Late Stage Hypersonic Boundary Layer Transition

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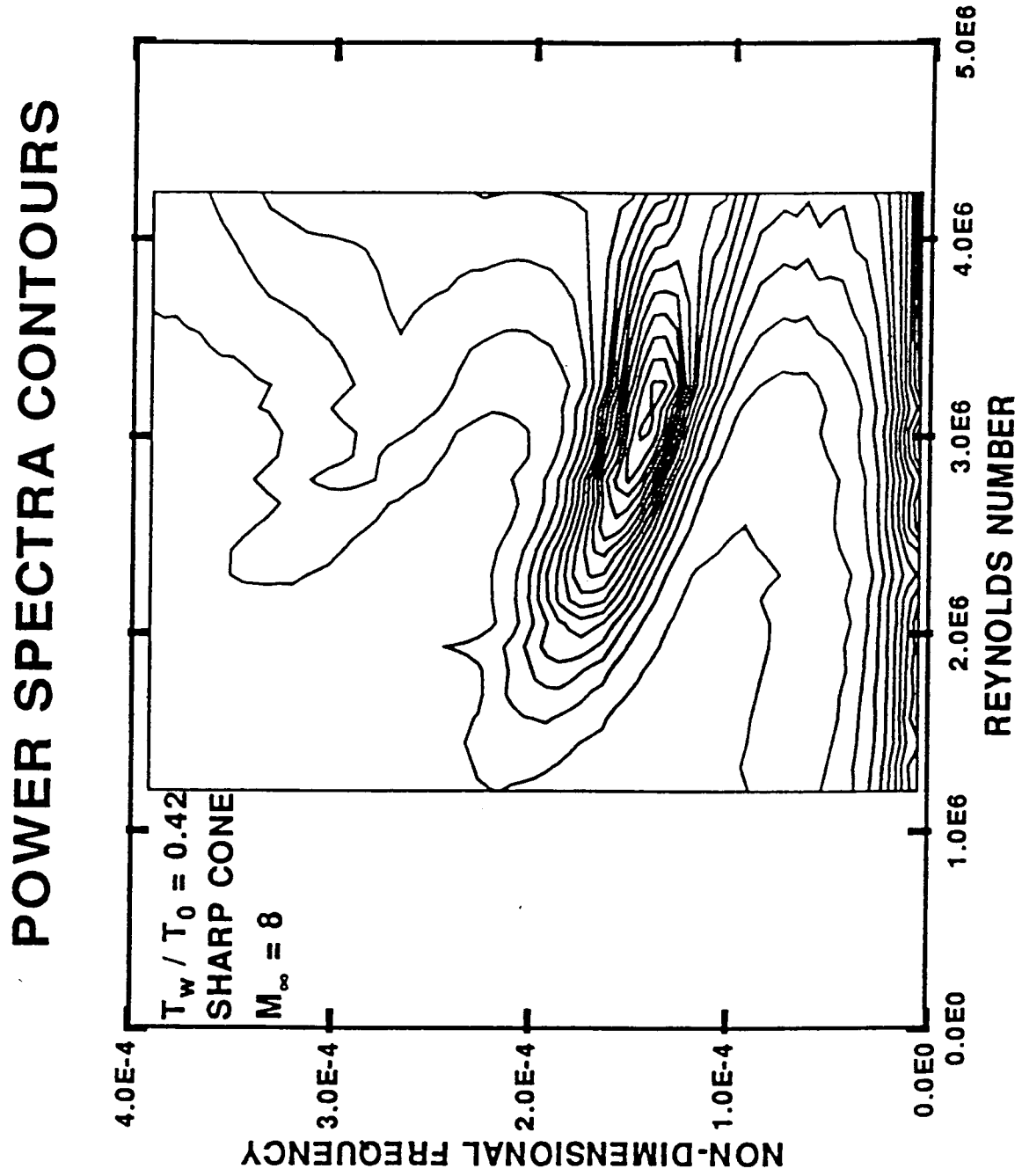
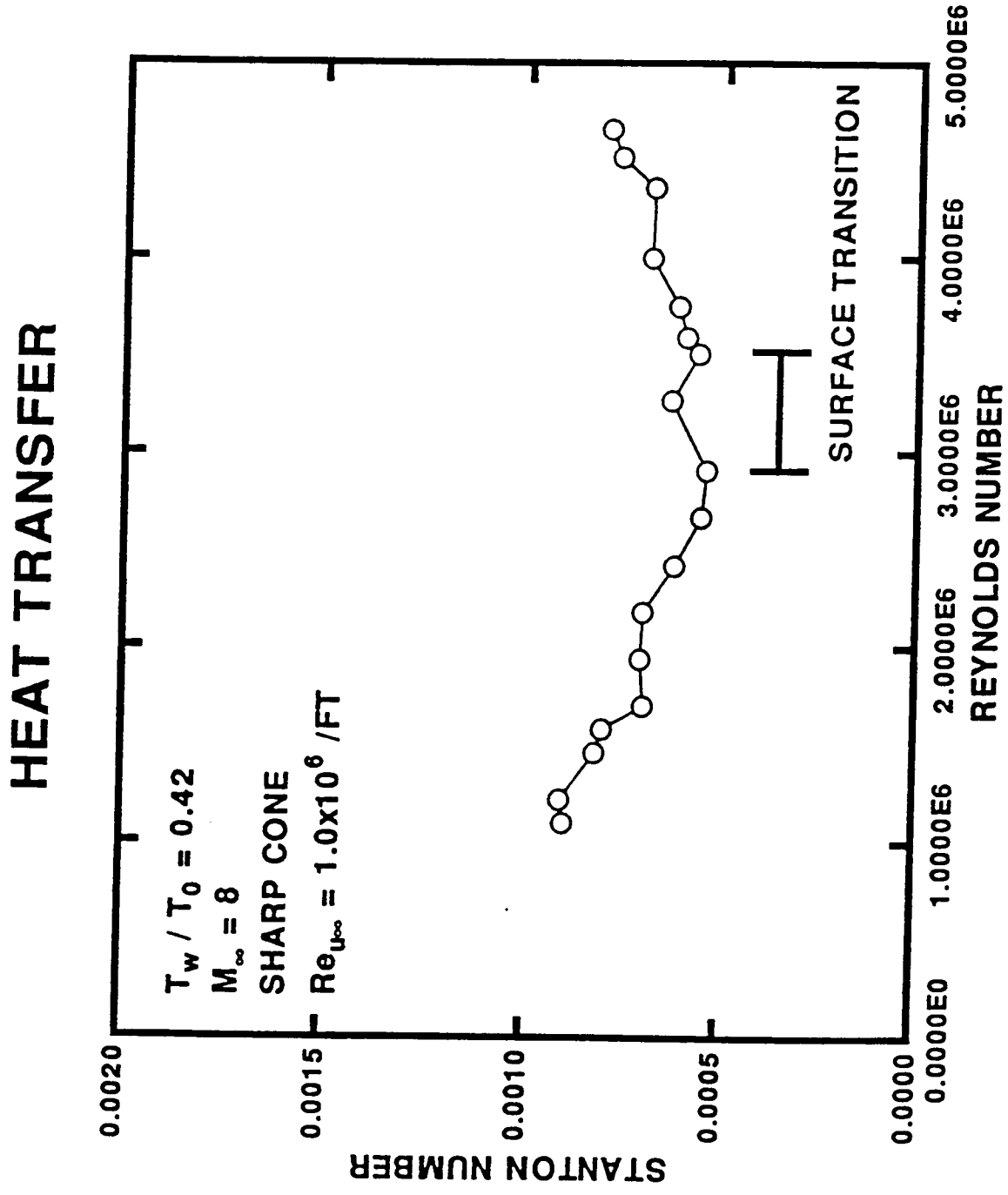
Abstract

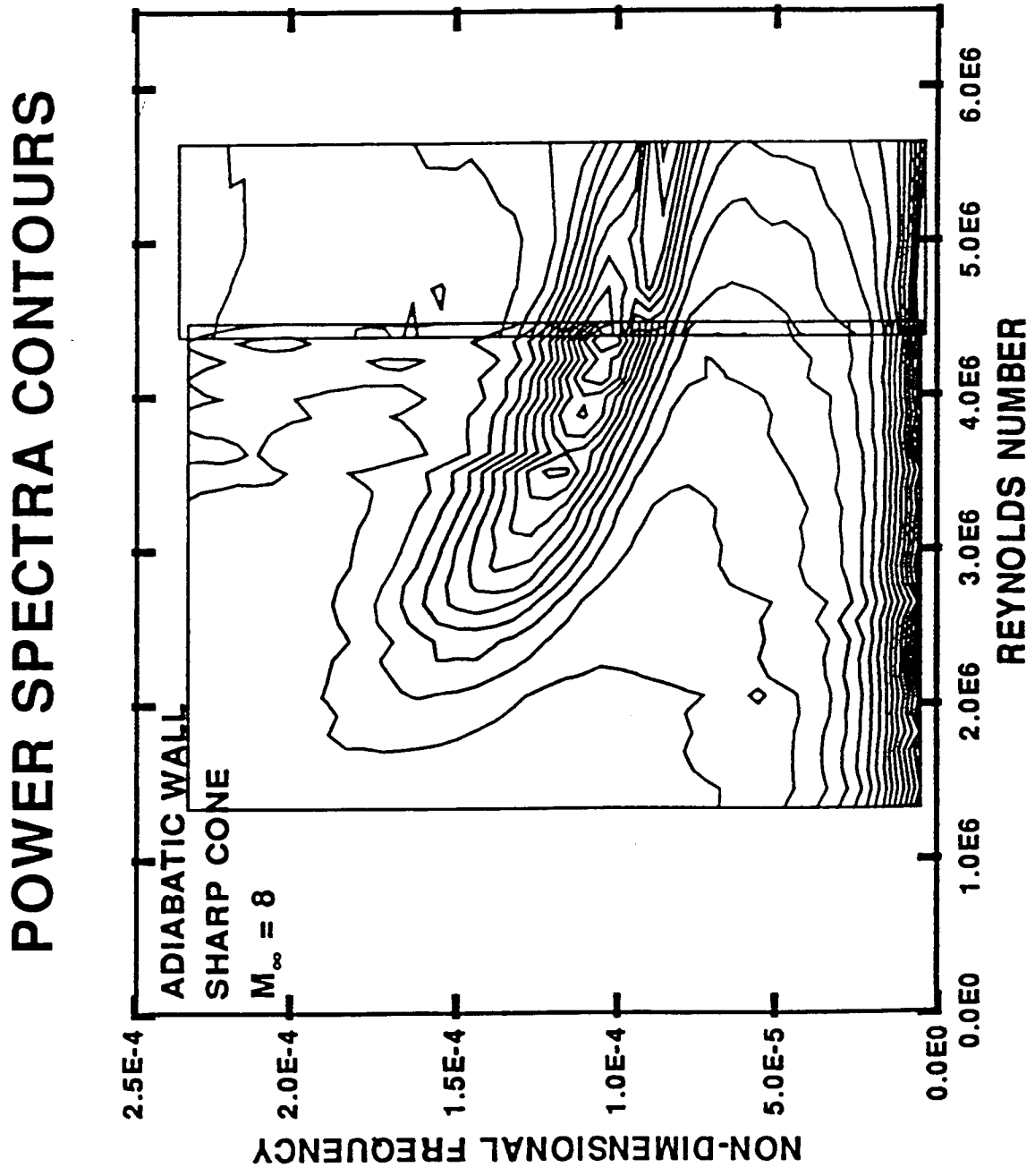
Our knowledge of late-stage hypersonic boundary layer transition is very limited, since most theoretical and experimental work has concentrated on the linear disturbance amplification regime. Although experiments show nonlinear higher harmonics beginning at approximately one-half the transition Reynolds number, there is no experimental evidence for subharmonics, in contrast to subsonic boundary layer transition. A practical definition of transition is the location where mean surface heat transfer first begins to rise above laminar values. Hot wire spectra show that prior to transition, spectral dispersion occurs, with second mode energy decreasing, and energy at neighboring frequencies increasing. Near the transition point, disturbance energy begins to spread from the critical layer toward the wall. Greater emphasis on the breakdown region is planned for future experiments.

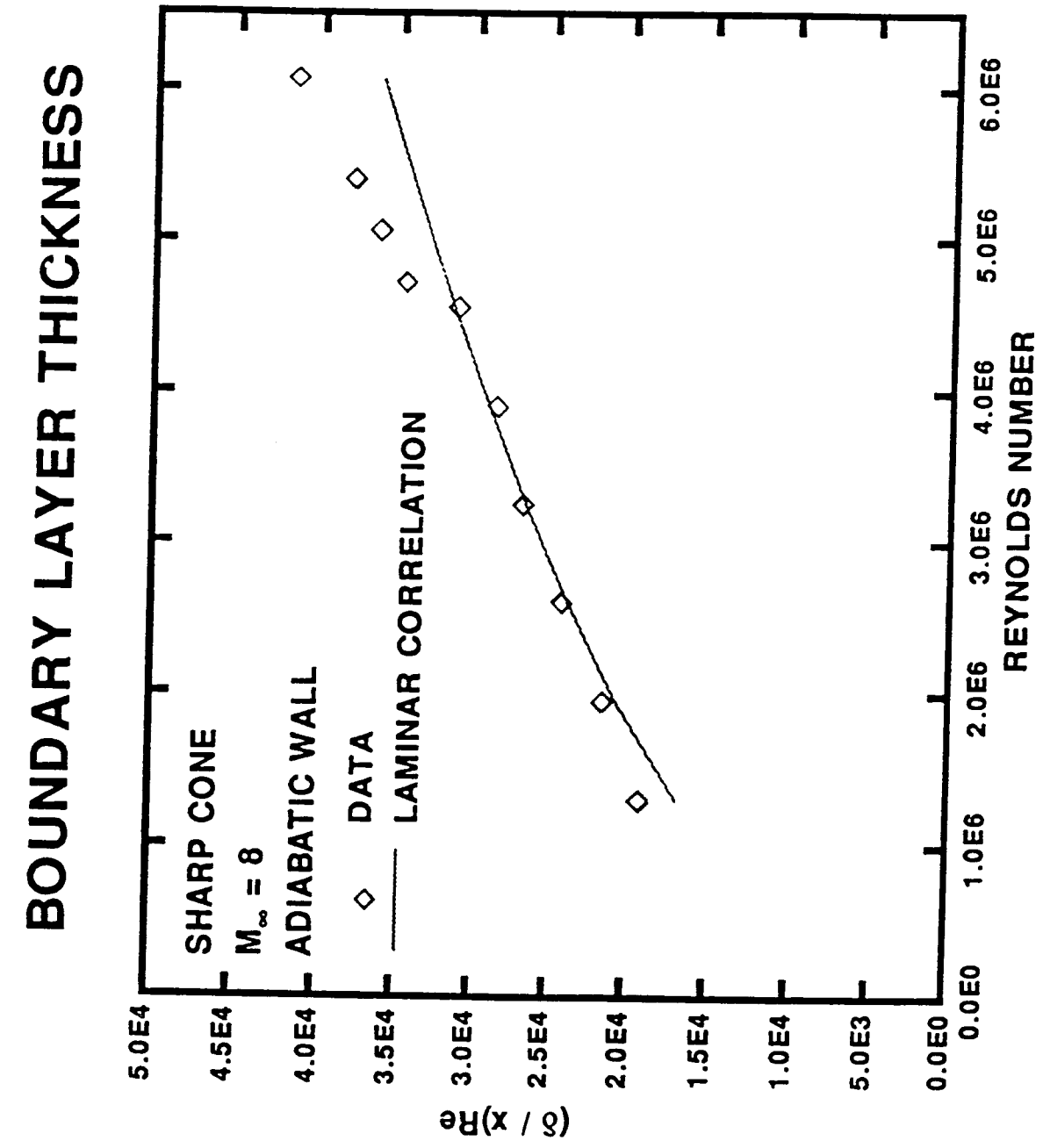
DATA MATRIX

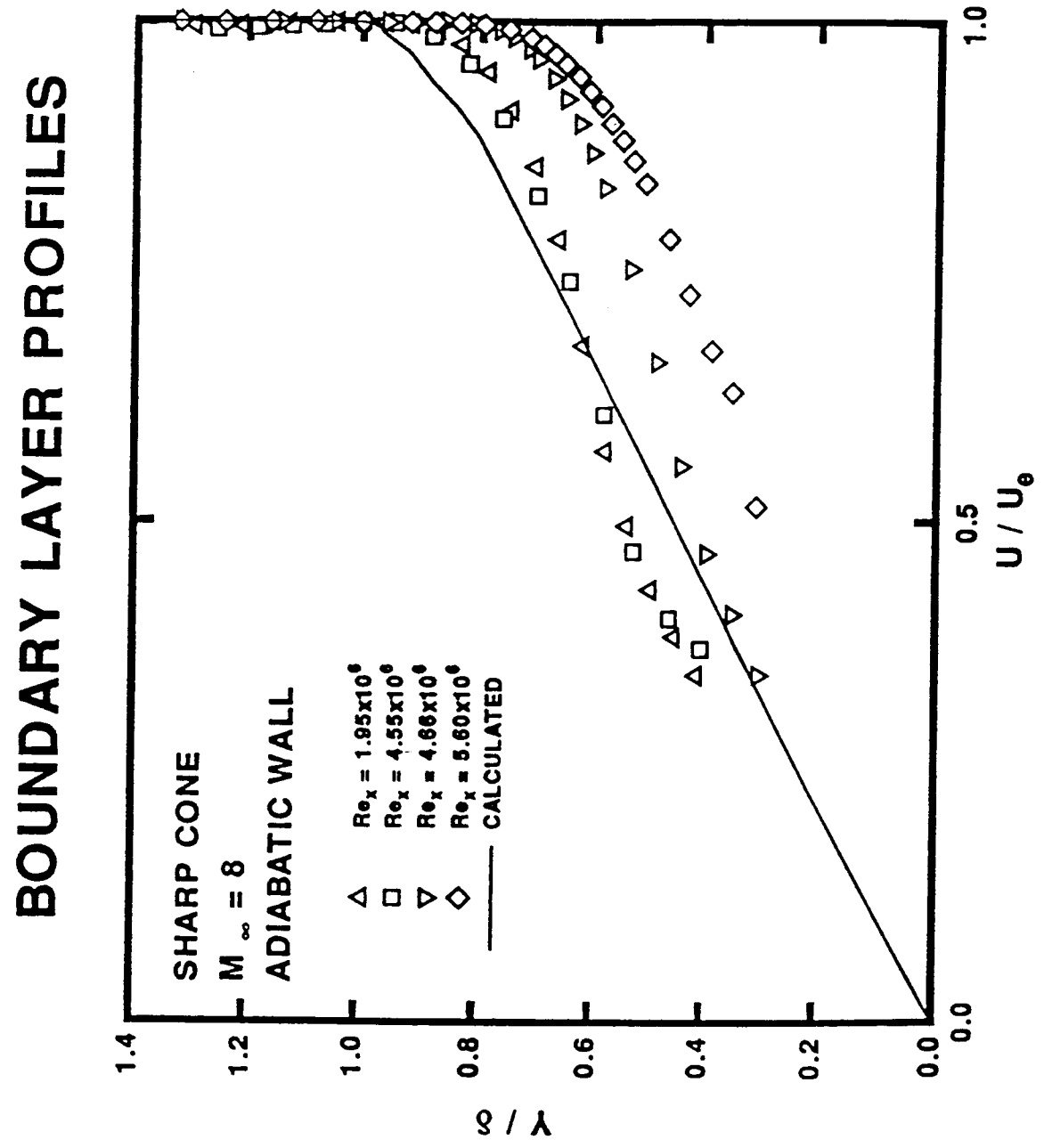
	ADIABATIC	COLD WALL
POWER SPECTRA	√	√
HEAT TRANSFER		√
SHADOWGRAPH		√
BL THICKNESS	√	
VELOCITY PROFILES	√	
BICOHERENCE	√	

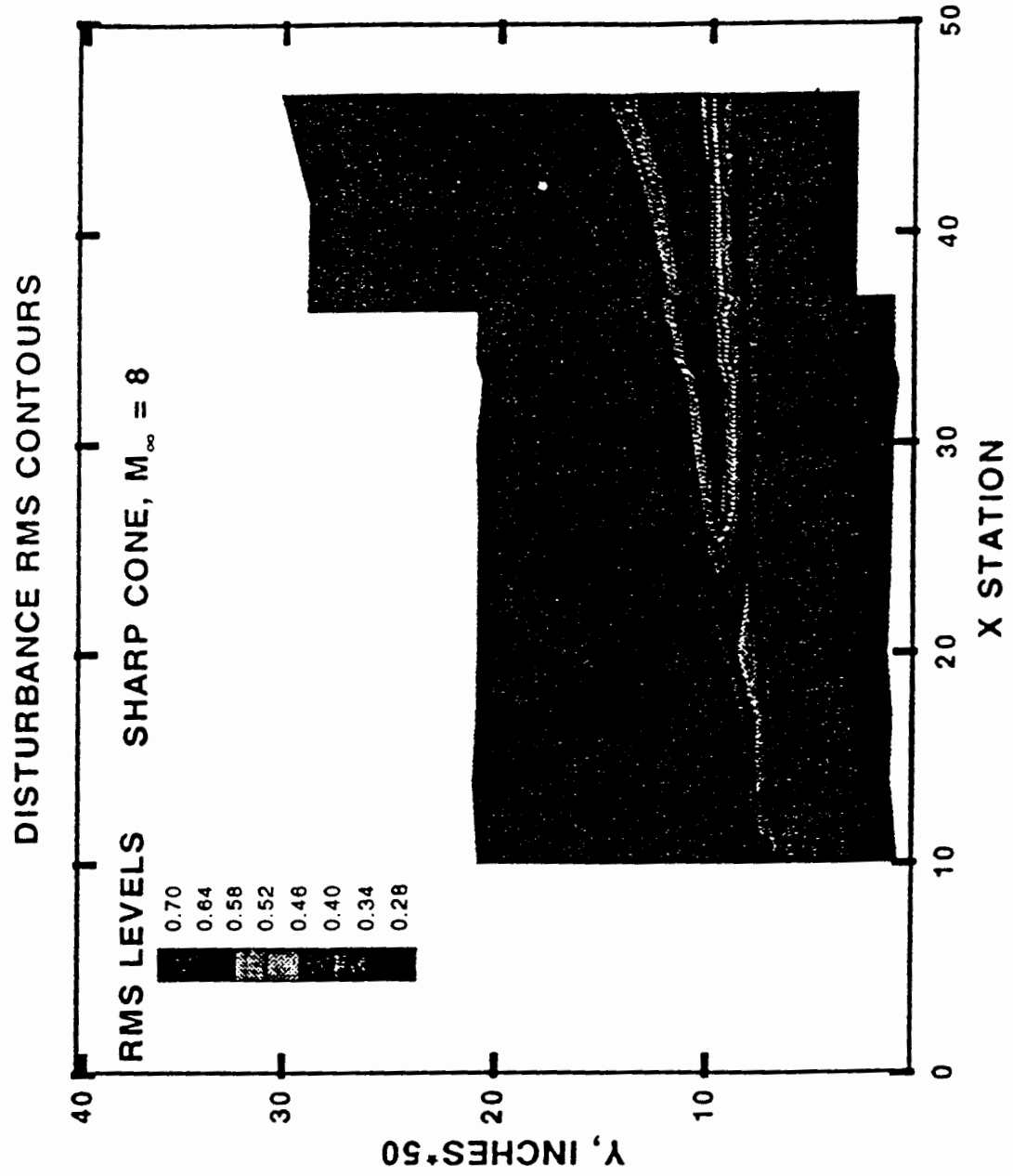

POWER SPECTRA CONTOURS
$T_w / T_0 = 0.42$
SHARP CONE
$M_\infty = 8$
NON-DIMENSIONAL FREQUENCY
4.0E-4
3.0E-4
2.0E-4
1.0E-4
0.0E0
0.0E0
1.0E6
2.0E6
3.0E6
4.0E6
5.0E6
REYNOLDS NUMBER

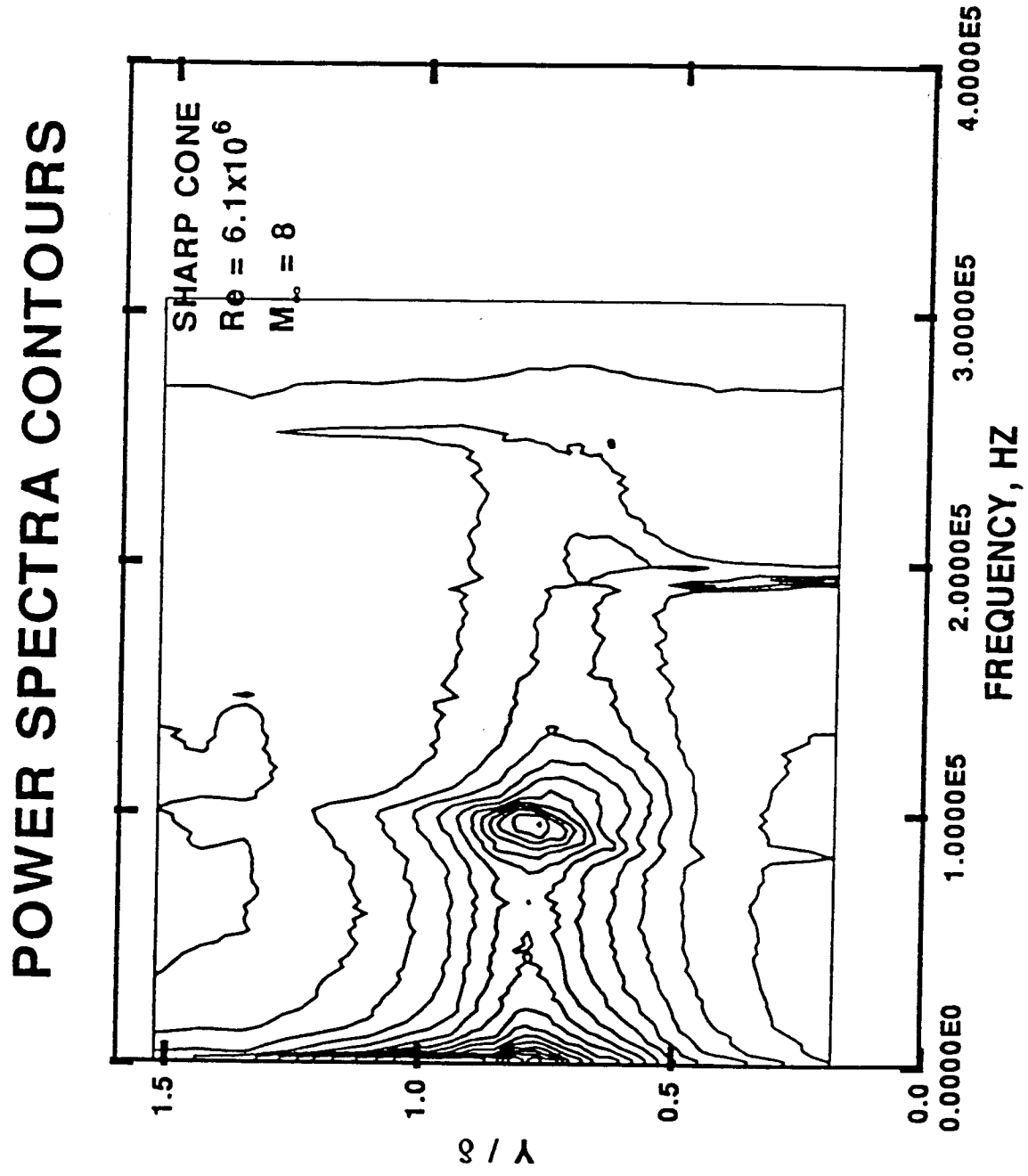

HEAT TRANSFER
$T_w / T_0 = 0.42$
$M_\infty = 8$
SHARP CONE
$Re_{U\infty} = 1.0x10^6$ /FT
SURFACE TRANSITION
STANTON NUMBER
0.0020
0.0015
0.0010
0.0005
0.0000
0.0000E0
1.0000E6
2.0000E6
3.0000E6
4.0000E6
5.0000E6
REYNOLDS NUMBER

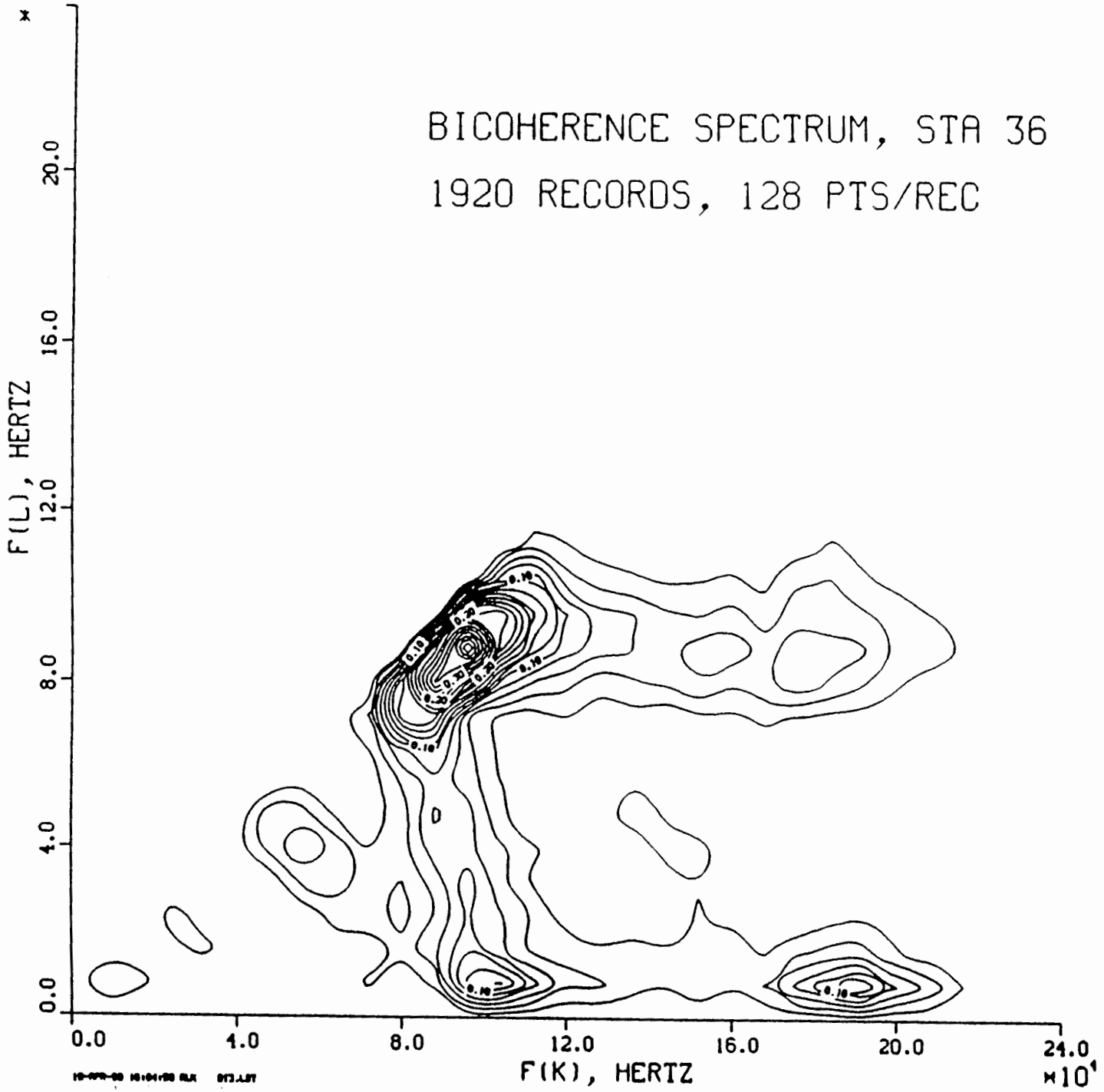

POWER SPECTRA CONTOURS
ADIABATIC WALL
SHARP CONE
M_∞ = 8
NON-DIMENSIONAL FREQUENCY
2.5E-4
2.0E-4
1.5E-4
1.0E-4
5.0E-5
0.0E0
REYNOLDS NUMBER
0.0E0
1.0E6
2.0E6
3.0E6
4.0E6
5.0E6
6.0E6

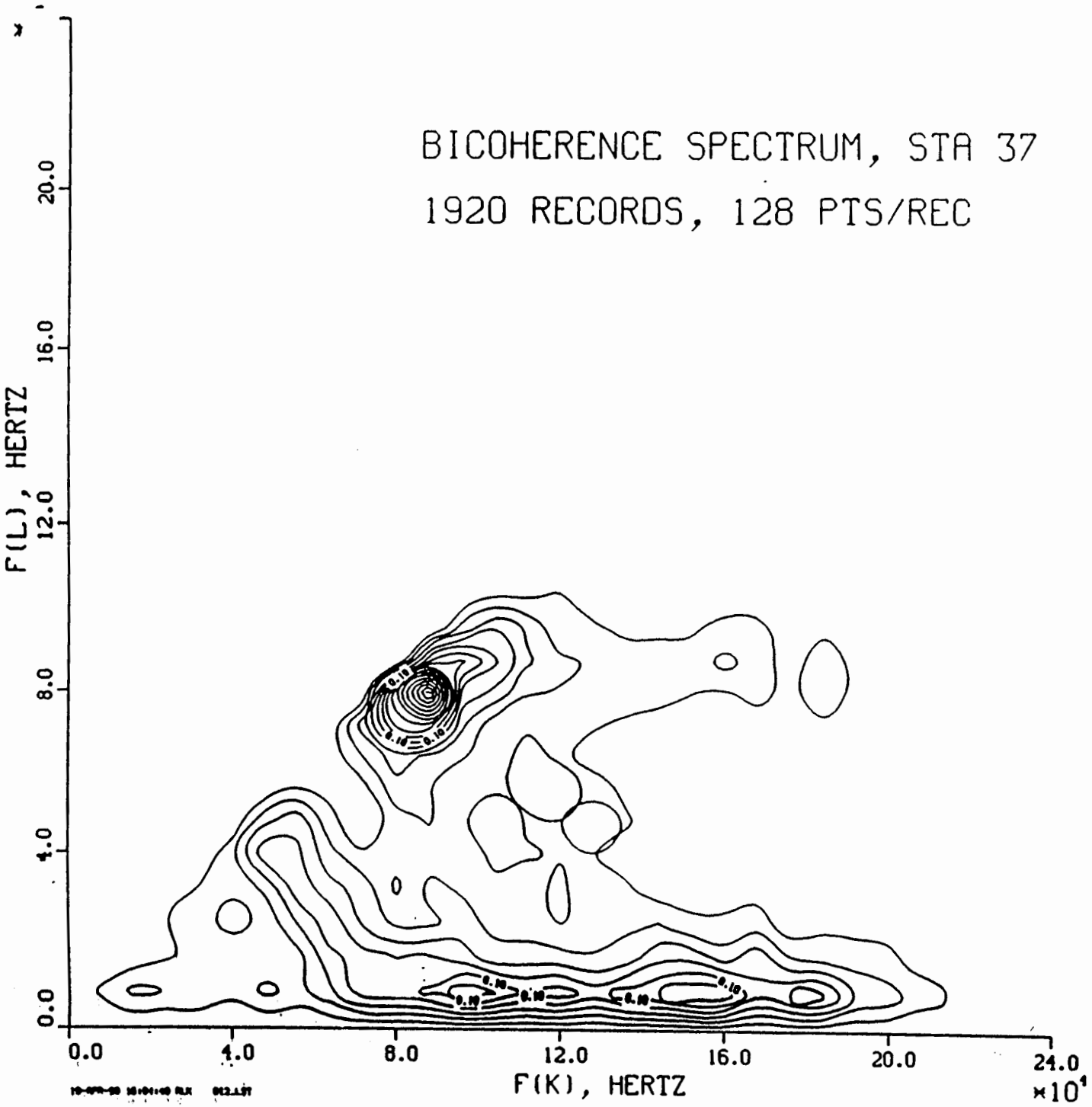

BOUNDARY LAYER THICKNESS
SHARP CONE
$M_\infty = 8$
ADIABATIC WALL
DATA
LAMINAR CORRELATION
$(\delta / x)Re$
REYNOLDS NUMBER
5.0E4
4.5E4
4.0E4
3.5E4
3.0E4
2.5E4
2.0E4
1.5E4
1.0E4
5.0E3
0.0E0
1.0E6
2.0E6
3.0E6
4.0E6
5.0E6
6.0E6

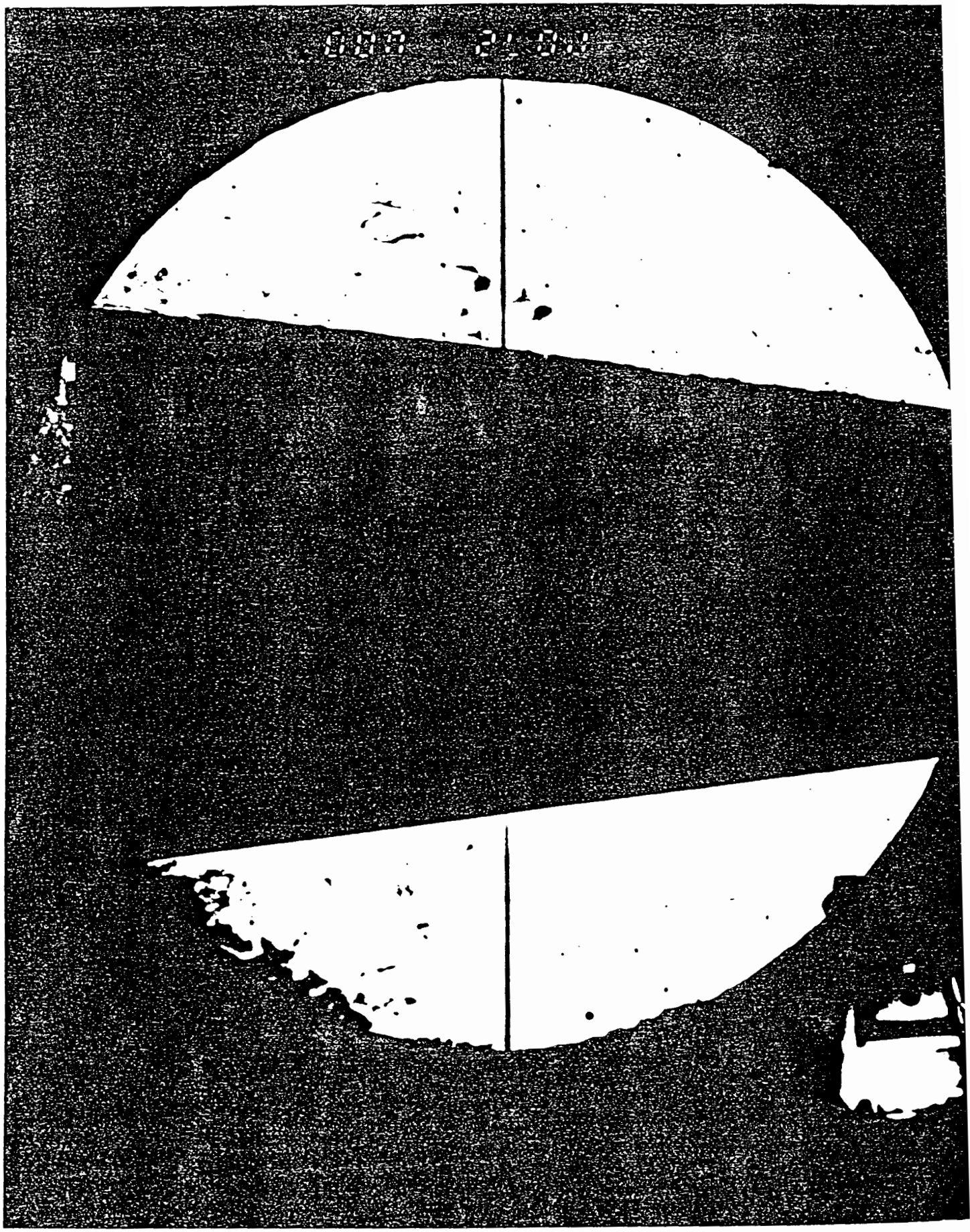

BOUNDARY LAYER PROFILES
SHARP CONE
M ∞ = 8
ADIABATIC WALL
Re x = 1.95x10^6
Re x = 4.55x10^6
Re x = 4.86x10^6
Re x = 5.60x10^6
CALCULATED
y / δ
U / U e
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.0


DISTURBANCE RMS CONTOURS
SHARP CONE, M_∞ = 8
RMS LEVELS
0.70
0.64
0.58
0.52
0.46
0.40
0.34
0.28
Y, INCHES*50
40
30
20
10
0
10
20
30
40
50
X STATION


POWER SPECTRA CONTOURS
SHARP CONE
Re = 6.1x10^6
M∞ = 8
Y / δ
1.5
1.0
0.5
0.0
0.0000E0
1.0000E5
2.0000E5
3.0000E5
4.0000E5
FREQUENCY, HZ


BICOHERENCE SPECTRUM, STA 36
1920 RECORDS, 128 PTS/REC
F(L), HERTZ
0.0
4.0
8.0
12.0
16.0
20.0
F(K), HERTZ
0.0
4.0
8.0
12.0
16.0
20.0
24.0
×10¹


BICOHERENCE SPECTRUM, STA 37
1920 RECORDS, 128 PTS/REC
F(L), HERTZ
0.0
4.0
8.0
12.0
16.0
20.0
F(K), HERTZ
0.0
4.0
8.0
12.0
16.0
20.0
24.0
×10⁴



CONCLUSIONS

- HIGHER HARMONICS APPEAR EARLY
- NO EVIDENCE OF SUBHARMONICS
- SECOND MODE SATURATIONS MARKS:
  HEAT TRANSFER INCREASE
  BL THICKNESS INCREASE
  PROFILE FILLING
  DISTURBANCE SPREADING
  SPECTRAL DISPERSION
- ROLE OF BURSTS UNEXPLORED