Navier-Stokes Analysis of a Side-Wall Choke for the Langley 8-Foot Transonic Pressure Tunnel

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Overview

- Statement of problem
  - Issues
  - Constraints
- Solution procedure
  - Approach
  - Flow solver
  - Grid generation
- Results
  - Side-wall simulation
  - Wind tunnel simulation
- Summary

Background
8' TPT

- Requirement for downstream choke
  - High flow quality by reducing upstream noise propagation
  - $0.70 \leq M_{ts} \leq 0.95$

- Preliminary design based upon minimal aerodynamic analysis
  - Experimental verification not possible in time for CDR
  - Additional aerodynamic questions raised

- Chose to conduct CFD analysis
  - Decision (choke / no choke) postponed one month for results
  - Time critical

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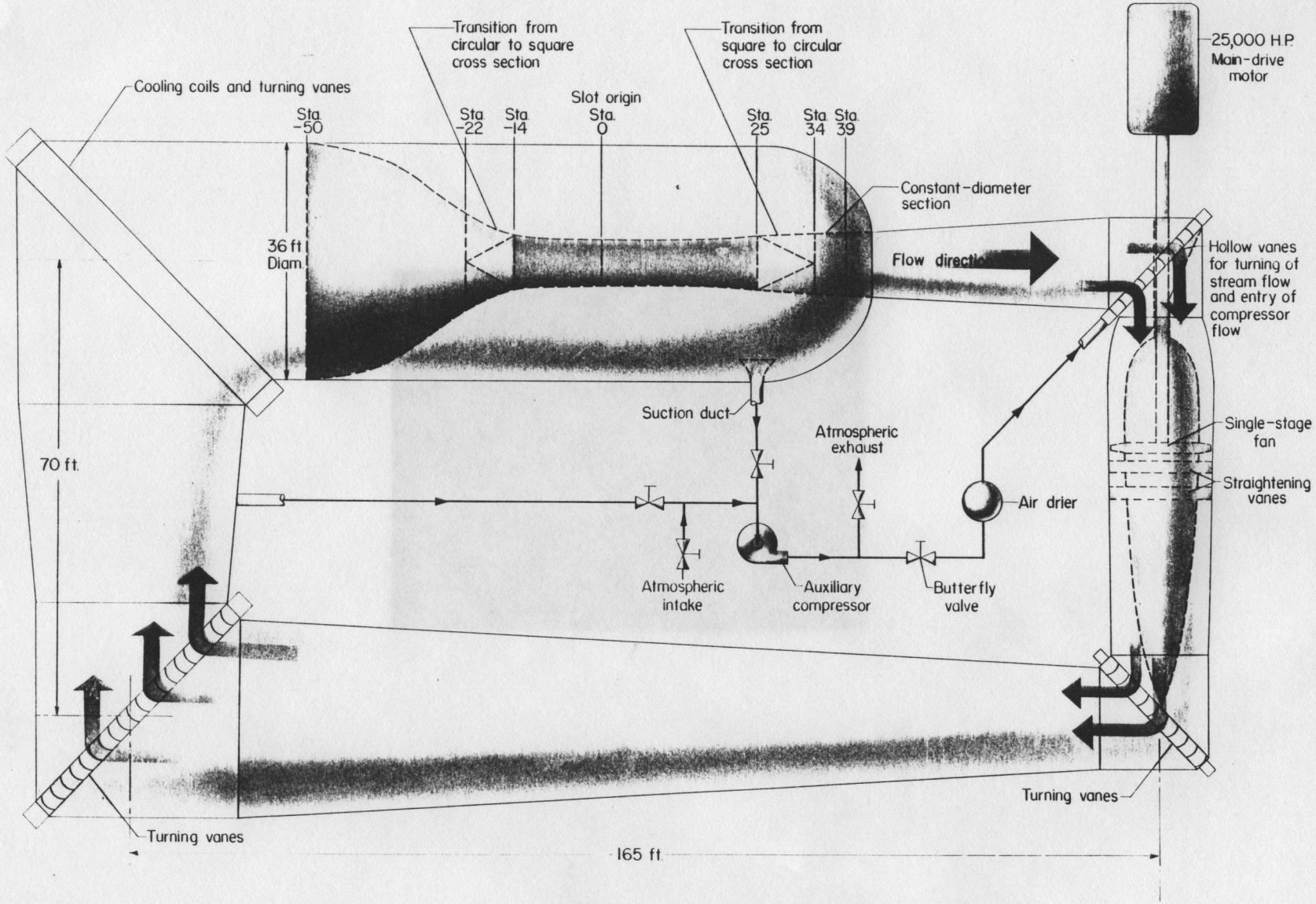

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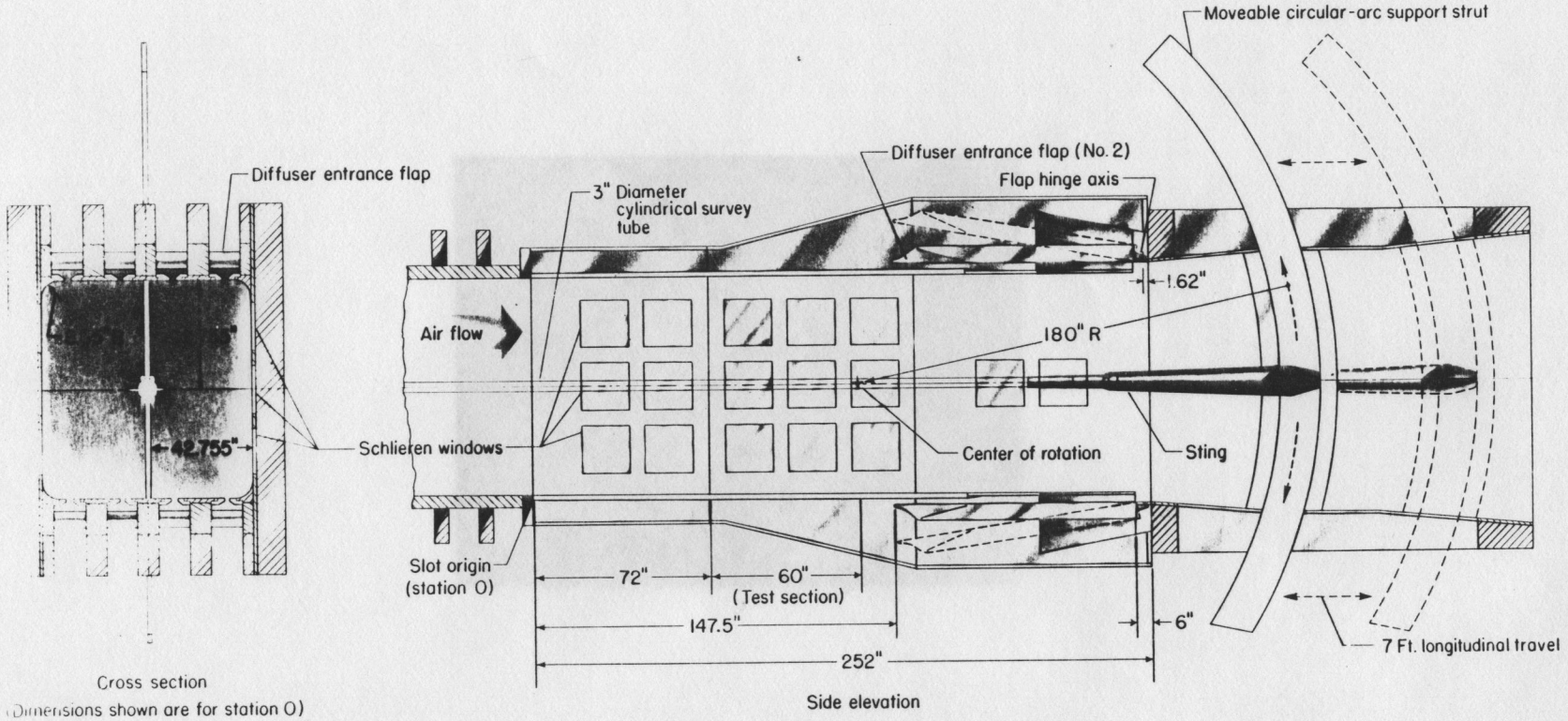
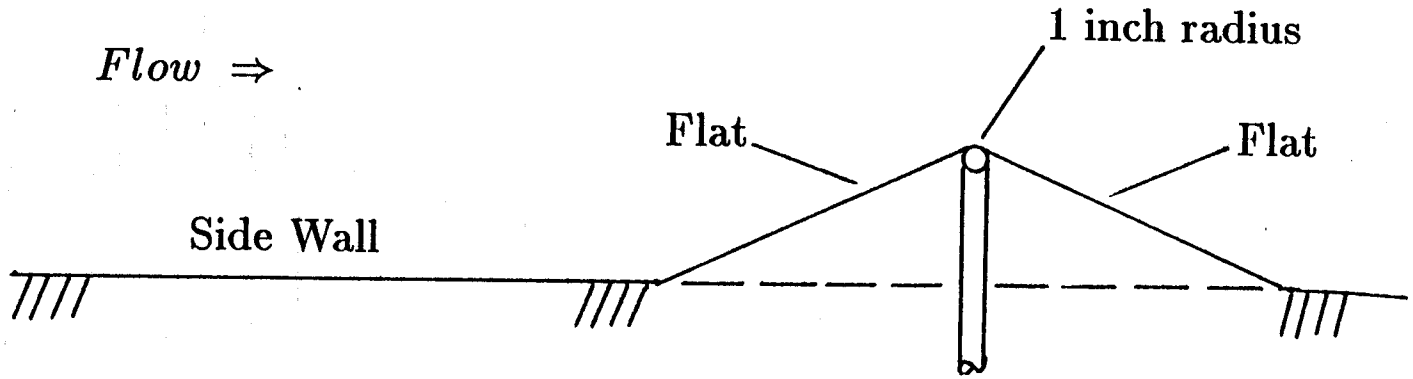


Slotted-throat and diffuser-entrance regions of the Langley 8-foot transonic pressure tunnel.

Side-Wall Choke

Conceptual Design Features



- Simple
- Adjustable displacement
- Longitudinal location constrained
- Chord $\approx 4ft.$
- Extend essentially from floor to ceiling

Issues for CFD Analysis

- Displacement required to choke flow
- Extent of flow separation
- Loads on choke
- Total pressure losses

Problem Constraints

- Flow separation question
  - Navier-Stokes
  - Multiple turbulence models desirable
- Results needed immediately (1 month)
- 3-D methods ruled out
  - Grid generation time consuming
  - Flow solvers would require modification
  - Setup and run times would be too long
- 2-D methods advantages
  - Reasonable answers to most questions
  - Rapid turnaround
  - Flow solver available

Approach

- Perform fully turbulent calculation with TLNS2D (Swanson)

- Use design conditions for maximum displacement
  - $M_{ts} = 0.7$
  - $R = 3 \times 10^6/ft.$

- Model side wall geometry only
  - Qualitative assessment
  - Proper side-wall curvature
  - Adjust choke displacement and pressure ratio to choke at M_{ts}
  - Neglect tunnel 3-D area effects

- Simulate 3-D area effects in 2-D code
  - Quantitative assessment

Navier-Stokes Formulation - TLNS2D

$$\hat{Q}_{,t} + (\hat{F} - \hat{F}_v)_{,\xi} + (\hat{G} - \hat{G}_v)_{,\eta} = 0$$

- Explicit time integration with 5-stage Runge-Kutta scheme
- Finite volume spatial discretization - central differencing

$$\frac{\partial}{\partial t} \int \int_{\Omega} Q dA + \int_{\partial\Omega} \vec{F} \cdot \hat{n} d\ell = 0$$

- Second-order accuracy in space and time
- Controlled artificial dissipation - blended 2^{nd} and 4^{th} order

Navier-Stokes Formulation - TLNS2D
Concluded

$$\hat{Q}_{,t} + (\hat{F} - \hat{F}_v)_{,\xi} + (\hat{G} - \hat{G}_v)_{,\eta} = 0$$

- Thin-layer approximation - $F_v = 0$

- Acceleration techniques for steady-state solutions
  - Local time stepping
  - Variable coefficient implicit residual smoothing
  - Mesh sequencing & multigrid iteration

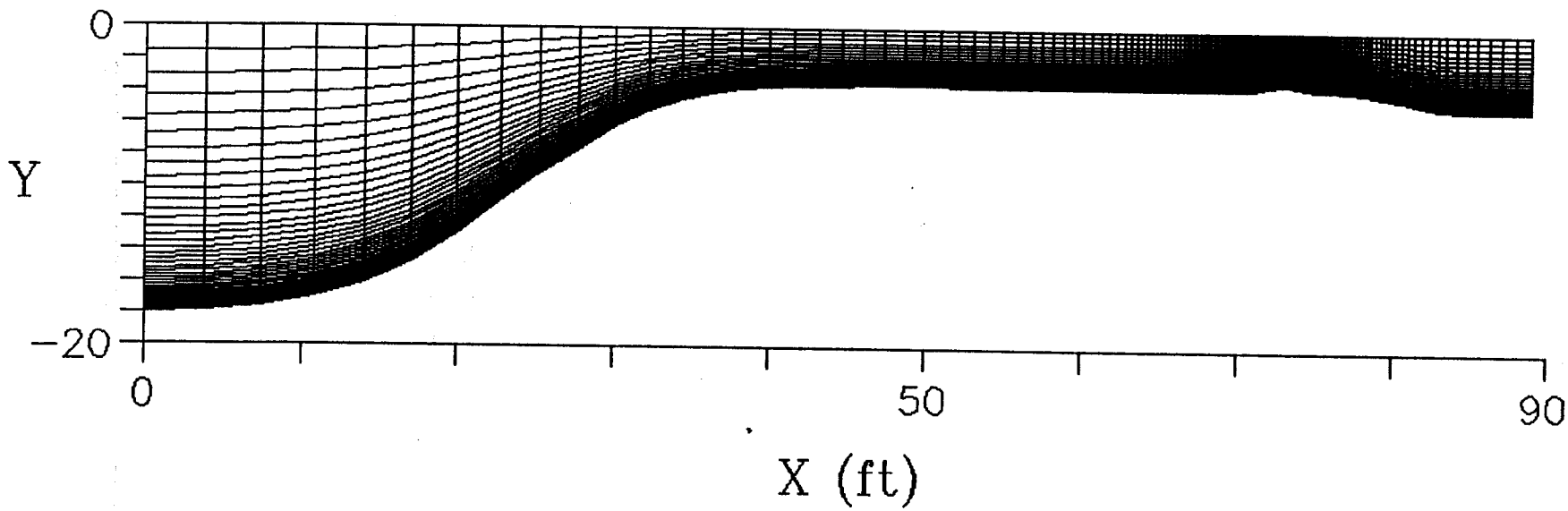
- Turbulence models
  - Cebici-Smith
  - ⋆ Baldwin & Lomax
  - Johnson-King

Grid Generation

- Algebraic grid
  - H topology
  - Inflow - contraction
  - Outflow - high-speed diffuser
  - 385×97
  - 37,345 points

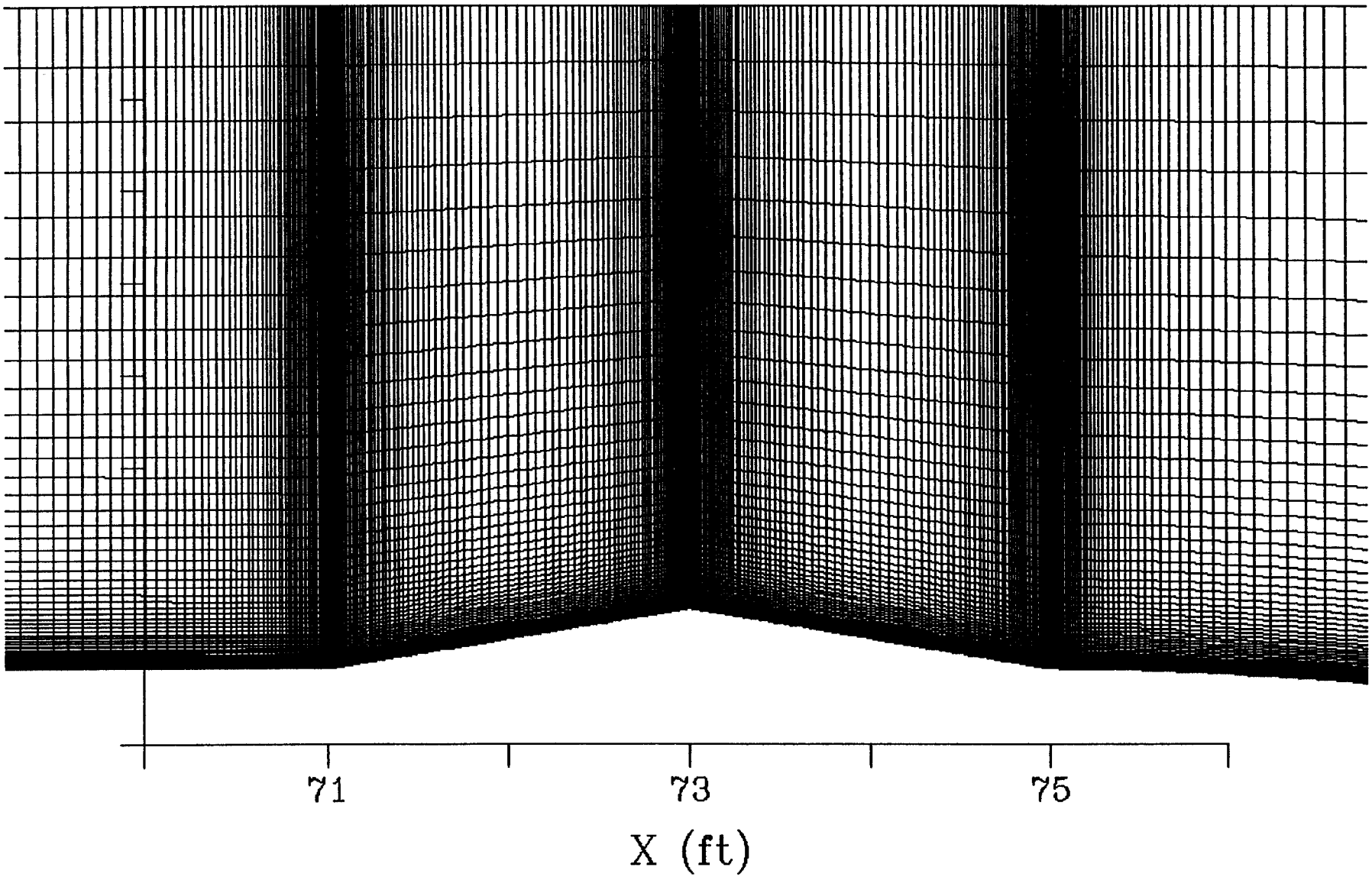
- Exponential stretching
  - Longitudinal - choke details
  - Lateral - side-wall boundary layer
  - $y^+ \approx 2$

Side Wall Simulation Grid



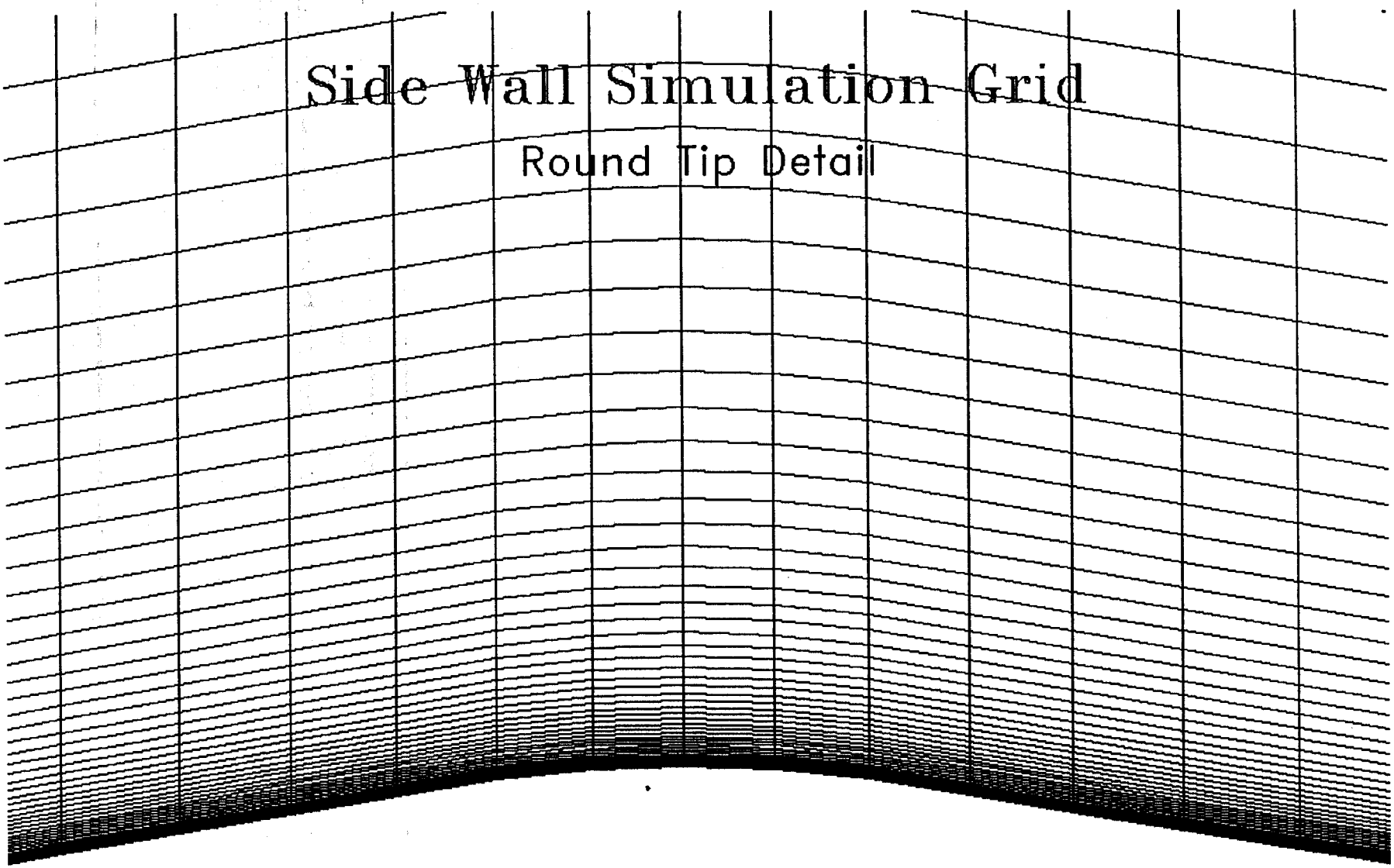
Side Wall Simulation Grid

Choke Section



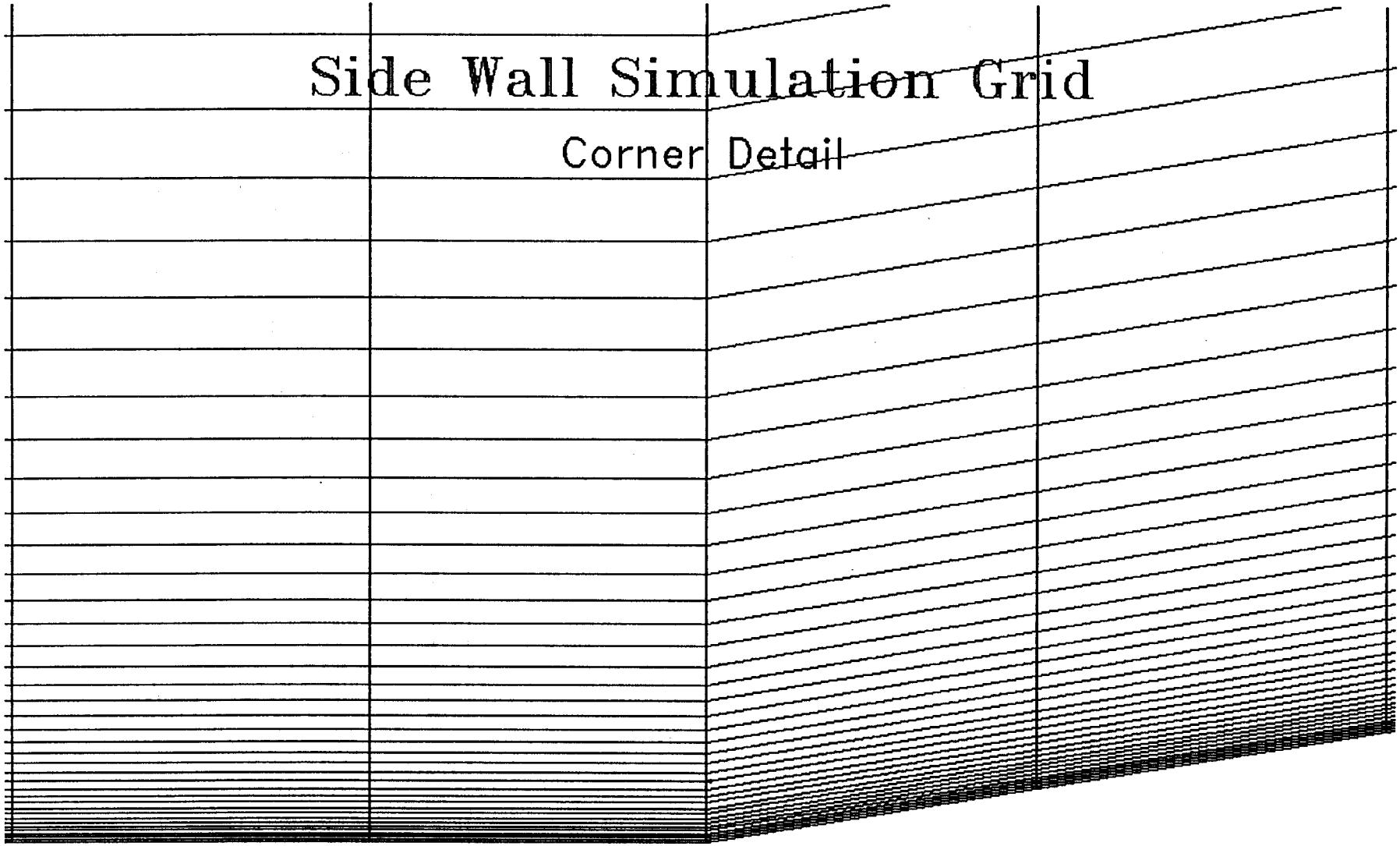
Side Wall Simulation Grid

Round Tip Detail



Side Wall Simulation Grid

Corner Detail



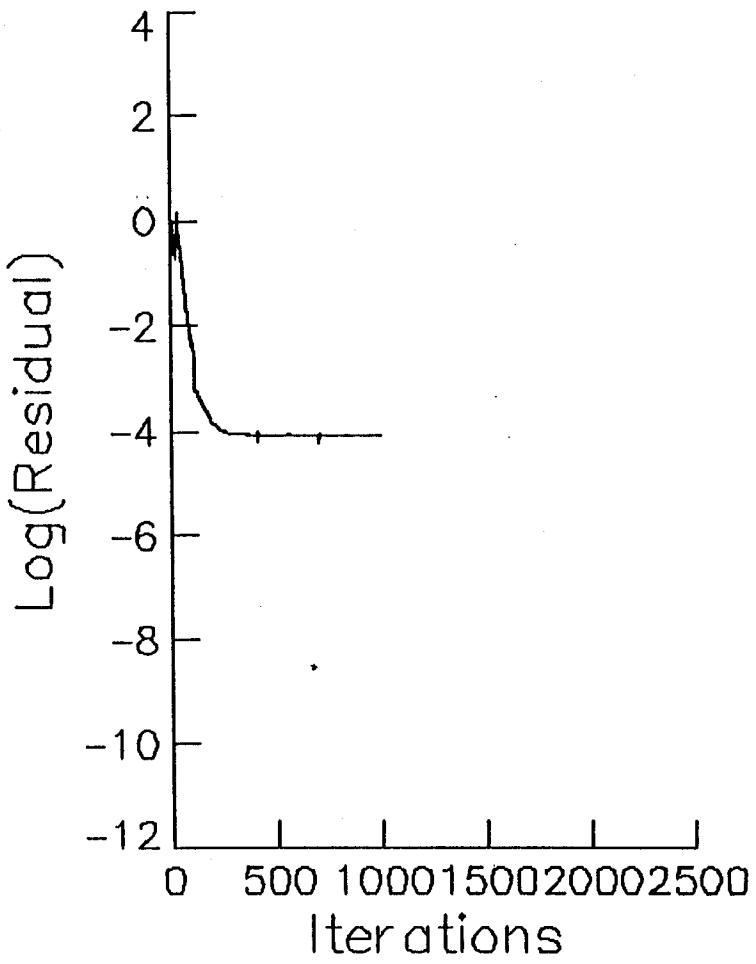
Computed Results

$M_{ts} = 0.7,\ R = 3.0 \times 10^6/ft.$

- Convergence
- Side-wall simulation
  - Qualitative features
  - Comparison - with / without choke
- Wind tunnel simulation
  - Comparison with Tunnel Calibration Data
  - Choke effects

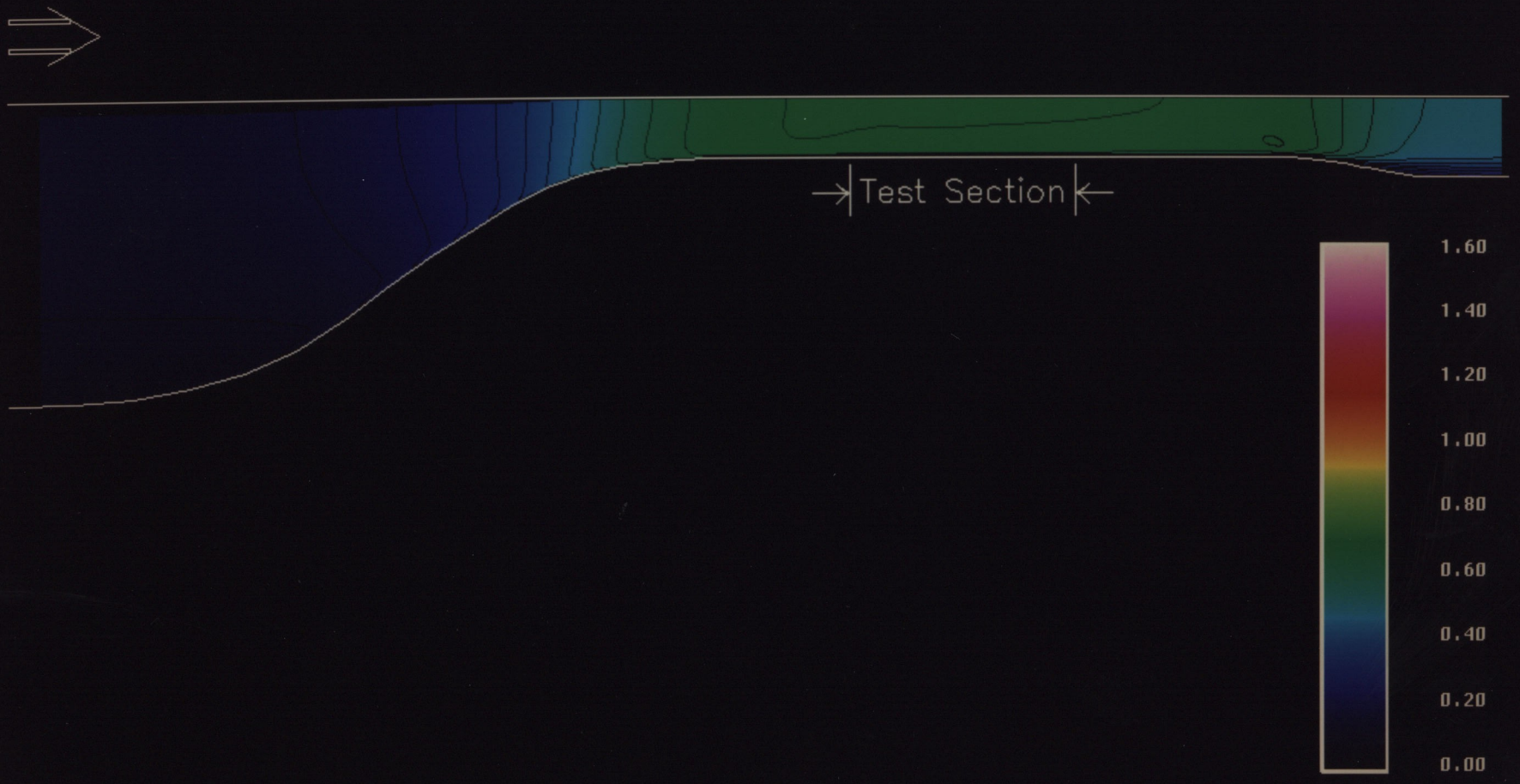
Convergence Properties

Side-Wall, No Choke



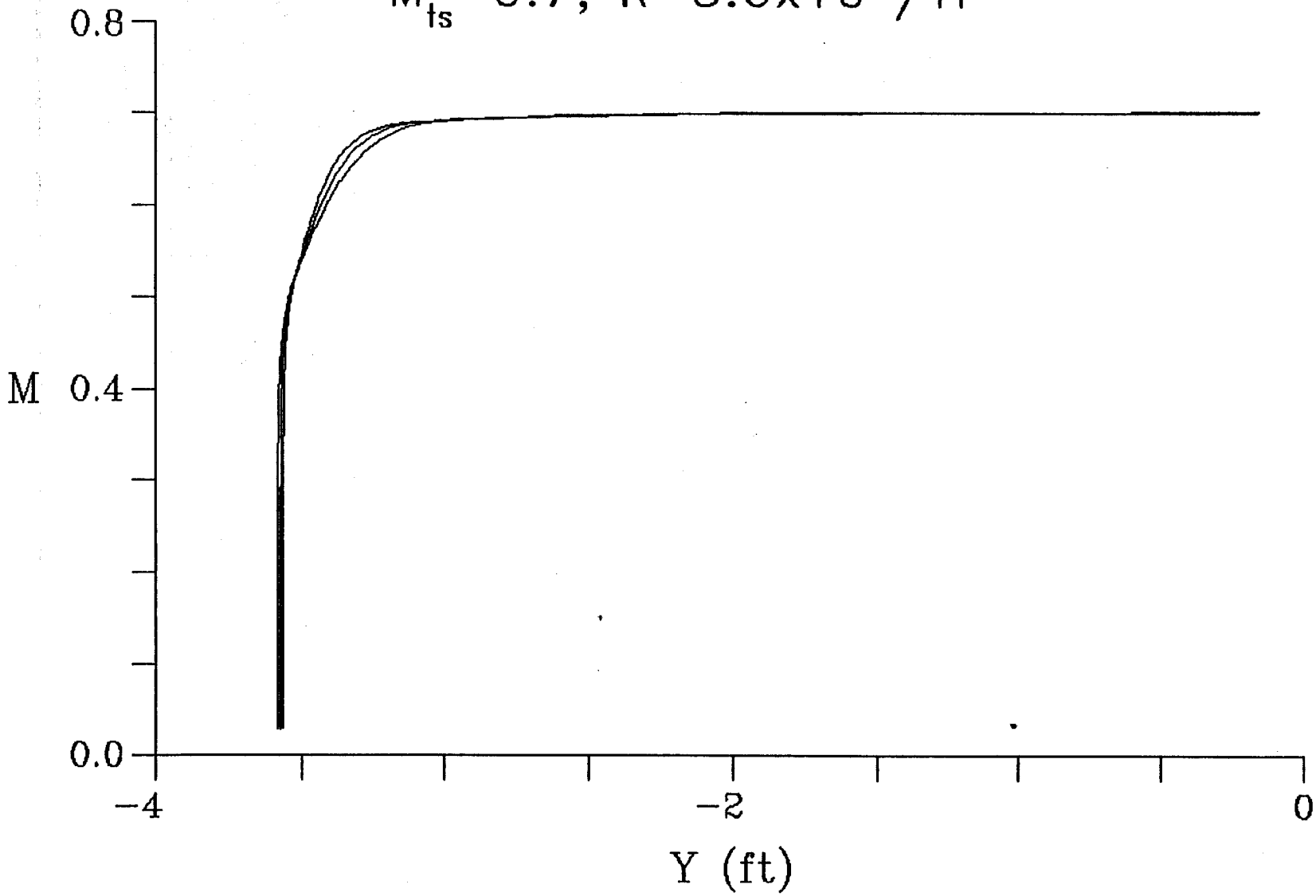
Side Wall Simulation without Choke

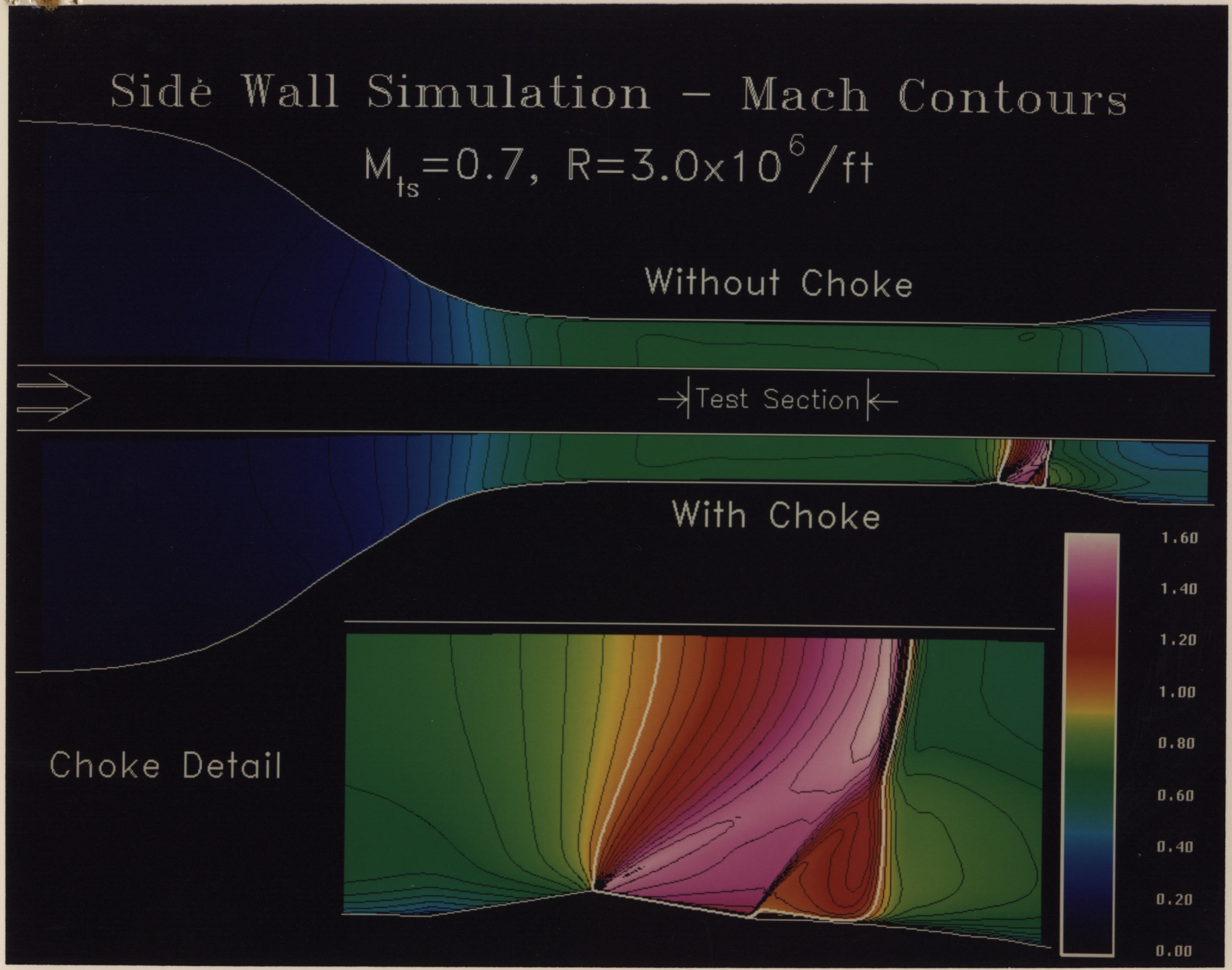
Mach Contours, M_{ts}=0.7, R=3.0x10^{6}/ft



Test Section Mach Profiles

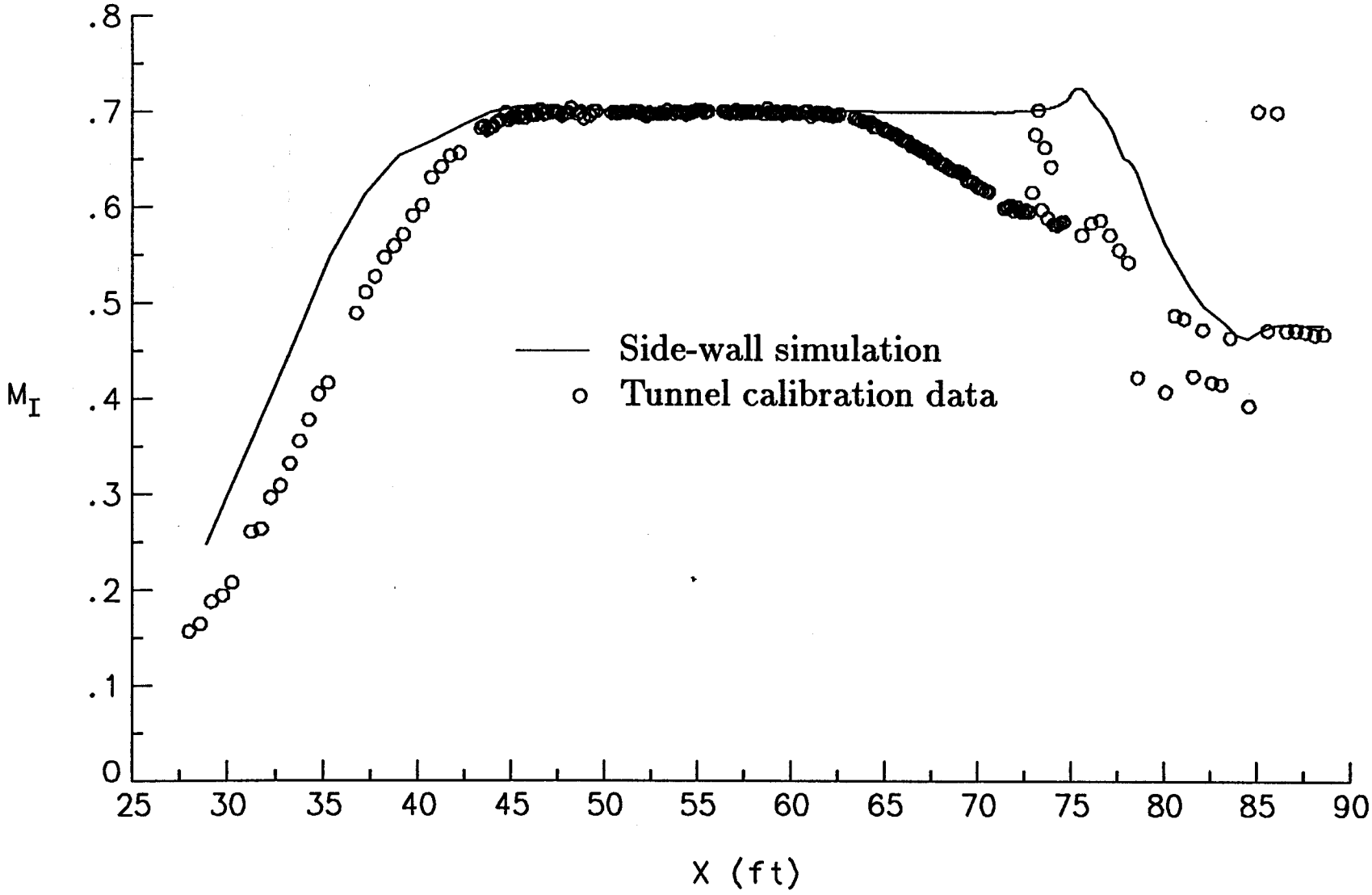
M_{ts}=0.7, R=3.0x10^6/ft




Side Wall Simulation - Mach Contours
M_{ts}=0.7, R=3.0x10^6/ft
Without Choke
Test Section
With Choke
Choke Detail
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00

Comparison of Side-Wall Simulation to Tunnel Data

$M_{ts} = 0.7,\ R = 3.0 \times 10^6/ft.$



Wind Tunnel Simulation

- Additional factors contributing to cross-sectional area
  - Floor & ceiling divergence
  - Floor & ceiling reentry flaps
  - Corner fillets
  - Sting & arc sector

- Approximate these effects in 2-D computation
  - 2-D flow $\Longleftrightarrow$ fixed height channel flow
  - Retain proper side-wall geometry
  - Represent area changes as width changes
  - Select choke crest station as reference station
  - Change centerline bc to inviscid wall bc

- Initial results close to empty tunnel calibration data
  - Negative offset in wall $M_I \Rightarrow$ slightly too much area
  - Calibration decrement on the order of δ^*

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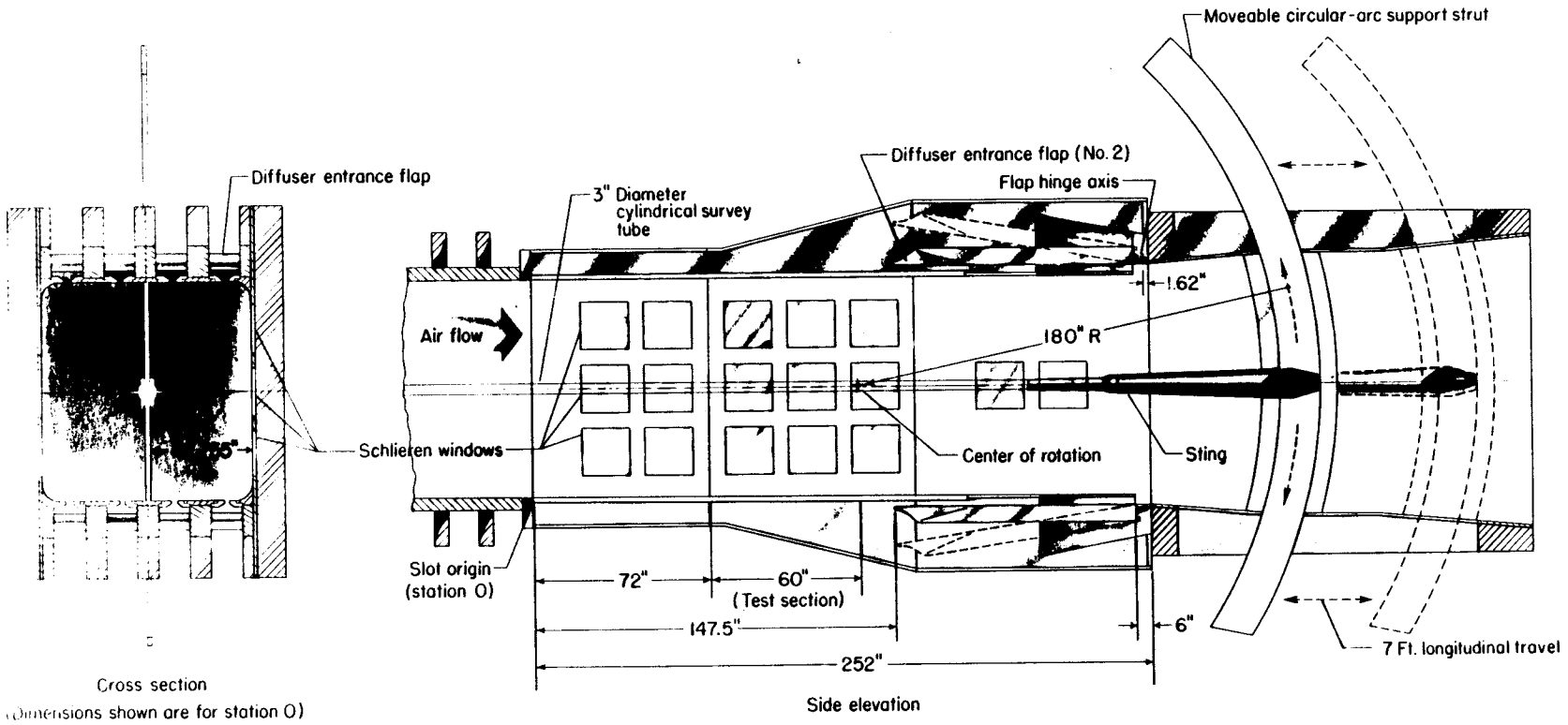
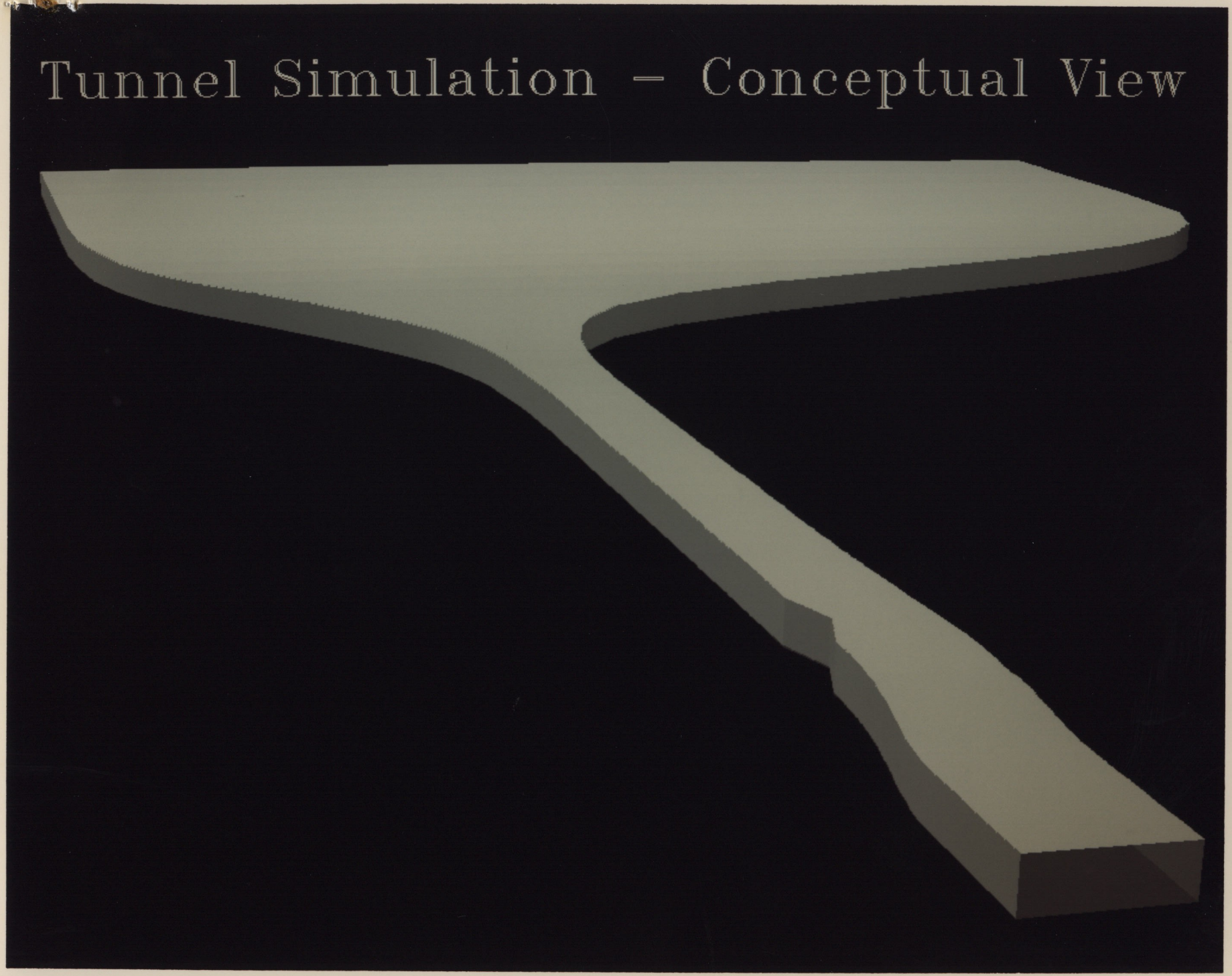
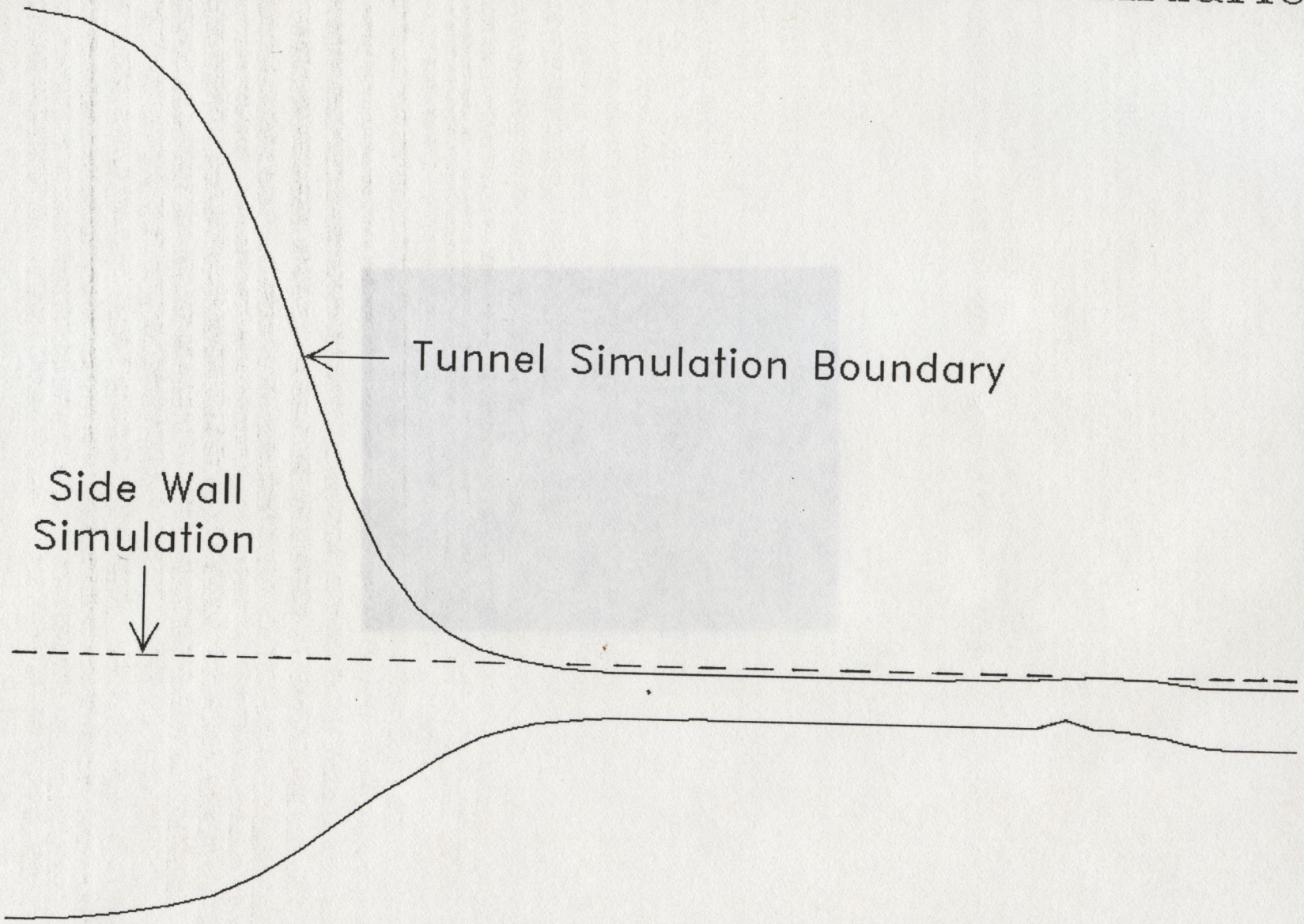


Slotted-throat and diffuser-entrance regions of the Langley 8-foot transonic pressure tunnel.

Tunnel Simulation – Conceptual View

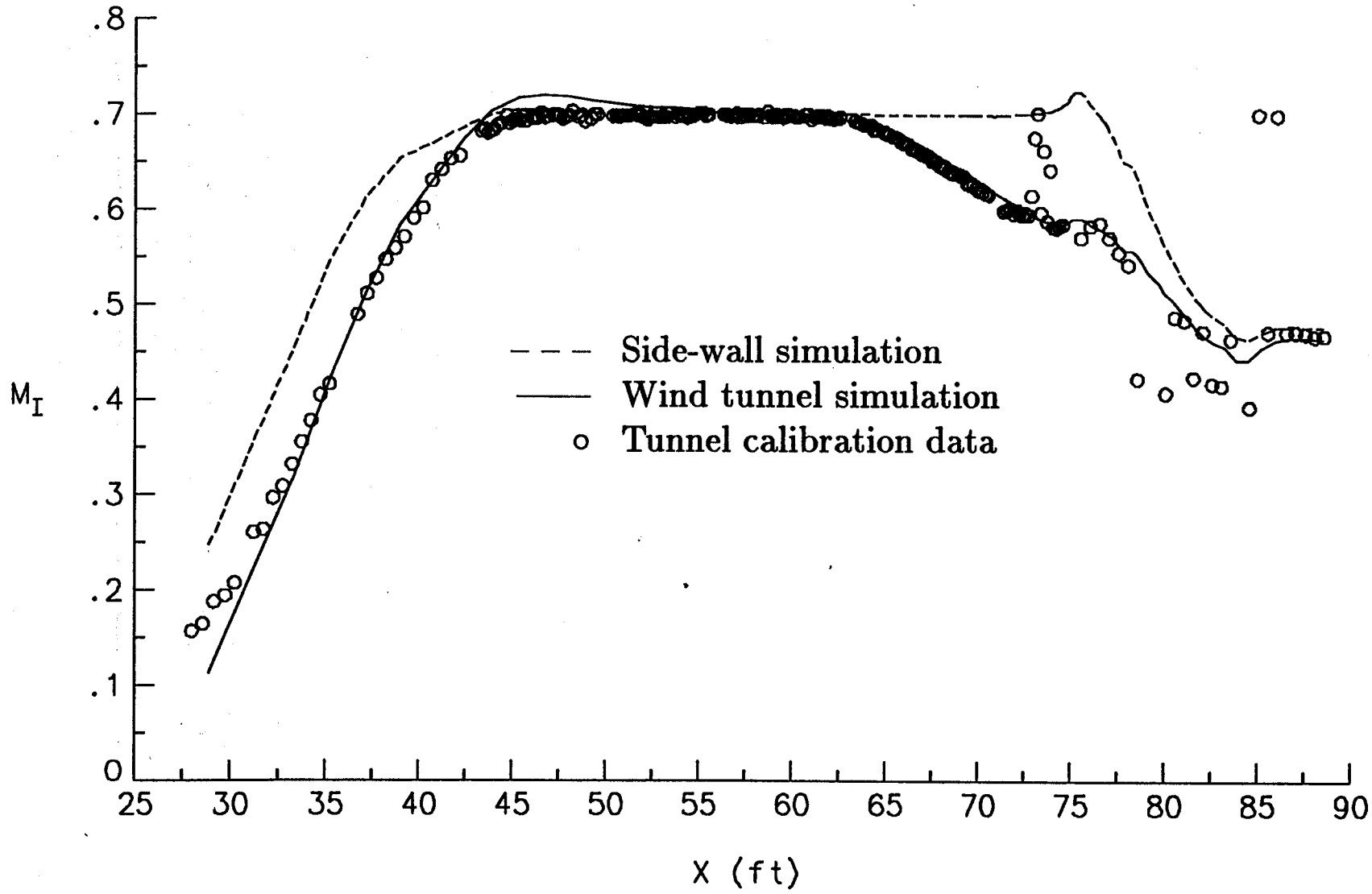


Side Wall and Tunnel Simulation Boundaries



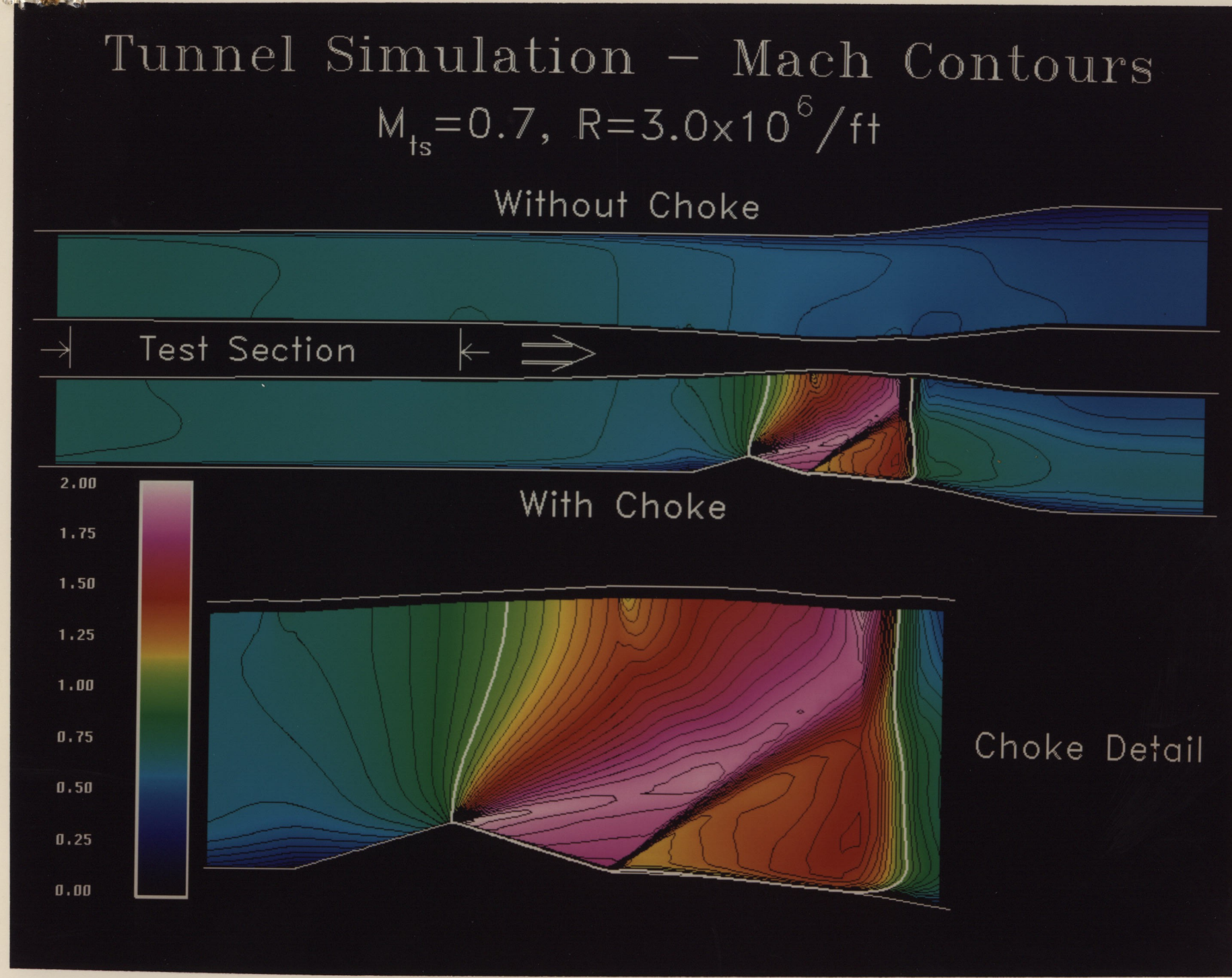
Comparison of Wind Tunnel Simulation to Tunnel Data

$M_{ts} = 0.7,\ R = 3.0 \times 10^6/ft.$



Tunnel Simulation – Mach Contours

M_{ts}=0.7, R=3.0x10^{6}/ft



Comparison of Side-Wall and Tunnel Choke Properties

$M_{ts} = 0.7,\ R = 3.0 \times 10^6/ft.$

	Side-wall simulation	Wind tunnel simulation
Choke displacement	3.9 inches	7.2 inches
Choke wall angle	$\pm 7°$	$\pm 17°$
Maximum Mach number	1.6	2.0

Summary

- Meaningful simulation of side-wall choke achieved
  - Simple approximation of 3-D area effect in 2-D code
  - Quantitative estimate of tunnel Mach distribution
  - Computations imply proposed choke design will work
  - Additional displacement required

- Solutions obtained quickly enough to effect decision process
  - $\approx$ 37,000 points
  - $\approx$ 15 minutes of Cray-2 time

- Proceed with design of two-wall side-wall choke
  - Loads provided