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JET ENGINE DEMOUNTABLE TEST CELL EXHAUST SYSTEM PHASE - COANDA/--ETC(U)
APR 79 R E BALLARD , W F BYERS N00140-76-C-1229
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NAVAL AIR ENGINEERING CENTER

REPORT NAEC-92-112

LAKEHURST, N.J.
08733

LEVEL II



# JET ENGINE DEMOUNTABLE TEST CELL EXHAUST SYSTEM PHASE

# COANDA/REFRACTION NOISE SUPPRESSION CONCEPT ADVANCED DEVELOPMENT

Propulsion Support Equipment Divison
Ground Support Equipment Department
Naval Air Engineering Center
Lakehurst, New Jersey 08733

April 1979



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Prepared for:
Commander, Naval Air Systems Command
AIR-340E
Washington D.C. 20361

NAEC-92-112

# JET ENGINE DEMOUNTABLE TEST CELL
# EXHAUST SYSTEM PHASE

## COANDA/REFRACTION NOISE SUPPRESSION CONCEPT
## ADVANCED DEVELOPMENT


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The successfully demonstrated Coanda/refraction air-cooled exhaust noise suppressor system is applied to the Navy requirement for effective exhaust noise suppression in jet engine demountable test cells. The technical approach consists of analytical studies and one-sixth scale model tests using simulated afterburning engine exhausts. Revisions are made to the previously developed system to improve noise suppresssion capability while reducing the system overall size and initial cost. Revisions include moving secondary air inlets to reduce enclosure size and improve cooling, shortening the Coanda surface to provide more acoustically treated exhaust stack and providing variations in exhaust

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20. Abstract (Cont'd)

stack configuration such as single and dual acoustic splitters and acoustic wedges up the back wall. Extensive data were recorded and analyzed to identify the aerothermodynamic and acoustic trends related to these configuration changes. Results present recommendations for an air-cooled Coanda/refraction exhaust system for application to demountable test cells.


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## SUMMARY

A one-sixth scale model test program was conducted in the Boeing-Wichita Acoustic Arena with the purpose of improving the previously developed Coanda exhaust suppressor system by reducing the size and cost without reducing noise suppression capability. This improved exhaust suppressor system would then be placed behind a test stand enclosure to form a complete demountable test cell system. The reduction in size of the exhaust suppressor system was accomplished by: (1) moving the secondary air inlets from the side to above the ejector/Coanda which greatly reduced the width and (2) by reducing the Coanda surface length from a 90° turn to 65° which shortens the Coanda height and allows a shorter stack weight while maintaining the required length of acoustically treated exhaust stack.

Flow dynamics and acoustic testing were accomplished with several exhaust muffler (stack) configurations including short versions with single and dual acoustic splitters and acoustic wedges at the back wall and a tall stack without splitters or wedges. These tests were run using a nozzle flow that reproduced (as near as possible) the afterburning flow conditions (Tjet = 3170°F, Pt/Pa = 1.943) for the TF30-PW-412A engine. The model nozzle diameter was one-sixth that of the full scale engine nozzle throat at full afterburning.

The results of these tests indicated that the exhaust stack configurations with acoustic baffles (splitters) in the flow should not be used in production with the current Coanda configuration. This was concluded because of local hot areas on these splitters with measured temperatures as high as 1370°F. The dual wedge configuration did not demonstrate any such temperature problem; however, the improvement in acoustic attenuation was not significant enough to allow a reduction in stack height to the 30-foot full scale height simulated. It is possible that configurations with acoustic splitters could be used if the mixing in the ejectors and Coanda turning were increased to lower the temperature of flow into the stack. It may be possible to do this with the development of a wider ejector/Coanda system.

The recommended configuration from the results of these tests was a 40-foot stack height with no splitters or wedges in the stack, the 65-degree Coanda surface and three-ejector transition with an enclosure that places the secondary air intakes above the Coanda/ejector set.

## PREFACE

The development of the Navy Coanda exhaust suppressor system began in 1971 with the awarding of a feasibility study contract to Boeing-Wichita. Existing ground range suppressors for military afterburning engines were water-cooled units pumping up to 800 gallons of water per minute into the exhaust plume to cool the 3000°F exhaust gases and reduce the flow velocity. This resulted in excessive maintenance problems due to corrosion and a dirty, sooty exhaust and compounded operational and system complexity with controls, plumbing, pumps, etc. The Navy recognized the life cycle cost advantages of an air-cooled system and that the Coanda effect may be the key to development of an operationally successful afterburning jet deflector since it requires no components of the suppressor in the exhaust flow.

The success of the original feasibility study resulted in follow-on development work by Boeing-Wichita for the Navy, culminating in a full-scale Coanda exhaust suppressor demonstration unit that was successfully demonstrated in late 1975.

Since that successful full-scale demonstration of a demountable suppressor, the Navy has awarded Boeing-Wichita a contract to develop specific adaptations of the Coanda suppressor for improved demountable configurations, retrofit of existing class "C" test cells and "hush-house" (aircraft enclosed) type ground runup suppressors. This document reports the results of the analysis and tests performed to improve the demountable test cell configuration by reducing size and cost.

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# I. INTRODUCTION

In 1971 Boeing-Wichita was awarded a competitive Navy contract (N00156-72-C-1053) to study the feasibility of utilizing the Coanda effect as an afterburning jet exhaust deflector in an air-cooled ground runup noise suppressor. Most U.S. military ground runup suppressors existing at that time were water-cooled, utilizing up to 800 gallons of water per minute to cool the higher than 3000°F afterburning exhaust plume. This resulted in corrosion problems, a dirty, sooty exhaust and compounded operational and system complexity with controls, plumbing, pumps, diffusers and water supply. Military suppressor users preferred an air-cooled system but none had been developed that were operationally successful.

The 1971 Navy contract was the first of four Navy Coanda noise suppressor contracts awarded to Boeing-Wichita. The analysis and model tests accomplished under that contract (reported in Reference (a)) proved the feasibility of using the Coanda effect for jet deflection and illustrated the advantageous noise directivity change due to refraction. The second contract (N00156-73-C-1794 awarded in 1973) made use of scale model testing to develop a configuration suitable for full-scale demonstration. The results of that contract were reported in Reference (b). In 1974 the third Navy contract (N00156-74-C-1710) was awarded under which a full-scale Coanda suppressor demonstration unit was built and successfully demonstrated. The full-scale test program was reported in Reference (c). Additional model scale testing included in that program was reported in Reference (d).

The fourth Navy contract, under which the work described in this report was accomplished, was awarded in 1976. This contract (N00140-76-C-1229) had the following multiple task objectives:

- Jet Engine Demountable Test Cell Phase – Improve the demountable test cell configuration by increasing exhaust muffler noise suppression to allow a reduction in exhaust system size and cost.
- Jet Engine Class "C" Test Cell Exhaust System Phase – Develop a configuration for retrofit of existing "C" test cells to the Coanda air-cooled exhaust suppressor system.
- Aircraft "Hush-House" Exhaust System Phase – Develop a means of adapting the Coanda air-cooled exhaust suppressor system to a "hush-house" application.
- Coanda Exhaust Suppressor System Design Handbook – Develop the necessary procedures and parametric data necessary to provide a comprehensive outline of the method used to make a "first cut" design of a Coanda exhaust suppressor system with a given set of exhaust conditions.

Each of these tasks is reported in separate final reports. The task results reported in this document are for the Jet Engine Demountable Test Cell Phase.

References

a. Ballard, R. E., Brees, D. W., and Sawdy, D. T., "Feasibility and Initial Model Studies of a Coanda/Refraction Type Noise Suppressor System," The Boeing Company, Wichita, Kansas, Document D3-9068, January 1973.

b. Ballard, R. E., and Armstrong, D. L., "Configuration Scale Model Studies of a Coanda/Refraction Type Noise Suppressor System," The Boeing Company, Wichita, Kansas, Document D3-9258, October 1973.

c. "Test Cell Experimental Program Coanda/Refraction Noise Suppression Concept – Advanced Development," Final Technical Report for Navy Contract N00156-74-C-1710, Navy Document Number NAEC-GSED-97, The Boeing Company, Wichita, Kansas, March 1976.

d. "Aircraft System One-Sixth Scale Model Studies, Coanda/Refraction Noise Suppression Concept – Advanced Development," Final Technical Report for Scale Model Portion of Navy Contract N00156-74-C-1710, Navy Document Number NAEC-GSED-98, The Boeing Company, Wichita, Kansas, March 1976.

The primary objective of this task was to "streamline" the operational configuration of the existing full-scale demonstration unit by reducing the overall suppressor size while maintaining or improving its noise suppression capabilities. This was to be accomplished with analytic studies and one-sixth scale model tests. The principal configuration changes attempted were:

- Reduction of Coanda surface turning angle from 90° to 65° thus allowing a shorter stack height.
- Reduction of the Coanda enclosure size.
- Movement of the secondary air inlets from the sides to the top of the enclosure. This allows a large reduction in suppressor width.
- Several exhaust muffler configurations such as single and dual acoustic splitters and acoustic wedges at the back wall of the enclosure.

This work will finalize the recommended design for a production version of the recently developed Coanda exhaust suppressor system for demountable test cell application.

## II. TEST EQUIPMENT AND PROCEDURES

**A. Test Equipment.** The following paragraphs describe the test facility, the data acquisition equipment and the test model, including the instrumentation used.

1. TEST FACILITY. The model testing was accomplished in the Boeing-Wichita Acoustic Arena facility shown on Figure 1. The Arena wall is 16 feet high, inclined at an angle of 30 degrees to the vertical and is 100 feet in diameter at the base. The burner (hot gas generator) is a two-stage configuration. The first stage is a J47 jet engine burner can and spray nozzles, capable of reaching gas temperatures of 1500°F at the 15-pound per second maximum airflow rate. The second, or afterburning stage, consists of a central fuel spray nozzle and eight radial spray bars and a flame holder. This stage is water jacketed and can boost the jet exhaust temperature to 3300°F. The primary airflow source has 300 psia line pressure. A secondary airflow source is available with a 60 psia line pressure with a maximum flow rate of 40 pounds per second of cold air to simulate fan flows. The burner control instrumentation, fuel and airflow controls are housed in a small building next to the Arena with a window for visual observation of the model. These controls and instrumentation are shown on Figure 2.

2. DATA ACQUISITION EQUIPMENT

a. The data acquisition instrumentation, computer and printer are housed at a remote site and are shown on Figure 3. A pictorial block diagram of the Acoustic Arena data acquisition system is shown on Figure 4.

b. The Arena data acquisition system is built around the Varian 620/L Mini-Computer, which is a general purpose digital computer. The central processing unit of the computer has a 12K memory system. The input/output system provides the interface between the computer electronic system and the electro-mechanical devices that input data to the computer or output the computed results. The Beehive CRT (cathode ray tube) terminal enables control of the computer and the printer lists the data. The Tri-Data model 4036 provides program loading or storage of data on magnetic tape. The multiplexer allows each channel to be sampled sequentially or randomly, as required. The A/D converter converts the analog signal to a digital voltage level. A pressure scanner valve allows all the total pressures to be measured by the same $\pm$ 5.0 psid transducer. Ambient pressure was measured by a 15 psia transducer. A second pressure scanner valve and a $\pm$ 2.5 psid transducer were used to measure static pressures. Statham pressure transducers were used.

c. Temperature measurements were taken through four temperature scanners. Thermocouples were Iron-Constantan and Cromel-Alumel; Pace and Research Incorporated reference junctions were used.

d. For both temperatures and pressures, signal processing was accomplished by use of a B & F Instruments, Inc. signal conditioner and a Dynamics amplifier. The conditioned signal was connected to a monitor panel which permitted manual monitoring capability as well as calibration monitoring.

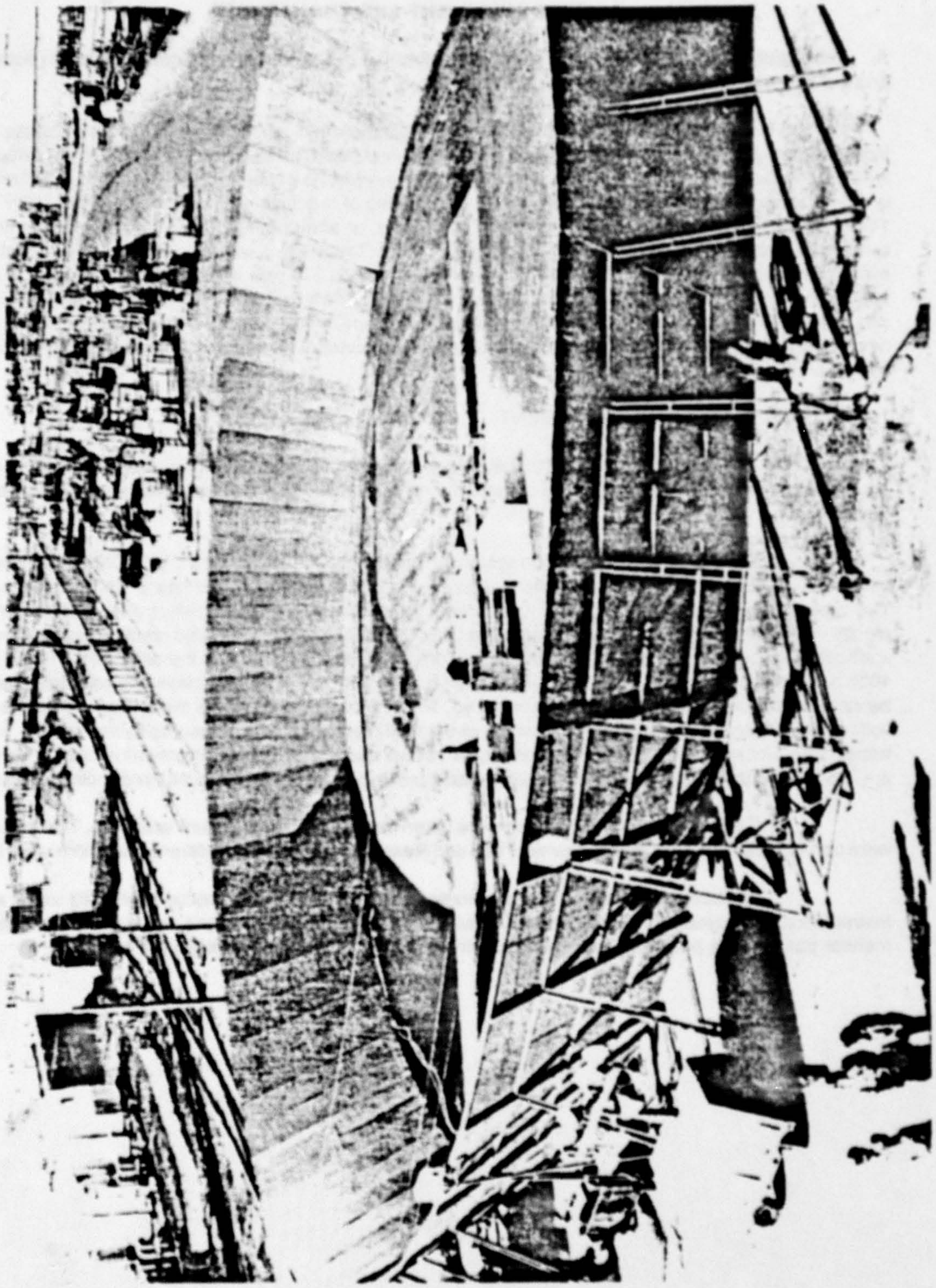

FIGURE 1: BOEING-WICHITA ACOUSTIC ARENA TEST FACILITY

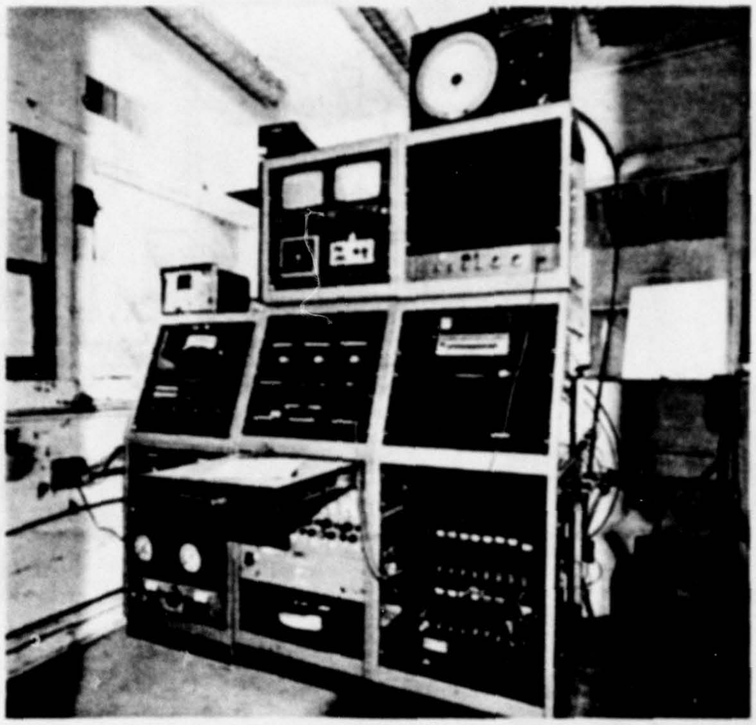

FIGURE 2: BURNER AND AIRFLOW CONTROLS

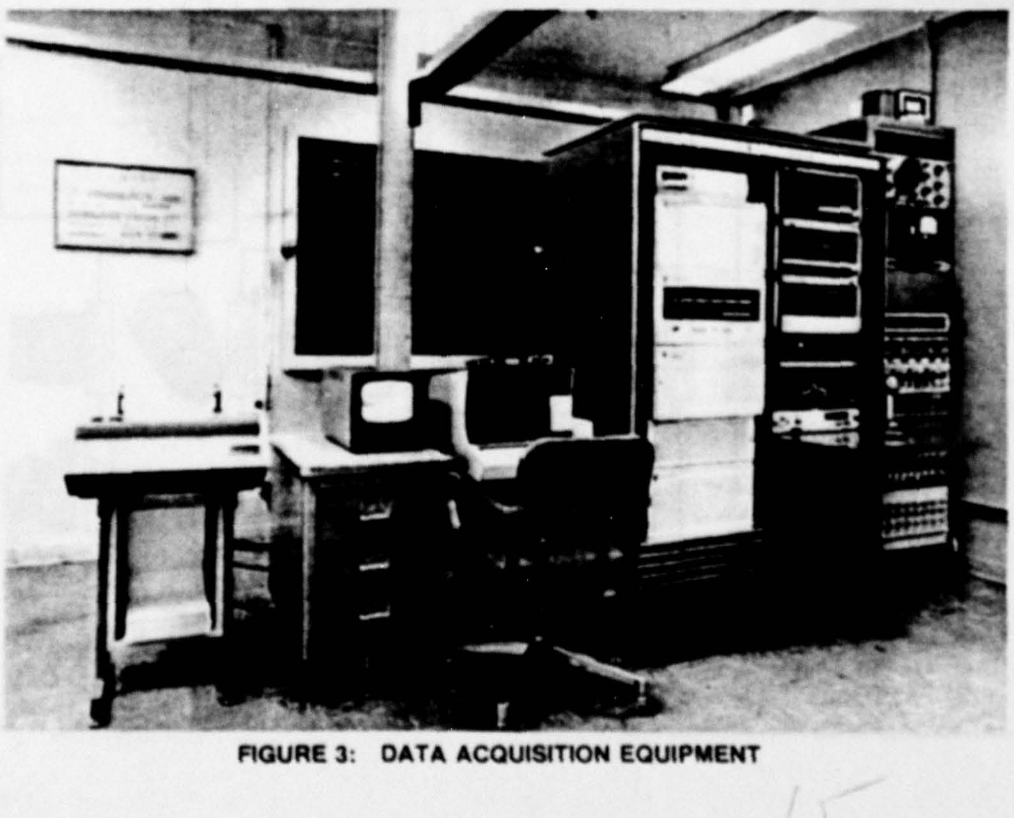

FIGURE 3: DATA ACQUISITION EQUIPMENT

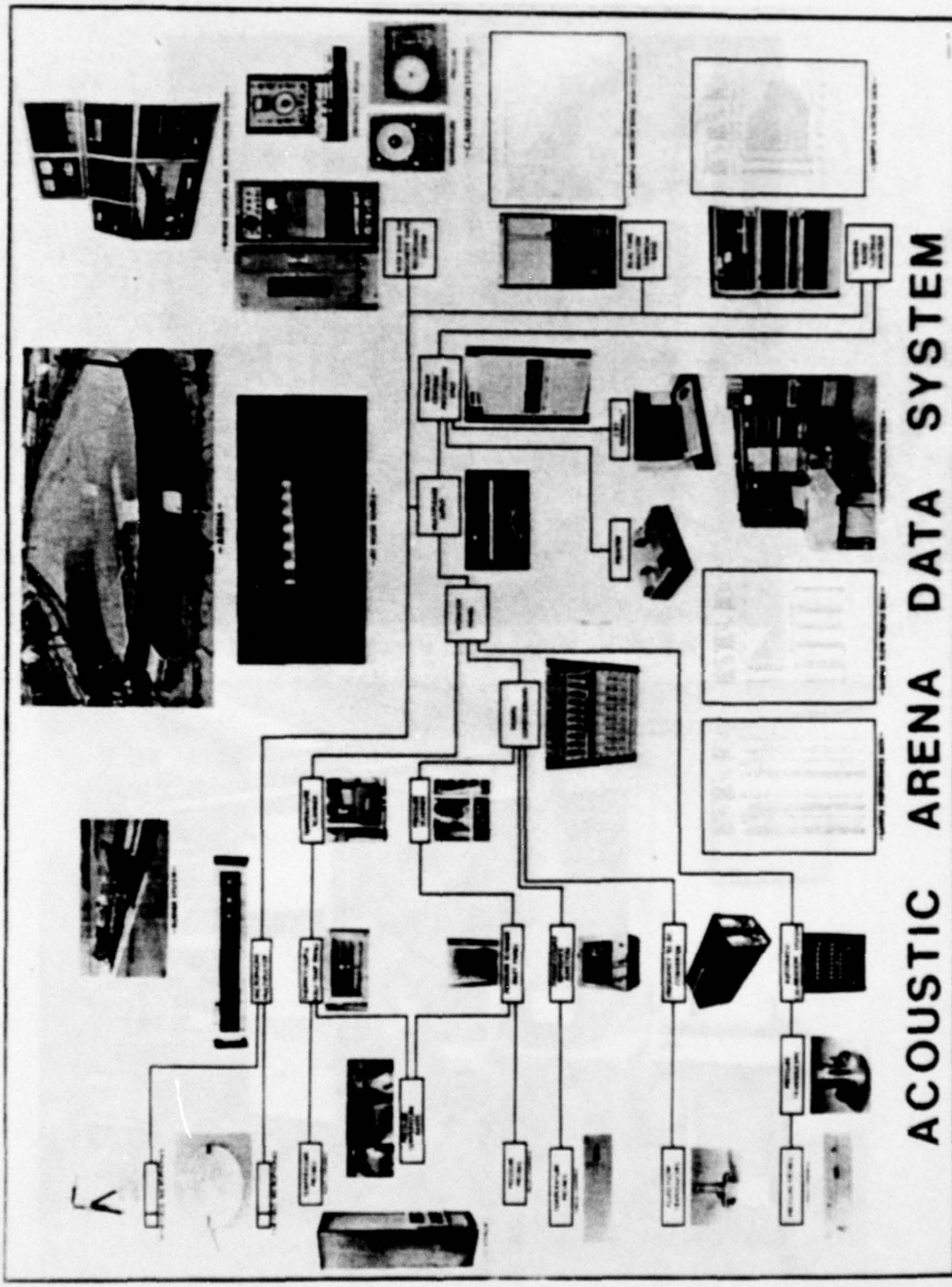


FIGURE 4: ACOUSTIC ARENA DATA ACQUISITION SYSTEM

e. The fuel flow was measured by a 1 gpm turbine-type flow transducer in the primary fuel line and a 5 gpm turbine-type flow transducer in the afterburner fuel line. The signal was conditioned by a Cox signal conditioner and the signal sent to the monitor panel. The flow rates were also displayed on digital voltmeters in the test control room. The monitor panel inputs were paralleled to the multiplexer input panel where further monitoring was possible. The signals then went into the multiplexer for processing.

f. The acoustic instrumentation system begins with the Bruel & Kjaer Models 4135 and 4136 microphone buttons. These are coupled to General Radio Model 560-P42 preamplifiers. A microphone scanner selects the proper channel for input to the autogain amplifier for signal processing. The General Radio Model 1925 Real-time Analyzer integrates the signal over an eight-second time interval and the computer interfaces the signal to the computer input. The far field acoustic microphones are flush mounted in disks, as shown on Figure 5, to obtain ground plane data that are free of reflective interference. Two computer programs were used for data acquisition. One program was used for performance data and the other for acoustic data, when recorded.

g. The acoustics program allows manual selection of the microphone data to be recorded. When the data from each microphone are analyzed, the computer signals the microphone scanner to advance one position. Data are taken sequentially. The analyzed acoustic data are printed in tabular form and plots of SPL versus frequency in one-third octave bands. Compilations of OASPL and PNL converted to full-scale equivalent distances are also provided. Examples of the acoustic data output format are illustrated on Figures 6 and 7.

h. The performance program provided automatic data acquisition. Once the program was started, all parameters were sampled and the scanners automatically controlled by the computer. The raw performance data, in the form of digital voltages, were converted to engineering units and calculation performed in the CPU. The data were then listed in tabulated form. Typical sample performance data output formats are illustrated on Figures 8 and 9.

3. MODEL DESCRIPTION

a. The Coanda demountable test cell has two enclosure sections: the test stand enclosure, including the primary air intake; and the ejector/Coanda enclosure, including the secondary air intake and exhaust muffler (stack). Only the latter enclosure was simulated in these model tests. A cutaway drawing of the complete test cell as it is currently visualized is shown on Figure 10.

b. The ejector/Coanda enclosure was fabricated in two sections. The forward section, which includes the secondary air intake, was fabricated of wood and simulates the internal lines of the enclosure and the secondary air intake. The aft section of the ejector/Coanda enclosure which includes the exhaust muffler (stack) was fabricated of sheet steel and simulates the enclosure and stack internal lines. Both sections are shown on Figures 11 and 12 with a short stack configuration.

c. The secondary air intake baffles were fabricated with wooden frames, an impervious septum in the center and 50 percent open area perforated steel plate face sheets on each side. The acoustic backing material was one inch thick Johns-Manville Glas-Mat 1200 fiberglass. The baffle leading edges are rounded to produce inlet bellmouths. The secondary air intake consists of 17 flow passages that simulate full-scale dimensions of 4.875 inches by 14 feet (96.69 ft$^2$). The baffles are 24 inches long which simulates 12 feet at full scale. An acoustically treated secondary air intake cover was provided with an opening facing forward for the purpose of isolating the noise emitting from this inlet from the far field microphone measurements. It also shields the microphone placed above the inlet (to measure the attenuation provided by the intake baffles) from noise emitting from the exhaust stack. Figure 13 shows the intake cover installed on the model.

d. Several exhaust stack configurations were tested, as shown on Figures 14 through 20. For each configuration, the sidewalls of the lower aft enclosure, as well as all inner surfaces of the exhaust stack, are acoustically treated with Johns-Manville Glas-Mat 1200 fiberglass backing and 50 percent open area perforated face sheet.

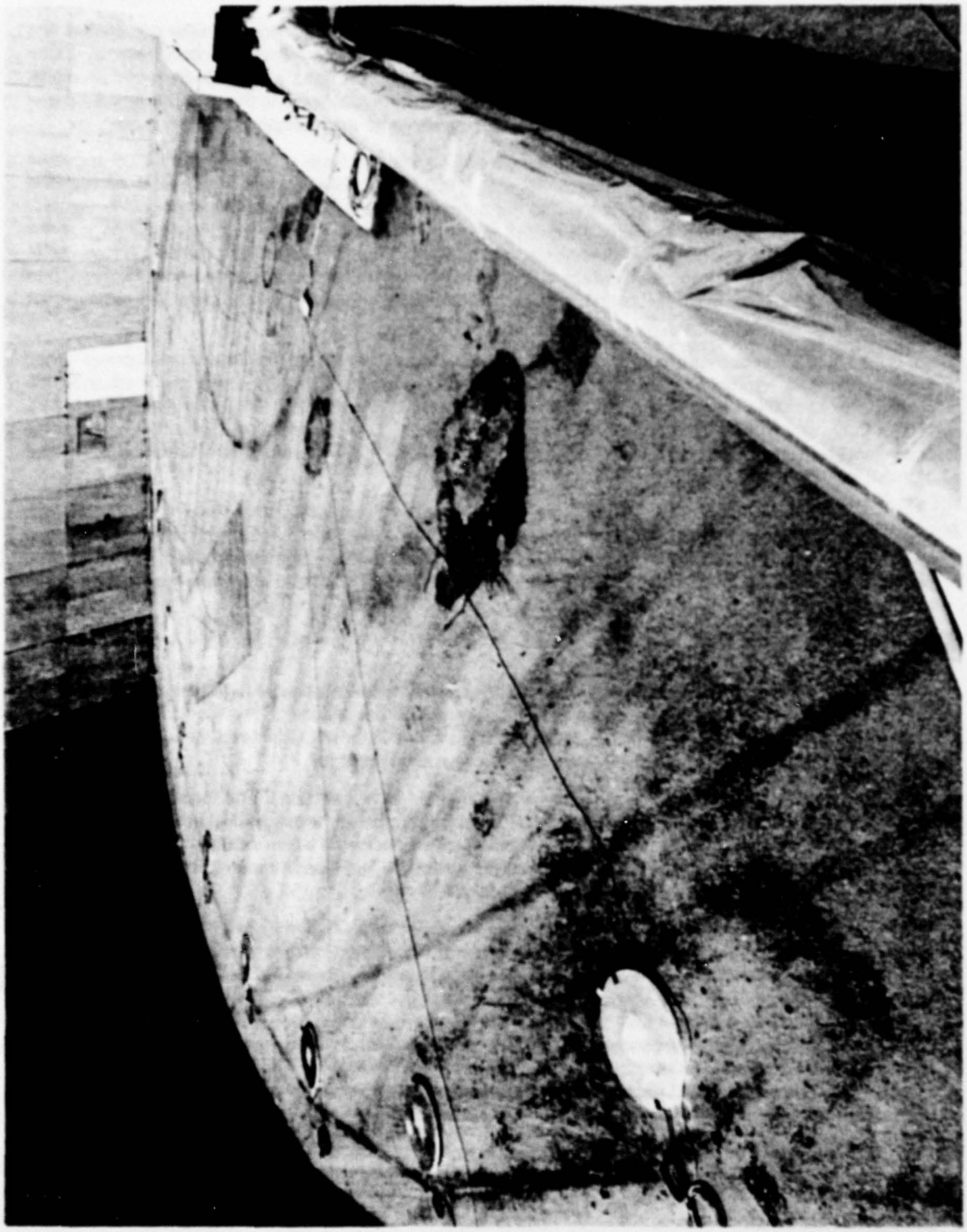

FIGURE 5: FAR FIELD ACOUSTIC MICROPHONE ARRAY

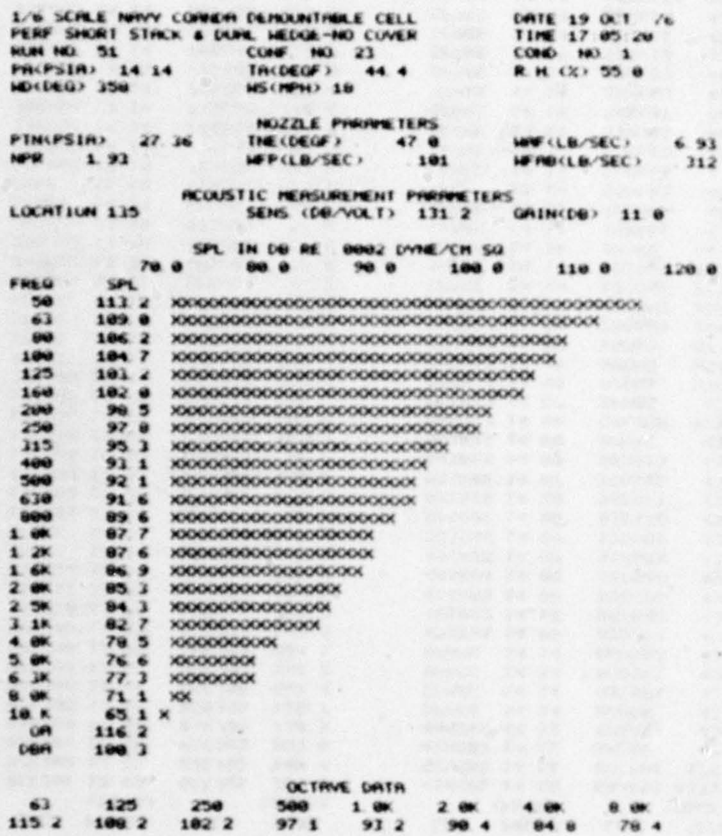


FIGURE 6: EXAMPLE OF INDIVIDUAL MICROPHONE ACOUSTIC DATA

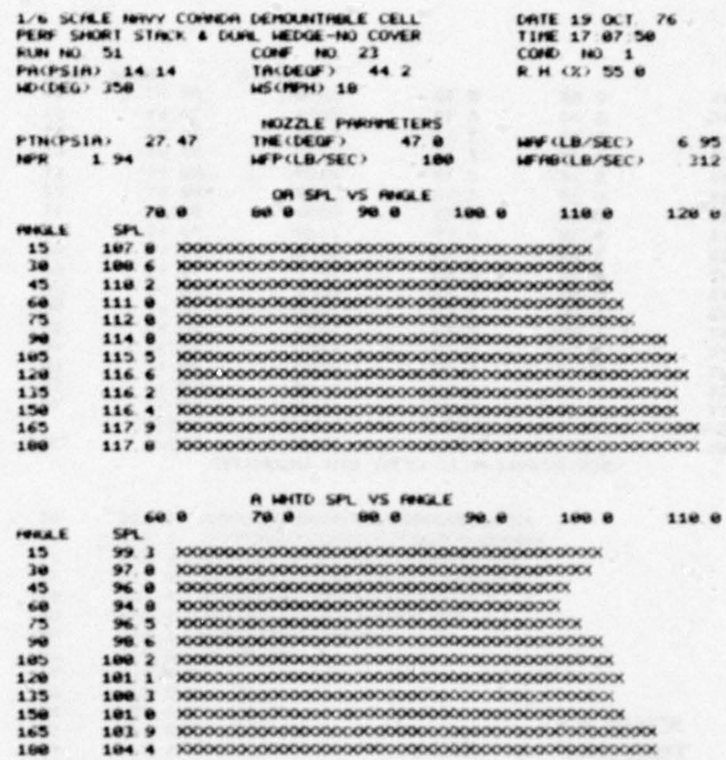


FIGURE 7: EXAMPLE OF ACOUSTIC SUMMARY DATA

```
1/6 SCALE NAVY COANDA DEMOUNTABLE CELL          DATE 19 OCT. 76
PERF SHORT STACK & DUAL WEDGE-NO COVER          TIME 17:07:50
RUN NO. 51          CONF. NO. 23                COND. NO. 1
 PA(PSIA)  14.14    TA(DEGF)   44.2             R.H.(%) 55.0
WD(DEG) 350         WS(MPH) 18

                    NOZZLE PARAMETERS
PTN(PSIA)   27.47   TNE(DEGF)      47.0         WAF(LB/SEC)    6.95
NPR    1.94         WFP(LB/SEC)    .100         WFAB(LB/SEC)   .312
```

| LOC | PRESS (PSIA) | LOC | TEMP (DEGF) | LOC | PRESS (PSIA) | LOC | TEMP (DEGF) |
|---|---|---|---|---|---|---|---|
| 01EJ01 | 13.69 | 01EJ01 | 284.3 | 41NZ01 | 14.12 | 64TPB1 | 1111.4 |
| 02EJ02 | 13.23 | 02EJ02 | 189.4 | 42NZ02 | 14.11 | 65CF01 | 179.2 |
| 03EJ03 | 12.98 | 03EJ03 | 883.6 | 43NZ03 | 14.12 | BADRR | 47.7 |
| 04EJ04 | 13.01 | 04EJ04 | 736.9 | 44NZ04 | 14.12 | SPARE | 43.1 |
| 05EJ05 | 13.11 | 05EJ05 | 128.7 | SPARE | 14.14 | BADRR | 43.1 |
| 06EJ06 | 12.84 | 06EJ06 | 692.4 | SPARE | 14.14 | 84DS01 | 43.1 |
| 07EJ07 | 13.68 | 07EJ07 | 568.2 | SPARE | 14.14 | 85DS02 | 43.1 |
| 08EJ08 | 13.92 | 08EJ08 | 884.1 | SPARE | 14.14 | 86DS03 | 43.1 |
| 09EJ09 | 14.17 | 09EJ09 | 640.2 | 45IR01 | 14.09 | 87DS04 | 43.1 |
| 10EJ10 | 13.74 | 10EJ10 | 774.3 | 46IR02 | 14.10 | 88DS05 | 43.1 |
| 11EJ11 | 13.62 | 11EJ11 | 884.1 | 47IR03 | 14.08 | 89DS06 | 43.1 |
| 12EJ12 | 13.97 | 12EJ12 | 838.0 | 48IR04 | 14.08 | 90DS07 | 43.1 |
| SPARE | 14.14 | 62EJ13 | 145.5 | 49IR05 | 14.08 | 91DS08 | 43.1 |
| SPARE | 14.14 | 63EJ14 | 1017.5 | 50IR06 | 14.09 | 92DS09 | 43.1 |
| 13CD01 | 13.44 | SPARE | 46.7 | 51IR07 | 14.09 | 93DS10 | 43.1 |
| 14CD02 | 13.28 | 69EN01 | 521.2 | 52IR08 | 14.08 | 94DS11 | 43.1 |
| 15CD03 | 12.43 | 70EN02 | 444.2 | 53IR09 | 14.07 | 95DS12 | 43.1 |
| 16CD04 | 12.48 | 68EN03 | 46.7 | 54IR10 | 14.09 | 96DS13 | 43.0 |
| 17CD05 | 12.45 | 13CD01 | 185.7 | 55IR11 | 14.08 | SPARE | 43.1 |
| 18CD06 | 12.65 | 14CD02 | 493.0 | 56IR12 | 14.08 | CALSUB | 921.2 |
| 19CD07 | 12.79 | 15CD03 | 835.2 | 57IR13 | 14.07 | SPARE | 43.0 |
| 20CD08 | 13.45 | 16CD04 | 937.4 | 58IR14 | 14.09 | 97DW1 | 938.6 |
| SPARE | 14.14 | 17CD05 | 955.4 | 59IR15 | 14.08 | 98DW2 | 834.7 |
| SPARE | 14.14 | 18CD06 | 949.9 | 60IR16 | 14.09 | 99DW3 | 573.9 |
| SPARE | 14.14 | 19CD07 | 1025.0 | 61IR17 | 14.08 | 100DW4 | 394.3 |
| SPARE | 14.14 | 20CD08 | 869.1 | SPARE | 14.14 | 101DW5 | 818.0 |
| 23EN01 | 14.01 | SPARE | 46.7 | SPARE | 14.14 | 102DW6 | 727.0 |
| 24EN02 | 13.99 | 40SP01 | 55.6 | SPARE | 14.14 | 103DW7 | 433.1 |
| 25EN03 | 13.95 | 41SP02 | 57.8 | SPARE | 14.14 | SPARE | 47.7 |
| 26EN04 | 13.95 | 42SP03 | 57.8 | SPARE | 14.14 | 48RK01 | 47.7 |
| SPARE | 14.14 | SPARE | 46.7 | SPARE | 14.14 | 49RK02 | 48.5 |
| PREF | 15.12 | 71SS01 | 629.1 | PREF | 15.14 | 50RK03 | 47.7 |
| 27ER01 | 14.15 | 72SS02 | 893.3 | SPARE | 14.14 | 51RK04 | 47.7 |
| 28ER02 | 14.14 | 73SS03 | 902.9 | SPARE | 14.14 | 52RK05 | 47.7 |
| 29ER03 | 14.14 | 74SS04 | 834.5 | SPARE | 14.14 | 53RK06 | 48.5 |
| 30ER04 | 14.14 | 75SS05 | 740.4 | SPARE | 14.14 | 54RK07 | 48.5 |
| 31ER05 | 14.14 | 76SS06 | 357.4 | SPARE | 14.14 | 55RK08 | 48.5 |
| 32ER06 | 14.14 | 77SS07 | 122.8 | SPARE | 14.14 | 56RK09 | 48.5 |
| 33ER07 | 14.14 | 78SS08 | 528.2 | SPARE | 14.14 | 57RK10 | 47.7 |
| 34ER08 | 14.14 | 79SS09 | 533.8 | SPARE | 14.14 | 58RK11 | 47.7 |
| 35ER09 | 14.14 | 80SS10 | 873.9 | SPARE | 14.14 | 59RK12 | 47.7 |
| 36ER10 | 14.14 | 81SS11 | 882.9 | SPARE | 14.14 | 60RK13 | 47.7 |
| 37ER11 | 14.14 | 82SS12 | 831.1 | SPARE | 14.14 | 61RK14 | 47.7 |
| 38ER12 | 14.14 | 83SS13 | 819.3 | SPARE | 14.14 | SPARE | 47.7 |
| 39ER13 | 14.14 | TREF | 989.2 | SPARE | 14.14 | TREF | 988.7 |
| 40ER14 | 14.14 | SPARE | .0 | SPARE | 14.14 | SPARE | .0 |

**FIGURE 8: EXAMPLE OF TABULATED PRESSURE AND TEMPERATURE DATA**

```
1/6 SCALE NAVY COANDA DEMOUNTABLE CELL          DATE 28 SEPT 76
SH STK-EXIT RK FWD&INLET RK 0"LEFT C/L          TIME 13:43:00
RUN NO. 29          CONF. NO. 5                 COND. NO. 1
PA(PSIA)  14.08     TA(DEGF)   61.2             R.H.(%) 64.0
WD(DEG) 355         WS(MPH) 9

                    NOZZLE PARAMETERS
PTN(PSIA)   27.69   TNE(DEGF)      68.5         WAF(LB/SEC)    6.93
NPR    1.96         WFP(LB/SEC)    .099         WFAB(LB/SEC)   .313

                 EXIT RAKE VELOCITY PROFILE

                    0     200.0     400.0     600.0     800.0    1000.0
LOC   (FT/SEC)
 01     -72.6 X
 02     -72.4 X
 03     -71.0 X
 04     -38.9 X
 05     -70.6 X
 06     -84.0 X
 07     138.7  XXXXXXXX
 08     315.3  XXXXXXXXXXXXXXXXXX
 09     436.4  XXXXXXXXXXXXXXXXXXXXXXXXX
 10     502.4  XXXXXXXXXXXXXXXXXXXXXXXXXXXX
 11     531.5  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 12     545.3  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 13     589.3  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 14     567.1  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
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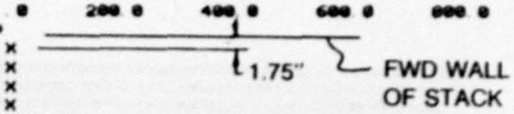



SECONDARY AIR INLET FLOW PARAMETERS

| LOC | PS (PSIA) | MACH NO. | TT (DEGF) | VP (FT/SEC) | WAF (LB/SEC) |
|---|---|---|---|---|---|
| 01 | 14.02 | .0750 | 61.2 | 83.9 | .137 |
| 02 | 14.03 | .0715 | 61.2 | 88.0 | .138 |
| 03 | 14.01 | .0867 | 61.2 | 97.0 | .158 |
| 04 | 14.00 | .0903 | 61.2 | 101.0 | .164 |
| 05 | 14.00 | .0896 | 61.2 | 100.3 | .163 |
| 06 | 14.01 | .0827 | 61.2 | 92.6 | .151 |
| 07 | 14.02 | .0790 | 61.2 | 88.4 | .144 |
| 08 | 14.01 | .0865 | 61.2 | 96.8 | .158 |
| 09 | 14.01 | .0872 | 61.2 | 97.6 | .159 |
| 10 | 14.01 | .0817 | 61.2 | 91.4 | .149 |
| 11 | 14.00 | .0885 | 61.2 | 99.0 | .161 |
| 12 | 14.00 | .0875 | 61.2 | 97.9 | .159 |
| 13 | 14.00 | .0907 | 61.2 | 101.5 | .165 |
| 14 | 14.02 | .0778 | 61.2 | 87.0 | .142 |
| 15 | 14.02 | .0808 | 61.2 | 90.3 | .147 |
| 16 | 14.01 | .0862 | 61.2 | 96.5 | .157 |
| 17 | 14.00 | .0889 | 61.2 | 99.5 | .162 |

TOTAL FLOW 2.614

**FIGURE 9: EXAMPLE OF EXHAUST VELOCITY, INLET AIRFLOW VELOCITY AND AIRFLOW DATA**

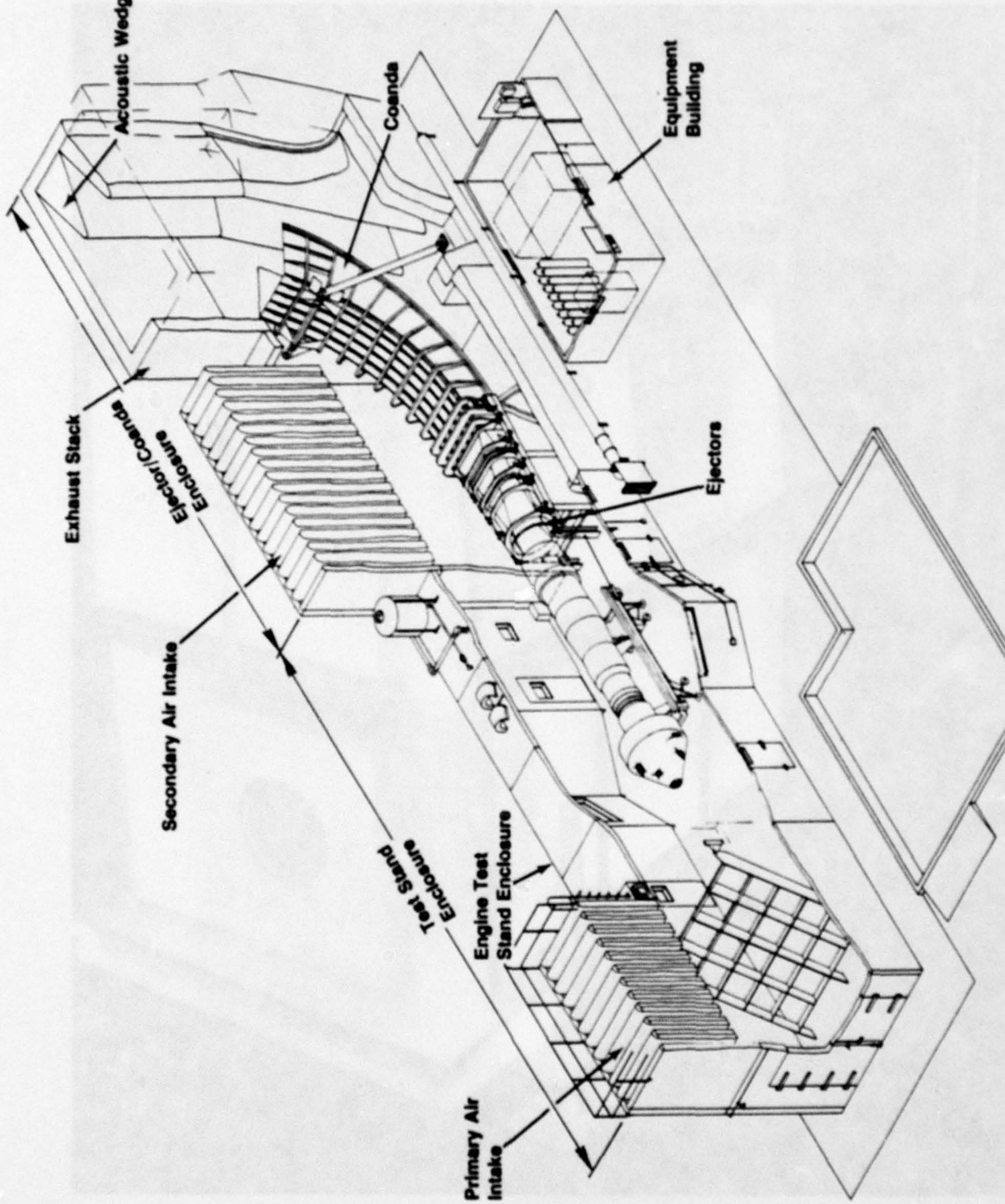



FIGURE 10: COANDA DEMOUNTABLE TEST CELL (CUTAWAY)

41

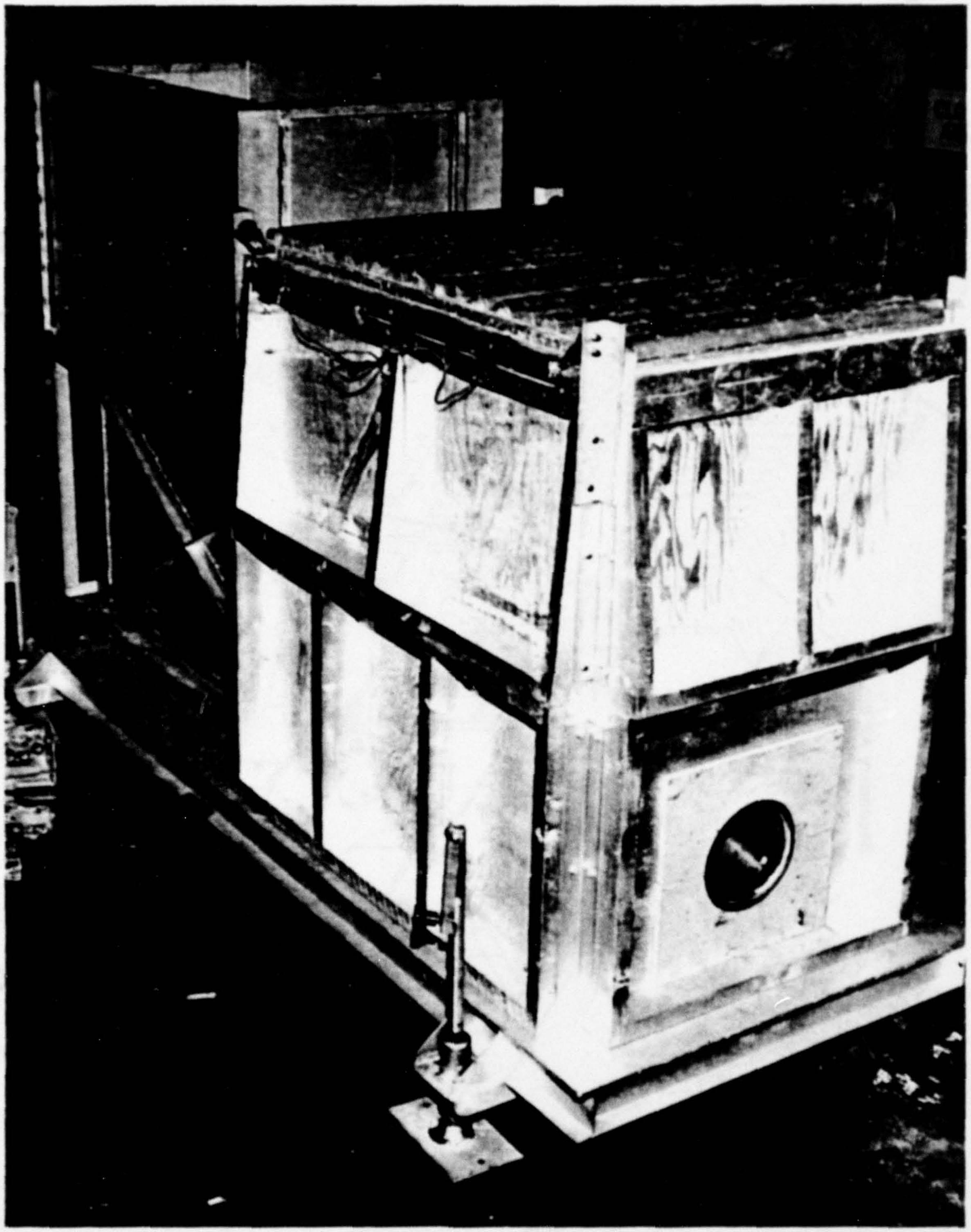


FIGURE 11: COANDA ENCLOSURE MODEL INSTALLED ON SUPPORT FLOOR

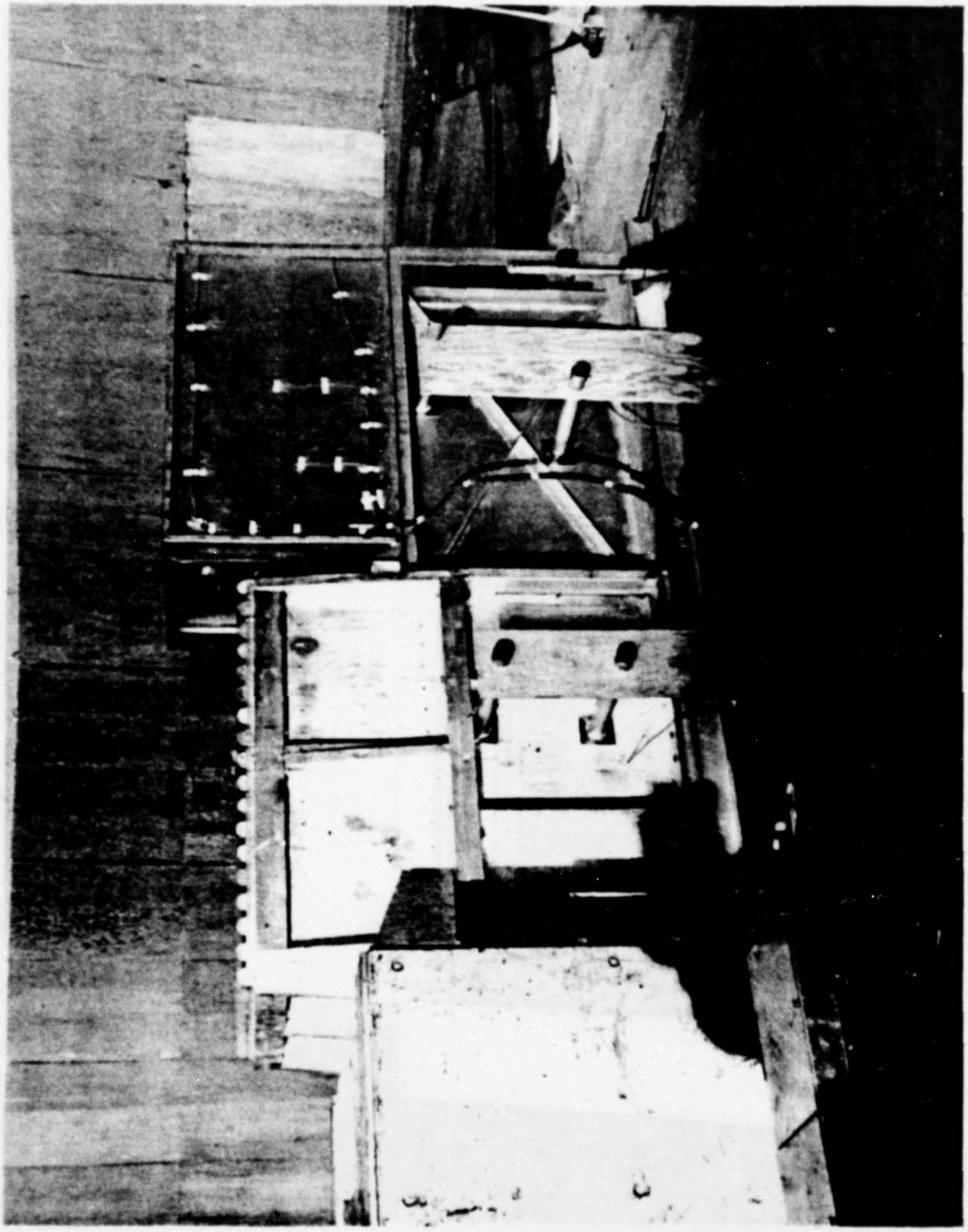


FIGURE 12: COANDA DEMOUNTABLE TEST CELL MODEL INSTALLED IN TEST ARENA FACILITY

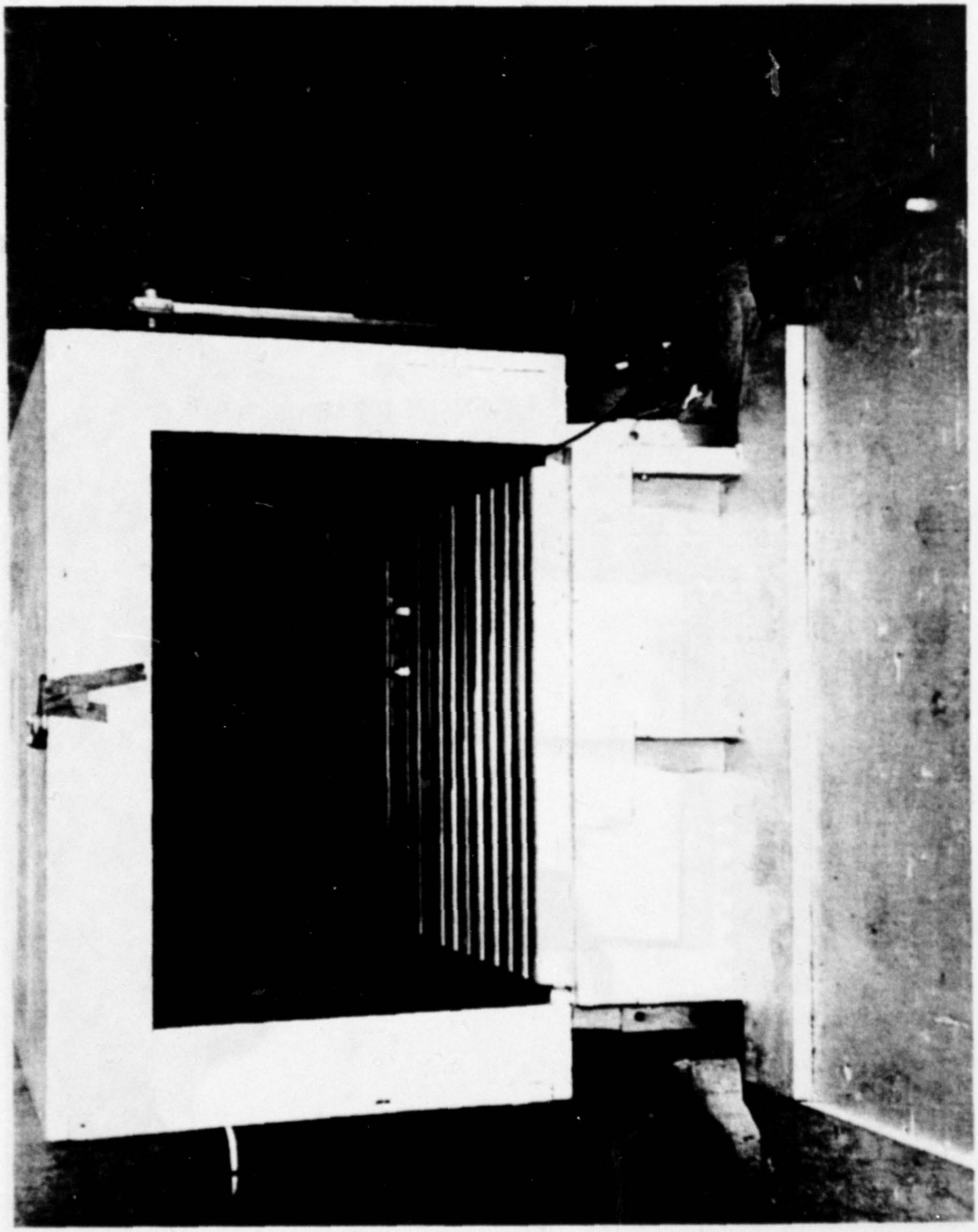


**FIGURE 13: ACOUSTICALLY TREATED TEST CELL MODEL INLET COVER**

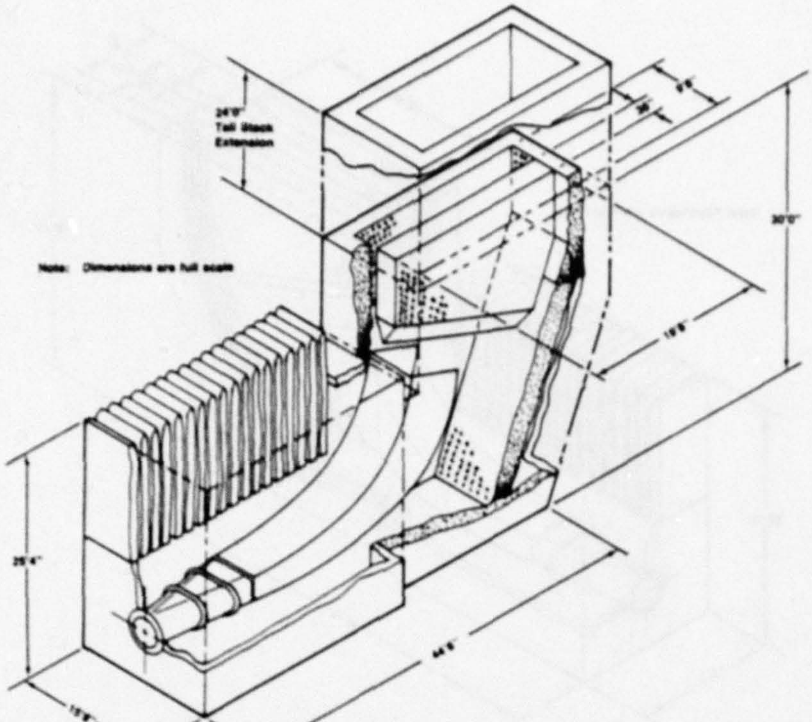



**FIGURE 14: SCHEMATIC OF SINGLE SPLITTER EXHAUST STACK CONFIGURATION**

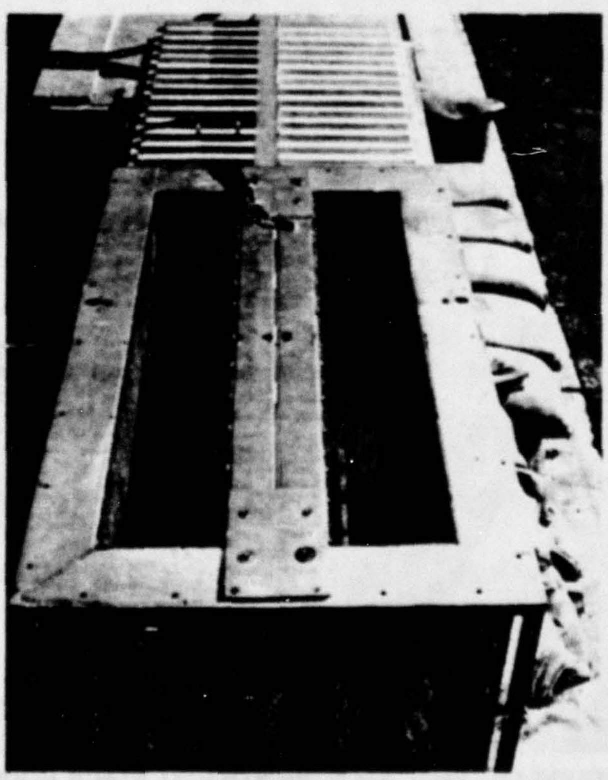


**FIGURE 15: SINGLE SPLITTER EXHAUST STACK MODEL**

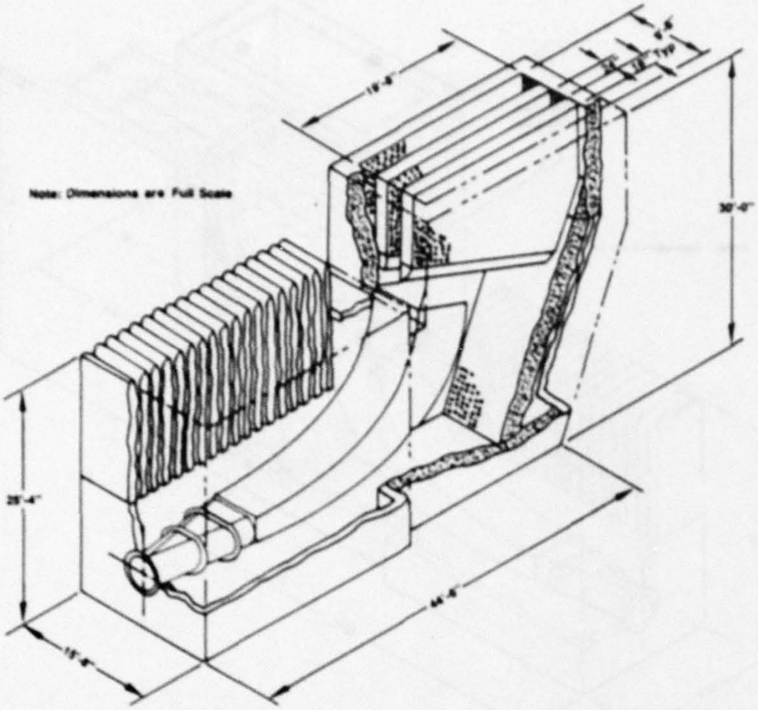



**FIGURE 16: SCHEMATIC OF DUAL SPLITTER EXHAUST STACK CONFIGURATION**

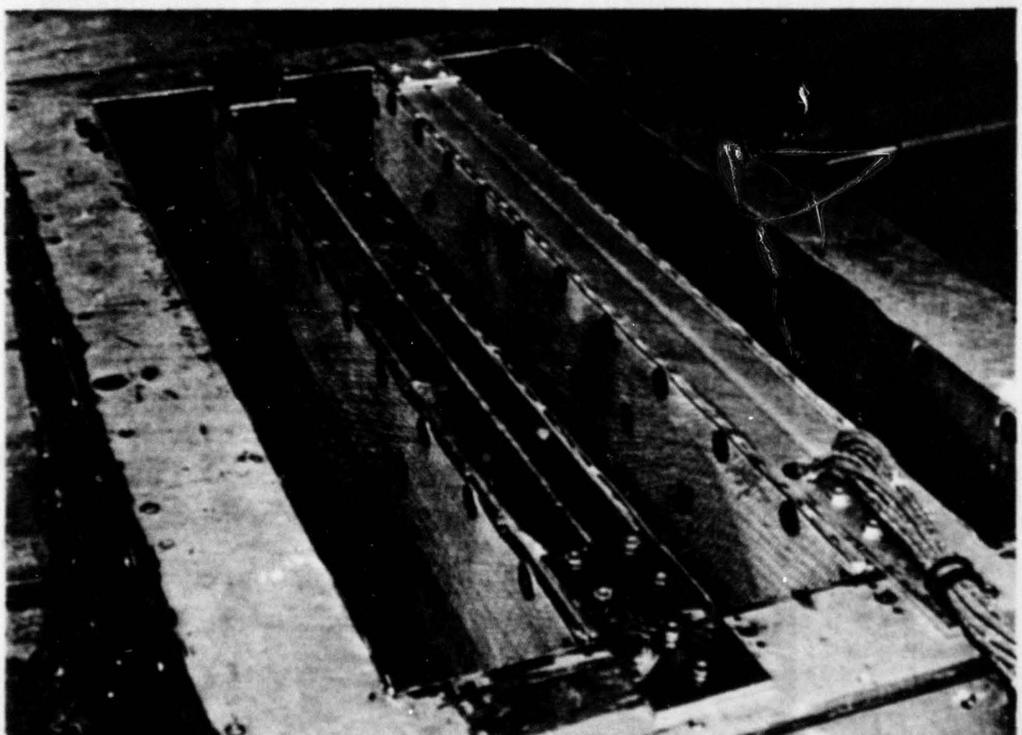


**FIGURE 17: DUAL SPLITTER EXHAUST STACK MODEL**

FIGURE 18: TYPICAL EXHAUST STACK SPLITTER CONSTRUCTON

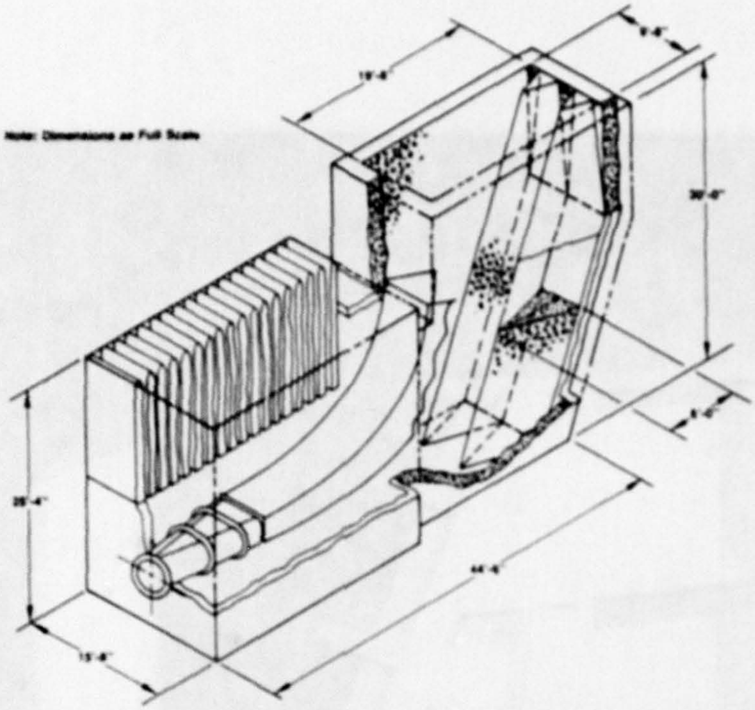


FIGURE 19: SCHEMATIC OF ACOUSTIC WEDGE EXHAUST STACK CONFIGURATION

FIGURE 20: ACOUSTIC WEDGE EXHAUST STACK MODEL

e. The single splitter exhaust stack configuration (Figures 14 and 15) has a single splitter attached to the forward and aft stack walls and centered on the Coanda flow. The splitter is equivalent to 36 inches thick (full scale) with a center impervious septum, Johns-Manville Glas-Mat 1200 backing material and 50 percent open area perforated plate face sheet. A sloping back wall that reaches to the floor has similar acoustic treatment that is equivalent to 24 inches thick (full scale). An exhaust stack extension that is equivalent to 24 feet (full scale) was provided that is acoustically treated and has the same cross sectional dimensions as the lower stack outer walls. This stack height provides a configuration with the same L/H ratio (1/2 x acoustically treated area/flow area) as a stack with a total height of 40 feet and an internal width dimension equal to 80 inches (full scale). This is the same flow passage width as the configuration with the splitter when the splitter width is excluded. Both the sort stack outer walls and the stack extension are provided with the capability of varying the backing depth between 2.75 inches and 4.13 inches (model scale). All configurations are provided with the capability of hard wall covering the acoustic treatment.

f. The dual splitter configuration (Figures 16 and 17) is similar to the single splitter except that two splitters, each equivalent to 18 inches (full scale) thick, are placed in the short exhaust stack. The same acoustic treatment as was used for the single splitter is used, only half as thick. The stack walls are left the same as with the single splitter.

g. Figure 18 illustrates the typical construction of the exhaust stack splitter with the perforated face sheet and acoustic backing material removed.

h. The acoustic wedges up the back wall of the enclosure and stack, shown on Figures 19 and 20, have the effect of producing a large L/H ratio while removing the splitter from the hottest and highest velocity flow. These two wedges are equivalent to eight feet deep (full scale) and each has a base width that is half the width of the back wall. The face sheet is 50 percent open area perforated plate and the backing material is Johns-Manville Glas-Mat 1200. The remainder of the stack and enclosure walls is left the same as in previous tests.

i. A dimensional schematic of the ejector set and Coanda surface used inside the enclosures described above is shown on Figure 21. The ejector set is fabricated of .090-inch thick stainless steel and the Coanda of .25-inch thick mild steel. A support structure and ground plane are provided for the ejectors, Coanda and acoustic enclosures. The ground plane simulates a 60-inch (full scale) distance below the engine centerline. Figure 22 shows the ejector set installed on the ground plane and support structure, and Figure 23 shows the addition of the Coanda surface and an acoustic burner cover. The purpose of the burner cover was to isolate any burner noise generated from the microphone locations since only the exhaust noise was to be measured. Figure 24 shows the interior of the burner cover and Figure 25 shows the exhaust nozzle, ejector and burner cover end plate interface. The burner cover end plate was used only when no ejector/Coanda enclosure was present. The forward wall of the ejector/Coanda enclosure became the divider between the burner cover and enclosure whenever an enclosure was being tested (see Figure 11).

j. Burlap bags filled with sand were used around the entire lower enclosure, as shown on Figures 26 and 27, to isolate the wall transmitted noise. This was necessary since it is very difficult to simulate full-scale wall transmission characteristics in model scale, and previous full-scale testing has shown adequate wall transmission loss capability.

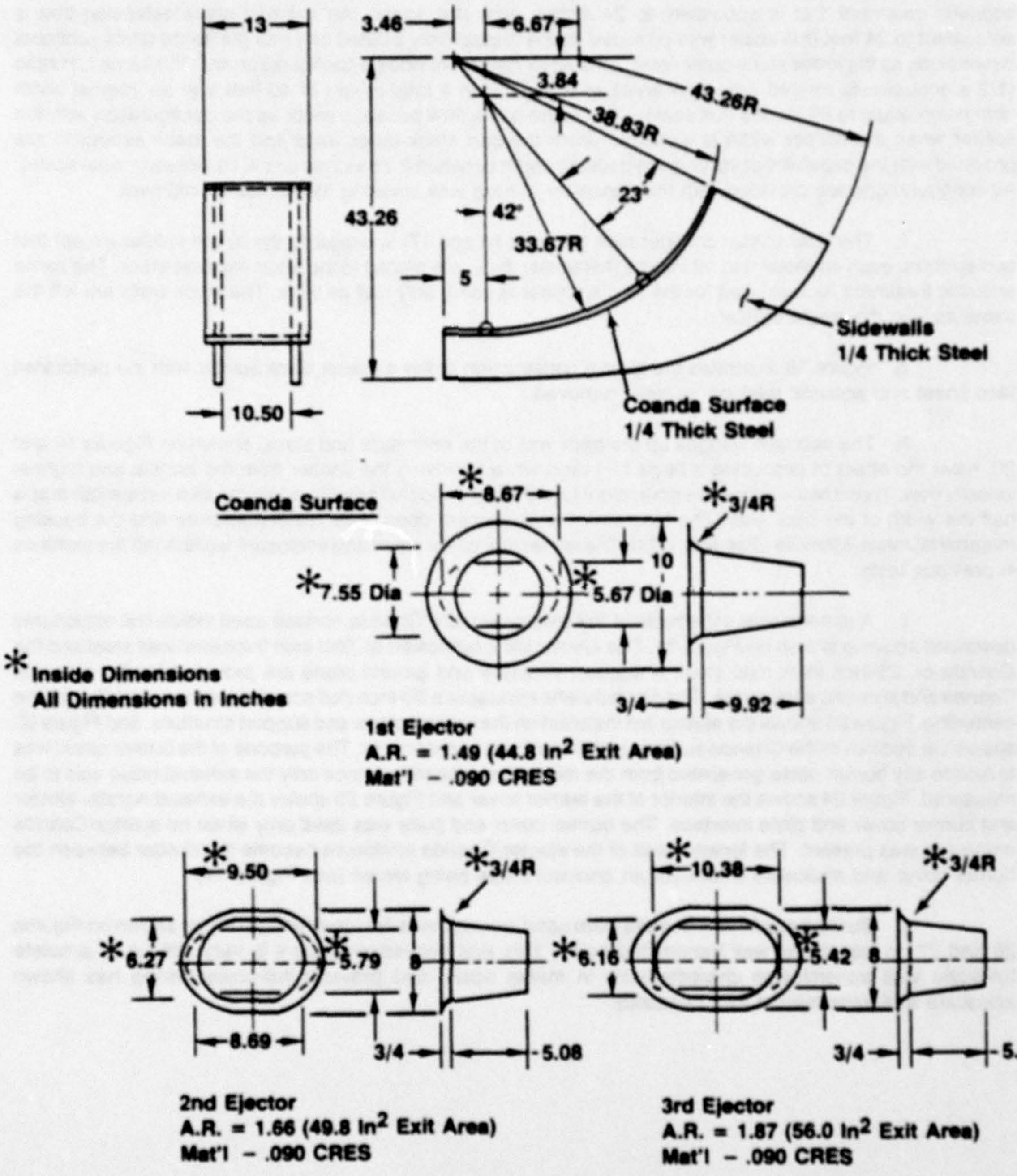



FIGURE 21. DIMENSIONAL DRAWINGS OF SCALE MODEL COANDA SURFACE AND EJECTORS

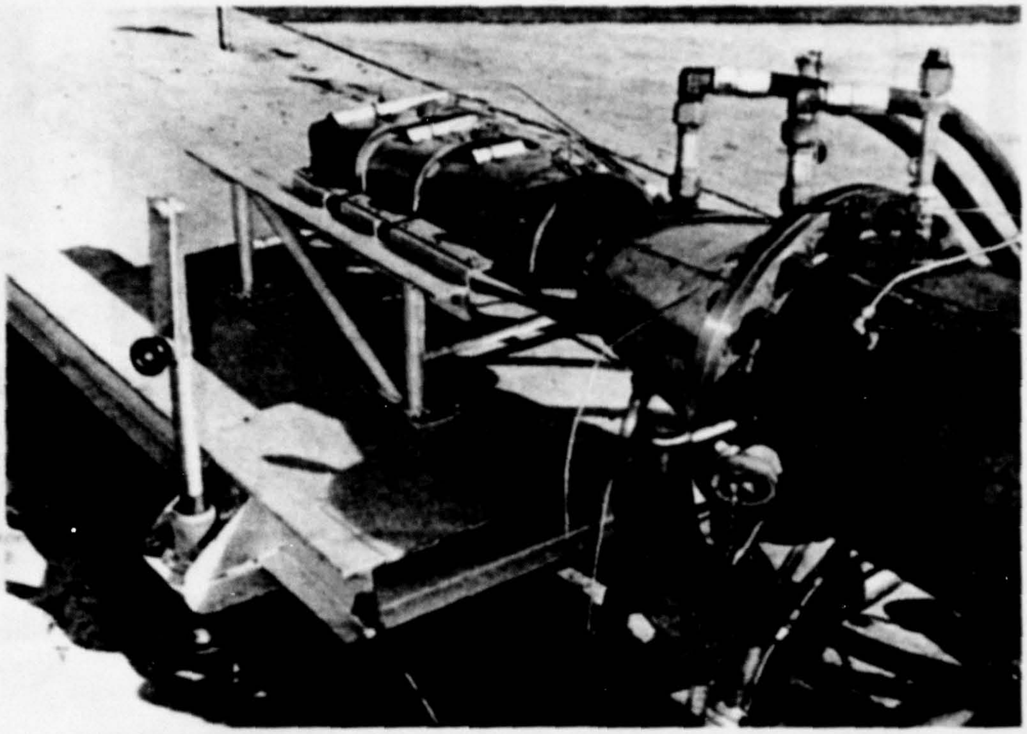


FIGURE 22: EJECTOR SET INSTALLED ON GROUND PLANE AND SUPPORT STRUCTURE

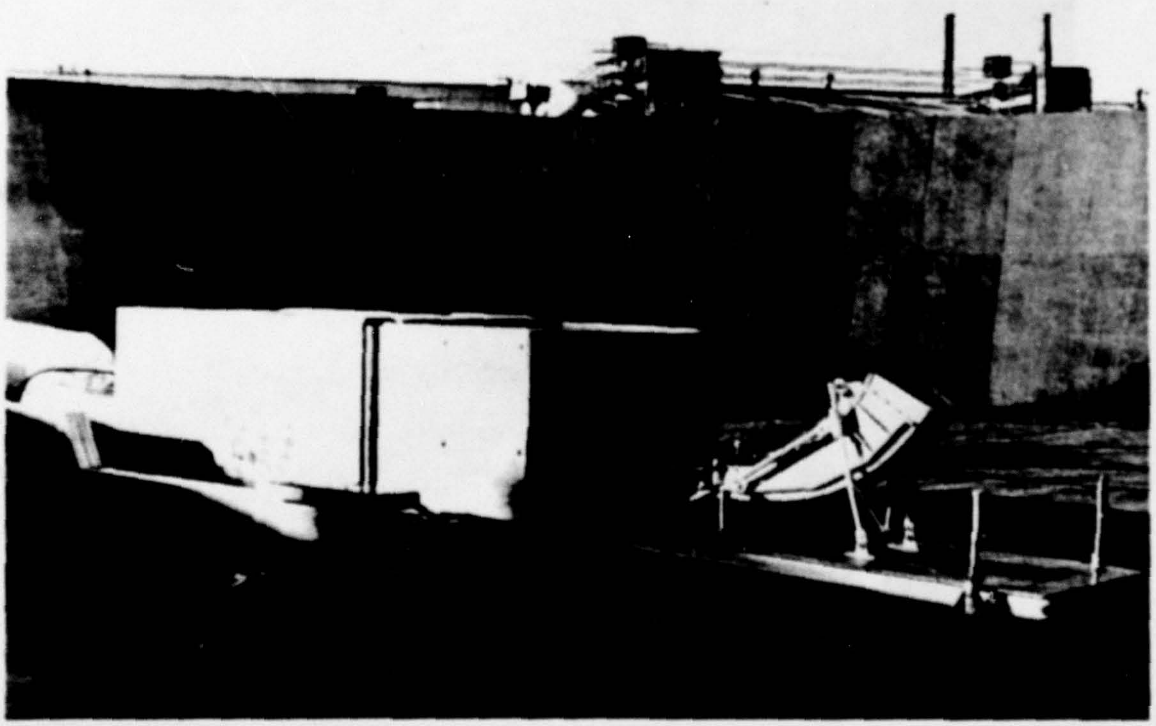


FIGURE 23: COANDA AND EJECTOR SET INSTALLED ON GROUND PLANE AND SUPPORT STRUCTURE WITH BURNER ACOUSTIC COVER

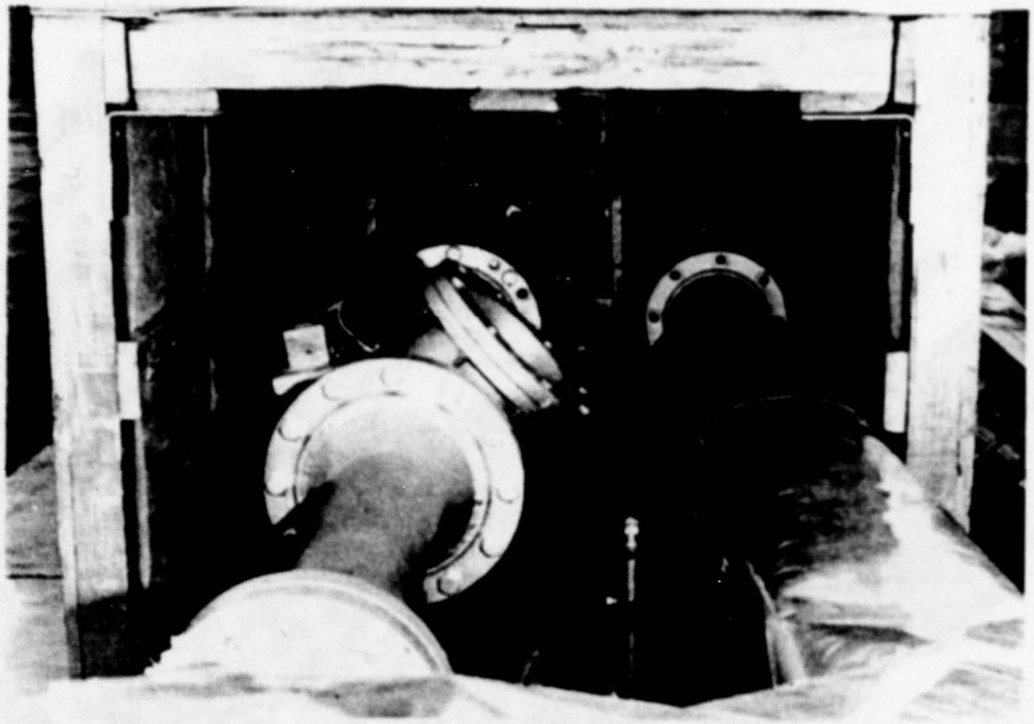


FIGURE 24: VIEW SHOWING INTERIOR OF BURNER ACOUSTIC COVER

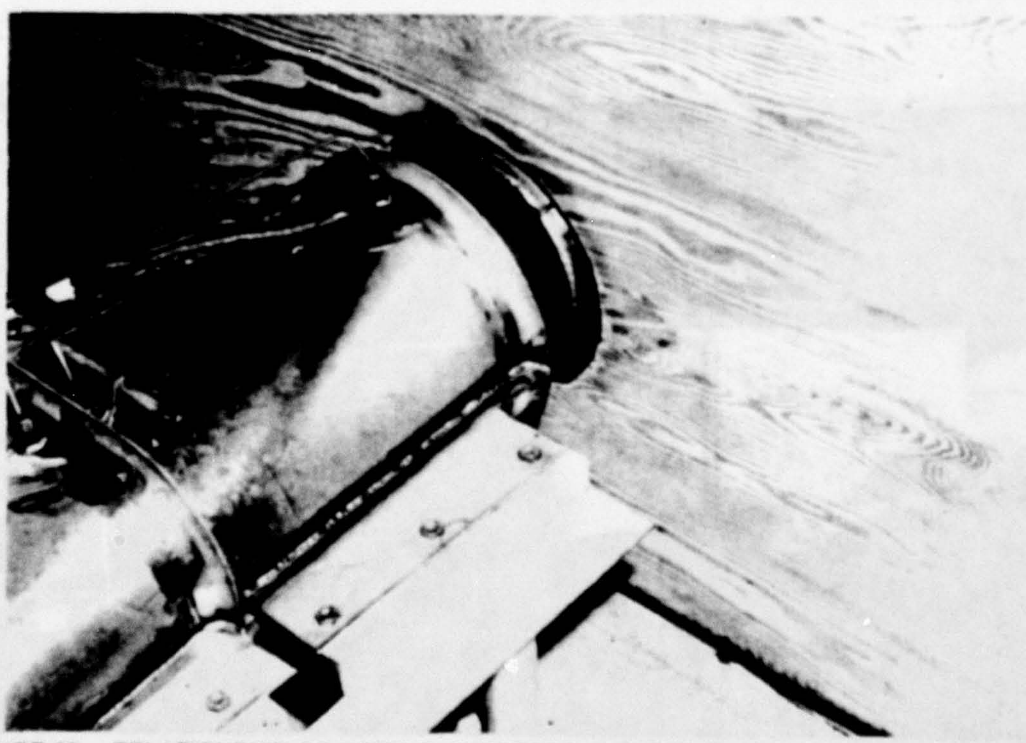


FIGURE 25: RELATIONSHIP OF NOZZLE, EJECTORS AND END PLATE OF BURNER ACOUSTIC COVER

FIGURE 26: MODEL WITH SHORT EXHAUST STACK, WALL TRANSMISSION ISOLATION (SANDBAGS), AND BURNER ACOUSTIC COVER

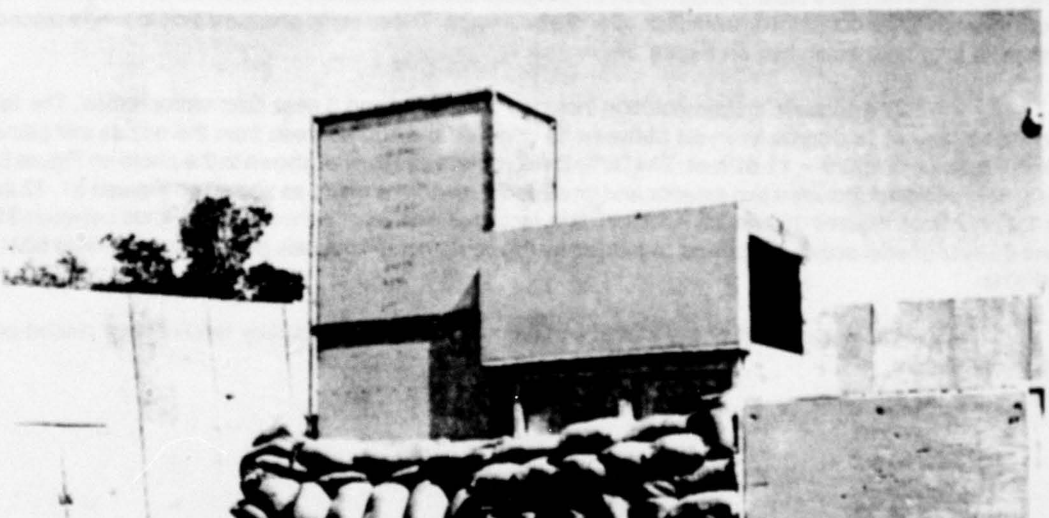


FIGURE 27: MODEL WITH TALL EXHAUST STACK, WALL TRANSMISSION ISOLATION (SANDBAGS), BURNER ACOUSTIC COVER AND SECONDARY AIR INLET ACOUSTIC COVER

## 4. INSTRUMENTATION

a. Figure 28 shows the relationship of the exhaust nozzle to the ejectors and Coanda surface. The location of the ejector and Coanda surface pressure and temperature instrumentation is also shown. Each of the three ejectors has four static pressure ports and four outside surface temperature thermocouples. The Coanda surface has eight each of static pressure ports and outside surface temperature thermocouples at approximately 10-degree intervals on the centerline starting at the entrance to the Coanda.

b. The exhaust flow characteristics above the center of the Coanda surface were measured by an exit rake (shown on Figure 29) which has 14 each of total pressure probes and total temperature probes. The probe positions are incremented based on a logarithmic scale with the smallest increment nearest the forward wall of the Coanda. This was required to measure the most number of points where the velocity gradient was largest. Figure 30 shows the exit rake installed at the exhaust stack exit indicating how exhaust flow characteristics were measured with the enclosure around the Coanda surface.

c. Figures 31, 32 and 33 show the location of the thermocouples added to the enclosure and exhaust stack for the single splitter, dual splitter and acoustic wedge configuration, respectively. These thermocouples were to measure the surface temperatures attained by the enclosure and exhaust stack inner walls.

d. Four static pressure probes were located in the enclosure interior with two centrally located below the inlet (one on each sidewall) and two centrally located below the exhaust stack (one on each sidewall). The probes were positioned 10 inches above ground. These probes determined the cell depression in the inlet and exhaust areas of the Coanda enclosure system.

e. The enclosure inlet(s) was instrumented to determine the secondary flow entrainment. Each channel in the inlet had a static pressure port at the centerline approximately 0.75 channel widths downstream from the start of the constant area section after the bellmouth. These static pressure pickups were placed on a movable inlet rake as shown on Figure 34.

f. The acoustic instrumentation included 12 far field and 3 near field microphones. The far field positions were at 15-degree intervals between 15 degrees and 180 degrees from the nozzle exit plane at a radial distance of 250/6 = 41.67 feet. The far field microphone array was shown in the photo on Figure 5. The near field positions included two exterior and one interior to the enclosure as shown on Figures 31, 32 and 33 in the photos on Figures 35 and 36. Acoustic data recorded was 24 one-third octave bands between 315 Hz and 65 KHz (model scale) which was converted by the computer to full-scale equivalents between 50 Hz and 10 KHz.

g. Table 1 is a list of the instrumentation used and the accuracy requirement placed on that instrumentation.

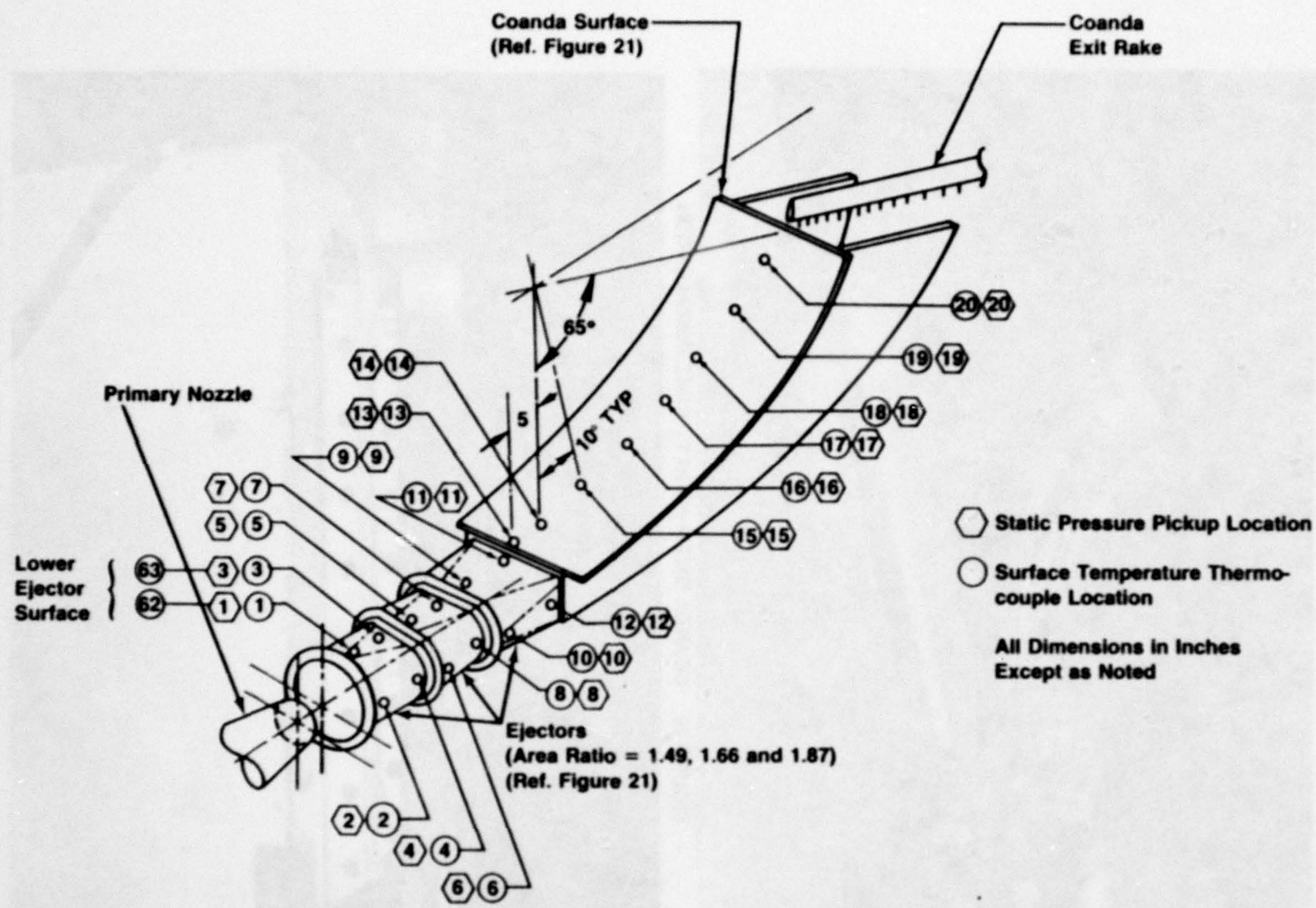



FIGURE 28: SCHEMATIC OF EJECTORS & COANDA SURFACE TEST SETUP AND INSTRUMENTATION

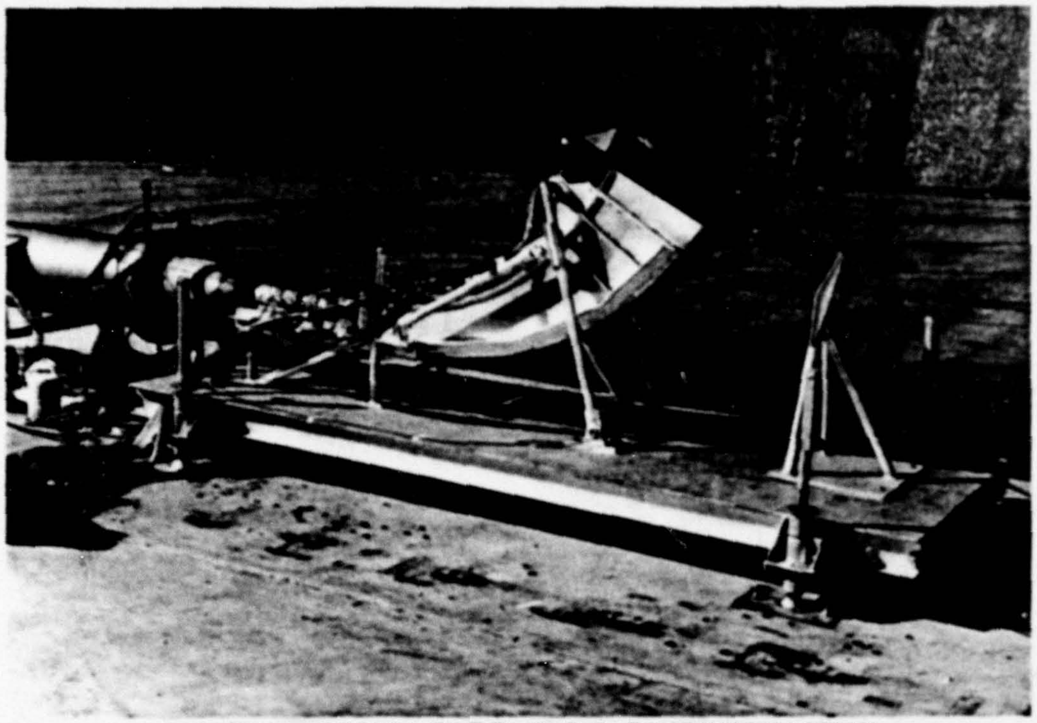


FIGURE 29: COANDA EXIT $P_T$ AND $T_T$ RAKE INSTALLATION

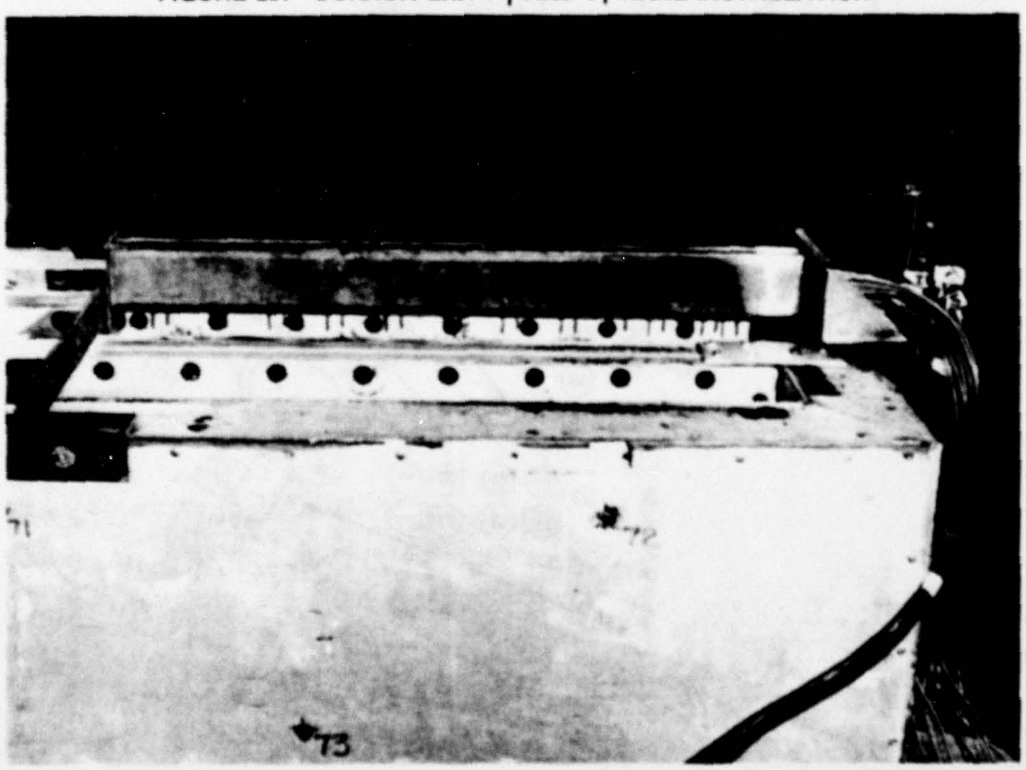



FIGURE 30: EXHAUST STACK EXIT $P_T$ AND $T_T$ RAKE INSTALLATION

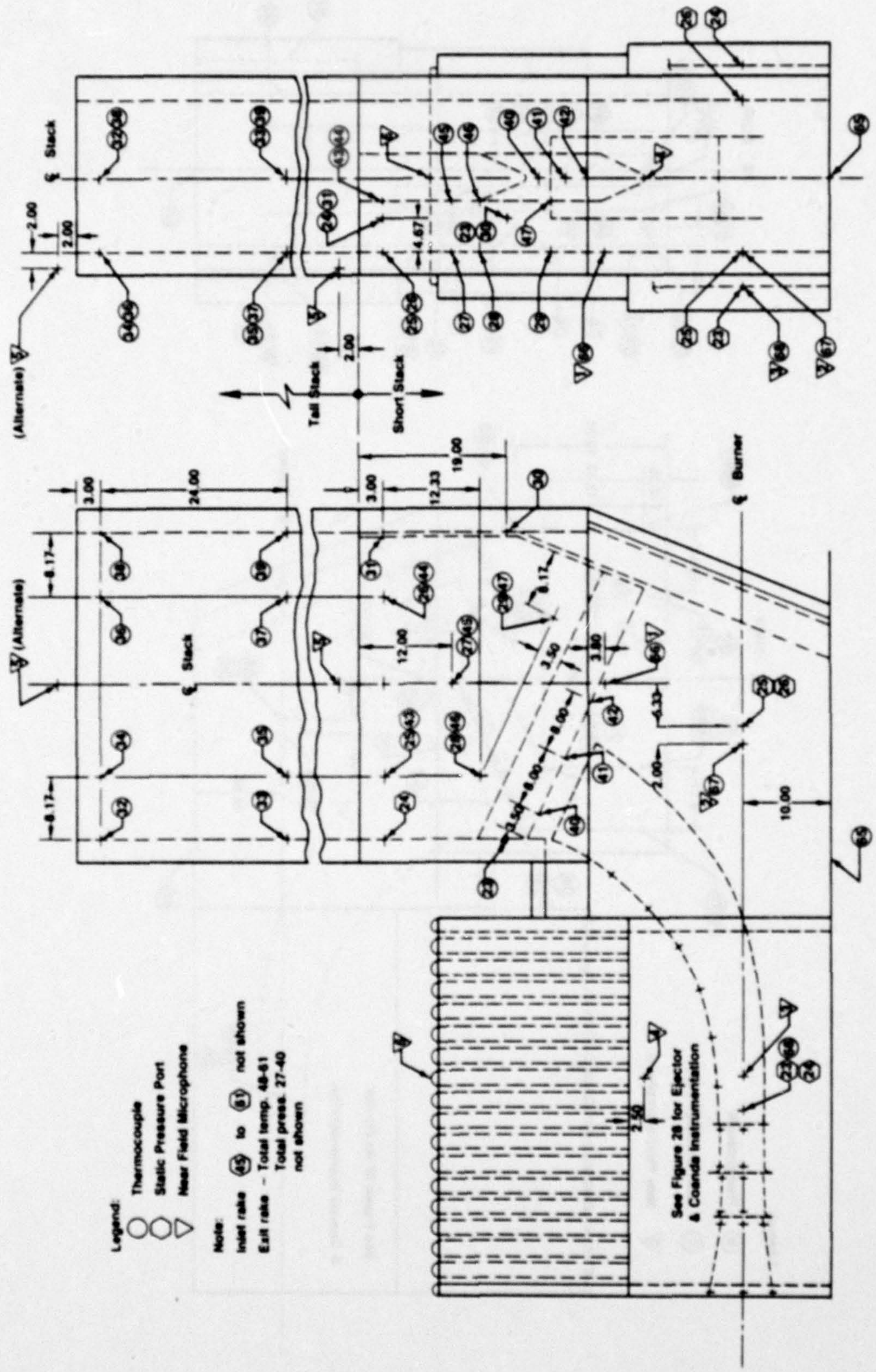



FIGURE 31: SCHEMATIC OF ENCLOSURE INSTRUMENTATION – SINGLE SPLITTER AND TALL EXHAUST STACK CONFIGURATIONS

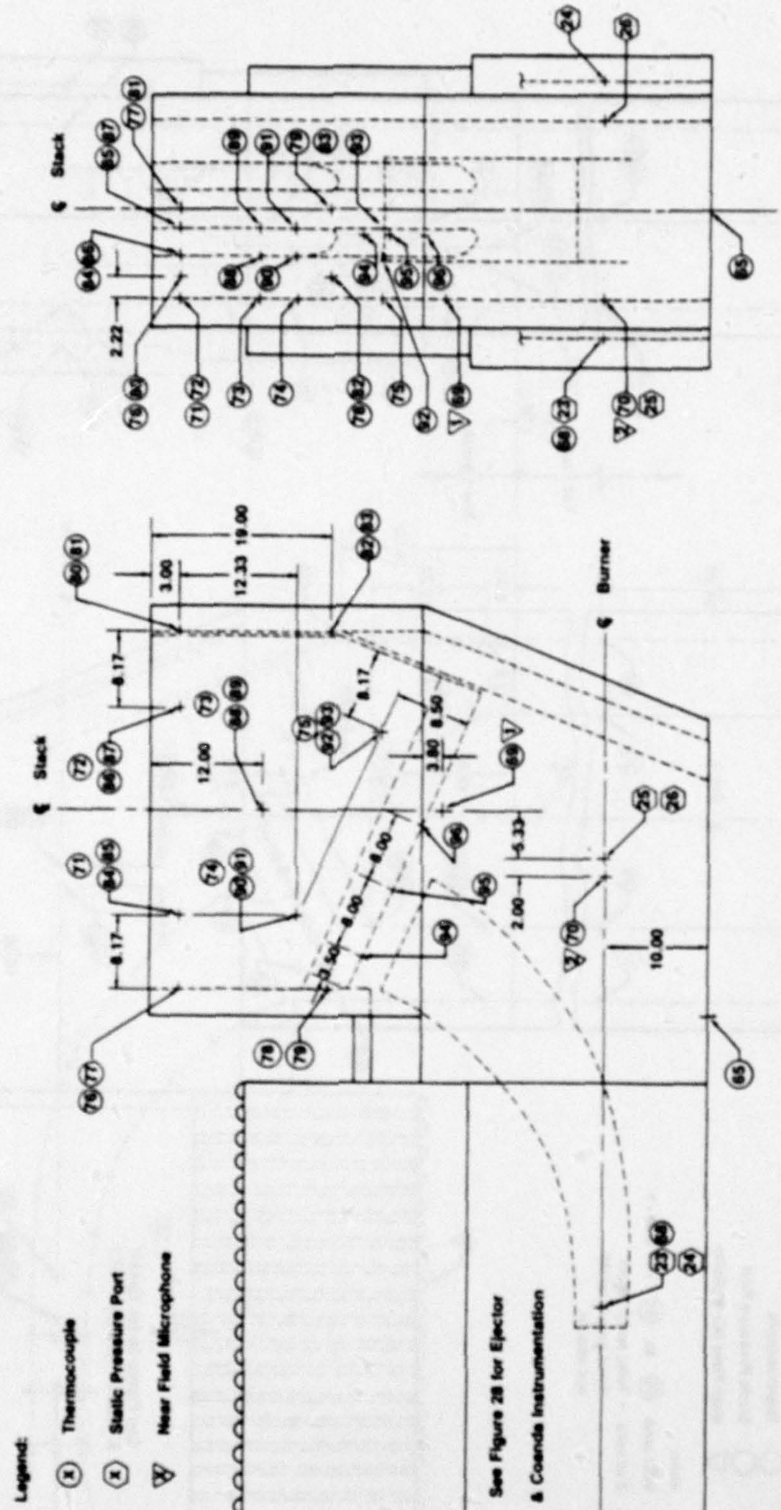



FIGURE 32: SCHEMATIC OF ENCLOSURE INSTRUMENTATION – DUAL SPLITTER EXHAUST STACK CONFIGURATION

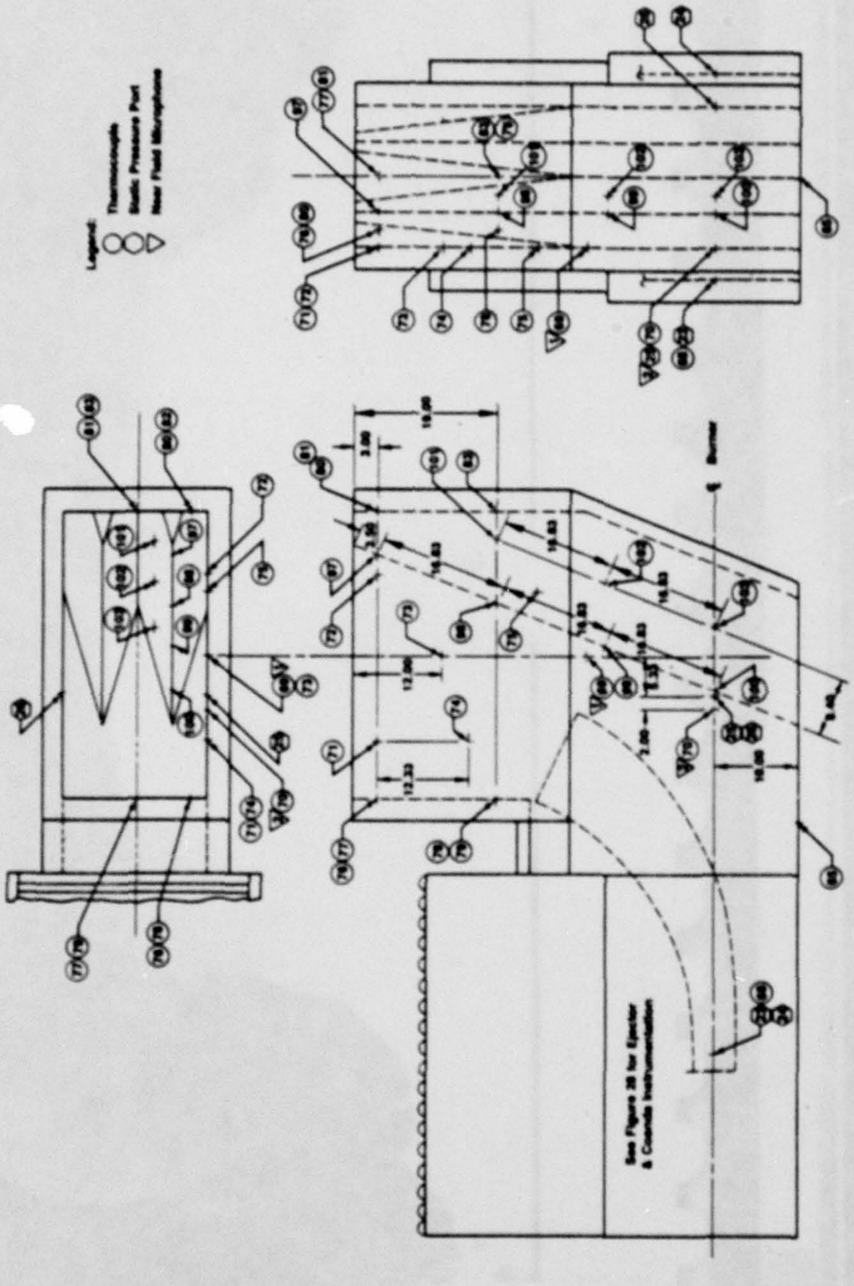


**FIGURE 33: SCHEMATIC OF ENCLOSURE INSTRUMENTATION – ACOUSTIC WEDGE EXHAUST STACK CONFIGURATION**

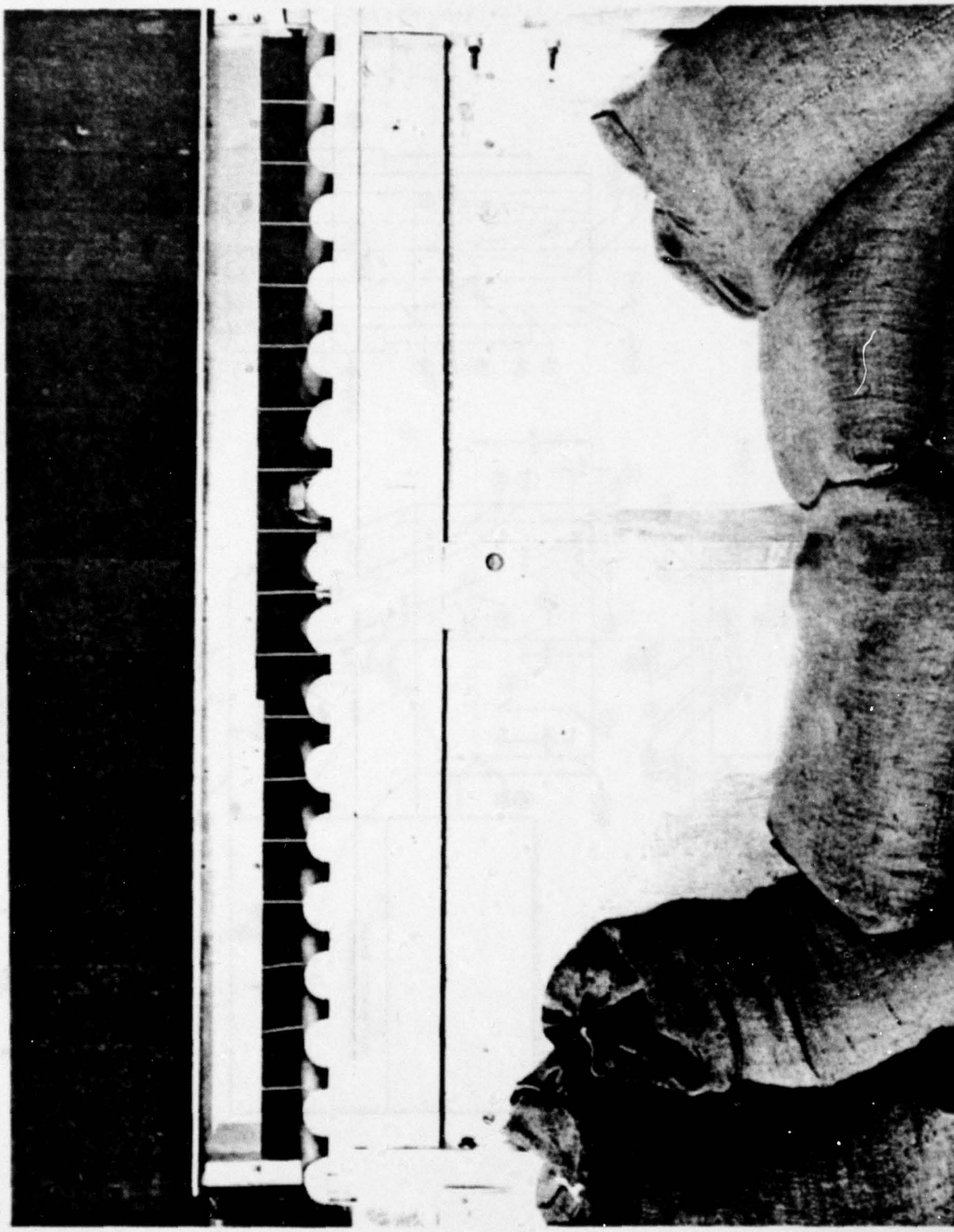


FIGURE 34: SECONDARY AIRFLOW INLET Ps RAKE INSTALLATION

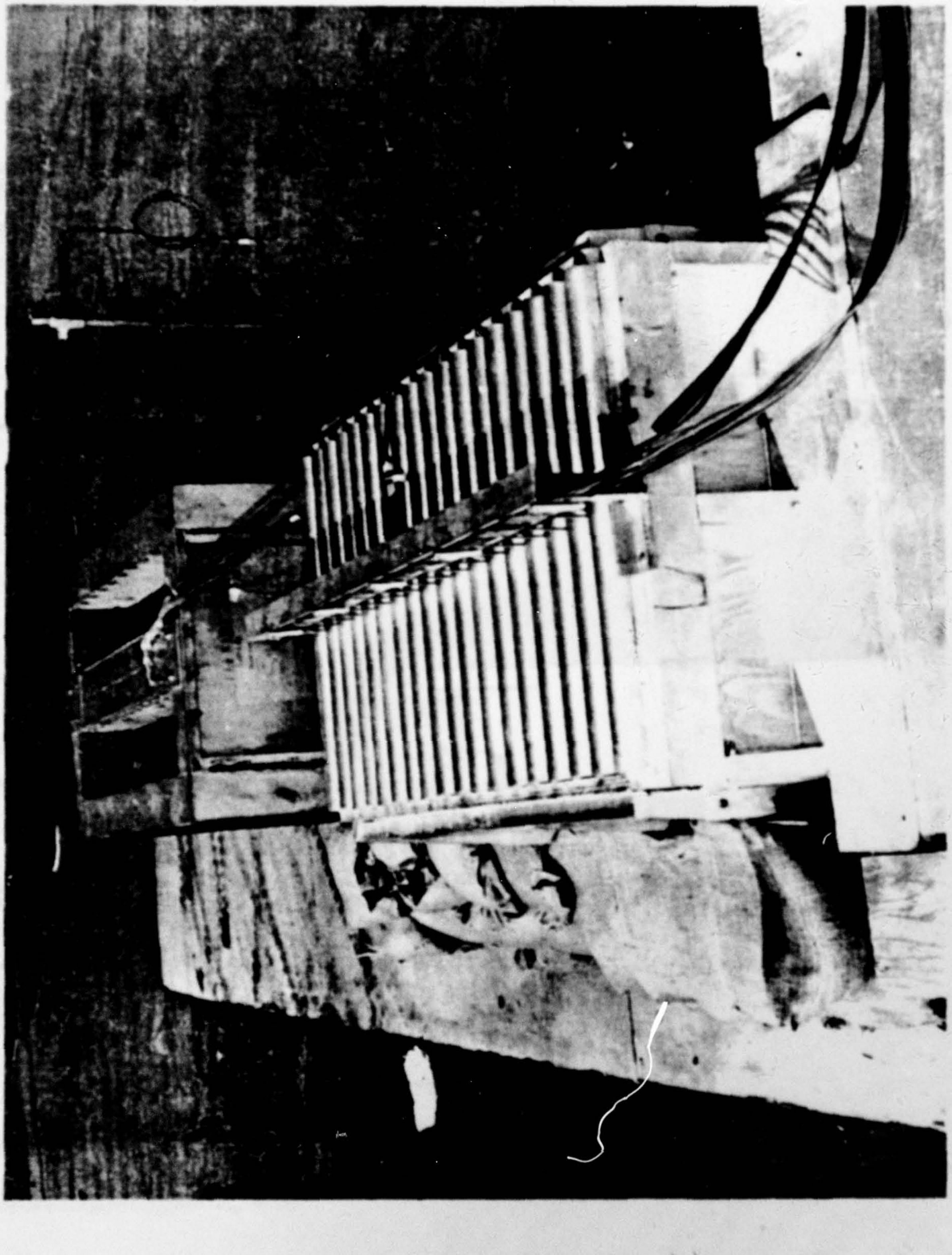


FIGURE 35: SHORT EXHAUST STACK MODEL WITH NEAR FIELD MICROPHONES INSTALLED

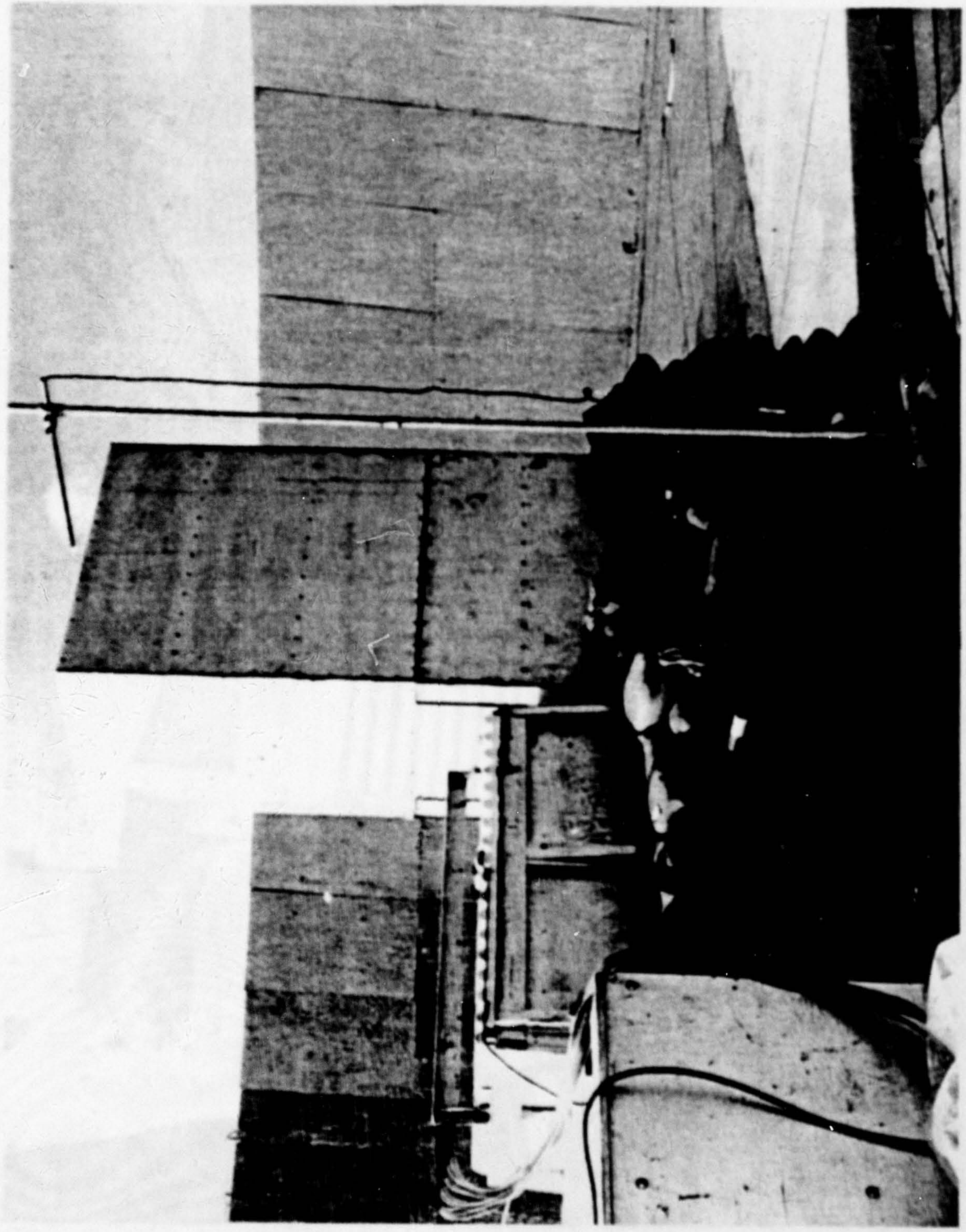


FIGURE 36: TALL EXHAUST STACK MODEL WITH NEAR FIELD MICROPHONES INSTALLED

**TABLE 1**
**INSTRUMENTATION REQUIREMENT LIST**

| Location and Measurements | Units | No. | Range | Accuracy |
|---|---|---|---|---|
| Ejector static pressure | psia | 12 | 10.0 to Amb. | ±1% |
| Coanda surface static pressure | psia | 8 | 10.0 to Amb. | ±1% |
| Enclosure inlet static pressure | psia | 17 | 13.0 to Amb. | ±1% |
| Enclosure interior static pressure | psia | 4 | 13.0 to Amb. | ±1% |
| Exit rake total pressure | psia | 14 | Amb. to 17.0 | ±1/2% |
| Ejector metal surface temperature | °F | 12 | Amb. to 1300 | ±2% |
| Coanda metal surface temperature | °F | 8 | Amb. to 1200 | ±2% |
| Enclosure interior sidewall temperature | °F | 3 | Amb. to 600 | ±2% |
| Exhaust stack metal surface temperature: | | | | |
| • Tall stack without splitter | °F | 17 | Amb. to 1000 | ±2% |
| • Short stack with single splitter | °F | 17 | Amb. to 1200 | ±2% |
| • Short stack with dual splitter | °F | 16 | Amb. to 1200 | ±2% |
| • Short stack with dual wedges | °F | 19 | Amb. to 1000 | ±2% |
| Exit rake total temperature | °F | 14 | Amb. to 1400 | ±2% |
| Far field microphones | *dB | 12 | 50 to 140 | ±1 dB |
| Near field microphones | *dB | 3 | 70 to 160 | ±1 dB |

*Data are recorded in one-third octave SPL (re. 0.002 dyne/cm2)

h. In addition to the instrumentation listed, the following (Table 2) environmental and flow condition data were recorded:

**TABLE 2**
**ENVIRONMENTAL AND FLOW CONDITIONS REQUIRED**

| Location and Measurements | Units | No. | Range | Accuracy |
|---|---|---|---|---|
| Ambient pressure | psia | 1 | 13.8 - 14.2 | ±1/2% |
| Nozzle exhaust total pressure | psia | 1 | Amb. to 35 | ±1/2% |
| Nozzle exhaust pressure ratio | – | 1 | 1.2 - 2.5 | ±1% |
| Ambient temperature | °F | 1 | – | ±2% |
| Nozzle exhaust gas temperature | °F | 1 | Amb. to* | ±2% |
| A/B cooling water in temperature | °F | 1 | 40 to 80 | ±2% |
| A/B cooling water out temperature | °F | 1 | 40 to 180 | ±2% |
| Nozzle airflow | lb/sec | 1 | 0 to 7.5 | ±1% |
| Primary burner fuel flow | lb/sec | 1 | 0 to .1 | ±2% |
| Afterburner fuel flow | lb/sec | 1 | 0 to .3 | ±2% |
| A/B cooling water flow | lb/sec | 1 | 9 to 12 | ±2% |
| Wind speed | mph | 1 | 0 to 20 | ±5% |
| Wind direction | deg. | 1 | 0 to 360 | ±15° |
| Relative humidity | % | 1 | 0 to 100 | ±2% |

***Afterburner temperature is calculated from airflow and fuel flow data used to set up afterburner condition.**

**B. Test Procedures.**

a. The target values of afterburner nozzle pressure ratio and exhaust gas total temperature were 1.943 and 3630°R, respectively, for simulation of the exhaust of a TF30-P-412A engine. Exit temperature was set for each run by setting to a constant value of burner fuel flow at the target afterburner nozzle pressure ratio. This method of setting exhaust temperature was necessary due to lack of instrumentation capable of measuring the extremely high exhaust gas temperatures used for the test.

b. A calculation procedure was developed to determine the exhaust gas temperature based on the burner fuel flow, airflow, water jacket heat loss and an assumed burner efficiency of 95 percent. A heat balance was written about the afterburner shown schematically in Figure 37, resulting in Equation (1).

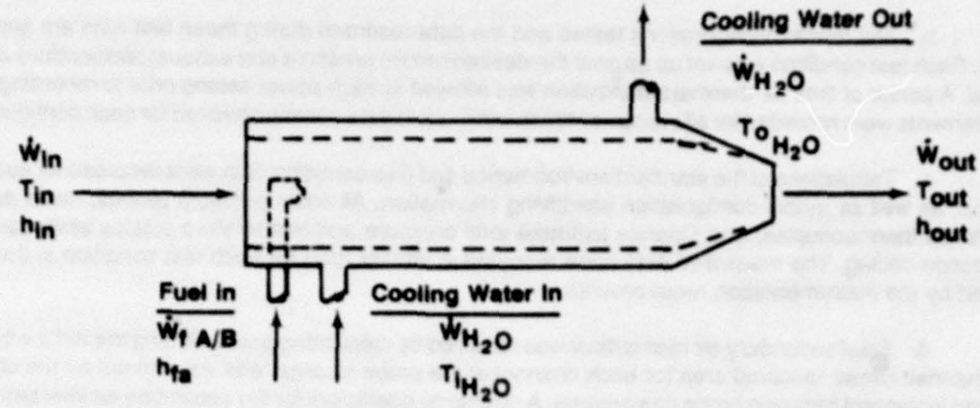



**FIGURE 37: ARENA AFTERBURNER SCHEMATIC**

$$\dot{W}_{f\ A/B}(h_{fa} + \eta_B H_v) = \dot{W}_{out} h_{out} + \dot{W}_{H_2O}\, Cp_{H_2O}\, (\Delta T_{H_2O}) - \dot{W}_{in} h_{in} \qquad (1)$$

Solving Equation (1) for exhaust flow enthalpy ($h_{out}$) results in Equation (2):

$$h_{out} = \frac{\dot{W}_{f\ A/B}(h_{fa} + \eta_B H_v) - \dot{W}_{H_2O}\, Cp_{H_2O}\, (\Delta T_{H_2O}) + \dot{W}_{in} h_{in}}{\dot{W}_{out}} \qquad (2)$$

Equations (3) and (4) below are stated equations for combustion products from Reference (e).

$$h_a = R_8T^8 + R_7T^7 + R_6T^6 + R_5T^5 + R_4T^4 + R_3T^3 + R_2T^2 + R_1T + R_0 \qquad (3)$$

($R_0$ through $R_8$ are constants defined in Section VII.)

$$h_{fc} = R_{f8}T^8 + R_{f7}T^7 + R_{f6}T^6 + R_{f5}T^5 + R_{f4}T^4 + R_{f3}T^3 + R_{f2}T^2 + R_{f1}T + R_{f0} \qquad (4)$$

($R_{f0}$ through $R_{f8}$ are constants defined in Section VII.)

Equations (3) and (4) from Reference (e) have a stated temperature range of 300° to 4000°R. However, the effects of disassociation are not believed to be included in the equations.

$$h = \frac{h_a + (f/a)\, h_{fc}}{1 + (f/a)} \qquad (5)$$

Using Equations (2), (3), (4) and (5) with appropriate test data allows an iterative solution for jet exit temperature.

Ref. e: "GENEG-A Program for Calculating Design and Off-Design Performance for Turbojet and Turbofan Engines," NASA – Lewis Research Center Document Number TND-6552, February 1972.

b. The model configurations tested and the data recorded during those test runs are shown in Table 3. Each test condition was set up as near the desired nozzle pressure and exhaust temperature as was practical. A period of time for thermal stabilization was allowed at each power setting prior to recording data. Measurements were recorded for all instrumentation within each data column checked for each configuration.

c. Tabulations of the standard environmental and flow condition data were recorded for each test condition, as well as model configuration identifying information. All static pressure probes, metal surface temperature thermocouples, and Coanda exit rake total pressure and temperature probes were assigned identification coding. The measured data were recorded in tabular form for each test condition in the units specified by the instrumentation requirements.

d. Total secondary air inlet airflow was obtained by calculating and summing the airflow through each channel. Cross sectional area for each channel at the probe location was determined by the channel width and increment between probe movements. A discharge coefficient for the secondary air inlet bellmouth of 0.98 was used in the airflow calculation.

e. Exit rake total temperature and total pressure data were used to calculate Mach number and velocity of flow at each probe location. These data were tabulated and the velocity profiles computer plotted.

f. Acoustic data reduction included conversion of the 24 one-third octave band model scale measured data to full-scale equivalent frequencies, including conversion to standard day conditions and application of absorption coefficients for the model scale frequencies and distance. The data were tabulated in one-third and full octave band SPL as well as computed OASPL and "A" weighted SPL. The one-third octave SPL values were computer plotted.

# TABLE 3
## TEST CONFIGURATIONS & DATA REQUIREMENTS

| Conf No. | Run No. | Nozzle Conditions | | | Enclo. Walls | | Stack Config. | | | | Splitter Configuration | | | | | | Acoustic Cover | | Performance Data | | | | | | | | Acoustic Data | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Walls | | Height | | | | | | | | | | Eject. & Coanda | | Encl. & Stack | | Splitter or Wedge | | Rakes | | | |
| | | Dia | $P_t/P_a$ | $T_j$ | Perf | Hard | Perf | Hard | 30' | 54' | No. Split | Single Split | Dual Split | Dual Wedge | Perf | Hard | Inlet | Burner | P | T | P | T | P | T | Inlet | Exit | Far Field | Near Field |
| 1 | 4 | 6.18 In. | 1.943 | 1 | — | | Heat Rejection – No Model – Nozzle Only | | | | | | | | | | | | | | | | | | | | | |
| 1 | 10 | | 1.943 | 3170 °F | — | | Baseline – No Model – Nozzle Only (TF30) | | | | | | | | | | | | | | | | | | | | X | |
| 1 | 11 | | 2.43 | 3095 °F | — | | Baseline – No Model – Nozzle Only (J75) | | | | | | | | | | | | | | | | | | | | X | |
| 2 | 15 | 6.18 In. | 1.943 | 3170 °F | — | | Nozzle & Ejectors Only | | | | | | | | | | | | X | X | | | | | | | X | |
| 3 | 21 | 4.31 In. | 2.105 | 703 °F | — | | Nozzle, Ejectors & Coanda Only | | | | | | | | | | | | X | X | | | | | | X | | |
| 3 | 20, 24 | 6.18 In. | 1.943 | 3170 °F | — | | Nozzle, Ejectors & Coanda Only | | | | | | | | | | | | X | X | | | | | | (20) X | (24) X | |
| 4 | 25 | | | | | | Nozzle, Ejectors & Coanda Only | | | | | | | | | | | X | X | X | | | | | | | X | |
| 5 | 26-30 | | | | | X | 2.75 Thk | | X | | | X | | | X | | | X | | | | | | | 3 X (27-30) | | (26) X | (27) X |
| 6 | 31 | | | | | X | 2.75 Thk | | X | | | X | | | X | | X | X | X | X | X | X | | X | | | X | X |
| 7 | 33 | | | | | X | 2.75 Thk | 2 | X | | | X | | | X | | X | X | X | X | X | X | | X | | | X | X |
| 8 | 32 | | | | | X | 2.75 Thk | | X | | X | | | | | | X | X | X | X | X | X | | X | | | X | X |
| 9 | 36 | | | | | X | 2.75 Thk | | | X | X | | | | | | X | X | X | X | X | X | | X | | | X | X |
| 9 | 37 | | | | | X | 2.75 Thk | | | X | X | | | | | | | X | X | X | X | X | | X | | | X | X |
| 10 | 38 | | | | | X | 2.75 Thk | | X | | | X | | | | X | X | X | | | | | | | | | X | X |
| 11 | 39 | 6.18 In. | 1.943 | 3170 °F | | X | | X | X | | | X | | | | X | X | X | | | | | | | | | X | X |

1 Setup on A/B Fuel Flow = .27 Lb/Sec With Primary Burner Exit Temp. = 1000 °F

2 Hardwall Cover Lower Back Wall

3 Move Inlet Rake to Positions of 0.0, 4.0, 8.0 and 12.0 Inches From Model ℄

**TABLE 3 (CONTD)**
**TEST CONFIGURATIONS & DATA REQUIREMENTS**

| Conf. No. | Run No. | Nozzle Conditions | | | Enclo. Walls | | Stack Config. | | | | Splitter Configuration | | | | | | Acoustic Cover | | Performance Data | | | | | | | | Acoustic Data | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Walls | | Height | | | | | | | | | | Eject. & Coanda | | Encl. & Stack | | Splitter or Wedge | | Rakes | | | |
| | | Dia | $P_t/P_a$ | Tj | Perf | Hard | Perf | Hard | 30' | 54' | No. Split | Single Split | Dual Split | Dual Wedge | Perf | Hard | Inlet | Burner | P | T | P | T | P | T | Inlet | Exit | Far Field | Near Field |
| 12 | 40 | 6.18 in. | 1.943 | 3170 °F | | X | | X | X | | X | | | | | | X | X | | | | | | | | | X | X |
| 13 | 41 | | | | | X | | X | | X | X | | | | | | X | X | | | | | | | | | X | X |
| 14 | 44 | | | | | X | 4.12 Thk | | X | | X | | | | | | X | X | | | | | | | | | X | X |
| 15 | 45 | | | | | X | 4.12 Thk | | | X | X | | | | | | X | X | | | | | | | | | X | X |
| 16 | 46 | | | | | X | 4.12 Thk | | | X | X | | | | | | | X | | | | | | | X | | X | X |
| 17 | 1 | | | | | | 4.12 Thk | | | | | | | | | | | | | | | | | | | | | |
| 18 | 48 | | | | | 4 X | 4.12 Thk | | X | | X | | | | | | | X | | | | | | | X | | X | X |
| 19 | 59 | | | | 4.00 Thk | | 4.12 Thk | | X | | | | X | | X | | X | X | X | X | X | X | | X | | | X | X |
| 20 | 58 | | | | 4.00 Thk | | 4.12 Thk | | X | | X | | | | | | X | X | X | X | X | X | | | | | X | X |
| 21 | 60 | | | | 4.00 Thk | | 4.12 Thk | | X | | | X | | | X | | X | X | X | X | X | X | | X | | | X | X |
| 22 | 50 | | | | 4.00 Thk | | 4.12 Thk | | X | | X | | | X | X | | X | X | X | X | X | X | | X | | | X | X |
| 23 | 51-55 | | | | 4.00 Thk | | 4.12 Thk | | X | | X | | | X | X | | | X | X | X | X | X | | X (51-54) | 3 X | | (55) X | (55) X |
| 24 | 61 | | | | | X | 4.12 Thk | | X | | | | X | | X | | X | X | X | X | X | X | | X | | | X | X |
| 25 | 66-69 71 | | | | | X | | X | X | | | | X | | | X | X | X | X | X | X | X | | | | 5 X (66-69) | (71) X | (71) X |
| 26 | 62-65 | 6.18 in. | 1.943 | 3170 °F | | X | | X | X | | | | | X | | X | X | X | X | X | X | X | | | | 5 X (63-65) | (62) X | (62) X |

4 Exterior Sandbags Removed
5 Position Exit Rake at Center and One Side Flow Passage

## III. TEST RESULTS

The pertinent results of the testing previously outlined are discussed in the following paragraphs:

### A. Aerothermodynamics

1. The calculation procedure described in VII.B. above was used to calculate the exhaust gas temperature for each valid data run based on the pressure ratio and fuel flow values recorded. The resulting exit temperatures are listed in Table 4. The average exhaust temperature of 3551°R was deemed adequate although it was about 80 degrees below the target temperature of 3630°R.

2. Figure 38 compares the measured secondary inlet pressure loss with the predicted loss calculated from boundary layer solutions for the inlet flow. The secondary airflow rate was calculated from the inlet rake static pressure measurements taken in the constant area section of the inlet flow passages. The rake was positioned on the inlet centerline for Runs 26, 46 and 48. The rake was located in four different positions for Runs 27 through 30 and 51 through 54 to measure inlet flow profiles for each position. The resulting area weighted flow rates were summed to obtain an estimate of the total secondary air inlet flow rate.

3. Table 5 presents secondary air entrainment data including a breakdown of entrainment by individual components. The entrainments at the ejector inlets ($W_{e1}$, $W_{e2}$, $W_{e3}$) are calculated values obtained with Boeing computer codings. These values could not be accurately measured without costly additional instrumentation. The total secondary air entrainment at the second and third ejectors and the Coanda surface is a value measured at the secondary air inlet ($W_s$). The total system entrainment would include the calculated first ejector entrainment and the measured inlet airflow ($W_{e1} + W_s$). The Coanda surface secondary air entrainment ($W_{cs}$) is the measured inlet secondary airflow ($W_s$) minus the calculated second and third ejector entrainment ($W_{e2} + W_{e3}$). The Coanda surface entrainment coefficient ($\alpha$), shown as Equation (6), is the ratio of Coanda surface secondary air entrainment to the total airflow entering the Coanda surface ($W_{cp}$).

$$\alpha = \frac{\dot{W}_{cs}}{\dot{W}_{cp}} = \frac{\dot{W}_s - (\dot{W}_{e2} + \dot{W}_{e3})}{\dot{W}_{jet} + \dot{W}_{e1} + \dot{W}_{e2} + \dot{W}_{e3}} \qquad (6)$$

4. Figure 39 gives surface temperatures and pressures along the centerline of the Coanda surface at the locations shown on Figure 28 without the acoustic enclosure. The static pressure data indicate good flow attachment through the length of the surface. The surface temperature data indicate a peak temperature of 1628°R (1168°F) which exceeds the design goal by 168 degrees.

5. Figures 40 through 43 present Coanda surface temperatures and pressures along the centerline at the locations shown on Figure 28 for configurations with the enclosure. These data show that the stack configuration had little effect on the Coanda surface pressures and temperatures which indicate, in turn, a negligible effect on Coanda flow attachment and mixing. However, when these data are compared to Figure 39, it is apparent that the presence of the enclosure is beneficial to Coanda surface cooling. With the enclosure, the peak surface temperature was 1481°R (1021°F) which is 147 degrees cooler than without the enclosure. The reason for the increased cooling is the position of the secondary air inlets. The ejectors and Coanda surface are immersed in the cool secondary air being entrained by the Coanda surface mixing. Efforts to normalize the Coanda surface temperatures by referring to ambient or primary jet temperature were abandoned because the mixing process precludes agreement throughout the temperature range. Actual measured surface temperatures are therefore presented on Figures 39 through 43.

6. Figure 44 shows the flow conditions at the exit of the Coanda surface with no enclosure present as illustrated on Figure 29. These flow velocity, Mach number and exit total temperature profiles indicate excellent flow attachment to the Coanda surface at the exit (65-degree) position. The peak flow velocity is seen to be only five inches (model scale) from the Coanda surface. Coanda surface cooling is also excellent as seen by the peak flow total temperature of 1750°F at approximately two inches from the Coanda surface while the metal surface temperature of the Coanda at that point was only 1425°R (average from last thermocouple – see Figure 39).

**TABLE 4**
**MODEL A/B EXIT TEMPERATURE CALCULATED FROM ENTHALPY RISE***

| Run No. | Exit Temp. °R | Run No. | Exit Temp. °R |
|---|---|---|---|
| 10 | 3515 | 45 | 3521 |
| 15 | – | 46 | 3540 |
| 20 | 3573 | 47 | 3559 |
| 21 | 1170 | 48 | 3523 |
| 24 | 3581 | 50 | 3528 |
| 25 | 3529 | 51 | 3586 |
| 26 | 3390 | 52 | 3562 |
| 27 | 3496 | 53 | 3620 |
| 28 | 3492 | 54 | 3538 |
| 29 | 3572 | 55 | 3573 |
| 30 | 3606 | 56 | 3648 |
| 31 | 3507 | 57 | – |
| 32 | 3578 | 58 | – |
| 33 | 3522 | 59 | – |
| 34 | 3553 | 60 | 3563 |
| 36 | 3561 | 61 | 3534 |
| 37 | 3548 | 62 | 3582 |
| 38 | 3645 | 63 | 3569 |
| 39 | 3585 | 64 | 3551 |
| 40 | 3558 | 65 | 3588 |
| 41 | 3509 | 66 | 3568 |
| 42 | 3543 | 67 | 3528 |
| 43 | 3555 | 68 | 3514 |
| 44 | 3506 | 69 | 3566 |
| | | 71 | 3571 |

***Enthalpy rise based on fuel flow, LHV = 18,400 BTU/Lb and a burner efficiency of 95 percent.**

**Test average exit temperature = 3551 °R**
**Standard Deviation = ± 43.4 °F**

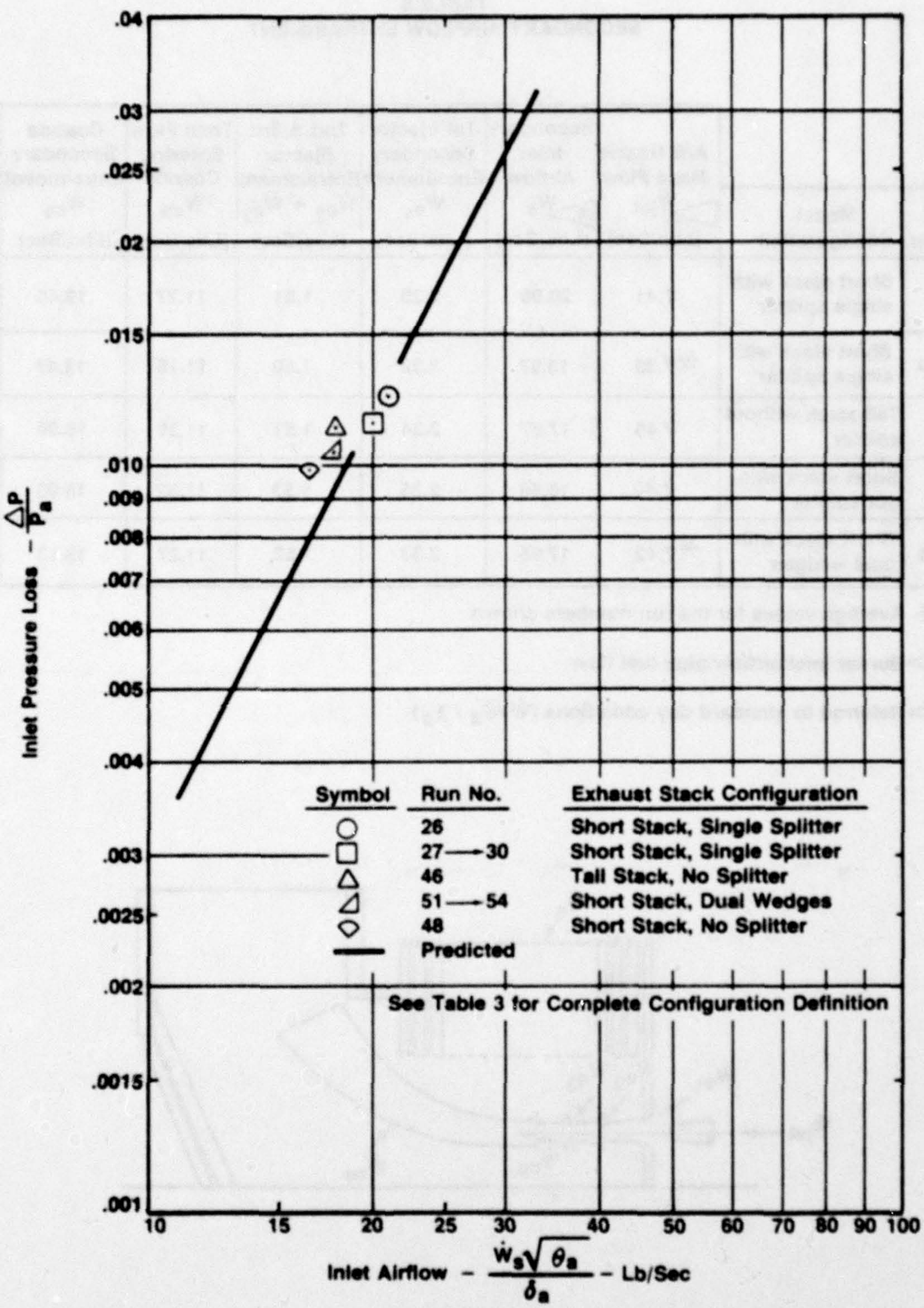



**FIGURE 38: SECONDARY AIR INLET PRESSURE LOSS VS. INLET AIRFLOW**

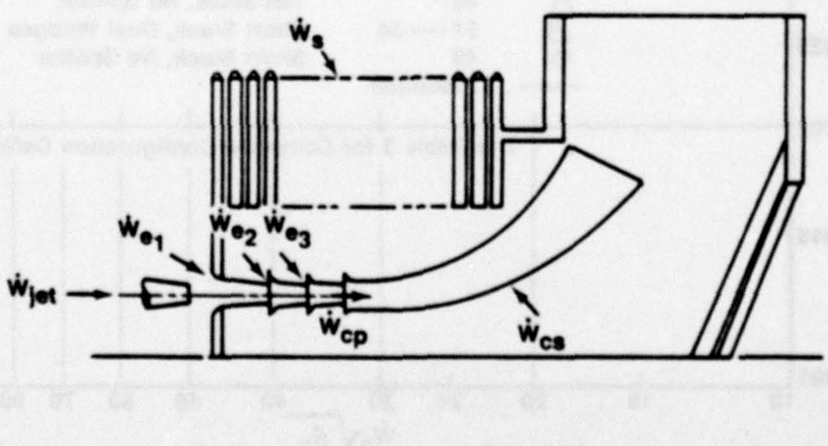
## TABLE 5
## SECONDARY AIRFLOW ENTRAINMENT

| Run Number | Model Configuration | A/B Nozzle Mass Flow ▷ $\dot{W}_{jet}$ (Lbs/Sec) | Secondary Inlet Airflow ▷X $\dot{W}_s$ (Lbs/Sec) | 1st Ejector Secondary Entrainment $\dot{W}_{e_1}$ (Lbs/Sec) | 2nd & 3rd Ejector Entrainment $\dot{W}_{e_2} + \dot{W}_{e_3}$ (Lbs/Sec) | Total Flow Entering Coanda $\dot{W}_{cp}$ (Lbs/Sec) | Coanda Secondary Entrainment $\dot{W}_{cs}$ (Lbs/Sec) | Coanda Entrainment Coefficient $\dot{W}_{cs}/\dot{W}_{cp}$ |
|---|---|---|---|---|---|---|---|---|
| 26 | Short stack with single splitter | 7.41 | 20.96 | 2.35 | 1.51 | 11.27 | 19.45 | 1.73 |
| 27-30 | Short stack with single splitter | *7.33 | 19.97 | 2.32 | 1.50 | 11.15 | 18.47 | 1.66 |
| 46 | Tall stack without splitter | 7.45 | 17.87 | 2.34 | 1.51 | 11.30 | 16.36 | 1.45 |
| 48 | Short stack without splitter | 7.44 | 16.56 | 2.35 | 1.53 | 11.32 | 15.03 | 1.33 |
| 51-54 | Short stack with dual wedges | *7.42 | 17.65 | 2.33 | 1.52 | 11.27 | 16.13 | 1.45 |

* Average values for the run numbers shown

▷ Burner inlet airflow plus fuel flow

▷X Referred to standard day conditions ($\dot{W}\sqrt{\theta_a} / \delta_a$)



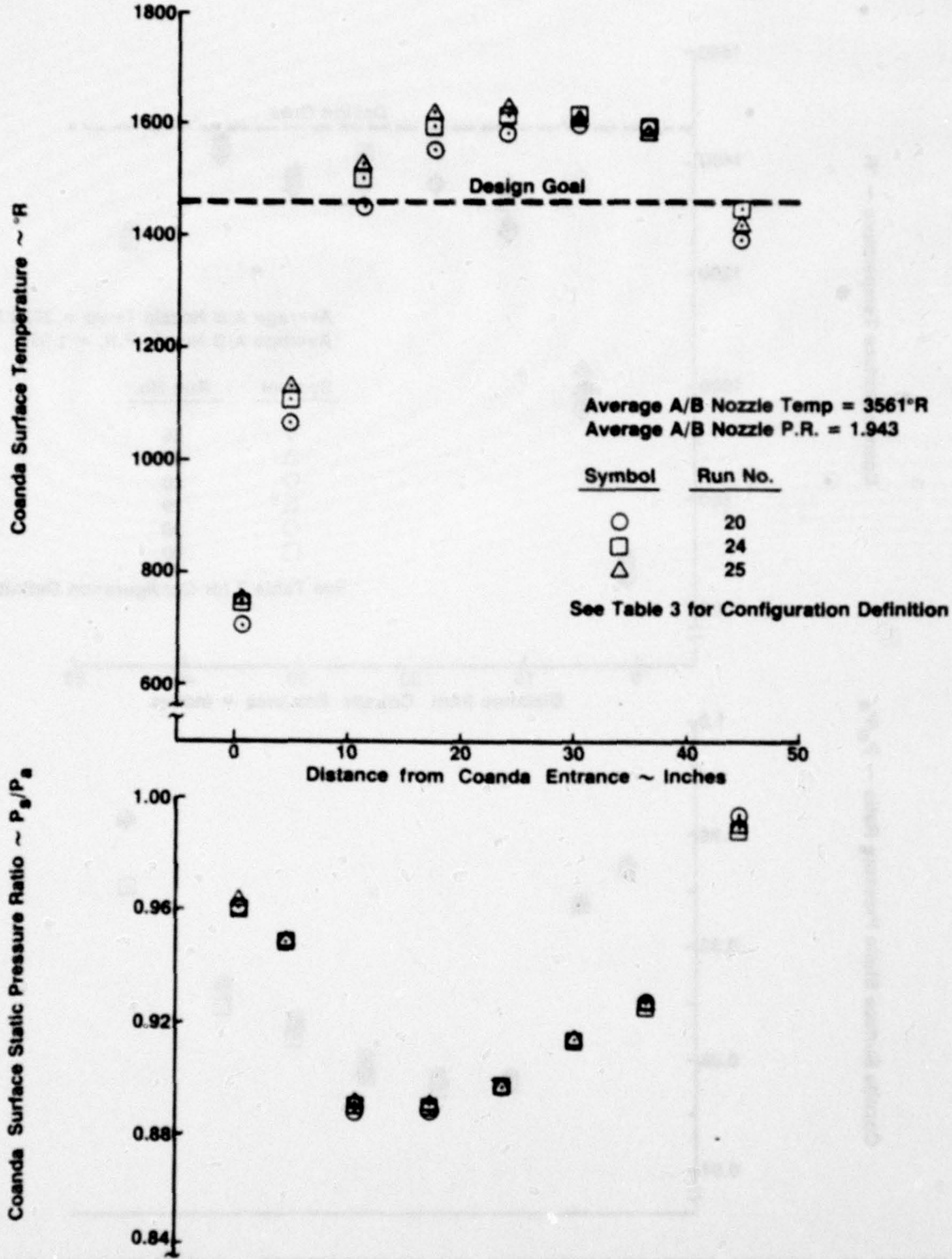



FIGURE 39: COANDA SURFACE PRESSURES AND TEMPERATURES – NO ACOUSTIC ENCLOSURE CONFIGURATION

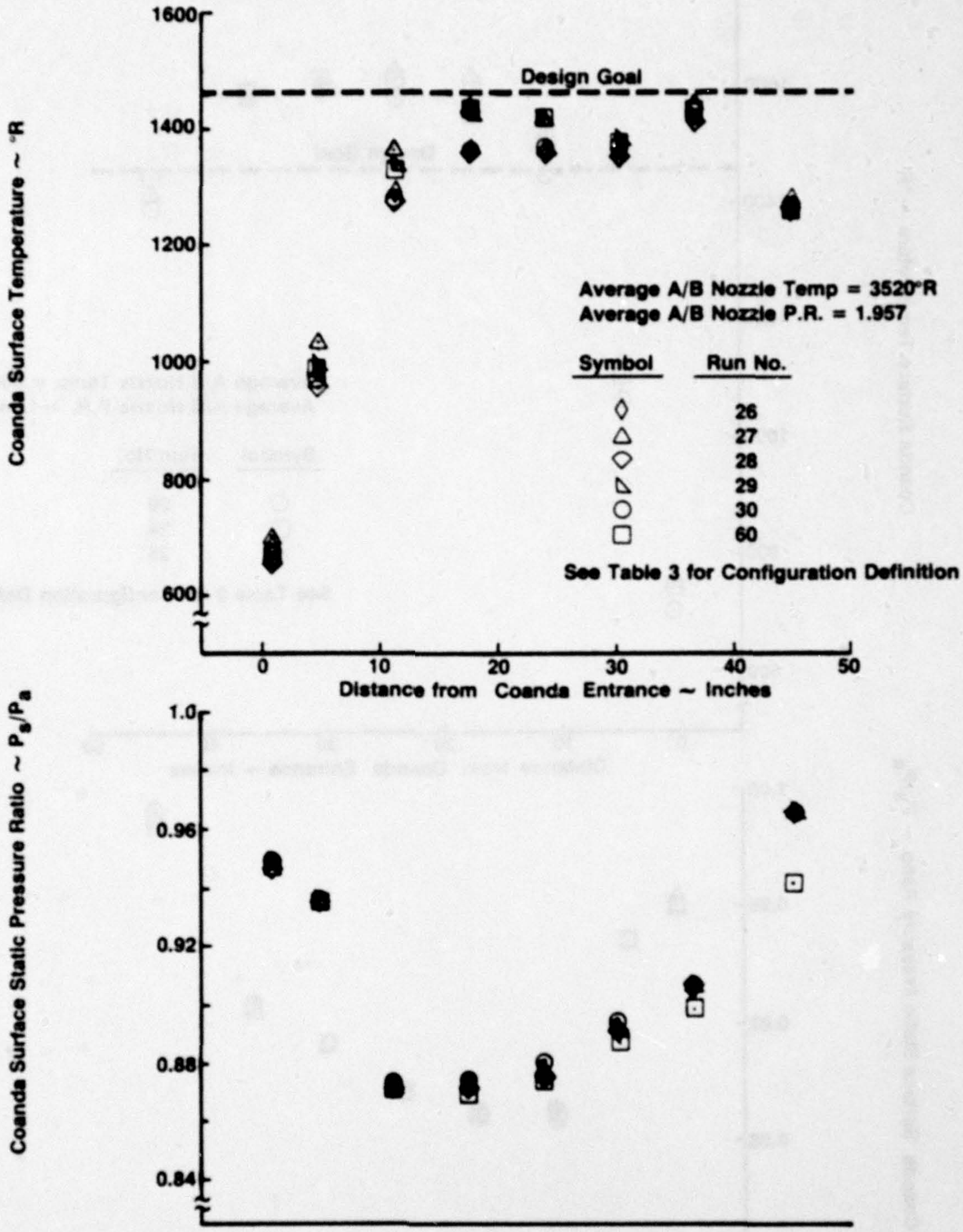



FIGURE 40: COANDA SURFACE PRESSURES AND TEMPERATURES – SHORT EXHAUST STACK WITH SINGLE SPLITTER CONFIGURATION

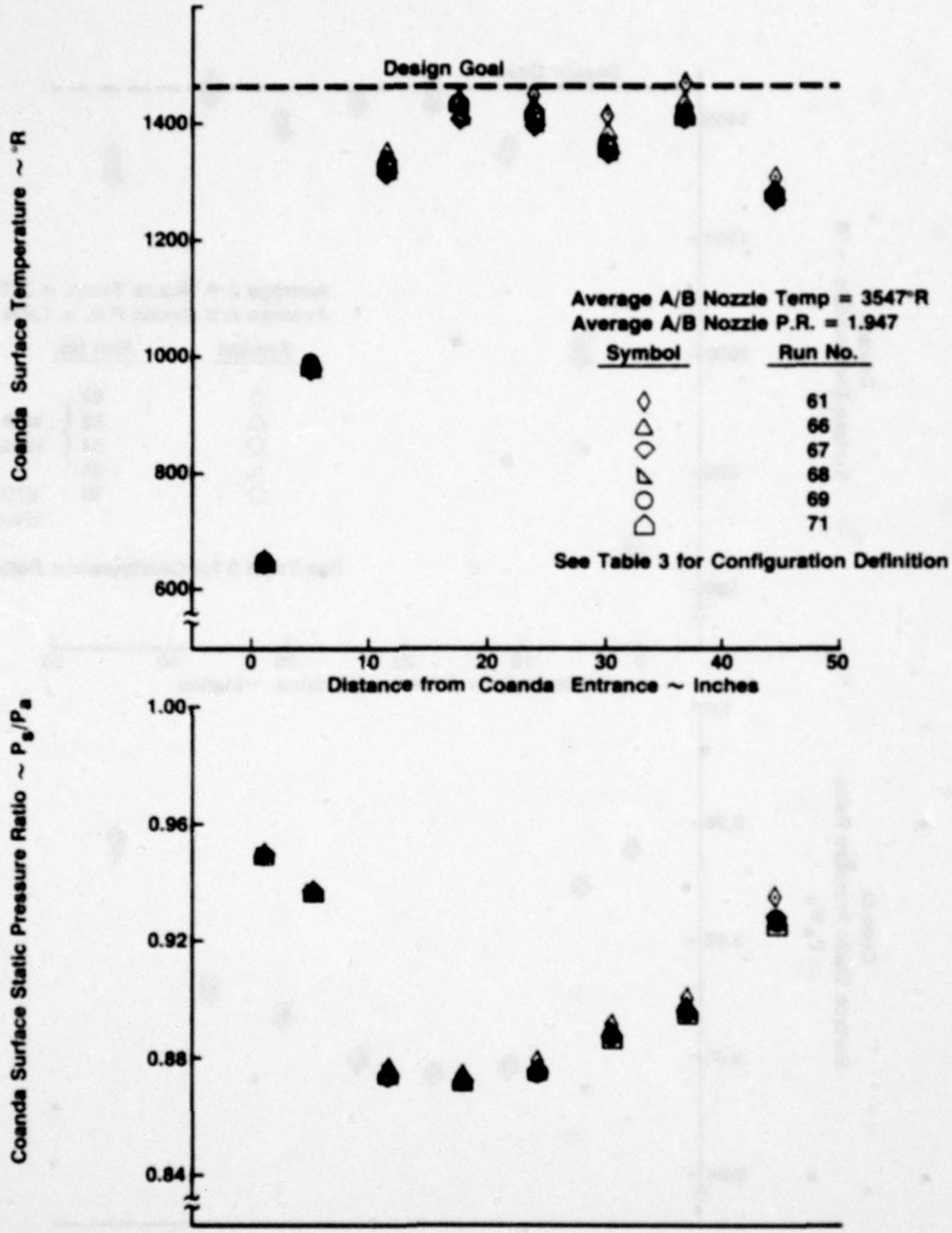



FIGURE 41: COANDA SURFACE PRESSURES AND TEMPERATURES – SHORT EXHAUST STACK WITH DUAL SPLITTER CONFIGURATION

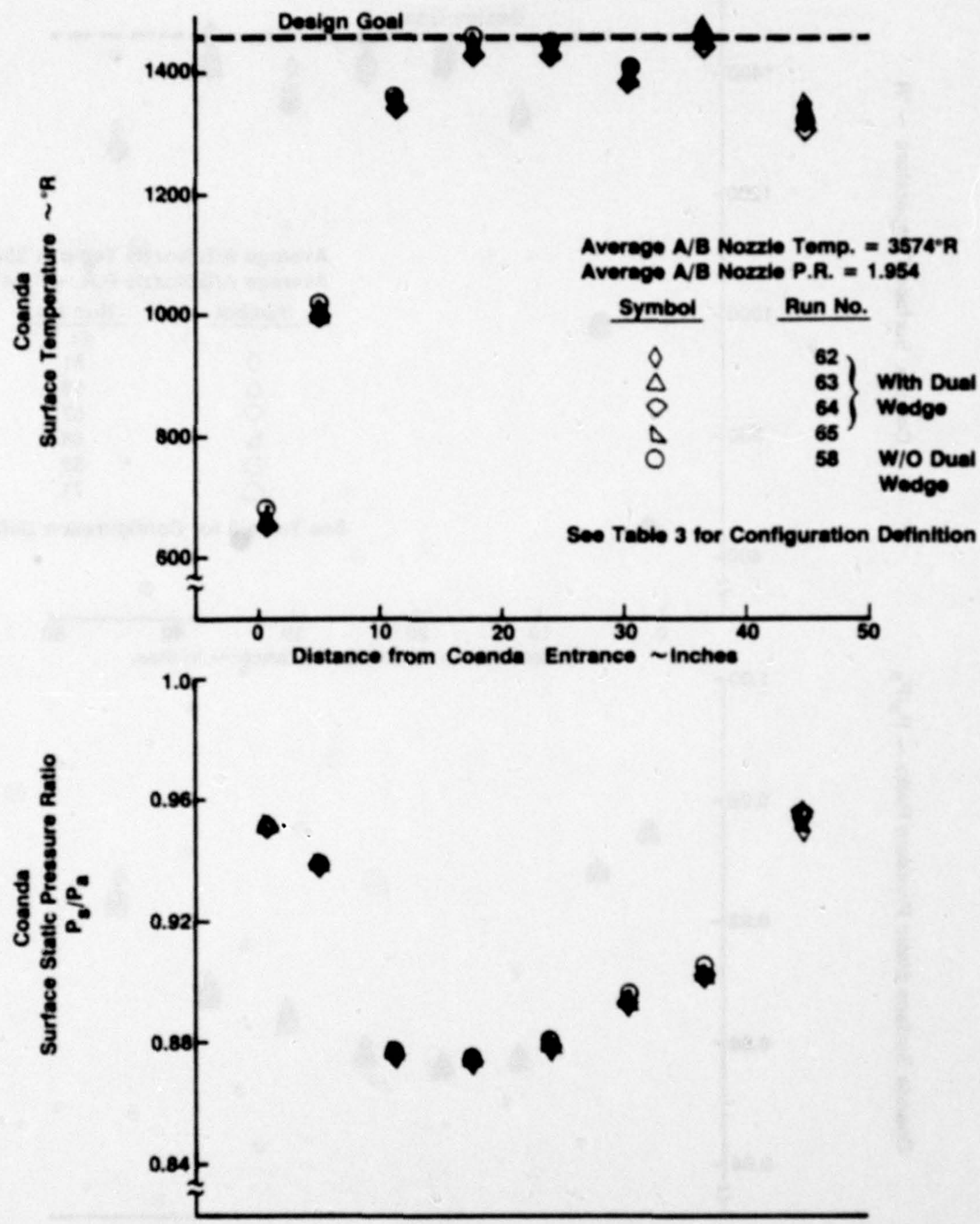



FIGURE 42: COANDA SURFACE PRESSURES AND TEMPERATURES – SHORT EXHAUST STACK WITH AND WITHOUT DUAL WEDGES

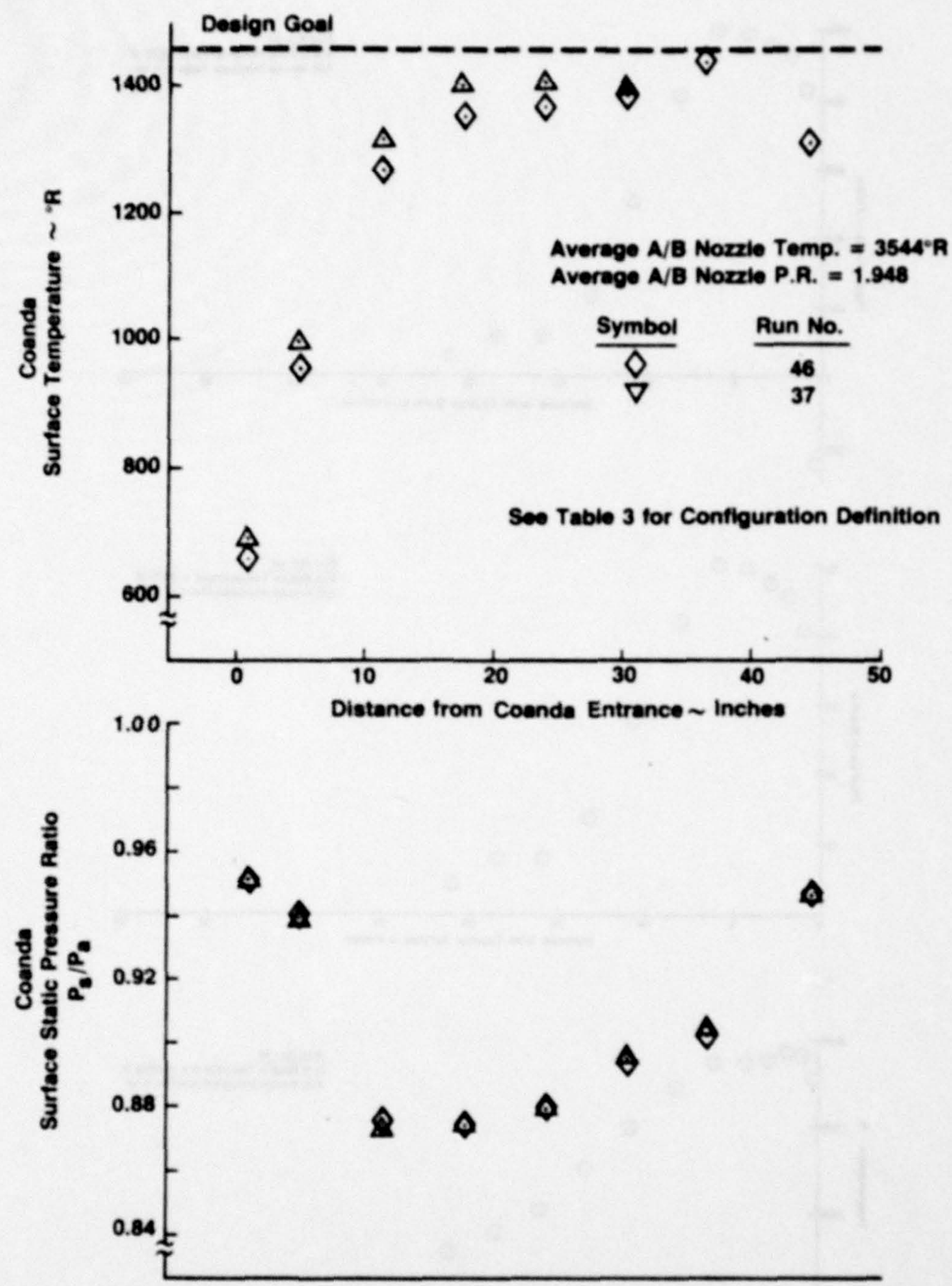



FIGURE 43: COANDA SURFACE PRESSURES AND TEMPERATURES – TALL EXHAUST STACK WITHOUT SPLITTER OR WEDGES

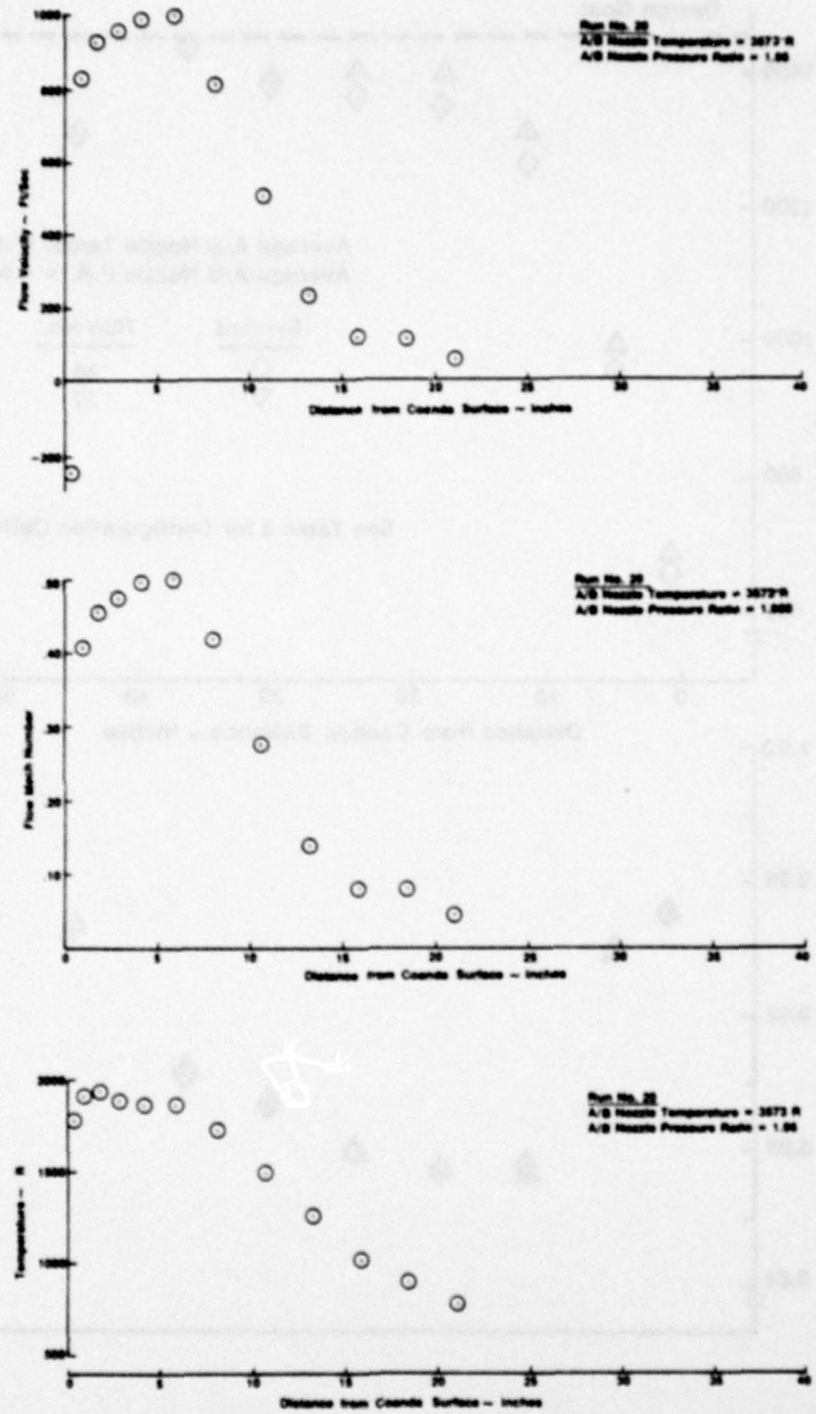


FIGURE 44: COANDA EXIT FLOW VELOCITY, MACH NUMBER AND TEMPERATURE PROFILES – NO ACOUSTIC ENCLOSURE

7. Figures 45 through 47 present exhaust stack exit flow velocity, Mach number and temperature profiles for each of the three short stack configurations tested (single splitter, dual splitter and dual wedges). All three configurations illustrated a region of reverse flow (shown by negative velocities) near the forward wall of the exhaust stack. This is caused by the 65-degree exit from the Coanda surface into a vertical (90-degree) exhaust stack. The velocity in these reverse flow regions was estimated using the pressure reading from the exit total pressure rake as a static pressure and ambient pressure as the total pressure. This procedure was used when rake pressure measurements were below ambient which indicates local reverse flow. Use of these rake pressure readings as static pressures is an acceptable procedure due to the low velocities in the reverse flow regions.

8. Tables 6 and 7 list the ejector surface temperatures along the top and side centerlines, respectively, for the various model configurations. The locations of these thermocouples were shown on Figure 28. The values shown are averages for all test runs of that particular configuration, along with the maximum and minimum deviation from that average. The ambient and afterburning nozzle temperatures are also presented. In general, there is no significant change in ejector surface temperatures due to changes in stack configuration or removal of the acoustic cover from the secondary air inlet. There is a significant change in ejector surface temperatures, however, between the configuration without an enclosure and those that are enclosed. The reduced ejector temperatures with the enclosure present are due to the secondary air inlet position just as was discussed earlier for the Coanda surface temperatures. With the enclosure installed, the maximum average temperature was at the exit of the first ejector and was 986°F which is below the design goal of 1000°F.

9. Tables 8 through 11 list the exhaust muffler internal surface temperatures for the various model configurations at afterburning primary nozzle conditions. The location of the thermocouples where the measurements were taken was shown on Figures 31, 32 and 33. The values listed are averages of all test runs of that particular configuration. Also listed are the maximum and minimum deviations from that average. The large deviations shown are not the result of poor instrumentation but rather from the large fluctuations within the exhaust stack due to turbulent flow. These data indicate that Coanda surface mixing has to be improved before a configuration with splitters could be used. The single splitter had local areas that reached 1295°F average temperature while the dual splitter configuration reached 1370°F. These temperatures exceed the 1000°F design goal by too much to ensure expected life cycles. The dual wedge configuration did not demonstrate any such high temperature regions because there were no components immersed directly in the hottest portion of the exhaust flow. This was also true for the tall stack configuration which had no splitters or wedges.

**B. Acoustics.**

1. The use of models for acoustic testing will give indications of configuration superiority when the same acoustic lining design is used. The magnitude of the attenuation obtained from model testing may not be attributed to full-scale hardware since the lining materials were not physically scaled; for example, the ratio of fiber diameter to wavelength or the scaling of perforated sheet hole diameter and thickness. Therefore, the direct comparison of model acoustic results to full-scale criterion must not be interpreted as having or not having satisfied a particular full-scale criterion, since the linings were not and possibly cannot be precisely scaled. However, as stated above, indications can be gained as to which configurations are superior acoustically. Full-scale linings must then be optimized and designed to provide the necessary suppressor noise reduction to satisfy the acoustic criterion.

2. The primary acoustic objective of this program was to compare (by one-sixth scale model tests) several configurations of exhaust muffler for a demountable exhaust suppressor system utilizing the Coanda air-cooled concept as applied to a Model TF30-P-412 nozzle at afterburning operation. Two lining thicknesses of stack wall lining were tested for relative acoustic performance to determine the additional low frequency attenuation of the thicker lining, if any. Four different short stack configurations were tested to establish which design was acoustically superior. These consisted of no splitter, single splitter, dual splitter and dual wedge short stack configurations. The test results were compared to MIL-N-83155B, Grade II criterion on a 250-foot scale radius.

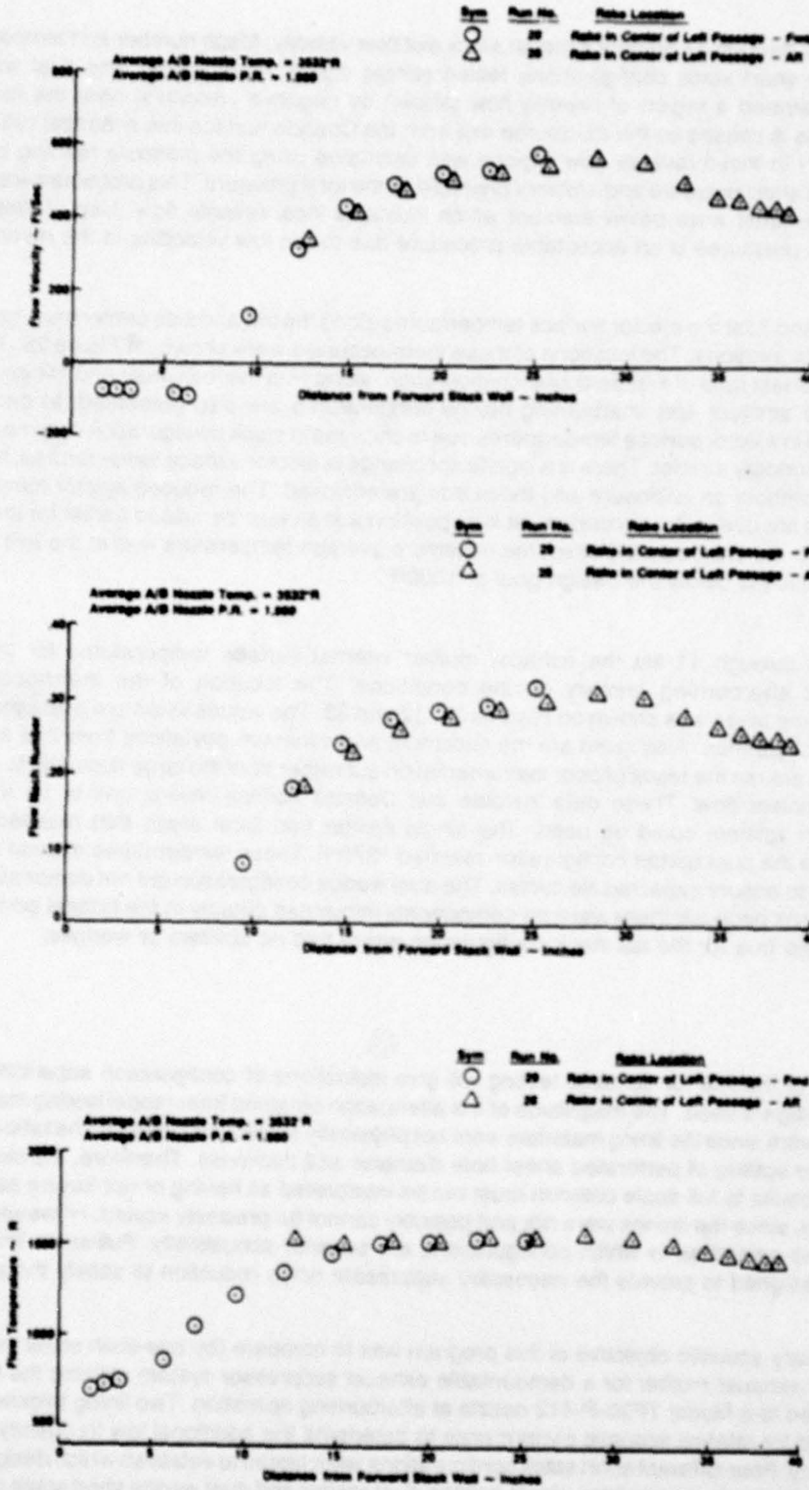


FIGURE 45: EXIT FLOW VELOCITY MACH NUMBER AND TEMPERATURE PROFILES – SHORT EXHAUST STACK WITH SINGLE SPLITTER CONFIGURATION

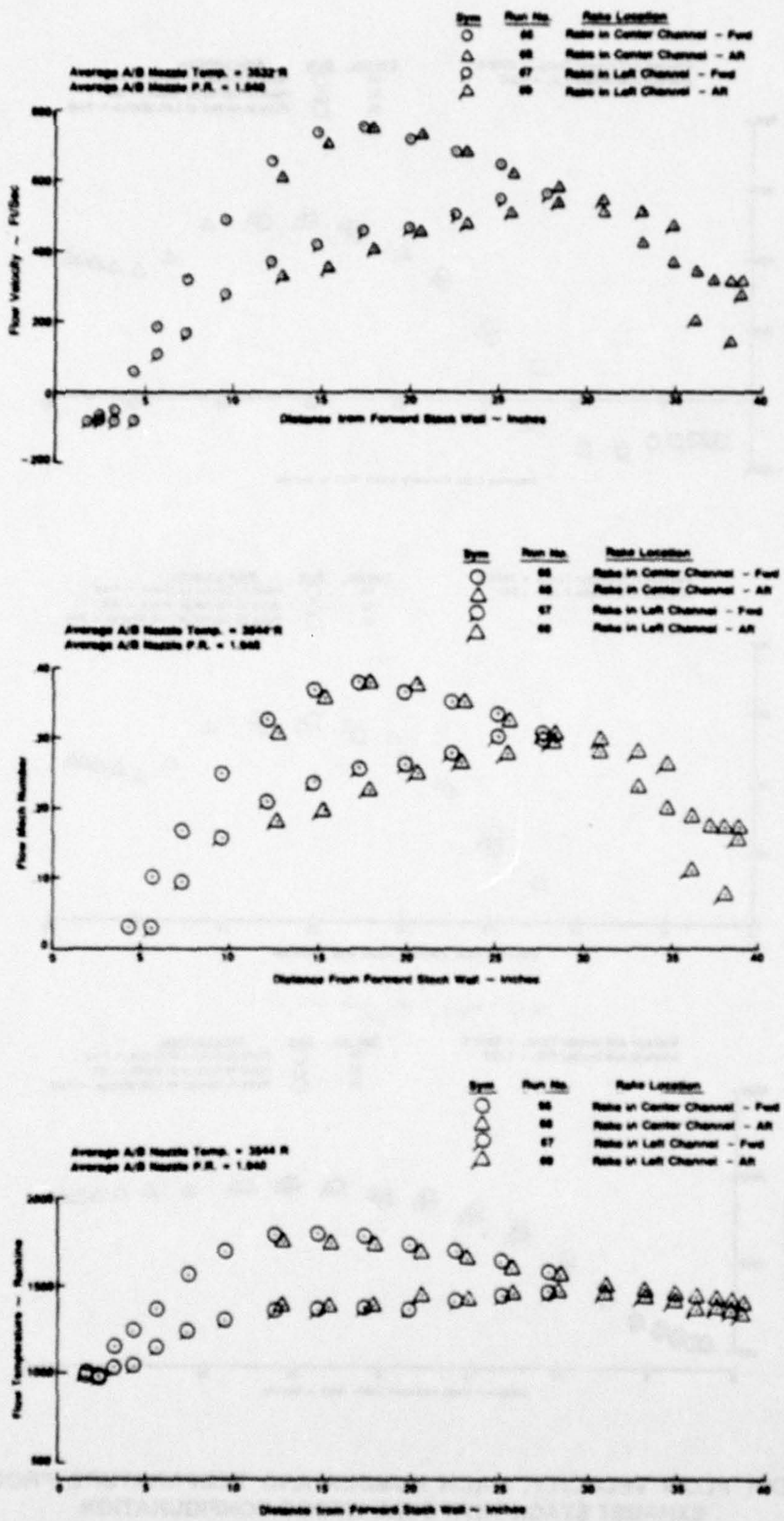


FIGURE 46: EXIT FLOW VELOCITY, MACH NUMBER AND TEMPERATURE PROFILES – SHORT EXHAUST STACK WITH DUAL SPLITTER CONFIGURATION

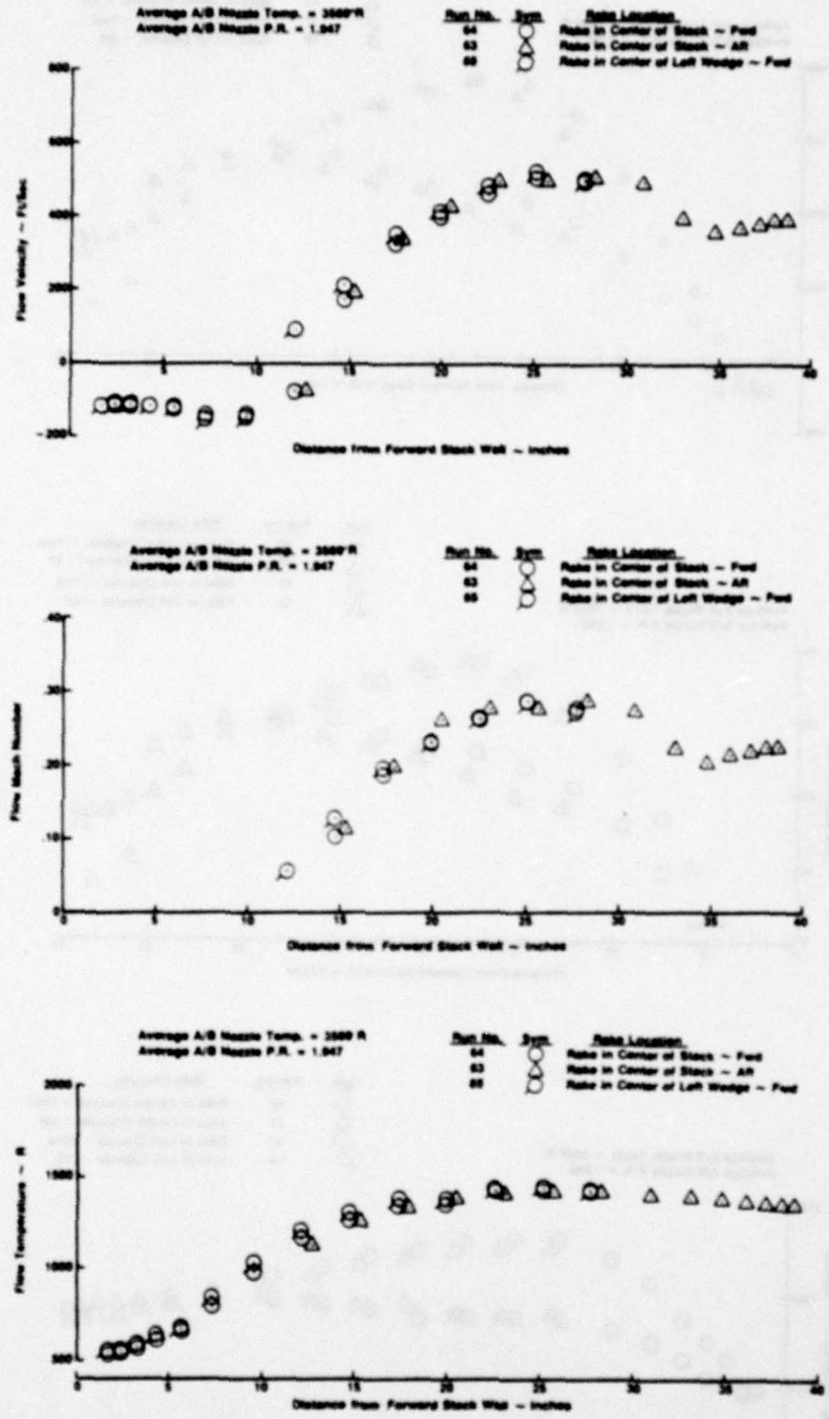


**FIGURE 47: EXIT FLOW VELOCITY, MACH NUMBER AND TEMPERATURE PROFILE – SHORT EXHAUST STACK WITH DUAL WEDGE CONFIGURATION**

TABLE 6
TOP CENTERLINE EJECTOR SURFACE TEMPERATURES
TEST AVERAGE TEMPERATURE (°F) WITH MAXIMUM AND MINIMUM DEVIATION

| Model Configuration | Ambient Temperature $T_a$ | Ambient Temperature $T_{jet}$ | Ejector No. 1 $T_1$ | Ejector No. 1 $T_3$ | Ejector No. 2 $T_5$ | Ejector No. 2 $T_7$ | Ejector No. 3 $T_9$ | Ejector No. 3 $T_{11}$ |
|---|---|---|---|---|---|---|---|---|
| Ejectors and Coanda only, no acoustic enclosure | $79^{+4}_{-5}$ | $3101^{+20}_{-32}$ | $380^{+19}_{-25}$ | $1060^{+46}_{-34}$ | $190^{+12}_{-15}$ | $674^{+31}_{-28}$ | $780^{+38}_{-35}$ | $932^{+33}_{-28}$ |
| Short stack without splitter and without inlet acoustic cover | 56 | 3063 | 292 | 880 | 139 | 552 | 644 | 763 |
| Short stack without splitter and with inlet acoustic cover | $64^{+11}_{-11}$ | $3089^{+29}_{-43}$ | $314^{+53}_{-32}$ | $909^{+55}_{-39}$ | $145^{+16}_{-17}$ | $556^{+35}_{-29}$ | $641^{+41}_{-35}$ | $782^{+48}_{-29}$ |
| Short stack with single splitter and without inlet acoustic cover | $70^{+17}_{-12}$ | $3060^{+86}_{-130}$ | $307^{+27}_{-20}$ | $916^{+71}_{-64}$ | $147^{+17}_{-13}$ | $574^{+27}_{-41}$ | $652^{+41}_{-30}$ | $783^{+59}_{-50}$ |
| Short stack with single splitter and with inlet acoustic cover | $70^{+23}_{-10}$ | $3100^{+85}_{-53}$ | $298^{+10}_{-11}$ | $885^{+27}_{-36}$ | $145^{+24}_{-9}$ | $549^{+28}_{-28}$ | $617^{+32}_{-36}$ | $766^{+28}_{-29}$ |
| Short stack with dual splitters and without inlet acoustic cover | $45^{+2}_{-2}$ | $3087^{+24}_{-33}$ | $285^{+34}_{-24}$ | $986^{+26}_{-26}$ | $129^{+6}_{-3}$ | $597^{+16}_{-13}$ | $672^{+15}_{-17}$ | $854^{+20}_{-22}$ |
| Short stack with dual wedges and without inlet acoustic cover | $48^{+2}_{-1}$ | $3113^{+15}_{-22}$ | $288^{+19}_{-17}$ | $985^{+11}_{-9}$ | $136^{+2}_{-2}$ | $606^{+4}_{-7}$ | $686^{+8}_{-5}$ | $854^{+7}_{-5}$ |
| Short stack with dual wedges and with inlet acoustic cover | 44 | 3068 | 274 | 860 | 127 | 548 | 612 | 775 |
| Tall stack without splitter and without inlet acoustic cover | $71^{+14}_{-14}$ | $3084^{+4}_{-4}$ | $294^{+4}_{-4}$ | $886^{+17}_{-18}$ | $144^{+16}_{-16}$ | $549^{+22}_{-22}$ | $627^{+28}_{-29}$ | $764^{+15}_{-16}$ |
| Tall stack without splitter and with inlet acoustic cover | $64^{+18}_{-11}$ | $3078^{+23}_{-29}$ | $305^{+32}_{-43}$ | $908^{+30}_{-27}$ | $140^{+23}_{-14}$ | $551^{+13}_{-4}$ | $625^{+23}_{-26}$ | $783^{+23}_{-25}$ |

TABLE 7
SIDE CENTERLINE EJECTOR SURFACE TEMPERATURES
TEST AVERAGE TEMPERATURE (°F) WITH MAXIMUM AND MINIMUM DEVIATION

| Model Configuration | Ambient Temperature $T_a$ | Ambient Temperature $T_{jet}$ | Ejector No. 1 | | Ejector No. 2 | | Ejector No. 3 | |
|---|---|---|---|---|---|---|---|---|
| | | | $T_2$ | $T_4$ | $T_6$ | $T_8$ | $T_{10}$ | $T_{12}$ |
| Ejectors and Coanda only, no acoustic enclosure | $79^{+4}_{-5}$ | $3101^{+20}_{-32}$ | $179^{+26}_{-25}$ | $694^{+65}_{-56}$ | $693^{+48}_{-49}$ | $804^{+56}_{-50}$ | $765^{+49}_{-55}$ | $862^{+56}_{-50}$ |
| Short stack without splitter and without inlet acoustic cover | 56 | 3063 | 175 | 712 | 677 | 794 | 753 | 835 |
| Short stack without splitter and with inlet acoustic cover | $64^{+11}_{-11}$ | $3089^{+29}_{-43}$ | $166^{+27}_{-36}$ | $640^{+65}_{-65}$ | $631^{+43}_{-64}$ | $734^{+58}_{-71}$ | $702^{+42}_{-61}$ | $780^{+52}_{-64}$ |
| Short stack with single splitter and without inlet acoustic cover | $70^{+17}_{-12}$ | $3060^{+86}_{-130}$ | $174^{+13}_{-18}$ | $690^{+39}_{-48}$ | $651^{+44}_{-68}$ | $774^{+47}_{-61}$ | $718^{+40}_{-61}$ | $814^{+41}_{-57}$ |
| Short stack with single splitter and with inlet acoustic cover | $70^{+23}_{-10}$ | $3100^{+85}_{-53}$ | $174^{+19}_{-17}$ | $660^{+54}_{-97}$ | $644^{+54}_{-93}$ | $753^{+59}_{-104}$ | $705^{+51}_{-86}$ | $787^{+53}_{-91}$ |
| Short stack with dual splitters and without inlet acoustic cover | $45^{+2}_{-2}$ | $3087^{+24}_{-33}$ | $156^{+12}_{-14}$ | $661^{+31}_{-32}$ | $625^{+41}_{-33}$ | $744^{+40}_{-34}$ | $699^{+35}_{-30}$ | $799^{+73}_{-46}$ |
| Short stack with dual wedges and without inlet acoustic cover | $48^{+2}_{-1}$ | $3113^{+15}_{-22}$ | $167^{+6}_{-7}$ | $680^{+10}_{-16}$ | $641^{+9}_{-20}$ | $757^{+9}_{-18}$ | $716^{+9}_{-23}$ | $791^{+12}_{-20}$ |
| Short stack with dual wedges and with inlet acoustic cover | 44 | 3068 | 172 | 701 | 664 | 782 | 745 | 815 |
| Tall stack without splitter and without inlet acoustic cover | $71^{+14}_{-14}$ | $3084^{+4}_{-4}$ | $167^{+12}_{-13}$ | $636^{+39}_{-39}$ | $606^{+28}_{-28}$ | $713^{+42}_{-42}$ | $680^{+23}_{-23}$ | $759^{+34}_{-35}$ |
| Tall stack without splitter and with inlet acoustic cover | $64^{+18}_{-11}$ | $3078^{+23}_{-29}$ | $166^{+22}_{-17}$ | $637^{+48}_{-33}$ | $624^{+35}_{-22}$ | $730^{+47}_{-23}$ | $685^{+36}_{-20}$ | $768^{+50}_{-26}$ |

TABLE 8
EXHAUST MUFFLER TEMPERATURES –
SHORT STACK WITH SINGLE SPLITTER CONFIGURATION ($T_a = 70^{+17}_{-10}$ °F)

| Thermocouple Number (See Fig. 31) | General Location (See Figure 31 for Exact Location) | Average Measured Temperature With Maximum and Minimum Deviation (°F) |
|---|---|---|
| $T_{23}$ | Stack Forward Wall – Lower | 781 $^{+64}_{-47}$ |
| $T_{24}$ | Stack Forward Wall – Upper | 386 $^{+38}_{-42}$ |
| $T_{25}$ | Stack Sidewall – Upper Forward | 837 $^{+23}_{-33}$ |
| $T_{26}$ | Stack Sidewall – Upper Aft | 963 $^{+49}_{-22}$ |
| $T_{27}$ | Stack Sidewall – Center | 1023 $^{+21}_{-45}$ |
| $T_{28}$ | Stack Sidewall – Lower Forward | 802 $^{+54}_{-76}$ |
| $T_{29}$ | Stack Sidewall – Lower Aft | 888 $^{+60}_{-59}$ |
| $T_{30}$ | Stack Aft Wall – Lower | 884 $^{+32}_{-36}$ |
| $T_{31}$ | Stack Aft Wall – Upper | 986 $^{+53}_{-59}$ |
| $T_{40}$ | Splitter Leading Edge – Forward | 1294 $^{+32}_{-32}$ |
| $T_{41}$ | Splitter Leading Edge – Center | 1129 $^{+38}_{-27}$ |
| $T_{42}$ | Splitter Leading Edge – Aft | – – |
| $T_{43}$ | Splitter Sidewall – Upper Forward | 922 $^{+26}_{-16}$ |
| $T_{44}$ | Splitter Sidewall – Upper Aft | 1034 $^{+37}_{-51}$ |
| $T_{45}$ | Splitter Sidewall – Center | 1136 $^{+31}_{-58}$ |
| $T_{46}$ | Splitter Sidewall – Lower Forward | 1295 $^{+26}_{-31}$ |
| $T_{47}$ | Splitter Sidewall – Lower Left | 812 $^{+58}_{-61}$ |
| $T_{65}$ | Enclosure Floor – Aft | 208 $^{+45}_{-38}$ |
| $T_{66}$ | Aft Enclosure Sidewall – Upper | 568 $^{+113}_{-41}$ |
| $T_{67}$ | Aft Enclosure Sidewall – Lower | 497 $^{+46}_{-25}$ |

TABLE 9
EXHAUST MUFFLER TEMPERATURES –
SHORT STACK WITH DUAL SPLITTER CONFIGURATION ($T_a = 54 \begin{smallmatrix}+10\\-9\end{smallmatrix}$°F)

| Thermocouple Number (See Fig. 32) | General Location (See Figure 32 for Exact Location) | Average Measured Temperature With Maximum and Minimum Deviation (°F) |
|---|---|---|
| $T_{65}$ | Enclosure Floor – Aft | 210 ± 8 |
| $T_{69}$ | Aft Enclosure Sidewall | 738 |
| $T_{70}$ | Aft Enclosure Sidewall | 649 |
| $T_{71}$ | Stack Sidewall – Upper Forward | 772 ±28 |
| $T_{72}$ | Stack Sidewall – Upper Aft | 970 ±31 |
| $T_{73}$ | Stack Sidewall – Center | 1019 ±33 |
| $T_{74}$ | Stack Sidewall – Lower Forward | 803 ± 9 |
| $T_{75}$ | Stack Sidewall – Lower Aft | 901 ±23 |
| $T_{76}$ | Stack Forward Wall – Upper Outboard Passage | 317 ±19 |
| $T_{77}$ | Stack Forward Wall – Upper Center Passage | 924 ±20 |
| $T_{78}$ | Stack Forward Wall – Lower Outboard Passage | 1164 ±11 |
| $T_{79}$ | Stack Forward Wall – Lower Center Passage | 1318 ± 7 |
| $T_{80}$ | Stack Aft Wall – Upper Outboard Passage | 982 ±27 |
| $T_{81}$ | Stack Aft Wall – Upper Center Passage | 1005 ± 4 |
| $T_{82}$ | Stack Aft Wall – Lower Outboard Passage | 925 ±27 |
| $T_{83}$ | Stack Aft Wall – Lower Center Passage | 870 |
| $T_{84}$ | Splitter Sidewall – Upper Forward Outboard Passage | 737 ±40 |
| $T_{85}$ | Splitter Sidewall – Upper Forward Center Passage | 1302 ±14 |
| $T_{86}$ | Splitter Sidewall – Upper Aft Outboard Passage | 1043 ±31 |
| $T_{87}$ | Splitter Sidewall – Upper Aft Center Passage | 1088 ±11 |
| $T_{88}$ | Splitter Sidewall – Center Outboard Passage | 1115 ±37 |
| $T_{89}$ | Splitter Sidewall – Center – Center Passage | 1229 ±10 |
| $T_{90}$ | Splitter Sidewall – Lower Forward Outboard Passage | 1197 ±33 |
| $T_{91}$ | Splitter Sidewall – Lower Forward Center Passage | 1370 ±12 |
| $T_{92}$ | Splitter Sidewall – Lower Aft Outboard Passage | 860 ±23 |
| $T_{93}$ | Splitter Sidewall – Lower Aft Center Passage | 899 ± 5 |
| $T_{94}$ | Splitter Leading Edge Forward | 1368 ±26 |
| $T_{95}$ | Splitter Leading Edge – Center | 1219 +21 |
| $T_{96}$ | Splitter Leading Edge – Aft | 893 ±12 |

TABLE 10
EXHAUST MUFFLER TEMPERATURES –
SHORT STACK WITH DUAL ACOUSTIC WEDGE CONFIGURATION ($T_a = 45 {}^{+2}_{-6}$ °F)

| Thermocouple Number (See Fig. 33) | General Location (See Figure 33 for Exact Location | Average Measured Temperature With Maximum and Minimum Deviation (°F) |
|---|---|---|
| $T_{69}$ | Aft Enclosure Sidewall – Upper | $517 {}^{+65}_{-35}$ |
| $T_{70}$ | Aft Enclosure Sidewall – Lower | $418 {}^{+26}_{-42}$ |
| $T_{71}$ | Stack Sidewall – Upper Forward | $588 {}^{+41}_{-43}$ |
| $T_{72}$ | Stack Sidewall – Upper Aft | $874 {}^{+28}_{-25}$ |
| $T_{73}$ | Stack Sidewall – Center | $902 {}^{+23}_{-21}$ |
| $T_{74}$ | Stack Sidewall – Lower Forward | $810 {}^{+27}_{-33}$ |
| $T_{75}$ | Stack Sidewall – Lower Aft | $722 {}^{+18}_{-19}$ |
| $T_{76}$ | Stack Forward Wall – Upper Corner | $331 {}^{+37}_{-31}$ |
| $T_{77}$ | Stack Aft Wall – Upper Center | $119 {}^{+20}_{-17}$ |
| $T_{78}$ | Stack Forward Wall – Lower Corner | $517 {}^{+40}_{-35}$ |
| $T_{79}$ | Stack Forward Wall – Lower Center | $519 {}^{+27}_{-17}$ |
| $T_{80}$ | Stack Aft Wall – Upper Corner | $865 {}^{+46}_{-29}$ |
| $T_{81}$ | Stack Aft Wall – Upper Center | $876 {}^{+54}_{-34}$ |
| $T_{82}$ | Stack Aft Wall – Lower Corner | $807 {}^{+41}_{-38}$ |
| $T_{83}$ | Stack Aft Wall – Lower Center | $808 {}^{+62}_{-42}$ |
| $T_{97}$ | Wedge Leading Edge – Upper | $924 {}^{+36}_{-32}$ |
| $T_{98}$ | Wedge Leading Edge – Upper Center | $840 {}^{+67}_{-36}$ |
| $T_{99}$ | Wedge Leading Edge – Lower Center | $545 {}^{+41}_{-43}$ |
| $T_{100}$ | Wedge Leading Edge – Lower | $392 {}^{+33}_{-32}$ |
| $T_{101}$ | Wedge Sidewall – Upper Center | $795 {}^{+52}_{-42}$ |
| $T_{102}$ | Wedge Sidewall – Lower Center | $671 {}^{+56}_{-59}$ |
| $T_{103}$ | Wedge Sidewall – Lower | $464 {}^{+61}_{-49}$ |

TABLE 11
EXHAUST MUFFLER TEMPERATURES –
TALL STACK CONFIGURATION ($T_a$ = 82°F)

| Thermocouple Number (See Fig. 31) | General Location (See Figure 31 for Exact Location) | Average Measured Temperature With Maximum and Minimum Deviation (°F) |
|---|---|---|
| $T_{23}$ | Forward Stack Wall – Lower Section | 855 |
| $T_{24}$ | Forward Stack Wall – Lower Section | 958 |
| $T_{25}$ | Stack Sidewall – Lower Section | 1058 |
| $T_{26}$ | Stack Sidewall – Lower Section | 954 |
| $T_{27}$ | Stack Sidewall – Lower Center | 119 |
| $T_{28}$ | Stack Sidewall – Lower Section | 1043 |
| $T_{29}$ | Stack Sidewall – Lower Section | 641 |
| $T_{30}$ | Aft Stack Wall – Lower Section | 151 |
| $T_{31}$ | Aft Stack Wall – Lower Center | 929 |
| $T_{32}$ | Forward Stack Wall – Upper Section | 464 |
| $T_{33}$ | Forward Stack Wall – Upper Section | 746 |
| $T_{34}$ | Stack Sidewall – Upper Section | 577 |
| $T_{35}$ | Stack Sidewall – Upper Section | 888 |
| $T_{36}$ | Stack Sidewall – Upper Section | 952 |
| $T_{37}$ | Stack Sidewall – Upper Section | 1028 |
| $T_{38}$ | Aft Stack Wall – Upper Section | 941 |
| $T_{39}$ | Aft Stack Wall – Upper Section | 1001 |
| $T_{65}$ | Enclosure Floor – Aft | 216 |
| $T_{66}$ | Aft Enclosure Sidewall – Upper | 415 |
| $T_{67}$ | Aft Enclosure Sidewall – Lower | 193 |
| $T_{68}$ | Forward Enclosure Sidewall | 94 |

3. All lined surface areas consisted of Johns-Manville Glas-Mat 1200 material covered with perforated sheet of 45 percent open area, 5/64-inch diameter holes and .047-inch thickness. This material is a mechanically bonded glass fiber insulating blanket for use to 1200°F. It is manufactured entirely of long textile glass fibers and contains no binders, thereby assuring mechanical integrity during extended exposure at elevated temperatures.

4. No attempt was made to optimize the lining design experimentally to obtain improved acoustic performance. The material selected was based on temperature requirements and lead time availability. The acoustically preferred material (J-M Cerafelt) had a lead time incompatible with the test schedule. It is anticipated that the Cerafelt would perform better than the Glas-Mat 1200 but the magnitude of improvement is uncertain without testing.

5. The lining material, as manufactured and delivered, was not of uniform thickness and density. Therefore, the material for each acoustic panel was weighed and an average density calculated. The lining material acoustic properties are thus given in terms of the average density (pcf) and average resistivity (rayl/cm). The resistivity was determined by flow resistance testing and defined as a function of density by:

$$R = .118\ \rho^{2.75}\ \text{(rayl/cm)}$$

where $\rho$ is the density (pcf).

The acoustic panels for the suppressor components had the properties given in Table 12.

TABLE 12
ACOUSTIC PANEL PROPERTIES

| | Lining Thickness (Inches) | Average Density (PCF) | Average Resistivity (RAYL/CM) |
|---|---|---|---|
| Short stack walls (1) | 2.75 | 11.63 | 100.5 |
| Short stack walls (2) | 4.13 | 11.58 | 99.33 |
| Tall stack extension (1) | 2.75 | 11.48 | 96.99 |
| Tall stack extension (2) | 4.13 | 11.79 | 104.4 |
| Single splitter | 2.75 | 11.7 | 102.2 |
| Dual splitter | 1.38 | 11.26 | 92.0 |
| Dual wedge | * | 10.59 | 77.69 |
| Enclosure back wall | 4.13 | 12.18 | 114.1 |
| Enclosure lower sidewalls | 4.13 | 11.43 | 95.8 |
| Secondary air inlet | .94 | 10.45 | 74.9 |

*See Figure 19

Note: Lining thicknesses are model scale.

**TABLE 13**
**ACOUSTIC TEST CONFIGURATION SUMMARY**

| | Run Number | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 26 | 31 | 32 | 33 | 36 | 37 | 38 | 39 | 40 | 41 | 44 | 45 | 46 | 55 | 58 | 59 | 60 | 61 | 62 | 71 |
| 1. Model nozzle | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 2. Secondary air cover | | | X | X | X | X | | X | X | X | X | X | X | | | | | | | | |
| 3. Short stack (1) | | X | X | X | X | | | X | X | X | | | | | | | | | | | |
| 4. Short stack (2) | | | | | | | | | | | | X | | | X | X | X | X | X | X | X |
| 5. Tall stack (1) | | | | | | X | X | | | | X | | | | | | | | | | |
| 6. Tall stack (2) | | | | | | | | | | | | | X | X | | | | | | | |
| 7. Back wall lining | | X | X | X | * | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | * |
| 8. Lower wall lining | | | | | | | | | | | | | | | X | X | X | X | * | * | * |
| 9. Single splitter | | X | X | | X | | | * | * | | | | | | | | | X | | | |
| 10. Dual splitter | | | | | | | | | | | | | | | | | X | | X | | * |
| 11. Dual wedge | | | | | | | | | | | | | | | X | | | | | | |

**Notes:**

**All runs had burner cover except Run No. 10**

***Denotes hard wall elements**

**(1) Denotes 2.75-inch lining thickness (16.5-inch full scale)**

**(2) Denotes 4.13-inch lining thickness (24.8-inch full scale)**

6. The test configurations that produced significant acoustic results are defined in Table 13. These configurations represent a parametric variation of suppressor elements to determine which combination produced the best noise suppression using the lining design discussed above. The short stack (full-scale 30-foot height) and tall stack (full-scale 54-foot height) utilized two lining thicknesses, 2.75-inch and 4.13-inch model scale (16.5-inch and 24.8-inch) full scale, respectively). The acoustic effectiveness of each lining element was determined by testing with hard walls substituted for the linings.

7. The walls of the suppressor were sandbagged (Figures 26 and 27) to prevent sound transmission through the walls from establishing the acoustic noise floor for the suppressor system. An acoustically treated burner cover (Figures 23, 24 and 25) was placed around the primary burner and afterburner section to stimulate the engine test cell. The sandbagged walls and the burner cover permitted the acoustic evaluation of the secondary air inlet and exhaust stack without significant noise contribution from the walls and simulated engine enclosure. This condition was verified experimentally.

8. The one-sixth scale model sound pressure levels were measured at ground level on a 41.67-foot radius (250-foot full scale) at 15-degree intervals from 15 degrees to 180 degrees. The atmospheric absorption was removed from the third octave band model scale data, the frequencies translated to full scale and the standard day (77°F and 70 percent relative humidity) atmospheric corrections applied to obtain the full-scale 250-foot data. The third octave band data were converted to full octaves so that direct comparison could be made to the Grade II criterion of MIL-N-83155B.

The Grade II criterion applies to a microphone height of five feet above the ground plane. Sound pressure levels measured near the ground plane will not exhibit the amplitude interference produced at the five-foot microphone by acoustic path length differences between the direct and ground plane reflected signals. Therefore, the ground plane acoustic data presented here will be conservatively high. A theoretical estimate of the magnitude that the ground plane microphone exceeds that of a five-foot high microphone for source heights of 30 feet and 54 feet (exit of short and tall stacks) at a horizontal distance of 250 feet is shown on Figure 48. These corrections should be subtracted from the ground plane measured data for a more accurate comparison to the MIL-N-83155B, Grade II criterion.

The far field data are presented in four sets so that direct comparisons can be made to determine the relative acoustic efficiencies between configurations. The baseline data for the TF30-P-412 model nozzle at afterburner condition and the MIL-N-83155B, Grade II far field criterion are represented on each data set for the 12 angles between 15 degrees and 180 degrees.

The first data set, Figures 49 to 51, determines the lining efficiencies for the short single splitter stack configurations with the 2.75-inch wall lining. Refer to Table 13 for the exact configuration definition. These comparisons show the effectivity of the lined stack walls and the lined splitter relative to their hard wall counterparts. The data indicate that the suppressor redirected the sound radiation producing levels higher than the baseline at several angular locations. This set of data shows that significant attenuation (10 to 15 db in the midfrequency range) can be obtained with a single splitter short stack using the lining design discussed previously. The overall A-weighted sound pressure level (OA dBA) is also given for each configuration.

The second data set, Figures 52 to 54, compares the performance of the tall stack configurations utilizing 2.75-inch and 4.13-inch wall linings and with and without the secondary air inlet cover. The effectiveness of the wall lining was determined relative to the hard wall configuration. The comparisons show that the 4.13-inch lining does not produce significantly higher attenuations than the 2.75-inch lining and, therefore, for this lining design, the thinner lining was as effective. The configurations with and without the secondary air inlet cover indicate that the air inlet did not contribute significantly to the far field levels. Therefore, the far field levels are determined by the noise radiated from the exhaust stack, since the noise radiated from the sandbagged suppressor walls was insignificant.

The third data set, Figures 55 to 57, compares the configurations that show the transition from the 30-foot (no splitter) to the 54-foot full-scale stack height. Originally, two full-scale stack heights were selected to be tested, a 30-foot stack with one or two splitters and a 40-foot stack without splitters. The 30-foot stack single splitter divided the flow area into two passages with 40-inch full-scale duct heights. The proposed 40-foot stack was to have the same flow area. To prevent the necessity of modifying the structure of the model at the stack location, the length of the short stack was extended to a height of 45 feet (full-scale) which results in an equivalent length to duct height ratio to that of the proposed 40-foot stack. Therefore, the 54-foot and 40-foot stack will provide similar acoustic attenuation; however, the 14-foot increase in stack height will result in lower levels on the ground plane at the 250-foot full-scale radius due to the directivity of the stack. Assuming a linear relationship between the stack height and directivity effect, the amount to be added to the measured 54-foot stack data to obtain the approximate 40-foot stack levels can be obtained. Thus, comparing Runs 40 and 41 for the 30-foot and 54 foot hard wall stacks and adding 14/24 of the difference to the levels for the lined 54-foot stack data will give the approximate levels for the 40-foot lined stack. This computation was not applied to the data since the important feature of the comparisons is the relative performance of the different configurations. The spectrum differences between the hard wall and lined configurations for the two stack heights give the respective lining attenuations.

The fourth data set, Figures 58 through 60, compares those short stack configurations that utilize either splitters or wedges. The wedges were tested to determine their low frequency effectivity. The comparisons show that they provide more attenuation at the low frequencies (below 500 Hz) but less at the high frequencies than the dual splitter configuration.

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| Symbol | Acoustic Configuration |
| --- | --- |
| O | 30-Ft. Source Height, 5-Ft. Microphone Height @ 250 Ft. |
| □ | 54-Ft. Source Height, 5-Ft. Microphone Height @ 250 Ft. |

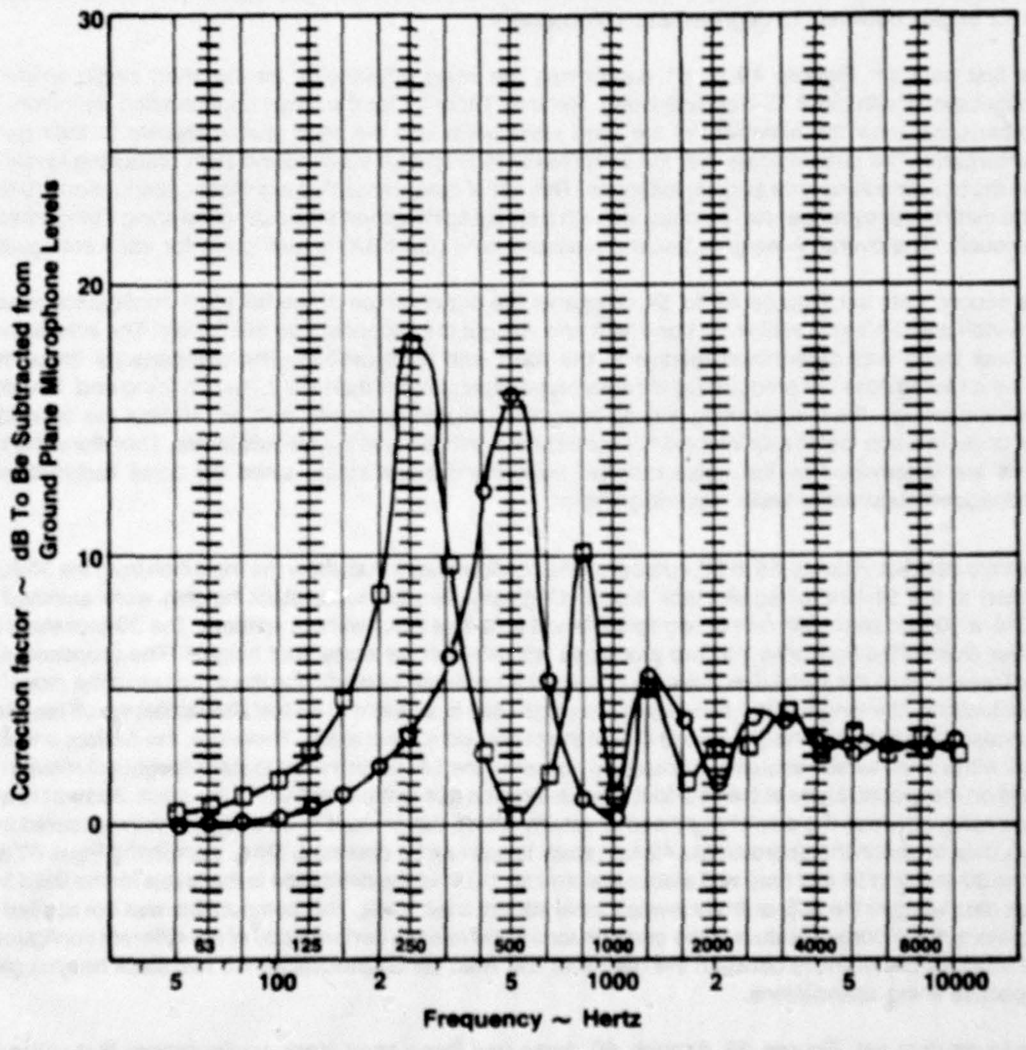


**FIGURE 48: GROUND PLANE REFLECTION CORRECTION FACTOR FOR 5-FOOT MICROPHONE HEIGHT**

| Symbol | Run | OA DBA 15° | 30° | 45° | 60° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| – – | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 104.46 | 108.06 | 110.50 | 114.39 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 26 | 97.85 | 95.21 | 97.57 | 98.77 | Total Stack Lined W/O Inlet Cover |
| △ | 31 | 100.23 | 94.68 | 94.64 | 96.29 | Total Stack Lined W/Inlet Cover |
| + | 33 | 99.63 | 94.70 | 96.56 | 98.54 | Total Stack Lined, Hard Back Wall |
| × | 38 | 97.49 | 94.98 | 98.24 | 99.84 | Hard Wall Splitter, Stack Walls & Back Wall Lined |
| ◇ | 39 | 101.71 | 101.38 | 104.37 | 107.91 | Total Hard Wall Stack, Lined Back Wall |

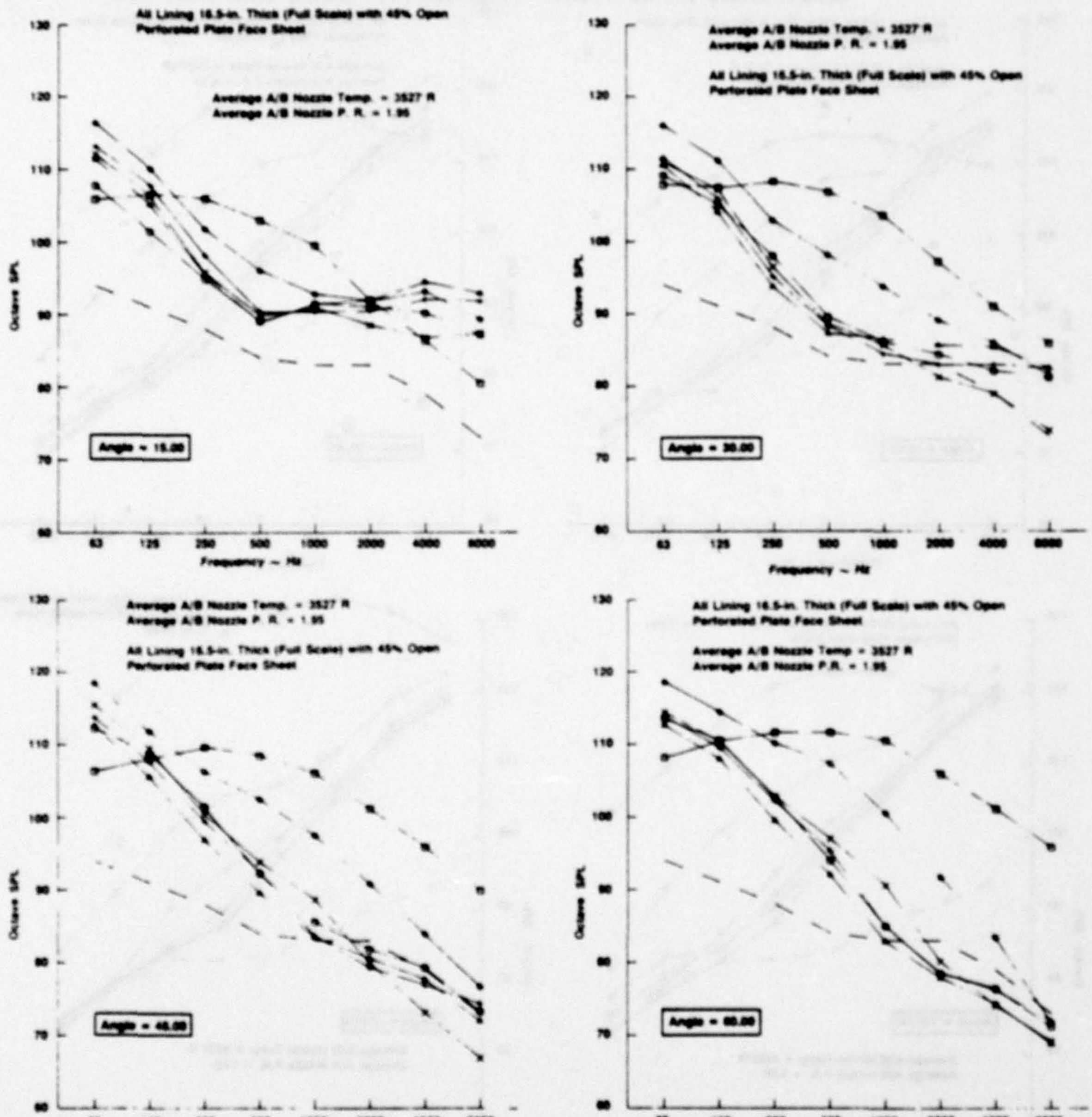


FIGURE 49: FAR FIELD ACOUSTIC DATA – 15°, 30°, 45° AND 60° POSITIONS – SHORT EXHAUST STACK WITH SINGLE SPLITTER CONFIGURATION

| Symbol | Run | OA DBA 75° | OA DBA 90° | OA DBA 105° | OA DBA 120° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| – – | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| □ | 10 | 116.49 | 120.56 | 124.73 | 133.08 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ○ | 26 | 99.05 | 98.13 | 102.83 | 101.90 | Total Stack Lined W/O Inlet Cover |
| △ | 31 | 97.46 | 100.40 | 102.28 | 102.15 | Total Stack Lined W/Inlet Cover |
| + | 33 | 100.26 | 99.99 | 103.70 | 103.35 | Total Stack Lined, Hard Back Wall |
| X | 38 | 100.89 | 101.12 | 105.15 | 104.25 | Hard Wall Splitter, Stack Walls & Back Wall Lined |
| ◇ | 39 | 108.31 | 110.60 | 111.96 | 110.87 | Total Hard Wall Stack, Lined Back Wall |

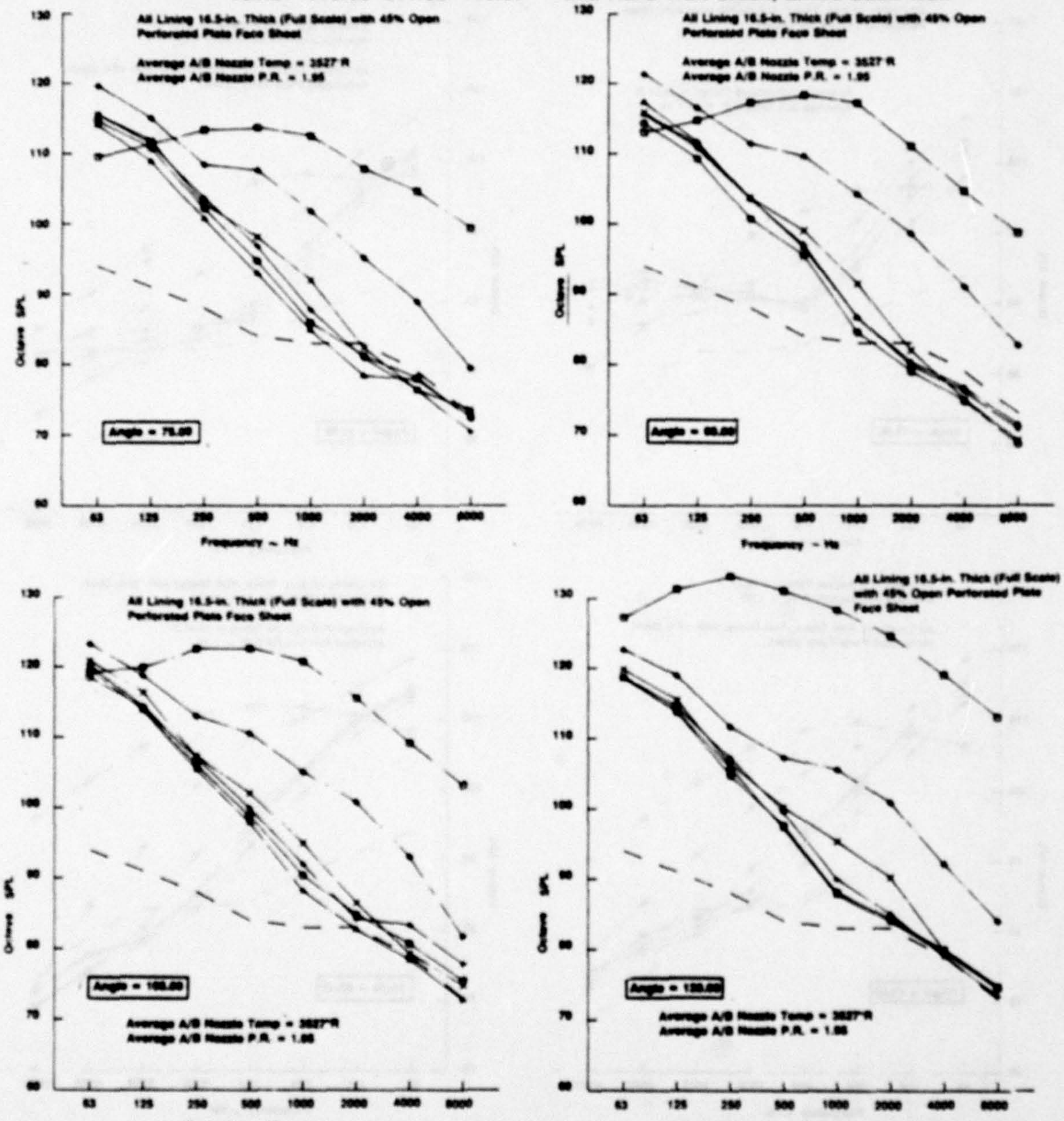


FIGURE 50: FAR FIELD ACOUSTIC DATA – 75°, 90°, 105° AND 120° POSITIONS – SHORT EXHAUST STACK WITH SINGLE SPLITTER CONFIGURATION

| Symbol | Run | OA DBA 135° | 150° | 165° | 180° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| - - - | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| □ | 10 | 128.74 | 122.47 | 108.71 | 98.71 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ○ | 26 | 101.45 | 103.52 | 104.47 | 102.58 | Total Stack Lined W/O Inlet Cover |
| △ | 31 | 102.71 | 103.36 | 105.02 | 103.09 | Total Stack Lined W/Inlet Cover |
| + | 33 | 104.06 | 104.72 | 105.98 | 104.10 | Total Stack Lined, Hard Back Wall |
| × | 38 | 105.15 | 106.18 | 107.26 | 106.28 | Hard Wall Splitter, Stack Walls & Back Wall Lined |
| ◇ | 39 | 112.16 | 112.73 | 113.31 | 111.87 | Total Hard Wall Stack, Lined Back Wall |

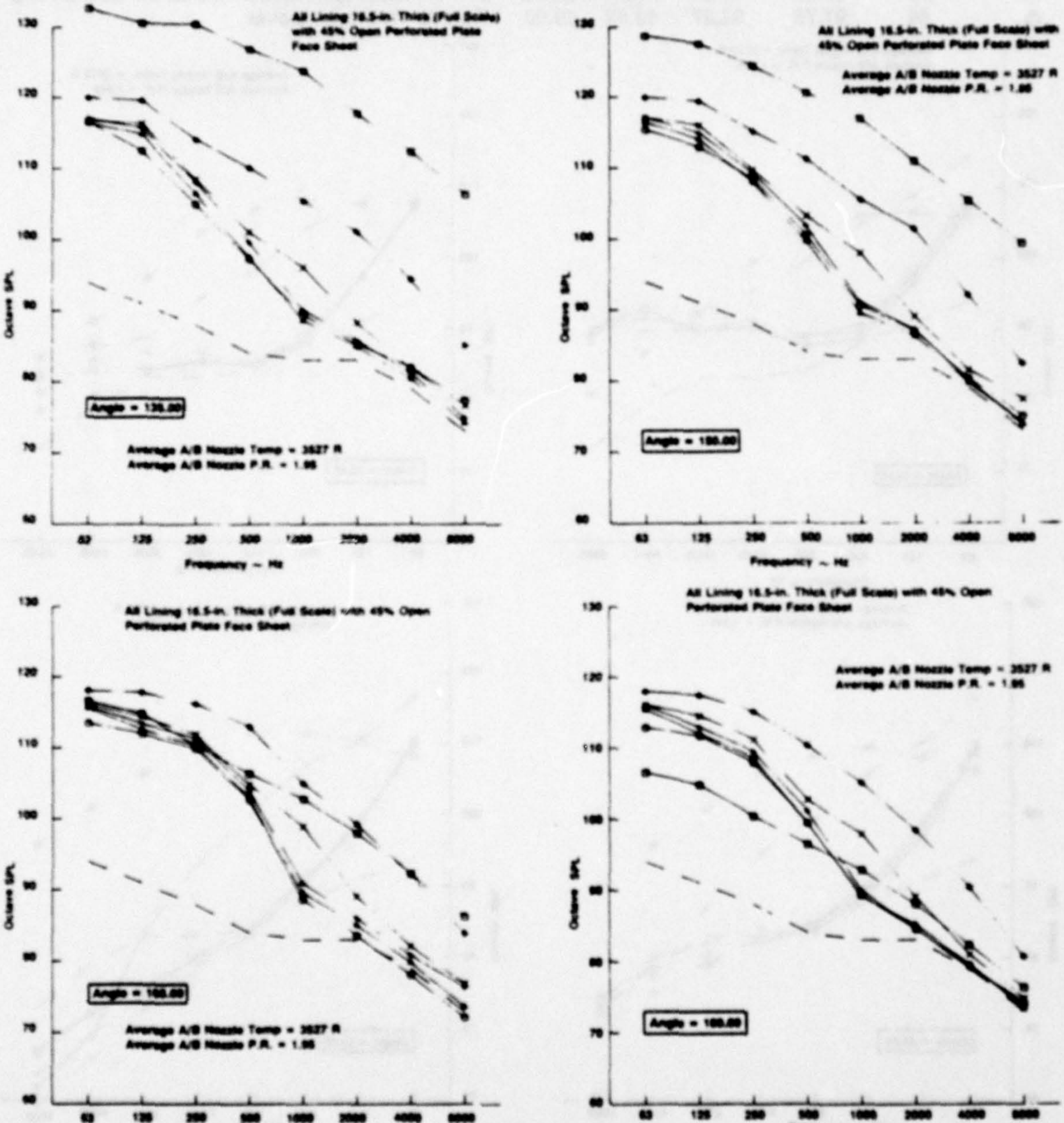


**FIGURE 51: FAR FIELD ACOUSTIC DATA – 135°, 150°, 165° AND 180° POSITIONS – SHORT EXHAUST STACK WITH SINGLE SPLITTER CONFIGURATION**

| Symbol | Run | OA DBA 15° | 30° | 45° | 60° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| - - | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 104.46 | 108.06 | 110.50 | 114.39 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 36 | 97.33 | 92.11 | 89.89 | 89.39 | 54 Ft. Total Stack Lined W/16.5-in. Wall Lining |
| △ | 37 | 96.96 | 91.45 | 90.46 | 89.86 | 54 Ft. Total Stack Lined W/O Inlet Cover |
| + | 41 | 102.99 | 101.35 | 102.43 | 102.75 | 54 Ft. Total Hard Wall Stack |
| × | 45 | 97.78 | 94.03 | 91.22 | 89.32 | 54 Ft. Total Stack Lined W/24.8 in. Wall Lining |
| ◇ | 46 | 97.75 | 92.57 | 89.68 | 89.90 | Run 45 W/O Inlet Cover |

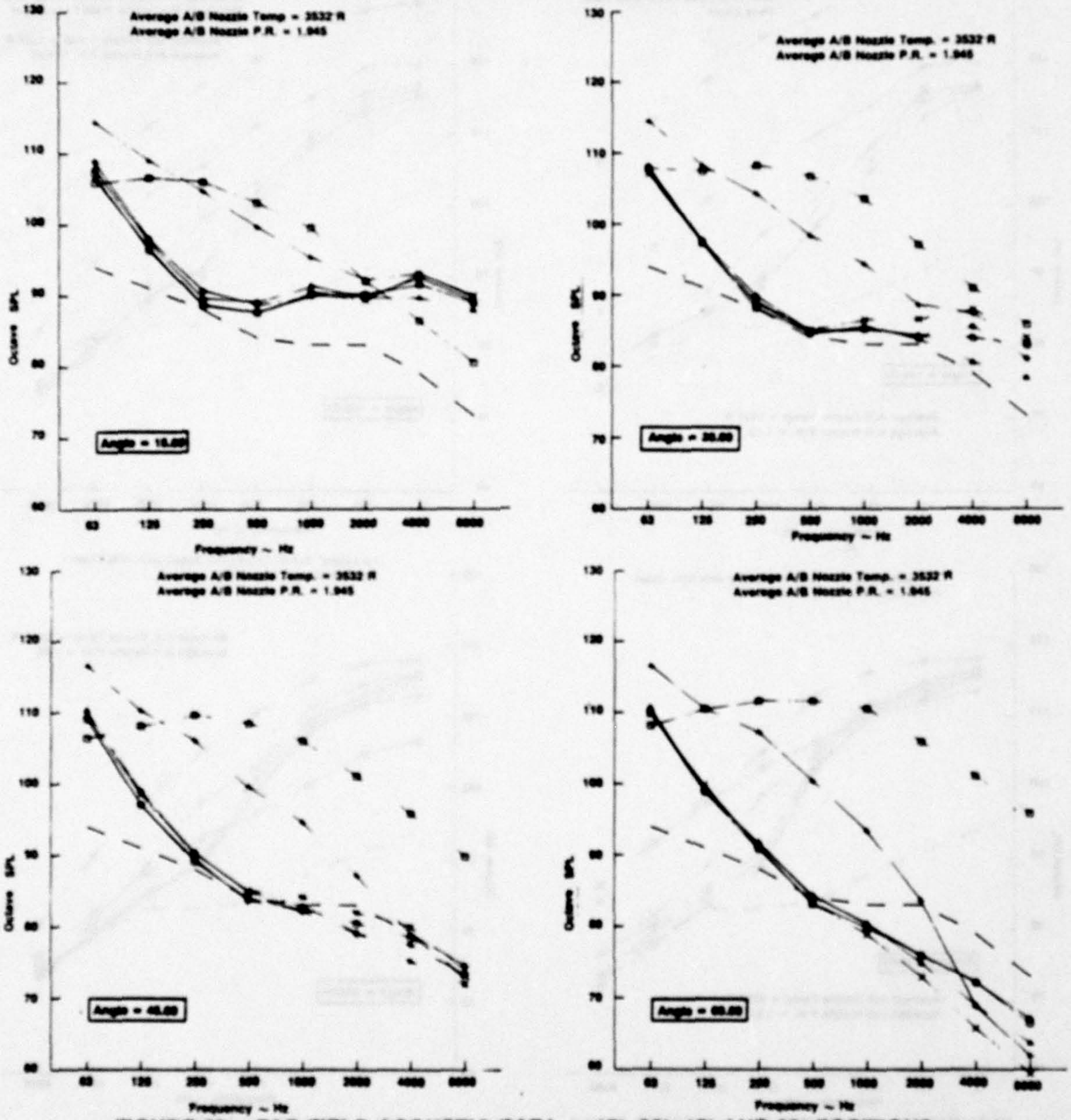


**FIGURE 52: FAR FIELD ACOUSTIC DATA – 15°, 30°, 45° AND 60° POSITIONS – TALL EXHAUST STACK WITHOUT SINGLE SPLITTER CONFIGURATION**

| Symbol | Run | OA DBA 75° | 90° | 105° | 120° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| - - | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 116.49 | 120.56 | 124.73 | 133.08 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 36 | 89.73 | 87.77 | 90.01 | 90.59 | 54 Ft. Total Stack Lined W/16.5-In. Wall Lining |
| △ | 37 | 90.14 | 90.31 | 90.50 | 90.45 | 54 Ft. Total Stack Lined W/O Inlet Cover |
| + | 41 | 104.13 | 103.69 | 104.29 | 104.31 | 54 Ft. Total Hard Wall Stack |
| × | 45 | 90.54 | 90.29 | 91.48 | 90.48 | 54 Ft. Total Stack Lined W/24.8 In. Wall Lining |
| ◇ | 46 | 90.64 | 88.56 | 90.73 | 89.87 | Run 45 W/O Inlet Cover |

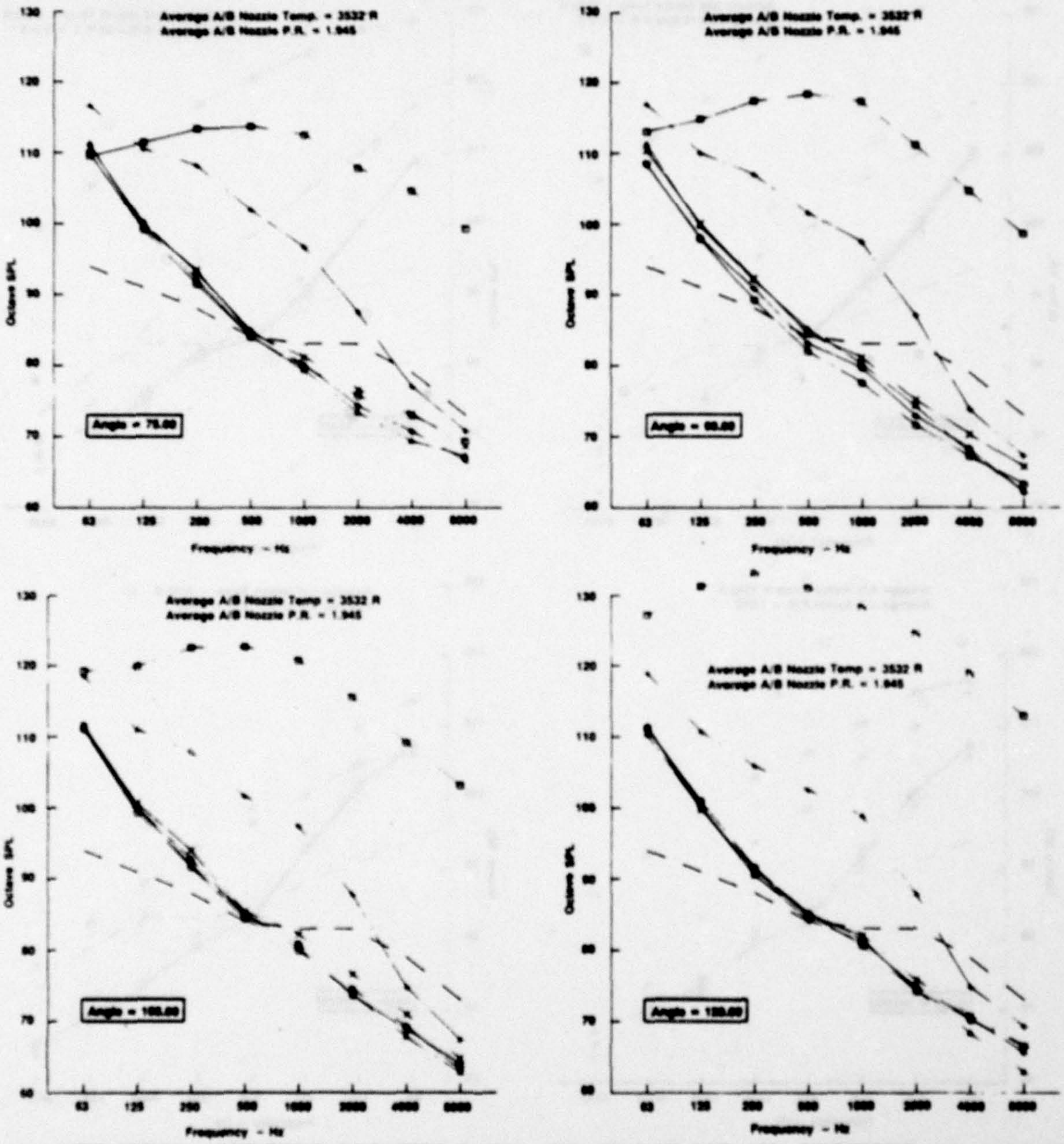


**FIGURE 53: FAR FIELD ACOUSTIC DATA – 75°, 90°, 105° AND 120° POSITIONS – TALL EXHAUST STACK WITHOUT SINGLE SPLITTER CONFIGURATION**

| Symbol | Run | OA DBA 135° | 150° | 165° | 180° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| - - | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| □ | 10 | 128.74 | 122.47 | 108.71 | 98.71 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 36 | 90.17 | 89.41 | 89.47 | 90.02 | 54 Ft. Total Stack Lined W/16.5-in. Wall Lining |
| △ | 37 | 90.40 | 89.64 | 89.36 | 89.79 | 54 Ft. Total Stack Lined W/O Inlet Cover |
| + | 41 | 103.00 | 101.70 | 101.65 | 101.23 | 54 Ft. Total Hard Wall Stack |
| X | 45 | 91.11 | 89.83 | 88.15 | 90.33 | 54 Ft. Total Stack Lined W/24.8 in. Wall Lining |
| ◇ | 46 | 90.25 | 90.03 | 90.11 | 89.40 | Run 45 W/O Inlet Cover |

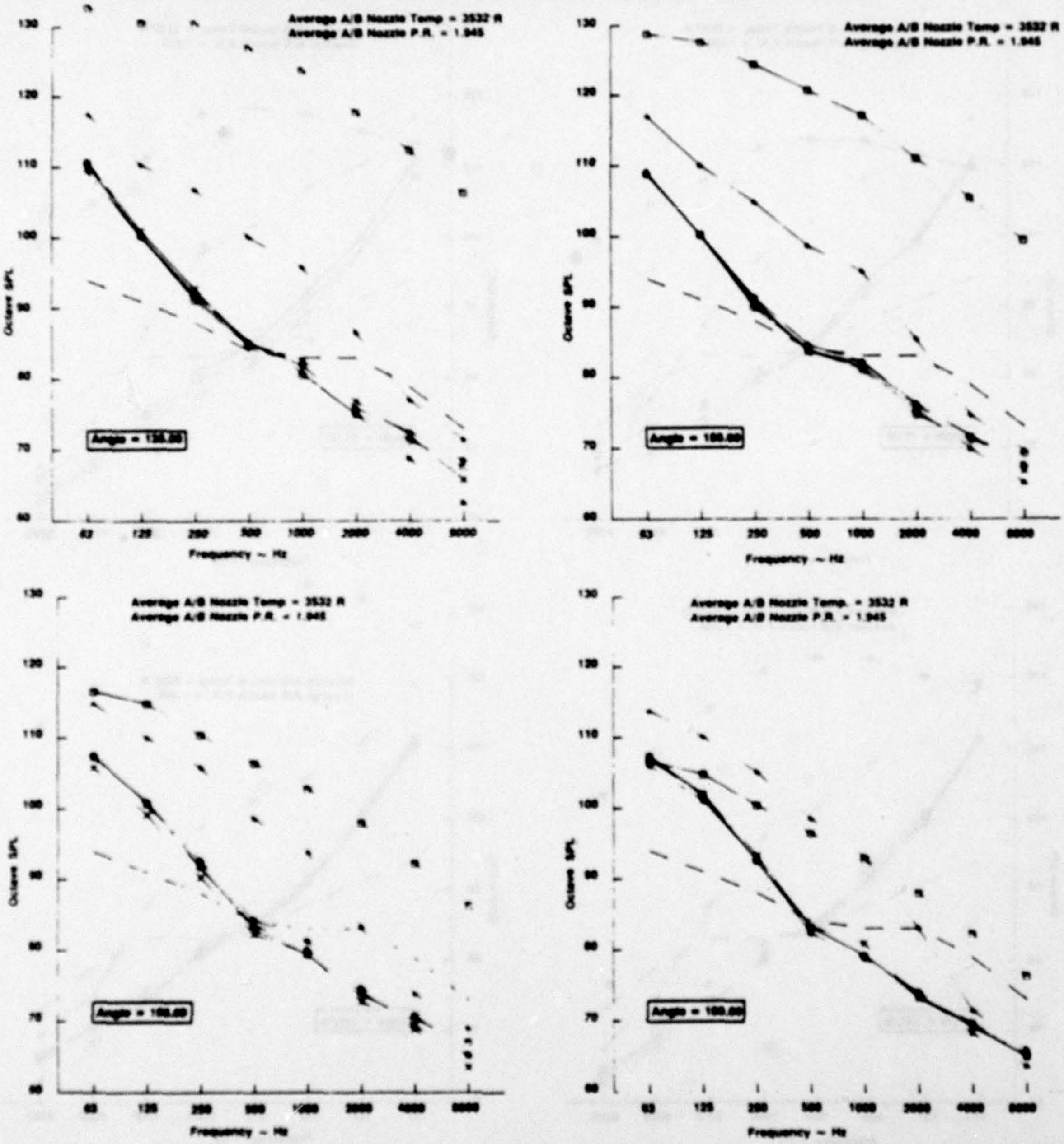


FIGURE 54: FAR FIELD ACOUSTIC DATA – 135°, 150°, 165° and 180° POSITIONS – TALL EXHAUST STACK WITHOUT SPLITTER CONFIGURATION

| Symbol | Run | OA DBA 15° | 30° | 45° | 60° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| - - | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 104.46 | 108.06 | 110.50 | 114.39 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 32 | 100.97 | 95.81 | 96.72 | 99.22 | 30 Ft. Total Stack Lined W/16.5-In. Wall Lining |
| ▲ | 36 | 97.33 | 92.11 | 89.89 | 89.39 | 54 Ft. Total Stack Lined W/16.5-In. Wall Lining |
| + | 37 | 96.96 | 91.45 | 90.46 | 89.86 | 54 Ft. Total Stack Lined W/O Inlet Cover |
| × | 40 | 100.66 | 101.27 | 104.30 | 106.53 | 30 Ft. Hard Wall Stack |
| ◇ | 41 | 102.99 | 101.35 | 102.43 | 102.75 | 54 Ft. Total Hard Wall Stack |
| ♠ | 44 | 98.37 | 95.68 | 96.72 | 98.00 | 30 Ft. Total Stack Lined W/24.8 In. Wall Lining |
| ⌛ | 45 | 97.78 | 94.03 | 91.22 | 89.32 | 54 Ft. Total Stack Lined W/24.8 In. Wall Lining |

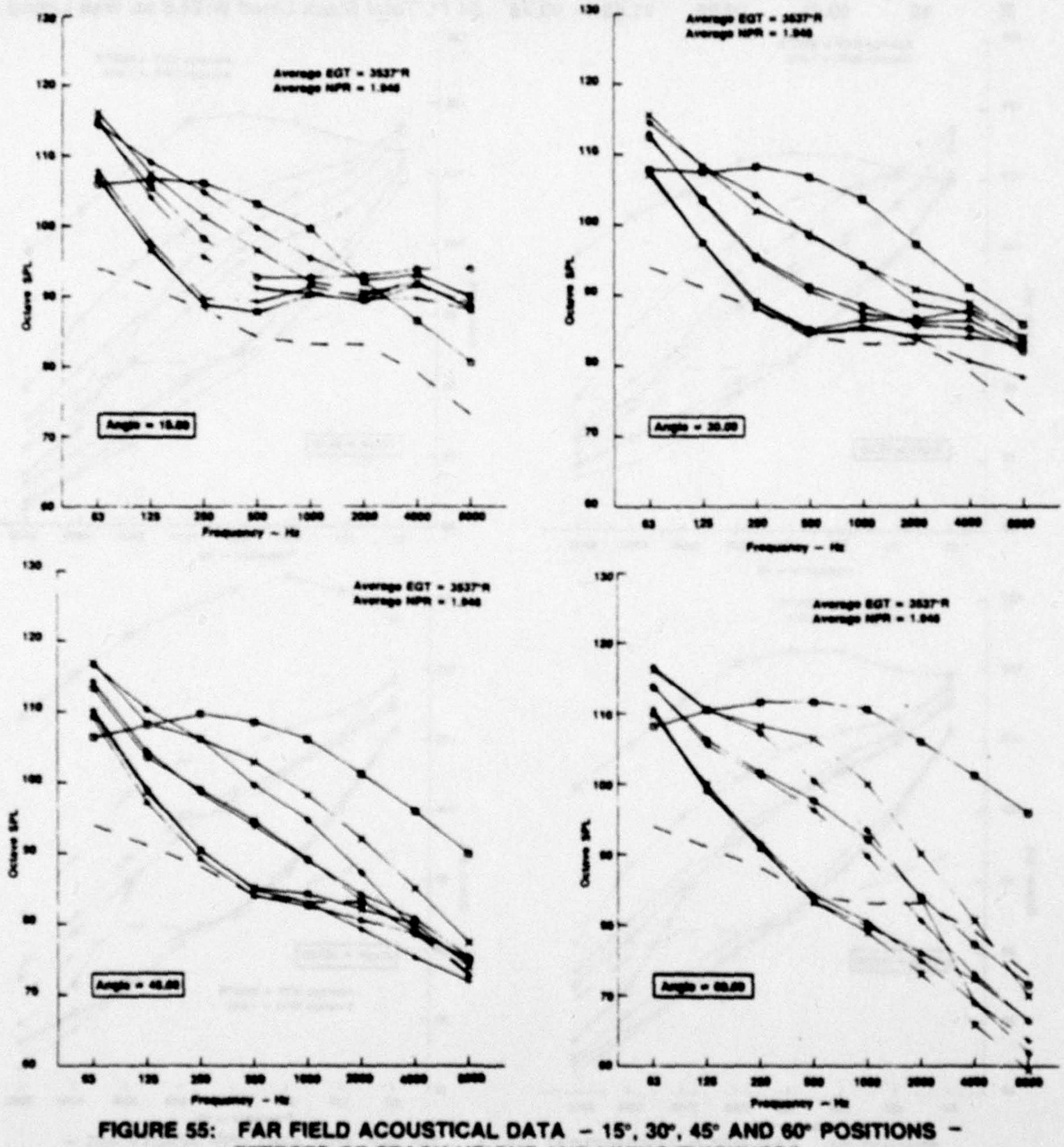


FIGURE 55: FAR FIELD ACOUSTICAL DATA – 15°, 30°, 45° AND 60° POSITIONS – EFFECTS OF STACK HEIGHT AND LINING THICKNESS

| Symbol | Run | OA DBA 75° | OA DBA 90° | OA DBA 105° | OA DBA 120° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| - - | – | 90.00 | 90.00 | – | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 116.49 | 120.56 | 124.73 | 133.08 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 32 | 98.68 | 98.38 | 102.85 | 103.02 | 30 Ft. Total Stack Lined W/16.5-In. Wall Lining |
| ▲ | 36 | 89.73 | 87.77 | 90.01 | 90.59 | 54 Ft. Total Stack Lined W/16.5-In. Wall Lining |
| + | 37 | 90.14 | 90.31 | 90.50 | 90.45 | 54 Ft. Total Stack Lined, W/O Inlet Cover |
| × | 40 | 107.67 | 108.14 | 110.10 | 110.96 | 30 Ft. Hard Wall Stack |
| ◇ | 41 | 104.13 | 103.69 | 104.29 | 104.31 | 54 Ft. Total Hard Wall Stack |
| ✦ | 44 | 99.70 | 101.07 | 103.30 | 103.34 | 30 Ft. Total Stack Lined W/24.8 In. Wall Lining |
| ⌅ | 45 | 90.54 | 90.29 | 91.48 | 90.48 | 54 Ft. Total Stack Lined W/24.8 In. Wall Lining |

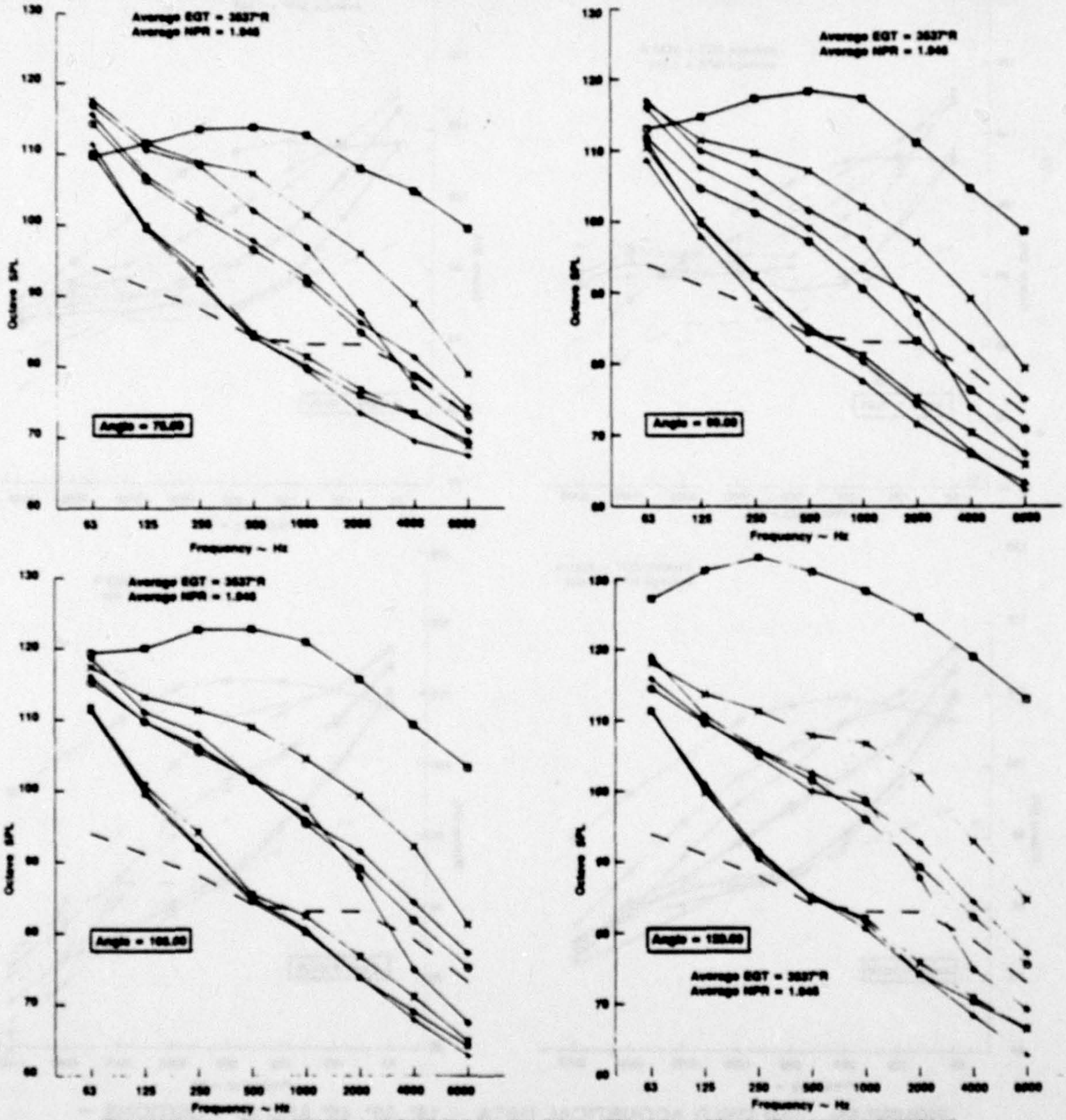


**FIGURE 56: FAR FIELD ACOUSTICAL DATA – 75°, 90°, 105° AND 120° POSITIONS – EFFECTS OF STACK HEIGHT AND LINING THICKNESS**

| Symbol | Run | OA DBA 135° | 150° | 165° | 180° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| - - | – | 90.00 | 90.00 | 90.00 | | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 128.74 | 122.47 | 108.71 | 98.71 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 32 | 104.04 | 106.00 | 107.11 | 107.07 | 30 Ft. Total Stack Lined W/16.5-in. Wall Lining |
| ▲ | 36 | 90.17 | 89.41 | 89.47 | 90.02 | 54 Ft. Total Stack Lined W/16.5-in. Wall Lining |
| + | 37 | 90.40 | 89.64 | 89.36 | 89.79 | 54 Ft. Total Stack Lined, W/O Inlet Cover |
| × | 40 | 110.25 | 112.16 | 113.73 | 112.94 | 30 Ft. Hard Wall Stack |
| ◇ | 41 | 103.00 | 101.70 | 101.65 | 101.23 | 54 Ft. Total Hard Wall Stack |
| ✦ | 44 | 105.05 | 106.24 | 108.02 | 108.36 | 30 Ft. Total Stack Lined W/24.8 In. Wall Lining |
| ⧖ | 45 | 91.11 | 89.83 | 88.15 | 90.33 | 54 Ft. Total Stack Lined W/24.8 In. Wall Lining |

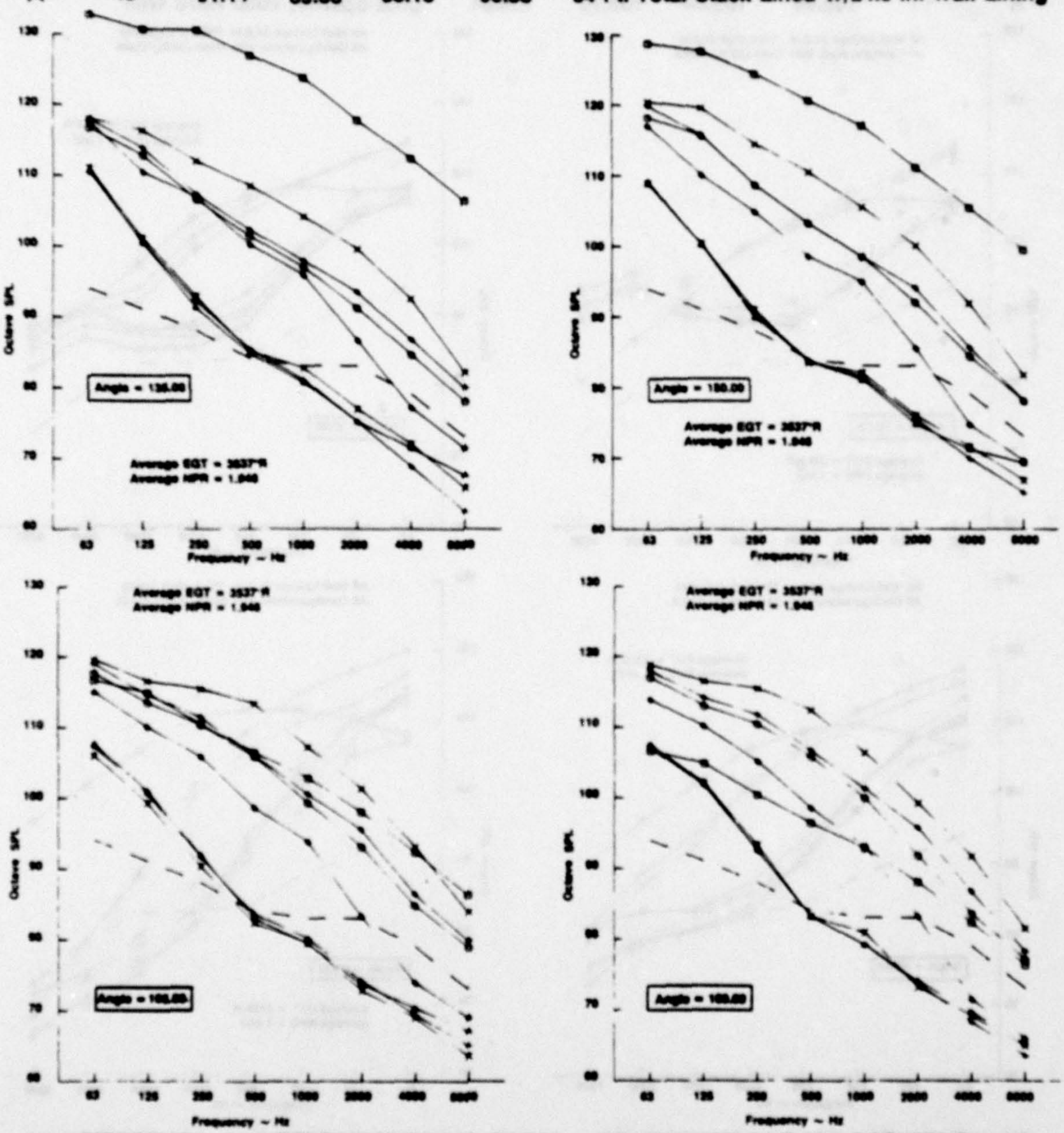


FIGURE 57: FAR FIELD ACOUSTICAL DATA – 135°, 150°, 165° AND 180° POSITIONS – EFFECTS OF STACK HEIGHT AND LINING THICKNESS

| Symbol | Run | OA DBA 15° | OA DBA 30° | OA DBA 45° | OA DBA 60° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| – – | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 104.46 | 108.06 | 110.50 | 114.39 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 55 | 98.81 | 97.34 | 94.71 | 94.07 | Dual Wedge |
| △ | 58 | 99.97 | 98.50 | 97.45 | 97.31 | W/O Dual Wedge or Splitters |
| + | 59 | 98.68 | 94.99 | 95.76 | 97.90 | Dual Splitter |
| × | 60 | 97.87 | 94.95 | 96.22 | 97.81 | Single Splitter |
| ◇ | 61 | 99.19 | 96.63 | 96.27 | 98.67 | Dual Splitter W/Hard Lower Walls |
| ✦ | 62 | 105.25 | 106.94 | 107.13 | 106.72 | Dual Wedge, Total Hard Wall |
| ⌛ | 71 | 105.86 | 105.64 | 108.18 | 109.84 | Dual Splitter, Total Hard Wall |

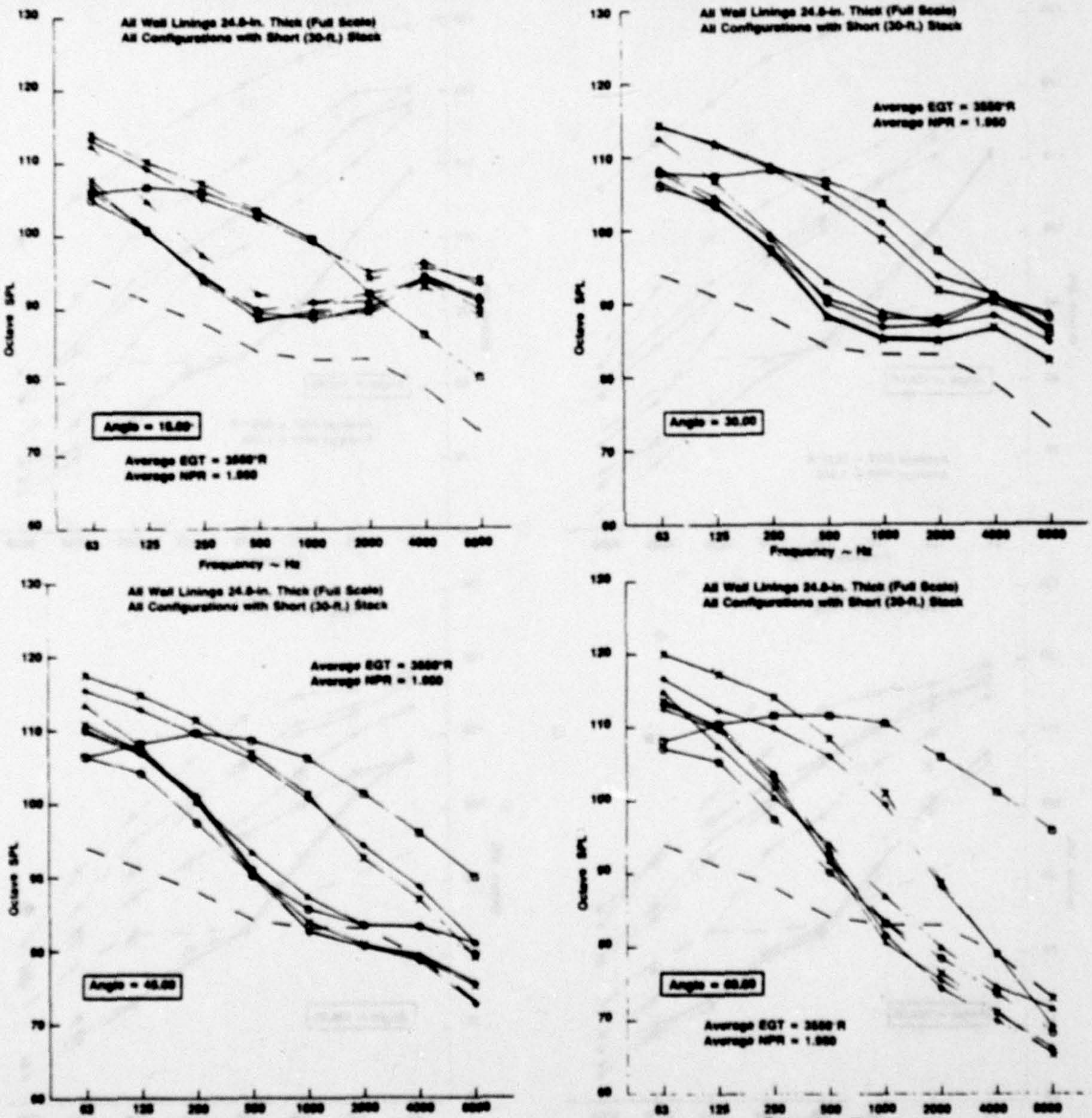


**FIGURE 58: FAR FIELD ACOUSTIC DATA – 15°, 30°, 45° and 60° POSITIONS – COMPARISON OF SINGLE AND DUAL SPLITTERS AND ACOUSTIC WEDGES**

| Symbol | Run | OA DBA 75° | OA DBA 90° | OA DBA 105° | OA DBA 120° | Identification (See Table 3) |
|---|---|---|---|---|---|---|
| - - | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 116.49 | 120.56 | 124.73 | 133.08 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 55 | 95.59 | 97.40 | 98.81 | 99.65 | Dual Wedge |
| ▲ | 58 | 97.93 | 99.03 | 100.57 | 102.25 | W/O Dual Wedge or Splitters |
| + | 59 | 99.06 | 101.43 | 104.45 | 102.47 | Dual Splitter |
| × | 60 | 98.28 | 101.00 | 102.78 | 102.45 | Single Splitter |
| ◇ | 61 | 99.07 | 101.43 | 103.51 | 102.52 | Dual Splitter W/Hard Lower Walls |
| ✦ | 62 | 108.17 | 109.06 | 110.47 | 112.30 | Dual Wedge, Total Hard Wall |
| ⊠ | 71 | 110.64 | 112.31 | 113.08 | 112.97 | Dual Splitter, Total Hard Wall |

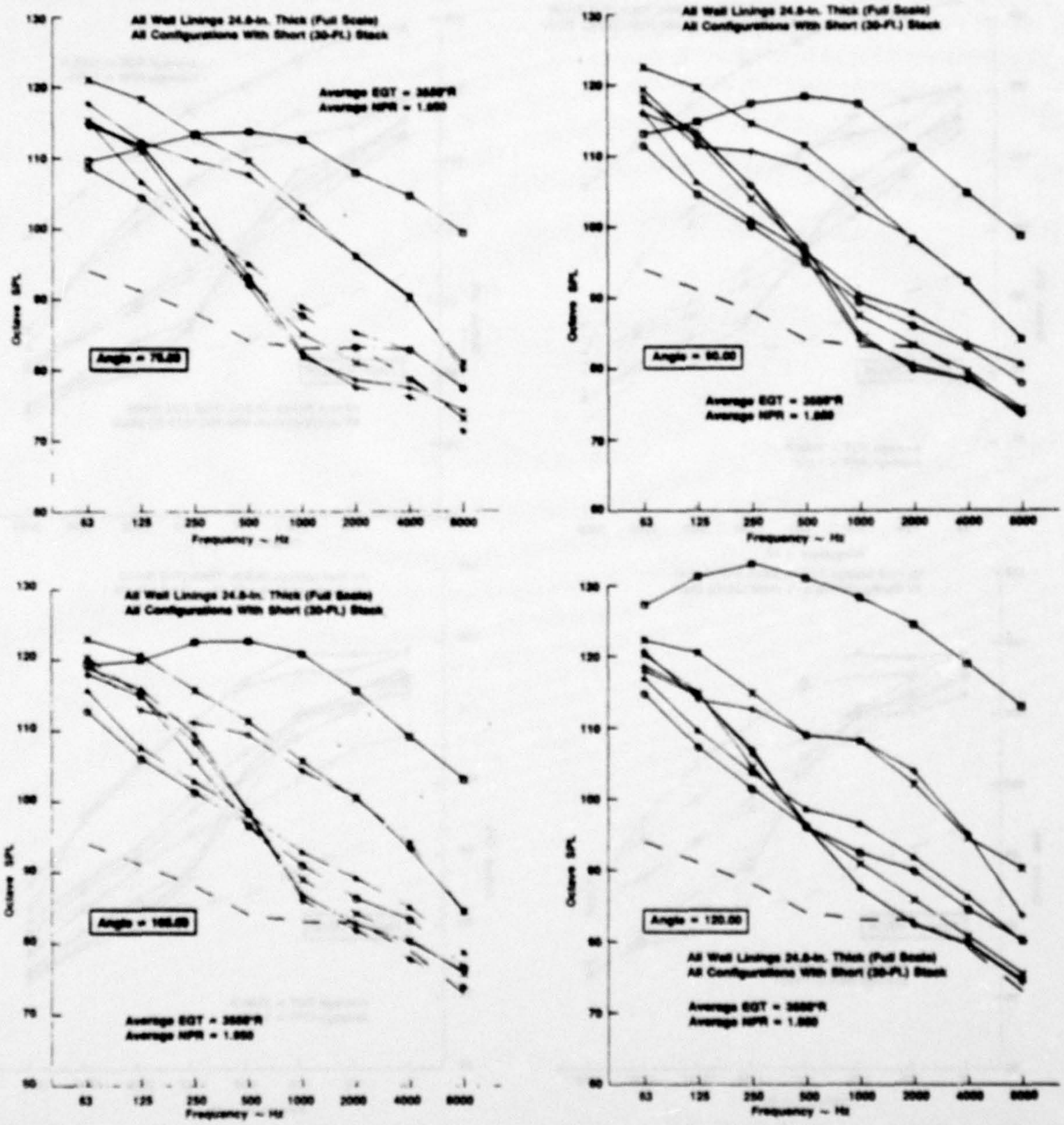

FIGURE 59: FAR FIELD ACOUSTIC DATA – 75°, 90°, 105° and 120° POSITIONS – COMPARISON OF SINGLE AND DUAL SPLITTERS AND ACOUSTIC WEDGES

| | | OA DBA | | | | |
|---|---|---|---|---|---|---|
| **Symbol** | **Run** | **135°** | **150°** | **165°** | **180°** | **Identification (See Table 3)** |
| - - | – | 90.00 | 90.00 | 90.00 | 90.00 | Far Field Criteria MIL-N-83155B Grade II |
| ⊡ | 10 | 128.74 | 122.47 | 108.71 | 98.71 | Baseline, TF-30-P-412 Afterburner Nozzle |
| ⊙ | 55 | 99.86 | 100.20 | 104.19 | 103.28 | Dual Wedge |
| △ | 58 | 101.94 | 102.14 | 105.96 | 106.01 | W/O Dual Wedge or Splitters |
| + | 59 | 101.64 | 102.57 | 105.41 | 104.21 | Dual Splitter |
| × | 60 | 100.68 | 101.22 | 104.30 | 102.95 | Single Splitter |
| ◇ | 61 | 101.74 | 102.41 | 103.71 | 103.52 | Dual Splitter W/Hard Lower Walls |
| ✦ | 62 | 112.68 | 112.60 | 114.26 | 114.36 | Dual Wedge, Total Hard Wall |
| ⊠ | 71 | 112.66 | 113.30 | 115.50 | 115.33 | Dual Splitter, Total Hard Wall |

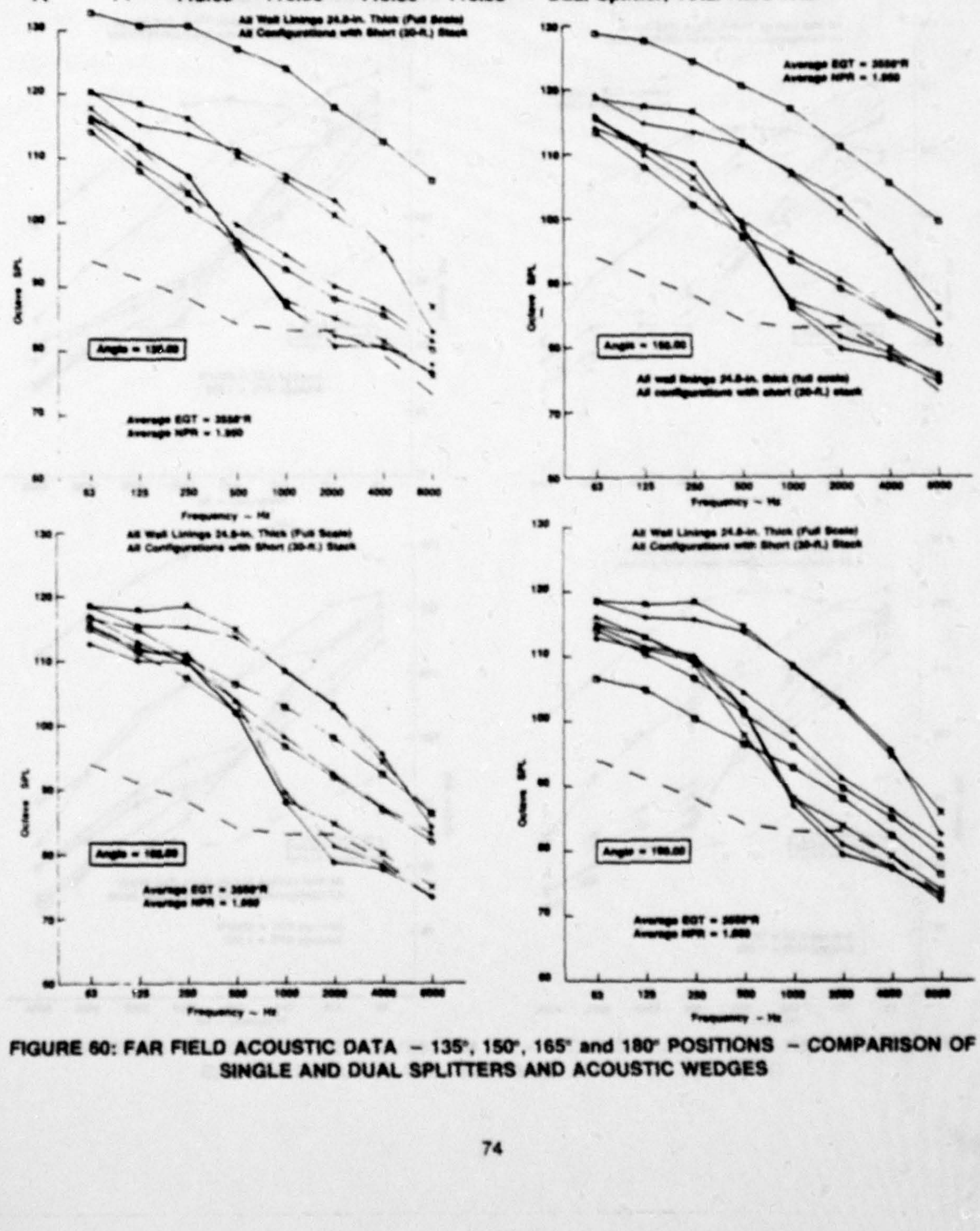

FIGURE 60: FAR FIELD ACOUSTIC DATA – 135°, 150°, 165° and 180° POSITIONS – COMPARISON OF SINGLE AND DUAL SPLITTERS AND ACOUSTIC WEDGES

The near field data are presented on a one-third octave band basis on Figure 61. The microphone locations and identification are given on Figure 31. These data are representative of the sound pressure levels that exist interior to the suppressor system. These data are from Run 39 for the short single splitter stack configuration with the stack and splitter walls hard. The effectivity of the secondary air inlet lining is indicated by the difference between the levels of microphones N4 and N6. The acoustic performance of the secondary air inlet was adequate relative to the performance of the exhaust suppressor system. An accurate determination of the sound radiated from the secondary air inlet could not be obtained since the noise radiated from the exhaust stack exit was the dominant noise source of the suppressor system.

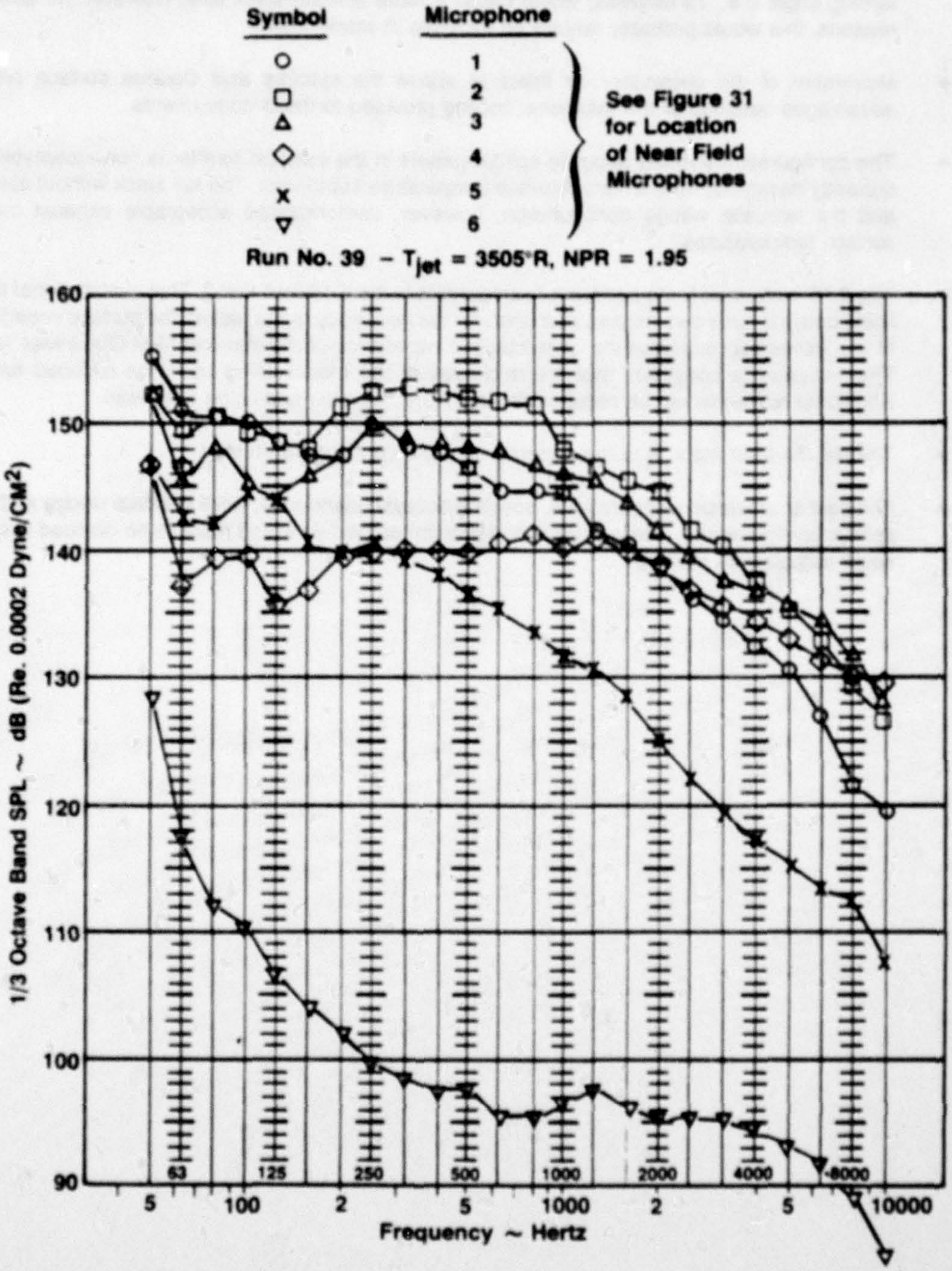


FIGURE 61: NEAR FIELD ACOUSTIC DATA – SHORT EXHAUST STACK CONFIGURATION WITH SINGLE SPLITTER – ALL HARDWALL LINED

## IV. CONCLUSIONS

The conclusions that may be drawn from his series of model tests are:

- The 65-degree Coanda flow turning was sufficient to allow the flow to exit vertically from the stack without detrimental impingement of the aft stack wall. The acoustic wedges seem to cause more attachment to the aft stack wall than the other configurations. For that configuration, a greater turning angle (i.e., 73 degrees) would cause a more uniform stack flow. However, for acoustic reasons, this would probably require an increase in stack height.

- Movement of the secondary air inlets to above the ejectors and Coanda surface proved advantages because of the additional cooling provided to those components.

- The configuration utilizing acoustic splitter panels in the exhaust muffler is not acceptable (as currently designed) from a metal surface temperature standpoint. The tall stack without splitters and the acoustic wedge configuration, however, demonstrated acceptable exhaust muffler surface temperatures.

- The 2.75-inch stack lining performed comparable to the 4.13-inch lining. This indicates that these lining designs have thicknesses such that, for the frequency range tested, the surface impedance of the linings approximates the characteristic impedance of the material (J-M Glass-Mat 1200). This indicates a possibility that the thickness of the model lining could be reduced further. Additional testing would be required to determine the minimum lining thickness.

- The tall (54-foot) stack was the superior acoustic configuration tested.

- The best short stack configurations, from the acoustic standpoint, were the dual wedge and dual splitter configurations. The superior configuration of the two would have to be decided from full scale optimization studies.

# V. RECOMMENDATIONS

The following recommendations are made based on the results of the testing described in this report and the primary goals of the Navy Coanda ground noise suppressor program:

- Model testing should be accomplished with the goal of improving the mixing in the ejectors and Coanda flow turning. The result of improved mixing would be lower temperature and lower velocity flow through the exhaust's muffler (stack) so that configurations with splitters could be used. This could possibly be accomplished by widening the ejectors and Coanda surface thereby increasing the area of flow available for mixing, reducing the height of the sheet of hot flow entering the Coanda surface which, in turn, would reduce the mixing length.

- The recommended production configuration consists of an exhaust stack without splitters or wedges and with a flow exit area equal to that used for the configurations with splitters (6.67 feet wide by 19.67 feet deep which is 131 square feet full scale). The stack height above ground should be at least 40 feet with the capability of adding to this height, if necessary, to improve acoustic suppression. The exhaust muffler stack walls and lower enclosure back wall should be lined with at least 35 percent open perforated sheet backed by 18 inches of acoustic treatment (Johns-Manville 1000 series Spinglas or equivalent). The lower enclosure should be the double, isolated wall construction developed previously and reported in Reference 3. The secondary air inlets should be placed above the ejectors and Coanda surface as in the model tested. The ejector and Coanda surface configurations shown on Figure 21 scaled up to full size (6 x model) should be used. This recommended configuration is presented in more detail on the Reference (f) configuration control drawings supplied to the Navy.

Reference (f): Naval Air Engineering Center Drawing 690AS108, "Drawing Tree – Noise Suppressor System, Coanda/Refraction."

## VI. REFERENCES

a. Ballard, R. E., Brees, D. W., and Sawdy, D. T., "Feasibility and Initial Model Studies of a Coanda/Refraction Type Noise Suppressor System," The Boeing Company, Wichita, Kansas, Document D3-9068, January 1973.

b. Ballard, R. E., and Armstrong, D. L., "Configuration Scale Model Studies of a Coanda/Refraction Type Noise Suppressor System," The Boeing Company, Wichita, Kansas, Document D3-9258, October 1973.

c. "Test Cell Experimental Program Coanda/Refraction Noise Suppression Concept – Advanced Development," Final Technical Report for Navy Contract N00156-74-C-1710, Navy Document Number NAEC-GSED-97, The Boeing Company, Wichita, Kansas, March 1976.

d. "Aircraft System One-Sixth Scale Model Studies, Coanda/Refraction Noise Suppression Concept – Advanced Development," Final Technical Report for Scale Model Portion of Navy Contract N00156-74-C-1710, Navy Document Number NAEC-GSED-98, The Boeing Company, Wichita, Kansas, March 1976.

e. "GENEG-A Program for Calculating Design and Off-Design Performance for Turbojet and Turbofan Engines," NASA – Lewis Research Center Document Number TND-6552, February 1972.

f. Naval Air Engineering Center Drawing 690AS108, "Drawing Tree – Noise Suppressor System, Coanda/Refraction."

## VII. LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

| | |
|---|---|
| A.R. | Ejector area ratio – ratio of ejector minimum flow area to primary exhaust nozzle area |
| $C_{P_{H_2O}}$ | Specific heat of water |
| f/a | Fuel-to-air ratio |
| h | Total enthalpy, btu/lb |
| $h_a$ | Total enthalpy for air, btu/lb |
| $h_{fa}$ | Enthalpy of incoming fuel (assumed to be 23 btu/lb) |
| $h_{fc}$ | Enthalpy correction factor for combustion products, btu/lb |
| $h_{in}$ | Total enthalpy of afterburner inlet airflow, btu/lb |
| $h_{out}$ | Total enthalpy of afterburner exhaust, btu/lb |
| $H_v$ | Lower heating value of fuel, 18,400 btu/lb |
| $P_a$ | Ambient pressure, psia |
| $P_s$ | Static pressure, psia |
| P.R. | Nozzle pressure ratio – exit total pressure/ambient |
| R | Resistivity, rayl/cm |
| $R_0$ | $-1.7558886$ |
| $R_1$ | $2.5020051 \times 10^{-1}$ |
| $R_2$ | $-2.576844 \times 10^{-5}$ |
| $R_3$ | $2.1839826 \times 10^{-8}$ |
| $R_4$ | $-1.6794594 \times 10^{-12}$ |
| $R_5$ | $-3.0256518 \times 10^{-15}$ |
| $R_6$ | $1.270263 \times 10^{-18}$ |
| $R_7$ | $-2.0752522 \times 10^{-22}$ |
| $R_8$ | $1.264425 \times 10^{-26}$ |
| $R_{f_0}$ | $30.58153$ |
| $R_{f_1}$ | $7.3816638 \times 10^{-2}$ |
| $R_{f_2}$ | $6.129315 \times 10^{-4}$ |
| $R_{f_3}$ | $-4.5906332 \times 10^{-7}$ |

## LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (CONT'D)

| | |
|---|---|
| $R_{f_4}$ | $2.4921698 \times 10^{-10}$ |
| $R_{f_5}$ | $-8.4102208 \times 10^{-14}$ |
| $R_{f_6}$ | $1.7021525 \times 10^{-17}$ |
| $R_{f_7}$ | $-1.9050949 \times 10^{-21}$ |
| $R_{f_8}$ | $9.0848388 \times 10^{-26}$ |
| $T$ | Temperature, °R or °F |
| $T_{in}$ | Afterburner inlet temperature, °R |
| $T_{out}$ | Afterburner exhaust temperature, °R |
| $T_{L_{H_2O}}$ | Cooling water inlet temperature, °R |
| $T_{H_{H_2O}}$ | Cooling water outlet temperature, °R |
| $\Delta T_{H_2O}$ | Cooling water temperature rise, degrees |
| $\dot{W}_{cp}$ | Total airflow at Coanda entrance, lb/sec |
| $\dot{W}_{cs}$ | Secondary airflow entrained along Coanda surface, lb/sec |
| $\dot{W}_{e_1}$ | Secondary airflow entrained at first ejector entrance, lb/sec |
| $\dot{W}_{e_2}$ | Secondary airflow entrained at second ejector entrance, lb/sec |
| $\dot{W}_{e_3}$ | Secondary airflow entrained at third ejector entrance, lb/sec |
| $\dot{W}_{f\ A/B}$ | Afterburner fuel flow, lb/sec |
| $\dot{W}_{fp}$ | Primary burner fuel flow, lb/sec |
| $\dot{W}_{H_2O}$ | Cooling water flow rate, lb/sec |
| $\dot{W}_{A/B}$, $\dot{W}_{jet}$ | Total jet exhaust flow, lb/sec |
| $\dot{W}_s$ | Measured secondary air intake airflow, lb/sec |
| $\alpha$ | Coanda entrainment coefficient $- \dot{W}_{cs}/\dot{W}_{cp}$ |
| $\theta_a$ | Ambient temperature (°R)/518.67 |
| $\delta_a$ | Ambient pressure (psia)/14.696 |
| $\rho$ | Density, pcf |
| $\eta_B$ | Afterburner efficiency |

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