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The Aerodynamics of Curved Jets and Breakaway in Coanda Flares

Volume 2 of 2

Peter Senior

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University of Durham
School of Engineering and Applied Science

Thesis submitted AD 1991 for
the Degree of Doctor of Philosophy

10 FEB 1992

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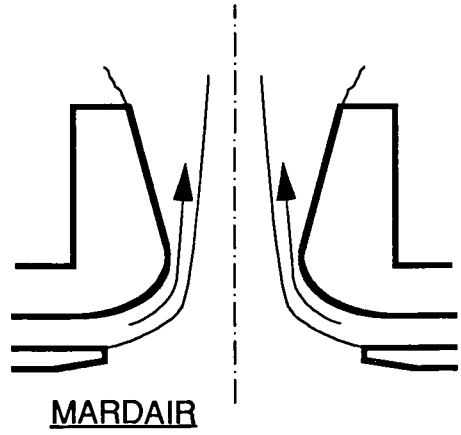

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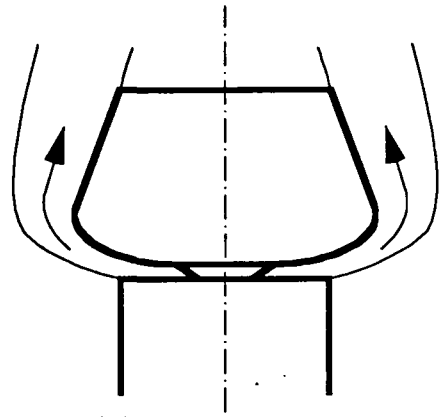

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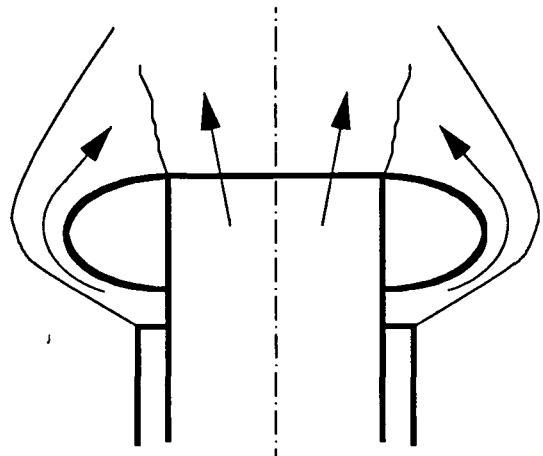

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Figure 1.1. Coanda Flare Variants

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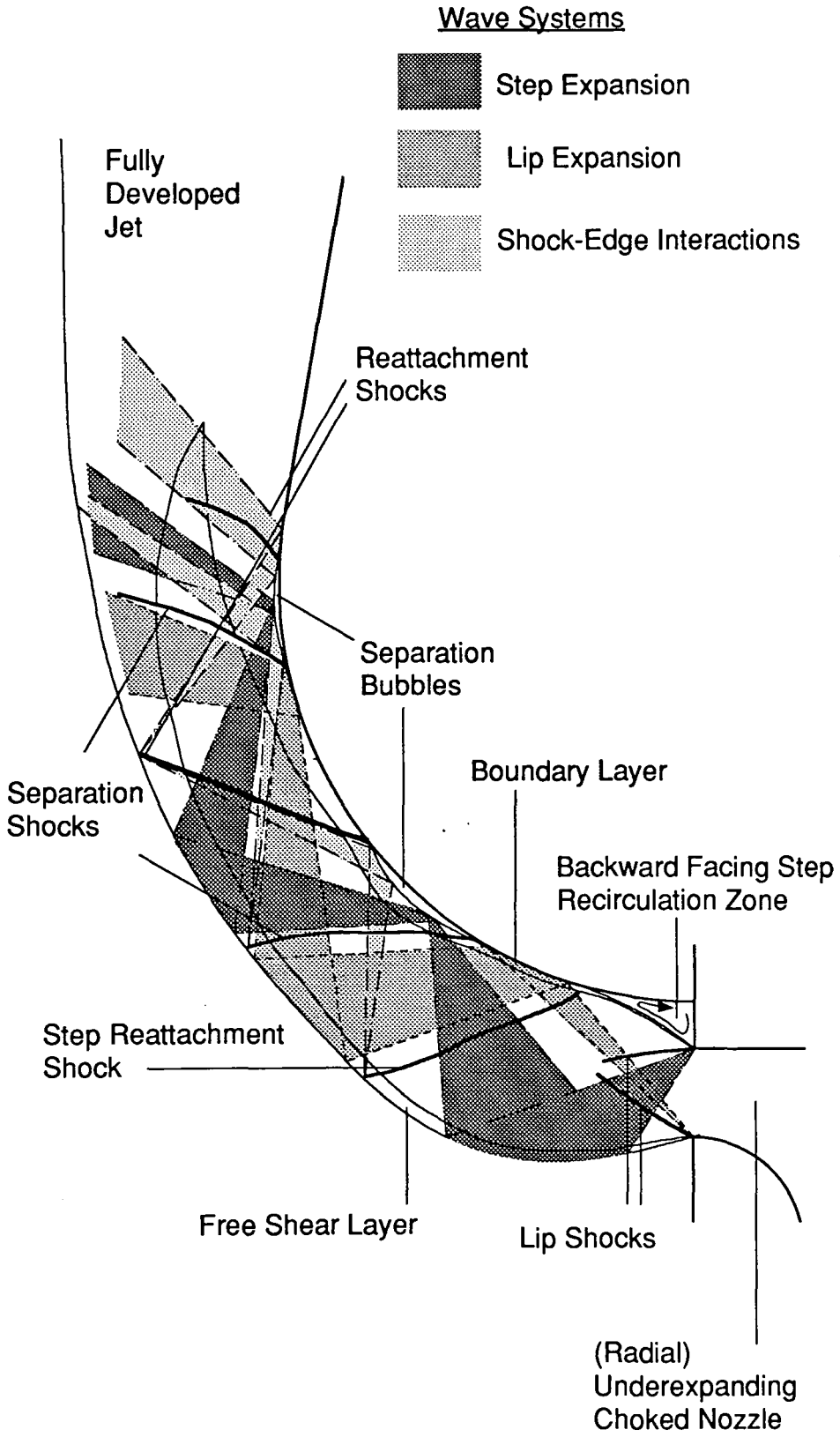
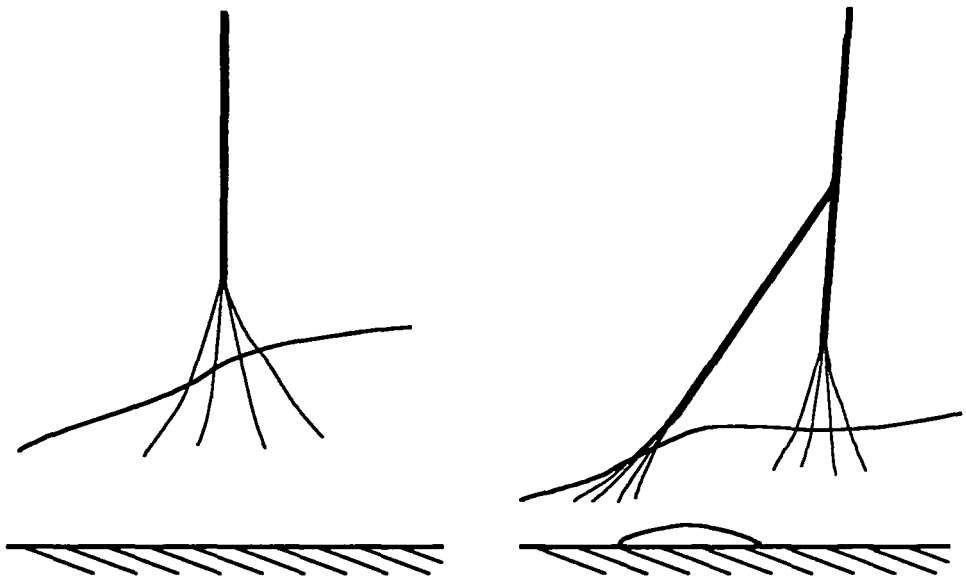
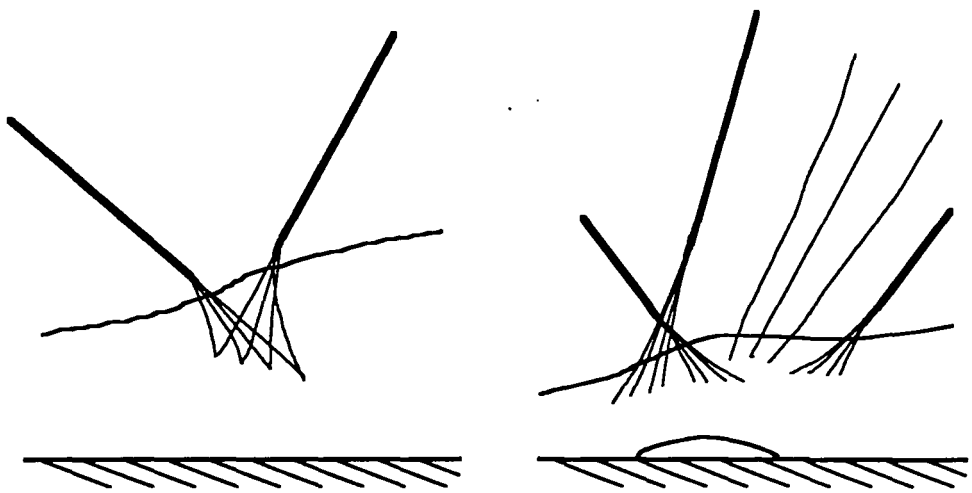


Figure 2.1. Coanda Flare Flowfield Schematic



a) Normal, Attached

b) Normal, Separated



c) Oblique, Attached

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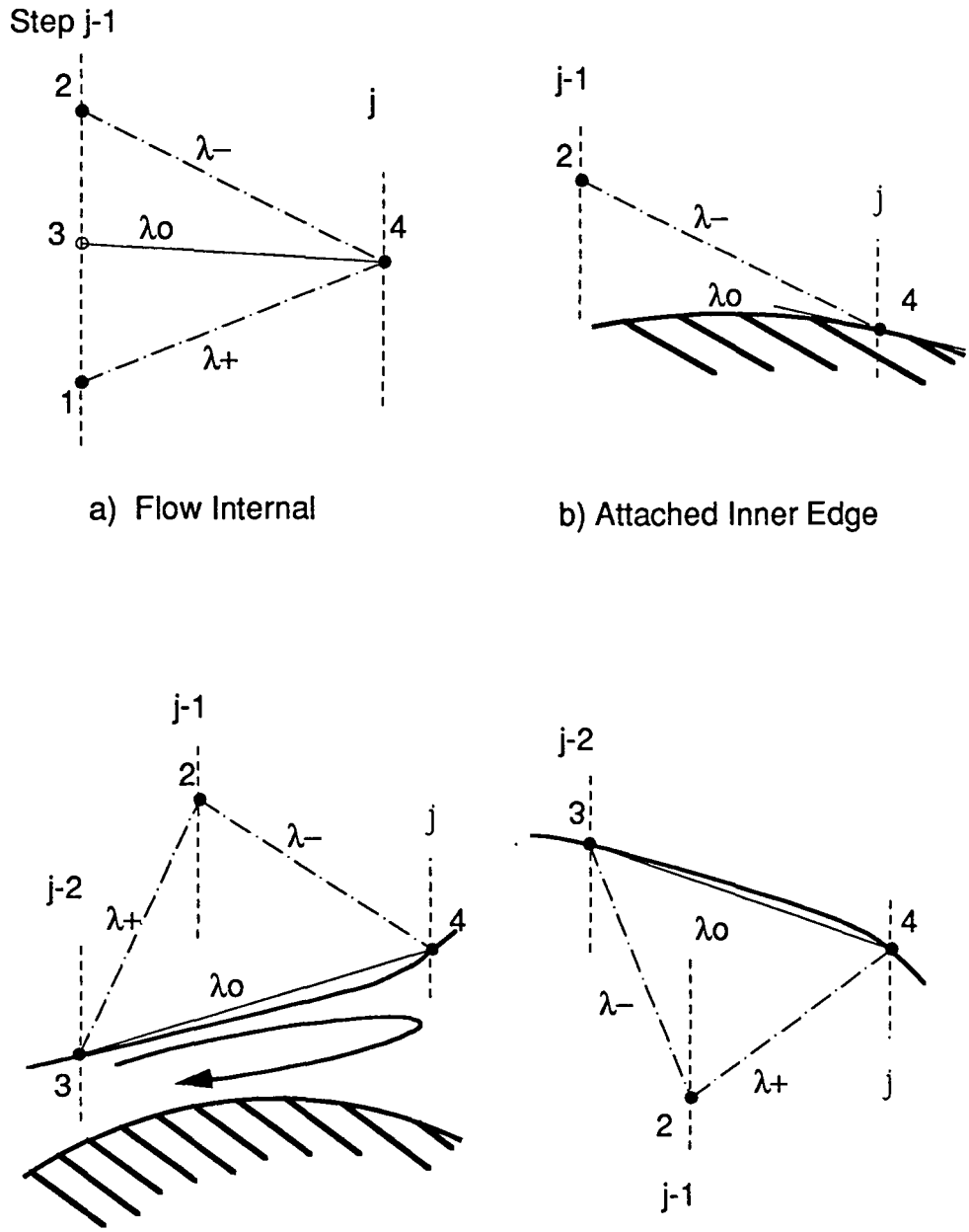
Figure 2.2. Shock-Boundary Layer Interactions



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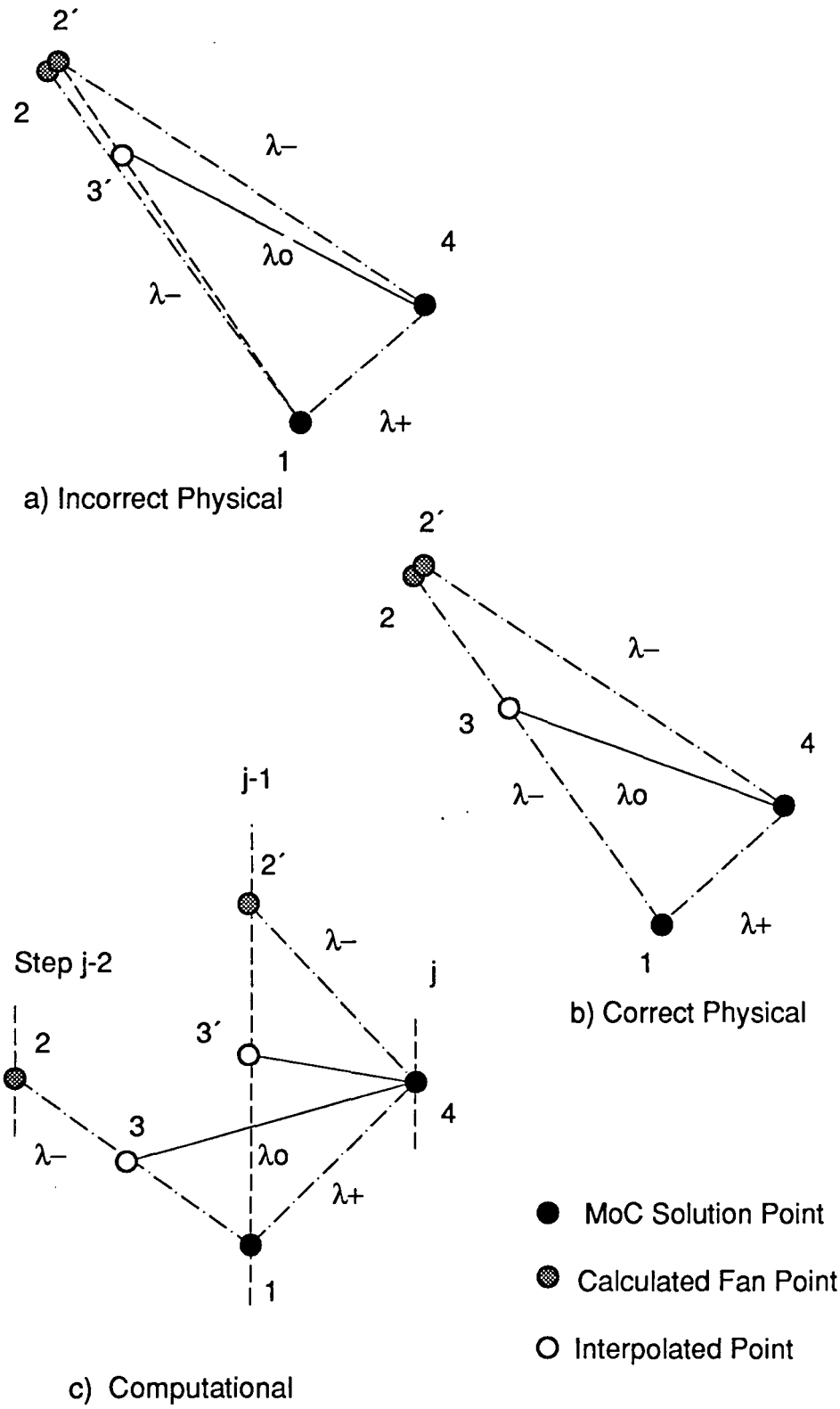

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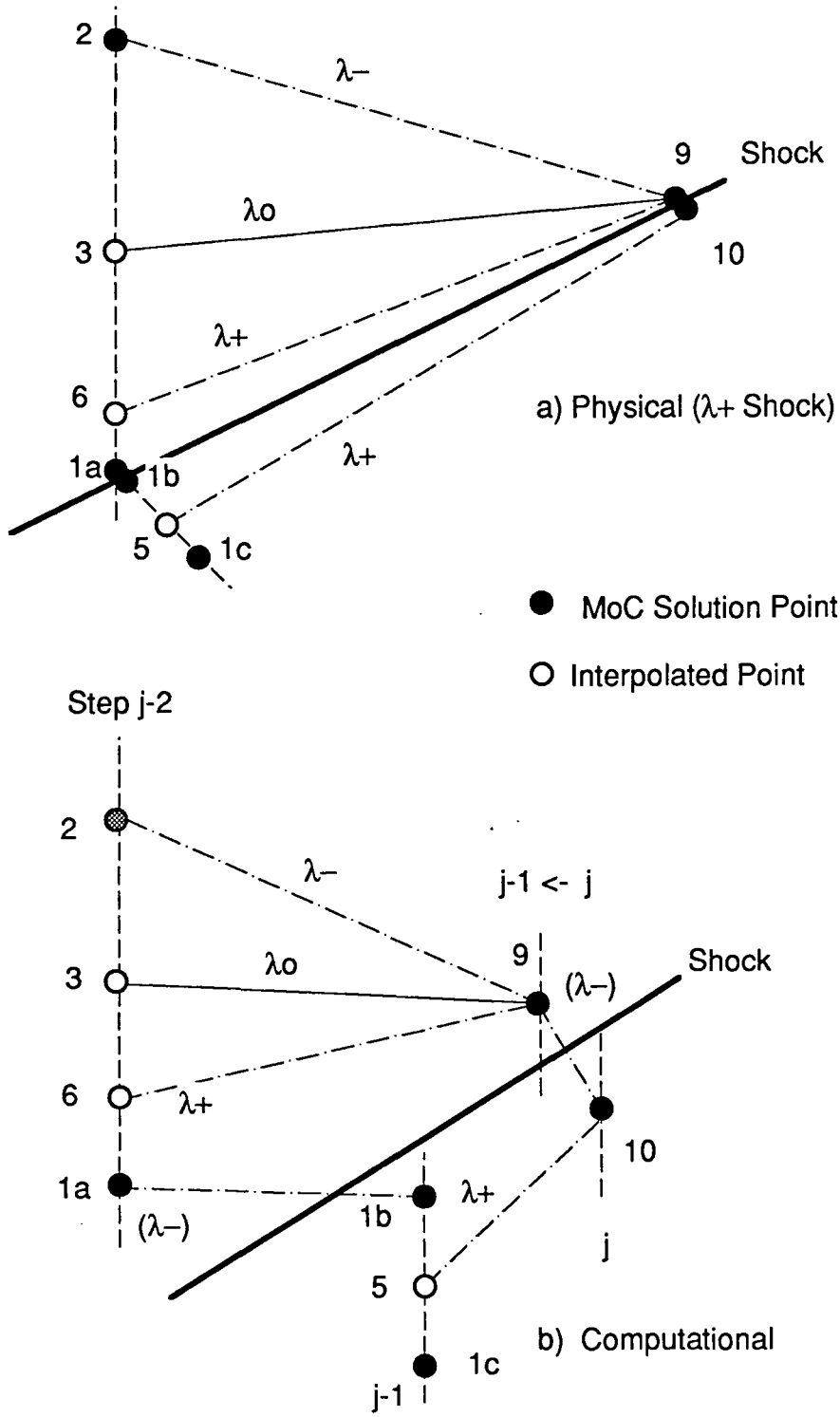

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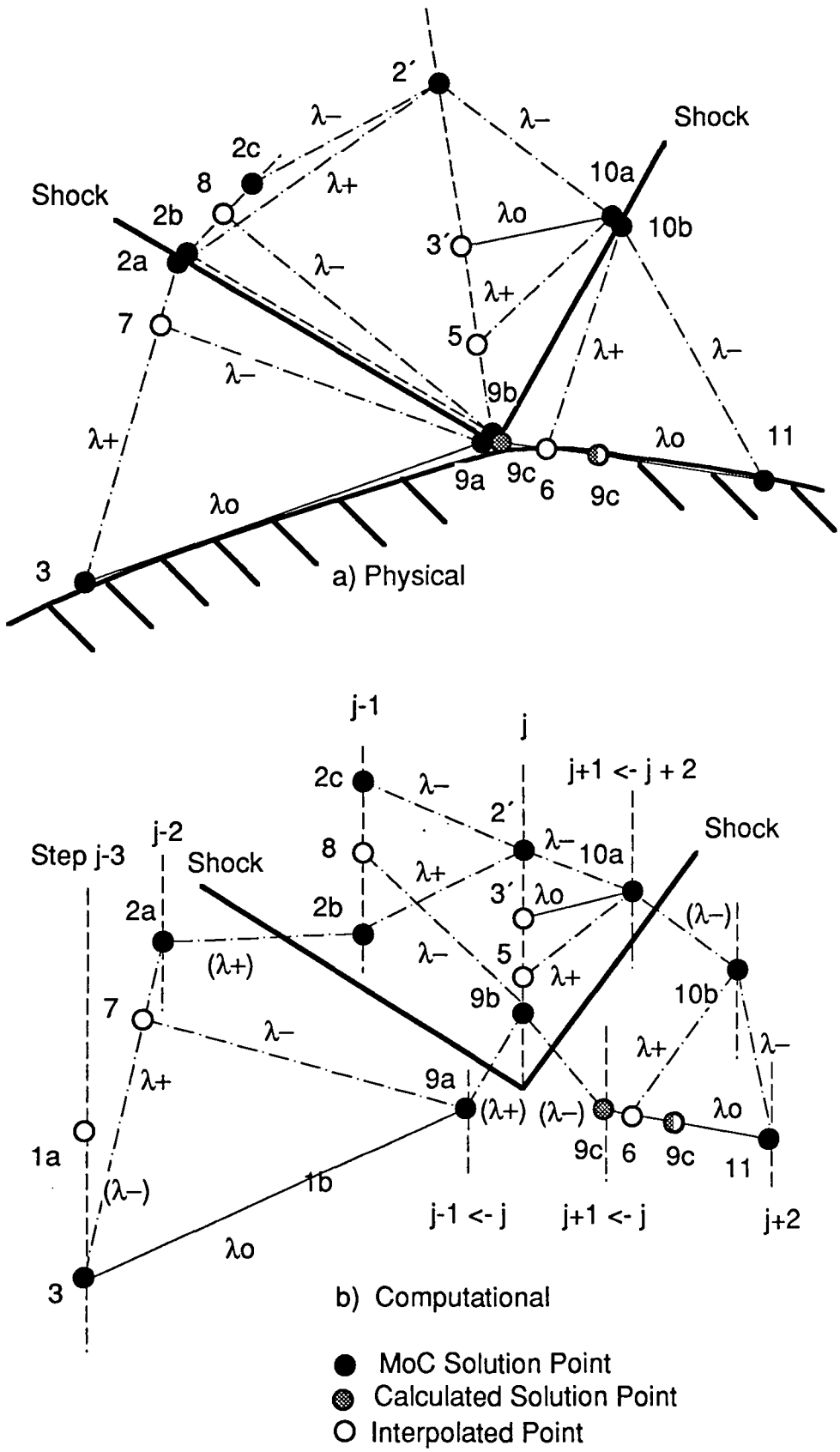
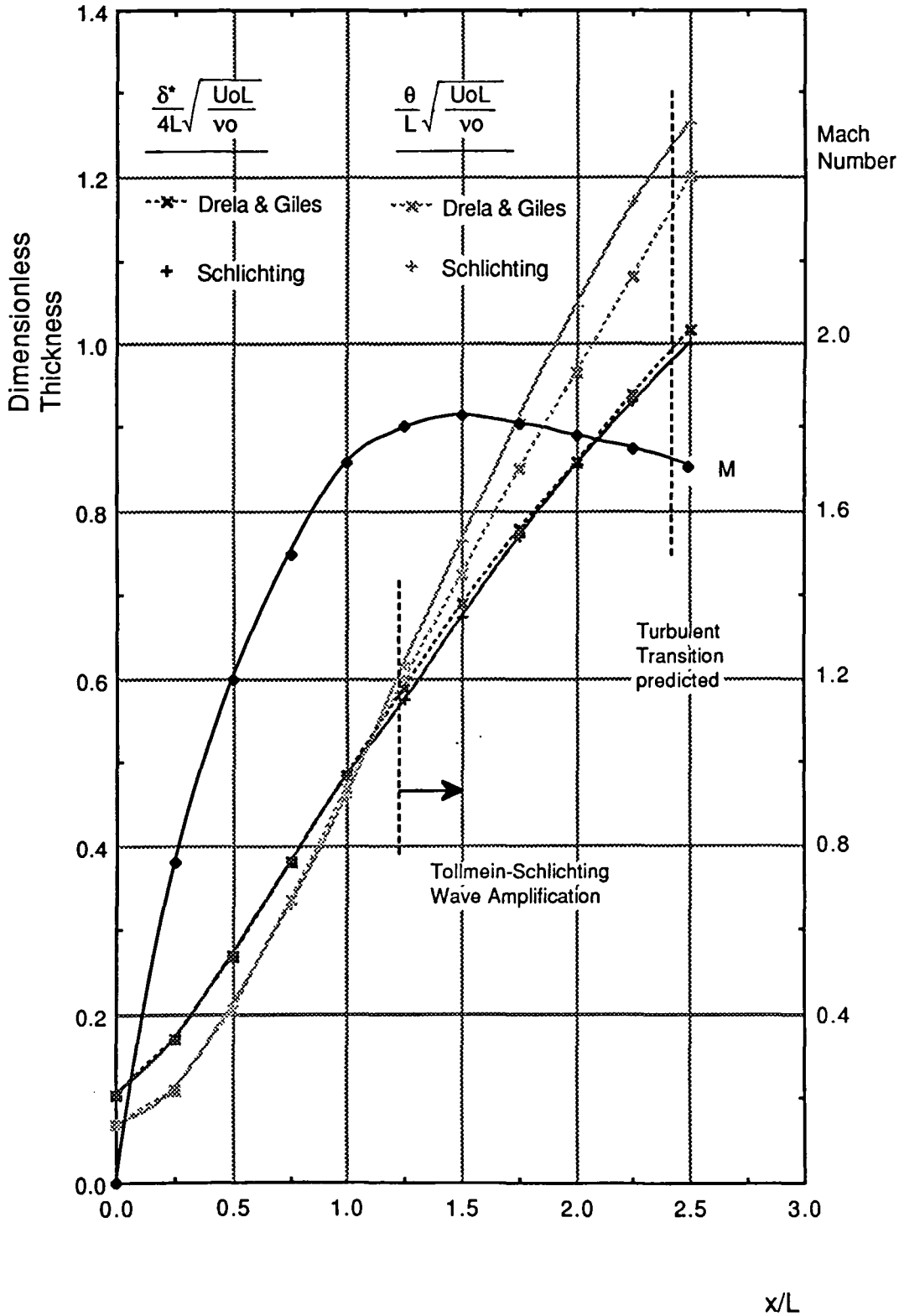


Figure 4.4. Edge Shock Reflection MoC Unit Processes



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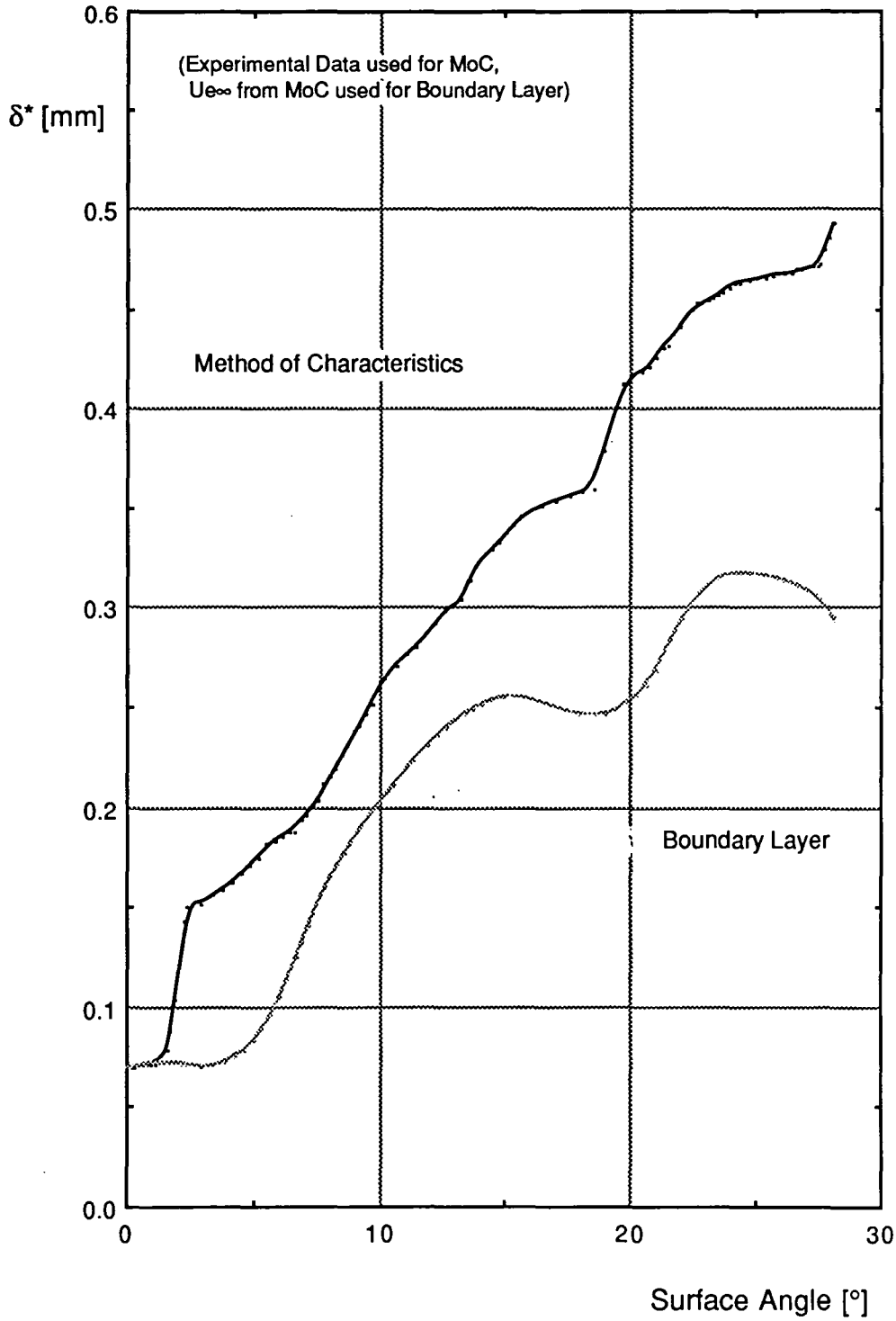


Figure 4.6. Comparison of Method of Characteristics with Boundary Layer Method

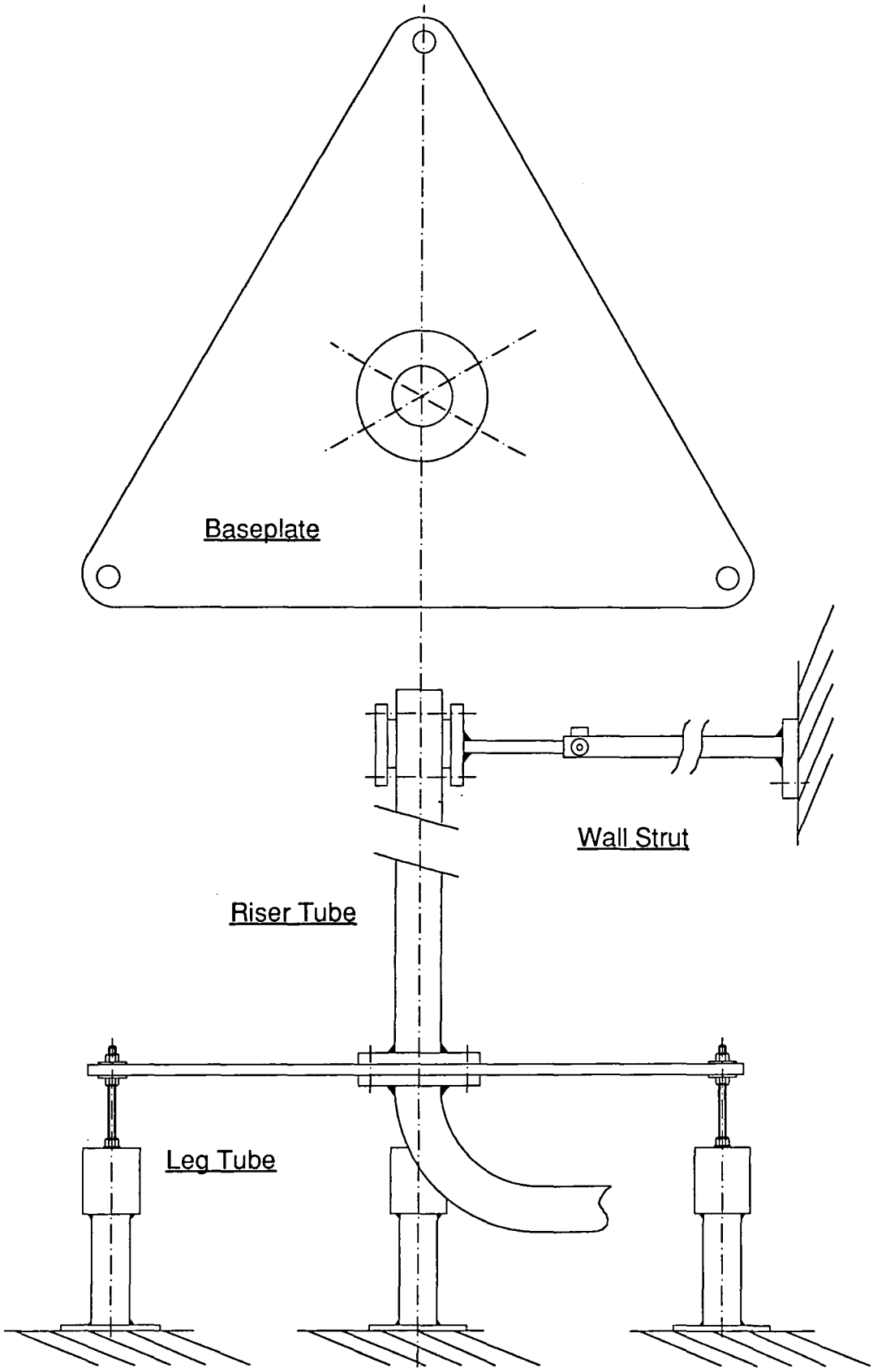
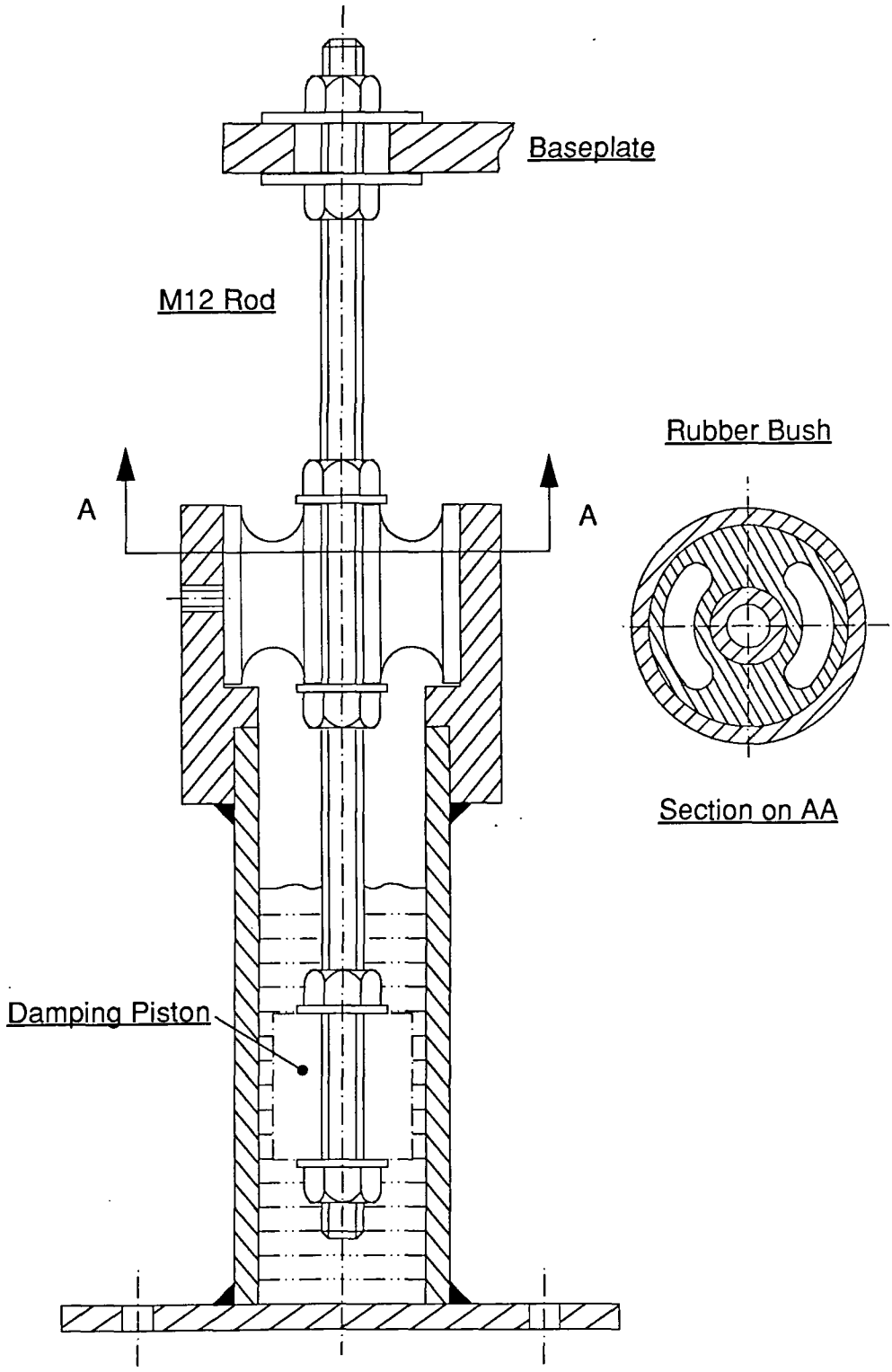


Figure 5.1. Mechanical Rig Suspension



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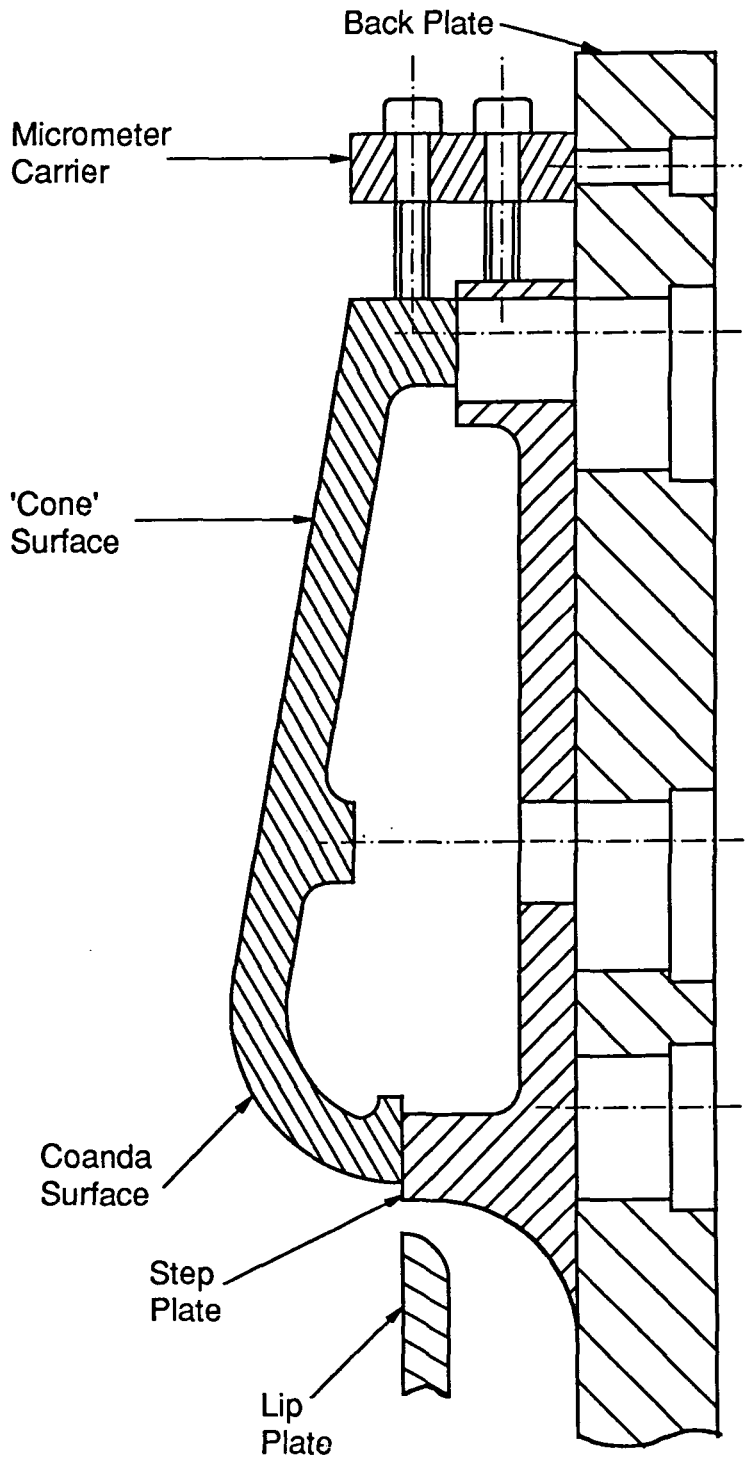


Figure 5.3. Planar Flare Model

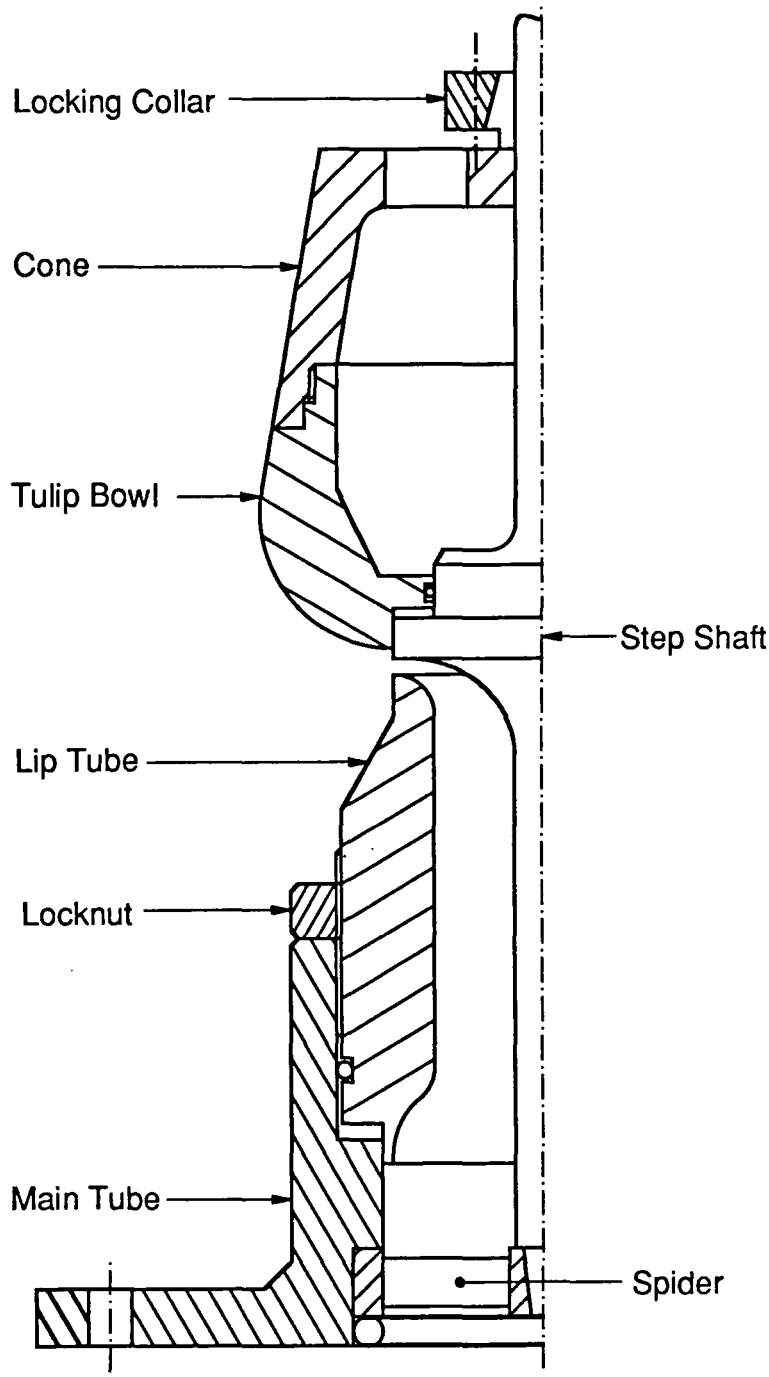
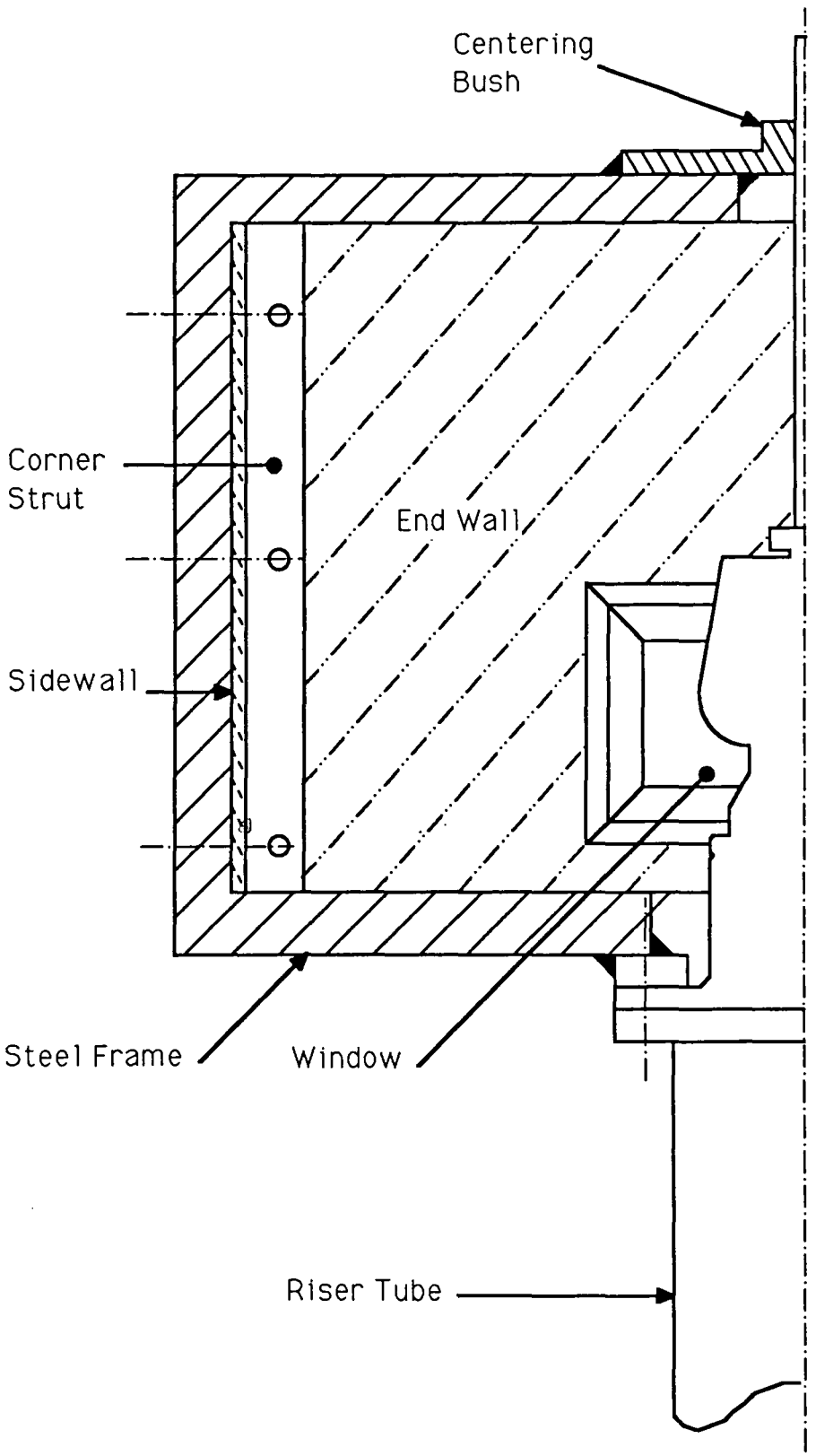


Figure 5.4. Axisymmetric Flare Model



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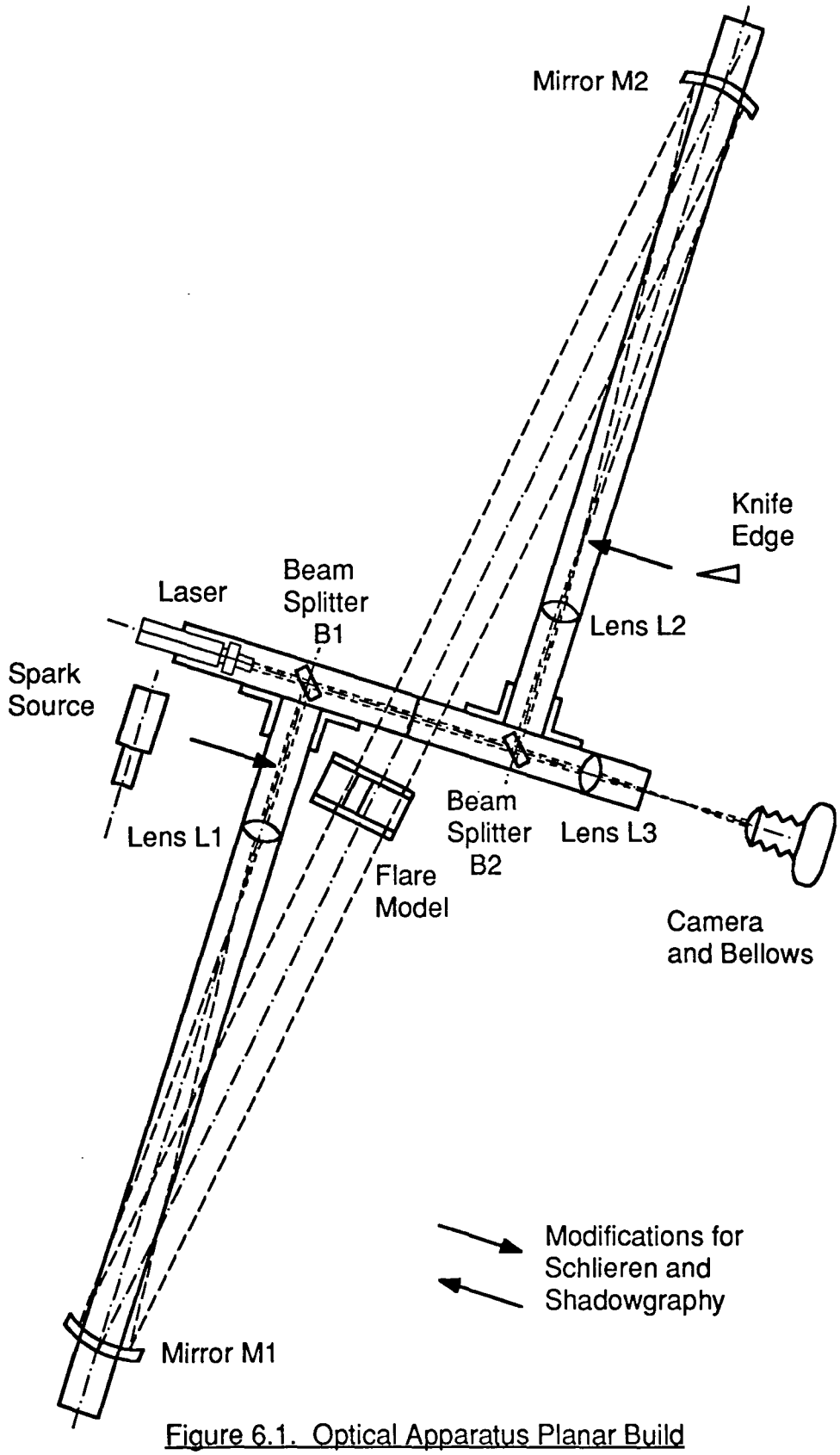


Figure 6.1. Optical Apparatus Planar Build

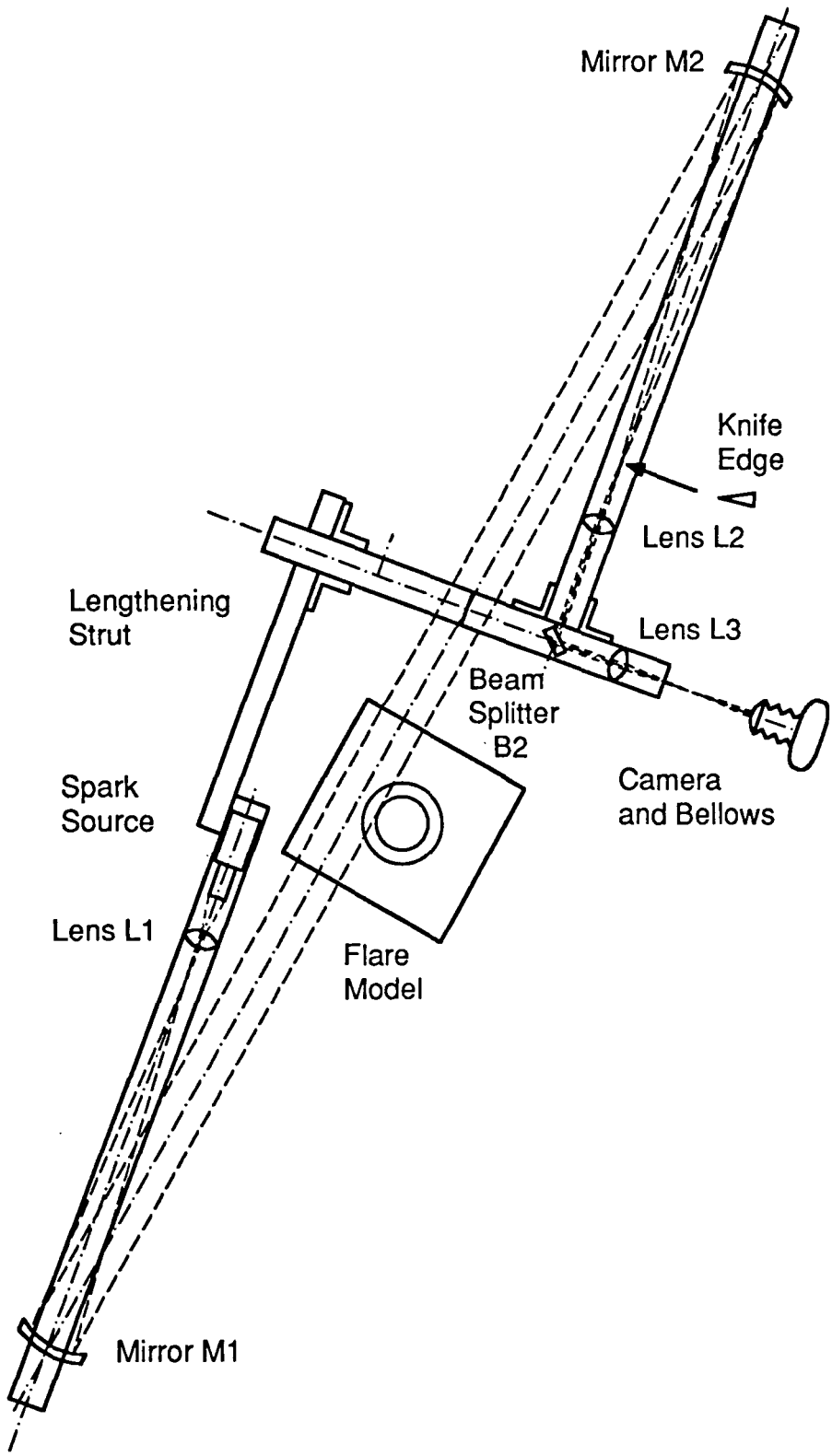


Figure 6.2. Optical Apparatus Axisymmetric Build

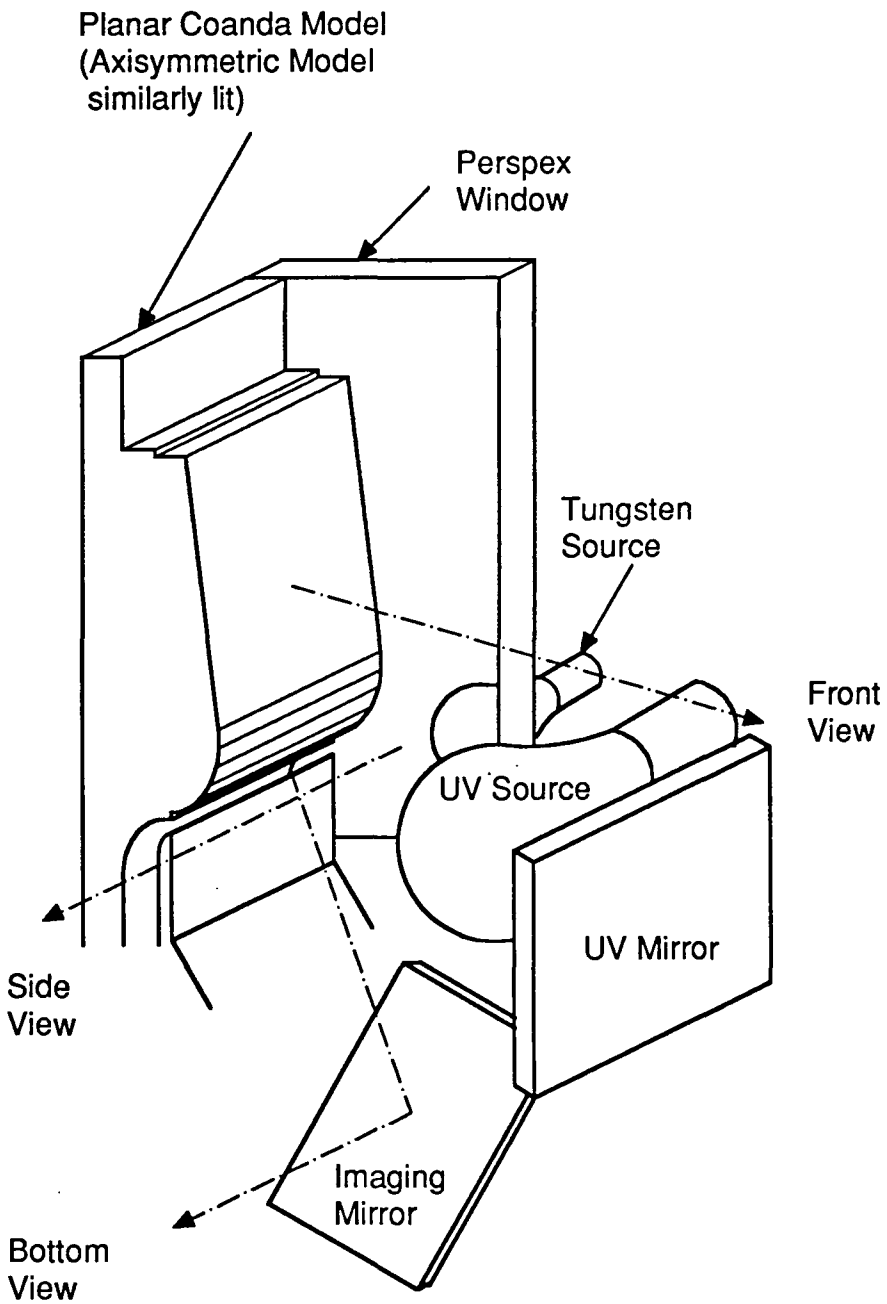
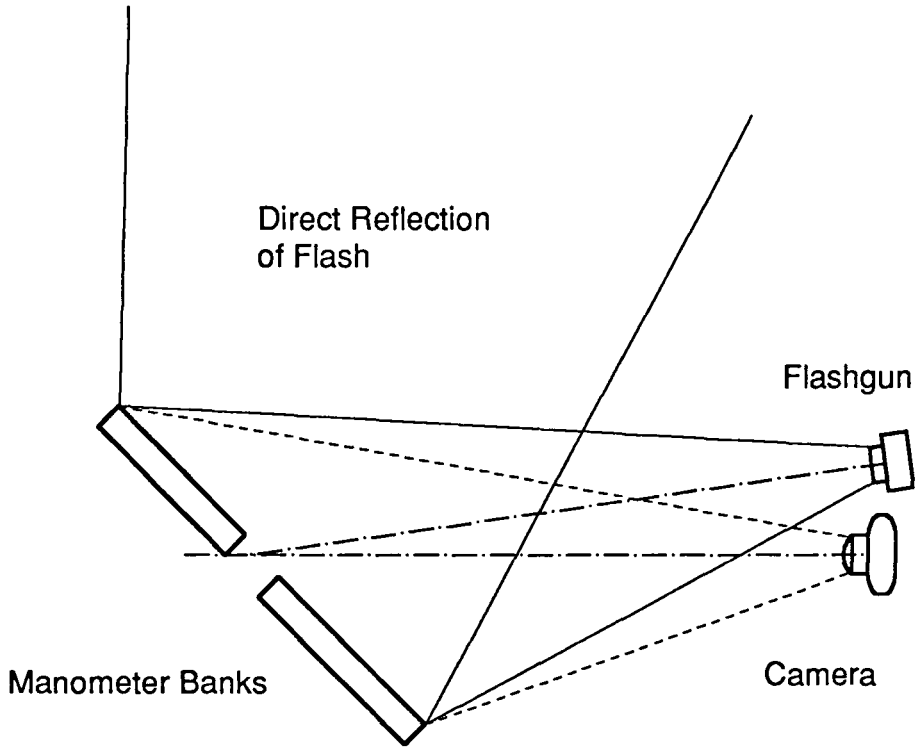


Figure 6.3. Flare Model Surface Flow Visulation Photography Layout



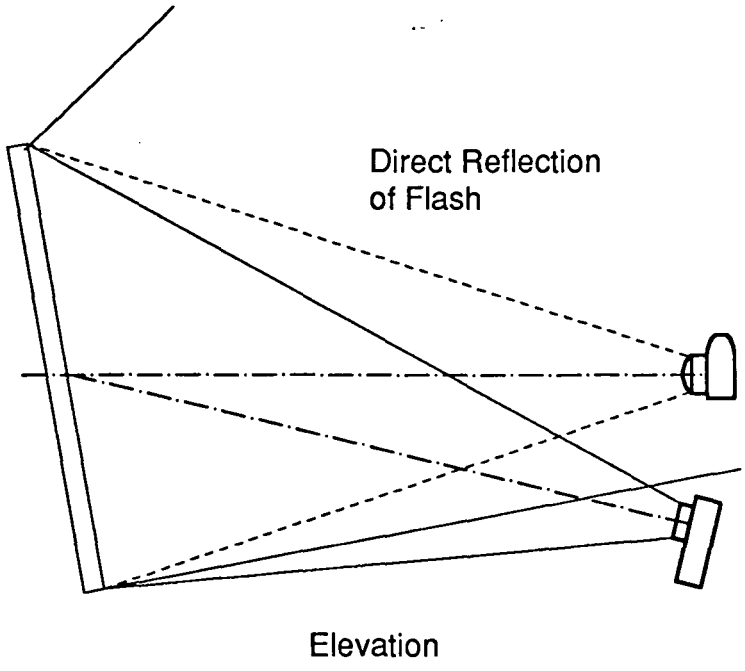


Figure 6.4. Manometer Tube Photography

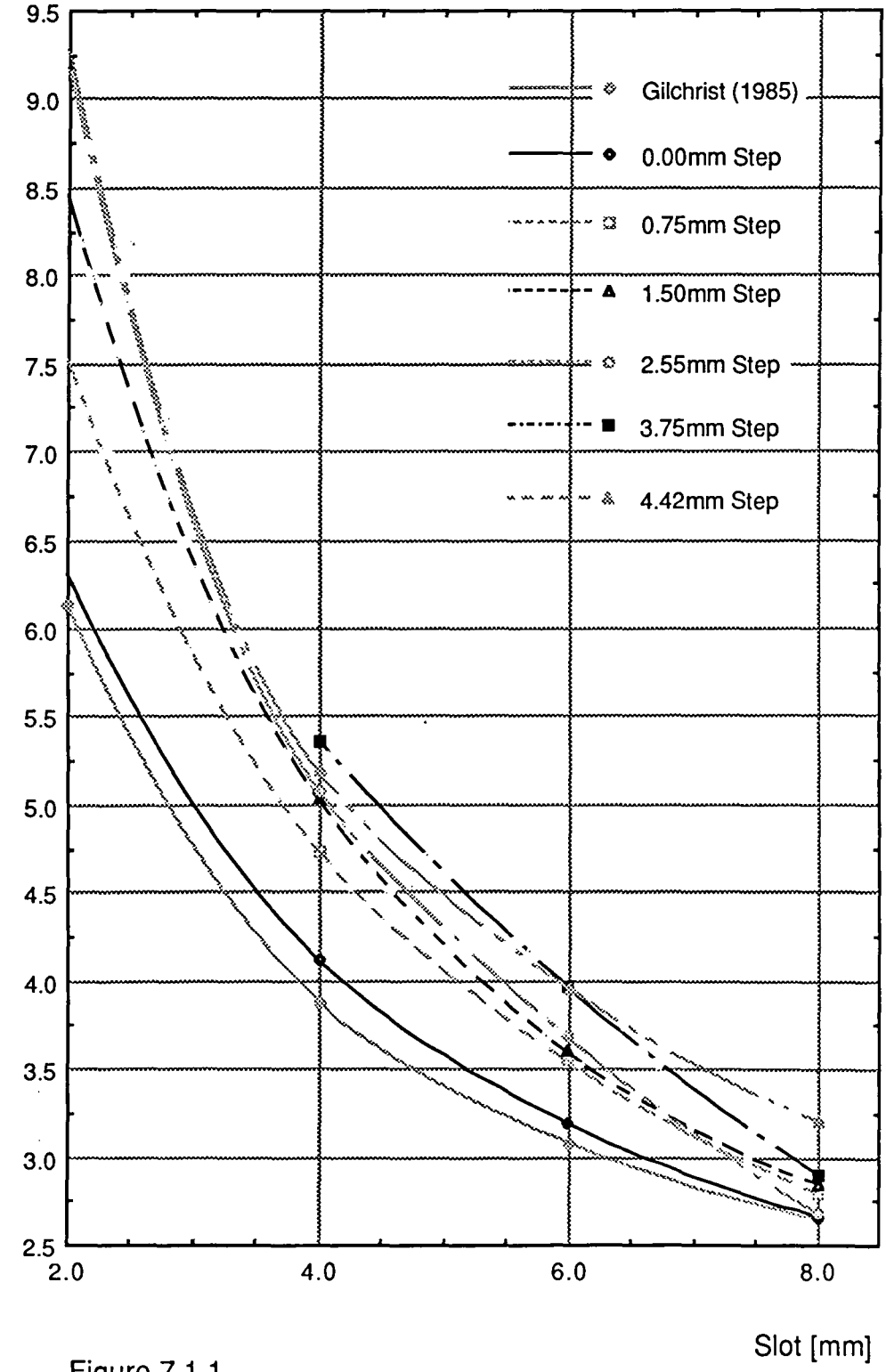


Figure 7.1.1.

Planar Coanda Model
Breakaway Behaviour

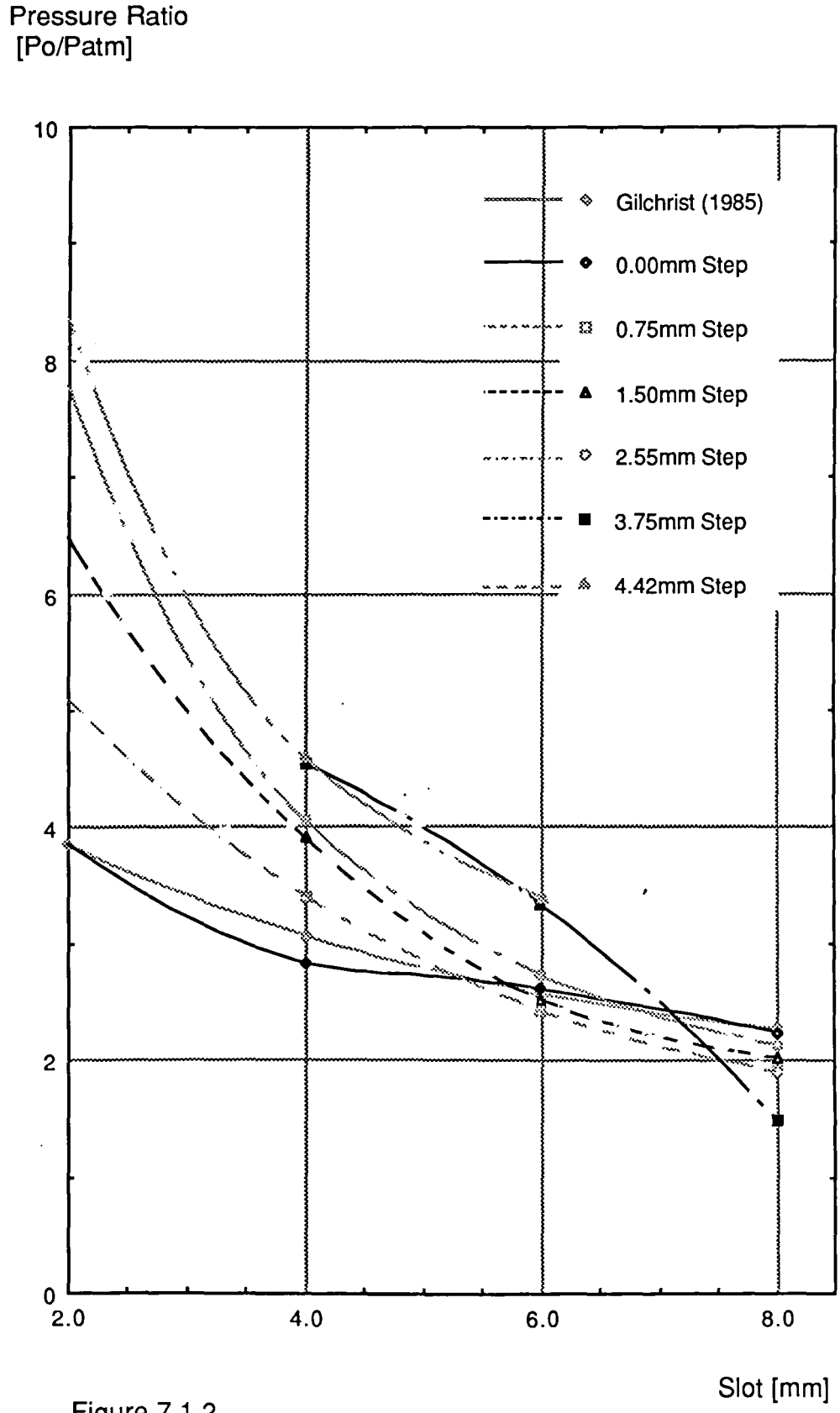


Figure 7.1.2.

Planar Coanda Model
Reversion Behaviour

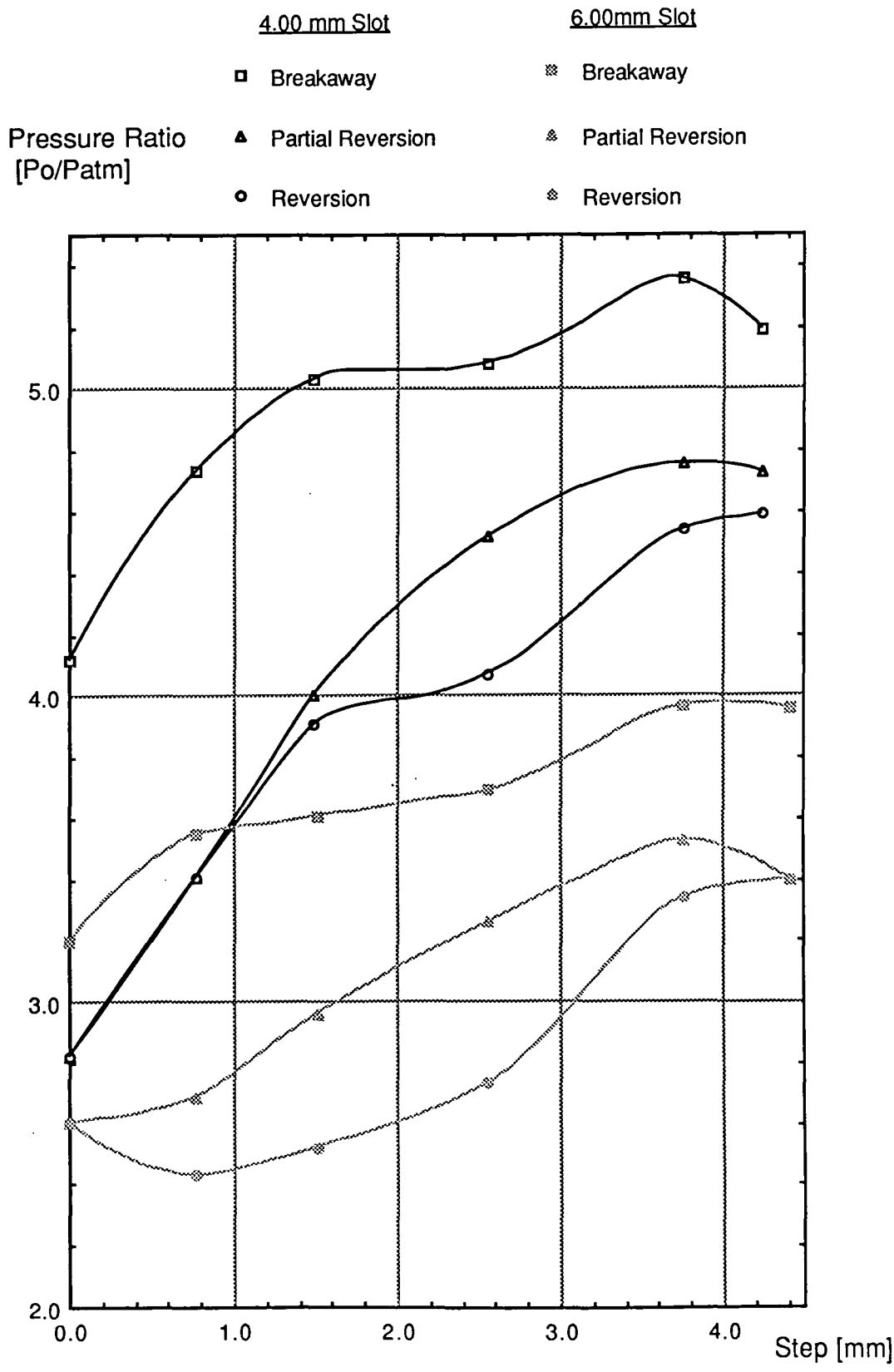


Figure 7.1.3.

Planar Coanda Model
Partial Reversion Behaviour

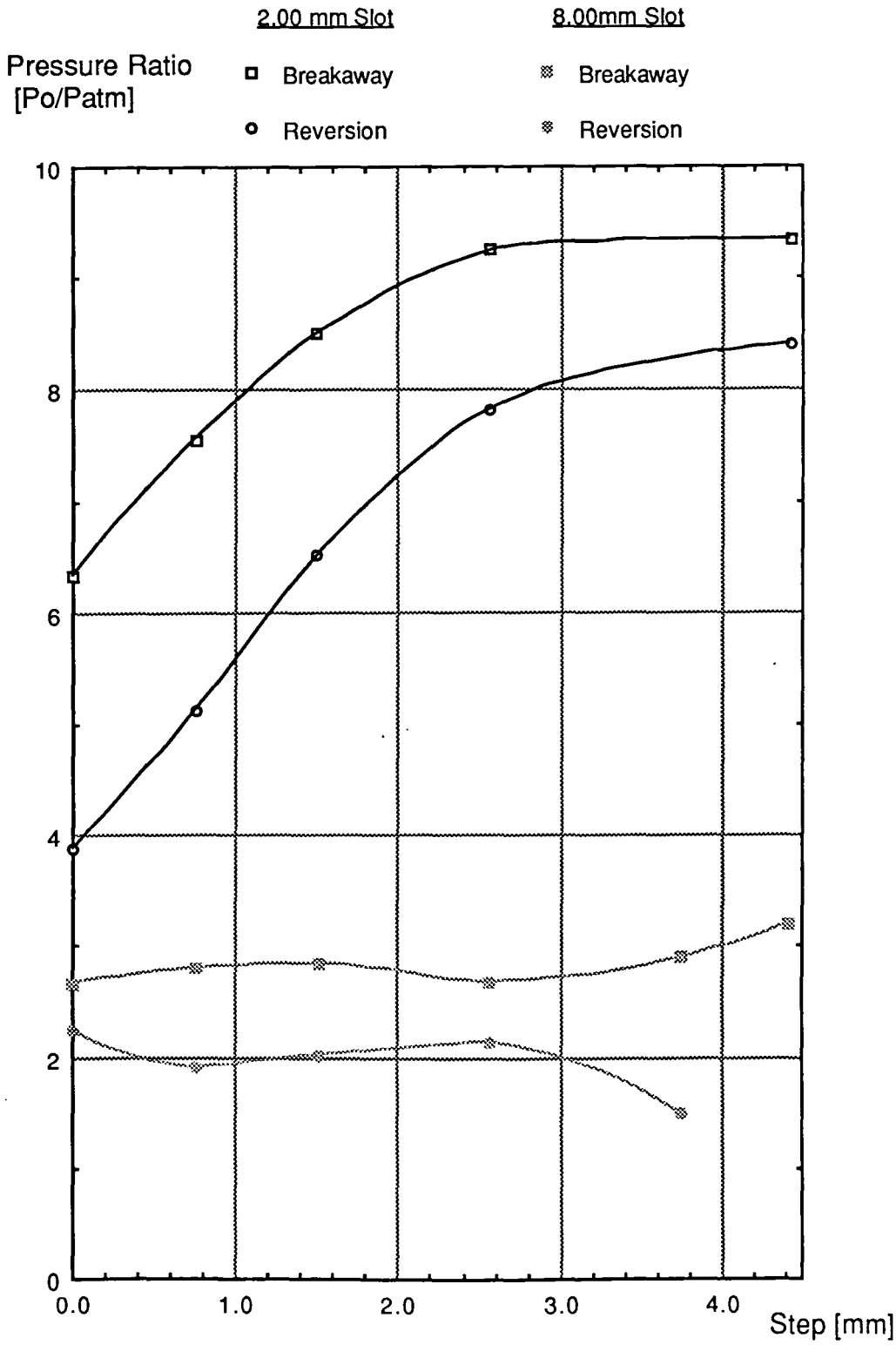


Figure 7.1.4.

Planar Coanda Model
Breakaway/Reversion Behaviour

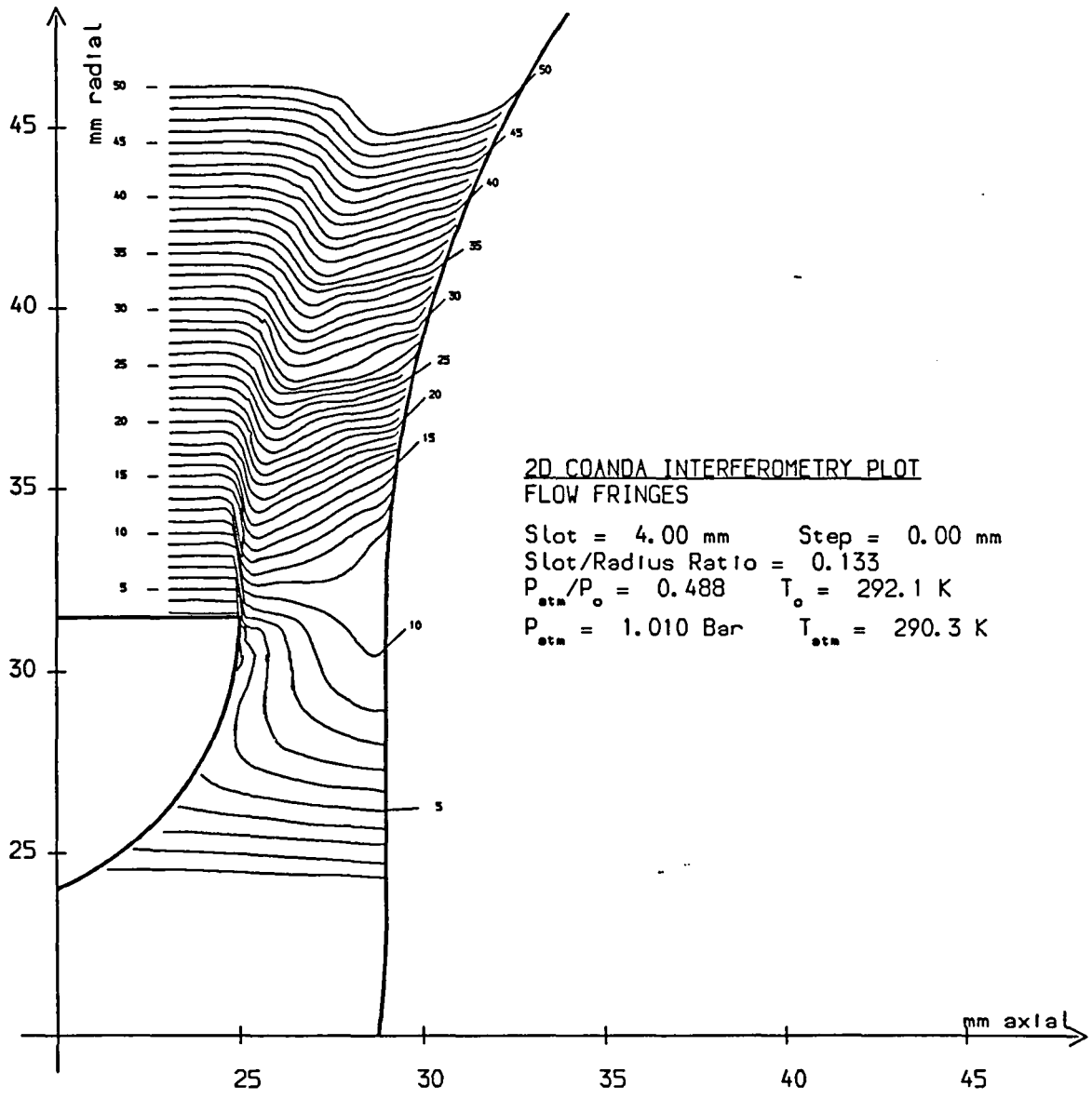


Figure 7.1.5 Interferometry Fringe Pattern -- Choking Conditions

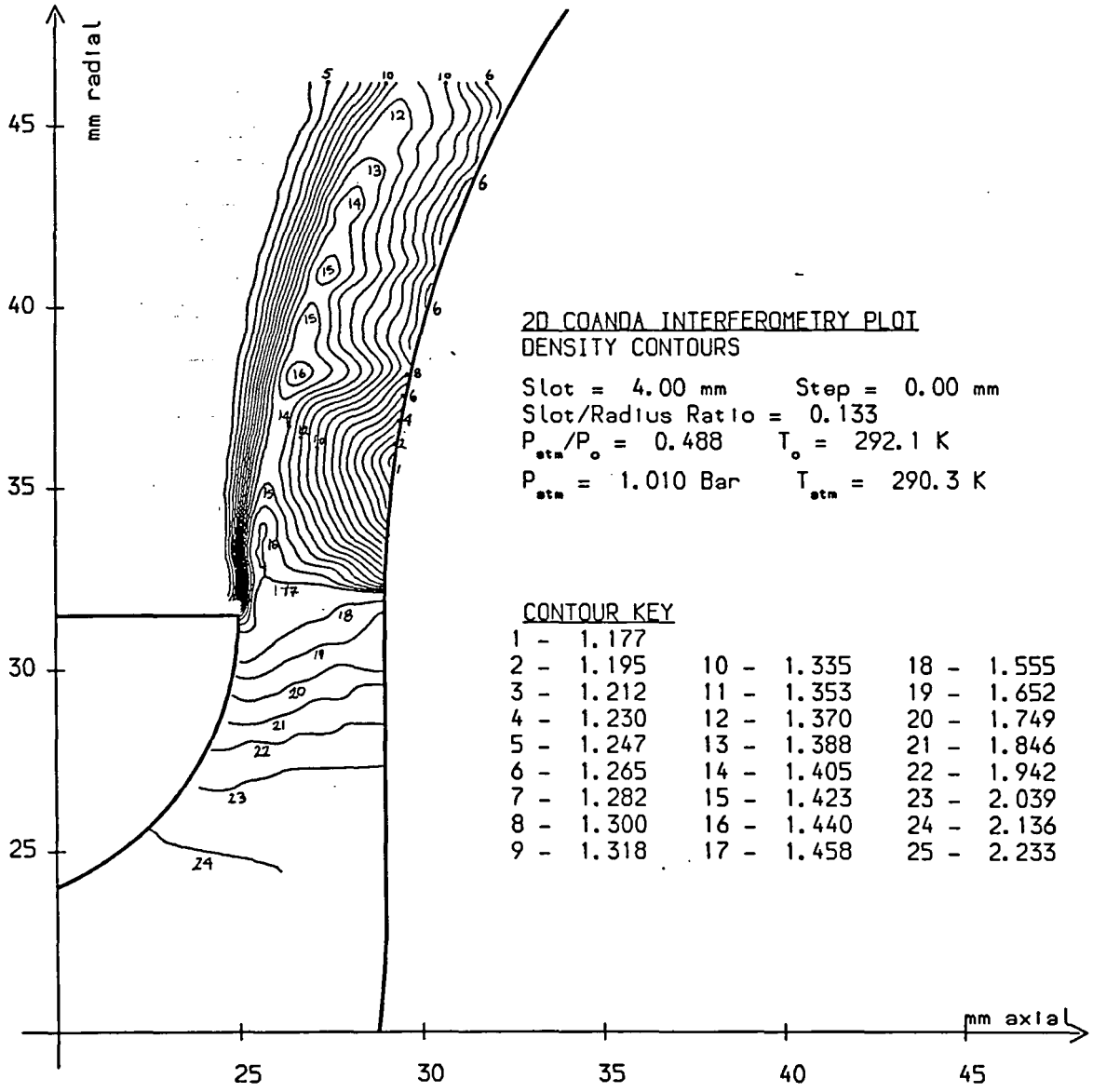


Figure 7.1.6 Interferometry Density Contours -- Choking Conditions

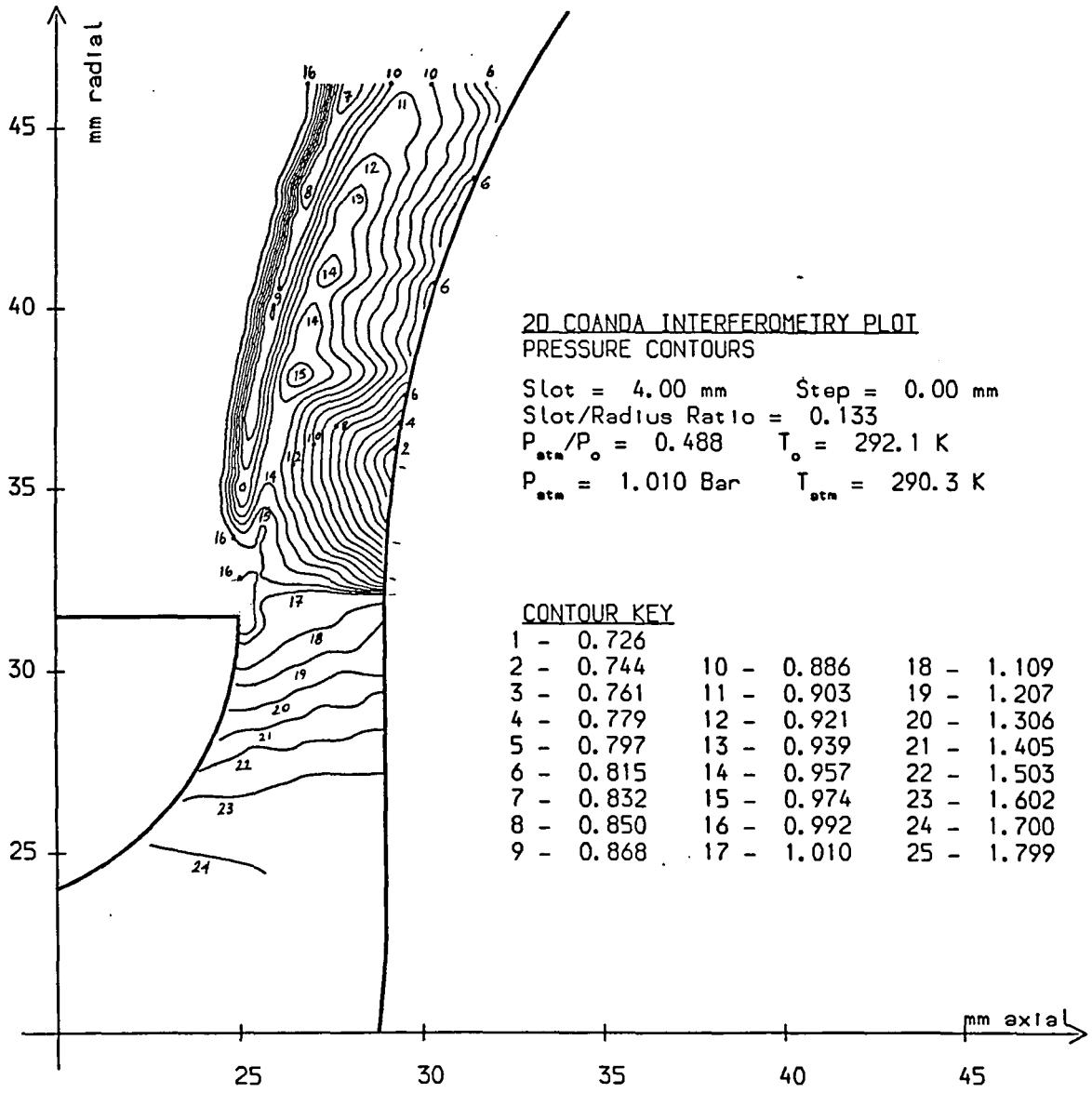


Figure 7.1.7 Interferometry Pressure Contours -- Choking Conditions

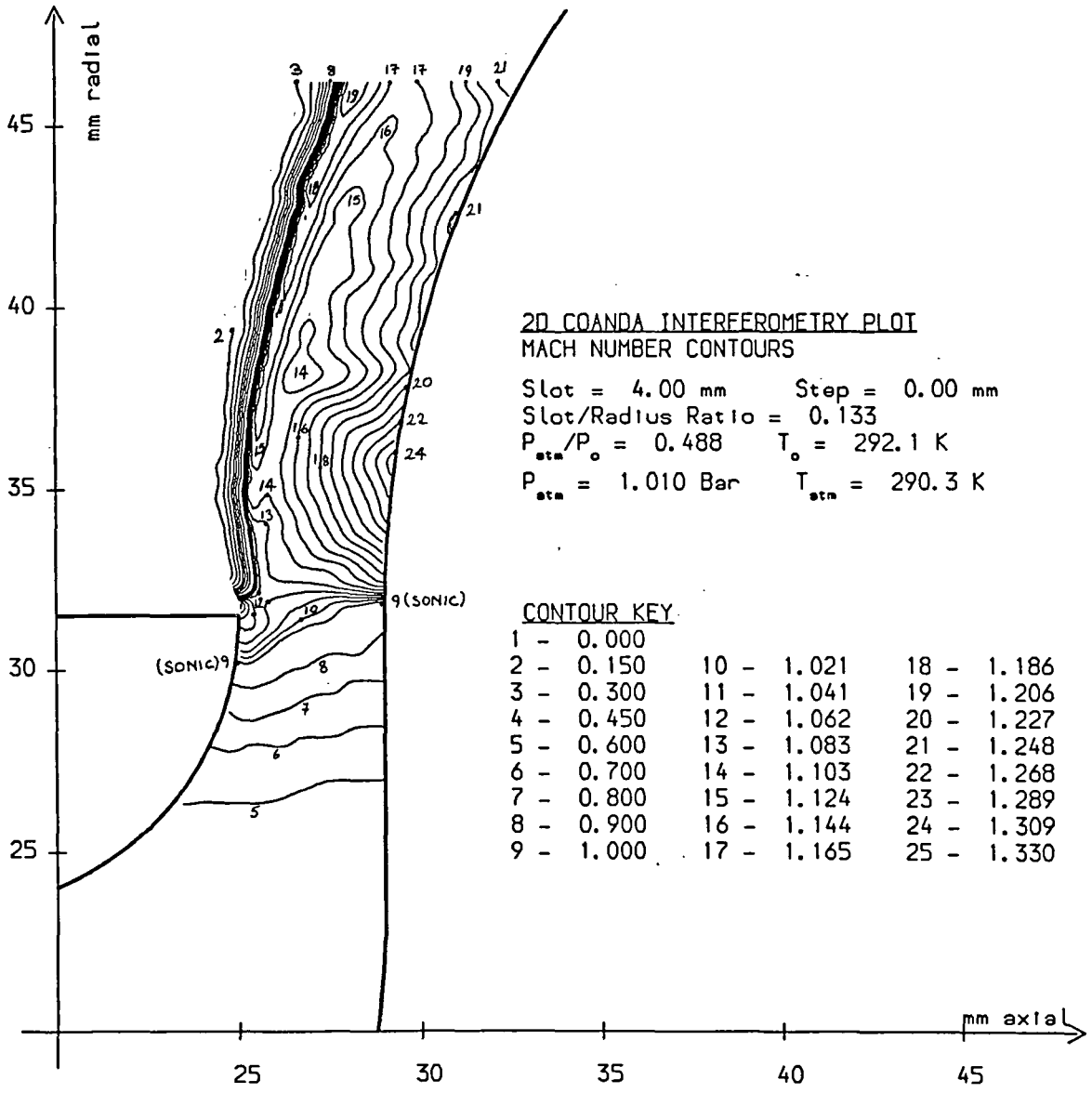


Figure 7.1.8 Interferometry Mach Number Contours -- Choking Conditions

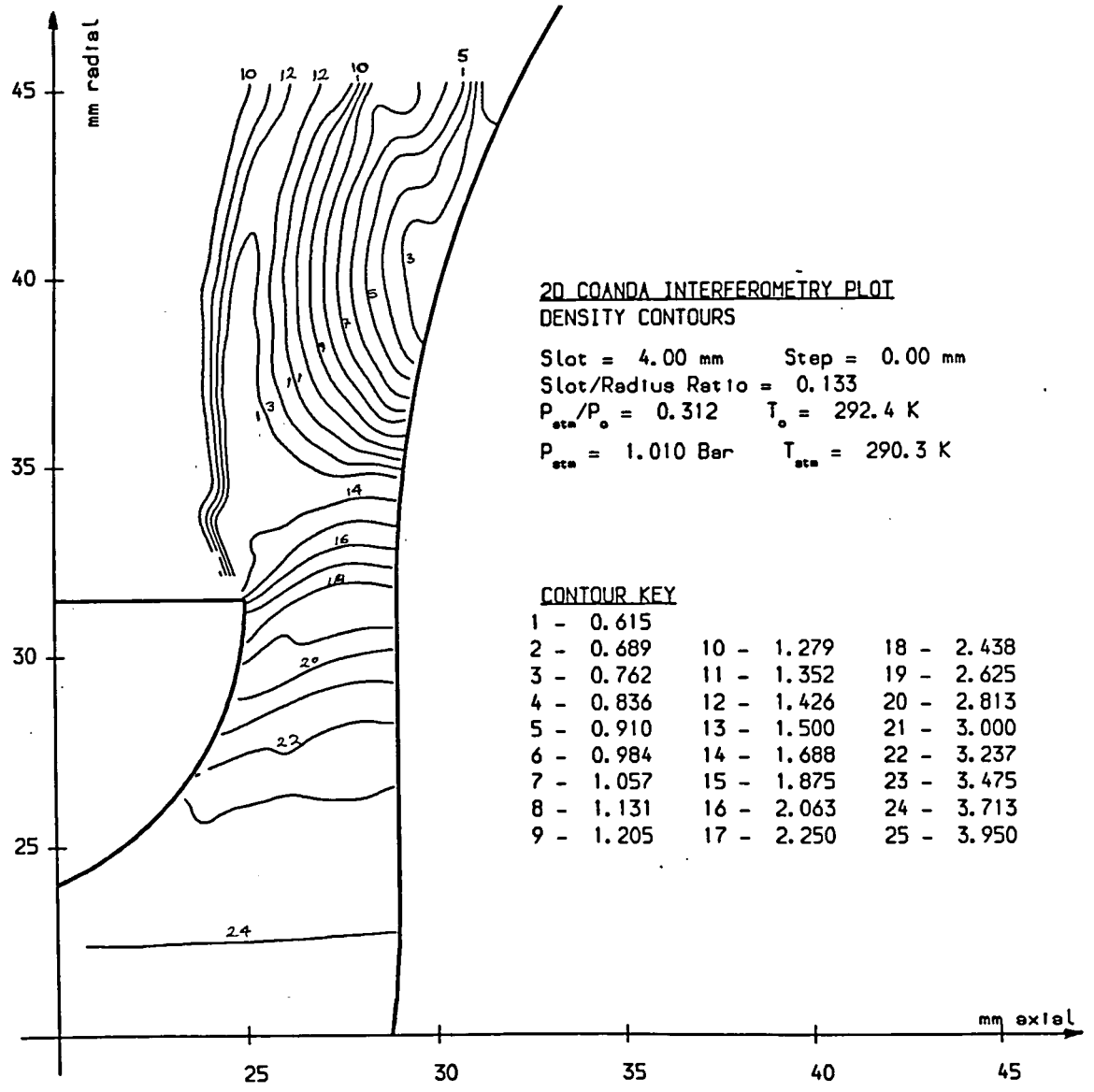


Figure 7.1.9 Interferometry Density Contours -- Underexpanding Conditions

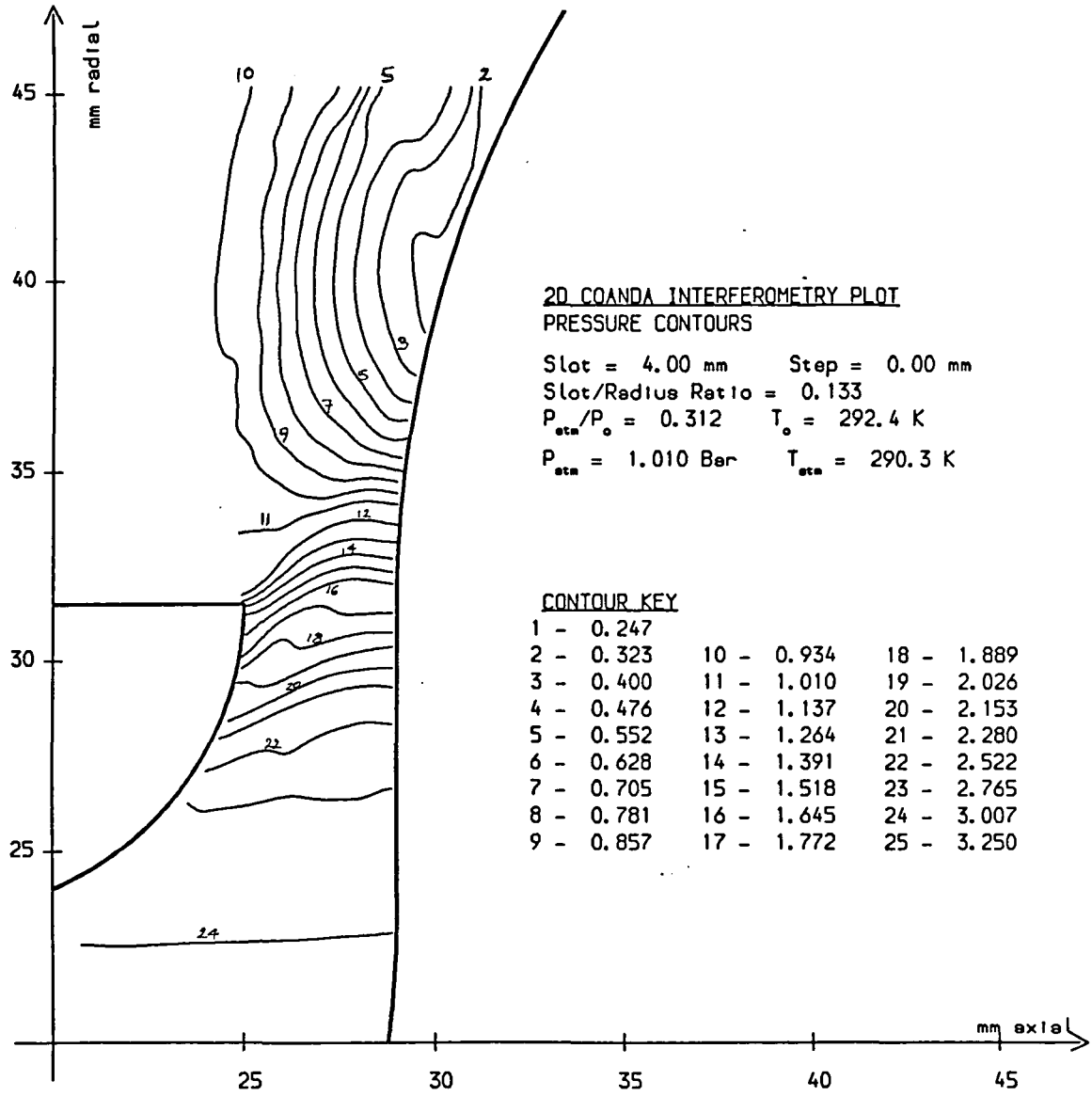


Figure 7.1.10 Interferometry Pressure Contours -- Underexpanding Conditions

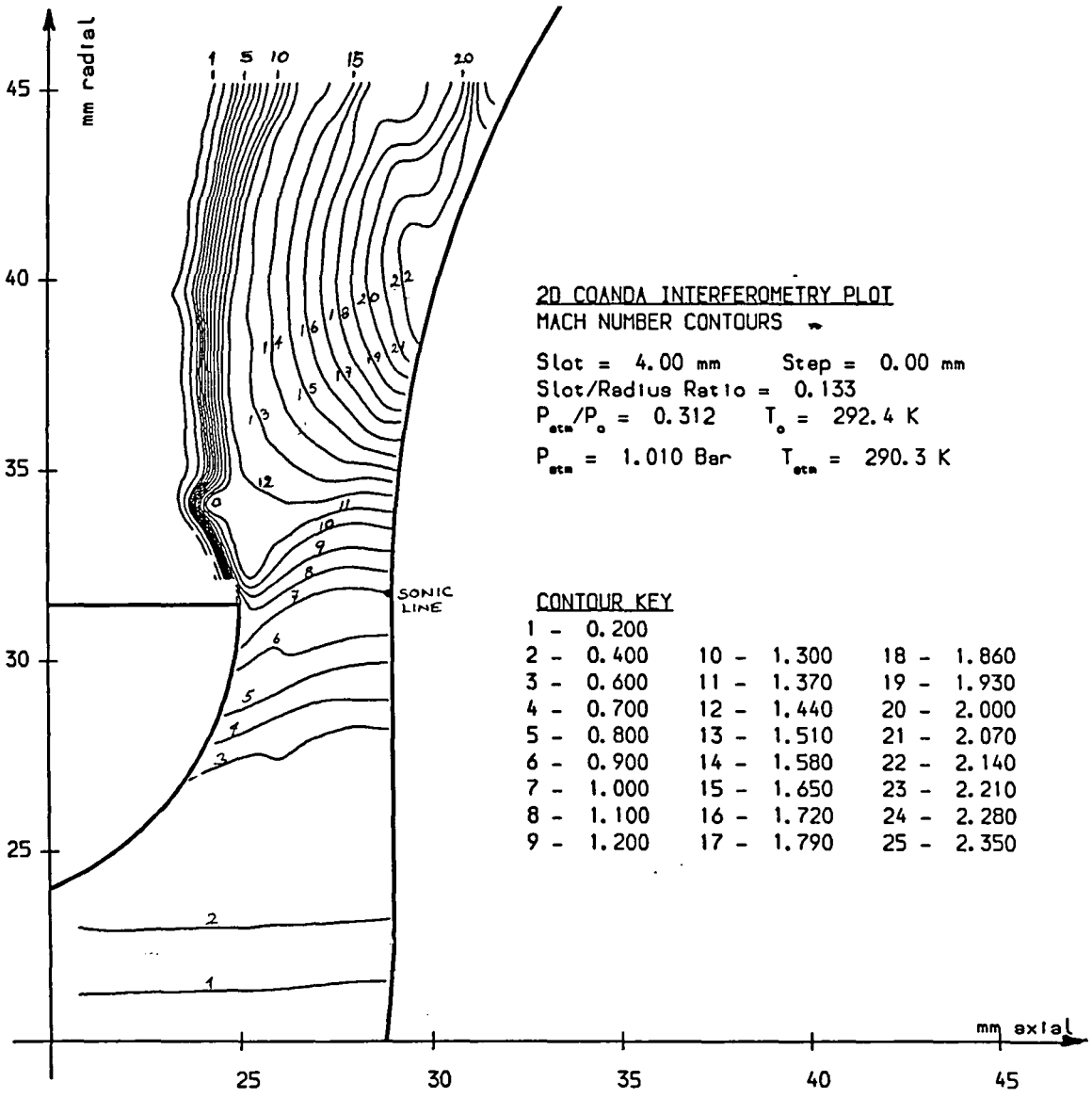


Figure 7.1.11 Interferometry Mach Number Contours -- Underexpanding Conditions

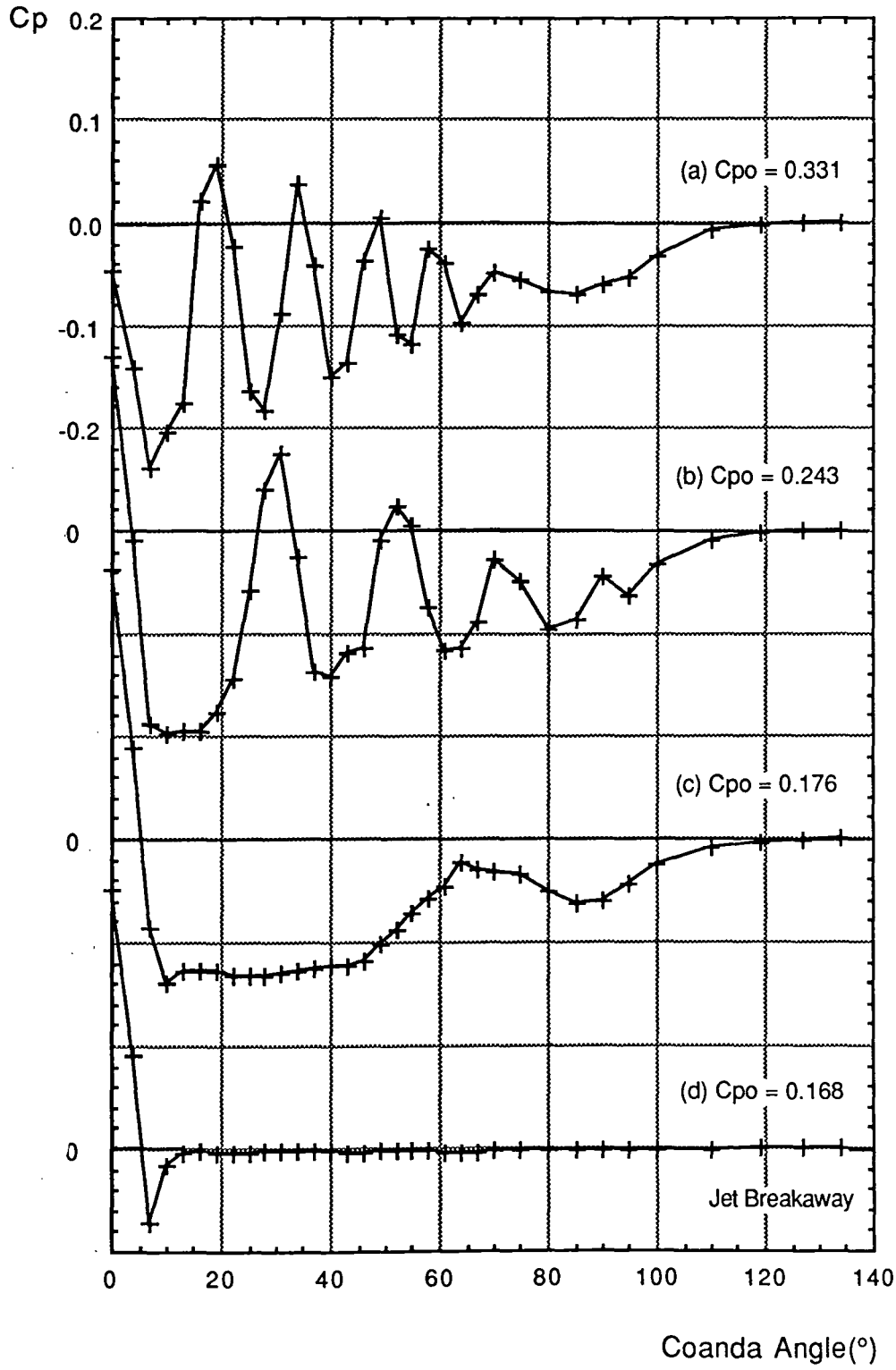


Figure 7.1.12.

Planar Coanda Model
Experimental Surface Pressures

Slot = 2.00 mm; Step = 0.00 mm

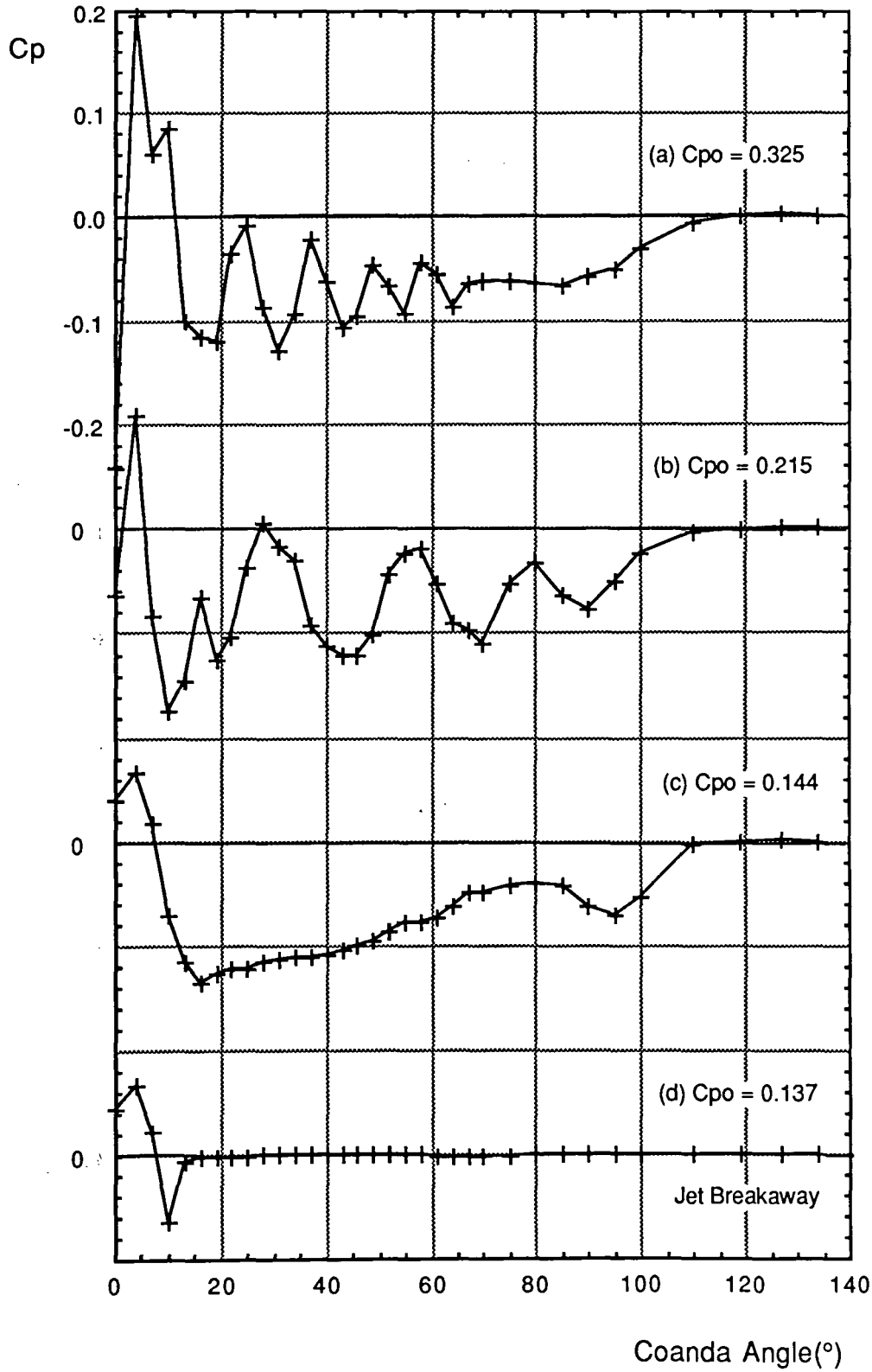


Figure 7.1.13.

Planar Coanda Model
Experimental Surface Pressures

Slot = 2.00 mm; Step = 0.75 mm

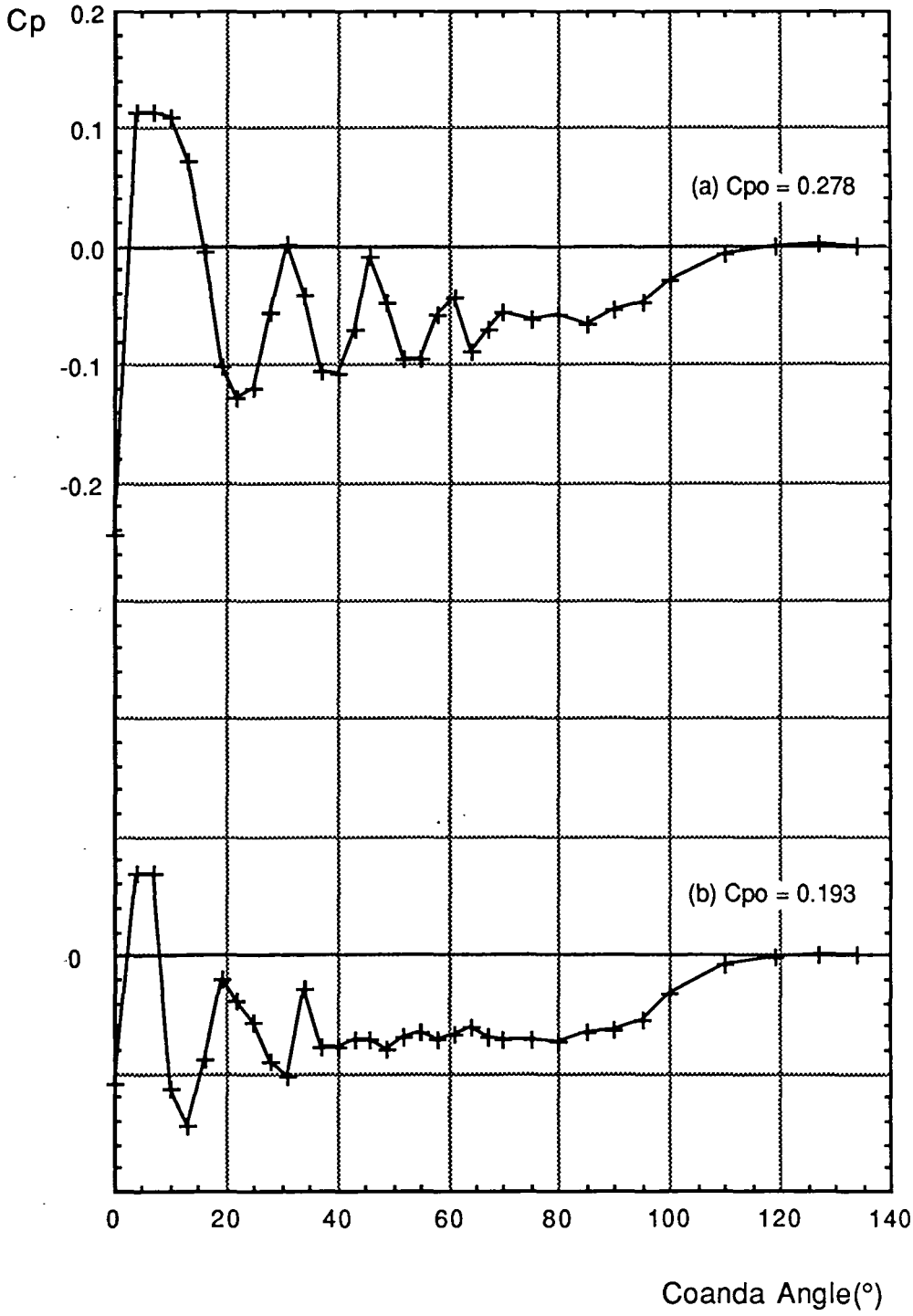


Figure 7. 1.14.

Planar Coanda Model
Experimental Surface Pressures

Slot = 2.00 mm; Step = 1.50 mm

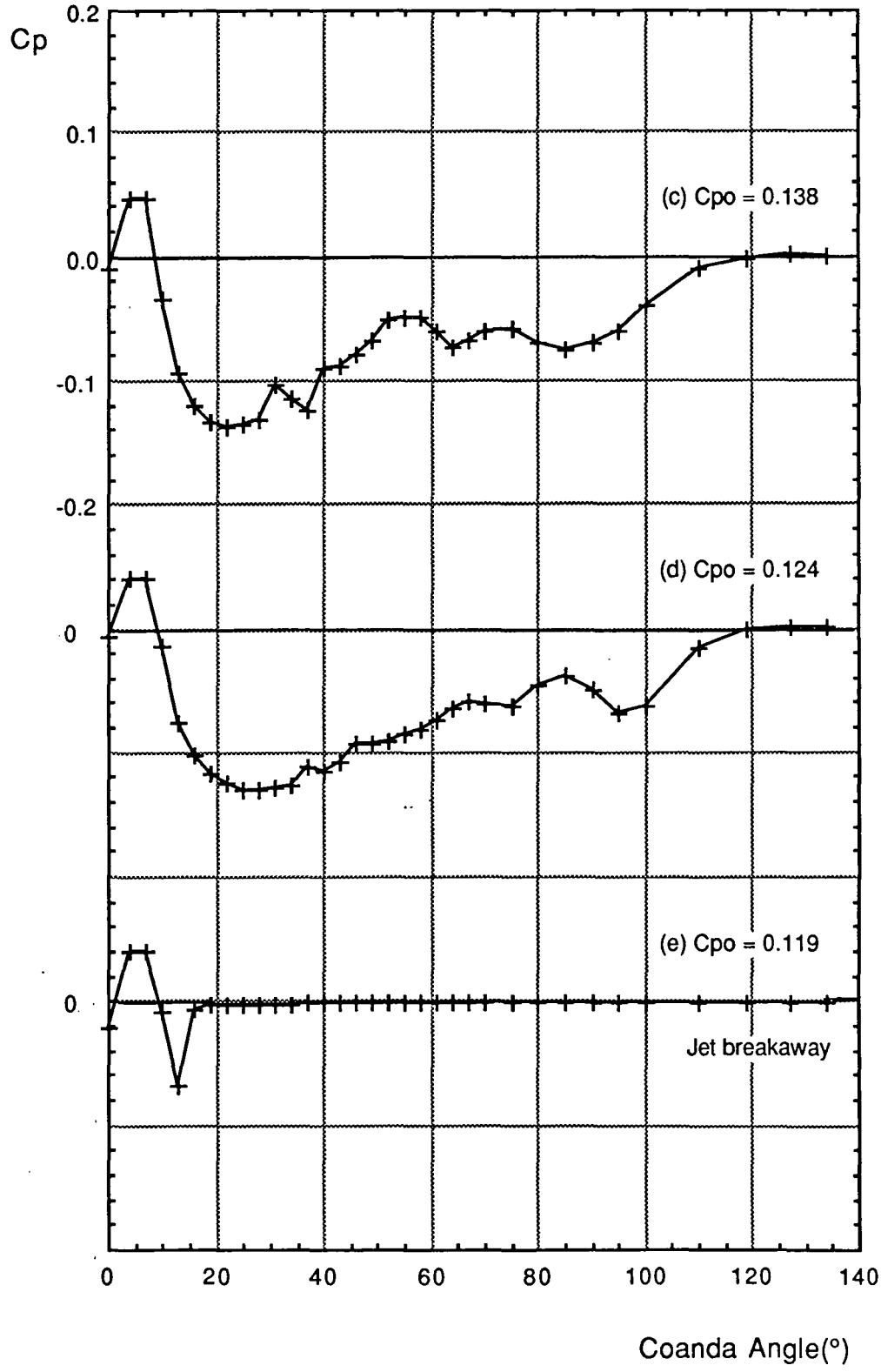


Figure 7. 1.15.

Planar Coanda Model
Experimental Surface Pressures

Slot = 2.00 mm; Step = 1.50 mm

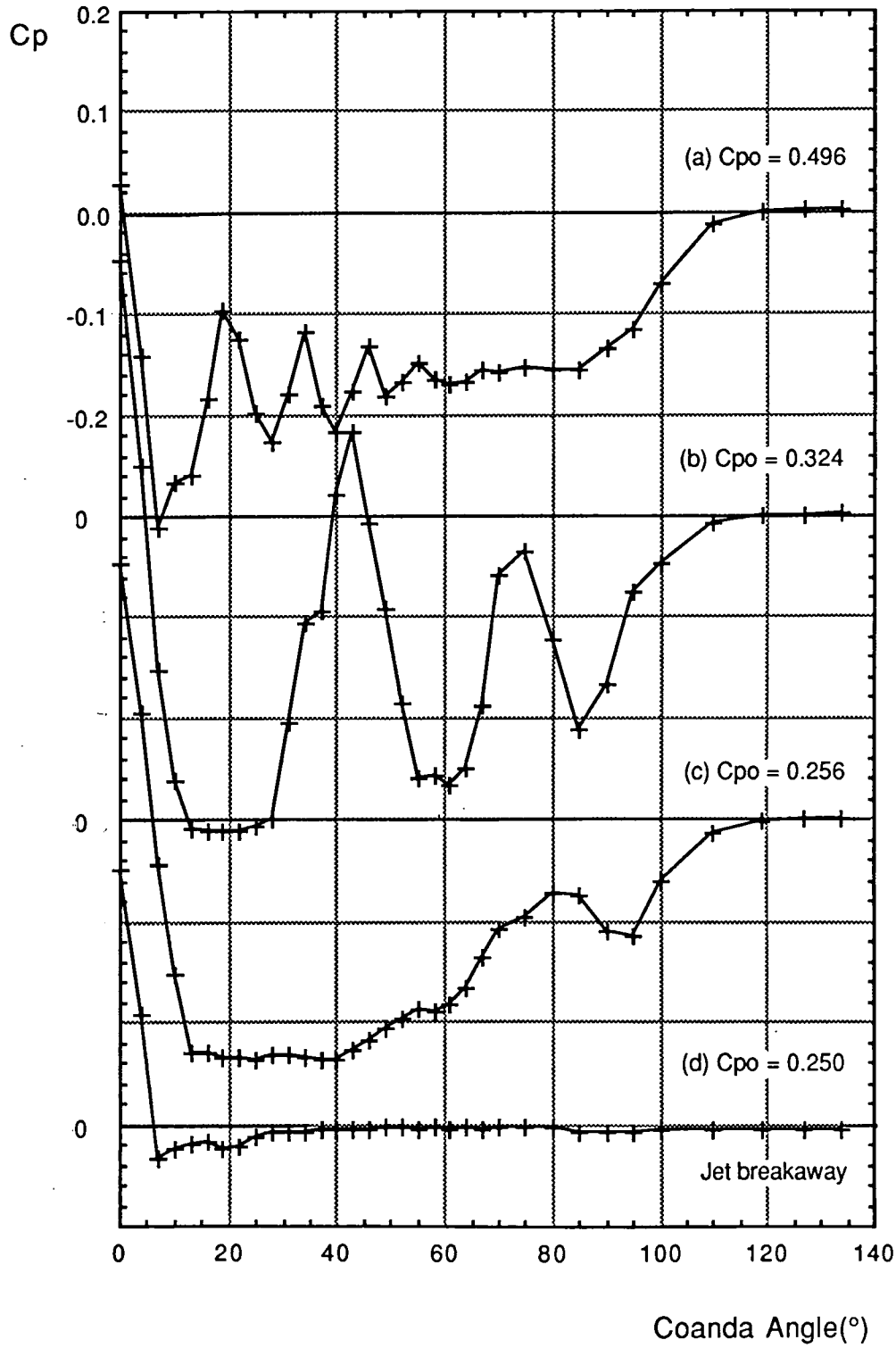


Figure 7. 1.16.

Planar Coanda Model
Experimental Surface Pressures

Slot = 4.00 mm; Step = 0.00 mm

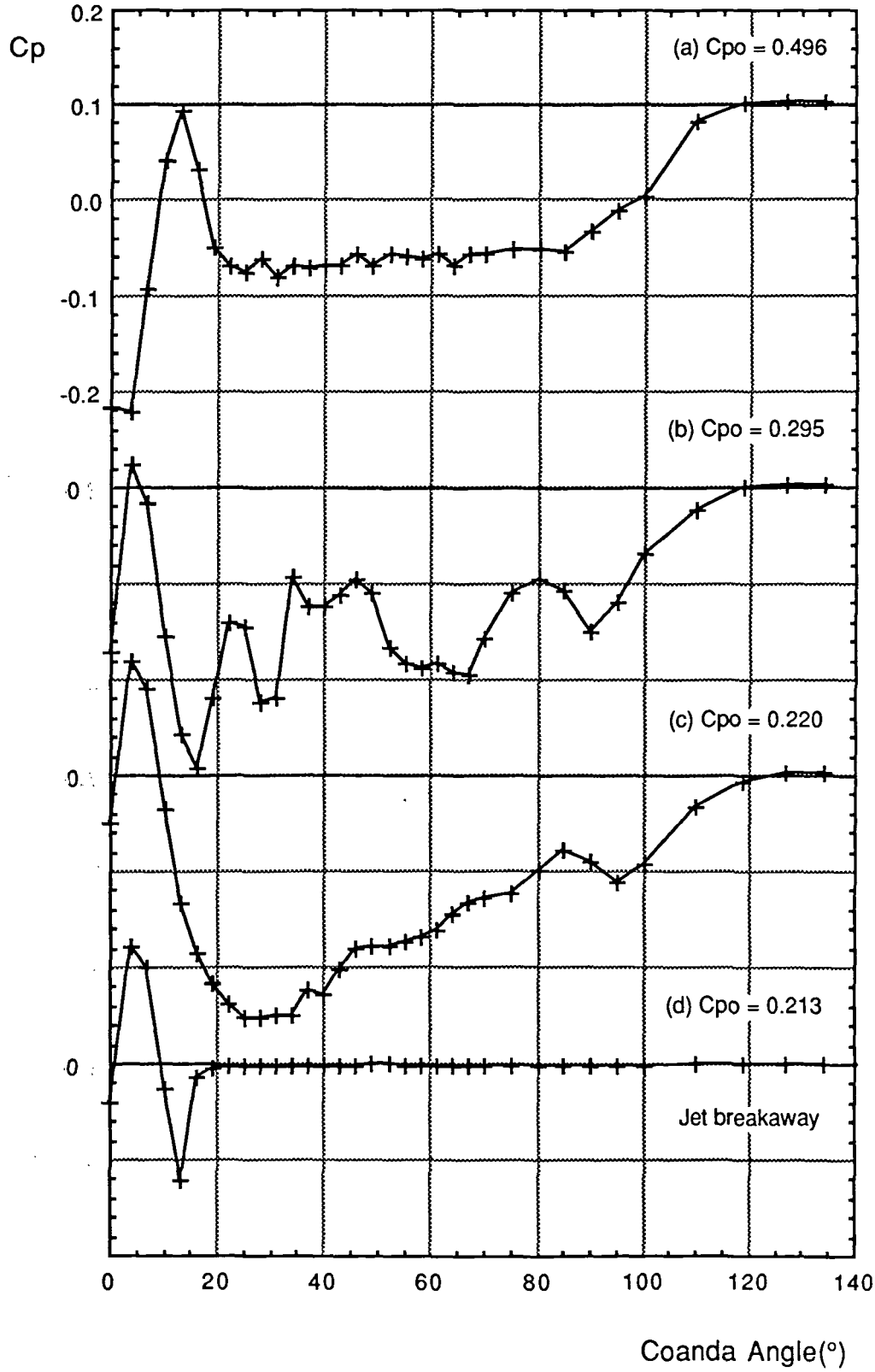


Figure 7.1.17.

Planar Coanda Model
Experimental Surface Pressures

Slot = 4.00 mm; Step = 0.75 mm

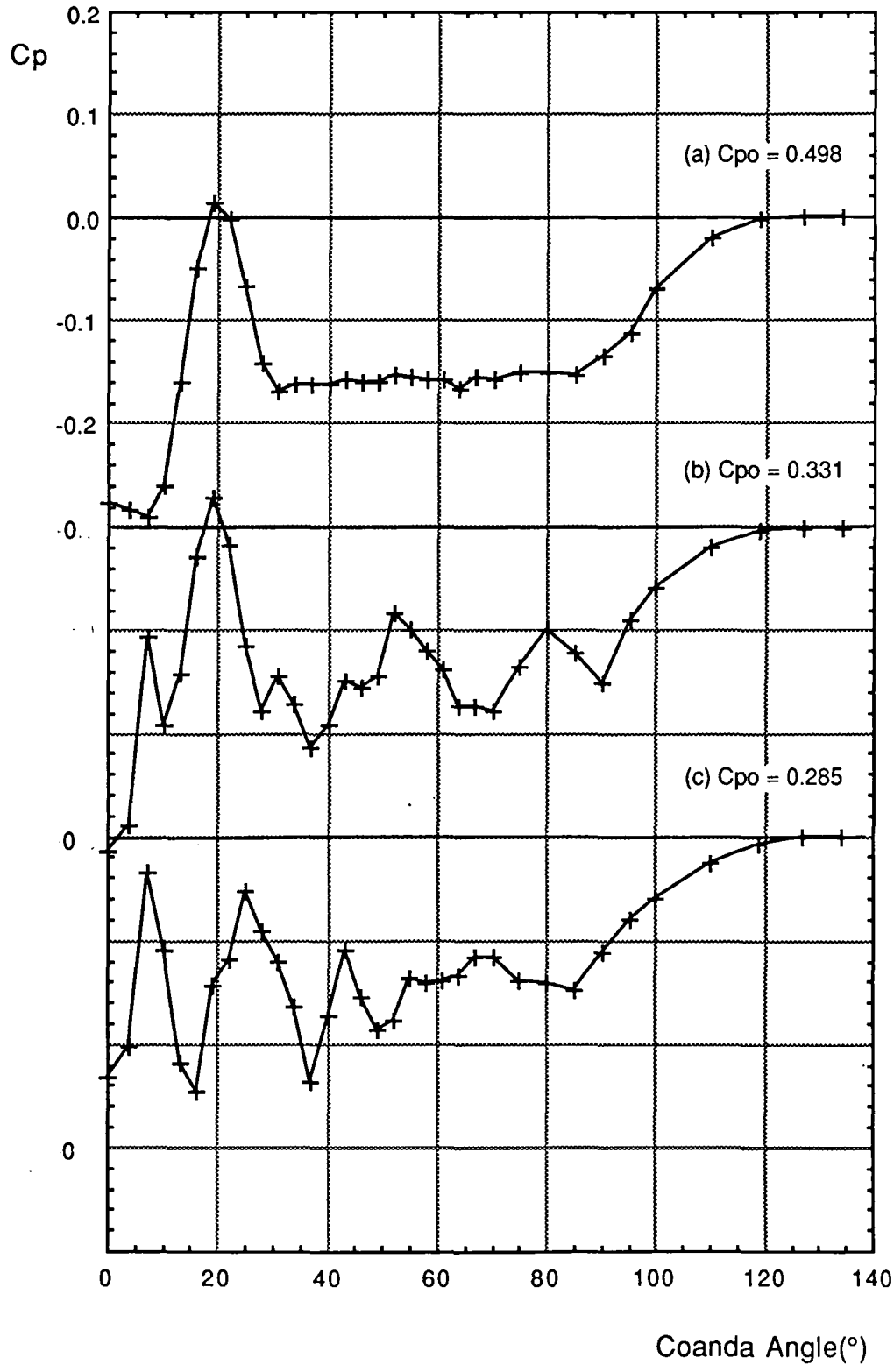


Figure 7.1.18.

Planar Coanda Model
Experimental Surface Pressures

Slot = 4.00 mm; Step = 1.50 mm

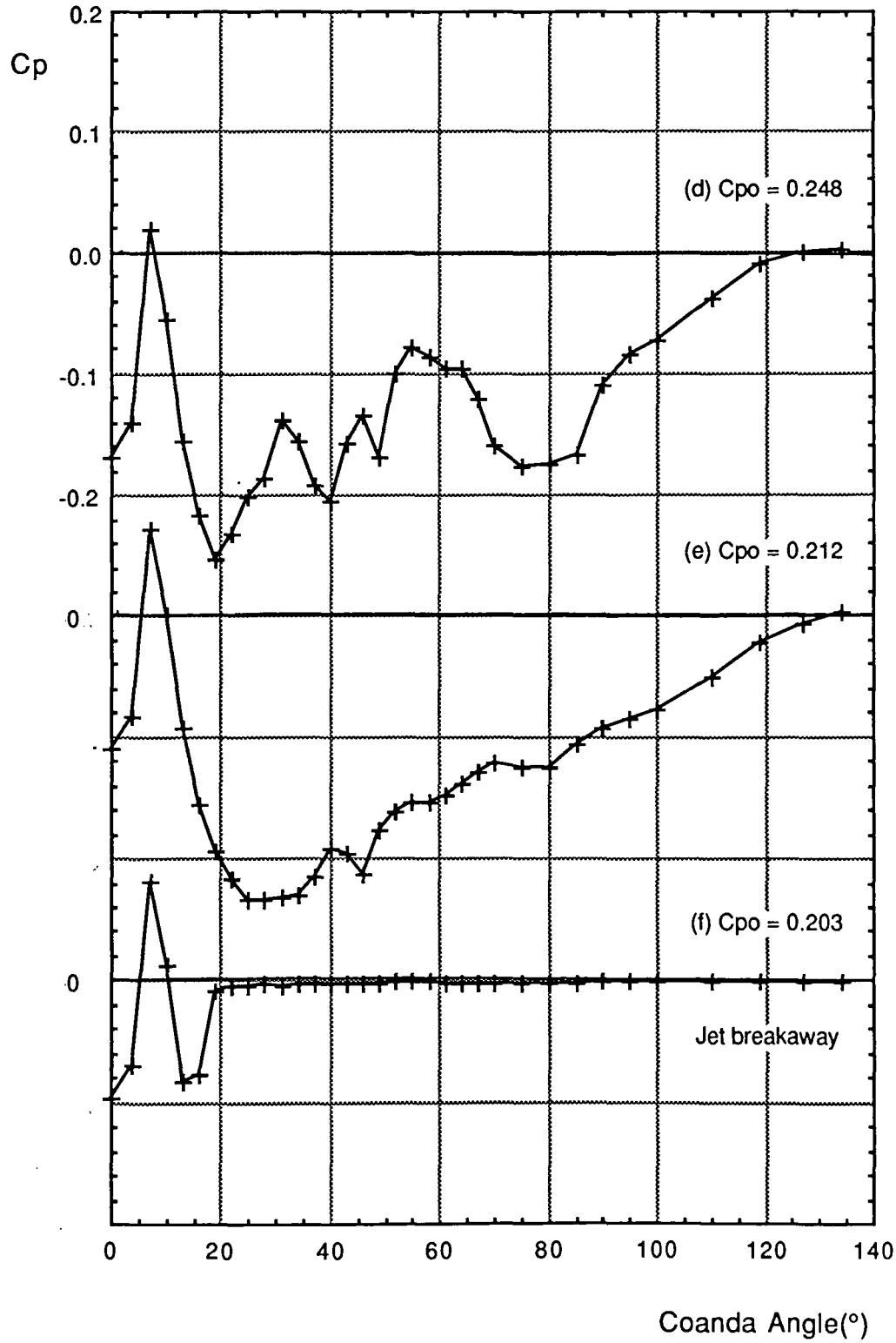


Figure 7.1.19.

Planar Coanda Model
Experimental Surface Pressures

Slot = 4.00 mm; Step = 1.50 mm

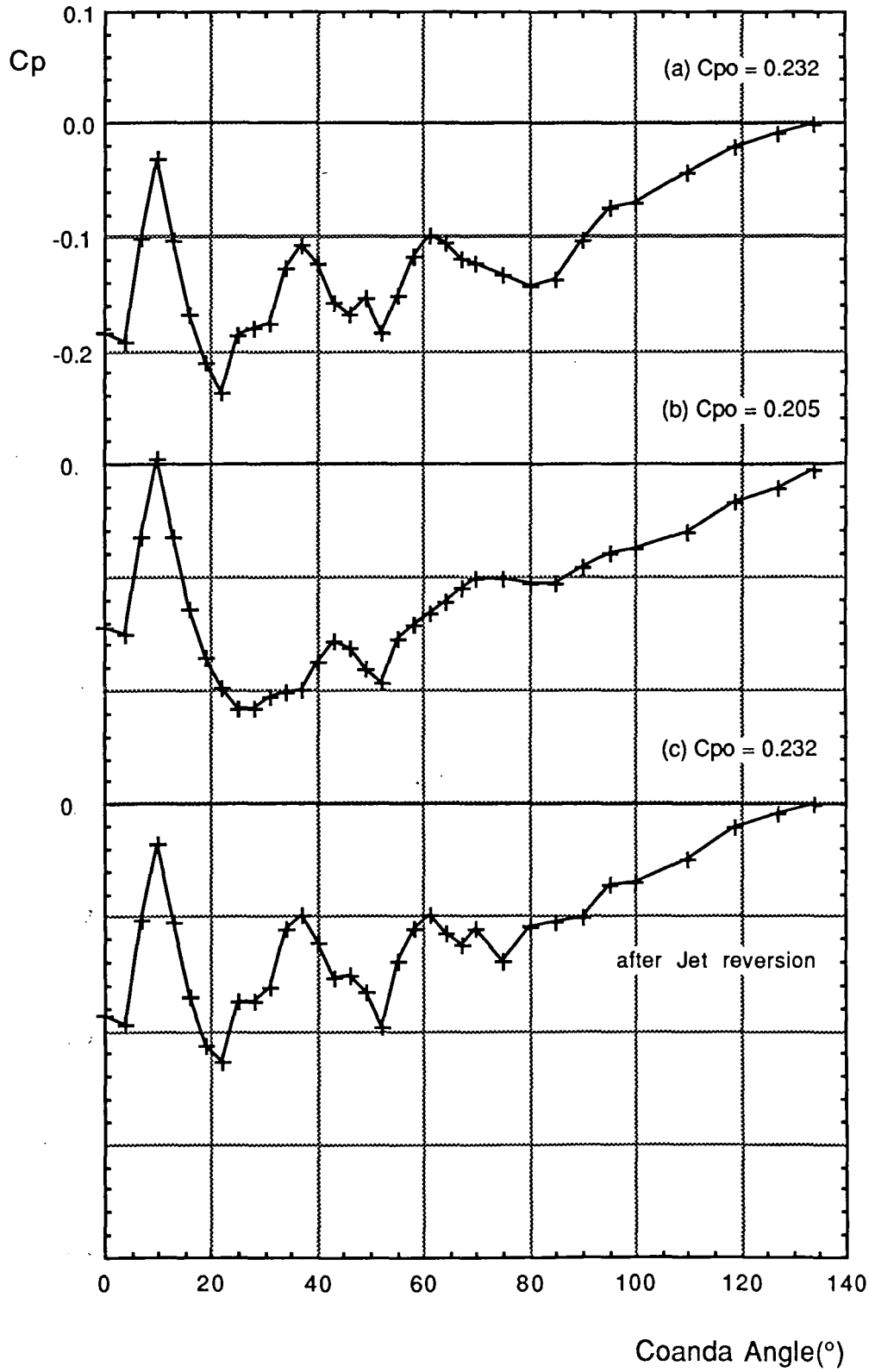


Figure 7.1.20.

Planar Coanda Model
Experimental Surface Pressures

Slot = 4.00 mm; Step = 2.55 mm

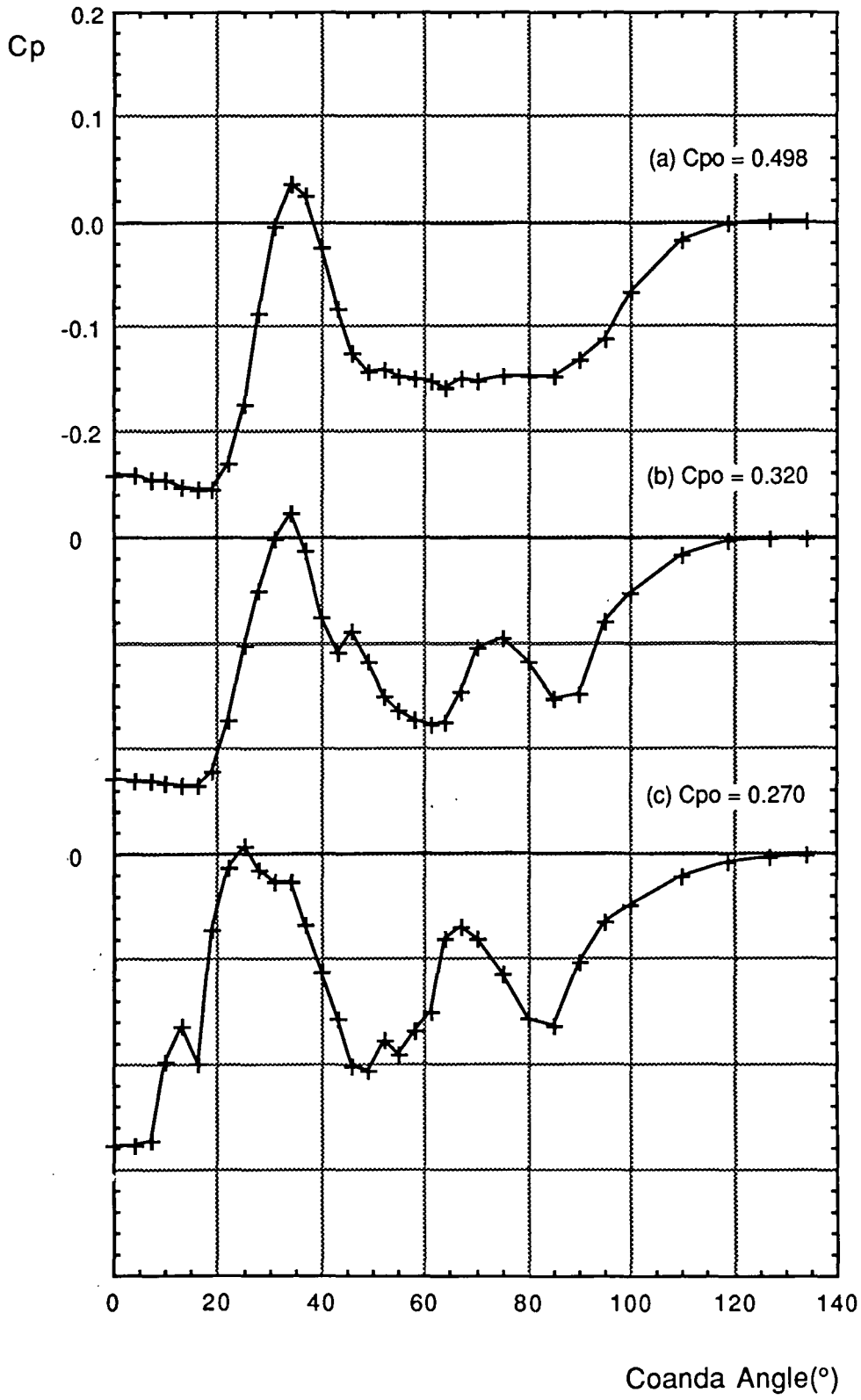


Figure 7.1.21.

Planar Coanda Model
Experimental Surface Pressures

Slot = 4.00 mm; Step = 3.76 mm

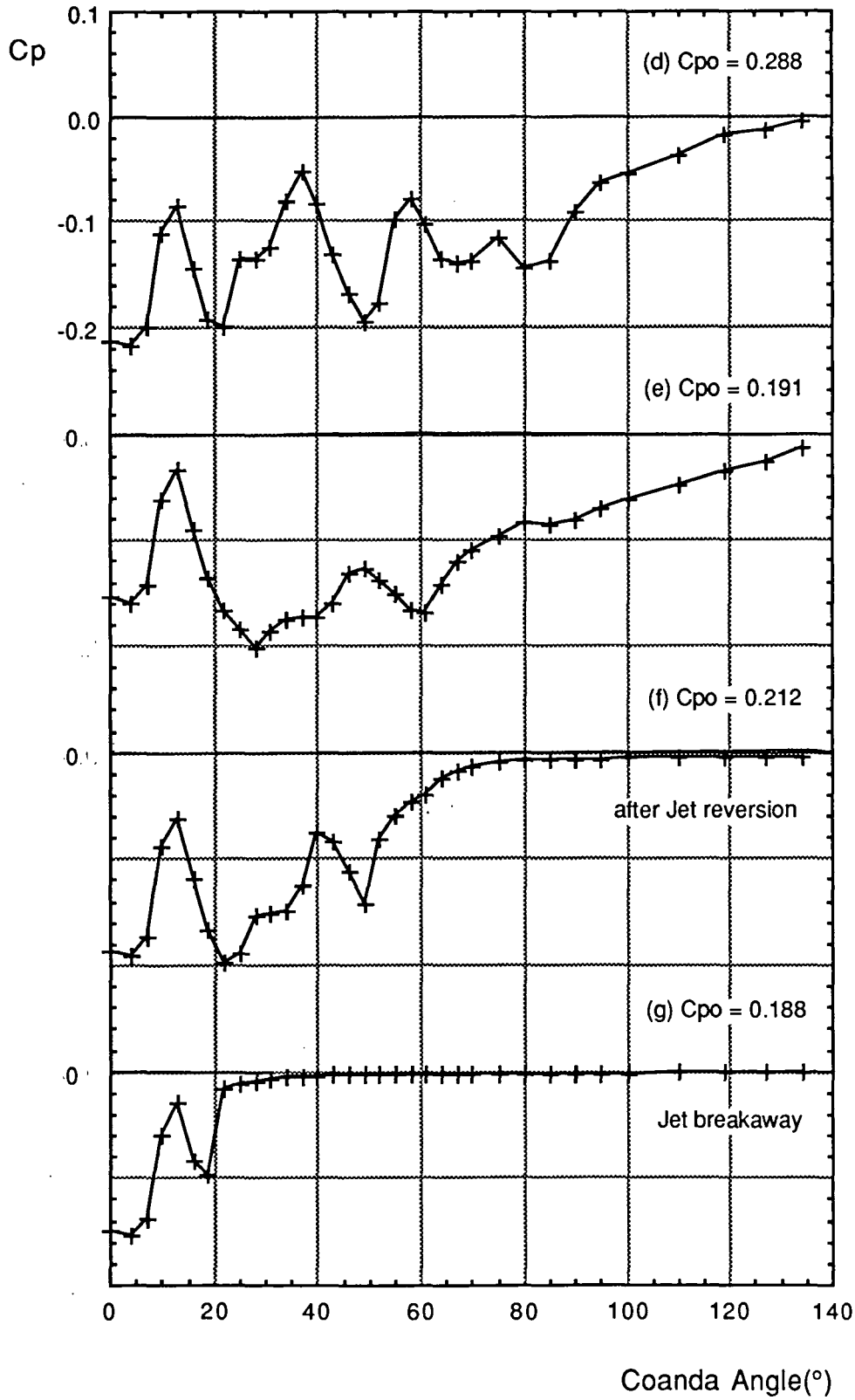


Figure 7.1.22.

Planar Coanda Model
Experimental Surface Pressures

Slot = 4.00 mm; Step = 3.76 mm

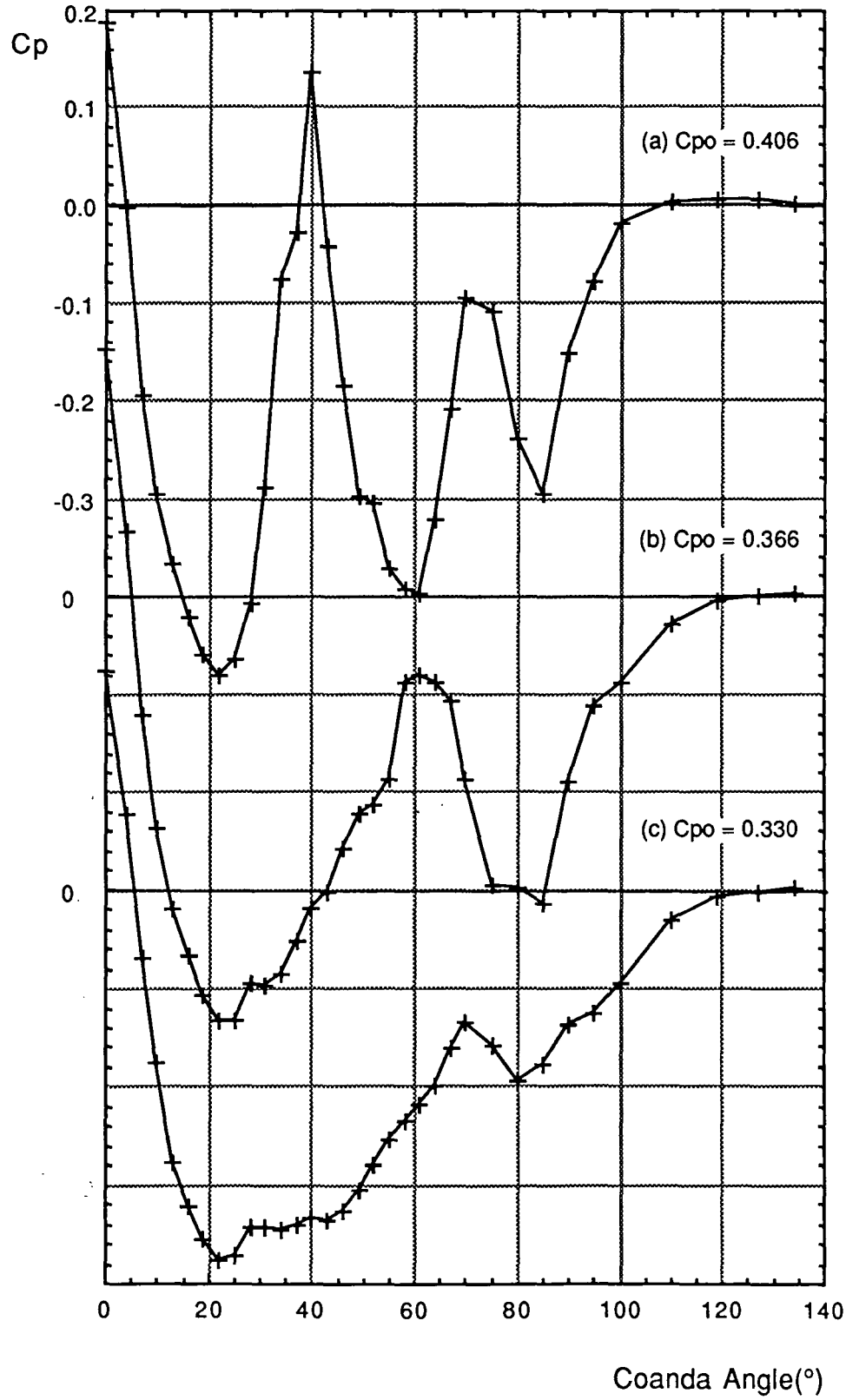


Figure 7.1.23.

Planar Coanda Model
Experimental Surface Pressures

Slot = 6.00 mm; Step = 0.00 mm

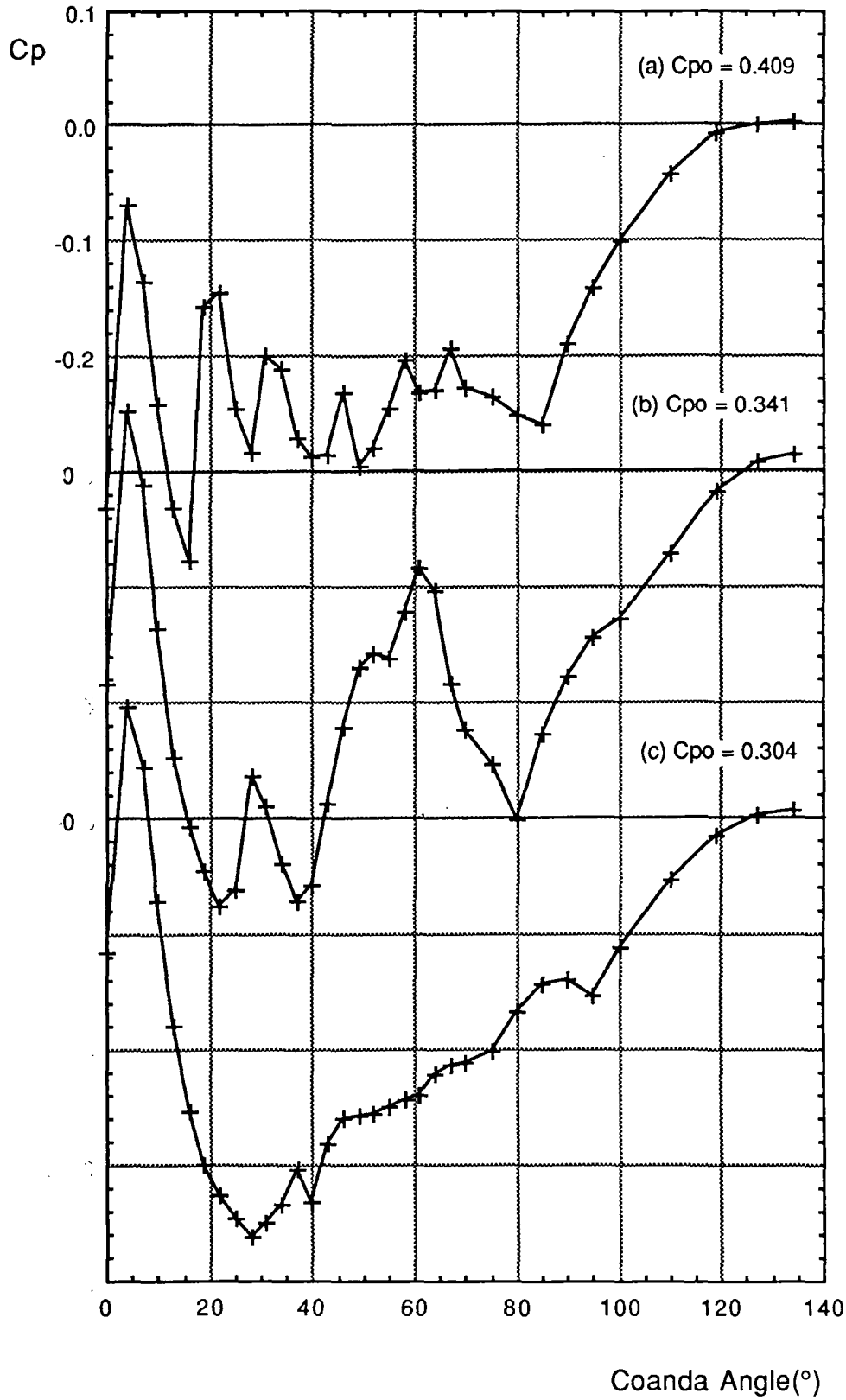


Figure 7.1.24.

Planar Coanda Model
Experimental Surface Pressures

Slot = 6.00 mm; Step = 0.75 mm

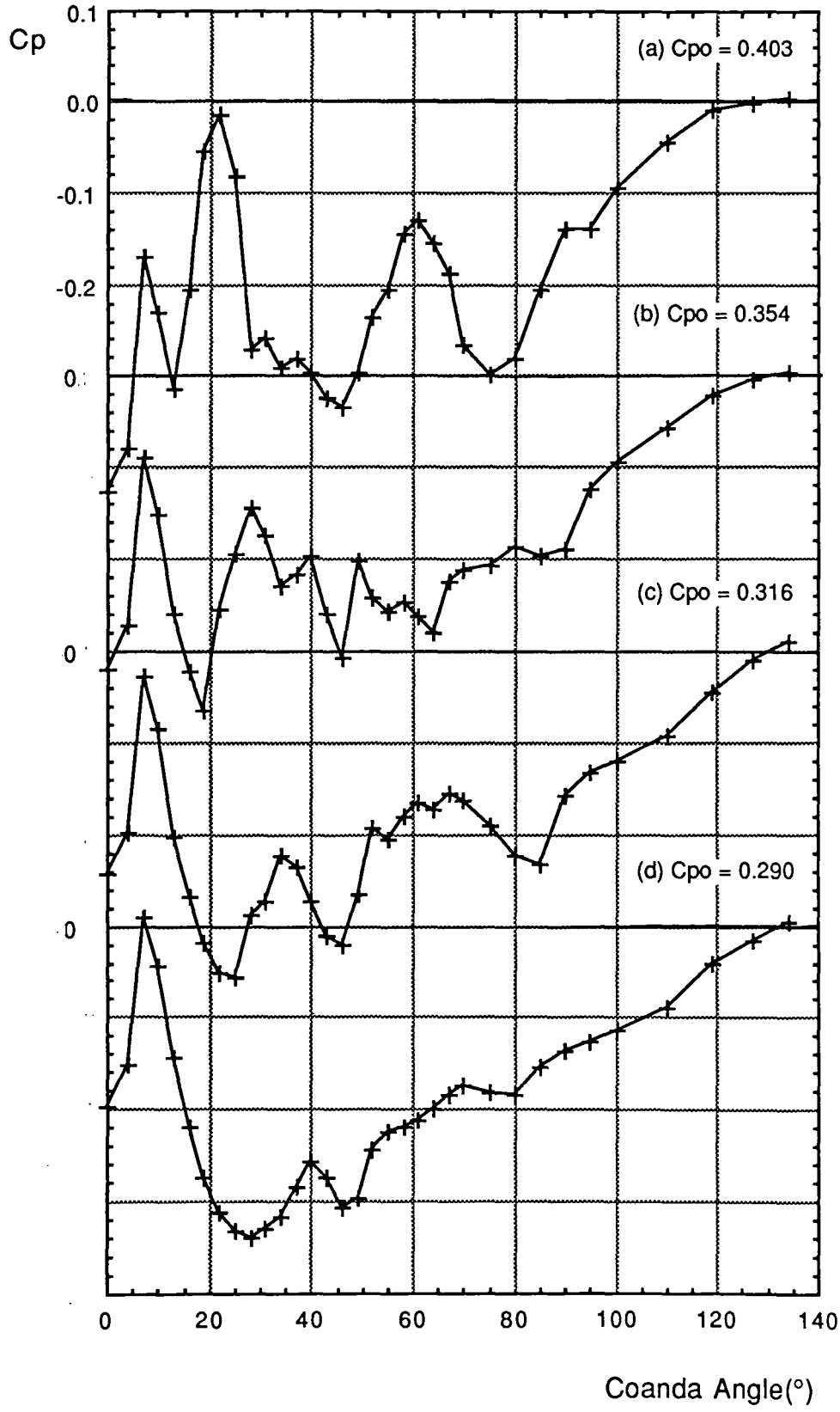


Figure 7.1.25.

Planar Coanda Model
Experimental Surface Pressures

Slot = 6.00 mm; Step = 1.50 mm

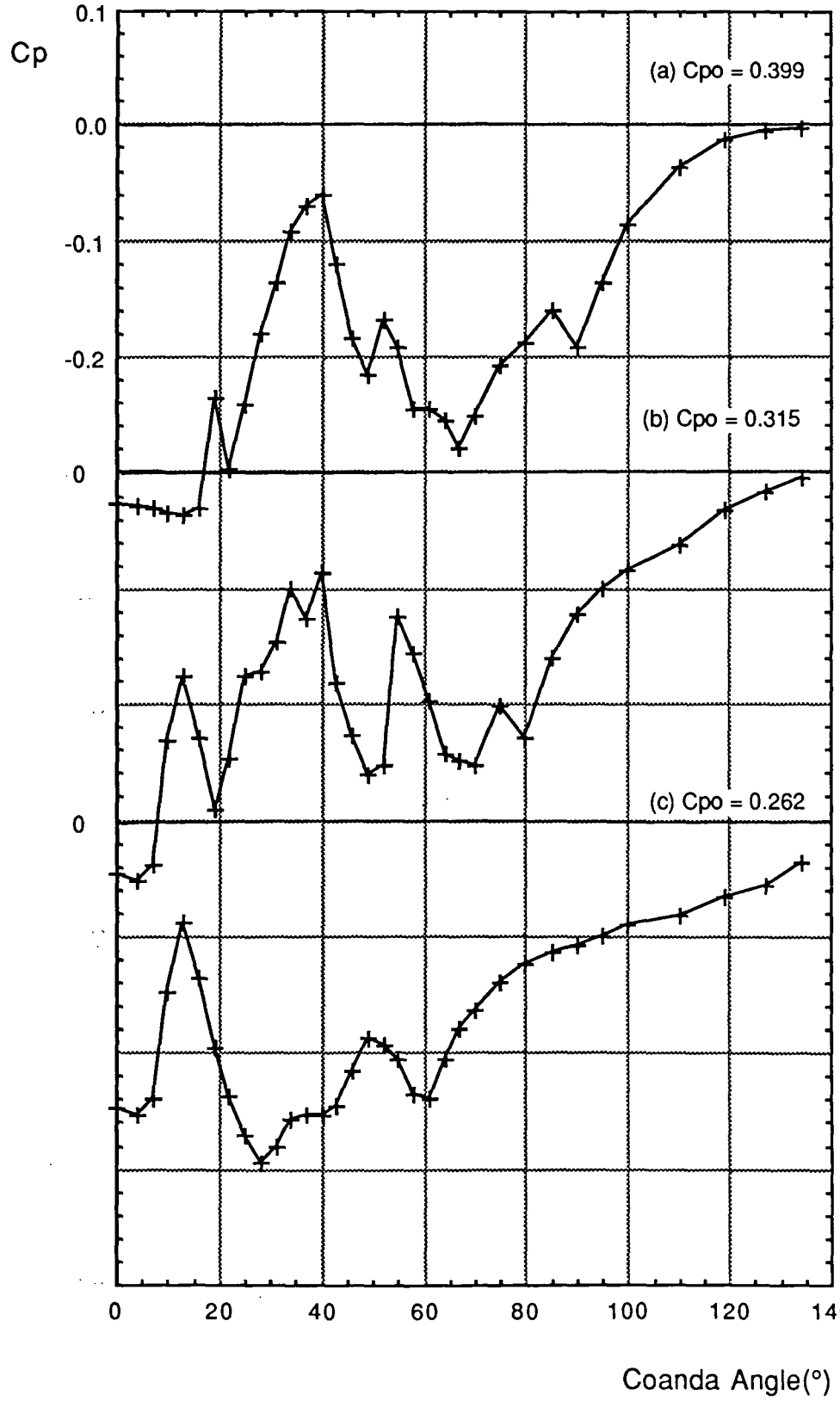


Figure 7.1.26.

Planar Coanda Model
Experimental Surface Pressures

Slot = 6.00 mm; Step = 3.75 mm

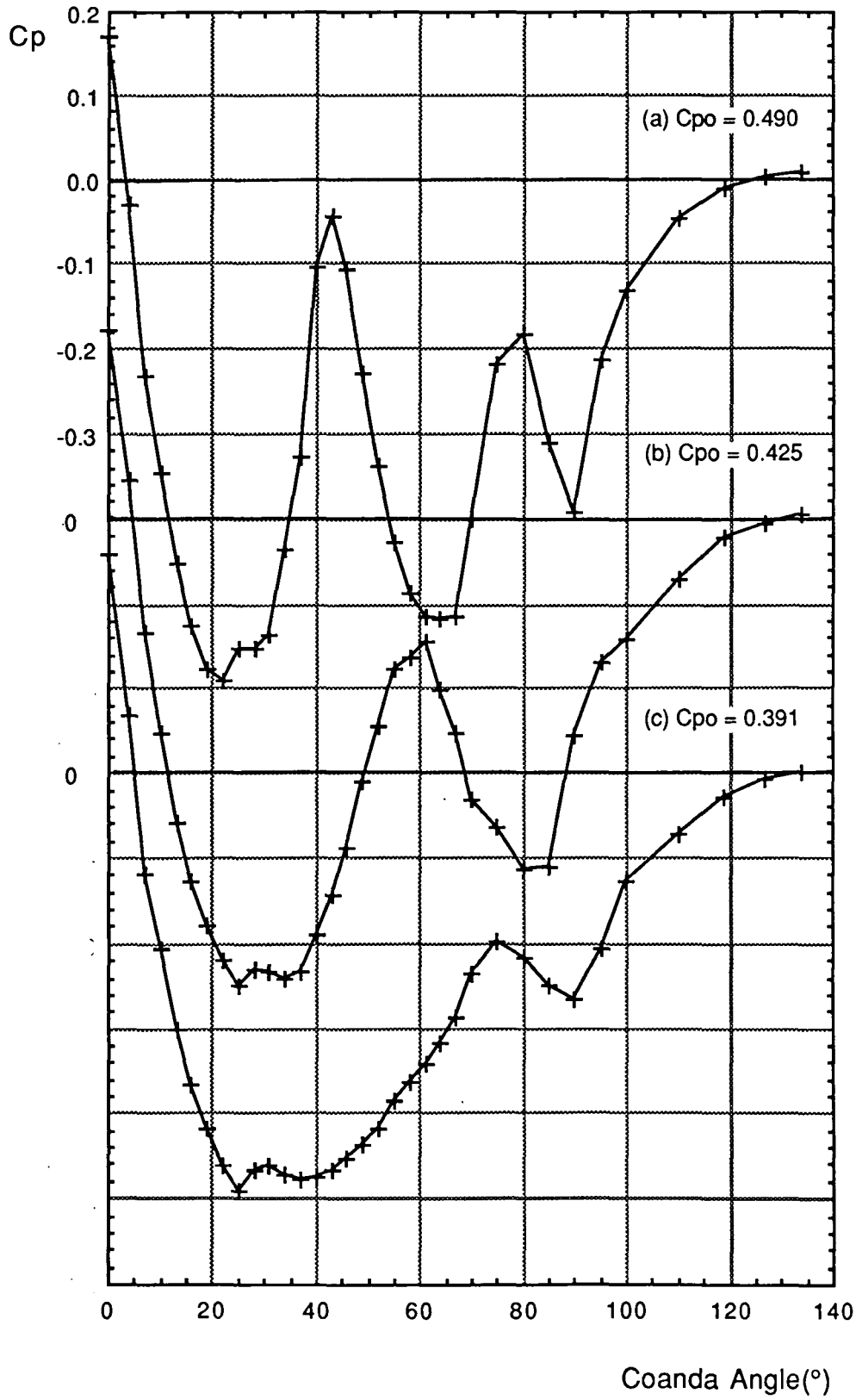


Figure 7.1.27.

Planar Coanda Model
Experimental Surface Pressures

Slot = 8.00 mm; Step = 0.00 mm

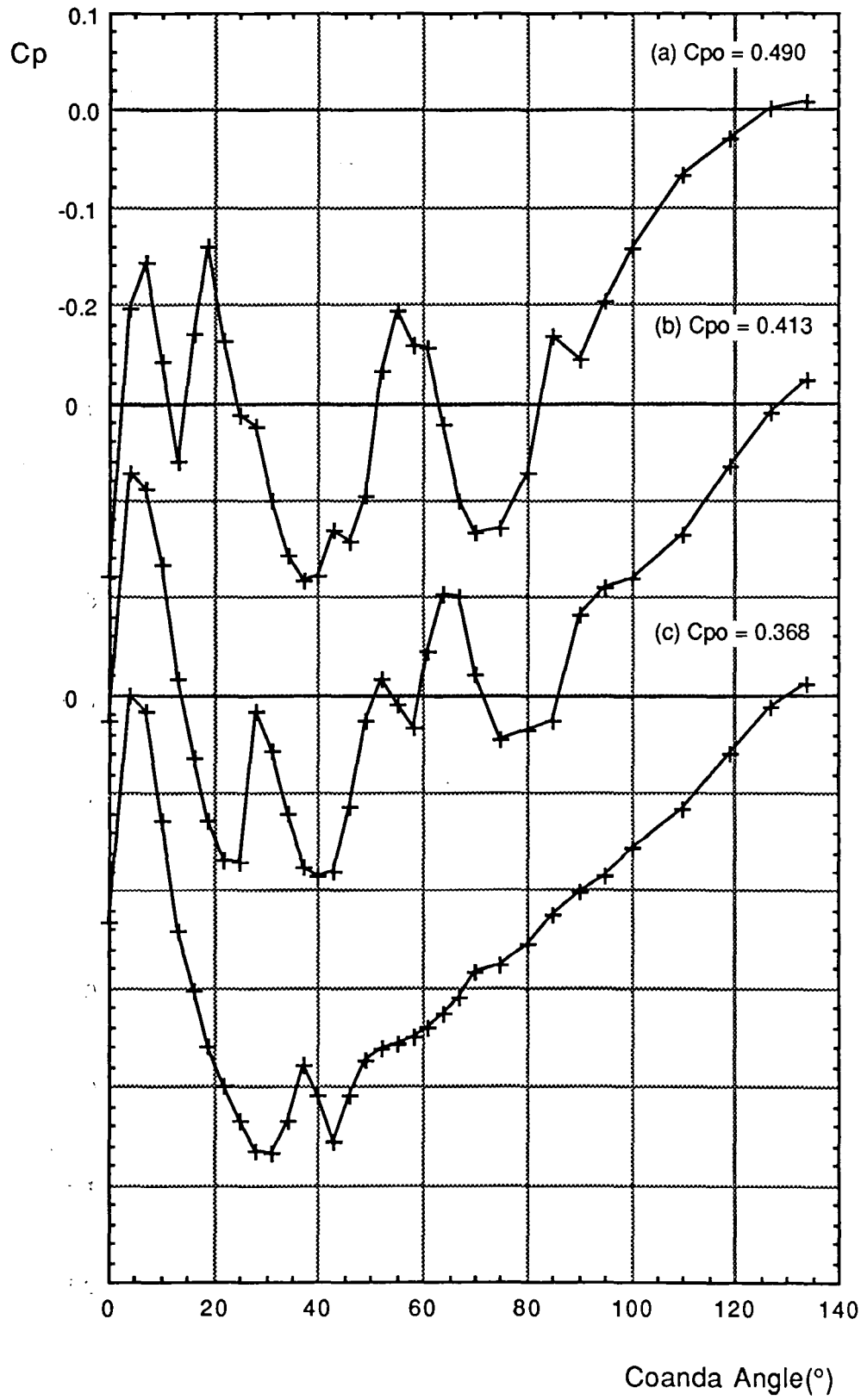


Figure 7.1.28.

Planar Coanda Model
Experimental Surface Pressures

Slot = 8.00 mm; Step = 0.75 mm

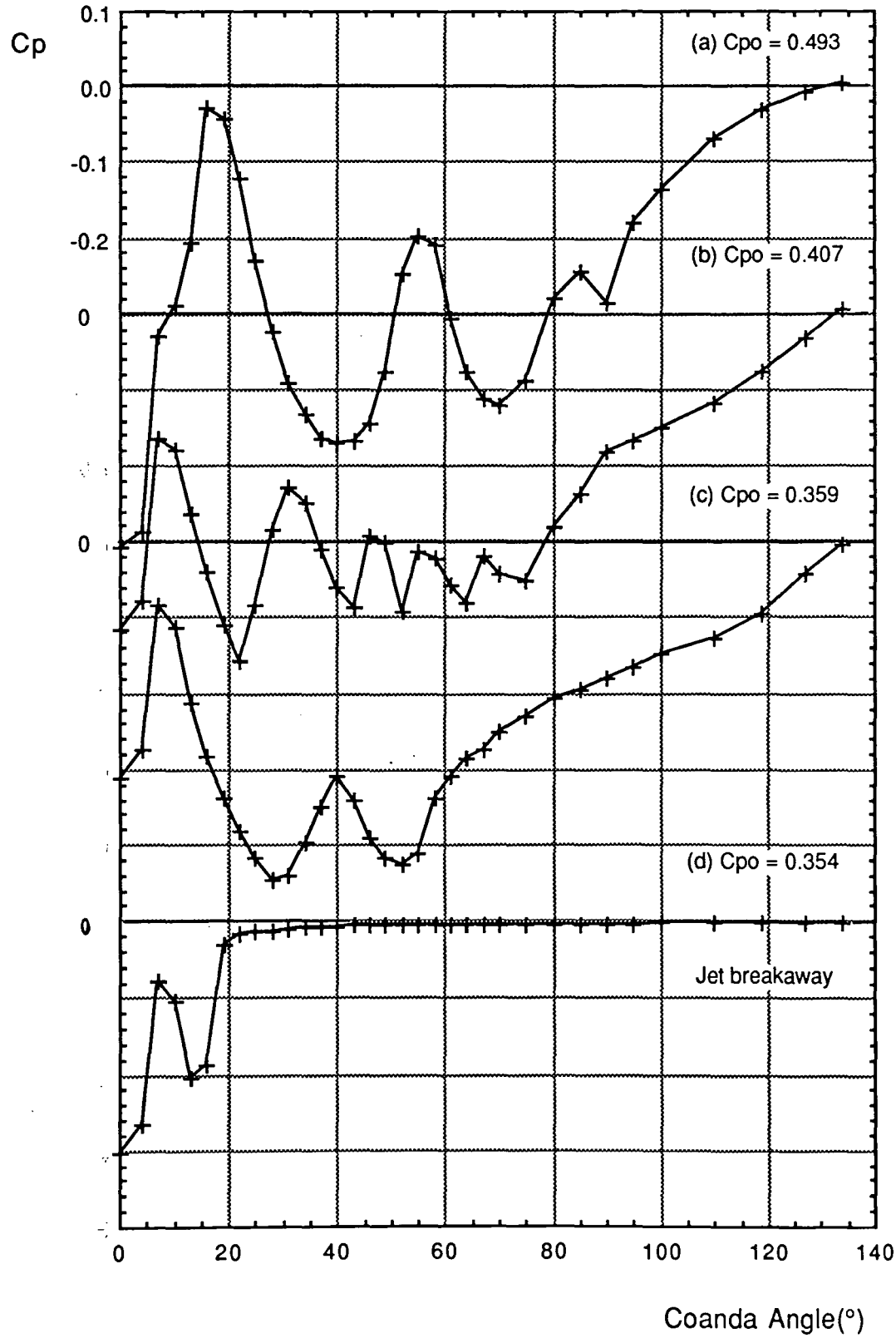


Figure 7.1.29.

Planar Coanda Model
Experimental Surface Pressures

Slot = 8.00 mm; Step = 1.50 mm

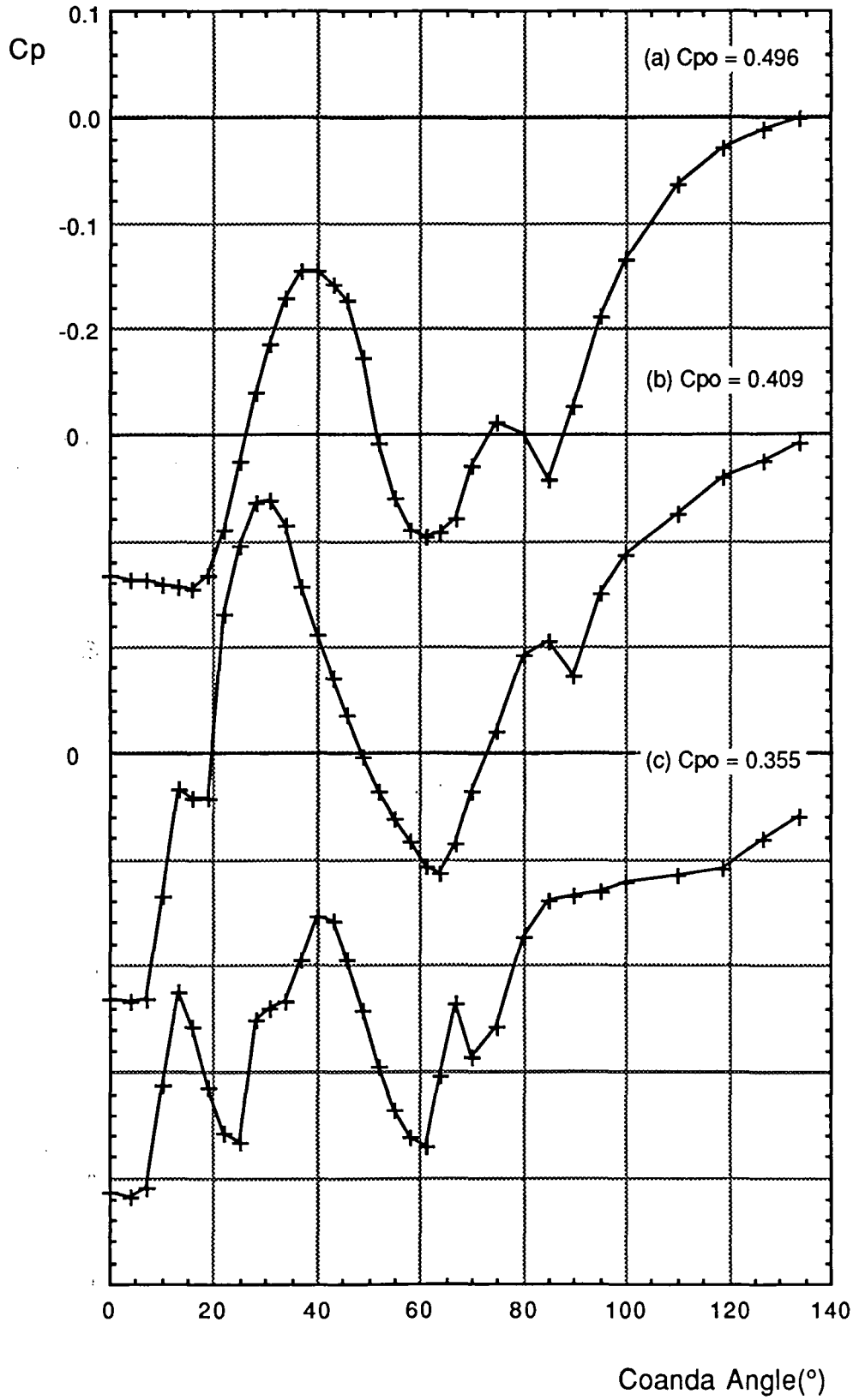


Figure 7.1.30.

Planar Coanda Model
Experimental Surface Pressures

Slot = 8.00 mm; Step = 3.75 mm

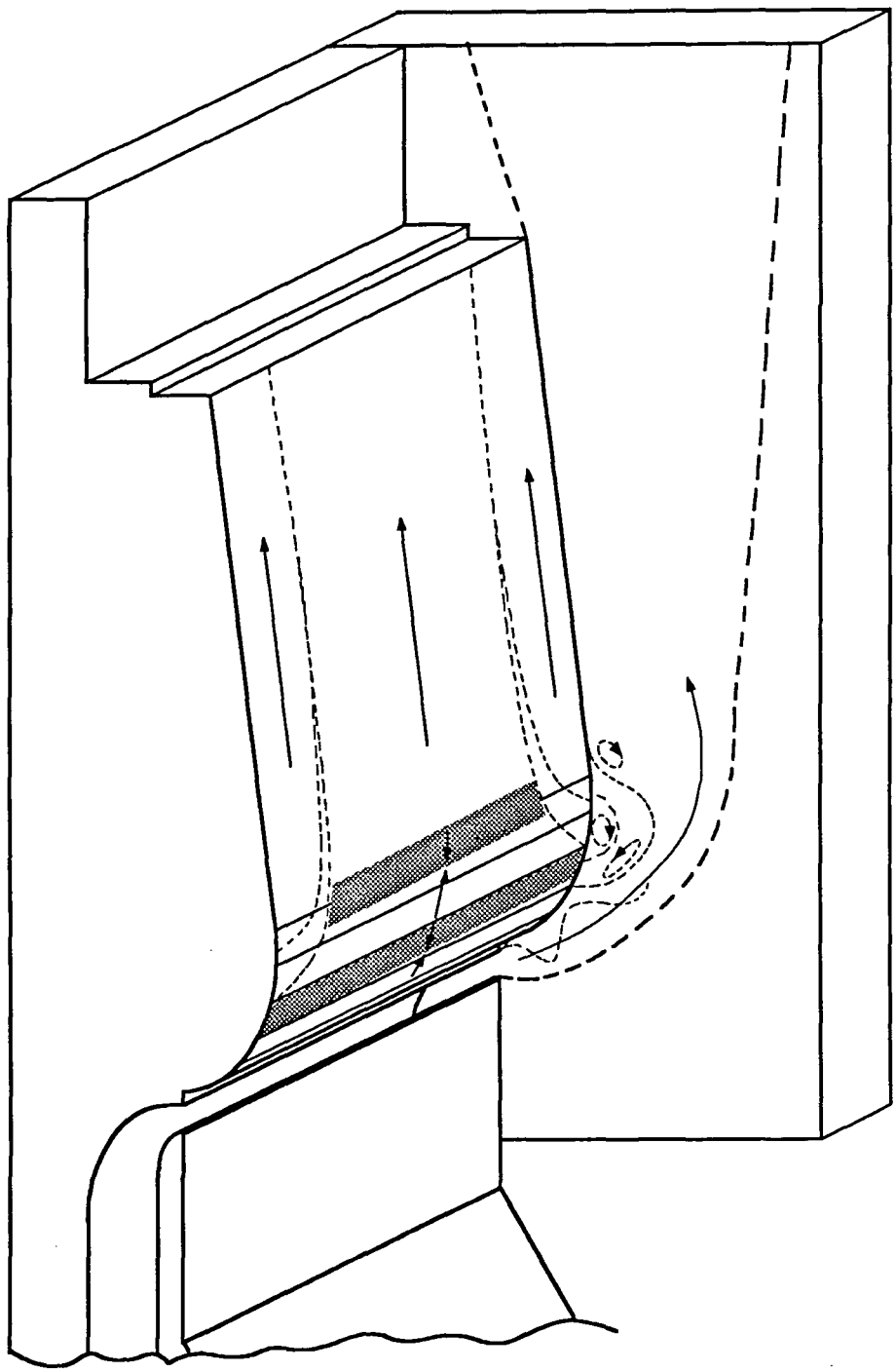


Figure 7.1. 31. Planar Flare Model Endwall Flow

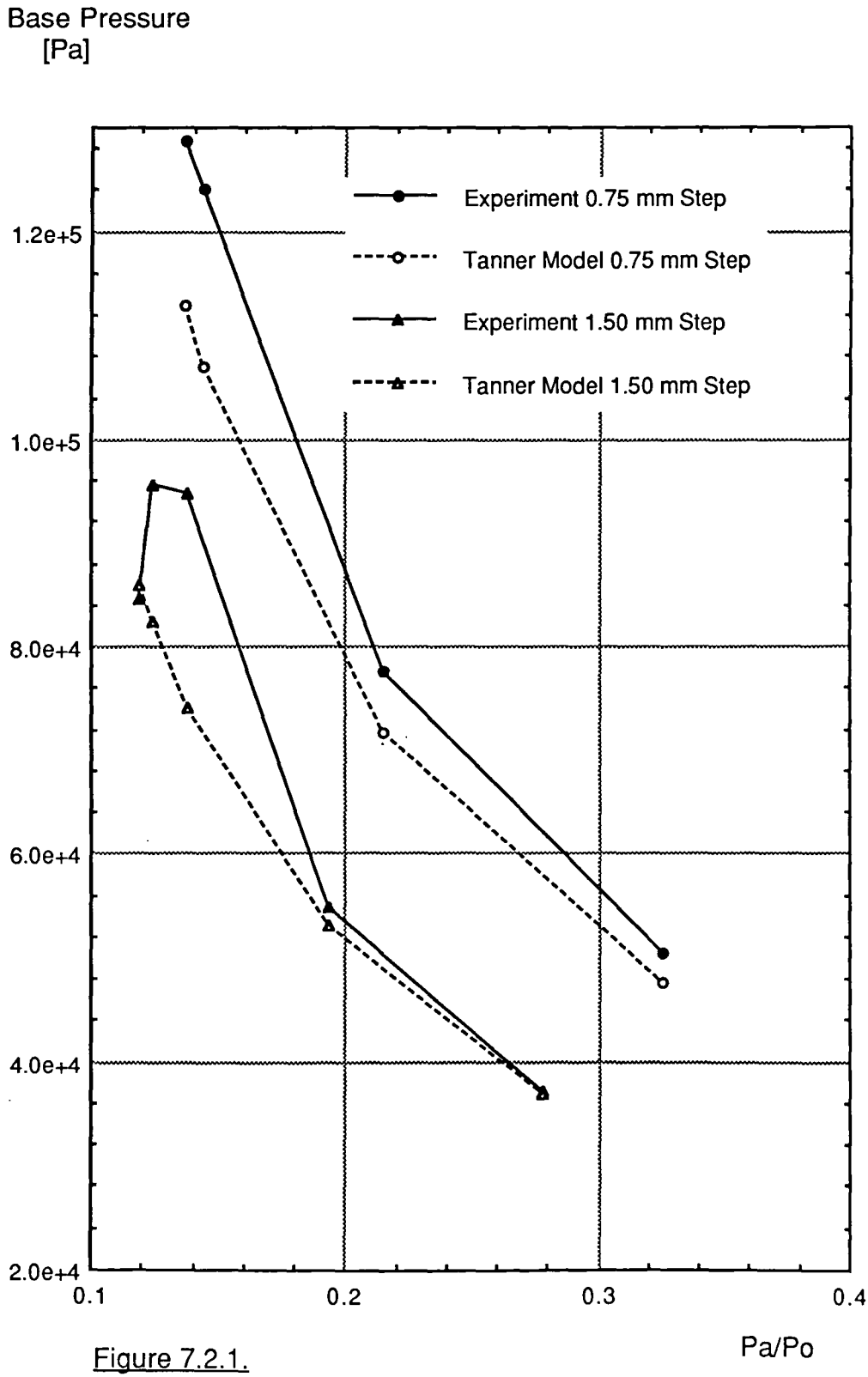


Figure 7.2.1.

Planar Coanda Model
Base Pressures: 2.00 mm Slot

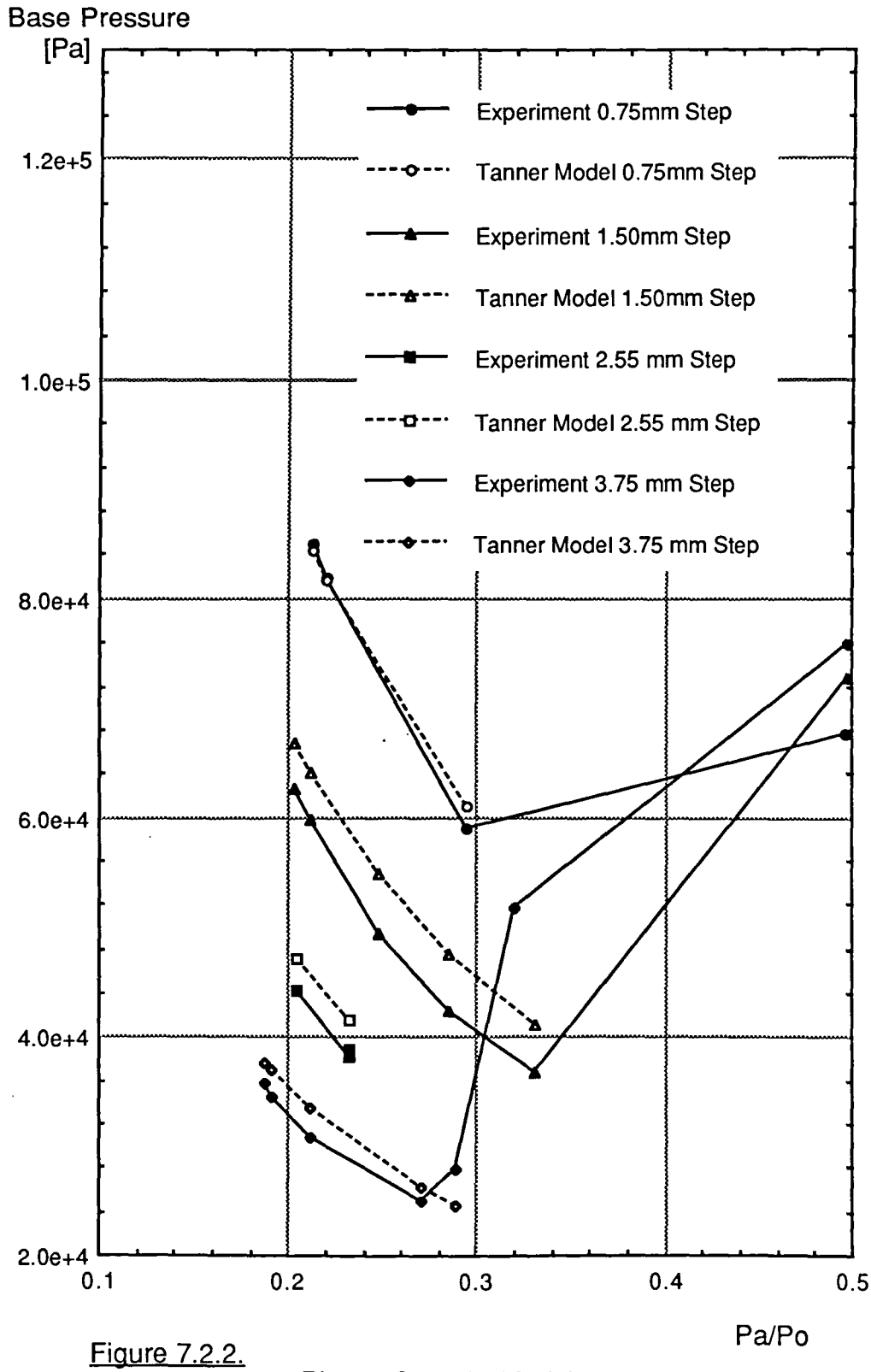


Figure 7.2.2.

Planar Coanda Model
Base Pressures: 4.00 mm Slot

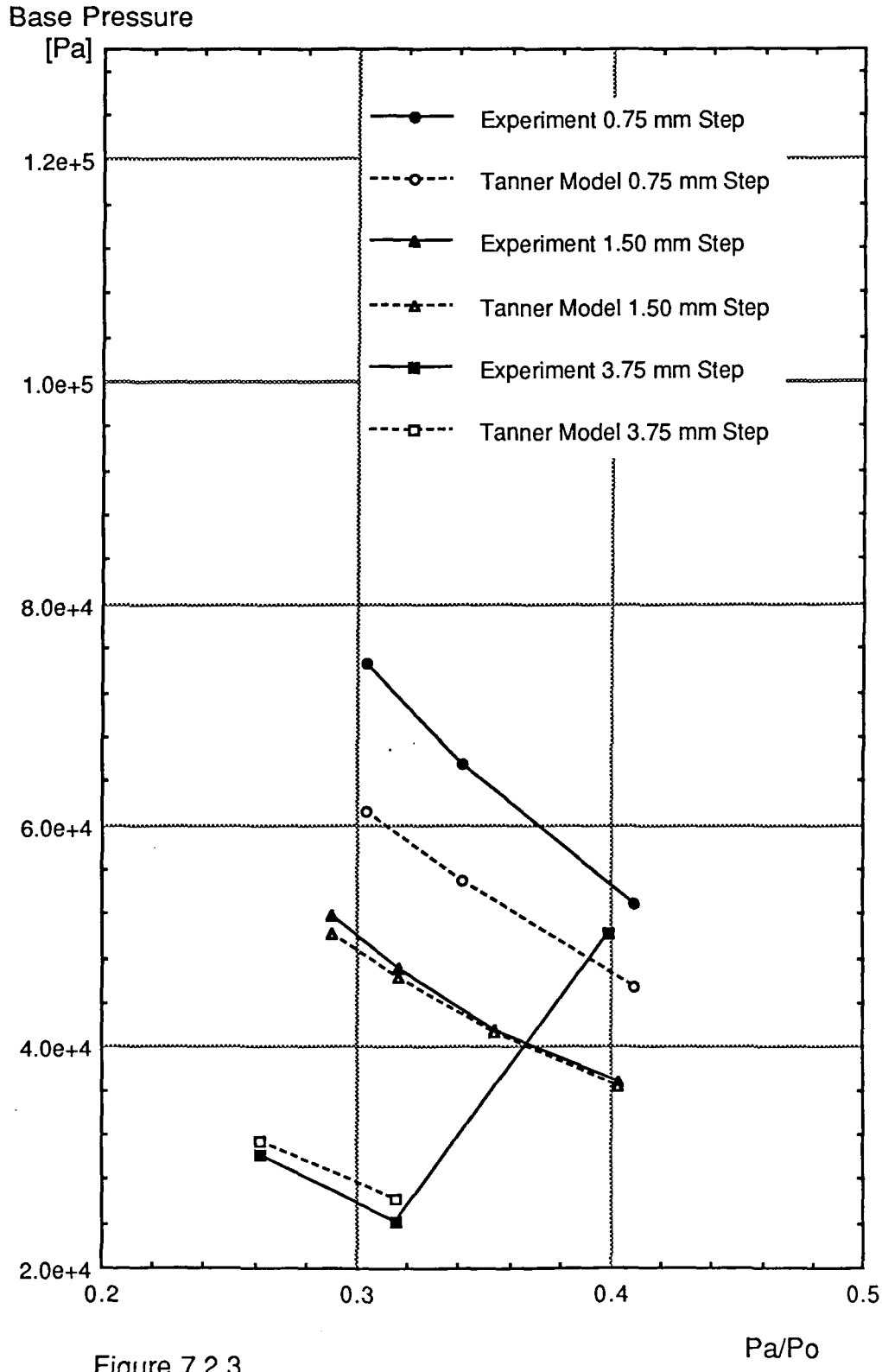


Figure 7.2.3.

Planar Coanda Model
Base Pressures: 6.00 mm Slot

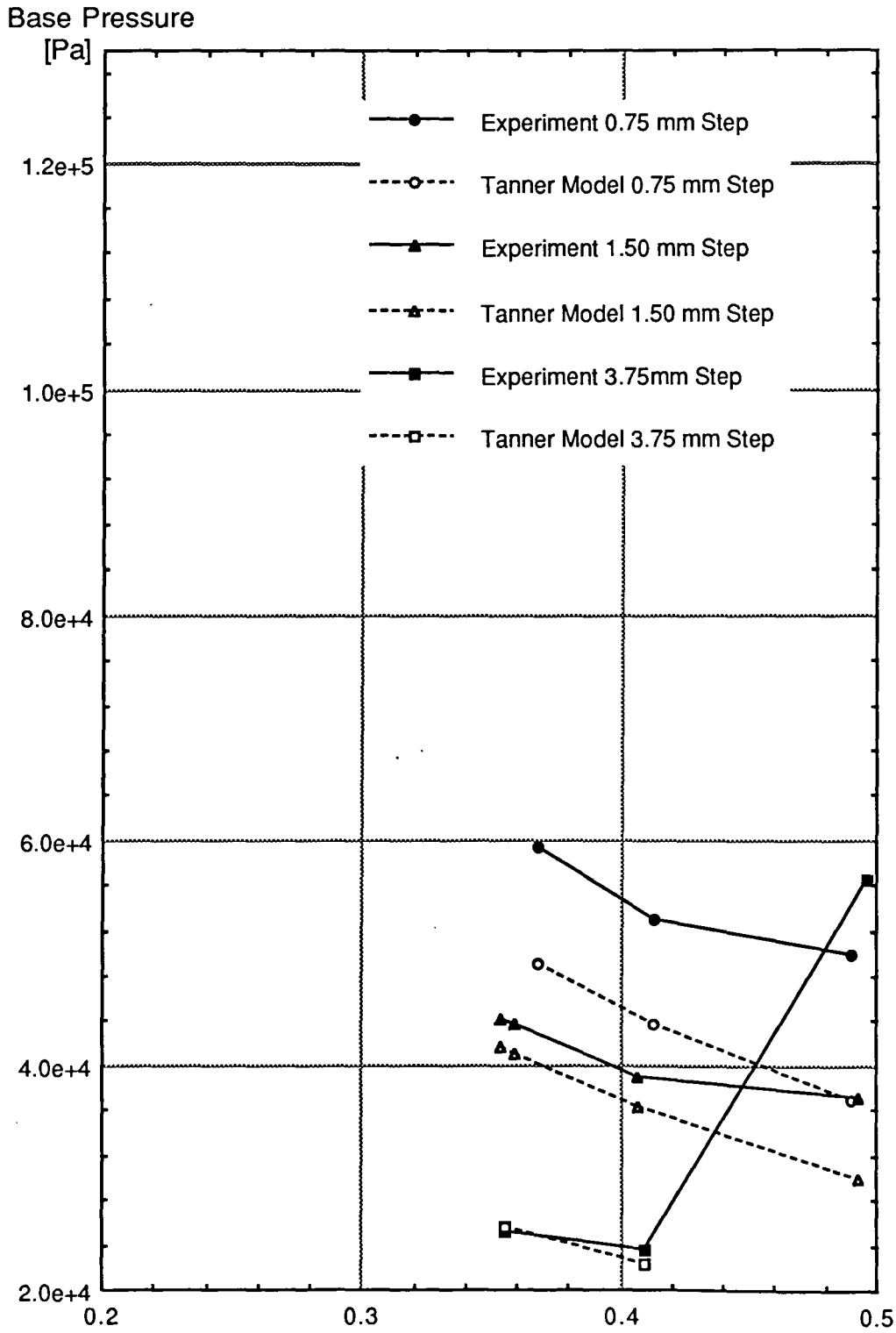


Figure 7.2.4.

Planar Coanda Model
Base Pressures: 8.00 mm Slot

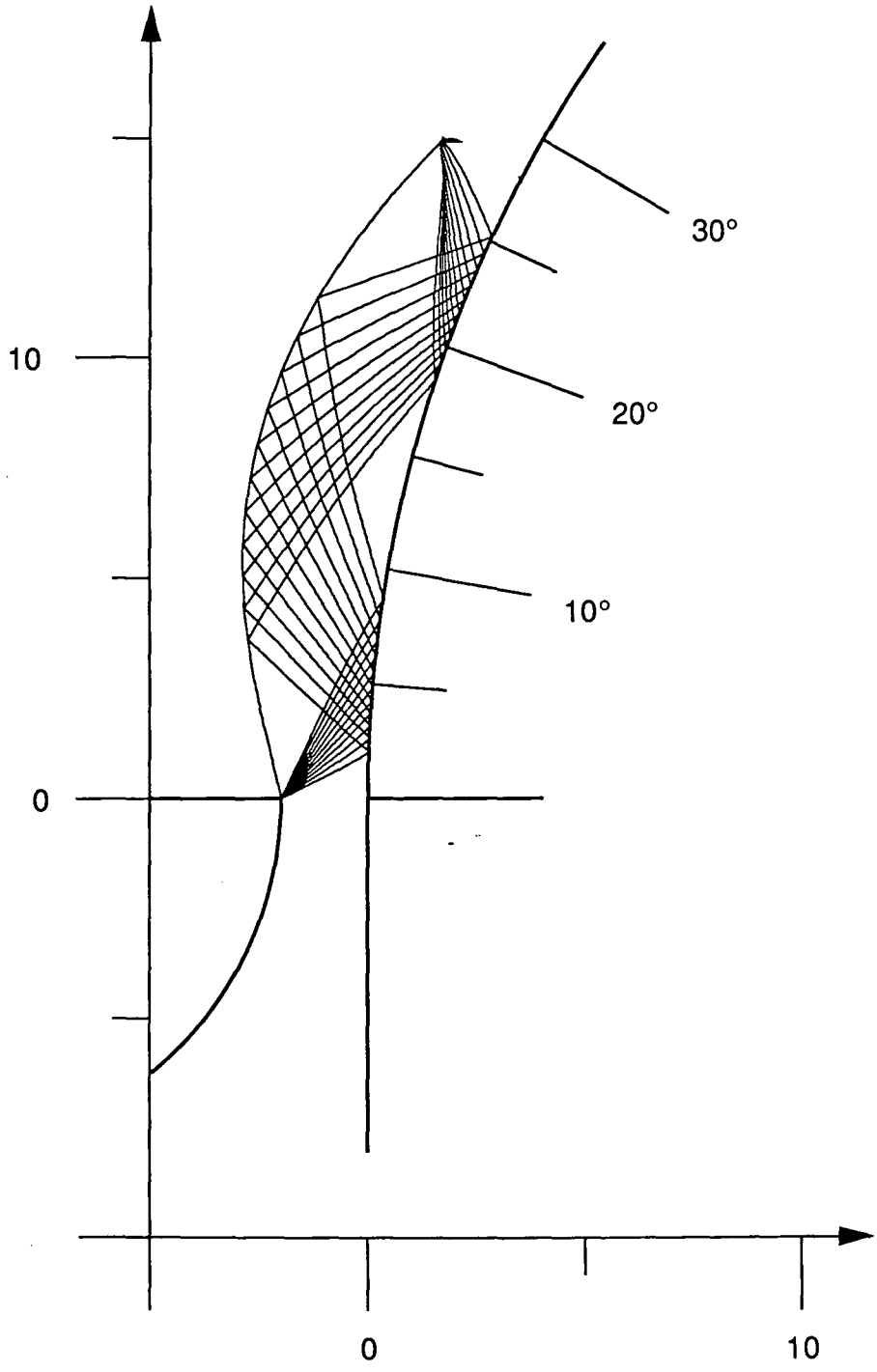


Figure 7.2.5.

Planar Coanda Model
Method of Characteristics Plot

Attached Jet; Shock Fitting
Slot = 2.00 mm Step = 0.00 mm
Patm/Po = 0.243

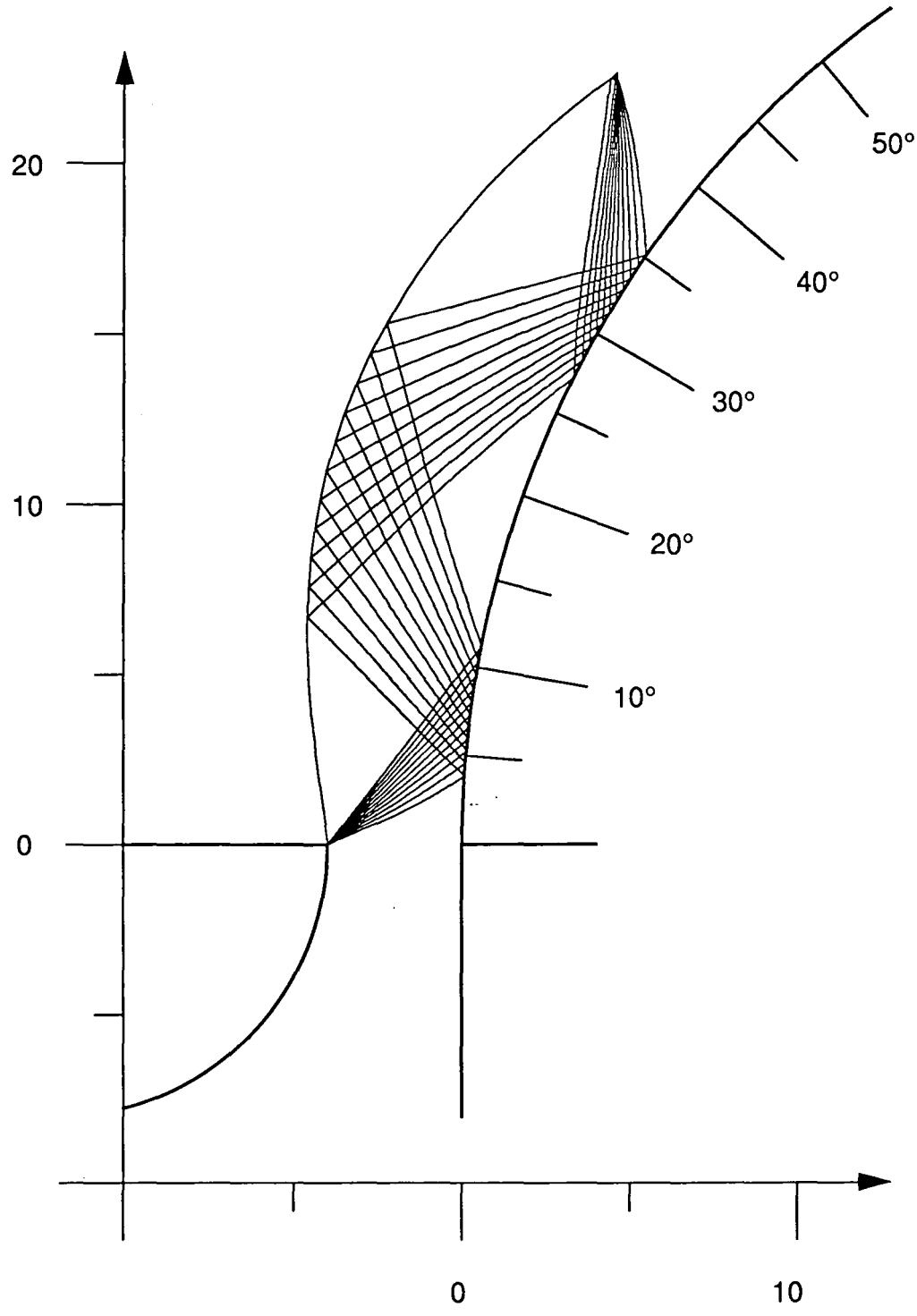


Figure 7.2.6.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting
Slot = 4.00 mm Step = 0.00 mm
Patm/Po = 0.324

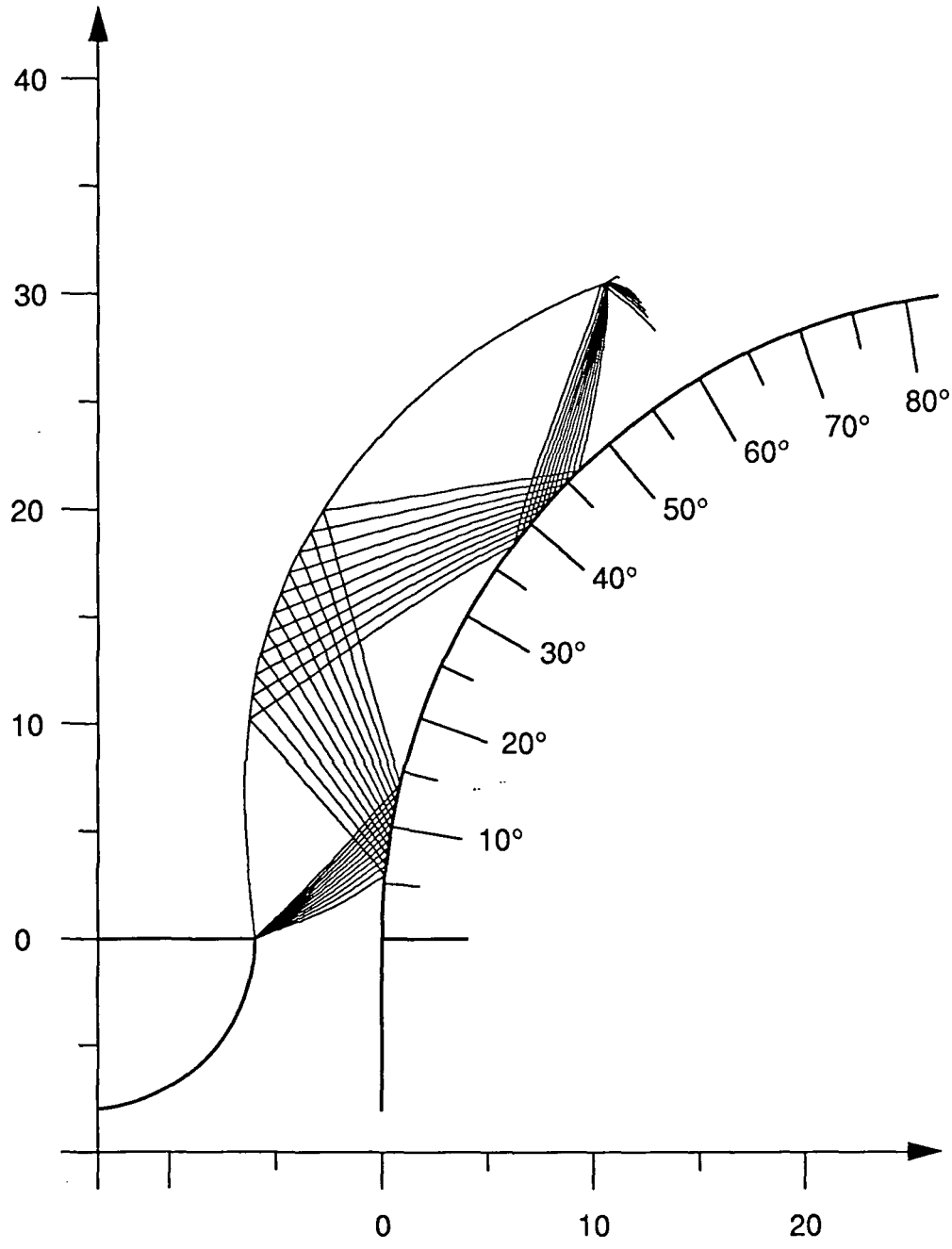


Figure 7.2.7.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting
Slot = 6.00 mm Step = 0.00 mm
Patm/Po = 0.366

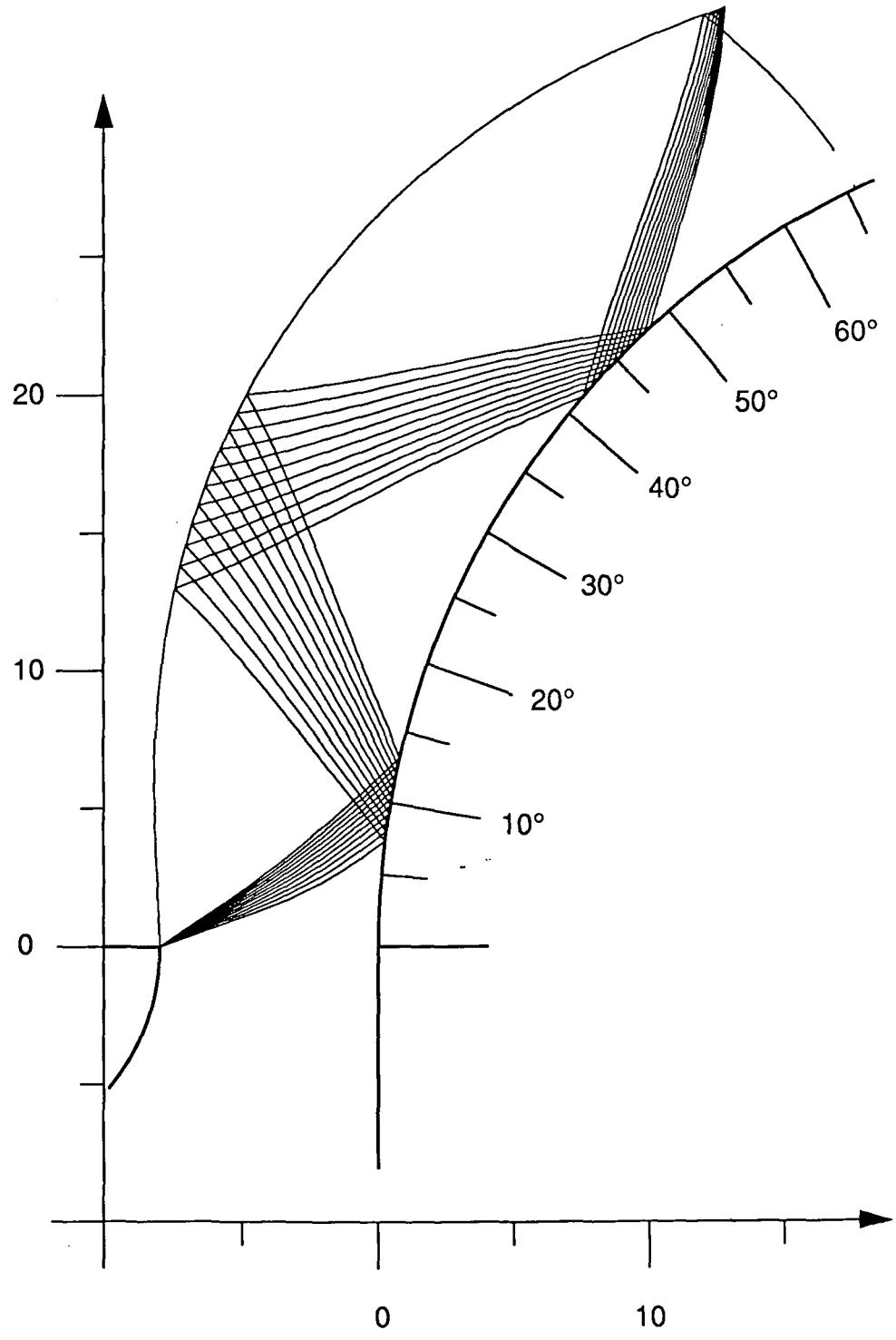


Figure 7.2.8. Planar Coanda Model
Method of Characteristics Plot
Shock Fitting
Slot = 8.00 mm Step = 0.00 mm
Patm/Po = 0.425

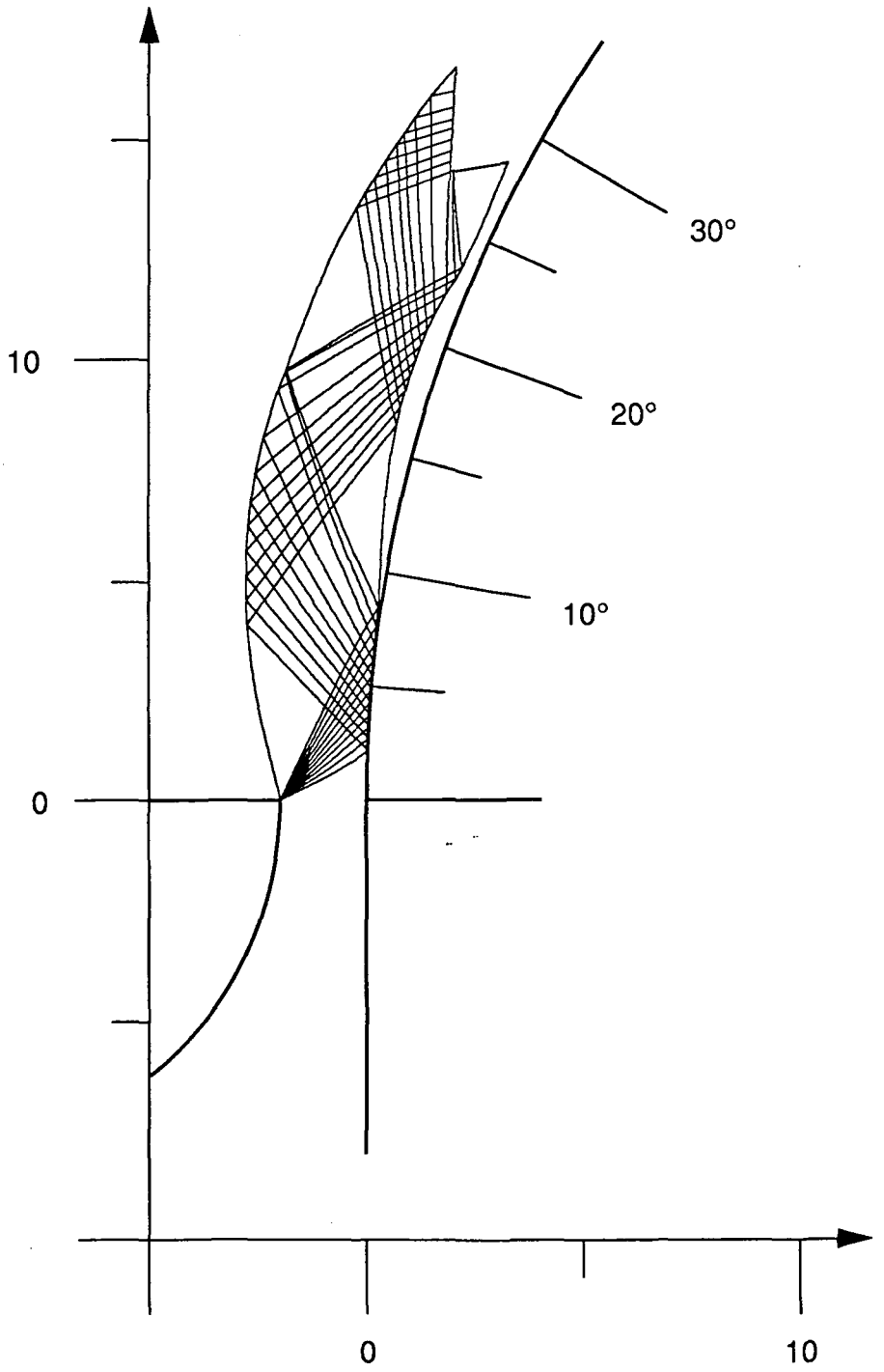


Figure 7.2.9. Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 2.00 mm Step = 0.00 mm
Patm/Po = 0.243

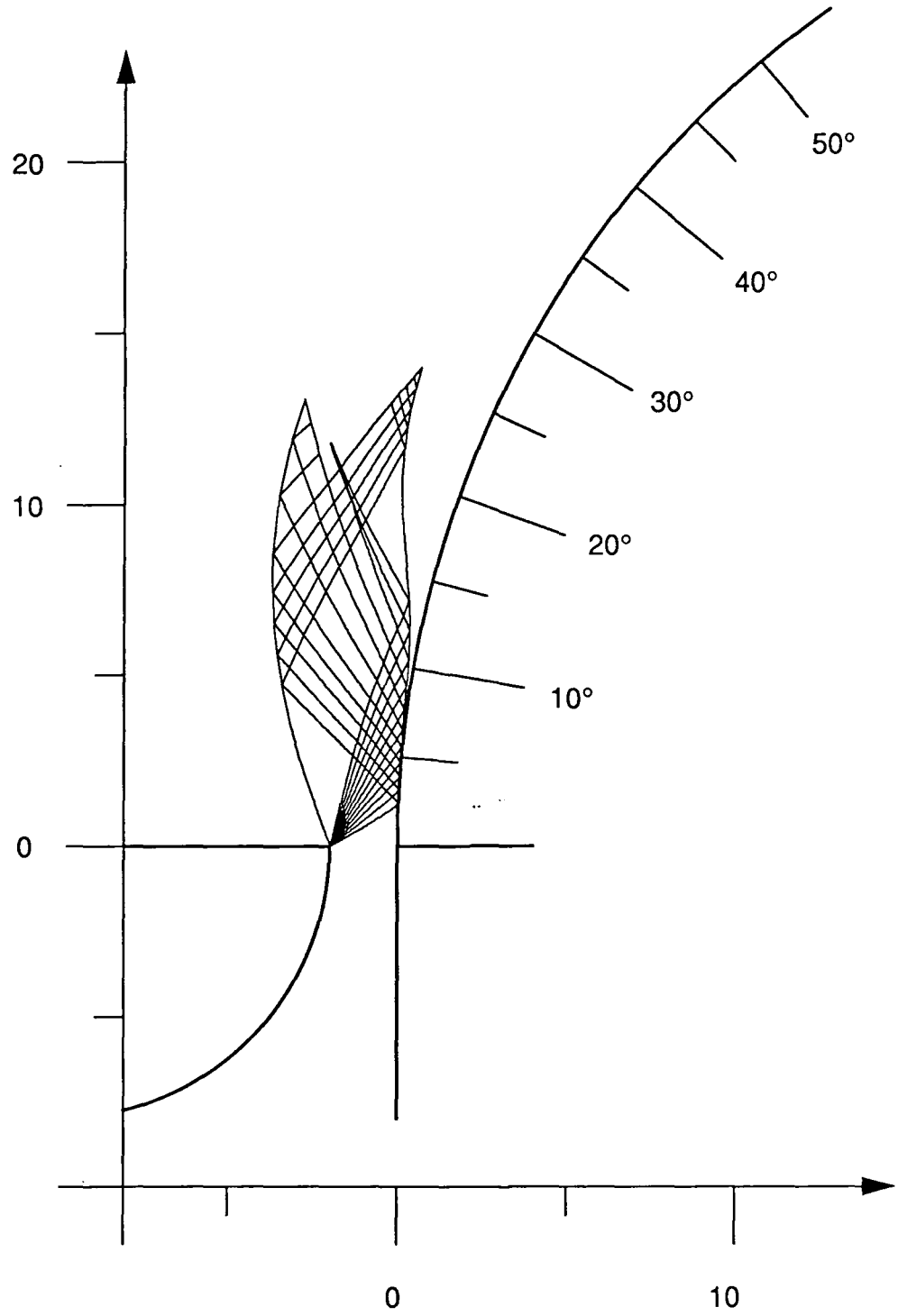


Figure 7.2.10. Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 2.00 mm Step = 0.00 mm
Patm/Po = 0.176

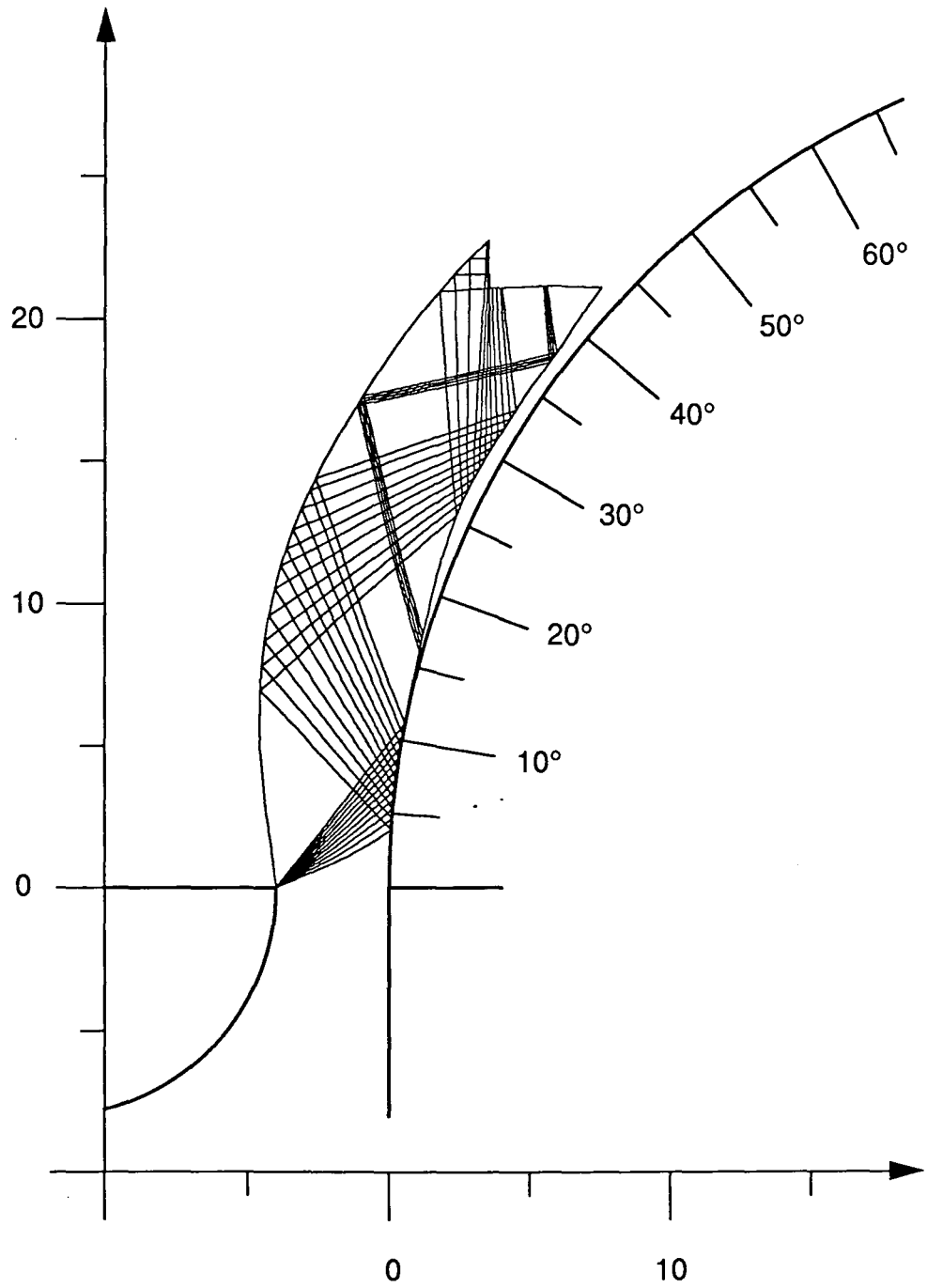


Figure 7.2.11.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 4.00 mm Step = 0.00 mm
Patm/Po = 0.324

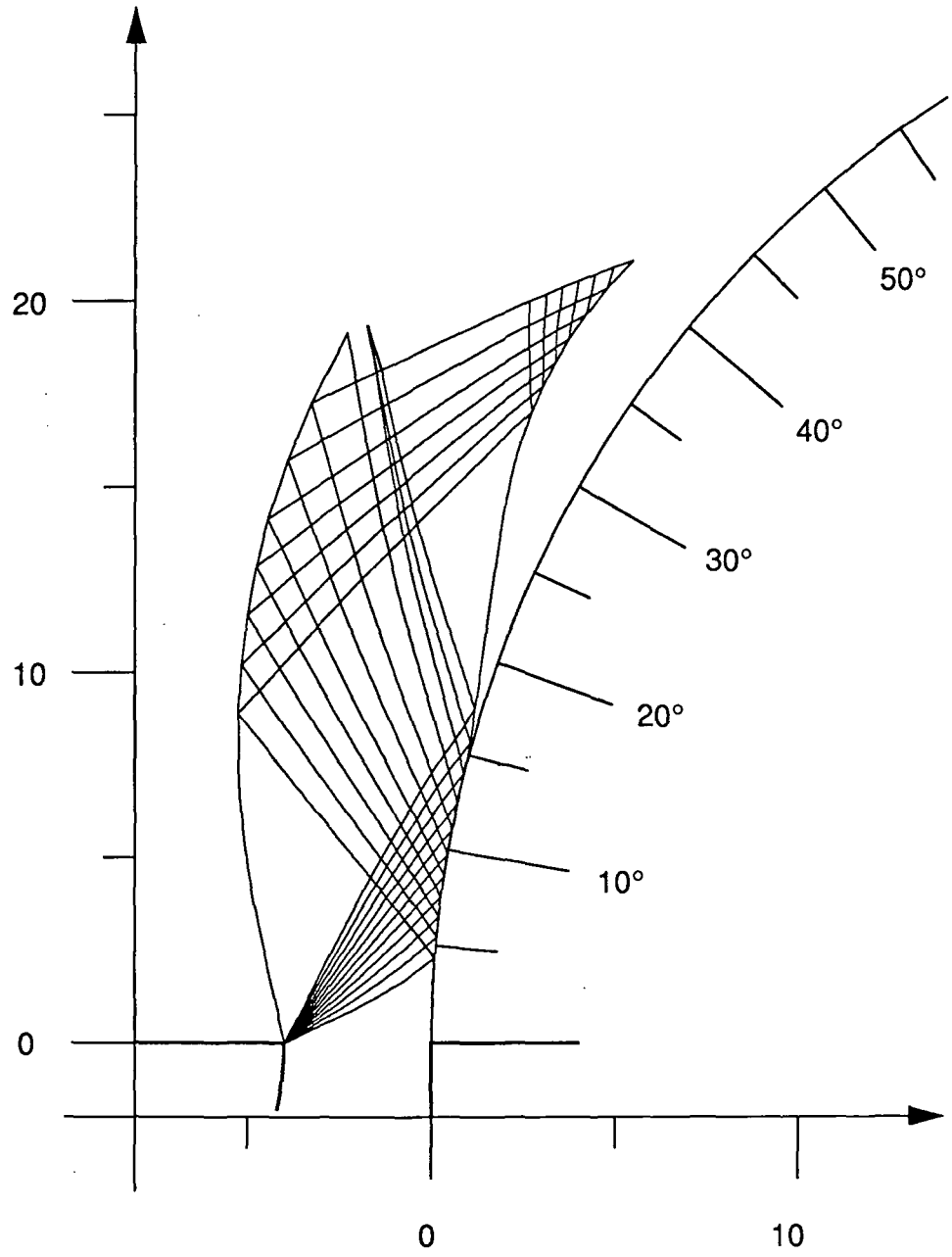


Figure 7.2.12.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 4.00 mm Step = 0.00 mm
Patm/Po = 0.256

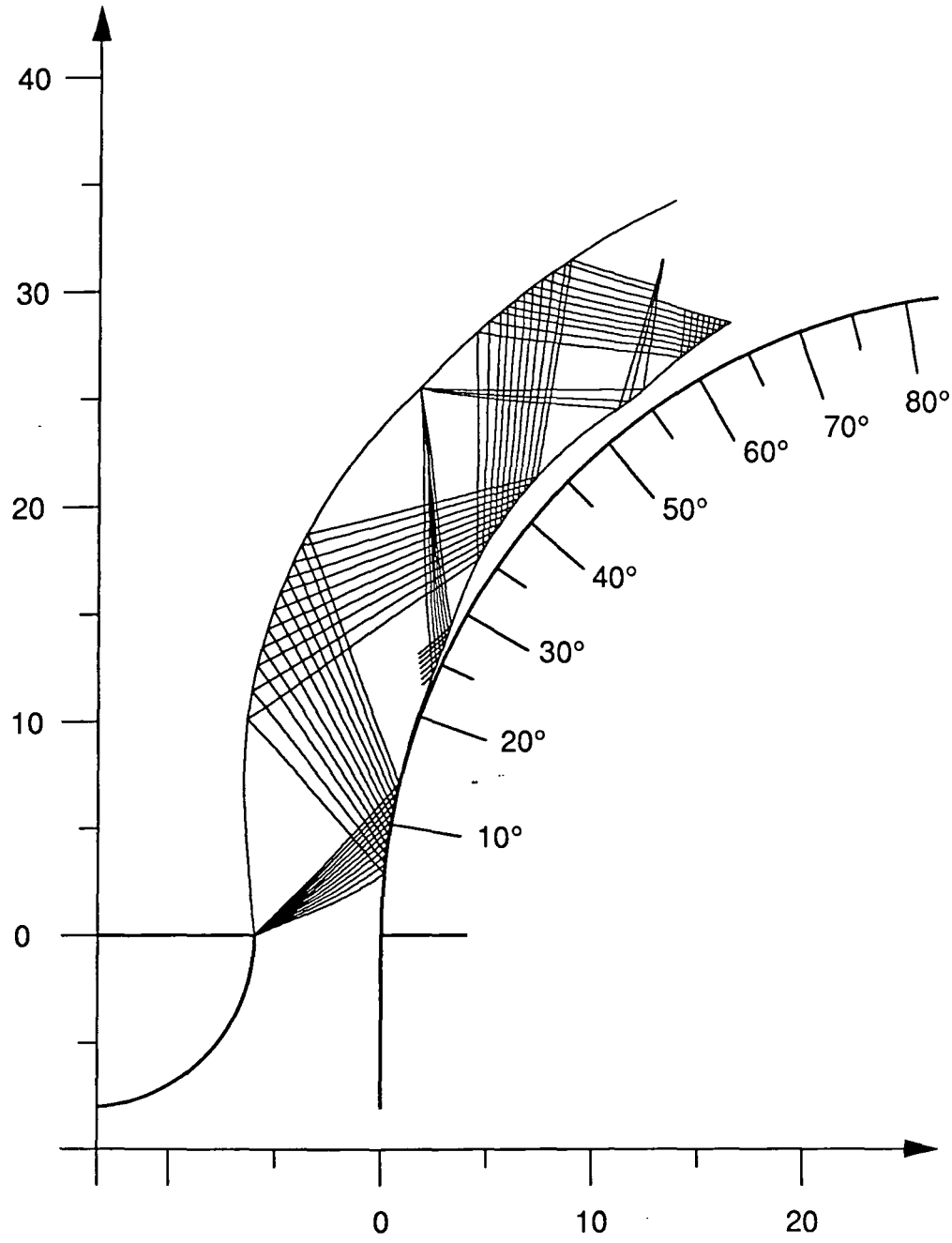


Figure 7.2.13.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 6.00 mm Step = 0.00 mm
Patm/Po = 0.366

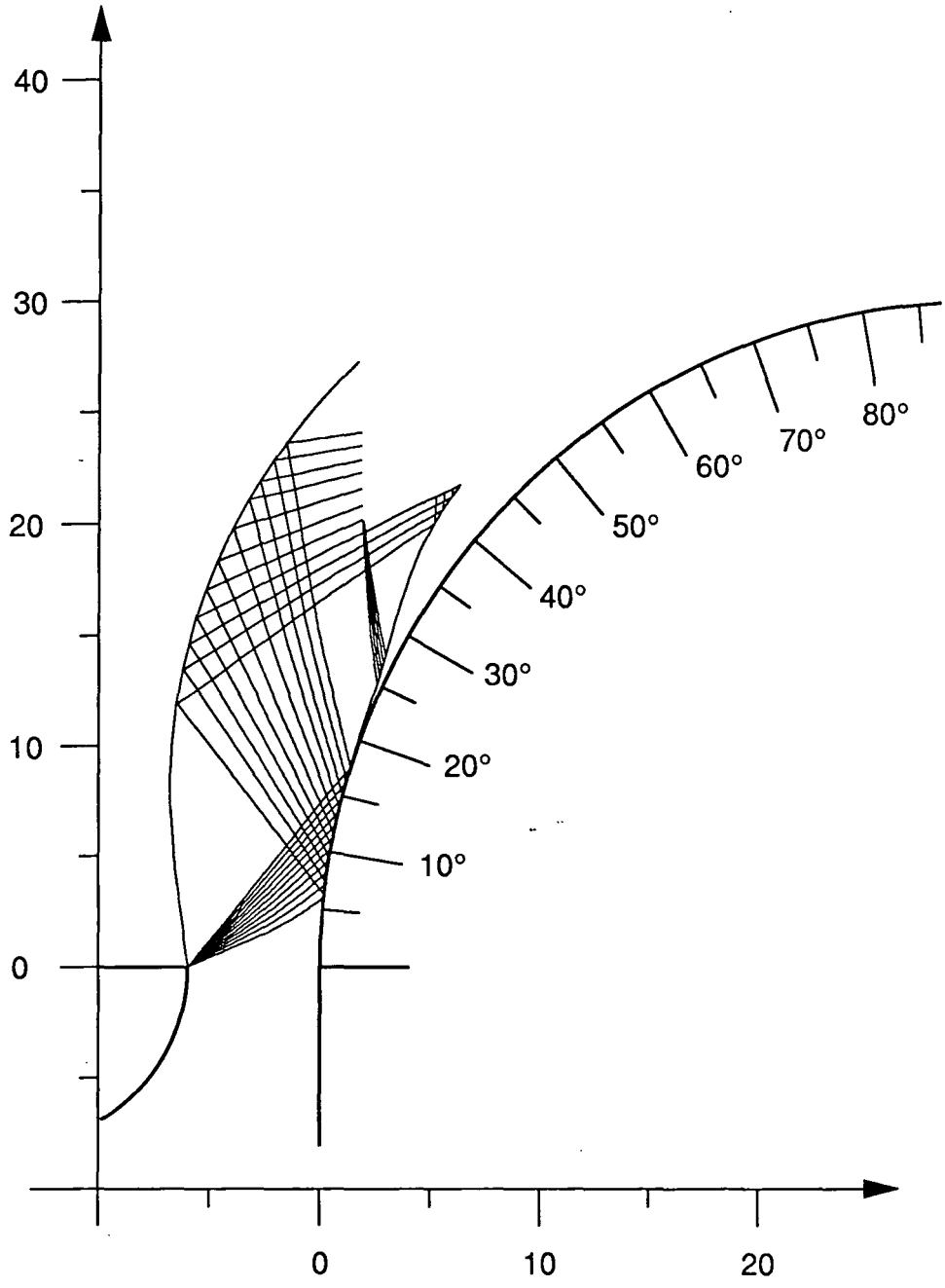


Figure 7.2.14.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 6.00 mm Step = 0.00 mm
Patm/Po = 0.330

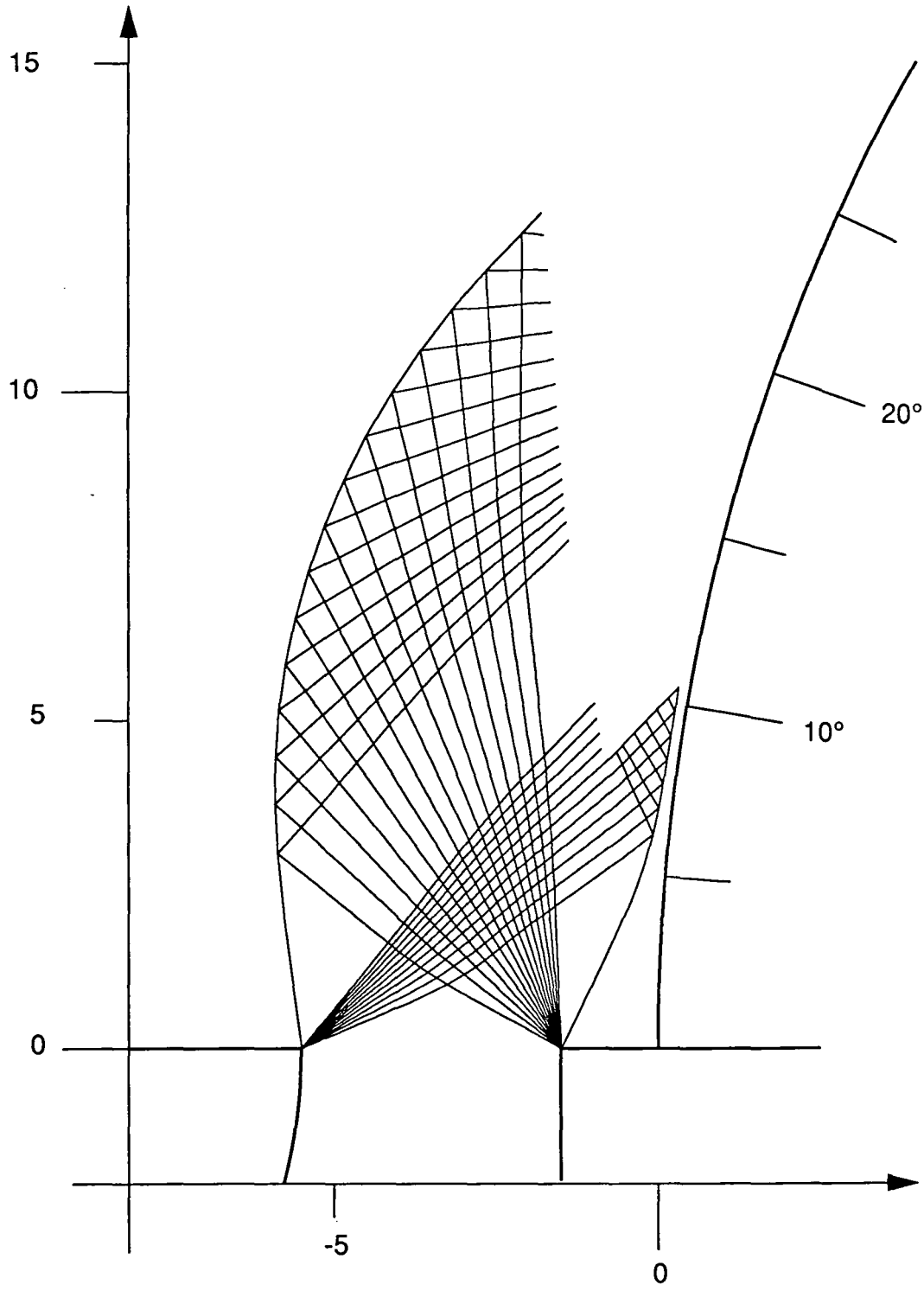


Figure 7.2.15. Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 4.00 mm Step = 1.50 mm
Patm/Po = 0.331

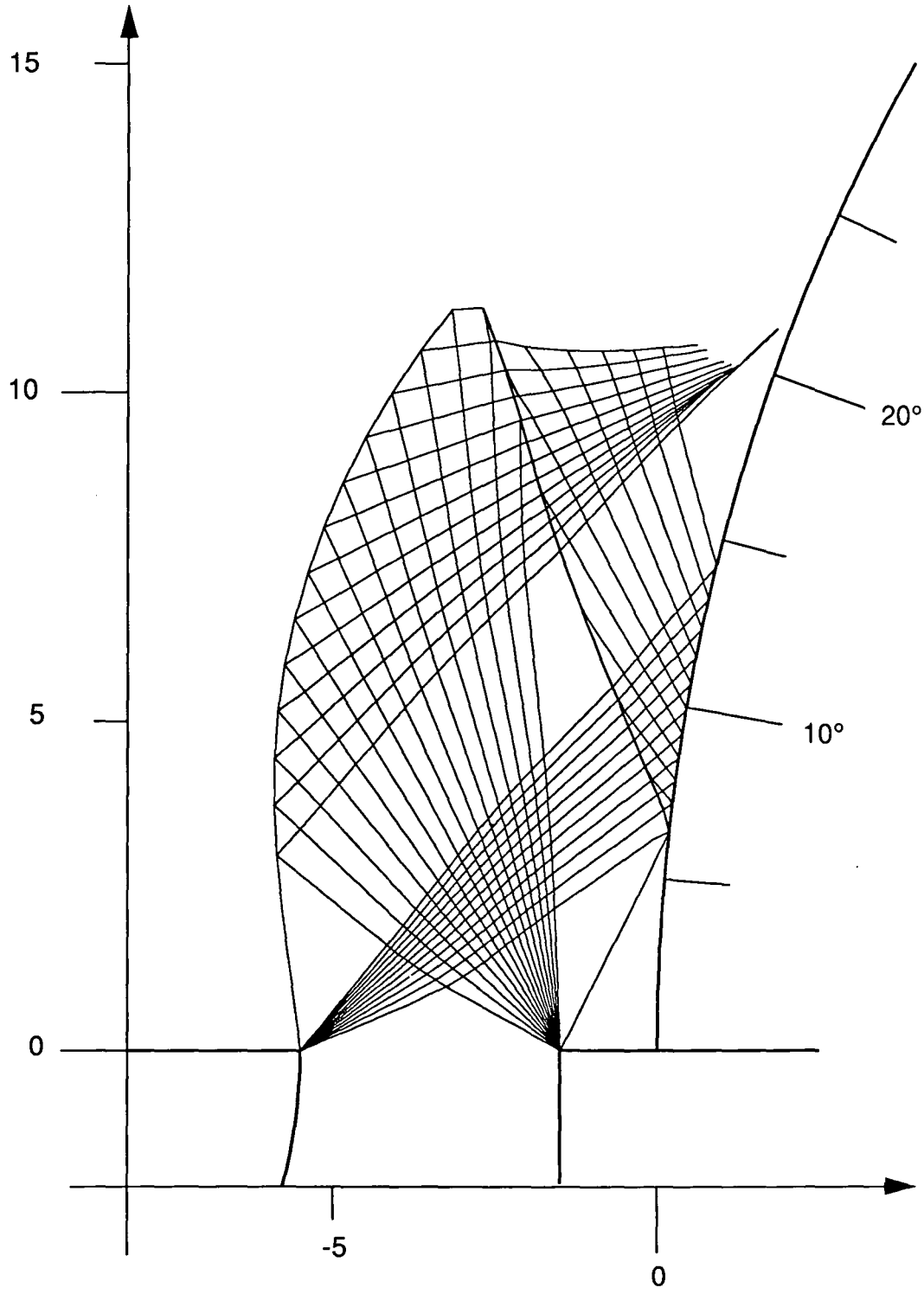


Figure 7.2.16. Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Experimental Base Pressure
Slot = 4.00 mm Step = 1.50 mm
Patm/Po = 0.331

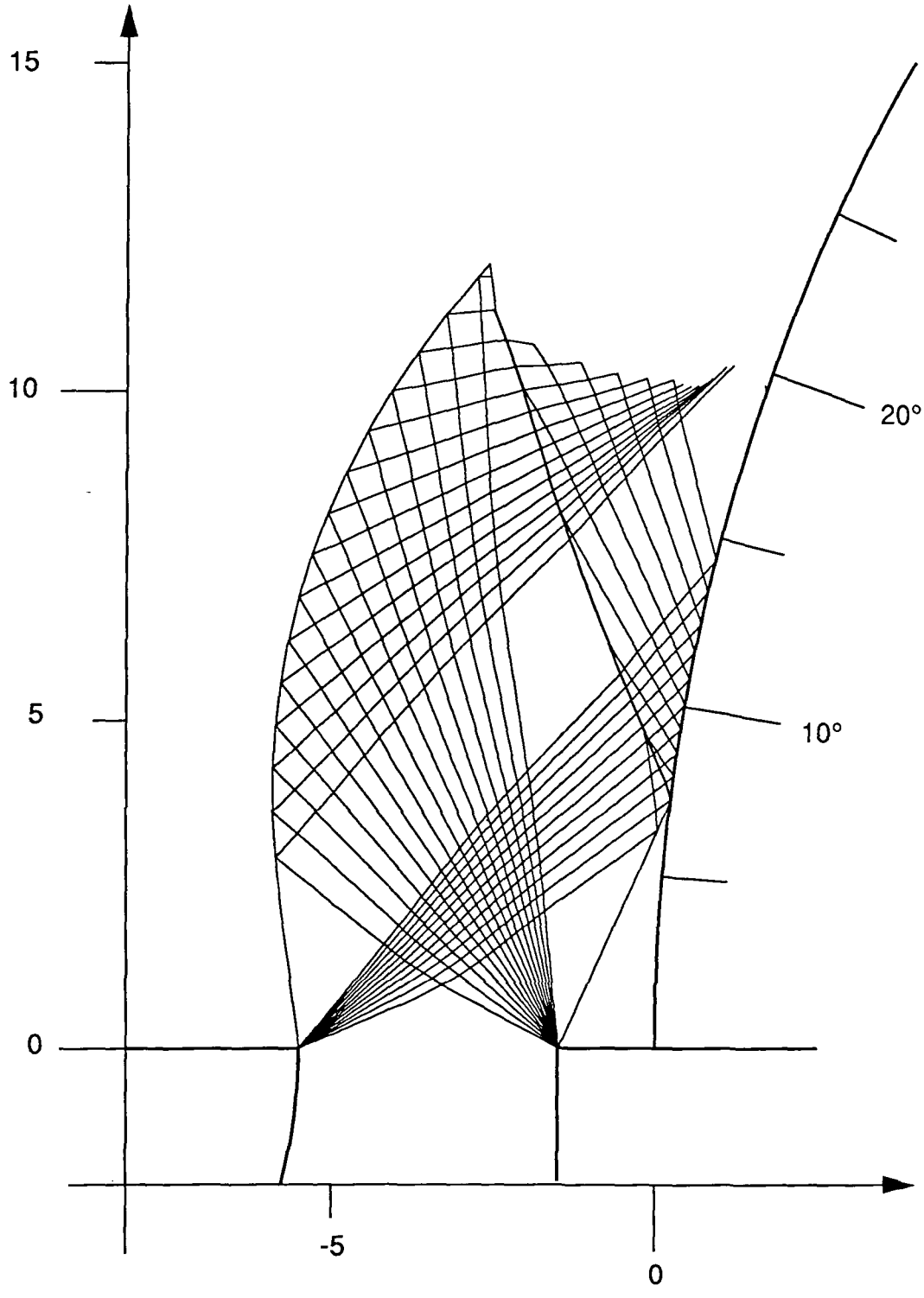


Figure 7.2.17. Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Base Pressure Model
Slot = 4.00 mm Step = 1.50 mm
Patm/Po = 0.331

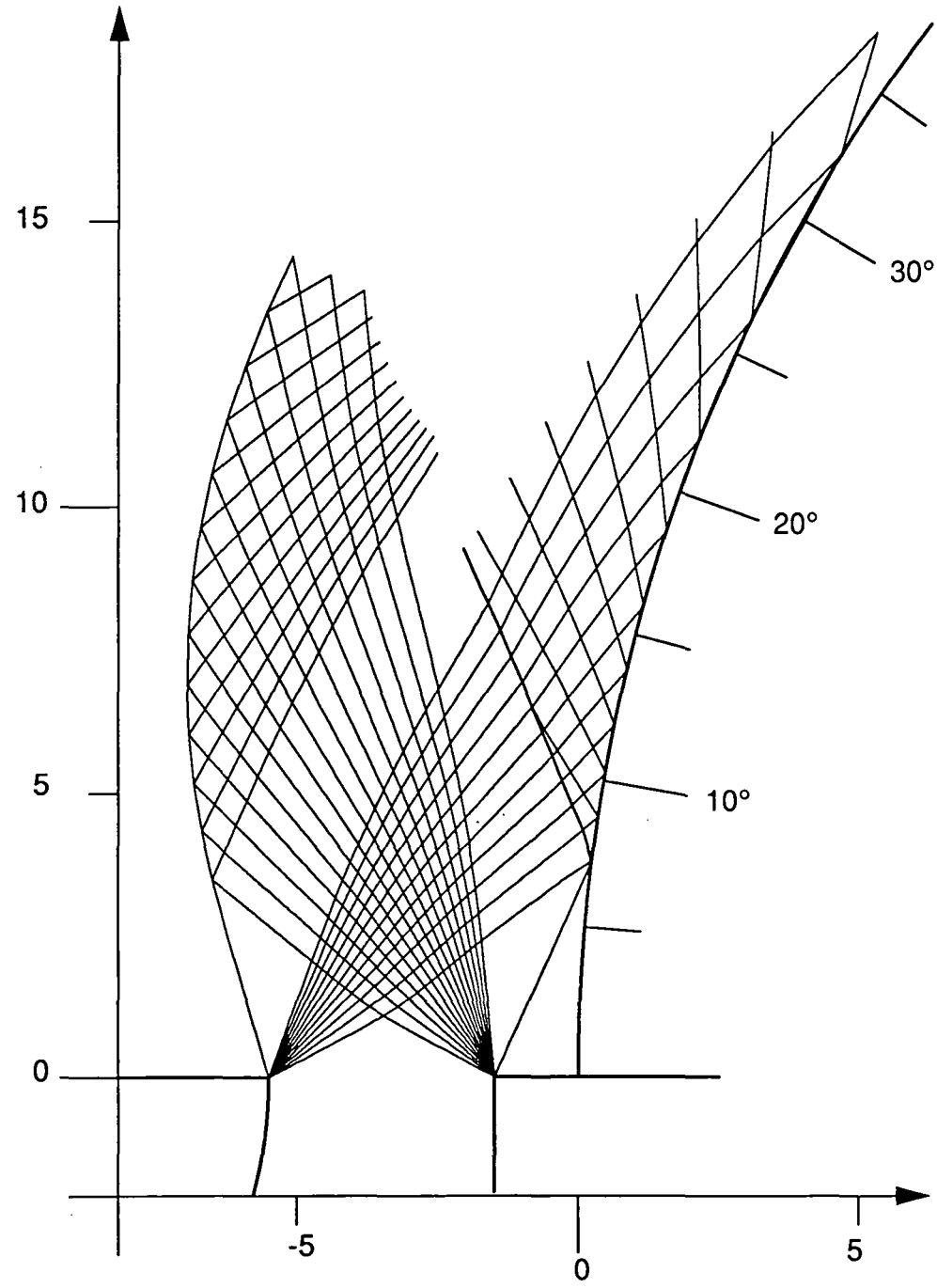


Figure 7.2.18. Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Base Pressure Model
Slot = 4.00 mm Step = 1.50 mm
Patm/Po = 0.212

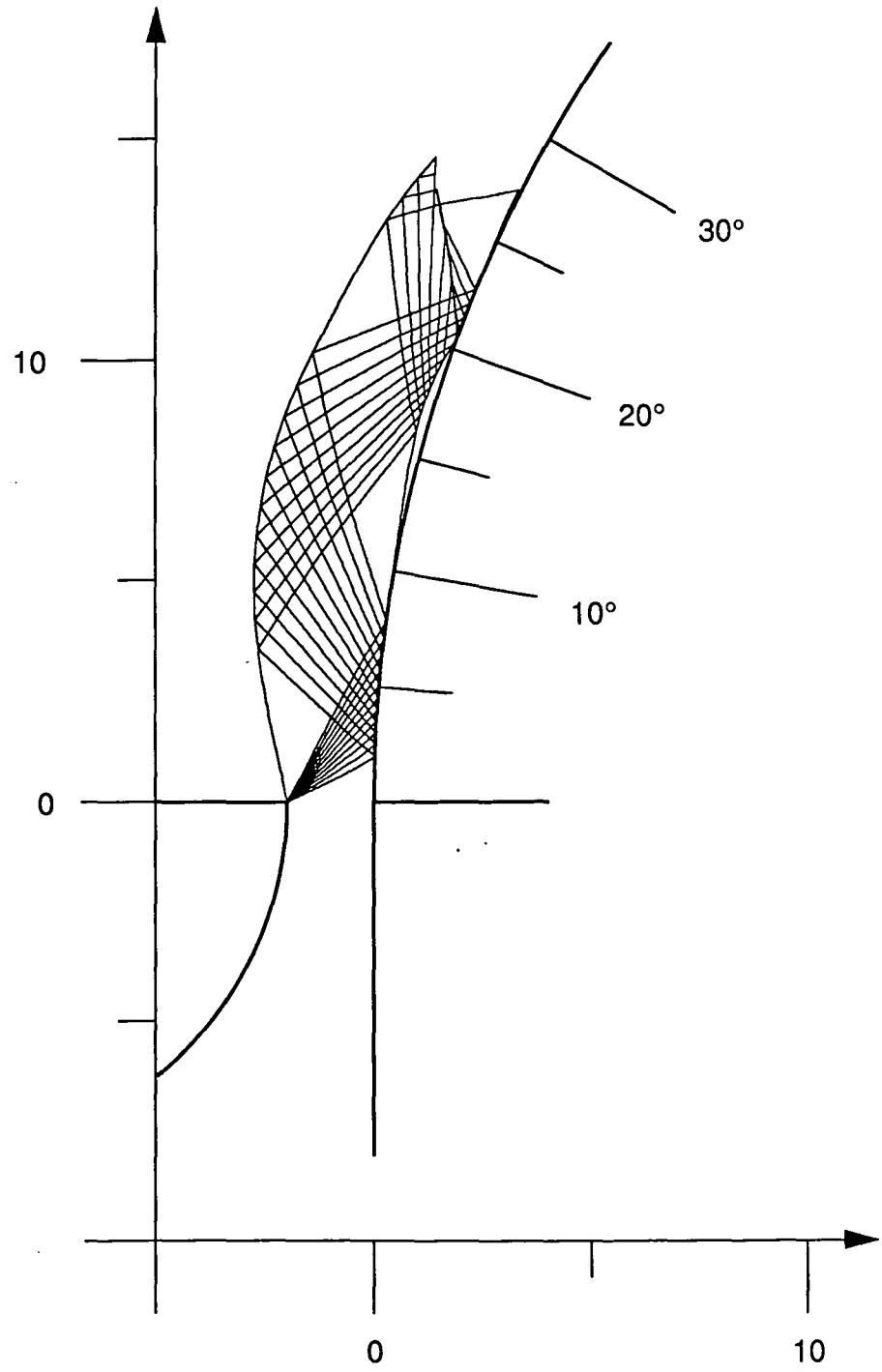


Figure 7.2.19.

Planar Coanda Model
Method of Characteristics Plot

Shock Fitting; Separation Model
Slot = 2.00 mm Step = 0.00 mm
Patm/Po = 0.258

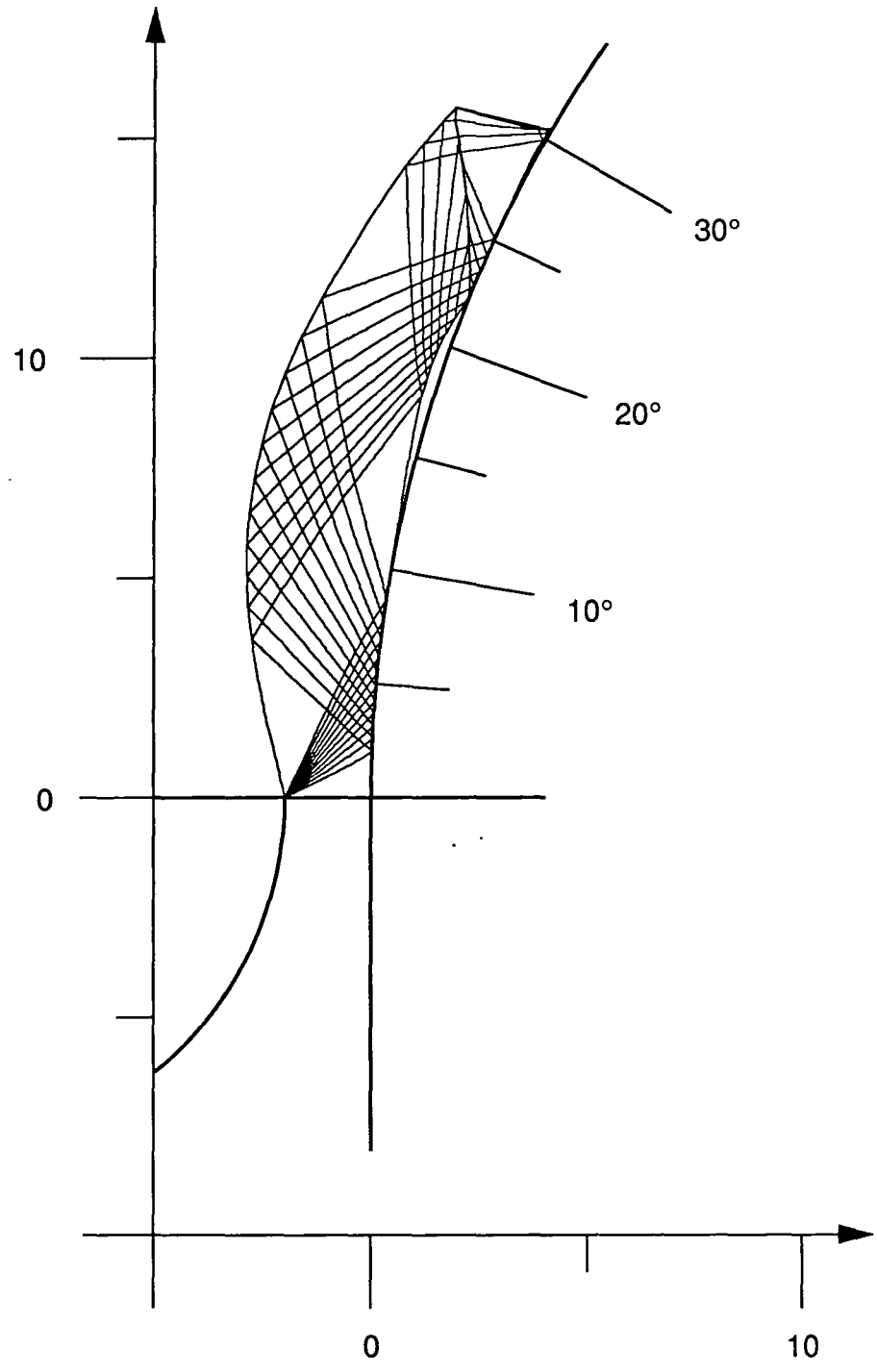


Figure 7.2.20.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting;Separation Model
Step = 2.00mm Slot = 0.00mm
Patm/Po = 0.243

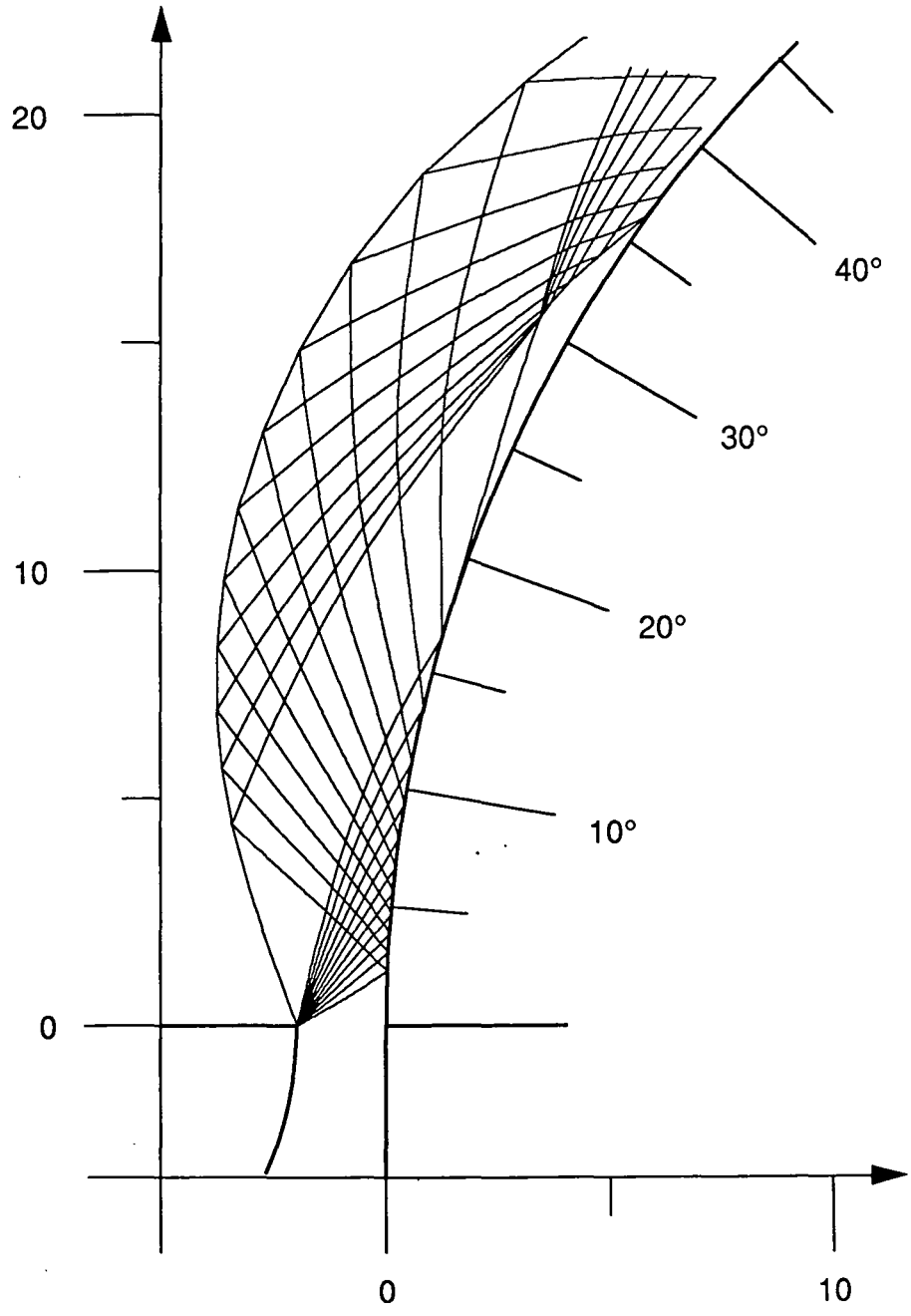


Figure 7.2.21.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 2.00 mm Step = 0.00 mm
Patm/Po = 0.176

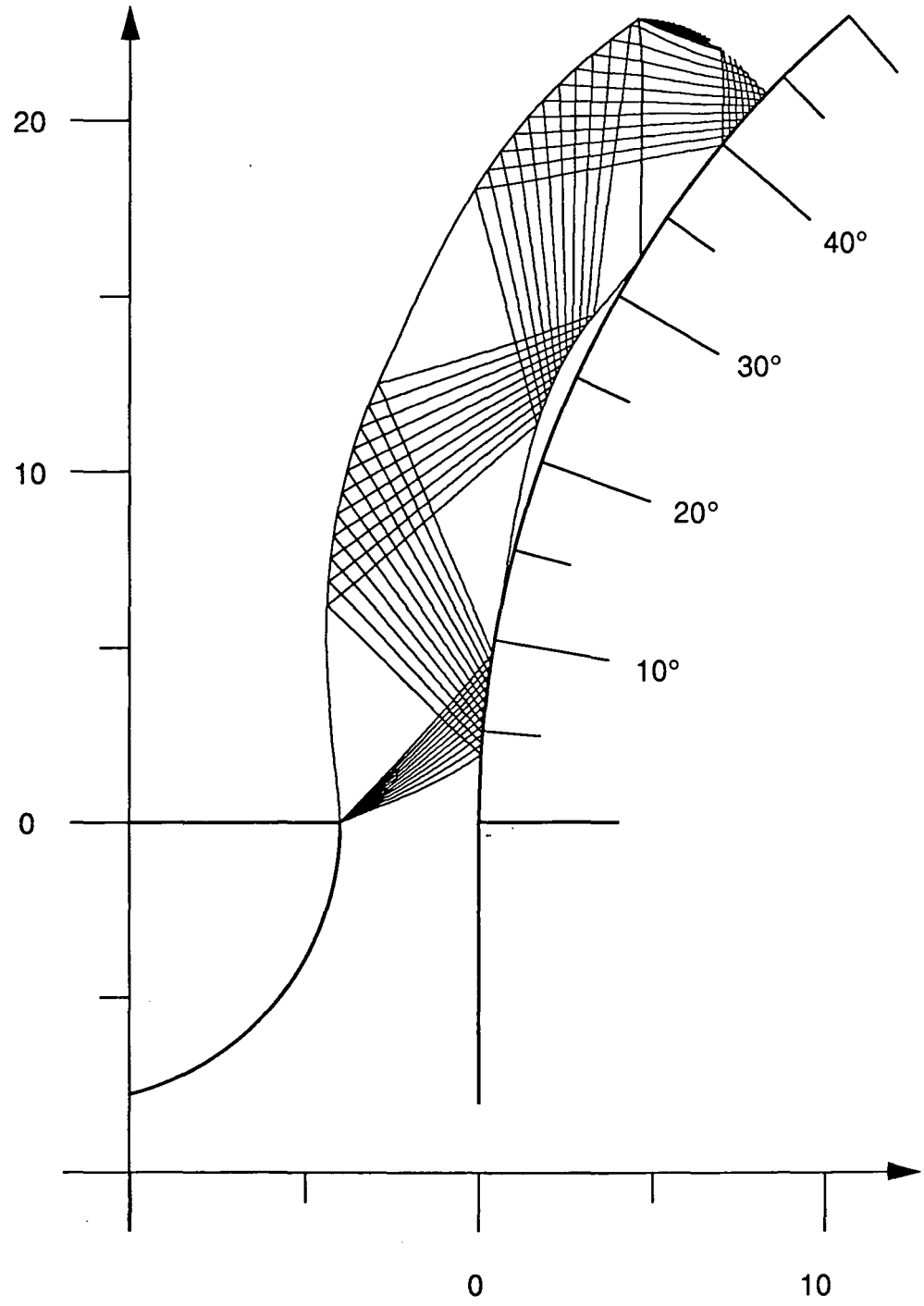


Figure 7.2.22.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 4.00 mm Step = 0.00 mm
Patm/Po = 0.355

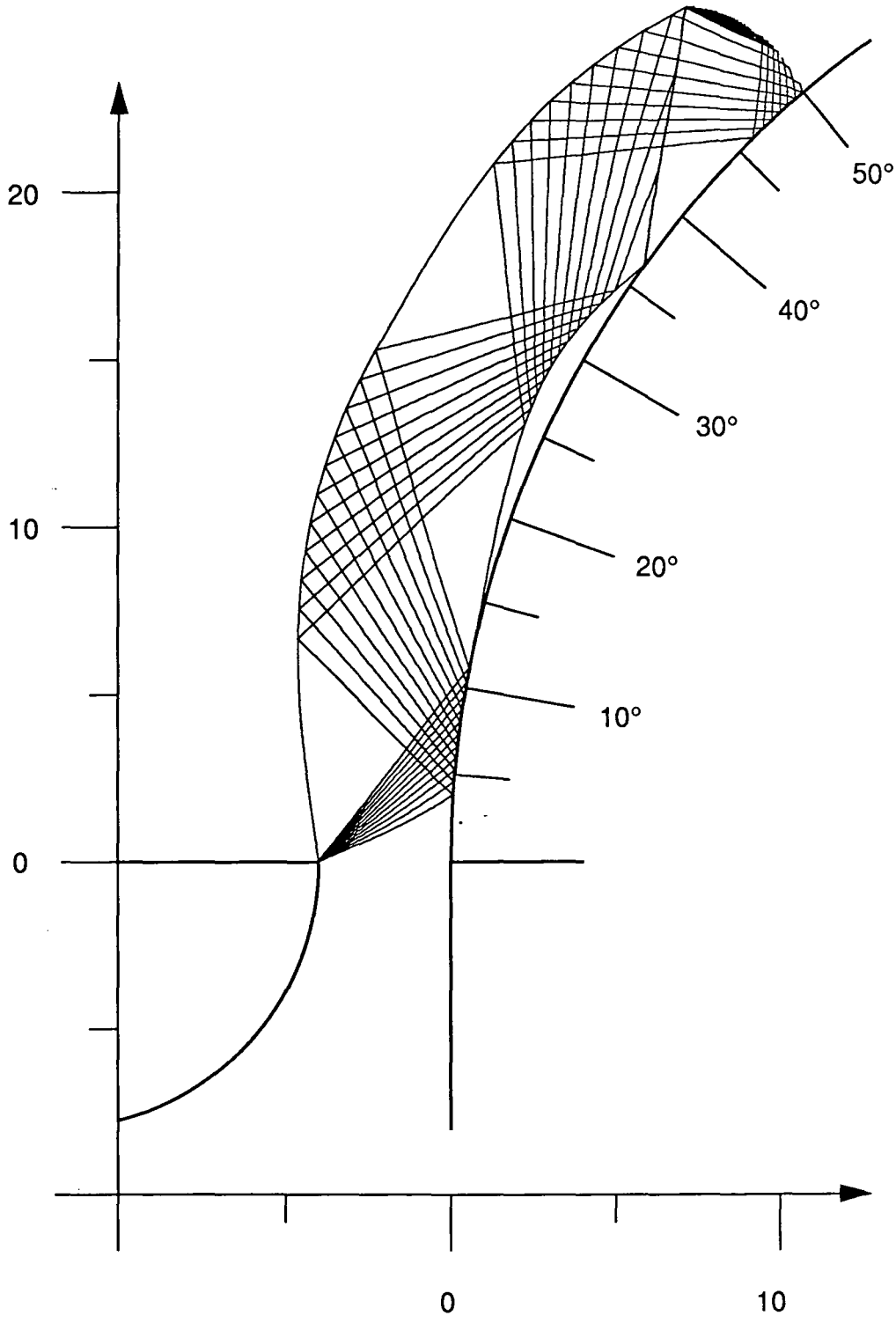


Figure 7.2.23.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 4.00 mm Step = 0.00 mm
Patm/Po = 0.324

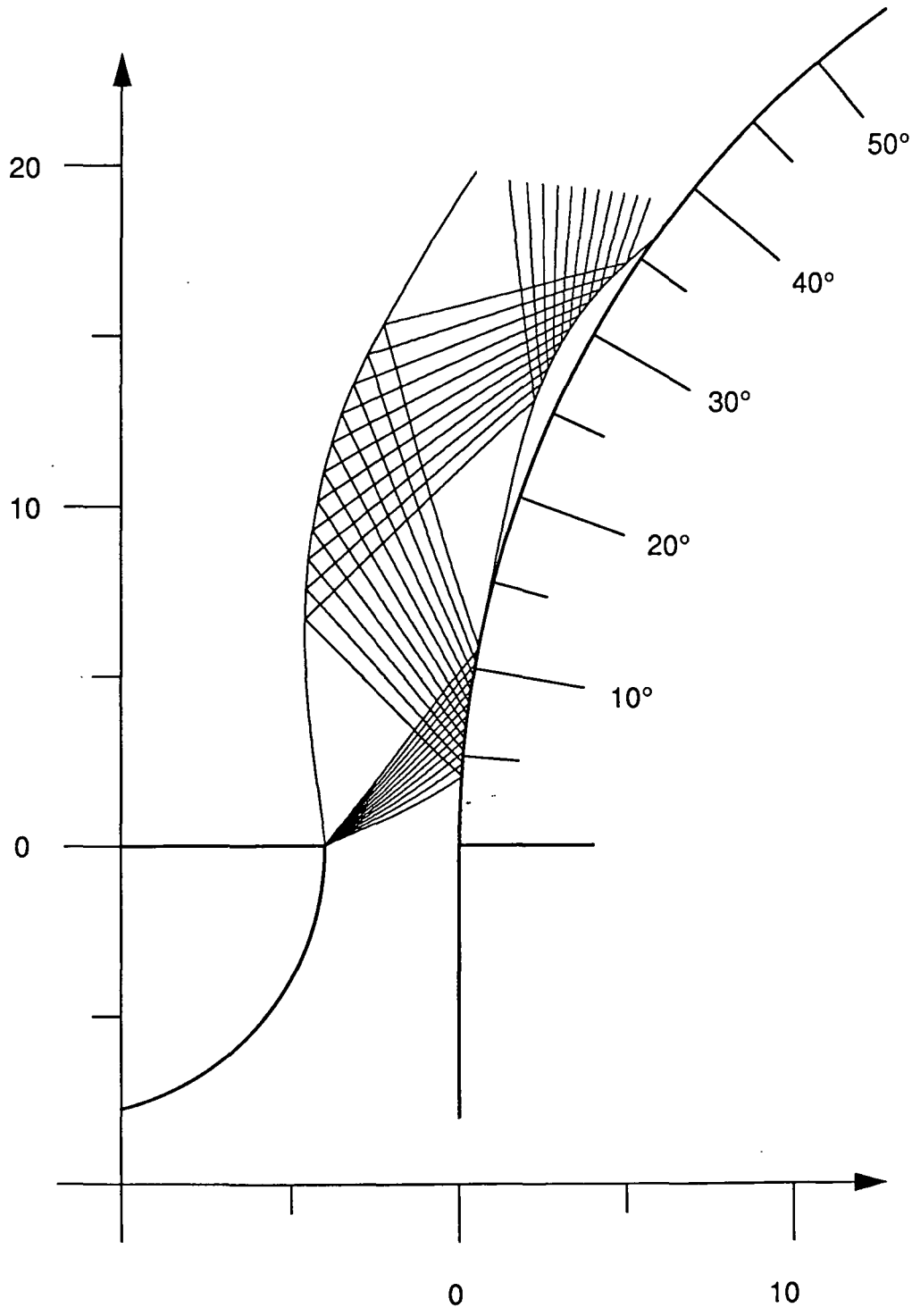


Figure 7.2.24.

Planar Coanda Model
Method of Characteristics Plot
Separation Model
Slot = 4.00 mm Step = 0.00 mm
Patm/Po = 0.324

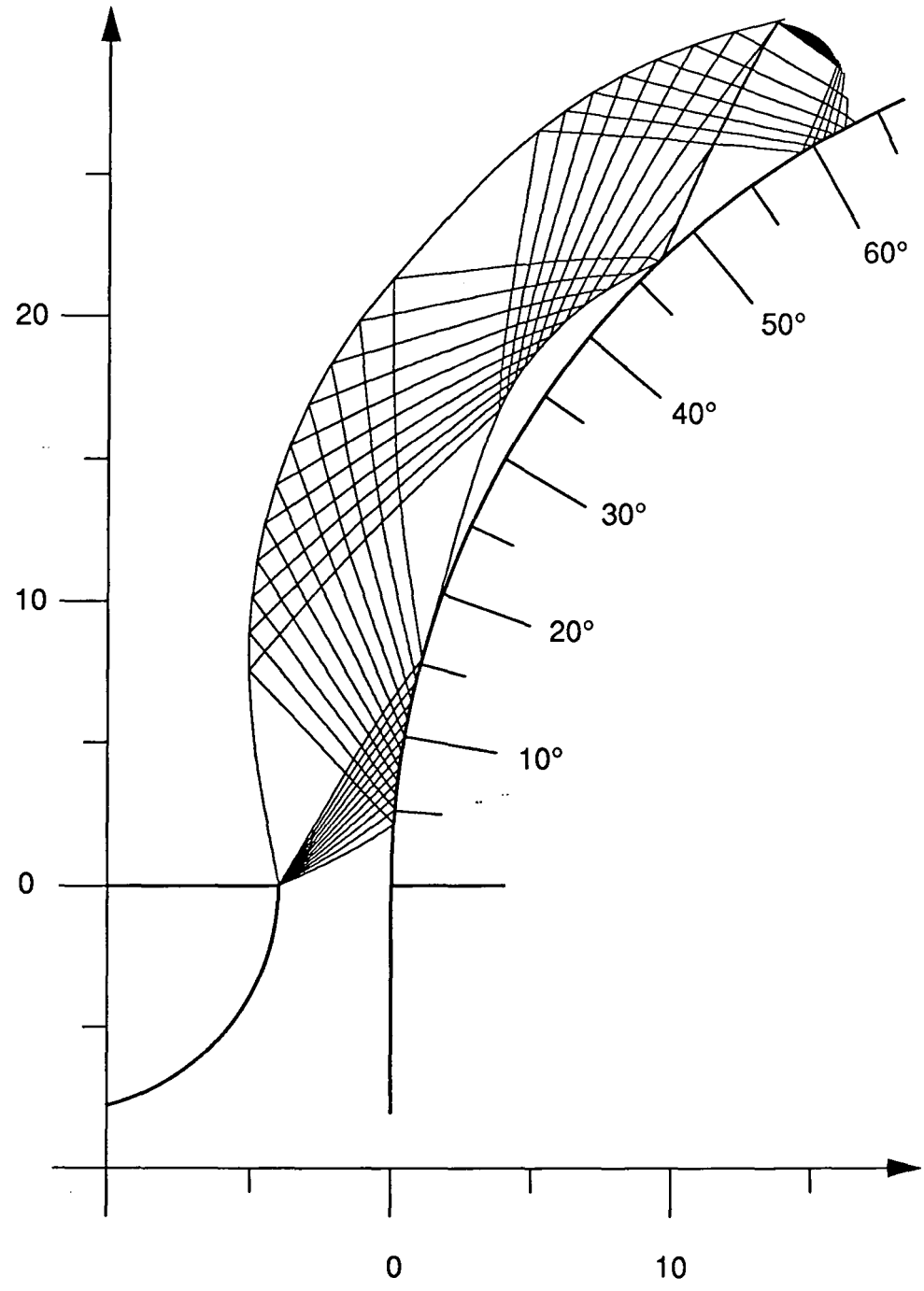


Figure 7.2.25.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 4.00 mm Step = 0.00 mm
Patm/Po = 0.277

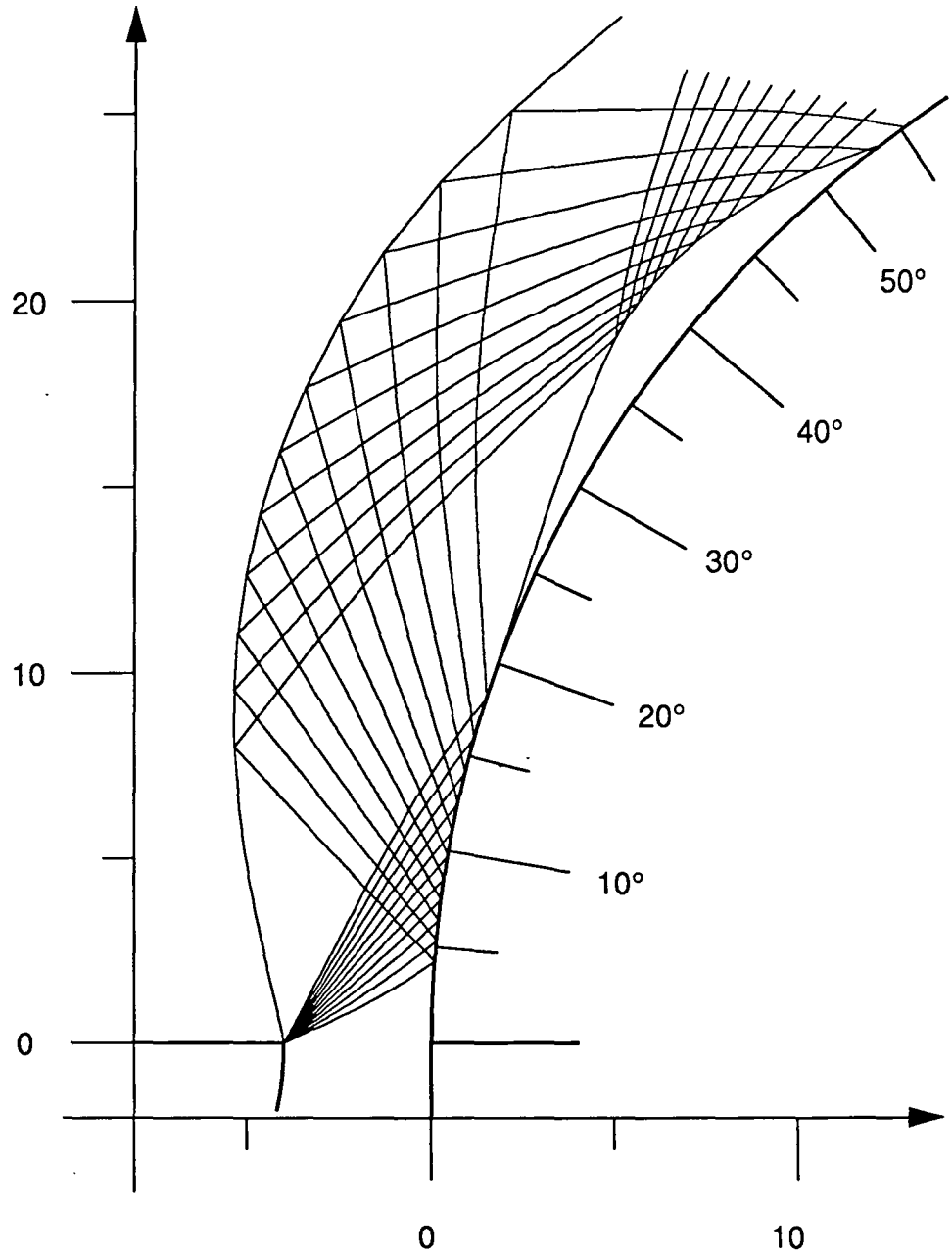


Figure 7.2.26.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 4.00 mm Step = 0.00 mm
Patm/Po = 0.256

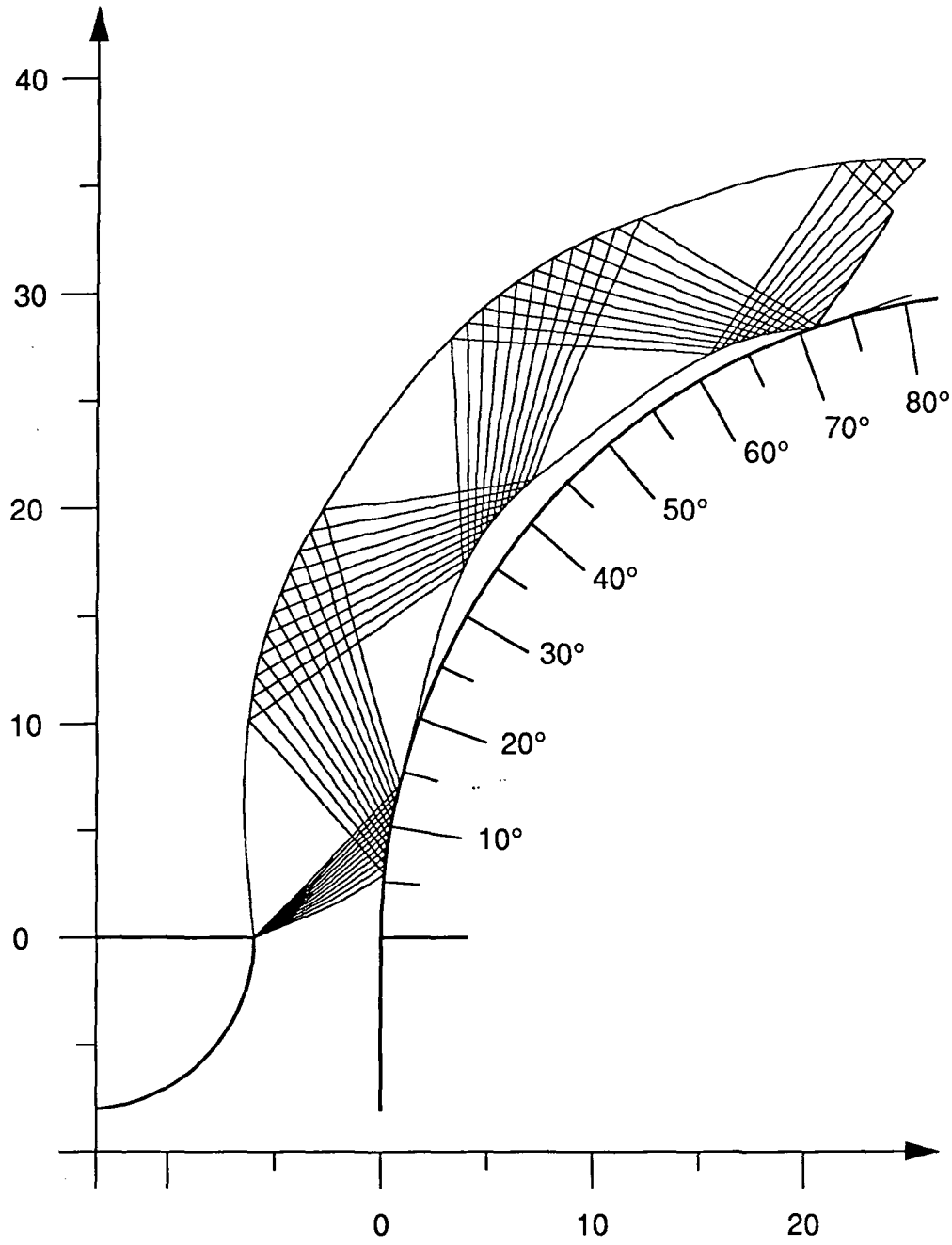


Figure 7.2.27.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 6.00 mm Step = 0.00 mm
Patm/Po = 0.366

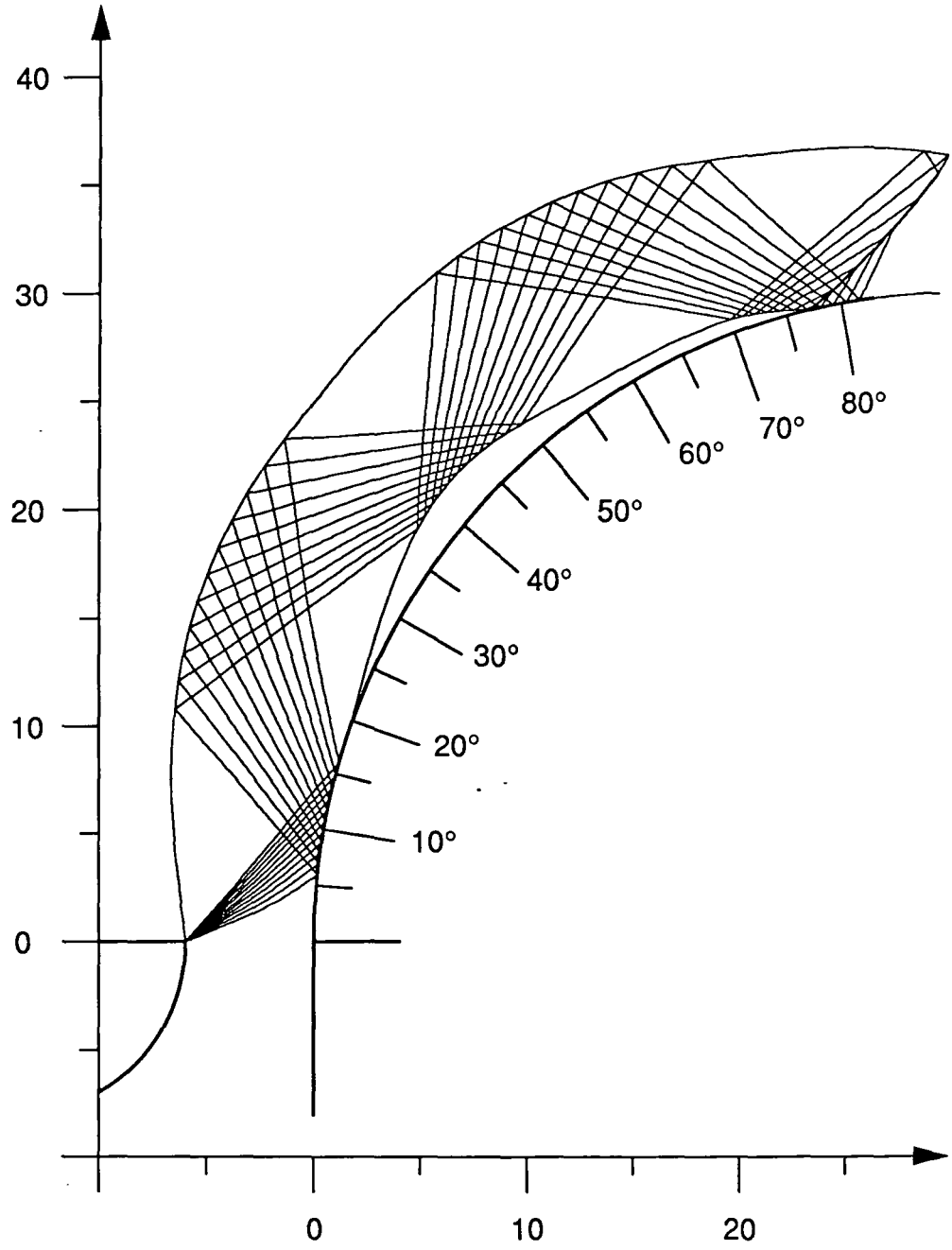


Figure 7.2.28. Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 6.00 mm Step = 0.00 mm
Patm/Po = 0.343

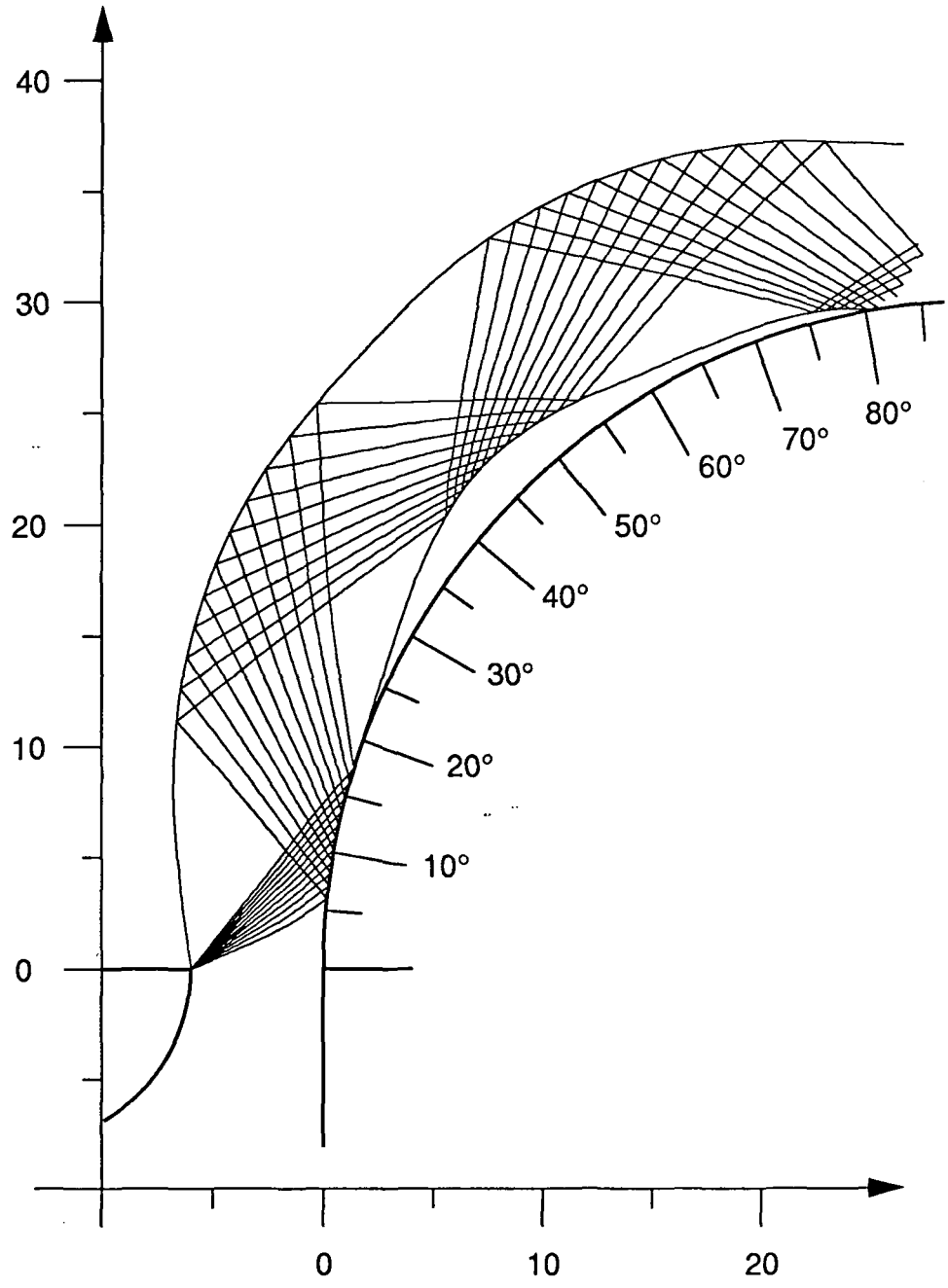


Figure 7.2.29.

Planar Coanda Model
Method of Characteristics Plot

Shock Fitting; Separation Model
Slot = 6.00 mm Step = 0.00 mm
Patm/Po = 0.330

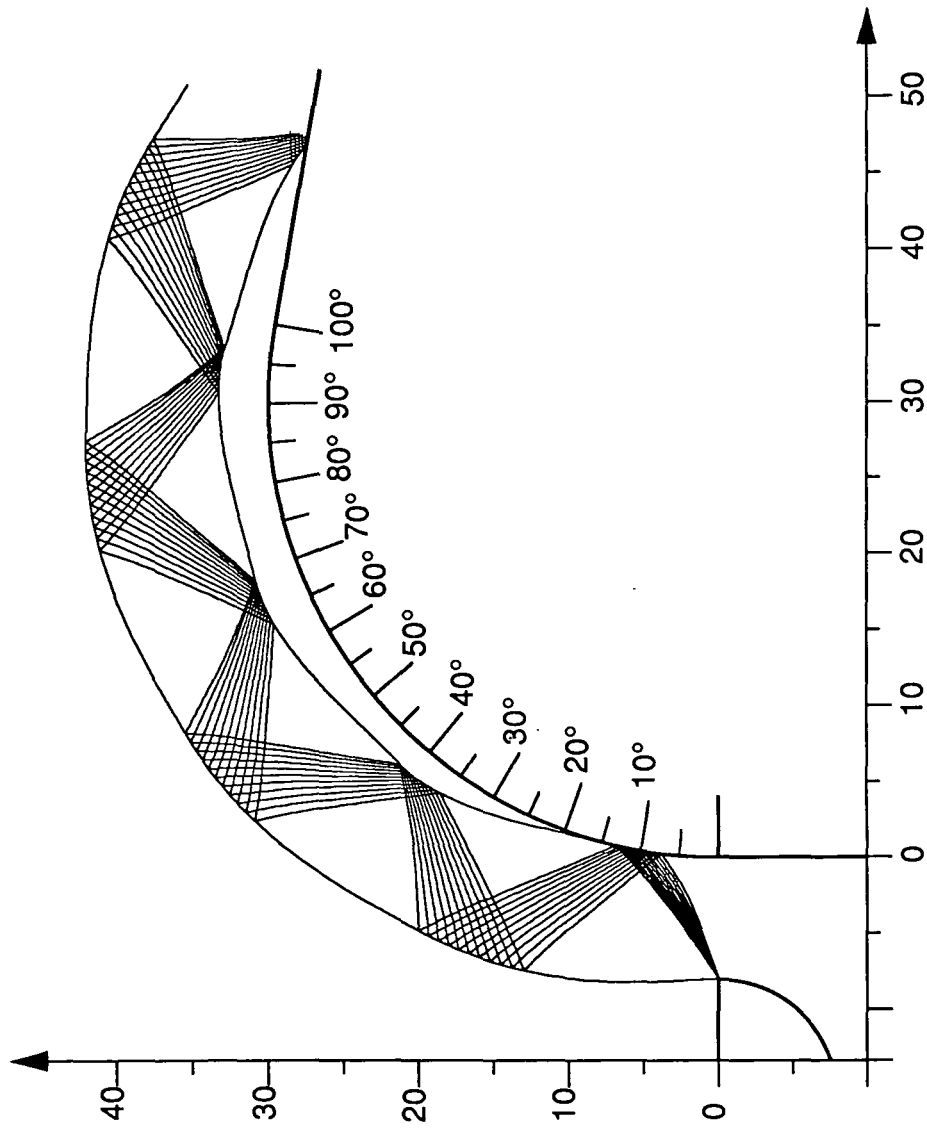


Figure 7.2.30.

Planar Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 8.00 mm Step = 0.00 mm
Patm/Po = 0.425

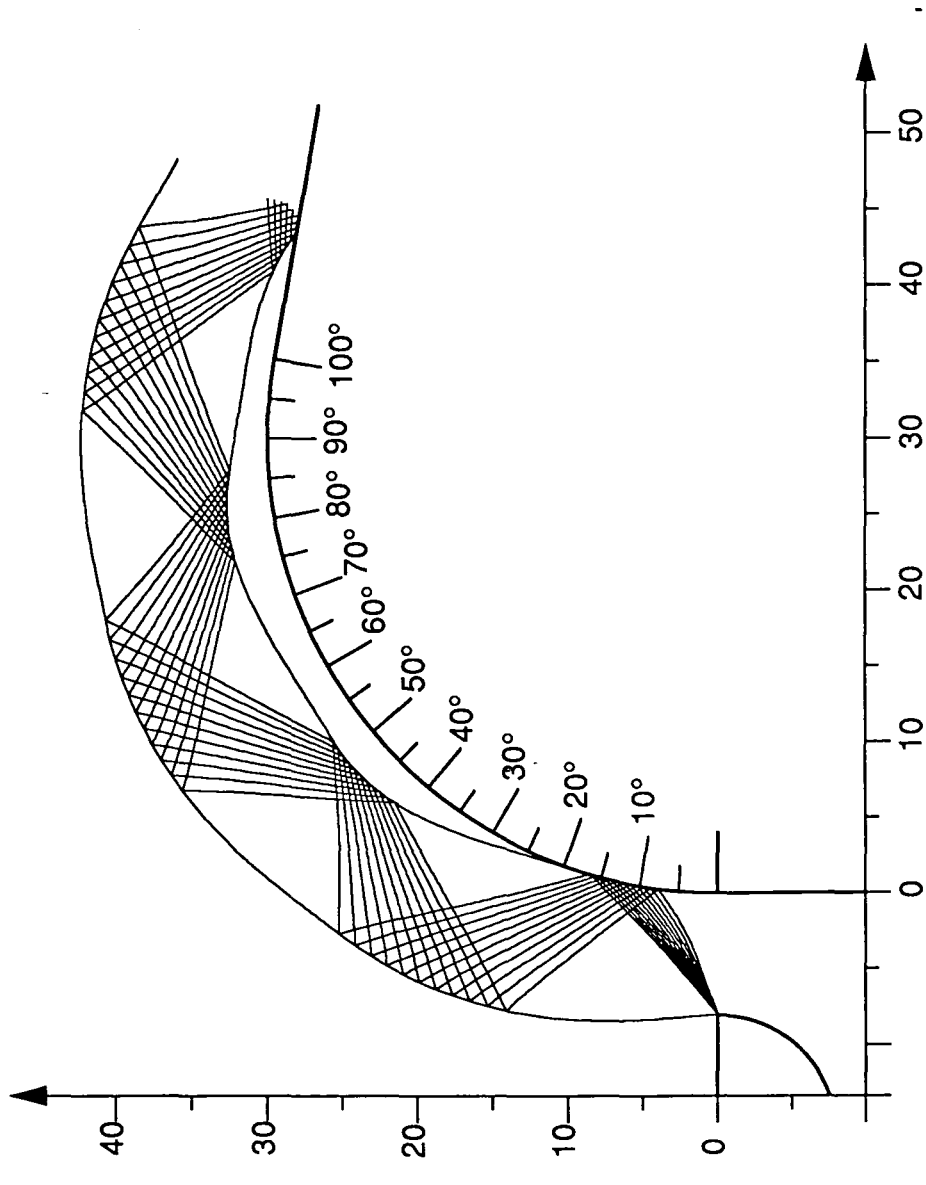


Figure 7.2.31.

Planar Coanda Model
Method of Characteristics Plot

Shock Fitting; Separation Model
Slot = 8.00 mm Step = 0.00 mm
Patm/Po = 0.391

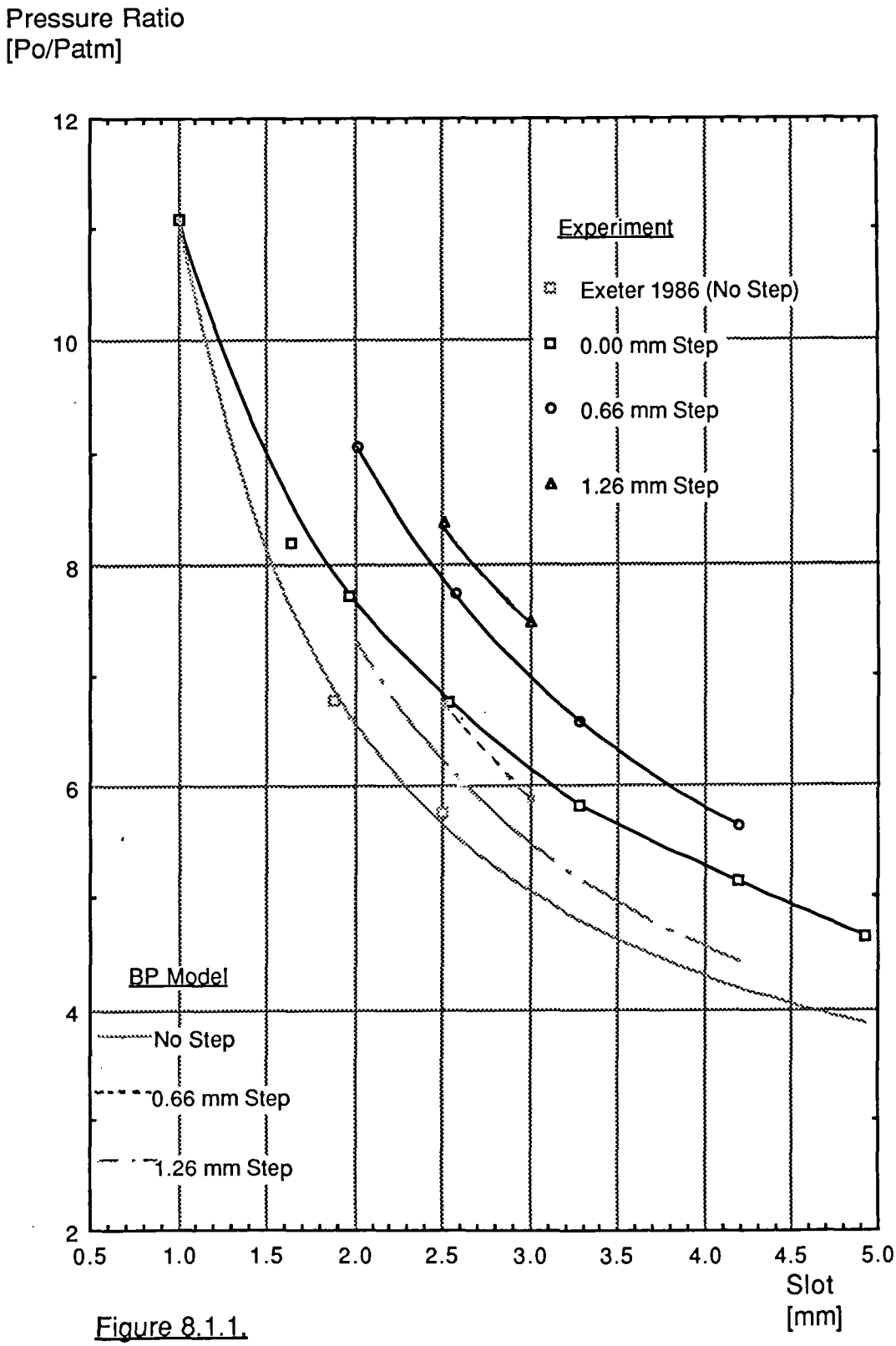


Figure 8.1.1.

Axisymmetric Coanda Model
Breakaway Performance

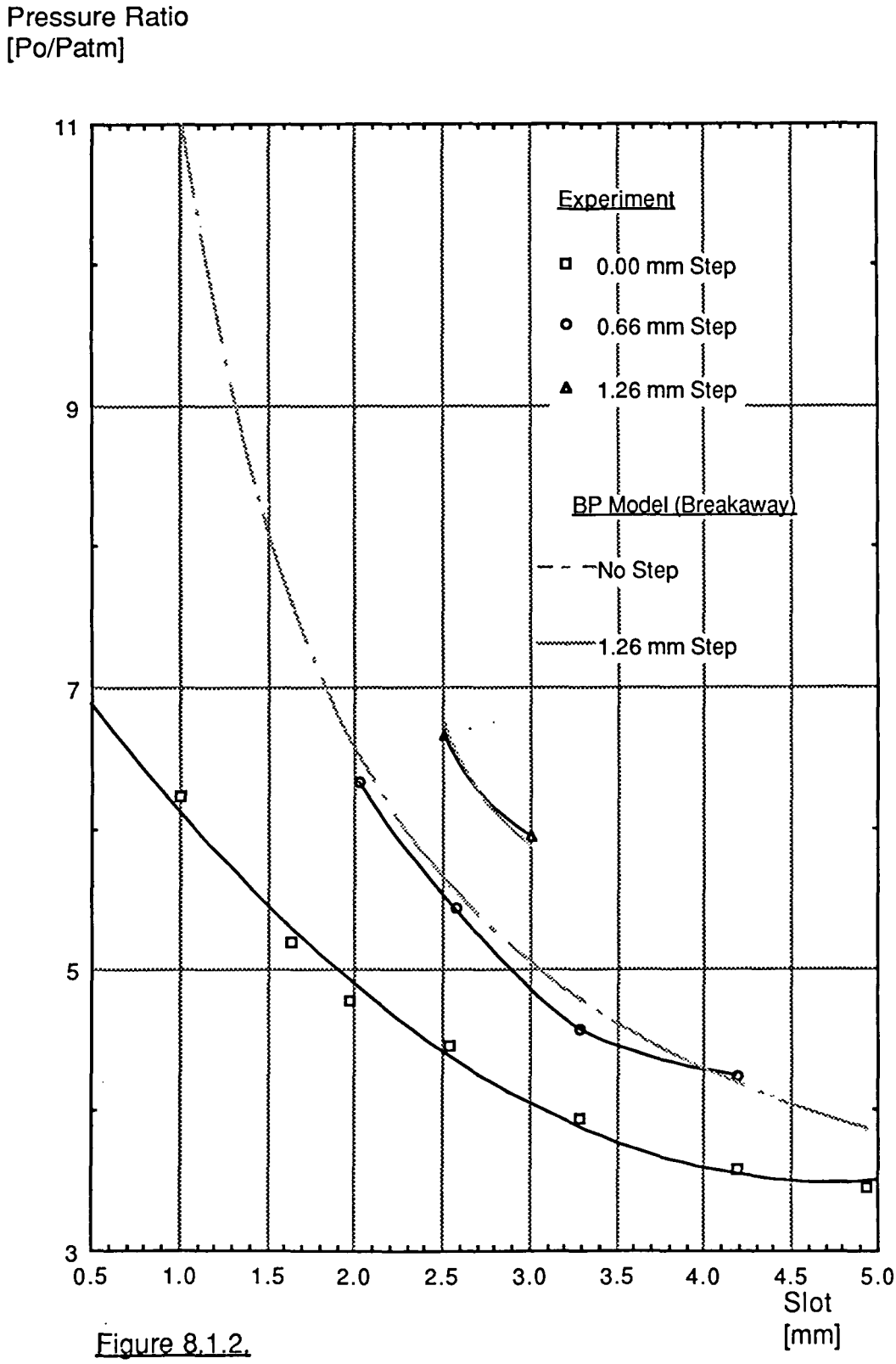


Figure 8.1.2.

Axisymmetric Coanda Model
Reversion Performance

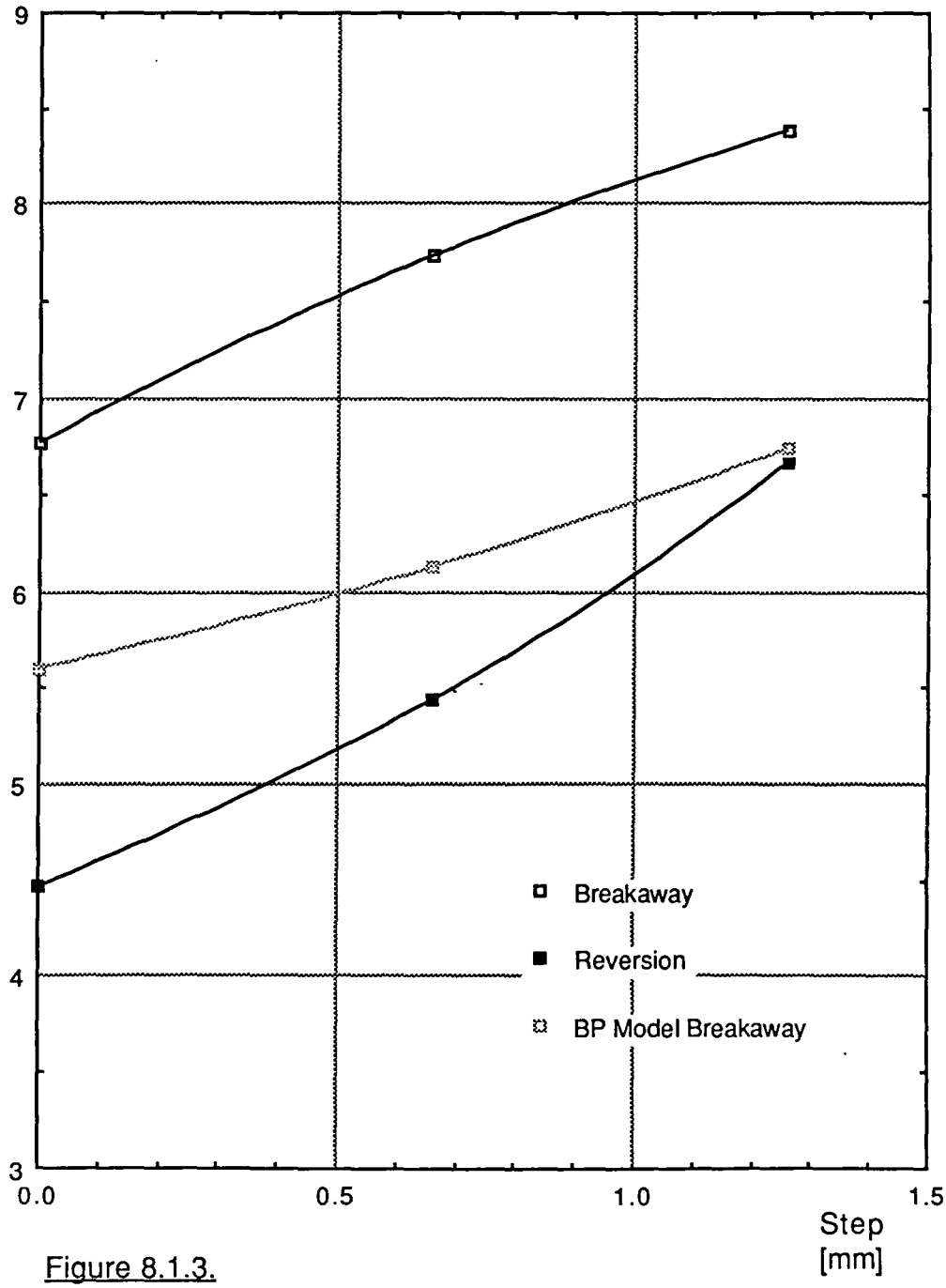


Figure 8.1.3.

Axisymmetric Coanda Model: 2.55mm Slot Breakaway/Reversion Behaviour

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Fig. 8.1.3 PLANAR COANDA MODEL PARTIAL REVERSION BEHAVIOUR.

Fig. 8.1.4

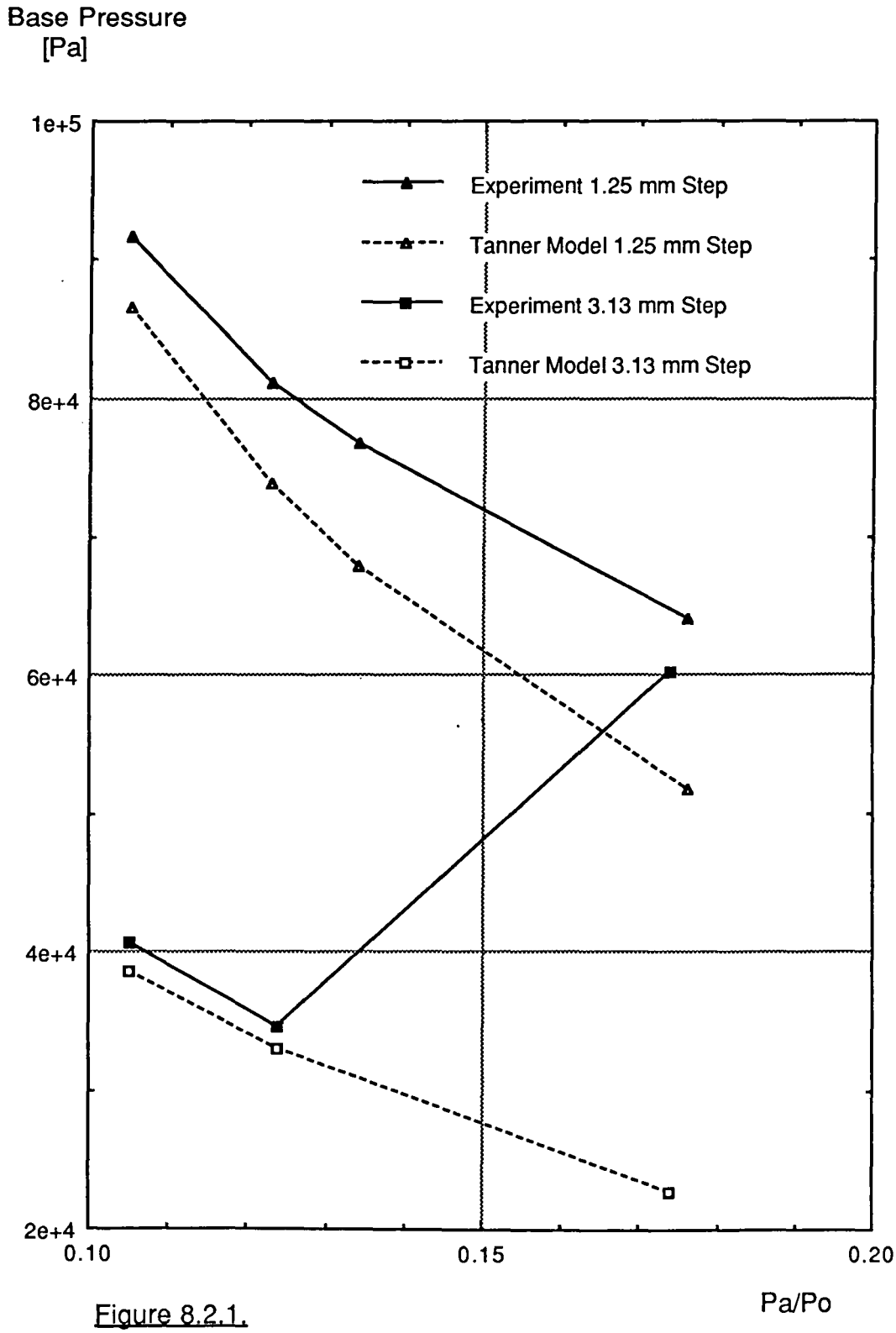


Figure 8.2.1.

Axisymmetric Coanda Model
Base Pressures: 1.67 mm Slot

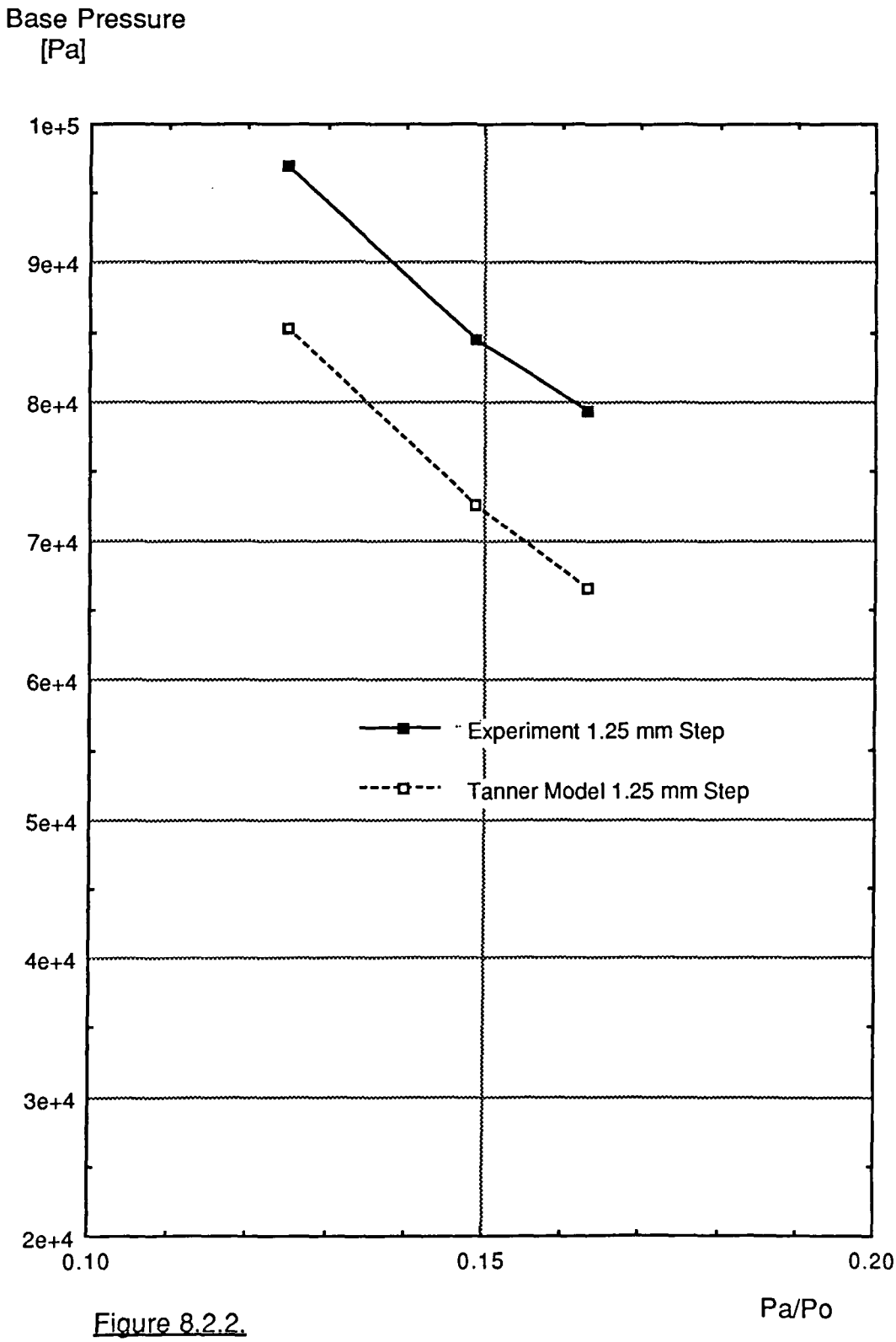


Figure 8.2.2.

Axisymmetric Coanda Model
Base Pressures: 2.55 mm Slot

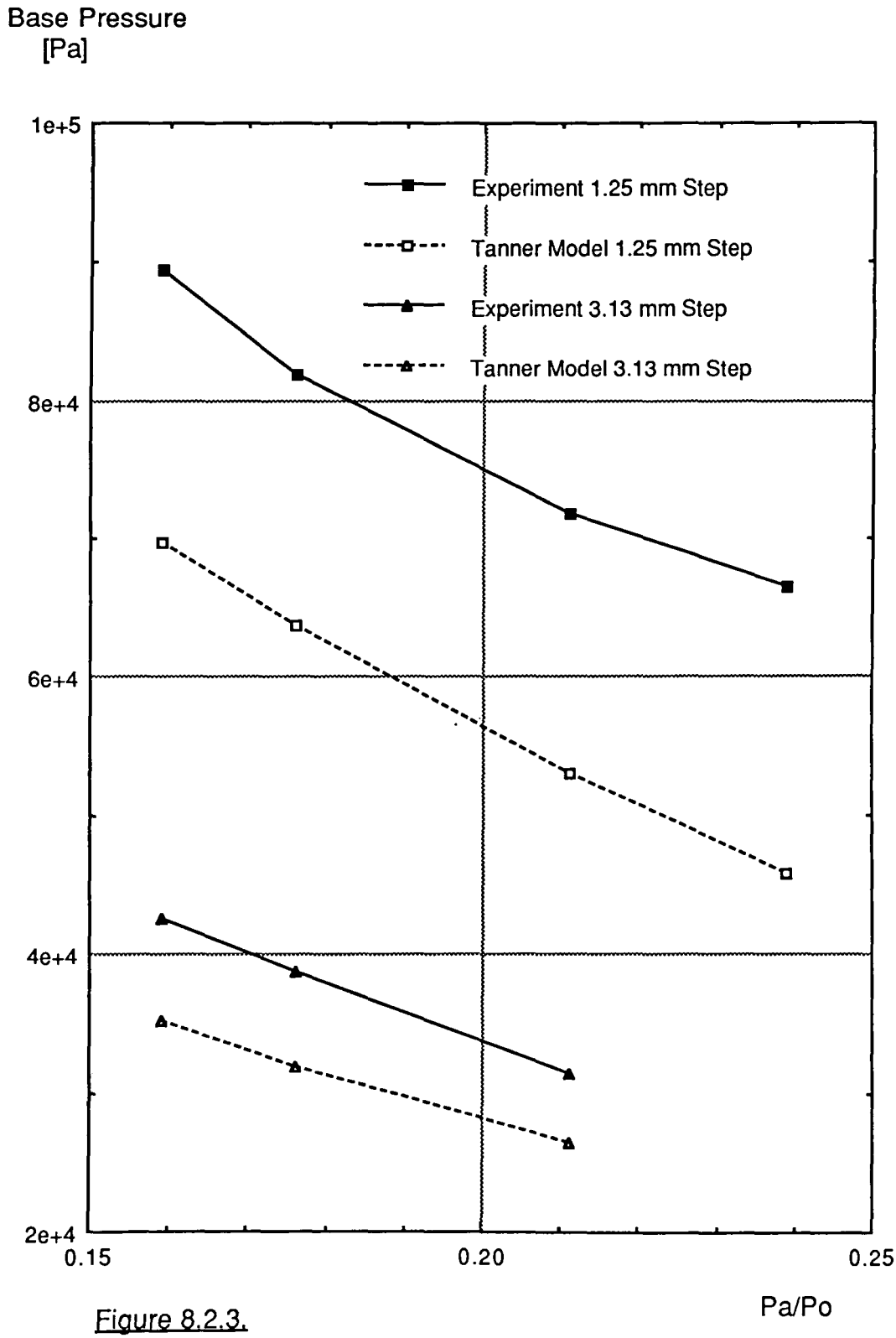


Figure 8.2.3.

Axisymmetric Coanda Model
Base Pressures: 3.33 mm Slot

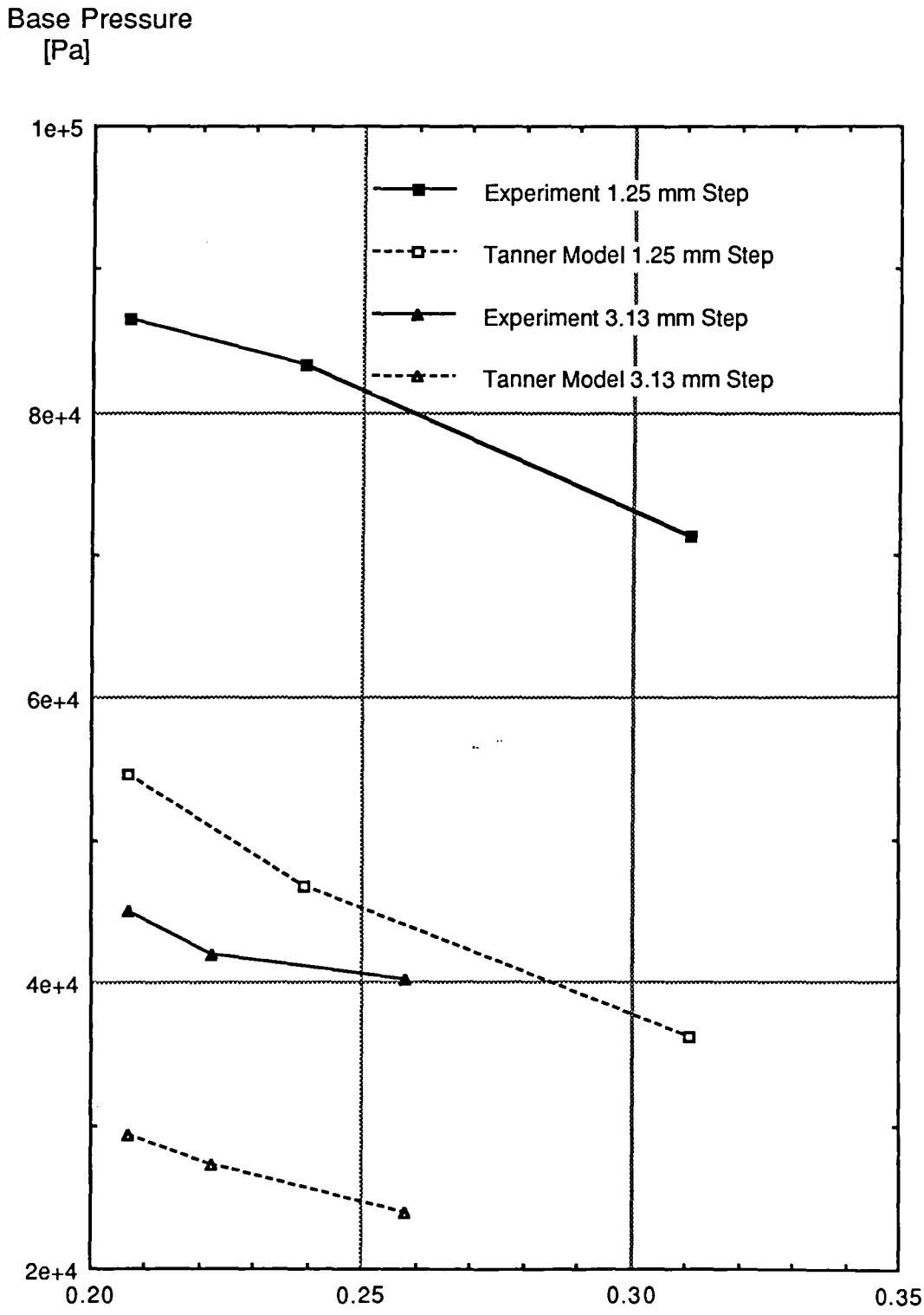


Figure 8.2.4.

Axisymmetric Coanda Model
Base Pressures: 5.00 mm Slot

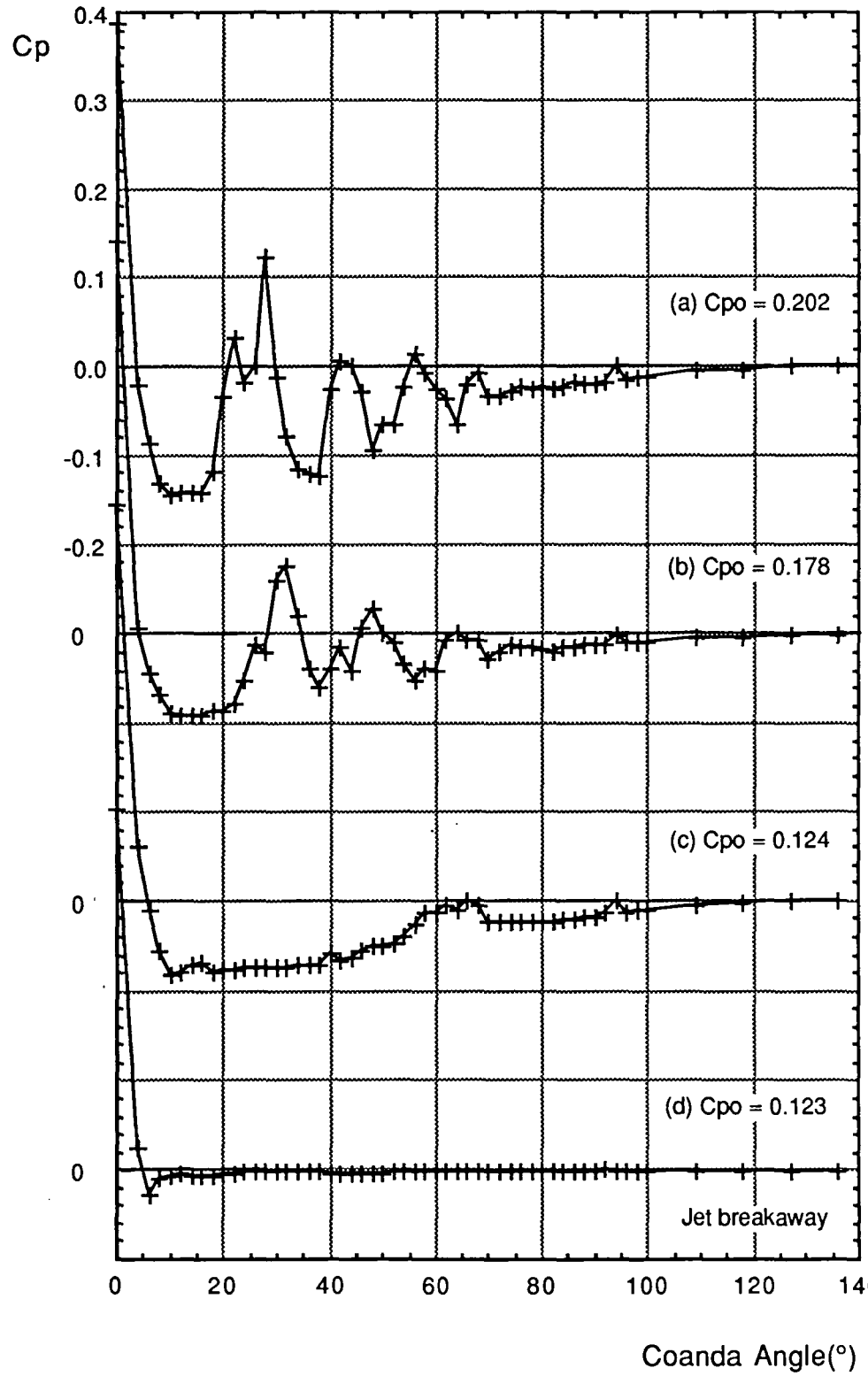


Figure 8.1.5.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 1.67 mm; Step = 0.00 mm

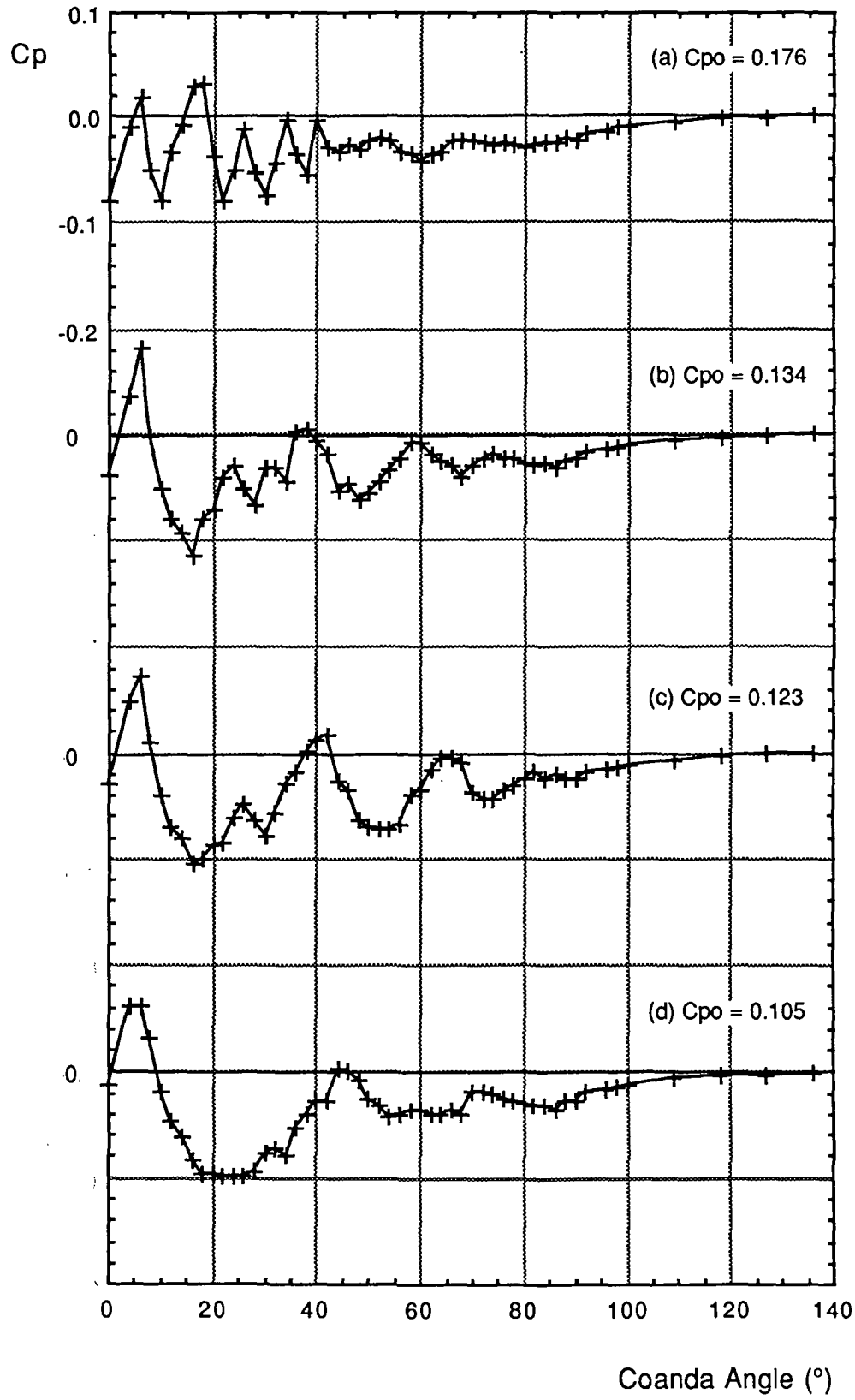


Figure 8.1.6.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 1.67 mm; Step = 1.25 mm

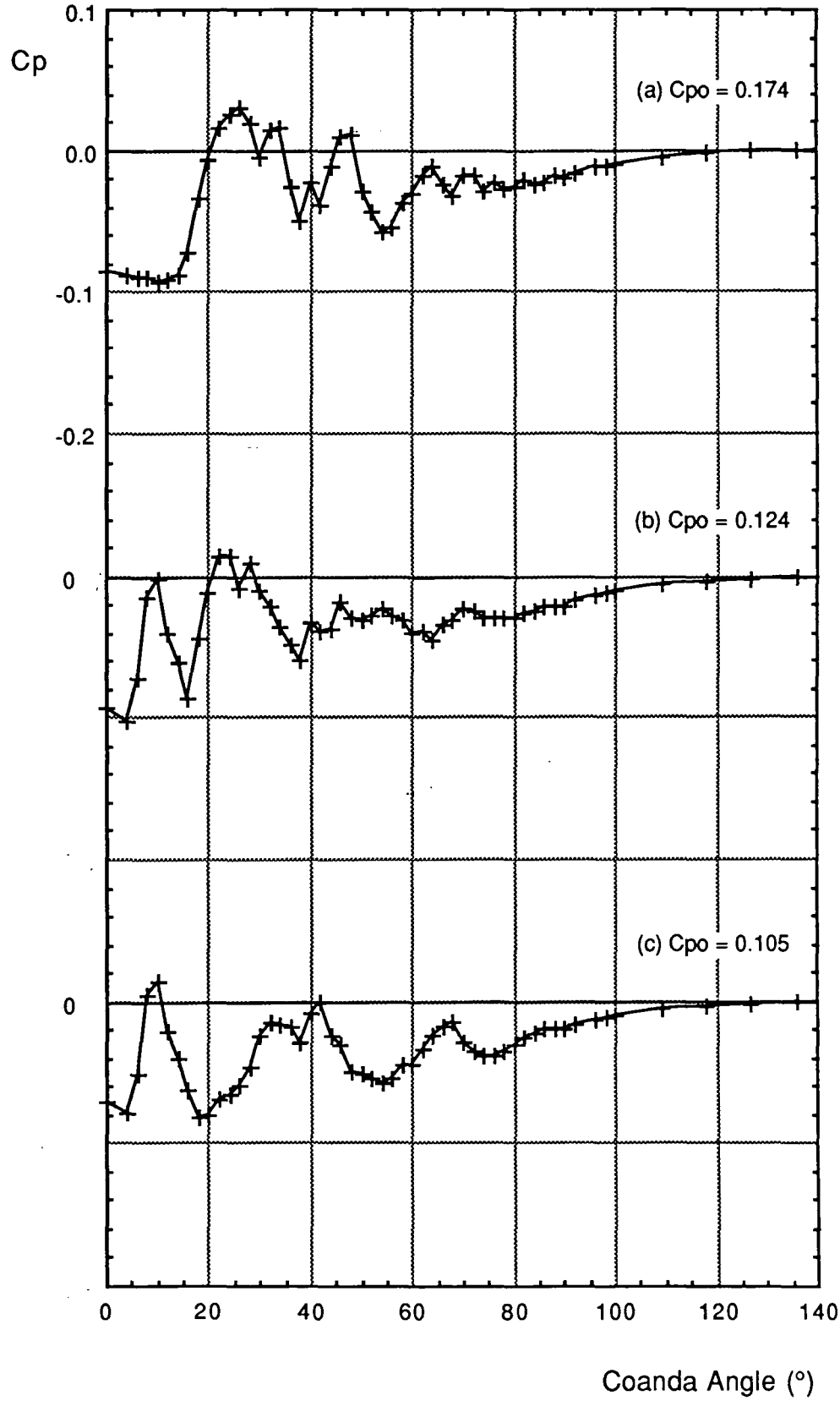


Figure 8.1.7.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 1.67 mm; Step = 3.13 mm

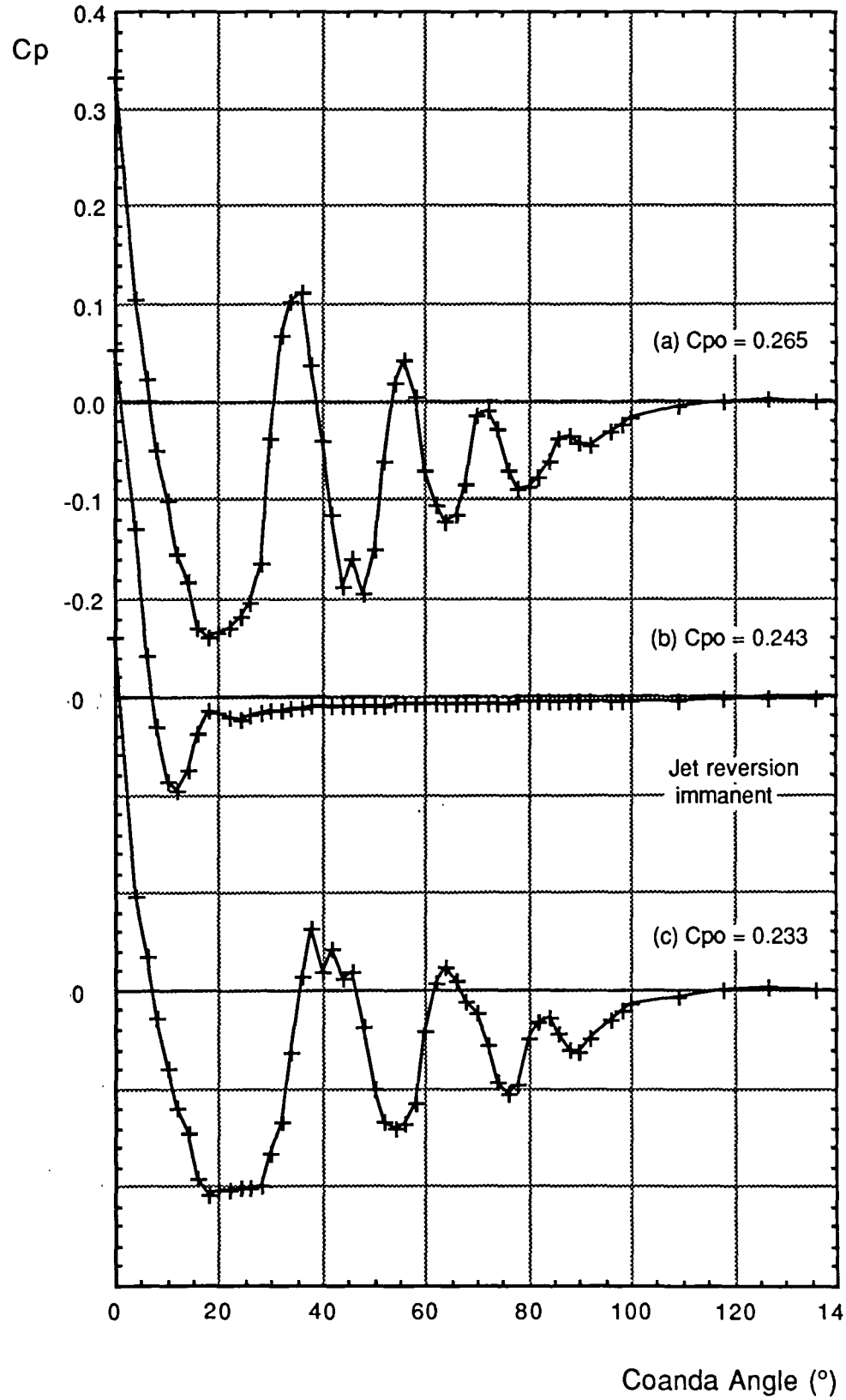


Figure 8.1.8.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 3.33 mm; Step = 0.00 mm

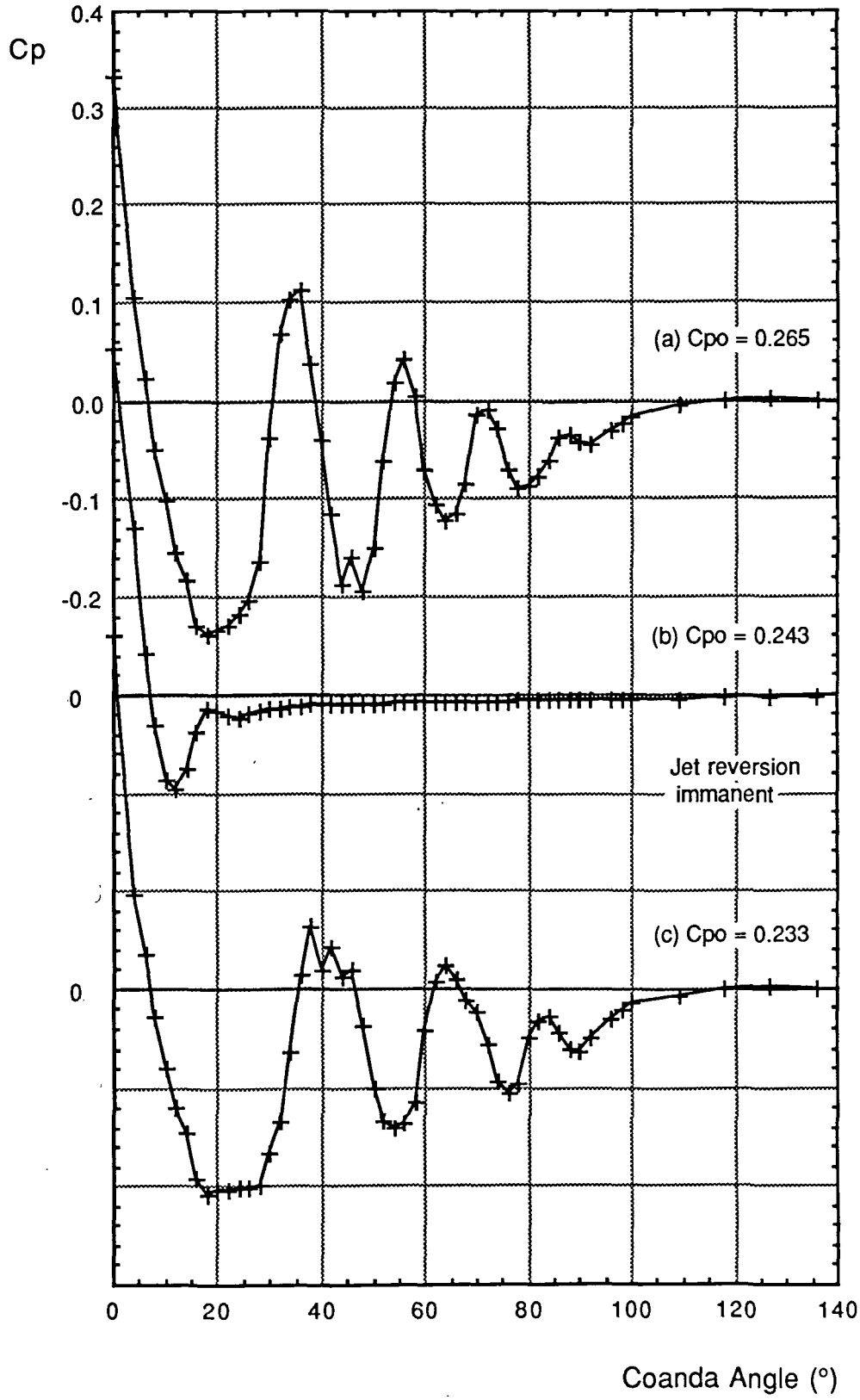


Figure 8.1.8.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 3.33 mm; Step = 0.00 mm

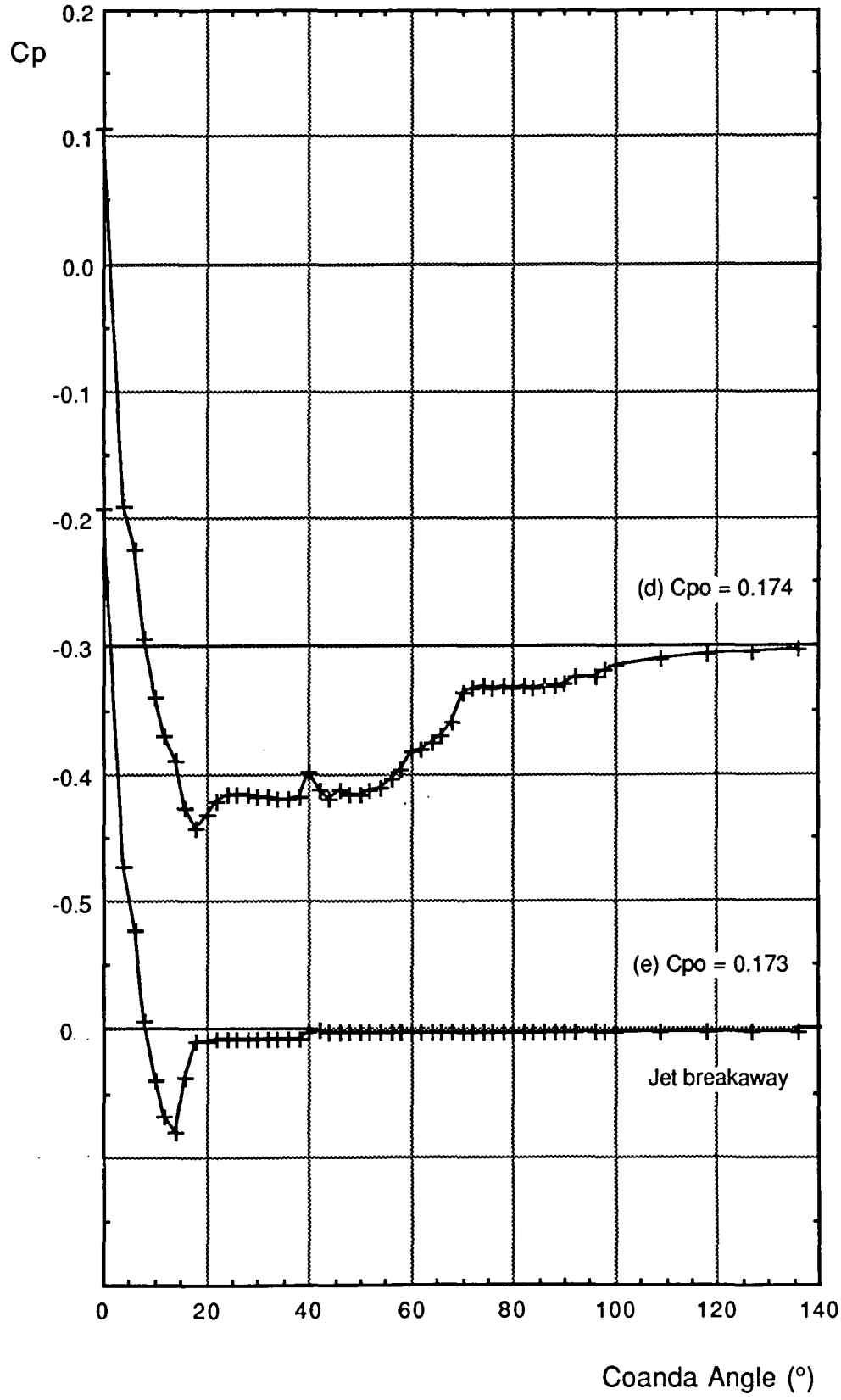


Figure 8.1.9.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 3.33 mm; Step = 0.00 mm

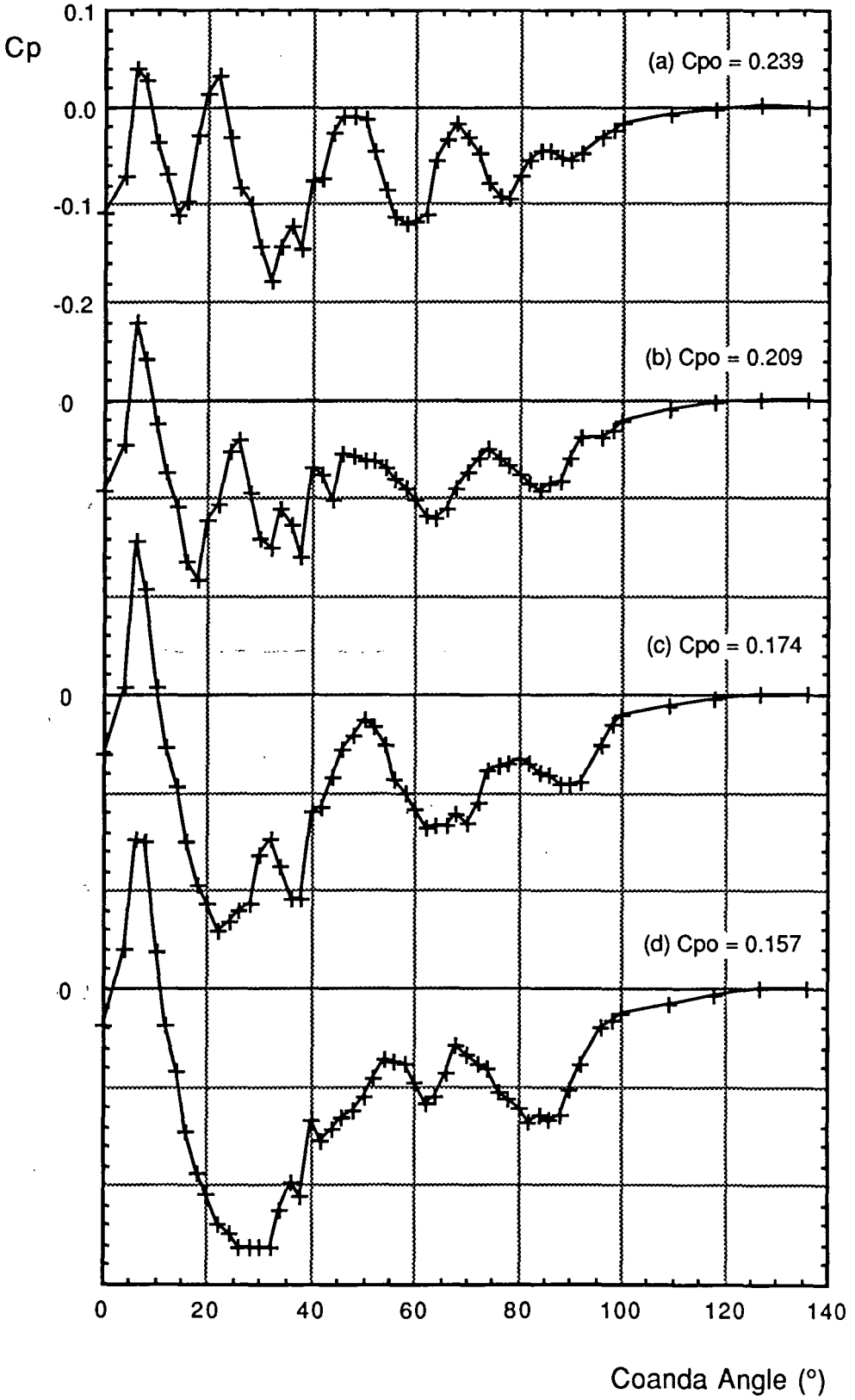


Figure 8.1.10.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 3.33 mm; Step = 1.25 mm

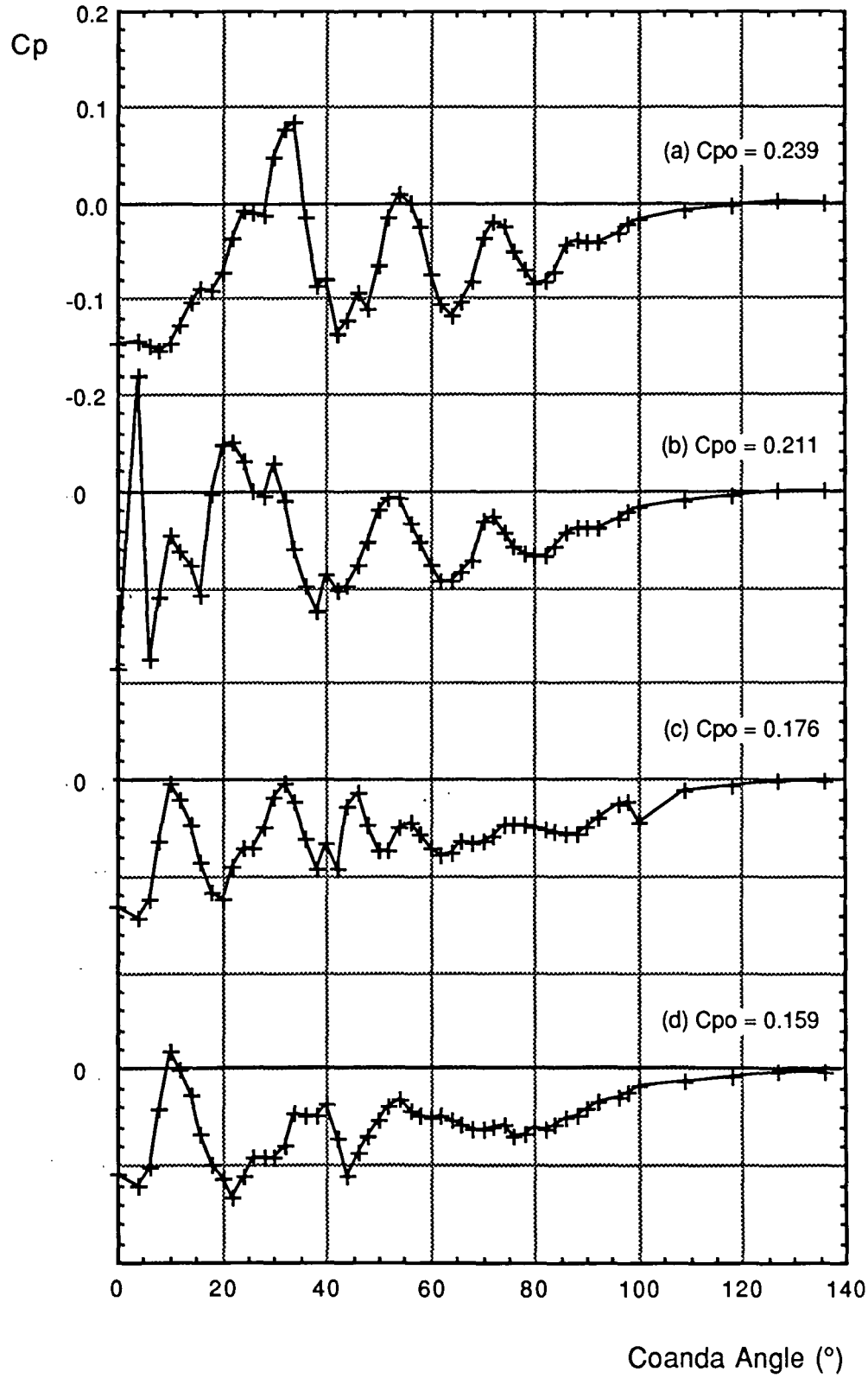


Figure 8.1.11.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 3.33 mm; Step = 3.13 mm

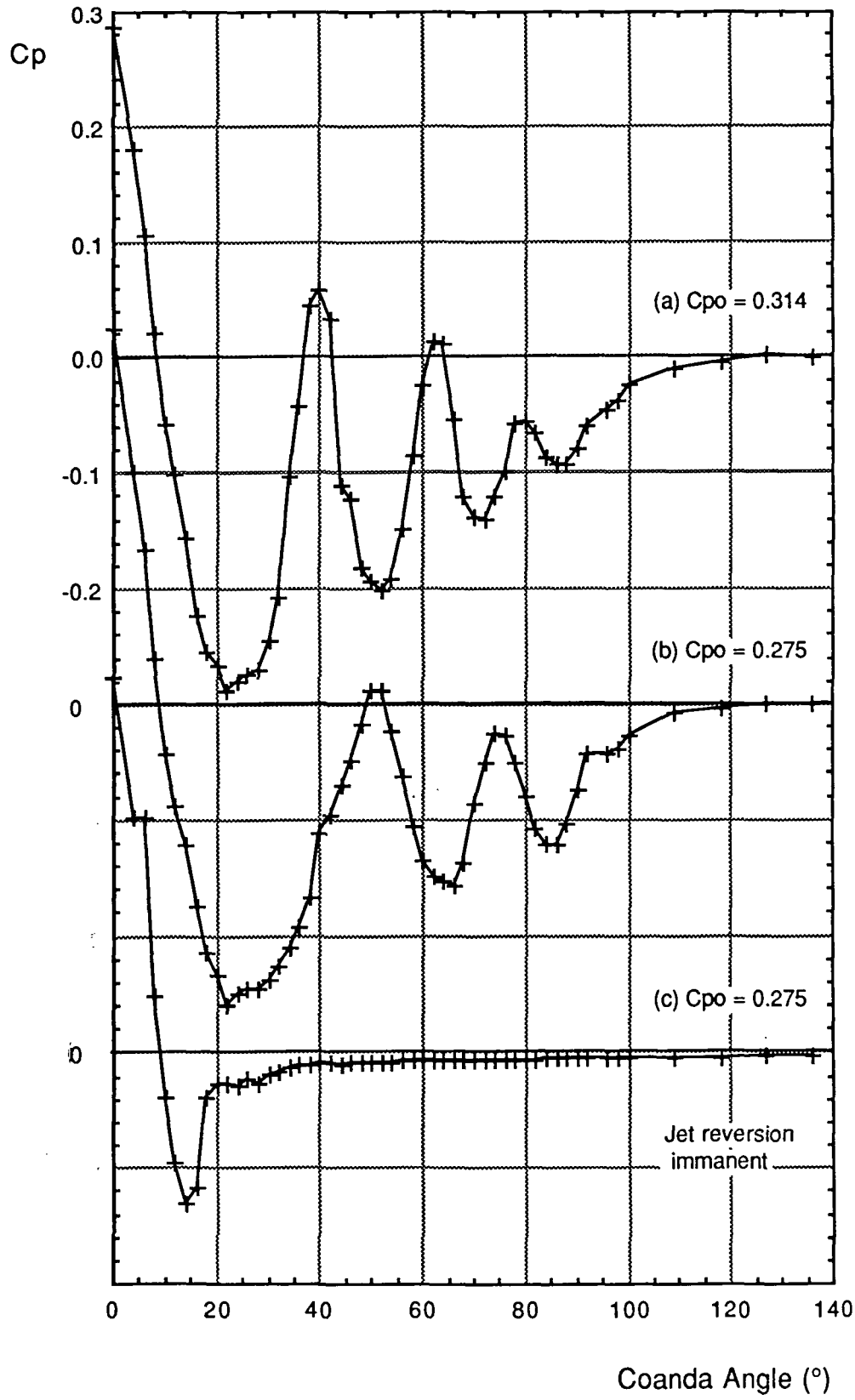


Figure 8.1.12.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 5.00 mm; Step = 0.00 mm

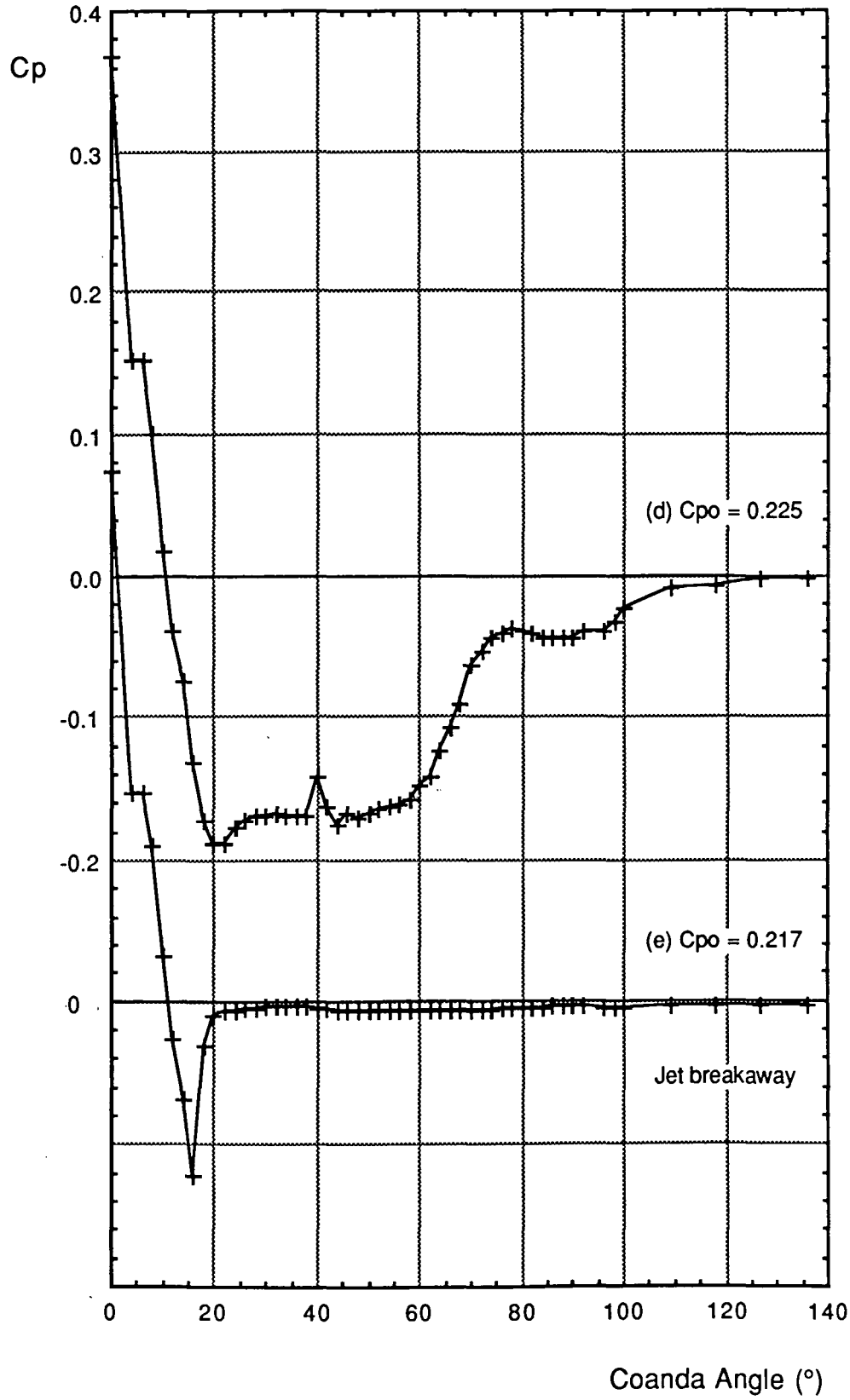


Figure 8.1.13.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 5.00 mm; Step = 0.00 mm

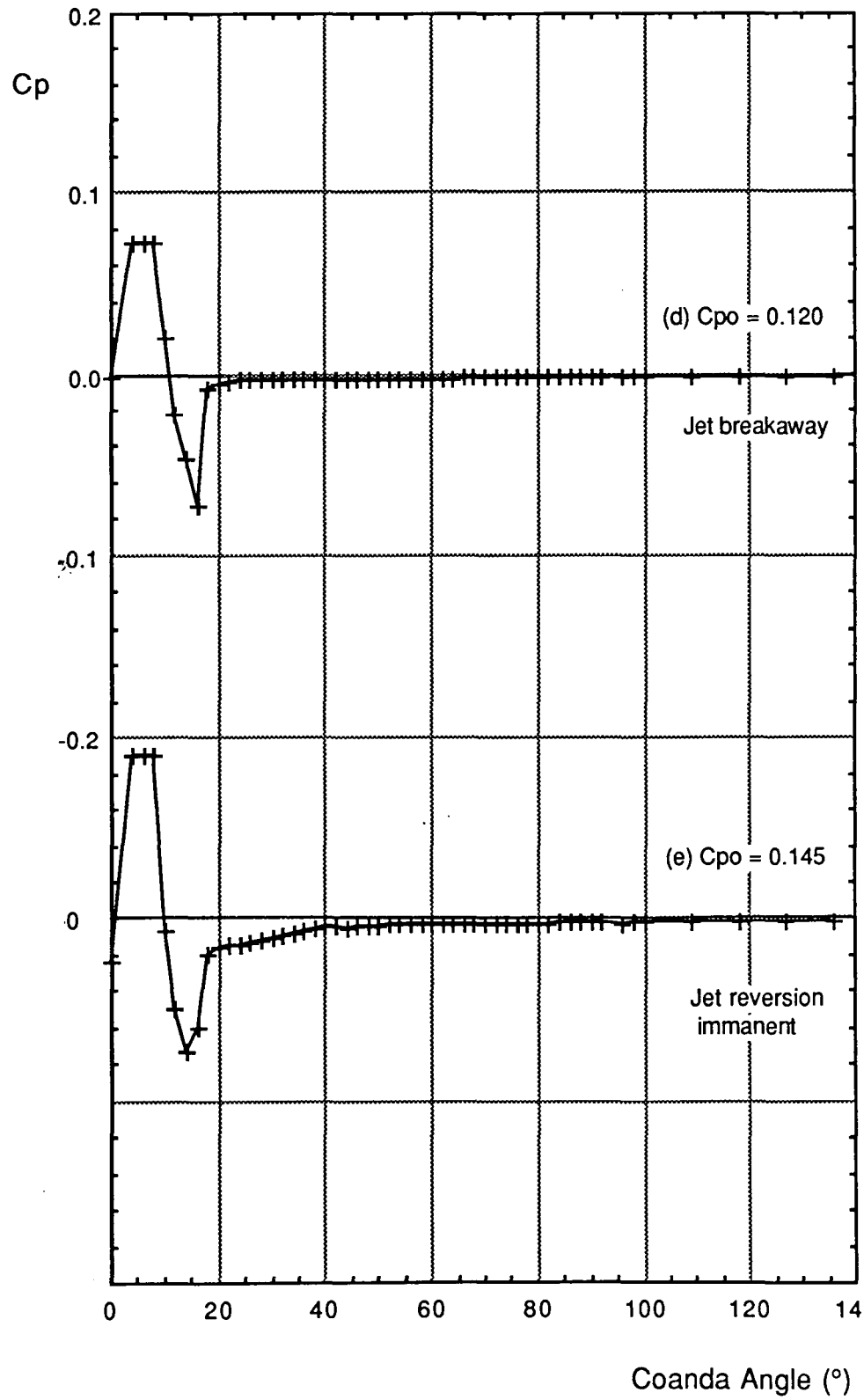


Figure 8.1.17.

Axisymmetric Coanda Model
Experimental Surface Pressures

Slot = 2.54 mm; Step = 1.25 mm

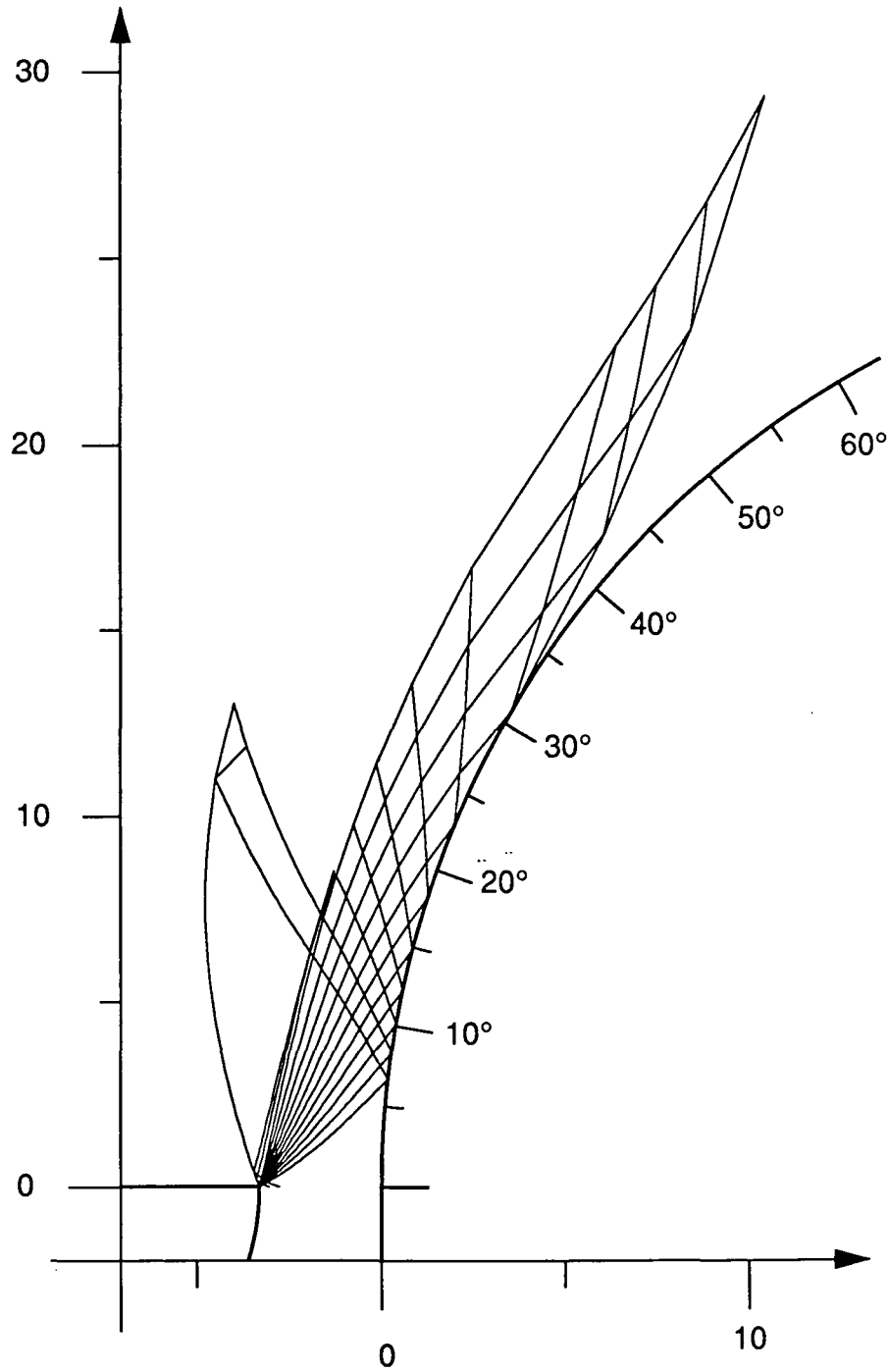


Figure 8.2.5. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting
Slot = 3.33 mm Step = 0.00 mm
Patm/Po = 0.174

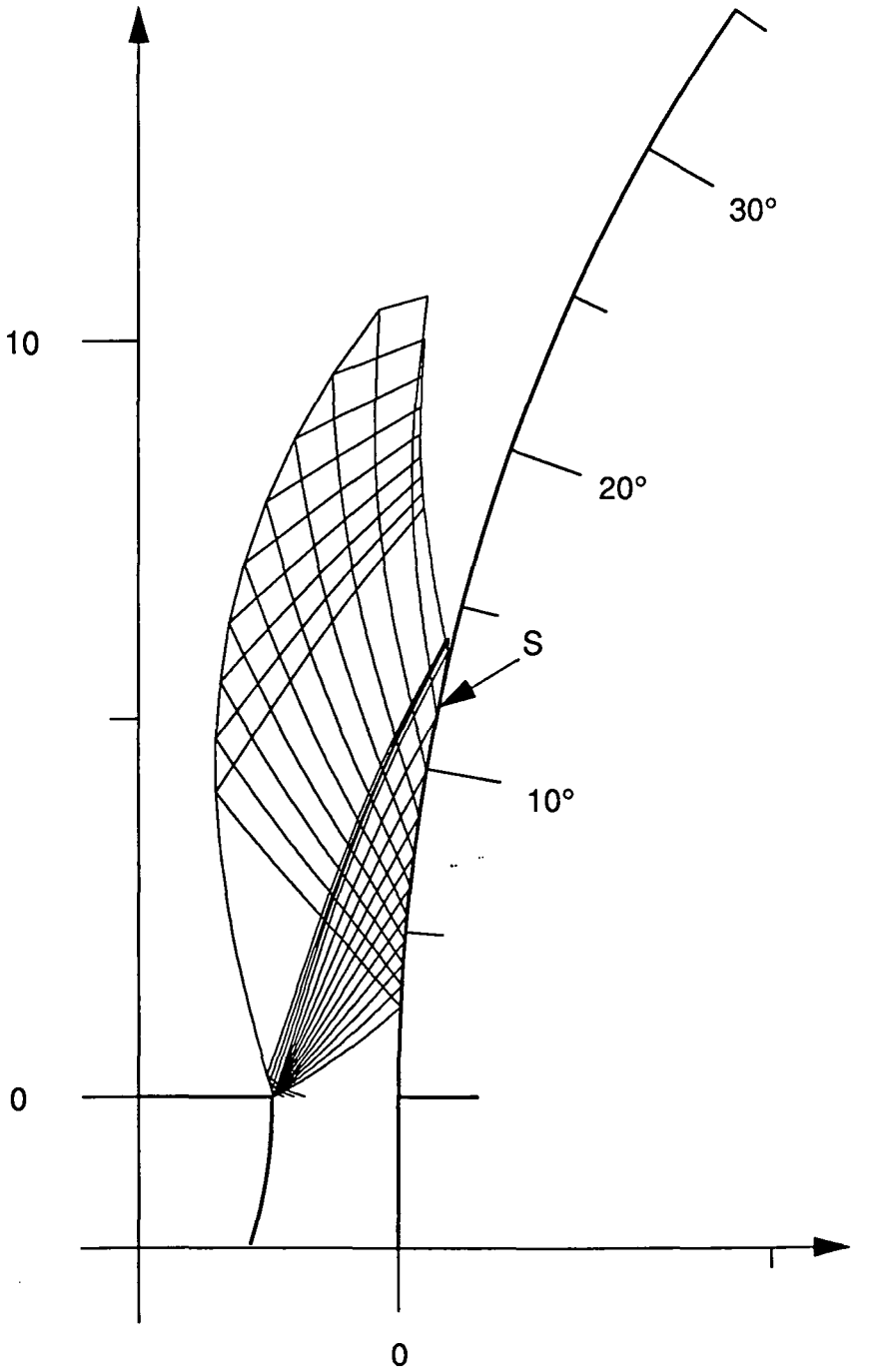


Figure 8.2.6. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 1.67 mm Step = 0.00 mm
Patm/Po = 0.202

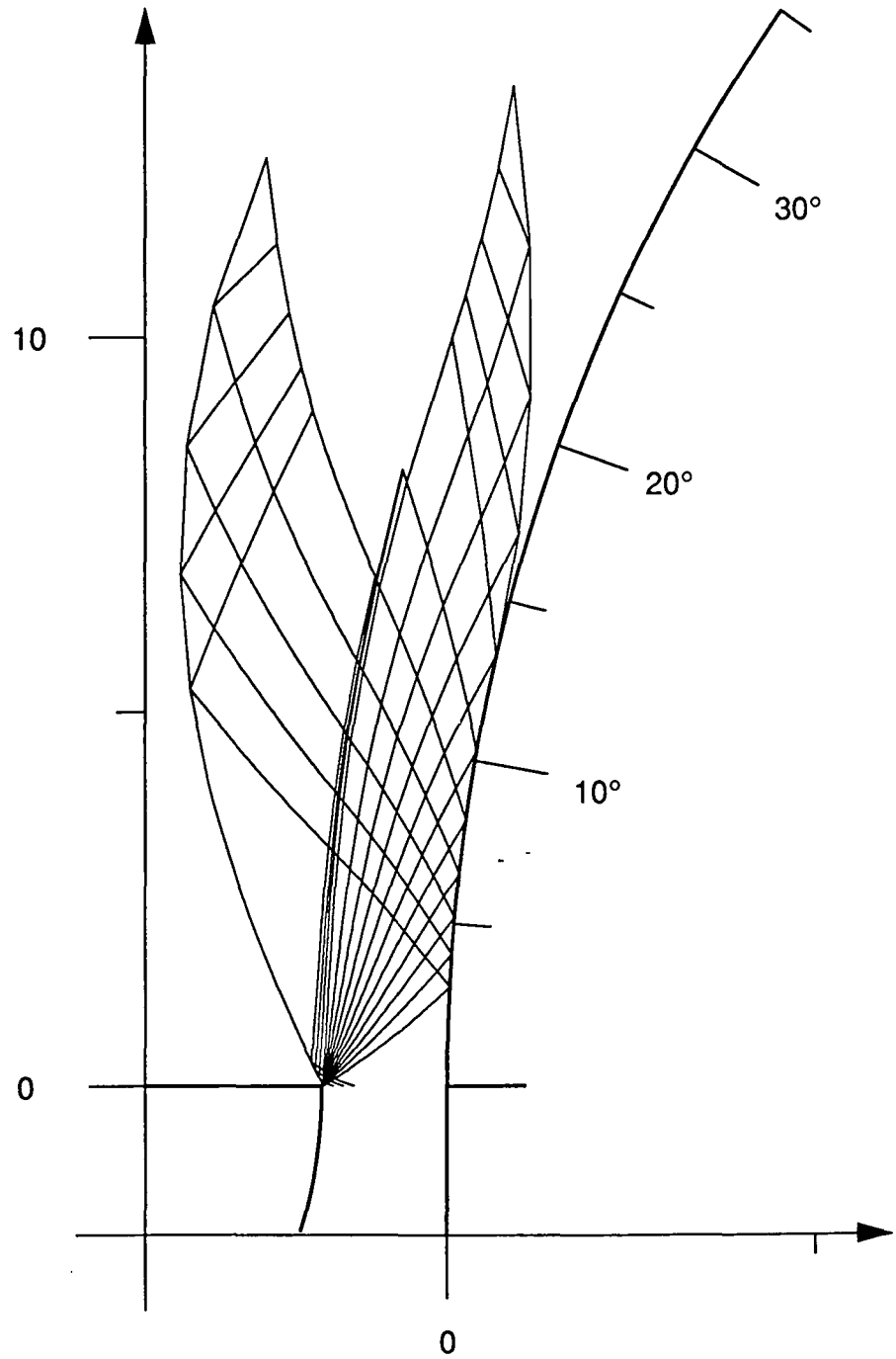


Figure 8.2.7. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 1.67 mm Step = 0.00 mm
Patm/Po = 0.124

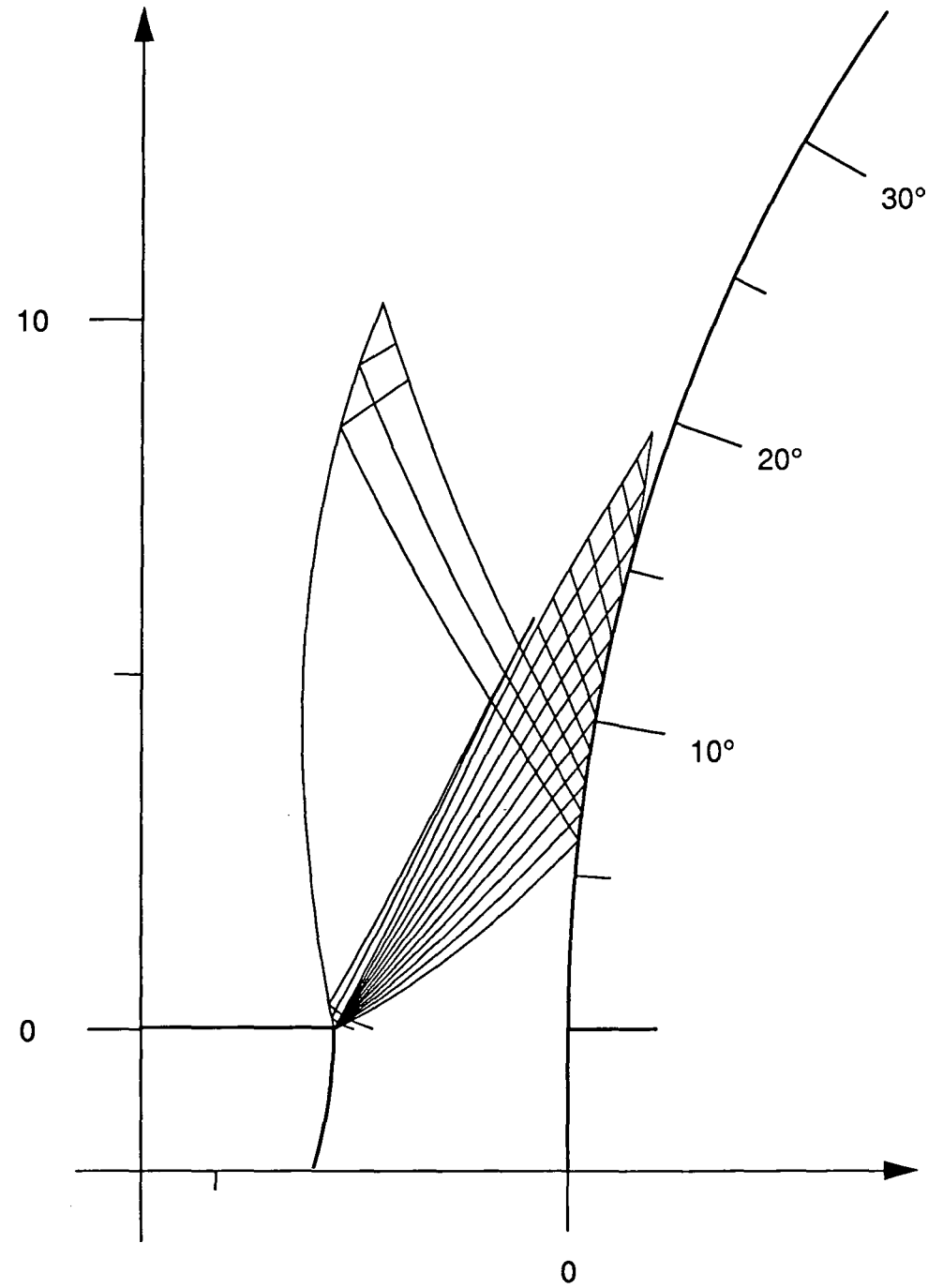


Figure 8.2.8. Axisymmetric Coanda Model
Method of Characteristics Plot

Shock Fitting; Separation Model
Slot = 3.33 mm Step = 0.00 mm
Patm/Po = 0.265

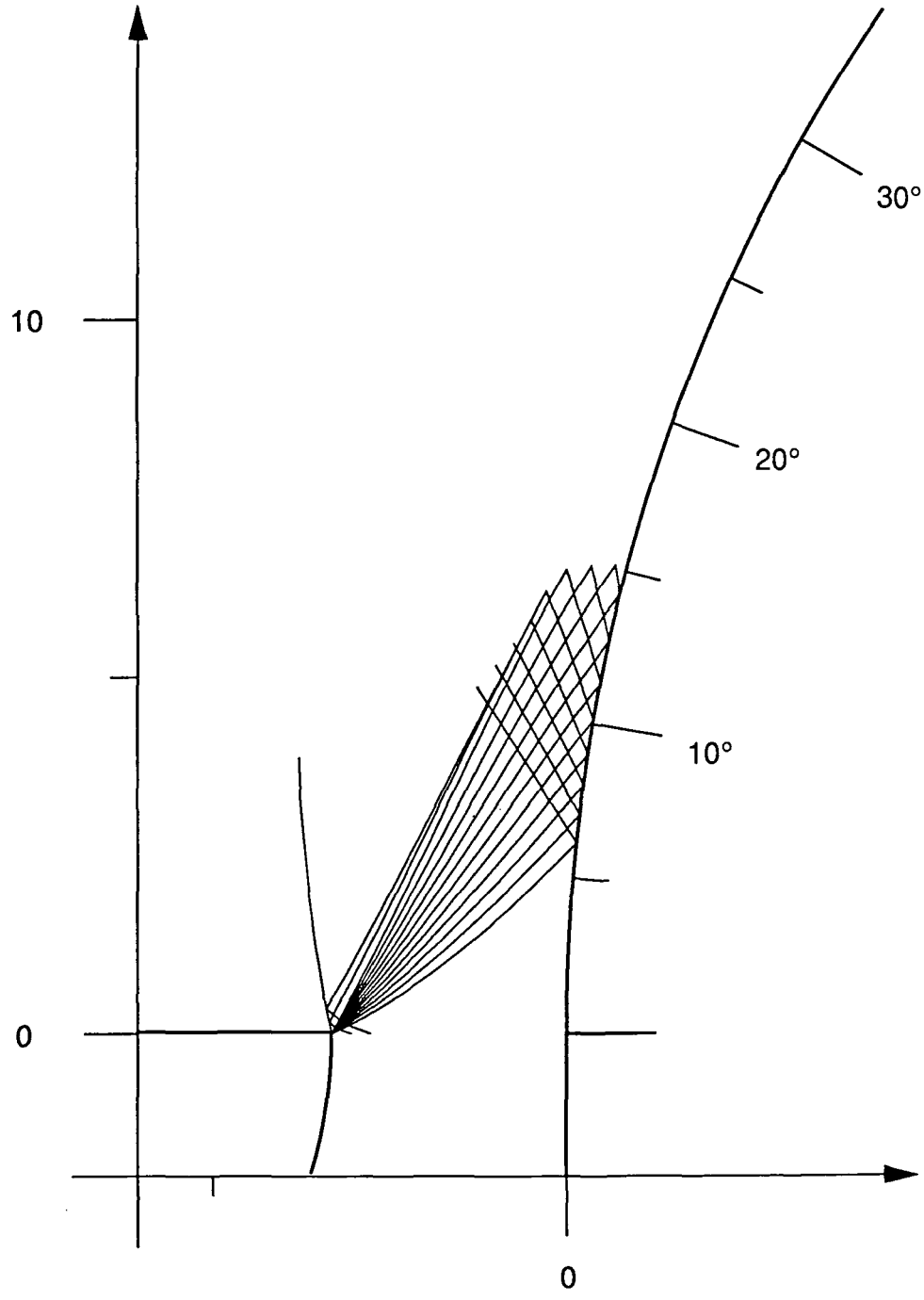


Figure 8.2.9. Axisymmetric Coanda Model
Method of Characteristics Plot
Separation Model
Slot = 3.33 mm Step = 0.00 mm
Patm/Po = 0.265

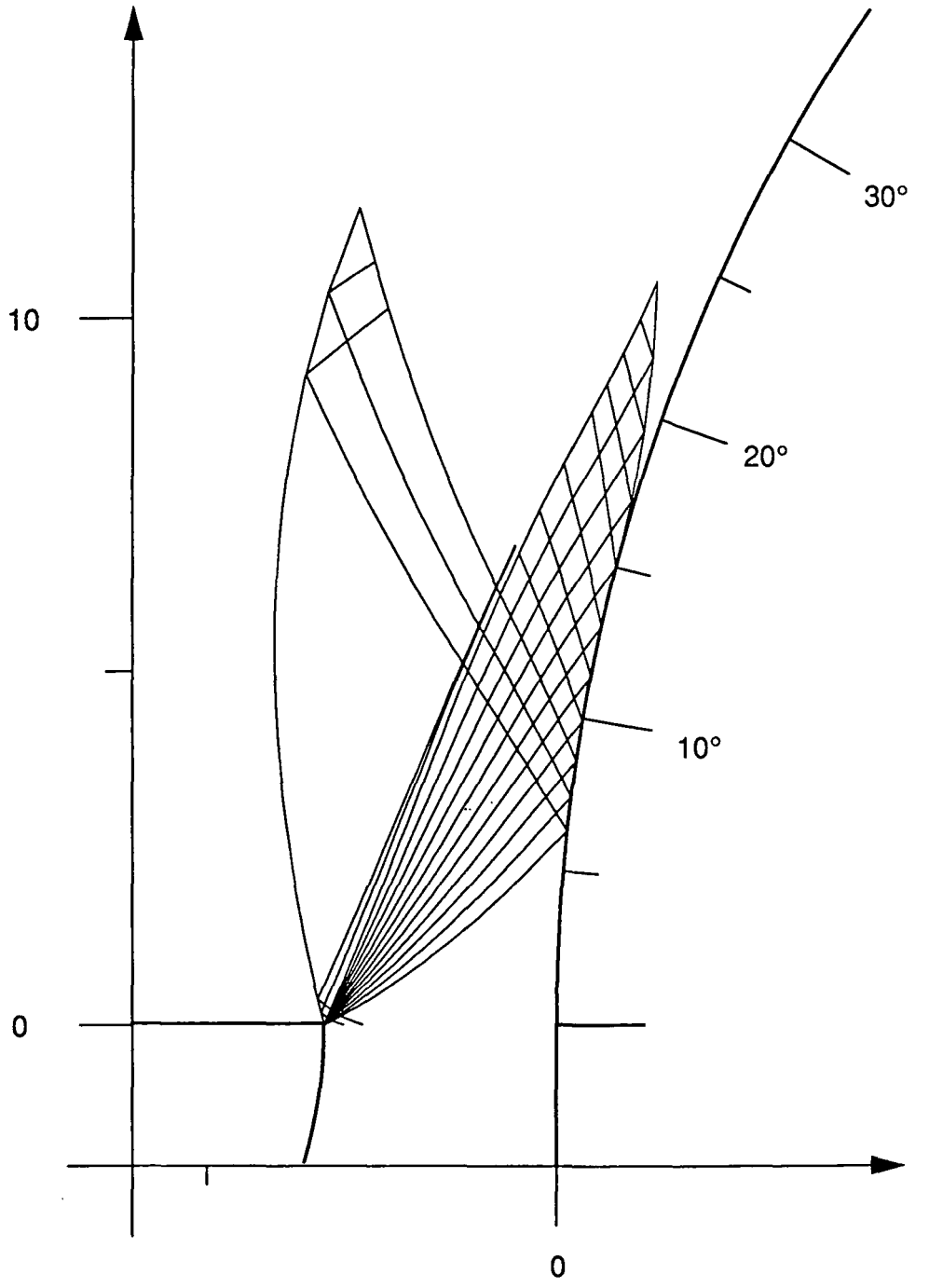


Figure 8.2.10. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 3.33 mm Step = 0.00 mm
Patm/Po = 0.233

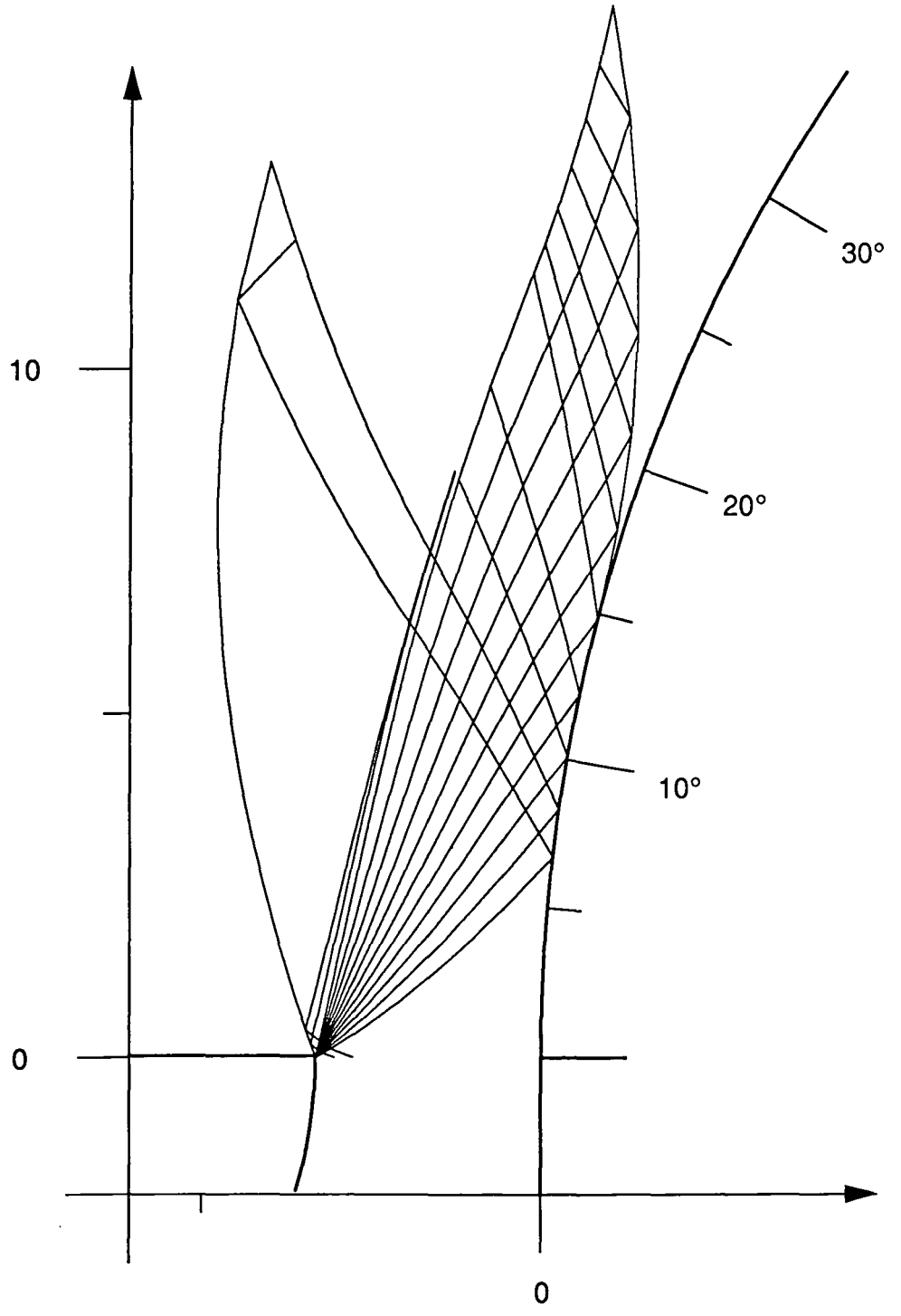


Figure 8.2.11. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Slot = 3.33 mm Step = 0.00 mm
Patm/Po = 0.174

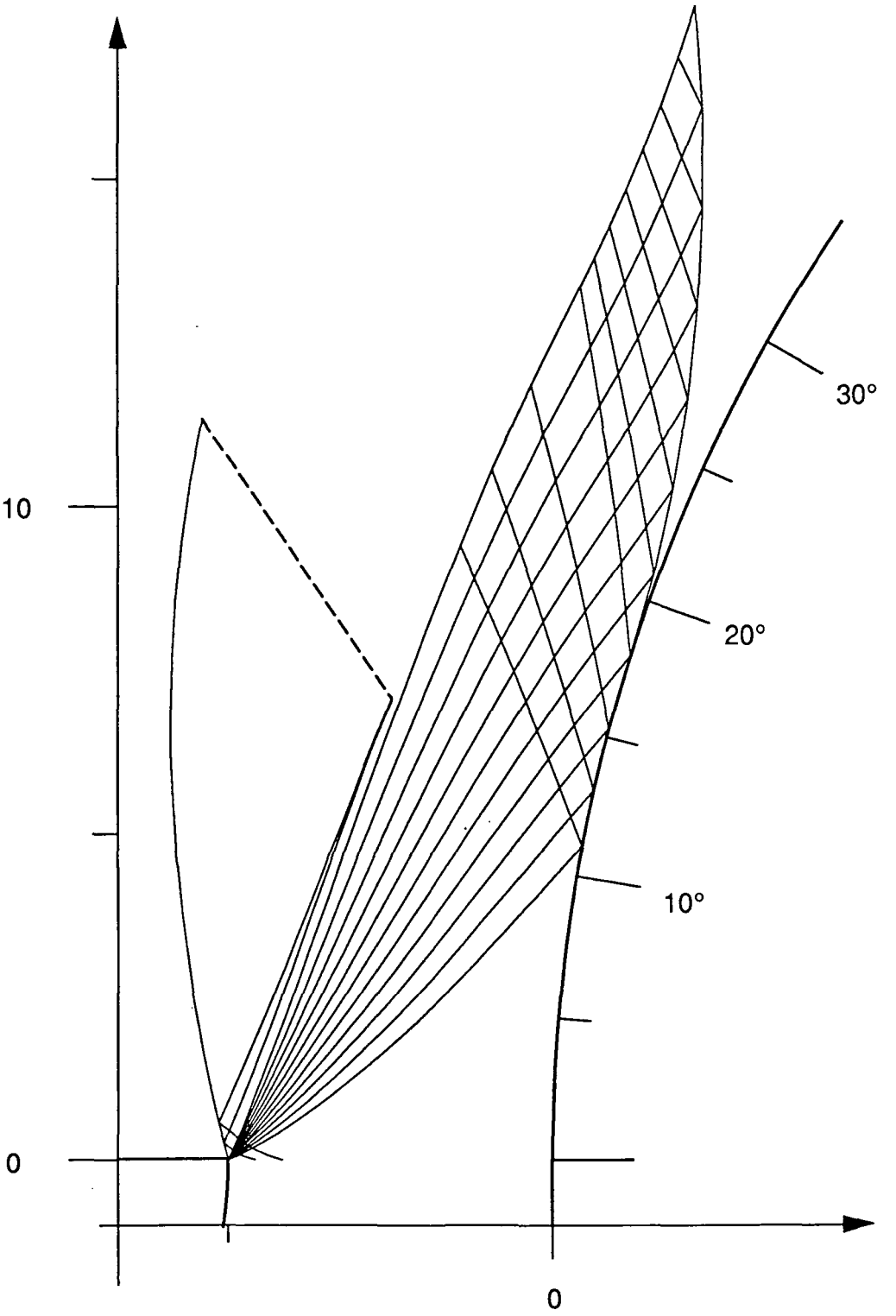


Figure 8.2.12. Axisymmetric Coanda Model
Method of Characteristics Plot

Shock Fitting; Separation Model
Slot = 5.00 mm Step = 0.00 mm
Patm/Po = 0.225

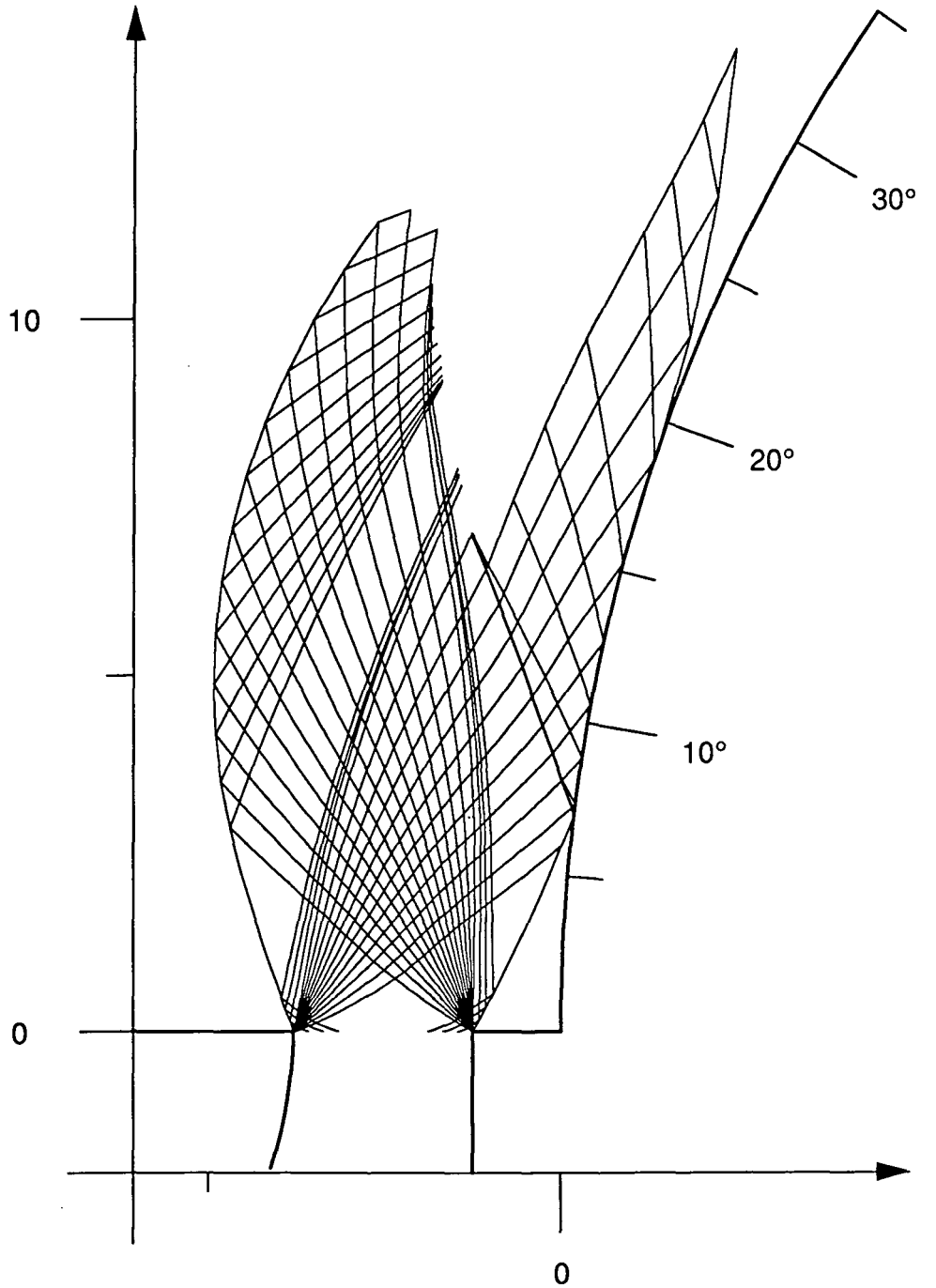


Figure 8.2.13. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Base Pressure Model
Slot = 2.54 mm Step = 1.25 mm
Patm/Po = 0.163

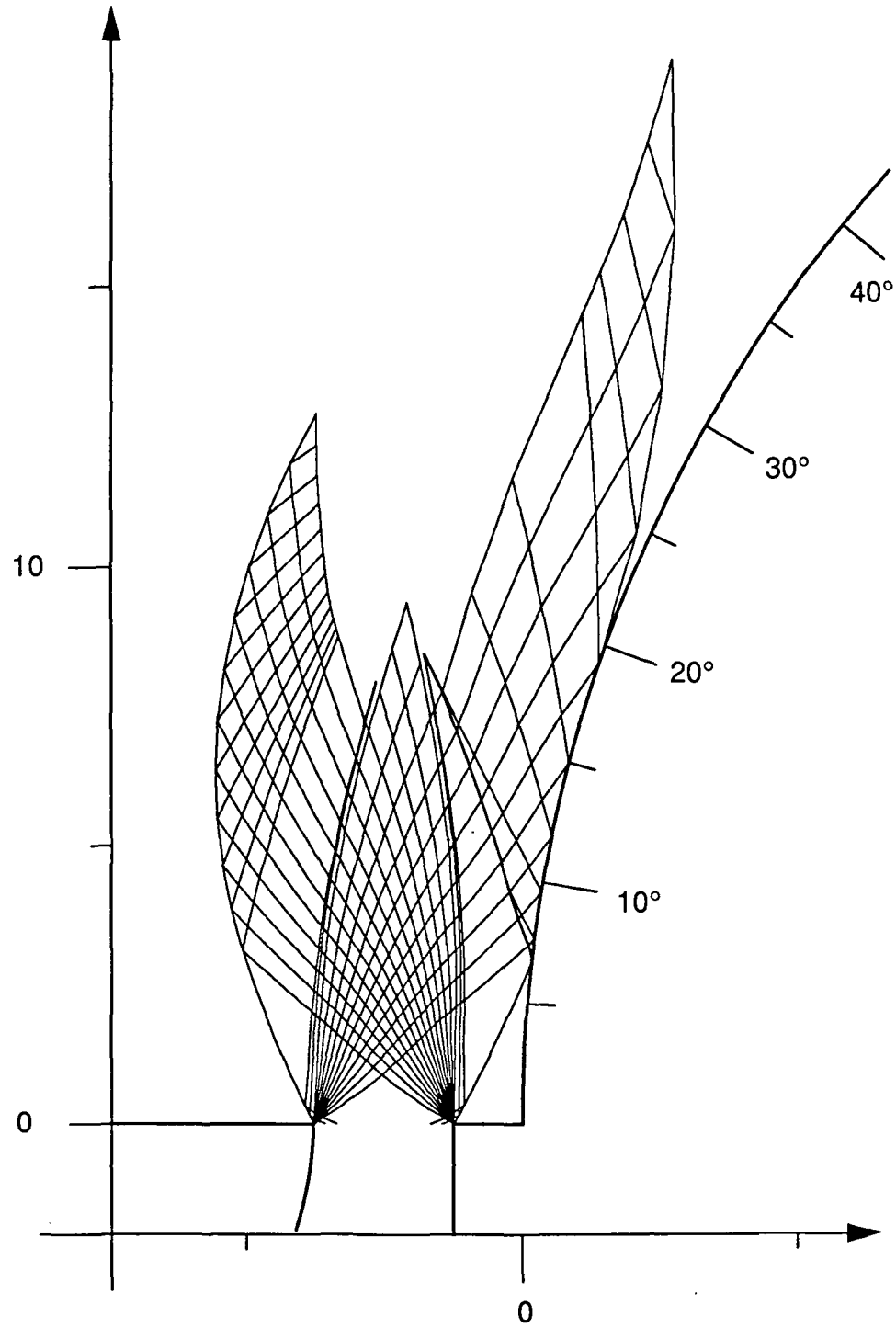


Figure 8.2.14.

Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Base Pressure Model
Slot = 2.54 mm Step = 1.25 mm
Patm/Po = 0.125

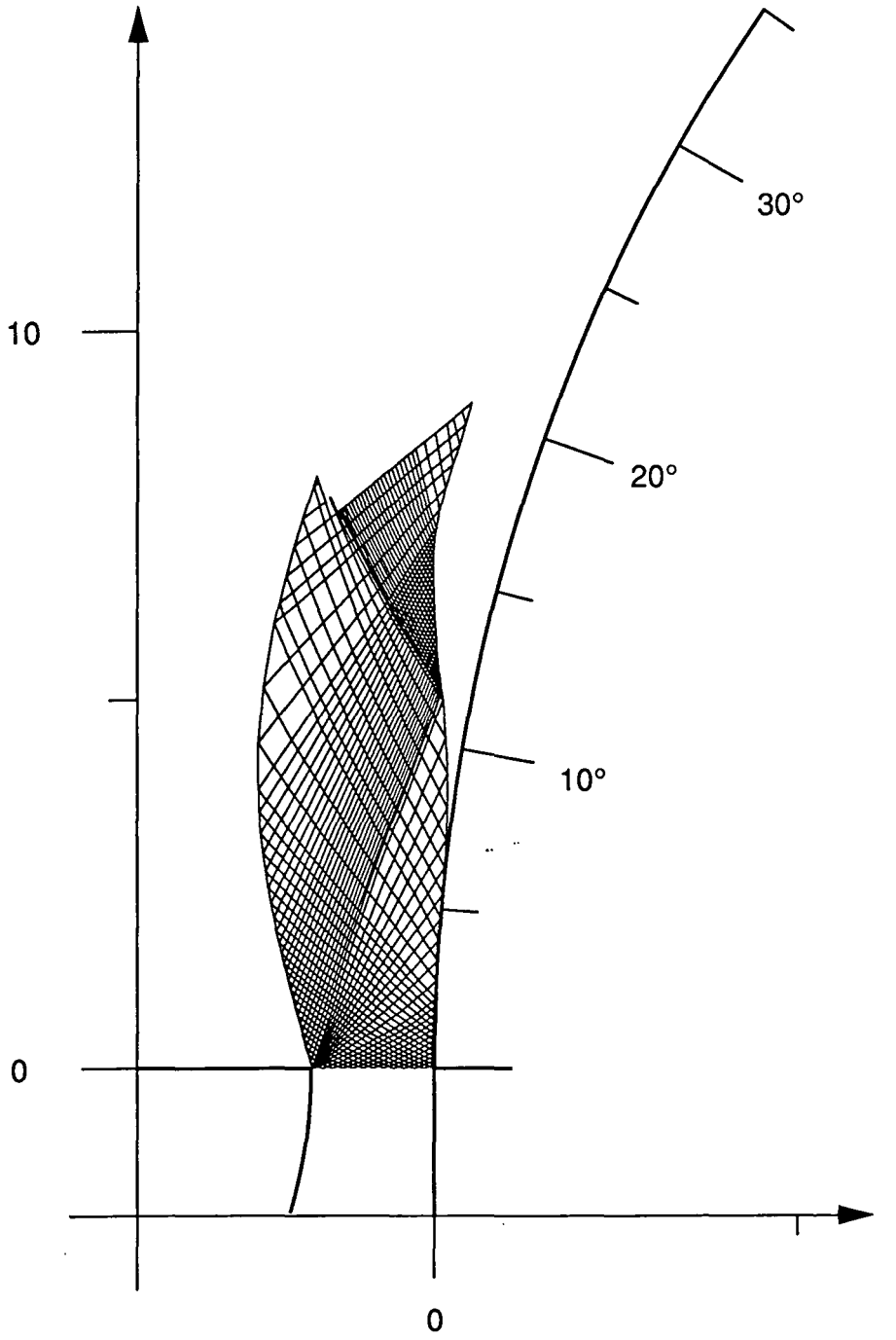


Figure 8.2.15. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 1.67 mm Step = 0.00 mm
Patm/Po = 0.202

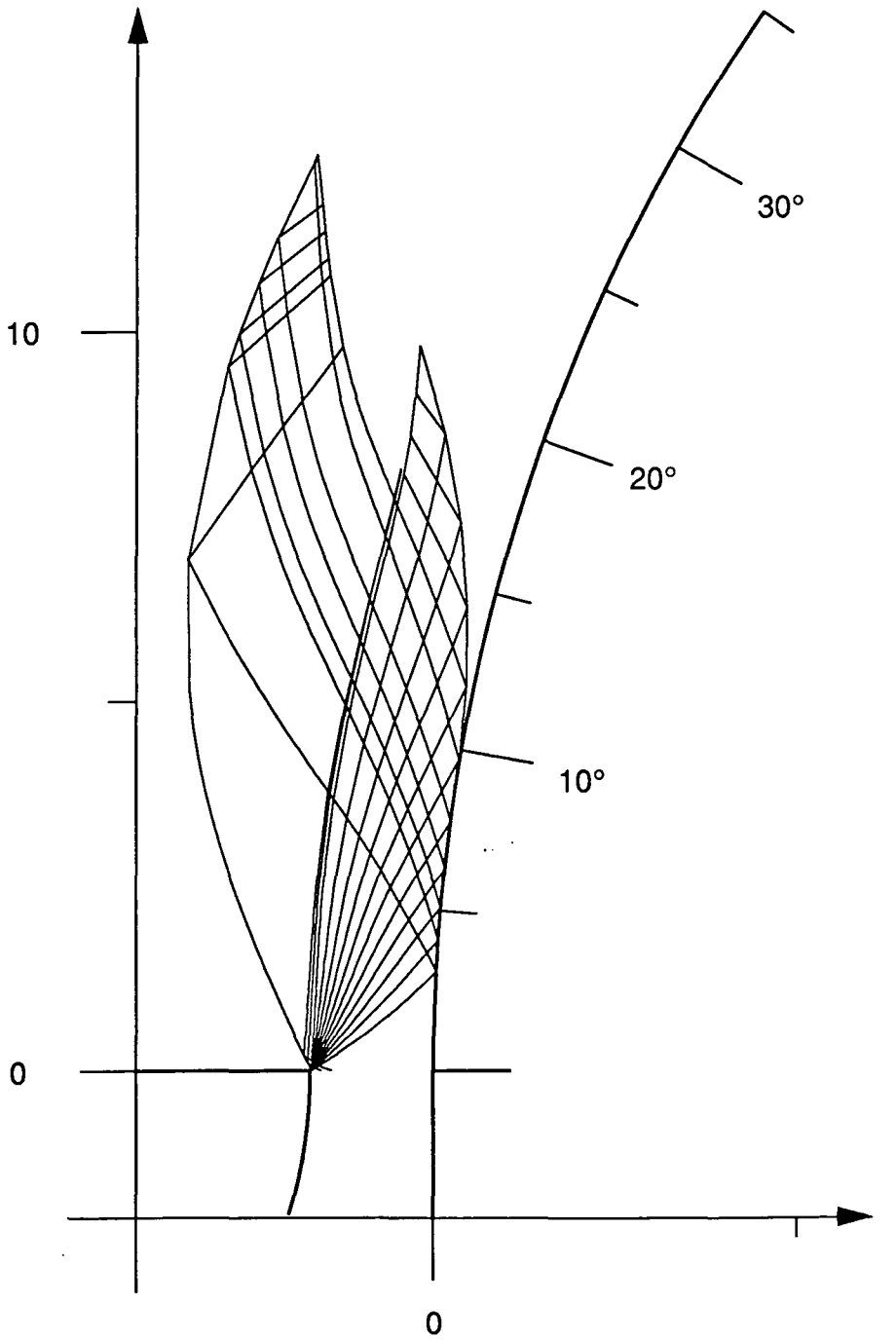


Figure 8.2.16.

Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 1.67 mm Step = 0.00 mm
Patm/Po = 0.124

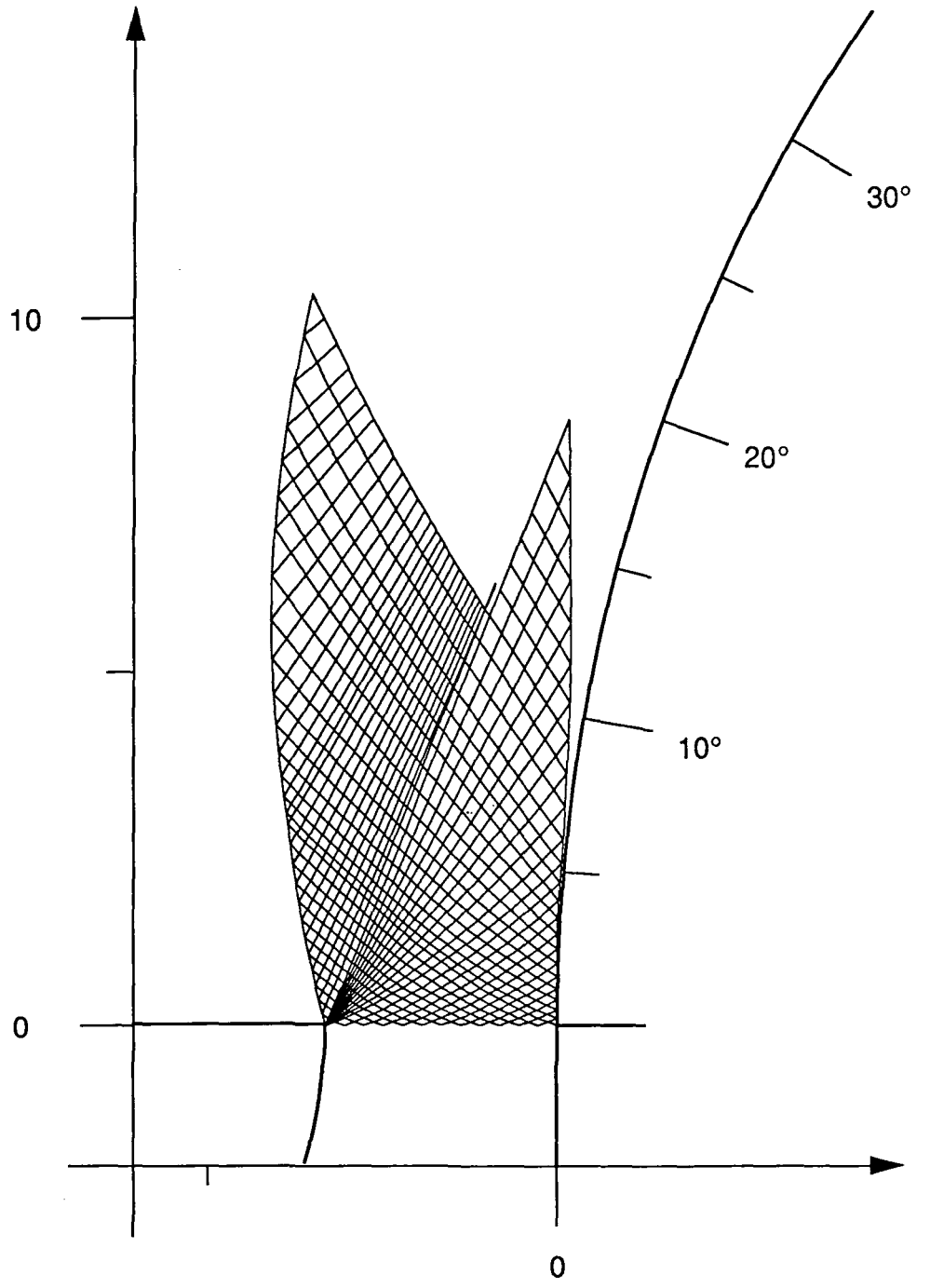


Figure 8.2.17. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 3.33 mm Step = 0.00 mm
Patm/Po = 0.233

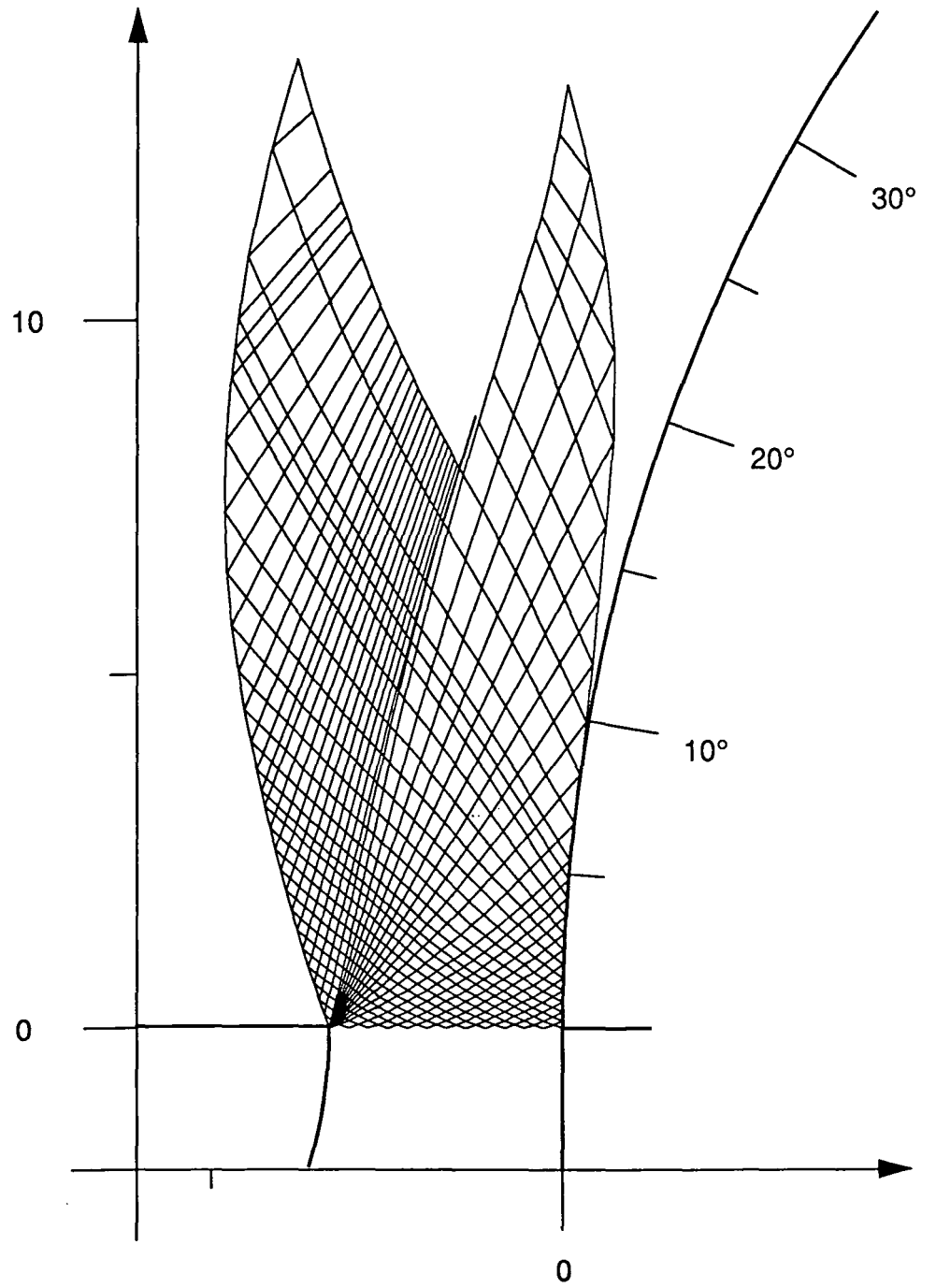


Figure 8.2.18. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 3.33 mm Step = 0.00 mm
Patm/Po = 0.174

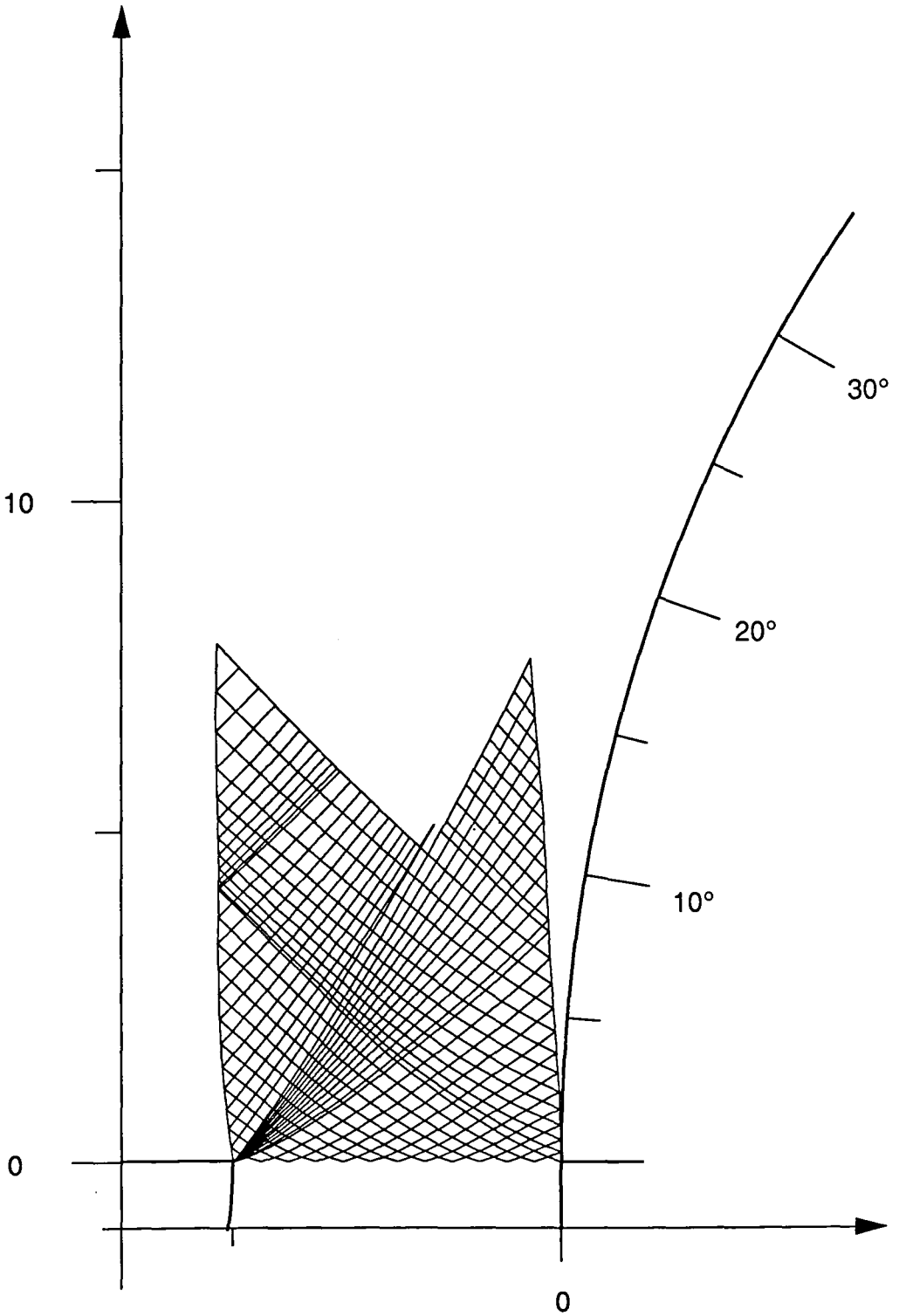


Figure 8.2.19. Axisymmetric Coanda Model
Method of Characteristics Plot

Shock Fitting; Experimental Surface Pressures
Slot = 5.00 mm Step = 0.00 mm
Patm/Po = 0.314

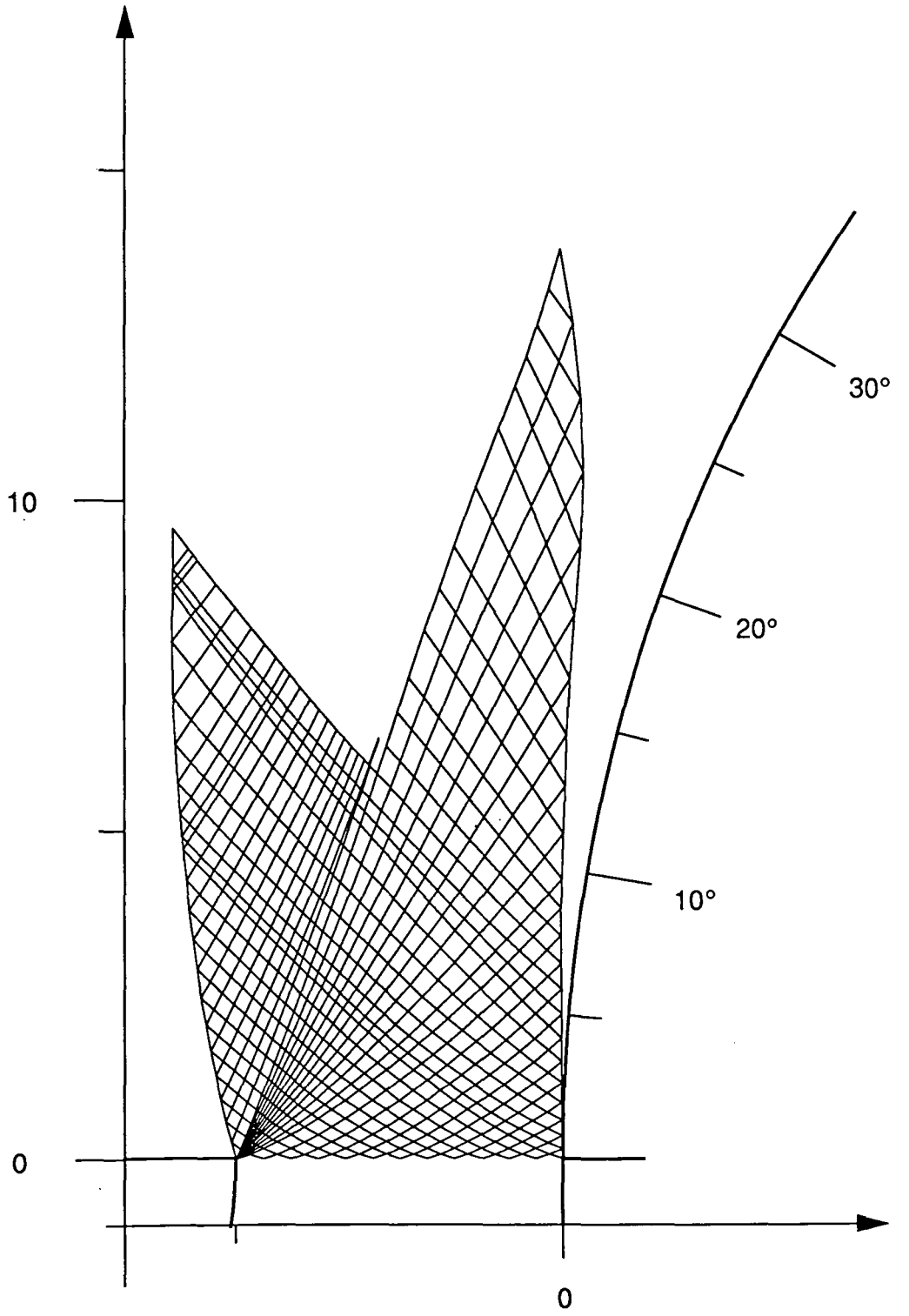


Figure 8.2.20. Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 5.00 mm Step = 0.00 mm
Patm/Po = 0.225

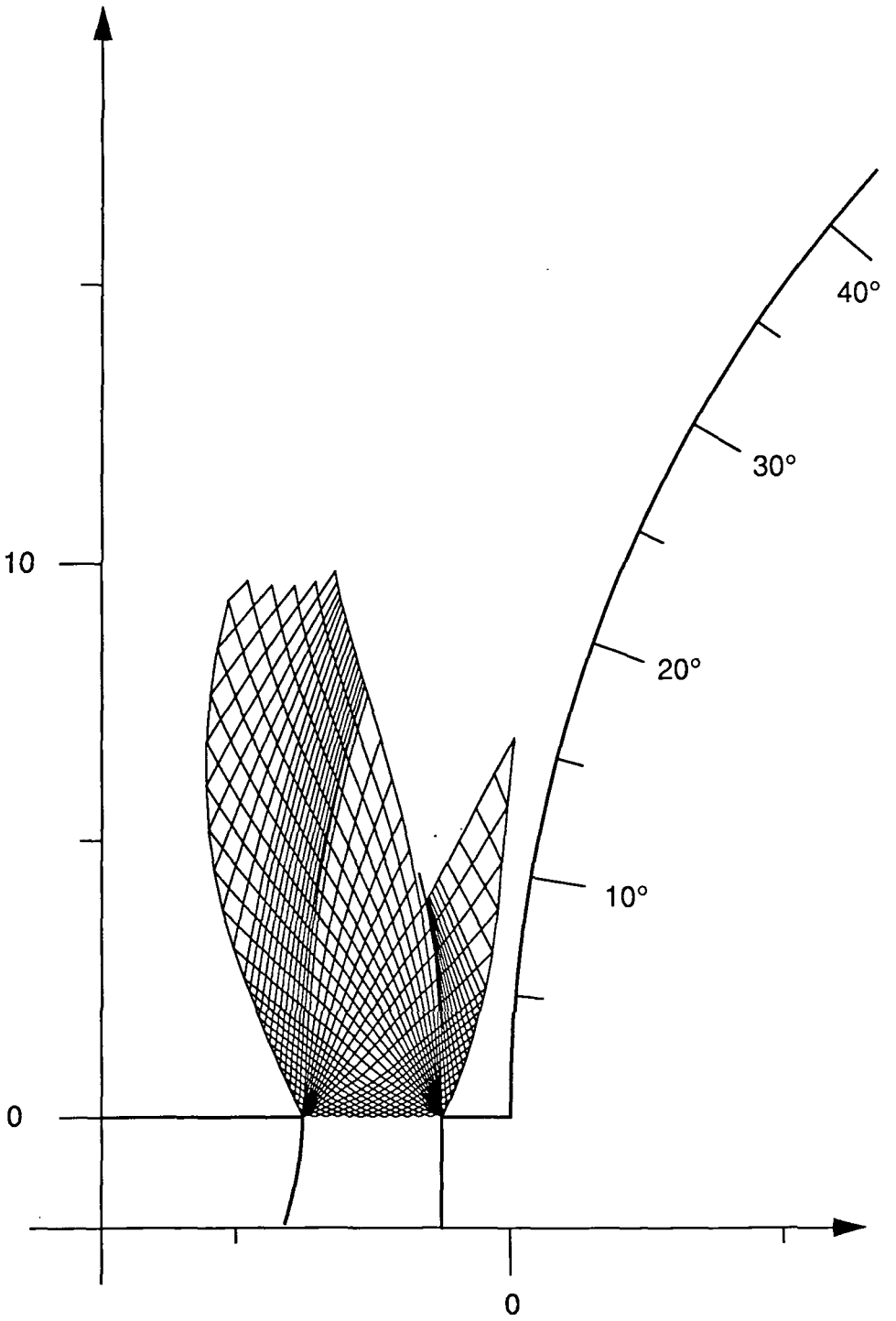


Figure 8.2.21.

Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Experimental Surface Pressures
Slot = 2.54 mm Step = 1.25 mm
Patm/Po = 0.125

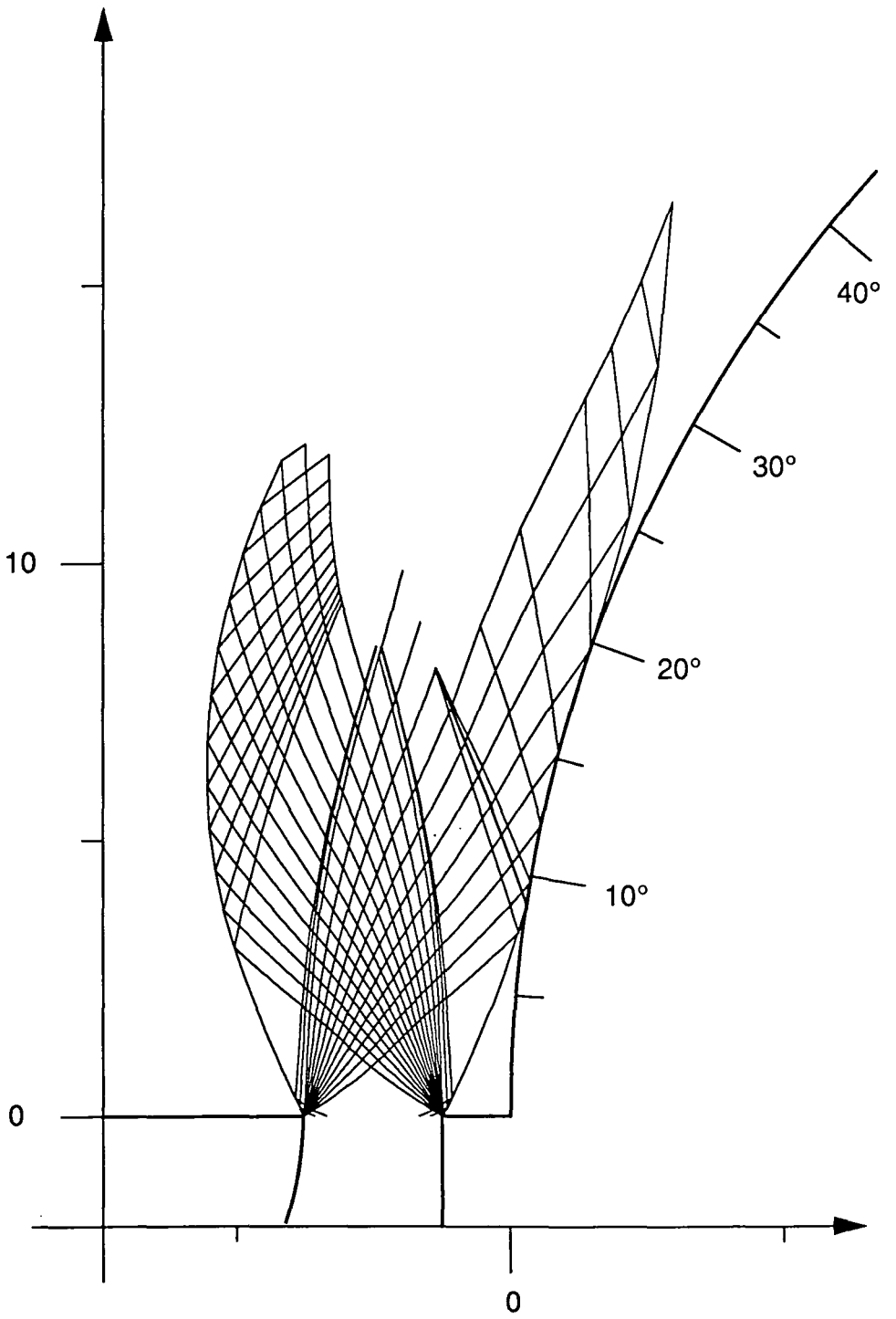


Figure 8.2.22.

Axisymmetric Coanda Model
Method of Characteristics Plot
Shock Fitting; Separation Model
Experimental Base Pressure
Slot = 2.54 mm Step = 1.25 mm
Patm/Po = 0.125

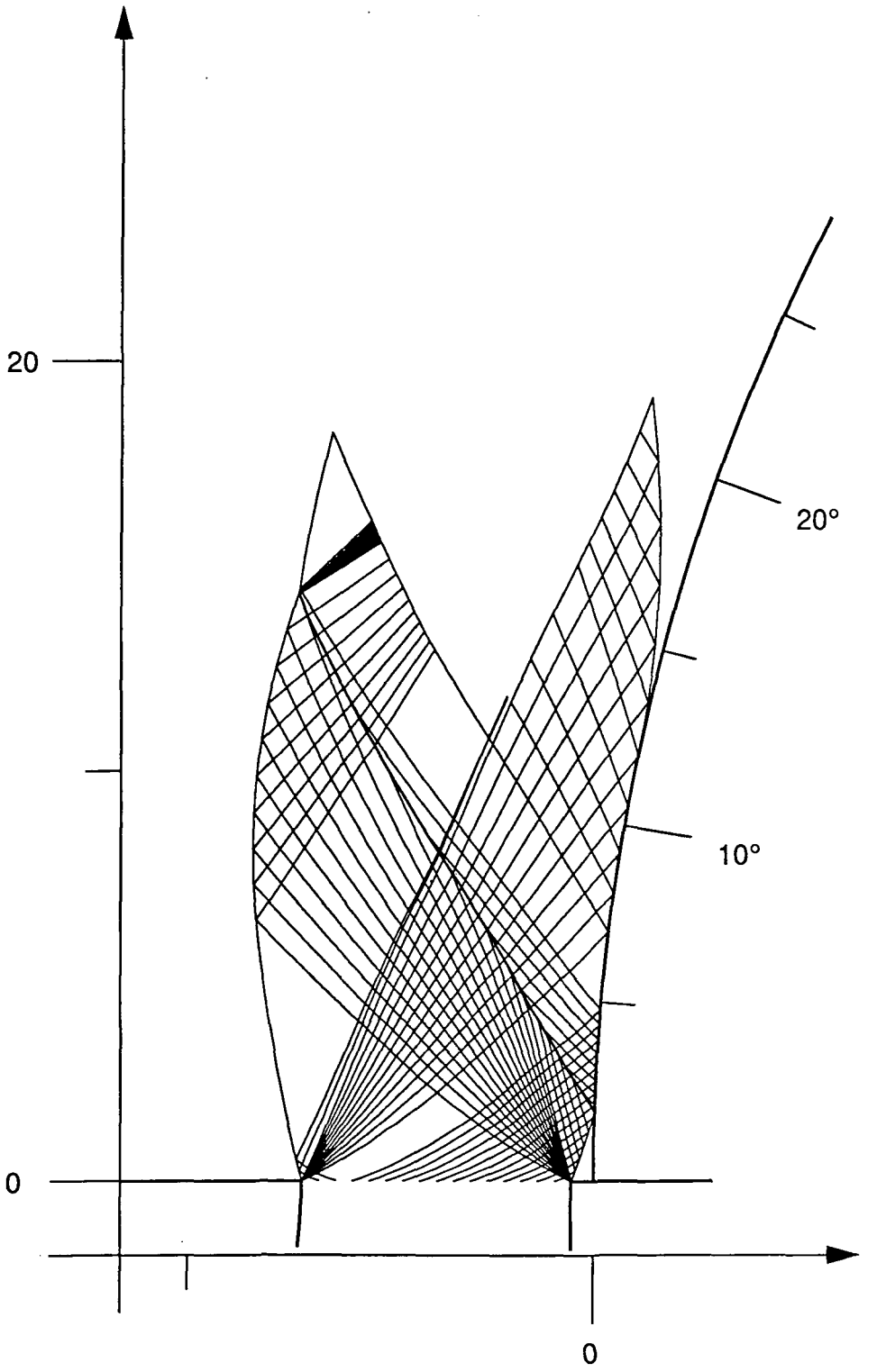


Figure 8.2.23. I8 Coanda (Field Tests)
Method of Characteristics Plot
Shock Fitting; Separation Model
Base Pressure Model
Slot = 6.65 mm Step = 0.55 mm
Patm/Po = 0.252

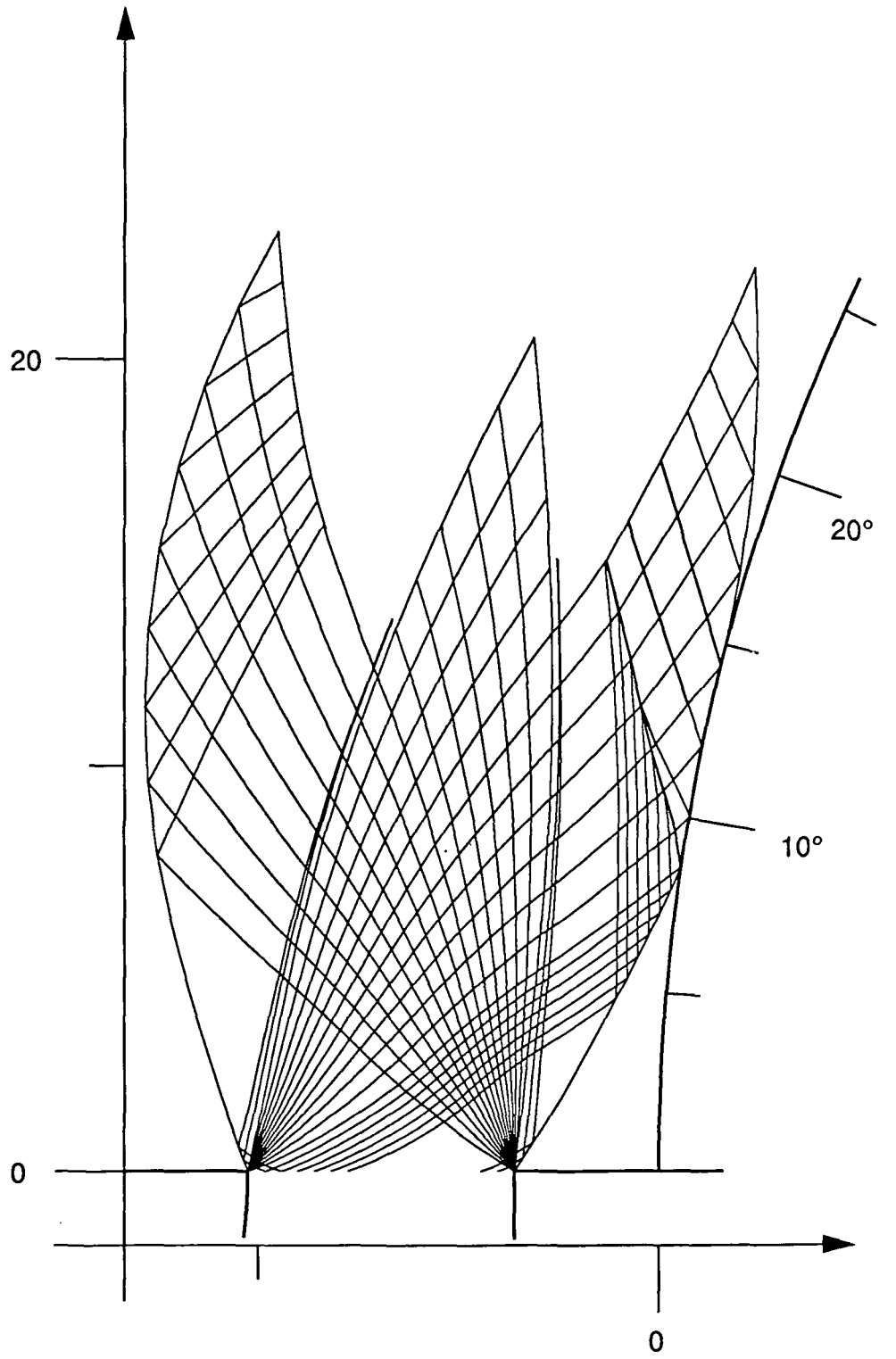


Figure 8.2.24. I8 Coanda (Field Tests)
Method of Characteristics Plot
Shock Fitting; Separation Model
Base Pressure Model
Slot = 6.65 mm Step = 3.60 mm
Patm/Po = 0.184

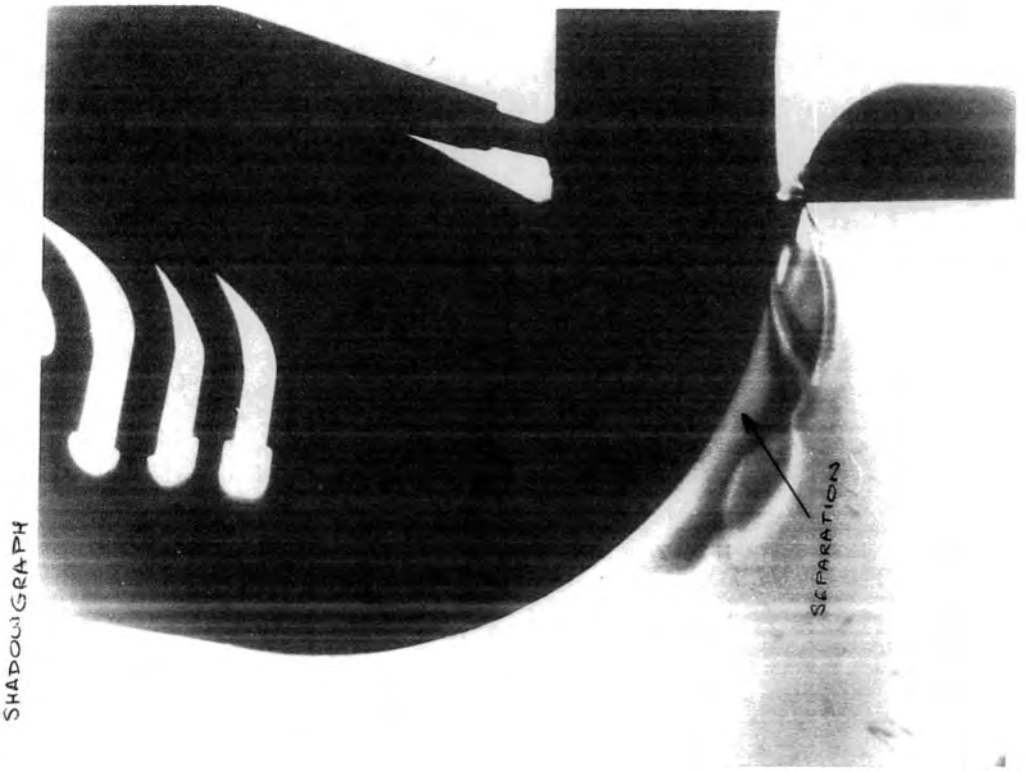


Plate 1a SLOT 2.00 STEP 0.00
C_{po} 0.176

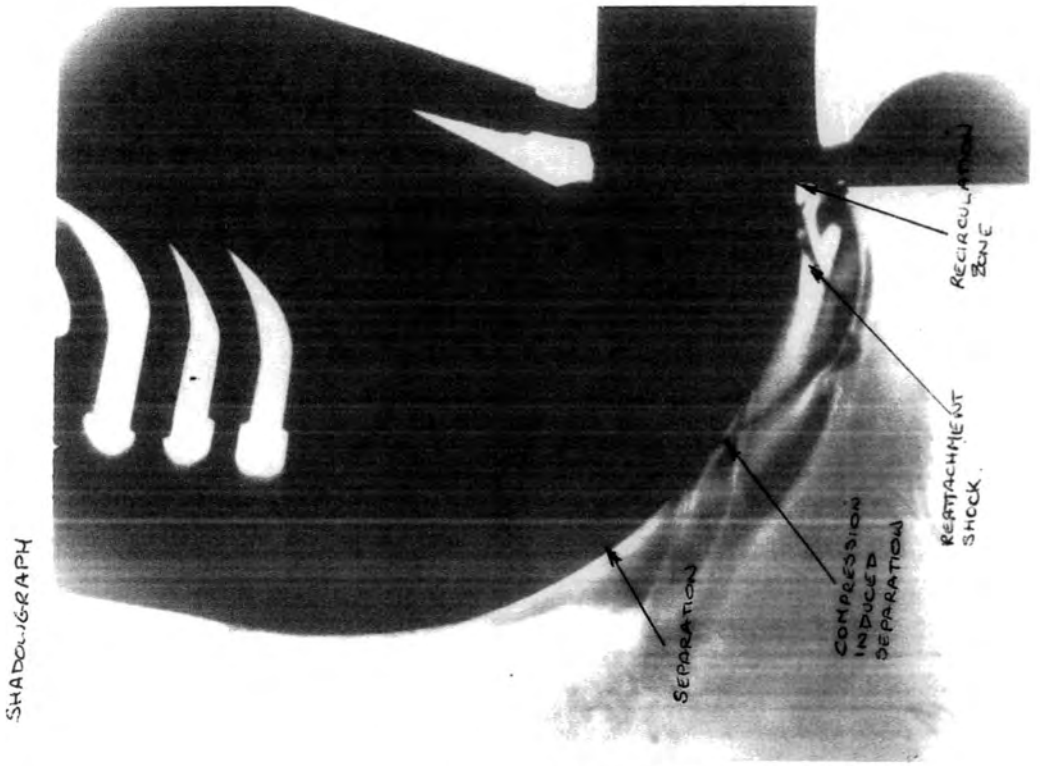


Plate 1b SLOT 2.00 STEP .50
C_{po} 0.124

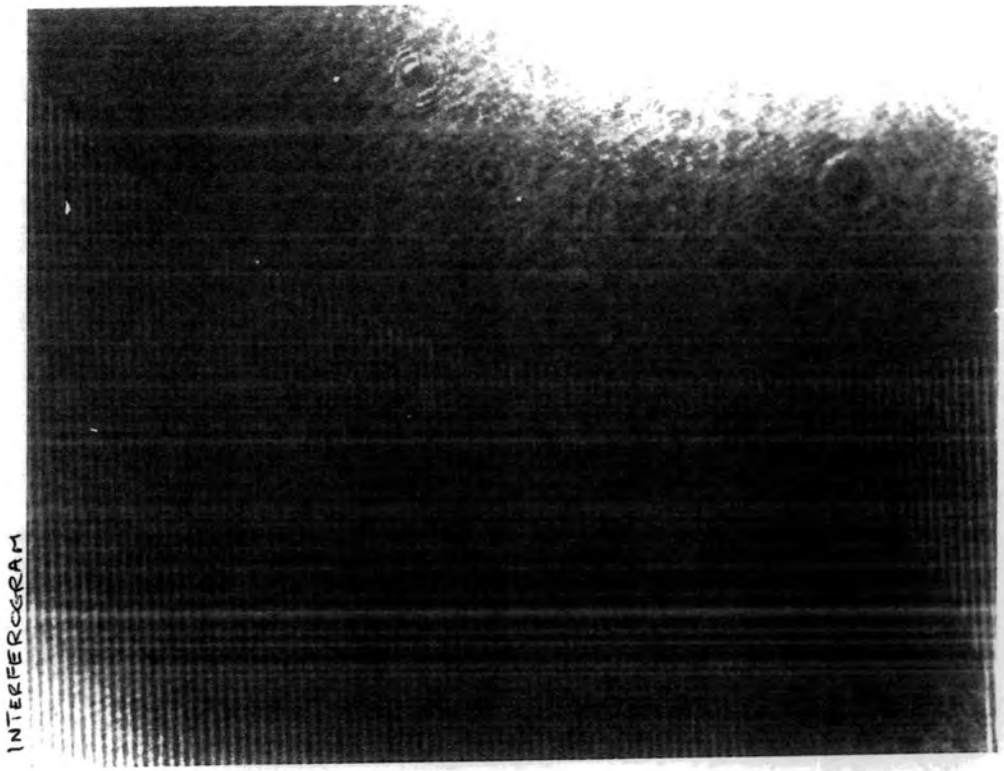


Plate 2a SLOT 4.00 STEP 0.00
NO FLOW

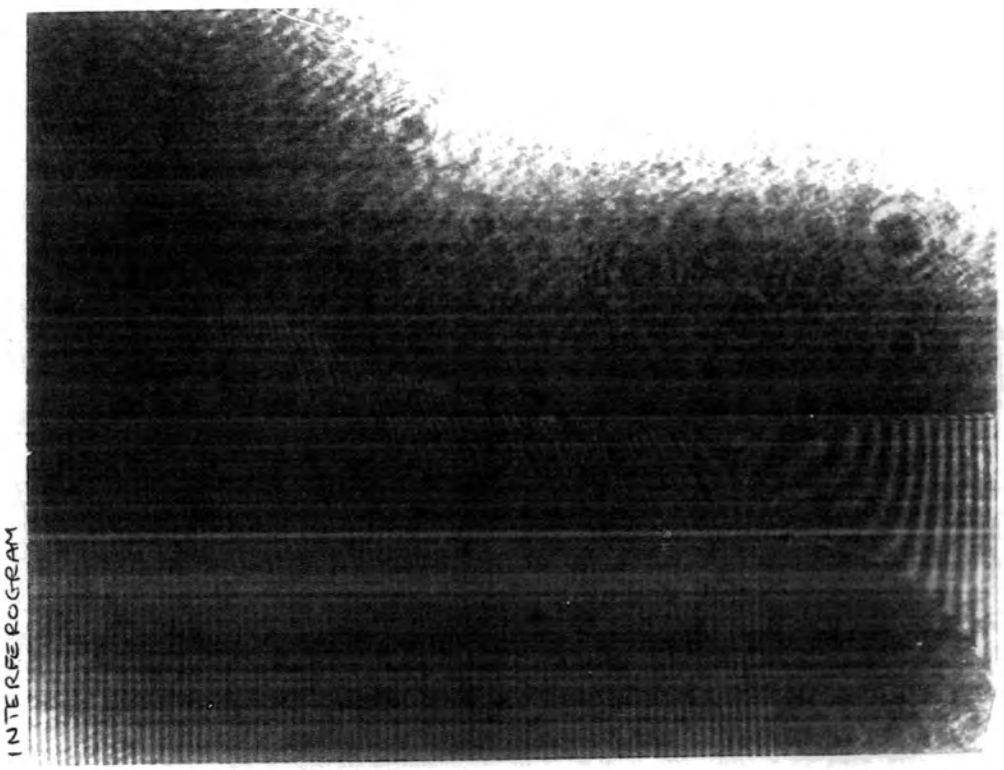


Plate 2b SLOT 4.00 STEP 000
C_{p_0} 0.488

Plate 3a SLOT 4.00 STEP 0.00
C_{po} 0.525

Plate 3b SLOT 4.00 STEP 0.00
C_{po} 0.256

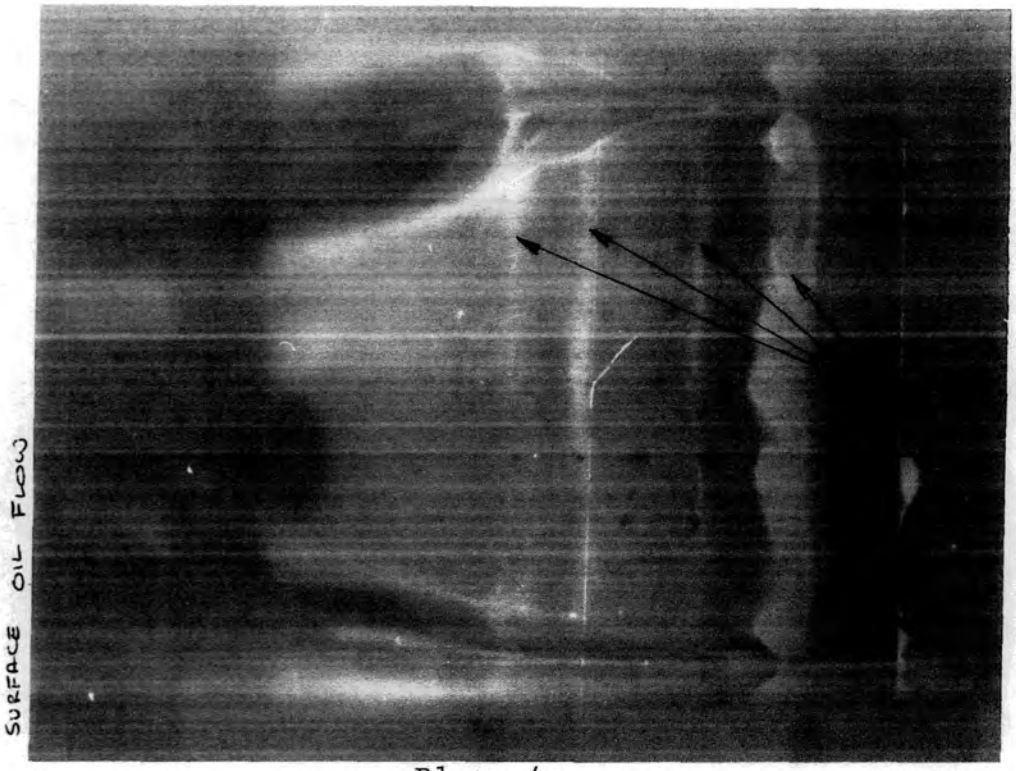


Plate 4a SLOT 4.00 STEP 0.00
C_{p_o} 0.324

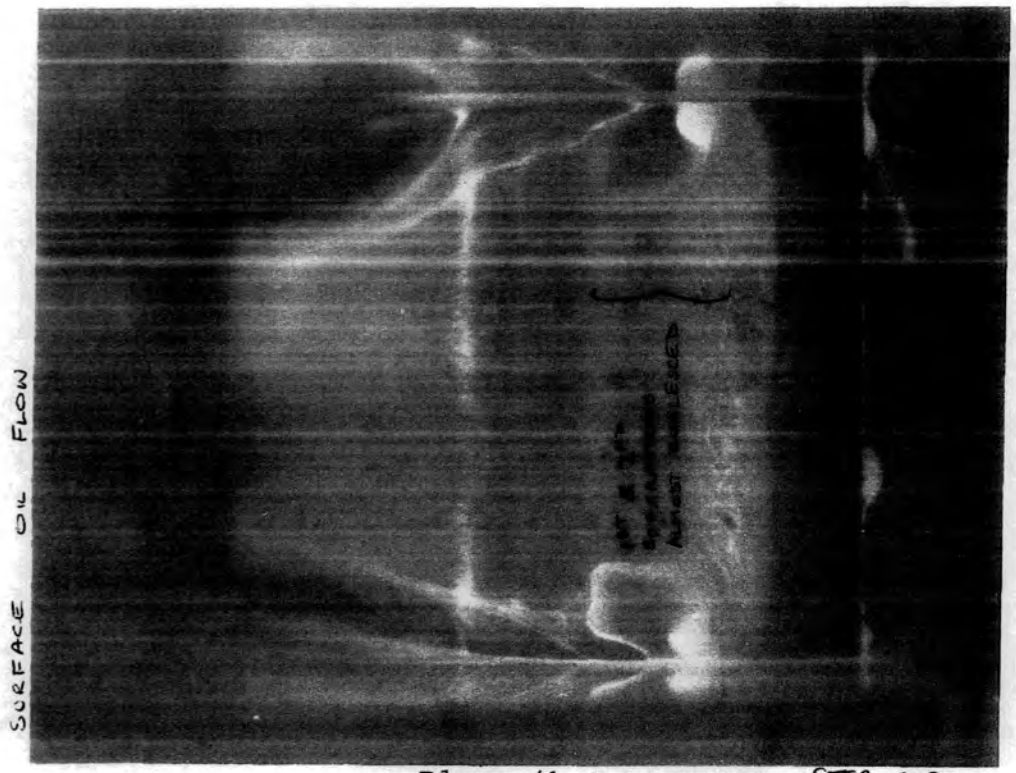


Plate 4b SLOT 4.00 STEP 0.00
C_{p_o} 0.256

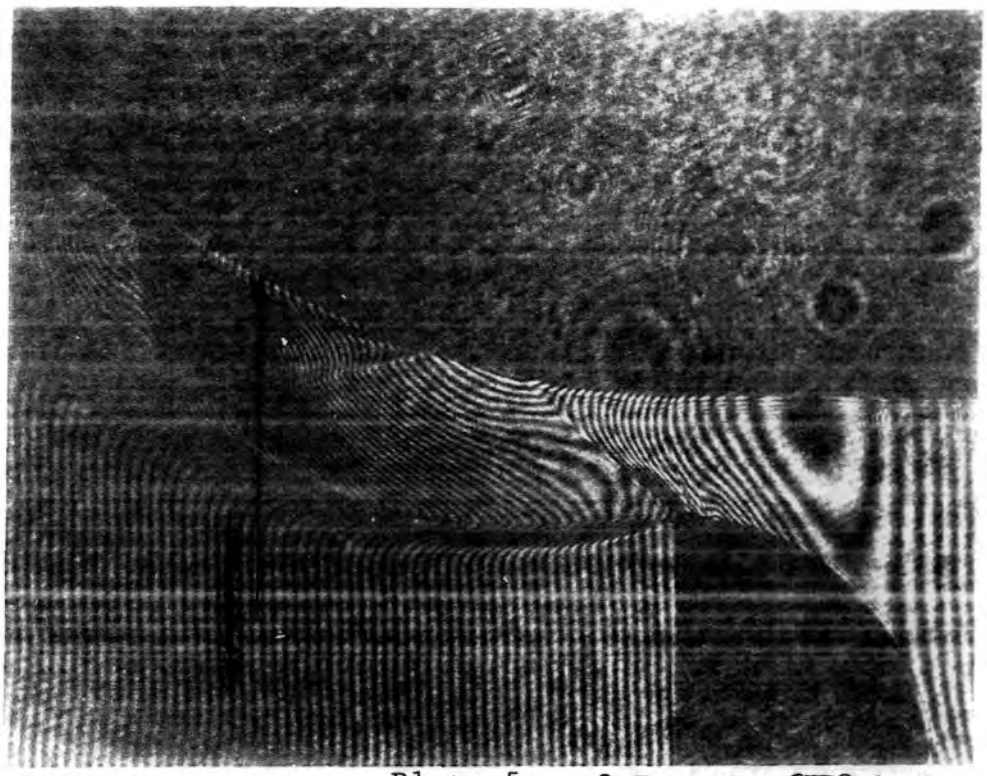


Plate 5a SLOT 4.00 STEP 0.00
C_{p_0} 0.312

Plate 5b SLOT 4.00 STEP 1.50
C_{p_0} 0.331

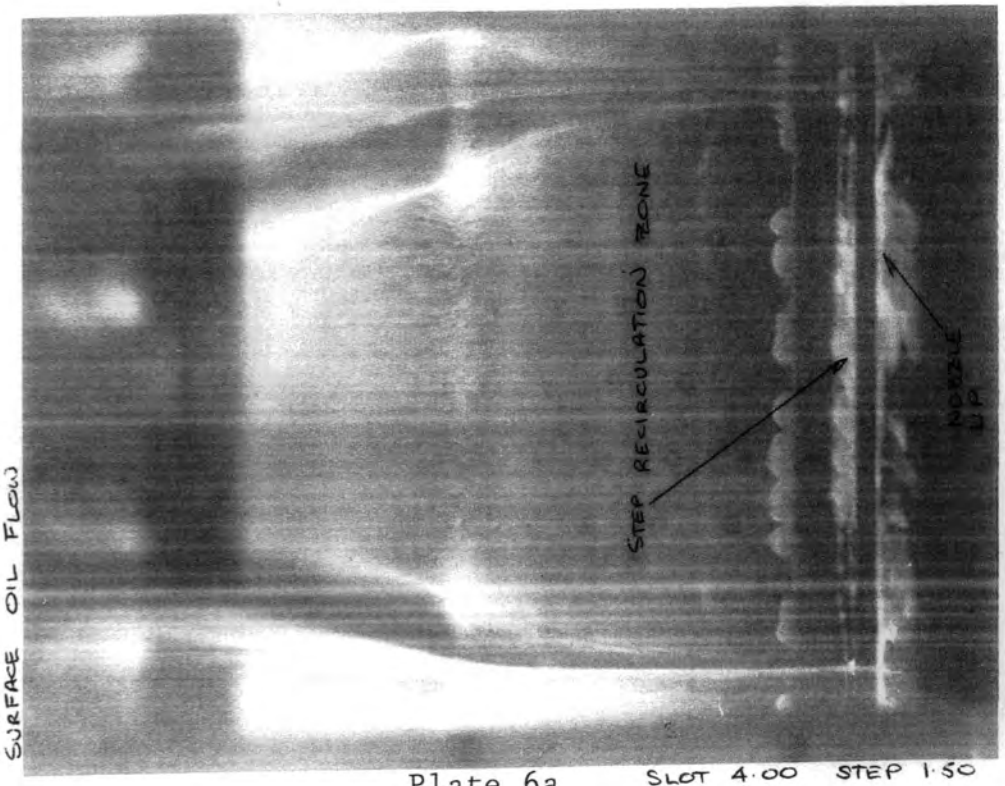


Plate 6a SLOT 4.00 STEP 1.50
C_{p_0} 0.331

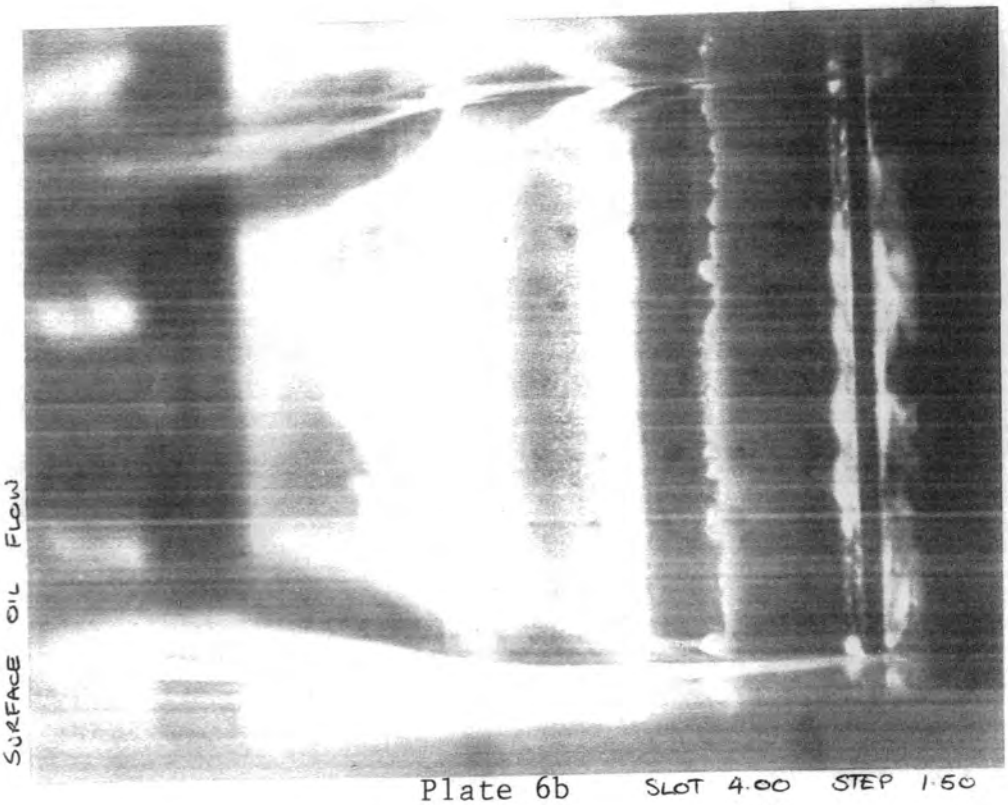


Plate 6b SLOT 4.00 STEP 1.50
C_{p_0} 0.256

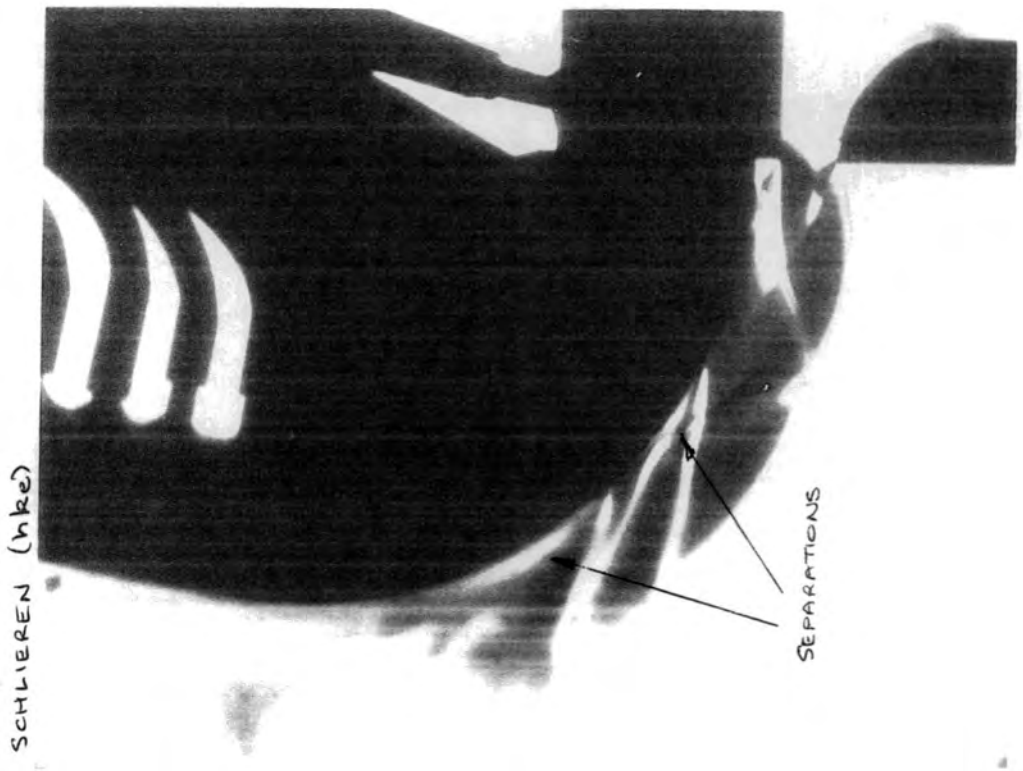


Plate 7a SLOT 4.00 STEP 1.50
C_{p_0} 0.212

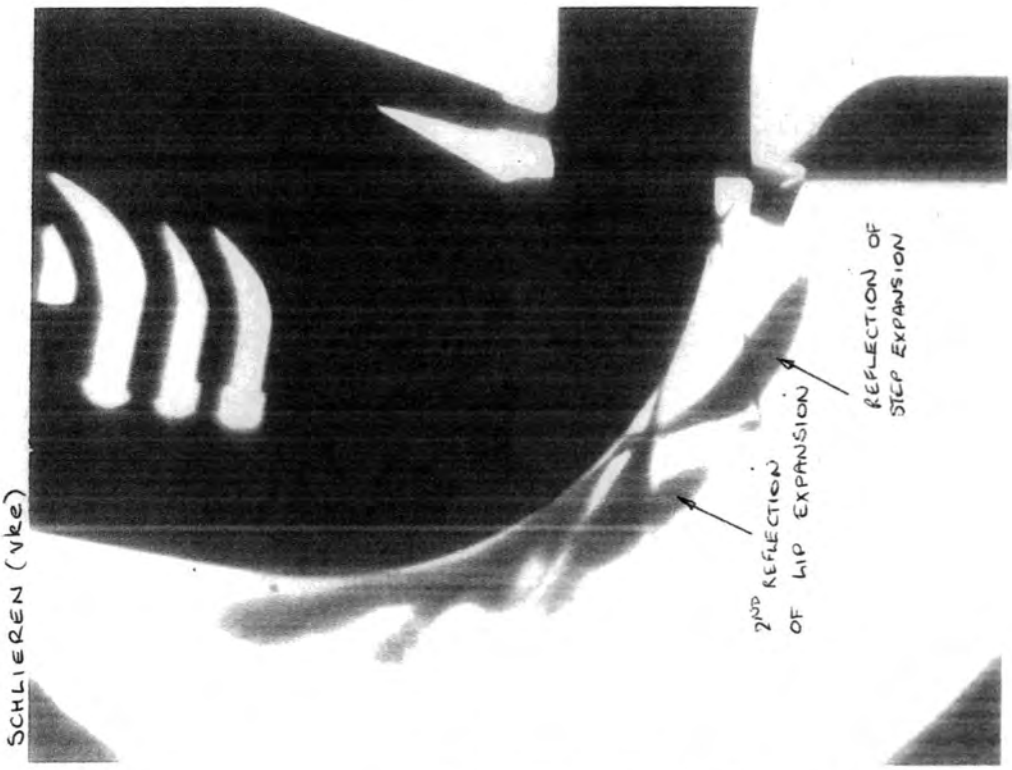


Plate 7b SLOT 4.00 STEP 2.55
C_{p_0} 0.205

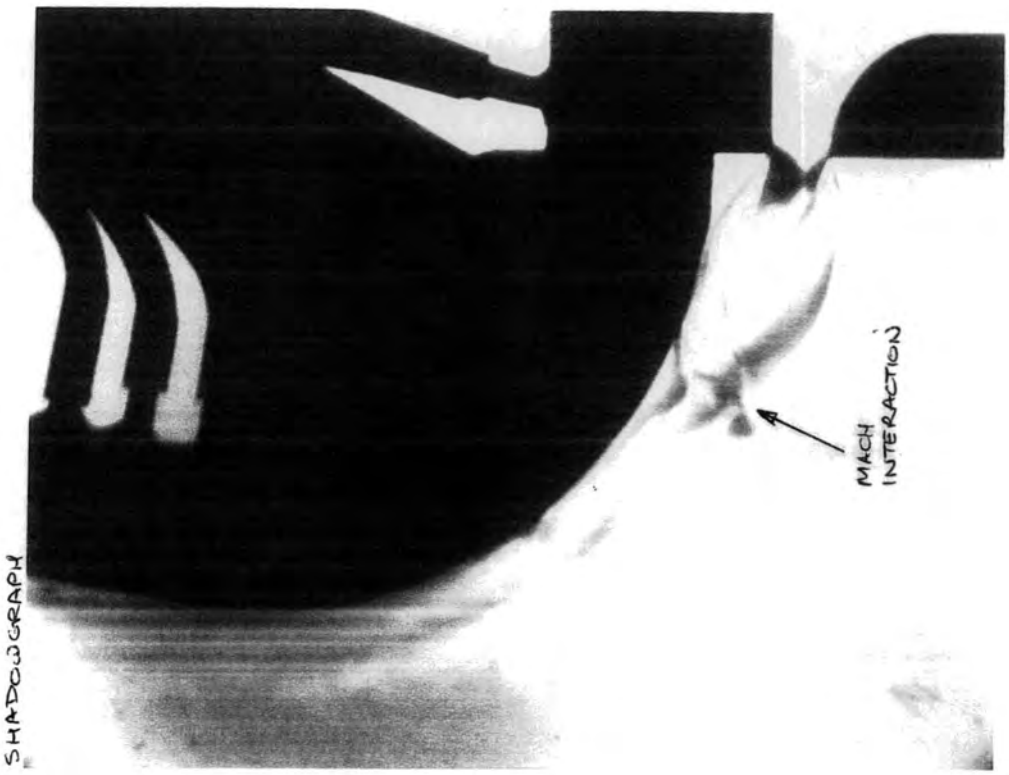


Plate 8a SLOT 4.00 STEP 3.76
C_{p_0} 0.228

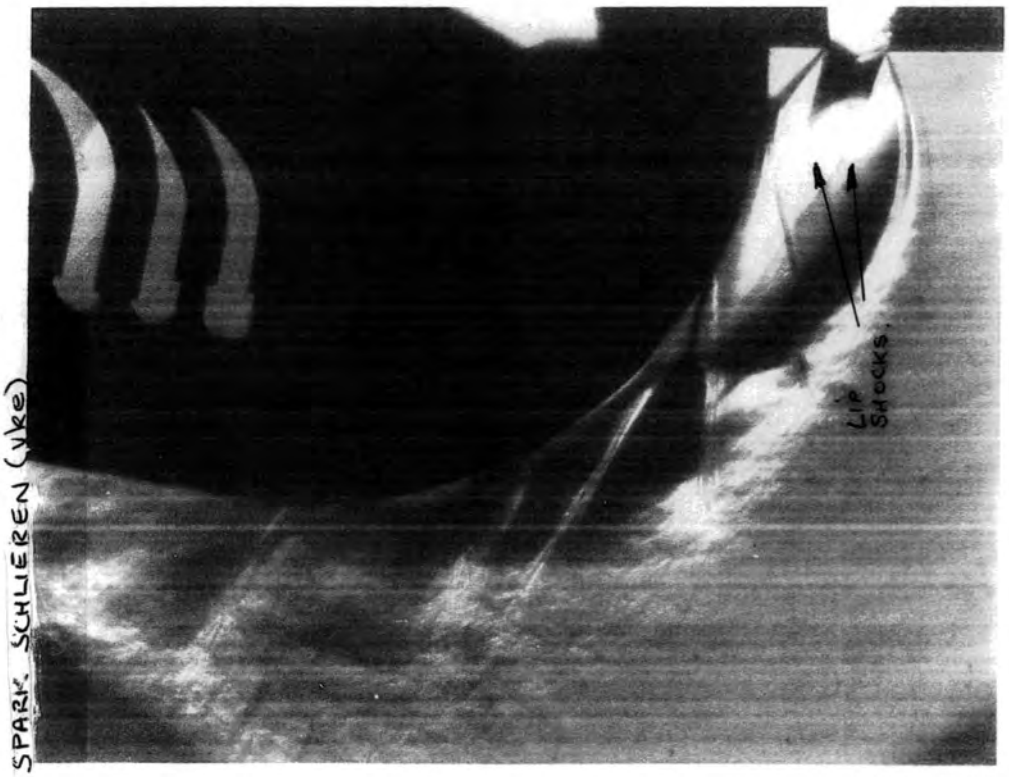


Plate 8b SLOT 4.00 STEP 3.76
C_{p_0} 0.191

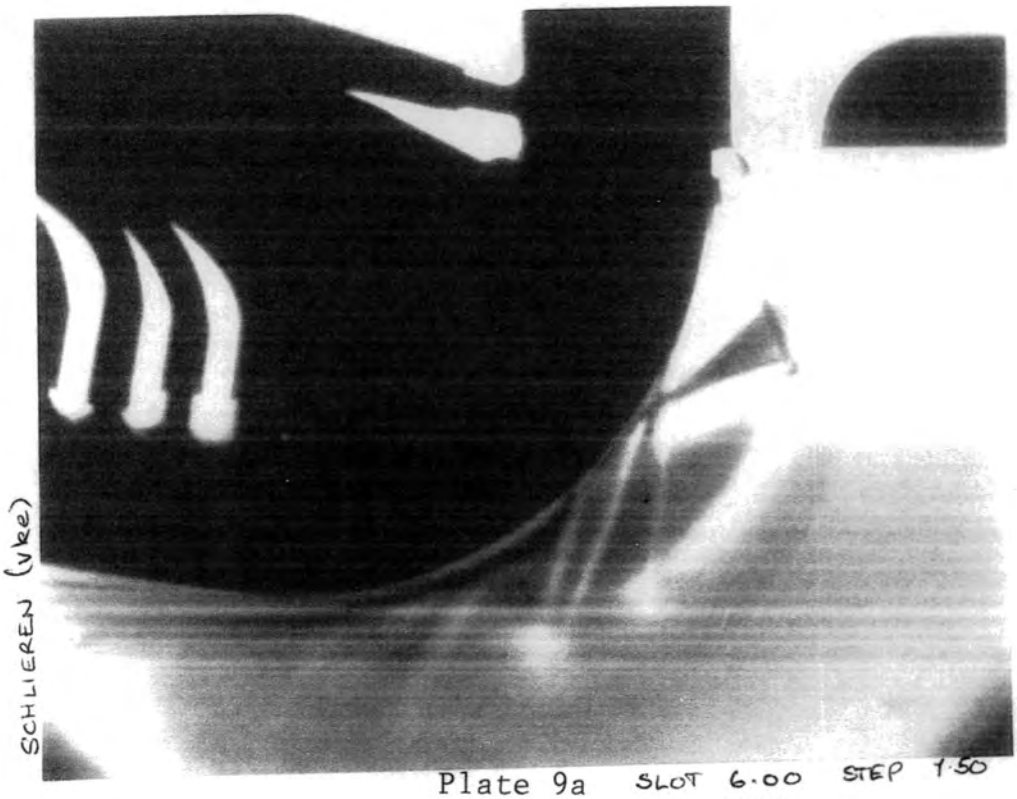


Plate 9a SLOT 6.00 STEP 1.50
C_{p_0} 0.290

Plate 9b SLOT 6.00 STEP 3.75
C_{p_0} 0.315

Plate 10a SLOT 8.00 STEP 1.49
C_{p_0} 0.359

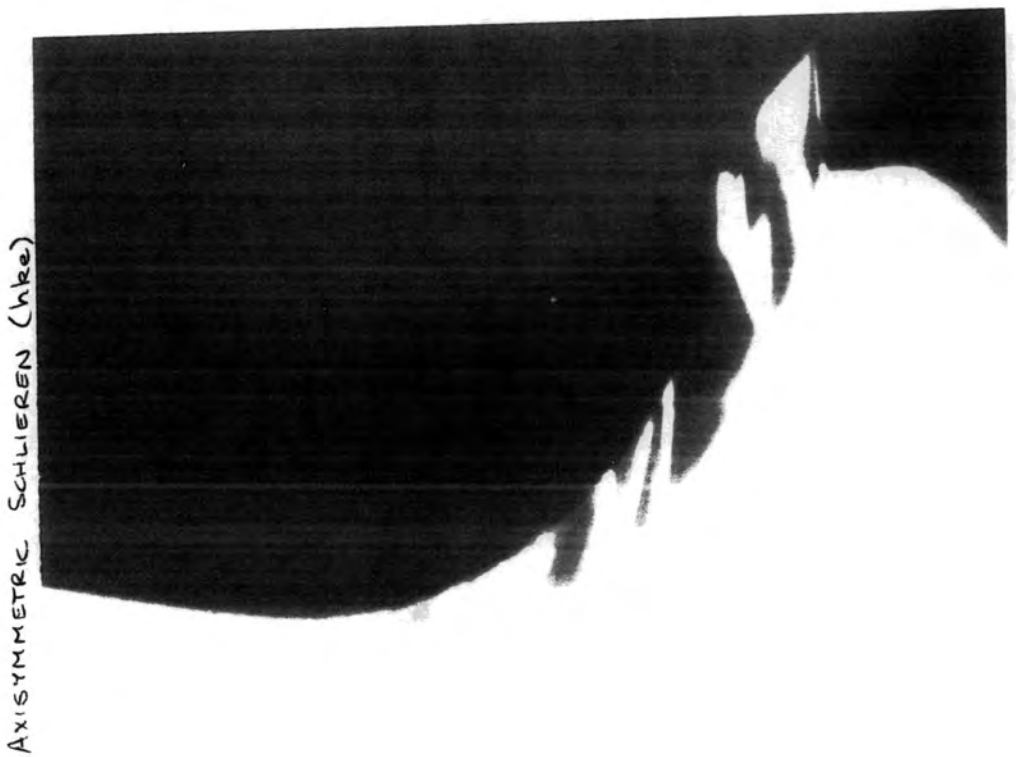


Plate 10b SLOT 5.00 STEP 1.25
C_{p_0} 0.207

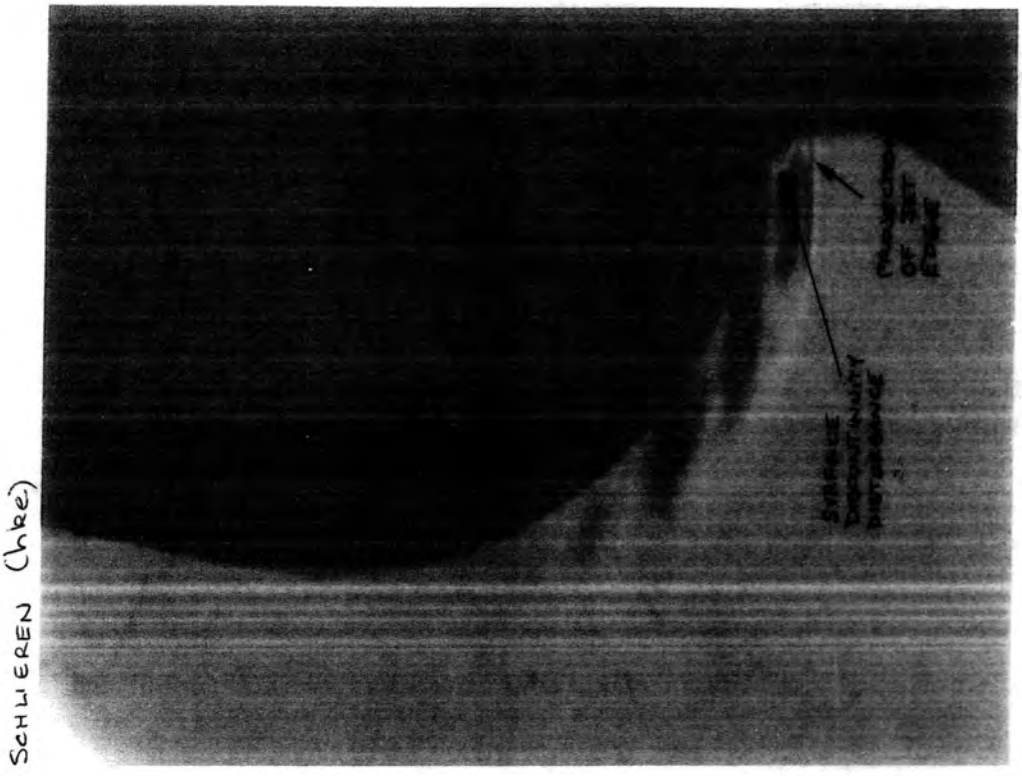


Plate 11a SLOT 1.67 STEP 0.00
C_{p0} 0.124

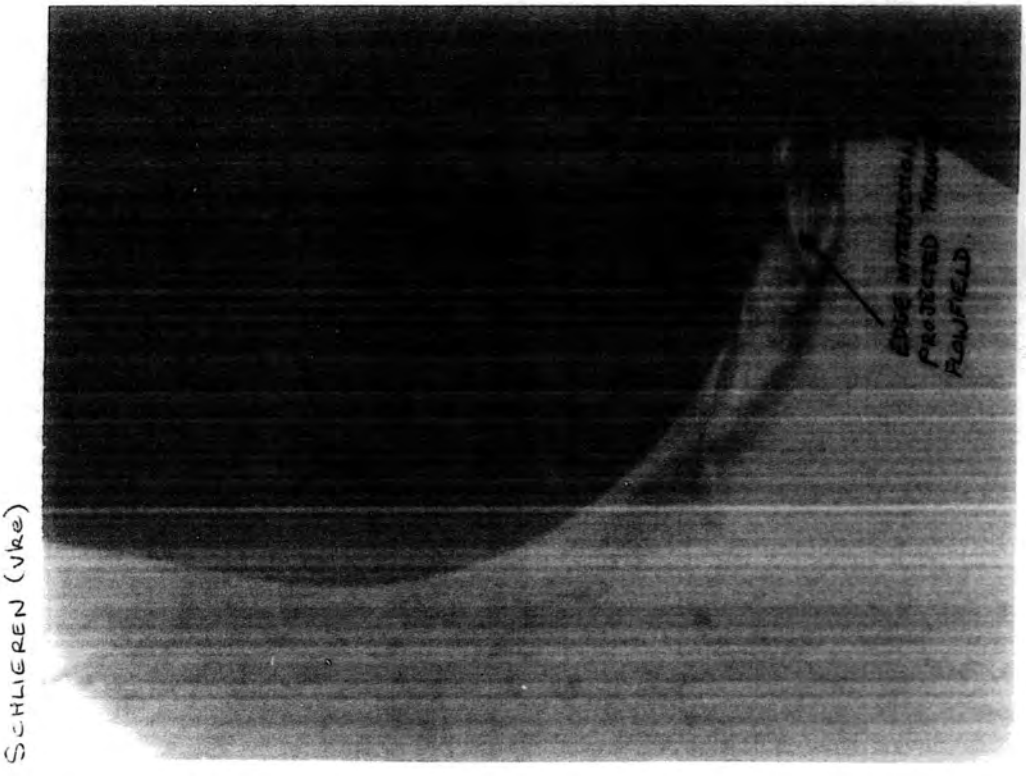


Plate 11b SLOT 1.67 STEP .25
C_{p0} 0.105

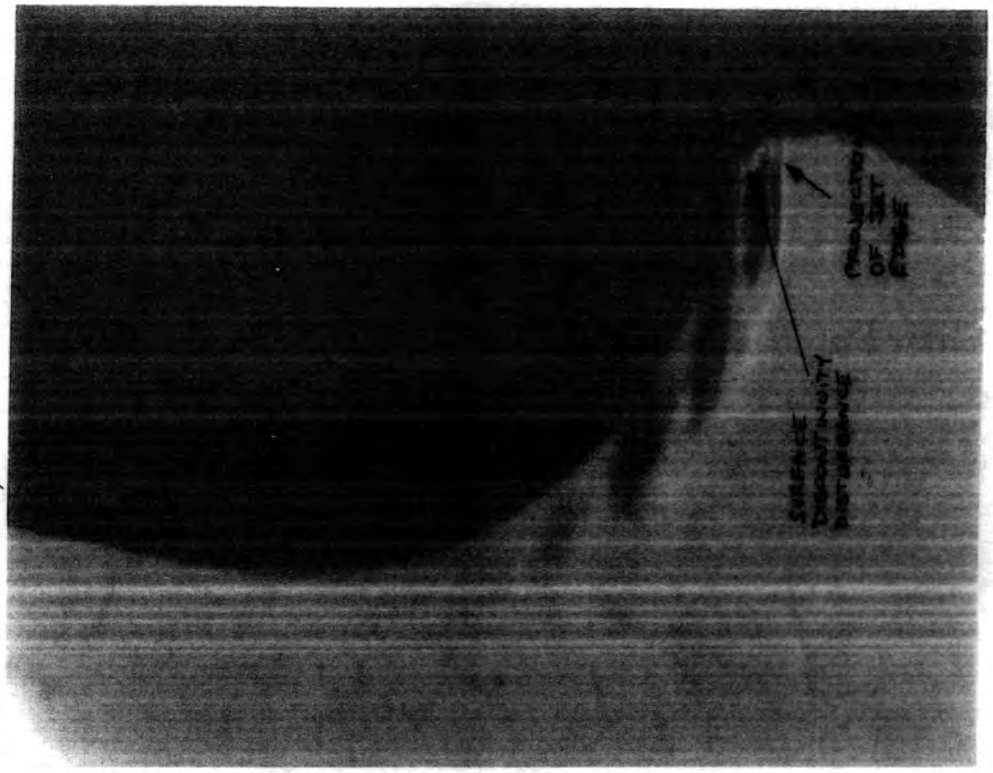


Plate 11a SLOT 1.67 STEP 0.00
C_{p0} 0.124

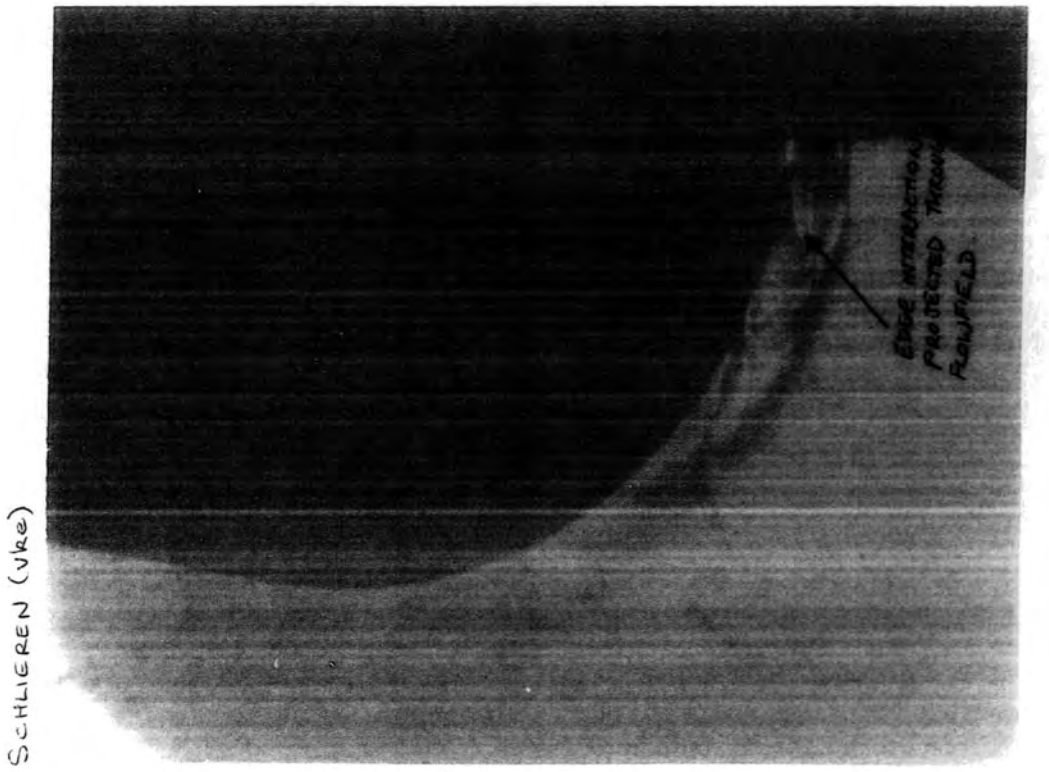


Plate 11b SLOT 1.67 STEP .25
C_{p0} 0.105

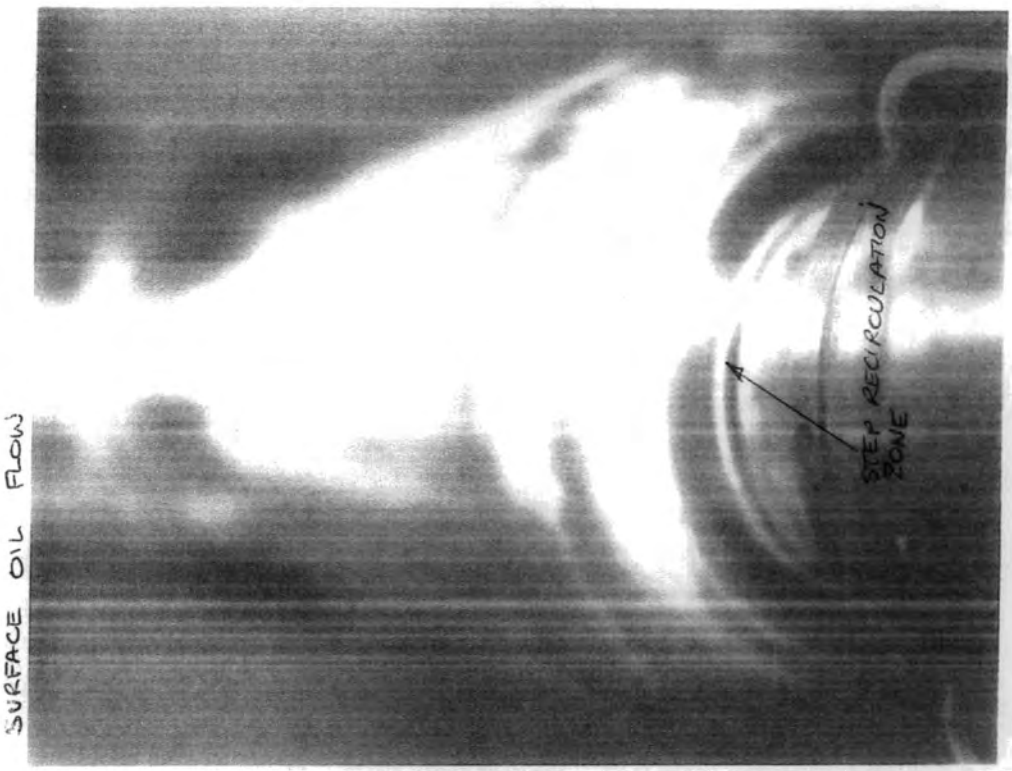


Plate 13a SLOT 2·54 STEP 1·25
C_{p_0} 0·125

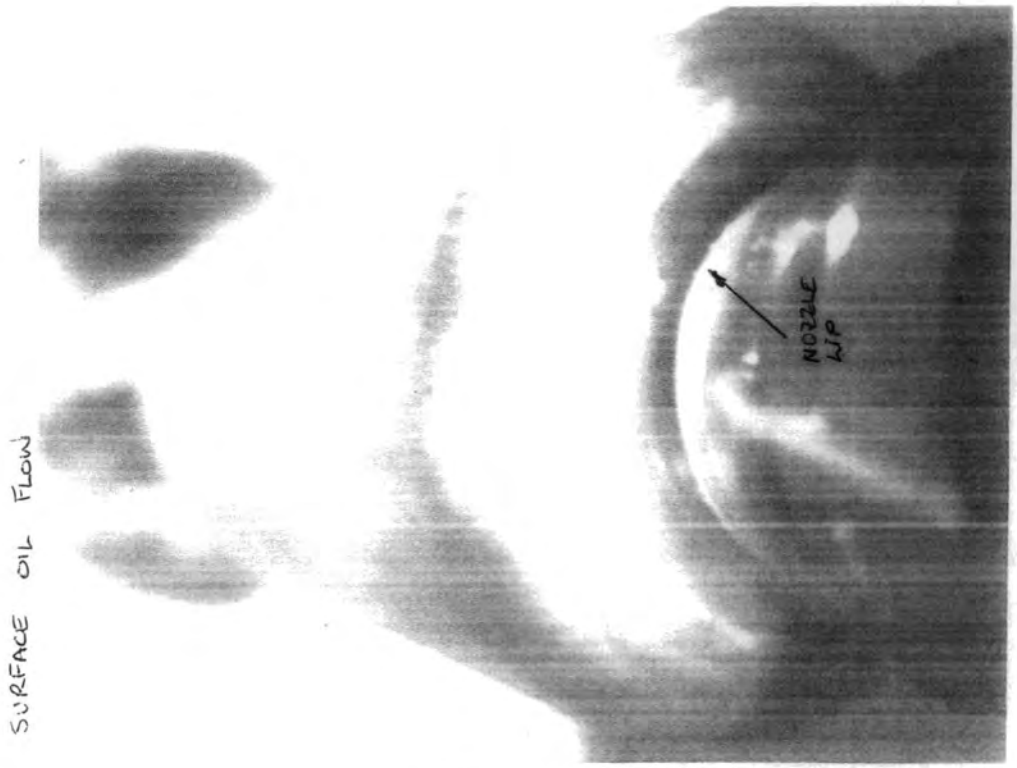


Plate 13b SLOT 3·33 STEP 0·00
C_{p_0} 0·174

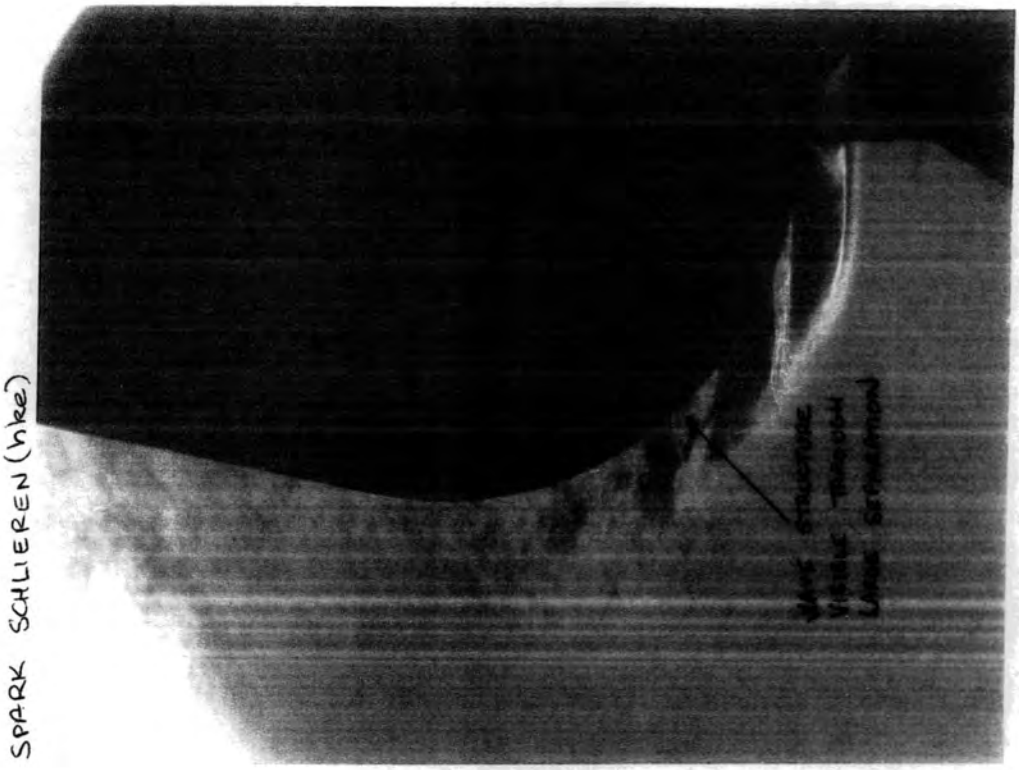


Plate 14a SLOT 3.33 STEP 0.00
C_{p_0} 0.174

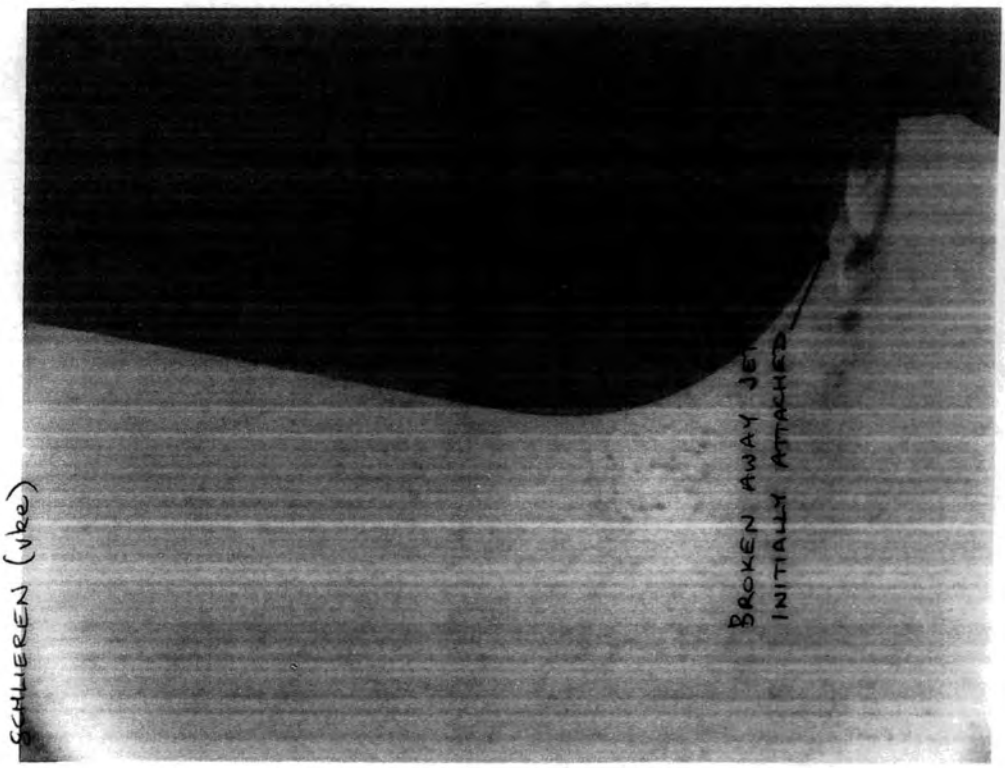


Plate 14b SLOT 3.33 STEP 0.00
C_{p_0} 0.243

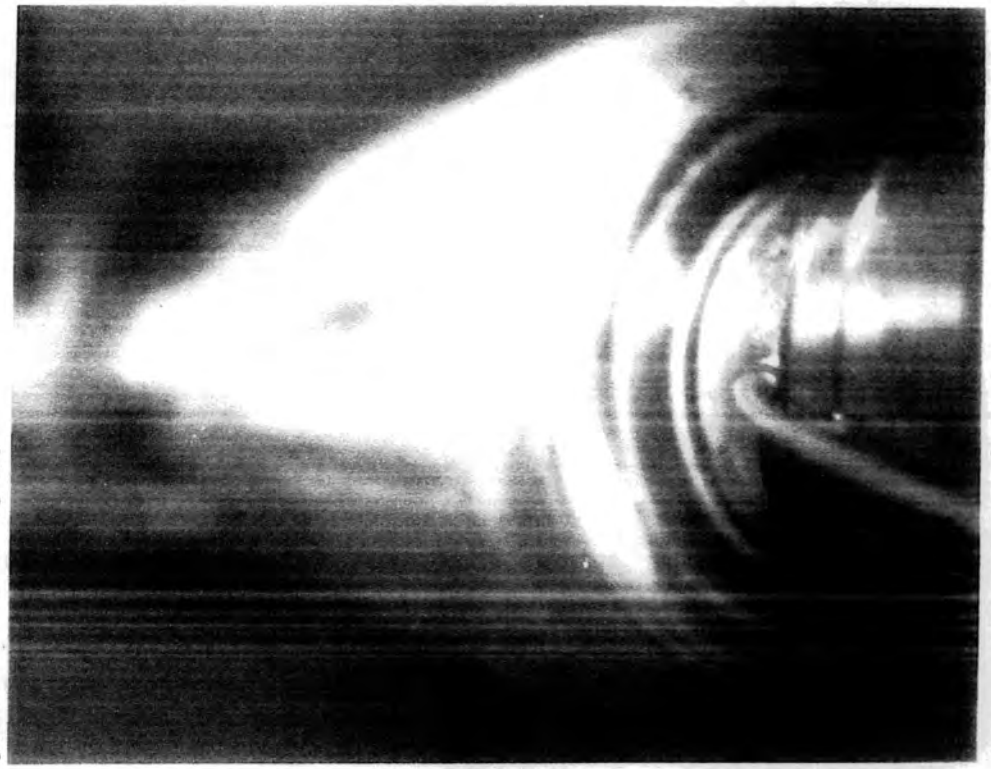


Plate 15a SLOT 3.33 STEP 1.25
C_{p_0} 0.209

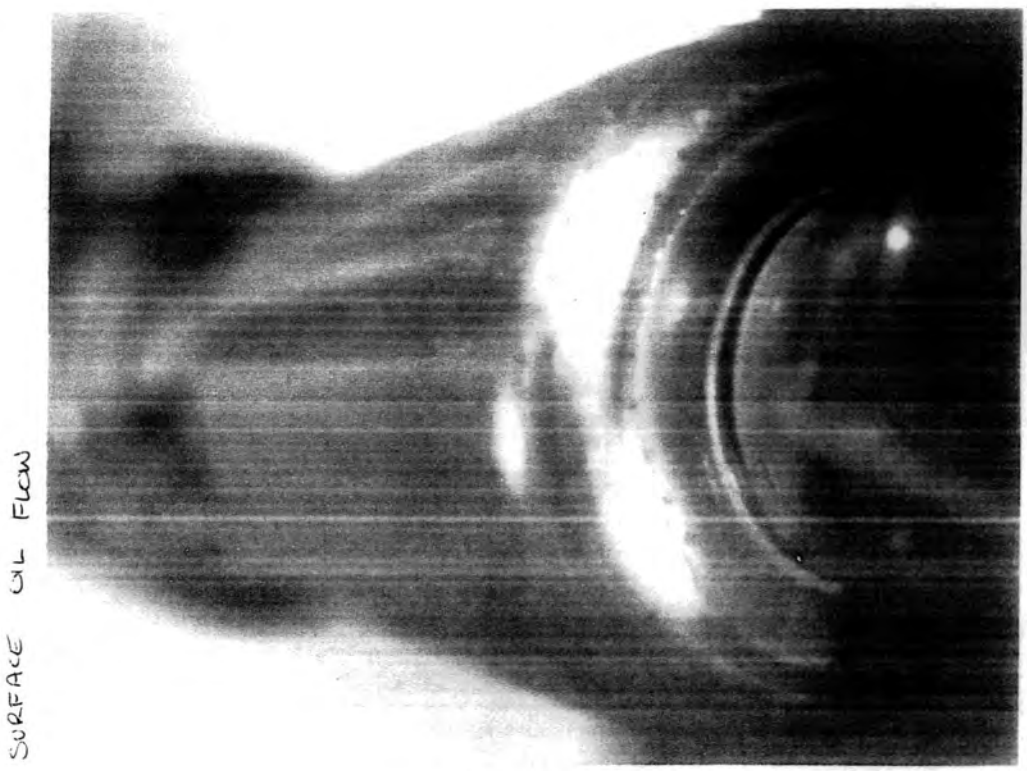


Plate 15b SLOT 3.33 STEP 1.25
C_{p_0} 0.174

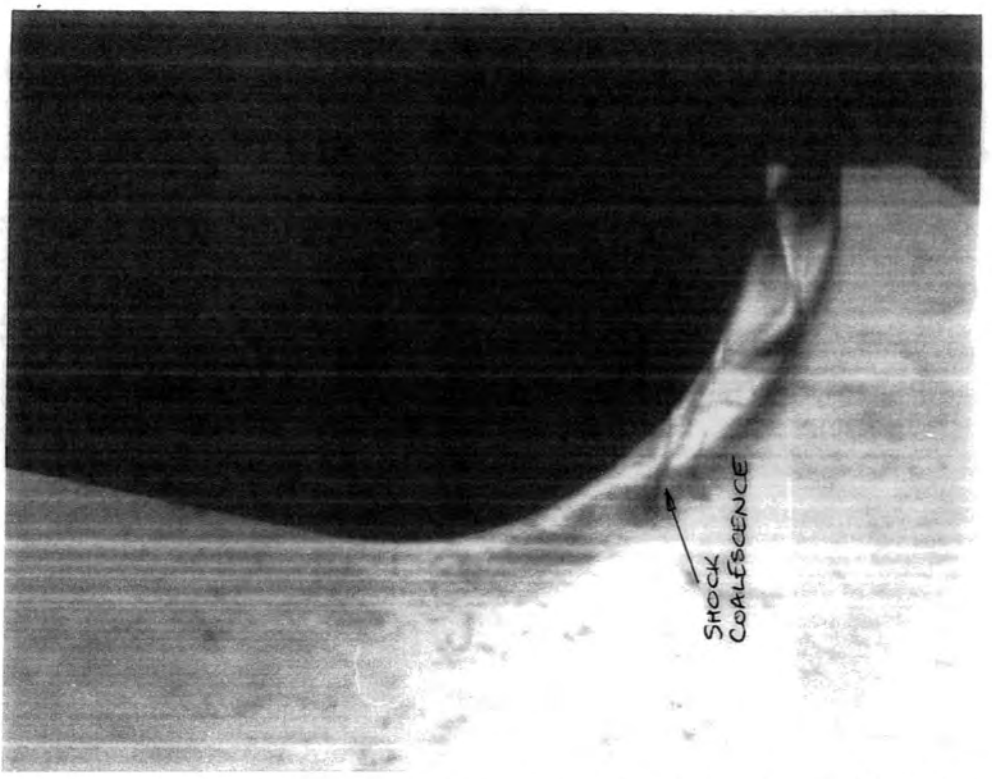


Plate 16a SLOT 3.33 STEP 1.25
C_{p_0} 0.157.

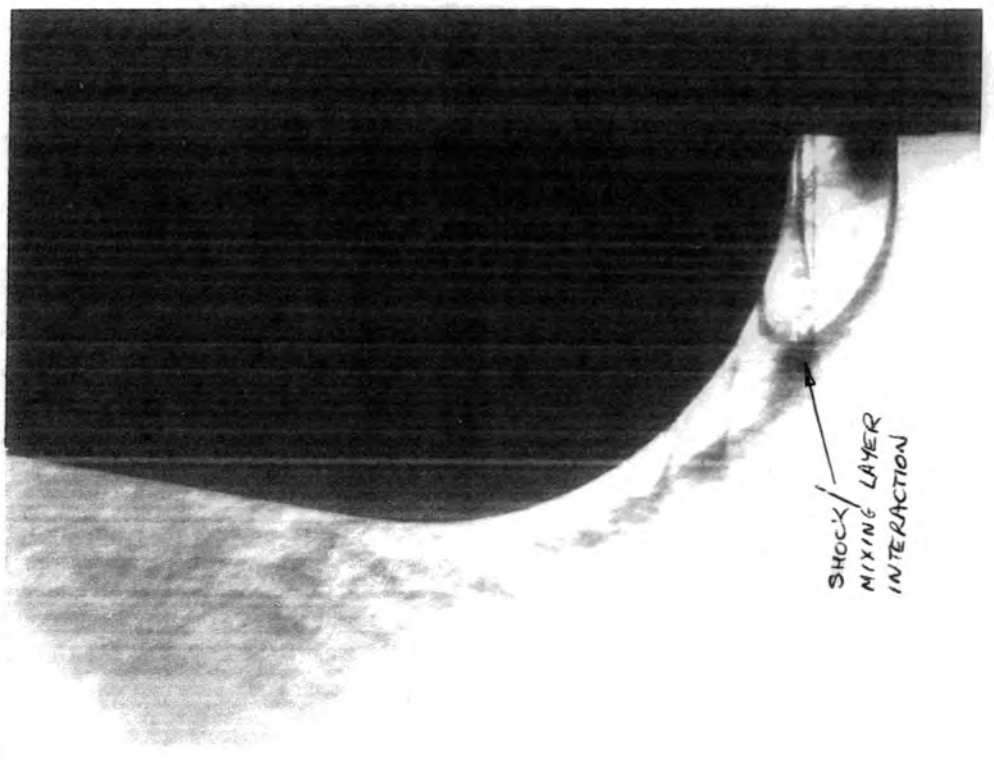


Plate 16b SLOT 3.33 STEP 3.13
C_{p_0} 0.159

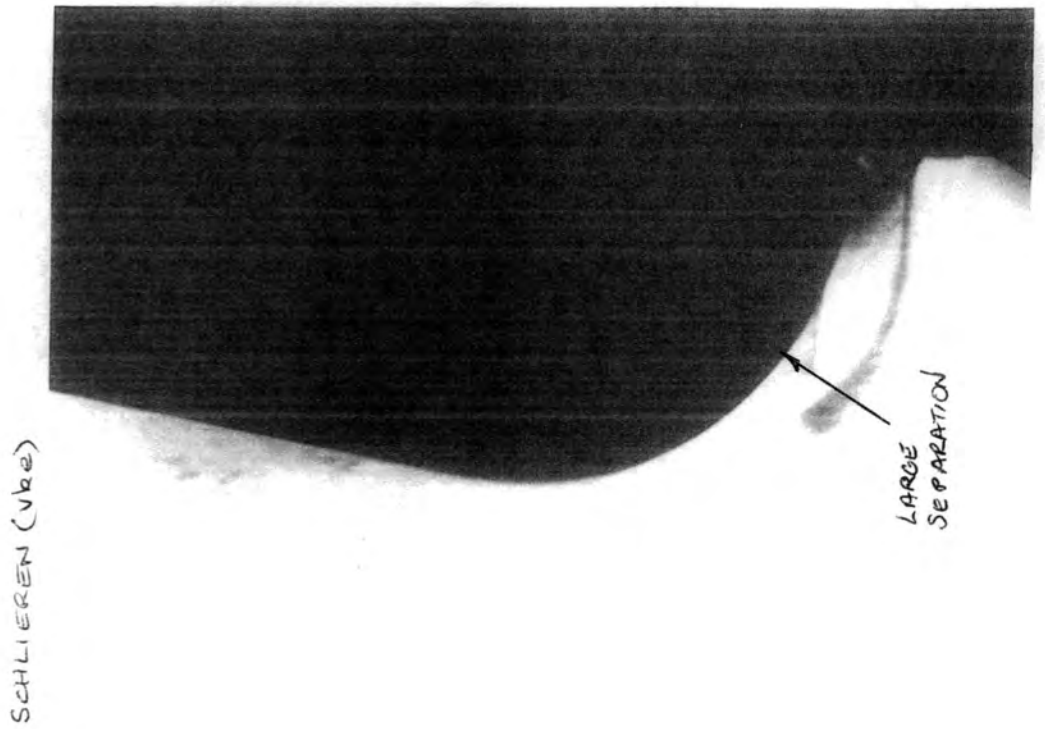


Plate 17a SLOT 5.00 STEP 0.00
C_{p_0} 0.225

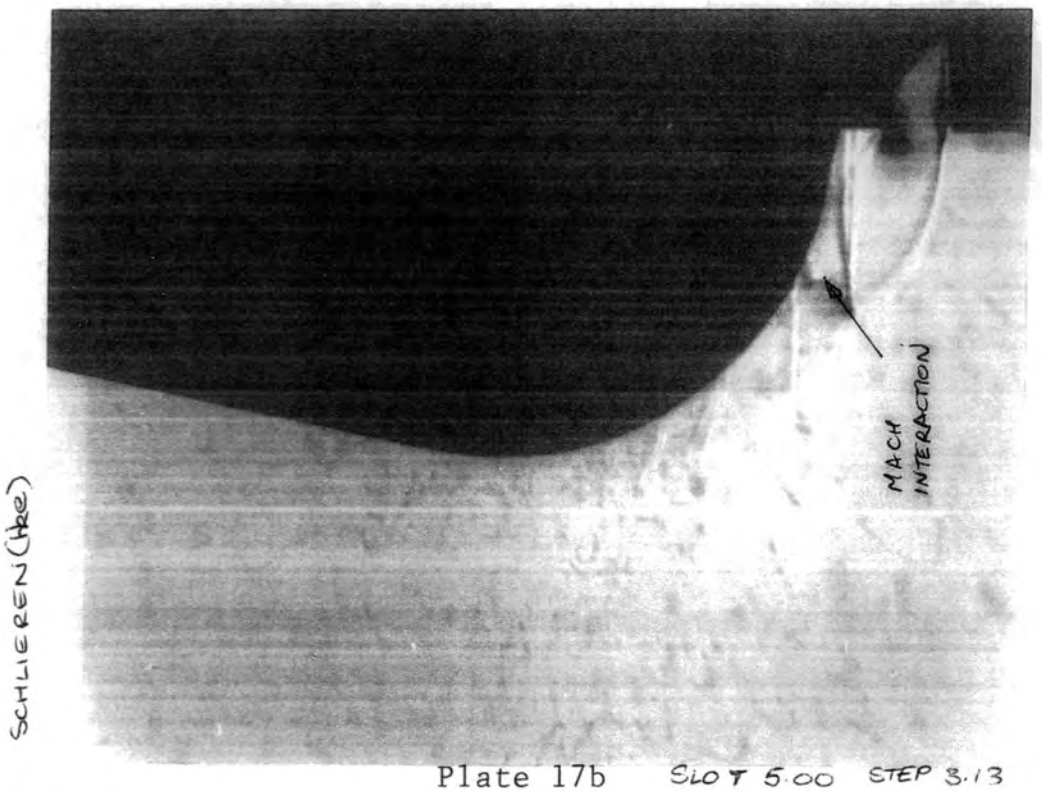


Plate 17b SLOT 5.00 STEP 3.13
C_{p_0} 0.222

Plate 18a SLOT 6.65 STEP 0.55
C_{p_0} 0.252

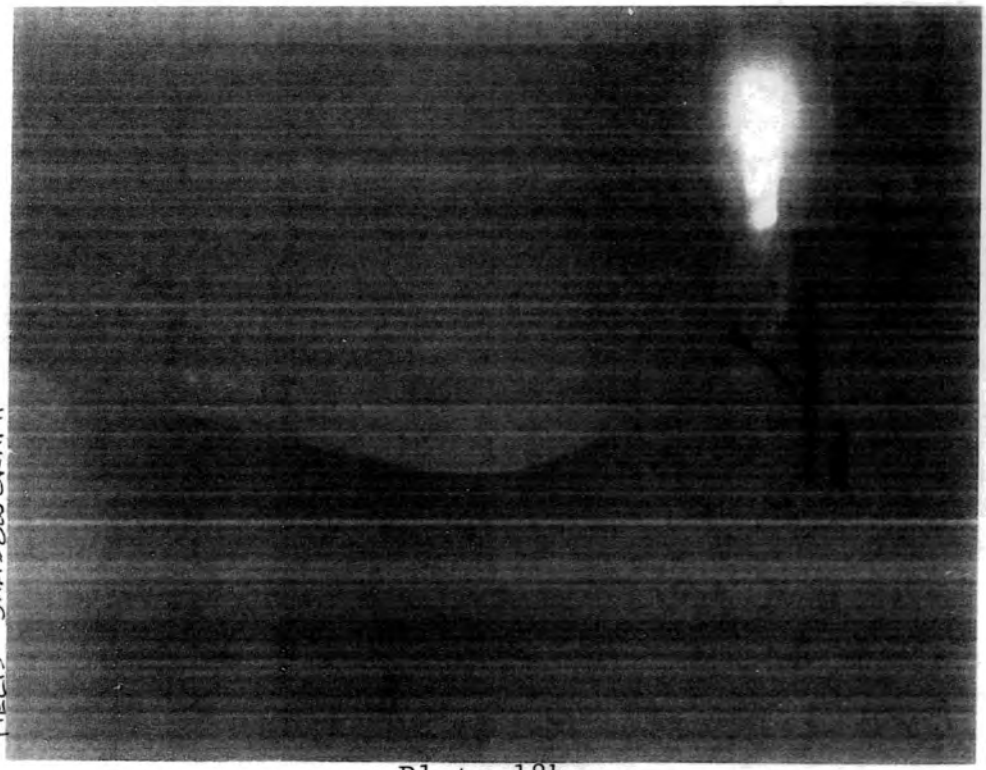
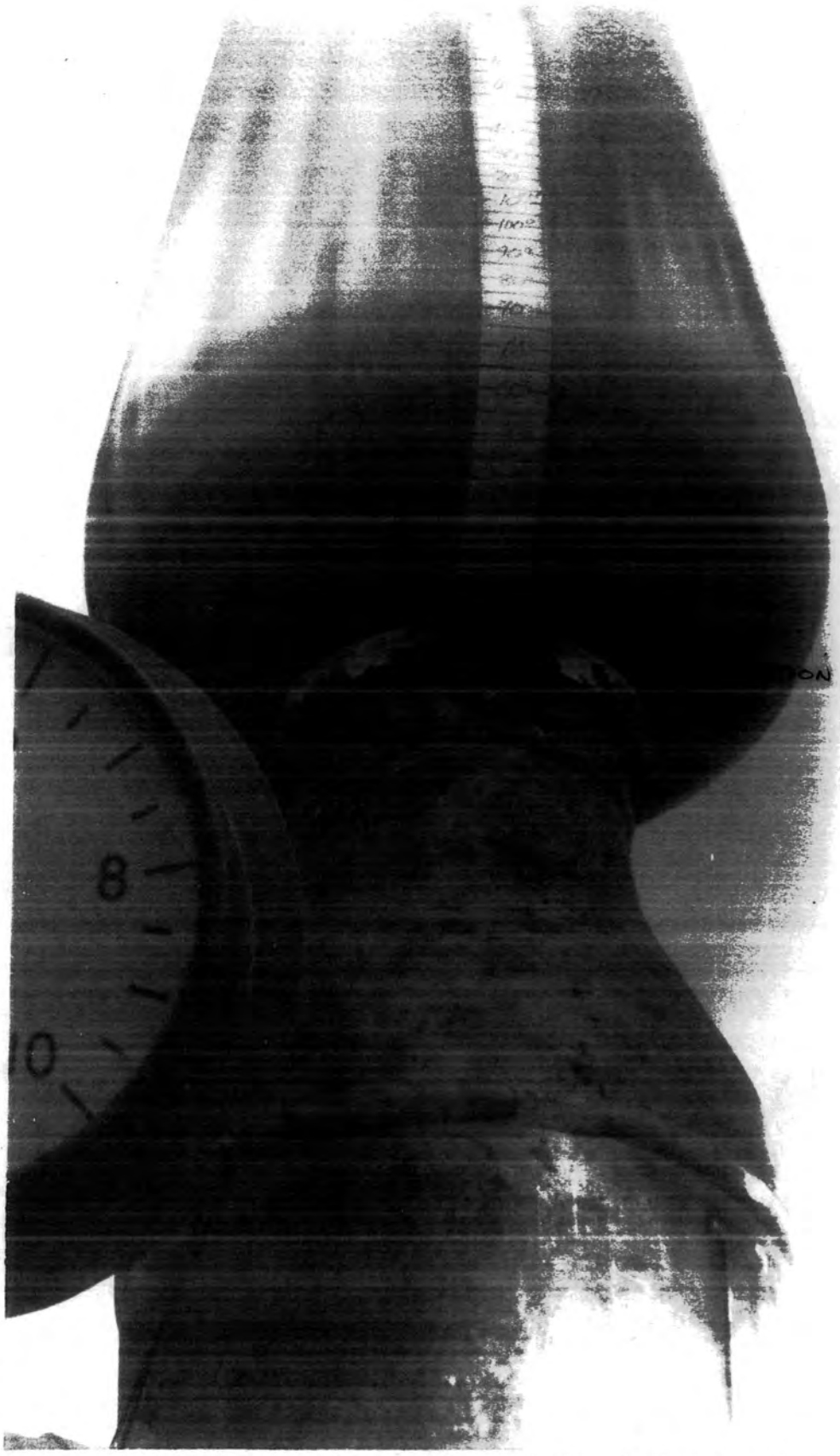


Plate 18b SLOT 6.65 STEP 3.60
C_{p_0} 0.184



FIELD SURFACE OIL FLOW

Plate 19 SLOT 6.65 STEP 3.60
C_{po} 0.184