National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

Reply to Attn of: P 05-173

April 11, 2005

Captain H. Ray Lahr
18254 Coastline Drive
Malibu, CA 90265-5704

Dear Captain Lahr:

Your Freedom of Information Act (FOIA) request, submitted to the Central Intelligence Agency (CIA), was forwarded to the National Aeronautics and Space Administration (NASA) with NASA documents for a release determination. Your request was received on April 11, 2004.

Your request is being processed in chronological order based upon the date it was received. NASA processes all FOIA requests in a multi-track processing system, based upon the date of receipt and the amount of work and time involved in processing the request. The agency determines whether the request is simple or complex. In order for a request to be expedited, the requestor must demonstrate a compelling or urgent need and demonstrate that failure to obtain the information could pose an imminent threat to life or physical safety or loss of substantial due process rights.

Questions regarding this action should be in writing to this center at the address shown on the letterhead.

Cordially,

Kellie N. Robinson

Kellie N. Robinson
Freedom of Information Act Officer

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

Reply to Attn of: 05-173 May 4, 2005

Captain H. Ray Lahr
18254 Coastline Drive
Malibu, CA 90265

Dear Captain Lahr:

This is in response to your request submitted to the Central Intelligence Agency (CIA), forwarded to the National Aeronautics and Space Administration (NASA) with NASA documents for a release determination. Your request was received on April 11, 2004.

Our Agency conducted a review of the referred documents and has no objections to its release in full.

Questions regarding this action should be in writing to this Center at the address shown on the letterhead.

Cordially,

Kellie N. Robinson

Kellie N. Robinson
Freedom of Information Act Officer

Enclosures

cc:
CIA
Information and Privacy Coordinator
Washington, DC 20505

UNCLASSIFIED

v1.0

EXTRA Tracking Document

Document Number	OGC-11648-03
Date Registered	12/2/2003
Date of Document	12/1/2003
Classification	Unclassified
Control Marks	
Subject	LETTER TO SCOTT W. MULLER - - RE: CAPTAIN H. RAY LAHR V. NATIONAL TRANSPORTATION SAFETY BOARD NO. CV 03-8023-CBM (CTX)
To	ROBERT EATINGER
Originator: Person	JAN L. LUYMES
Agency	DOJ
Component	
Abstract	
Attachments	Attach0.TIF -- OGC-11648-03
Softcopy Files	No File Attachments Available
Original Media Type	PP

Route To For Action	Route To For Information

Additional Route To For Action	Additional Route To For Information

Suspense Date	12/30/2003
Precedence	ROUTINE
Lead Office	
Dissemination Instructions	
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Comments	
Keywords	
File Code	● Permanent ○ Temporary
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Action Officer	Linwood C. Sawyer-Jr
DAC Action History	12/02/2003 03:00:14 PM Linwood C. Sawyer-Jr – document created
Document Status	Unknown

Role	Actionee	Status	Created	Due	Completed	Comments	Attachmen

Location History

Workflow History

12/02/2003 15:03:52 Linwood C. Sawyer-Jr -- document created
12/02/2003 15:04:04 Linwood C. Sawyer-Jr -- document edited

F-2004-00078
Diana

OCT 09 2003

Captain H. Ray Lahr (ret)
18254 Coastline Drive
Malibu, CA 90265-5704
(310) 459-2232

October 10, 2003

Freedom of Information Act Request

By facsimile (703) 613-3007 (two pages total)
(& by regular mail)

Information and Privacy Coordinator
CENTRAL INTELLIGENCE AGENCY
Washington, D.C. 20505

Re: Freedom of Information Act Requests, Numbered 4 - 109
NTSB's probe into downing of TWA Flight 800
July 17, 1996 East Moriches, NY (DCA96MA070)

Dear Coordinator:

There are two corrections for my Freedom of Information Act request letter dated October 8, 2003, (captioned as above and enclosed).

1. The correct return address is 18254 Coastline Drive.
2. "and certified Return Receipt requested" should be removed.

Sincerely,

H Ray Lahr

H. Ray Lahr

OCT 0 8 2003

Captain H. Ray Lahr (ret)
8524 Coastline Drive
Malibu, CA 90265
(310) 459-2232

October 8, 2003

F-2004-00078
Diana

Freedom of Information Act Request

Information and Privacy Coordinator
CENTRAL INTELLIGENCE AGENCY
Washington, D.C. 20505

By facsimile (703) 613-3007 Pages: this page 1. CIA FOIA Response 2. Excel printout 30. Total 33

And by regular mail, and certified Return Receipt requested.

Re: Freedom of Information Act Requests, Numbered 4 – 109
NTSB's probe into downing of TWA Flight 800
July 17, 1996 East Moriches, NY (DCA96MA070)

Dear Coordinator:

This is a Freedom of Information Act request under 5 U.S.C. 552 et seq. In November 1997, during the course of the captioned investigation, the NTSB and FBI released the CIA-produced video-animation of Flight 800 continuing to fly, over 3,000 up, after the nose of the aircraft separated from the fuselage. These Requests are for all records upon which this publicly released aircraft flight path climb conclusion was based, and the 105 FOIA Requests are itemized in the enclosed Excel printout and disk. Additional identification information appears at the beginning of the Excel printout.

I intend to publish my findings, significantly contributing to the public understanding of the workings of government, public safety, and therefore request a waiver of any fees otherwise applicable. This request is not contingent on fee waiver, I agree to pay fees up to $150, and so please call me in the unlikely event that you need authority for me to incur fees in excess of $150.

You referred me to the National Transportation Safety Board by January 26, 2001 FOIA response, a copy of which is enclosed. The NTSB has denied having records identified in this request in Lahr v. NTSB et. al., C.D.C.A. Case No. CV 02-8708-AHM(RZx).

Sincerely,

H. Ray Lahr

H. Ray Lahr

Enclosures -- 30-page Excel printout & disk, January 26, 2001 CIA FOIA Response.

DYER — CIA DENIAL OF FOIA REQUEST 1·26·01

Central Intelligence Agency

Washington, D.C. 20505

JAN 26 2001

Mr. Ray Lahr
18254 Coastline Drive
Malibu, CA 90265

Reference: F-2000-02350

Dear Mr. Lahr:

This acknowledges receipt of your 10 November 2000 letter requesting records under the provisions of the Freedom of Information Act (FOIA). Specifically, your request is for records pertaining to **the computer program and data used to produce the computer simulation of TWA Flight 800, 17 July 1996, losing its nose section, then climbing about 3,000 feet.** For identification purposes we have assigned your request the number referenced above. Please refer to this number in future correspondence.

We understand your request to indicate your interest is focused on the separation of the aircraft's nose section from the fuselage, and the related data and resulting conclusions. We have researched this matter, and have learned that the pertinent data, and resulting conclusions, were provided by the National Transportation Safety Board (NTSB). CIA simply incorporated the NTSB conclusions into our videotape. Therefore, we are unable to provide the information you seek inasmuch as the agency that originated the information has the responsibility for making decisions about the release of its information. Accordingly, you may wish to submit your request to the NTSB at the following address:

The National Transportation Safety Board
Attention: FOIA Officer RE-5[illegible]
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594-2000

or

FAX: (202) 314-6598

We regret we cannot be of any further assistance in this matter.

Sincerely,

Kathryn I. Dyer
Information and Privacy Coordinator

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Produced/ withheld in part / withheld in full / no responsive records / other</td><td>CIA:
Exemptions asserted</td><td>Plaintiff:
Exemptions challenged / segregation</td><td>Plaintiff:
Contested as failure to identify / other</td></tr>
<tr><td>3</td><td colspan="6">This FOIA Request is for all records upon which the aircraft flight path climb conclusions are based, including, but not limited to, the underlying data and basis of all written reports and the November 1997 CIA-produced video-animation-conclusions. This includes but is not limited to all computer simulation and animation programs, and the data entered into all such programs, in each case correlating which data was entered into which program.

The first column is the FOIA Request number. The second column, A, is the description of the records sought, and the description sometimes continues in the next column, B. These requests are to be read as to be made both categorically and specifically. Your response will be under B and C.

For your convenience, the floppy disc is included. Feel free to just fill in columns B and C, the NTSB's response. Simple Excel instructions appear at the end.</td></tr>
<tr><td>4</td><td>CATEGORY 1: All records of formulas used by the NTSB in its computations of the zoom-climb conclusions, CATEGORY 2: All records of the weight and balance data used by the NTSB in its computations of the zoom-climb conclusions. (hereinafter referred to as ONE & TWO FORMULAS & DATA)</td><td></td><td></td><td></td><td></td><td></td></tr>
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8	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 4 – Main Wreckage Simulation – Longitudinal Motion Only (Altitude) [NTSB EX 22C p. 6]:				
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44	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 9 – Main Wreckage Simulation – Roll Angles for nominal simulations [NTSB EX 22C Addendum I p. 8]:				
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53	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 18 – Main Wreckage Simulation – Altitudes for fast simulations [NTSB EX 22C Addendum I p. 14]:				
54	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 19 – Main Wreckage Simulation – Roll angle for nose off at 749 sec [NTSB EX 22C Addendum I p. 15]:				
55	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 20 – Main Wreckage Simulation – Map view of nose off at 749 sec [NTSB EX 22C Addendum I p. 15]:				
56	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 21 – Main Wreckage Simulation – East position for nose off at 749 sec [NTSB EX 22C Addendum I p. 16]:				
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65	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 6 - Main Wreckage Simulation - Map view of nose off at 20:31:17.2 [NTSB EX 22F Addendum II p. 8];				
66	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 7 - Main Wreckage Simulation - East position for nose off at 20:31:17.2 [NTSB EX 22F Addendum II p. 8];				
67	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 8 - Main Wreckage Simulation - North position for nose off at 20:31:17.2 [NTSB EX 22F Addendum II p. 9];				
68	**ONE & TWO FORMULAS & DATA** records supporting NTSB Docket Materials	Figure 9 - Main Wreckage Simulation - Altitude for nose off at 20:31:17.2 [NTSB EX 22F Addendum II p. 9];				

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69	ONE & TWO FORMULAS & DATA records upon which CIA-produced animation (broadcast on all networks and CNN November 1997.)					
70	ONE & TWO FORMULAS & DATA any and all records you unidentified in your sepones to FOIA Request Nos 4 through 69 above.					

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71	CATEGORY 3: All records of the formulas and data entered into the computer simulations regarding the CIA and/or NTSB's zoom-climb conclusion, (hereinagter referred to as THREE - FORMULAS & DATA ENTERED INTO COMPUTER).					
72	THREE - FORMULAS & DATA ENTERED INTO COMPUTER BREAKUP Program [See NTSB Exhibit 22A, p. 4.]					

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73	THREE - FORMULAS / DATA ENTERED INTO COMPUTER BALLISTIC Program [See NTSB Exhibit 22A, p.13.]					
74	THREE - FORMULAS & DATA ENTERED INTO COMPUTER LONGITUDINAL MOTION SIMULATION CODE WITH AND WITHOUT MODIFICATION FOR BANK AND ROLL [See NTSB Exhibit 22C. p. 6.]					

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75	**THREE - FORMULAS & DATA ENTERED INTO COMPUTER** records upon which CIA-produced animation (broadcast on all networks and CNN November 1997.)					
76	**THREE - FORMULAS & DATA ENTERED INTO COMPUTER** any and all records you unidentified in your sepones to FOIA Request Nos 71 through 75 above.					

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77	**CATEGORY 4: All records reflecting whether or not the CIA conducted the computer simulations and video animations in-house &, if not, all records of when, where, and by whom the computer simulations were performed (hereinafter FOUR SIMULATIONS BY WHOM).**					
78	**FOUR SIMULATIONSBY WHOM** BREAKUP Program [NTSB Exhibit 22A, p. 4]					
79	**FOUR SIMULATIONSBY WHOM** BALLISTIC Program [NTSB Exhibit 22A, p.13.]					

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80	**FOUR SIMULATIONS BY WHOM** LONGITUDINAL MOTION SIMULATION CODE WITH AND WITHOUT MODIFICATION FOR BANK AND ROLL [See NTSB Exhibit 22C, p. 6.]					
81	**FOUR SIMULATIONS BY WHOM** records upon which CIA-produced animation (broadcast on all networks and CNN November 1997.)					
82	**FOUR SIMULATIONS BY WHOM** any and all records unidentified in your sepones to FOIA Request Nos 77 through 81 above.					

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83	CATEGORY 5: The computer simulation and animation programS used by the CIA and/or the NTSB (hereinafter FIVE COMPUTER SIMULATION ITSELF).					
84	FIVE COMPUTER SIMULATION ITSELF BREAKUP Program [See NTSB Exhibit 22A, p. 4.]					
85	FIVE COMPUTER SIMULATION ITSELF BALLISTIC Program [See NTSB Exhibit 22A, p. 13.]					

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86	**FIVE COMPUTER SIMULATION ITSELF** LONGITUDINAL MOTION SIMULATION CODE WITH AND WITHOUT MODIFICATION FOR BANK AND ROLL [See NTSB Exhibit 22C, p. 6.]					
87	**FIVE COMPUTER SIMULATION ITSELF** records upon which CIA-produced animation (broadcast on all networks and CNN November 1997), was based.					

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1	10/6/03 FOIA Request Nos. 4 through 109.	**CIA:** Identification / description of records	**CIA:** Produced/ withheld in part / withheld in full / no responsive records / other	**CIA:** Exemptions asserted	**Plaintiff:** Exemptions challenged / segregation	**Plaintiff:** Contested as failure to identify / other
88	FIVE COMPUTER SIMULATION ITSELF any and all records unidentified in your reseponses to FOIA Request Nos 83 through 87 above.					
89	**CATEGORY 6: The printout of the computer simulations used by the CIA and/or NTSB (hereinafter SIX COMPUTER PRINTOUTS)**					
90	SIX COMPUTER PRINTOUTS BREAKUP Program [See NTSB Exhibit 22A, p. 4.]					

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91	**SIX COMPUTER PRINTOUTS** BALLISTIC Program [See NTSB Exhibit 22A, p. 13.]					
92	**SIX COMPUTER PRINTOUTS** LONGITUDINAL MOTION SIMULATION CODE WITH AND WITHOUT MODIFICATION FOR BANK AND ROLL [See Exhibit 22C, p. 6.]					
93	**SIX COMPUTER PRINTOUTS** records upon which CIA-produced animation (broadcast on all networks and CNN November 1997.)					

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94	**SIX COMPUTER PRINTOUTS** any and all records unidentified in your reseponses to FOIA Request Nos 89 through 93 above.					
95	**CATEGORY 7: All records of the timing sequence of the zoom climb, including but not limited to radar, radio transmissions, and the flight data recorder (hereinafter SEVEN - TIMING SEQUENCES -- RADAR, RADIO, FDR).**					

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96	**SEVEN - TIMING SEQUENCES -- RADAR, RADIO, FDR** records upon which CIA-produced animation (broadcast on all networks and CNN November 1997.)					
97	**SEVEN - TIMING SEQUENCES -- RADAR, RADIO, FDR** any and all records unidentified in your reseponses to FOIA Request Nos 95 through 96 above.					

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98	**CATEGORY 8: All records of the correlation of the zoom-climb calculations with the actual radar plot (hereinafter EIGHT - RADAR PLOT CORRELATION**					
99	**EIGHT - RADAR PLOT CORRELATION** records upon which CIA-produced animation (broadcast on all networks and CNN November 1997), was based.					
100	**EIGHT - RADAR PLOT CORRELATION** any and all records unidentified in your reseponses to FOIA Request Nos 98 through 99 above.					

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101	CATEGORY 9: All records of the information provided by Boeing to the NTSB used by the NTSB to calculate these zoom-climb conclusions (hereinafter NINE - INFO PROVIDED BY BOEING).					
102	NINE - INFO PROVIDED BY BOEING records upon which CIA-produced animation (broadcast on all networks and CNN November 1997.)					

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1	*10/6/03* FOIA Request Nos. 4 through 109.	**CIA:** Identification / description of records	**CIA:** Produced/ withheld in part / withheld in full / no responsive records / other	**CIA:** Exemptions asserted	**Plaintiff:** Exemptions challenged / segregation	**Plaintiff:** Contested as failure to identify / other
103	NINE - INFO PROVIDED BY BOEING any and all records unidentified in your reseponses to FOIA Request Nos 101 through 102 above.					
104	CATEGORY 10: All records of the process by which the NTSB arrived at its zoom-climb conclusions (hereinafter TEN - ALL RECORDS GENERATED OR RECEIVED).					

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1	*10/6/03* **FOIA Request Nos. 4 through 109.**	**CIA: identification / description of records**	**CIA: Produced/ withheld in part / withheld in full / no responsive records / other**	**CIA: Exemptions asserted**	**Plaintiff: Exemptions challenged / segregation**	**Plaintiff: Contested as failure to identify / other**
105	**TEN - ALL RECORDS GENERATED OR RECEIVED** records upon which CIA-produced animation (broadcast on all networks and CNN November 1997.)					
106	**TEN - ALL RECORDS GENERATED OR RECEIVED** any and all records unidentified in your reseponses to FOIA Request Nos 104 through 105 above.					

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1	10/6/03 FOIA Request Nos. 4 through 109.	CIA: Identification / description of records	CIA: Produced/ withheld in part / withheld in full / no responsive records / other	CIA: Exemptions asserted	Plaintiff: Exemptions challenged / segregation	Plaintiff: Contested as failure to identify / other
107	CATEGORY 11: All records generated or received by the NTSB used in its computations of its zoom-climb conclusions (hereinafter ELEVEN - ALL RECORDS OF PROCESS)					
108	ELEVEN - ALL RECORDS OF PROCESS records upon which CIA-produced animation (broadcast on all networks and CNN November 1997.)					

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1	10/6/03 FOIA Request Nos. 4 through 109.	CIA: Identification / description of records	CIA: Produced/ withheld in part / withheld in full / no responsive records / other	CIA: Exemptions asserted	Plaintiff: Exemptions challenged / segregation	Plaintiff: Contested as failure to Identify / other
109	ELEVEN - ALL RECORDS OF PROCESS any and all records unidentified in your reseponses to FOIA Request Nos 107 through 108 above.					

Explanatory Notes:

The CIA presented its flight path conclusions a November 1997 animation.

The NTSB Trajectory Study includes 31 Figures (graphs) in Exhibit 22C, 23 Figures in Addedum I, and 10 Figures in Addendum II. Formulas and data underlying these graphs do not appear the the public record, and, if you relied on any of these 64 graphs in your computer simulations or animation, all such records are responsive.

The Requestor does not know which computer programs the CIA used.

The NTSB used three computer programs

1. The BREAKUP program described in NTSB Exhibit 22A page 4.
2. The BALLISTIC program described in NTSB Exhibit 22A page 13.
3. The LONGITUDINAL SIMULATION program described in NTSB Exhibit 22C page 6.

Microsoft Excel Instructions:

Put curser in cell and type information.
To print, highlight area to be printed, click "File," "print," "selection," "OK."

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Audibility of the Center Fuel Tank Explosion of TWA Flight 800

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November 17, 1999

Summary

The disturbance signal generated by the explosion of the center fuel tank of TWA Flight 800 was predicted for 39 observer locations, accounting for 60 of the 83 observers provided by the NTSB. For three of these locations the audibility of the signal was also predicted. It was determined that the predicted signal was audible for all three locations. Since the three signals for which an audibility analysis was carried out include the signal with the lowest amplitude it may be safely assumed that the signal was audible at all of the locations for which a signal was predicted.

Of the remaining observer positions provided by the NTSB, 11 fell into the shadow region, hence no signal could be predicted for these locations, and 12 were either too far away from the source, or too close to the shadow boundary, for the ray tracing program to converge. Hence no predictions were made for these locations. However, there is no reason to suspect that there was no signal at these locations, nor that such signal was inaudible.

Overview

There are three components to most acoustic predictions. First, a determination of the source; second, the path analysis, or propagation analysis; third, the receiver analysis. The source analysis determines the pressure level and time variation of the signal at the source of the disturbance. The path or propagation analysis determines the changes in the signal as it travels from the source to the receiver. The receiver analysis determines whether or not a person could have heard the disturbance, and, perhaps, whether or not the person would have found the disturbance acceptable or annoying.

The prediction of the audibility of the blast wave produced by the explosion of the center wing tank of TWA Flight 800 is also accomplished in these three stages. First, a prediction of the blast wave signature in a region of space near the explosion is made using the theory of Harold L. Brode.[1] This is the source analysis. The signature of the source is predicted at a distance from the center of the explosion sufficient to allow the application of weak shock theory[2] to transform the predicted source signature to the predicted ground signature. This is the second stage, the propagation, or path, analysis. The propagation analysis is followed by a receiver analysis. This stage of the analysis addresses the problem of determining whether or not a person can actually hear the disturbance that the analysis has predicted will be present at the observer location. In the following, each of these stages in the prediction process will be considered in turn. The discussion of both the source prediction method, and the receiver, or audibility analysis is relatively short and straightforward. The bulk of the following discussion addresses the propagation analysis since this is where the major difficulty of the prediction process occurs.

Source

The effect of an explosion is to force most of the air within a spherical region of radius R(t) into a thin shell immediately behind a shock front, also of radius R(t), and expanding at speed $V_r = \frac{dR}{dt}$ in the radial direction. Thus, the disturbance pressure, as seen by a stationary observer, increases dramatically as the shock front and the thin shell of compressed air immediately behind it starts to pass over the observer location. This dramatic increase in pressure is followed by a short time interval during which the pressure

[1]"Numerical Solutions of Spherical Blast Waves", Harold L. Brode, Journal of Applied Physics, V. 26 #6, June 1955.
[2]"Extrapolation of Sonic Boom Pressure Signatures by the Wave form Parameter Method", Charles L. Thomas, NASA TN D-6832, June 1972.

drops from its peak value to a level below the ambient pressure, and a long time interval over which the pressure slowly returns to the ambient level, see Figure 1. One major difficulty in predicting the disturbance pressure signature on the ground is due to the large overpressure in the initial stage of the disturbance.

Most propagation analysis assumes infinitesimal pressure disturbances. This assumption allows linearization of the governing equations.[3] That is, most propagation analysis is based on equations obtained from the full governing equations by neglecting all terms that contain products of the unknown quantities. This simplifies the analysis considerably. However, this analysis is not applicable to the explosion problem.

Another model that may be applied to the explosion problem is weak shock theory.[4] In this theory, second order products of the unknown quantities are maintained in the governing equations, although higher order products are neglected. Thus, this theory is valid for disturbances whose peak overpressure is less than one tenth of the ambient atmospheric pressure, or those which, though initially having peak overpressures slightly greater than one tenth ambient, are such that these high pressures rapidly decay to less than one tenth ambient. This is the theory used in the current analysis to transfer the source signature to the ground. However, the disturbance pressure near the explosion is considerably greater than one tenth of the ambient pressure. Therefore, a model of the explosion is required that predicts the wave form at a distance from the explosion center sufficient to preclude disturbance pressures greater than one tenth of local atmospheric pressure. Just such a model is provided by the theory of reference 1.

In reference 1, H. L. Brode presents the results of the numerical integration of the equations governing a spherically symmetric blast wave field. He also provides empirical fits to the numerical data that allow the prediction of a blast wave disturbance field based upon two parameters, the ambient pressure, and the energy contained within the initial blast wave. It is assumed that the blast wave is expanding into a uniform, homogeneous medium, which is either stationary, or, through application of a Galilean coordinate transformation, moving with a uniform constant velocity. Neither assumption is strictly valid for the current problem. However, the blast wave predicted by the theory, for the ambient pressure and the energy level applicable to the current problem, reaches a peak

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[3]For basic acoustic theory see "Fundamentals of Acoustics, 2[nd] Ed.", Lawrence E. Kinsler, and Austin R. Frey, John Wiley & sons, 1962.
[4]"Linear and Nonlinear Waves", G. B. Whitham, John Wiley and Sons, New York, 1974. Chapter 9, *The Propagation of Weak Shocks*, pp. 312-338. This book contains what is probably the best introduction to nonlinear propagation and weak shock theory currently available.

overpressure of one tenth ambient in a propagation distance of less than 80 feet. At the altitude of the explosion the ambient pressure gradient is approximately 3.6×10^{-4} psi/ft., and the wind speed gradient is approximately 3.2×10^{-3} sec^{-1}. These gradients are sufficiently small that the error introduced by neglecting them are negligible over the propagation distance of 80 feet.

The ambient pressure at the altitude of Flight 800 at the time of the explosion is taken to be 8.6 psi. The energy of the explosion is taken as 2.9×10^{7} $Ft\text{-}LB_f$, this is equivalent to approximately 20 pounds of TNT. The calculation of this energy level is presented in Appendix A. Given these values the predicted wave form is as presented in Figure 1. This wave form occurs at approximately 80 feet from the explosion center, and is used as the input to weak shock theory. Weak shock theory is then used to determine the pressure disturbance on the ground.

Propagation

The propagation is complicated by two factors; first, meteorology, and second, nonlinearity. Consider the meteorological factor. The atmosphere is in motion, and that motion, given as a wind velocity, varies in both magnitude and direction with altitude. Also, the temperature varies with altitude. It is the sound speed variation, not the temperature variation itself, that affects the propagation. However, the sound speed is directly proportional to the square root of the absolute temperature. This is why temperature variation affects the propagation. The temperature effects are somewhat simpler than the wind effects, and will be discussed first. A short discussion of nonlinearity will be undertaken after completing the discussion of the meteorological factor. A third factor, neglected in the current study, is the effect of atmospheric turbulence on the received signal. Turbulence can increase, or decrease the amplitude of the disturbance.[5] These excursions from the mean amplitude predicted by the analysis of this study occur randomly, with higher amplitudes as likely as lower amplitudes. Further, it is highly unlikely that the effects of turbulence could change the conclusions arrived at in this report.

If the signal given in Figure 1 were to propagate through a homogeneous stationary medium to the ground according to linear theory, the signal received at the ground would be exactly the same as the source signal, except that the signal at the ground would be of lower amplitude. The amplitude at the ground would be decreased by the factor

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5 "Sonic Boom Research," NASA SP-147, A. R. Seebass, Ed., April 1967, pp. 25-48, *Sonic Boom Flight Research - Some effects of Airplane Operations and the Atmosphere on Sonic Boom Signatures*, Domenic Maglieri; pp. 49-64, *Some effects of the Atmosphere on Sonic Boom*, Edward J. Kane.

$\frac{r_0*}{r}$, where r is the distance the signal has propagated, and r_0 is the distance from the point where the source amplitude is given to the actual source location, in the present case approximately 80 feet. This follows from four facts. First, acoustic propagation, that is linear propagation, essentially translates the given signal along the propagation path unchanged. That this must be so for most audible signals can be seen by noting that if the signal were to change significantly as it propagated oral communication would not be possible. Second, the propagation is along straight lines. Third, the energy of the disturbance is conserved, and that energy is being spread over a larger area as the signal propagates away from the source. In fact, the area is proportional to r^2. Fourth, and finally, in a stationary homogeneous medium, the energy flux (The energy passing a given point per unit area, per unit time.) at a point in an acoustic disturbance field, subject to certain conditions that need not be discussed here, is proportional to p^2, where p is the disturbance pressure. Since energy is conserved, and the energy is spread over a larger area as r increases, the equation

$$r^2p^2 = p_0^2r_0^2$$

where p_0 and r_0 are the pressure and distance at an initial point on the propagation path, must hold. Thus we obtain

$$p = \frac{p_0r_0}{r}$$

and the signal is the same at the ground as at the source, although diminished in amplitude by the factor $\frac{r_0}{r}$. Thus, if the linear theory were valid, and the medium through which the blast wave from the explosion of the center wing tank of Flight 800 propagated were stationary and homogeneous, the pressure disturbance at each of the observers would be exactly the same as that given in Figure 1, multiplied by the factor

$\frac{80.0}{r}$, where r is the distance from the position of Flight 800 at the time of the explosion, to any given observer, this distance given in feet.

However, as mentioned previously, the medium through which the disturbance is propagating is neither homogeneous, nor stationary. When a temperature gradient exists within a medium the sound speed varies with position. When the sound speed varies with position the sound no longer travels along straight lines. The first, and the easiest affect on the disturbance field to determine is the change in where the disturbance signal will go. A more important, yet more subtle, affect is a change in amplitude. In order to understand this second affect, consider again the $\frac{1}{r}$ drop in pressure associated with spherical spreading losses in a homogeneous medium. The justification for this dependence on the pressure with propagation distance depended on the argument that the area of the sphere at any given radius r was proportional to r^2. Although this is true, the argument implies that the pressure at any given point in the medium depends on the behavior of the field over a large sphere through that point. Fundamentally, the field at a given point should depend only on more local factors. In fact one should be able to argue that the only global factor that can affect the field at a point is the path the disturbance has traversed, and that, beyond this, only local features of the medium and the field should be required. If on the sphere at the source location, that is for the explosion of Flight 800's fuel tank, on a sphere of radius 80. ft, centered on the position of the center of the fuel tank at the time of the explosion, we draw a circle with a small radius, for example, a radius of 1 inch, centered on the line connecting the center of the fuel tank with the observer for which we are attempting to calculate the disturbance field, and then draw a line from the source position through each point on the circle to the ground, we will obtain a cone shaped structure, with its apex at the source position, and its large end on the ground. This is a ray tube. By definition, the energy travels along the rays. Since our ray tube has its walls made of rays, no energy leaves the ray tube through its walls. Hence, all the energy injected at the apex of the ray tube must travel down the ray tube, and exit, if at all, at the large end of the ray tube. The ray tube concept allows us to eliminate the large sphere from our discussion of the spherical spreading losses. We now consider a central ray passing from the source to the receiver, and a bundle of rays around the central ray. This is our ray tube. Now, for propagation in a stationary homogeneous medium, the rays are all straight lines, the ray tube area increases as r^2, and the disturbance pressure decreases as r^{-1}. However, if the medium is not homogeneous, the ray is no longer a straight line. The ray tube area now depends on the shape of each of the rays making up the ray tube walls. This is the subtle way that temperature variation affects the disturbance amplitude. There is one more way the temperature variation can affect the amplitude of the wave form. The energy flux at a point in the medium is actually related to the product p*u, where p is the disturbance pressure, and u is the velocity of the medium induced by the disturbance. Generally, again subject to conditions which need not be considered here, $p = \rho c u$, where ρ is the local ambient density of the medium, and c is the local sound speed of the medium. Hence we have

$p*u = \frac{p^2}{\rho c}$. It was stated earlier that the energy flux was proportional to p^2. In a homogeneous medium ρc is a constant. Thus the previous statement is true. However in an inhomogeneous medium there is the, so called, ρc correction. This correction is required for the reason given here. It is accounted for in the weak shock theory code used for the current study. There are two further corrections included in the code. Again they are factors which are multiplied by the source signal to obtain the signal at the ground. In all cases one of these factors was $1 - \varepsilon_1$ the other $1 + \varepsilon_2$ where ε_1 and ε_2 are positive numbers very near zero. Hence the effect of these factors is negligible and they are not discussed here.

The variation in sound speed bends the rays in a way that is reasonably easy to calculate. Consider, for example, a disturbance propagating in a homogeneous, stationary medium within which the sound speed is c, and incident upon another stationary, homogeneous medium within which the sound speed is a. The situation under discussion is illustrated in Figure 2.

Let the ray in medium 1 make an angle θ with the normal to the interface separating the two media, and let the ray in medium 2 make an angle β with the normal to the interface. Then, by Snell's law the equation relating β to θ is[6]:

$$\frac{\sin(\theta)}{\sin(\beta)} = \frac{c}{a}$$

or

$$\sin(\beta) = \frac{a\sin(\theta)}{c}$$

This equation may be used to determine the "ray path" through a temperature stratified medium. It is important to note that, although two different numbers have been used to designate the rays in medium 1 and medium 2, in actuality, there is only a single ray. One may consider two segments of the ray, that in medium 1, and that in medium 2, but there is only a single ray.

Now, if $a > c$, that is the sound speed is greater in the second medium than in the first, $\sin(\beta) > \sin(\theta)$, hence $\beta > \theta$, (Note that both θ and β are between 0 and 90 degrees, inclusive.) and the ray has been bent toward the interface in passing from medium 1 to medium 2. Thus, if the sound speed were to decrease with altitude, that is if the temperature is lower at the flight altitude than it is on the ground, the rays will be bent away from the ground. On the other hand, if the temperature is lower on the ground than at the flight altitude, the rays will be bent toward the ground.

Rewriting the above equation in the form

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6 "Fundamentals of Acoustics, 2nd Ed.", Lawrence E. Kinsler, and Austin R. Frey, John Wiley & sons, 1962, p. 143.

$$\sin(\theta) = \frac{c \sin(\beta)}{a}$$

and letting $\sin(\beta) = 1$, that is, $\beta = 90$ degrees, which implies that the ray is parallel to the interface in medium 2, the equation

$$\sin(\theta) = \frac{c}{a}$$

is obtained. Now, for $0 \le \theta \le 90$ degrees, $0 \le \sin(\theta) \le 1$, hence the ray can become parallel to the interface in region 2 only if $a > c$, that is when the sound speed in the second medium is greater than the sound speed in the first. Since the sound speed increases with the temperature this phenomena can occur only if the temperature is higher in medium 2 than it is in medium 1. The angle of the ray in medium 1, at which the ray is parallel to the interface in medium 2, is

$$\theta_c = \mathrm{Sin}^{-1}(\frac{c}{a})$$

This angle is called the critical angle. This phenomena is of importance because, if the temperature is greater at the ground than at the flight altitude, then, for a spherical source, such as the explosion, there will be a set of rays that graze the ground. Any member of this set is called a shadow forming ray because no disturbance energy can make it to points on the ground beyond the shadow boundary, at least in the ray theory. There are mechanisms that act to allow acoustic energy to enter the shadow region. These are not discussed here. The shadow boundary is the locus of points at which the shadow forming rays graze the ground. For a stationary, temperature stratified medium the shadow boundary will be a circle centered at the point on the ground directly below the source. Hence a single calculation of the location of the intersection of a shadow forming ray and the ground serves to provide the radius of the circle that separates the shadow region from the region within which a signal will be received. For the atmosphere given in the Meteorological Factual Report[7], this shadow boundary lies about 20 Miles from the location of the source. Therefore, a signal will reach observers within a circle centered on the ground directly below the source position, and with a radius of 20 miles. The shadow boundary for this case is presented, along with the observer positions, in Figure 3, as can be seen, only two observers lie within the shadow region. The prediction with the wind included considerably alters the picture, and discussion of the effects of the wind will now be taken up.

In order to determine the effect of wind on the disturbance field consider a disturbance propagating in a homogeneous medium moving with uniform speed U in the

[7] <u>Meteorological Factual Report</u>, [DCA96MA070], pp. 3-4

positive x-direction, incident upon an interface separating medium 1 from a second homogeneous medium, also moving in the positive x-direction, but with speed V. As in the previous analysis the sound speed in medium 1 is c, that in medium 2 is [illegible]. The situation is illustrated in Figure 4.

Again the angle between the ray and the normal to the interface is θ in region 1, and β in region 2. The equation relating β to θ is[8]:

$$\frac{c}{\sin(\theta)} + U = \frac{a}{\sin(\beta)} + V$$

which reduces to the equation for stationary media when U = V = 0, as it should. Placing all known quantities on the right-hand-side gives

$$\sin(\beta) = \frac{a\sin(\theta)}{c + (U - V)\sin(\theta)}$$

Thus, it can be seen that the wind also bends the rays. Note, in fact, that the effect of the wind is to augment the sound speed in the second region by the amount $(U - V)\sin(\theta)$. This augmentation may be positive in two cases. First, if $\sin(\theta)$ is greater than zero, i.e., the disturbance is propagating with the wind, and U is greater than V, that is the flow speed is greater in region 1 than in region 2. Second, if $\sin(\theta)$ is less than zero, i.e., the disturbance is propagating against the wind, and U is less than V, that is the flow speed is less in region 1 than in region 2. In these cases the ray bending due to the wind is similar to the ray bending caused by an increase in sound speed in the propagation direction.

Also, this augmentation may be negative in two cases. First, if $\sin(\theta)$ is less than zero, i.e., the disturbance is propagating against the wind, and U is greater than V, that is the flow speed is greater in region 1 than in region 2. Second, if $\sin(\theta)$ is greater than zero, i.e., the disturbance is propagating with the wind, and U is less than V, that is the flow speed is less in region 1 than in region 2. In these cases the ray bending due to the wind is similar to the ray bending caused by an decrease in sound speed in the propagation direction.

Hence, the bending of the rays, by the wind itself, is in a different direction when the disturbance is propagating with the wind than it is if the disturbance is propagating against the wind. Another way to see this is to note that if the medium were to be moving in the negative x direction in both regions the above equation would become:

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[8] "Theoretical Acoustics," Philip M. Morse, and K. Uno Ingard, McGraw Hill, New York, 1968; pp. 708-710.

$$\sin(\beta) = \frac{a \sin(\theta)}{c - (|U| - |V|)\sin(\theta)}$$

where $|U|$ and $|V|$ represent the magnitude of the wind velocity in regions 1 and 2 respectively. Note that U and V are taken as positive in the previous equation. Therefore, the symmetry present in the temperature stratified medium is lost when there is a wind.

The wind in a real atmosphere varies in both speed and direction with altitude. Thus the analysis is slightly more complex than that described here for the simple case where the wind varies only in magnitude with altitude. For a more complete analysis of sound propagation in a stratified moving medium, see "Acoustics of a Moving Medium," by D. I. Blokhintsev.[9] The effects of the wind, like the effects of the temperature variation, include a change in the signal path, and an alteration of the amplitude of the signal through the variation of the cross-sectional area of the ray tube.

Since, near the ground, the wind speed generally increases with altitude, a disturbance propagating near the ground and with the wind is bent towards the ground, and a disturbance propagating near the ground and against the wind is bent away from the ground. The locus of the points where the shadow forming rays graze the ground is presented in Figure 5. Also shown in this figure are the observer positions and the ground position of TWA Flight 800 at the time of the explosion.

The other complicating factor is the high pressure in the source wave form. Although a linear disturbance propagates essentially unchanged, a high amplitude disturbance propagates nonlinearly, which changes the form of the disturbance as it propagates. In essence, the high amplitude portions of the wave form propagate faster than the low amplitude portions of the wave form. Hence the high amplitude portions of the wave form tend to overtake those low amplitude portions that are ahead of them, and continually increase the distance, or time, between themselves and those lower amplitude portions of the wave form that are behind them. Further, the wave form undergoes a slight loss in amplitude due to nonlinear losses. In addition, the wave form tends to become somewhat longer; that is two fixed observers at different locations along the propagation path, will measure wave forms of two different durations. The observer closer to the source will see a wave form of shorter duration than the observer farther from the source.

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[9] "Acoustics of a Nonhomogeneous Moving Medium," D. I. Blokhintsev, NACA TM 1399, 1946.

The theory used to propagate the signal from the source to the ground is weak shock theory, coupled with ray theory, also known as geometric acoustics. The discussion of this theory may be found in several references.[10] The theory assumes that the geometric theory is valid, which is certainly true for the problem considered here, except for observers located in the shadow region. No calculations were carried out for these observers, in fact the absence of rays at these observers precludes the calculation of the field there. The theory also neglects viscous dissipation and molecular relaxation. Both of these tend to dissipate energy, especially in regions with large gradients of the disturbance pressure. Weak shock theory, however, introduces its own dissipation. The major discrepancy between weak shock theory predictions and measurements of actual signals which are of large amplitude is that the actual signals do not reach their peak values as rapidly as the predicted signal, and the actual signal is more rounded, or not as angular as the predicted signal. However, correction for these rather minor discrepancies can be applied to the predicted signal.

Signal Prediction

The observers were given an observer number based on their distance from the source. Table I provides the NASA observer number and the corresponding NTSB observer number. A ray tracing program which accounted for winds that vary in both direction and magnitude with altitude, as well as variation in temperature, was used in an attempt to trace a ray from the source to each of the observers whose positions was provided to NASA. The weather data given in the National Transportation Safety Board report[11] was used for the atmospheric data. It was found that 11 of the 83 observers were in the shadow region, see Table II. No rays could be traced to these observers. Further, several of the observers were at large enough distances from the source, or close enough to the shadow boundary, to make it difficult to find a ray passing through them. In all 39 ray traces were made. Due to the fact that many positions had two or more observers, a ray was traced through the positions of 60 witnesses by these 39 ray traces, see Table III.

The wave form predicted by the theory of H. L. Brode, given in Figure 1, was used as a source to predict the signal

[10] "Acoustics An Introduction to Its Physical Principles and Applications," Allan D. Pierce, McGraw Hill, 1981; Chapters 8 and 11.

"Linear and Nonlinear Waves", G. B. Whitham, John Wiley and Sons, New York, 1974. Chapter 9.

[11] Meteorological Factual Report, [DCA96MA070], pp. 3-4

observed at each of these 39 positions. The Thomas Code[12] was modified to propagate the signal from a stationary source, rather than a supersonic aircraft, and used to propagate this input signal to the ground.

In order to verify that the modified code was providing reasonable results a series of tests was carried out. These may be divided into two categories. The first series of tests verified that the code reproduced simple known analytical solutions. The results of these tests are presented in Appendix B. The second test verified that the level and spectra predicted by the code were reasonable estimates of the disturbance produced by a given charge of TNT. The results of this test are presented in Appendix C.

The Thomas Code uses ray theory to determine the amplitude variation due to ray tube area variation, and weak shock theory to account for nonlinear effects. The audibility of 3 of these 39 signals was determined. These three were: the signal with the highest peak amplitude, NASA observer number 1, presented in Figure 6; the signal with the lowest peak amplitude, NASA observer number 74 presented in Figure 7; and a signal that could be considered as having the median peak amplitude, i.e., about as many observers had signals with higher peak amplitudes as had signals with lower peak amplitudes, NASA observer number 44 presented in Figure 8. If the lowest amplitude signal is audible it may be assumed that all of the signals are audible.

Further, there are at least two reasons why one cannot say that an observer in the shadow region did not hear the explosion of Flight 800's center fuel tank. First, there are mechanisms which allow acoustic energy to propagate into the shadow region. These are not accounted for in the current analysis, hence the analysis used in this study is not valid in the shadow region. Second, and perhaps more important, a slight change in the weather data would move the shadow boundary. The observers in the shadow region with the weather data used for this study might not be in the shadow region if only slightly different weather data were used. As an example, none of the observers within a circle of 20 mile radius centered on the ground position of Flight 800 at the time of the explosion are in a shadow region if the wind is neglected and only the given temperature data is used. This places only the observers at the two farthest positions (NASA observer numbers 82 and 83) in the shadow region. Also, it must be remembered that the meteorological data provided to NASA represents a small fraction of that which would be required to fully characterize the atmosphere from the aircraft to each observer at the time of the explosion.

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[12] "Extrapolation of Sonic Boom Pressure Signatures by the Wave form Parameter Method", Charles L. Thomas, NASA TN D-6832, June 1972.

Audibility analysis

Just because a signal exists at an observer location does not imply that the receiver would detect that signal. Two questions immediately come to mind. First; Is the received signal above the threshold of hearing? That is, is the signal loud enough to be heard in the absence of the ambient background noise? This question is answered by comparing the spectra of the predicted signal with minimum audible sound pressure levels as a function of frequency for otologically normal human subjects.

Second; Is the signal above the background noise? If the ambient noise level is sufficiently high, the signal from the explosion of Flight 800's fuel tank will be hidden in the background noise. This question is answered by comparing the spectra of the predicted signal with the spectra of typical (ambient) background noise levels present in residential areas.

If the signal from the explosion of Flight 800's fuel tank is of sufficient amplitude its spectra will be above both curves, and it can be concluded that a human observer would probably have "heard the explosion". If the signal is not of sufficient amplitude, its spectra will lie below one or both of the curves at all points, and it can be concluded that a human observer would probably not have "heard the explosion".

The audibility of the predicted blast wave is illustrated by means of Figure 9. The threshold of hearing[13] is shown and describes minimum audible sound pressure levels as a function of frequency for otologically normal human subjects. Also shown are typical (ambient) background noise levels present in residential areas[14]. The predicted blast wave signature, Figure 6, is transformed to the frequency domain and shown in the figure as one-third octave band spectra. The method used to predict the blast signature has not accounted for several phenomena present in the atmosphere, namely absorption due to viscous losses and molecular relaxation, and scattering effects due to turbulence. The major result of ignoring these effects is that the predicted shock associated with the blast wave has an instantaneous rise time. In reality, the rise time will be finite.[15] This factor has a strong influence on the spectrum, as is evident in the figure which shows spectra for two assumed rise times. The range covered by these two rise times is estimated to encompass the actual rise time

13"Normal Equal-Loudness Contours for Pure Tones and Normal Threshold of Hearing under Free Field Listening Conditions". International Organization for Standardization, Recommedation R 226 (December 1961)

14"Handbook of Noise Control, 2nd Edition", Edited by Cyril M. Harris, McGraw Hill. (1979)

15Plotkin, K.J., "Review of Sonic Boom Theory", AIAA-89-1105, AIAA 12th Aeroacoustics Conference, San Antonio, TX, April 10-12, 1989.

associated with such a blast signature. One final assumption is needed in order to compute blast spectra for comparison with the threshold of hearing and the background noise levels. The hearing threshold is measured for continuous sounds and the background noise is also relatively constant with time. In contrast, the blast signature is impulsive, the most audible part of the impulse being confined to the region near the shock. For the present calculation the so-called integration time of the human hearing system has been assumed to be 70 msecs.

Conclusion

From inspection of Figure 9 it is clear that the blast signature greatly exceeds the hearing threshold over a wide frequency range, regardless of the assumed rise time of the shock. It is also apparent from the figure that there is a frequency range over which each of the blast spectra exceed even the "high residential ambient" condition. It is thus concluded that there is a high probability that a blast wave as described would be audible to observer number 1. Figure 10 provides the comparison of the spectra for observer 74. Observers 72 and 73 were also located at this point so this is the signal predicted for them also. Further this is the signal with the lowest predicted amplitude. As can be seen by looking at Figure 10 there is a frequency range over which each of the blast spectra exceed even the "high residential ambient" condition. It is thus concluded that there is a high probability that a blast wave as described would be audible to observer number 74. Since this is the signal with the lowest amplitude it may safely be concluded that the blast wave was audible for all of the observers for which a prediction was made, see Table III. As mentioned previously, there is no reason to believe that the disturbance produced by the explosion of the center fuel tank of TWA Flight 800 was not audible at the remaining observer locations. Slight changes in the weather data would remove all of the observers in the shadow from the shadow. Further, those observers for which the propagation distance was great enough to make prediction difficult could also probably have heard the disturbance; the levels at observer 74 are high enough that spreading losses would be unable to attenuate the signal sufficiently for it to become inaudible in the remaining propagation distance.

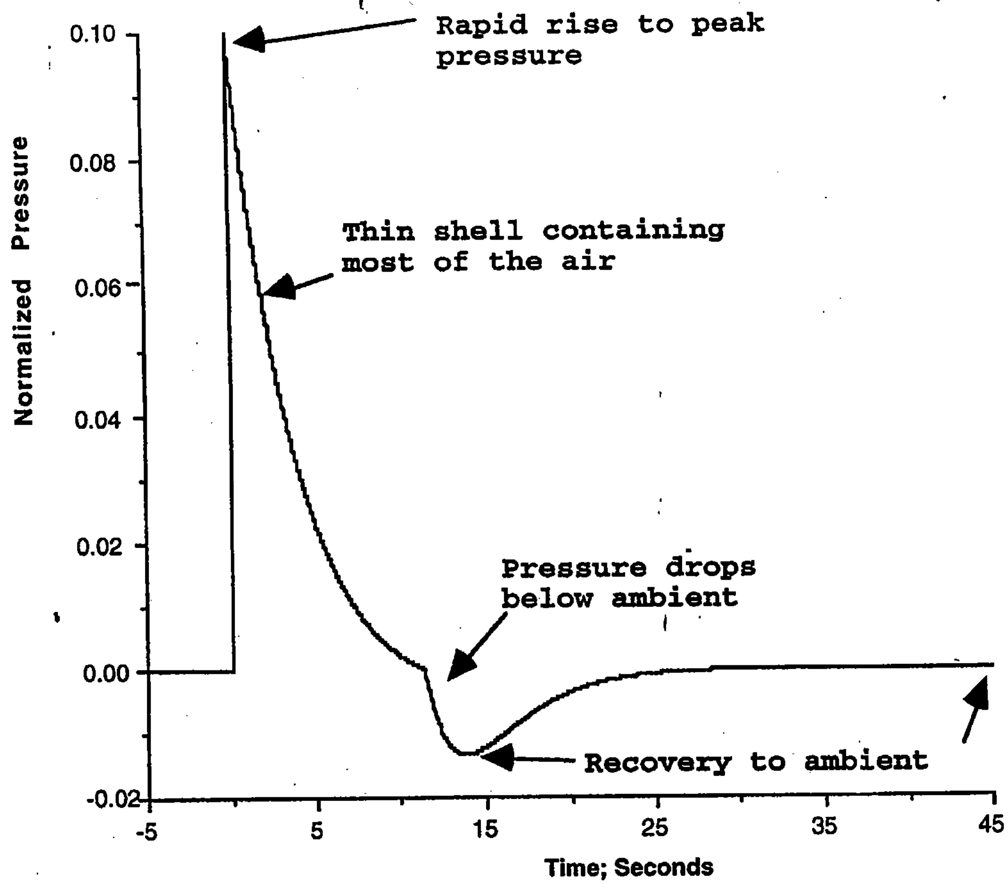

Figure 1. Source waveform, pressure normalized by the ambient pressure.

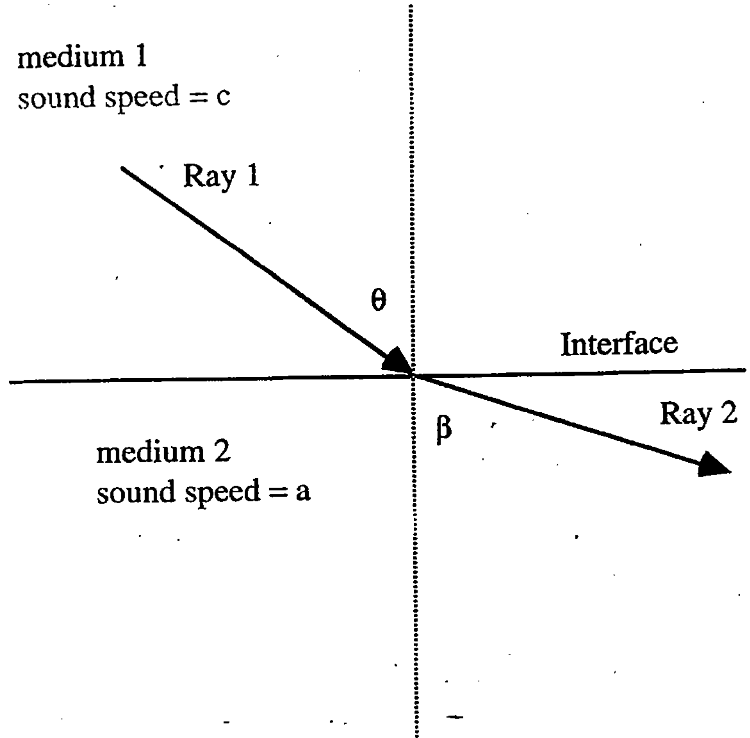

Figure 2. A disturbance propagating from a medium with sound speed c to a medium with sound speed a.

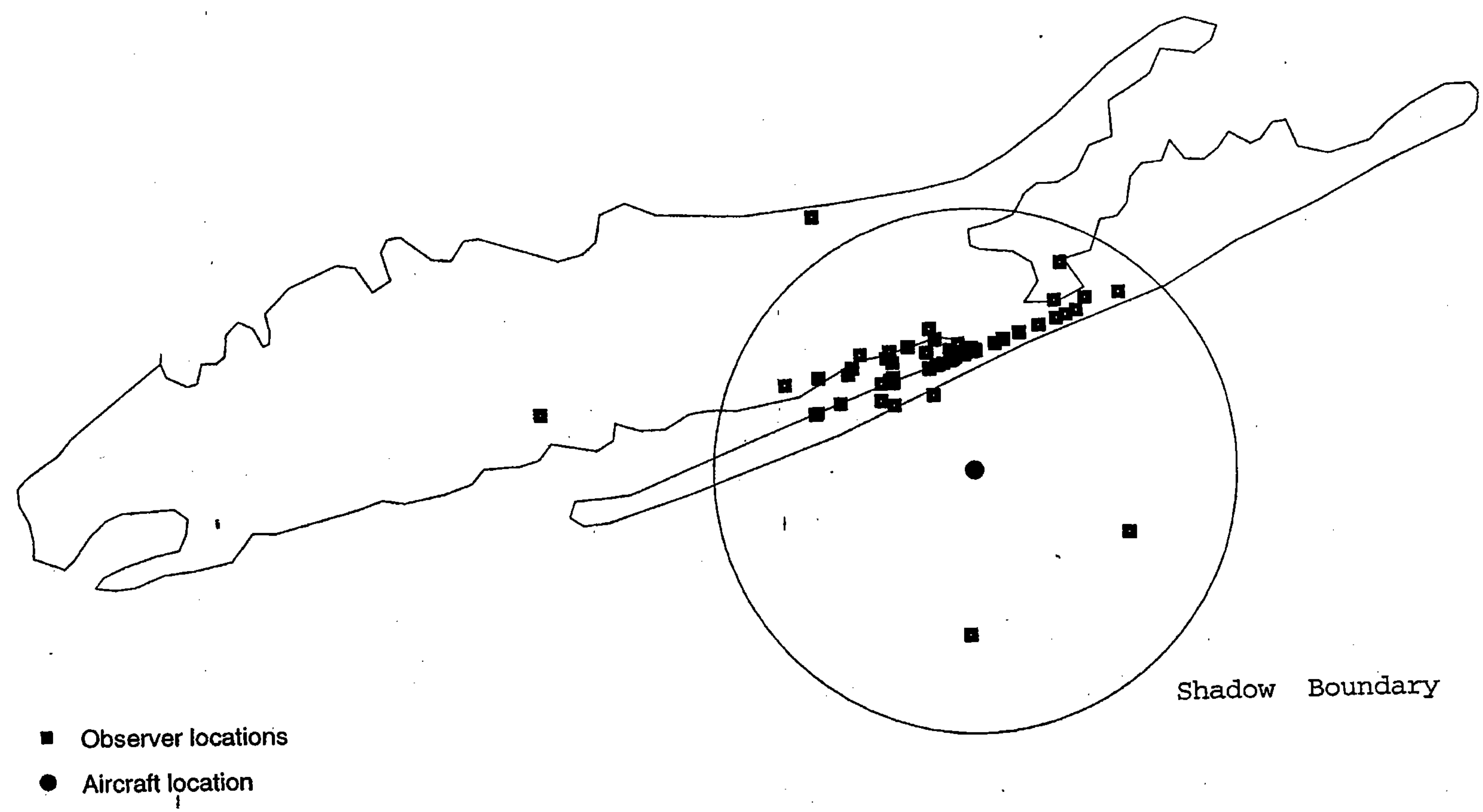

Figure 3. The shadow boundary for the temperature stratified atmosphere. Also shown are the observer locations and the ground position of Flight 800 at the time of the explosion

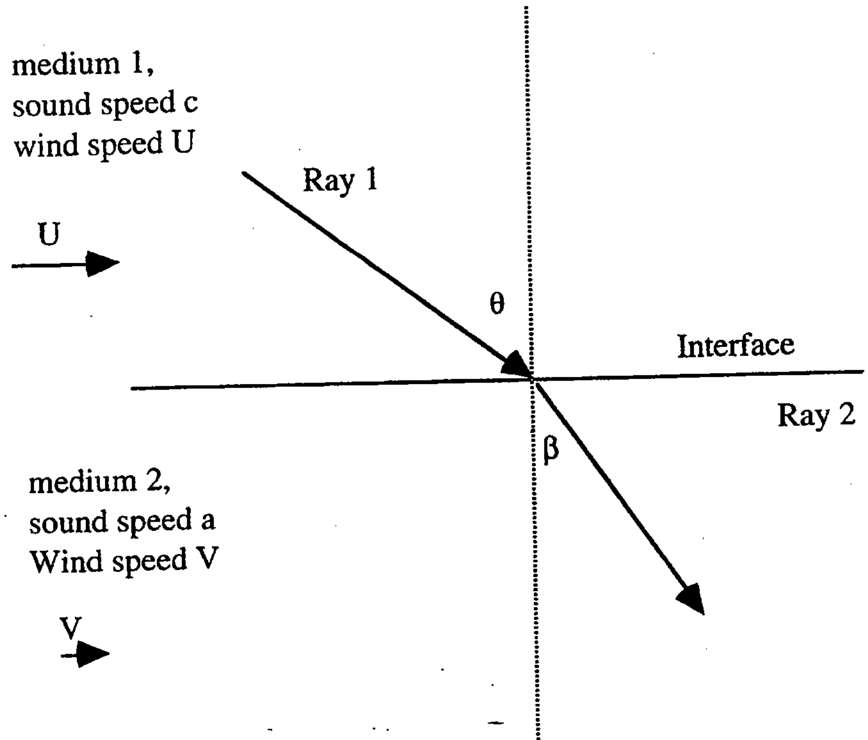

Figure 4. A disturbance propagating from a medium with sound speed c, and moving with speed U in the positive x direction, into a medium with sound speed a, moving with speed V also in the positive x direction

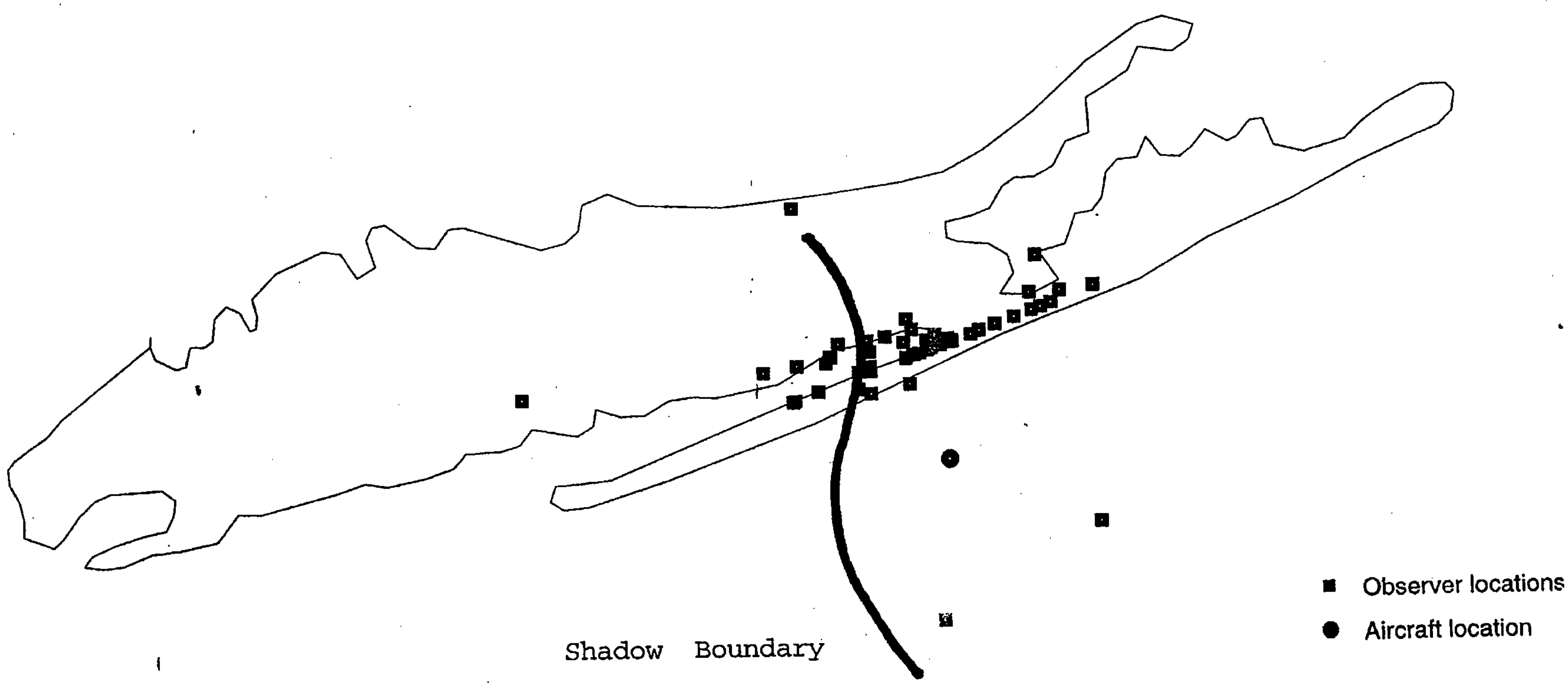

Figure 5. The shadow boundary for the wind and temperature stratified atmosphere. Also shown are the observer locations and the ground position of Flight 800 at the time of the explosion

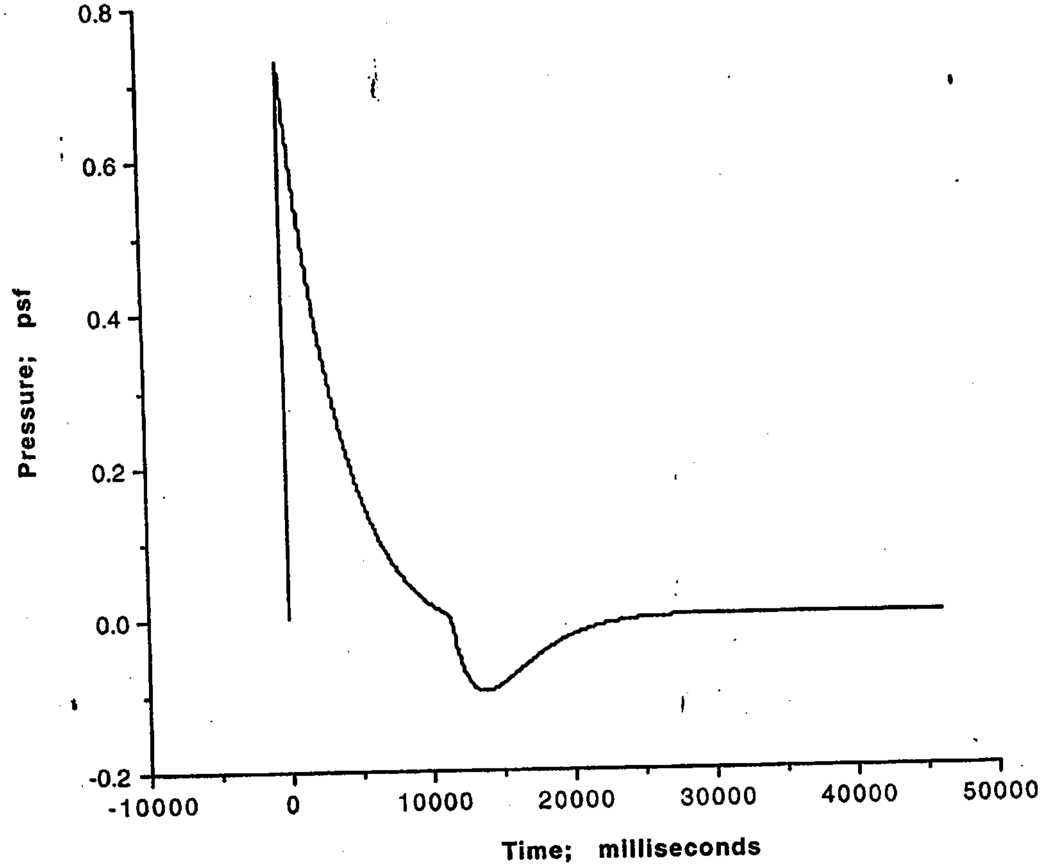

Figure 6. Waveform at observer 1

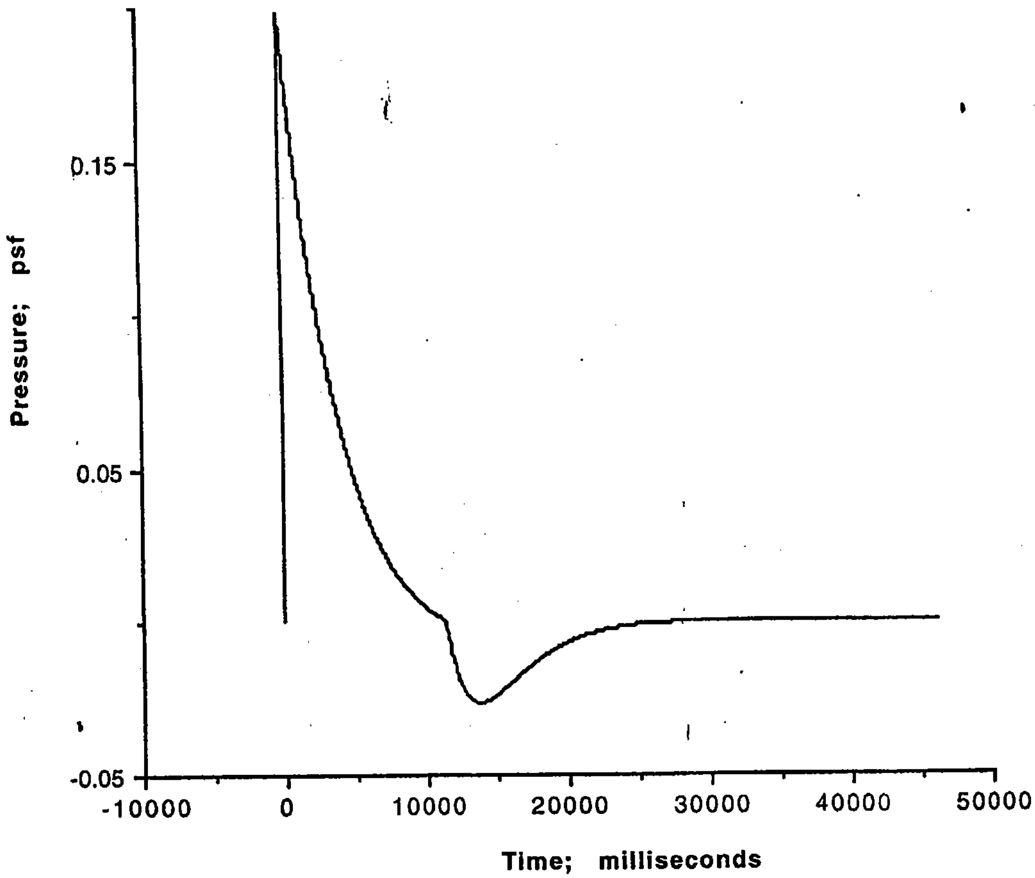

Figure 7. Waveform at observers 72, 73, and 74

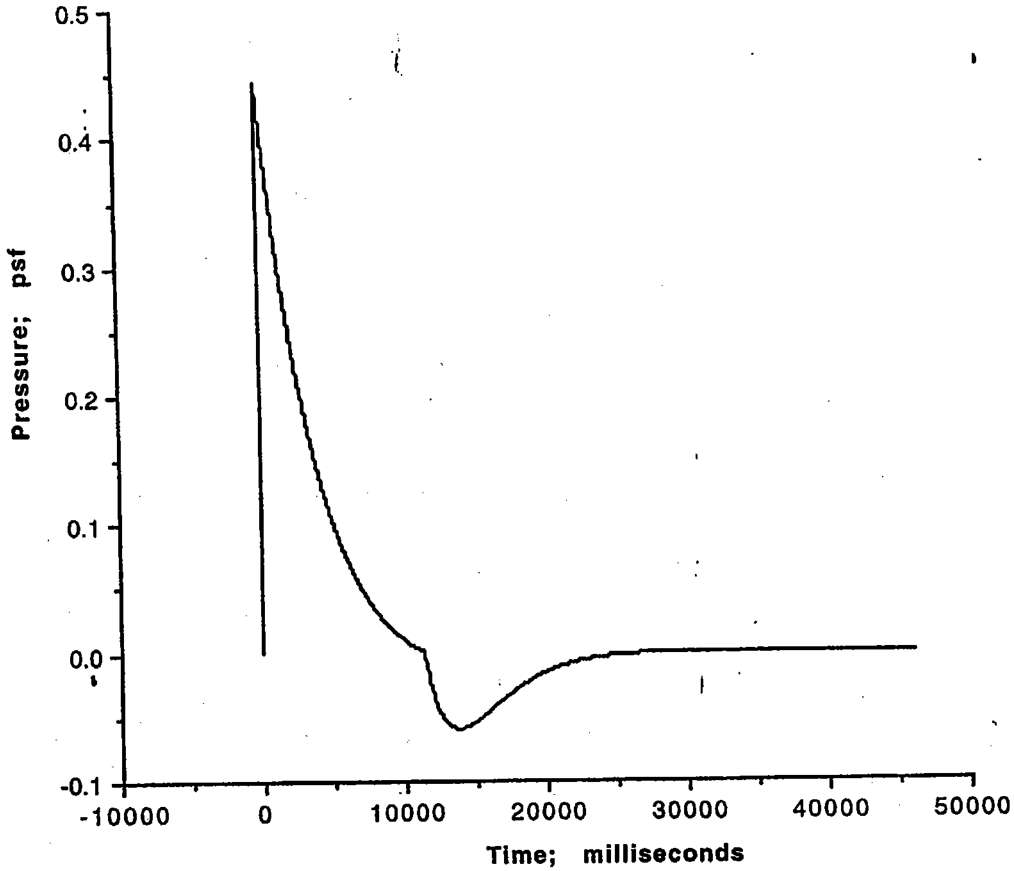

Figure 8. Waveform at observer 44

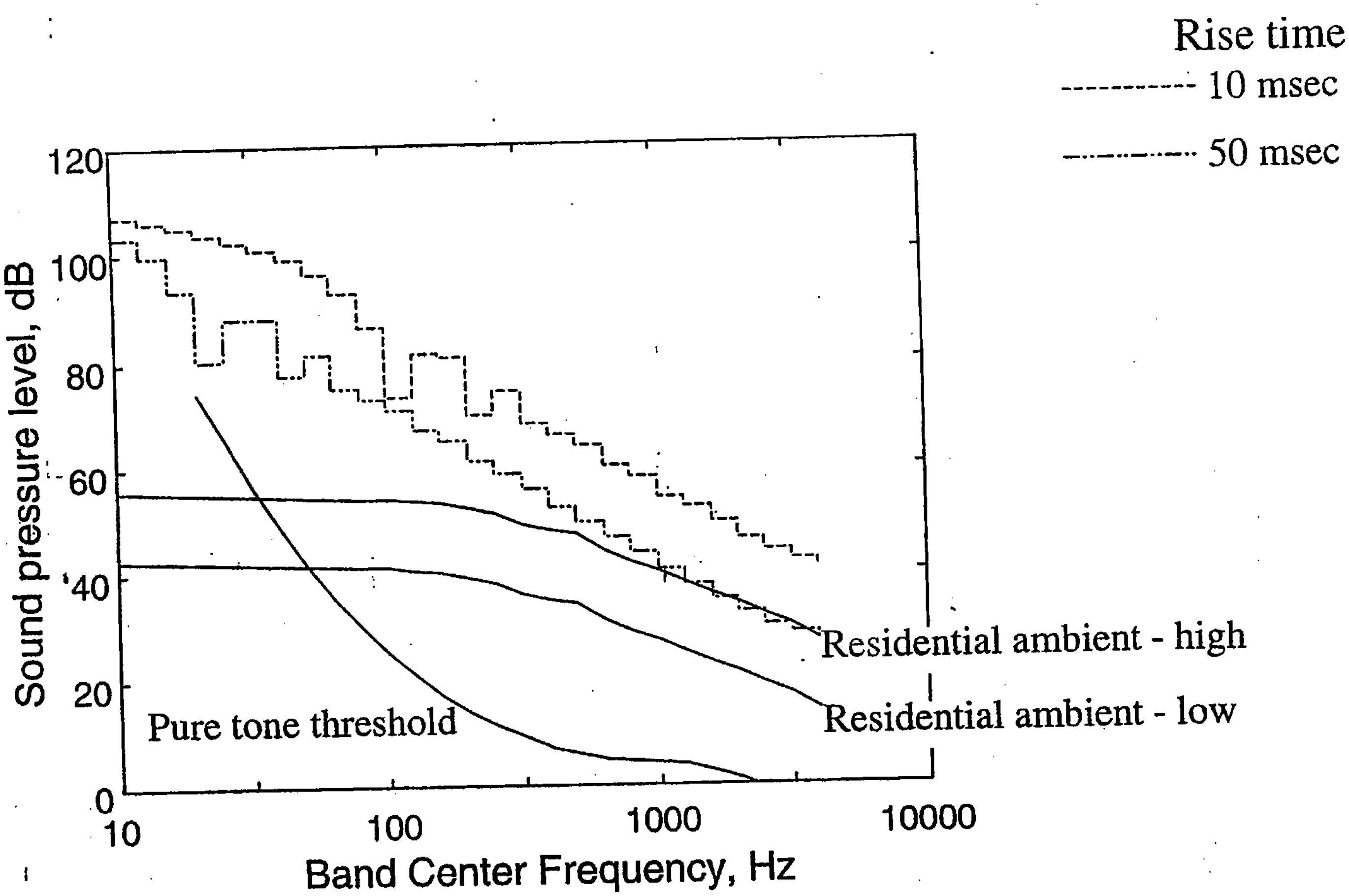

Figure 9. One-third octave band spectra for signal at observer 1.

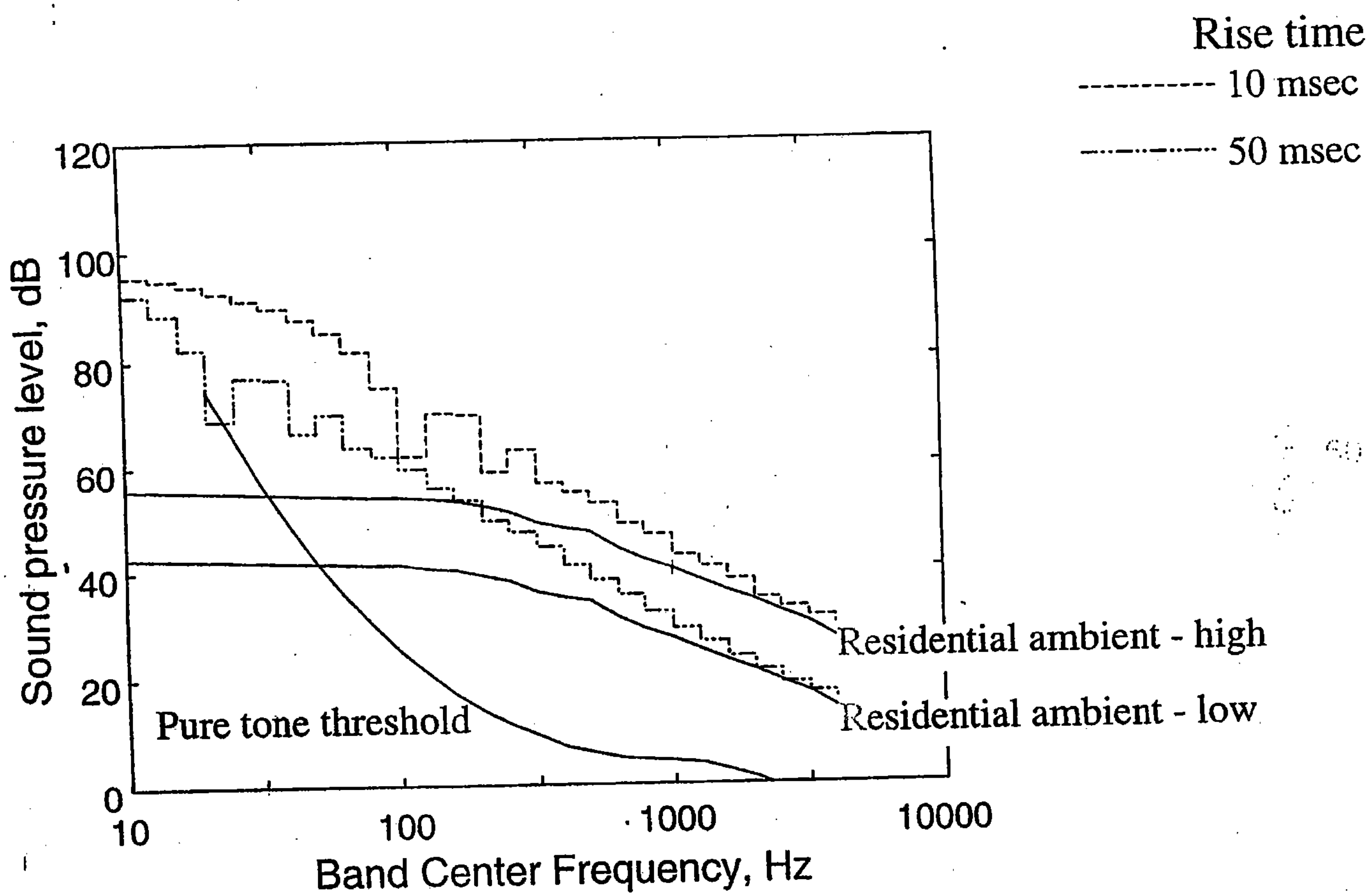

Figure 10. One-third octave band spectra for signal at observer 74.

Table I
NASA Observer Number and NTSB Observer Number

NASA observer #	NTSB observer #	NASA observer #	NTSB observer #
1	614	45	426
2	350	46	473
3	577	47	480
4	644	48	148
5	646	49	497
6	647	50	498
7	284	51	496
8	492	52	108
9	738	53	153
10	83	54	15
11	283	55	570
12	177	56	675
13	50	57	732
14	155	58	661
15	75	59	190
16	454	60	645
17	89	61	169
18	482	62	313
19	576	63	38
20	449	64	501
21	481	65	390
22	567	66	563
23	411	67	406
24	412	68	21
25	317	69	504
26	650	70	548
27	506	71	91
28	359	72	291
29	571	73	293
30	643	74	320
31	129	75	146
32	700	76	398
33	304	77	536
34	295	78	696
35	445	79	57
36	499	80	228
37	356	81	325
38	648	82	462
39	152	83	526
40	209		
41	461		
42	503		
43	248		
44	186		

Table II
Observers in the shadow region

NASA Observer Number	NTSB Observer Number
38	648
46	473
49	497
51	496
57	732
58	661
59	190
61	169
62	313
63	38
64	501

Table III
Observers for which a prediction was made

NASA observer #	NTSB observer #
1	614
2	350
3	577
4	644
5	646
6	647
7	284
8	492
9	738
10	83
11	283
12	177
13	50
14	155
15	75
16	454
17	89
18	482
19	576
20	449
21	481
22	567
23	411
24	412
25	317
26	650
27	506
28	359
29	571
30	643
31	129
32	700
33	304
34	295
35	445
36	499
37	356
39	152
40	209
41	461
42	503
43	248
44	186

NASA observer #	NTSB observer #
45	426
47	480
48	148
50	498
52	108
53	153
54	15
55	570
56	675
60	645
65	390
66	563
67	406
71	91
72	291
73	293
74	320

APPENDIX A
Calculation of the energy of the explosion

The energy in the explosion is estimated as follows. From the estimates of the fuel/air ratio in the center wing tank provided in the report "Jet A Explosion Experiments: Laboratory Testing"[1], and the estimate of the molecular weight of the fuel, and the estimate of the energy content per unit mass of fuel also contained in that report, along with an estimate of the volume of the center wing fuel tank provided in that report it is possible to obtain an estimate of the total energy available in the fuel vapor within the tank. These calculations are presented here.

<u>Relevant parameters:</u>

Fuel tank volume[2] 50. $meter^3$ = 1766. ft^3

Fuel air mass ratio:[3]
- Minimum 0.022
- Maximum 0.027

Average fuel tank temperature:[4]
- 33.5 C
- 92 F

Atmospheric pressure[5]
- 8.6 psi

Energy content of the fuel:[6]
- $q = 42.8$ MJ/kg

Molecular weight of the fuel:[7]
- $W = 160$

Molecular weight of air:[8]

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1 "Jet A Explosion Experiments: Laboratory Testing", Joseph E. Shepherd, J. Christopher Krok, and Julian J. Lee, June 6, 1997 corrected on November 21, 1997; Explosion Dynamics Laboratory Report FM97-5
2 Ibid., p. 1
3 Ibid. p. 56
4 Ibid. p. 54
5 Ibid. p. 9
6 Ibid. p. 22
7 Ibid. p. 22
8 "Acoustics An Introduction to Its Physical Principles and Applications," Allan D. Pierce, McGraw Hill, 1981, p. 29

$W_a = 29$

For the purposes of the current analysis let α be the fuel air mass ratio.
The analysis is as presented by Reynolds and Perkins.[9]

COMPONENT	$\frac{lbm}{lbm\ of\ mixture}$	$\frac{lbm}{lb_{mole}}$	$\frac{lbmole}{lbm\ of\ mixture}$	$\frac{lbmole}{lbmole\ of\ mixture}$
Fuel	$\frac{\alpha}{1+\alpha}$	160	$\frac{\alpha}{160(1+\alpha)}$	$\frac{29\alpha}{29\alpha+160}$
Air	$\frac{1}{1+\alpha}$	29	$\frac{1}{29(1+\alpha)}$	$\frac{160}{29\alpha+160}$
			$\frac{29\alpha+160}{29*160(1+\alpha)}$	

Column 1 of the table gives the mass of the component as a fraction of the total mass of the mixture. This is the mass ratio of the component.

Column 2 is the molecular weight of the component.

Column 3 is obtained by dividing the entry in column 1 by the entry in column 2. The final entry in column 3 is the sum of the entries in rows 1 and 2 of column 3.

The final column is obtained by dividing the entries in rows 1 and 2 of column 3 by the entry in row 3 of column 3. This is the volume fraction of the component.

The density of the mixture is given by the ideal gas law. The temperature is 92° F, or 552° R. The pressure is 8.6 psi, or 1238.4 PSF. The gas constant is the universal gas constant divided by the molecular weight of the mixture, or $\frac{1545}{\left[\frac{160*29\alpha}{29\alpha+160}+\frac{29*160}{29\alpha+160}\right]} = \frac{1545(29\alpha+160)}{29*160(1+\alpha)}$

For $\alpha = 0.022$

$R = 52.34$

$\rho =$ Pressure/(R*Temperature)

$= (8.6 pounds/in^2)*(144 in^2/ft^2)/((52.34 ft\text{-}lb_f/lb_m\text{-}°R)*(92 + 460)°R) = 0.043\ Lb_m/ft^3$

Thus the total mass is (Volume of fuel tank)*(density of vapor) = $1766.ft^3 * 0.043\ Lb_m/ft^3 = 75.9 Lb_m$

9 "Engineering Thermodynamics," William C. Reynolds, and Henry C. Perkins, McGraw Hill, 1970, p. 333 - 336.

Mass of fuel is $(\text{total mass}) * [\frac{\alpha}{1+\alpha}] = (75.9 Lb_m) * [\frac{0.022}{1 + 0.022}]$

$75.9 Lb_m * 0.0215 = 1.63\ Lb_m$

The energy content is $\frac{42.8*10^6 \text{ Joules}}{Kg} * \frac{Kg}{2.2\ Lb_m} * \frac{\text{cal.}}{4.186 \text{ Joules}} * 1.63 Lb_m \approx 7,600,000.$ calories

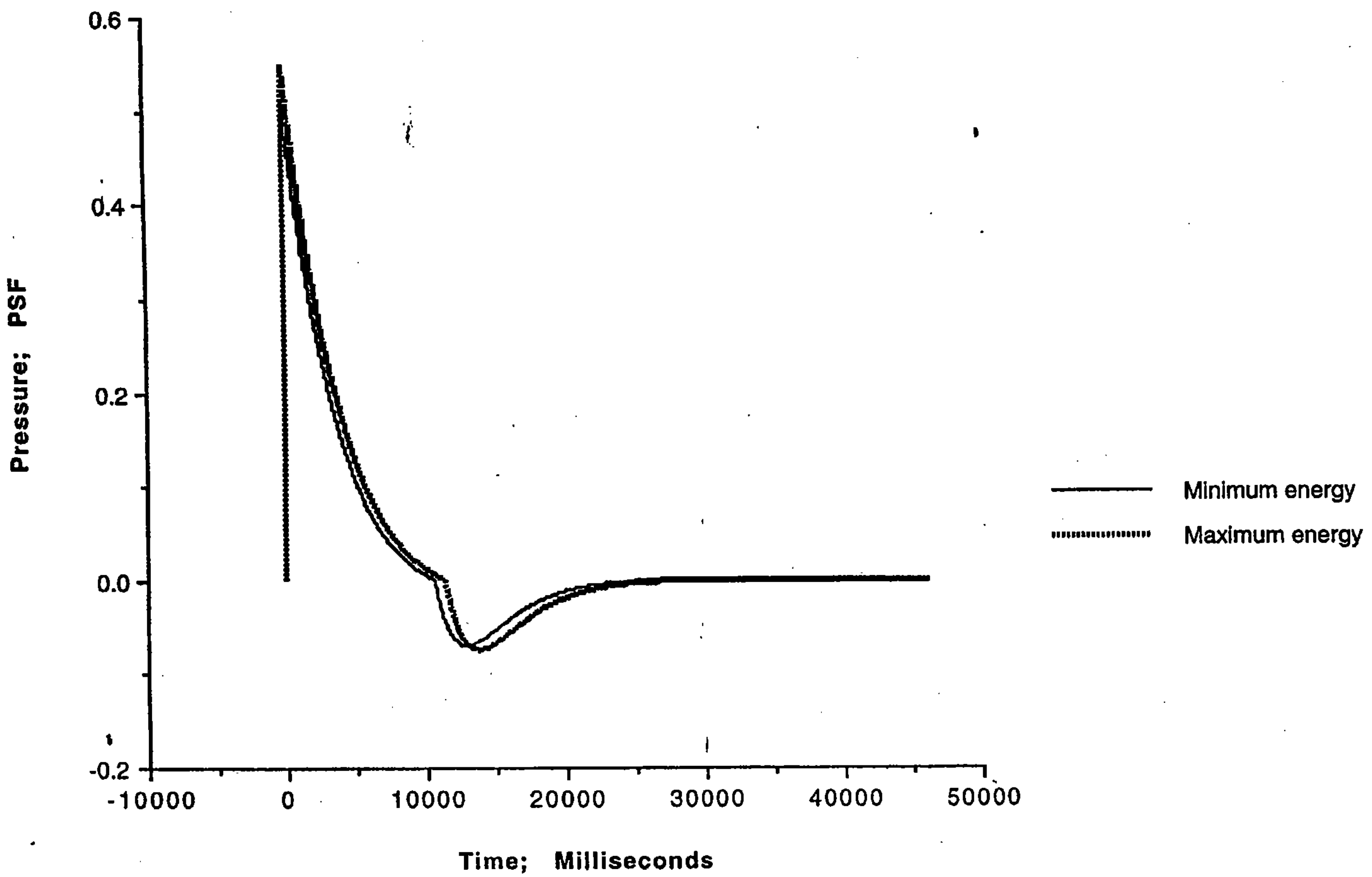
or (7,600,000. calories)*(778.16ft-lb_f/252 calories) ≈ 23,500,000.ft-lb_f.

or, (7,600,000. calories)*(2000 lb_m TNT/1,000,000,000 calories) ≈ 15.2 pounds of TNT;[10]

The same calculation for $\alpha = 0.027$ yields 29,000,000 Ft*Lb_f or approximately 18.8 pounds of TNT.

The difference in the energy of the explosion from minimum to maximum will yield very little difference in the disturbance field. A comparison of the predicted field at observer 20 is given in the figure.

[10]For the conversion factor from calories to Tons of TNT see "The effects of NUCLEAR WEAPONS," Samuel Glasstone, Editor, United States Atomic Energy Commission, June 1957, p. 556.



Comparison of predicted waveforms at observer 20, for maximum energy and minimum energy in initial explosion.

APPENDIX B
Numerical Calculations to Verify the Propagation Routine

Several calculations were performed to verify that the propagation code was providing reasonable results. These were: a linear plane wave, a nonlinear plane wave, a linear spherical wave, and a nonlinear spherical wave, all propagated for 20 miles in a stationary homogeneous medium. The ambient pressure at the aircraft altitude is taken to be 8.6 psi, and the source amplitude is taken as one-tenth of this in all four cases. Thus the source amplitude is 0.1*8.6 psi, or 123.84 psf. Also, a factor of two was applied to the signal at the end of 20 miles to account for pressure doubling on reflection from the ground.

For a linear plane wave the amplitude and waveform should be unchanged after propagating the 20 miles, except for the factor of two introduced by ground reflection. Thus the amplitude for the linear plane wave should be 247.68 psf. The resulting waveform is given in Figure B-1, which may be compared with Figure 1. Note that the waveform is unchanged. The amplitude was printed out after the computer run and is what it should be. Thus the program propagates the linear plane wave successfully. This implies that the program does not introduce spurious absorption or dispersion.

The nonlinear plane wave should be reduced in amplitude as compared with the linear plane wave due to the attenuation introduced by nonlinear effects. Further, the nonlinear plane wave should be of longer duration than the linear plane wave due to the nonlinear effects. As can be seen in figure B-2 the amplitude has been reduced slightly. The linear and nonlinear plane waves, after having been propagated for 20 miles, are compared in Figure B-3, both the decrease in amplitude and the increased duration of the nonlinear wave are clearly seen.

The third test case is a linear spherical wave. Here the waveform should be unchanged in shape, but reduced by a factor of $80./(5280.0*20.0) \approx 7.6*10^{-4}$ due to spherical spreading, and increased by a factor of two due to reflection at the ground. Thus the amplitude should be $247.68*7.57575*10^{-4}$ psf ≈ 0.188 psf. As seen in Figure B-4 the waveform is essentially unchanged. Again the amplitude was printed out after the computer run and it is correct.

Finally, the results of propagating the nonlinear spherical wave over 20 miles are presented in Figure B-5. Here the results are indistinguishable from the linear spherical wave case indicating that nonlinear effects are negligible in this case. This is to be expected because the spherical spreading decreases the amplitude of the wave rapidly enough that nonlinearities are negligible.

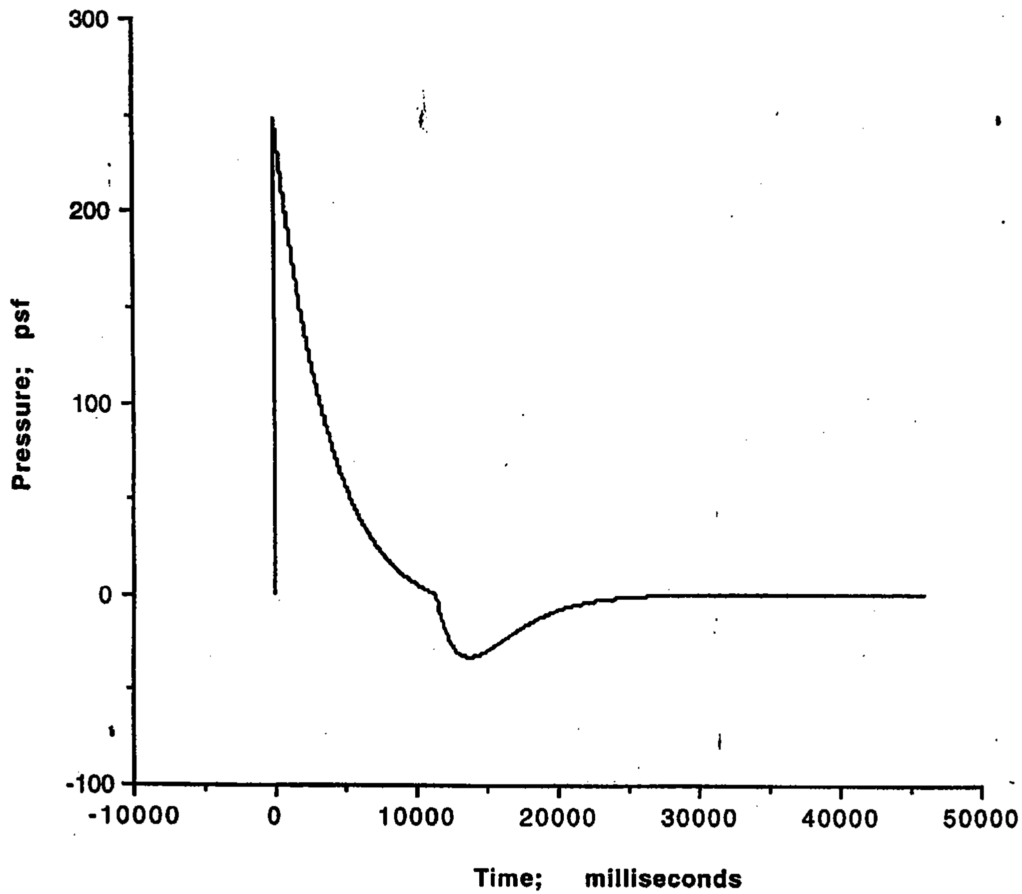


Figure B-1. Linear plane wave, propagated 20 miles, pressure doubling for reflection included.

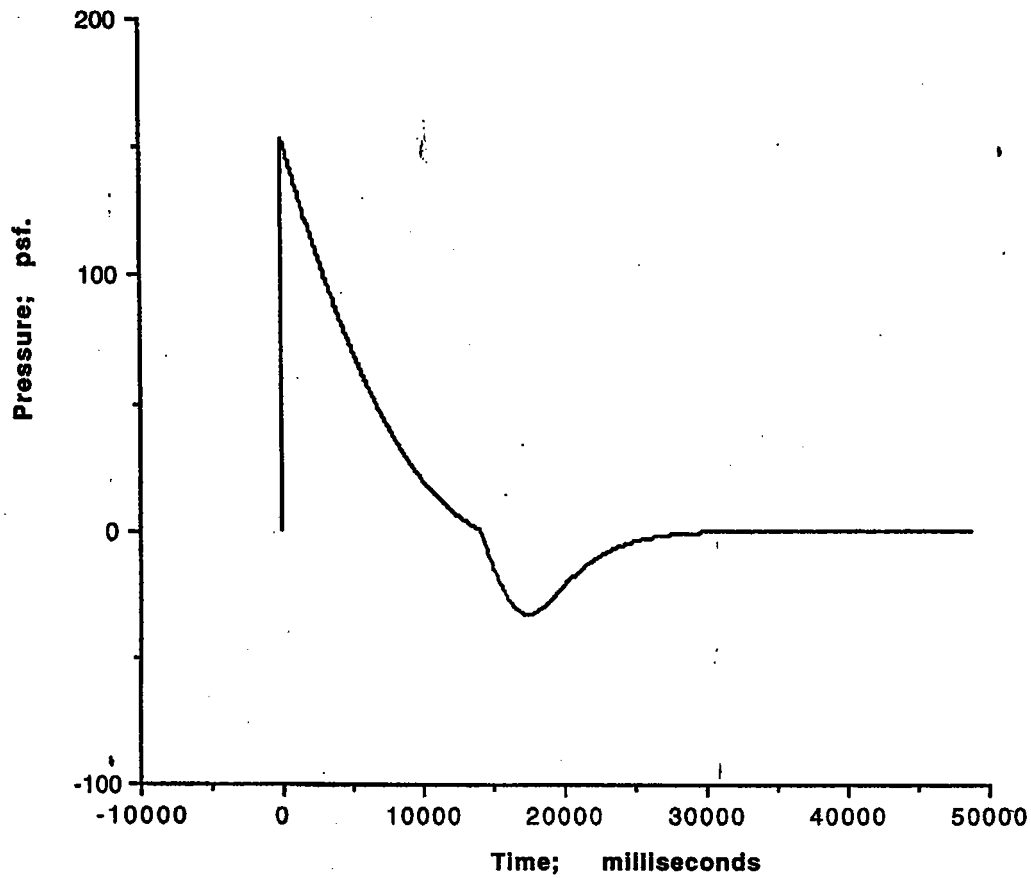


Figure B-2. Nonlinear plane wave propagated 20 miles. Pressure doubling for reflection included.

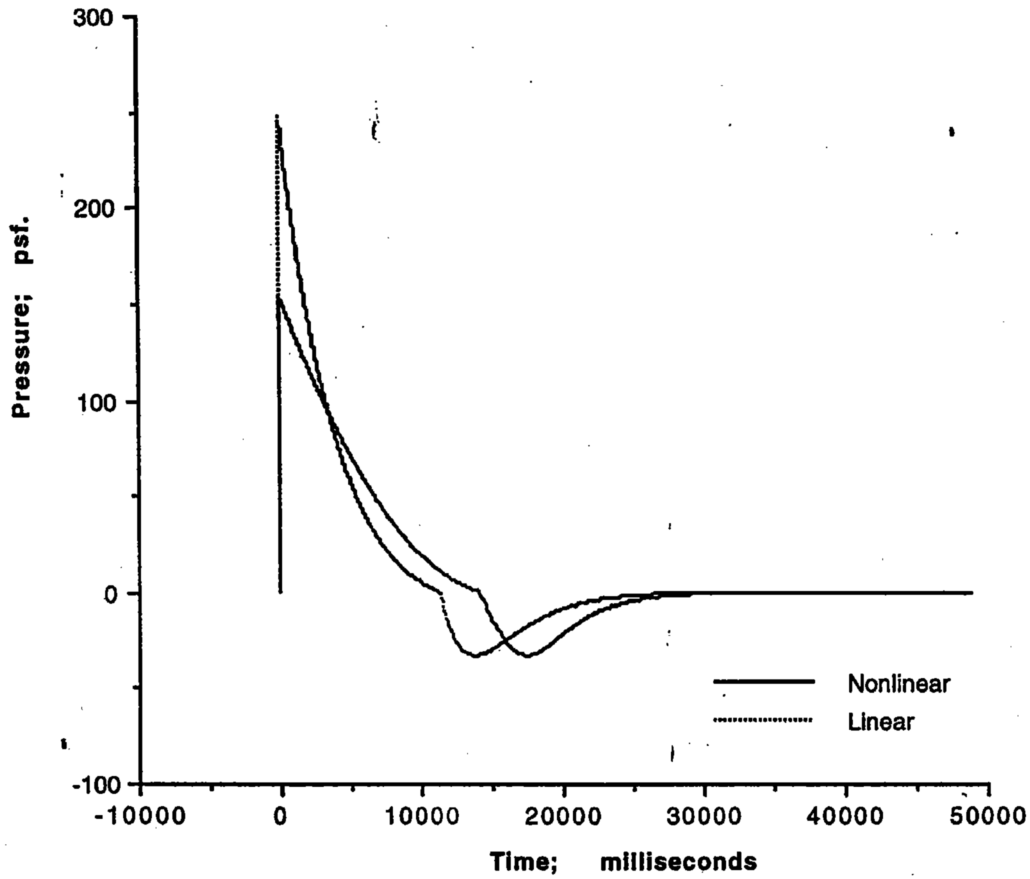


Figure B-3. Linear plane wave, Nonlinear plane wave comparison.

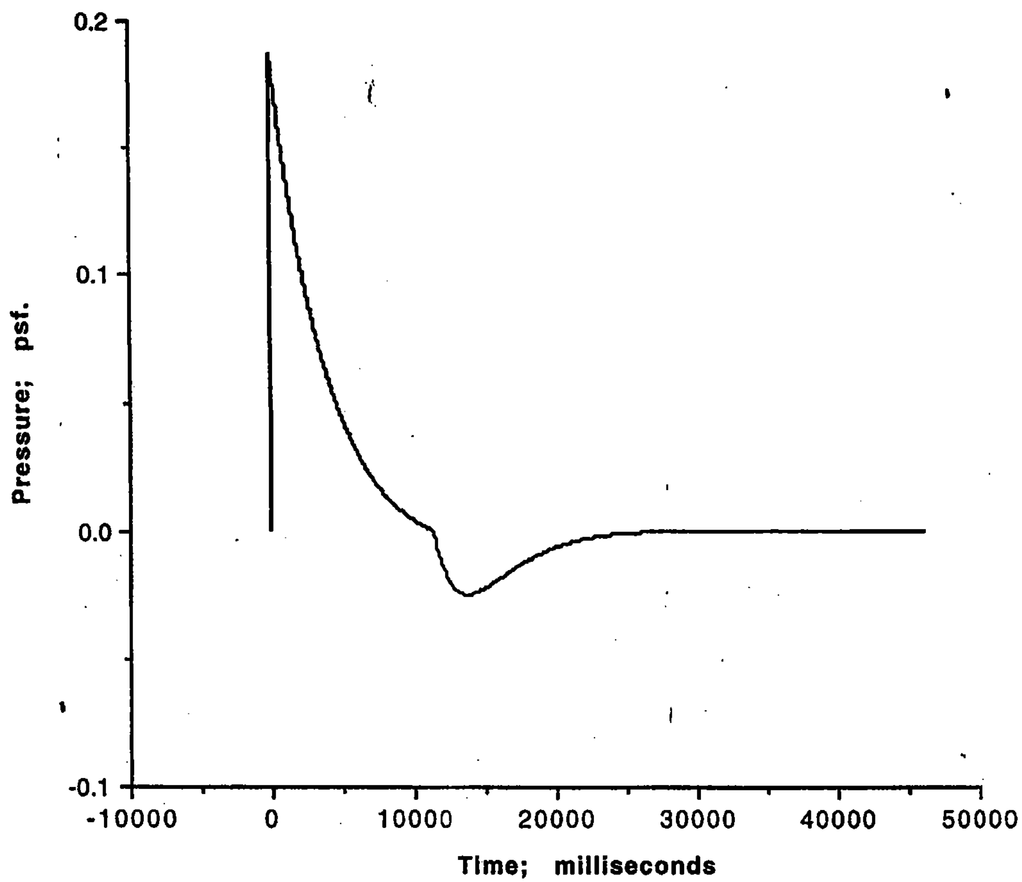


Figure B-4. Linear spherical wave propagated 20 miles. Pressure doubling for reflection included.

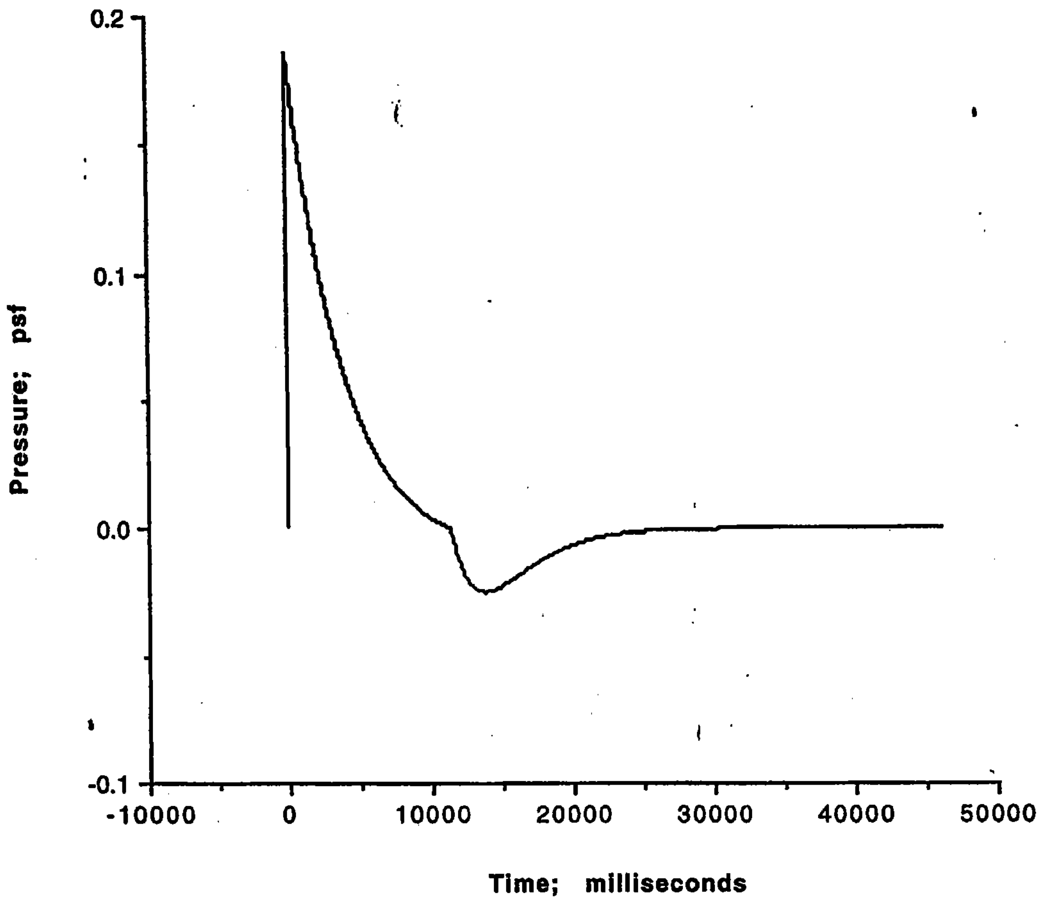


Figure B-5. Nonlinear spherical wave propagated 20 miles. Pressure doubling for reflection included.

Appendix C
Comparison of Predicted Spectra With Empirically Determined Spectra

As a final check on the analysis, a comparison with measured data was desired. Conditions directly comparable with those of Flight 800 were not available. However, the spectrum for an explosion of 5 pounds of TNT was available for an observer 10 miles away from the explosion. This explosion was on the ground, as was the observer.[1]

An empirical prediction valid for air to ground propagation from the explosion of 20 pounds of TNT may be obtained from this data in several steps. First, the spectrum is corrected by adding 3 dB to account for the difference between ground to ground and air to ground propagation. Then, 6 dB more must be added, in addition to shifting the spectra down 2/3 octave to account for the change in source strength from 5 pounds of TNT to 20 pounds of TNT. Finally, a correction of 11.5 dB is added to the empirical estimate to account for the difference in averaging time used, 1 second for the empirical estimate, and 70 milliseconds for the numerically obtained theoretical prediction. The resulting spectra is presented in Figure C-1, which may be compared with the spectra given for Observer 44 in Figure C-2. Note that Observer 44 is approximately 10.2 miles from the point of the explosion. Given the nature of the corrections, and the fact that the predicted spectra includes the effects of winds, temperature gradients and other atmospheric variables not accounted for in the empirical prediction, and the variation in spectra which is introduced by various values of the rise time, the comparison must be considered quite good. Thus it may be concluded that the overall prediction provides a signal which is a reasonable prediction of the disturbance which might be provided by the explosion of Flight 800's center fuel tank.

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[1] "The statistics of Amplitude and Spectrum of Blasts Propagated in the Atmosphere," Construction Engineering Research Laboratory Report N-13, Volume II, Appendices C through E, November 1976, Schomer, Goff, and Little, Figure D-39.

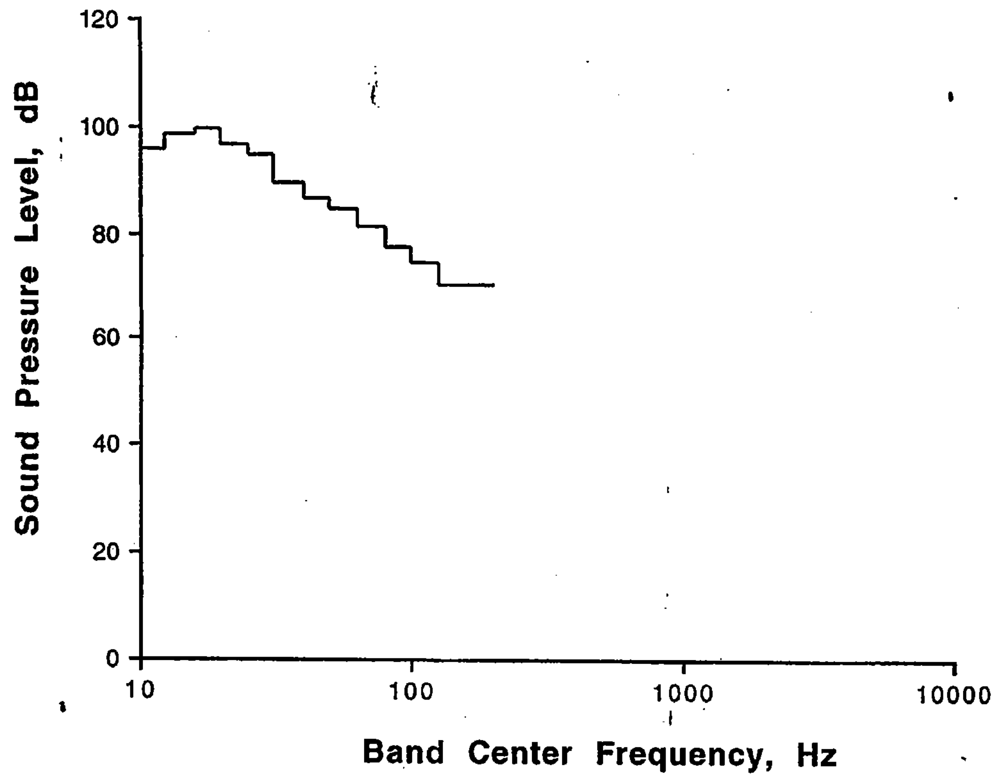

Figure C-1 **Empirical prediction of 20 pound TNT blast at 10 miles, air to ground, zero gradient conditions.**

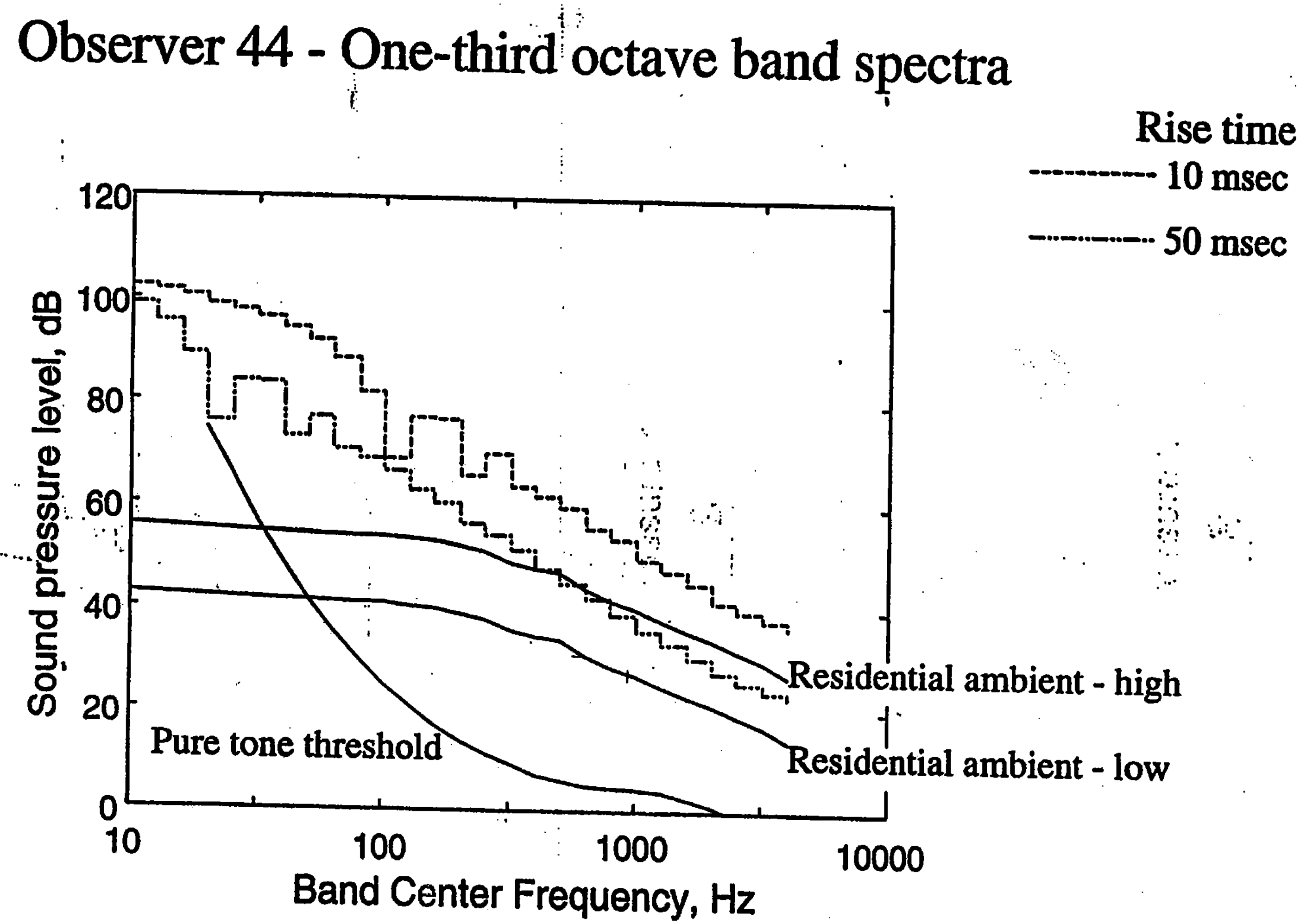

Figure C-2. The predicted spectra at 10.2 miles (Observer 44).