NASA/CP—2000-210524

Separate Flow Nozzle Test Status Meeting

December 2000

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NASA/CP—2000-210524

Separate Flow Nozzle Test Status Meeting

Proceedings of a conference held at and sponsored by
NASA Glenn Research Center
Cleveland, Ohio
September 9–10, 1997

National Aeronautics and
Space Administration

Glenn Research Center

December 2000

Note that at the time of research, the NASA Lewis Research Center
was undergoing a name change to the
NASA John H. Glenn Research Center at Lewis Field.
Both names may appear in this report.

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PREFACE

In 1995, NASA GRC initiated efforts to meet the US industry's rising need to develop jet noise technology for separate flow nozzle exhaust systems. Such technology would be applicable to long-range aircraft using medium to high by-pass ratio engines. With support from the Advanced Subsonic Technology Noise Reduction program, these efforts resulted in the formulation of an experimental study, the Separate Flow Nozzle Test (SFNT). SFNT's objectives were to develop a data base on various by-pass ratio nozzles, screen quietest configurations and acquire pertinent data for predicting the plume behavior and ultimately its corresponding jet noise. The SFNT was a team effort between NASA GRC's various divisions, NASA Langley, General Electric, Pratt&Whitney, United Technologies Research Corporation, Allison Engine Company, Boeing, ASE FluiDyne, MicroCraft, Eagle Aeronautics and Combustion Research and Flow Technology Incorporated.

SFNT found several exhaust systems providing over 2.5 EPNdB reduction at take-off with less than 0.5% thrust loss at cruise with simulated flight speed of 0.8 Mach. Please see the following SFNT related reports: Saiyed, et al. (NASA/TM—2000-209948), Saiyed, et al. (NASA/CP—2000-210524), Low, et al. (NASA/CR—2000-210040), Janardan et al. (NASA/CR—2000-210039), Bobbitt, et al. (NASA/CR—201-210706) and Kenzakowski et al. (NASA/CR—2001-210611.).

I wish to thank the entire SFNT team of nearly 50 scientists, engineers, technicians and programmers involved in this project. SFNT would have fallen well short of its goals without their untiring support, dedication to developing the jet noise technology.

Naseem Saiyed
SFNT Research Engineer

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September 10, 1997
NASA Lewis Bldg 86 Rm 100

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	Break	10:15
PW	PW noise reduction concept results Phased array results	10:30
	Lunch	12:00
GE	GE noise reduction concept results	1:00
LeRC	Diagnostic Measurements	2:30
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LeRC	Outstanding issues and schedule	3:15
LaRC	LaRC Separate Flow Testing Status	3:30
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All	Open Discussion	4:15
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Advanced Subsonic Technology

Separate Flow Nozzle Tests for

Engine Noise Reduction sub-element

Presented to AST Participants

September 10, 1997

Naseem H. Saiyed
NASA Lewis Research Center
Cleveland, Ohio

Baseline Configurations for all models

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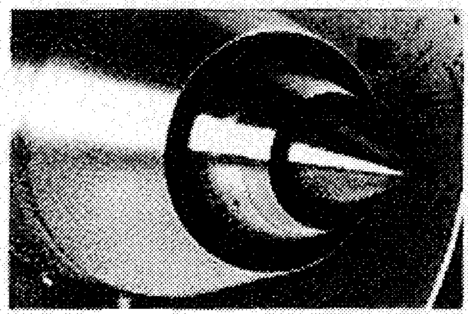

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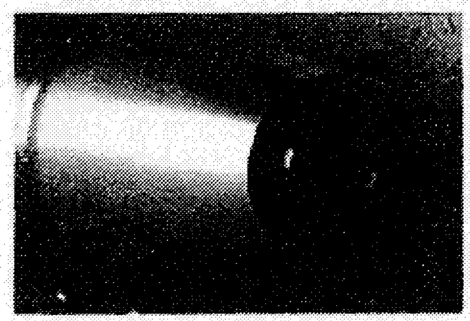

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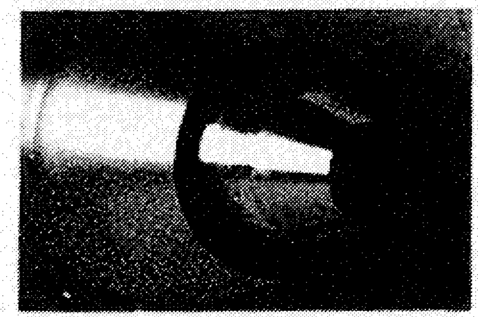

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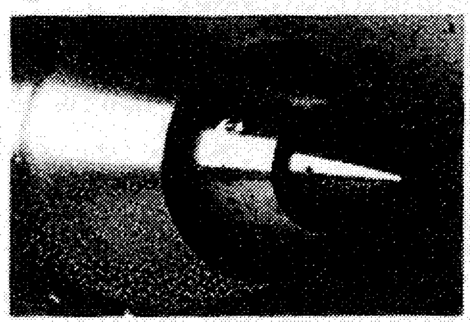

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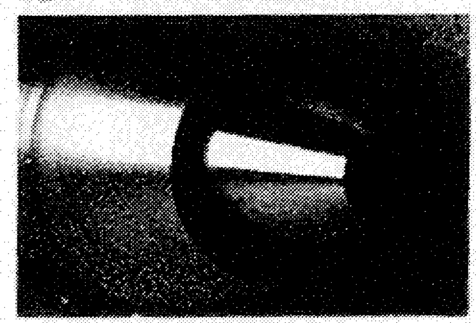

Baseline Cofigurations for all models

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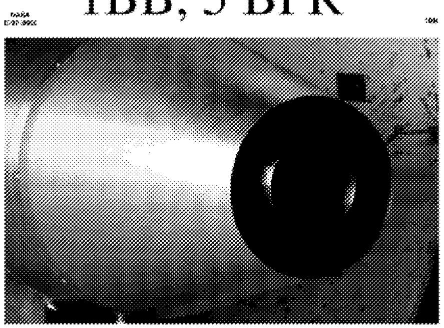

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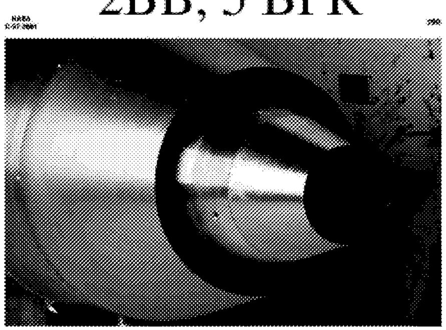

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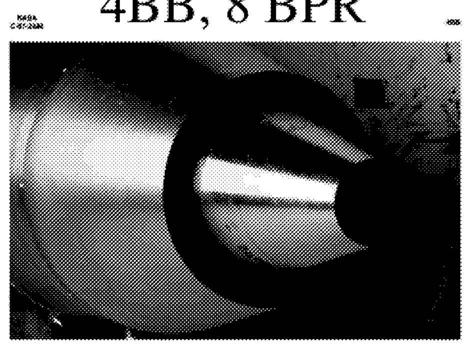

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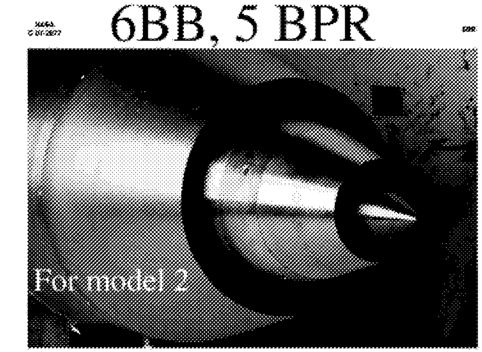

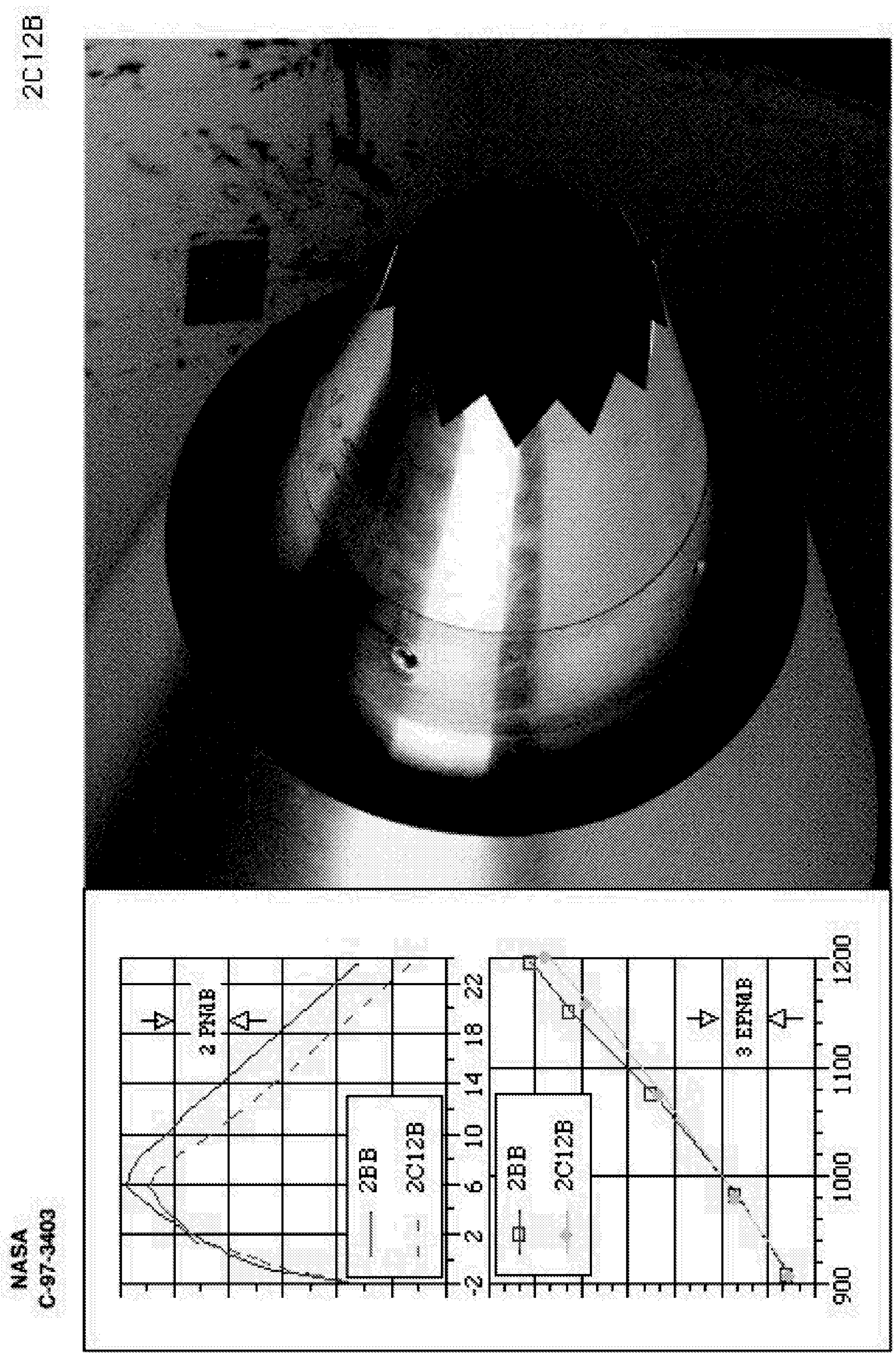
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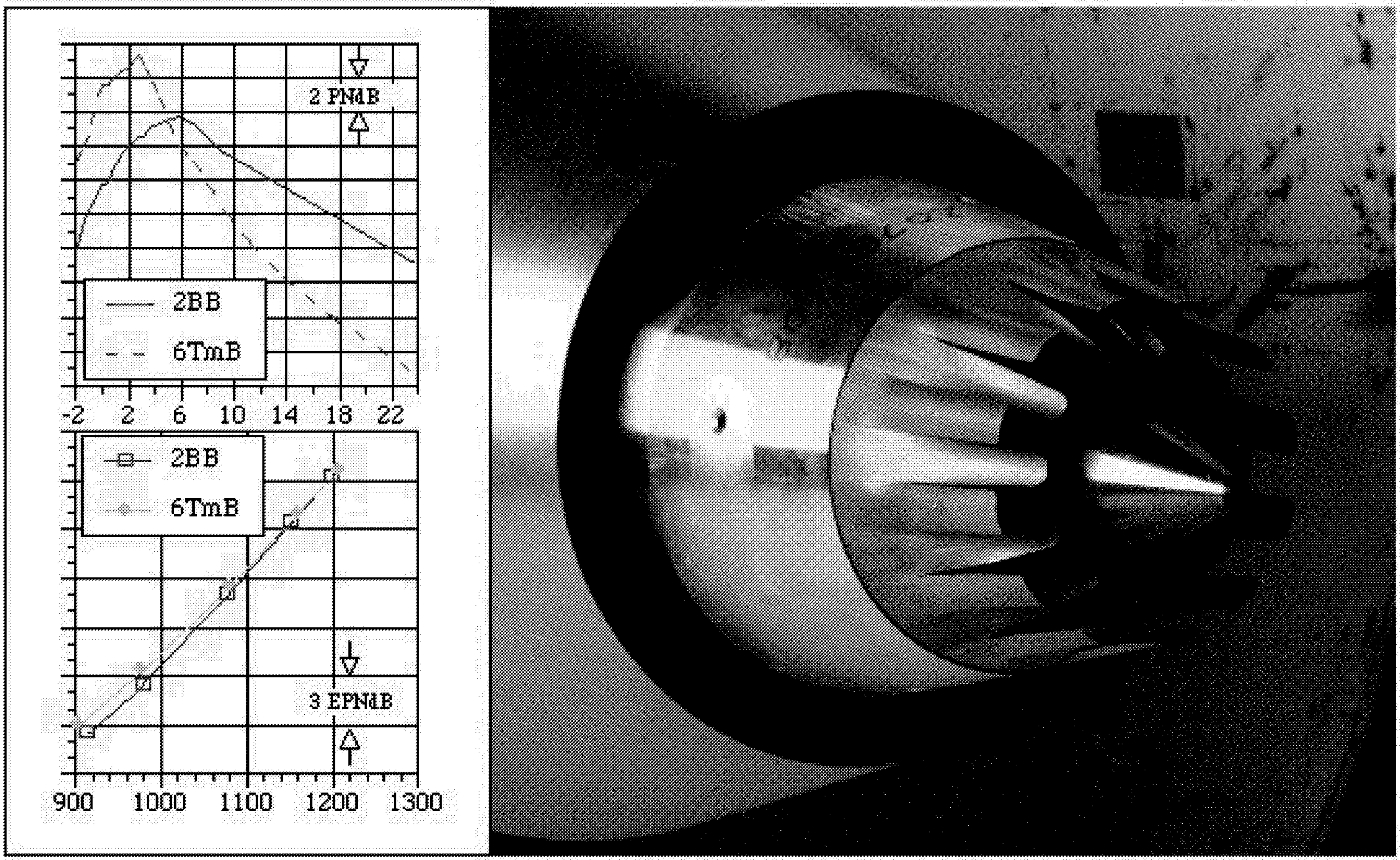

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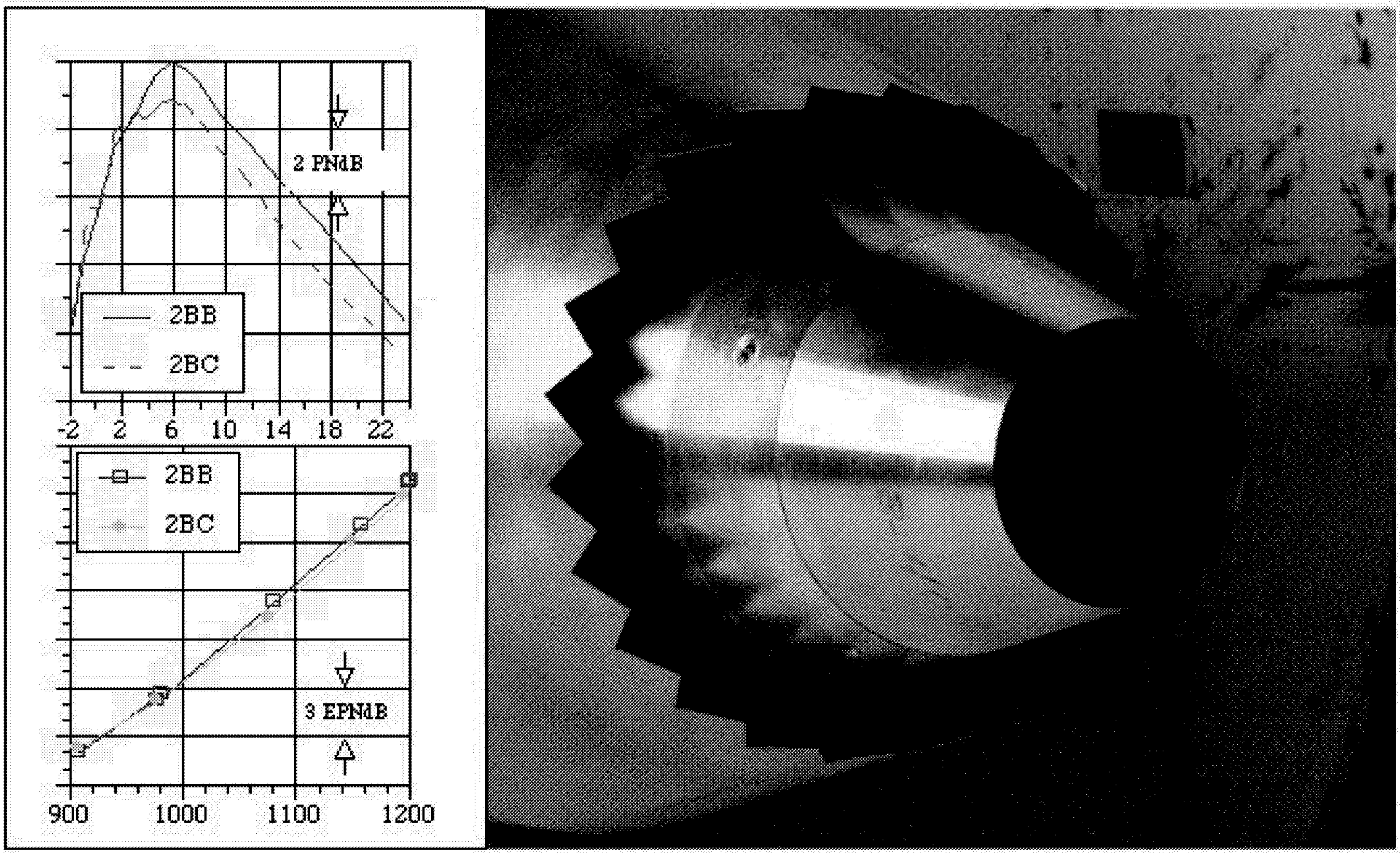

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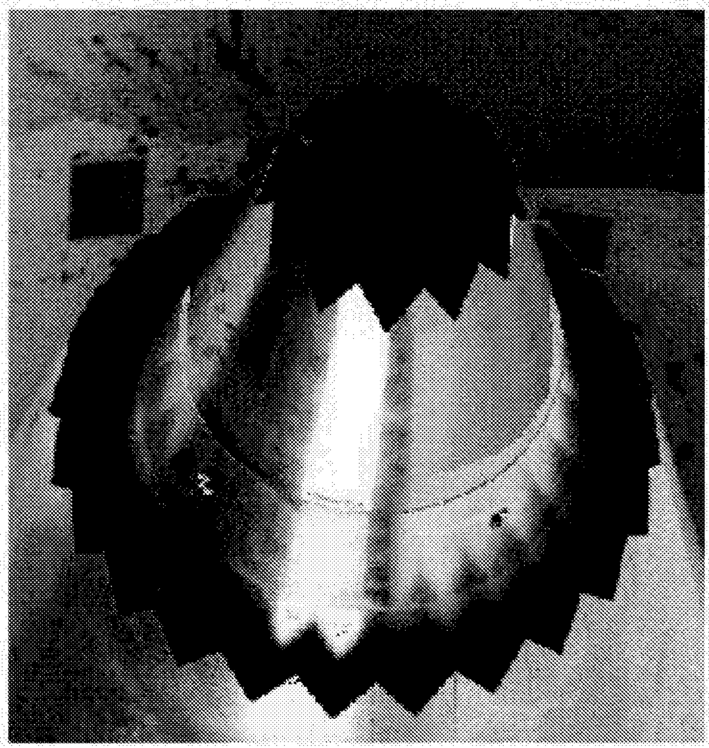

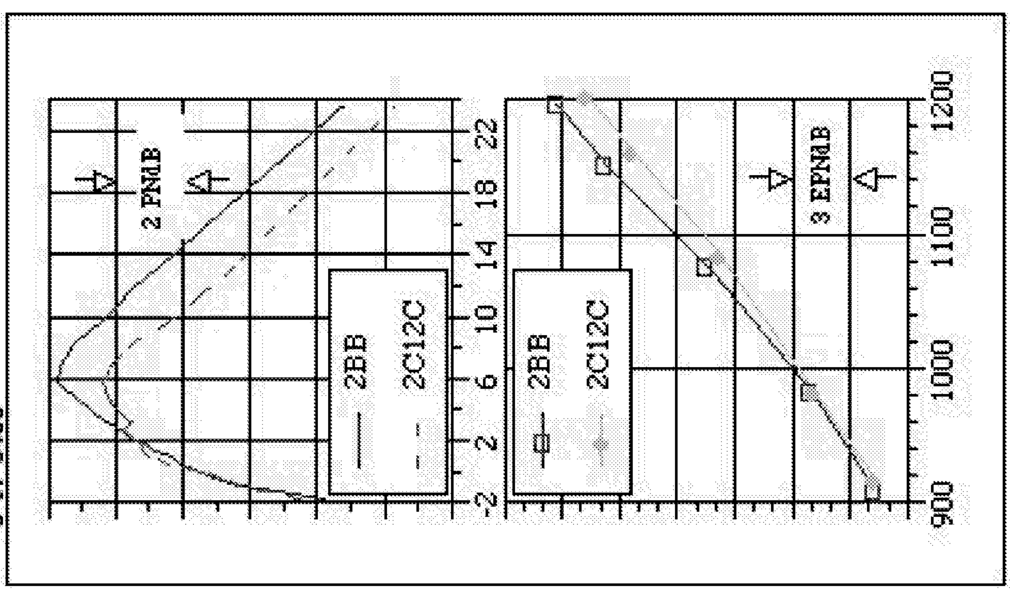
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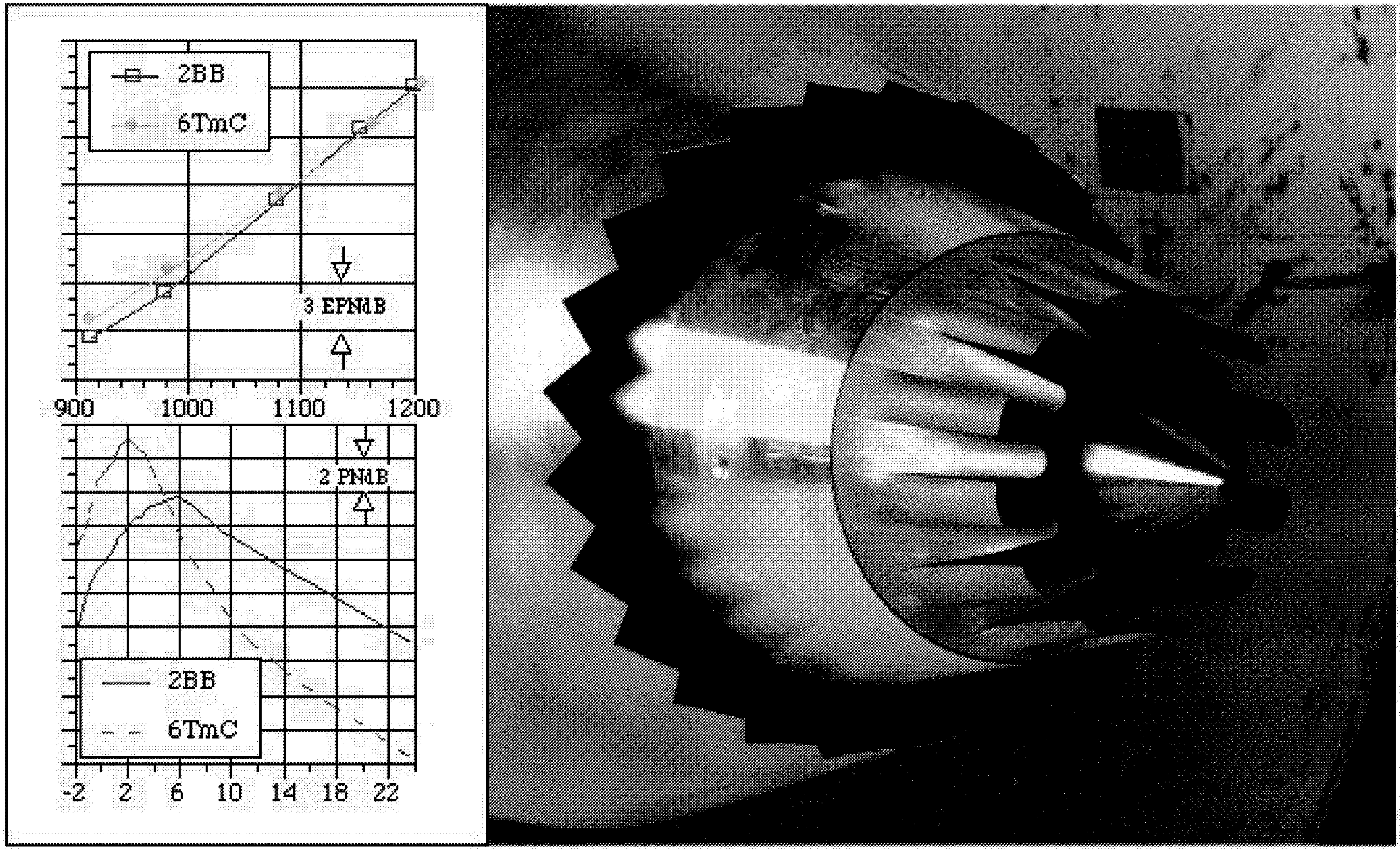

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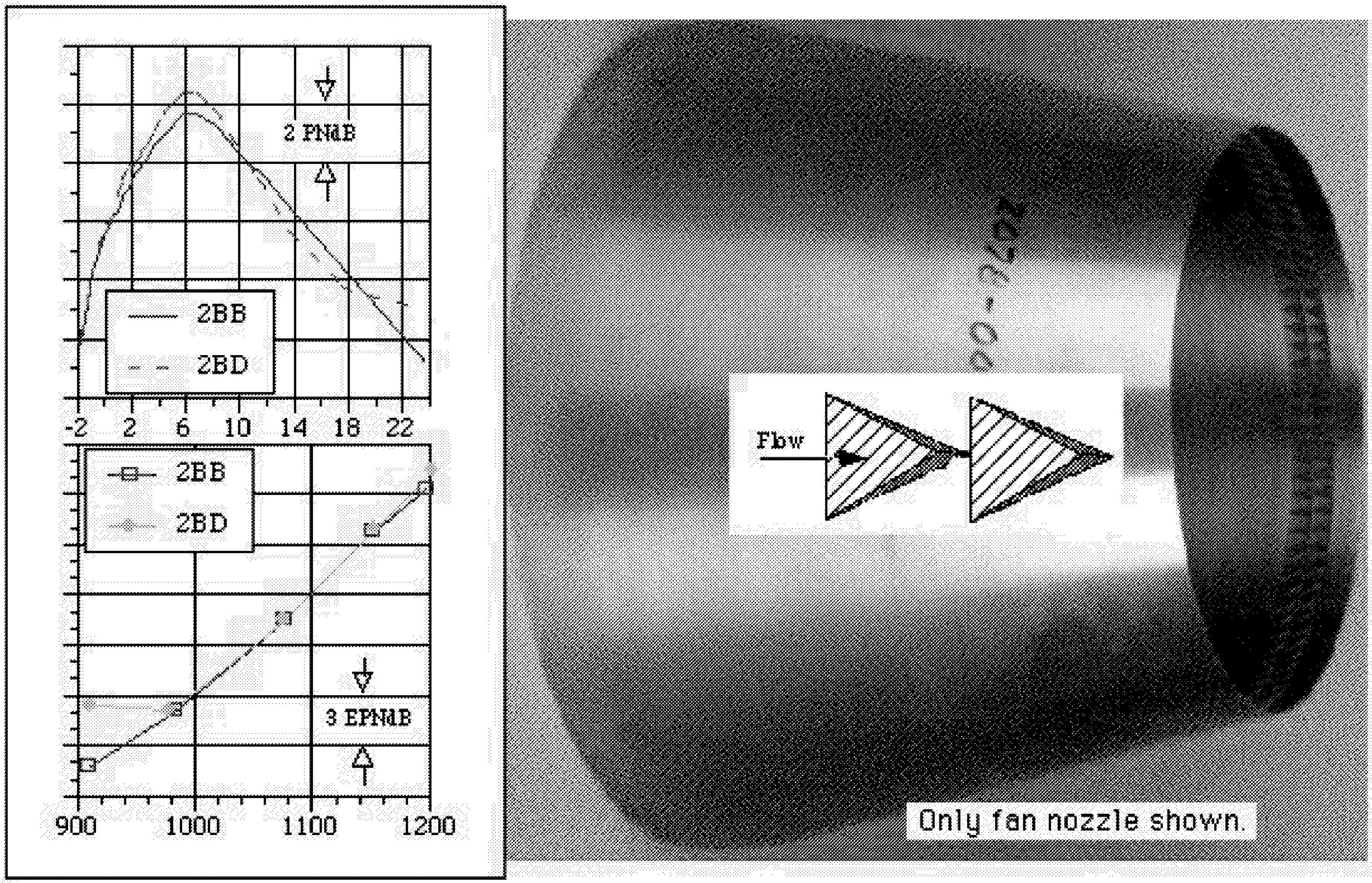

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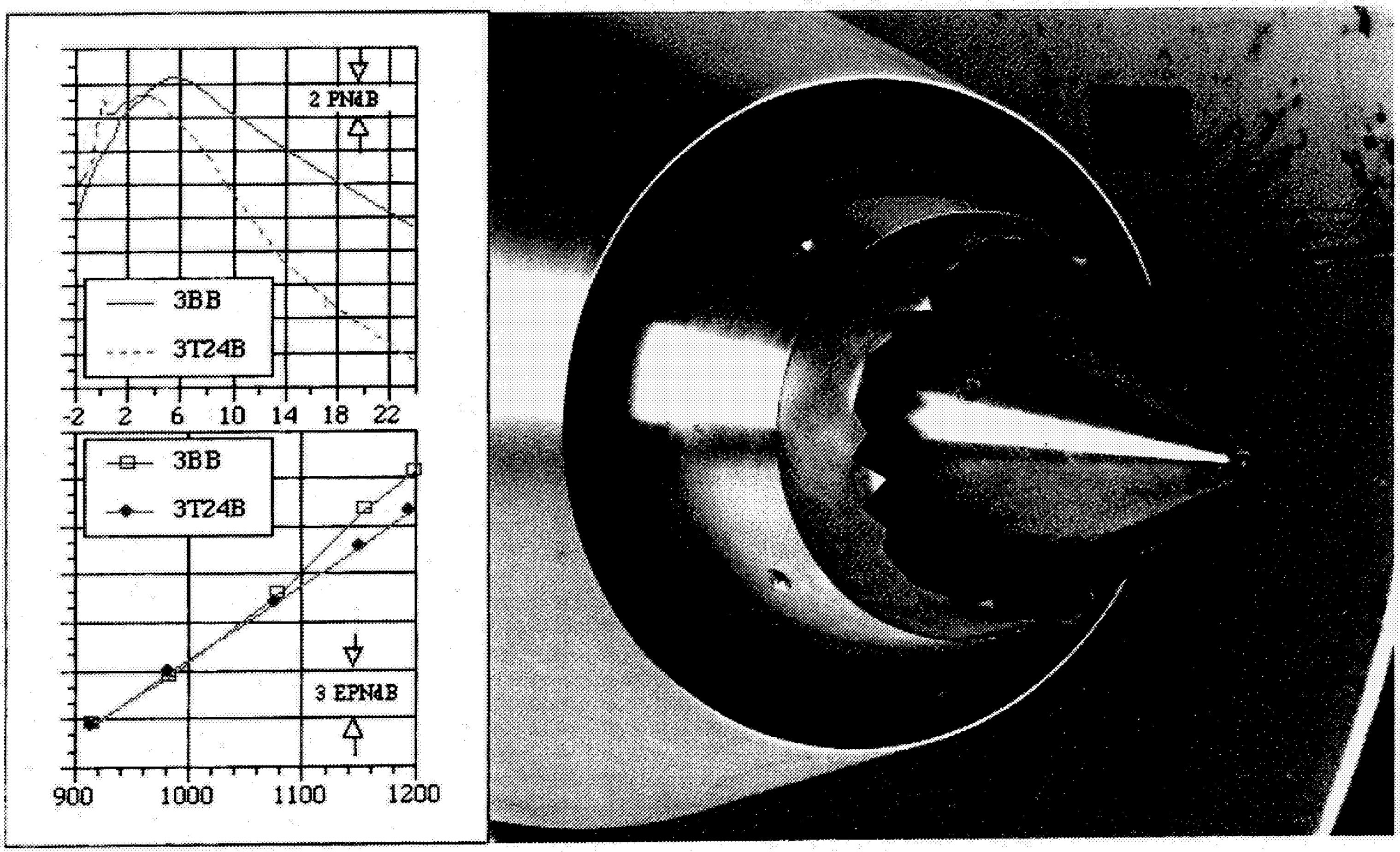

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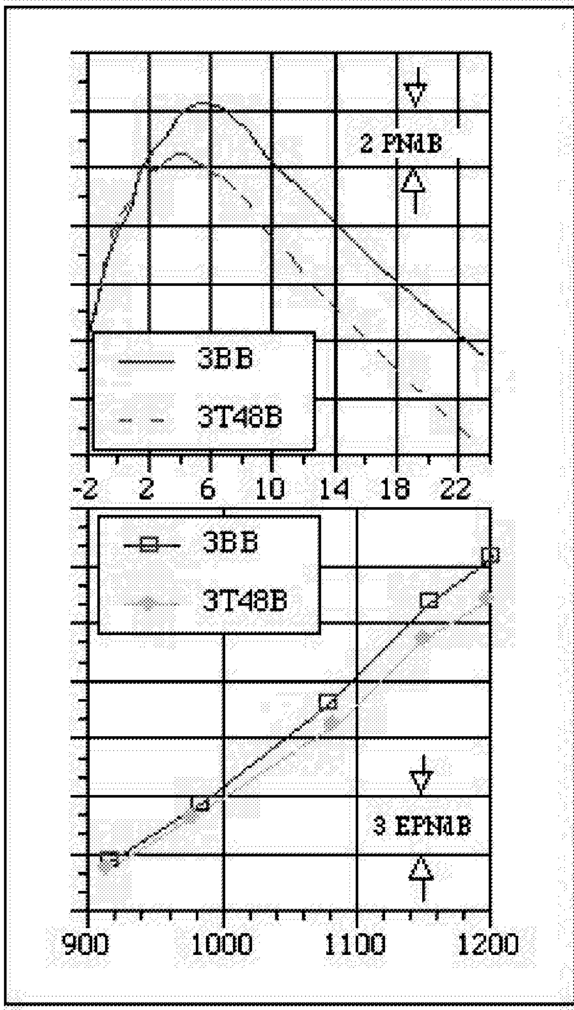

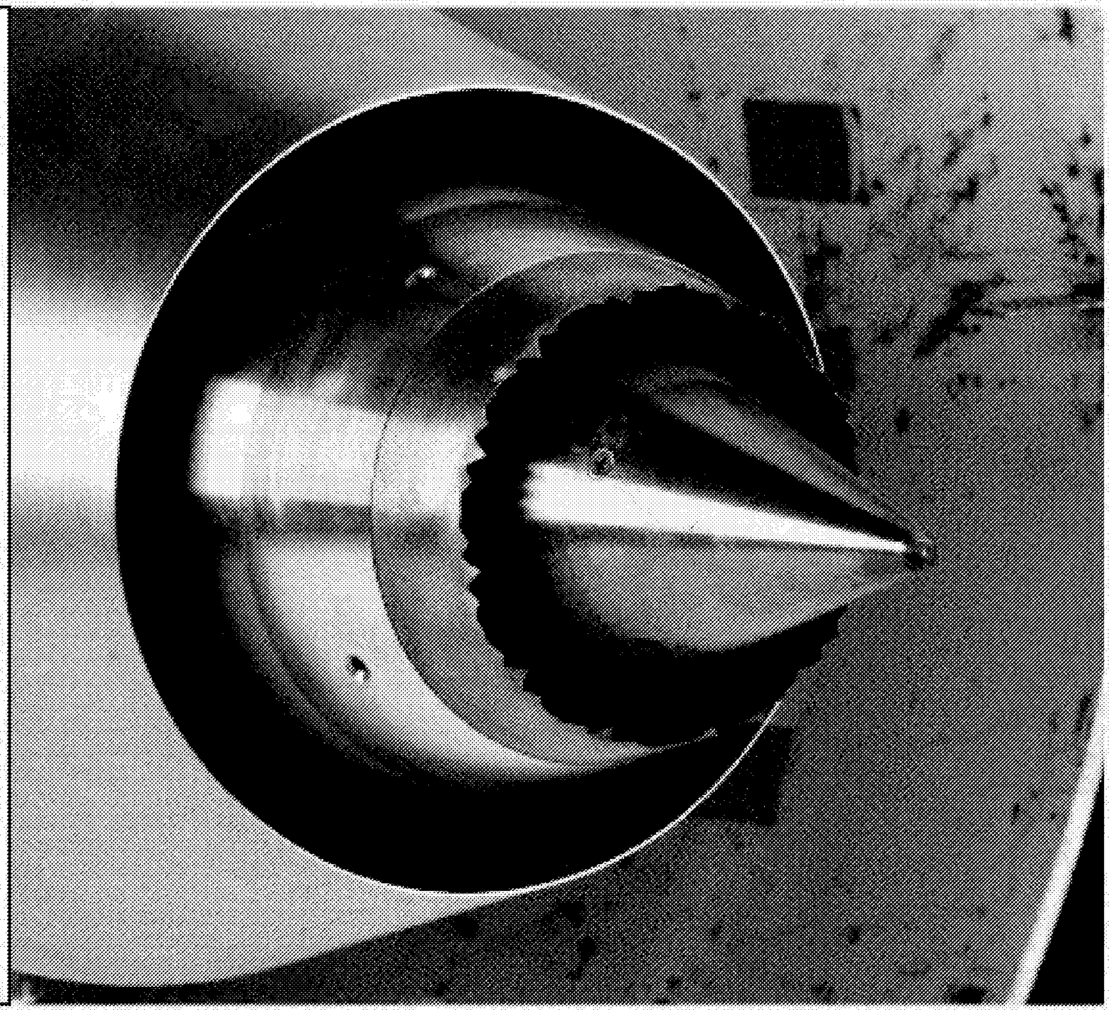

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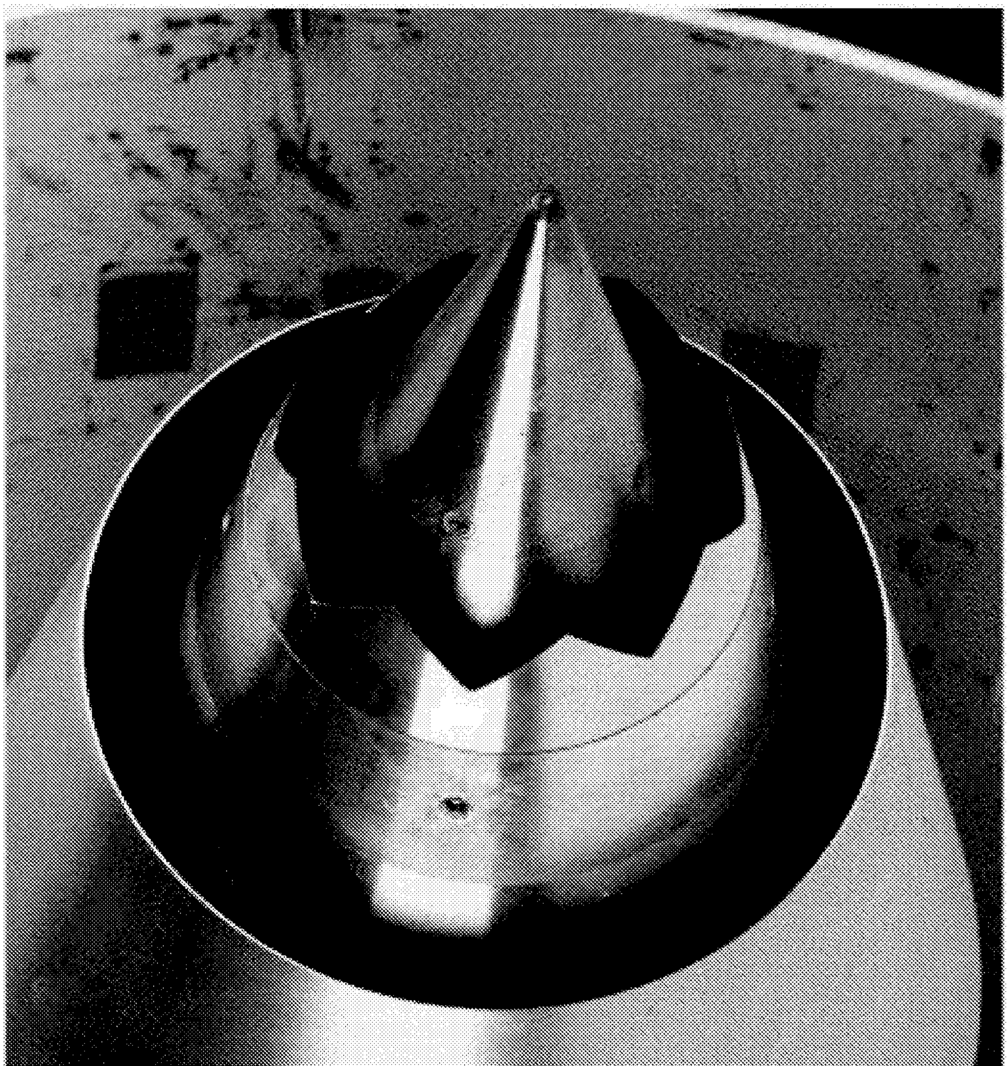

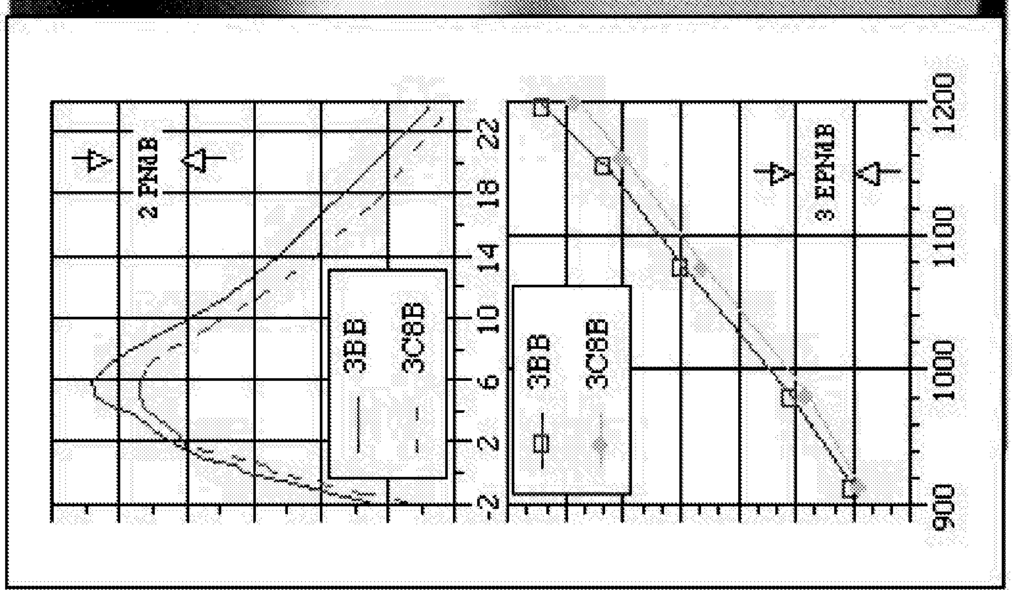

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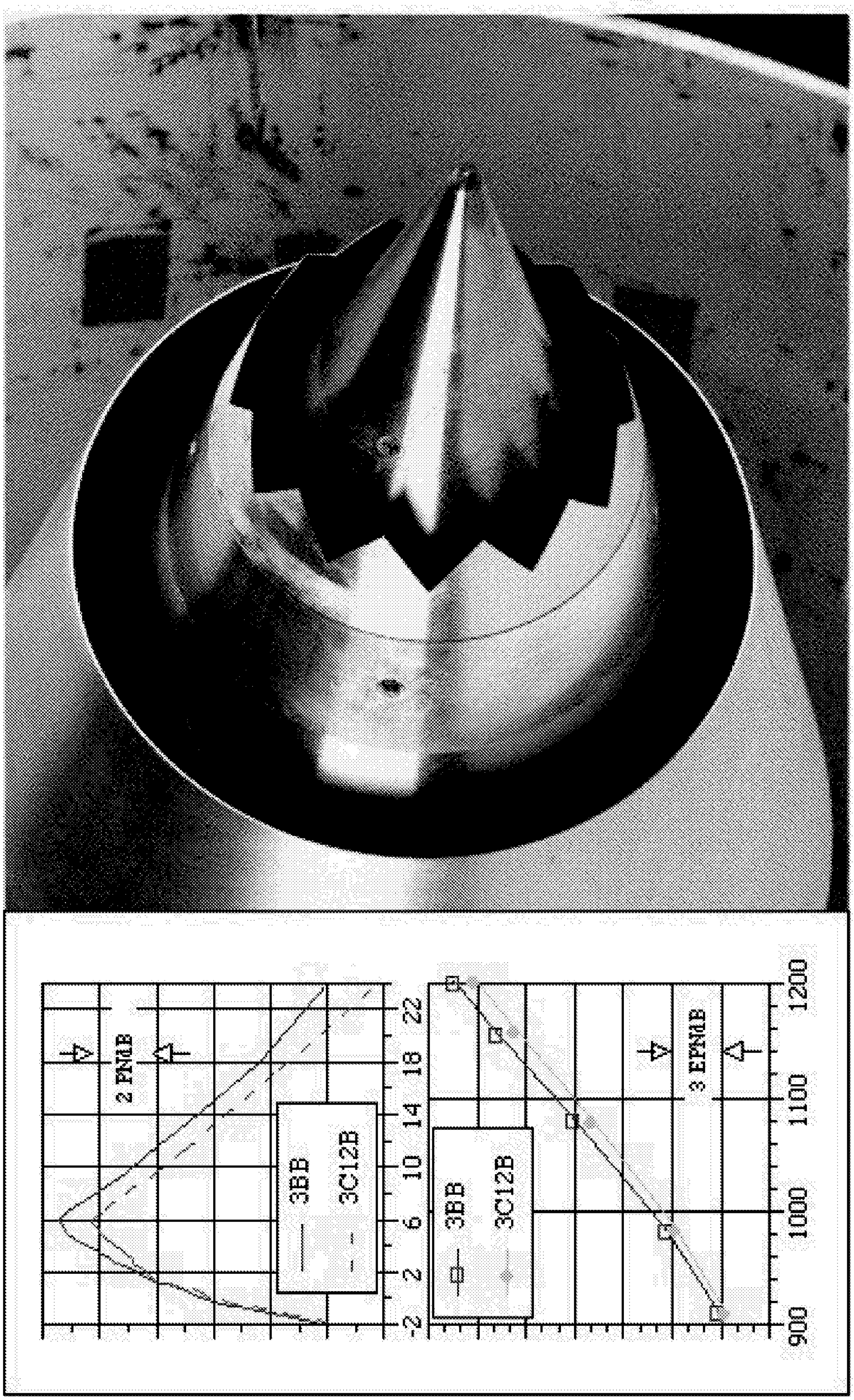

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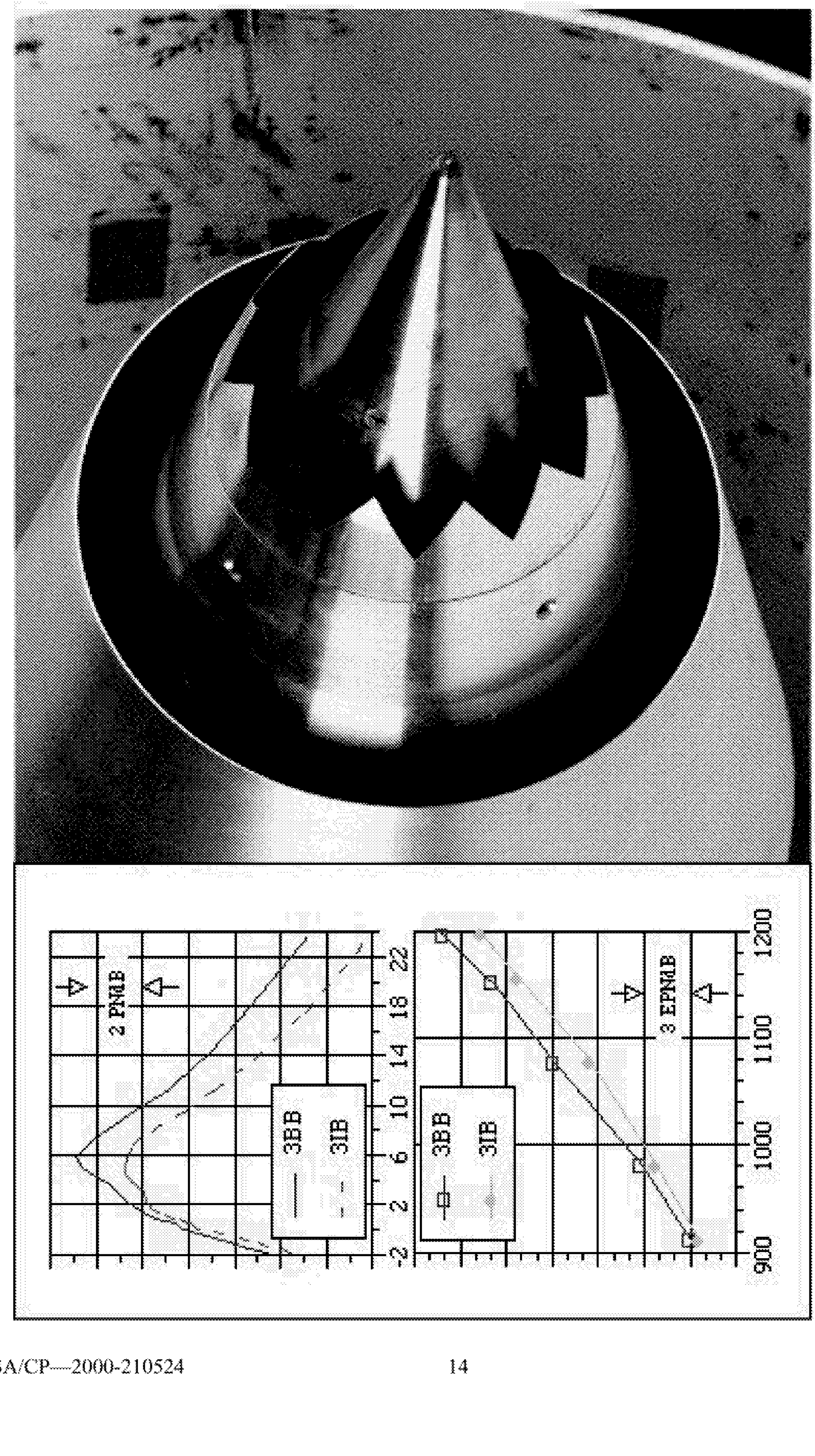

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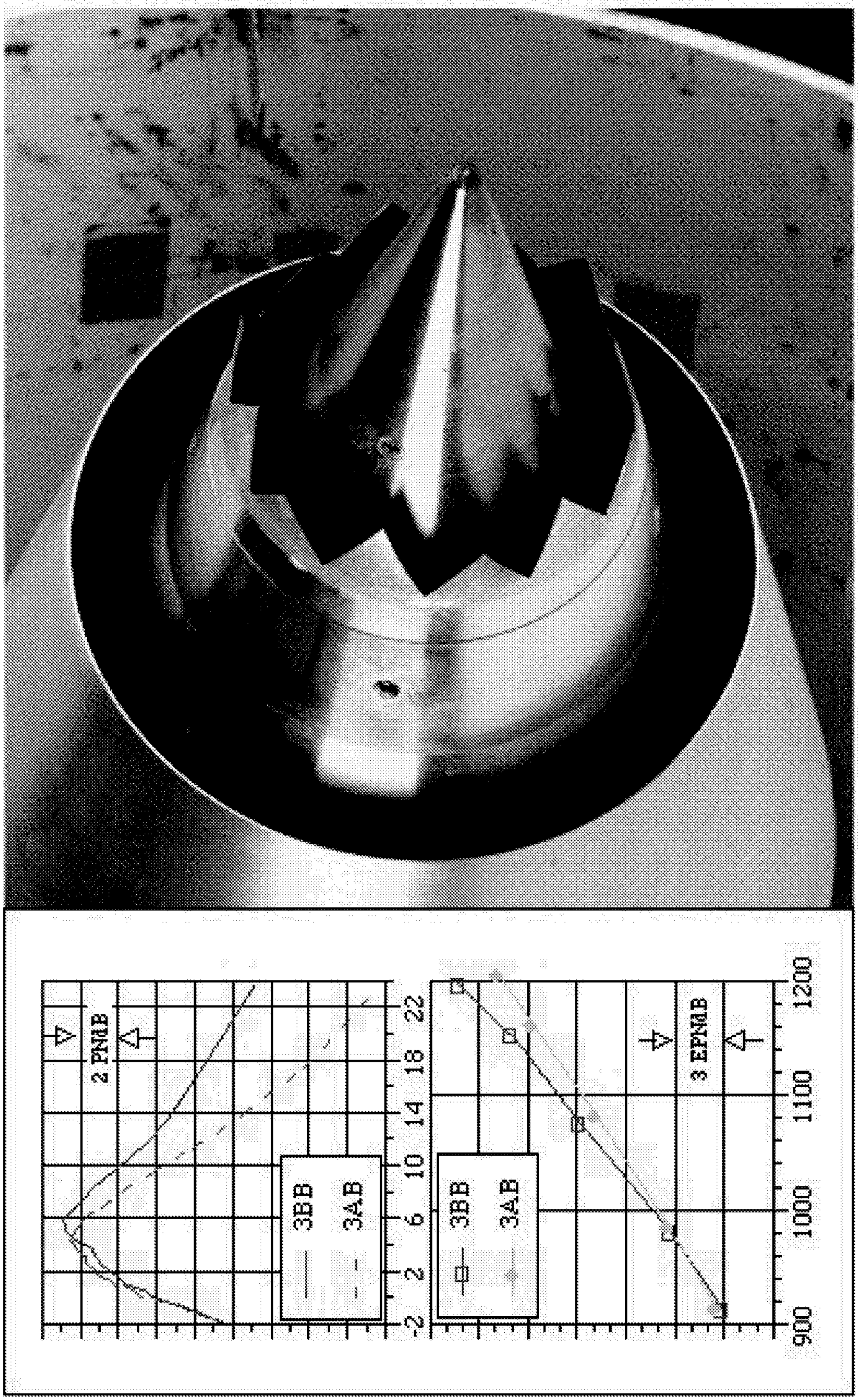

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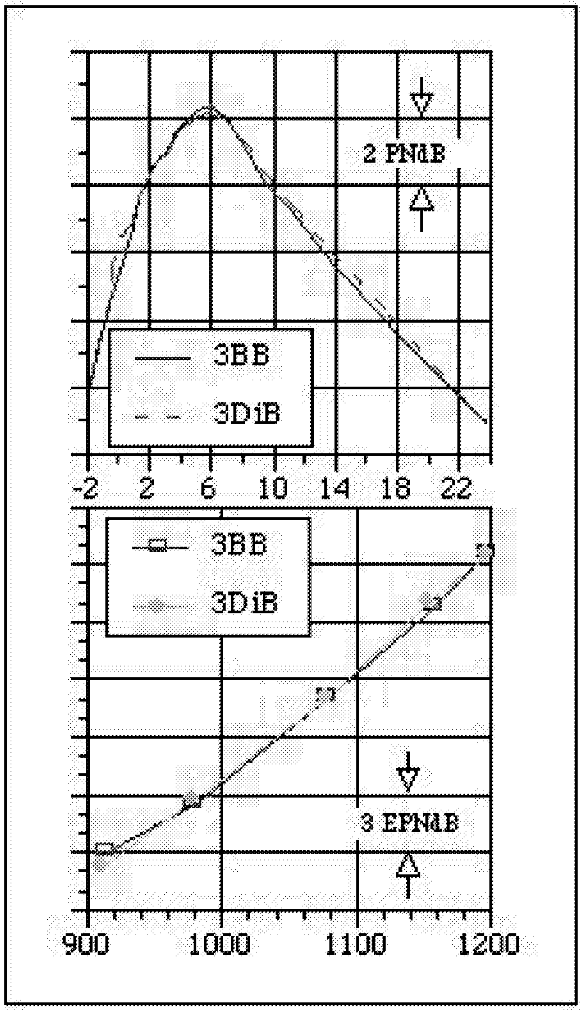

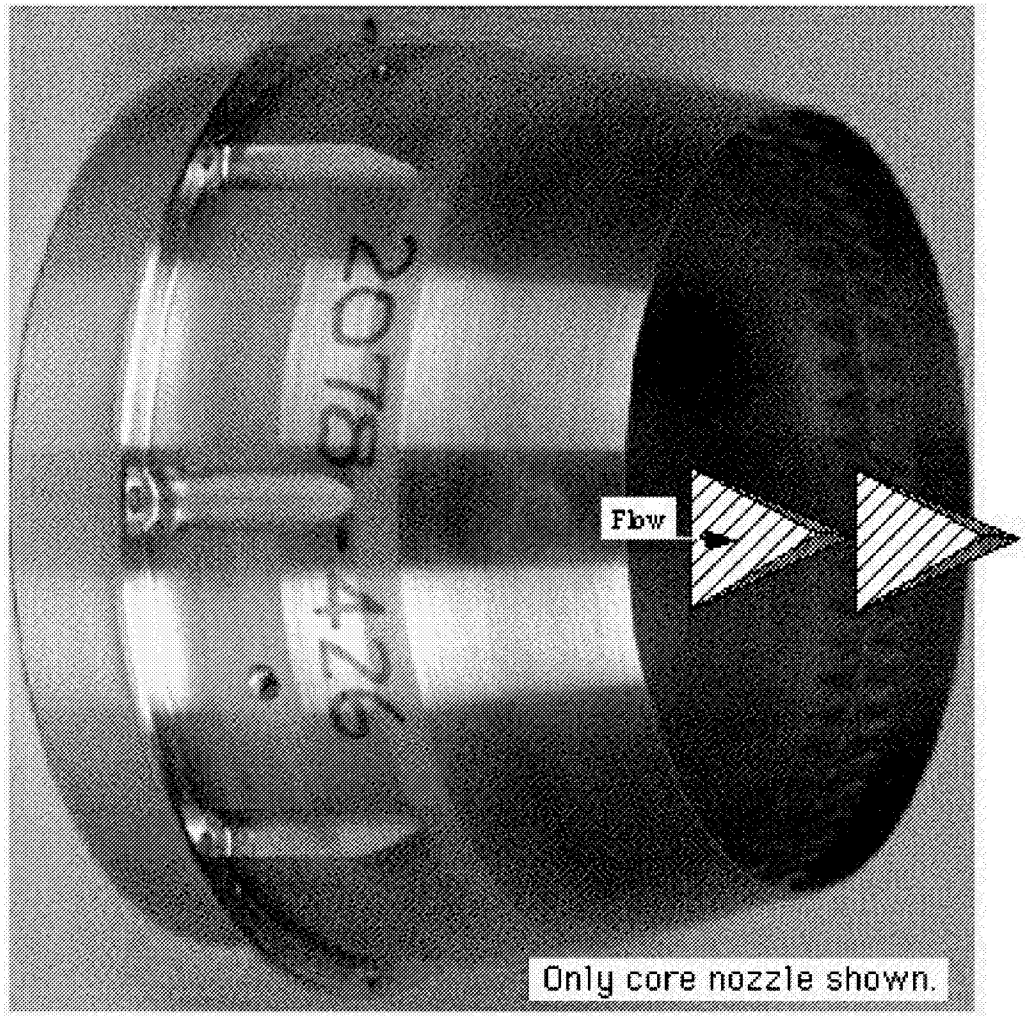

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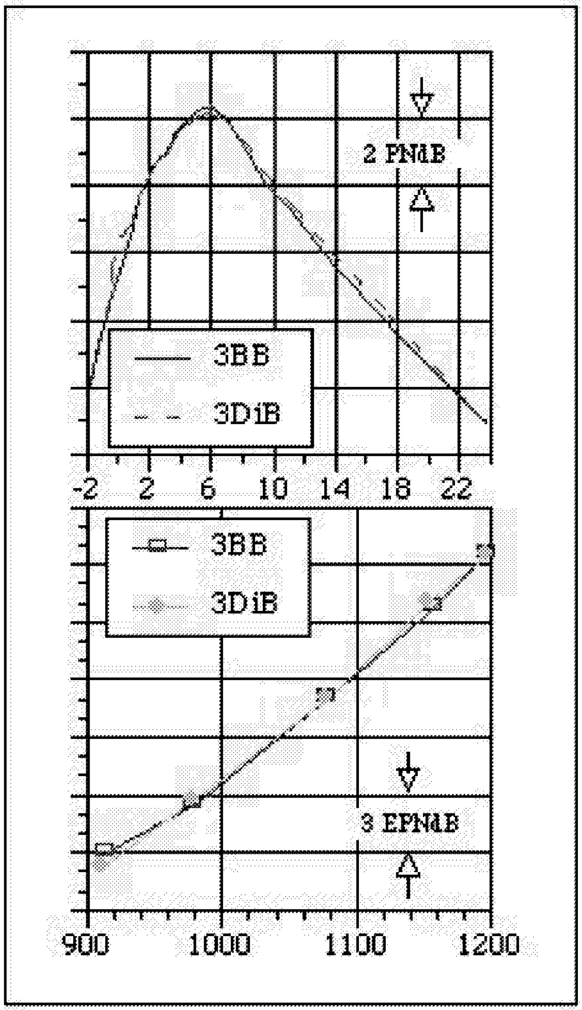

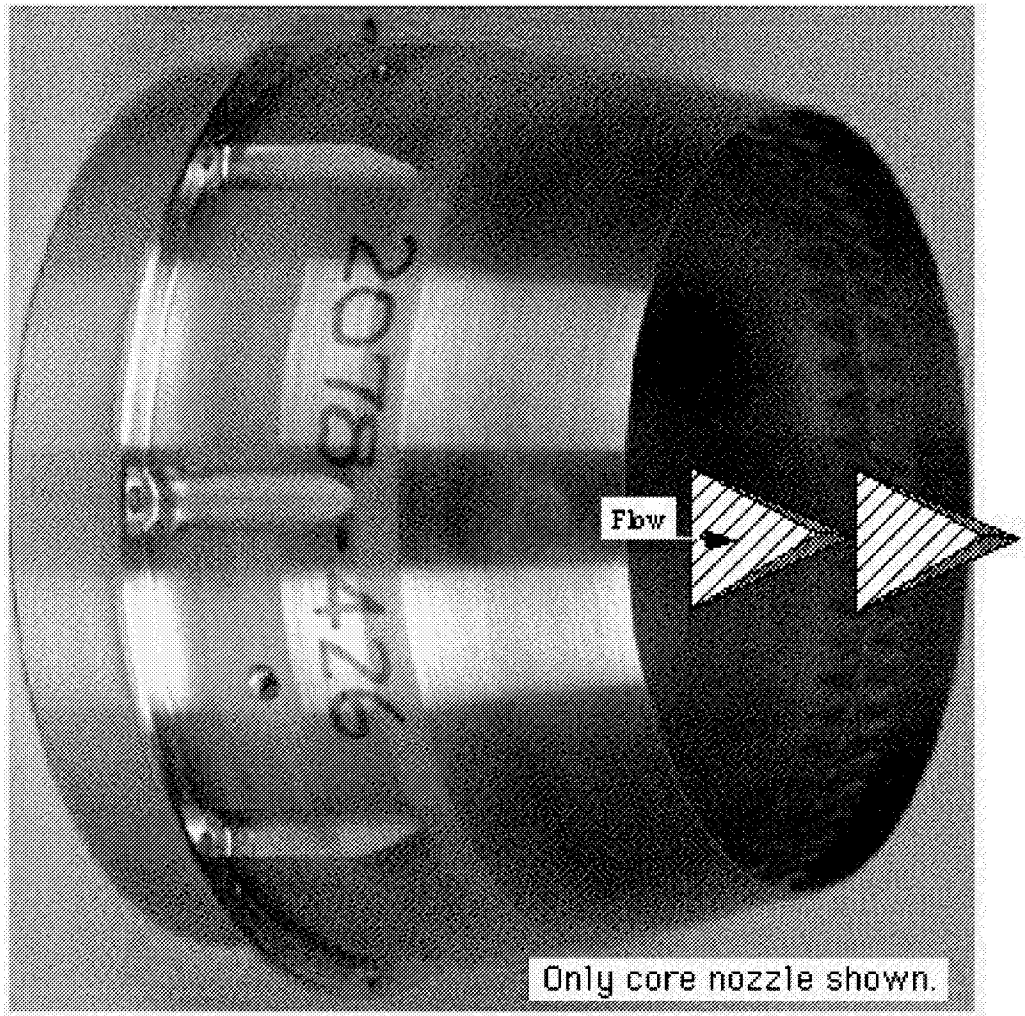

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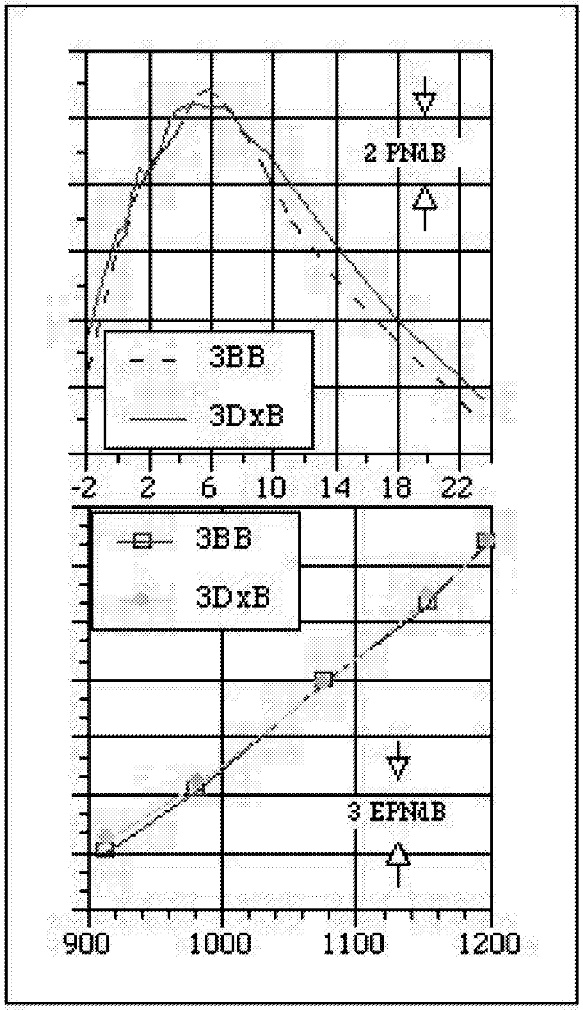

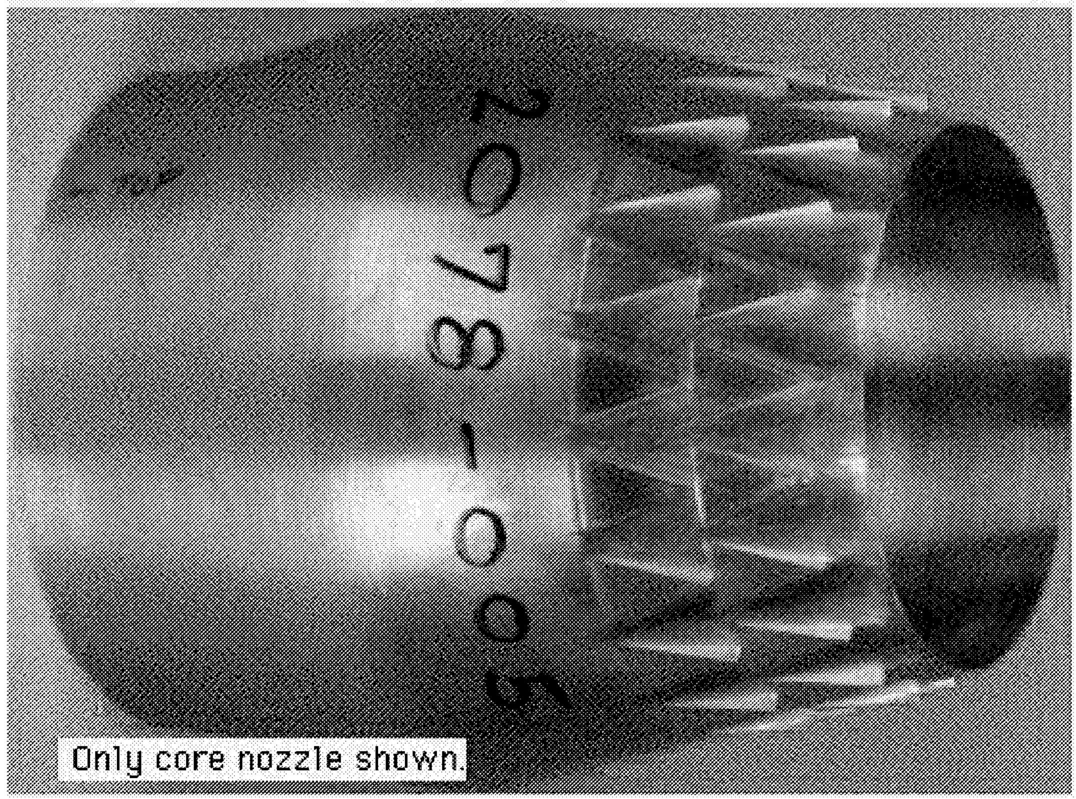

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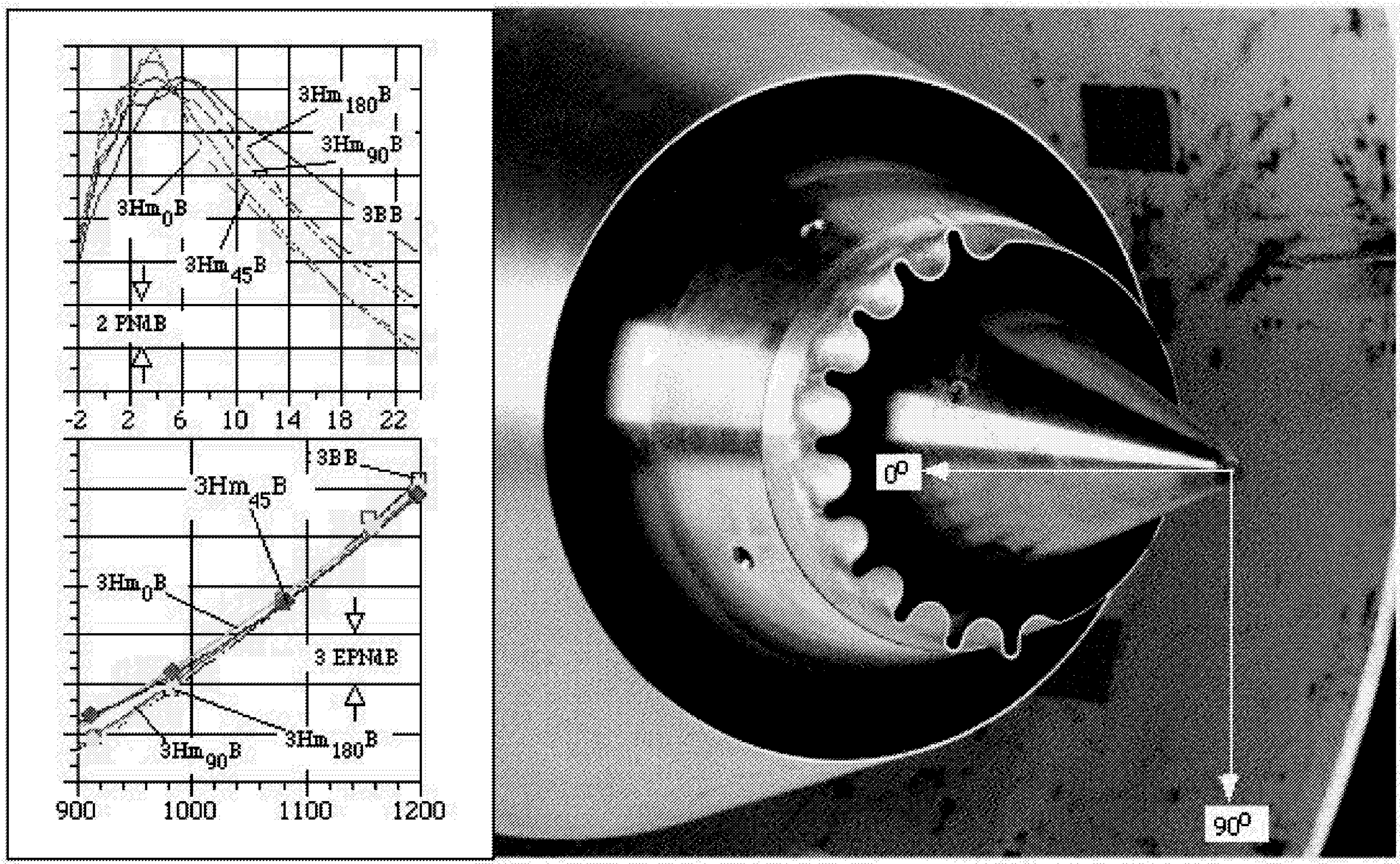

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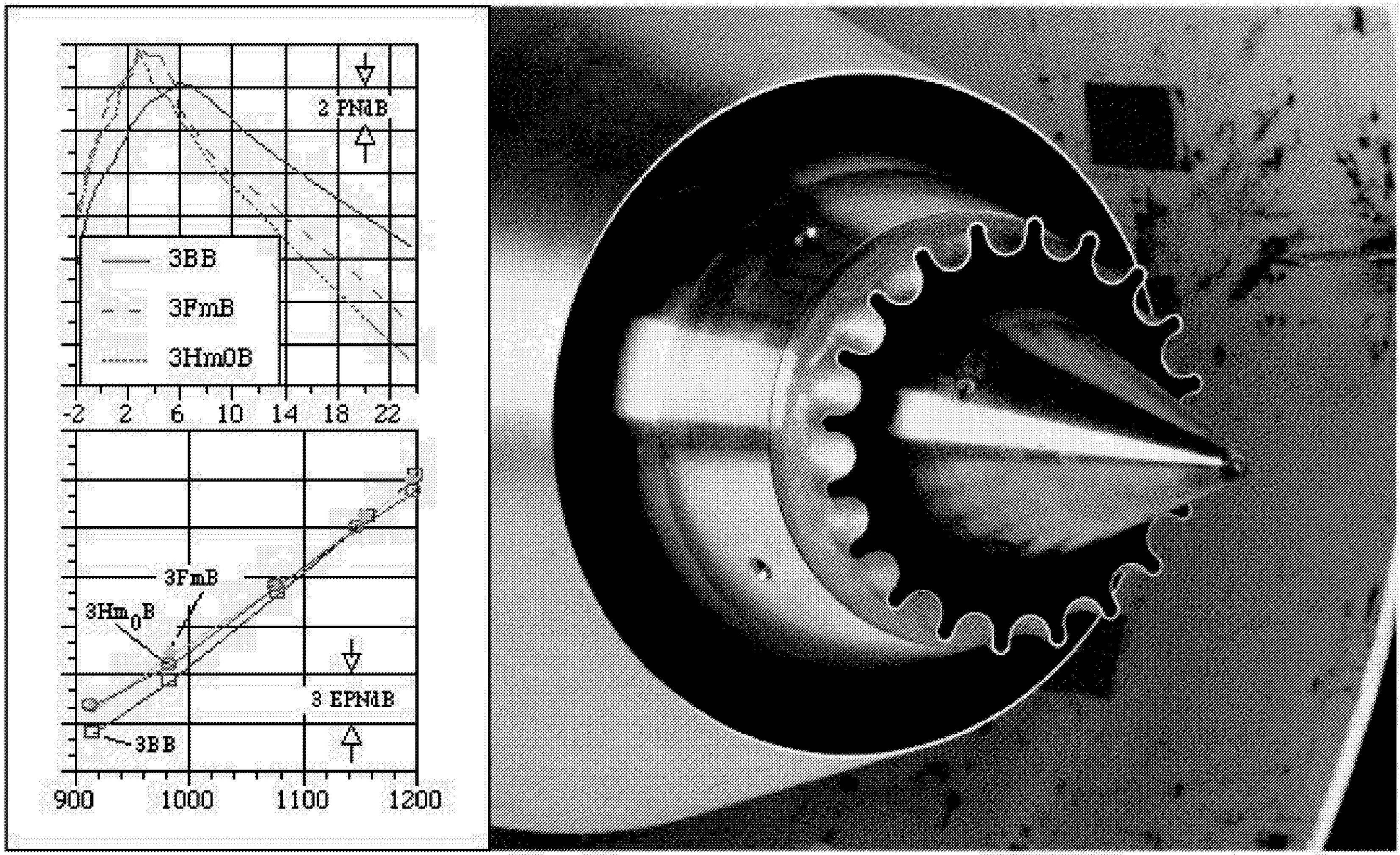

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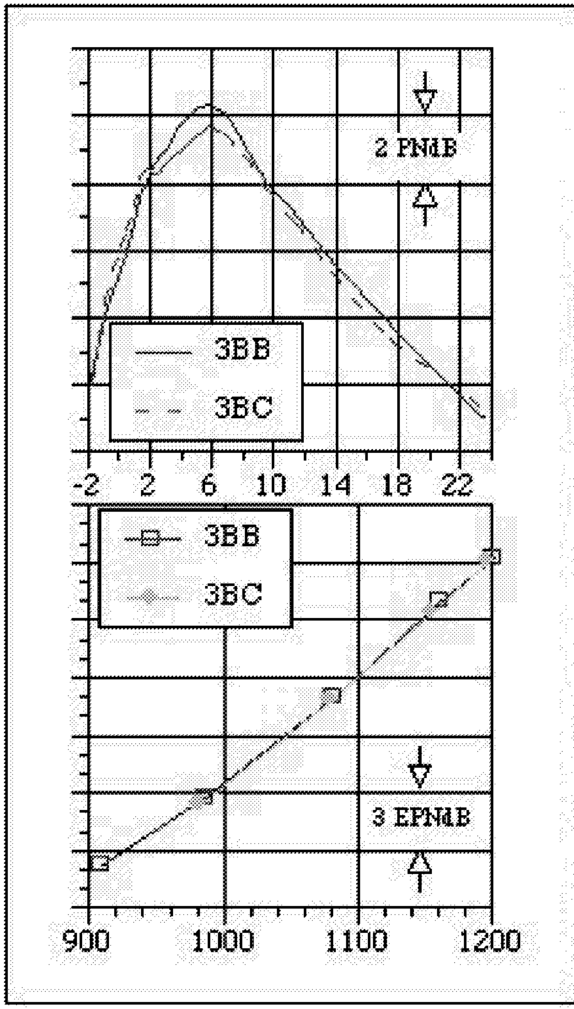

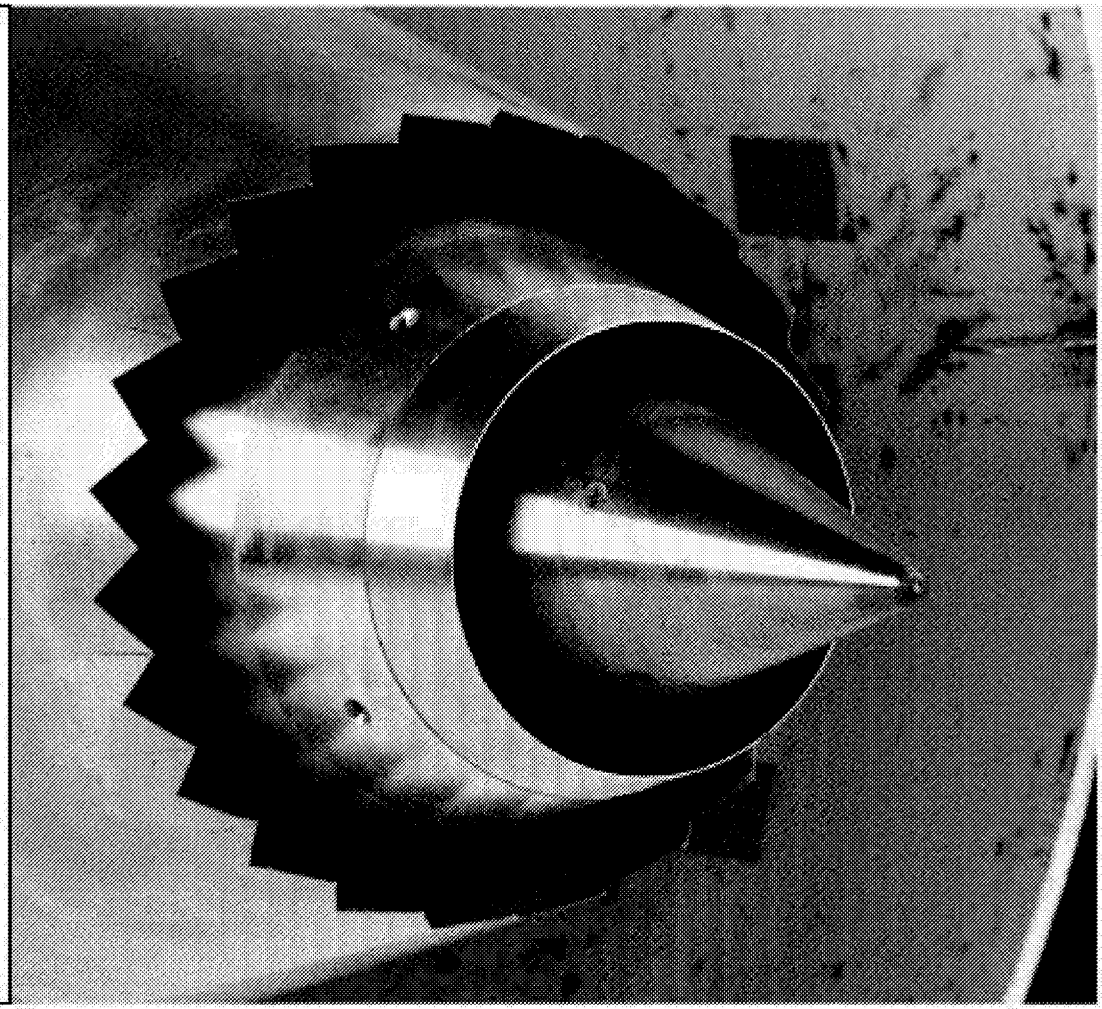

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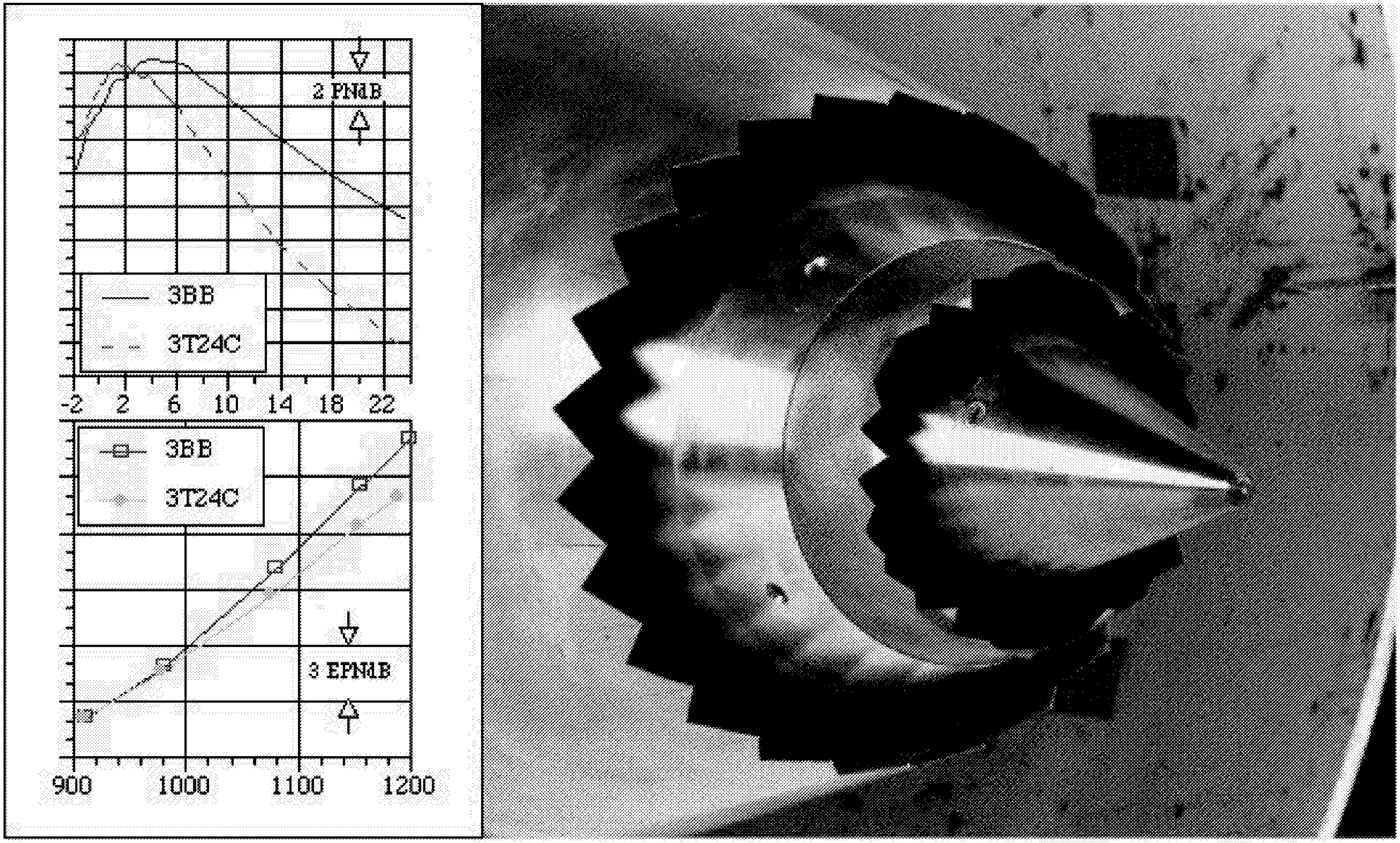

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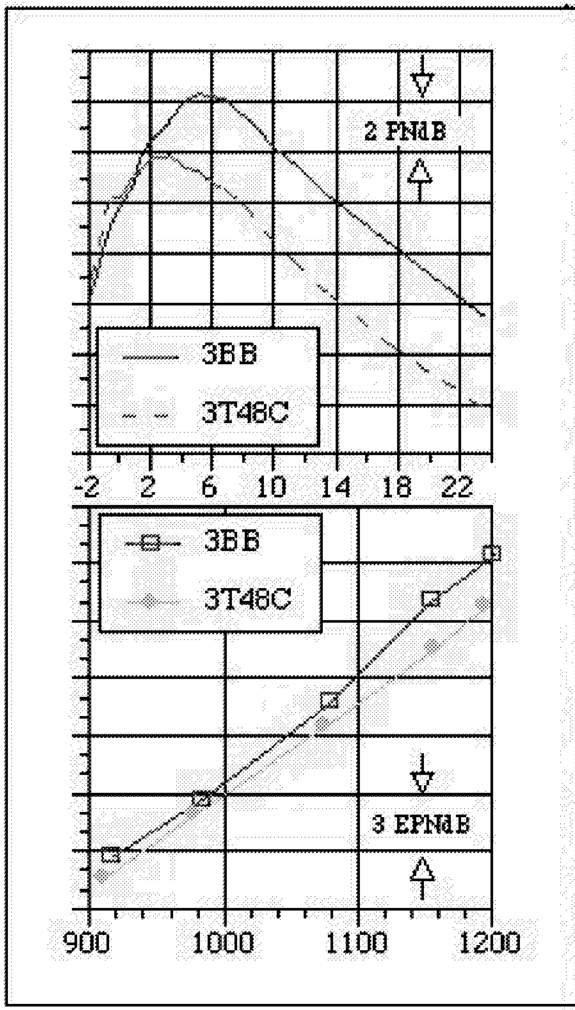

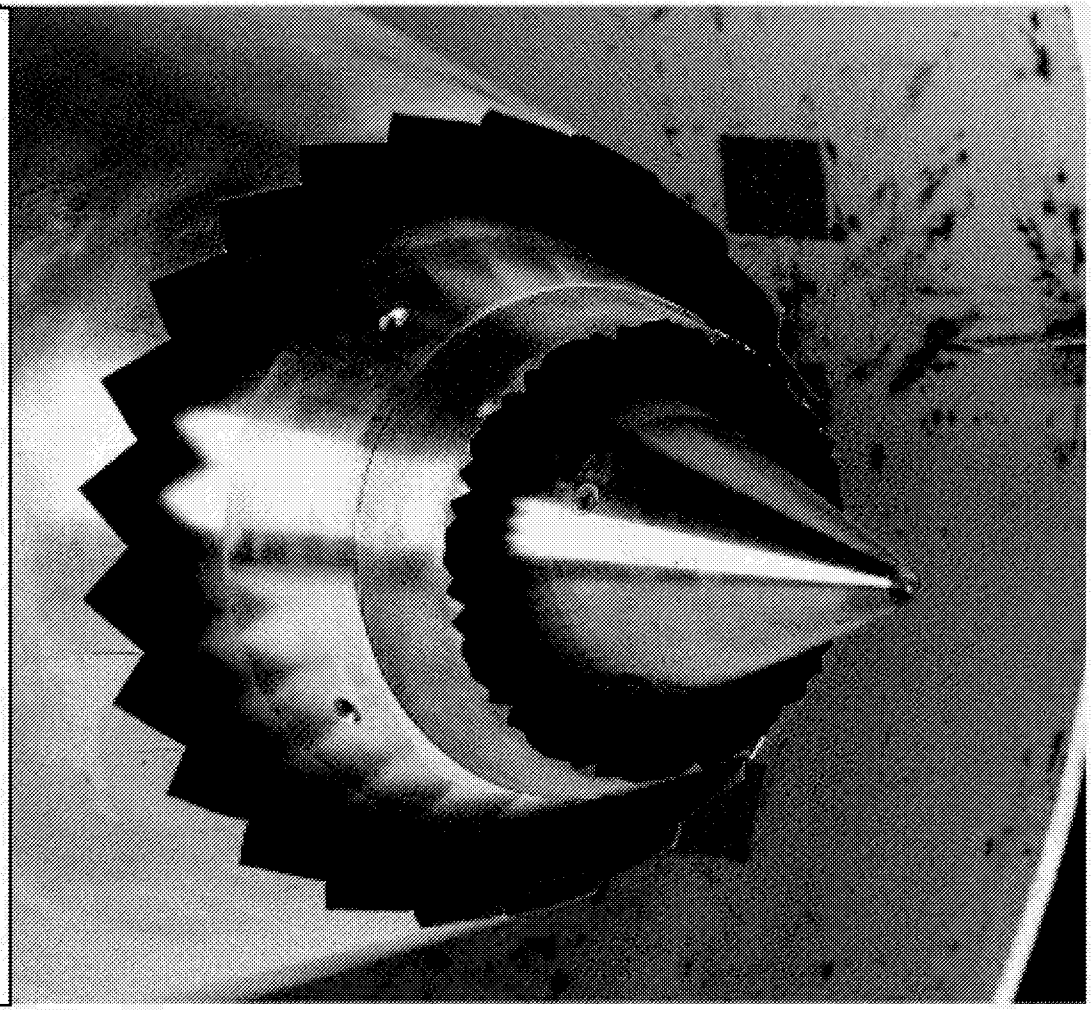

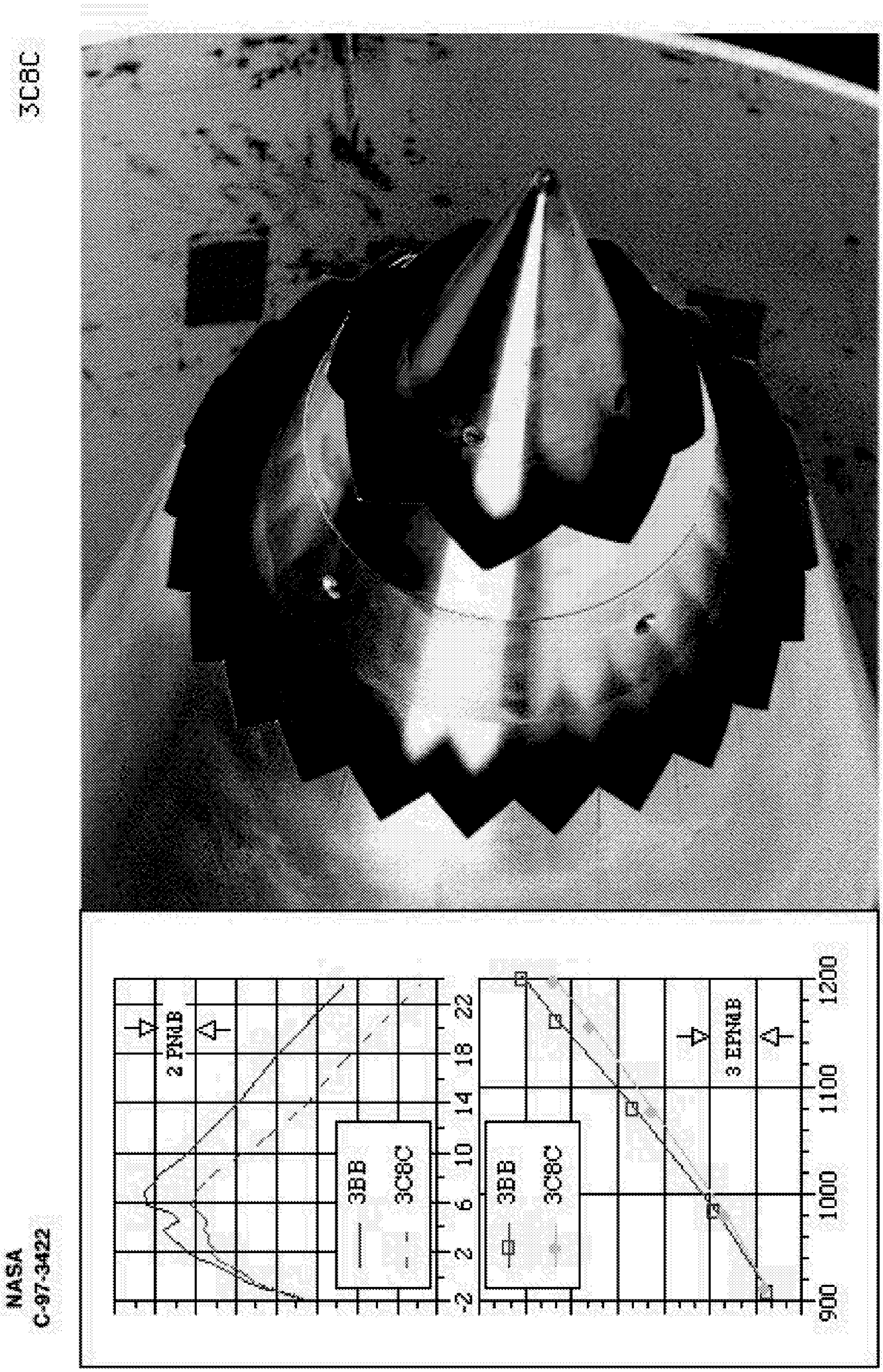
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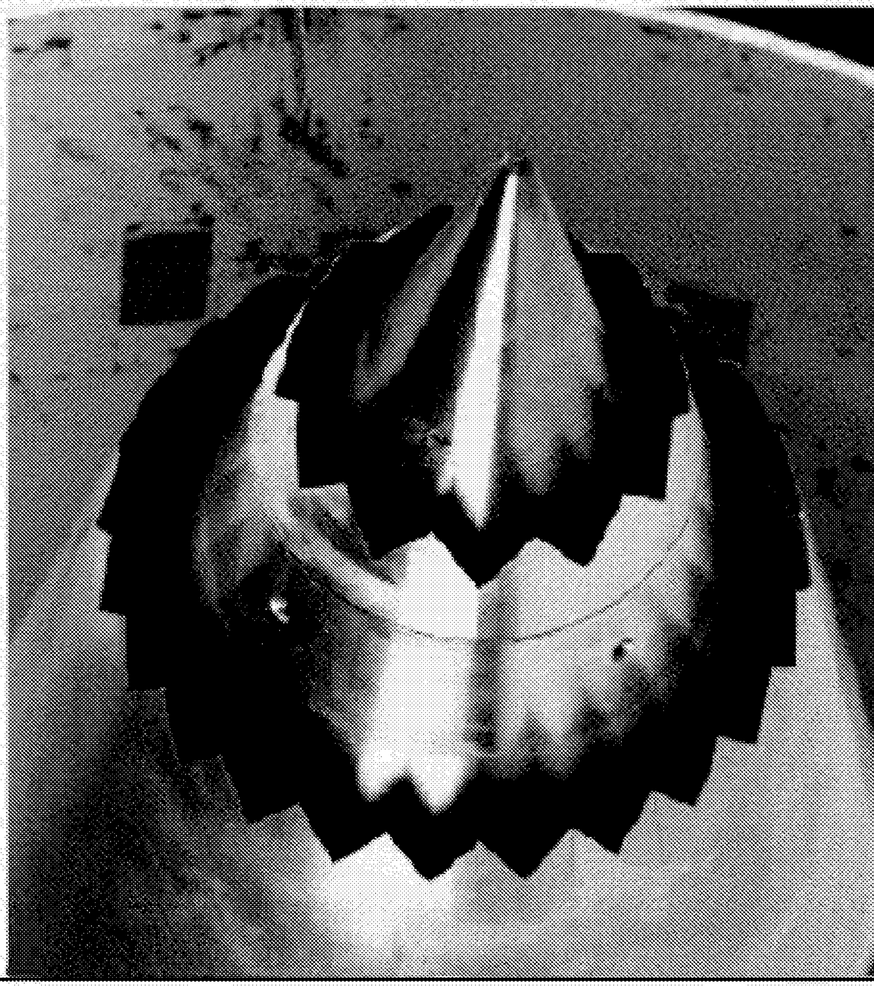
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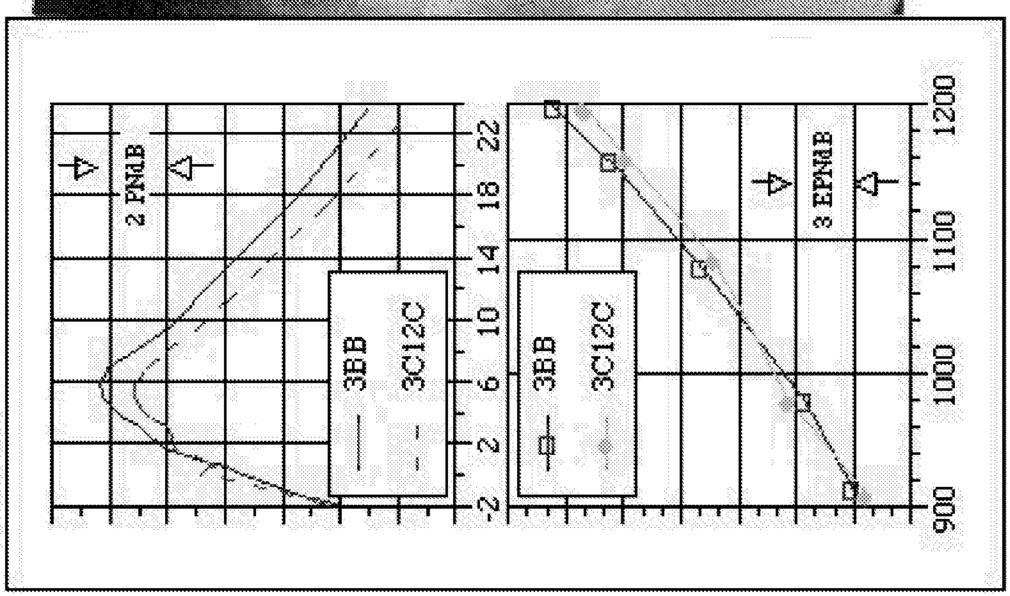
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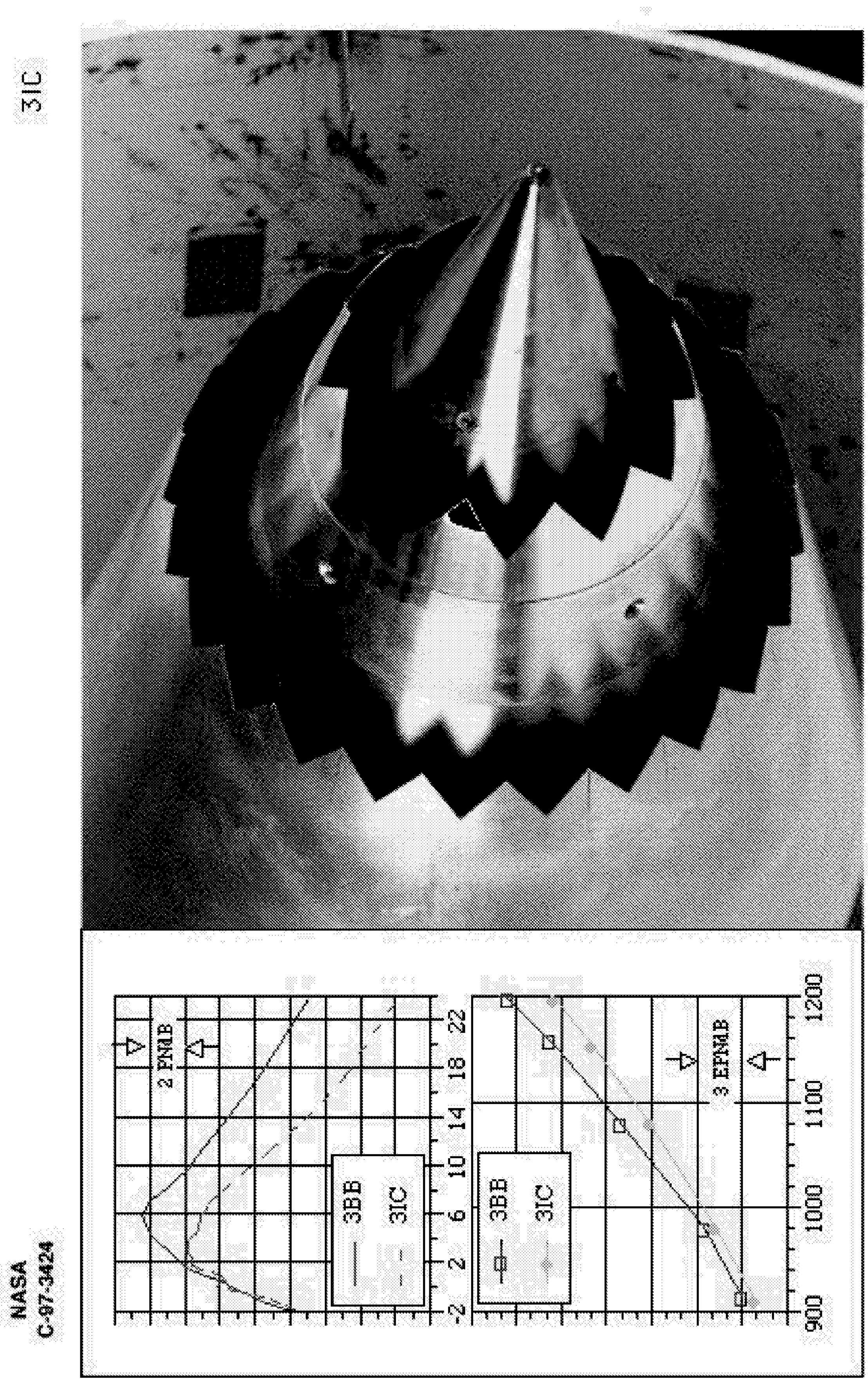
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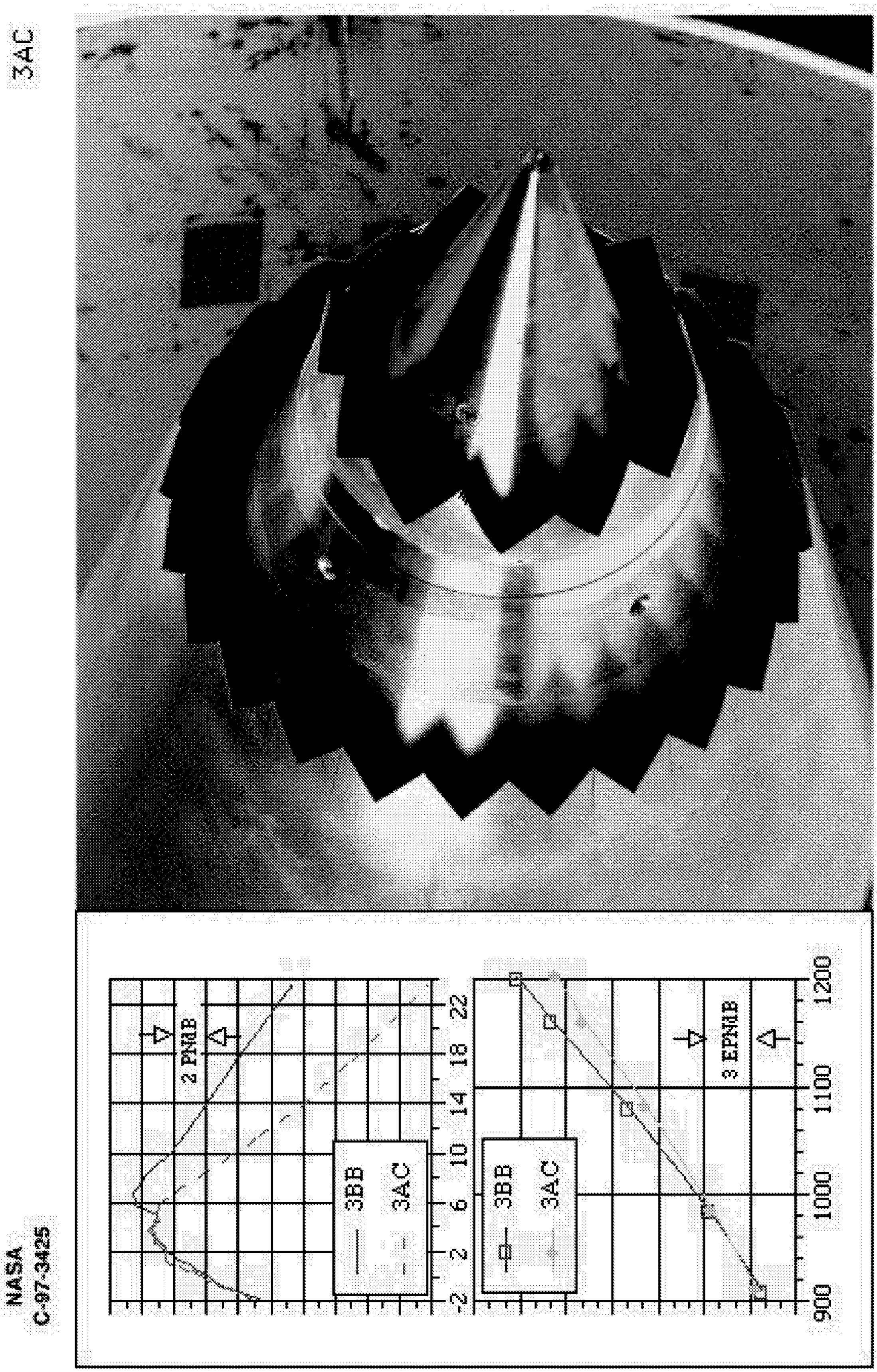
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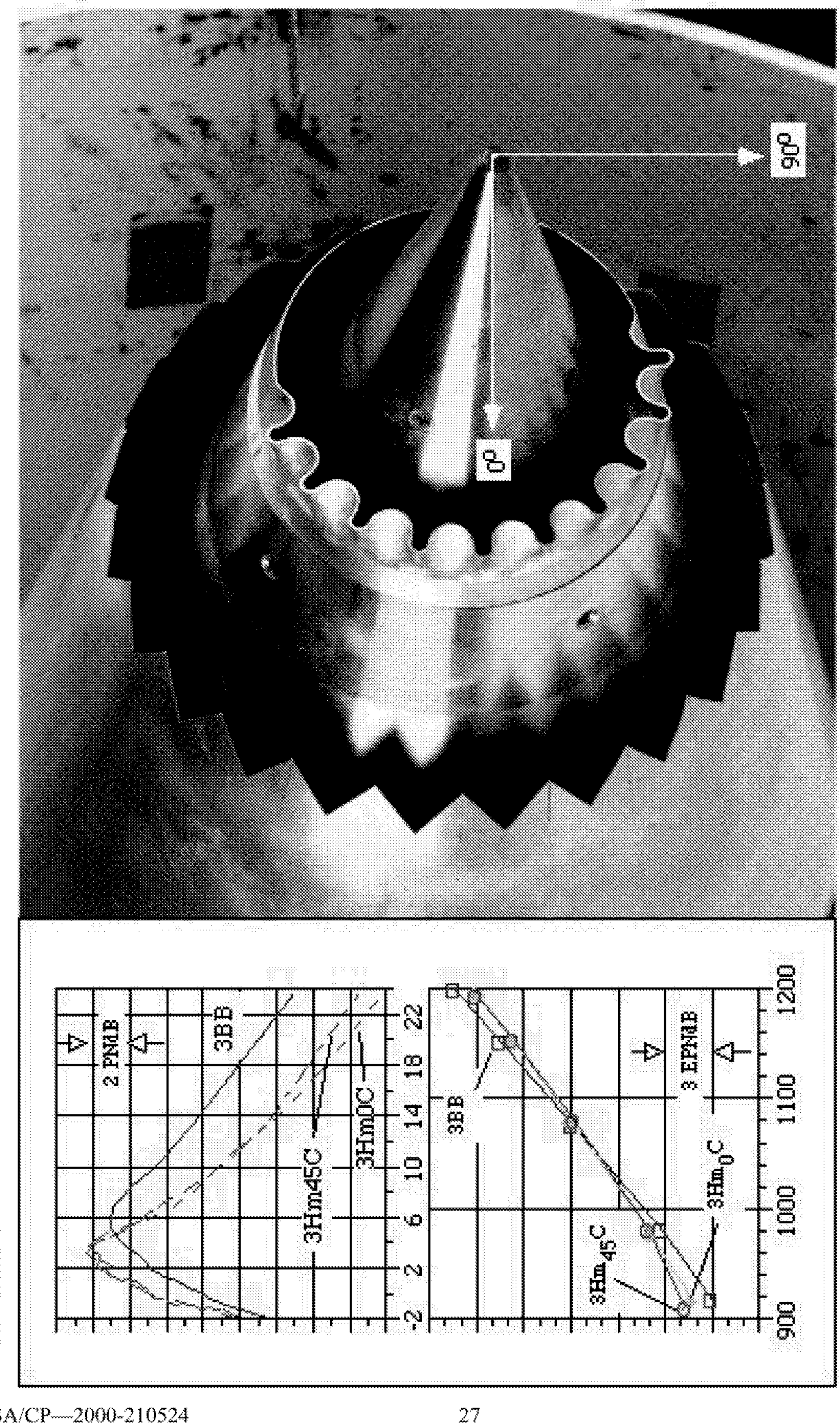

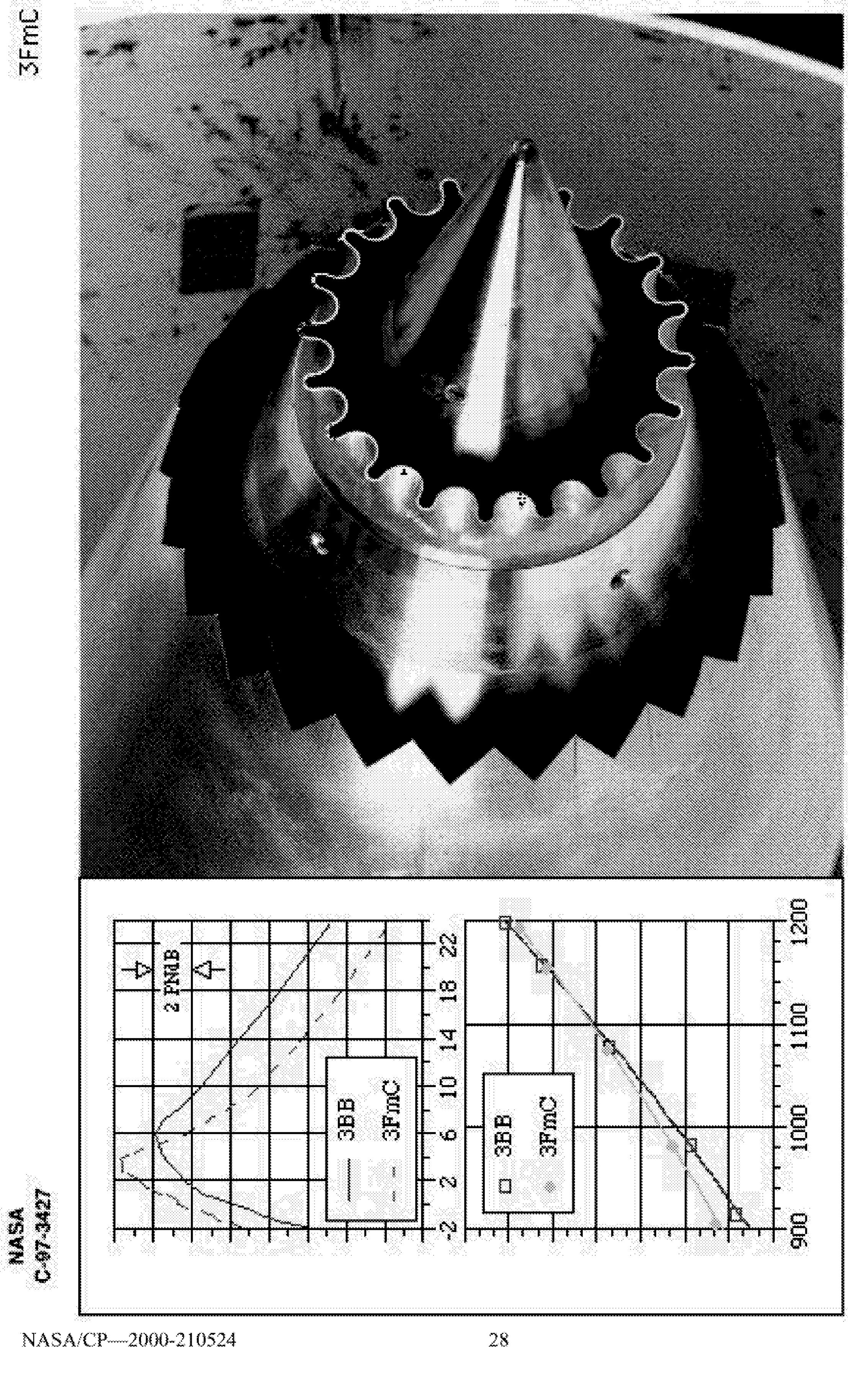

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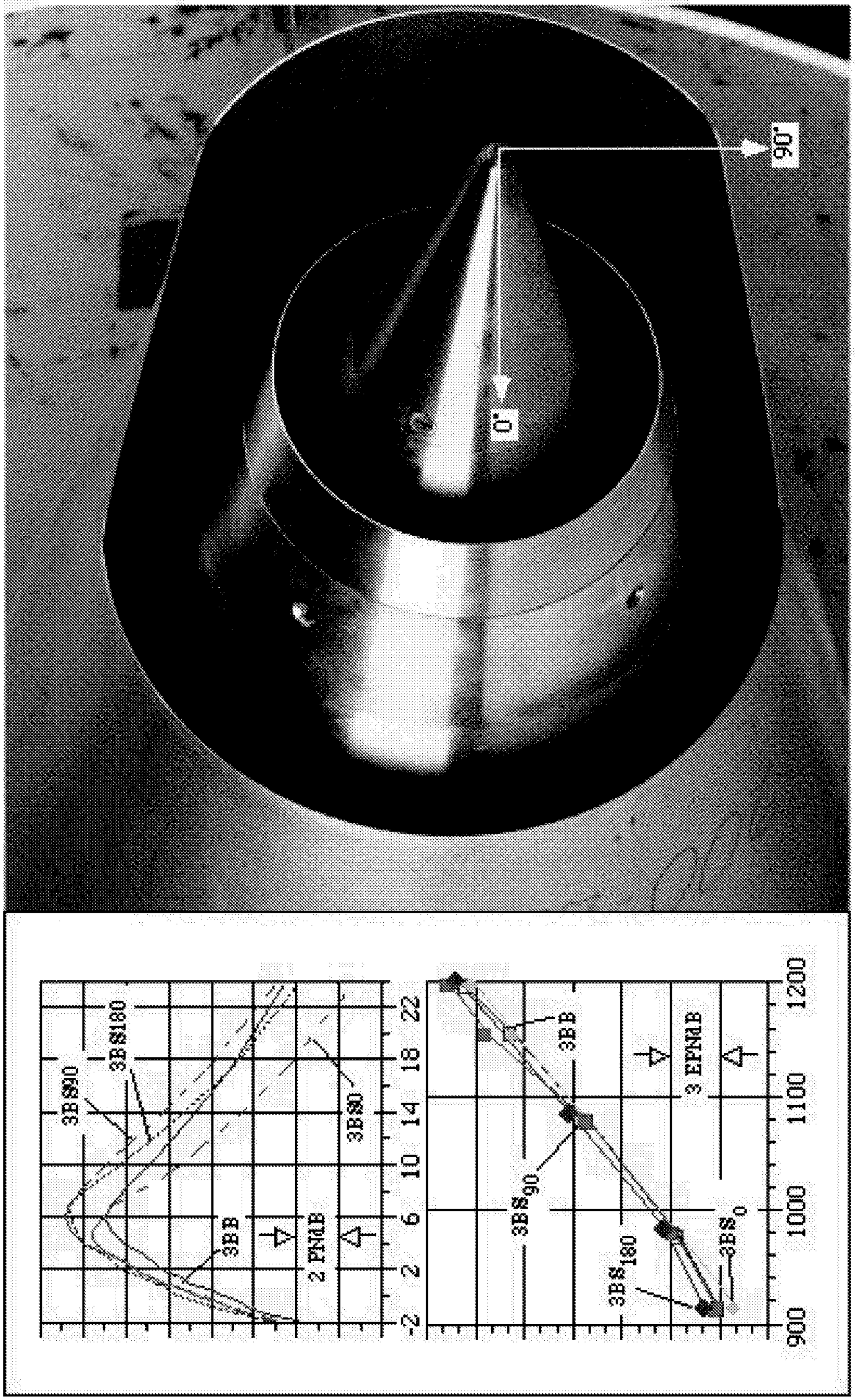

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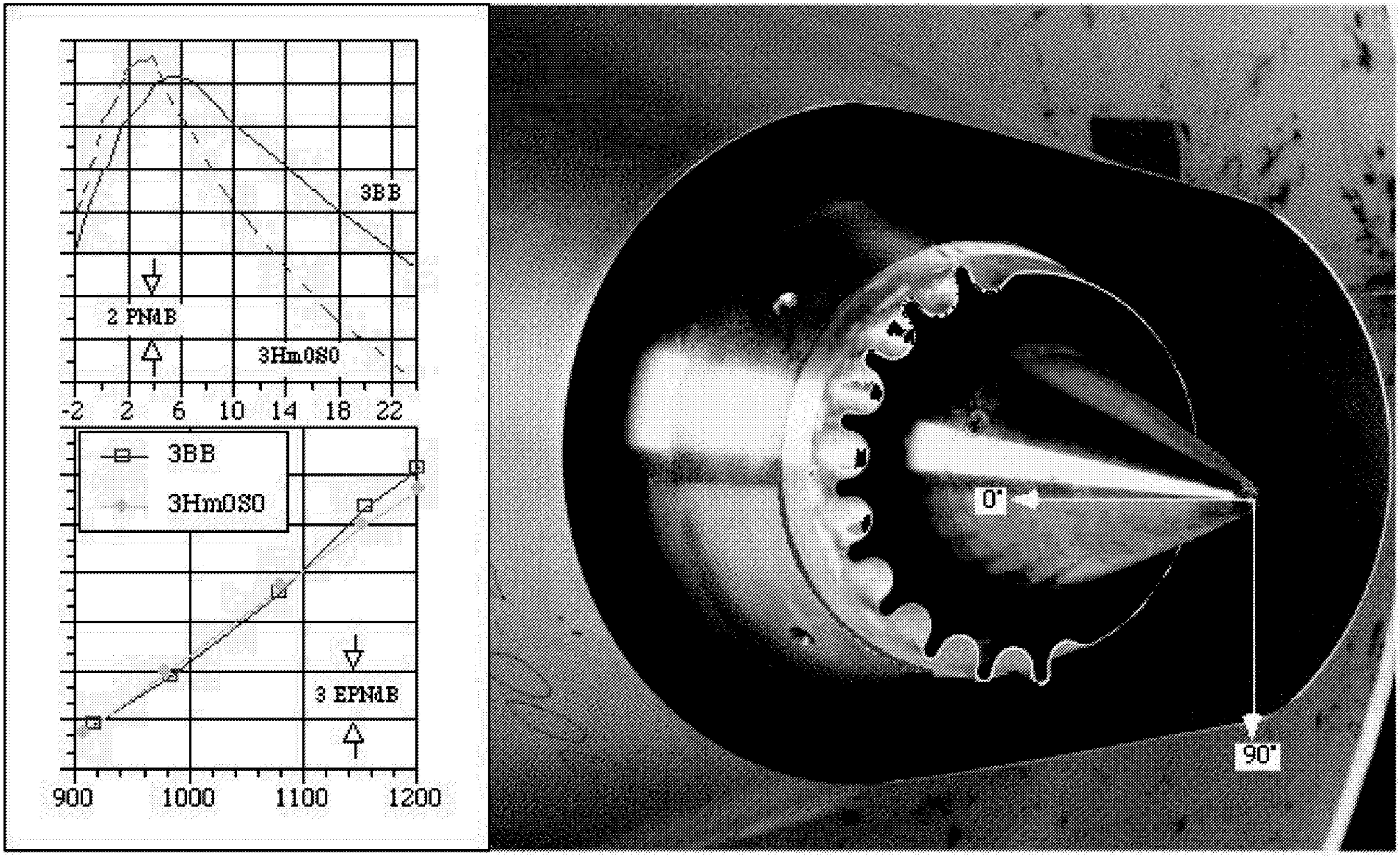

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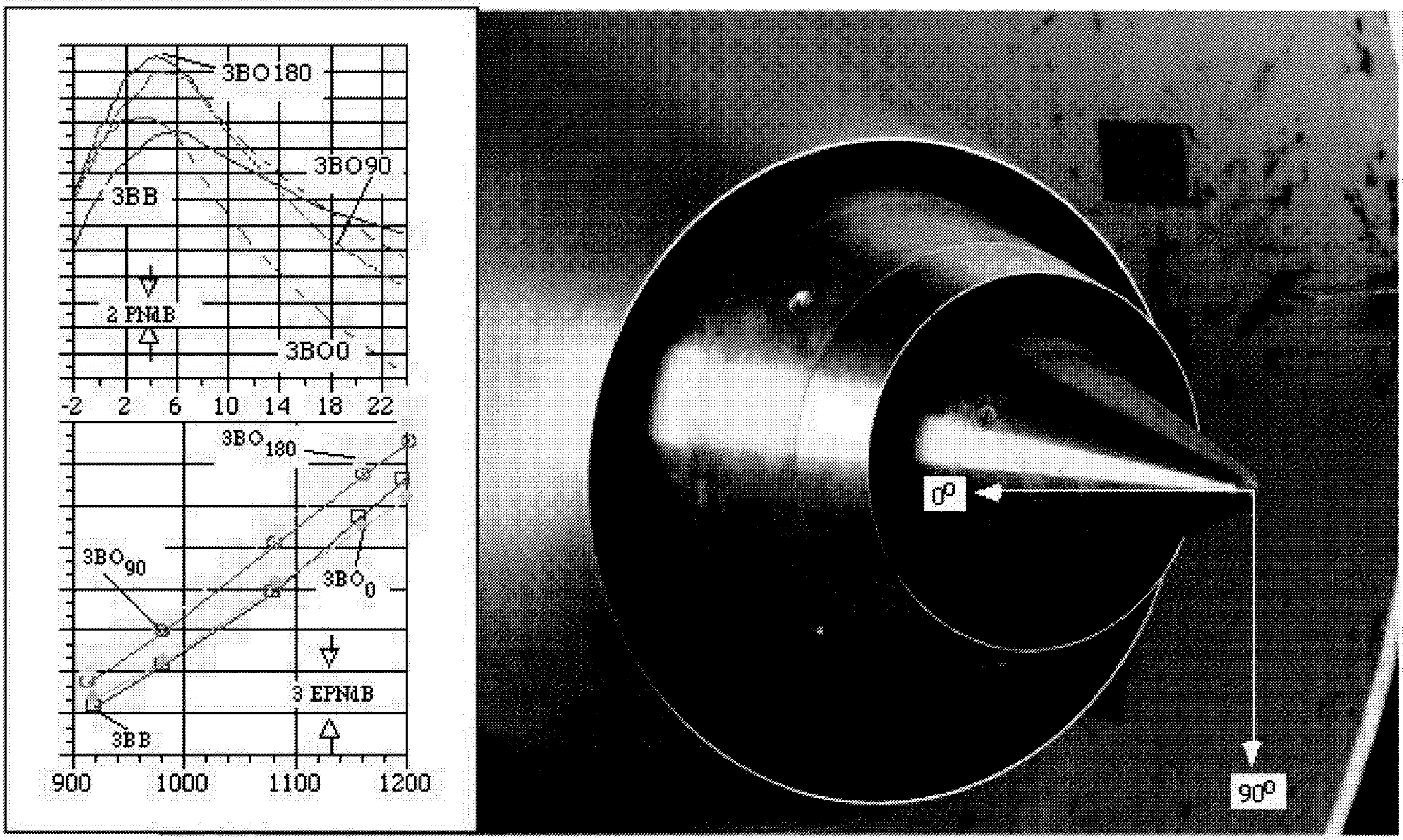

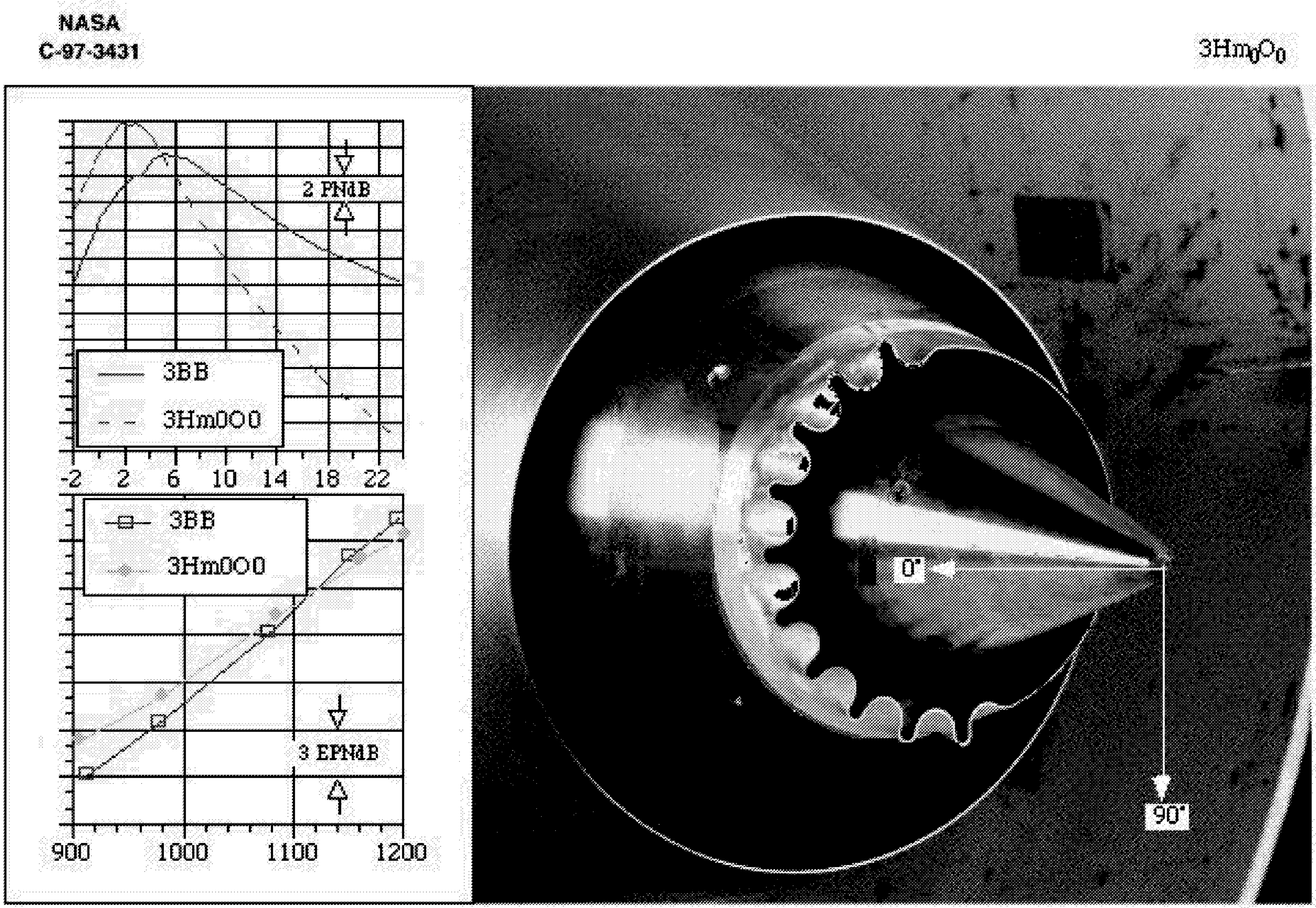
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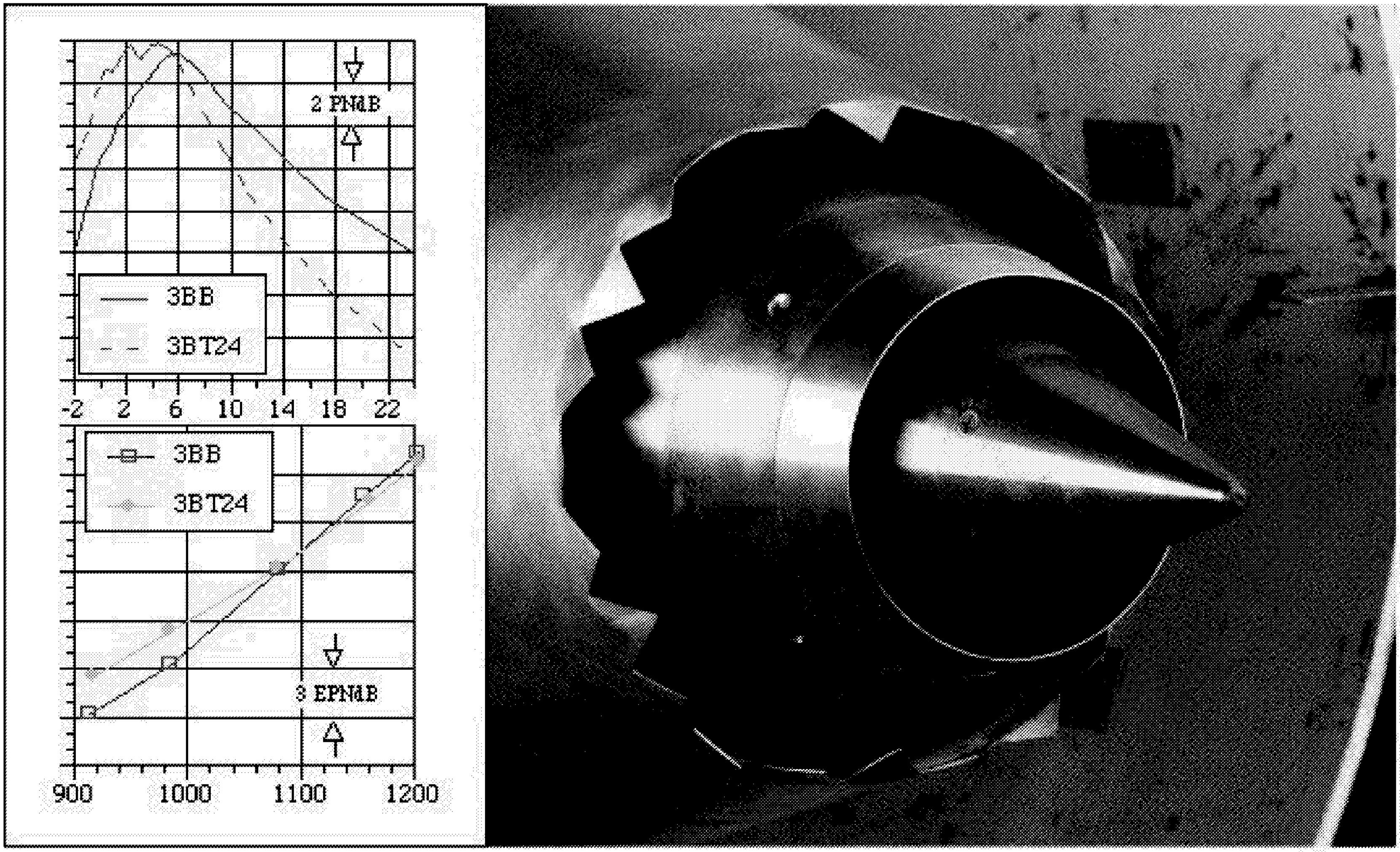

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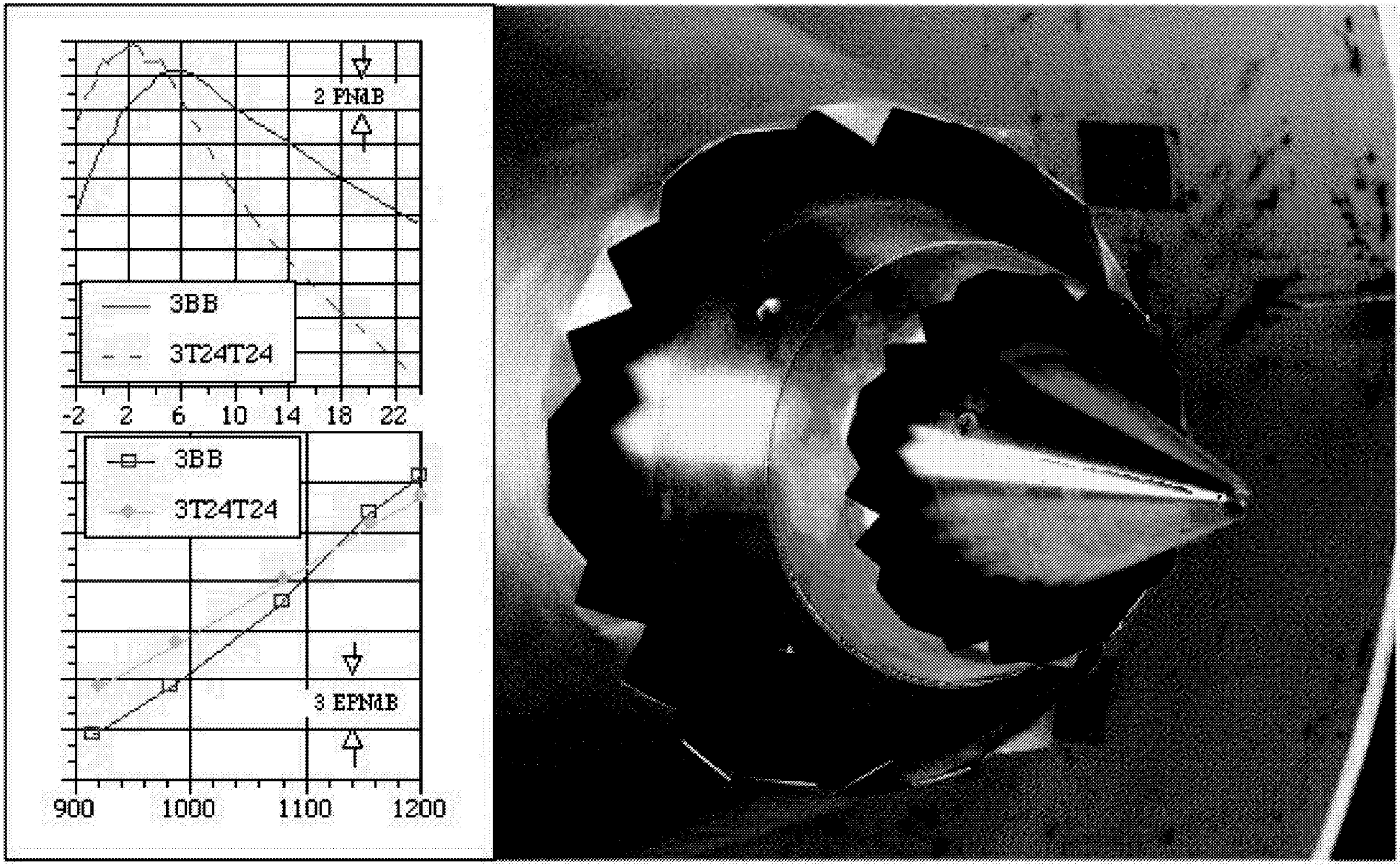

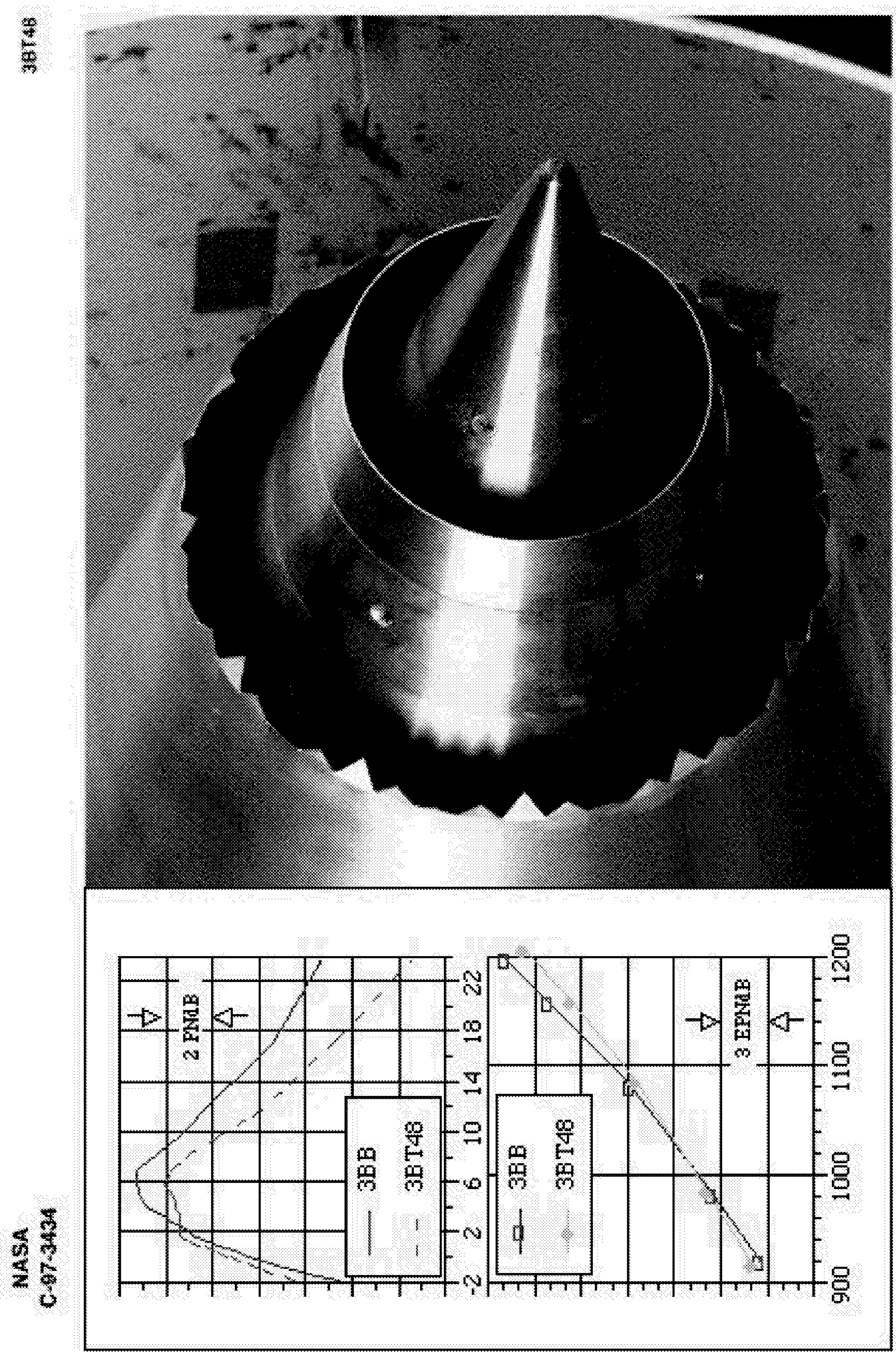
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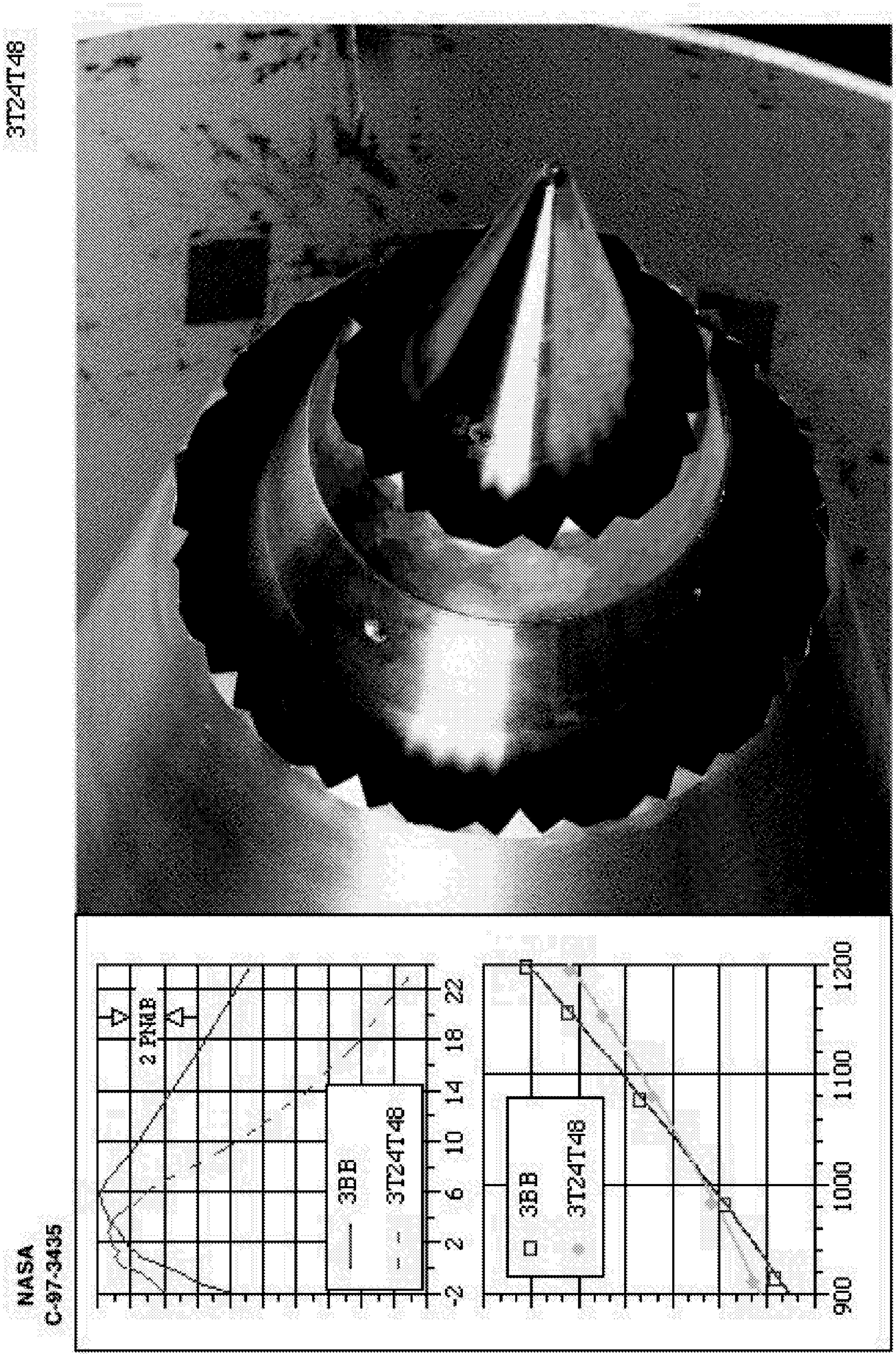
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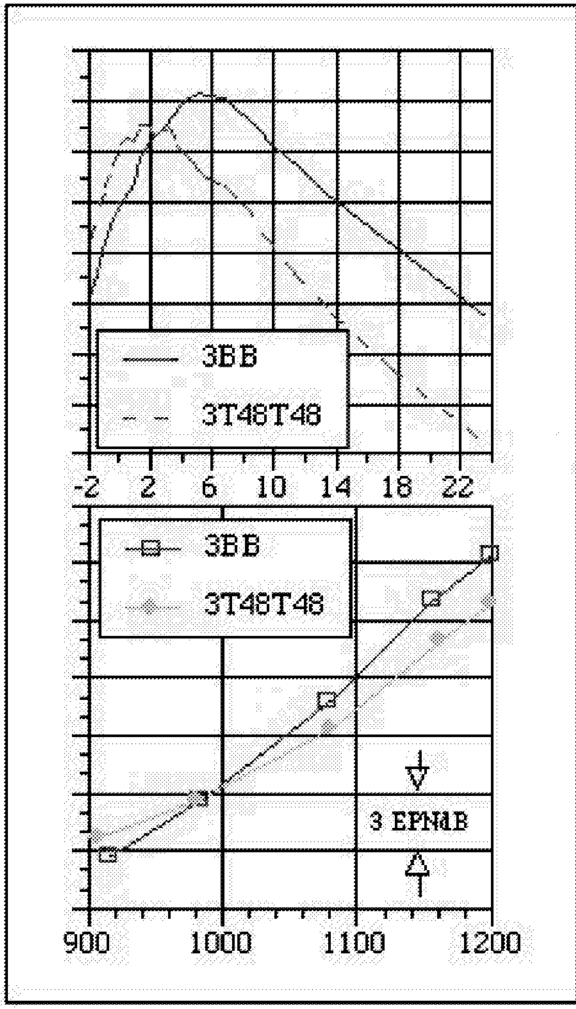
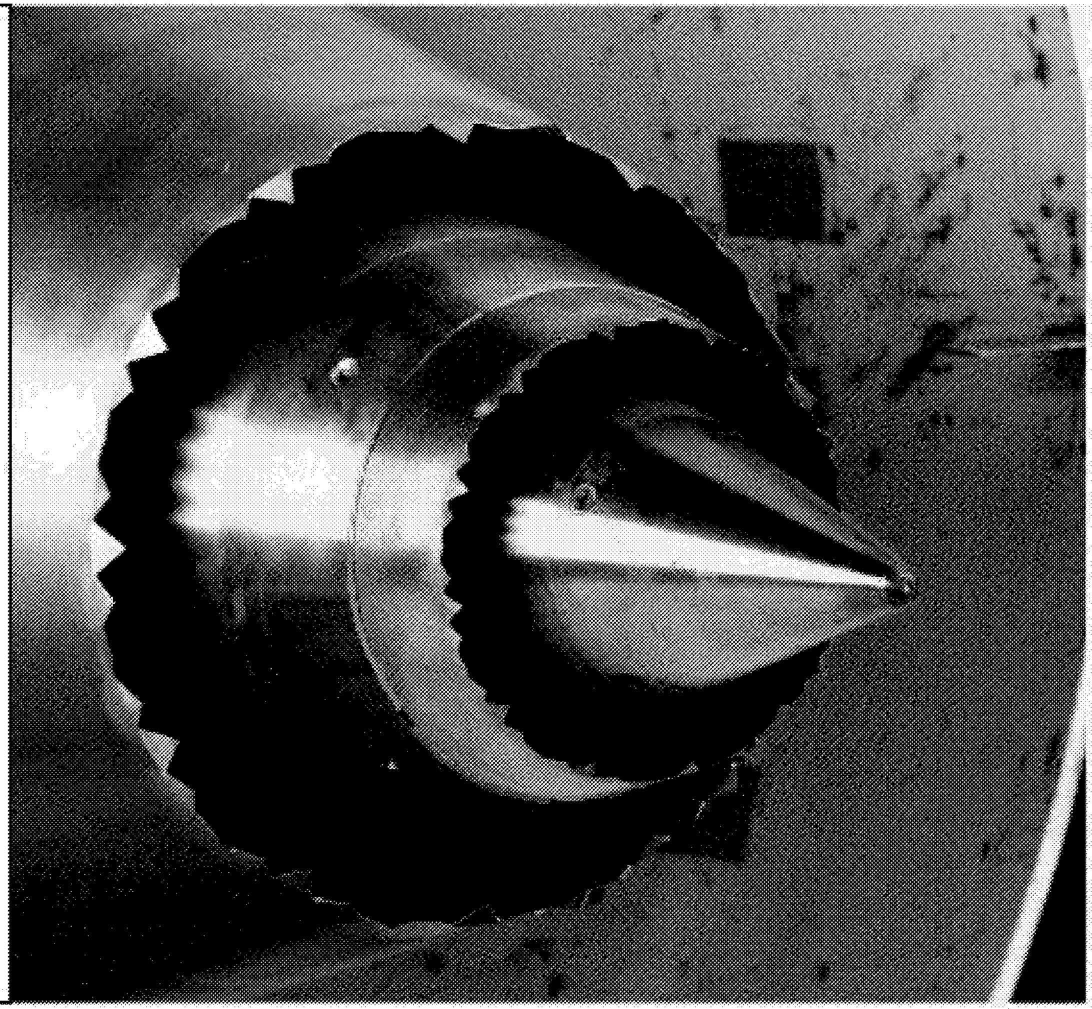
C-97-3436

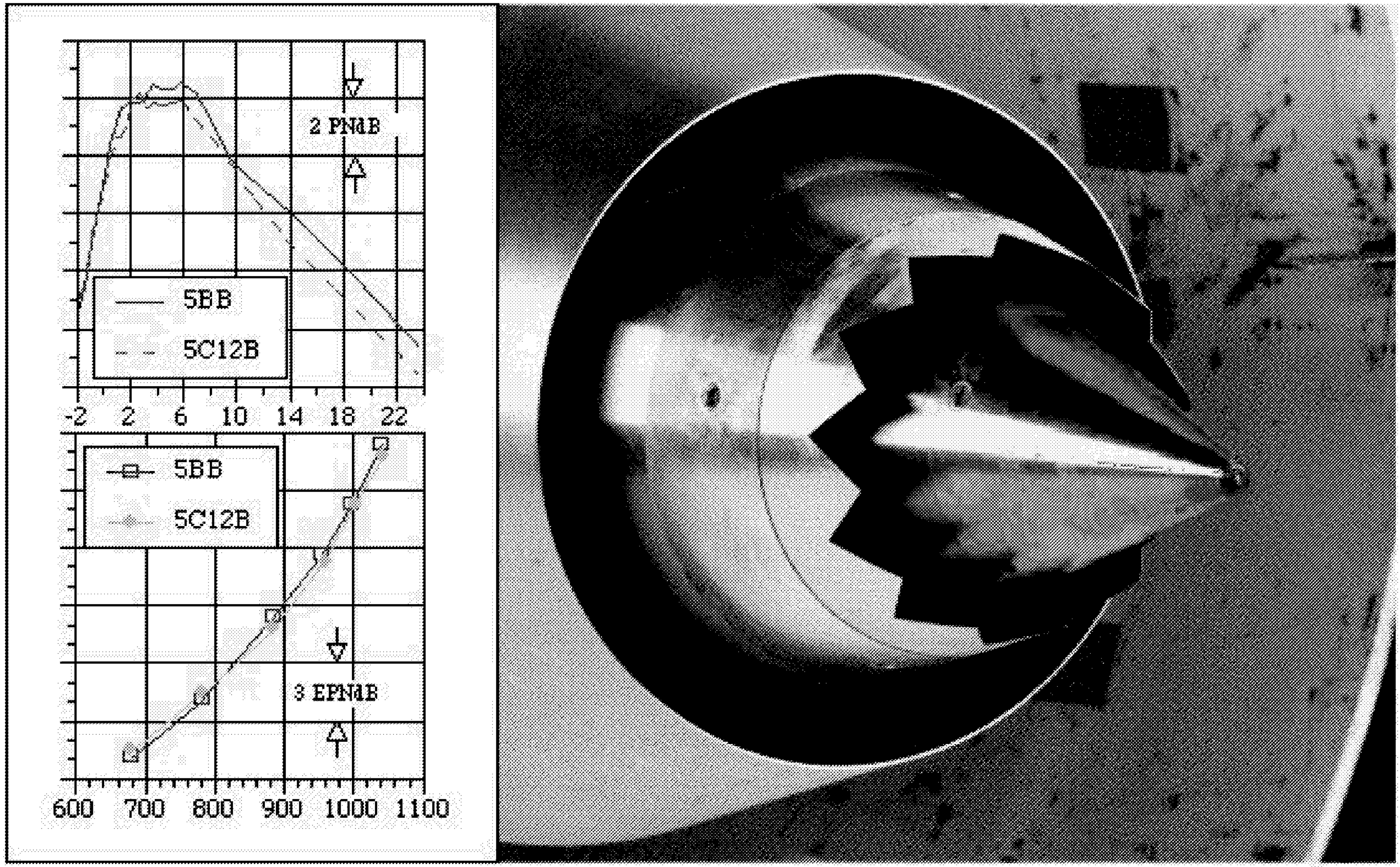
$3T_{48}T_{48}$





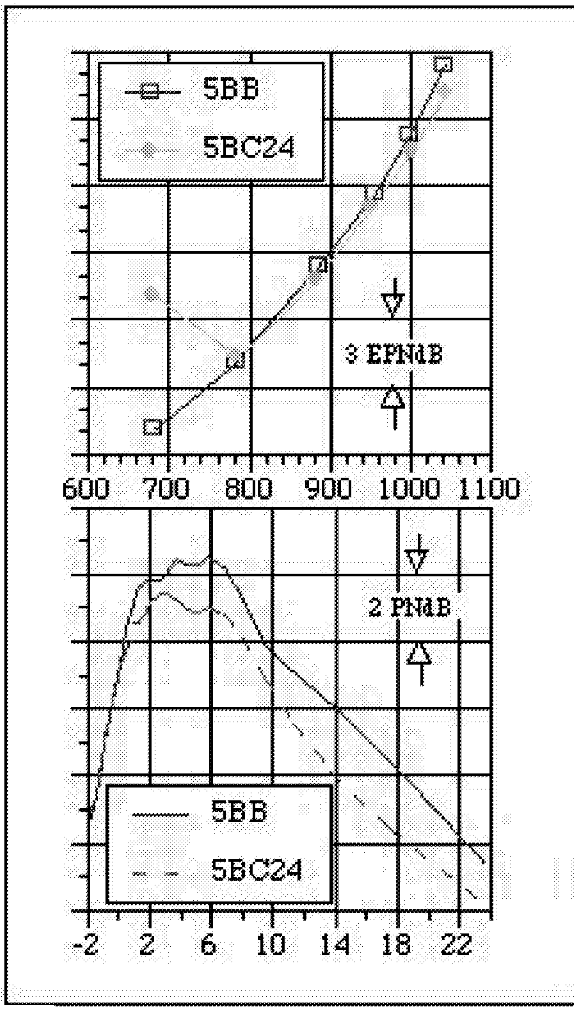
NASA
C-97-3437

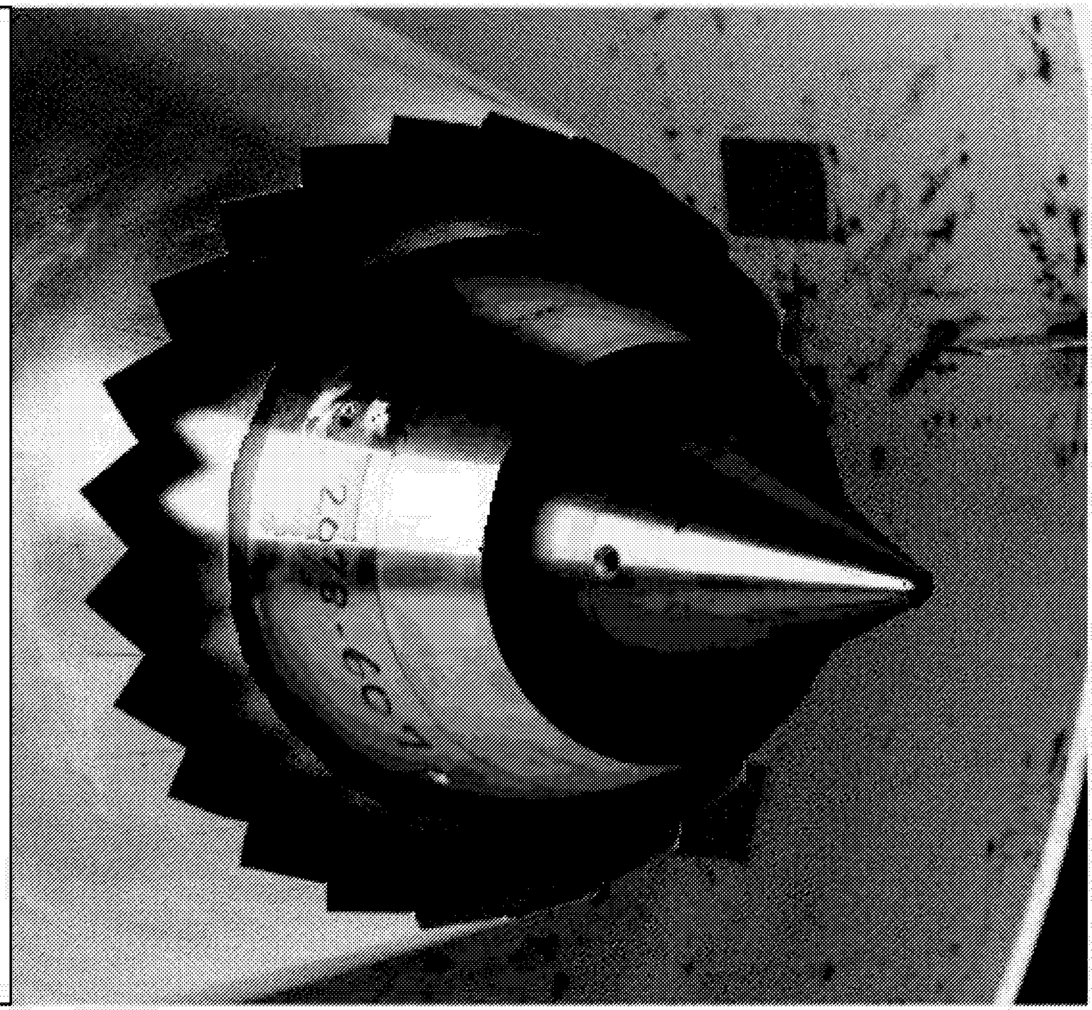
$5C_{12}B$



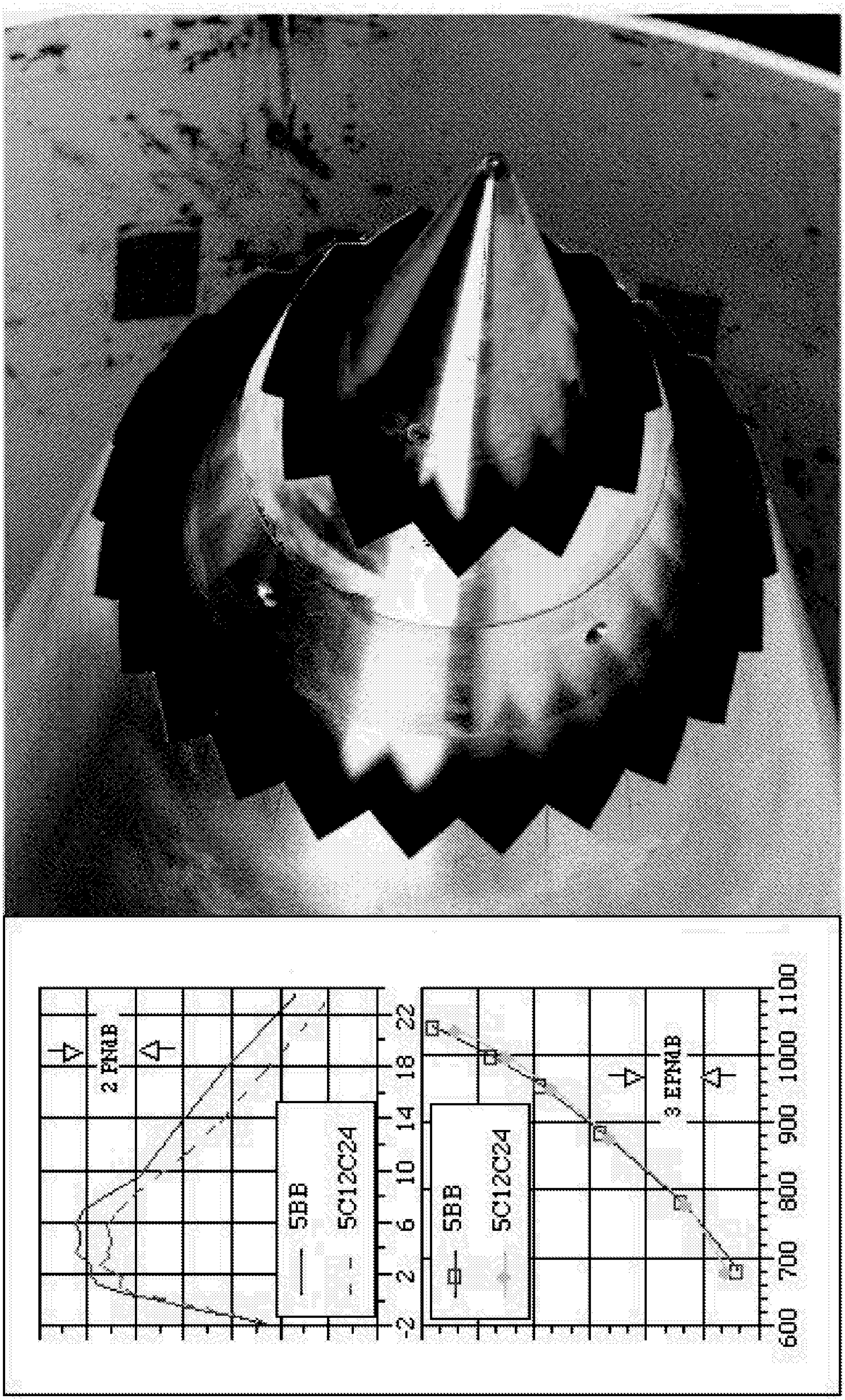
5BC

NASA
C-97-3438





$5C_{12}C$



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Advanced Subsonic Technology

Noise Reduction Element

Separate Flow Nozzle Tests for

Engine Noise Reduction sub-element

Presented to AST Participants

September 10, 1997

Naseem H. Saiyed
NASA Lewis Research Center
Cleveland, Ohio

Table of Contents

* Delta EPNLs at end of each model section.

Advanced Subsonic Technology (AST)

- Accelerate development of enabling technologies to maintain U.S. leadership in aeronautics
- Noise Reduction: One of 13 elements of AST

  Goal: Achieve 10 dB reduction relative to 1992 by 2000

- Engine Noise Reduction: One of five sub-elements of Noise Reduction

  Goal: Achieve 6 dB reduction relative to 1992 by 2000 for engine

  Intermediate jet noise goal:

  3 dB reduction by 1997

Separate Flow Nozzle Test (SFNT)

- Jet noise test in support of Engine Noise Reduction sub-element
- Cooperative effort between LeRC, PW, Boeing, GE and Allison
- Test objectives:
  - a. Develop data base for separate flow nozzles (acoustics, flow-field, and source location)
  - b. Screen various noise reduction concepts for full scale engine tests
- Scale model testing completed

General Information

- Data acquired in LeRC's Aeroacoustic and Propulsion Lab
- Anechoic dome with 25 microphones at 50 foot nominal radius from 45° to 160° at 5° increment
- EPNL confidence of +/- 0.25 EPNdB
- Forward flight of 0.28 Mach simulated with an ejector tunnel
- Scale factor of 8 used for full scale simulation
- Data presented for level fly-over at 1500 foot sideline, 14.7 psia, 77°F and 70% r.h., One engine only

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Test Matrix

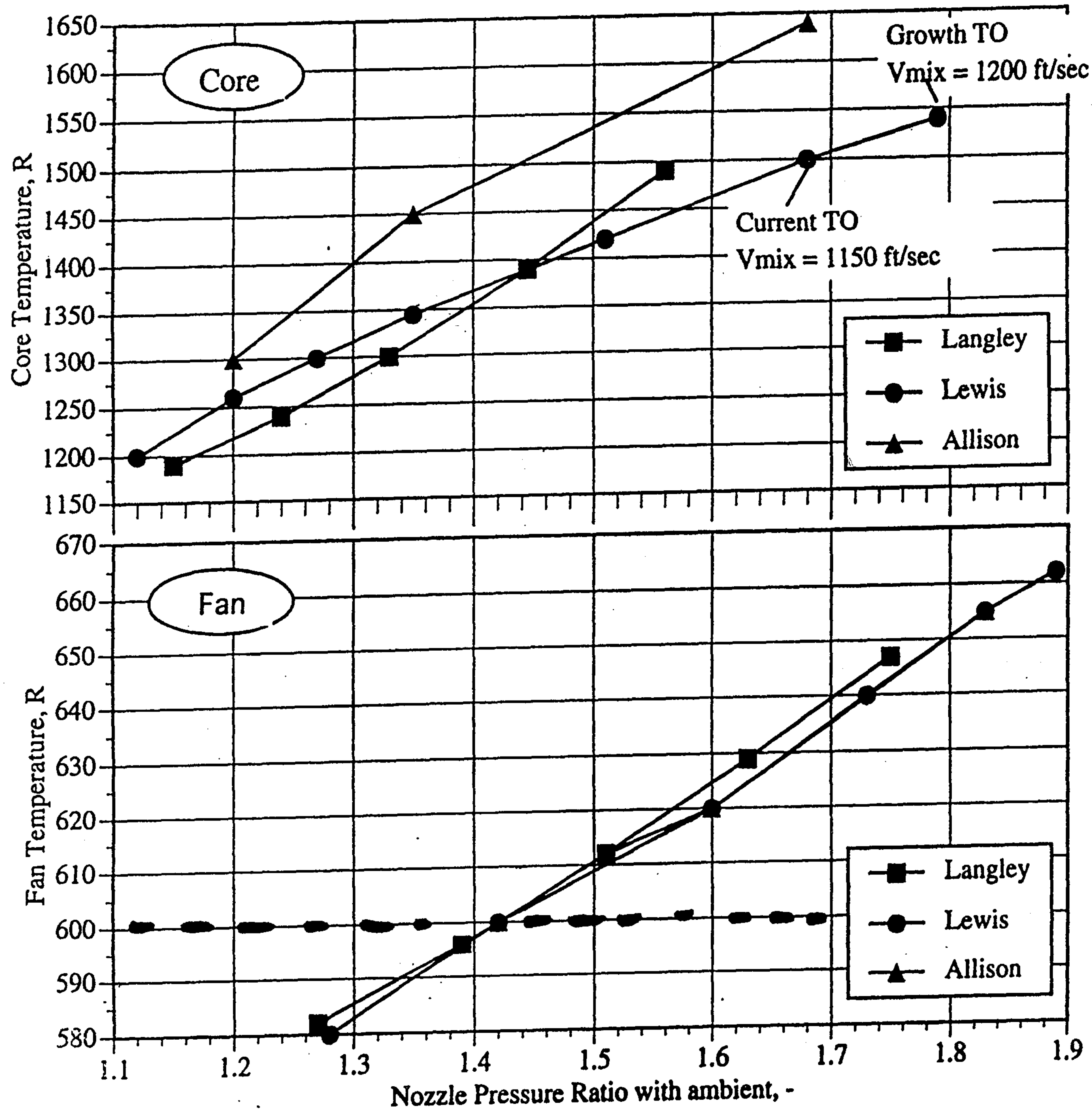
- Bypass Ratio 5 and 8
- Bypass Ratio 5 cycle points were a compromise between GE and PW
- Fan temperature maintained at 600 R due to excessive time in gaining "on-point" status
- Static and forward flight at 0.2 and 0.28 Mach
- Test Hardware parameters varied:

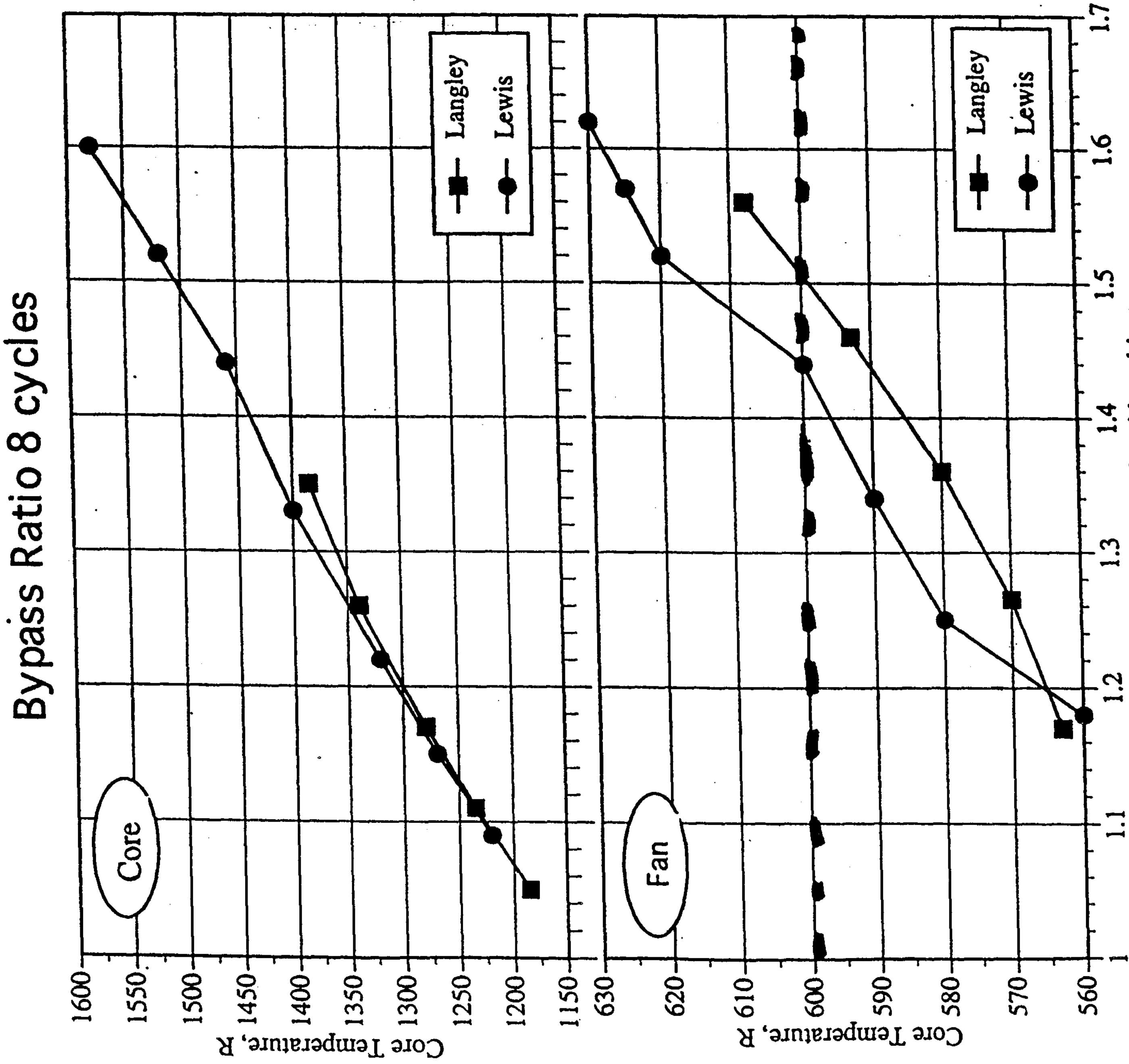
a. Core plug (internal and external)

b. Fan nozzles (chevrons, tabs, scarfed, off-set, doublets)

c. Core nozzles (vortex generator doublets, tabs, mixers, chevrons)

Bypass Ratio 5 cycles




Bypass Ratio 8 cycles
Core
Fan
Langley
Lewis
Core Temperature, R
Nozzle Pressure Ratio with ambient, -
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
630
620
610
600
590
580
570
560
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7

Test Hardware

- Hardware nomenclature:

A	12 Alternating flipper chevrons
B	Baseline (clean nozzle without any enhancer device)
C12 and C24	12 chevrons and 24 chevrons (for fan C24 = C)
Di	Interior doublet
Dx	Exterior doublet
Fm	Full mixer
Hm	Half mixer
I	12 Inward flipper chevrons
O	Fan off-set nozzle
S	Scarfed nozzle
T24 and T48	24 flipper tab and 48 flipper tabs
Tm	Tongue mixer

- Hardware designation: [model #][core nozzle][fan nozzle]

- Example: 3T24T48 = [model 3] with [24 tabs on core nozzle] and [48 tabs on fan nozzle]

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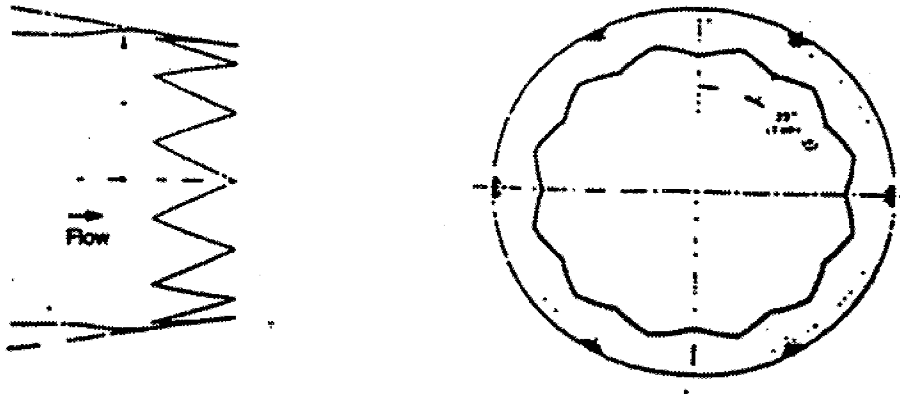
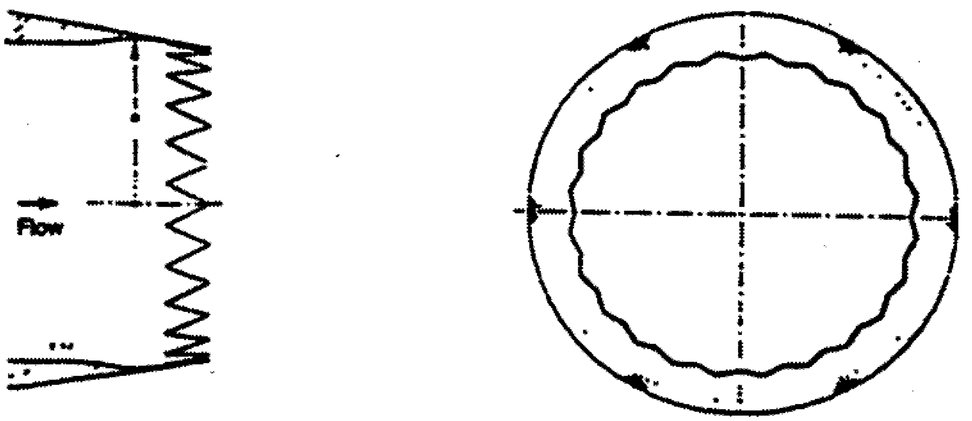


12 Chevrons Applied to External Plug Core Nozzle



24 Chevrons Applied to Fan Nozzle

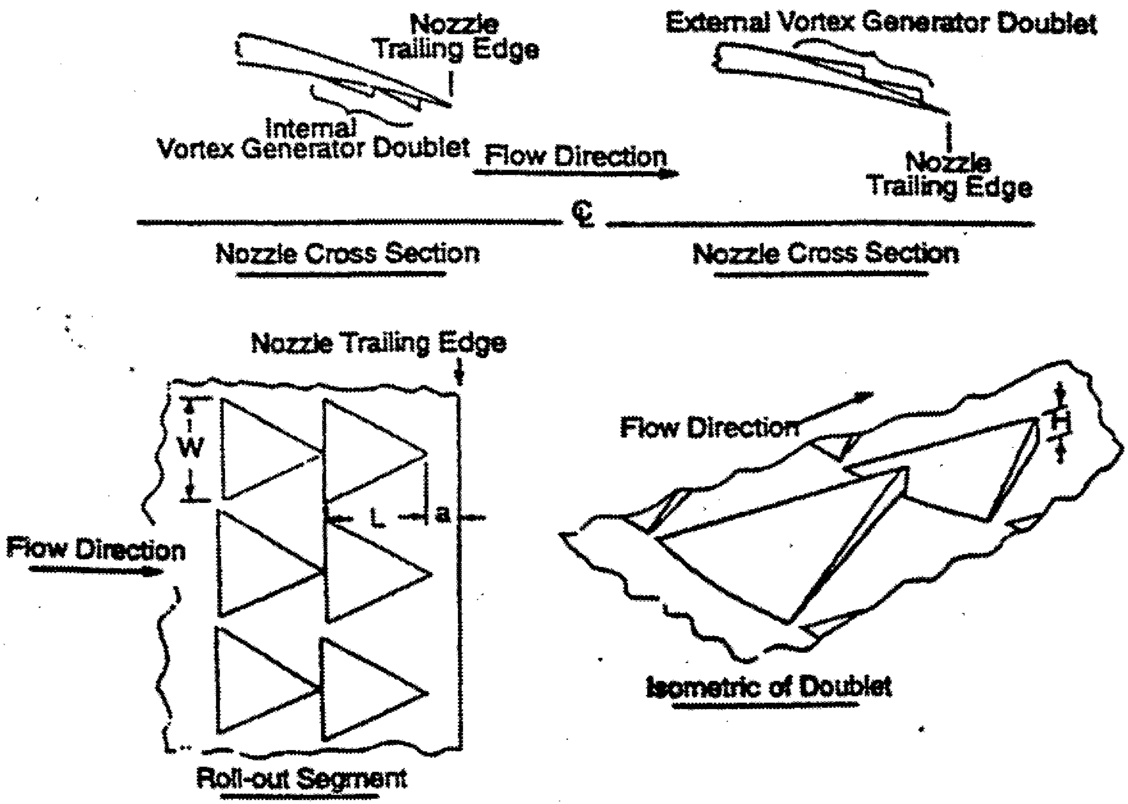
Flipper Chevron Located on External Plug Nozzle
(All Chevrons Penetrating the Core Flow)

Flipper Chevrons Located on External Plug Nozzle
(Alternating Chevrons Penetrating the Core/Fan Flows)

Figure 6.

Figure 7.

Vortex Generator Doublet Description



Doublet Design and Installation Information

Description	# Doublets	H [in.]	a [in.]	L [in.]	W [in.] (arc length)
internal placement on the BPR=5, external plug core nozzle	64	0.05	0.50	0.35	0.25
external placement on the BPR=5, external plug core nozzle	20	0.15	0.50	1.05	.75
internal placement on the fan nozzle common to models 2-5	96	0.06	0.60	0.42	0.30

Figure 8. Tongue Mixer Concept

CONTOUR 1 INSPECTIONS

X	R	INSPECTED THETA 15°	195°
4.0352	2.9232		
4.1346	2.9028		
4.7865	2.7709		
5.4423	2.6391		
6.0964	2.5072		
6.7493	2.3755		
7.4031	2.2436		

CONTOUR 2 INSPECTIONS

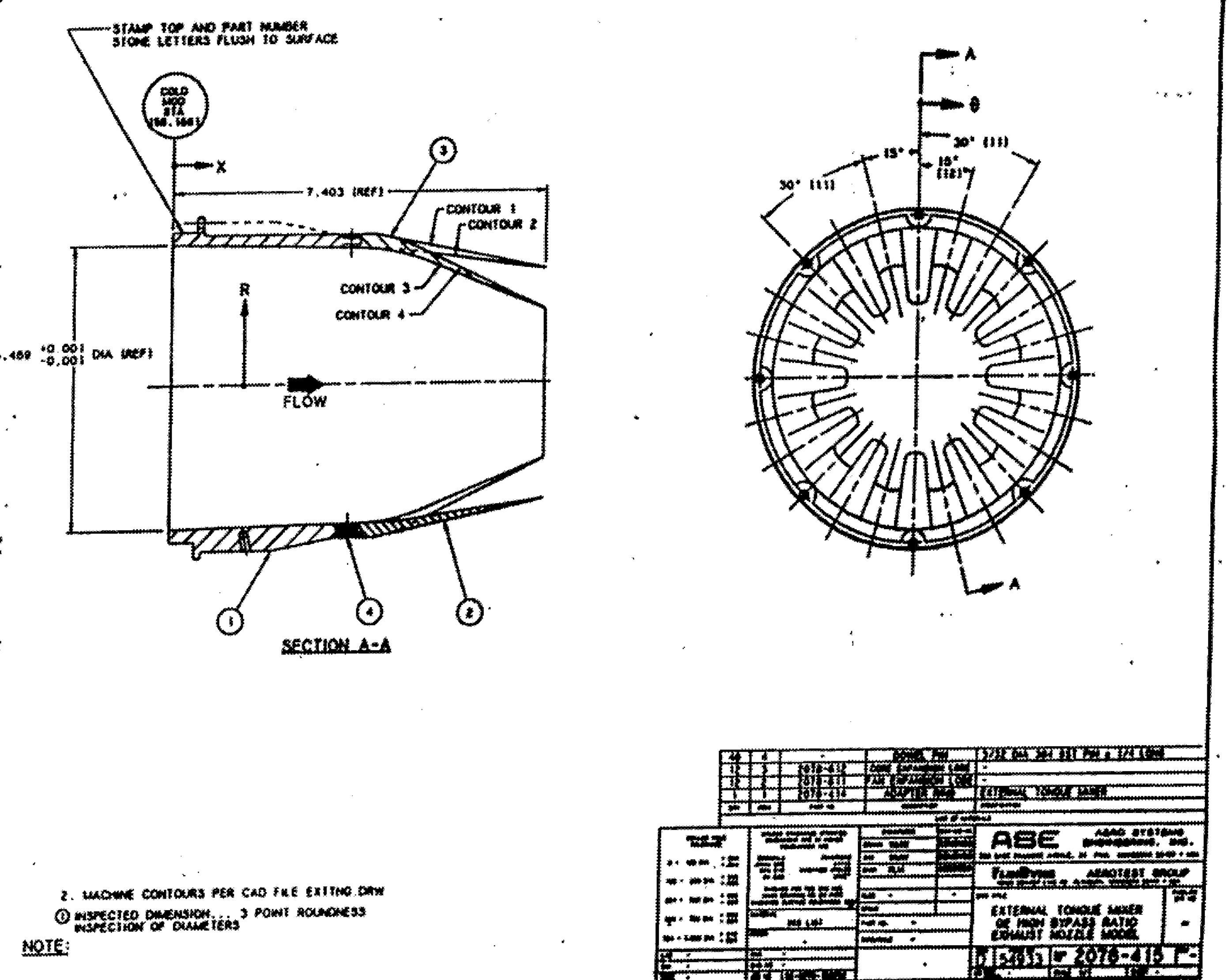
X	R	INSPECTED THETA 15°	195°
0.0000	2.7445		
0.4111	2.7351		
0.8235	2.7257		
1.2360	2.7163		
1.8477	2.7069		
2.0590	2.6976		
2.4718	2.6882		
2.8836	2.6788		
3.2958	2.6694		
3.7072	2.6600		
4.0232	2.6524		
4.3986	2.6357		
4.7430	2.5995		
5.0661	2.5517		
5.6650	2.4711		
6.2454	2.3901		
6.8238	2.3094		
7.4031	2.2286		

CONTOUR 3 INSPECTIONS

X	R	INSPECTED THETA 0°	180°
0.0000	2.7445		
0.4111	2.7351		
0.8235	2.7257		
1.2360	2.7163		
1.8477	2.7069		
2.0590	2.6976		
2.4718	2.6882		
2.8836	2.6788		
3.2956	2.6694		
3.7072	2.6598		
4.1402	2.6285		
4.5874	2.5463		
4.9820	2.4203		
5.3667	2.2810		
5.7669	2.1004		
6.1936	1.9393		
6.5862	1.7785		
7.0004	1.6172		
7.4031	1.4565		

CONTOUR 4 INSPECTIONS

X	R	INSPECTED THETA 0°	180°
4.0352	2.9232		
4.1346	2.9028		
4.3828	2.8417		
4.8224	2.7603		
4.9562	2.6594		
5.0667	2.5514		
5.5495	2.3359		
6.0139	2.1197		
6.4766	1.9035		
6.9394	1.6878		
7.4031	1.4715		



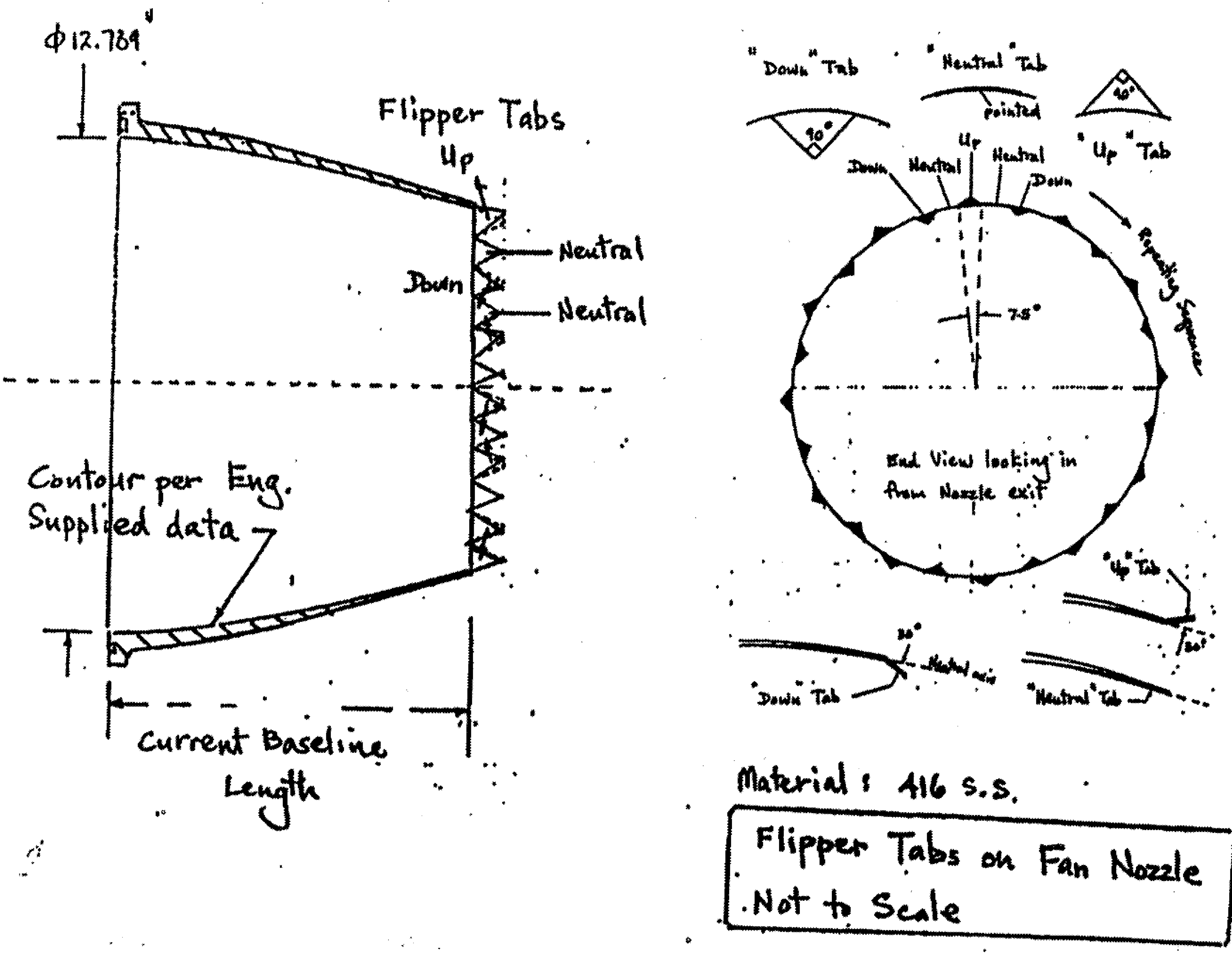


Figure 10. Fan Nozzle Flipper Tabs Example

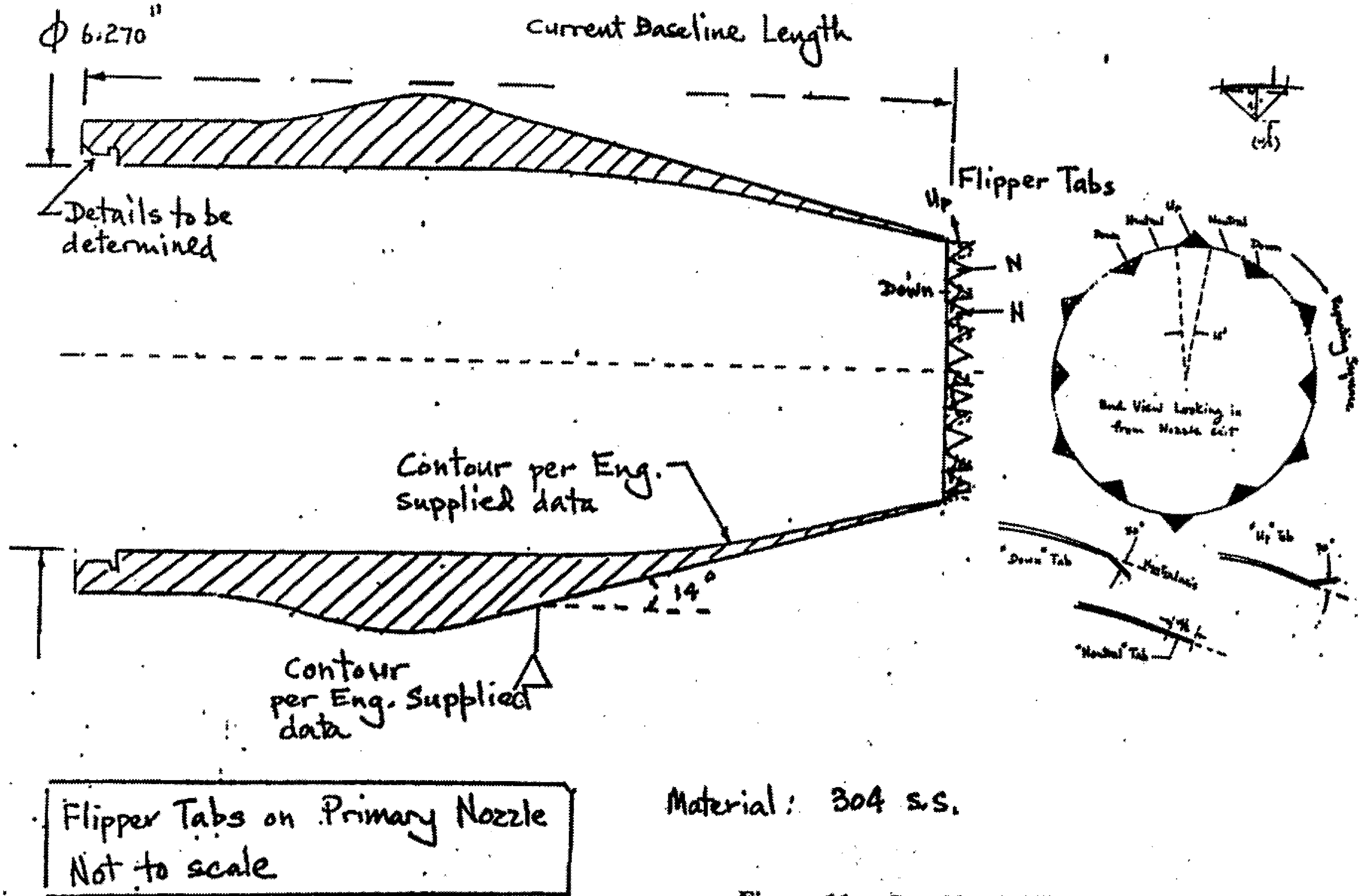


Figure 11. Core Nozzle Flipper Tabs Example

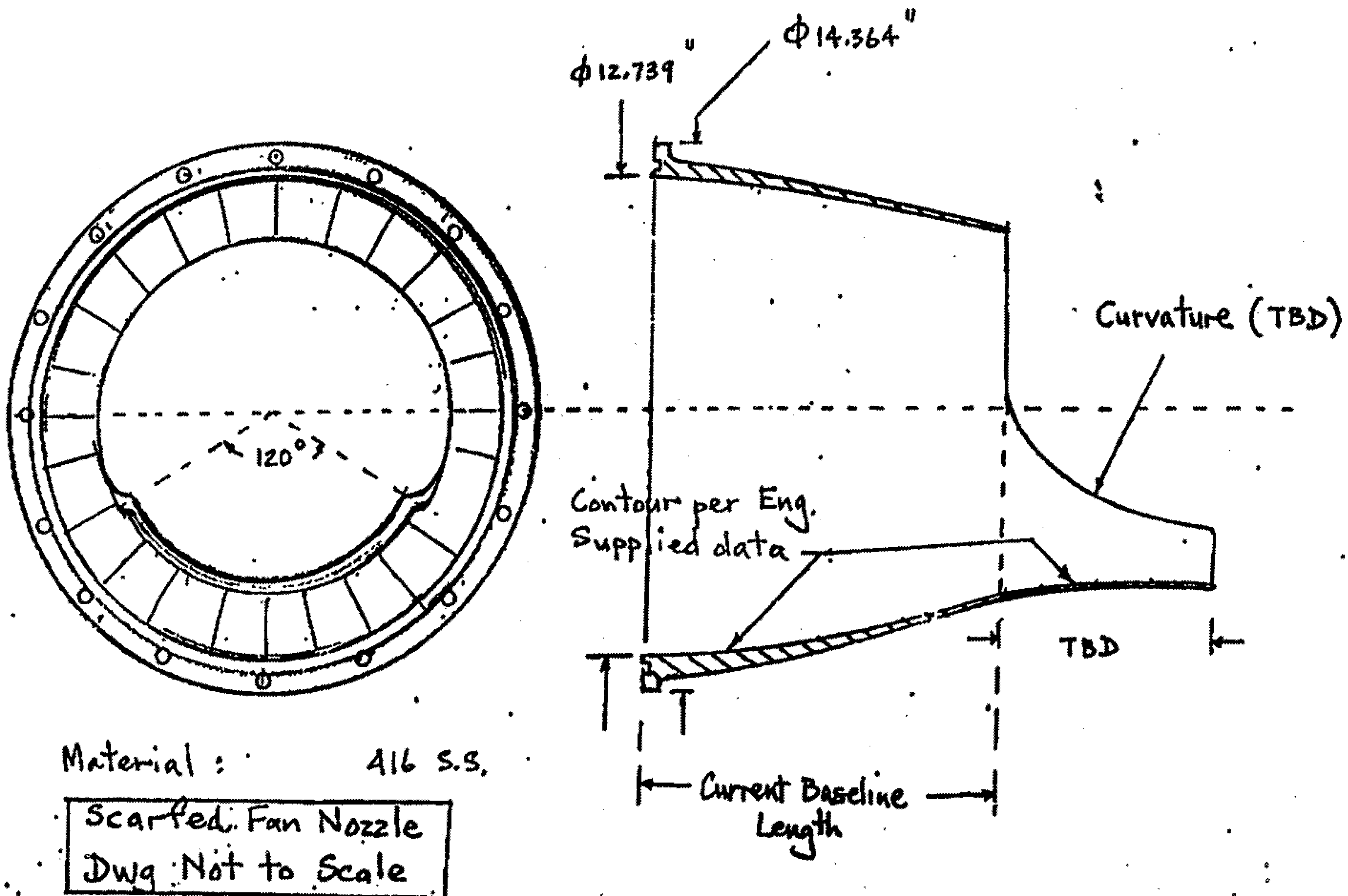


Figure 12. Scarfed Fan Nozzle Schematic

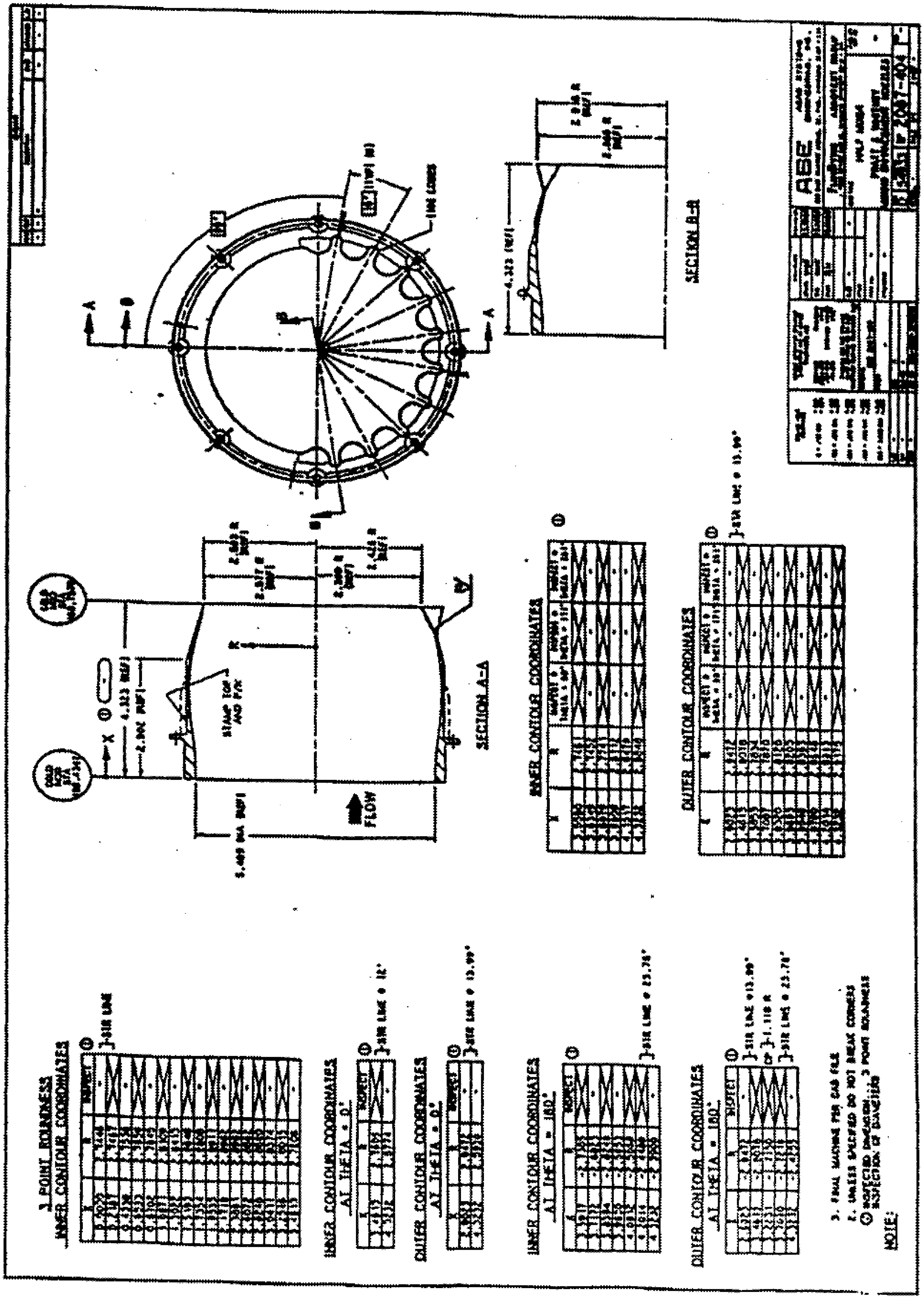


Figure 13. Half Mixer Concept

The offset centerline distance (z) will be a function of the axial distance (x) from the attachment flange of the fan nozzle. This offset distance is governed by the following equation:

$$z = \frac{H}{2}\left[\cos\left(\frac{\pi x}{L}\right) - 1\right]$$

where H is the maximum offset distance, and

L is the current baseline fan nozzle length.

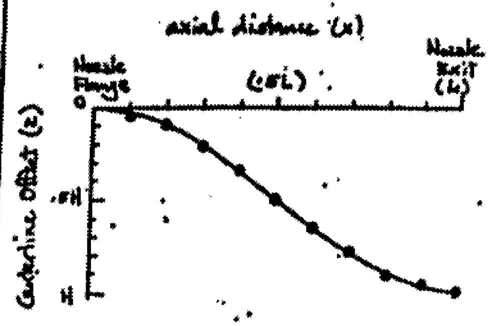
Two set of fan offset centerline nozzles are to be fabricated with the following maximum offset distances;

(1) H = 0.25", L = 10.216"

(2) H = 0.50", L = 10.216"

$$z = \frac{H}{2}\left[\cos\left(\frac{\pi x}{L}\right) - 1\right]$$

x	z
.0	0
.1L	-0.024H
.2L	-0.095H
.3L	-0.206H
.4L	-0.345H
.5L	-0.500H
.6L	-0.654H
.7L	-0.794H
.8L	-0.905H
.9L	-0.976H
L	-H



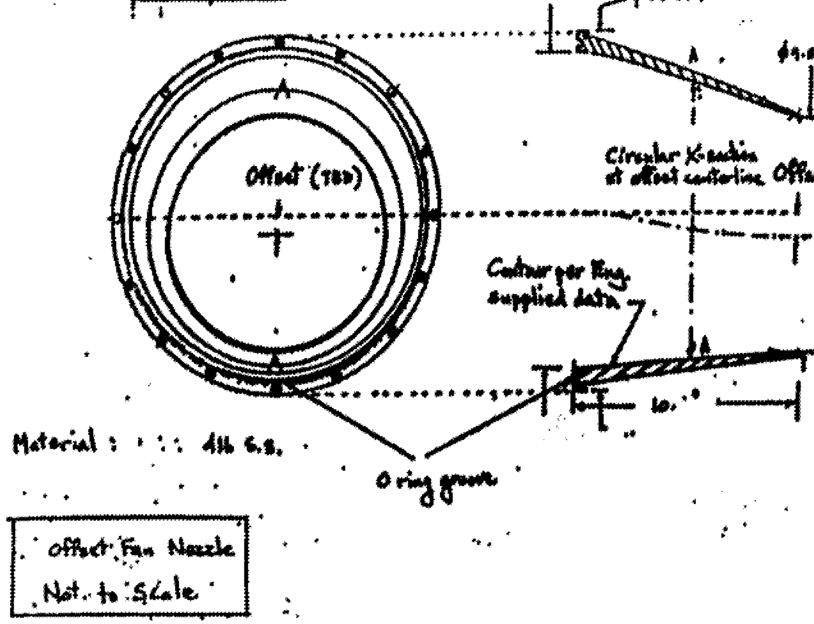


Figure 14. Offset Nozzle Concept

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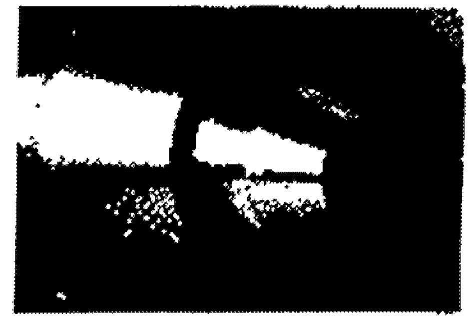
Baseline Configurations for all models

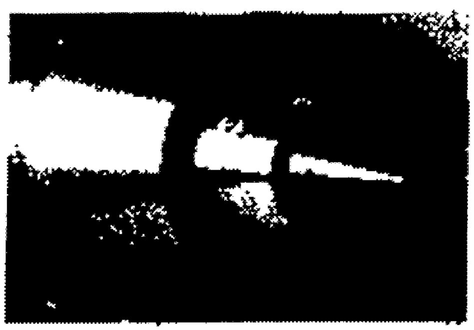
3BB, 5 BPR

2BB, 5 BPR



1BB, 5BPR

5BB, 8 BPR



4BB, 8 BPR

- Model 1: Co-Planar nozzle, 5 BPR (1BB)
- Model 2: Internal plug, shortened fan, 5 BPR

Core Nozzle	Fan Nozzle		
	B (baseline)	C24 (24 chevrons)	D (doublets)
B (baseline)	√	3	6
C12 (12 chevrons)	1*	4	
Tm (tongue mixer)	2	5	

* Note: These numbers refer to the photographs of hardware with pnl directivity and epnl vs vmix data superimposed .

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■ Model 3: External plug, shortened fan, 5 BPR (work horse)

Core Nozzle	Fan Nozzle						
	B (baseline)	C24 (24 chevrons)	D (internal doublet)	S (scarfed)	O (offset)	T24 (24 flipper tabs)	T48 (48 flipper tabs)
B (baseline)	√	17		26	28	30	32
T24 (24 flipper tabs)	7	18				31	33
T48 (48 flipper tabs)	8	19					34
C8 (8 chevrons)	9	20					
C12 (12 chevrons)	10	21					
I (12 Inward flip. chevrons)	11	22					
A (12 alternating flip chev)	12	23					
Di (internal doublet)	13						
Dx (external doublet)	14						
Hm (Half mixer)	15	24		27	29		
Fm (Full mixer)	16	25					

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- Model 4: Internal plug, shortened fan, 8 BPR
- Model 5: External plug, shortened fan, 8 BPR

Core Nozzle	Fan Nozzle	
	B (baseline)	C24 (24 chevrons)
B (baseline)	√	36
C12 (12 chevrons)	35	37

Table 1. Separate Flow Nozzle Acoustic Test Summary.

Test Config.	Config. Code	Model No.	BPR	Plug	Core Mixing Enhancer	Fan Concept Enhancer	Mixing Concept Orig.	Clock Pos.	Mach Number	Total No. of Power Settings	Data Points	Date Tested
1	100000	1	5	Int.	Base	Base	GEAE	0	0,0.20,0.28	Cyc. 1&2&5	42	3/20/97
2BB	200000	2	5	Int.	Base	Base	GEAE	0	0,0.20,0.28	Cyc. 1&2&5	38	3/25/97
2BB(r)	2000000	2	5	Int.	Base	Base	GEAE	0	0,0.20,0.28	Cyc. 1&2	16	4/21/97
2BD	200200	2	5	Int.	Base	96 Int. Doub.	GEAE	0	0.28	Cycle 2	10	3/25/97
2BC	200100	2	5	Int.	Base	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	18	3/28/97
2BC(r)	2000100	2	5	Int.	Base	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	7	4/21/97
2CC	201100	2	5	Int.	12 Chev.	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	17	3/27/97
2CC(r)	2010100	2	5	Int.	12 Chev.	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	7	4/21/97
2CC*	201800	2	5	Int.	12 Chev.	24 Chev.(blt)	GEAE/NASA	0	0.28	Cycle 2	6	3/27/97
2CB	201000	2	5	Int.	12 Chev.	Base	GEAE	0	0,0.20,0.28	Cycle 2	18	3/27/97
2TmB	210000	2	5	Int.	Tongue Mix.	Base	GEAE/AEC	0	0,0.20,0.28	Cycle 2	21	3/26/97
2TmC	210100	2	5	Int.	Tongue Mix.	24 Chev.	GEAE/AEC	0	0,0.20,0.28	Cycle 2	21	3/26/97
3BB	300000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycles 1&2	38	4/1/97
3BC*	300900	3	5	Ext.	Base	24 Chev.(vg)	GEAE/NASA	0	0.28	Cycle 2	6	4/1/97
3BC	300100	3	5	Ext.	Base	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	23	4/2/97
3BS(0)	300700	3	5	Ext.	Base	Scarf Noz.	P&W	0	0,0.20,0.28	Cycle 2	18	4/2/97
3BS(90)	300709	3	5	Ext.	Base	Scarf Noz.	P&W	90	0,0.20,0.28	Cycle 2	7	4/2/97
3BS(180)	300718	3	5	Ext.	Base	Scarf Noz.	P&W	180	0,0.20,0.28	Cycle 2	7	4/2/97
3BOmax(0)	3000500	3	5	Ext.	Base	Max. Offset Noz.	P&W	0	0,0.20,0.28	Cycle 2	8	4/9/97
3BOmax(0)(r)	3000500	3	5	Ext.	Base	Max. Offset Noz.	P&W	0	0.28	Cycle 2	5	4/10/97
3BOmax(90)	3000509	3	5	Ext.	Base	Max. Offset Noz.	P&W	90	0,0.20,0.28	Cycle 2	7	4/10/97
3BOmax(180)	3000518	3	5	Ext.	Base	Max. Offset Noz.	P&W	180	0,0.20,0.28	Cycle 2	7	4/10/97
$3BT_{24}$	3000300	3	5	Ext.	Base	24 Flip Tabs	P&W	0	0,0.20,0.28	Cycle 2	7	4/11/97
$3BT_{48}$	3000400	3	5	Ext.	Base	48 Flip Tabs	P&W	0	0,0.20,0.28	Cycle 2	8	4/10/97
$3T_{24}T_{24}$	3070300	3	5	Ext.	24Flip Tabs	24 Flip Tabs	P&W	0	0,0.20,0.28	Cycle 2	8	4/23/97
$3T_{24}B$	3070000	3	5	Ext.	24 Flip Tabs	Base	P&W	0	0,0.20,0.28	Cycle 2	8	4/23/97
$3T_{48}B$	3080000	3	5	Ext.	48 Flip Tabs	Base	P&W	0	0,0.20,0.28	Cycle 2	8	4/23/97
$3T_{48}T_{48}$	3080400	3	5	Ext.	48 Flip Tabs	48 Flip Tabs	GEAE/P&W	0	0,0.20,0.28	Cycle 2	7	4/23/97
3T48C	3080100	3	5	Ext.	48 Flip Tabs	24 Chev.	P&W	0	0.28	Cycle 2	5	4/23/97
3HmB(0)	3090000	3	5	Ext.	Half Mix.	Base	P&W	0	0,0.20,0.28	Cycle 2	18	4/3/97
3HmB(0)(r)	3090000	3	5	Ext.	Half Mix.	Base	P&W	0	0,0.20,0.28	Cycle 2	9	4/8/97
3HmB(0)(r)	3090000	3	5	Ext.	Half Mix.	Base	P&W	0	0.28	Cycle 2	5	4/17/97
3HmB(90)	3090009	3	5	Ext.	Half Mix.	Base	P&W	90	0,0.20,0.28	Cycle 2	7	4/3/97
3HmB(180)	3090018	3	5	Ext.	Half Mix.	Base	P&W	180	0,0.20,0.28	Cycle 2	7	4/3/97
3HmB(45)	3090045	3	5	Ext.	Half Mix.	Base	P&W	45	0,0.20,0.28	Cycle 2	9	4/17/97

Notes: (blt) = boundary layer trip
(vg) = vortex generators
Total Number of Data Points includes background noise conditions

Table 1. – AAPL Separate Flow Nozzle Acoustic Test Summary (Concluded).

Test Config.	Config. Code	Model No.	BPR	Plug	Mixing Enhancer	Concept Enhancer	Concept Orig.	Clock Pos.	Mach Number	Power Settings	Data Points	Date Tested
2BD	200200	2	5	Int.	Base	96 Int. Doub.	GEAE	0	0.28	Cycle 2	10	3/25/97
3HmS(0)	3090700	3	5	Ext.	Half Mix.	Scarf Noz.	P&W	0	0,0.20,0.28	Cycle 2	13	4/3/97
3HmC(0)	3090100	3	5	Ext.	Half Mix.	24 Chev.	GEAE/P&W	0	0,0.20,0.28	Cycle 2	18	4/4/97
3HmC(0)(r)	3090100	3	5	Ext.	Half Mix.	24 Chev.	GEAE/P&W	0	0,0.20,0.28	Cycle 2	1	4/8/97
3HmC(45)	3090145	3	5	Ext.	Half Mix.	Base	GEAE/P&W	45	0,0.20,0.28	Cycle 2	15	4/8/97
3HmOmax(0)	3090500	3	5	Ext.	Half Mix.	Max. Offset Noz.	P&W	0	0,0.20,0.28	Cycle 2	12	4/9/97
$3C_{12}B$	3010000	3	5	Ext.	12 Chev.	Base	GEAE	0	0,0.20,0.28	Cycle 2	10	4/11/97
$3C_{12}C$	3010100	3	5	Ext.	12 Chev.	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	8	4/15/97
$3C_8C$	3020100	3	5	Ext.	8 Chev.	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	7	4/16/97
$3C_8B$	3020000	3	5	Ext.	8 Chev.	Base	GEAE	0	0,0.20,0.28	Cycle 2	7	4/14/97
3IB	3030000	3	5	Ext.	12 In–Flip Chevs	Base	GEAE	0	0,0.20,0.28	Cycle 2	7	4/14/97
3IB(r)	3030000	3	5	Ext.	12 In–Flip Chevs	Base	GEAE	0	0,0.20,0.28	Cycle 2	7	4/15/97
3IC	3030100	3	5	Ext.	12 In–Flip Chevs	24 Chev.	GEAE	0	0,0.20,0.28	Cycles 2&6	7	4/15/97
3IC(r)	3030100	3	5	Ext.	12 In–Flip Chevs	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	27	4/18/97
3AC	3040100	3	5	Ext.	12 Alt–Flip Chevs	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 2	7	4/16/97
3AB	3040000	3	5	Ext.	12 Alt–Flip Chevs	Base	GEAE	0	0,0.20,0.28	Cycle 2	7	4/14/97
3DiB	3050000	3	5	Ext.	64 Int. Doub.	Base	GEAE	0	0,0.20,0.28	Cycle 2	9	4/15/97
3DxB	3060000	3	5	Ext.	20 Ext.Doub.	Base	GEAE	0	0,0.20,0.28	Cycle 2	7	4/17/97
5BB	5000000	5	8	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycles 3&4	24	4/22/97
5BC	5000100	5	8	Ext.	Base	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 4	8	4/22/97
5CC	5010100	5	8	Ext.	12 Chev.	24 Chev.	GEAE	0	0,0.20,0.28	Cycle 4	8	4/22/97
5CB	5010000	5	8	Ext.	12 Chev.	Base	GEAE	0	0,0.20,0.28	Cycle 4	8	4/22/97
4BB	4000000	4	8	Int.	Base	Base	GEAE	0	0,0.20,0.28	Cycles 3&4	24	4/21/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	20	4/4/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0	Cycle 2	21	4/7/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	10	4/8/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	11	4/9/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	10	4/10/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	7	4/11/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	8	4/14/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	12	4/15/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	8	4/16/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	8	4/17/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cyc. 1&2&6	20	4/18/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	7	4/23/97

Notes: (blt) = boundary layer trip
(vg) = vortex generators
Total Number of Data Points includes background noise conditions

Table 2. Additional AAPL Separate Flow Nozzle Acoustic Testing.

Test Config.	Config. Code	Model No.	BPR	Plug	Mixing Enhancer	Concept Enhancer	Concept Orig.	Clock Pos.	Mach Number	Power Settings	Data Points	Date Tested
3HmOmax(0)	3090500	3	5	Ext.	Half Mix.	Max. Offset Noz.	P&W	0	0,0.20,0.28	Cycle 2	12	4/9/97
2BB(r)	2000000	2	5	Int.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	10	5/12/97
6TmB	6100000	2	5	New	Tongue Mix.	Base	GEAE/AEC	0	0,0.20,0.28	Cycle 2	7	5/12/97
6TmC	6100100	2	5	New	Tongue Mix.	24 Chev.	GEAE/AEC	0	0,0.20,0.28	Cycle 2	7	5/12/97
7BB	7000000	4	14	New	Base	Base	NASA	0	0,0.20,0.28	Cycle 7	7	5/12/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,0.20,0.28	Cycle 2	10	5/13/97
3FB	3110000	3	5	Ext.	Full Mix.	Base	NASA	0	0,0.28	Cycle 2	6	5/13/97
3HmB(0)r	3090000	3	5	Ext.	Half Mix.	Base	P&W	0	0,0.28	Cycle 2	6	5/13/97
3FC	3110100	3	5	Ext.	Full Mix.	24 Chev.	GEAE/NASA	0	0,0.28	Cycle 2	6	5/13/97
3T24T48	3070400	3	5	Ext.	24 Flip Tabs	48 Flip Tabs	P&W	0	0,.28	Cycle 2	6	5/13/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0,.20,.28	Cycle 2	10	6/17/97
3T24C	3070100	3	5	Ext.	24 Flip Tabs	24 Chev.	GEAE/P&W	0	0,.20,.28	Cycle 2	8	6/17/97
3BB(r)	3000000	3	5	Ext.	Base	Base	GEAE	0	0.28	Cycle 2	5	6/18/97
3T24B(r)	3070000	3	5	Ext.	24 Flip Tabs	Base	P&W	0	0.28	Cycle 2	6	6/18/97

Note: Matrix does not include flexible wire (attached to centerbody plug trailing edge) configurations testing conducted on 6/18/97.

Table 3. AAPL Separate Flow Nozzle Phased Array (NASA) Test Summary.

Seq.	Test Config.	Model #	BPR	Plug	Core Nozzle	Fan Nozzle	Clock Position	M	Cycle/P.S.	Escort Rdgs.	Date Tested
1	2BB	2	5	Int.	Base	Base	N/A	?	?	?	3/25/97
2	2BD	2	5	Int.	Base	96 Int. Doub.	N/A	?	?	?	3/25/97
3	2CC	2	5	Int.	12 Chev.	24 Chev.	N/A	0,.28	2/20	339,340	3/27/97
4	2BC	2	5	Int.	Base	24 Chev.	N/A	0,.28	2/20	352,353	3/28/97
5	3HmB(90)	3	5	Ext.	Half Mix.	Base	90	0,.28	2/21	497,500	4/3/97
6	3HmB(180)	3	5	Ext.	Half Mix.	Base	180	0,.28	2/21	505,507	4/3/97
7	3BB	3	5	Ext.	Base	Base	N/A	0,.28	2/20,21	549,561	4/4/97
8	3BB	3	5	Ext.	Base	Base	N/A	0	2/Special	576–585	4/7/97
9	3HmB(0)	3	5	Ext.	Half Mix.	Base	0	0,.28	2/21	603,606	4/8/97
10	3BOmax(0)	3	5	Ext.	Base	Max. Offset Noz.	0	.28	2/21	655 or 657	4/9/97
11	3HmOmax(0)	3	5	Ext.	Half Mix.	Max. Offset Noz.	0	0,.28	2/20,21	668,670	4/9/97
12	3BOmax(90)	3	5	Ext.	Base	Max. Offset Noz.	90	0.28	2/20	690	4/10/97
13	3BOmax(180)	3	5	Ext.	Base	Max. Offset Noz.	180	0.28	2/20	697	4/10/97
14	3BT48	3	5	Ext.	Base	48 Flip Tabs	N/A	0.28	2/20	709	4/10/97
15	3BT24	3	5	Ext.	Base	24 Flip Tabs	N/A	0.28	2/20	727	4/11/97
16	3C12B	3	5	Ext.	12 Chev.	Base	N/A	0.28	2/20	741	4/11/97
17	3IB	3	5	Ext.	12 In–Flip Chevs.	Base	N/A	0.28	2/20	771	4/14/97
18	3AB	3	5	Ext.	12 Alt–Flip Chevs.	Base	N/A	0.28	2/20	778	4/14/97
19	3DiB	3	5	Ext.	64 Int. Doub.	Base	N/A	.28	2/20	801	4/15/97
20	3IC	3	5	Ext.	12 In–Flip Chevs.	24 Chev.	N/A	.28	2/20	816	4/15/97
21	3C12C	3	5	Ext.	12 Chev.	24 Chev.	N/A	.28	2/20	824 or 828	4/15/97
22	3C8C	3	5	Ext.	8 Chev.	24 Chev.	N/A	.28	2/20	843	4/16/97
23	3AC	3	5	Ext.	12 Alt–Flip Chevs.	24 Chev.	N/A	.28	2/20	851	4/16/97
24	3HmB(45)	3	5	Ext.	Half Mix.	Base	45	.28	2/20	875	4/17/97
25	3DxB	3	5	Ext.	20 Ext. Doub.	Base	N/A	.28	2/20	882	4/17/97
26	3IC	3	5	Ext.	12 In–Flip Chevs.	24 Chev.	N/A	.28	2/20	892	4/18/97
27	3BB	3	5	Ext.	Base	Base	N/A	.28	2/20	918	4/18/97
28	2BC	2	5	Ext.	Base	Base	N/A	.28	2/20	958	4/21/97
29	4BB	4	8	Int.	Base	Base	N/A	.28	4/41	975	4/21/97

Table 4. AAPL Separate Flow Nozzle Phased Array (Boeing) Test Summary.

Seq.	Test Config.	Model #	BPR	Plug	Core Nozzle	Fan Nozzle	Clock Position	Array Angle	M	Cycle/P.S.	Escort Rdgs.	Date Tested
1	1	1	5	Int.	Base	Base	N/A	90	0,.2,.28	2/1–7,21–23	1088–1101	4/28/97
2	3IB	3	5	Ext.	12 In–Flip Chevs.	Base	N/A	90	0,.28	2/21–23	1102–1106	4/29/97
3	3IC	3	5	Ext.	12 In–Flip Chevs.	24 Chev.	N/A	90	0,.28	2/21–23	1107–1111	4/29/97
4	3BB	3	5	Ext.	Base	Base	N/A	90	0,.2,.28	2/20–24	1112–1119	4/29/97
5	3AB	3	5	Ext.	12 All–Flip Chevs.	Base	N/A	90	0,.28	2/21–23	1120–1124	4/30/97
6	3T24T48	3	5	Ext.	24 Flip Tabs	48 Flip Tabs	N/A	90	0,.28	2/21–23	1125–1129	4/30/97
7	3T48T48	3	5	Ext.	48 Flip Tabs	48 Flip Tabs	N/A	90	0,.2,.28	2/20–24	1130–1138	4/30/97
8	3T48B	3	5	Ext.	48 Flip Tabs	Base	N/A	90	0,.28	2/21–23	1139–1143	4/30/97
9	3HmB(0)	3	5	Ext.	Half Mix.	Base	0	90	0,.28	2/21–23	1144–1147	5/1/97
10	3HmB(90)	3	5	Ext.	Half Mix.	Base	90	90	0,.28	2/21,23	1148–1150	5/1/97
11	3HmB(180)	3	5	Ext.	Half Mix.	Base	180	90	0,.28	2/21,23	1151–1153	5/1/97
12	3T24B	3	5	Ext.	24 Flip Tabs	Base	N/A	90	0,.28	2/21–23	1154–1158	5/1/97
13	3T24T24	3	5	Ext.	24 Flip Tabs	24 Flip Tabs	N/A	90	0,.28	2/21–23	1159–1163	5/2/97
14	3BOmax(0)	3	5	Ext.	Base	Max. Offset	0	90	0,.28	2/21,23	1164–1166	5/2/97
15	3BOmax(180)	3	5	Ext.	Base	Max. Offset	180	90	0,0.28	2/21,23	1167–1169	5/2/97
16	3C12B	3	5	Ext.	12 Chev.	Base	N/A	90	0.28	2/21–23	1170–1172	5/2/97
17	2BB	2	5	Int.	Base	Base	N/A	90	0,.28	2/21,23	1173–1175	5/2/97
18	2BB	2	5	Int.	Base	Base	N/A	120	0,.28	2/21–23	1176–1180	5/5/97
19	3BB	3	5	Ext.	Base	Base	N/A	120	0,.28	2/21–23	1181–1185	5/5/97
20	3T24B	3	5	Ext.	24 Flip Tabs	Base	N/A	120	.28	2/21–23	1186–1188	5/5/97
21	3T24T24	3	5	Ext.	24 Flip Tabs	24 Flip Tabs	N/A	120	.28	2/21–23	1189–1191	5/5/97
22	3IC	3	5	Ext.	12 In–Flip Chevs.	24 Chev.	N/A	120	0,.28	2/21–23	1192–1196	5/6/97
23	3HmB(0)	3	5	Ext.	Half Mix.	Base	0	120	0,.28	2/21,23	1197–1199	5/6/97
24	3HmB(90)	3	5	Ext.	Half Mix.	Base	90	120	0,.28	2/21,23	1200–1202	5/6/97
25	3HmB(180)	3	5	Ext.	Half Mix.	Base	180	120	0,.28	2/21,23	1203–1205	5/6/97
26	3T24B	3	5	Ext.	24 Flip Tabs	Base	N/A	120	0	2/21,23	1206–1207	5/6/97
27	3T24T24	3	5	Ext.	24 Flip Tabs	24 Flip Tabs	N/A	120	0	2/21,23	1208–1209	5/6/97
28	3BOmax(0)	3	5	Ext.	Base	Max. Offset	0	120	0,.28	2/21–23	1210–1214	5/7/97
29	3BOmax(180)	3	5	Ext.	Base	Max. Offset	180	120	0,.28	2/21–23	1215–1219	5/7/97
30	3BS(0)	3	5	Ext.	Base	Scarf	0	120	0,.28	2/21–23	1220–1224	5/7/97
31	3BS(180)	3	5	Ext.	Base	Scarf	180	120	0,.28	2/21–23	1225–1229	5/7/97

Table 5. AAPL Separate Flow Nozzle Plume Survey Test Summary.

Sequence	Test Config.	Model #	BPR	Plug	Core Nozzle	Fan Nozzle	Clock Position	Date Tested
1	3BB	3	5	Ext.	Base	Base	N/A	5/20/97
2	3C12B	3	5	Ext.	12 Chev.	Base	N/A	5/20/97
3	3C12C	3	5	Ext.	12 Chev.	24 Chev.	N/A	5/21/97
4	3BC	3	5	Ext.	Base	24 Chev.	N/A	5/22/97
5	3IC	3	5	Ext.	12 In–Flip Chevs.	24 Chev.	N/A	5/22/97
6	3T24C	3	5	Ext.	24 Flip Tabs	24 Chev.	N/A	5/22/97
7	3C8B	3	5	Ext.	8 Chev.	Base	N/A	5/23/97
8	3IB	3	5	Ext.	12 In–Flip Chevs.	Base	N/A	5/23/97
9	3AB	3	5	Ext.	12 Alt–Flip Chevs.	Base	N/A	5/23/97
10	3HmB(90)	3	5	Ext.	Half Mix.	Base	90	5/23/97
11	3FB	3	5	Ext.	Full Mix.	Base	N/A	5/27/97
12	3T48B	3	5	Ext.	48 Flip Tabs	Base	N/A	5/27/97
13	3T24B	3	5	Ext.	24 Flip Tabs	Base	N/A	5/27/97
14	3T24T24	3	5	Ext.	24 Flip Tabs	24 Flip Tabs	N/A	5/27/97
15	3BT24	3	5	Ext.	Base	24 Flip Tabs	N/A	5/28/97
16	3BOmax(90)	3	5	Ext.	Base	Max. Offset Noz.	90	5/28/97
17	3T24T48	3	5	Ext.	24 Flip Tabs	48 Flip Tabs	N/A	5/28/97
18	4BB	4	8	Int.	Base	Base	N/A	5/29/97
19	1	1	5	Int.	Base	Base	N/A	5/30/97
20	6TmB	2	5	New	Tongue Mix.	Base	N/A	5/30/97
21	7BB	4	14	New	Base	Base	N/A	5/30/97
22	3BB	3	5	Ext.	Base	Base	N/A	6/30/97
23	3BC	3	5	Ext.	Base	24 Chev.	N/A	6/30/97
24	3BT24	3	5	Ext.	Base	24 Flip Tabs	N/A	6/30/97

Note: For all configurations, M=.28 & Cycle 2/Point 21 where test conditions.

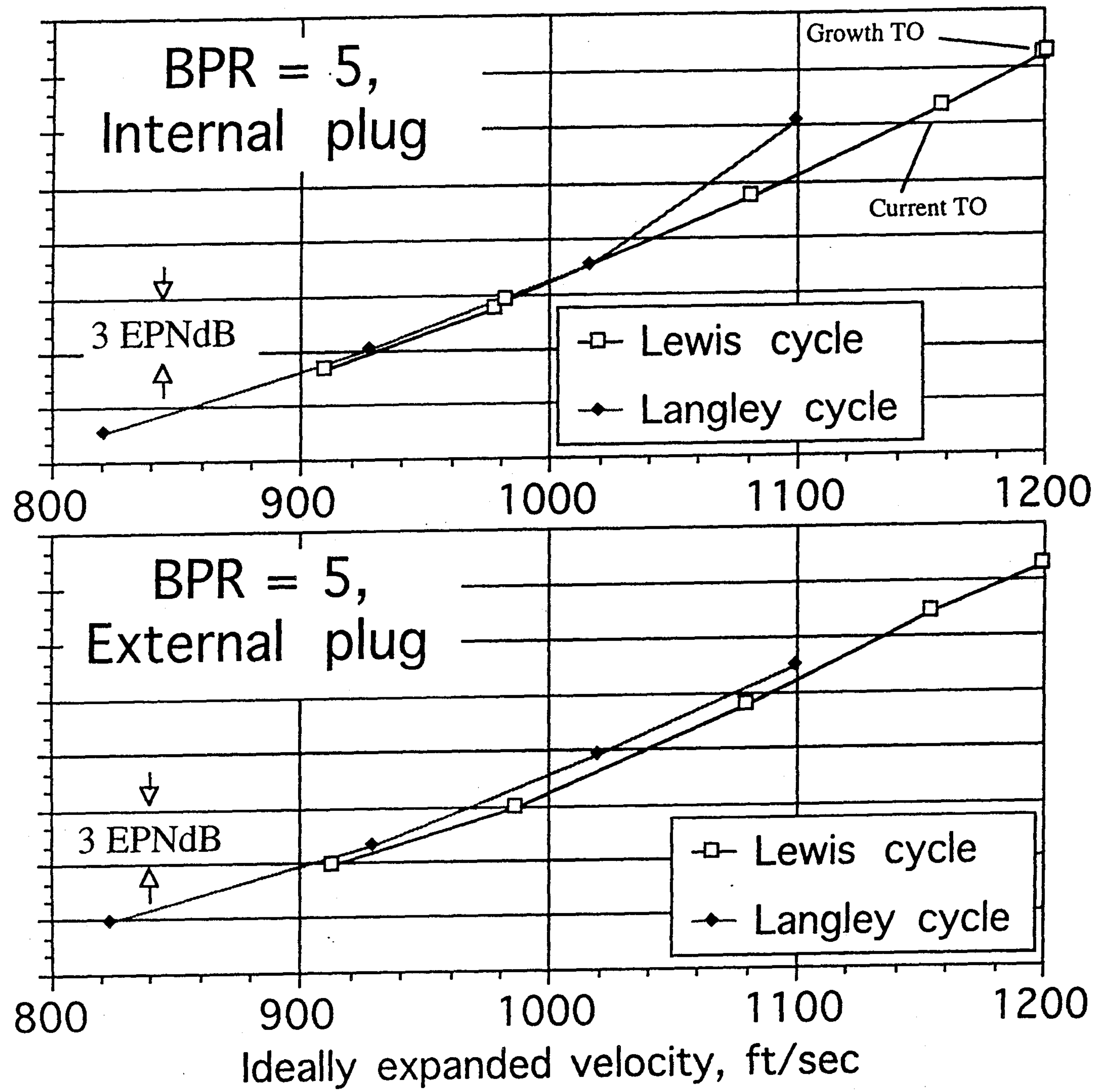
Table 6. AAPL Separate Flow Nozzle IR Camera Test Summary.

Configuration	Date	Mach No.	Cycle/Power Setting	Corresponding Escort Rdg.	IR #
?	?	?	?	?	1
?	?	?	?	?	2
?	?	?	?	?	3
3HmB(0)	4/8/97	0.28	2/20	603	4
3HmB(0)	4/8/97	0.20	2/21	605	5
3HmB(0)	4/8/97	0.0	2/21	606	6
3HmC(45)	4/8/97	0.28	2/?	?	7
3BB	4/9/97	0.0	2/21	640	8
3BB	4/9/97	0.28	2/21	642	9
3BOmax(0)	4/9/97	0.28	2/23	652	10
3BOmax(0)	4/9/97	0.28	2/22	653	11
3BOmax(0)	4/9/97	0.28	2/21	654	12
3BOmax(0)	4/9/97	0.28	2/20	655	13
3BOmax(0)	4/9/97	0.0	2/21	659	14
3HmOmax(0)	4/9/97	0.28	2/23	664	15
3HmOmax(0)	4/9/97	0.28	2/21	665	16
3HmOmax(0)	4/9/97	0.28	2/20	668	17
3HmOmax(0)	4/9/97	0.0	2.21	670	18
3HmOmax(0)	4/9/97	0.0	2/20	671	19
3BOmax(90)	4/10/97	0.28	2/21	689	20
3BOmax(90)	4/10/97	0.0	2/21	692	21
3BOmax(180)	4/10/97	0.28	2/21	696	22
3BOmax(180)	4/10/97	0.28	2/20	697	23
3BOmax(180)	4/10/97	0.0	2/21	699	24
3BT24	4/11/97	0.28	2/20	727	25
3C12B	4/11/97	0.28	2/20	741	25(?)
3C8B	4/14/97	0.28	2/20	762	1
3IB	4/14/97	0.28	2/20	771	2
3AB	4/14/97	0.28	2/20	778	3
3DiB	4/15/97	0.28	2/20	801	4
3IC	4/15/97	0.28	2/20	816	5
3C12C	4/15/97	0.28	2/20	824	6
3C12C	4/15/97	0.28	2/20	826	7
3BB	4/16/97	0.28	2/24	832	8
3BB	4/16/97	0.28	2/23	834	9
3BB	4/16/97	0.28	2/22	835	10
3BB	4/16/97	0.28	2/21	836	11
3BB	4/16/97	0.28	2/20	837	12
3C8C	4/16/97	0.28	2/20	843	13
3AC	4/16/97	0.28	2/22	849	14

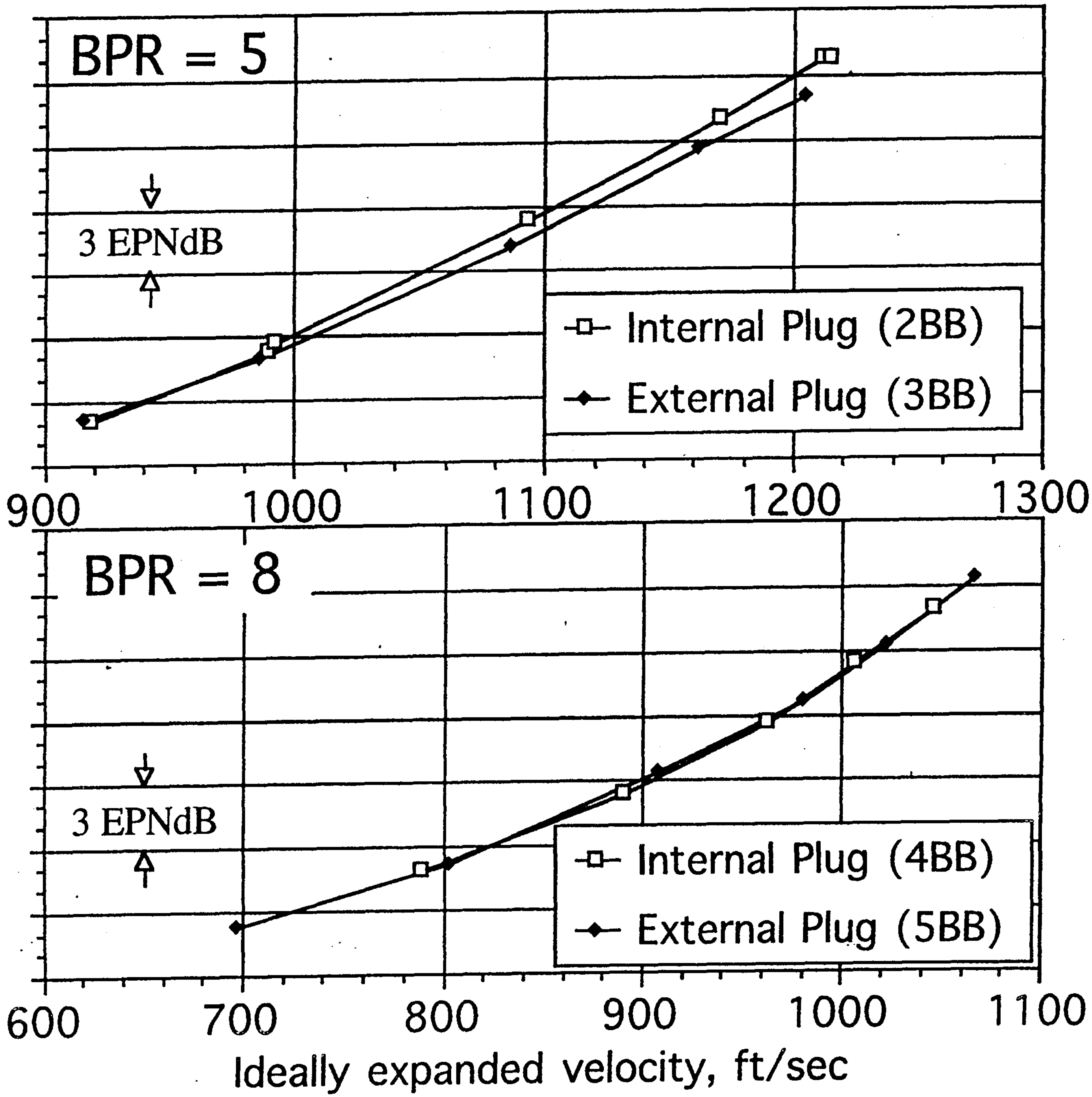
Table 6. AAPL Separate Flow Nozzle IR Camera Test Summary (Concluded).

Configuration	Date	Mach No.	Cycle/Power Setting	Corresponding Escort Rdg.	IR #
3AC	4/16/97	0.28	2/20	851	15
3AC	4/16/97	0.28	2/21	853	16
3HmB(45)	4/17/97	0.28	2/20	875	17
3DxB	4/17/97	0.28	2/20	882	18
3IC	4/18/97	0.28	2/20	892	19
3BB	4/18/97	0.28	2/20	918	20
2BB	4/21/97	0.28	2/20	945	21
2BC	4/21/97	0.28	2/20	958	21(?)
3AC	4/16/97	0.28	2/20	851	15
3AC	4/16/97	0.0	2/21	853	16
?	?	?	?	?	1
4BB	4/21/97	0.28	4/41	975	2
5CB	4/22/97	0.28	4/41	1023	3
3T24B	2/23/97	0.28	2/20	1057	4
3BB	4/23/97	0.28	2/20	1073	5
3T48C	4/23/97	0.28	2/20	1080	6
3T48T48	4/23/97	0.28	2/20	1085	7
?	?	?	?	?	1
6TmB	5/12/97	0.28	2/21	1251	2
6TmB	5/12/97	0.28	2/20	1252	3
6TmC	5/12/97	0.28	2/21	1258	4
6TmC	5/12/97	0.28	2/20	1259	5
3BB	5/13/97	0.28	2/21	1275	6
3FB	5/13/97	0.28	2/21	1283	7
3FB	5/13/97	?	Special	1286	8
3HmB	5/13/97	0.28	2/21	1290	9
3FC	5/13/97	0.28	2/21	1296	10
3T24T48	5/13/97	0.28	2/21	1302	11

Engine cycle impact



Internal and External Plug for 5 and 8 BPR engines



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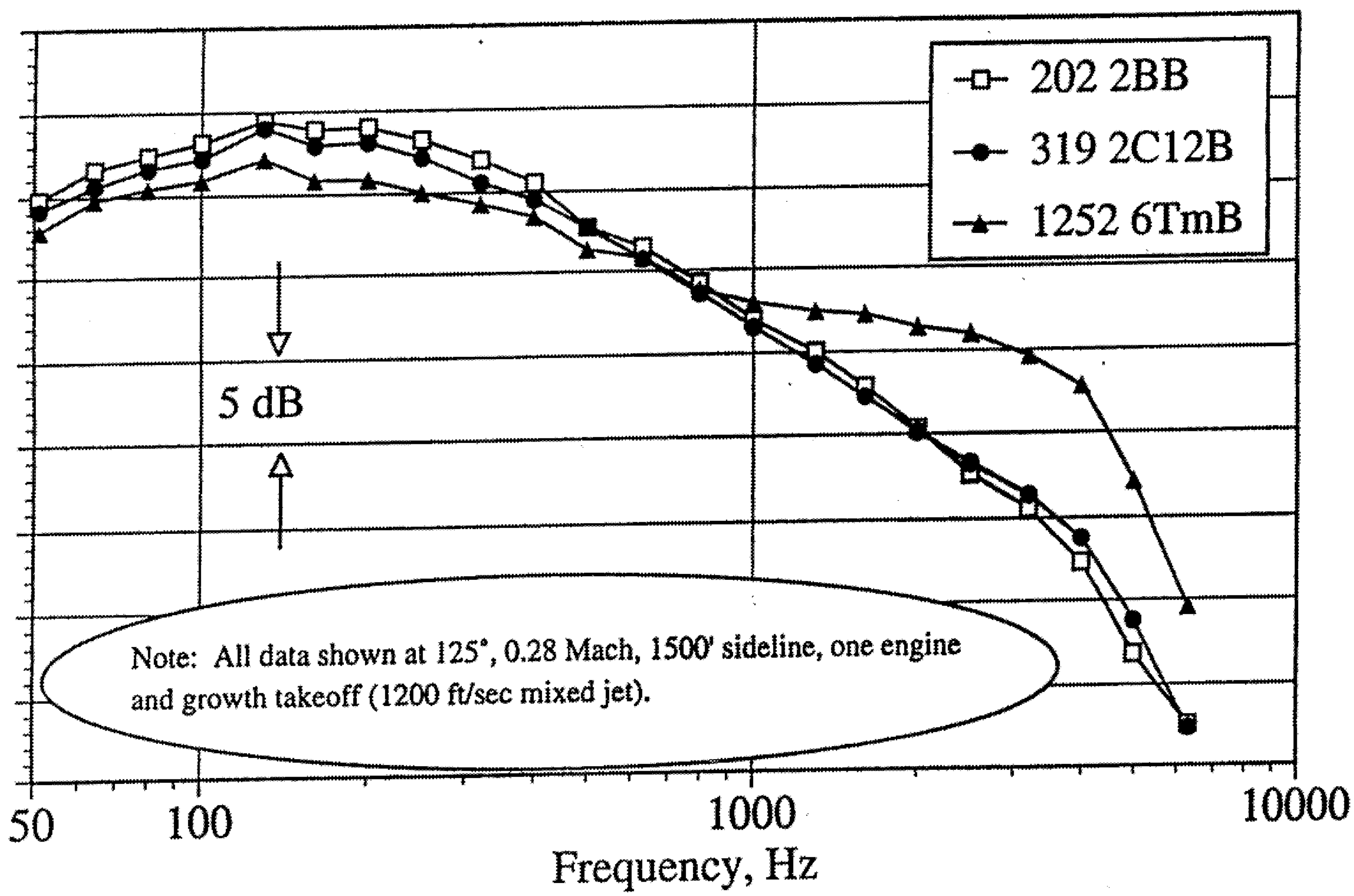
MODEL 2

BPR 5, Internal Plug

Impact of Core 12 chevrons and Core Tongue Mixer with baseline fan

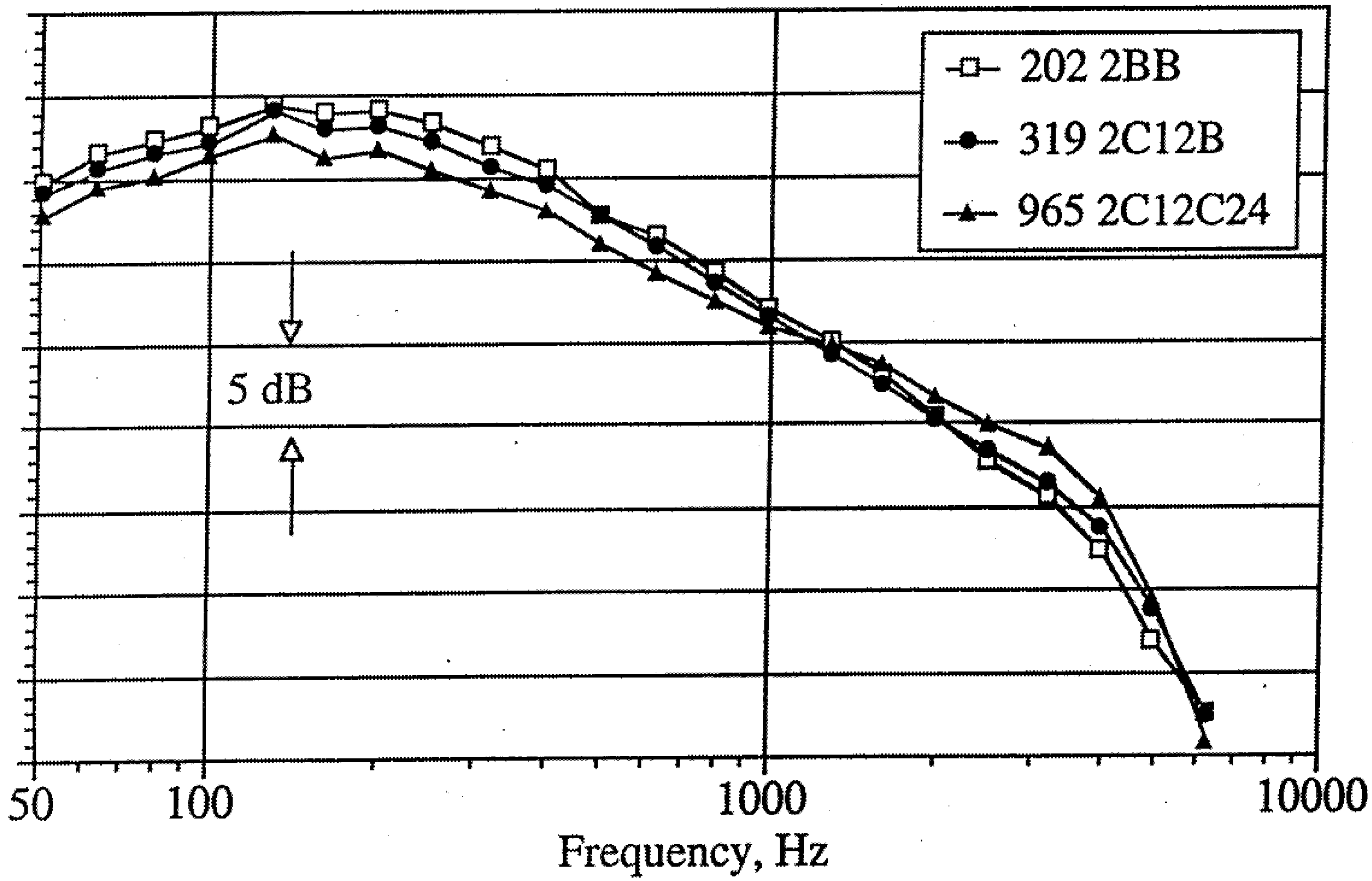


12 Chevrons reduce jet noise and create mixing noise.
Tongue mixer significantly reduces jet noise and creates intense mixing noise.

BPR 5, Internal Plug

31

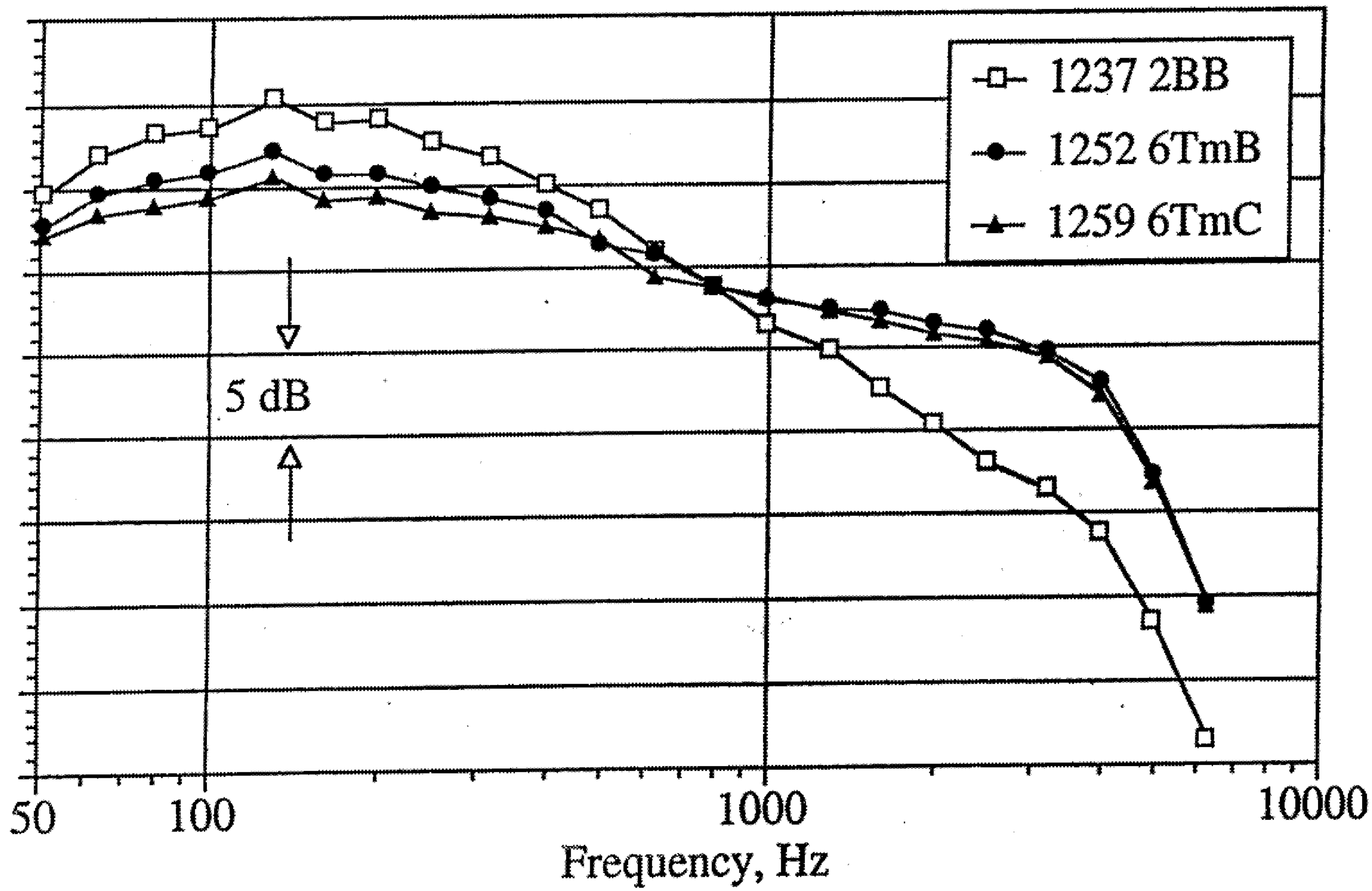
Impact of Core 12 chevrons with 24 Chevrons on Fan



Fan chevrons reduce jet noise but create mixing noise.

BPR 5, Internal Plug

Impact of Core Tongue mixer with 24 Chevrons on Fan

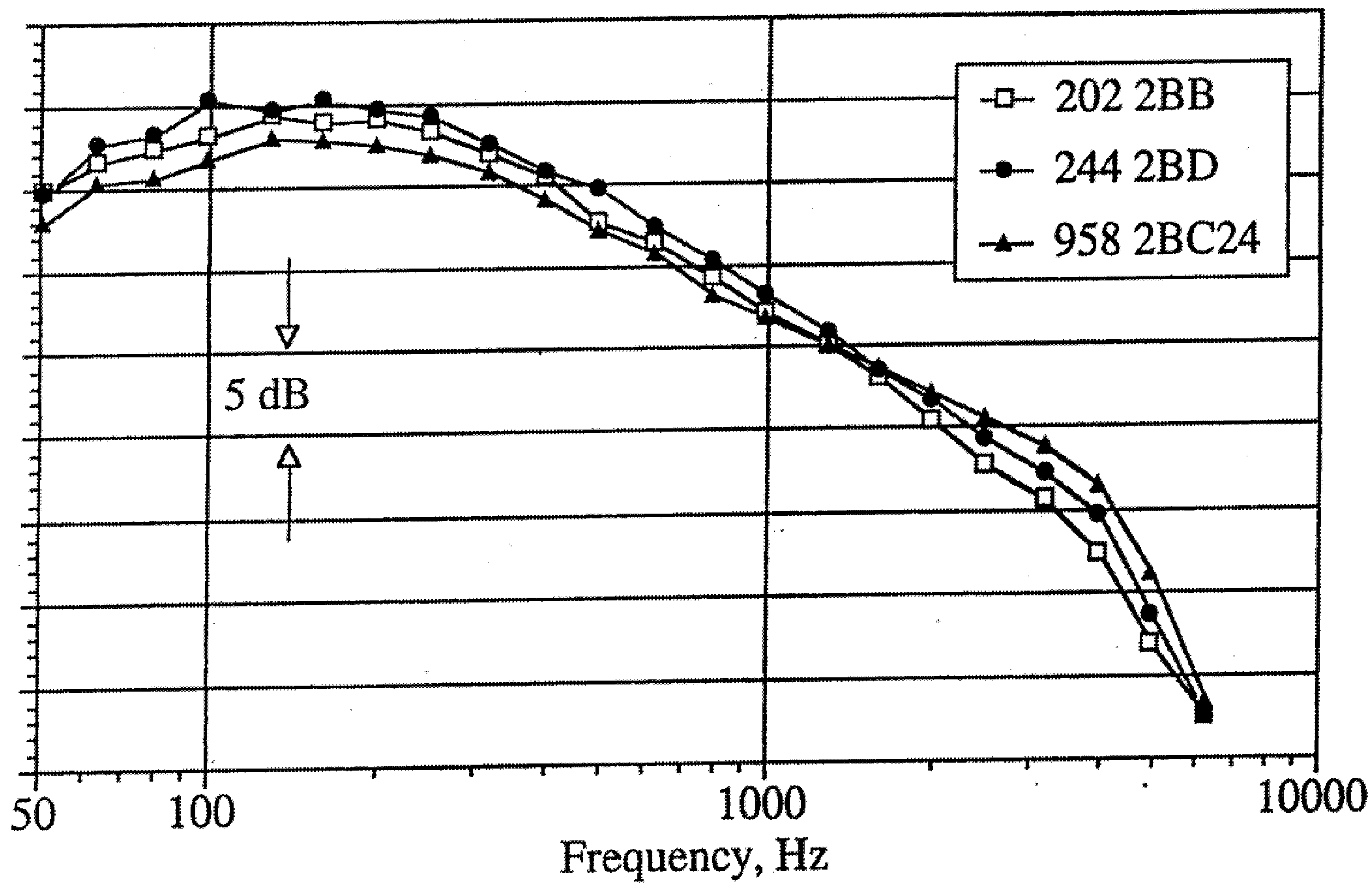


Fan chevrons reduce jet noise and slightly reduce mixing noise generated from Tongue mixer.

BPR 5, Internal Plug

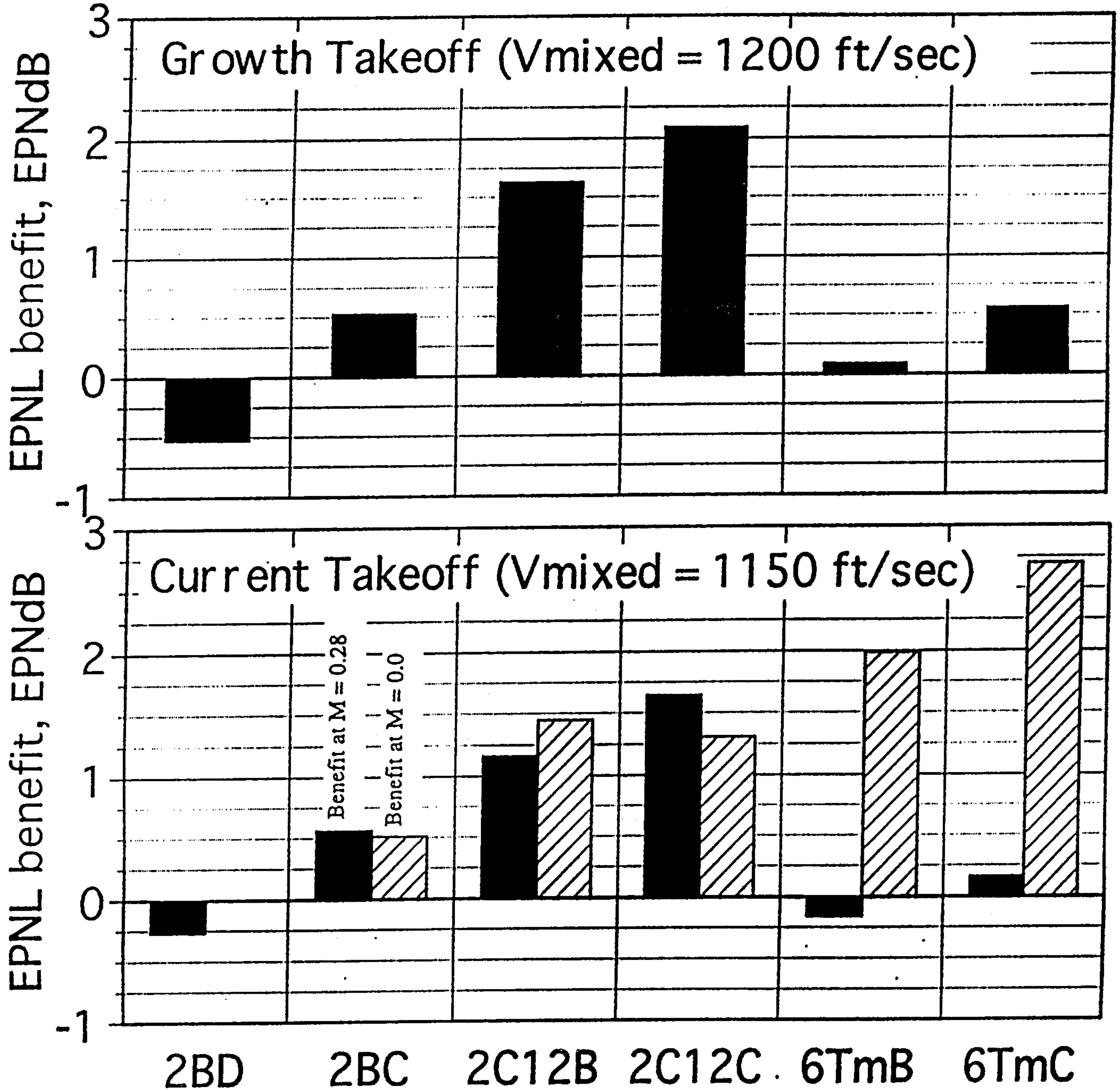
331

Impact of Fan 96 Doublets and 24 Chevrons on baseline core



Fan doublets create broad-band noise slightly greater than baseline.
Fan Chevrons reduce the jet noise and create mixing noise.

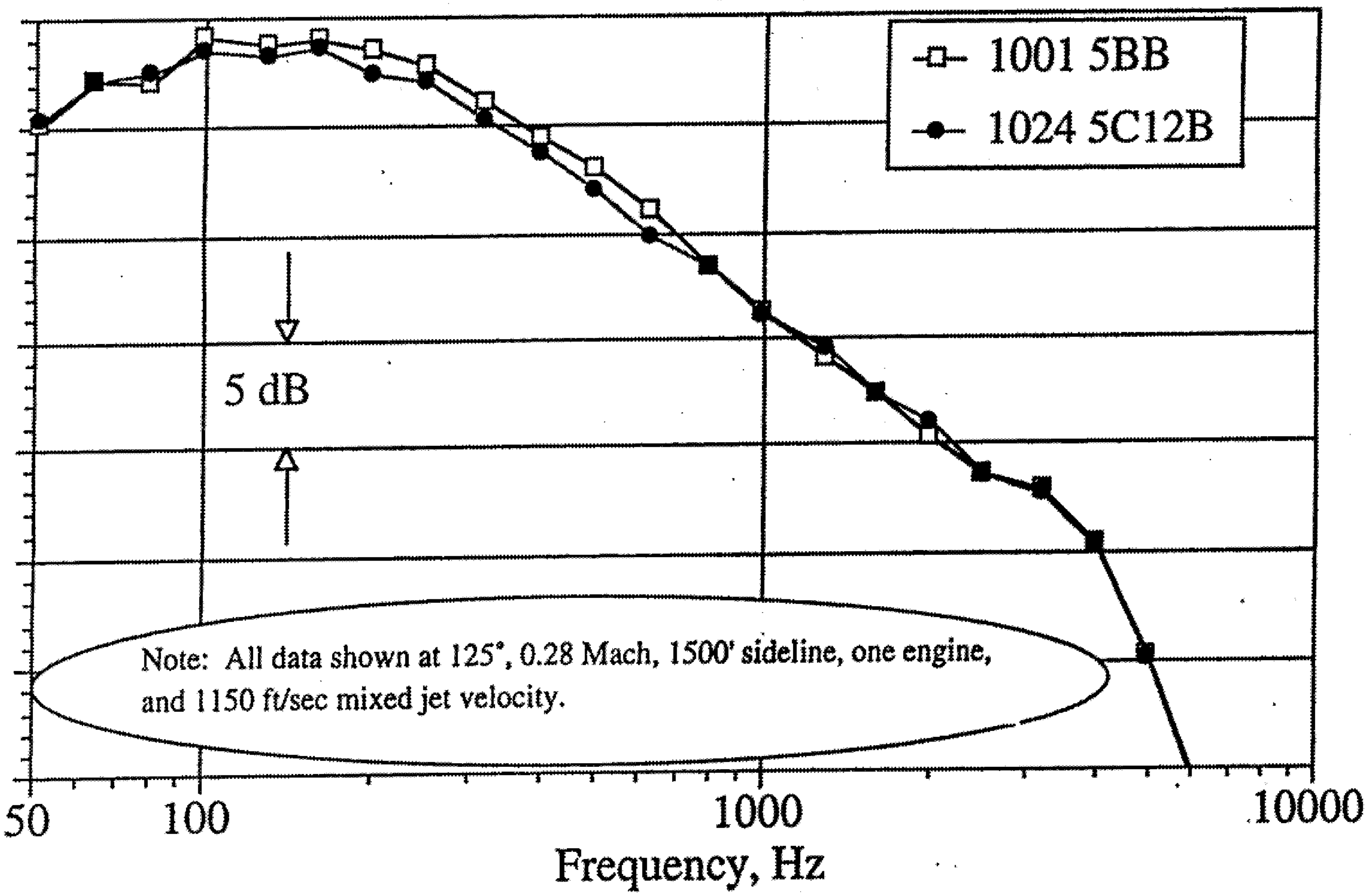
EPNL Benefits with Various Noise Suppresors
Internal Plug with 5 BPR engine



MODEL 5

BPR 8, External Plug

Impact of12 Chevrons on core with baseline fan



12 Chevrons on core reduce jet noise with little mixing noise increase.

BPR 8, External Plug

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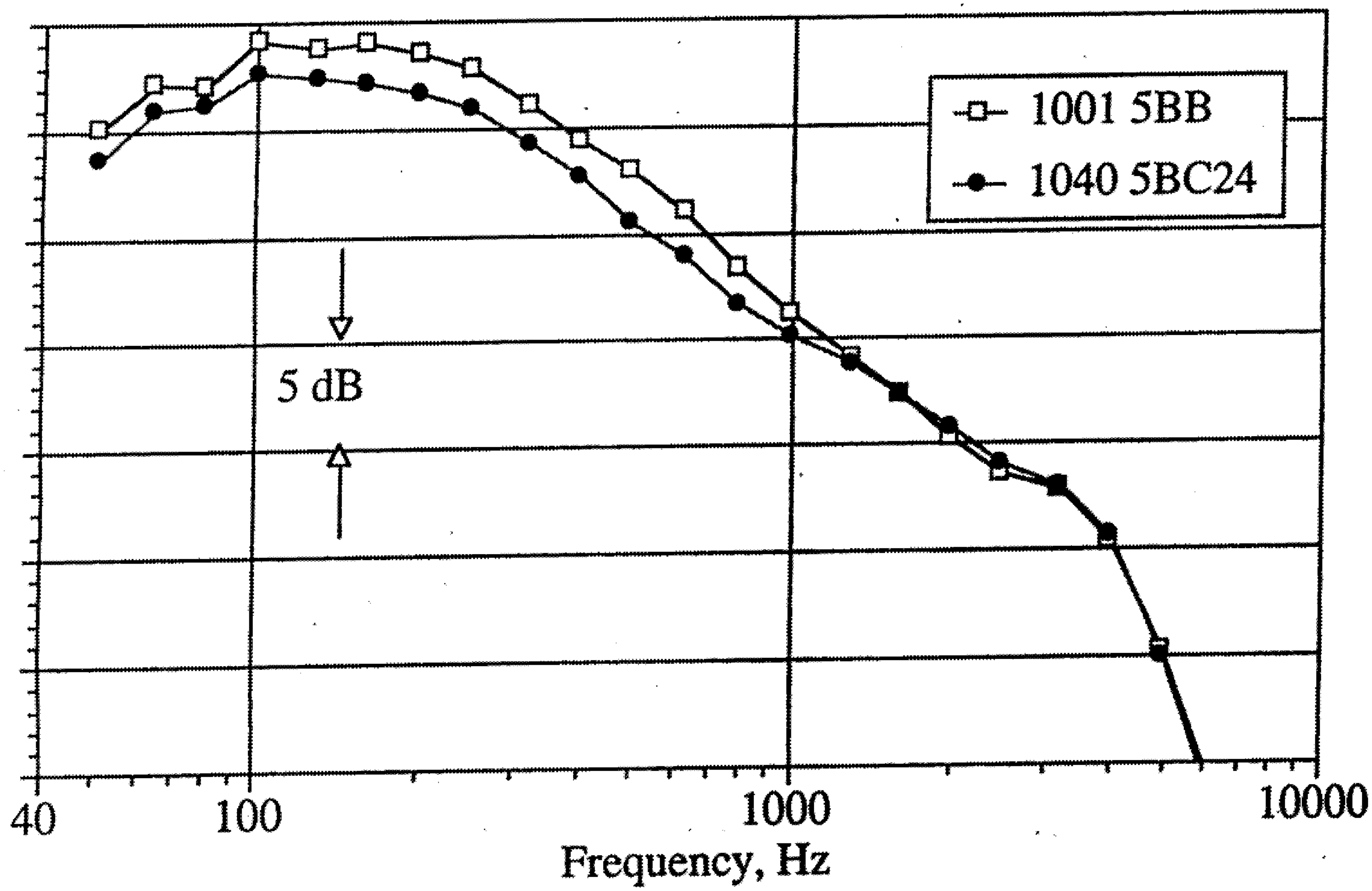
Impact of 24 Fan Chevrons with baseline core

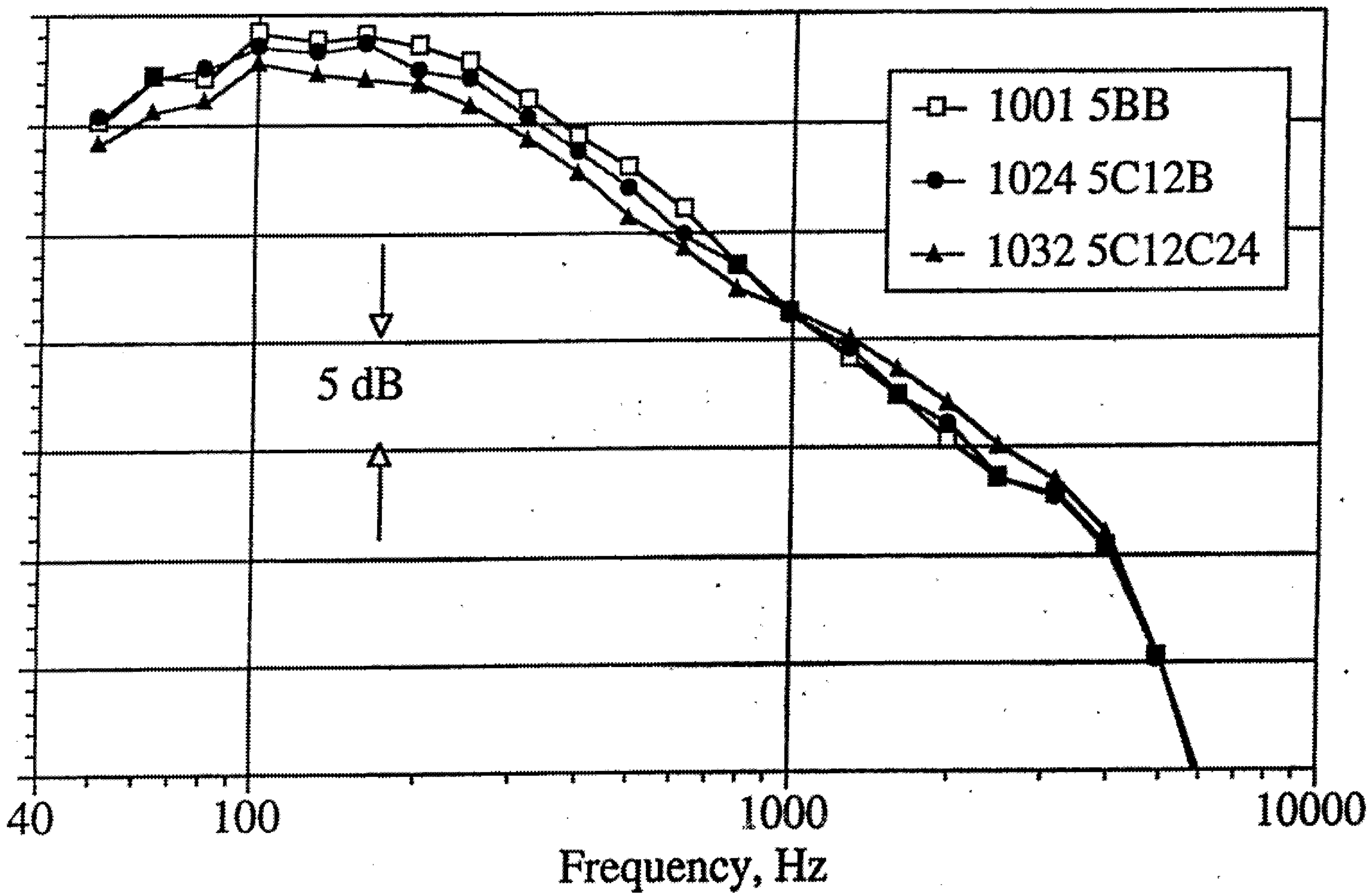


24 Fan chevrons reduce jet noise without increase in mixing noise.

BPR 8, External Plug

38

Impact of 24 Fan Chevrons with 12 Core Chevrons

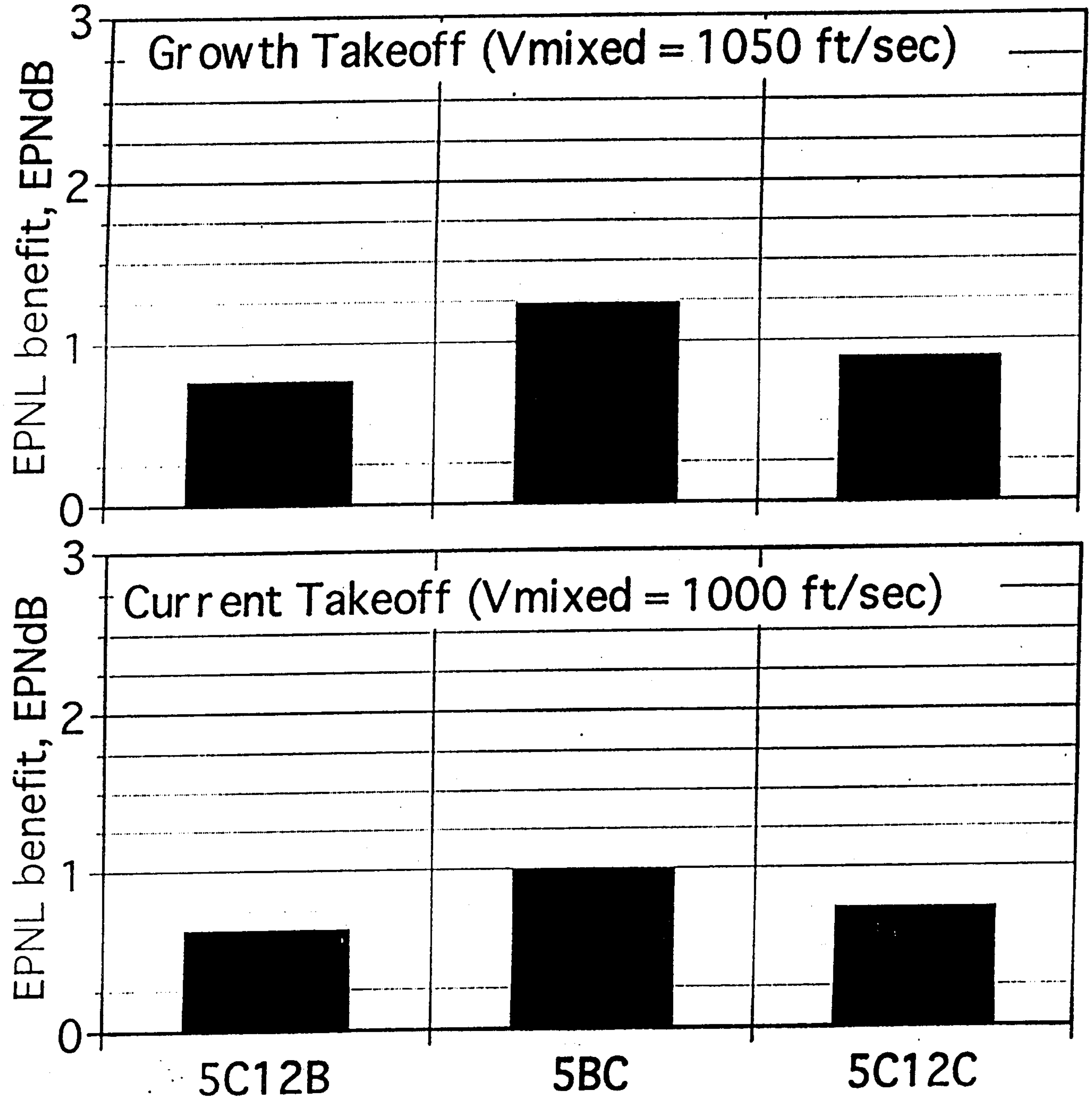


24 Chevrons reduce jet noise but increase mixing noise.

BPR 8, External Plug

39

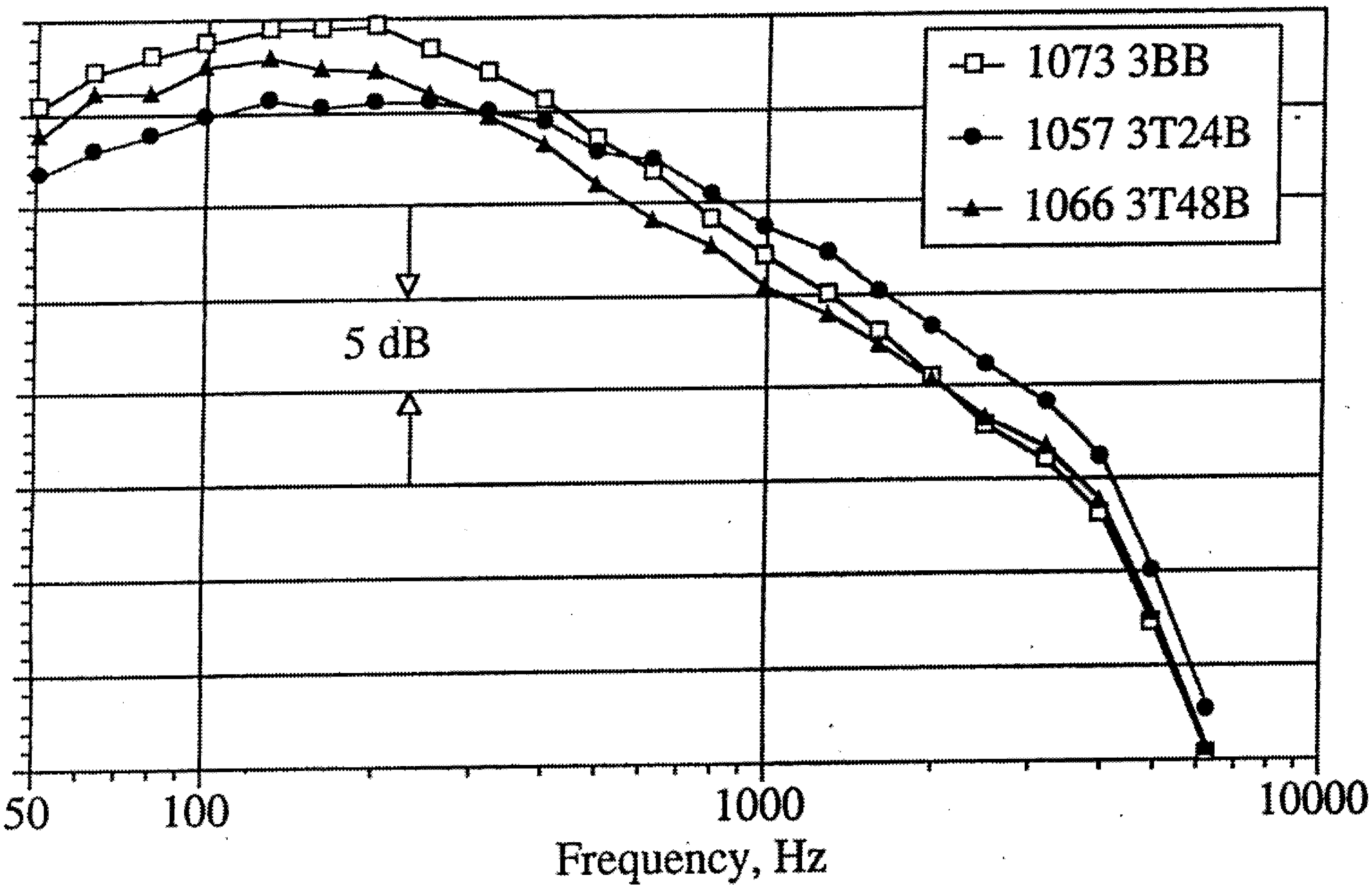
EPNL Benefits with Various Noise Suppresors External Plug with 8 BPR engine



MODEL 3

BPR 5, External Plug

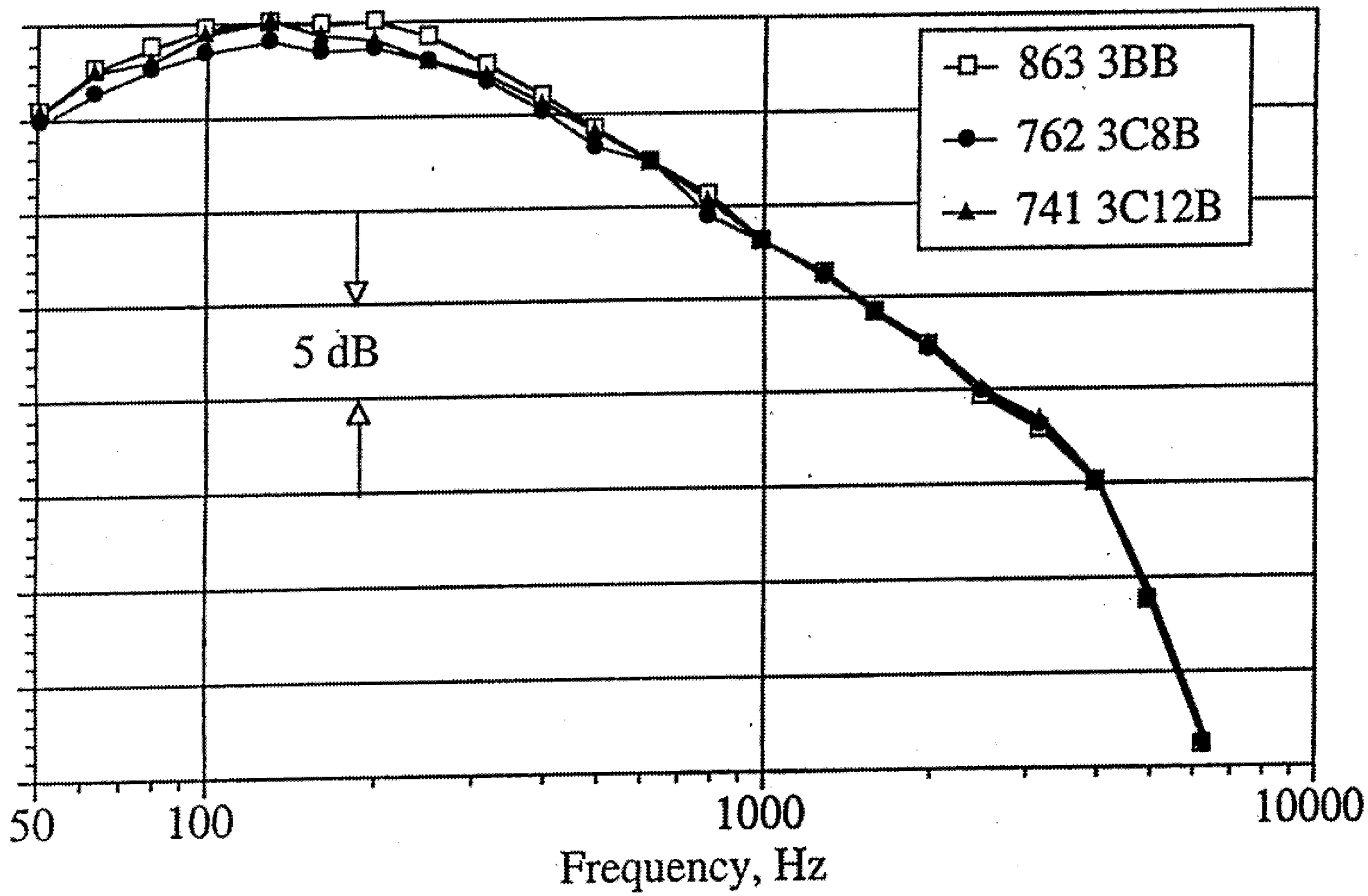
Impact of Core tab count, 24 and 48, with baseline fan



24 tabs on core create more mixing noise than baseline and 48 tabs.
48 tabs mixing noise is identical to the baseline.

BPR 5, External Plug

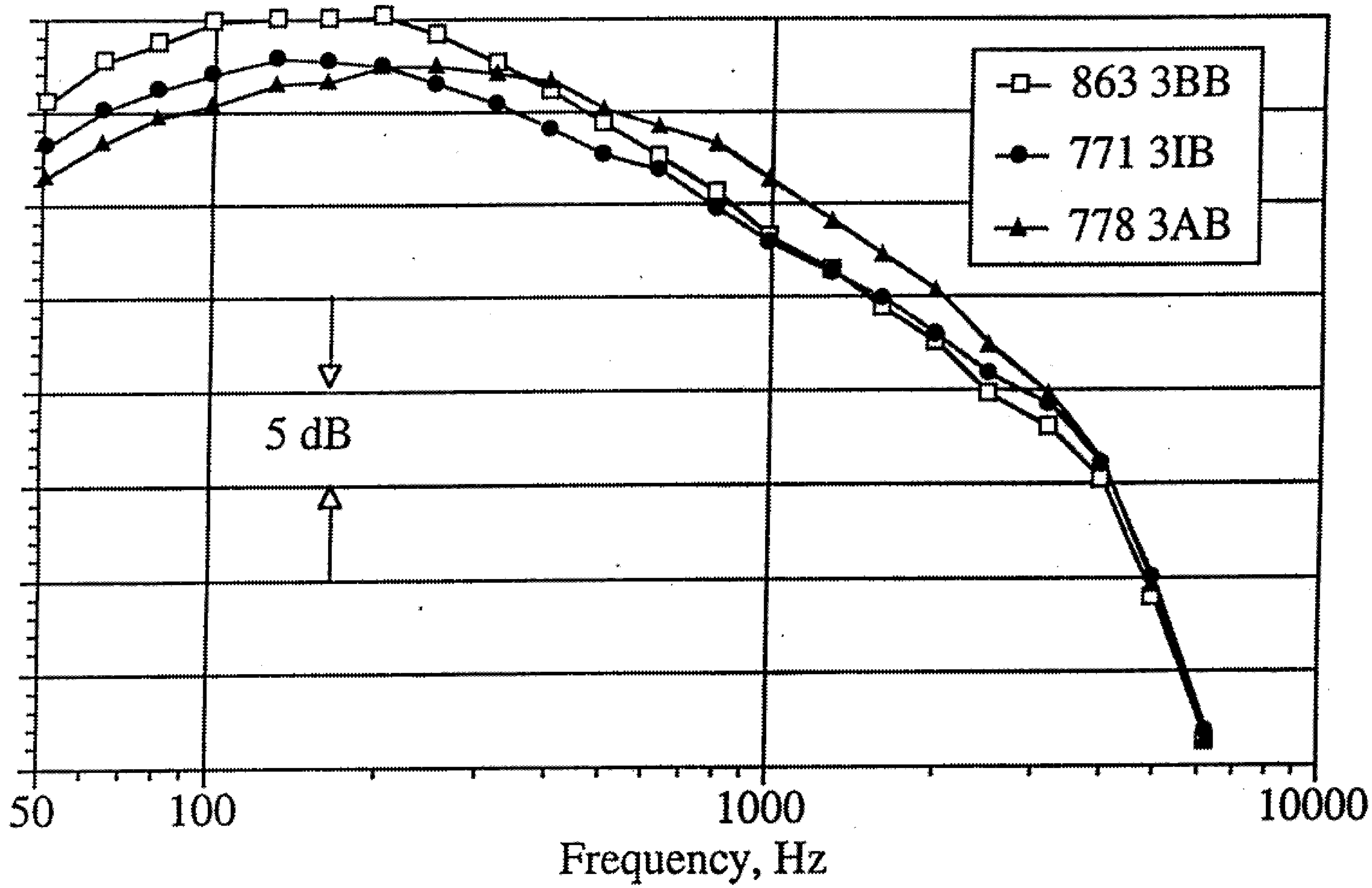
Impact of Core chevrons, 8 and 12, with baseline fan



8 Chevrons reduce the low-frequency noise more than 12 chevrons. Neither device has a high-frequency component above the baseline.

BPR 5, External Plug

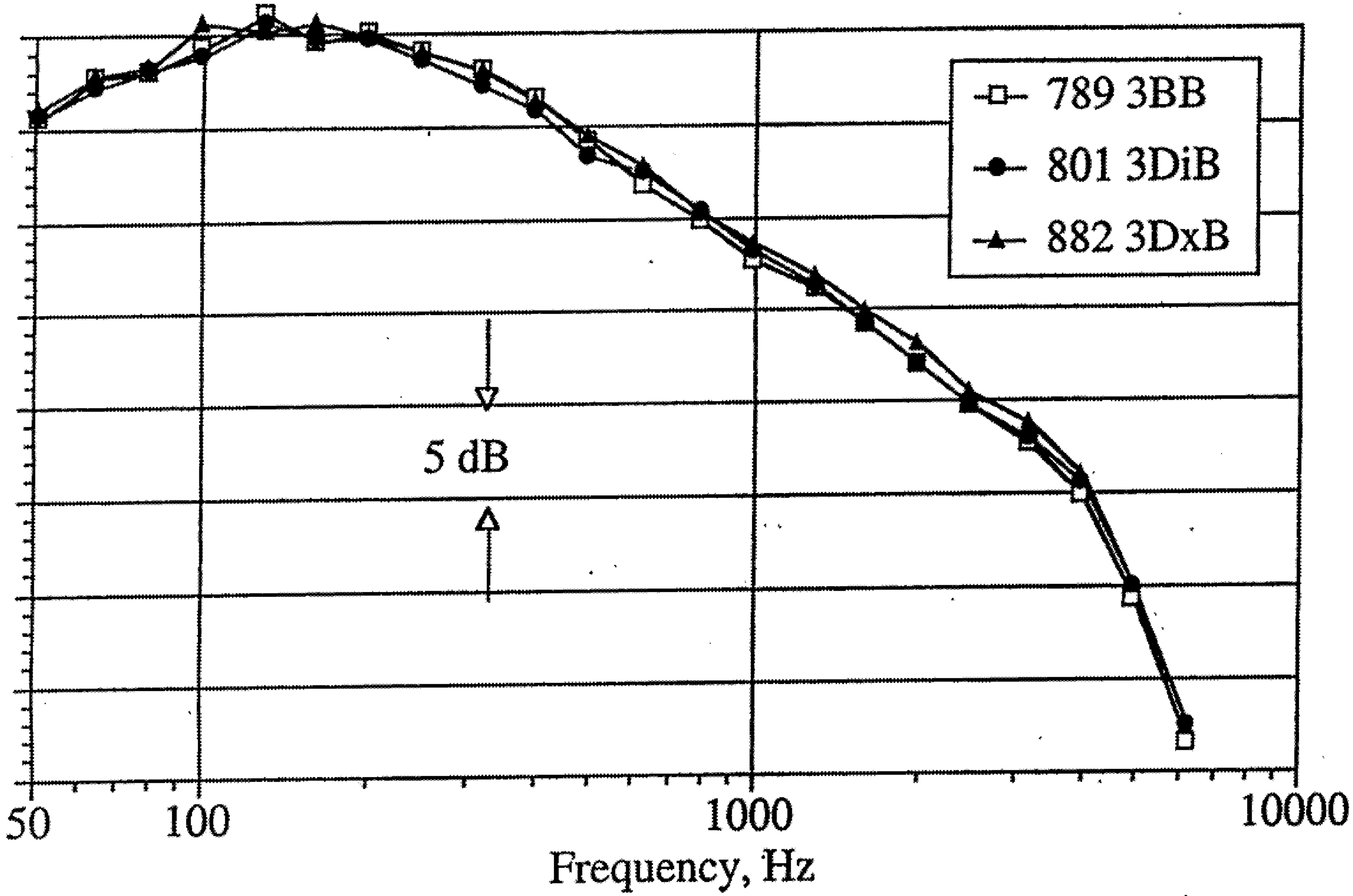
Impact of Core Inward and Alternating chevrons with baseline fan



Inward chevrons reduce the low-frequency noise WITHOUT appreciable high frequency noise.

BPR 5, External Plug

Impact of Core Internal and External Vortex Generating Doublets with baseline fan

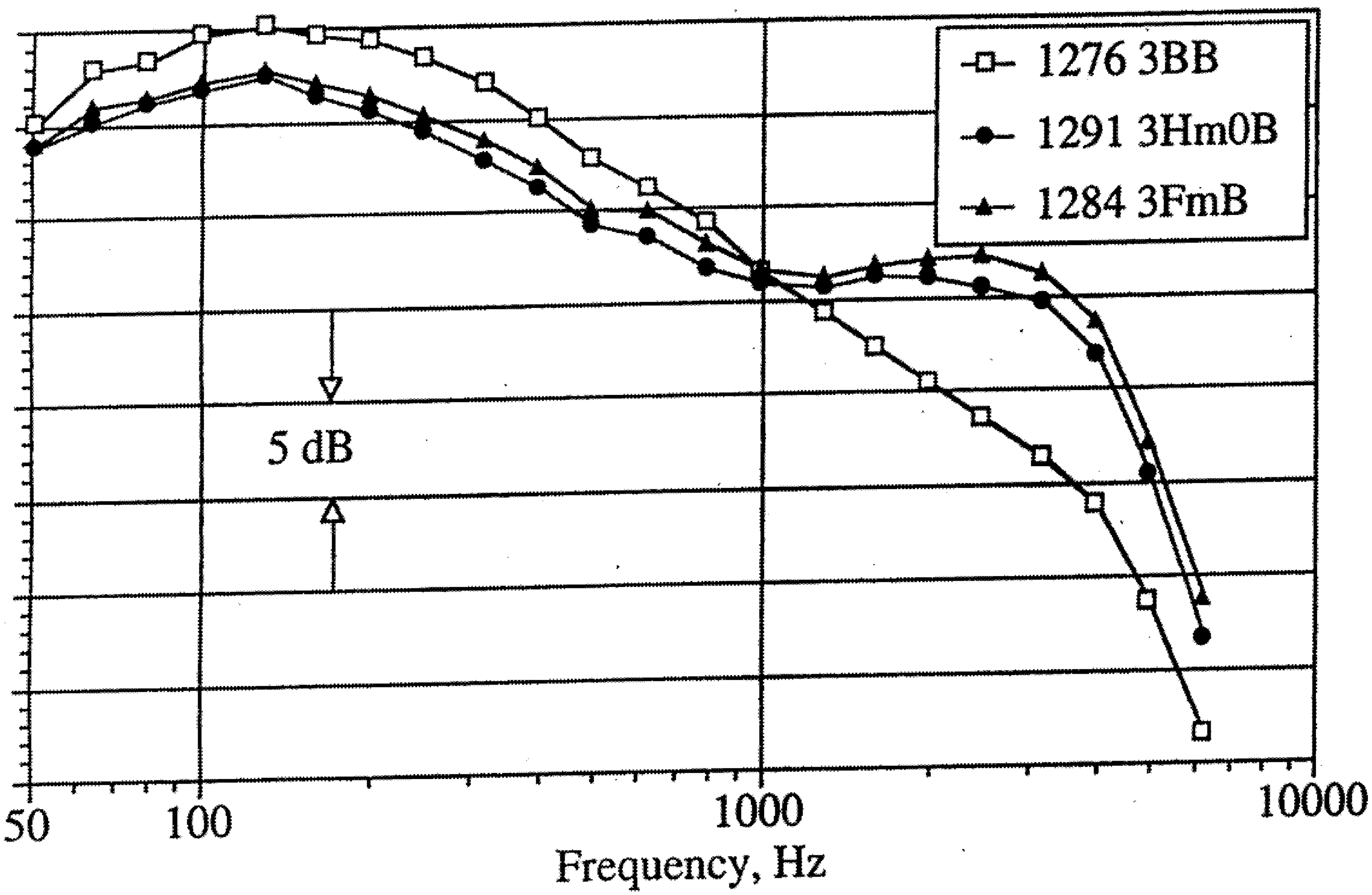


Doublets do not provide significant variations from baseline.

BPR 5, External Plug

451

Impact of Core Full and Half mixer with baseline fan (Half mixer at 0°)

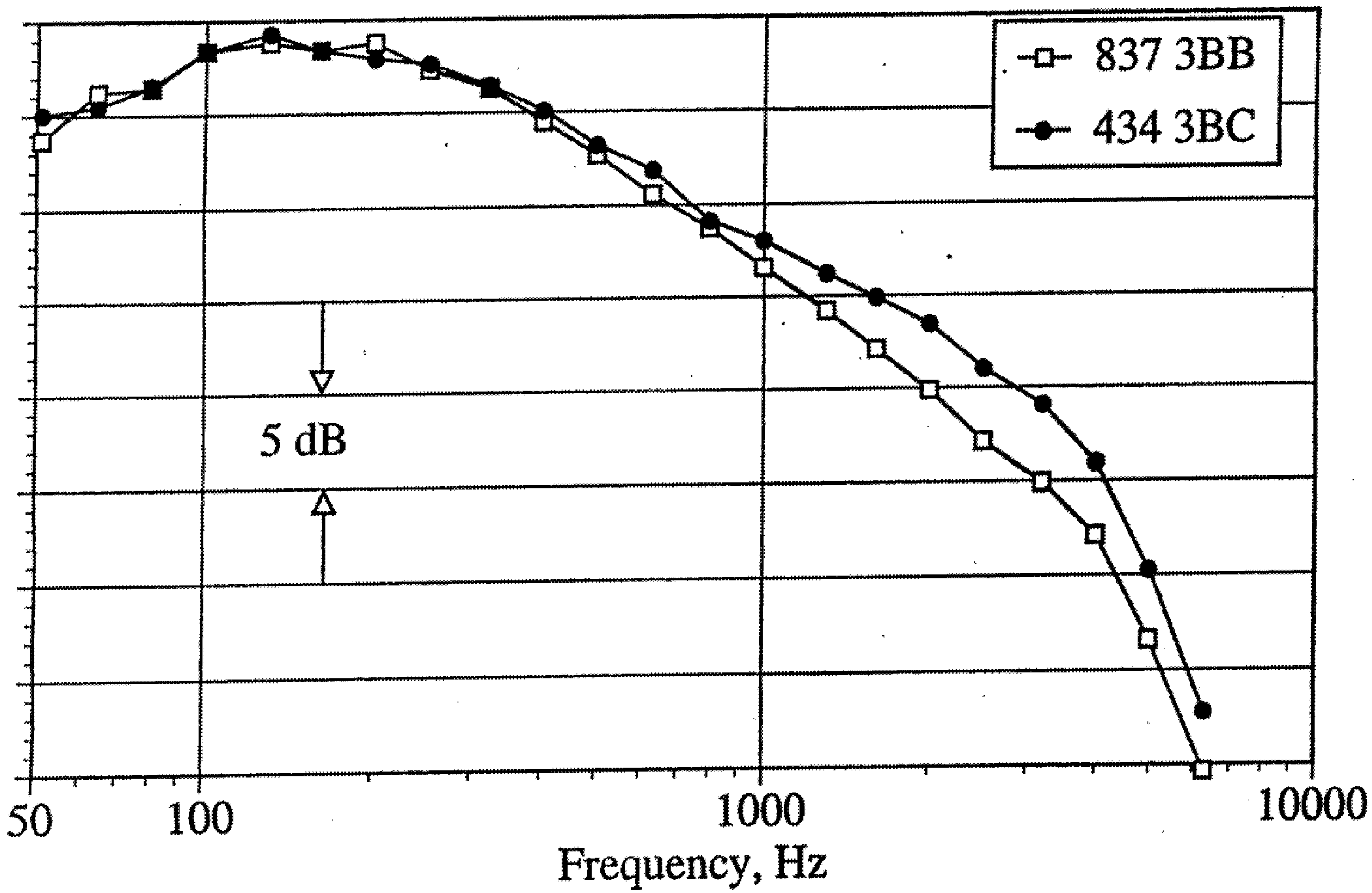


Mixers reduce low frequency but create high frequency.
Half-mixer is quieter than full mixer for nearly all frequencies.

BPR 5, External Plug

46

Impact of 24 Chevron Fan with Baseline Core

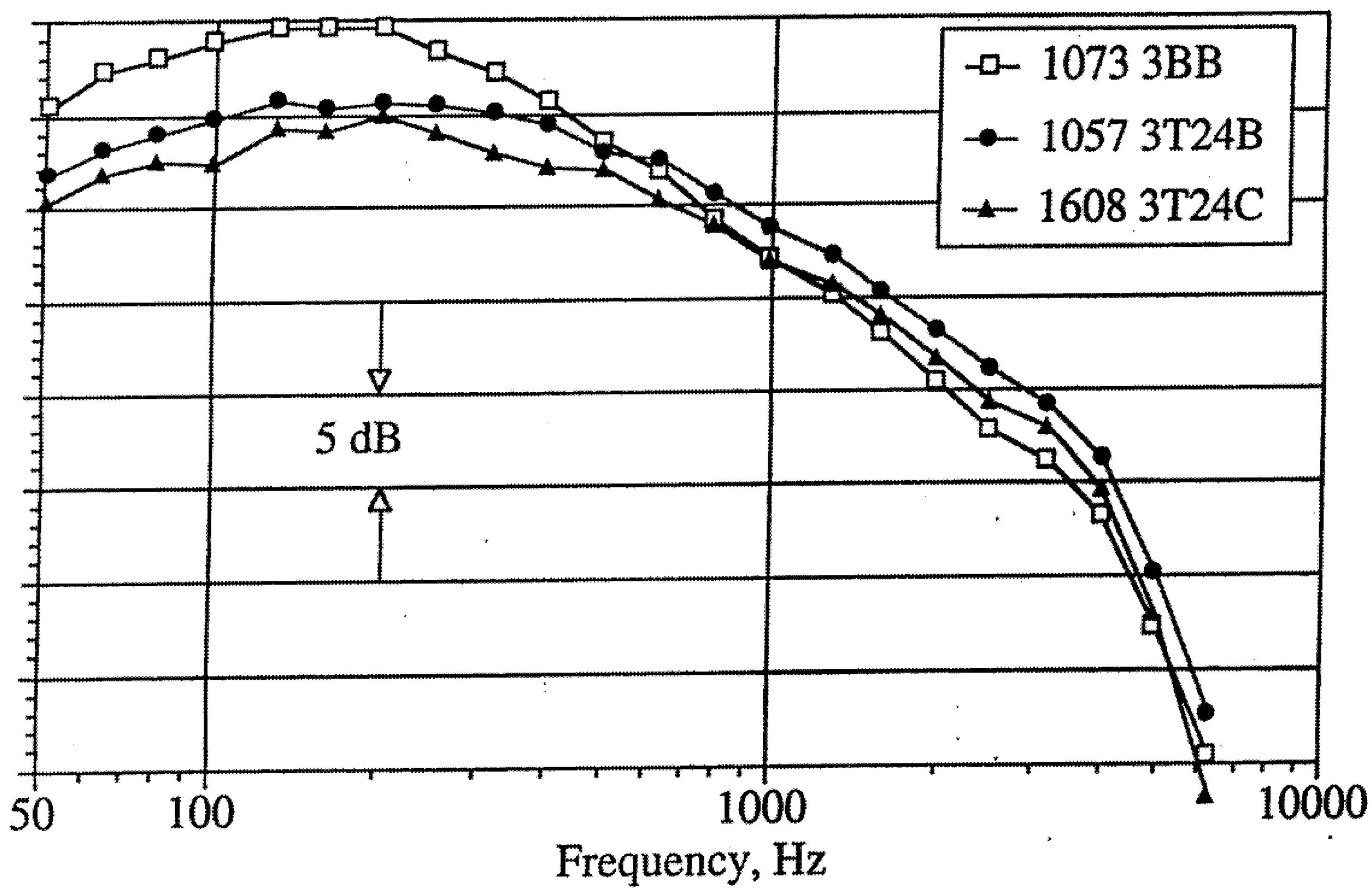


24 Chevron fan creates high frequency noise.

BPR 5, External Plug

471

Impact of 24 Chevron fan on 24-Tab core

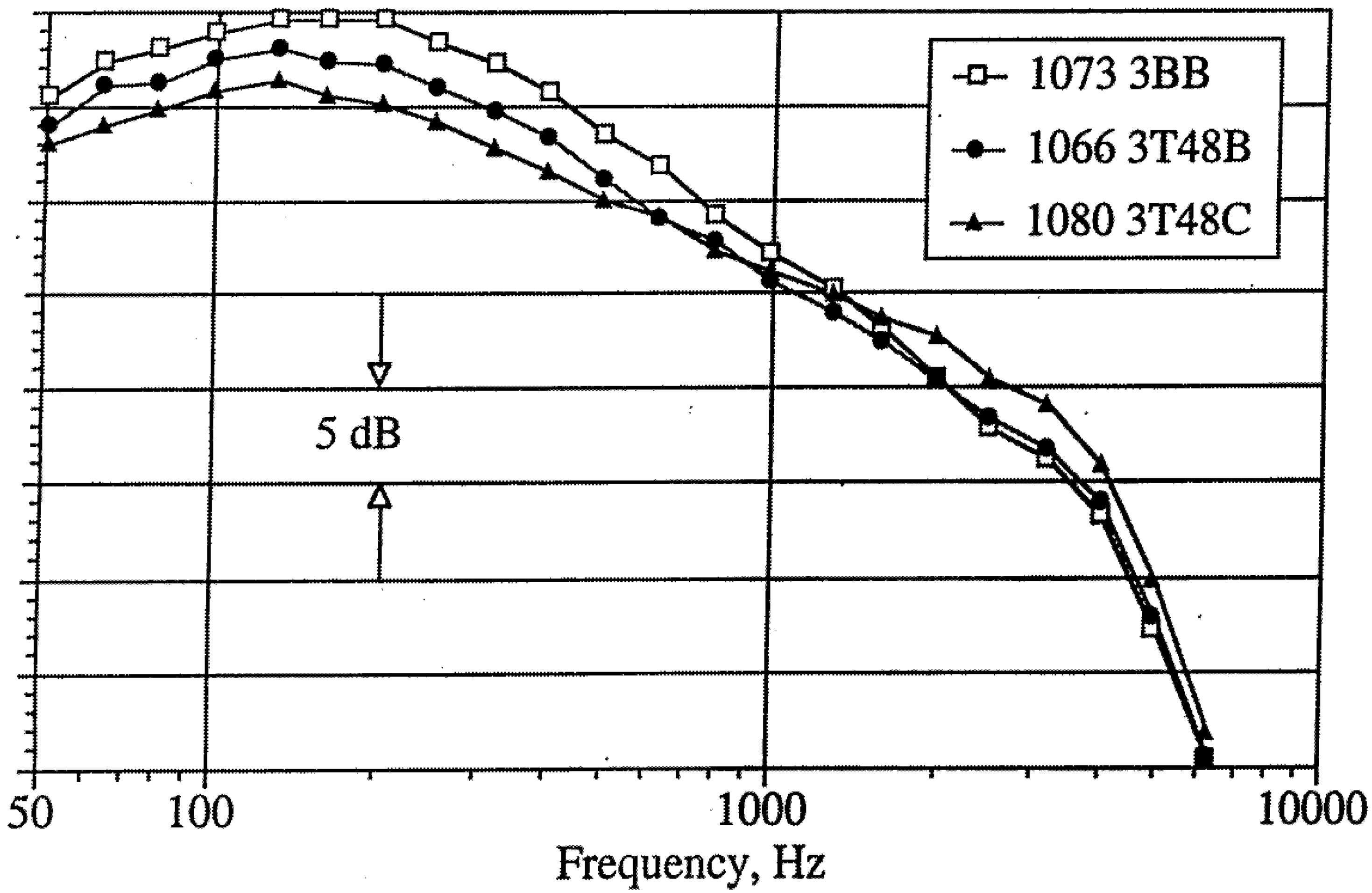


Fan chevrons reduce the broad-band noise including the high frequency mixing noise for 24-Tab core.

BPR 5, External Plug

481

Impact of 24 Chevron fan on 48 Tab core

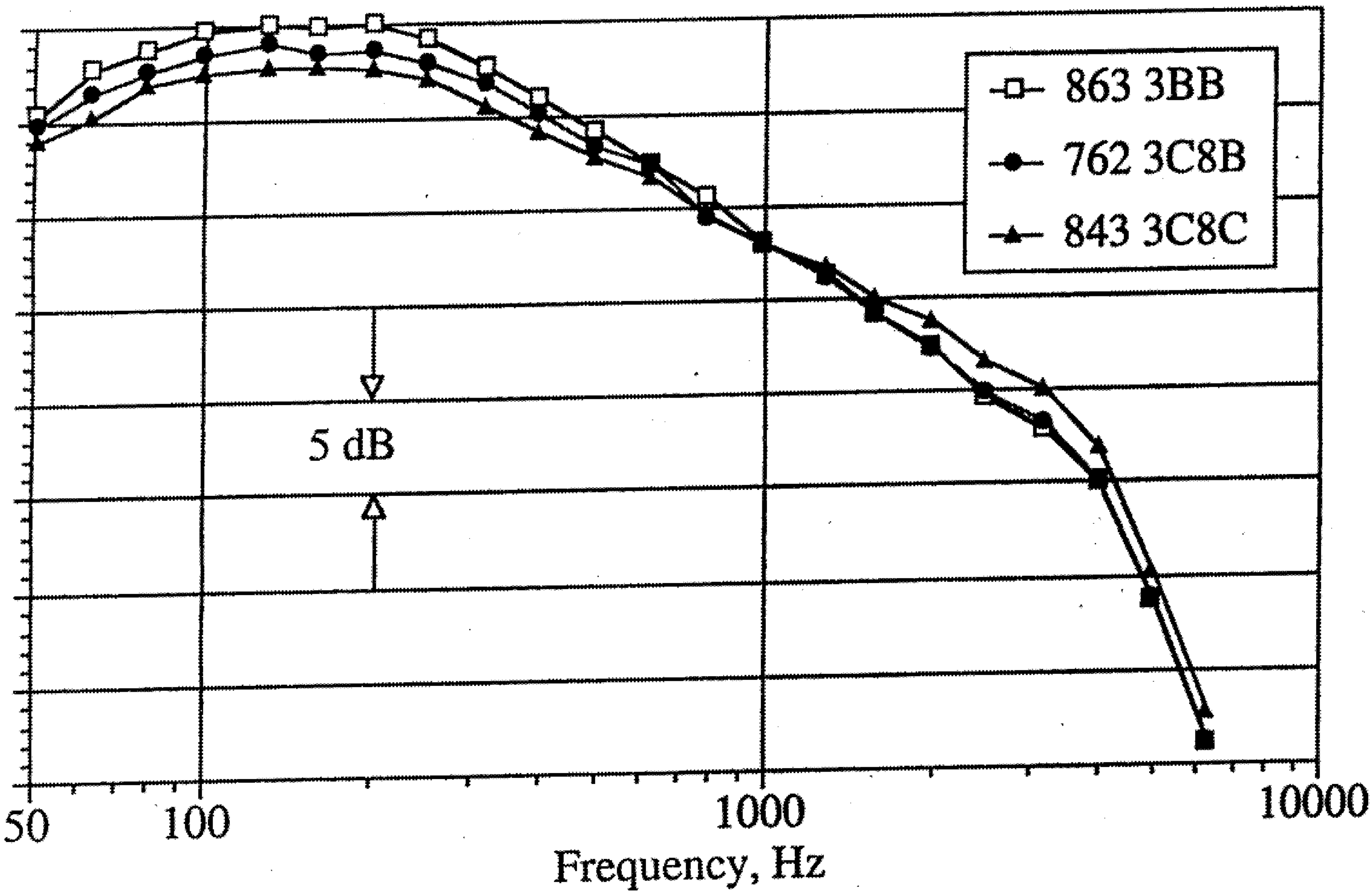


Fan chevrons reduce the low-frequency but increase the high frequency.

BPR 5, External Plug

49)

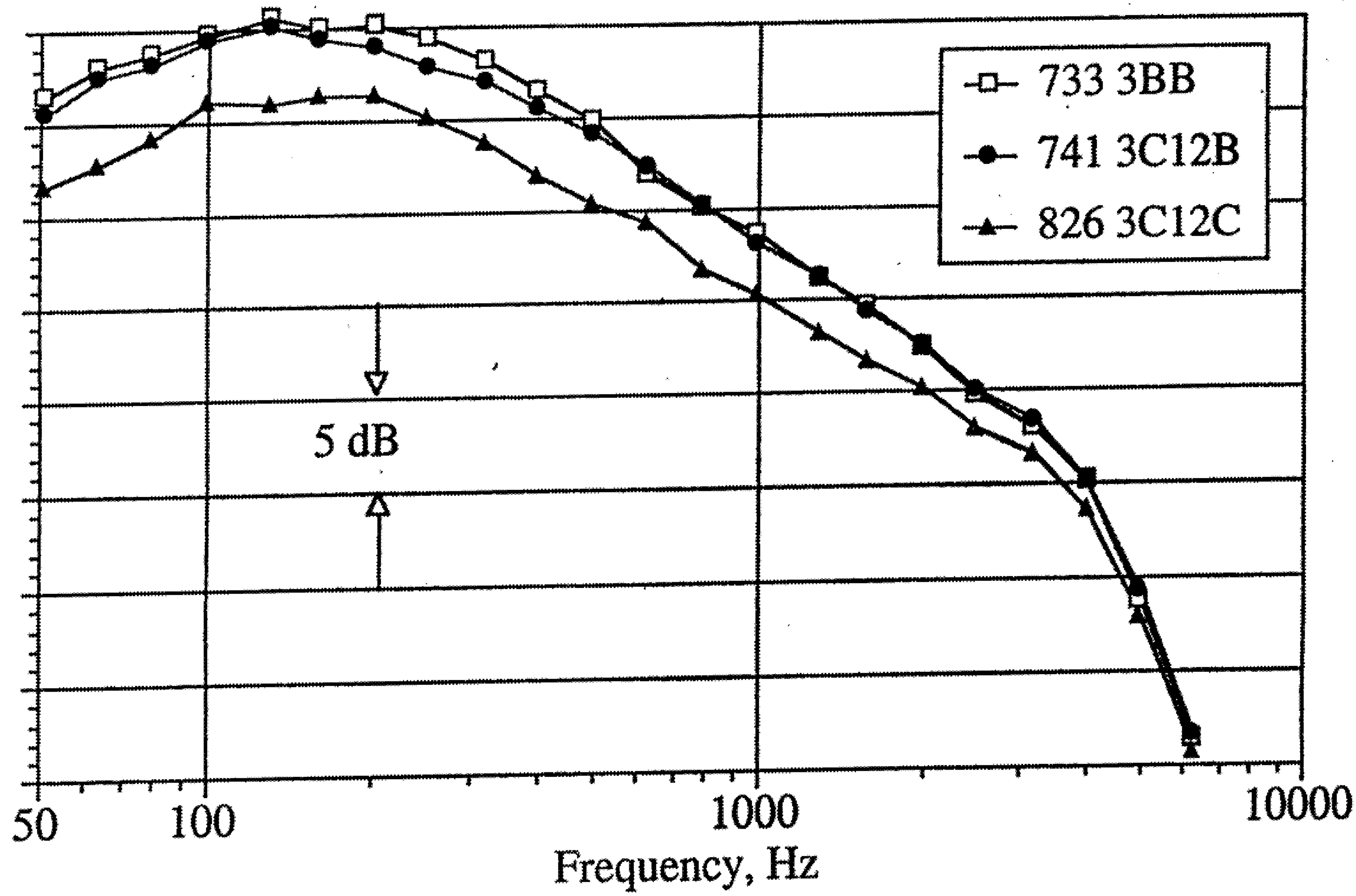
Impact of 24 Chevron fan on 8 Chevron Core



Fan chevrons significantly reduce low-frequency noise and slightly increase the high frequency noise.

BPR 5, External Plug

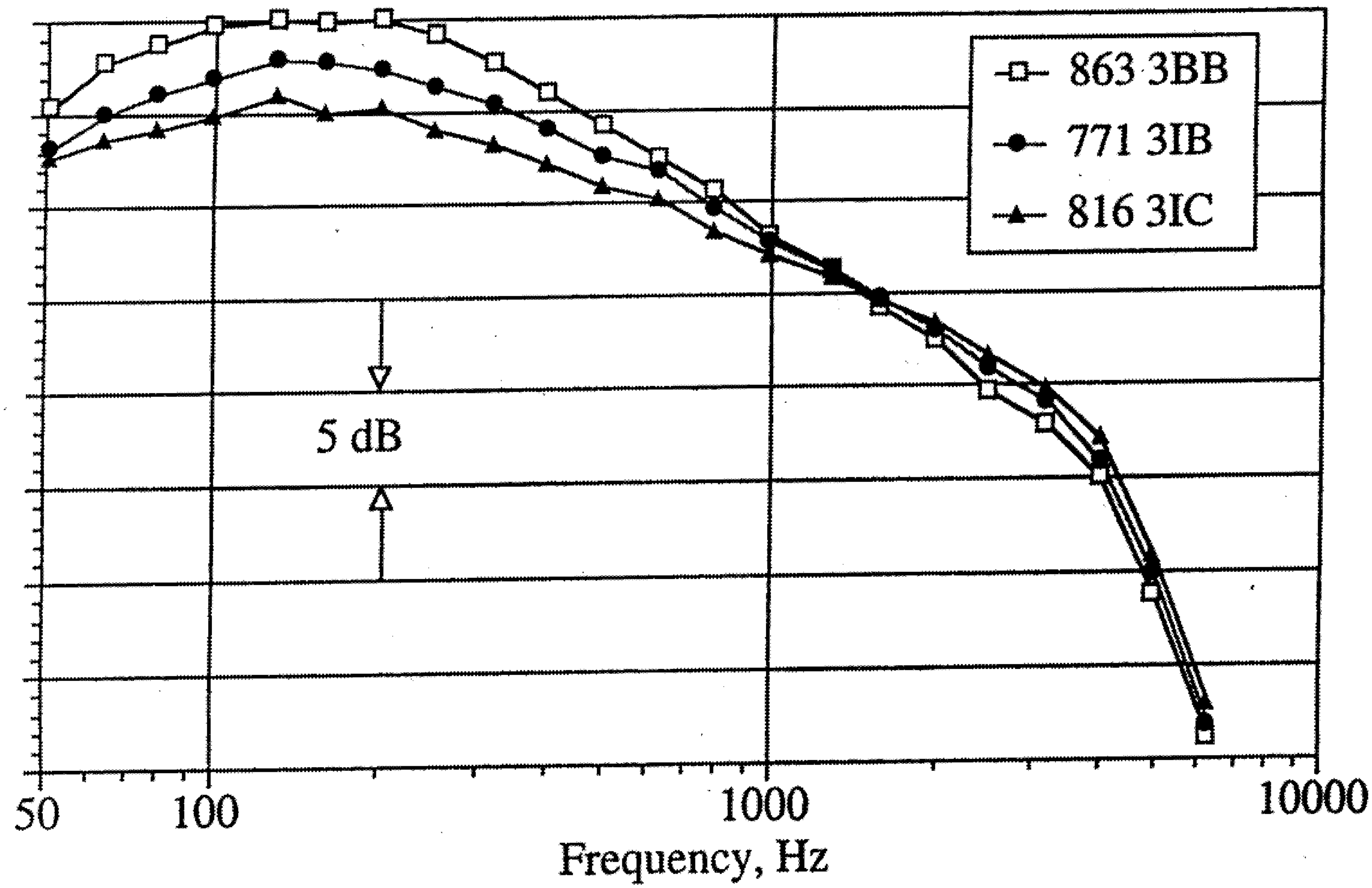
Impact of 24 Chevron fan on 12 Chevron Core



Fan chevrons significantly reduce broad-band noise.

BPR 5, External Plug

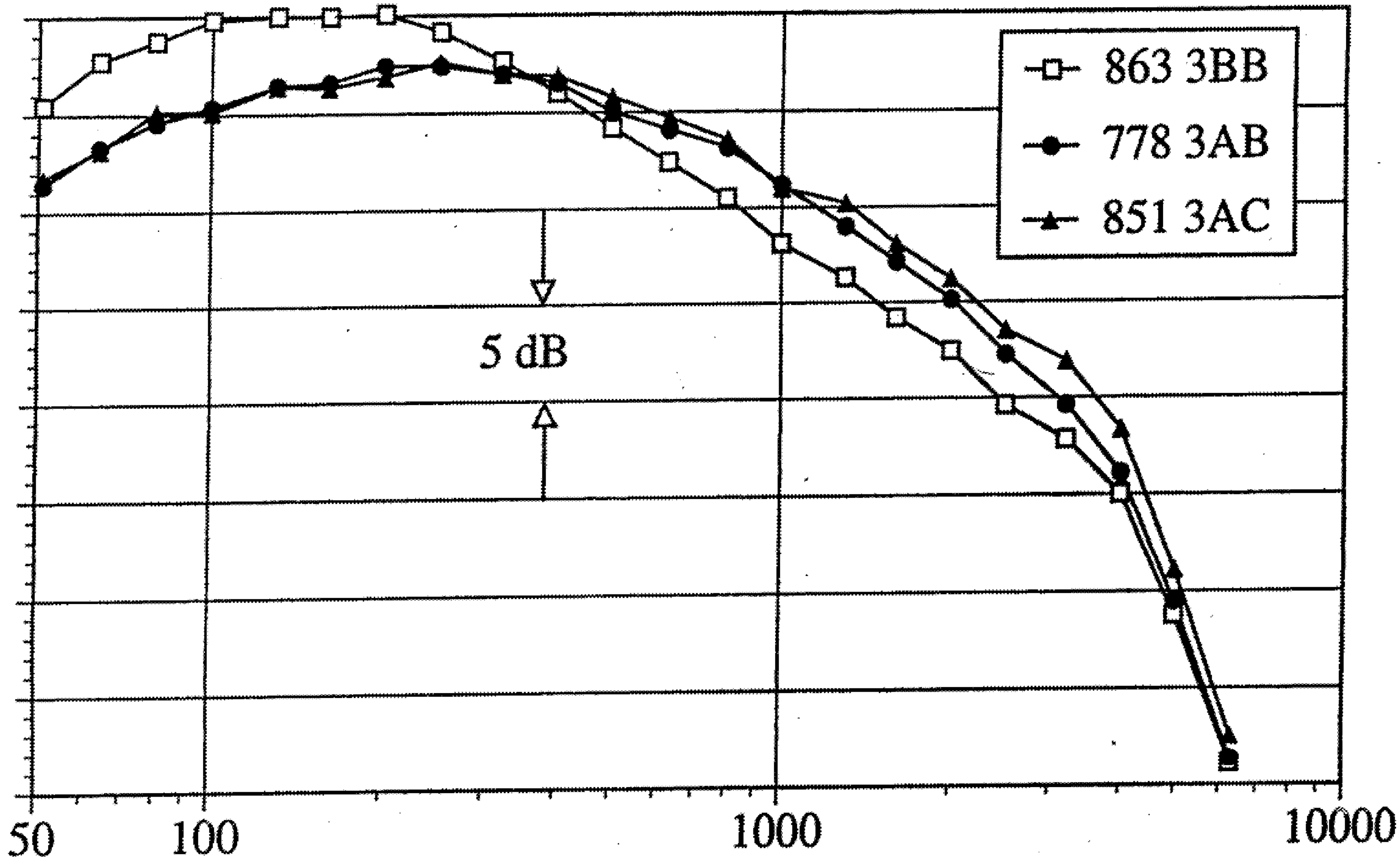
Impact of 24 Chevron fan on 12-Inward Chevron Core



Fan chevrons significantly reduce low-frequency noise and slightly increase the high frequency noise.

BPR 5, External Plug

Impact of 24 Chevron fan on 12-Alternating Chevron Core

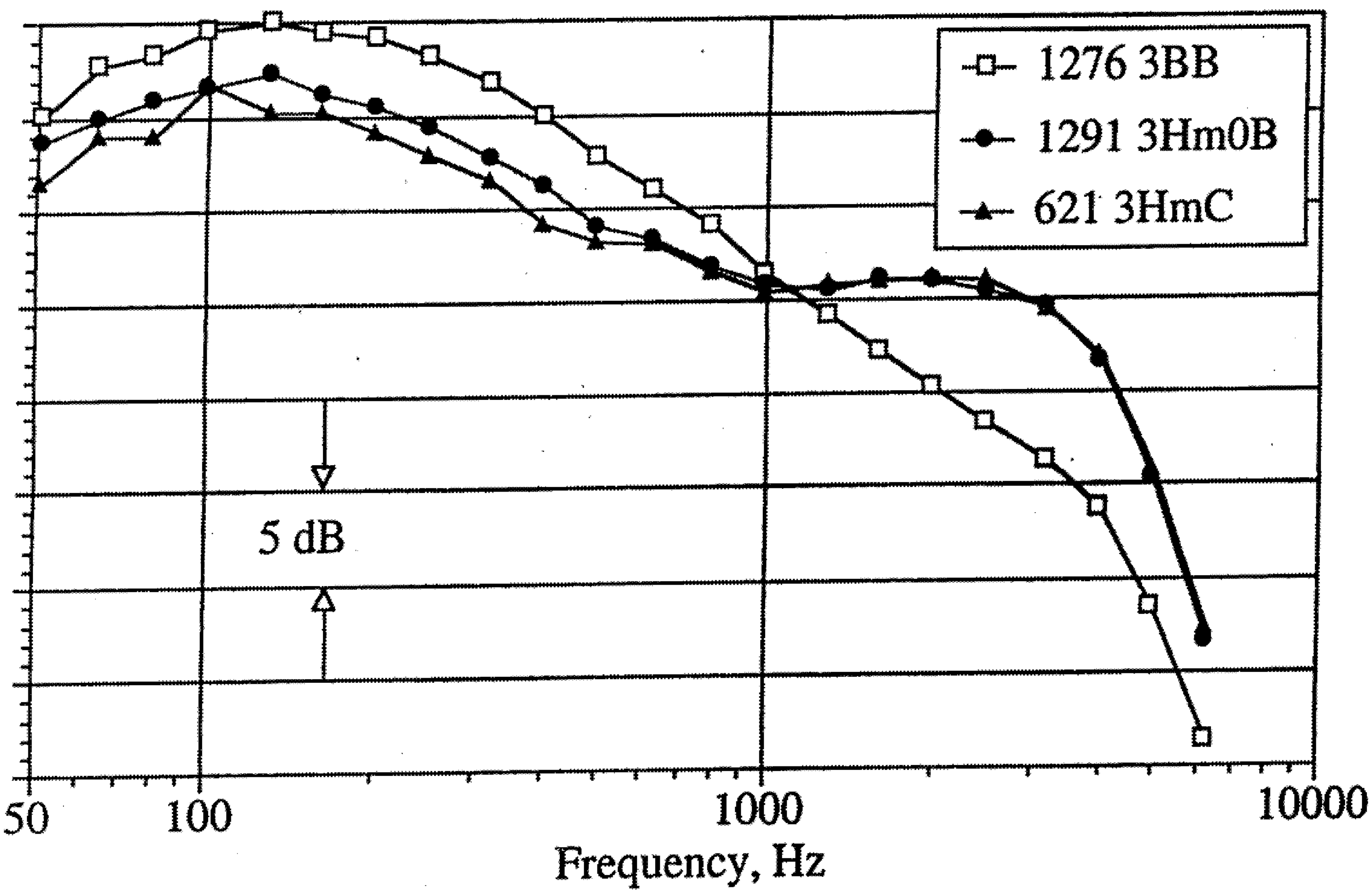


Fan chevrons slightly increasse the high frequency noise over the Alternating core chevrons.

BPR 5, External Plug

31

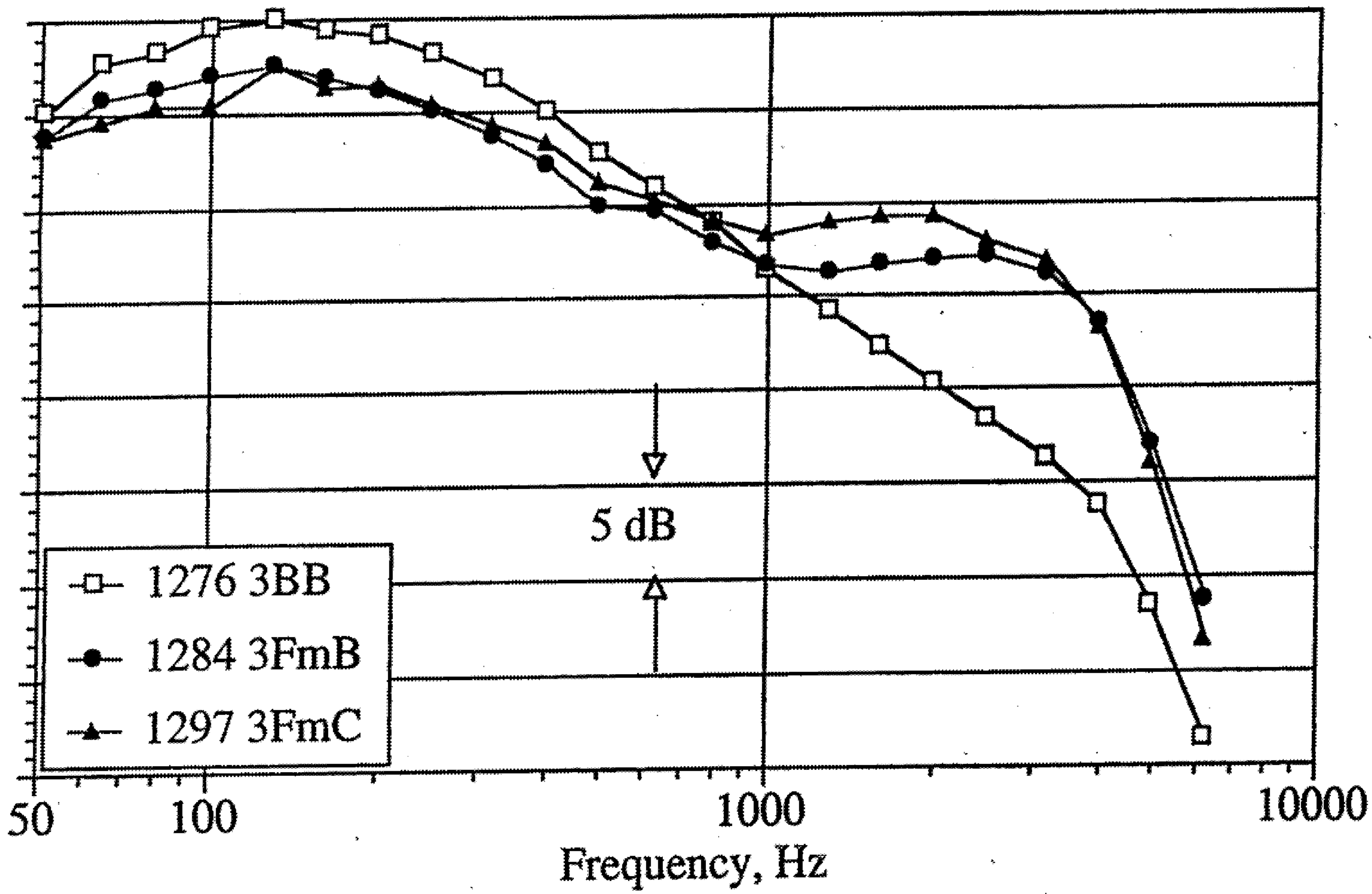
Impact of 24 Chevron fan on core Half-mixer



Fan chevrons reduce jet noise but do not change mixing noise.

BPR 5, External Plug

Impact of 24 Chevron fan on core Full-mixer

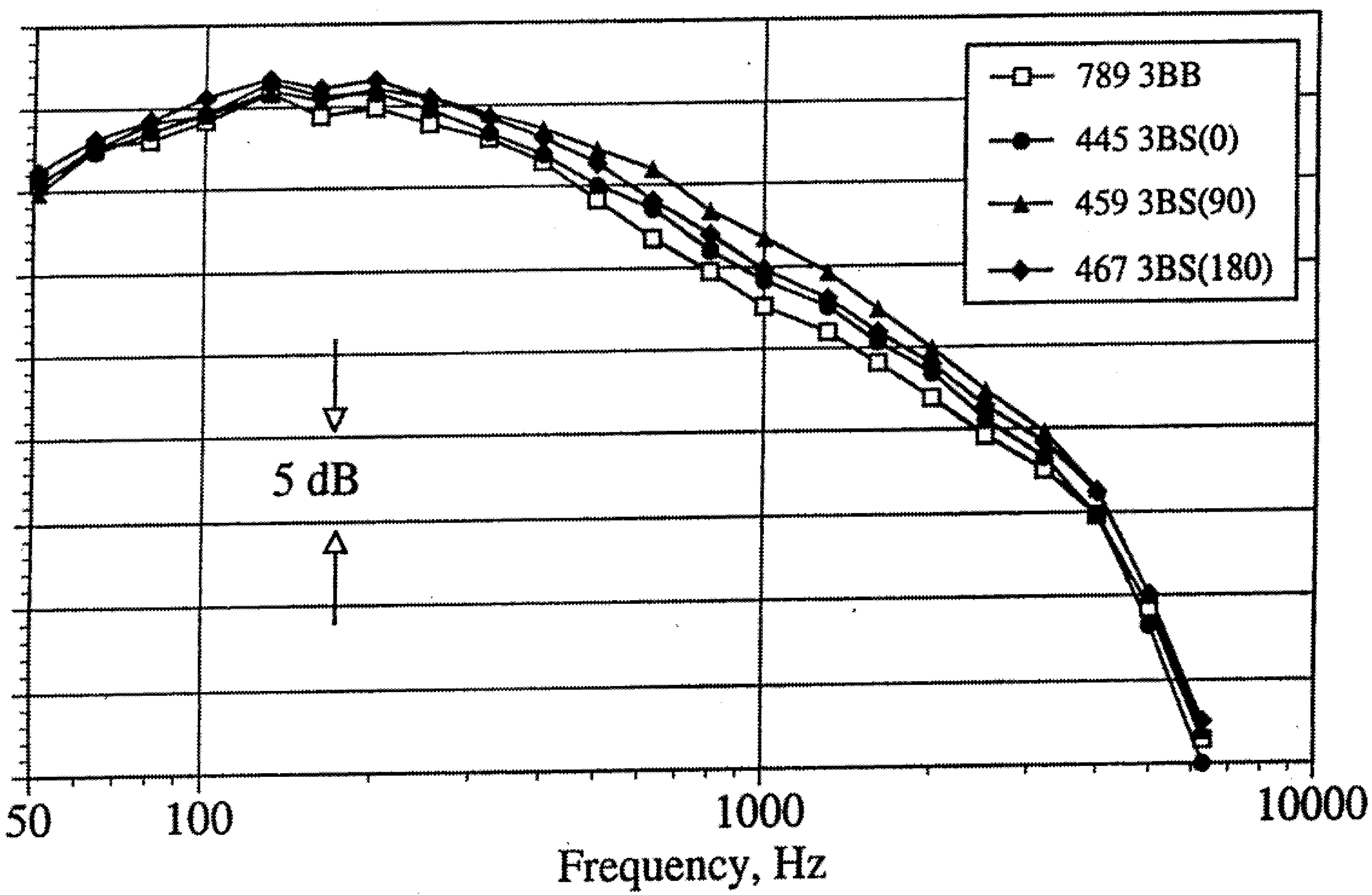


Fan chevrons increase the medium frequencies.

BPR 5, External Plug

5

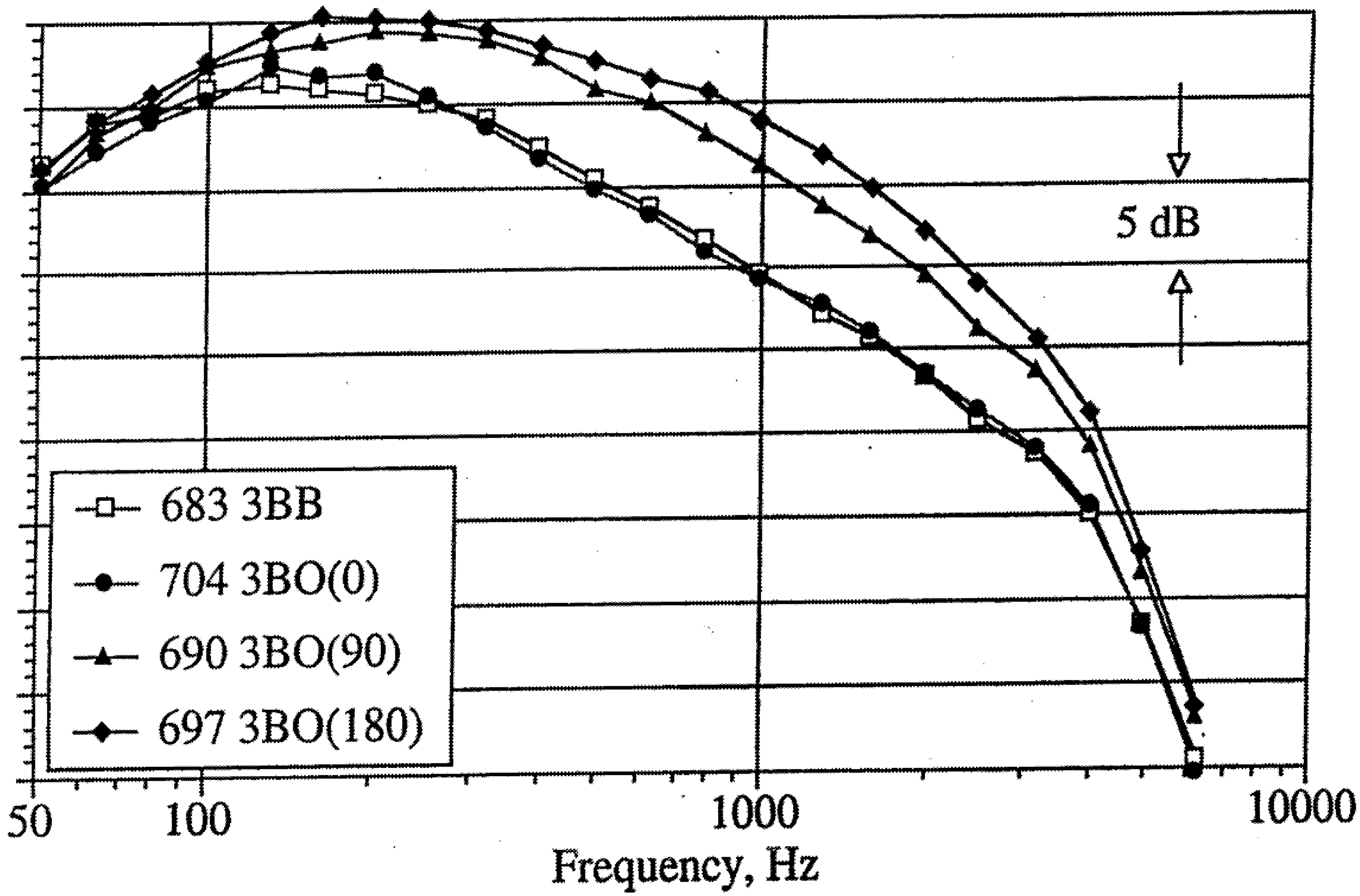
Impact of Scarfed fan nozzle with baseline core



Scarfing creates significant transition noise
90° is the loudest.

BPR 5, External Plug

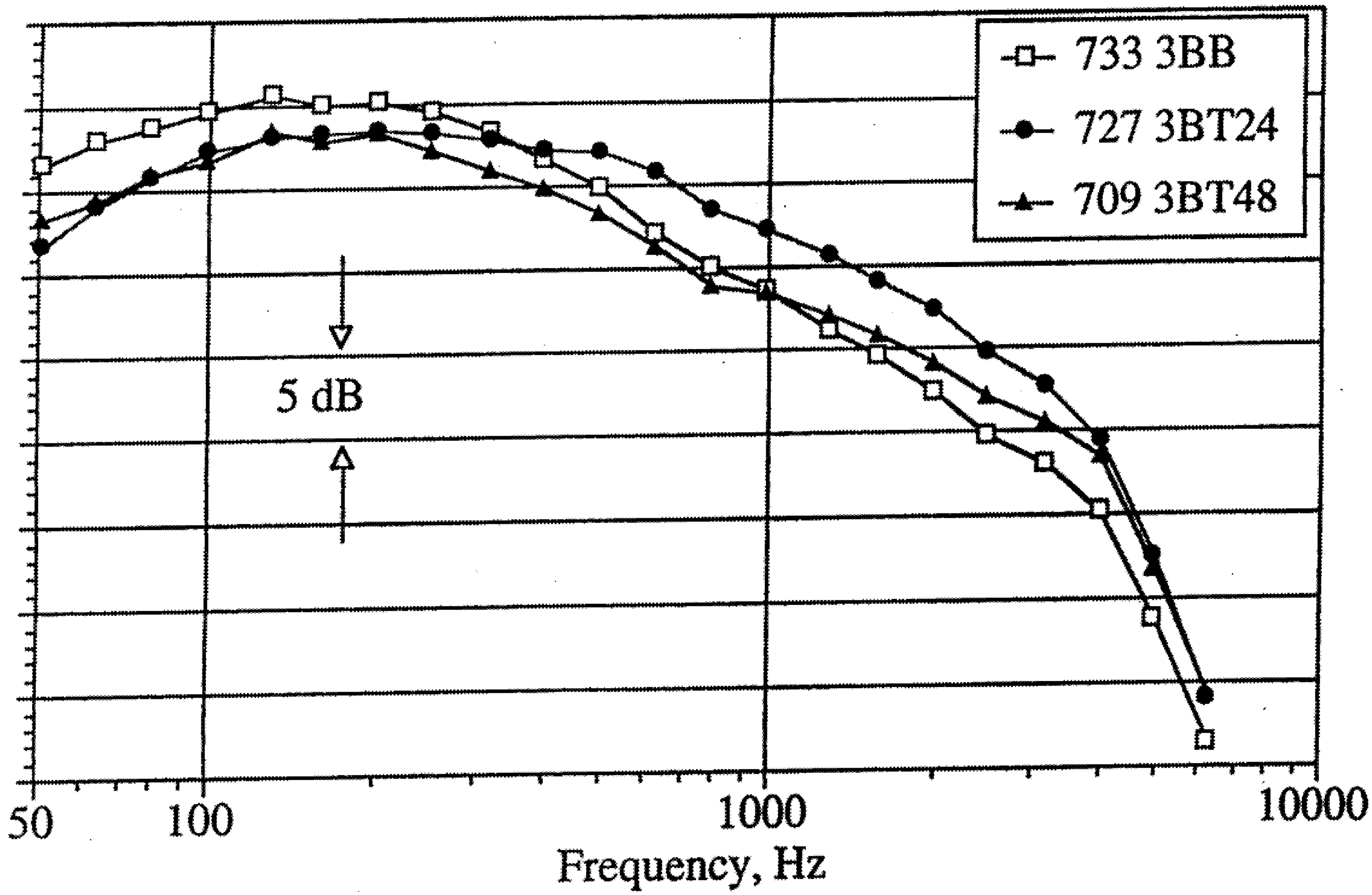
Impact of Off-set fan nozzle with baseline core



Off-set fan nozzle at 90 or 180 is very loud.

BPR 5, External Plug

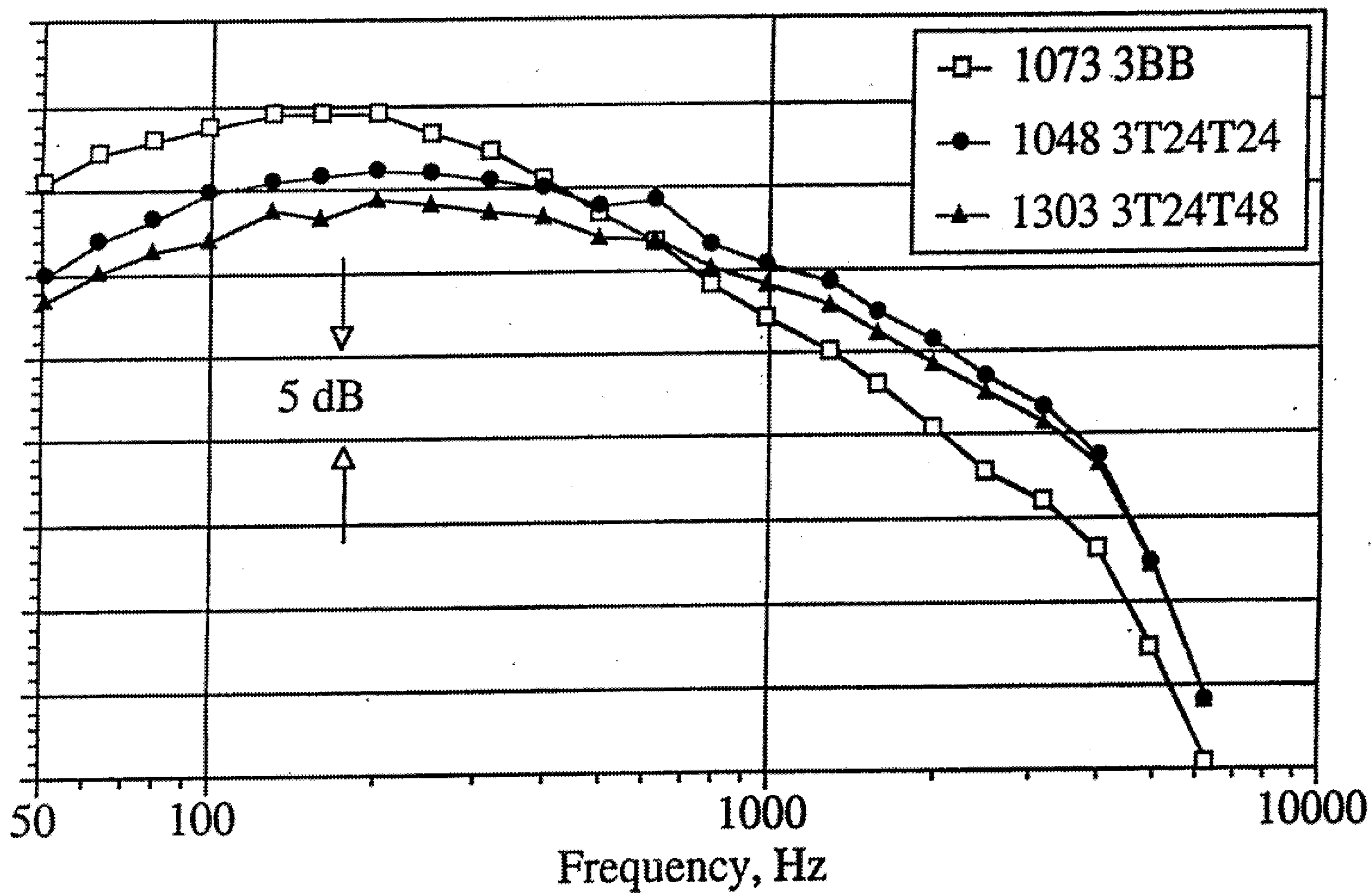
Impact of Fan tabs (24 and 48) with baseline core



Fan 24 and 48 Tabs have same jet noise reduction, but 24 tabs create more more mixing noise than 48 tabs.

BPR 5, External Plug

Impact of Fan tabs (24 and 48) with 24 Tab core

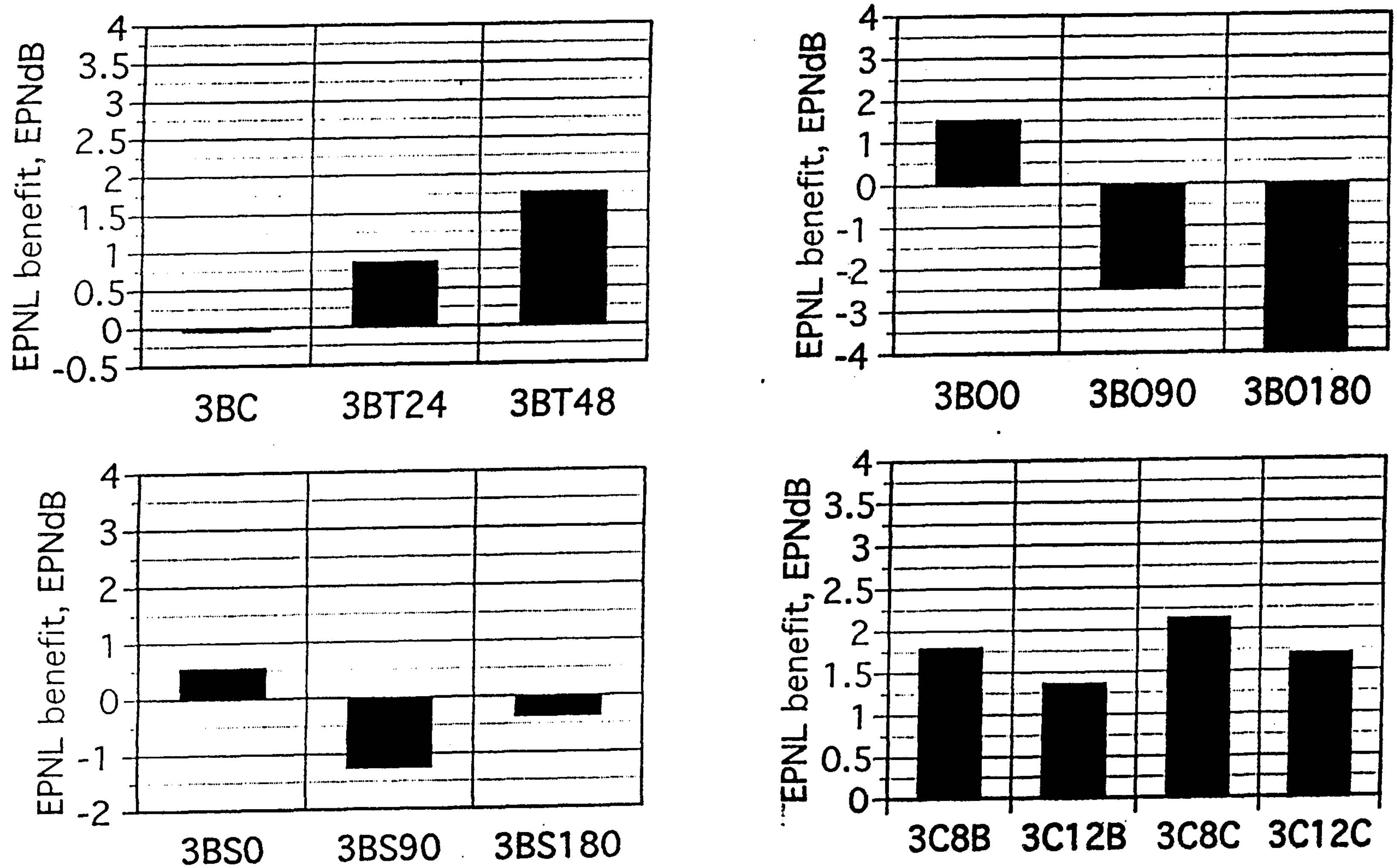


48 Tab fan reduces low-frequency more than 24 tab.

BPR 5, External Plug

EPNL Benefits with Various Noise Suppresors External Plug with 5 BPR engine

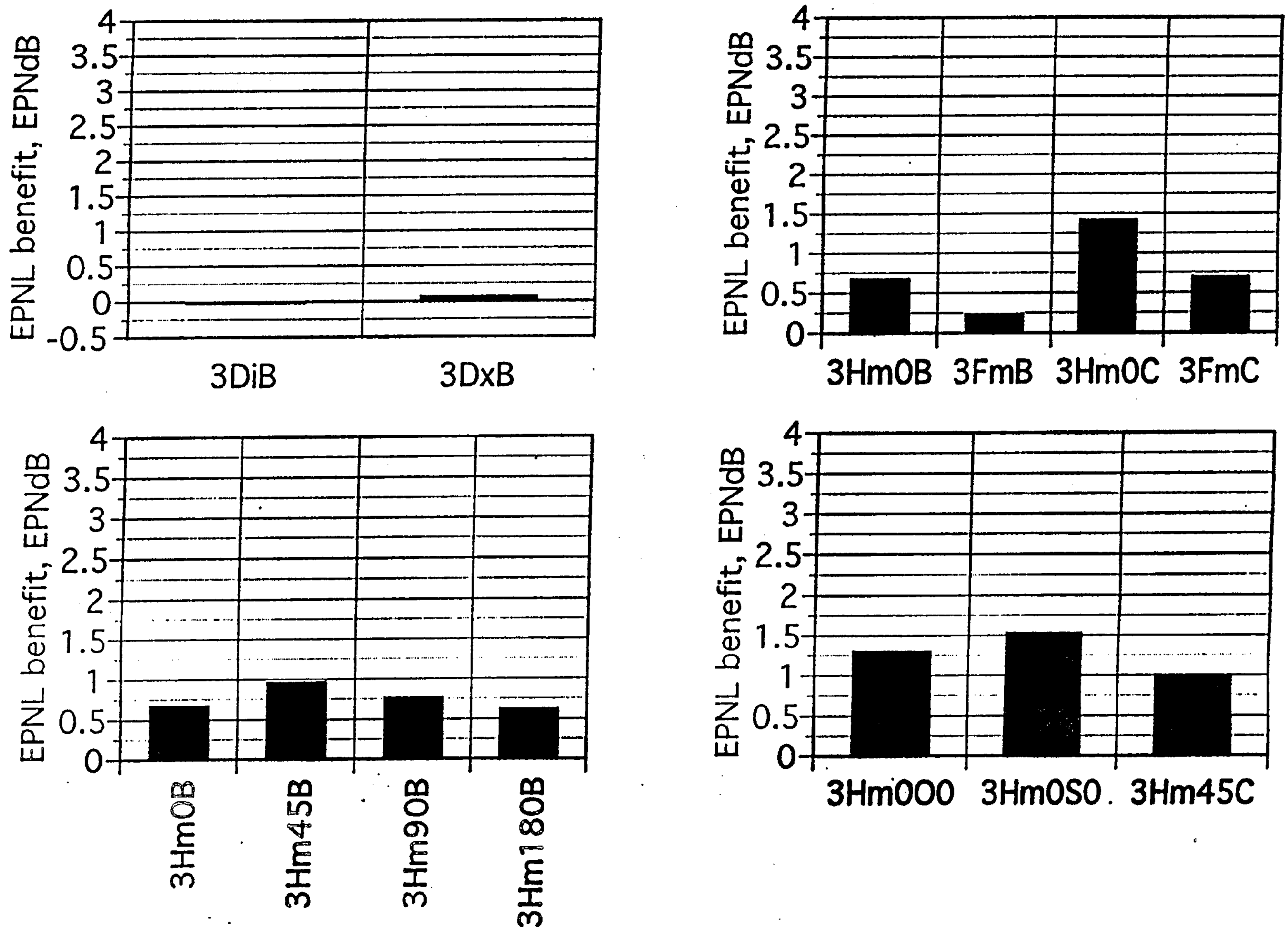
Growth Takeoff (Vmixed = 1200 ft/sec)



1 all epnls 02:56:22 PM September 9, 1997

EPNL Benefits with Various Noise Suppresors External Plug with 5 BPR engine (continued)

Growth Takeoff (Vmixed = 1200 ft/sec)



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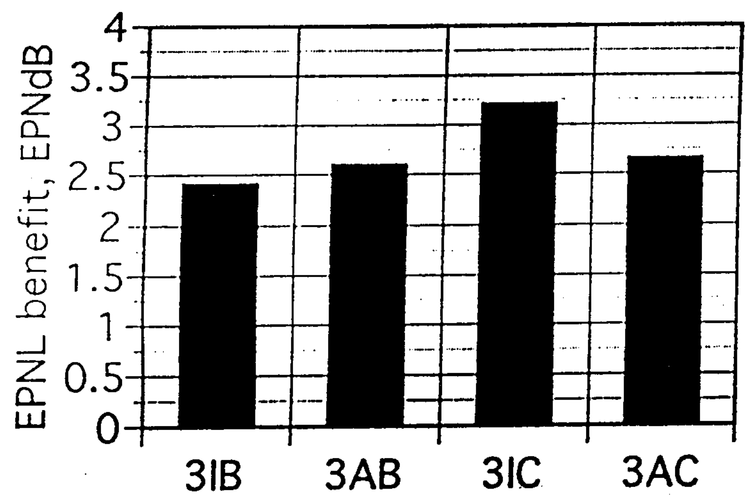
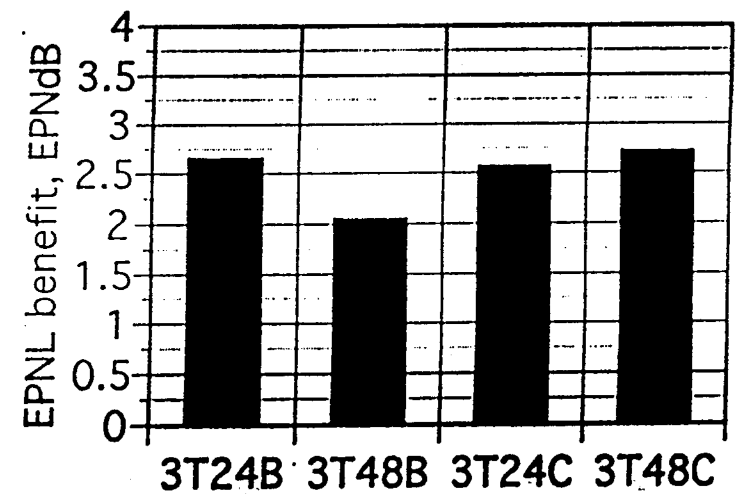
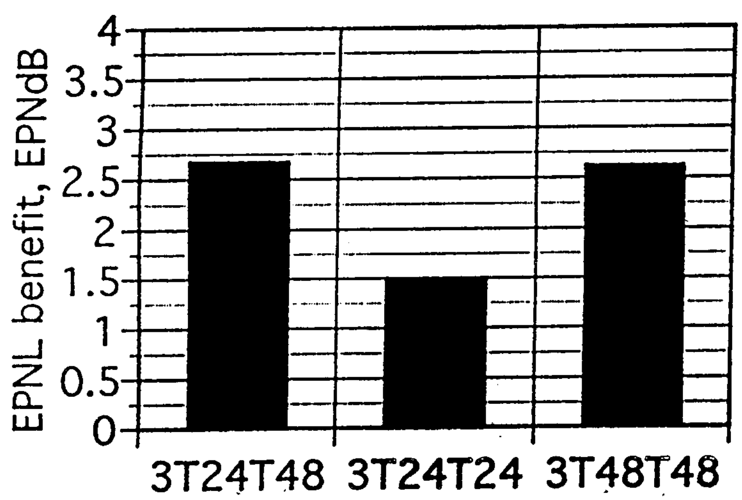
EPNL Benefits with Various Noise Suppresors External Plug with 5 BPR engine (completed)

Growth Takeoff (Vmixed = 1200 ft/sec)

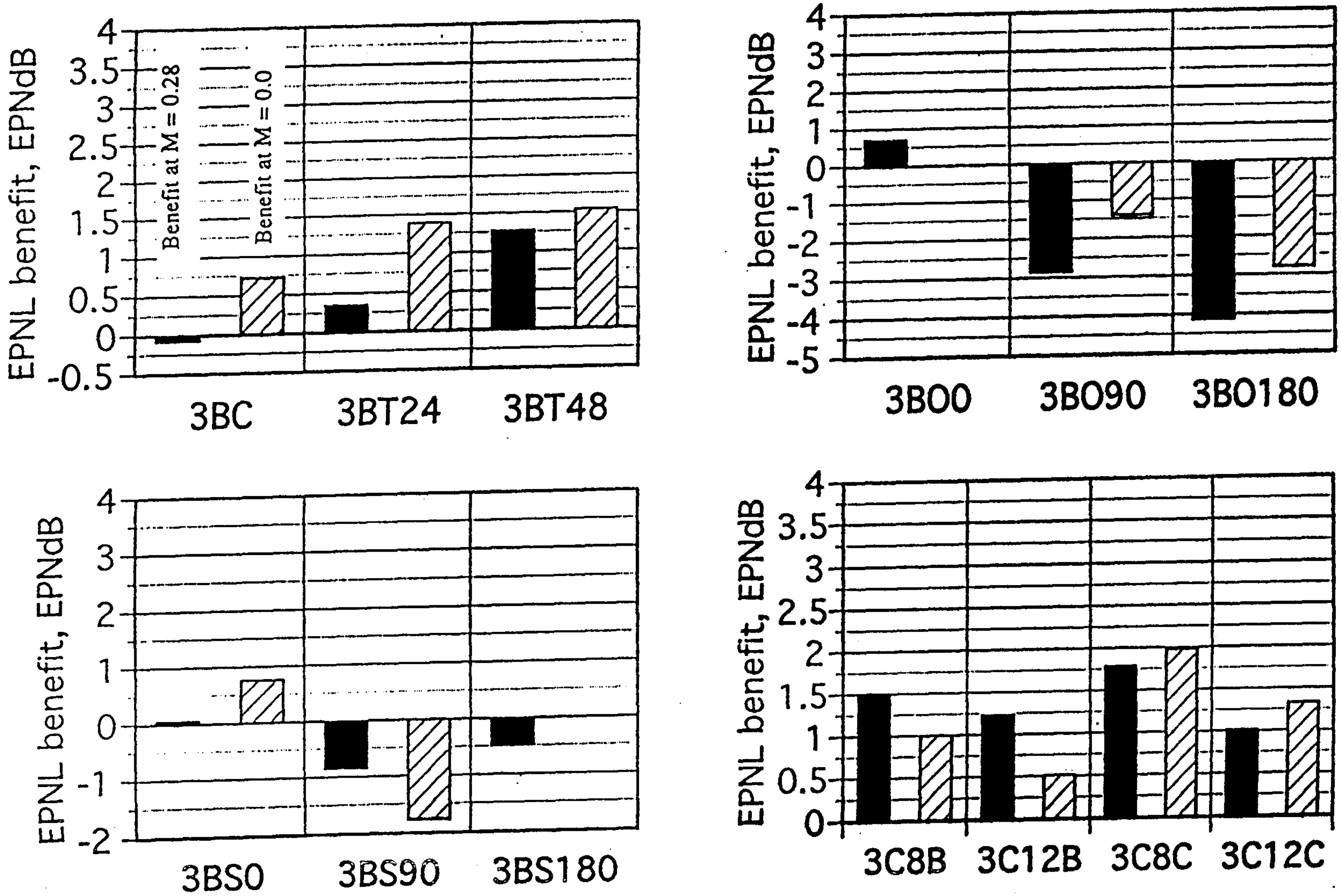






EPNL Benefits with Various Noise Suppresors External Plug with 5 BPR engine (static and flight)

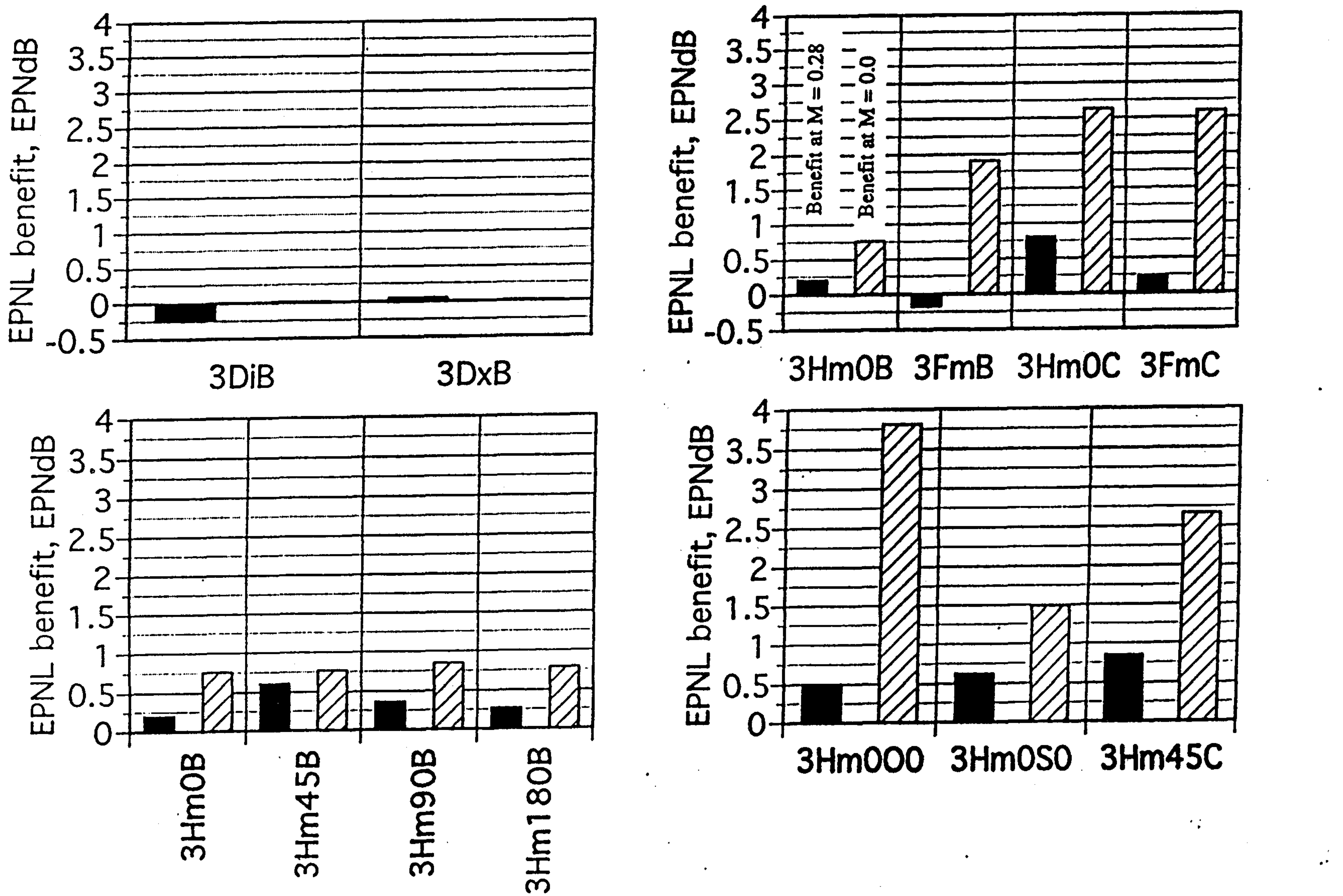
Current Takeoff (Vmixed = 1150 ft/sec)



EPNL Benefits with Various Noise Suppresors External Plug with 5 BPR engine (static and flight)

Current Takeoff (Vmixed = 1150 ft/sec)

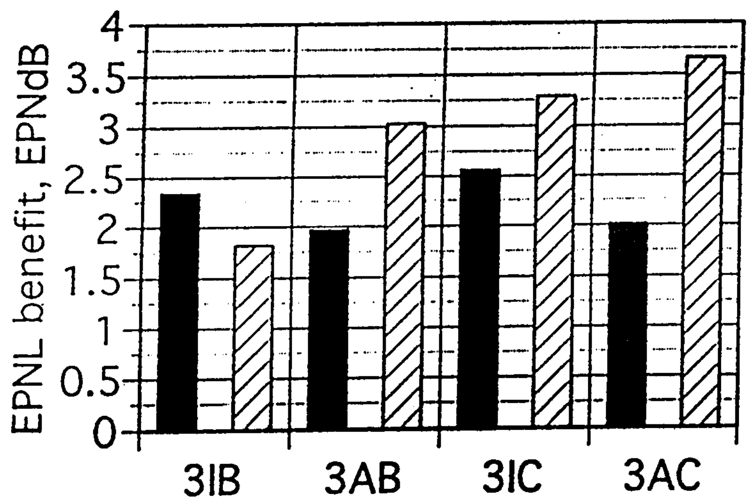
continued

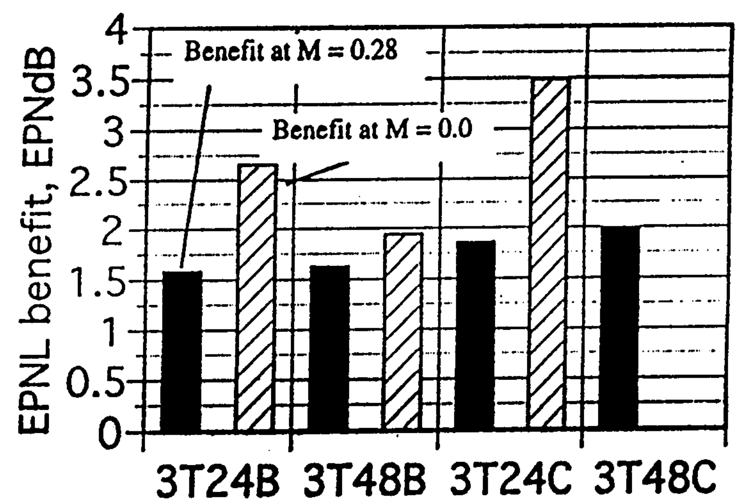


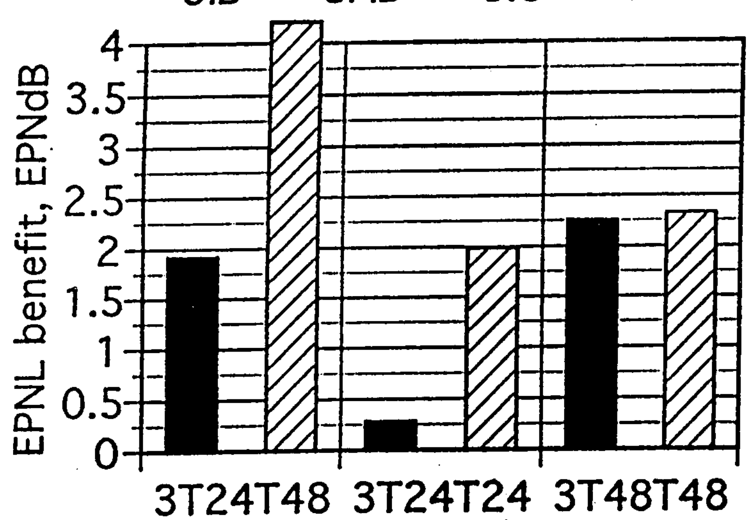
EPNL Benefits with Various Noise Suppresors External Plug with 5 BPR engine (static and flight)

Current Takeoff (Vmixed = 1150 ft/sec)

completed







BPR 5, External Plug Summary (Model 3)

Core Nozzle	Fan Nozzle: B (baseline)	Fan Nozzle: C24 (24 chevrons)
B (baseline)	BB	wrt BB: No change in jet noise. Creates mixing noise.
T24 (24 flipper tabs)	[1]Significantly reduces jet noise but creates mixing noise	[2]Reduces jet noise, transition noise and mixing noise
T48 (48 flipper tabs)	Reduces jet noise, but less than T24. Minute mixing noise	Reduces jet noise but creates mixing noise
C8 (8 chevrons)	Reduces jet noise. No mixing noise.	Reduces jet noise and slightly increases mixing noise
C12 (12 chevrons)	Reduces jet noise, but less than C8. No mixing noise.	Reduces jet noise, transition noise and mixing noise.
I (12 Inward flip. chevrons)	Moderately reduces jet noise. Creates small amount of mixing noise.	Significantly reduces jet noise with slight increase in mixing noise
A (12 alternating flip chev)	Significantly reduces jet noise. Creates significant transitioning noise and mixing noise.	No change in jet noise. Creates more mixing noise
Di (internal doublet)	Not much difference.	Not done
Dx (external doublet)	Not much difference.	Not done
Hm (Half mixer)	Significantly reduces jet noise. Creates intense mixing noise.	Reduces jet noise. No change in mixing noise.
Fm (Full mixer)	Less reduction than Hm for jet noise. Creates intense mixing noise (even more than Hm).	No change in jet noise or mixing noise. Creates transition noise.

1 Note: Fan baseline column comparisons are made against the baseline core and baseline fan nozzles.

2 Note: Fan chevron column comparisons are made against the core device with baseline fan nozzles.

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BPR 5, External Plug Summary (Model 3) concluded

Core / Nozzle	Fan Nozzle: B (baseline)	Fan Nozzle: T24	Fan Nozzle: T48
B (baseline)	BB	wrt BB: Reduces jet noise but creates significantly high transition and mixing noise	wrt BB: Reduces jet noise, transition noise and creates moderate mixing noise.
T24 (24 flipper tabs)		wrt BB: Moderately reduces jet noise. Creates transition and mixing noise.	[3]Reduces jet noise, transition noise. No change in mixing noise.

Core / Nozzle	Fan Nozzle: B (baseline)	Fan Nozzle: Scarfed	Fan Nozzle: Offset
B (baseline)	BB	wrt BB: Creates high transition frequencies at all rotations. 90° rotation is noisest.	wrt BB: 0° rotation is nearly identical to BB. Other rotations creates transitioning noise.

[3] Note: Fan T48 column comparison is made against the core device with T24 fan nozzle.

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BPR 5, Internal Plug Summary (Model 2)

Core / Nozzle	Fan Nozzle		
	B (baseline)	C24 (24 chevrons)	D (96 doublets)
B (baseline)	BB	wrt BB: Reduce jet noise and increase mixing noise.	wrt BB: Broad-band small increase.
C12 (12 chevrons)	[4] Slighty reduce jet noise. Minimal increase in mixing noise	Jet noise is reduced and mixing noise is enhanced.	
Tm (tongue mixer)	Significantly reduce jet noise and increase mixing noise.	Jet noise is reduced. Mixing noise is unchanged.	

BPR 8, External Plug Summary (Model 5)

Core / Nozzle	Fan Nozzle	
	B (baseline)	C24 (24 chevrons)
B (baseline)	BB	wrt BB: .
C12 (12 chevrons)	[5] Slightly reduce jet noise with no change in mixing noise	

4 Note: See notes 1 and 2.

5 Note: See notes 1 and 2.

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BPR 5, External Plug Summary (Model 3)

Core Nozzle	Fan Nozzle					
	(wrt 3BB) Baseline Fan			(wrt core devices) 24 Chevron		
	Jet Noise	Transition	Mixing	Jet noise	Transition	Mixing
B (baseline)	0	0	0	0	+	++
T24 (24 flipper tabs)	----	++	++	--	--	--
T48 (48 flipper tabs)	---	--	0	---	0	++
C8 (8 chevrons)	--	0	0	--	0	++
C12 (12 chevrons)	-	0	0	---	---	-
I (12 Inward flip. chevrons)	---	0	+	---	0	+
A (12 alternating flip chev)	----	+++	+++	0	0	++
Di (internal doublet)	0	0	0			
Dx (external doublet)	0	0	0			
Hm (Half mixer)	----	0	+++	--	0	0
Fm (Full mixer)	---	0	++++	0	++	0

BPR 5, External Plug Summary (Model 3) concluded

Core Nozzle	Fan Nozzle						
		Scarfed (wrt 3BB)			Off-set		
	Angle	Jet Noise	Transition	Mixing	Jet noise	Transition	Mixing
B (baseline)	0°	0	+	+	0	0	0
B (baseline)	90°	0	++	+	++++	++++	++++
B (baseline)	180°	0	+	+	++++	++++	++++

Core Nozzle	Fan Nozzle					
	T24 (24 flip. tabs) (see footnote 1)			T48 (48 flip. tabs) (see footnote 2)		
	Jet Noise	Transition	Mixing	Jet noise	Transition	Mixing
B (baseline)	- -	+++	++++	- - -	- -	++
T24 (24 flipper tabs)	- - -	+++	++++	- - - -	- -	0

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BPR 5, Internal Plug Summary (Model 2)

Core Nozzle	Fan Nozzle								
	Baseline			C24 (24 chevrons)			D (96 doublets)		
	Jet noise	Transition	Mixing	Jet noise	Transition	Mixing			
B (baseline)				- -	0	++	+	+	+
C12 (12 chevrons)	-	0	+	- - -	0	++			
Tm (tongue mixer)	- - -	0	++++	- -	0	-			

BPR 8, External Plug Summary (Model 5)

Core Nozzle	Fan Nozzle					
	Baseline			C24 (24 chevrons)		
	Jet noise	Transition	Mixing	Jet noise	Transition	Mixing
B (baseline)				- -	-	0
C12 (12 chevrons)	-	0	0	- -	-	+

Conclusions

- High quality <u>and</u> quantity data (acoustics, plume flow field and source location)
- Jet noise reduction goal of 3 EPNdB in model scale accomplished using 3IC configuration (3.2 EPNdB reduction)
- Several concepts provided 2.5 - 2.7 EPNdB reduction
- Test clearly demonstrated need for balancing jet noise reduction with increased transition and mixing noise
- 24 Fan chevrons reduced jet noise in some cases, but increased mixing noise reduced its benefits
- Core tabs and chevrons reduced jet noise with little or no gain in mixing noise (T24 on core is an exception)
- Doublets did not provide any significant EPNL reductions

- Half mixer and Full mixer reduced jet noise and increased mixing noise.
- Half mixer reduced jet noise more than full mixer and increased mixing noise less than full mixer. (Half is better than full).
- Core tabs and chevrons reduced jet noise with little or no gain in mixing noise (T24 on core is an exception)
- Scarfed fan created transition and mixing noise at all rotations without decreasing jet noise. (90° was loudest)
- Offset fan nozzle created jet, transition and mixing noises at 90° and 180°. 0° did not create or reduce any form of noise.
- 24 Tab fan reduced the jet noise but increased the transition and mixing noise
- 48 Tab fan reduced the jet and the transition noise and increased the mixing noise

- Tongue mixer reduced jet noise and increased mixing noise.
- Data base in place to explore full-scale verification candidates

SEPARATE FLOW NOZZLE JET NOISE TEST STATUS MEETING at NASA Lewis Research Center

Presentation Outline

- **o Test Objective**
- **o PW's Jet Noise Reduction Nozzle Concepts**
  - **o Descriptions of PW's Nozzles "Acoustic" Features**
  - **o CFD Analyses for Selected Nozzles**
  - **o Review of Test Results**
    - **o Noise Data Repeatability / Normalization Factors Applied**
    - **o Noise Comparisons for Selected Concepts, EPNL, PNL Directivities, Spectra**
    - **o Summary of EPNL Reductions for PW's Nozzle Concepts Tested**
    - **o Plume Survey Temperature Profiles**
    - **o Boeing's Phased–Array Microphone System Source Noise Location Results**
- **o Discussion of Measured Acoustics and Related Aero Data**

J.Low / T. Barber / S. Bhat

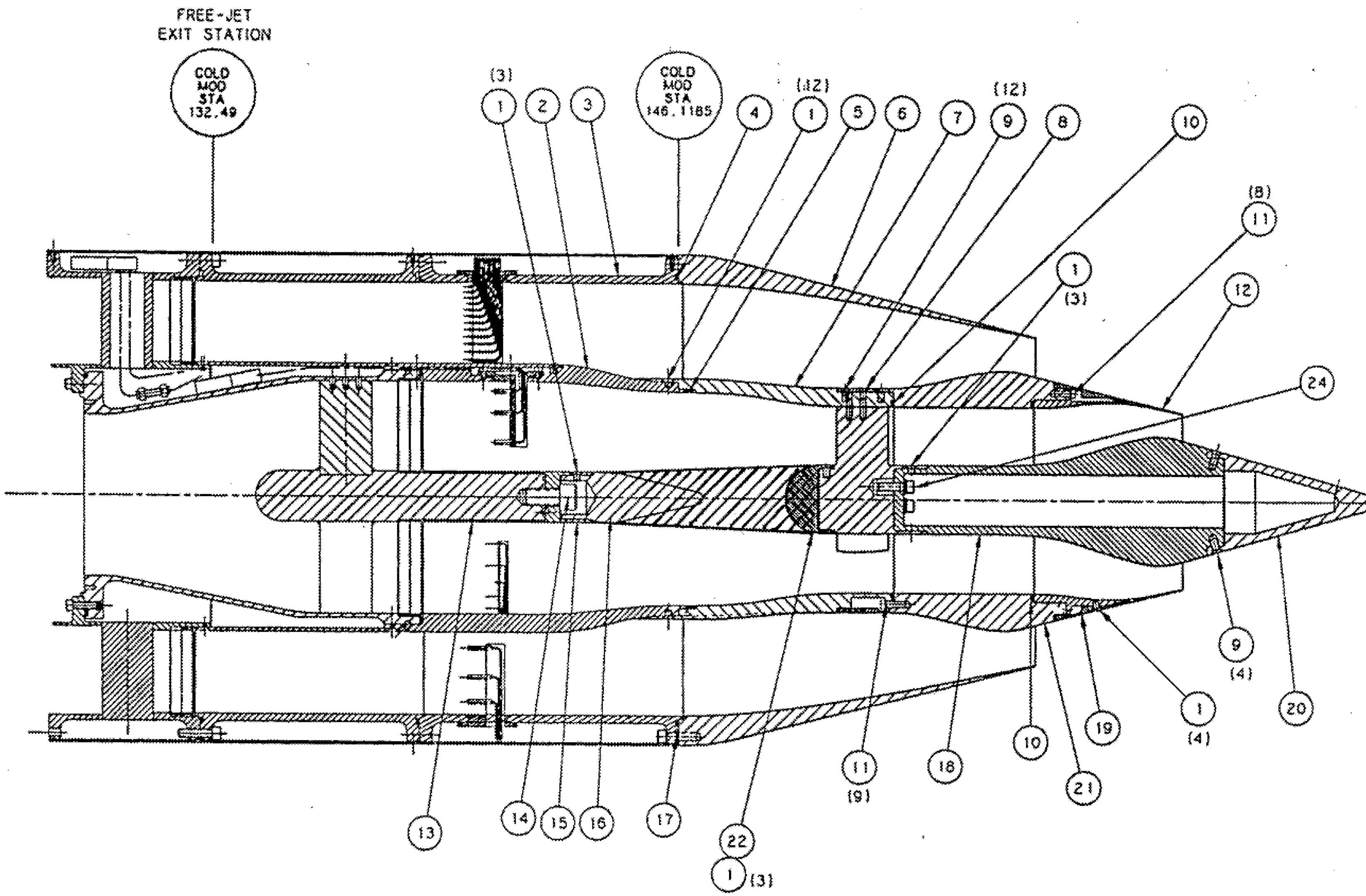
September 10, 1997

AST TASK 14.2 JET NOISE TEST OBJECTIVE

- Conduct model jet noise tests, demonstrating a 3 dB reduction in jet noise (relative to 1992 technology) for nonmixed, separate flow high bypass ratio (BPR) engine/nacelle installations with minimal changes in engine and nacelle geometry.

Baseline Nozzle System with Separate Flow, External Plug and BPR of 5

Model # 3



Nomenclature For Naming Nozzle Configurations

Nozzle Configuration W XX YY

Model # (W)

1 = Coplanar (BPR=5)　**2** = Internal Plug (BPR=5)　**3** = External Plug (BPR=5)

4 = Internal Plug (BPR=8)　**5** = External Plug (BPR=8)

Core Nozzle Mixing Enhancer (XX)

B = Baseline Axisymmetric Nozzle

C12 = 12 Chevrons

C8 = 8 Chervons

I = 12 Inward Flipper Chervons

A = 12 Alternating Flipper Chevrons

Di = 64 Internal Doublet Vortex Generators

Do = 20 External Doublet Vortex Generators

T24 = 24 Flipper Tabs (P&W)

T48 = 48 Flipper Tabs (P&W)

Hm = 10–mini=lobed Half Mixer (P&W)

Tu = Tongue Mixer (Allison)

Fm = 20–mini–lobed Full Mixer (P&W)

Fan Nozzle Mixing Enhancer (YY)

B = Baseline Axisymmetric Nozzle

C = 24 Chevrons

Di = 96 Internal Doublet Vortex Generators

T24 = 24 Flipper Tabs (P&W)

T48 = 48 Flipper Tabs (P&W)

Omax = Maximum Offset Centerline Nozzle (P&W)

S = Scarfed Nozzle (P&W)

Ct = 24 Chevrons with B.L. trip

Cv = 24 Chevrons with external VGs

PW's JET NOISE REDUCTION NOZZLE CONCEPTS

Core Jet Noise Reduction Concepts

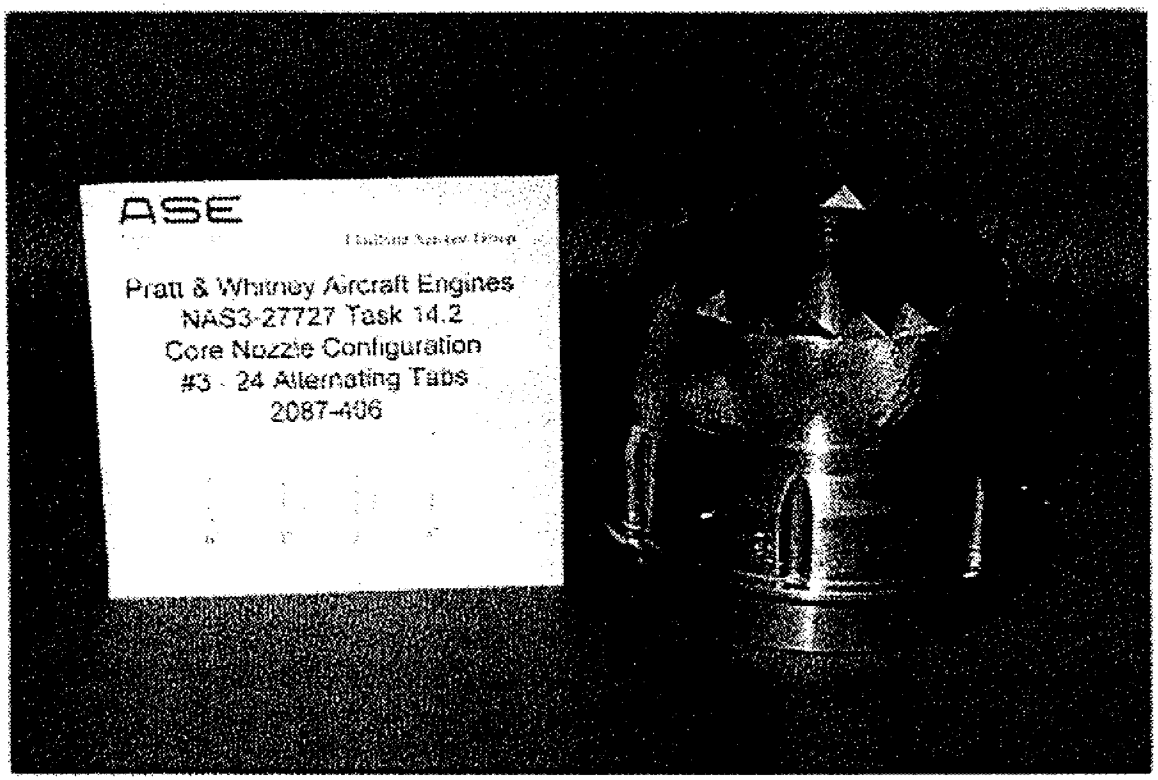
- 24 Flipper Tabs
- 48 Flipper Tabs
- 10 mini–lobed Half Mixer
- 20 mini–lobed Full Mixer

Fan Jet Noise Reduction Concepts

- 24 Flipper Tabs
- 48 Flipper Tabs
- Scarfed / "Sugar Scoop"
- Offset Centerline

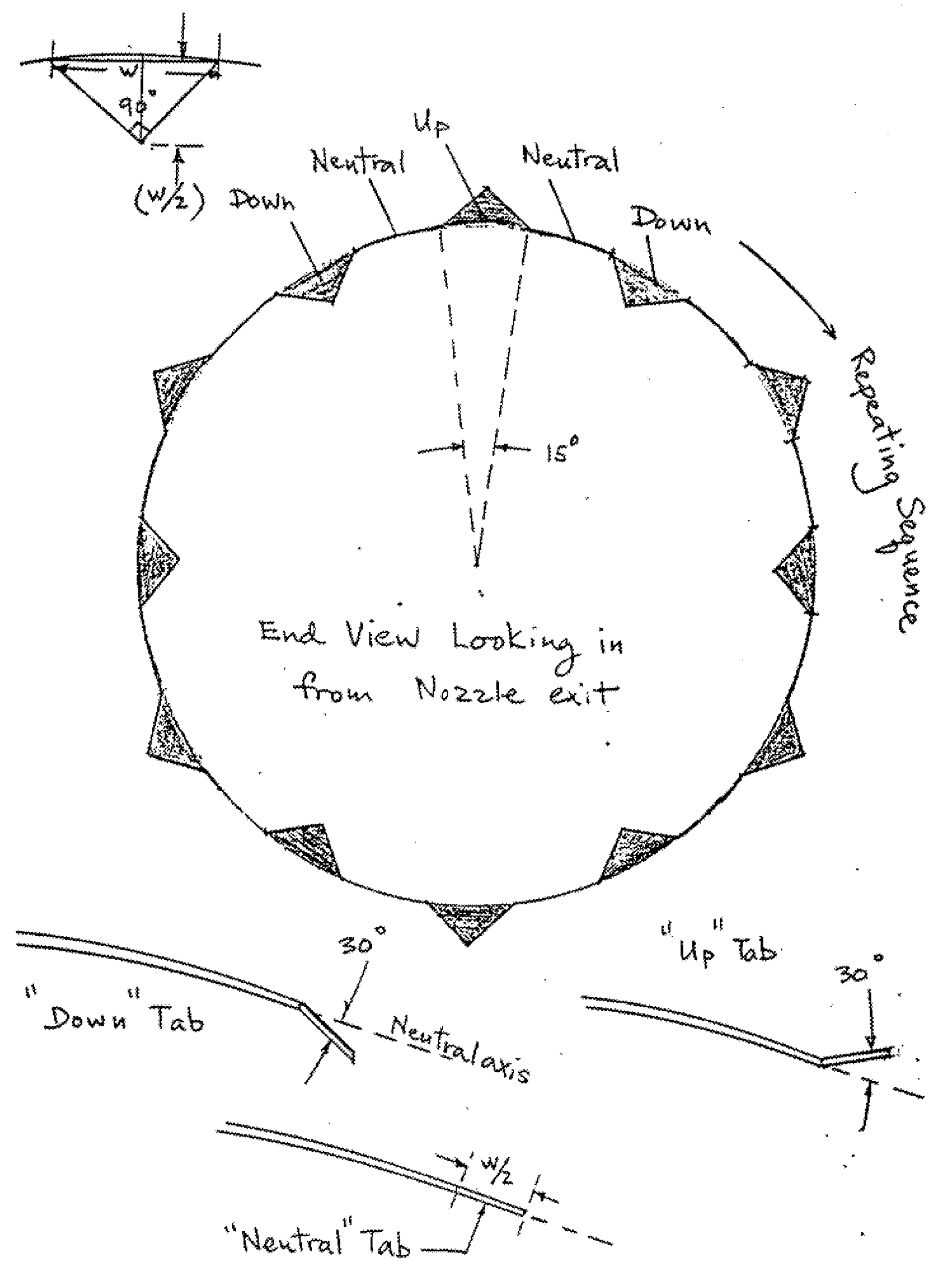
*** Combinations of PW's "best" core nozzle concepts and GE's "best" fan nozzle concepts were also tested.**

PW's 24 Flipper Tabs Core Nozzle



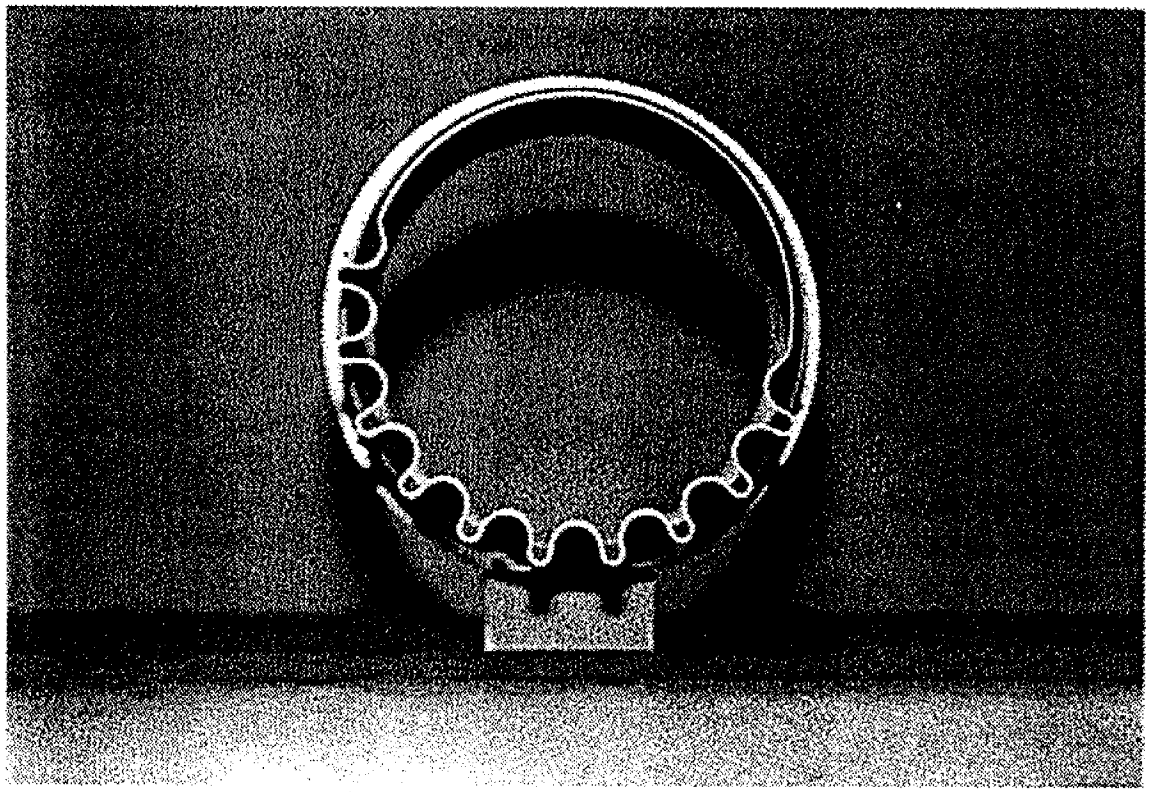
Sketch of the Tab Arrangement for the 24 Flipper Tabbed Core Nozzle

(6 up, 6 neutral, 6 down, 6 neutral)

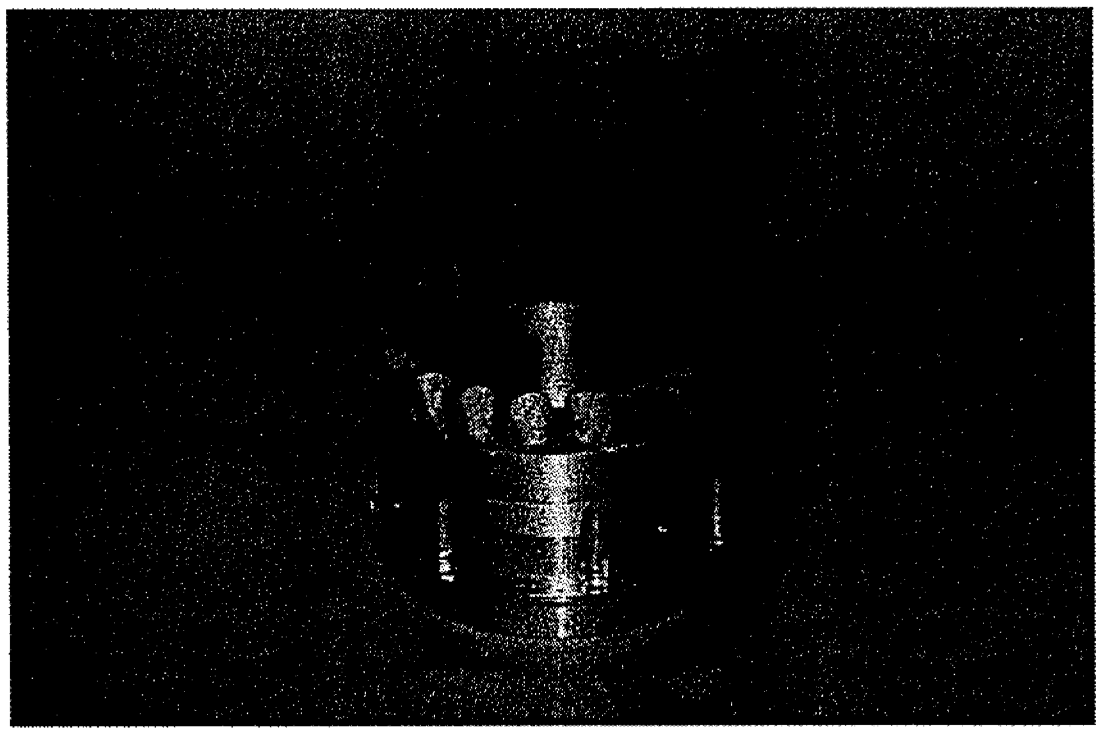


PW's 48 Flipper Tabs Core Nozzle

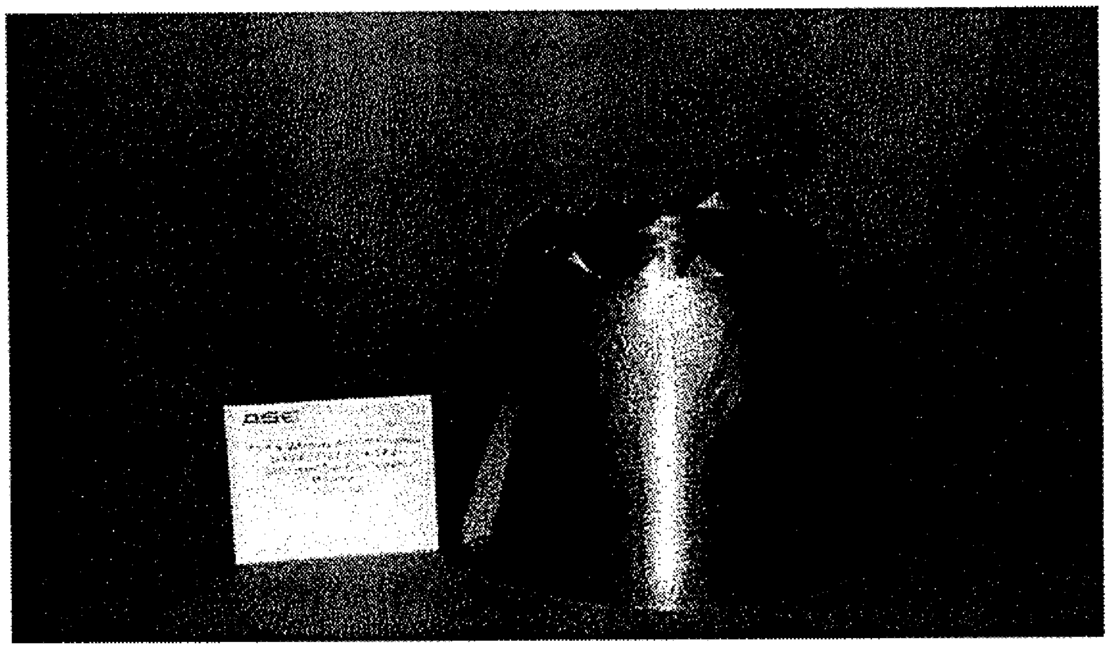
PW's 10 mini-lobed Core Half Mixer



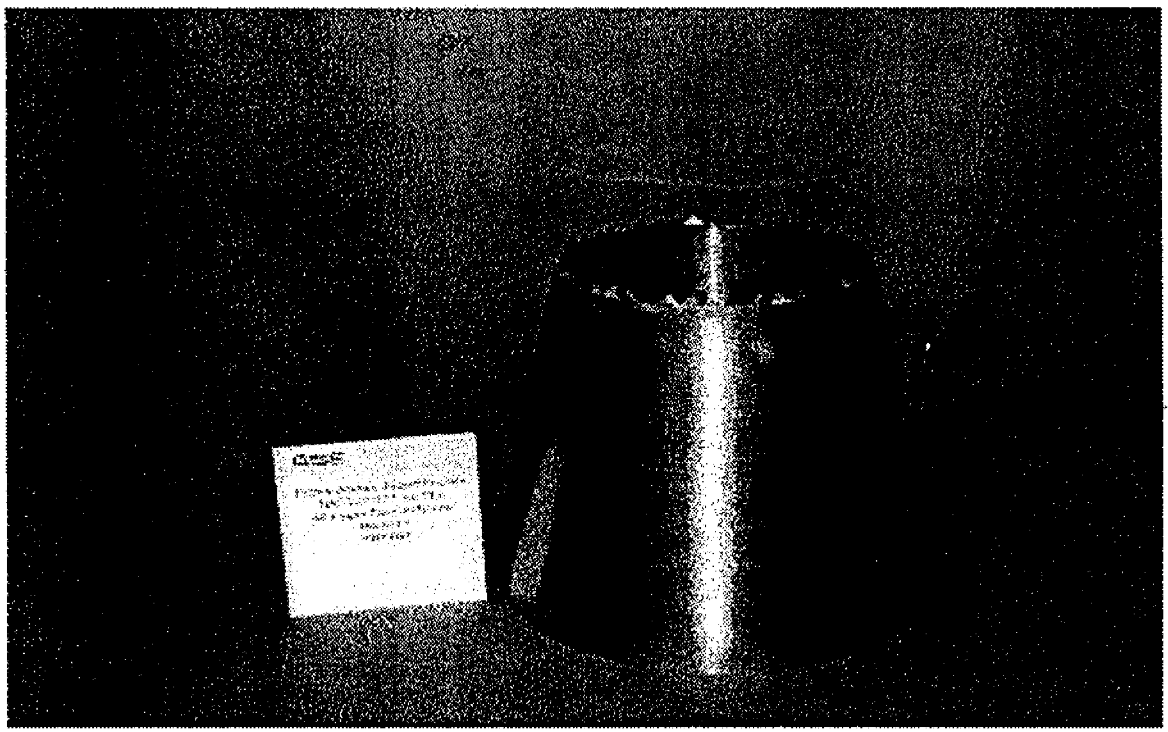
PW's 10 mini-lobed Core Half Mixer



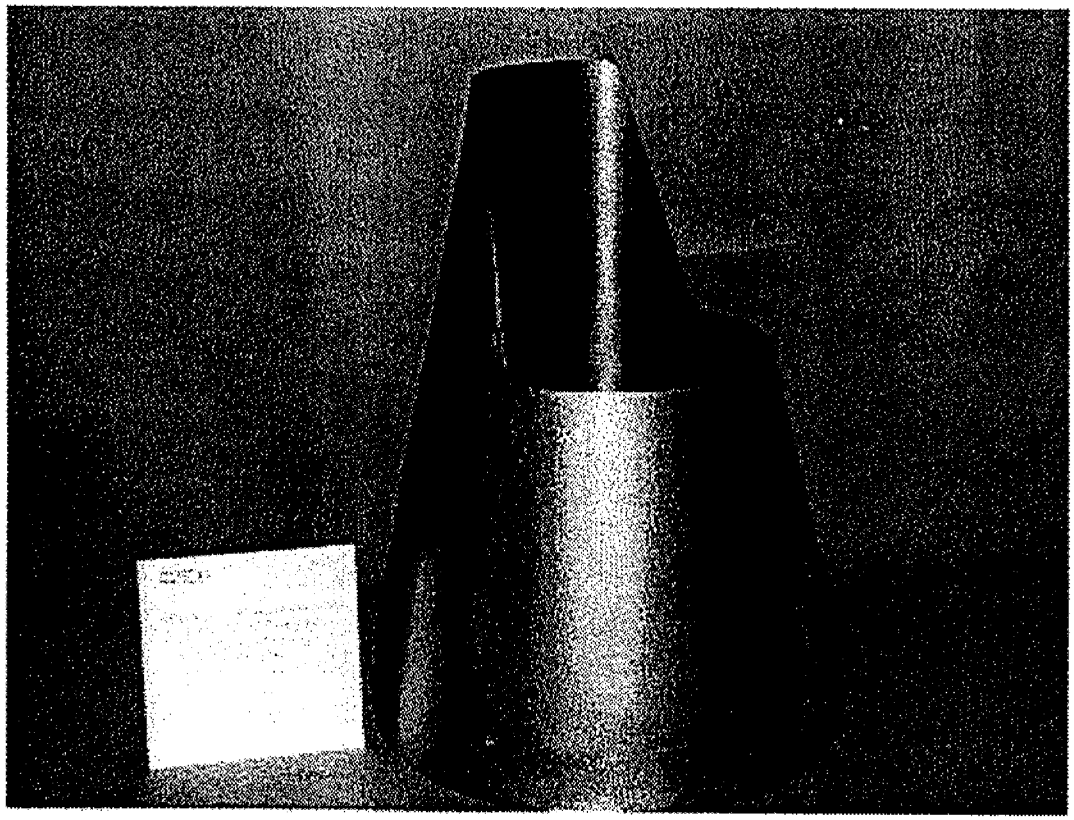
PW's 24 Flipper Tabs Fan Nozzle



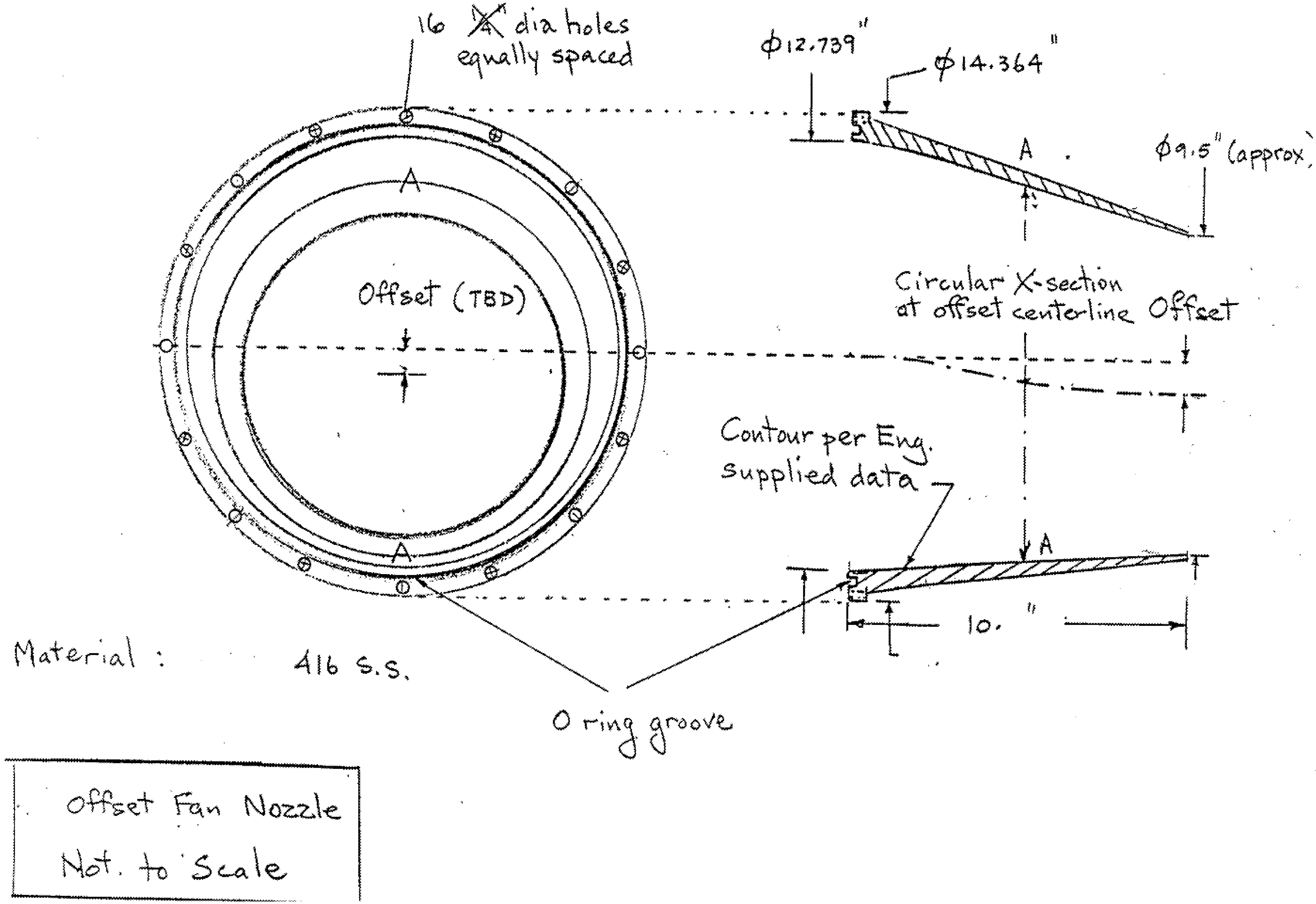
PW's 48 Flipper Tabs Fan Nozzle



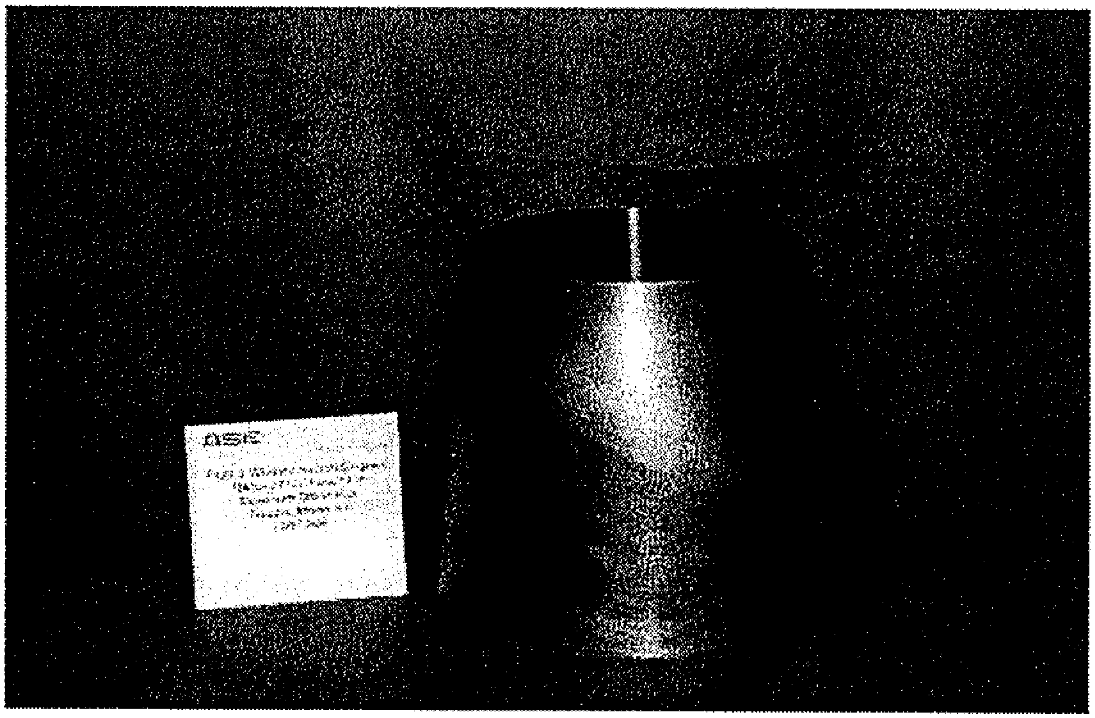
PW's Scarfed Fan Nozzle



SKETCH SHOWING OFFSETTING OF THE CENTERLINE OF FAN NOZZLE AS FUNCTION OF NOZZLE AXIAL LENGTH



PW's Offset Centerline Fan Nozzle



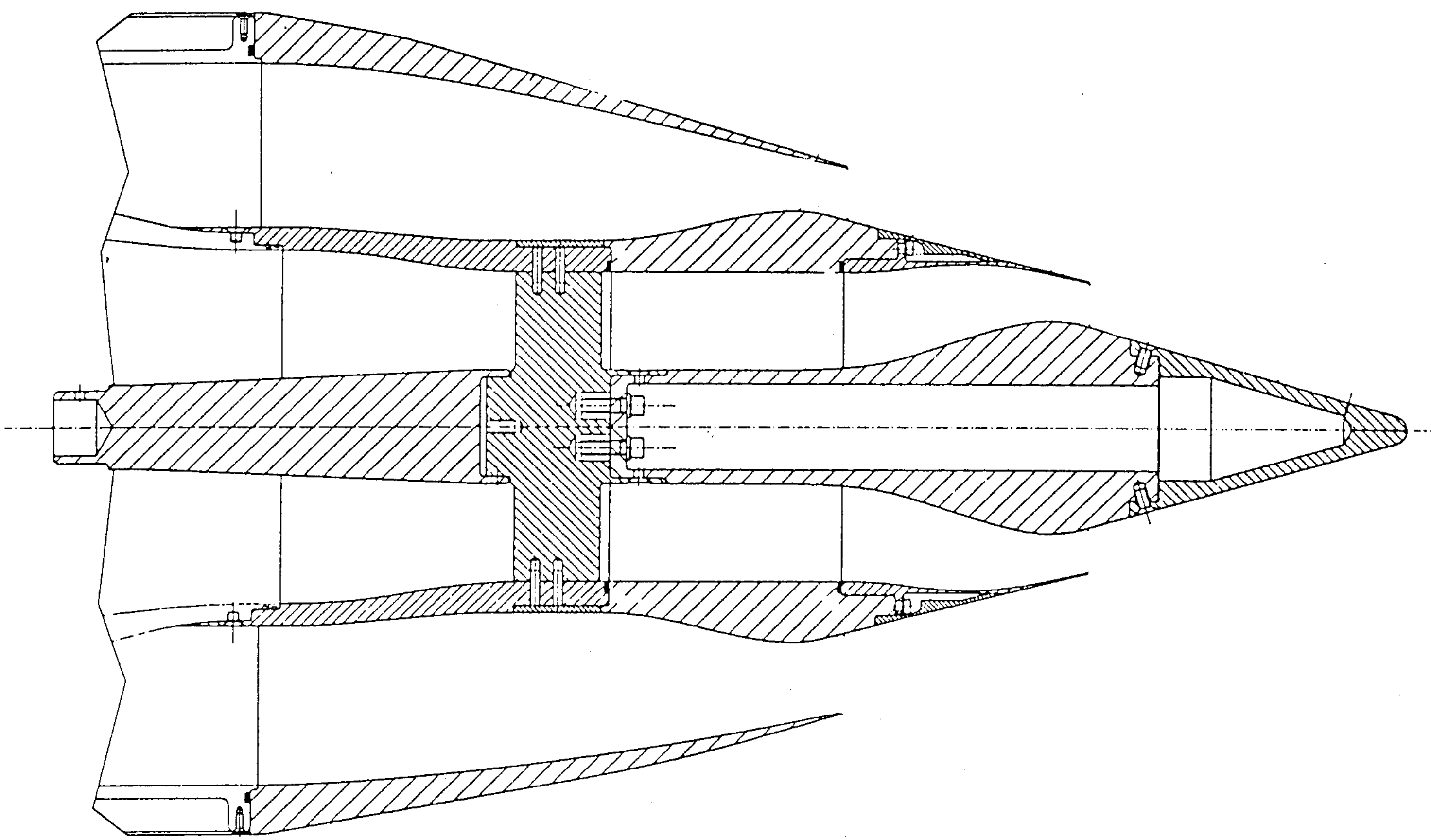
CFD Analysis for Selected Nozzles

Thomas J. Barber
United Technologies Research Center

CFD Analysis Parametrics

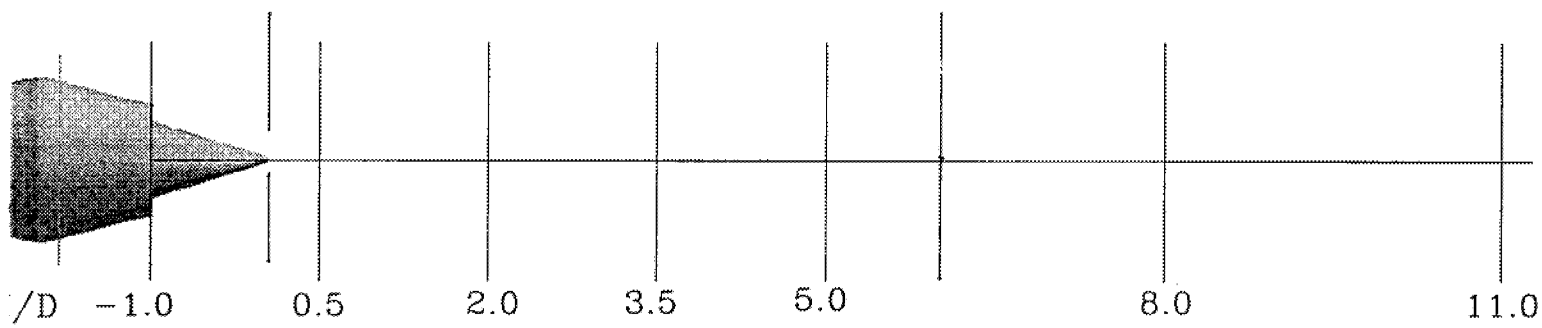
- NASTAR Navier-Stokes Analyses Performed for HBPR Separate Flow Nozzles
  - $k-\varepsilon$ Model Used With Wall Functions
- Take-Off Condition Only Simulated
  - M = 0.3, Ptp = 3184 psf, Ttp = 1491R
- Grid Independence Studies Have Been Performed
  - Axisymmetric (3BB): 35K Points
  - Scarfed (3BS): 300K Points
  - Offset (3BOmax): 400K Points
  - Blended Mixer (3HB): 1200K Points
- Results Referenced to Fan Nozzle Diameter (D)

Schematic of HBPR Exhaust System

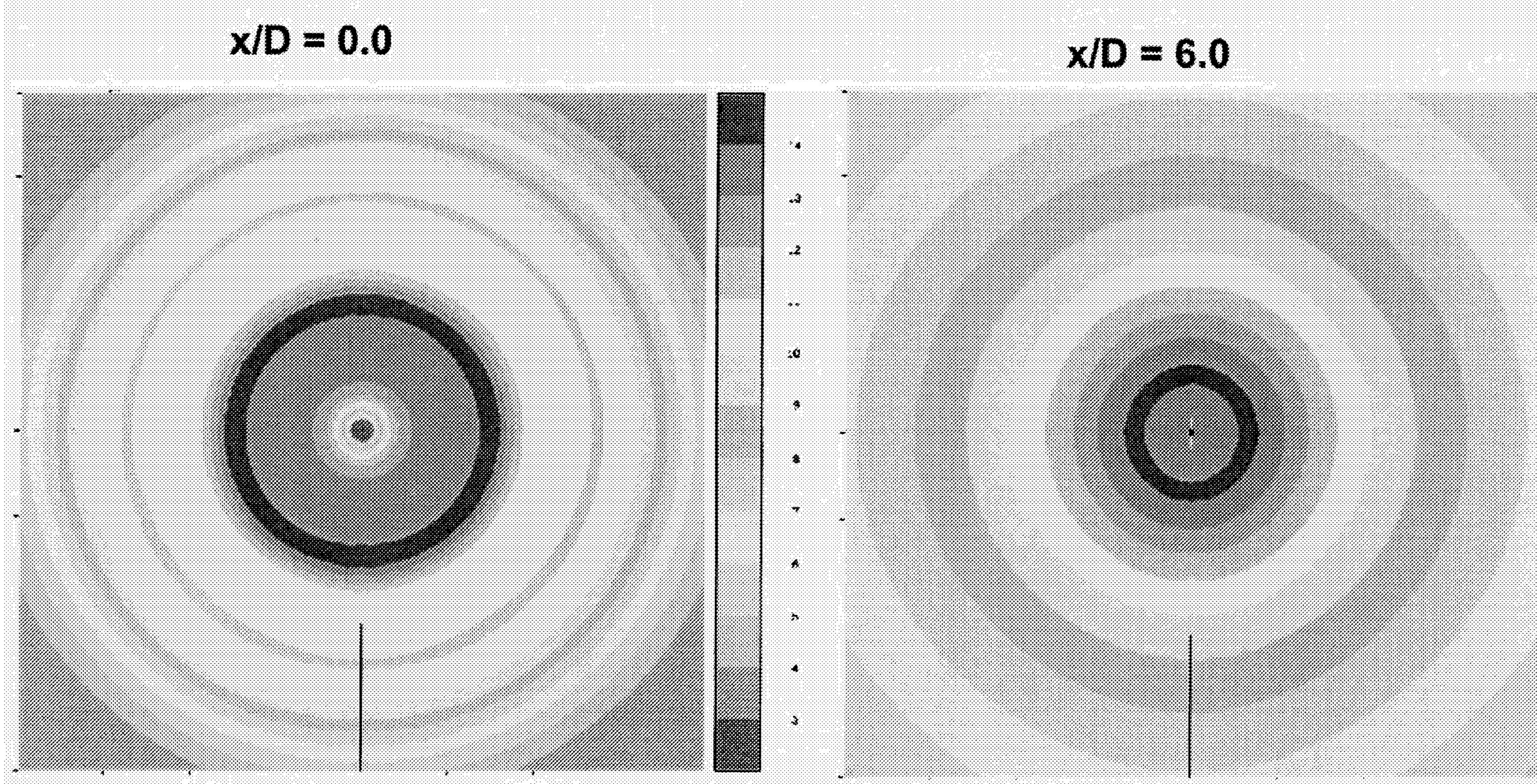


Computational Domain

- All Coordinates Normalized by Fan Nozzle T.E. Diameter
- Axial Coordinate Origin at Centerbody T.E.



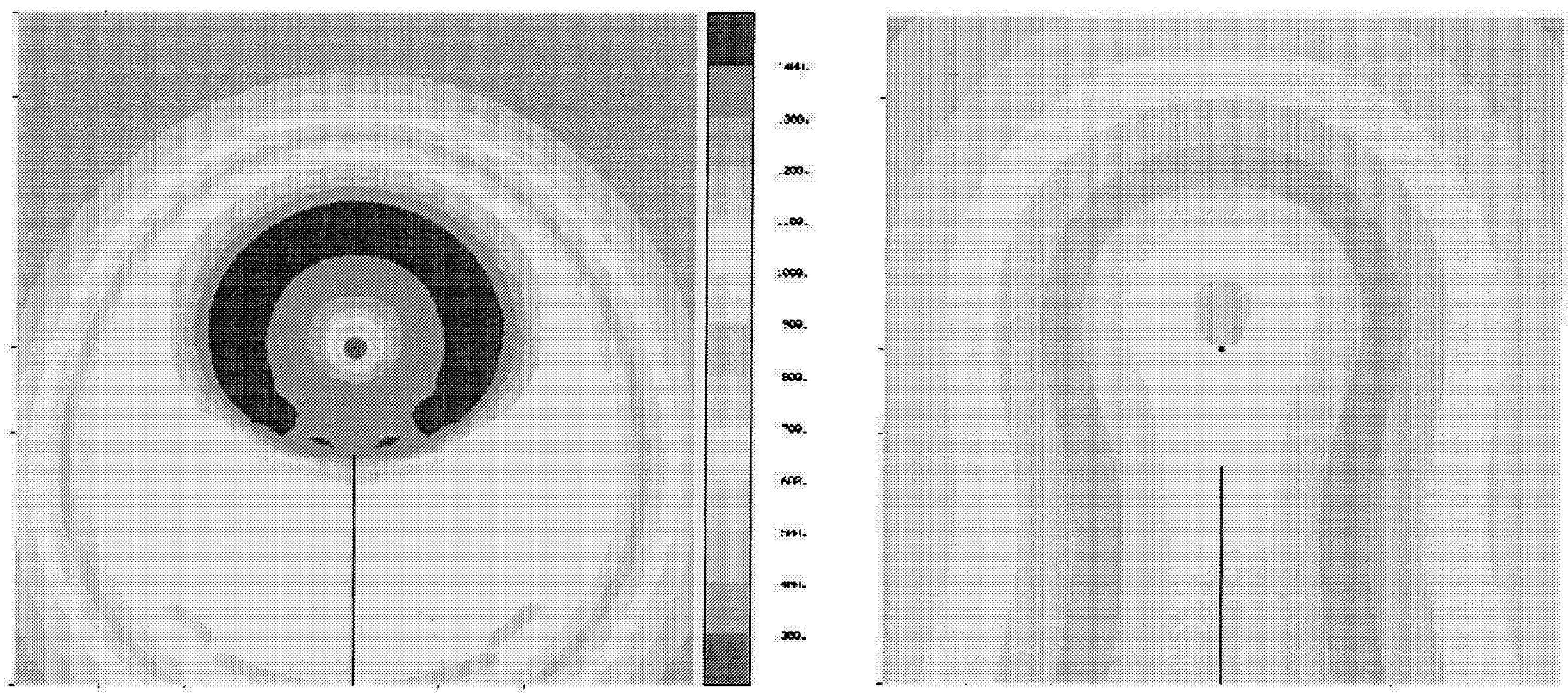
Axial Velocity 3BB-Axisymmetric



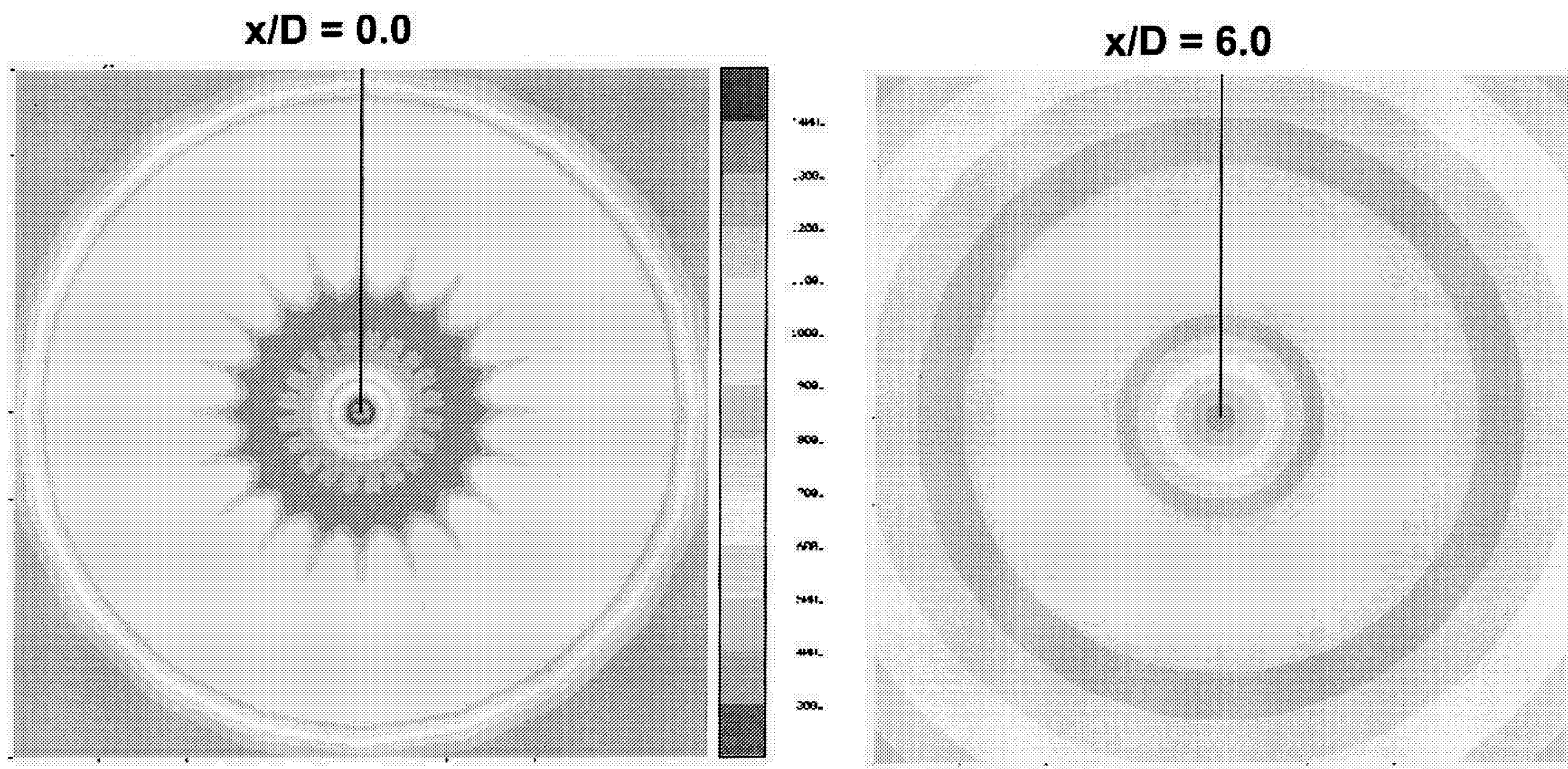
Axial Velocity 3BOmax

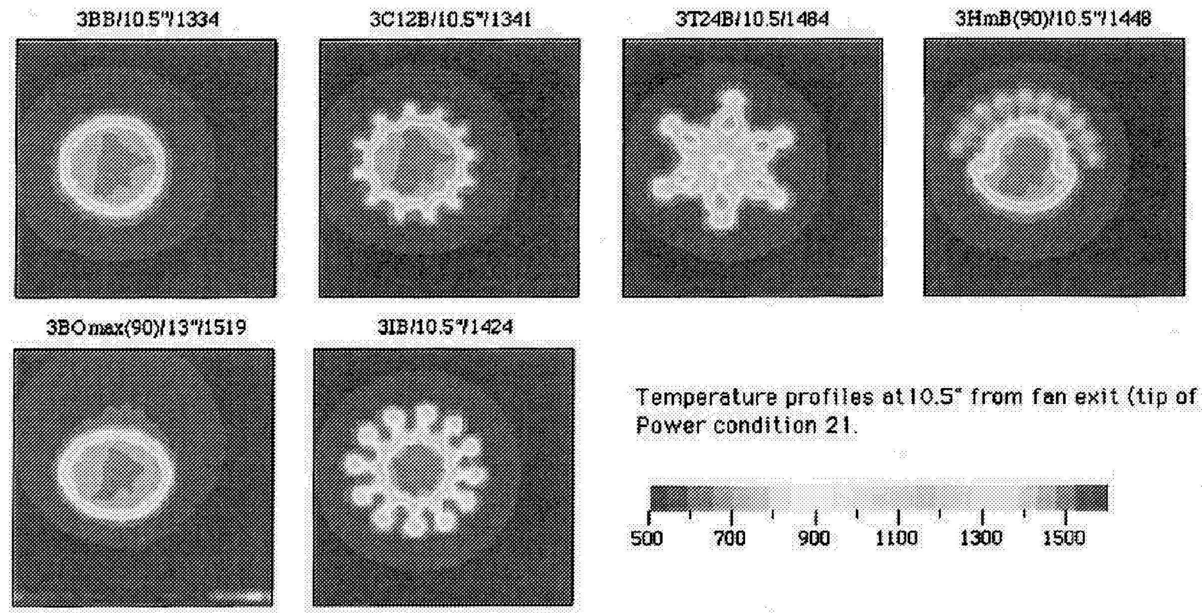
x/D = 0.0

x/D = 6.0

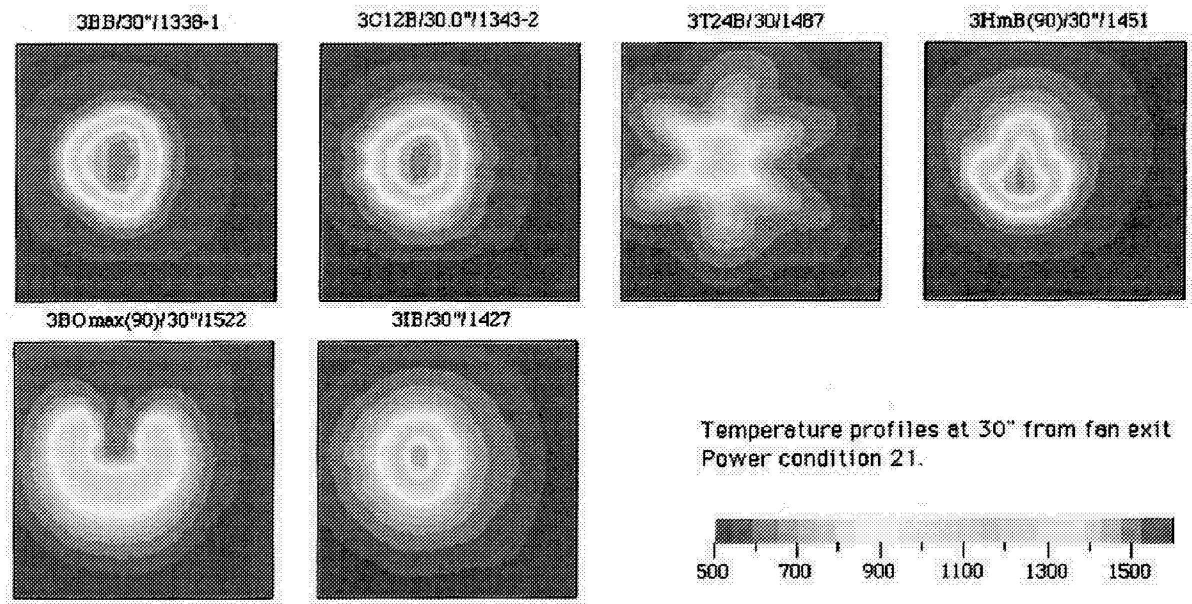


Axial Velocity 3HB-Mixer





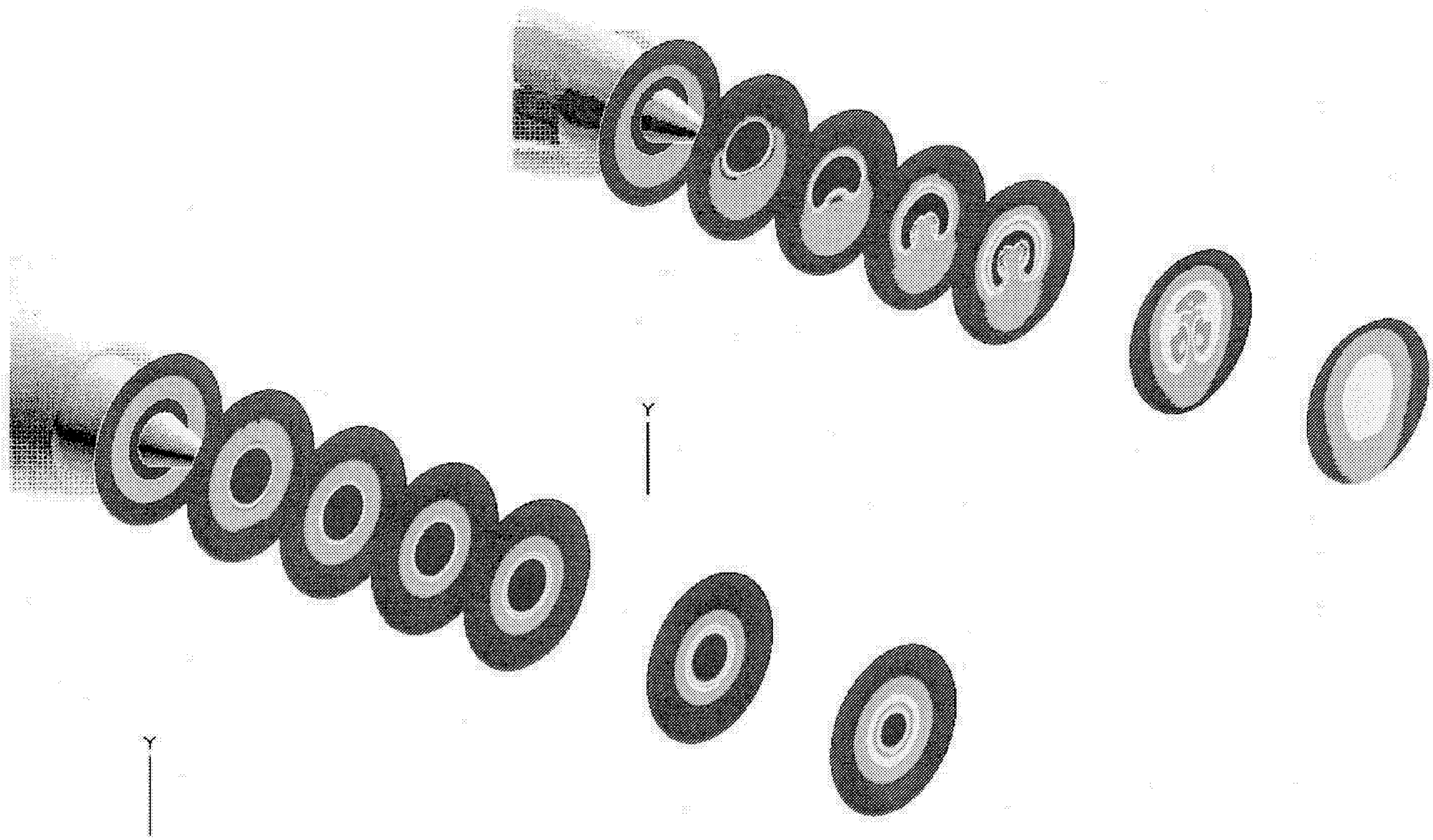
Temperature profiles at 10.5" from fan exit (tip of plug)
Power condition 21.



Temperature profiles at 30" from fan exit
Power condition 21.

Total Temperature Contours

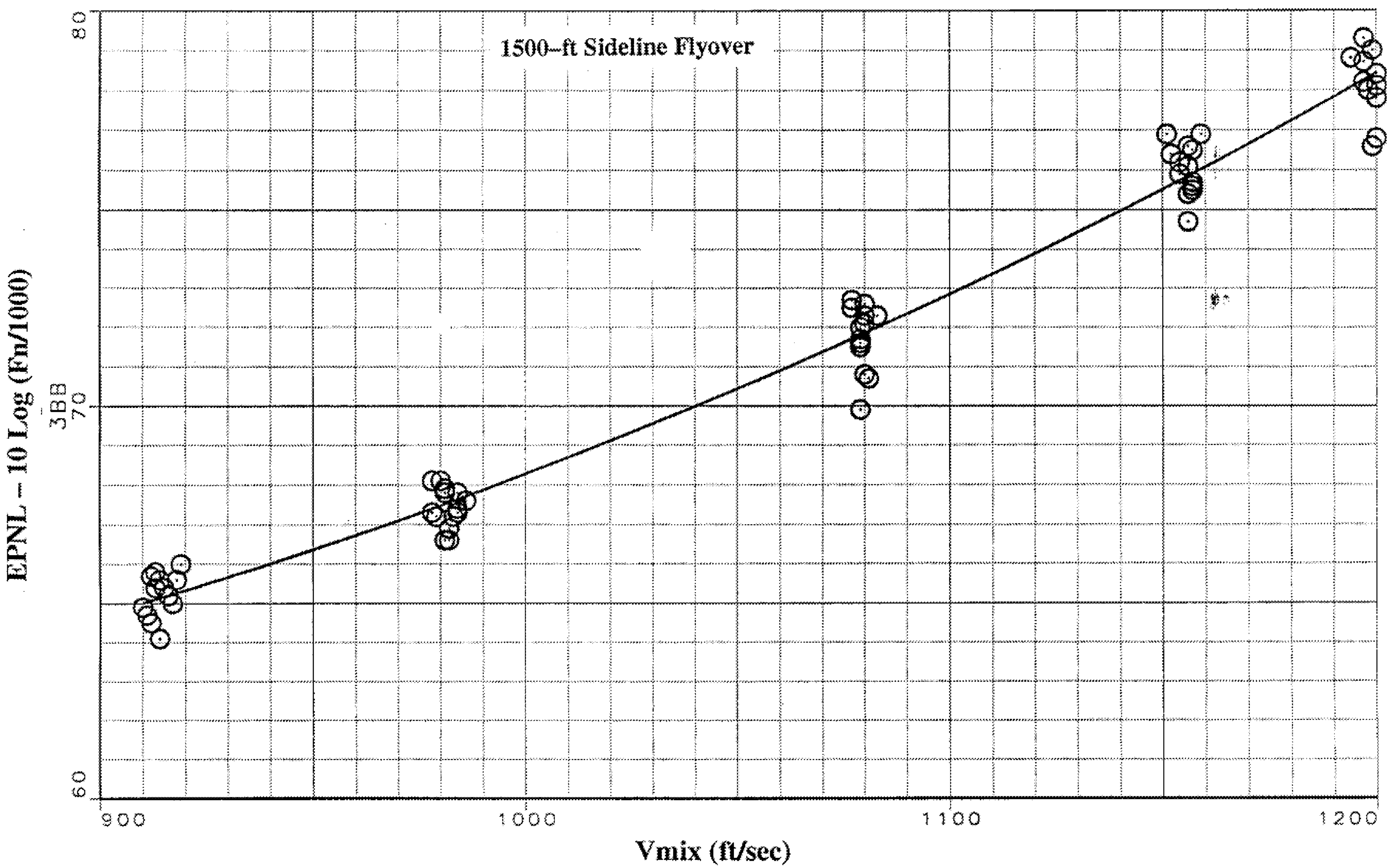
Axisymmetric & Offset Nozzles



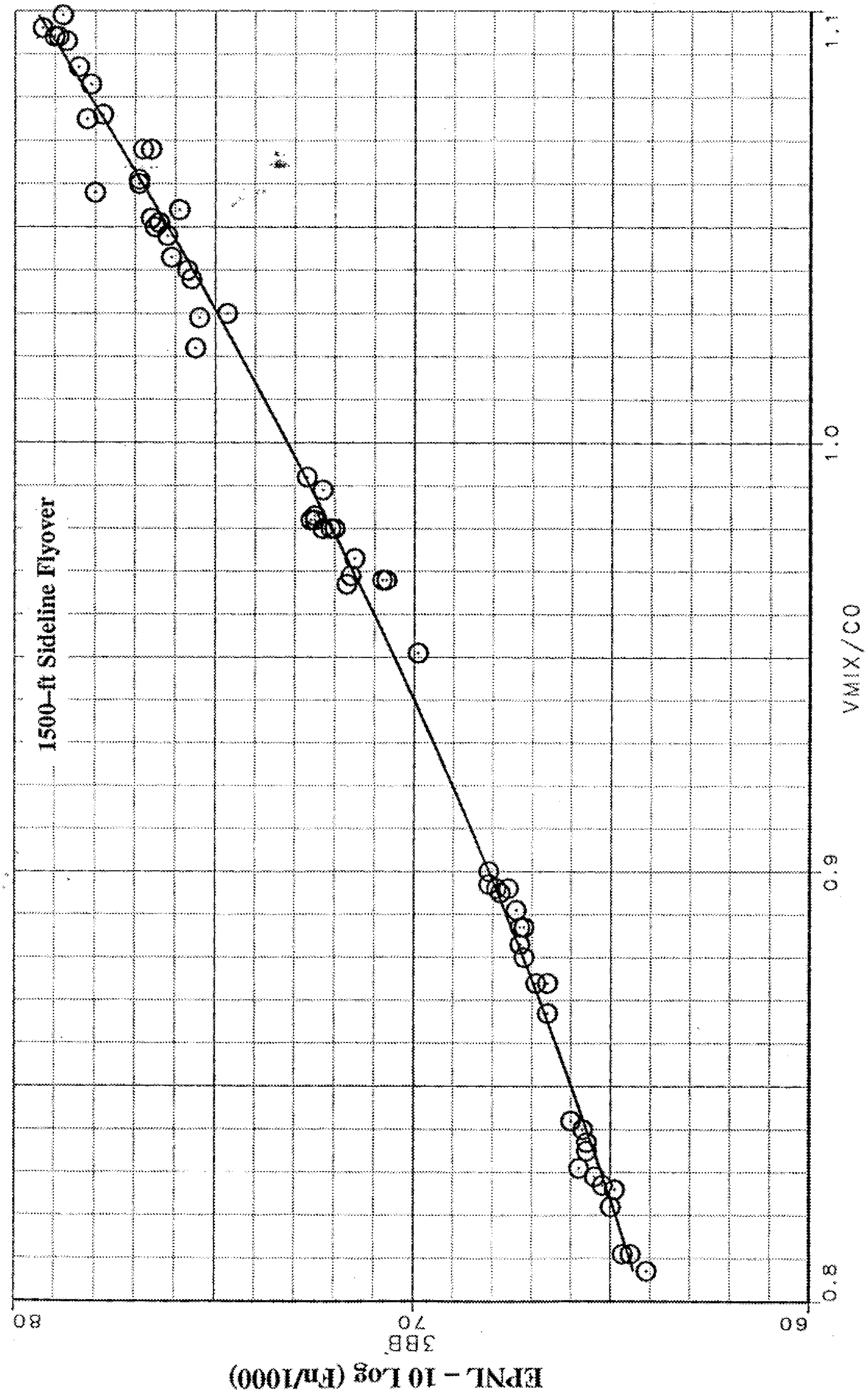
REVIEW OF TEST RESULTS

- **Noise Data Variability Due to :**
  - variations in test day ambient temperatures
    (29 deg. F – 74 deg. F)
  - variations in jet velocities and idealized net thrusts from differences in nozzles pressure ratios and temperatures settings for test conditions.

MODEL #3 BASELINE NOZZLE EPNL VARIATIONS FOR REPEAT RUNS TAKEN UNDER A RANGE OF TEST DAY AMBIENT TEMPERATURES (29 deg. F – 74 deg. F)



MODEL #3 BASELINE NOZZLE NOISE CURVE REPLOTTED AS EPNL vs VMIX/C0
(NORMALIZED FOR AMBIENT TEMPERATURE DIFFERENCES)



REVIEW OF TEST RESULTS

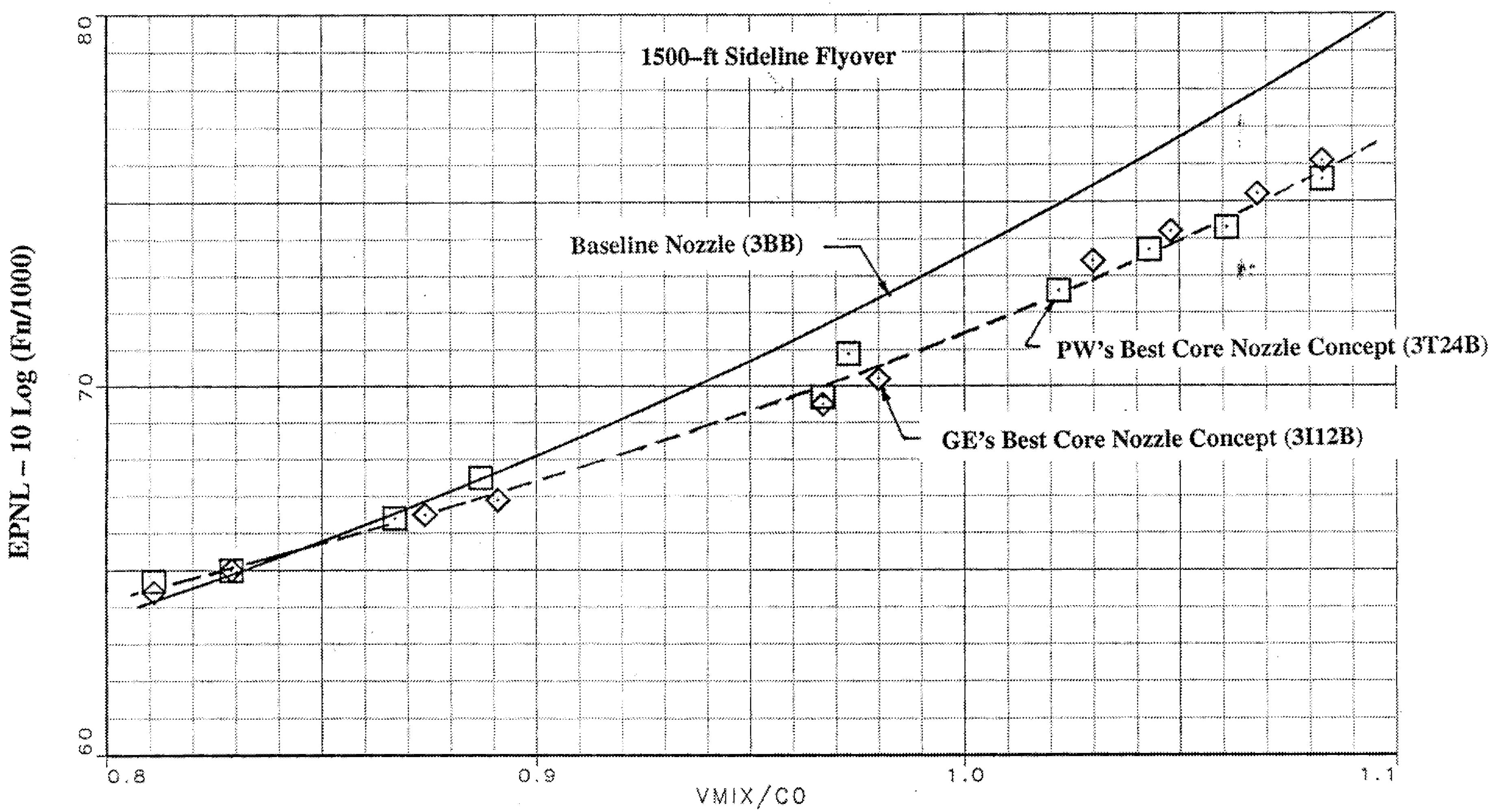
o Noise Comparisons For Baseline and Selected Nozzle Concepts (PW's and GE's "best" Core Nozzle Concepts) – 3BB vs 3T24B vs 3IB

- o EPNL vs VMIX/C0
- o PNL Directivities
- o SPL and NOY Spectra

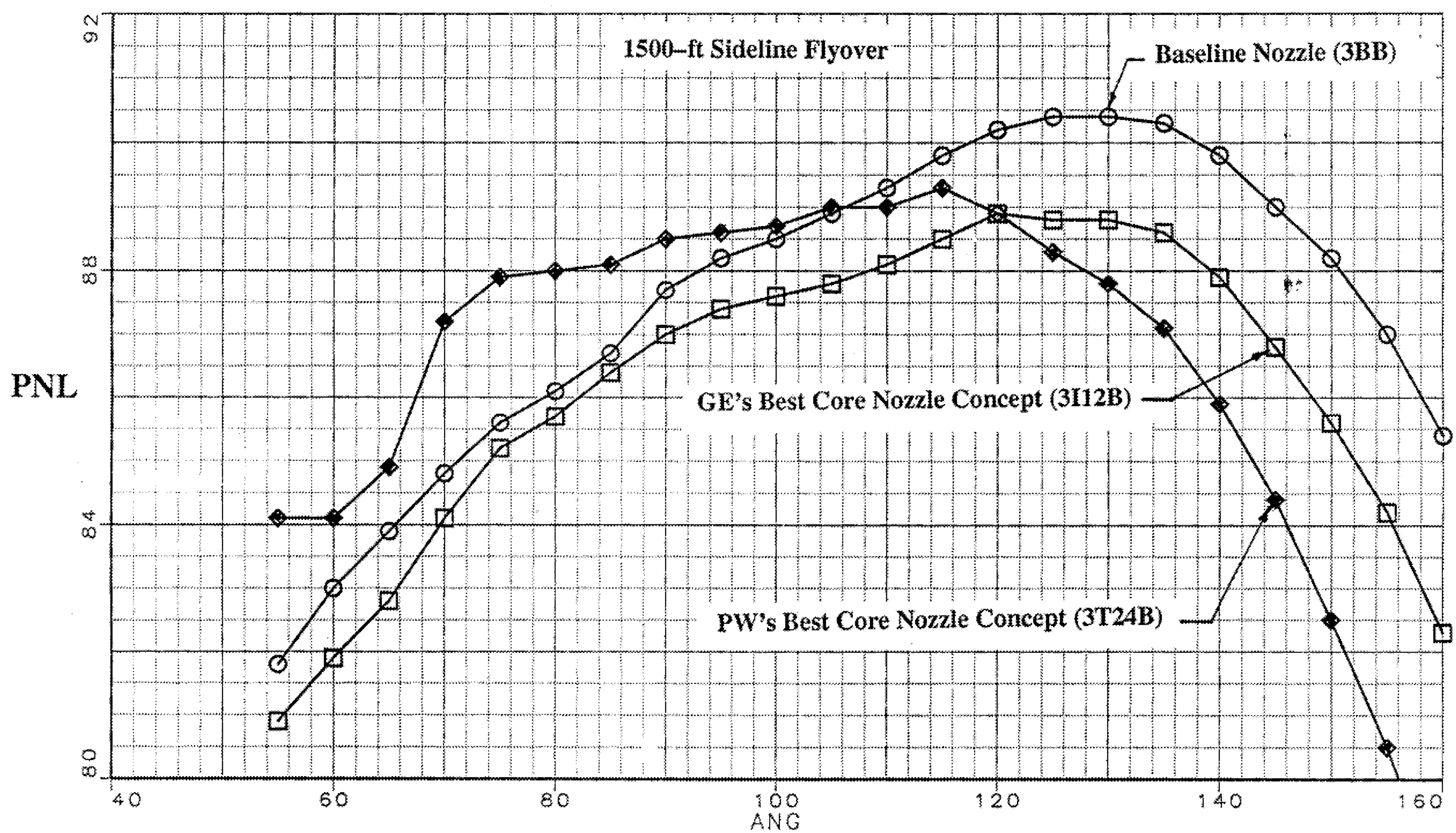
o Summary of EPNL Reductions for PW's Nozzle Concepts Tested.

COMPARISON OF BASELINE AND SELECTED CORE NOZZLE CONCEPTS

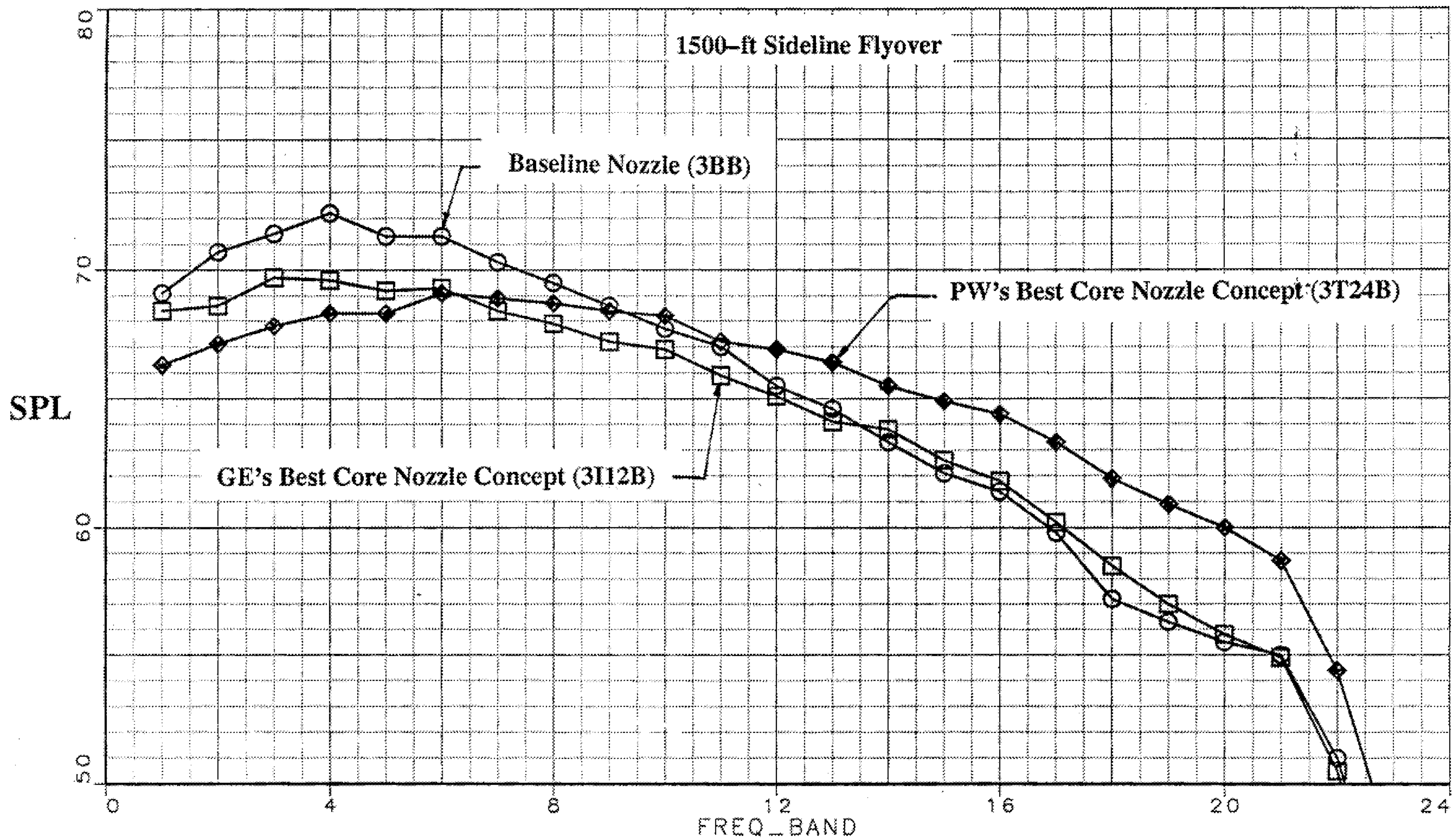
EPNL vs VMIX/C0



COMPARISON OF BASELINE AND SELECTED CORE NOZZLE CONCEPTS
PNL DIRECTIVITIES

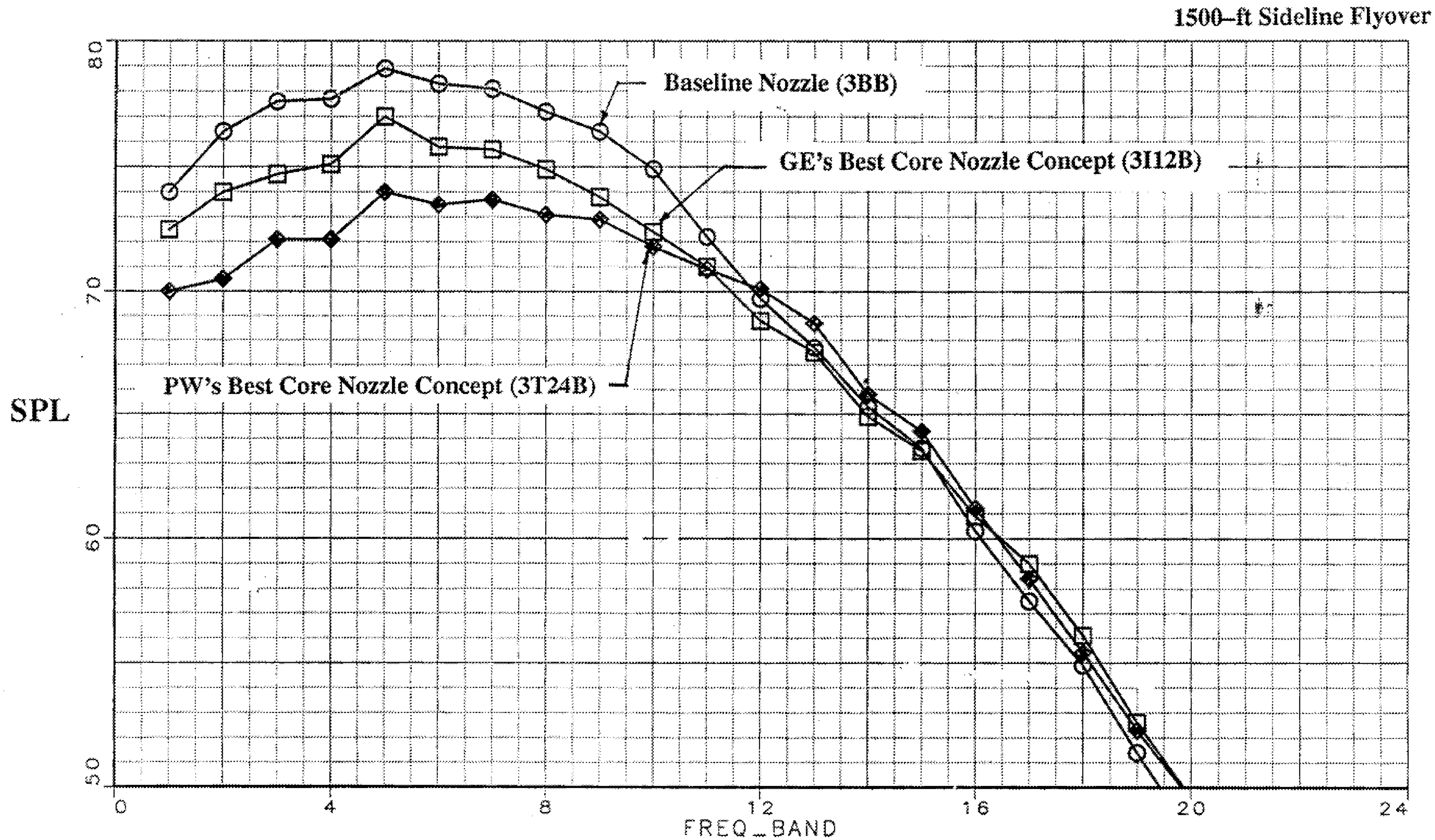


COMPARISON OF BASELINE AND SELECTED CORE NOZZLE CONCEPTS
SPL SPECTRA at Baseline Nozzle Inlet Angle of 80 degrees.



COMPARISON OF BASELINE AND SELECTED CORE NOZZLE CONCEPTS

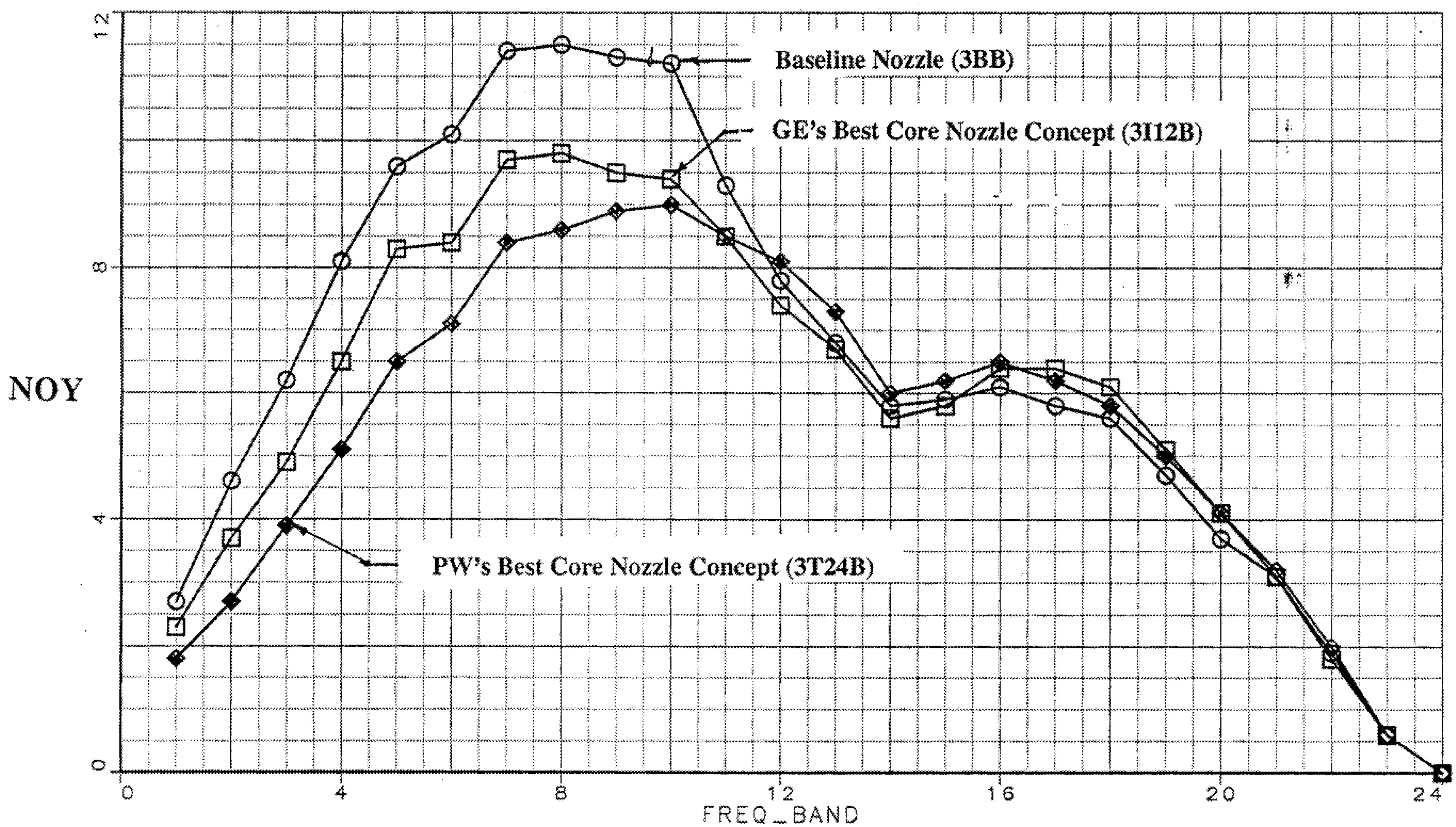
SPL SPECTRA at Baseline Nozzle Peak PNLT Angle (130 deg)



COMPARISON OF BASELINE AND SELECTED CORE NOZZLE CONCEPTS

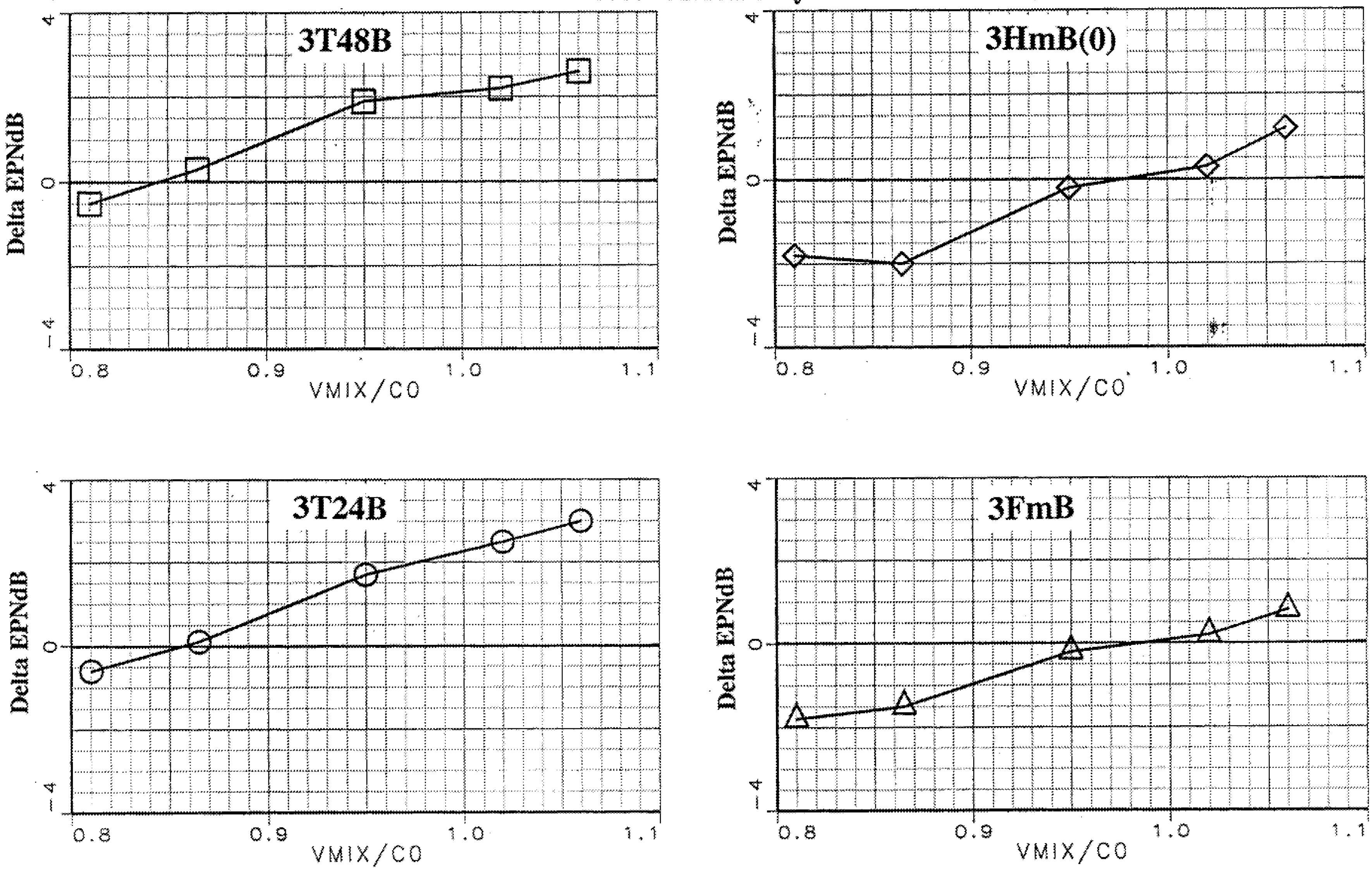
NOY SPECTRA at Baseline Nozzle Peak PNLT Angle (130 deg)

1500–ft Sideline Flyover



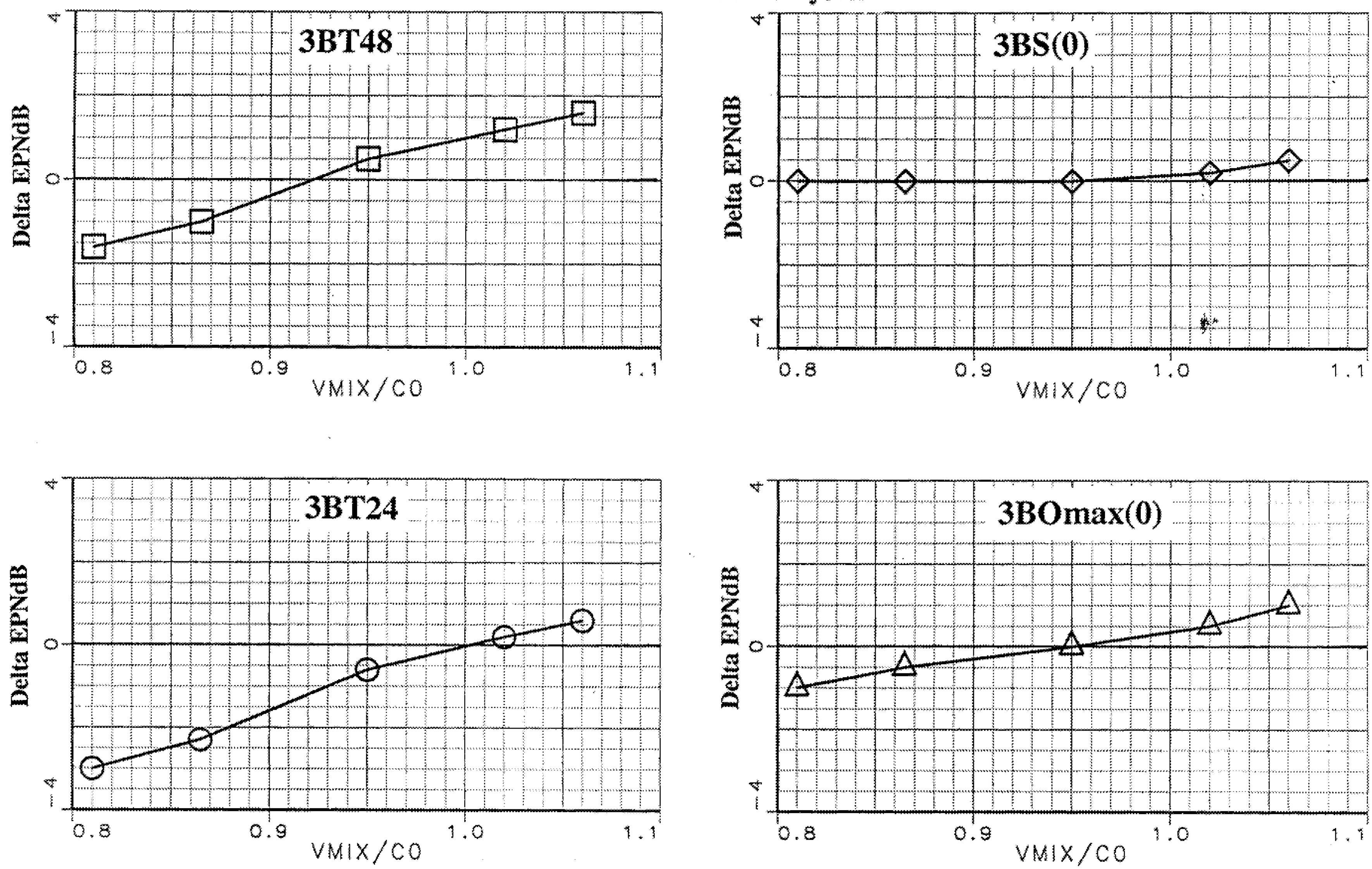
EPNL REDUCTIONS for PW's CORE NOZZLE CONCEPTS

1500–ft Sideline Flyover



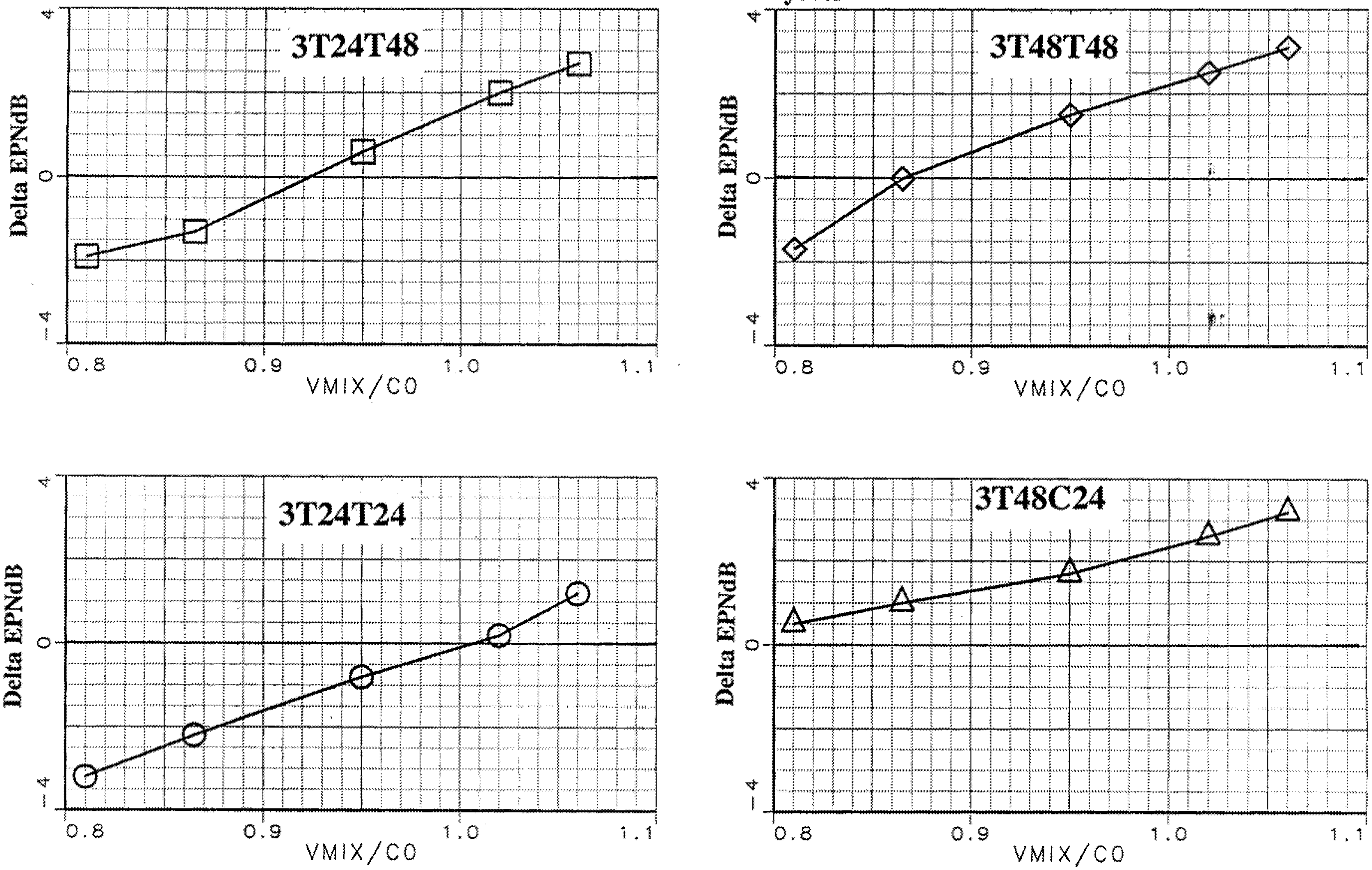
EPNL REDUCTIONS for PW's FAN NOZZLE CONCEPTS

1500–ft Sideline Flyover



EPNL REDUCTIONS for PW's COMBINED CORE & FAN NOZZLE CONCEPTS

1500–ft Sideline Flyover

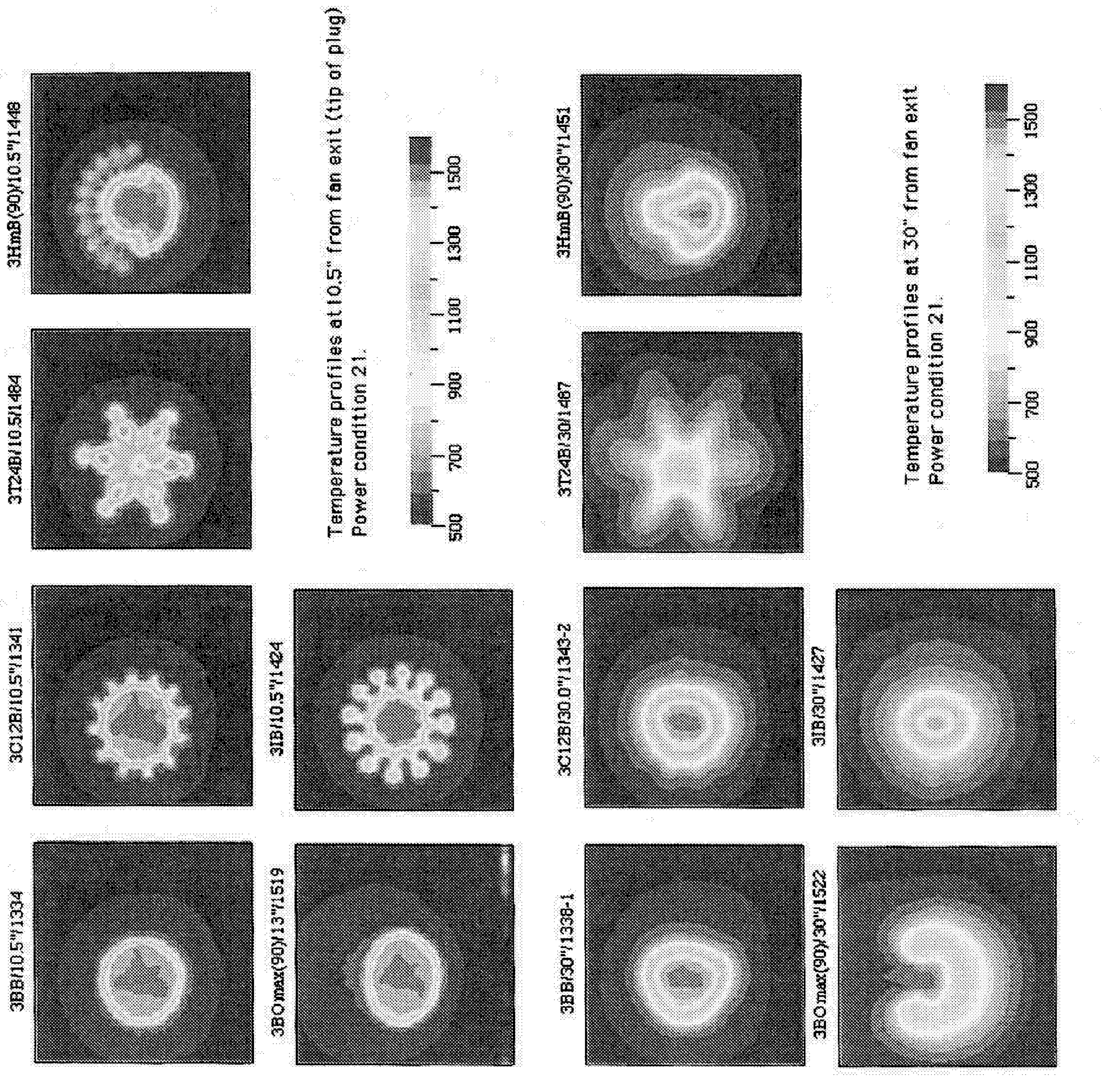


SUMMARY / CONCLUSION

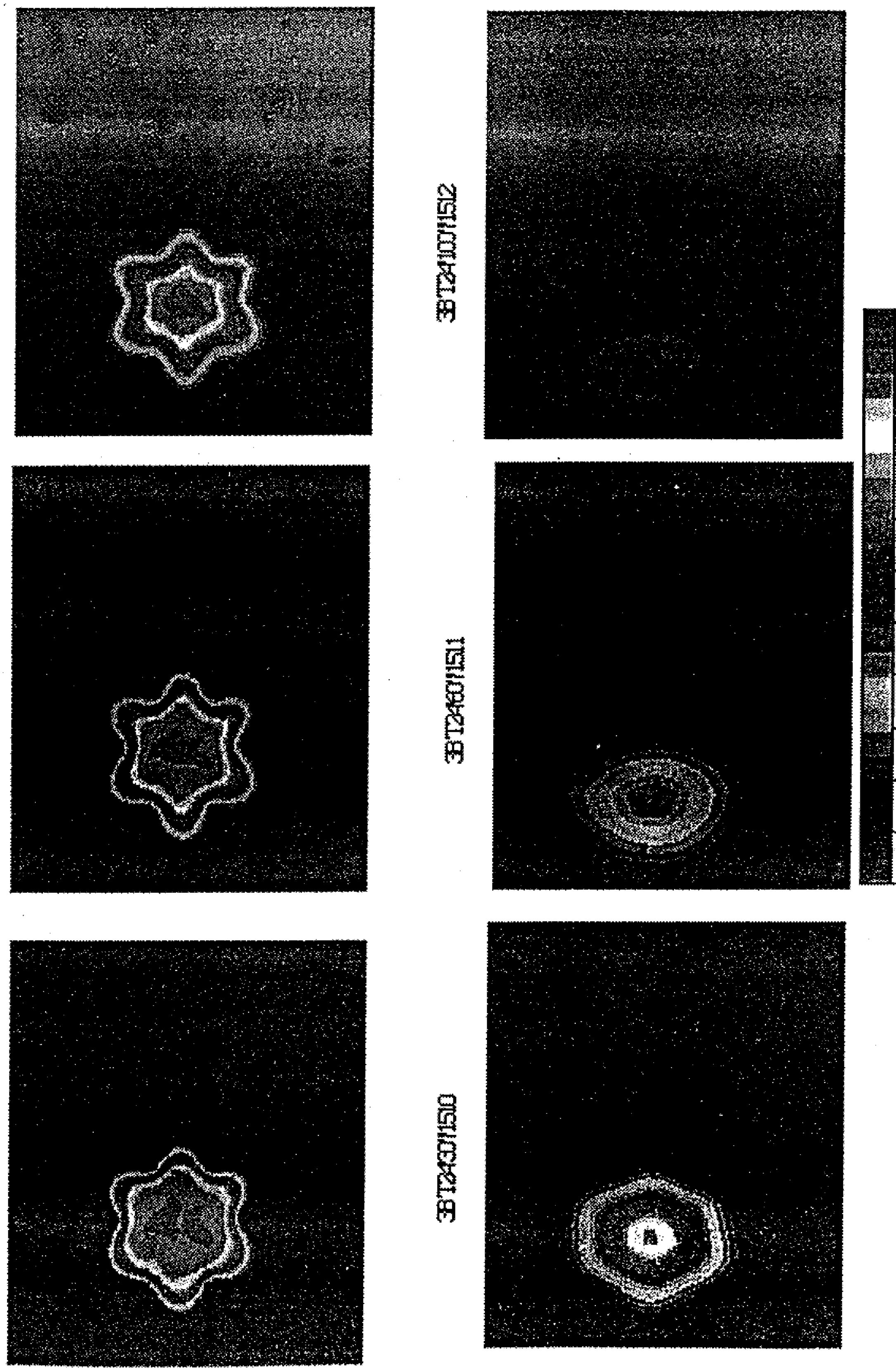
- CONCEPTS THAT PROMOTE MIXING OF THE CORE STREAM ARE MORE EFFECTIVE THAN THOSE THAT WORK ON THE FAN STREAM.

PLUME SURVEY TEMPERATURE PROFILES

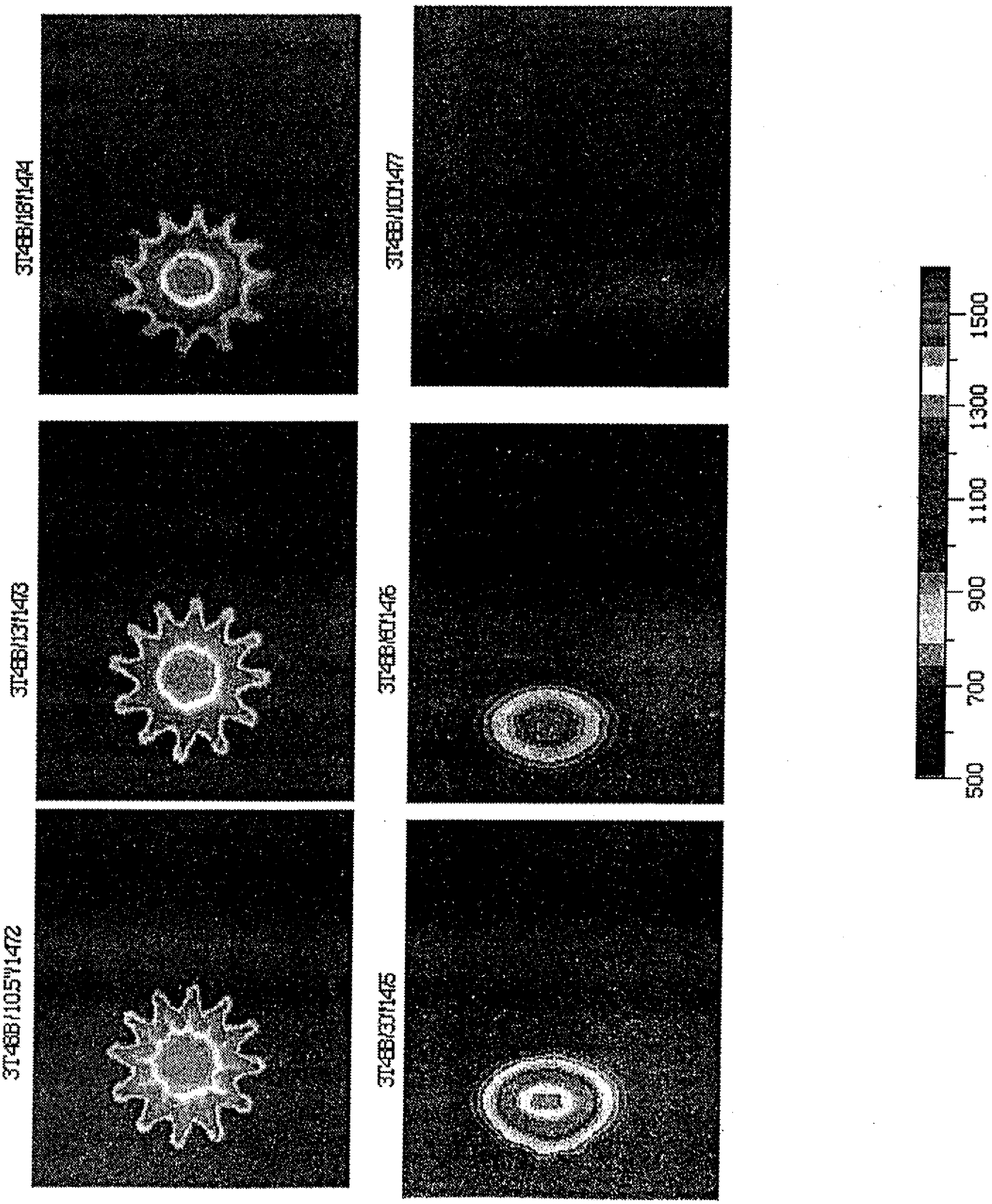
for Selected Nozzles

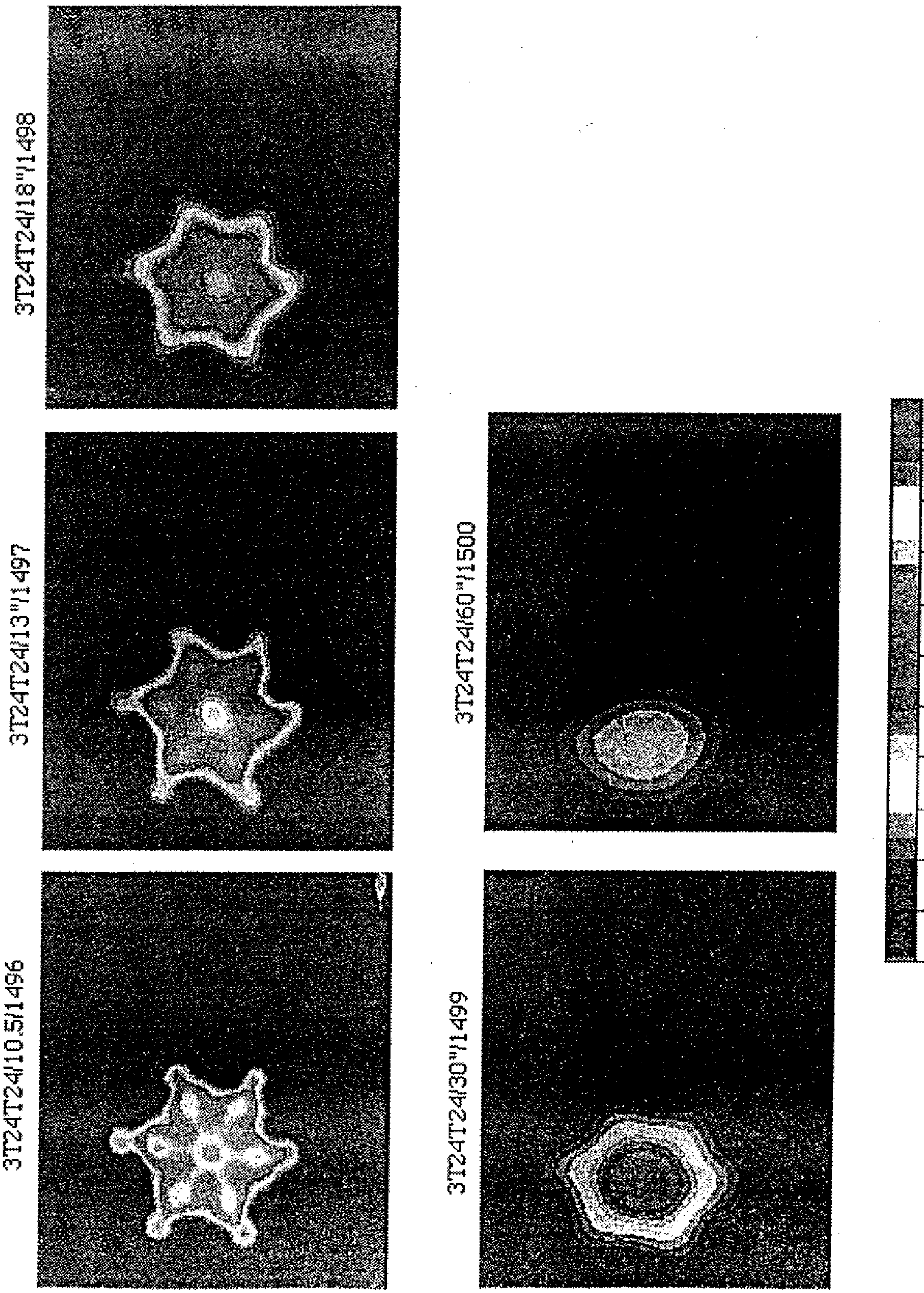


3BB/10.5"/1334
3C12B/10.5"/1341
3T24B/10.5/1484
3HmB(90)/10.5"/1448
3BOmax(90)/13"/1519
3IB/10.5"/1424
Temperature profiles at 10.5" from fan exit (tip of plug)
Power condition 21.
500
700
900
1100
1300
1500
3BB/30"/1338-1
3C12B/30.0"/1343-2
3T24B/30/1487
3HmB(90)/30"/1451
3BOmax(90)/30"/1522
3IB/30"/1427
Temperature profiles at 30" from fan exit
Power condition 21.
500
700
900
1100
1300
1500



500
700
900
1100
1300
1500


500
700
900
1100
1300
1500



3T24T24/10.5/1496
3T24T24/13"/1497
3T24T24/18"/1498
3T24T24/30"/1499
3T24T24/60"/1500
500
700
900
1100
1300
1500

Phased array measurements for the Separate Flow Jet Noise test at LeRC

Srini Bhat/ John Premo
Boeing Commercial Airplane Group
September 10, 1997

Overview

Phased array measurements for the SFJN test at LeRC

- Introduction
- Description of phased arrays
- Setup for the SFJN test
    - Boeing supplied resources
    - LeRC provided resources
- Phased array acquisition and processing
- Review of selected results
    - Selected 1/3 octave band contours
    - Selected integrated spectra
- Conclusions

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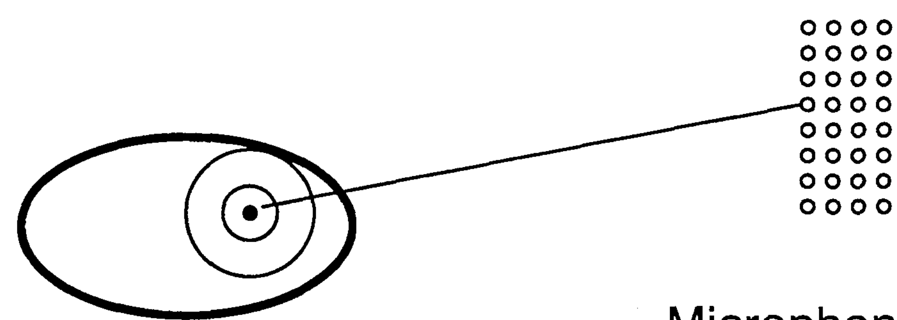
Description of phased arrays

Phased array measurements for the SFJN test at LeRC

phased arrays – system of microphones which allows the sound from a particular location or direction to be selectively measured through coherent addition of the microphone signals



Setup for the SFJN test

Phased array measurements for the SFJN test at LeRC

Three arrays were used during testing.

- **Each array has its own advantages**

Array A: Large 7 arm logarithmic spiral

- **Determines source density in two dimensions**
- **Located below the jet at 90 and 120 degrees**
- **Works well from 1000 to 8000 Hertz**

Array B: Small 7 arm logarithmic spiral (contained within array A)

- **Determines source density in two dimensions**
- **Located below the jet at 90 and 120 degrees**
- **Works well from 8000 to 50000+ Hertz**

Array C: Sideline linear array

- **Image in one direction along axis of jet**
- **Works well from 1000 to 50000 Hertz**

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Phased Array Acquisition and Processing

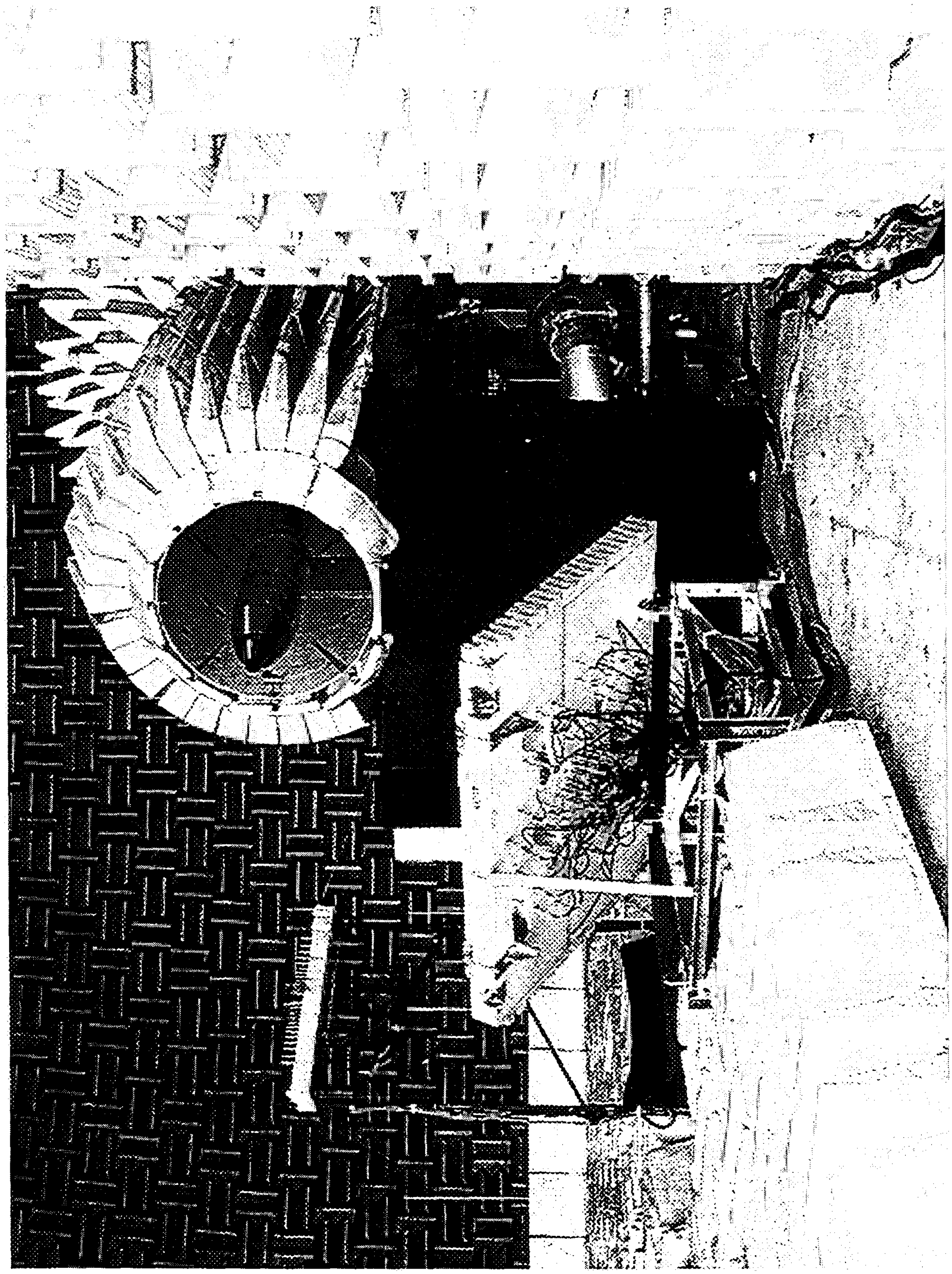
Phased array measurements for the SFJN test at LeRC

Boeing supplied resources

- **Microphones, amplifiers, cables, and arrays**
- **Data acquisition hardware**

LeRC supplied resources

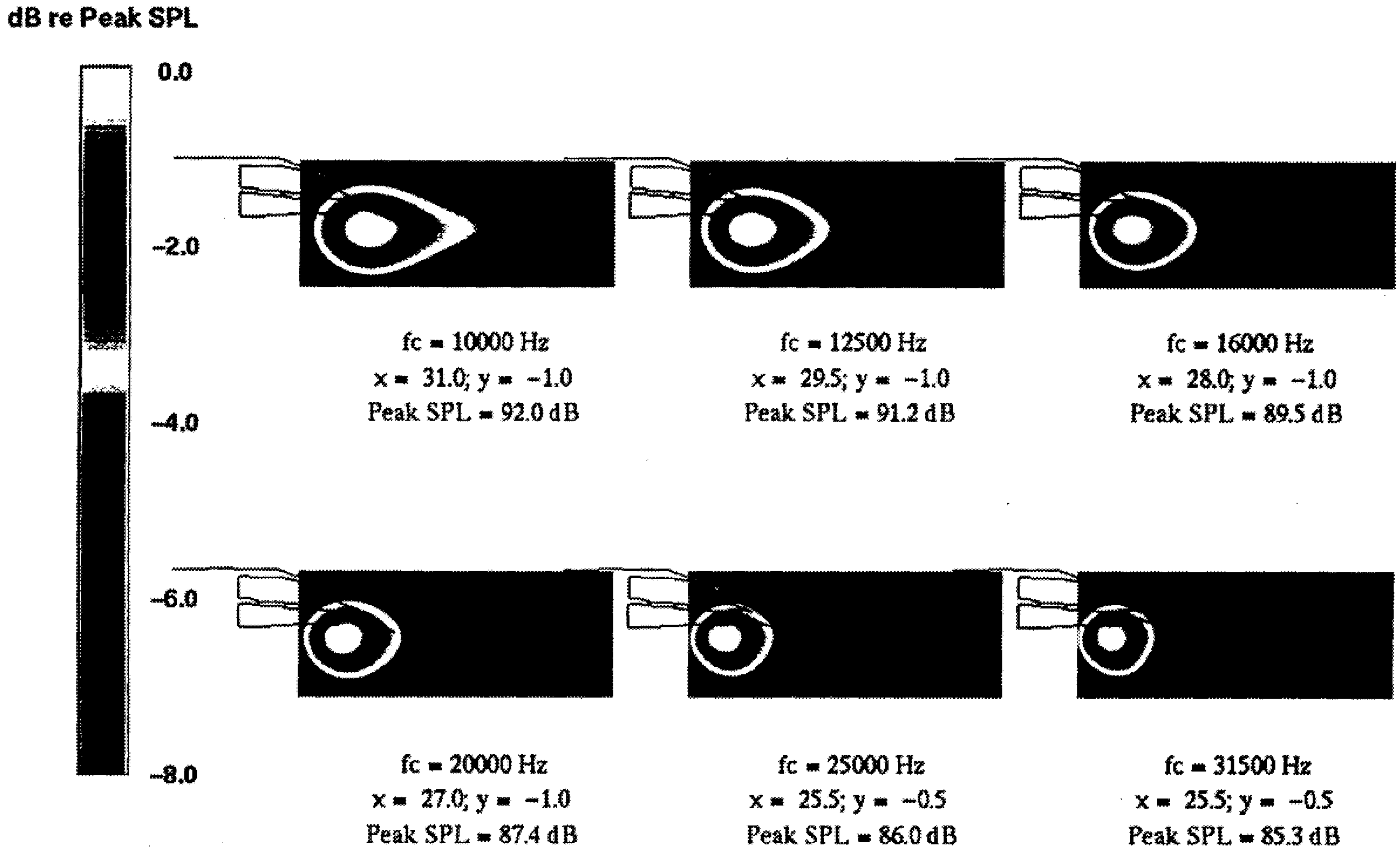
- **Access to the LACE cluster parallel computer for processing**
- **SGI computer with the FAST program for viewing the processed data**



Separate Flow Jet Noise Reduction Test

Model 3BB viewed with array B

Run: 1115 Point: 21 Mach: 0.28



Review of Selected Results

Phased array measurements for the SFJN test at LeRC

General Results:

- **Looks like there are two separate source regions**
  - **Region 1: Near the the nozzle exit**
  - **Region 2: Several nozzle diameters downstream of the nozzle exit**

Possible Explanation:

- **Two regions correspond to different source mechanisms**
  - **Region 1 is primarily due to secondary/ambient mixing and any nozzle trailing edge and duct noise**
  - **Region 2 is more the classical jet noise region**

Review of Selected Results

Phased array measurements for the SFJN test at LeRC

General Results:

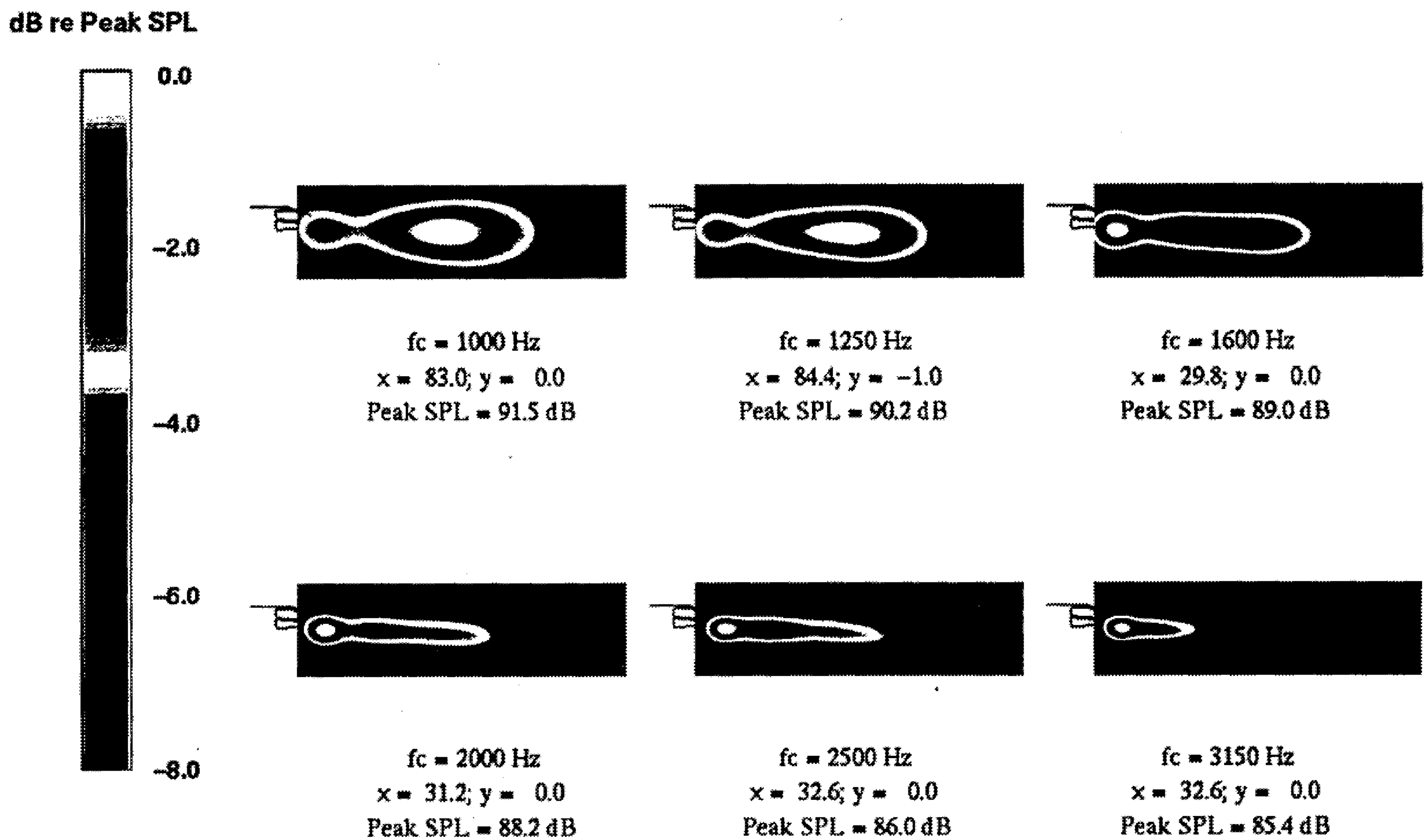
- **The relative importance of the two regions change with frequency**
    - **Region 1: dominates at higher frequencies**
    - **Region 2: dominates at low frequencies**

Note that the peak levels as a function of frequency remain relatively constant within each region. However, the center of mass of the source density moves progressively closer to the nozzle as the frequency is increased and Region 1 starts to dominate Region 2.

Separate Flow Jet Noise Reduction Test

Model 3BB viewed with array A

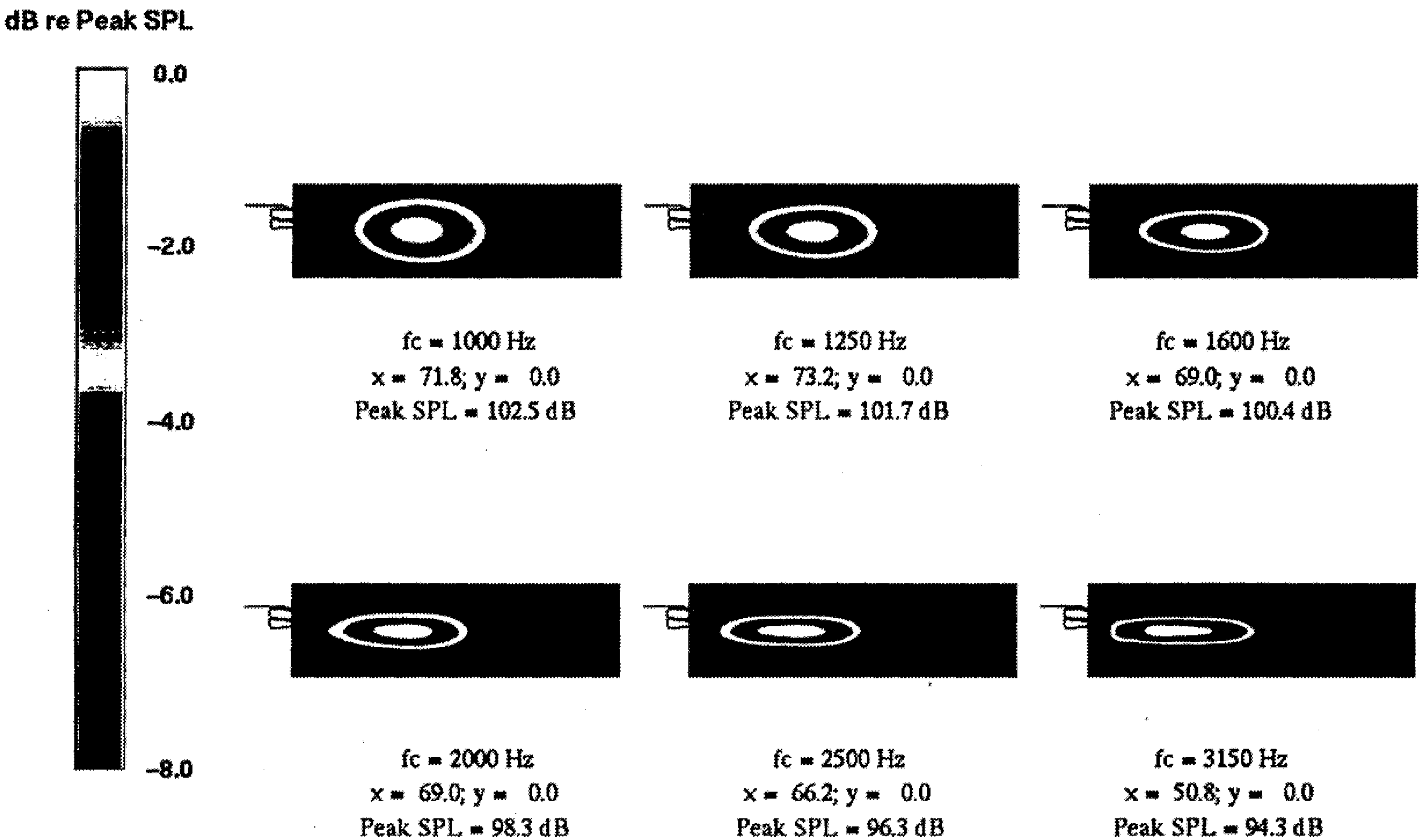
Run: 1113 Point: 23 Mach: 0.28



Separate Flow Jet Noise Reduction Test

Model 3BB viewed with array A

Run: 1119 Point: 23 Mach: 0.00



Review of Selected Results

Phased array measurements for the SFJN test at LeRC

Comparison of sources versus power settings:

- **The upstream region is less affected by increases in power than the downstream**

Possible Explanation:

- **Two regions correspond to different source mechanisms**
  - **Region 1 likely scales as M^6 or M^7**
  - **Region 2 likely scales as M^8**

Comparison of sources versus tunnel Mach number:

- **The upstream region is less affected by increases in tunnel Mach number than the downstream**

Possible Explanation:

- **Same as above**

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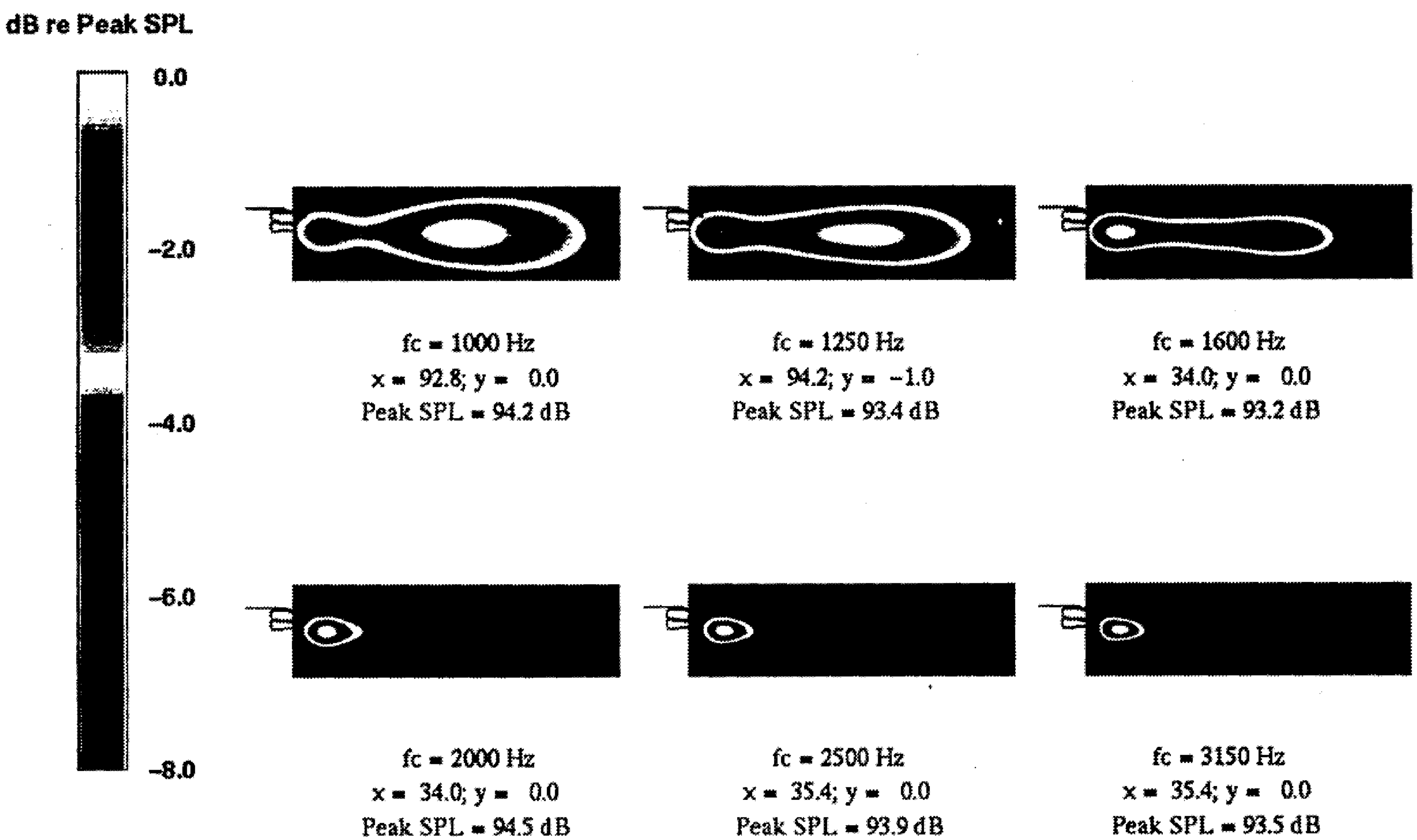
Separate Flow Jet Noise Reduction Test

Model 31C viewed with array A

Run: 1109 Point: 21 Mach: 0.28



Review of Selected Results

Phased array measurements for the SFJN test at LeRC

Comparison of baseline to enhanced mixing nozzles:

- **The upstream region has increased levels**
- **The downstream region has decreased levels**

Possible Explanation:

- **Increased mixing from the devices**
  - **Increases the turbulence intensities/mixing upstream**
  - **Decreases the relative velocities downstream**

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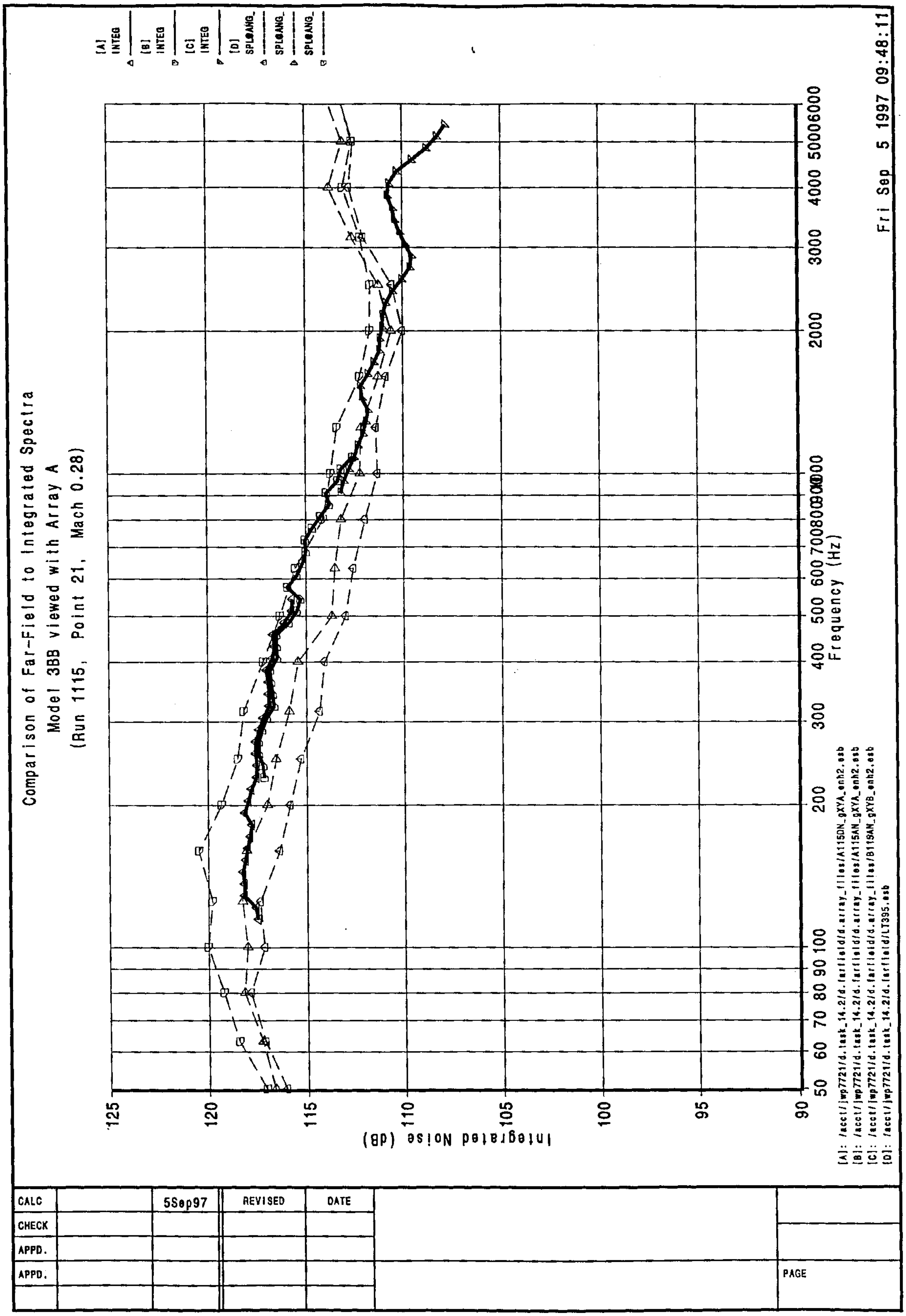
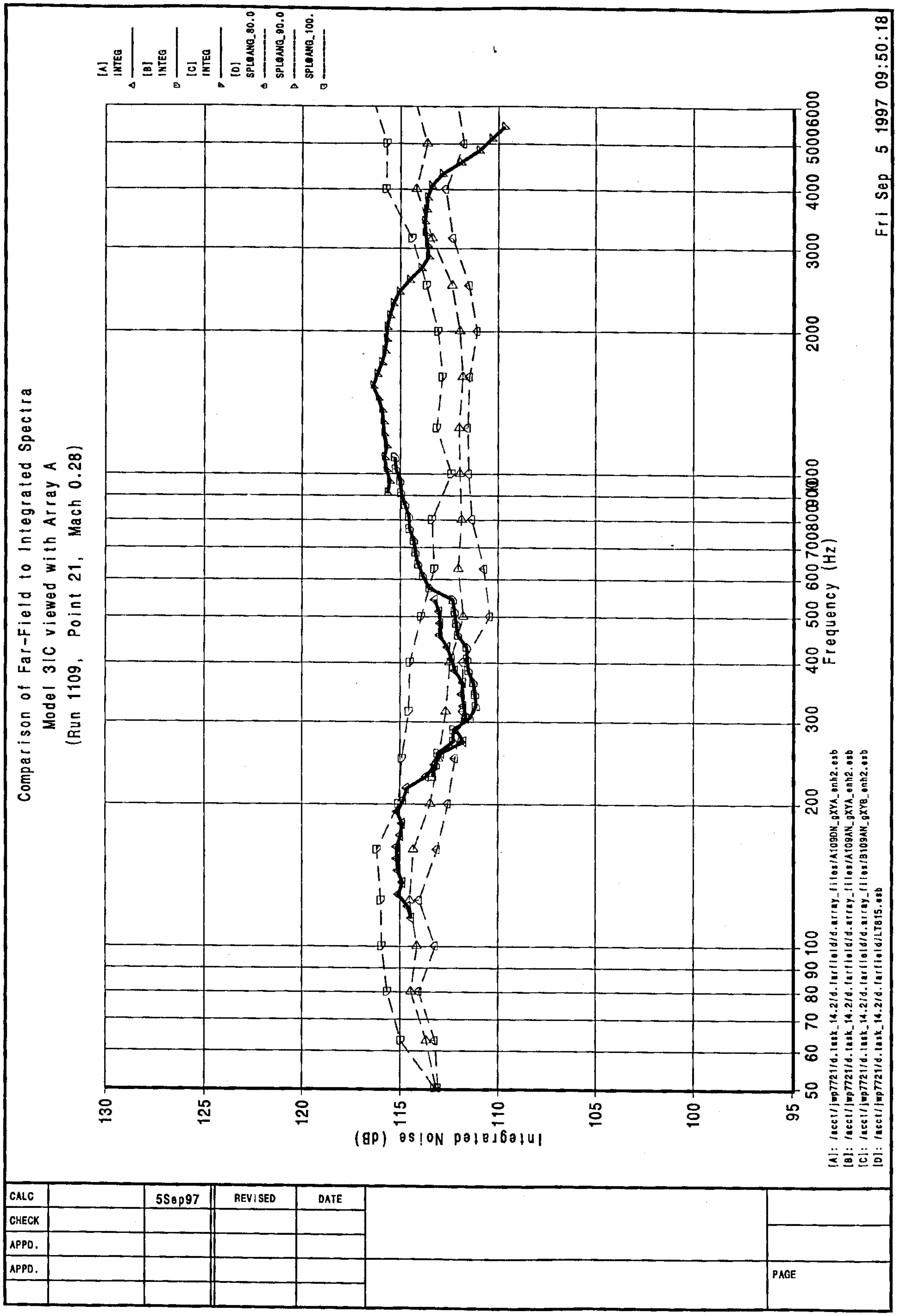


Comparison of Far-Field to Integrated Spectra
Model 3BB viewed with Array A
(Run 1115, Point 21, Mach 0.28)
Integrated Noise (dB)
Frequency (Hz)
Fri Sep 5 1997 09:48:11
CALC
5Sep97
REVISED
DATE
CHECK
APPD.
APPD.
PAGE



Comparison of Far-Field to Integrated Spectra
Model 3IC viewed with Array A
(Run 1109, Point 21, Mach 0.28)
[A] INTEG
[B] INTEG
[C] INTEG
[D] SPL@ANG_80.0
SPL@ANG_90.0
SPL@ANG_100.
Integrated Noise (dB)
130
125
120
115
110
105
100
95
Frequency (Hz)
50
60
70
80
90
100
200
300
400
500
600
700
800
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3000
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Fri Sep 5 1997 09:50:18
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5Sep97
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Conclusions

Phased array measurements for the SFJN test at LeRC

- Phased arrays can be used to qualitatively image jet noise sources
- Two separate source regions:
  - upstream near nozzle exit (Region 1)
  - downstream several nozzle diameters (Region 2)
- The upstream region is less affected by increases in power than the downstream
- The upstream region is less affected by increases in tunnel Mach number than the downstream
- Jet Mixing devices:
  - increase upstream sources (Region 1)
  - decrease downstream sources (Region 2)
- Preliminary results of using phased array measurements to determine far–field spectra are promising

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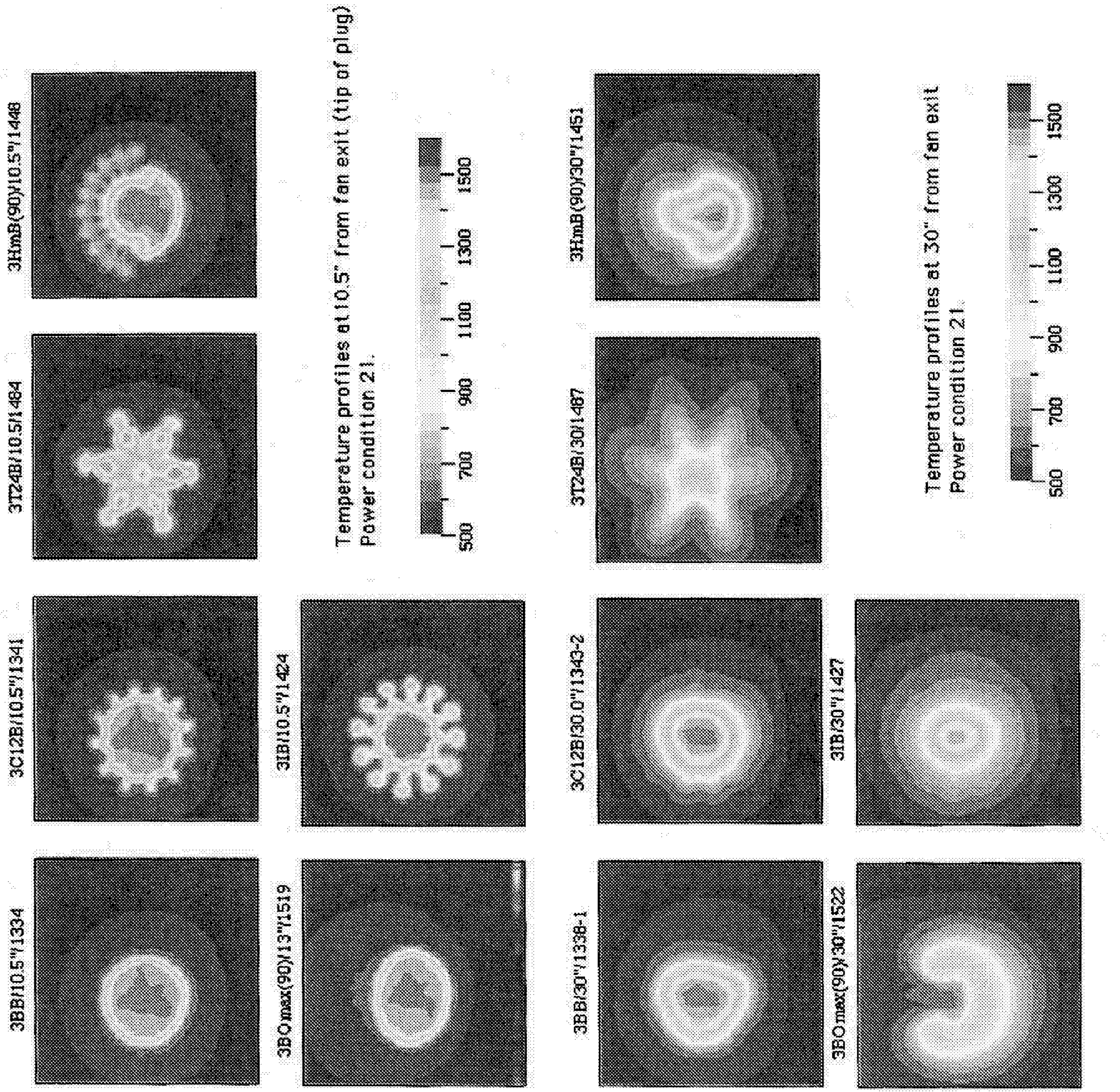
11

Discussion of Measured Acoustic & Related Aero Data

Thomas J. Barber

United Technologies Research Center


3BB/10.5"/1334
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3HmB(90)/30"/1451
3BOmax(90)/30"/1522
3IB/30"/1427
Temperature profiles at 30" from fan exit
Power condition 21
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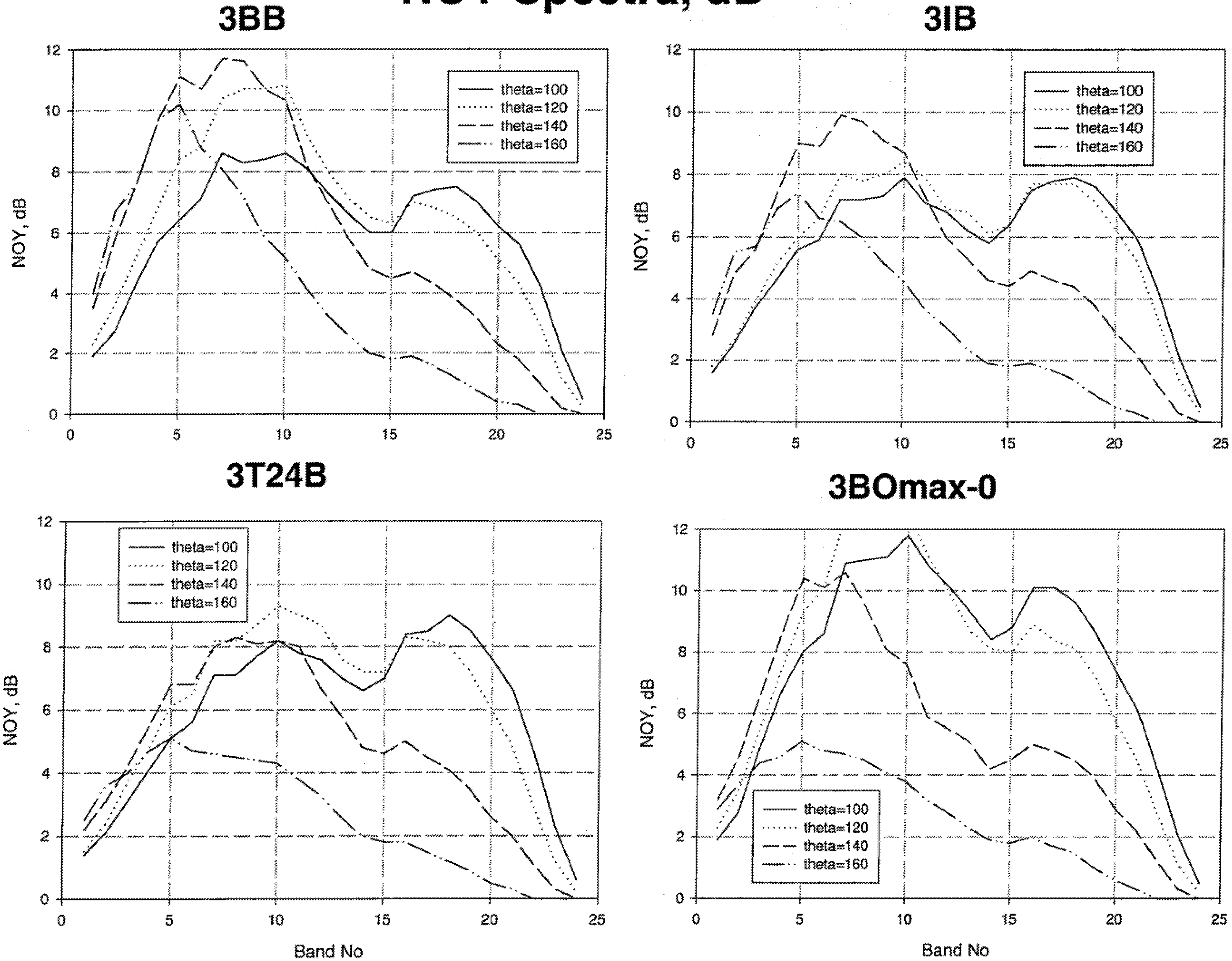
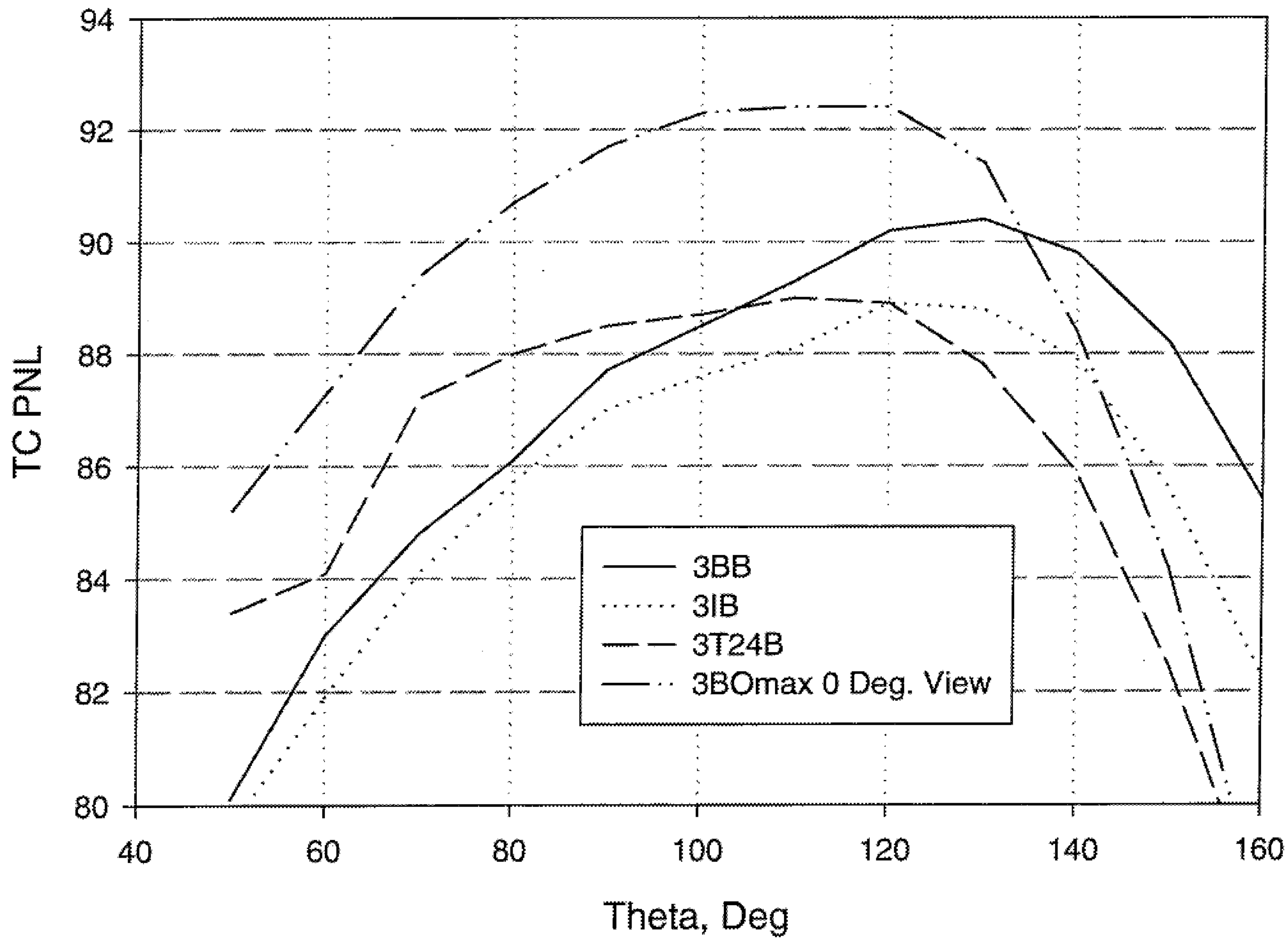
1100
1300
1500

NOY Spectra, dB



PNLT Directivity, dB

1500 Foot Sideline Fly-over



Critical Propulsion and Noise Reduction Technologies for Future Commercial Subsonic Engines

NASA Contract NAS3-27720

Area of Interest 14.3: Separate Flow Exhaust System Noise

NASA/AST Separate Flow Test Status Meeting

Cleveland, September 10, 1997

B A Janardan, G E Hoff, J W Barter, J F Brausch,
P R Gliebe, R S Coffin, S Martens, B R Delaney
GE Aircraft Engines, Cincinnati
W N Dalton, V G Mengle, B R Vittal, V D Baker, F Smith
Allison Engine Company, Indianapolis

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Outline

1. **Objectives, Approach & Goal**
2. **Baseline Nozzles & Test Cycle Definition**
3. **Repeatability & Baseline Nozzle Results**
4. **Noise Reduction Concepts**
5. **Noise Reduction Test Configurations of BPR=5 Internal Plug Nozzle & Acoustic Results**
6. **Noise Reduction Test Configurations of BPR=5 External Plug Nozzle & Acoustic Results**
7. **Noise Reduction Test Configurations of BPR=8 External Plug Nozzle & Acoustic Results**
8. **Summary**

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Area of Interest 14.3: Separate Flow Exhaust System Noise

Objectives: Establish Empirical Jet Noise Database for Separate Flow Nozzles (BPR = 5, 8). Explore Jet Noise Reduction Concepts (with Low Thrust Loss) for Separate Flow Nozzles

Approach: Model Design & Fabrication
5 Baseline Separate Flow Configurations (BPR = 5, 8)
Baseline Nozzles Representative of Langley/MD Designs
11 Jet Mixing Enhancement Concepts (both Core & Fan)
Mixing Concepts Screening Selection
Hardware Adapted to NASA Lewis Jet Rig System
Assistance in Test Planning & Test Coverage at Lewis AAPL
Data Analyses & Report

Goal: 1.5+ dB Jet Noise Reduction Relative to Separate Flow Designs

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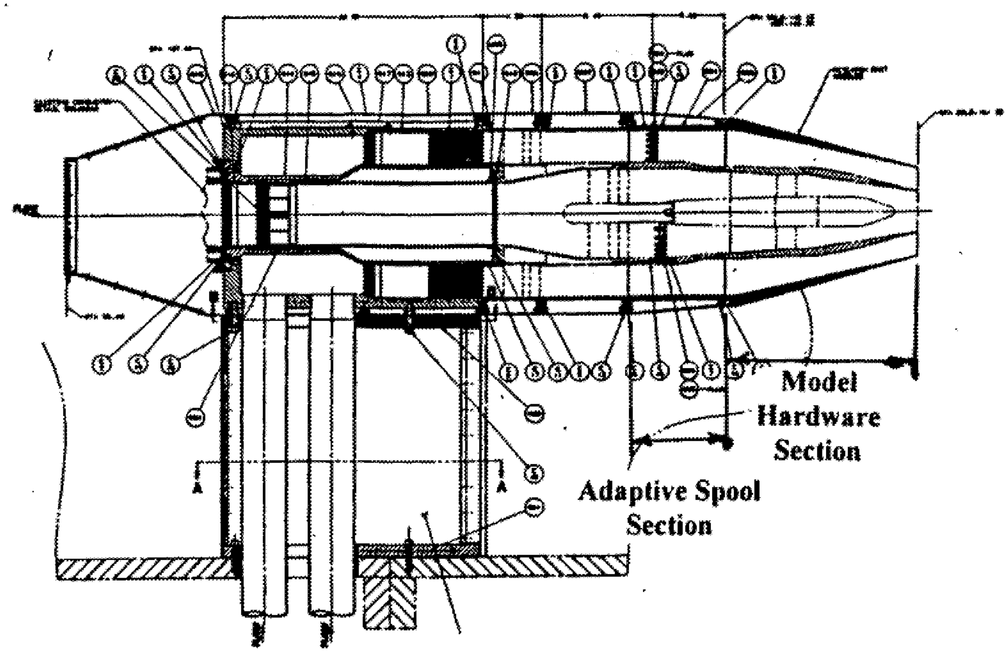
AAPL Jet Exit Rig Configuration for Separate Flow Nozzle Test



- NASA Lewis responsible for hardware upstream of break planes and adaptive spool
- GEAE/AEC responsible for baseline model test hardware design downstream of adaptive spool and their fabrication
- GEAE/AEC responsible for design and fabrication of selected noise reduction concept hardware (P&W also designed and fabricated different noise reduction concept hardware under a separate NASA contract)

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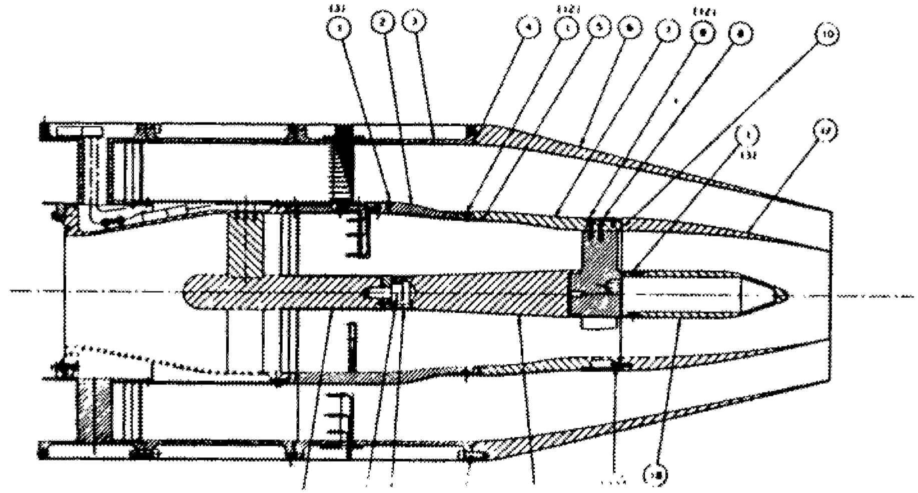
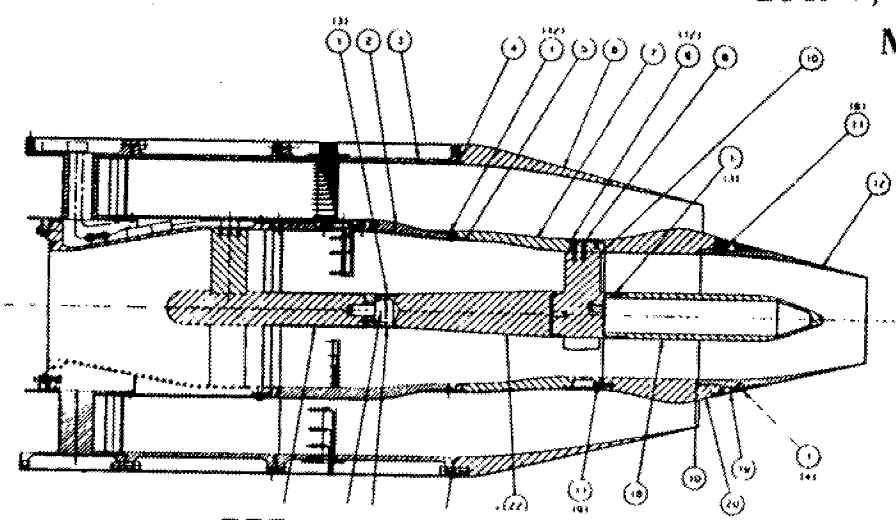
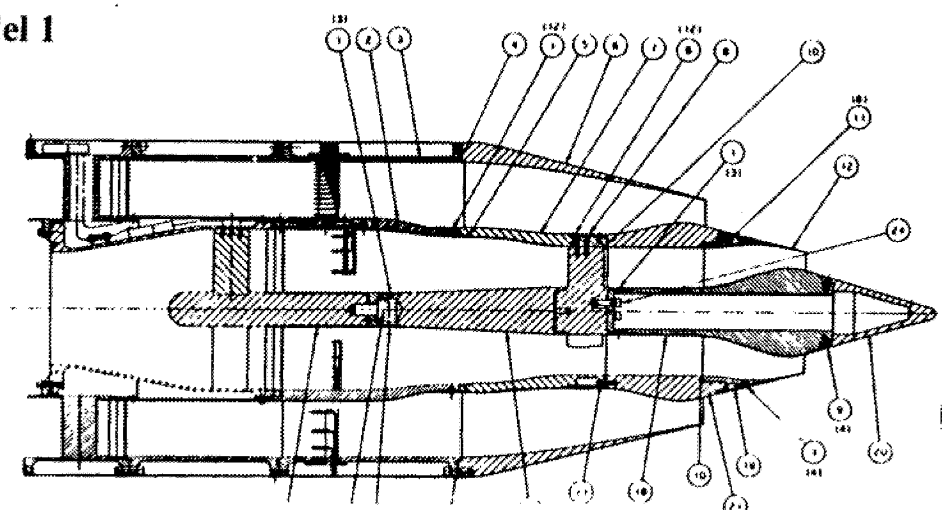
Baseline Nozzles: BPR = 5



BPR=5; Coplanar Nozzle
Model 1

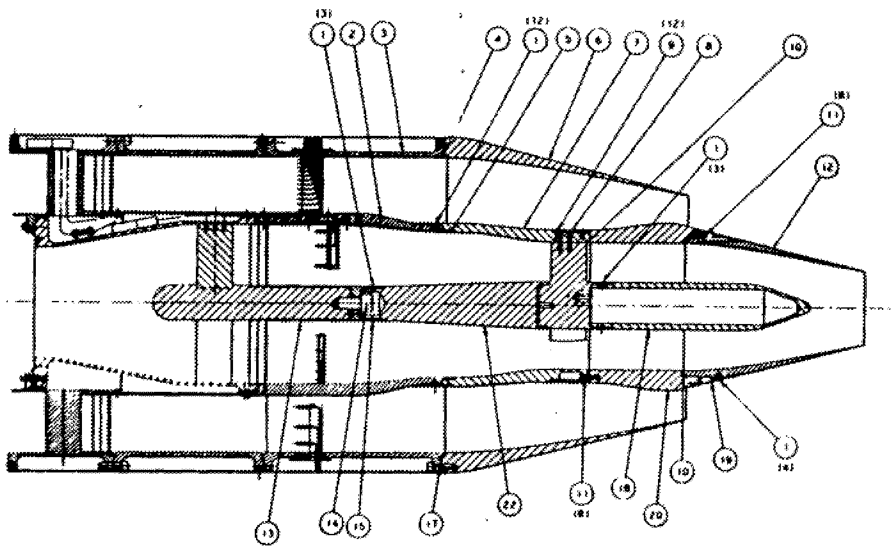


BPR=5; Internal Plug
Model 2



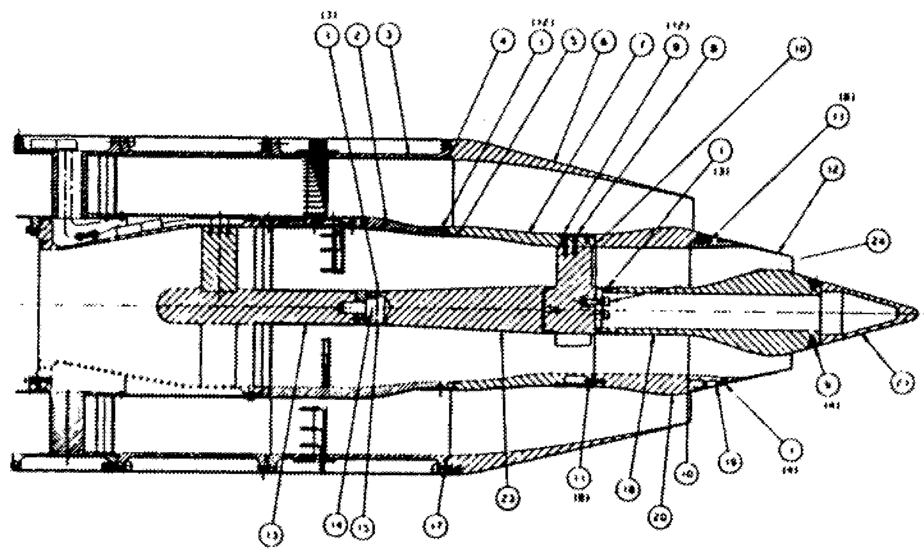
BPR=5; External Plug
Model 3

Baseline Nozzles: BPR = 8



BPR=8; Internal Plug

Model 4



BPR=8; External Plug

Model 5

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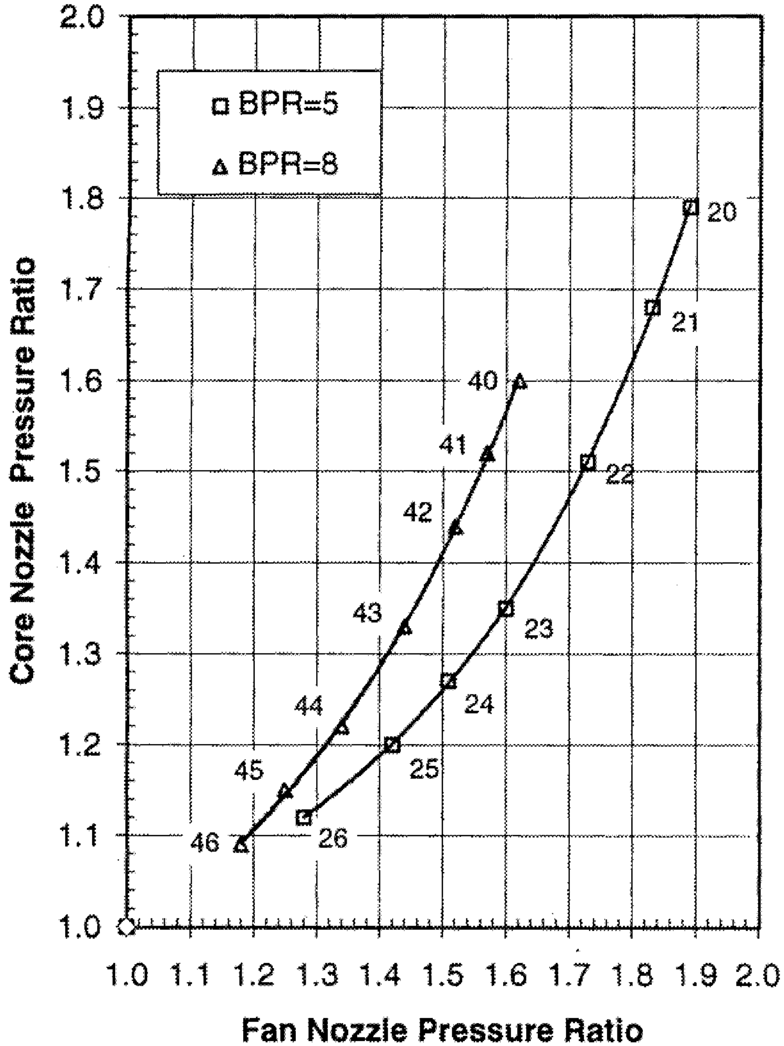
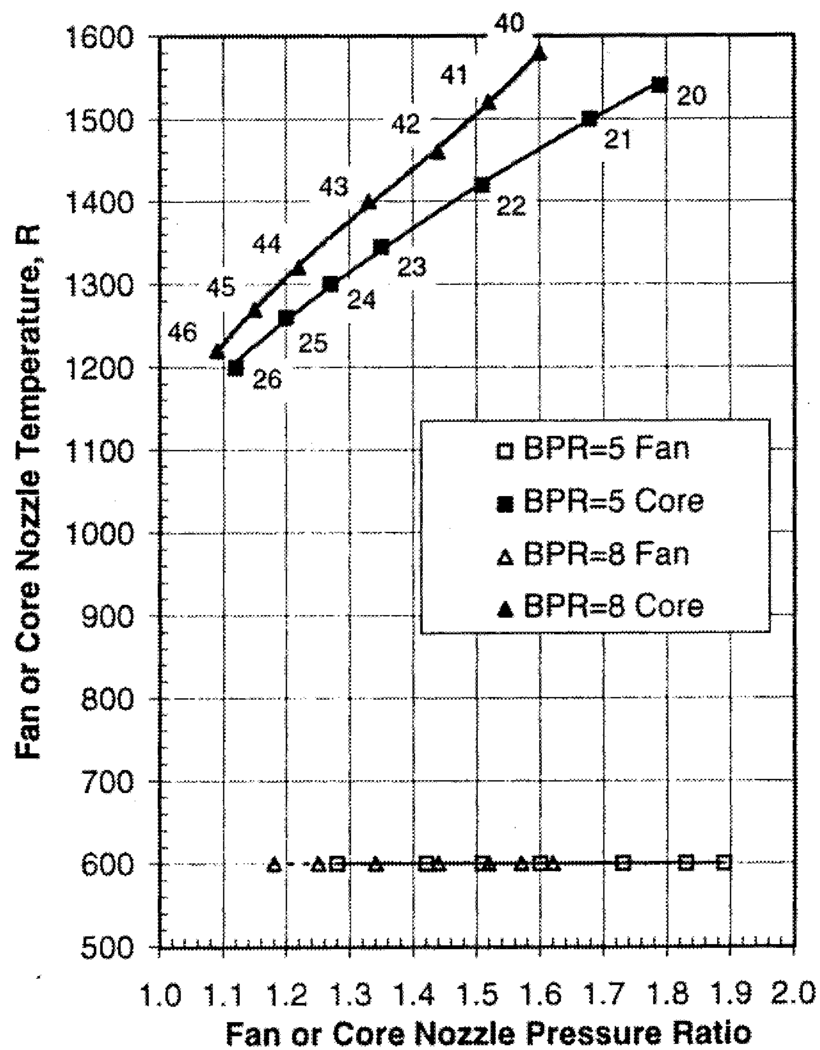
BPR = 5 & 8 ; Power Setting Parameters of Test Points





baj29/a14pit09.doc

Repeatability

Baseline Models 2 & 3 (BPR=5)

Results of Baseline Nozzles

Baseline Models 1, 2, 3 (BPR=5) & 4, 5 (BPR=8)

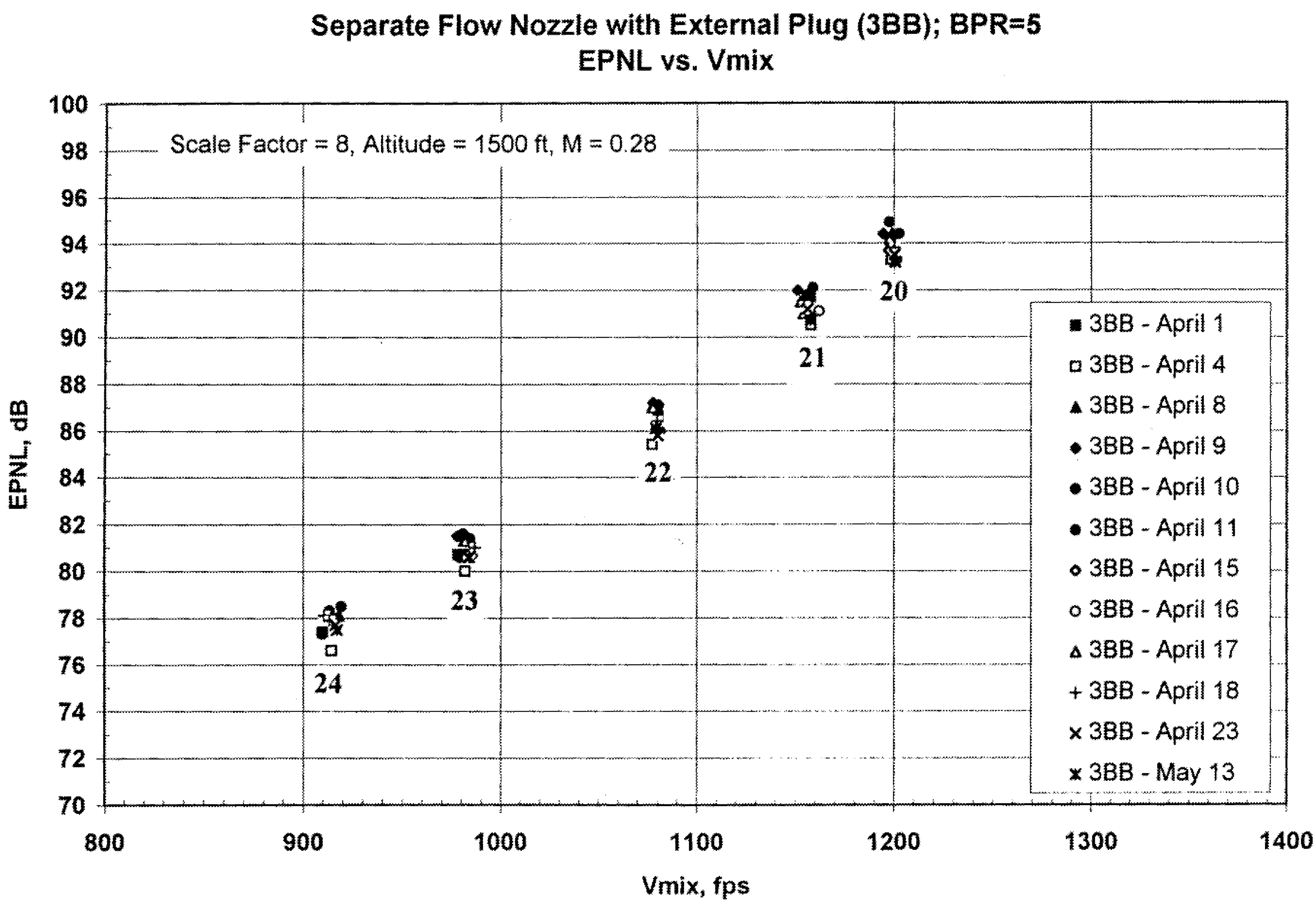
Coplanar Nozzles Vs Internal Plug Vs External Plug

Baseline Models 1 vs 2 vs 3 (BPR=5)

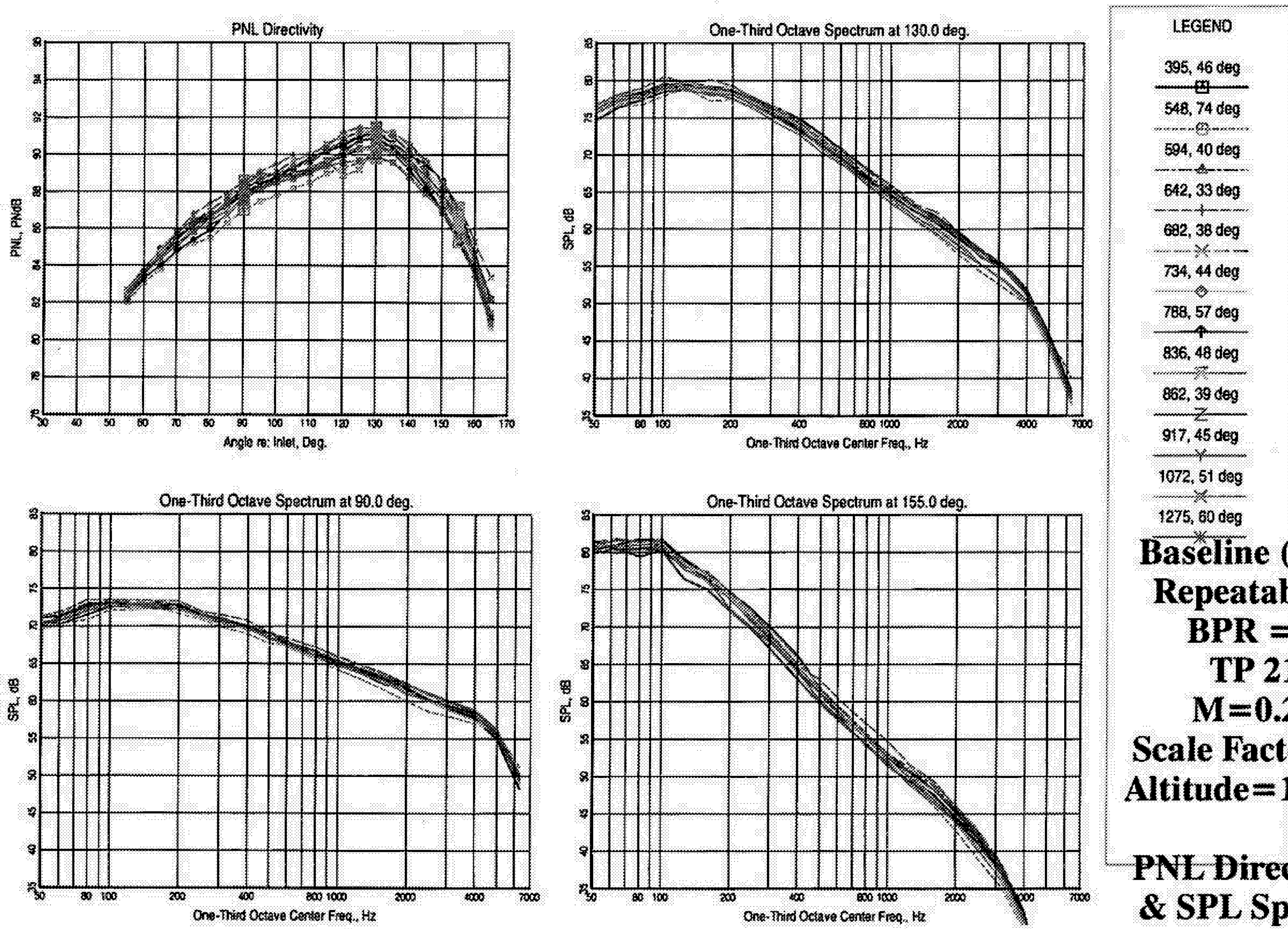
Internal Plug Vs External Plug

Baseline Models 4 vs 5 (BPR=8)

baj29/a14pit09.doc

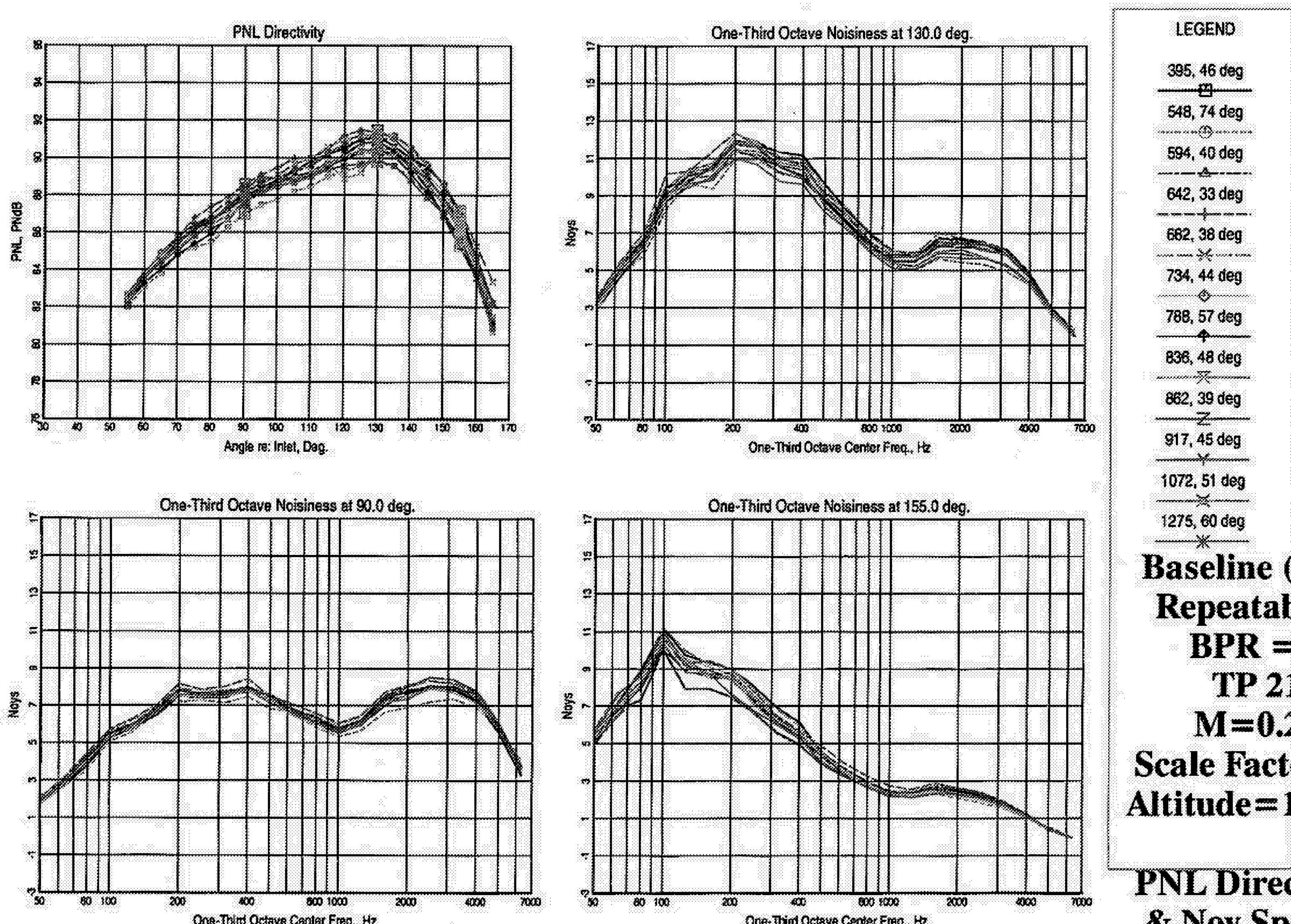


GE Aircraft Engines
baj46/AAPL03B XLS/Chart1



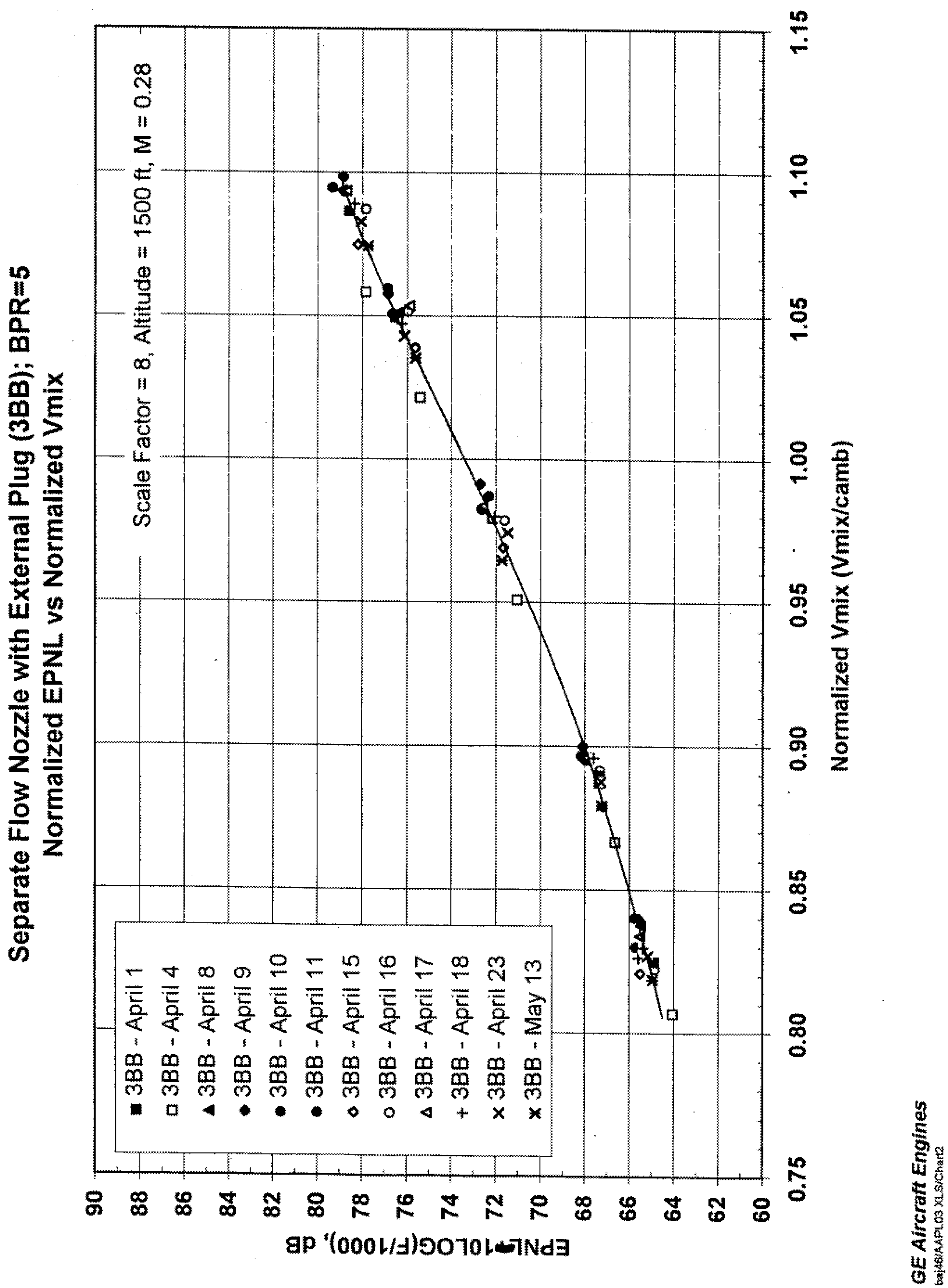
Baseline (3BB)
Repeatability
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

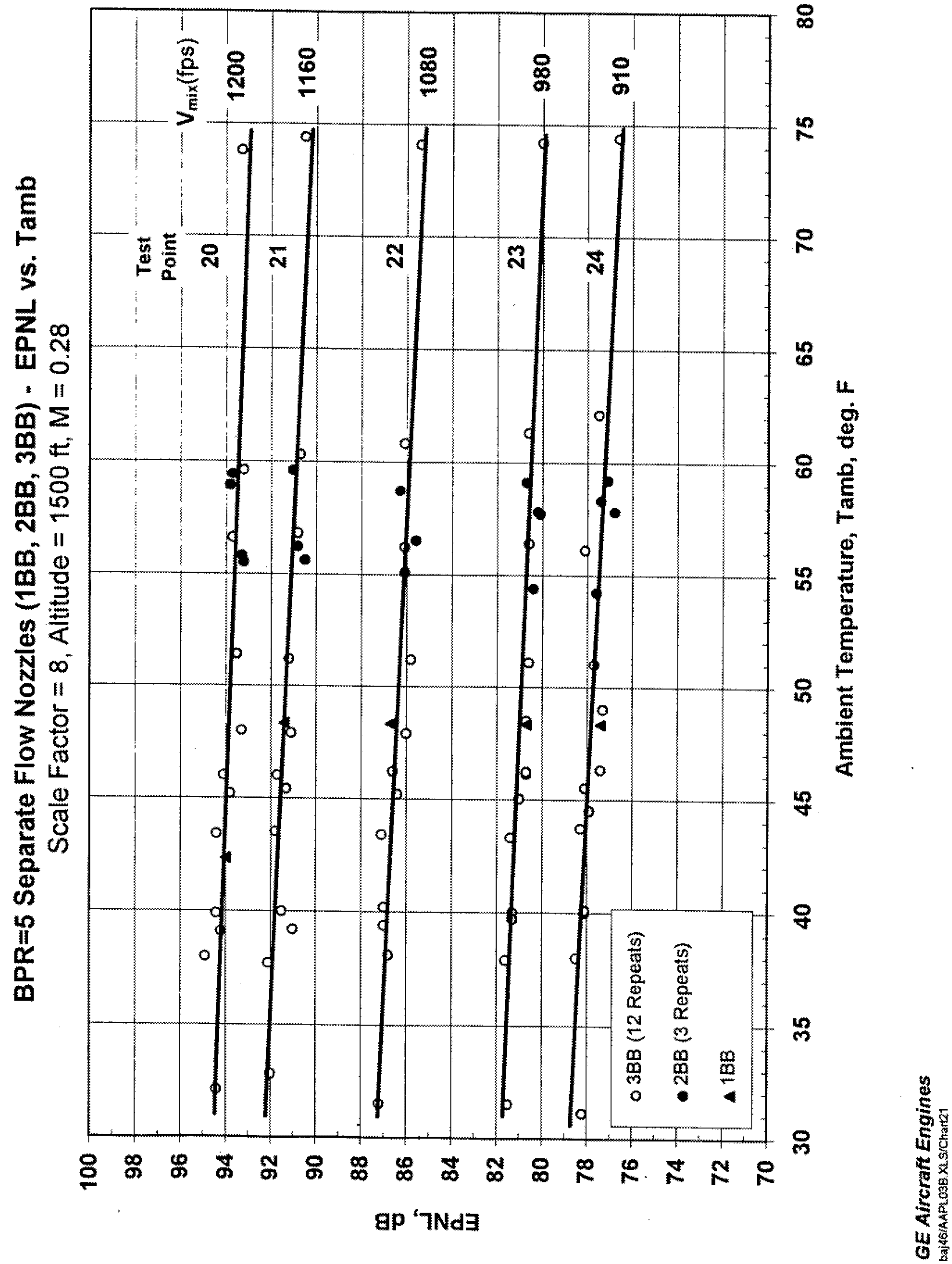
PNL Directivity
& SPL Spectra



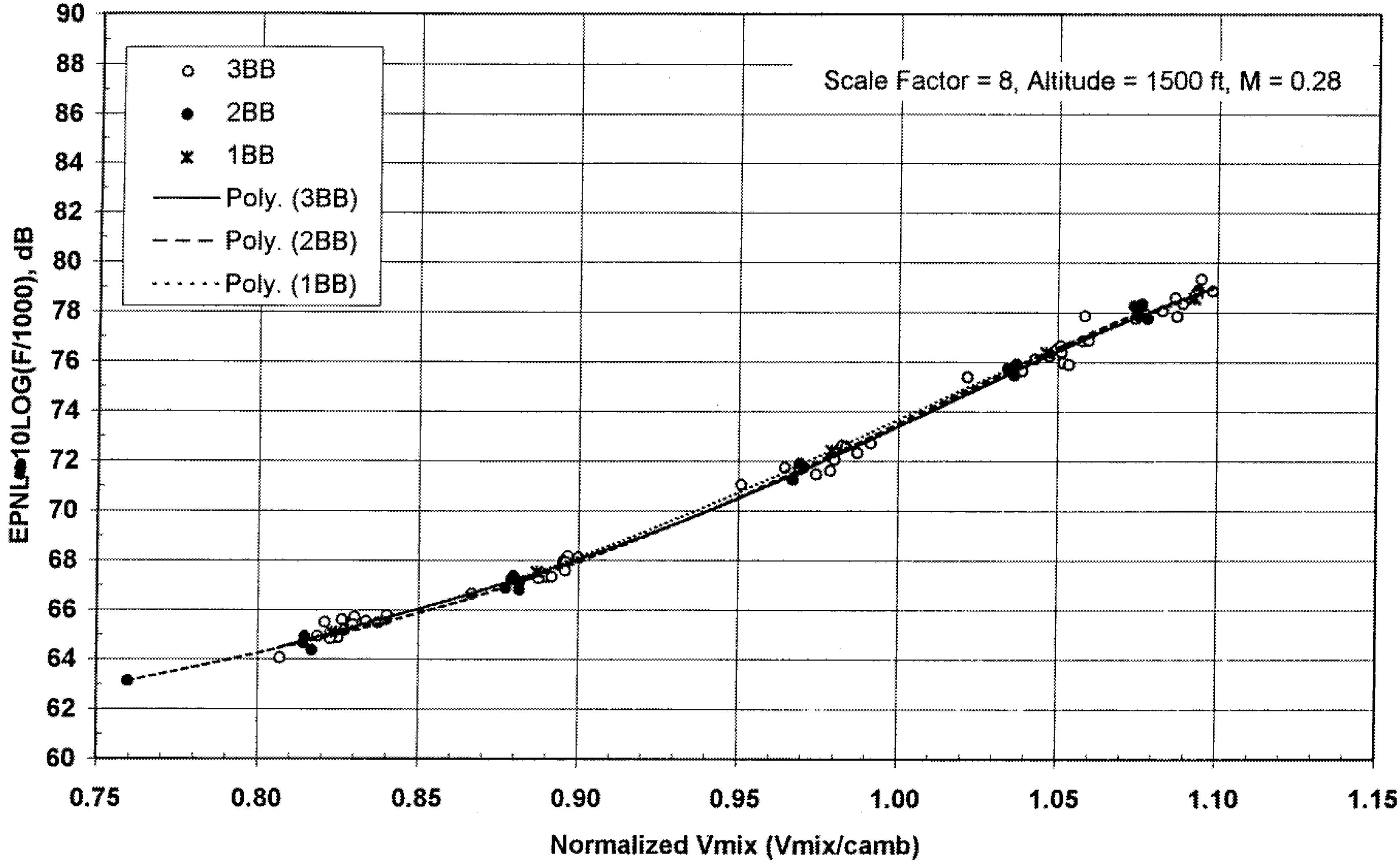
Baseline (3BB) Repeatability
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity & Noy Spectra

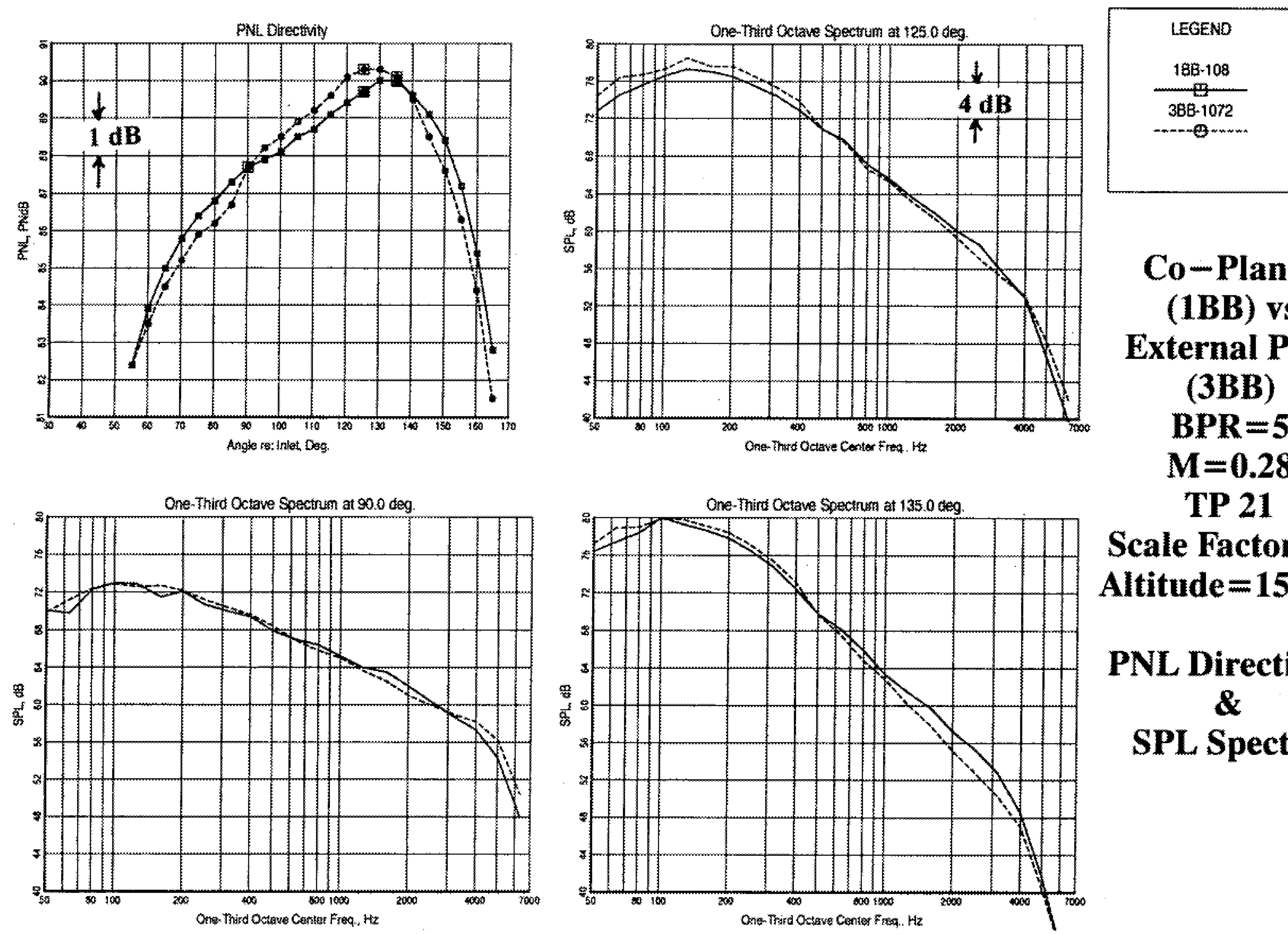

Separate Flow Nozzle with External Plug (3BB); BPR=5
Normalized EPNL vs Normalized Vmix
Scale Factor = 8, Altitude = 1500 ft, M = 0.28
3BB - April 1
3BB - April 4
3BB - April 8
3BB - April 9
3BB - April 10
3BB - April 11
3BB - April 15
3BB - April 16
3BB - April 17
3BB - April 18
3BB - April 23
3BB - May 13
EPNL-10LOG(F/1000), dB
Normalized Vmix (Vmix/camb)
90
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
GE Aircraft Engines
baj46/AAPL03 XLS/Chart2


BPR=5 Separate Flow Nozzles (1BB, 2BB, 3BB) - EPNL vs. Tamb
Scale Factor = 8, Altitude = 1500 ft, M = 0.28
EPNL, dB
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
Ambient Temperature, Tamb, deg. F
30
35
40
45
50
55
60
65
70
75
80
Test Point
20
21
22
23
24
V_{mix}(fps)
1200
1160
1080
980
910
○ 3BB (12 Repeats)
● 2BB (3 Repeats)
▲ 1BB
GE Aircraft Engines
baj46/AAPL03B.XLS/Chart21

BPR=5 Sep Flow Nozzles; Coplanar (1BB), Int Plug (2BB) & Ext Plug (3BB)
Normalized EPNL vs Normalized Vmix

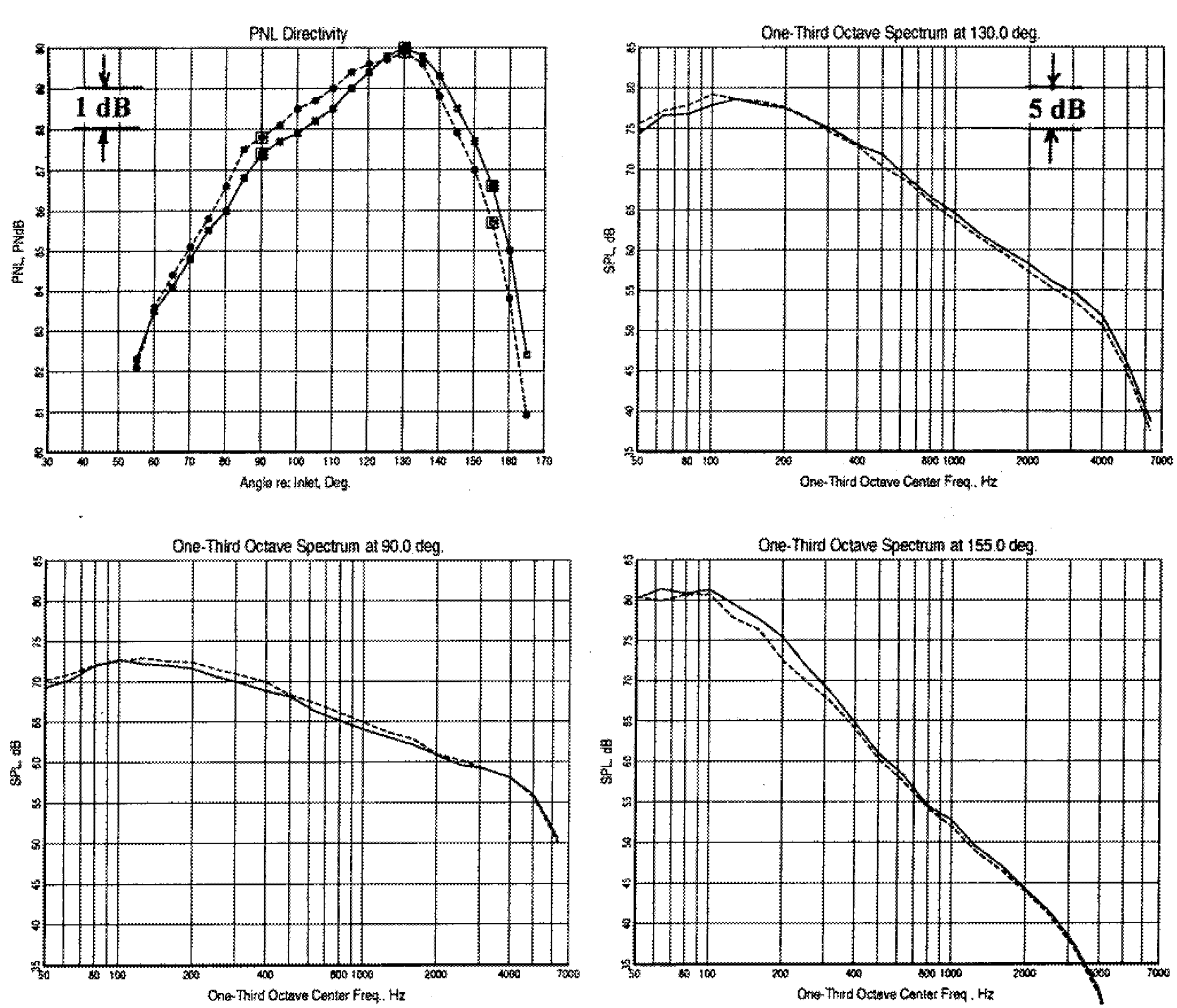


GE Aircraft Engines
baj46/AAPL03B.XLS/Chart16



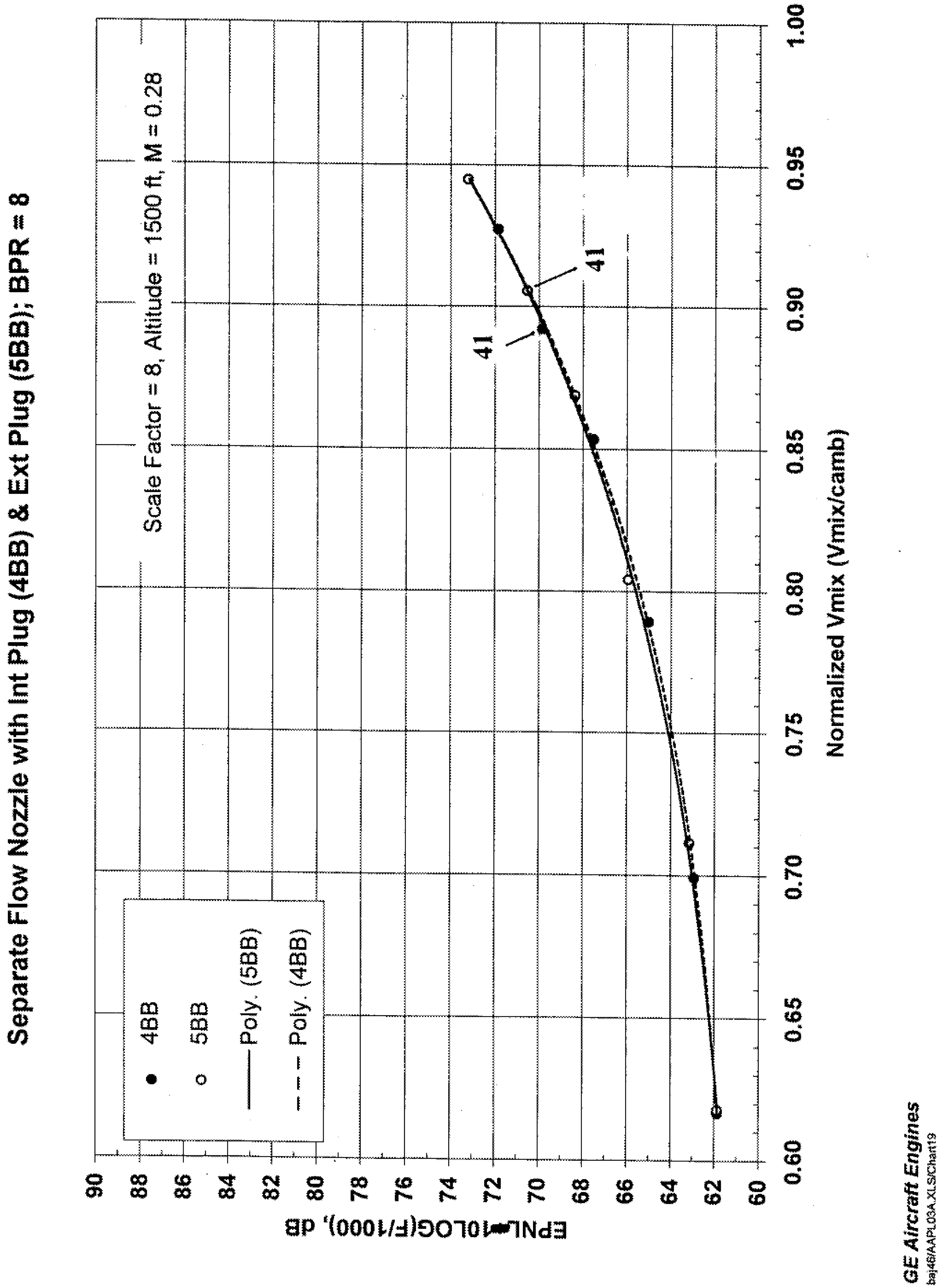
Co—Planar (1BB) vs External Plug (3BB)
BPR=5
M=0.28
TP 21
Scale Factor =8
Altitude=1500 ft

PNL Directivity & SPL Spectra

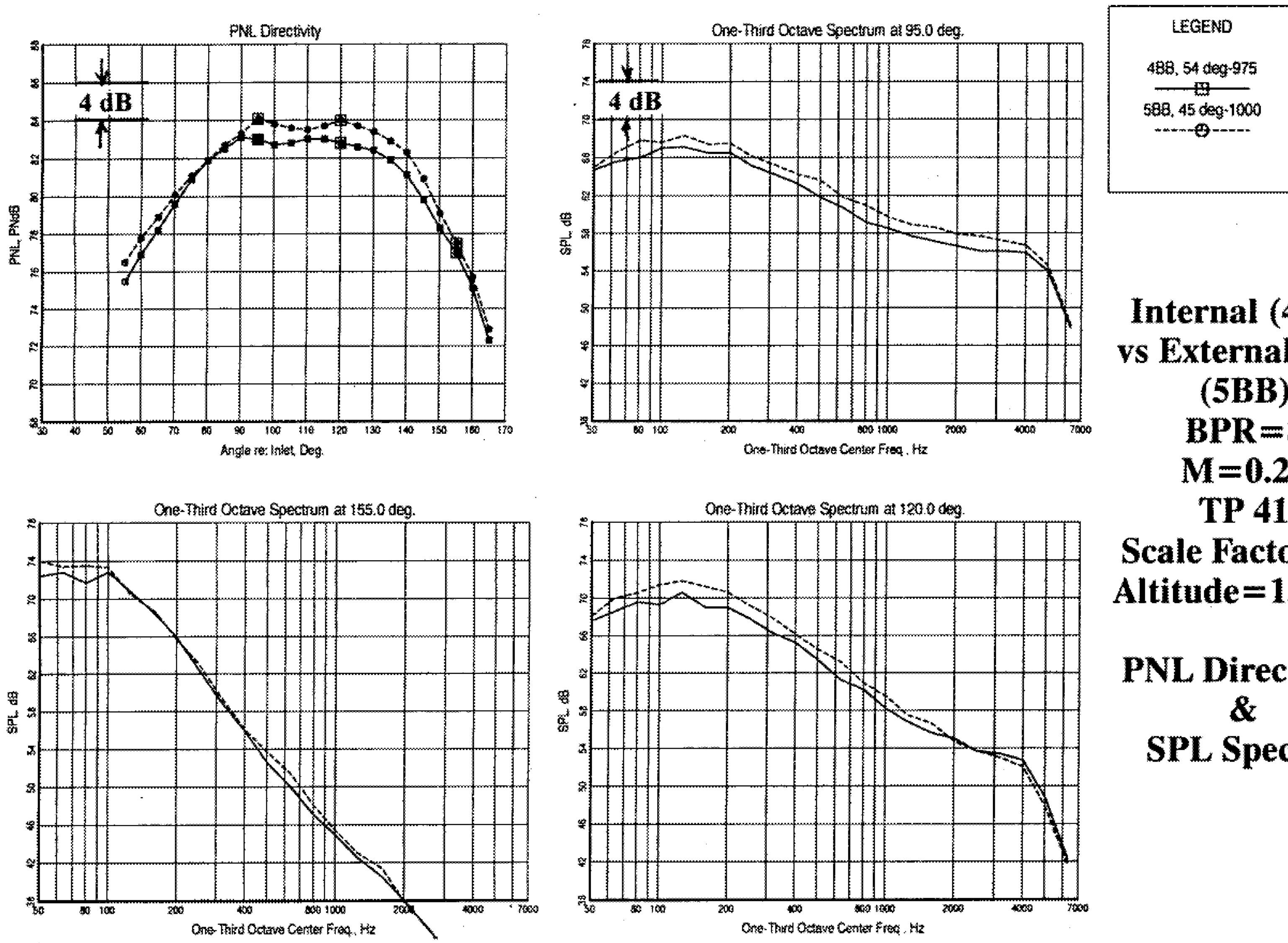


Internal (2BB)
vs
External Plug
(3BB)
BPR=5
M=0.28
TP 21
Scale Factor =8
Altitude=1500 ft

PNL Directivity
&
SPL Spectra



Separate Flow Nozzle with Int Plug (4BB) & Ext Plug (5BB); BPR = 8
Scale Factor = 8, Altitude = 1500 ft, M = 0.28
4BB
5BB
Poly. (5BB)
Poly. (4BB)
41
41
EPNL-10LOG(F/1000), dB
90
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
Normalized Vmix (Vmix/camb)
GE Aircraft Engines
baj46/AAPL03A.XLS/Chart19



Internal (4BB) vs External Plug (5BB)
BPR=8
M=0.28
TP 41
Scale Factor =8
Altitude=1500 ft

PNL Directivity & SPL Spectra

Summary - Repeatability & Baseline Nozzle Results

- Baseline 3BB Was Repeated 12 Times (Probably a Record For Number of Repeats of A Baseline)
- For a Given Test Point Setting, Noise Level Was Dependent Upon Ambient Temperature
- Repeatability Was Established With Normalization
- No Significant Acoustic Differences Were Noted Between Coplanar (1BB), Internal Plug (2BB) & External Plug (3BB) Baseline BPR=5 Nozzles
- No Significant Acoustic Differences Were Noted Between Internal Plug (4BB) & External Plug (5BB) Baseline BPR=8 Nozzles
- Normalized & Correlated Baseline Nozzle EPNL Database Will Be Used To Compare & Evaluate Tested Noise Reduction Concepts

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Noise Reduction Concepts Selected for Evaluation

Core Nozzle	Model 1	Model 2	Model 3	Model 4	Model 5	Fan Nozzle*	Model 1	Model 2	Model 3	Model 4	Model 5
Chevron (8)			x			Chevron (24)		x	x	x	x
Chevron (12)		x	x		x						
Flipper Chevron (12) (Inward Flip)			x								
Flipper Chevron (12) (Alternately Flip)			x								
Vortex Generating Doublet (64) (Core Flow Side)			x			Vortex Generating Doublet (96) (Fan Flow Side)		x	x	x	x
Vortex Generating Doublet (20) (Fan Flow Side)			x								
Tongue Mixer		x									

* Fan Nozzle Hardware Is Common For Models 2 Through 5

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Noise Reduction Test Configurations of Model 2

With Fan Nozzle Noise Reduction Concepts

2BC, 2BD

With Core Nozzle Noise Reduction Concepts

2C12B, 2TmB, 6TmB

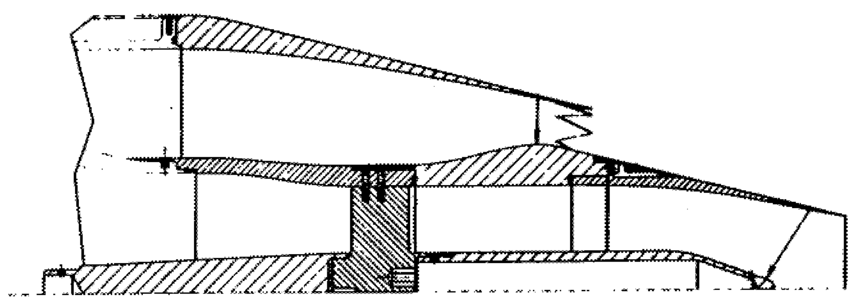
With Core & Fan Nozzle Noise Reduction Concepts

2C12C, 2TmC, 6TmC

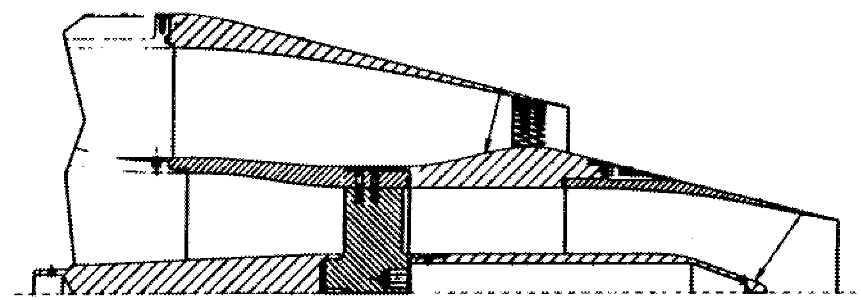
Noise Reduction Test Configurations with Model 2

BPR = 5, Internal Plug

With Different Fan Nozzles



2BC



2BD

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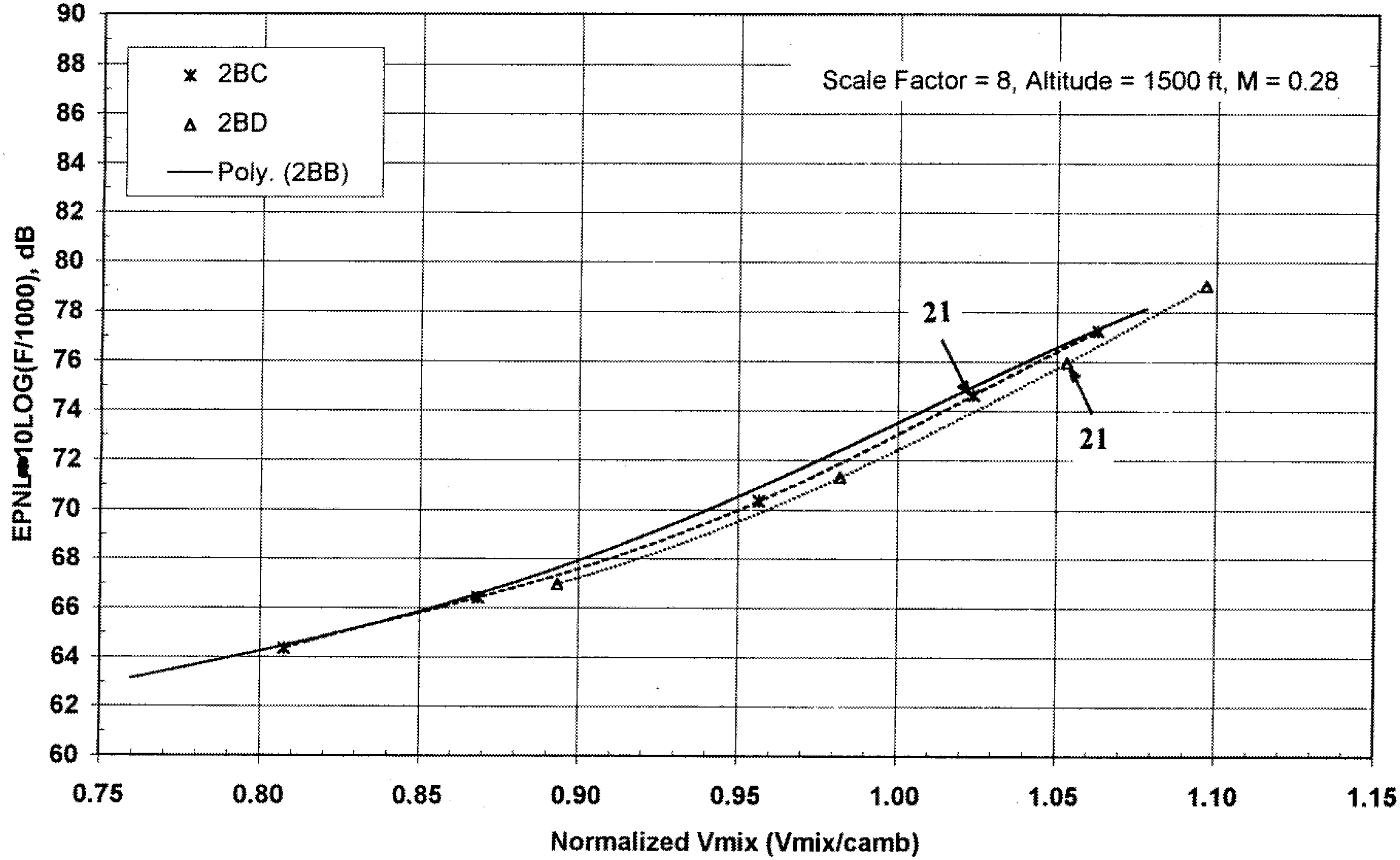
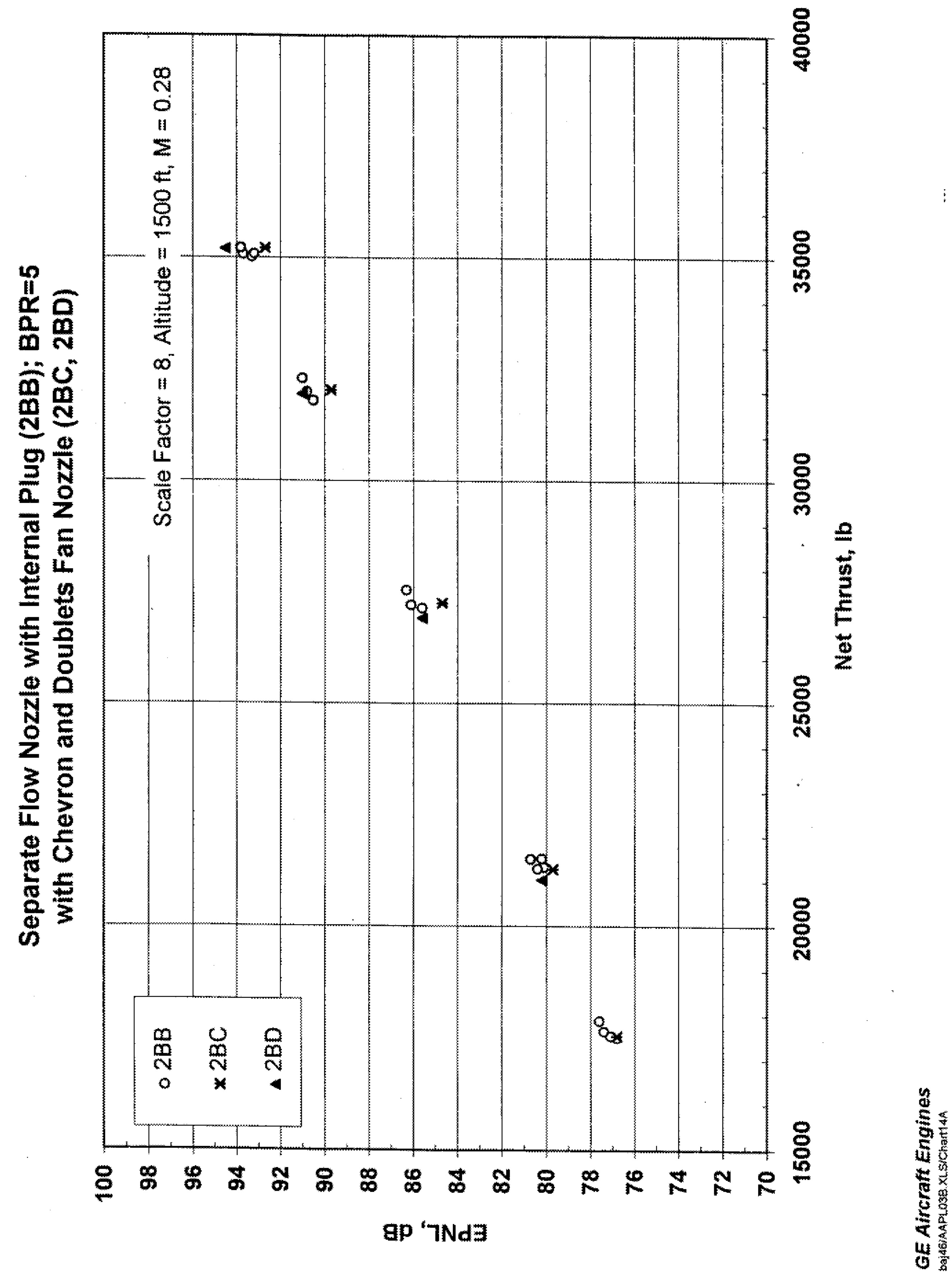
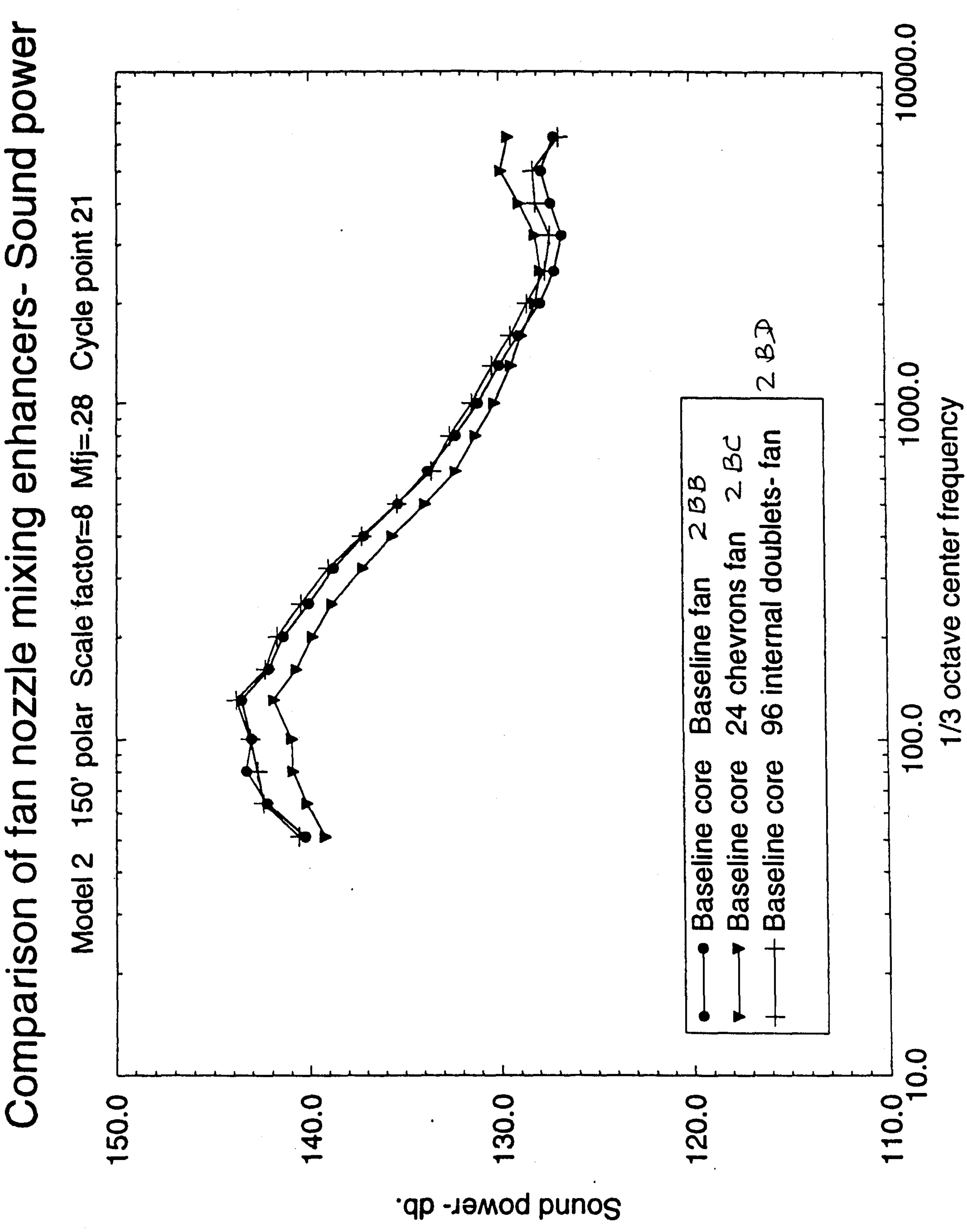
Separate Flow Nozzle with Internal Plug (2BB); BPR=5 with Chevron and Doublets Fan Nozzle (2BC, 2BD)

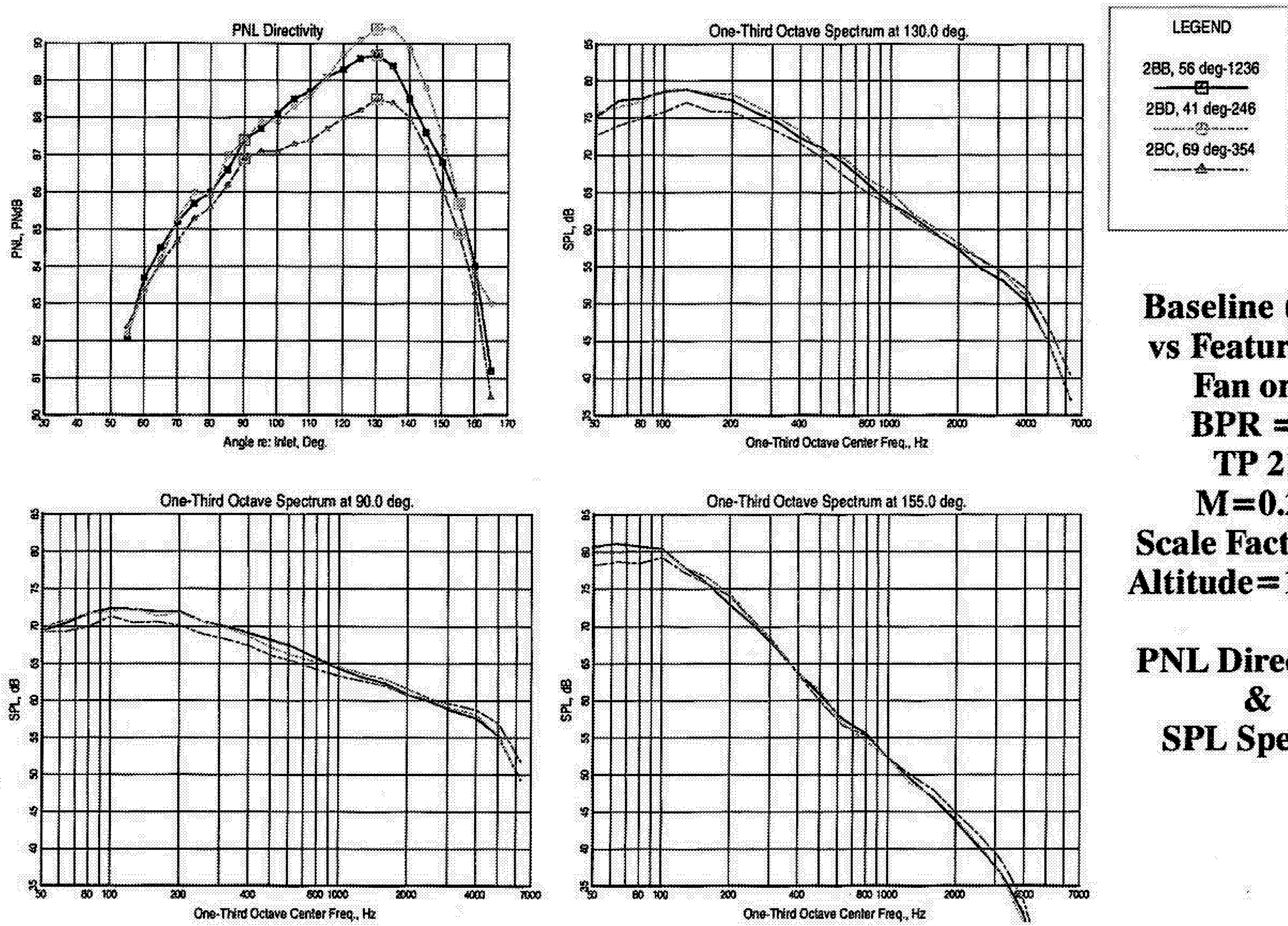


GE Aircraft Engines
baj46/AAPL03.XLS/Chart14


Separate Flow Nozzle with Internal Plug (2BB); BPR=5
with Chevron and Doublets Fan Nozzle (2BC, 2BD)
Scale Factor = 8, Altitude = 1500 ft, M = 0.28
2BB
2BC
2BD
EPNL, dB
Net Thrust, lb
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
15000
20000
25000
30000
35000
40000
GE Aircraft Engines

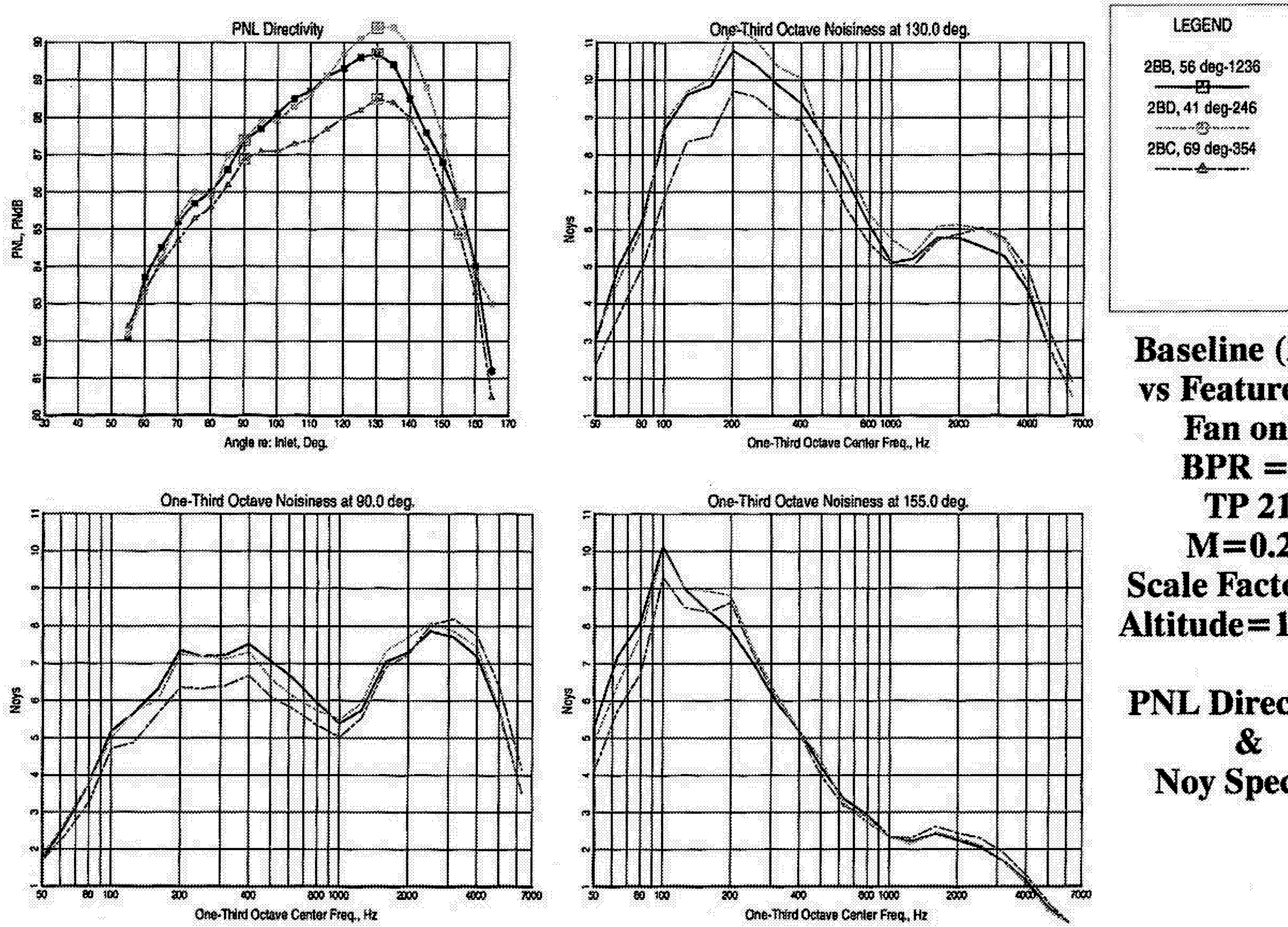


Comparison of fan nozzle mixing enhancers- Sound power
Model 2 150' polar Scale factor=8 Mfj=.28 Cycle point 21
Sound power- db.
150.0
140.0
130.0
120.0
110.0
10.0
100.0
1000.0
10000.0
1/3 octave center frequency
Baseline core Baseline fan 2BB
Baseline core 24 chevrons fan 2BC
Baseline core 96 internal doublets- fan 2BD



Baseline (2BB)
vs Features on
Fan only
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity
&
SPL Spectra



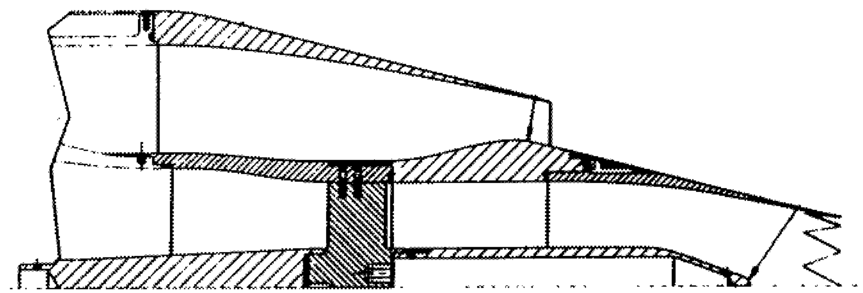
Baseline (2BB)
vs Features on
Fan only
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity
&
Noy Spectra

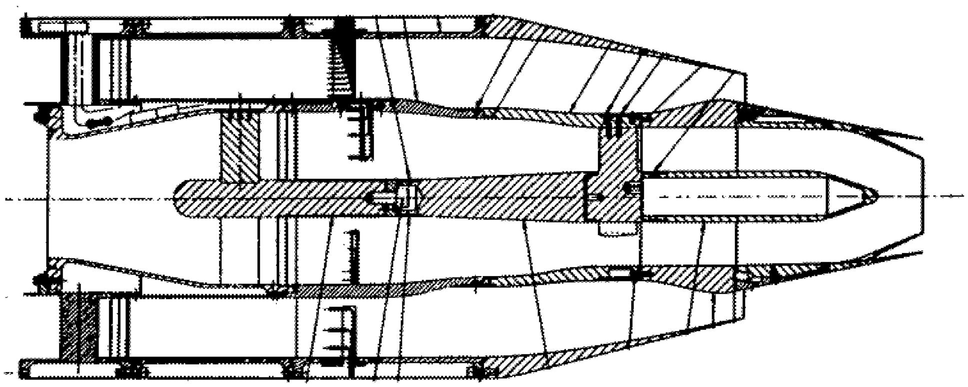
Noise Reduction Test Configurations with Model 2

BPR = 5, Internal Plug

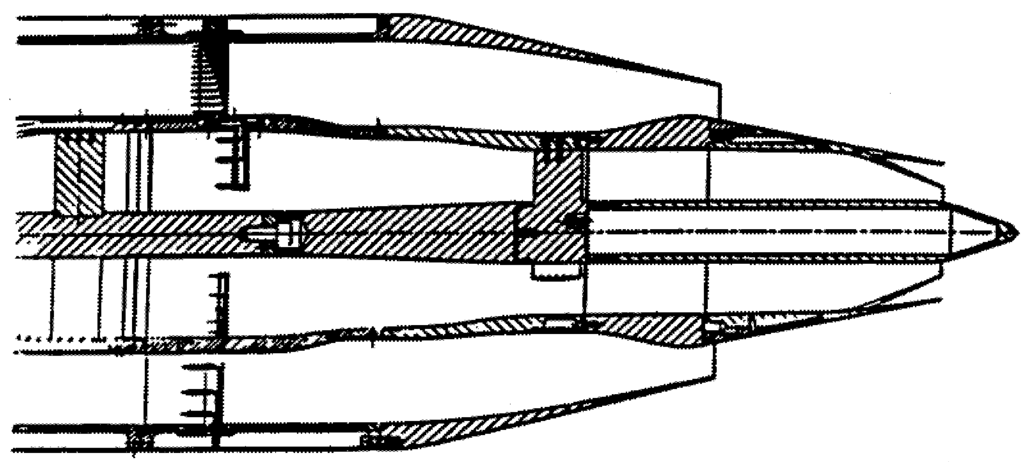
With Different Core Nozzles



2C12B



2TMB



6TMB

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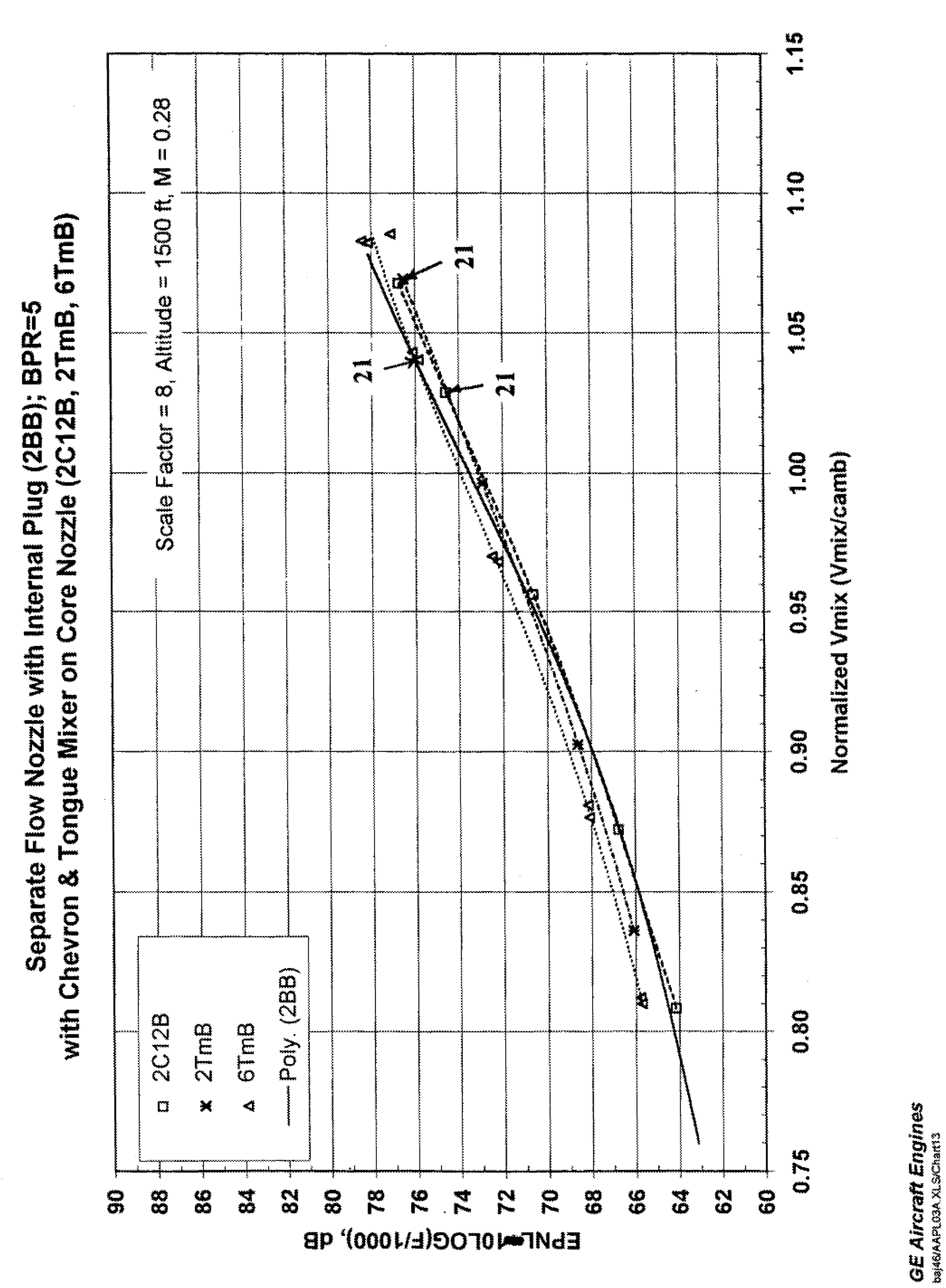
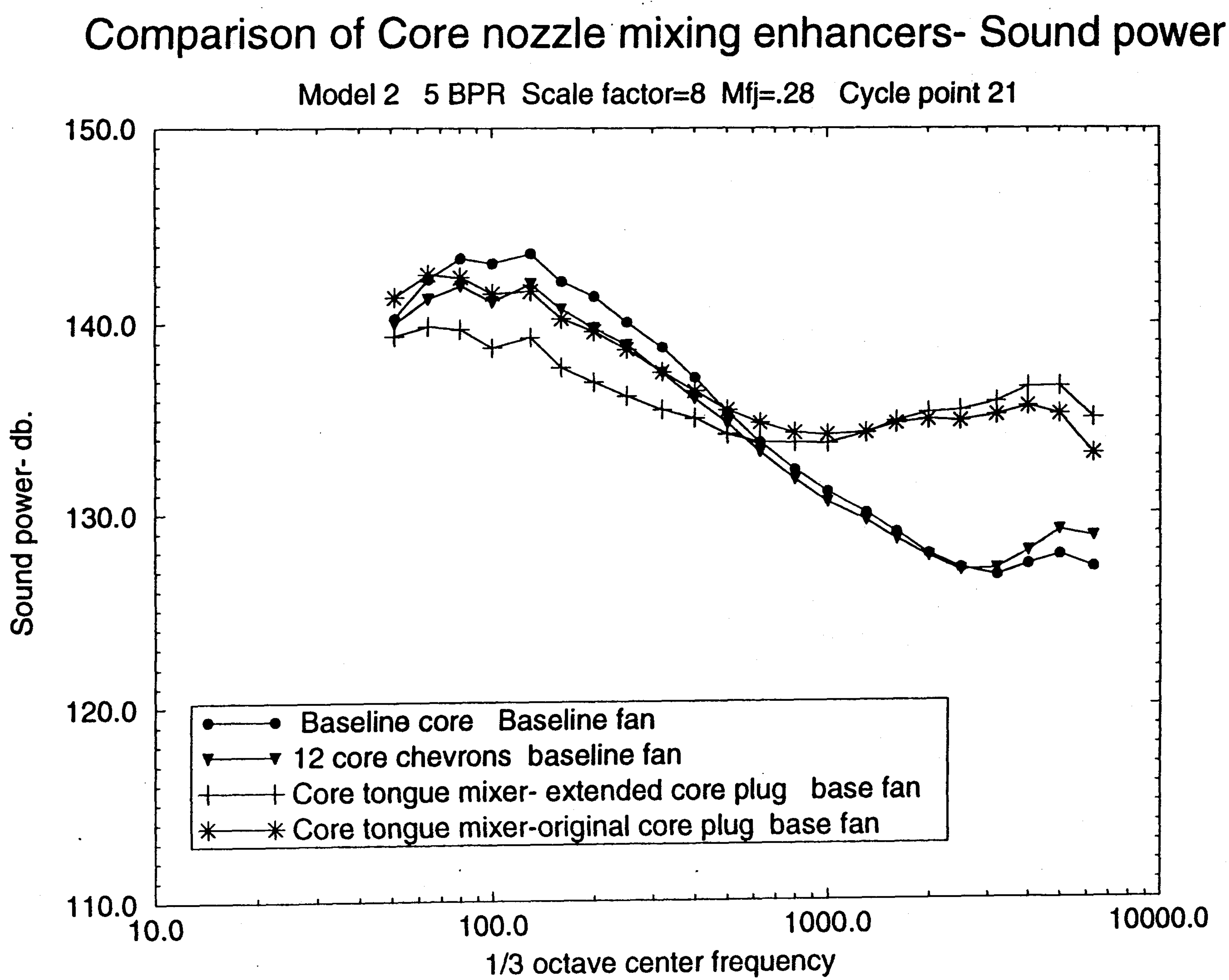
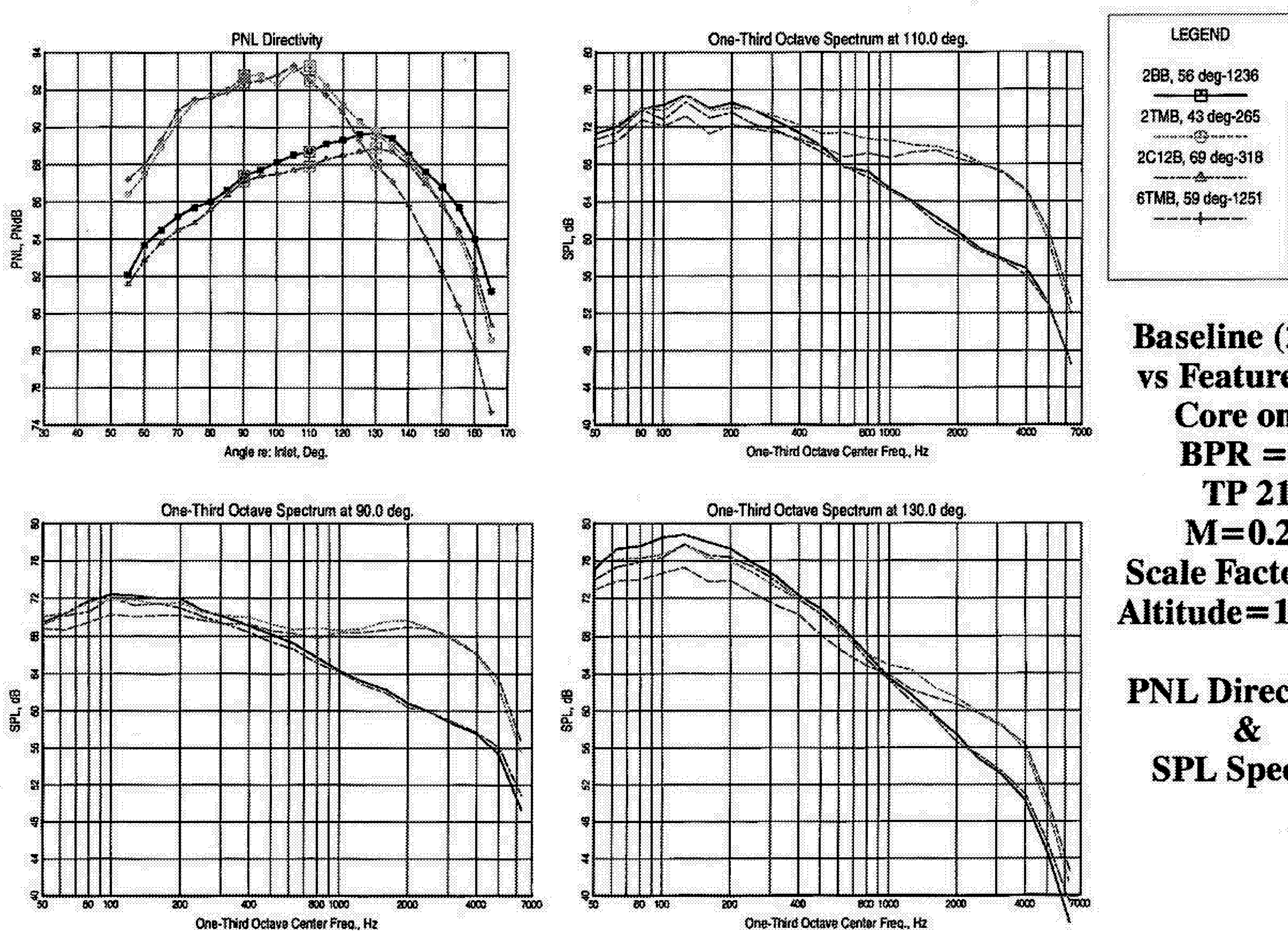


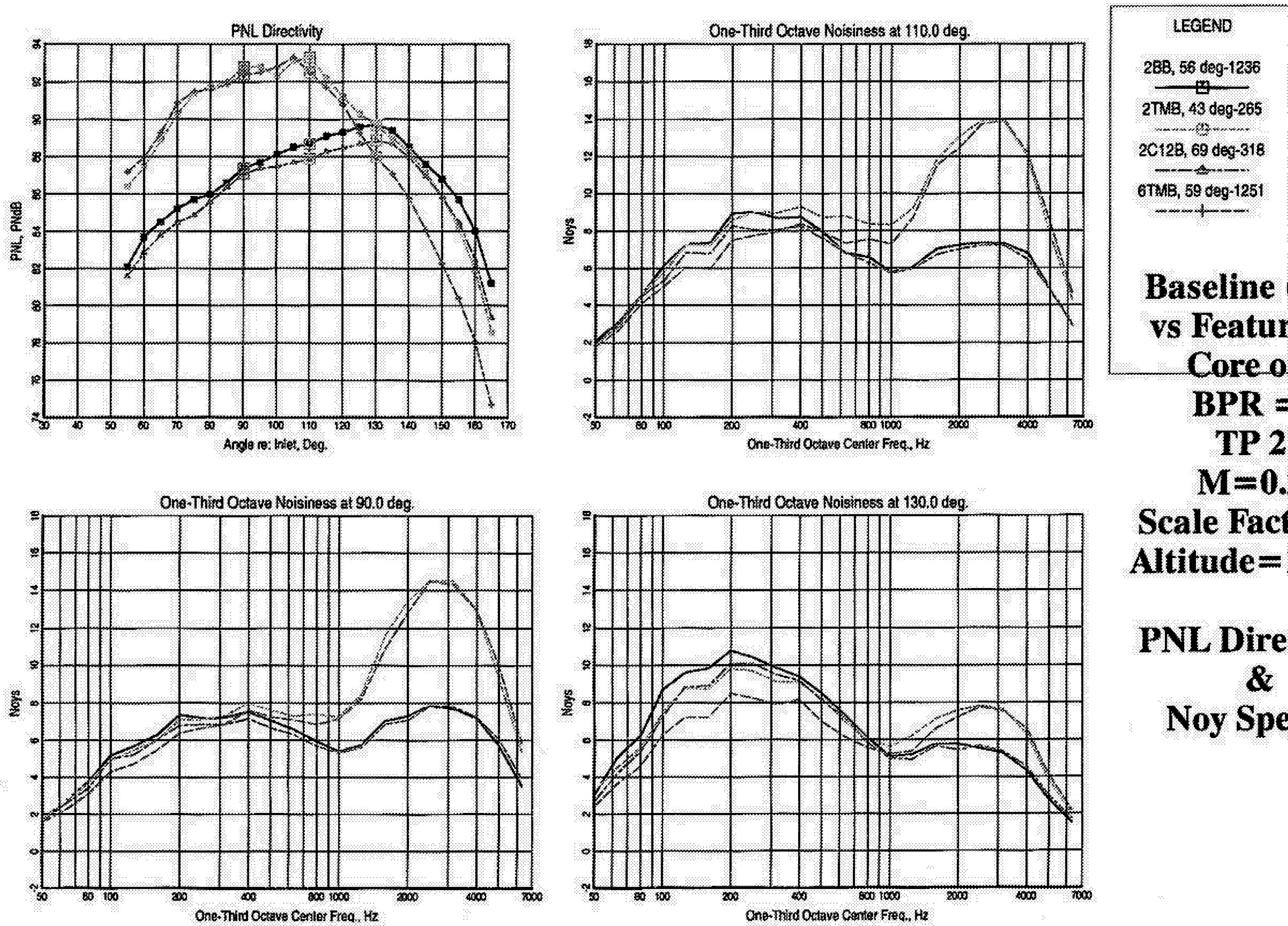
Separate Flow Nozzle with Internal Plug (2BB); BPR=5
with Chevron & Tongue Mixer on Core Nozzle (2C12B, 2TmB, 6TmB)
Scale Factor = 8, Altitude = 1500 ft, M = 0.28
2C12B
2TmB
6TmB
Poly. (2BB)
21
21
21
EPNL-10LOG(F/1000), dB
90
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
Normalized Vmix (Vmix/camb)
GE Aircraft Engines
baj46/AAPL03A.XLS/Chart13


Comparison of Core nozzle mixing enhancers- Sound power
Model 2 5 BPR Scale factor=8 Mfj=.28 Cycle point 21
150.0
140.0
130.0
120.0
110.0
Sound power- db.
10.0
100.0
1000.0
10000.0
1/3 octave center frequency
Baseline core Baseline fan
12 core chevrons baseline fan
Core tongue mixer- extended core plug base fan
Core tongue mixer-original core plug base fan



Baseline (2BB) vs Features on Core only
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity & SPL Spectra



Baseline (2BB) vs Features on Core only

BPR = 5

TP 21

M=0.28

Scale Factor =8

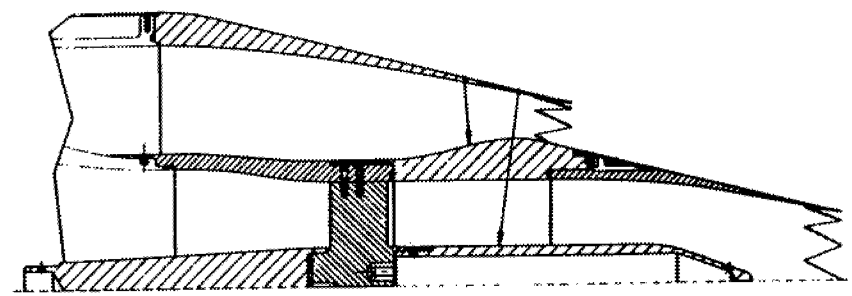
Altitude=1500 ft

PNL Directivity & Noy Spectra

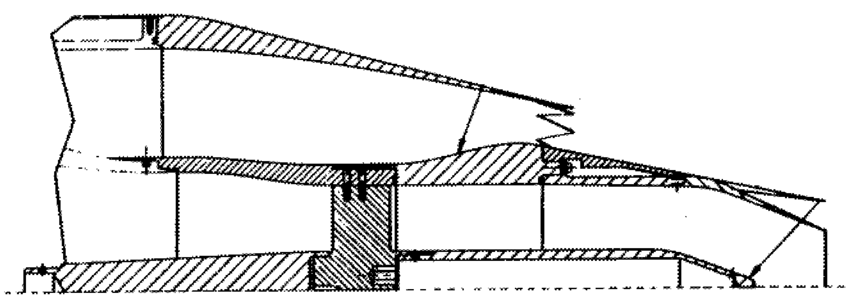
Noise Reduction Test Configurations with Model 2

BPR = 5, Internal Plug

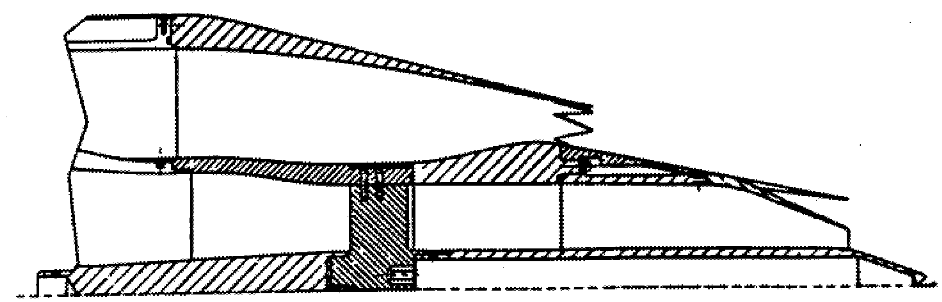
With Different Core & Fan Nozzles



2C12C



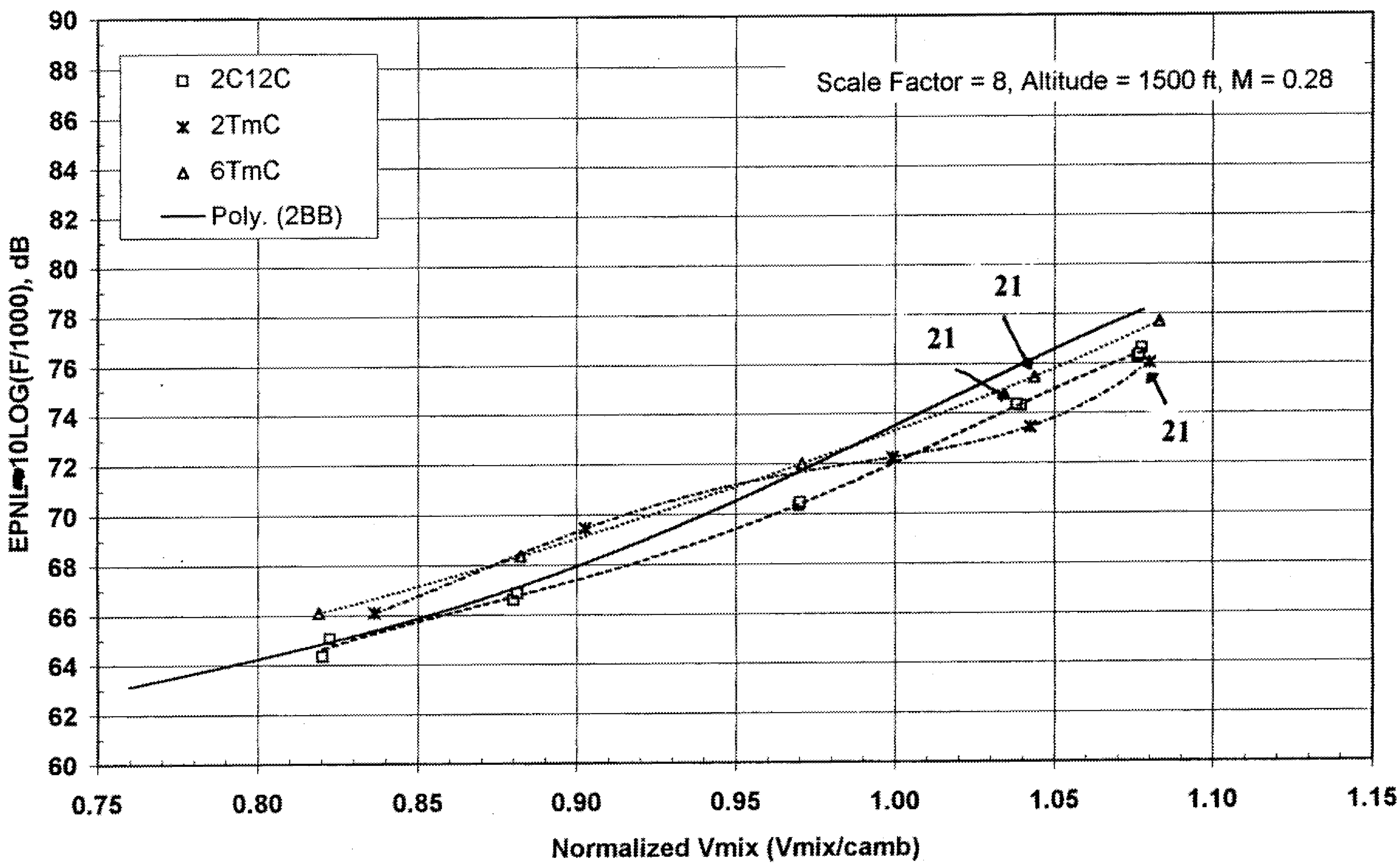
2TMC



6TMC

baj29/a14pit09.doc

Separate Flow Nozzle with Internal Plug (2BB); BPR=5
with Chevron & Tong-Mix on Core and Chevron on Fan Nozzle(2TmC, 2CC)



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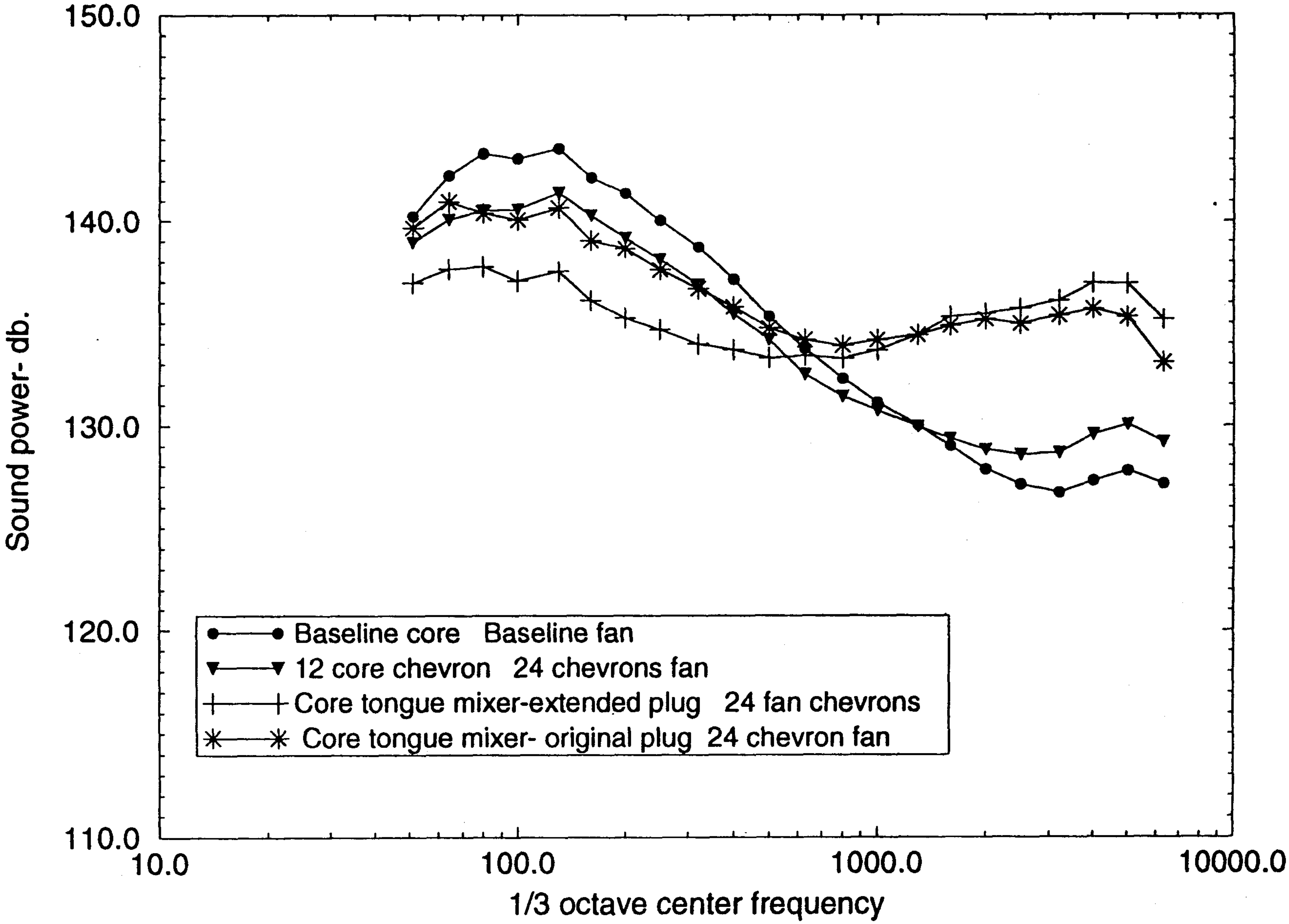
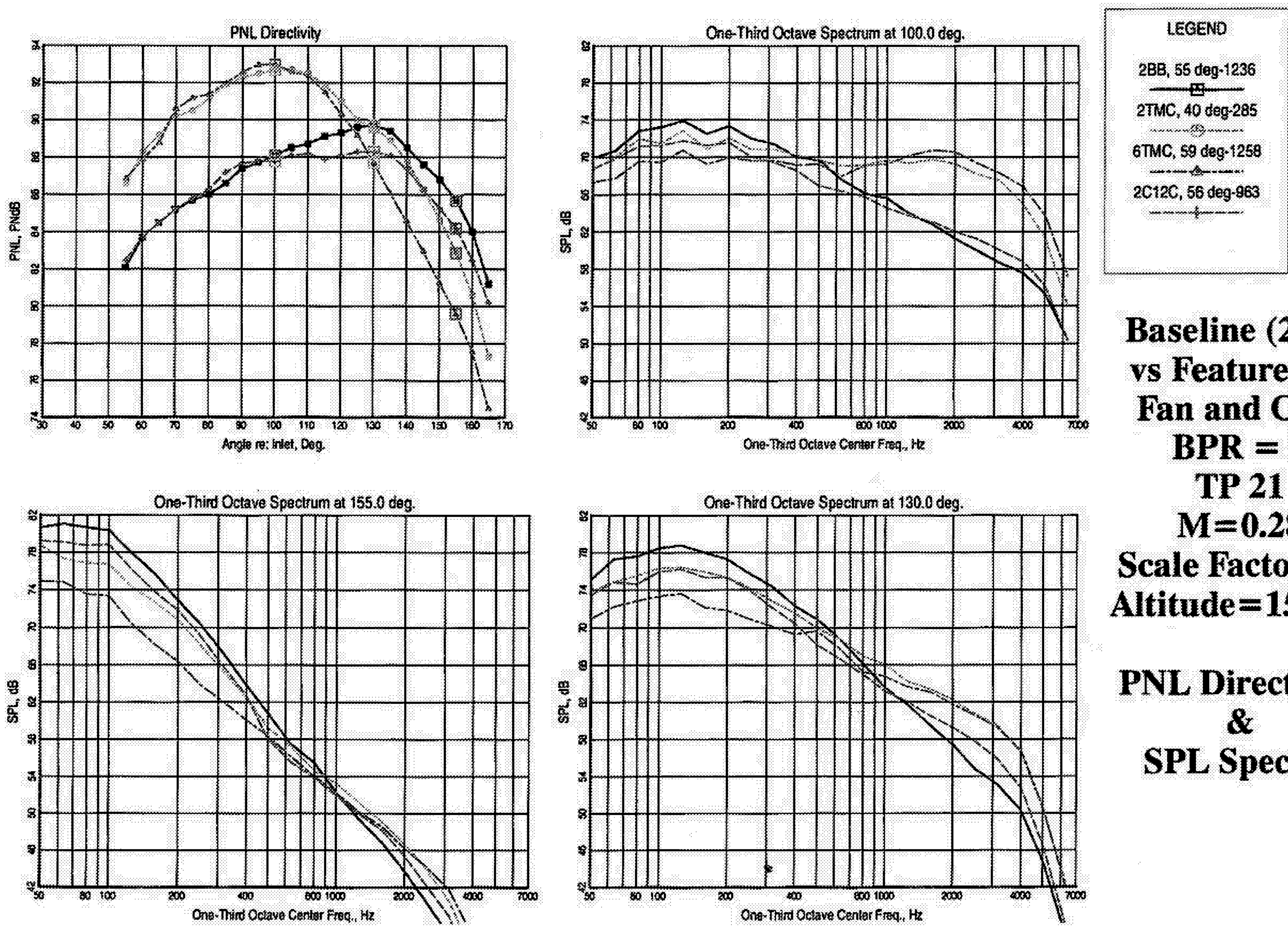
Comparison of combined nozzle mixing enhancers- Sound power

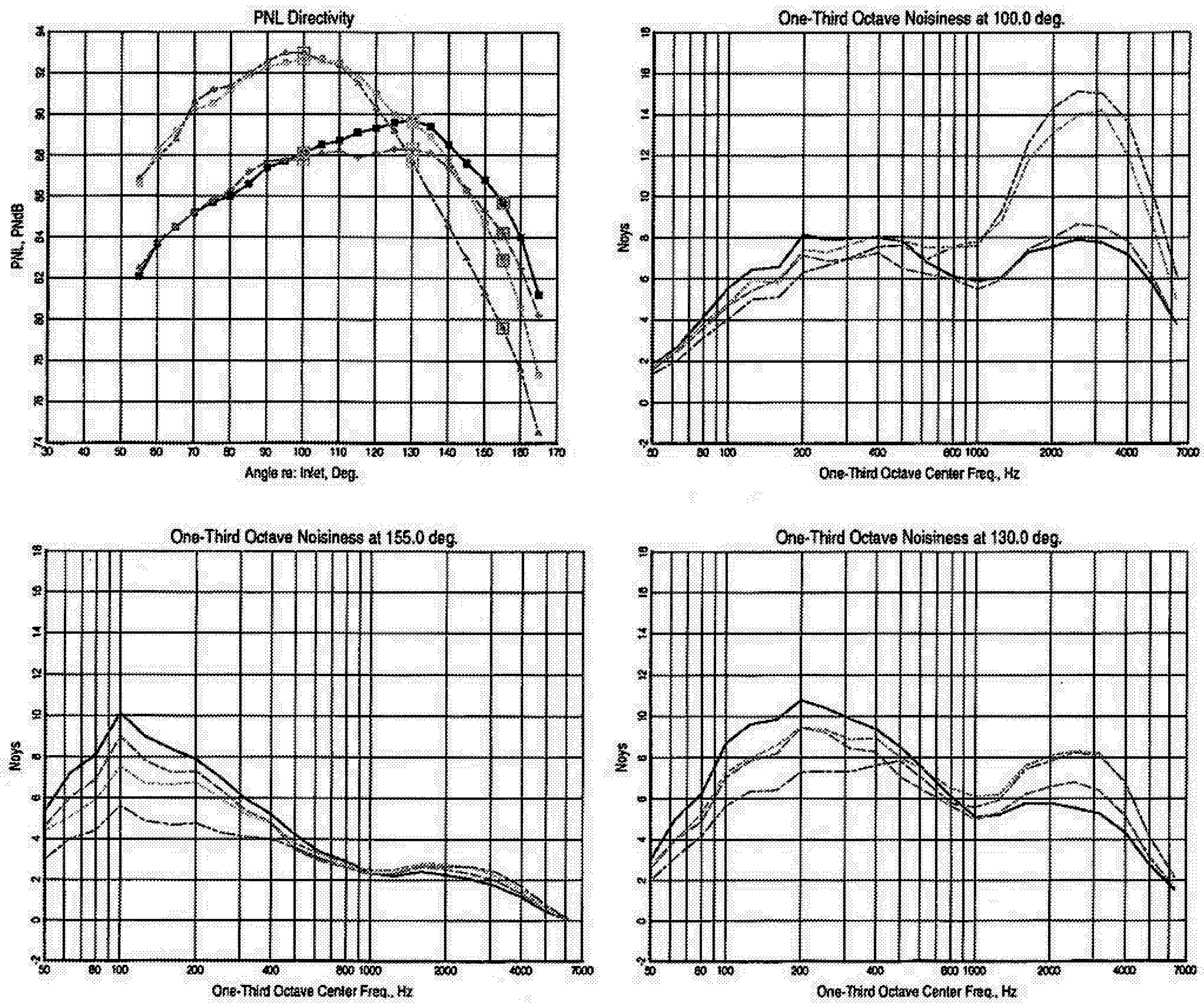
Model 2 150' polar Scale factor=8 Mfj=.28 Cycle point 21

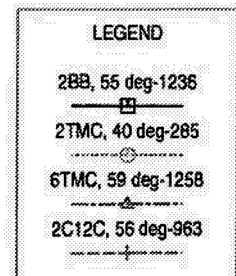




Baseline (2BB)
vs Features on
Fan and Core
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity
&
SPL Spectra





Baseline (2BB) vs Features on Fan and Core

BPR = 5

TP 21

M=0.28

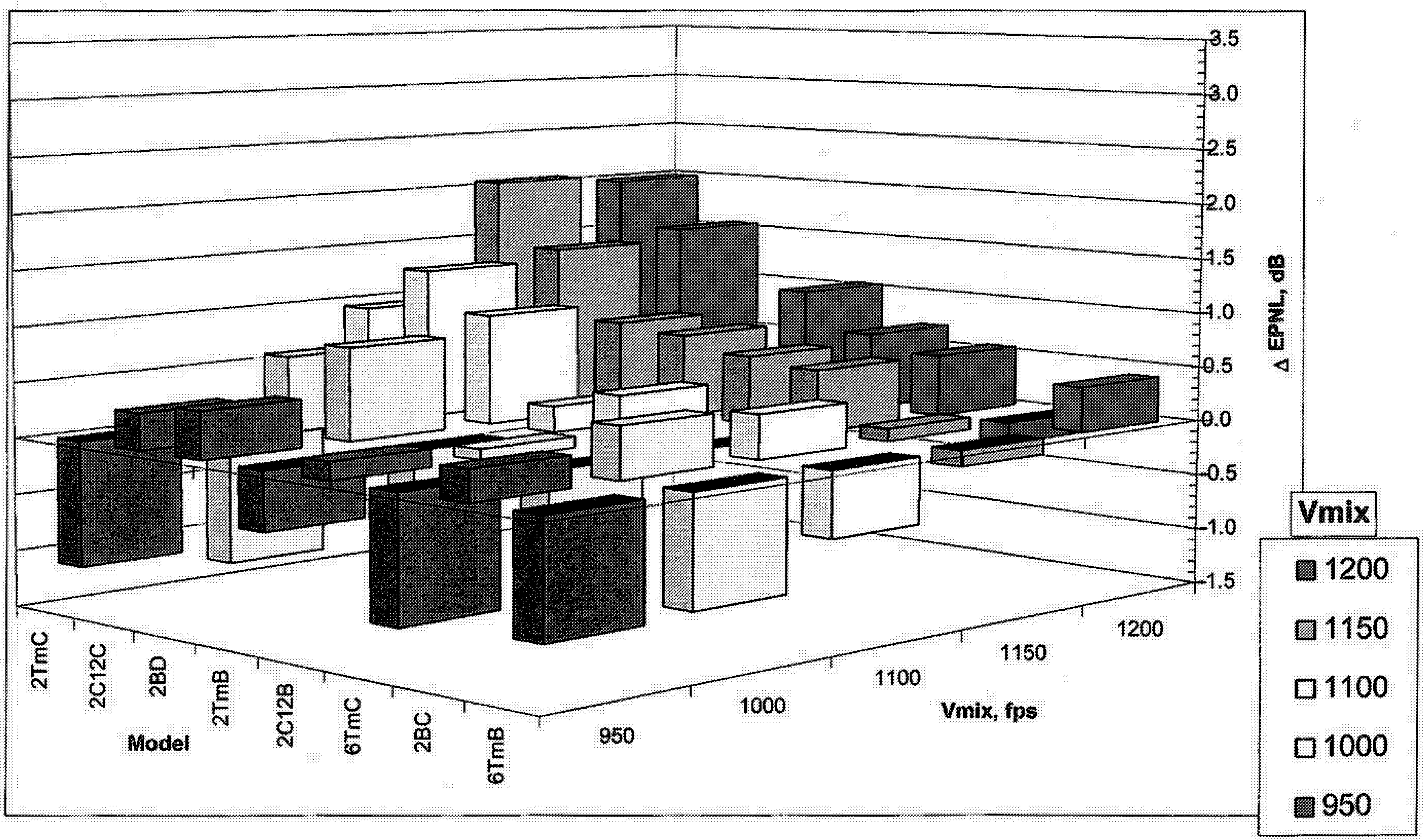
Scale Factor =8

Altitude=1500 ft

PNL Directivity & Noy Spectra

Noise Benefits Relative to Baseline Model 2

Tamb = 50°F; Scale Factor = 8; Altitude = 1500 ft; M = 0.28



GE Aircraft Engines

GCK /aoi14.3/epnls.xls Mod. 2 – 1200 Column 3D (2) 9/8/97

Summary - Noise Reduction Test Concepts of BPR=5 Internal Plug Nozzle (Model 2)

- Some Mixing Concepts Change Slope of EPNL vs V_{mix}
- There is Tradeoff Between Low Frequency Jet Noise Reduction Due to Improved Mixing & High Frequency Noise Increase From Vortex Generation
- Test Noise Reduction Concepts Used Separately on Core Or Fan Provide $\cong$ 1 EPNdB Benefit At Typical Sideline Condition
- Test Noise Reduction Concepts Used Combined on Core And Fan Provide $\cong$ 1.5 to 2 EPNdB Benefit At Typical Sideline Condition
- Test Noise Reduction Concepts Provide Little Benefit Or Noise Increase At Typical Cutback Condition

baj29/a14pit09.doc

Noise Reduction Test Configurations of Model 3

With Fan Nozzle Noise Reduction Concept

3BC

With Core Nozzle Noise Reduction Concepts

3DiB, 3DxB

3C8B, 3C12B, 3IB, 3AB

With Core & Fan Nozzle Noise Reduction Concepts

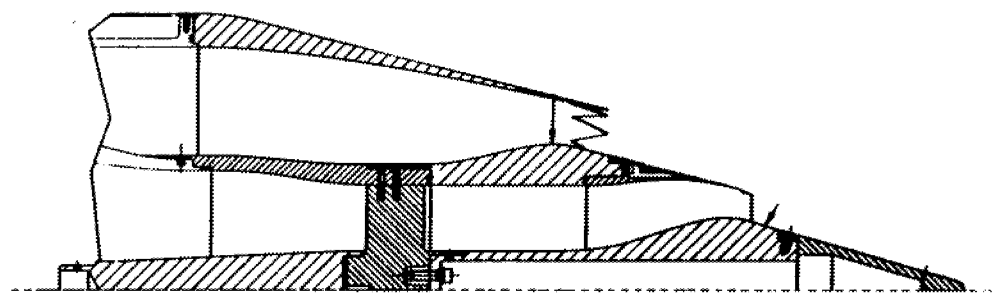
3C8C, 3C12C, 3IC, 3AC

baj29/a14pit09.doc

Noise Reduction Test Configurations with Model 3

BPR = 5, External Plug

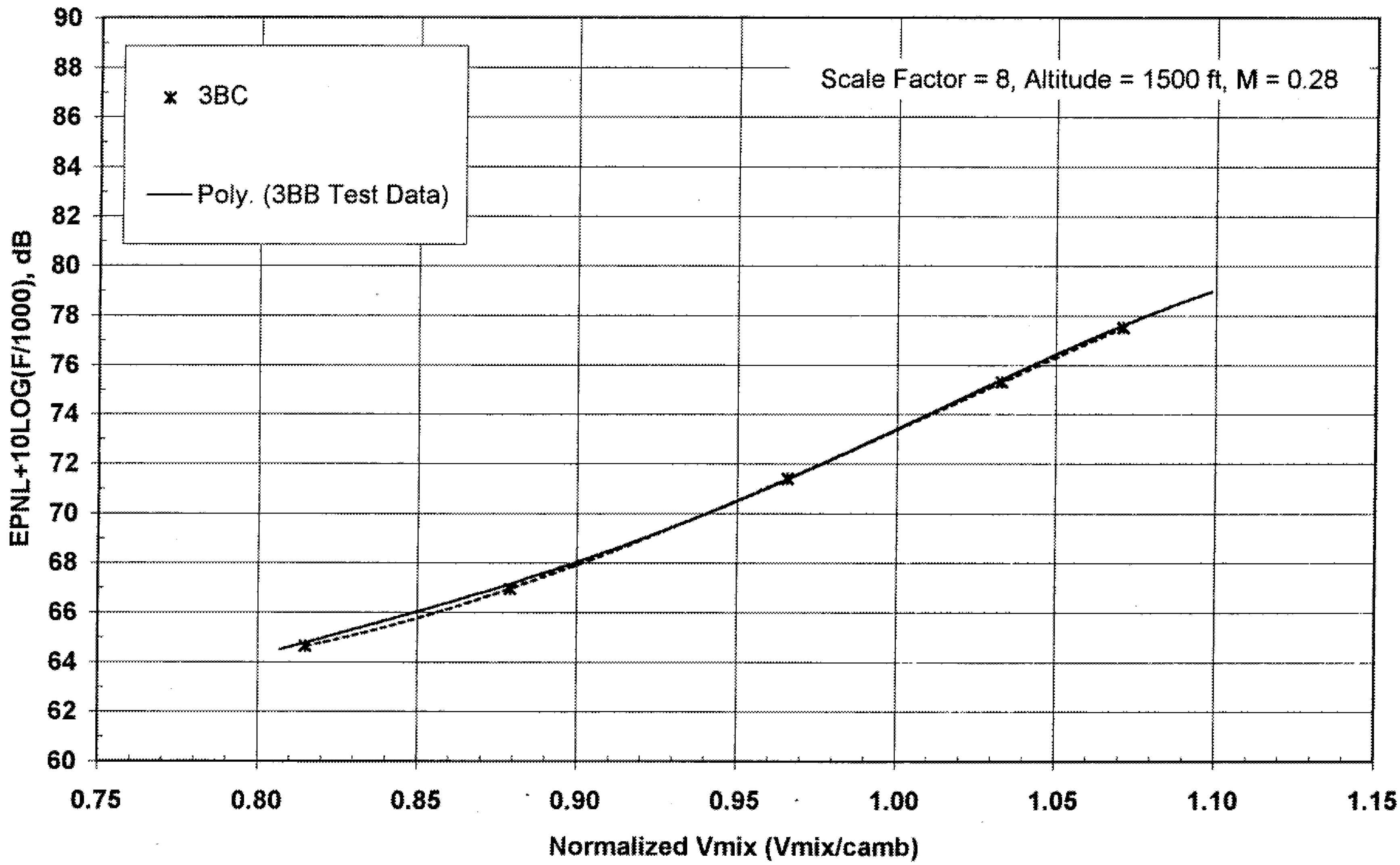
With Different Fan Nozzle



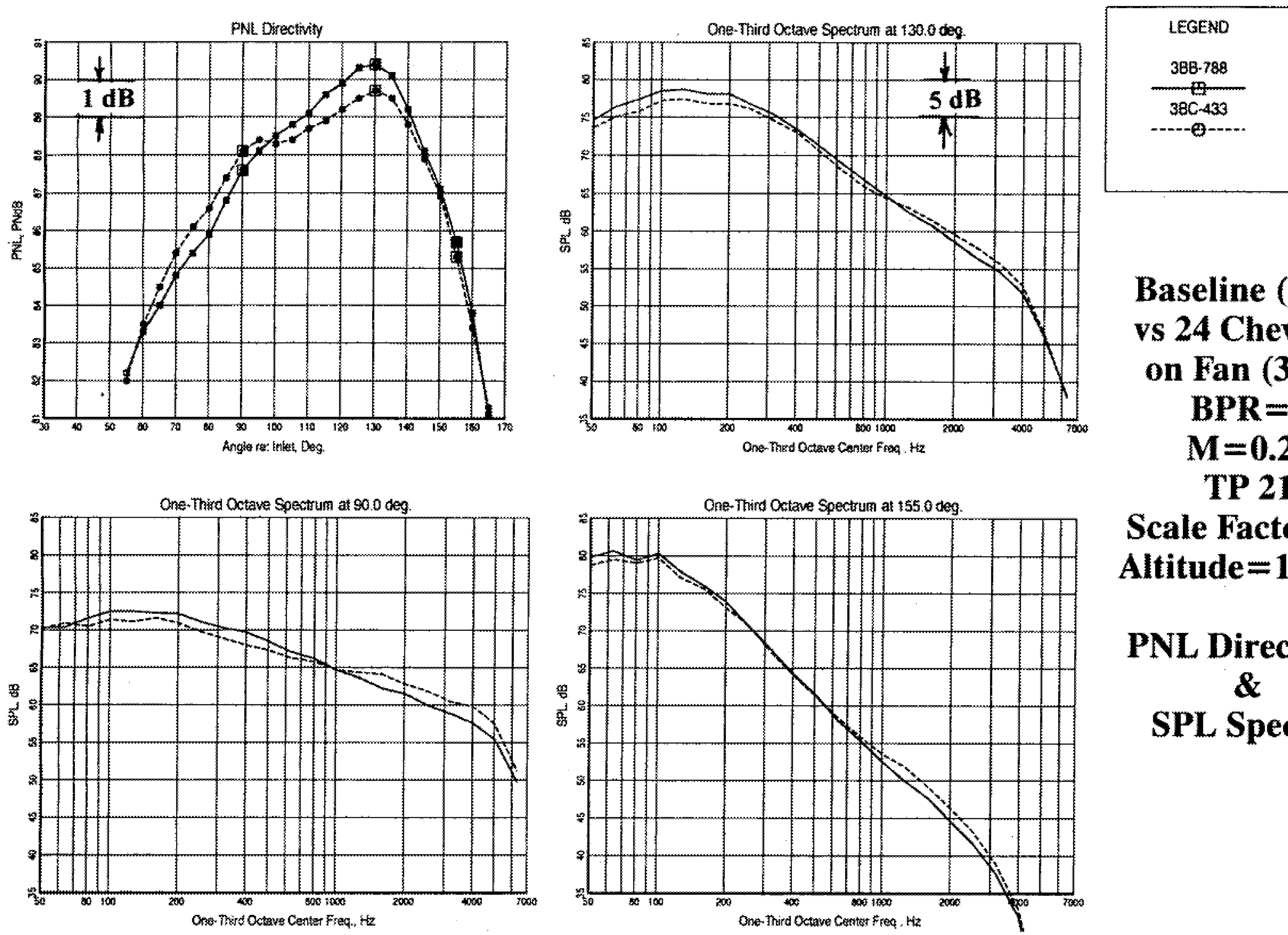
3BC

baj29/a14pit09.doc

Separate Flow Nozzle with External Plug; BPR=5
With 24 Chevron Fan Nozzle (3BC)

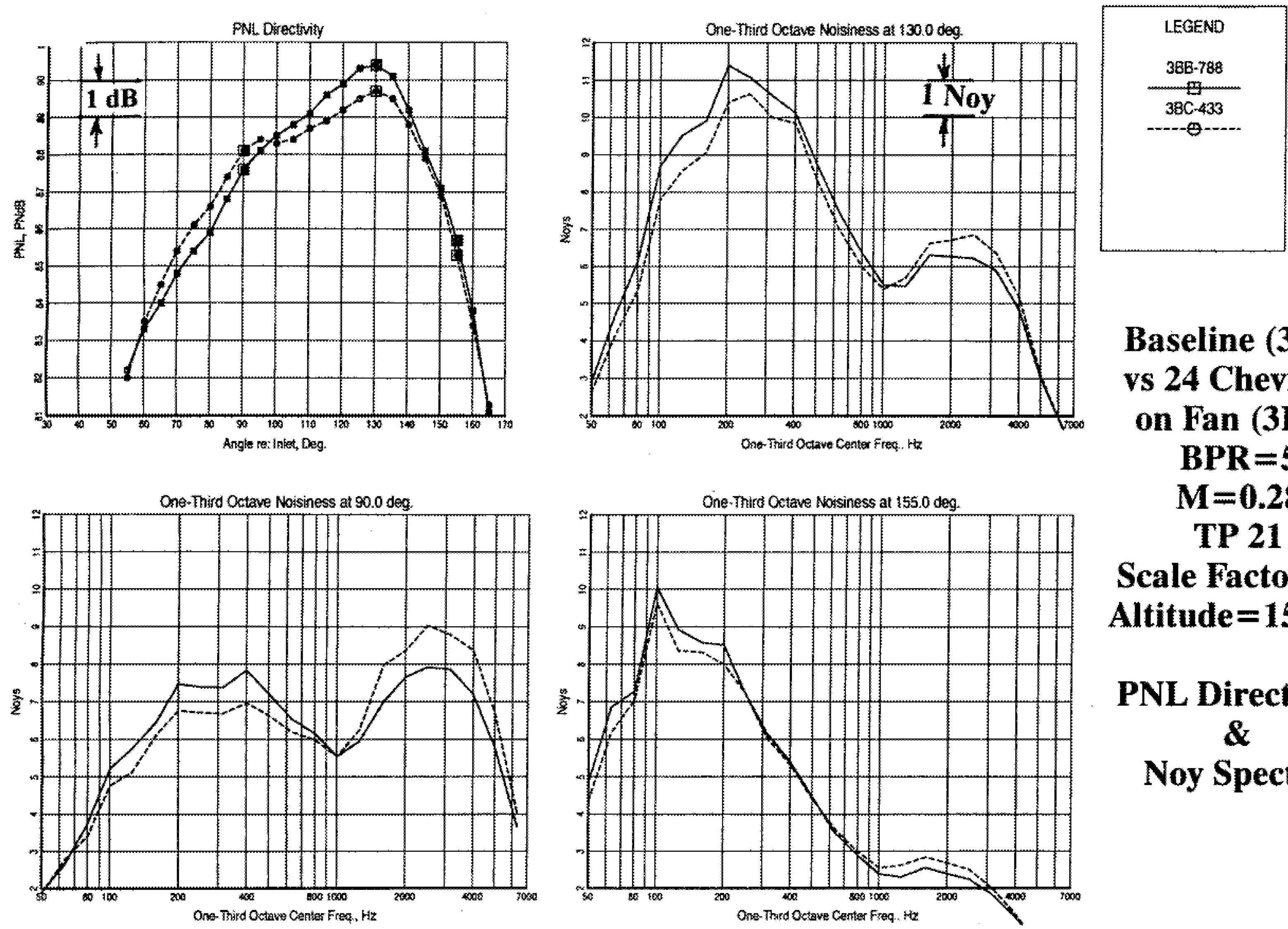


GE Aircraft Engines
baj46/AAPL03A.XLS/Chart5



Baseline (3BB)
vs 24 Chevrons
on Fan (3BC)
BPR=5
M=0.28
TP 21
Scale Factor =8
Altitude=1500 ft

PNL Directivity
&
SPL Spectra



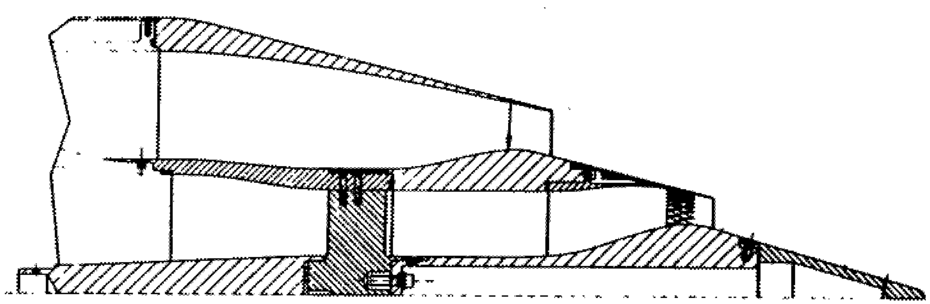
Baseline (3BB)
vs 24 Chevrons
on Fan (3BC)
BPR=5
M=0.28
TP 21
Scale Factor =8
Altitude=1500 ft

PNL Directivity
&
Noy Spectra

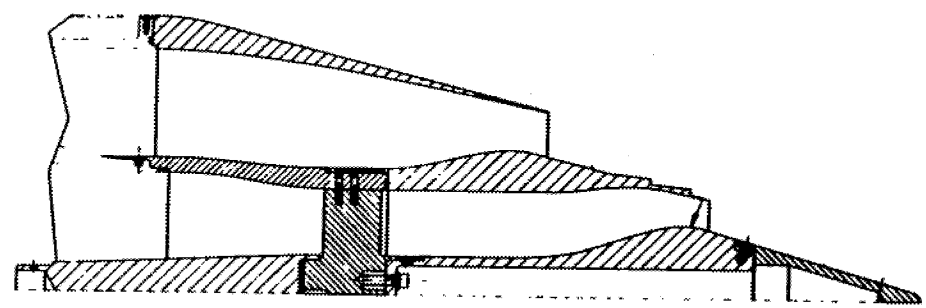
Noise Reduction Test Configurations with Model 3

BPR = 5, External Plug

With Doublets on Core Nozzle



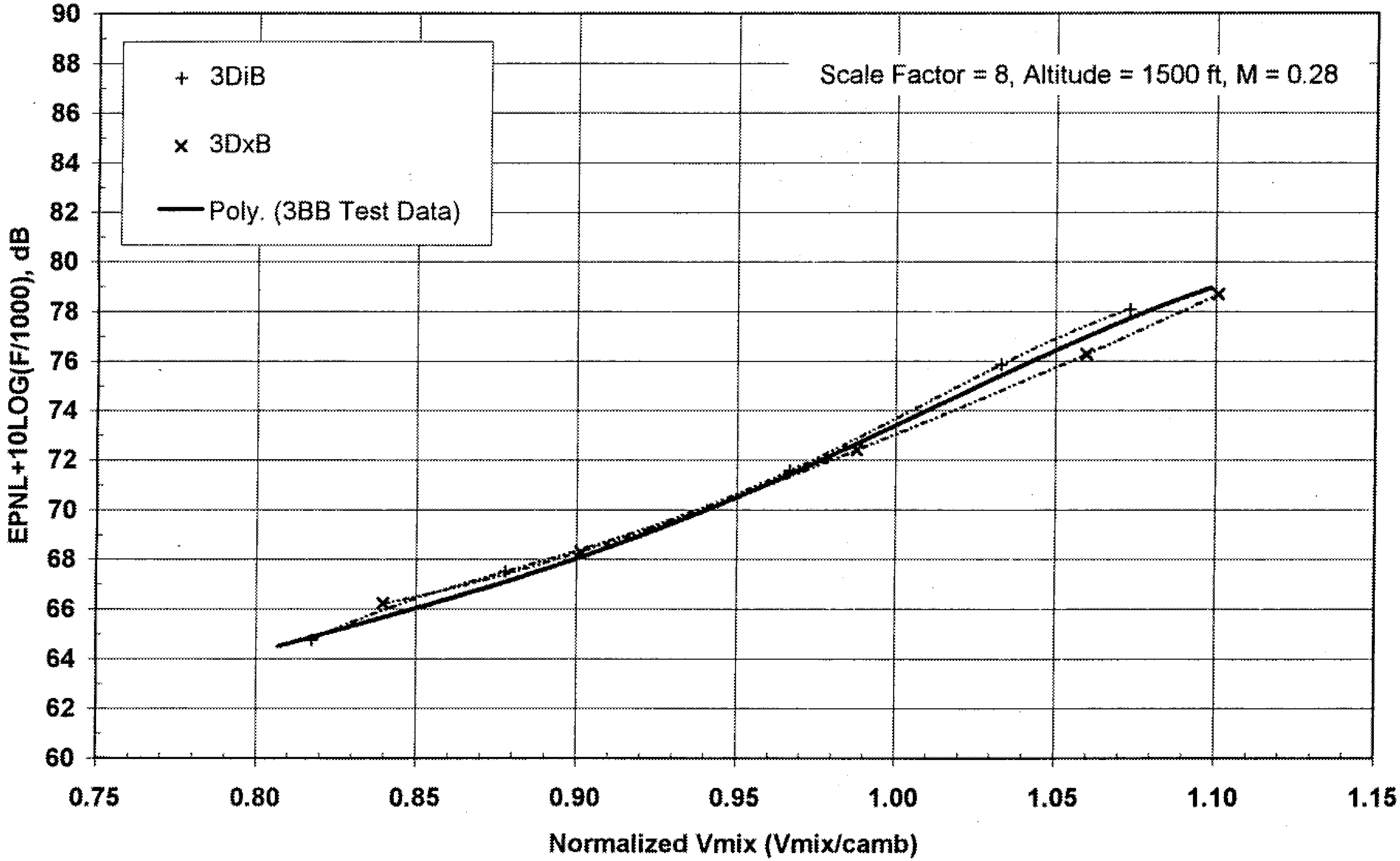
3DIB



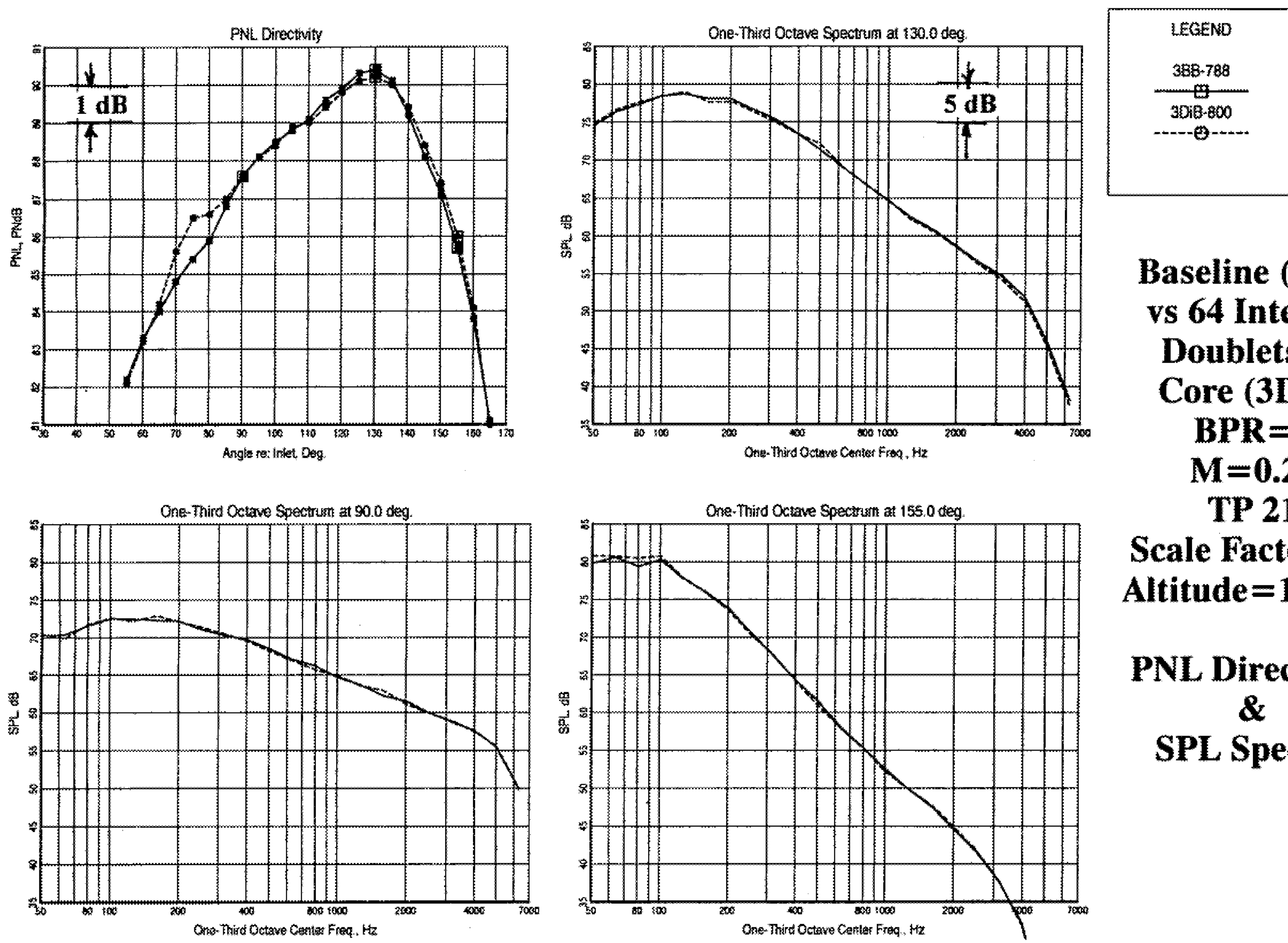
3DXB

baj29/a14pit09.doc

Separate Flow Nozzle with External Plug; BPR=5
With Doublet Noise Reduction Features on Core Nozzle (Di, Dx)

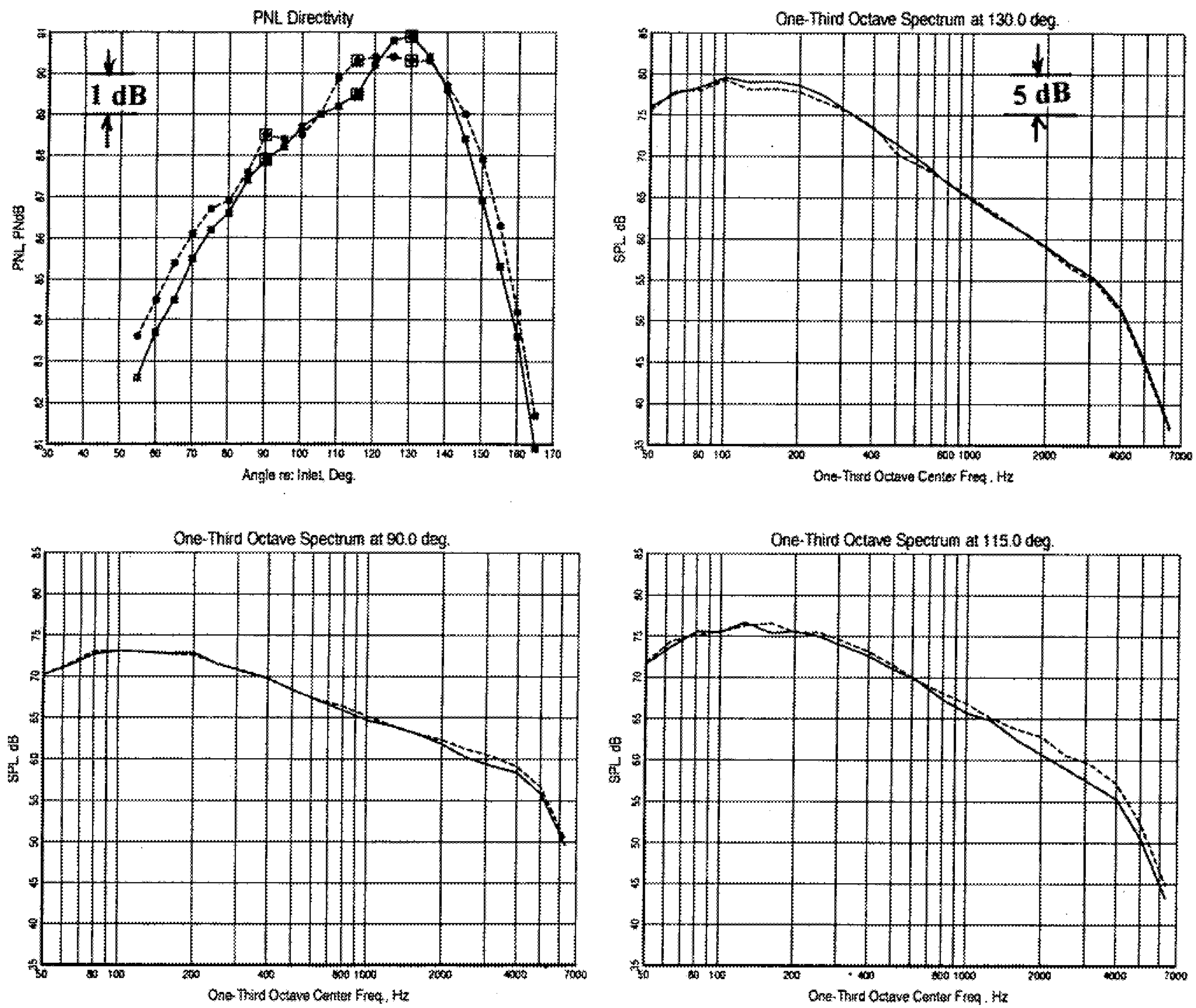


GE Aircraft Engines
baj46/AAPL03A.XLS/Chart8



Baseline (3BB) vs 64 Internal Doublets on Core (3DiB)
BPR=5
M=0.28
TP 21
Scale Factor =8
Altitude=1500 ft

PNL Directivity & SPL Spectra



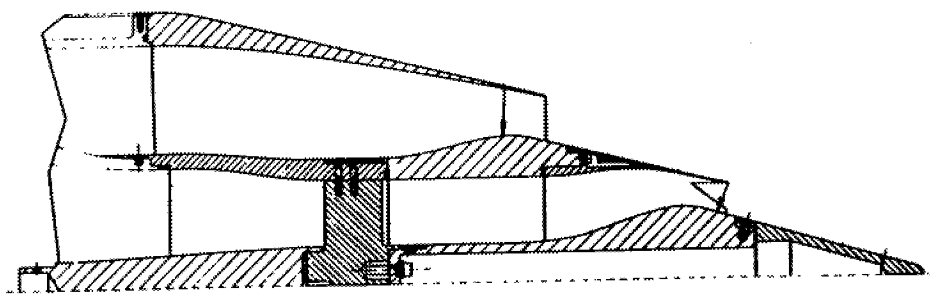
Baseline (3BB) vs 20 External Doublets on Core (3DxB)
BPR=5
M=0.28
TP 21
Scale Factor =8
Altitude=1500 ft

PNL Directivity & SPL Spectra

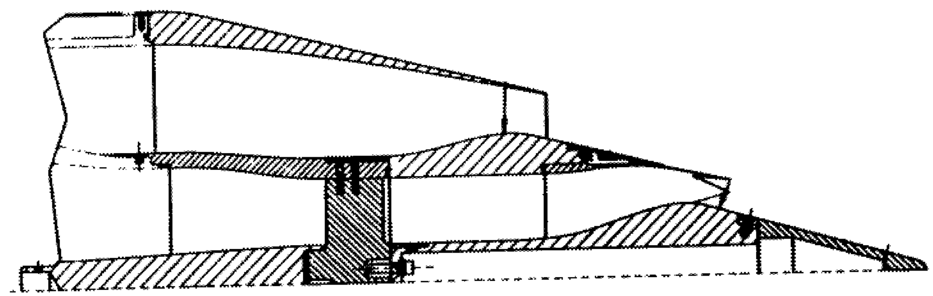
Noise Reduction Test Configurations with Model 3

BPR = 5, External Plug

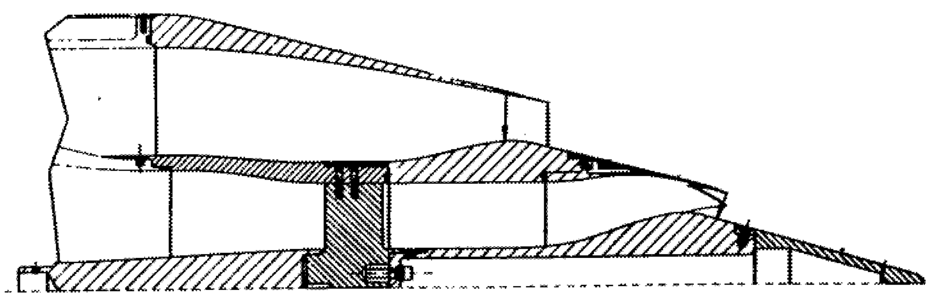
With Different Core Nozzles



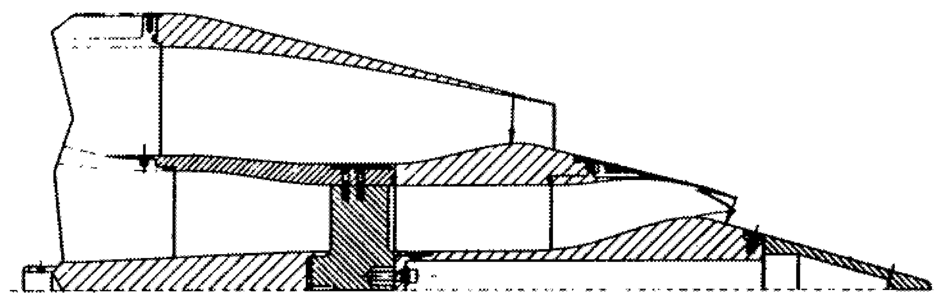
3C8B



3C12B



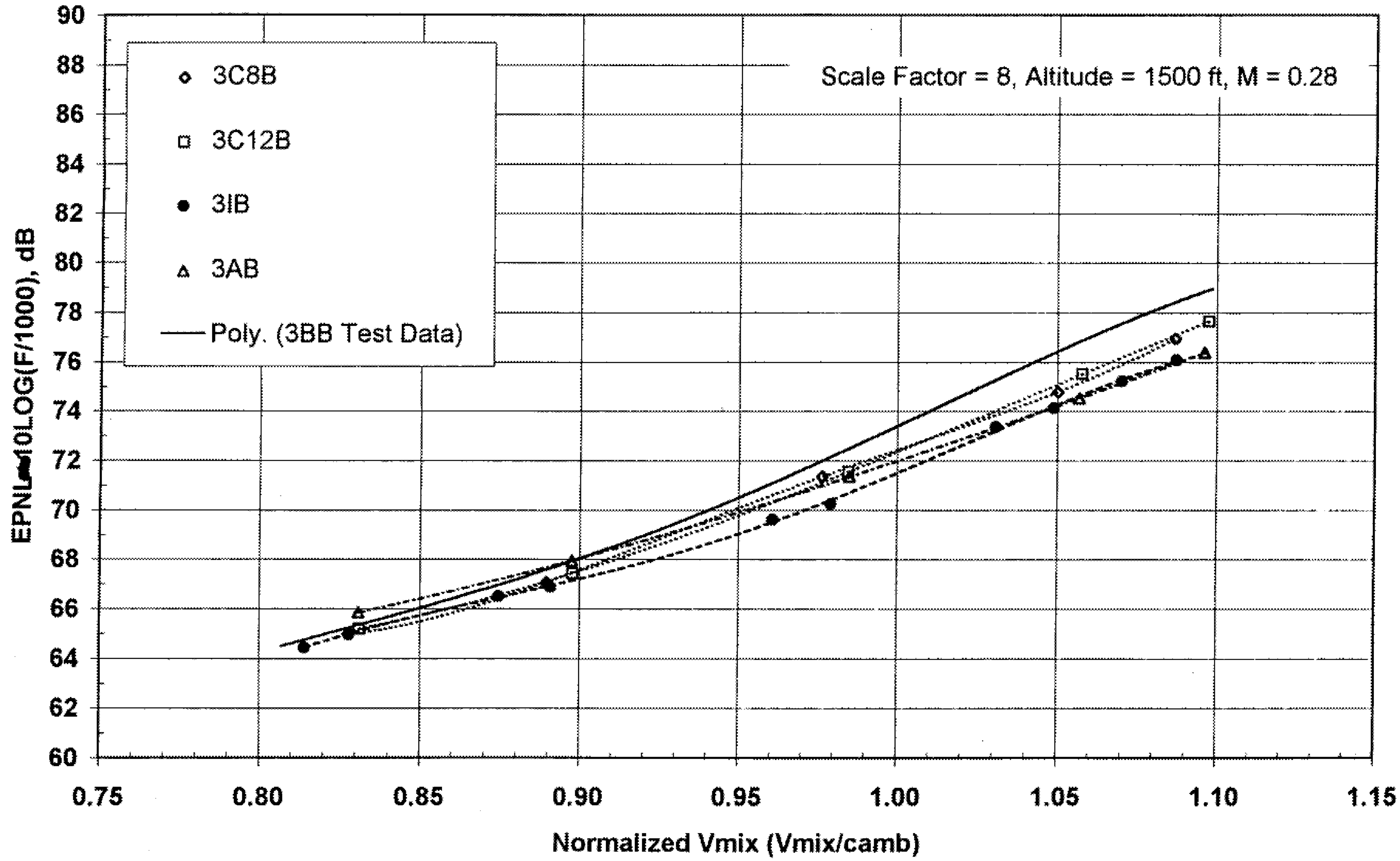
3IB



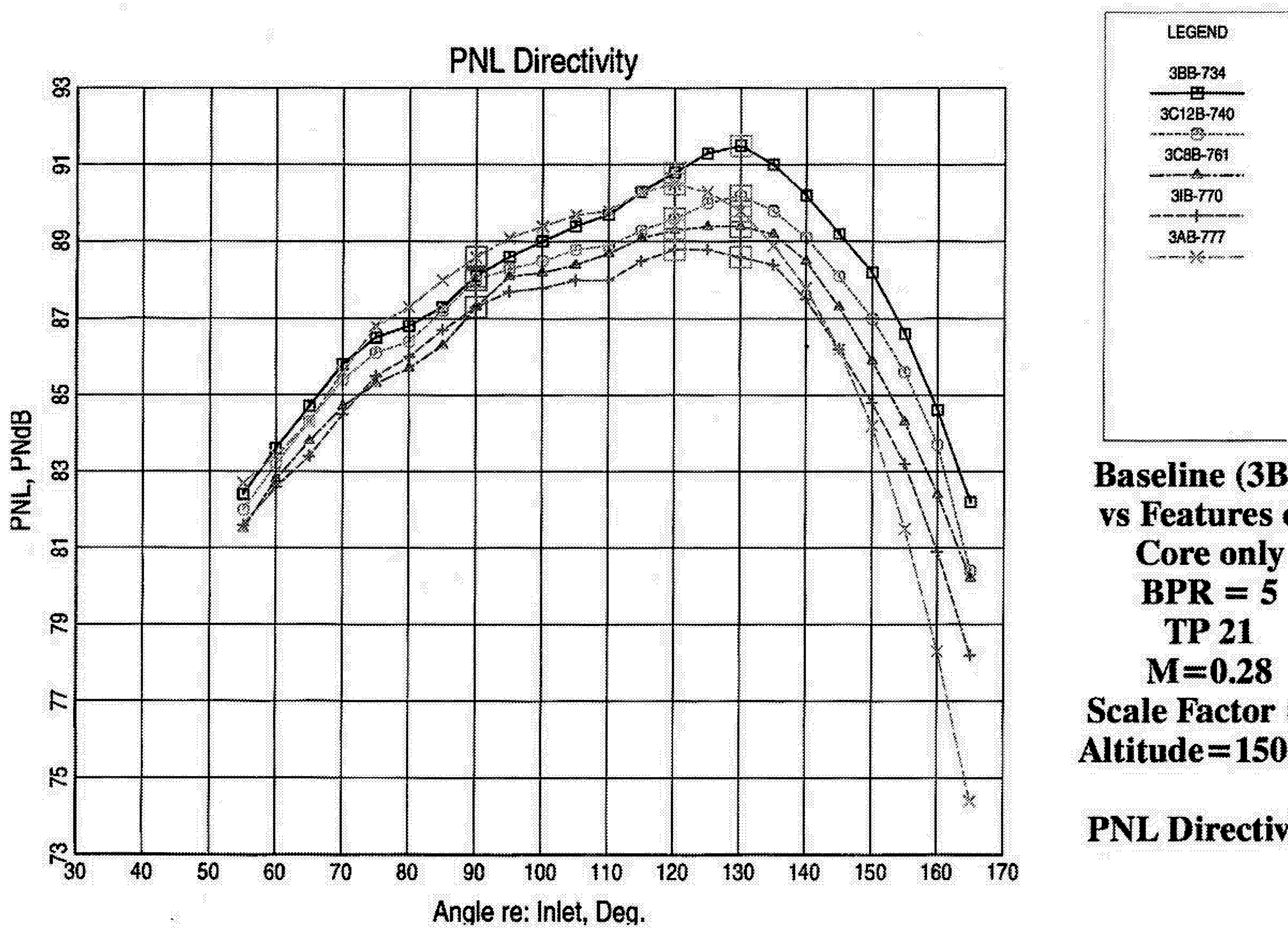
3AB

baj29/a14pit09.doc

Separate Flow Nozzle with External Plug; BPR=5
With Four Different Chevron Core Nozzles (C8, C12, I, A)

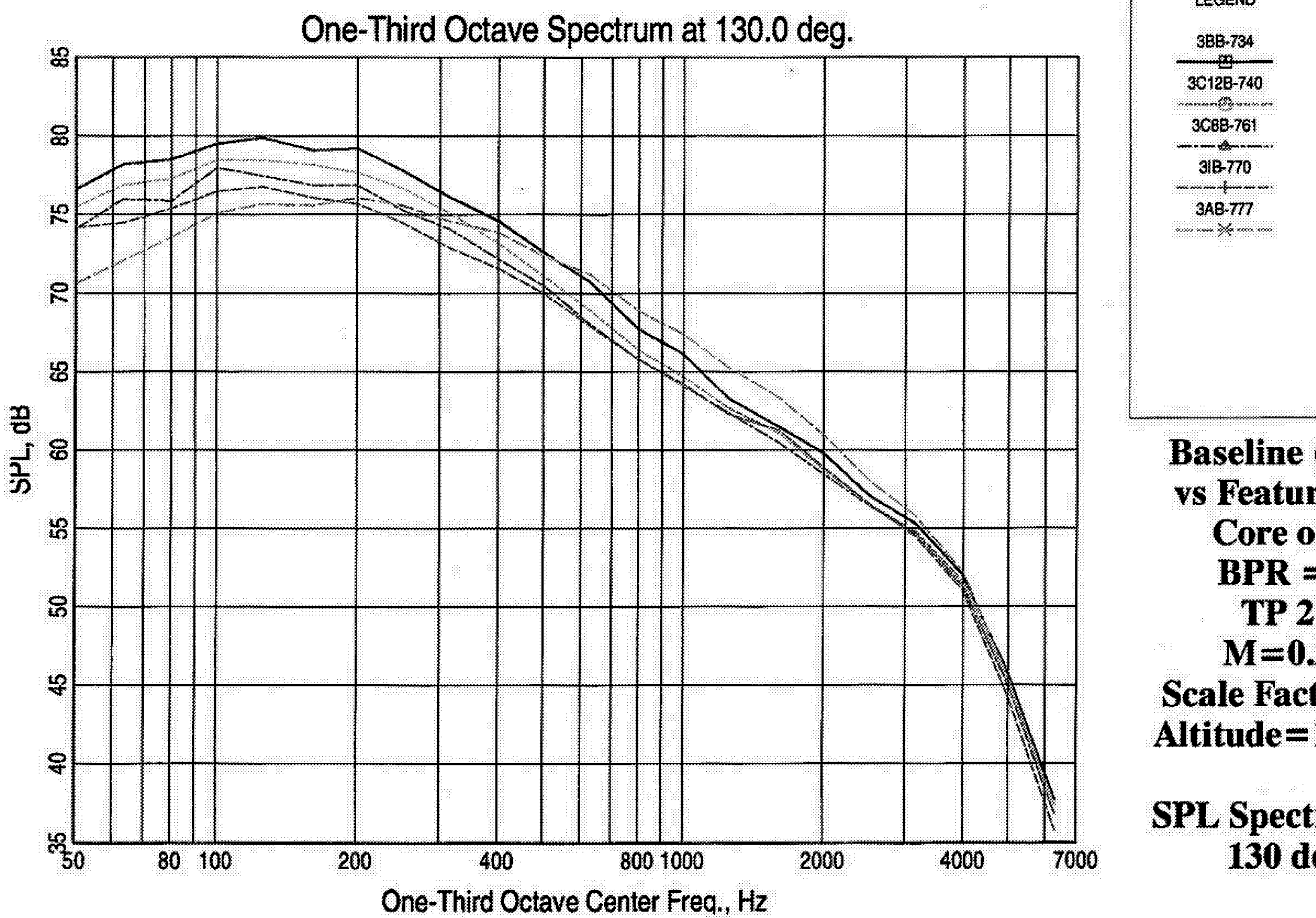


GE Aircraft Engines
baj46/AAPL03.XLS/Chart4



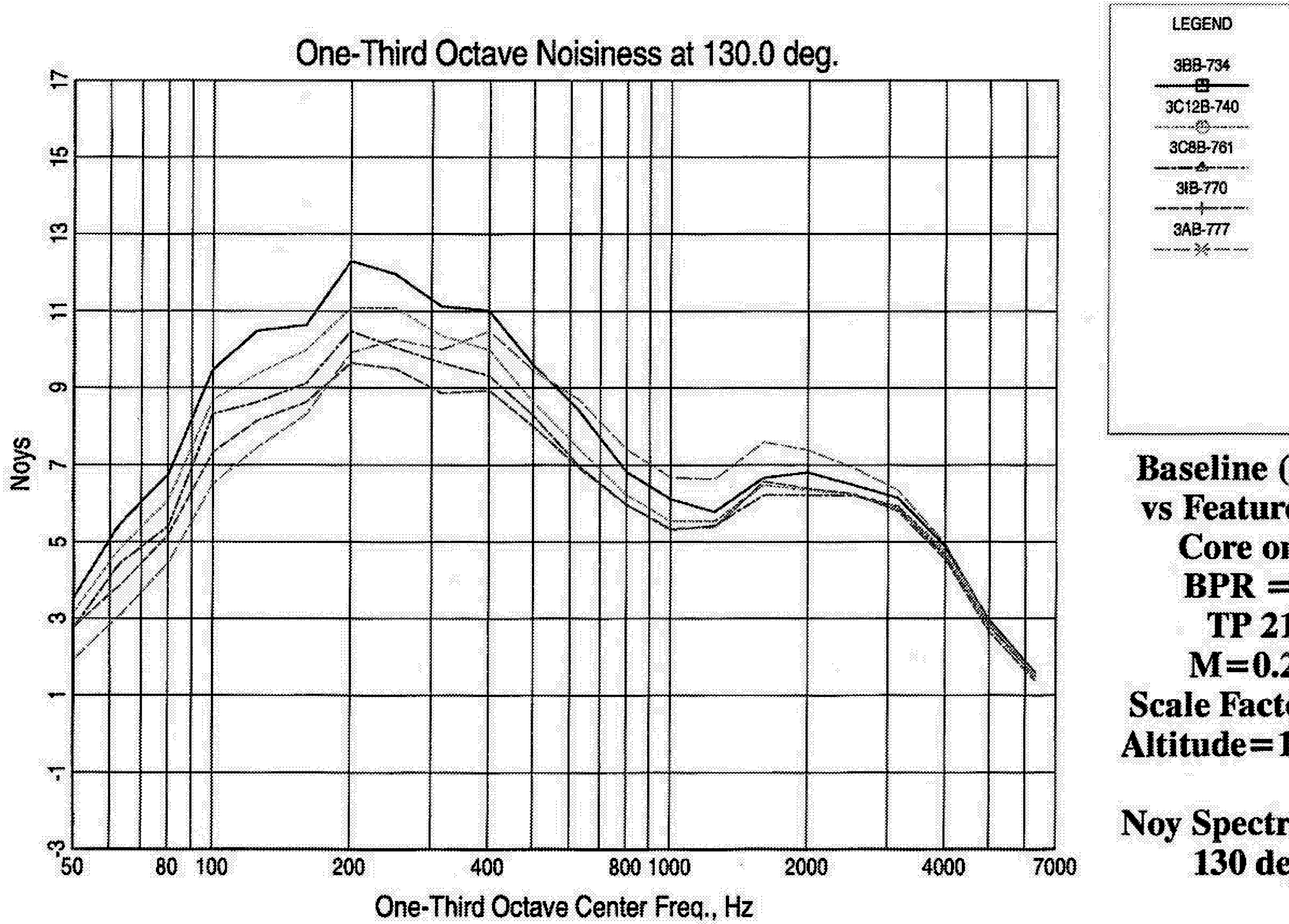
Baseline (3BB) vs Features on Core only
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity



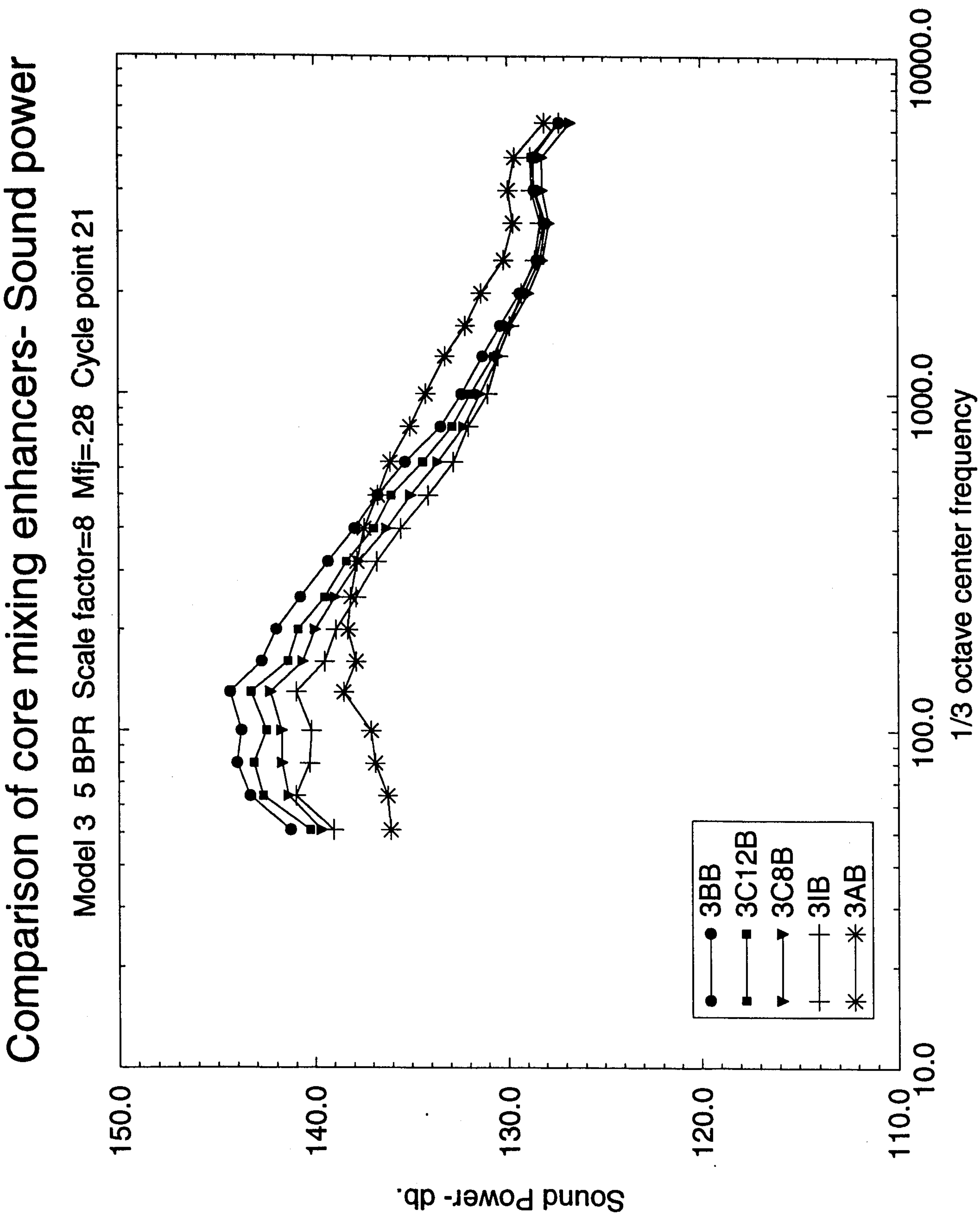
Baseline (3BB)
vs Features on
Core only
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

SPL Spectrum at
130 deg



Baseline (3BB)
vs Features on
Core only
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

Noy Spectrum at
130 deg

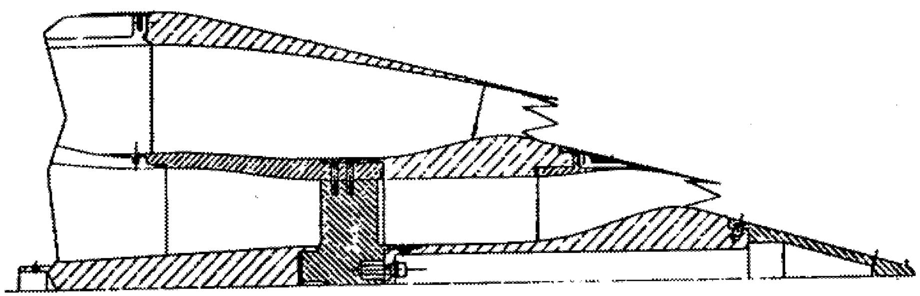


Comparison of core mixing enhancers- Sound power
Model 3 5 BPR Scale factor=8 Mfj=.28 Cycle point 21
Sound Power- db.
150.0
140.0
130.0
120.0
110.0
10.0
100.0
1000.0
10000.0
1/3 octave center frequency
3BB
3C12B
3C8B
3IB
3AB

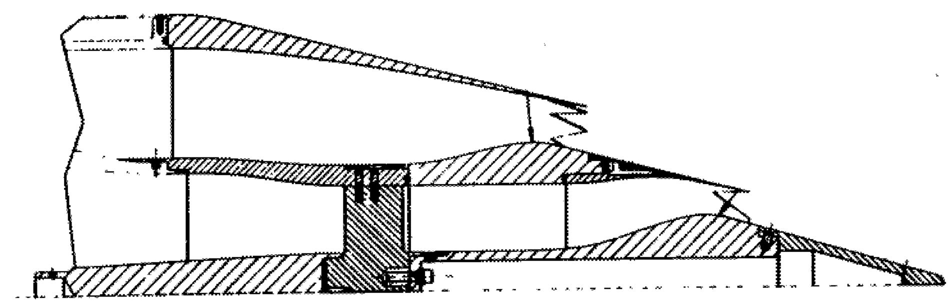
Noise Reduction Test Configurations with Model 3

BPR = 5, External Plug

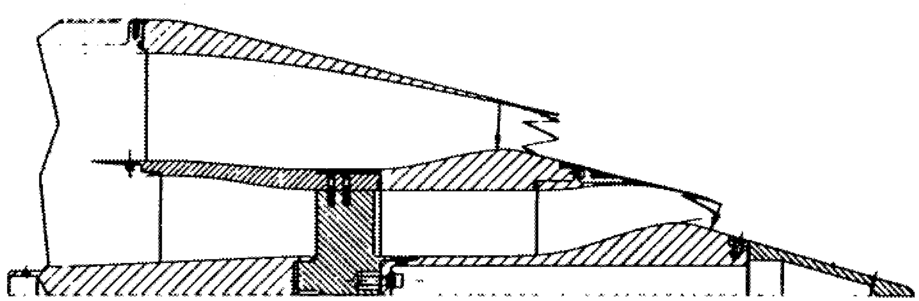
With Different Core & Fan Nozzles



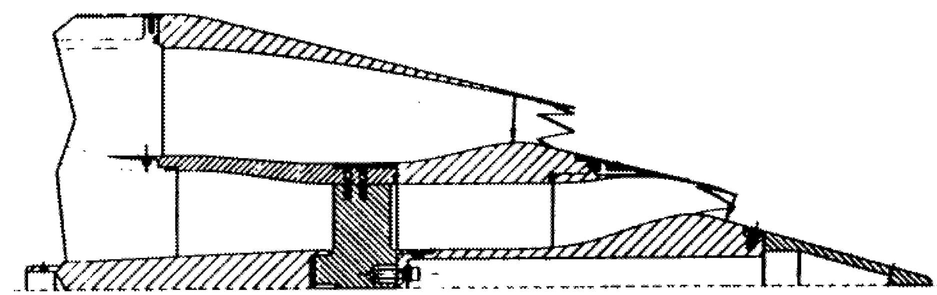
3C12C



3C8C



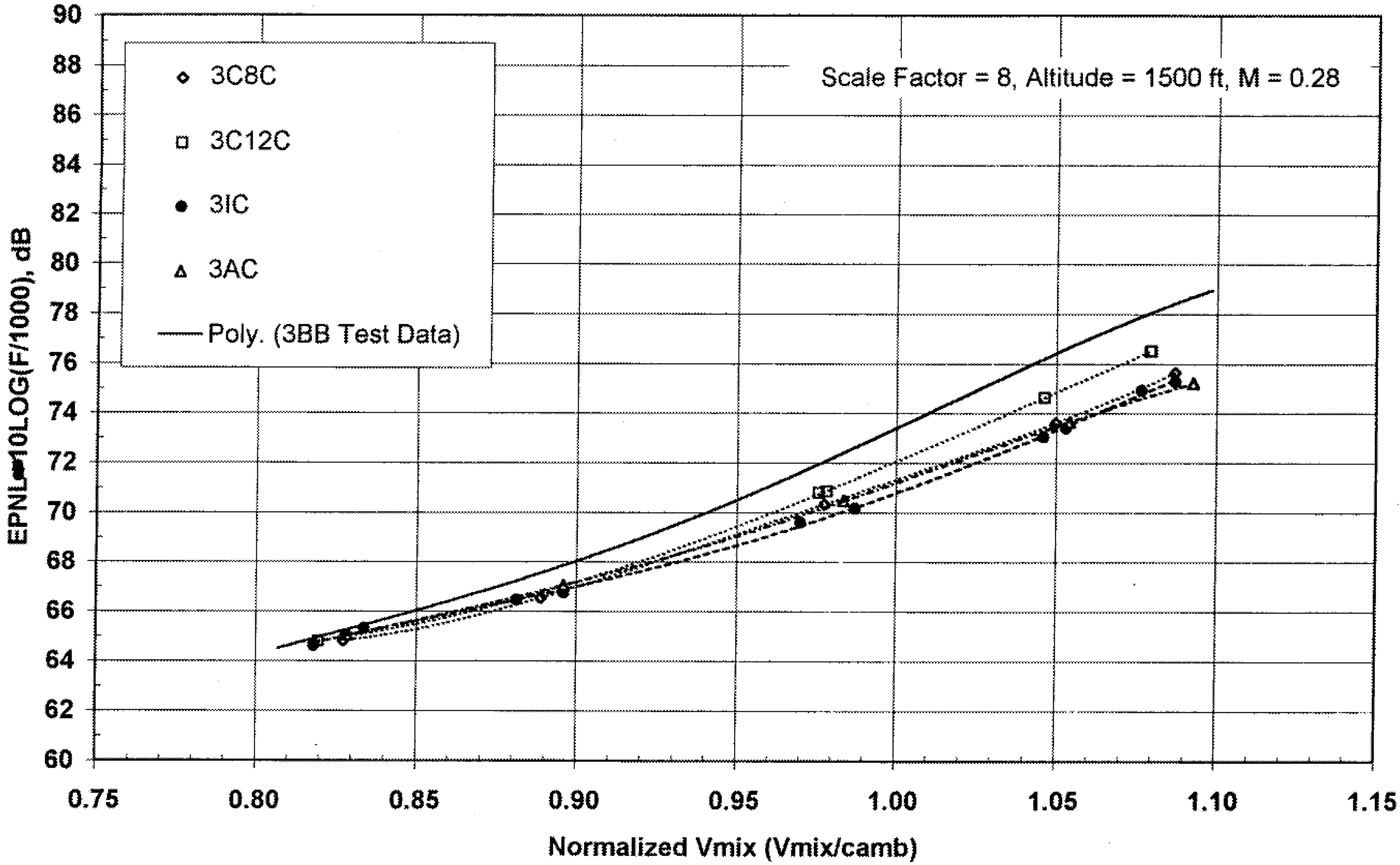
3IC



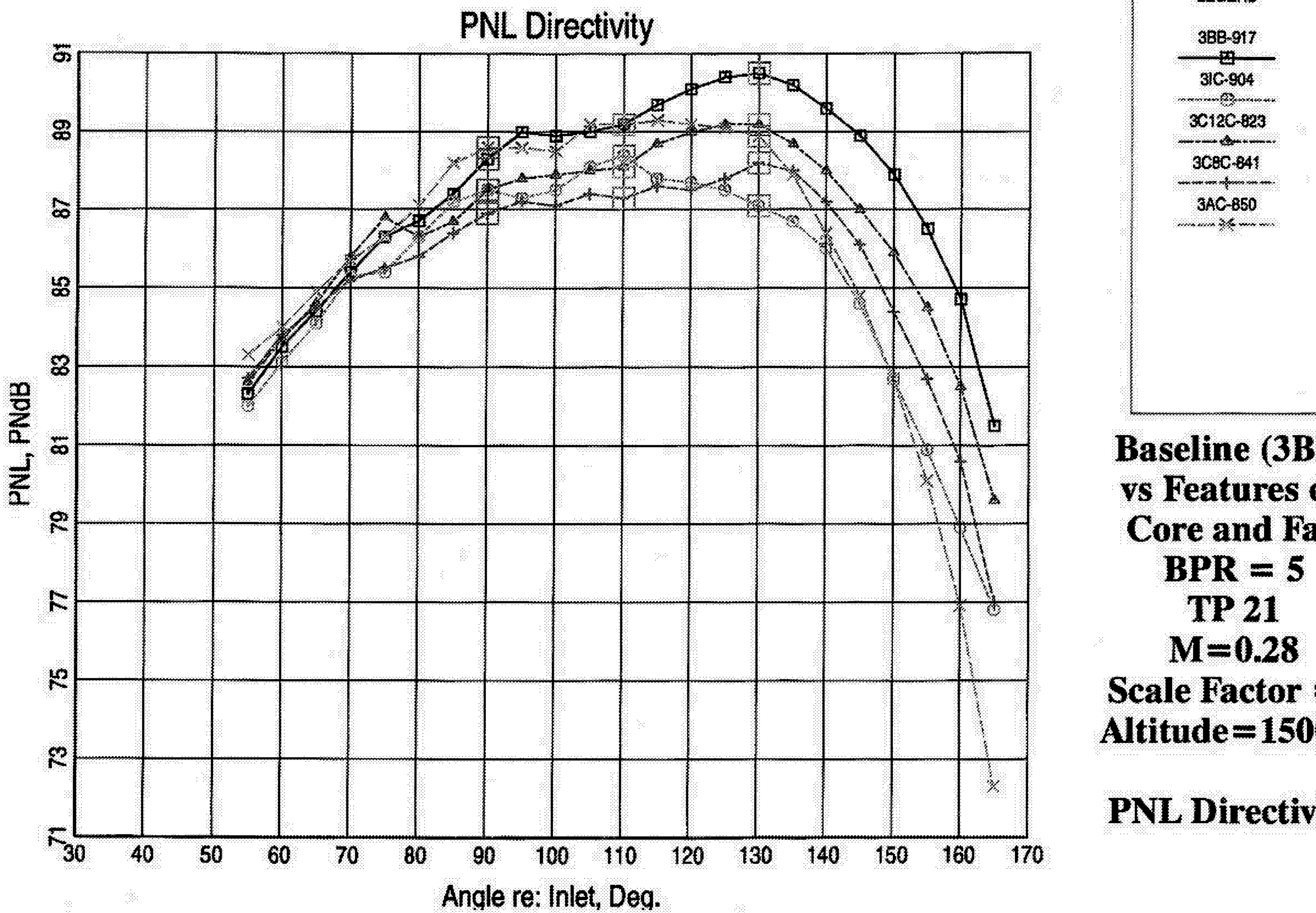
3AC

baj29/a14pit09.doc

Separate Flow Nozzle with External Plug; BPR=5
With Four Different Core & Fan Chevron Nozzle (3C8C,3C12C,3IC,3AC)

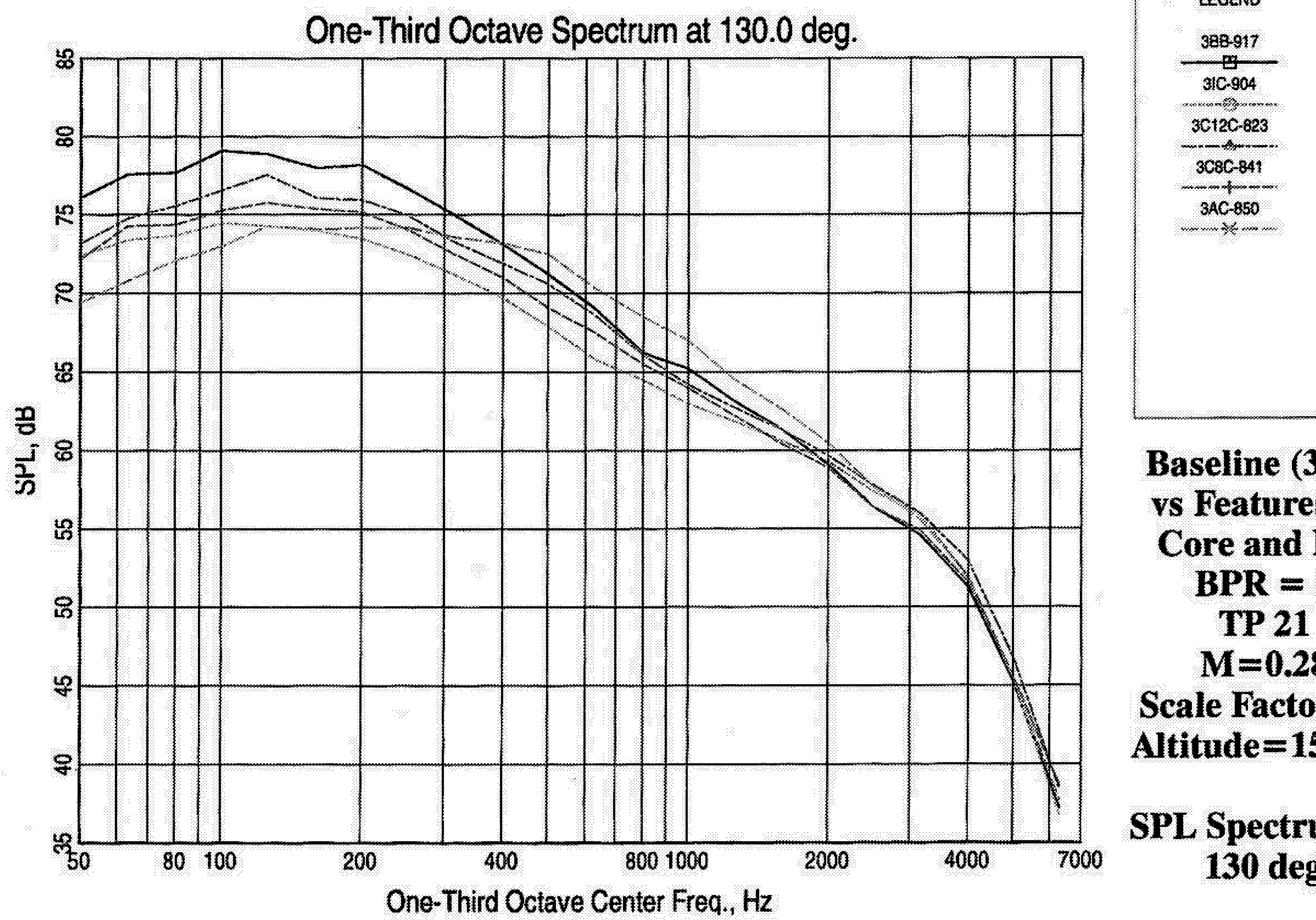


GE Aircraft Engines
baj46/AAPL03A.XLS/Chart7



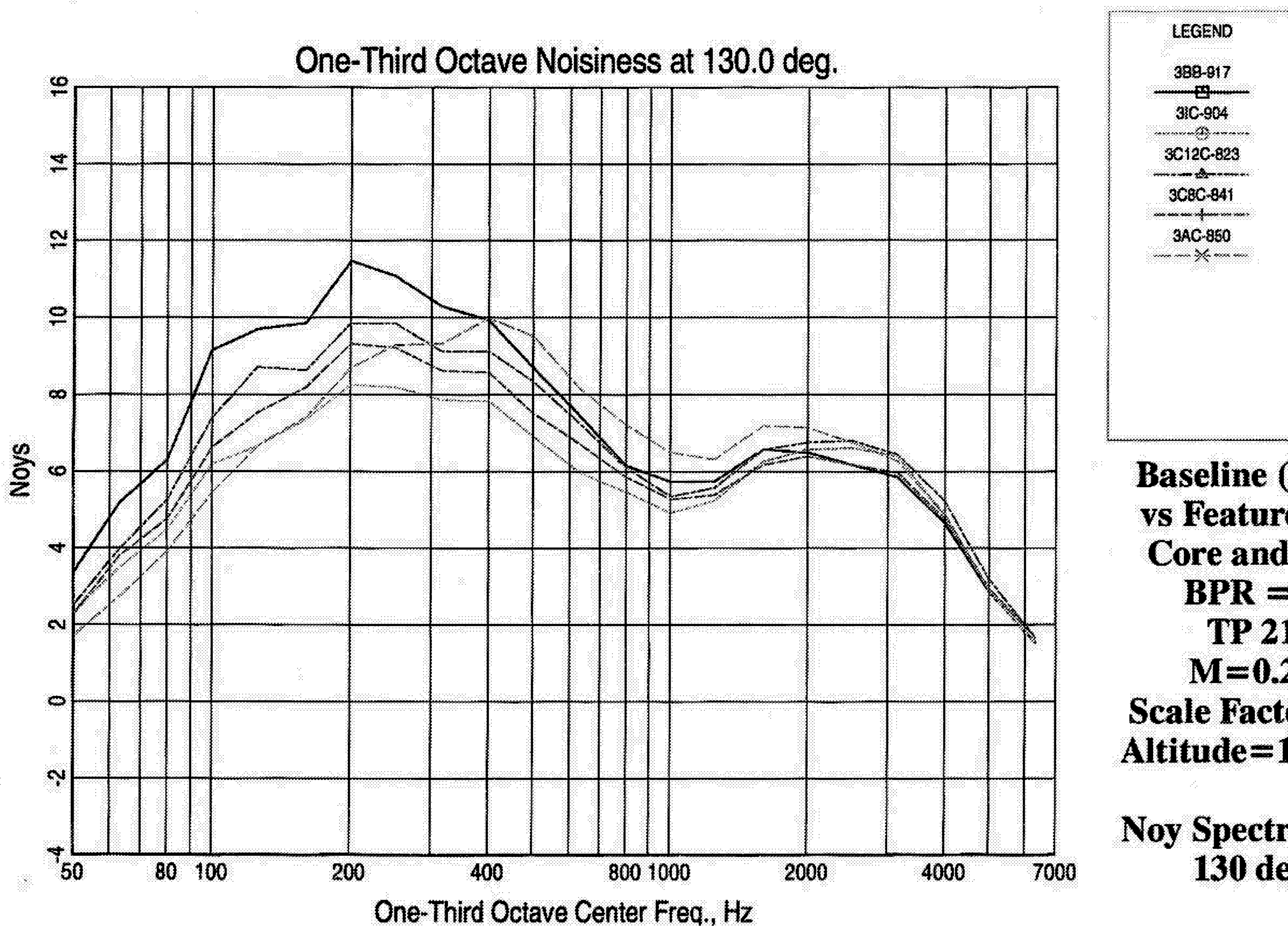
Baseline (3BB) vs Features on Core and Fan
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity



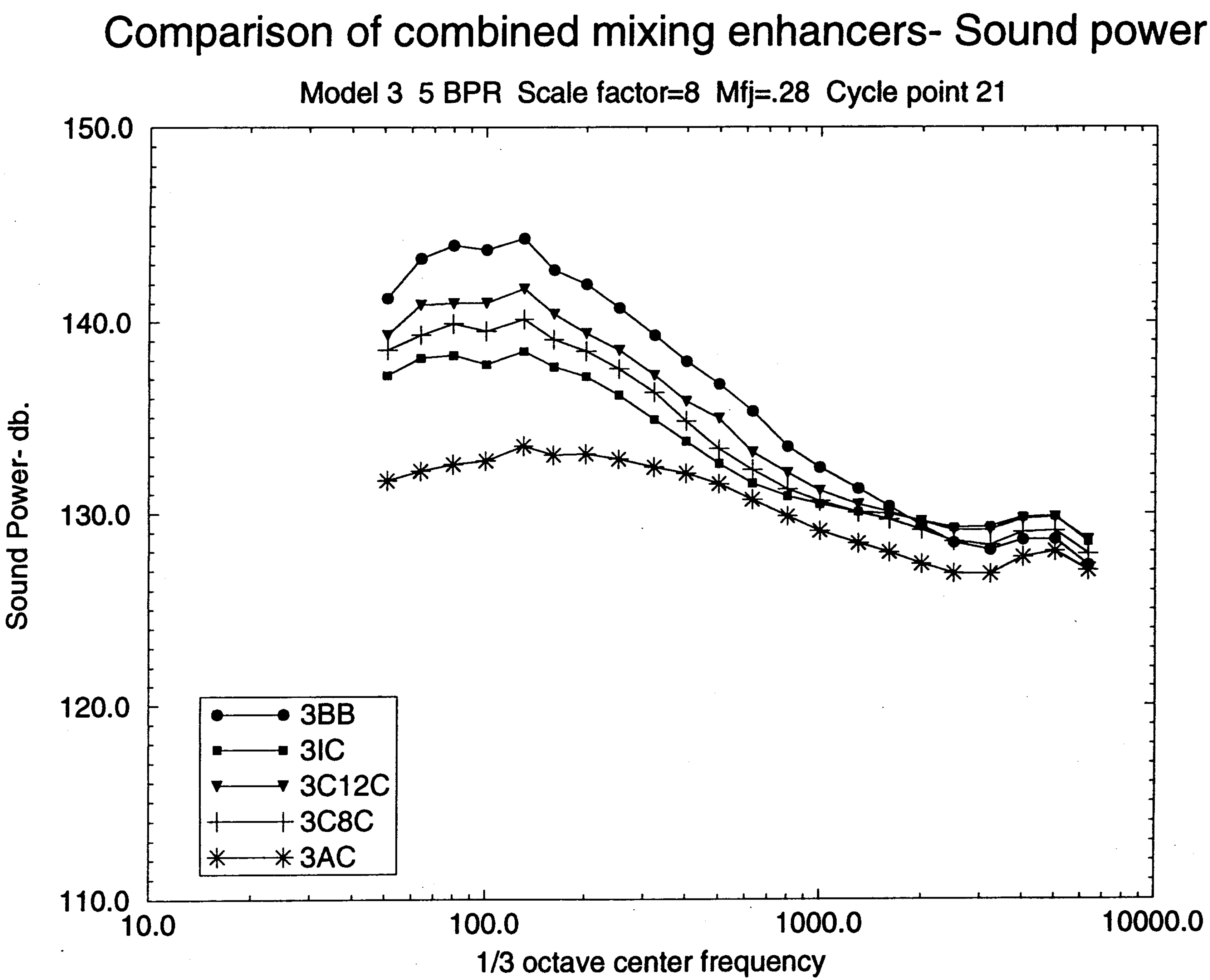
Baseline (3BB)
vs Features on
Core and Fan
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

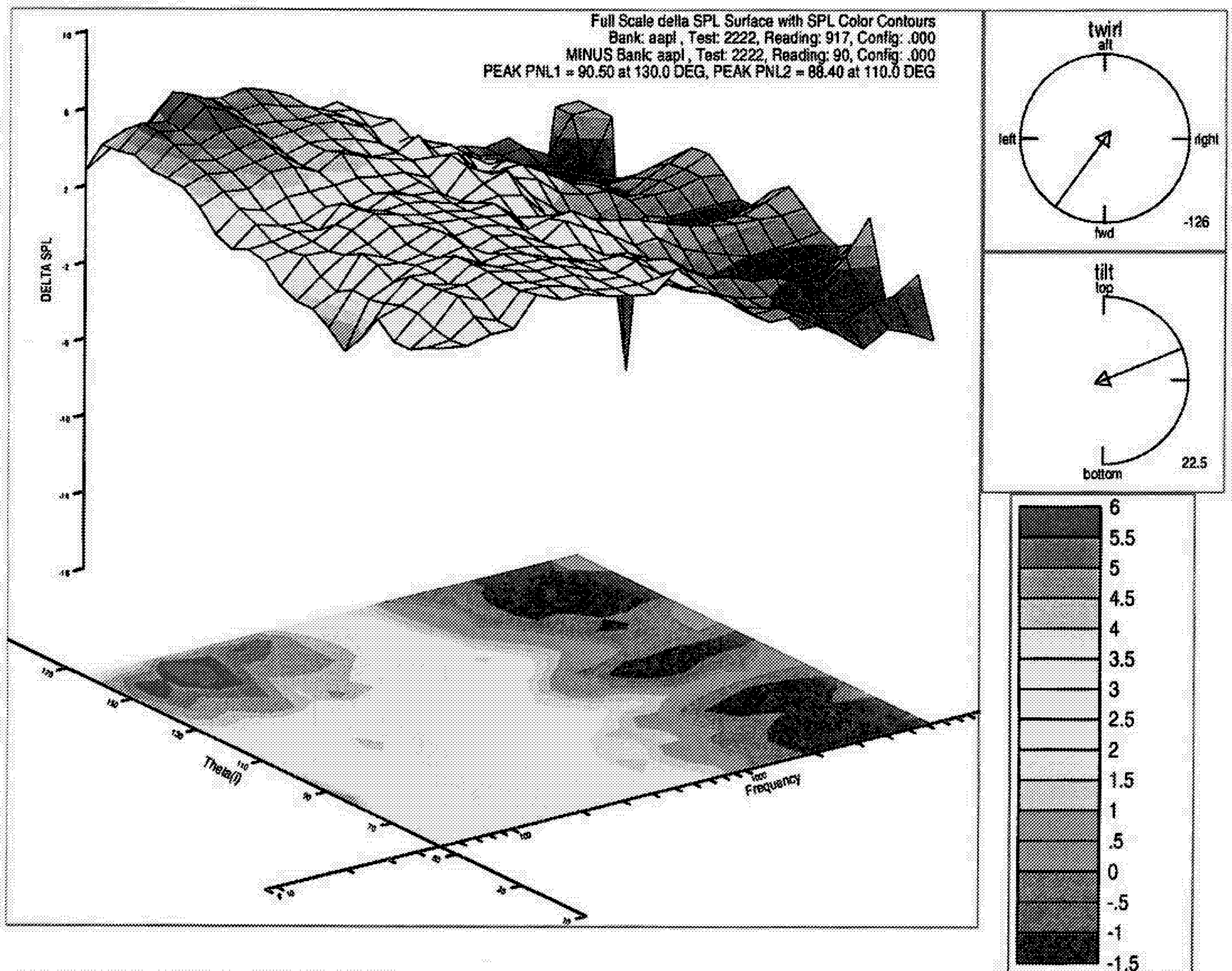
SPL Spectrum at
130 deg



Baseline (3BB) vs Features on Core and Fan
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

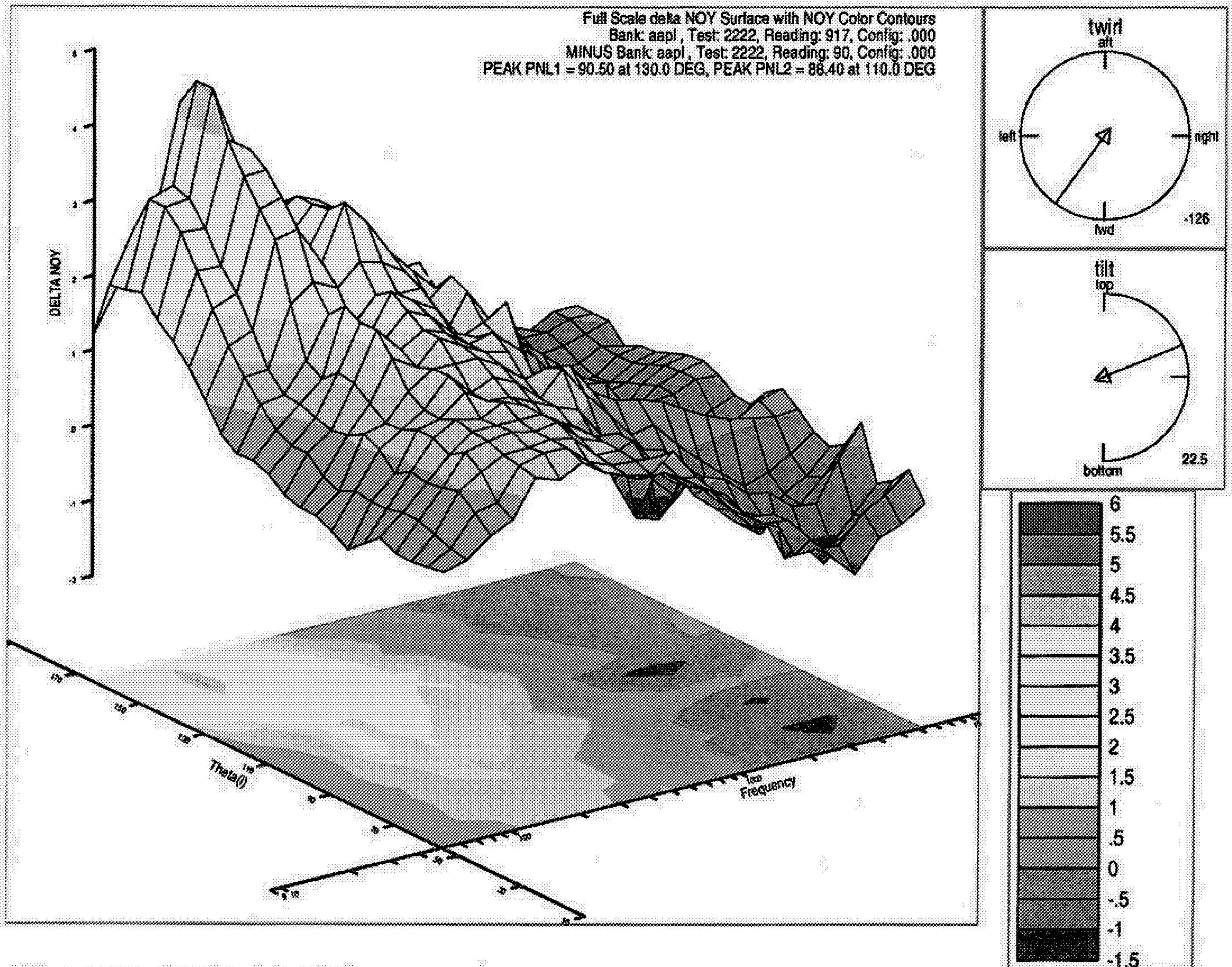
Noy Spectrum at 130 deg


Comparison of combined mixing enhancers- Sound power
Model 3 5 BPR Scale factor=8 Mfj=.28 Cycle point 21
150.0
140.0
130.0
120.0
110.0
Sound Power- db.
10.0
100.0
1000.0
10000.0
1/3 octave center frequency
3BB
3IC
3C12C
3C8C
3AC



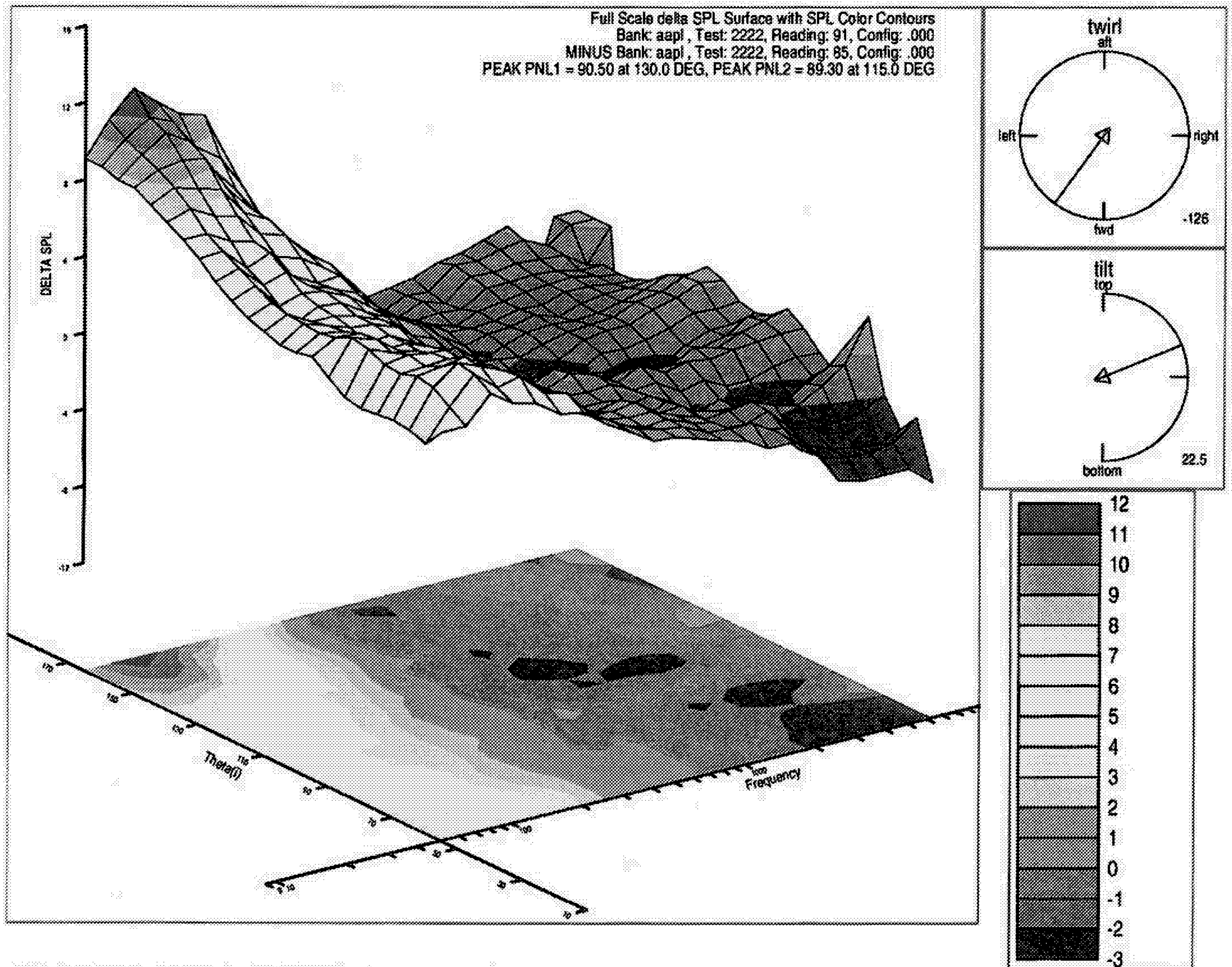
15.09 09/04/97 ml04150936.cdf ae6302t@c0787 X11 PLOT 1
EGS LIB 5.4f 08/04/97 (EGSREP.XCPOST 5.4f 08/04/97 on c0787)
spectsco ver. 1.2 24 Jan 1995

SPL values of 3BB minus SPL values of 3IC
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft



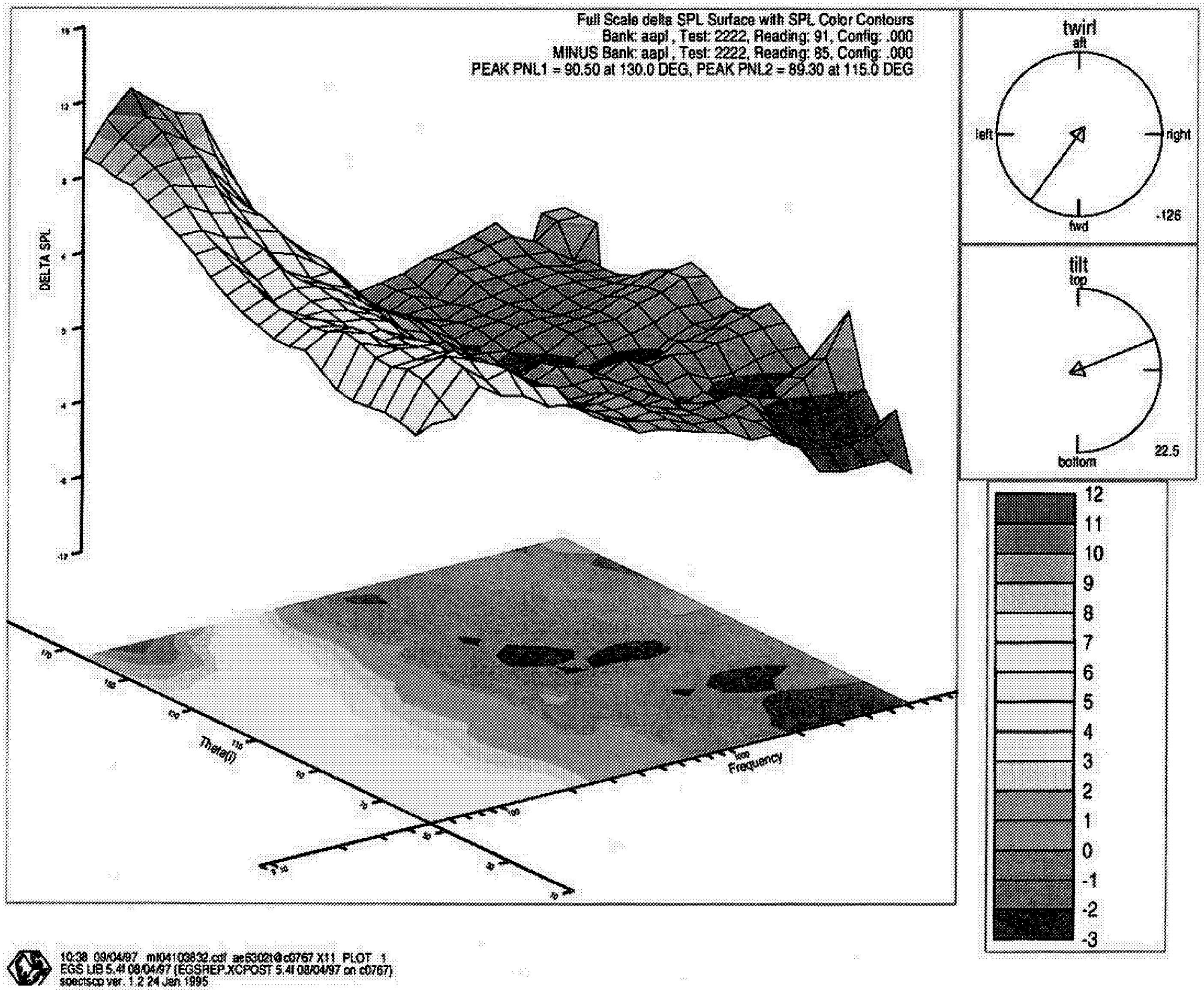
15:26 09/04/97 ml04152604.cdf ae6302t@c0767 X11 PLOT 1
EGS LIB 5.4f 08/04/97 (EGSREP.XCPOST 5.4f 08/04/97 on c0767)
soectsco ver. 1.2 24 Jan 1995

Noy values of 3BB minus Noy values of 3IC
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft



SPL values of 3BB minus SPL values of 3AC
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

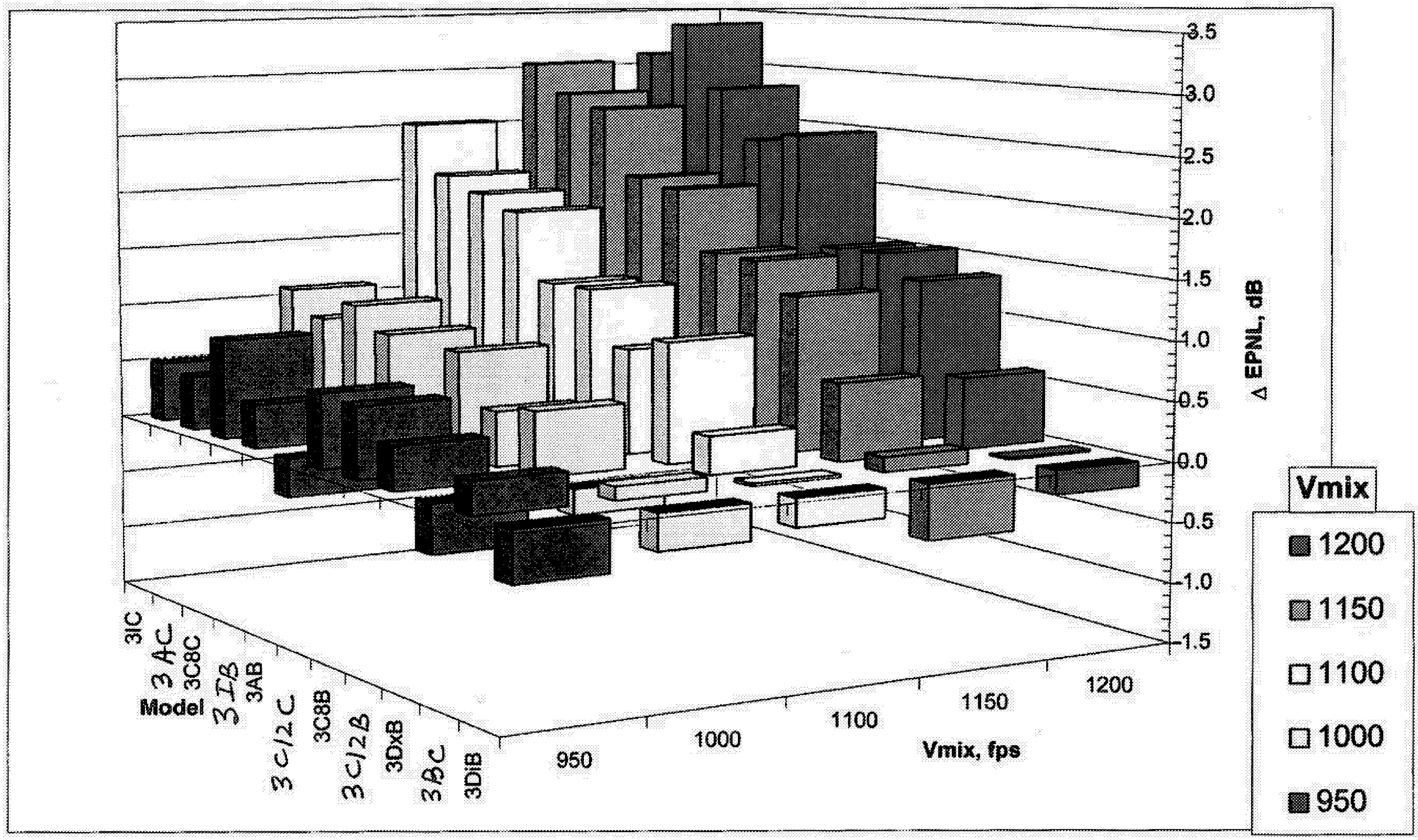
10:38 09/04/97 ml04103832.cdf ae6302t@c0767 X11 PLOT 1
EGS LIB 5.4I 08/04/97 (EGSREP.XCPOST 5.4I 08/04/97 on c0767)
soectscp ver. 1.2 24 Jan 1995



SPL values of 3BB minus SPL values of 3AC
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

Noise Benefits Relative to Baseline Model 3

Tamb = 50°F; Scale Factor = 8; Altitude = 1500 ft; M = 0.28



GE Aircraft Engines

G.Kontos /aoi14.3/epnls.xls Mod. 3 – 1200 Column 3D (2)

Summary - Noise Reduction Test Concepts of BPR=5 External Plug Nozzle (Model 3)

- Core Nozzle Doublets (Both Internal & External of Core Nozzle) Provide No Significant Noise Benefit
- At Typical Sideline Condition Following Benefits Were Noted:
  1) Both 8 Chevron & 12 Chevron Core Nozzles $\cong$ 1 to 1.5 EPNdB
  2) Inward & Alternate Flip Core Chevron Nozzles $\cong$ 2.5 EPNdB
  3) Addition of Fan Chevron Increases Core Chevron Nozzle Benefits upto An Additional Maximum Benefit of 1.0 EPNdB
  4) 3IC & 3AC $\cong$ 3.0 & 3.4 EPNdB
- Chevron Core Nozzles Gave Significant Low Frequency Jet Noise SPL Reduction. Except for Alternate Flip Core Chevron Nozzle, Chevron Nozzles Did Not Increase High Frequency SPL
- Test Concepts Provide 0.5 to 1 EPNdB Benefit at Typical Cutback Condition

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Noise Reduction Test Configurations of Model 5

With Fan Nozzle Noise Reduction Concept
5BC

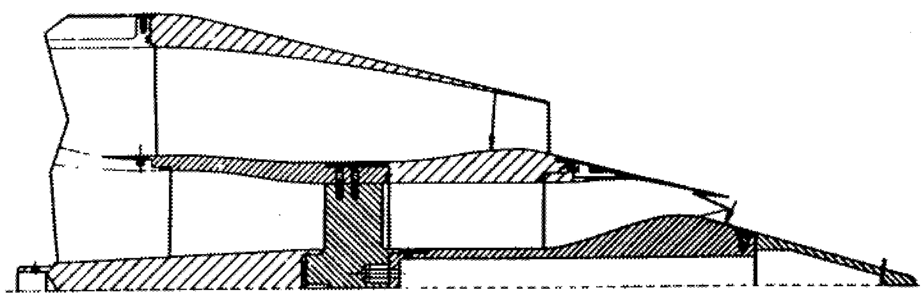
With Core Nozzle Noise Reduction Concept
5C12B

With Core & Fan Nozzle Noise Reduction Concepts
5C12C

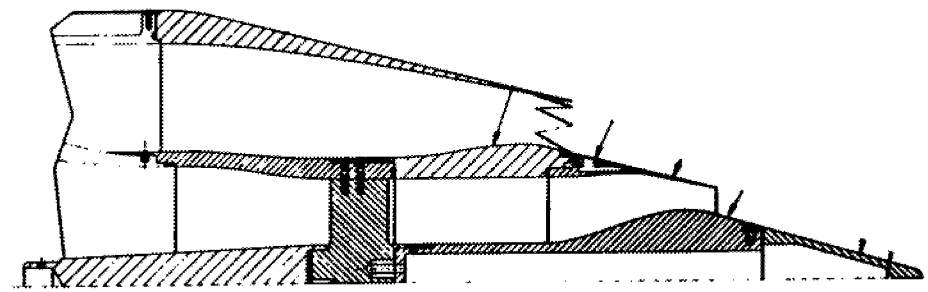
Noise Reduction Test Configurations with Model 5

BPR = 8, External Plug

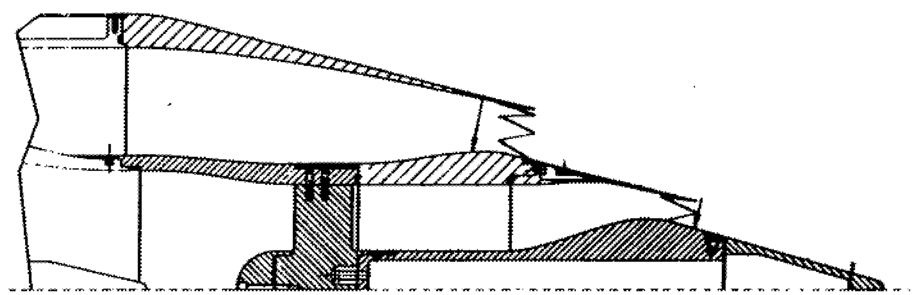
With Chevron Core and Fan Nozzles



5C12B

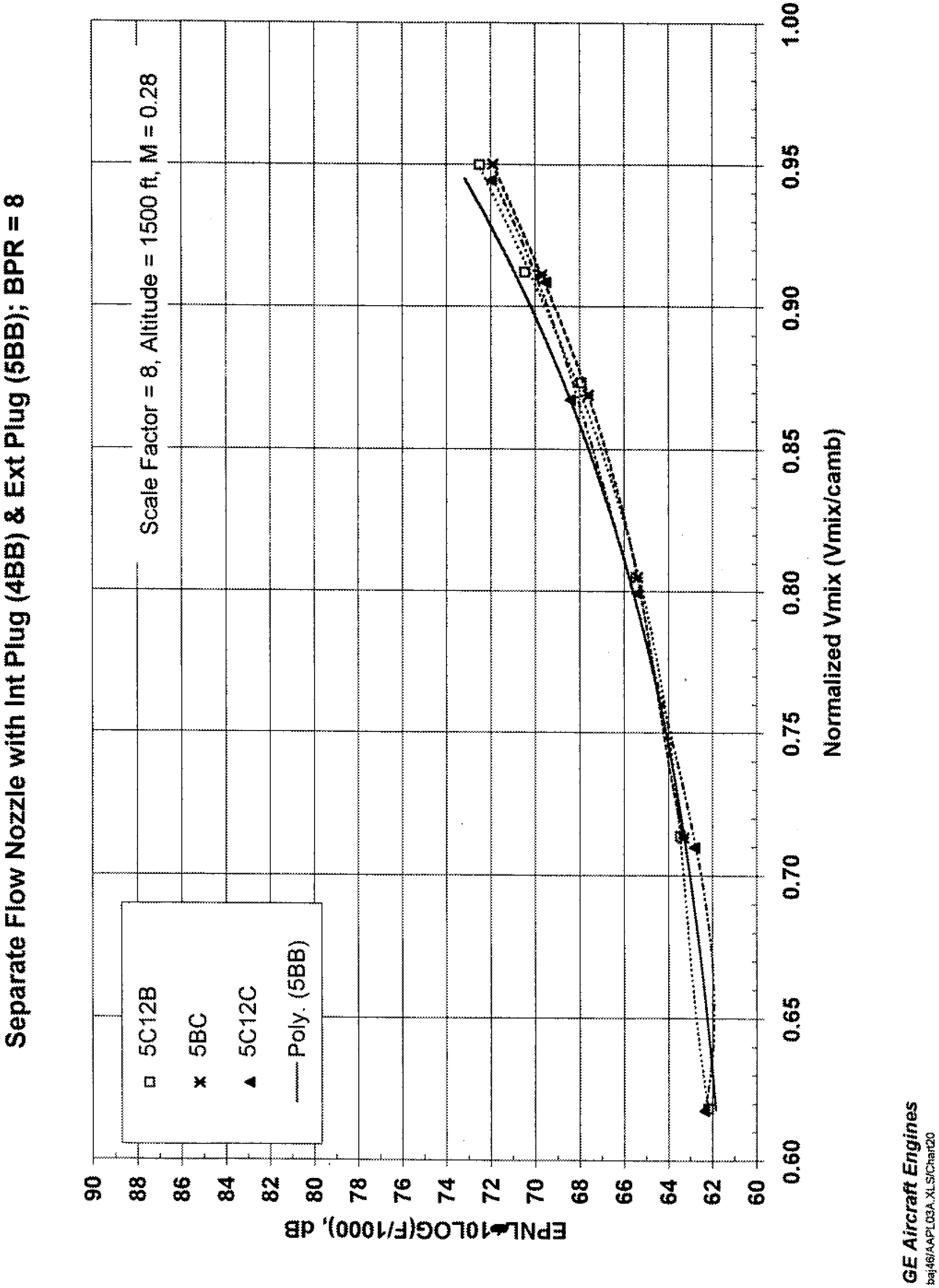


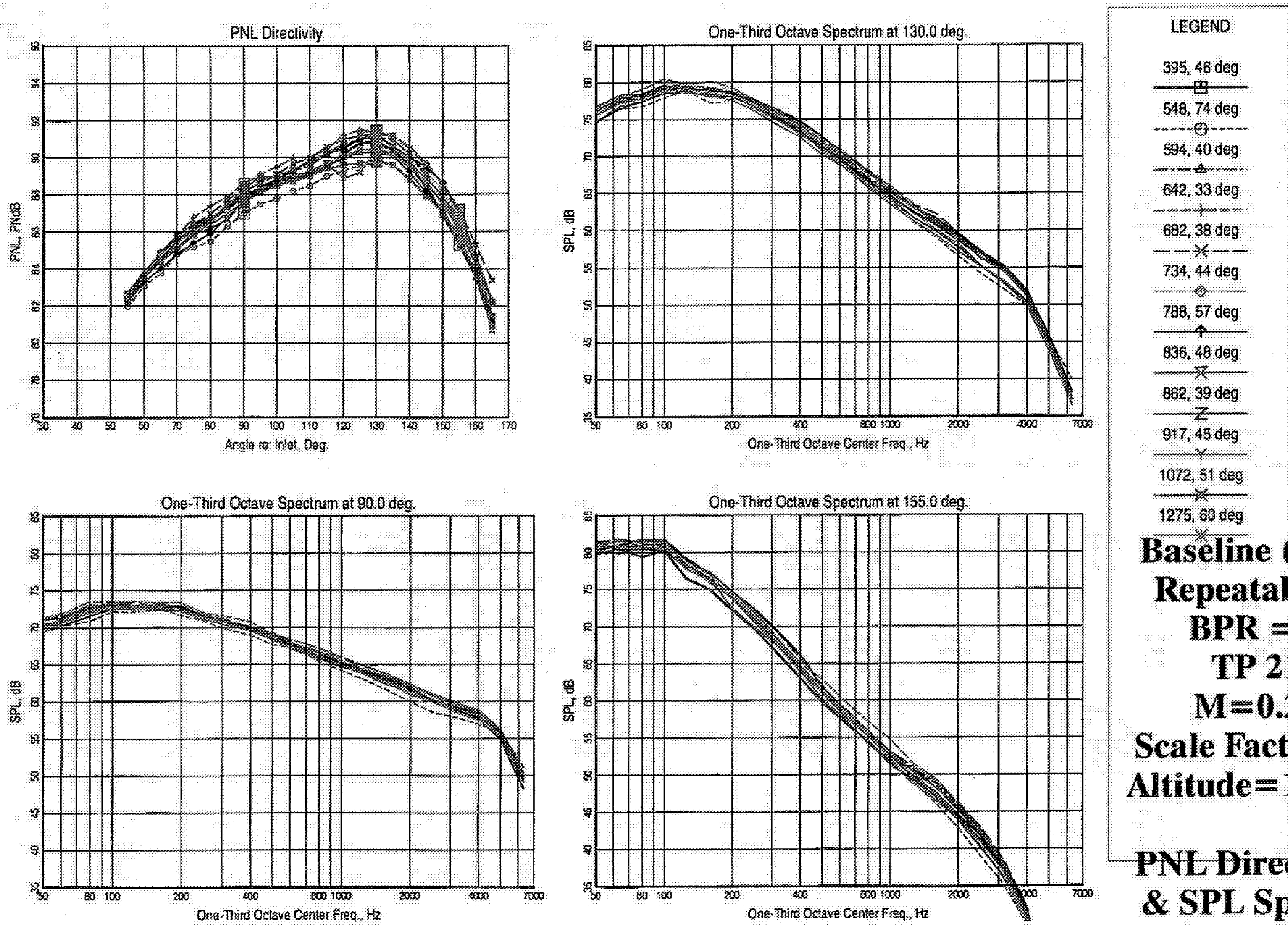
5BC



5C12C

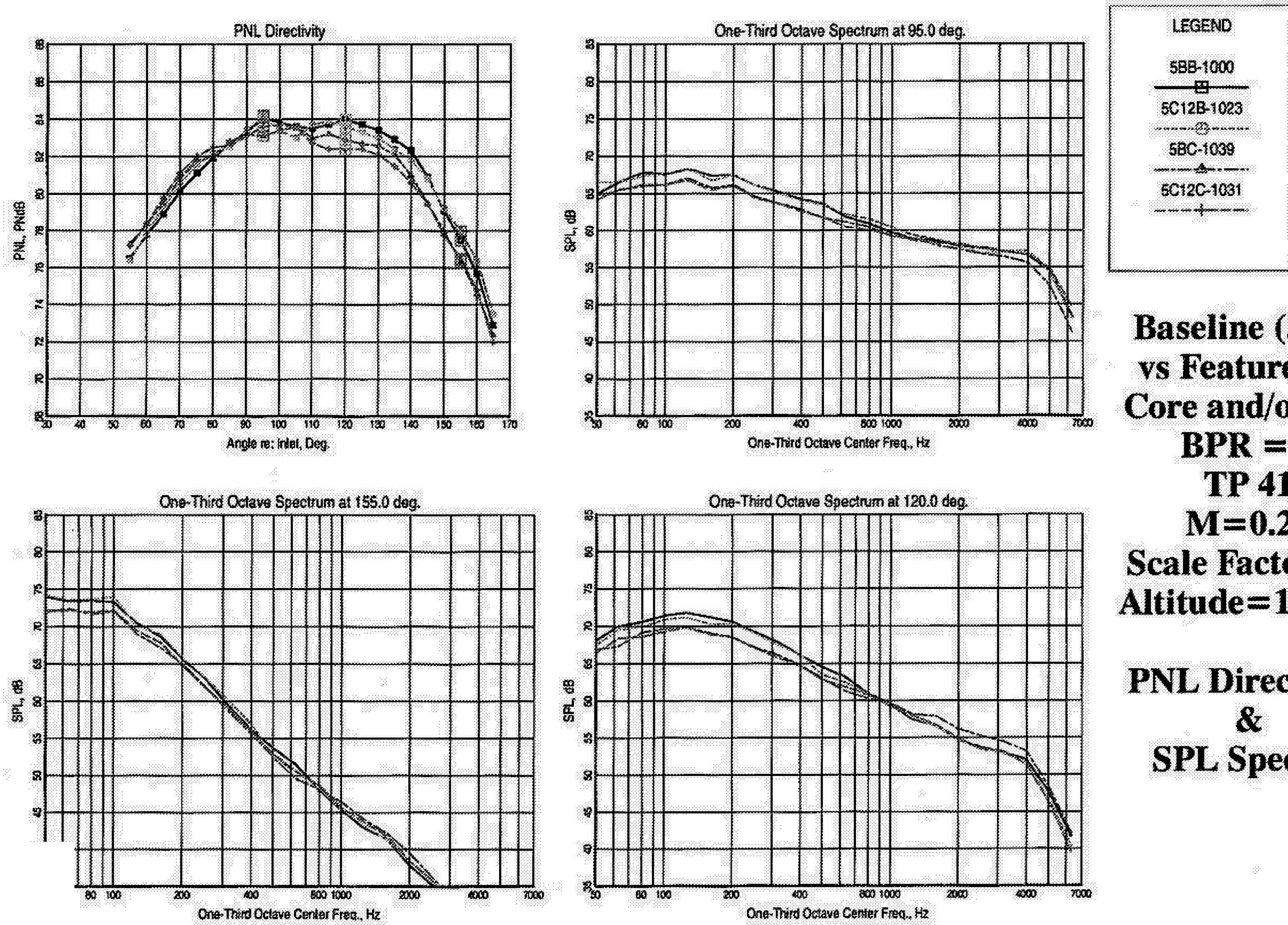
baj29/a14pit09.doc


Separate Flow Nozzle with Int Plug (4BB) & Ext Plug (5BB); BPR = 8
Scale Factor = 8, Altitude = 1500 ft, M = 0.28
5C12B
5BC
5C12C
Poly. (5BB)
EPNL-10LOG(F/1000), dB
90
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
Normalized Vmix (Vmix/camb)
GE Aircraft Engines
baj46/AAPL03A.XLS/Chart20



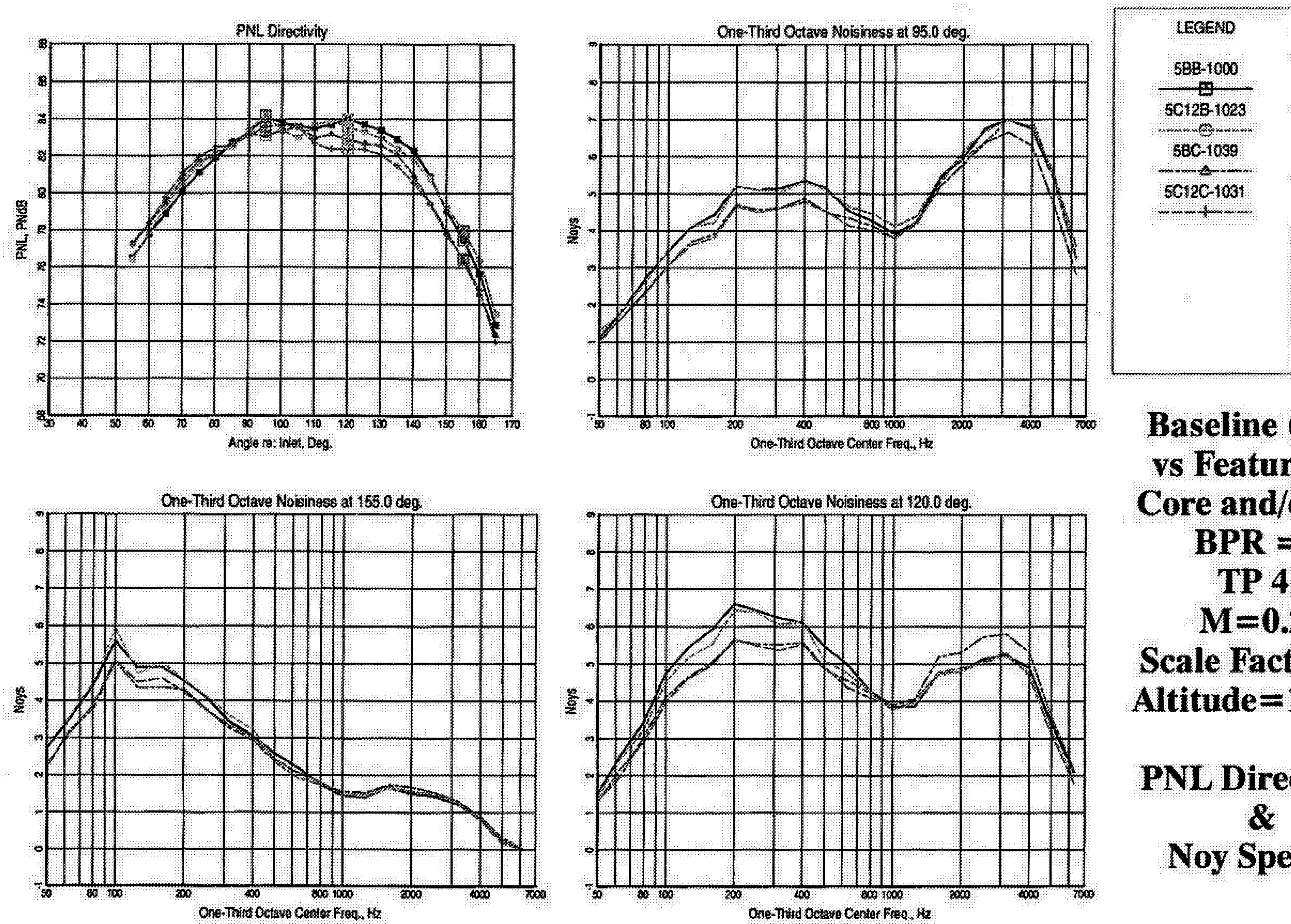
Baseline (3BB)
Repeatability
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity & SPL Spectra



Baseline (5BB) vs Features on Core and/or Fan
BPR = 8
TP 41
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity & SPL Spectra



Baseline (5BB)
vs Features on
Core and/or Fan
BPR = 8
TP 41
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity
&
Noy Spectra

Summary - Noise Reduction Test Concepts of BPR=8 External Plug Nozzle (Model 5)

- Chevron Noise Reduction Concepts Used Separately on Core Or Fan Provide $\cong$ 1 EPNdB Benefit At Typical Sideline Condition
- Chevron Noise Reduction Concepts Used Combined on Core And Fan Provide $\cong$ 1.5 EPNdB Benefit At Typical Sideline Condition

baj29/a14pit09.doc

Summary

- **Successful Separate Flow Acoustic Test Program Completed**
- **Concepts Identified That Give Significant Jet Noise Reduction**
- **Some Concepts Meet NASA Stretch Goal of 3.0 EPNdB Jet Noise Reduction At Typical Takeoff Condition**
- **Good Cooperation Between NASA & Industry Participants During Planning & Execution of Test Program**
- **Need to Assess Performance Impact of Significant Noise Reduction Concepts**

baj29/a14pit09.doc

SFNT97 Flow Field Measurements

Nozzle geometry → Flow → Sound

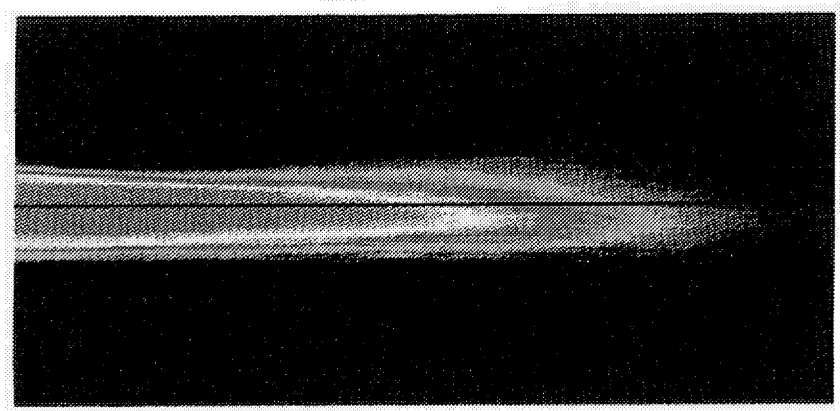
- IR for online diagnostics with acoustics
- Ptot,Ttot, Pstat rake surveys for mean flow measurements
- Focused Schleiren for density and some turbulence structure
- Laser sheet visualization for near-nozzle diagnostics
- Two-point hotwire measurements for turbulence models

SFNT97: IR Camera

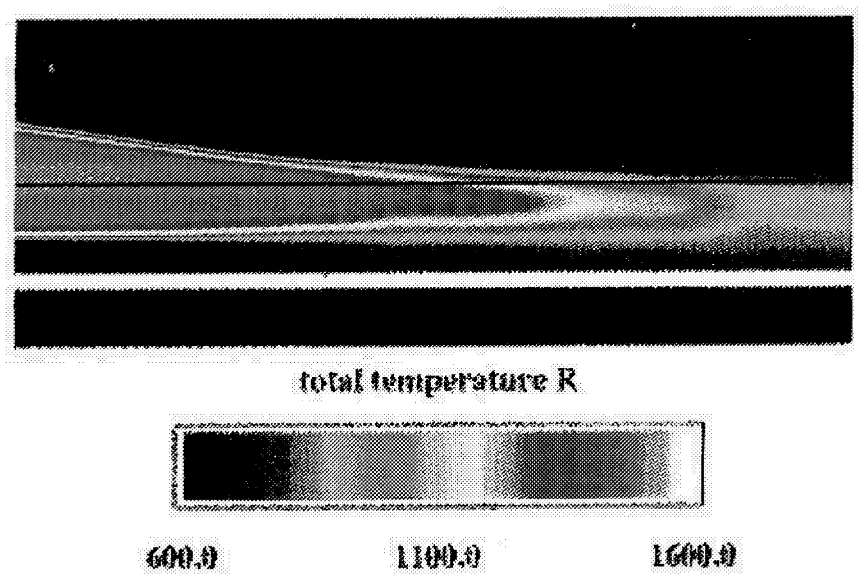
IR Camera On-line

Non-intrusive flow diagnostic with acoustic testing

330



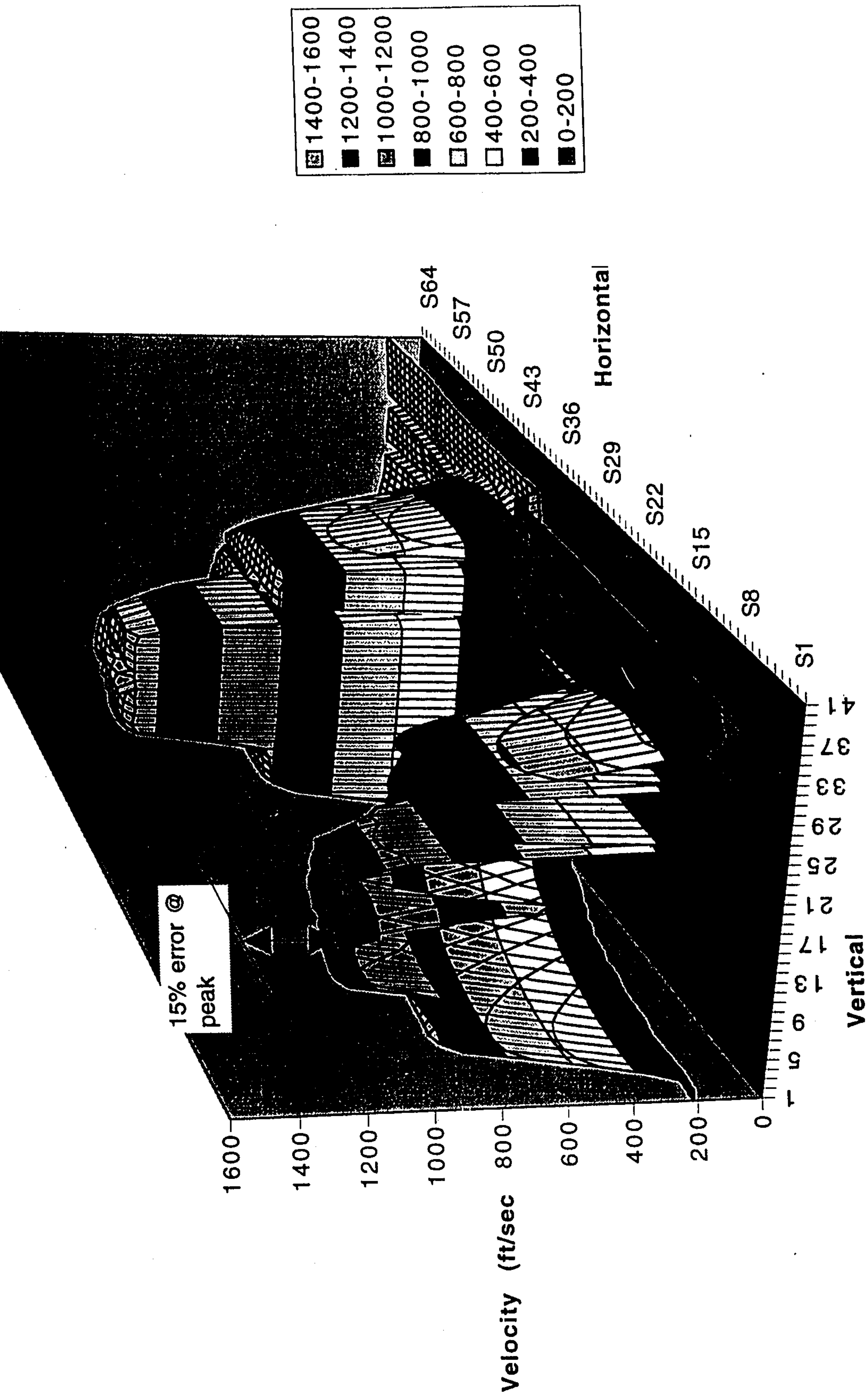
Total temperature rake data



Plume Survey Rake Instrumentation

- Four vertical rakes (Z)
  - 10” total span
  - 1/4” Δz p_{tot}
  - 1/4” Δz t_{tot}
  - 1/2” Δz p_{stat} x2 rakes
- Traverse actuation in horizontal plane (X,Y)
- pstat only measured in first two cross-sections (10.5” and 13.5”)
- Velocity obtained using $p_{stat} = p_{amb}$ is denoted by “velocity*”

Comparison of velocity calculated with and without measured s pressure — X=10.5"



Model 3 Configurations Tested

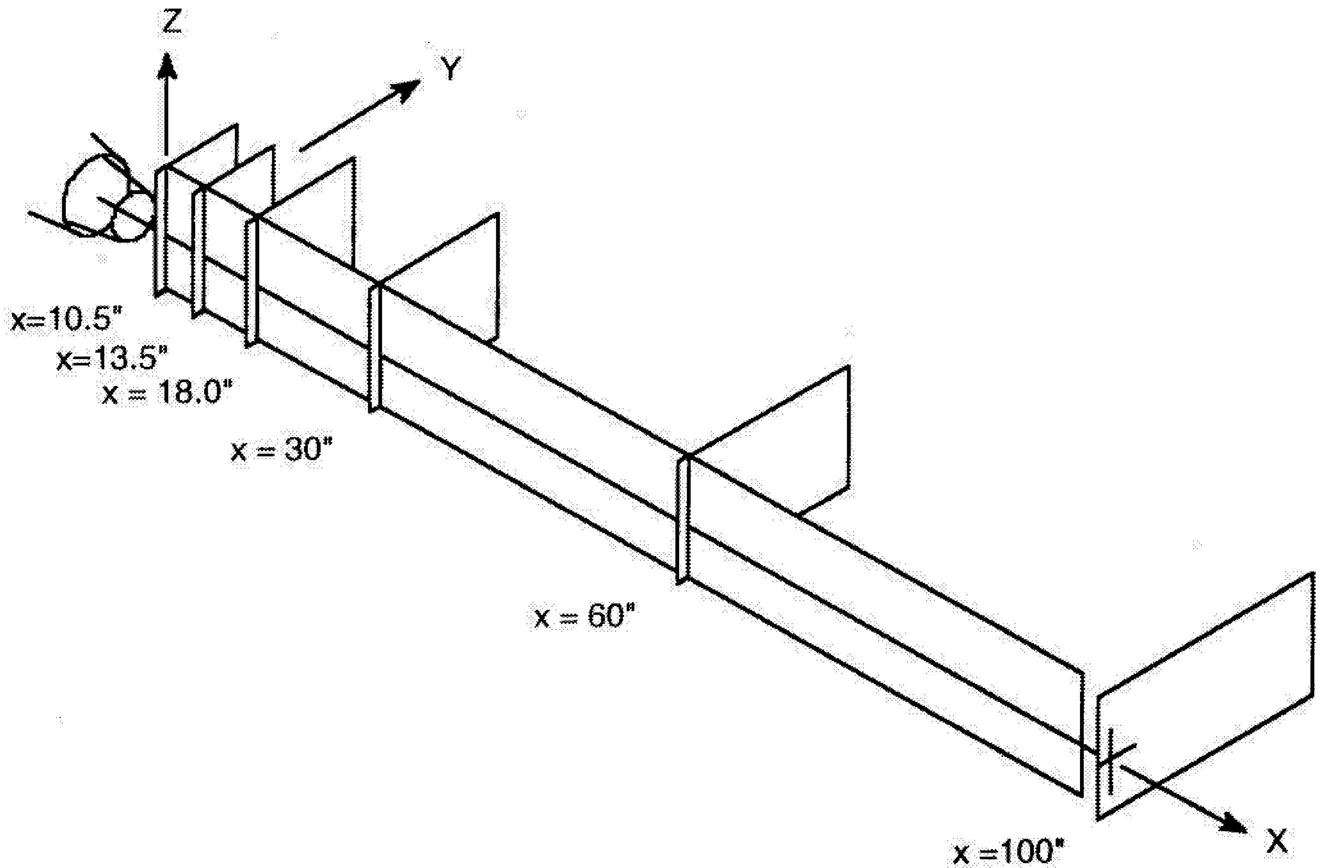
Fan mixers

Core mixers	B	C24	Scarf	Offset	T24	T48
B	X	X		X	X	
T24	X	X			X	X
T48	X					
C8	X					
C12	X	X				
I	X	X				
A	X					
H	X					
F	X					

Other Configurations Tested

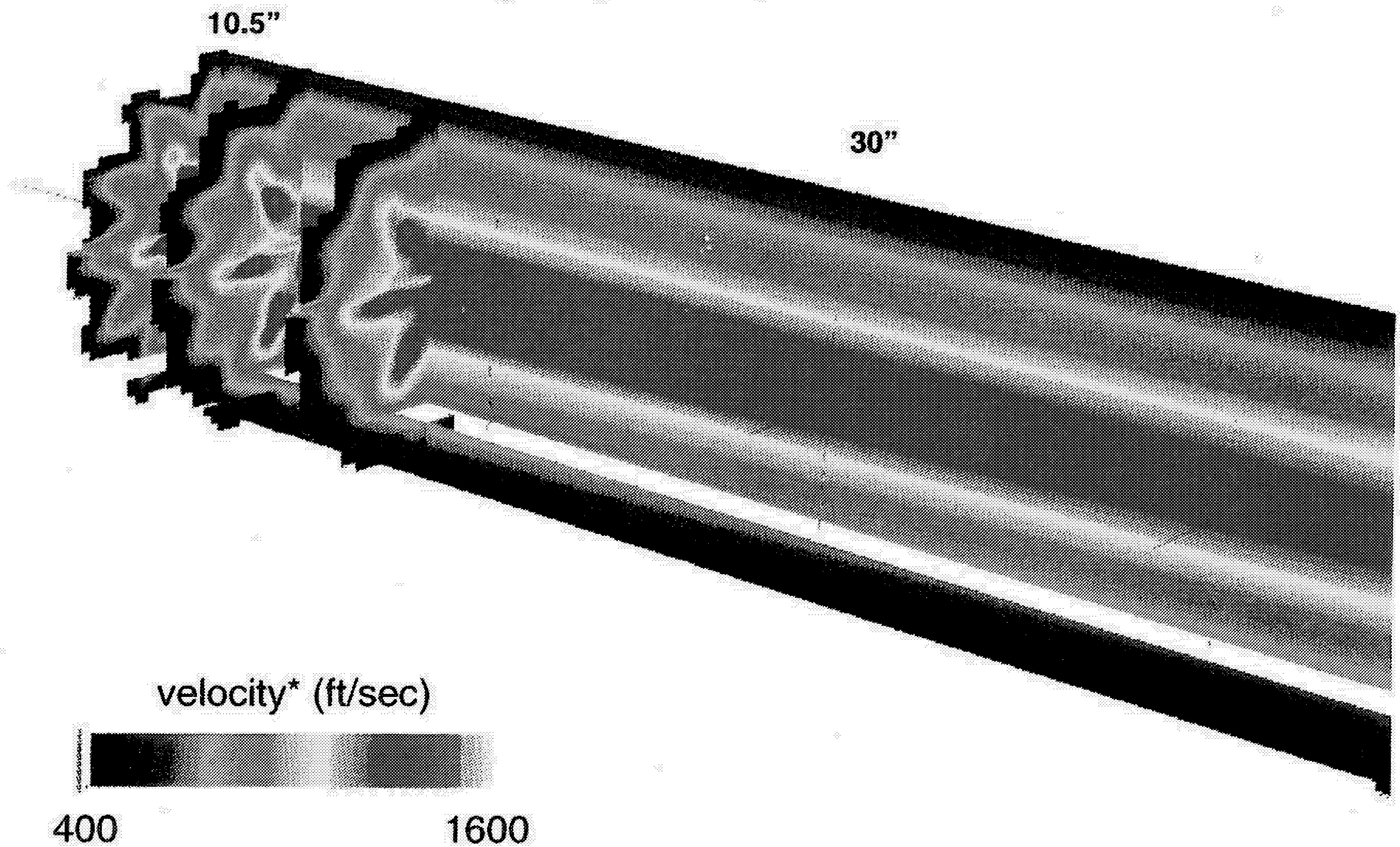
- 1BB
- 2BB
- 4BB
- 6TmB
- 7BB

SFNT97 Plume Survey



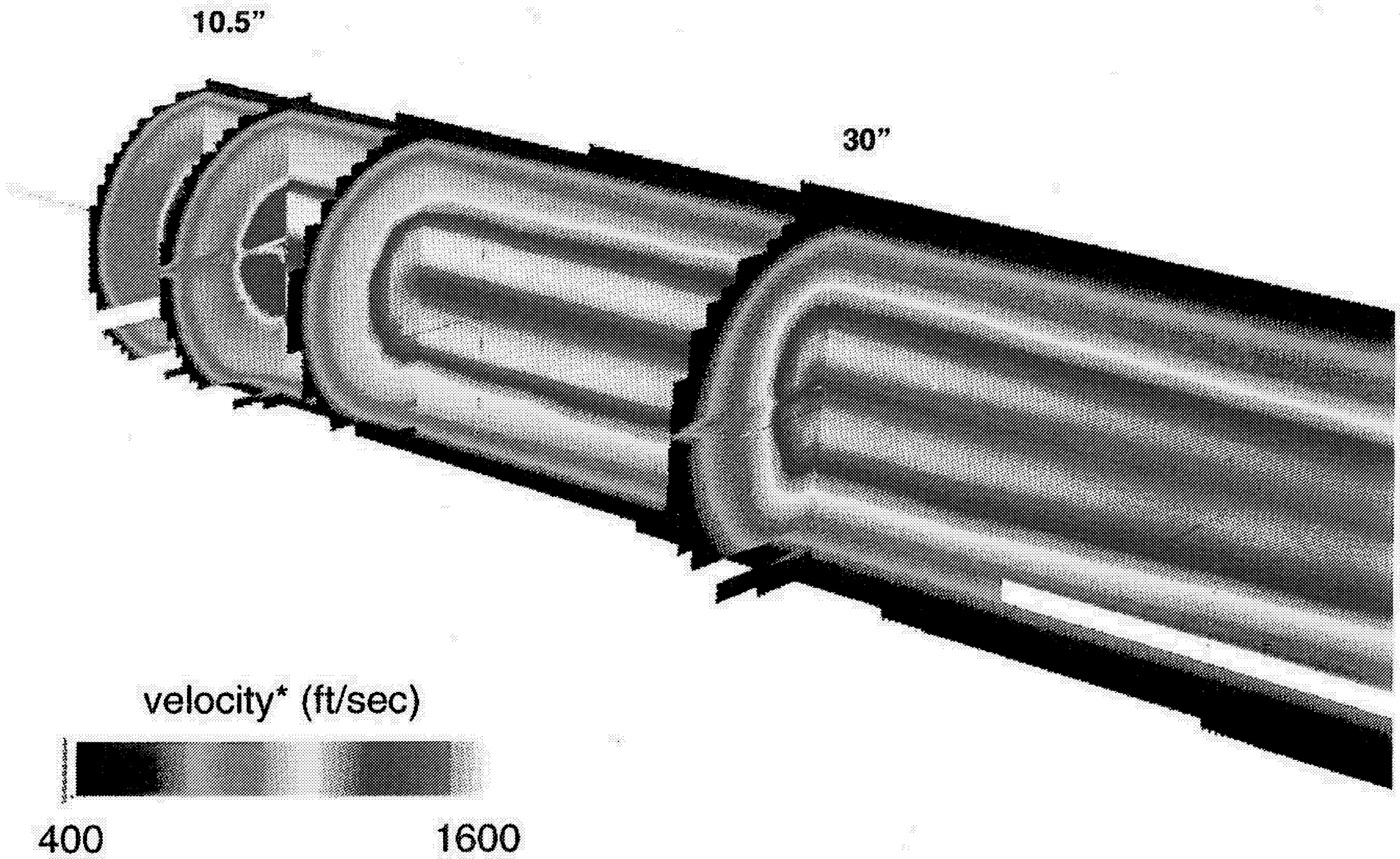
SFNT97: Plume survey

Mean velocity field
3T24T48
Cycle point 21, M=0.28



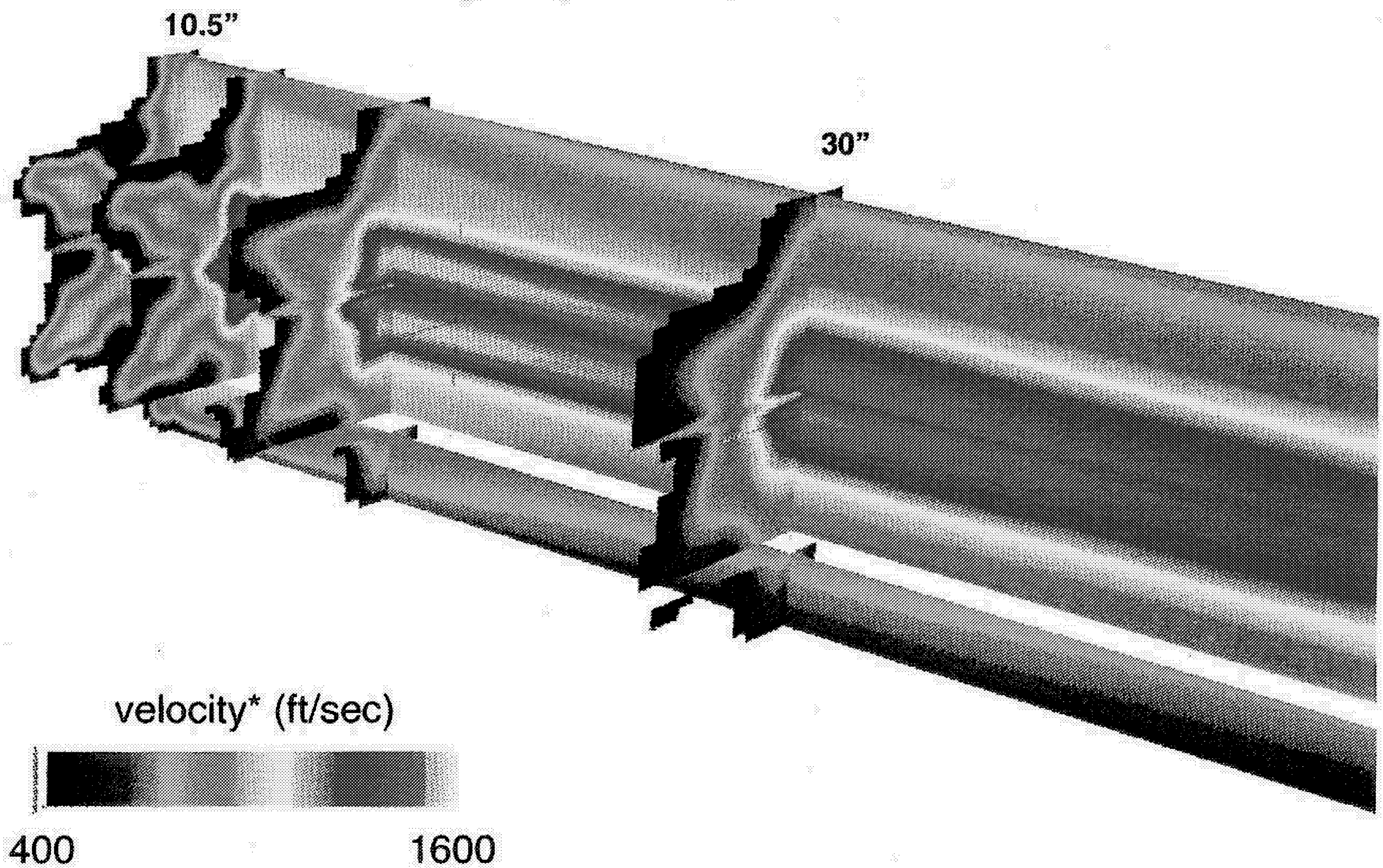
SFNT97: Plume survey

Mean velocity field
3BB
Cycle point 21, M=0.28



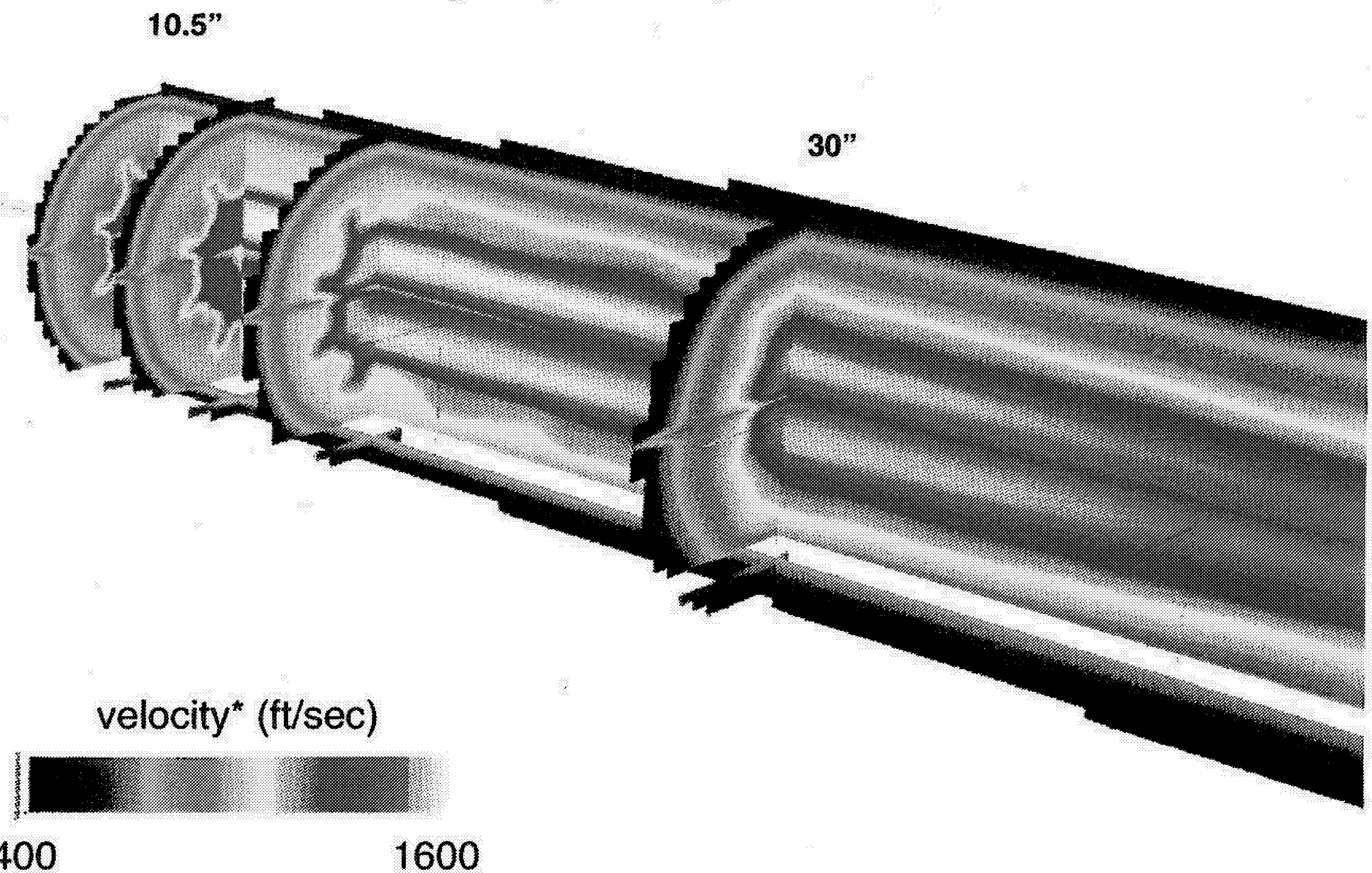
SFNT97: Plume survey

Mean velocity field
3BT24
Cycle point 21, M=0.28



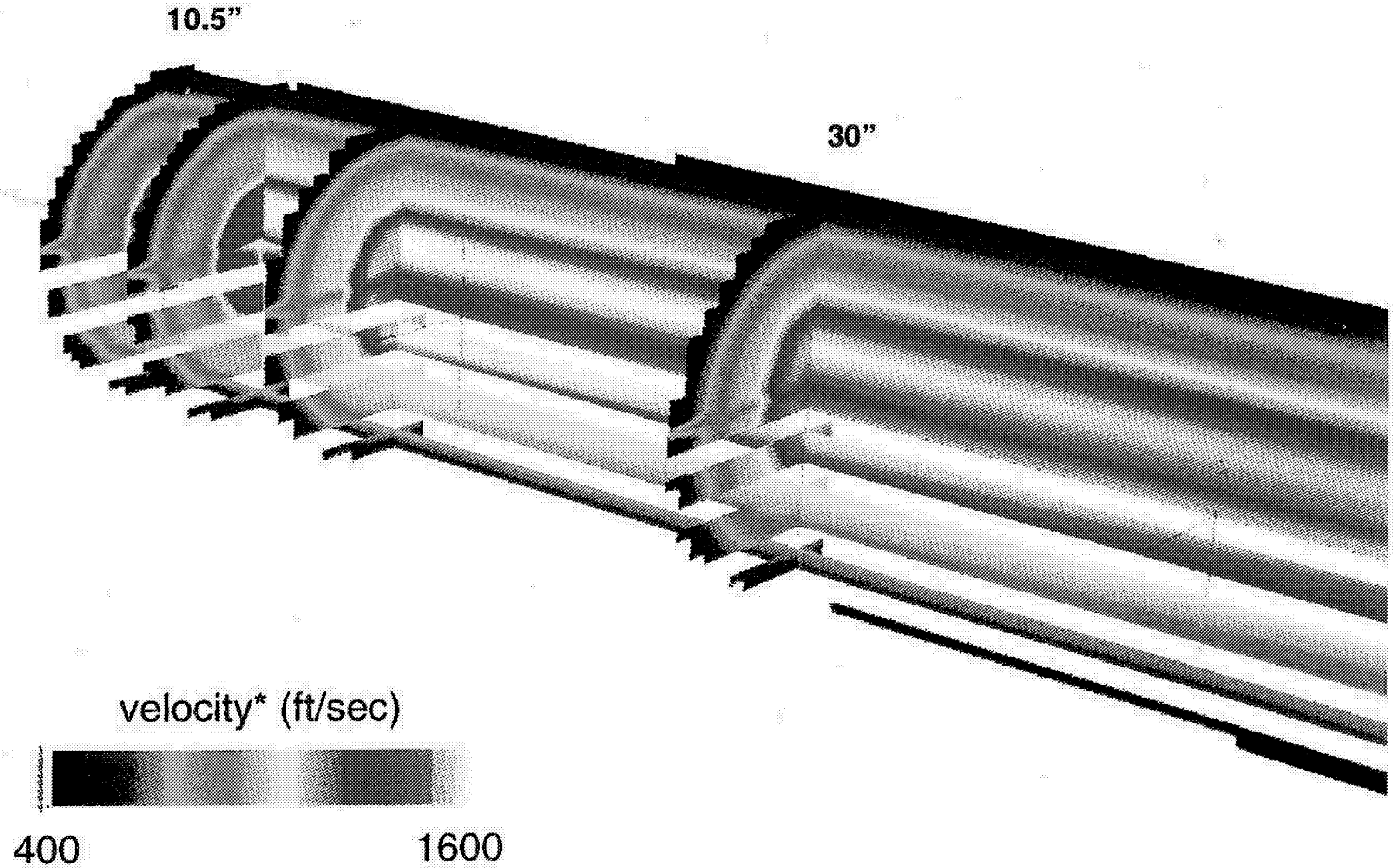
SFNT97: Plume survey

Mean velocity field
3C8B
Cycle point 21, M=0.28



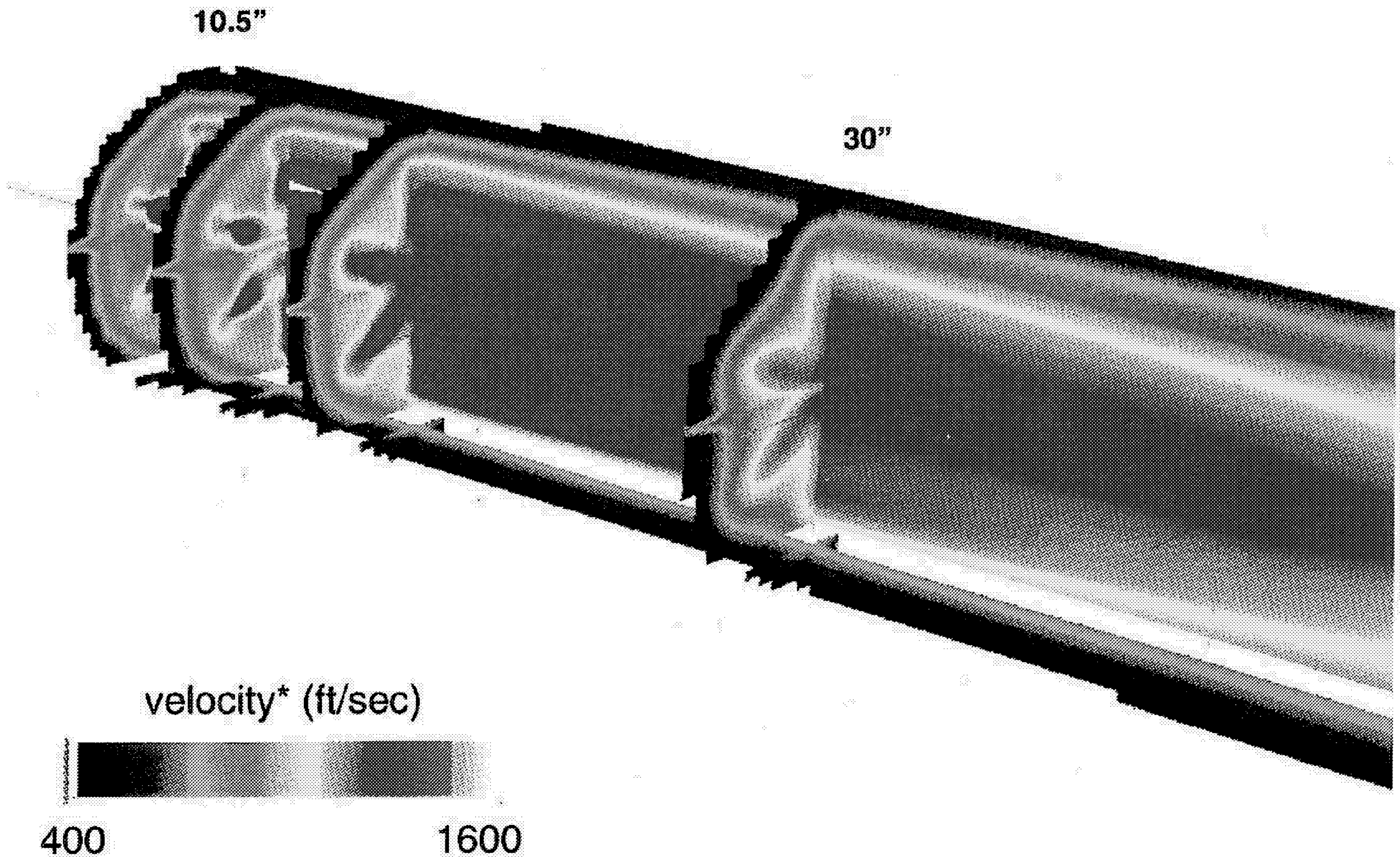
SFNT97: Plume survey

Mean velocity field
3BC24
Cycle point 21, M=0.28



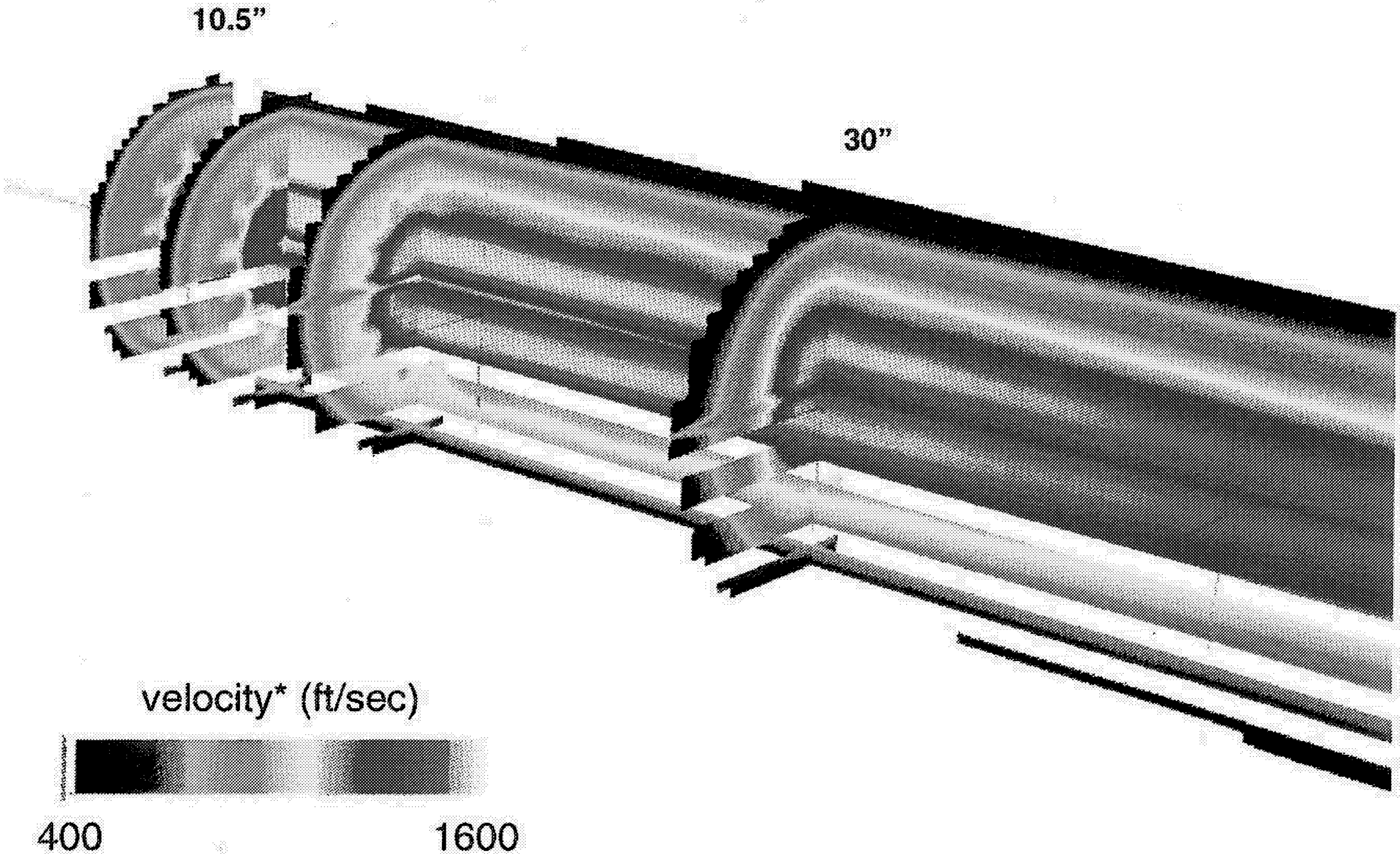
SFNT97: Plume survey

Mean velocity field
3T24C24
Cycle point 21, M=0.28



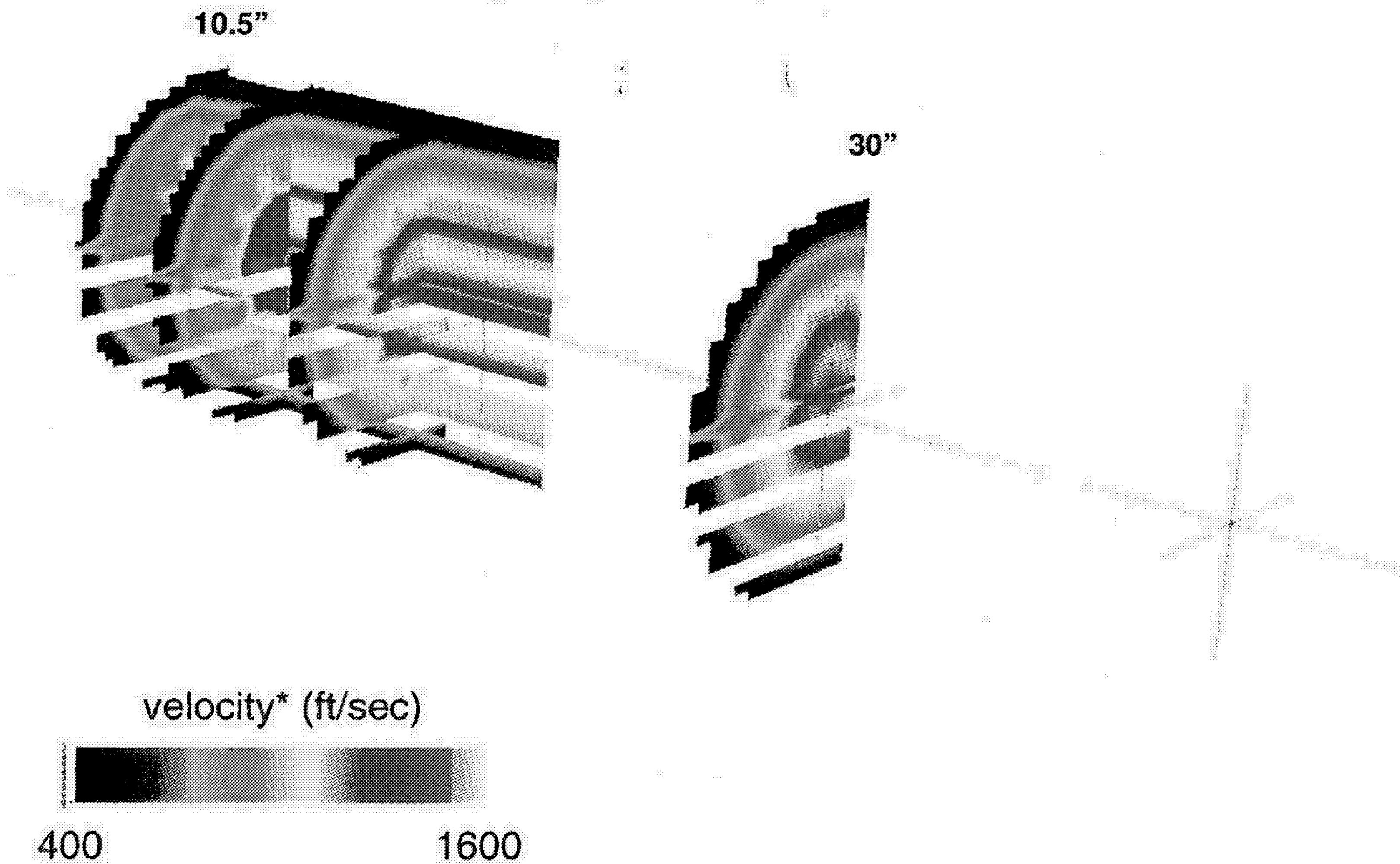
SFNT97: Plume survey

Mean velocity field
3C12B
Cycle point 21, M=0.28



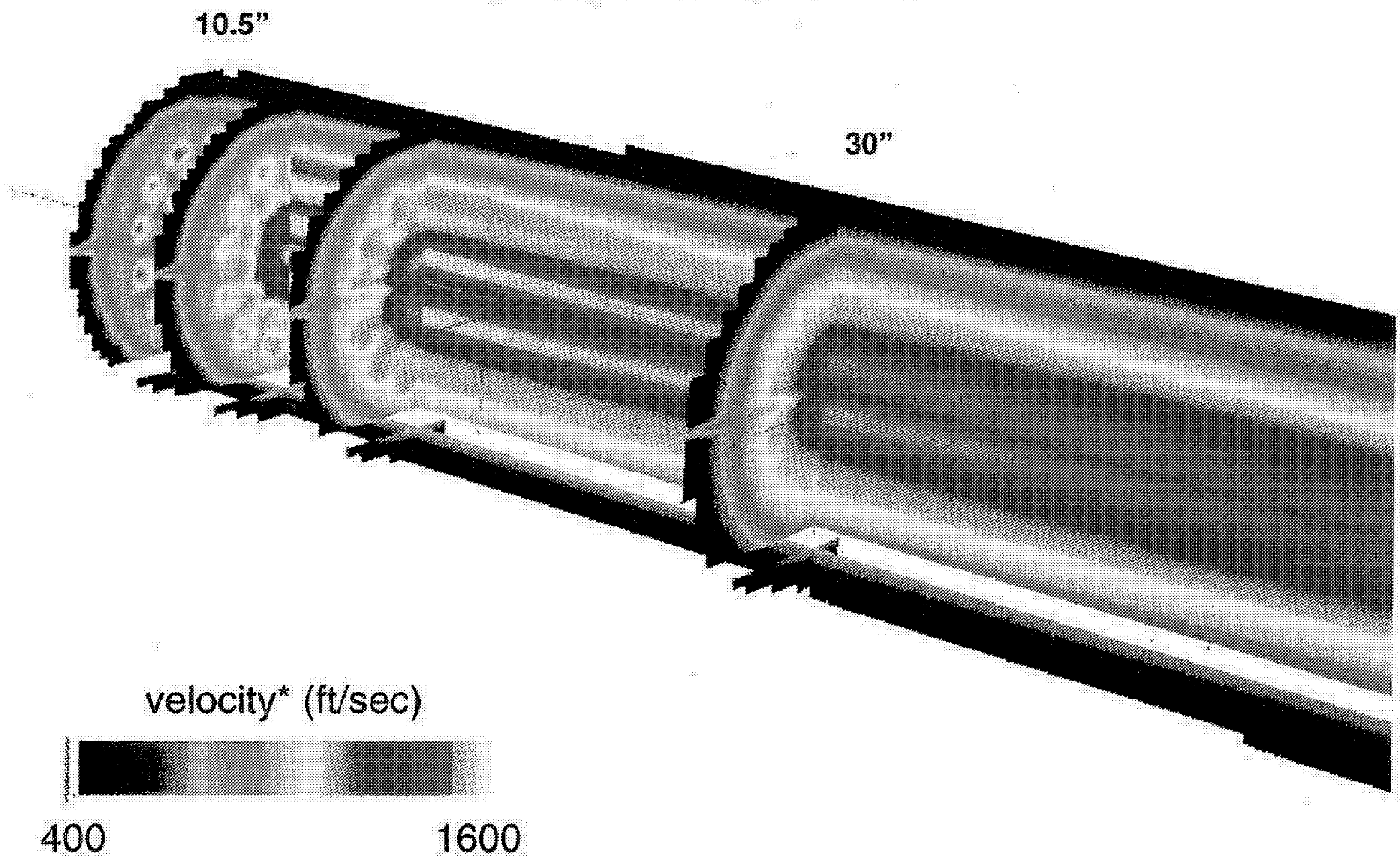
SFNT97: Plume survey

Mean velocity field
3C12C24
Cycle point 21, M=0.28



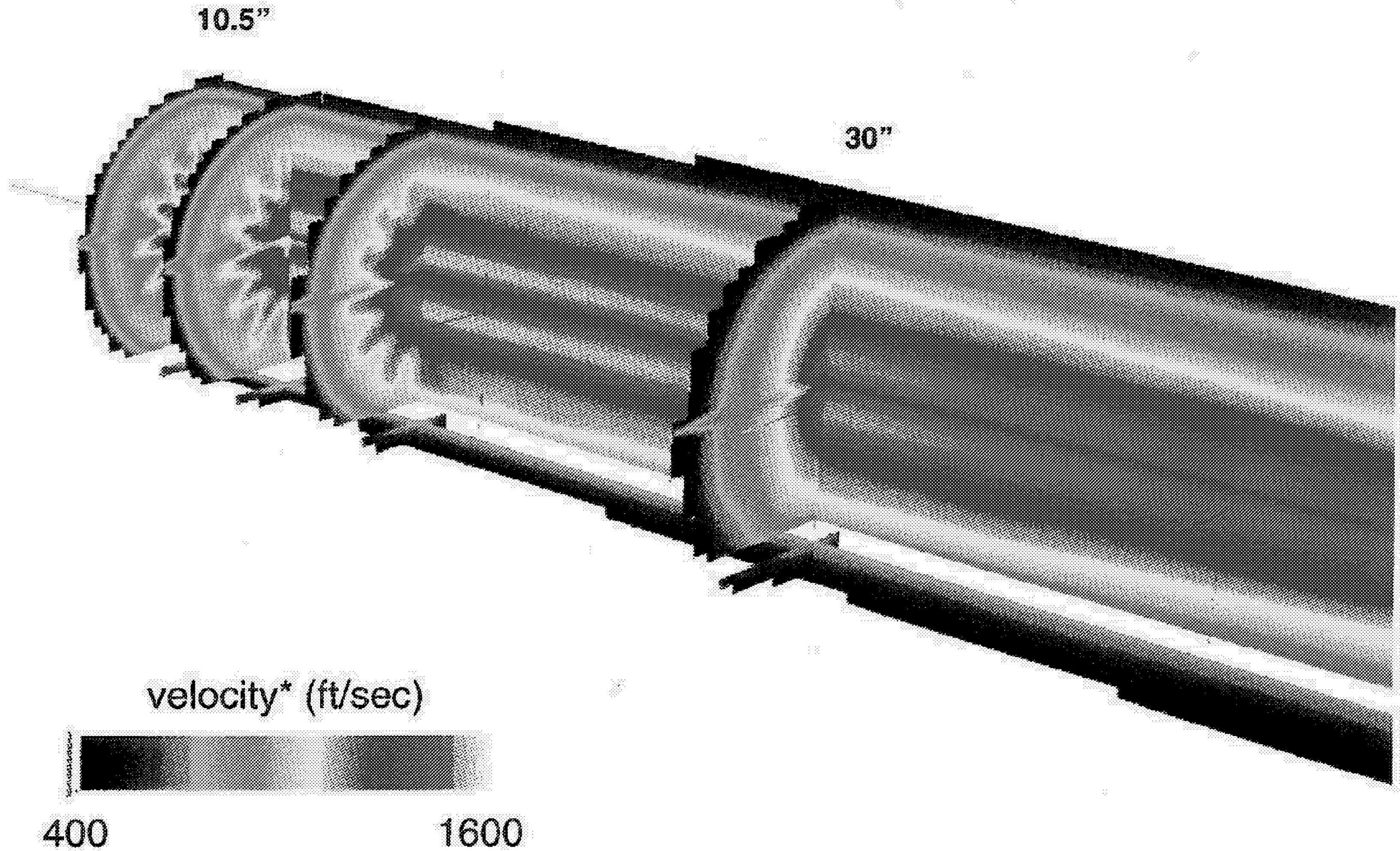
SFNT97: Plume survey

Mean velocity field
3IC24
Cycle point 21, M=0.28



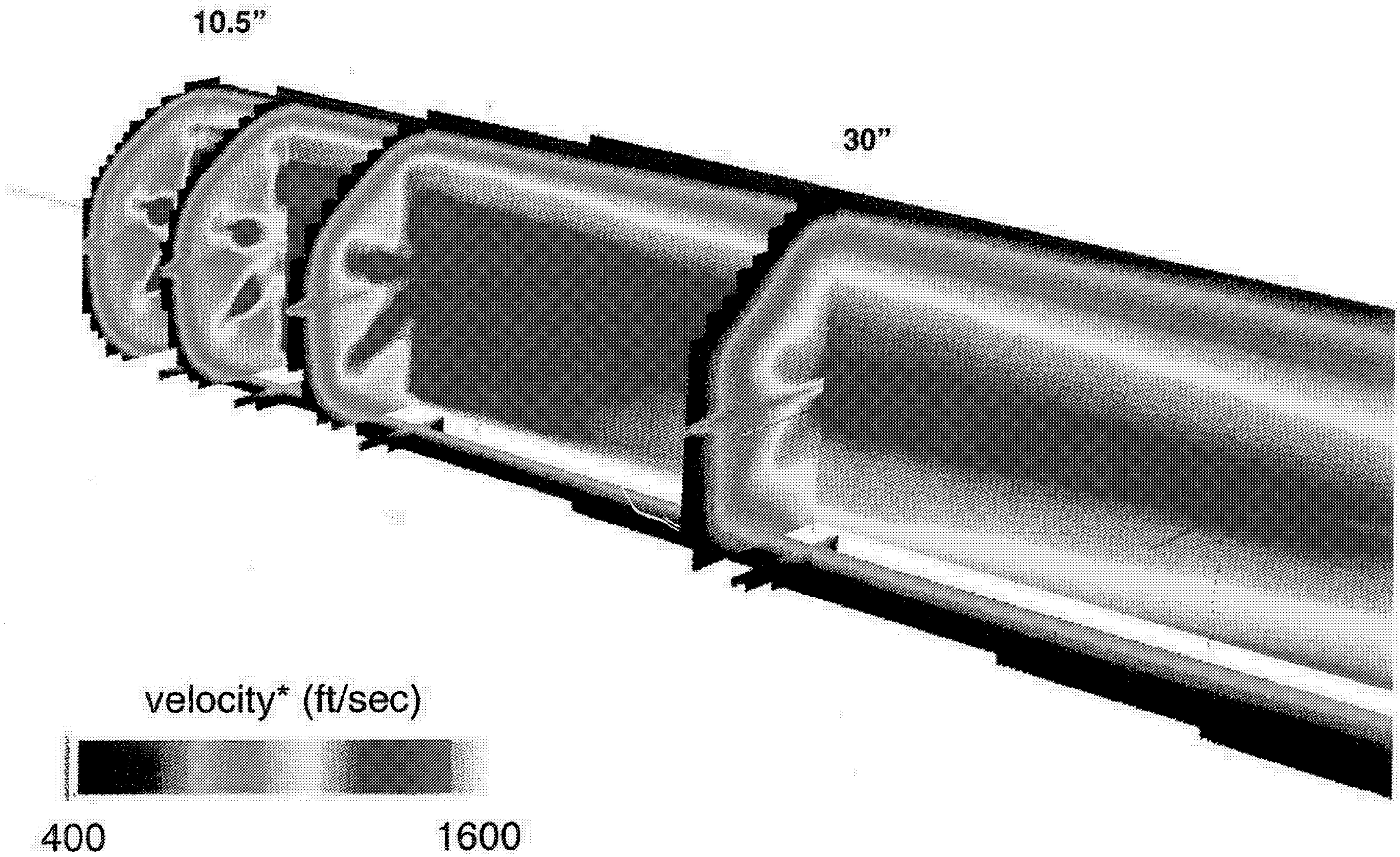
SFNT97: Plume survey

Mean velocity field
3T48B
Cycle point 21, M=0.28



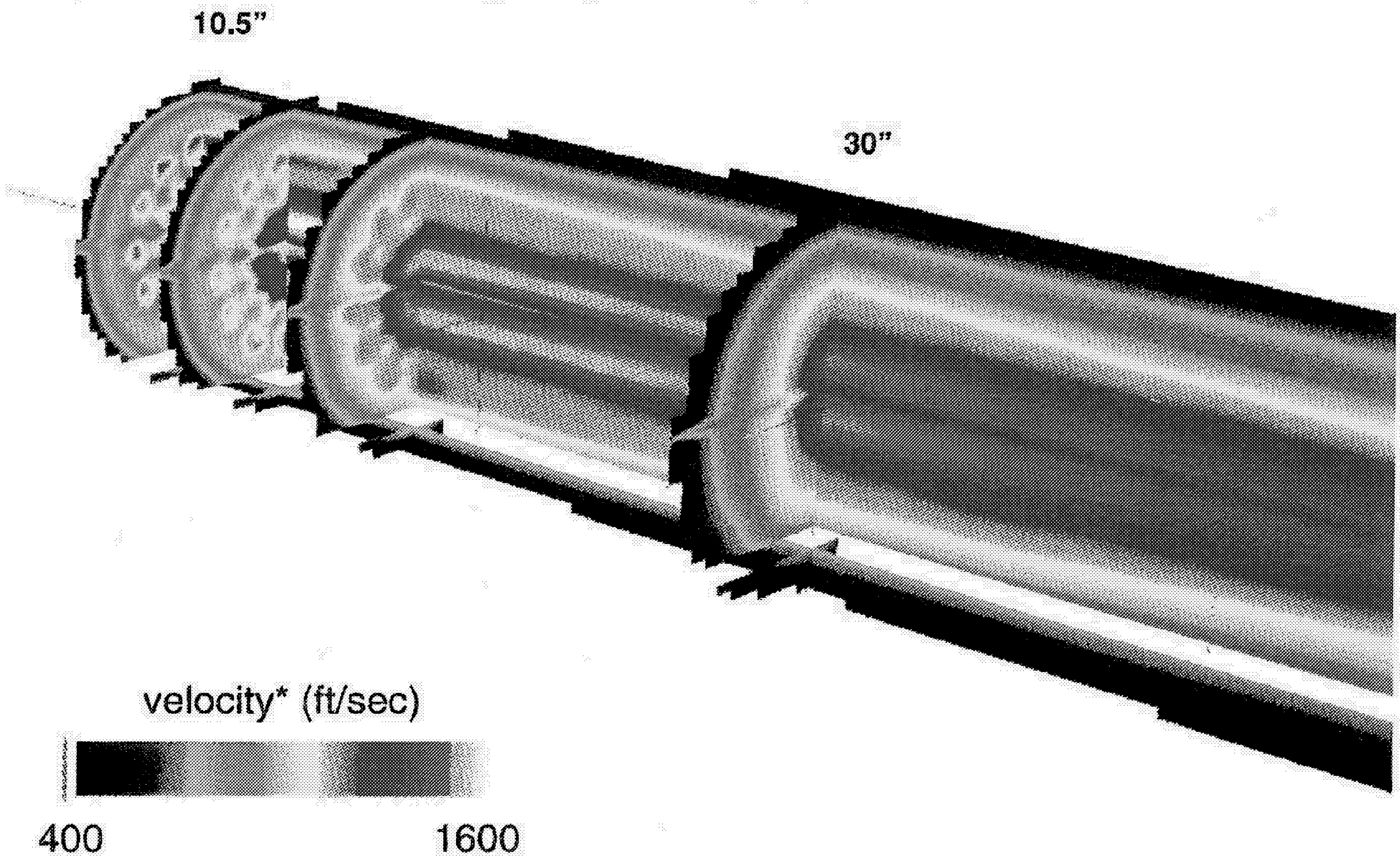
SFNT97: Plume survey

Mean velocity field
3T24B
Cycle point 21, M=0.28



SFNT97: Plume survey

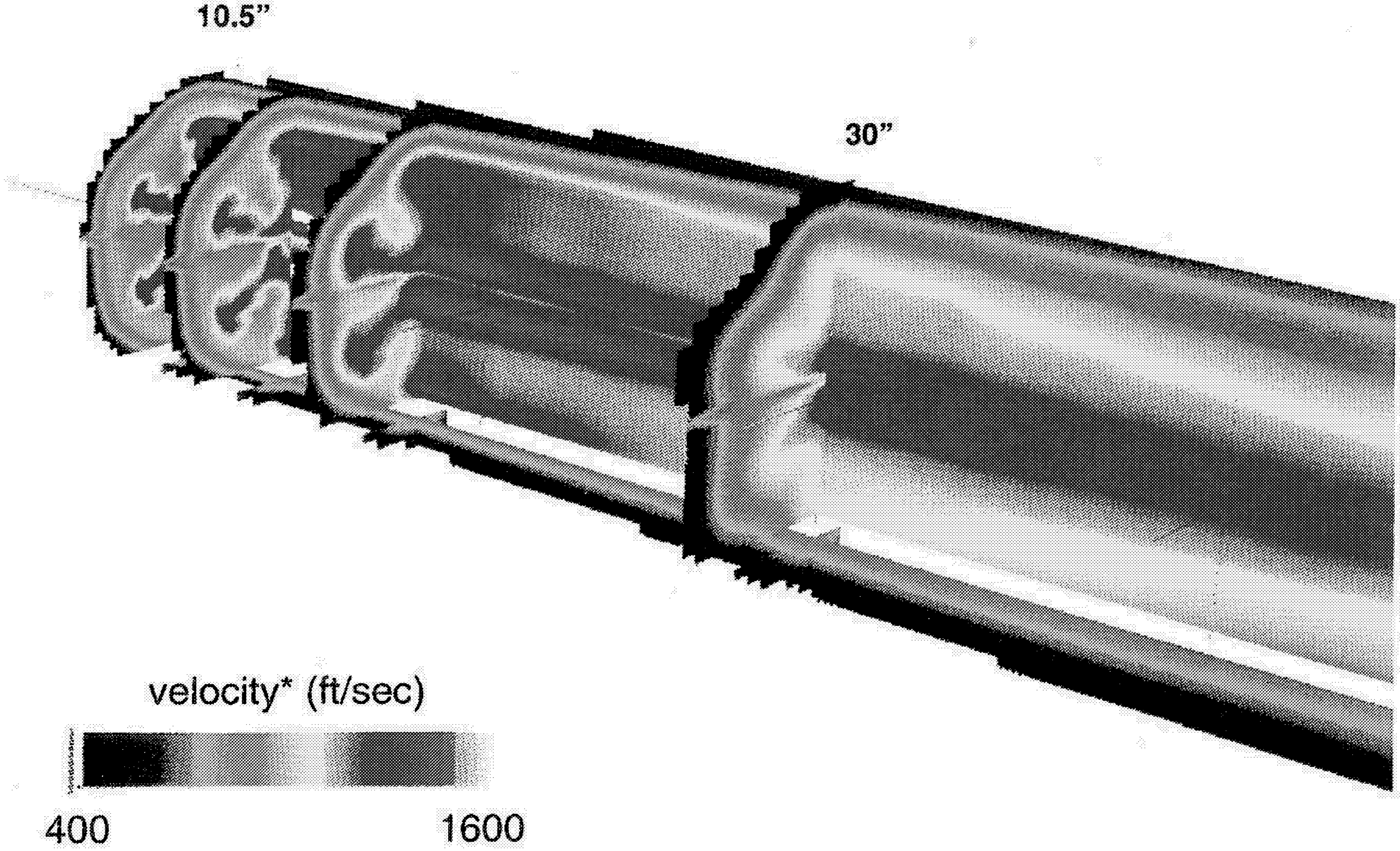
Mean velocity field
3IB
Cycle point 21, M=0.28



SFNT97: Plume survey

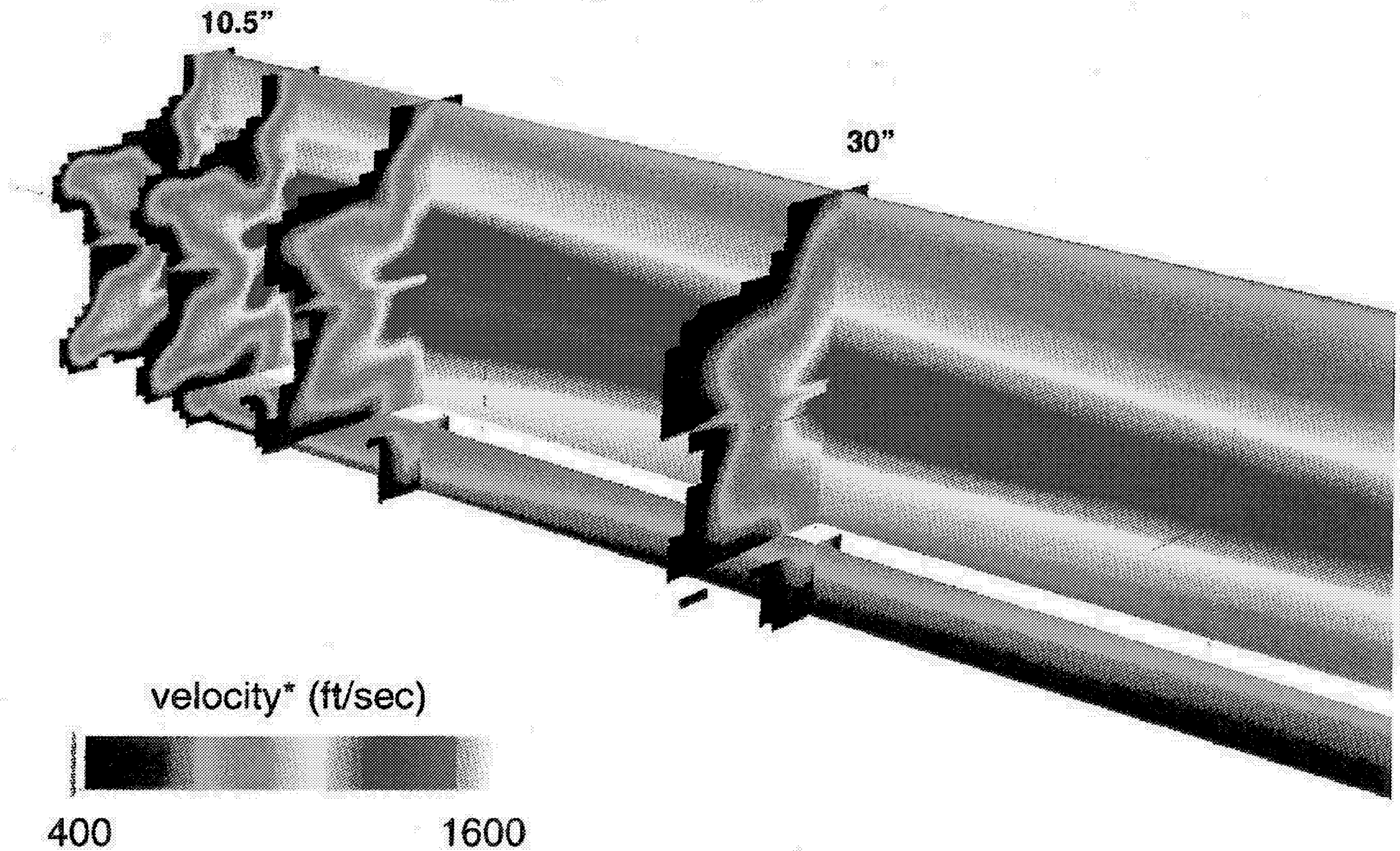
Mean velocity field 3AB

Cycle point 21, M=0.28



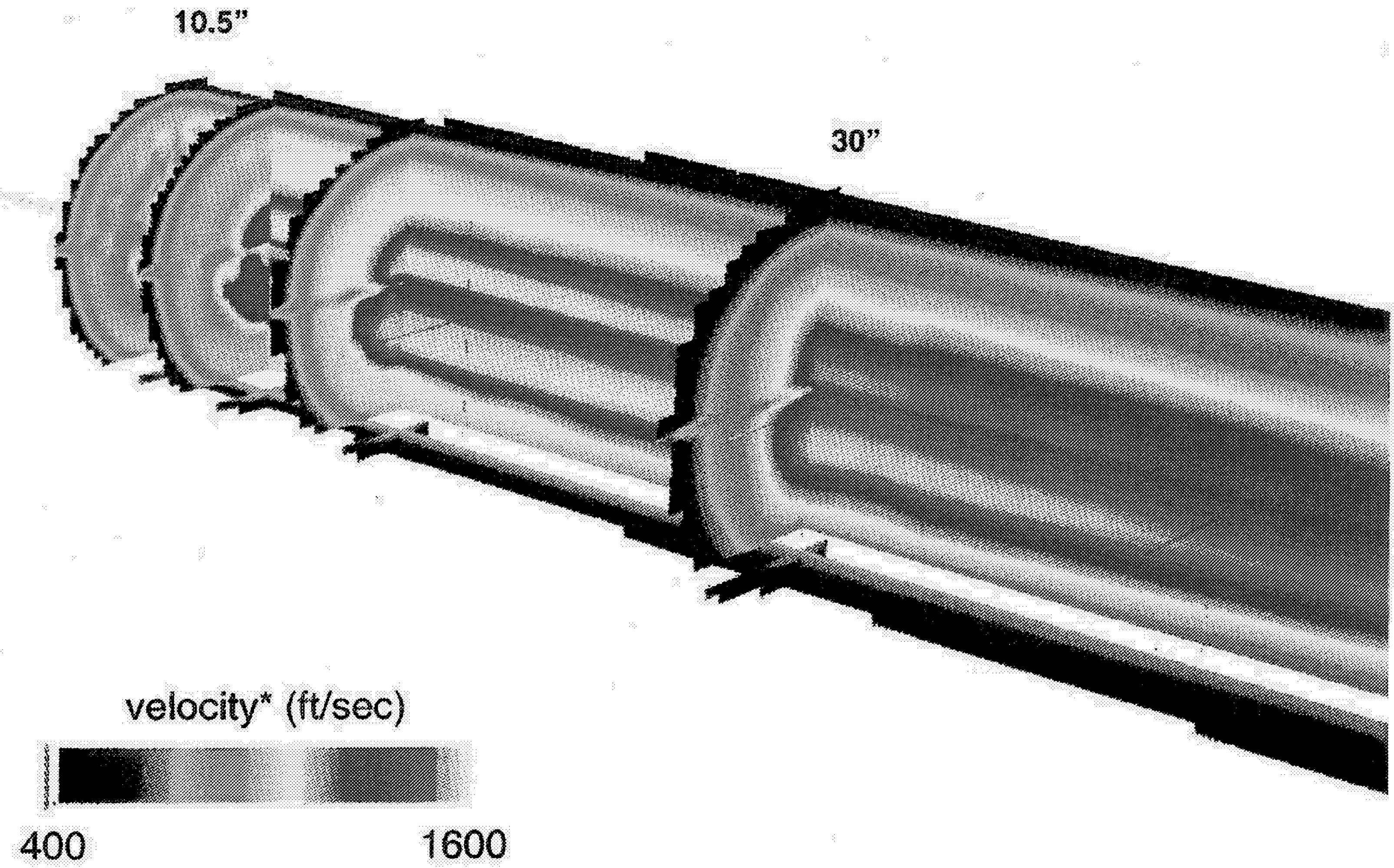
SFNT97: Plume survey

Mean velocity field
3T24T24
Cycle point 21, M=0.28



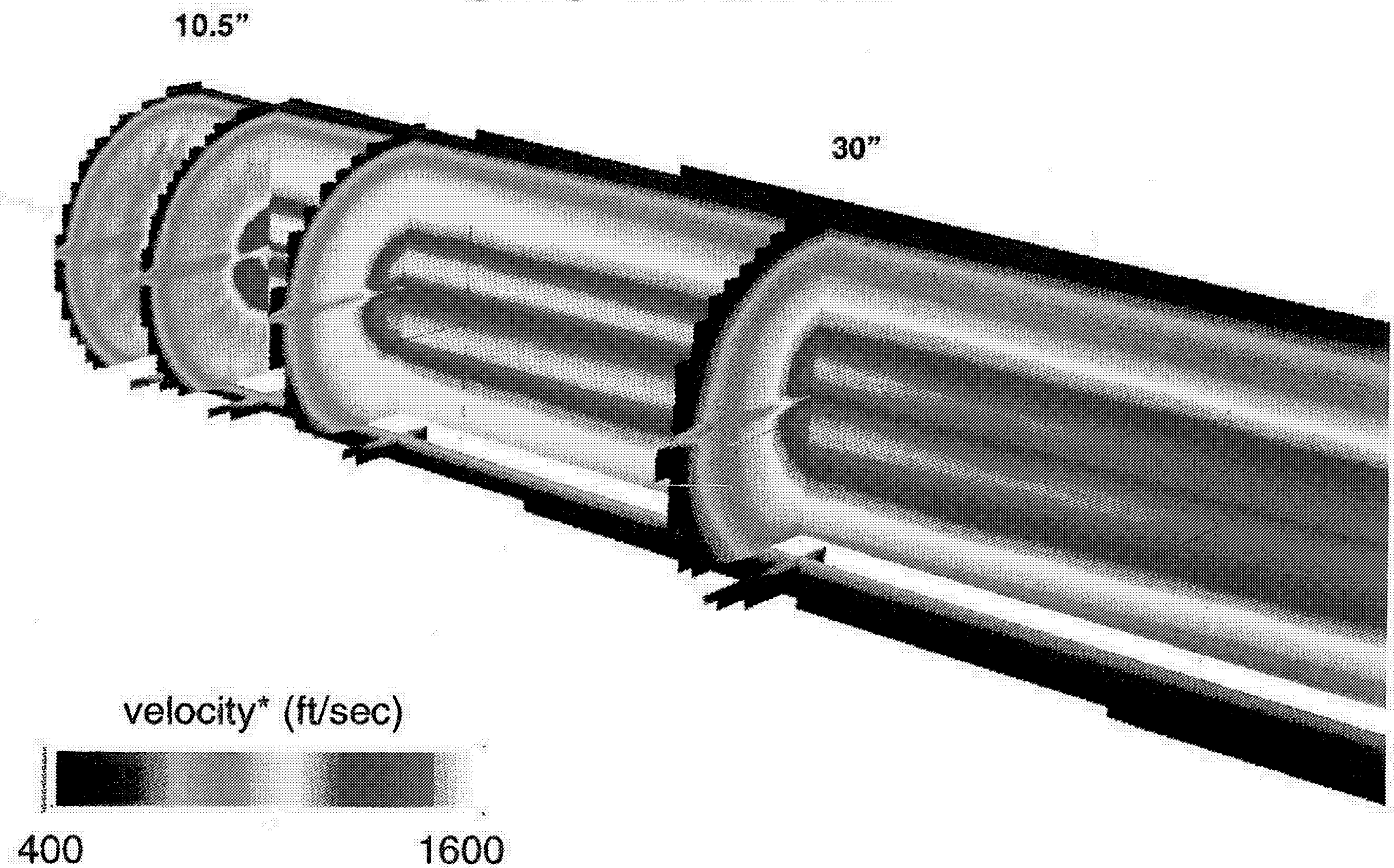
SFNT97: Plume survey

Mean velocity field
3HB
Cycle point 21, M=0.28



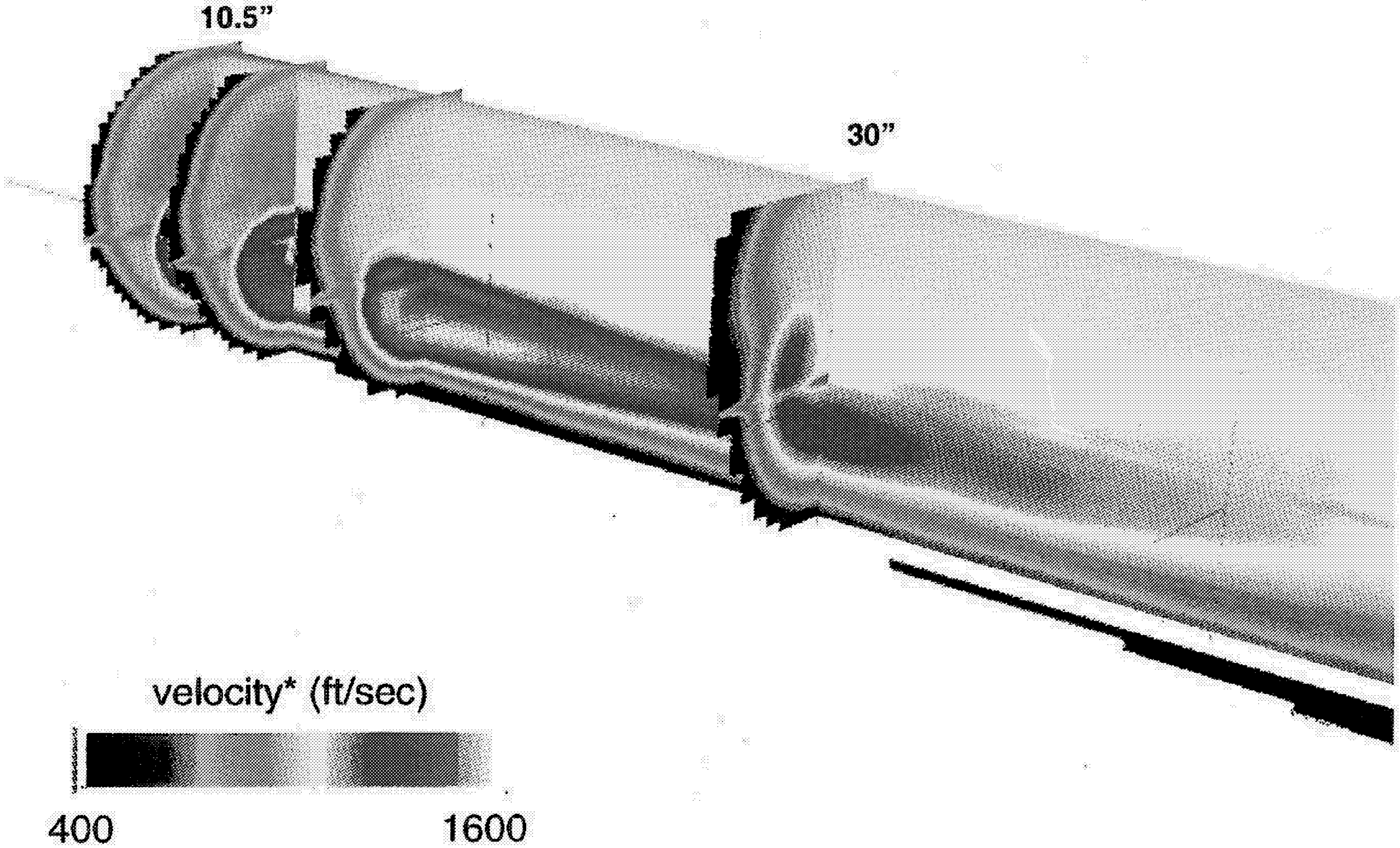
SFNT97: Plume survey

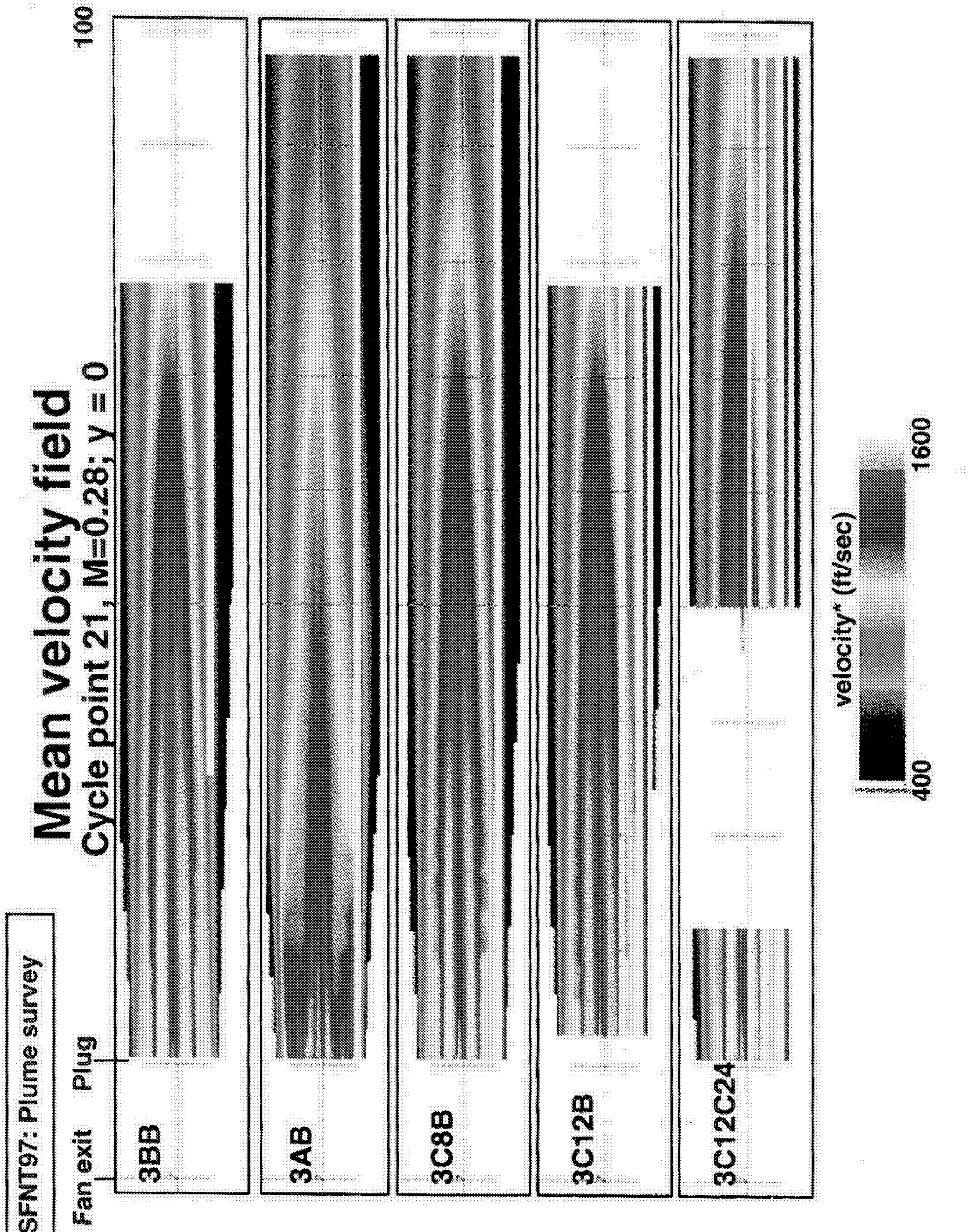
Mean velocity field
3FB
Cycle point 21, M=0.28

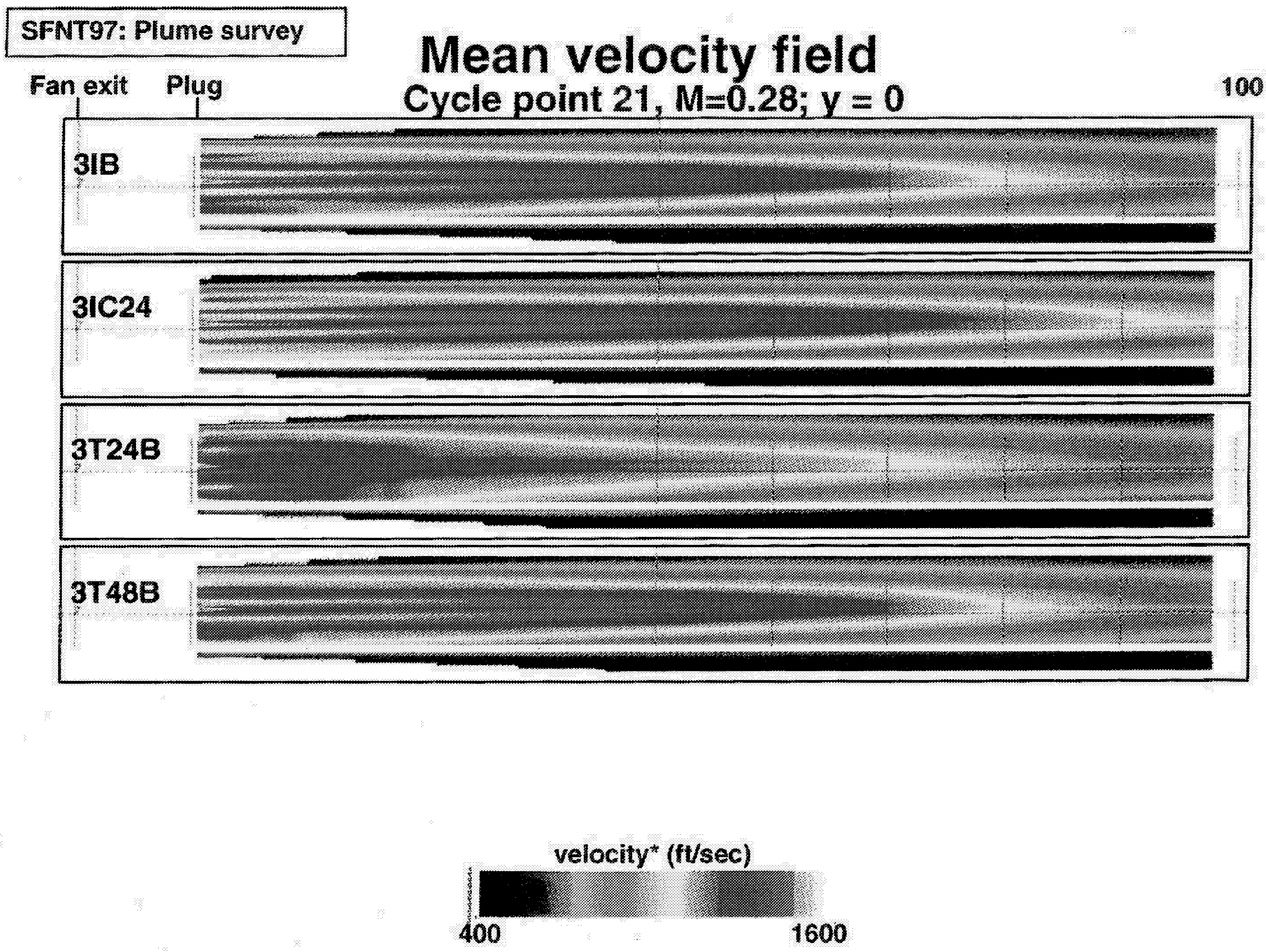


SFNT97: Plume survey

Mean velocity field
3BO
Cycle point 21, M=0.28



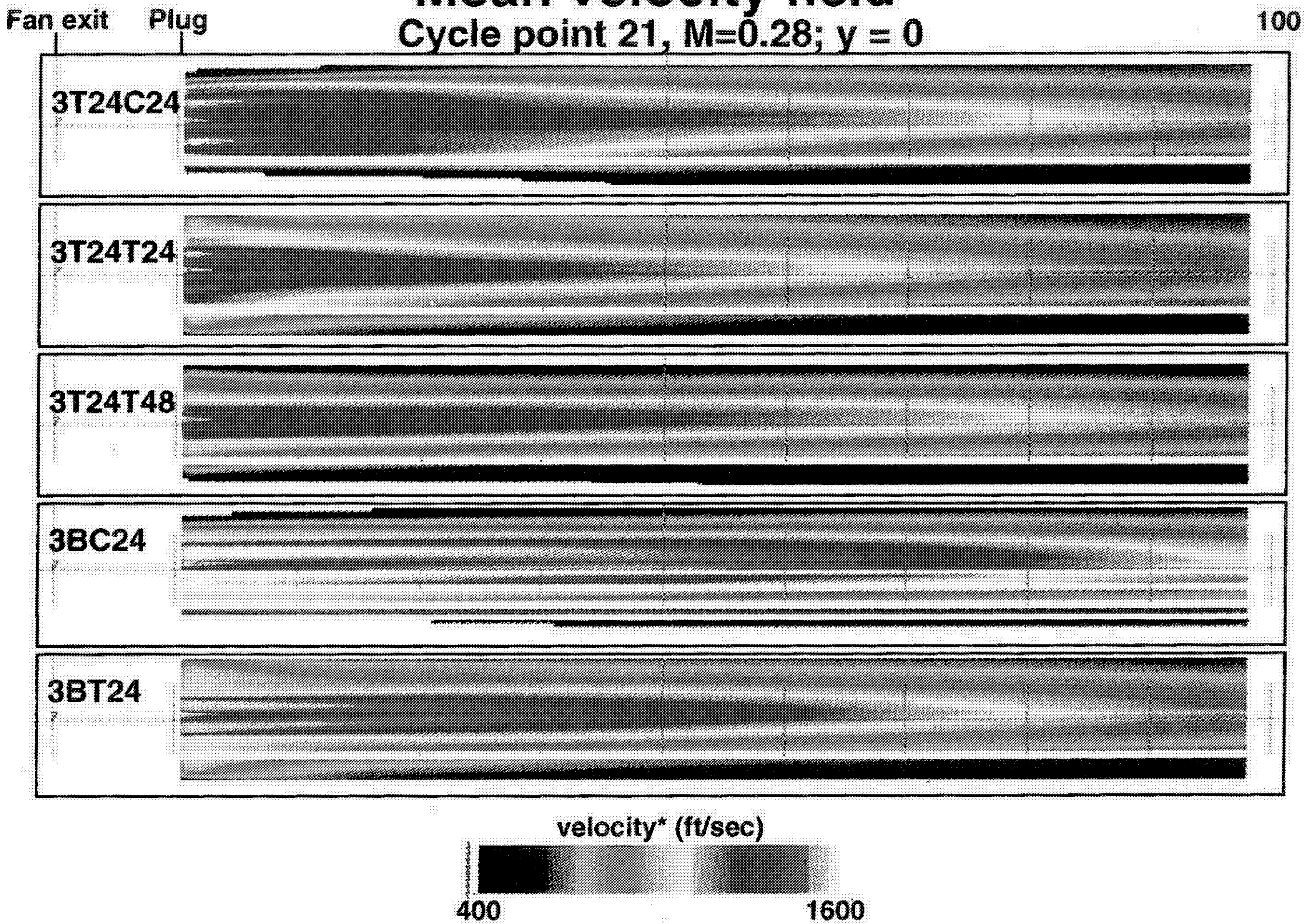

SFNT97: Plume survey
Mean velocity field
Cycle point 21, M=0.28; y = 0
Fan exit
Plug
100
3BB
3AB
3C8B
3C12B
3C12C24
velocity* (ft/sec)
400
1600


SFNT97: Plume survey
Mean velocity field
Cycle point 21, M=0.28; y = 0
Fan exit
Plug
100
3IB
3IC24
3T24B
3T48B
velocity* (ft/sec)
400
1600

SFNT97: Plume survey

Mean velocity field

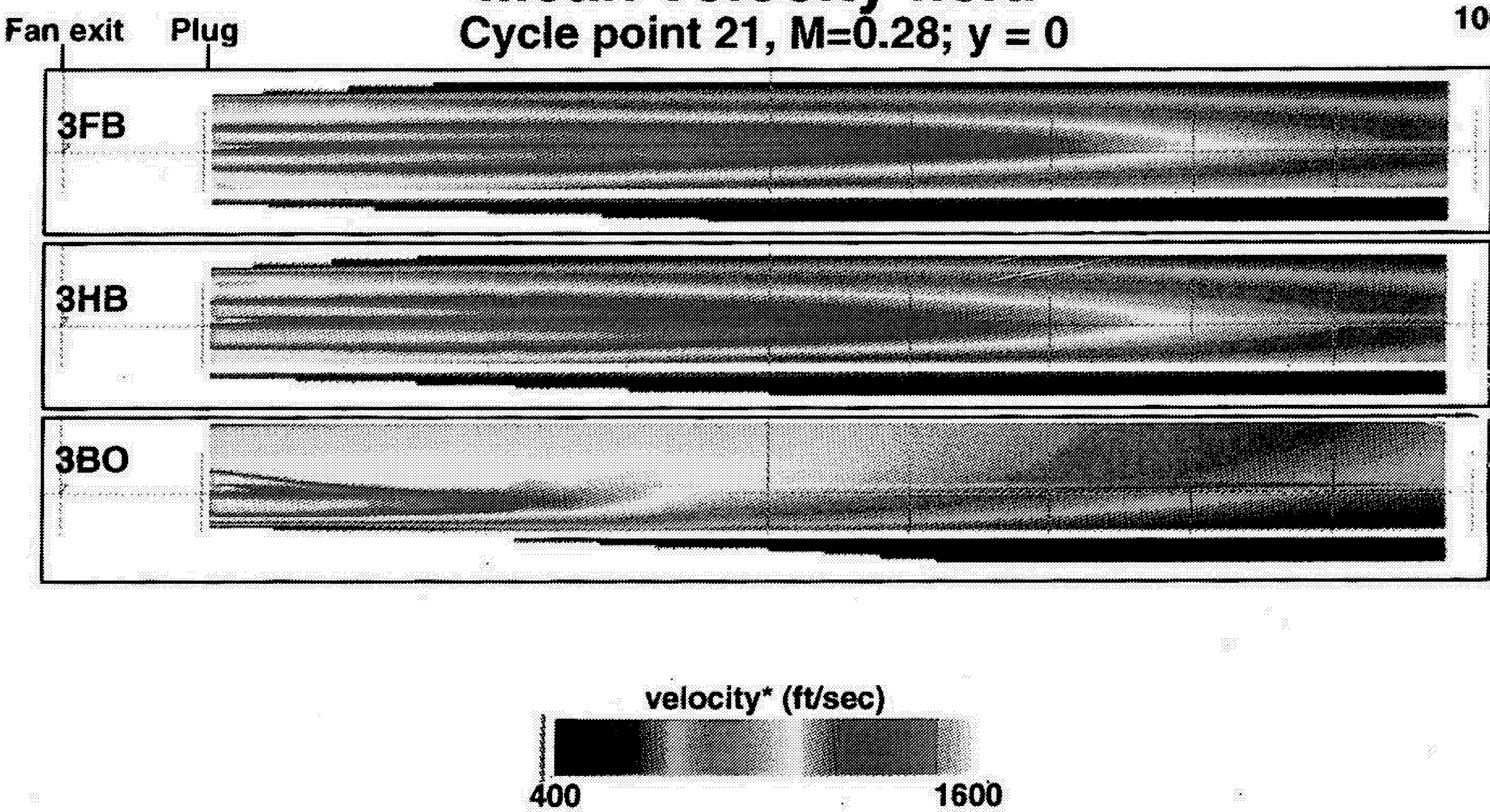
Cycle point 21, M=0.28; y = 0



SFNT97: Plume survey

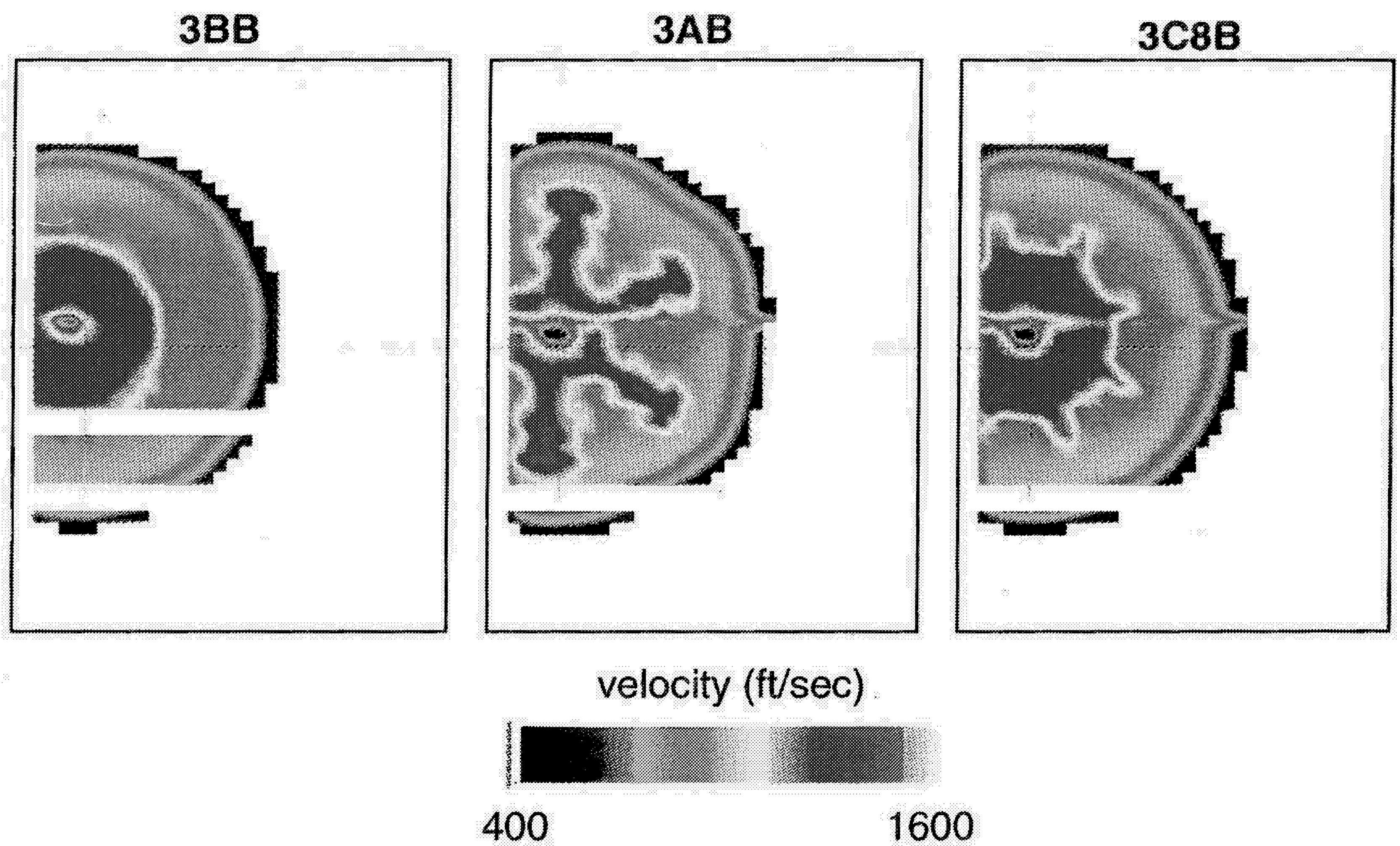
Mean velocity field

Cycle point 21, M=0.28; y = 0



Mean velocity field

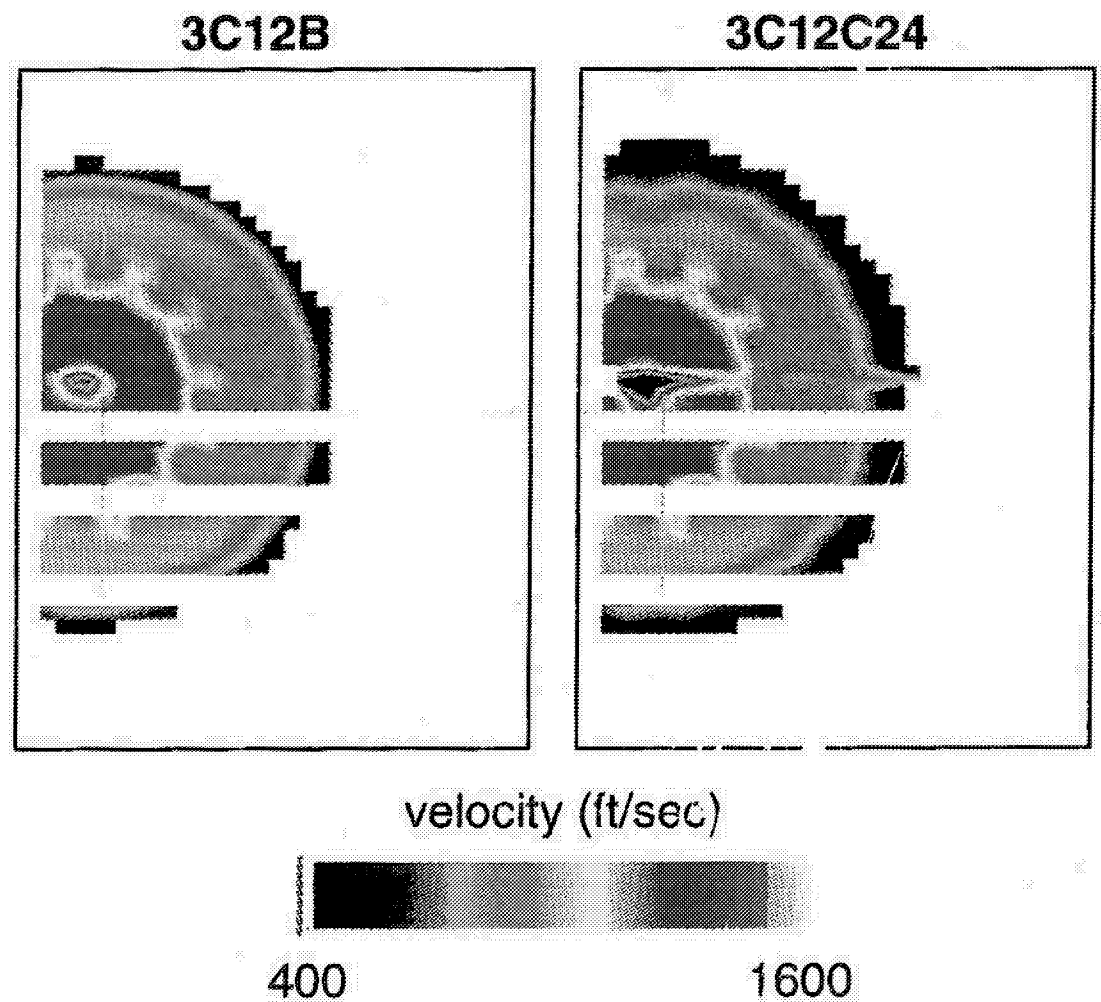
Cycle point 21, M=0.28; x=10.5”



SFNT97: Plume survey

Mean velocity field

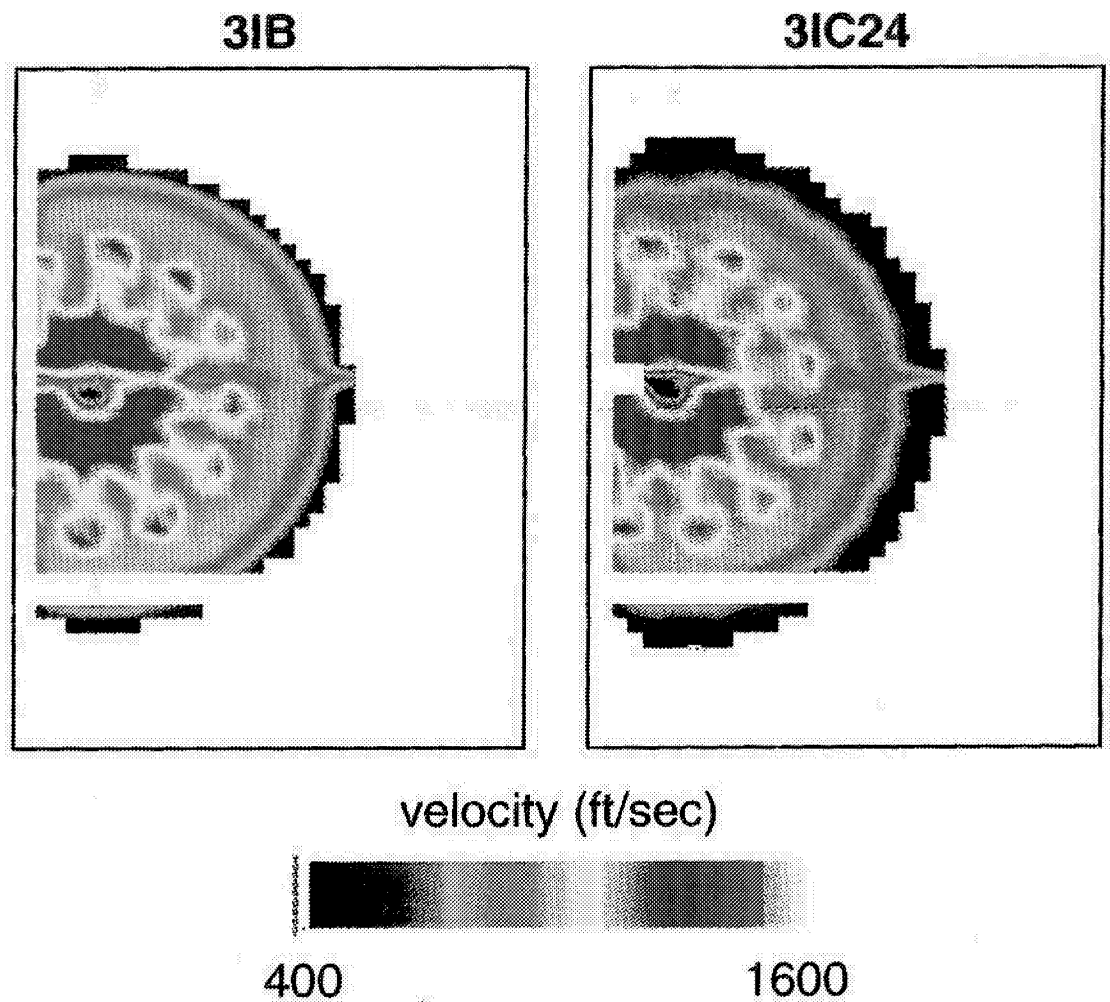
Cycle point 21, M=0.28; x=10.5”



SFNT97: Plume survey

Mean velocity field

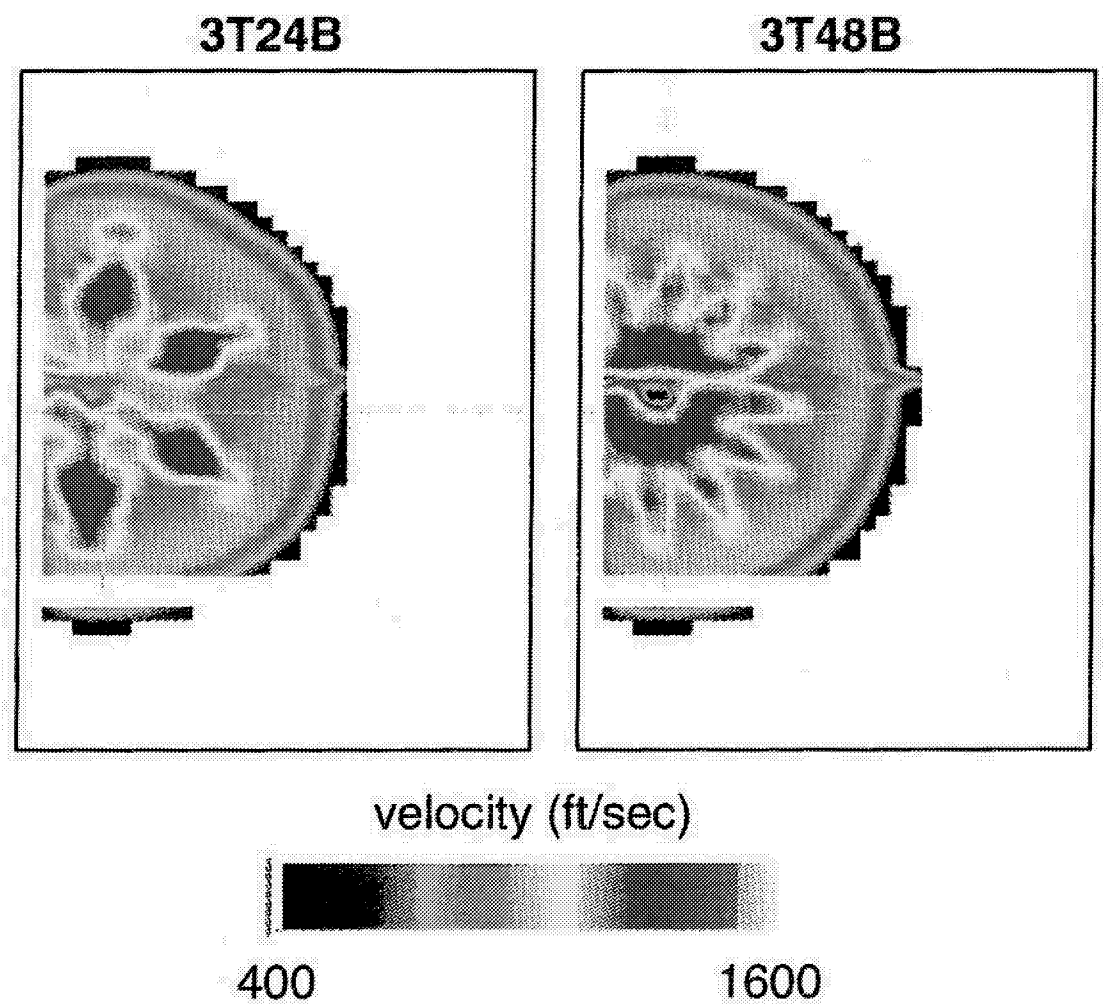
Cycle point 21, M=0.28; x=10.5"



SFNT97: Plume survey

Mean velocity field

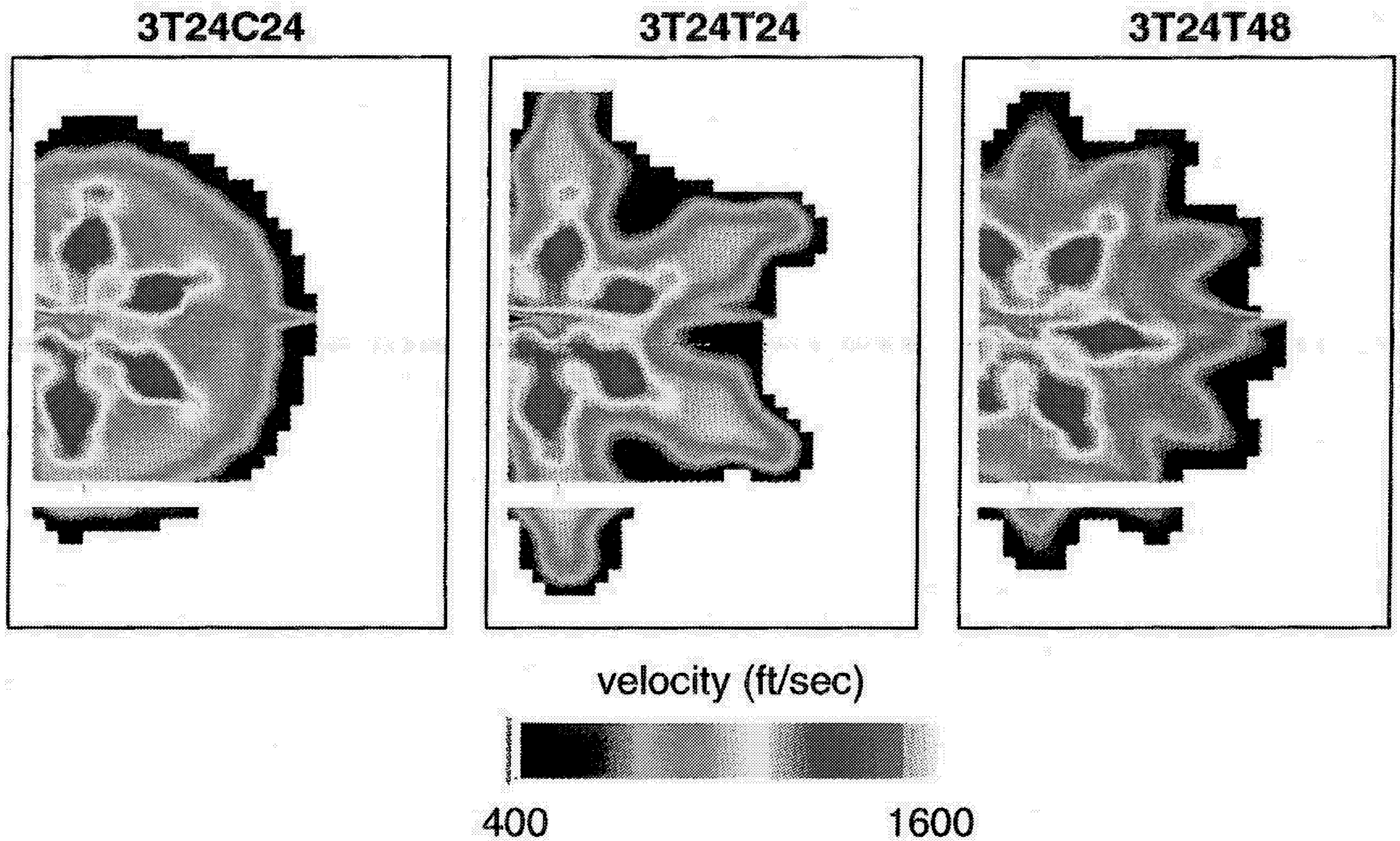
Cycle point 21, M=0.28; x=10.5”



SFNT97: Plume survey

Mean velocity field

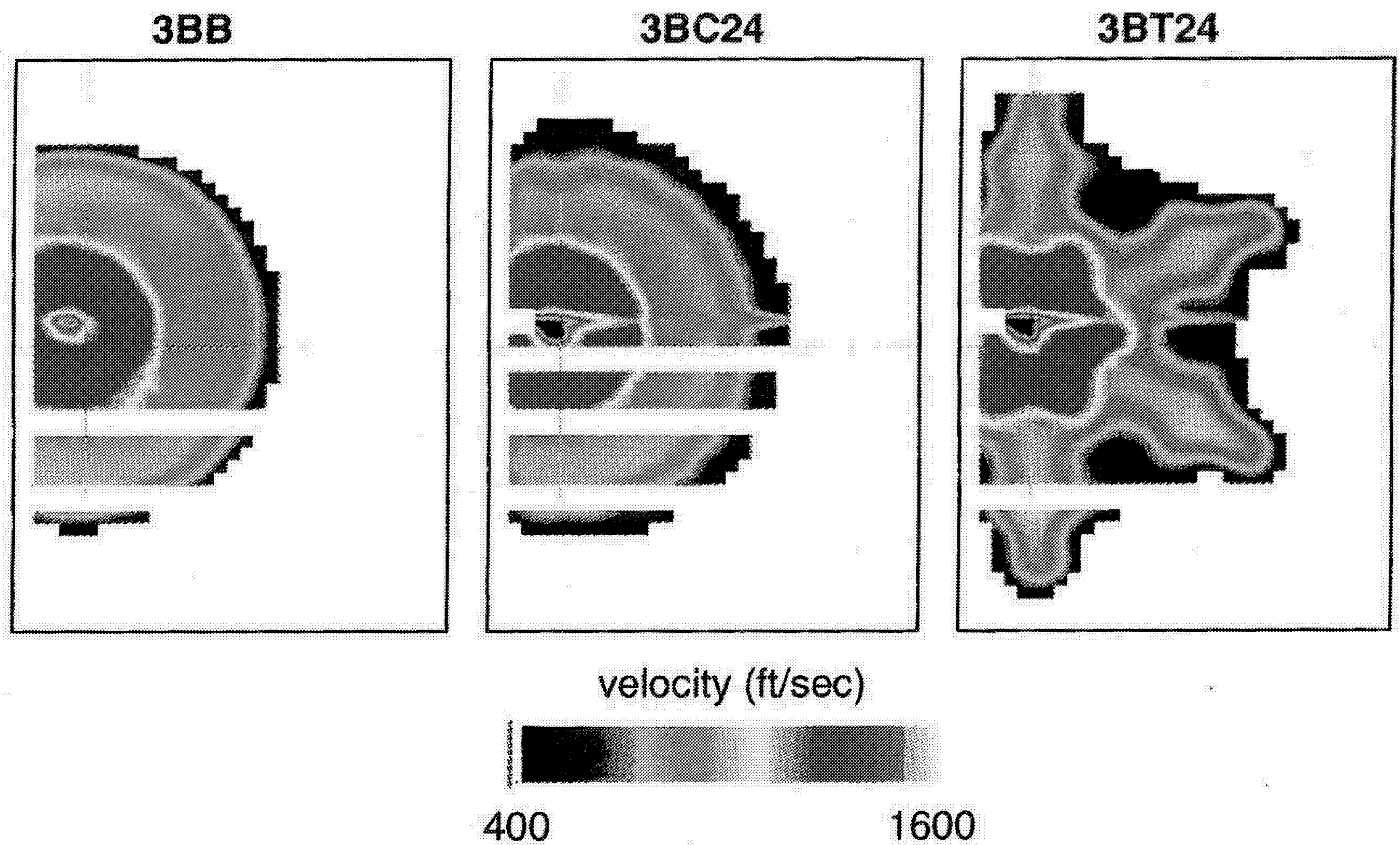
Cycle point 21, M=0.28; x=10.5”



SFNT97: Plume survey

Mean velocity field

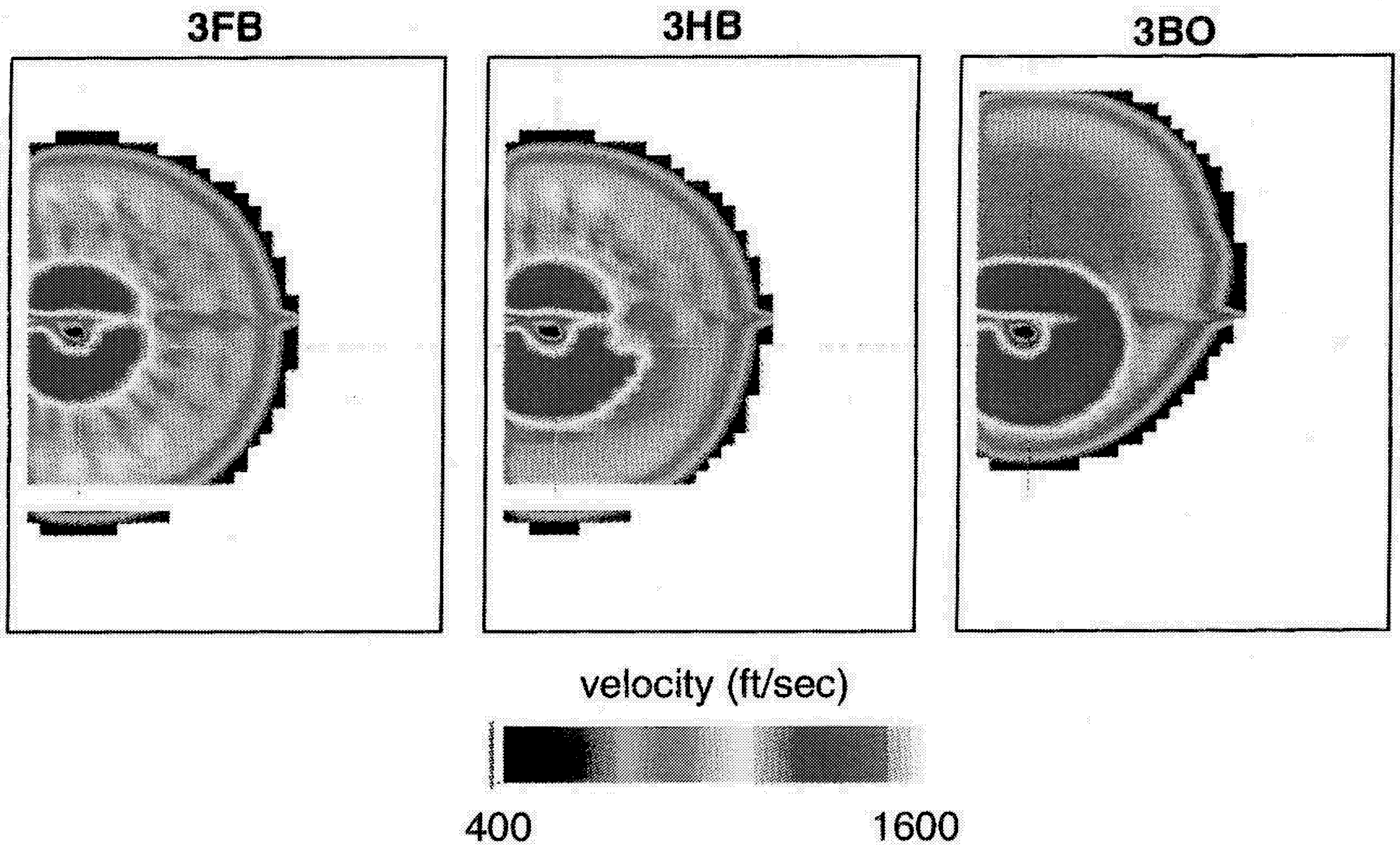
Cycle point 21, M=0.28; x=10.5”



SFNT97: Plume survey

Mean velocity field

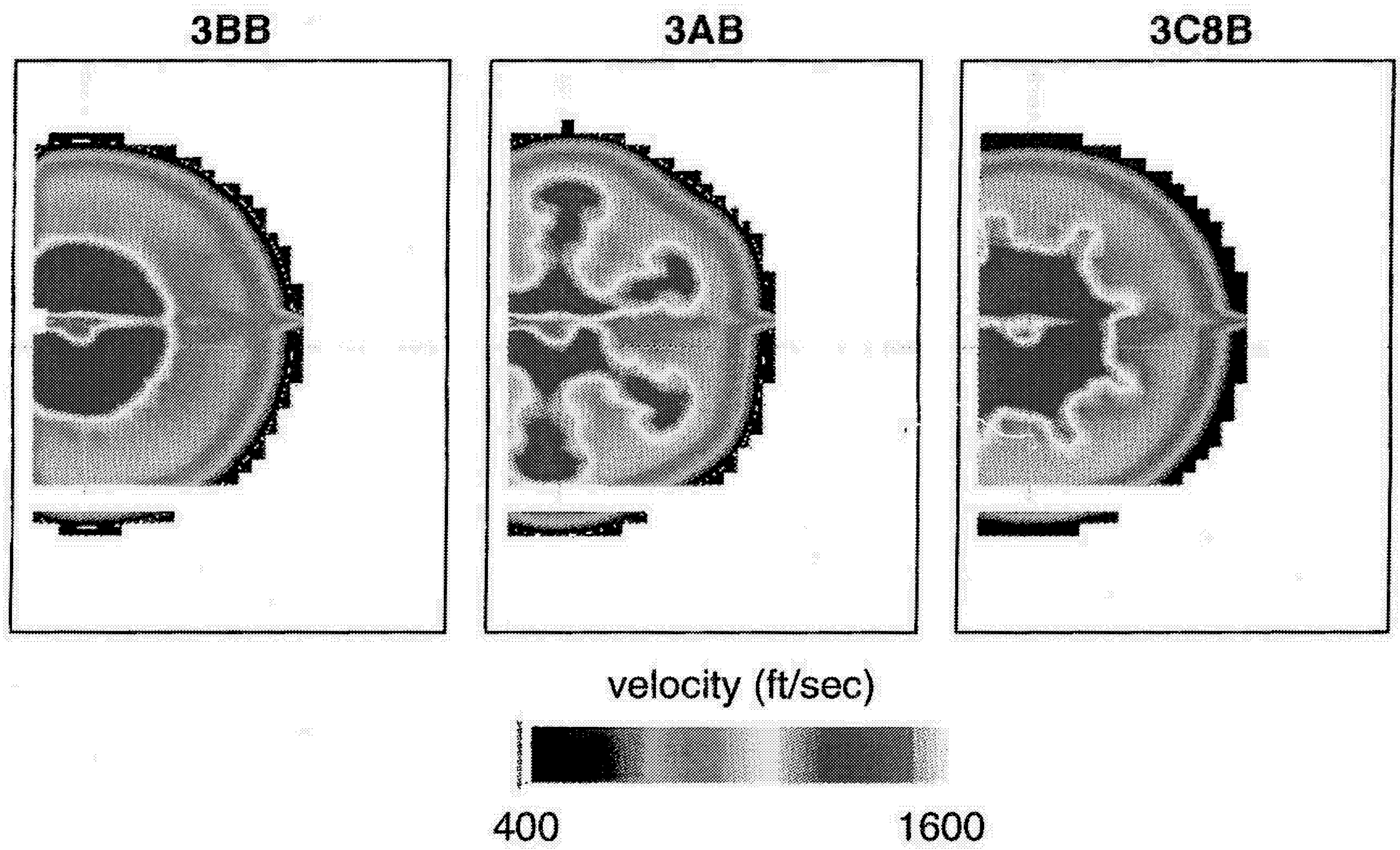
Cycle point 21, M=0.28; x=10.5"



SFNT97: Plume survey

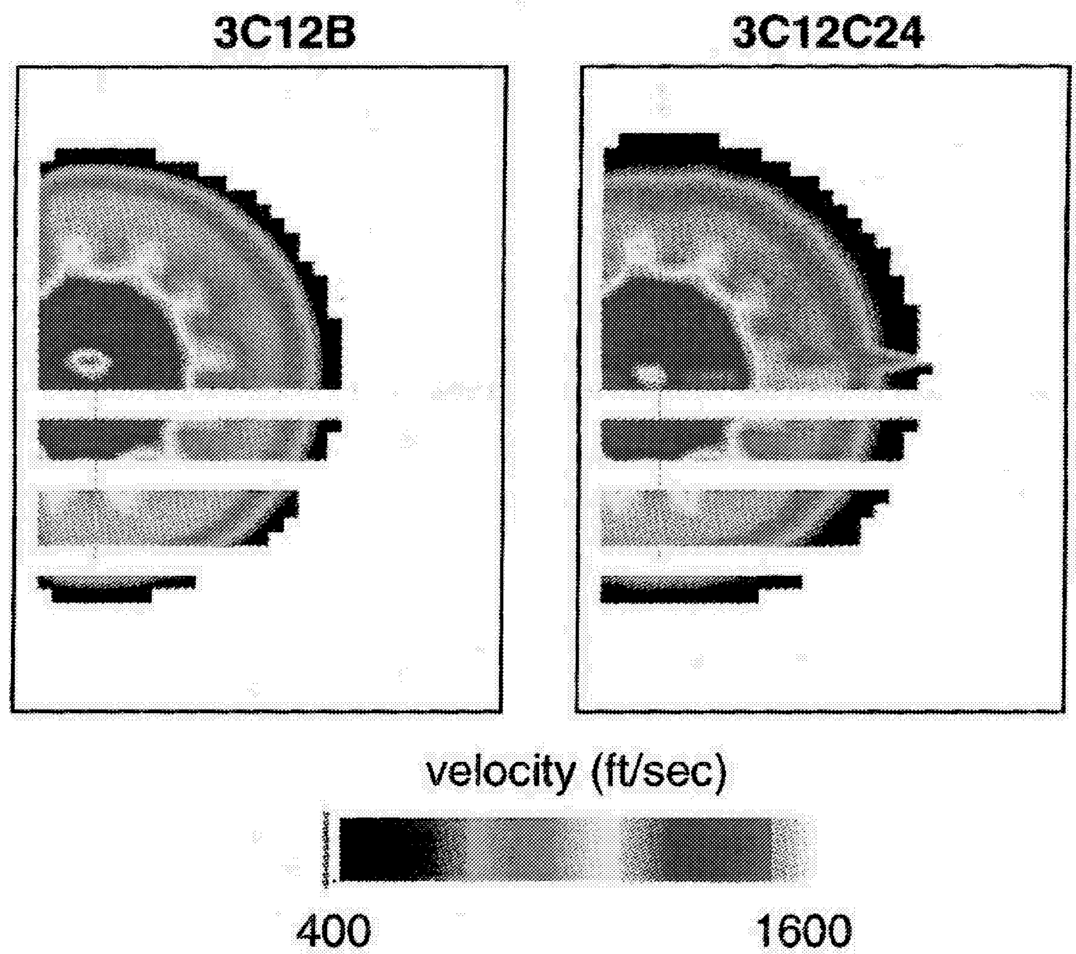
Mean velocity field

Cycle point 21, M=0.28; x=13.5"



SFNT97: Plume survey

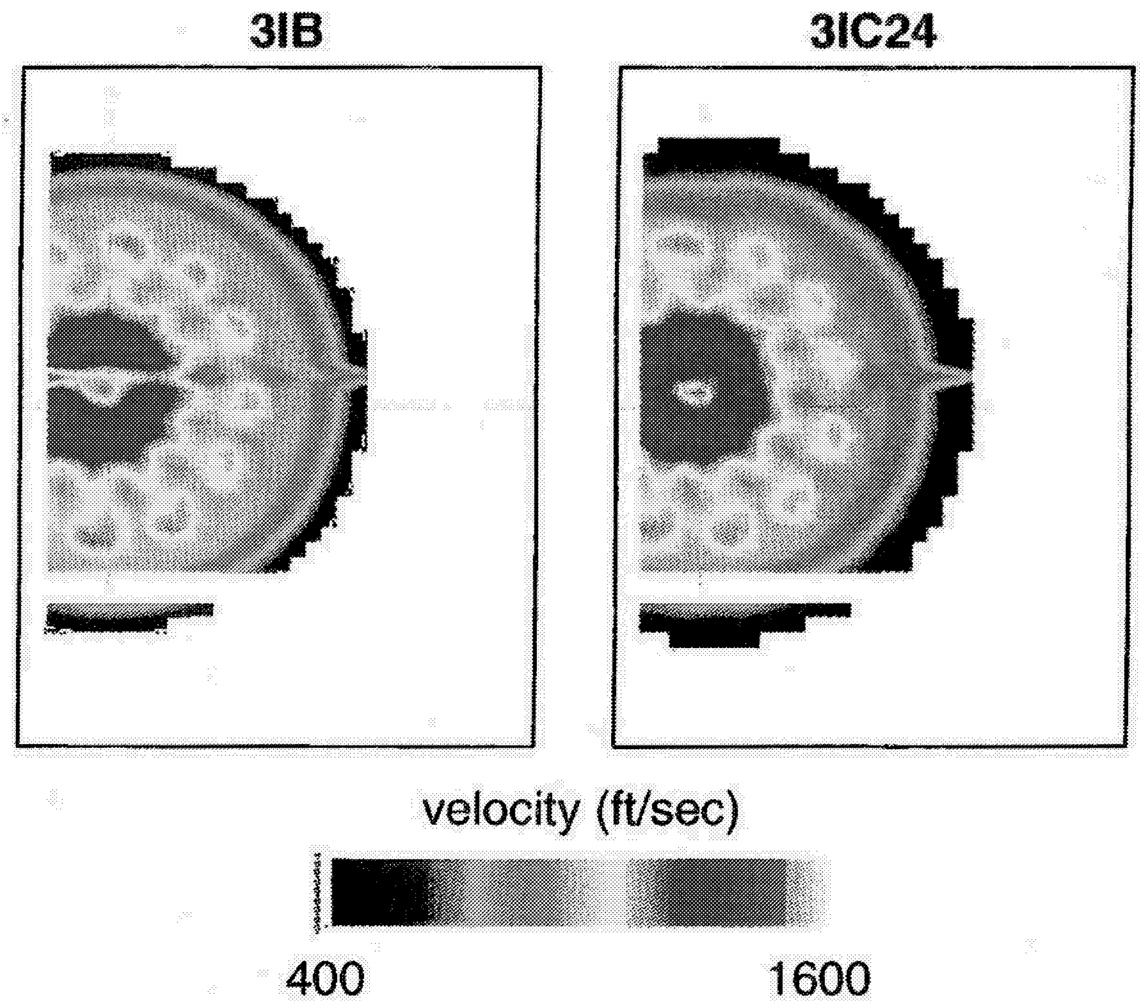
Mean velocity field
Cycle point 21, M=0.28; x=13.5”



SFNT97: Plume survey

Mean velocity field

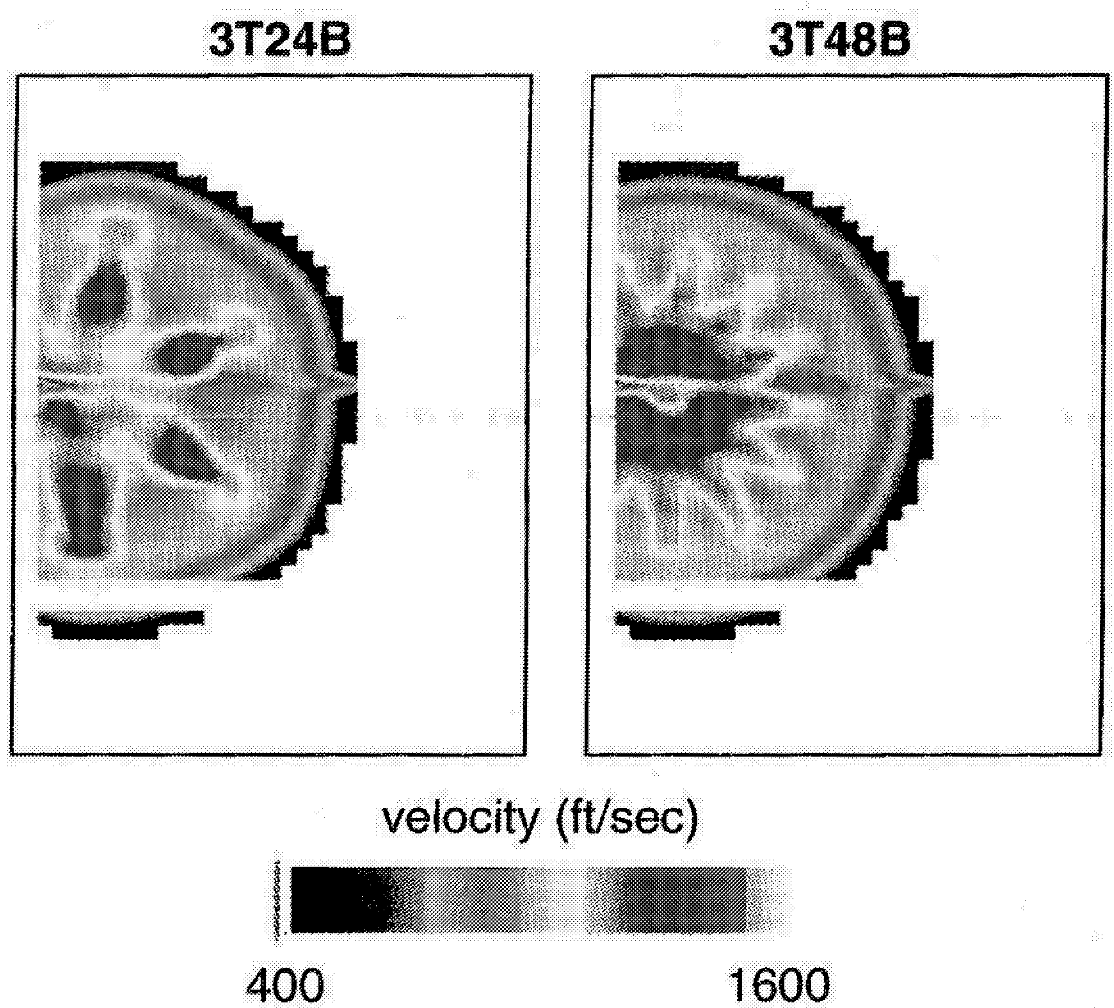
Cycle point 21, M=0.28; x=13.5”



SFNT97: Plume survey

Mean velocity field

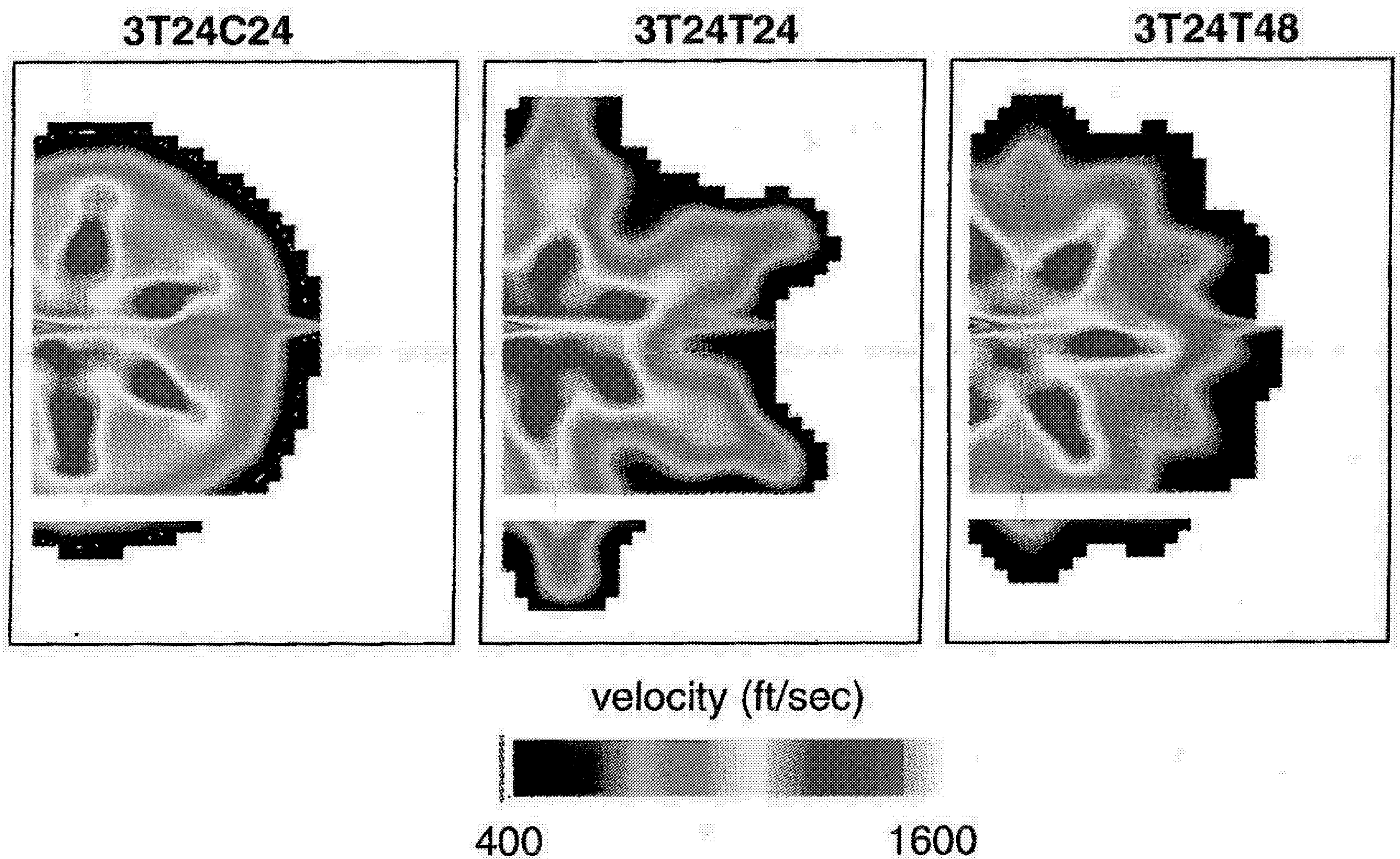
Cycle point 21, M=0.28; x=13.5”



SFNT97: Plume survey

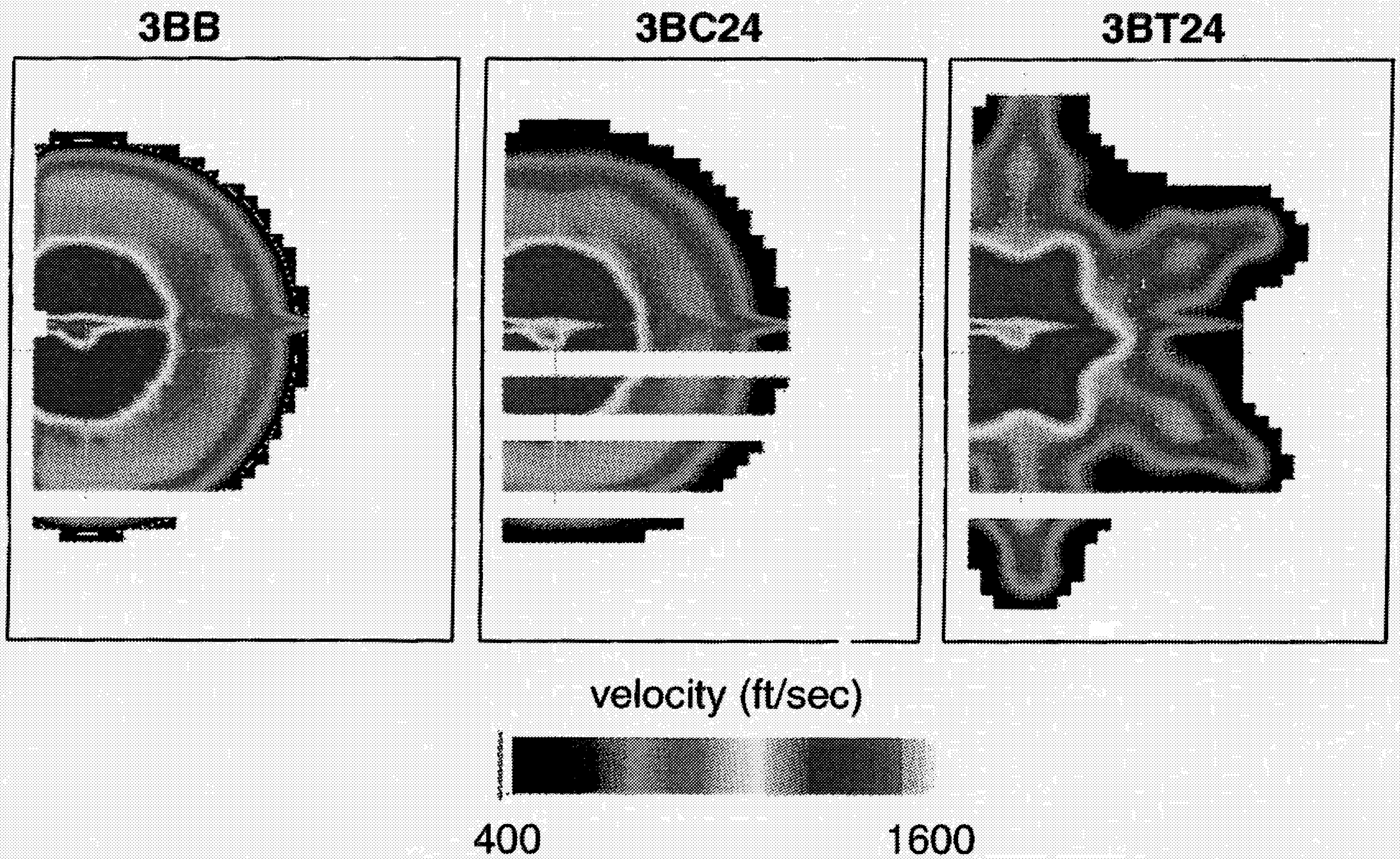
Mean velocity field

Cycle point 21, M=0.28; x=13.5"



Mean velocity field

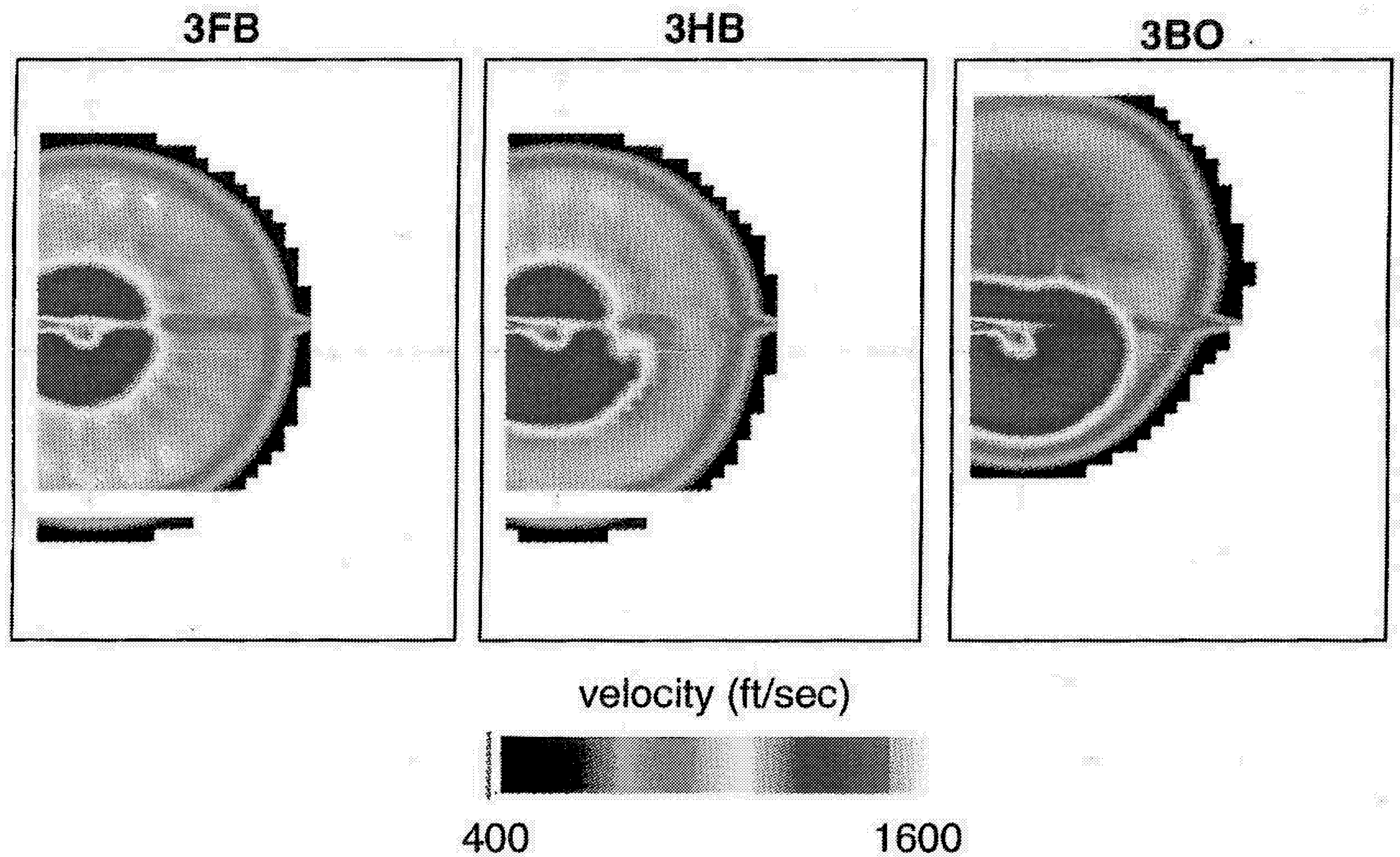
Cycle point 21, M=0.28; x=13.5"



SFNT97: Plume survey

Mean velocity field

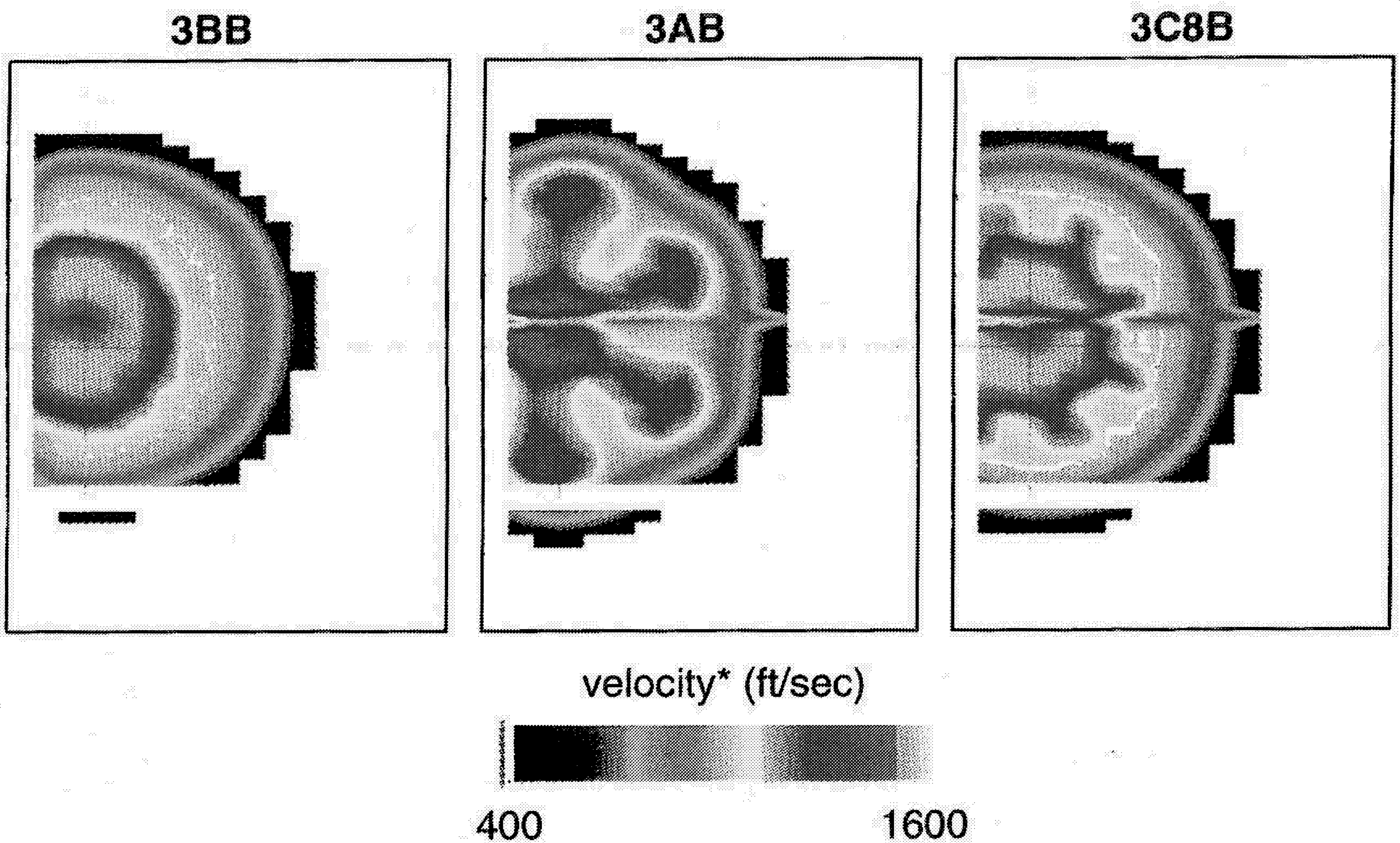
Cycle point 21, M=0.28; x=13.5”



SFNT97: Plume survey

Mean velocity field

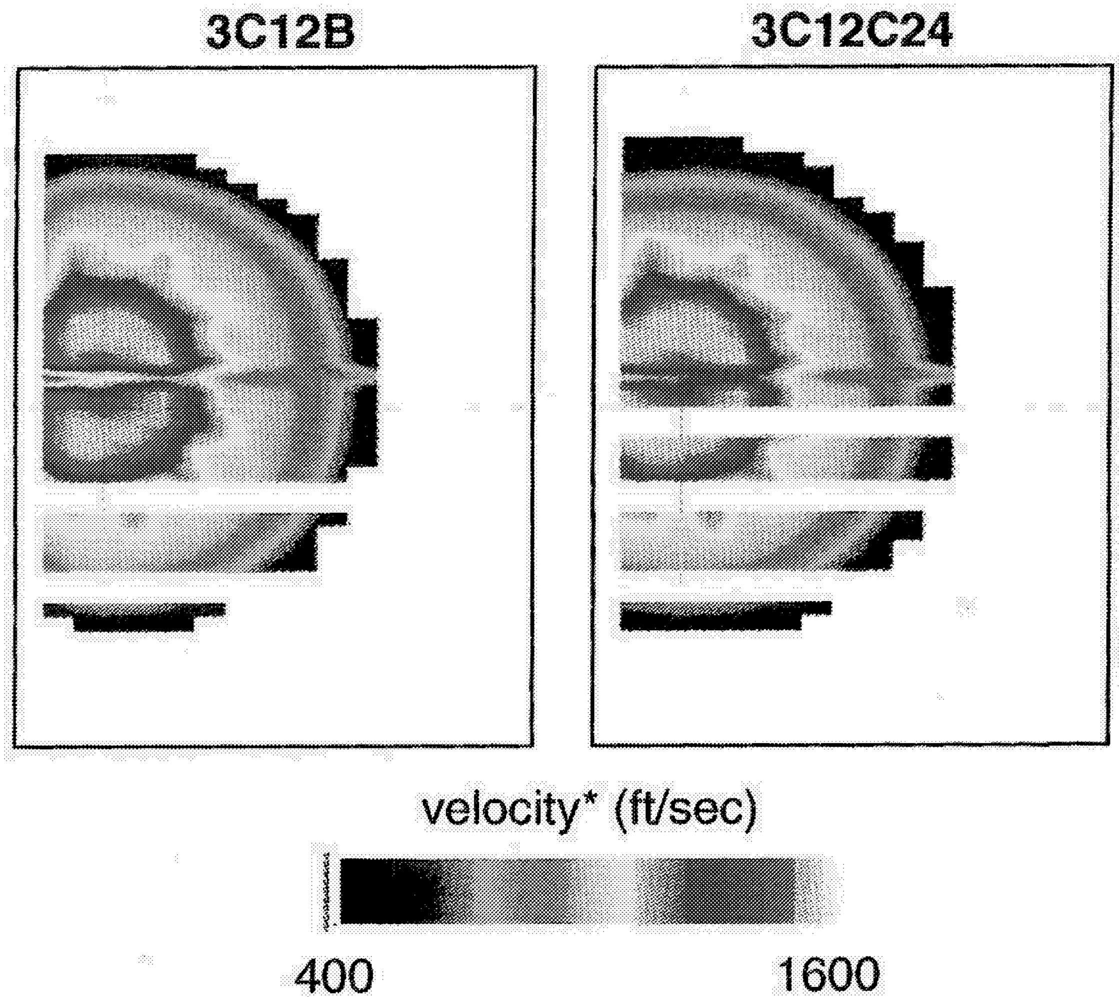
Cycle point 21, M=0.28; x=18”



SFNT97: Plume survey

Mean velocity field

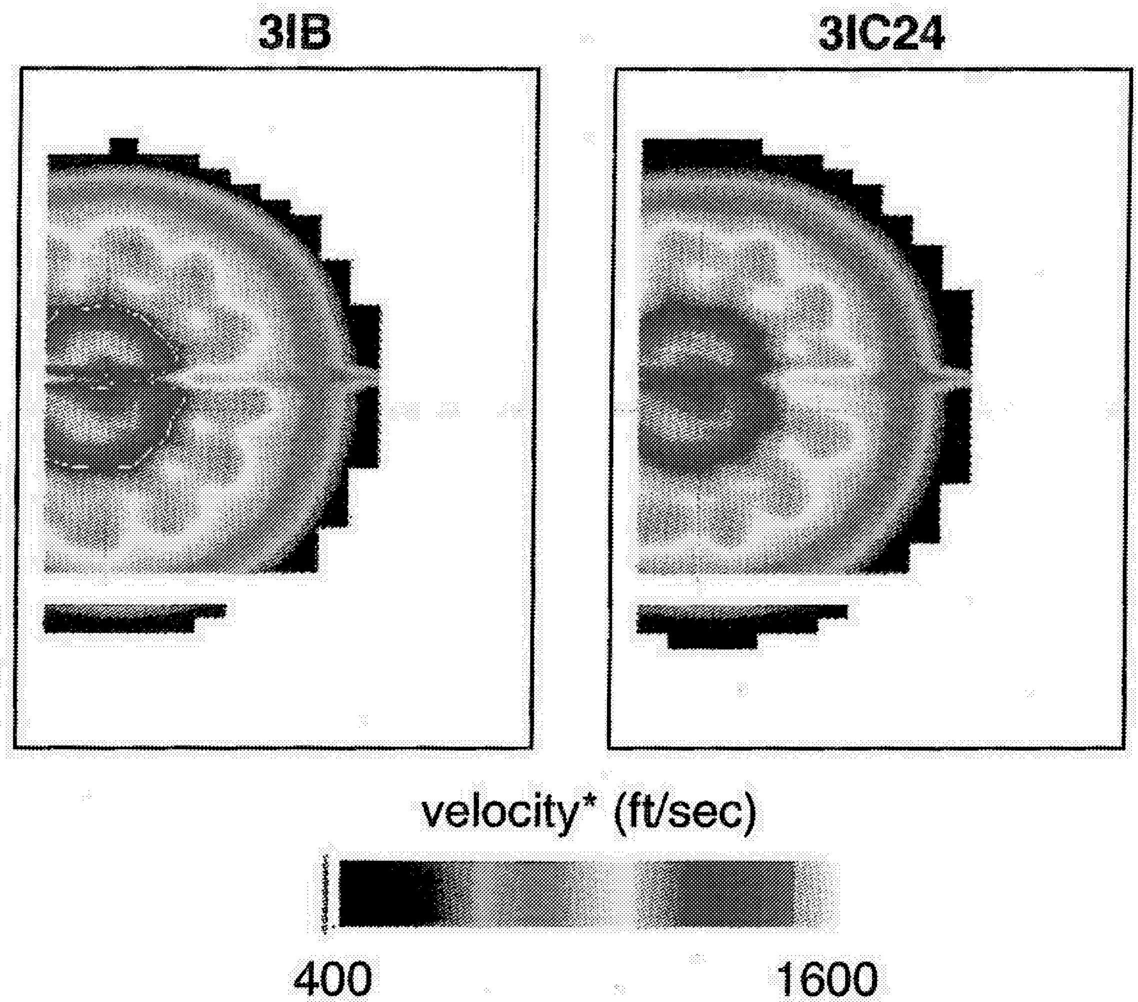
Cycle point 21, M=0.28; x=18"



SFNT97: Plume survey

Mean velocity field

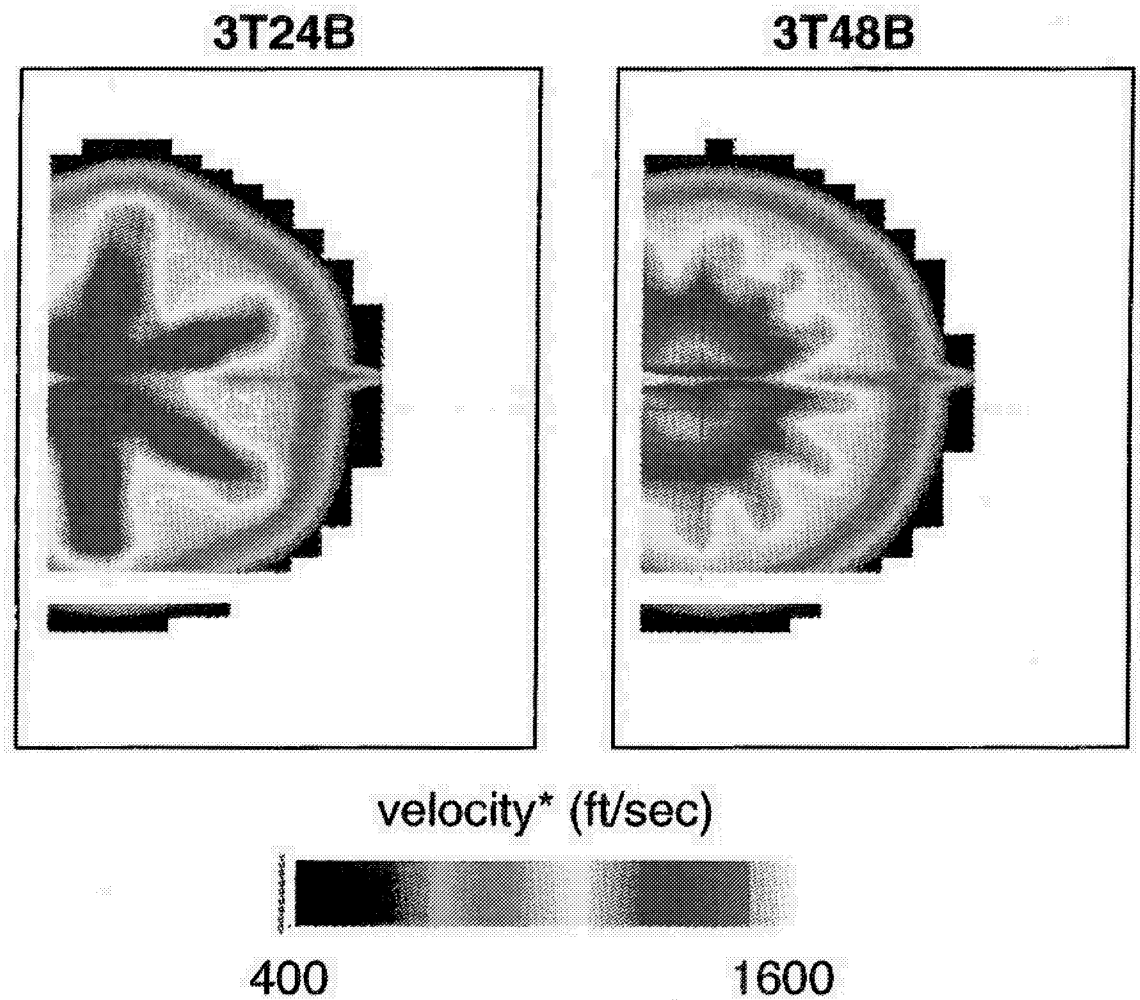
Cycle point 21, M=0.28; x=18”



SFNT97: Plume survey

Mean velocity field

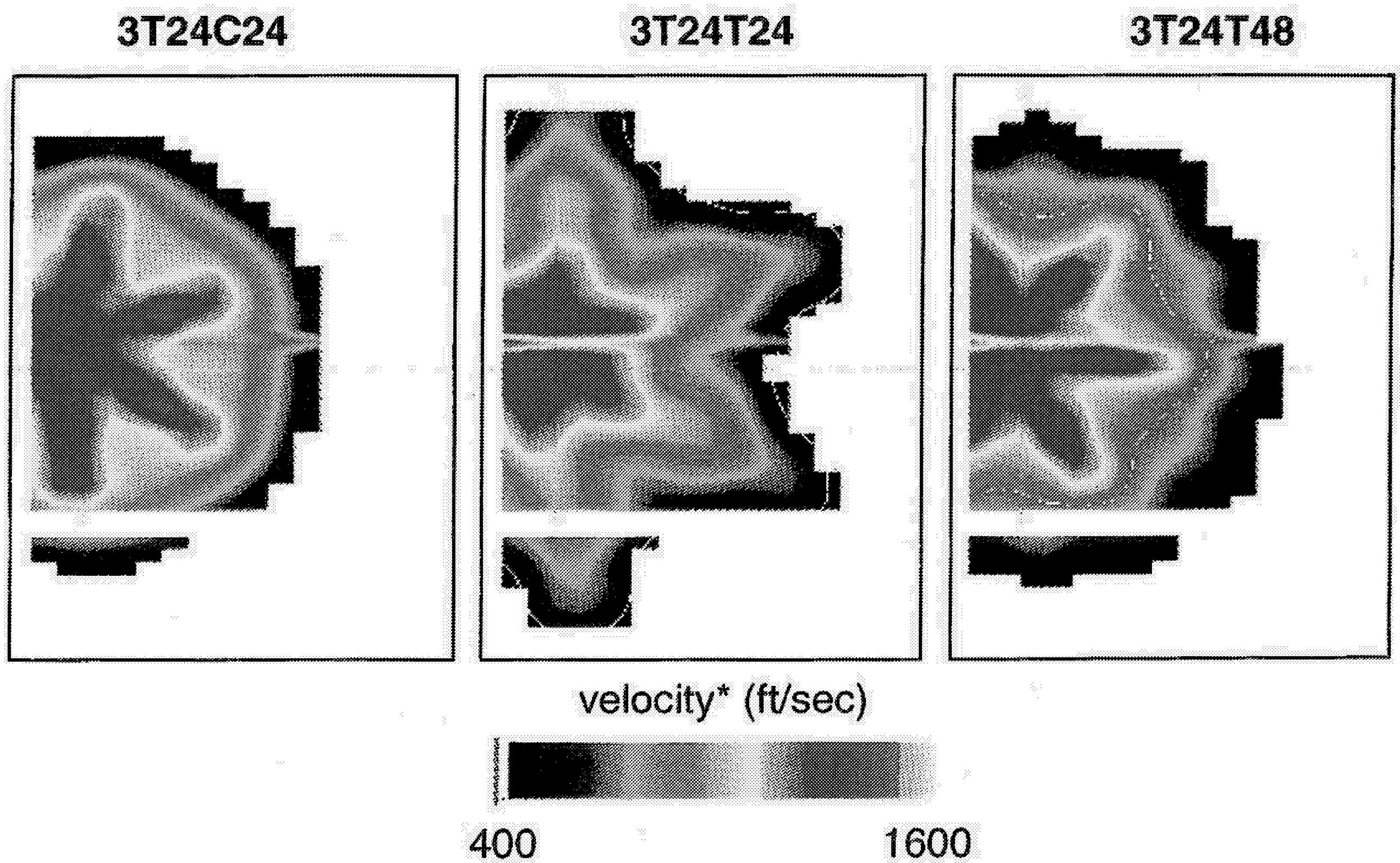
Cycle point 21, M=0.28; x=18"



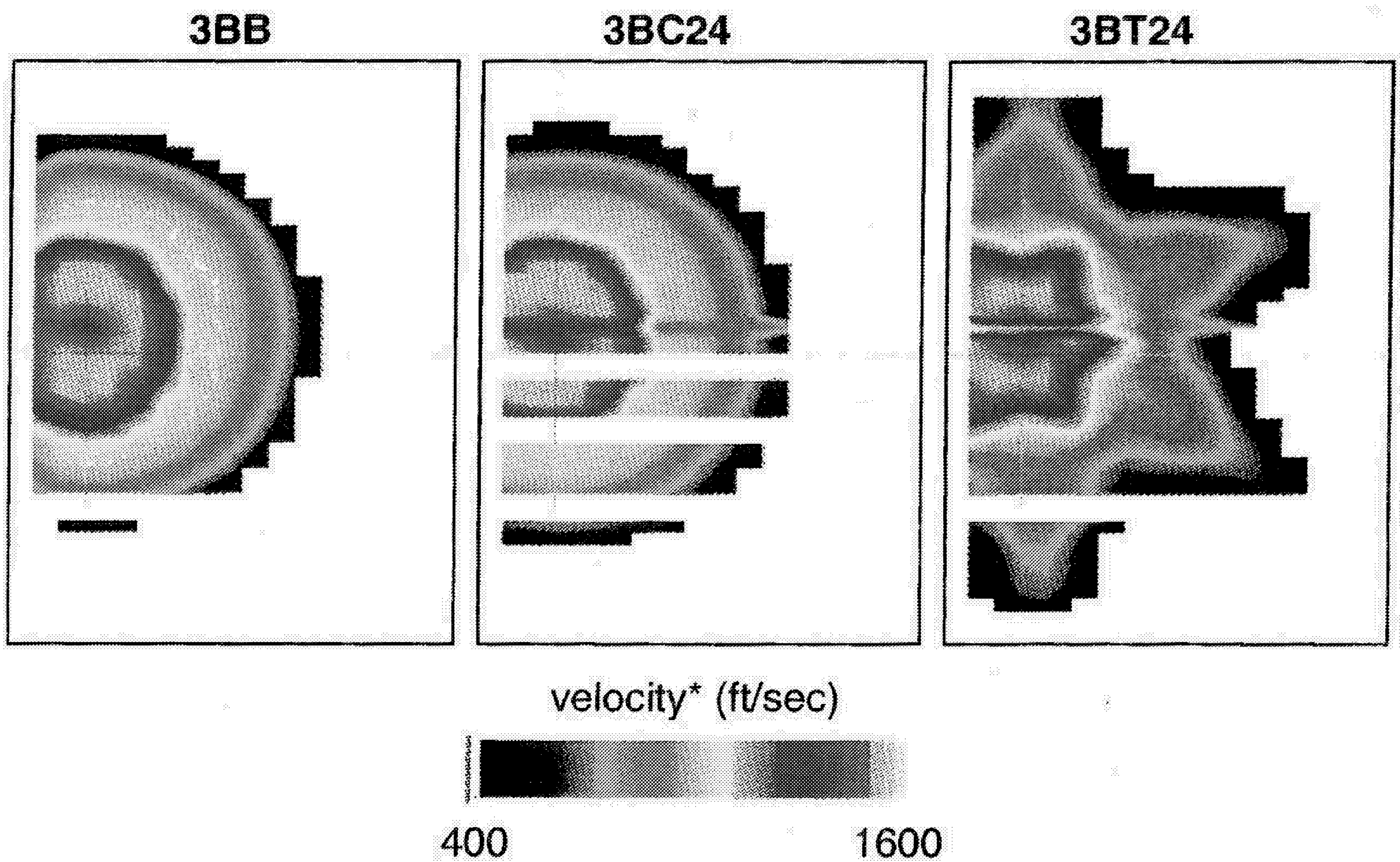
SFNT97: Plume survey

Mean velocity field

Cycle point 21, M=0.28; x=18”



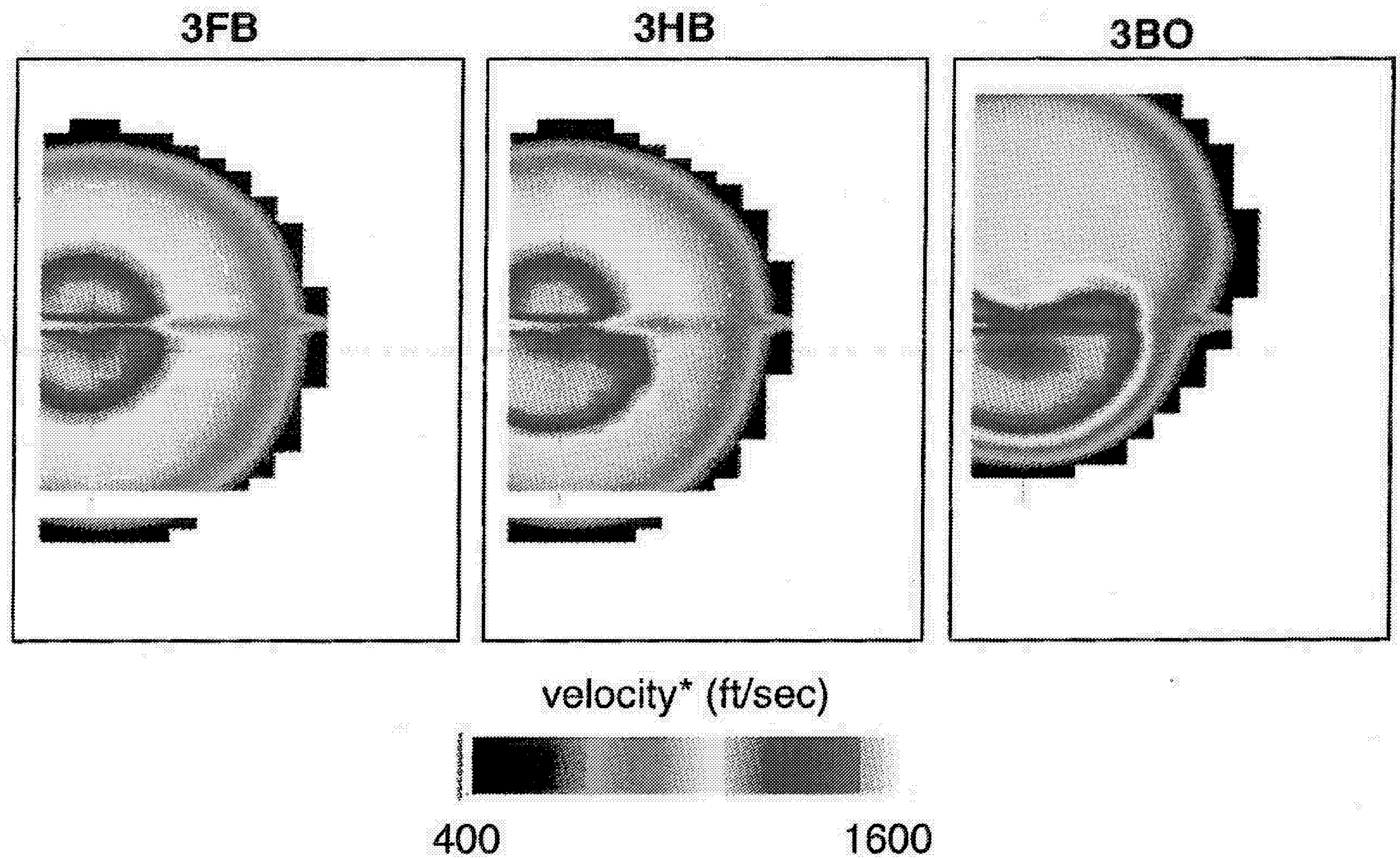
Mean velocity field
Cycle point 21, M=0.28; x=18”



SFNT97: Plume survey

Mean velocity field

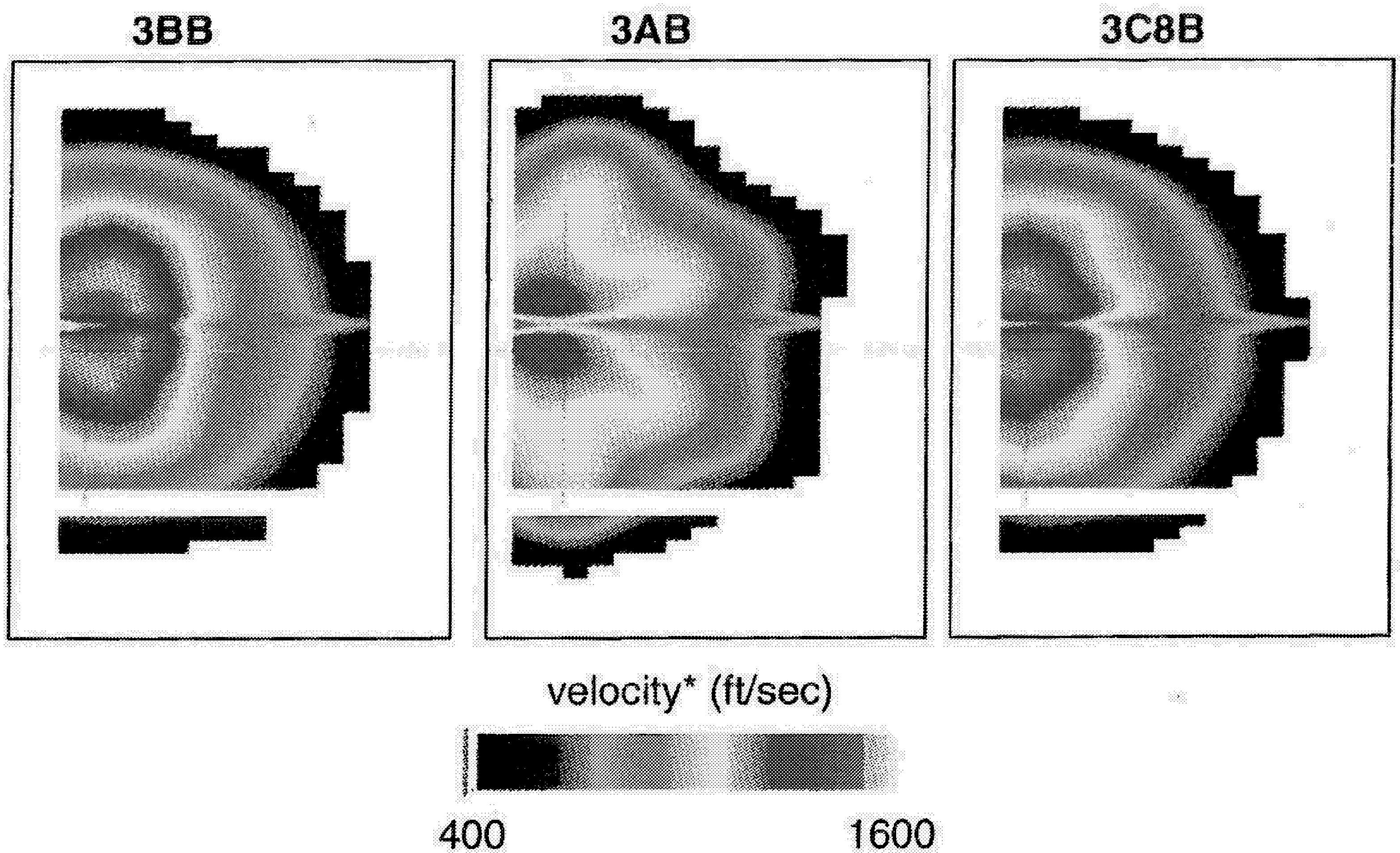
Cycle point 21, M=0.28; x=18”



SFNT97: Plume survey

Mean velocity field

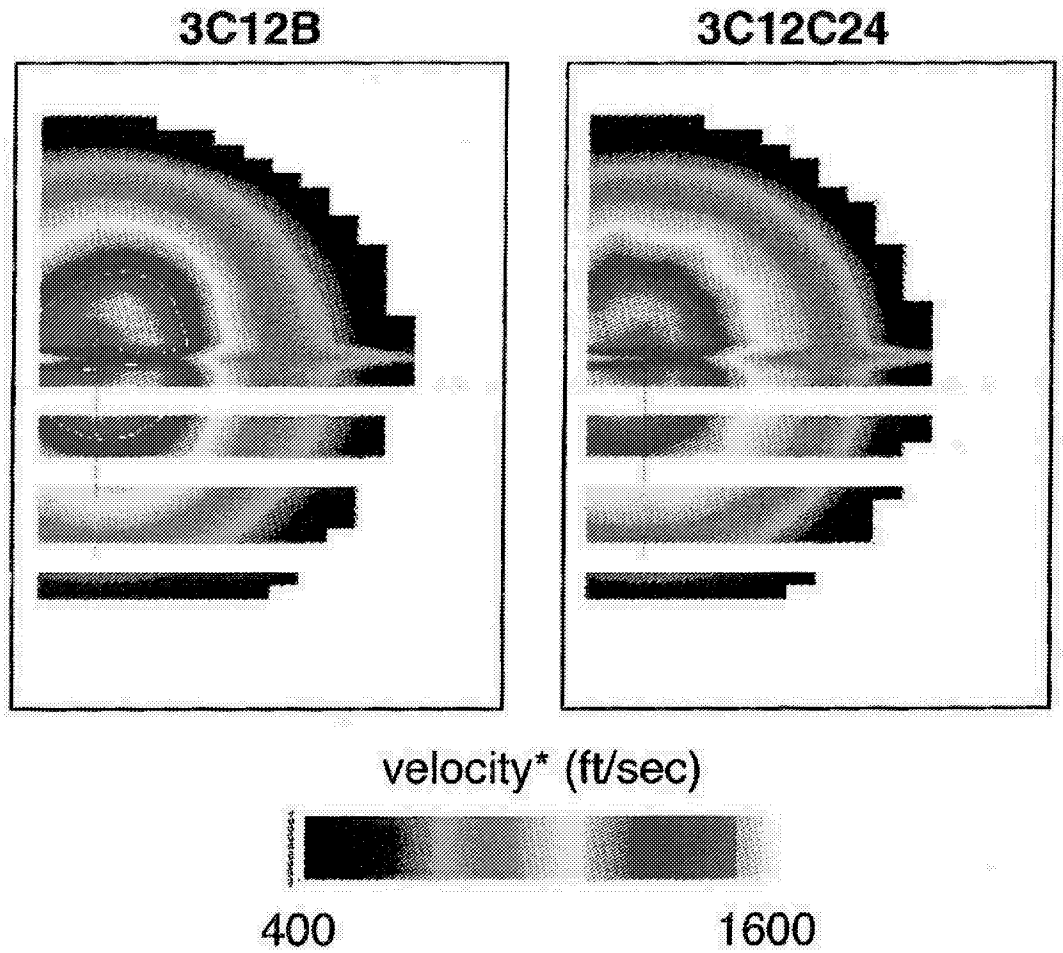
Cycle point 21, M=0.28; x=30"



SFNT97: Plume survey

Mean velocity field

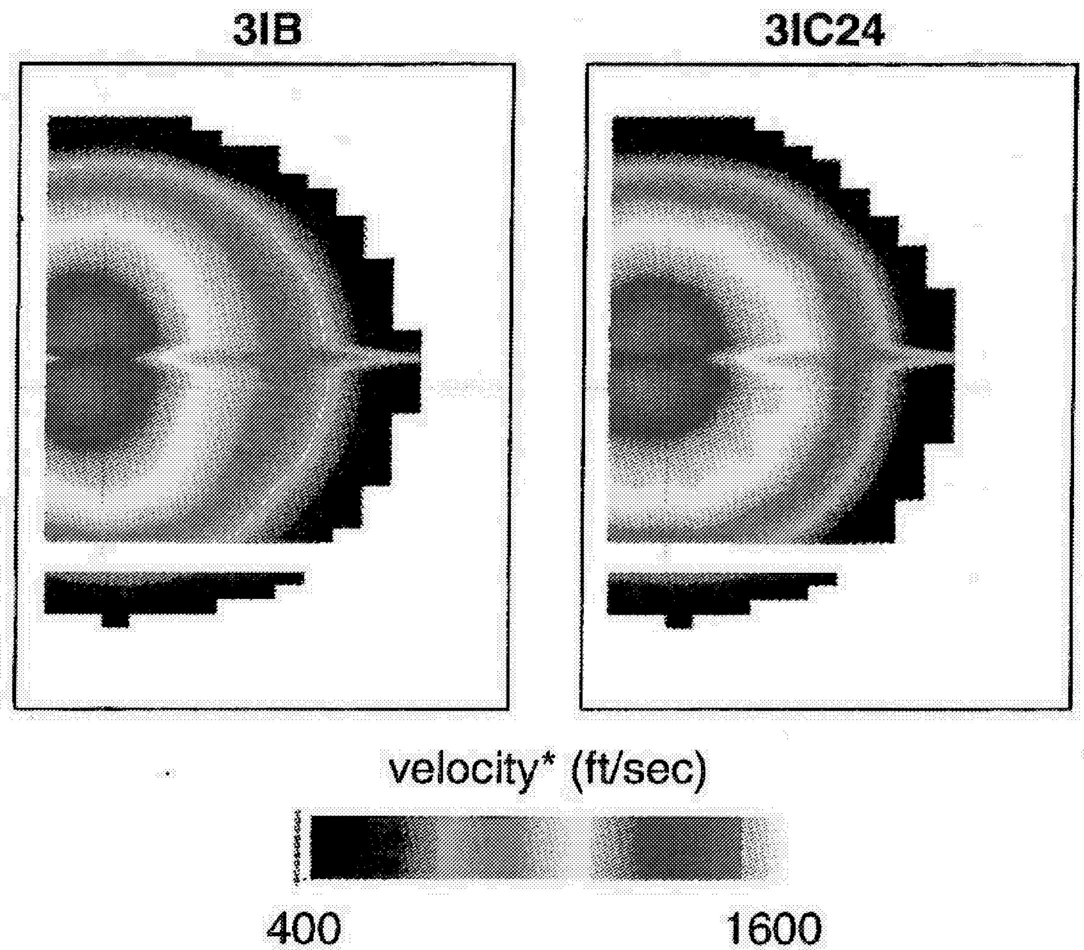
Cycle point 21, M=0.28; x=30"



SFNT97: Plume survey

Mean velocity field

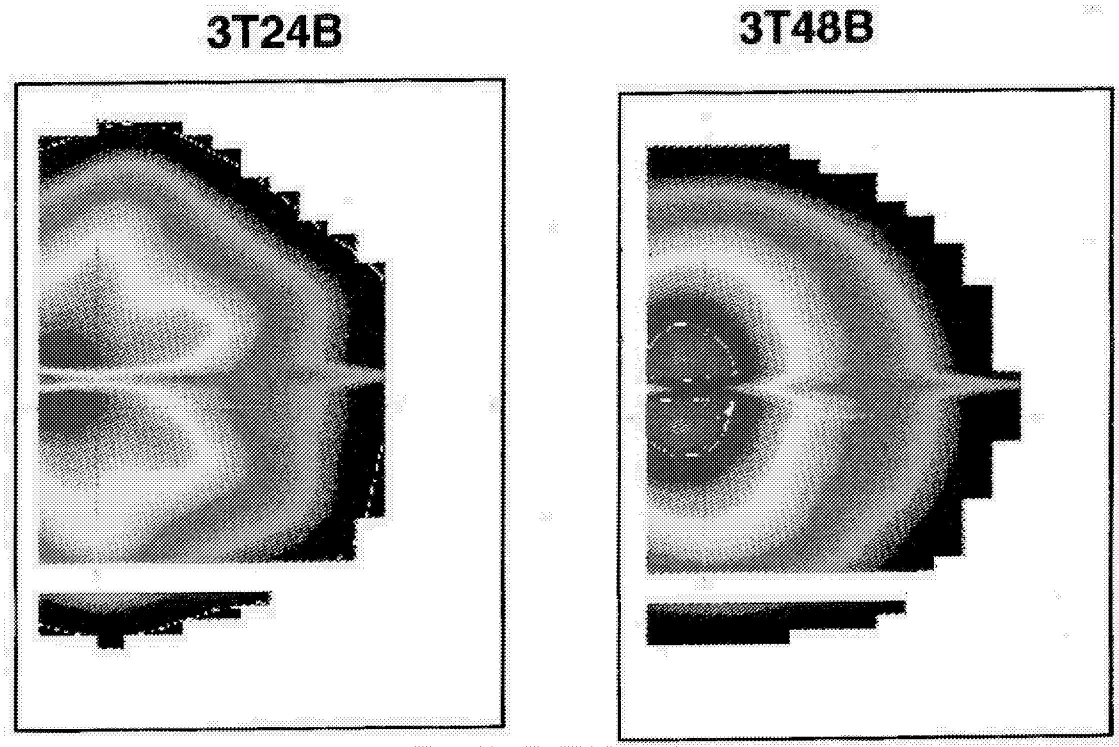
Cycle point 21, M=0.28; x= 30"



SFNT97: Plume survey

Mean velocity field

Cycle point 21, M=0.28; x= 30”

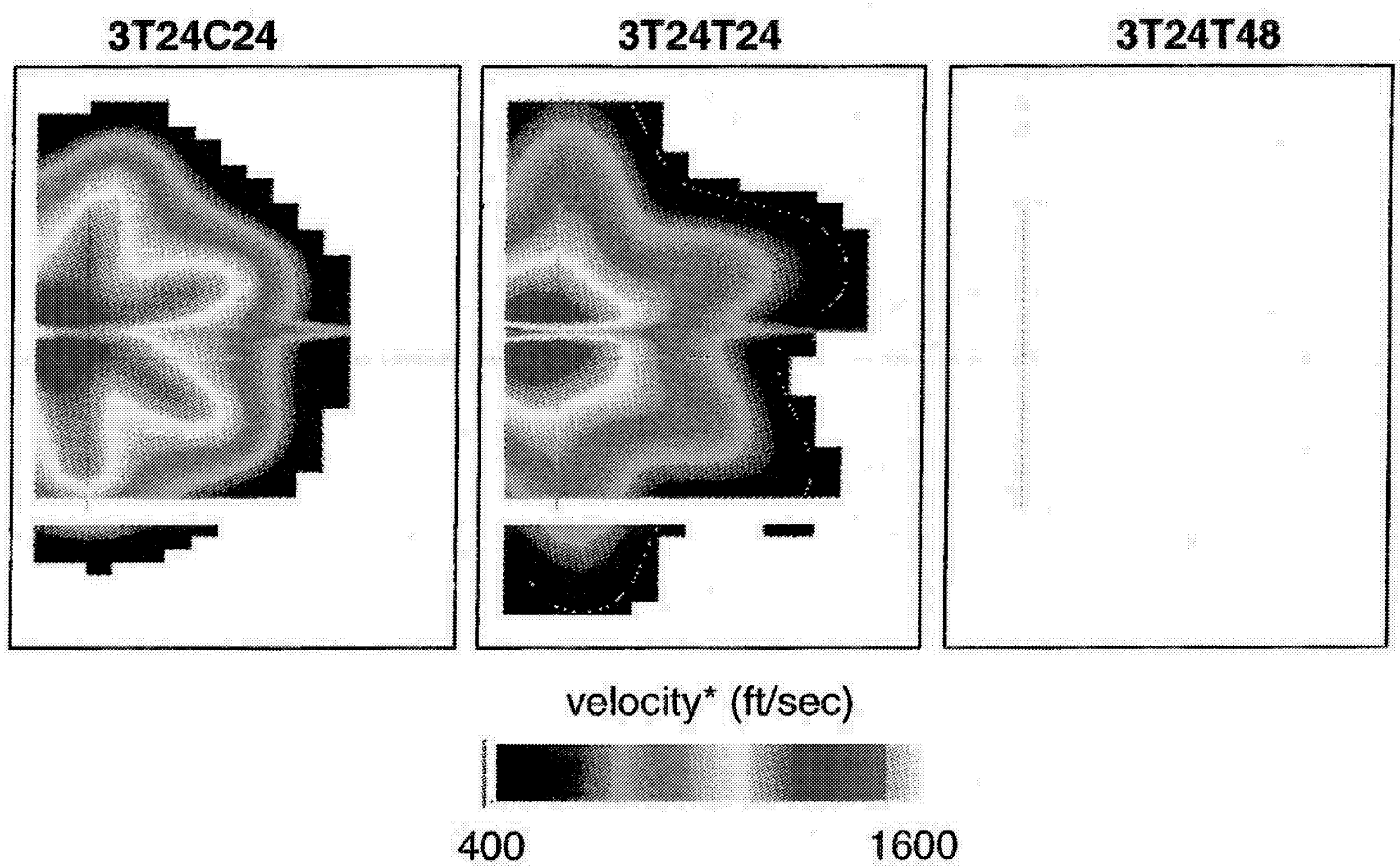


velocity* (ft/sec)

SFNT97: Plume survey

Mean velocity field

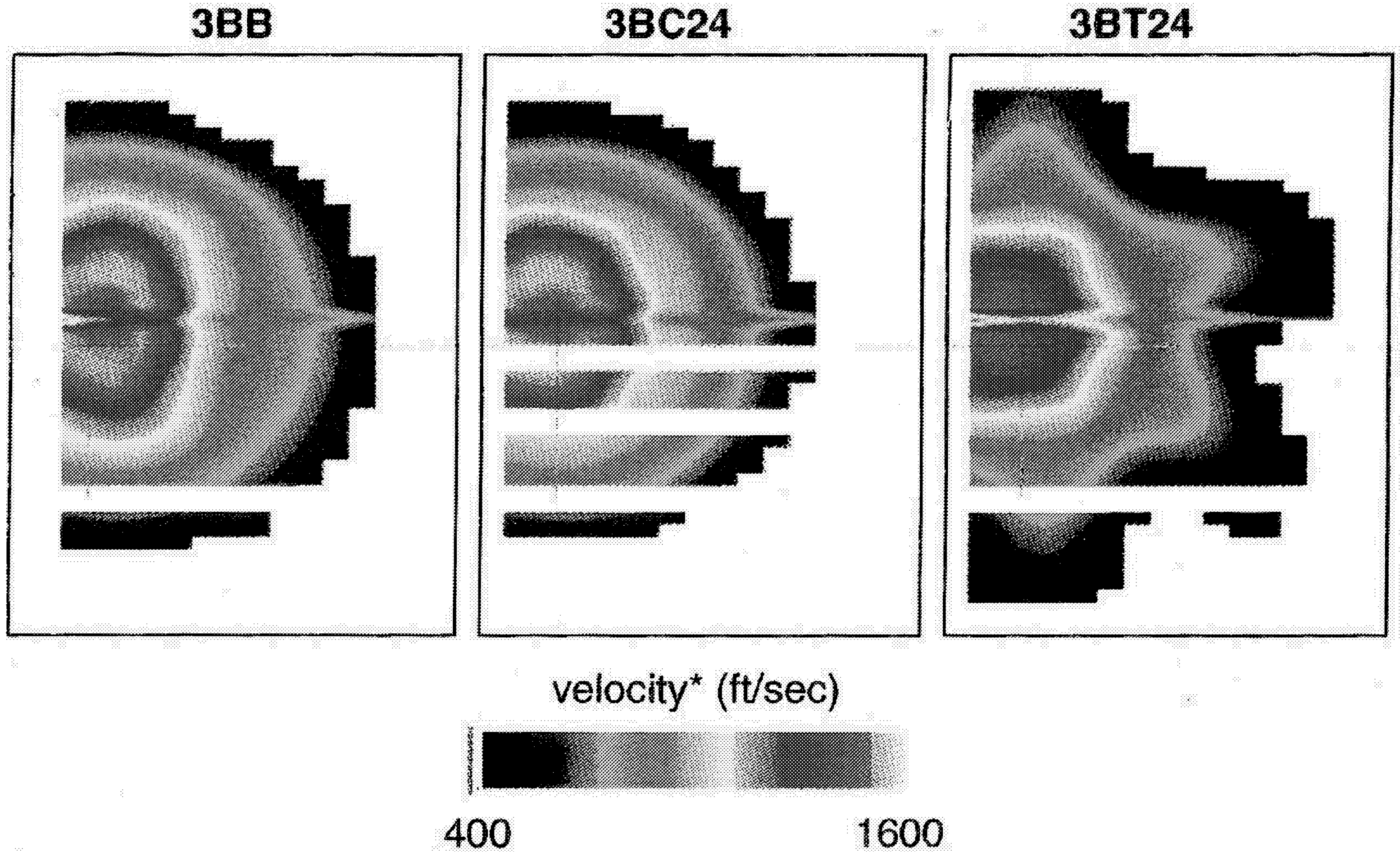
Cycle point 21, M=0.28; x= 30"



SFNT97: Plume survey

Mean velocity field

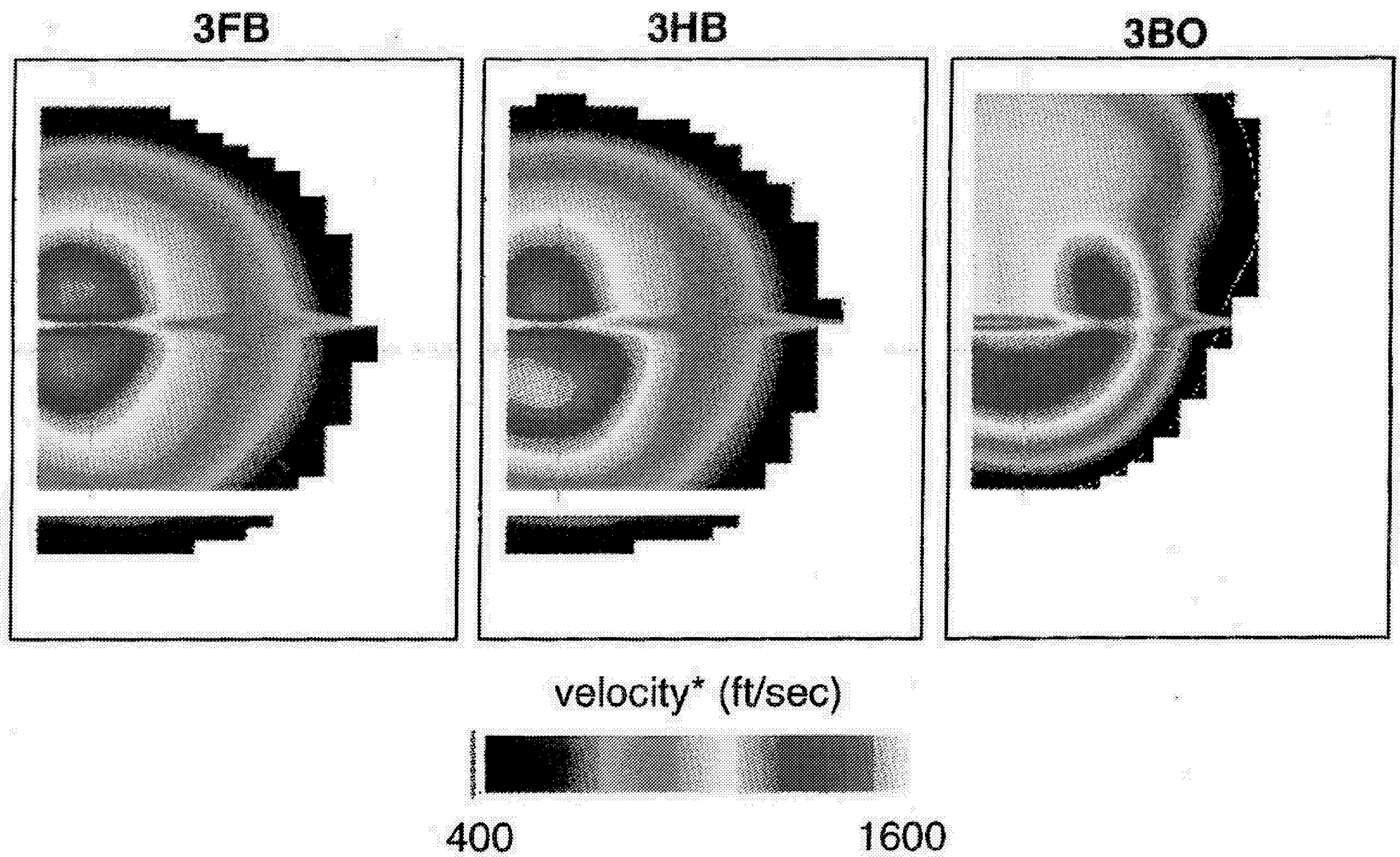
Cycle point 21, M=0.28; x= 30”



SFNT97: Plume survey

Mean velocity field

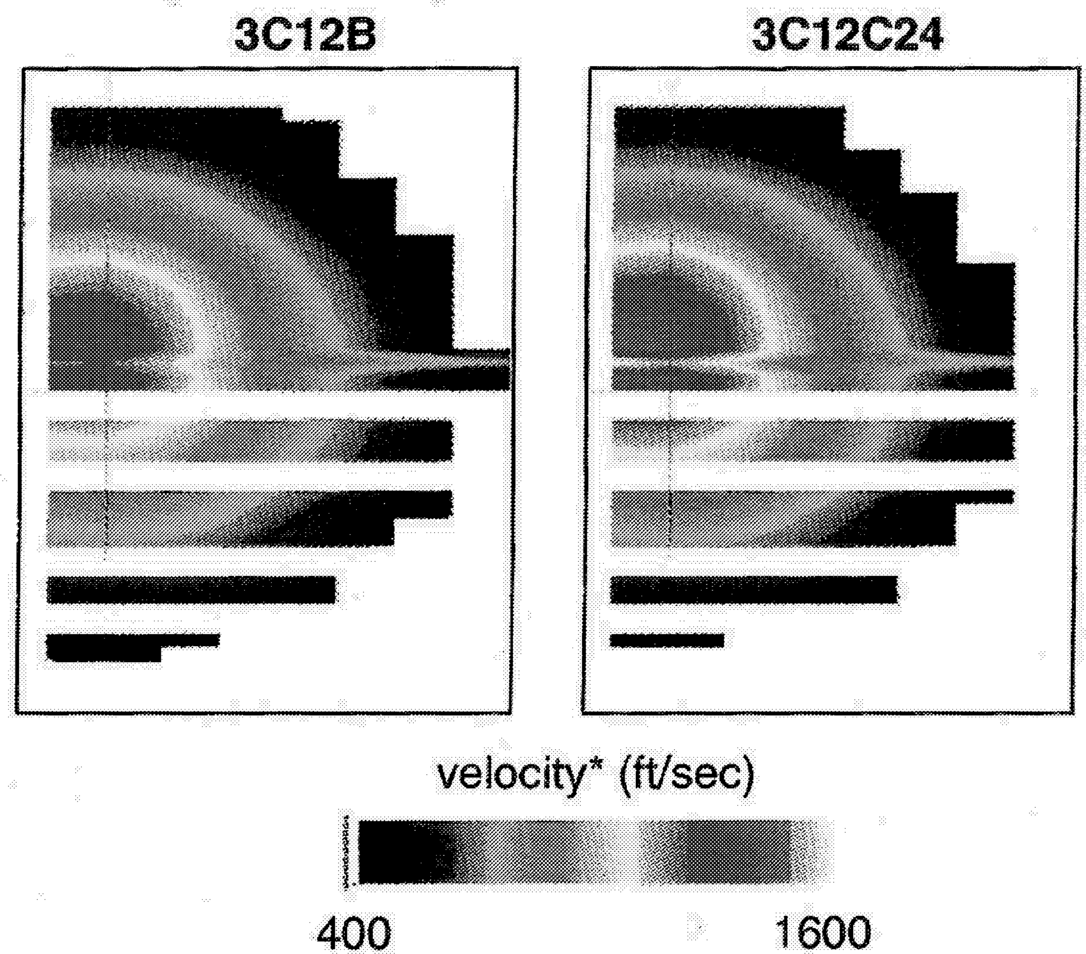
Cycle point 21, M=0.28; x= 30"



SFNT97: Plume survey

Mean velocity field

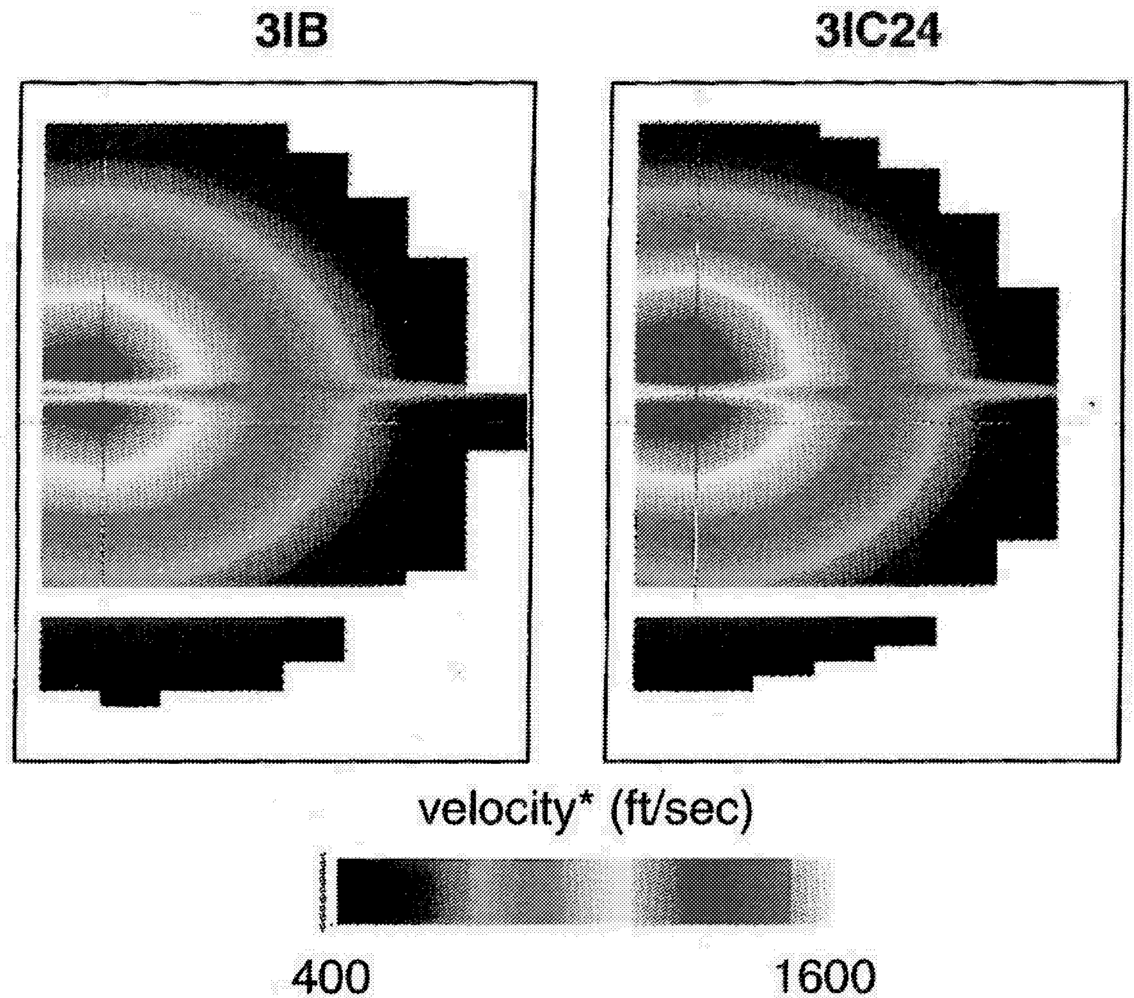
Cycle point 21, M=0.28; x=60”



SFNT97: Plume survey

Mean velocity field

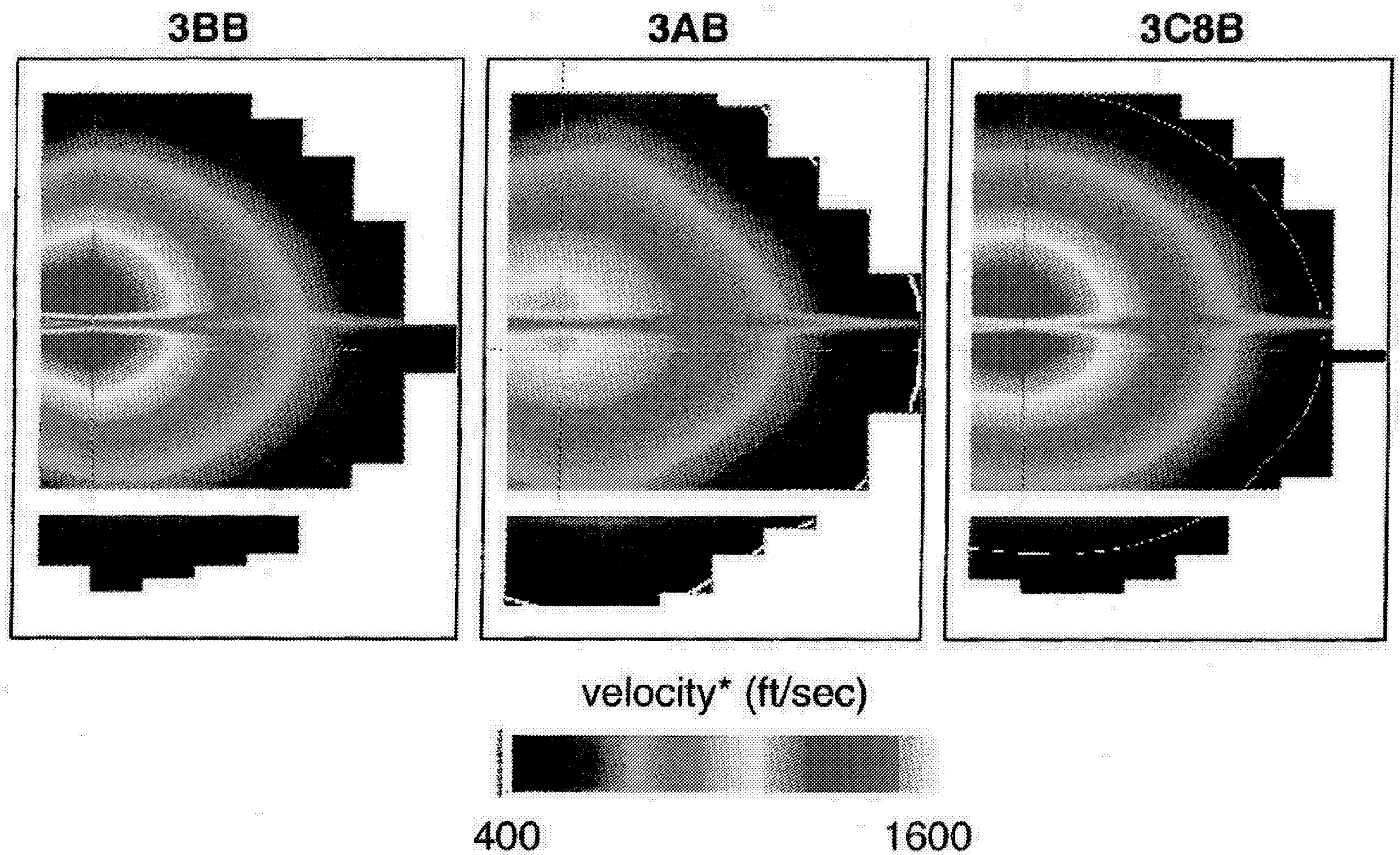
Cycle point 21, M=0.28; x= 60”



SFNT97: Plume survey

Mean velocity field

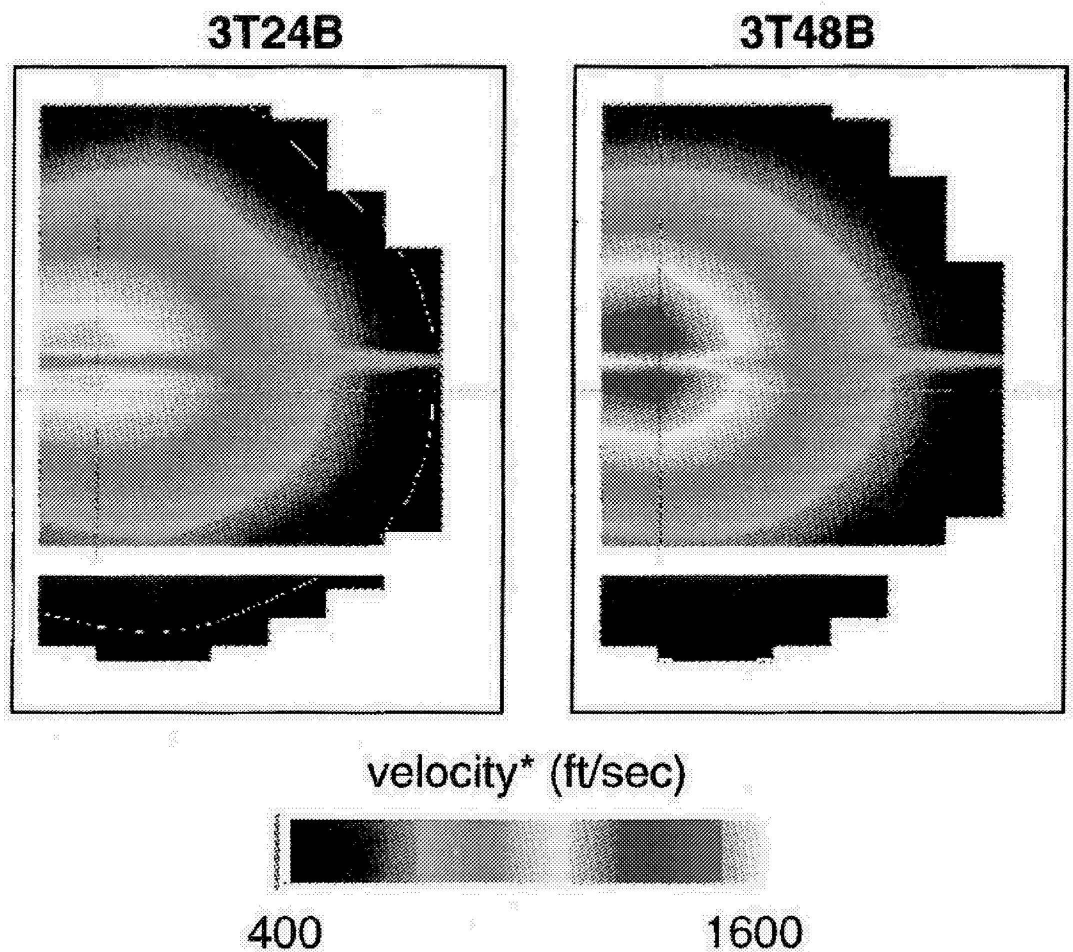
Cycle point 21, M=0.28; x=60"



SFNT97: Plume survey

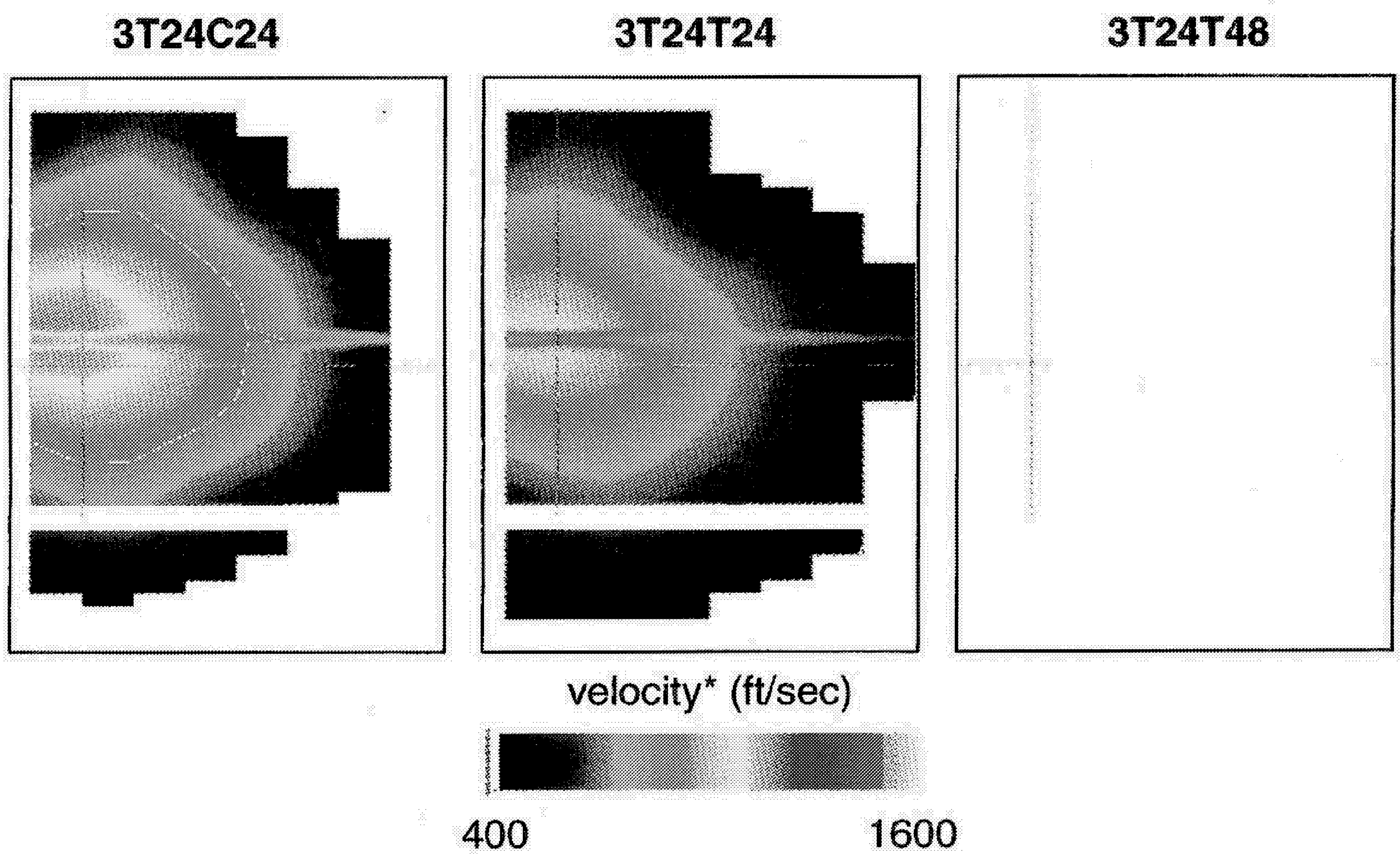
Mean velocity field

Cycle point 21, M=0.28; x= 60”



SFNT97: Plume survey

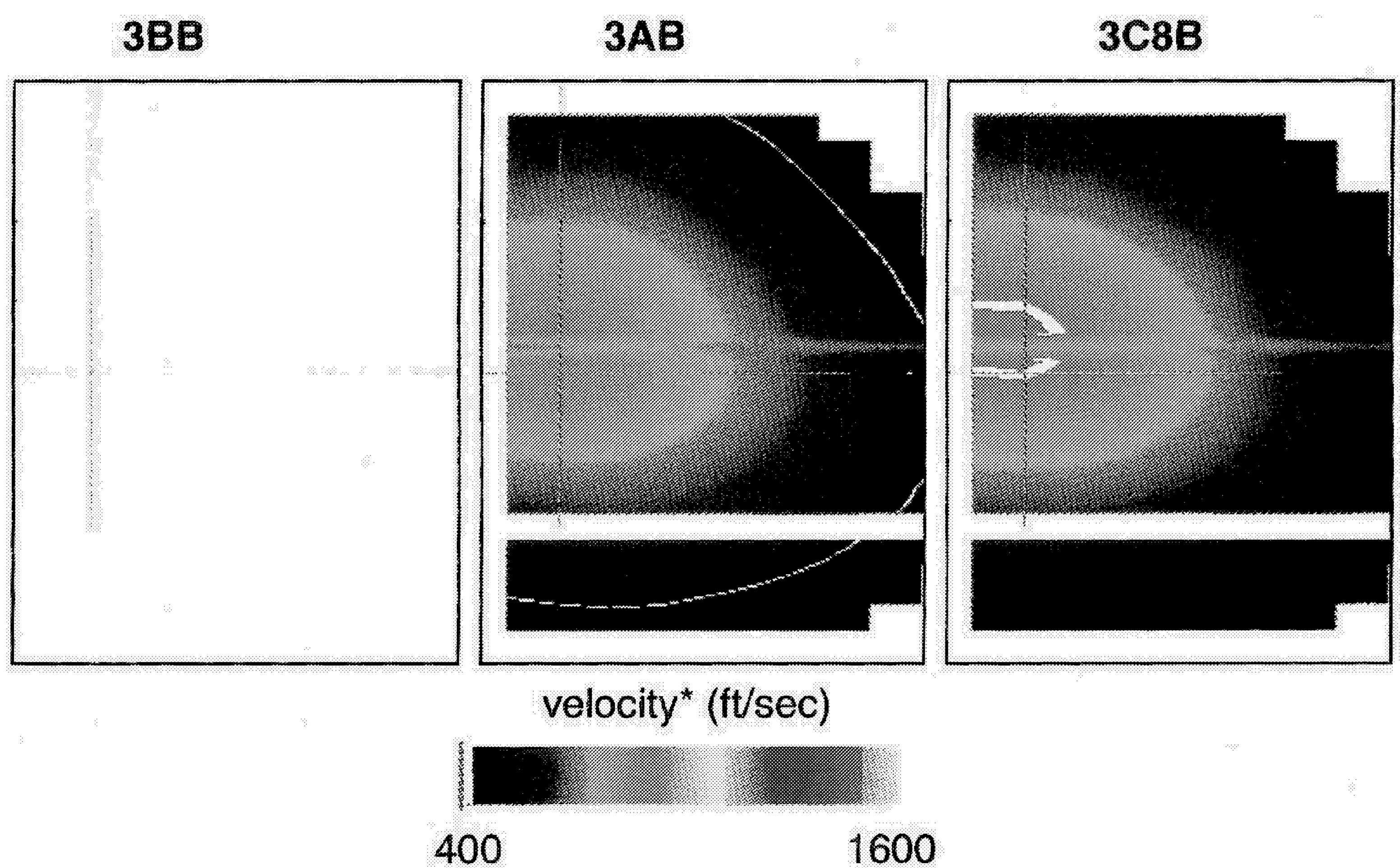
Mean velocity field
Cycle point 21, M=0.28; x= 60”



SFNT97: Plume survey

Mean velocity field

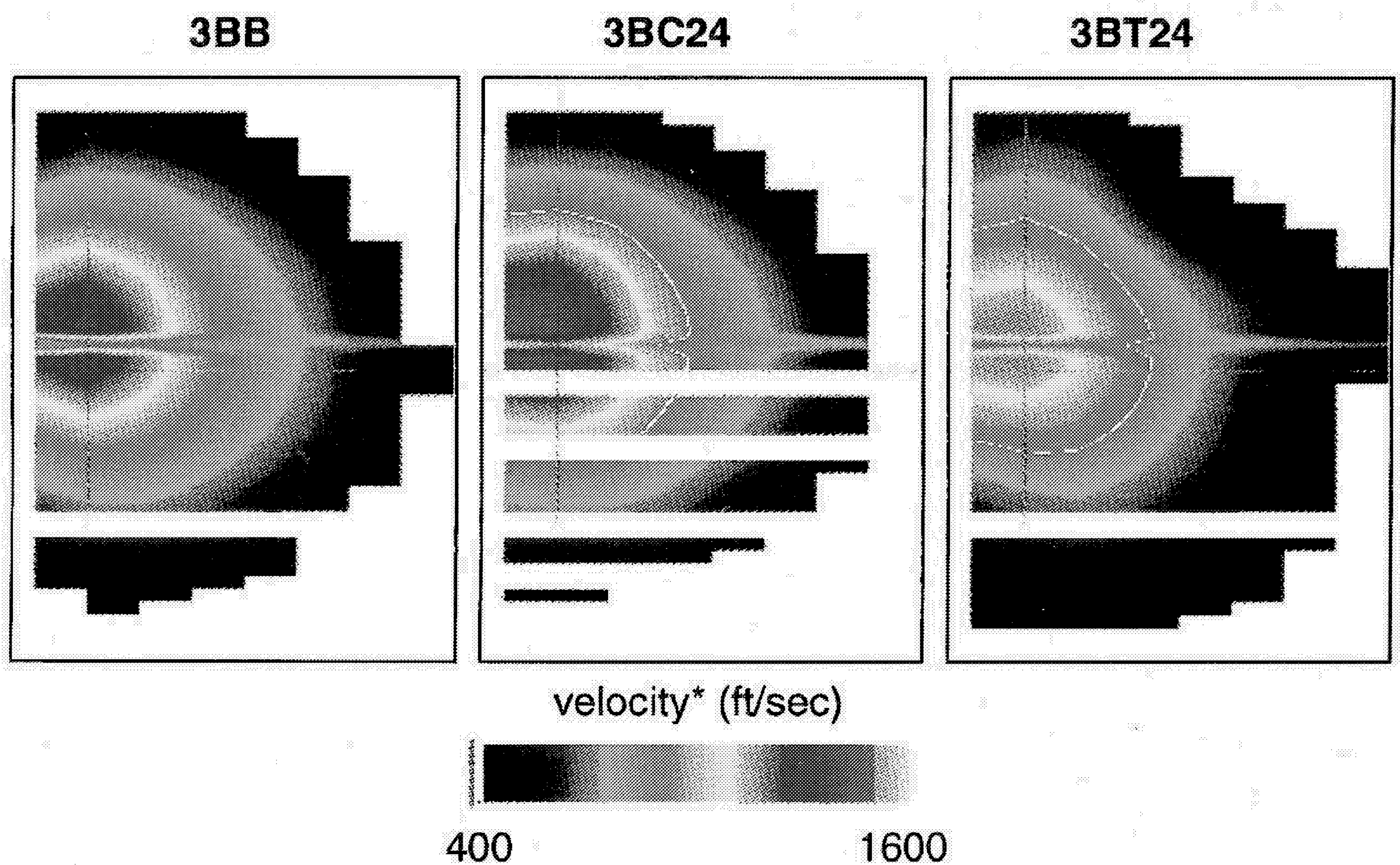
Cycle point 21, M=0.28; x=100”



SFNT97: Plume survey

Mean velocity field

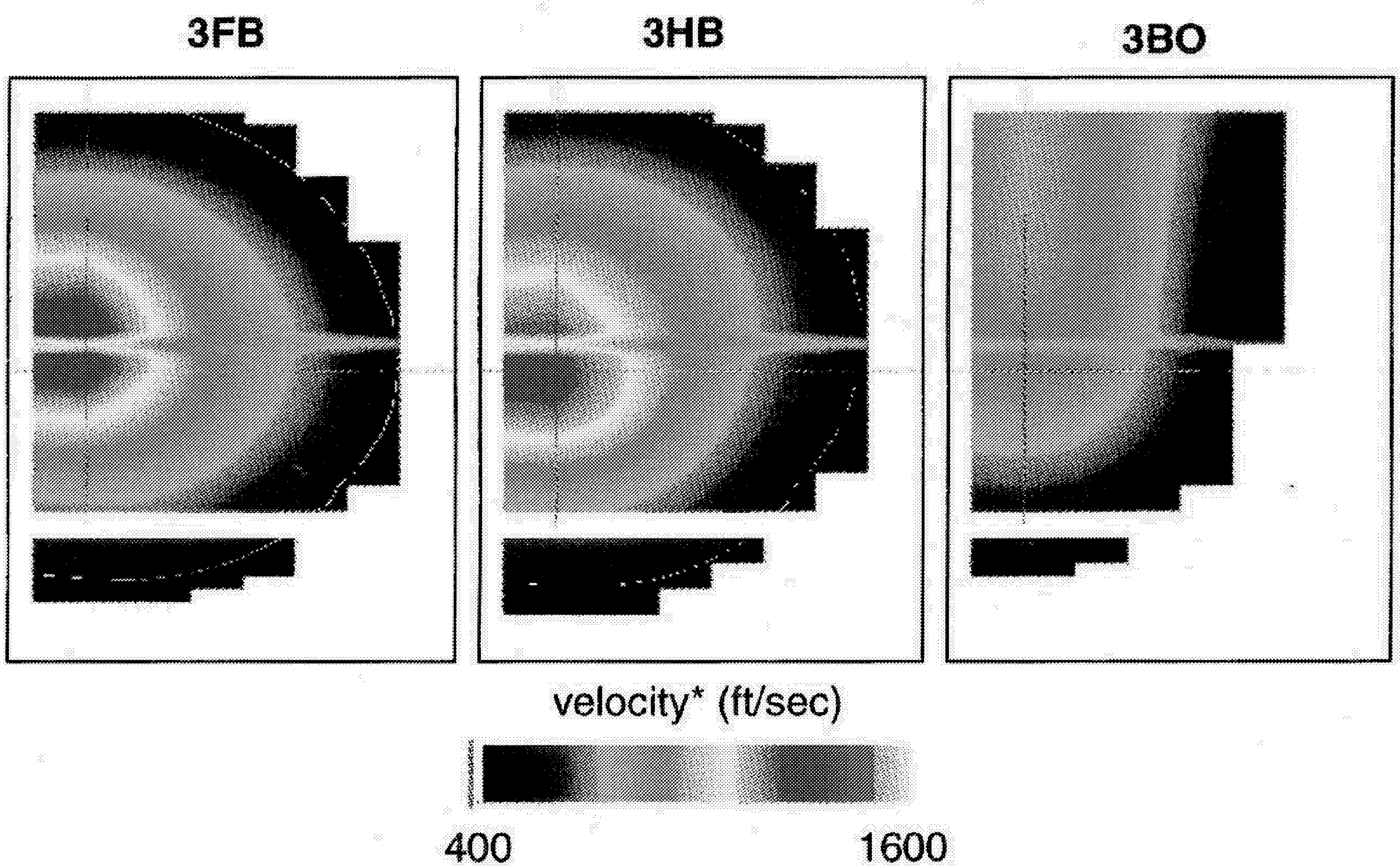
Cycle point 21, M=0.28; x= 60"



SFNT97: Plume survey

Mean velocity field

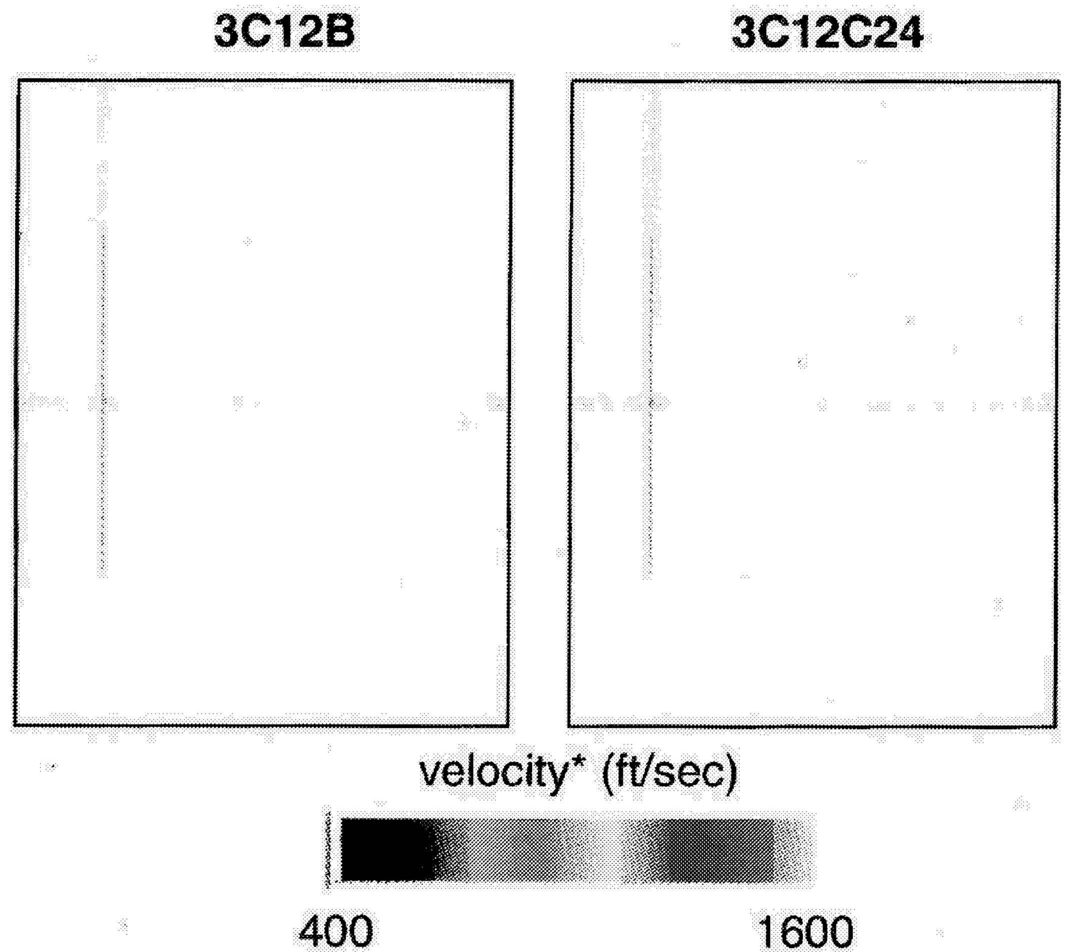
Cycle point 21, M=0.28; x= 60”



SFNT97: Plume survey

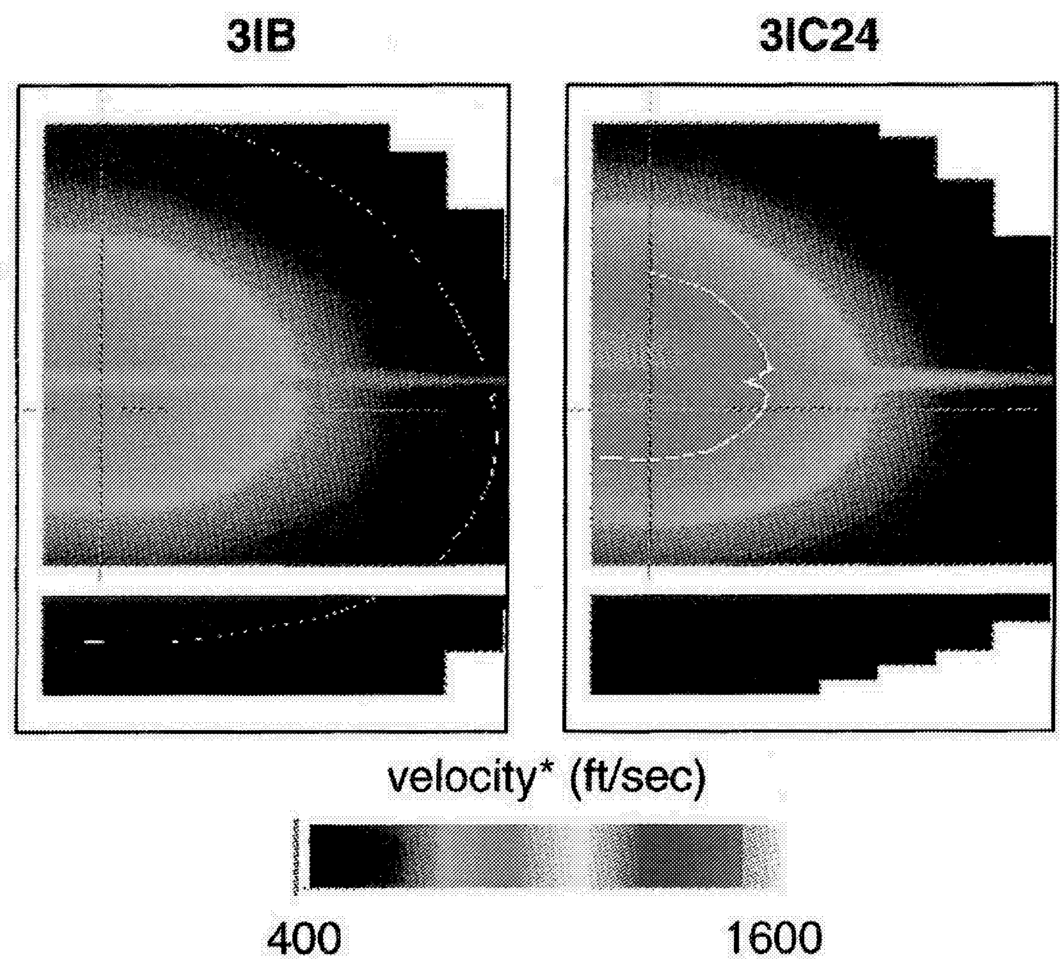
Mean velocity field

Cycle point 21, M=0.28; x=100"



Mean velocity field

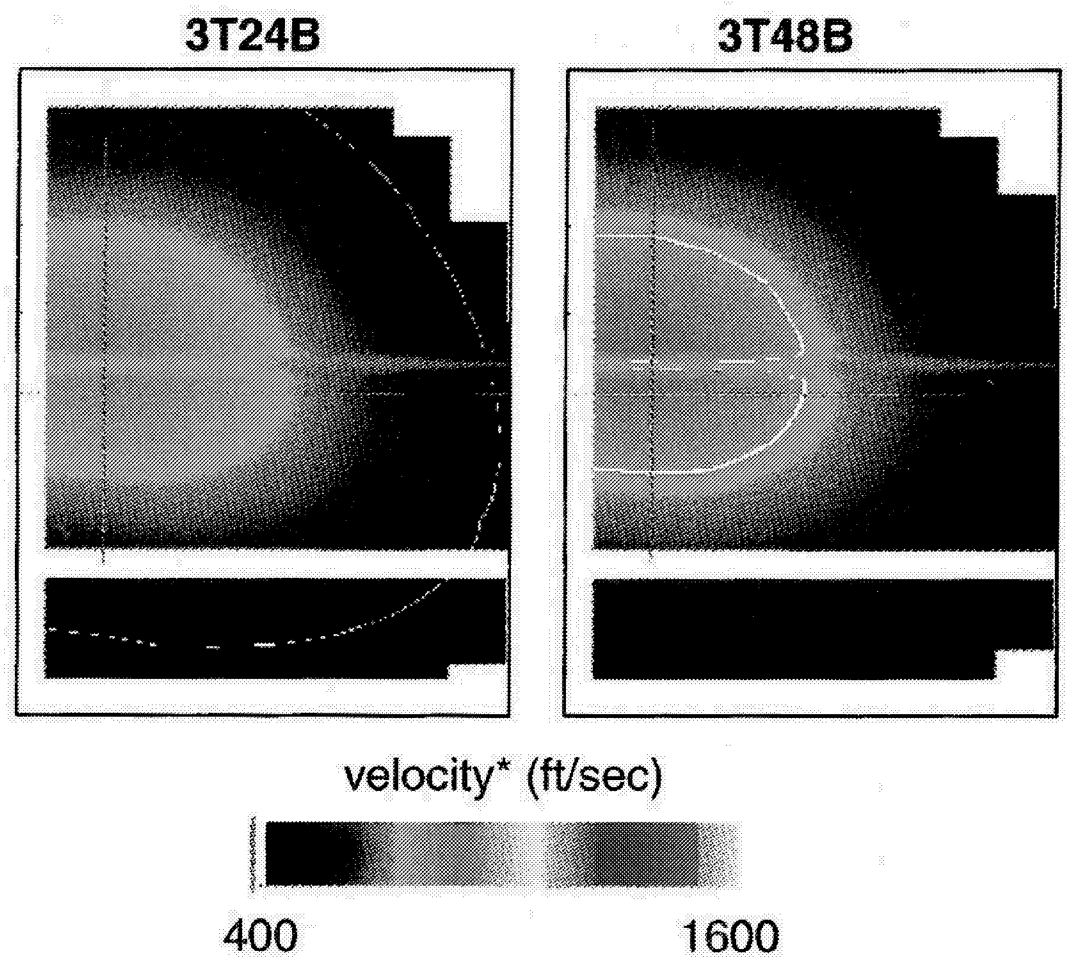
Cycle point 21, M=0.28; x= 100"



SFNT97: Plume survey

Mean velocity field

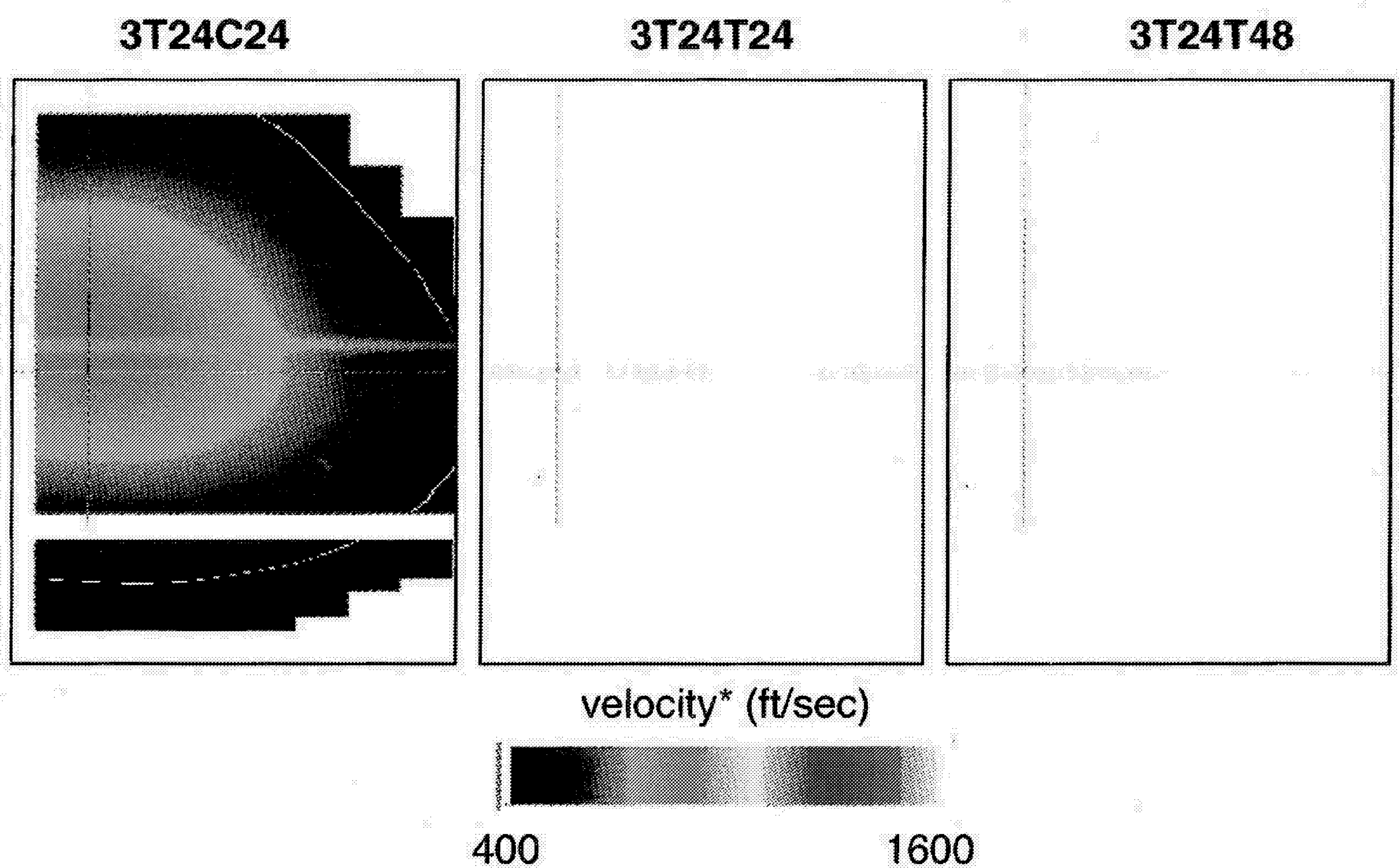
Cycle point 21, M=0.28; x= 100”



SFNT97: Plume survey

Mean velocity field

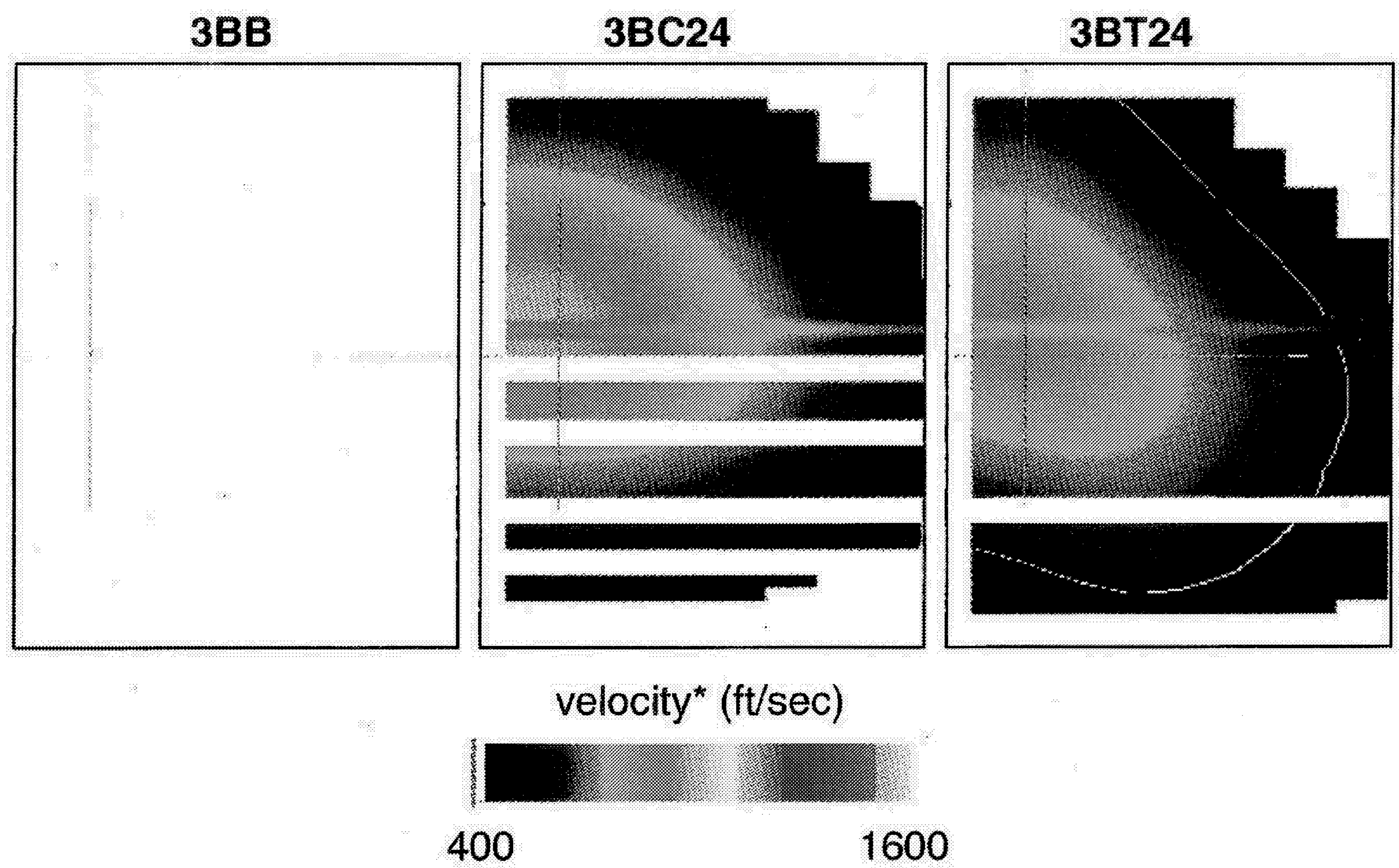
Cycle point 21, M=0.28; x= 100”



SFNT97: Plume survey

Mean velocity field

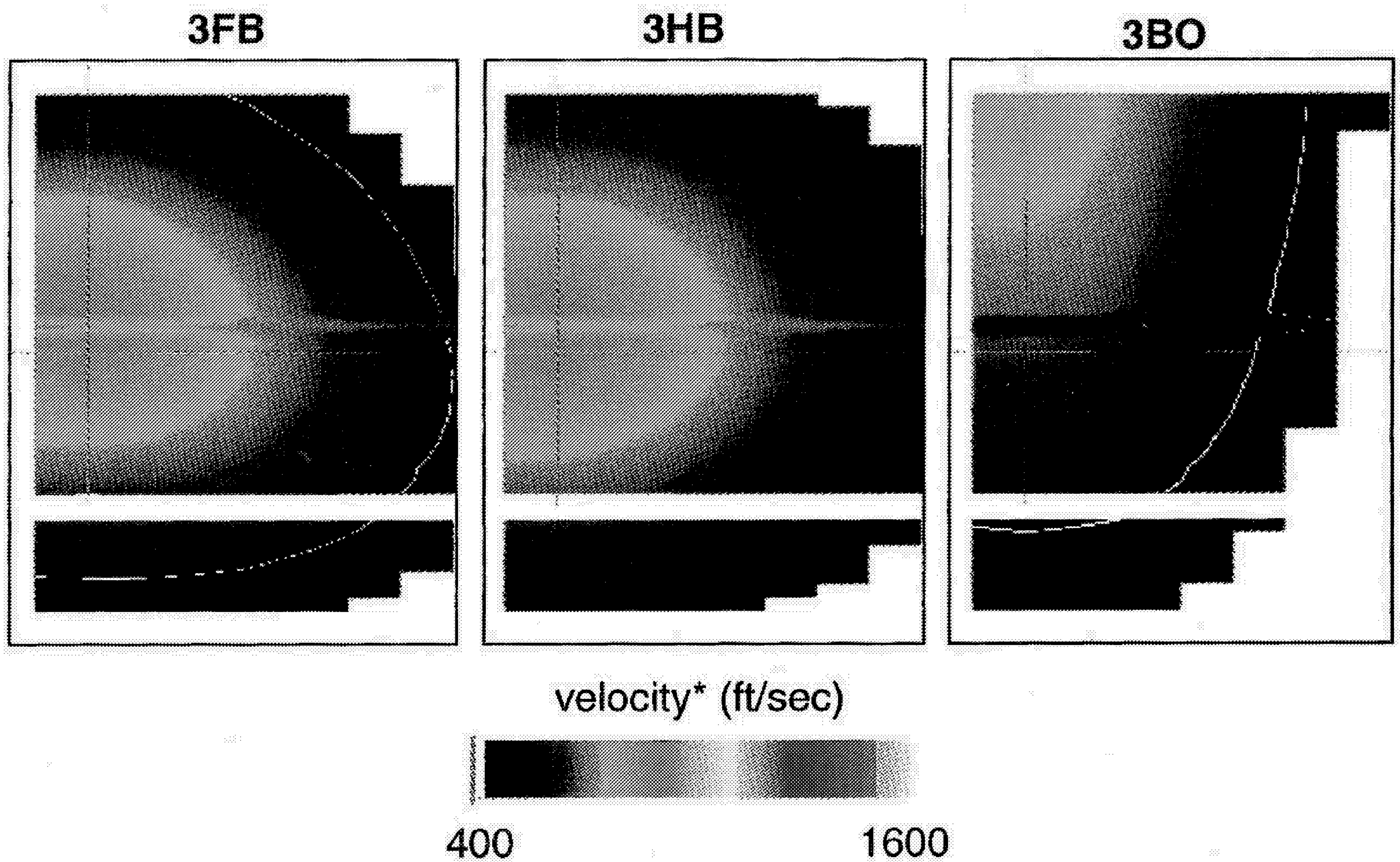
Cycle point 21, M=0.28; x= 100”



SFNT97: Plume survey

Mean velocity field

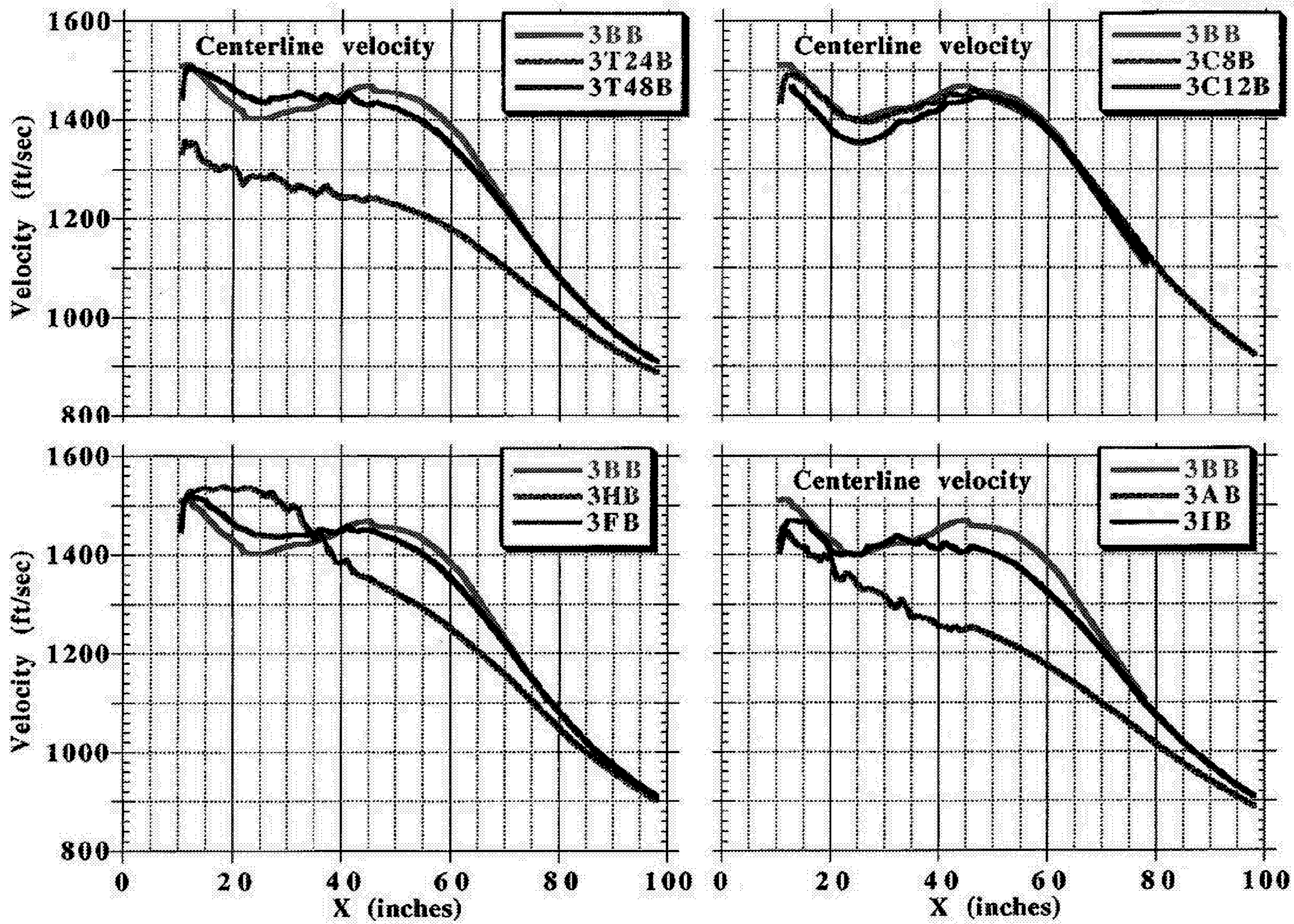
Cycle point 21, M=0.28; x= 100"



SFNT97: Plume survey

Velocity profiles
Core mixer comparisons

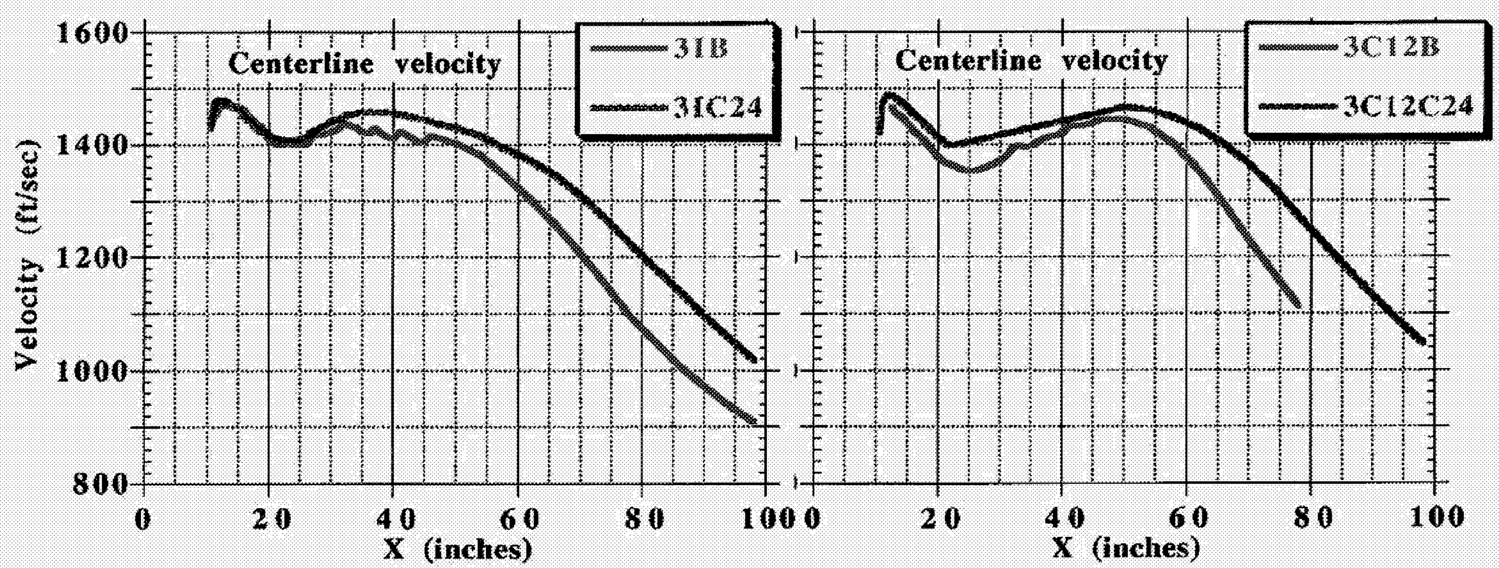
y = 0.0”
z = -0.5”



SFNT97: Plume survey

Velocity profiles
Fan mixer: Effect of chevron

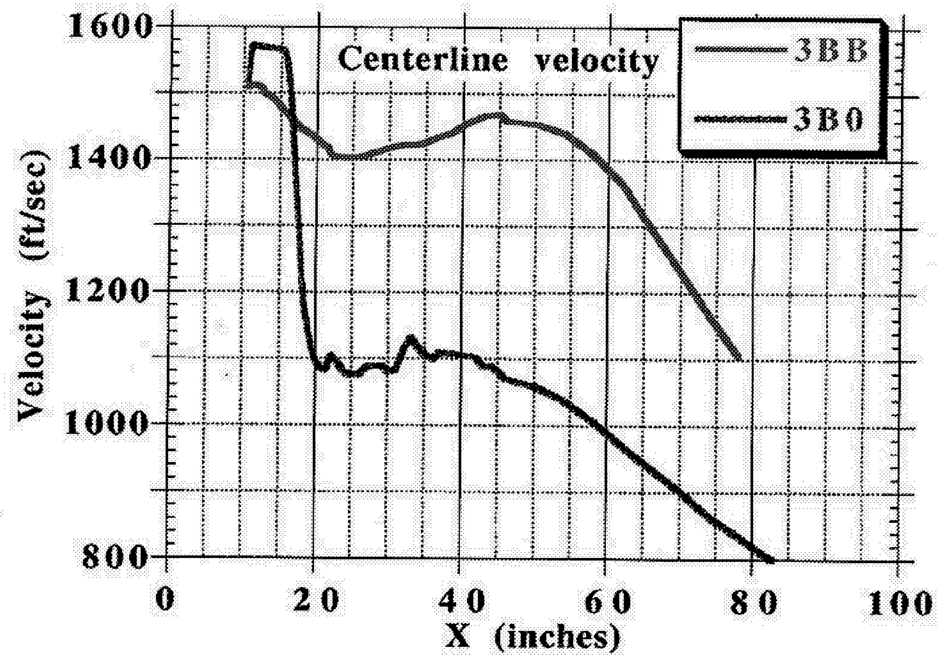
y = 0.0”
z = -0.5”



SFNT97: Plume survey

Velocity profiles
Fan: Offset Nozzle

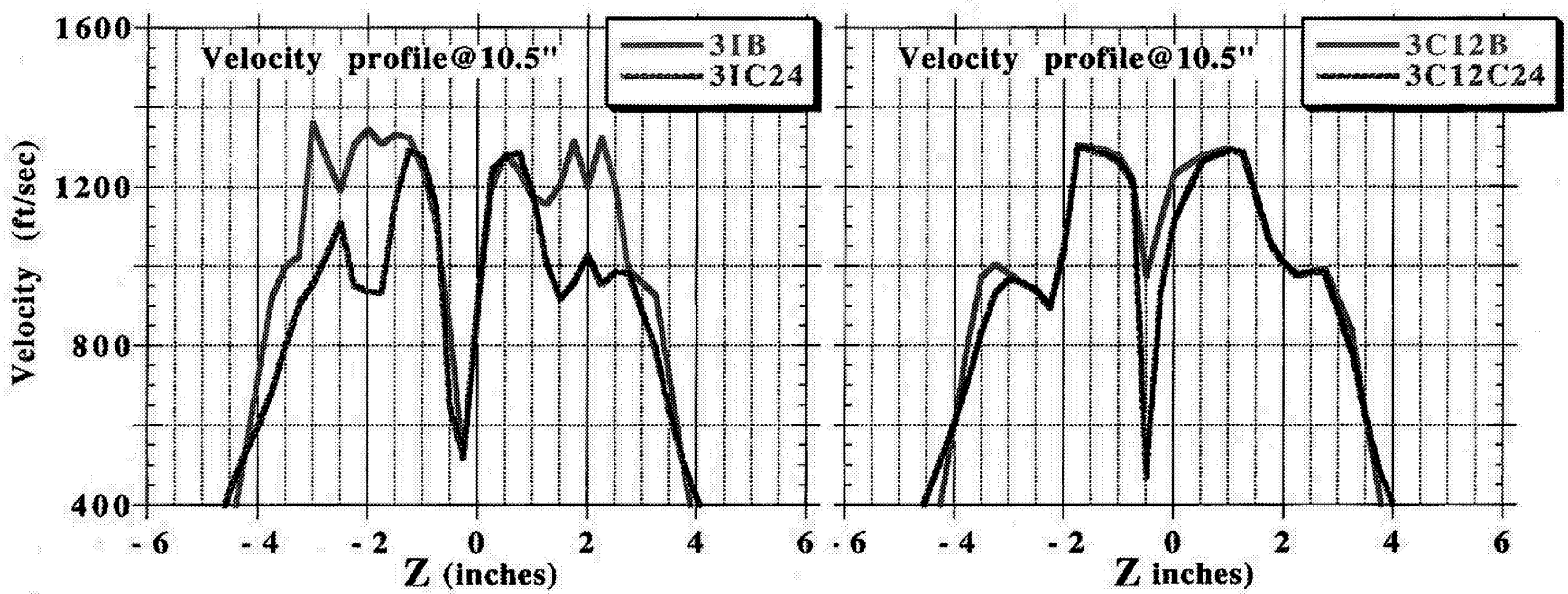
y = 0.0"
z = -0.5"



SFNT97: Plume survey

x = 10.5”
y = 0.0”

Velocity profiles
Fan mixer: Effect of chevrons



Focused Schleiren

Model 3 Configurations

Model 3	B	C24	T24
B	X	X	X
C8	X		
A	X		
I	X		
F	X		
H	X		
T24	X		
T48	X		

- **10"diameter view taken every 6" along x for 16" < x < 46"**
- **All data taken at Cycle Point 21, M = 0.28**

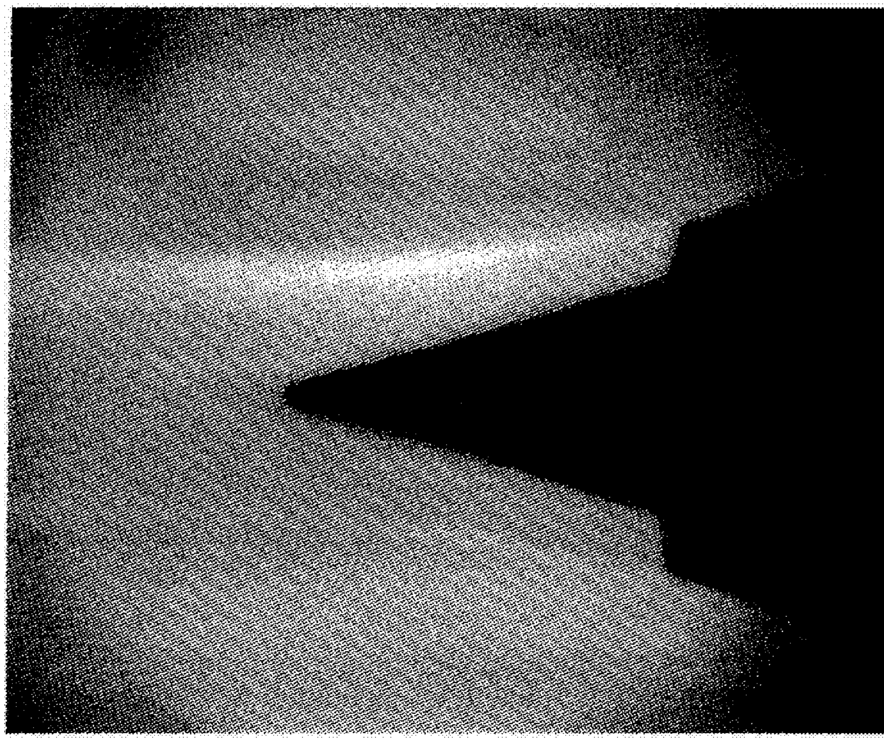
Model 2 configurations

2BB
2TmB

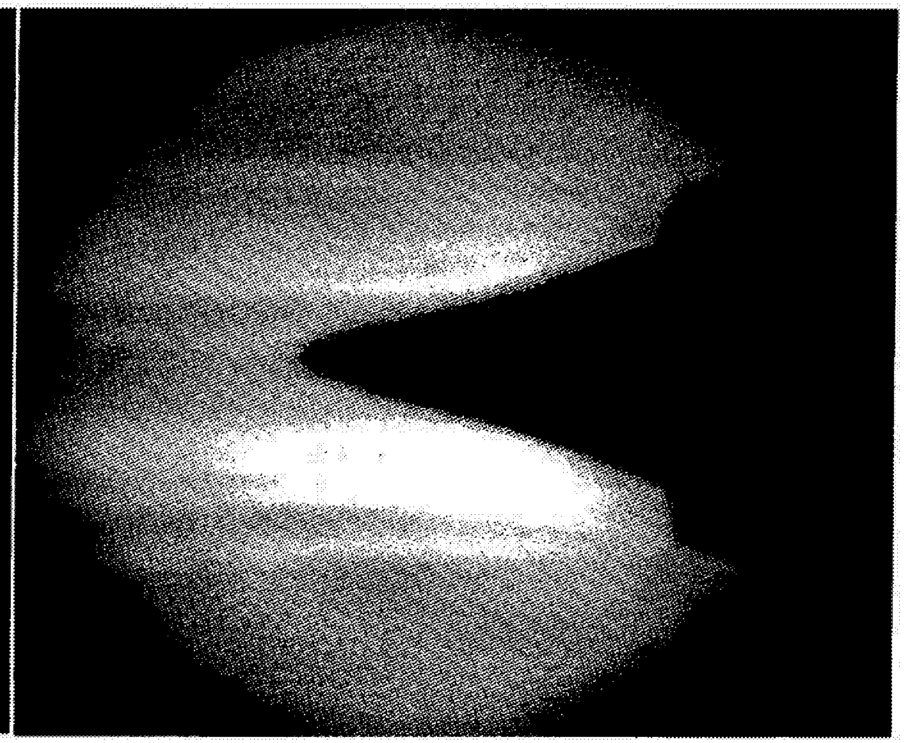
SFNT97: Focused Schlieren

Near Nozzle Schleiren
Initial divergence and longitudinal distortion

3BB

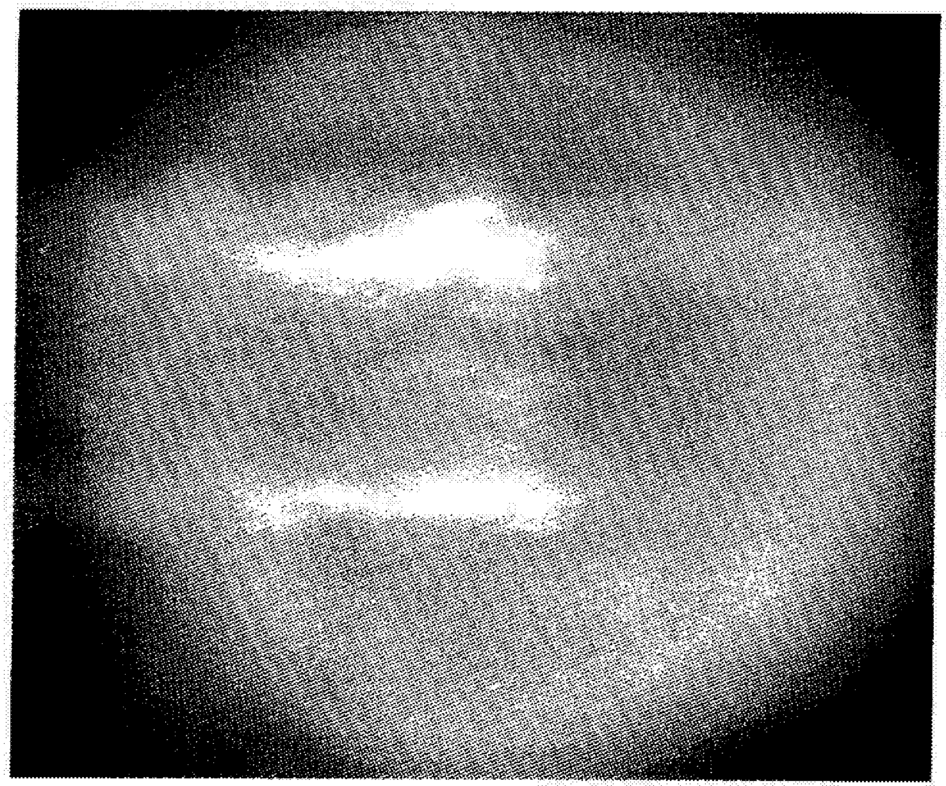


3T24B



Downstream Schleiren
Unsteady turbulent structure

3BT24
cycle point 21, x=46"
shutter speed 1/2000 sec



Measurements of two-point space-time correlations using hotwires

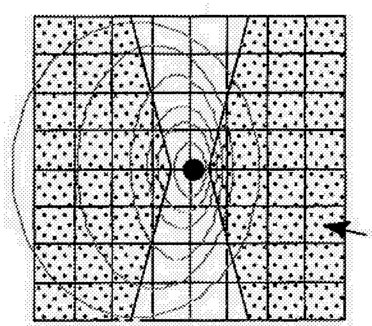
- MGB prediction method assumes isotropic, homogeneous turbulence
- Shear layers are not isotropic, nor homogeneous.
- Q: How far from these assumptions is reality and what are some actual valid turbulence models?
- Q: By how much have previous measurements been incorrect in neglecting probe interference?
- Q: What is the frequency dependence of the space-time correlation matrix? (Space-time separation assumption)

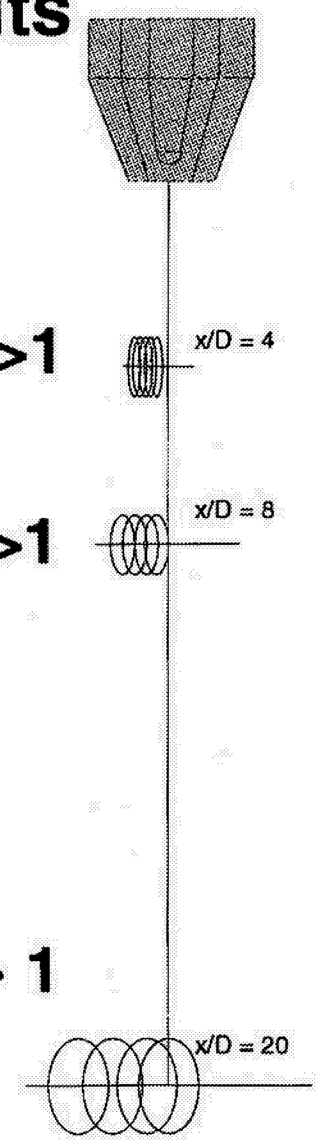
Measurements/Statistics

- Attempt to answer these by taking data in simple round jet (core of model 1).
- Used two x-wires separated by ξ on independent traverses.
- Used combination of probes to take space-time correlations for several radii at 3 axial locations
  - $uu(\xi,\tau;\mathbf{x})$, $uv(\xi,\tau;\mathbf{x})$, $uw(\xi,\tau;\mathbf{x})$, $vv(\xi,\tau;\mathbf{x})$, $ww(\xi,\tau;\mathbf{x})$
  - $uuuu(\xi,\tau;\mathbf{x})$, $uuvv(\xi,\tau;\mathbf{x})$, $uvuv(\xi,\tau;\mathbf{x})$, $vvvv(\xi,\tau;\mathbf{x})$, $wwww(\xi,\tau;\mathbf{x})$, $uwuw(\xi,\tau;\mathbf{x})$
- Will calculate $\mathcal{L}_{11}/\mathcal{L}_{22}$ and A_{1111}, A_{1212}, A_{2222} as a function of radius, axial location, and frequency.

Expected Turbulence Results

Contours of uu





$\mathcal{L}_{11}/\mathcal{L}_{22} >> 1$

$\mathcal{L}_{11}/\mathcal{L}_{22} > 1$

$\mathcal{L}_{11}/\mathcal{L}_{22} \sim 1$

SFNT97

Preliminary Flow Field Insights

- Complicated flow fields defy simple analysis
  - Centerline decay
  - Spread rate
- Fan mixer:
  - C24 'thickens' fan/ambient shear layer; no deformation of core flow
  - C24 *decreases* core decay re baseline!
  - T24 distorts fan/ambient shear layer and deforms the core flow
  - T24 *increases* core decay re baseline.
  - Offset nozzle caused 'vectored' flow, with fan flow splitting the core flow downstream.

Preliminary Flow Field Insights , Cont.

- Core mixer:
  - 'I' chevron has more impact on core/fan shear layer than 'C' chevron.
  - C8 gave stronger initial deformation than C12. Little effect by 60".
  - Tabs were doubly effective because they alternated in/out and gave strong deformation (destruction!) of core/fan shear layer.
  - Half mixer better mixed than full by 60".
  - T24 better mixed than T48.
  - Alternating Tab ('A') performed similarly to T24, especially downstream.

LaRC SEPARATE FLOW TESTING STATUS

JACK SEINER

JET NOISE LABORATORY

NASA LANGLEY RESEARCH CENTER

SEPTEMBER 10, 1997

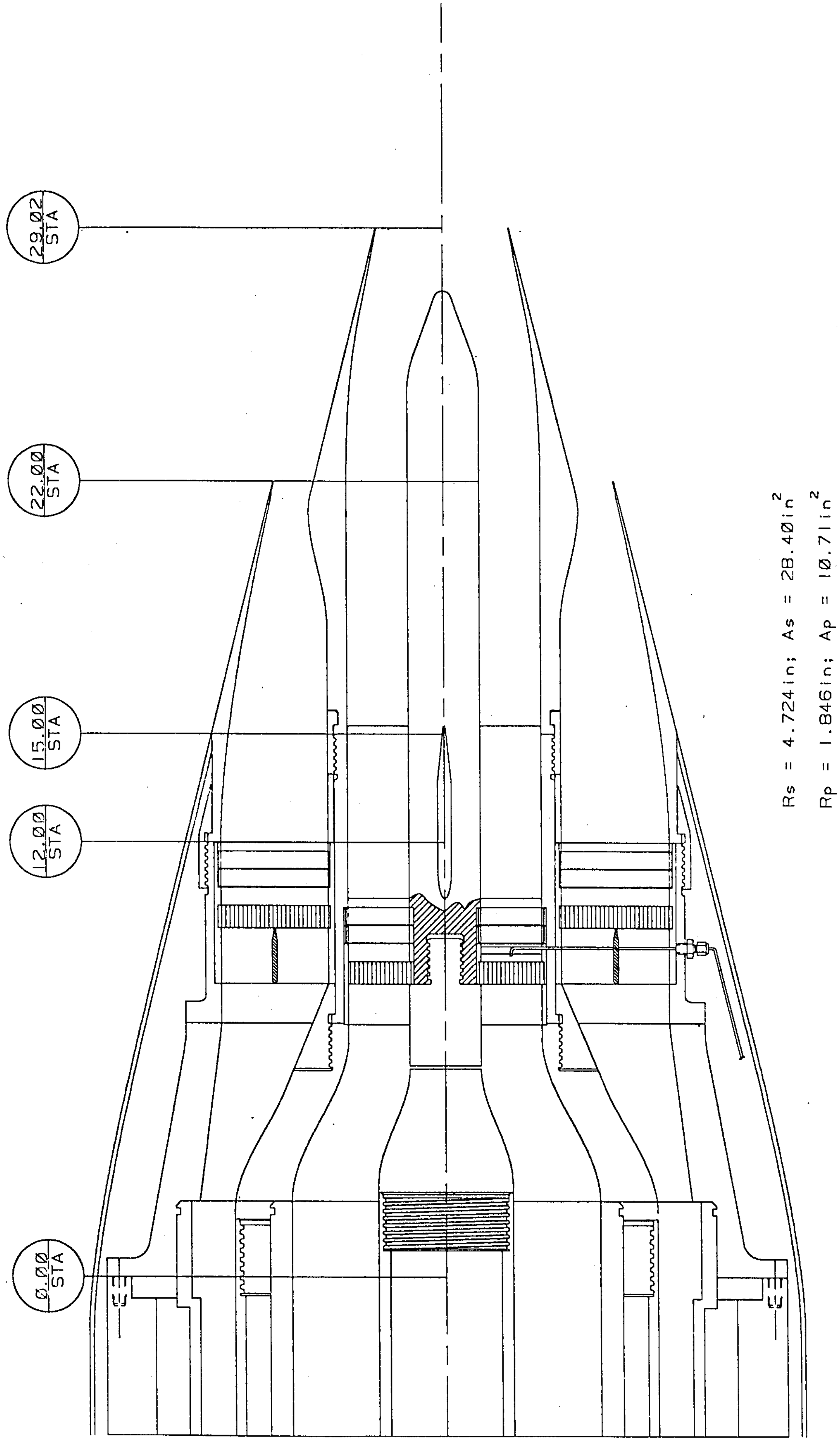
PROGRAM OBJECTIVES

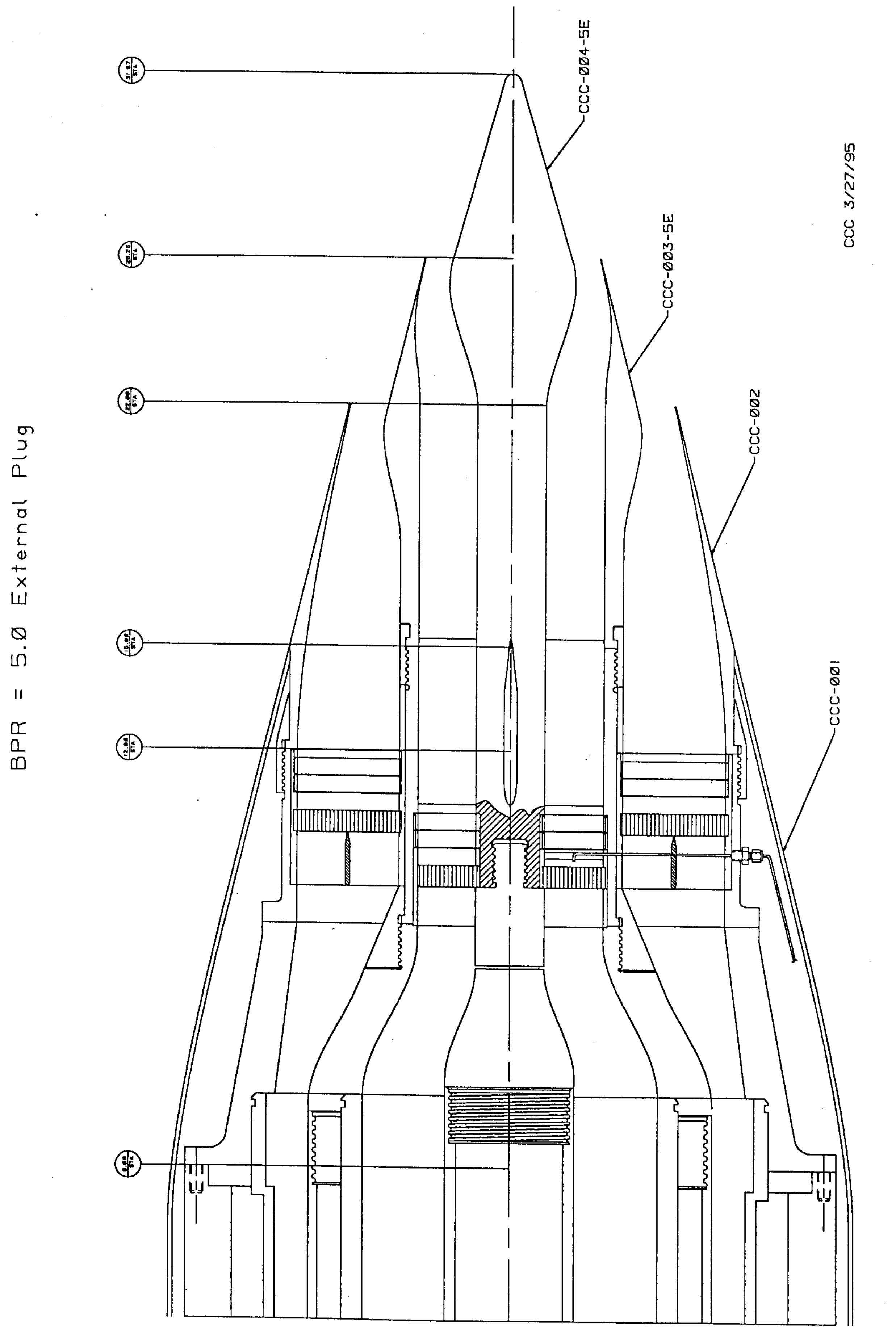
- DEVELOP JET NOISE DATA BASE FOR SEPARATE FLOW NOZZLES WITH BYPASS RATIO'S 5 TO 14.
- EVALUATE EFFECT OF PYLON ON NOISE.
- DEVELOP LOW PERFORMANCE IMPACT NOISE SUPPRESSION CONCEPTS.
- EVALUATE POTENTIAL FOR ACTIVE CONTROL OF JET NOISE.

PROGRESS TO DATE

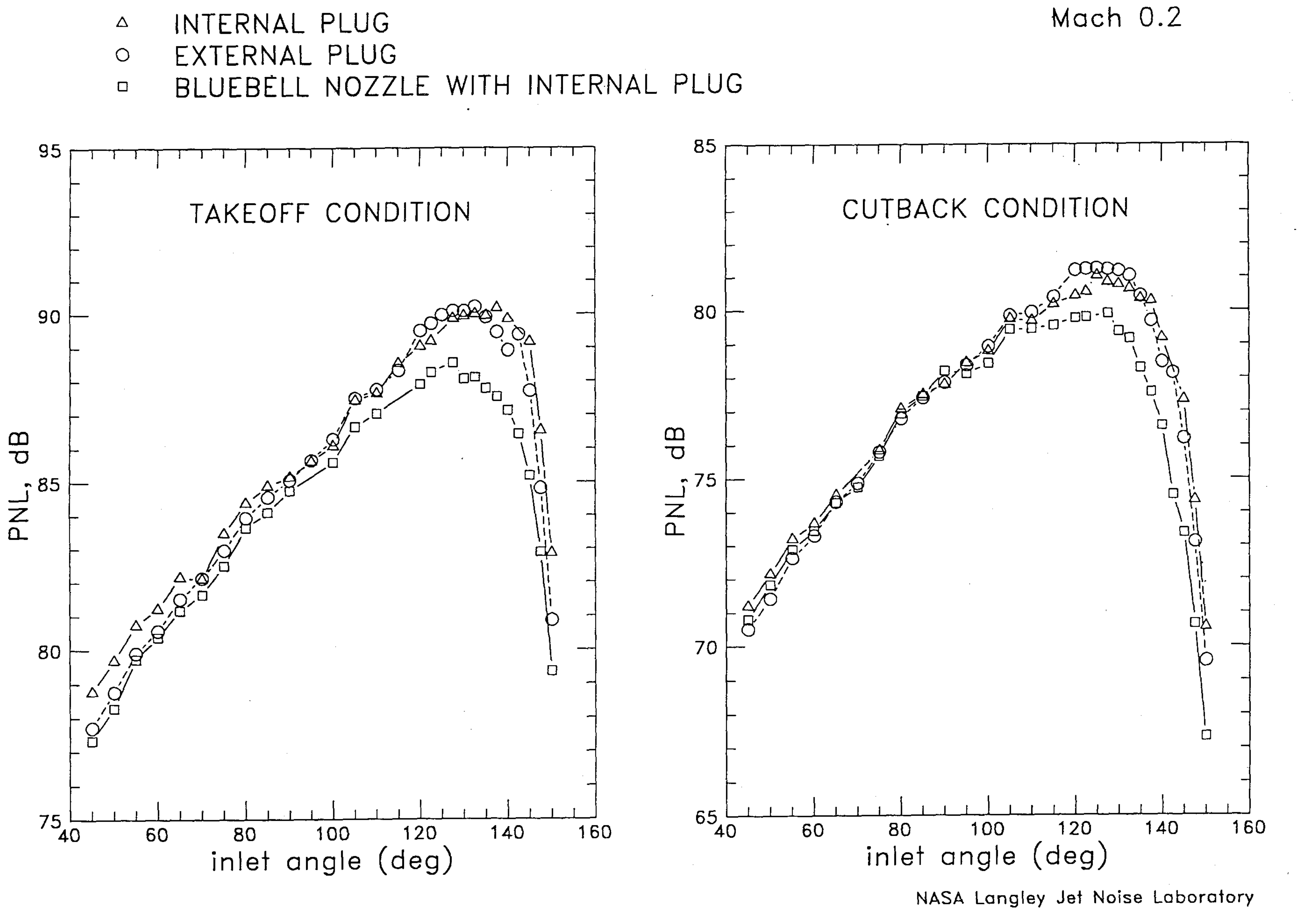
- COMPLETED ACOUSTIC DATA BASE FOR RC AND SEPARATE FLOW NOZZLES WITH INTERNAL AND EXTERNAL PLUGS FOR BPR=5.
- ACQUIRED PERFORMANCE & ACOUSTIC DATA FOR BLUEBELL PRIMARY AND SECONDARY RAMPS.

BPR = 5.0 Internal Plug




BPR = 5.0 External Plug
CCC-004-5E
CCC-003-5E
CCC-002
CCC-001
CCC 3/27/95

JNL SIDELINE AST PNL COMPARISIONS



FUTURE STUDIES

- COMPLETE DATA BASE STUDY
- VALIDATE NUMERICAL SIMULATION STUDIES
- OBTAIN RELIABLE PERFORMANCE DATA FOR SUPPRESSOR NOZZLES.
- EVALUATE POTENTIAL OF GLOW DISCHARGE AND SYNTHETIC JET ACTUATORS.

NASA AST Jet Noise Meeting

Installed Jet Noise

Thonse R. S. (Srini) Bhat

September 10, 1997

NASA Lewis Research Center

NOISE ENGINEERING TECHNOLOGY

NASA AST Jet Noise Meeting

Outline:

- Test facility
- Hardware & instrumentation layout
- Test configurations
- Results
  - — Spectral plots
  - — Phased array data
  - — Velocity profiles
- Concluding remarks

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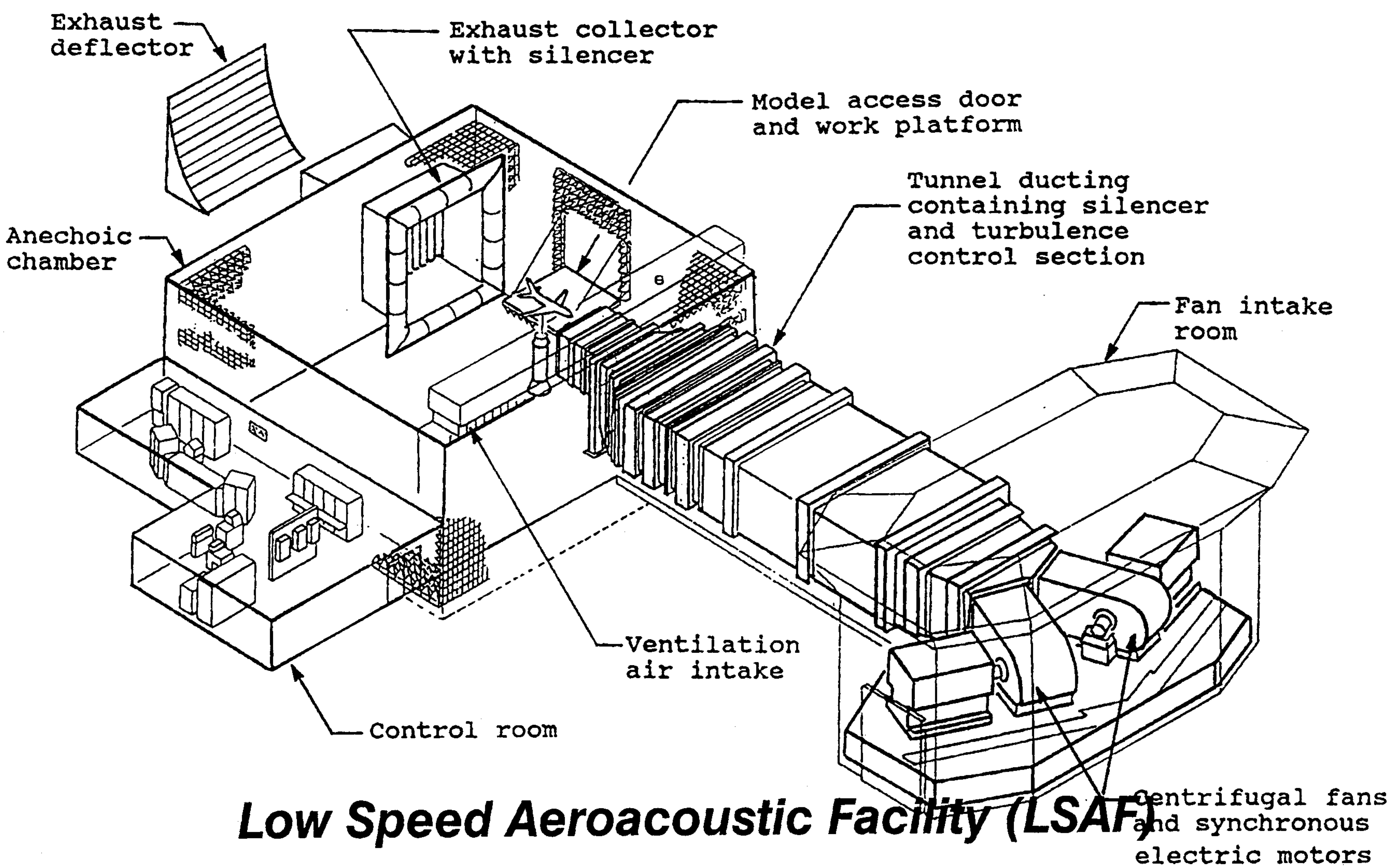
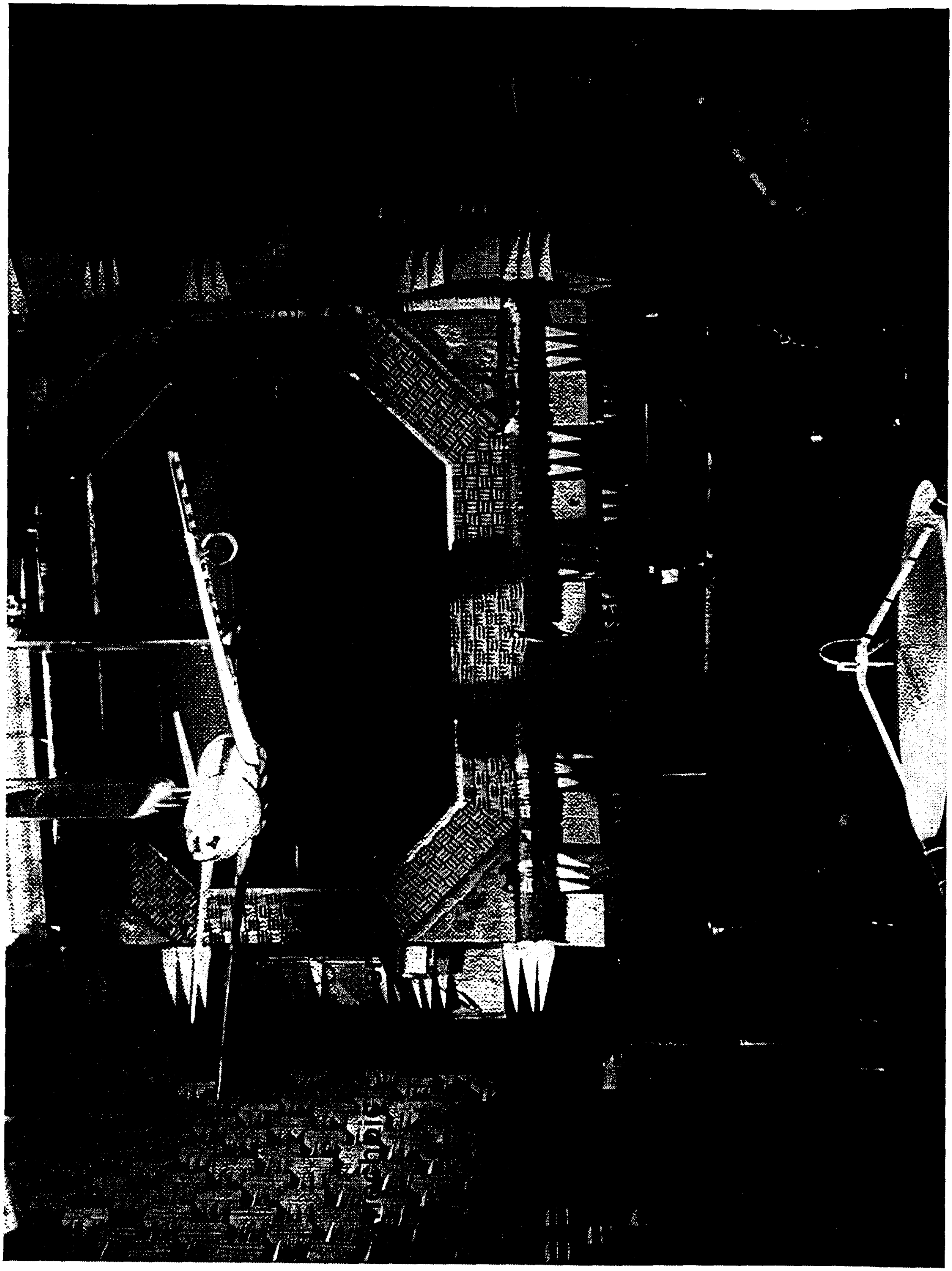


Low Speed Aeroacoustic Facility (LSAF)



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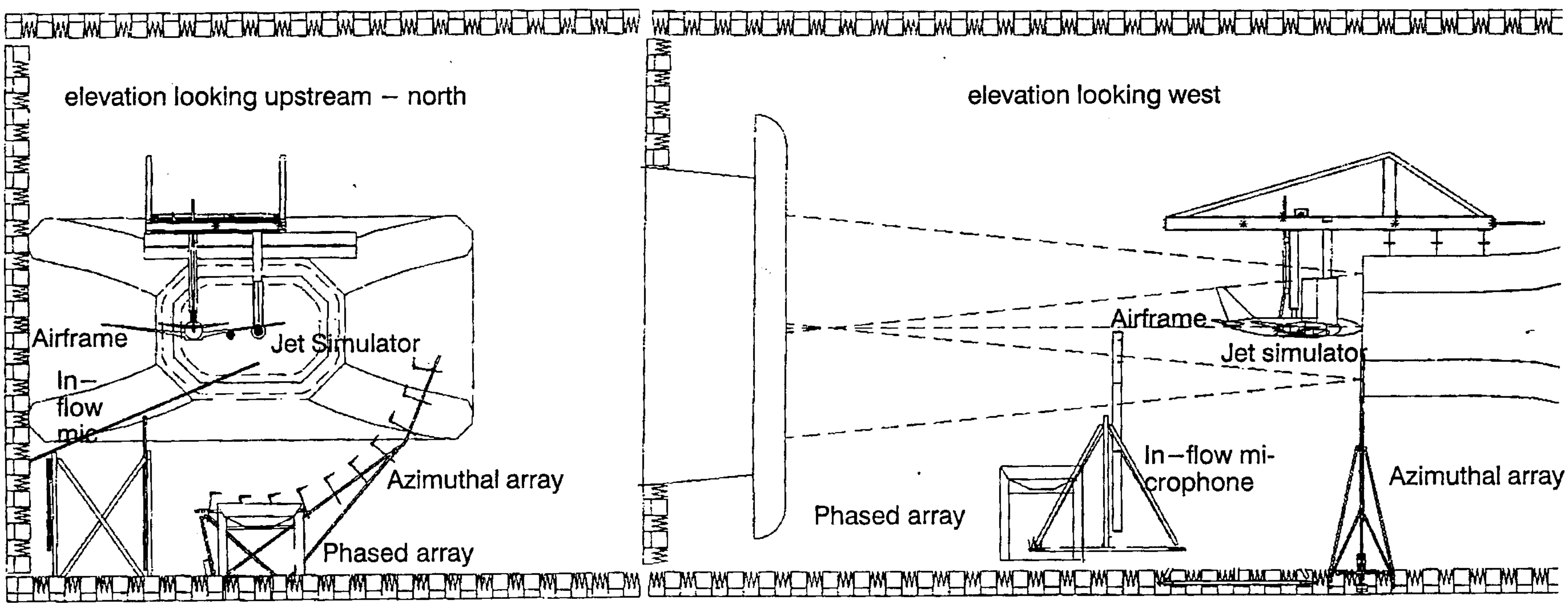

Hardware & Instrumentation Layout

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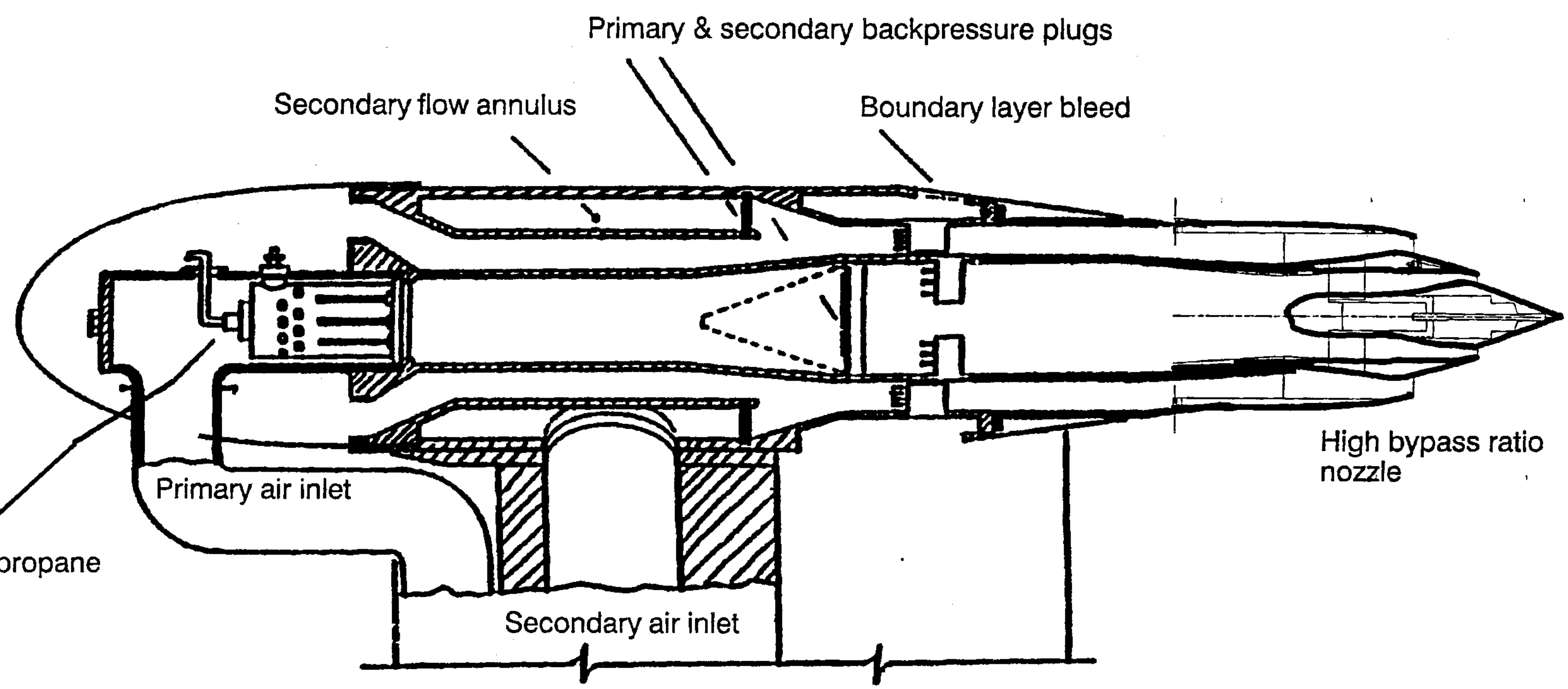

Dual Flow Jet Generator

NOISE ENGINEERING TECHNOLOGY

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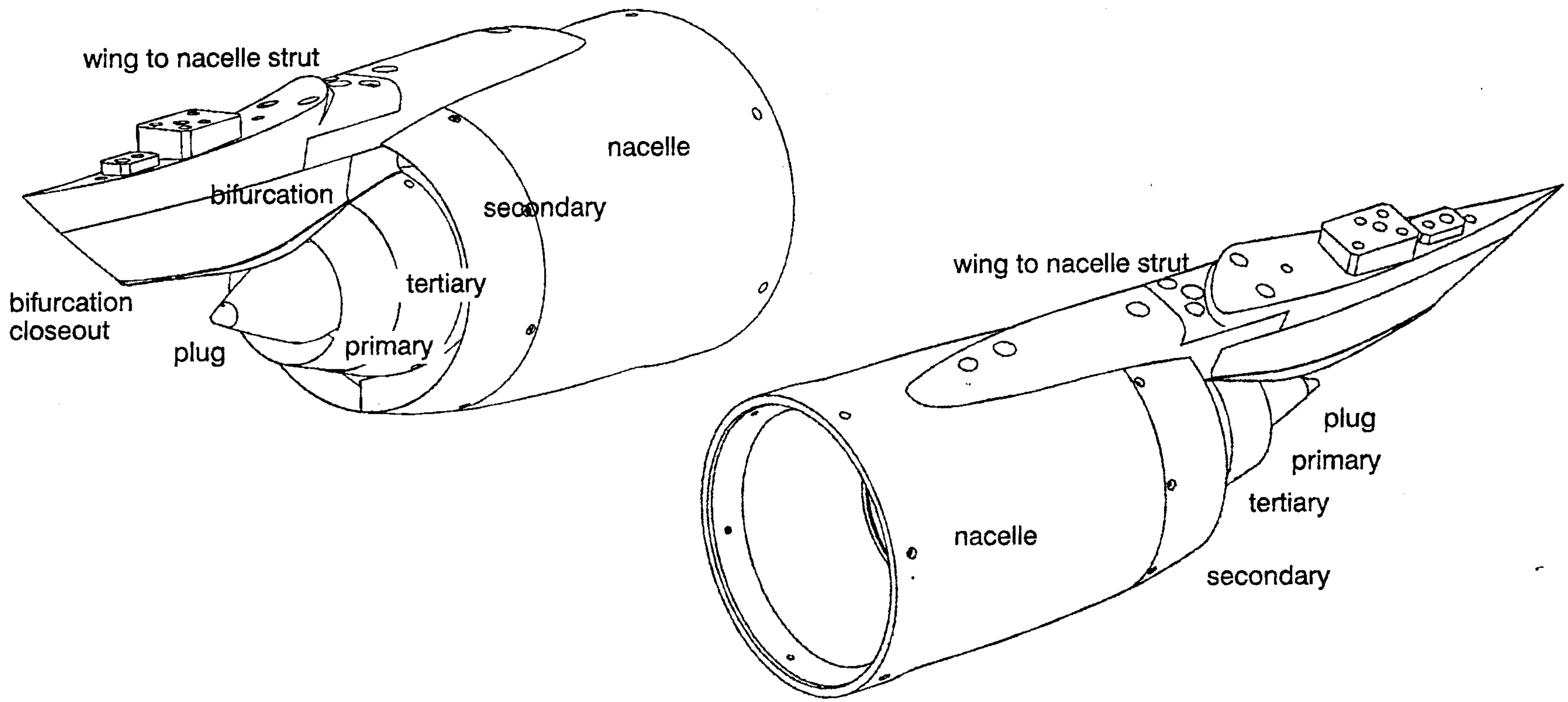

Baseline Nozzle Configuration

NOISE ENGINEERING TECHNOLOGY

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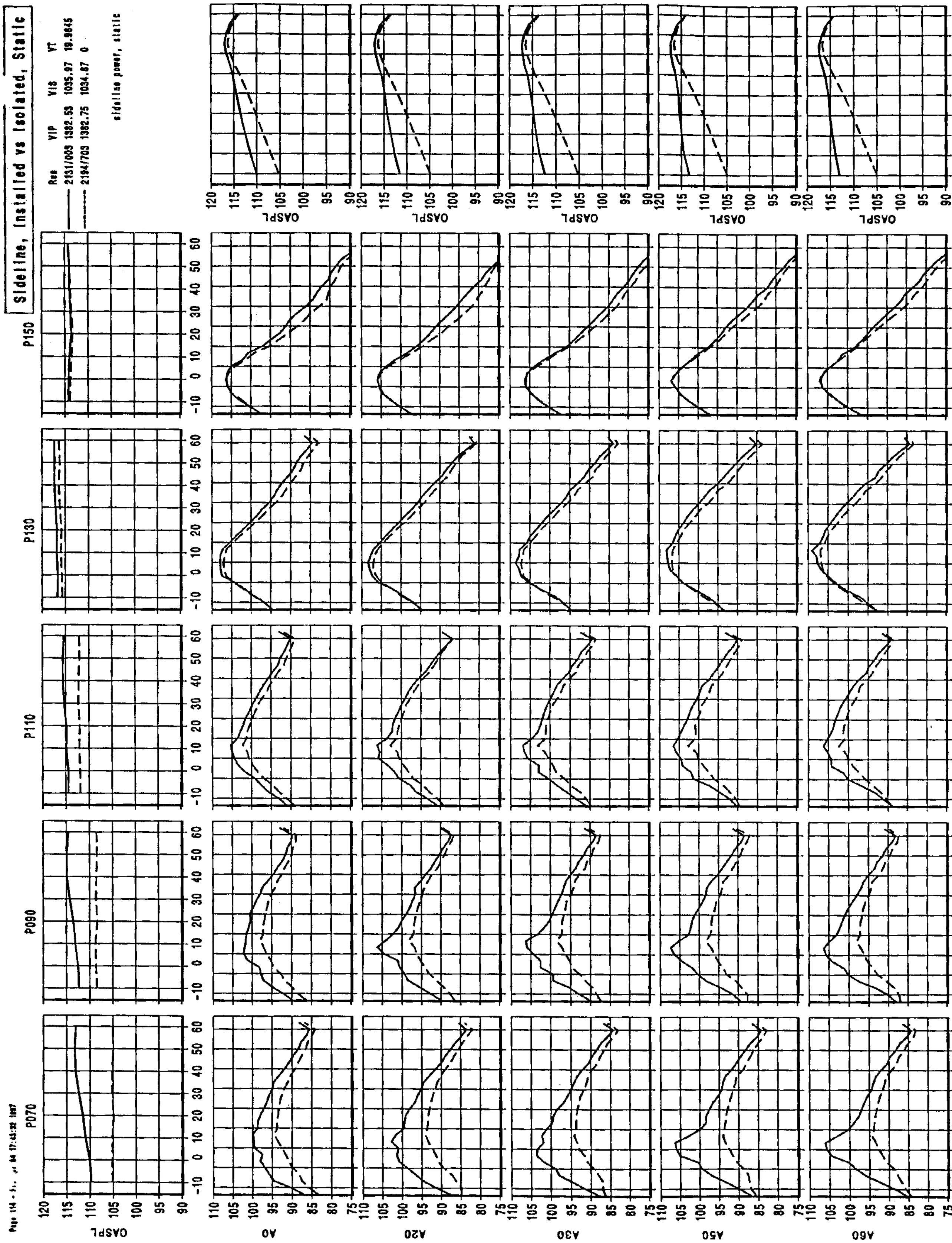
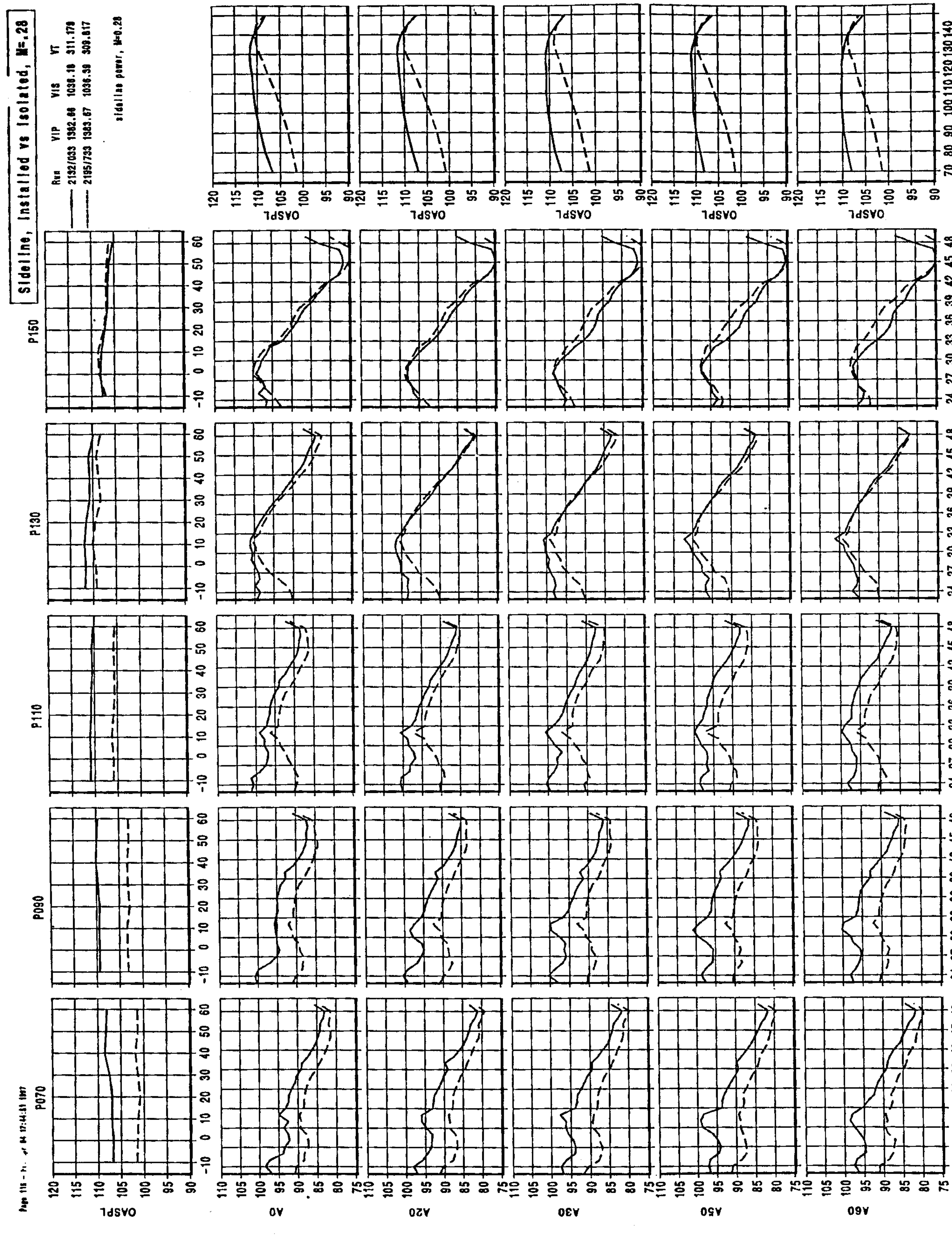
Test Configurations:

- *Installed jet (inboard)*
  - *— different power settings*
  - *— various flap settings*
  - *— different angle–of–attacks*
  - *— different installation locations*
  - *— changes in bifurcation*
- *Isolated jet*

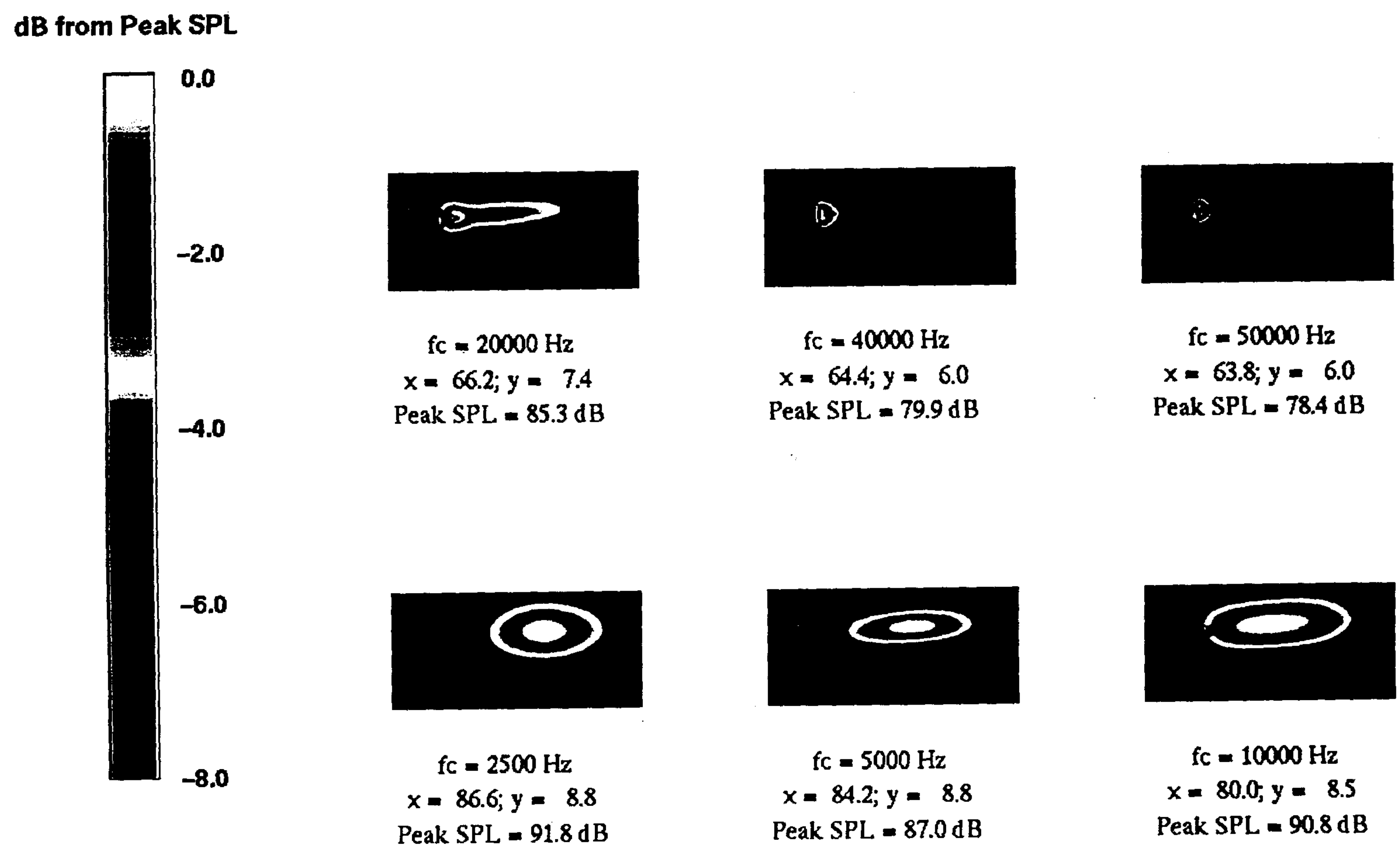

Sideline, Installed vs Isolated, Static
Run VIP VIS VT
2131/003 1382.53 1035.97 19.9645
2194/703 1382.75 1034.87 0
sideline power, static
P070
P090
P110
P130
P150
OASPL
A0
A20
A30
A50
A60
BANDNO
POLAR



Sideline, Installed vs Isolated, M=.28
Run VIP VIS VT
2192/033 1382.66 1036.18 311.178
2195/733 1383.67 1036.39 309.617
sideline power, M=0.28
P070
P090
P110
P130
P150
OASPL
A0
A20
A30
A50
A60
BANDNO
POLAR

LSAF 1043 – Installed Jet Noise

Run: 2194 **Mach: 0.0**



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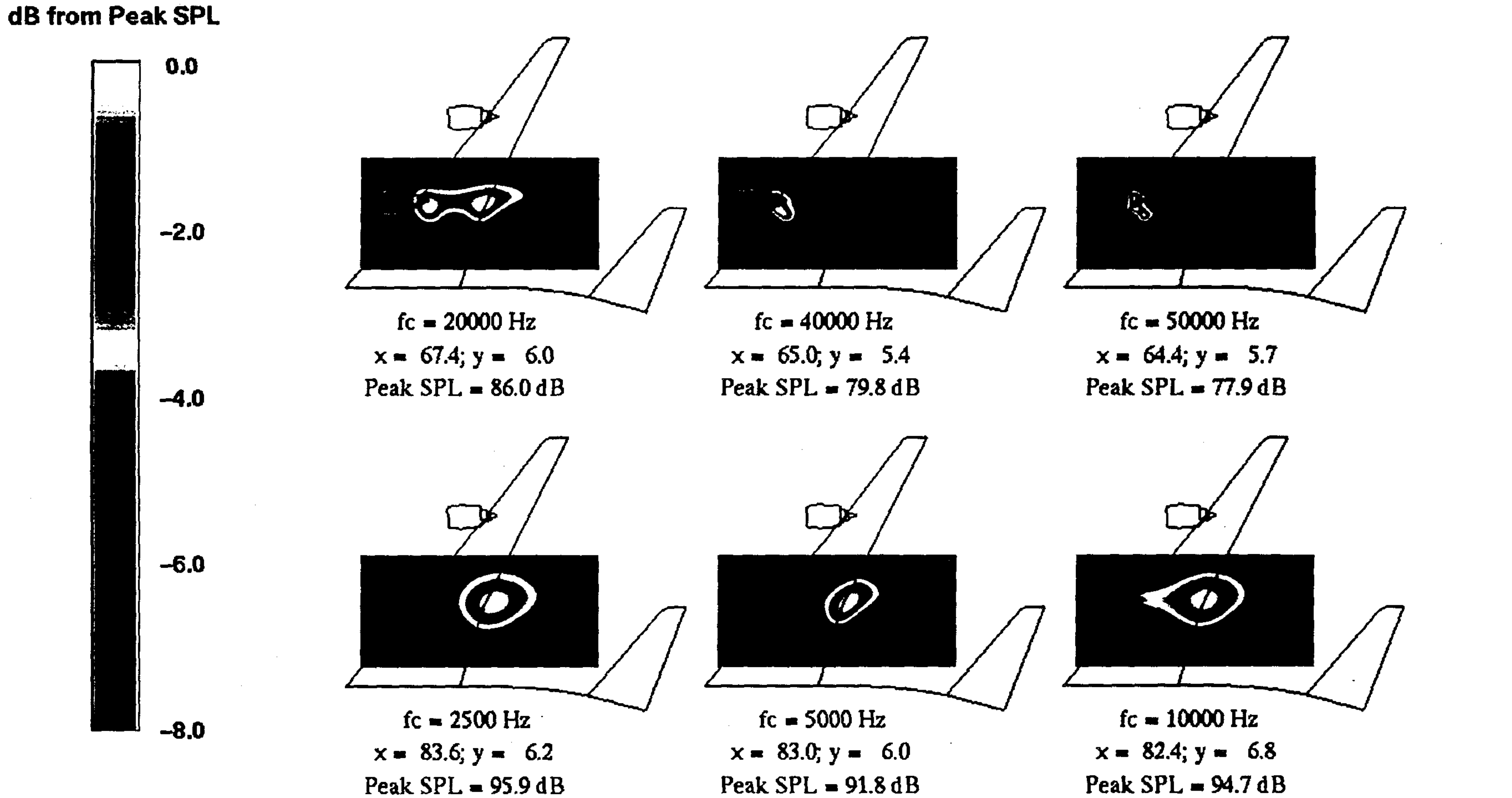
LSAF 1043 – Installed Jet Noise

Run: 2131 **Mach: 0.0**



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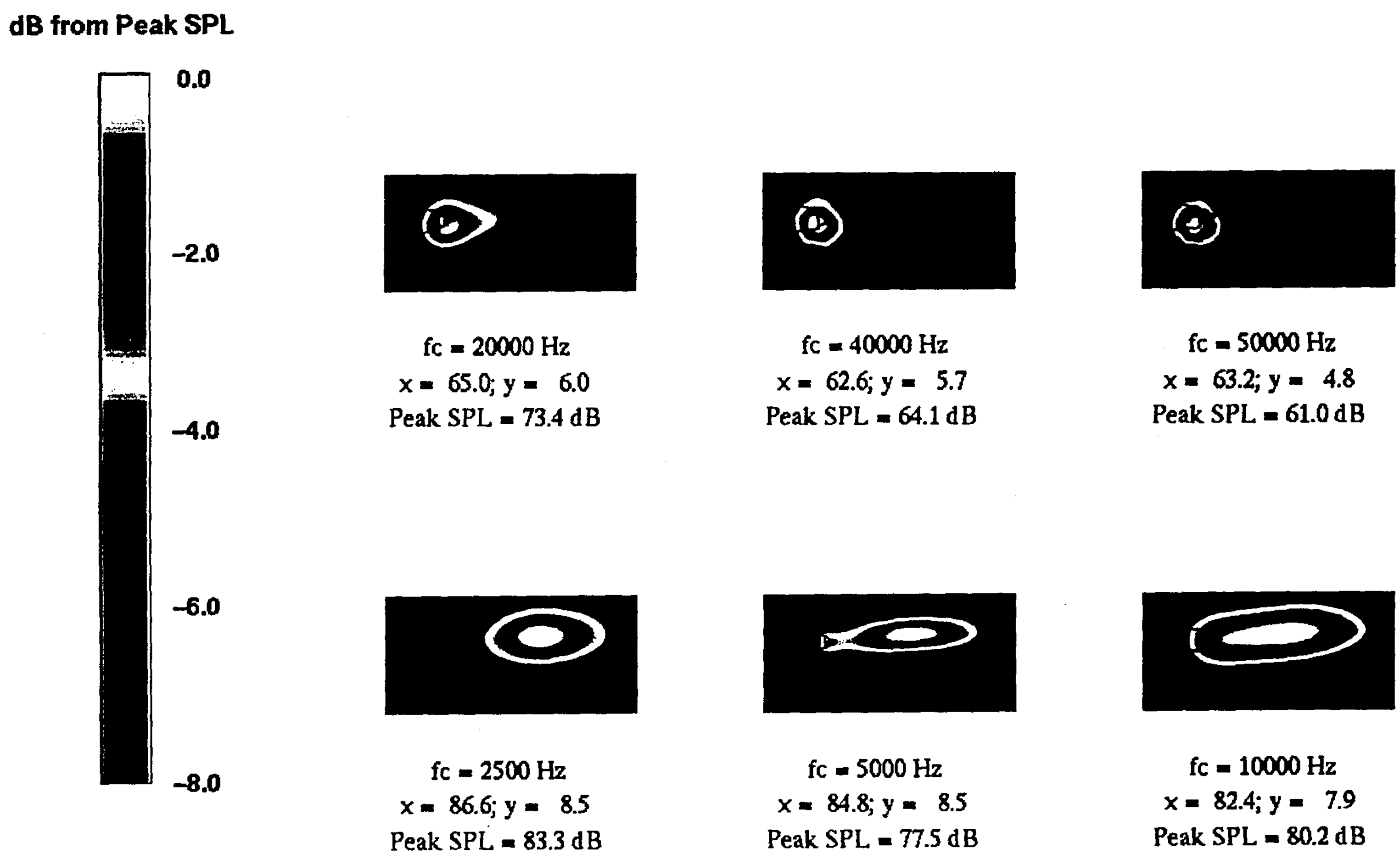
LSAF 1043 – Installed Jet Noise

Run: 2195 **Mach: 0.28**



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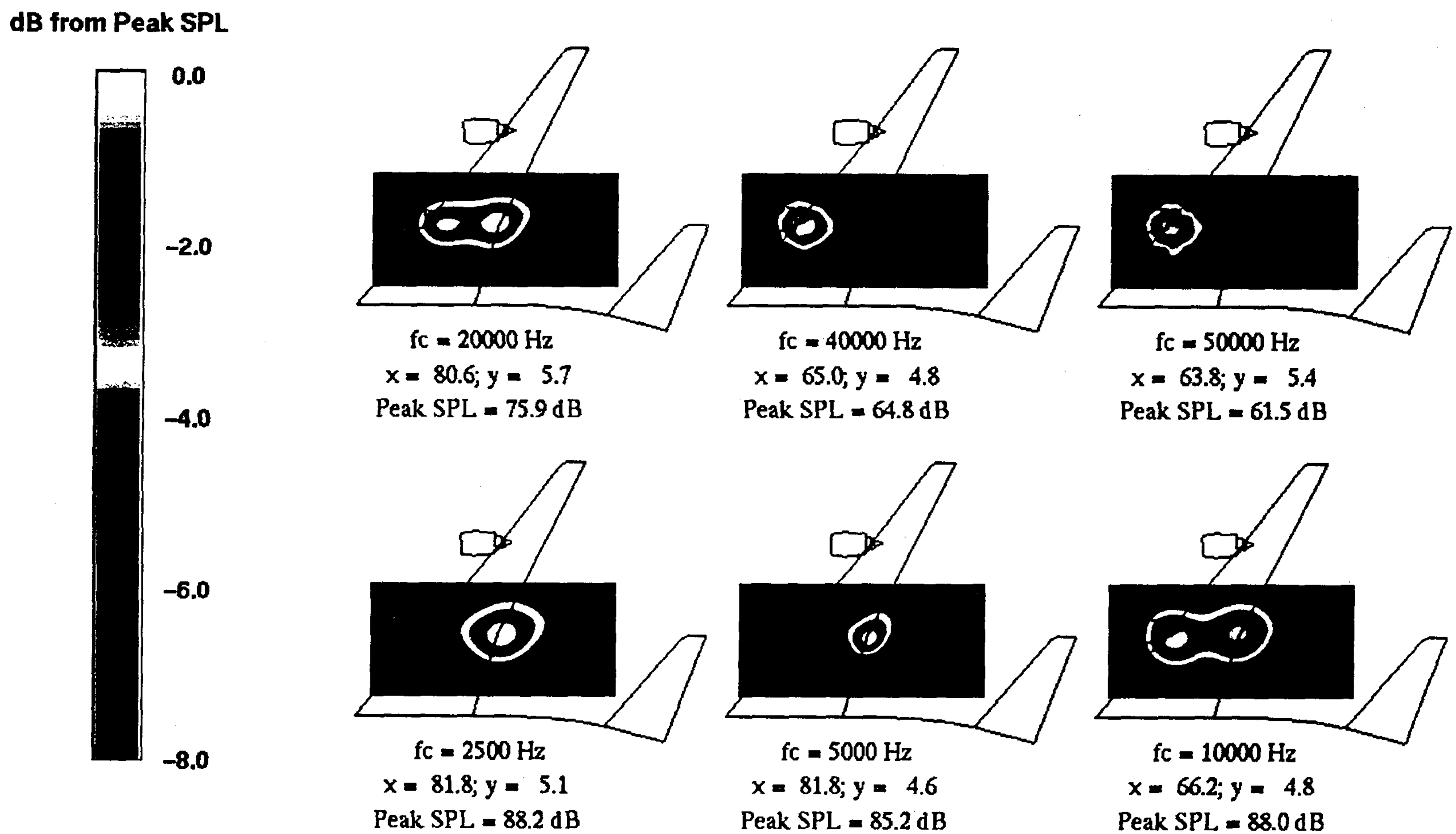
LSAF 1043 – Installed Jet Noise

Run: 2132 **Mach: 0.28**



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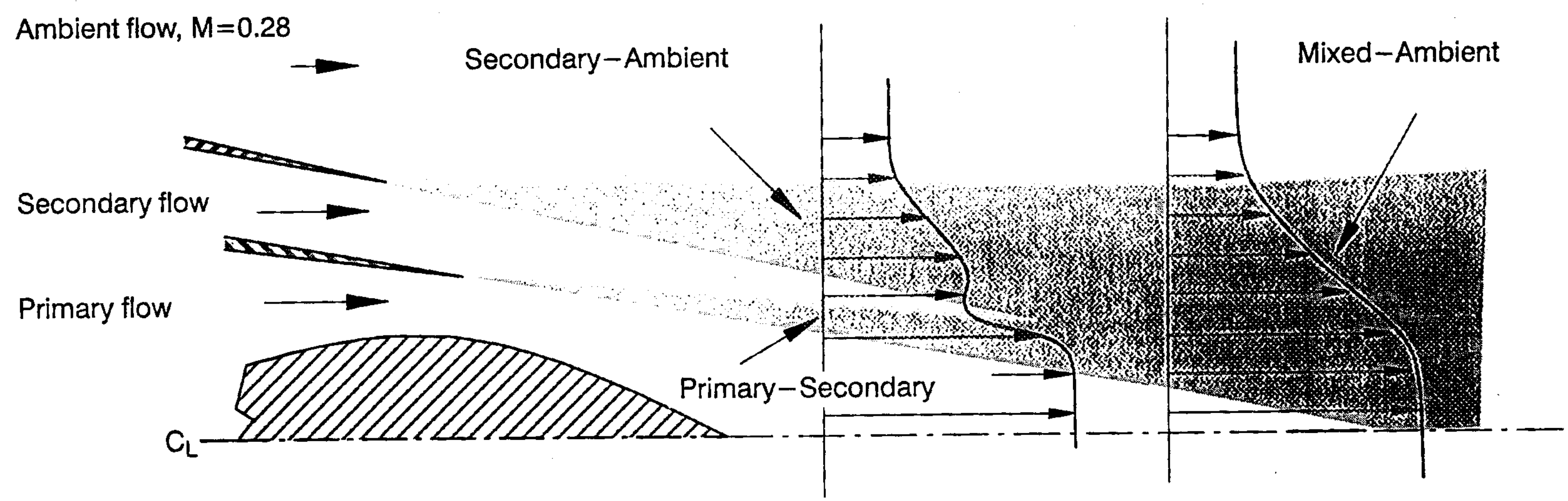

Schematic of Jet Noise Source Model

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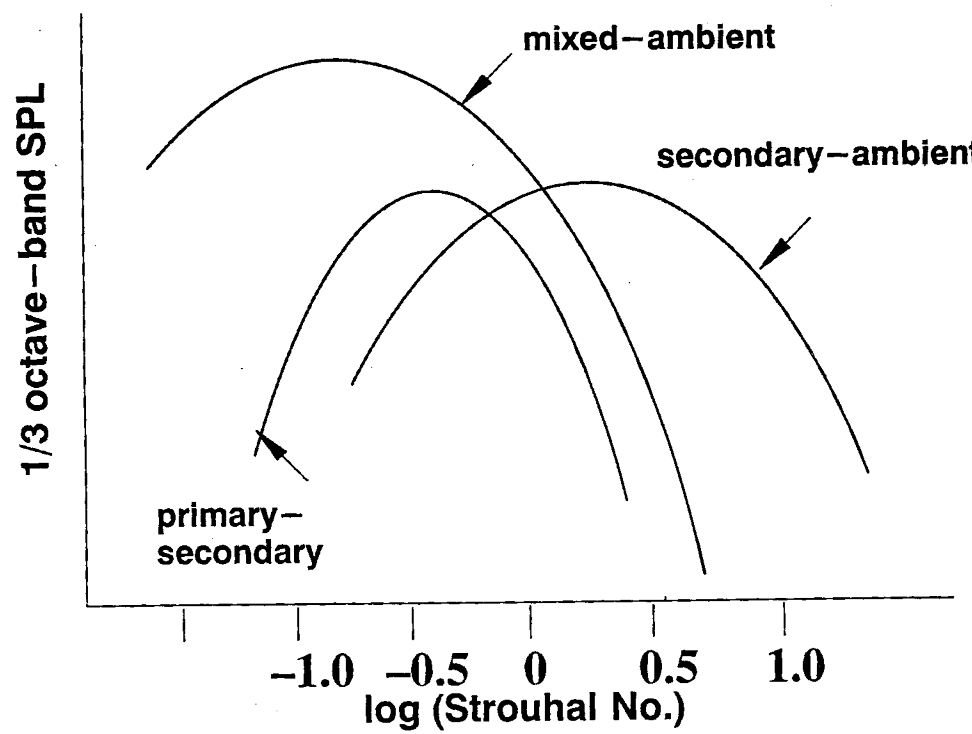

Schematic of Jet Noise Component Spectra

NOISE ENGINEERING TECHNOLOGY

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Concluding remarks:

- *Installation increases noise*
- *Noise increases with increasing flap deflection*
- *Secondary–ambient & mixed–ambient compo nents are dominant*
- *Noise for installed jet is not axi–symmetric*
- *Modeling of installation effects is in progress*

Jet Noise Analysis and Separate Flow Nozzle Test Workshops
Sept. 9-10, 1997

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13. ABSTRACT ***(Maximum 200 words)***

NASA Glenn, in partnership with US industry, completed an exhaustive experimental study on jet noise reduction from separate flow nozzle exhaust systems. The study developed a data base on various bypass ratio nozzles, screened quietest configurations and acquired pertinent data for predicting the plume behavior and ultimately its corresponding jet noise. Several exhaust system configurations provided over 2.5 EPNdB jet noise reduction at take-off power. These data were disseminated to US aerospace industry in a conference hosted by NASA GRC whose proceedings are shown in this report.

14. SUBJECT TERMS
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