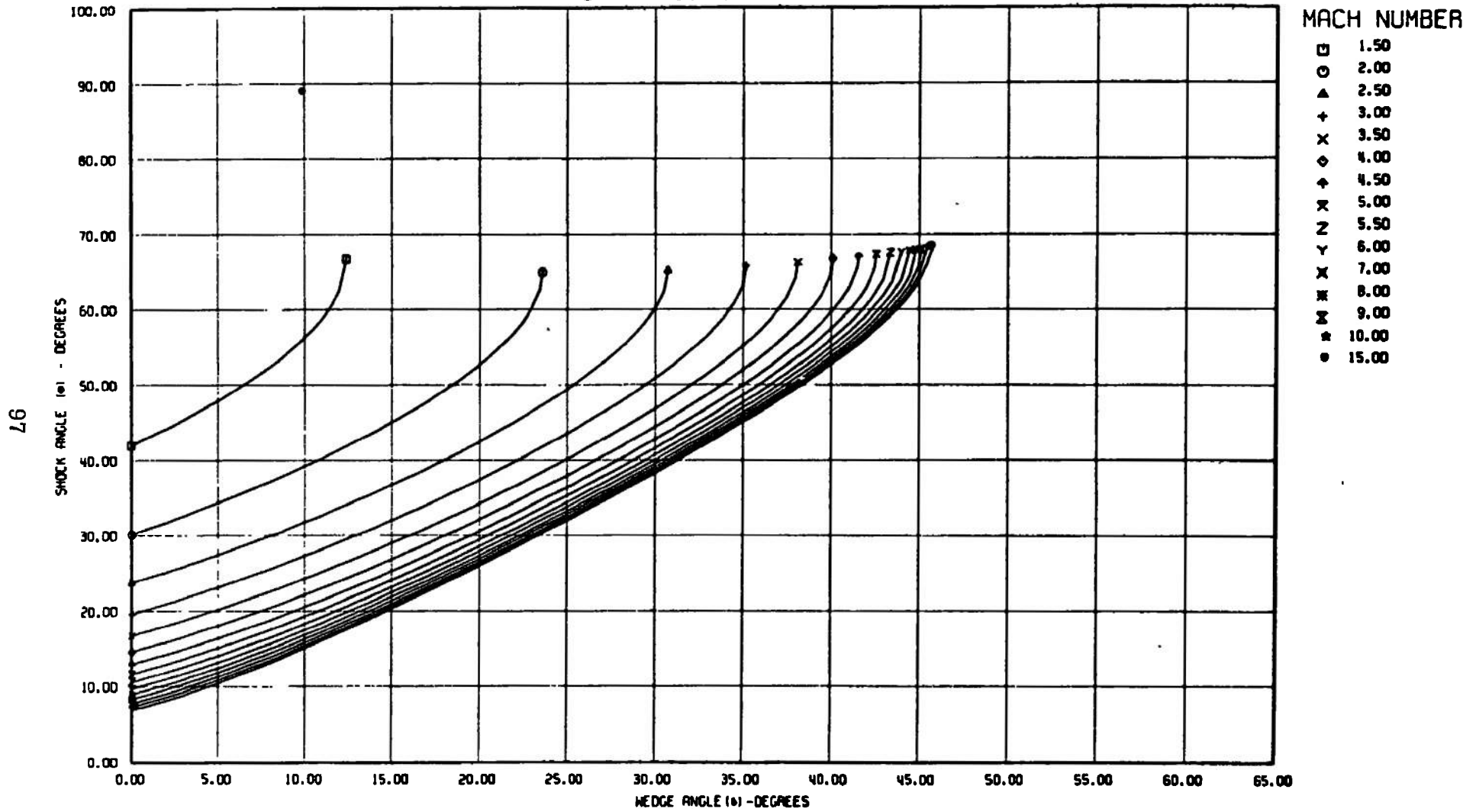


Fig. 15 $\gamma = 1.36$

OBLIQUE SHOCK
GAMMA=1.36

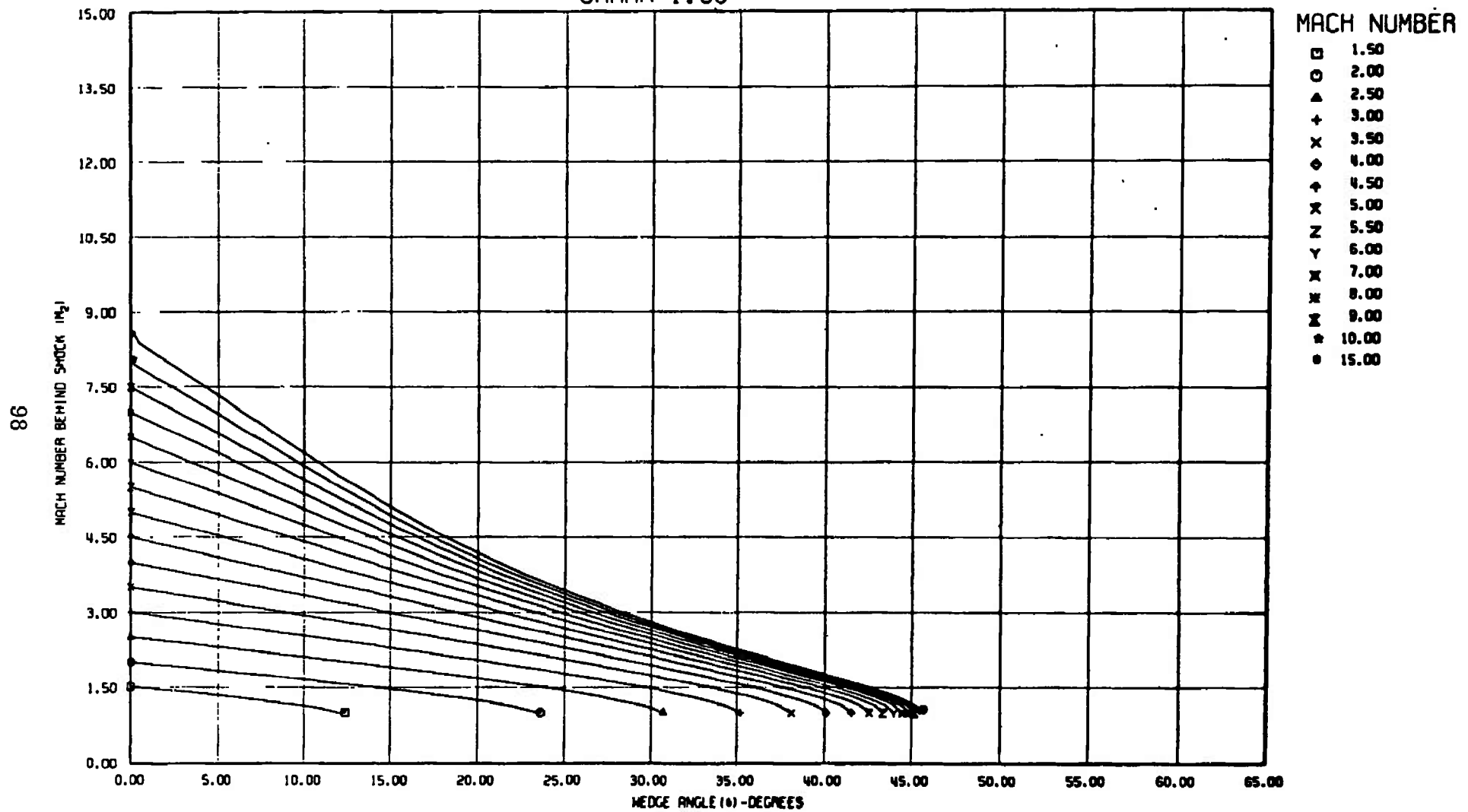


Fig. 15 Continued

OBLIQUE SHOCK
GAMMA=1.36

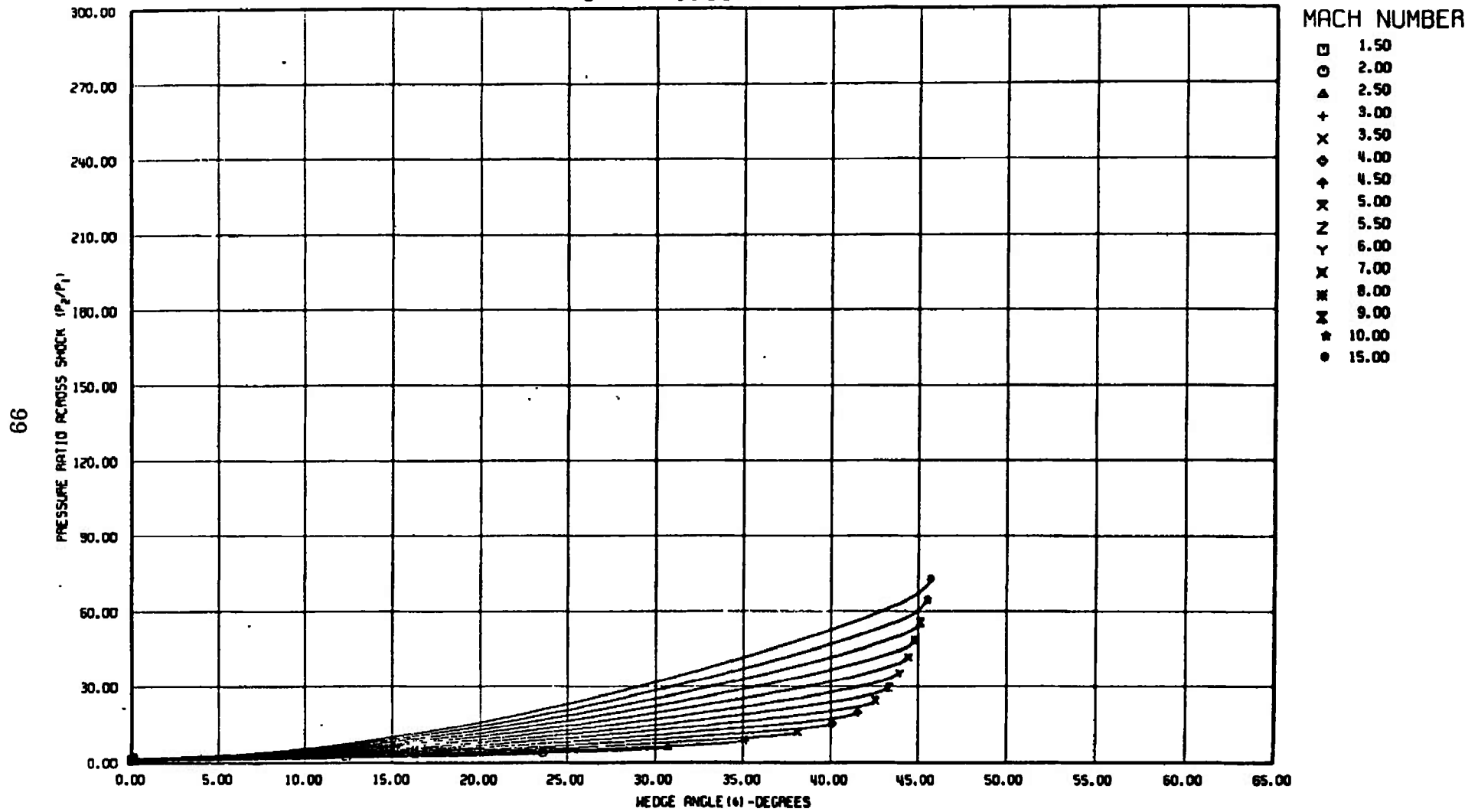


Fig. 15 Continued

OBLIQUE SHOCK
GAMMA=1.36

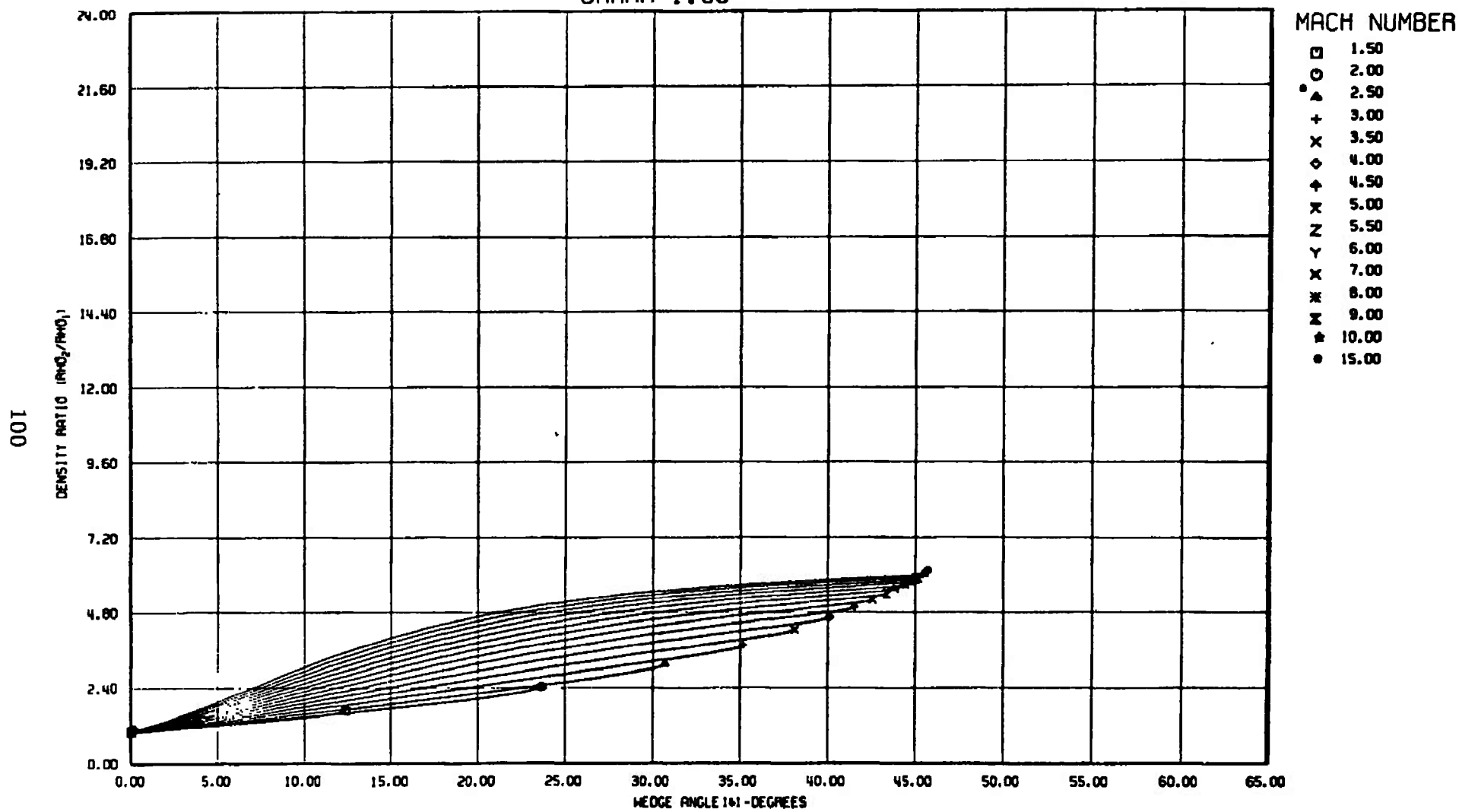


Fig. 15 Continued

OBLIQUE SHOCK
GAMMA=1.36

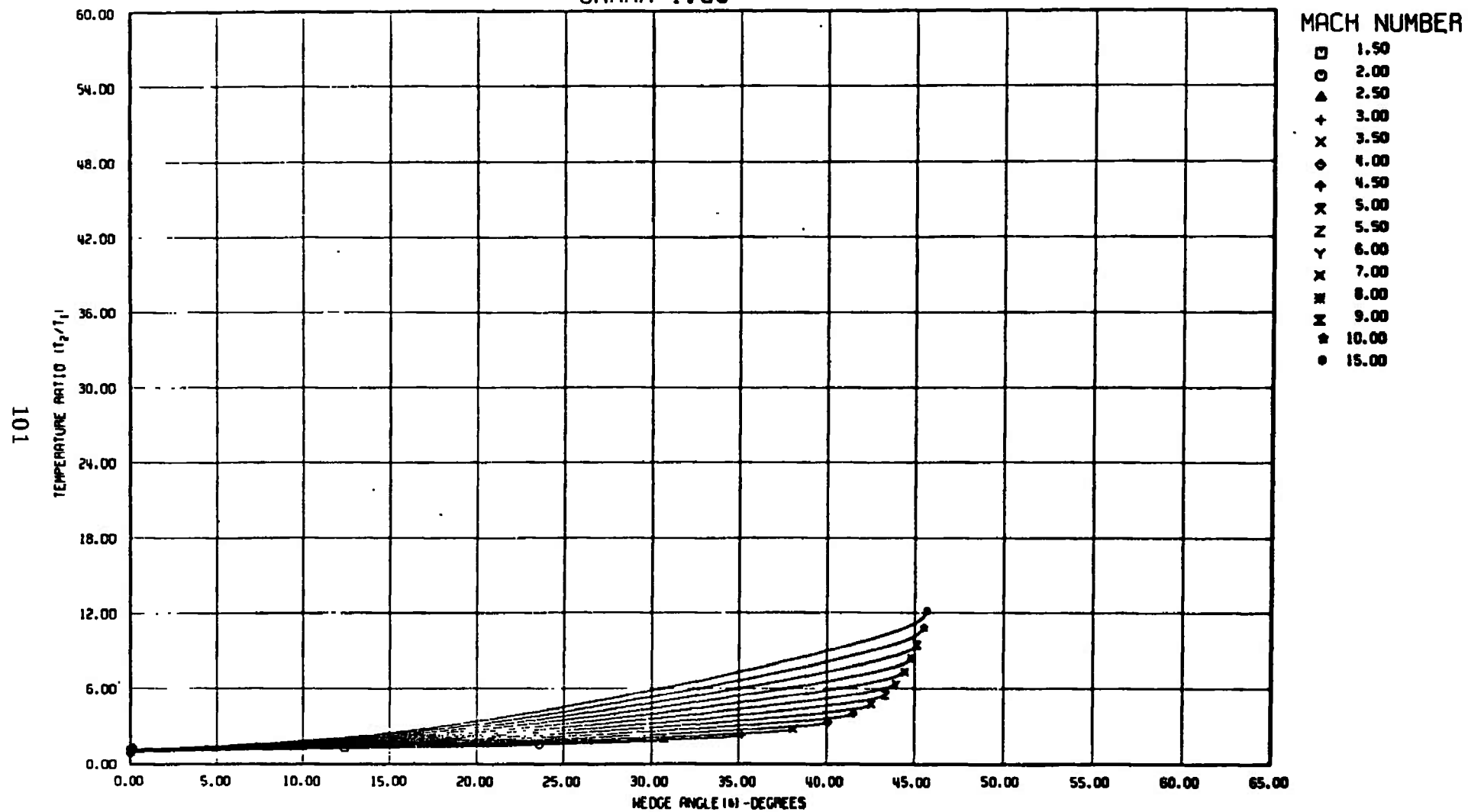


Fig. 15 Continued

OBLIQUE SHOCK GAMMA=1.36

102

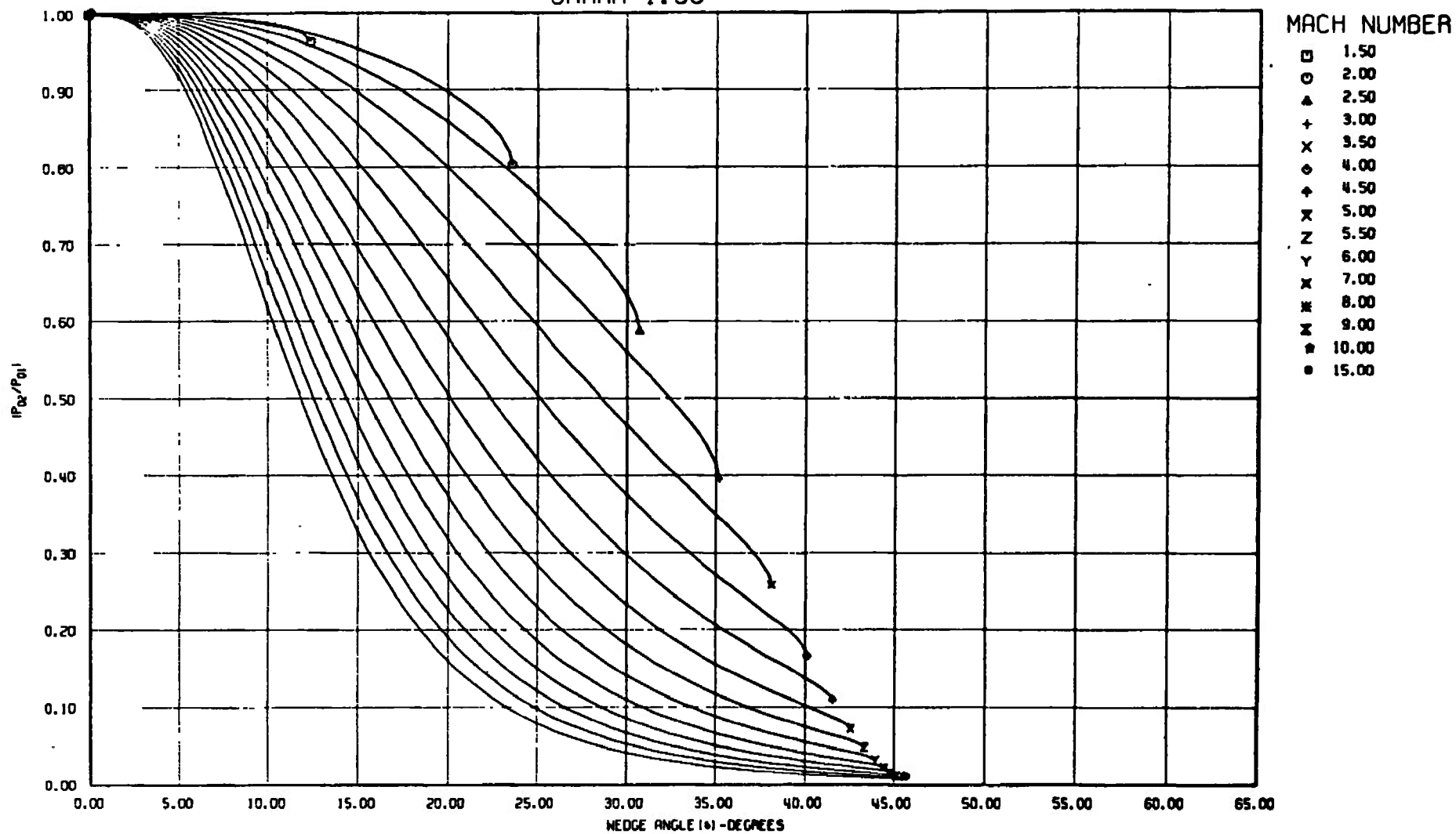


Fig. 15 Continued

OBLIQUE SHOCK GAMMA=1.36

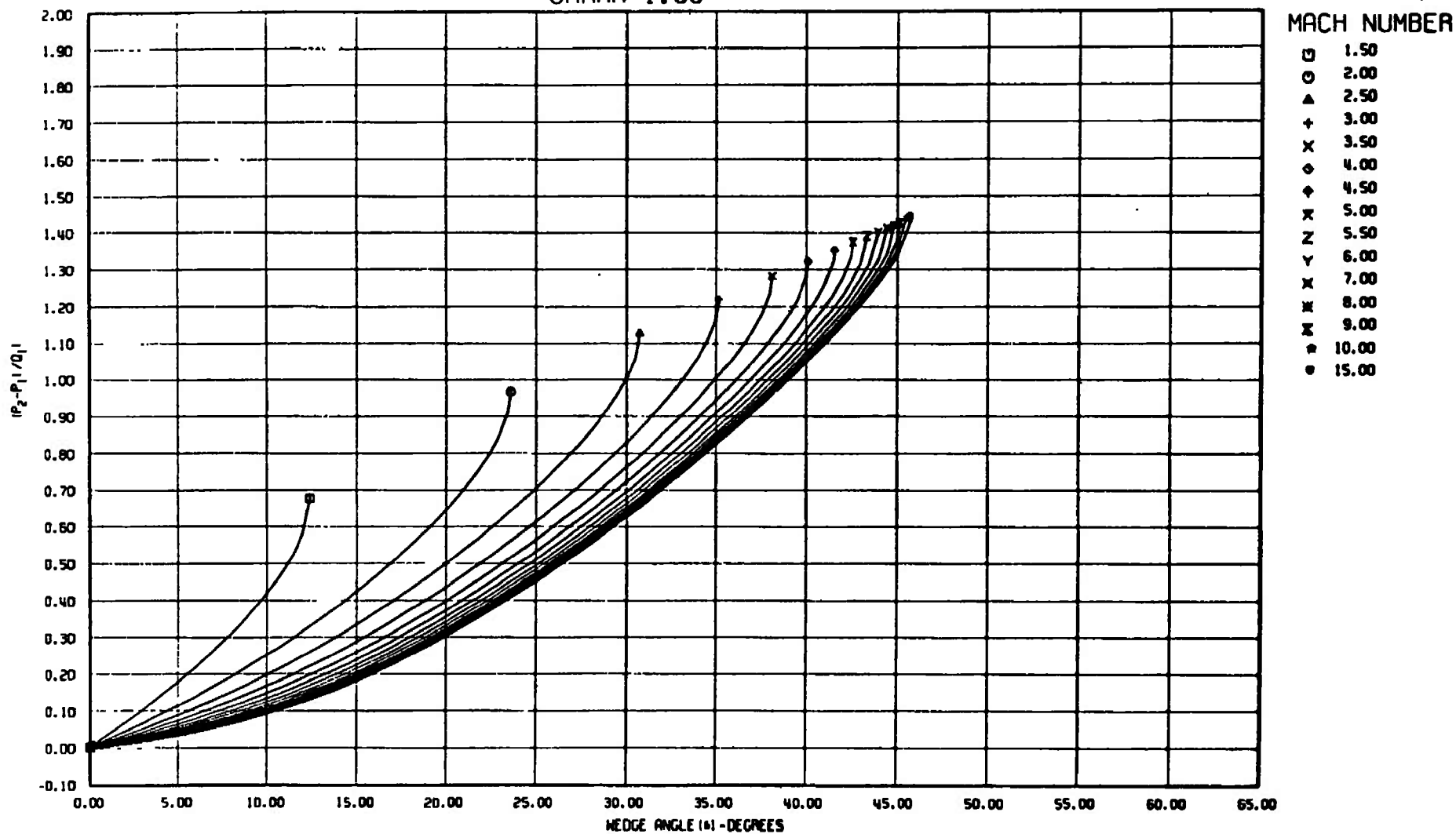


Fig. 15 Concluded

OBLIQUE SHOCK $\gamma = 1.38$

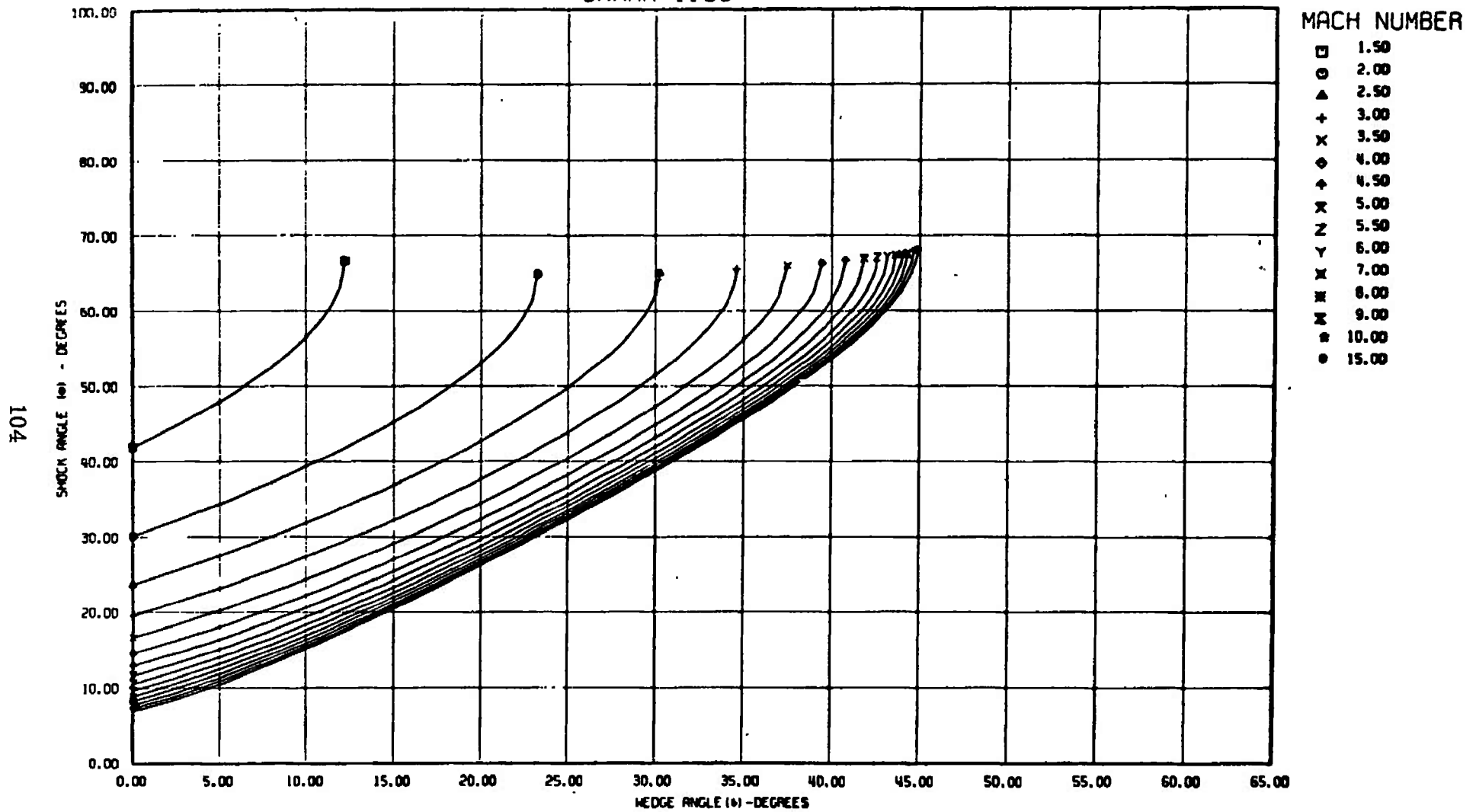


Fig. 16 $\gamma = 1.38$

OBLIQUE SHOCK
 $\gamma = 1.38$

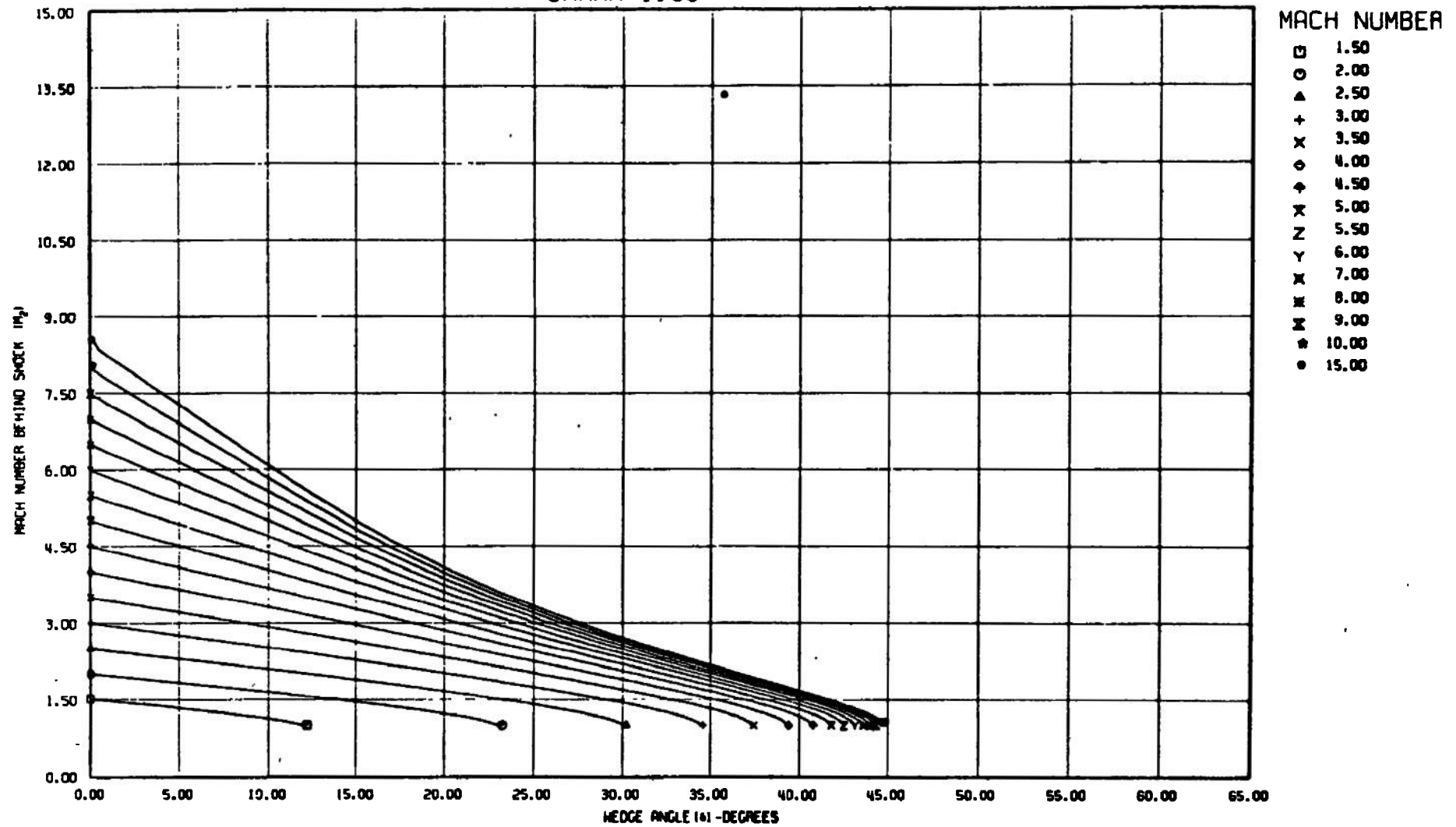


Fig. 16 Continued

OBLIQUE SHOCK GAMMA=1.38

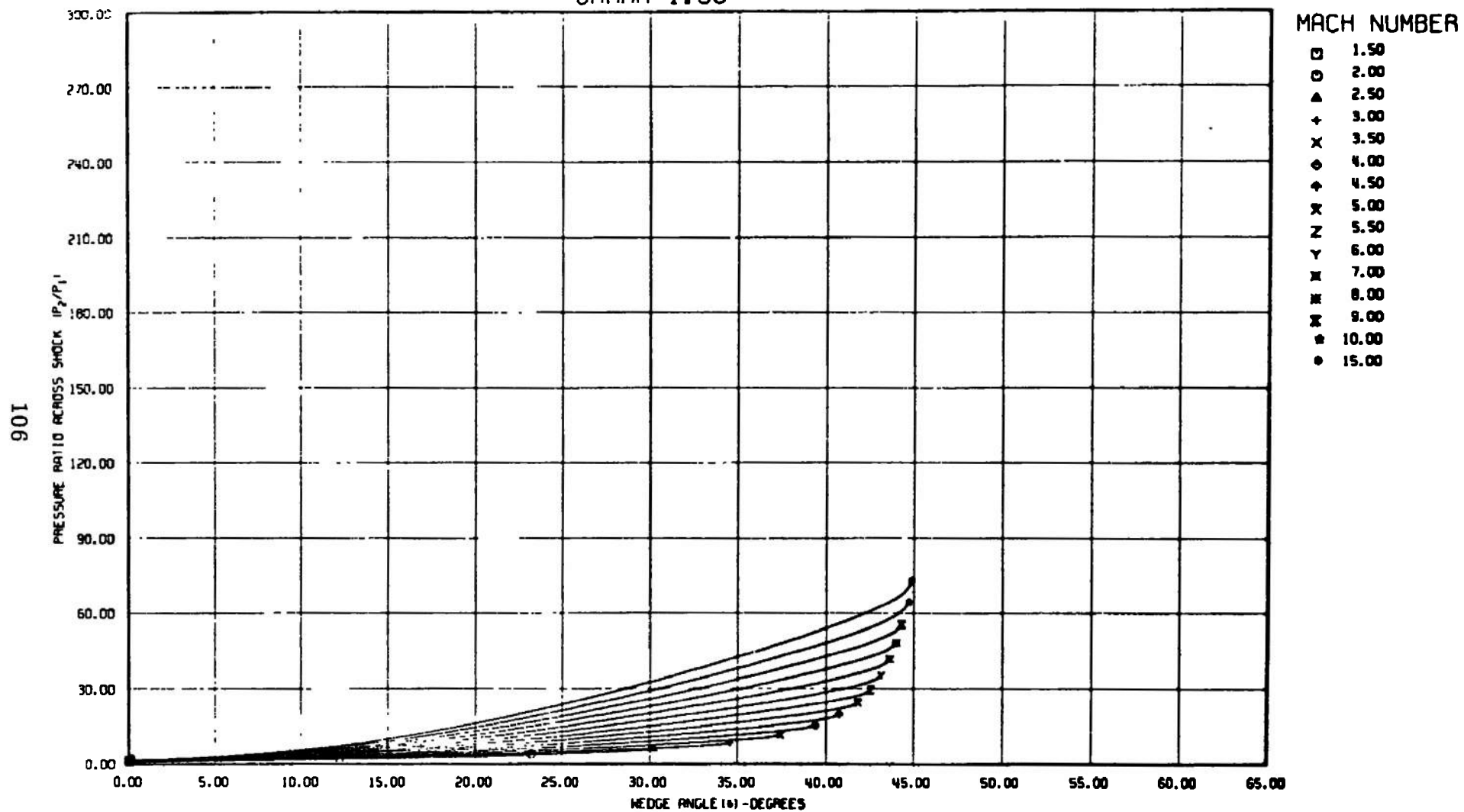


Fig. 16 Continued

OBLIQUE SHOCK
GAMMA=1.38

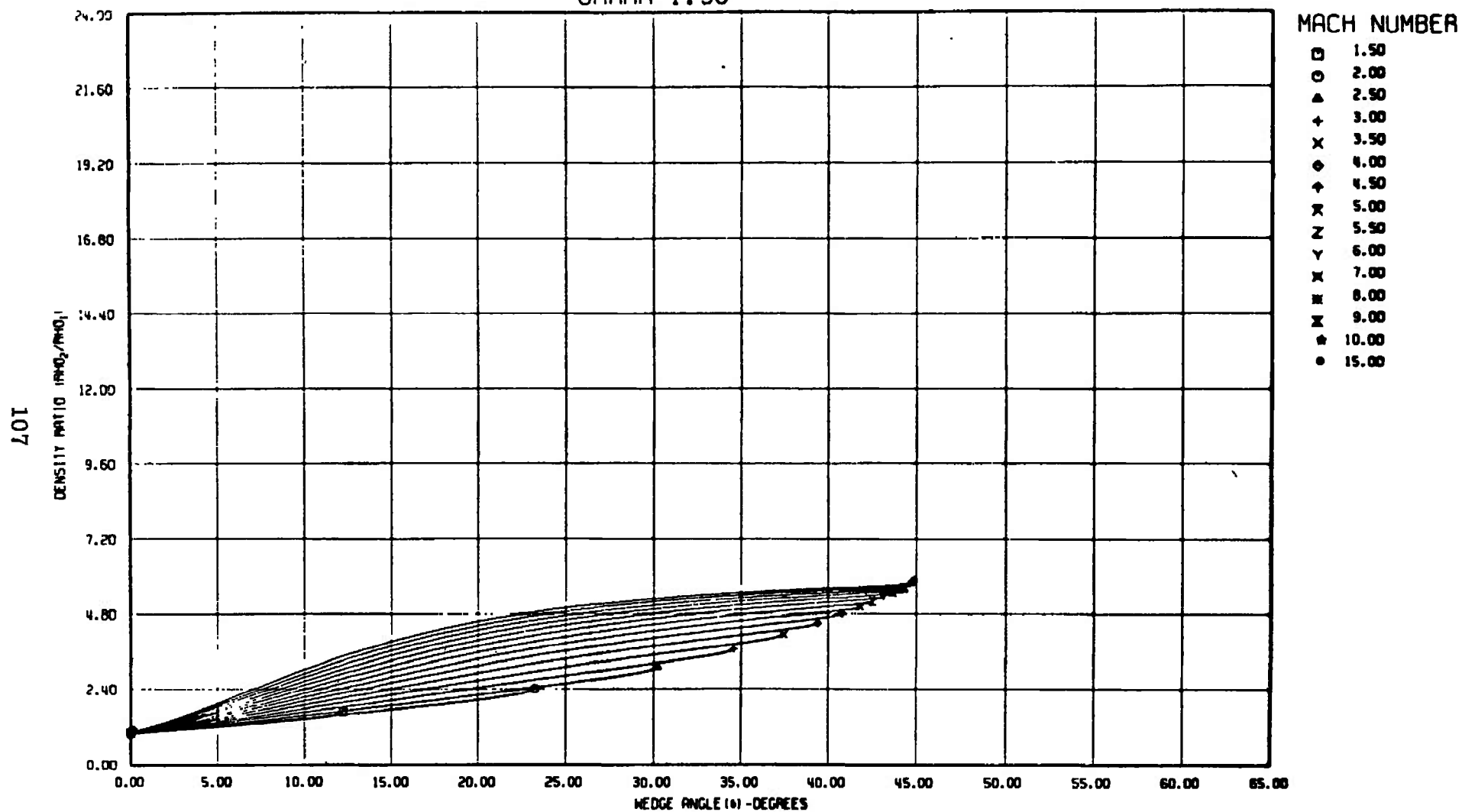


Fig. 16 Continued

OBLIQUE SHOCK GAMMA=1.38

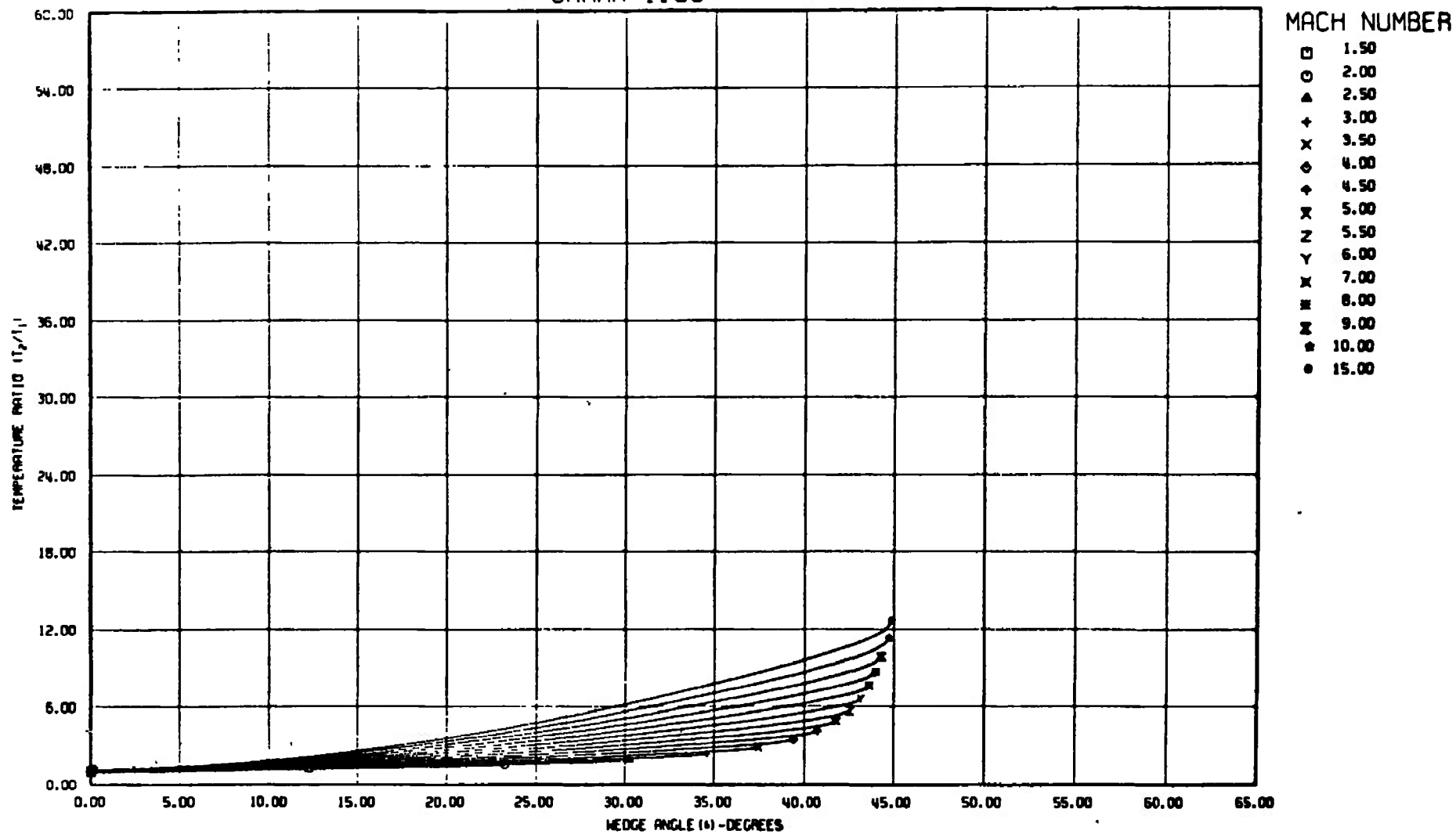


Fig. 16 Continued

OBLIQUE SHOCK GAMMA=1.38

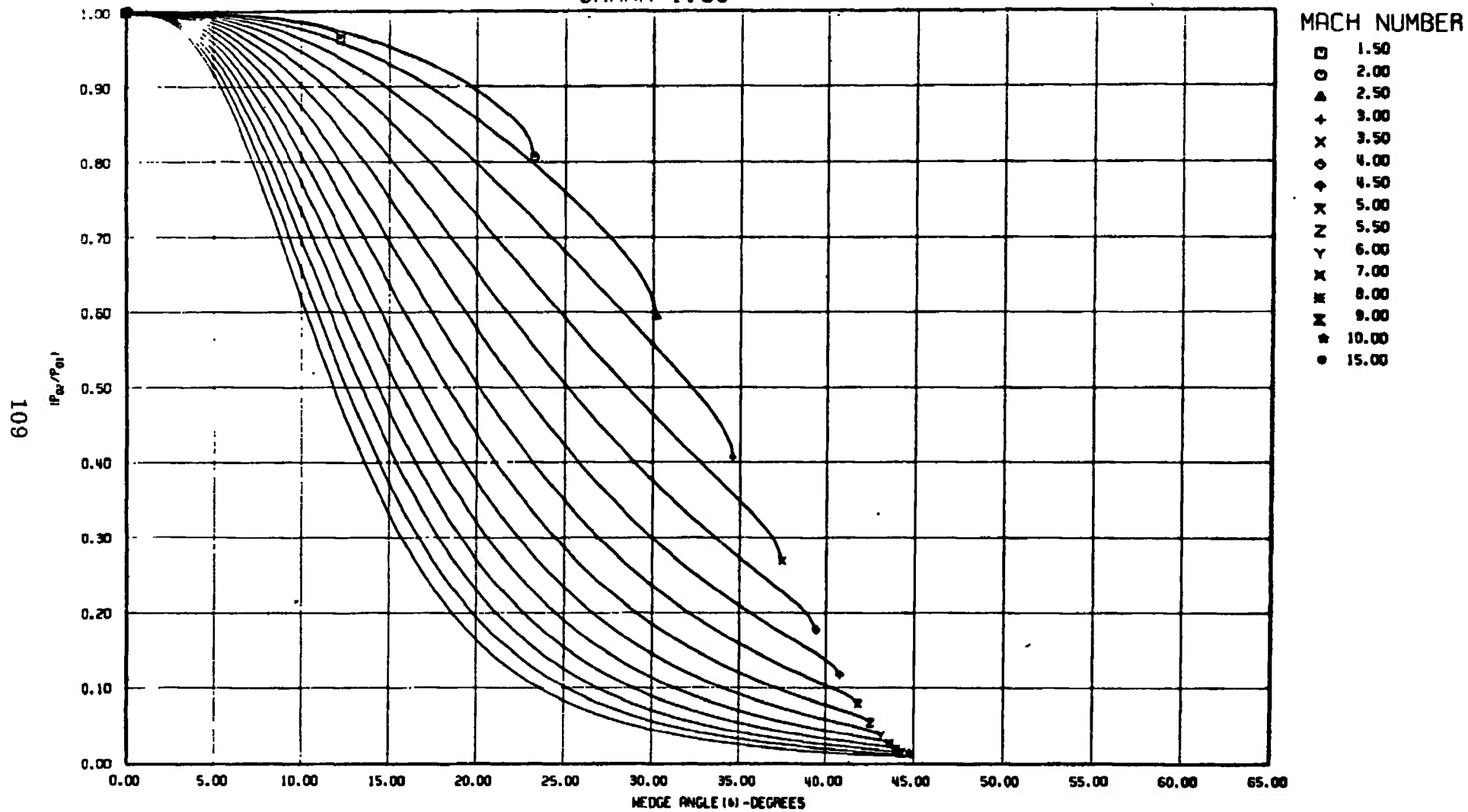


Fig. 16 Continued

OBLIQUE SHOCK GAMMA=1.38

110

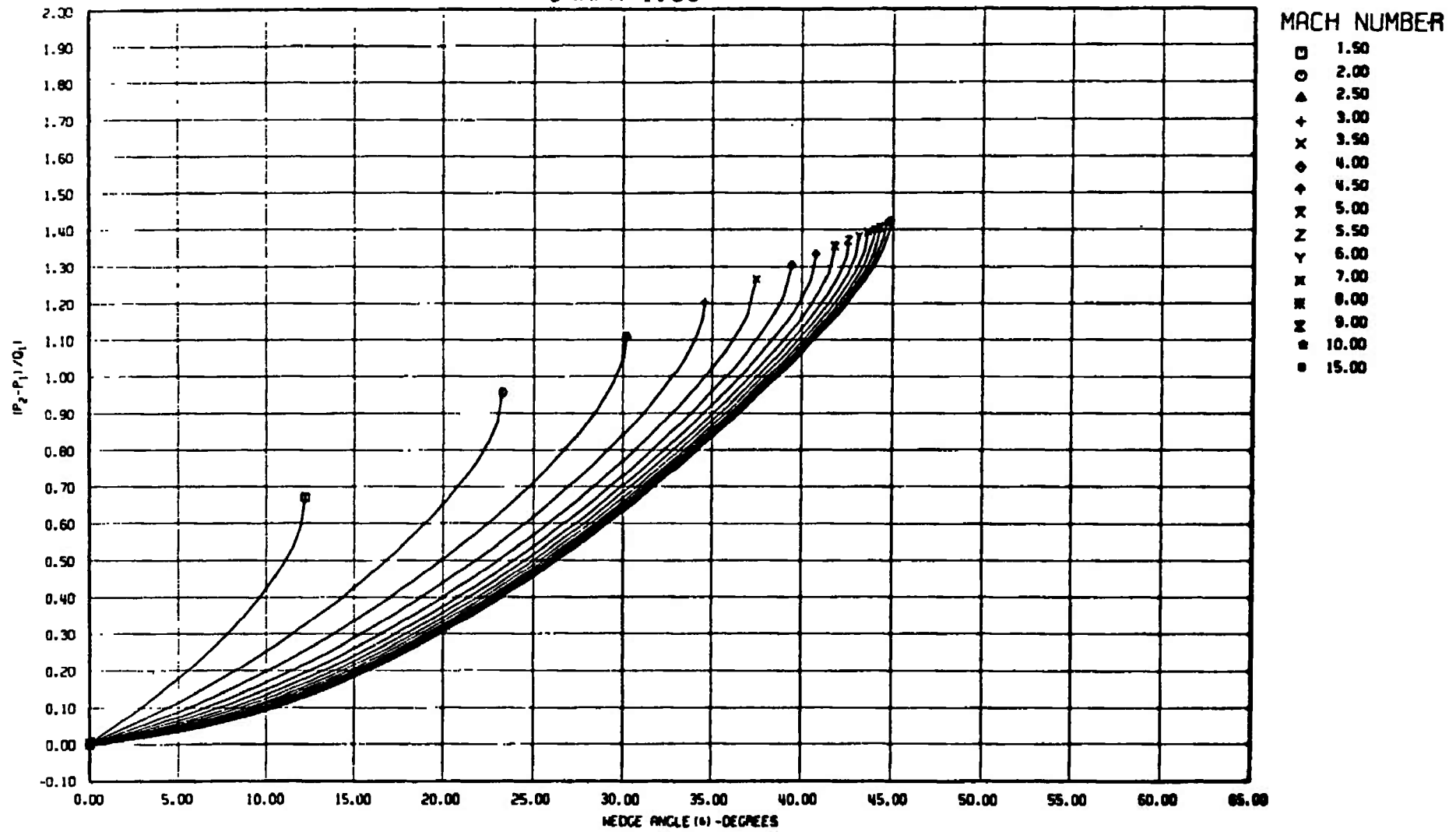


Fig. 16 Concluded

OBLIQUE SHOCK
 $\gamma = 1.40$

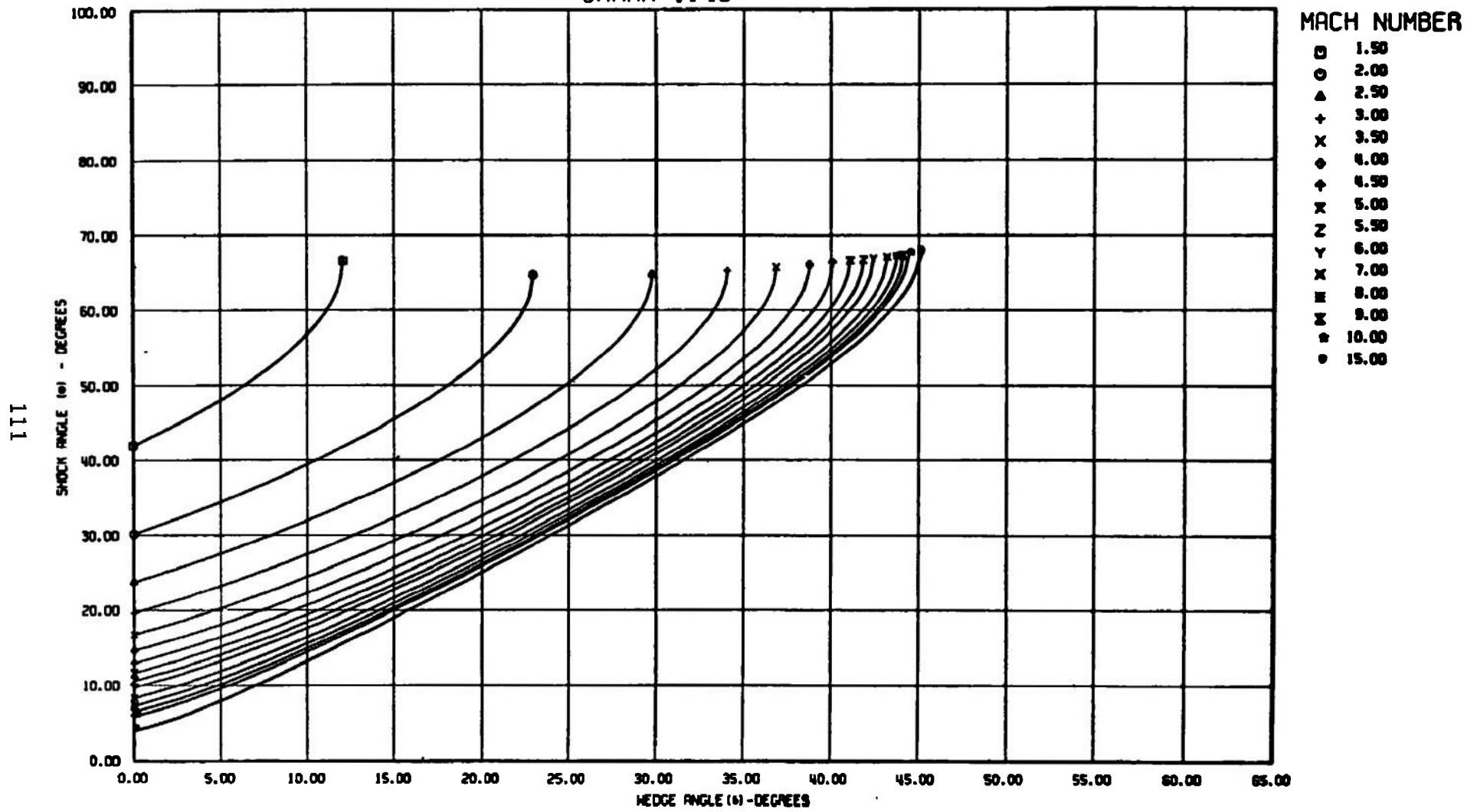


Fig. 17 $\gamma = 1.40$

OBLIQUE SHOCK GAMMA=1.40

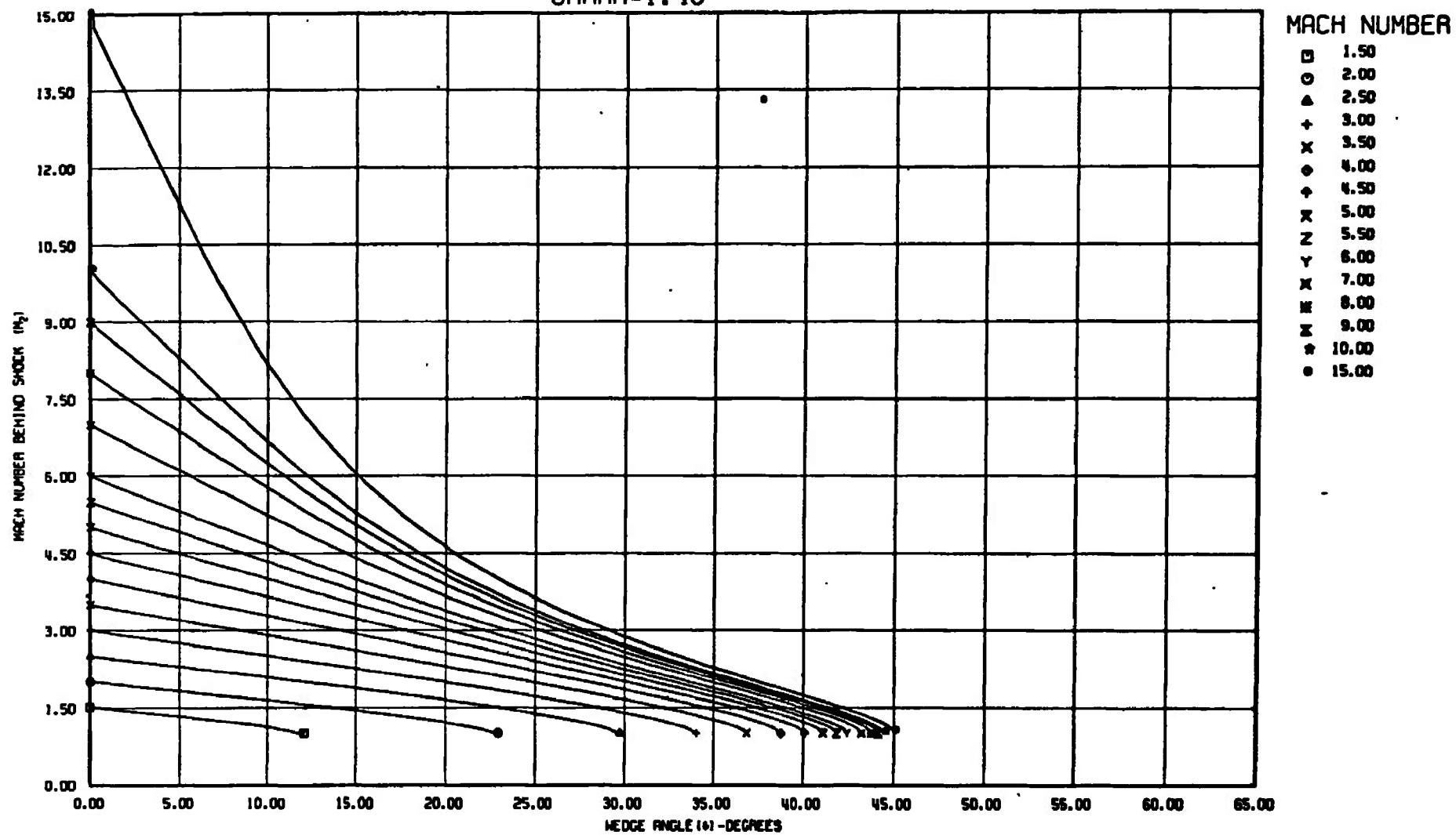
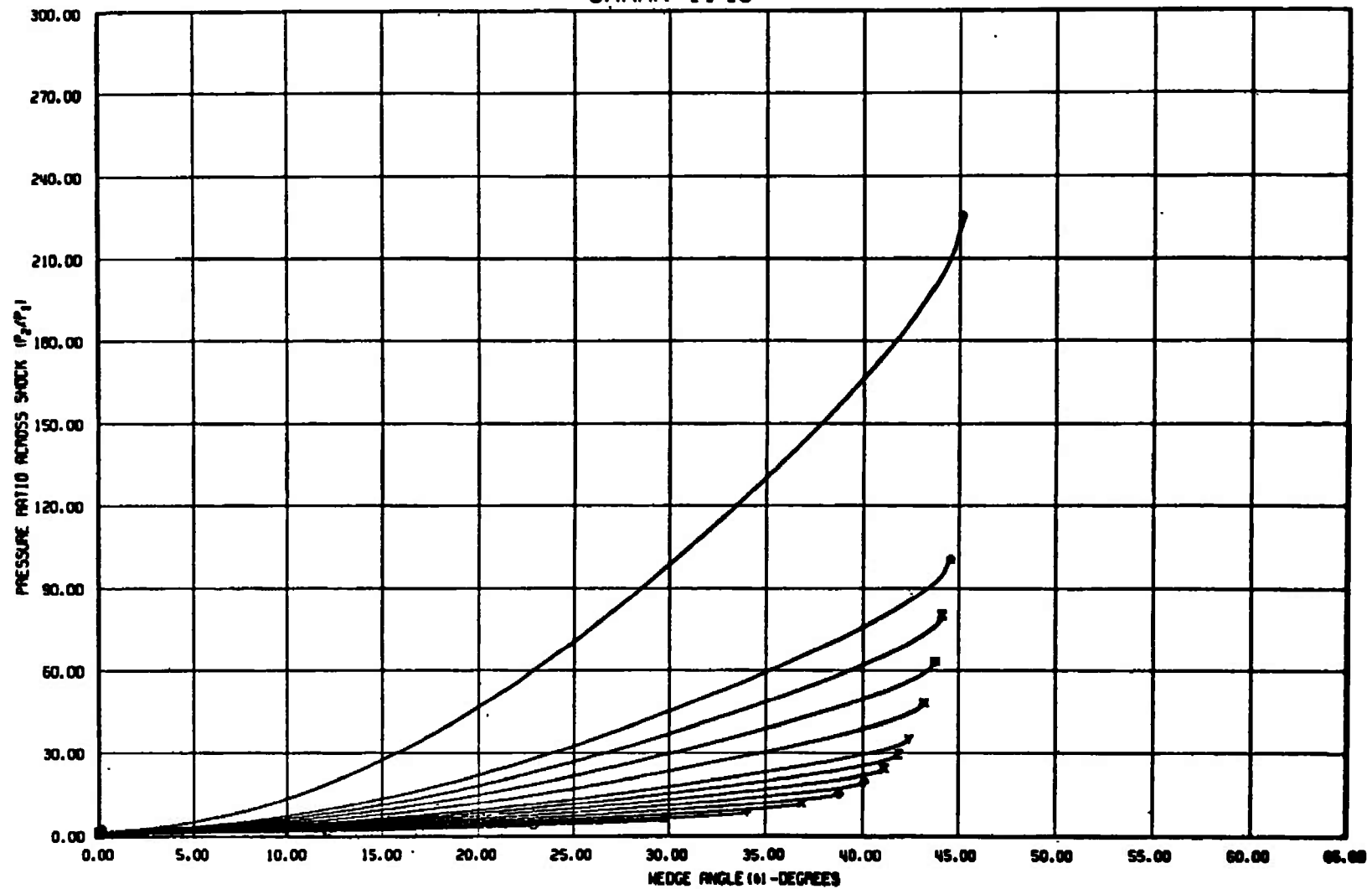


Fig. 17 Continued

OBLIQUE SHOCK GAMMA=1.40



MACH NUMBER

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- △ 2.50
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- x 5.00
- y 5.50
- z 6.00
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- x 9.00
- x 10.00
- x 15.00

Fig. 17 Continued

OBLIQUE SHOCK GAMMA=1.40

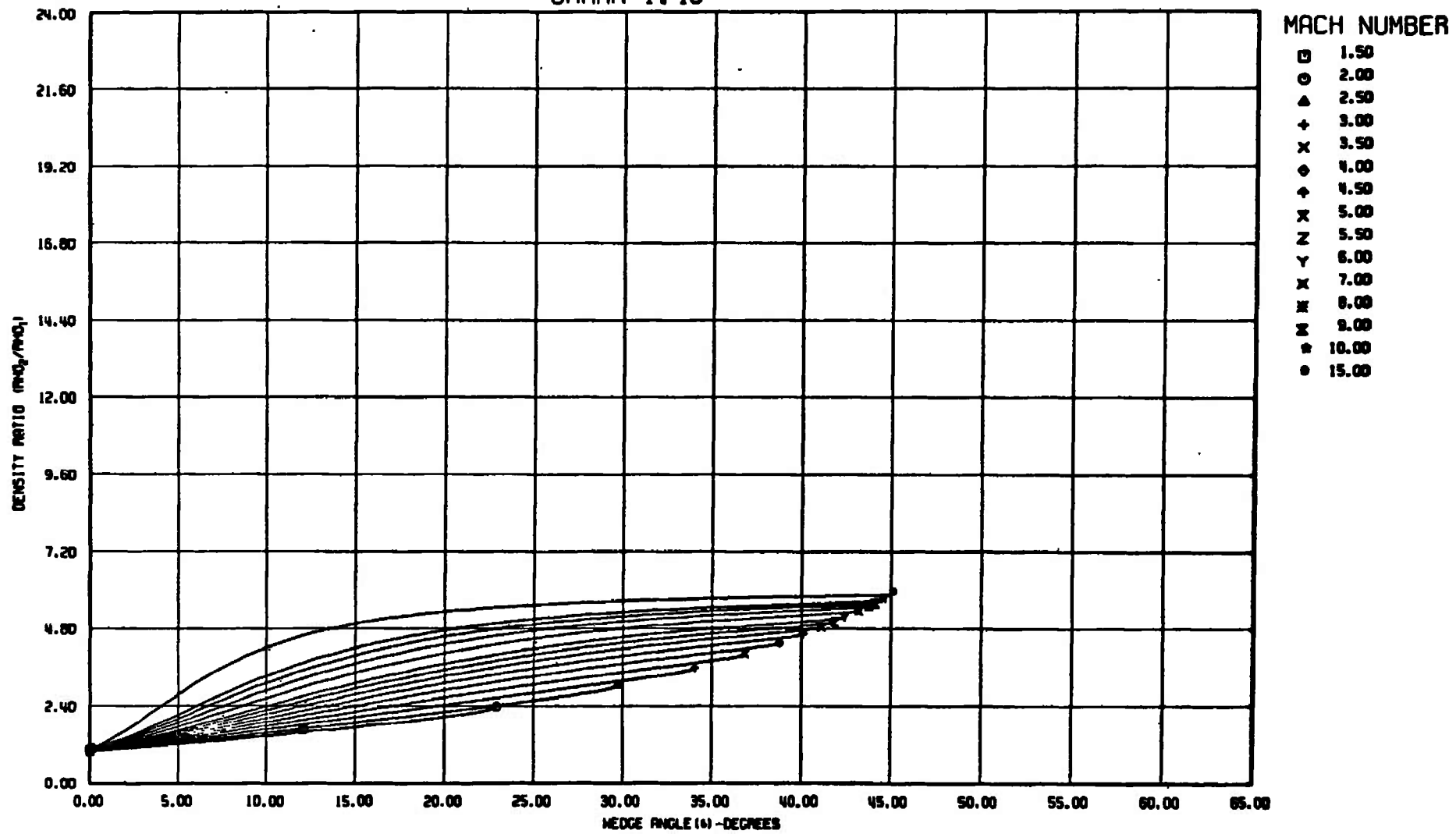
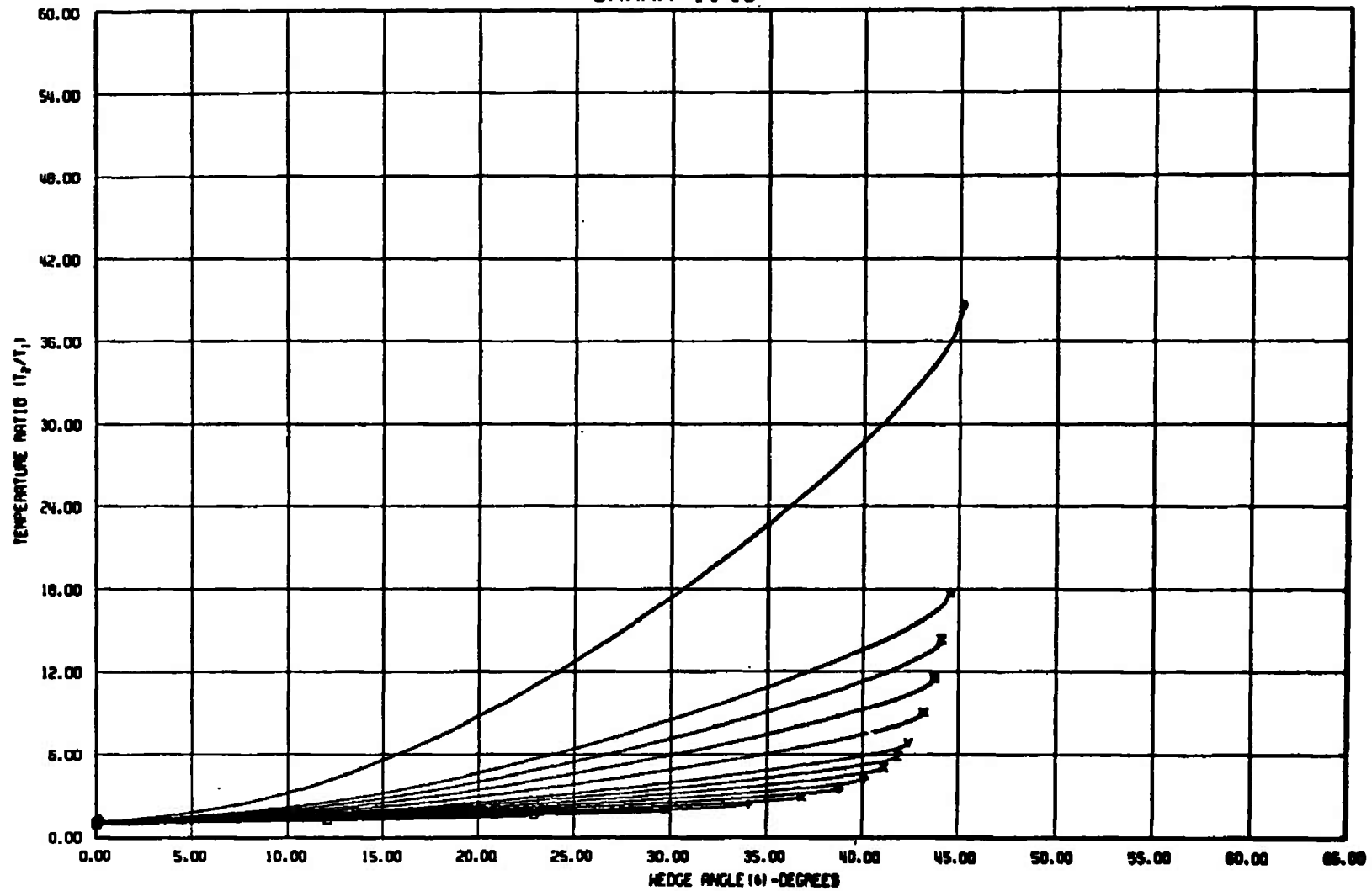


Fig. 17 Continued

OBLIQUE SHOCK
GAMMA=1.40



MACH NUMBER

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- ⊕ 4.50
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- ⊚ 5.50
- ⊛ 6.00
- ⊜ 7.00
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- ⊡ 15.00

Fig. 17 Continued

OBLIQUE SHOCK
GAMMA=1.40

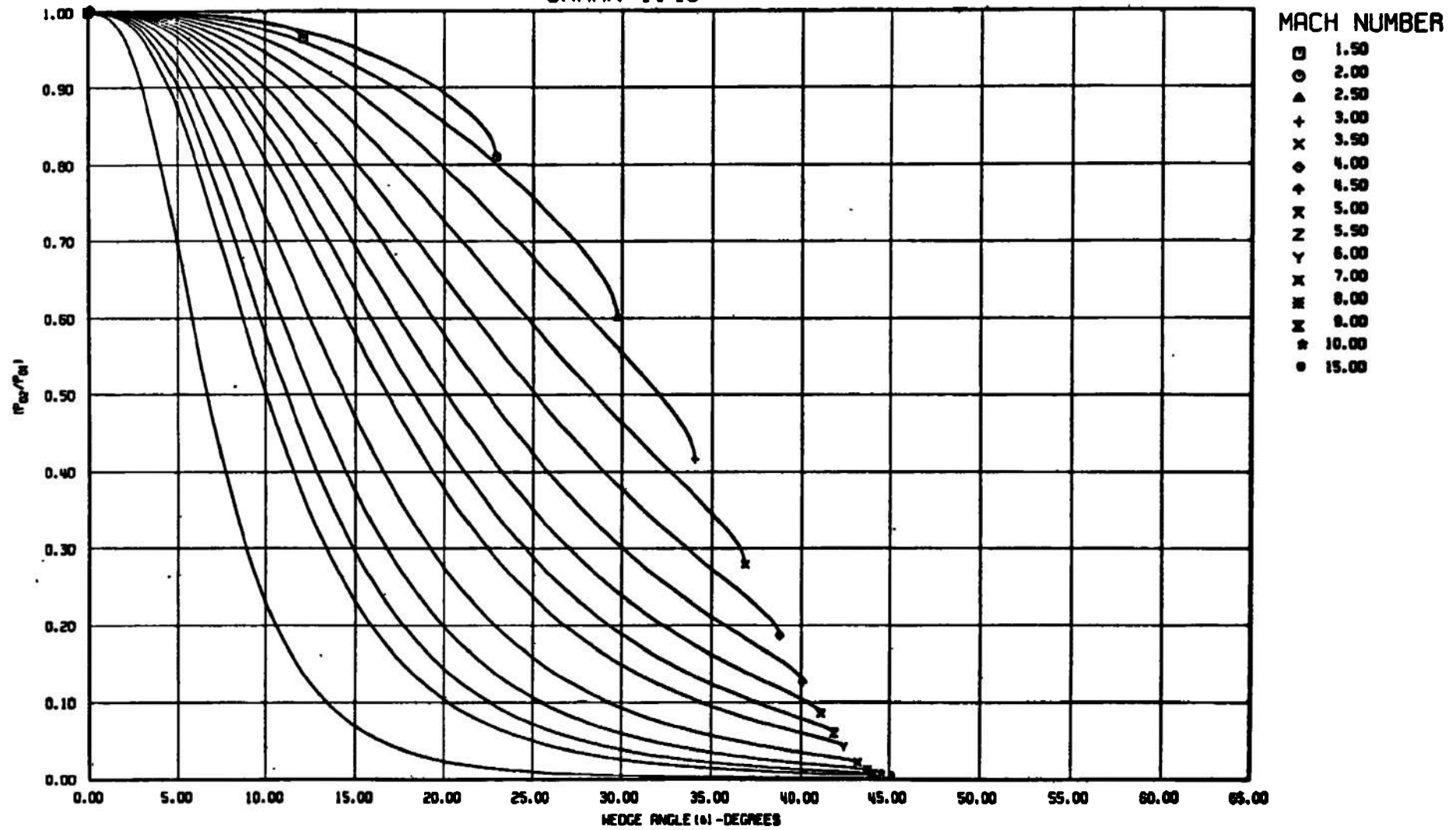


Fig. 17 Continued

OBLIQUE SHOCK GAMMA=1.40

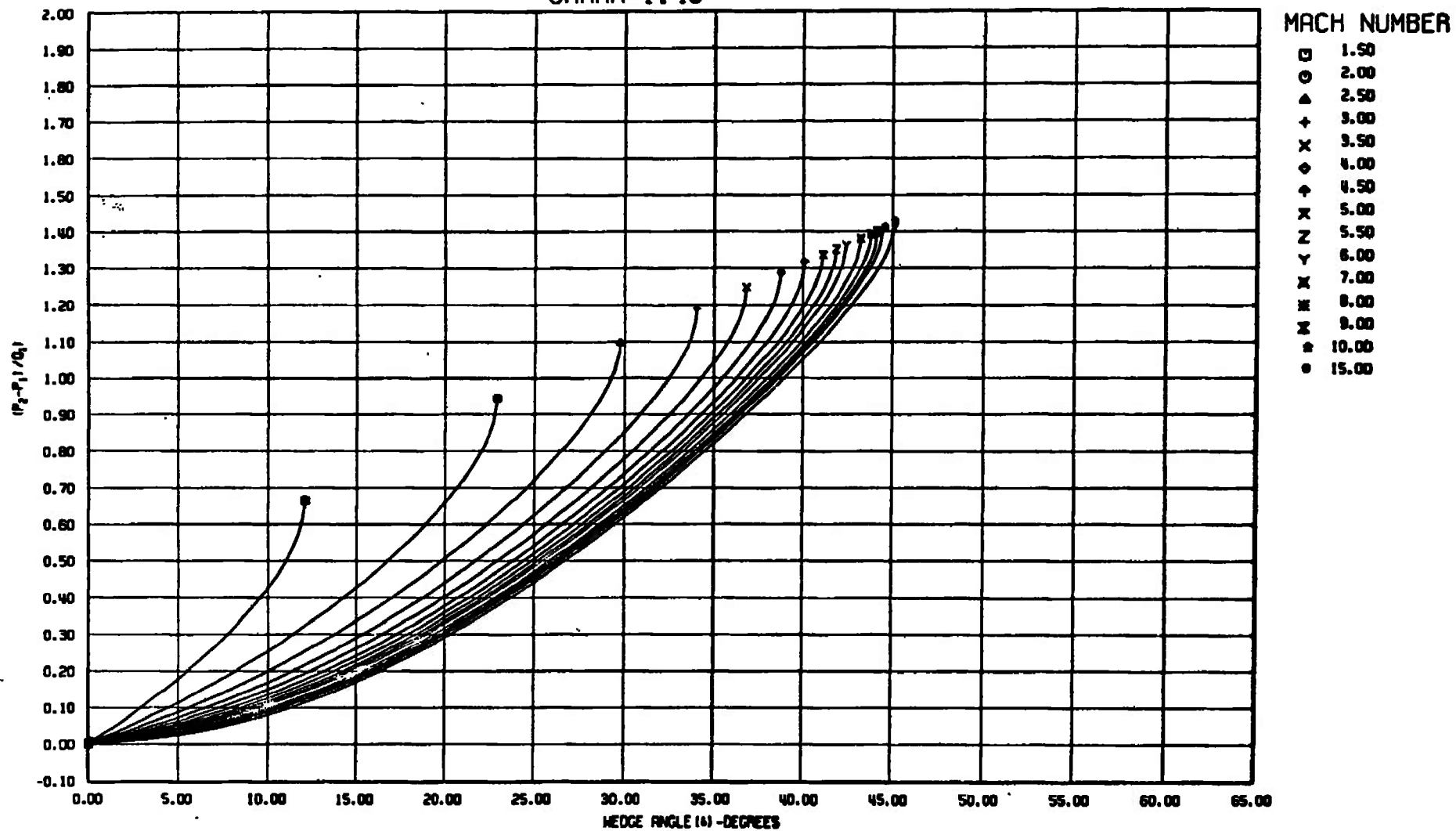


Fig. 17 Concluded

OBLIQUE SHOCK GAMMA=1.42

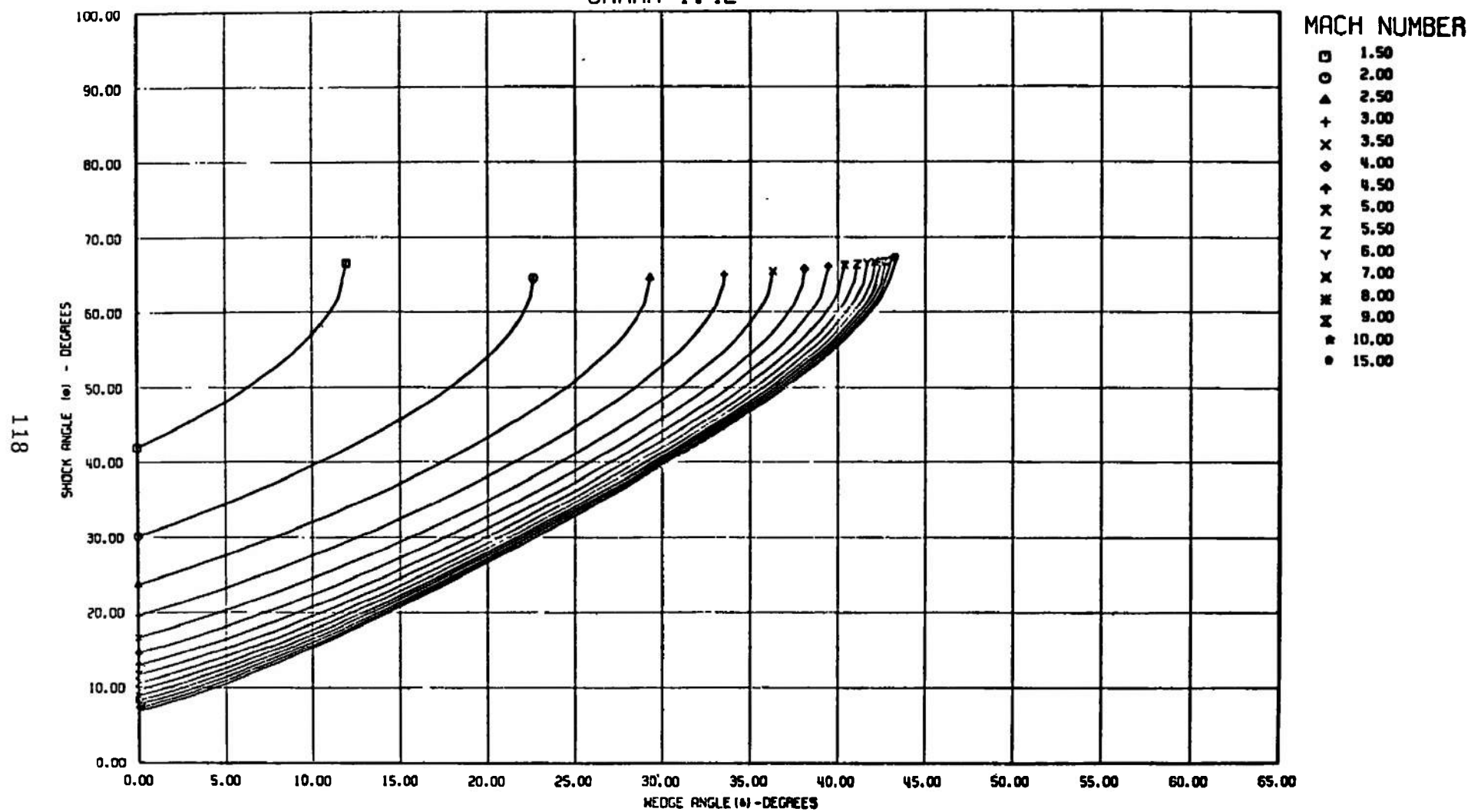


Fig. 18 $\gamma = 1.42$

OBLIQUE SHOCK GAMMA=1.42

119

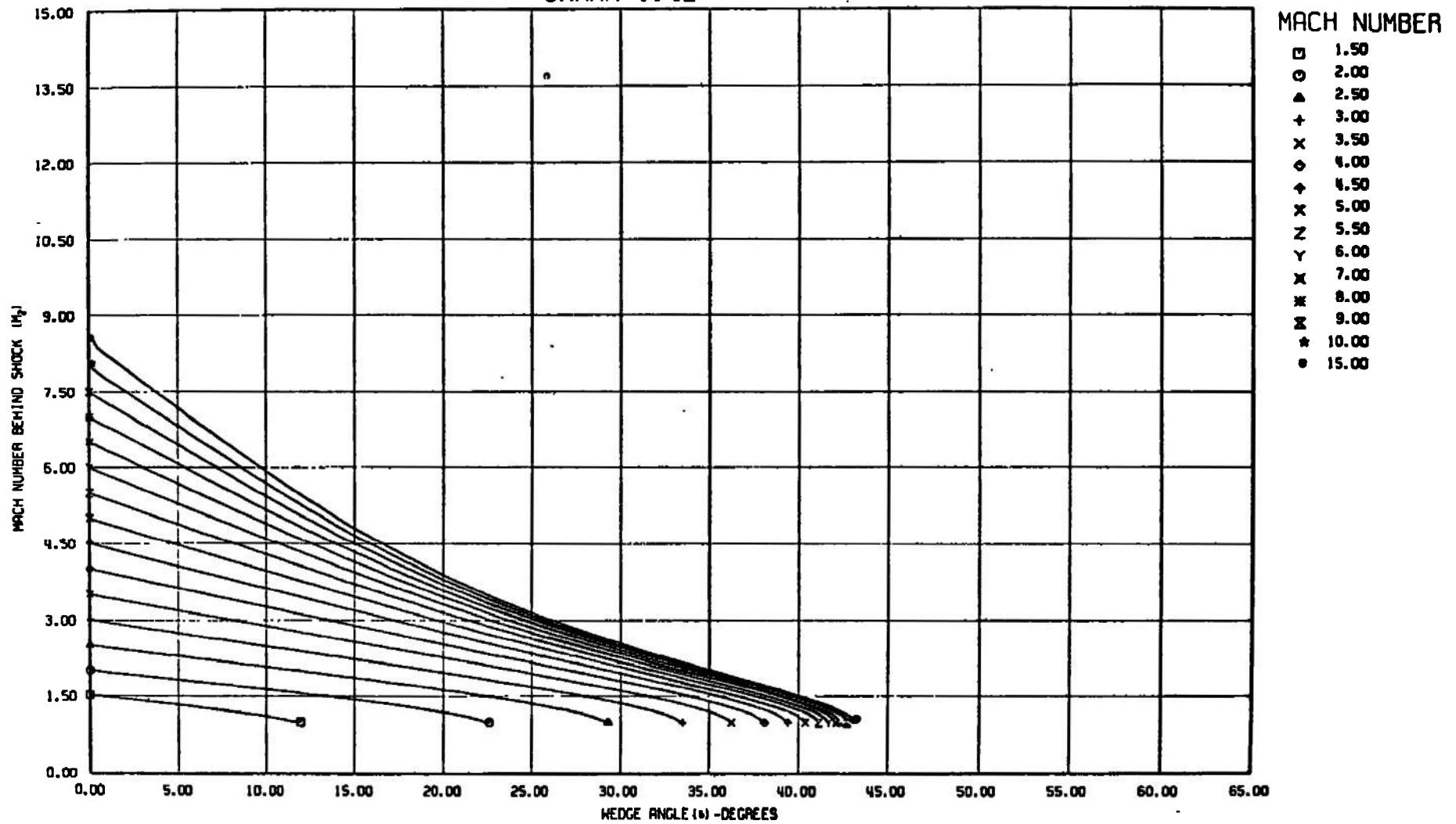


Fig. 18 Continued

OBLIQUE SHOCK GAMMA=1.42

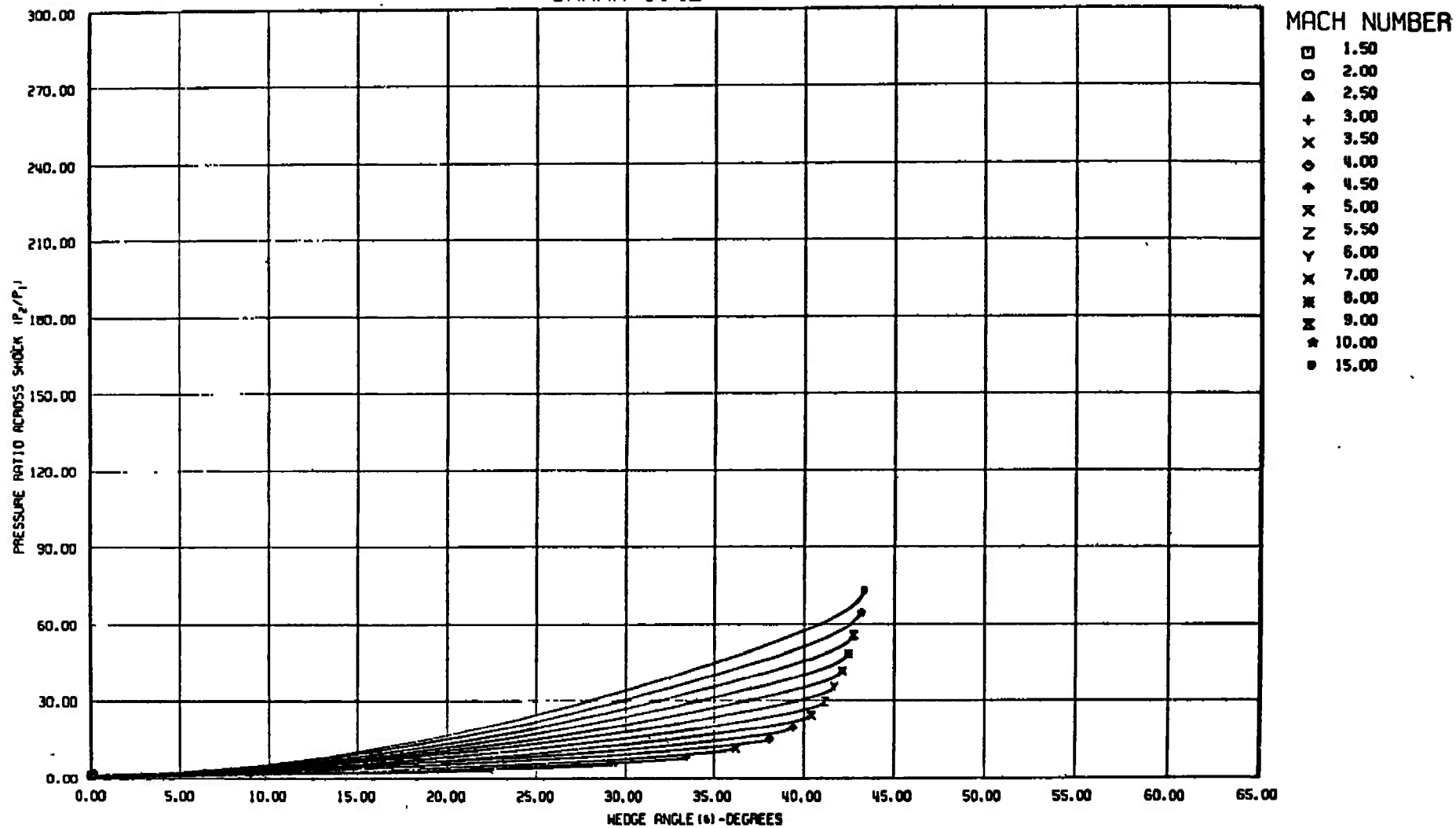


Fig. 18 Continued

OBLIQUE SHOCK GAMMA=1.42

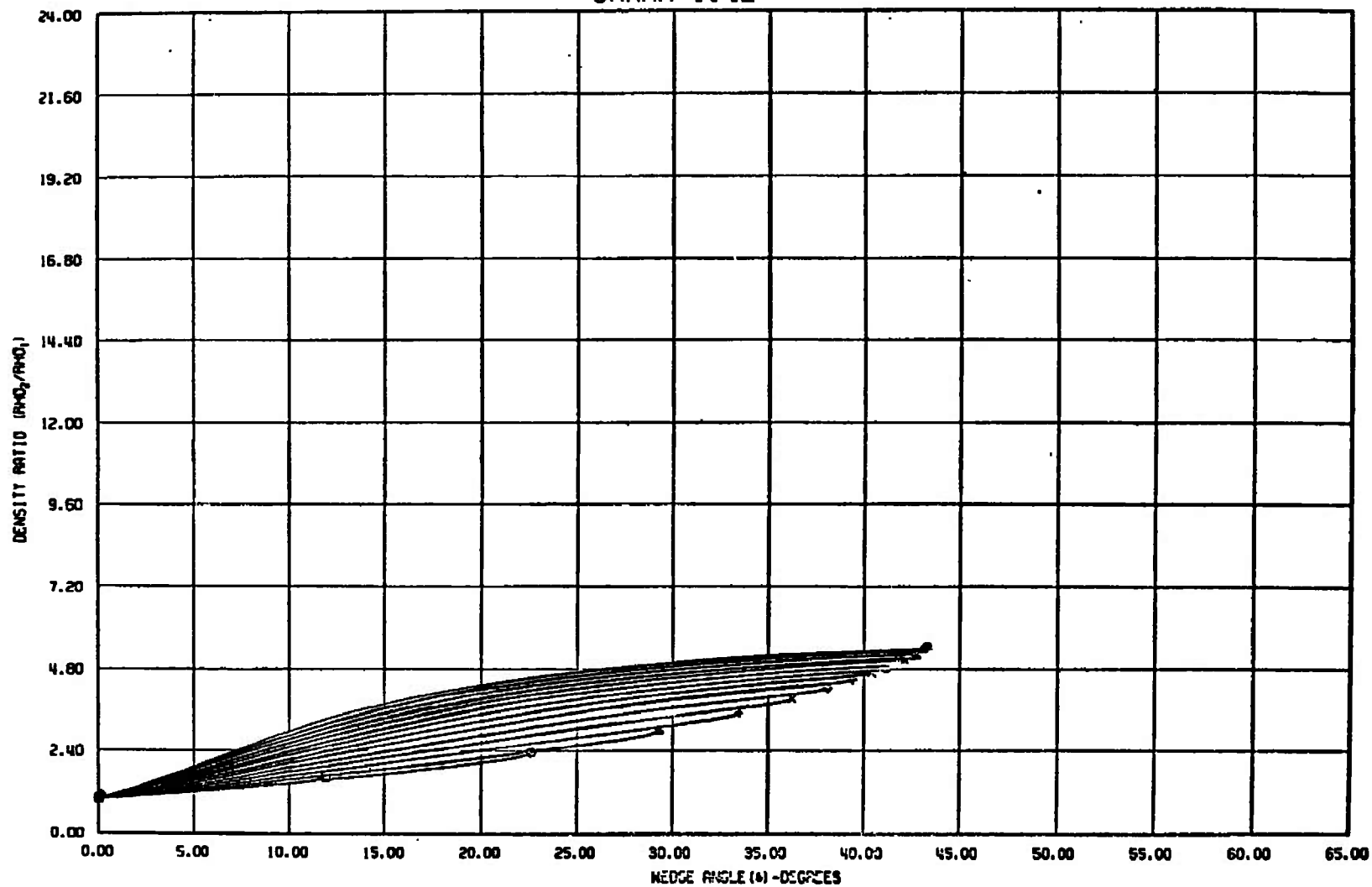
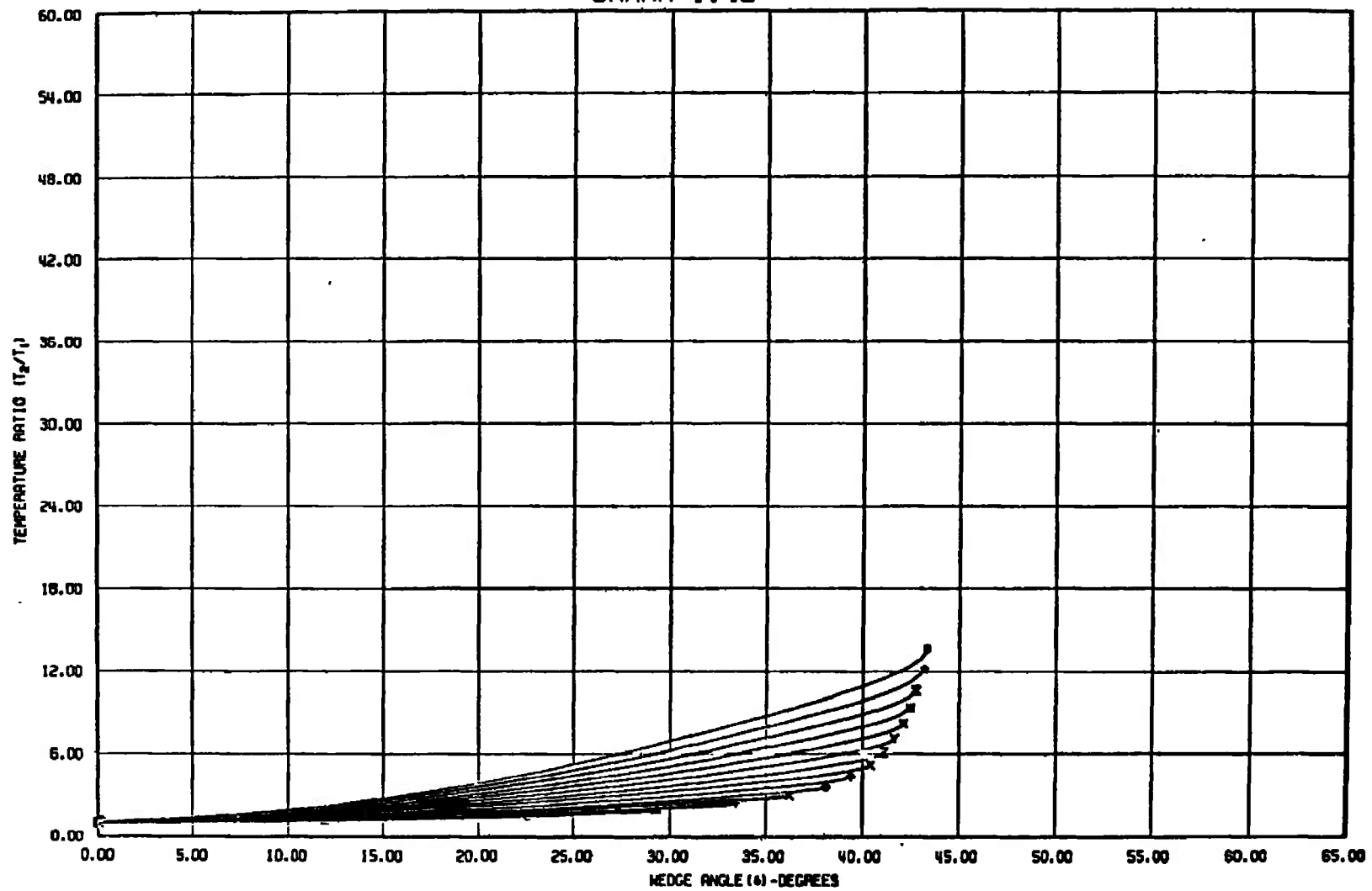


Fig. 18 Continued

OBLIQUE SHOCK GAMMA=1.42

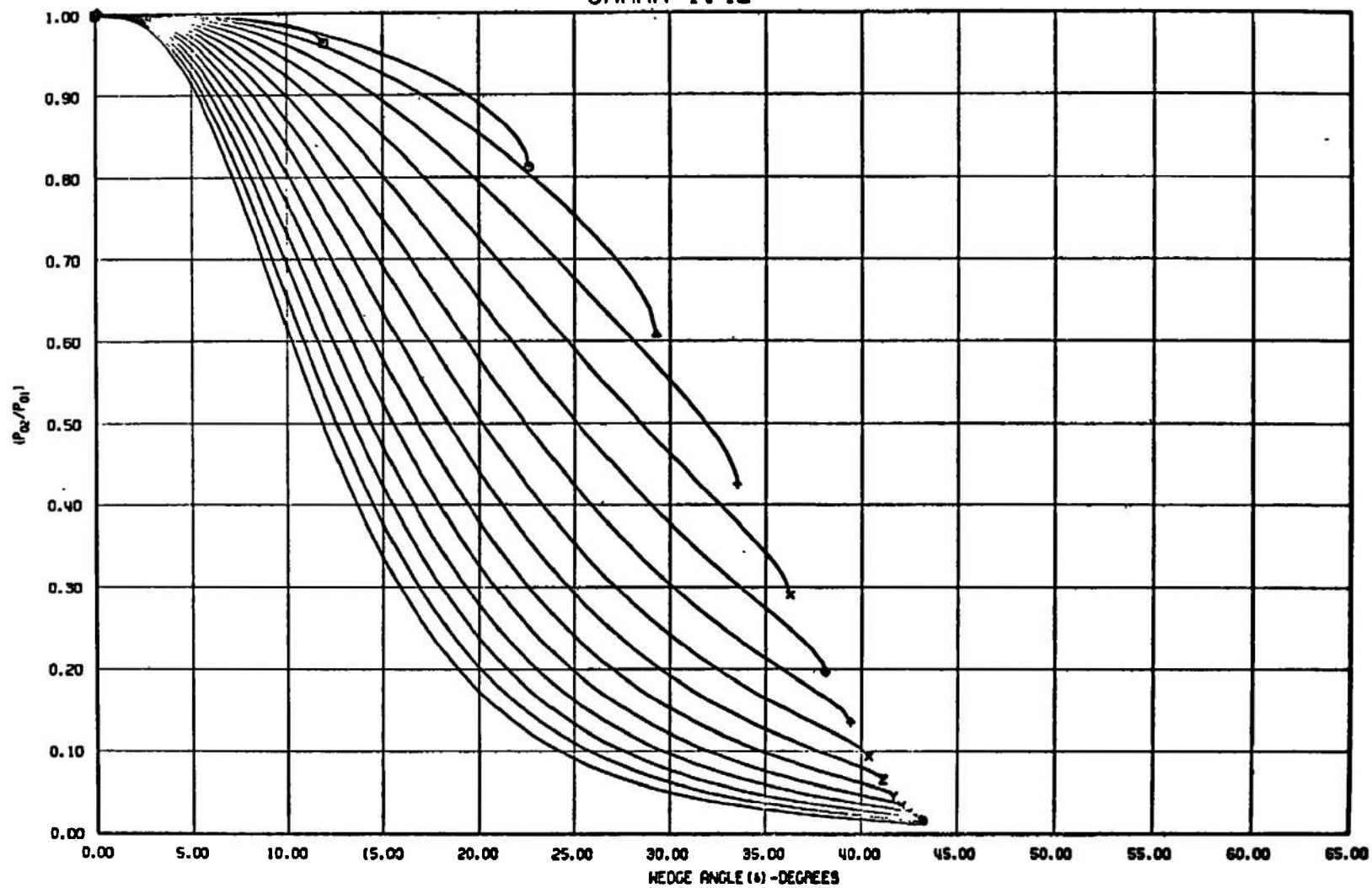


MACH NUMBER

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- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- † 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- ≡ 8.00
- z 9.00
- ★ 10.00
- 15.00

Fig. 18 Continued

OBLIQUE SHOCK
GAMMA=1.42



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- † 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- x 8.00
- x 9.00
- * 10.00
- 15.00

Fig. 18 Continued

OBLIQUE SHOCK
GAMMA=1.42

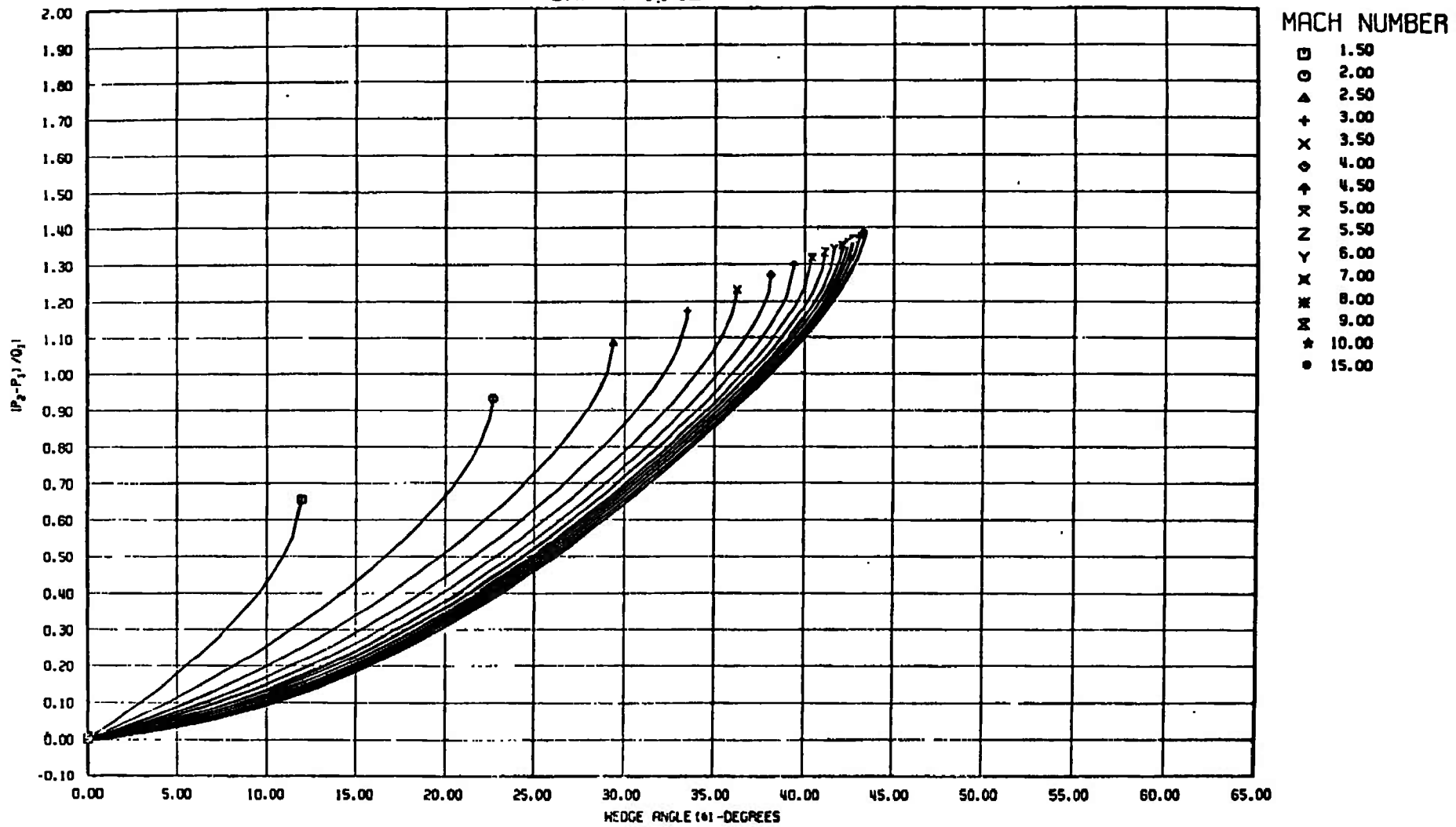


Fig. 18 Concluded

OBLIQUE SHOCK $\gamma = 1.44$

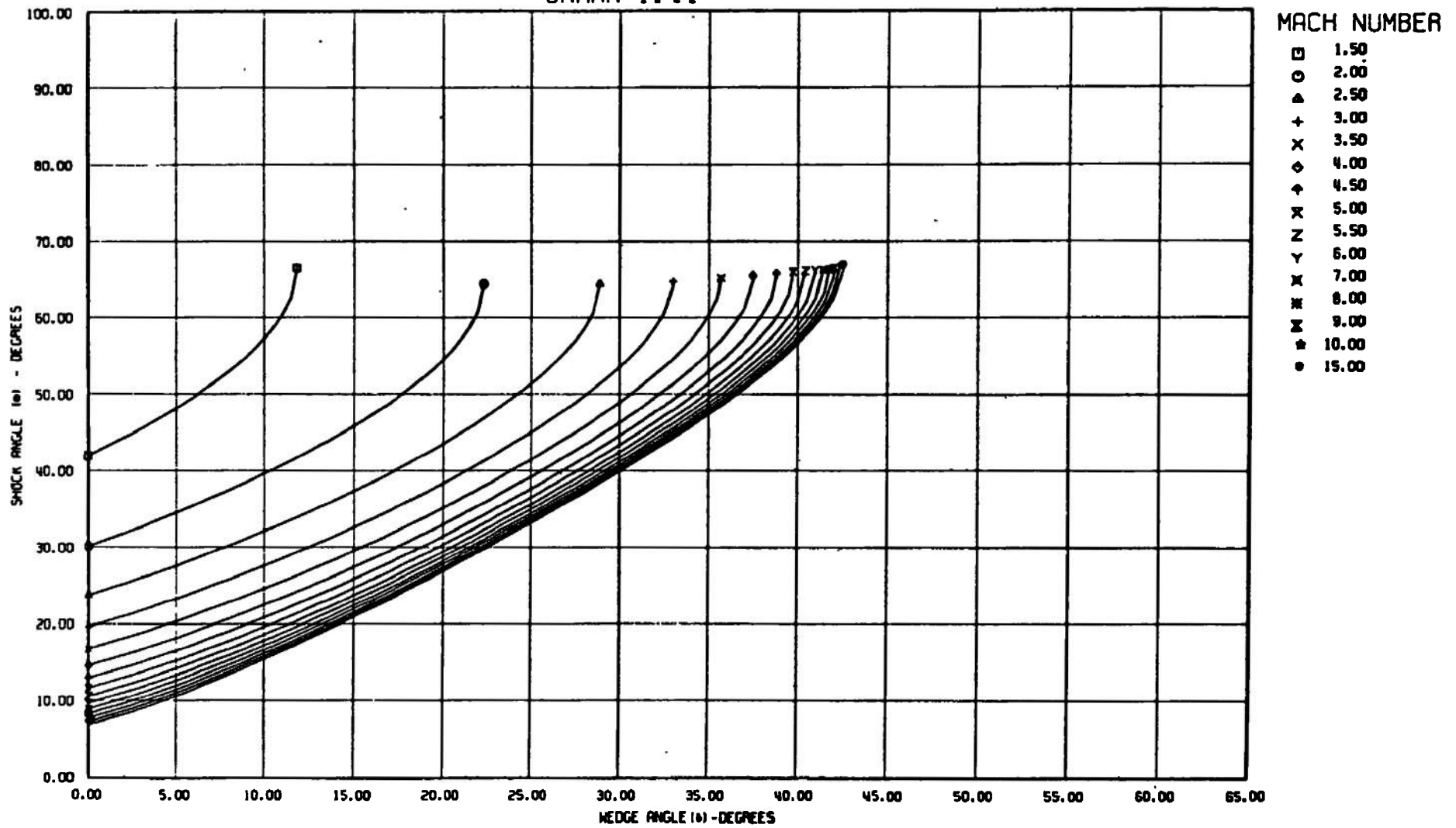


Fig. 19 $\gamma = 1.44$

OBLIQUE SHOCK GAMMA=1.44

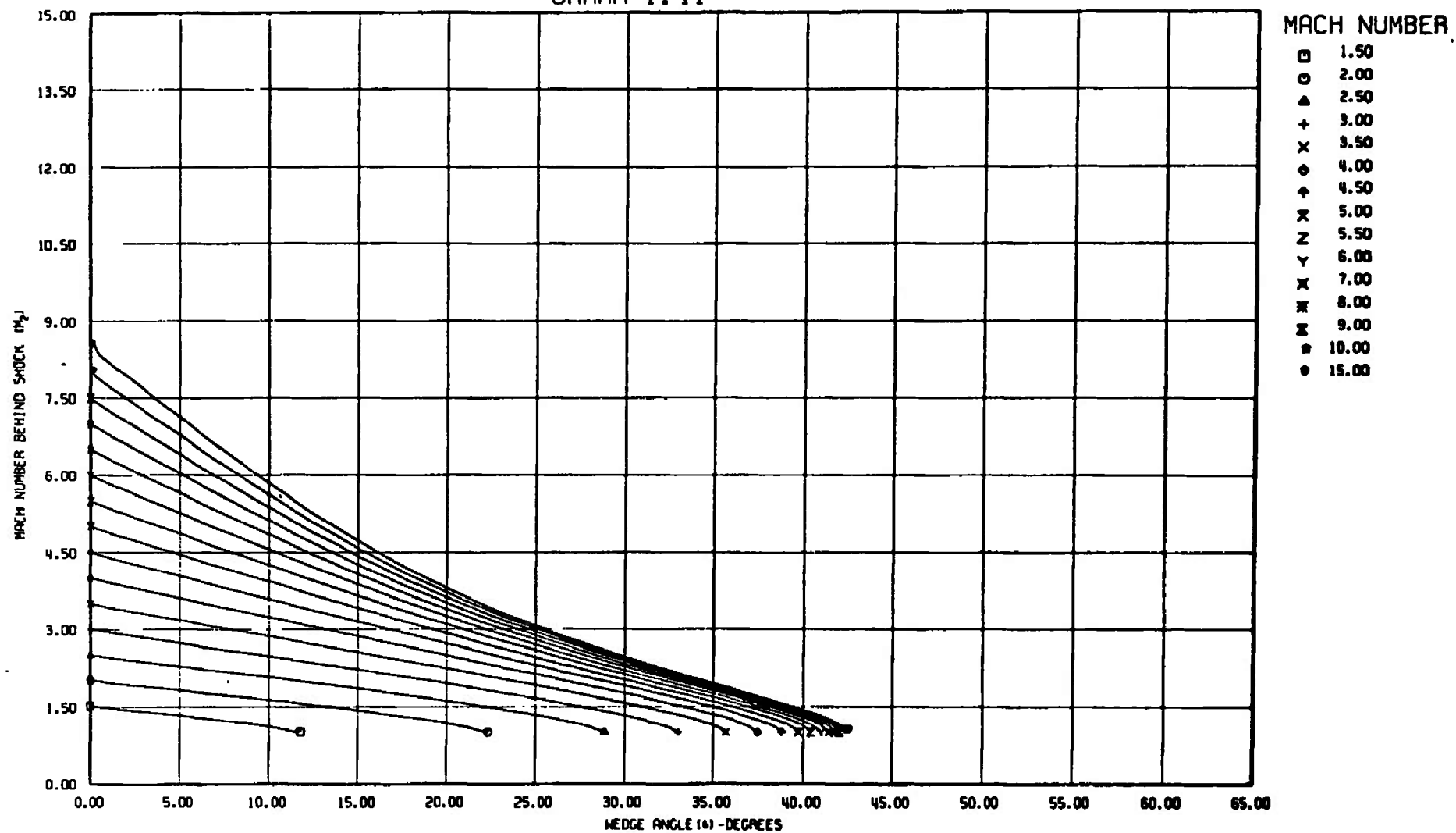


Fig. 19 Continued

OBLIQUE SHOCK GAMMA=1.44

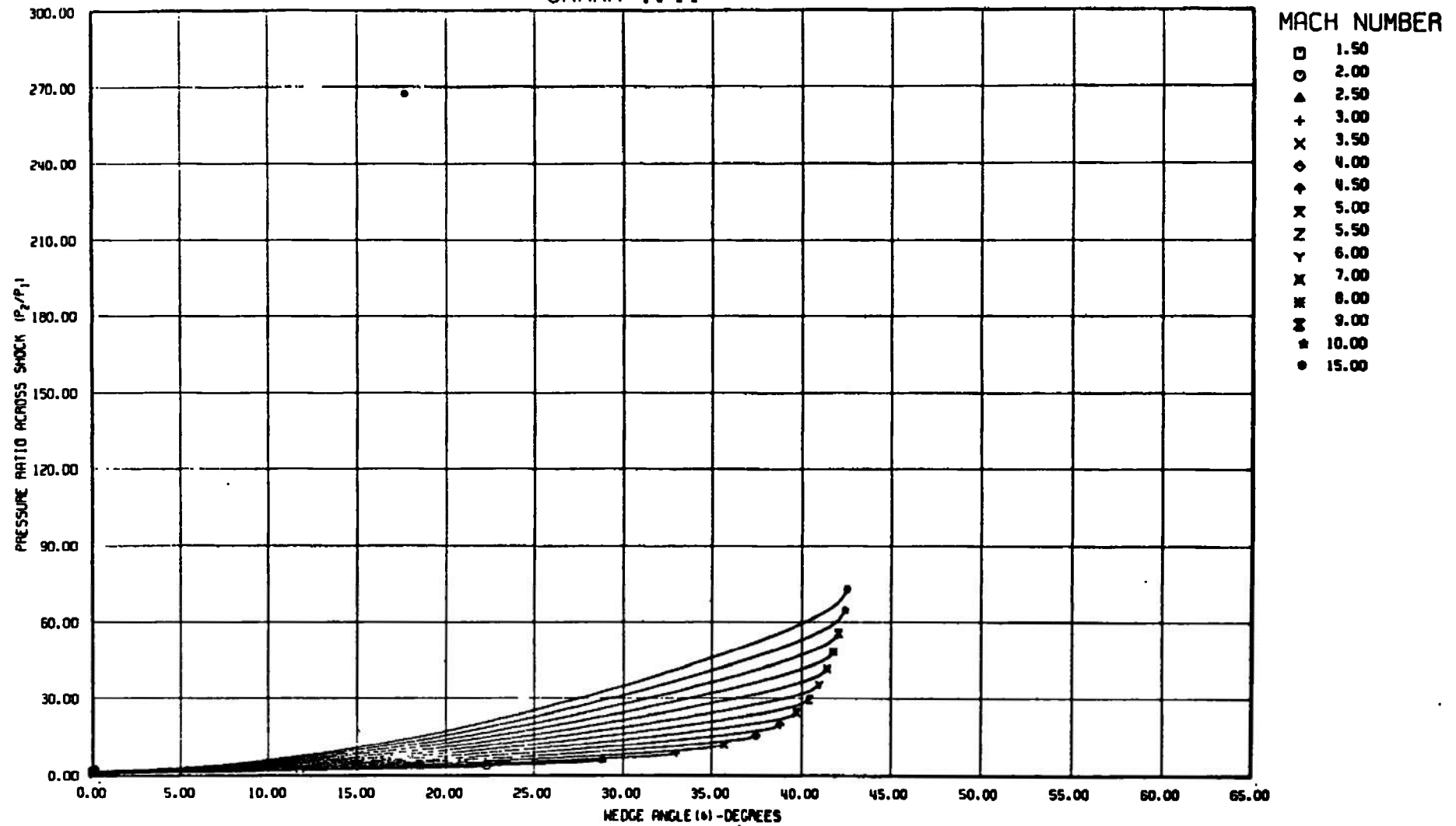


Fig. 19 Continued

OBLIQUE SHOCK
GAMMA=1.44

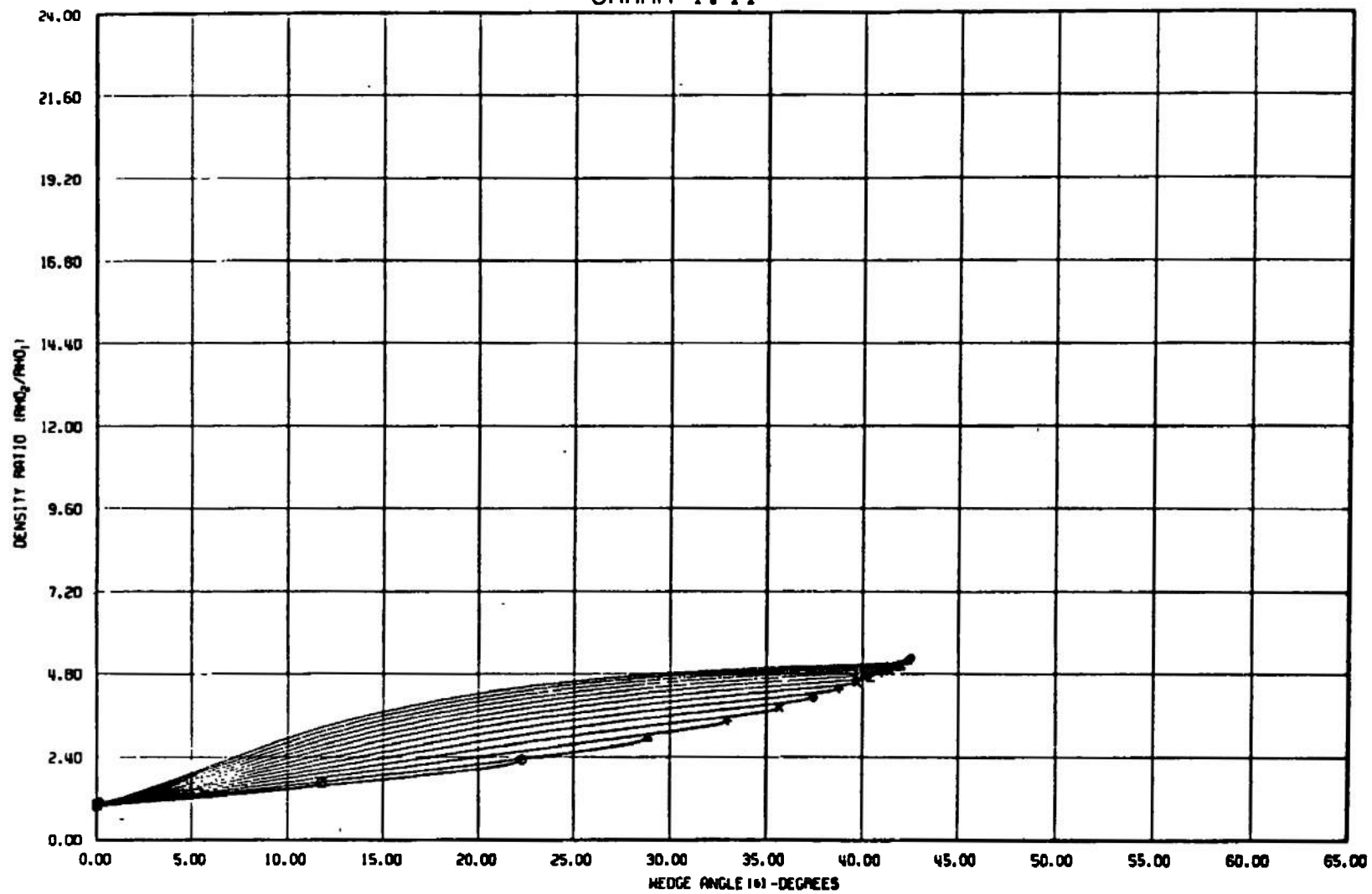


Fig. 19 Continued

OBLIQUE SHOCK
GAMMA=1.44

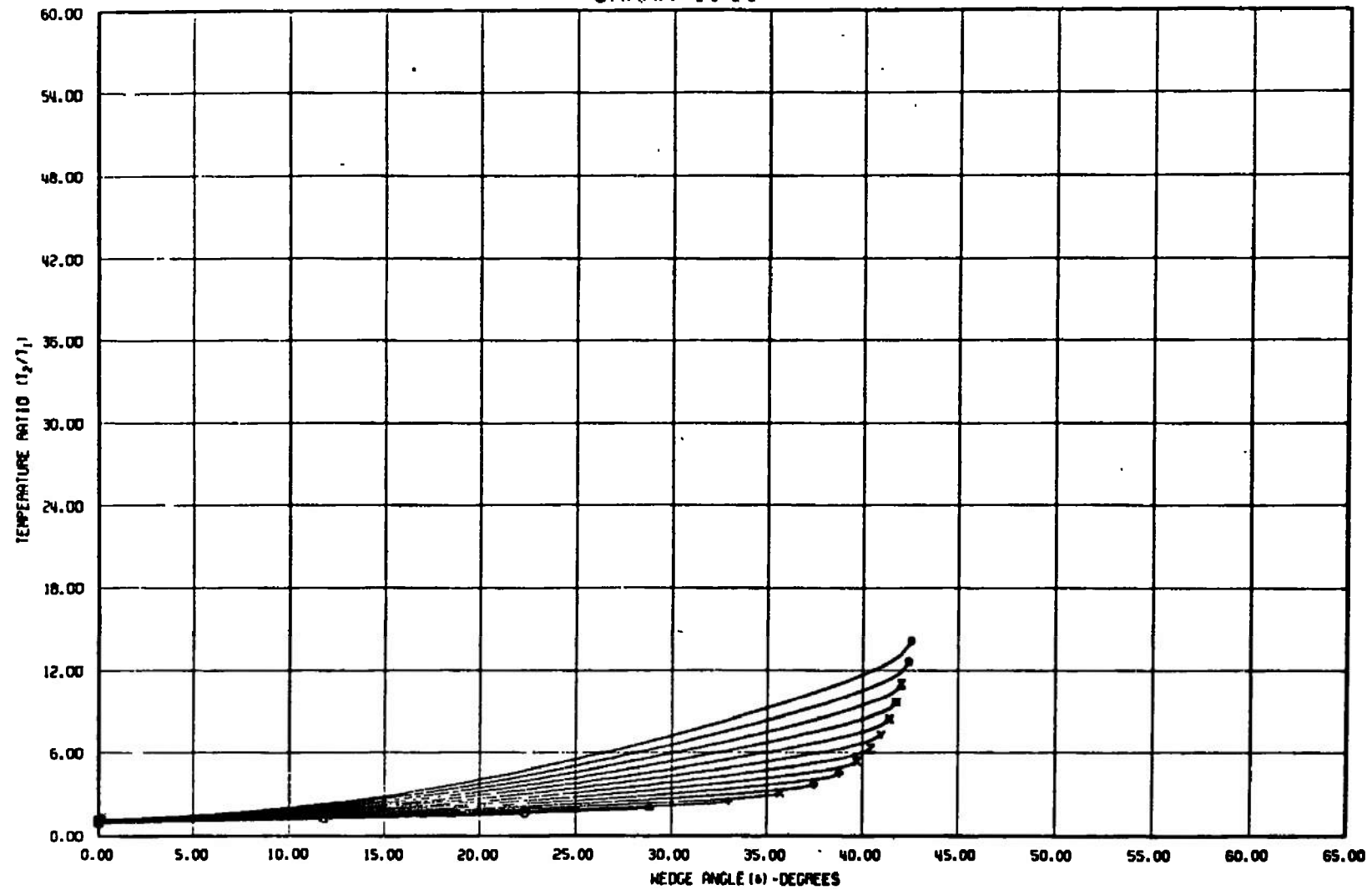


Fig. 19 Continued

OBLIQUE SHOCK
GAMMA=1.44

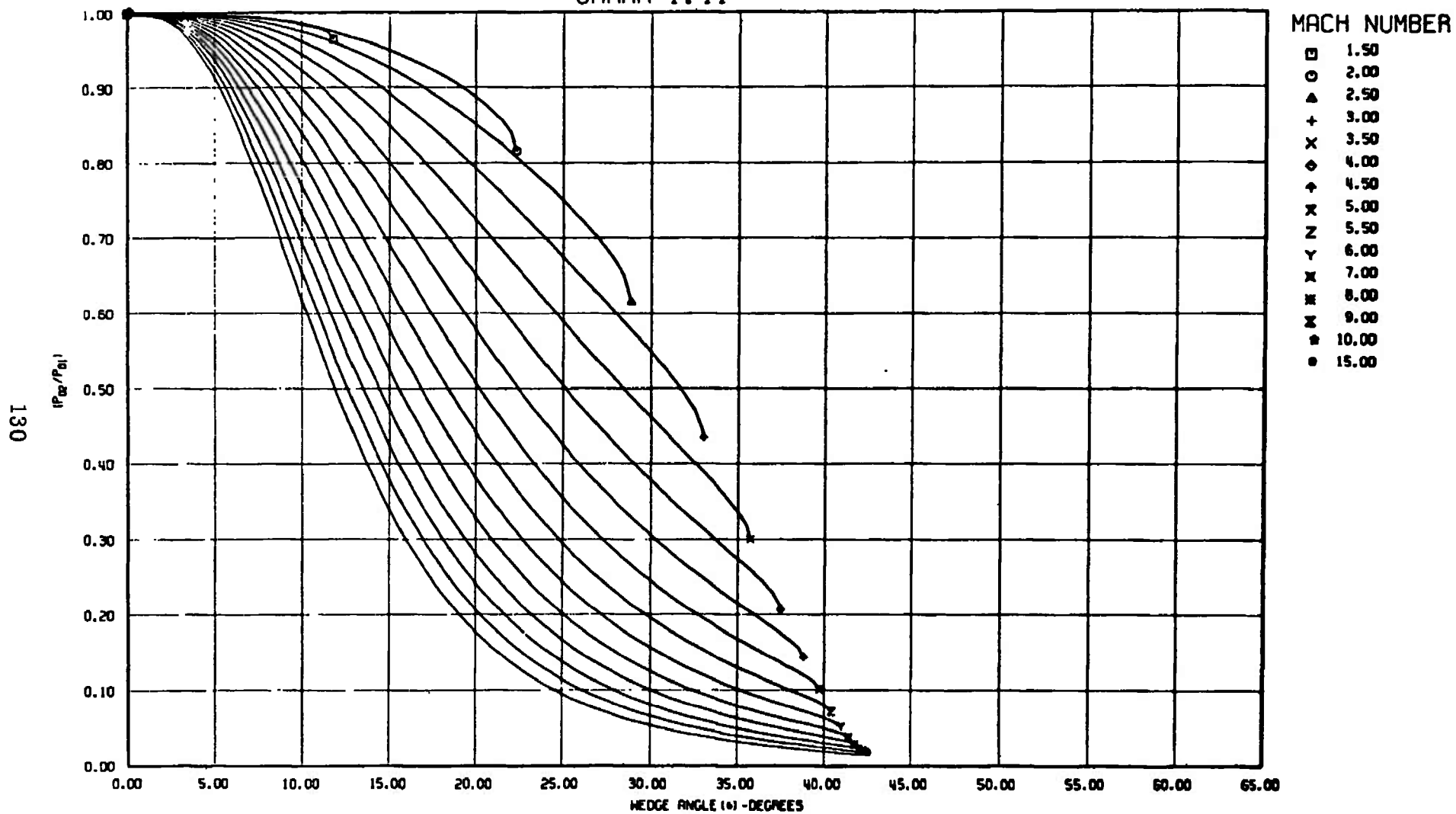
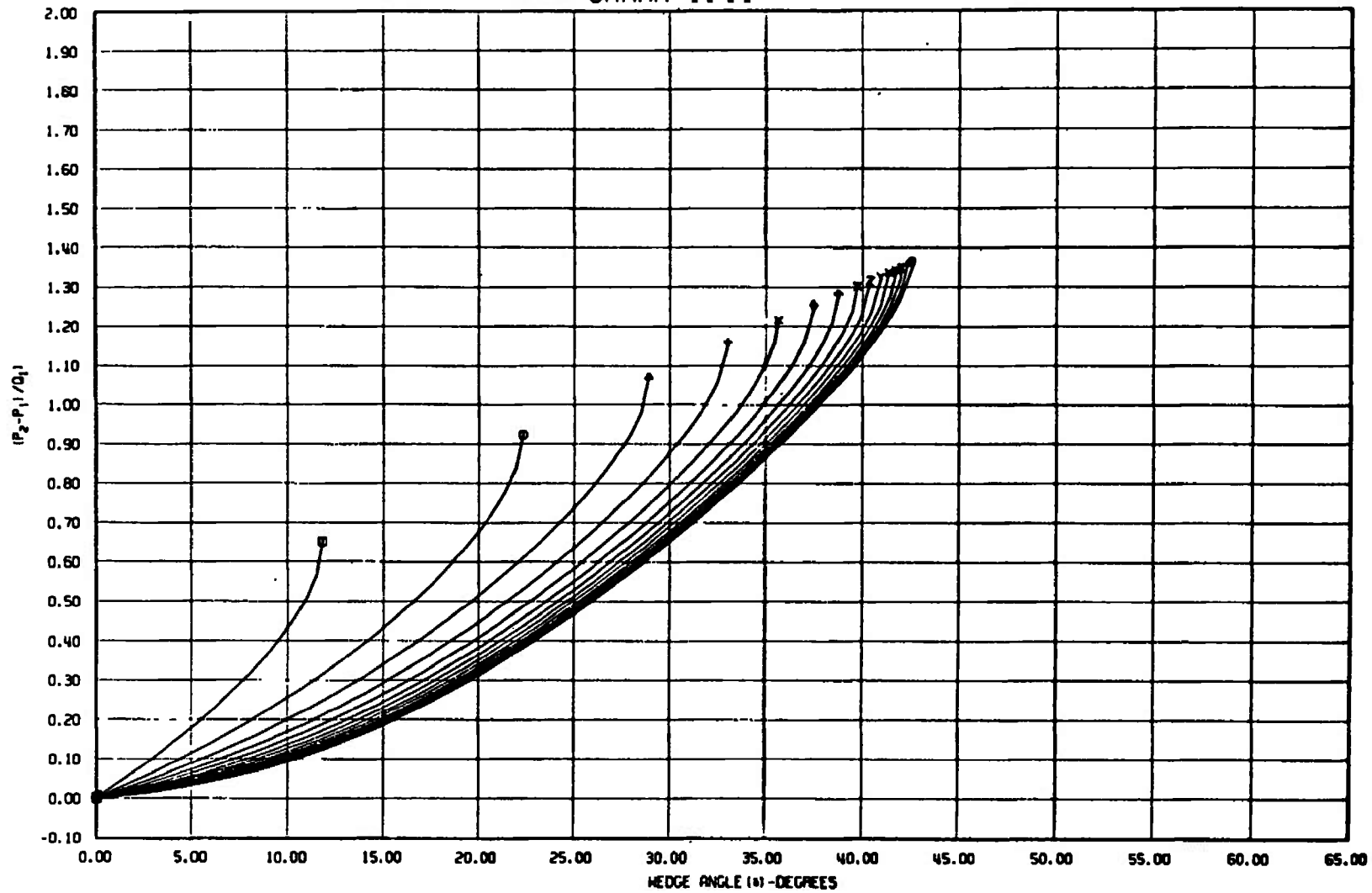


Fig. 19 Continued

OBLIQUE SHOCK GAMMA=1.44



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- +
- x 3.50
- ◇ 4.00
- ◆ 4.50
- ⌘ 5.00
- Z 5.50
- Y 6.00
- ⌘ 7.00
- ⌘ 8.00
- ⌘ 9.00
- ★ 10.00
- 15.00

Fig. 19 Concluded

OBLIQUE SHOCK $\gamma = 1.46$

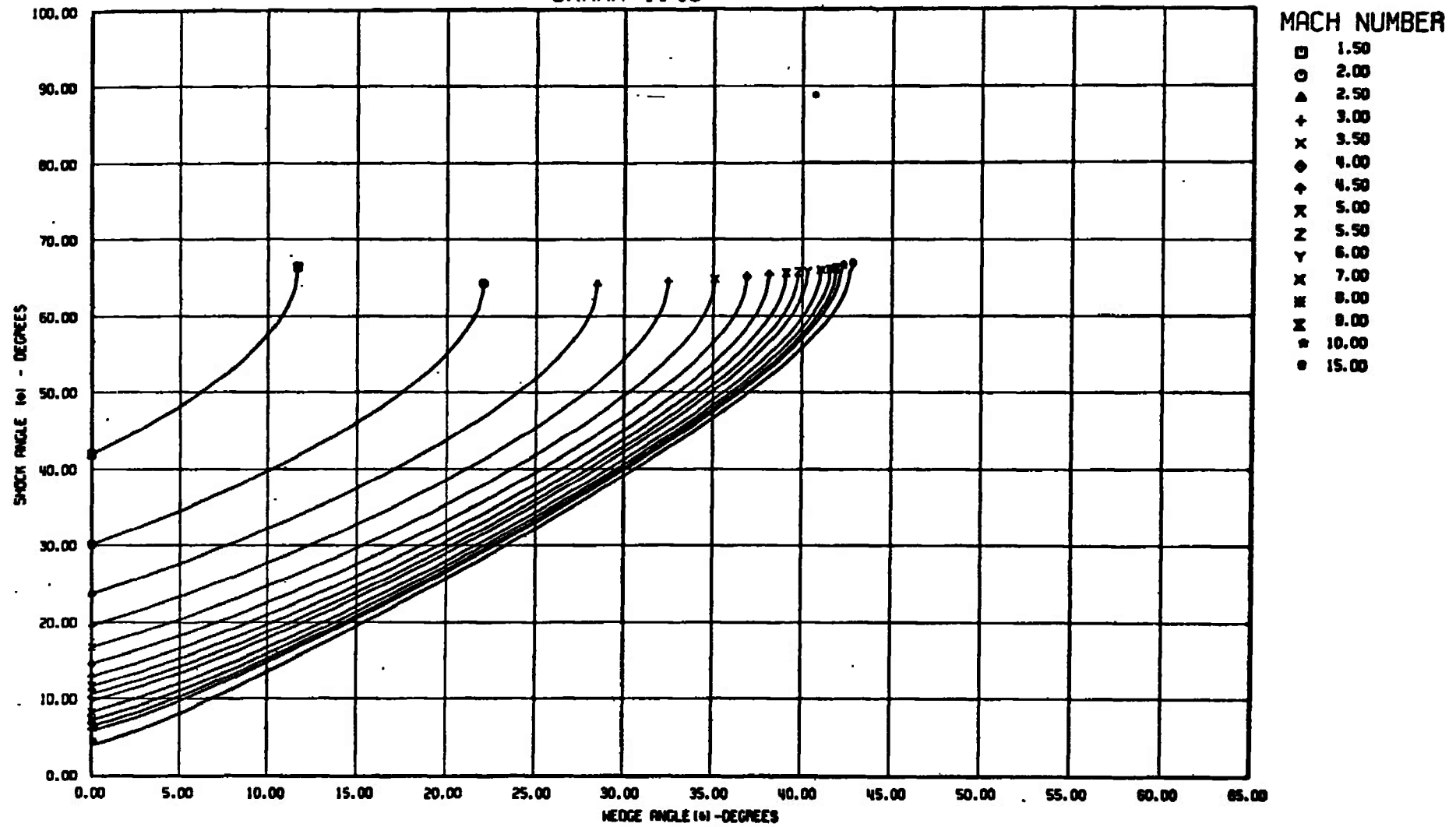


Fig. 20 $\gamma = 1.46$

OBLIQUE SHOCK
 $\gamma = 1.46$

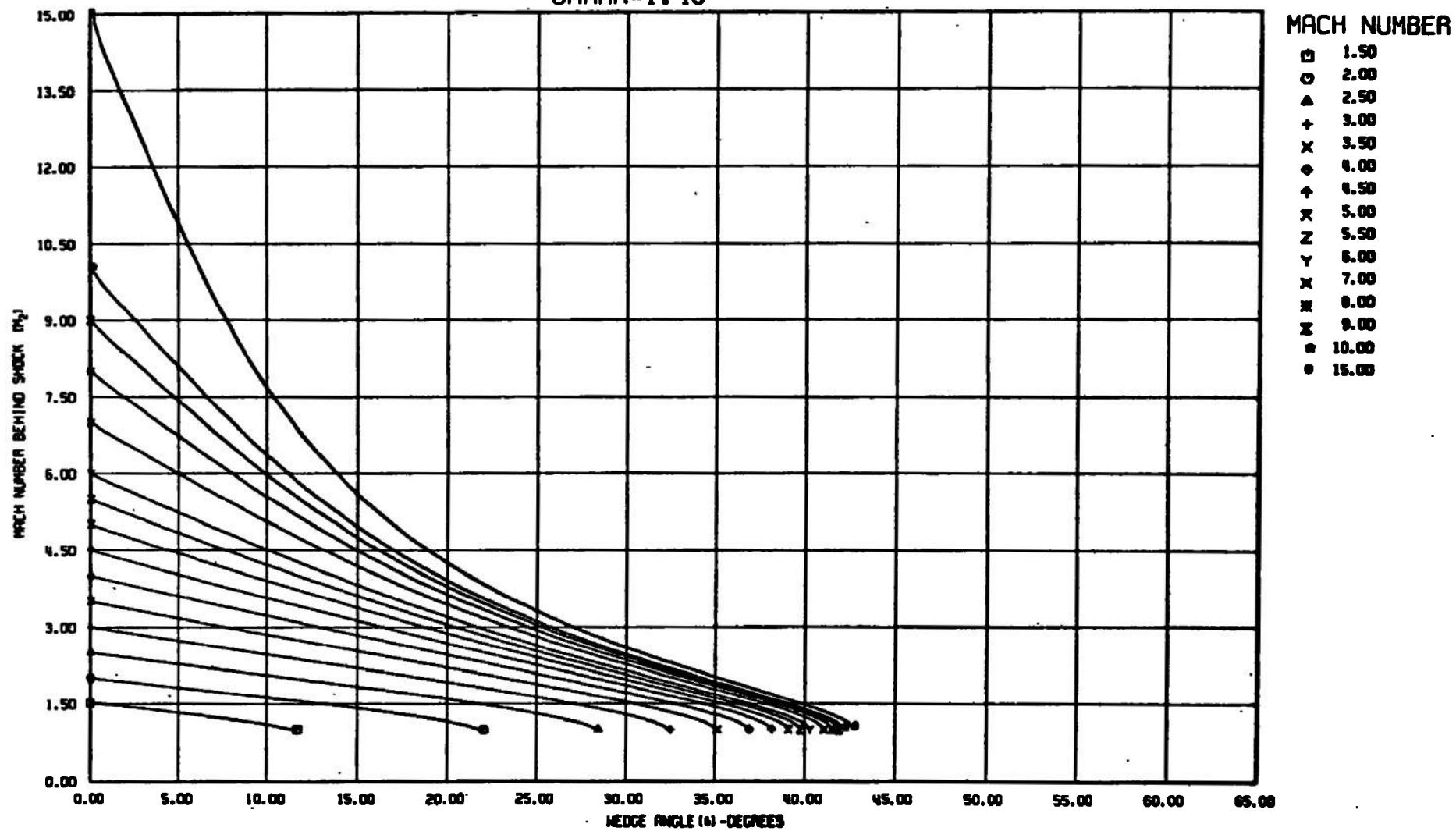


Fig. 20 Continued

OBLIQUE SHOCK GAMMA=1.46

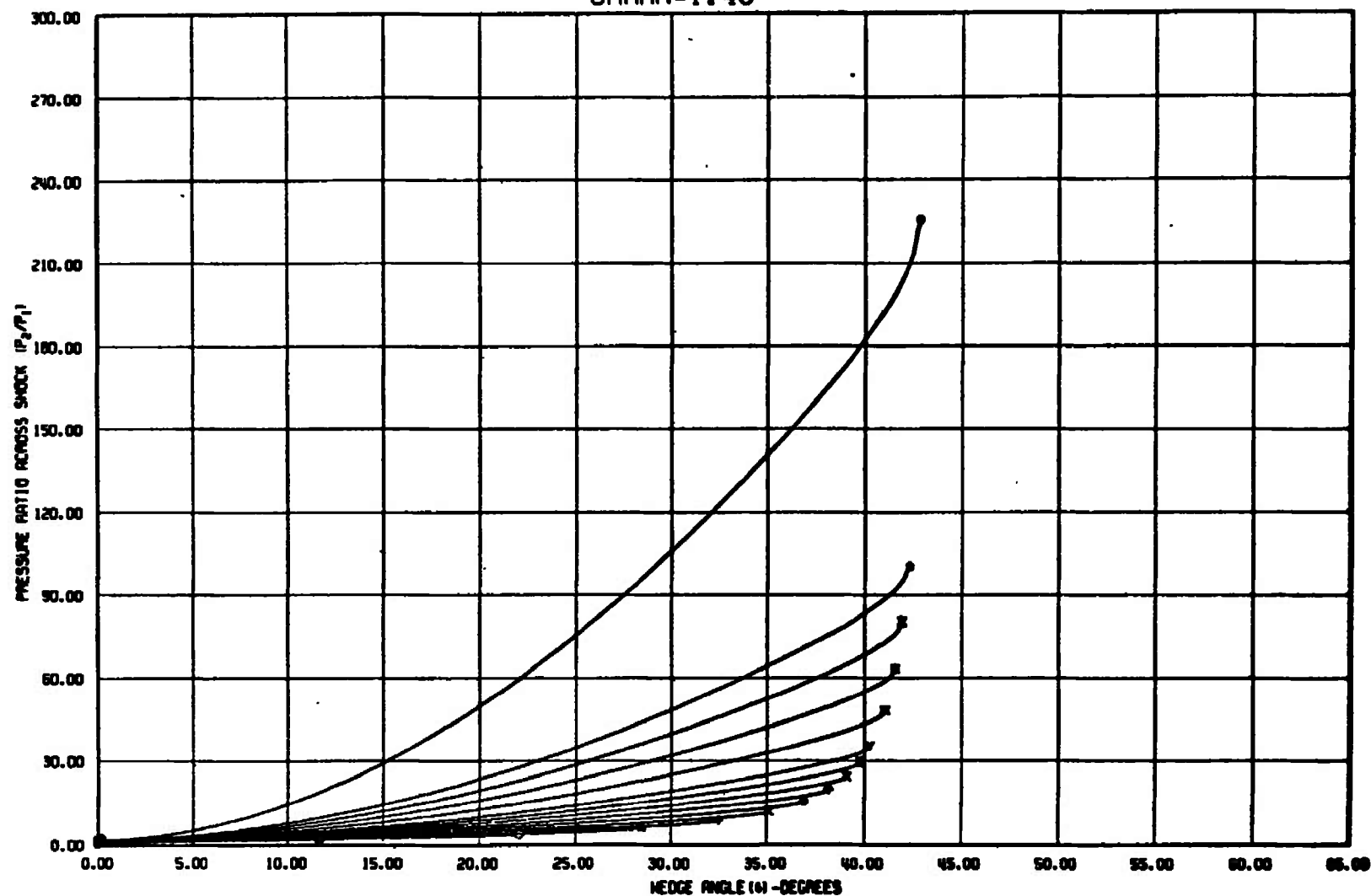


Fig. 20 Continued

OBLIQUE SHOCK
 $\gamma = 1.46$

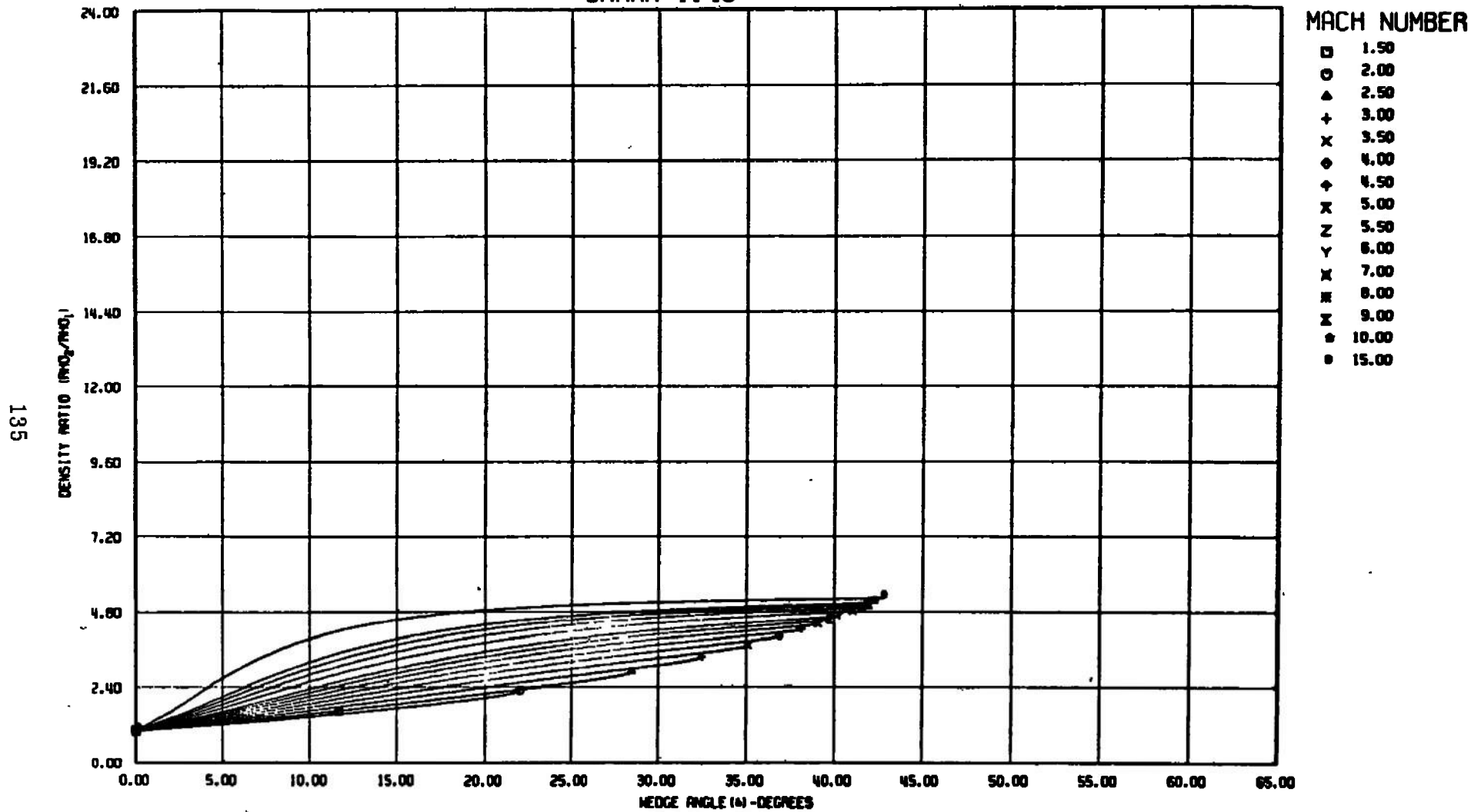


Fig. 20 Continued

OBLIQUE SHOCK
GAMMA=1.46

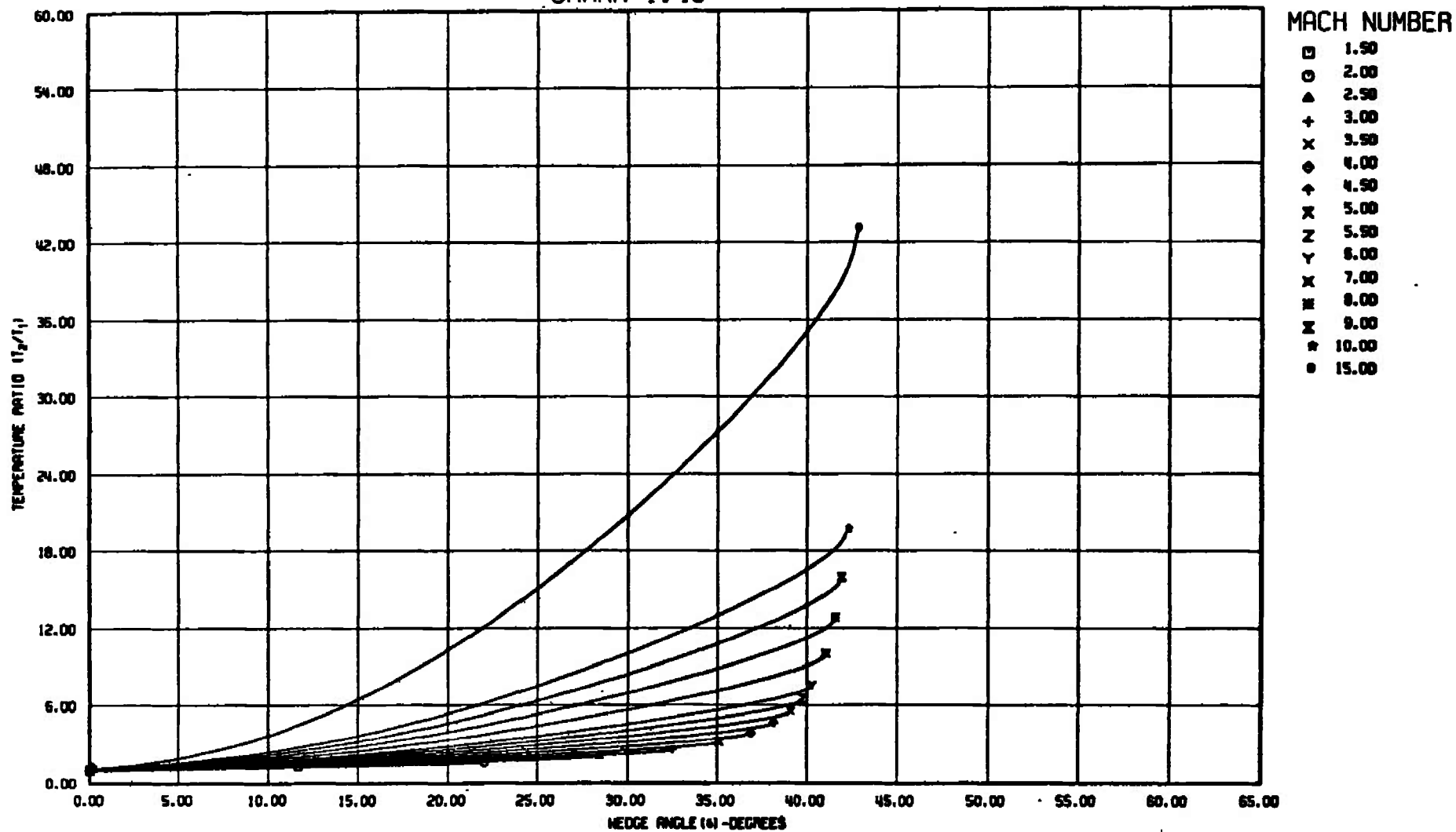


Fig. 20 Continued

OBLIQUE SHOCK GAMMA=1.46

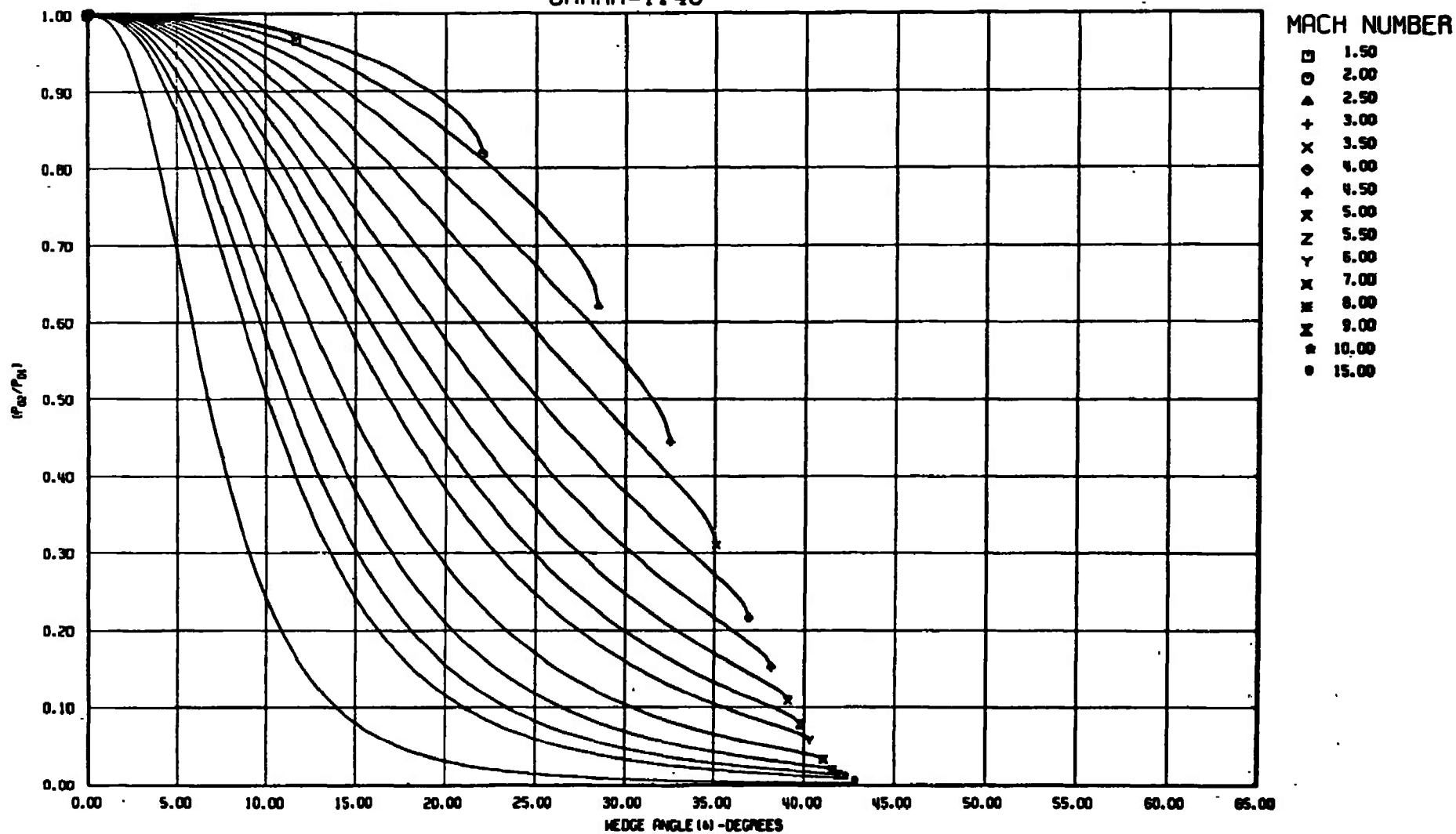
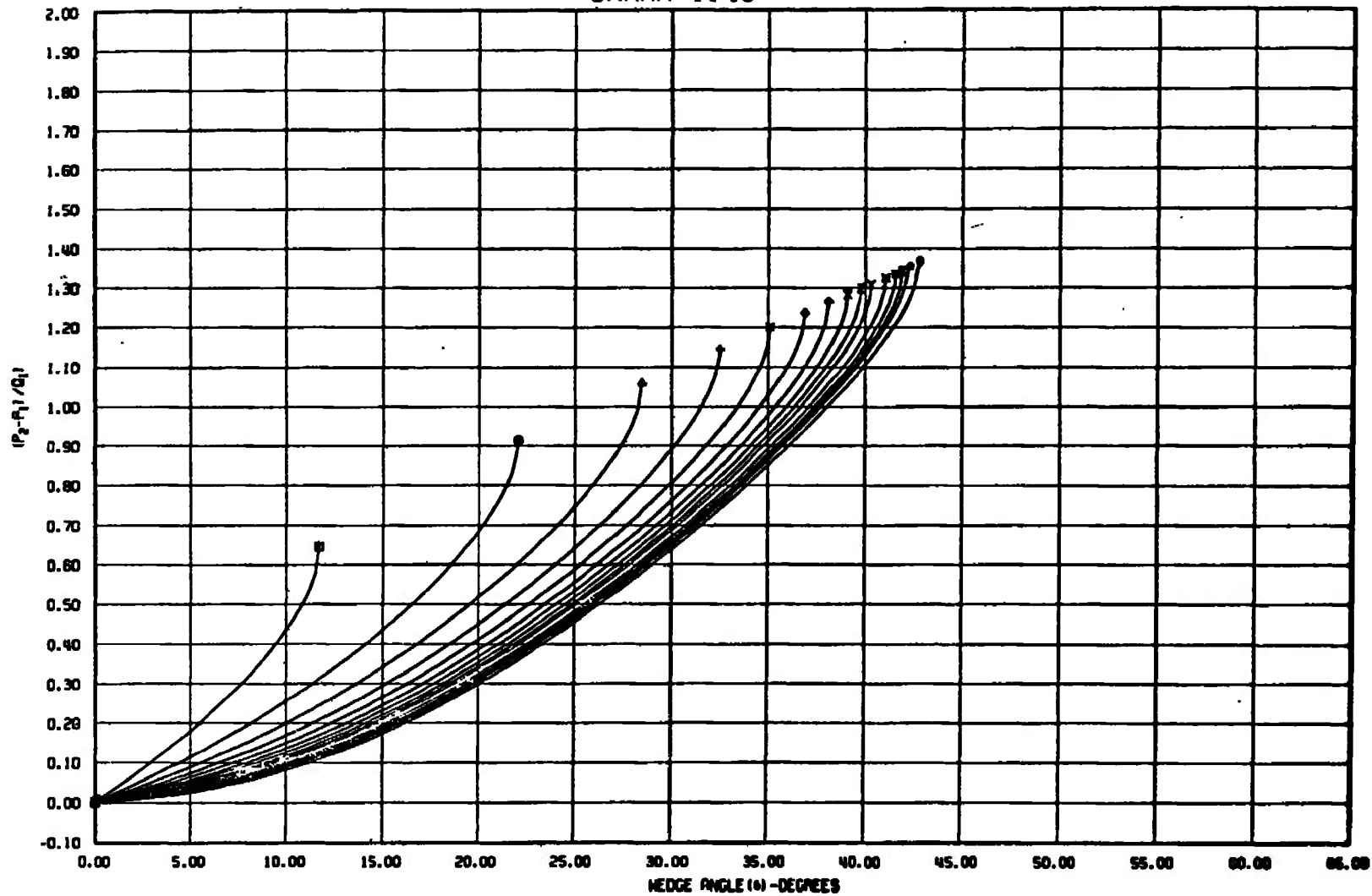


Fig. 20 Continued

OBLIQUE SHOCK GAMMA=1.46



MACH NUMBER

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- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- ⋈ 4.50
- ⊗ 5.00
- ⊘ 5.50
- ⋈ 6.00
- ⊗ 7.00
- ⊘ 8.00
- ⋈ 9.00
- ⊗ 10.00
- ⋈ 15.00

Fig. 20 Concluded

OBLIQUE SHOCK GAMMA=1.48

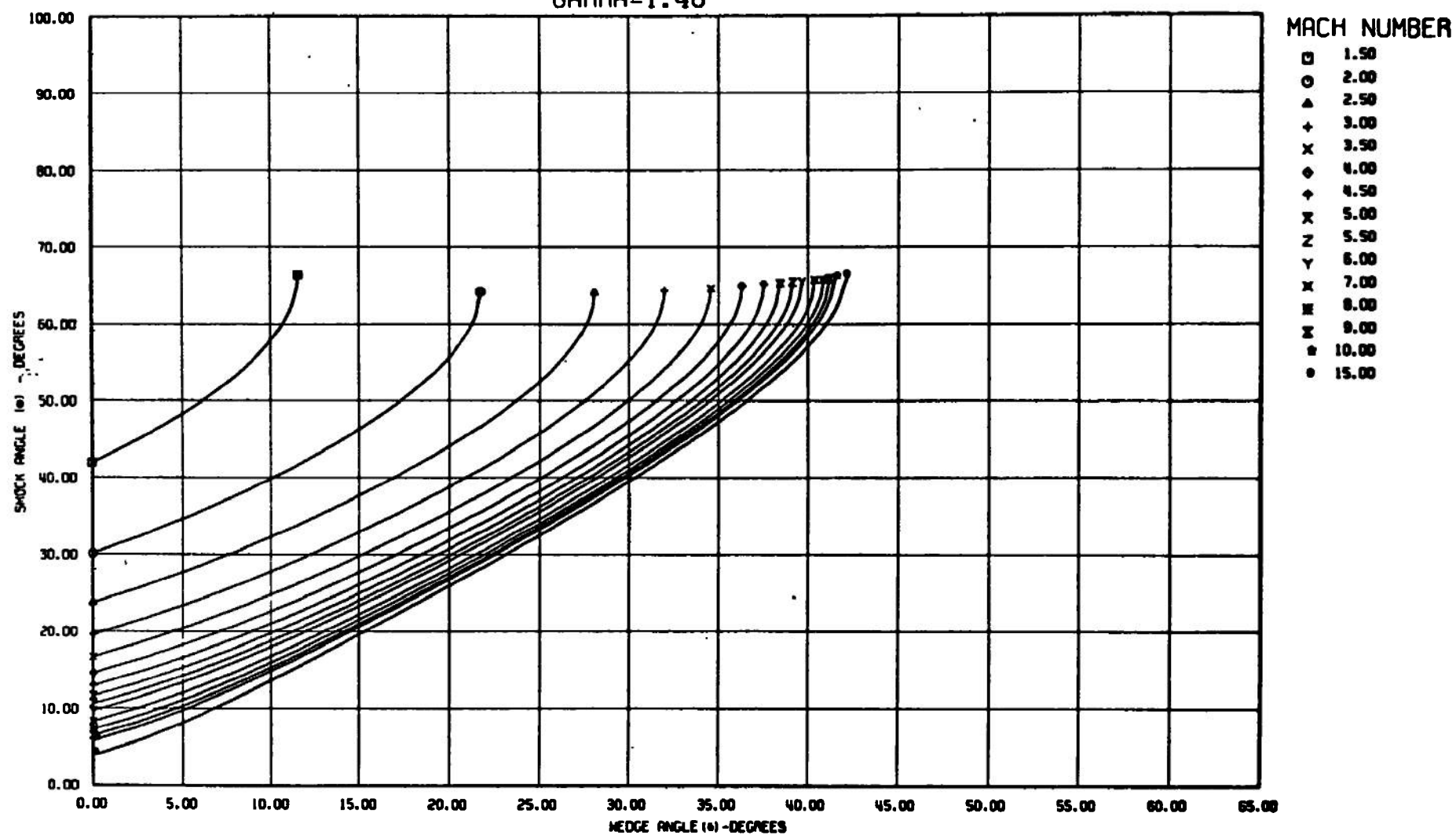


Fig. 21 $\gamma = 1.48$

OBLIQUE SHOCK GAMMA=1.48

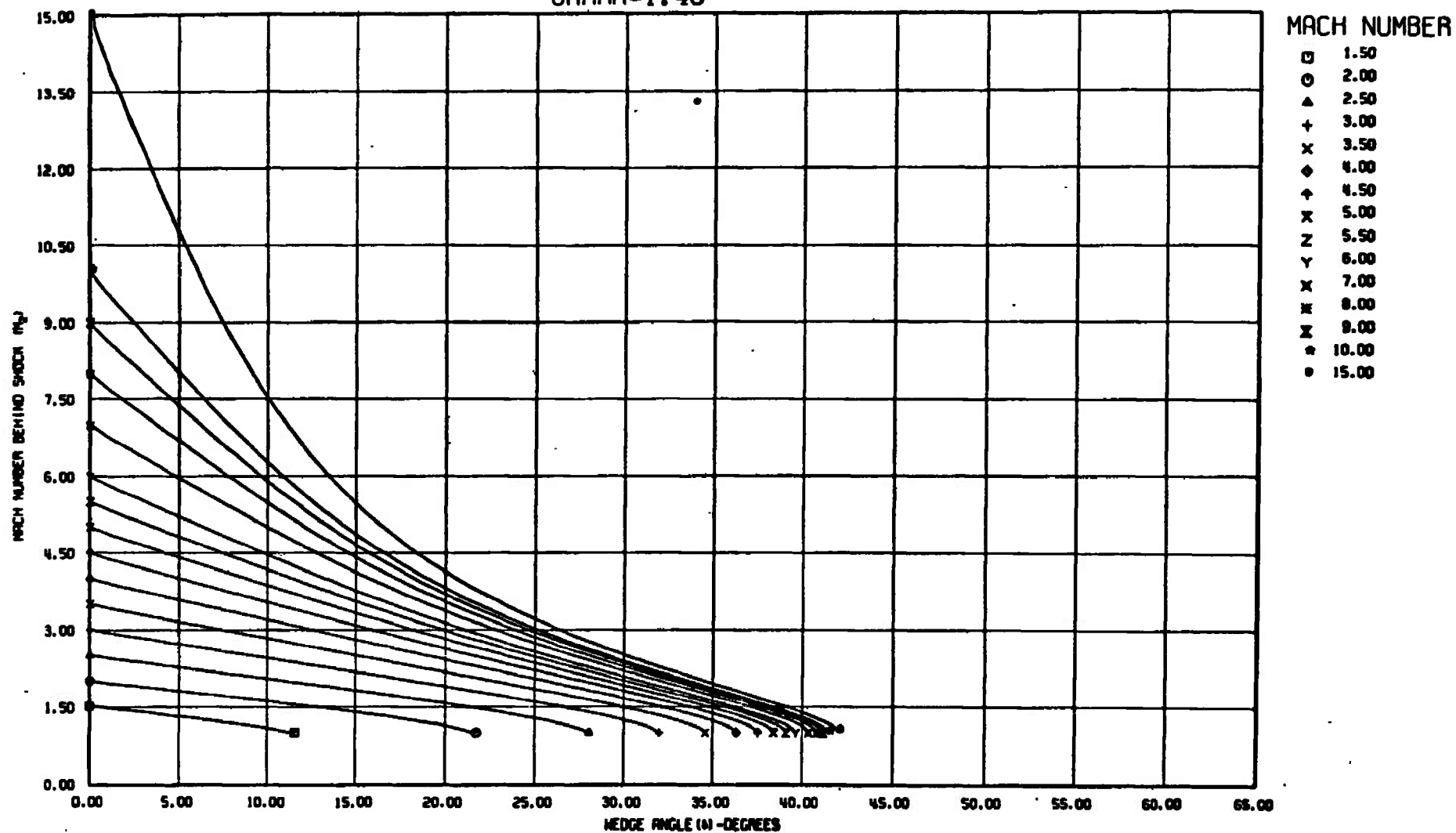


Fig. 21 Continued

OBLIQUE SHOCK GAMMA=1.48

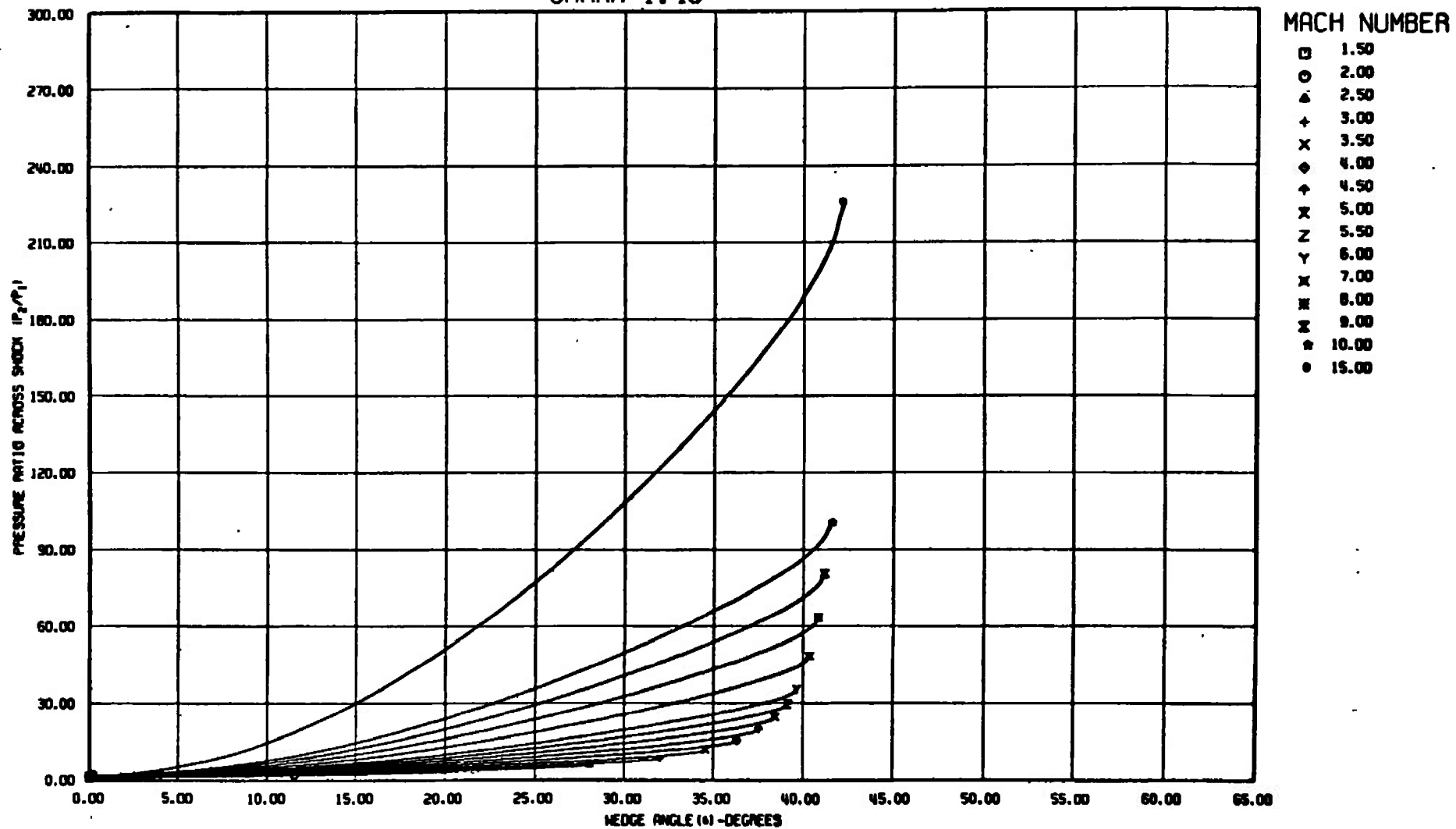


Fig. 21 Continued

OBLIQUE SHOCK
GAMMA=1.48

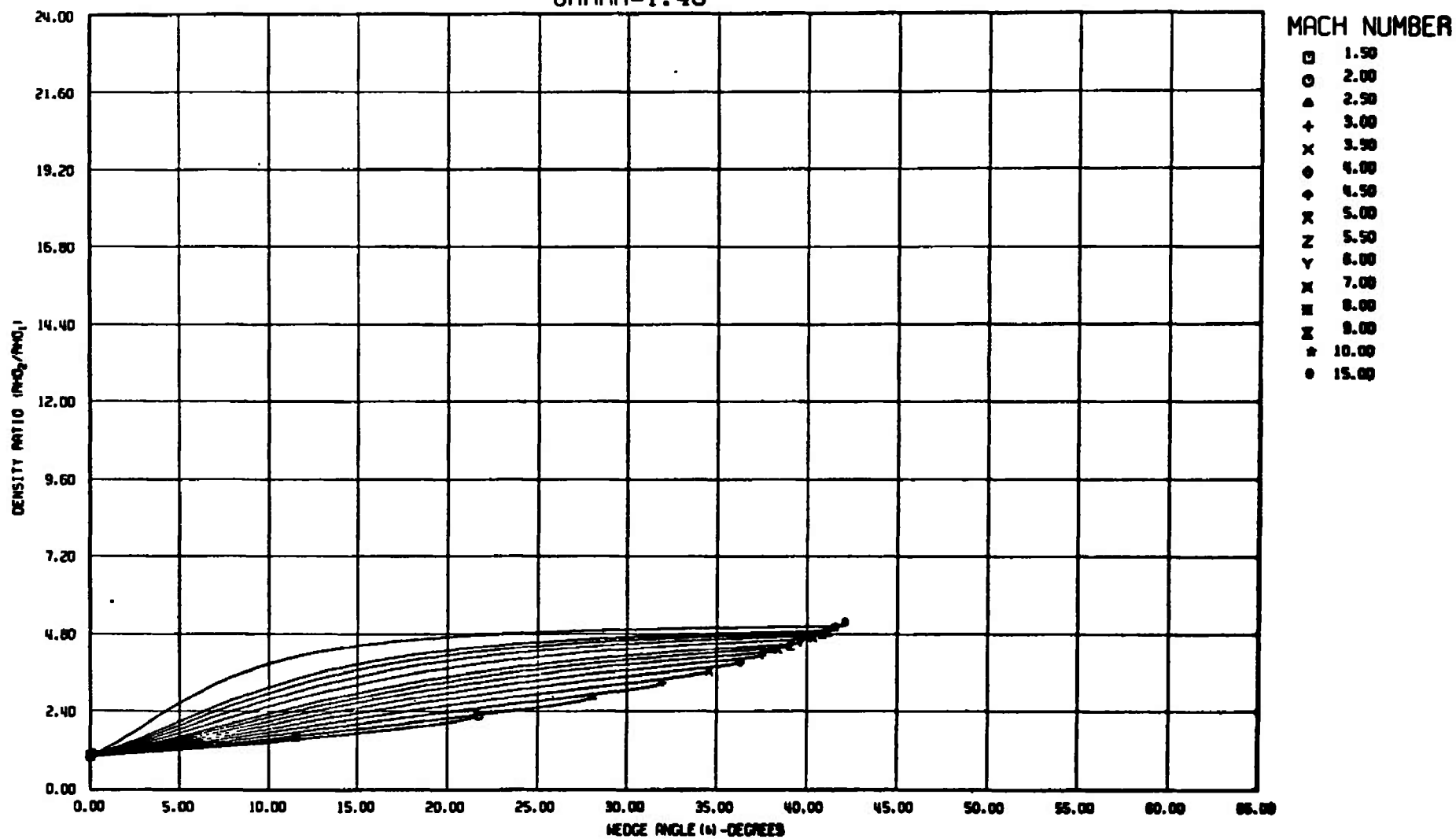


Fig. 21 Continued

OBLIQUE SHOCK GAMMA=1.48

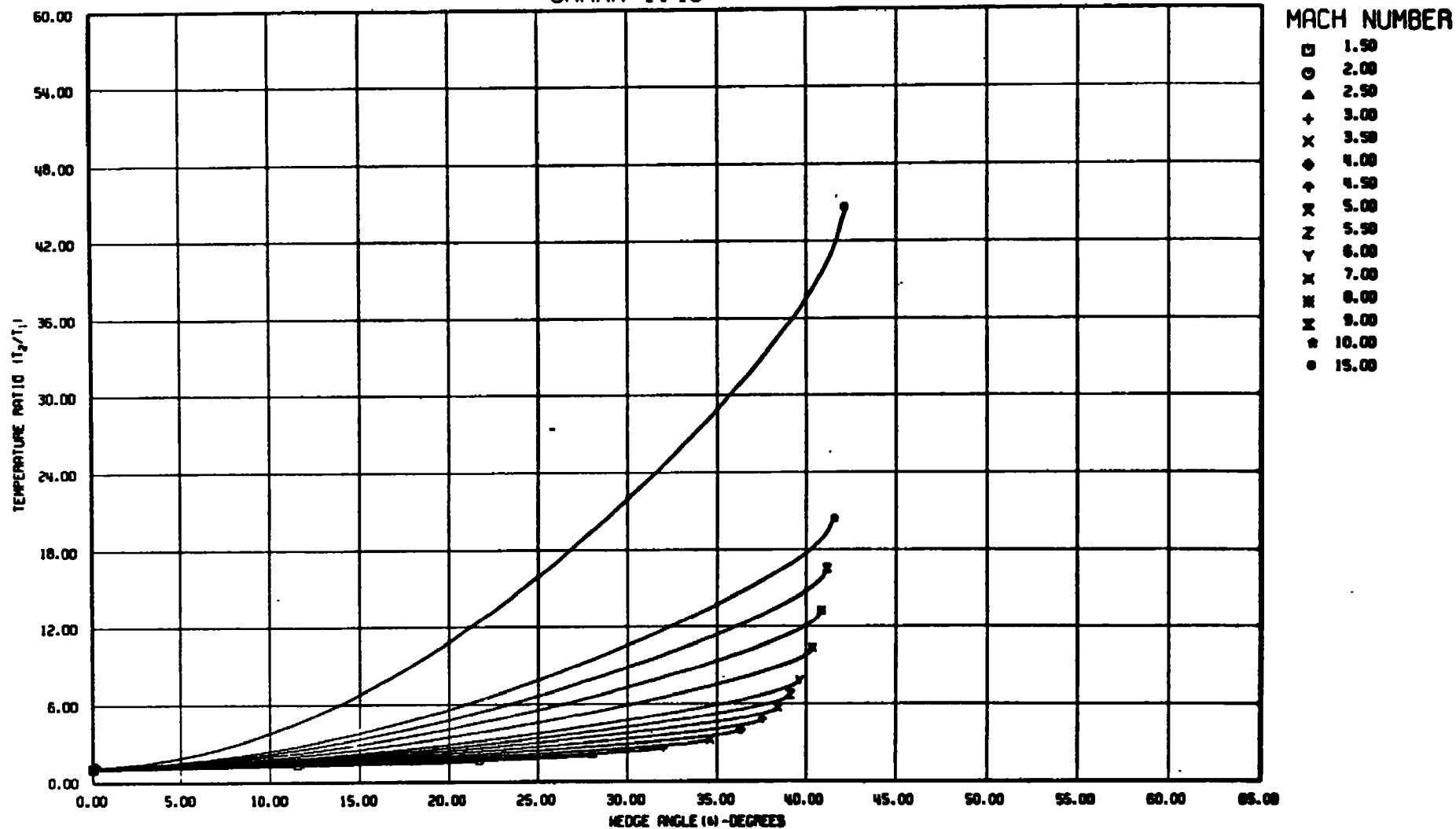
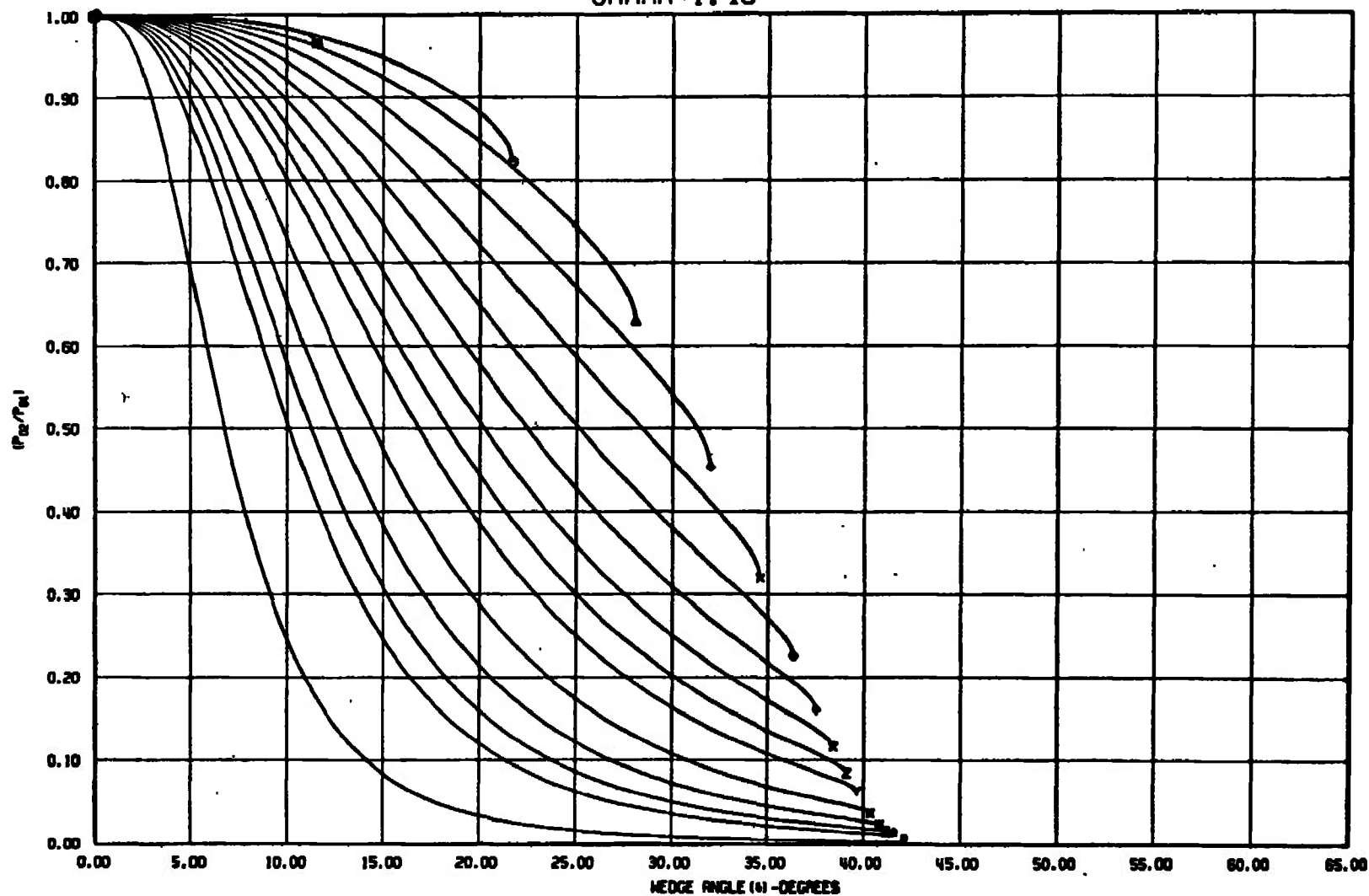


Fig. 21 Continued

OBLIQUE SHOCK
GAMMA=1.48

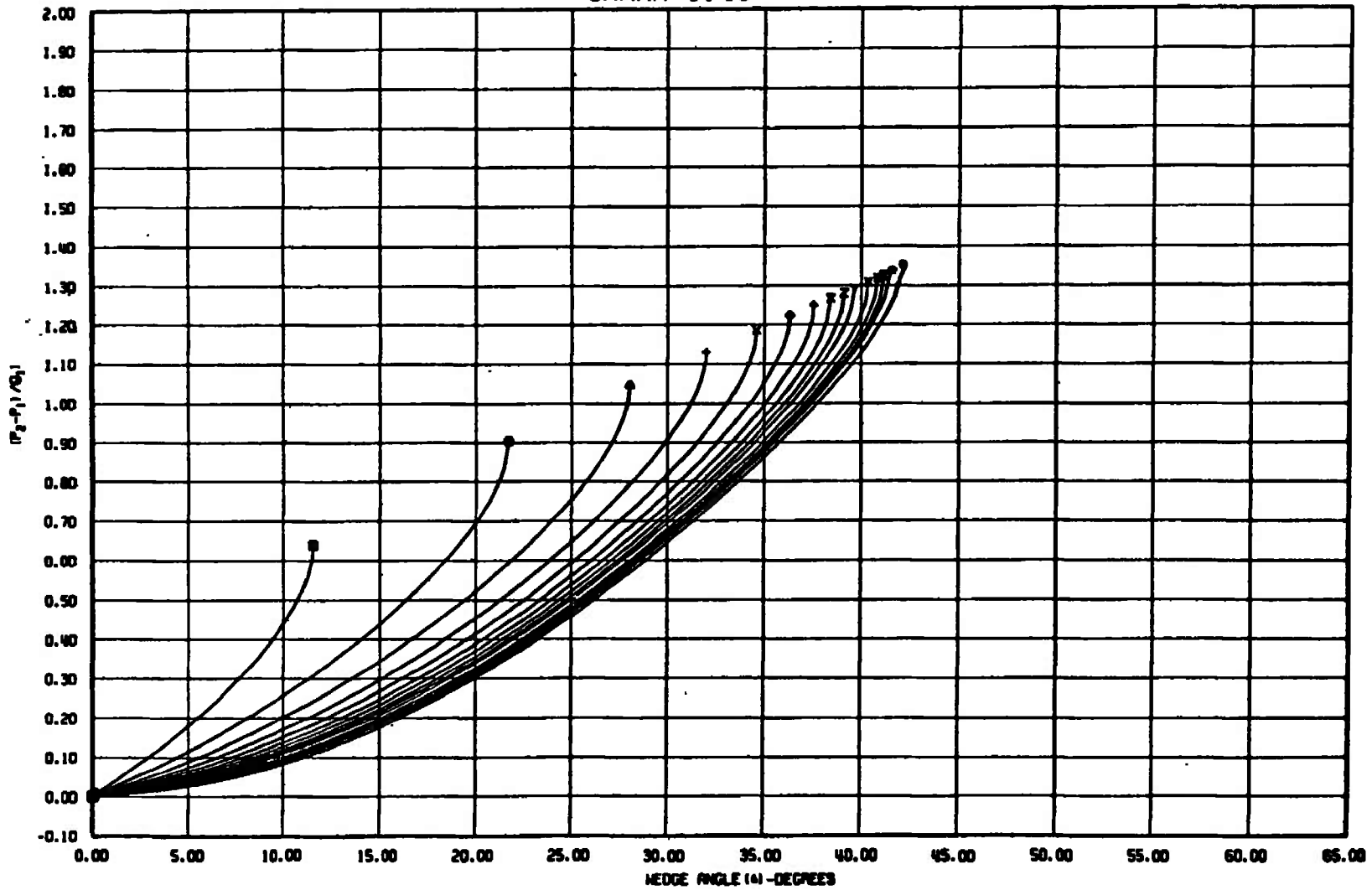


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- +
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- ≡ 8.00
- x 9.00
- *
- 10.00
- 15.00

Fig. 21 Continued

OBLIQUE SHOCK $\gamma=1.48$



MACH NUMBER

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- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- + 4.50
- * 5.00
- x 5.50
- y 6.00
- x 7.00
- * 8.00
- x 9.00
- * 10.00
- 15.00

Fig. 21 Concluded

OBLIQUE SHOCK GAMMA=1.50

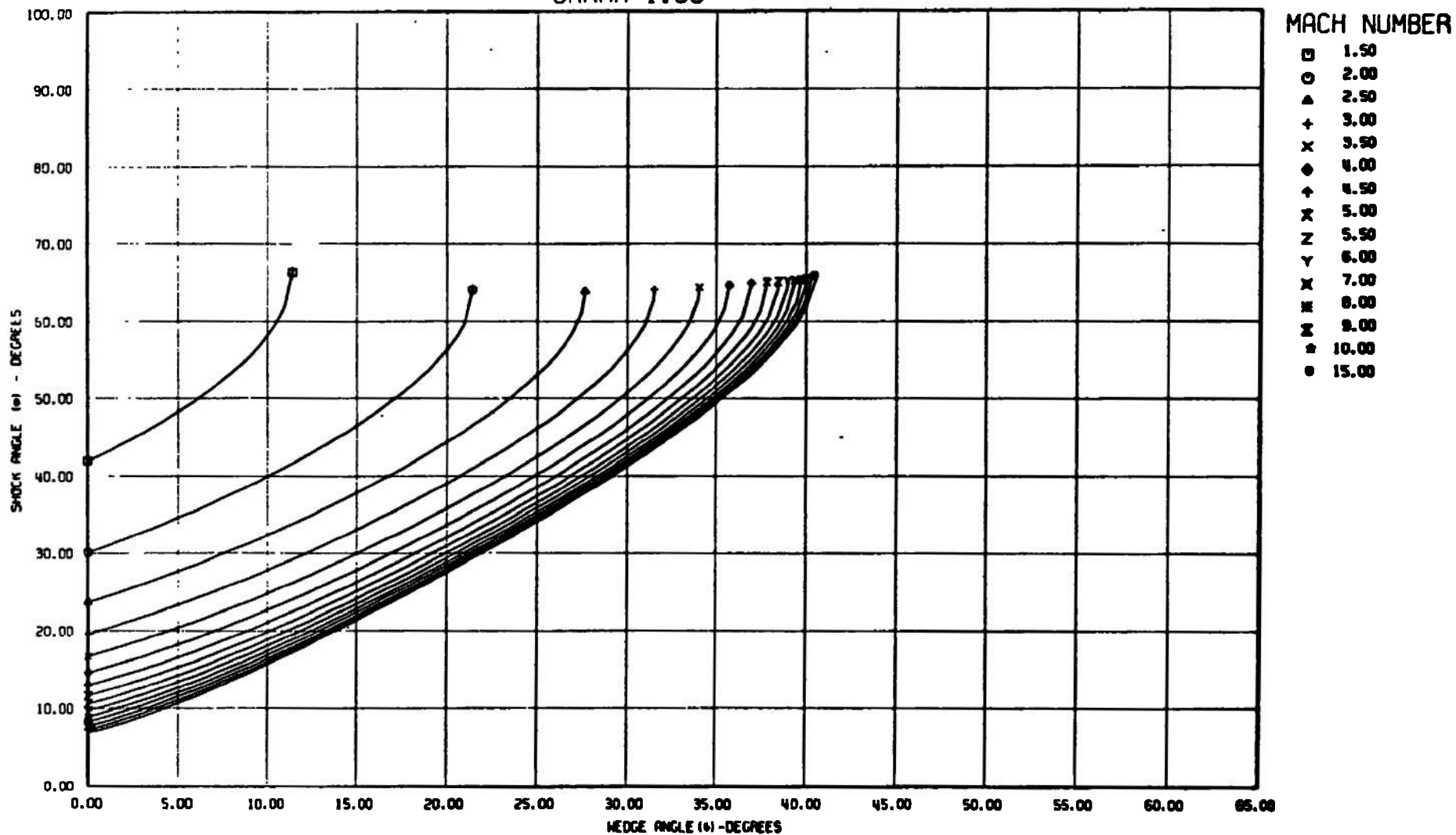


Fig. 22 $\gamma = 1.50$

OBLIQUE SHOCK GAMMA=1.50

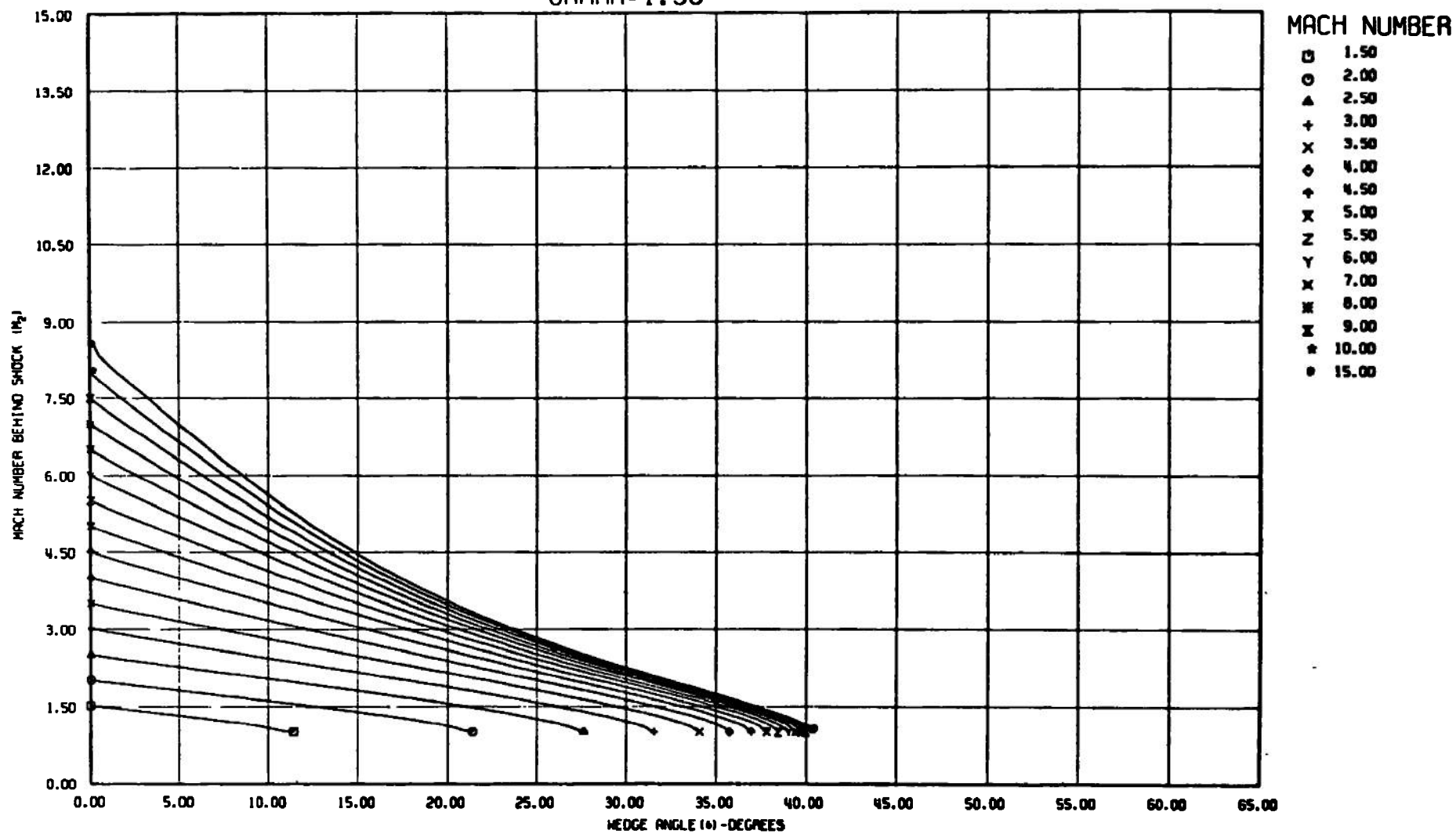
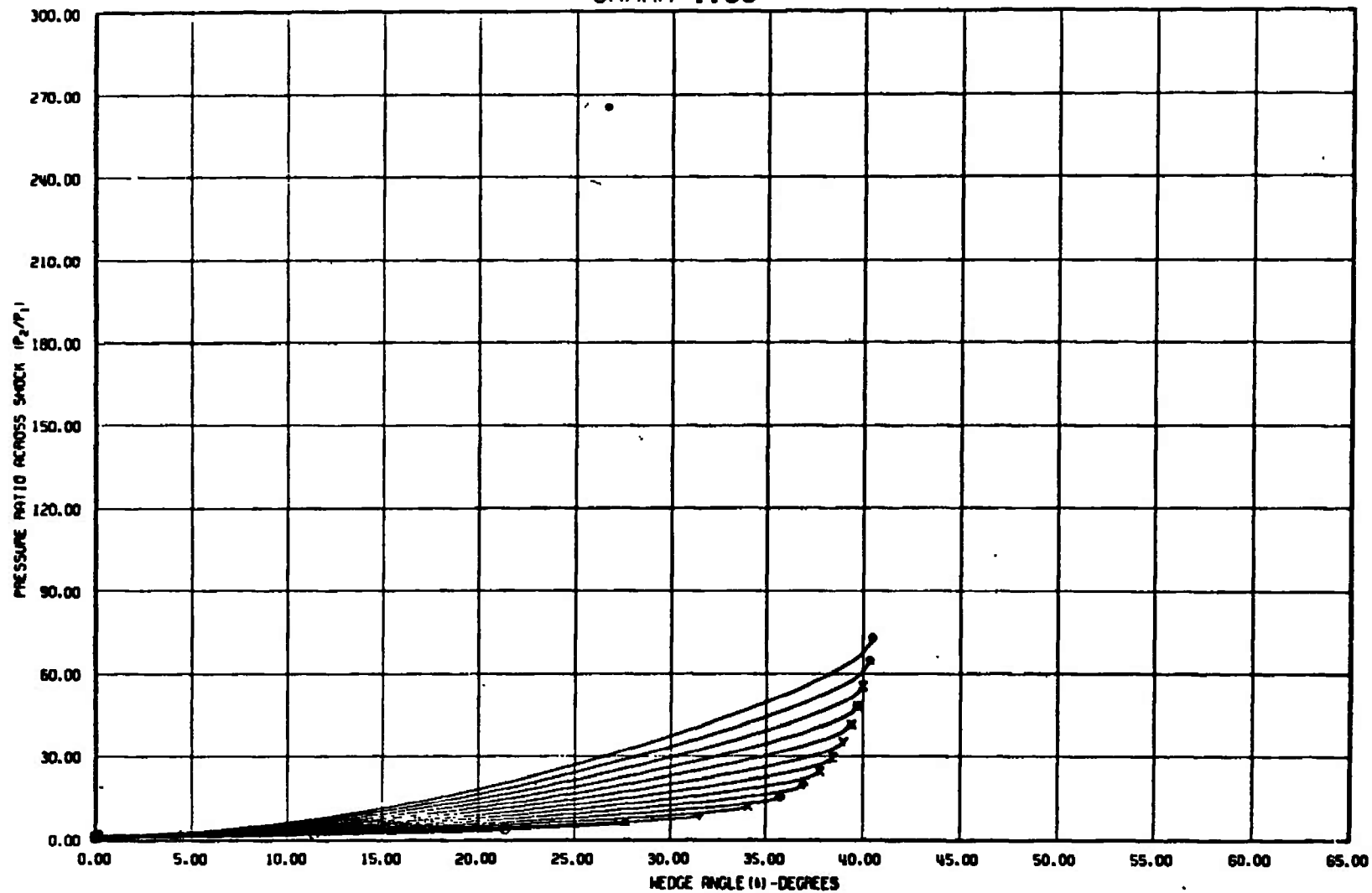


Fig. 22 Continued

OBLIQUE SHOCK GAMMA=1.50



MACH NUMBER

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- ⋈ 4.50
- x 5.00
- Z 5.50
- Y 6.00
- x 7.00
- ⊠ 8.00
- x 9.00
- ★ 10.00
- 15.00

Fig. 22 Continued

OBLIQUE SHOCK GAMMA=1.50

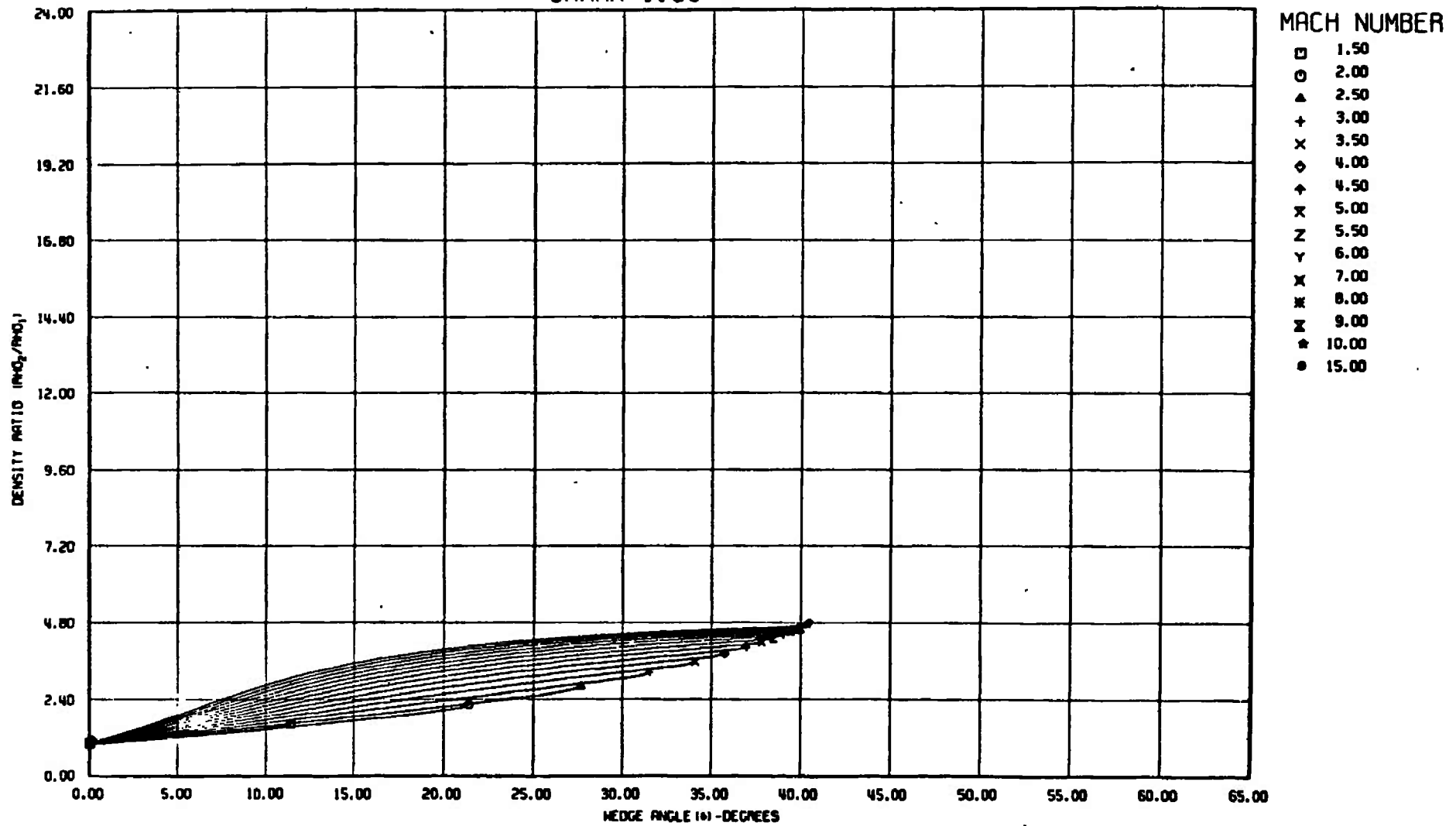


Fig. 22 Continued

OBLIQUE SHOCK
GAMMA=1.50

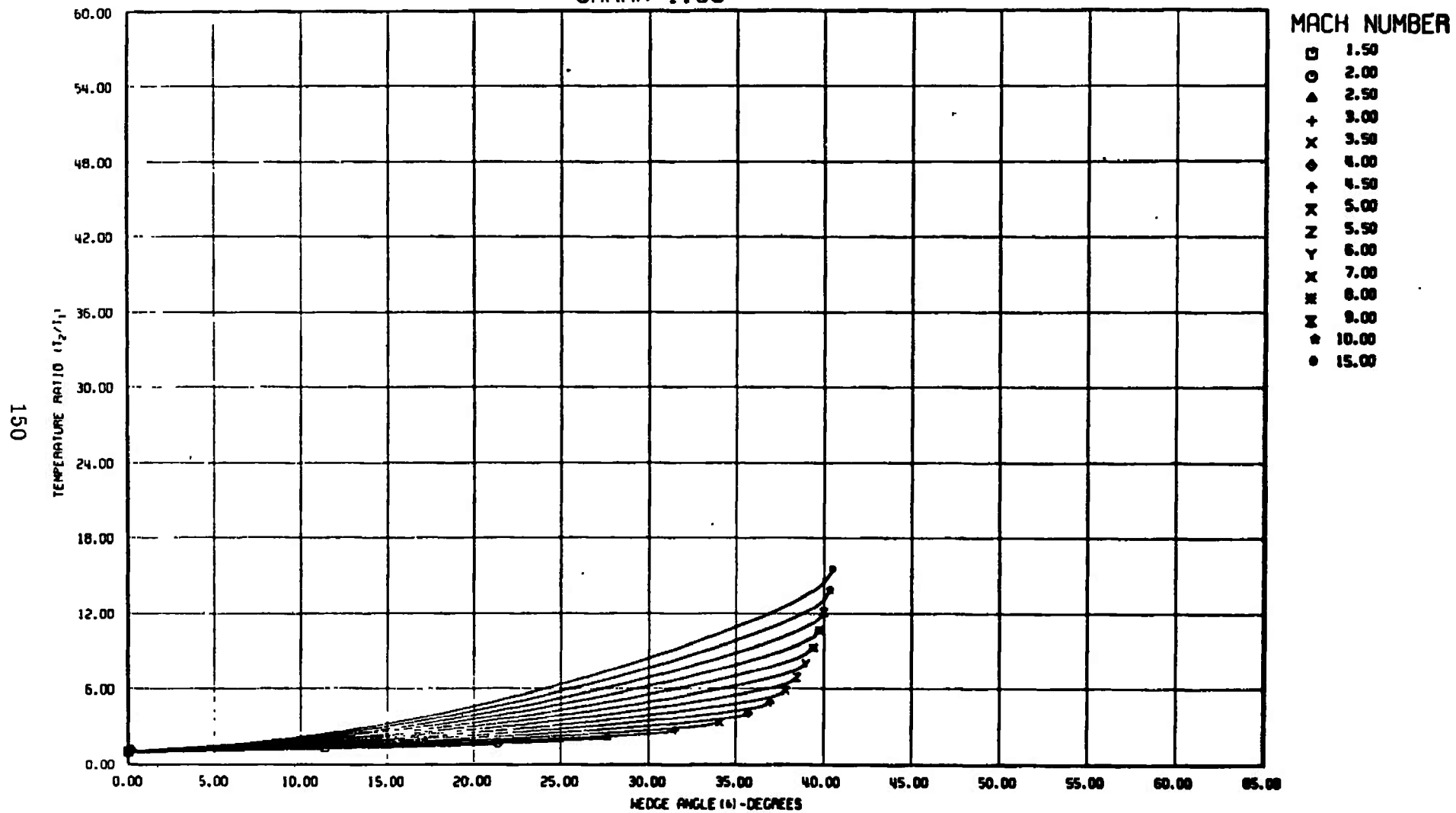


Fig. 22 Continued

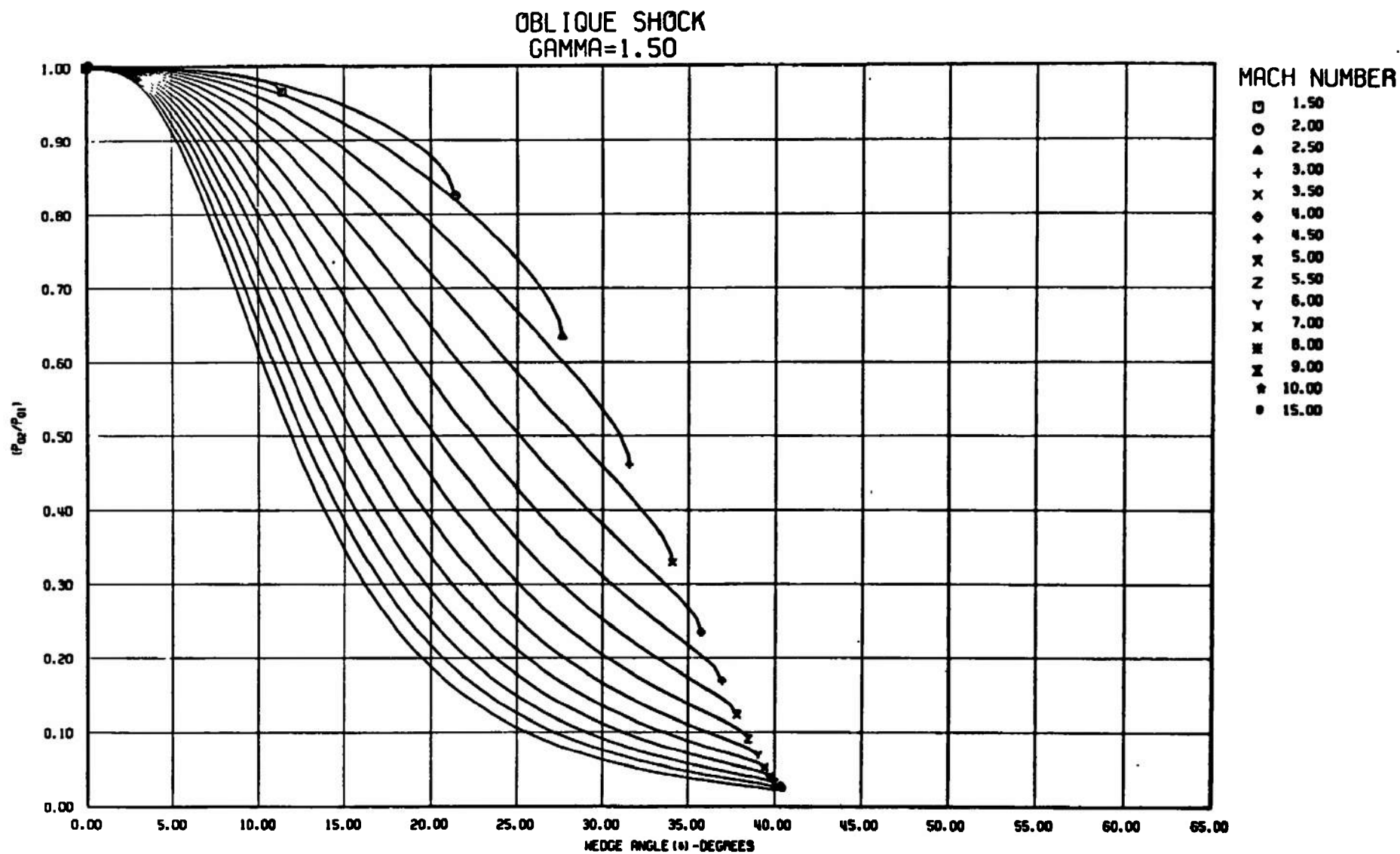
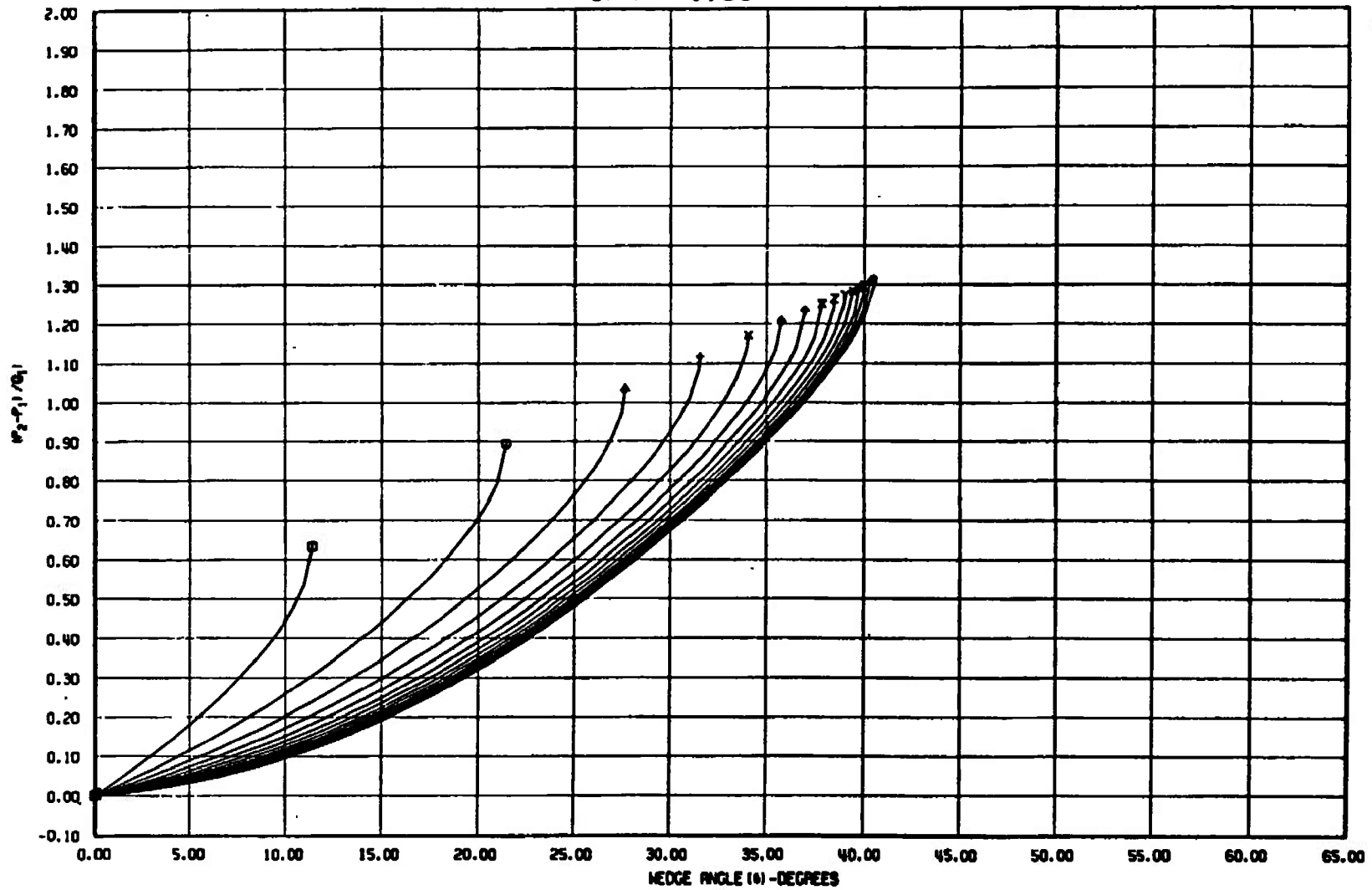


Fig. 22 Continued

OBLIQUE SHOCK GAMMA=1.50



MACH NUMBER	
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△	2.50
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⋈	4.50
×	5.00
z	5.50
y	6.00
x	7.00
≡	8.00
≡	9.00
*	10.00
•	15.00

Fig. 22 Concluded

OBLIQUE SHOCK GAMMA=1.52

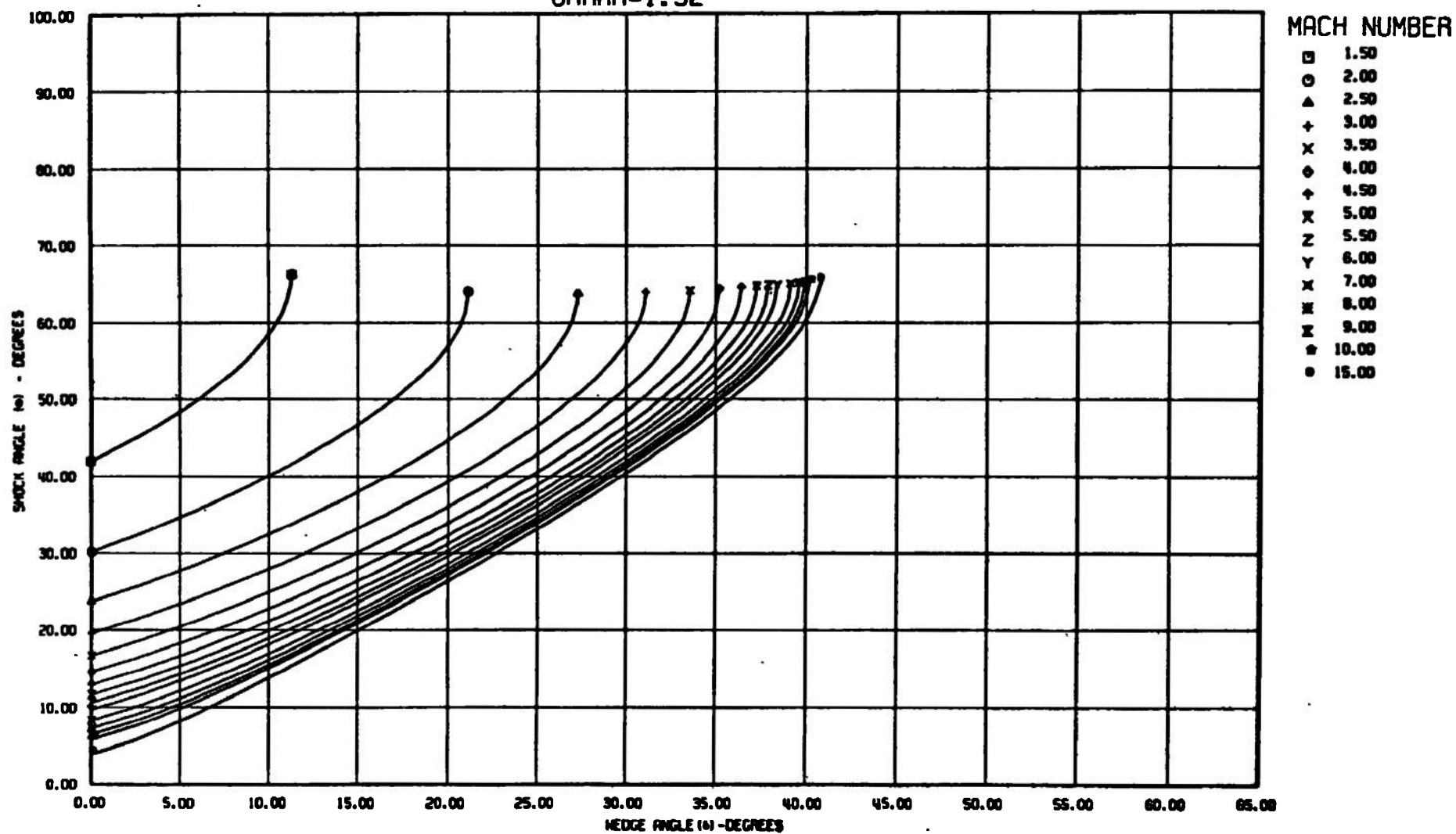


Fig. 23 $\gamma = 1.52$

OBLIQUE SHOCK GAMMA=1.52

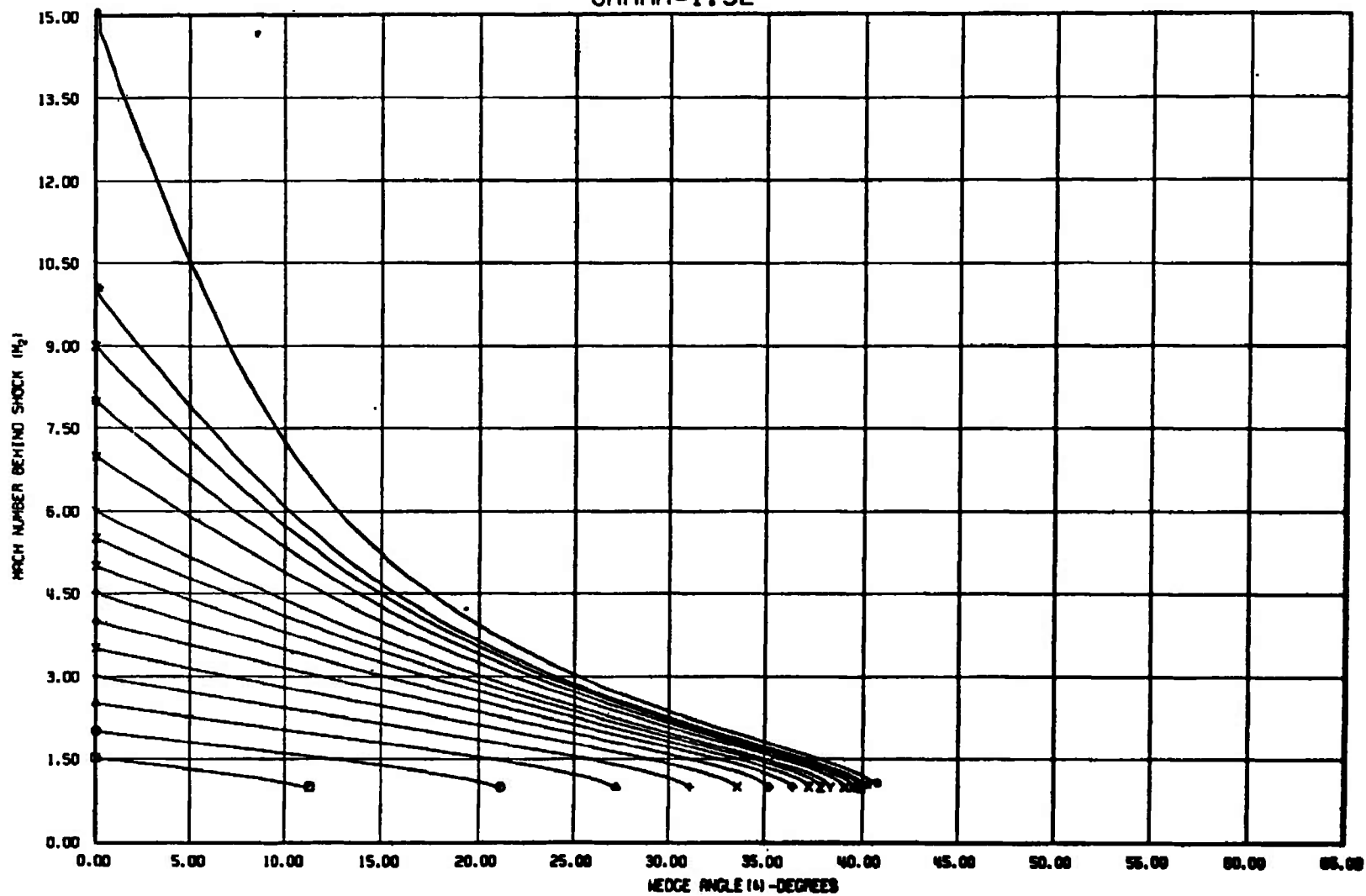


Fig. 23 Continued

OBLIQUE SHOCK
GAMMA=1.52

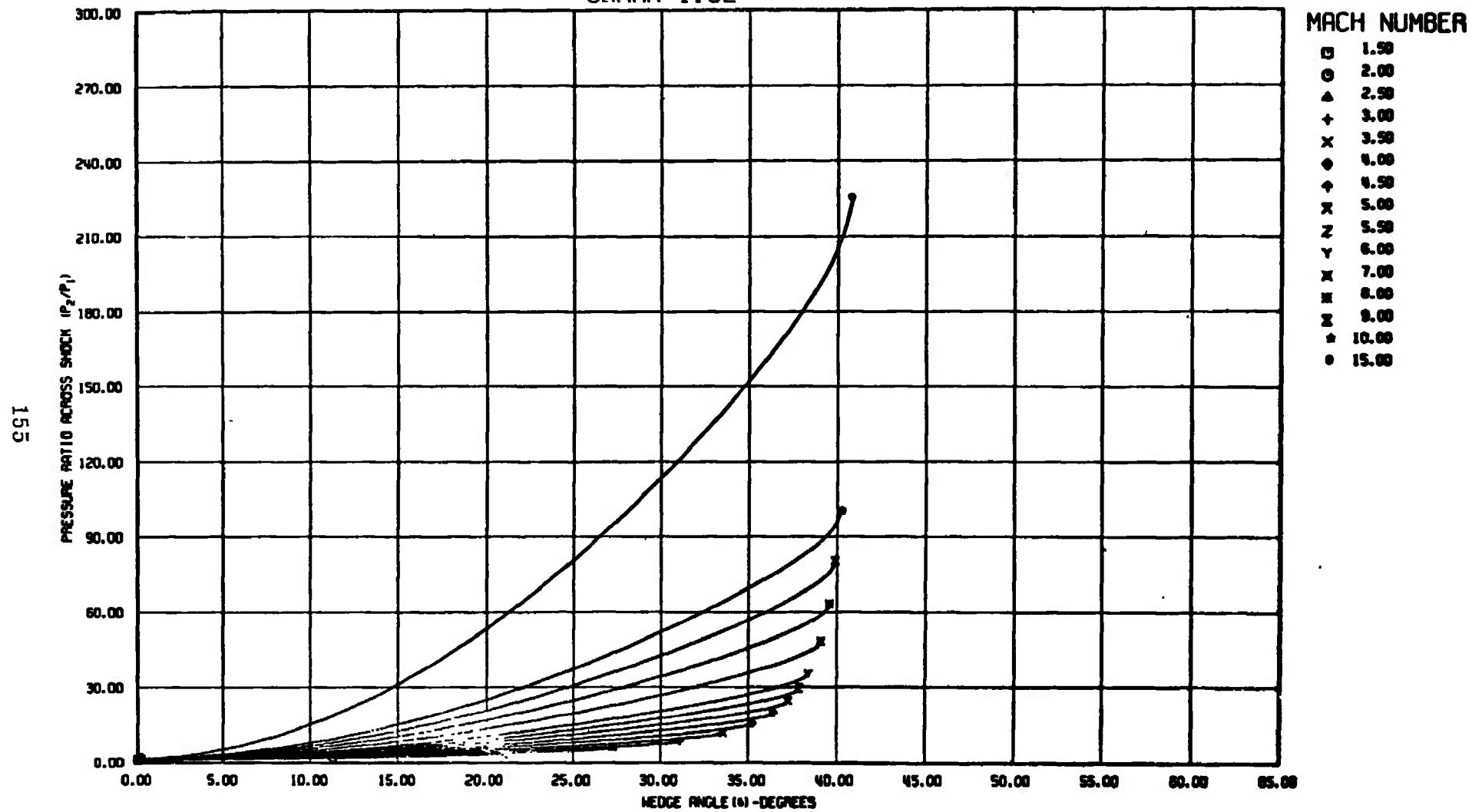


Fig. 23 Continued

OBLIQUE SHOCK
GAMMA=1.52

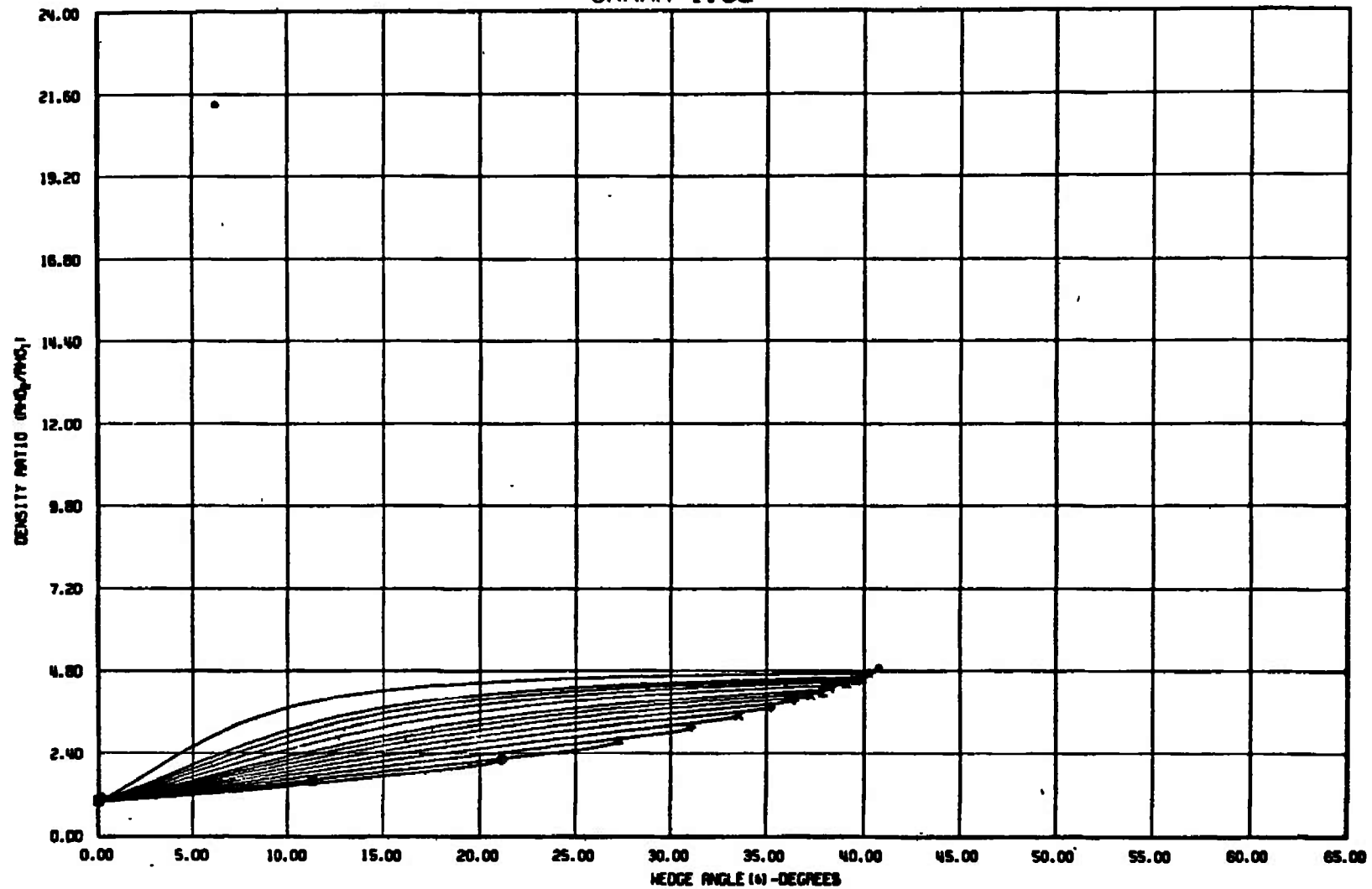
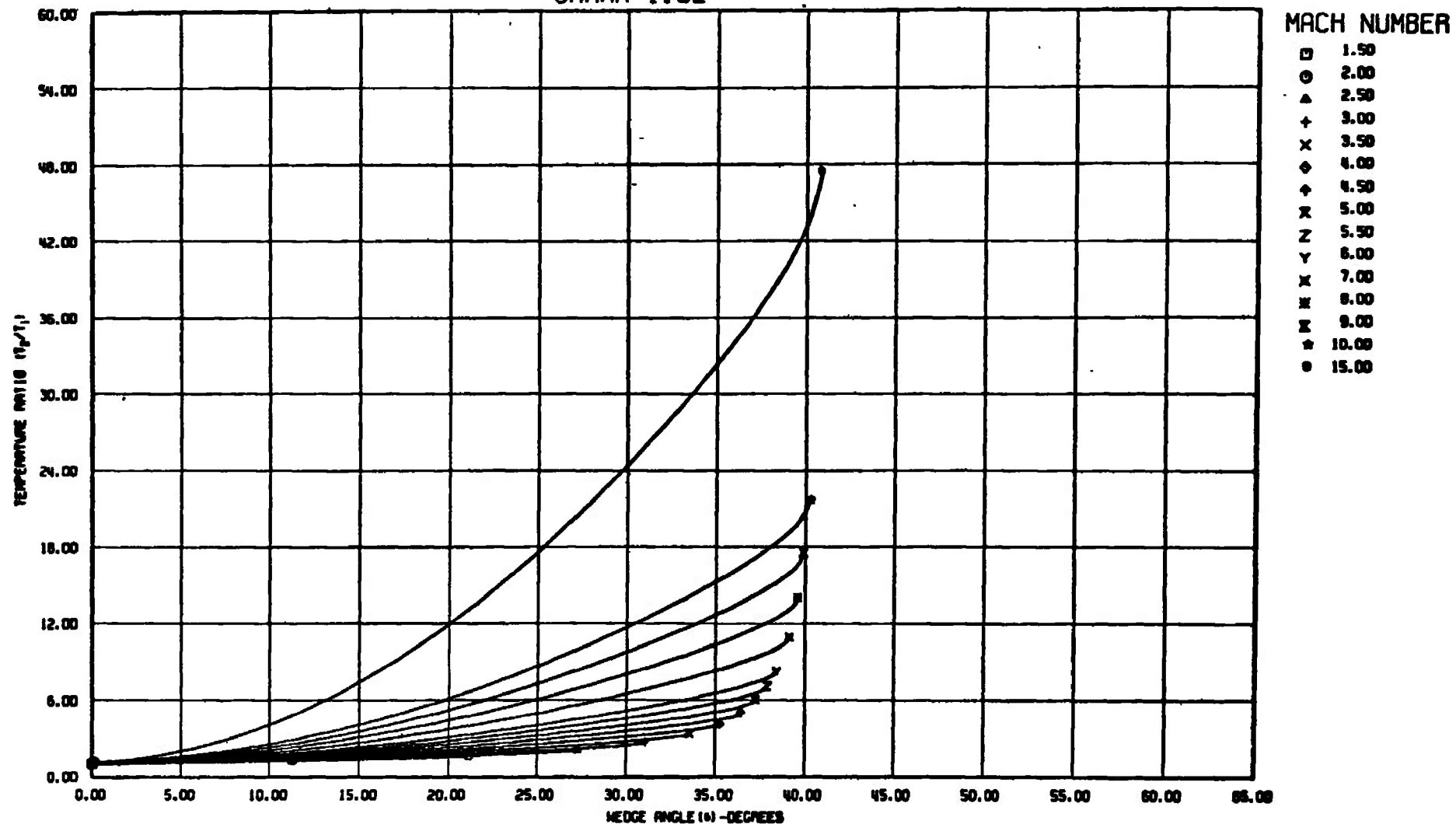


Fig. 23 Continued

OBLIQUE SHOCK
GAMMA=1.52



157

Fig. 23 Continued

OBLIQUE SHOCK GAMMA=1.52

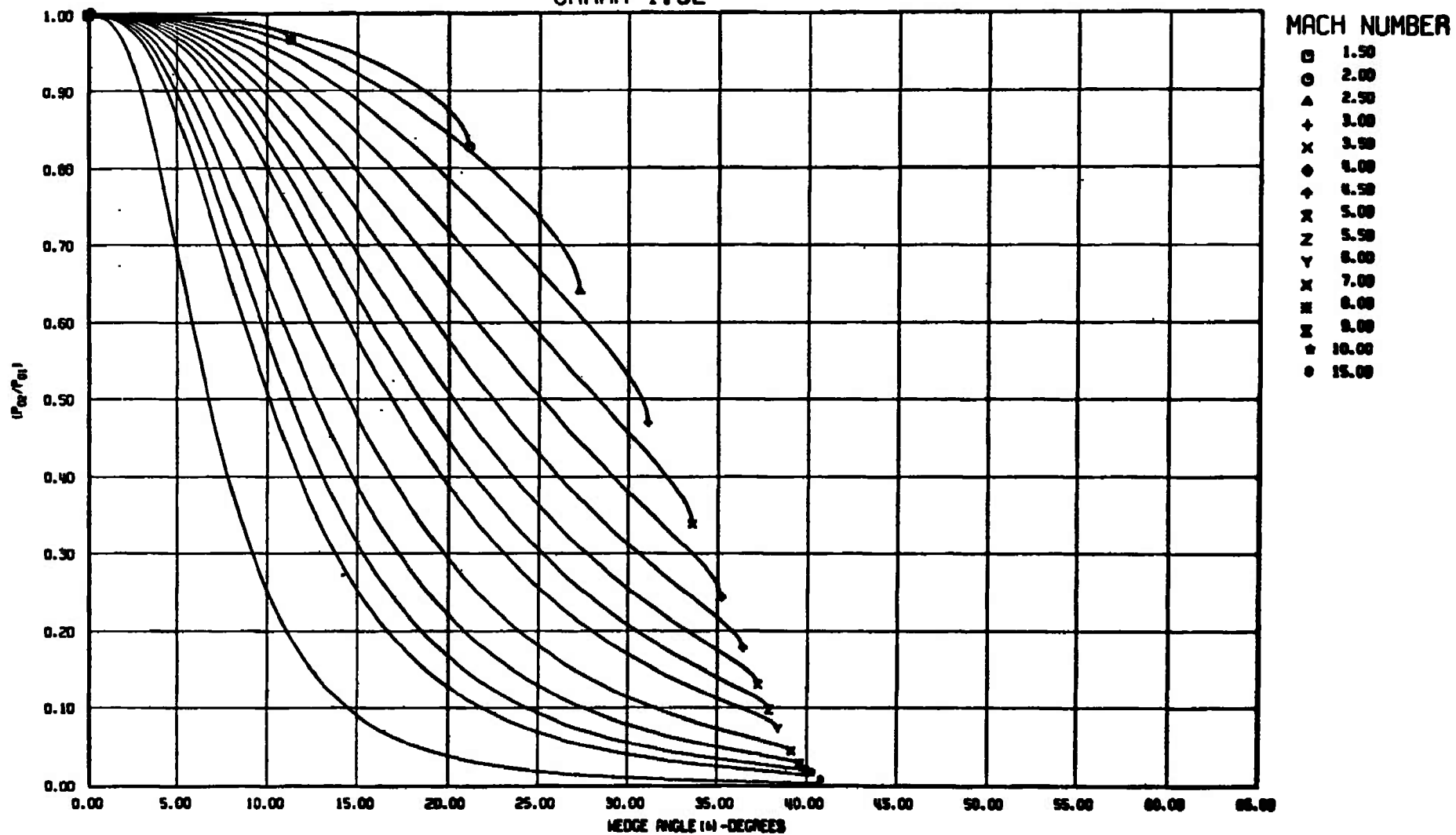
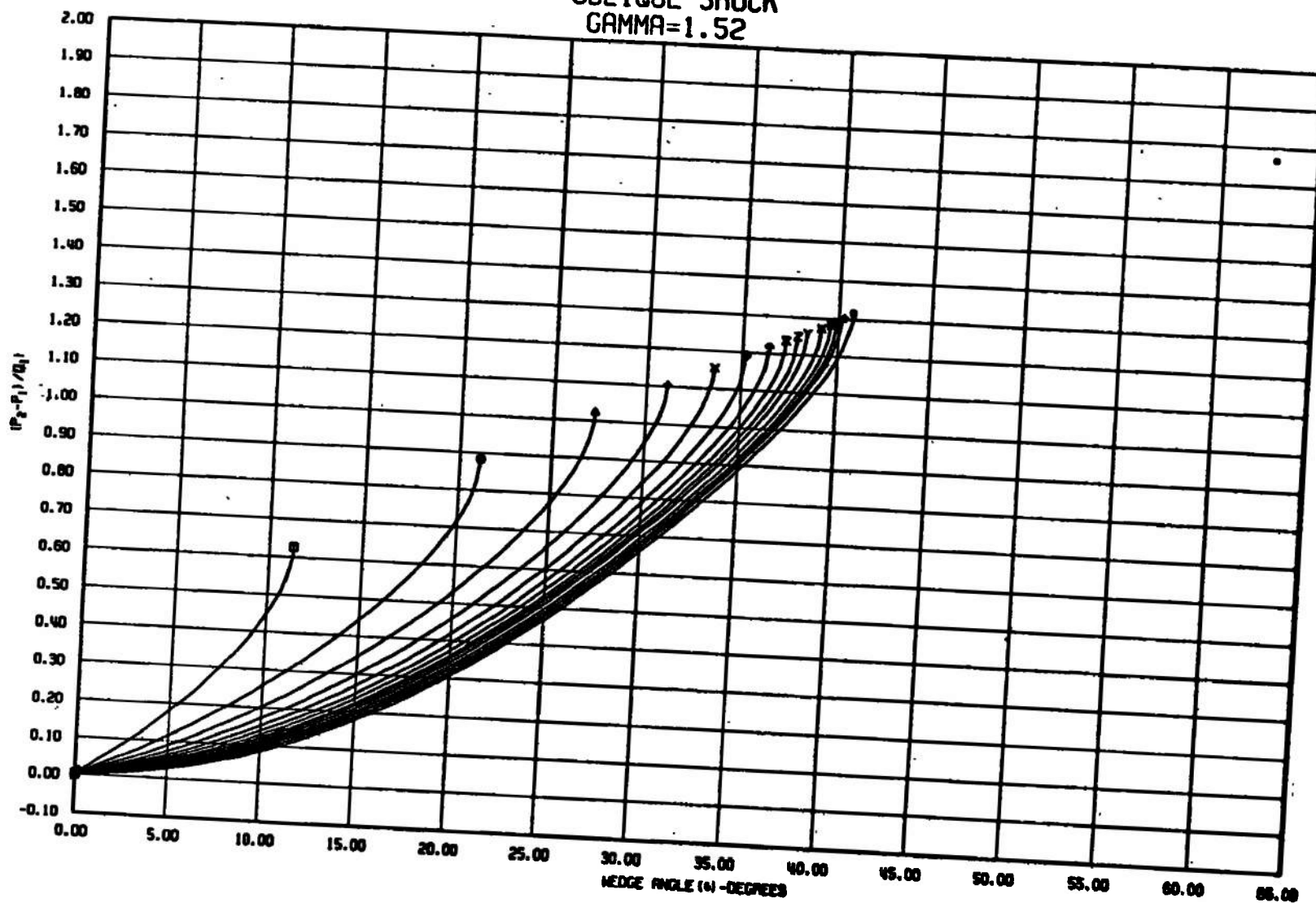


Fig. 23 Continued

OBLIQUE SHOCK
GAMMA=1.52



MACH NUMBER

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- 2.00
- △ 2.50
- +
- × 3.50
- 4.00
- ◊ 4.50
- × 5.00
- z 5.50
- Y 6.00
- x 7.00
- ≡ 8.00
- Σ 9.00
- ★ 10.00
- 15.00

Fig. 23 Concluded

OBLIQUE SHOCK GAMMA=1.54

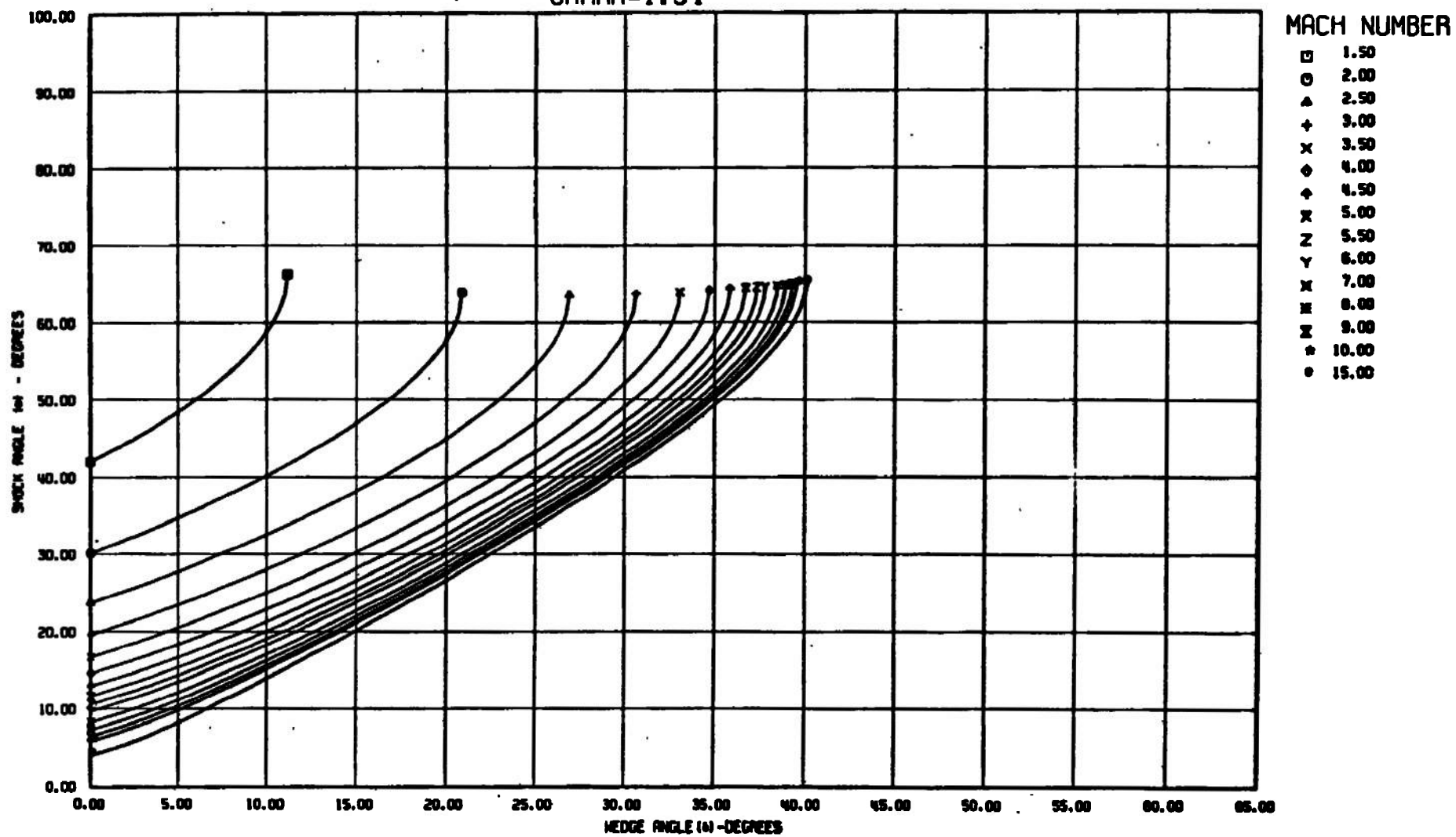


Fig. 24 $\gamma = 1.54$

OBLIQUE SHOCK GAMMA=1.54

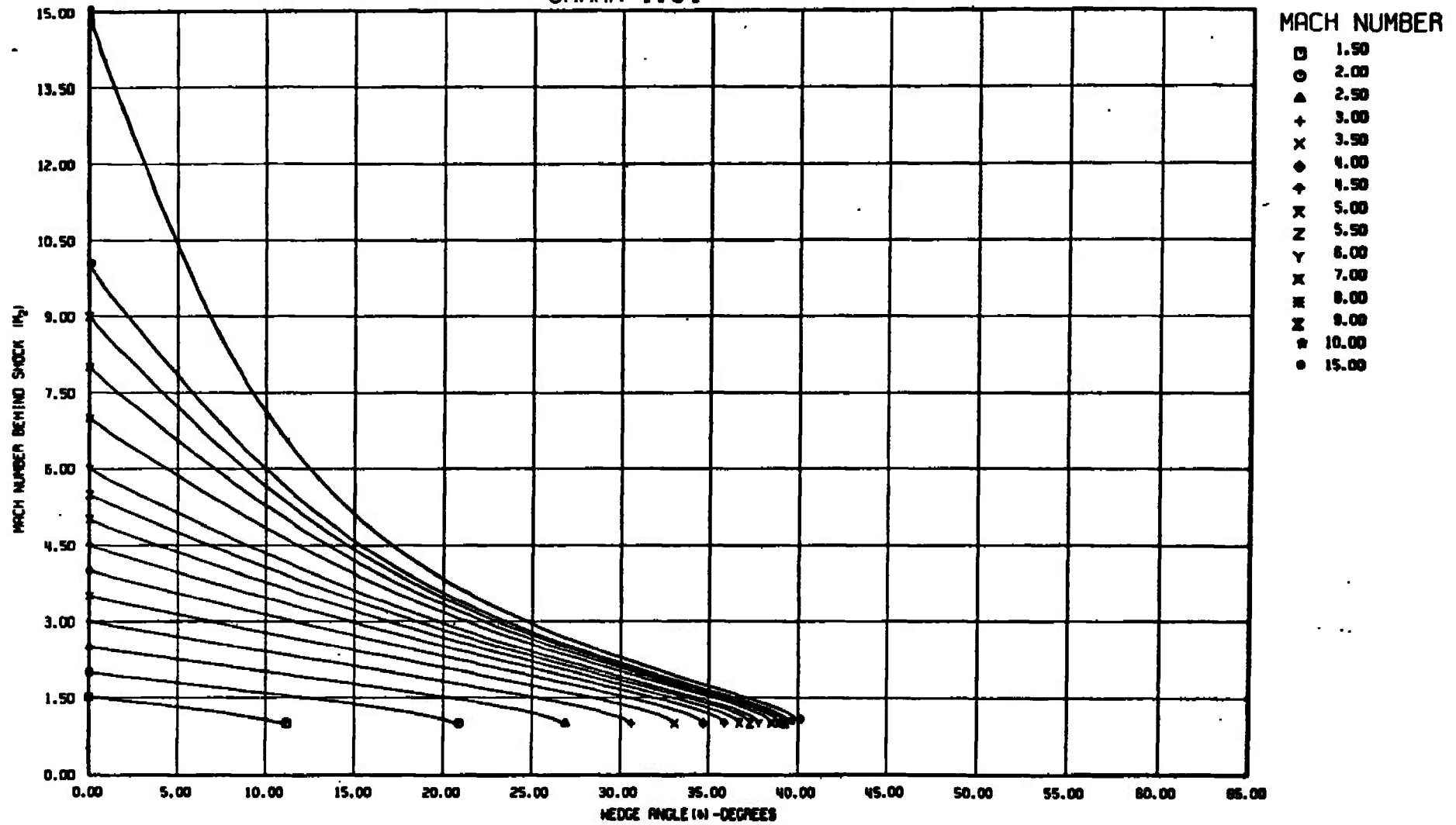


Fig. 24 Continued

OBLIQUE SHOCK GAMMA=1.54

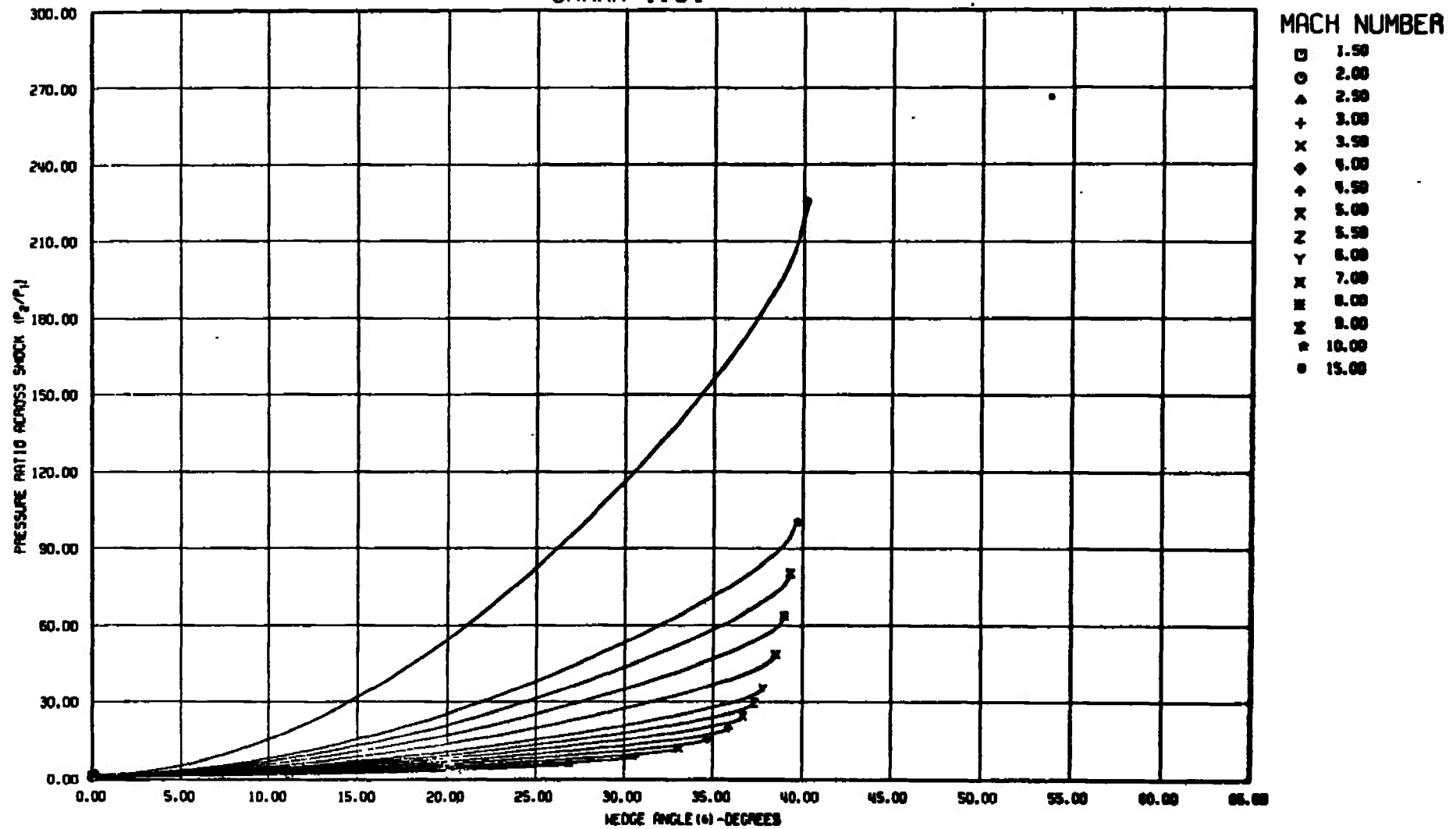


Fig. 24 Continued

OBLIQUE SHOCK $\text{GAMMA}=1.54$

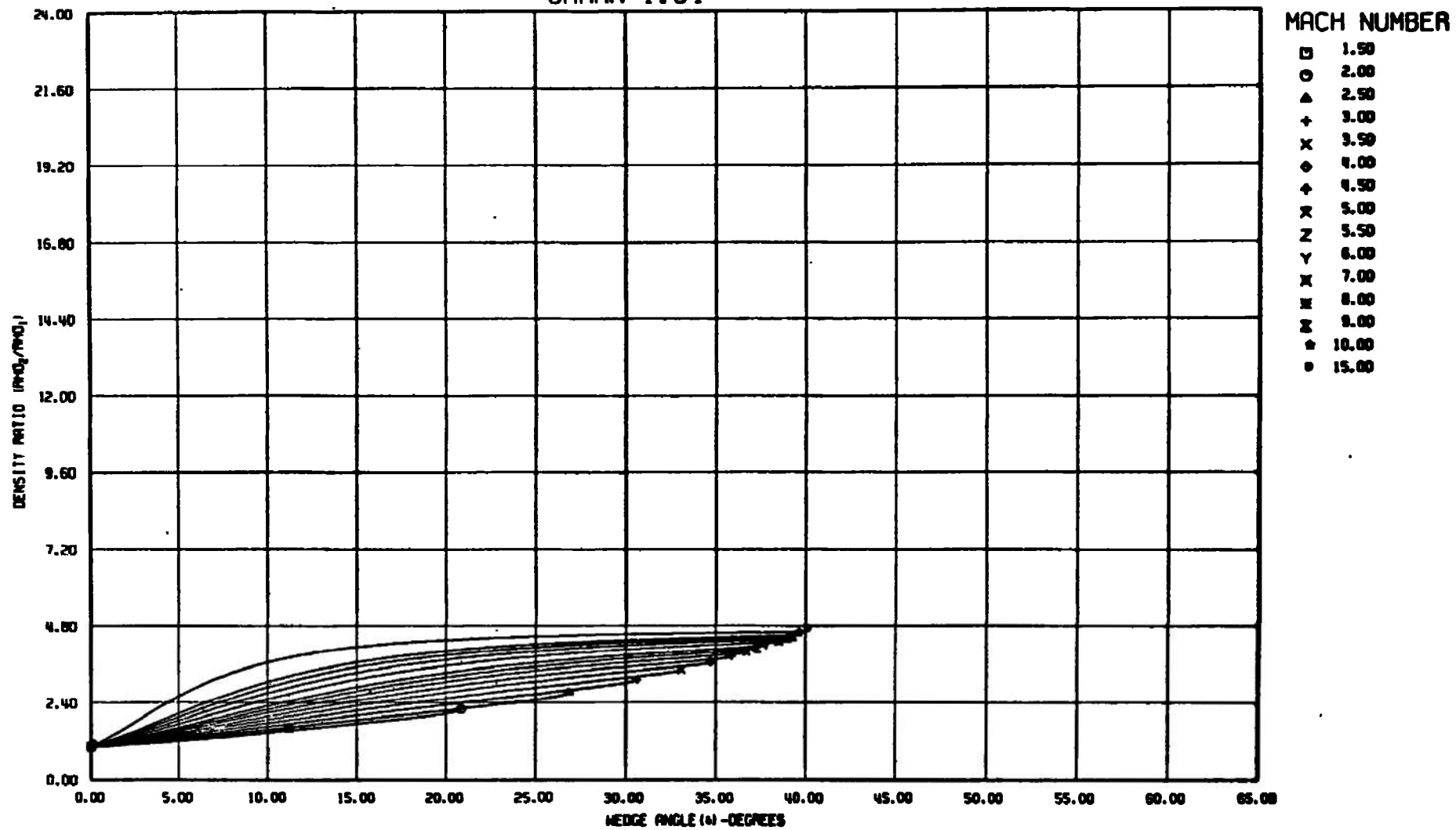


Fig. 24 Continued

OBLIQUE SHOCK GAMMA=1.54

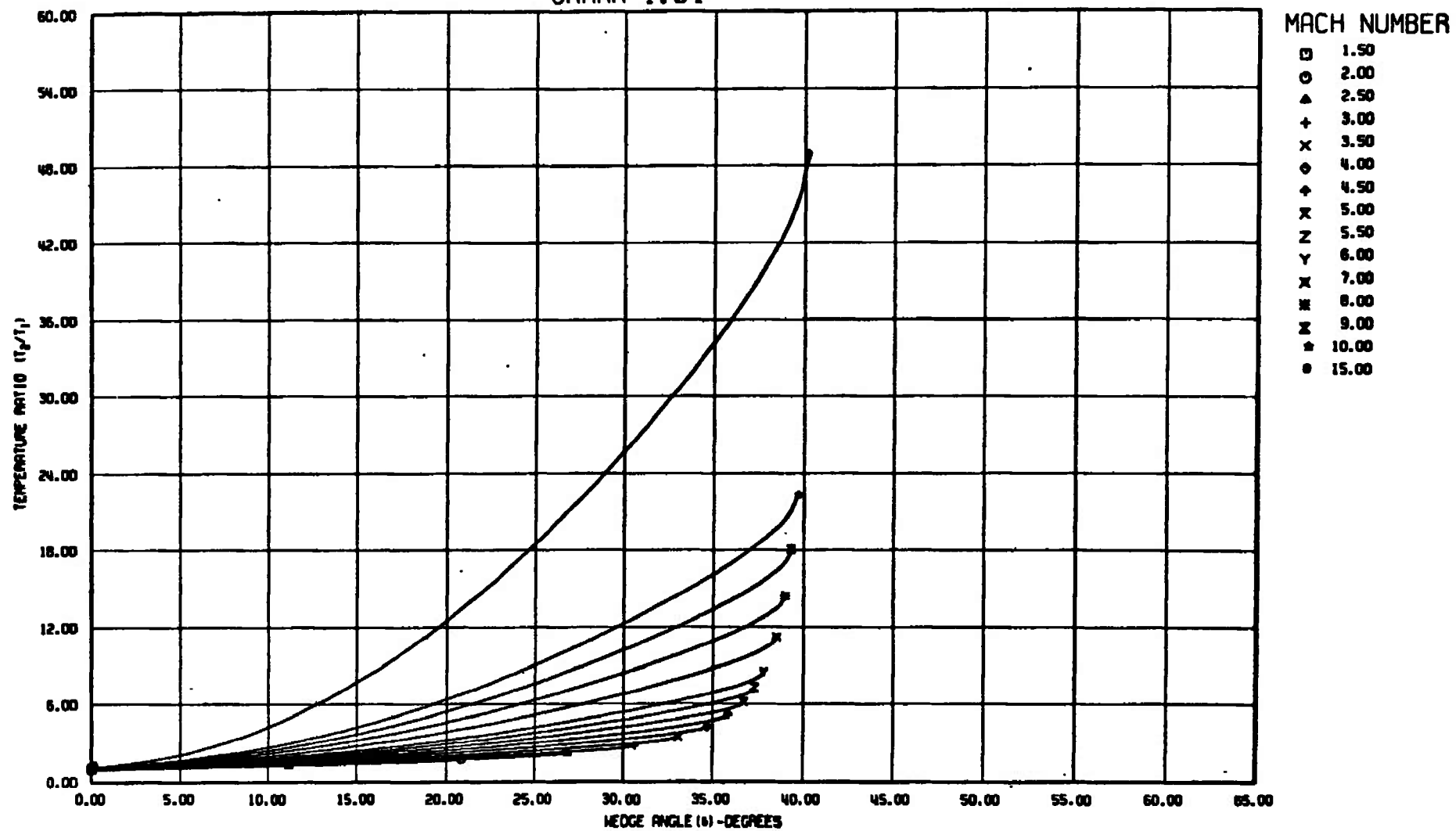


Fig. 24 Continued

OBLIQUE SHOCK GAMMA=1.54

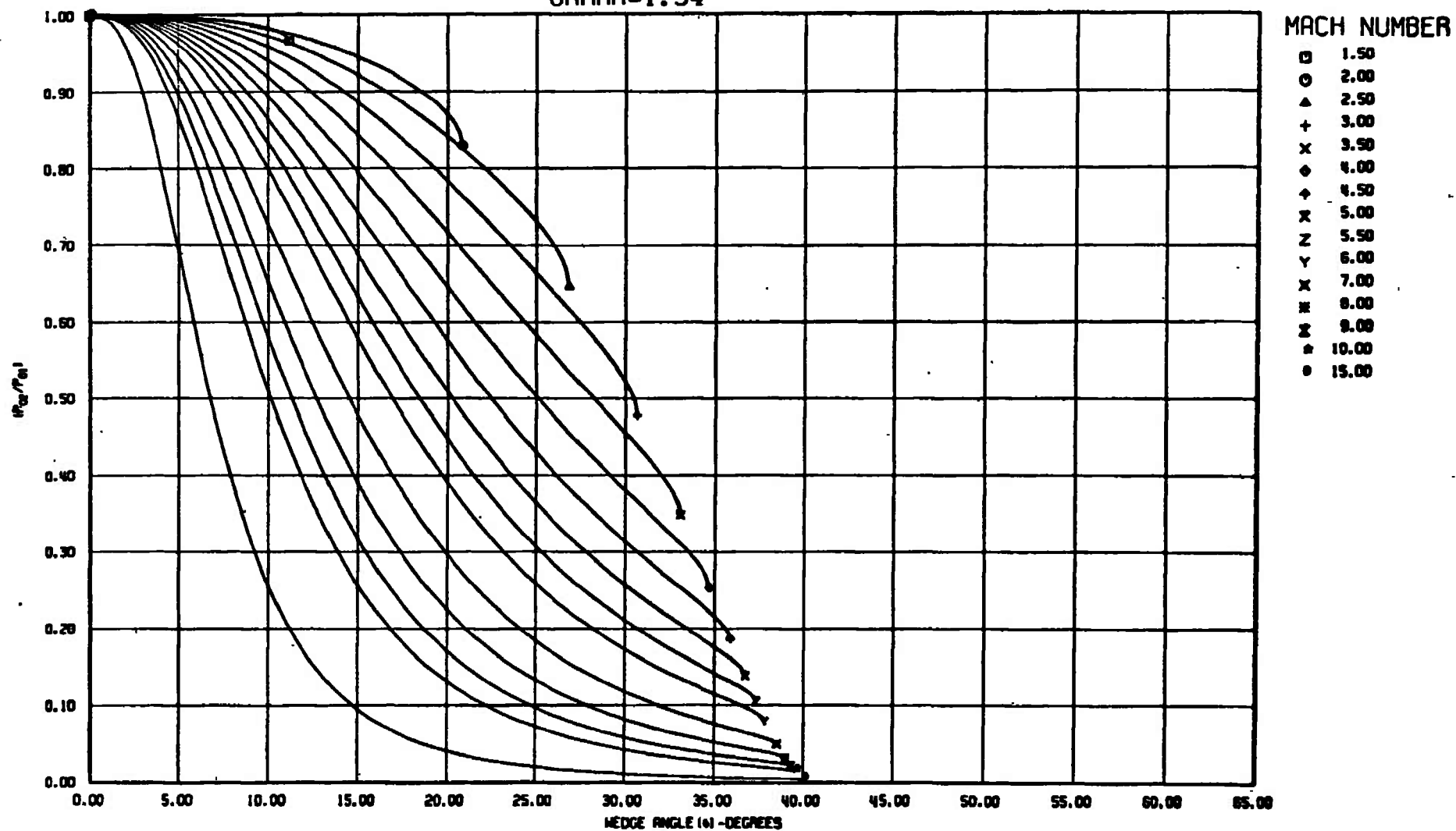


Fig. 24 Continued

OBLIQUE SHOCK GAMMA=1.54

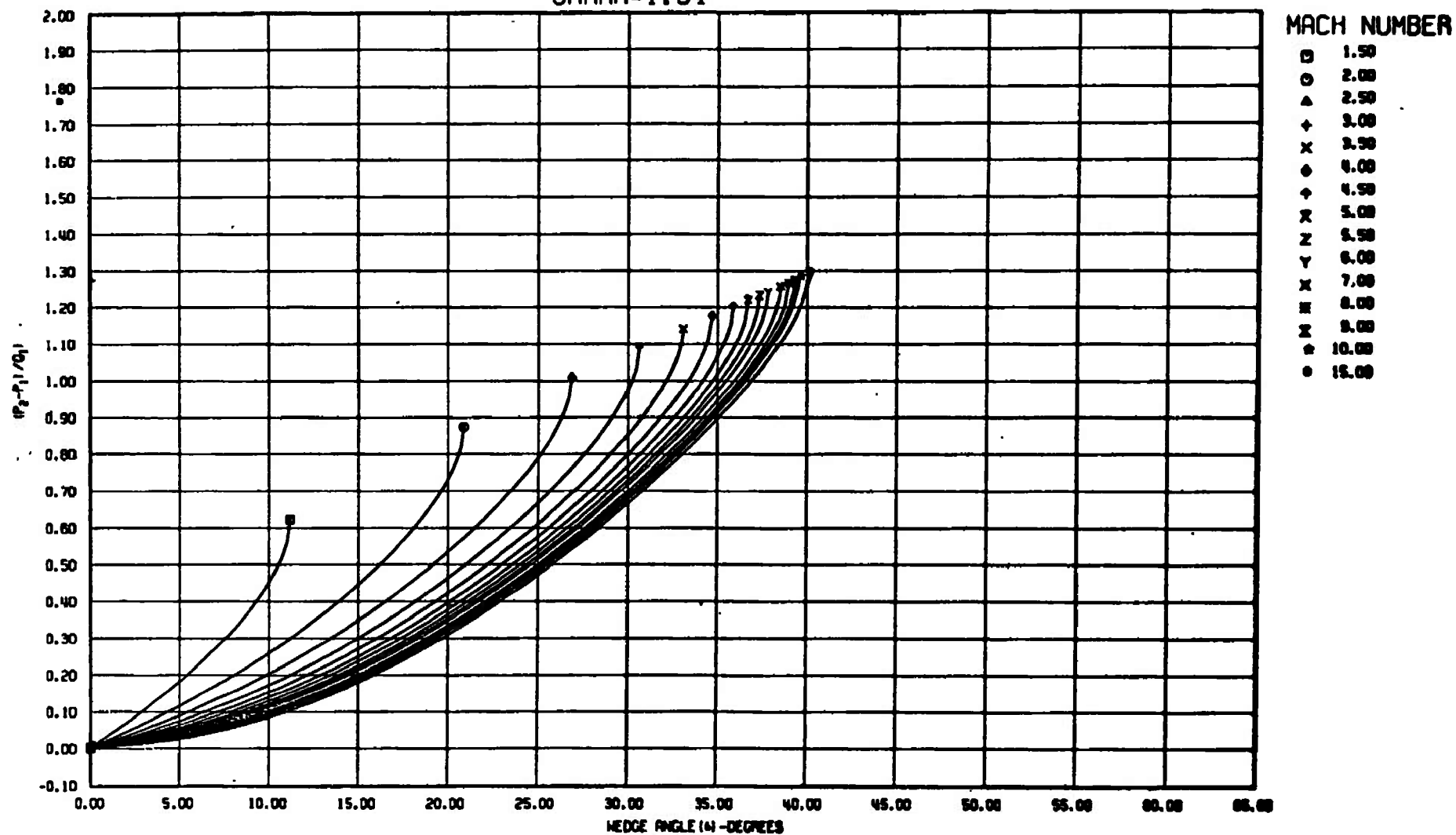


Fig. 24 Concluded

OBLIQUE SHOCK GAMMA=1.56

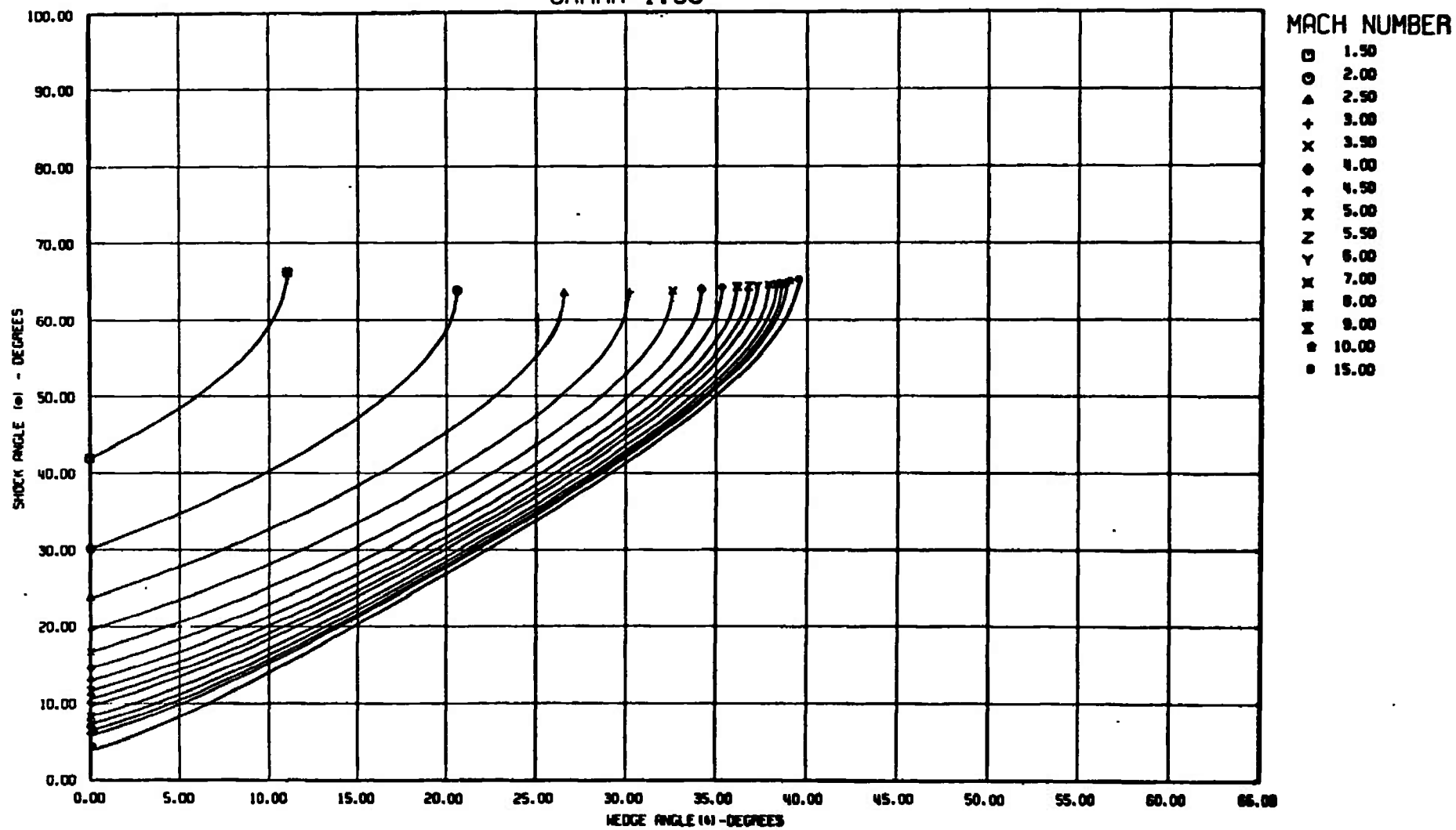
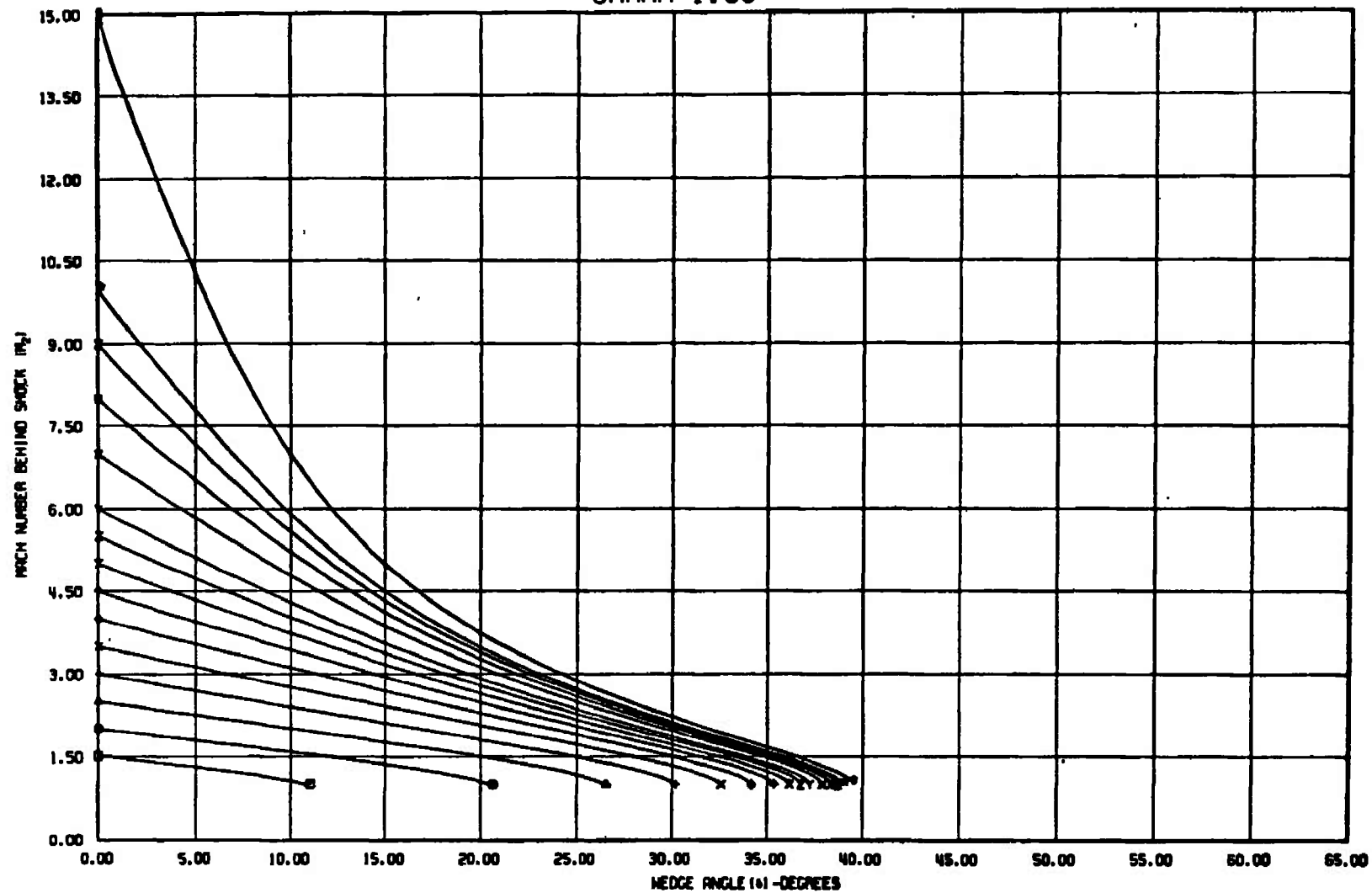


Fig. 25 $\gamma = 1.56$

OBLIQUE SHOCK GAMMA=1.56



MACH NUMBER

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- 2.00
- △ 2.50
- + 3.00
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- ◇ 4.00
- ◊ 4.50
- × 5.00
- z 5.50
- y 6.00
- x 7.00
- ≡ 8.00
- ≡ 9.00
- ★ 10.00
- 15.00

Fig. 25 Continued

OBLIQUE SHOCK GAMMA=1.56

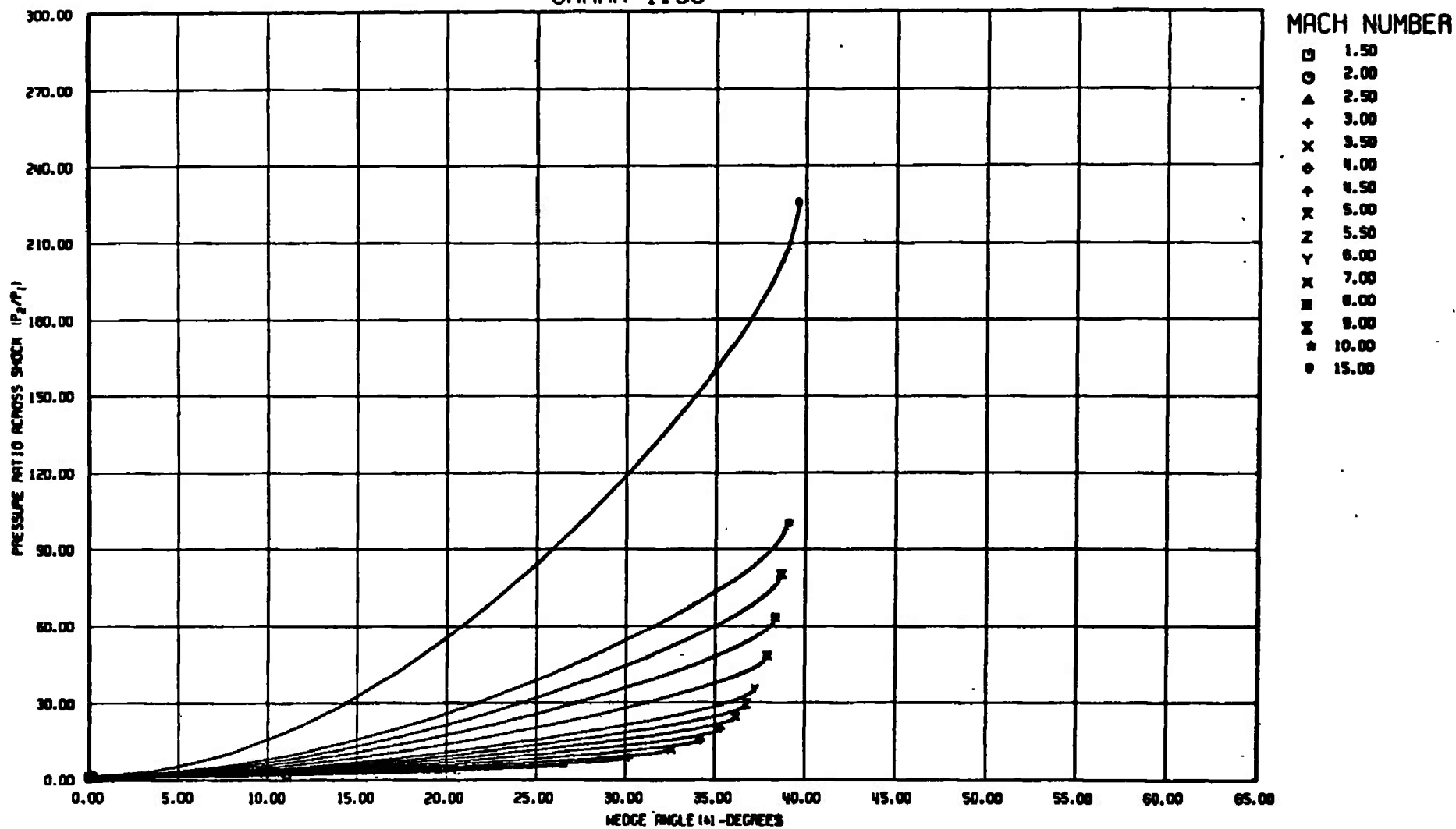


Fig. 25 Continued

OBLIQUE SHOCK GAMMA=1.56

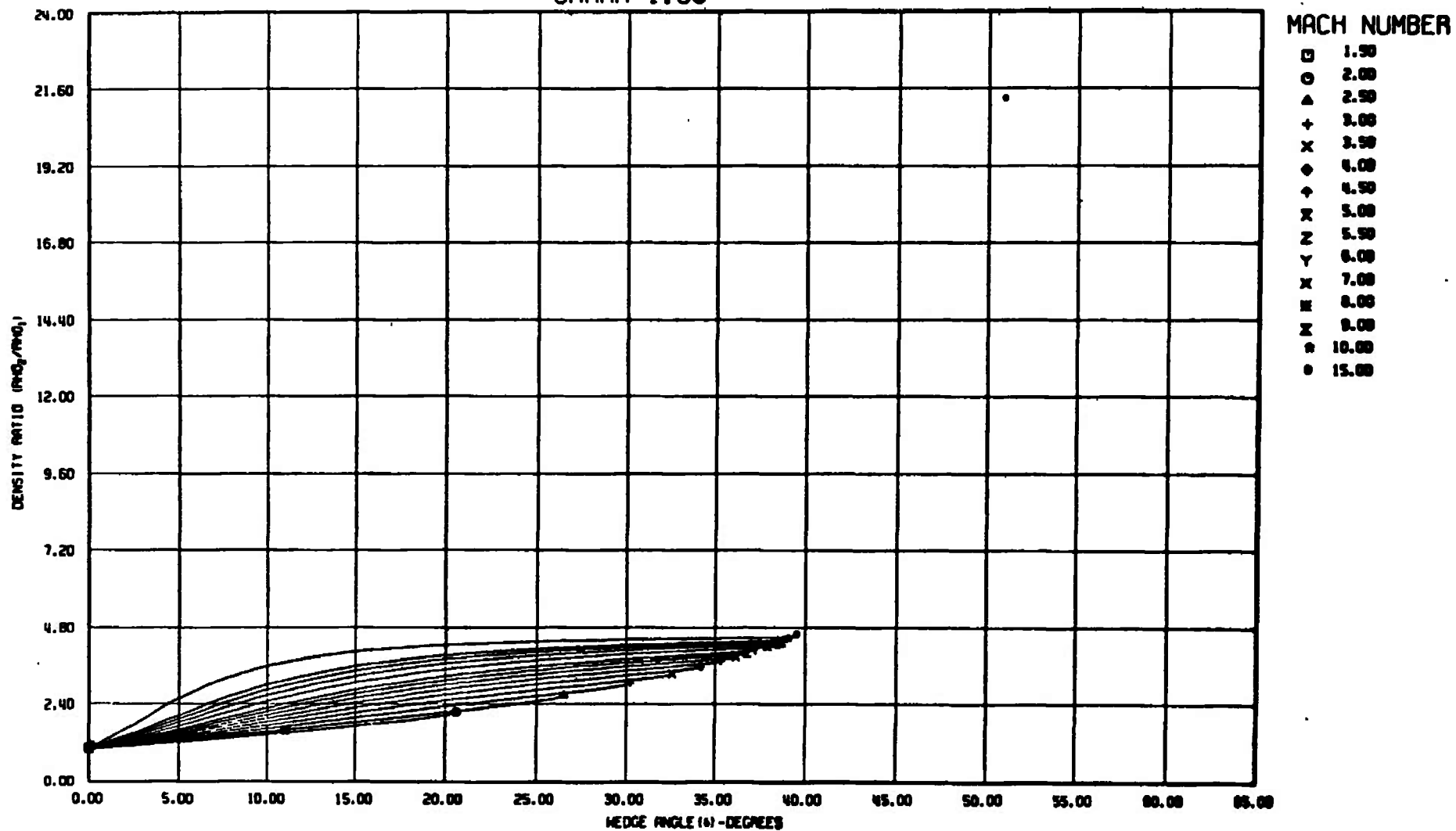


Fig. 25 Continued

171

OBLIQUE SHOCK GAMMA=1.56

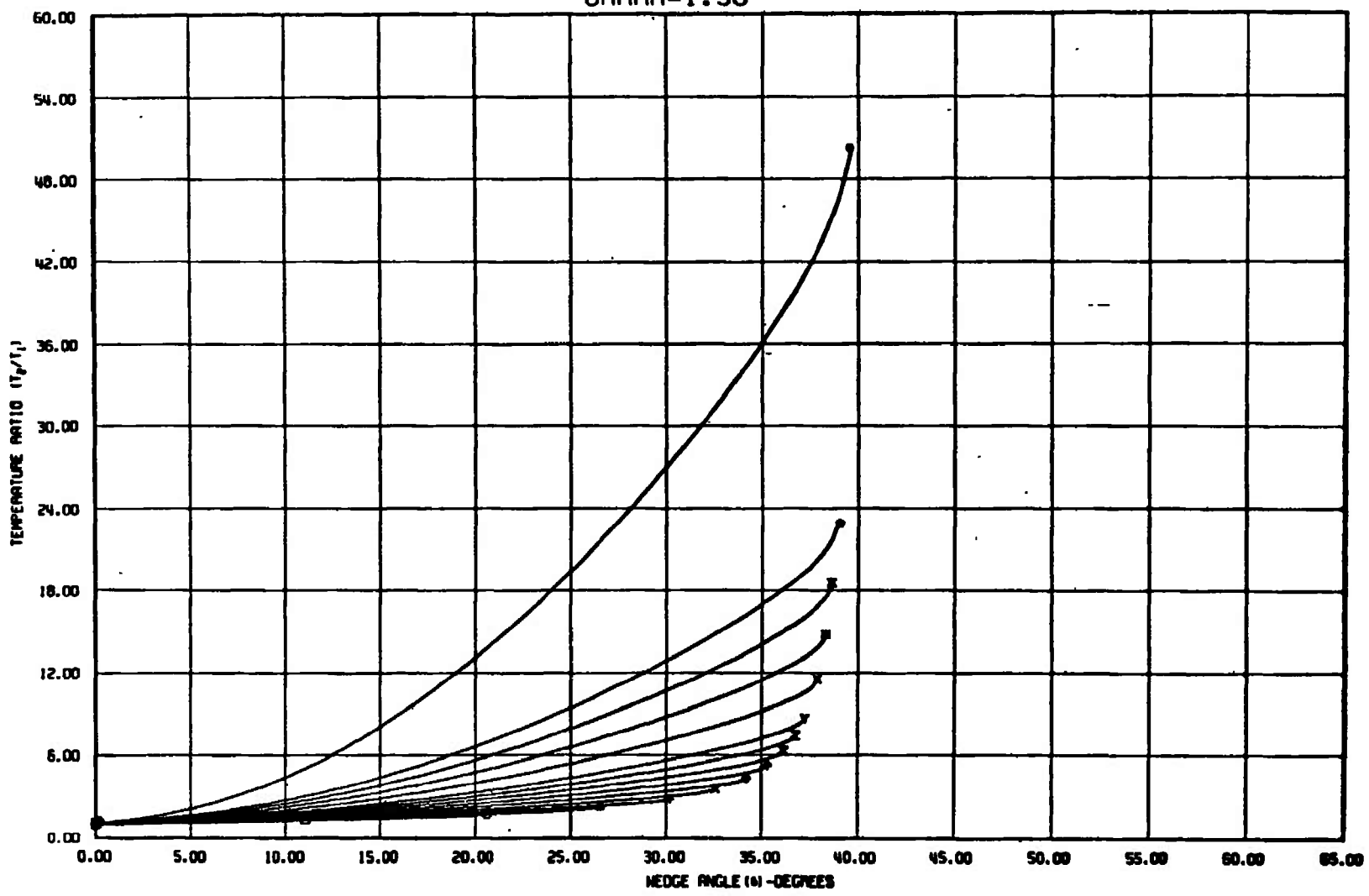


Fig. 25 Continued

OBLIQUE SHOCK
GAMMA=1.56

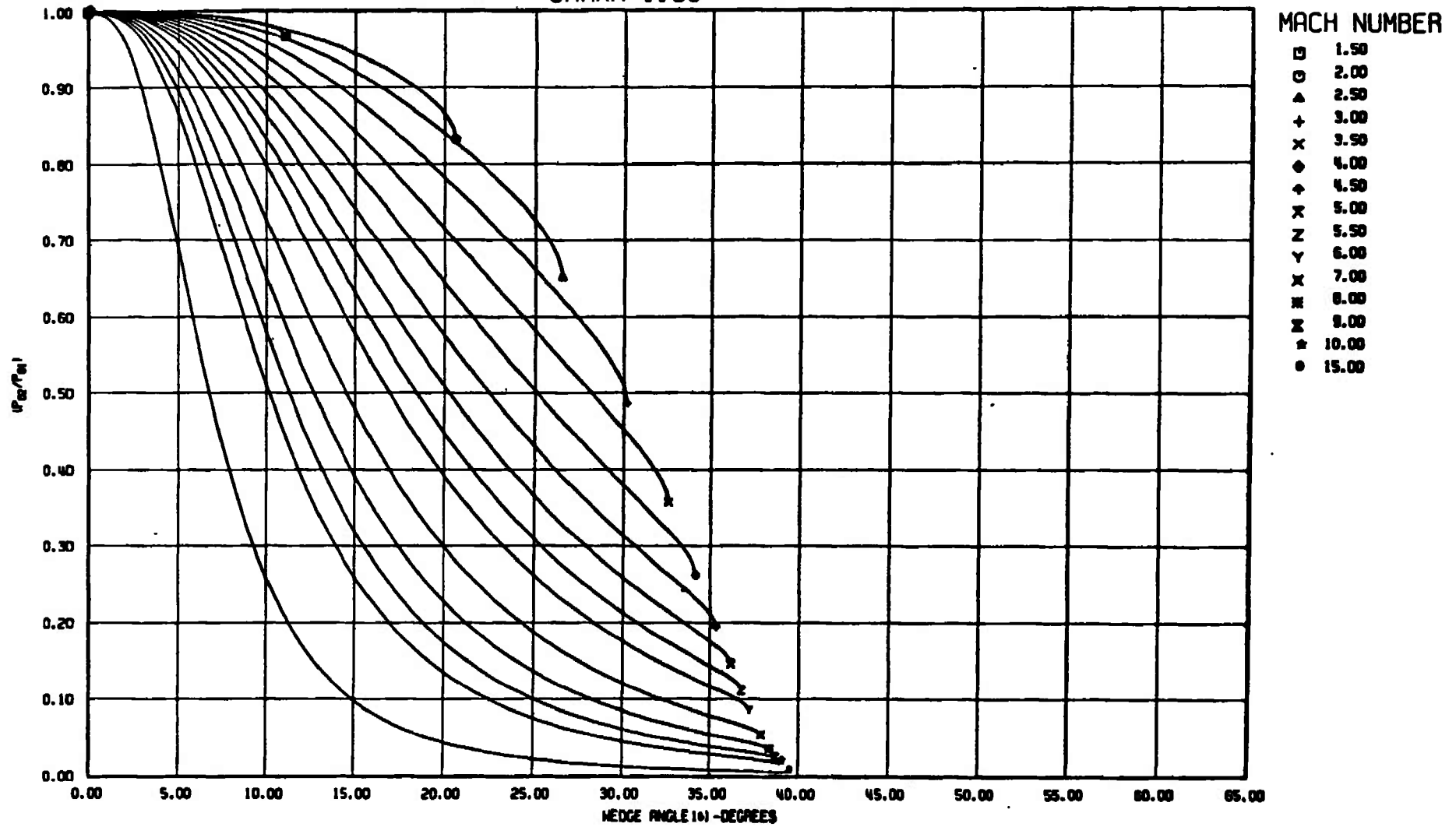


Fig. 25 Continued

OBLIQUE SHOCK
GAMMA=1.56

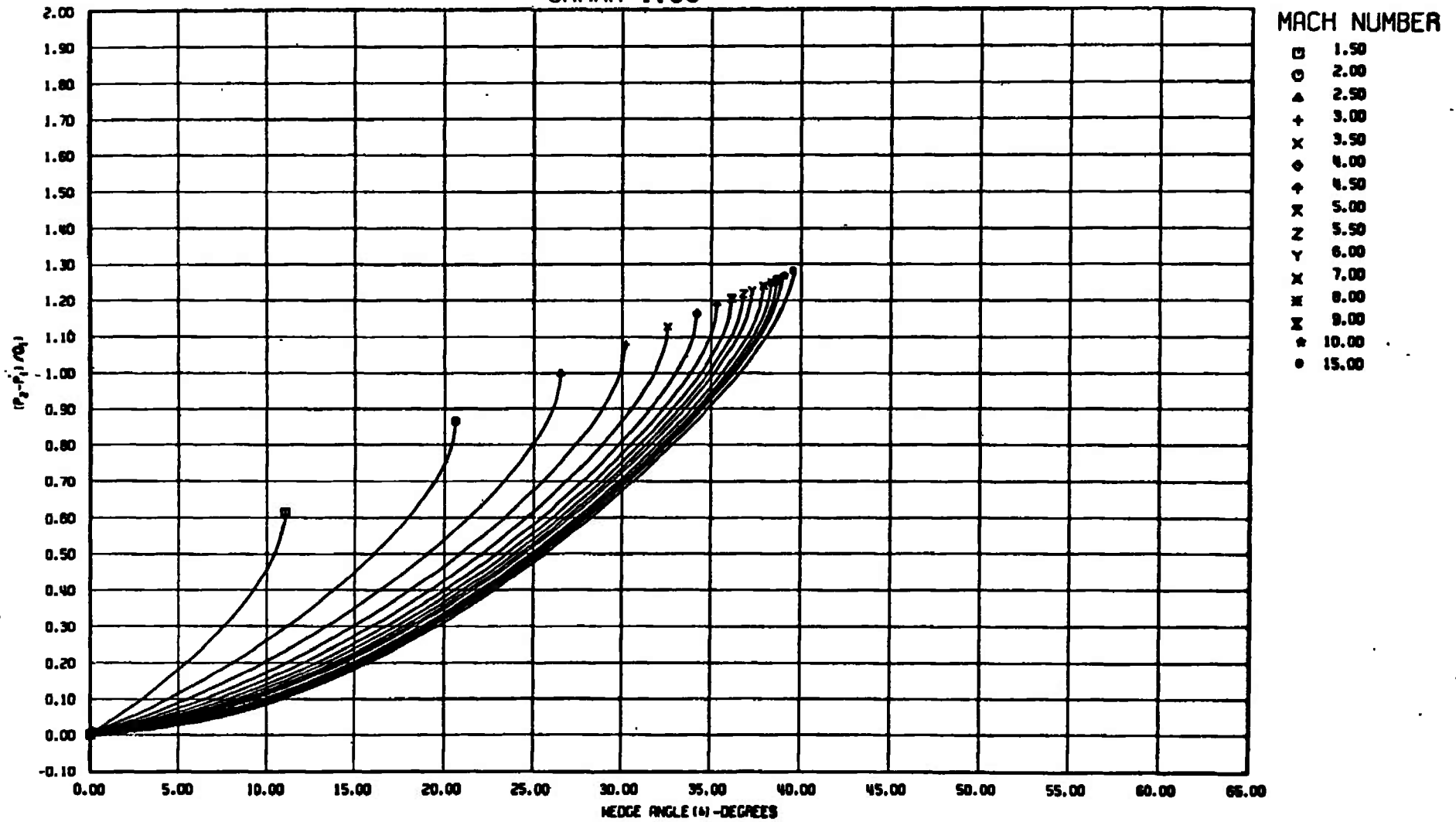
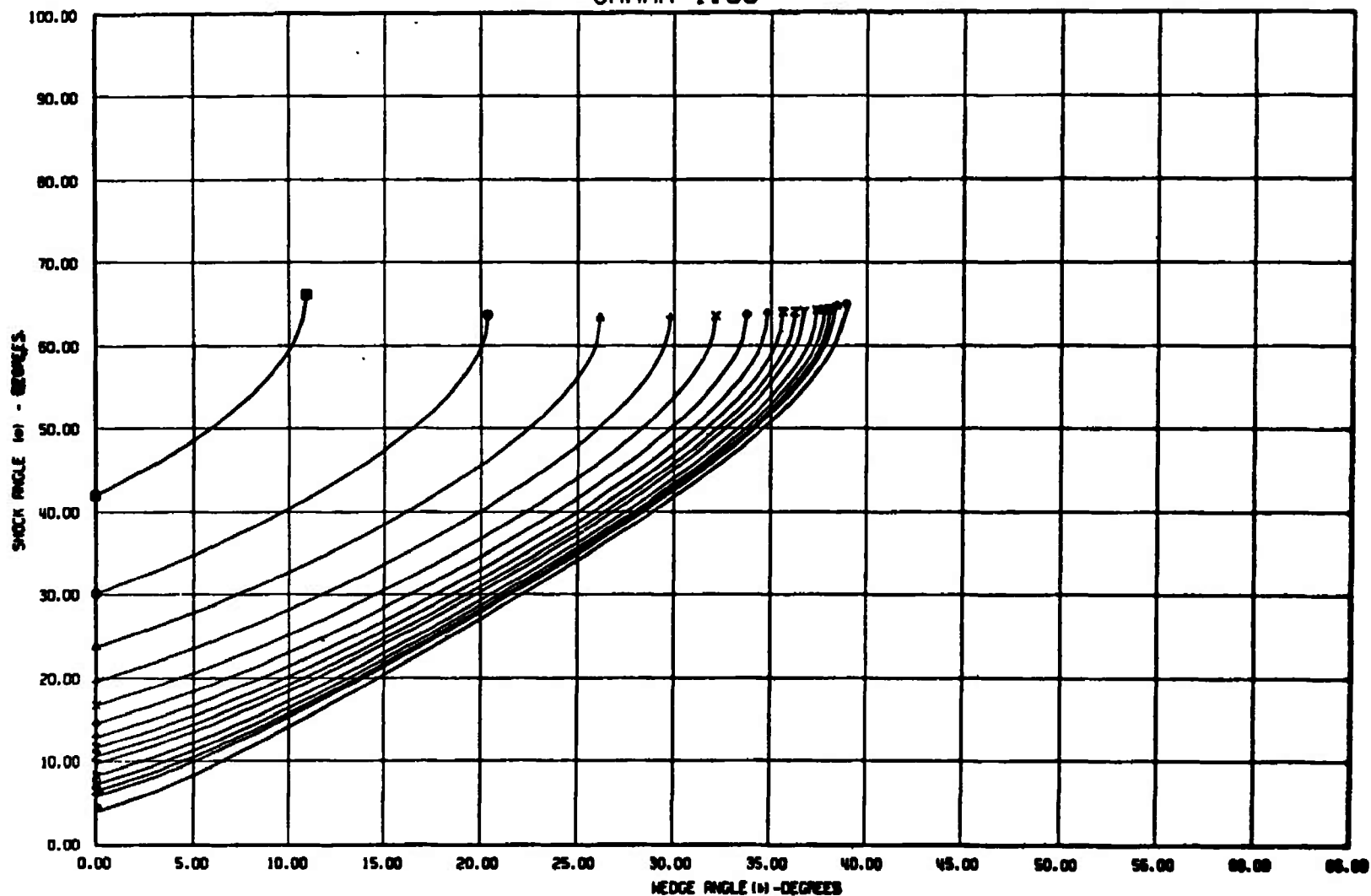


Fig. 25 Concluded

OBLIQUE SHOCK $\gamma = 1.58$



MACH NUMBER

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- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◊ 4.00
- ◊ 4.50
- x 5.00
- z 5.50
- y 6.00
- x 7.00
- h 8.00
- z 9.00
- 10.00
- 15.00

Fig. 26 $\gamma = 1.58$

OBLIQUE SHOCK
 $\gamma = 1.58$

175

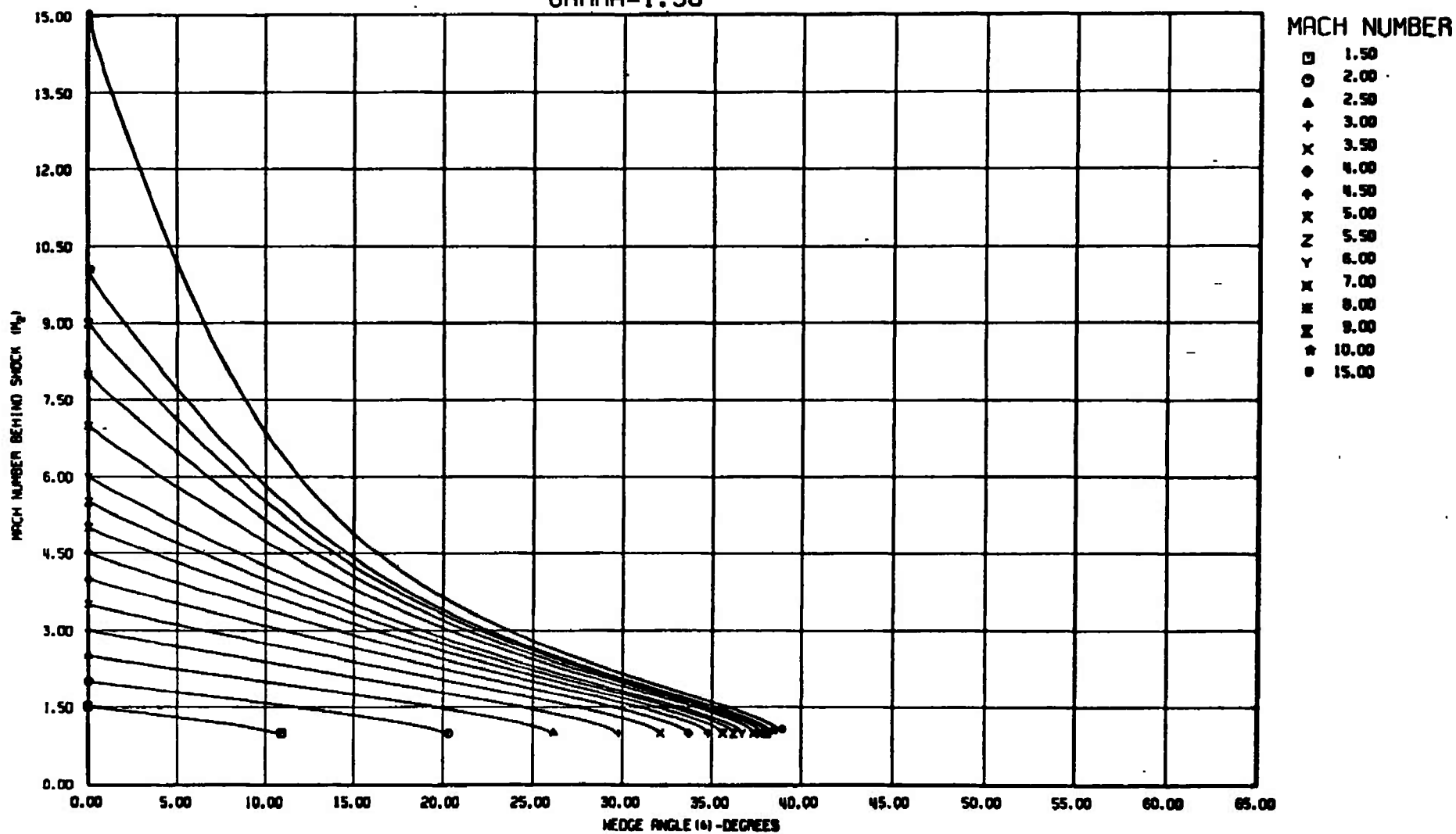
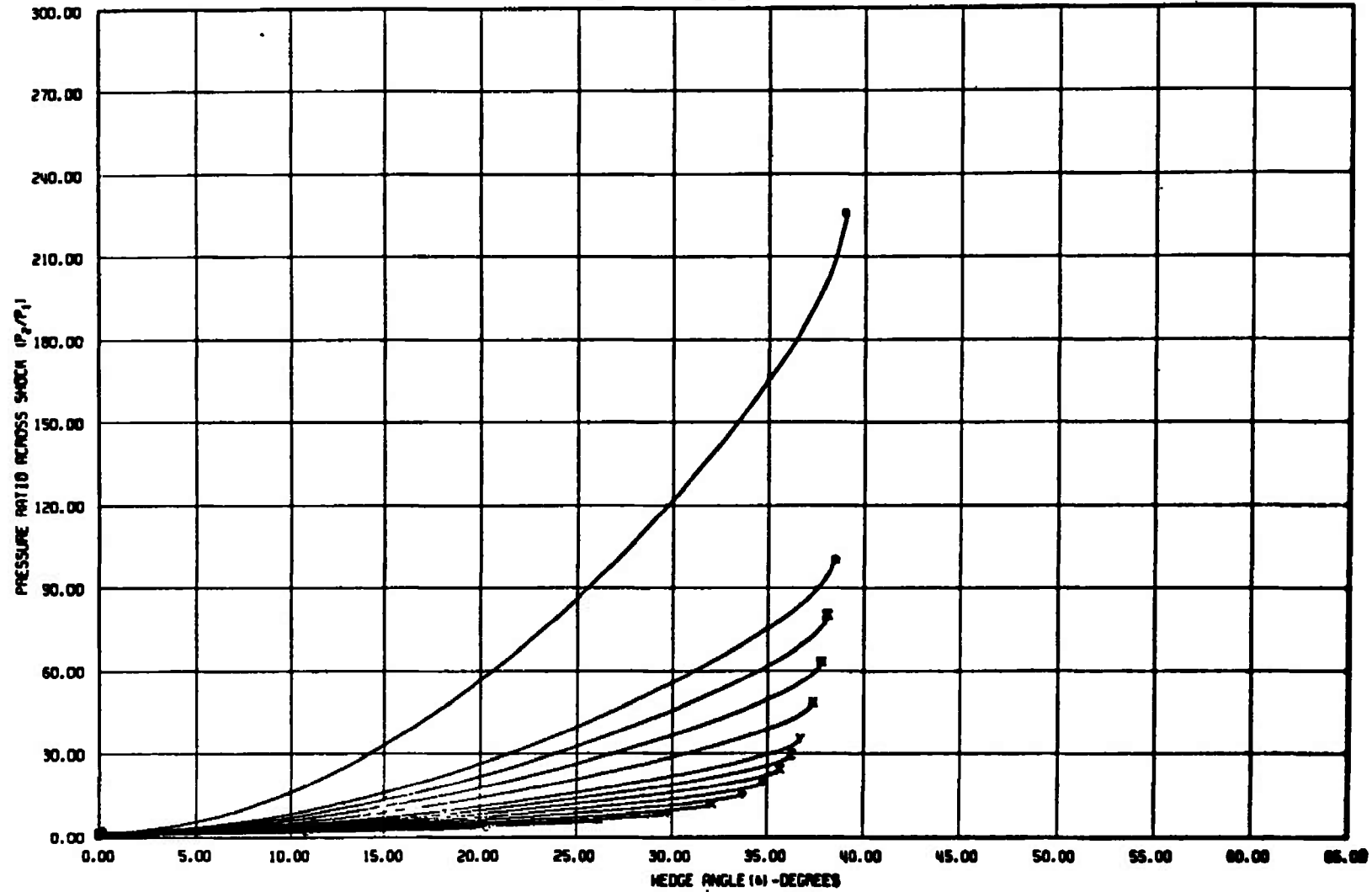


Fig. 26 Continued

OBLIQUE SHOCK
GAMMA=1.58



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- ◊ 4.50
- x 5.00
- Z 5.50
- Y 6.00
- x 7.00
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- X 9.00
- ★ 10.00
- 15.00

Fig. 26 Continued

OBLIQUE SHOCK
 $\gamma = 1.58$

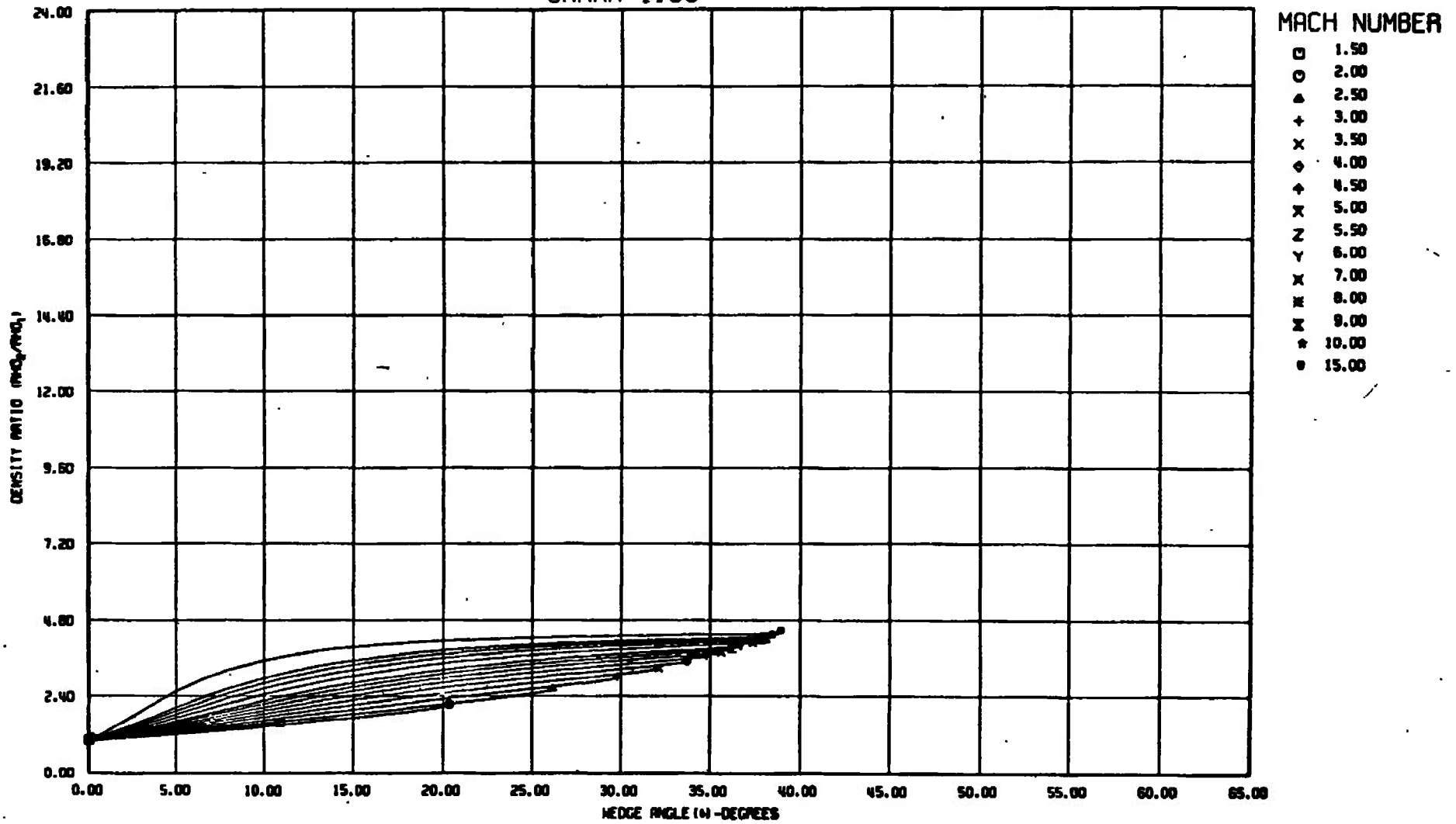
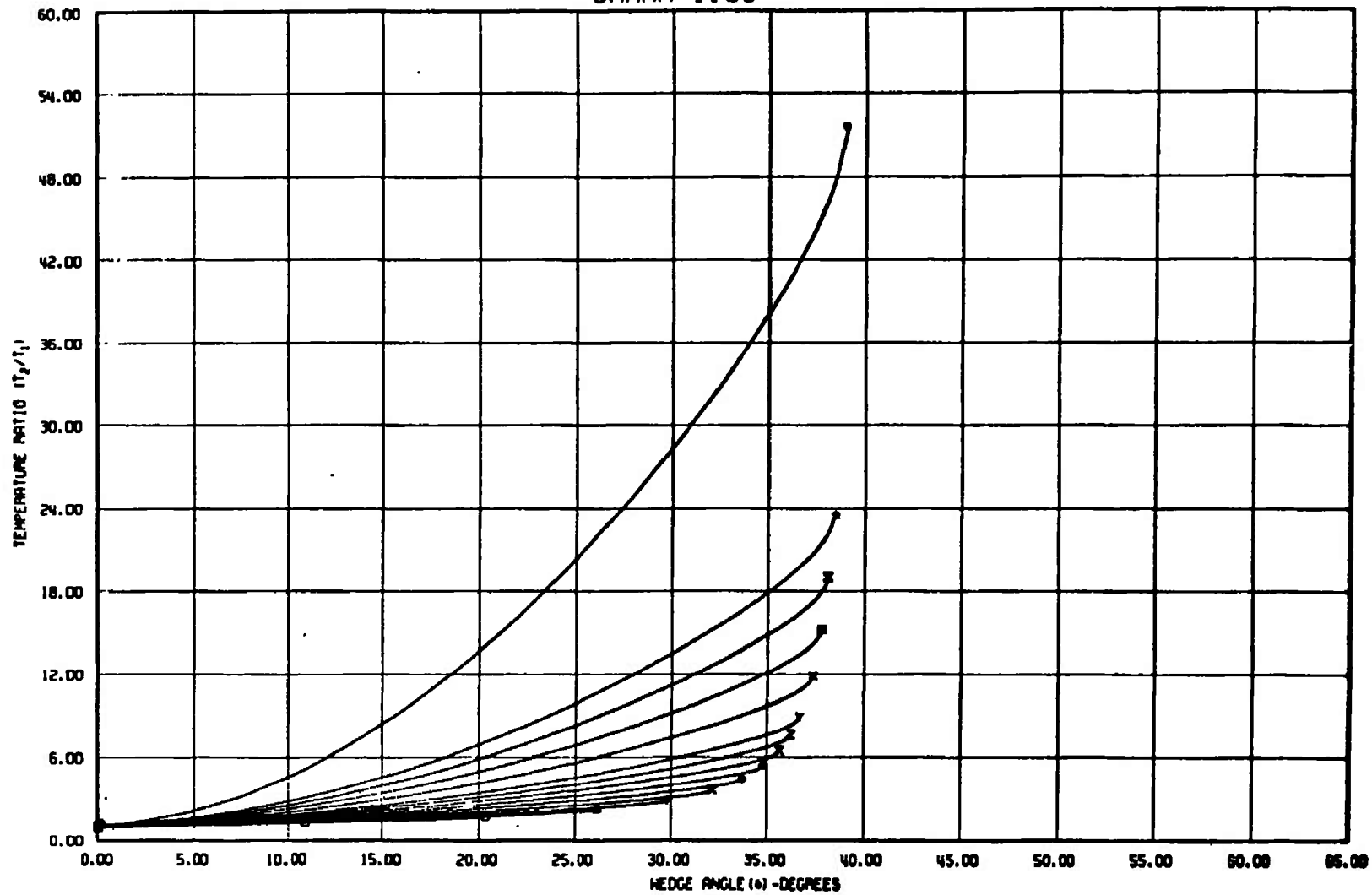


Fig. 26 Continued

OBLIQUE SHOCK GAMMA=1.58



MACH NUMBER

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- 2.00
- △ 2.50
- + 3.00
- x 3.50
- ◇ 4.00
- ⊕ 4.50
- x 5.00
- z 5.50
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- x 7.00
- ≡ 8.00
- x 9.00
- ☆ 10.00
- 15.00

Fig. 26 Continued

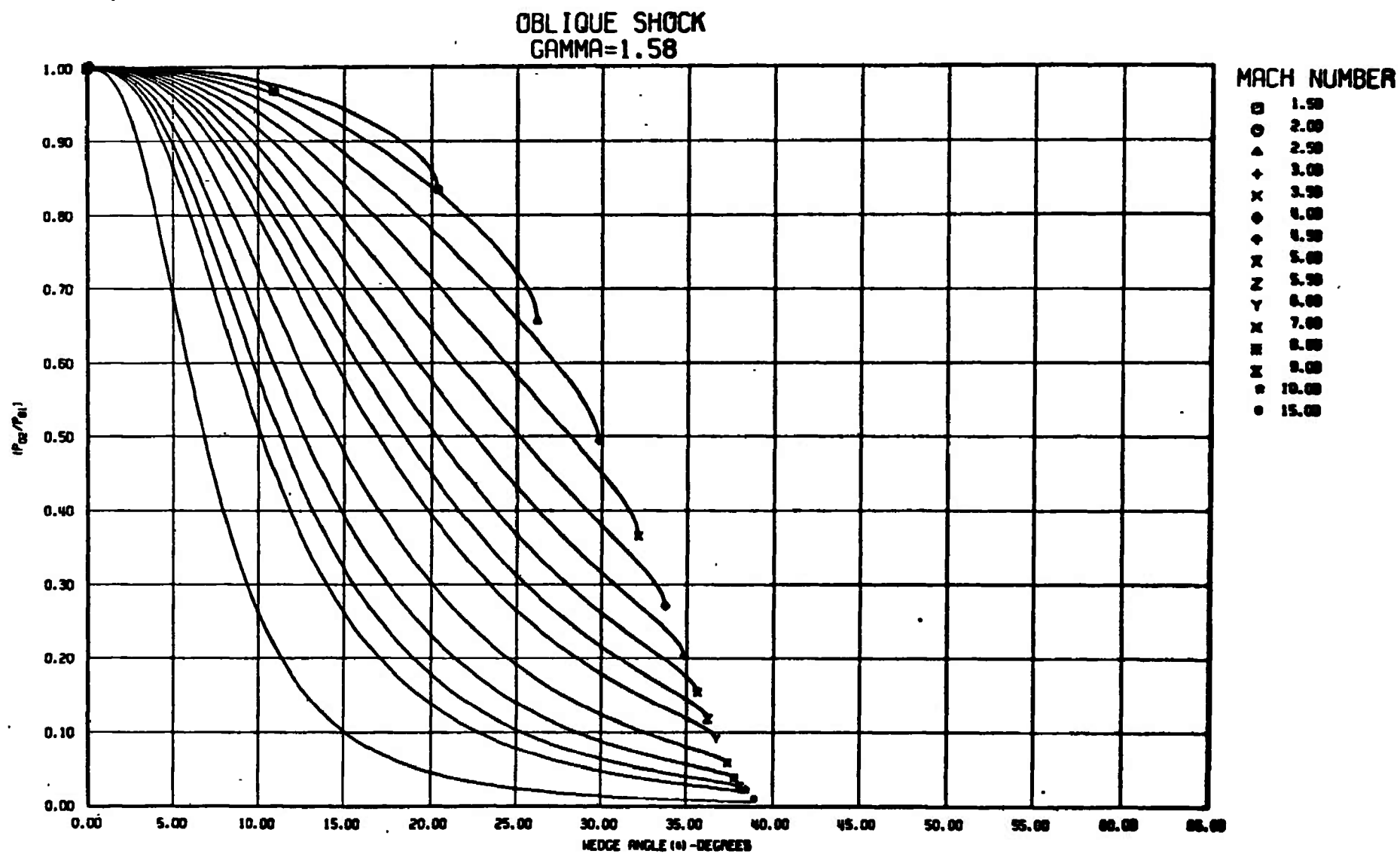
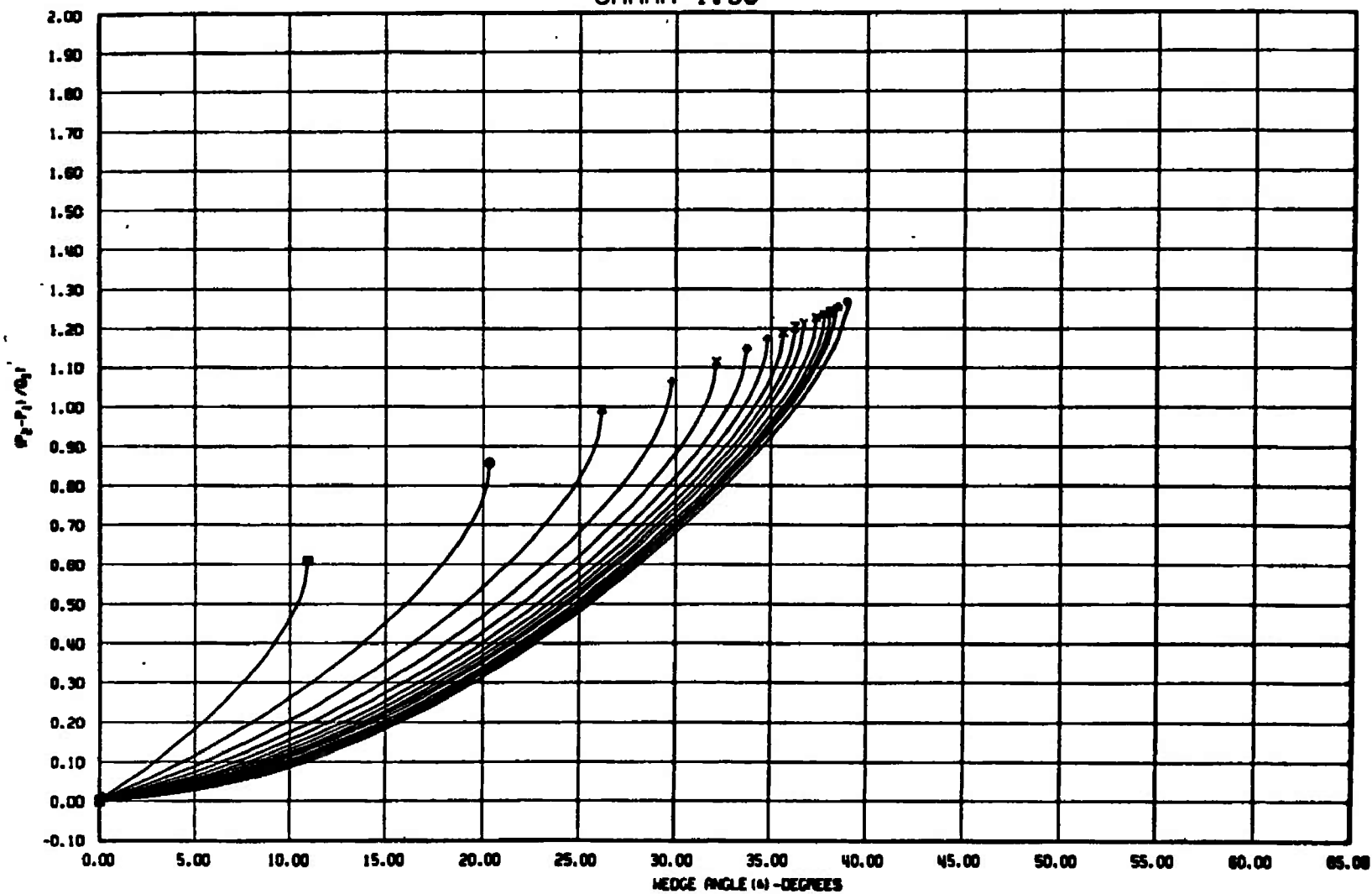


Fig. 26 Continued

OBLIQUE SHOCK GAMMA=1.58

180



MACH NUMBER

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- 2.00
- △ 2.50
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- × 3.50
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- ⊕ 4.50
- × 5.00
- z 5.50
- Y 6.00
- × 7.00
- ≡ 8.00
- × 9.00
- ★ 10.00
- 15.00

Fig. 26 Concluded

OBLIQUE SHOCK $\gamma = 1.60$

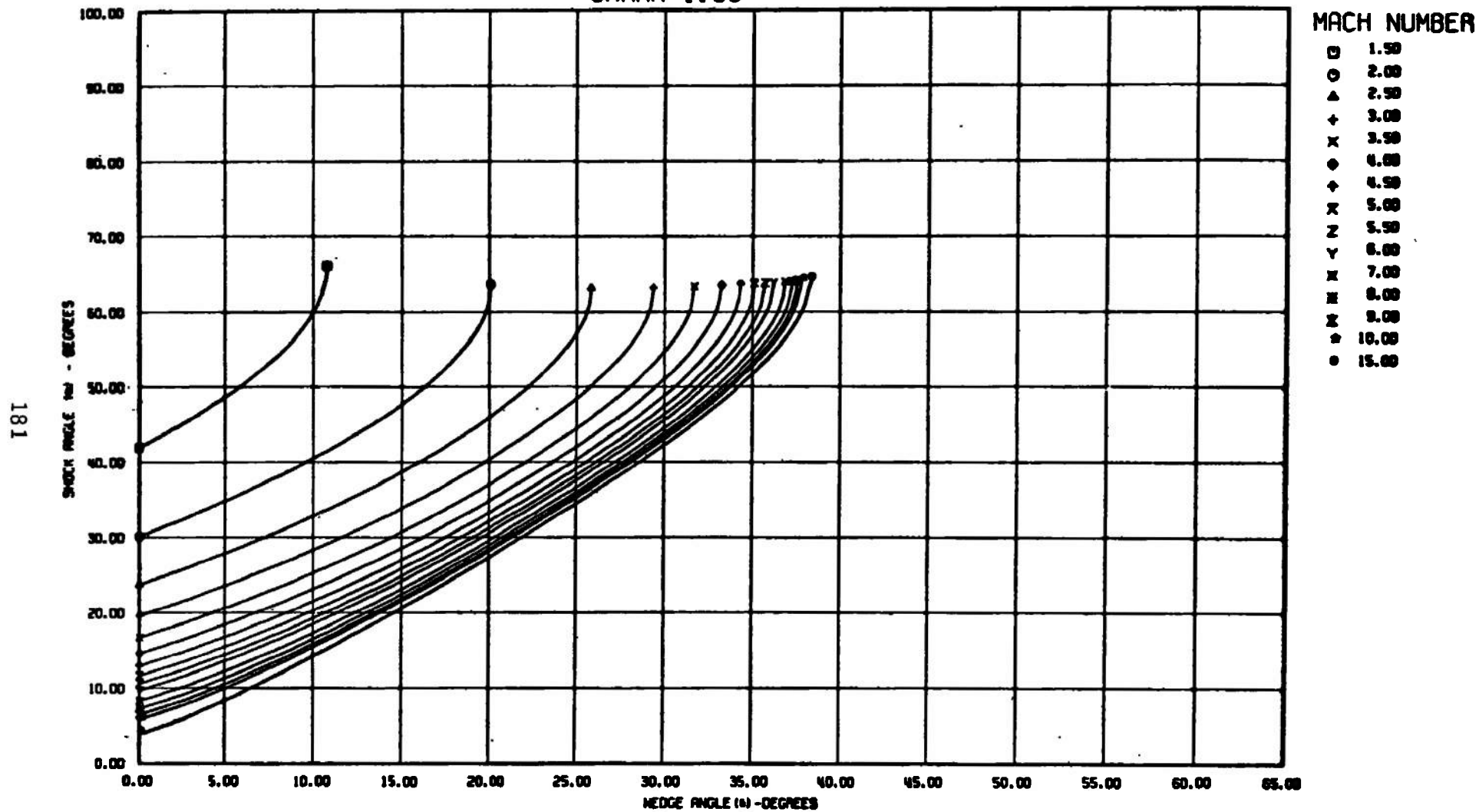


Fig. 27 $\gamma = 1.60$

OBLIQUE SHOCK $\gamma = 1.60$

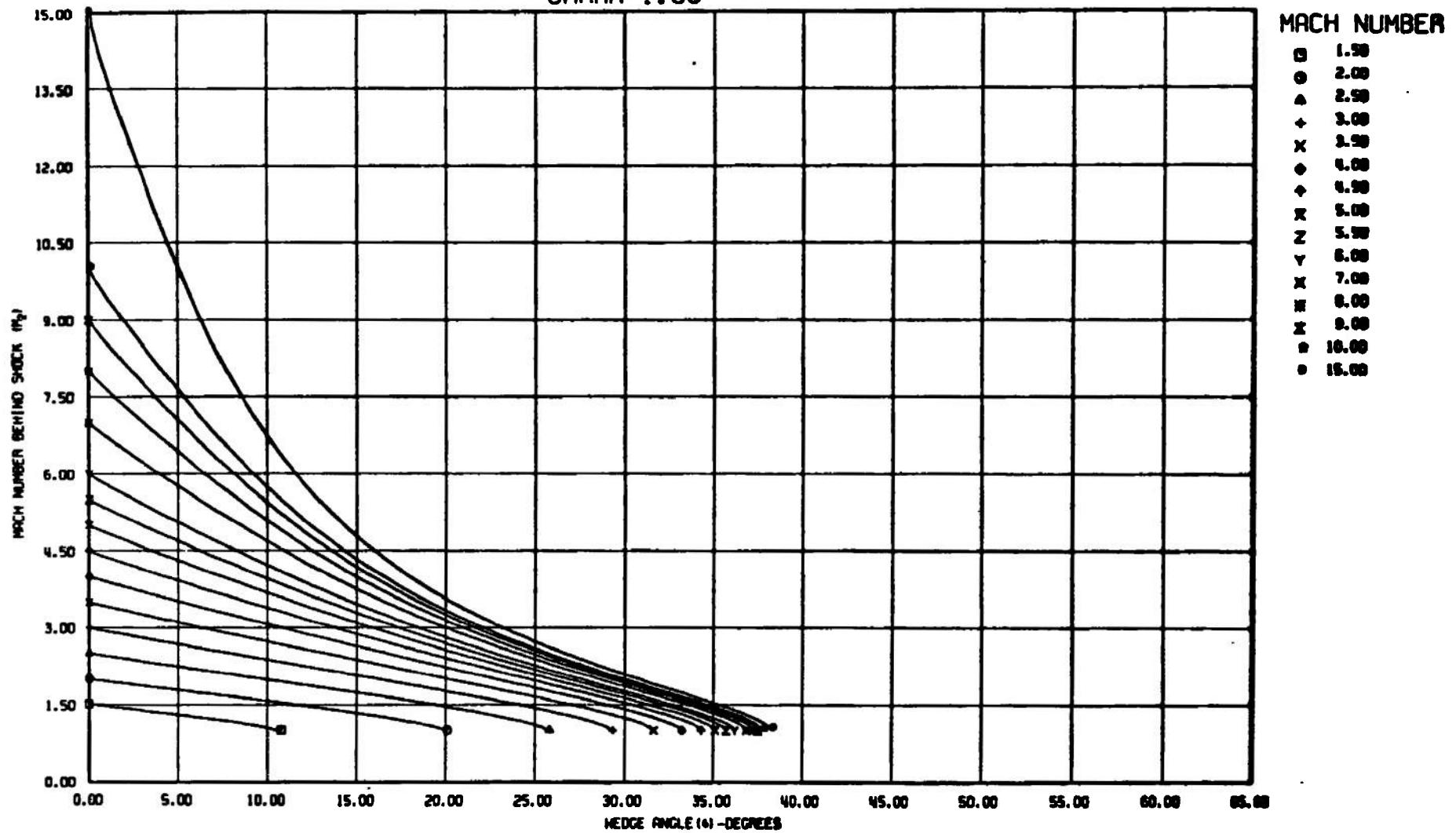


Fig. 27 Continued

OBLIQUE SHOCK GAMMA=1.60

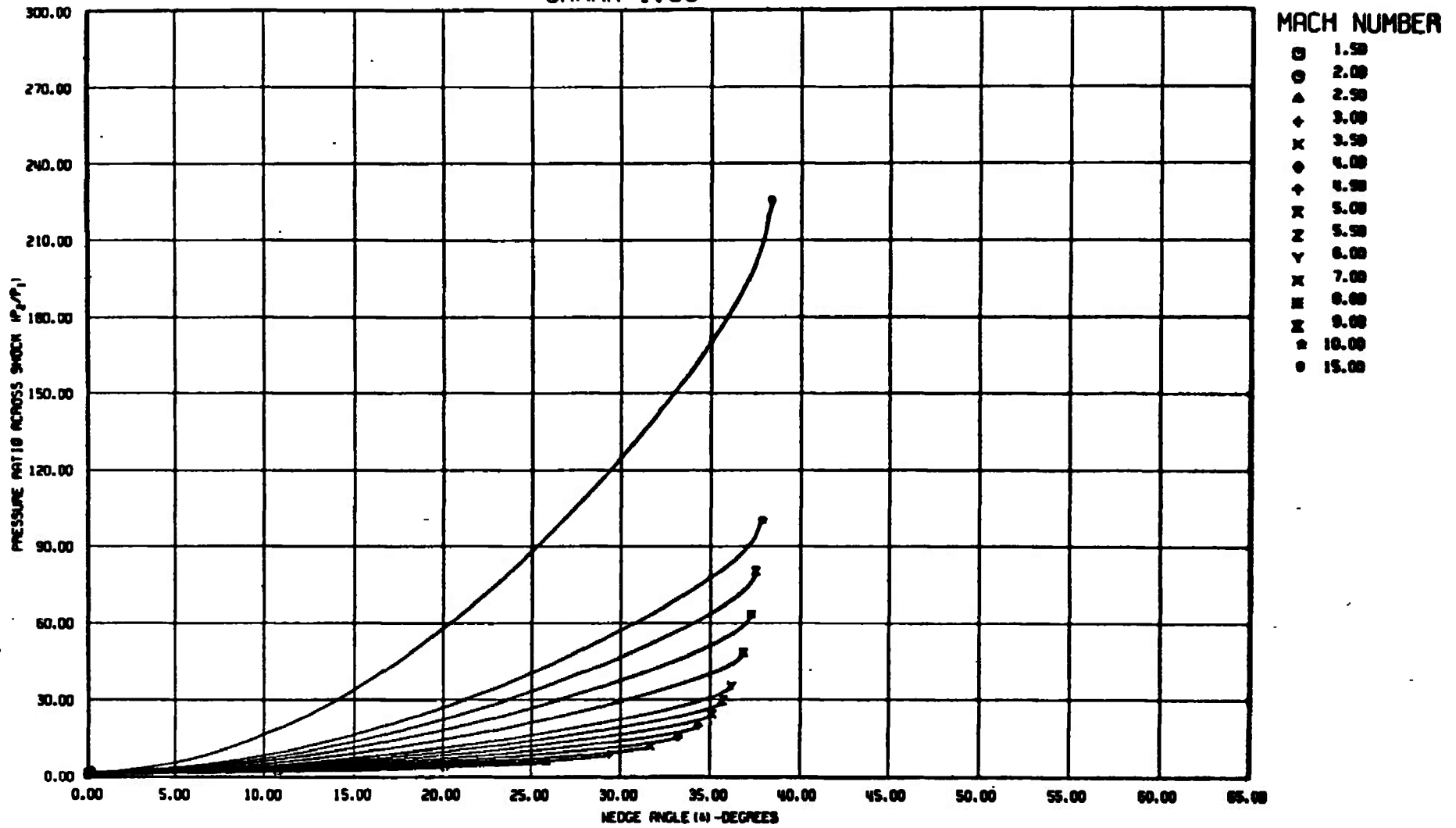


Fig. 27 Continued

OBLIQUE SHOCK GAMMA=1.60

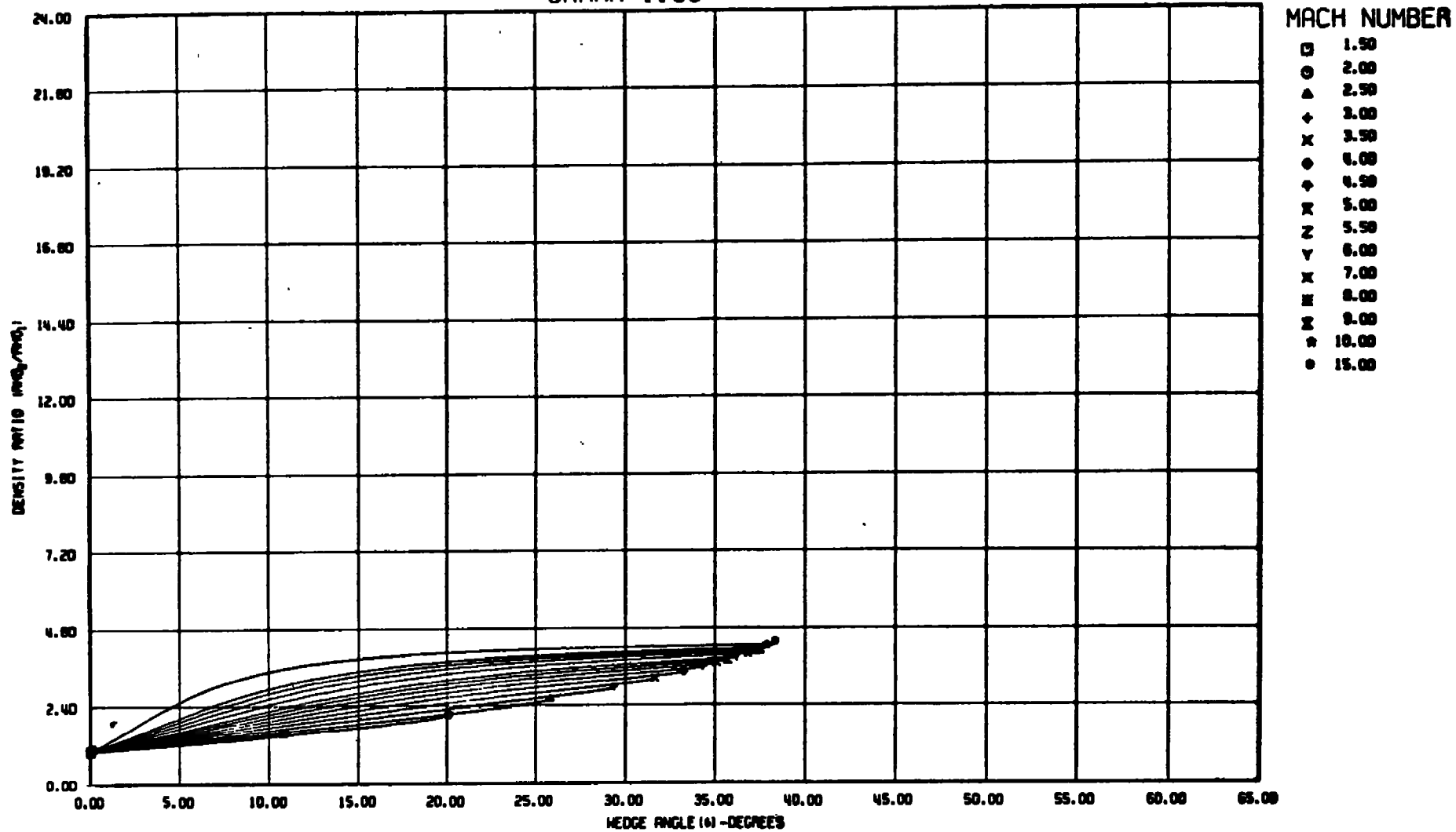


Fig. 27 Continued

OBLIQUE SHOCK GAMMA=1.60

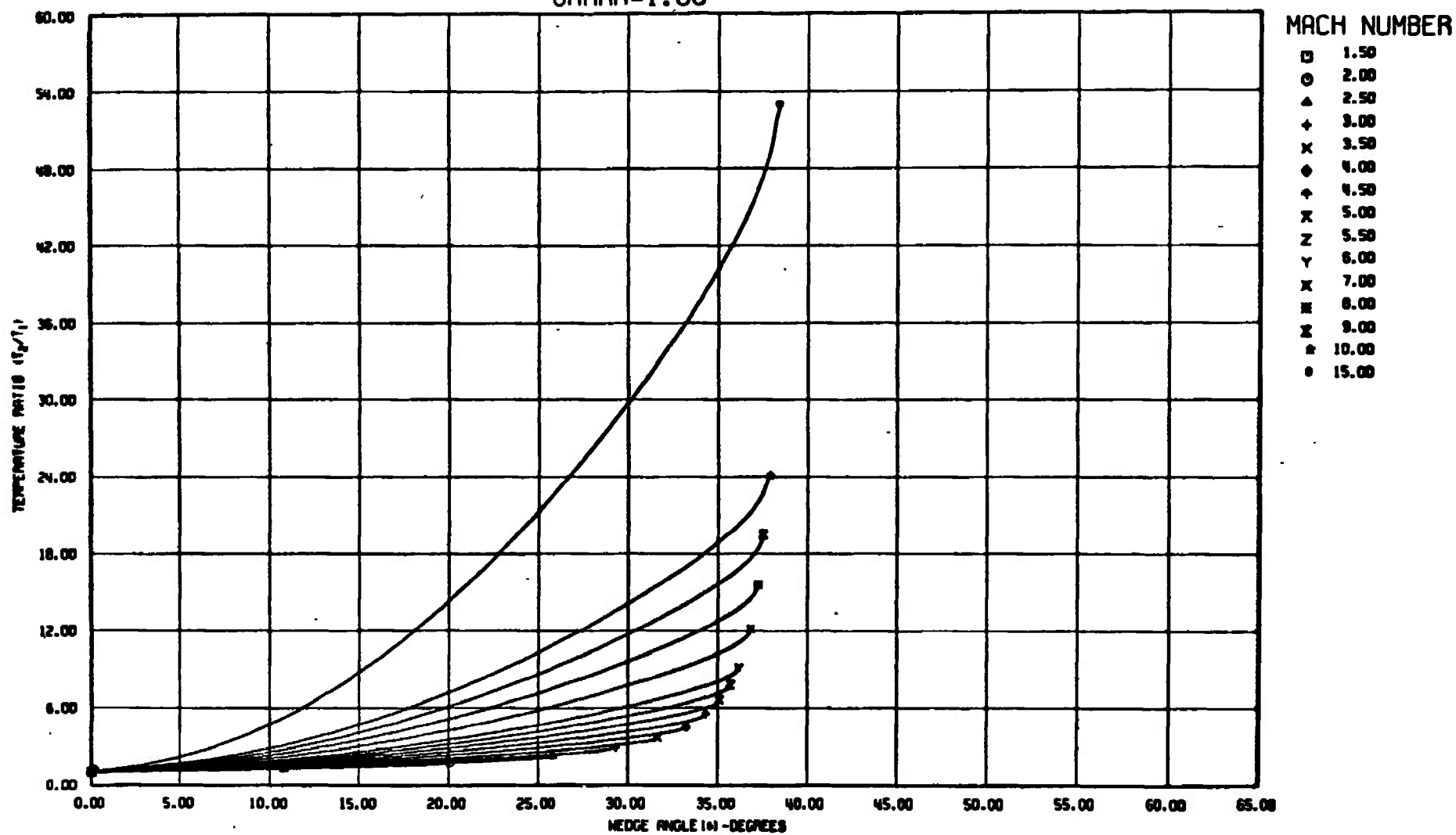


Fig. 27 Continued

OBLIQUE SHOCK GAMMA=1.60

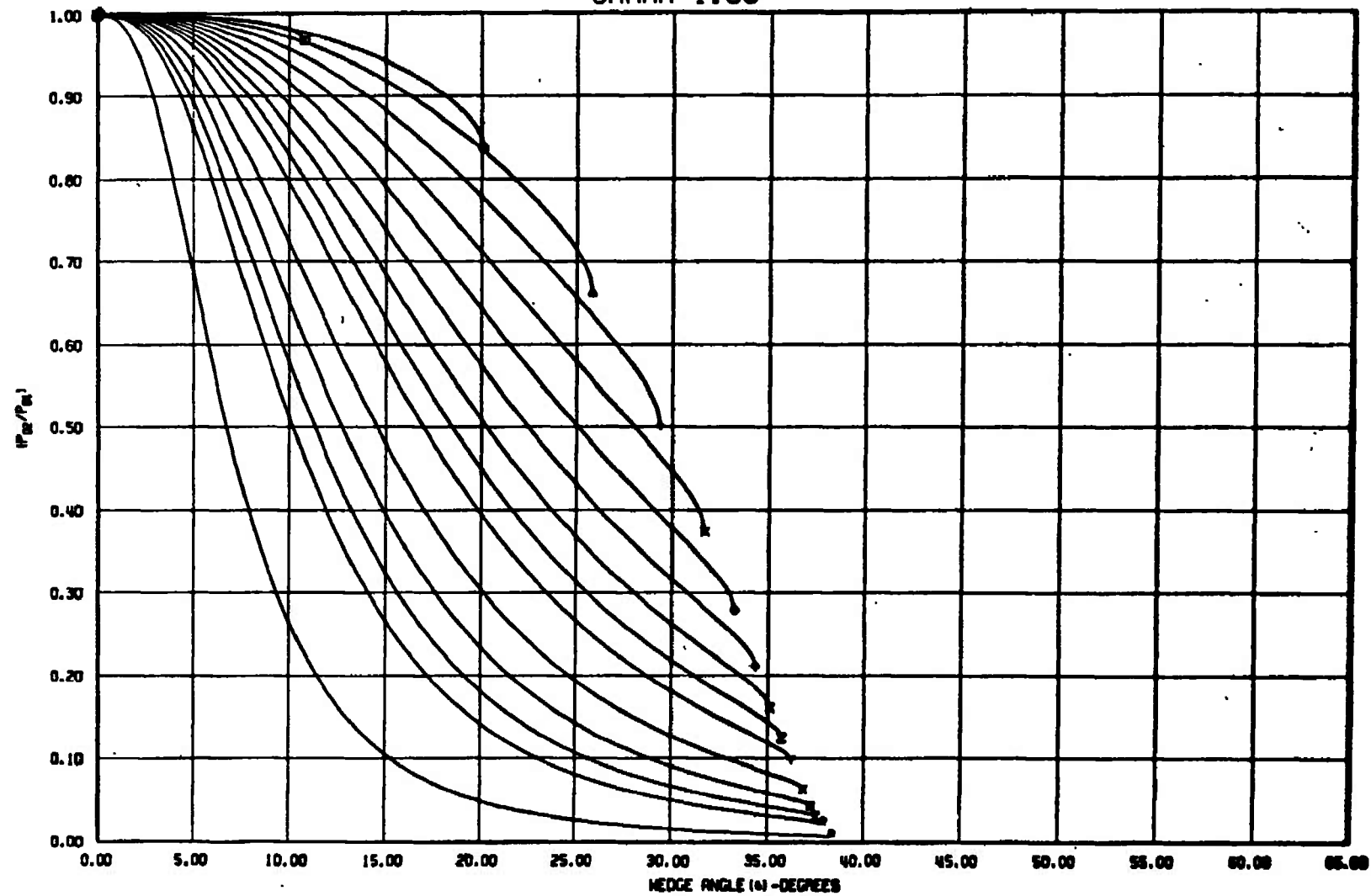


Fig. 27 Continued

OBLIQUE SHOCK GAMMA=1.60

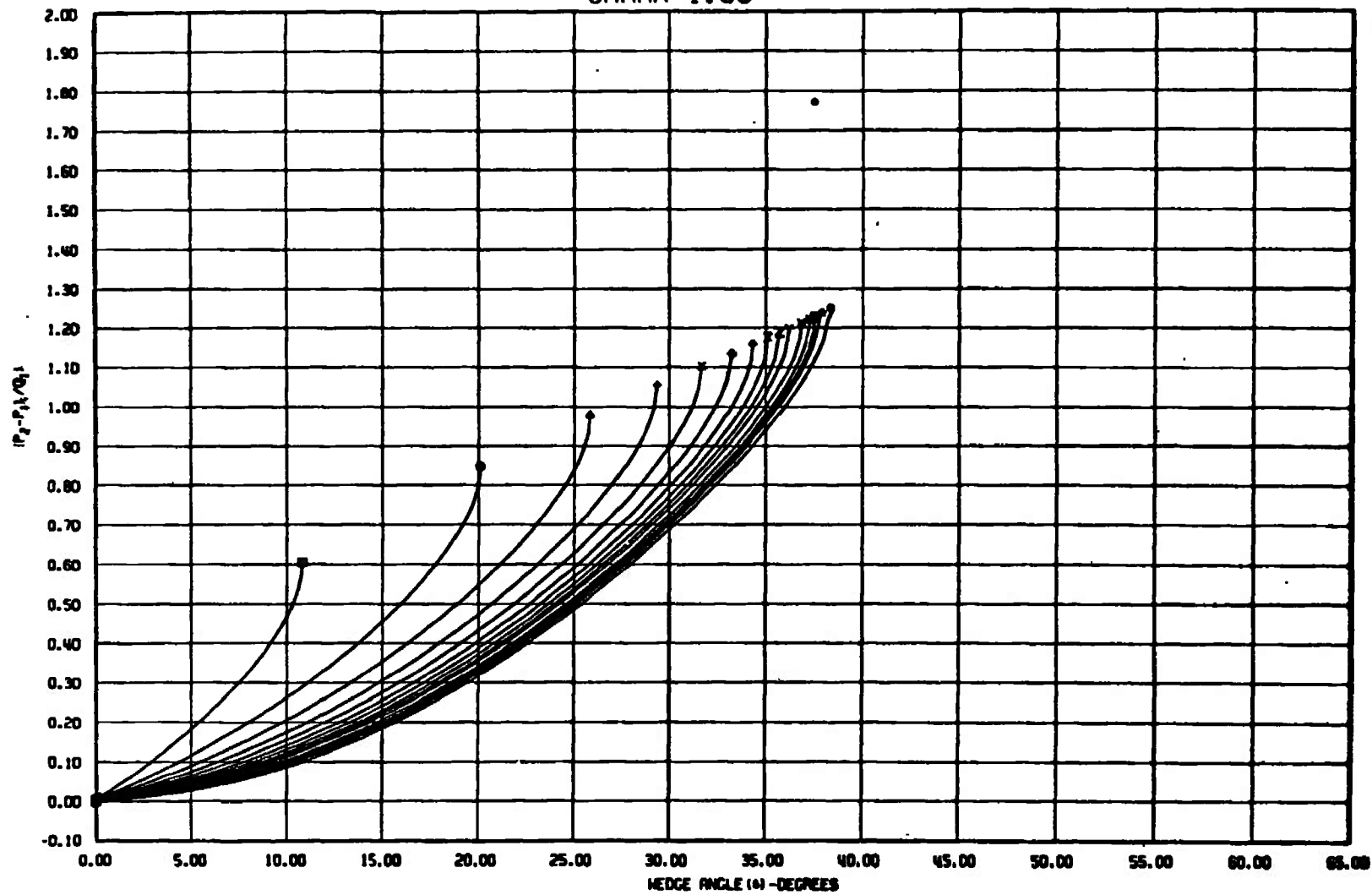


Fig. 27 Concluded

OBLIQUE SHOCK $\gamma = 1.62$

188

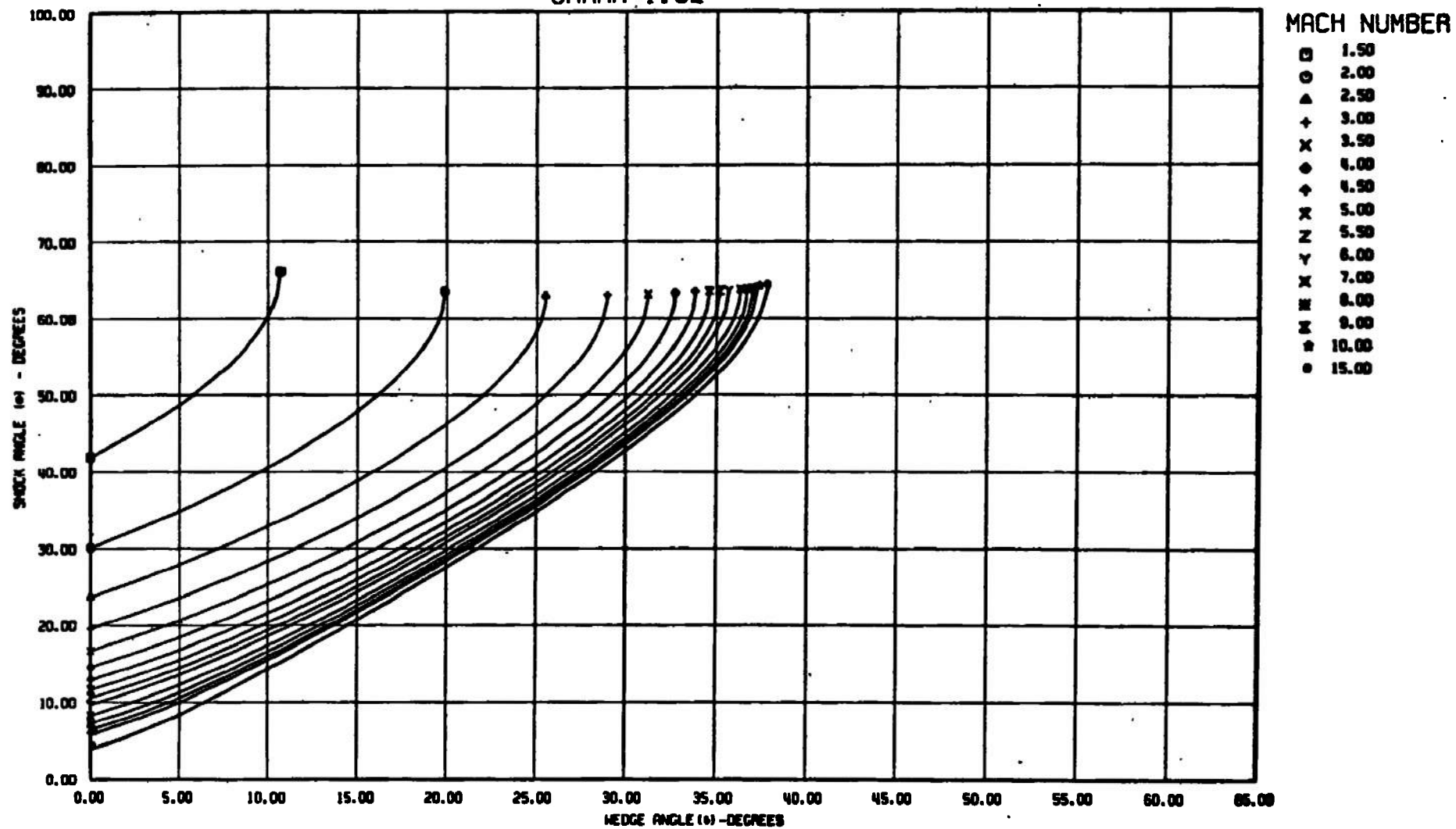


Fig. 28 $\gamma = 1.62$

OBLIQUE SHOCK $\gamma = 1.62$

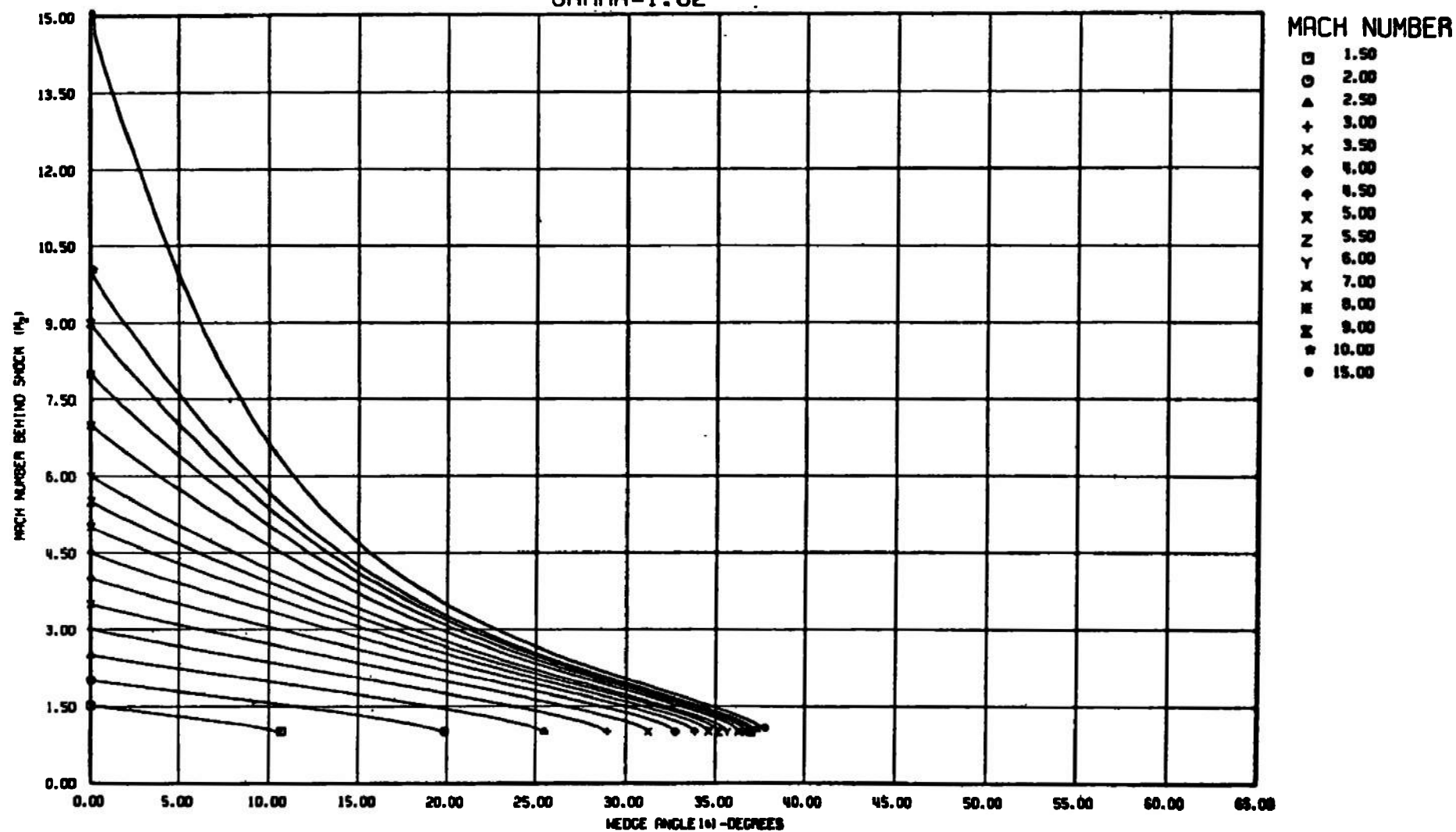


Fig. 28 Continued

OBLIQUE SHOCK GAMMA=1.62

190

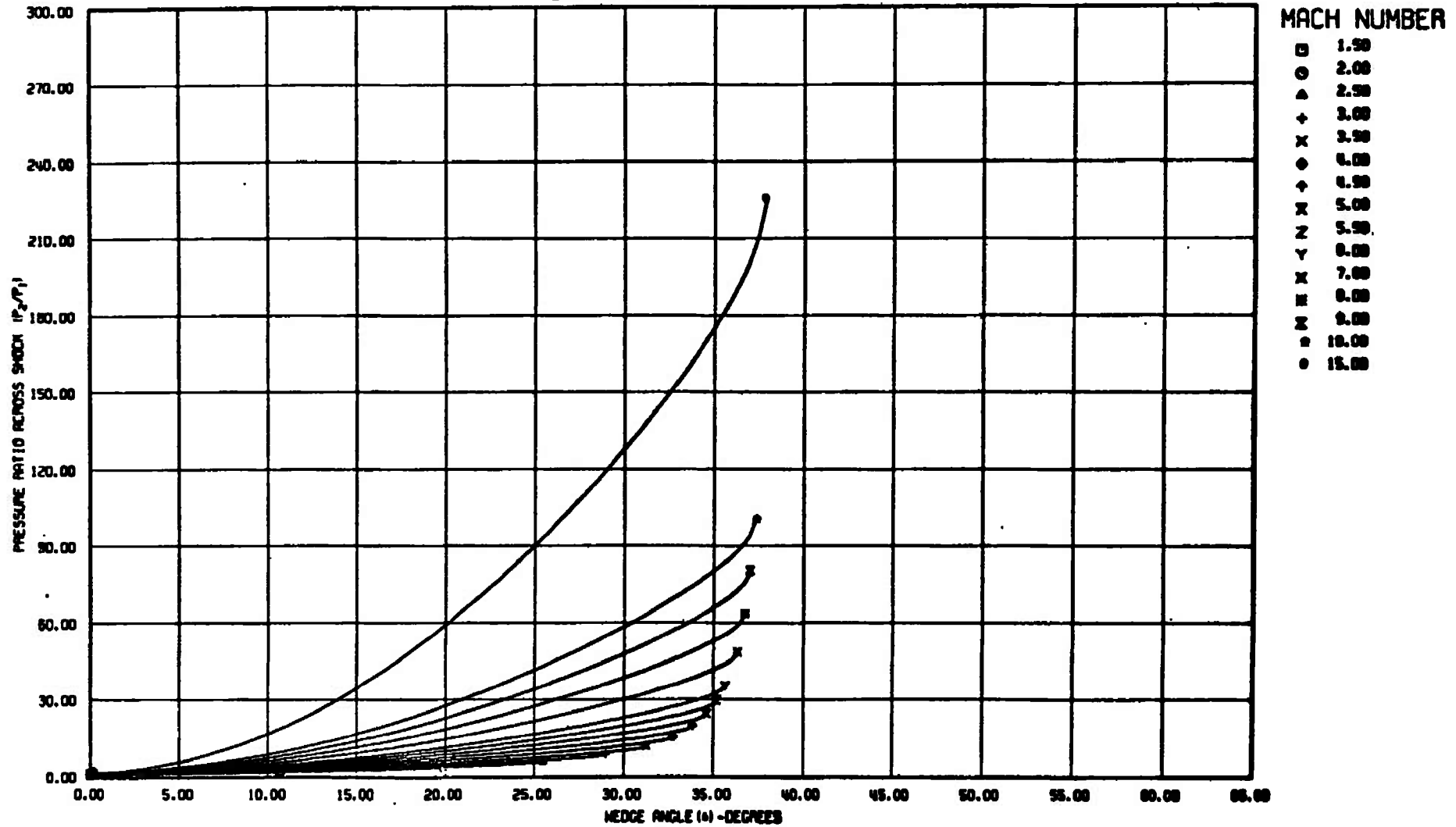


Fig. 28 Continued

OBLIQUE SHOCK GAMMA=1.62

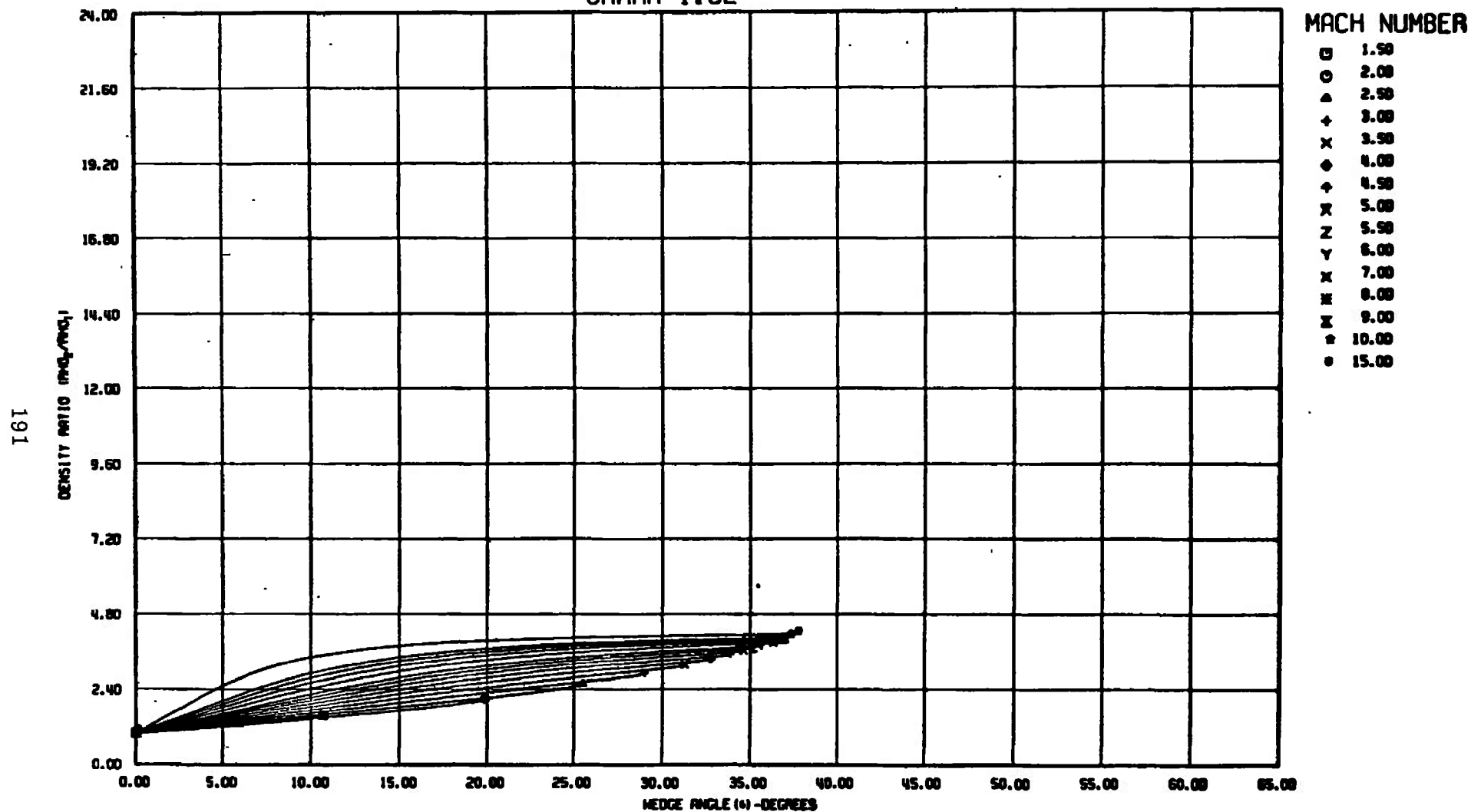


Fig. 28 Continued

OBLIQUE SHOCK GAMMA=1.62

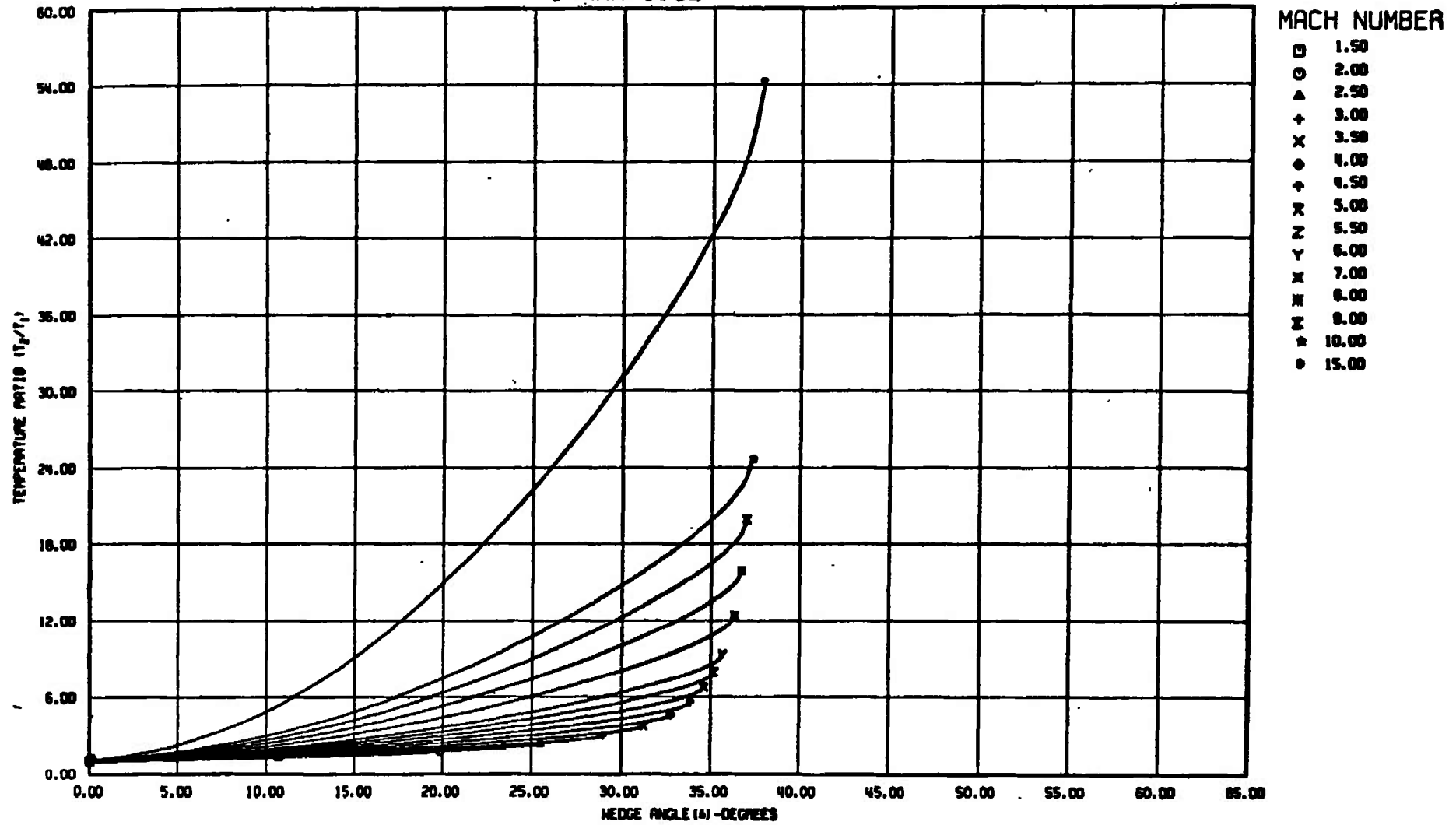


Fig. 28 Continued

OBLIQUE SHOCK
GAMMA=1.62

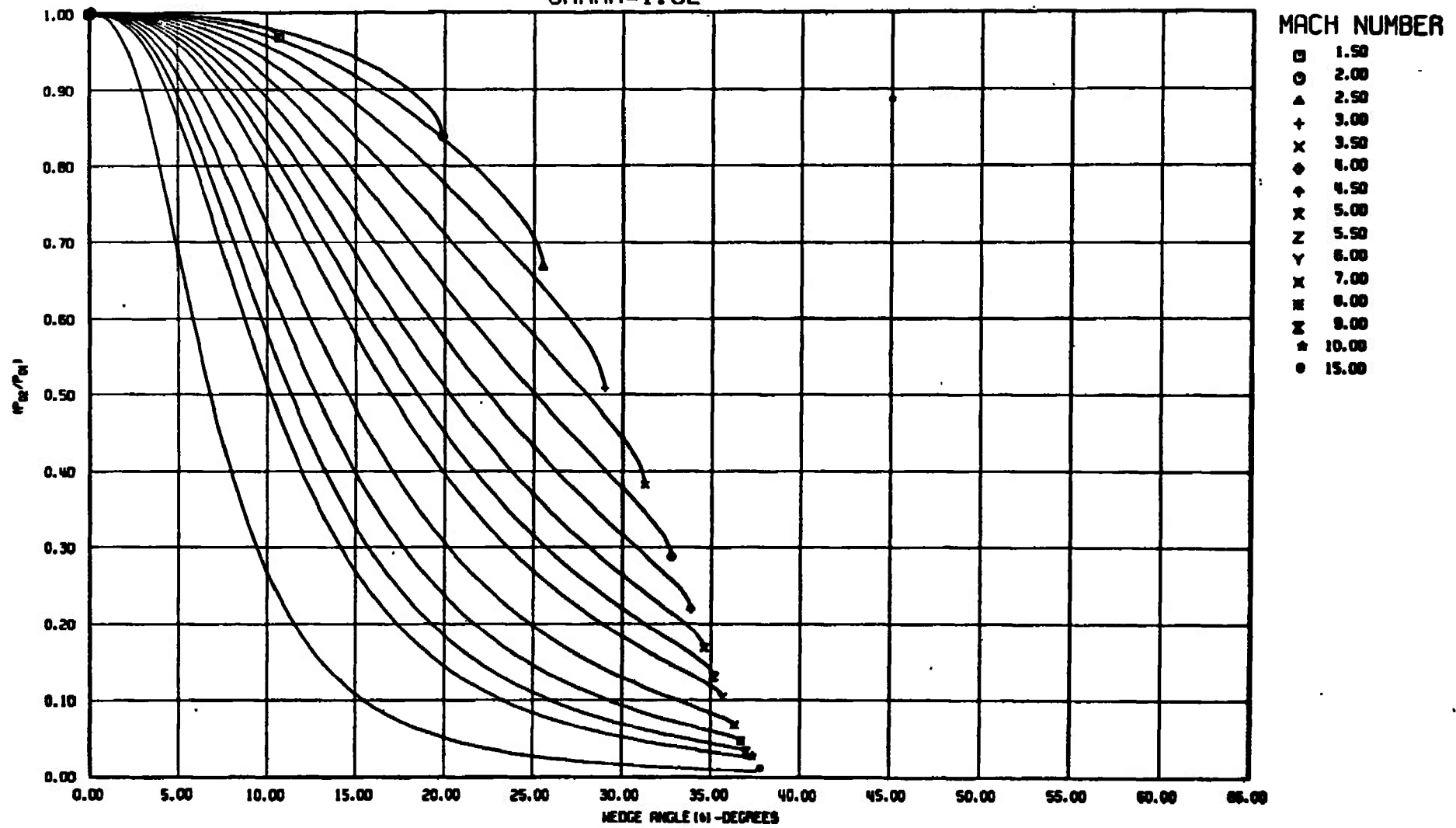


Fig. 28 Continued

OBLIQUE SHOCK GAMMA=1.62

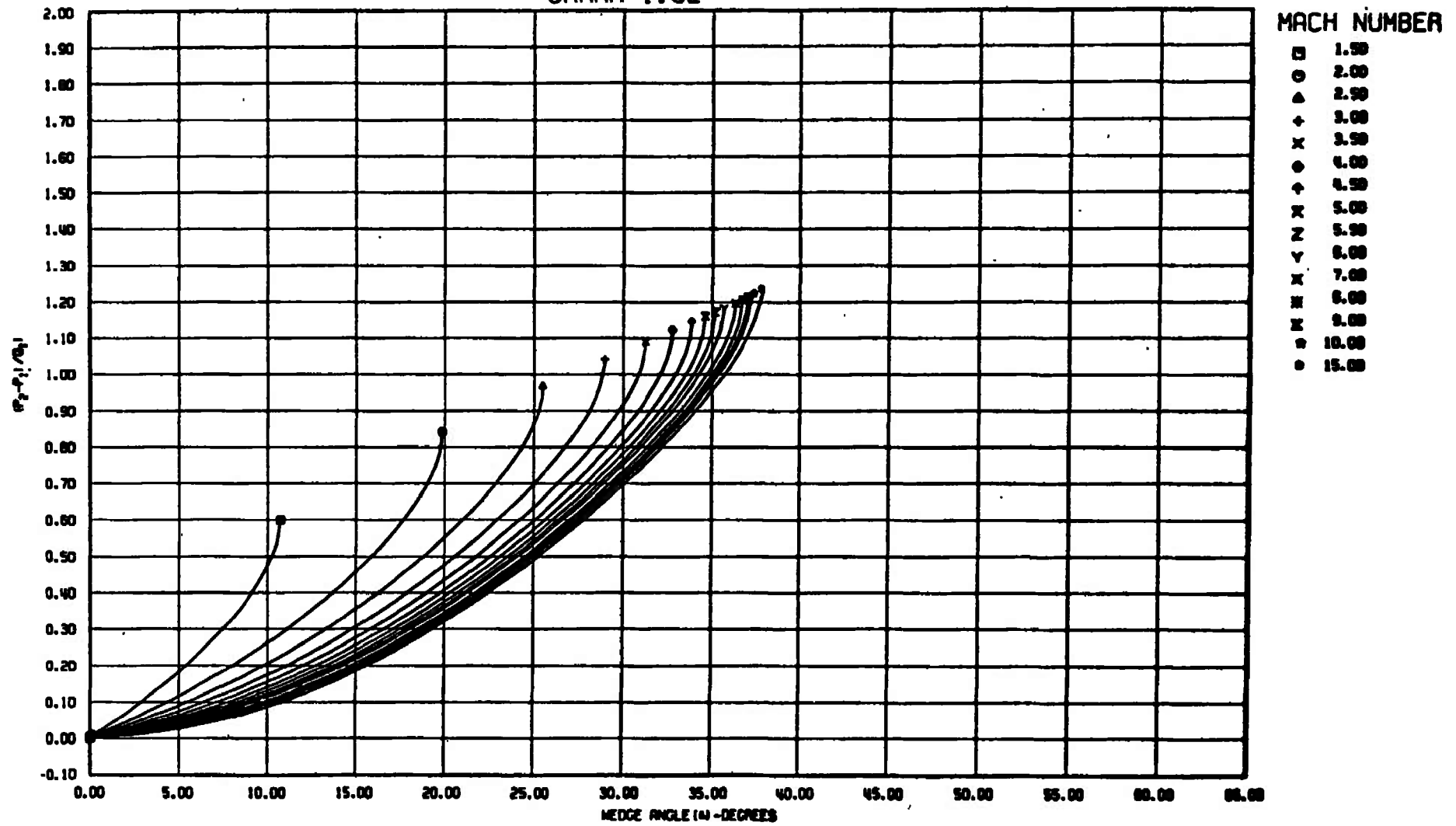


Fig. 28 Concluded

OBLIQUE SHOCK GAMMA=1.64

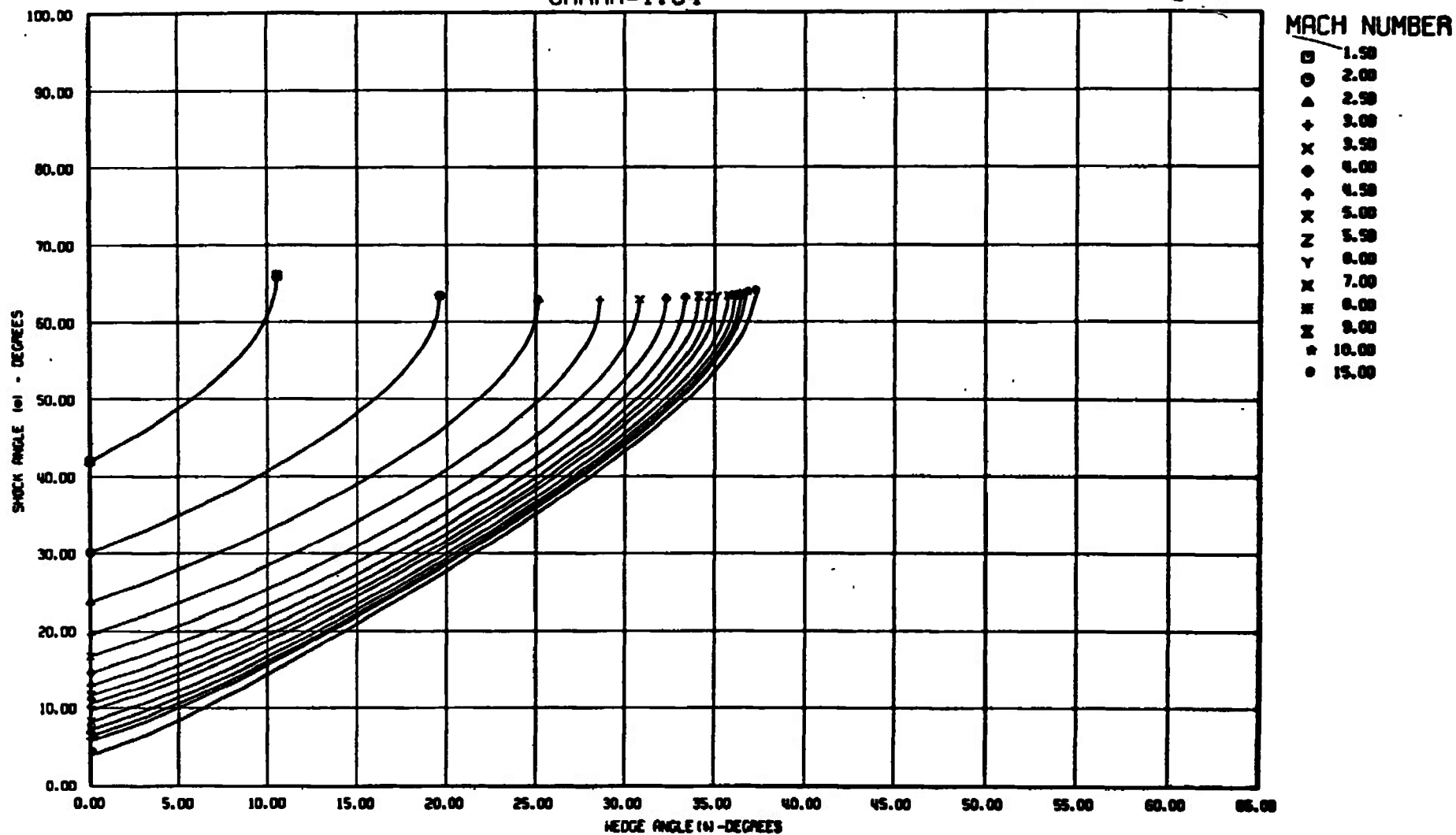


Fig. 29 $\gamma = 1.64$

OBLIQUE SHOCK GAMMA=1.64

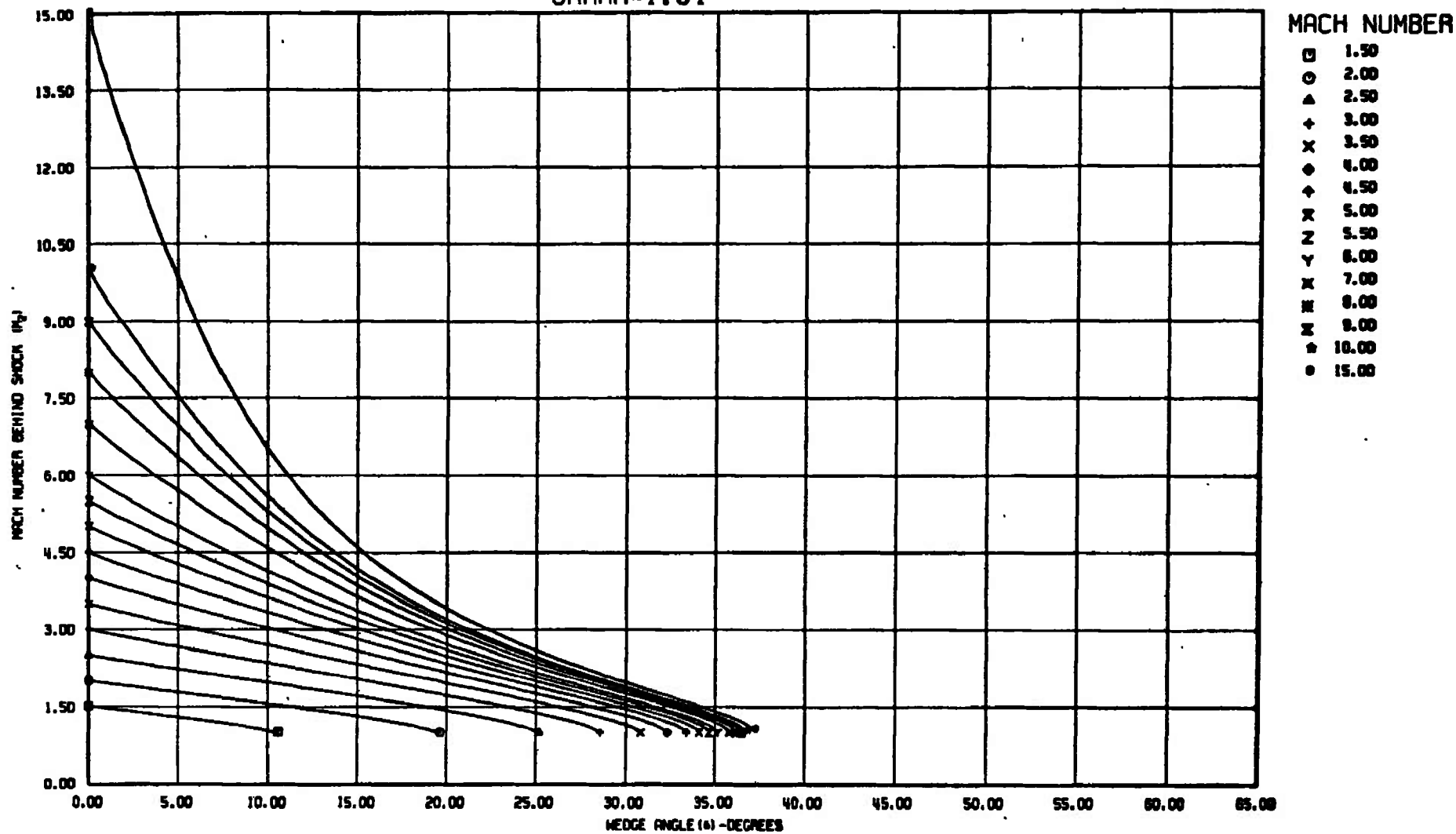


Fig. 29 Continued

OBLIQUE SHOCK
GAMMA=1.64

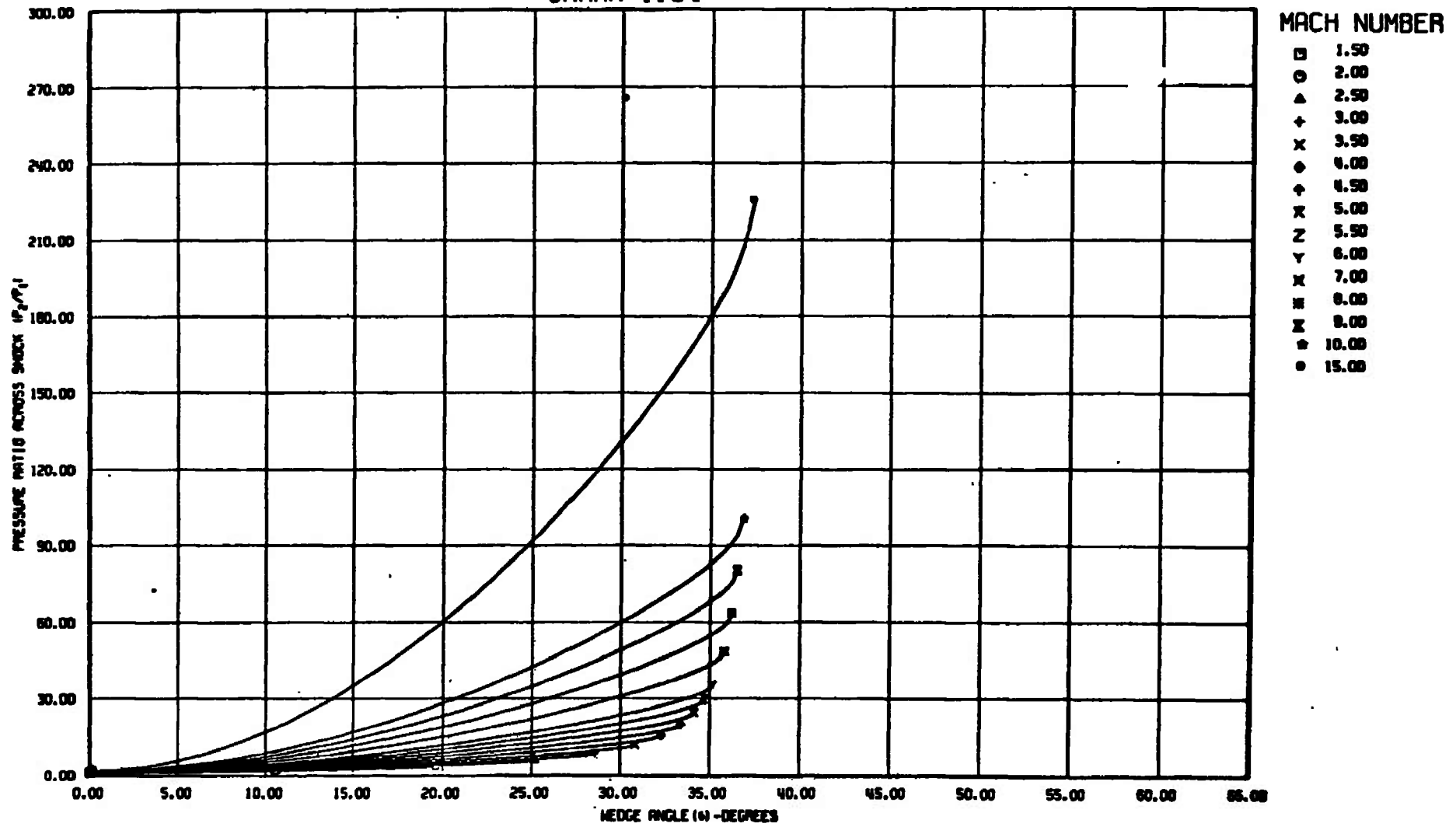


Fig. 29 Continued

OBLIQUE SHOCK GAMMA=1.64

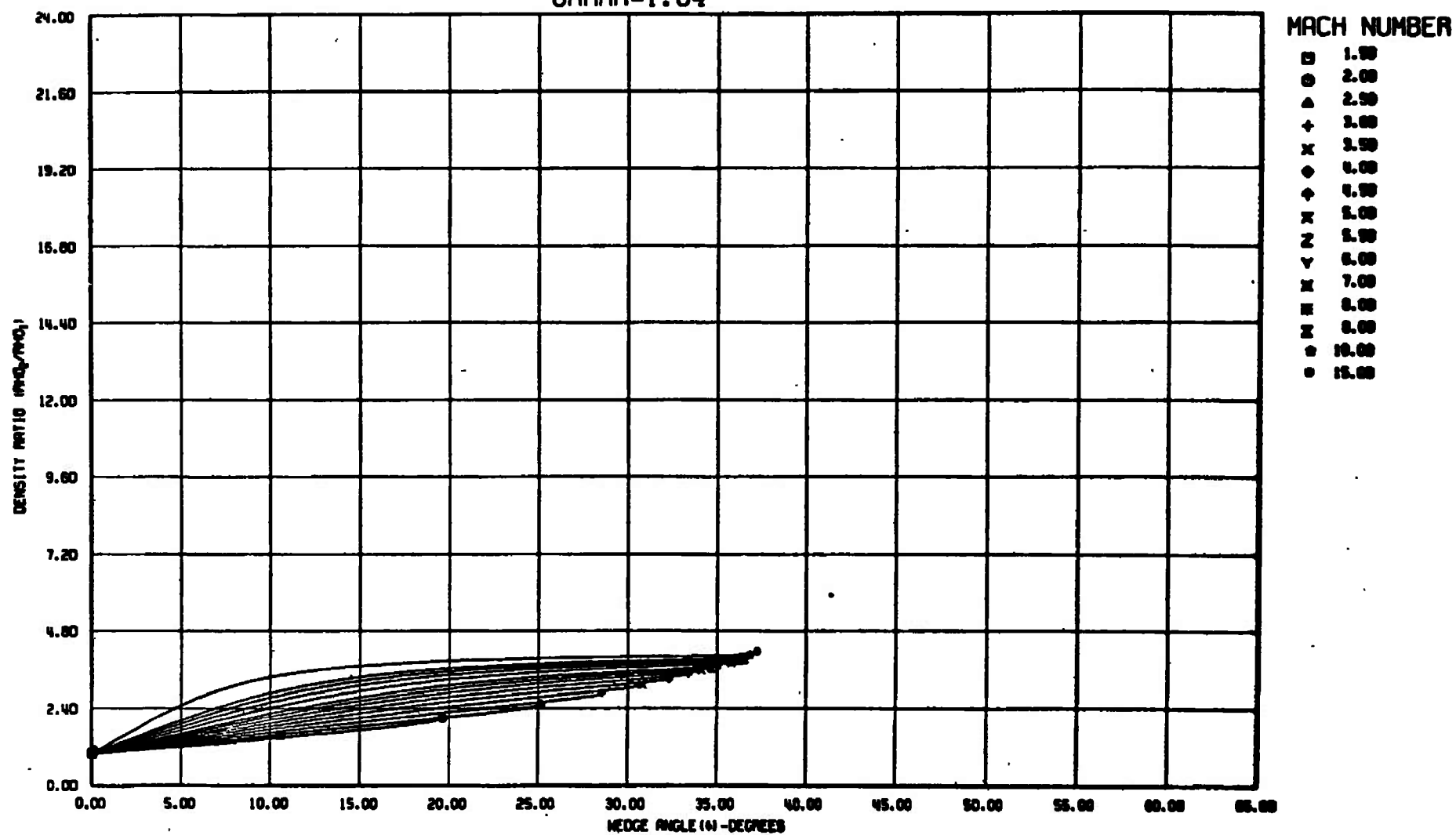


Fig. 29 Continued

OBLIQUE SHOCK GAMMA=1.64

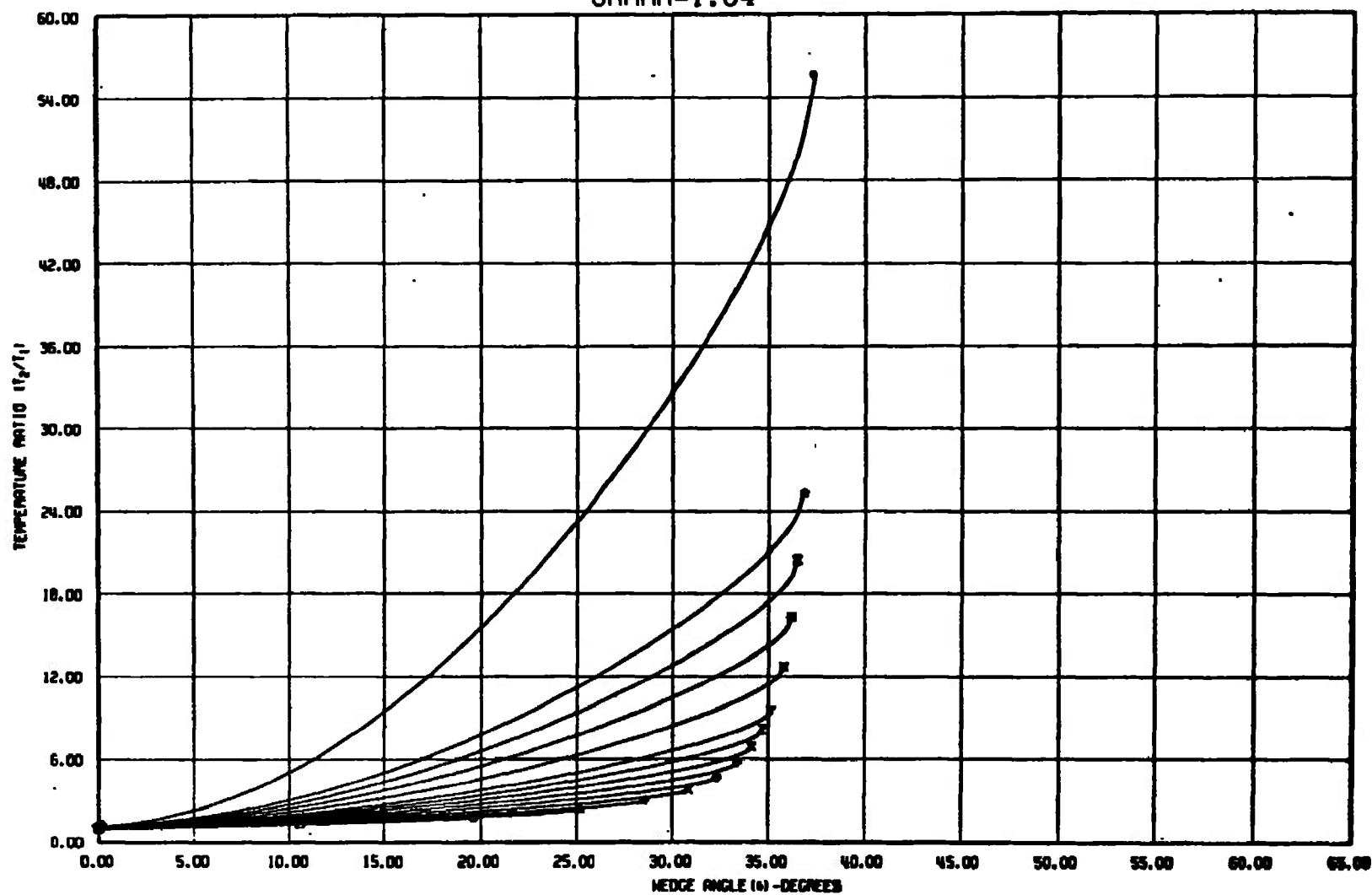


Fig. 29 Continued

OBLIQUE SHOCK GAMMA=1.64

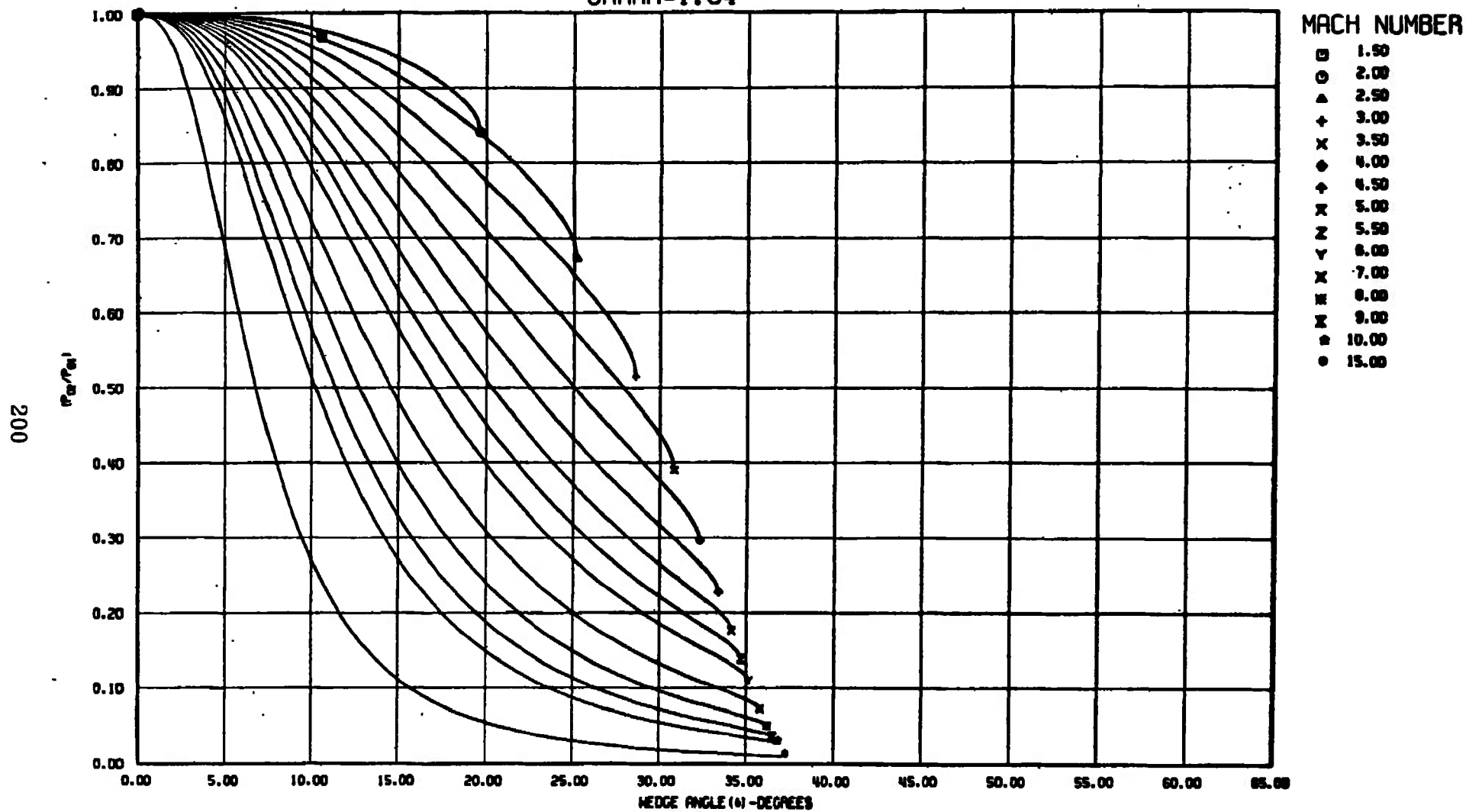


Fig. 29 Continued

OBLIQUE SHOCK
GAMMA=1.64

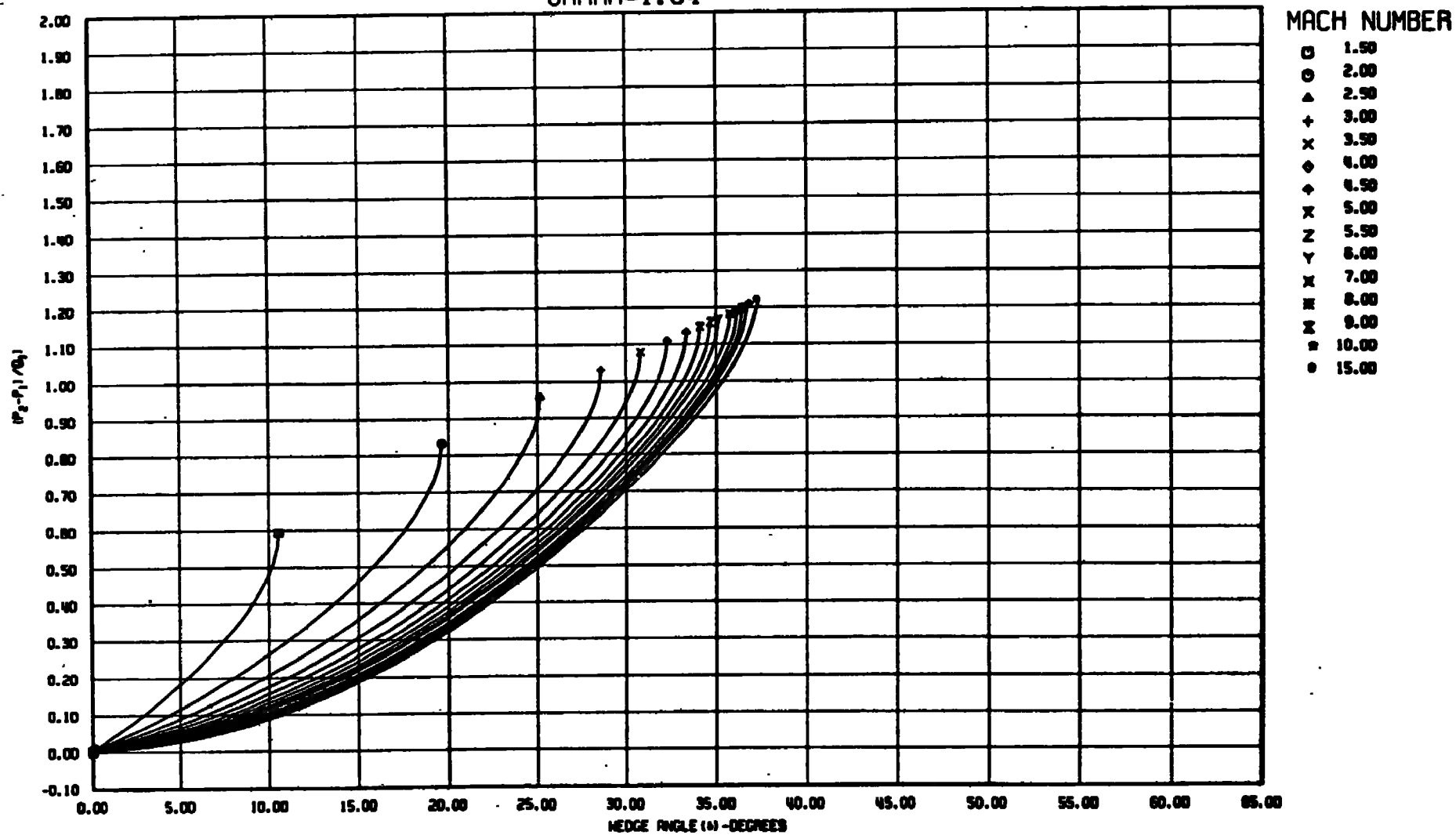


Fig. 29 Concluded

OBLIQUE SHOCK $\gamma = 1.66$

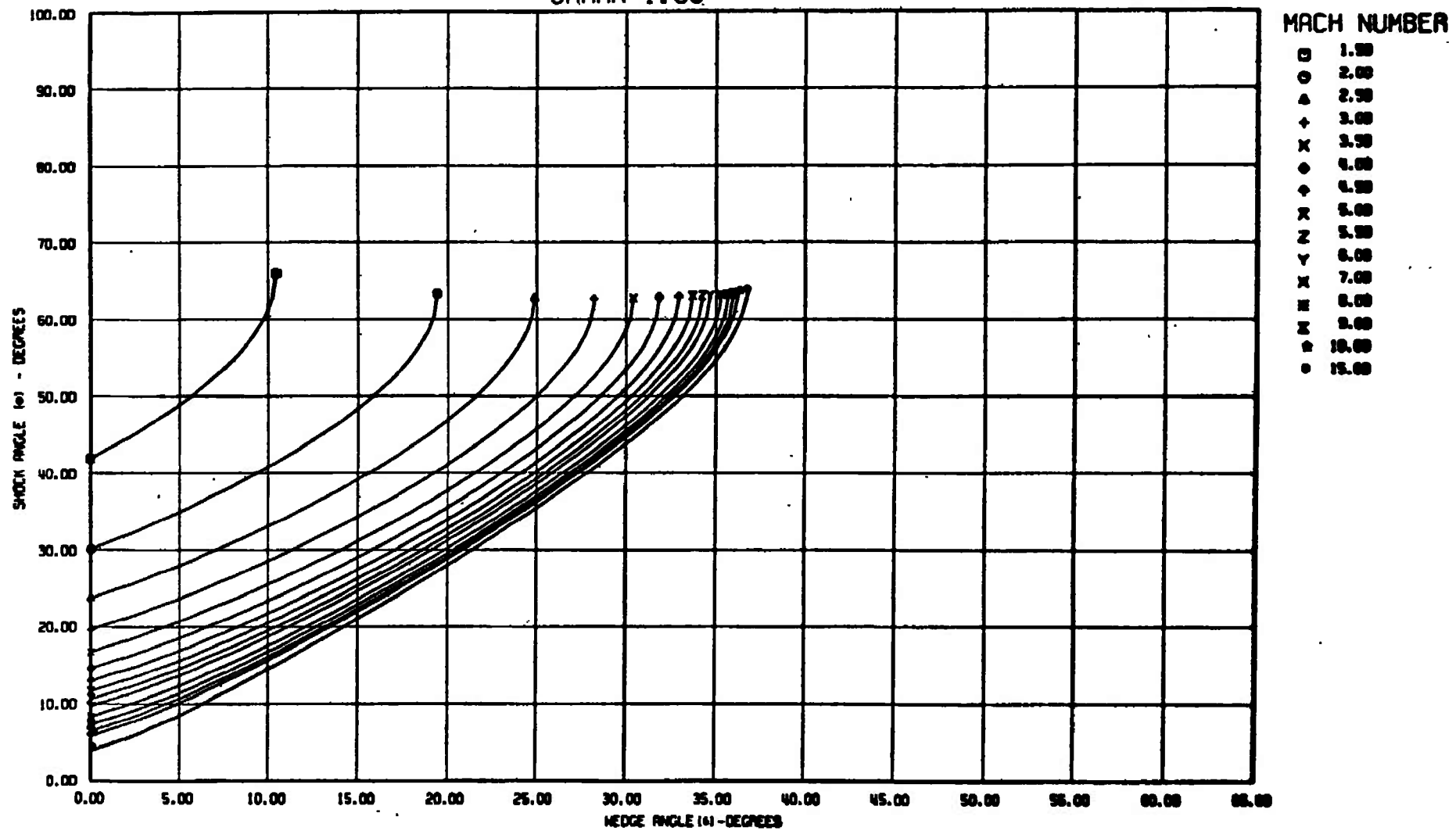


Fig. 30 $\gamma = 1.66$

OBLIQUE SHOCK GAMMA=1.66

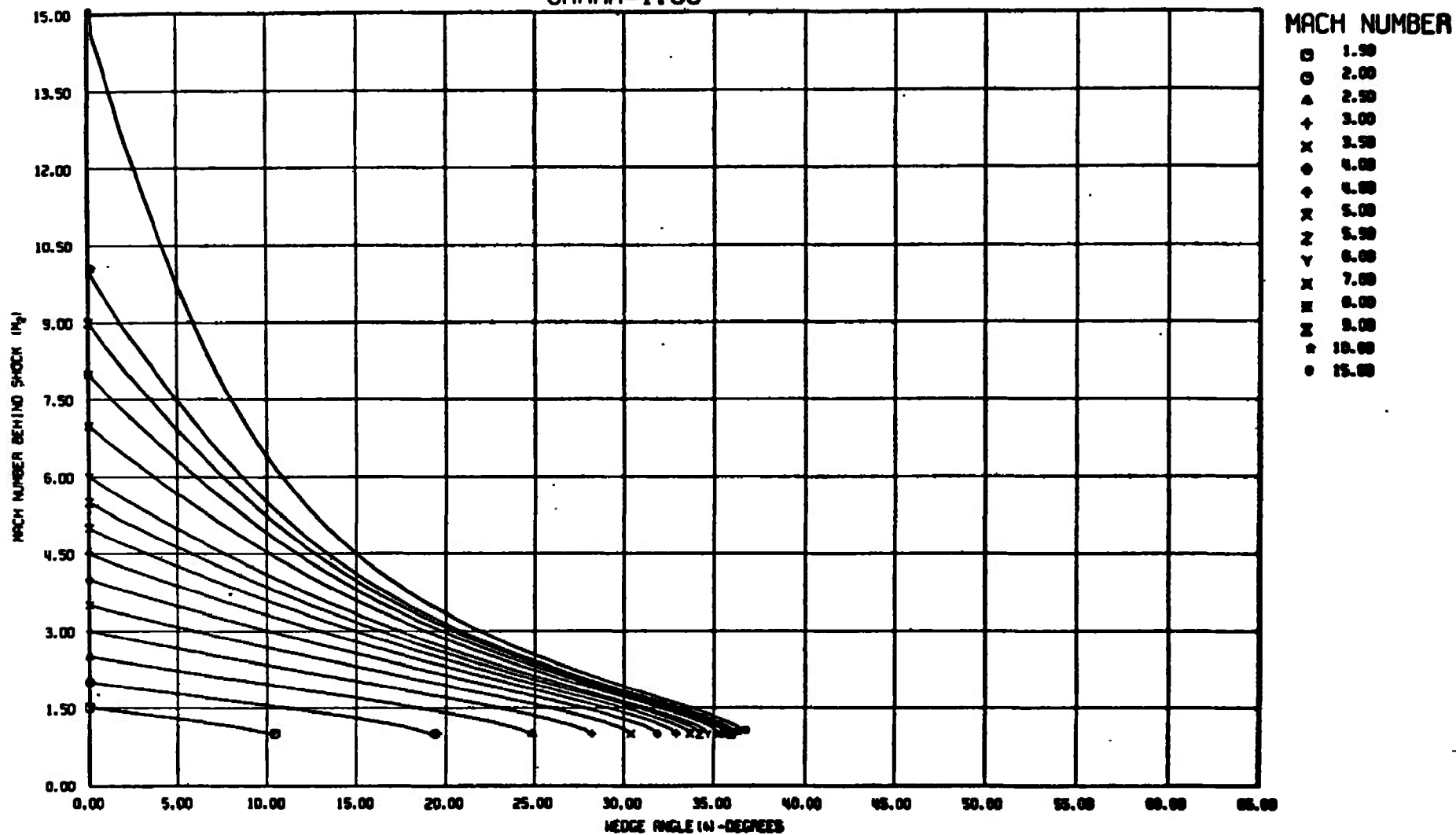


Fig. 30 Continued

OBLIQUE SHOCK GAMMA=1.66

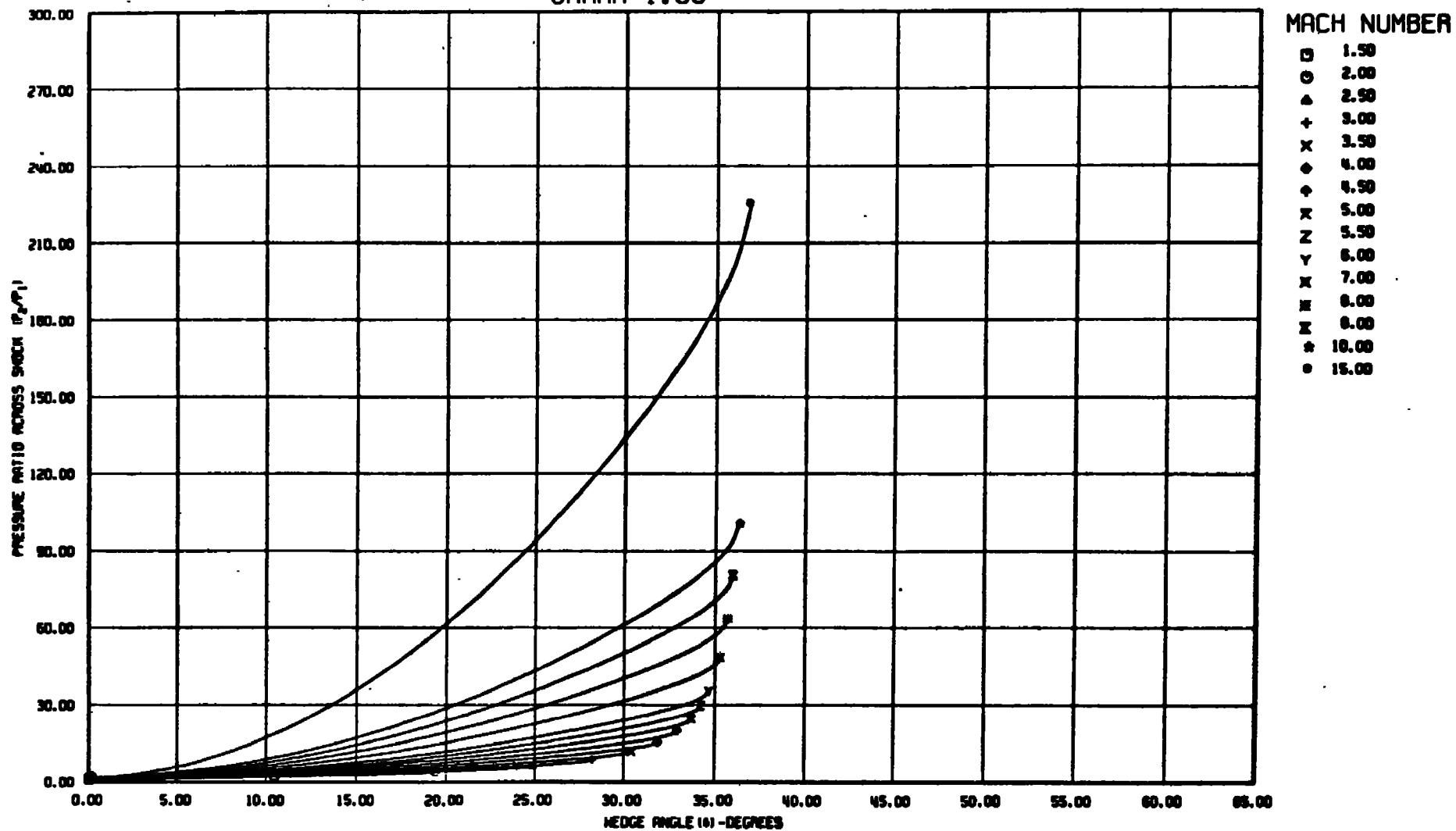


Fig. 30 Continued

OBLIQUE SHOCK
 $\gamma = 1.66$

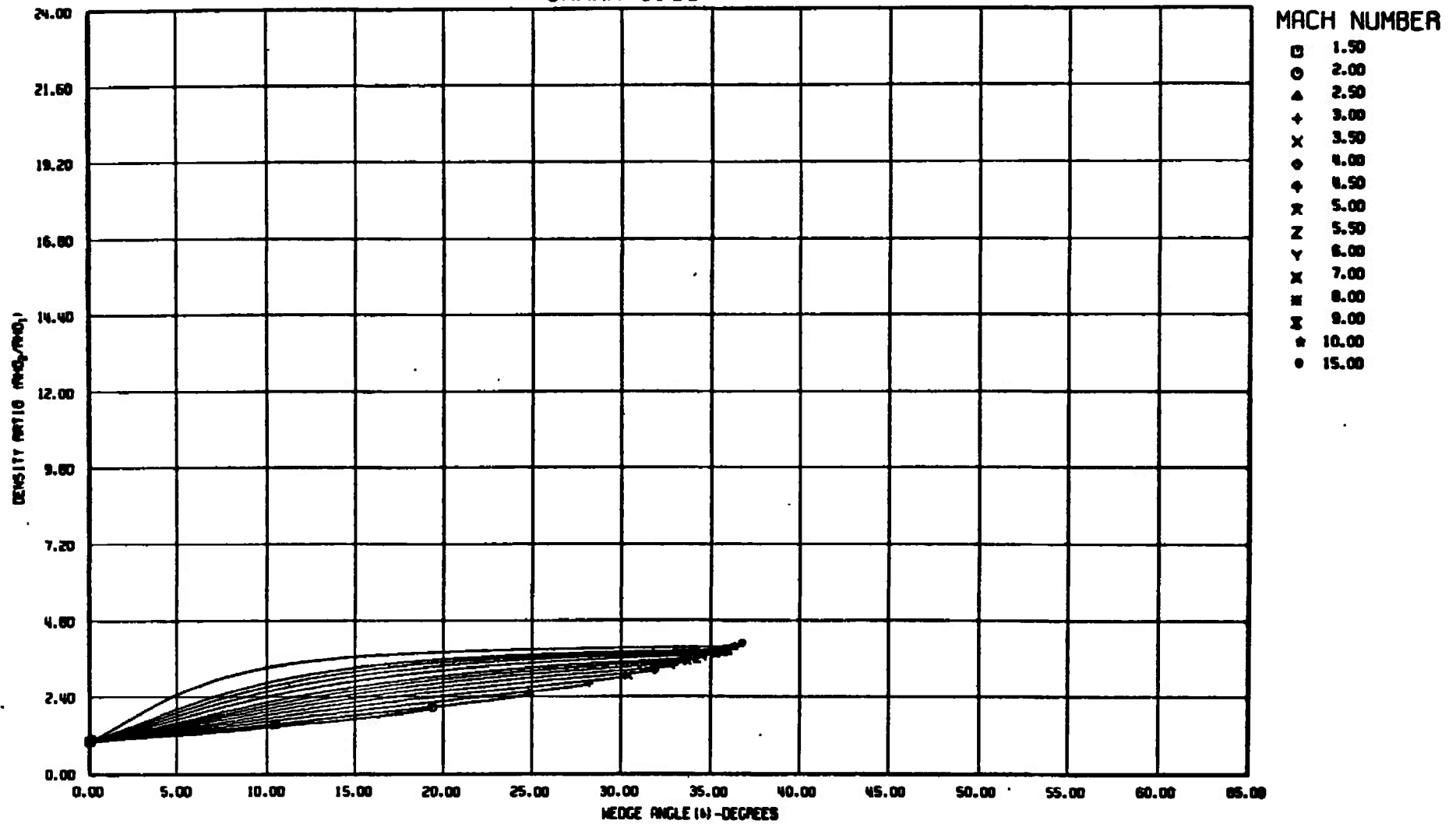


Fig. 30 Continued

OBLIQUE SHOCK GAMMA=1.66

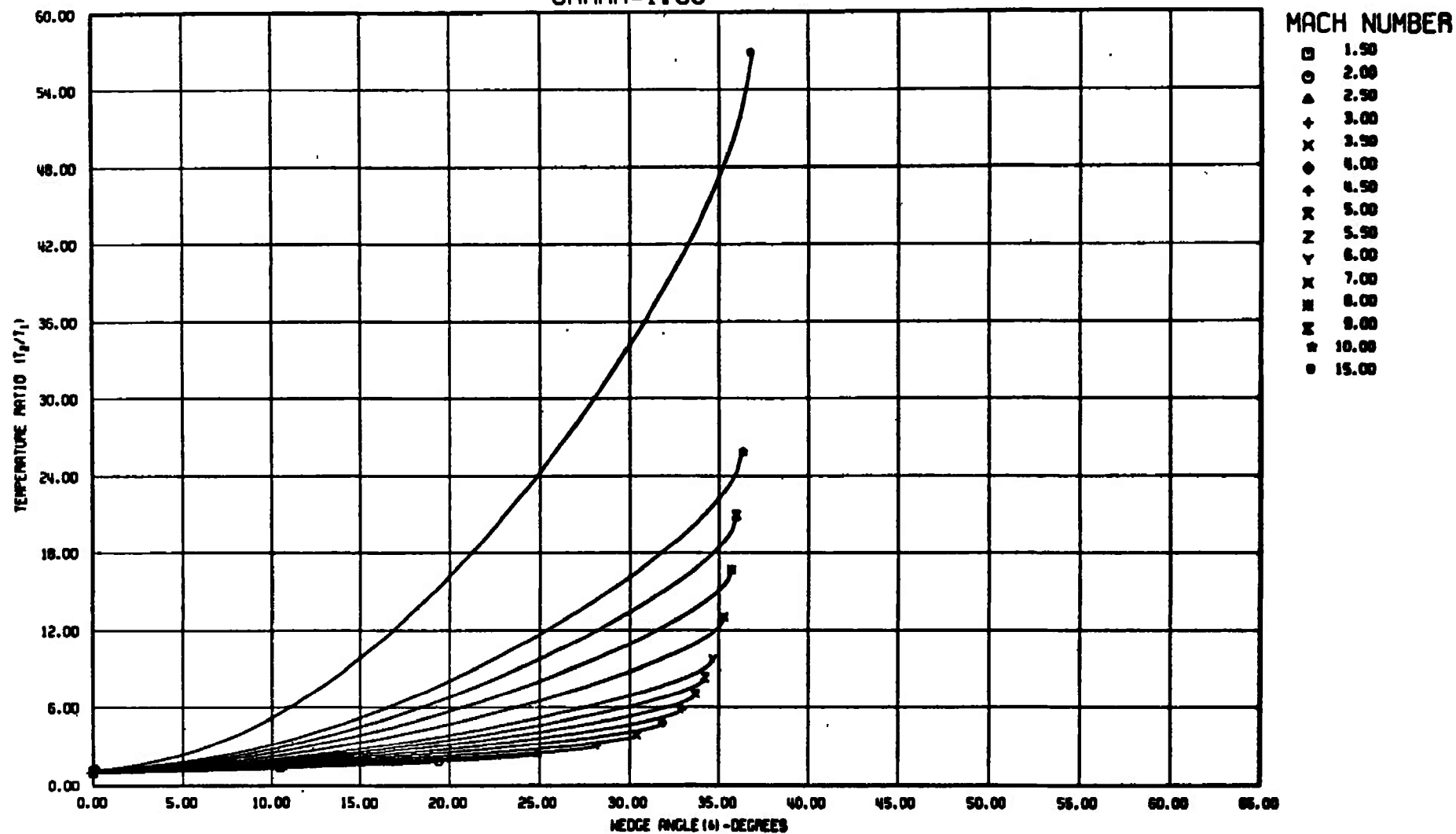


Fig. 30 Continued

OBLIQUE SHOCK GAMMA=1.66

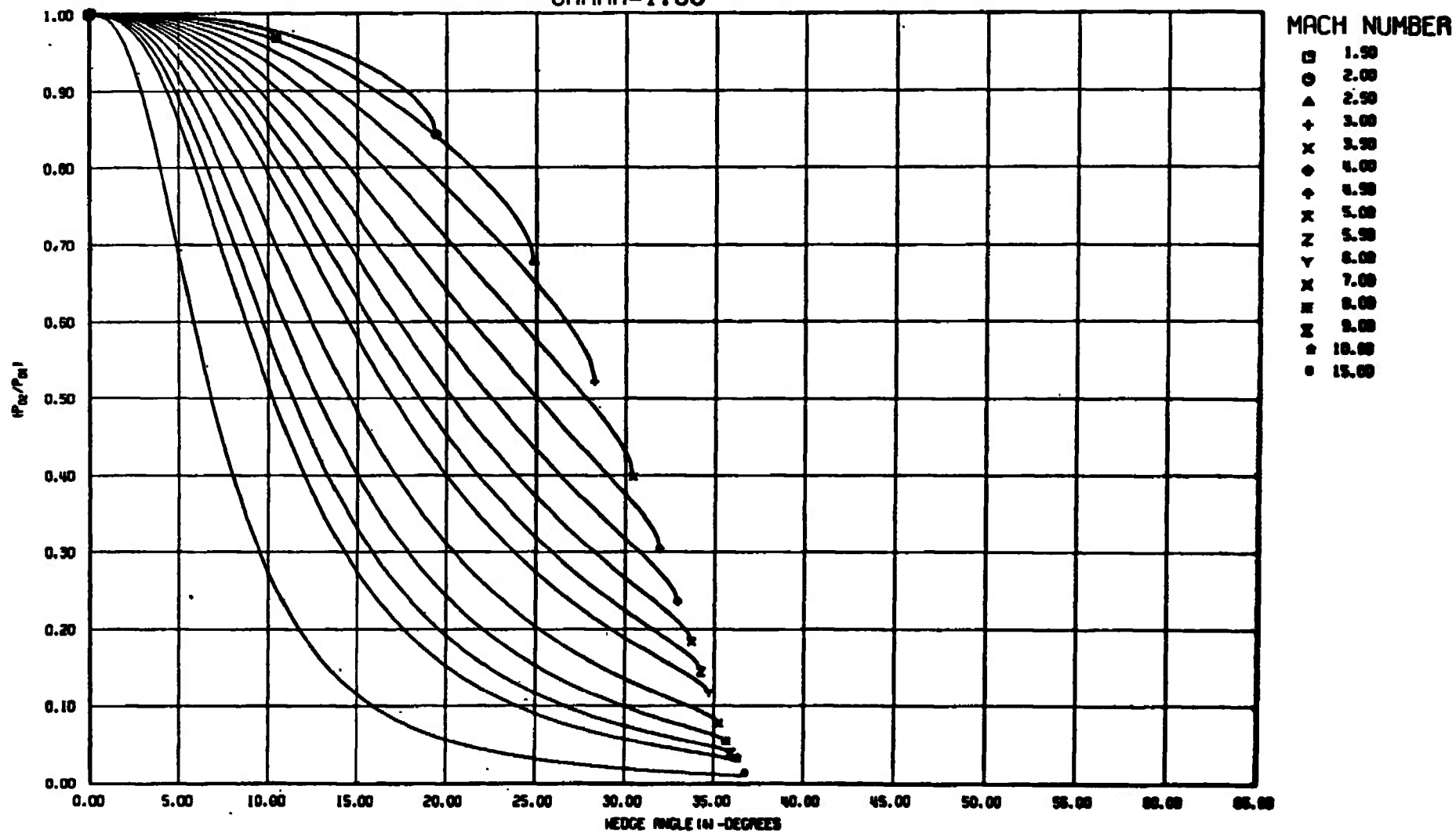


Fig. 30 Continued

OBLIQUE SHOCK GAMMA=1.66

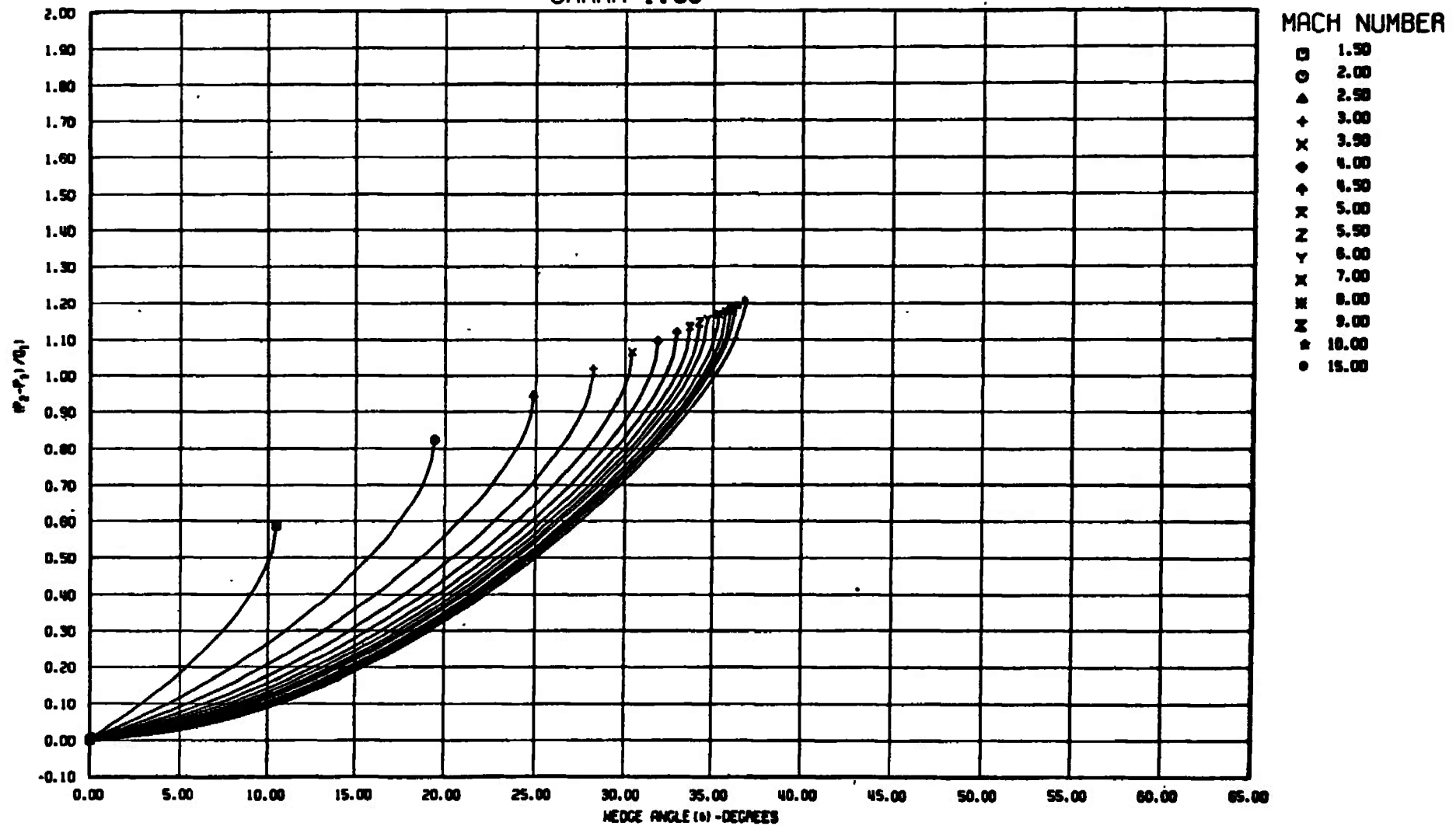


Fig. 30 Concluded

OBLIQUE SHOCK GAMMA=1.667

209

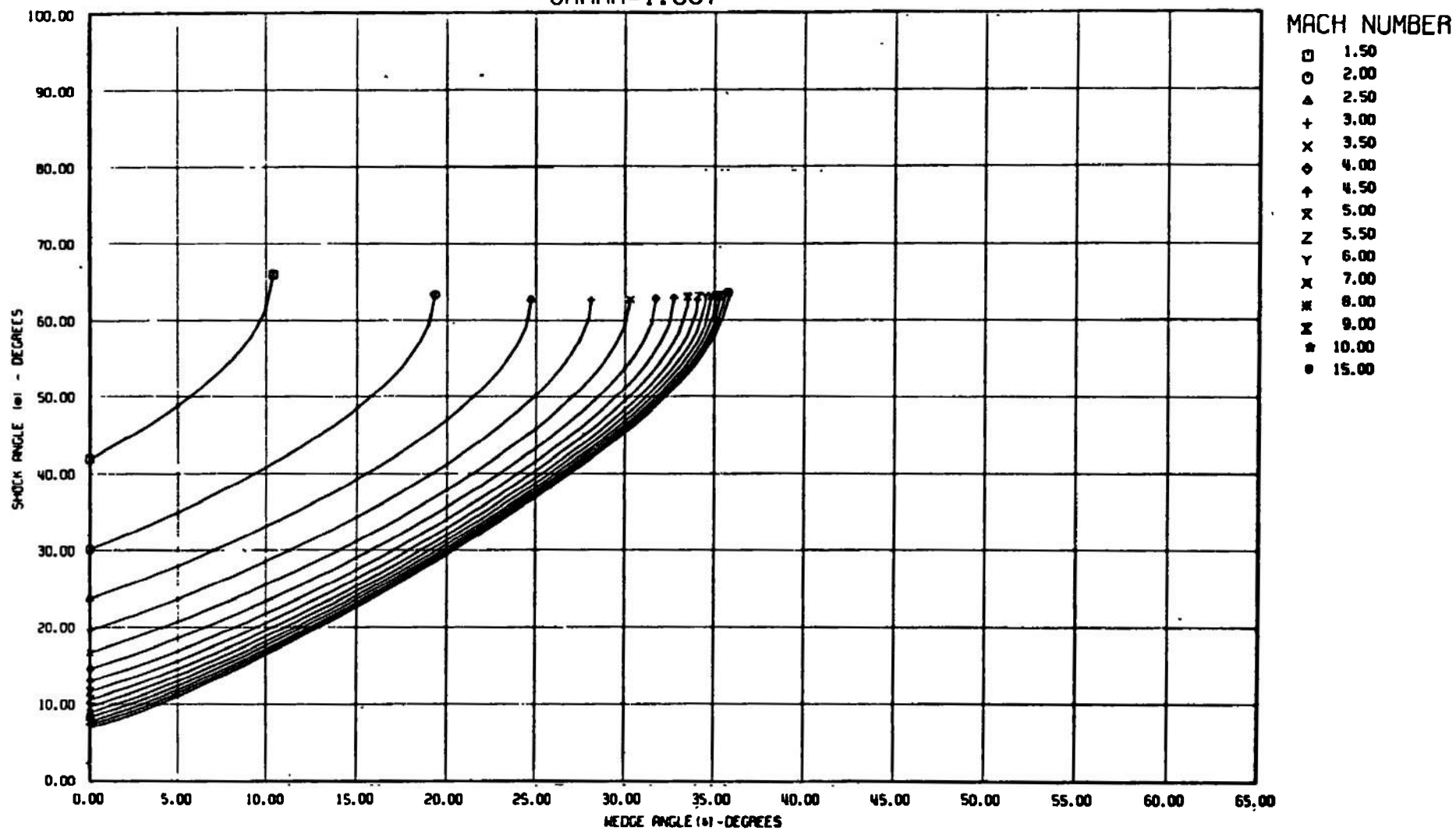


Fig. 31 $\gamma = 1.667$

OBLIQUE SHOCK GAMMA=1.667

210

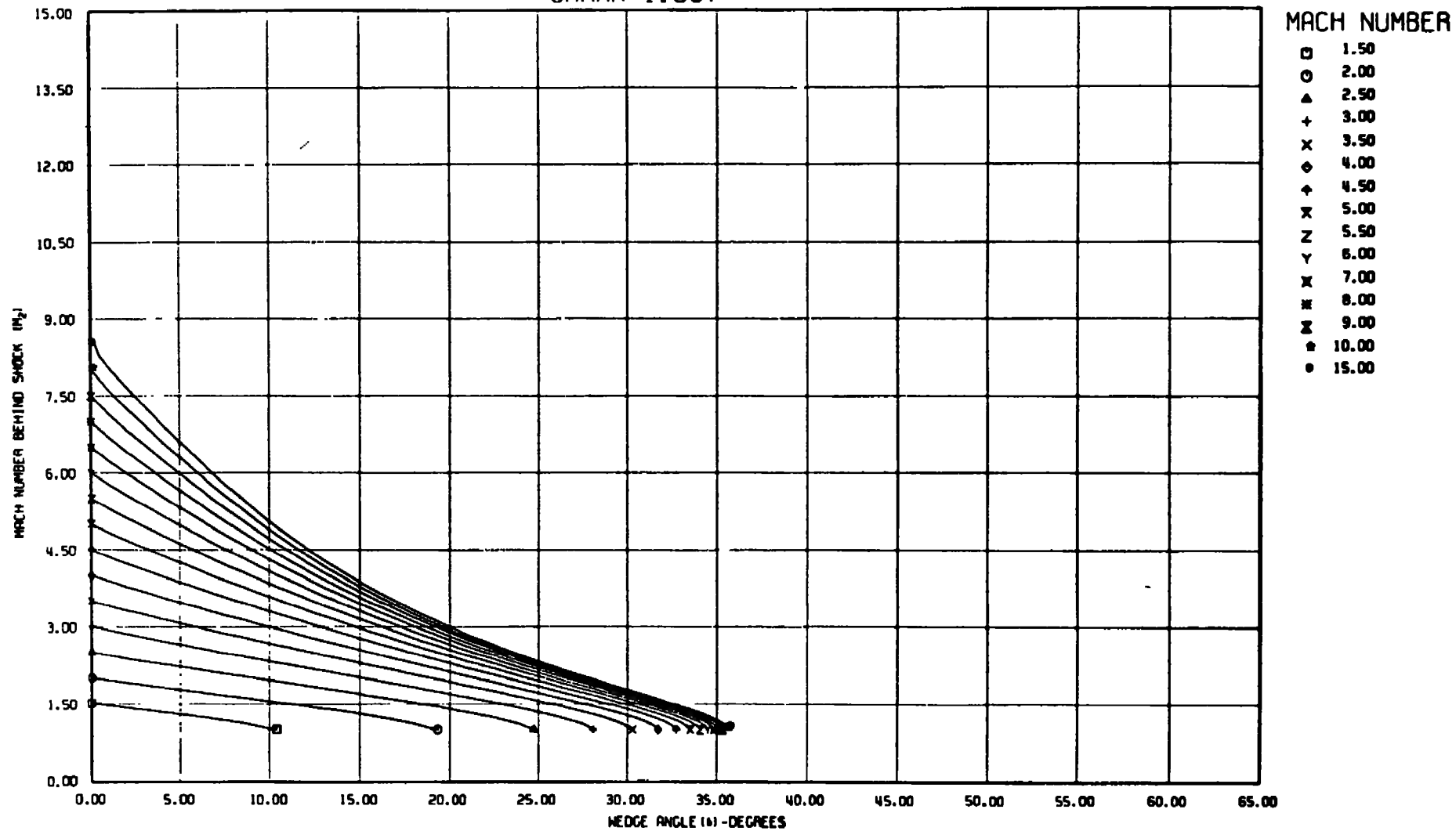
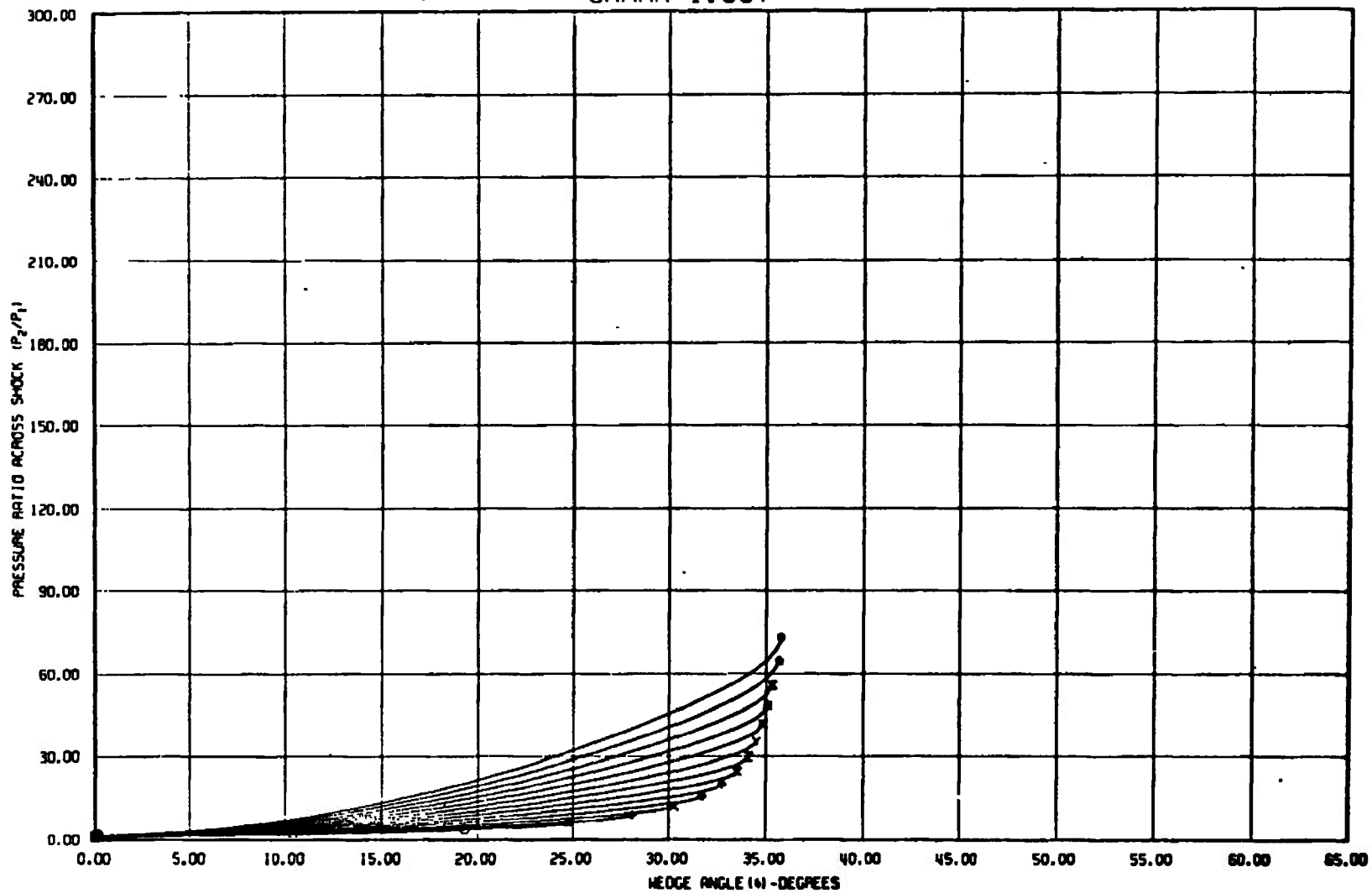


Fig. 31 Continued

OBLIQUE SHOCK
GAMMA=1.667



MACH NUMBER

- 1.50
- 2.00
- △ 2.50
- +
- x 3.50
- 4.00
- ◆ 4.50
- x 5.00
- Z 5.50
- Y 6.00
- x 7.00
- 8.00
- Σ 9.00
- ★ 10.00
- 15.00

Fig. 31 Continued

OBLIQUE SHOCK
GAMMA=1.667

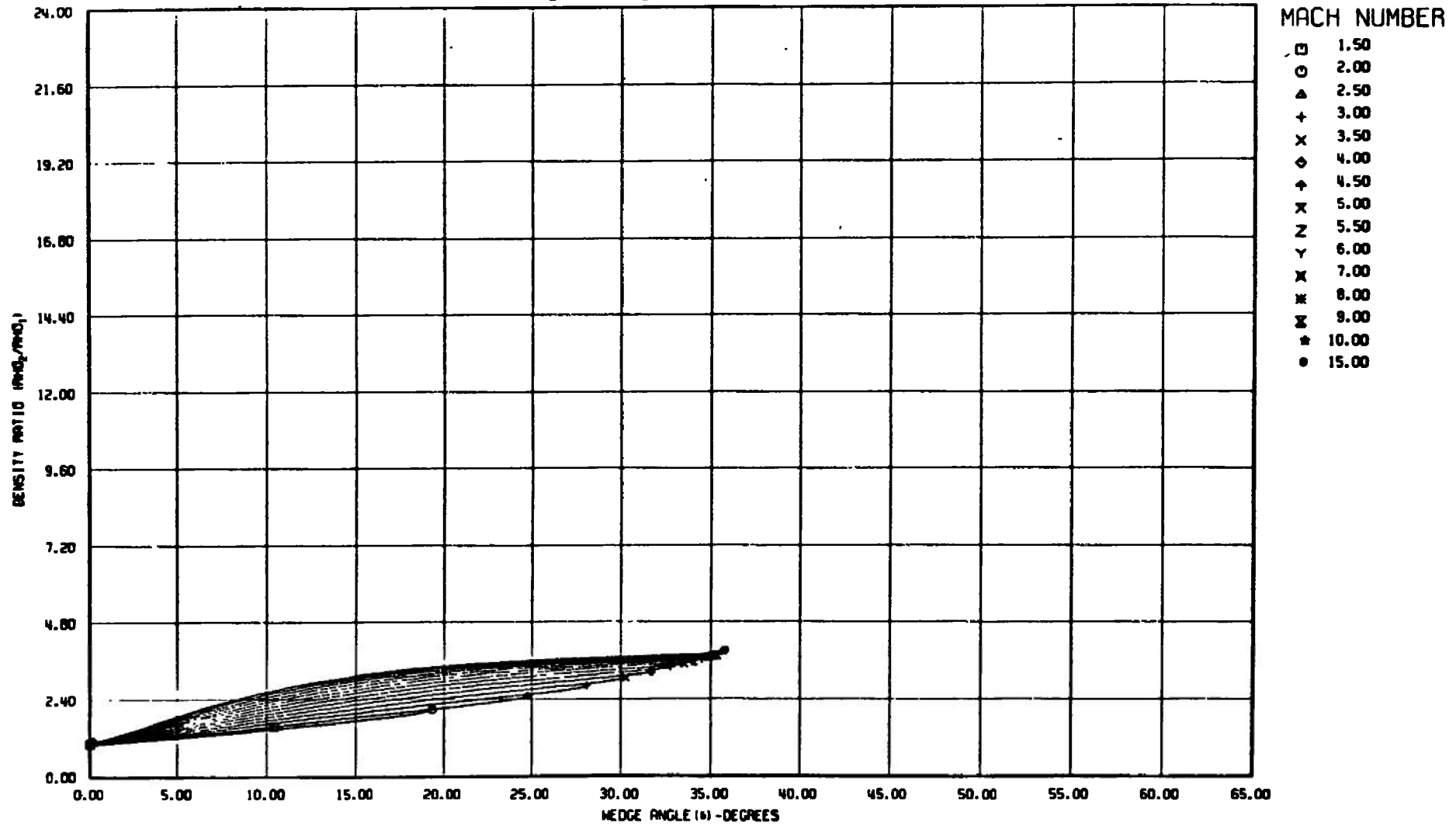


Fig. 31 Continued

OBLIQUE SHOCK
GAMMA=1.667

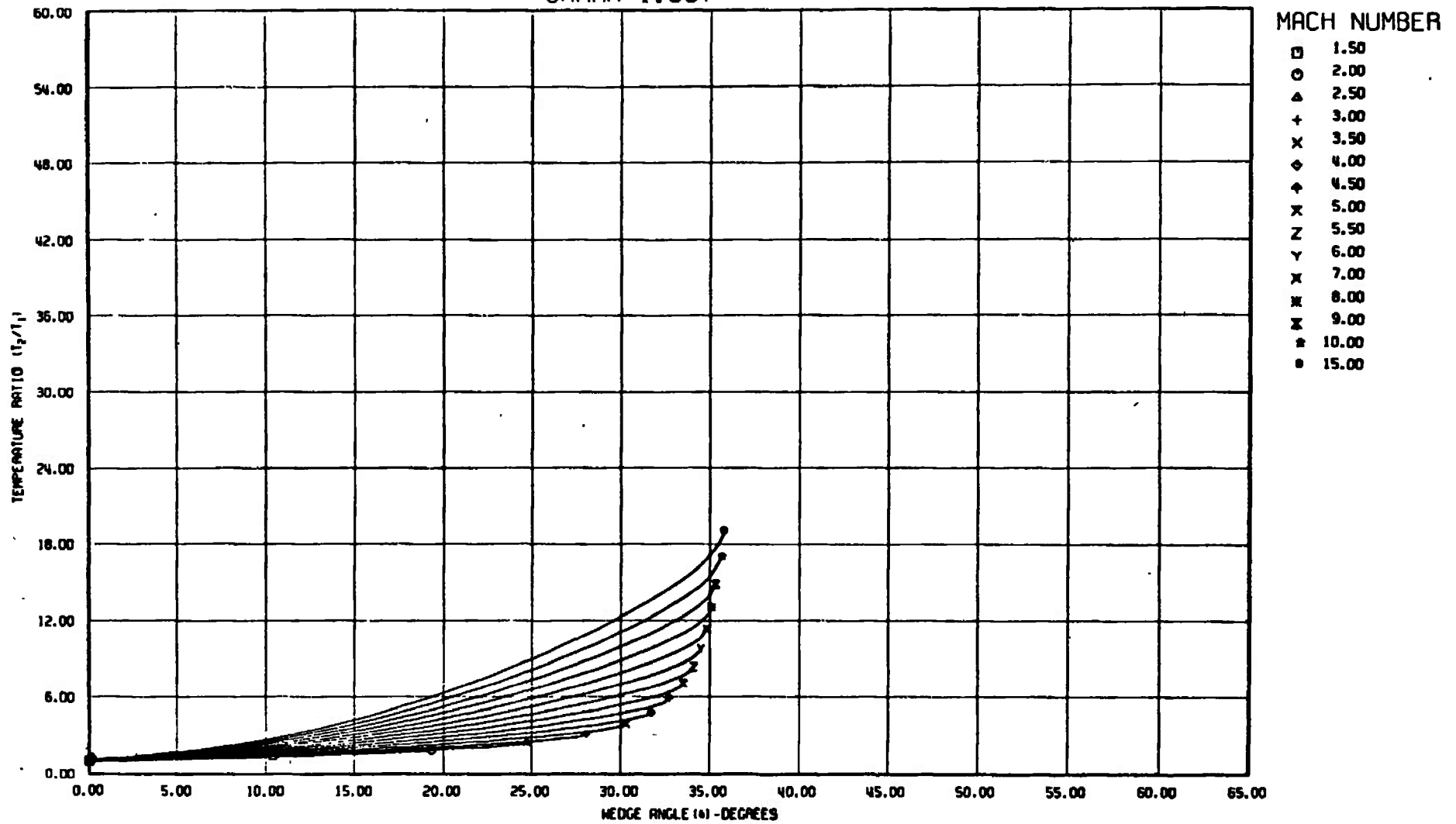


Fig. 31 Continued

OBLIQUE SHOCK GAMMA=1.667

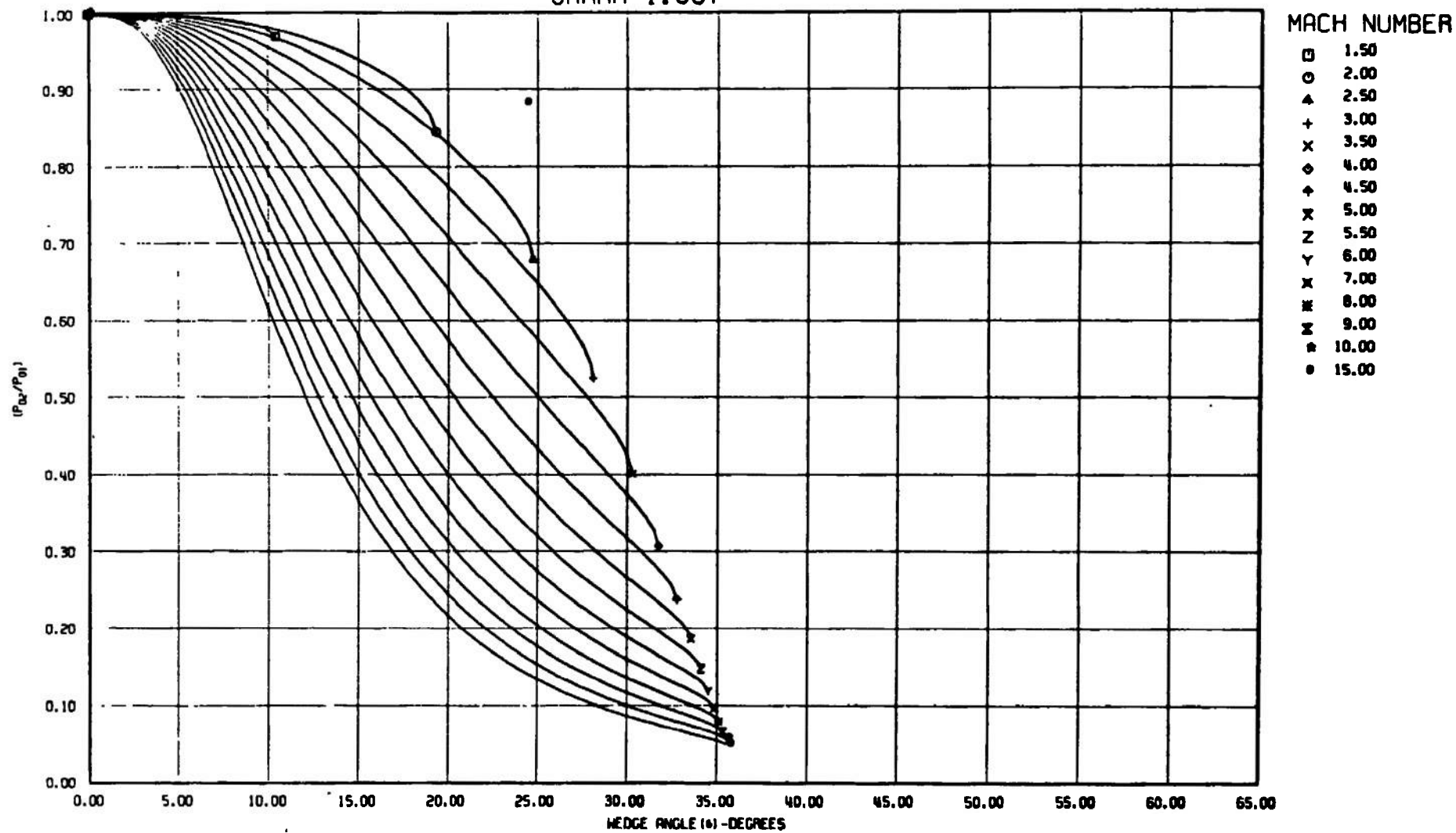


Fig. 31 Continued

OBLIQUE SHOCK
GAMMA=1.667

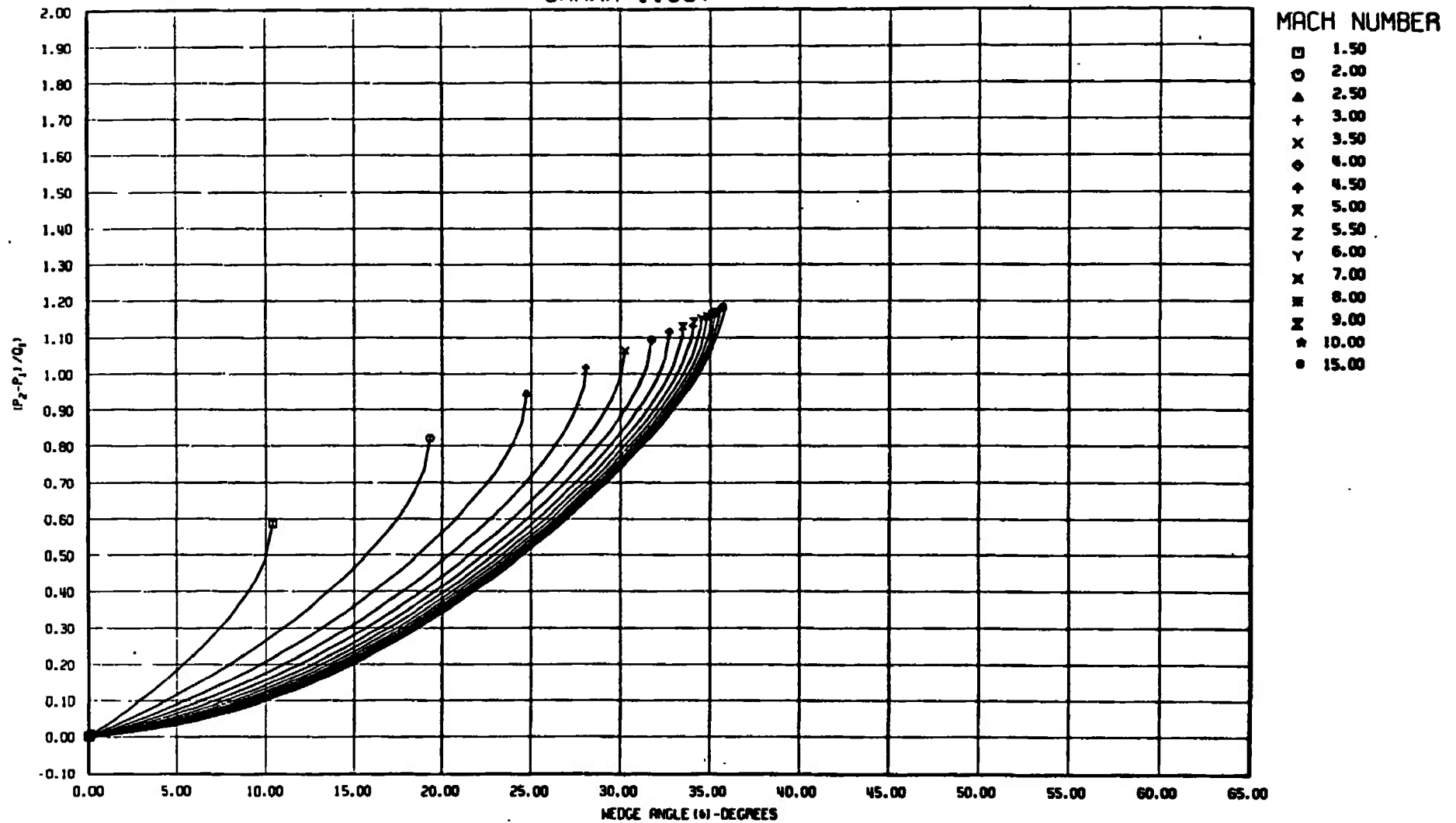


Fig. 31 Concluded

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13. ABSTRACT

This report is a presentation of graphs of the oblique-shock relationships for several ratios of specific heats at several Mach numbers. The specific heat ratios vary from 1.10 to 1.66 in increments of 0.02, and a plot is also shown for a specific heat ratio equal to 1.667. The Mach numbers range from 1.5 to 6.0 with increments of 0.5 and from 6.0 to 10.0 with increments of 1.0; Mach number 15.0 is presented separately.

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14.

KEY WORDS

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WT

ROLE

WT

ROLE

WT

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hypersonic flow

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