4 x 7 M MODELING PROGRAM

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SUBSONIC AERODYNAMICS BRANCH

NASA LANGLEY RESEARCH CENTER

THE USE OF SMALL-SCALE MODELING IN DEFINING FLOW IMPROVEMENTS FOR THE LANGLEY 4- BY 7-METER TUNNEL

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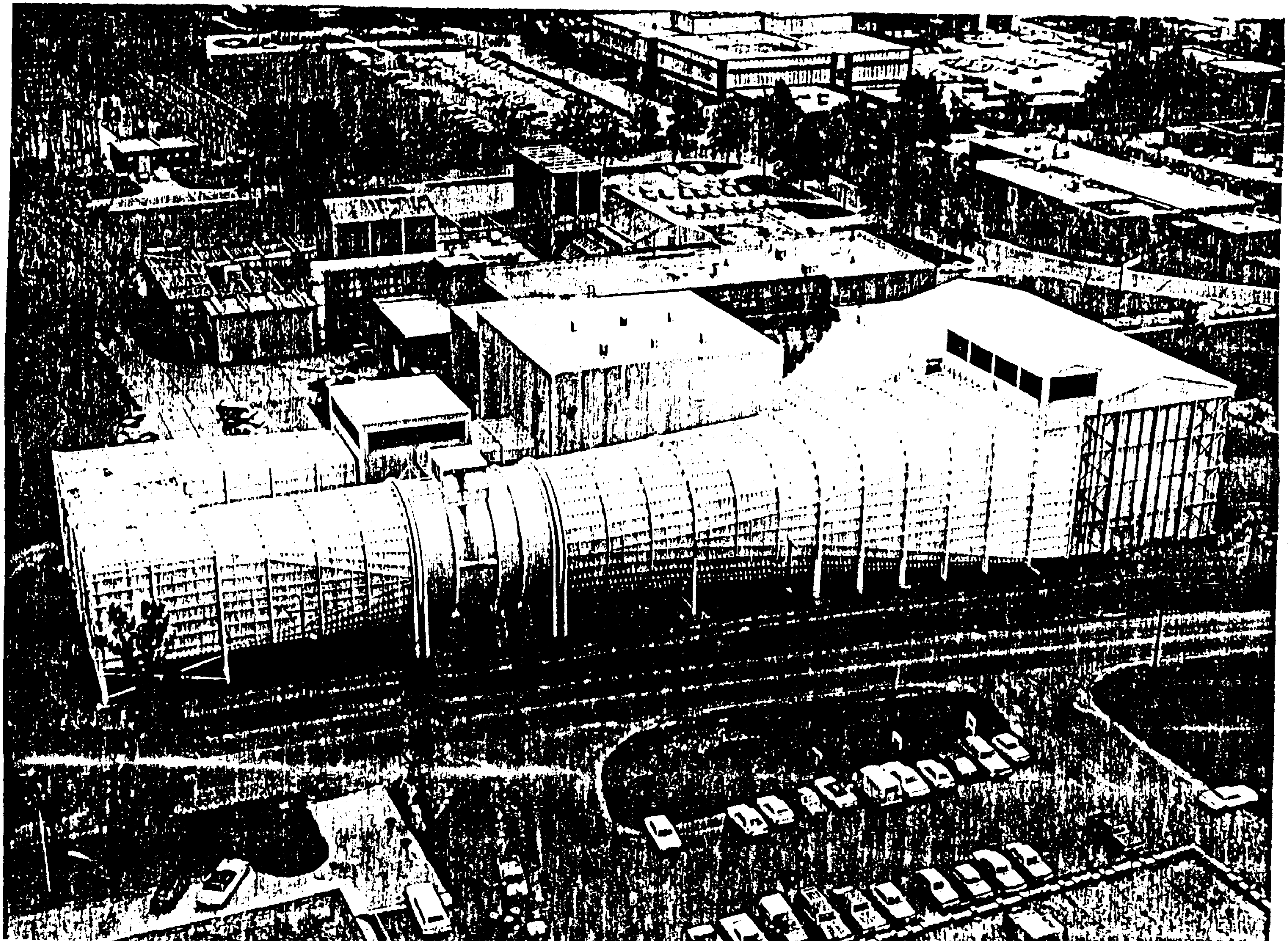
PRESENTED AT THE NASA LEWIS RESEARCH CENTER
WIND-TUNNEL MODELING WORKSHOP
CLEVELAND, OHIO
MARCH 20-21, 1984

OVERVIEW OF PRESENTATION

- DESCRIPTION OF THE 4- BY 7-METER TUNNEL
- DESCRIPTION OF 1/24-SCALE MODEL TUNNEL
- TUNNEL CIRCUIT FLOW CHARACTERISTICS
- OPEN TEST SECTION TURBULENCE CHARACTERISTICS
- CONCLUDING REMARKS

NASA
L-81-5962



LANGLEY 4- BY 7-METER TUNNEL DESCRIPTION

- TEST SECTION: 14.5 X 21.75 FT
- SPEED CAPABILITY: 0 TO 200 KTS
- 8000 HP DRIVE MOTOR
- MULTIPLE WALL CONFIGURATION CAPABILITY: CLOSED, SLOTTED, PARTIALLY OPEN, OPEN
- ACOUSTIC TEST CAPABILITY
- TEST SECTION ENTRANCE FLOOR SUCTION AND MOVING GROUND BELT
- AUTOMATED, TWO-COMPONENT LASER-VELOCIMETER SYSTEM
- AUTOMATED HIGH-PRESSURE AIR SYSTEM AND VARIABLE FREQUENCY POWER SUPPLY FOR POWER SIMULATION
- ON-LINE DATA REDUCTION AND DISPLAY

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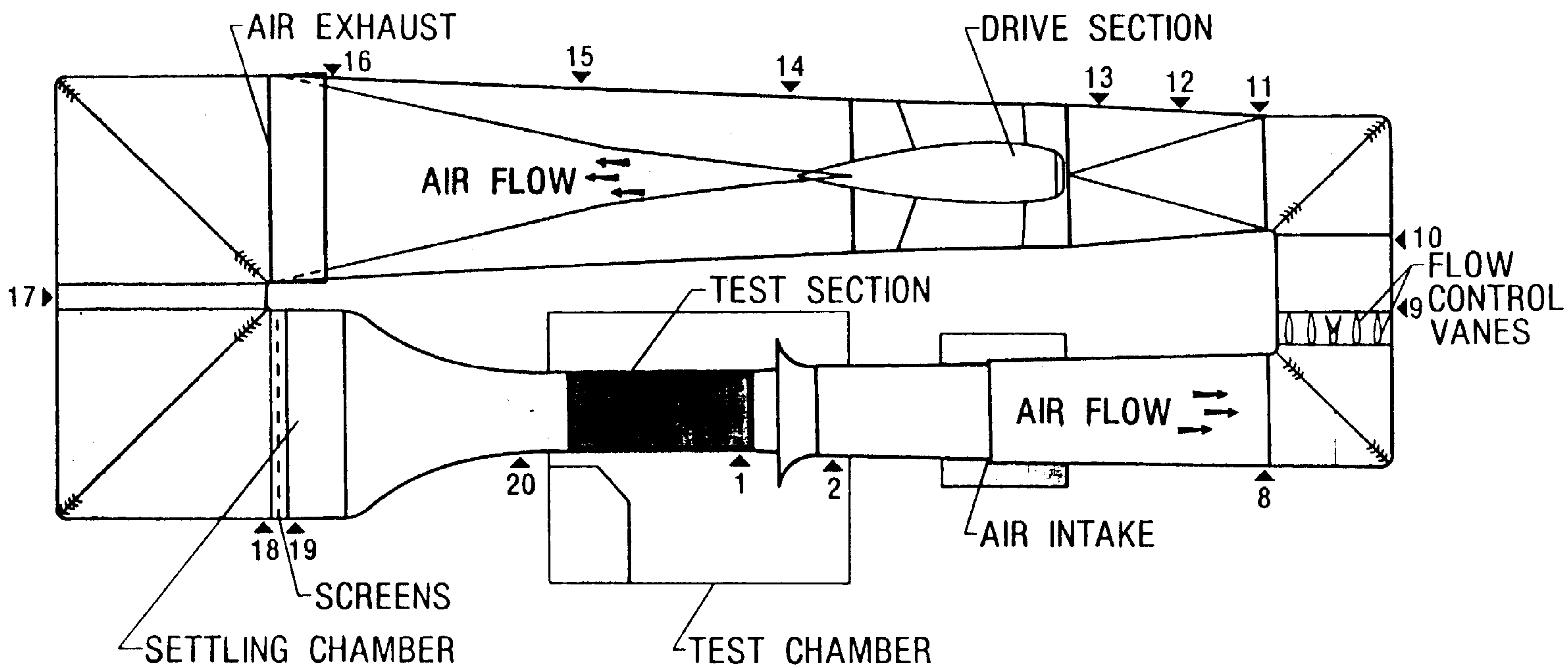
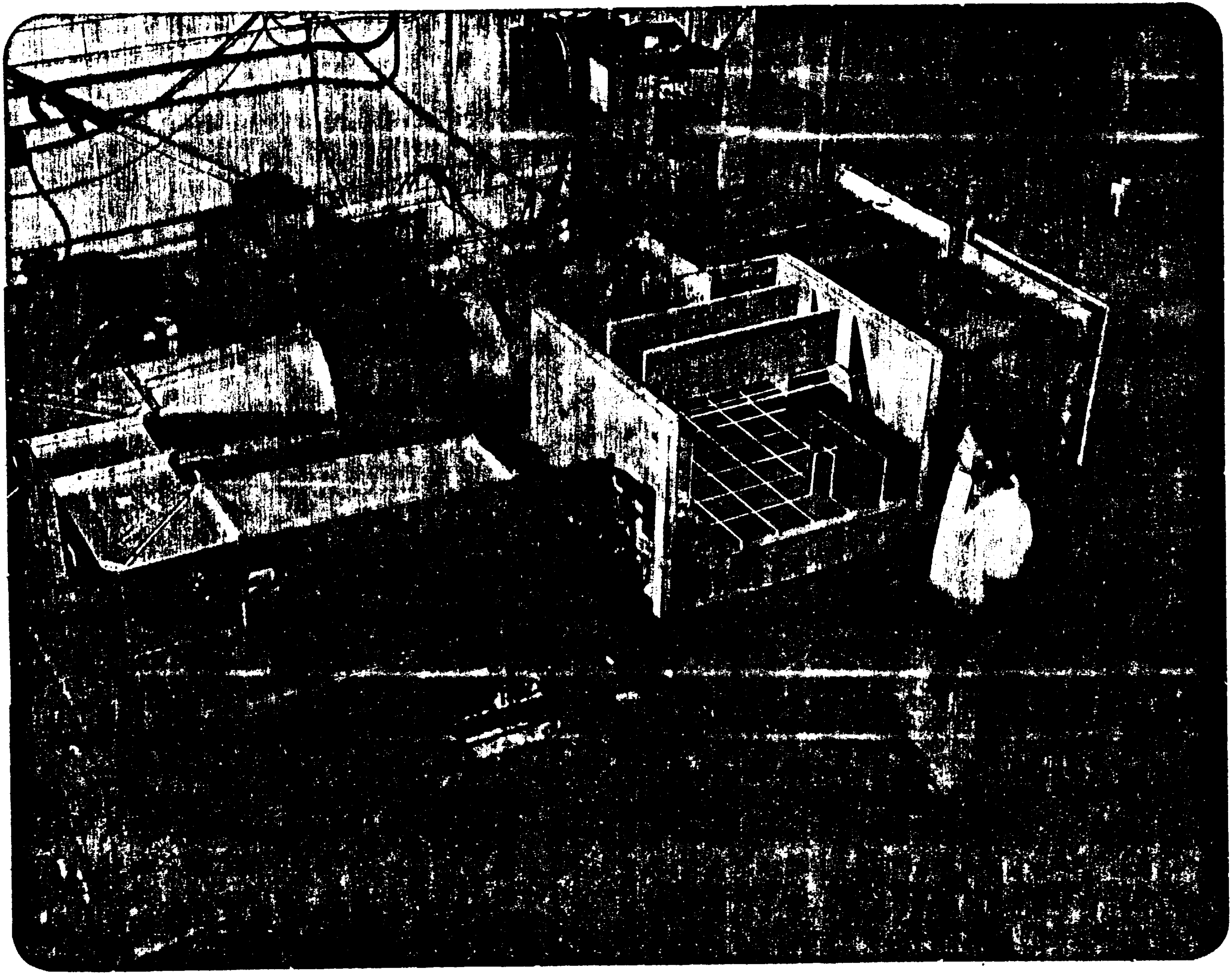
L-83-7.552

4 × 7 METER TUNNEL ARRANGEMENT





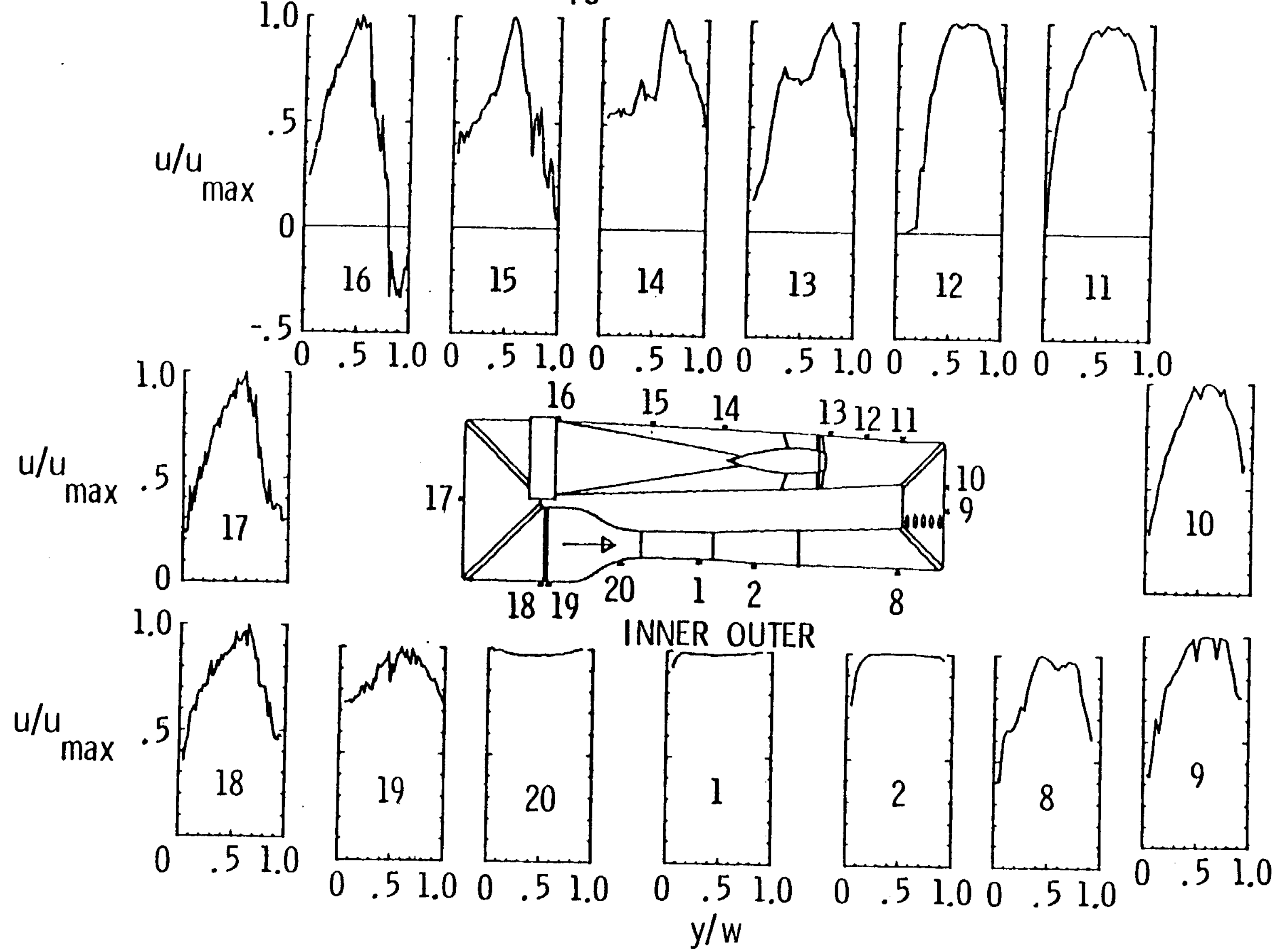
	4 X 7 TUNNEL	MODEL TUNNEL
AIR INTAKE	YES	YES
1ST CORNER VANES	55	~ 15
FLOW CONTROL VANES	YES	YES
2ND CORNER VANES	55	~15
2ND CORNER SCREEN	1/3	1/3
3RD DIFFUSER ANGLE	AS BUILT	SAME
PROP BLADES	CLOCKWISE (9)	COUNTERCLOCKWISE (8)
FLOW STRAIGHTENER VANES	YES	YES
4TH DIFFUSER ANGLE	AS BUILT	SAME
VENT	YES	YES
3RD CORNER VANES	99	~ 25
4TH CORNER VANES	202	~ 25
SETTLING CHAMBER	2 SCREENS	2 SCREENS

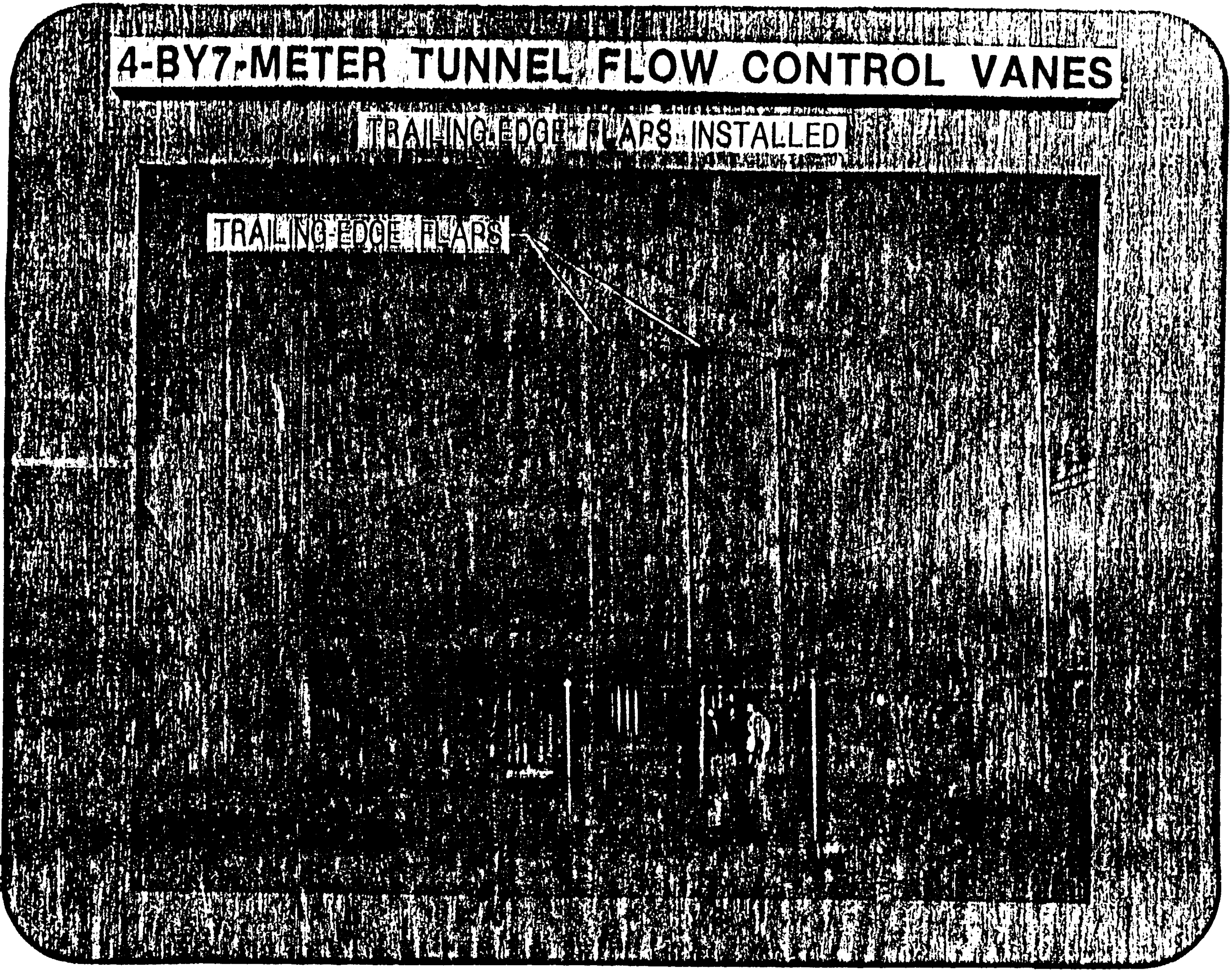
TUNNEL CIRCUIT FLOW CHARACTERISTICS

- 4- BY 7-METER TUNNEL
  - VELOCITY PROFILES MEASURED BY PROPELLER ANEMOMETER
- 1/24-SCALE MODEL TUNNEL
  - VELOCITY PROFILES MEASURED BY PITOT-STATIC TUBE
  - ATTEMPT TO MATCH 4- BY 7-METER TUNNEL CHARACTERISTICS
- CONTRACTION CONE BOUNDARY-LAYER CHARACTERISTICS

HORIZONTAL VELOCITY PROFILES-CLOSED TEST SECTION

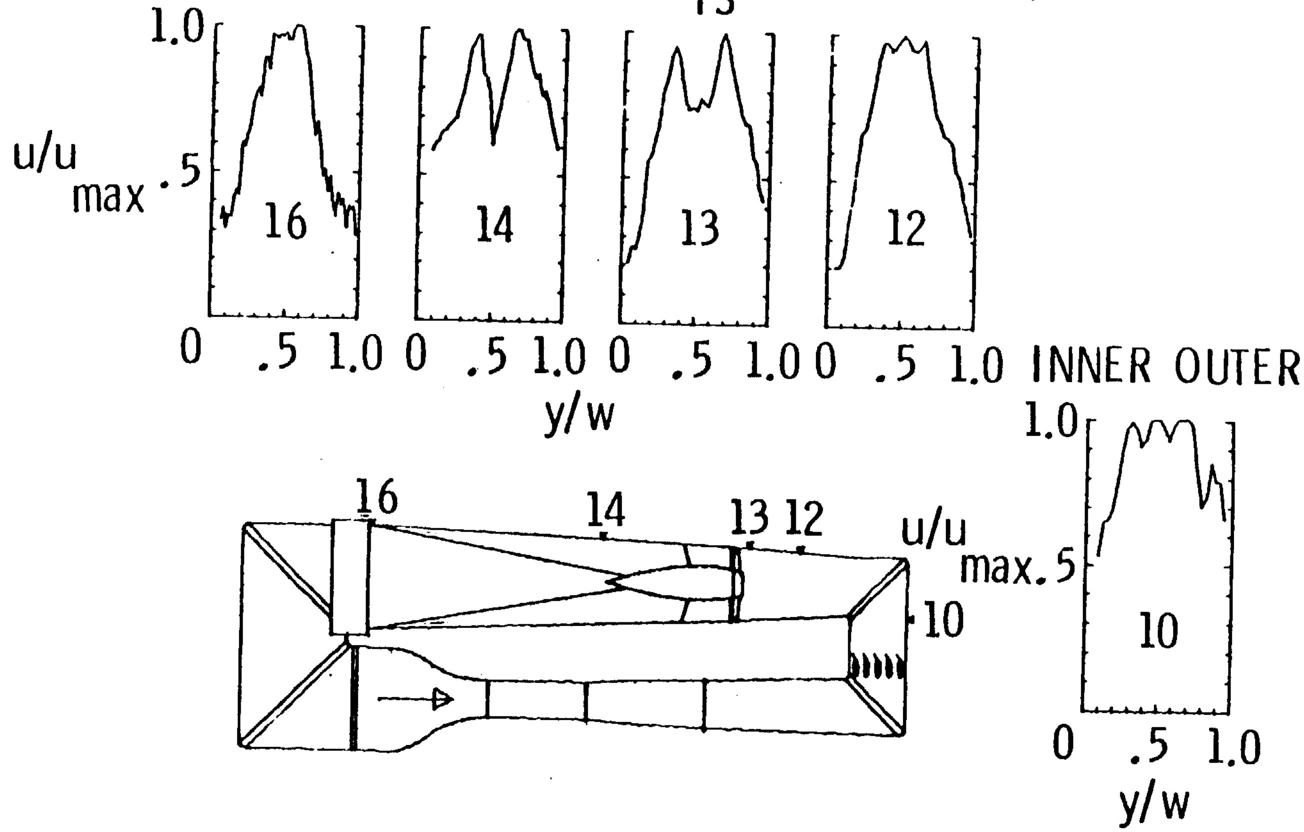
q_{TS} = 2.78 kpa (58 psf)



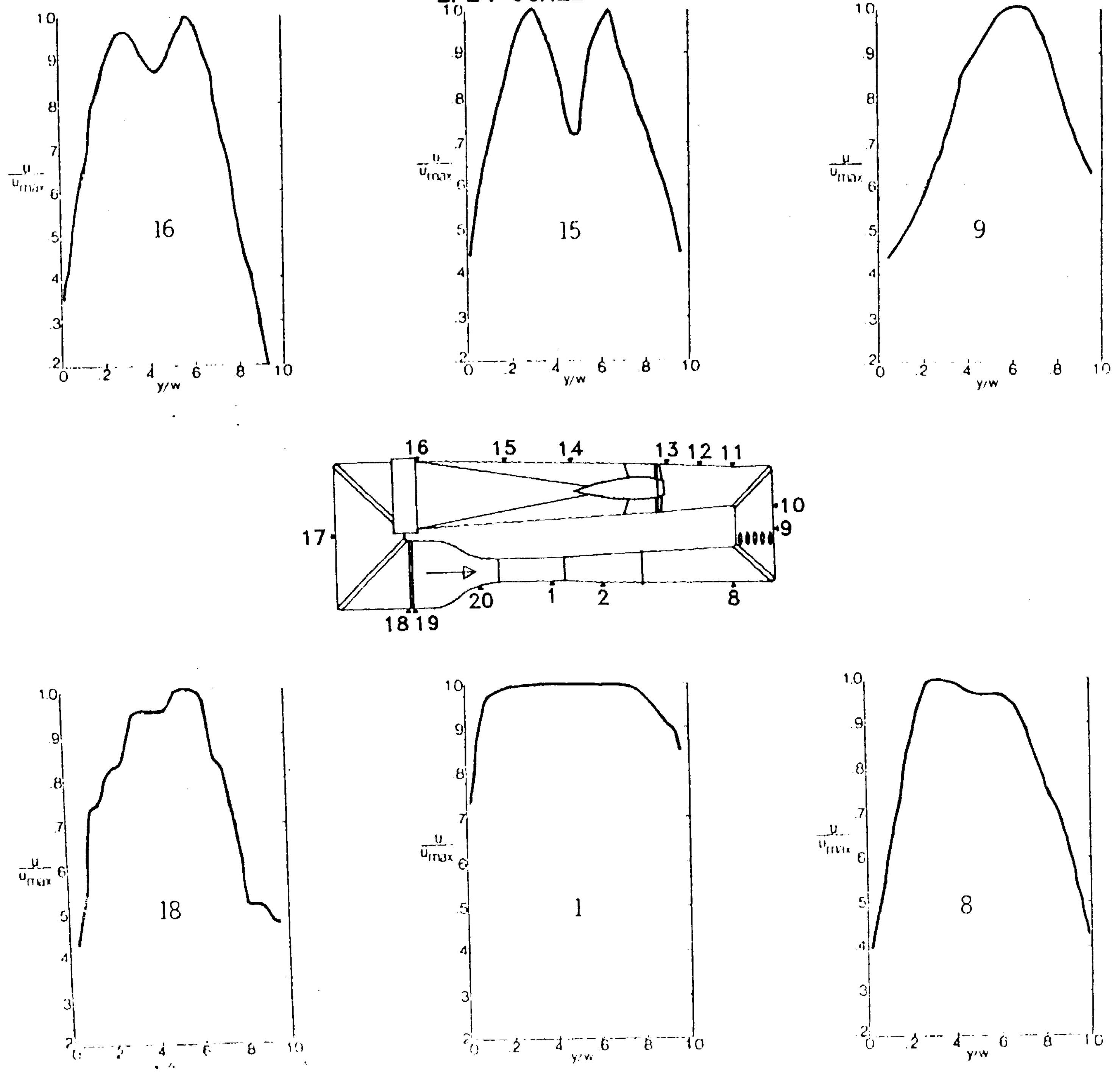

4-BY7-METER TUNNEL FLOW CONTROL VANES
TRAILING-EDGE FLAPS INSTALLED
TRAILING-EDGE FLAPS

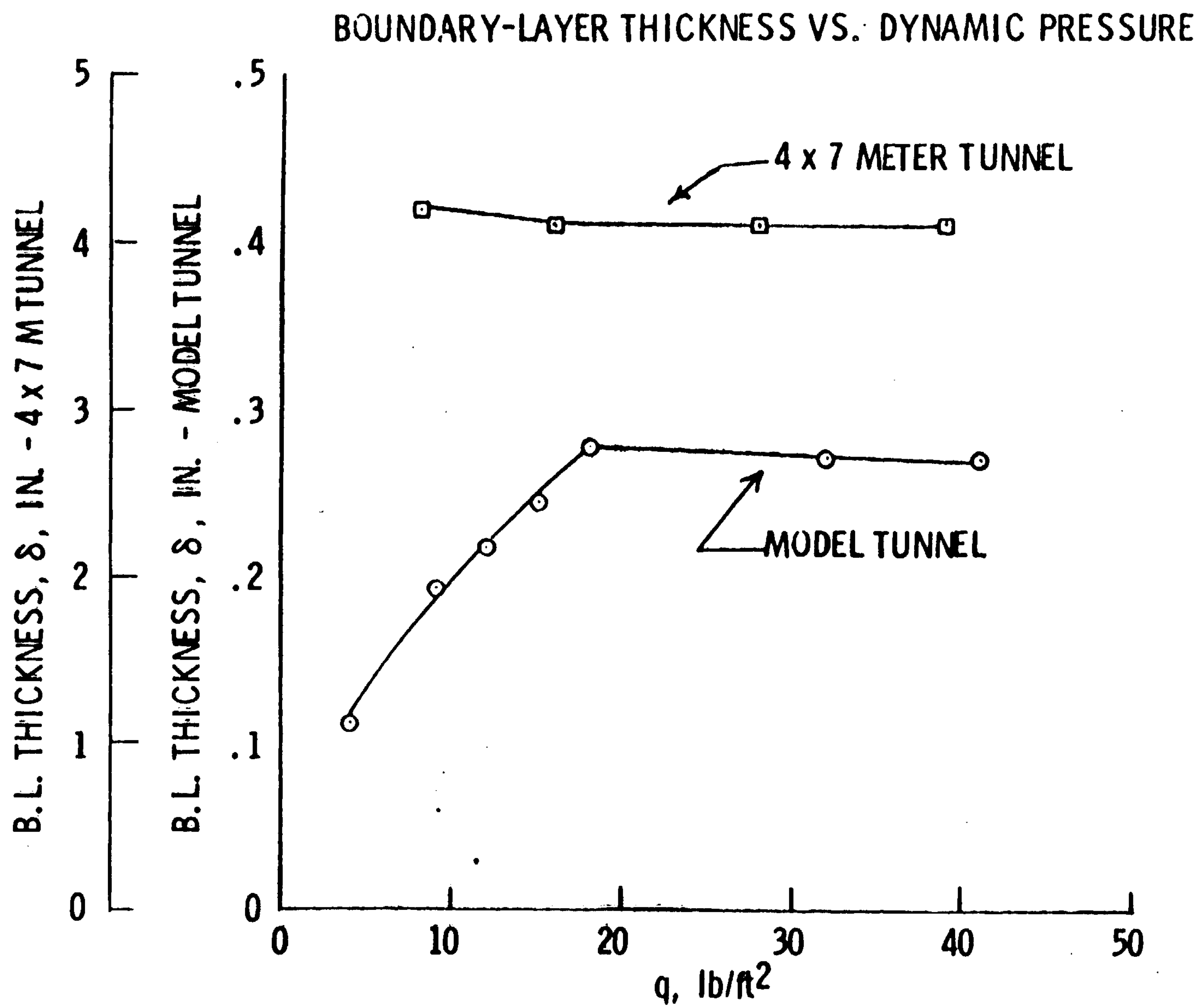
HORIZONTAL VELOCITY PROFILES-CLOSED TEST SECTION

FCV FLAPS INSTALLED, q_{TS}= 2.78 kpa (58 psf)



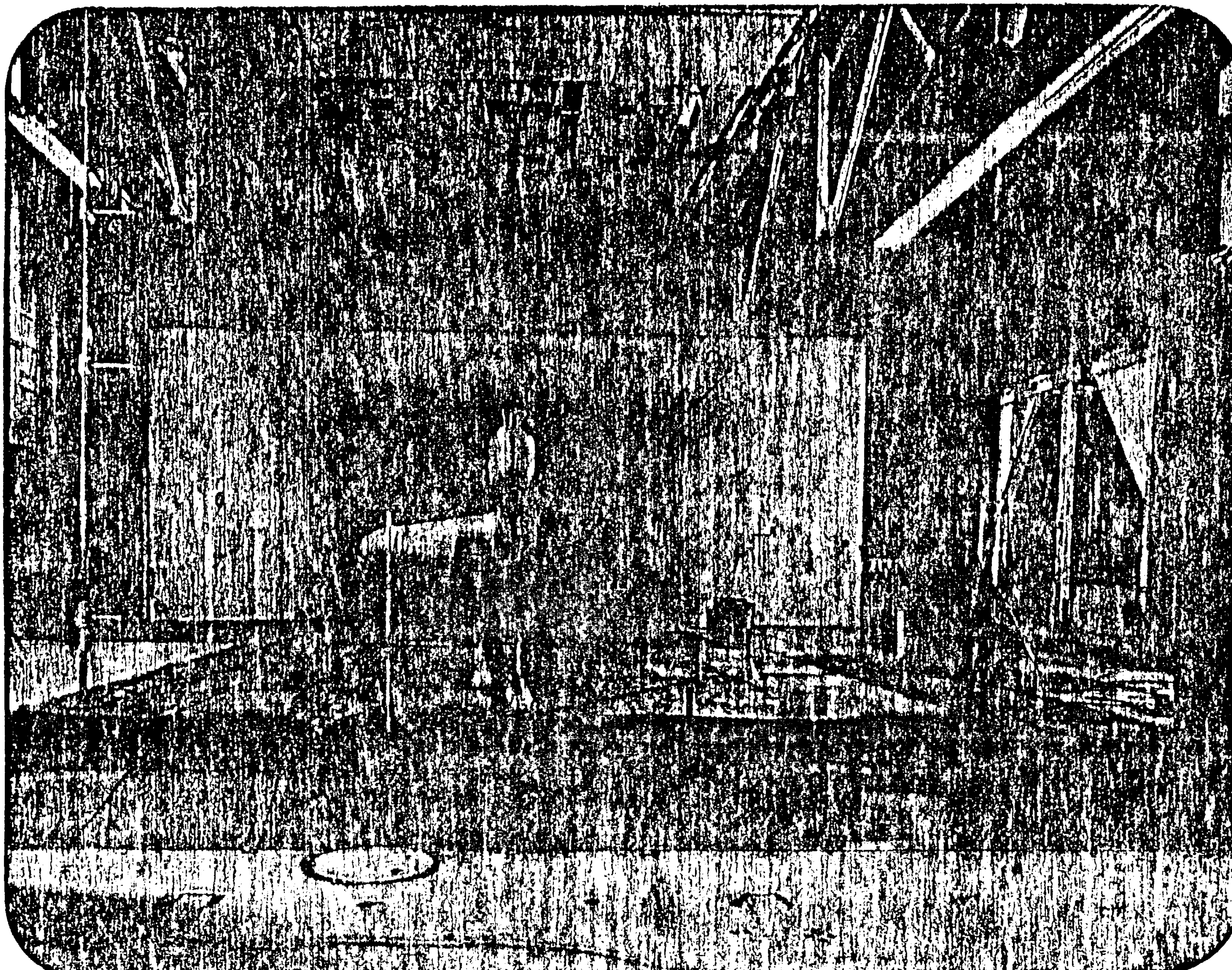
1/24-SCALE MODEL TUNNEL

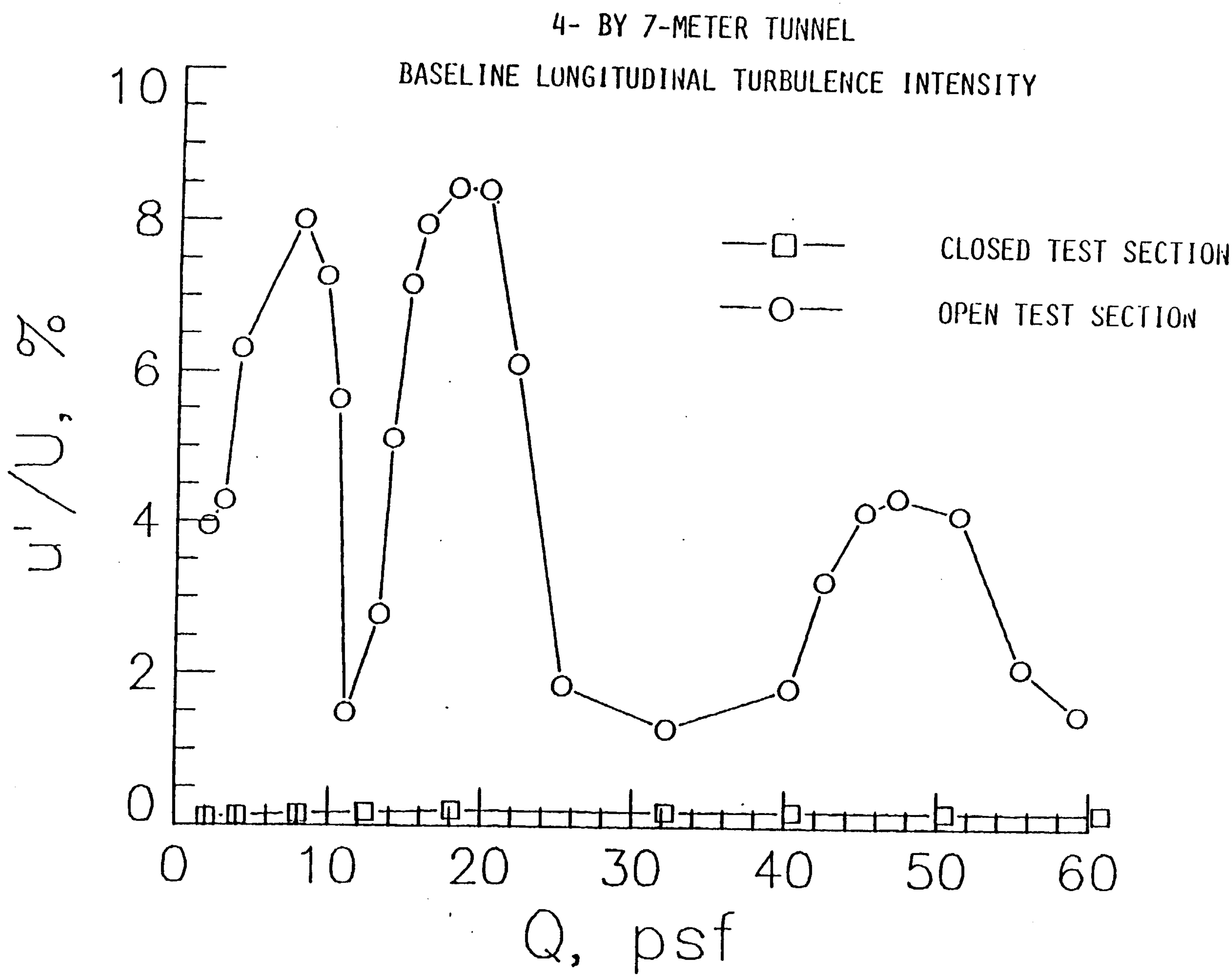


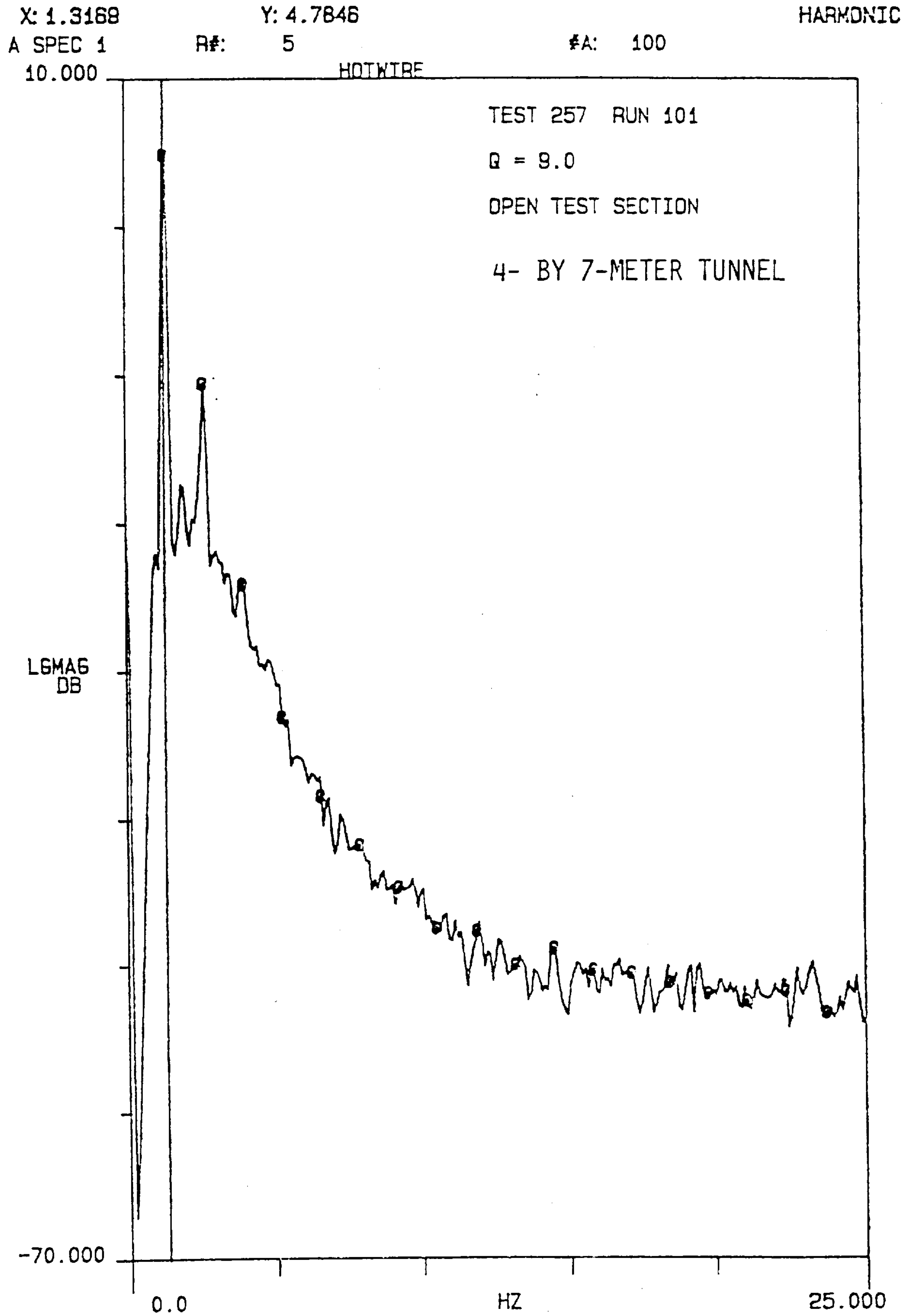


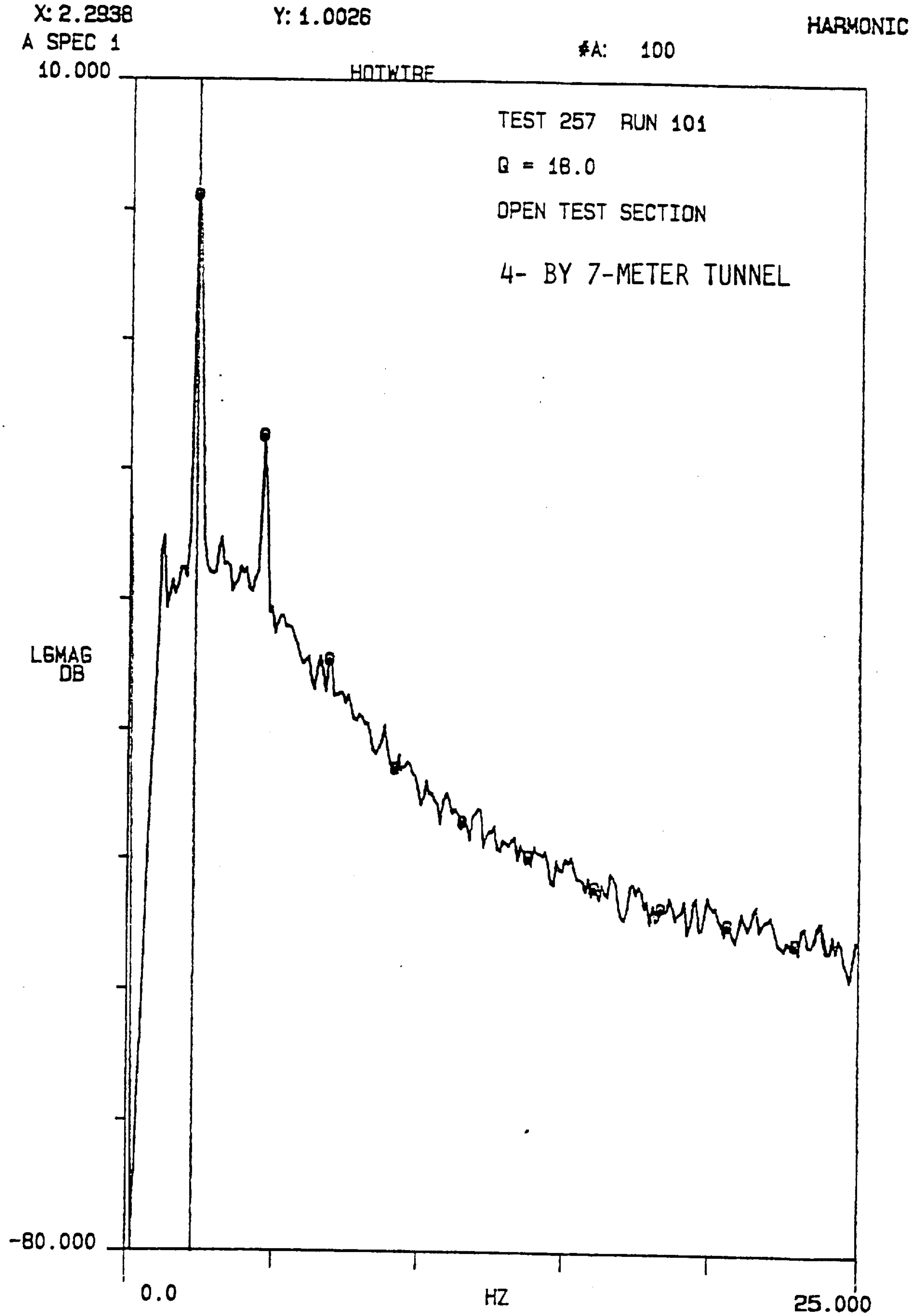
BOUNDARY-LAYER THICKNESS VS. DYNAMIC PRESSURE
4 x 7 METER TUNNEL
MODEL TUNNEL
B.L. THICKNESS, δ, IN. - 4 x 7 M TUNNEL
B.L. THICKNESS, δ, IN. - MODEL TUNNEL
q, lb/ft2
0
1
2
3
4
5
.1
.2
.3
.4
.5
10
20
30
40
50

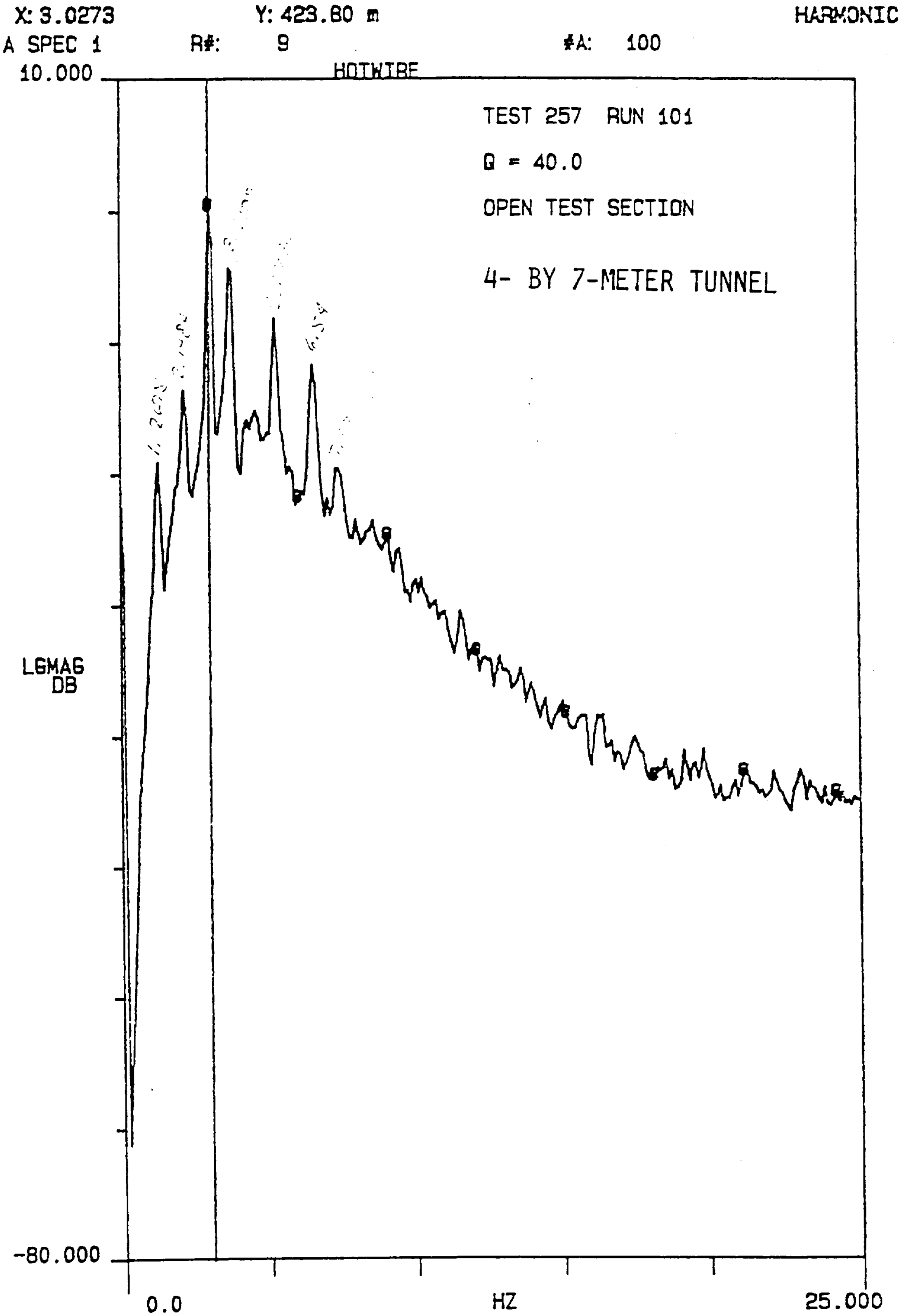
Space Administration



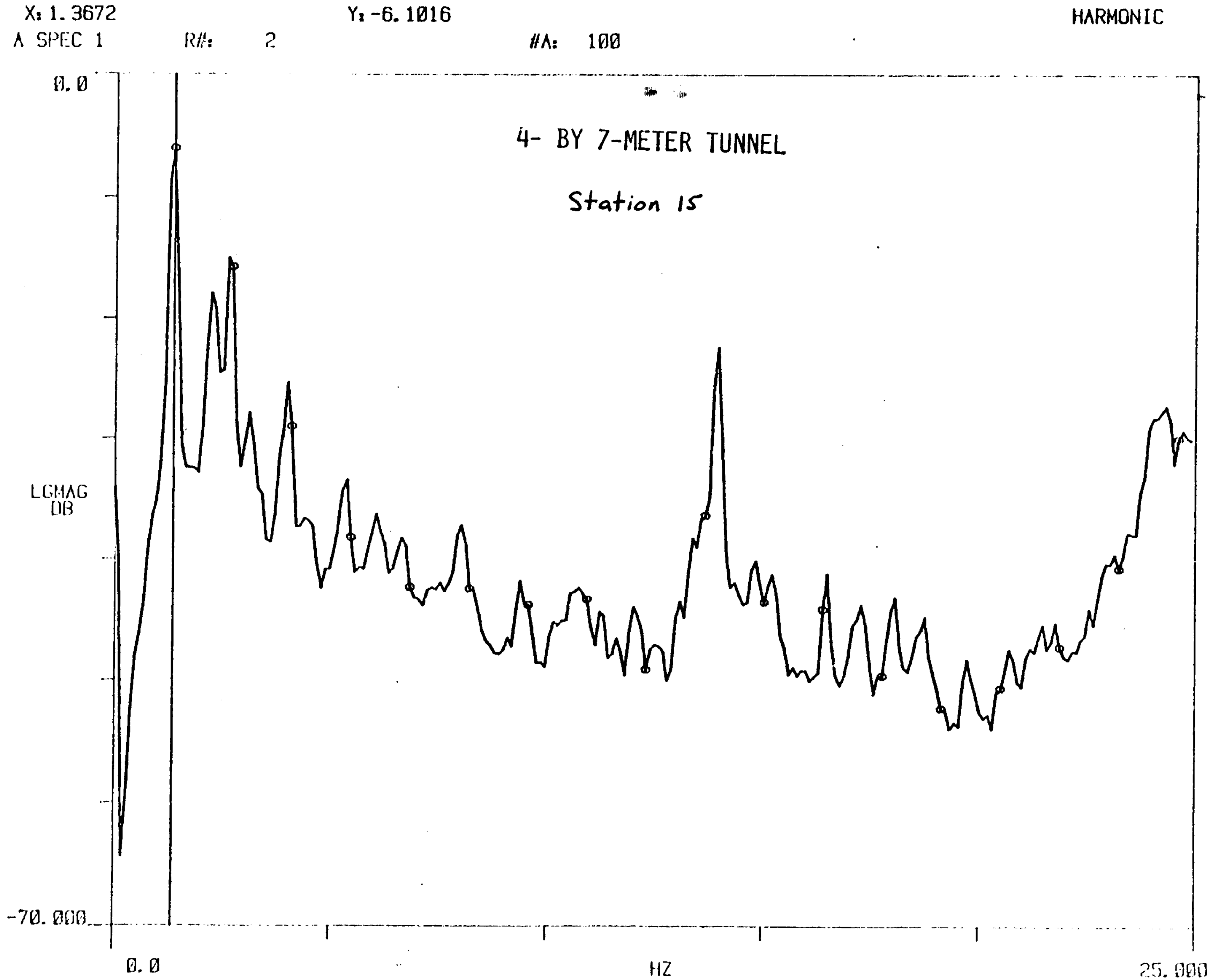

4- BY 7-METER TUNNEL
BASELINE LONGITUDINAL TURBULENCE INTENSITY
CLOSED TEST SECTION
OPEN TEST SECTION
u'/U, %
0
2
4
6
8
10
0
10
20
30
40
50
60
Q, psf

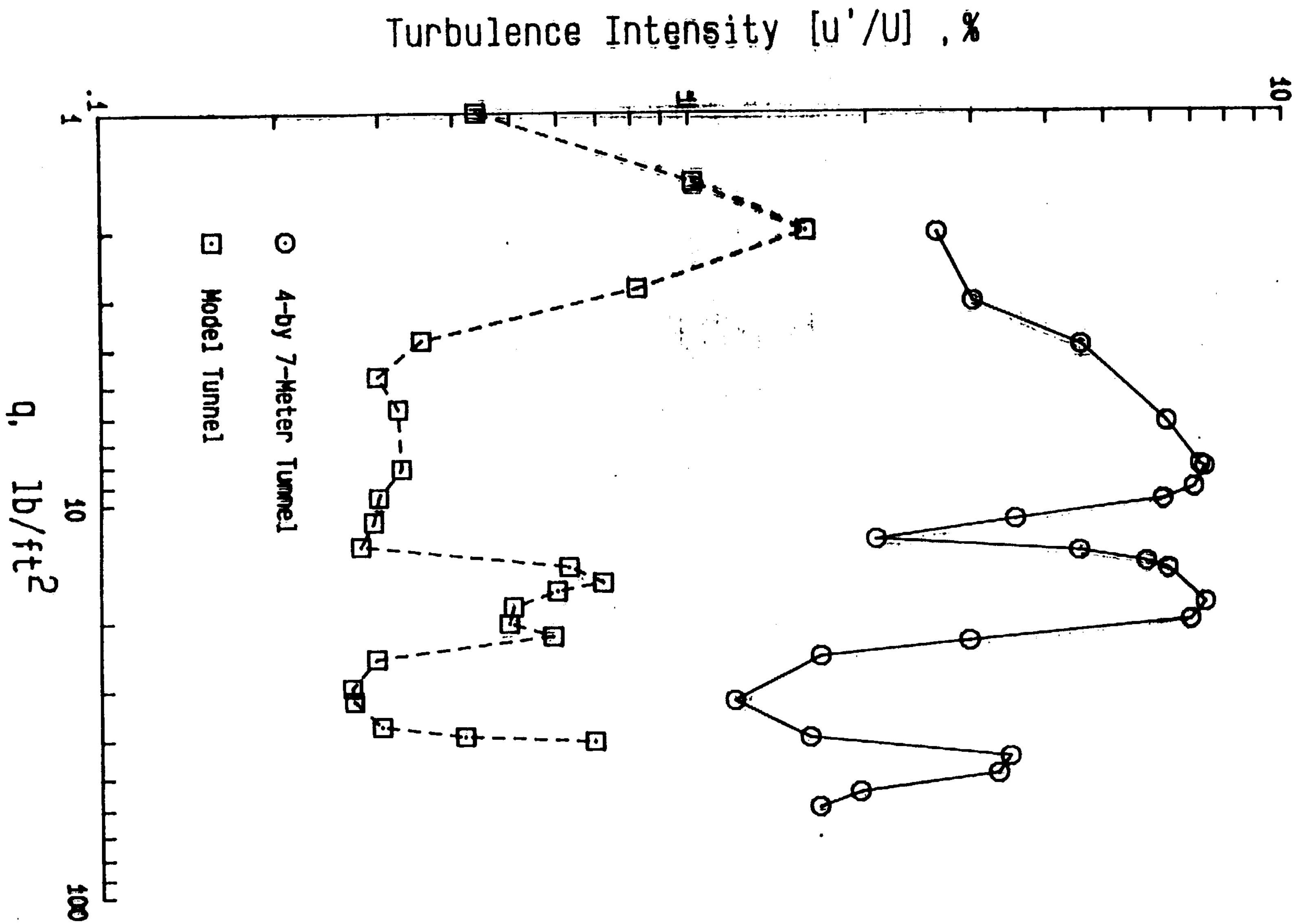

X: 1.3168
Y: 4.7846
HARMONIC
A SPEC 1
R#: 5
#A: 100
HOTWIRE
10.000
TEST 257 RUN 101
Q = 9.0
OPEN TEST SECTION
4- BY 7-METER TUNNEL
LGMAG
DB
-70.000
0.0
HZ
25.000


X: 2.2938
Y: 1.0026
HARMONIC
A SPEC 1
#A: 100
10.000
HOTWIRE
TEST 257 RUN 101
Q = 18.0
OPEN TEST SECTION
4- BY 7-METER TUNNEL
LGMAG
DB
-80.000
0.0
HZ
25.000

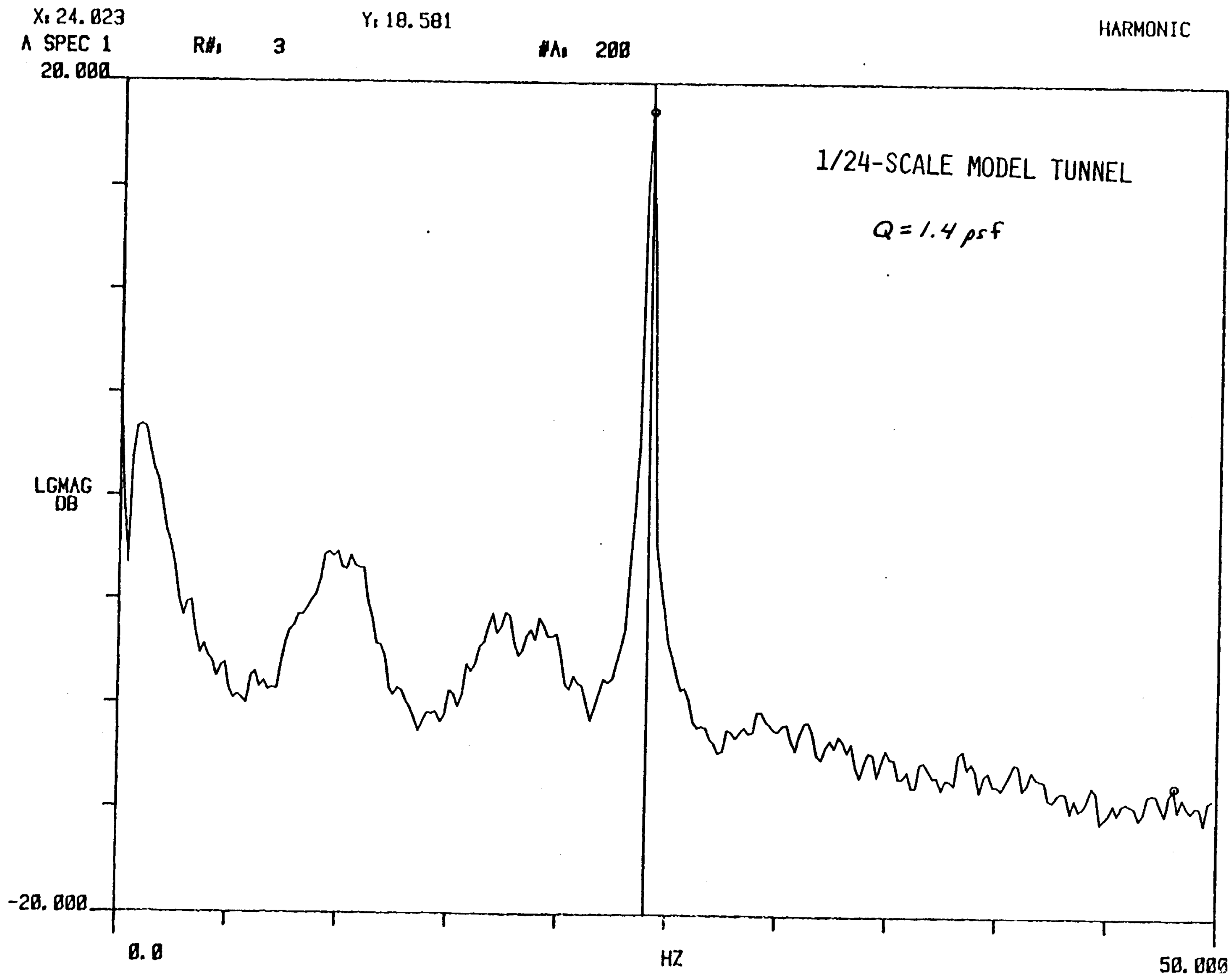

X: 3.0273
Y: 423.80 m
HARMONIC
A SPEC 1
R#: 9
#A: 100
HOTWIRE
10.000
TEST 257 RUN 101
Q = 40.0
OPEN TEST SECTION
4- BY 7-METER TUNNEL
LGMAG
DB
-80.000
0.0
HZ
25.000

OPEN 15, FCV=10, α=9, STA 15

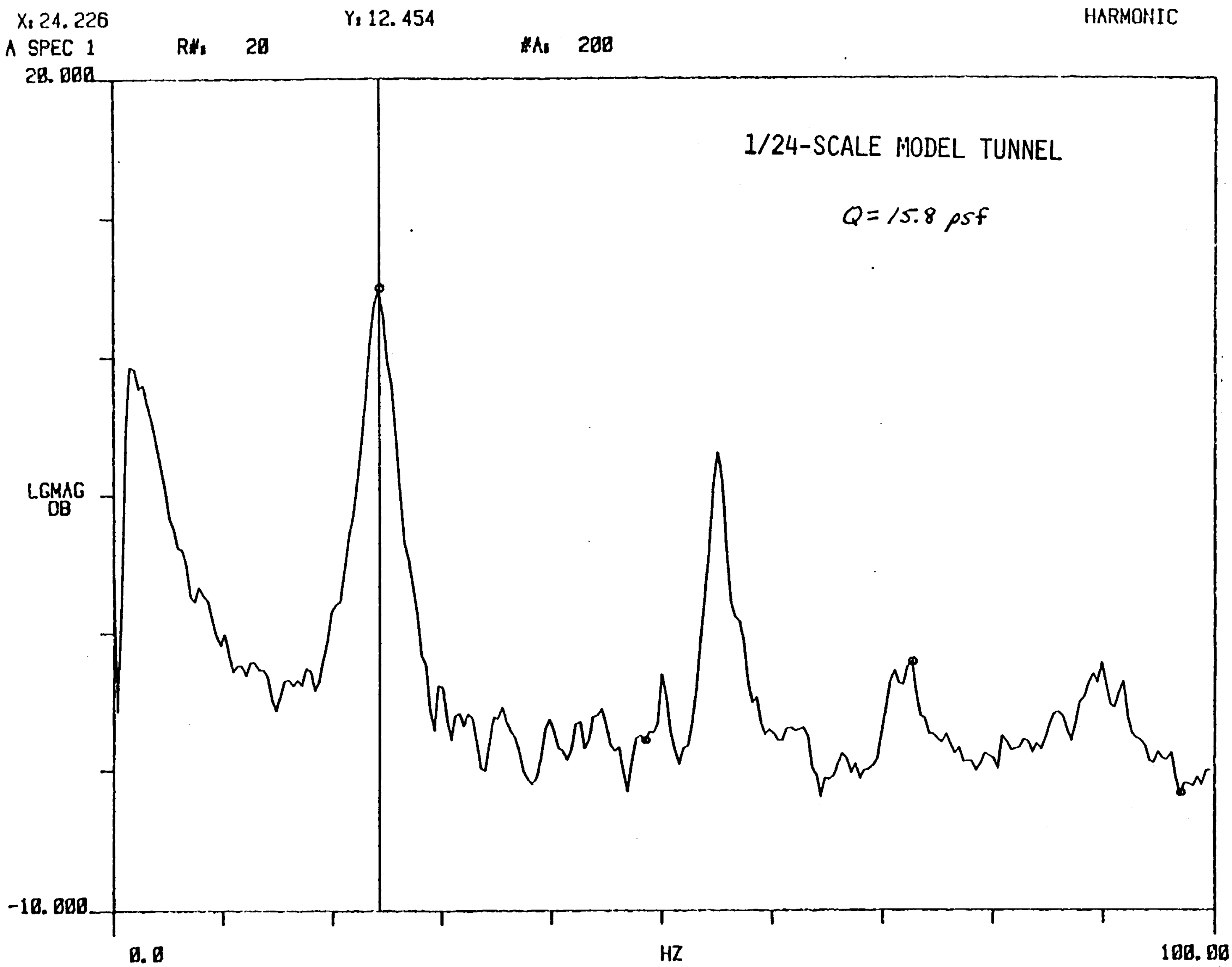




TURBULENCE INTENSITY VERSUS DYNAMIC PRESSURE



X: 24.023
Y: 18.581
HARMONIC
A SPEC 1
R#: 3
#A: 200
20.000
1/24-SCALE MODEL TUNNEL
Q = 1.4 psf
LGMAG
DB
-20.000
0.0
HZ
50.000


X: 24.226
Y: 12.454
HARMONIC
A SPEC 1
R#: 20
#A: 200
20.000
1/24-SCALE MODEL TUNNEL
Q = 15.8 psf
LGMAG
DB
-10.000
0.0
HZ
100.00

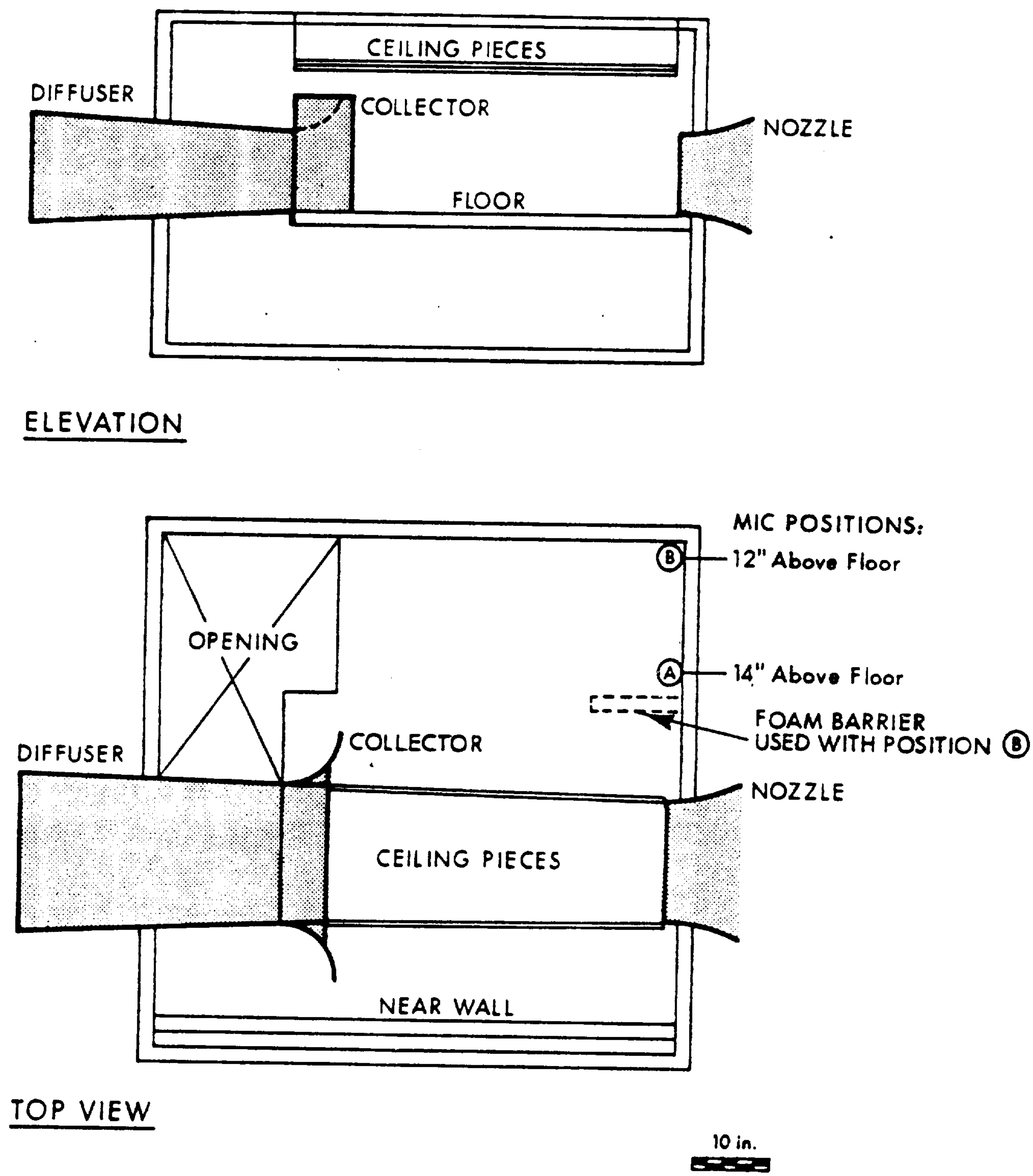


FIG. 24 AERODYNAMIC MODEL OF THE NASA LANGLEY V/STOL TUNNEL.

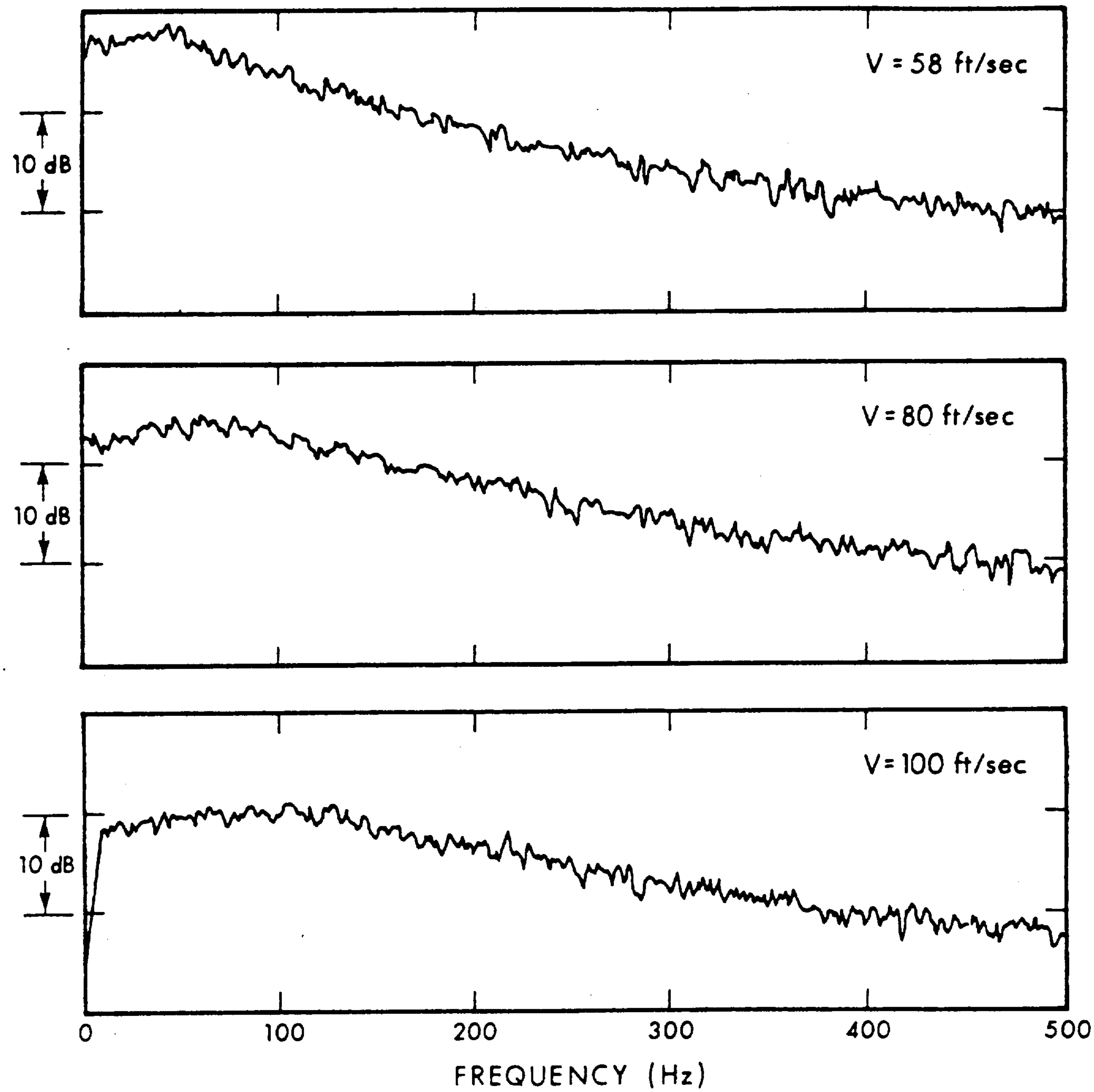
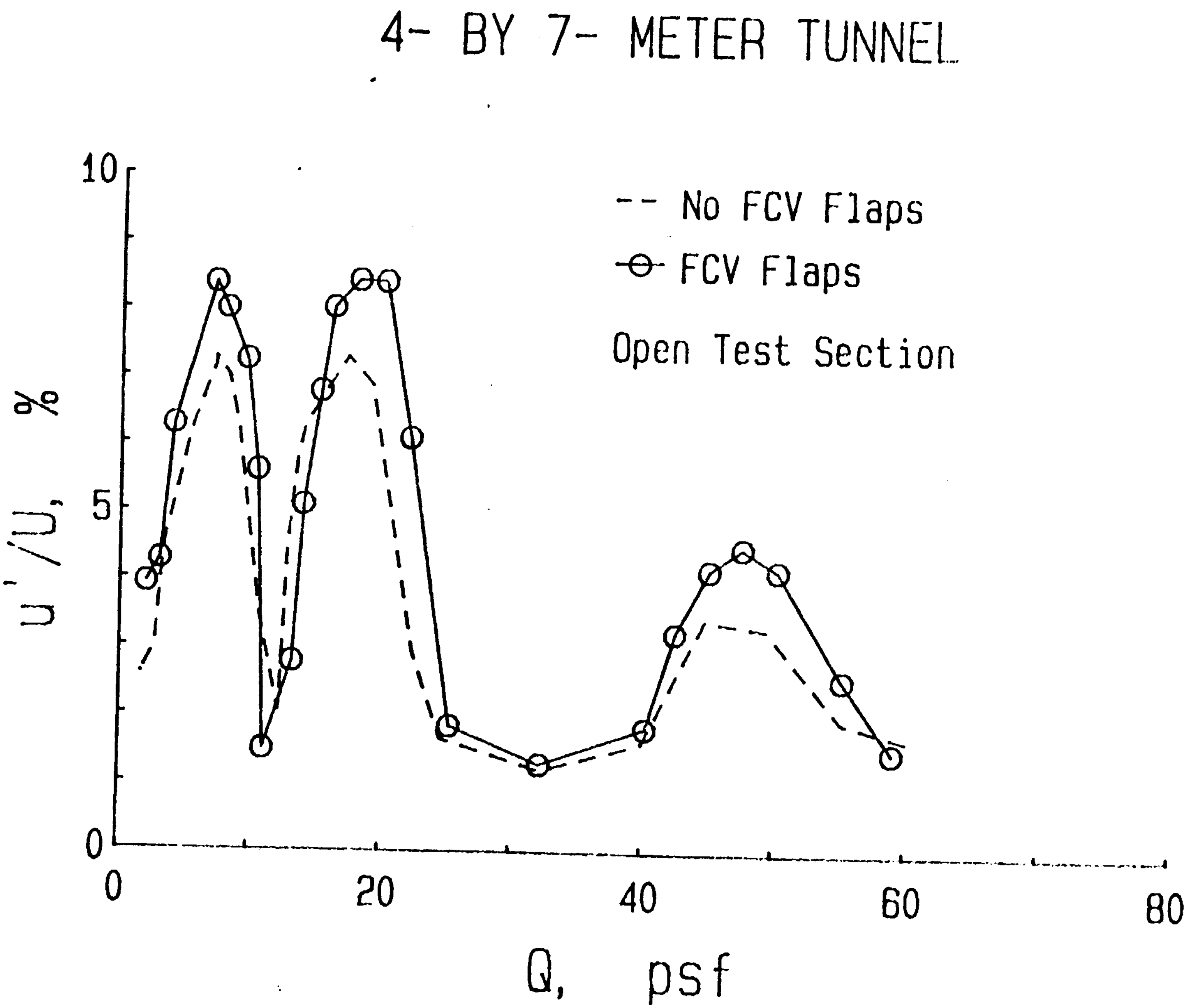
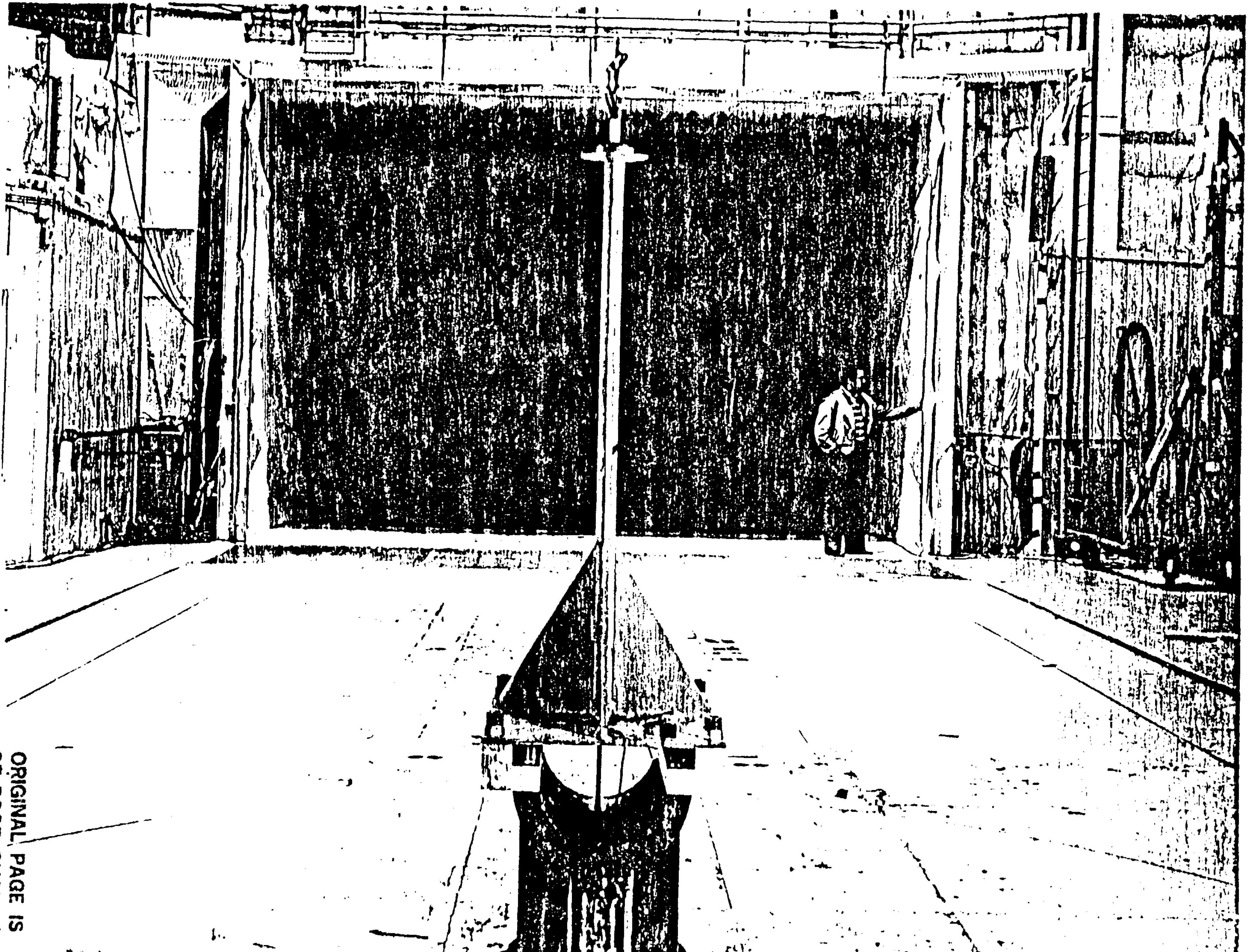


FIG. 28 TYPICAL HOT-WIRE VELOCITY SPECTRUM IN THE SHEAR LAYER.


4- BY 7- METER TUNNEL
-- No FCV Flaps
-⊖- FCV Flaps
Open Test Section
u'/U, %
10
5
0
0
20
40
60
80
Q, psf

NASA
L-82-10,890



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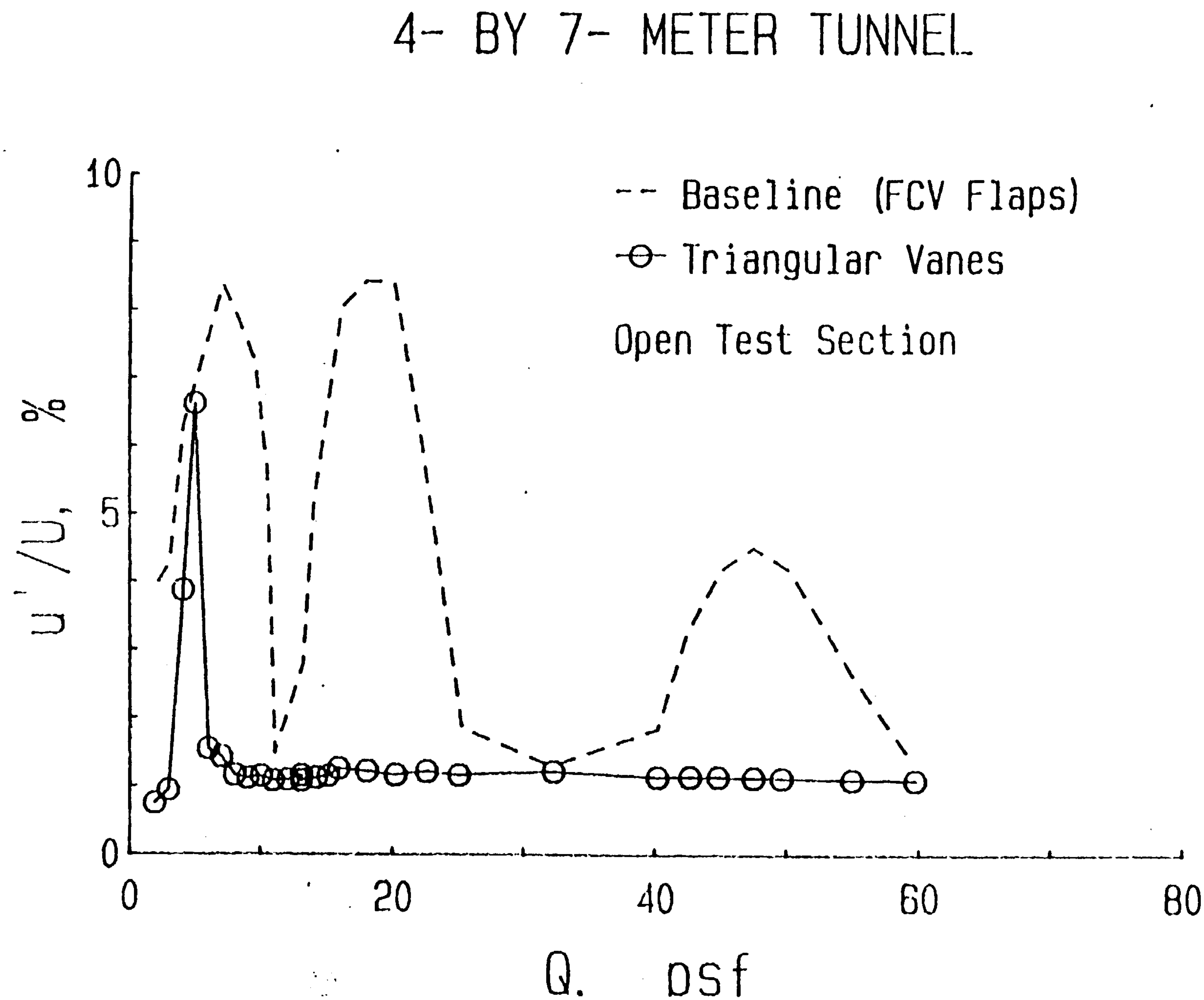
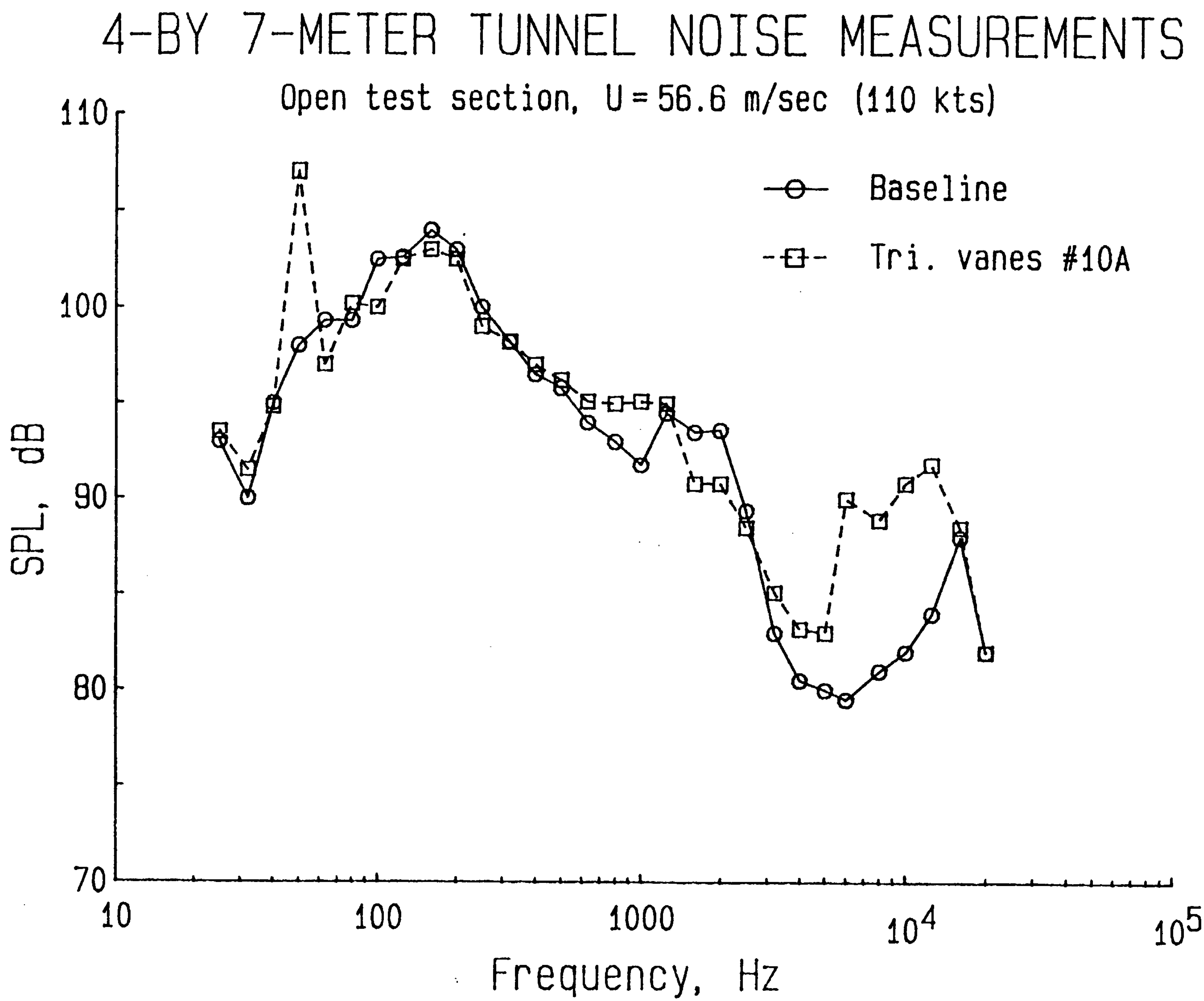
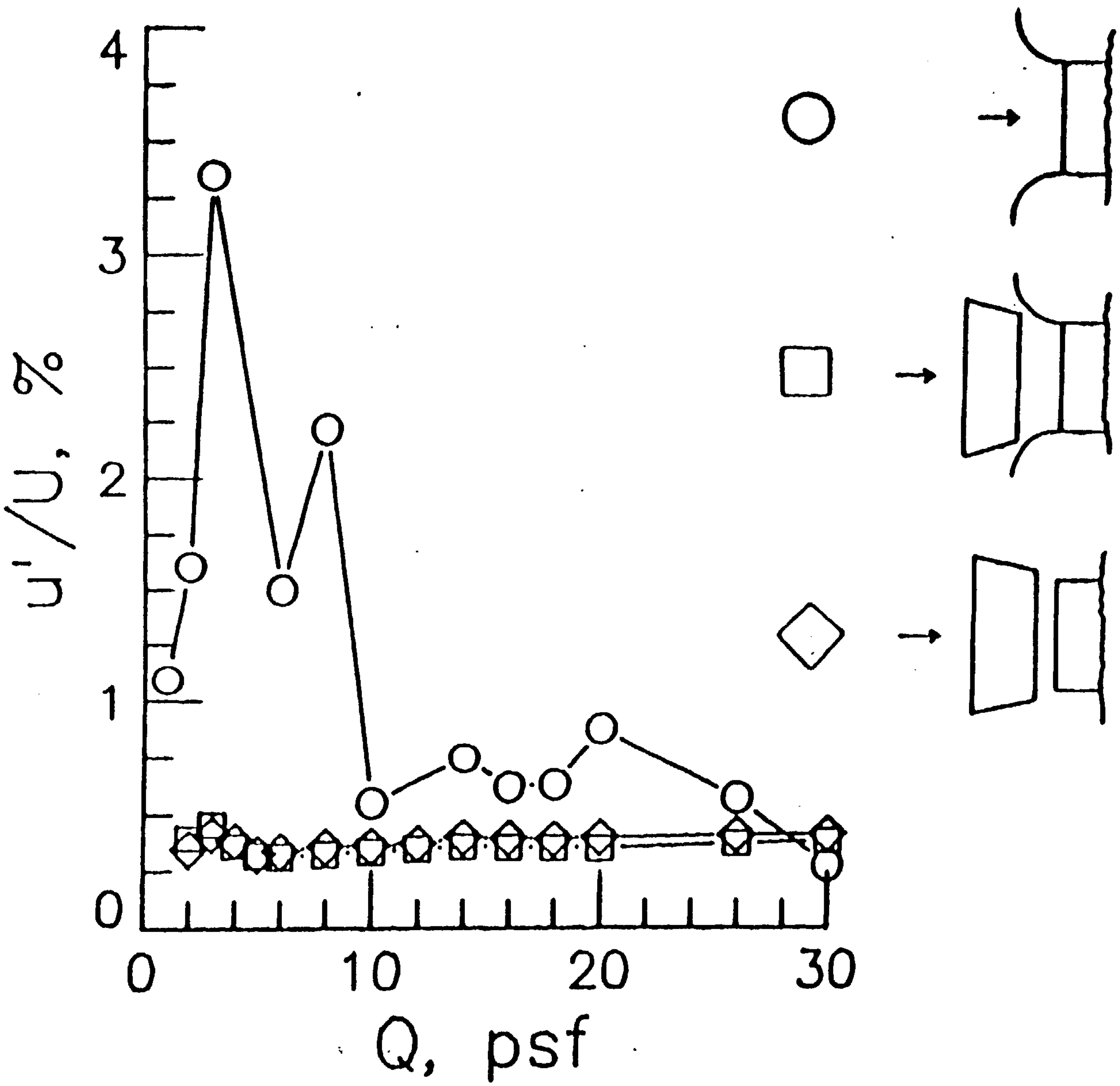

4- BY 7- METER TUNNEL
-- Baseline (FCV Flaps)
Triangular Vanes
Open Test Section
u'/U, %
10
5
0
0
20
40
60
80
Q. psf

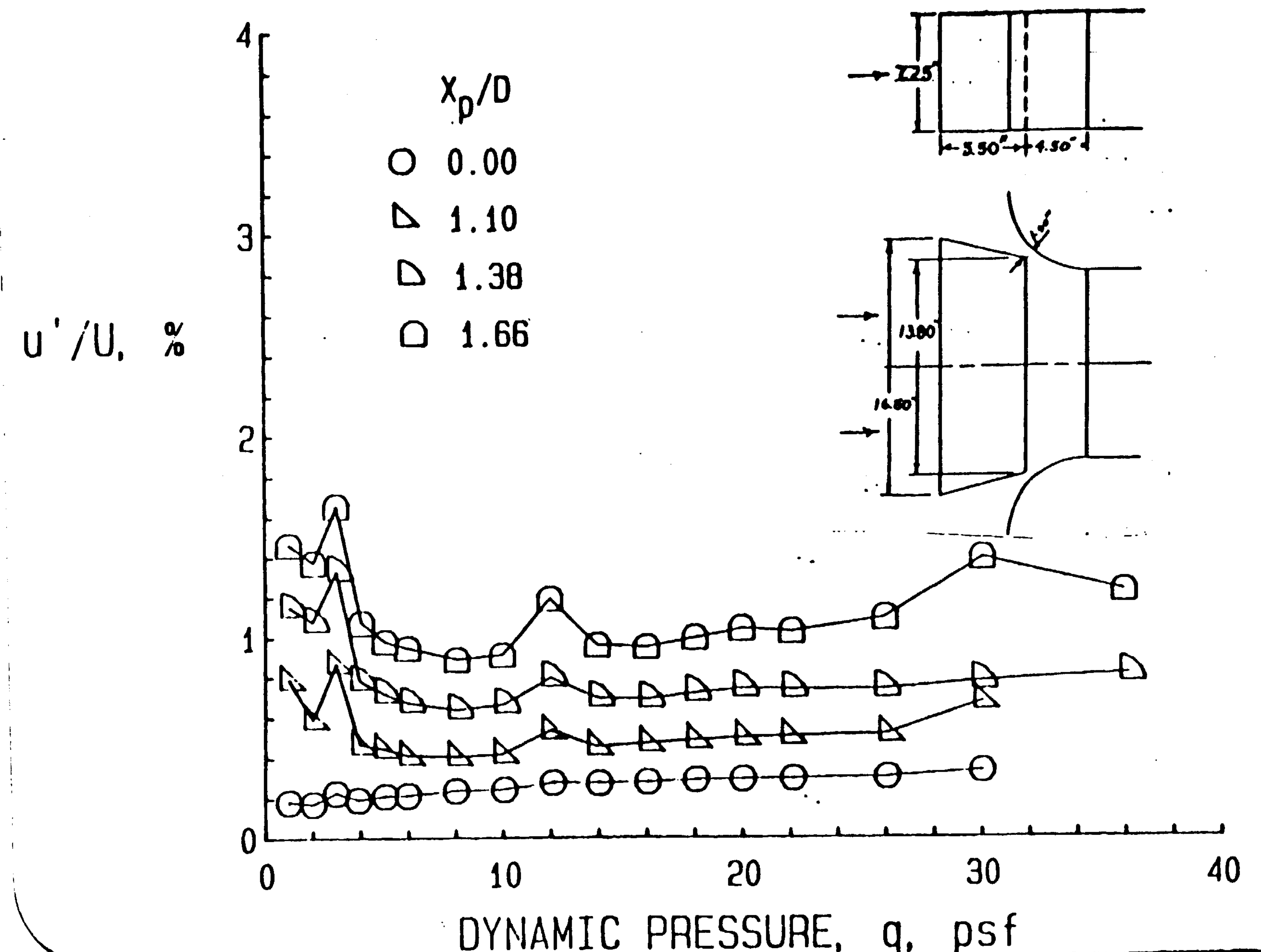


4-BY 7-METER TUNNEL NOISE MEASUREMENTS
Open test section, U = 56.6 m/sec (110 kts)
Baseline
Tri. vanes #10A
SPL, dB
110
100
90
80
70
10
100
1000
10^4
10^5
Frequency, Hz

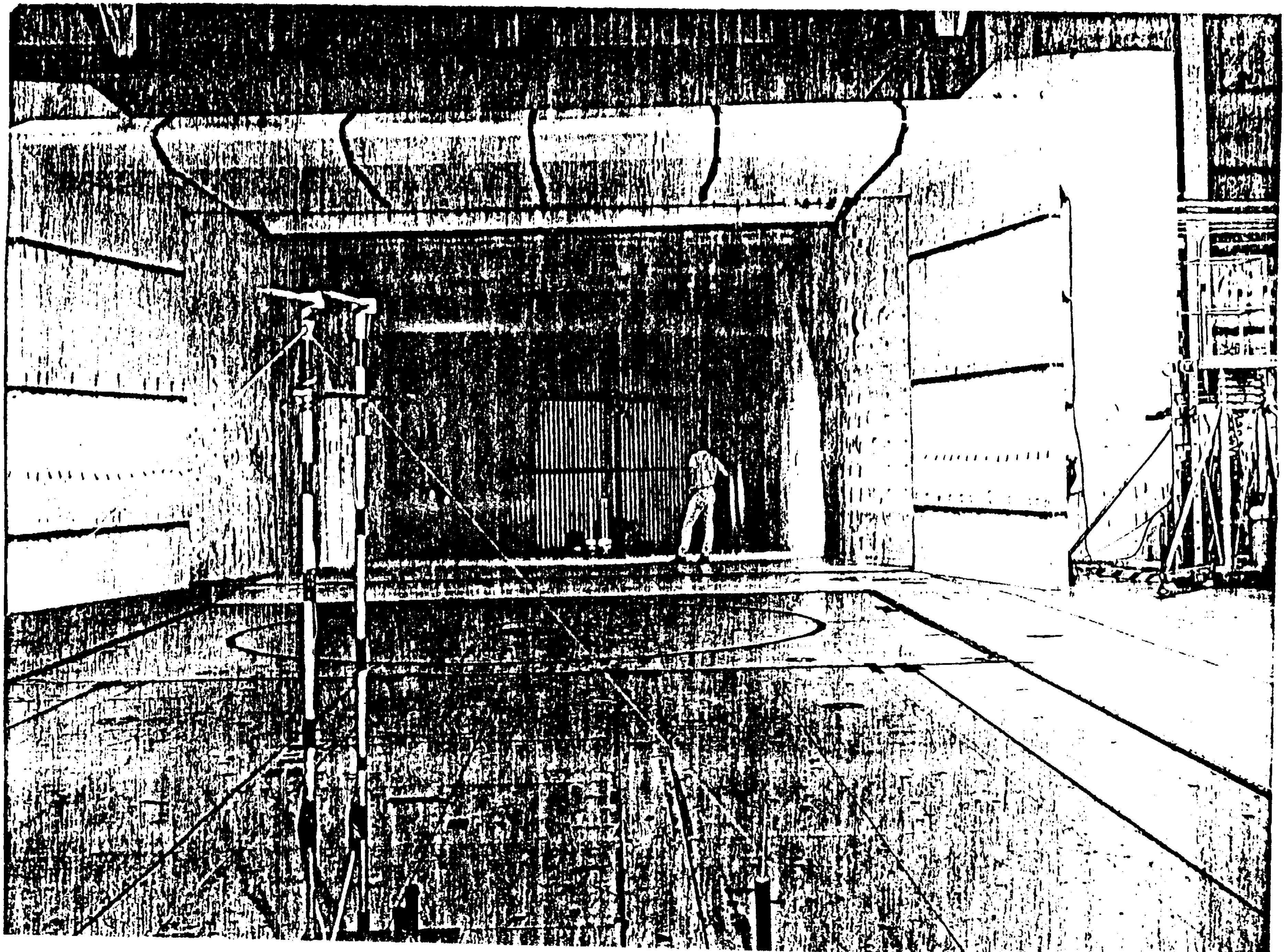
TURBULENCE MEASUREMENTS IN MODEL TUNNEL



EFFECT OF AXIAL LOCATION ON VELOCITY FLUCTUATIONS
COLLECTOR CONFIGURATION #7 - 1/D = 2.21

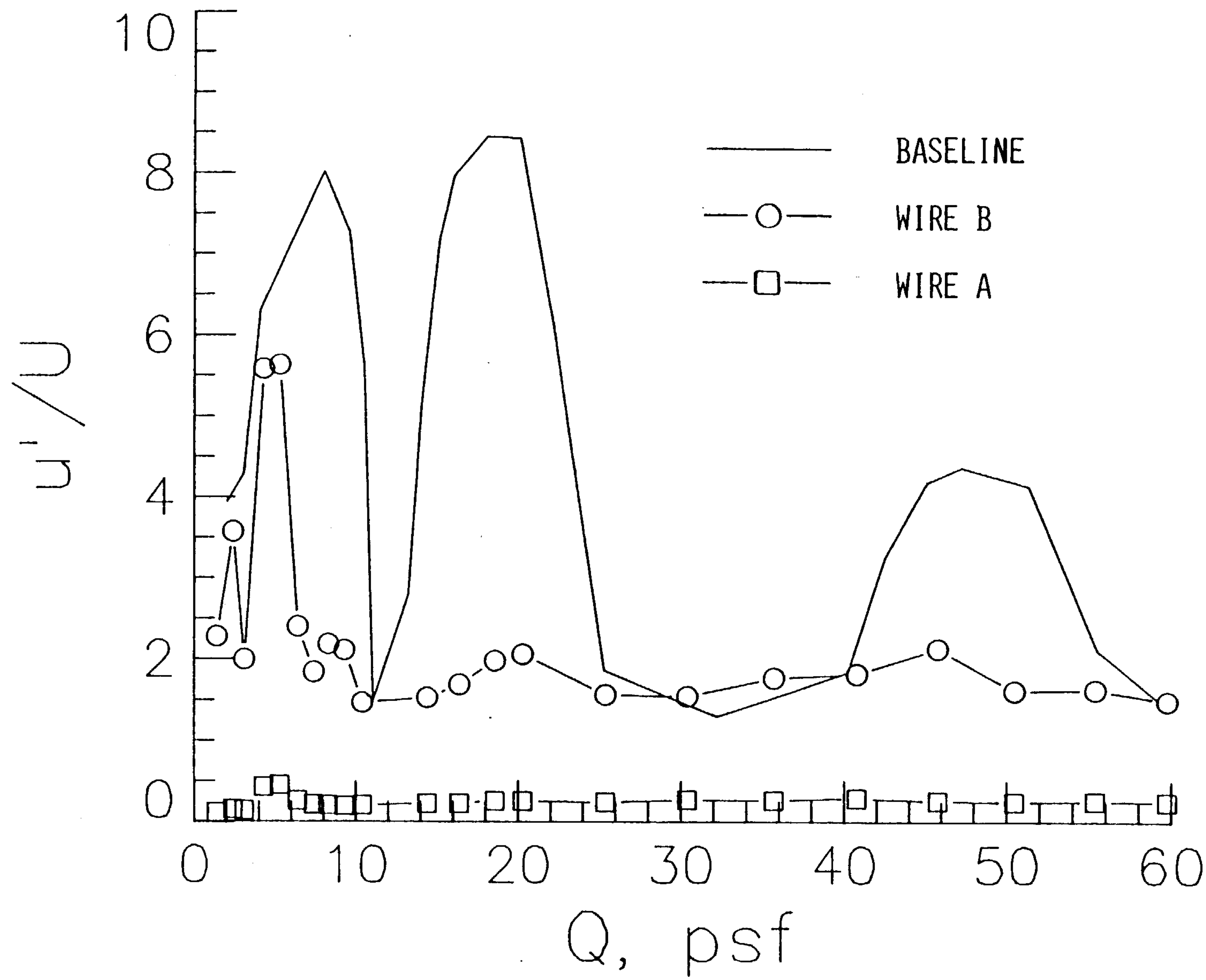


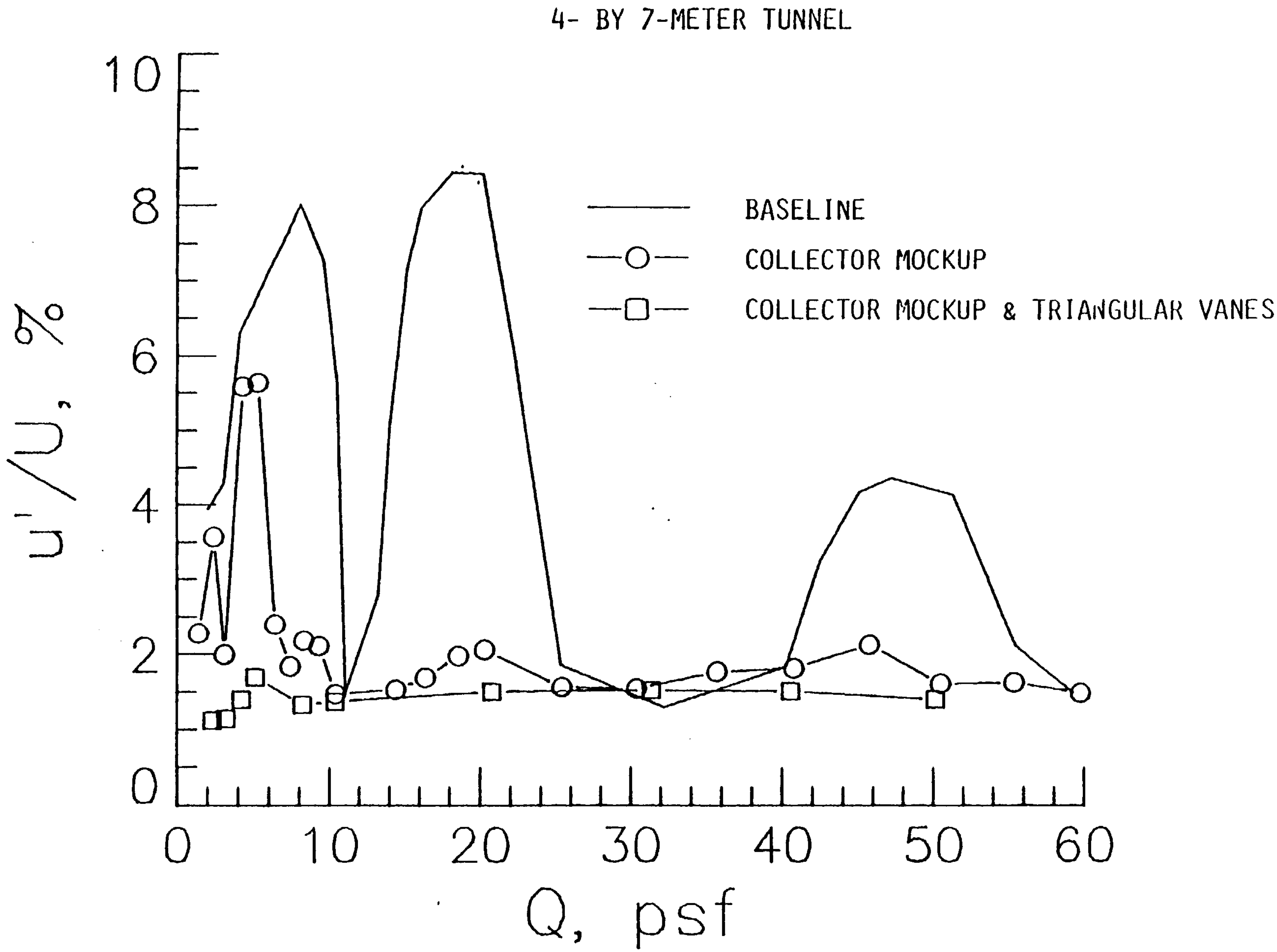
NASA
L-83-8,073



4- BY 7-METER TUNNEL

EFFECT OF COLLECTOR MOCKUP




4- BY 7-METER TUNNEL
BASELINE
COLLECTOR MOCKUP
COLLECTOR MOCKUP & TRIANGULAR VANES
u'/U, %
Q, psf
0
2
4
6
8
10
0
10
20
30
40
50
60

CONCLUDING REMARKS

- UNSUCCESSFUL IN MODELING VELOCITY PROFILES IN THE CIRCUIT OF THE 4- BY 7-METER TUNNEL. MODEL TUNNEL IS NOT AN ACCURATE DUPLICATE AND IS PROBABLY TOO SMALL

- MODEL TUNNEL HAS OPEN TEST SECTION TRENDS THAT ARE VERY SIMILAR TO THE 4- BY 7-METER TUNNEL

  - NO OBVIOUS SCALING FOR TURBULENCE INTENSITIES

  - FREQUENCIES SCALE APPROXIMATELY WITH THE GEOMETRIC RATIO

- COMPLETE CIRCUIT HAS A SIGNIFICANT EFFECT ON FLOW PULSATIONS

CONCERNS

- ACCURATE MODEL TUNNEL SIMULATION IS DIFFICULT AT BEST

- REYNOLDS NUMBER MATCHING MAY BE IMPORTANT IN DETERMINING FLOW SEPARATION ZONES

RECOMMENDATION

MAKE YOUR MODEL TUNNEL AS BIG AS POSSIBLE AND
PROVIDE FOR REYNOLDS NUMBER SIMULATION

AEDC MODELING PROGRAMS

R. DEAN HERRON

MANAGER, TEST OPERATIONS AND ENGINEERING BRANCH (CALSPAN)

ARNOLD ENGINEERING AND DEVELOPMENT CENTER

WIND TUNNEL MODELING AT AEDC

DEAN HERRON
ARVIN/CALSPAN FIELD SERVICES

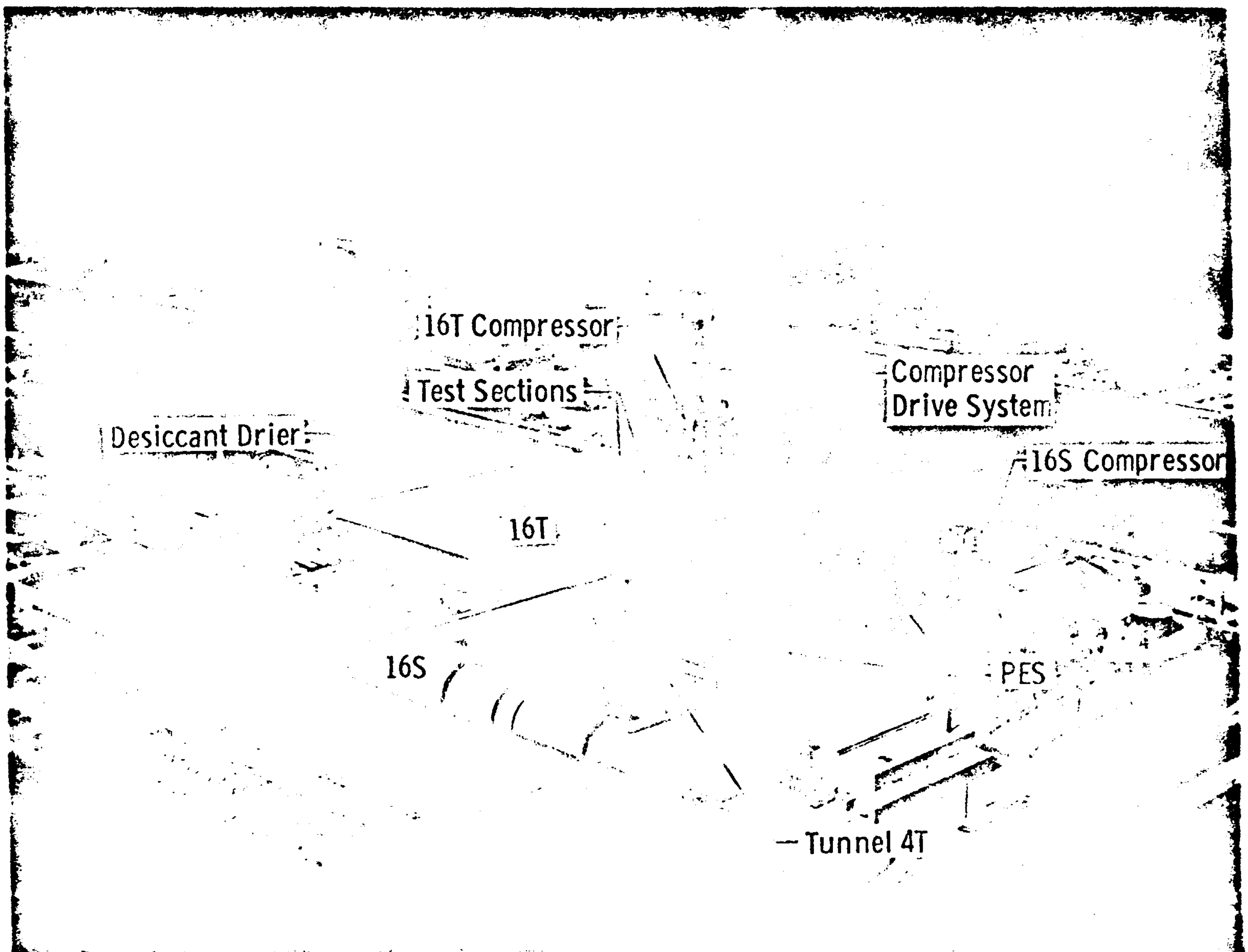
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND

PROPULSION WIND TUNNEL FACILITY

- 16T
- 16S
- 4T

VON KARMAN GAS DYNAMICS FACILITY

- APTU - AERODYNAMIC AND PROPULSION TEST UNIT



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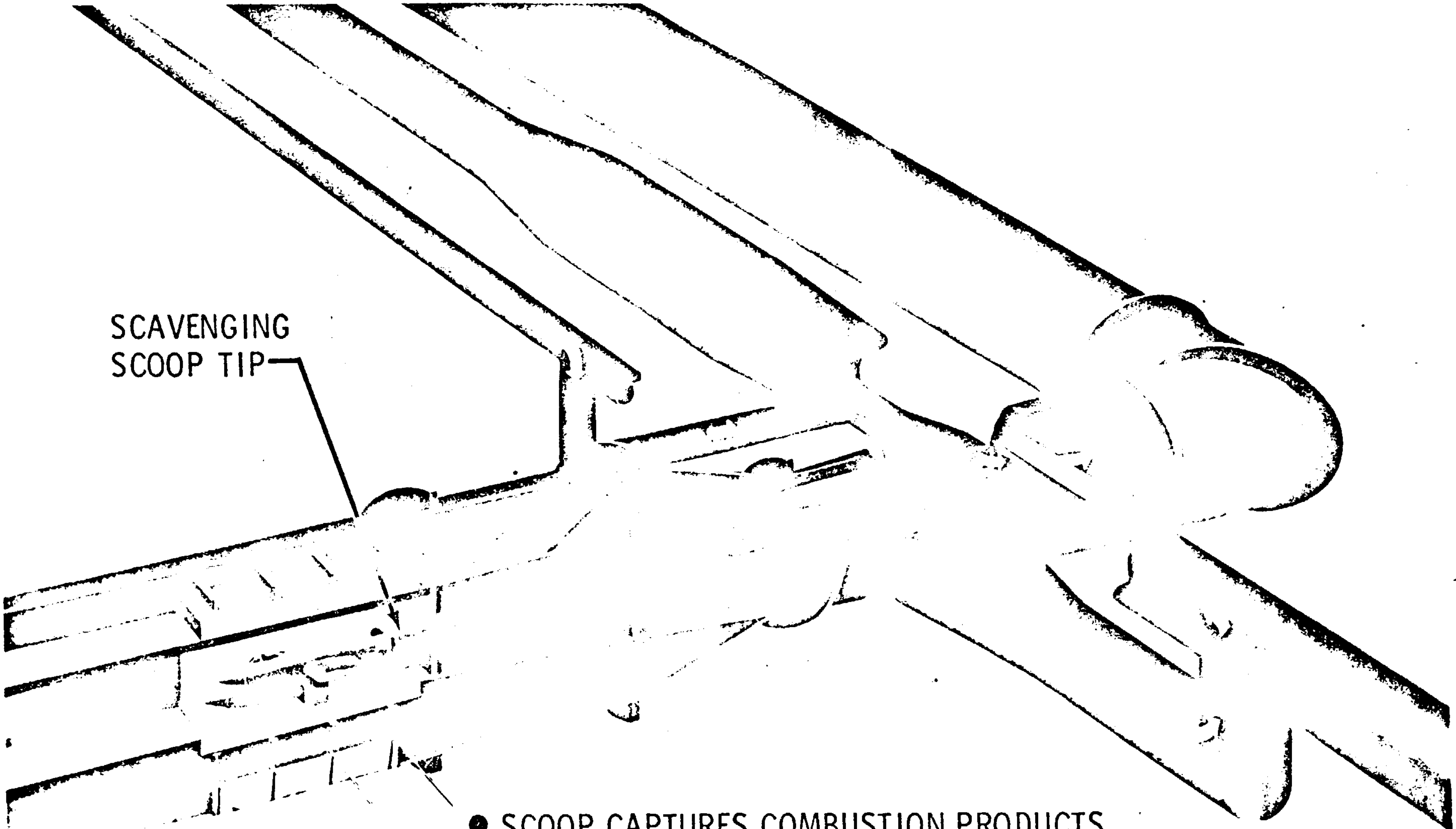
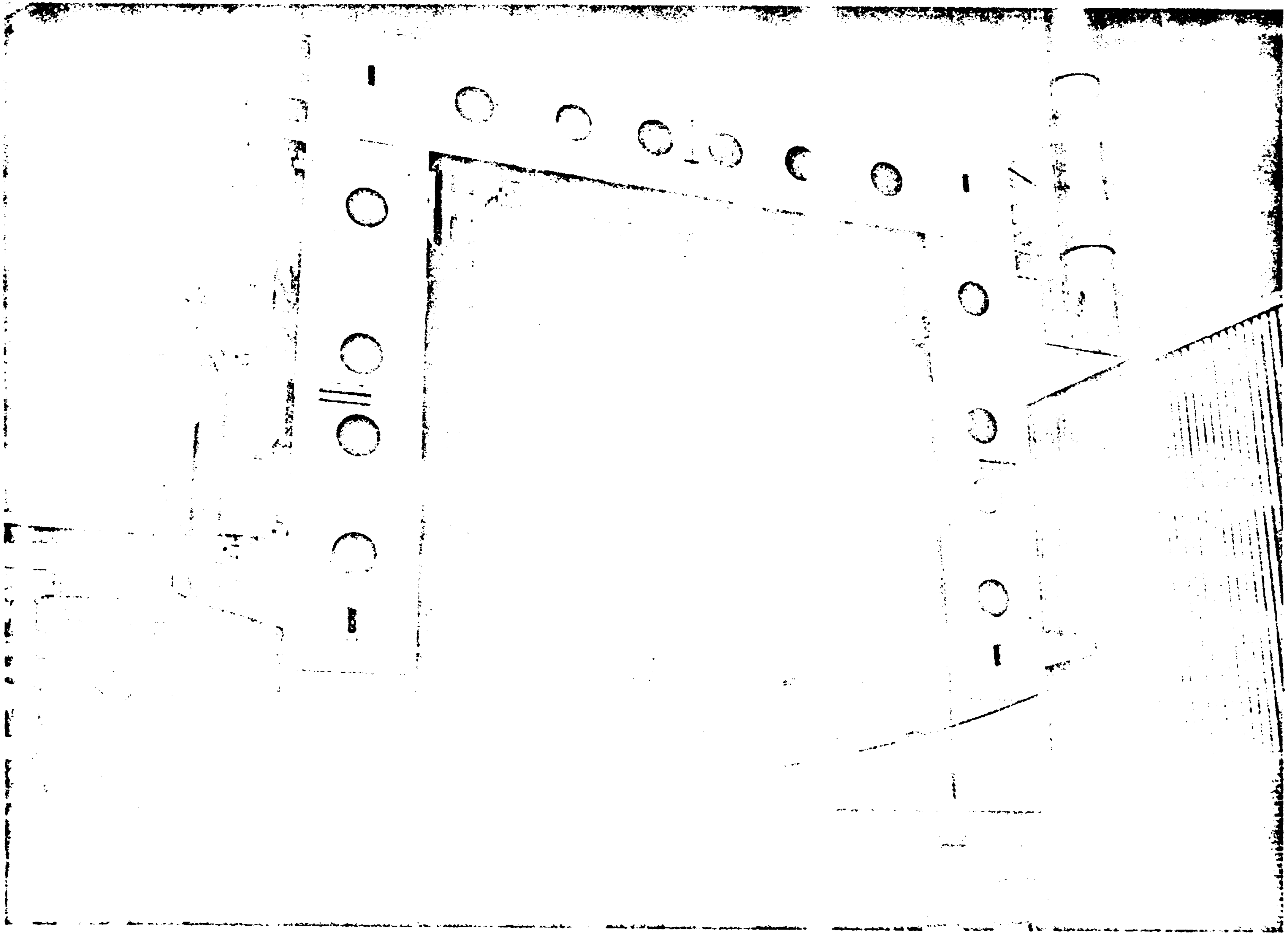
TUNNEL 16T SCAVENGING SYSTEM



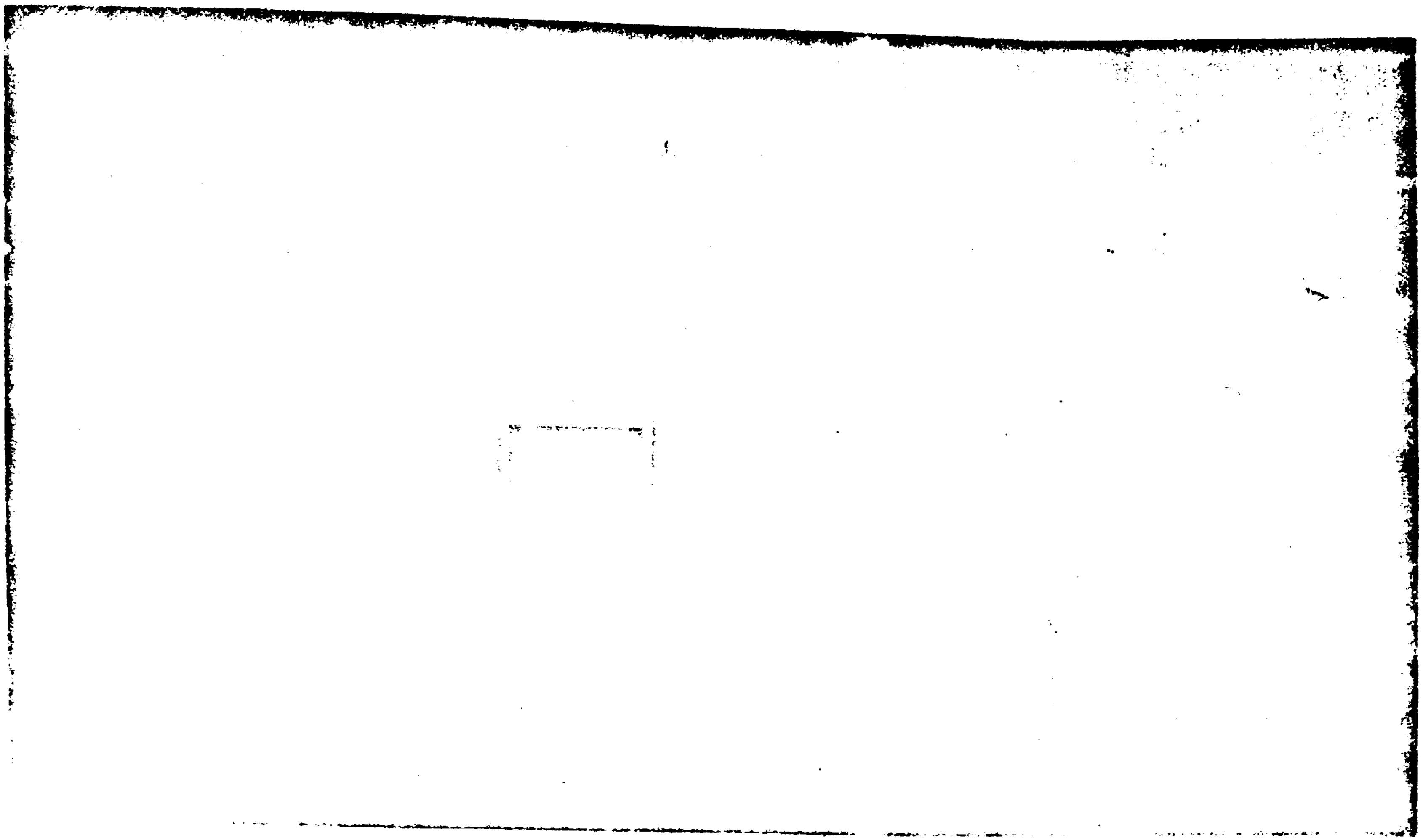
- SCOOP CAPTURES COMBUSTION PRODUCTS
- SCOOP PITCHES TO FOLLOW EXHAUST PLUME
- VARIABLE SCOOP GEOMETRIES AVAILABLE

TUNNEL 16T TEST SECTION TRANSFER CART



TUNNEL 16T VARIABLE GEOMETRY NOZZLE

COMPRESSOR PROTECTIVE SCREEN IN THE TUNNEL 16T DIFFUSER



HISTORY

DEVELOPMENT AND MODELING OF PWT-16T AND 16S

- DESIGN CRITERIA FOR PWT-16T AND 16S WERE LARGELY DETERMINED FROM COMPONENT STUDIES AT OTHER FACILITIES
- NATIONAL TRANSONIC PANEL - REVIEWED WORK
  NACA, WRIGHT FIELD, BOEING, S&P, OTHERS
- FINAL DESIGN BY SVERDRUP AND PARCEL, ST. LOUIS
- SOME DESIGN CONFIRMATION AND MANY LATER MODIFICATIONS DEVELOPED IN AEDC 1-FT TUNNELS

16T COOLER

- PROBABLY MOST USEFUL OF ALL MODEL TESTS - PINDZOLA
- MODEL IN GA TECH WIND TUNNEL (9-FT.)
- AERODYNAMICS AND STRUCTURAL DESIGN
- REVEALED MANY DEFICIENCIES
- SOME FIXES IDENTIFIED WERE <u>NOT</u> INCORPORATED - COSTS/CONTRACTOR
- SECTION TESTED AT UAC FOR SIMPLER FIXES
- HEAT TRANSFER OF FINNED TUBES - PURDUE UNIVERSITY
- <u>NOW</u> TRYING TO OBTAIN BETTER FIXES

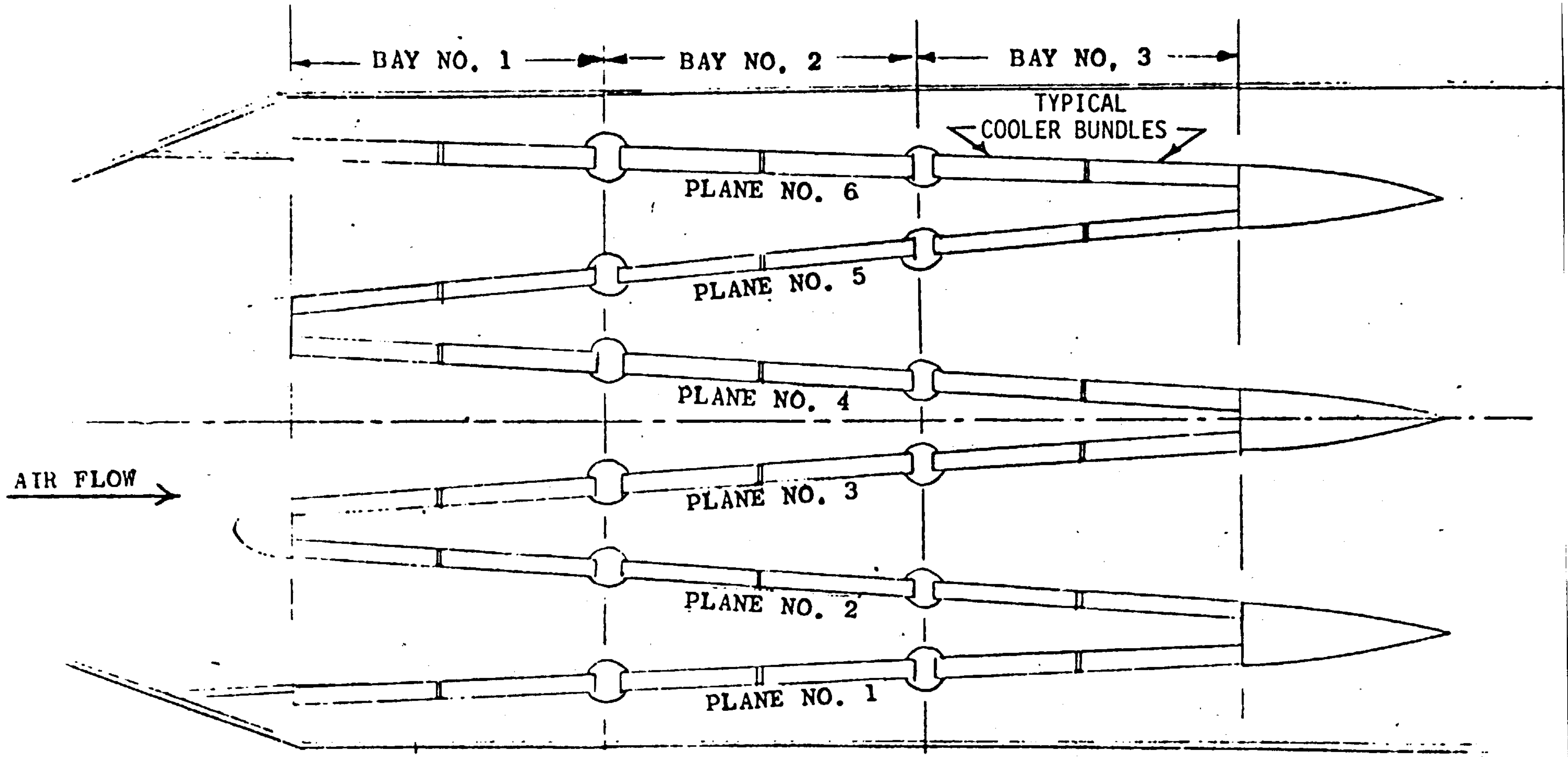


FIG. 2. 16T COOLER

SECTION VIEW, LOOKING NORTH.

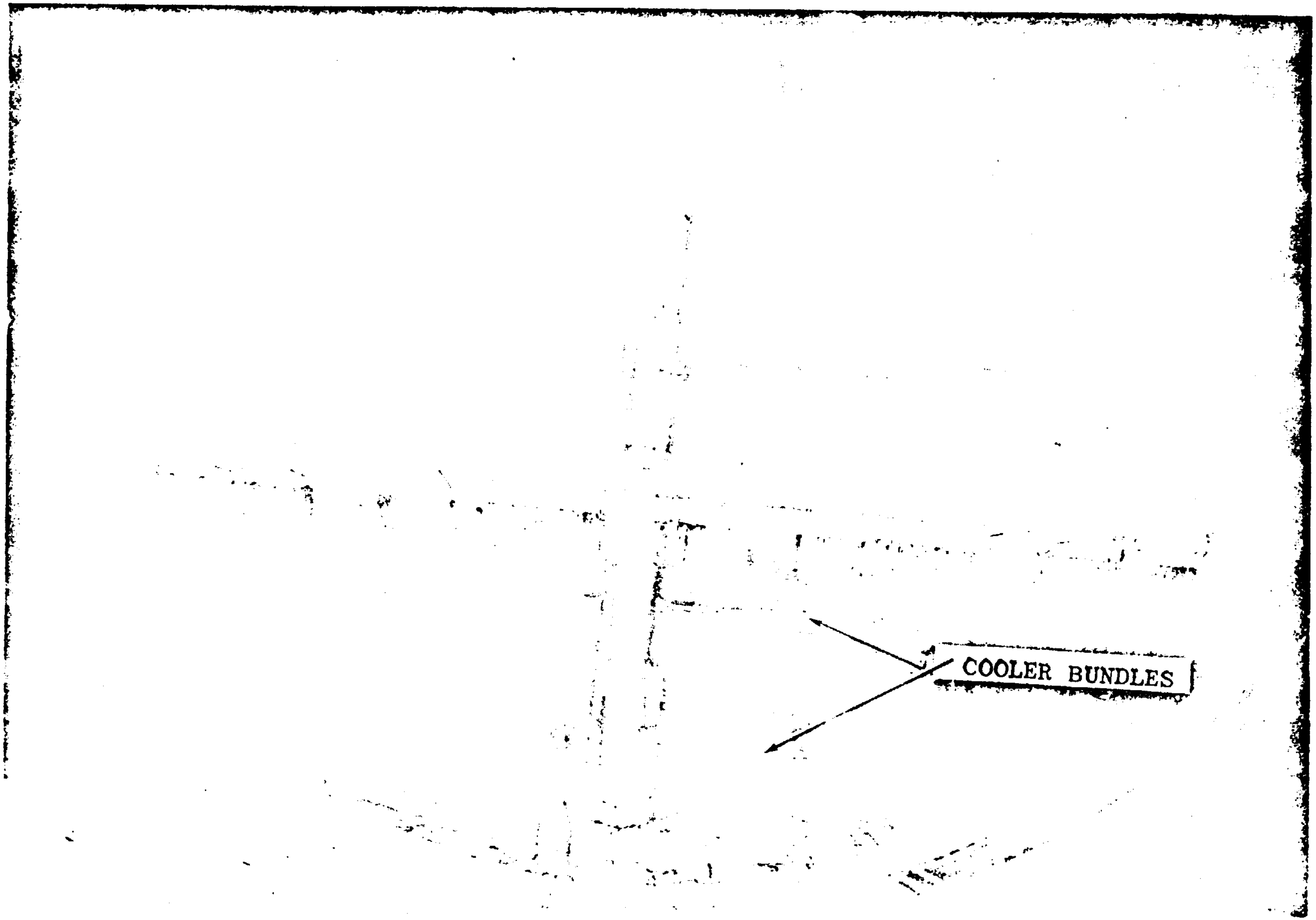


FIG. 1. VIEW OF THE COOLER ENTRANCE.

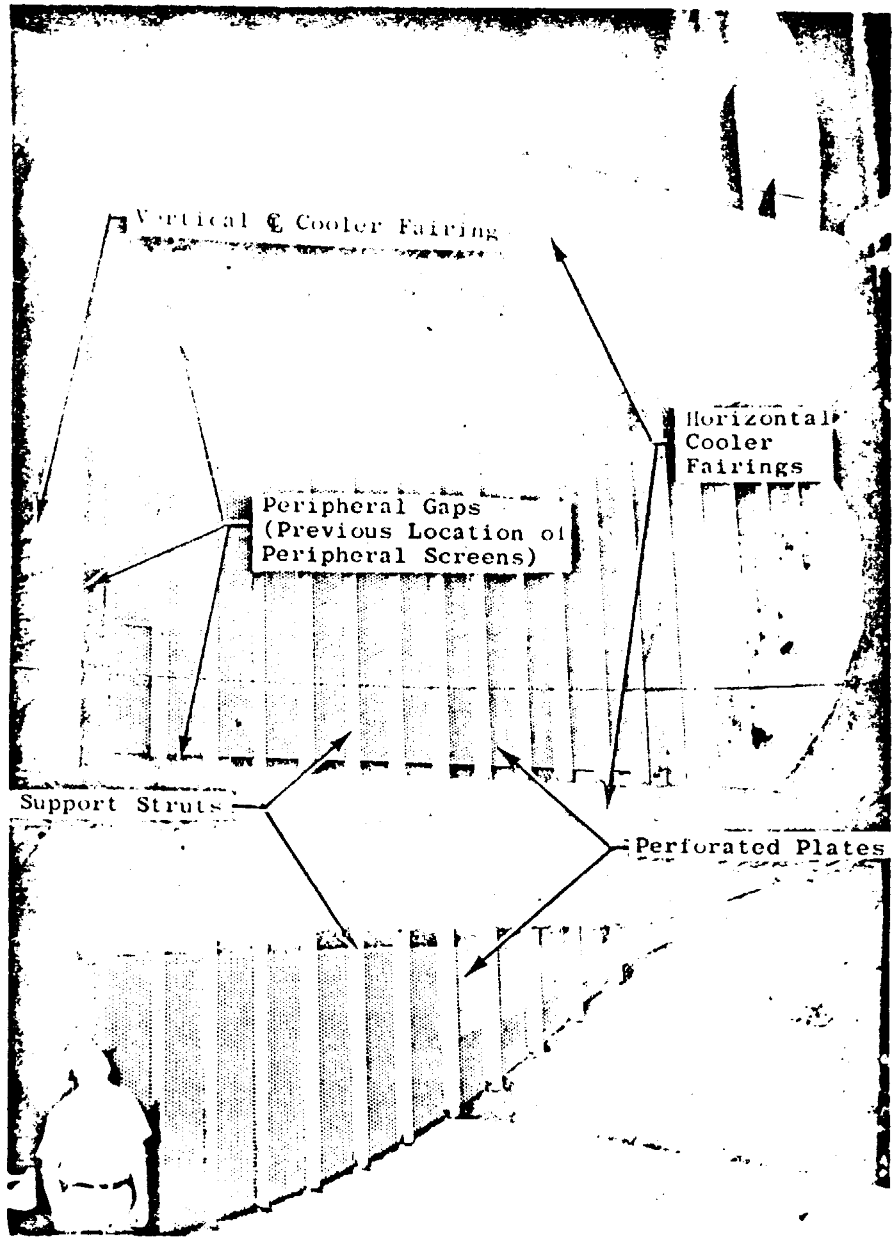


FIG. 3. VIEW OF COOLER EXIT SHOWING COOLER FAIRINGS AND PERFORATED PLATES

16T AND 16S COMPRESSORS

- o MODELS TESTED BY WESTINGHOUSE ELECTRIC
- o 16T - LOW SPEED
  (VECTOR TRIANGLE SIMILITUDE, INCOMPRESSIBLE)
- o 16S - HIGH-SPEED
  (1/16-SCALE, MACH-SCALED)
- o MANY MECHANICAL PROBLEMS WITH 9600 RPM 16S MODEL
- o LIMITED USEFULNESS - PINDZOLA'S RECOLLECTION
- o REPORTS ARE BELIEVED TO EXIST

DIFFUSER/SCAVENGING SCOOP -16T AND 16S

- UNIVERSITY OF MINNESOTA - PRIMARY STUDIES
- APPROXIMATE 6-INCH TUNNEL
- SOME WORK AT UNIVERSITY OF TEXAS (?)
- DIFFUSER, SCAVENGING SCOOP, AIR REMOVAL/RETURN STUDIES
- DESIGN REFINED AT AEDC

WALL CONFIGURATIONS

- o WALL DEVELOPMENT EFFORTS

  UAC - 22% POROUS, NORMAL HOLE CONFIGURATION
  CORNELL - VARIOUS POROUS STUDIES
  WRIGHT FIELD - SLOTTED WALL STUDIES

- o OHIO STATE - PWT CONFIGURATION DEVELOPMENT
  1-FT BLOWDOWN TUNNEL

- o INITIAL PWT CONFIGURATIONS - 20% POROUS, NORMAL HOLE

- o AEDC 1-FT TRANSONIC MODEL TUNNEL (TMT) LATER PATTERNED AFTER
  OSU, EXCEPT CONTINUOUS

- o 16T WALLS RECONFIGURED (1957) TO 6% POROUS, INCLINED HOLE
  BASED ON TMT TESTS

MODELING STUDIES

COMPONENT MODELING FACILITIES

- 1T (TMT) - 1 FT CONTINUOUS TUNNEL - VERY HEAVY USE
  APPROXIMATE MODEL OF 16T TEST SECTION AND DIFFUSER/SCOOP

- 1S (SMT) - 1 FT CONTINUOUS TUNNEL - DISMANTLED
  APPROXIMATE MODEL OF 16S NOZZLE, TEST SECTION, AND DIFFUSER/SCOOP

- ART (ACOUSTIC RESEARCH TUNNEL) - 6 INCH CONTINUOUS TUNNEL
  ATMOSPHERE IN-DRAFT TUNNEL FOR "QUIET" WALL DEVELOPMENT, VARIOUS DUCTING, SCREEN/HONEYCOMB STUDIES

AEDC'S GENERAL APPROACH

- o COMPONENT STUDIES PLUS ANALYTIC PREDICTIONS AND COMBINATIONS
- o PRESENT TREND - HEAVIER RELIANCE ON ANALYTIC PREDICTIONS, ESPECIALLY MATH MODELS
- o COMPONENTS

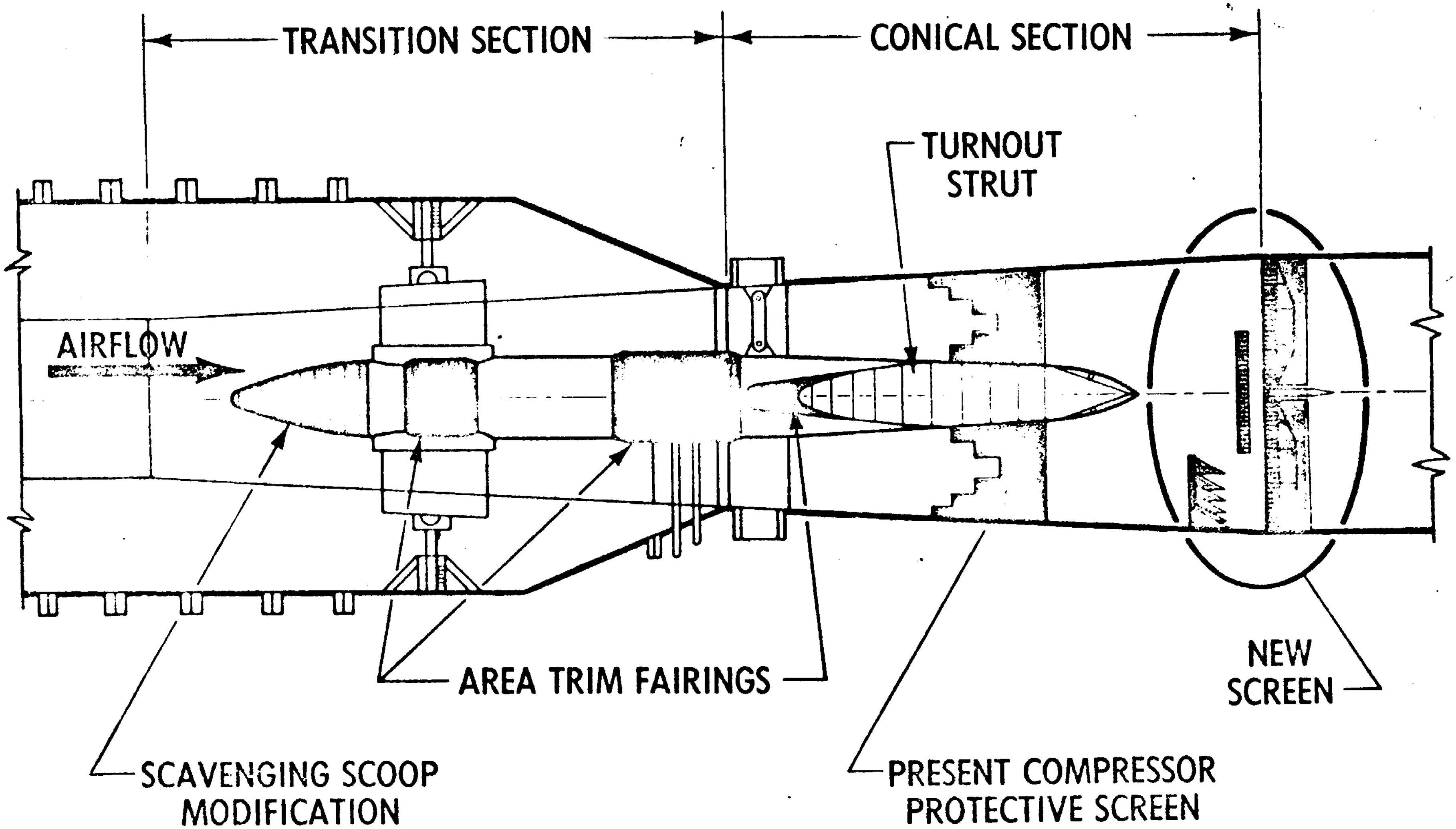
  SCALED-TEST SECTION, DIFFUSERS, MODEL SUPPORT SYSTEMS

  FULL SCALE-SCREENS/HONEYCOMB
- o ANALYTIC

  SEMI-EMPIRICAL MODELS

  "MATH MODELS"

PWT-16T DIFFUSER IMPROVEMENTS



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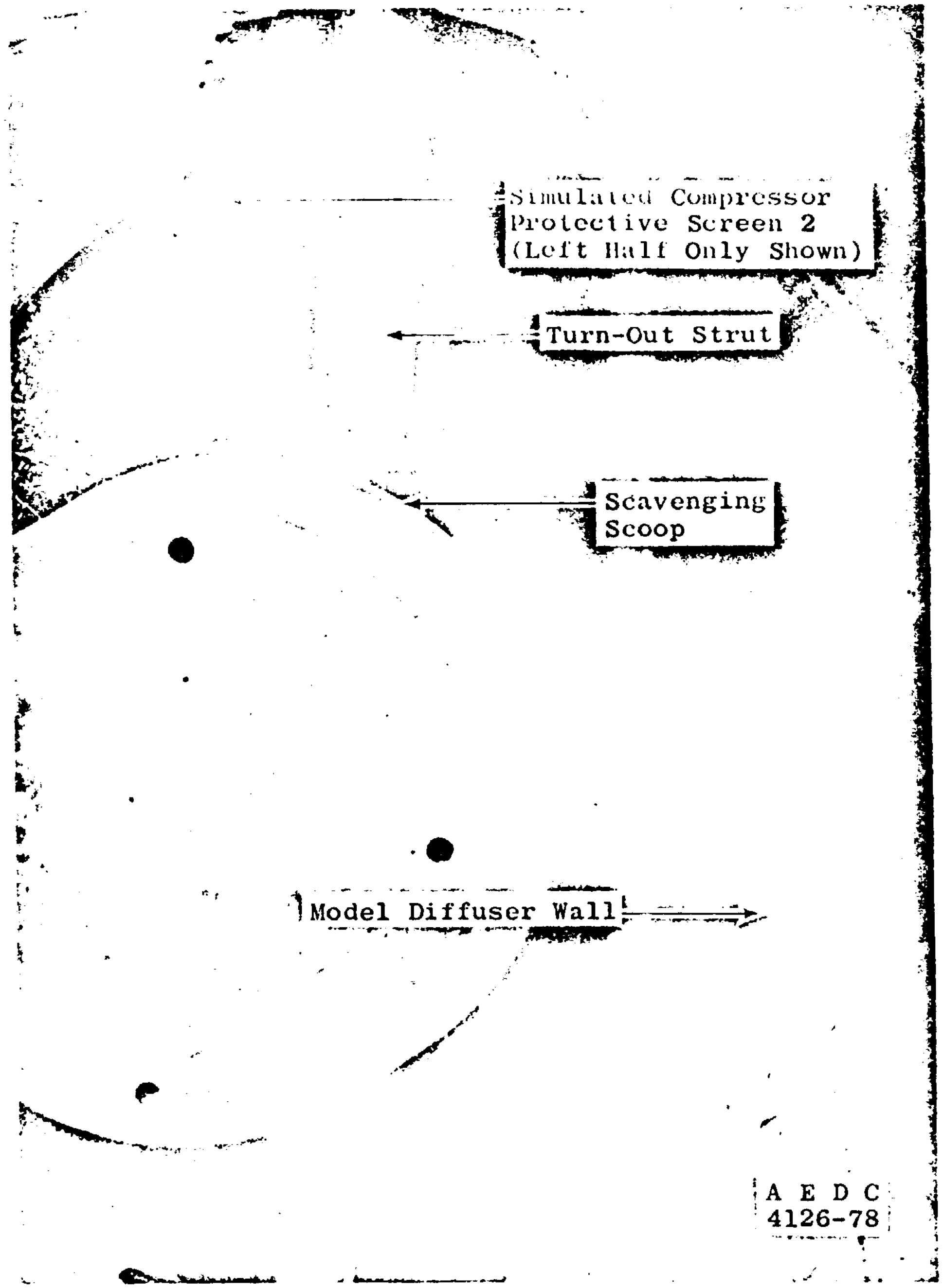
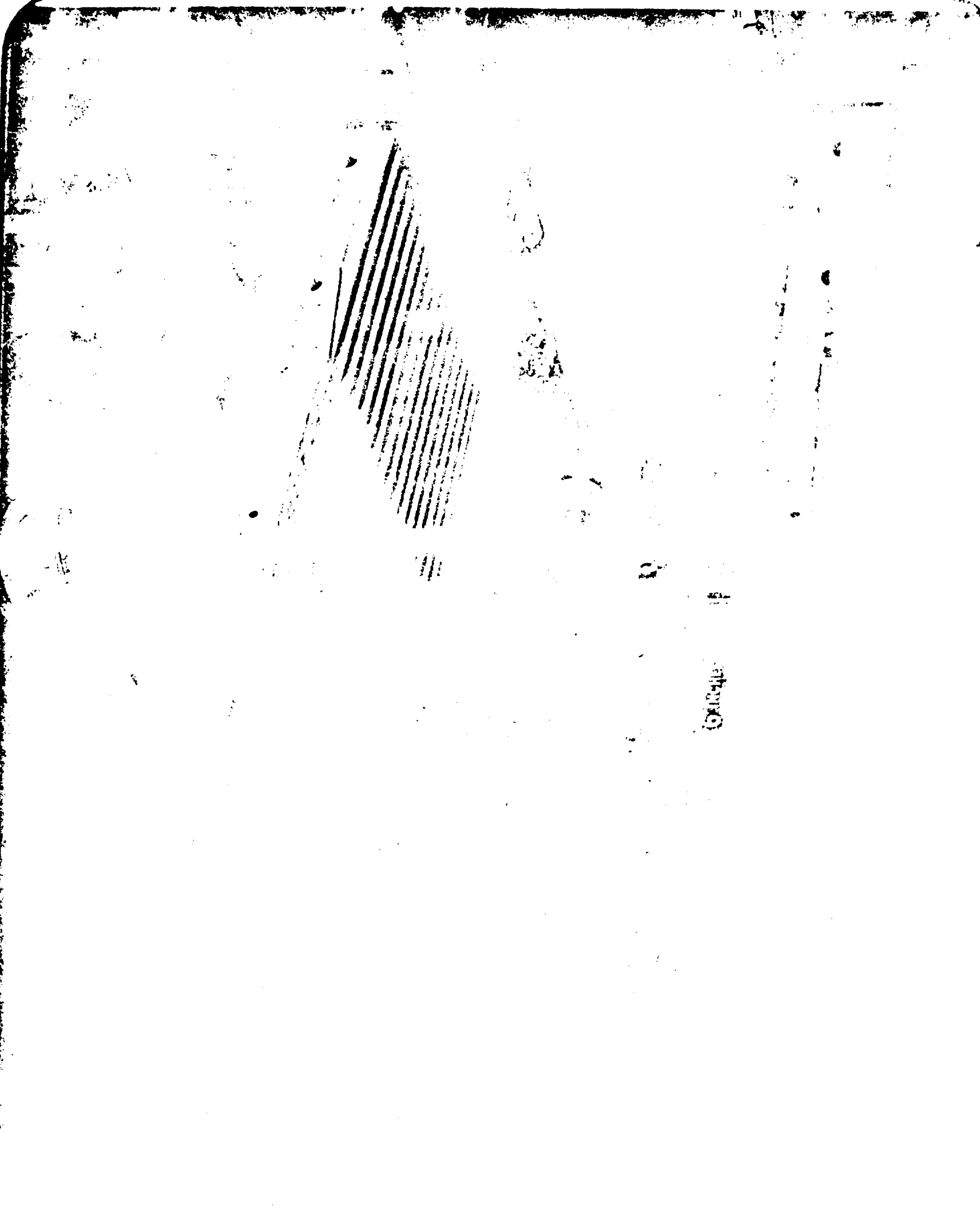


b. Installation
Figure 7. Concluded



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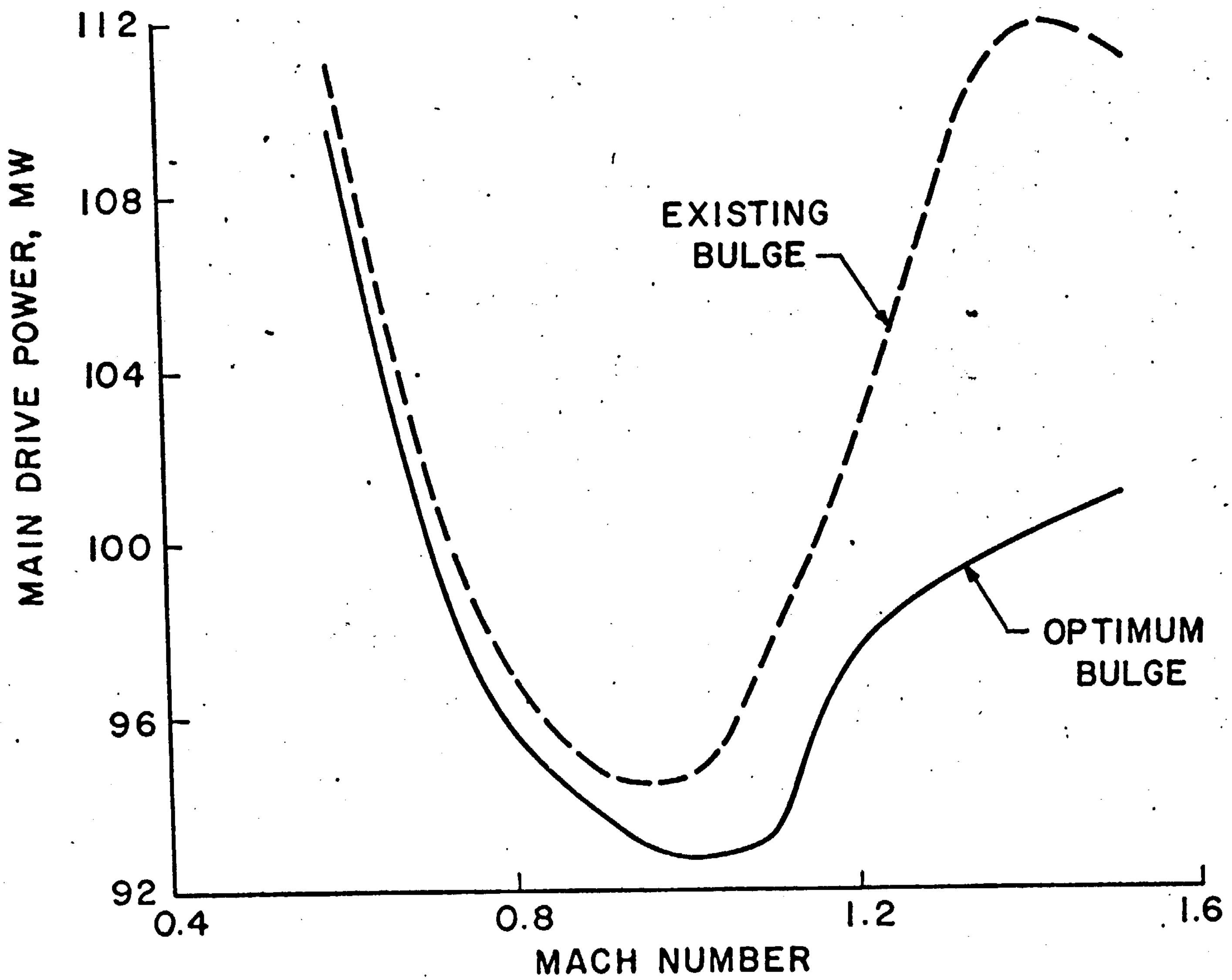
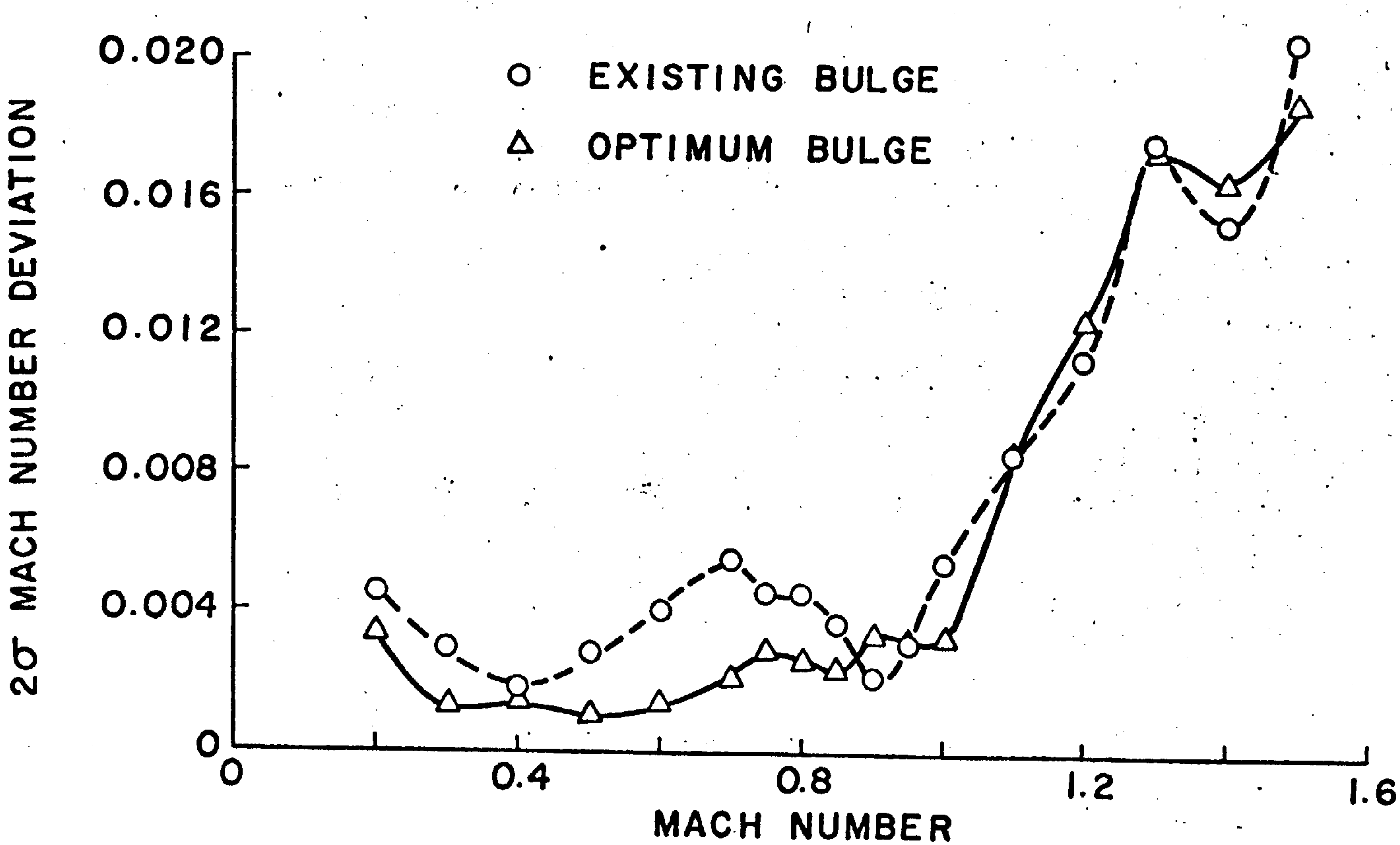
ESTIMATED POWER SAVINGS

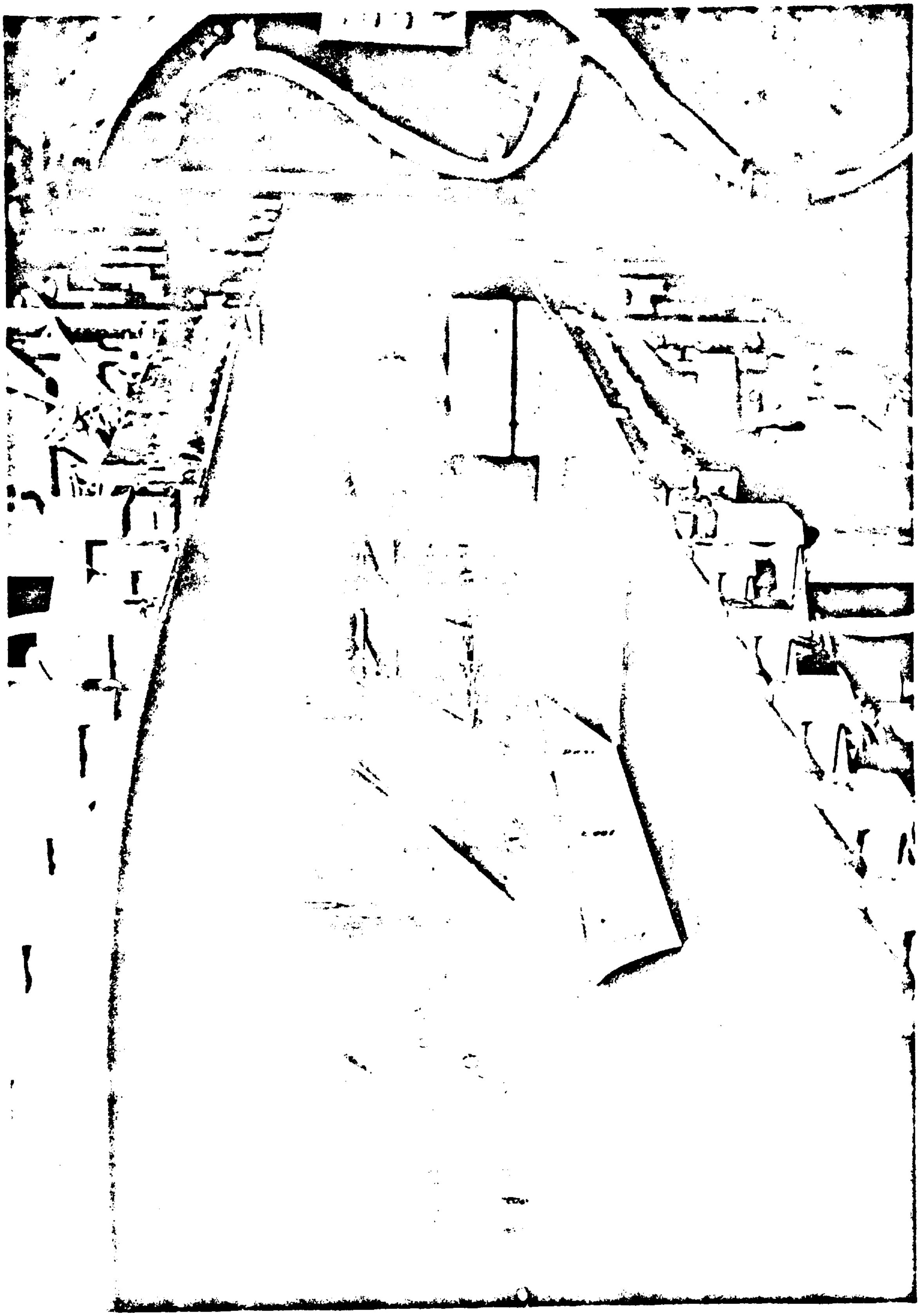
$128,000 ANNUAL SAVING
1.4 YEARS TO PAY BACK

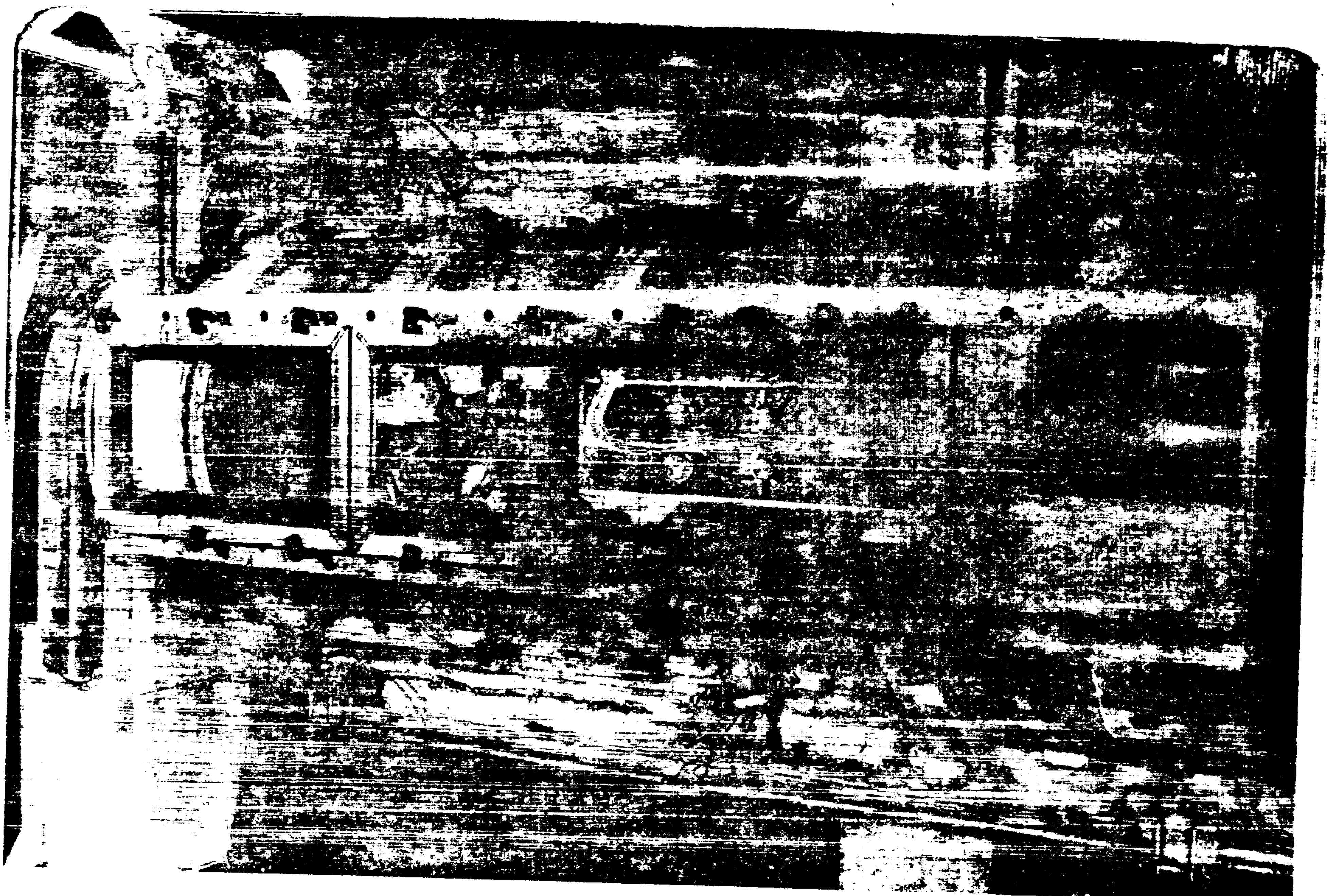


TUNNEL 1T MACH NUMBER DEVIATIONS



23



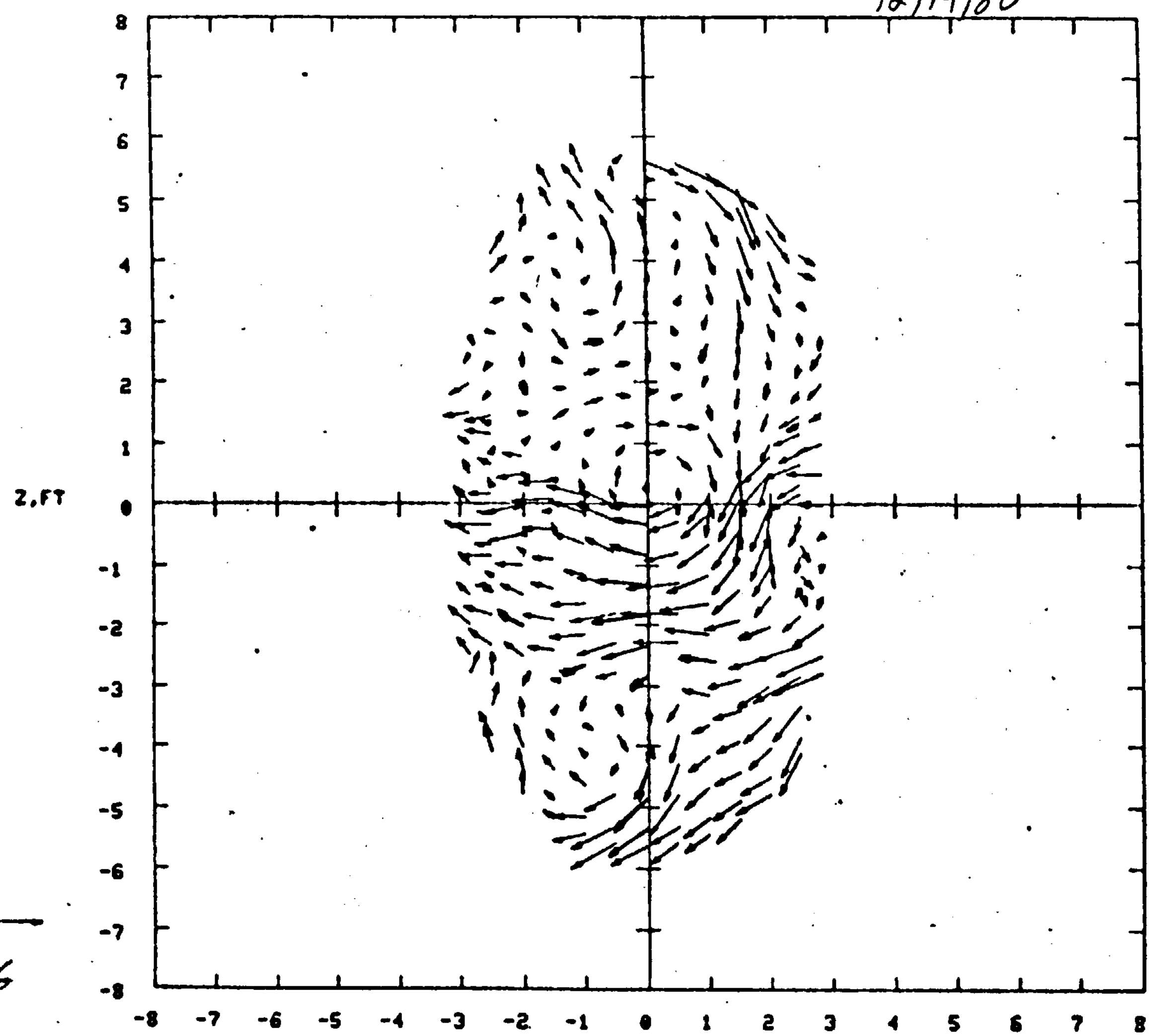


ORIGINAL PAGE IS
OF POOR QUALITY

ADAPTIVE WALL TEST SECTION OF AEDC TUNNEL 1T

2642B

12/19/80



1 - DFG

M = 0.4

BEFORE TURNING VANE ADJUSTMENT - **16T**

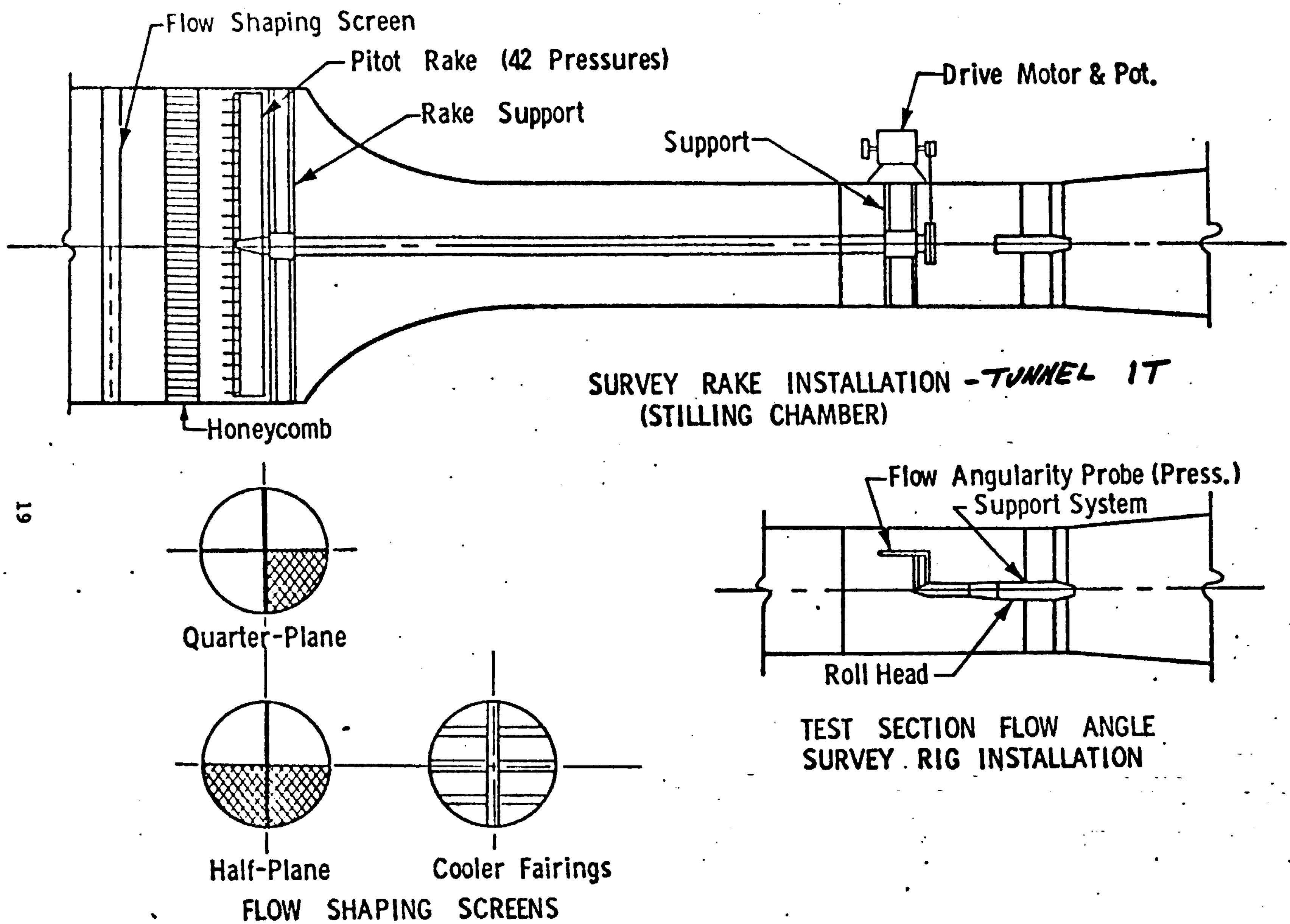


Figure 2. Schematic of Test Installation

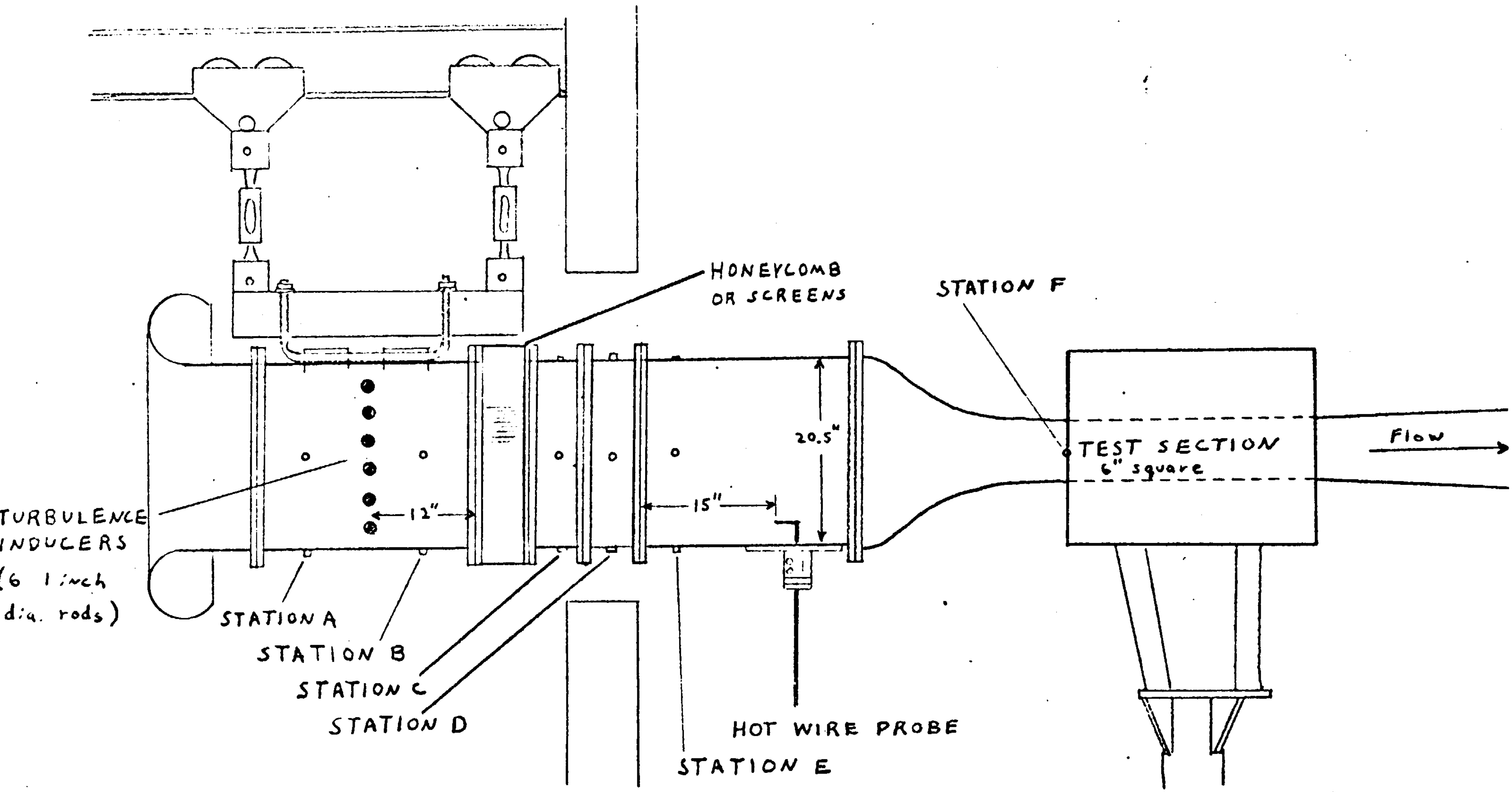


FIG. 1 ART PRESSURE ORIFICES

HONEYCOMB/SCREEN TESTS

- TO BE ADDED TO PWT-16T IN FY 86
- REDUCE FLOW ANGLE NON-UNIFORMITIES
- REDUCE FLOW TURBULENCE LEVEL
- MINIMUM POWER INCREASE DESIRED
- INITIAL CONFIGURATION SAME AS LANGLEY 8-FT
- LARGE SIZE (55 FT.) REQUIRED ADDITION OF 1-MESH BACKUP SCREEN
- EFFECT OF BACKUP SCREEN WAS MAJOR CONCERN
- COMPONENT TESTS IN ART (6-INCH ACOUSTIC RESEARCH TUNNEL)

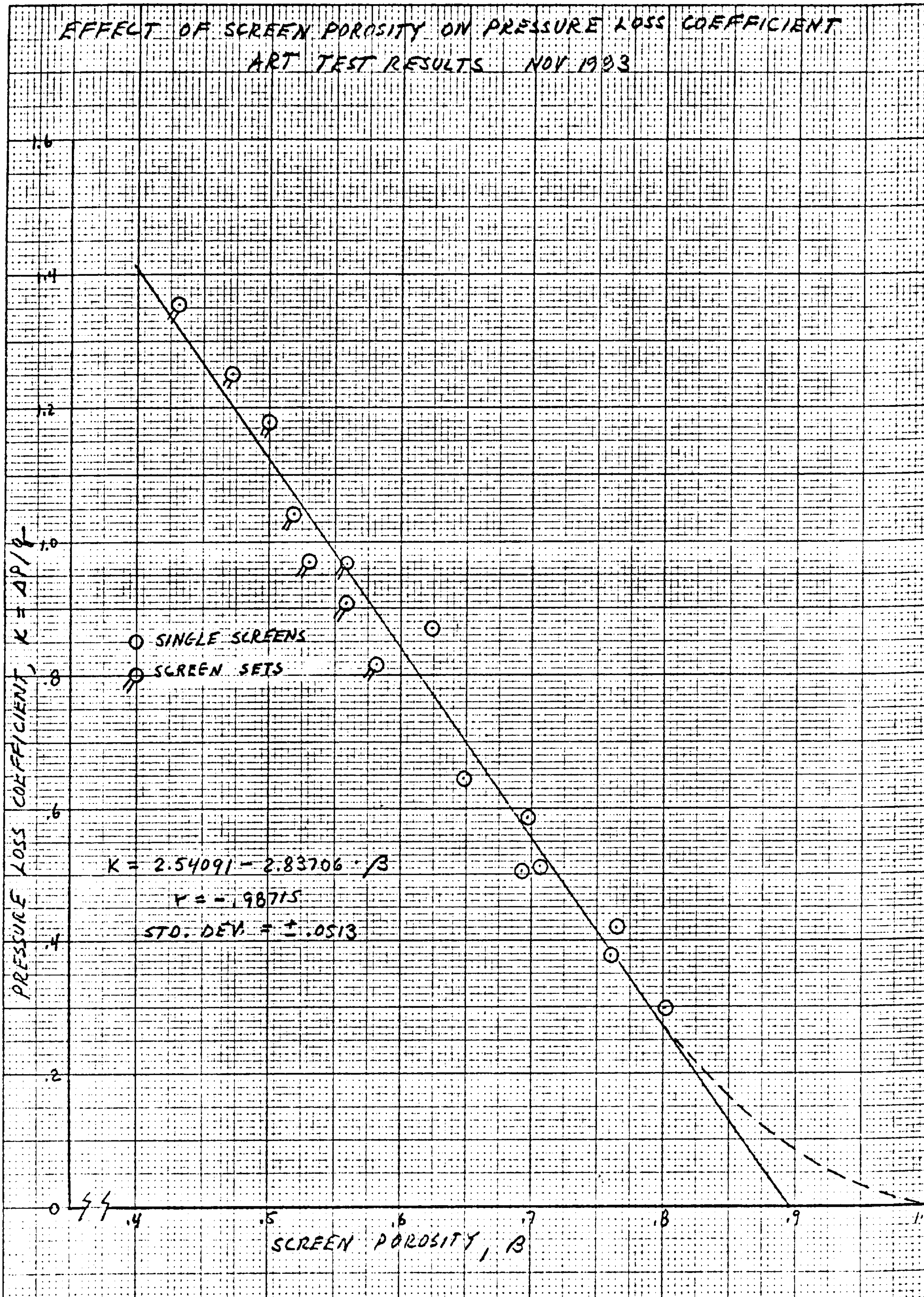


Figure 5 Relationship Between Screen Porosity and Pressure Losses

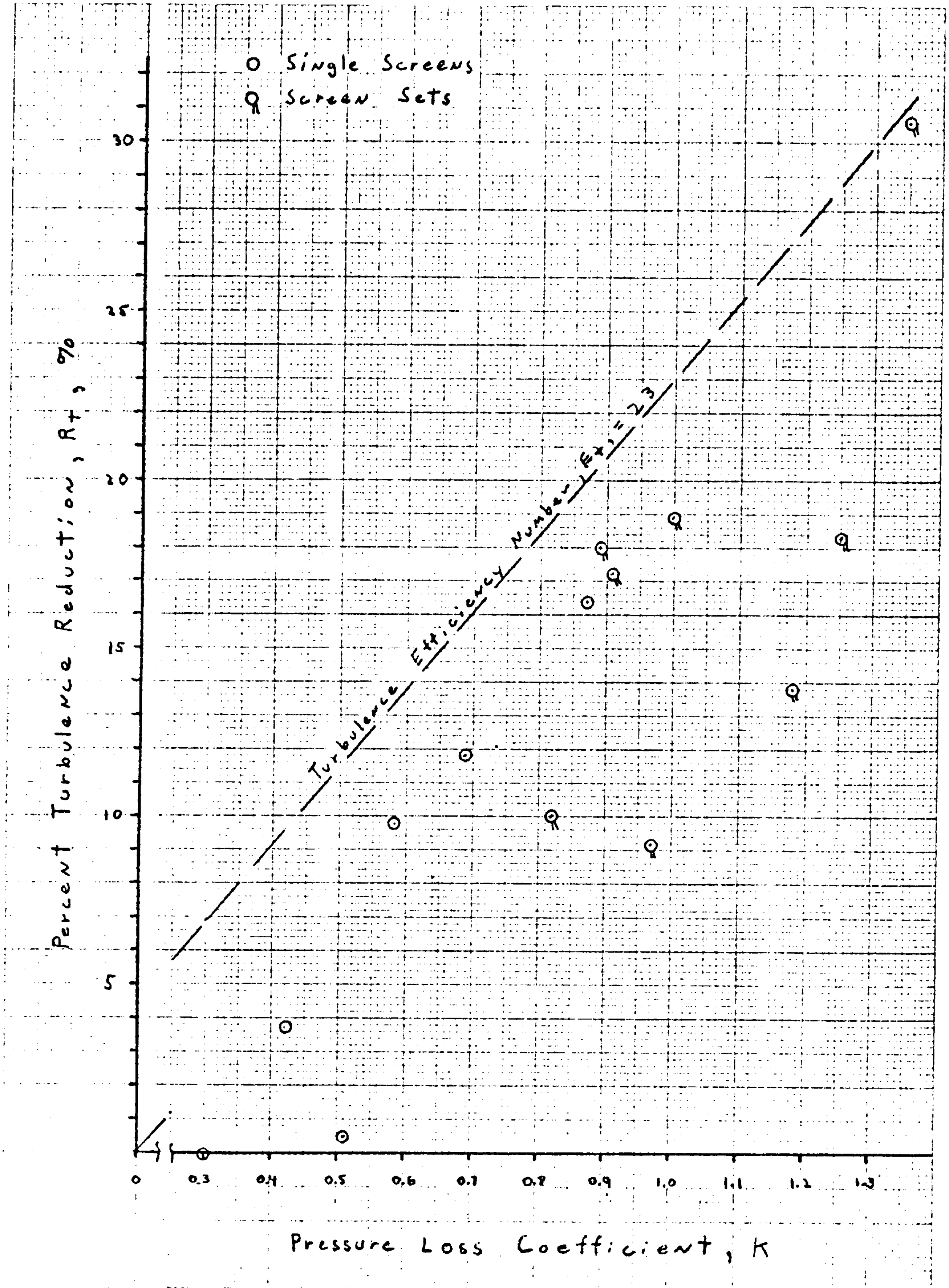


Figure 6 Turbulence Reduction of Screens and Screen Sets

RESULTS

- PRESSURE DROP AND TURBULENCE REDUCTION MEASURED FOR 25 CONFIGURATIONS
- EFFECT OF BACKUP SCREENS
  - PRESSURE DROP PROPORTIONAL TO "COMBINED" POROSITY
  - ADDING BACKUP IMPROVES TURBULENCE REDUCTION
- OTHER RESULTS
  - HONEYCOMB EFFECTIVE IN REDUCING TURBULENCE
  - HONEYCOMB/SCREEN COMBINATIONS MORE EFFECTIVE THAN PREDICTED FROM COMPONENTS
  - SCREEN SETS REDUCED FROM 4 TO 2

OTHER MODELING STUDIES

- o TEST INSTALLATIONS

  NUMEROUS STUDIES OF GENERAL AND SPECIFIC TEST INSTALLATIONS TO DETERMINE/MINIMIZE SUPPORT SYSTEM INTERFERENCE.

- o "QUIET" WALL RESEARCH

  WALL CONFIGURATIONS WITH "LOWER ACOUSTIC NOISE" LEVELS

- o EFFECT OF WINDOWS, OTHER SOLID PLATES (ALSO HOLES) ON THE TUNNEL FLOW

ANALYTIC MODELS

<u>STATIC</u>

- o DUCT FLOW
- o 16T TUNNEL
- o 16T AND 16S COMPRESSOR

<u>DYNAMIC</u>

- o APTU
- o 16T (WORK IN PROGRESS)

DUCT FLOW MODELS

JACKSON - AEDC-CW-01-6-76

- ONE-DIMENSIONAL COMPRESSIBLE PIPE-TYPE FLOW
- APPLIED TO MODELING ENTIRE WIND TUNNEL
- EXTENSIVE COLLECTION OF EMPIRICAL LOSS DATA
- INCLUDES COOLERS, SCREENS, HONEYCOMBS, TURNING VANES, ETC.
- ADAPTED TO HP9830 DESK COMPUTER
- COMPARISONS GOOD WITH PWT-16T AND LANGLEY TDT

GUNN, KRAFT, POOLE - AEDC COMPUTER PROGRAM SEP00058

- PRECEEDED JACKSON, ABOVE, AND SIMILAR
- USED ON LARGER COMPUTERS

PWT - 16T STATIC MATH MODEL

DAVID AND JACKSON - AEDC-TMR-79-P5

STICH - UNIVERSITY OF TENN. THESIS, MARCH 1984

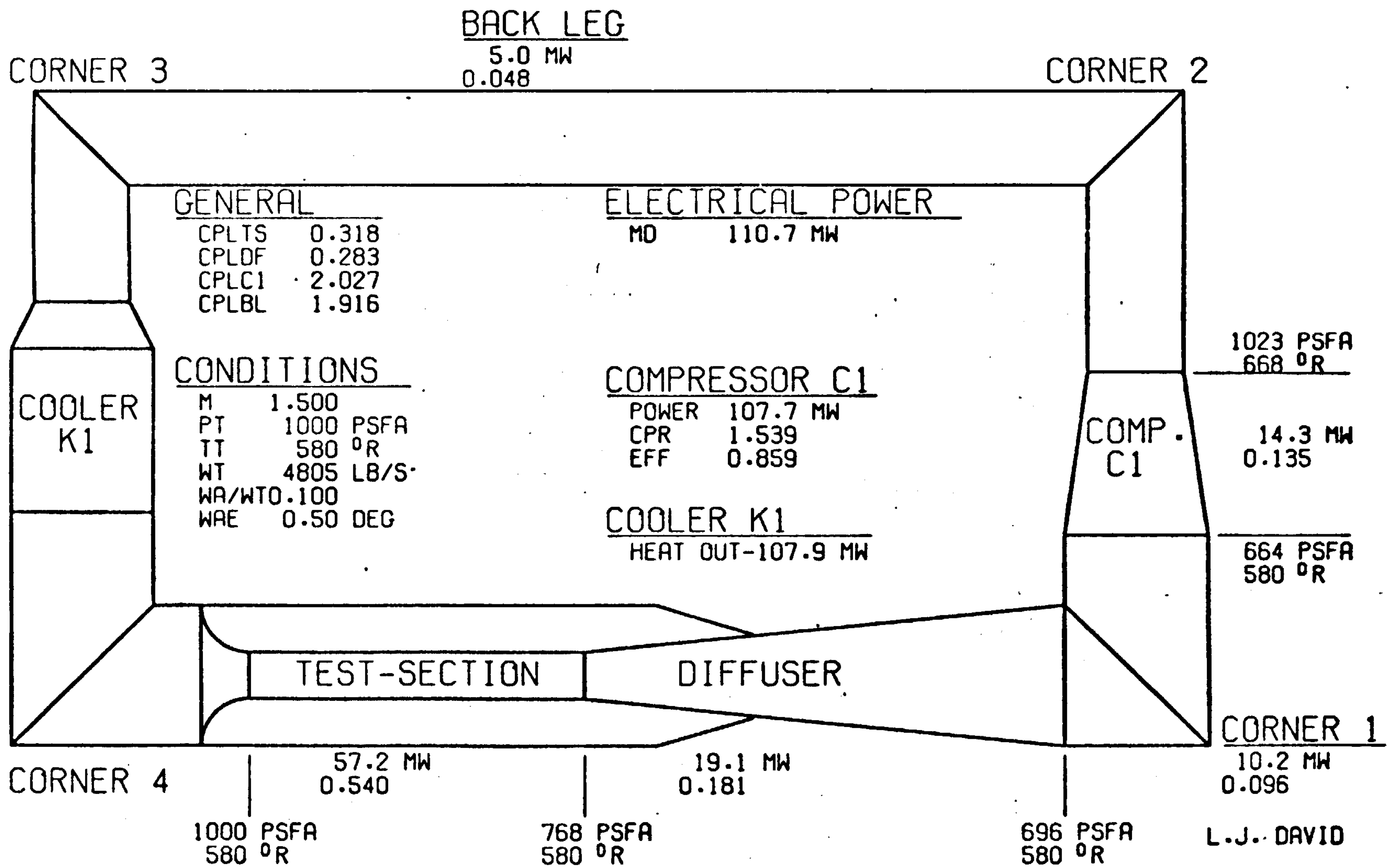
- o HISTORICAL PROGRAM - FROM HISTORICAL DATA BASE

  TUNNEL DIVIDED INTO 8 COMPONENTS, AND LOSSES MEASURED

- o ANALYTICAL PROGRAM

  COMPONENT LOSS FROM HISTORICAL PROGRAM

  EVALUATE IMPROVEMENTS



TUNNEL 16T-MODEL NO.2-ANALYTIC

WIND TUNNEL COMPRESSOR MATH MODELING

- o 16T C1 MATH MODEL COMPLETED FY 81

  PWT "CALIBRATED" COCODEC CODE (UNION CARBIDE - ERDA)

  ADEQUATELY MODELS PERFORMANCE

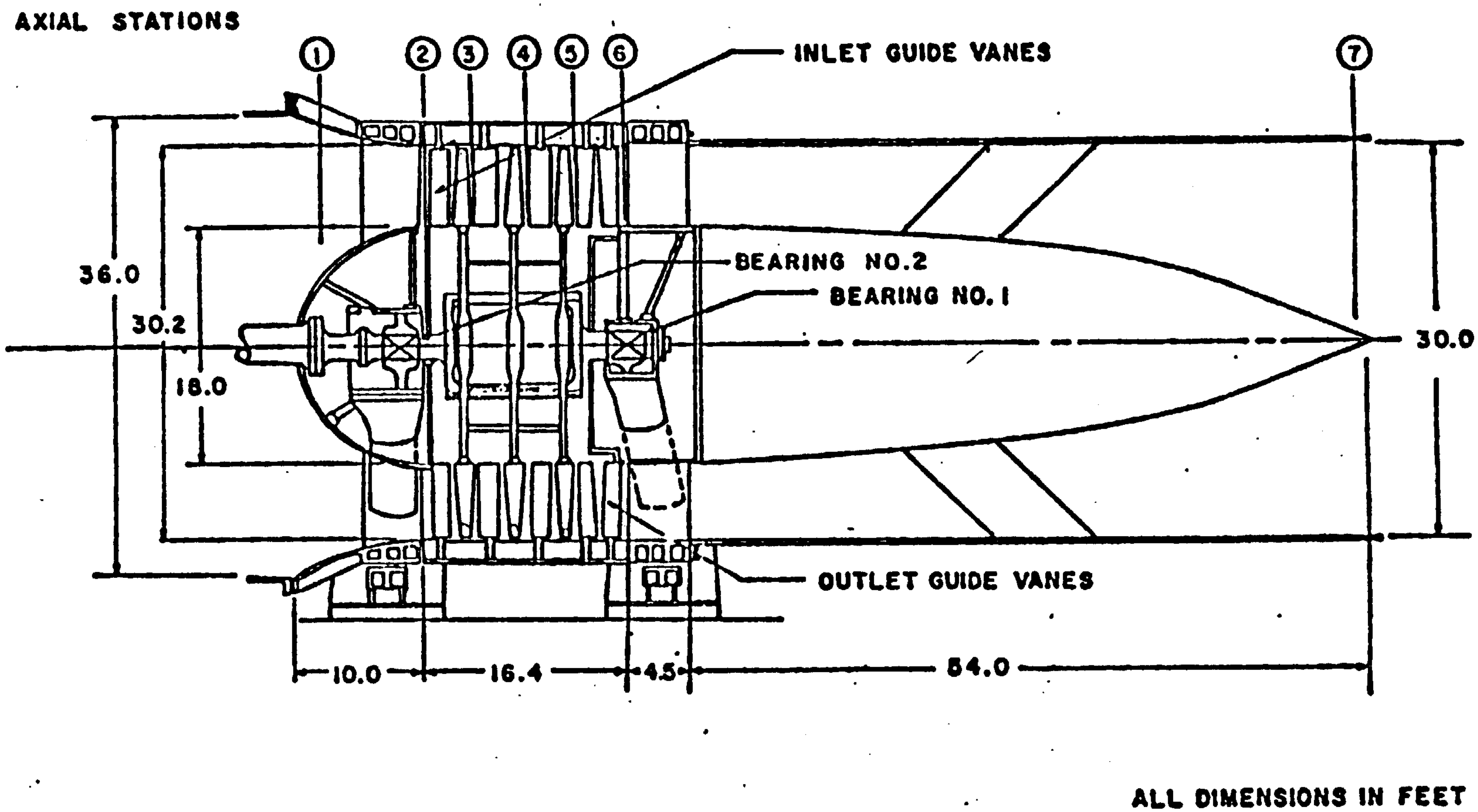
  DOES NOT ADEQUATELY PREDICT STALL

- o 16S C2345 MATH MODEL WORK STOPPED

  C2 HAS BEEN MODELED

  GENERALLY GOOD RESULTS

  FURTHER DEVELOPMENTS REQUIRED FOR 3 OR 4 BARREL CONFIGURATIONS

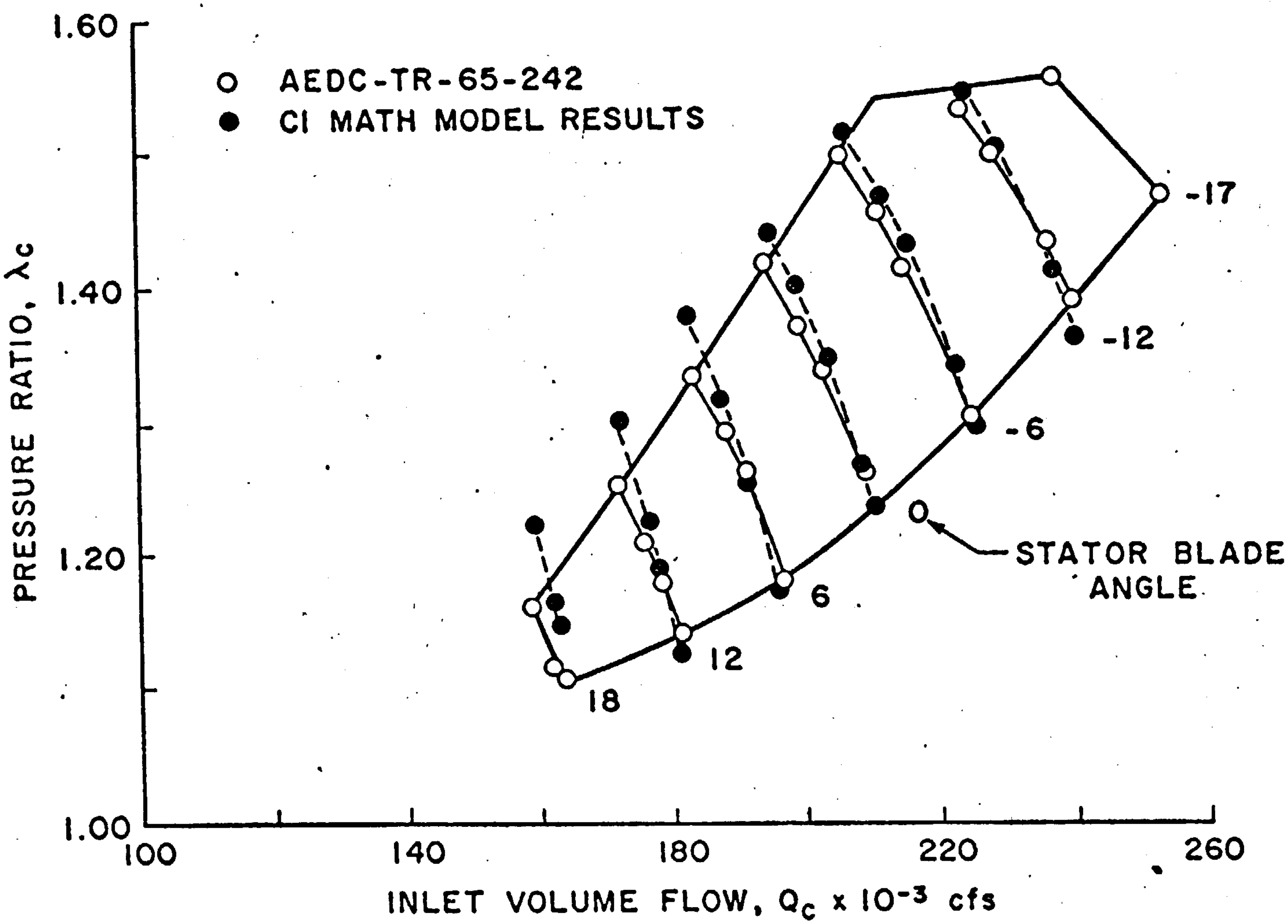


Design Conditions

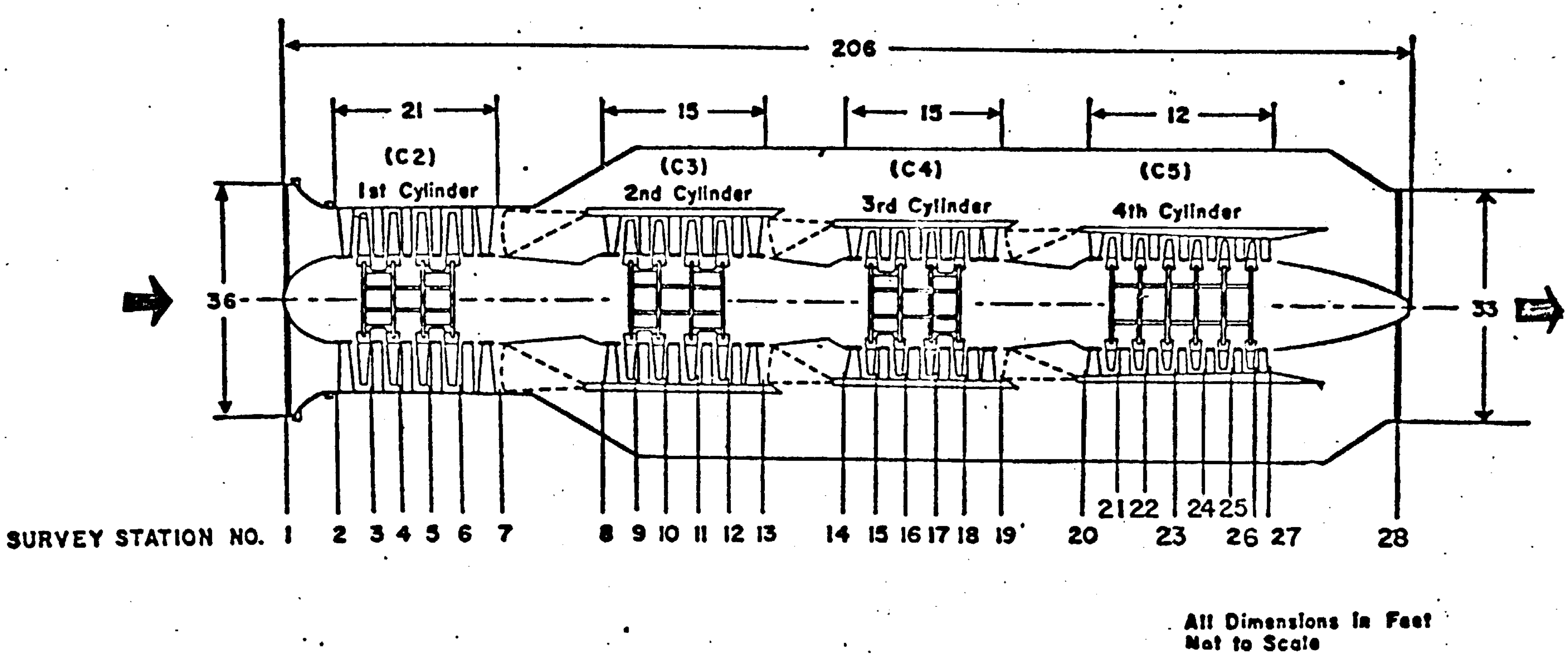
Tip Speed, 942 ft/sec (Absolute)
Hub Speed, 565 ft/sec (Absolute)
Design Pressure Ratio, 1.385
Design Inlet Volume Flow, 200,000 cfs
Flow Coefficient, 0.47
Work Coefficient, 0.308
Inlet Axial Velocity, 442 ft/sec

Figure 1. Tunnel 16T Compressor C1 Layout

COMPARISON OF TUNNEL 16T PERFORMANCE WITH CODE



TUNNEL 16S COMPRESSOR



Open Symbols: Data of Ref. 5

Solid Symbols: Present Calculations (COCODEC)

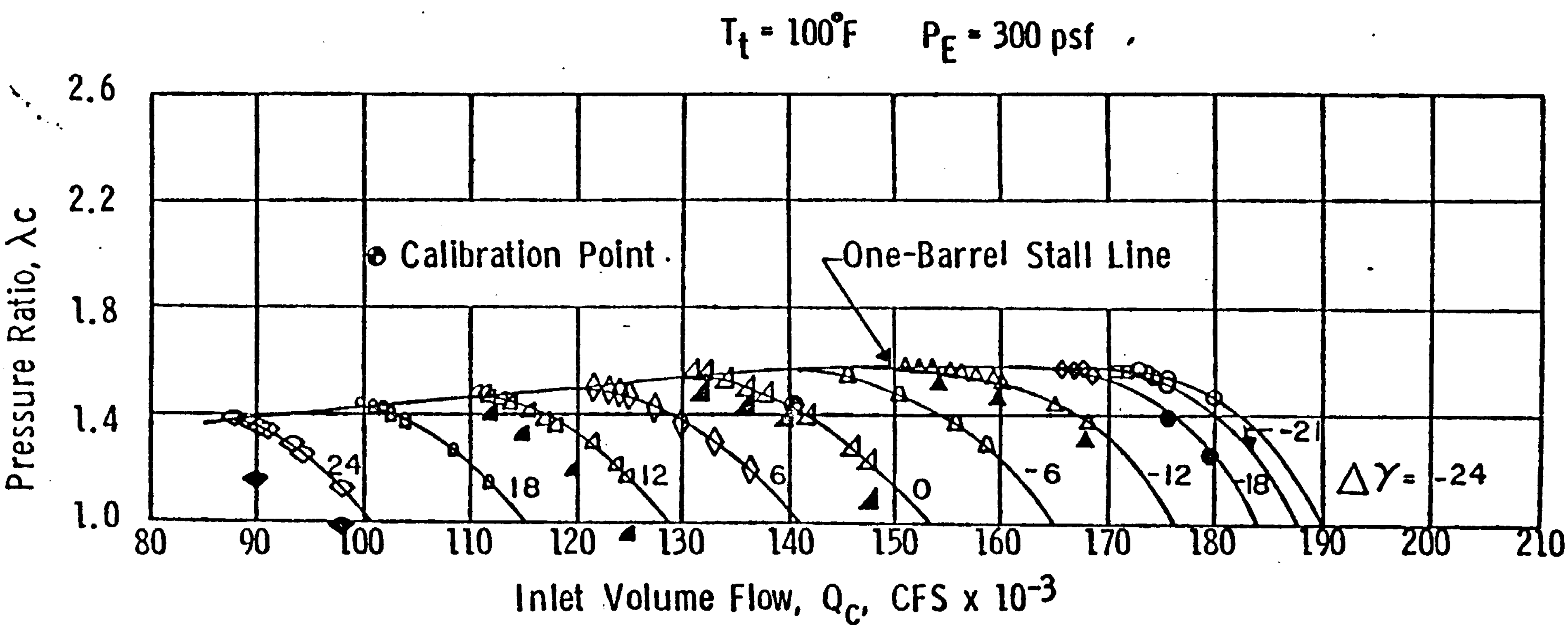
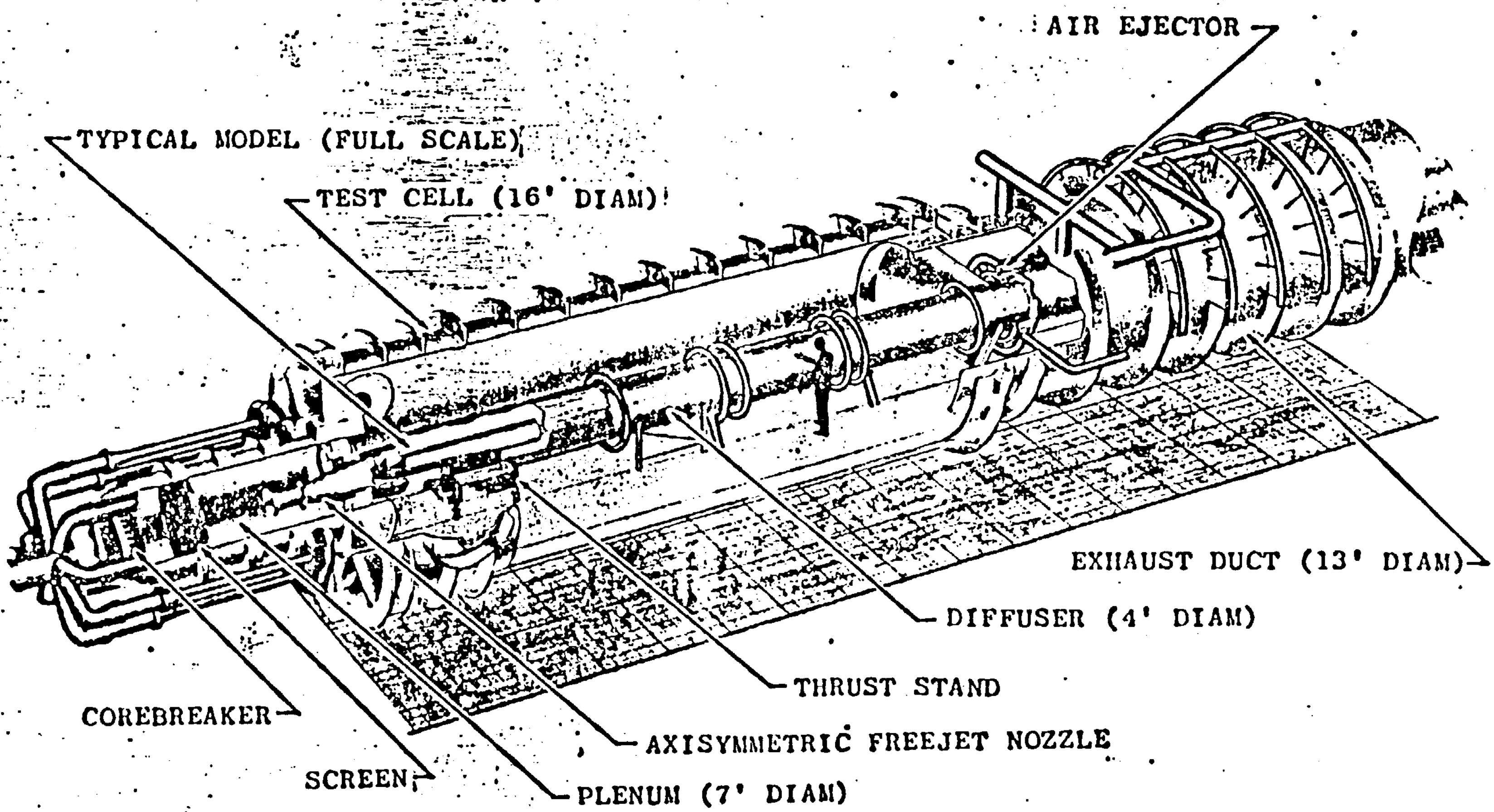


Fig. 9 Comparison of COCODEC Calculations for Compressor C2 with Measurements of Ref. 5.

AUTOMATION AND MATH MODELING IN THE APTU FACILITY AT AEDC

- BLOW-DOWN FACILITY
- PRIMARILY FOR RAMJET PROPULSION SYSTEM TESTING
- TRUE TEMPERATURE AERODYNAMIC TESTS
- HIGH TEMPERATURE TESTS.

AERODYNAMIC AND PROPULSION TEST UNIT (APTU)
TYPICAL FREEJET INSTALLATION



A. TYPICAL TEST INSTALLATION

FIGURE 1. AERODYNAMIC AND PROPULSION TEST UNIT (APTU)

APTU TEST CAPABILITIES

- Mach number range 2.0 to 4.5 (current nozzles)
- Stagnation pressure up to 300 psia (depending on Mach number)
- Vitiated air heater provides stagnation temperatures between 700 and 2000°R
- Cell pressure control
- Oxygen depletion replacement
- Run times to approximately 10 minutes.

MATH MODEL

- ACCURATE MATH MODEL OF THE PROCESS
- MODEL INCLUDES PROCESS, VALVES AND INSTRUMENTATION
- RUNS IN REAL TIME WITH CONTROLS SOFTWARE
- USED BEFORE ALL TEST RUNS TO CHECK OUT HARDWARE AND CONSTANTS.

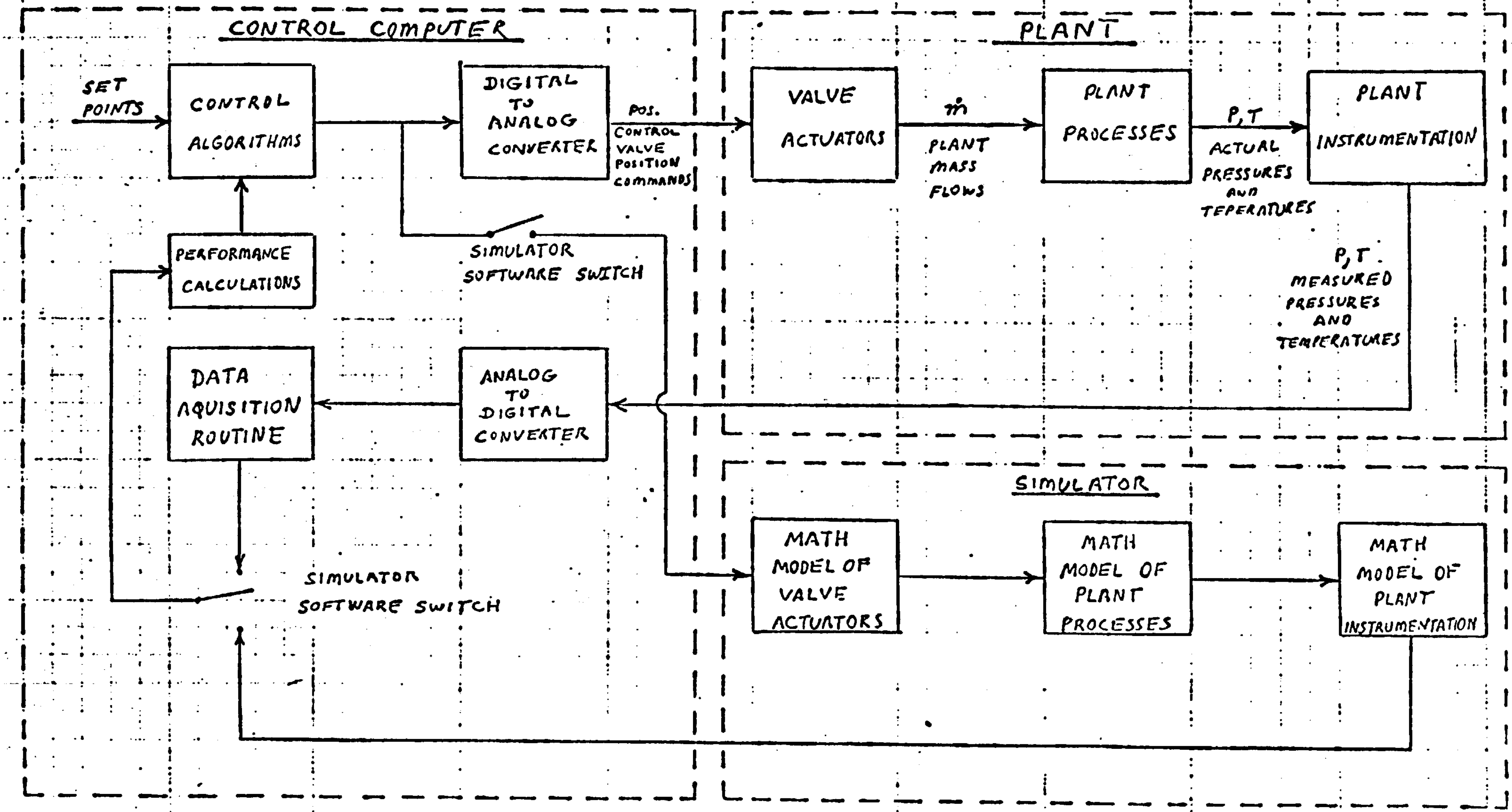
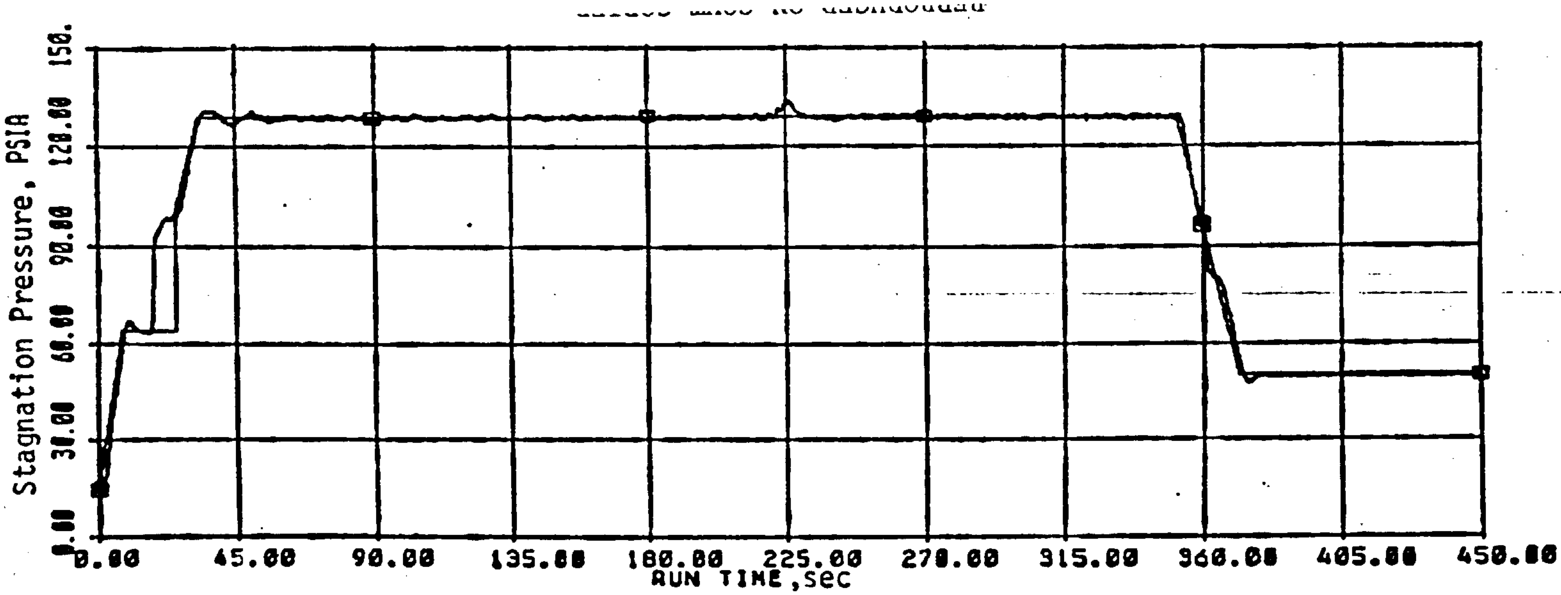
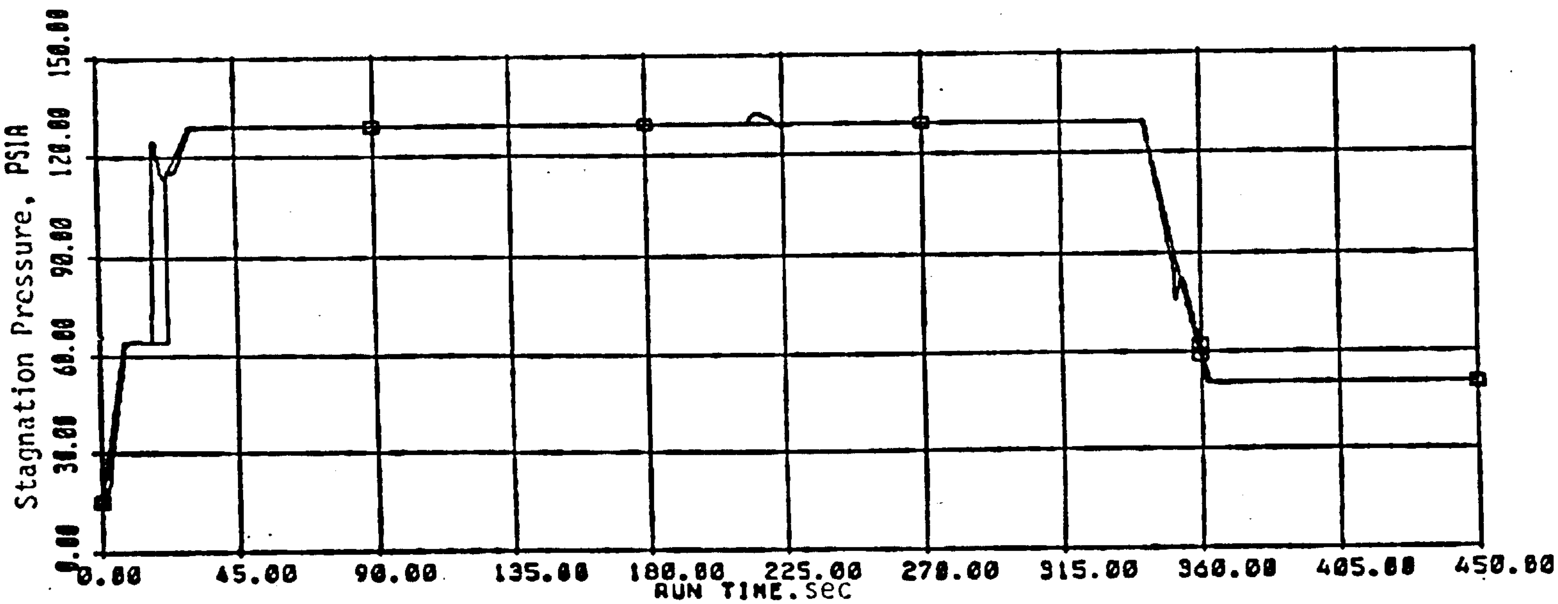


Figure 4 Block Diagram of the MFC Controls Software, APTU Plant System and MFC Simulator



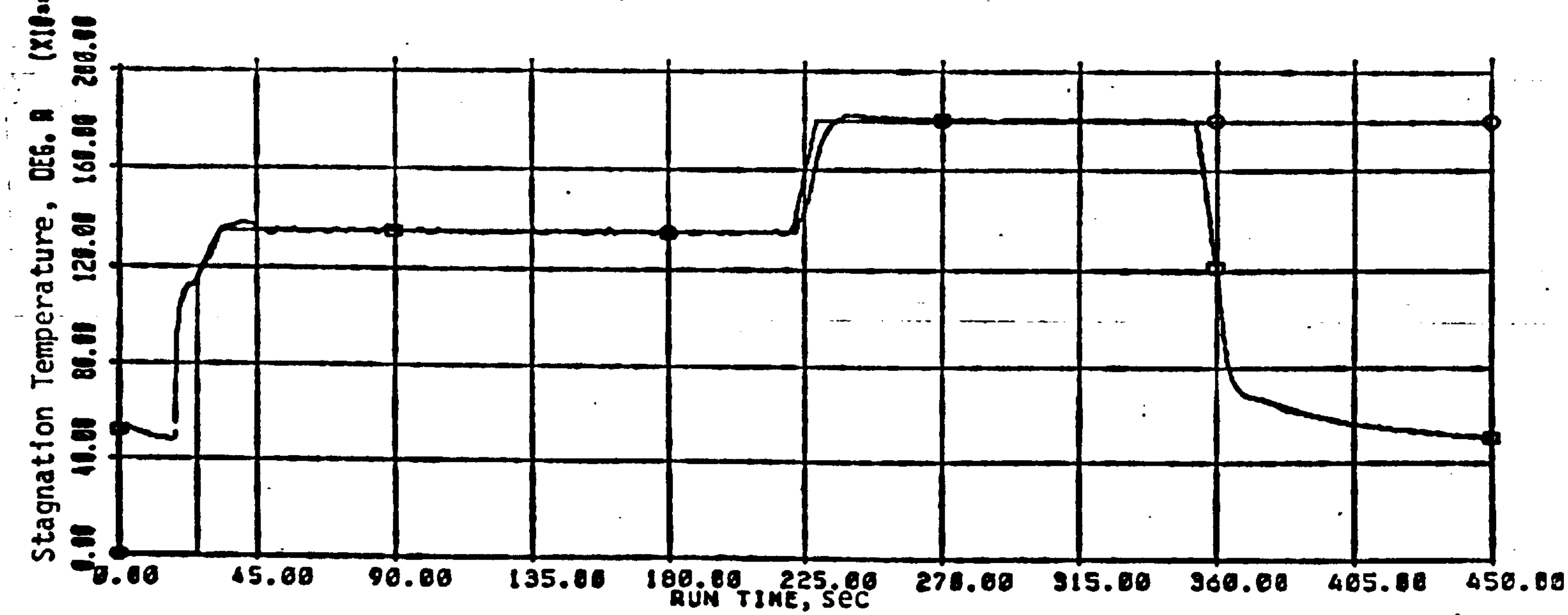
Actual Test Data



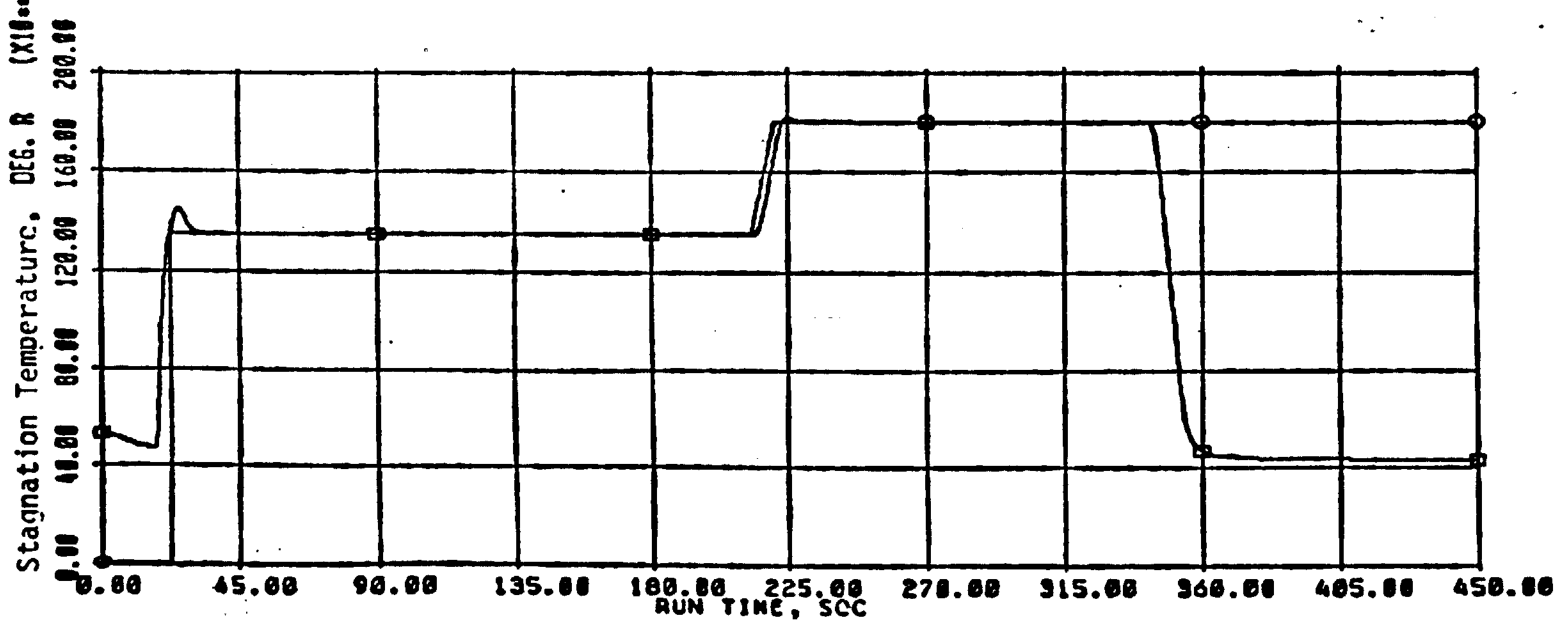
Math Model Simulation

a. Stagnation Pressure

Fig. 5 Comparison of APTU Math Model Simulation with Test Data



Actual Test Data



Math Model Run

b. Stagnation Temperature

Fig. 5 (continued)

KEY FACTORS IN SUCCESS

- MOVES MADE BY RAMPS
- ACCURATE MATH MODEL USED TO CHECK OUT SOFTWARE AND CONTROL STRATEGY DURING DEVELOPMENT AND ON-LINE OPERATIONS
- OPTIMUM CONTROL AT ALL CONDITIONS
- LINEARIZED CONTROL ELEMENT OUTPUTS
- MODERN SOFTWARE DEVELOPMENT TECHNIQUES.