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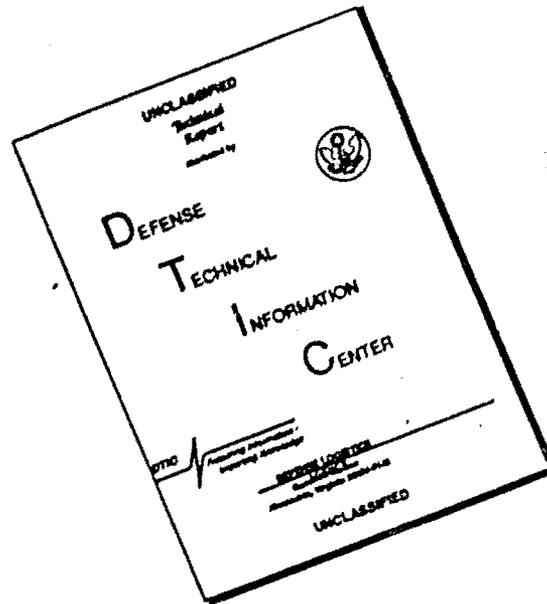
JET ENGINE TEST CELL
TEST AUGMENTER-SCRUBBER SYSTEM

FINAL REPORT December 1971

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CONTRACT N62467-70-C-0240
REPORT ON ABATEMENT OF
PARTICULATE EMISSIONS AND NOISE FROM
JET ENGINE TEST CELLS
INCLUDING REDUCTION OF GAS FLOW WITH
THE TESI AUGMENTER-SCRUBBER SYSTEM

December 1971

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AD-A

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ABSTRACT

The prototype scrubber and augmentation system designed for and operated in Black Point Test Cell Number 1 NARF-Jacksonville has abated emissions to the projected design level. The engines operated with the system were the J-79, TF-30, and J-52. Particulate emissions were reduced to the 0.002-0.005 gr/SCF level. The visible emissions fell well within the Ringleman 1/2 level after dissipation of the steam plume. No fallout was evident during operation of the system. It was further established that engine test performance was not affected by the TESI system.

The scrubber system was mounted on the exhaust stack of the cell thus obviating the necessity for costly ducting and the requirement for ground utilization.

The size requirement of the scrubber was reduced significantly with the use of a new augmentser design that decreased the induced air to jet exhaust flow ratio from values in the range of 2:1 to 0.4-0.6:1. This new augmentser can reduce the augmentation even further, thus providing the potential of retrofit of existing cells to accommodate engines larger than now being tested. Sound levels were reduced by the installation of the scrubber from 6-10 decibels (dBA), where the original sound level was of the order of 90-95 dBA.

In order to prevent the mere transfer of pollution from airborne to waterborne, a loop system should be considered for all installations. The TESI scrubber recovers 74-96% of the energy of combustion in the engine and recovers up to 95% of the submicron particulates (up to 1/2 ton/day). Thus clean-up and cooling of the water with total recycle is necessary for all installations.

LIST OF TABLES

- 2.1 EFFECT OF NEW AUGMENTER ON SECONDARY AIR FLOW
- 7.1 EFFECT OF RECYCLE ON AUGMENTATION FLOW
- 7.2 NOMENCLATURE FOR AUGMENTER DERIVATION
- 7.3 OBSERVED AUGMENTATION RATIOS
- 7.4 MODEL PREDICTED AUGMENTATION RATIOS
- 8.1 VARIATION IN PARTICULATE LOADING AS FUNCTION
OF PROBE POSITION
- 8.2 PARTICULATE EMISSIONS FROM JET ENGINES IN
TEST CELL
- 8.3 COMPARISON OF PARTICULATE LOADINGS FOR TURBO-
FAN ENGINES
- 8.4 PROJECTED FALLOUT FROM ENGINE TEST CELL
- 9.1 PERFORMANCE CHARACTERISTICS - SCRUBBER
- 9.2 LOSS OF FRESH WATER IN AUGMENTER - SCRUBBER
OPERATION
- 10.1 REDUCTION IN AUGMENTATION
- 11.1 EMISSION LEVELS FROM CONTROL SYSTEM
- 12.1 RIVER WATER TEMPERATURES
- 12.2 RESULTS OF ANALYSIS OF SCRUBBER WATER
(NARF DATA)
- 12.3 RESULTS OF ANALYSIS OF SCRUBBER WATER
(SOUTHERN ANALYTICAL LAB)
- 13.1 OVERALL "A" SCALE SOUND LEVELS

LIST OF FIGURES

- 5-1 Nucleation Scrubber
- 5-2 Air Baffles

- 6-1 Plan of Water System
- 6-2 River Water Intake System

- 7-1 Augmenter
- 7-2 Schematic for Equation Development
- 7-3 Model Predicted Augmenter Performance
at Constant Outlet Area
- 7-4 Model Predicted Augmenter Performance
at Constant Augmentation Area
- 7-5 Effect of Water Injection on Augmentation

- 8-1 Sampling Probe Locations
- 8-2 Particle Size Distribution - J-79 Engine - Idle
- 8-3 Particle Size Distribution - J-79 - 95%
- 8-4 Particle Size Distribution - J-79 Engine - Afterburner
(Min.)
- 8-5 Particle Size Distribution - J-79 Engine - Afterburner
(Max.)
- 8-6 Particle Size Distribution - J-52 Engine - Idle
- 8-7 Particle Size Distribution - J-52 Engine - Military
- 8-8 Recovered Particulates in Scrubber Water

- 9-1 Scrubber - Temperature and Thermal Conditions -
J-79 Operation

- 10-1 TF-30 Exhaust Profile - Military Mode
- 10-2 J-79 Exhaust Profile - Military Mode
- 10-3 TF-30-P8-B Correlation S.N. 664330
- 10-4 TF-30-P8-B Correlation S.N. 664330
- 10-5 J-52-P8-B Correlation S.N. 677211
- 10-6 J-79 Engine Pumping Characteristics (letter from G.E.)
- 10-7 J-79-GE-8 Engine Pumping Characteristics

- 11-1 Cell Exhaust Prior to Installation of Scrubber
- 11-2 System Exhaust TF-30 Military
- 11-3 System Exhaust J-79 Military
- 11-4 System Exhaust J-79 A/B (following title page)

- 12-1 Diffusion Model - Temperature in River
- 12-2 River Temperatures - Military and A/B Modes - J-79 Operation
- 12-3 Waste Waters Certificate of Analysis or Tests

- 13-1 Sound Levels, J-79 Military
- 13-2 Sound Levels, J-79 A/B
- 13-3 Sound Levels, TF-30 Military

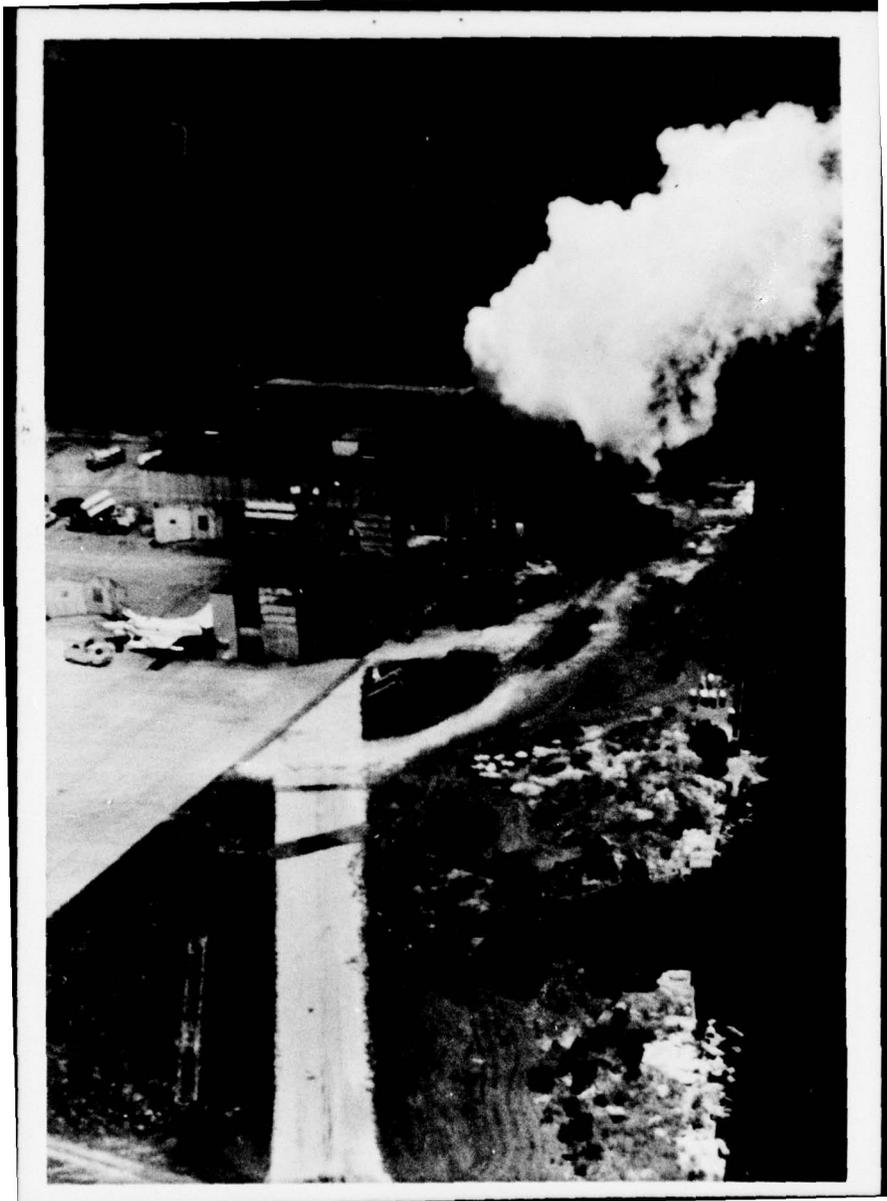
TABLE OF CONTENTS

CHAPTER

<u>PART I:</u>	<u>OVERVIEW</u>	
	Overall Task	1
	Summary	2
	Recommendations	3
	Design Parameters, Criteria, and Costs	4
<u>PART II:</u>	<u>DESIGN CONSIDERATIONS</u>	
	Scrubber	5
	Water System	6
	Augmenter	7
<u>PART III:</u>	<u>PERFORMANCE</u>	
	Effluent from Engines & Recov- ery by Scrubber	8
	Scrubber	9
	Augmenter	10
<u>PART IV:</u>	<u>CONFORMANCE WITH ENVIRONMENTAL REQUIREMENTS</u>	11
<u>PART V:</u>	<u>SECONDARY EFFECTS</u>	
	Effluent Water	12
	Sound Level	13

LIST OF APPENDICES

- 8A - ANALYTICAL METHODS AND PROCEDURES FOR
ENGINE EXHAUST, SCRUBBER EXHAUST, AND
WATER
- 9A - TEST DATA - SCRUBBER
- 13A - SOUND LEVELS - RAW DATA



OVERVIEW: Overall Task

- 1.1 The task for this project was established by NAVFAC, Southern Division, as follows:

A. General Requirements

The Engineering Service Contractor shall perform the following services:

1. Determine by field test with test cell 774 operating in its present configuration; (a) types of pollutants emitted, (b) flow rates at appropriate points in the cell, (c) operating pressures and temperatures at appropriate points in the cell, (d) noise levels, (e) Ringleman test of effluent and (f) other operating data that may be required to design a nucleation type scrubber system and to determine by post installation test, its effectiveness.
2. Design a nucleation type scrubber system and an augmentation system for the test cell which will abate pollution to a degree commensurate with local and Federal regulations and which will conform to other local and Federal regulations (such as thermal and particulate pollution of water). Design should provide for use of any materials available at NARF, Jacksonville.
3. Erection of the design system, including necessary alterations.
4. Accomplish post installation tests necessary to determine the effectiveness of the scrubber and to establish the validity of the augmentation formula derived under contract N62467-70-C-0078.
5. Based upon tests in item 4 above, determine and accomplish modifications and/or adjustments required to optimize the operation of the abatement system.
6. Retest as necessary to determine effectiveness of the final system.

PART I
Chapter I

1.1 A. General Requirements (Continued)

7. Prepare a report evaluating performance of the abatement and augmentation systems and recommending criteria and design parameters to be used in modifying other existing test cells and constructing new cells for the abatement of pollutant emission.

NOTES: All tests other than air pollution tests will be provided by NARF, Jacksonville personnel. Testing done under this contract shall be accomplished by subcontract with an approved firm with demonstrated capabilities for the testing involved. The final test in item 6 above shall be scheduled so as to permit observation by various Government representatives to be determined. Pollution tests will be accomplished as follows:

	<u>Test Before</u> Any <u>Modification</u>	<u>Test Prior</u> To <u>Optimization</u>	<u>Final</u> <u>Test</u>
<u>J-79-8</u>	x	x	x
<u>CBC Engine</u> (Probably <u>J-52 P8</u>)	x		x

This report fulfills Task 7.

- 1.2 TESI wishes to acknowledge the aid and cooperation of members of NAVAIR, NAVFAC and NARF-JAX in bringing this system to its state of operation. As a result of this aid, the task requirements have been exceeded in the following areas:

1. 3 engines were tested rather than 2 (by mutual agreement).
2. Gas analyses were made to include loadings and particle size as well as Ringleman.
3. Gas flows through the test cell were reduced up to 1/2 of the conventional flow.

OVERVIEW: Summary

- 2.1 Evaluation of the performance of the test system for pollution abatement of operating effluents from a jet engine test cell was conducted at NARF, Jacksonville, Black Point Cell No. 1, during the period from December 1970 through May 1971. Characteristics of performance were obtained with the following engines:

J-52
J-79
TF-30

under operating conditions of idle through afterburner throttle setting conditions where applicable.

- 2.2 The results of the tests are as follows:

- 2.2.1 Abatement of particulate emissions was achieved for all engines at all conditions of test to well within all existing codes and regulations. The system performed in accordance with design projections for particulate emissions.

Existing codes call for Ringleman 1/2 as emission equivalent opacity after evaporation of steam. Executive Order 11282 implies a requirement of 0.008 grains/cu. ft. Design projection was 0.004 grains/ cu. ft.

The effluents from the system were:

J-52	Average	0.0026	grains/cu. ft.
TF-30	Average	0.0017	grains/cu. ft.
J-79	Average	0.0044	grains/cu. ft.

The Ringleman equivalent after dissipation of the steam was below Ringleman 1/2.

2.2.2 Reduction in total gas flow in the test cell in the order to 38-47% was achieved via use of the proprietary augments. The reductions in augmentation flows were as follows:

TABLE 2.1

EFFECT OF NEW AUGMENTER ON SECONDARY AIR FLOW

		<u>Augmentation</u>		<u>Ratio</u>	<u>Percent Reduction</u>		
		<u>Initial</u>	<u>36"D Throat</u>	<u>NEW</u>	<u>AUG</u>	<u>in Augmentation</u>	
						<u>Air with New Aug</u>	
				<u>36"D Throat</u>	<u>30"D Throat</u>		
J-79	Mi1	2.1 ¹	1.06 ²			50	
J-79	A/B	1.9 ¹	0.64 ³			67	
TF-30	Mi1	1.22 ¹	0.62	0.38		49	
TF-30	Mi1	2.12	0.62	0.38		71	
						82	

- 1 - Forcing cone placed on old augments. The forcing cone reduced augmentation 50% below conventional operation.
- 2 - All positions except 16" (See Table 7-3)
- 3 - All at position +2" (Reading 1.06 - 100% variation from other four deleted).

PART I
Chapter 2

2.2.2. (Continued)

Overall flow reduction through the test cell was:

		<u>Reduction in Total Flow - (%)</u>	
		<u>Large Cone</u>	<u>Small Cone</u>
J-79 ¹	Mil	34	
J-79 ¹	A/B	44	
TF-30 ¹	Mil	27	38
TF-30 ²	Mil	49	56

- 1 - Comparison is with forcing cone on old augments.
- 2 - Comparison with forcing cone that had been normally used in the installation.

The objective of flow reduction was the decrease of size and cost of the abatement systems. The implications are that larger engines can now be tested in existing cells if appropriate changes to the thrust systems are made.

2.2.3 Sound levels were reduced from 6-10 decibels (dBA) after installation of the scrubber indicating potential for reduction of installation of high maintenance sound attenuation equipment in test cells where the scrubber is installed. All data with the scrubber in operation were taken in the northwest quadrant and thus included intake noise. The reduction in sound level, therefore, is considered conservative.

2.2.4 The test system has been in continuous operation since April 1971 in stable regime and providing effective reduction in test cell gas flow, abatement

2.2.4 (Continued)

of particulate emissions, and sound level reduction.

2.2.5 Effluent water temperatures exceeded those projected on the basis of estimated heat transfer coefficients in the scrubber. Whereas peak effluent water temperatures of 145°F had been anticipated, the water effluent temperature during J-79 A/B operation was 165°F to 168°F. During military operation for the J-79 (the hottest engine tested), the temperature rise at the surface of the river was of the order of 25°F, and 6°F at 1 foot below the surface at a distance of 40 feet from the discharge. A mathematical model based on average of 33% of the time in military throttle and 5% in afterburner with an average scrubber water temperature rise over the 5-hour operating period of 13.8°F, showed a 4°F average rise in river water at a distance of 100 ft from the discharge point. The actual temperature rise in the scrubber water for this type of cycle is 26.3°F. Thus, an average rise of 8°F would be projected.

2.2.6 Although SO₂ exhaust could be anticipated from the specifications of JP-5 fuel, the sulfur maximum in the fuel is rarely evident and SO₂ levels were always below 10 PPM in the exhaust.

2.2.7 The solids recovered in the scrubber are not consistent in behavioral characteristics. In some cases, settling rates indicated a 5-25 micron agglomerate as the major constituent. In other cases, a stable emulsion was evident. Separation and recycle studies are indicated.

OVERVIEW: Recommendations

Regarding the present installation, it is recommended that:

- 3.1 A prototype cooling tower be installed to provide for recirculation of the water through the system and preclude emission of particulate or thermal pollution into the river.
- 3.2 A solids and oil separation system be installed in the circuit to provide a sludge that can be added to the fuel in the boiler plant.

Regarding future installations, it is recommended that:

- 3.3 Consideration be given to augments design in order to maintain a minimum 400-500°F temperature in the mixed jet augmentation air flow prior to quench. A variable throat TESI augments can be used in order to properly minimize flow for engines of different exhaust nozzle diameter.
- 3.4 The slope of the packed scrubber be increased to prevent breakthrough of water from the sides.
- 3.5 Thorough consideration of angle of gaseous emission from the scrubber with regard to effect on sound levels be made.

OVERVIEW: Design Parameters, Criteria, and Costs

The size and operation of the scrubber were evaluated based on the performance of the prototype. As a result of this study, the following parameters were established:

- 4.1 Height of packed section can be increased to 20 feet without adverse effects on performance.
- 4.2 The size of the scrubber can be reduced from 10% to 20% based on the Jacksonville unit. Thus the face dimension of the scrubber could have been reduced from 960 ft² to 840 ft², thus reducing the length of the scrubber from 30 feet to 26 feet.
- 4.3 The scrubber can accept outlet flows in the range of 100 - 450 ft/min and inlet flows of 100-600 ft./min.
- 4.4 Stability was maintained at an irrigation rate of 5-25 GPM/ft² of irrigation area. Face spray flux was effective in the order of 1-3 GPM/ft².
- 4.5 Effective operation is achieved with irrigation with water in the range of 1-3 GPM per 100 CFM of outlet gas, as a function of inlet gas temperature.
- 4.6 A demister zone of 1 ft. of 1-inch Tellerettes is required.
- 4.7 Pressure drop of 6 in. w.g. should be considered as a maximum, although in operations, reliable data indicated that a maximum of 3-4 in. w.g. occurred.

PART I
Chapter 4

- 4.8 The system was designed for 10 in. w.g. static pressure and was effective.
- 4.9 Top roll turning vanes should be used at the top of the scrubber.
- 4.10 The maximum operating temperature of the packing should be 175°F.
- 4.11 The cooling tower load, based on performance data, was higher than that predicted because of the high heat transfer rates. The thermal absorption is a function of the inlet temperature of the quenched gas. It represented 83-96% of the thermal value of the fuel burned when the quenched gas temperature was below 140°F and 74% of the thermal value of the fuel burned at an inlet temperature of 172°F.
- 4.12 The cost of the scrubber installed, exclusive of piping and pumps that will vary with the installation and engines tested, is of the order of 25¢ to 45¢ per ACFM inlet to the scrubber. This variation is a function of the dimensions of the stack and the height above the ground level.

The cost of the cooling tower, exclusive of pumps, piping, and sump is estimated to range from 0.14-0.25¢/ (Btu/hr) for "average" design conditions and 0.05-0.10¢/ (Btu/hr) for the responsive proprietary system at the maximum load condition. The ground space will range from 5 to 10 ft² per 10⁶ Btu/hr at "average" design and 2 to 4 ft² per 10⁶ Btu/hr at maximum conditions.

DESIGN CONSIDERATIONS: TEST SCRUBBER

5.1 Description:

The TEST Scrubber (Fig. 5-1) is a cross flow nucleation system (proprietary) that provides for collection of submicron particulates via the nucleation phenomenon (a combined process of particle growth via condensation, improved particulate collision resulting from wetting via condensation, and codiffusional drag).

The scrubber was designed as two identical reflection sections mounted with independent supports parallel to the 20 ft sides of the stack. The overall scrubber dimensions are 30 feet long x 20 feet high x 28'6" wide, including gullwings and sides. The packed sections have a face dimension of 30 ft x 17 ft and each contained a 4'6" depth of 2-inch nominal Tellerettes followed by a divider support plate and 9 inches of 1-inch nominal Tellerettes. The 2-inch packing was irrigated with 4000 GPM for each 30-foot section. The water feed is divided into two components, sprays at 20 PSIG washing the 30 ft x 17 ft face at the rate of 1000 GPM per section and top distributors irrigating the 4'6" depth of the 2-inch packing at the rate of 3000 GPM per section. The 1-inch Tellerettes (9-inch depth) are not irrigated and serve as a demister section.

The gas flow (quenched test cell gas) is distributed to the two packed section faces by turning vanes on each side of the stack. The face sprays are used for initial reduction in temperature as well as to protect the packing from any "hot spot conditions" resulting from incomplete quenching in the augments section.

After leaving the packed demister, the gas is directed upwards at an angle of 45° by gull wings mounted on the scrubber section.

The liquid effluent is collected in sloped bottom troughs containing baffles to prevent gas bypass. The collected liquid is discharged by gravity to the river via a sealed underflow weir and an overflow weir.

5.2 The characteristics of the scrubber are as follows:

No. of scrubbers	-	2
Type of scrubber	-	Packed, cross flow, nucleation
Face Dimension for Gas Flow, Each Scrubber	-	30' x 17'
Depth of Packing	-	4'6" - 2" Tellerettes for cross flow nucleation 9" - 1" Tellerettes for demisting
Volume of Packing	-	4600 cu.ft. - 2" Tellerettes 770 cu.ft. - 1" Tellerettes
Grating	-	Polyethylene 1" x 1" grating with 2" shelves for strength.
Separation between Recovery and Demisting Sections	-	Polyethylene grating with 1" x 1" mesh cover.
Face Sprays	-	4 each section (4"D) - 8 total; 29' long, 8 nozzles per distributor
Top Distributor	-	3 (6"D x 30') each scrubber section - 6 total. Each distributor 20 nozzles (120 total)
Top Baffles	-	2 each side, 4 total 2'6" x 30' each.

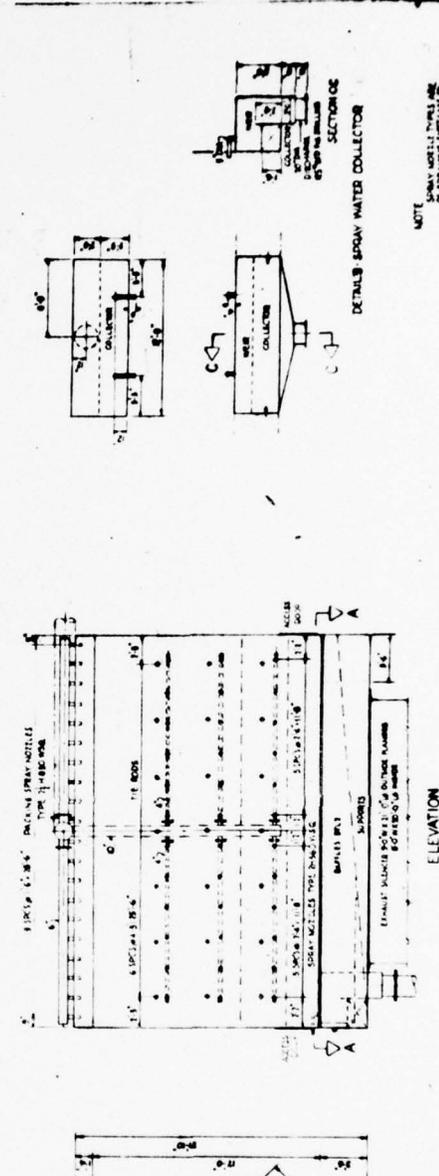
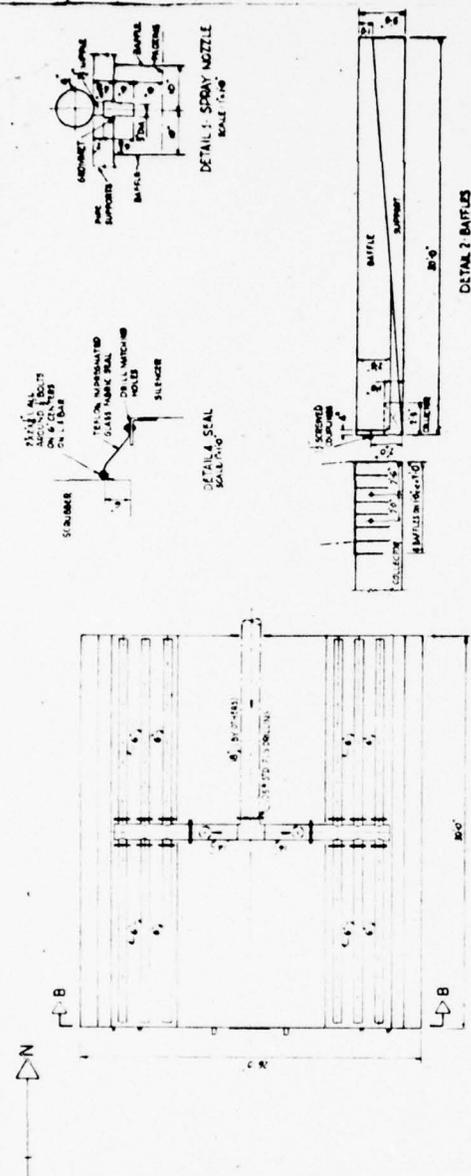
PART II
Chapter 5

5.2 (Continued)

- | | |
|----------------|---|
| Bottom Baffles | - 6 on 1-foot centers following full length of sump with 2' x 4" notches at deep end. |
| Bottom Sump | - 2 required, 1 for each scrubber; 30' long x 7' wide x 1' deep at shallow end and 3/6" deep at flooded end - Discharge through 24" D pipe. |
| Gull Wings | - 4 on each section of scrubber - 8 total. 6' x 30' each. |
| Turning Vanes | - 2 each side - 4 total. 2-3' Radius, 2-6' Radius plus straight sections - Epoxy painted steel. |
| Cover Sections | - Corrugated FRP - Fiberglass reinforced plastic |

Pipe baffles (FRP) were added at the top section of the existing stack because of severe maldistribution of gas flow entering the scrubber section. These were placed on the south end of the scrubber. Baffles consisted of 4' lengths of 3" D FRP pipe mounted on 7-1/2" centers (Fig. 5-2). The scrubber is independently supported. The top of the trough is breeched to the top of the stack by 1/4" thick Neoprene sheet.

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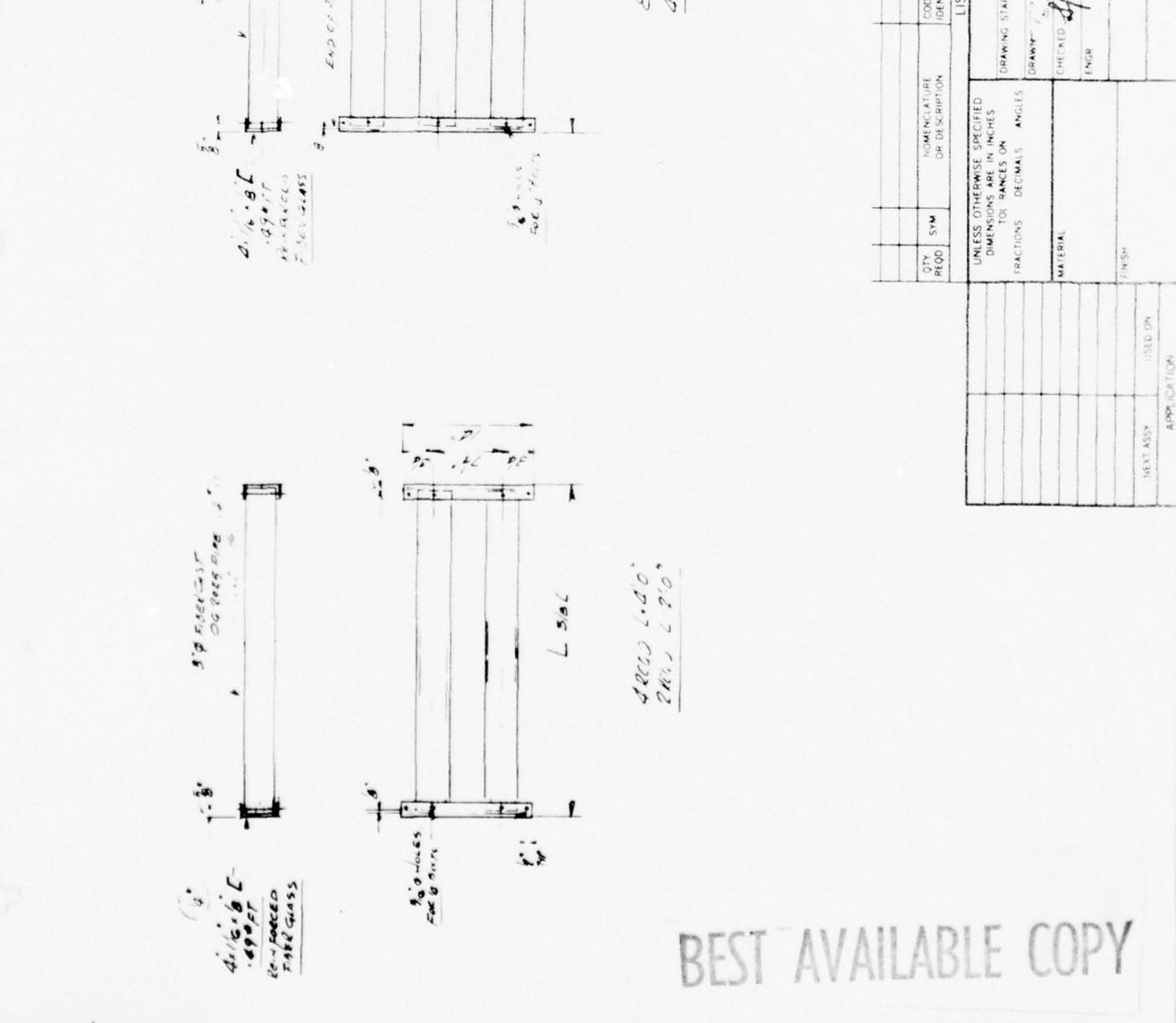


NOTE: THIS UNIT SHALL BE OF BRASS OR STAINLESS STEEL

INSULATION REQUIRED	
BLACK PONY ENGINE TEST CELL	
NASA'S BRASS FACILITY	
JACKSONVILLE, FLA.	

4 3 2 1

REVISIONS		DATE	APPROVED
ZONE	DESCRIPTION		



36C L-1-0
38L L-2-0

36C L-1-0
38L L-2-0

QTY	SYM	NOMENCLATURE OR DESCRIPTION	CODE IDENT	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTE	UNIT	ZONE	ITEM NO.
LIST OF MATERIALS OR PARTS LIST									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES FRACTIONS DECIMALS ANGLES		DRAWING STARTED DATE		DRAWN		CHECKED		ENGR	
MATERIAL		DRAWING NO.		DATE		DRAWN		ENGR	
FINISH		DRAWN		DATE		DRAWN		ENGR	
HEAT ASSY	USED ON	APPLICATION							
TELLER ENVIRONMENTAL SYSTEMS, INC. NEW YORK, N.Y. AIR BAFFLES NAVAL AIR REMOVAL FACILITY JACKSONVILLE, FLA. SIZE CODE IDENT NO. P-103-218 SCALE 1" = 1'-0"									

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DESIGN CONSIDERATIONS: Water System

6.1 The water system for the TEST scrubber-augmenter unit consists of two major components:

- 1- River water for packed scrubber
- 2- Fresh water for augmenter

The flow diagram for the system, is indicated in Figure 6-1. The water intake system is shown in Figure 6-2.

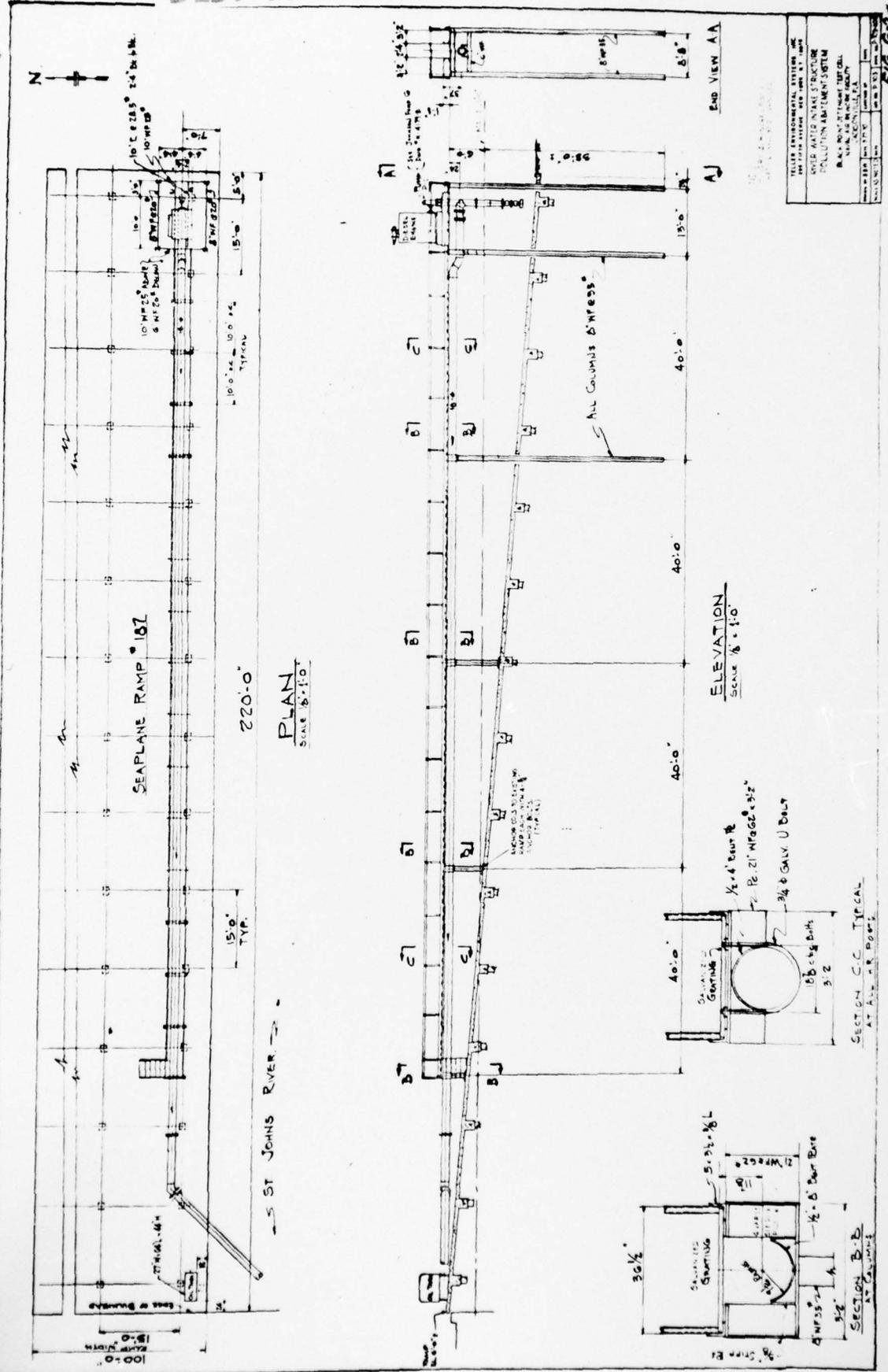
6.2 River water is pumped at the rate of 8000 GPM (81 foot head) by a Johnston Vertical Mixed Flow Right Angle Drive 2-Stage Pump, Model F-250, driven by a 250 HP Diesel Engine, Cummins Model NT 280-1F. The intake of the pump submerged in the river was placed approximately 250 feet from the bulkhead, to achieve proper submergence. The 18" D carbon steel transfer line to the scrubber was approximately 350 feet long. Flow was measured by a by-pass orifice flowmeter. The discharge from the scrubber was 20" D and was placed along the bulkhead discharging at rip rap into the river at a 260 feet distance from the scrubber. The displacement of inlet and outlet, 540 feet on an east-west line and 120 feet on a north-south line, was chosen to minimize the potential of recycle to the scrubber. No evidence of recycle was observed.

6.3 The quench water was supplied from two (2) 20,000 gallon tanks with common feed from the station potable water system. Two pumps were used to provide water under head to the quench zone, one for the venturi throat spray ring and one for the diverging section sprays. The pumps were started by the test cell operator with starter switches in the control room.

The spray ring pump specifications were:

Ketchum Pump Model 3 ADIO
Head 175 ft.
600 GPM
50 HP Motor

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TELLER ENVIRONMENTAL SYSTEMS, INC. 1001 FIFTH AVENUE, SUITE 211, DENVER, CO 80202	
WATER INTAKE STRUCTURE POLLUTION ABATEMENT SYSTEM	
PROJECT LOCATION: TYPICAL PROJECT NO.: 88-001-001	
DRAWN BY: [Name] CHECKED BY: [Name]	DATE: [Date]

Fig. 63-

6.3 (Continued)

The diverging section spray pump provided by the U. S. Navy was a:

Ketchum Pump Model 5874
Head 175 ft.
500 GPM
30 HP Motor

The water feed to the augments was delivered through 6"D lines with positive shutoffs controlled from the test cell operating room.

DESIGN CONSIDERATIONS: Augmenter

- 7.1 The augmenter system (Fig. 7-1) (6'4"D x 12') was designed to provide for reduction of augmentation with minimal or no physical interference with the flow of the jet. The flow system was conceived as follows:
- 7.1.1 Converging throat (25°) as entrance for the jet exhaust stream. The throat diameter, 3'0" is 6" greater than the exhaust bell diameter of the largest engine to be tested.
- 7.1.2 A minimum horizontal open distance of 1'0" with no directional structure before the position of the diverging venturi section ($\sim 7^\circ$). The open space houses the recessed high velocity spray ring and the remaining annular area for recycle flow.
- 7.1.3 The recessed annular spray ring is a 6"D pipe rolled to a 4'0" centerline diameter and perforated with 1/4"D spray orifices (40). These spray orifices direct the flow at a velocity of 80 fps radially into the jet exhaust stream.
- 7.1.4 The diverging section of the venturi, expanding at a half angle of approximately 7° , is hollow and is perforated with 1/4"D orifices to provide secondary quench water at 60 ft/sec to 80 ft/sec. The outer diameter of the diverging section is 4'7", thus providing an annular cross section between the diverging section and the augmenter I.D. of 13.1 ft². This represents 41.8% of the total augmenter cross section, and is the flow area for the recycle gas.
- 7.1.5 A recycle circular baffle is placed 1'8" downstream from the end of the diverging conical section in

7.1.5 (Continued)

order to aid the recycle of the quenched gas. The flange height is 4" and can act as a baffle. One additional baffle was provided to increase the scoop baffle height to 12".

7.1.6

A removable axially located hollow conical core buster was located with the leading point 6" upstream of the trailing edge of the diverging section. This unit was placed in the augmentor to determine the necessity for final breaking of the jet core. The core buster was 32-1/4"Ø orifices for secondary irrigation and quenching.

BASIS OF DESIGN

- 7.2 The objective of this augmentor system (Fig. 7-1) was to minimize the total gas flow in the exhaust in order to reduce the capital cost and size of the pollution abatement system. The secondary objective was to reduce the total gas flow with the possibility resulting that the existing test cells, with thrust bed modification, could be used for the new, larger engines that are adopted by the Navy.

The design and development of this augmentor was based on the following:

Hypothesis 1: The presence of non-aerodynamic fixed bodies in the path of the jet exhaust, as a secondary effect, precludes reduction in augmentation because of the turbulence developed. As a result of turbulence occurring in augmentors with fixed bodies in the path of the gas stream, the engine must be blanketed with secondary air, in the order of augmentation of 1-3, in order to maintain engine stability.

7.2 (Continued)

Hypothesis 2: The kinetic energy of the exhaust, approximately 1/2 of the total energy in the A/B range (calculated), can be relieved by entrainment, turbulence, or pressure drop due to friction. The most effective mode is entrainment combined with friction loss in an area outside the main flow zone, because it minimizes reflection of instability to the engine. The design objective was to maintain, as much as feasible, the entrainment mechanism but to provide it, not with secondary air only, but with flashing water and an internal recycle. The annular space around the diverging section was the mechanism projected to achieve both these phenomena. Based on the cross sectional area of the annulus, the following internal recycle augmentation rates for the J-79 were projected:

TABLE 7.1
Effect of Recycle on Augmentation Ratio

Internal Recycle Velocity sfps	Recycle Flow		Internal Augmentation Ratio
	SFCS	lb/sec	
50	655	52.9	0.29
100	1310	105.8	0.59
150	1965	158.5	0.88
200	2620	211.6	1.08

Thus by air flow recycle alone, assuming an augmentation ratio of 2.0, reduction to ratios of 0.92 to 1.71 could be achieved within the recycle velocity range of 50 to 200 sfps, provided the

7.2 (Continued)

Hypothesis 2: (Continued)

recycle air is introduced at the venturi throat. If the recycle air does not return at the throat, no significant effect will occur. An additional and major factor for the reduction of augmentation is that the recycle flow, entering the augments at the throat of the venturi, carries unevaporated water in the stream. If it enters at the periphery of the jet exhaust, it can flash to a vapor thus satisfying a part of the need for jet exhaust entrainment. This type of augmentation is most desirable because it fulfills the system's dual need for thermal and momentum transfer. The steam augmentation is also condensible and, therefore, does not burden the pollution control system with non-condensable flow.

The problem in design was that the quantitative prediction of the quantity of droplet flow back to the throat is, to say the least, difficult. However, spray orifices were located near the trailing edge of the diverging section of the venturi in order to maximize the recycle quantity.

Hypothesis 3:

The air scoop was incorporated in the design in order to maximize the recycle. The recycle phenomenon should occur because of decrease of the velocity of the gas stream as it expands into the diverging zone of the venturi. Inasmuch as the ratio of the two cross sections is 2.6, the system gas flow will have a ratio of 6.7 velocity heads. With a total augmentation ratio of 2 (sum of external, recycle, and flash), an increase in static pressure of 3 to 5 in. w.g. was estimated at the trailing edge of the diverging section of the venturi. This increase in static pressure is theoretically capable of causing a recycle rate in the annular section as high as 800 fps exclusive of friction and reversal losses.

7.2 (Continued)

Hypothesis 3: (Continued)

The air scoops were placed in the augmen-
ter on an experimental basis in order to
aid the turnaround.

Hypothesis 4: The core buster in aerodynamic form was
placed, in removable condition, in the
augmenter if final destruction of the jet
core was required. The maximum jet dia-
meter (J-79 AB) was 28 inches. Under
these conditions, it would naturally dis-
sipate at a distance of 20 feet from the
engine discharge. Inasmuch as the aug-
menter was only 12 feet long, it was in-
dicated that the possibility existed for
presence of the hot core at the termina-
tion of the augmenter.

7.3 AUGMENTER - THEORETICAL EVALUATION

7.3.1 The use for augmentation in the test cell has been justi-
fied on the basis of cooling the exhaust gases from the
jet engines for protection of structure and sound attenu-
ation equipment, cooling of the engine, and stabilization
of the engine. Thus, a large quantity of augmented air
was desired as long as drag turbulence in the cell and
the velocities in the acoustic treatment section were with-
in acceptable limits. However, with the imposition of
the pollution control, the total gas flow becomes criti-
cal because of its effect on capital and operating costs,
and size of the pollution control system.

7.3.2 The objective of the TESI augmenter system was to minimize
the non-condensable gas flow without affecting the engine
operation. The theoretical evaluation was made to guide
the achievement of this objective. The following assump-
tions were made in the model:

7.3.2 (Continued)

- (i) Ideal gas law is valid.
- (ii) Energy loss in droplet formation is negligible.
- (iii) Gas leaving the augmentser is saturated with water vapor.
- (iv) Frictional losses are considered negligible except for the recycle flow.
- (v) Gases leave outlet stack at ambient pressure.

TABLE 7-2
NOMENCLATURE FOR AUGMENTER DERIVATION

Augmenting Air:

μ	Relative Mass Rate,	$\frac{\text{lbm/sec. of augmenting air}}{\text{lbm/sec. of engine exhaust}}$
θ_a	Relative Temperature,	$\frac{\text{augmenting air temp., } ^\circ\text{R}}{\text{engine exhaust temp., } ^\circ\text{R}}$
P_a	Relative Pressure,	$\frac{\text{ambient air pressure}}{\text{engine exhaust pressure}}$
A_a	Relative Flow Area,	$\frac{\text{flow area for augmenting air}}{\text{area of engine exhaust}}$

Water:

ν	Relative Mass Rate,	$\frac{\text{lbm/sec. of water}}{\text{lbm/sec. of engine exhaust}}$
T_w	Temperature of water,	$^\circ\text{F}$
λ	Latent heat of vaporization	
C_{p_w}	Specific heat of water	

7.3.2

TABLE 7-2 (Continued)

Water: (Continued)

X	Relative Velocity, $\frac{\text{velocity of water}}{\text{velocity of engine exhaust}}$
θ	angle of water injection with respect to axis of the augmentser.

Engine Exhaust:

M_E	Mach No.
C_p	Specific heat of engine exhaust.
T_E	Temperature of engine exhaust, °R
γ	Specific heat ratio for engine exhaust
P_E	Engine exhaust pressure, PSIA
P_s	Relative ambient pressure, $\frac{14.7}{P_E}$

Outlet Flow:

ψ	Relative Mass Rate, $\frac{\text{lb /sec. of total outlet flow}}{\text{lbm/sec. of engine exhaust}}$
θ_o	Relative Temperature, $\frac{\text{outlet gas temperature, } ^\circ\text{R}}{\text{engine exhaust temperature, } ^\circ\text{R}}$
P_o	Relative Pressure, $\frac{\text{outlet pressure}}{\text{engine exhaust pressure}}$
A_o	Relative area of Augmentser, $\frac{\text{outlet flow area}}{\text{area of engine exhaust}}$
A_s	Relative stack area, $\frac{\text{outlet stack area}}{\text{area of engine exhaust}}$

7.3.3 (Continued)

Momentum balance:

$$\frac{1}{\gamma M_E^2} \left\{ 1 + P_a A_a - A_o \left(P_o - P_{R_2} \right) - P_o A_o \right\} =$$

$$\frac{\psi^2 \theta_o}{P_o A_o} + \frac{\eta^2 \theta_o}{A_R} \left[\frac{1}{P_o} - \frac{1}{P_{R_2}} \right] - 1 - \frac{\mu^2 \theta_a}{P_a A_a} - v X \cos \theta$$

7-2

Energy Balance:

$$1 + \mu \theta'_a + \gamma \left[\frac{C_{P_w} T_w - \lambda}{C_P (T_E - 460)} \right] - \psi \theta'_o =$$

$$\left(\frac{\gamma - 1}{2} \right) \left(\frac{M_E^2}{1 - \frac{460}{T_E}} \right) \left\{ \frac{\psi^3 \theta_o^2}{P_o^2 A_o^2} + \frac{\eta^3 \theta_o^2}{A_R^2} \left[\frac{1}{P_o^2} - \frac{1}{P_{R_2}^2} \right] - 1 - \frac{\mu^3 \theta_a^2}{P_a^2 A_a^2} - v X^2 \right\}$$

7-3

where: $\theta'_a = \frac{\theta_a - k}{1 - k}$ and $\theta'_o = \frac{\theta_o - k}{1 - k}$ and

$$k = 460/T_E$$

7.3.3 (Continued)

Equation for Saturation Condition:

$$\ln \left(y_w \frac{P_o P_E^{760}}{14.7} \right) = 21.17 - \frac{9720}{\theta_o T_E} \quad 7.4$$

$$y_w = \frac{(v + \xi_a \mu + \xi_E) / 18}{\left\{ \left[\left(1 - \xi_a \right) \mu + 1 - \xi_E \right] / 29 \right\} + \left\{ \left[v + \xi_a \mu + \xi_E \right] / 18 \right\}} \quad 7-5$$

Outlet Pressure

$$P_o = P_s \frac{\left[1 + \left(\frac{\gamma-1}{2} \right) M_E^2 \frac{\psi^2 \theta_o}{A_s^2 P_s^2} \right]^{\frac{\gamma}{\gamma-1}}}{\left[1 + \left(\frac{\gamma-1}{2} \right) M_E^2 \frac{\psi^2 \theta_o}{A_o^2 P_o^2} \right]^{\frac{\gamma}{\gamma-1}}} \quad 7-6$$

Pressure Drop through the Annulus:

$$P_o - P_{R2} = 2f \left(\frac{L}{D} \right) \frac{\eta^2 \theta_o}{A_R^2 P_o} \gamma M_E^2 \quad 7-7$$

7.3.3 (Continued)

The above equations, derived for a fixed geometry and given engine parameters, are quite general. The variables in these equations are explained in TABLE 7-2). The variables - namely pressure, temperature, flow areas and mass rates - are made dimensionless based on the engine parameters.

Equations 7-1, 7-2, and 7-3 are conventional mass, momentum, and energy balances. Equations 7-4 and 7-5 relate the partial pressure of water at saturated conditions as a function of temperature in the range of 130°F-170°F. Equation 7-6 relates the augments outlet pressure as a function of the outlet velocity. Equation 7-7 describes the pressure drop for recycle flow assuming non-compressible isothermal flow.

The above equations 7-1 through 7-7 define the simplified augments flow conditions. In general, knowing the geometry and the engine exhaust parameters, there are eight unknowns:

$$u, v, \psi, P_o, \theta_o, Y_w, P_{R_2} \text{ and } \eta$$

Thus, it is possible to obtain the values of first seven unknown variables for an assumed value of the recycle. (η).

The major difference between this model and that presented in the initial report (Cont. No. N62467-70-C-0078) is consideration of the effect of saturation of the gas and the recycle phenomenon.

7.3.4 CALCULATIONS

The simultaneous solution of the design equations was carried out on a computer. The calculations were carried out for the following data:

7.3.4 (Continued)

(A)	<u>J-79-8 MAX A/B</u>	<u>TF-30-P8 MIL</u>
Mass flow, lbm/sec	180	260
Temperature, °F	3140	618
Exhaust pressure, PSIA	36	28.9
Engine nozzle dia.,"	30-1/8	26-5/8
Dew Point, °F	80	80
 (B) Ambient air:		
Temperature = 80°F		Dew Point = 60°F
Pressure = 14.7 PSIA		
 (C) Water:		
Temperature = 80°F		Injection Velocity = 80 ft/sec
Angle of Injection = 90°F		
 (D) Outlet Stack Area = 80 ft ²		
		Pressure at Outlet of Stack = 14.7 PSIA
 (E) Recycle Flow Annulus:		
Length: = 4.0 ft.		Equivalent dia. - 1.5 ft
Frictional coefficient =		0.05 (assumed)

7.4 DISCUSSIONS

7.4.1 In the earlier study (Contract No. N62467-70-C-0078),

7.4.1 (Continued)

pp. 20), it was established that the air augmentation could be minimized by manipulation of the augmentor dimensions. From the present theoretical study, the effect of changing augmentor dimensions is indicated in Figures 7-3 and 7-4, and TABLE 7-4).

- 7.4.2 The decrease in relative augmentation flow area at a constant outlet area brings about a decrease in augmentation ratio. (Figure 7-3). This effective "close-coupling" is dependent upon the engine location with respect to the inlet cone and the jet exhaust diameter. For example, for engine locations away from the inlet cone, the limiting constant and its magnitude is determined by the annulus between the engine exhaust core and the venturi throat, or radial distance to converging throat (if controlling). Thus beyond a given point, the distance of the tailpipe from the throat should not affect augmentation ratios greatly.

Therefore, it is implied that the augmentation ratio will be vary greatly with change of distance of the jet exhaust to the throat. This was confirmed with the TF-30 (TABLE 7-3). However, a 15% to 20% increase in augmentation was observed in the case of the J-79 (Military firing) at a critical distance change from 14" to the 16" position (TABLE 7-3).

For J-79-8 engine at Max. A/B rating, the engine location will be critical in that the limiting augmentation flow area could be determined by the clearance between the engine shroud and the inlet cone. With engine core expansion to a diameter of 33" at the 36" venturi throat, the relative augmentation flow area is 0.22 and, consequently, augmentation ratio was predicted to be about 0.65 (TABLE 7-4). These values of augmentation ratios are in range of the observed limits (0.55-0.94). (TABLE 7-3). The lower values of augmentation achieved in test work may be attributed to boundary eddies developing in the jet exhaust, resulting in an effective decrease of the augmentation area.

- 7.4.3 For a constant relative augmentation flow area, the augmentor performance with respect to variations in outlet

7.4.3 (Continued)

diameter is shown in Figure 7-4. As the downstream outlet diameter increases, the exhaust gases are slowed down and, consequently, the augmentation ratio is increased. Conversely, it is possible to decrease the augmentation ratio by decreasing the outlet diameter.

7.4.4 For the J-79-8 engine at Max. A/B condition, the calculative saturation temperature is in the range of 160°F-175°F and is relatively independent of the augmentation ratio.

7.4.5 At first glance, the theoretical analysis indicates (see computer results, TABLE 7-4) that for a given geometry, the recycle ratio does not affect the augmentation ratio. This behavior was observed in the actual data when the recycle flow was blanked off. Referring to Figure 7-4, it is seen that the augmentation increases with the increase in the outlet diameter for a constant augmentation flow area. Inasmuch as the presence of recycle flow has an effect of decreasing the outlet velocity, the total augmentation may increase. However, with the partial augmentation requirements supplied by the recycle flow, the induced non-condensable augmentation may still remain constant. It is believed that for the recycle flow to reduce the induced non-condensable augmentation, the injection of recycle flow must be obtained at the inlet cone such that simultaneous reduction in augmentation flow area is achieved. Inasmuch as this effect of reducing augmentation area by the recycle flow was not accounted for in the theoretical model, the theoretical analysis was incomplete and no augmentation effects were predicted.

7.4.6 In the earlier study (Contract No. N62467-70-C-0078, pp. 1-6), it was pointed out that the quench input downstream of the augments forcing cone would not affect the degree of augmentation. (Figure 7-5). This behavior is also established in Figure 7-3, where it is seen that augmentation ratio is essentially independent

7.4.6 (Continued)

of irrigation at a constant outlet area condition. Data obtained by NARF personnel for the TF-30 and J-79 engines indicated no statistically valid decrease in augmentation for the J-79 with introduction of 600 GPM of quench as opposed to no water and approximately 8% reduction (within range of accuracy of the data) for the TF-30 with the same water variation. (TABLE 7-4).

EFFECT OF TEST AUGMENTER
ON TOTAL AIR FLOW

TABLE 7-3

<u>ENGINE</u>	<u>AUGMENTER CONDITION</u>	<u>OPERATION MODE</u>	<u>QUENCH GPM</u>	<u>AUGMENTER RATIO</u>	<u>AIR FLOW LB/SEC</u>	
J52-P6	Old Augmenter	Military	0	1.9	411	
J52-P8	New	Military	200	1.26	317	
	New	Military	200	1.43	341	
J52-8B CBC	New -aft position	Military	100	1.30	322	
TF30-P8	Old Augmenter	Military	0	2.12	843	
	Old Aug.+ F.C.	Military	0	1.11	569	
	Old Aug.+ F.C.	Military	0	1.21	596	
	Old Aug.+ F.C.	Military	0	1.34	633	
	New -Mod. Cone	Military	200	0.38	373	
	New - 7" clear	Military	150	0.60	433	
	New -12" clear	Military	150	0.66	448	
	New -12" clear	Military	150	0.67	452	
	New - 7" clear	Military	150	0.68	453	
	New -16" clear	Military	200	0.54	416	
	New - 7" clear	Military	150	0.68	453	
	New -16" clear	Military	200	0.54	416	
	TF30-P6	Old Aug.+ F.C.	Military	600	1.19	577
		Old Aug.+ F.C.	Military	0	1.3	622
	J79-8B	Old Aug.+ F.C.	Military	0	2.1	561
Old Aug.+ F.C.		Military	600	2.08	554	
New 16"		Military	200	1.25	405	
New 16"		Military	200	1.25	402	
New 14"		Military	200	1.06	371	
New 14"		Military	200	1.02	363	
New 2"		Military	200	1.06	371	
New 14"		Military	200	1.10	377	
Old Aug.+ F.C.		MAX A/B	600	1.9	521	
New + 2"		MAX A/B	1000	1.06	370	
New + 2"		MAX A/B	1000	0.55	278	
New + 14"		MAX A/B	1000	0.94	350	
New + 14"		MAX A/B	1000	0.79	323	
New + 14"		MAX A/B	1000	0.85	332	
New + 2"		MAX A/B	1000	0.78	320	
New + 14"		MAX A/B	1000	0.83	329	
New + 2"		MIN A/B	1000	0.82	327	
J79-10	New + 2"	Military	200	0.99	359	
	New - 10"	Military	200	1.14	384	
	New + 2"	MAX A/B	1000	0.55	277	
	New - 10"	MAX A/B	1000	0.68	303	

TABLE 7.4 (A)

MODEL PREDICTED AUGMENTATION RATIOS
FOR J-79-8 ENGINE AT MAX A/B

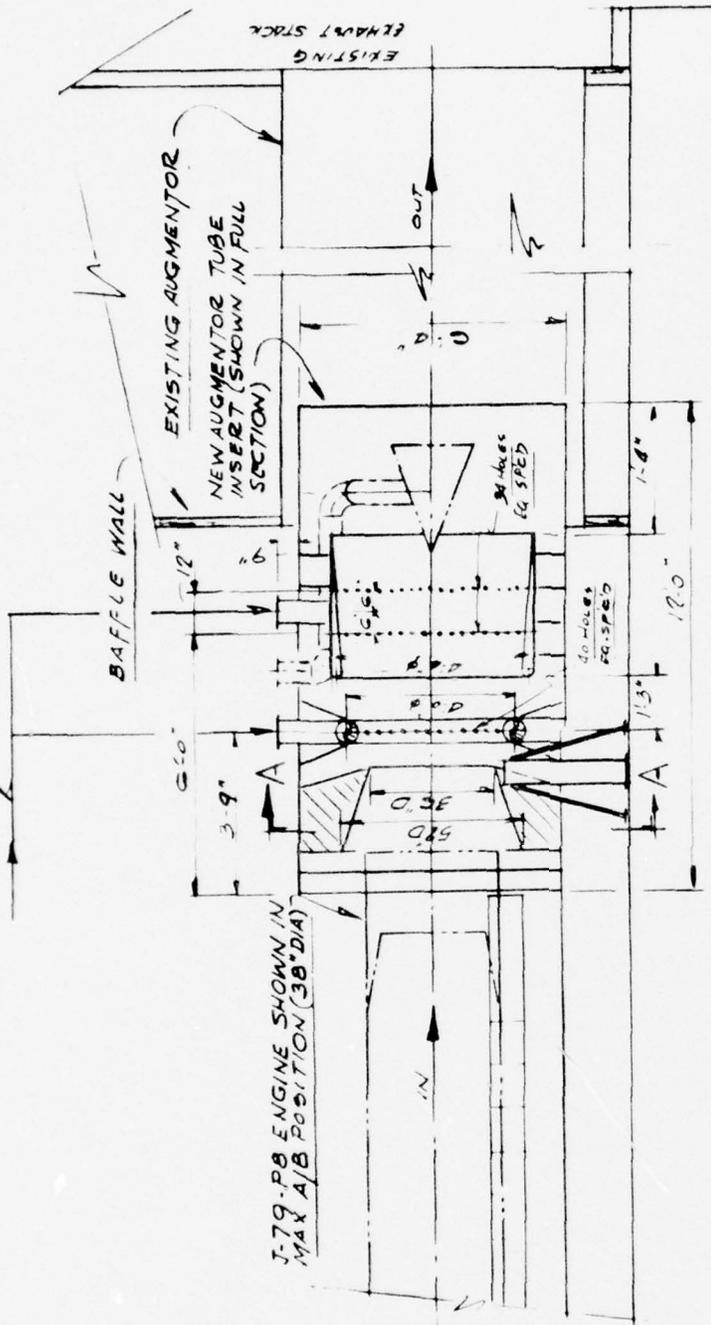
<u>Recirculation Ratio</u>	<u>Aug. Area Ratio</u>	<u>Outlet* Pressure (IN-H₂O)</u>	<u>Exhaust Area Ratio</u>	<u>Aug. Ratio</u>	<u>Irrigation Ratio</u>	<u>Sat. Temp (°F)</u>
η	A_a	P_o	A_o	μ	ν	
0.0	0.10	-20.75	5.14	0.48	0.87	173
0.0	0.30	-31.10	5.14	0.77	0.80	167
0.0	0.50	-35.09	5.14	0.93	0.78	160
0.0	0.70	-37.56	5.14	1.00	0.77	158
0.0	0.90	-38.02	5.14	0.98	0.76	160
0.0	0.34	-23.38	6.00	1.10	0.86	165
0.0	0.34	-16.79	8.00	1.54	1.07	166
0.0	0.34	- 7.16	10.00	1.90	1.36	168
0.0	0.34	- 4.47	12.00	2.19	1.69	171
0.27	0.34	-32.26	5.14	0.82	0.80	166
0.41	0.34	-32.32	5.14	0.82	0.80	166
0.54	0.34	-32.42	5.14	0.82	0.80	166
0.68	0.34	-32.48	5.14	0.83	0.80	166
0.82	0.34	-32.53	5.14	0.83	0.80	166
0.95	0.34	-32.54	5.14	0.83	0.80	166
1.09	0.34	-32.45	5.14	0.82	0.80	166

*Static pressure in inches w.g. at the augments outlet.

NOTATION:

- η - Recirculation Ratio
- A_a - Augmentation Area Ratio
- A_o - Exhaust Area Ratio
- ν - Irrigation Ratio

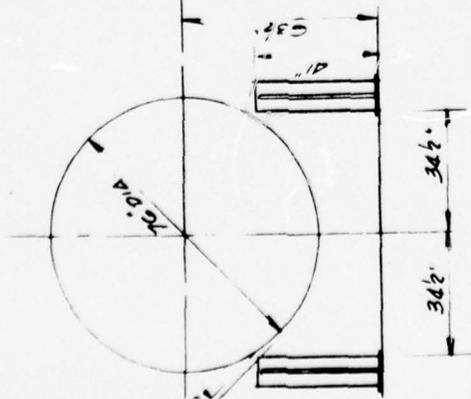
WATER INLET
(6" STD PIPE TH)



SECTIONAL ELEVATION OF EAST BLACK POINT TEST CELL (T.C. 1)

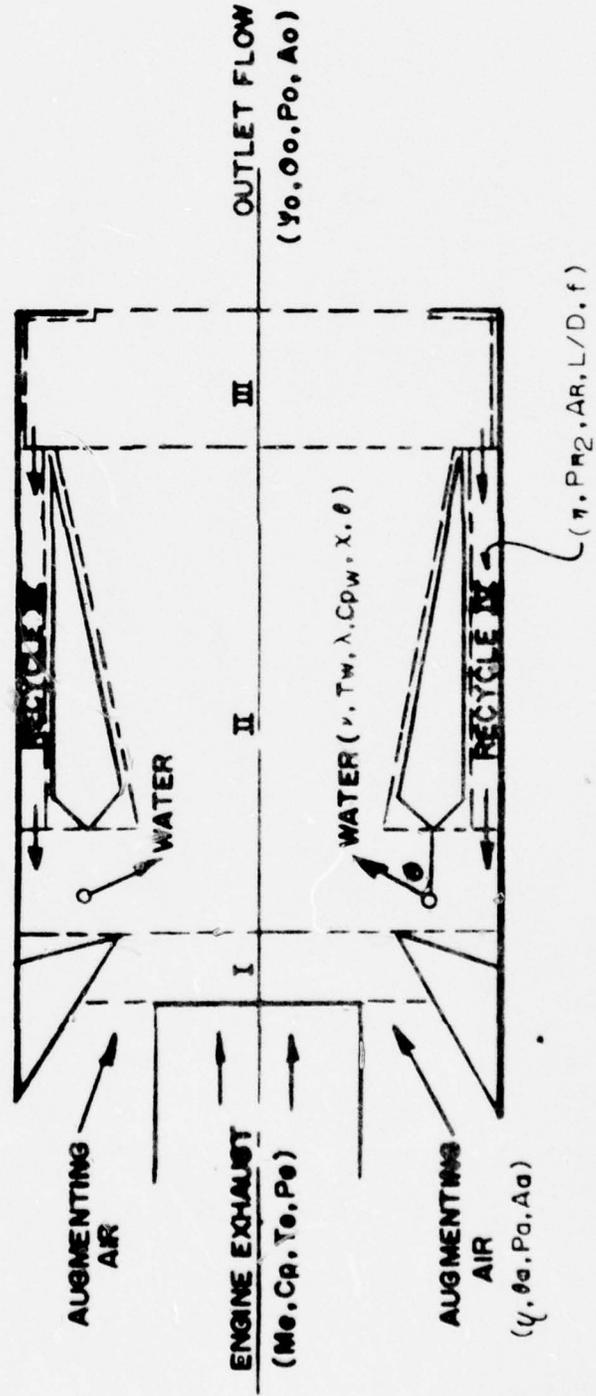
SCALE 1"=30"

FIG. 7-1
P-103-801



SECTION A-A

BEST AVAILABLE COPY



SCHEMATIC FOR EQUATION DEVELOPMENT

MODEL PREDICTED AUGMENTOR PERFORMANCE
AT CONSTANT OUTLET AREA

ENGINE: J-79-8 MAX. A/B

RELATIVE OUTLET AREA, $A_o = 5.14$

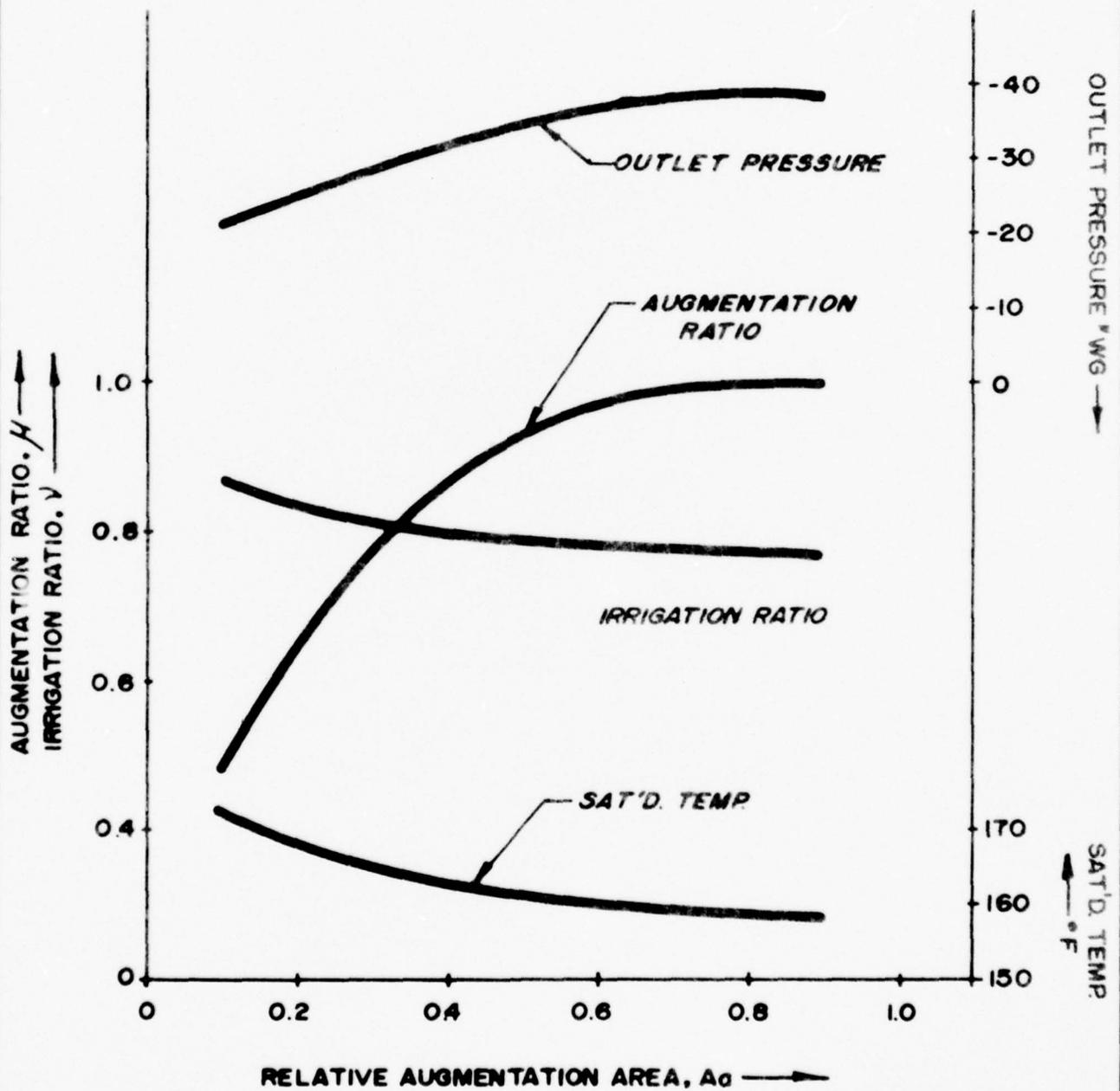


FIG. 7-3

MODEL PREDICTED AUGMENTOR PERFORMANCE AT
CONSTANT AUGMENTATION AREA

ENGINE: J-79-B, MAX. A/B

RELATIVE AUGMENTATION AREA $A_d = 0.34$

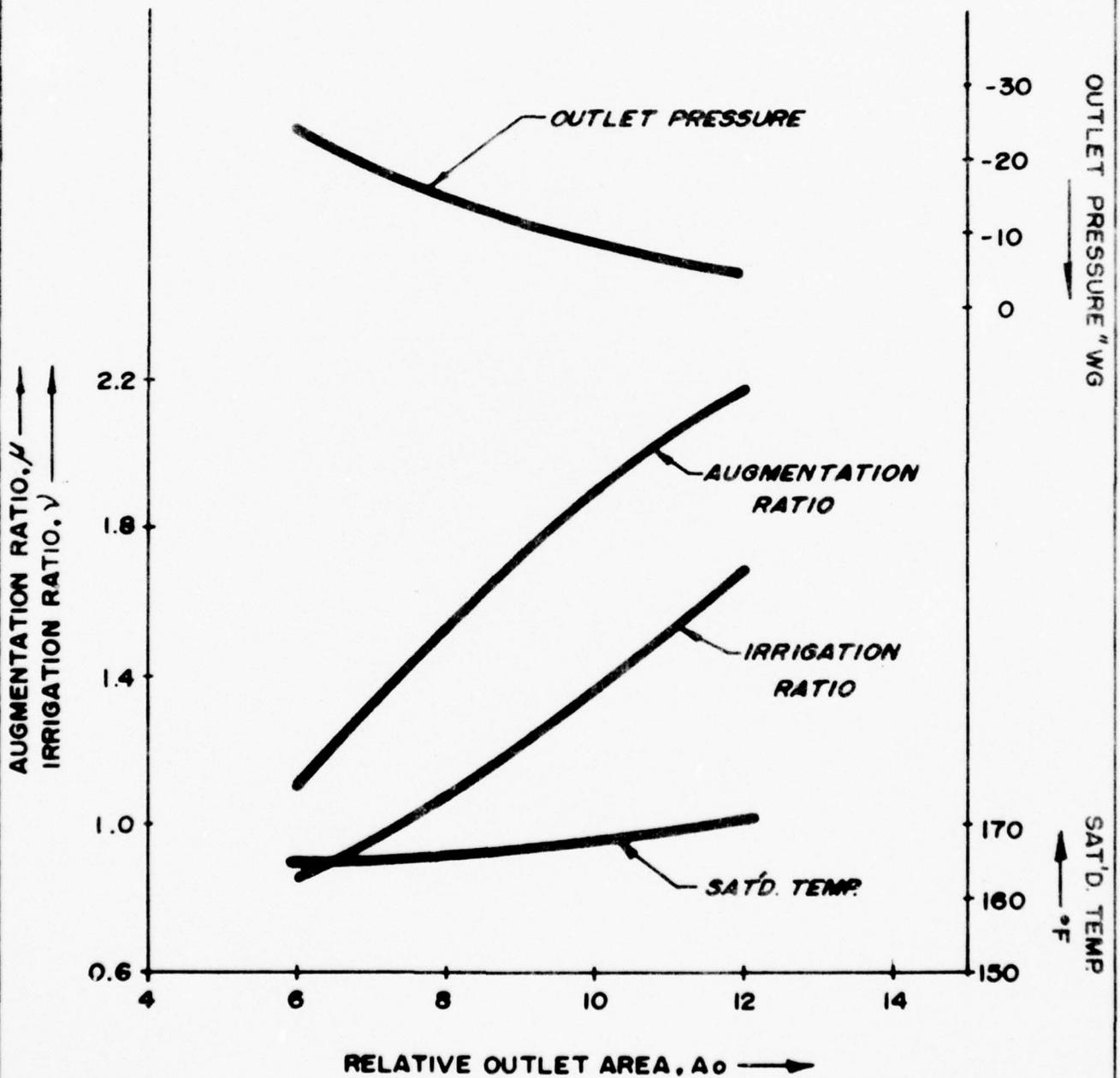
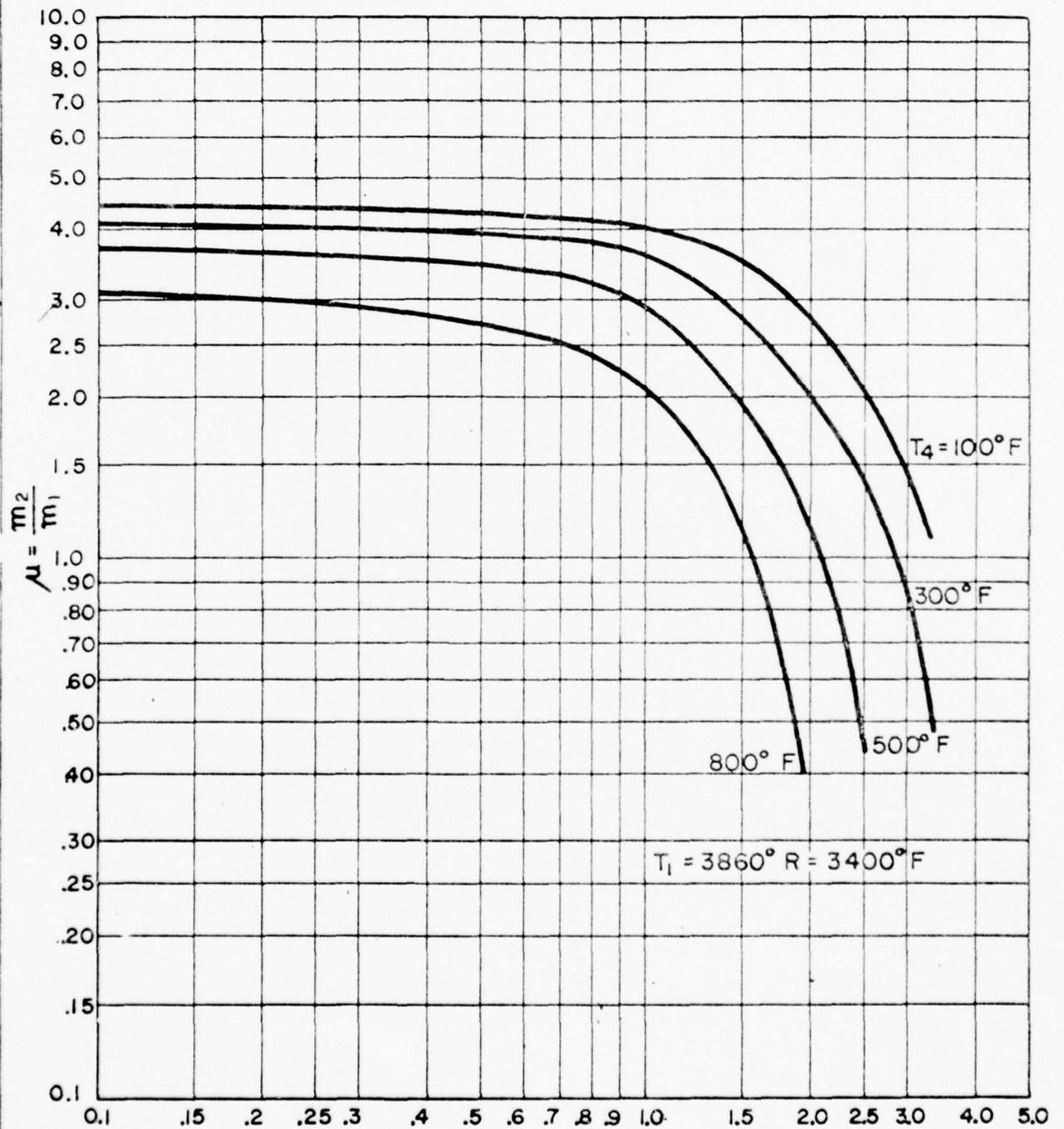


FIG. 7-4

THE EFFECT OF WATER INJECTION ON THE
SECONDARY AIR INDUCED FOR A FIXED JET TEMPERATURE



$$v = \frac{m_{H_2O}}{m_1}$$

FIG.7-5

PERFORMANCE:

Effluent From Engines and Recovery by Scrubber *

- 8.1 In order to establish the severity of the problem of control of emissions, the quantity, concentration, and particle size distribution of the jet engine emissions were investigated at the exhaust of Jet Test Cell at Black Point, Jacksonville Naval Air Station.

Emission levels were obtained by NARF Chemical Service Laboratories at NAX-NAS and Environment/One. Particle size distribution was established by Environment/One and solids captured by the scrubber were determined by the NARF Chemical Service Laboratories. (Sampling technique by Environment/One is indicated in Appendix 8A).

It should be noted that as a result of severe maldistribution in the gas flow pattern in the exhaust stack of Test Cell 1, the determination of the emission level was difficult. A "core" of high velocity (exceeding 260 fps) occupied approximately 20% of the total stack area (Figure 8-1). The variations in concentrations of particulates in each area sampled are indicated as follows:

(SEE FOLLOWING PAGE FOR TABLE 8-1)

* (Analytical Methods and Procedures - Appendix 8A)

TABLE 8-1

	<u>Point</u>	<u>Mass collected grams</u>	<u>Velocity (fps)</u>	<u>Temperature °F</u>
J-79 Normal Time Sampled 5 min.	1	.0030	120	400
	2	.0024	230	400
	3	.0014	60	400
	4	.0019	226	400
	5	.0022	>260	400
	6	.0029	165	400
				(Reported)
Min. AB Time Sampled 4 min.	1	.0029	130	345
	2	.0038	260	410
	3	.0022	98	320
	4	.0033	165	410
	5	.0025	>260	320
	6	.0033	184	345
Max. AB Time Sampled 4 min.	1	.0066	163	375
	2	.0035	>260	375
	3	.0045	105	375
	4	.0049	165	375
	5	.0066	>260	375
	6	.0053	165	375

8.2 The average emissions established in the tests made are tabulated and compared with the "grain loading" calculated on the basis of the solids collected in the scrubber.

TABLE 8-2

PARTICULATE EMISSIONS FROM JET ENGINES IN TEST CELL						
		E M I S S I O N S			-	G R A I N S / S C F
ENGINE	MODE	ENV/ONE-1	NARF	ENV/ONE-2(3)	Based on Solids Collected in Scrubber Water, (1,2) (Does not include drain)	
J-79	IDLE	0.0092		0.0153	0.0029	}
	NORMAL			0.0234	0.0131	
	MILITARY	0.021	0.0348	0.0388	0.065	
	AB	0.059		Questionable	0.08	
J-52	IDLE	0.0034		0.0044		
	NORMAL			0.0157		
	MILITARY	0.0059	0.0128	0.0088	0.041	
TF-30	IDLE			0.0079	0.006	
	NORMAL			0.0079	0.0083	
	MILITARY		0.0054	0.0096	0.054	

Key:

1 - Gas flow on which loading is based:

J-79	Mil	320,000	scfm	TABLE 7-1
J-79	A/B	260,000	scfm	TABLE 7-1
J-79	Normal	300,000	scfm	Assumed
J-79	Idle	200,000	scfm	Assumed
TF-30	Mil	350,000	scfm	TABLE 7-1
TF-30	Normal	300,000	scfm	Assumed
TF-30	Idle	200,000	scfm	Assumed
J-52	Mil	350,000	scfm	Assumed
J-52	Normal	300,000	scfm	Assumed
	Idle	200,000	scfm	Assumed

2 - Solids collected at base of stack were not measured.

3 - A portion of the particulates were collected prior to this sample because of condensation in the stack and the internal section of the scrubber. This is evident from the total black coating of the internals.

8.2 (Continued)

The effect of high concentration pockets that may not have measured in "averaging" tests in the large cross section stack was raised when data became available regarding the particulates recovered in the scrubber. The solids collected in the scrubber water at military mode ranged from 1.3 to 5.6 times that indicated by the gas effluent tests.

A comparison of particulate loadings obtained from the point gas sampling, those based on solids collected in the scrubber water, and data obtained by other sources are indicated in TABLE 8-3. Although the engines are not the same, they are all turbofans with the JT8D considered "dirty" and the JT9D considered "clean."

TABLE 8-3

COMPARISON OF PARTICULATE LOADINGS
FOR TURBOFAN ENGINES BASED ON GAS
SAMPLING IN STACK, WATER RECOVERY,
AND EXTERNAL DATA SOURCES

	Particulate Loading Grains/SCF			
	<u>From Gas</u> <u>Coll. (Av)</u>	<u>From</u> <u>Scrubber</u> <u>Water and</u> <u>Exhaust Gas</u>	<u>P & W</u>	<u>Northern</u> <u>Research</u>
IDLE	0.0079	0.006 (200,000 scfm)		0.002
NORMAL	0.0079	0.0083 (300,000 scfm)	0.025	
MILITARY	0.0096 0.0054	0.054 (400,000 scfm)	0.022	0.016

8.2 (Continued)

Discussions were held with Pratt and Whitney personnel whose most recent data indicate that inorganics constitute a significant portion of the total emissions, and carbonaceous material loading appears to be low. The major concern, however, is that the capture of the sub-micron carbonaceous particulates by normal probes may be poor and normal gas analysis of engine emissions may be erroneous. The material captured by the nucleation scrubber may, therefore, be the only realistic measure of engine emissions.

It, therefore, appears that the early data taken at high flows at the stack level was subject to severe error, especially at high flows where maldistribution was evident (Figures 10-1, 10-2, Chapter 10). The particle loading obtained by gas sampling appears to be less at military conditions than indicated by either the engine manufacturer or Northern Research. At this condition, however, the recovered material indicates that the measurements by the engine manufacturers may be low by a factor of 2 to 3.

- 8.3 The particles recovered from the gas stream with no spray section used in the augmentor were analyzed for particle size distribution (Figures 8-2 to 8-7). It is indicated by population count that approximately 80-90% are less than 1 micron in diameter. Approximately 20-30% by weight are less than 1 micron in diameter. This information is similar to that transmitted by Pratt and Whitney. The Pratt and Whitney study indicated a 0.01-1.0 micron range of particle size with a mean particle size of 0.1 micron.

It was suggested in the initial study (N62467-70-C-0078) that there existed a tendency for agglomeration of the particles. As indicated in the study, "Evidence of the agglomeration tendency indicated in the photomicrographs obtained at Pratt and Whitney Aircraft, where both chain and cluster agglomerates of carbon particles are well identified with chain lengths exceeding 20 particles in many cases."

8.4 Samples of scrubber liquid effluent indicated that agglomeration occurred at various times during recovery in the scrubber. The particles were highly visible and achieved sizes estimated to be in the 5-20 micron range. At other times, no agglomeration was evident and stable suspensions occurred in the scrubber water. The density appears to be lower than that anticipated for carbon. As solid carbon, the specific gravity should be in the range of 1.2-1.8. However, the stability of suspensions almost colloidal in the base, in J-79 operations, implies that the particles, inherently hydrophobic, are coated with JP-5 or degraded JP-5 products, thus lowering the specific gravity to the range of 1.0 to 1.3.

8.5 The quantity of the recovered material is higher than anticipated from gas phase analysis. From measurements taken by NARF (Figure 8-8), it is indicated that as much as 36-44 PPM of undissolved solids accumulated in the scrubber water during military mode for both the J-79 and TF-30. Thus, for a 180 lb/sec engine, the captured solids, formerly depositing as fallout on the community, were accumulated at the rate of 140-170 lb/hr at military mode.

Based on 16 hour operation (Norfolk pattern), the fallout (exclusive of unburned fuel at A/B, part of which goes back in the sump) for a J-79 or TF-30 test is as follows:

TABLE 8-4
PROJECTED FALLOUT FROM ENGINE TEST CELL

	<u>%</u>	<u>Hours</u>	<u>Fallout - lbs*</u>	
			<u>J-79</u>	<u>TF-30</u>
Mil and/or A/B	45	7.2	1260	1040
NR	40	6.4	205	103
Idle	10	1.6	13	6
Turnaround	<u>5</u>	<u>0.8</u>	—	—
<u>TOTAL</u>	<u>100</u>	<u>16.0</u>	<u>1478</u>	<u>1149</u>

*This does not include solids that were collected in the scrubber plenum and dropped into the stack drain. The effluent estimate is, therefore, conservative.

8.5 (Continued)

The fallout from the 11,000 lb thrust engine (exclusive of A/B, part of which appears to have been discharged into the sump) is of the order of 0.6 to 0.75 tons/operating day. Inasmuch as CBC discharge (J-52 CBC) is of the same order of magnitude, the discharge from a 35,000 lb thrust engine could be of the order of 1.9 to 2.4 tons/operating day.

SAMPLING PROBE LOCATIONS

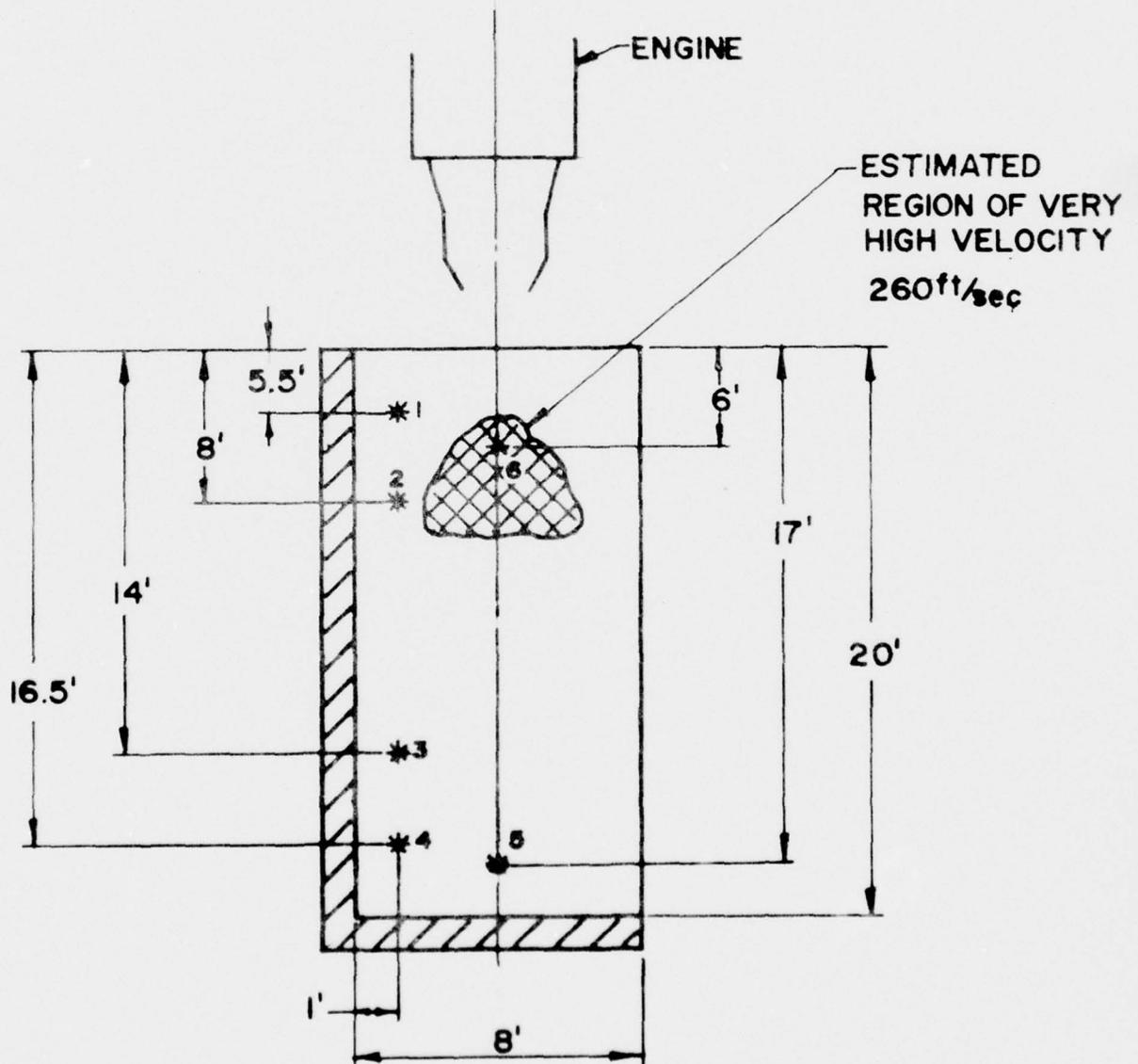


FIG. B-1

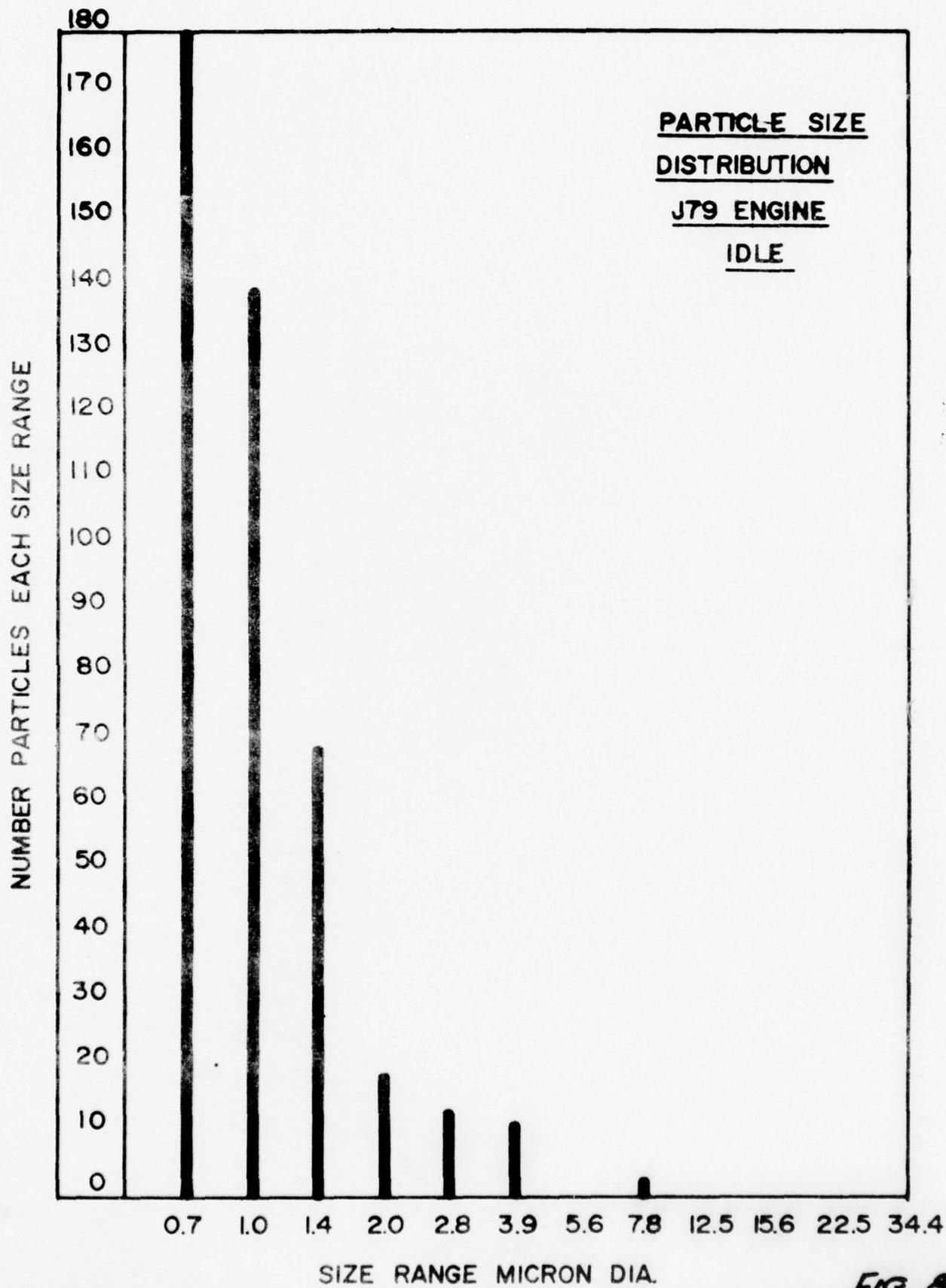


FIG. 8-2

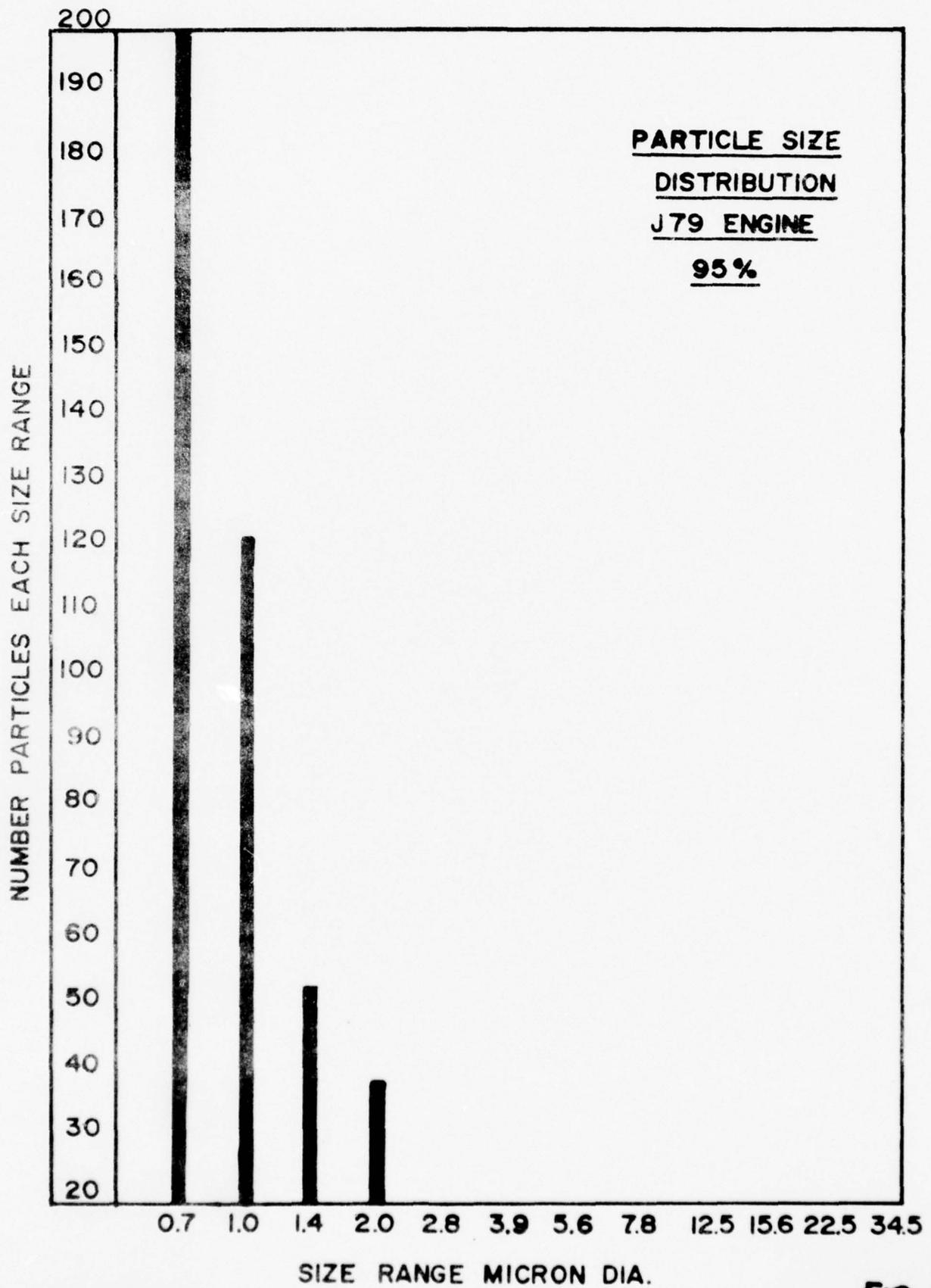


FIG. 8-3

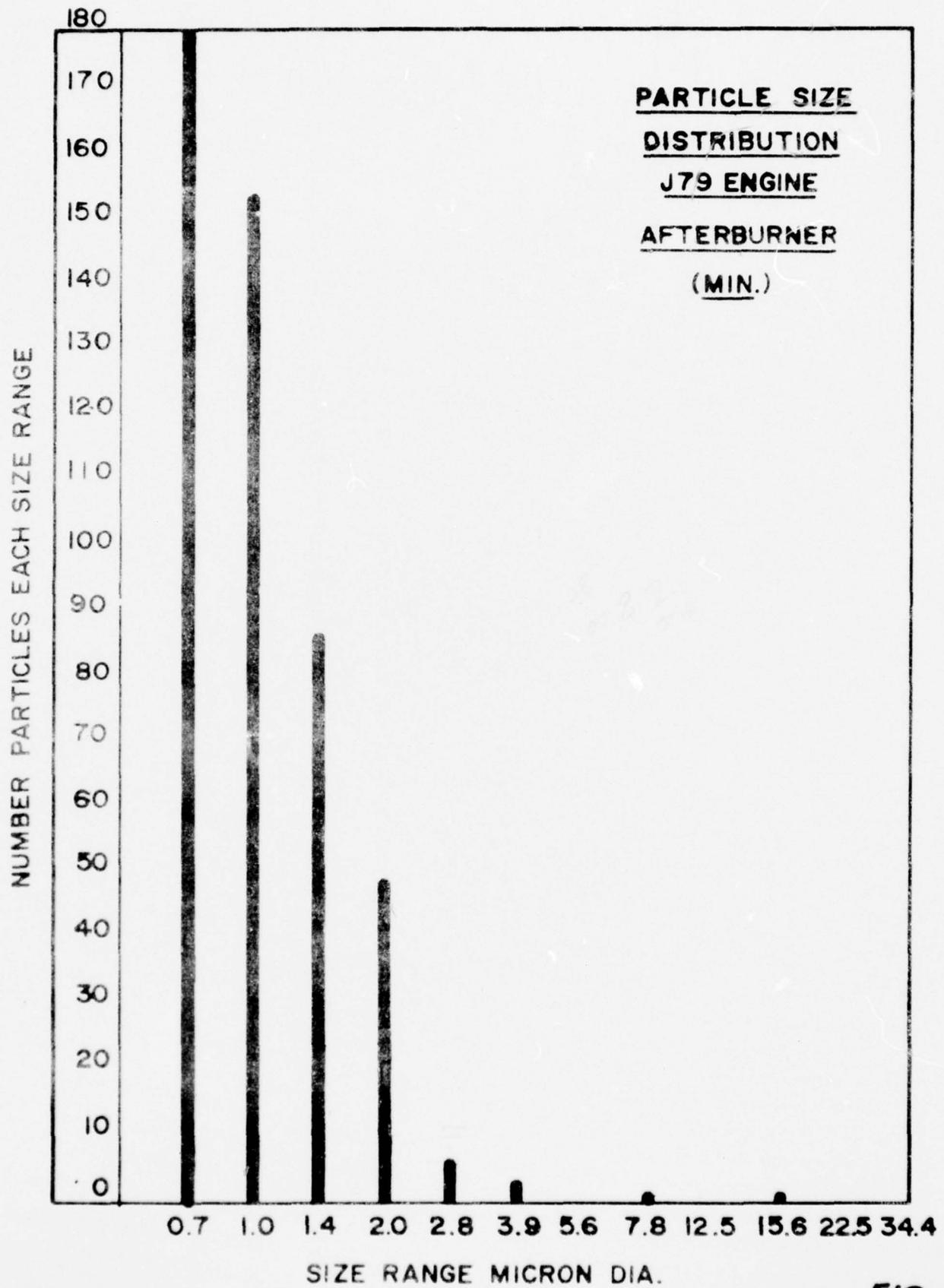


FIG. 8-4

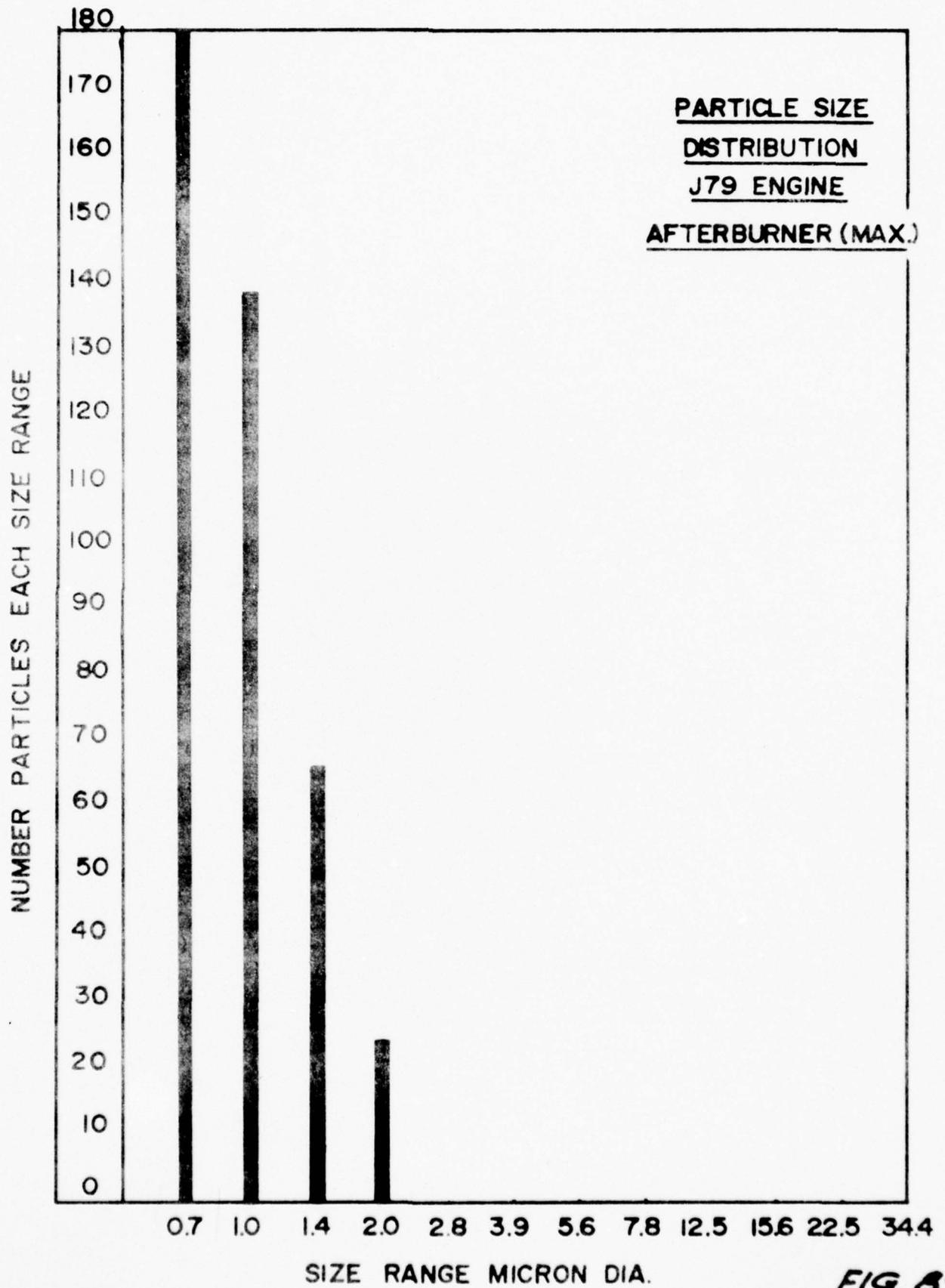


FIG. 8-5

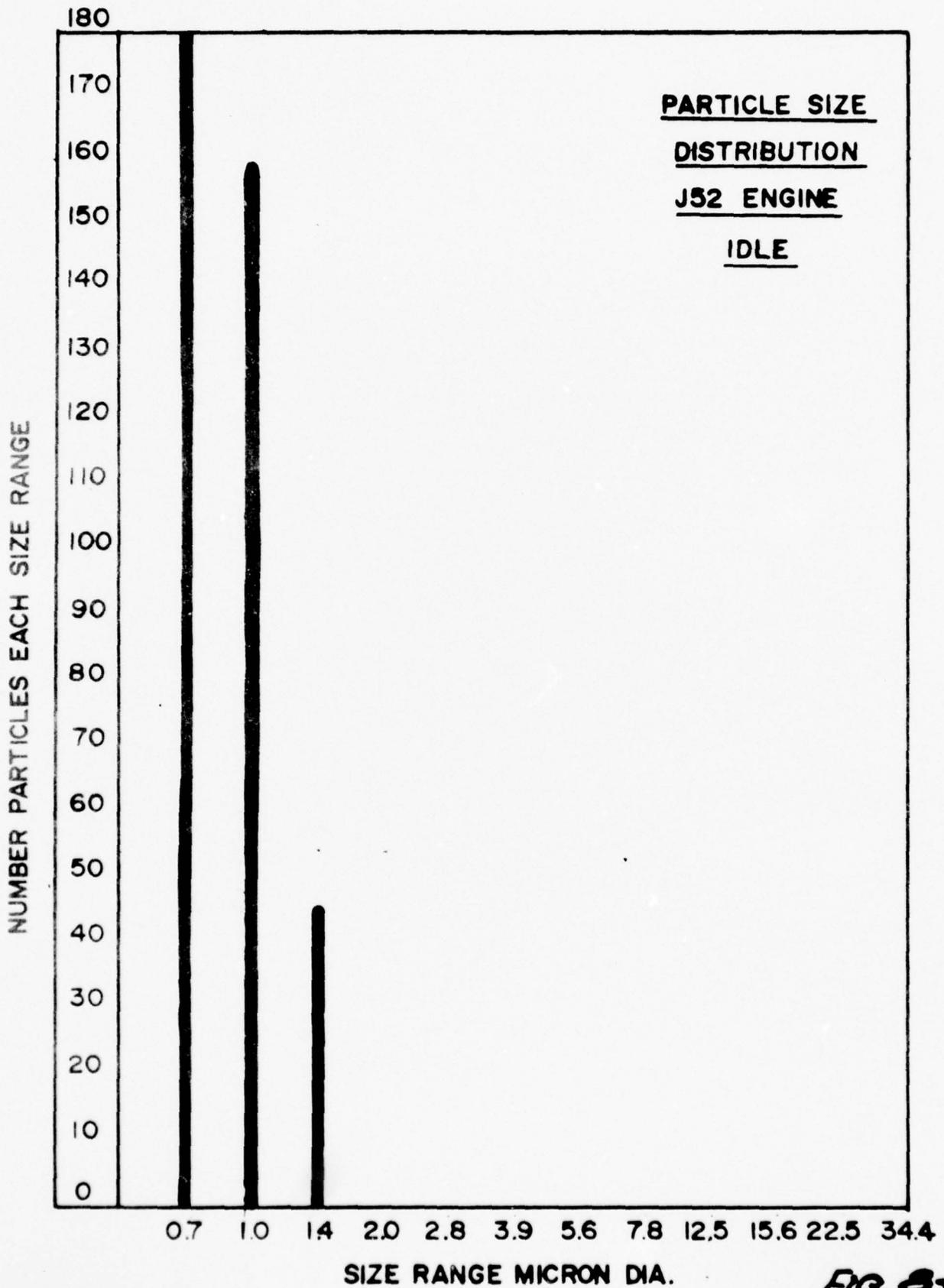


FIG. 86

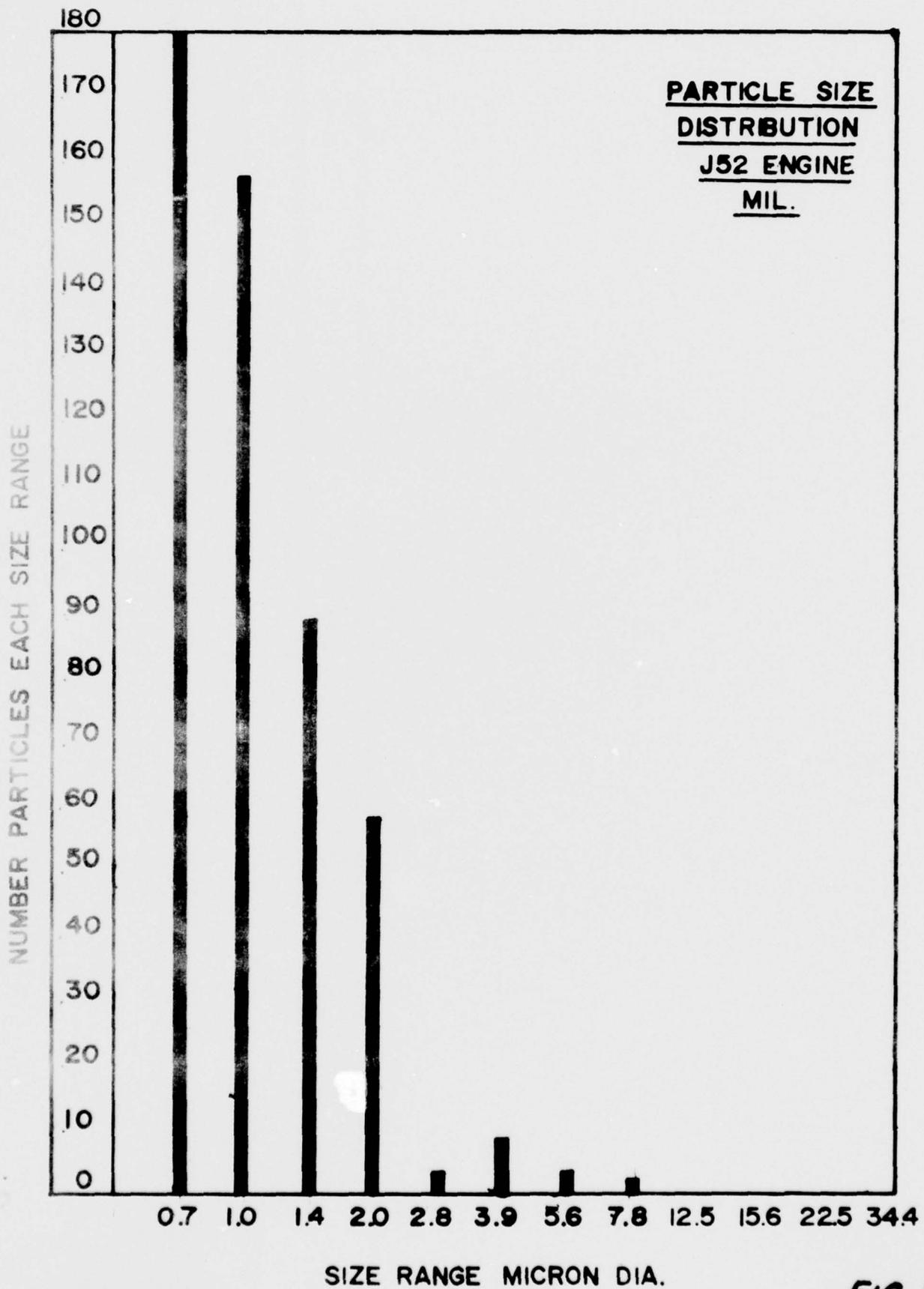


FIG 8-7

PERFORMANCE: TEST Scrubber

- 9.1 The scrubber was in stable regime over the entire operating ranges of the engines tested. Tests were run with the following engines:

J-79
TF-30
J-52

The scrubber is now on production operation for the J-52 and TF-30.

- 9.2 Typical run data are indicated in TABLE 9-1, and field data accumulated as a basis for TABLE 9-1 are available in Appendix 9-A.
- 9.3 In the runs tubulated, the scrubber water flow ranged from 4500 GPM to 8300 GPM, although a series of runs were made by NARF personnel where water flows as low as 1000 GPM were used. The river water temperature, 60°F to 74°F, had no visible effect on the operation or efficiency of the scrubber. The engines were tested in the range of 200 lb to 17000 lb thrust with quench temperatures up to 172°F and effluent temperatures up to an average of 125°F (Calculated by thermal balance).
- 9.4 The thermal transfer in the scrubber far exceeded the design projection. The design calculations were based on a K_{HA} of 1500. At afterburner conditions for the J-79, outlet water temperature of 130-135°F was predicted whereas the outlet water temperature, under operating conditions, was 168°F. Thus, the thermal transfer was 100% greater than indicated in design. The K_{HA} under the operating conditions was of the order of 3000 - 4000 Btu/(hr) (ft³) (Btu/lb), based on the reduction in thermal gradient.

9.4 (Continued)

The Scrubber responded to the thermal demand of the gas stream. Based on the thermal pick-up by the water, in excess of 85% of the energy of combustion was recovered up to and including military mode at maximum afterburner (TABLE 9-1). For example, for the J-79 in military mode, the thermal pick-up was 162×10^6 Btu/hr, whereas the thermal value of the fuel burned was 169×10^6 Btu/hr. In the case of the TF-30, 124×10^6 Btu was absorbed by the water while the fuel value was 149×10^6 Btu/hr. The thermal value of the fuel burned was 592×10^6 Btu/hr.

The relationship of heat absorbed by the scrubber and temperature of exhaust gas with thrust is indicated in Figure 9-1. The temperature of the scrubber exhaust is constant up to a thermal load of 100,000,000 Btu/hr. Beyond this, the exhaust gas temperature rose to a calculated maximum of 125°F (average) at afterburner mode, at a thermal load of 437,000,000 Btu/hr. The observed effluent gas temperature at the bottom of the scrubber at the south end of the scrubber was measured to be 150°F to 160°F. The behavior of the cross flow mechanism would project a gas temperature in the range of 135°F to 150°F at this effluent point. The deviation is believed to have been caused by severe maldistribution of gas effluent in the test cell stack with the majority of the gas flowing through the south end of the stack. An implied confirmation of this phenomenon is indicated in the visual observations section - (9.9.2), wherein baffles placed in the stack to minimize the maldistribution were found to have been subjected to velocities in the 300 ft/sec range although the "average" velocity should be in the 50 ft/sec range.

- 9.5 The pressure drop through the scrubber was originally estimated in design to achieve a maximum of 4-6 in.w.g. during afterburner operation. Measurement of the static pressure inside the scrubber, equal to the pressure drop through the packed section, was complicated by the condensation of water in the transfer lines to the manometer,

9.5 (Continued)

especially in military and afterburner modes. Readings as high as 12 in.w.g. were recorded but were questionable because of condensation in the lead lines. In the case of the J-79 engine test, reliable readings up to 1 in.w.g. were measured up to a thrust of 6000 lb. Subsequent tests made by military conditions for the J-79 and TF-30 were "averaged" by manifolding the probes at 6 points along the length of the scrubber with lead lines at the same level of the probes. At military, the pressure drop through the scrubber was found to range from 0.8 in.w.g. to 1.1 in.w.g. for both the J-79 and TF-30.

9.6 The gas flow through the scrubber was calculated by the application of augmentation data obtained by NARF personnel prior to installation of the scrubber. One test made subsequent to the installation indicates a reduction in augmentation for the TF-30 in military mode from 0.6 to 0.39. This would represent a 12% reduction in flow as estimated in TABLE 7-1. Inasmuch as augmentation data were only acquired by NARF for military and afterburner modes, analysis of flows were calculated for these conditions.

As a result of installation of the new augmentor, flows were substantially reduced from that occurring with conventional augmentor design. The study of effect on gas flows by the TESI augmentor is indicated in Chapter 5. The effect of reduced augmentation flow resulted in the decrease in pressure drop in the scrubber and a reduction in the correction gas flow G/ϕ in lb/(hr) (ft²) from 2,260 projected to 1,830 actual, a decrease of 19% in mass load. The gas flows in lb/sec at augmentation levels measured by NARF are indicated in TABLE 9-1.

The gas flows to the scrubber from the stack ranged from 440,000 to 480,000 ACFM at maximum demand conditions and gas emission from the scrubber ranged up to 358,000 ACFM, the maximum occurring at TF-30, military mode. Although there appears to be a maximum of 400,000 ACFM exhaust at J-79 AB mode, this is believed to be incorrect because of effluent temperatures at the maldistribution maximum flow

9.6 (Continued)

point and at the lower section of the scrubber. As indicated in Section 9-4, the calculated average effluent gas temperature at these conditions is 125°F rather than the 150°F - 160°F measured and that the effluent flow is of the order of 290,000 ACFM.

Operating conditions for the scrubber, therefore, indicate that the maximum gas flows are equivalent to a corrected mass flow of $G/\phi = 1,830$ at inlet and 1,610 at outlet, both values well within the capacity of the TESI scrubber.

The velocity of the effluent gas from the scrubber ranged up to approximately 6 fps average at maximum operating conditions.

9.7 The water flow to the scrubber ranged up to 8,300 GPM. Twenty-five percent of this flow was diverted to face sprays in order to protect the packing and support grids from "hot spotting." The remainder (75-80%) of flow was used for irrigation of the packing. The irrigation of the packing was thus 11,700 lb/(hr) (ft²) at maximum conditions.

Stable liquid flow operation occurred except for TF-30 military and J-79 afterburner conditions. During these operating conditions, considerable overflow occurred from the sides of the water sump. The phenomenon is reflective of an inadequacy of the approach angle of the packed section and maldistribution of gas flow. The angle of the packed face to the vertical is 4°46' with a lateral displacement of the bottom of the face to the top of the face of 1.33 ft. Observation of side overflow indicates that the water exits from the

9.7 (Continued)

outside face at a level of 2'-3' above the bottom support plate. Thus, the lateral displacement should have been 2'6" rather than 1'4" with the angle of attack of 9°.

- 9.8 Evaluation was made of the water balance in the system. The basis for the evaluation was the water content of the gas entering the scrubber (quench water evaporation) and the water content of the gas leaving the scrubber. The difference is the make-up water required for scrubber operation (TABLE 9-2), and does not include the cooling tower losses. The make-up losses were as follows:

TABLE 9-2

Loss of Fresh Water in Augmentor-Scrubber Operation

	<u>Water Net Loss GPM</u>	<u>Percent of Quench Requirements</u>	<u>Percent Recovery of Quench Water</u>
J-79 Mil	68	18	82
J-79 Min AB	100	23	77
J-79 Max AB ¹	204	21	79
TF-30 Mil	61	21	79

¹ Calculated from Thermal Balance

9.9 APPEARANCE AFTER OPERATION

- 9.9.1 Inspection of the scrubber subsequent to the initial runs indicated no deterioration of components. The packing facing the stack exhaust section had a coating

SCRUBBER - TEMP. & THERMAL CONDITIONS J-79 OPERATION

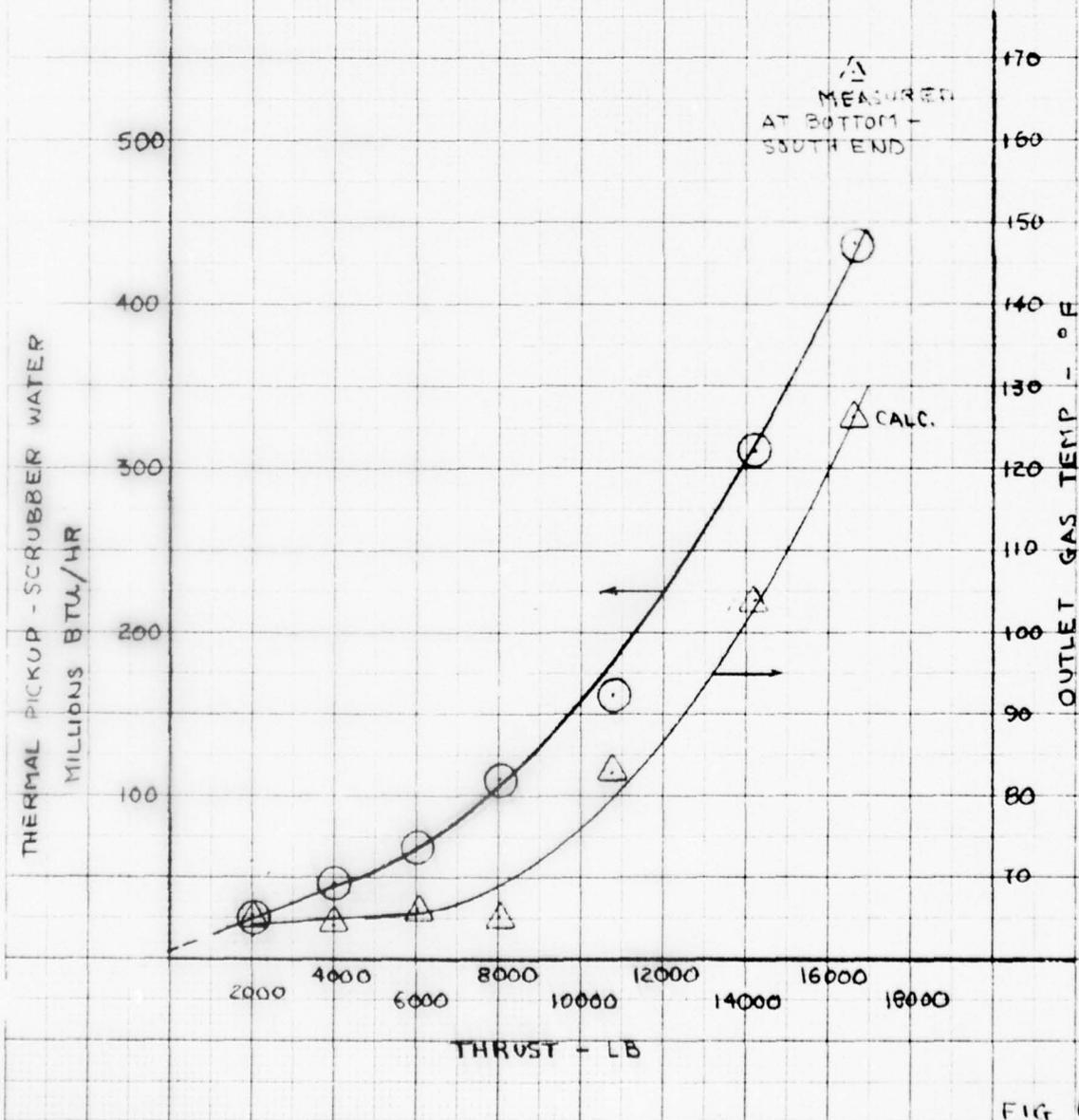


FIG 9-1

9.9.1 (Continued)

of carbon and appeared more translucent than when originally placed in the scrubber. It was noted that both the grating and the packing on the south end of the scrubber were darker than the sections at the north end, indicating maldistribution in the scrubber with higher flows occurring at the south end.

- 9.9.2 Pipe baffles were installed at the south end at the top of the stack in order to redistribute the flows (Figure 5-2). Initially, some of these baffles were ripped from the stainless steel bolts indicating that they were exposed to velocities far in excess of that projected in design.

[With a flow of 500,000 ACFM after quench, the "average" velocity in the 160 ft² stack would be 52 ft/sec. Consideration of the sound attenuation units occupying 50% of the cross section and assuming that no expansion occurs subsequent to passage through the sound attenuation units, the "average" velocity would be 104 ft/sec. Inspection of the baffles indicate 90° bends in 1/4 inch bolts and tearing of 1/4" thick FRP walls. The force estimated to achieve this phenomenon is of the order of 50 to 100 lbs. For a 4 foot long piece of pipe, this is equivalent to 50 to 100 lb/ft² with full head conversion. The velocity required to produce this force, if fully converted to a head loss, would be of the magnitude of 300 FPS].

- 9.9.3 Although the shell was originally light green, the roof and side wall areas between the packed zone and the stack were coated with carbon deposition after three engine runs. The remainder of the shell and gull wings were only slightly dirty after 2 months of operation.

9.10 APPEARANCE DURING OPERATION

- 9.10.1 During operation up to thrusts of 8000 lbs, the stack emission was wispy with a very low exhaust velocity appearance. At military mode, the quantity of steam in the exhaust projected as much as 20 feet. In the case of the TF-30 during military mode, water flowed from the lower sections of both sides of the scrubber to a height ranging from 1 to 2 feet. In the case of the J-79, this phenomenon was evident only during afterburner regime.

During the afterburner operation, the steam plume pervaded as much as 300 feet before it dissipated. Traces of residual were observable but not on a consistent basis. The residual was light yellow in color.

SCRUBBER - TEMP. & THERMAL CONDITIONS

J79 OPERATION

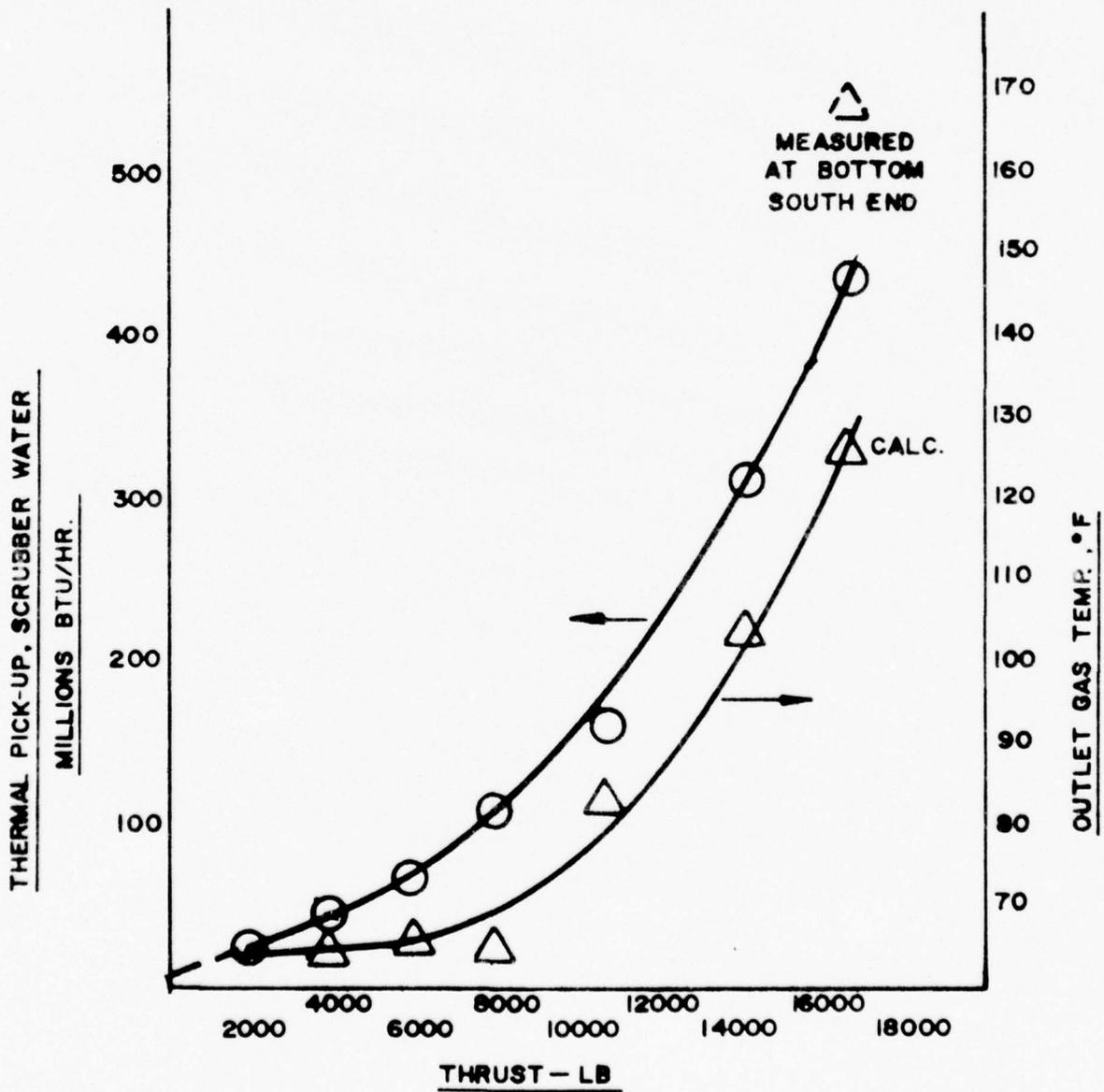


FIG. 9-1

PERFORMANCE: Augmenter

10.1 VISUAL:

The performance of the augmenter with air scoop removed was observed by both Navy and TESI personnel. The maximum system demand occurred during test of the J-79 in A/B. It was observed that the jet exhaust flame appeared to fill the entire venturi throat. The first spray ring that appeared to penetrate the jet completely at lower engine rate bent into the jet at a diameter of approximately 1-1/2 feet at military rates. The recycle phenomenon was quite pronounced at A/B operation. It blended with the jet at the trailing edge of the converging section of the venturi, and water droplet recycle was observable.

The residual core of the jet exhaust subsequent to the primary spray appeared to be 6" to 12" in diameter. Thus it should have dissipated in 5 feet to 9 feet. Inasmuch as the distance traversed to the core buster was only 4 feet, residual jet core existed at this position.

10.2 MECHANICAL:

The augmenter system did not appear to be overstressed. No shell or internal vibrations were noticeable.

Failure did occur on the core buster supporting struts because of incomplete dissipation of the jet core and lack of protection of the struts. The hot zone was approximately 2 inches wide at the failure area, indicating that the residual core at this point was approximately 6 inches in diameter and would dissipate in approximately 4-1/2 feet.

10.3 THERMAL:

No thermal damage was visible to any portion of the augmenter. Some discoloration was noted at the venturi throat and appeared to be caused by radiation rather than convection.

10.4 MEASUREMENTS:

Performance data were obtained by Navy personnel with the following engines:

J-52
J-79 Through A/B
TF-30

Data were obtained as follows:

- 1 - Water consumption
- 2 - Augmentation
- 3 - Temperature profiles in stack
- 4 - Velocity profiles in stack

10.4.1 WATER CONSUMPTION

The limiting test for water consumption was based on the J-79 in A/B mode. Based on fuel consumption and total enthalpy (thermal + kinetic equivalent), the exhaust jet enthalpy is of the order of 170,000 Btu/sec.

The contribution of the enthalpy of augmentation air is relatively low.

<u>Augmentation Ratio</u>	<u>Thermal Contribution to the Exhaust Btu/sec</u>
0.5	1575
1.0	3150
2.0	6300
3.0	9450

10.4.1 WATER CONSUMPTION (Continued)

The quench water feed rate provided for this maximum duty was calculated to be 950 GPM. Design for the system was established at 650 GPM for the primary ring quench and 500 GPM for secondary quench, either at the diverging zone of the venturi or at the core buster.

No significant data were obtained with regard to secondary quench until pump adjustments were made. Burnout of the core buster vanes occurred prior to pump correction.

10.4.2 AUGMENTATION

The degree of external augmentation in one physical orientation of the TEST augmeter is compared with those values obtained with the previously used 48"D and 72" forcing cone augmeter. The data on the conventional augmeter were obtained by NARF. The data on the TEST augmeter were obtained and supplied by NARF with TESI personnel present in some of the runs.

The reductions in augmentation achieved with the TEST augmeter were:

TABLE 10-1

REDUCTION IN AUGMENTATION

<u>Augmentation Ratio</u>		<u>~ Percent</u>	<u>Remarks</u>
<u>Initial</u>	<u>Final</u>	<u>Reduction</u>	
1.9	0.64	67% for the J-79 in A/B	Where 48"D forcing cone was used in old augmeter
1.21	0.62	50% for the TF-30 in MIL	
1.9	1.33	30% for the J-52 in MIL	
2.12	0.38	82% for the TF-30 in MIL	Where 72"D forcing cone was used in old augmeter and 30" throat was used in the TESI unit.

10.4.2 (Continued)

The differences in effect are ascribed to the change in the ratio of the augmentation area to the exhaust area (TABLE 7-3). A proposed solution is to have a variable throat diameter. However, this was not necessary in the Black Point installation inasmuch as the limiting factors in the design of the scrubber system were the largest engine and the flows related to its performance, and the minimum temperature of the combined stream of jet exhaust and augmentation air. Both were adequate.

Data submitted verbally by NARF indicated that the recycle velocity in the annulus is 100 fps. If this flow returned to the vena contracta of the venturi, it would create an internal augmentation of approximately 0.6. As a result, the total gaseous augmentation in the J-79 would be of the order of 1.1 to 1.2. However, with recycle blanked off, no significant change in external augmentation was observed indicating that no significant recycle returned to the vena contracta.

The bounce spray effect projected and described in the initial study (Contract No. N62467-70-C-0078, pp. 20-21) was observed to operate via entrainment carry of the recycle gas into the throat of the venturi arrangement. It is believed that this phenomenon contributed to the reduction in augmentation air flow.

It is possible, based on the experience gained in the test program, that further reduction in augmentation may be achieved by:

- 1 - Arranging recycle air flow into the venturi throat;
- 2 - Decreasing the recycle scoop-baffle diameter with effect of increasing the recycle augmentation;
- 3 - Injecting water directly into the recycle annulus to increase the quantity of bounce spray-flash.

It should be noted that mere addition of water to

10.4.2 (Continued)

the spray section will not, in itself, decrease augmentation significantly. This can be observed in TABLE 5-3 where water injection was used in the TF-30 and the J-79 military regime. These tests, run to confirm the mathematical model submitted in the preliminary study, indicated a reduction in augmentation of only 8.5% for the TF-30 and zero for the J-79. For water to decrease augmentation, it must be fed at the throat. The recycle mechanism can achieve this with minimum possibility of water contact with the engine.

10.4.3 TEMPERATURE PROFILE - VELOCITY PROFILE

The data taken for the TF-30 and J-79 regarding temperature and velocity distribution from the stack are plotted in Figures 10-1 and 10-2. In the case of the TF-30, the temperature and velocity profiles are consistent for the three latitudinal bands and apparently follow a distribution established by the four baffles at the bottom of the stack. The first baffle requires too high an angle of turn and is located too high to critically affect flow. The point temperatures apparently are related to the point velocities and the baffle position. Temperatures decrease with velocity within a specific baffle position (Figure 10-1) and in a direct relationship in positions 1-8, but in a totally different direct relationship in positions 9 and 10 (Figure 10-2). These plots indicate the temperature maldistribution may not at all be related to the mixing in the aug-
menter but the mode of temperature measurement.

In the case of the J-79 data (Figure 10-2), the spread of the data is far greater than that observed for the TF-30. Again, the anomalous behavior at positions 9 and 10 are evident. An inverse type of relationship of temperature and velocity occur in positions 1-5. However, the scatter of both velocity and temperature is too great to provide any pattern at positions 6-8.

The plot of temperature vs. velocity represents only latitude A. The anomaly of positions 9 and 10 are

10.4.3 (Continued)

are, again, quite evident. But except for one and possibly two points, a relationship of temperature and velocity appears to exist.

This relationship of temperature and velocity may result from the existence of entrained water. The gases are highly humidified, but not uniformly, and the temperature recorded may be a form of wet bulb that is highly responsive to velocity, and not reflective of the true temperature of the stream. It is evident in these profiles that modification of the existing baffles be undertaken in order to preclude the anomalous behavior at positions 9 and 10 and to minimize variation in flow.

It was noted by NARF-JAX that during maximum A/B mode in J-79 test, a temperature greater than 1800°F was measured at the axis downstream of the TESI aug-
menter. Based on temperatures measured at various radial distances, it was estimated that the core is a maximum of 6" in diameter and, therefore, represents between 5% and 15% of the flow. Dissipation of this core before the baffle section must predominate because of the normal breakup mechanism.

10.4.4 ENGINE STATUS

Of significant concern to both NARF and TESI personnel was the possible effect of the aug-
menter on engine performance. Initial data compared with correlation runs in the test cell under evaluation (JAX Black Point 1) indicated no observable variations in the relationships of:

TF-30, J-52	$F_n/\delta T_2$	(Thrust)	(Figs 10-3, 10-4)
TF-30, J-52	$N_2/\sqrt{\theta T_2}$	(RPM)	(Figs 10-3, 10-4)
TF-30	$W_F/\delta T_2 \sqrt{\theta T_2}$	(Fuel Flow)	(Fig 10-3)
TF-30	$T_{T5} \text{ } ^\circ\text{F}/\theta T_2$	(Exhaust Gas Temp)	(Fig 10-3)

10.4.4 (Continued)

Some deviation was noted in J-52 performance with the TESI augments (Fig. 10-5). Data for J-79 characteristics were transmitted to General Electric Company. In a letter dated 18 January 1971 from General Electric (Exhibit Fig. 10-6), it was indicated "that the internal engine performance did not change (for test dates shown)."

The correlation curve transmitted by General Electric (Fig. 10-7) indicated no change in engine performance.

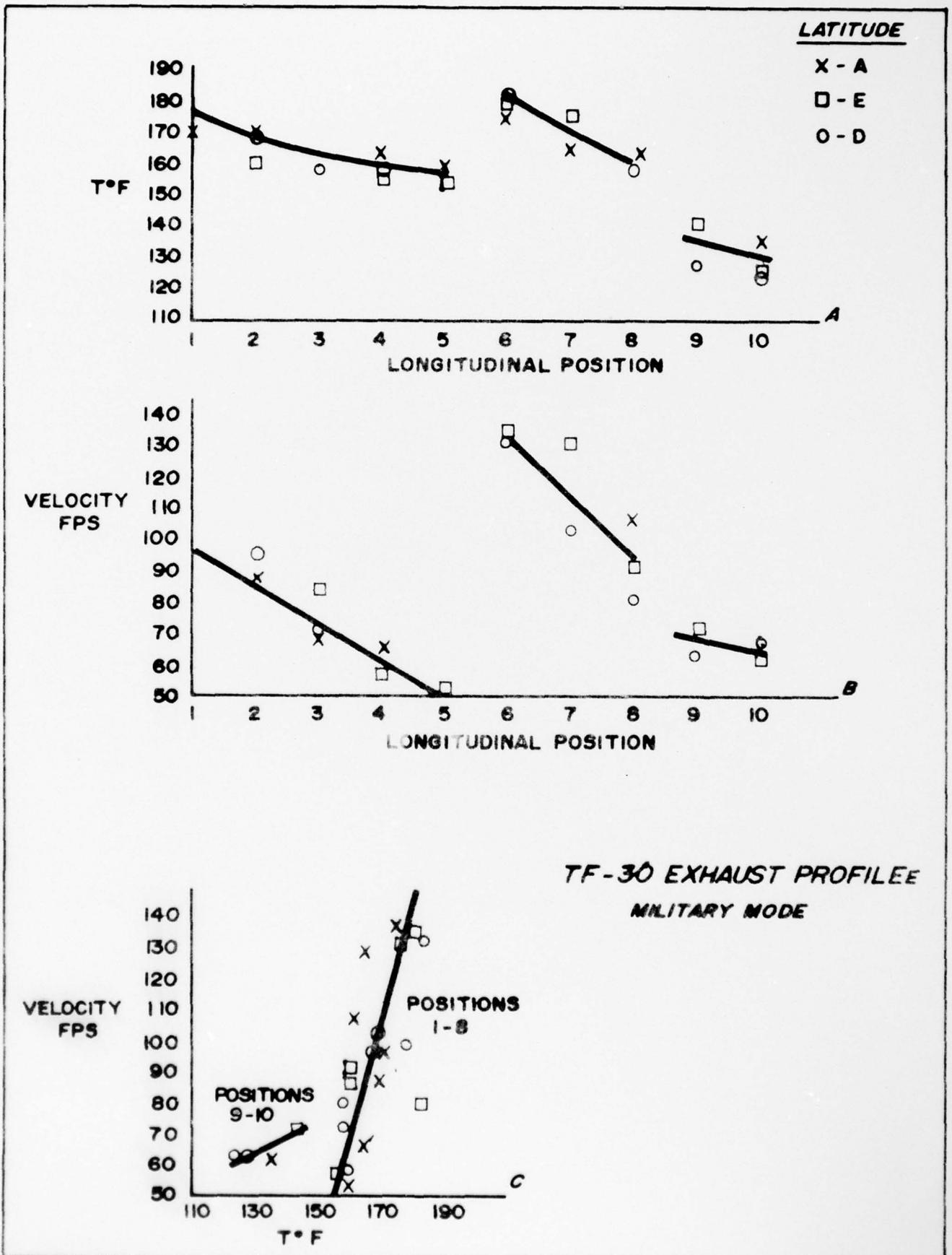


FIG. 10-1

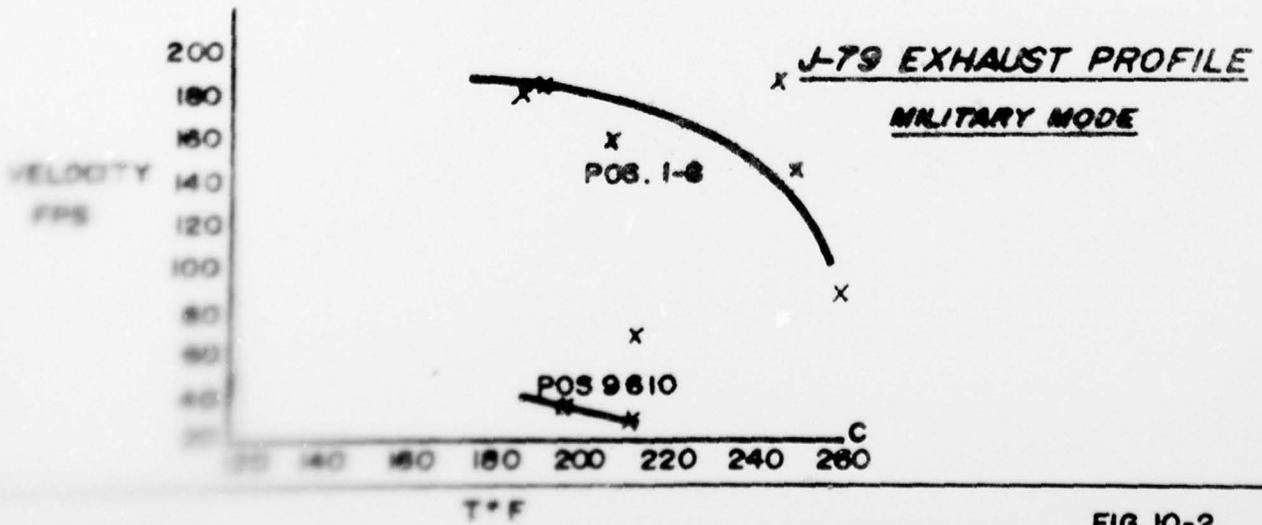
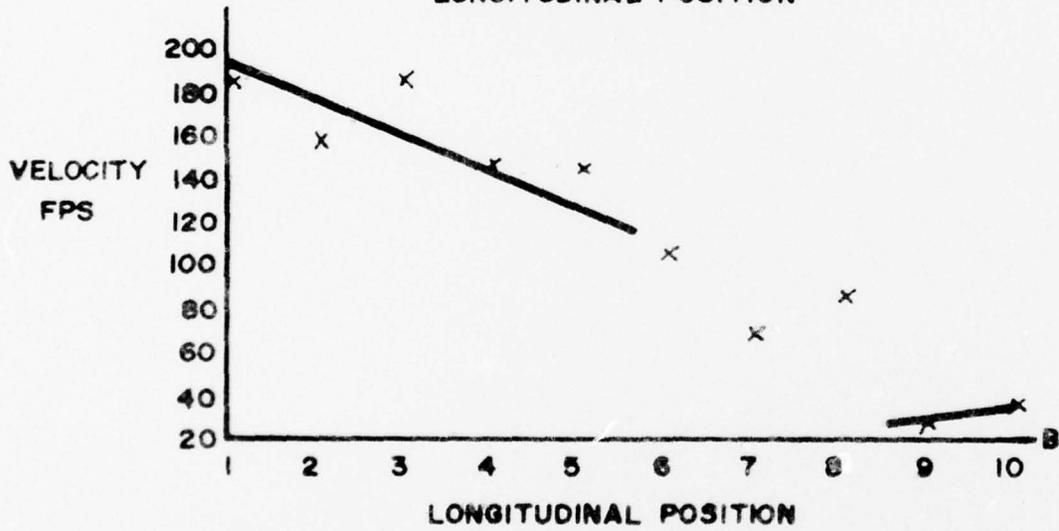
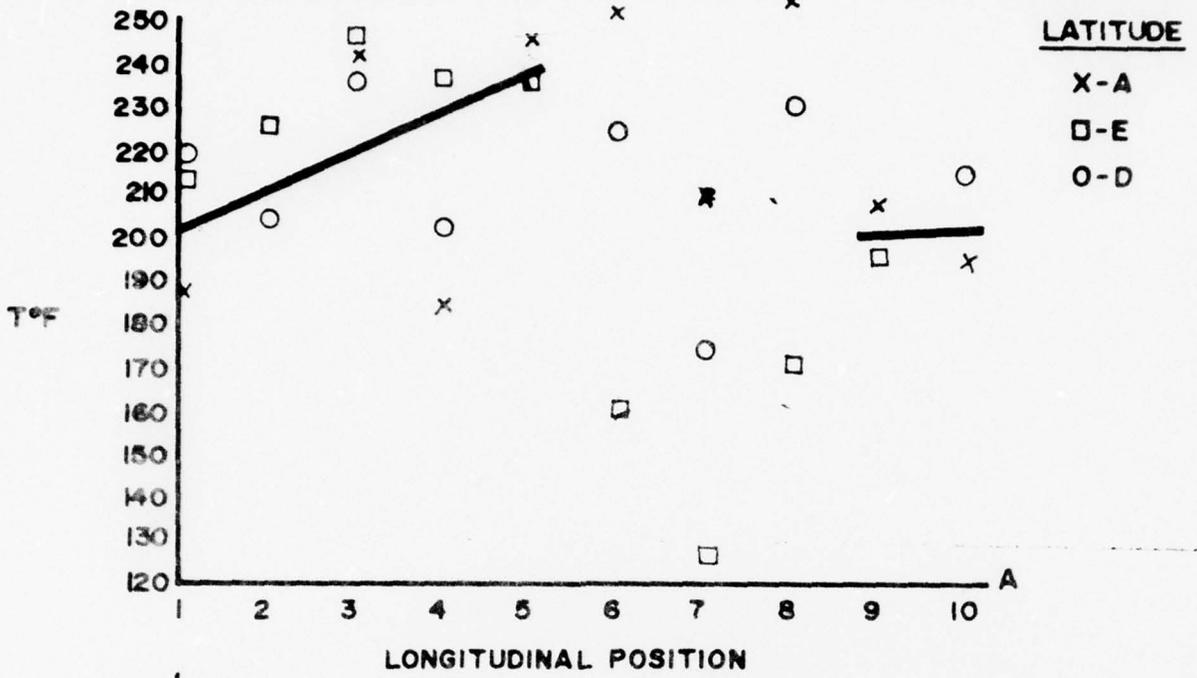
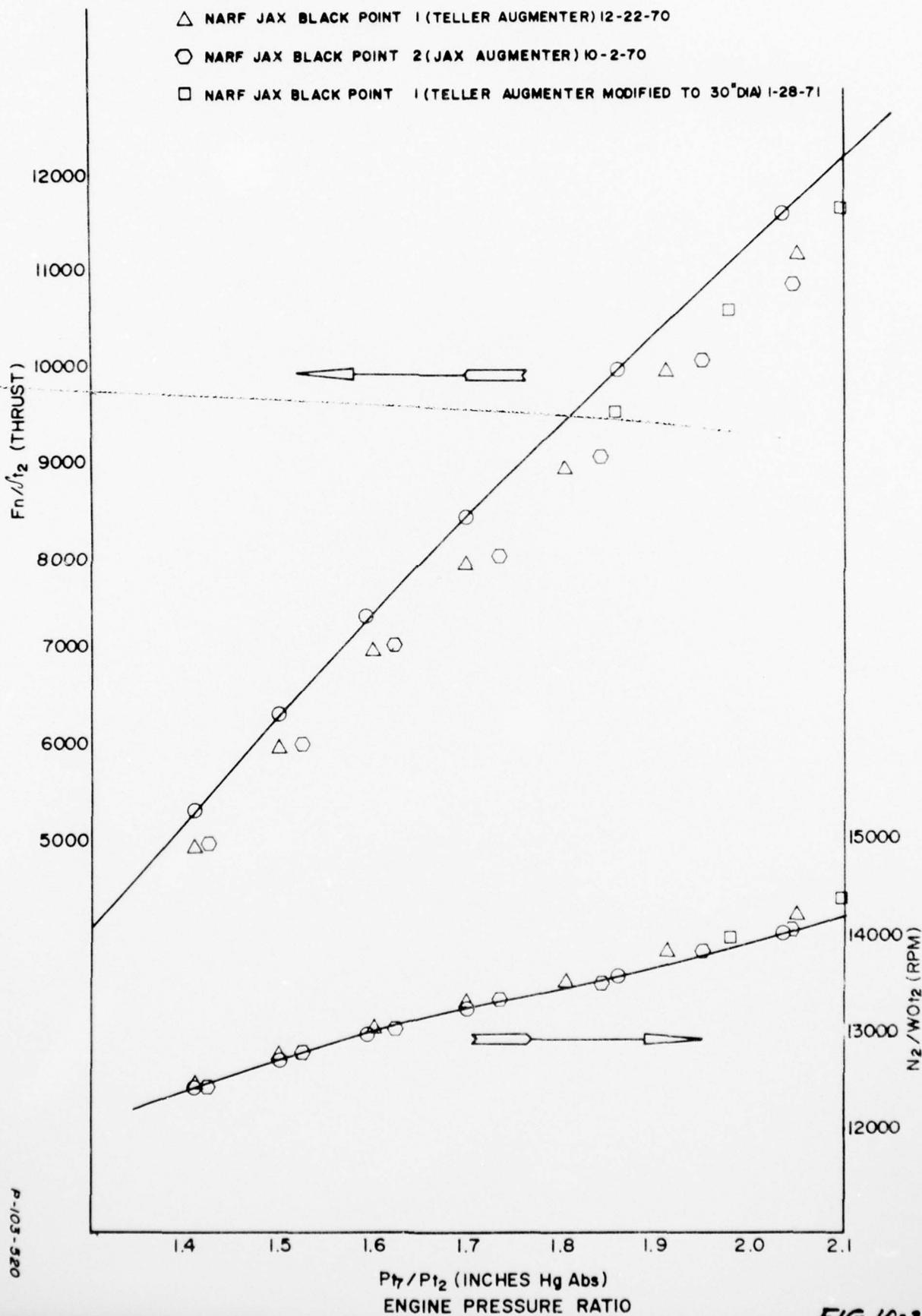


FIG. 10-2

TF30-P8-B CORRELATION S.N.664330

- NARF NORVA TEST CELL 12
- △ NARF JAX BLACK POINT 1 (TELLER AUGMENTER) 12-22-70
- NARF JAX BLACK POINT 2 (JAX AUGMENTER) 10-2-70
- NARF JAX BLACK POINT 1 (TELLER AUGMENTER MODIFIED TO 30° DIA) 1-28-71

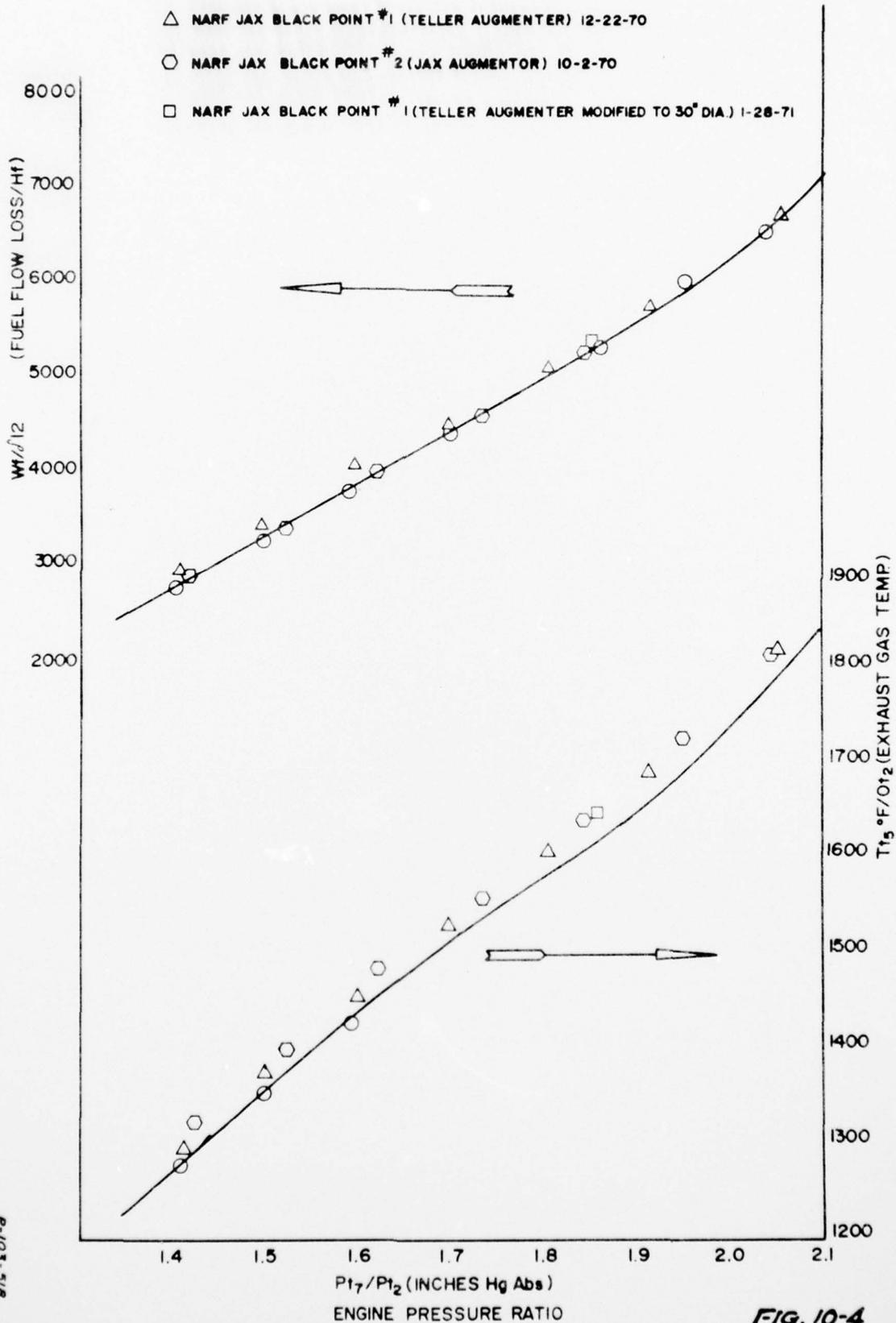


P-105-520

FIG 10-2

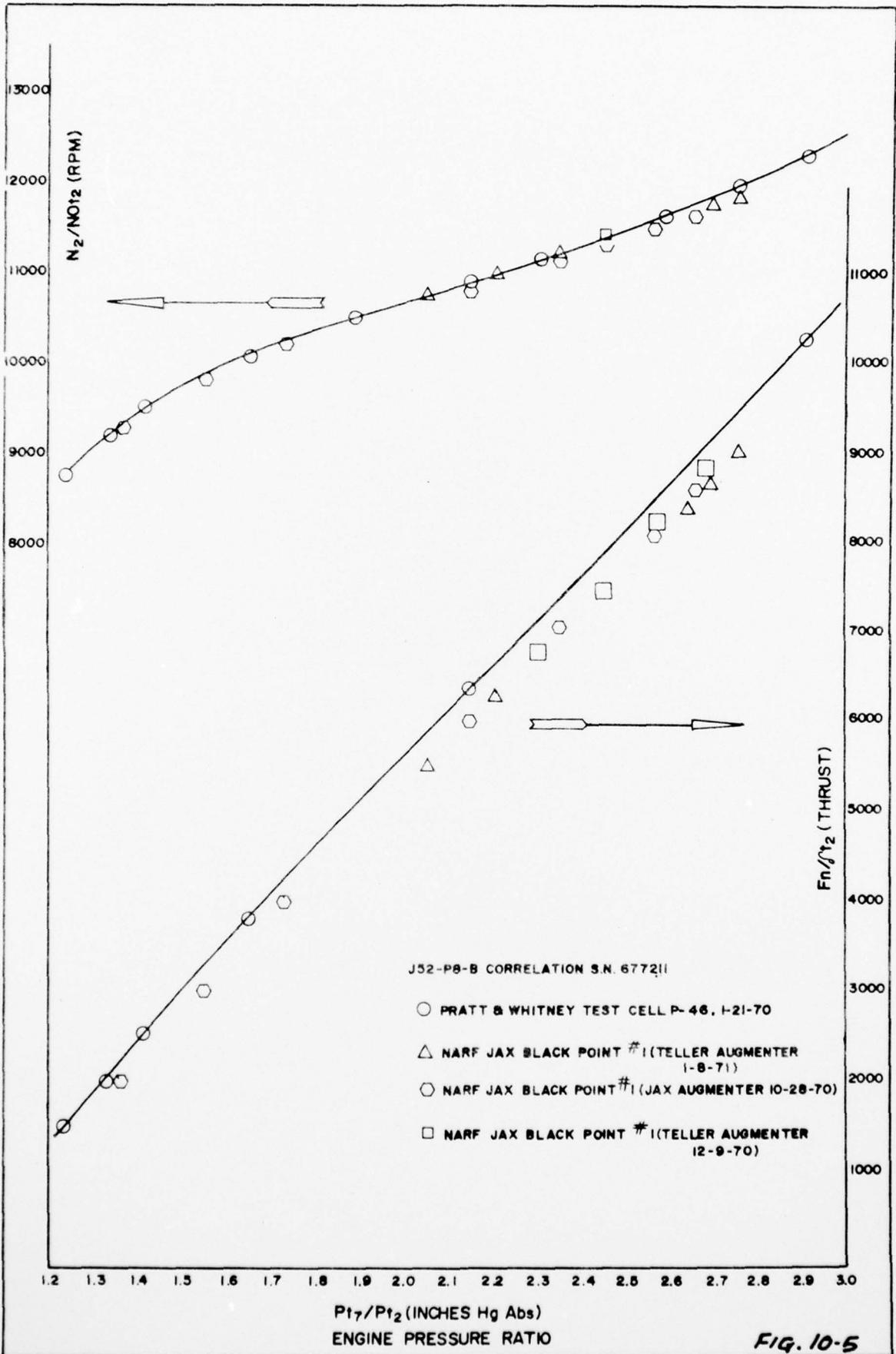
TF-30-P8-B CORRELATION S.N. 664330

- NARF NORVA TEST CELL #12
- △ NARF JAX BLACK POINT #1 (TELLER AUGMENTER) 12-22-70
- NARF JAX BLACK POINT #2 (JAX AUGMENTOR) 10-2-70
- NARF JAX BLACK POINT #1 (TELLER AUGMENTER MODIFIED TO 30° DIA.) 1-28-71



P-103-518

FIG. 10-4



P-105-517

GENERAL  ELECTRIC

EVENDALE PLANT
CINCINNATI, OHIO 45215

• SUBJECT

NAS JACKSONVILLE PERFORMANCE COMPLAINT

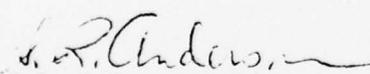
FILE: J79PA-1618

January 18, 1971

J.L. Price
J79 Project
N161

The curve (Engine Pumping Characteristics) for engine 421-731 requested by NAS Jacksonville is enclosed. This curve indicates that the internal engine performance did not change (for test dates shown).

It should be noted that this curve represents one engine only and since the same test cell was used, it is also probable one set of instrumentation is also involved. Should a considerable number of different engines be tested and also possibly in different test cells, the data will form a band with the width dependent on the actual engine quality and instrumentation variations.


S.R. Anderson, Engineer
J79 Performance

/blc
Attachment
Curve: J79PA-1618-1

MAIL DROP N134
DIAL COMM 8 • 332 3414

COPIES:

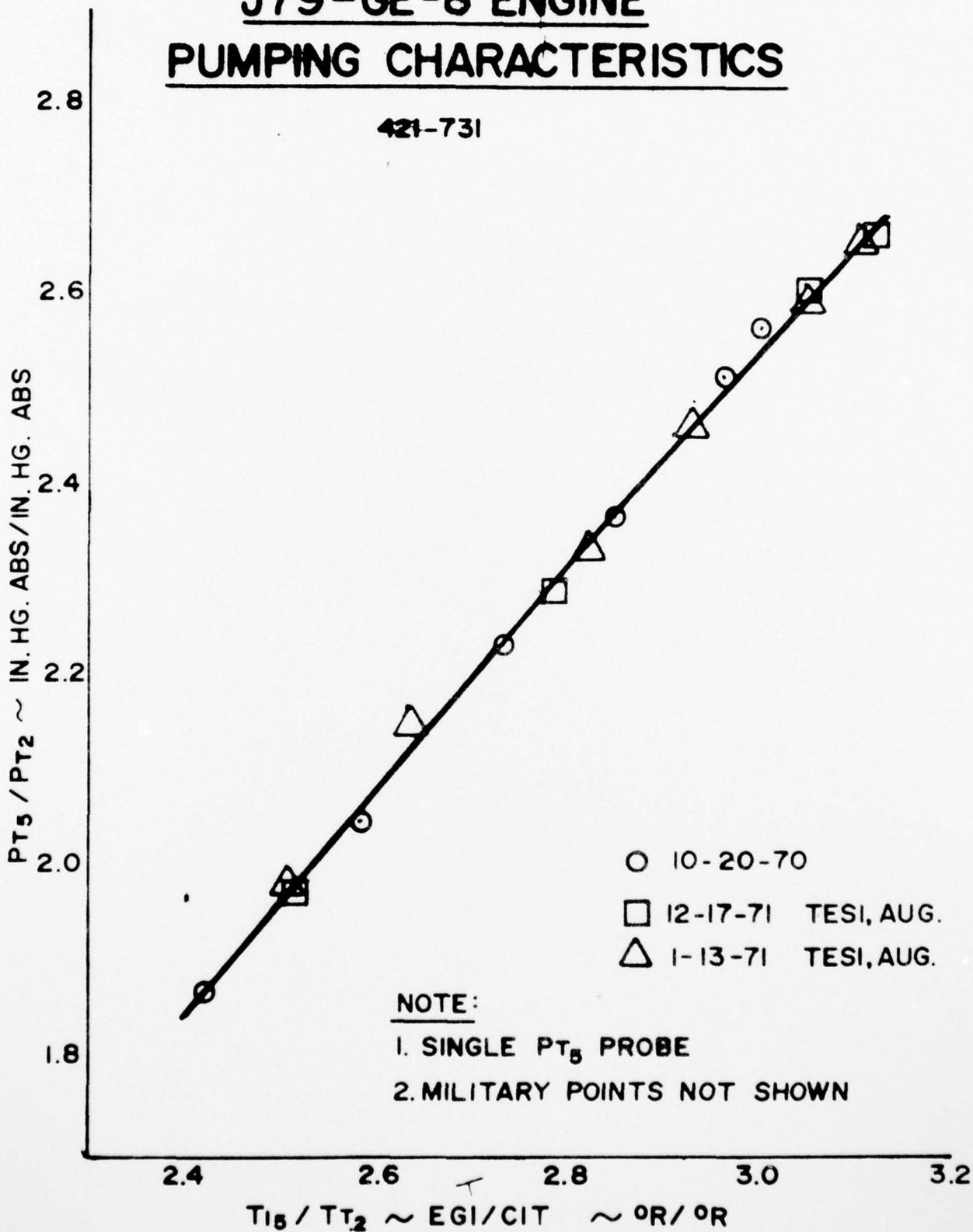
RL Campbell
PL Love
TB Parker
HM Hicks
DRB 661
File



FIGURE 10-6

J79-GE-8 ENGINE PUMPING CHARACTERISTICS

421-731



NOTE:

1. SINGLE PT_5 PROBE
2. MILITARY POINTS NOT SHOWN

J79 PA-1618-1

CONFORMANCE WITH ENVIRONMENTAL REQUIREMENTS

11.1 The criteria for recovery of particulate emissions from the exhaust of jet engine test stands were established in the "Pollution Abatement Study and Systems Analysis for Jet Engine Test Cells" (U.S. Navy Contract No. N62467-70-C-0078). These criteria were based on the following sources:

- 1 - Executive Order 11282 establishing conformance with state and local community regulations or, in the absence of such regulations, with Section 5 of the Executive Order;
- 2 - Section 5 (E.O. 11282) Paragraph 76.9 related to combustion processes establishing a permissible emission level of 0.28 per million Btu;
- 3 - "Air Quality Criteria for Particulate Matter" U.S. Department of Health, Education and Welfare (January 1969) that establishes the concern for effects on visibility of particles in the size range of 0.1-1 micron and the desirability of achieving ground level concentrations of these particles less than 0.000033 grains/ft³.

The most restrictive local regulations, Bay Area Control District, California, establish a Ringleman Smoke Shade requirement of 1/2 except for 3 minute excursions to Ringleman 3. As a very approximate relationship, this limits the emission concentration to 0.010 grains/cu.ft. Baltimore, Maryland has recently established a zero Ringleman requirement.

On the basis of the Executive Order 11282, the emission level, converted to test stand gas flow, is limited to 0.008 grains/cu.ft. It was recommended in the initial study that a performance objective of 0.004 grains/cu.ft. be established so that even with transient difficulties, the 0.008 grains/cu.ft. level would be achieved.

11.2 Data obtained by Environment/One on the emissions from the scrubber system under the range of operating conditions required for engine testing, for three engines,

11.2 (Continued)

are as follows:

TABLE 11-1
EMISSION LEVELS FROM TEST CONTROL SYSTEM

<u>ENGINE</u>	<u>MODE</u>	<u>PARTICULATE EMISSIONS Grains/cu.ft.</u>	<u>RINGLEMAN</u>			
J-79	Idle	0.0024	Less	than	1/2	
	Normal	0.0029	"	"	"	
	Military	0.0024	"	"	"	
TF-30	Idle	0.0019	"	"	"	
	Normal	0.0014	"	"	"	
	Military	0.0018	"	"	"	
J-79	Idle	0.0052	"	"	"	These tests are question- ed by ENVIRON- MENT/ONE.
	Normal	0.0029	"	"	"	
	Military	0.0062	"	"	"	
	Max. A/B	0.0033	"	"	"	

In all conditions, the exhaust from the TESI scrubber system is well within the requirements of any established or recommended restrictions with emission levels ranging from 18% to 78% of the E.O. 11282 for performance and averaging 37% of the E.O. 11282 performance level. The analytical procedure conducted by Environment/One is indicated in Appendix 11-A.

A comparison of the visual or Ringleman conditions before and after introduction of the TEST system is indicated in Figures 11-1 through 11-4.

With respect to SO₂ and NO_x emissions, the normal concentrations within jet engine emissions prior to entering the scrubber were found to be less than 20 PPM for each gas or less than 15% of the limits in any projected legislation. Thus, control is not required.

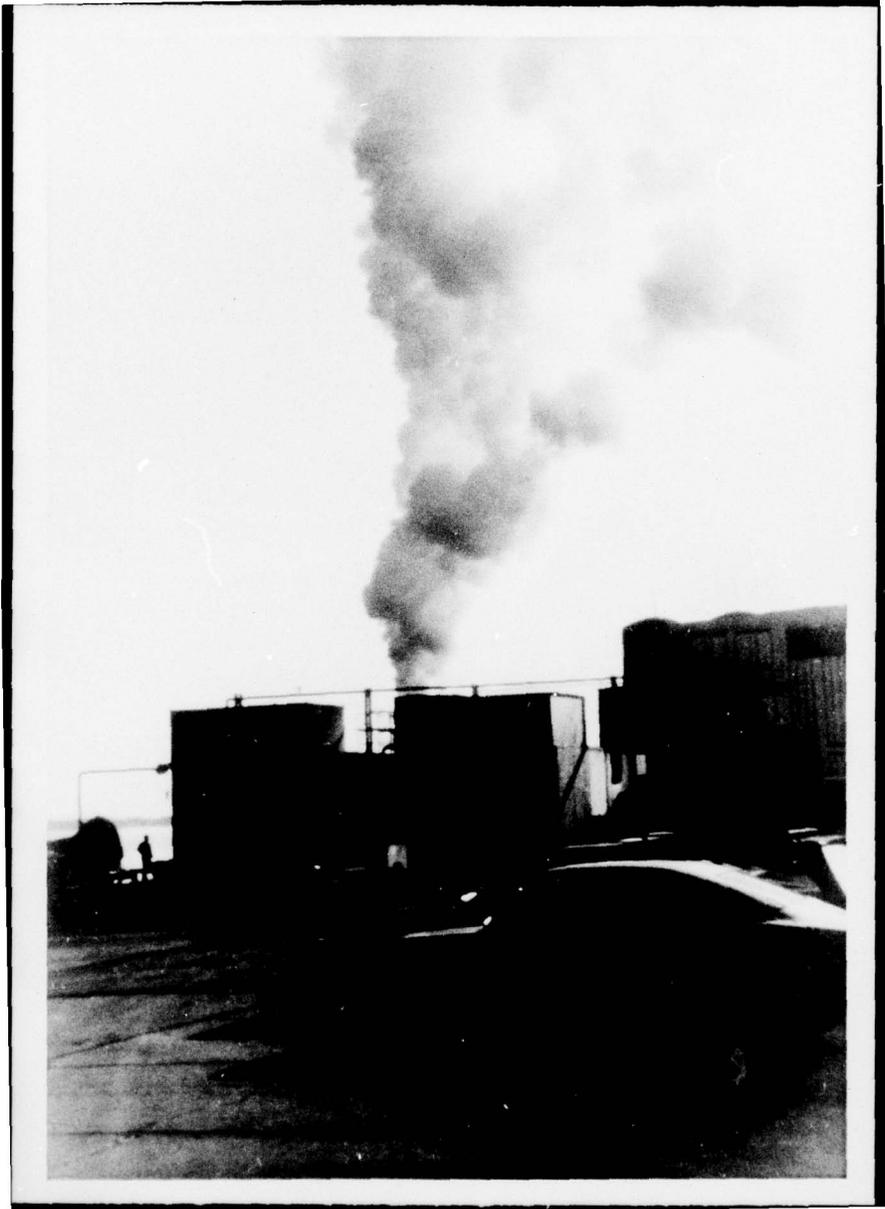






FIGURE 11.3

SECONDARY EFFECTS: Effluent Water

- 12.1 The effluent water temperature ranged from 74° at idle to 160°F at maximum afterburner mode for the J-79. This was higher than anticipated in design as indicated in the performance analysis section 7.

Based on the anticipated effluent water temperature and an outflow of 8,000 GPM, a water temperature profile was established for the river water. The basis for this analysis was not the point temperature development, but on the average heat release, resulting from the combustion of fuel over a test cycle, the typical cycle was considered to be 5 hours with 33% of the time consumed at military operation and 5% at afterburner. The average heat pickup was estimated at 15,000 Btu/sec resulting in an average temperature rise of the water of 13.8°F in the scrubber. The river flow velocity was assumed to be zero. The relationships established for river water rise for large warm effluent streams (Jen. Y. & Wiegel, R. L., Journal of the Power Division, Proc. AXCE, Paper No. 4801, April 1966) were as follows:

Equations

Based on semi-empirical model:

$$\frac{T_m - T_w}{T_D - T_w} = 7 \frac{D}{X} \quad (12.1) \quad \text{Where:}$$

- T_m = Temperature along the center line of warm water jet, °F
 T_w = Temperature of receiving water, 80°F
 T_D = Temperature of the discharge water, °F
 D = Diameter of the discharge pipe, ft.
 X = Horizontal coordinate along the jet axis, measured from the point of discharge, ft.
 7 = Empirical constant from the experimental data.

12.1 (Continued)

Equations

Based on semi-empirical model:

$$\frac{T - T_w}{T_m - T_w} = \exp - \left\{ 3F^{1/2} \left(\frac{y}{X} \right)^2 \right\} \quad (12.2)$$

Where:

- T = Temperature at any point, °F
- y = Horizontal coordinate normal to the jet axis measured from the jet axis, ft.
- F = Froude no. defined as.

$$F = \frac{V_D}{\sqrt{\frac{\Delta\rho}{\rho_O} g D}} \quad (12.3)$$

Where:

- V_D = Discharge velocity, ft/sec
- ρ_O = Density of discharge water.
- $\Delta\rho$ = $\rho_w - \rho_O$
- ρ_w = Density of the receiving water.
- g = 32.2 ft/sec²

12.1 (Continued)

The computer printout of the average conditions are indicated in Figure 12-1. The printout indicates that a 4° rise in water temperature will occur in an area projecting 40 feet into the river and approximately 8 feet wide. In a test with a J-79 engine, the following information was obtained by NARF personnel (Figure 12-2):

TABLE 12-1

RIVER WATER TEMPERATURES

Mode of Operation	Distance from Bulkhead (feet)	Temperature °F within 20' of Discharge Line		
		0	1'	2' (depth)
Military	40	85	66	66
Minimum A/B	40	100	69	68
Maximum A/B	80	80	72	70
Military	80	82	70	65

River Water Temperature = 61°F

The significantly larger increase in temperature compared with model projection is based on two factors. These data represent only 33% to 50% of the operation and the heat transfer capability of the scrubber is twice that originally projected.

The water quality data were obtained by NARF personnel and by Southern Analytical Laboratory (NAVFAC contract). The data relative to a significant factor, suspended solids, was determined only at NARF.

The data are reported in TABLES 12-2 and 12-3. The NARF suspended solids data are plotted in Figure 8-8.

TABLE 12-2
RESULTS OF ANALYSIS OF SCRUBBER WATER (NARF DATA)

DATE	D.O. (APHA)		B.O.D. (APHA)		HYDROCLONES (ASTMD-1340)		UNDISSOLVED ¹ SOLIDS		TURBIDITY (APHA)							
	5/4	5/5	5/4	5/5	5/4	5/5	5/4	5/5	5/4	5/5						
ENGINE	J52	TF30	J79	J52	TF30	J79	J52	TF30	J79	J52	TF30	J79	J52			
River	5.7	6.7	6.8	1.0	1.7	1.1	4	4	5	15	10.6	13.8	28	20	30	80
Idle	8.1	7.8	7.8	1.6	2.8	2.6	7	6	6	31.6	11.4	15.6	47	22	38	37
Normal Rated	6.4	6.4	7.0	1.4	1.2	2.3	6.0	7	7	87.0	14.6	21.4	31	24	62	37
Military	5.5	5.6	5.5	1.2	2.5	2.0	6.0	9	10	17.8	46.8	59	37	62	100	71
Max AB			2.3			1.8			12			52.6				70

¹ Filtered on 145 millipore

SOUTHERN ANALYTICAL LABORATORY

A DIVISION OF TECHNICAL SERVICES, INC.
103 STOCKTON STREET - P. O. BOX 628
JACKSONVILLE, FLORIDA 32201



Industrial Chemists

ANALYSIS OF INDUSTRIAL MATERIALS
RESEARCH - TECHNICAL REPORTS

Laboratory No. 8761 June 15, 1971
 Sample of Waste Water
 Date Received May 4, 5 & 6, 1971
 For Commanding Officer, Southern Division, Naval Facilities Engineering Command
P. O. Box 10068, Charleston, S. C. 29411 - Attn: Mr. R. B. Foster
 Marks: Pollution Abatement Device, Jet Engine Test Cell, Naval Air Rework
Facility - Black Point, NAS, Jacksonville, Florida

CERTIFICATE OF ANALYSIS OR TESTS

		Oxygen Demand, Biochemical	Dissolved Oxygen	Unburned Hydrocarbons	Turbidity
J-52 Engine	Military	3.2 mg/l	6.05 mg/l	0.7 mg/l	7 JU
	Idle	1.8 "	7.9 "	0.4 "	5 "
	Normal	2.3 "	6.6 "	0.6 "	40 "
TF-30 Engine	Idle	2.2 "	7.6 "	0.5 "	7 "
	Normal	2.4 "	6.2 "	0.7 "	4 "
	Military	2.0 "	6.0 "	0.8 "	15 "
J-79 Engine	Idle	2.4 "	7.1 "	0.9 "	5 "
	Military	2.5 "	5.6 "	0.9 "	40 "
	Max AB Run #1	4.4 "	4.4 "	1.87 "	66 "
	Max AB Run #2	2.7 "	4.9 "	1.2 "	48 "
River 5/4		1.4 "	6.8 "	0.4 "	4 "
River 5/5		1.6 "	6.8 "	0.3 "	4 "

TABLE 12-3
RESULTS OF ANALYSIS OF
SCRUBBER WATER SOUTHERN
ANALYTICAL LAB.

Respectfully submitted,

SOUTHERN ANALYTICAL LABORATORY, INC.

BY Henry C. Gray, Jr.

- 12.2 Comparison of BOD data indicates that the average increase reported by both groups is of the order of less than 1 PPM for all but A/B runs (Southern Analytical). Within the accuracy of analysis, there appears to be little or no reduction in dissolved oxygen with scatter of increases and decreases reported.
- 12.3 The NARF data indicate an increase in unburned hydrocarbons up to 7 PPM at A/B operation for the J-79 and a 2-3 PPM increase for military operations, whereas the Southern Analytical data indicate a maximum increase in 1.5 for A/B operation and a magnitude of 0.5 PPM for all other modes of operation.
- 12.4 The turbidity increase reported, observed by NARF personnel, was greatest for military ranging from 19 to 70 JU, whereas the Southern Analytical data indicated a rise of 11 to 36 JU for military mode and up to 62 for afterburner operation.
- 12.5 The undissolved solids increase was measured by NARF personnel and formed a basis for material balance for recovery of particulates by the TEST scrubber. The data for the TF-30 and J-79 were consistent through military and are indicated in Figure 8-8. The data for the J-52 runs were scattered. The only apparent inconsistency was the low quantity of particulates 18.8 PPM or 80 lb/hr of solids recovered during A/B operation of the J-79.

This discrepancy was due to the possibility that much of the unburned fuel (large particles) were captured by the internal section of the scrubber, were drained from the stack basin, and flowed through the separator into the river. Implied evidence of this phenomenon was obtained subsequent to the test program when various modes of separation of the particulates from circulation water were tested. Separation was achievable at times by centrifugation of the scrubber effluent water but not from the stack drainage. The only difference in effect can be attributed to the variation in specific gravity. The stack bottom particulates were probably covered with a film of JP-5 resulting in the lower specific gravity.

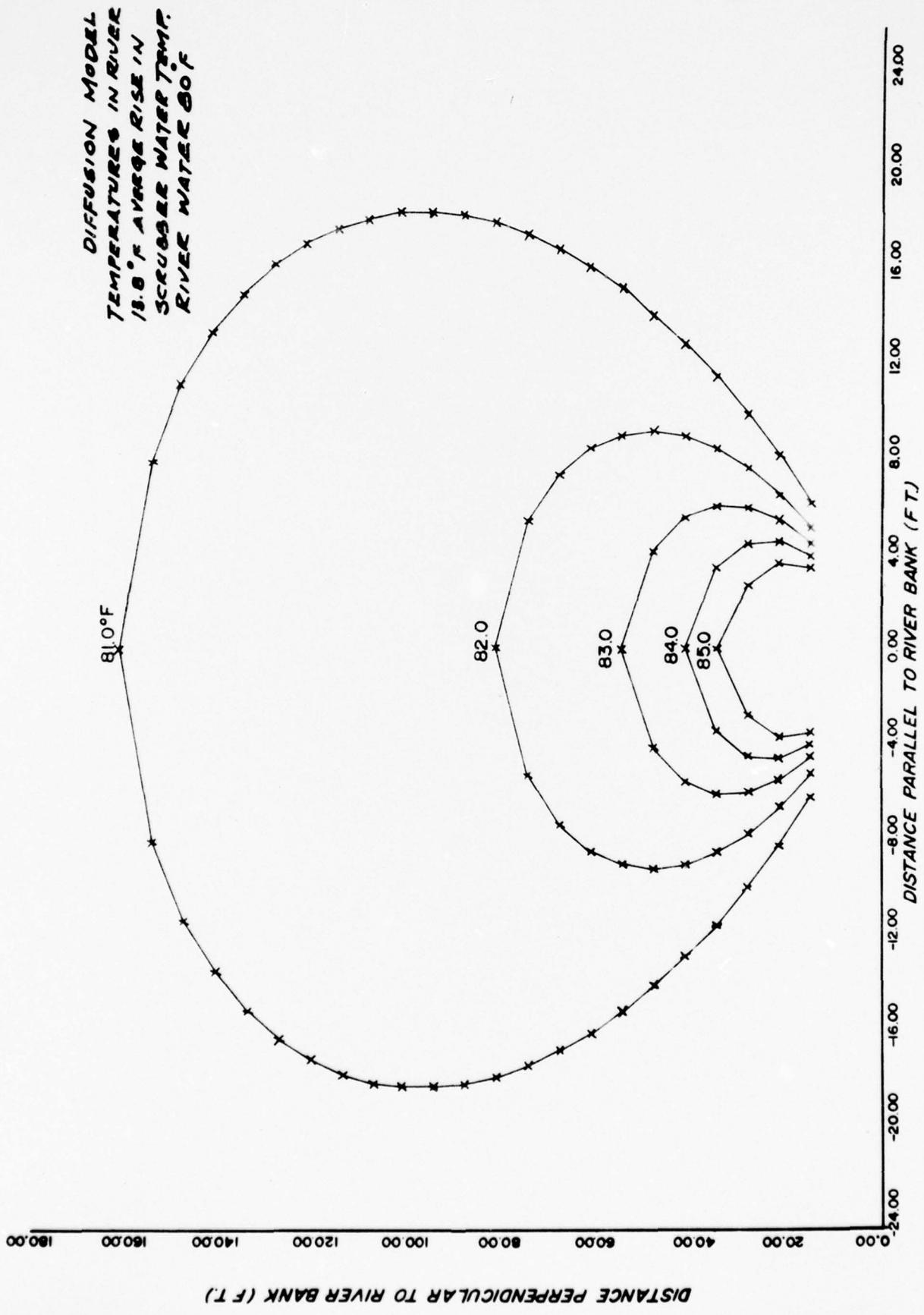


FIG 12-1 P-103-516

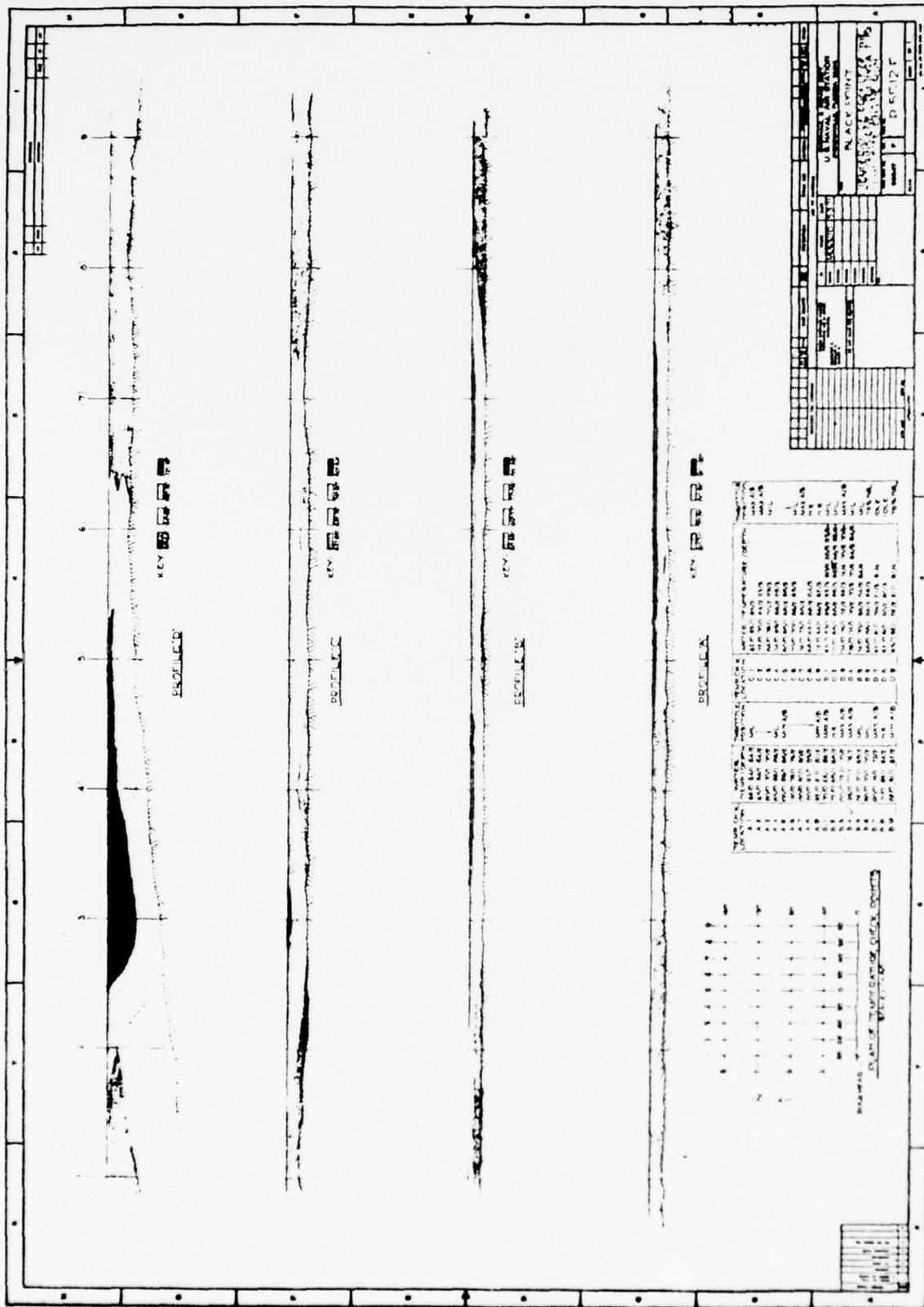


FIG. 12-2

SOUTHERN ANALYTICAL LABORATORY

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JACKSONVILLE, FLORIDA 32201



Industrial Chemists

ANALYSTS OF INDUSTRIAL MATERIALS
RESEARCH - TECHNICAL REPORTS

Laboratory No. 8386

April 21, 1971

Sample of Waste Waters

Date Received April 8, 1971

For Commanding Officer, Southern Division, Naval Facilities Engineering Command,
P. O. Box 10068, Charleston, S. C. 29411

Marks: Attn: R. B. Foster

Black Point - NAS - Jacksonville, Fla.

CERTIFICATE OF ANALYSIS OR TESTS

	<u>River Inlet</u>	<u>Max AB</u>	<u>Military</u>	<u>Idle</u>
Oxygen Demand, F ₂ chemical	4 mg/l	25 mg/l	6 mg/l	14 mg/l
Dissolved Oxygen	8.2 "	3.15 "	5.5 "	7.9 "
Turbidity (Jackson Units)	55 JU	95 JU	80 JU	65 JU
Hydrocarbons	5 mg/l	16 mg/l	10 mg/l	9 mg/l

579

TABLE 12-3

Respectfully submitted,

SOUTHERN ANALYTICAL LABORATORY, INC.

BY Harvey C. Gray, Jr.

SECONDARY EFFECTS: Sound Level

13.1 Significant reductions in sound level from the test stand (Black Point No. 1) were observed subsequent to installation of the TESI scrubber system. The comparison of the sound levels achieved with the total TESI system (scrubber and augmentor) compared with the prior conventional installation at Black Point Cell No. 1 are indicated in Figures 13-1, 13-2, and 13-3. The sound levels were obtained for operation with the:

TF-30	Military
J-79	Military
J-79	Maximum Afterburner

13.2 The three sets of curves form a similar pattern where significant reductions in sound level were achieved in the range of 31.5 - 400 cycles/sec and from 1000 to 16000 cycles/sec, and little or no change in the range of 400 - 2000 cycles/sec. The reduction in sound level as indicated by Overall "A" scale as measured by the Octave Band Analyzer ranged from 6 - 10 decibels for the engines evaluated.

TABLE 13-1

Overall "A" Scale Sound Levels

Decibels

<u>Engine</u>	<u>Operating Mode</u>	<u>Without Scrubber</u>	<u>With Scrubber</u>
TF-30	Military	100	90
J-79	Max A/B	103	95
J-79	Military	98	92

13.2 (Continued)

In the study report (Contract No. N62467-70-C-0078), it was projected that the packing would contribute to sound attenuation only at frequencies greater than 300 cycles/sec, but would have a significant effect only at frequencies greater than 1200 cycles/sec. (TABLE 9-4 Study Report). This magnitude of reduction was achieved with operation of the J-79 engine where reductions in sound level of 13 decibels was achieved at 4000 cycles/sec and a reduction of greater than 25 decibels was achieved at 8000 cycles/sec.

What was unanticipated was the reduction in sound level at the 16 - 250 cycle/sec range. The maximum reduction was 6 - 10 decibels at 63 cycles/sec.

Raw data in Appendix 13A.

SOUND LEVEL, J79 MIL
250' DISTANCE, 3 POINTS
N-NW FROM CELL

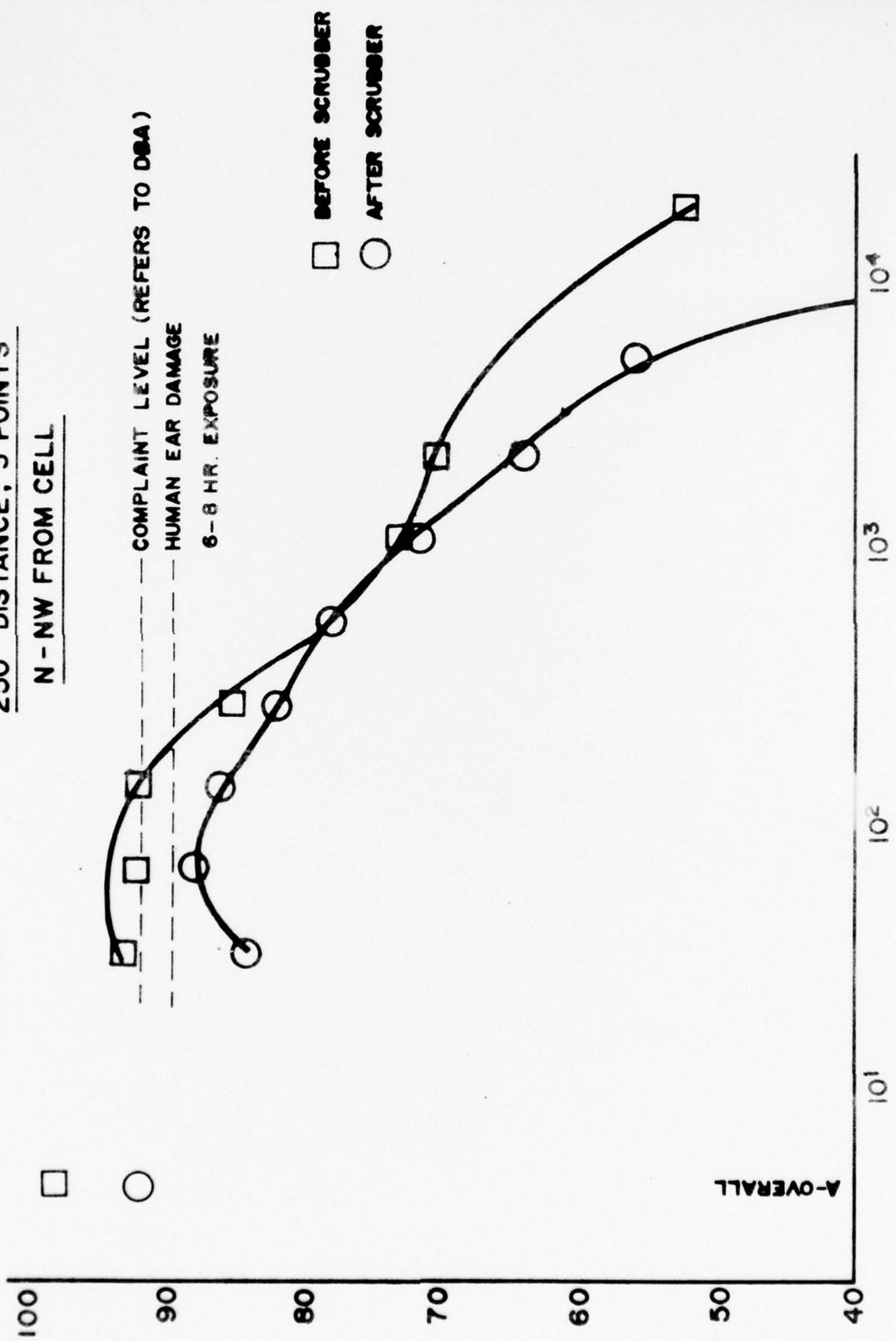


FIG. 13-1

CYCLES/SEC. HZ

A-OVERALL

SOUND LEVEL, J79 A/B
250' DISTANCE POINT
N-NW FROM CELL

COMPLAINT LEVEL (REFERS TO DBA)
HUMAN EAR DAMAGE
6-8 HOUR EXPOSURE

BEFORE SCRUBBER
AFTER SCRUBBER

□

○

A-OVERALL

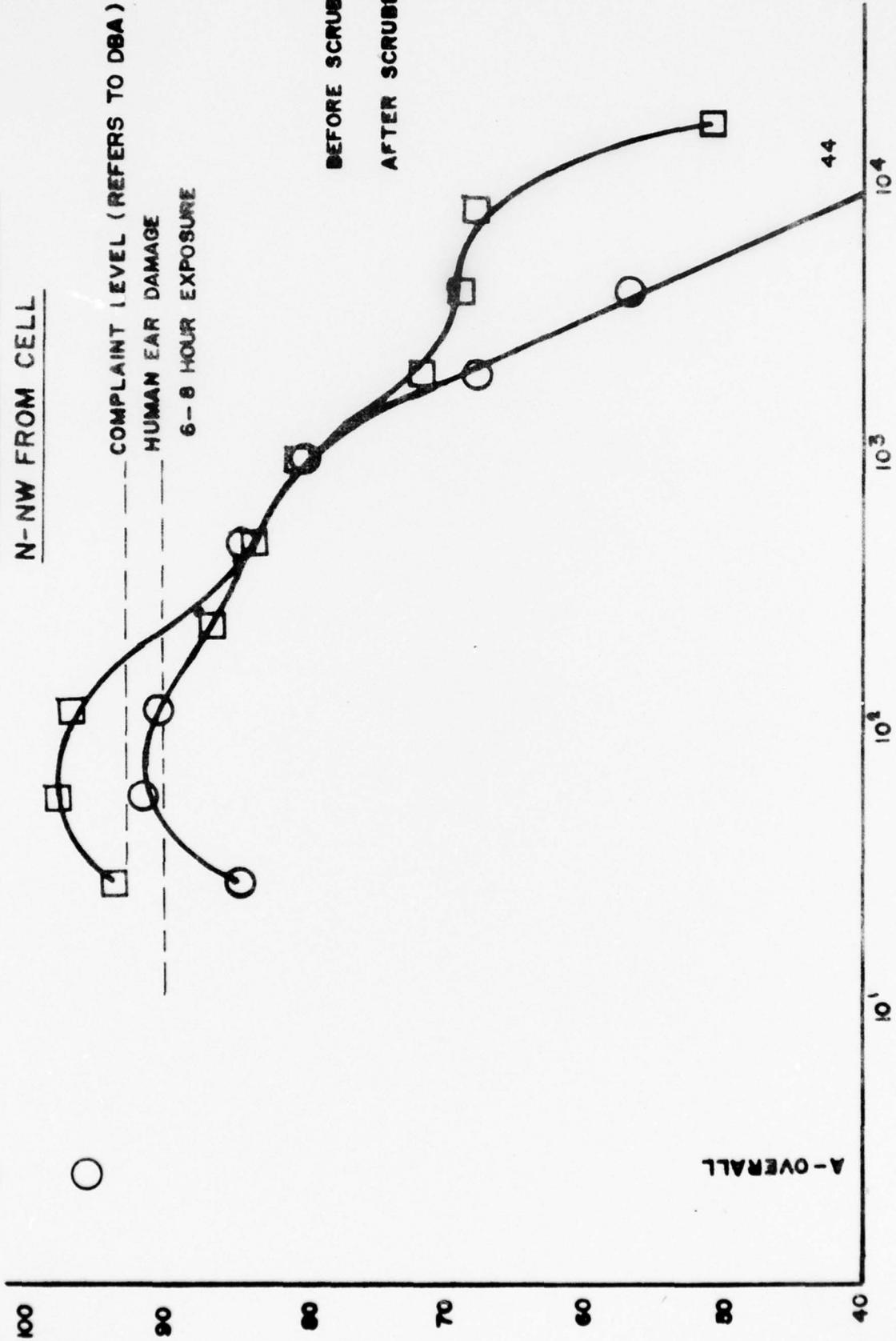


FIG 13-2

CYCLE / SEC. HZ

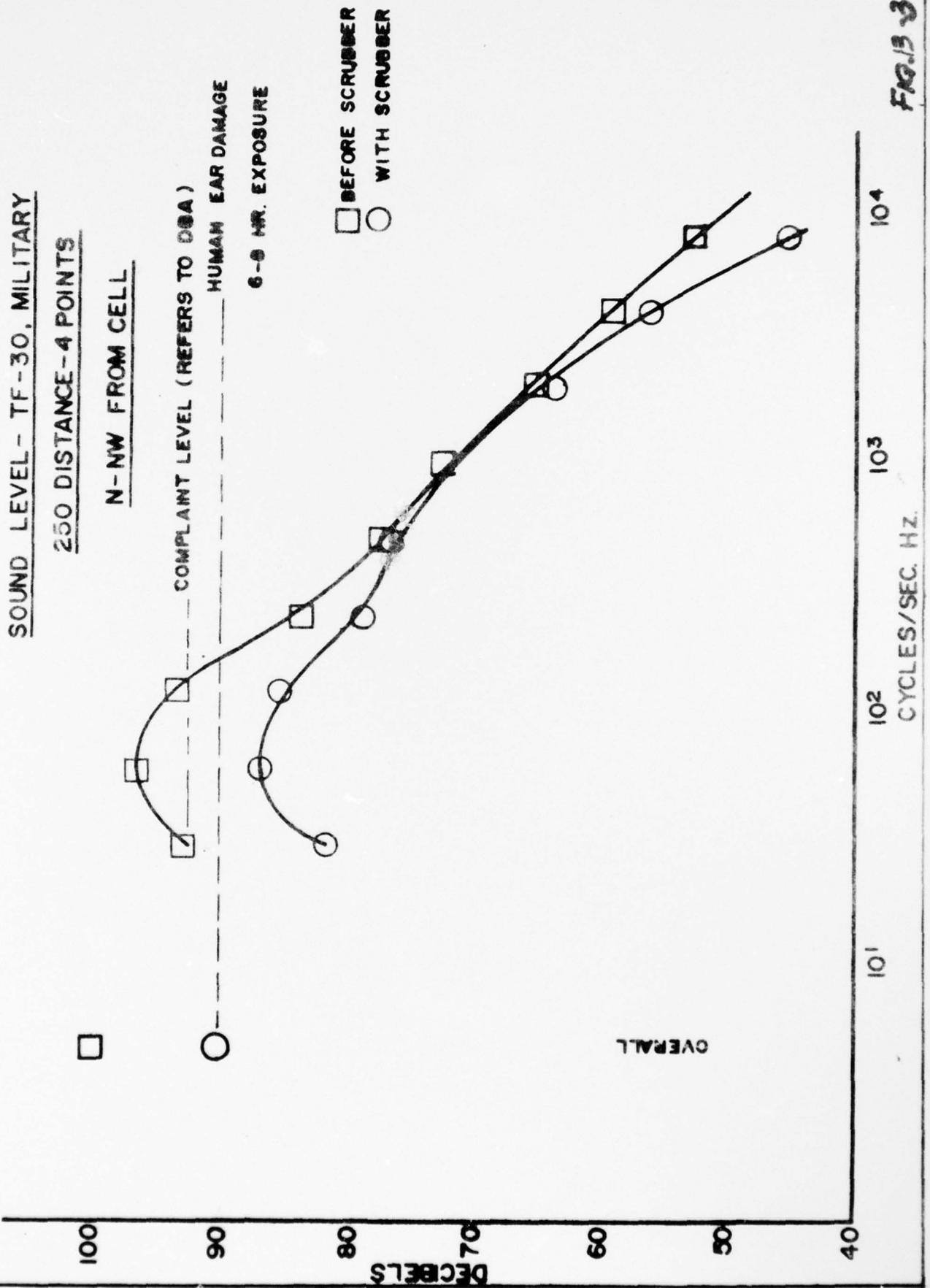


FIG. 13-3

Environment/One

The procedure for determination of effluent loading at the stack was as follows for six points.

1. Determine velocity for sample point by pitot tube and water manometer corrected for average effluent temperature. (8-1).
2. Select critical orifice allowing for isokinetic sampling at sample probe inlet. Probe inlet was fixed as 0.120 inches diameter. Five critical orifices were available, 11.5 to 26 liters/minute.
3. Locate two weight sampling probes at test point. Make pressure and temperature measurement at critical orifice for monitoring and flow corrections. Sample for 3 to 10 minutes, depending on effluent particle loading. Filter material used was Gilman Type "E" 47 mm.
4. Replace weight sampling probe with Milipore filter Type HA 47 mm and sampling probe for size distribution. Using same probe flow setting take 5-10-15 second samples after each probe pair change.
5. Repeat step (3-4) for two additional pairs of weight probe sample locations.
6. Wash out weight probes with water and collect on filter for weighing.
7. Take gas samples at edge of effluent stream, with MSA Universal Sampling pump and detector tubes.

Engine parameters and exhaust gas temperature data were provided by test cell crew. Two engines were tested: J-79 for; idle, 95% load, afterburner min and afterburner max, and the J-52 engine for idle and military power settings.

ANALYSIS OF DATA

Weight of material on each filter was determined after bringing filter to same humidity condition at which initial clean weights have been determined. Weights were normalized for actual probe flow and sample times and averaged. Average wash water sample weight was added to filter weights and loading corrected for effluent discharge at 70°F, 14.7 psi. This loading is expressed in grains/ft³.

ANALYSIS OF DATA (Continued)

A Milipore filter sample for each run was analyzed by microscope with 450 power and the size distribution determined by means of a Portion retical and stage micrometer. Counting locations were determined by random selection.

Gas analysis data were read directly from calibration charts. No indication was obtained on either the 103C or 103D SO₂ detection tubes. Data for the 95% and afterburner min. tests were not obtained. Gas concentration values were obtained only at the edge of the effluent stream and could be in error due to dilution factors.

Samples for water analyses were collected as follows:

1. The river water sample for background was taken from 3/4" pipe located on the side of the inlet water line approximately 2/3 of the distance from the river to the scrubber. One sample was taken at the beginning of each day's engine operations. NARF Jax April 6, 7 and 16, 1971 samples were 15 gals. and May 4, 5 and 6 were 5 gal. samples. Southern Analytical samples were all 5 gals. Water flow was 8000 gpm at time of samples.
2. Scrubber water effluent samples were taken at the outfall from the approximate center. The water was directed to the sample bottles through a 2" pipe which was 6' long. One sample was collected during each engine setting. The volume of sample taken and effluent water flow were the same as reported in para. 1 above.

The train used consists of the following: The line from the manifold feeds into an impinger consisting of a bubbling impinger containing distilled water followed by a similar impinger with no water. The output of the second impinger is transferred directly into a Swinex - 47 filter holder containing a Gelman Type A glass 47mm filter. This train is followed by the air moving system consisting of a flow adjusting needle valve, a thermometer, a Thomas Series 727-CA-39 vacuum pump and a Dwyer Rotameter. Although the flow was monitored constantly during all runs, it was not necessary to make any adjustments.

The gases were sampled as follows: Horizontal slotted pipes were mounted at two points in the outlet guides at the 8 ft and 12 ft level. Projecting out of the slots in these pipes were intake nozzles consisting of stainless steel tubing, .250 inch O.D., .010 inch wall 4 inches long. Six of these nozzles were manifolded together by connection to copper pipe for each level of sampling, so that they were uniformly spaced (± 1 inch) five feet apart along the length of the slotted pipe. This manifold was connected to the sampling train by an 8 foot length of Tygon tubing.

The procedure during a run was as follows: Upon a signal from the engine operator that the desired engine condition had been reached, the pumps were all started. Time was measured from this point, by starting a stopwatch. The flow was immediately adjusted and the operation of each train checked. At the end of the selected time, the pumps were stopped and the operator signaled to stop the engine. After the engine was shut down, the nozzles were removed, all the pipes were flushed with acetone, the Tygon tubing flushed with water and the impingers were washed with acetone. All of these flushings were preserved with the bubbler water as part of the sample collected for that run. The filters were removed and each placed in a separate plastic Petri dish. The devices were then reassembled for the following run:

It had been our intention to point the nozzles into the direction of flow by observing the static pressure while rotating the slotted pipe, and stopping at the point where a maximum was observed. However, the flow rate was so slow that no variation could be observed. Therefore, we simply pointed the nozzles by visually aligning them with the flow.

The temperature at the impinger rose rather slowly during each run at a maximum of about 120°F.

The loadings as reported were the averages of the weighings of material gathered on two runs each, from a total of 12 points.

1. The sampling train employed is as follows:
 - a. 10' stainless steel probe connected to the 1st impinger by means of a 10" long teflon lined silicone rubber tube.
 - b. Dry Greenberg-Smith Impinger (cooled with 1,1,1-trichloroethane and dry ice.)
 - c. 2 Greenberg-Smith Impingers containing 250 cc water.
 - d. 1 Filter assembly containing a Millipore Type AP25 glass prefilter, one .45 micron Milipore filter, one .22 micron Milipore filter.
 - e. 1 Impinger with desicant.
 - f. Meriane PFB laminar flowmeter with connections, a thermocouple, differential pressure gauge, and absolute pressure gauge.
 - g. Needle Valve.
 - h. Vacuum pump
2. Nine points were sampled at 10 minutes for each point for a total volume sampled of 30-40 c.f. Stack velocity was determined by means of a pitot tube and uncleaned wavometer and temperature by means of a thermocouple and Honeywell detector.

Correct settings for sampling rate were determined from raw data by means of a computer program designed to give stops at air velocity at standard day conditions, air volume in cfm, flow rate in laminal air flow meter, differential pressure required for flow meter rate. Calculations required 10-20 seconds and were rechecked after initial setting. Accuracy of equipment use is $\pm 1.0\%$

3. Samplings collected were washed from the impingers and probed with distilled water and acetone. All samples were evaporated to dryness and the filters were dried to constant weight, to determine total solids weight. Total weights were from 11 to 68 mg.

3/20/71

BLACK POINT TEST CELL
SCRUBBER TEST PROGRAM

F-2 = 56°

APPENDIX 9A

Time	No.	Engine Characteristics		Water Flow GPM	T E M P E R A T U R E ° F										P In. H ₂ O Internal		
		RPM	Thrust		Quench Tower		at stack before entering scrubber					EXIT Scrubber		River Water		Scrubber Water	
					17	18	19	20	21	22	23	24	0-1	0-2	IN	OUT	OUT
0907	J-79	5012	340	50	84	74	88	90	89	92	68	65	68	62	60	63	
0915	"		340/1000	50	98	89	128	100	100	102	83	82	66	62	"	64	0.1
0925	"	5720	1020	50	102	98		108	105	105	102	95	68	62	"	68	0.14
0935	"	5930	1540	150	104	101		105	104	105	104	100	62	62	"	68	
0940	"	6095	2020	150	104	101		105	105	105	104	101	65	62	"	72	0.24
0945	"	6307	3000	150	106	105		107	106	106	106	106	66	61	"	76	0.35
0950	"	6447	4000	150	110	110		112	112	112	112	112	66	64	"	80	0.31
0955	"	6562	5000	150	116	114		116	116	116	115	115	68	64	"	85	0.4
1000	"				116	116		116	116	118	116	117	67	64	"	85	0.4
1000	"	6615	5500	150	118	118		120	119	120	119	119	68	63	"	88	0.4
1010	"	6680	6000	150	121	121		123	122	123	122	121	68	64	"	90	1.81
1020	"	6753	6500	150	122	122		124	124	125	124	-	66	64	"	95	2.81
1030	"	6825	7050	150	123	123		126	125	126	125		66	66	"	98	4.01

1 - Water in Manometer lines
results in question.

TEST DATA - SCRUBBER

APPENDIX 9A

BLACK POINT TEST CELL
SCRUBBER TEST PROGRAM

3/20/71

Ambient - 58°F

Time	No.	Engine Characteristics		Water Flow		EXIT		T E M P E R A T U R E ° F		River Water IN	Scrubber Water OUF	P In. H ₂ O Internal
		RPM	Thrust	Quench	Tower	GPM	GPM	at stack before entering scrubber	Scrubber on			
1125	J-79											
1135	"	6966	8000	500	6100	128	126	130	130	130	127	92
1150	"	7100	9300	300	6900	131	130	135	134	124	131	100
1200	"	7278	10240	300	6900	132	132	135	136	136	133	102
1207	"	7691	10780	500	6900	135	134	137	139	140	136	107
1350	"	7687	10880	Full	7400	133	128	130	133	132	130	103
1357	"	7688	10820	Front	7400	133	132	136	137	138	134	104
To Min AB												
1405	"	7698	13080	Both Ring & Venturi	7400	149	140	146	148	149	145	131
1410	"	6699	13140	"		153	154	156	156	158	154	136
1420	"	7696	14240	"	7400	160	146	151	154	156	152	144
To Max AB												
1530	"		16600	"	8100	162	144	152	156	150	160	168
1545	"	7700	16600	"		175	168	170	172	174	174	
1547	"							172	160			8.6 ¹

1 - Water in Manometer lines results in question.

TEST DATA - SCRUBBER

APPENDIX 9A

BLACK POINT TEST CELL
SCRUBBER TEST PROGRAM

4/16/71

T E M P E R A T U R E ° F

Time	Engine No.	Engine Characteristics		Water Flow		EXIT at stack before entering scrubber					Exit fm 2 locations on Scrubber		River Water		Scrubber Water		OUT-FAIR	P In. H ₂ O Internal	
		RPM	Thrust	Quench	Tower	17	18	19	20	21	22	23	0-1	0-2	IN	OUT			IN
1010	TF-30	740	560	100	8000	92	85	-	97	98	98	86	78	83	73	75	75		
1015	"	7110	6320	100	-	111	107	-	114	114	114	107	78	78	74	90	90		
1030	"	4780	8320	700	-	114	113	-	120	119	118	114	76	78	74	95	95		
1045	"	6940	11200	700	-	124	122	-	128	127	126	123	76	75	74	105	105	102	
1100	"	4720	8240	700	-	114	113	-	120	119	117	115	76	76	74	94	94	91	
1110	"	3640	6390	100	-	112	111	-	116	116	114	112	75	75	74	90	90	86	
1120	"	740	700	100	-	96	88	-	105	100	99	92	74	74	74	76	76	74	
J-79 Engine on 8 April 1971																			
1330	J-79-10	5043	200	100	8300	114	100	86	112	111	113	115	62	90	66	ND	ND		
1337	"	7029	7500	600	8300	116	106	95	120	117	118	117	67	72	64	"	"		
1343	"	7485	11300	600	8300	135	133	130	140	138	139	135	64	93	64	"	"		
1350	"	7184	13540	1100	8300	157	160	157	162	167	158	155	64	74	64	"	"		
1355	"	7483	17180	1100	8300	175	170	163	175	174	177	170	142	174	64	"	"		
1400	"	7231	9200	600	8300	130	135	118	150	147	146	147	64	68	-	"	"		
1410	"	6985	7300	600	8300	125	126	107	138	129	127	127							
1420	"	5050	200	100	8300	118	107	82	132	122	121	122	68	72	64	ND	ND		
1430	"	7490	11400	600	8300	135	136	122	147	142	140	138	68	72	64	"	"		
1510	"	7495	11360	600	8300	131	124	-	139	137	134	131	74	85	64	"	"		
1515	"	7495	11360	600	6000	134	134	-	145	141	139	137	82	104	64	"	"		
1517	"	7495	11360	600	5000	134	134	-	145	141	139	137	85	120	64	"	"		
1520	"	7495	11360	600	4000	134	134	-	145	141	139	137	82	104	64	"	"		
1523	"	7495	11360	600	3000	134	134	-	145	141	139	137	102	138	64	"	"		

APPENDIX 13A - 1 of 14

SOUND PREFERENCE LEVEL (SPL) STUDY DATA SHEET

AND HAS FAX 8240/7 (368)

LOCATION: BP-1 DATE: 12-30-70 TIME: 1030

NOISE SOURCE: AT MIL POWER SER NO: 1558-BP DATA BY:

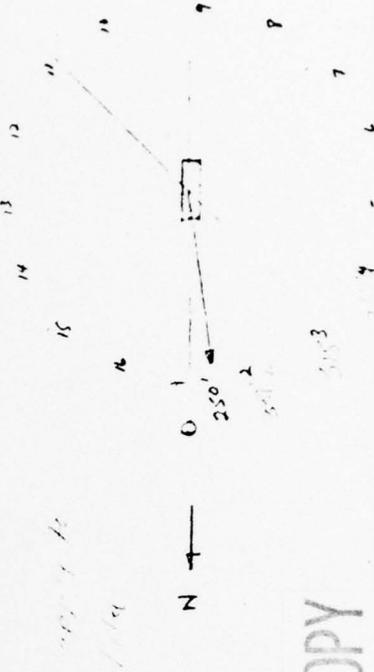
SOUND LEVEL METHOD: TF-30 664330 ULTRA BAND ANALYZER: 1558-BP MICROPHONE: 140E 1606PM

ULTRA BAND ANALYZER: 1560-PC

POSITION	db A "A" SCALE	OVERALL 20 HF - 20 KHF	FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)									
			31.5	63	125	250	500	1000	2000	4000	8000	16,000
1	84	104	96	101	98	89	82	75	70	65	60	<44
2	80	100	94	97	95	85	78	75	66	62	56	<44
3	76	97	91	94	89	79	71	70	59	51	46	<44
4	77	99	92	92	90	80	76	67	60	55	48	<44
5	73	96	90	93	82	74	73	66	58	57	52	<44
6	86	99	94	98	92	86	85	79	75	70	65	47
7	82	105	97	102	98	93	88	84	82	80	70	52
8	88	104	98	101	99	95	87	85	77	74	68	50
9	89	103	97	100	98	90	84	80	77	77	67	52
10	90	103	98	101	92	85	82	73	68	66	58	<44

REMARKS:

TEMP 48°F
 WIND VEIL 10K
 " D.R 010°
 REL Hum 8070



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APPENDIX 13A - Page 3 of 14

SOUND PIRE LEVEL (SPL) STUDY DATA SHEET
 (S-0 HAS JAX 6260/2 (3.68))

LOCATION: **NAVAIRESORRFAC JAX FLA BLACK POINT TEST CELLS (EAST CELL # 1)** DATE: **8 JULY 1970** TIME: **0845 - 1315**
 NOISE SOURCE: **J-79-8 ENGINE (Bu. No. 401649) in East Test Cell** DATA BY: **BYRD-MORRISON-ALLE**
 SOUND LEVEL METER: **GENERAL RADIO CO.** SER. NO. **OCTAVE BAND ANALYZER** SER. NO. **888** MICROPHONE: **CERAMIC**

POSITION	db A "A" SCALE	OVERALL 20 Hz - 20 KHz		OCTAVE BAND ANALYZER										SER. NO.	MICROPHONE	FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)	
		31.5	63	125	250	500	1000	2000	4000	8000	16,000						
1 Mil. Pwr.	84	95	97	95	87	79	75	73	69	65	51						
1 Afterburner	88	96	98	96	88	85	80	81	80	78	62						
2 Mil. Pwr.	83	92	92	92	87	78	74	73	69	67	505						
2 Afterburner	90	94	94	93	91	85	81	84	80	79	63						
3 Mil Pwr	77	91	88	87	80	71	69	64	60	55	44						
3 Afterburner	80	92	90	87	82	73	74	72	68	67	52						
4 Mil Pwr	76	89	87	85	75	71	72	67	62	60	45						
4 Afterburner	82	89	88	85	81	77	73	74	72	70	57						
5 Mil Pwr	73	86	89	81	71	70	68	64	58	56	44						
5 Afterburner	78	88	89	82	73	73	71	71	70	69	54						

REMARKS:

JUND PRE LEVEL (SPL) STUDY DATA SHEET
 SMO MAX JAX 6260/2 (3.68)

LOCATION: MAVAIRE-CORFAC JAX FLA BLACK POINT TEST CELLS (EAST CELL # 1) DATE: 8 JULY 1970 TIME: 0945 - 1315
 NOISE SOURCE: J-79-8 ENGINE (Bu. No. 401649) in Fast Test Cell DATA BY: HYRD-M. CRUISE-ALLEN
 SOUND LEVEL METER: GENERAL RADIO CO. SER. NO. OCTAVE BAND ANALYZER SER. NO. MICROPHONE: CERAMIC

POSITION	db A "A" SCALE	OVERALL 20 Hz - 20 KHz		FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)									
		31.5	63	125	250	500	1000	2000	4000	8000	16,000		
6 Mil Pwr	84	93	95	91	83	81	81	76	70	68	53		
6 Afterburner	92	95	95	91	86	88	83	83	82	83	69		
7 Mil Pwr	85	92	95	94	83	83	80	73	66	60	45		
7 Afterburner	88	96	96	94	84	83	82	79	75	74	59		
8 Mil Pwr	88	95	96	94	92	86	82	78	74	69	54		
8 Afterburner	94	98	98	94	94	90	85	86	86	85	71		
9 Mil Pwr	88	95	96	93	92	86	82	76	72	66	51		
9 Afterburner	94	100	98	94	94	90	86	87	84	83	69		
10 Mil Pwr	94	95	97	96	93	89	87	86	85	79	65		
10 Afterburner	98	100	98	96	95	93	92	92	91	88	73		

REMARKS:

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J-79-8 250'

SOUND LEVEL (SPL) STUDY DATA SHEET
 BND-NAS JA-6-4072 (3-68)

Continuation Data Sheet (2 of 3)

LOCATION: **NAVAIREWORKFAC JAX FLA BLACK POINT TEST CELLS (EAST CELL #1)** DATE: **8 JULY 1970** TIME: **0845 - 1315**

NOISE SOURCE: **J-79-8 ENGINE (Bu. No. 401649) in East Test Cell** DATA BY: **BYRD-MORRISON-AL**

SOUND LEVEL METER: SER NO: _____ MICROPHONE: _____

OCTAVE BAND ANALYZER: SER NO: _____

POSITION	db A "A" SCALE	OVERALL 20 Hz - 20 kHz	FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)									
			31.5	63	125	250	500	1000	2000	4000	8000	16,000
11 Mil. Pwr.	92	102	94	98	93	91	89	87	86	81	75	63
11 Afterburner	97	105	97	98	95	93	93	91	90	90	88	73
12 Mil. Pwr.	93	102	94	97	93	92	90	87	83	80	75	65
12 Afterburner	97	104	96	98	95	95	93	92	89	88	87	73
13 Mil. Pwr.	92	100	93	95	90	89	88	86	82	79	76	61
13 Afterburner	96	103	95	95	92	91	92	91	89	87	84	70
14 Mil. Pwr.	91	100	96	93	92	89	88	87	82	78	74	61
14 Afterburner	94	103	97	94	93	92	90	91	89	86	86	71
15 Mil. Pwr.	89	101	96	94	95	91	86	84	80	79	73	58
15 Afterburner	94	103	98	96	96	94	90	88	86	84	82	69

REMARKS:

16 Mil. Pwr. 84 100 94 95 92 88 82 78 73 70 66 50
 16 Afterburner 89 102 97 95 93 89 83 79 77 74 69 55

All SPL measurements at 250 feet distance from center of test cell at 22 1/2 increments. (Sheets 1, 2 & 3)
 Acoustic calibration done immediately before and after measurements (G.R. Transistor Oscillator & Sound Level Calibrator
 Positions 3, 4, 5 and 6 are partially shielded by other structures.
 Temperature: 82 - 92 Wind: 2 - 8 knots (generally at the lower velocity) direction 230° - 190°.

Roland E. Byrd
 ROLAND E. BYRD
 INDUSTRIAL HYGIENIST

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J-79-8, 250

JND PR
JND N'S JAX (3.68)

LOCATION: NAVARENEONTAC JAX FIA BLACK POINT TEST CELLS (EAST CELL # 1)
 NOISE SOURCE: J-79-8 ENGINE (Cu. No. 401619) in East Test Cell
 SOUND LEVEL METER: GENERAL RADIO CO. SER. NO. 315
 OCTAVE BAND ANALYZER: BAND NOISE ANALYZER
 SER. NO. 888
 MICROPHONE: CERAMIC
 DATE: 8 JULY 1970
 TIME: 0745 - 1315
 DATA BY: BYRON MORRISON-ALLEN

POSITION	db A "A" SCALE	FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)										
		OVERALL 20 Hz - 20 KHz	31.5	63	125	250	500	1000	2000	4000	8000	16,000
1 Mil Fw	88	106	102	100	99	90	84	83	82	75	70	56
1 Afterburner	94	106	102	101	99	91	88	87	87	84	84	72
2 Mil Fw	87	104	98	96	99	91	83	82	78	73	70	58
2 Afterburner	93	105	100	98	98	92	85	85	87	84	84	72
7 Mil Fw	94	106	102	102	96	89	91	88	84	80	78	63
7 Afterburner	100	110	104	103	99	93	96	93	93	91	93	80
8 Mil Fw	96	108	103	105	101	93	94	91	86	85	78	63
8 Afterburner	101	112	107	107	102	95	97	95	94	94	93	81
*9 Mil Fw	93	107	103	104	98	91	91	88	83	78	73	60
*9 Afterburner	100	113	109	108	101	94	95	93	93	91	91	79

REMARKS:
 SPL measurements on this data sheet at 125 feet distance from center of test cell at 2210 increments, except
 *9 Position at sea-wall approximately 100 feet from center of the test cell.

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J-79-8 . 1256

APPENDIX 13A - Page 7 of 14

JND: PRES LEVEL (SPL) STUDY DATA SHEET

JND N 15 JAN 62 Rev. 4 (13-68)

SOUND LEVEL METER	POSITION	db A "A" SCALE	OVERALL 20 Hz - 20 KHz	OCTAVE BAND ANALYZER								SER. NO.	MICROPHONE	DATE	TIME	DATA BY
				31.5	63	125	250	500	1000	2000	4000					
14	Mil Pwr	91	105	102	98	93	90	88	86	84	81	80	80	62		
14	Afterburner	97	107	104	99	99	93	90	91	90	89	89	89	77		
15	Mil Pwr	90	105	100	99	99	91	87	85	81	77	75	75	60		
15	Afterburner	94	106	103	100	99	94	89	89	87	86	85	85	72		
16	Mil Pwr	90	106	102	100	99	93	85	84	82	78	74	74	60		
16	Afterburner	95	107	103	101	99	95	89	89	88	87	86	86	73		

REMARKS:

SPL measurements on this data sheet at 125 feet distance from center of test cell at 22nd increments. Acoustic calibration done immediately before and after meas. (G.R. Transistor Oscillator & Sound Level Calibrator) Temperature: 82° - 89° F. Wind: 2 - 8 knots (generally at lower velocity) direction: 230° - 190°.

Roland E. Byrd

ROLAND E. BYRD
INDUSTRIAL HYGIENIST

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To: Codo 612

NAVAL AIR WORK FACILITY, NAS JACKSONVILLE, FLORIDA (BAC) T. AREA)		DATE	TIME								
J-79-10 JET ENGINE in TEST CELL (EAST) AT BLACK PT. (WITH POLLUTION ABATEMENT SYSTEM IN OPER.)		8 APRIL 1971	1300 - 1500								
GENERAL RADIO CO. TYPE 1558-FF OCTAVE BAND NOISE ANALYZER		SER. NO. 888	DATA BY R. E. BYRD								
OCTAVE BAND ANALYZER		MICROPHONE 1560-B6 (CERAMIC)									
POSITION	dB A "A" SCALE	FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)									
	Overall 20 Hz - 20 kHz	31.5	63	125	250	500	1000	2000	4000	8000	16,000
1 (West Cell) at 75 ft. @ 02210	94	88	88	84	84	82	80	80	76	65	46
OTHER MEASUREMENTS LISTED BELOW: J-79 at MILITARY POWER OR MILITARY POWER WITH AFTER-BURNER (EAST CELL)											
Pwr. ft. @ 02210	86	87	95	94	89	85	78	76	68	57	< 44
Pwr. ft. @ 0000	81	86	91	88	83	81	72	66	59	45	< 44
Pwr. ft. @ 33710	76	84	88	85	78	75	69	64	57	< 44	< 44
Pwr. ft. @ 3150	76	81	86	85	85	79	71	61	54	< 44	< 44
rburner ft. @ 28710	81	84	91	90	86	84	79	67	56	< 44	< 44
rburner ft. @ 1800	99	101	106	103	102	97	92	90	84	76	60

Distance measurements are from center of East Test Cell

Wind: Direction: 0400 to 0200 Velocity: 3 - 5 knots Time Period: 1400 - 1500

Analyzer calibration immediately before and after SPL measurements with G. R. Co. Sound Level Calibrator Type 1552-B and Transistor Oscillator Type 1307-A.

Roland E. Byrd
ROLAND E. BYRD

APPENDIX 13A - Page 9 of 14

SOUND PRESSURE LEVEL (SPL) STUDY DATA SHEET
 AND HAS JAX 82602-1388

LOCATION: BLACK POINT - 1 DATE: 1-4-71 TIME: 0930
 NOISE SOURCE: J-79 MAY A/B DATA BY: MOYER
 SOUND LEVEL METER: 1558-AP (GR) MICROPHONE: 1560-P6 SFR NO: 1525 ALLIEN

POSITION	db A "A" SCALE	OVERALL 20 Hz - 20 kHz	FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)									
			315	63	125	250	500	1000	2000	4000	8000	16,000
1	95	108	99	102	103	96	88	87	85	79	75	61
2	93	108	100	102	103	98	85	87	83	80	73	58
3	86	103	96	98	99	90	81	81	75	70	64	54
4	86	103	93	97	96	86	83	80	71	68	67	50
5	80	100	92	98	90	82	79	75	68	66	64	49
6	93	106	96	100	99	94	92	89	83	78	75	66
7	84	106	100	102	98	88	83	76	70	64	58	44
8	94	108	101	102	106	99	91	89	85	81	74	59
9	94	108	101	101	104	98	92	92	85	80	73	59
10	95	108	100	103	104	98	92	90	85	83	76	59

ALL MEASUREMENTS MADE AT 250 FT FROM CENTER OF TEST CELL AT 2 1/2" INCREMENTS
 TEMP 61.0 F
 WIND 140° - 4K

ANALYZER CALIBRATED BEFORE AND AFTER MEASUREMENTS TAKEN.

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PRE-LEVEL (SPL) STUDY DATA SHEET
 HAS JAN 62/02 (3.88)

LOCATION: Black Point - 1 DATE: 1-4-71 TIME: 0930
 NOISE SOURCE: 4-79 MAX A/B DATA BY: MCYE ALLEN

SOUND LEVEL METER: 1558-BP (68) SER NO: 1525 MICRPHONE: 1560-PC

POSITION	db A "A" SCALE	OVERALL 20 Hz - 20 kHz	FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)									
			31.5	63	125	250	500	1000	2000	4000	8000	16,000
11	95	107	98	103	103	98	95	88	83	80	74	59
12	93	107	98	104	100	98	94	87	83	80	76	58
13	93	109	97	105	102	96	92	85	83	80	76	59
14	95	109	99	105	100	96	92	85	84	78	75	52
15	96	109	101	103	104	96	92	90	86	82	78	61
16	90	107	100	101	102	93	87	82	81	79	71	54

REMARKS:

SOUND PRESSURE LEVEL (SPL) STUDY DATA SHEET
 AND NAS 14X 610072 (3-68)

LOCATION: **BLACK POINT 1** DATE: **1-23-71** TIME: **1300**
 NOISE SOURCE: **J-52-88 CBC** DATA BY: **ALLEN**
 SOUND LEVEL METER: **1558-BP** MICROPHONE: **Ketelkowske**
 SER. NO: **1525** 1560 - PG

POSITION	4B A "A" SCALE	OVERALL 20 Hz - 20 kHz	OCTAVE BAND ANALYZER										FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)			
			31.5	63	125	250	500	1000	2000	4000	8000	16,000	2000	4000	8000	16,000
1	84	94	90	91	89	85	78	83	74	68	59	<44				
2	82	94	86	88	88	82	75	78	73	64	58	<44				
3	74 75	90 88	83 82	84 83	84 81	77 74	69 69	71-74 71	66 65	57 54	51 50	<44				
4	69	85	80	83	76	71	68	65	59	53	45	<44				
5	80	92	83	87	83	79	77	75	73	66	60	<44				
6	74	92	85	89	84	72	70	68	64	58	55	<44				
7	73	93	88	89	85	75	69	63	59	50	46	<44				
8	88	94	89	90	89	83	80	76	70	63	57	<44				
9	82	94	87	89	86	82	79	77	75	68	58	<44				

REMARKS: ALL SPL MEASUREMENTS AT 250 FT FROM CENTER OF TEST CELL AT 2 1/2° INCREMENTS. POSITIONS 11-16 CONT. ON SHEET 2. CALIBRATION OF ANALYZER CHECKED BEFORE AND AFTER MEASUREMENTS. TEMP. 75°F RH. D.P. 56% WIND: 200° 12K BAR 30.02 CLEAR SKIES

14 13 12 11 N A
 15 16 10 9 8 7 6 5 4 3 2 1 ← 260°

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NOISE LEVEL (SPL) STUDY DATA SHEET

FORM 6200/2 3-68

LOCATION: BLACK POINT 1 DATE: 1-23-71 TIME: 1300
 NOISE SOURCE: D-52-FA CAB DATA BY: ALLEN
 SOUND LEVEL METER: 442064511 SER. NO. MULTIPHONAL

POSITION	dB A "A" SCALE	OVERALL 20 Hz - 20 kHz	OCTAVE BAND ANALYZER								FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)			
			31.5	63	125	250	500	1000	2000	4000	8000	16,000		
11	87	94	86	89	90	81	82	79	79	73	63	<44		
12	81	94	85	91	87	80	84	78	75	71	62	<44		
13	86	96	87	94	89	80	86	79	78	72	63	<44		
14	85	96	89	91	86	80	82	78	73	67	58	<44		
15	84	96	90	91	89	80	82	79	74	64	54	<44		
16	84	97	90	93	93	82	82	78	78	73	64	45		
TOP OF EXHAUST														
STACK LEVEL WITH														
3' FROM EDGE	108	120	112	118	113	108	110	104	100	94	90	77		

REMARKS:

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SOUND PR RE LEVEL (SPL) STUDY DATA SHEET
 AND NAS JAS 8-02 (3-68)

LOCAL NO. NAVAL AIR REMORK FACILITY, NAS JACKSONVILLE, FLORIDA (BLACK FT. AREA) DATE 16 APRIL 1971 TIME 1035 - 1055
 NOISE SOURCE TF-30 JET ENGINE (PRODUCTION) in TEST CELL (EAST) AT BLACK FT. (POLLUTION ABATEMENT SYSTEM IN) R. E. BYRD DATA BY

POSITION	db A "A" SCALE	OVERALL 20 Hz - 20 kHz	FREQUENCY ANALYSIS BY OCTAVE BAND CENTER FREQUENCIES (Hz)									
			OCTAVE BAND ANALYZER					MICROPHONE				
			31.5	63	125	250	500	1000	2000	4000	8000	16,000
100 ft. @ 180°	90.8	105	98	103	98	95	89	81	78	73	66	51
125 ft. @ 022½°	85	98	86	95	93	87	84	78	73	69	63	48
250 ft. @ 0°	79.2	93.2	83.6	89.6	87.8	84.9	78.2	69.5	64.7	60.6	53.6	< 44
250 ft. @ 337½°	76.8	90.7	82.4	87.6	84.5	77	74	70	63	59	49	< 44
250 ft. @ 315°	76	89	79	85	85	77	74	72	62	52	45	< 44
250 ft. @ 287½°	81.9	90	81	85	84	79	79	78	65	53	45	< 44
	77.8	90.5	81.2	86.7	85.0	78.5	76.3	72.3	63.5	56	45.5	< 44

REMARKS: Distance measurements are from center of test cell.
 All SPL measurements made with engine at military power setting.

Wind direction: 120° Velocity: 7 knots

Noise Analyzer calibrated immediately before and after SPL measurements with G. R. Co. Sound Level Calibrator Type 1552-B and Transistor Oscillator Type 1307-A

Roland E. Byrd
 ROLAND E. BYRD

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LOCATION: NAVAIREWORKFAC JAX FLA BLACK POINT TEST CELLS (EAST CELL #1) DATE: 15 JULY 1970 TIME: 0900 - 1000
 NOISE SOURCE: TF - 30 ENGINE (Bu. No. 664252) in East Test Cell at MILITARY POWER SER. NO. 888 DATA BY: BYRD-MORRISON-ALLEN

POSITION	OCTAVE BAND NOISE ANALYZER										MICROPHONE	
	SER. NO. 315					SER. NO. 888						
	db A "A" SCALE	20 Hz - 20 KHz	OVERALL	63	125	250	500	1000	2000	4000		8000
1	84	103	99	97	95	84	80	78	76	73	73	60
2	83	101	96	94	93	85	76	76	75	73	74	63
7	90	103	98	99	93	84	87	84	84	82	82	70
8	94	105	100	100	98	88	89	88	86	86	83	72
9* (at 100')	91	105	101	102	94	89	87	86	82	80	79	67
13	92	103	100	98	93	86	85	86	86	85	84	72
14	89	103	99	94	93	86	83	83	83	82	80	69
15	87	101	98	94	94	86	82	81	79	77	76	63
16	88	102	98	97	94	92	82	82	79	78	76	63

REMARKS: All SPL measurements at 125 feet distance from center of test cell at 22 1/2° increments (except #9 at 100 ft.)
 Acoustic calibration done immediately before & after meas. (G.R. Transistor Oscillator & Sound Level Calibrator)

Temperature: 78° F to 84° F R.H.: 71% - 66% Wind: 230° - 260° 6 - 8 knots Clear skies
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To: Cocks 6/2