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PCBoom Version 7.3 User’s Guide

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Dedication

This User's Guide is dedicated to Dr. Kenneth Jay Plotkin for his decades of contributions to the advancement of sonic boom research and foundational development of the PCBoom software.

Table of Contents

Technical Support

This User's Guide and the PCBoom Quick Start Guide provide information on how to use the PCBoom suite. Questions, identification of bugs, and other suggestions for improvement should be directed to joel.b.lonzaga@nasa.gov.

1 Introduction

PCBoom is a suite of sonic boom propagation programs that applies full three-dimensional ray tracing based on geometrical acoustics. It predicts sonic boom ground waveforms (signatures) and footprints from supersonic flight vehicles performing arbitrary maneuvers using a variety of built-in or user-supplied near-field vehicle source definitions. It also computes loudness metrics, ground signature locations, and sonic boom propagation times. The nomenclature "PC" in PCBoom denotes that the programs were historically targeted to run on a Personal Computer.

1.1 About PCBoom

PCBoom has its roots in the NASA sonic boom program written by Thomas[1] in the early 1970s. Subsequent development consisted of adding focus boom prediction capability and extending the original code to handle full maneuvers as well as a variety of aircraft source inputs. Three-dimensional geometrical acoustics ray tracing algorithms were added while Thomas' original flat earth layered ray equations have been retained as an optional feature.

The current version of PCBoom determines the ray paths using either a) the three-dimensional ray tracing equations of geometrical acoustics, or b) the flat earth layered ray equations used by Thomas. The waveforms are predicted from a Burgers equation, which is numerically solved using solvers with varying levels of approximation. These solvers, described in more detail in Sections 2.3.2.2 and 3.1.2, are:

1. Lossless Burgers solver
   This solver is integrated in the main program and ignores atmospheric absorption resulting in a very fast calculation.
2. Legacy Burgers solver
   This solver is separate from the main program and accounts for atmospheric absorption. The solver can be run with or without a graphical user interface.
3. Enhanced Burgers solver
   Recently developed at NASA, this solver is integrated into the main program and accounts for atmospheric absorption. It is significantly more efficient than the Legacy Burgers solver. It also accounts for the full wind effects including Doppler and convective effects.

The functionality of PCBoom is provided by the main program, called FOBoom, and post-processing modules. The main program contains the algorithms for ray path determination and for waveform modeling using either the Lossless Burgers solver or Enhanced Burgers solver. In addition to FOBoom, there are modules that can be used to process the data generated by FOBoom or to analyze information in advance of running FOBoom. The modules are used to integrate certain propagation effects such as turbulence, model propagation emanating from the top of a supersonic aircraft, or interactively visualize signatures and footprints.

[1] Thomas, C. L., "Extrapolation of sonic boom pressure signatures by the waveform parameter method," Tech. Rep., NASA TN D-6832, 1972.

The FOBoom executable is run using a Command Prompt on a Windows Operating machine and a Terminal on either a Mac or Linux machine. The executable requires an argument, which is the name of an input file containing a series of keywords. The keywords control the input and output operations within FOBoom and provide instructions to the program for reading the initial aircraft signatures, flight conditions along its trajectory, and atmospheric profiles. The program extracts the initial signature along a specified direction and propagates it through the specified atmosphere until it reaches a desired altitude. The predicted waveform, ray path, propagation time, and other information are written as output files.

PCBoom 7.3 has the following capabilities:

- Specification of a vehicle nearfield signature as either an F-function, a nearfield pressure distribution $\Delta p/p_{inf}$ via data from a computational fluid dynamics (CFD) solution, a simple form from a library of aircraft, or a blunt hypersonic body
- Calculation of booms along particular rays, or across the full width of the primary sonic boom carpet
- Specification of arbitrary maneuvers in either local Cartesian coordinates or in geographic latitude and longitude
- Ray tracing through a 3D windy atmosphere over either a flat earth or over an ellipsoidal earth using the WGS-84 global reference system
- Calculation of spectra and a variety of loudness metrics for ground booms
- Calculation of the effect of terrain or finite ground impedance on boom signature reflection for receivers located above the ground
- Interactive sonic boom footprint and signature visualization
- Calculation of the effects of turbulence on sonic boom
- Calculation of secondary booms including tracing of "Over the Top" ray paths and computation of secondary sonic boom signatures
- Prediction of focused signatures from waveforms using a 2D lossy nonlinear Tricomi equation (LNTE), and also of the secondary post-boom signatures a distance away from the focal points
- Calculation with a launch vehicle mode including the effect of the vehicle itself and the effect of an underexpanded rocket plume
- Calculation of sonic boom waveforms below the surface of the ocean

1.2 About this User's Guide

This User's Guide is intended to guide users through extracting the files from the PCBoom package, configuring the PCBoom input files, and running the main PCBoom executable as well as the post-processor executables. This document will be updated and released with each subsequent version of PCBoom.

This guide is organized by categories of modules within PCBoom. For more information on updates in the current version of PCBoom, see Section 1.3.

- **Section 2** contains information on getting started with PCBoom and includes details on system specifications and installation, an overview of the PCBoom modules and workflows, and general information on running PCBoom.
- **Section 3** contains input, running, and output information for the primary propagation module, FOBoom.

- **Section 4** contains input, running, and output information for the modules PCBurg, PCBFoot, WCON, and Turbo, which can be used to provide additional calculation and visualization options using FOBoom output.
- **Section 5** contains input, running, and output information for the modules RayCau, LNTE, OTTER, POTRAY, and POTTI, which provide specialized functions for specialized workflows.
- **Section 6** contains information on the batch processing tool SonicBAT-Run-Fort, which facilitates calculation of atmospheric turbulence effects.
- **Appendix A** contains a glossary of key terms.
- **Appendix B** contains examples of a variety of analyses from start to finish.

For quick tips on getting started with PCBoom in Windows, MacOSX or CentOS Linux operating systems, see the PCBoom Quick Start Guide.

Use of this software suite requires an understanding of the physics of sonic boom generation and propagation. See the PCBoom Version 6.6 Technical Reference and User Manual[2] and Recent Enhancements to the NASA PCBoom Sonic Boom Propagation Code[3] for information on sonic boom theory.

1.3 Version 7.3 Updates

Highlights of the major updates included in PCBoom 7.3 are given below.

- Updates to the formats of the .wfm and .fpt output files
    - The .wfm and .fpt files have been updated to include the loudness in ASEL, BSEL, CSEL, ESEL, and ISBAP (see Sections 3.1.2, 3.2.1, and 3.2.3).
    - The .fpt file has also been updated to increase the precision of the longitude and latitude coordinates of the ground-ray intercepts.

- KZKFILTER_NWAVE keyword
    - The ability to apply precalculated KZK filters for N-waves to the output waveforms of the Enhanced Burgers solver is now available using the KZKFILTER_NWAVE keyword in the main input file (see Section 3.1.3).
    - The use of this keyword generates a new output file having the .twf extension (for turbulized waveform). Please see Section 3.2.2 for details.

[2] Page, J. A.; Plotkin, K. J.; and Wilmer, C. (2010), "PCBoom Version 6.6 Technical Reference and User Manual," Wyle Report WR 10-10, March 2010.

[3] Lonzaga, J.B., (2019), "Recent Enhancements to NASA's PCBoom Sonic Boom Propagation Code," in *AIAA Aviation 2019 Forum* (p. 3386).

2 Getting Started

This section contains information about system specifications, installation, PCBoom module descriptions, and running PCBoom.

2.1 System Specifications

The programs and majority of the subroutines are written in FORTRAN 77, while the remainder of the subroutines are written in FORTRAN 90/95. In this version, the main PCBoom program is called FOBoom, and the corresponding executable is called pcboom730win.exe for Windows, pcboom730osx for Mac OSX, and pcboom730cen for CentOS Linux operating systems. While the version 7.3.0 executables of the main program have been built for these operating systems, the post-processor modules have only been compiled for the Windows 10 Operating System. For more information on PCBoom post-processors, see Section 2.3.

2.2 PCBoom Setup

This section describes how to unpack and set up necessary files to run PCBoom on Windows, MacOSX and Linux systems. Step by step instructions on setting up PCBoom files are provided in the PCBoom Quick Start Guide.

Windows

The PCBoom software suite for Windows is provided as a self-extracting zip archive. To unpack, double-click on the PCBoom 7.3.0-unpack.exe file. A window will appear (Figure 2-1) where the PCBoom directory can be specified. Use the default location of C:\PCBoom\, or browse to the desired installation directory and press the Unzip button to unpack the files listed in Table 2-1.

The executables and folders that come with PCBoom are described in Table 2-1. pcboom730win.exe is the main PCBoom executable (FOBoom program). The post-processors folder contains the PCBoom post-processors that are available for Windows operating systems and are listed in Table 2-2. The additional folders contain filters, documents, and example files.

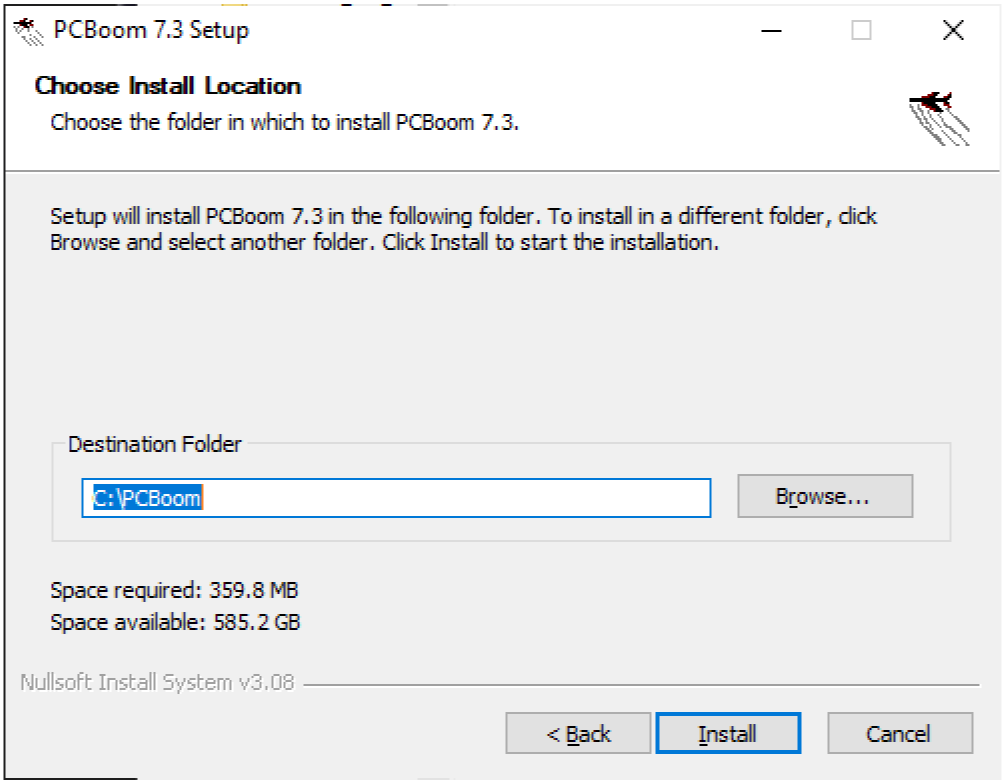


Figure 2-1 PCBoom file extraction window.

Table 2-1 PCBoom setup package contents for Windows.

Filename/Folder Name	Description
pcboom730win.exe	Main PCBoom executable for Windows Operating Systems for propagation of signatures in the FOBoom program using either the Lossless Burgers solver or the Enhanced Burgers solver
QuickStartGuidePCBoom730.pdf	Quick Start Guide for PCBoom 7.3
PCBoomUsersGuide730.pdf	User's Guide for PCBoom 7.3
Post-processors Folder	
pcburg730.exe	Legacy Burgers solver accounting for atmospheric absorption with a graphical user interface
headlessburgers730.exe	Legacy Burgers solver accounting for atmospheric absorption without a graphical user interface and for batch processing
pcbfoot730.exe	Prepares boom footprint and signature files for visualization in WCON, applies Taylor shock structures, and calculates metrics
wcon730.exe	Visualizes sonic boom footprints
filtview730.exe	Applies turbulence effects using finite impulse response filters
Turbo730.exe	Applies turbulence using a classical model for 3-D, linear acoustic propagation with turbulent temperature and wind variations
RayCau730.exe	Preprocessor for LNTE for visualization and calculation of ray caustic
lnte730.exe	2-D lossy nonlinear Tricomi equation (LNTE) to predict focused signatures
potray730.exe	Preprocessor for OTTER for computation of sonic boom ray paths
potti730.exe	Preprocessor for OTTER with an interactive display to graphically examine ray patterns
otter730.exe	Over-the-Top (OTT) interactive ray tracing
sonicbat-run-fort730.exe	Batch processing program that runs the main program and post-processors for modeling turbulence effects
Additional Folders	
Filters	This folder contains FIR filters used with the FiltView module
Examples	This folder and subfolders contain sample files that can be used with the examples described in Appendix B
sbpw3case1	This folder contains sample files that correspond to examples in the PCBoom Quick Start Guide
lm1021	This folder contains sample files that correspond to examples in the PCBoom Quick Start Guide

Mac OSX

The PCBoom software suite for Mac OSX is provided as a zipped folder (PCBoom730OsxFiles.zip), which contains the main PCBoom executable and supporting files. Before unzipping the folder, create a directory in which the PCBoom executable will be located. To unzip, open a terminal and change the directory to the PCBoom directory and run the unzip command. Next, run the ls command to list the files in the PCBoom directory as shown below.

Table 2-2 PCBoom setup package contents for MacOSX.

Filename/Folder Name	Description
pcboom730osx	Main PCBoom executable for MacOSX Operating Systems for propagation of signatures in the FOBoom program using either the Lossless Burgers solver or the Enhanced Burgers solver
QuickStartGuidePCBoom730.pdf	Quick Start Guide for PCBoom 7.3
PCBoomUsersGuide730.pdf	User's Guide for PCBoom 7.3
Additional Folders	
sbpw3case1	This folder contains sample files that correspond to examples in the PCBoom Quick Start Guide
lm1021	This folder contains sample files that correspond to examples in the PCBoom Quick Start Guide

Note that the only executable provided is pcboom730osx. The PCBoom Quick Start Guide and User's Manual are also provided. The directories sbpw3case1 and lm1021 contain sample files that correspond to examples in the PCBoom Quick Start Guide.

Linux CentOS

The PCBoom software suite for CentOS is provided as a zipped folder (PCBoom730CenFiles.zip), which contains the main PCBoom executable and supporting files. Before unzipping the folder, create a directory in which the PCBoom executable will be located. To unzip, open a terminal and change the directory to the PCBoom directory and run the unzip command. Next, run the ls command to list the files in the PCBoom directory as shown below.

Table 2-3 PCBoom setup package contents for CentOS.

Filename/Folder Name	Description
pcboom730cen	Main PCBoom executable for Linux CentOS Operating Systems for propagation of signatures in the FOBoom program using either the Lossless Burgers solver or the Enhanced Burgers solver
QuickStartGuidePCBoom730.pdf	Quick Start Guide for PCBoom 7.3
PCBoomUsersGuide730.pdf	User's Guide for PCBoom 7.3
Additional Folders	
sbpw3case1	This folder contains sample files that correspond to examples in the PCBoom Quick Start Guide
lm1021	This folder contains sample files that correspond to examples in the PCBoom Quick Start Guide

Note that the only executable provided is pcboom730cen. The PCBoom Quick Start Guide and User's Manual are also provided. The directories sbpw3case1 and lm1021 contain sample files that correspond to examples in the PCBoom Quick Start Guide.

2.3 PCBoom Modules Overview

The modules that make up PCBoom are shown in Figure 2-2. These consist of the main PCBoom program, FOBoom, as well as pre- and post-processors. Each module performs a discrete portion of sonic boom analysis and combinations of modules are used to complete analyses depending on analysis goals. These modules are introduced in Section 2.3.1 and are described in detail in the remaining sections of this User's Guide. A variety of workflows that describe how the modules can be used to accomplish analysis goals are described in Section 2.3.2.

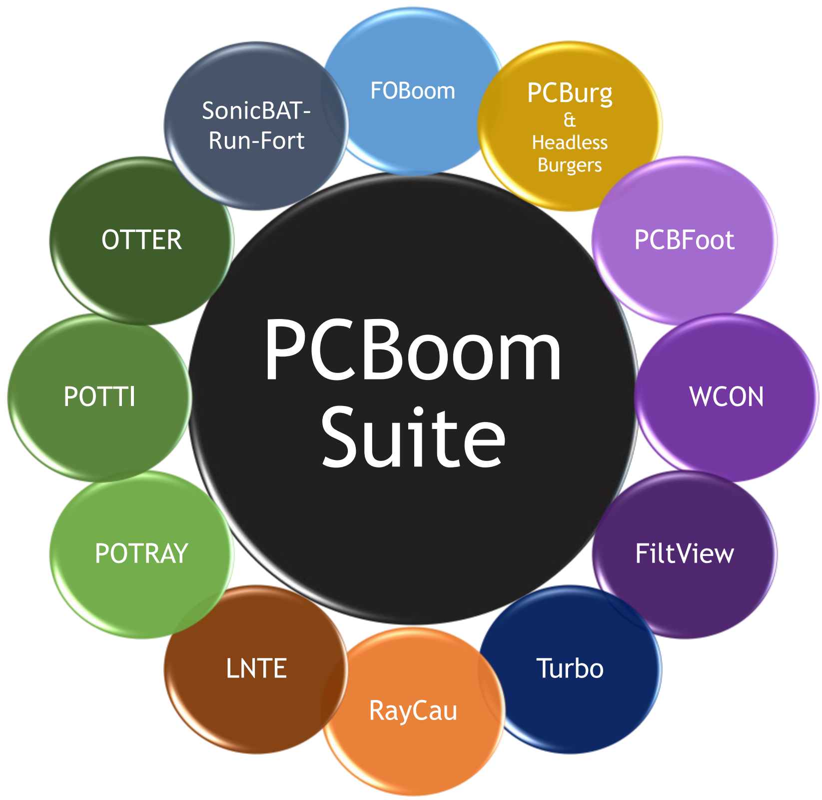


Figure 2-2 PCBoom modules.

2.3.1 Modules

The modules that make up the PCBoom program suite are introduced in this section and described in detail throughout this User's Guide.

FOBoom

The FOBoom program is the main PCBoom program (compiled as pcboom730win.exe for Windows, pcboom730osx for Mac OSX, and pcboom730cen for Linux CentOS) that computes sonic boom waveforms at user-specified altitudes using either the Lossless Burgers solver or the Enhanced Burgers solver. The computation involves sonic boom propagation through a specified atmosphere over user-specified azimuthal acoustic emission angles for a defined flight trajectory.

- Inputs: Noise source, trajectory, atmosphere, propagation methods, terrain, and ground type information are input through the use of keywords provided in the main input file and (optional) external files.
- Outputs: The main output file is an .out file for the Lossless Burgers solver or a .wfm or .fpt file for the Enhanced Burgers solver. Note that the Enhanced Burgers output files are not currently compatible with the post-processor modules. The .out file includes the waveforms at the requested output altitudes and is used as the input to the PCBFoot, TURBO, SonicBAT-Run-Fort, and Raycau modules. The .wfm file contains the waveforms at the requested altitudes and provides information on the ground-ray intersection, propagation time, noise metrics, and other data. FOBoom can output many additional files depending on analysis needs.

For detailed information on the FOBoom program, see Section 3. For more information on metrics, see Appendix A.

PCBurg

The PCBurg module is an implementation of the Legacy Burgers solver employing a graphical user interface to view the evolution of a sonic boom waveform from an initial altitude to the ground. It is a post-processor that takes in ray paths and age parameters contained in an .age file as well as signature F-functions contained in a .sig file. Both files are generated by the main PCBoom program. PCBurg incorporates atmospheric absorption into the nonlinear aging of the waveform as it propagates from the source to the ground. Accurate modeling of losses is important in analyzing loudness metric results due to the effect of shock structures on the higher frequency contents of the waveform. The graphical user interface displays different waveform parameters and sound level metrics including Pmax, ASEL, BSEL, CSEL, DSEL, ESEL, ZSEL, and PL.

- Inputs: Inputs include nonlinear aging parameters (.age) and initial signature (.ssg) files from the FOBoom program, and the focus file (.foc) from the RayCau module.
- Outputs: Signature and spectral output files as well as graphics can be saved at user specified altitudes. PCBurg also creates files suitable for LNTE focus analysis.

For detailed information on the PCBurg module, see Section 4.1. For more information on metrics, see Appendix A.

HeadlessBurgers
The HeadlessBurgers module is a post-processor for implementing the Legacy Burgers solver in batch processing mode. Thus, it contains the same physics as the PCBurg module without the graphical user interface.

- Inputs: Inputs include output signature aging and signature (.age and .ssg) files from the FOBoom program.
- Outputs: The Burgers signature output file (.bsg) is the output file for HeadlessBurgers, which contains the same information as the signature file obtained through PCBurg with the exception of caustic information.

For detailed information on the HeadlessBurgers module, see Section 4.1.3.

PCBFoot
The PCBFoot module is a post-processor that organizes the FOBoom footprint and signature outputs into structured files for use in WCON. Finite rise times are artificially obtained by applying Taylor shock absorption from which metrics are calculated. Note that PCBFoot addresses ground booms only; waveform prediction at elevated receiver heights requires the use of WCON.

- Inputs: Inputs include .out and .gmp FOBoom output files, and optionally the FOBoom .org output file that includes longitude and latitude of the origin for georeferencing (needed for visualization in WCON)
- Outputs: PCBFoot can output four different files in ASCII format containing results. These include the footprint, metric data, and isopemp data (.qwk), primary signature output (.sig), shock indices for signatures (.ind), and unit vectors for the end of ray incident angles (.ens). Outputs that contain boom summary information (.asc) and geodetic coordinates and metrics (.gnd) can also be produced.

For detailed information on the PCBFoot module, see Section 4.2. For more information on metrics, see Appendix A.

WCON
The WCON module is an interactive footprint and signature display post-processor. This module does some post-processing to obtain boom signatures (including secondary post-focus u-waves) at any user-specified location within the footprint, not just at specific ray ends. It also includes algorithms to compute ground effects based on local ground impedance, turbulence effects using several different methods, and booms that have penetrated beneath a water surface. Pmax, ASEL, BSEL, CSEL, DSEL, ESEL, ZSEL, PL, and Lpk metrics are also available in the WCON interface. The WCON module is run using input files written directly by PCBFoot.

- Inputs: Inputs include .qwk, .sig, .ind, .end, and .asc output files generated by PCBFoot.
- Outputs: Sonic boom contours and isopemps in .pdx files, signatures and spectra in ASCII (.txt) files can be saved by the user.

For detailed information on the WCON module, see Section 4.2.2. For more information on metrics, see Appendix A.

FiltView

The FiltView interactive display post-processor allows for estimation of the effects of turbulence on sonic boom waveforms via the use of finite impulse response (FIR) filters generated by the KZKFourier model. Pmax, ASEL, BSEL, CSEL, ESEL, and ISBAP metrics are also available in the FiltView interface. This module is most often called from within the WCON module but can also be run directly from the command line.

- Inputs: FiltView is accessed through the WCON display, see the WCON inputs description in Section 4.3.1 for more information.
- Outputs: Graphical output (.png) of the waveforms including turbulence as well as tabular metric information (.txt) can be saved by the user. Binary output for the waveforms is also available (.bin).

For detailed information on the FiltView module, see Section 4.3.4. For more information on metrics, see Appendix A.

Turbo

The Turbo module is a post-processor used to account for the effects of a 3D turbulent velocity field on sonic boom propagation using classical turbulence theory.

- Inputs: Inputs include .age, .out output files from FOBoom, the ablh.out and ablh.dat output files from FOBoom/SonicBAT-Run-Fort, as well as the .dat FOBoom input file, and a turbulence input file to specify additional turbulence information.
- Outputs: The Turbo module writes turbulent signatures into the FOBoom format output files (.out) so that existing post-processing methods can be used to examine output data. In addition, the tur.txt file is written with a summary of the run and results, and diagnostic information is written to a u86.txt file.

For detailed information on the Turbo module, see Section 4.4.

RayCau

The RayCau module is used to visualize and calculate individual ray characteristics with respect to the ground. The module is used in conjunction with FOBoom to identify the Burgers-Lossy Nonlinear Tricomi (LNTE) interface location to locate the focus delta ray.

- Inputs: Inputs include .out and .age output files from FOBoom.
- Outputs: .foc is the output file, which contains caustic information such as the ray elevation angle and diffraction boundary-layer thickness.

For detailed information on the RayCau module, see Section 5.1.

LNTE

The LNTE module is used to predict focused waveforms using the 2D lossy nonlinear Tricomi equation (LNTE). Since LNTE is 2D, it should only be used near the centerline / plane of symmetry.

- Inputs: XX_tricomi.inp is autogenerated by the LNTE given inputs from PCBurg. It is an input file, which contains PCBurg output waveforms extracted at both the Burgers-LNTE interface altitude and the ground height.
- Outputs: The .out file containing the pressure data matrix is available at a range of locations between specified min and max $\overline{z}$ values. The file is written in a binary format.

For detailed information on the LNTE module, see Section 5.1.

POTRAY

The POTRAY module is one of two preprocessors for the OTTER module. It is a ray propagation module, which traces ray paths in all directions and outputs ray paths and ground intercept data. The ray tracing in POTRAY is the same as the ray tracing in FOBoom, however, POTRAY does not include signature evolution and provides outputs with more points along the ray path than FOBoom.

- Inputs: The input file is a user-created POTRAY input file (.nml).
- Outputs: Output files are written for each time step. The main output files are the .hit files, .ray files, and .out files. For more information on POTRAY outputs, see Section 5.2.1.3.

For detailed information on the POTRAY module, see Section 5.2.1.

POTTI

The POTTI module is one of two preprocessors for the OTTER module. It is an interactive display program for visualization of the ray paths, including secondary sonic boom carpet locations computed in POTRAY and selection of individual rays for further examination of the sonic boom signature.

- Inputs: .hit, and .ray files computed in the POTRAY module
- Outputs: The end results of a POTRAY/POTTI analysis is a determination of trajectory times and azimuths that result in secondary boom rays. Rays of interest can then be processed in FOBoom.

For detailed information on the POTTI module, see Section 5.2.1.

OTTER

The OTTER post-processing module, together with POTRAY and POTTI preprocessors, allows the user to interactively view the signature evolution along complex 3D and over-the-top ray paths.

- Inputs: Inputs include .ott and .ots FOBoom output files, which describe the ray coordinates, atmospheric properties, amplitude, age parameters, and the F-function at the start of each ray.
- Outputs: Secondary sonic boom signature evolution visualization is the output. Graphical and tabular results can be saved by the user.

For detailed information on the OTTER module, see Section 5.2.3.

SonicBAT-Run-Fort
The SonicBAT-Run-Fort module is a batch processing tool that can sequence multiple modules such as FOBoom, HeadlessBurgers, and TURBO, compile results, and prepare files for further processing by other PCBoom post-processors such as PCBFoot and FiltView.

- Inputs: The same inputs that modules require if run outside of SonicBAT-Run-Fort are required, plus two user-generated files to specify input files and run options.
- Outputs: The same outputs that the combination of modules provide outside of SonicBAT-Run-Fort are created, however, results for multiple rays are compiled and prepared for further processing in additional PCBoom modules

For detailed information on the SonicBAT-Run-Fort module, see Section 6.1.

sBOOM
sBOOM is a propagation tool that is distributed separately from the PCBoom suite. It uses a time-domain Burgers solution algorithm and is called within SonicBAT-Run-Fort as the primary propagation solver in place of the Enhanced Burgers solver or the Legacy Burgers solver.

When SonicBAT-Run-Fort was originally developed, the sBOOM module was significantly faster than other available Burgers solvers, so it was included to facilitate fast computation of multiple rays. sBOOM version 2.01 (the version available when SonicBAT-Run-Fort was developed) and version 2.84 (the current version) are compatible with PCBoom version 7.3. sBOOM is available through the NASA Software Catalog by request at https://software.nasa.gov/.
For more information on how sBOOM can be used with the other PCBoom modules, see Section 6.1.

For more information on sBOOM, see the sBOOM documentation[4].

2.3.2 Workflows

The main PCBoom program and its post-processors can be sequenced depending on analysis goals. This section outlines fundamental workflows, presented to demonstrate fundamental relationships between the modules and goals that can be accomplished by using those workflows. Common analysis workflows are included, which demonstrate examples of more complex combinations of PCBoom modules that can be used to efficiently answer questions in practice.

FOBoom is the main PCBoom program, and many fundamental parameters for an analysis are defined in the FOBoom input file. See Section 3.1 for more information on FOBoom input options.

For examples with sample files for a subset of the workflows described in this section, see Appendix B.

[4] See the following sBOOM documentation:
Rallabhandi, S. K., "Advanced Sonic Boom Prediction Using the Augmented Burgers Equation," AIAA Journal of Aircraft, Vol. 48, No. 4, 2011, pp. 1245–1253. doi:10.2514/1.C031248
Rallabhandi, S. K., "Propagation Analysis of the 3rd Sonic Boom Prediction Workshop Cases using sBOOM," submitted to AIAA SciTech 2021 conference, 2021.

2.3.2.1 *Basic Workflows*

The two most basic workflows in PCBoom are shown in Figure 2-3. Note that these workflows do not include the effects of atmospheric absorption. The FOBoom program can be run alone to take vehicle and atmospheric input data and perform ray tracing and waveform evolution (Workflow 1) using the Lossless Burgers solver. The next level of analysis is to calculate metrics and view the results, which is accomplished through the combination of the PCBFoot and WCON post-processors (Workflow 2). PCBFoot must be run prior to WCON in order to apply artificial absorption and assemble the footprint from FOBoom outputs, apply Taylor shock structures, and calculate the metrics. Then, WCON can be used to visualize the results. Additional workflows in this section build upon this baseline.

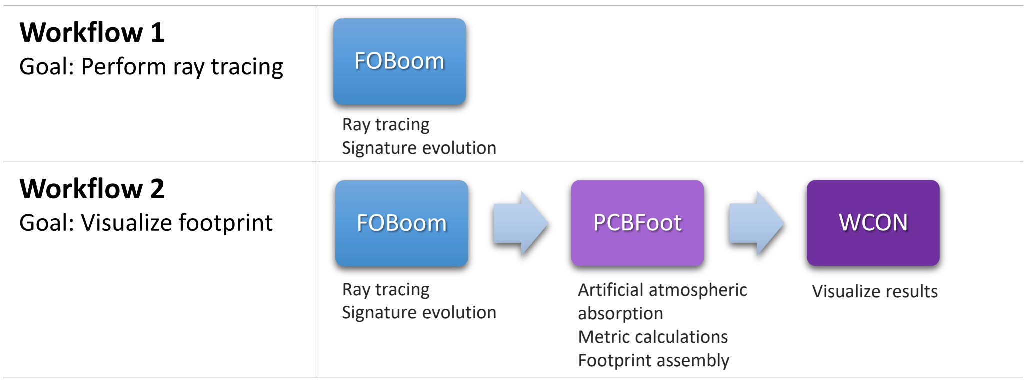


Figure 2-3 Fundamental workflows.

2.3.2.2 *Lossy Burgers Solver Workflows*

Workflows that solve the lossy Burgers equation for combined effects of nonlinearity and atmospheric absorption on sonic boom propagation are displayed in Figure 2-4.

The PCBoom suite of tools includes two different lossy Burgers solvers: a) Enhanced Burgers solver (within FOBoom) and b) the Legacy Burgers solver (PCBurg / HeadlessBurgers). Both solvers account for second-order nonlinearity, thermoviscous absorption, absorption and dispersion due to molecular relaxation of oxygen and nitrogen, and geometrical spreading. The Enhanced Burgers solver is faster and has better representation of the propagation physics. It does not use any numerical filtering, unlike the Legacy Burgers solver that allows for an optional filter to suppress Gibbs oscillations. For more information on the available solvers, see Section 3.1.2.

The interplay between nonlinearity and atmospheric absorption can be applied either in FOBoom by using the Enhanced Burgers (Workflow 3) or by using a combination of FOBoom and the PCBurg/HeadlessBurgers post-processor modules (Workflow 4). In order to compute a full footprint including the effects of atmospheric absorption using the PCBFoot and WCON modules, the SonicBAT-Run-Fort module must be used (Workflow 5). The output from the FOBoom program using the Enhanced Burgers solver is not currently interoperable with the other PCBoom post-processor modules, but a .fpt output file can be invoked, which contains the ground intersection locations, times, PL, and other info for the user-specified emission angles and aircraft trajectory timesteps.

Modeling with a lossy Burgers equation may also be done by using the sBOOM tool from within SonicBAT-Run-Fort (Workflow 6). This tool is not part of the PCBoom suite but is compatible with

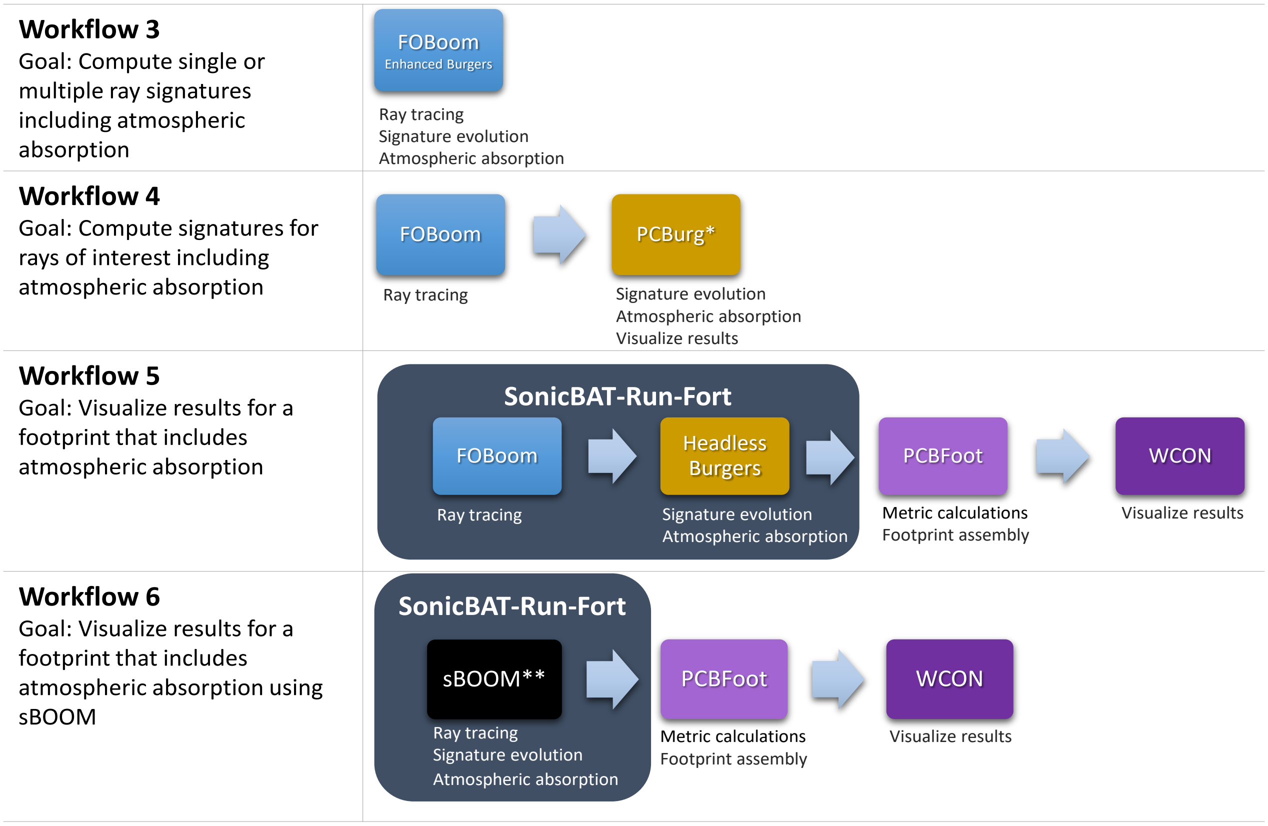
PCBoom. For more information on sBOOM, see sBOOM documentation[5]. HeadlessBurgers and sBOOM are interoperable with PCBFoot and WCON, however, sBOOM requires the use of SonicBAT-Run-Fort.

The main differences between workflows 3, 4, and 6 are:

- Workflow 3: FOBoom with the Enhanced Burgers solver
  - The advantage of using FOBoom with the Enhanced Burgers solver is that waveforms for multiple rays can be computed efficiently.
  - The disadvantage is that the results are not currently compatible with other PCBoom modules.
- Workflow 4: FOBoom, PCBurg/HeadlessBurgers
  - The advantage of using this method is PCBurg includes additional visualization capabilities. This method is consistent with legacy analyses.
  - The disadvantage is that only one ray can be computed at a time and the runtime is longer.
- Workflow 6: sBOOM
  - The advantage of using sBOOM is that it has shorter runtimes than those in workflow 4 and that the results can be used in other PCBoom modules when prepared by SonicBAT-Run-Fort.
  - sBOOM is maintained and distributed separately from the PCBoom suite of modules.

---

[5] See the following sBOOM documentation:
Rallabhandi, S. K., "Advanced Sonic Boom Prediction Using the Augmented Burgers Equation," AIAA Journal of Aircraft, Vol. 48, No. 4, 2011, pp. 1245–1253. doi:10.2514/1.C031248
Rallabhandi, S. K., "Propagation Analysis of the 3rd Sonic Boom Prediction Workshop Cases using sBOOM," submitted to AIAA SciTech 2021 conference, 2021.

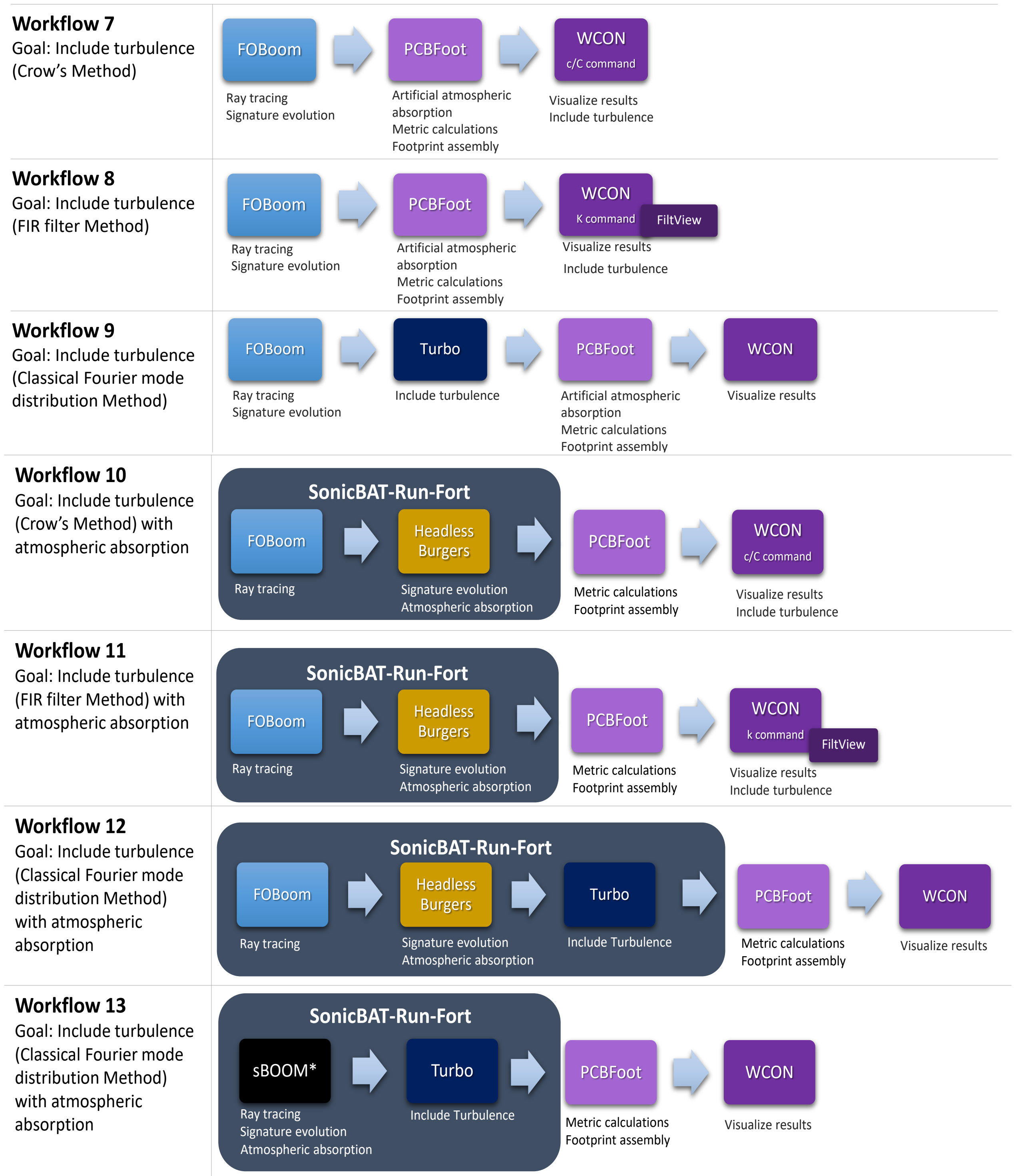


*HeadlessBurgers could be used in place of PCBurg if the user is not interested in viewing the signature evolution. Note that all rays will be computed as opposed to specified rays, when using HeadlessBurgers.
**sBOOM is not distributed with the PCBoom suite. See Section 6.1 for more information about sBOOM.

Figure 2-4 Lossy Burgers equation workflows.

2.3.2.3 Turbulence Workflows

The three methodologies for including the effects of atmospheric turbulence as implemented in PCBoom include: Crow's method within the WCON module; FIR filters in the WCON / FiltView module, and the classical Fourier mode distribution method in the Turbo module. Each workflow implements a different turbulence methodology and depending on which combination of propagation methodologies are to be employed, there are at least seven applicable workflows (Figure 2-5), all of which are explained in this section.



*sBOOM is not distributed with the PCBoom suite. See Section 6.1 for more information about sBOOM.

Figure 2-5 Turbulence workflows.

2.3.2.4 *Specialized Workflows*

Specialized workflows within PCBoom are shown in Figure 2-6. In addition to FOBoom, Workflow 14 uses the specialized RayCau and LNTE modules in order to predict focused signatures using the lossy nonlinear Tricomi equation. Workflow 15 uses the specialized POTRAY, POTTI, and OTTER modules to view the signature evolution along complex 3D and over-the-top ray paths. Workflow 16 uses the Workflow 2 modules with a methodology implemented in WCON to compute signatures below the surface of the ocean.

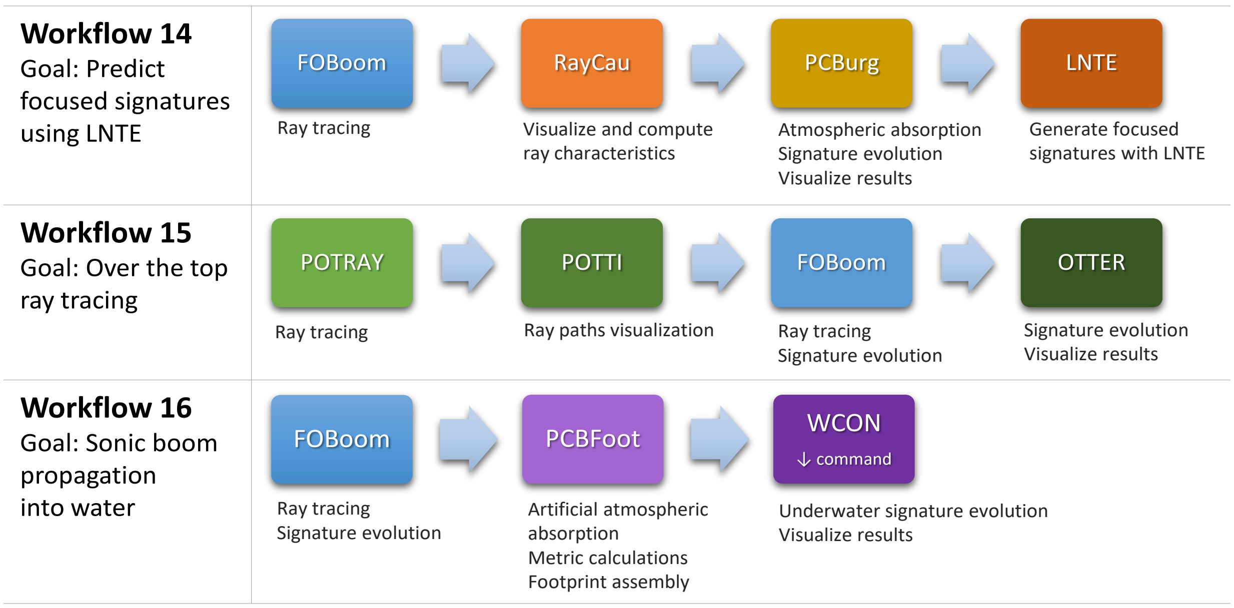
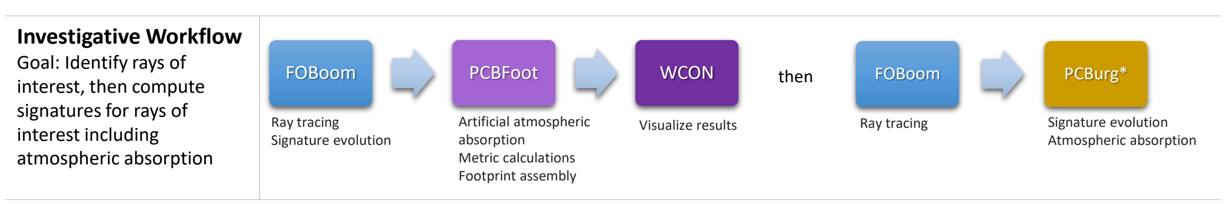


Figure 2-6 Specialized workflows.

2.3.2.5 *Investigative Workflow*

In some cases, using a subset of PCBoom modules to investigate data sets in order to identify ray(s) of interest may be useful. In this sample workflow, FOBoom, PCBFoot, and WCON are used to visualize a footprint and identify ray(s) of interest. Then, FOBoom and PCBurg/HeadlessBurgers are run on the identified ray(s) to include atmospheric absorption. For examples of additional workflows with sample files, see Appendix B.



*HeadlessBurgers could be used in place of PCBurg if the user is not interested in viewing the signature evolution. Note that all available rays or user specified rays may be computed, when using HeadlessBurgers.

Figure 2-7 Investigative workflow.

2.4 Running PCBoom

Analyses are typically started by running the main PCBoom program (FOBoom) to produce the specified output files, which are subsequently used as input files into additional modules (when using Windows operating systems). Note that the FOBoom input file name is considered to be the case name (casename) for an analysis and is used in all outputs associated with the analysis.

The PCBoom modules can be run from the command line or in a batch process in a Windows environment. Modules can be run in a batch process by creating a .bat file with the desired modules and inputs. An example of a batch file to run FOBoom, PCBFoot, and WCON in sequence is shown in Figure 2-8. In this example, the case name is “Example 1” and outputs are specified from within the FOBoom input file.

```
pcboom730win Example1
pcbfoot730 Example1
wcon730 Example1
pause
exit
```

Figure 2-8 Example .bat file.

For more information on commands for running each module, see the “Running [module name]” section for the module of interest.

The SonicBAT-Run-Fort module is a batch processing tool that can sequence the analysis of multiple trajectory points across modules such as FOBoom, HeadlessBurgers, and Turbo, compile results, and prepare files for further processing by additional PCBoom modules such as PCBFoot and WCON. The SonicBAT-Run-Fort module is described in Section 6.1.

For more information on running FOBoom in MacOSX or CentOS Linux environments, see the PCBoom Quick Start Guide.

3 Main PCBoom Program (FOBoom)

The main PCBoom program (FOBoom) propagates boom signatures through the specified atmosphere over the user-specified azimuthal acoustic emission angles for a defined flight trajectory using either a) the three-dimensional ray tracing equations of geometrical acoustics, or b) the flat-earth layered ray equations used by Thomas for ray path determination. FOBoom predicts sonic boom waveforms from a Burgers equation, which is numerically solved using solvers with varying levels of approximation as described below. FOBoom has a variety of options that can be invoked by the user depending on analysis needs.

The three Burger solver options available in PCBoom include the following:

1. Lossless Burgers solver (FOBoom, no BURGERS keyword): This solver is integrated in FOBoom and computes the signature evolution based on the Middle-Carlson-Hayes (MCH) age parameter resulting in a very fast calculation. Note that when the PCBFoot module is run using outputs from FOBoom with the lossless Burgers solver, artificial absorption and shock thickening are applied based on Taylor's method allowing loudness metric calculations.
2. Legacy Burgers solver (FOBoom with BURGERS keyword and post-processors PCBurg and HeadlessBurgers): This solver is decoupled from FOBoom and accounts for second-order nonlinearity, thermoviscous absorption, absorption and dispersion due to molecular relaxation of oxygen and nitrogen, and geometrical spreading. A filter can be enabled to suppress Gibbs oscillations since this solver is susceptible to Gibbs oscillations for booms with short rise time. The solver can be run with or without a graphical-user interface. See Section 3.1.2 for more information.
3. Enhanced Burgers solver (FOBoom with BURGERS keyword and additional inline inputs): This solver is integrated in the main program and accounts for second-order nonlinearity, thermoviscous absorption, absorption and dispersion due to molecular relaxation of oxygen and nitrogen, and geometrical spreading, as well as wind effects. It is more efficient than the Legacy Burgers solvers and is not susceptible to Gibbs oscillations. Hence, it does not require any numerical filtering. Information on using the Enhanced Burgers Solver for propagation is described in Section 3.1.2.

For more information on workflows using the lossy Burgers solvers, see Section 2.3.2.2.

Section 3.1 describes the inputs to FOBoom, Section 3.1.17 describes how to run FOBoom, Section 3.2 describes available outputs from FOBoom, and Section 3.3 provides troubleshooting information.

3.1 FOBoom Inputs

Since FOBoom is the main computational module in the PCBoom suite, many fundamental parameters are defined within the FOBoom input file including atmosphere, altitude, terrain, ray tracing, nearfield signature, vehicle, and trajectory information. This information is input through a sequence of keywords within the FOBoom input file and supplemental files.

The FOBoom input file, which historically uses a .dat file extension, is a fixed-format ASCII file that may be easily created or edited using a text editor such as Notepad, Vi, or Emacs.[6] FOBoom accepts many

[6] Note that PCBoom input files are not compatible with Microsoft Word or similar word processing programs that insert additional formatting into the file. Also, PCBoom files use 7-bit ASCII encoding. If a Windows text editor such as Wordpad is used, make sure the file is saved as ASCII, and not Unicode.

different keywords, some of which are optional. The keywords have some flexibility in the order in which they are entered in the input file, however, a recommended order is provided in Table 3-1. Specific order requirements are included in the following keyword description sections. Note that not all features are compatible with one another, for example the OTT functionality is not compatible with the BURGERS or LEGACY ray tracing options.

Table 3-1 Fundamental FOBoom keywords, descriptions, and order.

Keyword #	Keyword	Required/Optional	Description
1	CASENAME	Required	Case description entry. Echoed to output files
2	BURGERS	Optional	When accompanied by additional inputs, invokes the Enhanced Burgers solver option and produces .wfm or .fpt files. When used alone, triggers output of .age and .ssg files for use in the PCBurg/HeadlessBurgers modules.
3	KZKFILTER_NWAVE	Optional	Invokes the convolution of a set of KZK filters for N-waves with a waveform generated by the Enhanced Burgers solver and produces a .twf output file
4	HYSTATMO	Optional	Replaces the given pressure profile with an interpolated profile in 100 ft increments derived using the hydrostatic equation[7]
5	OUTPUTS	Optional	Specifies the types of output to be created
6	OTT	Optional	Triggers the creation of the .ott output file for use in the OTTER over-the-top ray tracing post processor
7	OTTRANGE	Optional	Triggers the creation of the .ott and .ots output files suitable for use in the OTTER post-processor over a specified range of input trajectory times
8	GROUND	Optional	Triggers output of .gmp file for PCBFoot calculation of ground impedance effects on the ground signatures and above ground waveforms.
9	ATMOS	Required	Specification of atmospheric data, or input to be used for atmospheric data
10	ALTITUDES	Required	Specifies altitudes at which to output a sonic boom waveform Note that if output altitudes are specified above the flight altitude, OTT and upward ray propagation will be enabled
11	TERRAIN	Optional	Allows for specification of an external file containing terrain data
12	RAYTRACING	Optional	Accepts ray tracing parameters to use for propagation. If not specified, the defaults specified in the RAYTRACING section (3.1.12) are used
13	MODE	Required	Allow for specification of input mode for vehicle and nearfield signature data
14	HIGHRES	Optional	Allows for specification of an external file to input desired signature sampling fidelity
15	TRAJECTORY	Required	Allows for specification of trajectory information or an external file containing trajectory information

[7] When HYSTATMO is in use, the .UN6 file notes the keyword activation, but outputs the atmosphere using 1000 ft increments.

16	REMARKS	Optional	Allows for comments within the input file

Several of the keywords have multiple input formats, allow for specification of external supplemental input files and data formats appropriate for the computational requirements and desired output. Specific input requirements for each keyword are described in Sections 3.1.1- 3.1.14. The sections are arranged by the recommended order in which they should be entered in the input file. The tables in these sections indicate additional information that is to be included in the line(s) following the keyword. Specific formatting such as columns, position, sequence, and spacing is also described. An example of how the keywords are included in the FOBoom input file with their supporting parameters is illustrated in Figure 3-1 where the keyword is followed by the additional parameters required for that keyword.

For examples of FOBoom input files that can be used in real analyses, see Appendix B and the supporting files.

```
CASENAME
SampleCaseName
OUTPUTS
4
SCREEN
UN6
U28
MCO
GROUND
200
5
...snip...
```

Figure 3-1 Example FOBoom input file structure.

3.1.1 Keyword CASENAME

The CASENAME keyword is required in the FOBoom input file and should be the first keyword in the FOBoom input file. This case name is used to create the output data files with three-letter extensions. Only one line of case name description is permitted. Any characters beyond the specified max length will not be repeated in the output files. Table 3-2 describes the CASENAME keyword.

Table 3-2 CASENAME keyword format description.

Line	Column	Max Length	Variable Name	Description
1	1-80	80	—	Case name

3.1.2 Keyword BURGERS

The BURGERS keyword is used to control options for different Burgers solvers:

1) It invokes the Enhanced Burgers solver for single or multiple rays. This requires additional inputs after the BURGERS keyword as described in Table 3-3. This option prompts the generation of the .wfm or .fpt output files. The .wfm file is generated when discrete emission ray azimuthal angles are specified in the RAYTRACING keyword section (i.e., setting the RAYTRACING keyword line 5 position 1 value to be an integer > 0 corresponding to the number of emission ray angles to compute, see Section 3.1.12). The .fpt file is written when the full extent of the sonic boom

carpet is requested (i.e., setting RAYTRACING keyword line 5 position 1 value to 0). A snippet of the main input file that invokes the Enhaced Burgers solver is shown in Figure **3-2**.

2) It creates supplemental output for subsequent post processing using the Legacy Burgers solver via the PCBurg or HeadlessBurgers modules for a single ray and prompts FOBoom to produce the additional files .age and .ssg. It is recommended that humidity data be provided in the atmosphere file, see Section 3.1.9. No further input data beyond the BURGERS keyword is required.
3) If the BURGERS keyword is not invoked, the default Lossless Burgers solver is used. This solver ignores the effects of atmospheric absorption.

If no humidity data are supplied in the atmosphere file (Section 3.1.9), a default value of 50% constant relative humidity will be used for the atmospheric profile for both BURGERS options. Note that the RAYTRACING keyword controls, which azimuth angles are written to the .age and .ssg files, while the BURGERS keyword is used to prompt the generation of these files.

Table 3-3 BURGERS keyword format description – Option 1: Enhanced Burgers solver.

Line	Position	Variable Type	Variable Name	Description
1	1	integer	step size code	Desired step size to be used in the Enhanced Burgers solution. The step size options of 1, 2, and 3 correspond to 200, 600, and 1000 ft along the ray, respectively. The larger the number, the larger the step size.[8] These step sizes may change in future PCBoom versions.
1	2	real	Sampling frequency	Minimum sampling frequency (e.g., 30e3 or 30000). FOBoom will determine the sampling frequency closest to what is requested that results in efficient calculation.

Note: For N-waves such as those generated by F-18 aircraft, a good compromise between computational speed and accuracy is to use “2” for the step size and at least 20 kHz for the sampling frequency.

```
CASENAME
F18LevEnhBurg
BURGERS
 2 50e3
ATMOS
ATT
USSTDANSI.ATT

...snip...
```

Figure 3-2 An example of the main input file invoking the Enhanced Burgers solver.

3.1.3 KZKFILTER_NWAVE

The KZKFILTER_NWAVE keyword invokes the application of a set of KZK filters for N-waves on a waveform generated by the Enhanced Burgers solver to include precalculated effects of turbulence on sonic booms. The KZK filters are finite-impulse response turbulence filters that have been formulated using a KZK nonlinear parabolic equation solver. The output waveform of the Enhanced Burgers solver is

[8] Lonzaga, J. B. "Recent Enhancements to NASA’s PCBoom Sonic Boom Propagation Code." In AIAA Aviation 2019 Forum, p. 3386. 2019.

a clean waveform predicted without turbulence in the ABL (Atmospheric Boundary Layer). This clean waveform is then turbulized by convolving with the turbulence KZK filters to capture the statistical effects of turbulence. The turbulized waveform is written on the .twf output file.

The .twf output file is generated when the KZKFILTER_NWAVE keyword is used in conjunction with the specification of discrete emission azimuthal angles in the RAYTRACING section (see Section 3.1.12) as well as the use of the Enhanced Burgers solver described in Section 3.1.2. The keyword must be followed by a line of real and integer numbers as described in Table 3-4. These numbers are user's inputs prescribing the turbulence condition from which the suitable KZK filter is chosen.

Table 3-4 KZKFILTER_NWAVE keyword format description.

Line	Position	Variable Type	Variable Name	Description
1	1	real	ABL height	Specifies the height (in feet) of the turbulent atmospheric boundary layer (ABL)
1	2	real	Relative humidity	Relative humidity within the ABL from 0 to 100 (in percent)
1	3	integer	Turbulence level	Value is either 1, 2, or 3. 1 is for low level, 2 for medium level, and 3 for high level

A snippet of the main input file that implements the KZK filters for N-waves is shown in Figure 3-3.

```
CASENAME
F18LevEnhBurgKZK
BURGERS
 2 50e3
KZKFILTER_NWAVE
 2000.0 20.0 3
ATMOS
ATT
USSTDANSI.ATT

...snip...
```

Figure 3-3 An Example of the main input file implementing the capability for KZK filters for N-waves.

3.1.4 Keyword HYSTATMO

The HYSTATMO Keyword replaces the user-supplied pressure profile with an interpolated profile in 100 ft increments derived using the hydrostatic equation. No additional input is needed.

The hydrostatic atmosphere model can be triggered by a) use of the HYSTATMO keyword or b) by not including explicit pressure data (through the INLINE or ATT keyword options) in the ATMOS keyword section.

3.1.5 Keyword OUTPUTS

The OUTPUTS keyword tells the program which types of output are desired. If additional outputs are specified on the command line, they will be output by the program as well. This command line capability allows for additional output not specified in the input file, without the requirement that changes be made to the input file.

The options for output within this keyword include SCREEN, U28, UN6, MCO, AGE, TRJOUT and WRITEOUT. Use of the AGE parameter generates both .age and .ssg files and is functionally the equivalent of using the BURGERS keyword. Note that the .out file is always output. Additional output files can be specified within keywords that relate to their specific functionality. WRITEOUT creates a weather output file atmos-out.txt for use by Turbo (or sBOOM).

For a full list of output files, description of their contents, and examples of select files, see Section 3.2. The input format for the OUTPUTS keyword is shown in Table 3-5.

Table 3-5 OUTPUTS keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of input lines to be expected.
2-N	1	Character	Input Type (SCREEN, U28, UN6, MCO, AGE, TRJOUT, WRITEOUT). One keyword per Line. Repeat line 2 for the number of input lines specified on line 1.

3.1.6 Keyword OTT

The OTT keyword triggers the creation of the "over the top" .ott and .ots output files suitable for use in the OTTER post-processor, which allows the user to interactively view the signature evolution along complex 3D ray paths. The rays included in the .ott and .ots files are those specified in the RAYTRACING keyword section, lines 5 and 6. See Section 5.2.3 for more information on the OTTER module. When keyword OTT is in use, the default is to output all trajectory times to the .ott and .ots files. To restrict the trajectory times included in these output files, see the OTTRANGE keyword section.

When OTT keyword is in use, the input atmospheric parameters (temperature and wind tables) may be modified such that the temperature and wind are constant from a short distance above the ground downward to the minimum atmospheric altitude (default = -10,000 Ft.). The reason for this is to avoid inconsistencies in the split ray steps at the ground reflection. The short distance above the ground is the speed of sound at the ground times the TSTEP parameter (default 0.5, or as specified in the RAYTRACING keyword line 5). The actual atmosphere in use by FOBoom is written to the .un6 file.

3.1.7 Keyword OTTRANGE

The OTTRANGE keyword triggers the creation of the "over the top" .ott and .ots output files suitable for use in the OTTER post-processor over a specified range of input trajectory times. The user can interactively view the signature evolution along complex 3D ray paths. The rays included in the .ott and .ots files are those specified in the RAYTRACING keyword section, lines 5 and 6. See Section 5.2.3 for more information on the OTTER module. The input format for the OTTRANGE Keyword is shown in Table 3-6. This keyword may be used to reduce the size of the .ott and .ots files and limit output to only those trajectory times specified by the OTTRANGE keyword parameters.

Table 3-6 OTTRANGE keyword format description.

Line	Input Parameters	Description
1	OTTRANGE ottmin ottmax	The OTTRANGE keyword is followed by the minimum trajectory time and the maximum trajectory time separated by a space between each parameter. The times must be consistent with the times in the input trajectory.

3.1.8 Keyword GROUND

The GROUND keyword is used to create an output ground mode parameter (.gmp) file and triggers subsequent PCBFoot analysis using algorithms, which determine the effects of local ground impedance in the form of flow resistivity on ground boom waveforms. The algorithms are used to replace the simple ground reflection parameter (see RAYTRACING keyword in Section 3.1.12) usually set to 1.9, which is an approximation for pressure doubling. The physically representative algorithm is based on the phase difference between direct and reflected rays for a specified receiver height and with specific ground impedance. Typical examples of the Specific Flow Resistivity ground impedance parameter defined in metric units (Rayls/m) can be found in Table 3-7. The units for Rayls are $N \cdot s/m^3$ (MKS) or $dyne \cdot s/cm^3$ (CGS) and 1 CGS Rayl = 10 MKS Rayl.

Table 3-7 Typical specific flow resistivity values.

Ground Cover	Specific Flow Resistivity (Rayls/m)
Snow Covered Ground	30
Forest Floor	50
Grassy Field	225
Roadside Dirt	650
Packed Sand	1,650
Hard Packed Dirt	3,000
Exposed Dirt/Rock	6,000
Asphalt	30,000
Water	1,000,000

The GROUND keyword must be followed by two real numbers whose formats are shown in Table 3-8.

Table 3-8 GROUND keyword format description.

Line	Position	Variable Type	Description
1	1	Real	Specific Flow Resistivity at the ground Typical Specific Flow Resistivity Values are defined in Table 3-7.
2	1	Real	Receiver height (ft AGL) above local ground

3.1.9 Keyword ATMOS

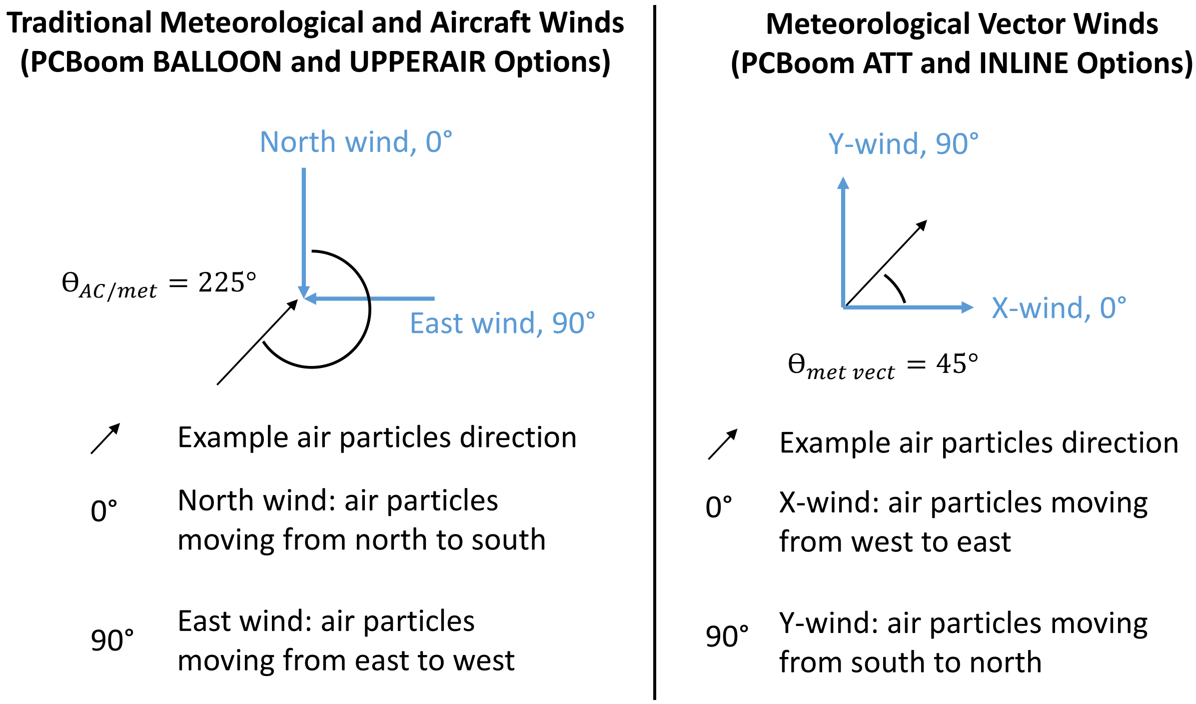
The ATMOS keyword is used to specify the method of input for prescribing atmospheric profiles used for FOBoom propagation. The ATMOS keyword must be followed on the next line by an option. Possible ATMOS keyword options include ATT, BALLOON, INLINE, UNIFORM, and UPPERAIR. Each of these keyword options are explained in the subsections following the keyword format definition.

This keyword must appear after the OUTPUTS keyword and before the TRAJECTORY keyword. Table 3-9 contains the ATMOS keyword definition.

Table 3-9 ATMOS keyword format description.

Line	Position	Variable Type	Description
1	1	Character	Specification of Atmospheric Input Method. This line should be followed by its specified parameters as defined in the following subsections.

The wind conventions used in the following sections are described in Figure 3-4.



Note: PCBoom ATT X-wind is equivalent to meteorological vector u-wind and zonal wind. PCBoom ATT Y-wind is equivalent to meteorological vector v-wind and meridional wind

Figure 3-4 Wind angle conventions.

3.1.9.1 ATT – External Atmosphere .att Input File

The ATT atmospheric input option specifies that the atmospheric profiles are supplied in an external file that follows the ATT input file format. In support of the lossy Burgers solvers (Legacy and Enhanced Burgers), the ATT file may contain humidity data. The ATT input option takes a file with the .att file extension, which contains the atmospheric profile data. In the FOBoom input file, the filename must be followed by the latitude (in decimal degrees) at which the aircraft is located when the acoustic ray is emitted to compute the local effective value of gravity, accounting for centrifugal force of the Earth's rotation.

The format for the ATT keyword option is shown in Table 3-10 while the format for the .att external file is shown in Table 3-11.

Within the external .att file, the first line is reserved for a comment regarding the nature of the file as shown in Figure 3-5. The second line is reserved for the atmospheric pressure on the ground, followed by a variable string and an integer corresponding to the number of pairs of real numbers. The first number in a pair is the altitude in thousands of feet and the second is the temperature in degrees Fahrenheit. The data sequence must be TEMP, WINDX (wind in the x-direction), WINDY (wind in the y-direction) and optionally, HUMIDITY and PRESSURE. See Figure 3-4 for information on the wind direction convention. In the external .att file, keywords are permitted but not required for backward compatibility to prior versions of FOBoom. The legacy external .att file format without keywords is shown in Table 3-12.

Table 3-10 ATMOS / External.att keyword format description.

Line	Position	Variable Type	Description
1	1	String	File Name - specifies an external atmosphere file (.att file) containing atmospheric data.
2	1	Float	Latitude in decimal degrees in the format defined in the INLINE input option (Section 3.1.9.3).

Table 3-11 ATMOS / External.att File Format Description.

Line	Position	Variable Type	Description
1	1	String	File Description - specifies the contents of the file. Not used by the program.
2	1	Float	Atmospheric pressure (psf) at the lowest altitude included in the .att file.(i)
3	1	String	Keyword for the atmospheric parameter. Options include: TEMP (deg F), WINDX (ft/s), WINDY (ft/s), HUMIDITY (%RH), PRESSURE (psf) in sections as specified in the INLINE atmosphere description (Section 3.1.9.3).
4	1	Integer	Number of altitudes (N) for which the data exists for the atmospheric parameter specified on line 3.
5-(N+5)	1	Float	Altitude (kft) in ascending order
5-(N+5)	2	Float	Value of the atmospheric parameter in the following units: TEMP (deg F) WINDX (ft/s) WINDY (ft/s) HUMIDITY (%RH) PRESSURE (psf) - optional For more information about the atmospheric parameters, see the INLINE atmosphere description (Section 3.1.9.3).
N+6	1	String	Repeat lines 3-5 but for a different atmospheric parameter (e.g., WINDX)

Note: (i) If the PRESSURE keyword is not specified (see line 3) then the hydrostatic pressure equation will be used to determine the atmospheric pressure at other altitudes in 1000 ft increments (100 ft increments if the HYSTATMO keyword is in use) based on associating this atmospheric pressure with the lowest altitude in the .att file TEMP section.

Table 3-12 ATMOS / External.att file legacy format description.

Line	Position	Variable Type	Description
1	1	String	File Description - Specifies the contents of the file. Not used by the program.
2	1	Float	Atmospheric pressure (psf) at the lowest altitude included in the .att file.(i)
3	1	Integer	Number of altitudes (N) for which the data exists for the atmospheric parameter. Data are entered for the atmospheric parameters in the following order without keyword specification: 1. TEMP 2. WINDX 3. WINDY 4. HUMIDITY 5. PRESSURE- optional
4-(N+4)	1	Float	Altitude (kft) in ascending order
4-(N+4)	2	Float	Value of the atmospheric parameter in the following units: TEMP (deg F) WINDX (ft/s) WINDY (ft/s) HUMIDITY (%RH) PRESSURE (psf) - optional For more information about the atmospheric parameters, see the INLINE atmosphere description (Section 3.1.9.3).
N+5	1	String	Repeat lines 3-4, but for the next atmospheric parameter

Note: (i) If the PRESSURE keyword is not specified (see line 3), then the hydrostatic pressure equation will be used to determine the atmospheric pressure at other altitudes in 1000 ft increments (100 ft increments if the HYSTATMO keyword is in use) based on associating this atmospheric pressure with the lowest altitude in the .att file TEMP section.

```
U.S. Standard Atmosphere, No Winds
2116.
TEMP
41
0. 59.0
1. 55.5
2. 51.9
3. 48.3
4. 44.7
5. 41.1
6. 37.6
7. 34.0
8. 30.5
9. 26.9
10. 23.4
11. 19.8
12. 16.2
13. 12.7
14. 9.1
15. 5.5
16. 2.0
17. -1.6
18. -5.1
19. -8.7
20. -12.3
21. -15.8
22. -19.4
23. -22.9
24. -26.5
25. -30.0
26. -33.6
27. -37.2
28. -40.7
29. -44.3
30. -47.8
31. -51.4
32. -54.9
33. -58.5
34. -62.1
35. -65.6
36. -69.2
37. -69.7
38. -69.7
39. -69.7
80. -69.7
WINDX
0
WINDY
0
HUMIDITY
0
```

```
U.S. Std Atmo, No Winds - Legacy Format
2116.
41
0. 59.0
1. 55.5
2. 51.9
3. 48.3
4. 44.7
5. 41.1
6. 37.6
7. 34.0
8. 30.5
9. 26.9
10. 23.4
11. 19.8
12. 16.2
13. 12.7
14. 9.1
15. 5.5
16. 2.0
17. -1.6
18. -5.1
19. -8.7
20. -12.3
21. -15.8
22. -19.4
23. -22.9
24. -26.5
25. -30.0
26. -33.6
27. -37.2
28. -40.7
29. -44.3
30. -47.8
31. -51.4
32. -54.9
33. -58.5
34. -62.1
35. -65.6
36. -69.2
37. -69.7
38. -69.7
39. -69.7
80. -69.7
0
0
0
```

Figure 3-5 Example external atmosphere (.att) file in current and legacy formats.

3.1.9.2 BALLOON – Rawindsonde Upper Air Profile

The BALLOON atmospheric input option takes a single file name and latitude in decimal degrees as inputs. The external BALLOON input specification is in the format of a Rawindsonde upper air profile file. See Figure 3-4 for information on the wind direction convention. Table 3-13 contains an input format description for this atmospheric input option, and Figure 3-6 contains a sample input file.

Table 3-13 ATMOS / BALLOON keyword format description.

Line	Position	Variable Type	Description
1	1	String	File Name - Specifies an external Rawindsonde upper air profile file to be used to input atmospheric data.
2	1	Float	Latitude in decimal degrees. Defined in the INLINE input option (Section 3.1.9.3).

```
GP022401204
TEST NBR 00171
W9000 GPS
EDWARDS AFB, CA
1100Z 28 AUG 05

 ALT   DIR  SPD  SHR TEMP   DPT  PRESS   RH ABHUM DENSITY I/R V/S VPS  PW
GEOMFT DEG  KTS /SEC DEG C DEG C  MBS   PCT G/M3  G/M3     N  KTS MBS  MM

 2372  220  5.1 .000 24.6  7.3  928.00  33 7.43 1081.27  285 674 10.21 0
 2500  237  9.9 .070 25.9  3.8  923.92  24 5.80 1072.96  273 675 8.00  0
 3000  273 21.2 .049 28.3  3.9  908.10  21 5.81 1045.93  267 678 8.08  1
 3500  291 16.2 .026 27.6  1.7  892.62  19 4.97 1030.83  259 677 6.90  2
 4000  257  7.8 .036 27.7 -1.2  877.33  15 4.02 1013.43  249 677 5.58  3

 … snip …

63000 123 20.4 .007 -69.4 -96.1  66.19  1 0.00 113.17 25 556 0.00 5
TERMINATION    63716 GEOPFT 19421 GEOPM  63.0 MBS
TROPOPAUSE  52017 FEET  114.80 MB -72.4 C -98.2 C

MANDATORY LEVELS
GEOPFT DIR KTS TEMP  DPT PRESS  RH

 2464  227  5  25.3  3.3  925.0 24
 4915  300  7  28.8 -20.6 850.0  3
 10423 326  5  14.9 -26.8 700.0  4
 19412 105  1 -6.3  -53.9 500.0  1
 25013 293 17 -17.6 -61.1 400.0  1

 … snip …

SIGNIFICANT LEVELS
GEOMFT DIR KTS TEMP  DPT  PRESS  IR  RH

 2372  220  5  24.6  7.3  928.0  285 33
 2611  250 16  27.2  4.8  920.4  274 24
 3006  273 21  28.3  4.0  907.9  267 21
 4159  236  7  27.3 -2.6  872.5  246 14
 4507  269  2  29.6 -14.2 862.2  229  5
 12469 67  12  10.1 -33.3 650.2  179  2
 16069 154  4  3.5  -47.8 568.9  160  1

 … snip …

TERMINATION
999 999
NNNN
```

Figure 3-6 Example rawindsonde balloon file.

3.1.9.3 INLINE – Inline Atmosphere Specification

The INLINE atmospheric input option causes the program to expect multiple sections within the FOBoom input file including TEMP, WINDX, WINDY, HUMIDITY and (optionally) PRESSURE. It is recommended to include these inputs directly after the INLINE keyword. The TEMP, WINDX, WINDY, HUMIDITY and PRESSURE data can appear in any order within the INLINE block of inputs, so long as these section headers are present.

The base input required for the INLINE keyword appears in Table 3-14, with tables following it containing the input specifications for TEMP, WINDX, WINDY, HUMIDITY and PRESSURE input as well as descriptions of these inputs.

The required inputs for the INLINE option are atmospheric pressure at the ground and latitude in decimal degrees. If the BURGERS keyword is in use or if the PCBurg/HeadlessBurgers modules are to be used, relative humidity data (%) should be specified in the input file using the HUMIDITY portion of the INLINE atmospheric input. If the HUMIDITY is not specified, a default uniform 50% relative humidity is assumed. The number of values for TEMP, WINDX, WINDY, and HUMIDITY need not correspond to one another and the altitudes for the various data sections may also differ.

Atmospheric pressure (units of pounds per square foot) must be defined at the atmospheric ground altitude. The atmospheric ground altitude corresponds to the altitude of the first point in the atmosphere definition. Altitudes are defined in terms of mean sea level (ft MSL). Note that the physical ground for signature output does not have to correspond to the atmospheric ground. It is common to run FOBoom for a location with physical ground altitude different from the altitude where the atmosphere is defined. This can happen if the ground altitude of the meteorological balloon launch location is not the same ground altitude at points of interest for which waveforms are to be computed. Latitude is used to compute the local effective value of gravity, accounting for centrifugal force of the earth's rotation.

Table 3-14 ATMOS / INLINE keyword format description.

Line	Position	Variable Type	Description
1	1	Float	Atmospheric pressure (psf) at the lowest altitude included in the TEMP option, see Section 3.1.9.3.1.(i)
	2	Float	Latitude in decimal degrees.

Note: (i) If the PRESSURE keyword is not specified (see line 3), then the hydrostatic pressure equation will be used to determine the atmospheric pressure at other altitudes in 1000 ft increments (100 ft increments if the HYSTATMO keyword is in use) based on associating this atmospheric pressure with the lowest altitude in the .att file TEMP section.

3.1.9.3.1 INLINE / TEMP Input Specification

The Temp option is used to input temperature information within the INLINE input format. The TEMP keyword should be followed by a value specifying the number of temperature pairs for altitude and temperature. Altitude should be specified in thousands of feet, MSL and temperature should be specified in degrees Fahrenheit. The input specification for the TEMP input is shown in Table 3-15. Altitude and temperature pairs should run from lowest altitude to highest. Additionally, the first altitude of the TEMP data input set must correspond to the ground altitude used for pressure, as specified on line 1 of the INLINE input description (Table 3-14).

Table 3-15 ATMOS / INLINE/ TEMP keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of temperature and altitude pairs to follow.
2-(N+1)	1 2	Float Float	Altitude (kft MSL). Temperature (degrees F). Repeat line 2 for the number of lines specified on line 1.

3.1.9.3.2 INLINE / WINDX Input Specification

The WINDX option is used to specify the X-component of wind speed (ft/s) at one or more altitudes. The x-component of the wind is to be given in the engineering vector sense rather than the traditional meteorological sense, and should contain data concerning the direction the wind is blowing toward. For example, an air particle moving from west to east has a positive value for X-wind. X-wind corresponds to vector u-wind and zonal wind in meteorological literature. Wind speeds should be given in pairs along with an altitude (ft MSL) for that specific wind speed. The wind angle convention is shown in Figure 3-4. If no wind is to be specified, it is acceptable to set the number of pairs to be used within the WINDX section to 0 to specify that no x-component will be specified for the wind. Table 3-16 defines the WINDX input format.

Table 3-16 ATMOS / INLINE/ WINDX keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of wind x-component and altitude pairs to follow. If no WINDX pairs are to be used, set to 0.
2-(N+1)	1 2	Float Float	Altitude. (kft. MSL) X-component of the wind (ft/s). Repeat line 2 for the number of lines specified on line 1.

3.1.9.3.3 INLINE / WINDY Input Specification

The WINDY input is used to specify the Y-component of wind speed (ft/s) at one or more altitudes. The y-component of the wind is to be given in the engineering vector sense rather than the traditional meteorological sense, and should contain data concerning the direction the wind is blowing toward. For example, an air particle moving from south to north has a positive value for Y-wind. Y-wind corresponds to vector v-wind and meridional wind in meteorological literature. Wind speeds should be given in pairs along with an altitude for that specific wind speed. The wind angle convention is shown in Figure 3-4. If no wind is to be specified, it is acceptable to set the number of pairs to be used within the WINDY section to 0 to specify that no y-component will be specified for the wind. Input values for the WINDY section should run from the lowest altitude to the highest. Table 3-17 defines the WINDY input format.

Table 3-17 ATMOS / INLINE/ WINDY keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of wind y-component and altitude pairs to follow. If no WINDY pairs are to be used, set to 0.
2-(N+1)	1 2	Float Float	Altitude. (kft MSL) Y-component of the wind (ft/s). Repeat line 2 for the number of lines specified on line 1.

3.1.9.3.4 INLINE / HUMIDITY Input Specification

The HUMIDITY option is used for the specification of humidity data and is recommended if any of the Burgers post-processors are to be used. Humidity should be input into the program as relative humidity, and must specify at least 2 altitudes with humidity data. Humidity data input format is shown in Table 3-18. If no humidity data is entered, a default uniform value of 50% RH is assumed.

Table 3-18 ATMOS / INLINE/ HUMIDITY keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of humidity and altitude pairs to follow. If no HUMIDITY pairs are to be used, set to 0.
2-(N+1)	1 2	Float Float	Altitude in thousands of feet. (kft MSL) Relative Humidity (%). Repeat line 2 for the number of lines specified on line 1.

3.1.9.3.5 INLINE / PRESSURE Input Specification

The PRESSURE option is used to input pressure information within the INLINE input format. The PRESSURE keyword should be followed on the next line by a value specifying the number of pressure and altitude pairs, which the user will be supplying to the program in the input file. Altitudes should be specified in thousands of feet and pressure should be specified in pounds per square foot. The input specification for the PRESSURE input is shown in Table 3-19. Altitude and pressure pairs should run from lowest altitude to highest. In addition, if the number of values for pressure is set to zero, the program will automatically create a stratified atmospheric profile of pressures based on the temperature and altitude pairs specified by the user and the pressure at the atmospheric ground (lowest altitude in the TEMP input, see Section 3.1.9.3.1).

Table 3-19 ATMOS / INLINE/ PRESSURE keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of pressure and altitude pairs to follow. If no PRESSURE pairs are to be supplied, set to 0.
2-(N+1)	1 2	Float Float	Altitude in thousands of feet. (kft MSL) Pressure (psf) Repeat line 2 for the number of lines specified on line 1.

3.1.9.4 UNIFORM – Uniform Atmosphere

Uniform atmosphere can also be used within FOBoom through the use of the UNIFORM atmospheric input option. When using a uniform atmosphere, an external ATT file or INLINE constant temperature should also be specified. This is a feature from the original Thomas program. To specify an external ATT file containing a constant temperature, EXTERN should be specified on the line following the UNIFORM keyword. For an INLINE temperature profile, INLINE should be specified following the UNIFORM keyword. The input format for the UNIFORM keyword is shown in Table 3-20.

Table 3-20 ATMOS / INLINE/ UNIFORM keyword format description.

Line	Position	Variable Type	Description
1	1	Character	Selection of INLINE or EXTERN specification for temperature data.
2	1	Float	Atmospheric pressure (psf) at the lowest altitude included in the TEMP input, see Section 3.1.9.3.1.(i)
3.A	1	Character	.att file name to be used with EXTERN specification.
3.B	1	Character	INLINE specification TEMP keyword followed by TEMP data (Table 3-15).

Note: (i) If the PRESSURE keyword is not specified (see line 3), then the hydrostatic pressure equation will be used to determine the atmospheric pressure at other altitudes in 1000 ft increments (100 ft increments if the HYSTATMO keyword is in use) based on associating this atmospheric pressure with the lowest altitude in the .att file TEMP section.

3.1.9.5 UPPERAIR – Multiday Upper Air File

A multiday external upper air profile file, with specification of data and profile time, may be used to define the atmosphere in PCBoom. Upper air profiles in the appropriate format are available from: http://weather.uwyo.edu/upperair/sounding.html.

A range of dates must be specified and the generated web page saved as ASCII text. The file name is then specified within the UPPERAIR input as well as a time and date, which reside within the file. See Figure 3-4 for information on the wind direction convention. The input format for UPPERAIR is shown in Table 3-21, and a sample upper air file is shown in Figure 3-7.

Table 3-21 ATMOS / INLINE/ UPPERAIR keyword format description.

Line	Column	Max Length	Variable Name	Description
1	1-80	80	—	File Name of the upper air file to be used.
2	1-10	10	ALAT	Latitude in decimal degrees. Defined in the INLINE input option section (Section 3.1.9.3). Line 2 must correspond to a sounding contained within the specified upper air file.
3	1-2 4-5	2 2	TT DD	Time to be used from the upper air file. (Generally 00 or 12) Day to be used from the upper air file.

```
72403 IAD Sterling Observations at 00Z 01 Jan 2007

---------------------------------------------------------------------------
  PRES  HGHT  TEMP  DWPT  RELH  MIXR  DRCT  SKNT  THTA  THTE  THTV
  hPa   m   C     %  g/kg  deg  knot   K   K   K
---------------------------------------------------------------------------
 1015.0   88  7.8  -0.2   57  3.73  150   10 279.8 290.3 280.4
 1000.0  212  6.8  -0.2   61  3.79  145   13 279.9 290.7 280.6
 988.7  305  6.0  -0.3   64  3.79  150   12 280.1 290.8 280.7
 983.0  353  5.6  -0.4   65  3.80  152   13 280.1 290.9 280.8
 952.4  610  3.5  1.1   84  4.37  160   17 280.5 292.8 281.2
 946.0  665  3.0  1.4   89  4.50  166   19 280.6 293.2 281.3

… snip …

  13.2 28956 -54.3 -87.1   1  0.02   55   13 752.8 753.0 752.8
  12.7 29227 -53.9 -86.9   1  0.02   37   17 763.3 763.5 763.3
  12.6 29261 -53.9 -86.9   1  0.02   35   17 764.4 764.6 764.4
  10.4 30480 -55.0 -87.1   1  0.02  100   13 803.3 803.5 803.3
  10.2 30630 -55.1 -87.1   1  0.02        808.2 808.5 808.2


  Station information and sounding indices

             Station identifier: IAD
               Station number: 72403
              Observation time: 070101/0000
              Station latitude: 38.97
             Station longitude: -77.47
             Station elevation: 88.0
              Showalter index: 6.31
                Lifted index: 22.88
  LIFT computed using virtual temperature: 23.21
                SWEAT index: 257.17
                  K index: 22.20
             Cross totals index: 19.40
           Vertical totals index: 20.30
            Totals totals index: 39.70
   Convective Available Potential Energy: 0.00
       CAPE using virtual temperature: 0.00
           Convective Inhibition: 0.00
       CINS using virtual temperature: 0.00
           Bulk Richardson Number: 0.00
     Bulk Richardson Number using CAPV: 0.00
 Temp [K] of the Lifted Condensation Level: 271.93
Pres [hPa] of the Lifted Condensation Level: 901.58
   Mean mixed layer potential temperature: 280.11
       Mean mixed layer mixing ratio: 3.91
       1000 hPa to 500 hPa thickness: 5548.00
Precipitable water [mm] for entire sounding: 27.26



 72403 IAD Sterling Observations at 12Z 01 Jan 2007

---------------------------------------------------------------------------
  PRES  HGHT  TEMP  DWPT  RELH  MIXR  DRCT  SKNT  THTA  THTE  THTV
  hPa   m   C   C   %  g/kg  deg  knot   K   K   K
---------------------------------------------------------------------------
 1003.0   88  8.2  7.6   96  6.57   0   0 281.1 299.3 282.2
 1000.0  110  8.2  7.7   97  6.63  185   5 281.4 299.7 282.5
 976.9  305  11.2  11.0   98  8.50  215   14 286.3 310.1 287.8
… snip …
```

Figure 3-7 Example multiday upper air profile file (sounding.txt).

3.1.10 Keyword ALTITUDES

The ALTITUDE keyword is required and is used to specify the number of altitudes at which a sonic boom waveform is output. The last altitude is the geometric ground (if TERRAIN keyword is not in use). If the number of altitudes specified is 1, a boom signature is only output at the ground. In this case, a line type 2 must follow the number of altitudes line. Altitudes should be entered in the table from highest altitude point to lowest. The lowest altitude is considered the ground altitude.

Table 3-22 contains a listing of the ALTITUDES keyword input format. The ALTITUDES keyword position within the input file can be variable, however, it must be placed between the OUTPUTS and TRAJECTORY keywords within the input file. If using the TERRAIN keyword, an output altitude of 0.0 signals FOBoom to use the local ground altitude. All altitudes are defined in terms of Mean Sea Level (MSL).

Table 3-22 ALTITUDES keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of altitudes at which to output sonic boom signature, including ground altitude (N)
2-(N+1)	1	Float	Output altitude (ft MSL) in descending order, starting with the highest altitude and ending with the lowest. The last value in the list is considered the ground altitude.

3.1.11 Keyword TERRAIN

The TERRAIN keyword can be used to specify an external binary file containing terrain data to be used by PCBoom. The TERRAIN keyword takes a single argument, which is used to specify the external file that contains the desired terrain data. The input format for the TERRAIN keyword, as well as the data format for the binary terrain data file, are supplied in Tables Table 3-23 and Table 3-24, respectively. An example of how to write a terrain file using MATLAB[9] is shown in Figure 3-8.

Table 3-23 TERRAIN keyword format description.

Line	Position	Variable Type	Description
1	1	String	Name of terrain file to be used.

Table 3-24 TERRAIN Binary Data File Format Description.

Position (Number of Bytes)	Variable Type	Description
1-64	String	Text
65-68	Real	Minimum altitude [Unused]
69-72	Real	Maximum altitude [Unused]
73-76	Real	Lower left corner X
77-80	Real	Lower left corner Y
81-84	Real	Grid interval per unit distance in X direction
85-88	Real	Grid interval per unit distance in Y direction
89-92	Integer	Number of values in X direction
93-96	Integer	Number of values in Y direction
97-N	Real	Grid contents (N = X*Y*4+96)[(i)]

Note: (i) When writing this array to the terrain file, NX should be the outermost loop, NY should be the inner loop.

[9] https://www.mathworks.com/products/matlab.html

```
terrain_file_name = 'cliff.dt0';
terrain_text = blanks(64);
terrain_text(1:22) = 'this is a steep cliff!';
min_alt = 1e3;%feet
max_alt = 1e4;%feet
lower_left_X = -106;%longitude deg E
lower_left_Y = 36;%latitude deg N
grid_interval_X = 120;%points per longitude deg
grid_interval_Y = 120;%points per latitude deg
NX = 241;
NY = 181;
grid_contents = ones(NX,NY).*min_alt;%feet
grid_contents(100:end,:) = max_alt;%feet

fid = fopen(terrain_file_name,'w');

    fwrite(fid,terrain_text.','char',0,'l');
    fwrite(fid,min_alt,'real*4',0,'l');
    fwrite(fid,max_alt,'real*4',0,'l');
    fwrite(fid,lower_left_X,'real*4',0,'l');
    fwrite(fid,lower_left_Y,'real*4',0,'l');
    fwrite(fid,grid_interval_X,'real*4',0,'l');
    fwrite(fid,grid_interval_Y,'real*4',0,'l');
    fwrite(fid,NX,'int',0,'l');
    fwrite(fid,NY,'int',0,'l');
    fwrite(fid,grid_contents,'real*4',0,'l');

fclose(fid);

figure
surf(grid_contents.','EdgeAlpha',.1)
xlabel('x')
ylabel('y')
zlabel('ft')
```

Figure 3-8 MATLAB script to write a terrain file.

3.1.12 Keyword RAYTRACING

The RAYTRACING keyword is optional. If the RAYTRACING keyword is not included in the FOBoom input file, default values described in the table below are used for the various RAYTRACING parameters.
In the Nonlossy Burgers solver and Legacy Burgers solver, ray tracing continues below the ground, to altitude ZBELOW. This is needed to properly trace caustics near the ground (the lowest altitude defined in the ALTITUDES keyword, Section 3.1.10), and is typically 2000 feet below the ground (however, ATMOS options UPPERAIR and BALLOON extrapolate to 10,000 feet below the ground).

ZMAX and ZMIN are the bracketing altitudes for which foci should be considered. If a focus occurs below ZMIN, the boom is taken to be that of the ground waveform and the below-ground focus is not considered. If a focus occurs above ZMAX, the post-focus boom at the ground will be ignored and the carpet waveform will be used. These altitudes are especially important for LNTE analyses. Note that if the enhanced Burgers is invoked and a focus is predicted, it will not produce a .wfm output for the focused rays.

In addition, RAYTRACING contains values to set other key propagation features, such as the azimuthal acoustic emission angles over which to compute the sonic boom waveforms and the numerical integration parameters for the computed ray tubes used in the Nonlossy and Legacy Burgers solvers. The Enhanced Burgers solver does not use these ray tubes and is, therefore, independent of these integration parameters. However, it is recommended to set the values of these parameters to avoid any unintended numerical errors.

The coordinate system used in this section is shown in Figure 3-9. This convention is also used in the WCON module.

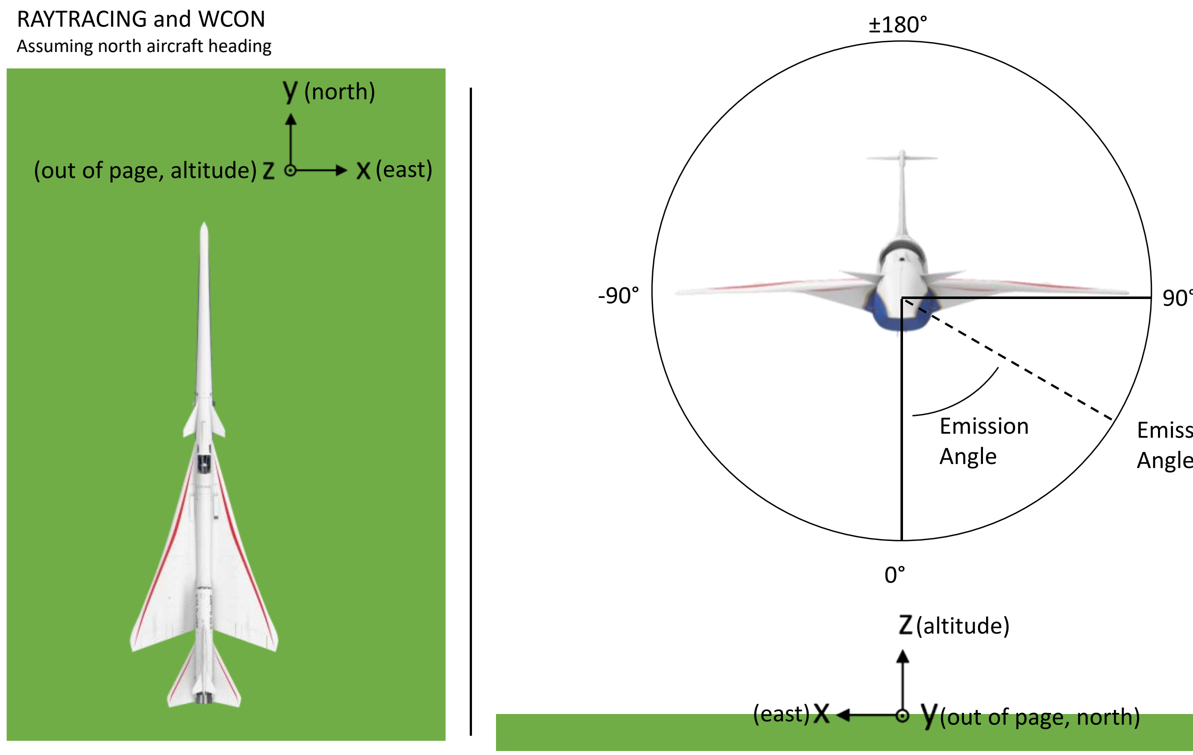


Figure 3-9 RAYTRACING coordinate axis definition.

Table 3-25 lists the parameters expected by the RAYTRACING keyword. If the number of azimuths at which a boom should be computed is greater than 0, line 6.A should be used. If no azimuths are specified for boom computation, line 6.B should instead be used.

Table 3-25 RAYTRACING keyword format description.

Line	Position	Variable Type	Description
1	1	Character	Selector for ray tracing mode. Options include: LEGACY: Legacy Mode (Thomas) SCHULELLIPSE: Schulten Ellipsoidal Earth, WGS84 SCHULSPHERE: Schulten Spherical Earth SCHULFLAT: Schulten Flat Earth SBOOM201: Lossy Burgers sBOOM post-processor version 2.01 with high resolution (250kHz) SBOOMMED201: Lossy Burgers sBOOM post-processor version 2.01 with medium resolution (125kHz) SBOOMLOW201: Lossy Burgers sBOOM post-processor version 2.01 with low resolution (51kHz) SBOOM284: Lossy Burgers sBOOM post-processor version 2.84 with high resolution (250kHz) SBOOMMED284: Lossy Burgers sBOOM post-processor version 2.84 with medium resolution (125kHz) SBOOMLOW284: Lossy Burgers sBOOM post-processor version 2.84 with low resolution (51kHz) [Default: LEGACY]
2	1 2 3	Float Float Float	Distance below ground altitude at which raytracing stops, ZBELOW [Default: -2000 ft.] Distance above flight altitude to consider a focus, ZMAX(i) [Default: 100,000 ft MSL.] Altitude below which foci are ignored, ZMIN (ii) [Default: 1500 ft below ground.]
3	1 2	Float Float	Ground Reflection Factor. 1.9 is standard. Use 1.0 if free field boom is desired, REFL. [Default: 1.9] ROVERL: Ray tracing begins at distance R0 from the aircraft. ROVERL = R0 /(Aircraft Length). [Default: 1.0)] Note that the ROVERL parameter in the Raytracing keyword input is overridden by R/L in the optional Cylinder keyword input (Section 3.1.13.2)
4(iii)	1 2 3	Float Float Float	Azimuth angle increment for the four corners of the ray tube, DPHI deg [Default: 0.5] Trajectory increment for caustics, DSTRAJ ft. [Default: 500] Time step integration along a ray, TSTEP. [Default: 0.5]
5	1	Integer	Number of azimuths at which to compute the boom, NPHIS [Default: 0, full extent of the sonic boom carpet]
6.A(iv)	1	Float	Azimuth angle (PHI) values (degrees) for propagation calculations. Values may be delimited over one or several lines as needed to provide NPHIS data points. Used if NPHIS > 0
6.B(iv)	1	Integer	Azimuthal increment in degrees for propagation calculations. Must be a whole number. Used if NPHIS = 0 [Default: 5]

Notes: (i) If focal zone detail (i.e., the post-focus u-wave) is not of interest, a typical value of ZMAX is 5000 feet above the ground. ZMAX should normally be set to a large number, above the flight altitude or highest altitude of concern if using the OTT keyword.
(ii) A typical value of ZMIN is 1500 feet below the ground.
(iii) In general, the default parameters that control the raytracing and calculation of the ray tube areas may be used, but for some special situations (i.e., over the top or focusing analysis), the Line 4 parameters might need to be changed. DPHI controls the azimuthal differential ray angles for the 4 corners of the ray tube. DSTRAJ is the trajectory point increment for auxiliary tubes (feet) and may affect computation of the caustic curvature and hence focus parameters. TSTEP is the integration along a ray which might need to be increased if insufficient array elements are available for very long ray paths as might occur during over the top analyses.
(iv) Either 6.A or 6.B should be used based on the desired analysis behavior.

3.1.13 Keyword MODE

The MODE keyword is used to define and describe the noise source and is required in the FOBoom input file along with information that is dependent on the specified mode. The location of these data within the FOBoom input file however can vary, and it may be defined anywhere within the input file between the CASENAME keyword and the TRAJECTORY keyword.

Each mode input type along with their required inputs will be explained in greater detail in the following subsections. Note that for cylinder modes, the arrays are allocated dynamically so the allowable number of points is a function of the available memory unless otherwise noted. The MODE keyword format is given in Table 3-26.

Table 3-26 MODE keyword format description.

Line	Position	Variable Type	Description
1	1	Character	Input Mode Selection. Options are: CARLSON, CFDDPP CYLINDER, CYLINDER_ASYMM, CYLINDERHIRES, CYLINDERM, CYLINDERX, CYLINDERXHIRES, CYLINDERVARYX, FFUNC, THOMAS, TIEGERMAN, or SEEB.

3.1.13.1 CARLSON – Carlson F-Function Mode

The CARLSON keyword is used to generate an N-wave F-function based on Carlson's simplified model.[17] The Carlson input options are introduced below and explained in detail in the following subsections.

- ACNAME: Basic Carlson F-function Mode – equivalent N-wave shapes identified by a lookup of preprogrammed aircraft parameters.
- AXISYMMETRIC: Axisymmetric Shape Factor Mode (also requires specific inputs in the TRAJECTORY keyword section).
- BASIC: Basic Carlson F-function Mode – equivalent N-wave shapes identified by the shape factor curve index number (IUN) and vehicle length and weight.
- LAUNCH: Launch Vehicle Mode – trailing plume effects included in the sonic boom calculations.
- LOOKUP: Shape Factor Table Lookup Mode.

The curve numbers in Table 3-27 are used as inputs in the majority of the modes.

Table 3-27 Carlson shape factor curve numbers.

Curve Number	Description	Shape Factor Curve Index Number (IUN)
1	Large fighter: F101	1
2	Small fighter: F104, F-5	2
3	Medium bomber: B-58, SR-71	3
4	Large bomber: B-70	4
5	Fixed wing fighters: F-15, F-16, F-18	5
6	Variable sweep airplanes: B-1, F-111, F-14	6
7	Concorde	7
8	Shuttle orbiter	8

The information needed for each of the input options for the Carlson mode for vehicle and signature specification are given in more detail below. The input format for the CARLSON keyword is shown in Table 3-28.

Table 3-28 MODE / CARLSON keyword format description.

Line	Position	Variable Type	Description
1	1	Character	Selection of ACNAME, AXISYMMETRIC, BASIC, LAUNCH, or LOOKUP input method.

3.1.13.1.1 CARLSON / ACNAME

The ACNAME input option is a simplified mode that allows the lookup of predetermined aircraft parameters based on the name of the aircraft. The ACNAME input option, optionally allows for changes to be made to the curve used, weight of the vehicle, vehicle length, thrust, and drag. At a minimum, however, the vehicle name must be specified. It should also be noted that while not all of the optional parameters need to be specified, they are read in by the program in a fixed format and must conform to the column numbers specified in the Table. Preprogrammed Carlson vehicle names as well as their equivalent input parameters are shown in Table 3-29. The input format for the ACNAME variation of the Carlson F-Function method is shown in Table 3-30.

Table 3-29 Preprogrammed Carlson F-function mode vehicle names and parameters.

Vehicle Name*	IUN	WT (klb)	AL (ft)	THRUST	DRAG
B-1	6	450.0	147	0	0
B-58	3	79.4	98	0	0
B-70	4	495.0	200	0	0
F-4	1	45.0	60	0	0
F-5	2	20.0	47	0	0
F-14	6	55.0	62	0	0
F-15	5	47.0	64	0	0
F-16	5	25.2	48	0	0
F-18	5	39.4	56	0	0
F-20	2	18.0	47	0	0
F-22	5	48.0	67	0	0
F-101	1	37.3	67	0	0
F-104	2	26.5	55	0	0
F-111	6	76.5	74	0	0
SR-71	3	90.0	107	0	0
T-38	2	20.0	47	0	0
Tornado	6	35.0	57	0	0
Concorde	7	387.0	190	0	0
Shuttle	8	187.0	121	0	0
Titan	13	2000	183.4	2500	500

*Spelling and capitalization of the vehicle names must match the Vehicle Name column exactly, otherwise F-15 aircraft is used by default.

Table 3-30 MODE / CARLSON / ACNAME keyword format description.

Line	Column	Max Length	Variable Name	Description
1	1-8	8	actype	Vehicle name corresponding to one of the pre-programmed vehicles in Table 3-29.
	13-17	5	IUN	IUN specification of a different Carlson shape factor curve index number from Table 3-27. (Optional)
	18-27	10	AL	Vehicle length specification (ft). (Optional)
	28-37	10	WT	Vehicle weight specification (klb). (Optional)
	38-47	10	THR	Vehicle Thrust (klb). (Optional)
	48-57	10	DRAG	Vehicle Drag (klb). (Optional)

3.1.13.1.2 CARLSON / AXISYMMETRIC

The AXISYMMETRIC input option is used to allow an axisymmetric shape factor to be supplied directly by the user as part of the TRAJECTORY. This shape factor can be updated via a NEWLOAD data line, as specified in the TRAJECTORY keyword section (Section 3.1.15). This feature can be used to dictate where in the trajectory the source characteristics change due to staging or firing of rockets. Table 3-31 shows the input format for the AXISYMMETRIC variation of the CARLSON vehicle and signature input.

Table 3-31 MODE / CARLSON / AXISYMMETRIC keyword format description.

Line	Position	Variable Type	Description
1	1	Float	Vehicle length (ft)
	2	Float	Vehicle weight (klb)
	3	Float	Vehicle thrust (rocket thrust) see LAUNCH (klb)
	4	Float	Vehicle drag (plume drag) see LAUNCH (klb)
	5	Float	FKSNEW, User Input Shape Factor (IUN)

3.1.13.1.3 CARLSON / BASIC

The BASIC input option is used to specify a predefined Carlson curve for use within FOBoom. The F-function is taken to be Carlson's simplified equivalent N-wave shape. The number of points in the signature (NX), the nondimensional pressure differential relative to the freestream pressure (denoted by symbol dp/p_{inf} or variable name DPP) and axial distance (X) are not read in from the FOBoom input file but are predefined within FOBoom. Supporting input data and input format are described in Table 3-32.

Table 3-32 MODE / CARLSON / BASIC keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Curve to be used (IUN in Table 3-27). 1-8 are valid values.
	2	Float	Vehicle length (ft)
	3	Float	Vehicle weight (klb)

3.1.13.1.4 CARLSON / LAUNCH

The LAUNCH input option triggers the computation of the sonic boom signature effects due to a trailing plume. The F-function for the vehicle body is Carlson's simplified equivalent N-wave shape. The additional F-function for the plume is based on a combination of Tiegerman's hypersonic blunt body model[27] and Carlson's equivalent N-wave. The number of points in the signature (NX), the non-dimensional pressure differential relative to the freestream pressure (dp/p_{inf} or DPP) and axial distance (X) are not read in from the FOBoom input file but are predefined within FOBoom. Supporting input data and input format are described in Table 3-33.

Table 3-33 MODE / CARLSON / LAUNCH keyword format description.

Line	Position	Variable Type	Description
1	1	Float	Vehicle length (ft)
	2	Float	Vehicle weight (klbs)
	3	Float	Vehicle thrust (rocket thrust) (klb)
	4	Float	Vehicle drag (plume drag) [(i)] (klb)
2	1	Integer	IUN curve number to be used (Table 3-27)
3	1	Character	File Name for Plume output file. Blank or “nul” if output is not desired[(ii)]

Notes: (i) Generally about 20% of thrust for most current large launch vehicles
(ii) This file will receive data needed to interface to H.K. Cheng's (University of Southern California) underwater penetration model[75]. If this file is not needed for further computation, include a blank line.

3.1.13.1.5 CARLSON / LOOKUP

The LOOKUP option uses a shape factor table lookup, which is defined in a file supplied by the user, typically developed from wind tunnel or CFD data. It is typically used for lifting body entry vehicles. This option requires that shape factor be provided from a table lookup as a function of alpha (angle of attack) and phi (azimuth).

The file with the shape factor lookup table must be in the same directory as the FOBoom input file, and have the following structure:

- NALPH, the number of alphas,
- The ALPHA values, small to large,
- Table of shapes (NALPH, 19), corresponding to shape factors at each alpha at azimuths from 0 to 180 degrees in 10-degree increments.

The input format is outlined in Table 3-34.

Table 3-34 MODE / CARLSON / LOOKUP keyword format description.

Line	Position	Variable Type	Description
1	1	Float	Vehicle length (ft)
	2	Float	Vehicle weight (klbs)
	3	Float	Vehicle thrust (rocket thrust) (klb)
	4	Float	Vehicle drag (plume drag) (klb)
	5	Float	Vehicle alpha (angle of attack)
2	1	Character	File Name for shape factor lookup. (FILENAME)

3.1.13.2 CFDDPP – Computational Fluid Dynamics dp/p_{inf}

The CFDDPP mode keyword specifies that an initial signature is written in a .dpp input file containing pairs of axial distance (X) measured along the body axis, nose to tail, and values of the nondimensional pressure differential relative to the freestream pressure (dp/p_{inf} or DPP). This format is compatible with the typical output file format of the NASA LAVA CFD code[10] but is applicable only to one azimuth (defined in the RAYTRACING keyword, see Section 3.1.12) and flight condition. Note that the distance from the aircraft to the CFD signature divided by the aircraft length (ROVERL) should be specified in the RAYTRACING keyword (Section 3.1.12).

The input definition is shown in Table 3-35, and the external file format is described in Table 3-36. Example external files are shown in Figure 3-10 and Figure 3-11.

Table 3-35 MODE / CFDDPP keyword format description (external .dpp file).

Line	Position	Variable Type	Description
1	1	String	"FILE" to specify an external file
2	1	String	File name (with .dpp extension) for external file containing the input pressure data
3	1	Float	Aircraft length (in, ft, or m as defined in the external file)
3	2	Float	Model length (in, ft, or m as defined in the external file)

[10] Kiris, C., et al. "The LAVA computational fluid dynamics solver." In 52nd Aerospace Sciences Meeting, p. 0070. 2014

Table 3-36 CFDDPP external file format description.

Line	Position/ Column	Variable Type	Description
1	Position: 1	String	This line is not read by FOBoom, but can be used for input into programs like TecPlot.[11] Examples include: ZONE T= "Azimuth = 0.000000" or Number of Waveforms = 1
2	Columns: 26-27	String	FOBoom checks to see if "ft" or "me" exists in columns 26-27 in order to convert the units from inches to feet or meters. Additional entries may exist on the line for use in other programs like TecPlot, but FOBoom only looks for the unit specification in columns 26-27. If "ft" or "me" is not specified, inches are assumed. (e.g., variables = "X","dp/p" ft)
3	Columns: 20-25	Character integer	FOBoom looks for the number of points in the signature in columns 20-25. Additional entries may exist on the line for use in other programs like TecPlot, but FOBoom only looks for the number of points in columns 21-25. (e.g., Number of Points = 2209)
4- *NX*	Position: 1 and 2	Float	Specify the axial distance, X (in, ft or m depending on the variables keyword) and dp/p_{inf} Repeat line for the number of points specified on line 3.

```
ZONE T= "Azimuth = 0.000000"
variables = "X","dp/p"   ft
Number of Points =  2209
   2.836060218E+02   0.000000000E+00
   3.336541433E+02  -5.773159728E-14
   3.670716701E+02  -3.752553823E-14
   3.670716704E+02  -3.752553823E-14
   3.670716902E+02  -3.730349363E-14
```

Figure 3-10 Example CFDDPP Keyword File Fragment

```
Number of Waveforms = 1
Pressure signature - inch dpp
Number of Points =  20454
   -0.233822697268116E+03    0.376663056404307E-08
   -0.233719327375425E+03    0.382873257863401E-08
   -0.233615957482733E+03    0.388769048168966E-08
   -0.233512587590042E+03    0.394340198608027E-08
   -0.233409217697350E+03    0.399577410350609E-08
```

Figure 3-11 Example CFDDPP keyword file fragment.

3.1.13.3 CYLINDER – Cylinder Pressure Input Mode

Pressure data defined on a cylinder aligned with the vehicle direction of flight and freestream flow, centered on the aircraft nose, may be used to input source pressure data to PCBoom. This input mode is typically used when obtaining data from computational fluid dynamics solutions. Note that only one side of the vehicle is input as symmetry about the vertical plane is assumed.

[11] Tecplot, Inc. 2008. "Tecplot 360 2008, User's Manual," Bellevue, Washington.

The axial pressure distribution at a finite cylinder radius is used as a starting signature for the sonic boom propagation. This format requires that the axial stations (X values) are the same at each downstream station for all azimuthal angles. This mode utilizes a weighted angle cubic fit around the cylinder at each axial (X) station down the body, and then extracts the pressure value at the desired azimuth. The starting data are not necessarily recovered exactly for matched azimuths. To avoid azimuthal interpolation, use CYLINDERXHIRES (3.1.13.8) or CYLINDERX (3.1.13.7) mode instead.

Table 3-37 MODE / CYLINDER keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of Cylinder files
2	1	Character	Cylinder filename and path (max 255 characters)
3	1	Float	Flight Condition G-load (1.0 = straight & level flight)
4	1	Float	Cylinder Radius normalized by the vehicle length R/L. Note that the ROVERL parameter in the Raytracing keyword input (Section 3.1.12) is overridden by R/L in the Cylinder keyword input.
4	2	Float	Aircraft length, L (ft)

Note: Repeat lines 2 and 3 for the number of cylinders specified on line 1.

```
CYLINDER
8                        !Number of Cylinders
2nHfG.PLT                !Cylinder PLT file
2.5                      !GLoad
Two_G.PLT
2.0
1nHfG.PLT
1.5
OneG.PLT
1.0
HalfG.PLT
0.5
ThirG.PLT
0.33333333333
QuarG.PLT
0.25
TnthG.PLT
0.10
1.0    49.7575           !R/L and Cyl Body Length
```

Figure 3-12 Example CYLINDER keyword file fragment.

The axis system used for the cylinder input.plt file is orthogonal and uses the following convention. The axis system is also shown in Figure 3-13.

+x	Out starboard wing
-x	Out port wing
+y	Vertically up
+z	Axially in the freestream direction

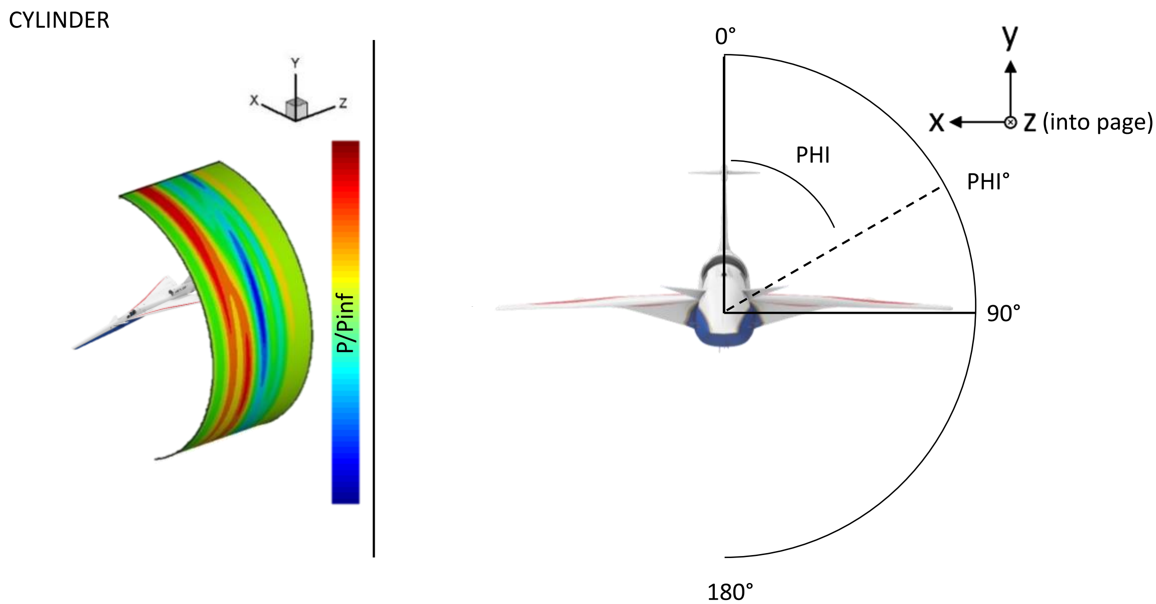


Figure 3-13 CYLINDER coordinate axis definition.

The cylinder inputs are organized into an ascii .plt file shown in Figure 3-14 with the format identified in Table 3-38. This ASCII format is consistent with one input by TecPlot and may be used to visualize the cylinder data as shown in Figure 3-15 and Figure 3-16. Note that the aircraft coordinate system phi angles listed in the example TecPlot file below are in a typical CFD coordinate system with 0° above the aircraft and 180° degrees below the aircraft. This differs from the RAYTRACING coordinate system, which uses azimuth angle 0° undertrack and 180° above the aircraft. PCBoom only extracts three columns of data in the .plt files: the distance along the aircraft whose value increases moving from nose to tail z (ft), the azimuthal angle phi, which is defined differently than the RAYRACING coordinate system, and the ratio of the local pressure to the freestream pressure p/p_{inf}. Note that since $dp = p-p_{inf}$ that $p/p_{inf} = 1+dp/p_{inf}$.

```
TITLE=" QSP F-5E CFD Euler/SBD24b Nose/Mach 1.40/AOA 1.720/Alt 32kft/Cylinder R/L =1.00"
VARIABLES="I" "J" "X(ft)" "Y(ft)" "Z(ft)"     "phi"  "u(fps)"  "v(fps)"  "w(fps)" "dP/Pinf" "dP(psi)"  "P/Pinf"    "Mach"
ZONE I =  91 J = 201
    1    1      .000    48.192    29.895      .00      .000      .010  1380.400    .00002    .00009  1.00002  1.39998
    2    1    -1.736    48.161    29.895     2.00      .000      .010  1380.400    .00002    .00009  1.00002  1.39998
    3    1    -3.470    48.070    29.895     4.00     -.001      .010  1380.400    .00002    .00009  1.00002  1.39998
    4    1    -5.200    47.919    29.895     6.00     -.001      .010  1380.400    .00002    .00008  1.00002  1.39998
    5    1    -6.924    47.708    29.895     8.00     -.001      .010  1380.400    .00002    .00008  1.00002  1.39998
    6    1    -8.639    47.436    29.895    10.00     -.002      .009  1380.401    .00002    .00008  1.00002  1.39999
    7    1   -10.344    47.105    29.895    12.00     -.002      .008  1380.402    .00002    .00007  1.00002  1.39999
    8    1   -12.036    46.714    29.895    14.00     -.002      .008  1380.402    .00002    .00007  1.00002  1.39999
    9    1   -13.713    46.264    29.895    16.00     -.002      .007  1380.403    .00002    .00006  1.00002  1.39999
   10    1   -15.374    45.757    29.895    18.00     -.002      .007  1380.404    .00002    .00006  1.00002  1.39999
   11    1   -17.015    45.191    29.895    20.00     -.002      .006  1380.404    .00001    .00006  1.00001  1.39999
   12    1   -18.637    44.569    29.895    22.00     -.002      .005  1380.405    .00001    .00005  1.00001  1.39999
   13    1   -20.235    43.891    29.895    24.00     -.002      .005  1380.405    .00001    .00005  1.00001  1.39999
   14    1   -21.809    43.157    29.895    26.00     -.002      .004  1380.406    .00001    .00004  1.00001  1.39999
   15    1   -23.356    42.368    29.895    28.00     -.002      .004  1380.406    .00001    .00004  1.00001  1.39999
   16    1   -24.875    41.526    29.895    30.00     -.002      .004  1380.407    .00001    .00004  1.00001  1.39999
   17    1   -26.363    40.632    29.895    32.00     -.002      .003  1380.407    .00001    .00003  1.00001  1.39999
   18    1   -27.820    39.686    29.895    34.00     -.002      .003  1380.407    .00001    .00003  1.00001  1.39999
   19    1   -29.242    38.690    29.895    36.00     -.002      .003  1380.408    .00001    .00003  1.00001  1.40000
   20    1   -30.629    37.645    29.895    38.00     -.002      .003  1380.408    .00001    .00003  1.00001  1.40000
   21    1   -31.979    36.552    29.895    40.00     -.002      .002  1380.408    .00001    .00003  1.00001  1.40000
   22    1   -33.289    35.413    29.895    42.00     -.002      .002  1380.408    .00001    .00003  1.00001  1.40000
... snip ...
```

Figure 3-14 Example cylinder.plt file fragment.

Table 3-38 cylinder.plt file input format description.

Line	Position	Variable Type	Description
1	1	Character*6	TITLE= followed by title description
	2	Character	Description enclosed in quotes
2	1	Character*10	VARIABLES= followed by variable names, each enclosed in quotes. Must appear in the sequence itemized in Line 4
	2	Character	Variable names, each independently enclosed in quotes.
3	1	Character*5	ZONE= keyword defining cylinder dimensions
	2	Character*3	I= definition of the circumferential dimension
	3	Integer	Number of points in circumferential dimension
	4	Character*3	J = definition of the axial dimension
	5	Integer	Number of points in the axial dimension
4	1	Integer	i
	2	Integer	j
	3	Real	x(ft)
	4	Real	y(ft)
	5	Real	z(ft) ← Used by FOBoom for determining source characteristics
	6	Real	Phi (0-180 deg) ← Used by FOBoom for determining source characteristics
	7	Real	u(fps)
	8	Real	v(fps)
	9	Real	w(fps)
	10	Real	dp/p_{inf}
	11	Real	dp(psi)
	12	Real	p/p_{inf} ← Used by FOBoom for determining source characteristics
	13	Real	Mach
			Line 4 is repeated once for each grid node. Total number of repeats is (i * j) from line 3.

Note: Of the pressure and velocity data, only p/p_{inf} is read. The rest are useful for image rendering (in programs like TecPlot), but FOBoom only reads z and p/p_{inf}.

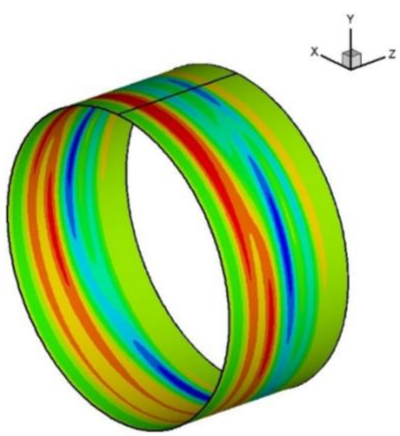


Figure 3-15 Example cylinder.plt file in 3-D.

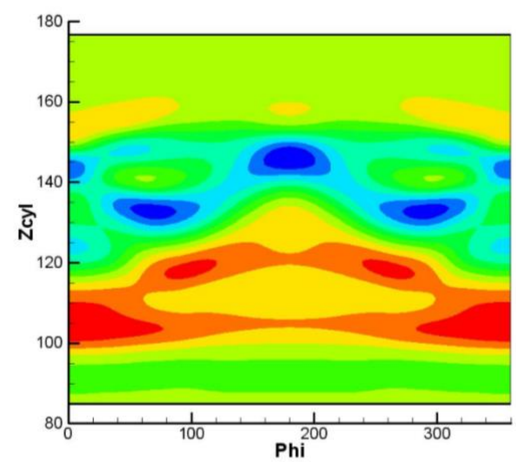


Figure 3-16 Example cylinder.plt file, unwrapped flat.

3.1.13.4 CYLINDER_ASYMM – Asymmetric cylinder definition

The CYLINDER_ASYMM keyword has the same conventions as the basic CYLINDER mode (3.1.13.3), except that CYLINDER_ASYMM mode allows for an asymmetric cylinder source definition. Format is the same as the basic CYLINDER mode (3.1.13.3), however, this mode allows for Phi input from 0 – 360 degrees, rather than 0-180 degrees as in basic CYLINDER mode. The coordinate axis system for CYLINDER_ASYMM is shown in Figure 3-17.

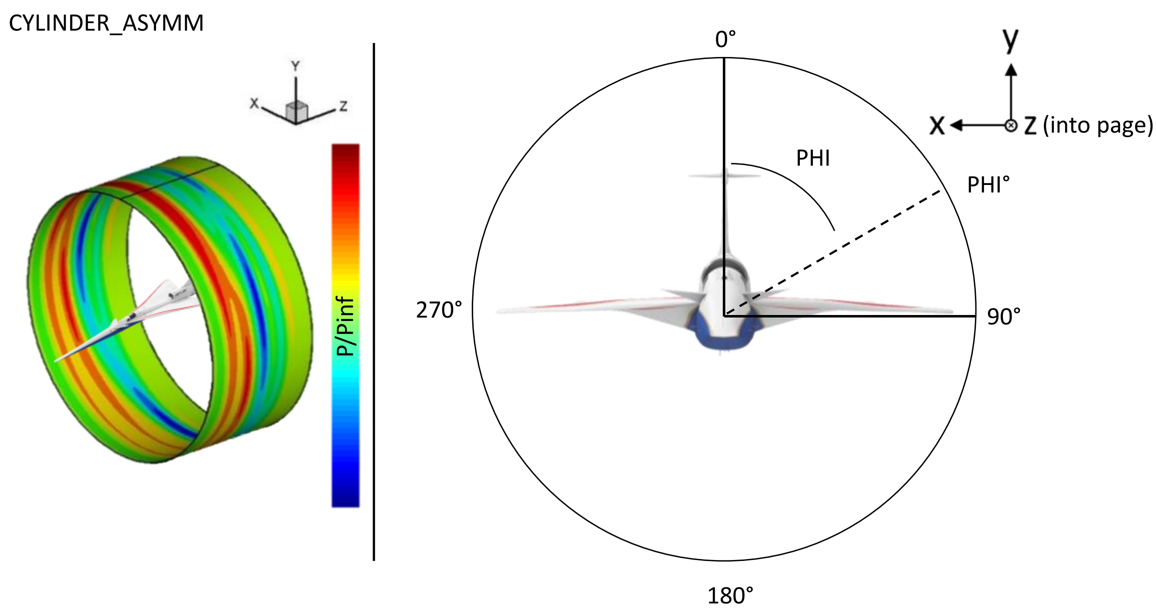


Figure 3-17 CYLINDER_ASYMM coordinate axis definition.

3.1.13.5 CYLINDERHIRES – High resolution cylinder definition

The CYLINDERHIRES keyword has the same conventions as the basic CYLINDER mode (3.1.13.3), except that in CYLINDERHIRES mode, FOBoom allows more input data points along the body axis direction. The format is also the same as the basic CYLINDER mode (3.1.13.3).

3.1.13.6 CYLINDERM – Cylinder definitions for different Mach numbers

The CYLINDERM keyword has the same conventions as the basic CYLINDER mode (3.1.13.3), with two exceptions. The first difference is that CYLINDERM mode allows for specification of different cylinders for different Mach numbers. The second difference is that CYLINDERM mode uses the same azimuth angle convention as RAYTRACING coordinate system, which uses azimuth angle 0° for the undertrack angle and 180° for the azimuth angle directly above the aircraft. The CYLINDERM keyword format is given in Table 3-39. The external file format is given in Table 3-40. An example external file is shown in Figure 3-18.

Table 3-39 MODE / CYLINDERM keyword format description.

Line	Position	Variable Type	Description
1	1	Character	Cylinder filename and path (max 255 characters)

Table 3-40 MODE / CYLINDERM keyword external file format description.

Sequence	Position	Description
1	n/a	Descriptor (e.g., LENG ROVERL) not used by FOBoom
2	1	Aircraft length, L (ft)
2	2	Cylinder Radius normalized by aircraft body length R/L
3	n/a	Descriptor (e.g., NX NTH NM) not used by FOBoom
4	1	Number of Points in the Signature, NX
4	2	Number of Azimuths, NTH
4	3	Number of Mach numbers, NM
5	n/a	Descriptor (e.g., X VALS) not used by FOBoom
6	multiple	X values for each NX
7	n/a	Descriptor (e.g., THETA VALS) not used by FOBoom
8	multiple	Theta (azimuth) values for each NTH
9	n/a	Descriptor (e.g., MACH NUMBER) not used by FOBoom
10	multiple	Mach number for each NM
11	n/a	Descriptor (e.g., DPP ARRAY) not used by FOBoom
12	multiple	dp/p_{inf} for NX*NTH*NM

```
LENG  ROVERL
   90.00000       10.00000
 NX  NTH  NM
        3263         361           1
X VALS
  -4.473403      -4.412951      -4.352500      -4.292049      -4.231597
  -4.171146      -4.110694      -4.050243      -3.989792      -3.929340
…snip…
   192.2959       192.3563       192.4168       192.4772       192.5377
   192.5981       192.6586       192.7190
 THETA VALS
  -180.0000      -179.0000      -178.0000      -177.0000      -176.0000
  -175.0000      -174.0000      -173.0000      -172.0000      -171.0000
…snip…
  175.0000       176.0000       177.0000       178.0000       179.0000
  180.0000
 MACH NUMBER
   1.45000000000000
 DPP ARRAY
-1.1983285E-08 -1.2586156E-08 -1.3148283E-08 -1.3670204E-08 -1.4154883E-08
-1.4607713E-08 -1.5036340E-08 -1.5450297E-08 -1.5860442E-08 -1.6278197E-08
…snip…
```

Figure 3-18 Example CYLINDERM keyword file fragment.

3.1.13.7 CYLINDERX – Cylinder definition without azimuthal interpolation

The CYLINDERX keyword has the same conventions as the basic CYLINDER mode (3.1.13.3), except that in the CYLINDERX mode, FOBoom selects the closest azimuth angle instead of interpolating the p/p_{inf} data to a specific azimuth angle. The format is the same as the basic CYLINDER mode (3.1.13.3).

3.1.13.8 CYLINDERXHIRES – High resolution cylinder without azimuthal interpolation

The CYLINDERXHIRES keyword has the same conventions as the CYLINDERX mode (3.1.13.7), except that in the CYLINDERXHIRES mode, FOBoom allows more input data points. The format is also the same as the CYLINDERX mode (3.1.13.7).

3.1.13.9 CYLINDERVARYX – Cylinder definition with different x values for each azimuth

The CYLINDERVARYX keyword allows starting pressure signatures at each azimuth to have different axial (X) points in the down the aircraft body direction. The code selects the closest azimuth angle instead of interpolating the p/p_{inf} data to a specific azimuth angle. In addition, this input mode allows for an arbitrary scale factor to be applied to the X values in the inputs to facilitate unit conversion from various CFD inputs. The user-specified X scale factor is multiplied by the X values in the input file to obtain the values within FOBoom. For example, if the Cylinder data are in meters, the X scale factor would be 3.28083 to convert meters to the required FOBoom units of feet. This mode does not handle multiple Mach or G-load inputs.

The CYLINDERVARYX format is described in Table 3-41. An example input format is provided in Figure 3-19. The cylinder inputs are organized into an ascii.plt text file shown in Figure 3-20 with the format described in Table 3-42.

Table 3-41 MODE / CYLINDERVARYX keyword format description.

Line	Position	Variable Type	Description
1	1	Character	Cylinder filename and path (max 255 characters)
2	1	Float	Cylinder Radius normalized by aircraft body length R/L Note that the ROVERL parameter in the Raytracing keyword input (Section 3.1.12) is overridden by R/L in the Cylinder keyword input.
2	2	Float	Aircraft length, L (ft)
2	3	Float	X scale factor (e.g., 3.28083 to convert from ft to m)

```
MODE
CYLINDERVARYX
Case1_dpp-mod.plt
3.0   110.0   3.2808
```

Figure 3-19 Example CYLINDERVARYX input format.

Table 3-42 cylindervaryx.plt file input format description.

Line	Position	Variable Type	Description
1	1 2	Character*6 Character	TITLE= followed by title description Description enclosed in quotes
2	1 2	Character*10 Character	VARIABLES= followed by variable names, each enclosed in quotes. Must appear in the sequence itemized in Line 4 Variable names, each independently enclosed in quotes.
3	1 2 3	Character*17 Float*10 Character	ZONE T= "Azimuth = keyword defining azimuth azimuthal angle in degrees End quotes to close the definition
4	1 2	Real Real	x(ft) dp/p_{inf}

Note: Lines 3 and 4 are repeated for each azimuth angle.

```
title="Near-field waveform file"
variables = "X","dp/p"
ZONE T= "Azimuth = -90.000000"
  8.6534689135547267824222e+01   0.0
  1.0180551663005560669717e+02   0.0000000000000000000000e+00
  1.2297521741307765807960e+02   0.0000000000000000000000e+00
  1.2335774141249622459782e+02   6.7003216705353494352104e-04
  1.2338486861245499426332e+02   6.6056504773169013016582e-04
  1.2341230061241330417943e+02   6.5247796691821893441676e-04
...snip...
  1.8307333975668851167029e+02   0.0000000000000000000000e+00
  2.0044693973028063282982e+02   0.0000000000000000000000e+00
  2.2049163370330870748148e+02   0.00
ZONE T= "Azimuth = -80.000000"
  8.6534689135547267824222e+01   0.0
  1.0180551663005560669717e+02   0.0000000000000000000000e+00
  1.2297521741307765807960e+02   0.0000000000000000000000e+00
  1.2388382621169657227256e+02   6.1721877899239879685517e-04
  1.2391125821165488218867e+02   6.1804630196183978074753e-04
```
Figure 3-20 Example CYLINDERVARYX.plt input format.

3.1.13.10 FFUNC – Simple F-Function Mode

Simple F-Function mode is useful if the input pressure distribution DPP ($\Delta p/p_{inf}$) is known only at zero (downward) azimuth and booms are expected to be N-waves. Number of points NX, acoustic pressure / freestream pressure ($\Delta p/p_{inf}$) and position along the axis of the aircraft X are read, but DPP is considered to be the F-function under the aircraft for a steady level flight condition at the user-specified reference Mach number (EMREF) and freestream pressure, also referred to as reference pressure (PVFFN) . The input F-function is scaled to other G-loads, flight parameters, and azimuths by use of Carlson's formulae.

The format used for input to FFUNC mode is given in Table 3-43. Simple F-Function mode also allows for inputs to be read from an external file by specifying "FILE" in the place of NX and following this with a file name from which X, DPP pairs can be read.

Table 3-44 contains input format keyword information to specify an external file. Table 3-45 contains a description of the required information for the external file specifying the number of F-Function points, and the X, DPP pairs.

Table 3-43 MODE / FFUNC keyword format description (inline).

Line	Position	Variable Type	Description
1	1	Integer	Number of points in the signature, NX
2-*NX*	1 2	Float Float	Axial distance, X (ft) F-Function, DPP. Repeat line 2 for the number of points specified on line 1.
NX+1	1 2 3 4	Float Float Float Float	Aircraft Length, L (ft) Vehicle Weight, WEIGHT (klb) Reference Mach Number, EMREF Reference Pressure, PVFFN
NX+2	1	Integer	Carlson shape factor curve index number (IUN) to be used, see Table 3-29 (Valid 1-8)

Table 3-44 MODE / FFUNC keyword format description (external file).

Line	Position	Variable Type	Description
1	1	Character	"FILE" to specify an external file
2	1	Character	File Name for external file containing NX, X, DPP.
3	1 2 3 4	Float Float Float Float	Aircraft Length, L (ft.) Vehicle Weight, WEIGHT (klb) Reference Mach Number, EMREF Reference Pressure, PVFFN
4	1	Integer	Carlson shape factor curve index number (IUN) to be used, see Table 3-29 (Valid 1-8)

Table 3-45 FFUNC external file format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of points in the Signature, NX.
2-*NX*	1 2	Float Float	Axial Distance, X (ft.) F-Function, DPP. Repeat line 2 for the number of points specified on line 1.

3.1.13.11 THOMAS – Original Thomas Form

THOMAS is the original Thomas code input format, where NX pairs of $\Delta p/p_{inf}$ and X are provided by the user. THOMAS is applicable only at one azimuth and flight condition. This input may come in two forms, an inline definition, and an external file definition. Axial coordinate X can be full scale for an aircraft of length "L", or subscale for a model length "ML".

The original Thomas model was intended for direct input of wind tunnel model data. Unless actual wind tunnel data are being used, it is common to use the full scale length for both. Supporting input data are NX, DPP, X, L and ML. $\Delta p/p_{inf}$ is dimensionless, and the lengths are in feet. This mode is appropriate for a single azimuth, corresponding to that for which DPP applies. The inline input definition is shown in Table 3-46, the input definition used to read from an external file is shown in Table 3-47, and the format of the external file itself is shown in Table 3-48. Note that the propagation starting radius is generally linked to the input source data and may be found in the RAYTRACING keyword section (Section 3.1.12).

Table 3-46 MODE / THOMAS keyword format description (inline).

Line	Position	Variable Type	Description
1	1	Integer	Number of Points in the Signature, NX
2-*NX*	1 2	Float Float	Axial Distance, X (ft) dp/p_{inf} Repeat line 2 for the number of points specified on line 1
NX +1	1 2	Float Float	Aircraft Length, L (ft) Model Length, ML (ft)

Table 3-47 MODE / THOMAS keyword format description (external file).

Line	Position	Variable Type	Description
1	1	Character	"FILE" to specify an external file
2	1	Character	File Name for external file containing NX, X, dp/p_{inf}
3	1 2	Float Float	Aircraft Length, L (ft) Model Length, ML (ft)

Table 3-48 THOMAS external file format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of points in the Signature, NX
2- *NX*	1 2	Float Float	Axial Distance, X (ft) dp/p_{inf} Repeat line 2 for the number of points specified on line 1

3.1.13.12 TIEGERMAN – Tiegerman Blunt Body Mode

The Tiegerman Blunt Body Mode is for use with drag dominated hypersonic blunt bodies. Input format for TIEGERMAN mode is shown in Table 3-49.

Table 3-49 MODE / TIEGERMAN keyword format description.

Line	Position	Variable Type	Description
1	1 2	Float Float	Aircraft Length, L (ft) Aircraft Weight, (klb)

3.1.13.13 SEEB – George-Seebass 6 Parameter Definition

This mode specifies that input is in the form of an external file containing a George-Seebass six parameter definition of the F-Function. A filename should be specified for the external file on the first line of the input. The SEEB input format definition is given in Table 3-50. PVFFN (Line 2, position 4) is the ambient pressure at the vehicle for the conditions for which the F-function was defined. A value of 0 means the F-function was defined at the flight altitude. This parameter is used to scale lift boom in the F-function input case. The SEEB external file format definition is given in Table 3-51.

Table 3-50 MODE / SEEB keyword format description.

Line	Position	Variable Type	Description
1	1	Character	File Name of file containing the 6 parameter definition to be used.
2	1 2 3 4	Float Float Float Float	Aircraft Length, L (ft) Vehicle Weight, WEIGHT (klb) Reference Mach Number, EMREF Reference Pressure, PVFFN (psf)

Table 3-51 SEEB external file format.

Line	Position	Variable Type	Description
1	1	Character	Keyword “seeb”
2	1	Character	Descriptor, not used by FOBoom
3	1	Real	Height of initial spike as dp/p_{inf}
4	1	Real	Duration of spike (msec)
5	1	Real	Height of start of ramp as dp/p_{inf}
6	1	Real	Constant defining start of negative portion as dp/p_{inf}
7	1	Real	Slope of isentropic compression as dp/p_{inf}
8	1	Real	Length of positive portion (msec)
9	1	Real	Length to rear spike (msec)

3.1.14 Keyword HIGHRES

The HIGHRES keyword allows for control of the fidelity of the signature sampling rate in other processors such as PCBurg, HeadlessBurgers, TURBO and sBOOM. If, after running SonicBAT-Run-Fort, the resultant waveforms look clipped or distorted in WCON (Section 4.3), try increasing the maximum number of points and adding leading and trailing zeroes to the input signature.

The format used for the HIGHRES keyword is specified in Table 3-52.

Table 3-52 HIGHRES text file format.

Line	Position	Variable Type	Description
1	1	Integer	Maximum number of points in the boom signature.
2	1	Integer	Sample rate of the boom signature in samples/sec.
3	1	real	Maximum duration of the boom signature in seconds.

3.1.15 Keyword TRAJECTORY

The Trajectory keyword describes the flightpath of the flight vehicle. Trajectory data are defined in a formatted manner and may be contained inline with the FOBoom input file or in an external trajectory file. The TRAJECTORY keyword must be the last keyword within the FOBoom input file (other than the REMARKS keyword). The trajectory data column specifics are provided in Table 3-53 for inline data input. Keyword options are described in Table 3-54 and Table 3-55 and contain column specifics for external file data input. Subsonic Mach numbers are allowed within the trajectory, but no propagation will be invoked for those portions of the trajectory. Note that no roll angle input is currently supported, however, during turning maneuvers, a coordinated turn is assumed and the appropriate bank angle is computed. The (Xplane, Yplane) is in the Earth-based coordinate system. The coordinate system is consistent with the coordinate system in the RAYTRACING keyword section, see Figure 3-9.

Table 3-53 Trajectory data column specifics, inline.

Line Type	Column	Variable Name	Description
1	1-8	Keyword(i)	Keywords, defined in Table 3-54
	11- 22	Tstart	Time, or time increment, depending on keyword, seconds
	23- 34	Xplane	X position of vehicle, feet
	35- 46	Yplane	Y position of vehicle, feet
	47- 58	Fltalt	Current altitude, feet
	59- 70	Mach	Mach number
	71- 82	dMdt	First derivative of Mach number, 1/sec
	83- 94	d2Mdt	Second derivative of Mach number, 1/sec^2
	95-106	Head	Heading, degrees clockwise from north
	107-118	Psidot	First derivative of heading, degrees/sec
	119-130	d2psi	Second derivative of heading, degrees/sec^2
	131-142	Fpa	Flight path (climb) angle, degrees
	143-154	Gamdot	First derivative of flight path angle, degrees/sec
	155-166	d2gam	Second derivative of flight path angle, degrees/sec^2
	167-178	Weight(ii)	Weight, kilopounds
	179-190	L(ii)	Aircraft length, feet
	191-202	Thrust(ii)	Thrust, kilopounds
	203-214	Drag(ii)	Plume drag, kilopounds
	215-226	Alpha(ii,iii)	Angle of attack, degrees
	227-238	Fks(ii)	Shape factor, integer
2	3-5		END

Notes: (i) Keyword determines which parameters matter, and controls trajectory processing.
(ii) Weight, Al, thrust, drag, alpha, and fks are generally used for launch/entry vehicles, whose length and configuration can change with staging.
(iii) Alpha is of interest only for CARLSON/LOOKUP, and FKSNIN for CARLSON/AXISYMMETRIC.

Table 3-54 TRAJECTORY keyword format description.

Keyword	Description
Keyword [i,ii]	This line is ignored by FOBoom processing but can be used to set up column headings for the benefit of someone reading the file.
REMARK	This line is ignored by FOBoom processing and can be used to include comments for the benefit of someone reading the file.
NEWTIME[iii]	Complete aircraft trajectory point. All parameters through D2GAM are read. A blank (no keyword) is the same as NEWTIME.
NEWLOAD[iii]	Same as NEWTIME (or blank), but weight, al, thrust, drag, alpha and fks are also read. If any of these are blank, the last previous value is used. Note that these parameters are specified earlier, in the vehicle definition, so it is not necessary for the first data line to be NEWLOAD - although it can be, and will override earlier values. NEWLOAD may be used for launch vehicles or aircraft source modes that rely on weight.
TADVNCE[iv]	Project the current trajectory forward, using the current position and derivatives. The only data item to appear is parameter Tstart (Table 3-53), which in this case is interpreted as the time to advance the trajectory.
NEWDERS[iv]	Same as TADVNCE, but uses new values of the second derivatives. Parameter Tstart (Table 3-53)must be present (as an advance time) and values must be present for the second derivatives that are to be updated. Any second derivative whose field is left blank will remain at its last input value.
NEWDIRS	Same as TADVNCE, but uses new values of the first and second derivatives. Parameter Tstart (Table 3-53)must be present (as an advance time) and values must be present for the first and second derivatives that are to be updated. Any first or second derivative whose field is left blank will remain at its last input value.
Longlat	Defines a geographic origin corresponding to the X, Y coordinate system. The first Xplane and Yplane coordinate must contain east longitude and north latitude, decimal degrees to specify the origin for the coordinate system in geographic units. The following coordinate data lines specify the trajectory in local, X, Y coordinates. These values are written to a file of type ".org" (origin), which is used as a reference in WCON.
geomode	Defines a geographic origin in geographic units, decimal degrees. The first Xplane, Yplane pair are taken to be 0, 0 in a local Cartesian system. The following coordinate data lines specify the trajectory in geographic units, east longitude and north latitude, decimal degrees. These values are written to a file of type ".org" (origin), which is used as a reference in WCON. The geomode keyword will also trigger generation of a .delt file which is only used when processing with SonicBAT-Run-Fort.
END	This signifies the end of the trajectory description.

Notes: (i) Keywords are 8 characters long, but begin in Column 2, so contain only 7 significant characters.
(ii) Keywords are case sensitive.
(iii) The most general (and accurate) method is to provide full data at each point via NEWTIME (blank) or NEWLOAD.
(iv) TADVNCE and NEWDIRS are approximations that are useful for simple maneuvers.

Table 3-55 Trajectory data column specifics, external file.

Line Type	Column	Variable Name	Description
1	1-4	FILE	FILE keyword specifies that an external file will contain the trajectory information.
2	1-6	n/a	Trajectory file name in columns 1 – 60. The format for the trajectory file is the same as line 1 of the inline specification option (Table 3-53).

Notes: Information in lines 1 and 2 may also be specified together on line 1 with the "FILE" variable in lower case (e.g., file sampletrajectory.trj).

3.1.16 Keyword REMARKS

The REMARKS keyword may be used throughout the file to create an area for comments. These are skipped over by FOBoom, but allow notes so other analysts can better identify key areas of the file, document reasons for the use of specific settings, or other purposes. The REMARKS keyword takes a single argument, which is followed by lines of text. The format used for the REMARKS keyword is specified in Table 3-56. Note that remarks can be placed between blocks of keyword inputs, but not in the middle of a particular keyword section.

Table 3-56 REMARKS keyword format description.

Line	Position	Variable Type	Description
1	1	Integer	Number of lines reserved for comments
2-N	1	Character	Remarks/Comment Lines. Repeat line 2 for the number of points specified on line 1.

3.1.17 Running FOBoom

To begin an analysis with FOBoom from the command prompt, first change the directory to the location of the FOBoom executable and input files. Then execute the following command:

```
FOBoom casename[.ext] [ioutputs]
```

where:

FOBoom — The name of the FOBoom executable (e.g., PCBoom730.exe).

casename[.ext] — The name of the input file. Inclusion of the extension (".ext") is optional. If the extension is not specified, ".dat" is assumed. Note that the FOBoom input file name is considered to be the case name (casename) for the analysis. This name is used in all outputs associated with the analysis.

[ioutputs] (optional) — Specifies desired output files. The following FOBoom output files may be generated by specifying the sum of the following options in the command rather than through the OUTPUTS keyword. Note that the .out file will always be produced in addition to the options listed below.

1 display progress on screen
2 output a .u28 file
4 output a .un6 file
8 output a .mco file
16 output an .age and .ssg file (Burgers capability)*
32 output an .ott and .ots file (over-the-top capability)*

Note: Additional output options can be specified through keywords in FOBoom.

The following command would execute FOBoom, using the Example 1 case inputs, display the progress on screen (option 1), produce .age and .ssg files (option 16), and produce the .out file. Commands for additional modules can be executed in a similar manner, for more information review the section that corresponds to the module of interest.

```
PCBoom730.exe Example1.dat 17
```

3.2 FOBoom Outputs

FOBoom outputs are specified in either the FOBoom input file (see Section 3.1.5), in the command to run FOBoom (see Section 3.1.17), or through the use of specific keywords. Details for the available outputs are described in this section. Examples of select output files are in the following subsections.

The primary output files from FOBoom include:

- Casename.wfm – An output file that is generated when the BURGERS keyword with the enhanced Burgers solution is used and when discrete emission ray azimuthal angles are specified in the RAYTRACING keyword section (i.e., setting the RAYTRACING keyword line 5 position 1 value to be an integer > 0 corresponding to the number of emission ray angles to compute, see Section 3.1.12). The main data written to this file is the output waveform that uses a reflection coefficient specified by the user in the RAYTRACING keyword section and that gives the time in sec and overpressure in psf. In addition to this waveform, it also contains information such as the ray coordinates on the ground (in feet), corresponding PL, aircraft time, ray propagation time, azimuthal angle, run-time, and sampling frequency.
- Casename.twf – An output file that is generated when both the KZKFILTER_NWAVE keyword and the BURGERS keyword with the enhanced Burgers solution are used and when discrete emission ray azimuthal angles are specified in the RAYTRACING keyword section (i.e., setting the RAYTRACING keyword line 5 position 1 value to be an integer > 0 corresponding to the number of emission ray angles to compute, see Section 3.1.12). The main data written to this file is the ground waveform that uses a reflection coefficient specified by the user in the RAYTRACING keyword section and that gives the time in sec and overpressure in psf. The output waveform is said to be turbulized by applying precalculated turbulence effects for N-waves using a set of KZK filters. In addition to this waveform, the .twf file also contains information such as the ray coordinates on the ground (in feet), corresponding PL, aircraft time, ray propagation time, azimuthal angle, run-time, and sampling frequency.
- Casename.fpt - An output file that is generated when the BURGERS keyword with the enhanced Burgers solution is used and the full extent of the sonic boom carpet is specified (i.e., setting RAYRACING keyword Line 5 position 1 value to be 0). It contains the ray coordinates on the ground (longitude and latitude in degrees), azimuthal angle, aircraft time and ray propagation time, maximum overpressure, PL and select weighted sound exposure levels.
- Casename.out file – A primary output file with fundamental results including the signature at the requested output altitudes (unless running with the Enhanced Burgers solver). Note that for analyses using the FOBoom Legacy module, PCBFoot must be run for final post-processing. Focus signatures in the FOBoom Legacy module are based on a single-shock solution, and are reliable for N-waves and other simple signatures. PCBFoot is not applicable to or interoperable with signatures computed using the Enhanced Burgers solver (Section 3.2.4).
- Casename.un6 file – An output file containing case inputs and a complete account of the PCBoom calculations, including incremental details about the signature and propagation physics (Section 3.2.6).

- Casename.u28 file – Shows the evolution of the boom and contains the signatures at the user requested altitudes including flight conditions, ray/signature coordinates, and azimuth. When the FOBoom Legacy module is run, this file is written for only one ray: at zero time, zero azimuth (Section 3.2.5).

FOBoom can also generate the following files for use in a post-processor:

- Casename.org – An output file that is generated when keyword longlat or geomode are included in the trajectory file (Section 3.1.15). This file contains the longitude and latitude of the origin that is passed to PCBFoot for geo-referencing and post processing by WCON and by RayCau.
- Casename.mco file – An output file with Mach number cutoff information (Section 3.2.7).
- Casename.age – An output file with aging details output at different altitudes along the traced rays. It is used by the PCBurg and Turbo modules.
- Casename.ssg – An output file with signature details output at different altitudes along the traced rays. It is used by the PCBurg and Turbo modules.
- Casename.trj – An output file with an individual trajectory point for use in Turbo (or sBOOM) using SonicBAT-Run-Fort. Note that sBOOM is not distributed with the PCBoom Suite. See Section 6.1 for more information about sBOOM.
- Atmos-out.txt – A weather output file for use in Turbo (or sBOOM) using SonicBAT-Run-Fort.
- Casename.ott – An output file containing the ray coordinates, atmospheric properties, and amplitude and age parameters at every time step along each ray. It is used in Over-the-top (OTTER) modules. It is similar to the .age file associated with the BURGERS keyword, but contains more quantities and the independent variable is time along the ray, rather than altitude.
- Casename.ots – An output file containing the F-function at the start of each ray. It is used in Over-the-top modules POTRAY, POTTI and OTTER. This is the same as the .ssg file associated with the BURGERS keyword, but given a different name to avoid confusion if both types of runs are done for the same base case.
- Casename.gmp file – An output file that is generated when the keyword GROUND is used in the FOBoom input file (Section 3.1.8). This file contains ground mode parameter information (Section 3.2.8).

3.2.1 Sample .wfm File

The .wfm file contains the waveform of the requested primary boom as well as other useful information about the boom. A portion of a sample .wfm file is shown in Figure 3-21

```
NASA PCBoom 7.3.0
Run on: 2022 Oct 24 09:48:45
    x(ft),   y(ft),     z(ft),    Tac(s),  tprop(s), phi(deg), Runtime(s)
  49979.20      0.00      0.00      0.00    69.08     0.00     0.10
   PL(dB)  ASEL(dB)  BSEL(dB) DSEL(dB) ESEL(dB) ISBP(dB)
   102.21    88.23    95.47    95.65    93.47   108.66
waveform: t(s), overpressure(psf), #pts =  16384
  -1.00000001E-01  -2.38578655E-03
  -9.99854435E-02  -2.38449192E-03
  -9.99708855E-02  -2.38320767E-03

... snip ...
```

Figure 3-21 A sample .wfm file.

The information contained in this output file are as follows.

- PCBoom version as well as the datestamp for data file generation

- The x and y components of the ray position are shown with respect to the aircraft position at which the ray is generated. They represent the ray displacement in the eastward and northward directions, respectively. Note that the vertical component z shown is the requested ray altitude.
- The .wfm file shows the aircraft time (Tac in sec) and the azimuthal angle (phi in degrees) at which the ray is generated as well as the boom propagation time (tprop in sec) and the computational runtime in second.
- The .wfm file also shows the calculated PL, select weighted sound exposure levels, and ISBAP (ISBP).
- The number of discrete points in the waveform is given by #pts. In this example, there are 16384 discrete points. In the succeeding lines, the first column is the retarded time t(s) while the second column is the overpressure in psf.

3.2.2 Sample .twf File

The .twf file contains the turbulized waveform of the requested primary boom as well as other useful information about the boom. The waveform is said to be turbulized because a precalculated KZK filter for N-waves is applied to include the effects of turbulence. A portion of a sample .twf file is shown in Figure 3-22

```
NASA PCBoom 7.3.0
Run on: 2022 Oct 24 09:51:06
    x(ft),   y(ft),     z(ft),    Tac(s),  tprop(s), phi(deg), Runtime(s)
  49979.20      0.00      0.00      0.00     69.08      0.00      0.08
PL  (dB):  -1sd,     mean,     +1sd
           97.77    100.73    103.07
waveforms (#pts =  12211)
   t(s),            overpressure [-1std,     mean,    +1std] (psf)
  -1.00000001E-01   0.00000000E+00   0.00000000E+00   0.00000000E+00
  -9.99804702E-02   0.00000000E+00   0.00000000E+00   0.00000000E+00
  -9.99609390E-02   2.84034092E-08  -3.31022397E-08   1.39516432E-08

... snip ...

ASEL(dB):  -1sd,     mean,     +1sd
           83.46     86.98     89.67
waveforms (#pts =  12211)
   t(s),            overpressure [-1std,     mean,    +1std] (psf)
  -1.00000001E-01   0.00000000E+00   0.00000000E+00   0.00000000E+00
  -9.99804702E-02   0.00000000E+00   0.00000000E+00   0.00000000E+00
  -9.99609390E-02  -2.83539996E-08   4.36910762E-08   2.37862347E-08

... snip ...
```

Figure 3-22 A sample .twf file.

The information contained in this output file are as follows.

- PCBoom version as well as the datestamp for data file generation
- The x and y components of the ray position are shown with respect to the aircraft position at which the ray is generated. They represent the ray displacement in the eastward and northward directions, respectively. Note that the vertical component z is the requested ray altitude for an analysis.
- The .twf file shows the aircraft time (Tac in sec) and the azimuthal angle (phi in degrees) at which the ray is generated as well as the boom propagation time (tprop in sec) and the computational runtime.
- The .twf file also shows the PLs of the turbulized waveforms resulting from the application of the KZK filters associated with the precalculated mean – 1 standard deviation (-1sd), mean, and mean + 1 stand deviation (+1sd).

- The number of discrete points in the waveforms is shown after the #pts. The waveforms are given in the succeeding lines. There are four columns: the first column is for the retarded time (t in sec) and the second, third, fourth columns are for the overpressures associated with the -1sd, mean, and +1sd filters, respectively.
- The first calculated loudness and waveforms written on this file are for the PL. They are then followed by those for the ASEL, BSEL, CSEL, ESEL, and ISBAP.

3.2.3 Sample .fpt File

The .fpt file contains the so-called sonic boom footprint, which is the sonic boom loudness at discrete points on the ground. The loudness is provided in terms of maximum overpressure (Pmx), Perceived Levels (PL), selected weighted sound exposure level, and ISBAP as shown in Figure 3-23.

```
NASA PCBoom 7.3.0
Run on: 2022 Oct 24 10:25:33
Run-time:     3.87 s
   lon(deg)    lat(deg)     PH(deg)    Ac_time(s) Prop_time(s)   Pmx(psf)     PL(dB)     ASEL(dB)     ...
  -86.828982   40.183480  -47.569988       0.000     145.075       0.554      91.942      77.631      ...
  -86.951294   40.282685  -40.000000       0.000     102.038       0.723      96.898      82.928      ...

... snip ...
```

Figure 3-23 A sample .fpt file.

The information contained in the .fpt output file are as follows.

- PCBoom version as well as the datestamp for data file generation
- Runtime in sec
- Ground coordinates (lon and lat in degrees) of the ray intercept with the ground
- Azimuthal angle (PH in degrees) and aircraft time (Ac_time in sec) at which a ray is generated
- Boom propagation time from the aircraft to the ground
- Loudness at the prescribed ground coordinates in terms of maximum overpressure (Pmx), Perceived Levels (PL), selected weighted sound exposure level, and ISBAP

3.2.4 Sample .out File

The .out file includes the primary ground boom signature and information about the boom. A portion of a sample .out file is shown in Figure 3-24.

```
Sample - Burgers mode, single ray
   0.50   0.250   500.0  5.00  1.00
        0 .    0. 45000 .  0.00    -49.84     49.84
   1.6000   0.0000   0.0000        50.35
    0.0000000000D+00    0.0000000000D+00    0.0000000000D+00
    0.0000000000D+00    0.0000000000D+00    0.0000000000D+00
    -49.84
 GROUND INTERCEPT =
    90814. 95139 .    0. 133.786   0.68787   0.72062  -0.08683
 GROUND  BOOM  SIGNATURE
  390
            0.000000          0.00043912
            0.100000          0.00728214
            0.200000          0.00881787
            0.300000          0.00980794
            0.400000          0.01071021
            0.500000          0.01156740
            0.600000          0.01243652
            0.700000          0.01328366
            0.800000          0.01414284

... snip ...
```

Figure 3-24 Example.out file.

The information contained in this output file as follows:

- Case name.
- Echo of the parameters given in the RAYTRACING keyword (Section 3.1.12).
- Echo of the flight conditions and trajectory points.
- The “GROUND INTERCEPT” location for the primary undertrack sonic boom. This line of data includes the ray intersection (X,Y,Z) (ft) the propagation time from the aircraft (sec), and the ray tangent unit vectors. If the geomode trajectory input option is used, ground intercept coordinates will also be displayed in latitude and longitude coordinates on the following line. For more information on the trajectory input options, see Section 3.1.15.
- The “GROUND BOOM SIGNATURE” the number of points is followed by the signature, T (msec) and P (psf).

3.2.5 Sample .u28 File

The .u28 file contains the signature information for all output altitudes specified in the input file. A portion of a sample .u28 file is shown in Figure 3-25. This example begins with header information and the starting signature. All data are labeled. The number preceding “msec” indicates the number of points in the following signature. The data blocks following the first snip respectively represent the signatures at the first two of four altitudes specified in the FOBoom input file using the ALTITUDES keyword.

```
Sample (PCBoom V 7.3.0 2021 Dec 16 12:55:06)
   4    1   (Number of altitudes, number of phis)

     Xtraj     Ytraj     Ztraj        R0      Phi      Mach     Ttraj
      0.00      0.00  33843.60    115.00     -2.00      1.38 72845.500

   13544   msec            psf               p0               a0            tprop
    0.00000E+00     0.21788E-05     0.57844E+03     0.10135E+04     0.72846E+05
    0.61517E-02     0.22147E-05
    0.12305E-01     0.22488E-05
    0.18457E-01     0.22810E-05
    0.24610E-01     0.23113E-05
    0.30761E-01     0.23396E-05
    0.36913E-01     0.23659E-05
    0.43065E-01     0.23901E-05
    0.49216E-01     0.24123E-05
    0.55370E-01     0.24323E-05
    0.61521E-01     0.24501E-05
    0.67674E-01     0.24658E-05
    0.73826E-01     0.24793E-05
    0.79978E-01     0.24906E-05
    0.86129E-01     0.24997E-05
... snip ...

           Xray            Yray            Zray         Xoffset
   -0.34260E+04    -0.15773E+04     0.30000E+05     0.00000E+00
   10155   msec            psf              p0               a0            tprop
    0.00000E+00     0.40017E-06     0.67852E+03     0.10337E+04     0.56029E+01
    0.65917E-02     0.40677E-06
    0.13185E-01     0.41303E-06
    0.19777E-01     0.41895E-06
    0.26370E-01     0.42451E-06
    0.32962E-01     0.42971E-06
    0.39553E-01     0.43454E-06
    0.46145E-01     0.43899E-06
    0.52737E-01     0.44305E-06
    0.59330E-01     0.44673E-06
    0.65922E-01     0.45000E-06
    0.72515E-01     0.45288E-06
    0.79107E-01     0.45536E-06
    0.85699E-01     0.45744E-06
    0.92291E-01     0.45912E-06
... snip ...

           Xray            Yray            Zray         Xoffset
   -0.26177E+05    -0.11530E+05     0.10500E+05     0.00000E+00
    7009   msec            psf              p0               a0            tprop
    0.00000E+00     0.22948E-06     0.14549E+04     0.11130E+04     0.36091E+02
    0.00000E+00     0.10454E+01
    0.78053E-01     0.10440E+01
    0.16883E+00     0.10425E+01
    0.25970E+00     0.10409E+01
    0.35067E+00     0.10393E+01
    0.44175E+00     0.10377E+01
    0.53293E+00     0.10361E+01
    0.62419E+00     0.10346E+01
    0.71556E+00     0.10330E+01
    0.80702E+00     0.10314E+01
    0.89857E+00     0.10298E+01
    0.99020E+00     0.10282E+01
    0.10819E+01     0.10266E+01
... snip ...
```

Figure 3-25 Example.u28 file.

The signatures at each output altitude are shown in the same data format as the starting signature: pressure (psf) versus time (milliseconds). The first signature line also shows the ambient pressure and sound speed a0 (ft/s) at that altitude, and the propagation time (seconds) from the aircraft. Note that because propagation begins at radius R0, the propagation time for the starting signature is nonzero.

3.2.6 Sample .un6 File

The .un6 file is the general output file for FOBoom. It contains a host of intermediate outputs and calculations obtained during the course of program execution. None of the FOBoom post-processors rely on the .UN6 file, as a result, it has a myriad of human-readable free-form content created during program execution. Portions of a sample .un6 file are shown in this section.

The .un6 file begins with a listing of the atmospheric conditions for the analysis (Figure 3-26). The "INITIAL WAVEFORM" is also provided. This waveform is an echo of the prescribed input starting signature. The .un6 file continues with detailed flight conditions and positional data, plus the starting and computed signature information for each prescribed emission angle and output altitude (Figure 3-27).

```
Sample1
    ATMOSPHERIC CONDITIONS

    P0G = 1950.10 PSF

           ZT, FEET       T0, DEG F          ZWX, FEET       VOX, FT/SEC        ZWY, FEET       V0Y, FT/SEC        HT, FEET          P, PSF

           -7628.0         97.160            -7628.0          3.90787           -7628.0          7.66963           -7628.0       1950.10315
            2372.0         97.160             2372.0          3.90787            2372.0          7.66963            2372.0       1950.10315
            3000.0         90.680             3000.0          6.21069            3000.0          0.65277            3000.0       1909.29724
            4000.0         84.920             4000.0         12.22917            4000.0         -1.50155            4000.0       1845.16455
            5000.0         79.700             5000.0          7.54445            5000.0          2.45134            5000.0       1782.72339
            6000.0         78.620             6000.0         14.12843            6000.0          2.49123            6000.0       1722.14111
            7000.0         74.660             7000.0         13.57280            7000.0         -9.15497            7000.0       1663.06213
            8000.0         71.060             8000.0         21.72851            8000.0         -7.90853            8000.0       1605.86279
            9000.0         66.740             9000.0         18.65791            9000.0         -5.35007            9000.0       1549.97913
           10000.0         62.240            10000.0         14.27420           10000.0         -5.19538           10000.0       1495.84961
           11000.0         58.820            11000.0         13.07836           11000.0         -5.02031           11000.0       1443.14014
           12000.0         55.220            12000.0          8.24639           12000.0         -4.95493           12000.0       1391.89258
           13000.0         51.080            13000.0         13.47945           13000.0        -10.15749           13000.0       1342.08582
           14000.0         46.940            14000.0         12.45339           14000.0         -8.39992           14000.0       1293.67834
           15000.0         41.540            15000.0         12.27816           15000.0         -7.08880           15000.0       1246.62842
           16000.0         37.040            16000.0         18.05682           16000.0          0.31518           16000.0       1200.85217
           17000.0         33.440            17000.0          9.71391           17000.0          4.32491           17000.0       1156.43335
           18000.0         28.580            18000.0         12.87936           18000.0          3.45102           18000.0       1113.22583
           19000.0         25.880            19000.0         14.65527           19000.0         10.26173           19000.0       1071.33398
           20000.0         21.740            20000.0         17.29373           20000.0          8.43471           20000.0       1030.63245
           21000.0         17.600            21000.0         16.70309           21000.0         10.84712           21000.0        991.28833
           22000.0         13.640            22000.0          9.28173           22000.0          8.35730           22000.0        953.11365
           23000.0          9.320            23000.0         18.55460           23000.0          0.64794           23000.0        916.02490
           24000.0          4.100            24000.0         15.16947           24000.0          0.79500           24000.0        880.12659
           25000.0         -0.400            25000.0         18.38523           25000.0         -2.58388           25000.0        845.23053
           26000.0         -4.180            26000.0         22.11303           26000.0          2.71514           26000.0        811.33698
           27000.0         -8.140            27000.0         21.87254           27000.0          5.04967           27000.0        778.63373
           28000.0        -12.640            28000.0         23.52519           28000.0          6.74574           28000.0        747.03723
           29000.0        -17.500            29000.0         25.98831           29000.0          0.45363           29000.0        716.35974
           30000.0        -22.360            30000.0         27.94940           30000.0          1.95441           30000.0        686.45477

... snip ...
```

Figure 3-26 Example.un6 file – part 1.

```
FLIGHT ALTITUDE =   37367.80 FEET

     MACH NUMBER =  0.1214400000000D+01

     HEADING =   90.000 DEGREES

     FLIGHT PATH ANGLE =   3.0  DEGREES

     DMACH/DT =  0.2680000000000D-02  /SEC

     PSI-DOT =  0.0000000000000D+00  DEGREES/SEC

     GAMMA-DOT =  0.0000000000000D+00  DEGREES/SEC

     XPLANE =     86204. FEET

     YPLANE =         0. FEET

     AIRCRAFT LENGTH =  81  FEET

     TIME =    80.000 SECONDS


     PHI =  -31.19 DEGREES    DPHI =  0.50  DEGREES

     TSTEP =    0.500 SECONDS,      DSTRAJ =    500.0 FEET



 STARTING RAY TUBE CALCULATION AT TIME =         80.0000
 AIRCRAFT POSITION =      86203.9         0.0     37367.8
 MACH NUMBER AND RATE ARE    1.2144000   0.0026800
 CLIMB ANGLE (DEG) AND RATE ARE    3.0000000   0.0000000
 HEADING ANGLE (DEG) AND RATE ARE   90.0000000   0.0000000
 AZIMUTH (RADIANS) IS   -0.5443683

Cutoff on ray  1  step #  267
X, Y, Z =    198926.4    -39071.6      9472.8 feet
Cutoff on ray  3  step #  267
X, Y, Z =    198926.4    -39071.4      9472.4 feet
 Based on ray points:
 NP1-3 =          212      170519.462481424       -29225.2512562479
   11097.8958736545
 NP1-1 =          214      171529.278251019       -29575.2710950581
   10982.4766226548
 NP1+1 =          216      172539.953305138       -29925.5887769399
   10871.3004352532
 A FOCUS HAS BEEN FOUND WITH A RAY CURVATURE OF
          KX =     0.3625986803D-06/FT     KY =    -0.1256830557D-06/FT     KZ =     0.3712977448D-05/FT
 COORDINATES FOR FOCAL POINT 1 ARE
     X =     0.1721785818D+06 FT     Y =    -0.2980033108D+05 FT     Z =     0.1091055351D+05 FT
 INCREMENT IN PHI =  -0.3560969E-05 /FT

... snip ...

 Caustic RRR,RRRR:   9862.42466045139       -533738.912760254
   122991.739978992        541168.015807655
 CAUSTIC CURVATURE IS
          KX =    -0.5542395460D-06/FT     KY =   -0.1720732524D-05/FT     KZ =     0.3827088258D-06/FT
 RELATIVE CURVATURE IS
          KX =           -0.321D-06/FT    KY =   -0.9969307939D-06/FT     KZ =     0.2217277881D-06/FT
 RELATIVE RADIUS OF CURVATURE =       0.934E+06 FT
 arg = p0(2) =   449.9673     ,   p0(1) =   448.6138

 STARTING PRESSURE SIGNATURE:  18 POINTS, ARG =   0.7241E+02
 R0 =    81.000

        X        P
      0.000  0.0000E+00
      1.647  0.1448E+02
      3.294  0.1512E+01
     83.992  0.3073E+01
     84.157 -0.9627E+01
    108.696 -0.9149E+01
    108.860 -0.4199E+02
    109.519 -0.1466E+02

... snip ...
```

Figure 3-27 Example.un6 file.

Within FOBoom, the emitted rays, indicated in the file by “PHI = “ (Figure 3-27), are computed in sequential order and the propagation continues along the ray from the vehicle to the ground. The rays appear in sequence within the .un6 file, with all output altitudes being written to the file for one emission angle before FOBoom and the .un6 output progress to the next ray. Only after all requested emission rays have been processed will the computation advance to the next trajectory timestep and the process repeated. Because of the voluminous information and potentially large file size, it is recommended that the .un6 file be created only for diagnostic purposes for a limited number of data points.

All intermediate output altitudes specified in the input file have detailed signature information reported to the .un6 file. The 30,000 ft output altitude for this case is illustrated in Figure 3-28. Also contained within this block of data is the location of the signature (Z,X,Y) in feet, the propagation time to that point (T), the number of points in the signature (i), the ambient pressure (p0) in psf, and speed of sound (a0) in ft/sec. The ground boom signature and location, as well as the reflection factor, are shown in Figure 3-29. If multiple rays are specified, there will be multiple “GROUND-RAY INTERSECTION” data sections in the .un6 file.

```
WAVEFORM AT Z =  30000.0 FEET,  X =   101269.8 FEET,  Y =    -5222.1 FEET,   T =     18.405 sec
     i =   64     p0 =   628.463 psf     a0 =    995.79 feet/sec


             T, MSEC             P, PSF

                0.00              0.000
                0.00              0.353
                8.61              0.174
               83.47              0.353
              152.16             -1.106
              158.22             -1.092
              158.22              0.004
              158.93              0.006
              169.84              0.012
              180.96              0.014
              192.17              0.015
              203.40              0.014
              226.50              0.000

... snip ...
```

Figure 3-28 Example.un6 file.

```
GROUND-RAY INTERSECTION

         X =   148639. FEET
         Y =   -10774. FEET
         T =    67.858  sec

     WAVEFORM AT THE GROUND          REFLECTION FACTOR = 1.90


             T, MSEC             P, PSF

                0.00              0.000
                0.00              0.679
                7.13              0.480
               72.79              0.976
              190.55             -2.341
              190.55              0.040
              198.76              0.040
              210.01              0.039
              233.83              0.000
```

Figure 3-29 Example.un6 file.

3.2.7 Sample .mco File

The .mco file (Figure 3-30) contains cutoff threshold information. The first four data items are the flight parameters. This is followed by the cutoff Mach number for level flight at that altitude, and the altitude above which the flight Mach number is below the cutoff condition.

```
       Time       Flt Alt      Heading         Mach      Mcutoff   No Boom Alt
       0.00          0.00         0.00       0.0000       0.9929      2070.00
      80.00      37367.80        90.00       1.2144       1.1451        Never
```

Figure 3-30 Example.mco file.

3.2.8 Sample .gmp File

The .gmp file is created when the GROUND keyword is used. It includes details about the ground boom parameters for use in PCBFoot. Table 3-57 itemizes the output parameters in the .gmp file. This file is ASCII and may be modified by the user in order to determine the effect of ground impedance (defined as a flow resistivity in CGS units) on the ground boom signature. The .gmp file is read automatically by PCBFoot. The ground reflection parameter (default 1.9) used in the analysis is specified in the RAYTRACING keyword and is echoed in the .out file. The ground impedance parameter may be modified as described. An example .gmp file is provided in Figure 3-31.

The .gmp file is ASCII and may be edited by the user (without rerunning FOBoom) in order to ascertain the effects of ground impedance on signatures for receiver heights and flow-resistivity values other than the initial values specified in the GROUND keyword section of the FOBoom input file.

Table 3-57 GROUND mode parameter (.gmp) file format.

Line	Position	Variable Type	Description
1	1-80	Character	Case description name. Repeat of the CASENAME keyword.
2	1	Real	Receiver height (ft) above local ground. The receiver height is used solely to determine the phase interference between direct and reflected rays. Values less than 30 ft. are recommended.
3	1	Real	Flow resistivity parameter in CGS units. See the keyword GROUND for more information.
4	1	Real	Local speed of sound (ft/sec) at the receiver based on the atmosphere in use.

```
Sample - Legacy mode
   1.000000
   5.000000
   200.0000
   1118.21948242188
```

Figure 3-31 Example.gmp file.

3.3 Error Messages and Focus Abort Codes

The error and warning messages, which FOBoom might generate, are itemized here along with an explanation and where appropriate, recommended changes to the input file. In some instances, values of particular variables are provided to the user. These are indicated in *italics* and explained with each error message in section 3.3.1. Occasionally, focusing conditions are encountered, which cause the program to halt execution. These numerical Focus abort codes are itemized in section 3.3.2.

3.3.1 Error Messages

Table 3-58 Error messages.

Error Message	Description
AgeMCH: Exceeded max points, *npts*	The signature length "*npts*" has exceeded a limitation of 50,000 points while in the agemch routine during the interpolation of fill points.
Fatal Error: NEWLOAD valid only for mode 3.	The NEWLOAD keyword was specified within the trajectory, but "CARLSON" mode wasn't the signature input mode specified in the input deck.
Fatal Error: invalid keyword.	The last keyword "*keyword*" found in the flight trajectory is invalid. Please check the flight trajectory input format and fix the trajectory in the input deck, or the external trajectory file.
Fatal Problem: Negative ambient pressure at ray end.	Pressure at the ray end was found to be less than 0.
Incompatible option: Cannot have both AGEout and OTTout...quitting.	Output of .age/.ssg files was specified through using the BURGERS keyword, the AGE keyword within the OUTPUTS keyword section, or via the command line. OTT file output was also selected using either the OTT keyword within the run file or via the command line. These two outputs are incompatible and only one should be used at a time.
Incompatible option: OTTout available only for 3-D ray tracing...quitting.	OTT output is only available for 3-D ray tracing modes, and is incompatible with legacy ray tracing modes. Please select a 3-D ray tracing mode if you wish to enable OTT output.
Input Error: latlong keyword is not consistent with geomode. Pick one or the other.	'longlat' keyword and 'geomode' keyword were both encountered in the same flight trajectory and are incompatible with one another. Please pick either geomode, or longlat, but not both.
Input Error: geomode keyword is not consistent with Cartesian trajectory and longlat." "Pick one or the other.	'longlat' keyword and 'geomode' keyword were both encountered in the same flight trajectory and are incompatible with one another. Please pick either geomode, or longlat, but not both.
Overran dimension at Z = zvalue, primary boom case. Try again with bigger time step, or contact support.	An array dimension has been overrun within the Tube routine while tracing a carpet boom or primary ray tube.
No valid vehicle source MODE selected. Revise the input file and try again.	The "MODE" keyword was specified without being followed by a valid vehicle mode keyword. Please pick the proper vehicle mode keyword and append the required data to the input deck immediately following the "MODE" keyword.

3.3.2 Focus Abort Codes

Unexpected exceptions to geometric handling sometimes occur when PCBoom is tracing rays and determining the geometry of a focus. These are flagged with a negative integer focus abort code, written to the .out file and an output message is generated in the .un6 file.

Table 3-59 contains a listing of the focus abort codes, a brief description and the generating subroutine (useful for diagnostic purposes). Table 3-60 lists the error messages from the .un6 file in alphabetical order and gives additional information about the exceptions encountered in program execution. For more details on the physical descriptions within the error messages, see the PCBoom Version 6.6 Technical Reference and User Manual.

Table 3-59 Focus abort codes and descriptions.

Code	Description	Routine
-1	Caustic intersected the lowest altitude	area
-2	Focal points were straddling a cusp	fhndlr
-3	An auxiliary ray cut off before focusing	area
-4	Focus above ZMAX	area
-5	The ray, in a carpet boom case, cut off	area
-6	An auxiliary trajectory point is subsonic	fob5
-7	N/A – PCBoom 4.18x and earlier only	
-8	Focus occurred less than 4 ray steps from the aircraft	fhndlr
-9	Overran dimensions in tube (Condition detected and NP1 set to -1 as a flag in tube) Not a focus issue.	FOBoom
-10	Both ray and caustic have zero curvature. Makes no physical sense, but can occur if the focus trace went bad in other ways.	fhndlr
-12	3-D radius of curvature is negative. Usually not actually negative but set to -1 by the curvature calculator when a focus point is missing. Essentially 3-D version of -1, -3, -6.	fob5
-13	Focfind failed to find the edge of the focal. Usually due to caustic radius being bigger than expected.	boom, boomq
-21,-23,-24	Aborts -1, -3, -4 in dual mode.	fob5

Table 3-60 Error messages from the .un6 file.

Error Message	Abort Code	Description
3-D focus trace lost: radcurv	-12	A negative curvature of value “radcurv” was encountered causing the focus to be lost.
Caustic surface has intersected the lowest ALT: aborting	-1	There was no focus found on the ray tube. Rather, a caustic was being traced, which intersected the lowest altitude.
Focal points are straddling a cusp.	-2	Abort due to being on the cusp of a caustic.
Focus above ZMAX; will not affect ground	-4	The focus was found to be above ZMAX and will therefore not impact the ground.
Focus point is too close to vehicle	-8	The focus was found to be too close to the vehicle (less than 4 propagation steps along the ray), the run was aborted.
No curvature; aborting	-10	A zero or negative curvature was encountered.
Ray *IRAY* has turned upward at Z = *altitude* ft. with no focus but it’s below the ground. However, a caustic was being traced. Abort	-3	A below ground ray (*IRAY*) turned upward at (*altitude*), however, since a caustic was being traced at the time, this becomes an abort case.

4 Additional Calculation and Visualization Options

The results from FOBoom can be used as input to additional PCBoom modules, depending on analysis goals. The details for the PCBurg, PCBFoot, WCON, and Turbo modules are described in this section.

4.1 PCBurg

The PCBurg module is an implementation of propagation that includes absorption from molecular relaxation based on the lossy Burgers equation, which more accurately accounts for how the atmosphere affects the signature. Molecular relaxation is particularly important when analyzing loudness metric results due to the effect of shock structure on the upper frequency content of booms. The PCBurg module contains a graphical user interface to view the signature as it evolves from the flight altitude to the ground. PCBurg is separate from and slower than the Enhanced Burgers propagation that can be invoked in the FOBoom input file.

Computation of Pmax, ASEL, BSEL, CSEL, DSEL, ESEL, ZSEL, and PL metrics is available in PCBurg. Note that before computing metrics, waveforms are zero padded to the next power of 2 in array length if they do not already have a power of 2 number of points. This is to conform to the signal processing requirements of the FFT algorithms.

Section 4.1.1 describes the inputs to PCBurg, Section 4.1.2 describes how to run PCBurg, 4.1.3 describes available outputs from PCBurg, and Section 4.1.4 describes the HeadlessBurgers module, which is a batch process alternative to PCBurg.

4.1.1 PCBurg Inputs

PCBurg accepts the following file types as inputs. See Section 3.2 for more information on the FOBoom output files. See Section 5.1.3 for more information on RayCau output files.

Casename.out:	The primary output from FOBoom, which contains signature data.
Casename.age:	A FOBoom output file with aging details output at different altitudes along the traced rays.
Casename.ssg:	A FOBoom output file with signature details output at different altitudes along the traced rays.
Casename.foc:	An optional file that is generated by the RayCau module and contains caustic information such as the ray elevation angle and diffraction boundary-layer thickness.

4.1.2 Running PCBurg

To run PCBurg, execute the following command:

PCBurg -casename [options]

where

PCBurg	The name of the PCBurg executable (e.g., pcburg730.exe).
-casename	A dash followed by the name of input files; do not include an extension.
[options] (optional)	Two-letter codes immediately followed by a data item as described in Table 4-1. E.g., PW-30 SR2 GR2.0 to represent a Phi of -30 deg, sample rate of 25,600 samples/sec, and ground reflection factor of 2.

Table 4-1 PCBurg options.

Option Code	Description	Data Item Options	Example
TW	Include "TW" to specify the aircraft time (Tac) for the desired ray.	Time in seconds, with up to 3 decimal places The default value is the first time in the PCBurg input files.	TW67.2 If desired ray is from Tac = 67.2 seconds
PW	Include "PW" to specify Phi angle for the 'wanted' ray.	List Phi angle, decimal degrees. Default is Phi = 0, the centerline.	PW-10.0
UN	Include "UN" to use a GIBBS filter to smooth some of the artifacts created by the FFT functions addressing sharp rise/decay in boom signatures	n/a	UN
FT	Include "FT" to read TW and PW from a *.foc file, and transfer focal zone information	n/a	FT
DF	Include "DF" to specify the step size adjustment factor. See text for discussion.	Default is 0.05. Often, using a value of 0.001 removes Gibbs artifacts. DF may not exceed 1.0	DF.001
GR	Include "GR" to apply a ground reflection factor to the signatures.	Default is 1.90.	GR1.9
RH	Include "RH" to apply constant relative humidity, as a percentage, to be used at all altitudes.	Default is the humidity profile in the age file. Up to 8 digits, including the decimal point may be used.	RH59
SR	Include "SR" to specify the sampling rate code for boom.	Values 1-4 are permitted and correspond to the sampling rates as follows. 1: 10000 samples per second 2: 25600 samples per second 3: 51200 samples per second 4: 102400 samples per second The default selection is 3 (51200 sps).	SR1

The "-casename" and options may be in any order. If any option is given more than once, the last occurrence applies. The options are listed above in the general order of priority in which a user is likely to need them. For example, the user will typically have a particular TW and PW of interest, usually determined after examining a footprint in WCON. It is less likely that the higher sampling rate (option SR) will be needed, and RH would usually be an investigative variable to understand trends. Note that smaller step sizes and higher sampling rates will increase the calculation time.

4.1.2.1 PCBurg Interface

When PCBurg opens, a display similar to Figure 4-1 is shown. This is the starting signature, propagated via thin shock theory to the first 1000 foot interval below the flight altitude. Information available from the Signature Display is described in Table 4-2. The Signature Display may be adjusted by the pressing the keys listed in Table 4-3. Table 4-4 lists the keys that control propagation.

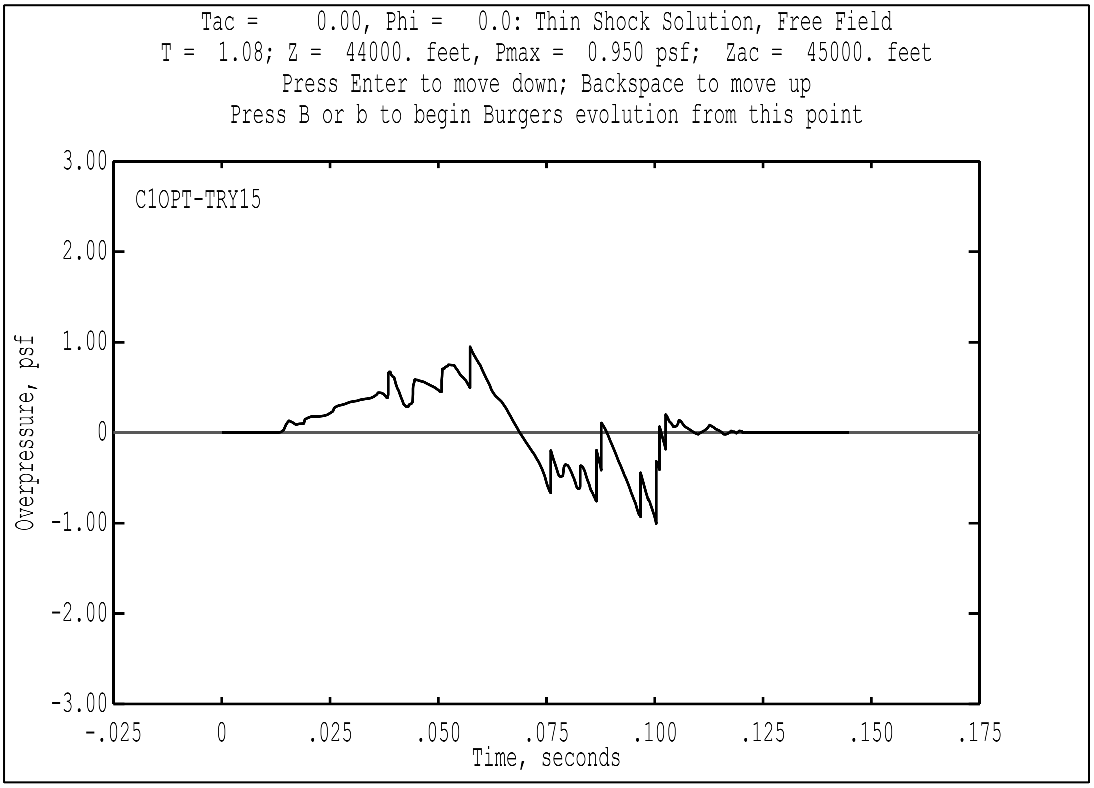


Figure 4-1 Initial display.

Table 4-2 PCBurg initial display parameters.

Parameter	Description
Tac	Time at which the ray originated (aircraft time), in seconds
Phi	Emitted ray azimuthal angle, in degrees (0 is below the aircraft)
Thin Shock Solution	"Thin Shock Solution" is displayed while the propagation method uses the thin shock solution (not the Burgers solution)
Free Field	"Free Field" is displayed while the ray is in the free field (ground reflection not included)
T	Propagation time, in seconds, from the noise source location to the current altitude
Z	Ray altitude, in feet, for the current signature
Pmax	Maximum overpressure in the signature, in pounds per square foot
Zac	Altitude of the aircraft at the ray origination time in MSL ft

Table 4-3 PCBurg display options.

Option	Description
PgUp	Zoom in on the time axis by a factor of 2
PgDn	Zoom out on the time axis by a factor of 2
< or >	Increase or decrease both ends on the time axis
Cursor Left	Pan to left along the time axis
Cursor Right	Pan to right along the time axis
Cursor Up	Zoom in on the pressure axis by a factor of 2
Cursor Down	Zoom out on the pressure axis by a factor of 2
Home	Zoom to original time and pressure axes limits
n	Zoom in on energy spectral density amplitude range
m	Zoom out on energy spectral density amplitude range
s	Switch display to energy spectral density
t	Switch display to pressure timeseries

Table 4-4 PCBurg propagation options.

Option	Description
Enter	Propagate down to the next lower 1000 foot altitude interval
Backspace	Un-propagate upward to the next higher interval (thin shock mode only)
b	Switch to Burgers propagation
g	Applies 1.9 ground reflection factor (at ground altitude only)
F6	Graphical output, in PDF or WMF format
F7	Tabular output of data in current display in ASCII format
Esc	Quit

The default display is in thin shock mode, without accounting for atmospheric absorption effects. Pressing the ”Enter” key propagates the waveform by a 1,000 ft vertical distance, which can be repeated until the waveform reaches the ground. Pressing the “g” key applies the user-specified ground reflection coefficient. Pressing either the “Enter” or “Backspace” key reverts to the free-field waveform.

Pressing “b” (or “B”) will initiate Burgers propagation. This can be done at any altitude except the ground. The ability to initiate Burgers at any altitude permits the user to ensure shock strengths have reduced sufficiently so as to ensure the signature has evolved into the acoustic far field where the lossy Burgers solution is valid. Once the “b” key is pressed, the display will change to that shown in Figure 4-2. The “Enter” key will continue propagation downward in 1000 foot altitude intervals. Backspace is inactive. When at the ground, the “g” key invokes ground reflection but is irreversible. PCBurg does not utilize the flow-resistivity or provide output signals for elevated receiver heights.

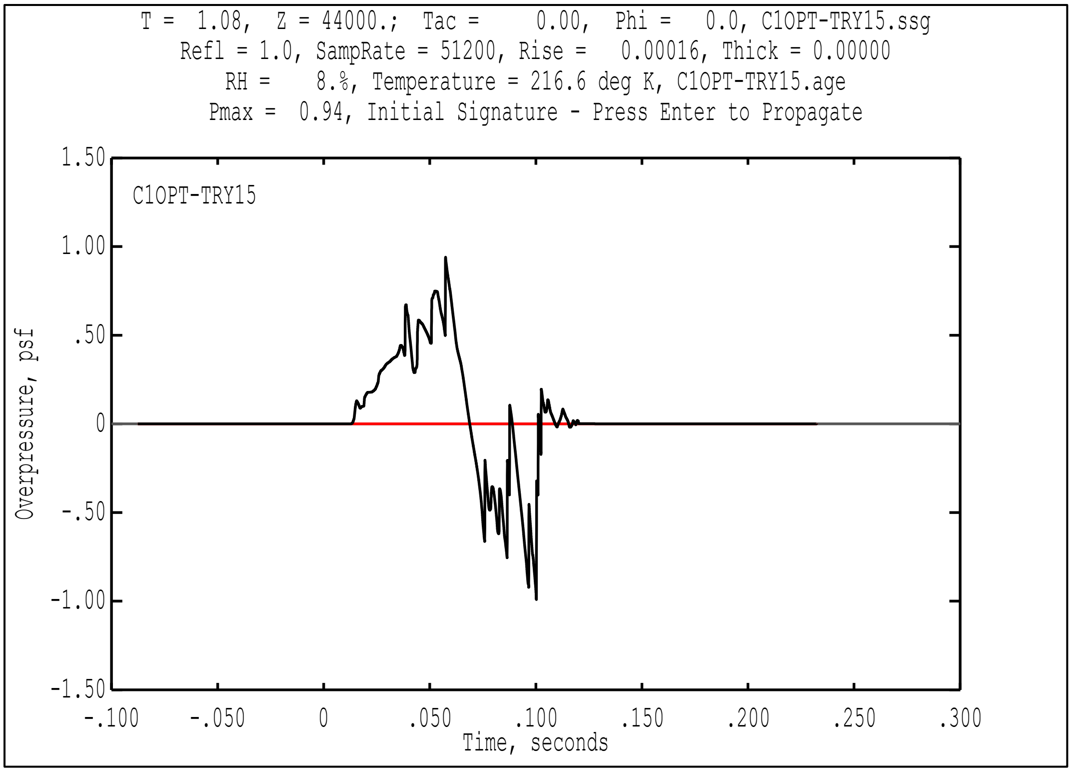


Figure 4-2 Display at the start of Burgers propagation.

By successively pressing the “Enter” key, the signature can be observed as it propagates downward. Calculation can take some time, particularly at higher altitudes. "Calculating…" appears on the display while this occurs.

The step size is an important numeric parameter, which is determined by PCBurg as follows:

- The steepest segment in the signature is identified.
- The propagation time in which this segment would become vertical due to nonlinear steepening is computed.
- The propagation time to vertical is multiplied by DF, which stands for dtFactor, a parameter less than 1.

The default value of DF is 0.05, a value that was found to be a good balance between computational speed and stability. This can be overridden by the DF option specified in Table 4-1. Larger values (but always less than 1.0) can speed up processing. Conversely, if instability artifacts are seen in the signature, the process can be restarted specifying a smaller value of DF. Instabilities usually appear either as Gibbs phenomenon spiking at peaks, or sometimes as high frequency oscillations around the peaks.

Figure 4-3 shows a final ground signature for the sample case shown in Figure 4-1 and Figure 4-2. Information available in the display during Burgers propagation is described in Table 4-5. Figure 4-4 shows the energy spectral density of the ground signature.

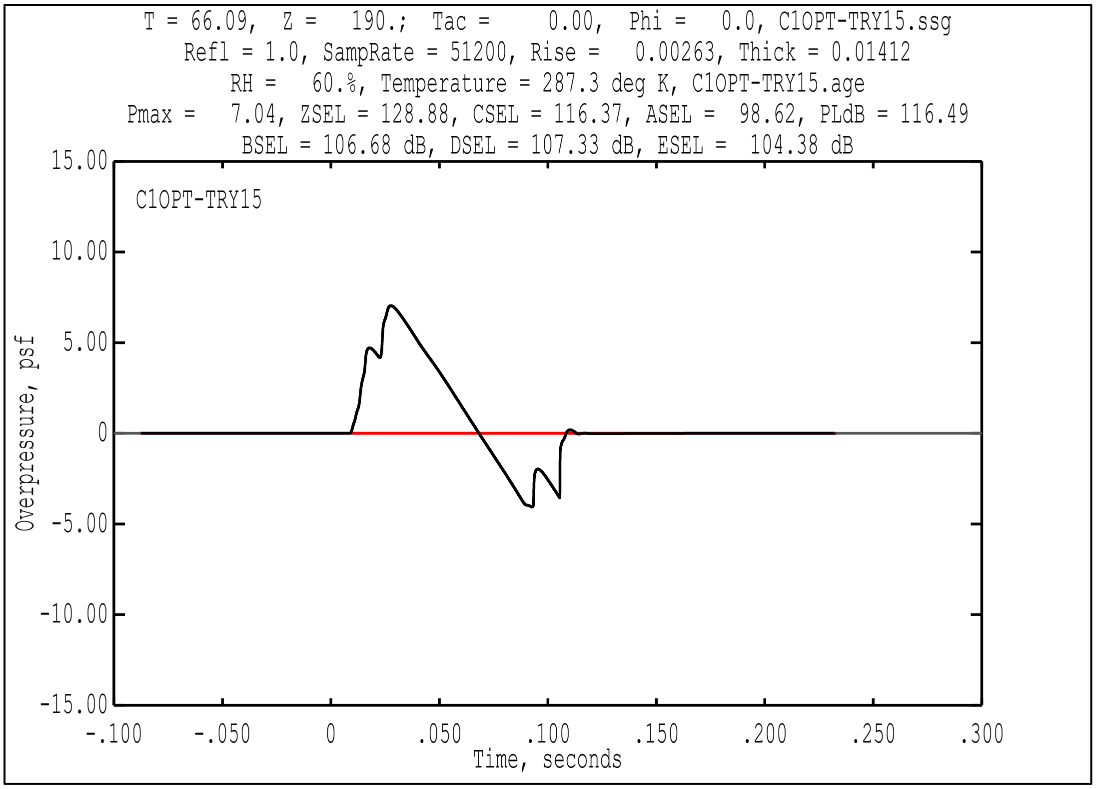


Figure 4-3 Burgers solution at the ground.

Table 4-5 PCBurg display and Burgers propagation parameters.

Parameter	Description
T	Time, in seconds for the waveform shown in the display
Z	Altitude of the display signature (ft)
Tac	Aircraft Trajectory time at which the ray originated, (s)
Phi	Ray emission azimuthal angle, in degrees (0 degrees is directly below the aircraft)
casename.ssg	The name of the .ssg file which provides the starting signature information
Refl	Ground reflection factor. 1.0 if not at the ground. Applied value if at the ground.
SampRate	Sampling rate in samples per second
Rise(i)	Rise time based on the maximum slope of the initial part of the signature, as if it represented a shock of amplitude P_{max}.
Thick(i)	The time from the point to where the signature is 10% of P_{max} to the point where it is 90% of P_{max}.
Filtered	"Filtered" will be displayed if the Gibbs filter is on (option "UN" in Table 4-1)
RH	Relative humidity at the current altitude (%)
Temperature	Temperature at the current altitude (K)
casename.age	The name of the .age file which provides the atmospheric information
Pmax	Maximum overpressure in the signature(psf)
ZSEL	Unweighted sound exposure level(dB)
CSEL	C-weighted sound exposure level (dB(C))
ASEL	A-weighted sound exposure level (dB(A))
PLdB	Stevens Mark VII Perceived Level of Loudness (dB)
BSEL	B-weighted sound exposure level (dB(B))
DSEL	D-weighted sound exposure level (dB(D))
ESEL	E-weighted sound exposure level (dB(E))

Notes: (i) Rise and Thick parameters are traditional measures of rise time for N-wave booms. They are only meaningful for N-wave and flat-top booms, not complex booms such as multi-shock examples.

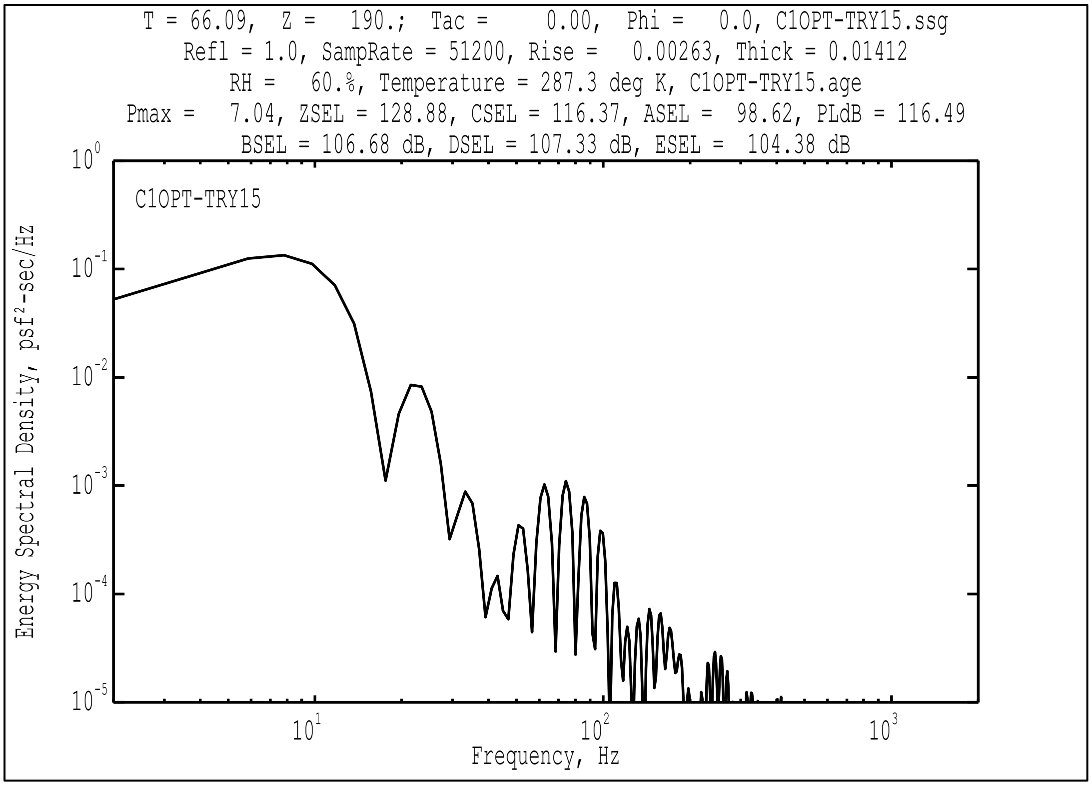


Figure 4-4 Energy spectral density of the Burgers solution at the ground.

4.1.3 PCBurg Outputs

PCBurg can output graphical or tabular data at any altitude.

To generate graphical output of the PCBurg screen at the current altitude:

1. Press the “F6” key
2. Select *Print* and follow the prompts to save in PDF format or *WMF Output* and follow the prompts to save in WMF output.

To generate the signature file in ASCII format (.txt) for the current altitude:

1. Press the “F7” key
2. Enter a name and click *Save*.

4.1.4 HeadlessBurgers

The HeadlessBurgers module contains the same physics as the PCBurg module without the graphical user interface. It was created in order to process FOBoom output files (.age and .ssg files) as a batch process.

The inputs to the HeadlessBurgers module are the same as PCBurg; the .age and .ssg as well as the options as described in Section 4.1.2. To run HeadlessBurgers, execute the following command.

```
HeadlessBurgers -casename [options]
```

where

HeadlessBurgers	name of the HeadlessBurgers executable (e.g., headlessburgers730.exe)
-casename	a dash followed by the name of the .age and .ssg output files from FOBoom which are used as input into PCBurg; do not include a file extension
options	two-letter codes immediately followed by a data item as described in Table 4-1.

The output from HeadlessBurgers is a .bsg (Burgers signature) file that contains the same information as the signature file obtained through PCBurg with the exception of the caustic information.

4.2 PCBFoot

The PCBFoot module is a post-processor that applies artificial aging to FOBoom output to approximate atmospheric absorption. It also organizes the FOBoom footprint and signature outputs into structured files for use in WCON. Finite rise times are artificially obtained by applying Taylor shock absorption, from which metrics are calculated. Note that before computing metrics, waveforms are zero padded to the next power of 2 in array length if they do not already have a power of 2 number of points. This is to conform to the signal processing requirements of the FFT algorithms. Also note that PCBFoot addresses ground booms only; waveform prediction at elevated receiver heights requires the use of WCON.

When PCBFoot reads the FOBoom .out file, it extracts data for plotting noise contours in WCON. This includes the ground intersection points for all the predicted rays and their signatures.

- For a nonfocus case, the boom signature at the ground is read. For a focus case, there is a last geometric signature and a focus signature as predicted by FOBoom.
- A focus below the ground may also have a ground signature. If both a ground signature and a below-the-ground signature occur, the program selects the smaller amplitude signature of the two.
- For a focus above the ground, the distance from the focal point to the ground is compared to the focal zone dimension XSTAR. If the focal zone reaches the ground, the focus signature is applied at the ray-ground intercept. If the focal zone is above the ground, then the post-focus signature is projected to the ray/ground intercept.

The focus signature data are modeled in PCBFoot based on a single-shock solution, which is reliable for N-waves and other simple signatures. The last geometric signature is output before FOBoom applies the Plotkin-Cantril method to predict the focus waveform. The formulation of the artificial atmospheric absorption contained within PCBFoot is not applicable to signatures computed using PCBurg/HeadlessBurgers.

Section 4.2.1 describes the inputs to PCBFoot, Section 4.2.2 describes how to run PCBFoot, and Section 4.2.3 describes available outputs from PCBFoot.

4.2.1 PCBFoot Inputs

PCBFoot accepts the following file types as inputs. See Section 3.2 for more information on the FOBoom output files.

Casename.out:	The primary output from FOBoom, which contains signature data.
Casename.gmp:	An optional file that is generated by FOBoom when the keyword GROUND is specified (Section 3.1.8) and contains ground mode parameter information. This file is required when ground impedance effects are to be included in the analysis.
Casename.org:	An optional file that is generated by FOBoom when the keyword longlat or geomode are included in the trajectory file. This file contains the longitude and latitude of the origin and is required for georeferencing visualizations and post-processing in WCON.
HIGHRES filename.txt:	An optional user-generated text file used in FOBoom, PCBFoot, and WCON to specify the sampling rate for the signature files, see Section 3.1.14.

Section 3.2 for more information on the FOBoom output files.

4.2.2 Running PCBFoot

To run PCBFoot, execute the following command:

PCBFoot casename[.ext] [ioutputs] [HIGHRES:filename.txt]

where

PCBFoot	The name of the PCBFoot executable (e.g., PCBFoot730.exe).
Casename[.ext]	The name of the input file(s). Inclusion of the extension (.ext) is optional. If the extension (.ext) is not specified, .out is assumed. A period may be included in the case name, but the .out extension must also be included (e.g., Flight_1057_04.30.09.15.23.29.out).
[ioutputs] (optional)	Specifies desired output files. The following PCBFoot output files may be generated by specifying the sum of the following options. The default ioutputs value is 5.

1	Display progress on the screen
2	Write a boom summary ASCII file (.asc)
4	Write signature files (.ind, .sig, .ens)
8	Do not compute loudness for .qwk file
16	Do not write .qwk file
32	Write .ind file, do not write .sig or .ens
64	Do not apply the Taylor Shock Structure to the signature in order to isolate the effects of the waveform steepening
128	Write .gnd file
256	Suppress the post-focus calculations Recommended to use in cases with non-N-wave booms and focusing.

[HIGHRES:filename.txt] (optional)	An optional file with “HIGHRES:” to signify that a HIGHRES file will be specified followed by the name of the file and extension .txt. Use this file to specify the sampling rate for the signature files from within an external file. Note: In order to run WCON with the HIGHRES option, PCBFoot and FOBoom must have been run with the same option and input file. See Section 3.1.14 for file format information.

The presence of any value for outputs will cause progress during computation to be displayed.

4.2.3 PCBFoot Outputs

PCBFoot outputs are specified in the command to run PCBFoot, see Section 4.2.2. Details for the available outputs are described in this section.

Casename.qwk:	This binary file contains footprint, metric data, and isopemp data and is required for WCON.
Casename.sig:	This binary file contains the primary signature output from PCBFoot and is required for WCON.
Casename.ind:	This is a companion binary file to the .sig file and contains the shock indices for the corresponding signatures. The .ind file is a required input file for WCON.
Casename.ens:	This binary file contains unit vectors for the end of ray incident angles. This information is taken from the FOBoom .out file and assembled within PCBFoot. The incident ray angle is used both by the ground effects algorithm in PCBFoot and by the underwater sonic boom penetration feature in WCON.
Casename.asc:	Boom summary output file that includes the aircraft position and flight condition and the centerline boom location, and overpressure information. Additionally, isopemp details are output for trajectory aircraft times in sequence.
Casename.gnd	An output that contains an ASCII table of geodetic coordinates and metrics wherever the maximum overpressure (P) is not zero. These results can be used with contouring applications outside of WCON.

4.3 WCON

The WCON module is an interactive sonic boom footprint and signature display module. This module interpolates boom signatures (including secondary post-focus u-waves) between ray ends provided by PCBFoot in order to allow users to retrieve boom signatures at desired locations.

Ground effects on the pressure waveform received at a user-specified elevation above ground level can be viewed in WCON if the GROUND keyword is invoked in FOBoom, see Section 3.1.8 . WCON includes algorithms to compute turbulence effects using several different methods and booms that have penetrated beneath a water surface. Additionally, the spectrum and residual shock spectrum of the booms can be displayed. Note that WCON addresses ground booms only.

Pmax, ASEL, BSEL, CSEL, DSEL, ESEL, ZSEL, PL, and Lpk metrics are available in WCON. Note that before computing metrics, waveforms are zero padded to the next power of 2 in array length if they do not

already have a power of 2 number of points. This is to conform to the signal processing requirements of the FFT algorithms.
Section 4.3.1 and subsections describe the inputs to WCON, Section 4.3.2 and subsections describe how to run and interact with WCON and the available displays, 4.3.3 describes available outputs from WCON, and Section 4.3.4 describes how the FiltView module is access from within WCON to include turbulence effects using Finite Impulse Response (FIR) filters.

4.3.1 WCON Inputs

WCON accepts the following file types as inputs. For more information on PCBFoot outputs, see Section 4.2.3.

Casename.qwk:	A binary PCBFoot output file that contains footprint, metric data, and isopemp data.
Casename.sig:	A binary PCBFoot output file that contains the primary signature output.
Casename.ind:	A binary PCBFoot output file that is a companion file to the .sig file. This file contains the shock indices for the corresponding signatures.
Casename.ens:	This binary file contains unit vectors for the end of ray incident angles. This information is taken from the FOBoom .out file and assembled within PCBFoot. The incident ray angle is used both by the ground effects algorithm in PCBFoot and by the underwater sonic boom penetration feature in WCON.
Casename.asc:	This binary file contains boom summary information that includes the aircraft position and flight condition, the centerline boom location, overpressure information, and isopemp details for trajectory aircraft times.
HIGHRES filename.txt:	An optional user-generated text file used in FOBoom, PCBFoot, and WCON to specify the sampling rate for the signature files, see Section 3.1.14.
Automating Scriptfilename.txt:	An optional user-generated text file to automate writing boom signatures to files, see Section 4.3.1.1 for more information.
corr.txt:	An optional user-generated text file to add graphical markers and a boundary to the Footprint Display, see Section 4.3.1.2 for more information.
SonicBAT-Run-Fort.config	This configuration file is required when accessing the FiltView module through WCON. Note that WCON is coded to search for a file named “SonicBAT-Run-Fort.config” containing FiltView executable information, whether or not the SonicBAT-Run-Fort module is used. See Section 6.1.1.2 for more information on this configuration file.

4.3.1.1 Script File Format

Boom signatures and a .bms file with information on the ray ends used to calculate the booms can be written from WCON to output files automatically through the use of a script file without the need to use the WCON interface. See Section 4.3.3 for more information on outputs generated by the presence of this input file.

The input format for the text file is shown in Table 4-6. Example script files using local coordinates and geographic units are shown in Figure 4-5, and Figure 4-6, respectively.

Note that when running WCON in script mode, there is no test to determine whether the provided coordinates are within the footprint. If the coordinates are outside the footprint, WCON will halt with an error.

Table 4-6 Script file format.

Line	Position	Variable Type	Description
1	1	Integer	ASCII key code for the desired keystroke option. This code should reflect the option in the WCON interface (Table 4-9) that allows for specifying the point of interest for the signature in, e.g., “p” to specify coordinates using local, X,Y coordinates or “l” to specify coordinates using geographic units when trajectory input uses the geomode keyword. p/P = 112 l/L = 108
2	1	Float	Coordinates separated by a comma Use local, X,Y coordinates (e.g., 1000, -3500) if “p” was specified on line 1 Use geographic units, east longitude and north latitude, decimal degrees (e.g., -117.8855285, 34.9080884) if “l” was specified on line 1
3	1	Integer	ASCII code (307) for the F7 keystroke
4	1	Character	Signature output file name with extension .txt
5	1	Integer	ASCII code (27) for the Esc keystroke
6+			Repeat lines 1-5 for each point of interest
Last line	1	Integer	Enter 600 to close WCON

```
112
1000,-3500
307
OutputFileName.txt
27
```

Figure 4-5 WCON script file example in local coordinates.

```
112
-117.8855285, 34.9080884
307
OutputFileName.txt
27
```

Figure 4-6 WCON script file example in geographic units.

4.3.1.2 corr.txt File Format

Graphical markers to highlight point locations and a boundary can be displayed in the Footprint Display by using a corr.txt file. If a file named corr.txt exists in the working directory, WCON will read its contents and display the defined items.

A point is identified by its coordinates and marker type. There must be at least one point listed in the file. The use of boundaries is optional and are identified by the coordinates of vertices in the order they will be connected. The format of the corr.txt file is detailed in the Table 4-7. Available marker types are shown with their associated marker numbers in Figure 4-7.

Table 4-7 corr.txt file format and contents.

Line(s)	Program Variable(s)	Format[(i)]	Description
1	yref, xref	2F	Reference point longitude, latitude[(ii)]
2	nmarks	1I	Number of point locations to follow this line[(iii)] Maximum number of points is 100.
nmarks	yhouse, xhouse, imark	2F,1I	Longitude, latitude, and marker type for each point
4+nmarks	N/A	C	Comment for following boundary (unused by wcon)[(iv)]
5+nmarks	npbnd	1I	Number of vertices in the boundary.[(v)] Max number of boundaries is 50.
npbnd	ybnd, xbnd	2F	Longitude and latitude of vertex. Max vertices is 100.

Notes: (i) All lines are list-directed read in Fortran. NI indicates N integers expected, NF indicates N real numbers expected, and C indicates variable character string. Separation of numbers can be by commas or spaces on that line.
(ii) If case is running in geomode, the reference point in the casename.qwk file will be used as reference. If not in geomode, a casename.org file will take precedence over the yref, xref in the corr.txt file. It is recommended to run in geomode for best alignment.
(iii) If there is only one point location for display, then record 2 is replaced by the point's coordinates. A max of 100 points is allowed.
(iv) Use of boundaries is optional. Maximum of 50 boundaries allowed. Lines 4 through npbnd repeated for each boundary to be displayed.
(v) A max of 100 vertices per boundary is allowed.

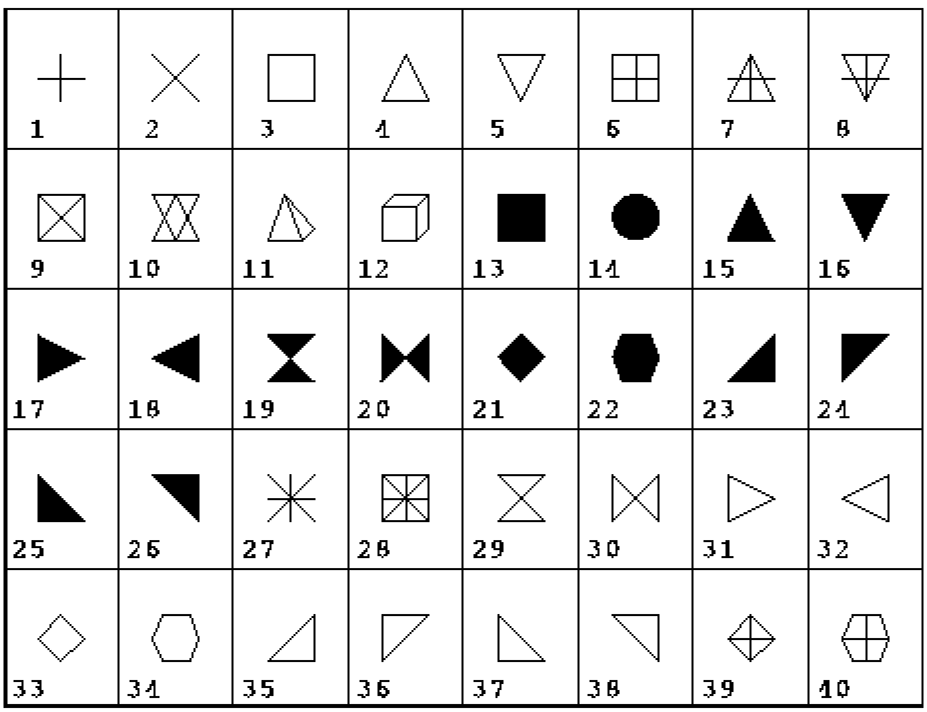


Figure 4-7 Types of point markers available with associated marker numbers.

4.3.2 Running WCON

To run WCON, execute the following command:

```
WCON casename [options] [-scriptfilename] [HIGHRES:filename.txt]
```

where

WCON	The name of the WCON executable (e.g., wcon730.exe).
casename	The name of the input files. Inclusion of the extension (".ext") is optional. If the extension (".ext") is not specified, ".qwk" is assumed.
[options] *(optional)*	a string with any or all of the t, p, c options, or x (e.g., tpc or x) where: t to show the trajectory in the footprint graphic p to show the isopemps in the footprint graphic c to show the contours in the footprint graphic x to show the trajectory, isopemps, and contours, restricting the drawing of contours to within the area containing the isopemps Note: When WCON opens, the trajectory, isopemps, and contours are shown on the plot by default (in the absence of specifying t, p, c, or x). It is recommended to specify any combination of t, p, and c when one or more of the options should be excluded from the plot.
[-scriptfilename] *(optional)*	An optional file with a dash to signify that a script file will be used followed by the name of the script file. Use this file to automate writing boom signatures for the points specified in the external file. Note that the scriptfilename is the full path name (limited to 60 characters) to the script file. See Section 4.3.1.1 for more information.
[HIGHRES:filename.txt] *(optional)*	An optional file with "HIGHRES:" to signify that a HIGHRES file will be specified followed by the name of the file and extension .txt. Use this file to specify the sampling rate for the signature files from within an external file. Note: In order to run WCON with the HIGHRES option, PCBFoot, and FOBoom must have been run with the same option and input file. See Section 3.1.14 for file format information.

The WCON interface has two displays, a Footprint and a Signature Display. The Footprint Display is shown upon opening WCON. See Section 4.3.2.1 for more information on the Footprint Display, section 4.3.2.2 for more information on the Signature Display.

4.3.2.1 WCON Interface: Footprint Display

The Footprint Display is the primary display in WCON and is shown when WCON opens.

The Footprint Display is made up of the following areas (Figure 4-8):

- Main Display – where data are plotted
- Main Display/Legend – the legend that corresponds to the plotted data
- Options Pane – Summary of available functions
- Data Pane – Displays information about the footprint

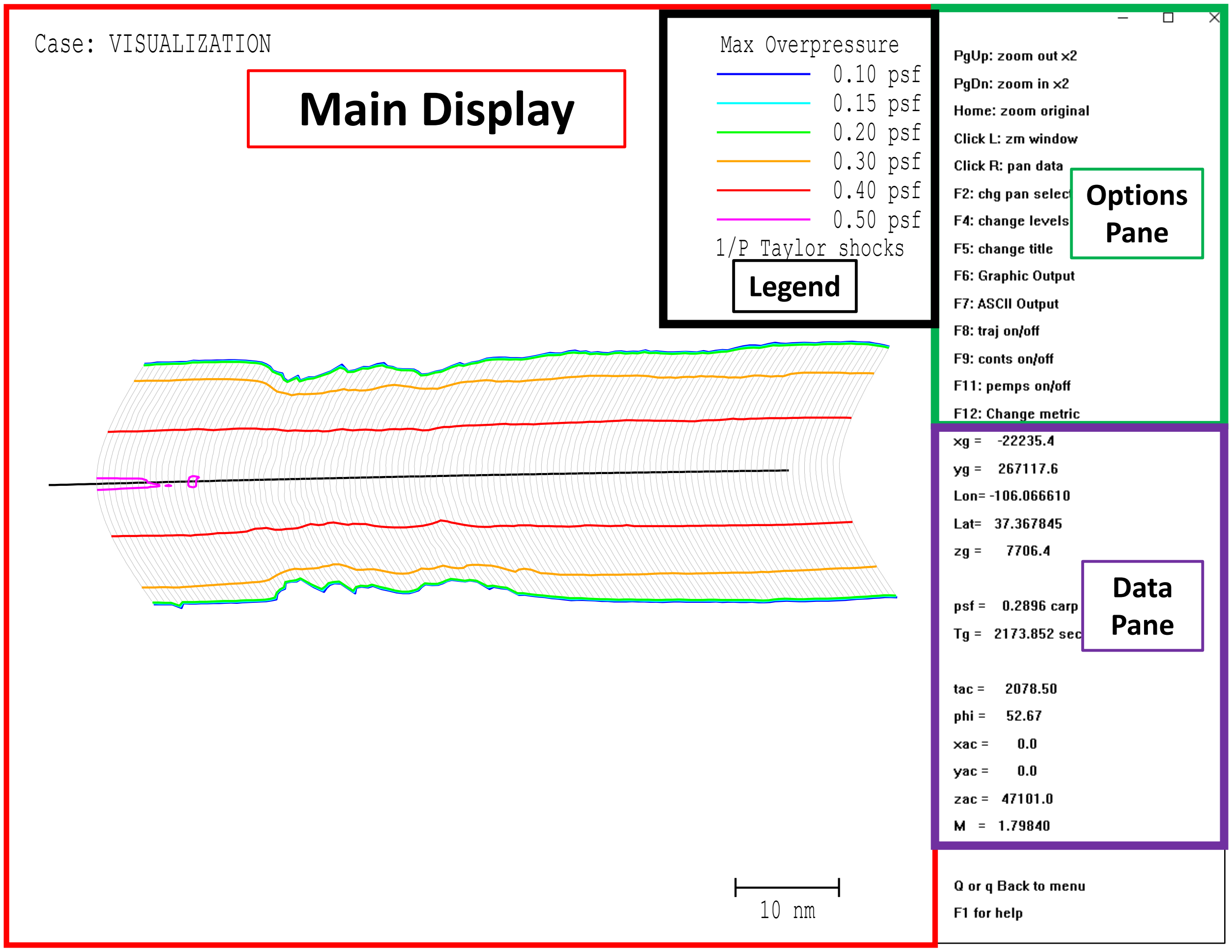


Figure 4-8 WCON footprint display areas.

The Main Display area shows the following footprint information on an X-Y plot upon opening (Figure 4-9):

- Title (the case name is the default title)
- Contours of equal overpressure (psf)
- A user-editable legend
- The trajectory
- The isopemps
- A size scale

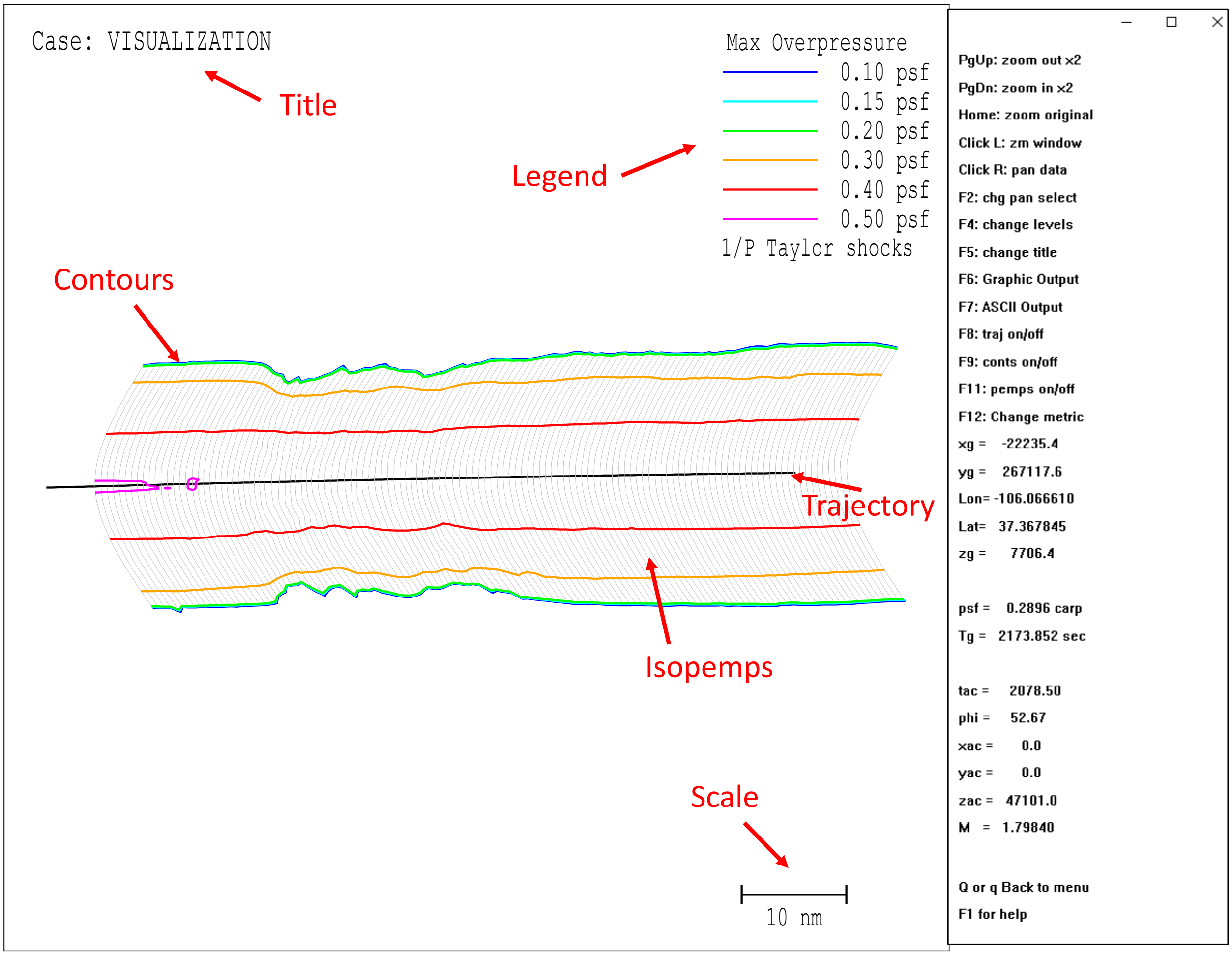


Figure 4-9 WCON footprint main display.

The Data Pane displays information about the boom on the ground and its origin at the aircraft.

The coordinates of the current position of the mouse pointer are shown, in feet, as xg, yg. The remaining parameters are the properties of the boom on the ray whose ground intercept is xg, yg. Note that this Data Pane is active even if the pointer is outside the footprint: data for the closest ray are always shown.

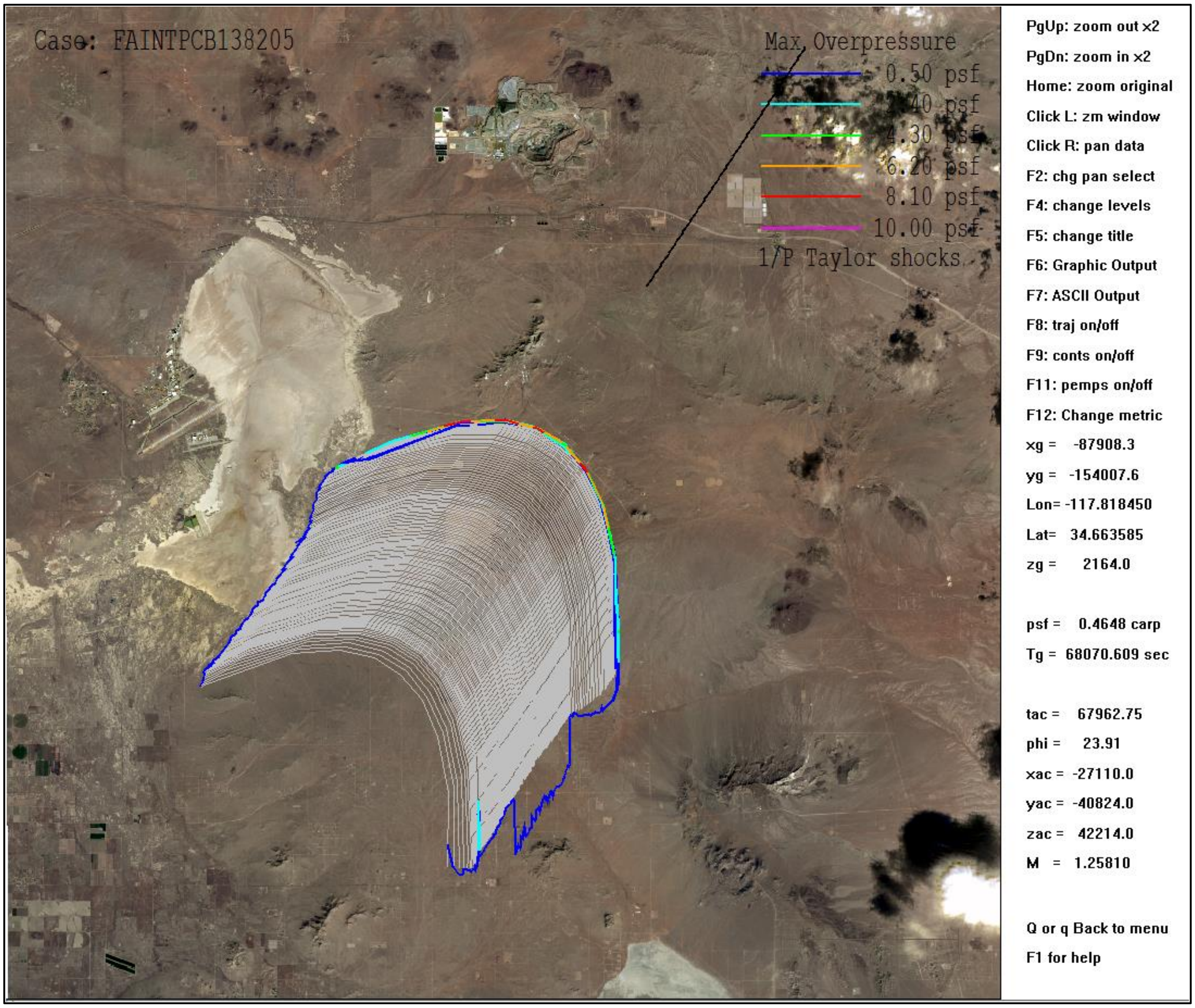


Figure 4-10 WCON footprint main display with background image [Source: NASA].

Table 4-8 describes the available data within the Footprint Display.

Table 4-8 WCON footprint display, data pane.

Parameter	Description
xg	X coordinate of the mouse pointer, in feet
yg	Y coordinate of the mouse pointer, in feet
Psf XXX [signature type]	The level for the metric shown in the legend followed by the type of signature; options include: *Metrics:* Maximum overpressure, in psf C Weighted SEL, in dB(C) Peak level, in dB Perceived loudness, in dB A Weighted SEL, in dB(A) Flat SEL, in dB(E) *Types of signatures:* *carp* *foc* *fill* *none* *post*
Phi	Azimuth angle, in degrees
Tac	Time at which the ray originated (aircraft time), in seconds
xac	X location of the aircraft from which the ray originated, in degrees
yac	Y location of the aircraft from which the ray originated, in Ft
zac	Altitude of the aircraft from which the ray originated, in Ft
M	Mach number of the aircraft from which the ray originated

There are many options for interacting with the footprint data by keystroke and by using the mouse. The Options Pane within the interface contains a subset of the total options. A full list of options is given in Table 4-9.

Table 4-9 WCON footprint display options.

Option	Description
PgUp	Press Page Up to zoom out by a factor of 2
PgDn	Press Page Down to zoom in by a factor of 2
Home	Press Home to return to original zoom level
Click L	Left-click and drag to zoom in on a specified area
Click R	Pan across this display by right-clicking once to specify the starting point, then again in to specify the new location for the starting point
F2	The scale, legend, title, and data can be repositioned in the interface by panning to another location. Press F2 to change the item to pan. The data in the Main Display is selected for panning by default. Available options include: Pan data Pan scale Pan legend Pan title
F4	Press F4 to open a dialog which allows for editing the contour level values for the current metric Pressing F4 also creates a file (.aux) that will store contour level for later reuse
F5	Press F5 to open a dialog which allows for editing of the title
F6	Press F6 to print the graphic to PDF, save the graphic in WMF format, or rescale the graphic
F7	Press F7 to generate tabular data in ASCII format for the footprint with extension .pdx
F8	Press F8 to turn the trajectory on/off in the Main Display
F9	Press F9 to turn the contours on/off in the Main Display
F11	Press F11 to turn the isopemps on/off in the Main Display
F12	Press F12 to change the metric; available options include: Max Overpressure C Weighted SEL Peak Level Loudness A Weighted SEL Flat SEL
Q or q	Press Q or q to return to the menu
F1	Press F1 to display the help screen Note that the wconhelp.rtf and plothelp.rft files must exist in same location as the WCON executable for the help screen to display help information
Additional Options Not Shown in the Interface	
CTRL+F11	Press CNTRL + F11 to display ray end points
l/L	Hover over the point of interest and press ‘l’ to open the *Specific Point Boom* dialog, specify the coordinates using geographic units, and press *OK* to open the Signature Display for the point of interest. This option is available when trajectory input uses the geomode keyword.
p/P	Hover over the point of interest and press ‘p’ to open the *Specific Point Boom* dialog, edit the coordinates if needed, and press *OK* to open the Signature Display for the point of interest.
r/R	Open the Signature Display and display the signature at the nearest ray (for a single wave associated with that ray).

4.3.2.2 WCON Interface: Signature Display

A time plot of the sonic boom signature can be displayed at any point within the footprint. The signature displayed can be associated with a particular ray or at a specific point on the ground. The WCON Signature Display is access through the WCON Footprint Display. See 4.3.2.1 for information on how to access the Signature Display.

Capability has been incorporated into WCON to predict the sonic boom signature envelope due to moderate or strong amplitude turbulence based on a scattering theory developed by Crow[59] and adapted to finite thickness shocks by Plotkin.[53]

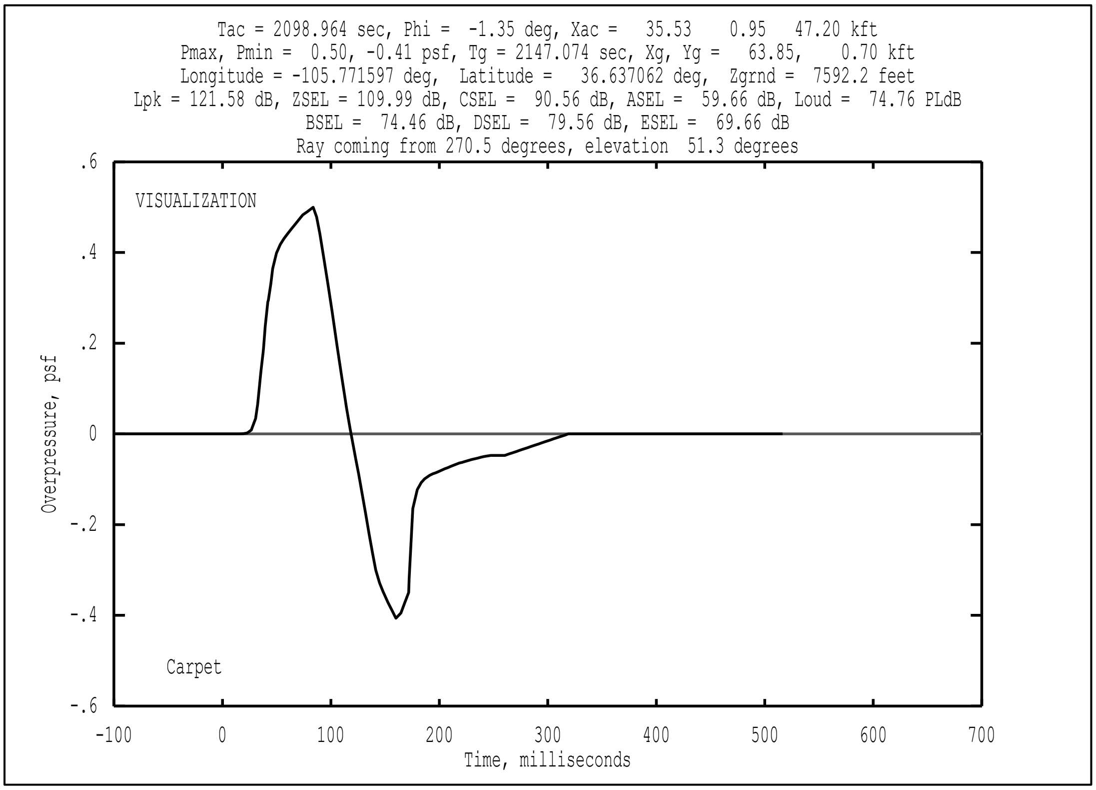


Figure 4-11 Example WCON signature display.

The data available within the Signature Display is shown above the plot. Table 4-10 describes the available data within the Signature Display.

Table 4-10 WCON signature display data.

Parameter	Description
Tac	Time at which the ray originated (aircraft time), in seconds
Phi	Azimuth angle, in degrees
Xac	Aircraft position at the time of signature generation, X, Y (feet) and Altitude (k feet)
Pmax, Pmin	Maximum and minimum overpressure in the signature, in pounds per square foot
Tg	Ray arrival time at the ground, in seconds
Xg, Yg	X and y coordinates of the point within the footprint corresponding to the displayed signature
Lpk	Peak overpressure Level, dB
ZSEL	Flat SEL, in dB
CSEL	C-weighted sound exposure level, in dB(C)
ASEL	A-weighted sound exposure level, in dB(A)
Loud	Perceived loudness, in dB
Ray coming from	Azimuth angle of ray emission at the aircraft, in degrees
elevation	Ray elevation angle at the ground location, in degrees

The options for interacting with the signature display are described in Table 4-11 and by pressing F1 while in the signature display.

Table 4-11 WCON signature display options.

<table>
<tr><th>Option</th><th>Description</th></tr>
<tr><td></></td><td>Adjust the current time axis maximum value</td></tr>
<tr><td>+/-</td><td>Adjust the pressure scale for the current time plot</td></tr>
<tr><td>a</td><td>Autoscale the current time plot</td></tr>
<tr><td>c/C</td><td>Add or remove the signature envelope based on Plotkin's implementation[53] of Crow's theory[59] for moderate amplitude turbulence
Note: only one turbulence model can be displayed at a time</td></tr>
<tr><td>k</td><td>Enter atmospheric conditions to automatically apply the appropriate filter to include turbulence effects using FIR filters based on KZK modeling by way of the FiltView module.

The atmospheric conditions include:
Boundary layer height in ft AGL
Relative humidity as a percentage at the ground
Turbulence strength (low, medium, or high)
<table>
<tr><th>Strength</th><th>$\mathbf{u}_*$ $(\mathbf{m/s})$</th><th>$\boldsymbol{w}_*$ $(\mathbf{m/s})$</th><th>$\boldsymbol{T}_*$ $(\mathbf{K})$</th><th>$\boldsymbol{\sigma}$vector $(\mathbf{m/s})$</th></tr>
<tr><td>Low</td><td>0.1</td><td>0.44</td><td>-0.5</td><td>0.31</td></tr>
<tr><td>Medium</td><td>0.35</td><td>1.55</td><td>-0.5</td><td>1.10</td></tr>
<tr><td>High</td><td>0.6</td><td>2.66</td><td>-0.5</td><td>1.89</td></tr>
</table>
where u* = friction velocity scale, w* = mixed-layer velocity scale, and T* = surface-layer temperature scale</td></tr>
<tr><td>n/m</td><td>Decrease (n) or increase (m) the spectrum plot amplitude range</td></tr>
<tr><td>p/P</td><td>Apply or remove turbulence effects using FIR filters based on empirical data.[66] This will apply a filter to the currently displayed signature. Upon turning on the FIR turbulence filter, a selection dialog will be displayed to allow for selection of the specific filter to be used. Current options are as follows:

Average turbulence
Big Spike (PSU Run 5, Filter 30, high turbulence)
Rounded (PSU Run 5, Filter 144, high turbulence)
Small Spike (PSU Run 5, Filter 400, low turbulence)
Tiny Round (PSU Run 5, Filter 200, low turbulence)
Little Spike, Little Round Combo (PSU Run 5, Filter 250, low turbulence)

Note: only one turbulence model can be displayed at a time</td></tr>
<tr><td>r/R</td><td>Show the residual shock spectrum of the boom</td></tr>
<tr><td>s/S</td><td>Show the spectrum (energy spectral density) of the boom</td></tr>
<tr><td>t/T</td><td>Show the time plot of the signature</td></tr>
<tr><td>Esc</td><td>Return to the footprint display</td></tr>
<tr><td>F1</td><td>Display the help screen
Note that the wconhelp.rtf and plothelp.rft files must exist in same location as the WCON executable for the help screen to display help information</td></tr>
<tr><td>F6</td><td>Print the graphic to PDF, save the graphic in WMF format</td></tr>
<tr><td>F7</td><td>Generate tabular data in ASCII format for the current display with extension .txt
In "t" mode, the time data will be output
In "s" or "r" mode, both the spectrum and the residual shock spectrum will be output</td></tr>
<tr><td>Home</td><td>Autoscale the current time plot (time axis)</td></tr>
<tr><td>Left Arrow</td><td>Shift the current time plot to left</td></tr>
<tr><td>Right Arrow</td><td>Shift the current time plot to right</td></tr>
<tr><td>Down Arrow</td><td>Move the receiver position to successive depths below the water surface</td></tr>
<tr><td>Page Down</td><td>Zoom out current time plot (time axis)</td></tr>
<tr><td>Page Up</td><td>Zoom in current time plot (time axis)</td></tr>
<tr><td>Left Click</td><td>Show the maximum value to the left of the mouse pointer.</td></tr>
<tr><td>Right Click</td><td>Right-click, move the mouse, then right-click on a second point to show the maximum value between the two points</td></tr>
</table>

4.3.3 WCON Outputs

WCON can output graphical or tabular data for the current Footprint or Signature Display at any point. For more information on available displays, see Section 4.3.2.

To generate graphical output of the current WCON screen:

1. Press the "F6" key
2. Select *Print* and follow the prompts to save in PDF format or *WMF Output* and follow the prompts to save in WMF output.

To generate tabular output of the current WCON screen:

1. Press the "F7" key
2. Enter a name and click *Save*.

If running WCON with a script file (Section 4.3.1.1) to generate signatures automatically, the signature files are created with the name as specified in the output file with .txt extension. A file with .bms extension is also written and contains the information shown in Table 4-12 for the ray ends used to calculate the booms.

The naming convention for the .bms file is:

Casename_xg_yg.bms

Where xg and yg are the position on the ground in feet relative to the case's origin in local coordinates (regardless of the coordinate system used within the script file).

Table 4-12 WCON .bms output file contents.

Line	Contents
1	Number of booms at x,y location in local coordinates (ft)
2	Boom number, Arrival Time(s), Pmax, min (psf)
3	Emission times of each of the four rays used to calculate signature(s)
4	Phi angle of emission for each of the four rays (deg)
5	Type of Booms used in calculation Carpet, Max Focus, Post Focus marked by T if any of the four rays had that type of boom
6+	Signature data time(s), pressure (psf)

Note: Lines 2 through 6+ repeated for each boom.

4.3.4 WCON with FiltView

A numeric turbulence model using finite impulse response (FIR) filters is available within the FiltView module, which is accessed through the WCON module[12]. Metrics including Pmax, ASEL, BSEL, CSEL, ESEL, and ISBAP can be computed on the filtered waveforms. Note that before computing metrics, waveforms are zero padded to the next power of 2 in array length if they do not already have a power of 2 number of points. This is to conform to the signal processing requirements of the FFT algorithms.

To apply FIR filters:

1. Enter the WCON module signature display by pressing "r" or "p" for the desired point.
2. In the signature display, press "k" to open the *Enter Turbulence Parameters* dialog.
3. Enter the information in the following fields:

[12] Note that the SonicBAT-Run-Fort configuration file is required for WCON to access the FiltView module. WCON is coded to search for a file named "SonicBAT-Run-Fort.config" containing FiltView executable information, whether or not the SonicBAT-Run-Fort module is used. See Sections 4.3.1 and 6.1.1.2 for more information.

a. *Boundary Layer Height* in feet AGL

b. *Relative Humidity* as a percentage at the ground

c. Select *Low, Medium* or *High* from the *Turbulence Strength* drop-down menu

Strength	u_* (m/s)	w_* (m/s)	T_* (K)	σvector (m/s)
Low	0.1	0.44	-0.5	0.31
Medium	0.35	1.55	-0.5	1.10
High	0.6	2.66	-0.5	1.89

where u* = friction velocity scale, w* = mixed-layer velocity scale, and T* = surface-layer temperature scale

4. Click *OK* to open the FiltView module interface (*PCBoom Turbulent Filter Viewer* dialog), see Figure 4-12.

a. By default, the FiltView display shows resulting waveforms from applying the mean and plus/minus standard deviation filters for the PL metric.

b. The preturbulized waveform will always be displayed in the plot.

5. Use the Page Up and Page Down keys to view resulting waveforms for the additional metrics shown in the Metric Table to the right of the plot.

a. The metric that is currently displayed in the plot is underlined in the Metric Table.

b. The preturbulized waveform will always be displayed in the plot.

A description of the metrics in the Metric Table is provided in Table 4-13.The geometric parameters of the boom ray and the atmospheric parameters entered by the user are displayed above the plot in the FiltView display and are described in Table 4-14.

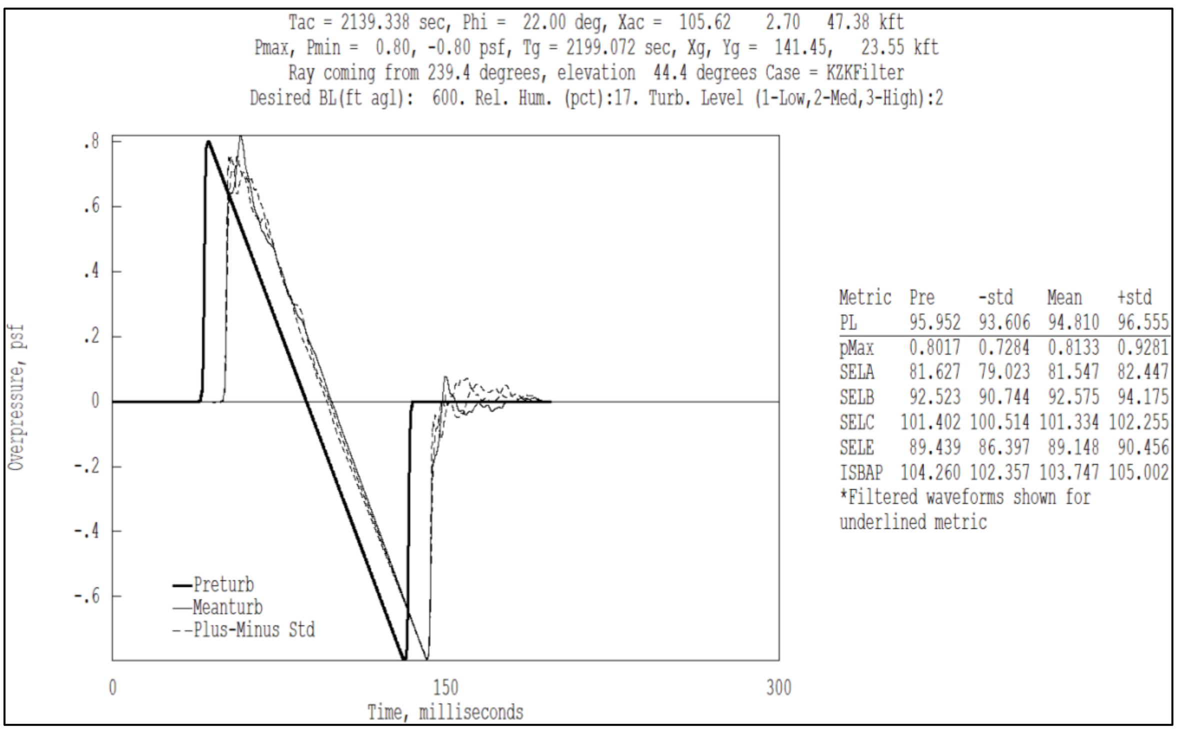


Figure 4-12 Example FiltView display.

Table 4-13 FiltView metrics.

Metric	Description
PL	Perceived loudness, in dB
pMax	Peak overpressure, in pdf)
SELA	A-weighted SEL, in dB(A)
SELB	B-weighted SEL, in dB(B)
SELC	C-weighted SEL, in dB(C)
SELE	E-weighted SEL, in dB(E)
ISBAP	Indoor Sonic Boom Annoyance Predictor

Table 4-14 FiltView display data.

Parameter	Description
Tac	Time at which the ray originated (aircraft time) in seconds
Phi	Azimuth angle in degrees
Xac	Aircraft position at the time of signature generation, X, Y (feet) and Altitude (k feet)
M	Aircraft flight Mach number at time Tac
Pmax, Pmin	Maximum and minimum overpressure in the signature
Tg	Time the ray arrives at the ground in seconds. Consistent with Tac.
Xg, Yg	X and y ground coordinates corresponding to the displayed signature
Ray coming from	Azimuth angle of ray emission at the aircraft, in degrees
elevation	Ray elevation angle at the ground location, in degrees
Case	Case name
Desired BL	Boundary Layer Height (ft)
Rel. Hum.	Relative humidity as a percentage at the ground as entered when entering FiltView
Turb. Level	Turbulence level selected when entering FiltView 1 = Low 2 = Medium 3 = High

Because FiltView is independent of WCON, multiple instances can be open at one time. This allows for the footprint to be displayed in WCON alongside multiple FiltView windows displaying varying levels of turbulence strength for comparison purposes.

Available outputs from FiltView include tabular metric information as well as graphical output.

To generate graphical output of the current FiltView screen:

1. Press the “Alt+s” key
2. Enter a name and click *Save*.

To generate tabular output of the current FiltView Metric Table:

1. Press the “Alt+m” key
2. Enter a name and click *Save*.

To generate binary output of the currently displayed turbulized waveforms:

1. Press the "F8" key
2. Three binary output files (.bin) for the mean, mean + standard deviation, and mean – standard deviation for the selected metric will be produced and named according to the selected metric, mean, and chosen sampling frequency.

To generate binary output of all turbulized waveforms:

1. Press the "F9" key
2. Binary output files (.bin) will be produced for all combinations of metrics, the mean, mean + standard deviation, and mean – standard deviation. The files are named according to the selected metric, mean, and chosen sampling frequency.

4.4 Turbo

The classical turbulence code within the Turbo module is a fully 3D, linear acoustic propagation allowing turbulent temperature and gust variation versus altitude along with mean temperature and wind variations. The Turbo module is compatible with SonicBAT-Run-Fort and HeadlessBurgers to generate results that superimpose the separate (no interactions) effects of nonlinear aging, rounding, mean and turbulent atmospheric variations.

Section 4.4.1 describes the inputs into Turbo, Section 4.4.2 describes how to run Turbo, and Section 4.4.3 describes available outputs from Turbo. Section 6.1 describes how to run SonicBAT-Run-Fort.

4.4.1 Turbo Inputs

Turbo accepts the following file types as inputs. See Section 3.2 for more information on the FOBoom output files.

Casename.dat:	The FOBoom input file.
Casename.out:	The primary output from FOBoom, which contains signature data.
Casename.age:	A FOBoom output file with aging details output at different altitudes along the traced rays.
ablh.out:	A FOBoom output file that contains information about the ray states at the altitude corresponding to the input atmospheric boundary-layer height.
Casename-tin.txt:	A user-generated turbulence input file to specify turbulence parameters and related modeling information. See Section 4.4.1.1 for more information.

4.4.1.1 Turbo Input File (tin.txt) File Format

The Turbo input file, casename-tin.txt, is organized into 3 groups: BEGIN, ATMDEF, and PROPAGATE to set initial parameters, define the additional atmosphere details, and specify propagation parameters. The format for the BEGIN section is described in Table 4-15, the format for the ATMDEF section is described in Table 4-16, and the PROPAGATE section is described in Table 4-17. The three sections must be included in the input file in the order BEGIN, ATMDEF, then PROPAGATE. In most cases, the keyword is followed by additional input and is read using a Fortran namelist structure.

Table 4-15 BEGIN section format description.

Line	Keyword	Variable Type	Max Length	Description
1	$BEGIN	Character	6	This keyword marks the start of the "BEGIN" section. No addition input is needed.
2	TINHEADER=	Character	80	Header description that will be included at the top of the output files
3	MOOUT=	Integer	1	Controls the level information written to the .u86 output file 0 – writes only the output needed by the step, intended for fastest automated running 1- writes the output needed to understand the results (interactive running) 2- write more output to understand the results (interactive running) The strength of turbulence and modes are listed first, followed by the ray X, Y, Z starting conditions and ground intersection point-per-line listing. 3 to 7 - additional detailed information will be output for debugging purposes. Will also cause slow execution.
4	IHzOUT=	Integer	Limit 65535	Time resolution in points/sec of output signatures Note the quantity does not affect execution time but does affect output storage size
5	IGENATM=	Integer	1	0-Gen new Atm Turbulence at beginning and use at all Phis and Times 1-Gen new Atm Turbulence for every Phi and Time step
6	$END	Character	5	This keyword marks the end of the "BEGIN" section. No additional input is needed.

Table 4-16 ATMDEF section format description.

Line	Keyword	Variable Type	Max Length	Description
1	$ATMDEF	Character	7	This keyword marks the start of the “ATMDEF” section. No addition input is needed.
2	HFT =	Double precision	n/a	Specifies the boundary layer (BL) height fraction of the two CT2 values (HF = H/ABLH) H is the height in feet ABLH is the atmospheric boundary-layer height in feet Note: This line takes two input values
3	CT2=	Double precision	n/a	Thermal structure parameter for turbulent temperature (dTemp) Note: This line takes two input values
4	HFV=	Double precision	n/a	Specifies the boundary layer (BL) height fraction of the two CV2 values (HF = H/ABLH) H is the height in feet ABLH is the atmospheric boundary-layer height in feet Note: This line takes two input values
5	CV2 =	Double precision	n/a	Inertial structure parameter for turbulent velocity (gusts) Note: This line takes two input values
6	FLMAX=	Real	n/a	L0 outer scale of turbulence (max wavelength) in feet
7	FLMIN=	Real	n/a	l0 inner scale of turbulence (min wavelength) in feet
8	NLMAXMORE=	Integer	n/a	Index of max scale of turbulence modeled (optional, defaults to NLMAX if set to 0)
9	NLMAX=	Integer	n/a	Index of L0 turbulence scale
10	IRAND=	Integer	1	Turbulence strength distribution options 1, 2, or 3. Even values (0 or 2) cause the phase of original of all Z-direction modes to be located at the top of the ABLH Odd values (1 or 3) provide a random Z phase for each module like the random X and Y phase in all cases 0 or 1: varies turbulence in both directions; follows von Karman with random phase and random direction of each plane split 0.50/0.50 per axis 2 or 3: turbulence variation is randomly apportioned; follows von Karman with random phase and random direction of each plane split randomly 0.25-0.75/0.25-0.75 per axis E.g., enter “3” to provide a random Z phase for each module with randomly apportioned turbulence
11	ISEED=	Integer	n/a	Seed for random number generation routine for turbulent state parameters - allows regeneration of same sequence Note: Saving atmospheres is always recommended because changes to programming, complier, planform and OpSys could affect RAND sequences
12	TURBATMFILE=	Character	80	Name of the output file in single quotes with .txt extension e.g., ‘ATMOS_TURBULENCE.TXT’.
13	$END	Character	6	This keyword marks the end of the “ATMDEF” section. No additional input is needed.

Table 4-17 PROPAGATE section format description.

Line	Keyword	Variable Type	Description
1	$PROPAGATE	Character	This keyword marks the start of the "PROPAGATE" section. No addition input is needed.
2	TIMESTEP=	Real	Time step (sec) for ray propagation If <0 uses |TIMESTEP|/(CV2+0.2*CT2), max 0.5 Note: propagation with turbulence requires smaller time steps than propagation without turbulence
3	LOUT=	Integer	0; this field is not used
4	NPHISIG=	Integer	0 means use PHIs read from <arg>.out file, -1= whole carpet
5	PHISIG=	Double precision	List of Ground PHIs for Output
7	NRAYTIMES=	Integer	Even# of Rays Before/Behind, During & After/Ahead being propagated
8	NRAYSWIDE=	Integer	Even# of Rays in width (meaning phi variation),
9	RAYSEP=	Real	Initial (at ABLALT) Ray Separation - in flight direction & along-isopemps
10	NSIGTIMES=	Integer	Number of output time instances for repeated output at SIGSEP spacing
11	SIGSEP=	Double precision	Signature spacing (ft) if multiple signatures are requested by NSIGTIMES
12	IGWRAP=	Integer	Is the ground wrapped? 0 no 1 repeat behind + ahead in time 2 repeat in time and carpet width If a ray propagates beyond a boundary of the current Turbo carpet, its effect can be simulated by effectively duplicating the calculated carpet to other side (1; behind + ahead in time, or 2; behind + ahead and left + right laterally) of itself and then calculating the effect of the ray that went beyond the boundary.
13	LINSIG=	Integer	Specify if the input signature is linear or discontinuous 0 Rounded and Continuous 1 Discontinuous
14	LOUTRAYS=	Logical	Save & Output RAYXYZ(TimeStep#), RAYVEC(TimeStep#), where TimeStep# is a counter for propagation steps
15	$END	Character	This keyword marks the end of the "PROPAGATE" section. No additional input is needed.

```
$BEGIN
TINHEADER= 'TURBO sample run case'
MOOUT=2
IHzOUT=6400
IGENATM=0
$END

$ATMDEF
HFT= 0.10, 1.00
CT2= 0.150, 0.150
HFV= 0.10, 1.00
CV2= 0.250, 0.250
FLMAX= 164.
FLMIN= 0.328
NLMAXMORE= 196
NLMAX=    164
IRAND=      3
ISEED=      1
TURBATMFILE= 'ATMOS_TURBULENCE.TXT'
$END

$PROPAGATE
TIMESTEP= 0.020d0
LOUT=0
NPHISIG=0
PHISIG=0.0
NRAYTIMES=20
NRAYSWIDE=20
RAYSEP=1d0
NSIGTIMES=1
SIGSEP=8d0
IGWRAP=2
LINSIG=1
LOUTRAYS=.FALSE.
$END
```

Figure 4-13 Sample tin.txt file.

4.4.2 Running Turbo

The Turbo module is typically run from within the SonicBAT-Run-Fort batch processor tool (Section 6.1), however, it can be run independently as well. The command to run Turbo is as follows:

Turbo casename

where

Turbo	Name of the Turbo executable (e.g., turbo730.exe).
casename	Name of the input files (including casename-tin.txt); do not include an extension.

If any of the input files are not read successfully, Turbo will write ERROR messages to casename-u86.txt and the screen. Turbo will attempt to continue by using default values to provide more output for error correction.

4.4.3 Turbo Outputs

The Turbo module writes turbulent signatures in the FOBoom format output files (.out) so existing post-processing methods can be used to examine and visualize output data including loudness calculations and plotting within WCON. In addition, the tur.txt file is written with a summary of the run and results with the level of detail as specified by the MOOUT keyword (Section 4.4.1.1).

Note that any ERROR message on the screen or in the casename-tin.txt or casename-u86.txt files indicates that values in the output files are invalid.

5 Specialized Tools

Specialized tools were created to model individual ray characteristics with respect to the ground (RayCau), predict focused signatures from waveforms using the 2D lossy nonlinear Tricomi equation (LNTE), and model over the top secondary booms (POTTI, POTRAY, OTTER). See Section 5.1 for more information on RayCau and LNTE. See Section 5.2 for more information on POTTI, POTRAY, and OTTER.

5.1 RayCau and LNTE

The RayCau and LNTE modules are used to model the post-focus or focus delta ray (Figure 5-1) for predicting focus booms.

The focus delta ray passes through a point orthogonal to the caustic-ground intercept at a distance delta (δ). This delta distance is known as the diffraction boundary-layer thickness. Zbar is the ratio of the normal distance from the caustic line intersection with the ground (Z) to the diffraction boundary layer thickness. At the perpendicular intersection of the diffraction boundary-layer and the focus delta ray (see Figure 5-1), geometric ray acoustic theory is no longer valid, and the Lossy Nonlinear Tricomi Equation is required to solve for the focus delta ray acoustic pressure and path by accounting for diffraction, reflection, and propagation behavior at the caustic edge. The transition point between modeling methods is referred to as the Burgers-LNTE interface point throughout this manual. It is located along the Zbar = 1 line, perpendicular to the caustic intersection with the ground (P). The FOBoom, RayCau, and PCBurg modules are run to propagate the waveform from the aircraft to the Burgers-LNTE interface point. Then the LNTE module is run to predict the path of the waveform from the Burgers-LNTE interface point to the ground and the pressure at the ground.

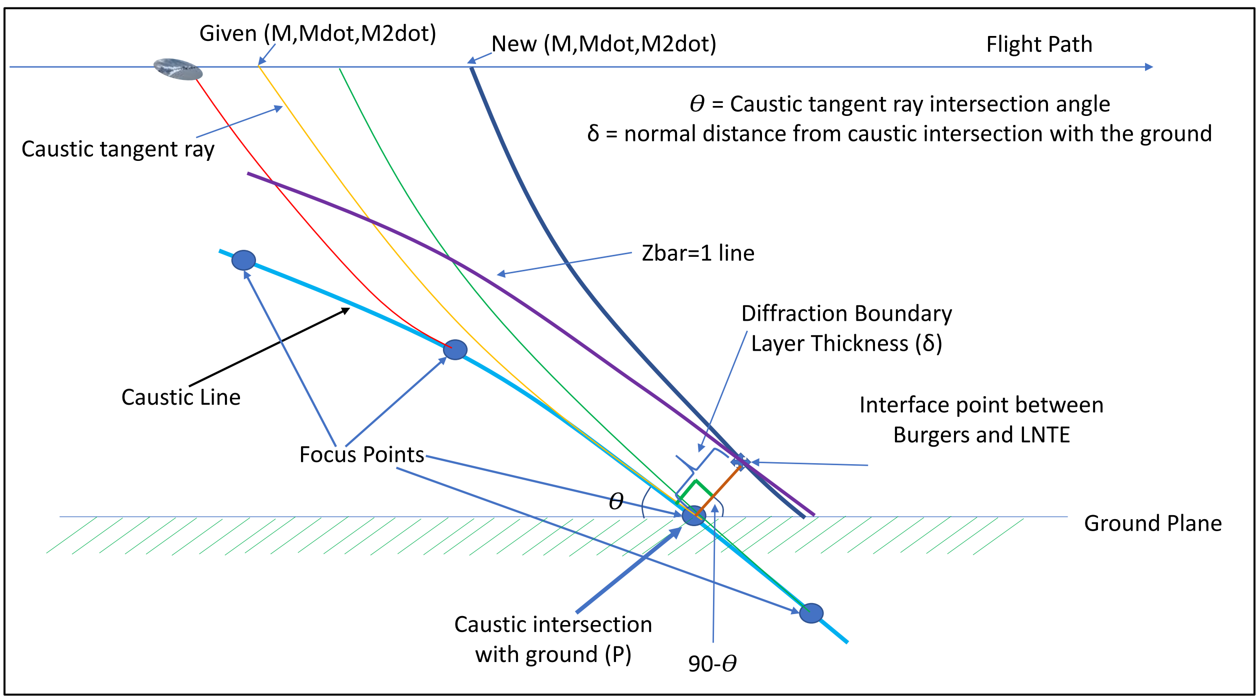


Figure 5-1 Focus delta ray geometry.[13]

[13] S. K. Rallabhandi and A. Loubeau, "Summary of propagation cases of the Third AIAA Sonic Boom Prediction Workshop," *Journal of Aircraft*, 59 (2022), pp. 578-594.

Section 5.1.1 describes the inputs to RayCau, Section 5.1.2 describes how to run and interact with RayCau, Section 5.1.3 describes available outputs from RayCau, Section 5.1.4 describes the inputs to LNTE, Section 5.1.5 describes how to run LNTE, and Section 5.1.6 describes available outputs from LNTE.

For an example workflow using RayCau and LNTE, see Section 2.3.2.4. For an example of how to complete this type of analysis, see Appendix B.9.

5.1.1 RayCau Inputs

RayCau requires the following two files as inputs. See Section 3.2 for more information on the FOBoom output files.

Casename.out:	The primary output from FOBoom, which contains signature data.
Casename.age:	A FOBoom output file with aging details output at different altitudes along the traced rays. It is created when the BURGERS keyword is used in the FOBoom input file.

5.1.2 Running RayCau

To run RayCau, execute the following command:

```
RayCau casename
```

where

RayCau	The name of the RayCau executable (e.g., raycau730.exe).
casename	The name of input files; do not include an extension.

5.1.2.1 RayCau Interface

When RayCau opens, a display similar to Figure 5-2 is shown. The red line represents the caustic tangent ray, the grey line represents the ground, the green circle represents the caustic intersection with the ground, and the black circle represents a focus point. The available data within the display are described in Table 5-1. The options that are available for the RayCau display are described in Table 5-2.

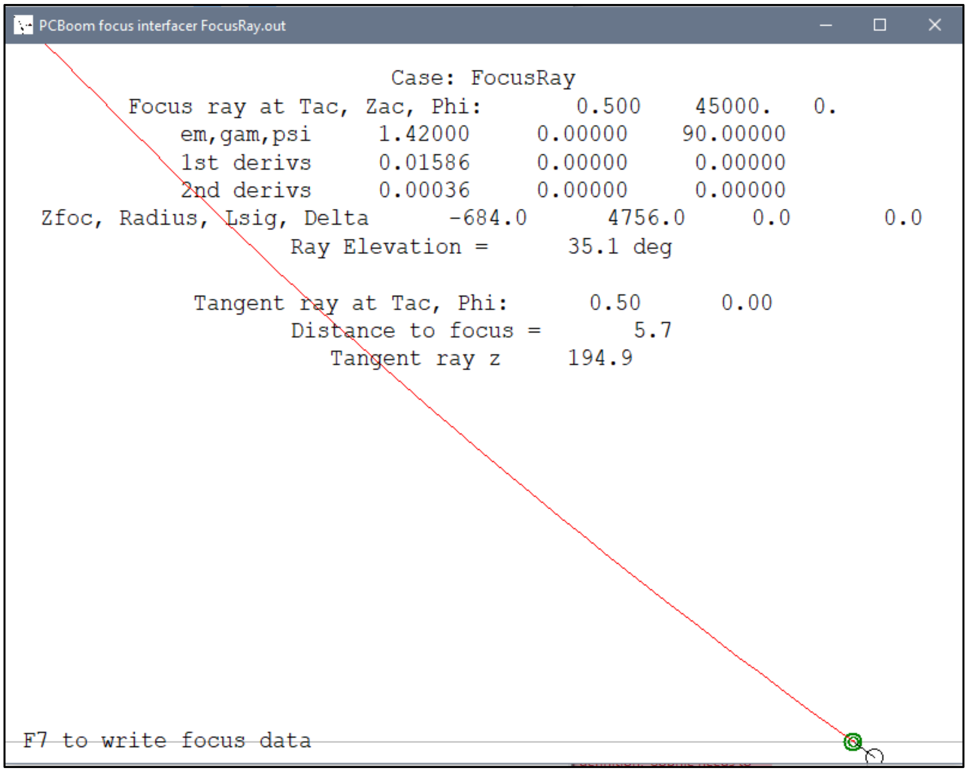


Figure 5-2 RayCau initial display.

Table 5-1 RayCau display data.

Parameter	**Description**
Case	Case name
Focus ray at Tac, Zac, Phi	Focus ray at: Time at which the ray originated (aircraft time), in seconds Altitude (z-coordinate) of the aircraft at the focus ray origination time Acoustic emission azimuthal angle, in degrees
em, gma, psi	Mach number, flight path angle in degrees, heading angle (deg)
1st derivs	First derivative of Mach number, 1/sec Flight path angle (deg/s) and heading (deg/s)
2nd derivs	Second derivative of Mach number, 1/sec2 Flight Path angle (deg/s) and heading (deg/s)
Zfoc, Radius, Lsig, Delta	Height of focus point (ft AGL), radius of curvature of the delta tangent ray (ft), signature length (msec), and diffraction distance delta as a function of the caustic curvature and signature length (ft).
Ray Elevation	Caustic tangent ray elevation angle, measured from the horizontal ground to the ray (deg).
Tangent ray at Tac, Phi	Tangent ray at: Time at which the ray originated (aircraft time) (s) Azimuth angle relative to the aircraft(deg)
Distance to Focus	Distance along the ray from the aircraft to the focus location(ft)
Tangent ray z	Altitude (z-coordinate) of the aircraft at the tangent ray origination time (ft)

Table 5-2 RayCau display options.

Option	Description
PgUp	Zoom in on the time axis by a factor of 2
PgDn	Zoom out from the time axis by a factor of 2
Left/Right Arrow	Adjust trajectory point of tangent ray
Up/Down Arrow	Adjust trajectory point of focus ray
< or >	Adjust azimuth angle
Esc	Quit

5.1.3 RayCau Outputs

To generate the text file output (.foc), press the “F7” key. This text file contains caustic information such as the ray elevation angle and diffraction boundary-layer thickness.

5.1.4 LNTE Inputs

LNTE accepts the following file types as inputs. See Section 3.2 for more information on the FOBoom output files.

filename.txt — An input file (.txt) that contains concatenated signature data manually created from two PCBurg signature file outputs (.txt) to include caustic information at ground height and signature information at the Burgers-LNTE interface

filename_tricomi_.inp: An input file that is generated by LNTE, which is used to predict the focused signatures by running LNTE a second time (Table 5-3).

In order for LNTE to produce the .inp file, PCBurg must be run twice - once to obtain caustic information at true ground height, and once to obtain the signature information at the Burgers-LNTE interface location. Signature files (.txt) must be generated for each PCBurg run. The inputs for the PCBurg runs are the .foc files generated by RayCau. The output signature files (.txt) from PCBurg must be concatenated so that both the caustic information calculated at the true ground height and the signature information at the Burgers-LNTE interface location are included in the same signature file (.txt) for input into LNTE for the .inp file generation. For an example of this procedure, see Appendix B.9.

Table 5-3 LNTE generated input file (filename_tricomi_.inp) data.

Line	Description
1	Header with the following text: "Tricomi format input file created from PCBoom Burgers output file: <Filename>.txt
2	Characteristic acoustic frequency (Hz)
2	Total radius of curvature (meters)
2	Temperature (Kelvin)
2	Atmospheric pressure (kPa)
2	Relative humidity (%)
2	x-wind component (meters/sec)
2	z-wind component (meters/sec)
2	Dimensionless distance below the caustic (ratio)
2	Dimensionless distance above the caustic (ratio)
2	Number of $\bar{z}$ axis layers
3	Number of points to read for the incoming wave (points)
3	Sample rate of the incoming wave (Hz)
4+	Incoming wave pressure data (psf)

Any of the focusing input parameters in the .inp file can be manually edited for subsequent LNTE runs. An example is demonstrated as the optional final step in Appendix B.9.

5.1.5 Running LNTE

To run LNTE, execute the following command:

```
LNTE filename.txt intoutputname.out [options]
```

where

LNTE	The name of the LNTE executable (e.g., lnte730.exe).
filename.txt	PCBurg output signature file (.txt) with both caustic information at ground height and signature information at the Burgers-LNTE interface
Intoutputname.out	Specify a name for the intermediate LNTE output file with .out extension. The .out file from the second time LNTE is run contains the final output information
[options] (optional)	The available options are described in **Table 5-4**. Multiple options can be specified with a space between each option. There is no required sequence for options.

Note that running LNTE can take a significant amount of time, on the order of hours, depending on the user's computer.

Table 5-4 LNTE options.

Option	Description
-ttN.NNN	to specify a maximum value of the pseudotime[14] step increment replace the "N" fields with desired numbers, e.g., –tt0.1 typical range: 0.1 to 0.5
-iiNNNNN	to specify the number of total iterations at which the calculations will stop and write a binary output file replace the "N" fields with desired numbers
-nl	to exclude nonlinear effects
-tv	to exclude thermoviscous effects
-or	to exclude oxygen relaxation effects
-nr	to exclude nitrogen relaxation effects
-df	to exclude diffraction effects this option requires some type of initialized pressure field[14] or else the solution will be all zeros this option must be used with either the –rr or –cc option (but not both)
-rr	to indicate that the input file is not the ASCII text input format and is instead reading a binary output file as an input file this is typically used when continuing forward from a previous solution for more iterations
-cc	to copy the incoming waveform specified in the ASCII text input file to each of the z-layers when initializing the computational domain
-pb	to read .txt file signature output from PCBurg
-tmNNN.N	to run up to a specified maximum pseudotime value. if the –ii option has also been specified, the code will stop at the earlier of the two specified values it is recommended to specify some arbitrarily high iteration count to prevent the code from stopping prior to the desired pseudotime value replace the "N" fields with desired numbers
-fsNNNNN.	to automatically resample the incoming waveform to a sample rate lower than the value specified with this option replace the "N" fields with desired numbers if this option is not specified, the default value of 32 kHz is used

[14] Salamone, J., "Solution of the Lossy Nonlinear Tricomi Equation with Application to Sonic Boom Focusing," Ph.D. Thesis, Pennsylvania State University, 2013.

5.1.6 LNTE Outputs

The main output from LNTE (<filename>.out) is a binary file with .out extension. It contains the pressure data matrix at a range of locations between specified min and max $\overline{z}$ values. It is recommended to plot the contents of the binary file in an external tool. An example of how the output file contents could be read in MATLAB[9] is shown in Figure 5-3. An additional output file (<filename>_pbcoords.txt) will be generated that maps the $\overline{z}$ locations from the Tricomi domain to the PCBoom coordinate system.

Table 5-5 LNTE output file contents.

Data Type	Data Description	Variable Names in Figure 5-3 Example Script
Integer	Total number of iterations	ncnt
Double	Total pseudotime	tval
Double	Sample rate, Hz	srate
Integer	Total points in the time axis	pcount
Double	d$\overline{z}$ spacing	dz
Integer	Number of $\overline{z}$ layers	zlen
Double	Characteristic acoustic frequency, Hz	fac
Double	Total radius of curvature, meters	Rtot
Double	Temperature, Kelvin	t0
Double	Atmospheric pressure, kPa	p0
Double	Relative humidity, %	rhum0
Double	x-wind, m/s	ux0
Double	z-wind, m/s	uz0
Double	$\overline{z}$ min	zmin
Double	$\overline{z}$ max	zmax
Double	Input waveform that has been zero-padded to the same number of points in the time axis, Pa	fin
Double	Pressure data matrix, Pa – starts at $\overline{z}$ min and moves up to $\overline{z}$ max in blocks of time axis slices at each $\overline{z}$ layer	alldata

```
fid=fopen('nwave_2.5khz_4000z_1200its.out', 'r');
ncnt=fread(fid,1,'int32');
tval=fread(fid,1,'double');
srate=fread(fid,1,'double');
pcount=fread(fid,1,'int32');
dz=fread(fid,1,'double');
zlen=fread(fid,1,'int32');
fac=fread(fid,1,'double');
Rtot=fread(fid,1,'double');
t0=fread(fid,1,'double');
p0=fread(fid,1,'double');
rhum0=fread(fid,1,'double');
ux0=fread(fid,1,'double');
uz0=fread(fid,1,'double');
zmin=fread(fid,1,'double');
zmax=fread(fid,1,'double');
fin=fread(fid,pcount,'double');
pdata=zeros(pcount,1);
alldata(zlen,pcount);
for k=1:zlen
    pdata=fread(fid,pcount,'double');
    alldata(k,:)=pdata';
end
```

Figure 5-3 Example MATLAB script to read LNTE output file contents.

5.2 POTRAY, POTTI, and OTTER

PCBoom's basic operating mode is to obtain primary boom footprints on the ground, corresponding to the central portion of Figure 5-4. Secondary booms are of interest in some cases, such as over the top booms generated by the Concorde that were observed in New England. These booms correspond to rays that initially propagate above the aircraft flight altitude but eventually arrive at the ground due to atmospheric refraction. As discussed in the PCBoom Technical Reference,[15] the secondary boom carpet is not as contiguous as the primary boom carpet, unlike Figure 5-4 might suggest. Specialized tools beyond PCBoom's customary footprint analysis modules were developed to address secondary booms, including rays that initially propagate downward and then are reflected back upward. These specialized modules account for the curvature of the Earth.

The specialized tools include POTRAY (Propagate Over Top Rays), which launches and classifies rays at all azimuths, POTTI (Plot Over The Top Isopemps), which examines ground intercepts and vertical ray profiles, and OTTER (Over The Topper), which propagates signatures along selected primary and secondary rays. POTRAY and POTTI are pre-analysis tools that are used before FOBoom. OTTER is the final analysis and signature module. Both POTTI and OTTER include visualization displays.

Section 5.2.1 and subsections describe how to use POTRAY (ray tracing) and POTTI (ray analysis), Section 5.2.2 describes how to use FOBoom for secondary over the top booms, and Section 5.2.3 describes how to use OTTER (signature evolution).

---

[15] Page, J. A.; Plotkin, K. J.; and Wilmer, C. (2010), “PCBoom Version 6.6 Technical Reference and User Manual,” Wyle Report WR 10-10, March 2010.

For an example workflow for an over the top ray tracing analysis, see Section 2.3.2.4. For an example of how to complete this type of analysis, see Appendix B.10.

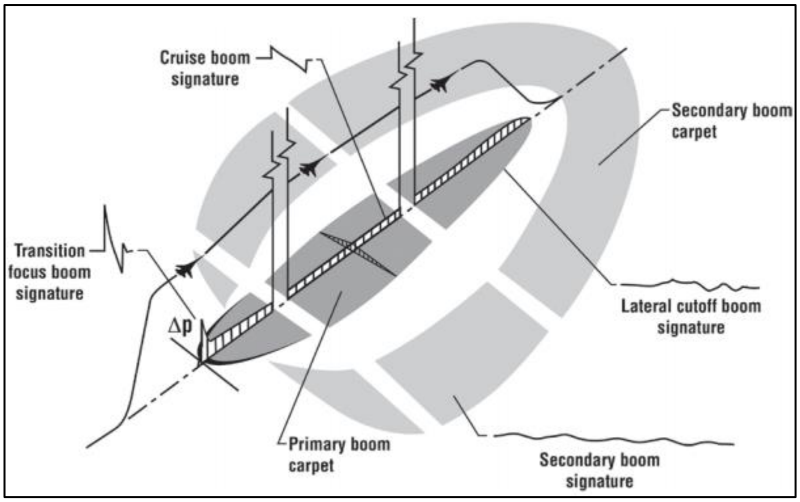


Figure 5-4 Primary and secondary boom carpets.[16]

5.2.1 POTRAY and POTTI

Using the POTRAY and POTTI modules prior to FOBoom allows for computation of sonic boom ray paths (POTRAY) and graphical examination of the ray patterns (POTTI) before performing the full ray tracing with FOBoom.

Rays can terminate in the following ways:

- Reach the ground after the prescribed number of bounces
- Leave the top of the atmosphere
- Get stuck in a channel and reach the dimensional limit

These cases are apparent from reviewing the ray patterns in the POTTI Ray Display, and are noted in the .ray path and .hit (ground intersection) files generated in POTRAY. FOBoom also notes these results and includes them in the .ott file.

The purposes of the POTRAY and POTTI pre-analyses are to determine trajectory times and azimuths that result in secondary boom rays that are of interest for subsequent detailed modeling in FOBoom.

5.2.1.1 POTRAY Inputs

POTRAY accepts the following file type as input.

filename.nml: A user-generated input file to specify parameters and external files to describe the trajectory and atmosphere. See Section 5.2.1.1.1.

---

[16] Maglieri, D., P. Bobbitt, K. Plotkin, K. Shepherd, P. Coen, D. Richwine, “Sonic Boom Six Decades of Research” NASA/SP-2014-622, June 2014.

5.2.1.1.1 POTRAY Input File (.nml) Format

POTRAY can be run by defining a trajectory or a single point in an input text file with a .nml extension.

The file format is detailed in Table 5-6 and an example .nml file with trajectory input is shown in Figure 5-5 and an example file with single point input is shown in Figure 5-6.

The input file must start with “&allinputs” and end with “/”. The remaining keywords may be in any order. Required keywords are atmfile, outfile, and either trjfile (for trajectory input) or keywords time0 through gamma in Table 5-5 (for single point input); the remaining keywords are optional. Note that keywords time0 through gamma in Table 5-5 are only used when running in single point mode and will be ignored if trajectory information is provided. If a trajectory file is not specified or if it is blank, POTRAY will assume a single point is being run.

Table 5-6 Contents of POTRAY input file.

Keyword	Variable Type	Description
&allinputs	Character	This keyword marks the start of the input definitions
trjfile =	String in single quotes	Trajectory file name with extension .trj in FOBoom file format (see 3.1.15)
atmfile =	String in single quotes	Atmosphere file name with extension .att in FOBoom file format, Thomas/ATT or BALLOON input type (see Sections 3.1.9.1 and 3.1.9.2)
outfile =	String in single quotes	Specify an output file name for the POTRAY output file with extension .out
zg =	Real	Ground elevation in feet
deltin =	Real	Integration time step, in seconds, along the ray
delt0 =	Real	Initial time step, in seconds, along the ray
time0 =	Real	Time, in seconds
gphi0 =	Real	Latitude, in degrees Used when trajectory input uses the longlat keyword to convert to geographic units
glambda0 =	Real	Longitude, in degrees Used when trajectory input uses the longlat keyword to convert to geographic units
hgt0 =	Real	Altitude, in feet
fmach =	Real	Mach number
head0 =	Real	Heading in degrees clockwise from north
gamma =	Real	Flight path (climb) angle, in degrees
kmode =	Integer	Ray trace mode: 1 for ellipsoidal earth 2 for spherical earth 3 for flat earth
nbmax =	Integer	Number of bounces to allow. Suggest starting with 1.
iphi1 =	Real	Lower limit of acoustic emission azimuthal angle, phi, range, in degrees
iphi2 =	Real	Upper limit of phi range, in degrees
idelphi =	Real	Phi step, i.e., ray trace every idelphi degrees from iphi1 to iphi2
seq =	character	Sequence letter for single-mode output file naming
/	character	This slash marks the end of the input definitions

```
&allinputs
trjfile  =  'Filename.trj'
atmfile  =  'Filename.att'
outfile  =  'Filename.out'
zg       =  0
iphi1    = -180
iphi2    =  180
idelphi  =   2
/
```

Figure 5-5 Sample .nml file – trajectory.

```
&allinputs
trjfile  =  'Concorde.trj'
atmfile  =  'Concorde.att'
outfile  =  'Concorde.out'

zg       =  0
deltin   = 0.2
delt0 = 0.5
time0 = 0.
gphi0  = 0.
glambda0 = 45
hgt0 = 4000.
fmach = 1.2
head0 = 90.
gamma  = 0.
imode  = 1

nbmax = 1
iphi1    = -180
iphi2    =  180
idelphi  =   2
seq  = 'a'
/
```

Figure 5-6 Sample .nml file –single point.

5.2.1.2 Running POTRAY

To run POTRAY, execute the following command:

`POTRAY filename.nml`

where

POTRAY	The name of the POTRAY executable (e.g., potray730.exe).
filename.nml	The POTRY input file name with extension .nml. See Section 5.2.1.1.1 for more information.

5.2.1.3 POTRAY Outputs

POTRAY writes a full ray file and three output files for each time step in the .trj file. The naming convention is:

`filenameNNNN.xxx`

Where `filename` is a user-defined file name, `NNNN` is a sequence number starting at 0001 (if run with trajectory input), and `xxx` is the extension type. If POTRAY is run with single point input, the output file is named `filename.xxx`. Note that if running POTTI and FOBoom with inputs generated from POTRAY with single point input, rename the files to avoid conflict.

The four output types are:

filenameNNNN.out	This full ray file contains a header with the input data followed by columns with rays in ECG (earth centered geocentric) and geographic coordinates (ft and decimal degrees), and the ray propagation time for each ray (s). Summary information about bounces at the end of each ray is also included.

	The .out files are large, but do not need to be saved. Because of the sequence number NNNN, there should not be a conflict between these out files and FOBoom's out file.
filenameNNNN.hit	This file contains isopemp data. The file has some structure, but is meant to be read by POTTI, not an analyst.
filenameNNNN.ray	This is a summary ray file with about 100 points (a subset of the .out file) for each ray. The file header contains input information and also the limits of a bounding box defining a plot area that holds all rays. The columns for each ray are: Rtp, Ztp: ray coordinates in a tangent plane under the ray start point, with R oriented in the direction of the ray long,lat,alt,tarr: ray geographical coordinates and arrival times. Tarr is absolute, the sum of trajectory time and propagation time Rgnd, Zgnd tangent plane coordinates of the ellipsoid under the ray
filenameNNNN.fil	An index file that contains time 0 for each trj time and the corresponding .ray file.

5.2.1.4 POTTI Inputs

POTTI accepts the following file types as input. See Section 5.2.1.3 for more information on the POTRAY output files.

filenameNNNN.hit	A POTRAY output file with isopemp data.
filenameNNNN.ray	A POTRAY output file with a summary of ray propagation information.
filename.ray	A POTRAY output file with summary information for a single point (as opposed to trajectory).

5.2.1.5 Running POTTI

It is typical to run POTTI with trajectory inputs so that the general ray pattern can be examined, however, POTTI can also be used to examine a single point.

To run POTTI, when trajectory information was included in the POTRAY run, execute the following command:

```
POTTI filename
```

where

POTTI	The name of the POTTI executable (e.g., potti730.exe).
filename	The name of the input files (without the 'NNNN' numbers); do not include an extension.

To run POTTI, when single point information was included in the POTRAY run, execute the following command:

```
POTTI filename.ray
```

where

POTTI	The name of the POTTI executable (e.g., potti730.exe).
filename.ray	The name of the input file with the ".ray" extension

5.2.1.5.1 POTTI Interface

When POTTI opens, a display similar to Figure 5-7 is shown when trajectory information has been provided. The isopemps are displayed along with the information that is described in Table 5-7. The options that are available for the POTTI display are described in Table 5-8 and Figure 5-8 shows a sample POTTI Ray display.

Table 5-7 POTTI display data.

Parameter	Description
Tac	Aircraft time, in seconds. The time in the trajectory file (or time0 in the .nml file if single point was used) when the ray was emitted from the aircraft.
filenameNNNN.hit	Input file name
Legend (upper right corner)	A legend that describes the types of isopemps Solid: Ray emitted from the aircraft propagates and lands on the ground forming part of the primary boom carpet Dashed: Ray emitted from the aircraft bounces off the ground, propagates upward and then refracts back downward before landing forming part of the secondary boom carpet Black: The absolute angle of phi < 90 deg, Red: The absolute angle of phi > 90 deg
Status bar (bottom of display)	The left portion of the status bar shows the cursor position in longitude, latitude (in degrees) If the mouse is near a the ray, the right portion of the status bar shows: Phi — Azimuth angle, in degrees Long — Longitude, in degrees Lat — Latitude, in degrees Tarr — Arrival time, in seconds Primary/Secondary/ No Ground — “Primary”, “Secondary” or “No Ground” to describe the circled ray impact point/end type For “No Ground” type points, long, lat will appear as “999” and arrival times are shown as stars (***)

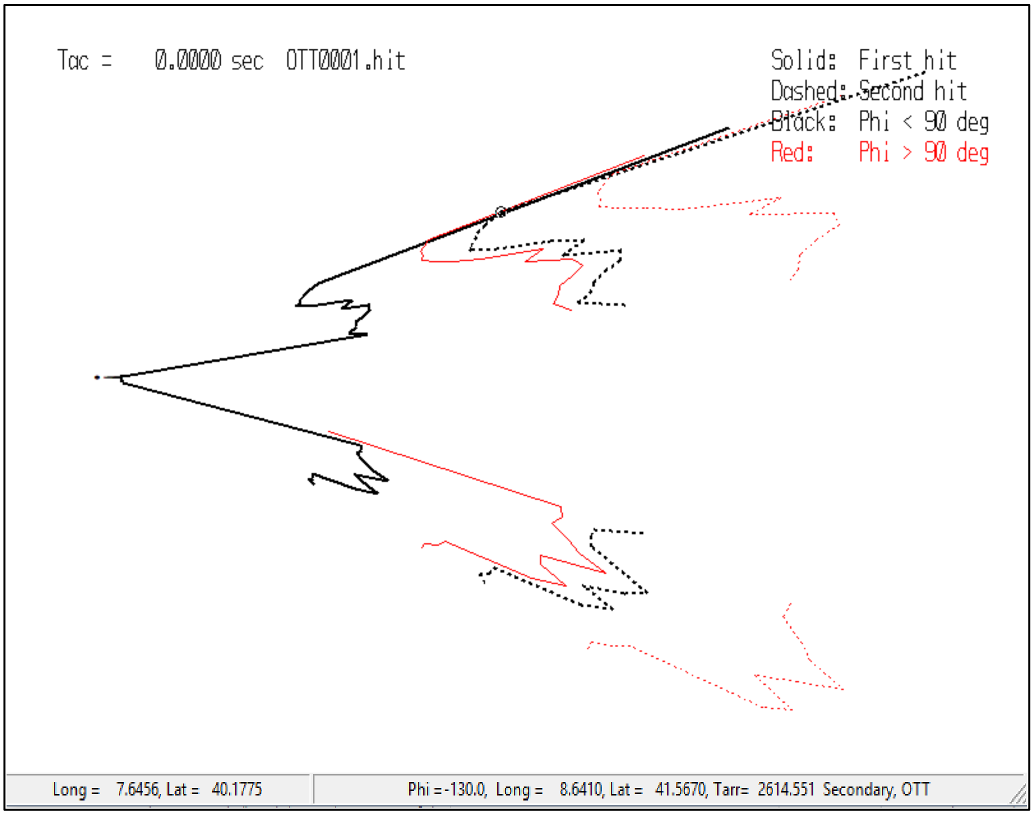


Figure 5-7 POTTI isopemp display.

Note that in the example shown in Figure 5-7, there are gaps in the isopemps. The primary boom, near the aircraft, appears as expected although it is rather elongated on the north side due to wind conditions. There are gaps in the phi values for which the boom reaches the ground due to refraction, and a considerable distance between first and second hits for reflected OTT rays.

Table 5-8 POTTI display options.

Option	Description
Arrow keys	Pan the display
Page up	Zoom in
Page down	Zoom out
Home	Restore original view
> or .	Advance to the next isopemp time step (the next .hit file)
< or ,	Display the previous isopemp time step (the previous .hit file)
Cursor	The closest ray impact point or end is circled when the cursor is moved If no circle appears and long/lat appear as 999, there is no impact point near the cursor
q	Advance to next higher azimuth angle (phi)
a	Displays the primary impact point The point where the ray impacts the ground, is also called a bounce point
s	Displays the secondary impact point with the ground The point where the ray impacts the ground after bouncing upward and then traveling back down to the ground
Enter	Opens the Ray Display, which shows the ray in a vertical cut containing the ray (Figure 5-8) The information available in the vertical cut display is described in Table 5-9. The same display options apply in the vertical cut display as the main display except >/. and </, Press Enter to Esc to return to the main display

Table 5-9 POTTI ray display data.

Parameter	Description
Black horizontal line	Black tangent plane line
Green line	Ellipsoid
Black bounce point	Current bounce point
Tac	Aircraft time in seconds for the circled ray impact or end point
filenameNNNN.hit	Input file name
Phi	Azimuth angle, in degrees
Long	Longitude, in degrees
Lat	Latitude, in degrees
Tarr	Arrival time, in seconds
Primary/Secondary/ No Ground	"Primary", "Secondary" or "No Ground" to describe the circled ray impact point/end type. For "No Ground" type points, long, lat will appear as "999" and arrival times are shown as stars (***)
Status bar (bottom of display)	The left portion of the status bar shows the cursor position in tangent plane coordinates Rtp, Ztp. If the mouse is within the span of the ray, the right portion of the status bar shows: Long Longitude, in degrees Lat Latitude, in degrees Alt Altitude, in feet Tarr Arrival time ,in seconds

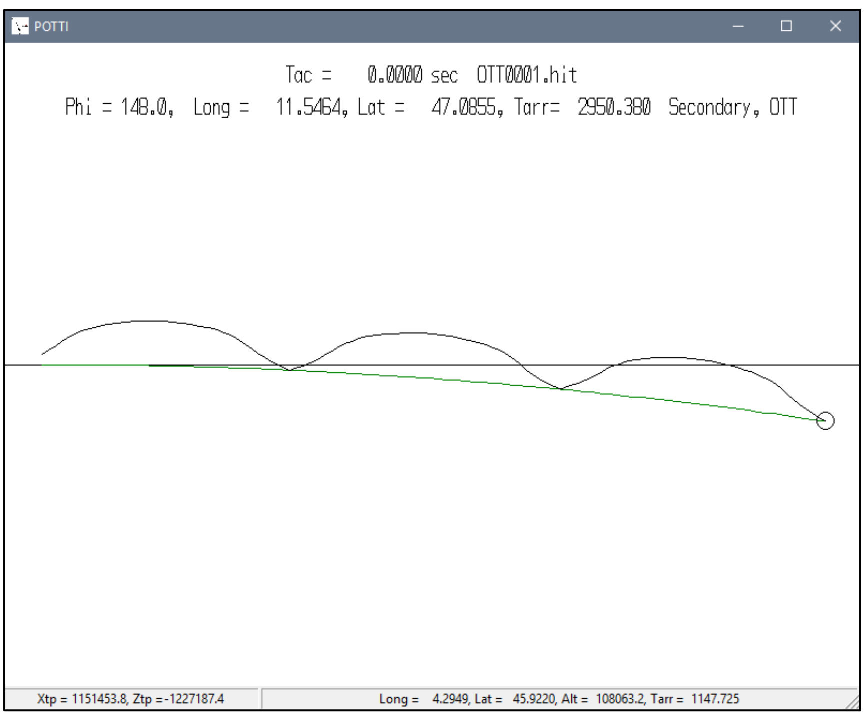


Figure 5-8 Typical POTTI ray display.

5.2.1.6 POTTI Outputs

The POTTI module does not produce a file or graphical output, but rather the end result of POTRAY/POTTI analysis is a determination of trajectory times, Tac, and azimuths, Phi, that result in secondary boom rays that are of interest for modeling in FOBoom.

5.2.2 FOBoom for Secondary Booms

Once the rays for analysis have been determined, FOBoom is used to perform the full ray tracing analysis. POTRAY propagates only single rays. FOBoom propagates ray tubes, and determines the ray tube areas, ray and caustic curvatures, age and amplitude parameters, and source characteristics for the modeled aircraft.

Following POTRAY/POTTI analysis, prepare input files for the FOBoom run as follows:

- Edit the trajectory file used in POTRAY to include only the time steps, Tac, of interest
- Add the OTT keyword (Section 3.1.6) to the .dat file
- A list of the phi values of interest (FOBoom input file, RAYTRACING keyword 3.1.12).

When FOBoom is run in OTT mode, two additional files are generated for use in OTTER:

Casename.ott	An output file containing the ray coordinates, atmospheric properties, and amplitude and age parameters at every time step along each ray. It is similar to the FOBoom .age file associated with the BURGERS keyword, but contains more quantities and the independent variable is time along the ray, rather than altitude
Casename.ots	An output file containing the F-function at the start of each ray. It is the same as the .ssg file associated with the BURGERS keyword but is given a different extension to avoid confusion if both types of run are done for the same base case.

An Over the Top (OTT) run generally takes longer per ray than a normal carpet boom run, so it is generally not the practice to run OTT in full carpet mode. The .out file is not generated in OTT mode. The OTT files size can be large.

Following the FOBoom run, the boom signatures are propagated along the rays using OTTER.

5.2.3 OTTER

The OTTER module propagates the boom signatures along the rays after running FOBoom using the OTT keyword. The OTTER module advances and ages the signature and visualizes the boom waveform along the secondary ray path using a lossless Burgers solver similar to the one in FOBoom. The full ray paths and initial F-functions (derived from the user-provided source characteristics) are computed by FOBoom (triggered by keyword OTT) and written to the appropriate OTTER input files.

5.2.3.1 OTTER Inputs

OTTER accepts the following file types. See Section 5.2.2 for more information on the FOBoom outputs for OTTER.

Casename.ott	A FOBoom output file containing the ray coordinates, atmospheric properties, and amplitude and age parameters at every time step along each ray.
Casename.ots	A FOBoom output file containing the F-function at the start of each ray.

5.2.3.2 *Running OTTER*

To run OTTER, execute the following command:

```
OTTER casename
```

where

OTTER	The name of the OTTER executable (e.g., otter730.exe).
casename	The name of the input files; do not include an extension.

5.2.3.2.1 Otter Interface

When OTTER opens, a display similar to Figure 5-9 is shown. The ray for the first aircraft time and azimuth angle (phi) in the case are displayed. There is a general similarity to the ray display in POTTI. The start of the ray is on the left side of the display, and propagation is to the right. There is usually (but not always) a focus on over the top rays. There can also be multiple foci. Information that is provided in the display is described in Table 5-10. The options that are available for the OTTER display are described in Table 5-11.

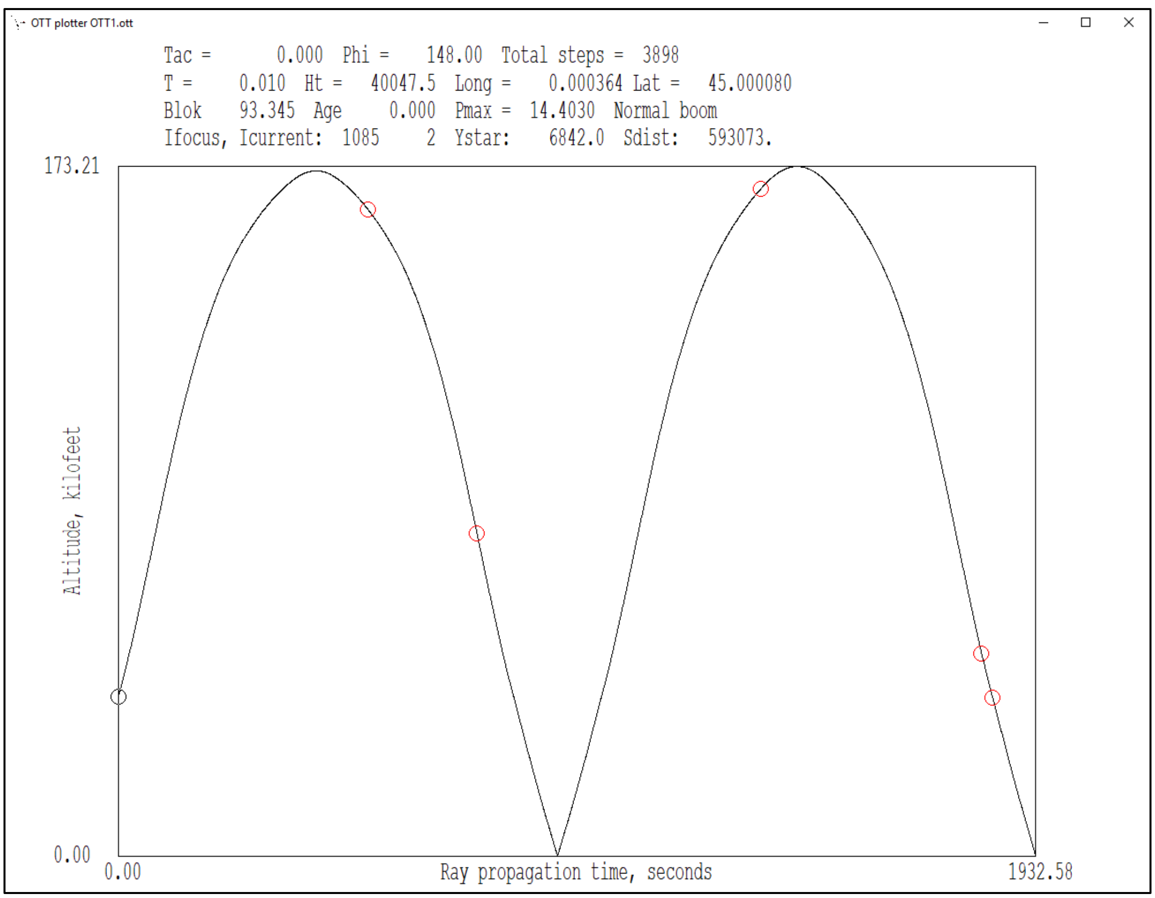


Figure 5-9 OTTER ray display.

Table 5-10 OTTER display data.

Parameter	Description
Red circle	Ray focus point
Black circle	Indicates current position on the ray – this position is movable by the user
Tac	Aircraft time, in seconds
Phi	Azimuth angle, in degrees
Total Steps	Total number of time steps in the analysis
T	Propagation time, in seconds, to the current point
Ht	Height above the ground, in feet
Long	Longitude, in degrees
Lat	Latitude, in degrees
Blok	Blokintsev parameter as computed in FOBoom
Age	Age parameter as computed in FOBoom
Pmax	Peak overpressure in the signature, in pounds per square foot
Boom Descriptor	Normal Boom Focal zone Post-focus
Ifocus, Icurrent	Indices of focus point and current point
Ystar	Focal zone dimension
Sdist	Distance from the current point to the focus, in feet A positive Sdist indicates that the focus has not yet been reached A negative Sdist indicates that the focus has been passed

Table 5-11 OTTER display options.

Option	Description
Right Arrow	Move forward 10 steps
Left Arrow	Move back 10 steps
CTRL + Right Arrow	Move forward 1 step
CTRL + Left Arrow	Move back 1 step
Home	Move to first ray point
End	Move to last ray point
b	Move to first bounce point
f	Move to first focus
Enter or Backspace	Open the Signature Display (Figure 5-10)
F1	Display help screen
Esc or q	Quit

These keys permit moving the analysis point to any location along the ray. When propagating the boom along the ray, focusing at the first focus is accounted for, as is the distortion and subsequent propagation and aging of the post-focus boom.

The Signature Display is similar to the WCON signature display and contains the same information parameters as the main OTTER Display (Table 5-10). The options that are available for the Signature Display are described in Table 5-12.

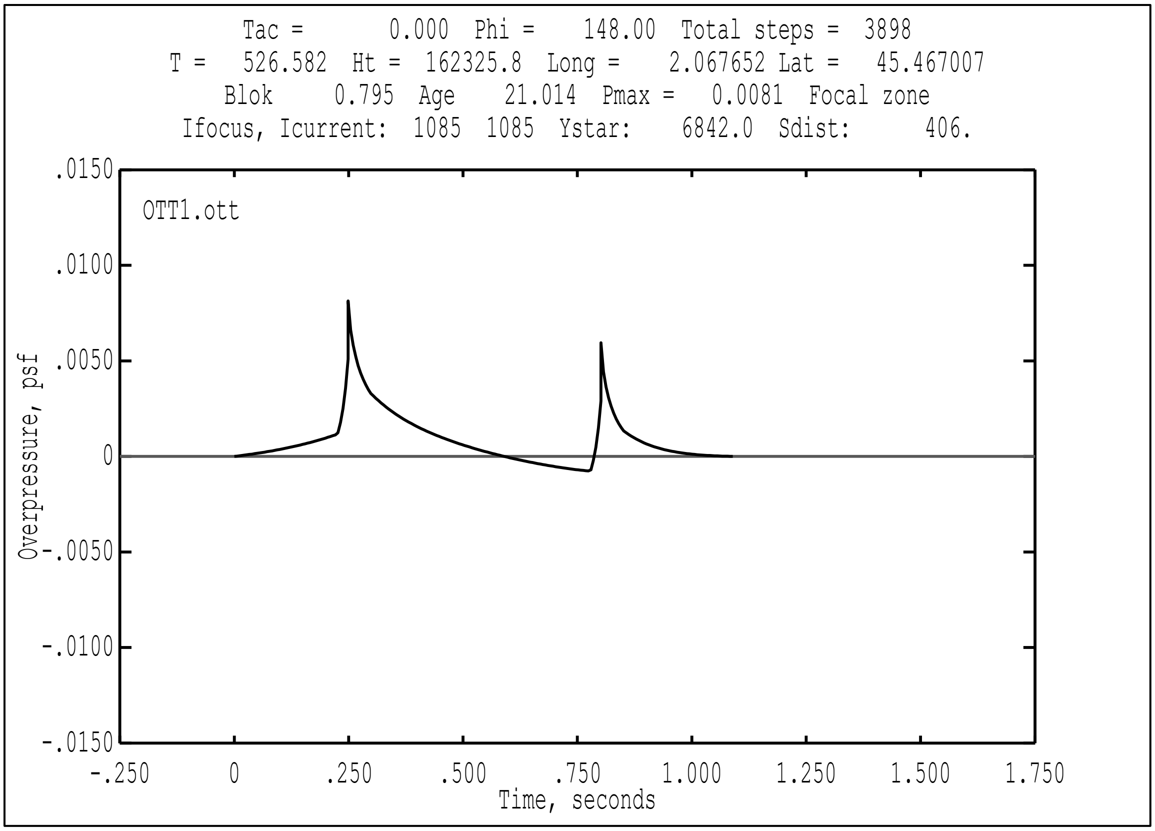


Figure 5-10 OTTER signature display.

Table 5-12 OTTER signature display options.

Option	Description
Right Arrow	Shift the plot to the right
Left Arrow	Shift the plot to the left
Page Up	Zoom in
Page Down	Zoom out
. or ,	Adjust the zoom on 1x,2x,4x,5x,8x,10x magnification sequence
Move the cursor Up	Zoom in on pressure axis
Move the cursor Down	Zoom out on pressure scale
Home	Default zoom level
t or T	Show the time plot of the signature
s or S	Show the spectrum (energy spectral density) of the boom
n,m	Adjust the spectrum amplitude range (in the spectrum display)
Enter or Backspace	Move 10 time steps forward or back
CTRL + Enter or CTRL + Backspace	Move 1 time step forward or back
F	Move to first focus
Esc or q	Return to Ray display

5.2.3.3 OTTER Outputs

OTTER can output graphical or tabular data for the current display at any point. For more information on available displays, see Section 5.2.3.2.

To generate graphical output of the current OTTER Signature Display:

1. Press the “F6” key
2. Select *Print* and follow the prompts to save in PDF format or *WMF Output* and follow the prompts to save in WMF format.

To generate tabular output of the current OTTER Signature Display:

1. Press the “F7” key
2. Enter a name and click *Save*.

6 Additional Processing Options

The PCBoom modules can be run either through the command line or in a batch script as described in Section 2.4. The SonicBAT-Run-Fort module offers additional batch processing options and is described in Section 6.1.

6.1 SonicBAT-Run-Fort

The SonicBAT-Run-Fort (SBRF) module is a batch processing tool that can sequence multiple modules such as FOBoom, HeadlessBurgers, and Turbo, compile results, and prepare files for further processing in additional PCBoom modules such as WCON. While these individual tools can be run separately by the user for specific rays and trajectory points, it is sometimes advantageous to examine a full footprint for multiple trajectory points and azimuthal angles in concert. SBRF orchestrates this process by running the tools as needed and assembling combined FOBoom .out and WCON .txt signature files using the lossy and turbulence calculations. Example workflows where this processing tool may be beneficial are described in Section 2.3.2. For an example of how to use SonicBAT-Run-Fort in an analysis, see Section Appendix B.7.

Note that a propagation tool that is distributed separately from the PCBoom suite called sBOOM, which uses a time-domain Burgers solution algorithm, can be used within SonicBAT-Run-Fort as the primary propagation module in place of FOBoom and HeadlessBurgers. sBOOM version 2.01 and version 2.84 are compatible with PCBoom version 7.3.

6.1.1 SonicBAT-Run-Fort Inputs

SonicBAT-Run-Fort accepts the following file type as input.

filename.txt:	A user-generated SBRF text file with keywords to specify inputs and use of additional modules. For more information, see Section 6.1.1.1.
Module input files	All input files associated with the modules identified in the SRBF input file. See Section 3.1 for information on FOBoom inputs, Section 4.1.1 for more information on HeadlessBurgers inputs. When one of the SBOOM modes is selected, FOBoom automatically creates the input files for sBOOM.
SonicBAT-Run-Fort.config:	A user-generated configuration file to specify the locations and order in which to process modules. For more information, see Section 6.1.1.2.

6.1.1.1 SonicBAT-Run-Fort Input File (.txt) Format

The SonicBAT-Run-Fort input file format is described in Table 6-1.

Table 6-1 SonicBAT-Run-Fort input file format description.

Line Sequence	Keyword/Input Type	Description
1	Casename.dat	The name of the FOBoom input file (Section 3.1) Note: Geomode trajectory (3.1.15) is required for SonicBAT-Run-Fort
2	ABL_ALTITUDE	Keyword to specify the Atmospheric Boundary-Layer (ABL) height on the following line Omit if not using the TURBO keyword
3	altitude	Atmospheric Boundary-Layer height (altitude) in feet, omit if not using the ABL_ALTITUDE keyword Omit if not using the TURBO keyword
4	PROP_METHOD	Keyword to specify the propagation method on the following line
5	Propagation module	Enter a propagation module keyword: FOBOOM to use the FOBoom program for initial propagation only BURGERS to use FOBoom and HeadlessBurgers for propagation to the ground SBOOM201 to use the Lossy Burgers sBOOM module for propagation to the ground with high resolution (250kHz) for sBOOM version 2.01 SBOOMED201 to use the Lossy Burgers sBOOM module for propagation to the ground with medium resolution (125kHz) for sBOOM version 2.01 SBOOMLOW201 to use the Lossy Burgers sBOOM module for propagation to the ground with low resolution (51kHz) for sBOOM version 2.01 SBOOM284 to use the Lossy Burgers sBOOM module for propagation to the ground with high resolution (250kHz) for sBOOM version 2.84 SBOOMED284 to use the Lossy Burgers sBOOM module for propagation to the ground with medium resolution (125kHz) for sBOOM version 2.84 SBOOMLOW284 to use the Lossy Burgers sBOOM module for propagation to the ground with low resolution (51kHz) for sBOOM version 2.84
6	GIBBS	Optional keyword for use with BURGERS propagation method to use a GIBBS filter to smooth some of the artifacts created by the FFT functions addressing sharp rise/decay in boom signatures
7	GROUND	Optional keyword to specify a ground reflection factor on the following line
8	Ground reflection factor as a real number	Ground reflection factor (e.g., 1.9)
10	BURGERS_SAMPLE_RATE	Keyword to specify a sample rate on the following line to be used by HeadlessBurgers This will overwrite any sample rates defined in input files
11	Sample rate	Desired sampling rate in samples per second
12	TURBO	Optional keyword to invoke the Turbo module for modeling turbulence
13	TINFILE	Keyword to specify the Turbo input file on the following line
14	Casename-tin.txt	The name of the Turbo input file (Section 4.4.1.1) Omit if not using the TURBO keyword

6.1.1.2 SonicBAT-Run-Fort Configuration File Format

The SonicBAT-Run-Fort input file format is described in Table 6-2.

Specify the keywords in the order in which the modules should be run for the analysis.

Table 6-2 SonicBAT-Run-Fort configuration file format description.

Keyword	Description
FOBOOM_DIR [file path]	The file path where the FOBoom executable is located E.g., FOBOOM_DIR C:\PCBoom\Case1 Default file path: Current directory or as specified by EXE_DIR
FOBOOM_EXE [exe name]	The name of the FOBoom executable with the .exe extension E.g., FOBOOM_EXE foboom730.exe Default executable name: FOBoom.exe
SBOOM_DIR [file path]	The file path where the sBOOM executable is located E.g., SBOOM_DIR C:\PCBoom\Case1 Default file path: Current directory or as specified by EXE_DIR
SBOOM_EXE [exe name]	The name of the sBOOM executable with the .exe extension E.g., SBOOM_EXE sboom.exe Default executable name: 03-sboomadjoint_windows_2.01wFocus.exe
TURBO_DIR [file path]	The file path where the Turbo executable is located E.g., TURBO_DIR C:\PCBoom\Case1 Default file path: Current directory or as specified by EXE_DIR
TURBO_EXE [exe name]	The name of the Turbo executable with the .exe extension E.g., TURBO_EXE turbo730.exe Default executable name: 04-TURBO.exe
HEADLESS_DIR [file path]	The file path where the HeadlessBurgers executable is located E.g., HEADLESS_DIR C:\PCBoom\Case1 Default file path: Current directory or as specified by EXE_DIR
HEADLESS_EXE [exe name]	The name of the HeadlessBurgers executable with the .exe extension E.g., HEADLESS_EXE headlessburgers730.exe Default executable name: HeadlessBurgers.exe
PCBFOOT_DIR [file path]	The file path where the PCBFoot executable is located E.g., PCBFOOT_DIR C:\PCBoom\Case1 Default file path: Current directory or as specified by EXE_DIR
PCBFOOT_EXE[exe name]	The name of the PCBFoot executable with the .exe extension E.g., PCBFOOT_EXE pcbfoot730.exe Default executable name: PCBFoot.exe
WCON_DIR [file path]	The file path where the WCON executable is located E.g., WCON_DIR C:\PCBoom\Case1 Default file path: Current directory or as specified by EXE_DIR
WCON_EXE [exe name]	The name of the WCON executable with the .exe extension E.g., WCON_EXE wcon730.exe Default executable name: WCon.exe
FILTVIEW_EXE [exe name]	The name of the FILTVIEW executable with the .exe extension E.g., FILTVIEW_EXE filtview730.exe Default executable name: FILTVIEW.exe Note that the FiltView executable is assumed to be located in the same directory as WCON.
EXE_DIR [file path]	Specification for the default directory containing the executables Specific directory specifications will override this value for that executable Default file path: Current directory

6.1.2 Running SonicBAT-Run-Fort

To run SonicBAT-Run-Fort, execute the following command:

```
SonicBAT-Run-Fort filename.txt
```

where

SonicBAT-Run-Fort	The name of the SonicBAT-Run-Fort executable (e.g., sonicbat-run-fort730.exe).
Filename.txt	The name of the input file SonicBAT-Run-Fort input file.

Note that when running with the BURGERS keyword, only the UN (Gibbs filter) and GR (ground reflectivity) options are available (Table 4-1). SonicBAT-Run-Fort automatically orchestrates the running of HeadlessBurgers or sBOOM one single ray at a time. Zero padding is added to the beginning and end of the signatures as required by sBOOM.

6.1.3 SonicBAT-Run-Fort Outputs

SonicBAT-Run-Fort outputs are dependent upon the modules selected for processing, however, results for multiple rays are compiled and prepared for further processing in additional PCBoom modules. Output files produced by running SonicBAT-Run-Fort will include "_ALL.out" in the filename.

- See Section 3.2 for information on FOBoom outputs
- See Section 4.1.3 for information on HeadlessBurgers outputs
- See Section 4.4.3 for information on Turbo outputs
- See the sBOOM documentation[17,18] for information on specific sBOOM outputs and note that SonicBAT-Run-Fort automatically reads, parses and uses the files needed to prepare inputs for WCON.

Note that if SBOOM or TURBO keywords are used, additional files are written with "ablh" in the filename. These are intermediate processing files, which result from the processing of single trajectory points. These are then assembled by SonicBAT-Run-Fort into composite_ALL files, which can then be utilized in WCON.

---

[17] Rallabhandi, S. K., "Advanced Sonic Boom Prediction Using the Augmented Burgers Equation," AIAA Journal of Aircraft, Vol. 48, No. 4, 2011, pp. 1245–1253. doi:10.2514/1.C031248.

[18] Rallabhandi, S. K., "Propagation Analysis of the 3rd Sonic Boom Prediction Workshop Cases using sBOOM," submitted to AIAA SciTech 2021 conference, 2021.

Appendix A Glossary

A select group of terms used frequently throughout this manual are described below.

ABL	Atmospheric Boundary Layer
ABLH	Atmospheric Boundary Layer Height
AGL	Above Ground Level
carpet	The area on the ground exposed to the direct downward propagating sonic boom rays from the aircraft, excluding upward propagating and secondary booms. The width of the carpet is dependent on aircraft altitude and speed and the atmospheric properties.
CFD	Computational Fluid Dynamics
.dat	FOBoom input file
dB	Decibel
FiltView	Finite impulse response filter viewer
FIR	Finite impulse response
FOBoom	Main propagation code, which includes focused boom capability. Considered to be the main sonic boom propagation module for PCBoom
Focused Boom	When isopemps overlap in time and space, their intersection represents a position where boom energy is concentrated, or focused, and a “superboom” exists
Footprint	The area on the ground exposed to the sonic boom
HeadlessBurgers	Burgers equation propagation module without a graphical user interface
Hz	Hertz
ISBAP	Indoor Sonic Boom Annoyance Predictor
KZK	Khokhlov-Zobolotskaya-Kuznetzov
KZKFourier	Khokhlov-Zobolotskaya-Kuznetzov Fourier
L	Aircraft Length, in ft
LNTE	Lossy Nonlinear Tricomi Equation
Lpk or Peak Level	Peak sound pressure level, in dB
ML	Model Length, in ft
Molecular relaxation	In PCBoom, molecular relaxation refers to the absorptive effects of oxygen and nitrogen molecular relaxation (based on relative humidity aloft) on sonic boom propagation
MSL	Mean Sea Level
OTTER	Over-the-Topper ray plotting program
PCBoom	Personal Computer sonic Boom program
PCBurg	PCBoom Burgers equation module with graphical interface
PCBFoot	PCBoom Footprint assembly module
Phi	Ray angle relative to the aircraft fixed coordinate system, also referred to as Azimuth angle, in degrees. 0 degrees is directly below the aircraft.
PL or PLdB	Stevens Mark VII Perceived Level, in dB
Pmax	The maximum peak overpressure in the signature. It is presented in units of pounds per square foot (psf).
POTRAY	Propagate Over-the-Top Rays module
POTTI	Plot Over-the-Top Isopemps interactive visualizer module
RayCau	Caustic Ray visualization module

SELA or ASEL	A-Weighted Sound Exposure Level, in dB(A)
SELB or BSEL	B-Weighted Sound Exposure Level, in dB(B)
SELC or CSEL	C-Weighted Sound Exposure Level, in dB(C)
SELD or DSEL	D-Weighted Sound Exposure Level, in dB(D)
SELE or ESEL	E-Weighted Sound Exposure Level, in dB(E)
SELZ or ZSEL	Z-Weighted (flat) Sound Exposure Level, in dB
Signature	An aircraft traveling at supersonic speed generates a disturbance in the form of shock waves. Near the aircraft, the shocks form a detailed pressure signature, which relates to the detail of the aircraft's geometry. As it propagates through the atmosphere, the signature evolves.
SonicBAT-Run-Fort	Sonic Booms in Atmospheric Turbulence developed program that calls/exercises multiple PCBoom modules in a single workflow Tool developed during the SonicBAT program that automatically calls and runs other Fortran programs (e.g., HeadlessBurgers, sBOOM, TURBO) and assembles their outputs suitable for use with other PCBoom modules such as WCON and FiltView
Turbo	Turbulence module
Waveform	See "Signature". "Waveform" and "signature" are used interchangeably throughout this guide.
WCON	Winteracter Contours program; Interactive footprint and signature display module

Appendix B Examples

This appendix provides instructions on completing selected example analyses. All files required to complete these examples are provided in the PCBoom software suite package, Examples folder. Note that these examples were developed using modules that are only compatible with a Windows operating system.

Examples included in this appendix demonstrate the features described in the list below where the first bullet summarizes the purpose of the analysis, the first sub-bullet describes the FOBoom inputs demonstrated in the analysis, and the last bullet describes additional modules demonstrated in the analysis.

- Appendix B.1: Visualization
  - FOBoom LEGACY RAYTRACING, ATT atmosphere, CYLINDER MODE input, TERRAIN
  - PCBFoot and WCON modules for visualization, as described in Workflow 2 (Section 2.3.2.1)
- Appendix B.2 Enhanced Burgers
  - FOBoom SCHULFLAT RAYTRACING, ATT atmosphere, CARLSON ACNAME MODE input
  - Molecular relaxation and footprint computation via Enhanced Burgers using the modified BURGERS keyword input, as described in Workflow 3 (Section 2.3.2.2).
- Appendix B.3: HeadlessBurgers
  - FOBoom LEGACY RAYTRACING, ATT atmosphere, CYLINDER MODE input, HIGHRES signature sampling
  - Lossy propagation/molecular relaxation to compute loudness metrics, as described in Workflow 4 (Section 2.3.2.2), where HeadlessBurgers is substituted for PCBurg
- Appendix B.4: Sonic Booms into Water
  - FOBoom LEGACY RAYTRACING, ATT atmosphere, CYLINDER MODE input
  - PCBFoot and WCON modules to propagate the boom underwater, as described in Workflow 16 (Section 2.3.2.4)
- Appendix B.5: KZK Filters
  - FOBoom LEGACY RAYTRACING, ATT atmosphere, CARLSON ACNAME MODE input
  - PCBFoot, WCON, and FiltView modules to apply turbulence using the FIR filter method, as described in Workflow 8 (Section 2.3.2.3)
- Appendix B.6: Crow's Method
  - FOBoom LEGACY RAYTRACING, ATT atmosphere, CARLSON ACNAME MODE input
  - PCBFoot and WCON modules to apply turbulence using Crow's Method, as described in Workflow 7 (Section 2.3.2.3)
- Appendix B.7 TURBO
  - FOBoom LEGACY RAYTRACING, BALLOON atmosphere, CYLINDER MODE input, HIGHRES signature sampling
  - SonicBAT-Run-Fort (FOBoom, HeadlessBurgers, and TURBO modules) to apply turbulence using the classical Fourier mode distribution method
  - PCBFoot and WCON modules for post-processing and visualization, as described in Workflow 12 (Section 2.3.2.3)
- Appendix B.8 sBOOM
  - FOBoom SBOOMLOW284 RAYTRACING, ATT atmosphere, CYLINDER MODE input, HIGHRES signature sampling
  - sBOOM module for signature propagation and molecular relaxation, as described in Workflow 13 (Section 2.3.2.3)

- Appendix B.9 Focus Delta Ray Solution
    - FOBoom LEGACY RAYTRACING, HYSTATMO atmosphere, THOMAS MODE input
    - RAYCAU, PCBurg, and LNTE modules to solve for the focused ground signatures, as described in Workflow 14 (Section 2.3.2.4)
- Appendix B.10 Over-the-Top (OTT)/Secondary Sonic Booms
    - FOBoom SCHULELLIPSE RAYTRACING, ATT atmosphere, CARLSON ACNAME MODE input, OTT keyword
    - POTRAY, POTTI, and OTTER modules to locate and visualize over-the-top/secondary sonic booms, as described in Workflow 15 (Section 2.3.2.4)

Note that these examples specify to include all example files and executables in the same folder. This is not a requirement of PCBoom, but it is required for the examples to run as presented in the instructions.

Instructions are written such that words in italics refer to words or phrases as they appear in the referenced file or interface for easy identification.

Appendix B.1 Visualization

Once ray tracing in FOBoom is completed, visualizing the footprint is useful to determine the impact of the booms on the ground. PCBFoot assembles the FOBoom output files spatially and temporally to allow WCON to display the aircraft trajectory, as well as sonic boom isopemps and pressure contours following the workflow shown in Figure B-1. WCON interpolates between data provided by FOBoom and PCBFoot such that any point within the footprint can be selected to display the signature associated with a particular ray or at a specific point on the ground.

Through this visualization process, particular rays of interest can be identified for which molecular relaxation may be applied in order to obtain more accurate signatures and loudness metrics that account for the atmospheric effects of lossy propagation. For examples in which molecular relaxation is applied on a particular ray of interest, see Appendix B.2 and Appendix B.9.

This example also demonstrates the use of a terrain file containing georeferenced ground coordinates in order to better locate the ground intercept for each ray. As the program traces the primary ray on each tube, it checks the ground elevation below the current ray end. When the ray crosses below local ground elevation, the ray time step is interpolated to obtain the point where the ray exactly intersects the ground. Without the use of this keyword and supplied terrain file containing elevations, FOBoom assumes the ground to be locally flat.

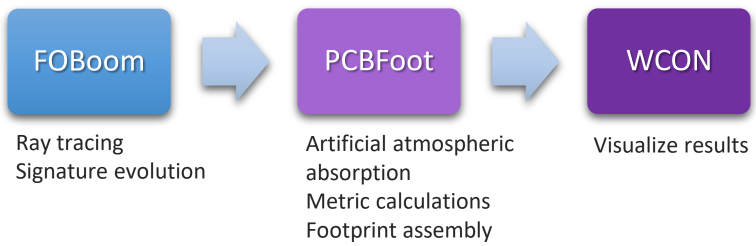


Figure B-1 Footprint visualization workflow.

1. **Create a directory that contains executables for FOBoom, PCBFoot and WCON modules.**
2. **Extract the contents of Examples.zip\01_Visualization\Inputs to the same directory as the executables. This should include .rtf documents that can be viewed in any Word processor.**
3. **Review the FOBoom input file Visualization.dat shown in Figure B-2**. **This file can be opened in any text editor.**
   a. Note that the *CASENAME* keyword is used to specify the name of the case as *Visualization*.
   b. Note that the *OUTPUTS* keyword section indicates 2 output types, including display of the command prompt screen and the .mco file. For more information on outputs, see Section 3.1.5.
   c. Note that the *ATMOS* keyword with the *ATT* option specifies that the external file *Visualization_Atmosphere.atm* contains the atmosphere data and the latitude of *36.0* degrees on the following line ties the atmosphere data to a location.
      i. Review the atmosphere file Visualization_Atmosphere.atm. This file can be opened in any text editor. For more information on the ATT file format, see Section 3.1.9.1.
   d. Note that the *ALTITUDES* keyword and following two lines in the file specify the number of altitudes of interest (1) and the altitude (0.0 ft MSL), which prompts FOBoom to use the local ground altitude provided in the terrain file. For more information on the ALTITUDES keyword, see Section 3.1.10.
   e. Note that the *RAYTRACING* keyword with the *LEGACY* option is used and the designation of the modeling parameters follow on the next 5 lines. For more information on the modeling parameters, see Section 3.1.12.
   f. Note that the *MODE* keyword is used with the *CYLINDER* option, which specifies that the external file *Visualization_Cylinder.plt* contains the starting signature in the Cylinder format. The following lines specifies the number of cylinders (1), the R/L ratio (2.0) and the vehicle length (175 ft).
      i. Review the input signature file Visualization_Cylinder.plt. This file can be opened in any text editor. Note that the data are presented in the units expected for the CYLINDER mode. For more information on the CYLINDER mode input, see Section 3.1.13.3.
   g. Note that the *TERRAIN* keyword is used, which specifies that the external binary file *Visualization_Terrain.dt0* contains georeferenced ground coordinates to describe the unique elevation changes for the flyover location of interest. For more information on the TERRAIN keyword, see Section 3.1.11.
   h. Note that the *TRAJECTORY* keyword with the *FILE* option specifies that the external file *Visualization_Trajectory.trj* contains the trajectory data. For more information on the TRAJECTORY inputs, see Section 3.1.15.
      i. Review the trajectory input file Visualization_Trajectory.trj. This file can be opened in any text editor. Note that it contains many points, which will be plotted in the WCON footprint display. Each trajectory point will also correspond to an isopemp in WCON.

```
CASENAME
Visualization
OUTPUTS
2
SCREEN
MCO
ATMOS
ATT
Visualization_Atmosphere.atm
36.0
ALTITUDES
1
0.0
RAYTRACING
LEGACY
    -2000.0  100000.0  -1500.0
    1.9  2.0
    0.5   500.0   0.5
    0
1
MODE
CYLINDER
1
Visualization_Cylinder.plt
1.0
2.0 175.0
TERRAIN
Visualization_Terrain.dt0
TRAJECTORY
FILE
Visualization_Trajectory.trj
END
```

Figure B-2 Visualization case input file.

4. **Review the batch script file Run_Visualization.bat shown in Figure B-3. This file can be opened in any text editor.**
   a. Line 1 runs FOBoom (*pcboom730win.exe*) with inputs specified in the *Visualization.dat* file.
   b. Line 3 runs PCBFoot, which uses the outputs from FOBoom (*Visualization*) as inputs. Note the ioutput (*6)* indicates output of a boom summary file (.asc), as well as the signature files .sig, .ind, and .ens, which are used as inputs for WCON.
   c. Line 5 runs WCON, which uses the outputs from PCBFoot to visualize the footprint and signatures.

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
pcboom730win.exe Visualization.dat
pause
pcbfoot730.exe Visualization 6
pause
wcon730.exe Visualization
pause
exit
```

Figure B-3 Visualization case batch script file.

5. **Run FOBoom**
    a. Double click *Run_Visualization.bat* for FOBoom to begin ray tracing at specified trajectory points.
    b. A command prompt will be displayed with times along the trajectory.
    c. Note that the .delt, .mco, .org, .out, and .un6 files have been written to the folder with the input files and executables.
6. **Run PCBFoot**
    a. When FOBoom processing is complete, press any key while in the command prompt to continue.
    b. The command prompt will display isopemp calculation progress along each trajectory point.
    c. Note that the .asc, .ens, .ind, .qwk, and .sig files have been written to the folder with the input files and executables. These data will be used to visualize the footprint in WCON.
7. **Run WCON**
    a. When PCBFoot processing is complete, press any key while in the command prompt to continue.
    b. The WCON interface will open to allow for visualization of the footprint including isopemps and pressure contours, as shown in Figure B-4. The data in the right column will change to represent the point at which the mouse is hovering. Note that zg changes as the mouse moves due to the use of the TERRAIN keyword.

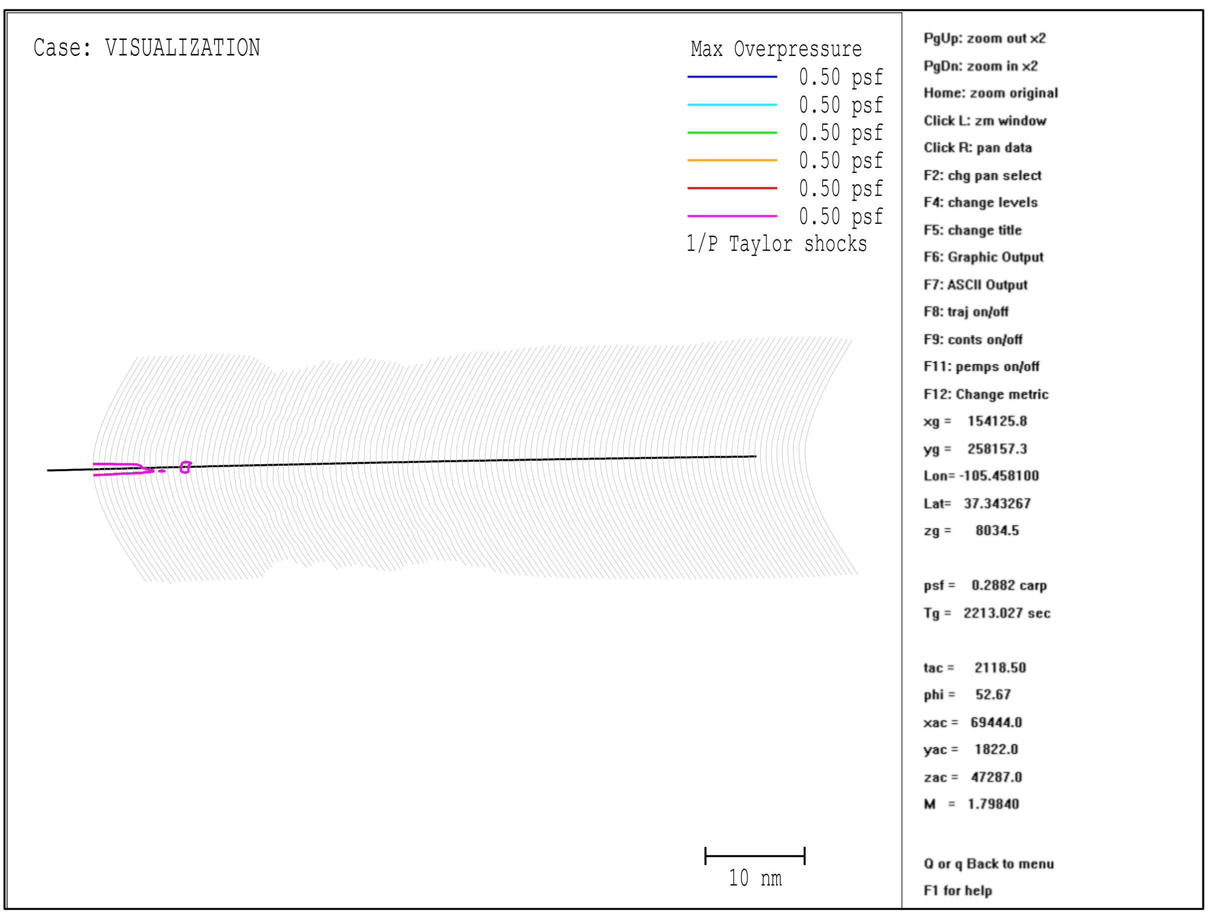


Figure B-4 Visualization case footprint displaying aircraft trajectory, boom isopemps, and pressure contours.

8. Interact with WCON Display

a. Note the key codes on the right side of the screen that can be used to modify the display.
b. Press the "F4" key to open the window in which the contour levels can be changed to produce a more useful display. For this example, match those shown in Figure B-5, then click *Done*. The resulting display is shown in Figure B-6.
c. Press the "F6" key to save the display.

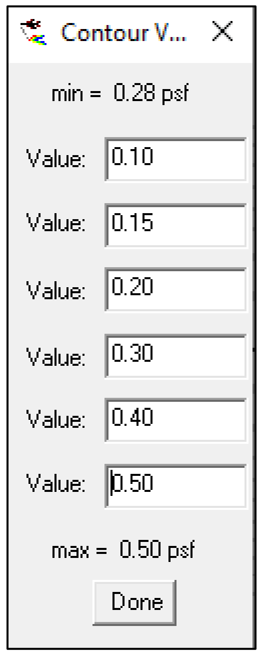


Figure B-5 Visualization case adjusted contour levels.

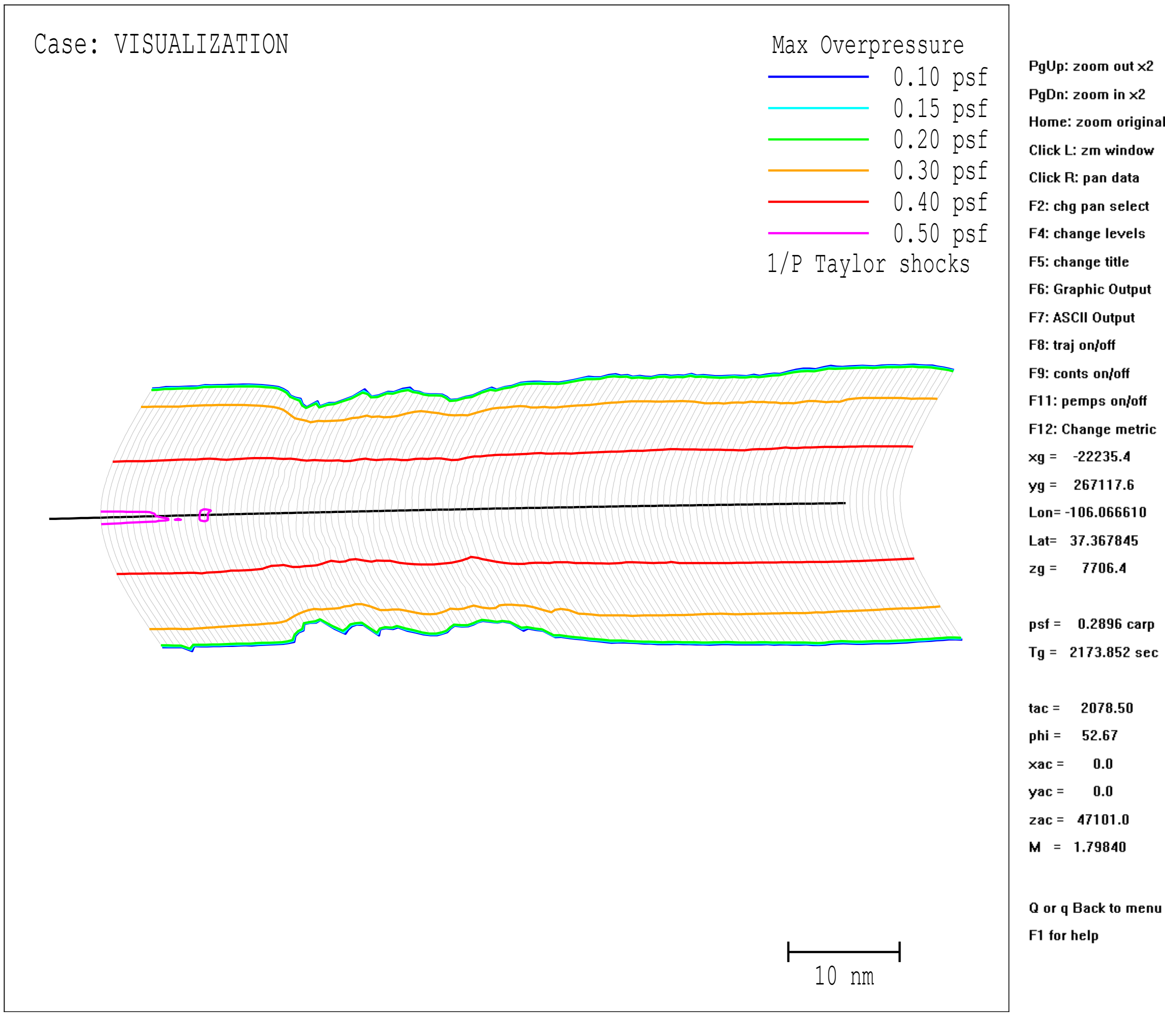


Figure B-6. Visualization case footprint display with adjusted contours.

9. Visualize Signature

a. Open the WCON signature view

   i. Press the “p” key while hovering the mouse over any point within the footprint.

   ii. A window will open in which the (x, y) coordinates can either be approved or edited to match the location of interest. For this example, edit the coordinates as shown in Figure B-7 and click *OK*. The resulting signature is shown in Figure B-8.

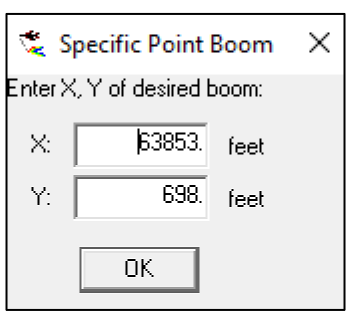


Figure B-7 Visualization case WCON signature example coordinates.

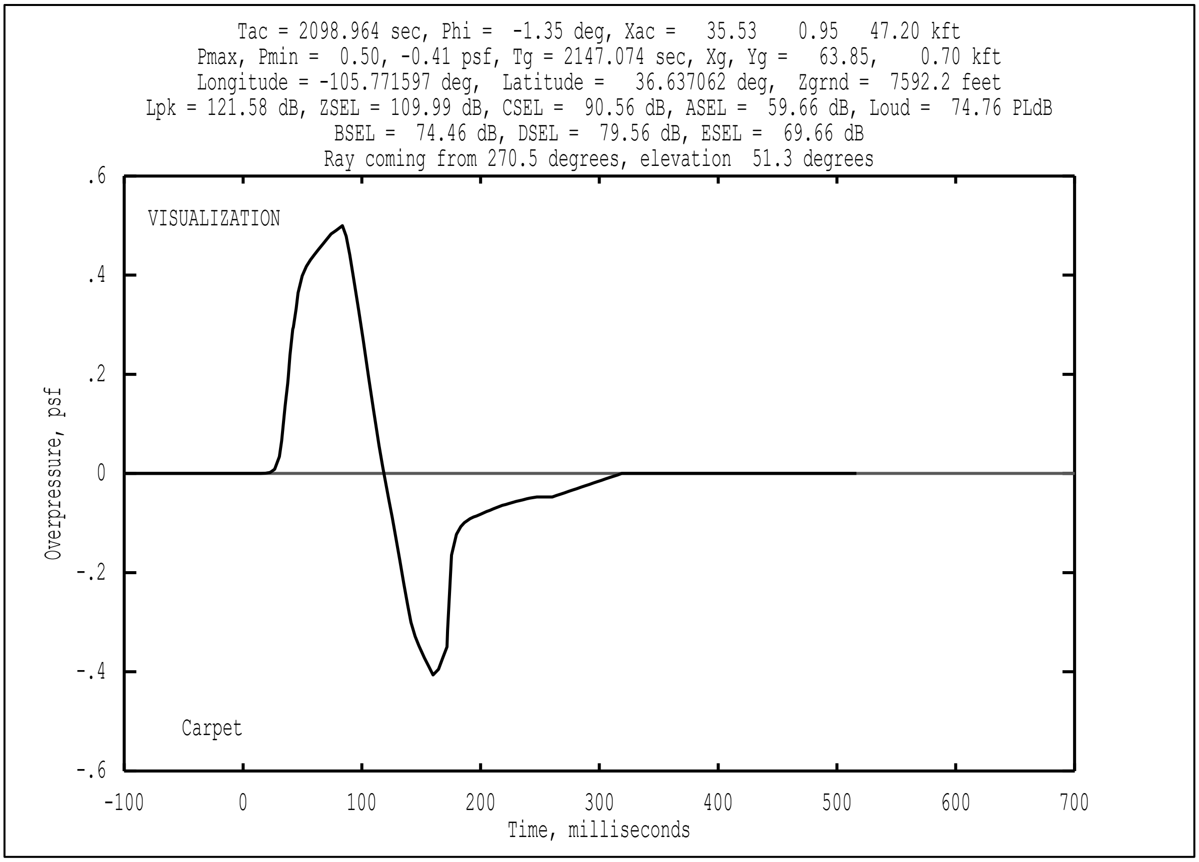


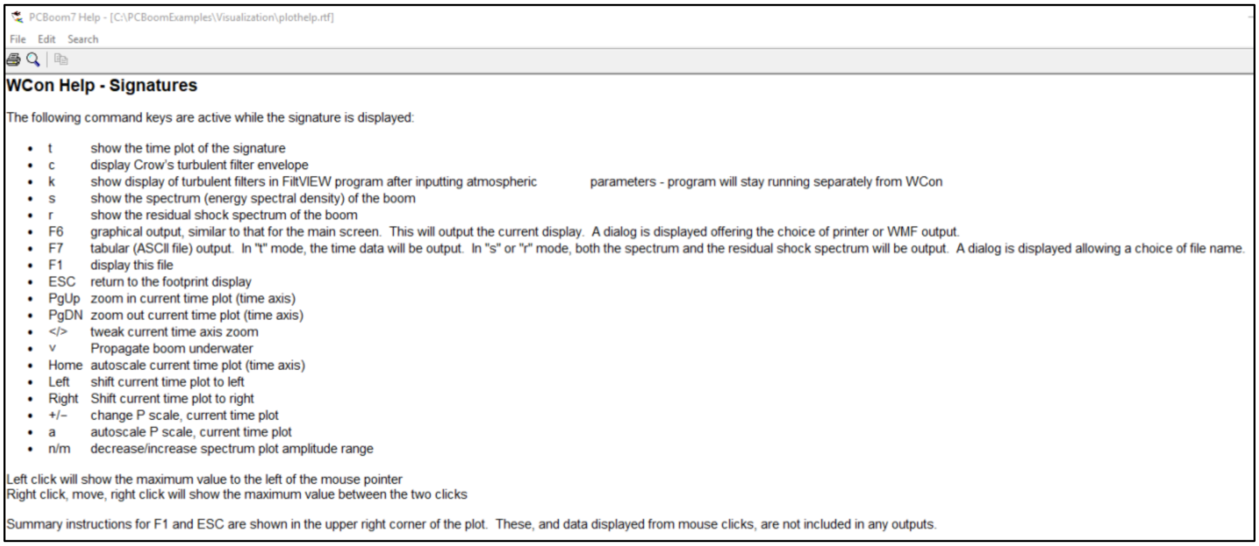
Figure B-8 Visualization case, signature view.

10. Interact with the Signature View

a. Press the “F1” key to open the Help menu, as shown in Figure B-9.

   i. Note that both the signature view and the help menu windows can be viewed simultaneously. Click back into the signature view in order to execute desired refinements to the plot by referencing the key commands described in the Help menu. For example, Figure B-10 shows the spectrum graphical display for the signature.

   ii. Upon finishing desired display refinements, press the “F6” key to save the current display, and “F7” to save the data pertaining to the current display in a text file.



PCBoom7 Help - [C:\PCBoomExamples\Visualization\plothelp.rtf]

File Edit Search

WCon Help - Signatures

The following command keys are active while the signature is displayed:

- t show the time plot of the signature
- c display Crow's turbulent filter envelope
- k show display of turbulent filters in FiltVIEW program after inputting atmospheric parameters - program will stay running separately from WCon
- s show the spectrum (energy spectral density) of the boom
- r show the residual shock spectrum of the boom
- F6 graphical output, similar to that for the main screen. This will output the current display. A dialog is displayed offering the choice of printer or WMF output.
- F7 tabular (ASCII file) output. In "t" mode, the time data will be output. In "s" or "r" mode, both the spectrum and the residual shock spectrum will be output. A dialog is displayed allowing a choice of file name.
- F1 display this file
- ESC return to the footprint display
- PgUp zoom in current time plot (time axis)
- PgDN zoom out current time plot (time axis)
- </> tweak current time axis zoom
- v Propagate boom underwater
- Home autoscale current time plot (time axis)
- Left shift current time plot to left
- Right Shift current time plot to right
- +/– change P scale, current time plot
- a autoscale P scale, current time plot
- n/m decrease/increase spectrum plot amplitude range

Left click will show the maximum value to the left of the mouse pointer
Right click, move, right click will show the maximum value between the two clicks

Summary instructions for F1 and ESC are shown in the upper right corner of the plot. These, and data displayed from mouse clicks, are not included in any outputs.

Figure B-9. WCON help menu.

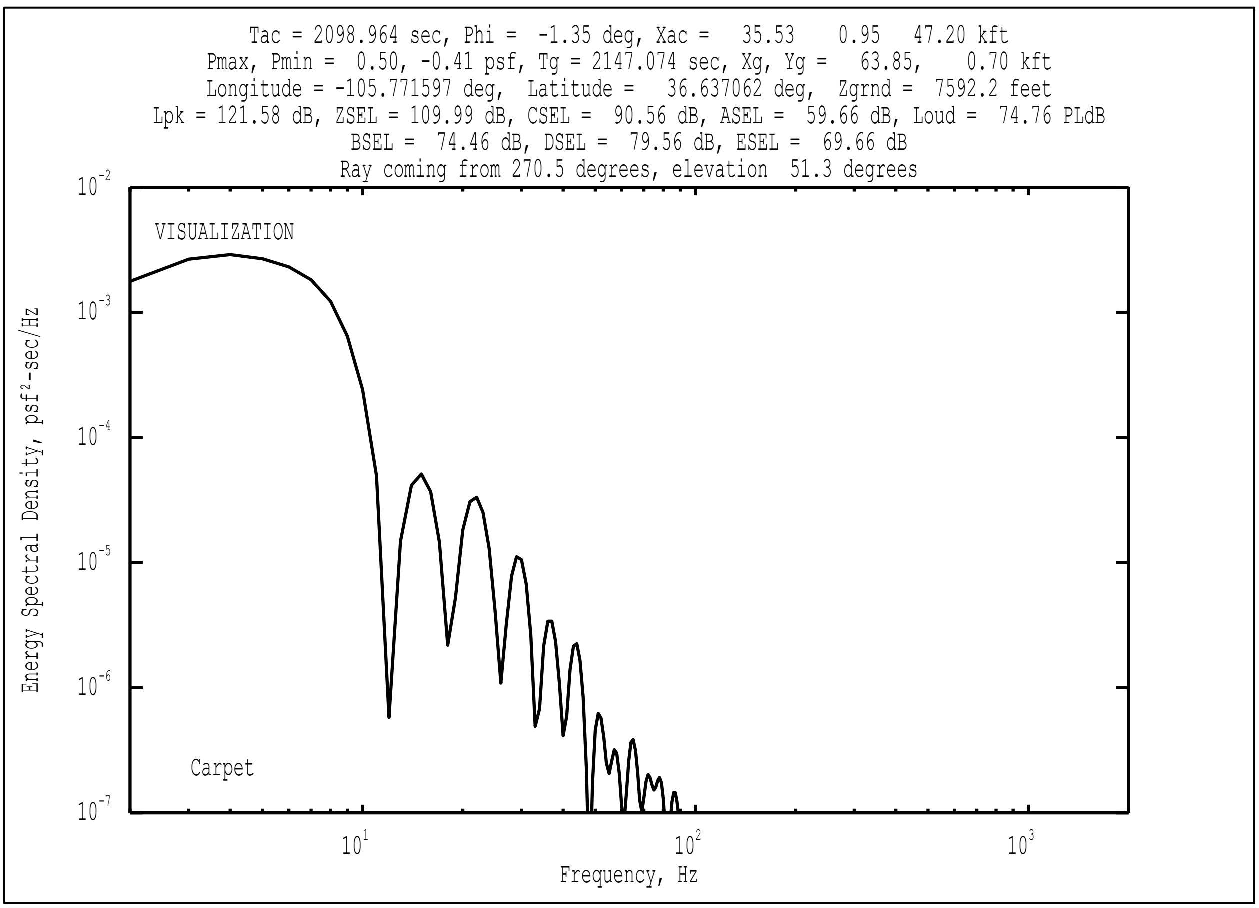


Figure B-10 Visualization case, spectrum display.

Appendix B.2 Enhanced Burgers

After completing ray tracing in FOBoom, it is common practice to calculate shock structures via molecular relaxation absorption processes on sonic boom signature evolution based on the Burgers equation. It is especially imperative to include molecular relaxation when analyzing loudness metric results because shock structure affects the upper frequency content of booms, thus impacting the loudness metric calculations. Molecular relaxation can be applied using several methods, see Section 2.3.2.2. This example demonstrates application of molecular relaxation using the Enhanced Burgers keyword format within FOBoom (Figure B-11).

Using the Enhanced Burgers keyword format within FOBoom is significantly faster than applying molecular relaxation via a Legacy Burgers solver (PCBurg or HeadlessBurgers). This keyword format also refines the prediction of sonic boom propagation by accounting for the full wind effects including the Doppler and convection effects on the ray path, absorption coefficient, Blokhintzev factor, coefficient of nonlinearity, and age parameter. However, the outputs of this keyword format are not compatible with WCON, thus one cannot visualize the computed footprint and ground signatures within the PCBoom suite. The output files are in ASCII format and can be processed by user-supplied external data processing and visualization tools.

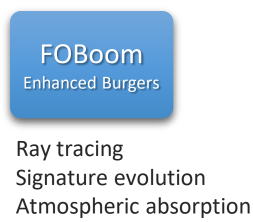


Figure B-11 Enhanced Burgers workflow.

1. **Create a directory that contains the executable for the FOBoom program.**
2. **Extract the contents of Examples.zip\02_EnhancedBurgers\Inputs to the same directory as the executable.**
3. **Review the FOBoom input file EnhancedBurgers.dat shown in Figure B-12. This file can be opened in any text editor.**
   a. Note that the *CASENAME* keyword is used to specify the name of the case as *EnhancedBurgers*.
   b. Note that the *OUTPUTS* keyword section only indicates the display of the command prompt screen. The other outputs will be prompted based on the BURGERS keyword format. For more information on outputs, see Section 3.1.5.
   c. Note that the *BURGERS* keyword is used along with the following line of inputs. The input options after the keyword specify that FOBoom will implement Enhanced Burgers. This will prompt the output of the .fpt, .org, .out, and .un6 files.
      i. Note that the input options specify that the Burgers solution will be computed with the medium step size (2) and a sampling frequency of 30 kHz, which are optimal settings for the CARLSON ACNAME F18 N-wave mode demonstrated in this example.
   d. Note that the *ATMOS* keyword with the *BALLOON* option specifies that the external file *EnhancedBurgers_Atmosphere.atm* contains the measured atmosphere data. The latitude of *29.291300* degrees indicates the location at which the balloon data were collected.

i. Review the atmosphere file EnhancedBurgers_Atmosphere.atm. This file can be opened in any text editor. For more information on the BALLOON file format, see Section 3.1.9.2.

e. Note that the *ALTITUDES* keyword and following two lines in the file specify the number of altitudes of interest (1) and the altitude (3.0 ft MSL) at which ground signatures will be calculated.

f. Note that the *RAYTRACING* keyword with the *SCHULFLAT* option is used and the designation of the modeling parameters follow on the next 5 lines. Note that Enhanced Burgers must be run using this keyword option. Also note that the input *0 on line 20* indicates that ray tracing will be completed for the full extent of the sonic boom carpet, thus producing the .fpt output file. For more information on the modeling parameters, see Section 3.1.12.

g. Note that the *MODE* keyword is used with the *CARLSON* and *ACNAME* options, which specify that the known source characteristics for the selected *F-18* aircraft will be used for the starting signature. For more information on the CARLSON mode, see Section 3.1.13.1.

h. Note that the *TRAJECTORY* keyword with the *FILE* option specifies that the external file *EnhancedBurgers_Trajectory.trj* contains the trajectory data. For more information on the TRAJECTORY inputs, see Section 3.1.15.

i. Review the trajectory input file EnhancedBurgers_Trajectory.trj. This file can be opened in any text editor.

```
CASENAME
EnhancedBurgers
OUTPUTS
1
SCREEN
BURGERS
 2 30e3
ATMOS
BALLOON
EnhancedBurgers_Atmosphere.atm
29.291300
ALTITUDES
1
     3.0
RAYTRACING
SCHULFLAT
 -2000. 100000. -1500.
 1.9 1.
 .5 500. .5
 0
 5.
MODE
CARLSON
ACNAME
F-18
TRAJECTORY
FILE
EnhancedBurgers_Trajectory.trj
```

Figure B-12 EnhancedBurgers case input file.

4. Review the batch script file Run_EnhancedBurgers.bat shown in Figure B-13. This file can be opened in any text editor.

a. Line 1 runs FOBoom (*pcboom730win.exe*) with inputs specified in the *EnhancedBurgers.dat* file.

```
pcboom730win.exe EnhancedBurgers.dat
pause
exit
```

Figure B-13 EnhancedBurgers case batch script file.

5. **Run FOBoom**
   a. Double click *Run_EnhancedBurgers.bat* for FOBoom to begin ray tracing at specified trajectory points.
   b. A command prompt will be displayed with times along the trajectory.
   c. Note that the .fpt, .org, .out, and .un6 files have been written to the folder with the input files and executables.
      i. The .fpt file contains the ground signatures at each azimuth angle as well as maximum overpressure, latitude/longitude ground intersection points, azimuth angles, PL, aircraft time, and ray propagation time. This file can be opened in any text editor.
6. **Modify the FOBoom input file to produce the .wfm file**
   a. Open EnhancedBurgers.dat.
   b. Edit lines 20 and 21 to match that shown in Figure B-14.
      i. Note that this edit now indicates that ray tracing will only be completed for only one azimuth angle, at phi = 0 degrees. When using Enhanced Burgers, any integer input on line 20 greater than 0 prompts the output of the .wfm file for the resulting waveform(s).
   c. Save the changes to overwrite the existing EnhancedBurgers.dat in the active directory.

```
CASENAME
EnhancedBurgers
OUTPUTS
1
SCREEN
BURGERS
 2 30e3
ATMOS
BALLOON
EnhancedBurgers_Atmosphere.atm
29.291300
ALTITUDES
1
     3.0
RAYTRACING
SCHULFLAT
 -2000. 100000. -1500.
 1.9 1.
 .5 500. .5
 1
 0.
MODE
CARLSON
ACNAME
F-18
TRAJECTORY
FILE
EnhancedBurgers_Trajectory.trj
```

Figure B-14 EnhancedBurgers case edited input file.

7. Run FOBoom

a. Double click *Run_EnhancedBurgers.bat* for FOBoom to begin ray tracing at specified trajectory points.

b. A command prompt will be displayed with times along the trajectory.

c. Note that the .org, .out, and .un6 files have been overwritten with new data and a new .wfm file has been created.

    i. The .wfm file contains the ground signature at the specified azimuth angle, as well as the ground intersection point (in feet), corresponding PL, aircraft time, ray propagation time, azimuthal angle, run-time, and sampling frequency. This file can be opened in any text editor.

Appendix B.3 HeadlessBurgers

After completing ray tracing in FOBoom, it is common practice to calculate shock structures via molecular relaxation absorption processes on sonic boom signature evolution based on the Burgers equation. It is especially imperative to include molecular relaxation when analyzing loudness metric results because shock structure affects the upper frequency content of booms, thus impacting the loudness metric calculations. Molecular relaxation can be applied using several methods, see Section 2.3.2.2. This example demonstrates application of molecular relaxation using the FOBoom and HeadlessBurgers modules (Figure B-15).

HeadlessBurgers is used for batch solving multiple rays at once, or to save computational time by producing quick results for a single ray, as demonstrated in this example. Rays of interest may be identified via footprint and signature visualization, as shown in Appendix B.1.

Both PCBurg and HeadlessBurgers contain the same molecular relaxation algorithms, but HeadlessBurgers requires less computational time because it does not have a graphic user interface. The PCBurg interface allows for manual propagation and signature visualization in order to view intermediate signatures as they evolve from the aircraft to the ground. For an example of molecular relaxation computed in PCBurg, see Appendix B.9.

Note that using the Enhanced Burgers keyword format within FOBoom is significantly faster than applying molecular relaxation via either external Burgers solver module. This keyword format invokes a different molecular relaxation algorithm that accounts for the full wind effects including the Doppler and convection effects in the governing equations. For an example of molecular relaxation computed using Enhanced Burgers, see Appendix B.2.

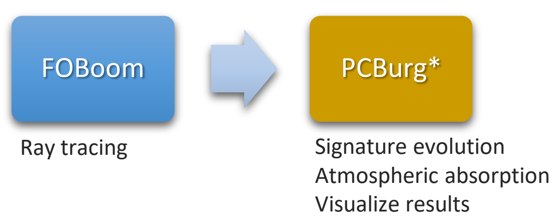


Figure B-15 Molecular relaxation workflow.

1. **Create a directory that contains executables for FOBoom and PCBurg modules.**
2. **Extract the contents of Examples.zip\03_HeadlessBurgers\Inputs to the same directory as the executables.**
3. **Review the FOBoom input file HeadlessBurgers.dat shown in Figure B-16, in which the spacing has been condensed for legibility in this format. This file can be opened in any text editor.**
   a. Note that the *CASENAME* keyword is used to specify the name of the case as *HeadlessBurgers*.
   b. Note that the *BURGERS* keyword is used to prompt the output of the .age and .ssg files, which will be used as inputs for HeadlessBurgers.
   c. Note that the *OUTPUTS* keyword section indicates 4 output types, including display of the command prompt screen and three types of output files. For more information on outputs, see Section 3.1.5.
   d. Note that the *ATMOS* keyword with the *ATT* option specifies that the external file *HeadlessBurgers_Atmosphere.atm* contains the atmosphere data and the latitude of *35.0* degrees on the following line ties the atmosphere data to a location.
      i. Review the atmosphere file HeadlessBurgers_Atmosphere.atm. This file can be opened in any text editor. For more information on the ATT file format, see Section 3.1.9.1.
   e. Note that the *ALTITUDES* keyword and following five lines in the file specify the number of altitudes of interest (4) and the altitudes in ft MSL.
   f. Note that the *RAYTRACING* keyword with the *LEGACY* option is used and the designation of the modeling parameters follow on the next 5 lines. Note the input parameter *-30* on line 26 designates the azimuth angle of interest (in degrees) for which molecular relaxation will be applied in HeadlessBurgers. For more information on the modeling parameters, see Section 3.1.12.
   g. Note that the *MODE* keyword is used with the *CYLINDER* option, which specifies that the external file *HeadlessBurgers_Cylinder.plt* contains the starting signature in the Cylinder format. The following lines specifies the number of cylinders (1), the R/L ratio (3.1299) and the aircraft length (233.3 ft).
      i. Review the input signature file HeadlessBurgers_Cylinder.plt. This file can be opened in any text editor. Note that the data are presented in the units expected for the CYLINDER mode. For more information on the CYLINDER mode input, see Section 3.1.13.3.
   h. Note that the *HIGHRES* keyword is used, which specifies that the external file *HeadlessBurgers_highSR.txt* contains information to control the fidelity of the analyzed signature for post-processing in HeadlessBurgers.
      i. Review the input file HeadlessBurgers_highSR.txt. This file can be opened in any text editor. Note that the data describe the maximum number of points, sampling rate, and duration of the signature.
   i. Note that the *REM* keyword precedes the *TRAJECTORY* keyword so that the trajectory data column headers can be displayed as desired for legibility within this input file without being read in FOBoom. This keyword can be used between keyword blocks to add information that will be ignored by FOBoom.
      i. Note that the *TRAJECTORY* keyword is followed by the trajectory data in *longlat* mode. For more information on the TRAJECTORY data format options, see Section 3.1.15.

```
CASENAME
HeadlessBurgers
BURGERS
OUTPUTS
4
SCREEN
UN6
U28
MCO
ATMOS
ATT
HeadlessBurgers_Atmosphere.atm
35.0000
ALTITUDES
4
40000.
20000.
10000.
0.
RAYTRACING
LEGACY
    -2000.0  100000.0  -1500.0
    1.9 3.1299
    0.5   500.0   0.5
    1
    -30.
MODE
CYLINDER
1
HeadlessBurgers_Cylinder.plt
1.0
3.1299  233.300
HIGHRES
HeadlessBurgers_highSR.txt
REM tstart xplane yplane fltalt mach dmdt d2mdt head psidot d2psi fpa gamdot d2gm Wt(klbs) Length(ft) Thrust(klb) Drag(klb) Alpha(deg) FKS
TRAJECTORY
 longlat   -118.0 35.0
    0.00   0.00   0.00  55000.0 1.6  0.00 0.00  90.0 0.00   0.00  0.00 0.00  0.00 0.00     233.33          0.00        0.00      0.00       0.00
END
```

Figure B-16 HeadlessBurgers case input file.

4. **Review the batch script file Run_HeadlessBurgers.bat shown in Figure B-17. This file can be opened in any text editor.**
   a. Line 1 runs FOBoom (*pcboom730win.exe*) with inputs specified in the *HeadlessBurgers.dat* file.
   b. Line 3 runs HeadlessBurgers with the input parameters that follow, including the azimuth angle of -30 degrees as specified in the FOBoom input file, a low sampling rate option for quicker computation and the ground reflection factor of 1.9 to include pressure doubling at the ground for accurate computation of loudness metrics. Ground surfaces are rarely perfectly hard or smooth, so it is common to use a reflection factor slightly less than 2. For more information on the HeadlessBurgers input parameters, see Section 4.1.1.

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
pcboom730win.exe HeadlessBurgers.dat
pause
HeadlessBurgers -HeadlessBurgers PW-30 SR2 GR1.9
pause
exit
```

Figure B-17 HeadlessBurgers case batch script file.

5. **Run FOBoom**
   a. Double click *Run_HeadlessBurgers.bat* for FOBoom to begin ray tracing at specified trajectory points.
   b. A command prompt will be displayed with times along the trajectory.
   c. Note that the .age, .mco, .org, .out, .ssg, .u28, and .un6 files have been written to the folder with the input files and executables.

6. **Run HeadlessBurgers**
   a. When FOBoom processing is complete, press any key while in the command prompt to continue.
   b. The command prompt will display the azimuth angle of the ray, which is being analyzed.
   c. Note that the .bsg file has been written to the folder with the input files and executables. This file can be opened in any text editor. These data include the pressure signature and loudness metrics at the ground.

Appendix B.4 Sonic Boom Propagation into Water

In order to evaluate the impact of the overpressure on marine life, PCBoom can simulate sonic boom propagation into water. Note that the propagation algorithm is only valid for modeling boom penetration into a deep, calm ocean, or to predict the boom on the surface of the water, which can be used as input into other models to account for wavy oceans or a shallow water region along a coastline. The underwater propagation algorithm is implemented on signatures extracted in WCON after ray tracing and footprint assembly are complete, as shown in Figure B-18.

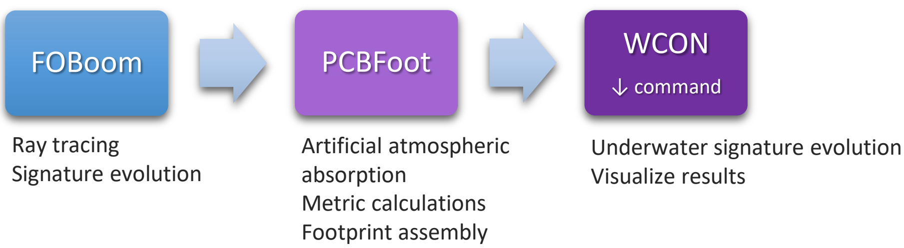


Figure B-18. Sonic boom propagation into water workflow.

1. **Create a directory that contains executables for FOBoom, PCBFoot and WCON modules.**
2. **Extract the contents of Examples.zip\04_SBPropIntoWater\Inputs to the same directory as the executables.**
3. **Review the FOBoom input file IntoWater.dat shown in Figure B-19. This file can be opened in any text editor.**
   a. Note that the *CASENAME* keyword is used to specify the name of the case as *IntoWater*.
   b. Note that the *OUTPUTS* keyword section indicates 2 output types, including display of the command prompt screen and the .mco file. For more information on outputs, see Section 3.1.5.
   c. Note that the *ATMOS* keyword with the *ATT* option specifies that the external file *IntoWater_Atmosphere.atm* contains the atmosphere data and the latitude of *36.0* degrees on the following line ties the atmosphere data to a location.
      i. Review the atmosphere file IntoWater_Atmosphere.atm. This file can be opened in any text editor. For more information on the ATT file format, see Section 3.1.9.1.
   d. Note that the *ALTITUDES* keyword and following two lines in the file specify the number of altitudes of interest (1) and the altitude (0.0 ft MSL), indicating sea level. For more information on the ALTITUDES keyword, see Section 3.1.10.
   e. Note that the *RAYTRACING* keyword with the *LEGACY* option is used and the designation of the modeling parameters follow on the next 5 lines. For more information on the modeling parameters, see Section 3.1.12.

i. Note the ground reflection factor of 2.0, rather than the typical 1.9, which is used to represent nominally hard ground. Water is nonporous and acoustically hard, so one should consider a reflection factor closer to 2.0 for boom impacts on water.

b. Note that the *MODE* keyword is used with the *CYLINDER* option, which specifies that the external file *IntoWater_Cylinder.plt* contains the starting signature in the Cylinder format. The following lines specifies the number of cylinders (1), the R/L ratio (2.0) and the aircraft length (175 ft).

ii. Review the input signature file IntoWater_Cylinder.plt. This file can be opened in any text editor. Note that the data are presented in the units expected for the CYLINDER mode. For more information on the CYLINDER mode input, see Section 3.1.13.3.

f. Note that the *TRAJECTORY* keyword with the *FILE* option specifies that the external file *IntoWater_Trajectory.trj* contains the trajectory data. For more information on the TRAJECTORY inputs, see Section 3.1.15.

i. Review the trajectory input file IntoWater_Trajectory.trj. This file can be opened in any text editor. Note that it contains many points, which will be plotted in the WCON footprint display. Each trajectory point will also correspond to an isopemp in WCON.

```
CASENAME
IntoWater
OUTPUTS
2
SCREEN
MCO
ATMOS
ATT
IntoWater_Atmosphere.atm
36.0
ALTITUDES
1
0.0
RAYTRACING
LEGACY
    -2000.0  100000.0  -1500.0
    2.0  2.0
    0.5   500.0   0.5
    0
1
MODE
CYLINDER
1
IntoWater_Cylinder.plt
1.0
2.0 175.0
TRAJECTORY
FILE
IntoWater_Trajectory.trj
END
```

Figure B-19 Into water case input file.

4. **Review the batch script file Run_IntoWater.bat shown in Figure B-20. This file can be opened in any text editor.**
   a. Line 1 runs FOBoom (*pcboom730win.exe*) with inputs specified in the *IntoWater.dat* file.
   b. Line 3 runs PCBFoot, which uses the outputs from FOBoom (*IntoWater*) as inputs. Note the ioutput (*6)* indicates output of a boom summary file (.asc), as well as the signature files .sig, .ind, and .ens, which are used as inputs for WCON.

c. Line 5 runs WCON, which uses the outputs from PCBFoot to visualize the footprint and signatures.

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
pcboom730win.exe IntoWater.dat
pause
pcbfoot730.exe IntoWater 6
pause
wcon730.exe IntoWater
pause
exit
```

Figure B-20 Into water case batch script file.

5. **Run FOBoom**
   a. Double click *Run_IntoWater.bat* for FOBoom to begin ray tracing at specified trajectory points.
   b. A command prompt will be displayed with times along the trajectory.
   c. Note that the .delt, .mco, .org, .out, and .un6 files have been written to the folder with the input files and executables.
6. **Run PCBFoot**
   a. When FOBoom processing is complete, press any key while in the command prompt to continue.
   b. The command prompt will display isopemp calculation progress along each trajectory point.
   c. Note that the .asc, .ens, .ind, .qwk, and .sig files have been written to the folder with the input files and executables. These data will be used to visualize the footprint in WCON.
7. **Run WCON**
   a. When PCBFoot processing is complete, press any key while in the command prompt to continue.
   b. The WCON interface will open to allow for visualization of the footprint including isopemps and pressure contours, as shown in Figure B-21. The data in the right column will change to represent the point at which the mouse is hovering.

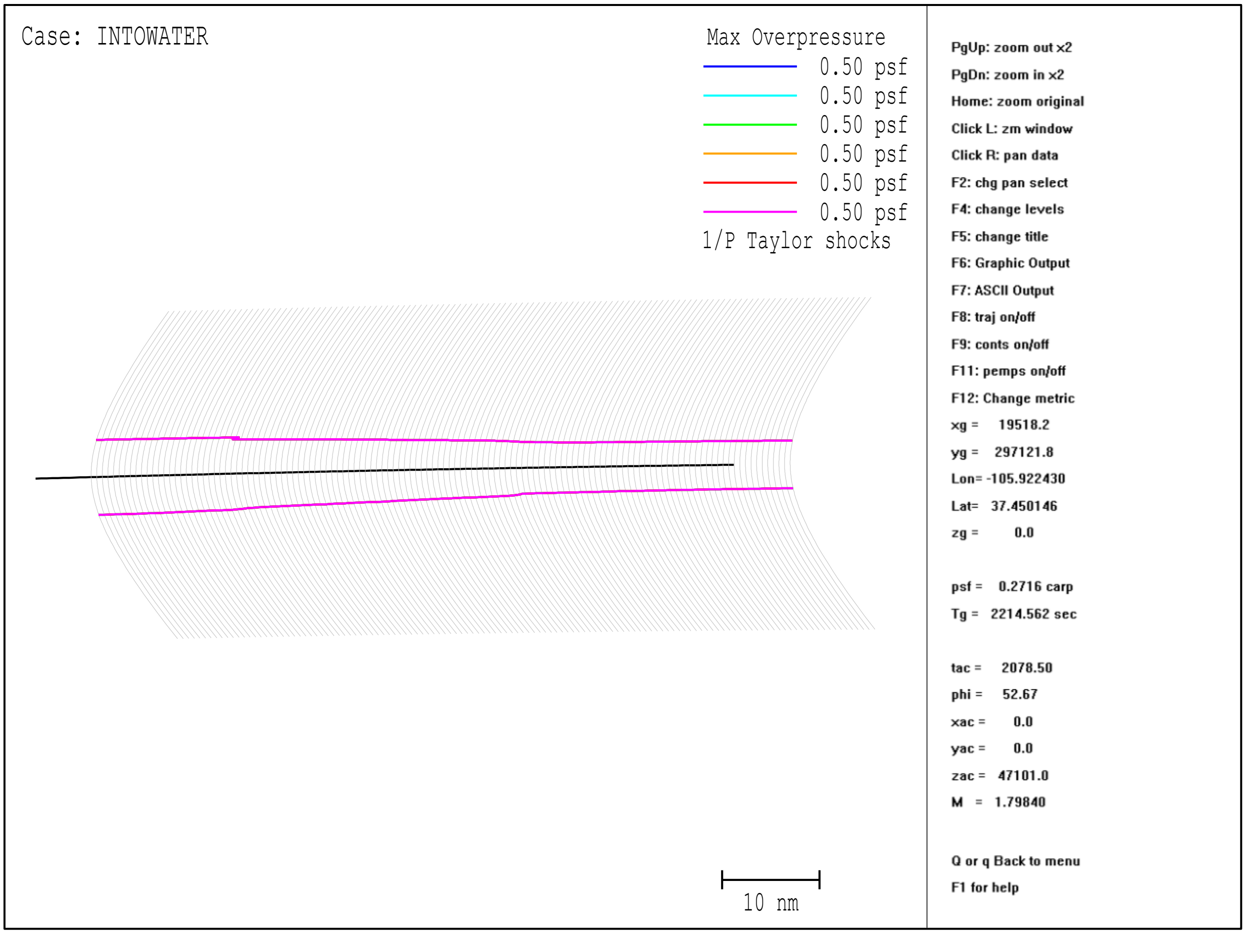


Figure B-21 Into water case footprint displaying aircraft trajectory, boom isopemps, and pressure contours.

8. Visualize Underwater Signature

a. Open the WCON signature view.

   i. Press the "p" key while hovering the mouse over any point within the footprint.

   ii. A window will open in which the (x, y) coordinates can either be approved or edited to match the location of interest. For this example, edit the coordinates as shown in Figure B-22 and click *OK*. The resulting signature representing the boom at the surface of the water is shown in Figure B-23.

   iii. Press the "Page Up" key to zoom in on the signature. Press the "down arrow" key to move the receiver 3 feet underwater, thus simulating underwater propagation. The resulting signature is shown in Figure B-24.

      1. Note that continuing to press the down arrow will simulate submerging the receiver further underwater, as shown in Figure B-25.

   iv. Press the "F6" key to save the current display, and "F7" to save the data pertaining to the current display in a text file.

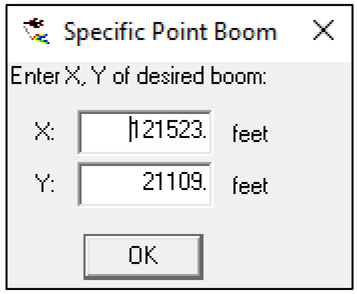


Figure B-22 Propagation into water signature example coordinates.

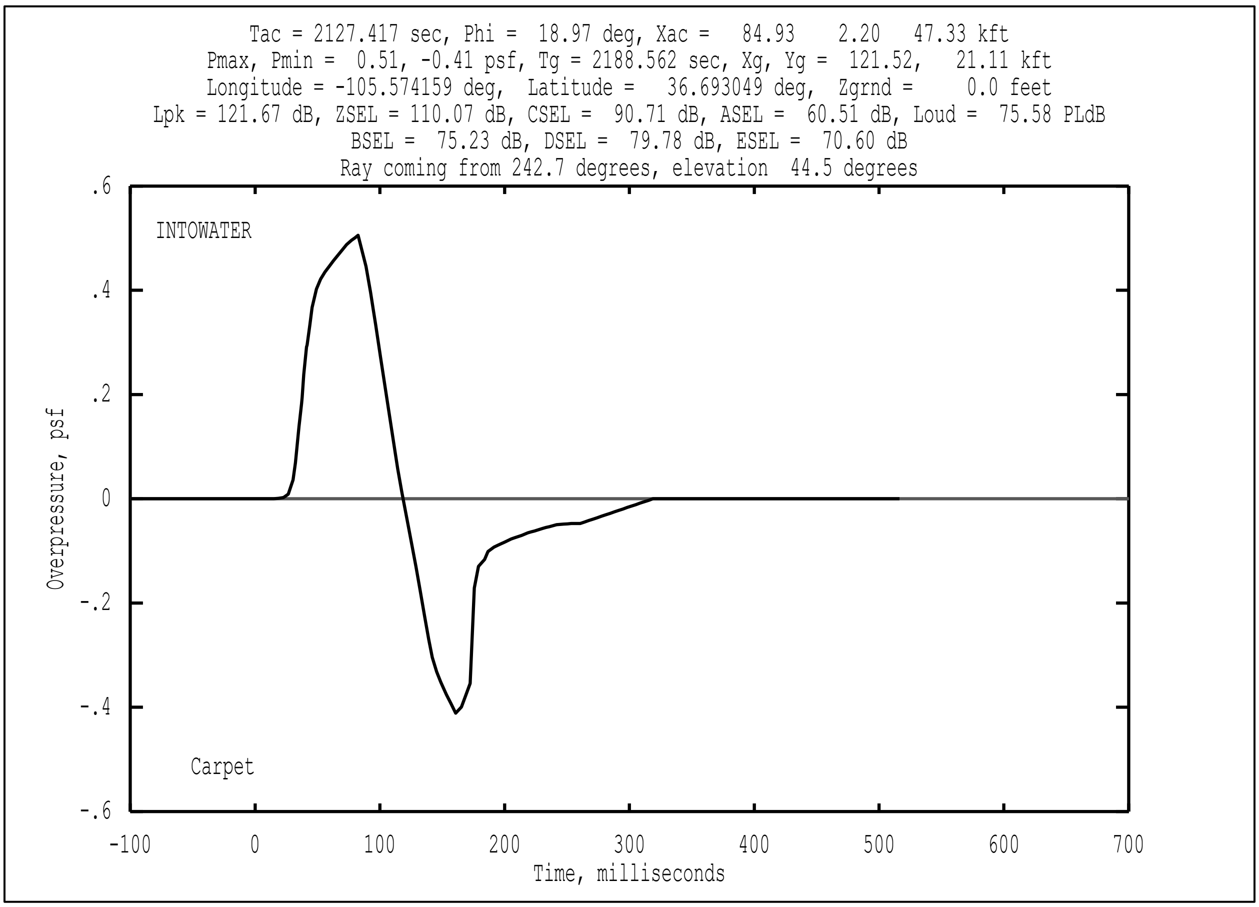


Figure B-23 Example WCON signature view – at water surface.

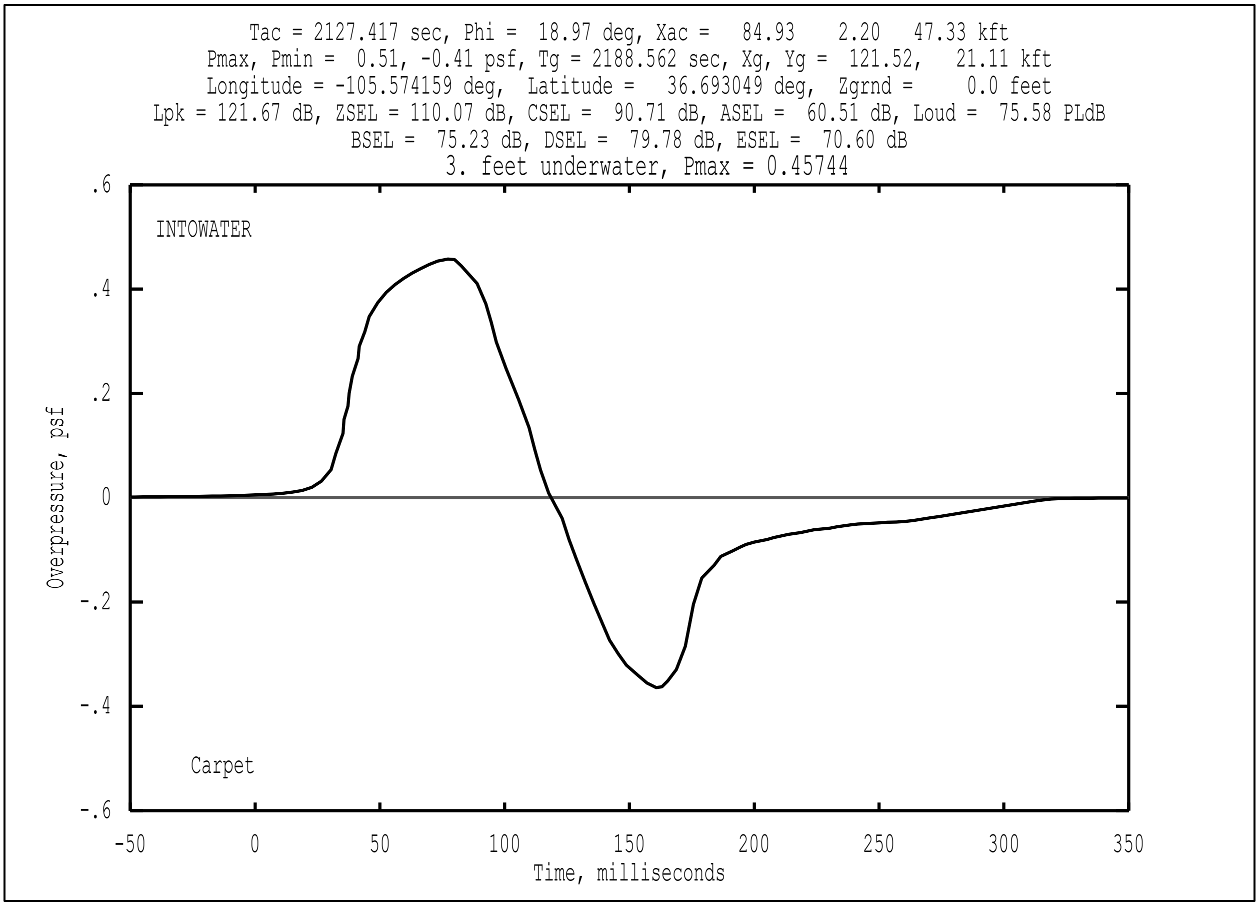


Figure B-24 Example WCON signature view – 3 ft underwater.

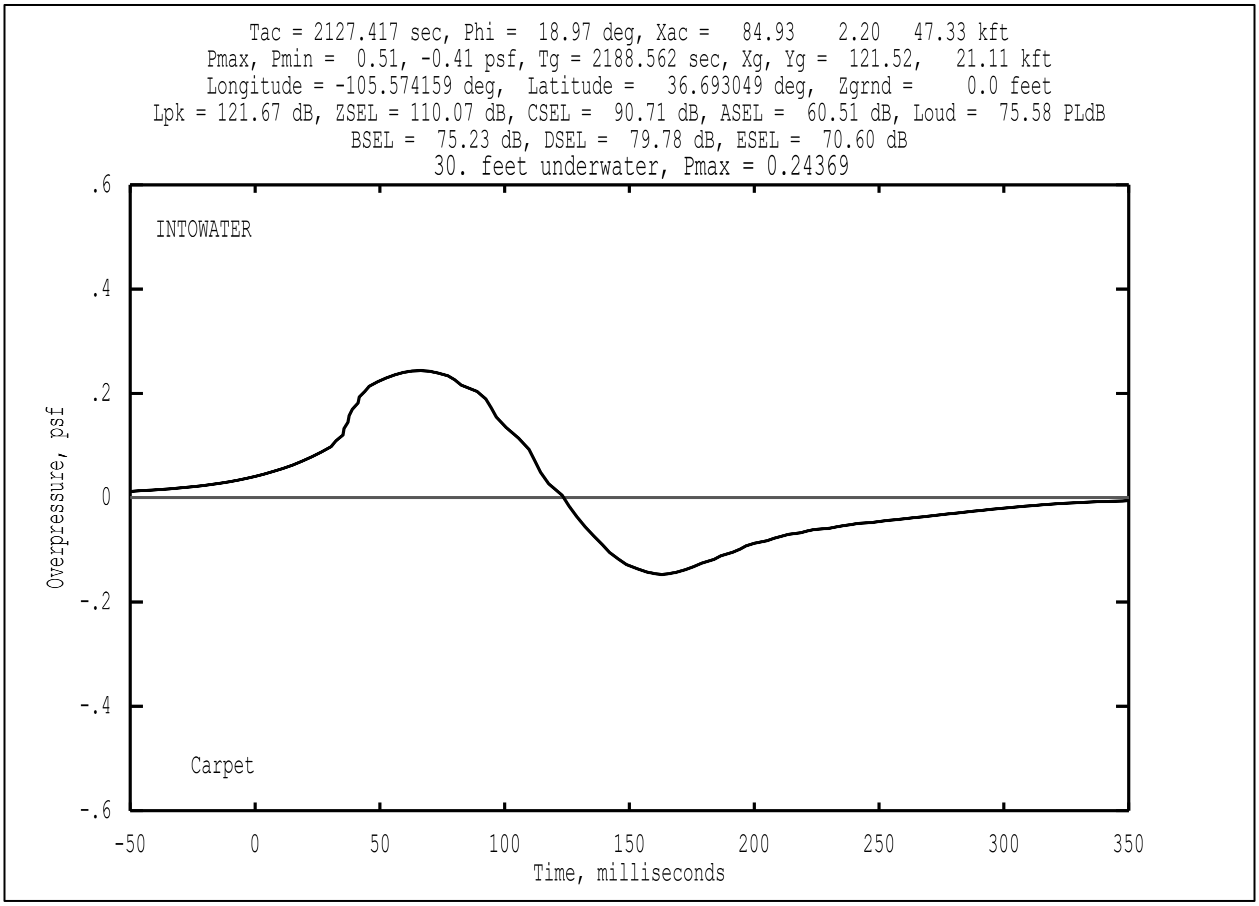


Figure B-25 Example WCON signature view – 30 ft underwater.

Appendix B.5 KZK Filters

Turbulence can be evaluated in the PCBoom suite using several methods, see Section 2.3.2.3. This example demonstrates turbulence analysis using the FiltView module. FiltView can be accessed through a keyboard command in the WCON signature visualization interface, as shown in Figure B-26. The tool applies an adjustable FIR filter to the selected signature in order to visualize and output turbulized signature data and the corresponding loudness metrics at that location.

WCON allows for visualization of the entire footprint including isopemps and contours computed in FOBoom and PCBFoot. Further detail can be gleaned from WCON by selecting a single point to view the pressure signature and computed loudness metrics at that location. Rather than clicking through each point individually, files including pressure signatures and loudness metrics can be output for several points of interest automatically through the inclusion of an external script file, as demonstrated in this example.

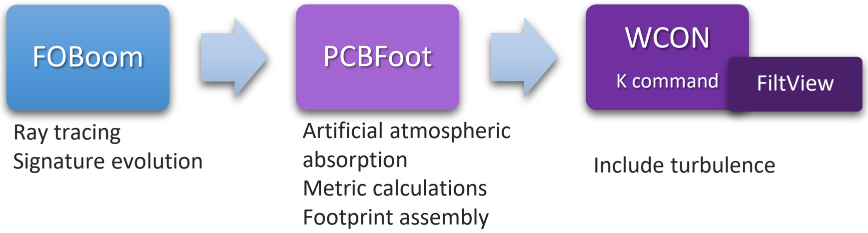


Figure B-26 KZK Filter workflow.

1. **Create a directory that contains executables for FOBoom, PCBFoot, WCON, and FiltView modules.**
2. **Extract the contents of Examples.zip\05_KZKFilters\Inputs to the same directory as the executables. This should include a folder of text files, each containing data for an FIR filter.**
3. **Review the FOBoom input file KZKFilters.dat shown in Figure B-27. This file can be opened in any text editor.**
    a. Note that the *CASENAME* keyword is used to specify the name of the case as *KZKFilter*.
    b. Note that the *OUTPUTS* keyword section indicates 4 output types, including display of the command prompt screen and three types of output files. For more information on outputs, see Section 3.1.5.
    c. Note that the *ATMOS* keyword with the *ATT* option specifies that the external file *KZKFilter_Atmosphere.atm* contains the atmosphere data, and the latitude of *34.0* degrees on the following line ties the atmosphere data to a location.
        i. Review the atmosphere file KZKFilter_Atmosphere.atm. This file can be opened in any text editor. For more information on the ATT file format, see Section 3.1.9.1.
    d. Note that the *ALTITUDES* keyword and following three lines in the file specify the number of altitudes of interest (2) and the altitudes in ft MSL for which data will be extracted.
    e. Note that the *RAYTRACING* keyword with the *LEGACY* option is used and the designation of the modeling parameters follow on the next 5 lines. For more information on the modeling parameters, see Section 3.1.12.
    f. Note that the *MODE* keyword is used with the *CARLSON* and *ACNAME* options, which specify that the known source characteristics for the selected *F-5* aircraft will be used for the starting signature. For more information on the CARLSON mode, see Section 3.1.13.1.
    b. Note that the *TRAJECTORY* keyword with the *FILE* option specifies that the external file *KZKFilter_Trajectory.trj* contains the trajectory data. For more information on the TRAJECTORY inputs, see Section 3.1.15.
        i. Review the trajectory input file KZKFilter_Trajectory.trj. This file can be opened in any text editor. Note that it contains many points, which will be plotted in the WCON footprint display. Each trajectory point will also correspond to an isopemp in WCON.

```
CASENAME
KZKFilter
OUTPUTS
4
MCO
SCREEN
U28
UN6
ATMOS
ATT
KZKFilter_Atmosphere.atm
34.0
ALTITUDES
2
9955.0
2267.0
RAYTRACING
LEGACY
2000.0 2000.0 1500.0
1.9 1.0
0.5 500.0 1.0
0
5
MODE
CARLSON
ACNAME
F-5
TRAJECTORY
FILE
KZKFilter_Trajectory.trj
END
```

Figure B-27 KZK Filter case input file.

4. **Review the batch script file Run_KZKFilter.bat shown in Figure B-28. This file can be opened in any text editor.**
   a. Line 1 runs FOBoom (*pcboom730win.exe*) with inputs specified in the *KZKFilter.dat* file.
   b. Line 3 runs PCBFoot, which uses the outputs from FOBoom (*KZKFilter*) as inputs. Note the ioutput (*6)* indicates output of a boom summary file (.asc), as well as the signature files .sig, .ind, and .ens, which are used as inputs for WCON.
   c. Line 5 runs WCON, which uses the outputs from PCBFoot to visualize the footprint.
   d. Note the script, which specifies automatic signature output.
      i. Review KZKFilter_Script.txt. This file can be opened in any text editor. Note the (x, y) coordinates of specified signature locations and output file names (alpha.txt, beta.txt, gamma.txt, and delta.txt). These locations will be marked with a red X symbol in the interface. For more information on WCON scripting commands, see Section 4.3.1.1.
   e. Note that the FiltView executable is not required in the batch script file because it will be accessed through WCON.

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
pcboom730win.exe KZKFilter.dat
pause
pcbfoot730.exe KZKFilter 6
pause
wcon730.exe KZKFilter -
KZKFilter_Script.txt
pause
exit
```

Figure B-28 KZK Filter case batch script file.

5. **Review the configuration file SonicBAT-Run-Fort.config,[19] as shown in Figure B-29. This file can be opened in any text editor.**
   a. Edit the file such that the directories (*_DIR) point to the extracted location of all files and executables for this case.
   b. Save the changes to overwrite the existing file.

```
FOBOOM_DIR C:\...
FOBOOM_EXE pcboom730win.exe
PCBFOOT_DIR C:\...
PCBFOOT_EXE pcbfoot730.exe
WCON_DIR C:\...
WCON_EXE wcon730.exe
FILTVIEW_DIR C:\...
FILTVIEW_EXE filtview730.exe
```

Figure B-29 KZK Filter case configuration file.

6. **Run FOBoom**
   a. Double click *Run_KZKFilter.bat* for FOBoom to begin ray tracing at specified trajectory points.
   b. A command prompt will be displayed with times along the trajectory.
   c. Note that the .delt, .mco, .org, .out, .u28, and .un6 files have been written to the folder with the input files and executables.
7. **Run PCBFoot**
   a. When FOBoom processing is complete, press any key while in the command prompt to continue.
   b. The command prompt will display isopemp calculation progress along each trajectory point.
   c. Note that the .asc, .ens, .ind, .qwk, and .sig files have been written to the folder with the input files and executables. These data will be used to visualize the footprint in WCON.
8. **Run WCON**
   a. When PCBFoot processing is complete, press any key while in the command prompt to continue.
   b. The WCON interface will open to allow for visualization of the footprint including isopemps and pressure contours, as shown in Figure B-30. The data in the right column will change to represent the point at which the mouse is hovering.
   c. Note the red Xs on the footprint marking the locations called out in KZKFilter_Script.txt
   d. Note the alpha, beta, gamma, and delta text files have been written to the folder with the input files and executables. These contain pressure signatures and loudness metrics at each of the marked locations.
   e. Note four .bms files have been written to the folder with the input files and executables. Each file contains information on the ray ends used to calculate the booms at a location of interest,

[19] Note that the SonicBAT-Run-Fort module is not used in this example. The configuration file is required for WCON to access the FiltView module. WCON is coded to search for a file named “SonicBAT-Run-Fort.config” containing FiltView executable information, whether or not the SonicBAT-Run-Fort module is used.

indicated by the (x, y) coordinates in the file name. For more information about the .bms file, see Section 4.3.1.1.

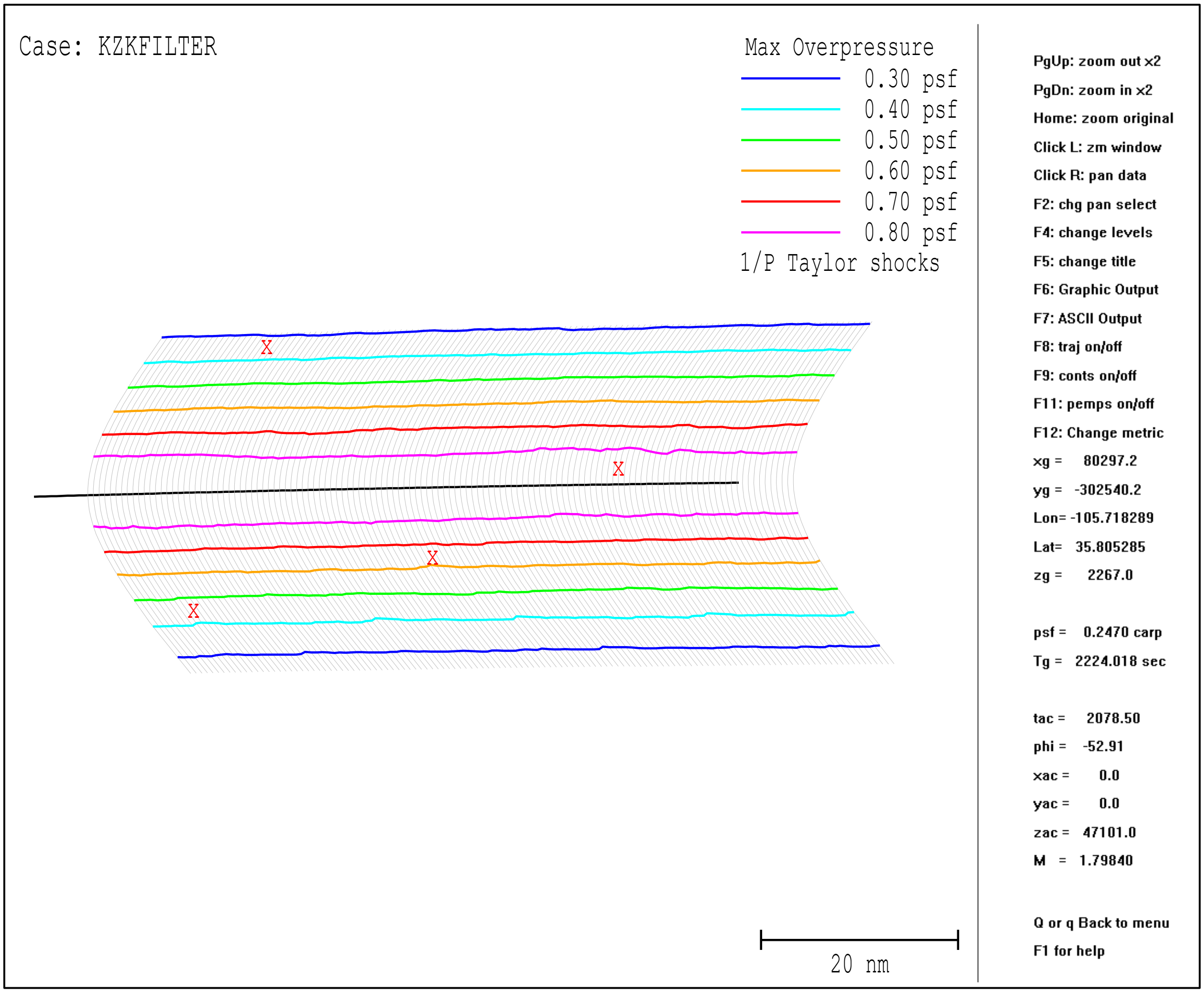


Figure B-30 KZK Filter case WCON footprint with marked locations of interest from script file.

9. Run FiltView

a. Open the WCON signature view.

i. Press the "p" key while hovering the mouse over any point within the footprint.

ii. A window will open in which the (x, y) coordinates can either be approved or edited to match the location of interest. For this example, edit the coordinates as shown in Figure B-31 and click *OK*.

iii. The WCON signature interface will open. Scroll by pressing the "page down" key until the full N-wave can be seen as shown in Figure B-32.

iv. Press the "k" key to open FiltView in order to view and output turbulized signatures and loudness metrics at this location.

v. A window will open in which the turbulence parameters can be adjusted. For this example, keep the default parameters as shown in Figure B-33 by clicking *OK.*

vi. A separate command prompt will open, followed by the FiltView interface, as shown in Figure B-34.

vii. Note that the files ID001_051200HZ_CH001.txt and ID001_051200HZ_CH001.bin have been written to the folder with the input files and executables, which describe the displayed turbulized pressure signature.

viii. Note that the displayed *filtered waveforms* indicate PL by default upon opening FiltView. Scrolling through the filtered signatures by pressing the “page down” key will change the displayed metric accordingly. Note the other display manipulation options in the *Scale* and *Help* menus at the top left corner of the screen.

ix. Once satisfied with the display, images of the current interface including filtered signatures and metrics can be saved by pressing “ALT+s” or using the *File* menu. An example image of the SELB turbulized waveforms with adjusted psf scaling is shown in Figure B-35. Data for the displayed turbulized waveforms alone can be output by pressing the “F8” key.

x. Also note that all metrics without signature data or plots can be output by pressing “Alt+m”, and all signature data without metrics or plots can be output by pressing the “F9” key.

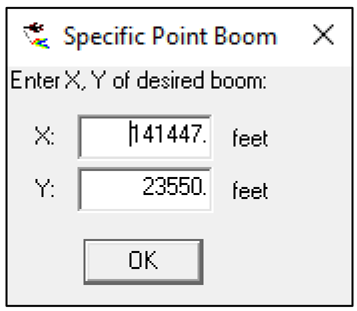


Figure B-31 KZK Filter case WCON signature example coordinates.

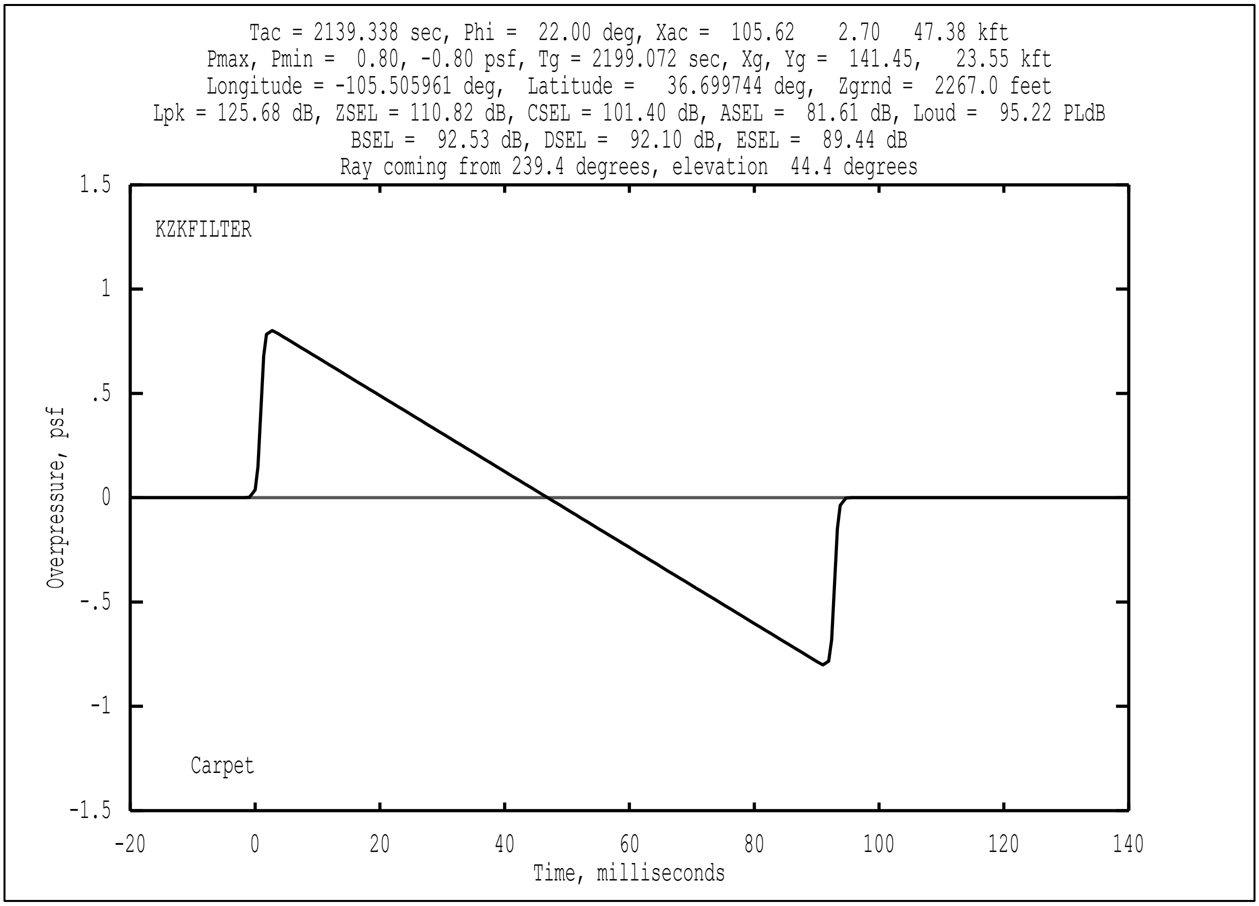


Figure B-32 KZK Filter case WCON signature view example – pre-FIR Filter.

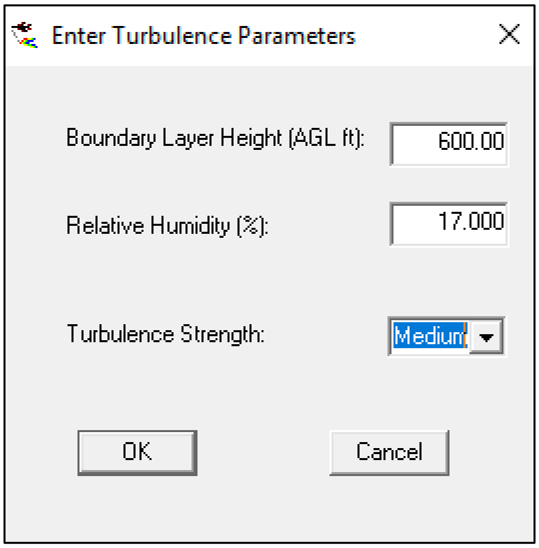


Figure B-33 KZK Filter default turbulence parameter window.

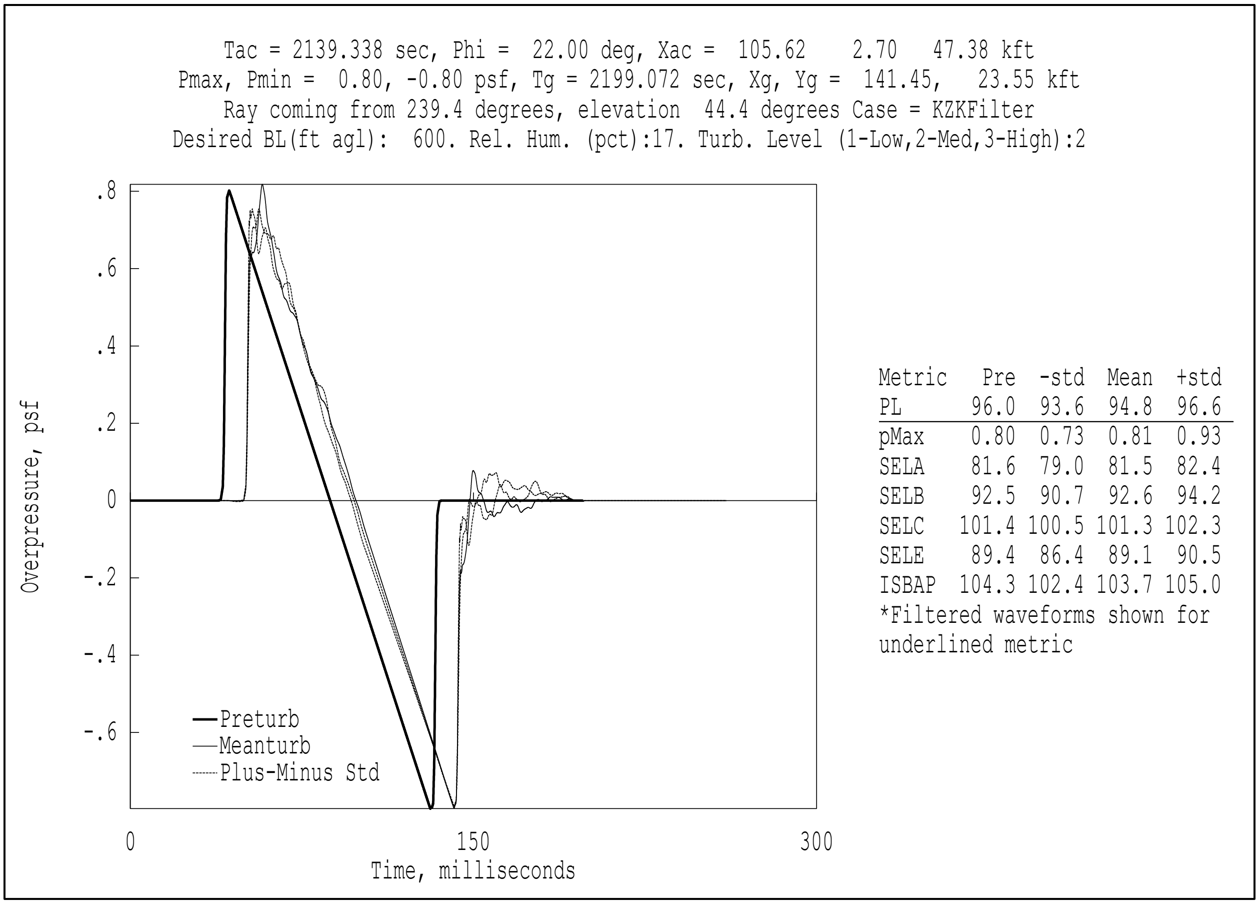


Figure B-34 FiltView interface with turbulized signatures and statistical loudness metrics.

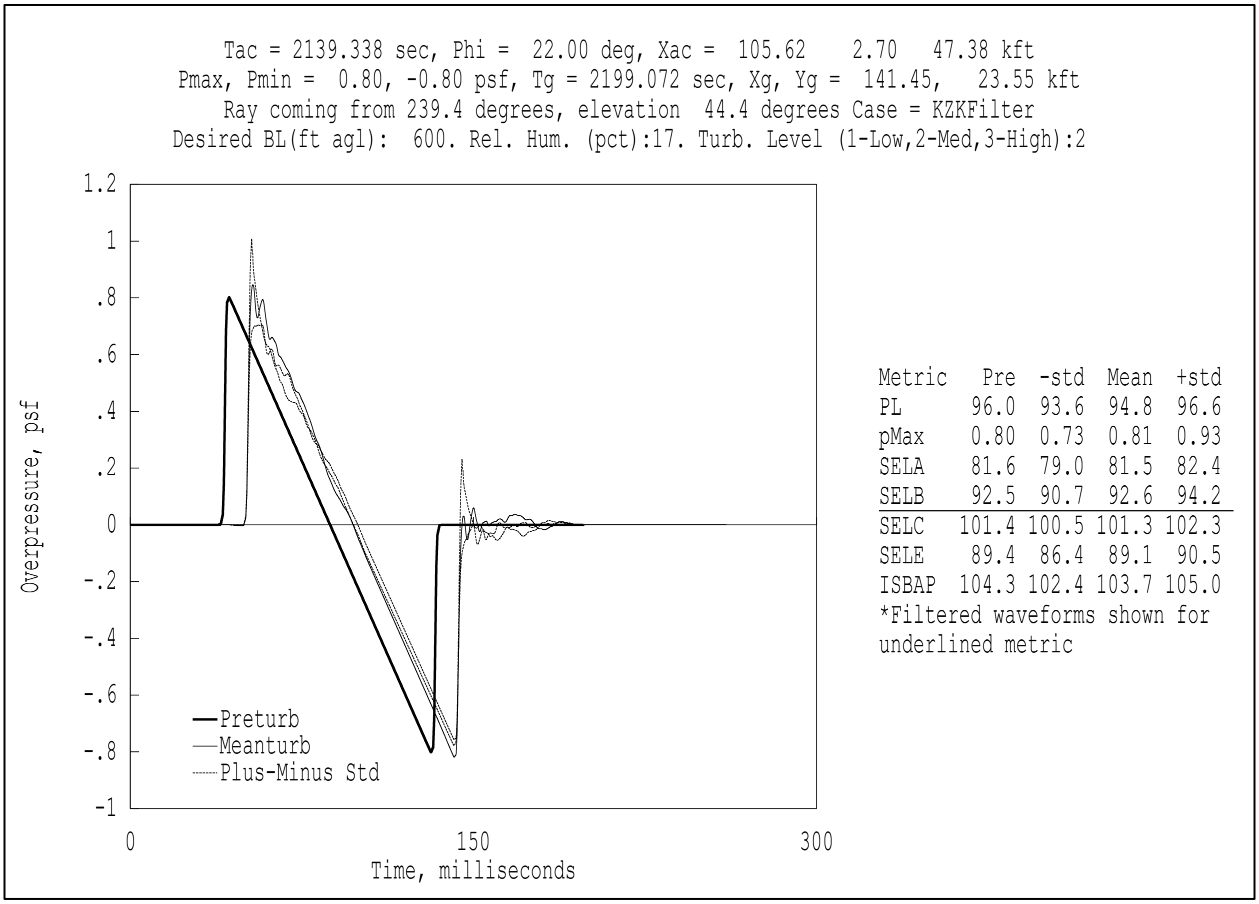


Figure B-35 FiltView interface showing the SELB turbulized waveforms.

Appendix B.6 Crow's Method

Turbulence can be evaluated in the PCBoom suite using several methods, see Section 2.3.2.3. This example applies Crow's method, which is accessed through WCON, as shown in Figure B-36. This method models turbulized waveforms by overlaying a turbulent filter envelope around the plotted signature at that location. The pressure vs time data for the visualized envelope can be output in tabular form.

WCON allows for visualization of the entire footprint including isopemps and contours computed in FOBoom and PCBFoot. Further detail can be gleaned from WCON by selecting a single point to view the pressure signature and computed loudness metrics at that location. Rather than clicking through each point individually, files including pressure signatures and loudness metrics can be output for several points of interest automatically through the inclusion of an external script file, as demonstrated in this example.

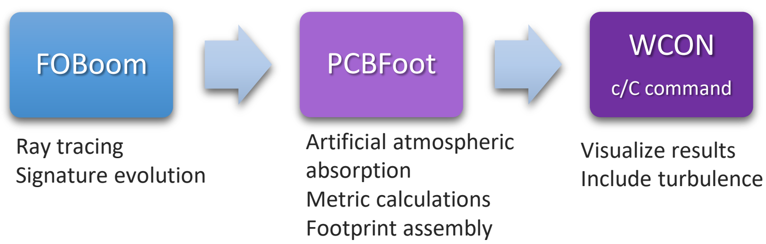


Figure B-36 Crow's method workflow.

1. **Create a directory that contains executables for FOBoom, PCBFoot, and WCON modules.**
2. **Extract the contents of Examples.zip\06_CrowsMethod\Inputs to the same directory as the executables.**
3. **Review the FOBoom input file CrowsMethod.dat shown in Figure B-37. This file can be opened in any text editor.**
   a. Note that the *CASENAME* keyword is used to specify the name of the case as *CrowsMethod*.
   b. Note that the *OUTPUTS* keyword section indicates 4 output types, including display of the command prompt screen and three types of output files. For more information on outputs, see Section 3.1.5.
   c. Note that the *ATMOS* keyword with the *ATT* option specifies that the external file *CrowsMethod_Atmosphere.atm* contains the atmosphere data and the latitude of *34.0* degrees on the following line ties the atmosphere data to a location.
      i. Review the atmosphere file CrowsMethod_Atmosphere.atm. This file can be opened in any text editor. For more information on the ATT file format, see Section 3.1.9.1.
   d. Note that the *ALTITUDES* keyword and following three lines in the file specify the number of altitudes of interest (2) and the altitudes in ft MSL for which data will be extracted.
   e. Note that the *RAYTRACING* keyword with the *LEGACY* option is used and the designation of the modeling parameters follow on the next 5 lines. For more information on the modeling parameters, see Section 3.1.12.
   f. Note that the *MODE* keyword is used with the *CARLSON* and *ACNAME* options, which specify that the known source characteristics for the selected *F-5* aircraft will be used for the starting signature. For more information on the CARLSON mode, see Section 3.1.13.1.

c. Note that the *TRAJECTORY* keyword with the *FILE* option specifies that the external file *CrowsMethod_Trajectory.trj* contains the trajectory data. For more information on the TRAJECTORY inputs, see Section 3.1.15.
    i. Review the trajectory input file CrowsMethod_Trajectory.trj. This file can be opened in any text editor. Note that it contains many points, which will be plotted in the WCON footprint display. Each trajectory point will also correspond to an isopemp in WCON.

```
CASENAME
CrowsMethod
OUTPUTS
4
MCO
SCREEN
U28
UN6
ATMOS
ATT
CrowsMethod_Atmosphere.atm
34.0
ALTITUDES
2
9955.0
2267.0
RAYTRACING
LEGACY
2000.0 2000.0 1500.0
1.9 1.0
0.5 500.0 1.0
0
5
MODE
CARLSON
ACNAME
F-5
TRAJECTORY
FILE
CrowsMethod_Trajectory.trj
END
```

Figure B-37 Crow's method case input file.

4. **Review the batch script file Run_CrowsMethod.bat shown in Figure B-38. This file can be opened in any text editor.**
    a. Line 1 runs FOBoom (*pcboom730win.exe*) with inputs specified in the *CrowsMethod.dat* file.
    b. Line 3 runs PCBFoot, which uses the outputs from FOBoom (*CrowsMethod)* as inputs. Note the ioutput (*6)* indicates output of a boom summary file (.asc), as well as the signature files .sig, .ind, and .ens, which are used as inputs for WCON.
    c. Line 5 runs WCON, which uses the outputs from PCBFoot to visualize the footprint.
    d. Note the script, which specifies automatic signature output.
        i. Review CrowsMethod_Script.txt. This file can be opened in any text editor. Note the (x, y) coordinates of specified signature locations and output file names (alpha.txt, beta.txt, gamma.txt, and delta.txt). These locations will be marked with a red X symbol in the interface. For more information on WCON scripting commands, see Section 4.3.1.1.

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
pcboom730win.exe CrowsMethod.dat
pause
pcbfoot730.exe CrowsMethod 6
pause
wcon730.exe CrowsMethod –Crow_Method.txt
pause
exit
```

Figure B-38 Crow's method case batch script file.

5. **Run FOBoom**
   a. Double click *Run_CrowsMethod.bat* for FOBoom to begin ray tracing at specified trajectory points.
   b. A command prompt will be displayed with times along the trajectory.
   c. Note that the .delt, .mco, .org, .out, .u28, and .un6 files have been written to the folder with the input files and executables.
6. **Run PCBFoot**
   a. When FOBoom processing is complete, press any key while in the command prompt to continue.
   b. The command prompt will display isopemp calculation progress along each trajectory point.
   c. Note that the .asc, .ens, .ind, .qwk, and .sig files have been written to the folder with the input files and executables. These data will be used to visualize the footprint in WCON.
7. **Run WCON**
   a. When PCBFoot processing is complete, press any key while in the command prompt to continue.
   b. The WCON interface will open to allow for visualization of the footprint including isopemps and pressure contours, as shown in Figure B-39. The data in the right column will change to represent the point at which the mouse is hovering.
   c. Note the red Xs on the footprint marking the locations called out in CrowsMethod_Script.txt.
   d. Note the alpha, beta, gamma, and delta text files have been written to the folder with the input files and executables. These contain pressure signatures and loudness metrics at each of the marked locations.
   e. Note four .bms files have been written to the folder with the input files and executables. Each file contains information on the ray ends used to calculate the booms at a location of interest, indicated by the (x, y) coordinates in the file name. For more information about the .bms file, see Section 4.3.1.1.

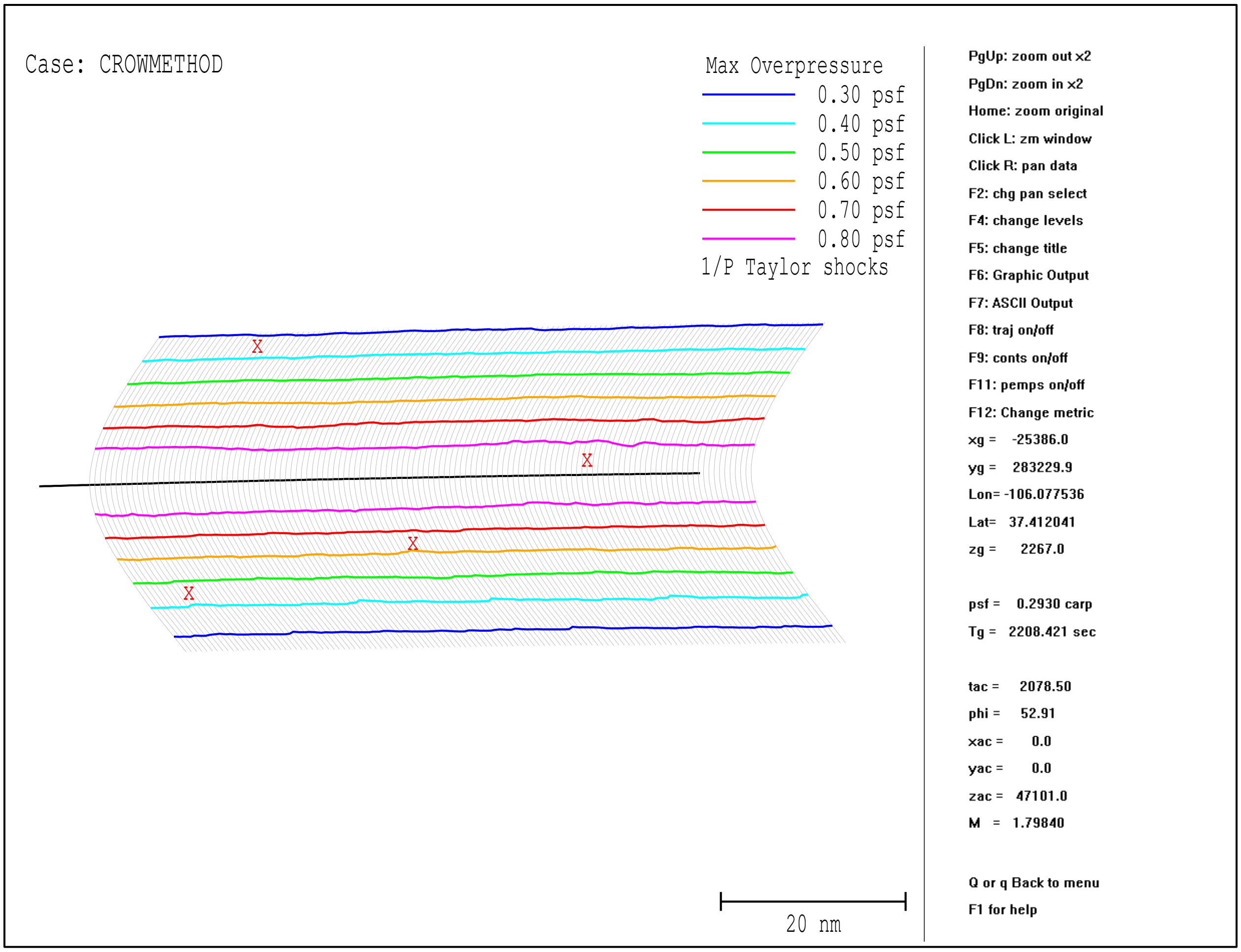


Figure B-39 Crow's method case WCON footprint with marked locations of interest from script file.

8. Apply Crow Turbulence Method

a. Open the WCON signature view.

i. Press the "p" key while hovering the mouse over any point within the footprint.

ii. A window will open in which the (x, y) coordinates can either be approved or edited to match the location of interest. For this example, edit the coordinates as shown in Figure B-40 and click *OK*.

iii. The WCON signature interface will open. Scroll by pressing the "page down" key until the full N-wave can be seen, as shown in Figure B-41.

iv. Press the "c" key to display a red Crow's turbulent filter envelope overlaid on the signature at this location.

v. Press the "F6" key to save this graphic. A window will pop up with printing options. Click *WMF Output* to save this graphic, as shown in Figure B-42.

vi. Press the "F7" key to write a text file detailing pressure signature data for the original waveform, as well as the top and bottom turbulized waveforms bounding the Crow's envelope.

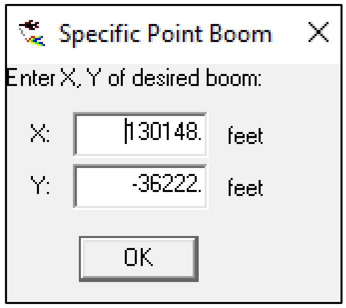


Figure B-40 Crow's method case WCON signature example coordinates.

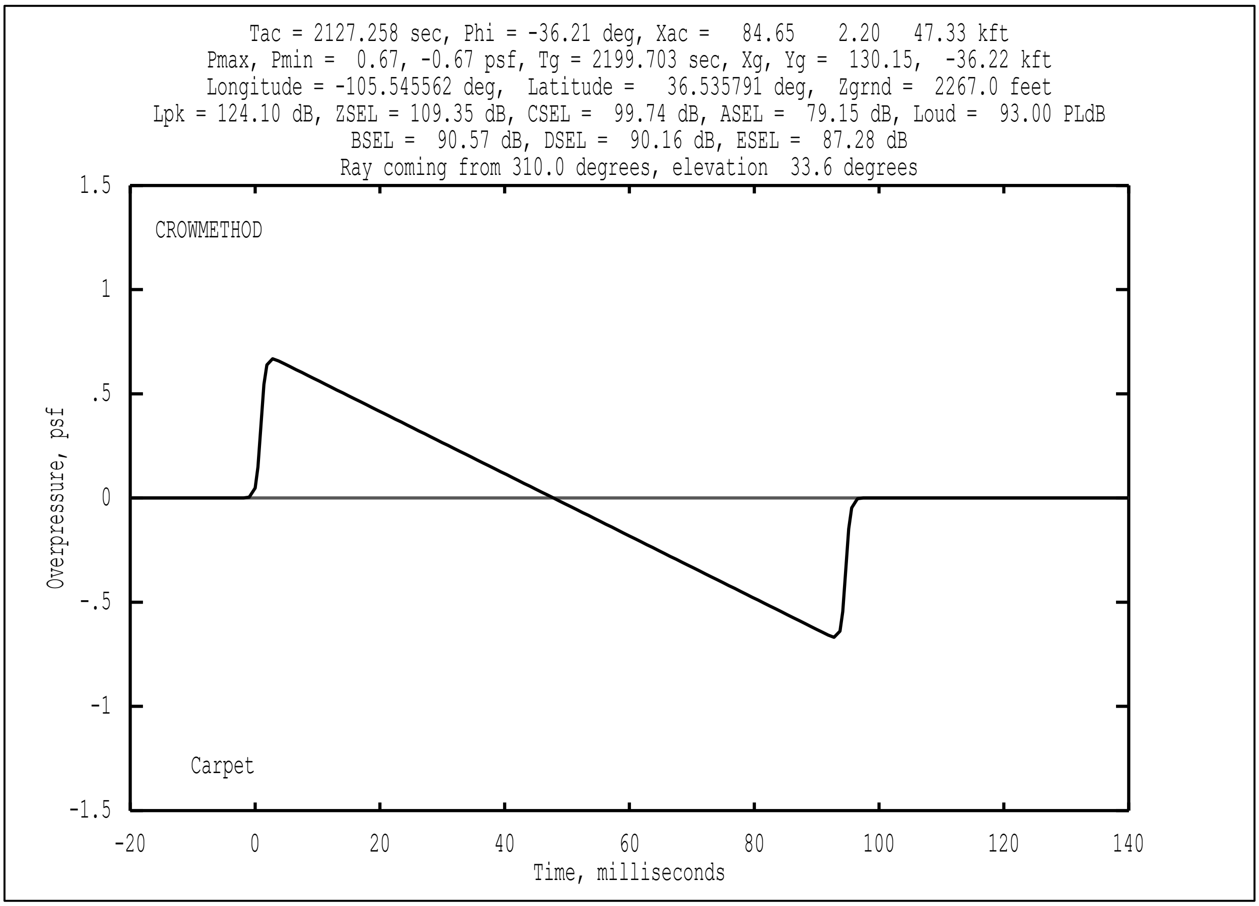


Figure B-41 Crow's method case WCON signature view example – pre-Crow's method envelope.

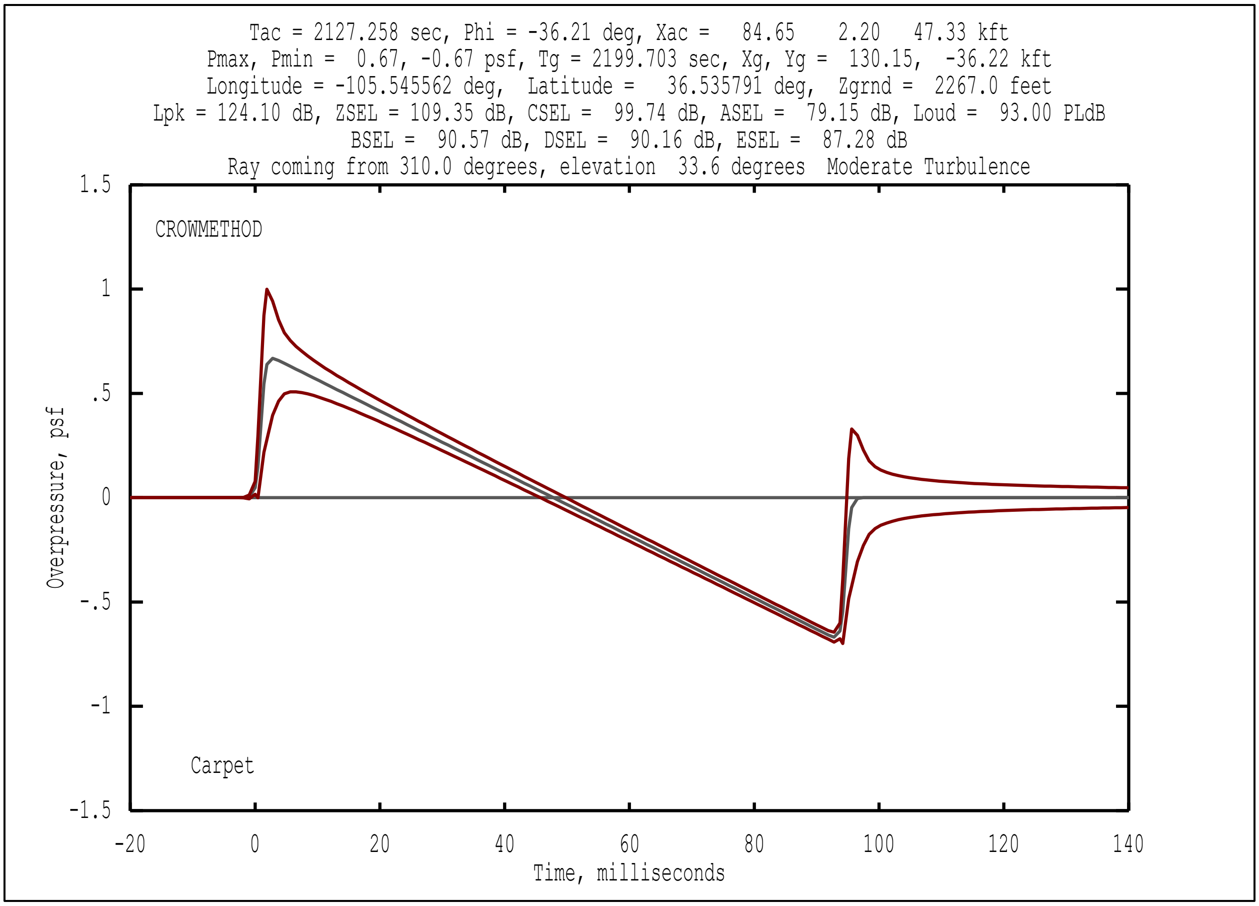


Figure B-42 Crow's filter envelope overlaid on WCON signature view.

Appendix B.7 Turbo

Turbulence can be evaluated in the PCBoom suite using several methods, see Section 2.3.2.3. This example implements the Turbo module within SonicBAT-Run-Fort, as shown in Figure B-43. Note that the Turbo module can be run outside of SonicBAT-Run-Fort but is most commonly implemented within the SonicBAT-Run-Fort utility, as demonstrated in this example.

The Turbo code implements a classical Fourier mode distribution method for modeling turbulence. That is, Turbo models 3D, linear acoustic propagation by allowing turbulent temperature and gust variation versus altitude, for up to 100 mean temperature and wind variations.

This example demonstrates the use of the Turbo module after completing raytracing in FOBoom and applying molecular relaxation in HeadlessBurgers. All three modules are called from SonicBAT-Run-Fort to streamline the analysis process, such that the inputs for the following module are automatically created and assembled by the SonicBAT-Run-Fort. SonicBAT-Run-Fort creates two FOBoom input .dat files for each trajectory point: one that is used to model propagation to ground level, and one that is used to model propagation to the altitude corresponding to the top of the atmospheric boundary layer. The latter .dat files are identified with filenames containing "ABLH", which stands for atmospheric boundary layer height. SonicBAT-Run-Fort runs FOBoom once with each input file, where the "ABLH" output (.out) files are read by Turbo to glean propagation information at the top of the atmospheric boundary layer.

Using HeadlessBurgers with the HIGHRES keyword within the FOBoom input file, applies molecular relaxation resulting in high-resolution signatures comprised of thousands of points. Turbo uses this high-resolution input to generate turbulized waveforms via the classical Fourier mode distribution method, which can be assembled and visualized in PCBFoot and WCON. This example also uses a corr.txt input file for WCON visualization. The file contains latitude and longitude coordinates of interest to be marked with a specified symbol in WCON. For more information in the corr.txt input file format, see Section 4.3.1.2.

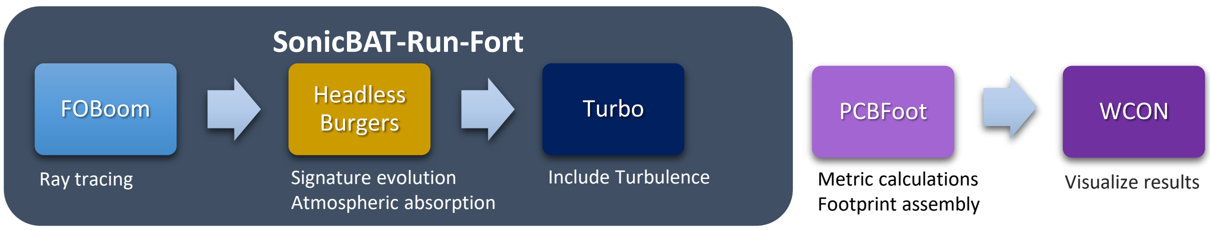


Figure B-43 Turbo workflow.

1. **Create a directory that contains executables for SonicBAT-Run-Fort, FOBoom, HeadlessBurgers, Turbo, PCBFoot, and WCON modules.**
2. **Extract the contents of Examples.zip\07_Turbo\Inputs to the same directory as the executables.**
3. **Review the SonicBAT-Run-Fort configuration file SonicBAT-Run-Fort.config, as shown in Figure B-44. This file can be opened in any text editor.**
   a. Edit the file such that the directories (*_DIR) point to the extracted location of all files and executables for this case.
   b. Note that this is the order in which the modules will be invoked by SonicBAT-Run-Fort.
   c. Save the changes to overwrite the existing SonicBAT-Run-Fort.config file.

```
FOBOOM_DIR C:\...
FOBOOM_EXE pcboom730win.exe
HEADLESS_DIR C:\...
HEADLESS_EXE headlessburgers730.exe
TURBO_DIR C:\...
TURBO_EXE turbo730.exe
PCBFOOT_DIR C:\...
PCBFOOT_EXE pcbfoot730.exe
WCON_DIR C:\...
WCON_EXE wcon730.exe
```

Figure B-44 Turbo case SonicBAT-Run-Fort configuration file.

4. **Review the SonicBAT input file SBRF_Turbo_Input.txt, as shown in Figure B-45. This file can be opened in any text editor.**
   a. Note that *SBRF_Turbo.dat* specifies the name of the FOBoom input file.
   b. Note that the *ABL-ALTITUDE* keyword and the following line specifies that the atmospheric boundary layer is located at 12500 ft MSL. This keyword is required for running the Turbo module in SonicBAT-Run-Fort in order to compute the turbulized waveforms.
   c. Note that the *PROP_METHOD* keyword with the BURGERS option is used, which specifies that FOBoom shall be run, followed by propagation to the ground in HeadlessBurgers.

i. Note that the BURGERS option *GIBBS* is used, which specifies that HeadlessBurgers shall apply Gibbs filtering to the signatures to smooth out any sharp FFT artifacts.

ii. Note that the BURGERS option *GROUND* and the following line specify that HeadlessBurgers shall apply a ground reflection factor of 1.9, which is used to represent nominally hard ground.

iii. Note that the BURGERS option *BURGERS_SAMPLE_RATE* and the following line specify that HeadlessBurgers shall sample the signatures at a rate of 22000 Hz.

d. Note that the *Turbo* keyword with the *TINFILE* option specifies that the external file *SBRF_Turbo-tin.txt* contains the controls for the Turbo model.

i. Review the Turbo control file SBRF_Turbo-tin.txt. This file can be opened in any text editor. For more information on the TIN file format, see Section 4.4.1.1.

```
SBRF_TURBO.dat
ABL_ALTITUDE
12500.
PROP_METHOD
BURGERS
GIBBS
GROUND
1.9
BURGERS_SAMPLE_RATE
22000
TURBO
TINFILE
SBRF_TURBO-tin.txt
```

Figure B-45 Turbo case SonicBAT-Run-Fort input file.

5. Review the FOBoom input file SBRF_Turbo.dat shown in Figure B-46. This file can be opened in any text editor.

a. Note that the *CASENAME* keyword is used to specify the name of the case as *SBRF_Turbo*.

b. Note that the BURGERS keyword is not used until invoked during the second FOBoom run based on the SonicBAT-Run-Fort input file in Figure B-45.

c. Note that the *OUTPUTS* keyword section indicates 5 output types, including display of the command prompt screen and four types of output files. For more information on outputs, see Section 3.1.5.

d. Note that the *ATMOS* keyword with the *BALLOON* option specifies that the external file *SBRF_ Turbo_Atmosphere.atm* contains the measured atmosphere data. The latitude of *34.9596* degrees indicates the location at which the balloon data were collected.

i. Review the atmosphere file SBRF_Turbo_Atmosphere.atm. This file can be opened in any text editor. For more information on the BALLOON file format, see Section 3.1.9.2.

e. Note that the *ALTITUDES* keyword and following two lines in the file specify the number of altitudes of interest (1) and the altitude (0.0 ft MSL) for which the signatures will be computed in HeadlessBurgers.

f. Note that the *RAYTRACING* keyword with the *LEGACY* option is used and the designation of the modeling parameters follow on the next 5 lines. Note the input parameters of *0* and 10 on line 23 designate the azimuth angles of interest (in degrees) for which molecular relaxation will be applied in HeadlessBurgers. For more information on the modeling parameters, see Section 3.1.12.

g. Note that the *MODE* keyword is used with the *CYLINDERM* option, which specifies that the external file *SBRF_Turbo_Cylinder.cyl*[20] contains the starting signature in the CYLINDERM format.
    i. Review the input signature file SBRF_Turbo_Cylinder.cyl. This file can be opened in any text editor. Note that the data are presented in the units expected for the CYLINDERM mode. For more information on the CYLINDERM mode input, see Section 3.1.13.6.
h. Note that the *HIGHRES* keyword is used, which specifies that the external file *SBRF_Turbo_highSR.txt* contains information to control the fidelity of the analyzed signature for post-processing in HeadlessBurgers.
    i. Review the input file HeadlessBurgers_highSR.txt. This file can be opened in any text editor. Note that the data describe the maximum number of points, sampling rate, and duration of the signature.
    ii. Note that in SonicBAT-Run-Fort, an identical sampling rate file with the extension .test is required. For SonicBAT-Run-Fort cases including BURGERS, another identical sampling rate file with the extension .burg is required. These are included in the Examples.zip\07_Turbo\Inputs folder and should already be extracted in the working directory.
d. Note that the *TRAJECTORY* keyword with the *file* option specifies that the external file *Turbo_SBRF_Trajectory.trj* contains the trajectory data. For more information on the TRAJECTORY inputs, see Section 3.1.15.
    i. Review the trajectory input file SBRF_Turbo_Trajectory.trj. This file can be opened in any text editor. Note that it contains nine points, which will each be processed twice in SonicBAT-Run-Fort. Output file names will be grouped with “0001” - “0009” to specify analysis of individual trajectory points. Summary output file names will include “ALL”.

[20] Cylinder input data provided by The Boeing Company.

```
CASENAME
SBRF_Turbo
OUTPUTS
5
MCO
SCREEN
U28
UN6
AGE
ATMOS
BALLOON
SBRF_Turbo_Atmosphere.atm
34.9596
ALTITUDES
1
 0.
RAYTRACING
LEGACY
 -2000. 100000. -1500.
 1.9 1.
 .5 500. .5
 2.
 0.0 10.
MODE
CYLINDERM
SBRF_Turbo_Cylinder.cyl
HIGHRES
SBRF_Turbo_highSR.txt
TRAJECTORY
file SBRF_Turbo_Trajectory.trj
```

Figure B-46 Turbo case FOBoom input file.

6. **Review the batch script file Run_SBRF_Turbo.bat shown in Figure B-47**. **This file can be opened in any text editor.**
    a. Line 1 runs SonicBAT-Run-Fort with inputs specified in the *SBRF_Turbo_Input.txt* file (Figure B-45). This text file will run FOBoom (pcboom730win.exe) twice, then HeadlessBurgers twice, then Turbo once. The executable names and directories are specified in the SonicBAT-Run-Fort.config file (Figure B-44). All modules within SonicBAT-Run-Fort will automatically run in succession.
    b. Line 3 copies the origin data from the file created in the first FOBoom run (*SBRF_Turbo.org*) to a new file (*SBRF_Turbo_ALL.org*), which will be read by PCBFoot and WCON to display the correct latitude and longitude coordinates.
    c. Line 5 runs PCBFoot, which uses the summary outputs from Turbo (*SBRF_Turbo_ALL.out*) as inputs. Note the "_ALL" contain data for all trajectory points 0001-0009, which is used by PCBFoot to assemble the footprint with all rays.
        i. Note the command *highres*, which prepares PCBFoot to expect high-resolution signatures from Turbo per the sampling parameters in the external file *SBRF_Turbo_highSR.test.*
    d. Line 7 runs WCON, which uses the *SBRF_Turbo_ALL.qwk* file from PCBFoot as input to visualize the footprint with all rays.
        i. Note the command *highres* prepares WCON to expect high-resolution signatures from Turbo per the sampling parameters in the external file *SBRF_Turbo_highSR.test.*

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
sonicbatrunfort730.exe SBRF_Turbo_Input.txtpause
copy /y SBRF_Turbo.org SBRF_Turbo_ALL.org
pause
pcbfoot730.exe SBRF_Turbo_ALL.out 7 highres:SBRF_Turbo_highSR.test
pause
wcon730.exe SBRF_Turbo_ALL.qwk highres:SBRF_Turbo_highSR.test
pause
exit
```

Figure B-47 Turbo case batch script file.

7. **Run FOBoom, HeadlessBurgers, and Turbo via SonicBAT-Run-Fort**
    a. Double click *Run_SBRF_Turbo.bat* for SonicBAT-Run-Fort to prompt FOBoom to begin ray tracing at all specified trajectory points.
    b. A command prompt will be displayed with times along the trajectory.
    c. Note that the “SBRF_Turbo” .age, .delt, .mco, .org, .out, .ssg, .u28, and .un6 files have been written to the folder with the input files and executables.
    d. SonicBAT-Run-Fort will then separate analysis into individual trajectory points. The following process will be completed in a loop over all trajectory points, with progress updated in the command prompt:
        i. Two FOBoom input files “SBRF_Turbo_000X.dat” and “SBRF_Turbo_000XABLH.dat” will be written to the folder with the input files and executables.
        ii. FOBoom will run twice, using both input files. Note that the “SBRF_Turbo_000X” and “SBRF_Turbo_000XABLH” .age, .delt, .mco, .org, .out, .ssg, .u28, and .un6 files have been written to the folder with the input files and executables, corresponding to each input file.
        iii. HeadlessBurgers will run at azimuth angles of 0 and 10 degrees, as specified in the FOBoom input file, using both “SBRF_Turbo_000X” and “SBRF_Turbo_000XABLH” FOBoom outputs. Note that the “SBRF_ Turbo _000X.bsg” and “SBRF_Turbo_000XABLH.bsg” files have been written to the folder with the input files and executables, corresponding to each input file.
        iv. TURBO will run only once for each trajectory point, combining “SBRF_Turbo_000X” and “SBRF_Turbo_000XABLH” outputs. Note that the “SBRF_Turbo_000X” -tin.txt, -tur.out, -tur.txt, and -u86.txt files have been written to the folder with the input files and executables.
8. **Copy origin file**
    a. When SonicBAT-Run-Fort processing is complete, press any key while in the command prompt to continue. The command prompt will show that the file *SBRF_Turbo_ALL.org* has been written to the folder with the input files and executables. This file contains the data in the origin file output from FOBoom (*SBRF_Turbo.org)* and will be read by PCBFoot and WCON.
9. **Run PCBFoot**
    a. When the copy command has been executed, press any key while in the command prompt to continue.
    b. The command prompt will display isopemp calculation progress along each trajectory point.

c. Note that the "SBRF_Turbo_ALL" .asc, .ens, .ind, .qwk, and .sig files have been written to the folder with the input files and executables. These data will be used to visualize the footprint with high-resolution signatures in WCON.

10. Run WCON

a. When PCBFoot processing is complete, press any key while in the command prompt to continue.

b. The WCON interface will open to allow for visualization of the footprint including isopemps and pressure contours overlaid on black X symbols marking the locations of interest from the corr.txt file, as shown in Figure B-48. The data in the right column will change to represent the point at which the mouse is hovering.

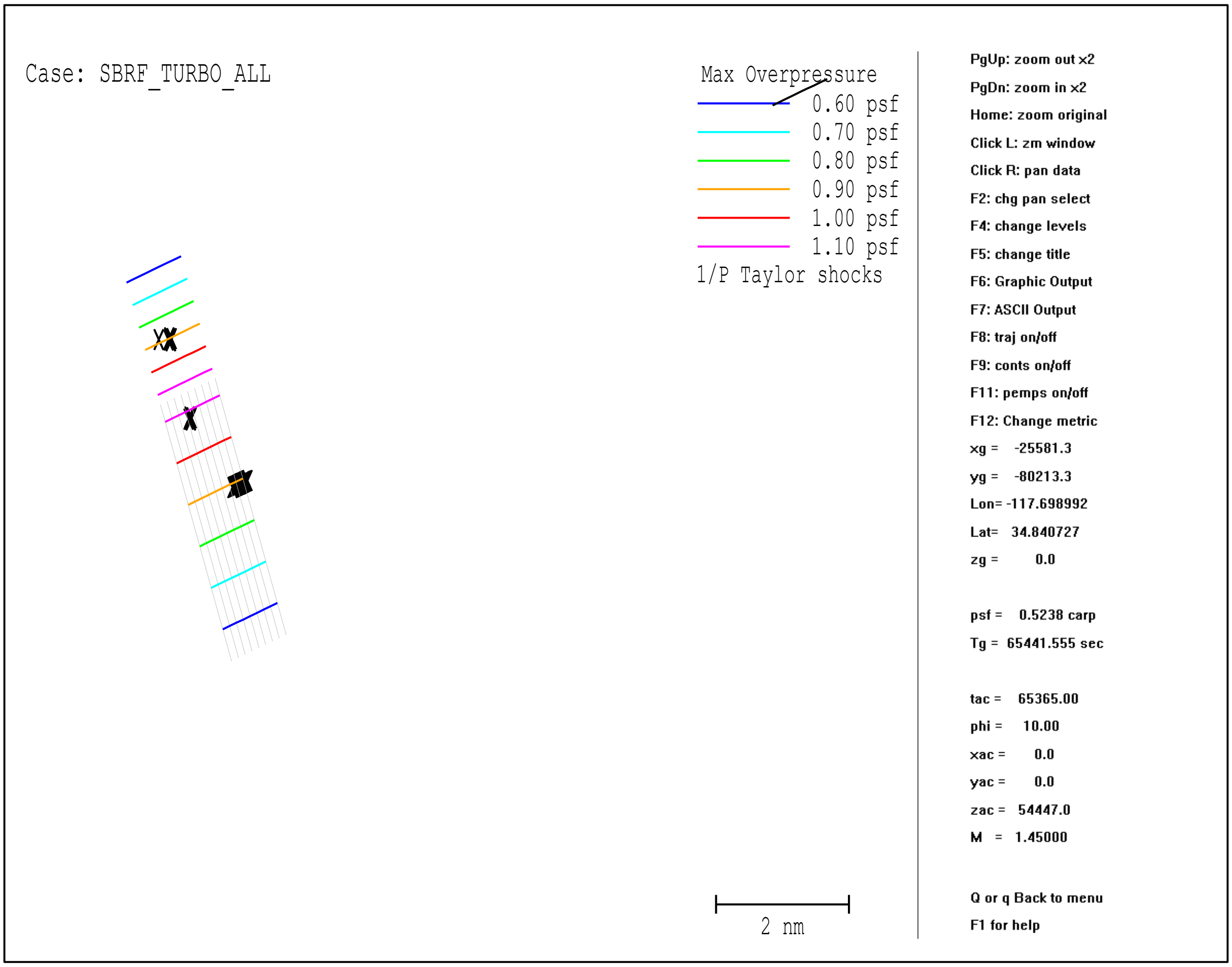


Figure B-48 Turbo case WCON footprint display with marked locations of interest from the corr.txt file.

11. Visualize turbulized signatures

a. Open the WCON signature view

i. Press the "p" key while hovering the mouse over any point within the footprint. Note that WCON will interpolate between the Turbo signatures to allow for high-resolution turbulized waveforms to be extracted at any point within the footprint.

ii. A window will open in which the (x, y) coordinates can either be approved or edited to match the location of interest. For this example, edit the coordinates as shown in Figure B-49 and click *OK*. Note that these (x, y) coordinates correspond to one of the locations of interest from the corr.txt file.
iii. The WCON signature interface will open, as shown in Figure B-50. Press the “<” key to adjust the time axis to zoom in on a single signature to better view the turbulent spiking details, as shown in Figure B-51.
iv. Press the “F6” key to save this graphic. A window will pop up with printing options. Click *WMF Output* to save this graphic.

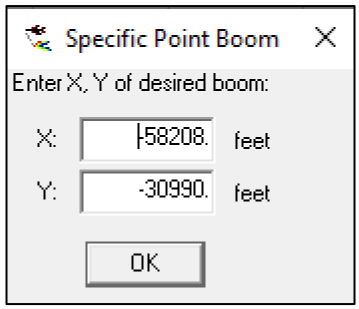


Figure B-49 Turbo case WCON signature example coordinates.

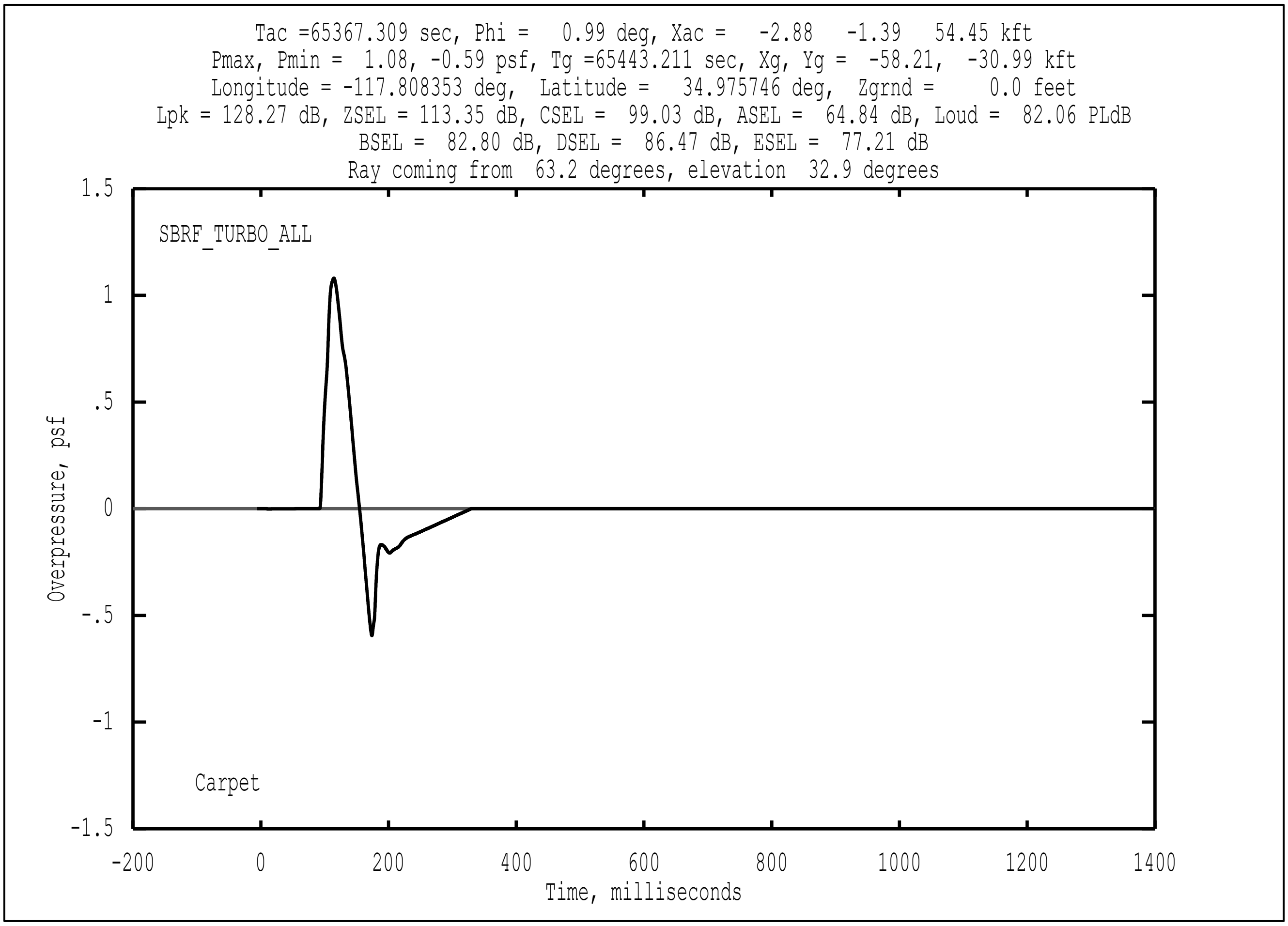


Figure B-50 Turbo case WCON turbulized signature view example.

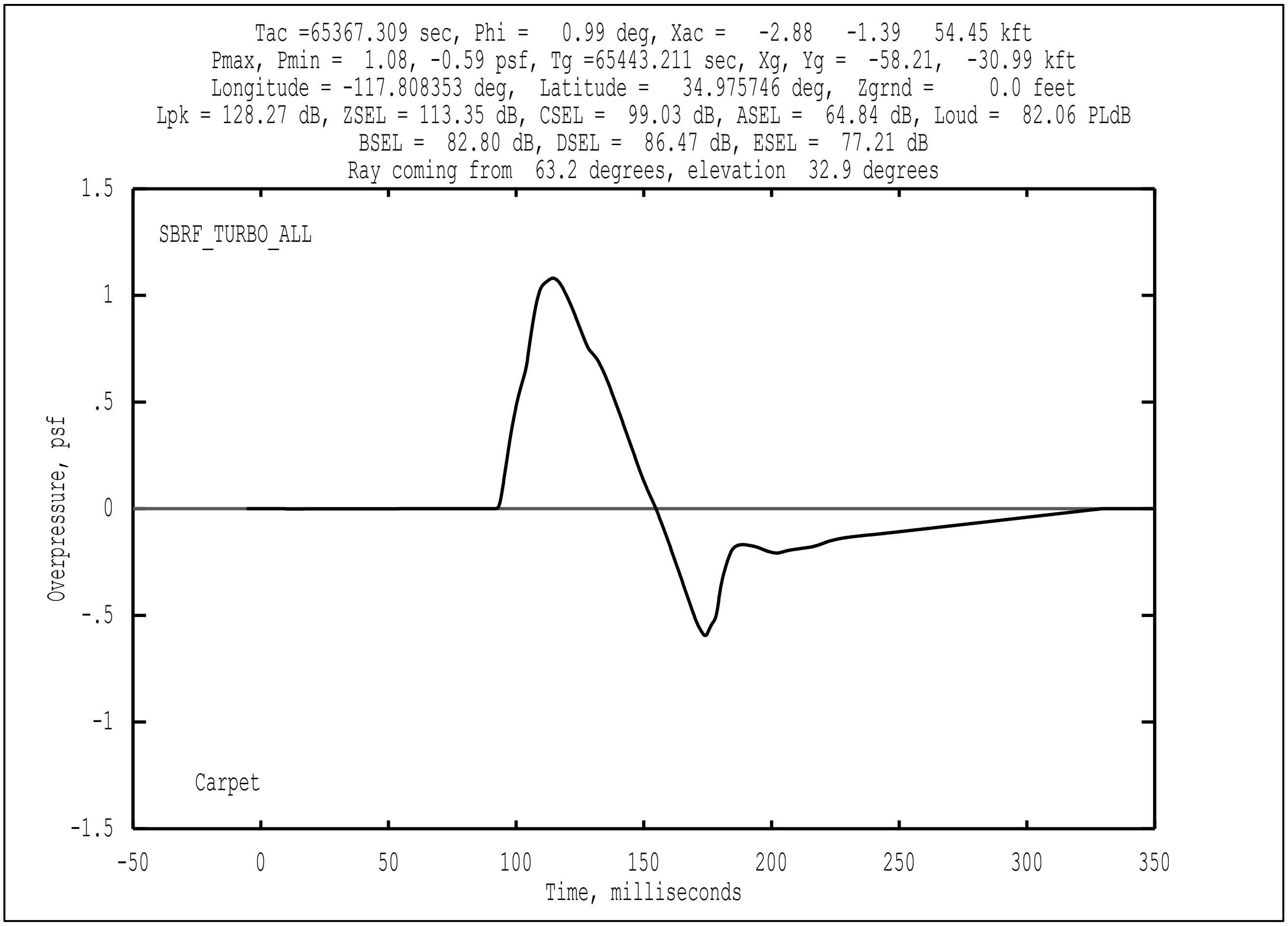
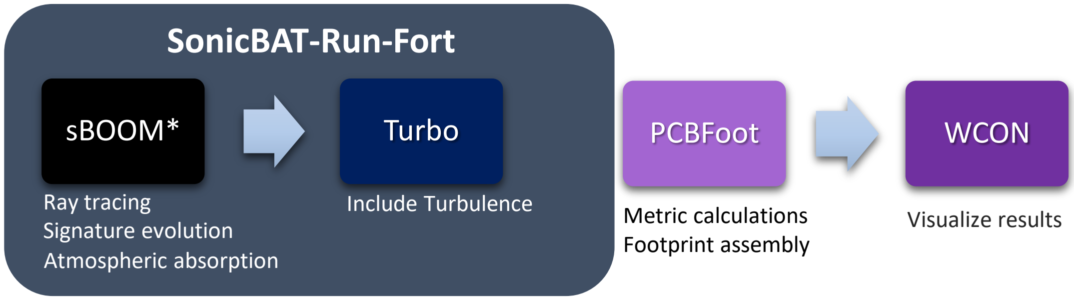


Figure B-51 Turbo case WCON signature view example – time axis zoom in to view turbulized signature.

Appendix B.8 sBOOM

sBOOM can be invoked using a series of keywords in FOBoom. In this workflow, FOBoom generates the input files, and sBOOM serves as the primary propagation module in place of FOBoom. sBOOM uses a time domain Burgers solution algorithm, so applying molecular relaxation in PCBurg or HeadlessBurgers is not necessary. sBOOM outputs are compatible with the PCBoom suite in that the footprint can be assembled and visualized in PCBFoot and WCON; however, the trajectory in this example consists of a single point, so there is no footprint to display.



*sBOOM is not distributed with the PCBoom suite.

Figure B-52 sBOOM workflow.

1. **Create a directory that contains executables for FOBoom and sBOOM modules.**
2. **Extract the contents of Examples.zip\08_sBOOM\Inputs to the same directory as the executables.**
3. **Review the FOBoom input file sBOOM.dat shown in Figure B-53, in which the spacing has been condensed for legibility in this format. This file can be opened in any text editor. This file can be opened in any text editor.**
   a. Note that the *CASENAME* keyword is used to specify the name of the case as *sBOOM*.
   b. Note that the *OUTPUTS* keyword section indicates 5 output types, including display of the command prompt screen and four types of output files. For more information on outputs, see Section 3.1.5.
   c. Note that the *ATMOS* keyword with the *ATT* option specifies that the external file *sBOOM_Atmosphere.att* contains the atmosphere data and the latitude of *35.0* degrees on the following line ties the atmosphere data to a location.
      i. Review the atmosphere file sBOOM_Atmosphere.att. This file can be opened in any text editor. For more information on the ATT file format, see Section 3.1.9.1.
   d. Note that the *ALTITUDES* keyword and following two lines in the file specify the number of altitudes of interest (1) and the altitude (0.0 ft MSL) for which data will be extracted
   e. Note that the *RAYTRACING* keyword with the *SBOOMLOW284* option is used and the designation of the modeling parameters follow on the next 5 lines. Note the input parameter -*30* on line 23 designates the azimuth angle of interest (in degrees) for which molecular relaxation will be applied in sBOOM. For more information on the modeling parameters, see Section 3.1.12.
   f. Note that the *MODE* keyword is used with the *CYLINDER* option, which specifies that the external file *sBOOM_Cylinder.plt* contains the starting signature in the Cylinder format. The following lines specifies the number of cylinders (1), the R/L ratio (3.1299) and the aircraft length (233.3 ft).
      i. Review the input signature file sBOOM_Cylinder.plt. This file can be opened in any text editor. Note that the data are presented in the units expected for the CYLINDER mode. For more information on the CYLINDER mode input, see Section 3.1.13.3.
   g. Note that the *HIGHRES* keyword is used, which specifies that the external file *sBOOM_highSR.txt* contains information to control the fidelity of the analyzed signature in sBOOM.
      i. Review the input file sBOOM_highSR.txt. This file can be opened in any text editor. Note that the data describes the maximum number of points, sampling rate, and duration of the signature.
   h. Note that the *REM* keyword precedes the *TRAJECTORY* keyword so that the trajectory data column headers can be displayed as desired for legibility within this input file without being

read in FOBoom. This keyword can be used at any point in the input file to add information that will be ignored by FOBoom.

i. Note that the *TRAJECTORY* keyword is followed by the trajectory data in *longlat* mode. For more information on the TRAJECTORY data format options, see Section 3.1.15.

```
CASENAME
sBOOM
OUTPUTS
5
SCREEN
UN6
U28
MCO
AGE
ATMOS
ATT
sBOOM_Atmosphere.ATT
35.0000
ALTITUDES
1
0.
RAYTRACING
SBOOMLOW284
    -2000.0  100000.0  -1500.0
    1.9 3.1299
    0.5   500.0   0.5
    1
    -30.
MODE
CYLINDER
1
sBOOM_Cylinder.PLT
1.0
3.1299  233.300
HIGHRES
sBOOM_highSR.txt
REM tstart xplane yplane fltalt mach dmdt d2mdt head psidot d2psi fpa gamdot d2gm Wt(klbs) Length(ft) Thrust(klb) Drag(klb) Alpha(deg) FKS
TRAJECTORY
 longlat   -118.0 35.0
    0.00   0.00   0.00  55000.0 1.6  0.00 0.00  90.0 0.00   0.00  0.00 0.00  0.00 0.00     233.33         0.00        0.00      0.00       0.00
END
```

Figure B-53 sBOOM case input file.

4. **Review the batch script file Run_sBOOM.bat shown in Figure B-54. This file can be opened in any text editor.**
    a. Line 1 runs FOBoom (*pcboom730win.exe*) with inputs specified in the *sBOOM.dat* file.
    b. Line 3 runs sBOOM using the inputs created by FOBoom.

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
pcboom730win.exe sBoom.dat
pause
sboom_Windows_2.84.exe
pause
exit
```

Figure B-54 sBOOM case batch script file.

Run FOBoom

c. Double click *Run_sBoom.bat* for FOBoom to begin ray tracing at specified trajectory points.
d. A command prompt will be displayed with times along the trajectory.
e. Note that the .age, .mco, .org, .out, .ssg, .u28, and .un6 files have been written to the folder with the input files and executables, as well as two .txt files, a .data file, and an .input file. These latter files are sBOOM input files.

5. Run sBOOM

a. When FOBoom processing is complete, press any key while in the command prompt to continue.
b. The command prompt will display computation progress for each trajectory time and azimuth angle.
c. Note that the .dat, .out, .plt, and .sig, files have been written to the folder with the input files and executables. These files contain ground signature and loudness metric data including atmospheric absorption due to molecular relaxation. They can be viewed in any text editor.

Appendix B.9 Focus Delta Ray Solution

The post-focus or focus delta ray is directly impacted by the caustic line, therefore, modeling the focus delta ray requires characterization of the caustic line as well as the ray. This necessitates that ray tracing, caustic calculation, and molecular relaxation (FOBoom, RayCau, and PCBurg) be executed twice; once to model the caustic line and once to model the focus delta ray. In addition to the caustic's physical impact on the nearby acoustic signatures, the caustic geometry is also used to pinpoint the focus delta ray path. Once the caustic and signature information are respectively output from FOBoom, RayCau, and PCBurg, the concatenated information can be passed to the LNTE module to complete the modeling.

The focus delta ray passes through a point orthogonal to the caustic-ground intercept at a distance delta (δ). This delta distance is known as the diffraction boundary-layer thickness. At the perpendicular intersection of the diffraction boundary-layer thickness and the focus delta ray (see Figure B-55, *Interface point between Burgers and LNTE)*, geometric ray acoustic theory is no longer valid and the Lossy Nonlinear Tricomi Equation (LNTE) is required to solve for the focus delta ray's acoustic pressure and path by accounting for diffraction, reflection, and propagation behavior at the caustic edge. The transition point between modeling methods will be referred to as the Burgers-LNTE interface point throughout this example because the FOBoom, RayCau, and PCBurg modules are run to propagate the waveform from the aircraft to the Burgers-LNTE interface point. Then the LNTE module is run to predict the path of the waveform from the Burgers-LNTE interface point to the ground and the pressure at the ground.

In order to model the propagation from the aircraft to the ground, the Burgers-LNTE interface point is manually calculated and used as the final altitude (ground height) for the purposes of the FOBoom, RayCau, and PCBurg modeling so the modules know where to terminate propagation using the geometric ray acoustic theory. In order to model the ray beginning at the aircraft, the time along the trajectory must also be known. This time, (TADVNCE) is determined through iteration until the ground intercept in the FOBoom .out file closely matches the calculated BURGERS-LNTE interface coordinate. Modeling is completed in LNTE from this point. A diagram of this workflow is presented in Figure B-56.

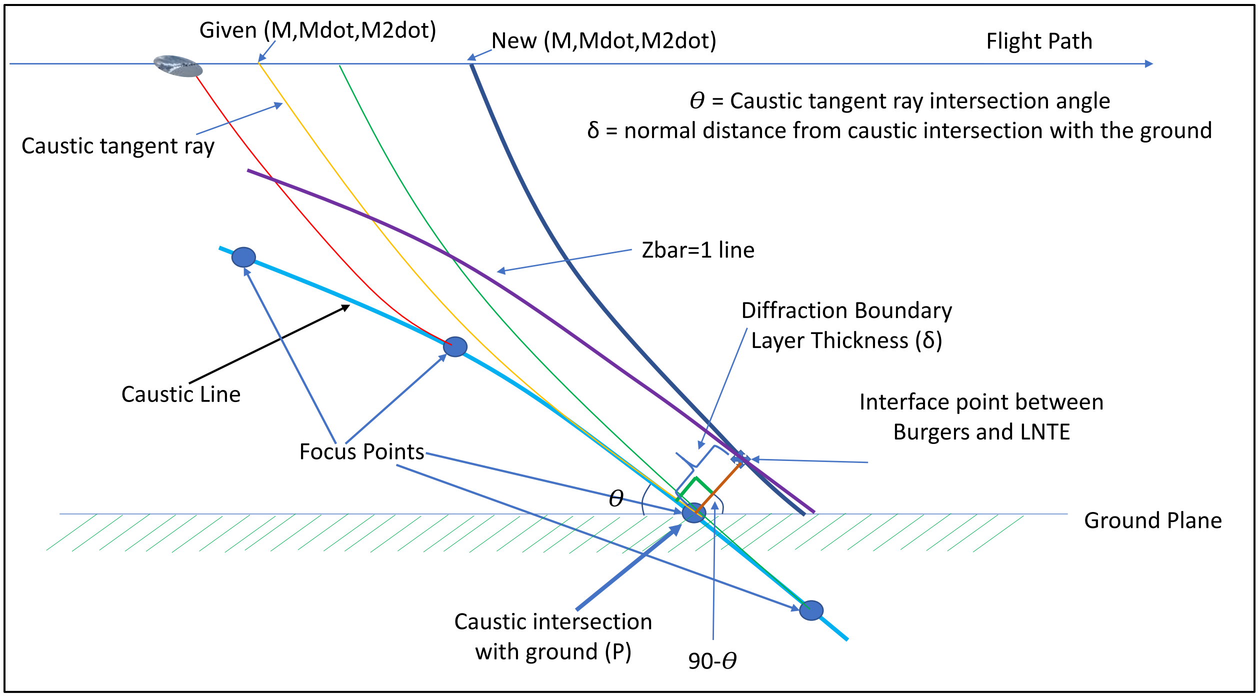
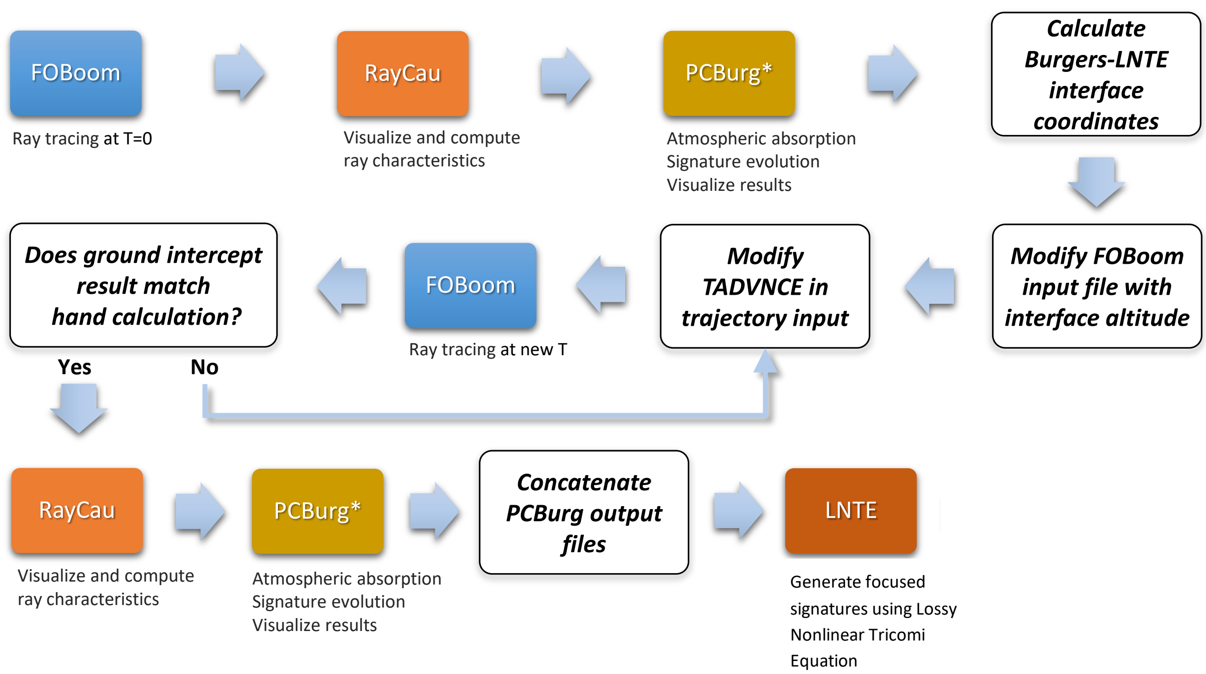


Figure B-55 Focus delta ray geometry.[21]



*Headless Burgers CANNOT be used in place of PCBurg in this context as the output file is not properly formatted to generate the required input file for the LNTE module.

Figure B-56 Focus delta ray solution workflow.

[21] S. K. Rallabhandi and A. Loubeau, "Summary of propagation cases of the Third AIAA Sonic Boom Prediction Workshop," Journal of Aircraft 59(3), pp. 578-594, 2022.

Figure B-56 contains detailed workflow information for this complex example. Actions that are completed by the user are described in the large white boxes with black border. Descriptions of actions completed by the PCBoom modules are presented as in the other workflow diagrams throughout this guide.

1. **Create a directory that contains executables for FOBoom, RayCau, PCBurg, and LNTE modules.**
2. **Extract the contents of Examples.zip\09_FocusDeltaRaySolution\Inputs to the same directory as the executables.**
3. **Review the FOBoom input file FocusRay.dat shown in Figure B-57. This file can be opened in any text editor.**
    a. Note that the *CASENAME* keyword is used to specify the name of the case as *FocusRay*.
    b. Note that the *BURGERS* keyword is used to prompt the output of the .age and .ssg files, which will be used as inputs for the PCBurg module.
    c. Note that the *HYSTATMO* keyword is used to replace the existing pressure profile in the atmosphere file with a hydrostatically interpolated pressure profile for a greater level of detail.
    d. Note that the *OUTPUTS* keyword section indicates 4 output types, including display of the command prompt screen and three types of output files. For more information on outputs, see Section 3.1.5.
    e. Note that the *ATMOS* keyword with the *ATT* option specifies that the external file *FocusRay_Atmosphere.atm* contains the atmosphere data and the latitude of *35.0* degrees on the following line ties the atmosphere data to a location.
        i. Pressure information from this file will be ignored and replaced with a hydrostatically interpolated pressure profile in 100 ft increments due to the use of the HYSTATMO keyword.
        ii. Review the atmosphere file FocusRay_Atmosphere.atm. This file can be opened in any text editor. For more information on the ATT file format, see Section 3.1.9.1.
    f. Note that the *ALTITUDES* keyword and following two lines in the file specify the number of altitudes of interest (1) and the altitude (190.28 ft MSL) for which data will be extracted
        i. In this example, 190.28 ft is the ground height.
    g. Note that the *RAYTRACING* keyword with the *LEGACY* option is used and the designation of the modeling parameters follow on the next 5 lines. Note the input parameter *0* on line 24 designates the azimuth angle of interest (in degrees) for which molecular relaxation will be applied in PCBurg. For more information on the modeling parameters, see Section 3.1.12.
    h. Note that the *MODE* keyword is used with the *THOMAS* and *FILE* options, which specify that the external file *FocusRay_StartingSignature.txt* contains the starting signature in the Thomas format. The following line specifies the aircraft length and model length.
        i. Review the input signature file FocusRay_StartingSignature.txt. This file can be opened in any text editor. Note that the data are presented in the units expected for the THOMAS mode. For more information on the THOMAS mode, see Section 3.1.13.11.
    i. Note that the *TRAJECTORY* keyword with the *FILE* option specifies that the external file *FocusRay_Trajectory.trj* contains the trajectory data.
        i. Review the trajectory input file FocusRay_Trajectory.trj. This file can be opened in any text editor. Note the location of the *TADVNCE* keyword. For more information on the TRAJECTORY data format options, see Section 3.1.15.

```
CASENAME
FocusRay
BURGERS
HYSTATMO
OUTPUTS
4
SCREEN
UN6
U28
MCO
ATMOS
ATT
FocusRay_Atmosphere.atm
35.0
ALTITUDES
1
190.28
RAYTRACING
LEGACY
    -2000.0  100000.0  -1500.0
    1.0 3.000
    0.25   250.0   0.1
    1
    0.
MODE
THOMAS
FILE
FocusRay_StartingSignature.txt
110.0   110.0
TRAJECTORY
FILE
FocusRay_Trajectory.trj
END
```

Figure B-57 FocusRay case input file.

4. **Review the batch script file Run_FocusRay.bat shown in Figure B-58**. **This file can be opened in any text editor.**
   a. Line 1 runs FOBoom (*pcboom730win.exe*) with inputs specified in the *FocusRay.dat* file.
   b. Line 3 runs RayCau, which uses the outputs from FOBoom (*FocusRay*) as inputs.
   c. Line 5 runs PCBurg with the input parameters that follow, including the azimuth angle of 0 degrees as specified in the FOBoom input file, the ground reflection factor of 1.0 to avoid pressure doubling at the ground, and the *FT* command, which generates a file to be used by the LNTE module. For more information on the PCBurg input parameters, see Section 4.1.1.
   d. Line 7 runs the LNTE module to compute the focused signatures. Note the indication to generate the input file using PCBurg output, designated by *-pb*. Also note the other convergence parameter inputs. For more information on the LNTE module inputs, see Section 5.1.4.

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
pcboom730win.exe FocusRay.dat
pause
raycau730.exe FocusRay
pause
pcburg730.exe -FocusRay TW0.0 PW0.0 SR3 GR1.0 FT UN
pause
lnte730.exe sig-989.txt FocusedSignatures.out -tt0.5 -ii999999 -tm18.0 -fs24000. -pb
pause
exit
```

Figure B-58 FocusRay case batch script file.

5. **Run FOBoom**
    a. Double click *Run_FocusRay.bat* for FOBoom to begin ray tracing at specified trajectory points.
    b. A command prompt will be displayed with times along the trajectory.
    c. Note that the .age, .mco, .org, .out, .ssg, .u28, and .un6 files have been written to the folder with the input files and executables.
6. **Run RayCau**
    a. When FOBoom processing is complete, press any key while in the command prompt to continue.
    b. The RayCau interface will open to allow for visualization of the caustic ray with respect to the ground and calculate physical caustic attributes.
    c. Press the “up” and “left” arrow keys to adjust the trajectory times until the *Focus ray at Tac* and *Tangent ray at Tac* are both equal to 0 seconds, as shown in **Figure B-59**.
    d. Press the “F7” key to write the focus (.foc) file and save it in the active directory.
    e. Note the *Ray Elevation* angle (Θ) in degrees and *Delta* diffraction boundary-layer thickness (δ) in feet from lines 4 and 11 of .foc file, respectively, as shown in **Figure B-60**.
    f. Press the “Esc” key to close RayCau.

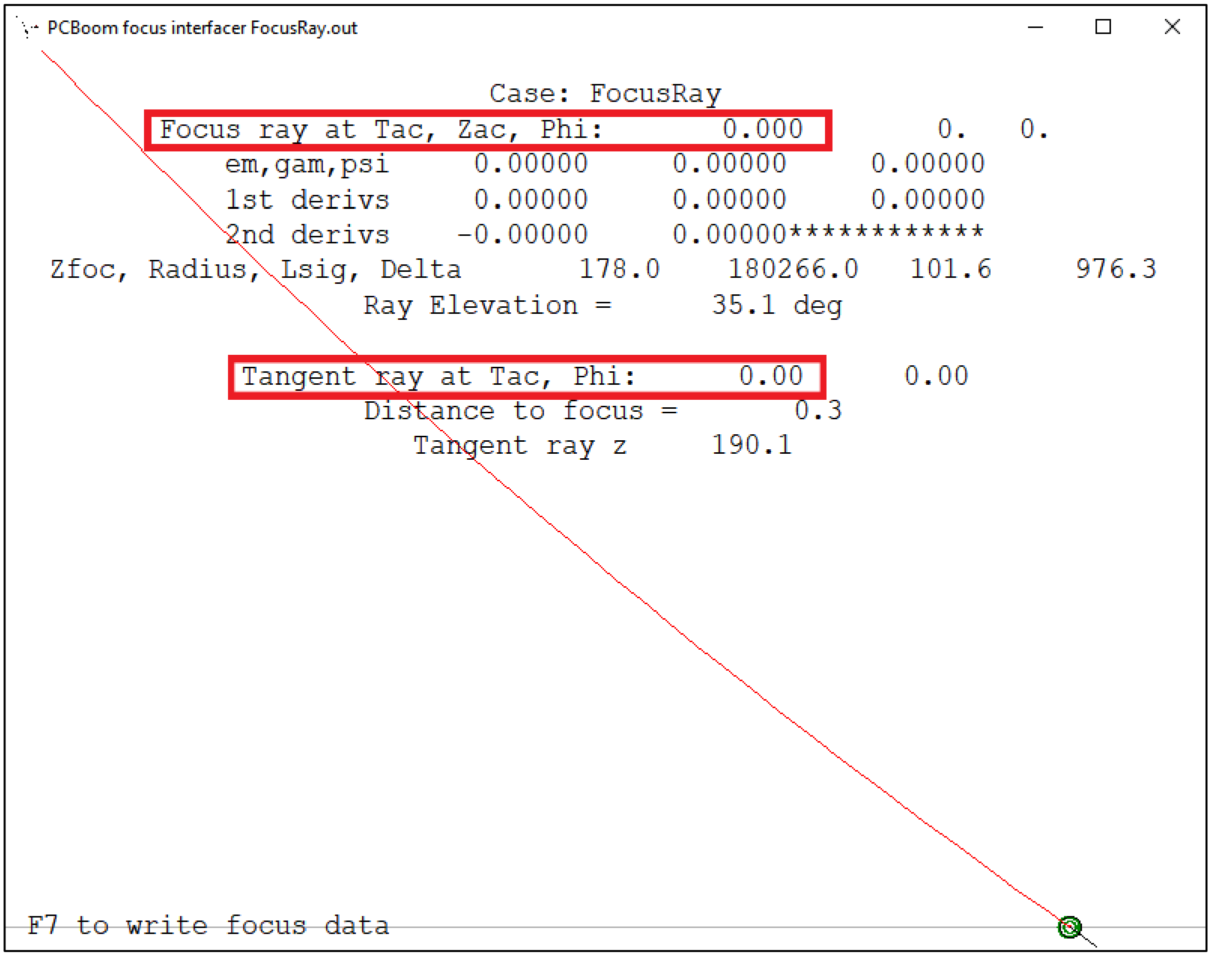
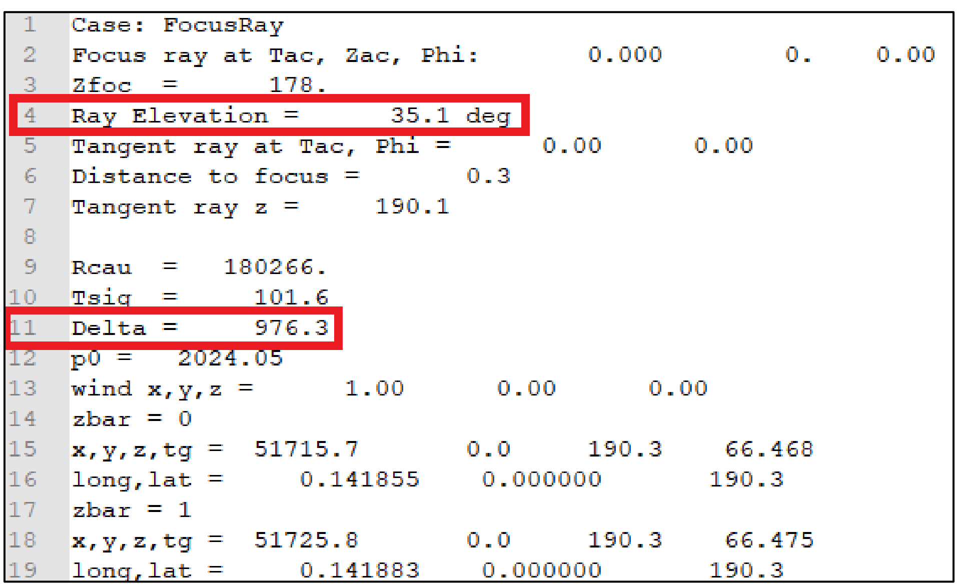


Figure B-59 RayCau interface manipulated to focus and tangent ray at Tac =0.



```
Case: FocusRay
Focus ray at Tac, Zac, Phi:      0.000       0.     0.00
Zfoc   =        178.
Ray Elevation =       35.1 deg
Tangent ray at Tac, Phi =     0.00       0.00
Distance to focus =      0.3
Tangent ray z =      190.1

Rcau   =    180266.
Tsig   =      101.6
Delta =      976.3
p0 =    2024.05
wind x,y,z =      1.00       0.00       0.00
zbar = 0
x,y,z,tg =   51715.7       0.0      190.3     66.468
long,lat =     0.141855    0.000000       190.3
zbar = 1
x,y,z,tg =   51725.8       0.0      190.3     66.475
long,lat =     0.141883    0.000000       190.3
```

Figure B-60 Resulting focus file including ray elevation angle and diffraction boundary-layer thickness.

7. Run PCBurg

a. When RayCau closes, press any key while in the command prompt to continue.
b. The PCBurg interface will open to allow for manual propagation of the signature to the ground, including molecular relaxation.
c. Press the “b” key *to begin Burgers evolution from this point*, as prompted in the interface.
d. Press the “Enter” key until the display stops changing.
    i. Pressing enter will propagate the signature in 1000 ft increments. The displayed metrics and plot will change with each keystroke. A red *Calculating…* will appear over the plot between computed altitudes before the display changes. Propagation terminates when the waveform has reached what FOBoom interprets to be the ground. In this example, propagation will terminate when the waveform altitude reaches 190 ft (*Z = 190)*, as specified in the FOBoom input file. See the final PCBurg display in Figure B-61.
e. Confirm that *Tac=0* as shown in Figure B-61.
f. Press the “F7” key to write the signature file at the ground. Save the file in the active directory with the altitude in the file name for clarity (sig-190.txt). This file will be used later in this example.
g. Close the command prompt by clicking the “X” button. This will also close PCBurg and will halt the batch script from moving on to the next step.

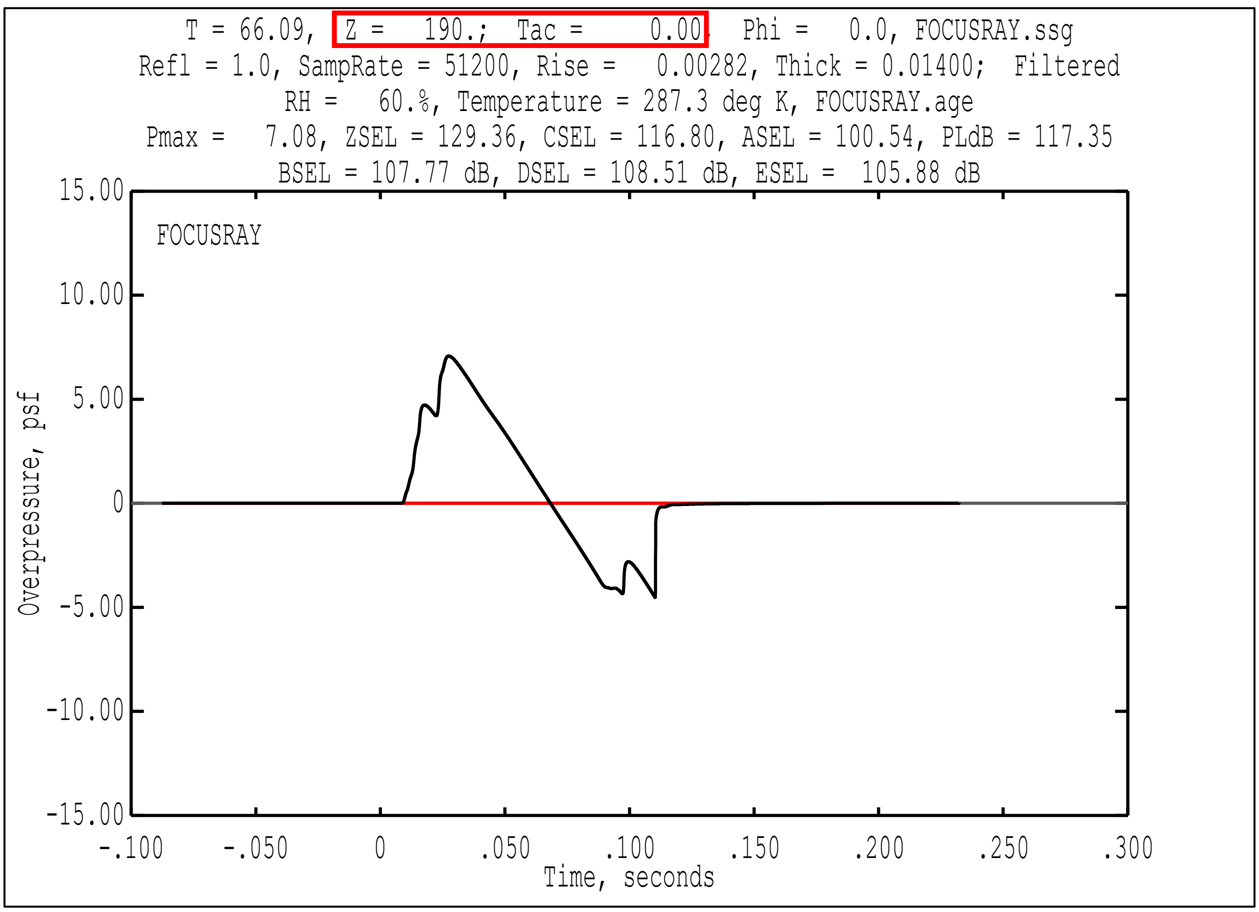


Figure B-61 PCBurg caustic ray propagation termination at true ground altitude and T_{ac}=0.

8. **Calculate the Burgers-LNTE interface coordinates**

The Burgers-LNTE interface coordinate can be calculated using the formula below when the aircraft is flying in the X-direction, as shown in Figure B-55.

a. Calculate the location of the focus delta ray ($X_{TADVNCE}$, Z) using the following formulas:

$$X_{TADVNCE} = X_{T=0} + \delta * \sin(\Theta)$$

$$Z = \delta * \cos(\Theta) + Z_{ground.}$$

where

$X_{T=0}$	See line 9 of the FOBoom .out file (Figure B-62)
δ	See step 6.e
Θ	See step 6.e
Z_{ground}	190.28, as specified in the FOBoom input file

For this example, the location of the delta ray is as follows:

$$X_{TADVNCE} = 51715.7 + 976.3 \times sin(35.1°) = \mathbf{52277.1\ ft}$$

$$Z = 976.3 \times cos(35.1°) + 190.28 = \mathbf{989.0\ ft}$$

```
8    GROUND INTERCEPT =
9     51715.7        0.0      190.3     66.468    0.81625    0.00000   -0.57770
10   FOCUS AT
11      51733.         0.       178.
12   RADIUS =    180266.
```

Figure B-62 FOBoom .out file with ground intercept information.

9. **Modify the FOBoom input file**

a. Open FocusRay.dat in a text editor

b. Modify line 17 (altitude of interest) to reflect the Z value calculated in step 8, see Figure B-63.

c. Save the changes to overwrite the existing FocusRay.dat in the active directory.

FOBoom will interpret the updated altitude of interest as the new ground height. If the ground intercept from the FOBoom output matches the calculated Burgers-LNTE intersection point, then the focus delta ray has been modeled properly. This altitude also indicates where PCBurg will terminate propagation to allow for signature extraction as input for LNTE.

```
CASENAME
FocusRay
BURGERS
HYSTATMO
OUTPUTS
4
SCREEN
UN6
U28
MCO
ATMOS
ATT
FocusRay_Atmosphere.atm
35.0
ALTITUDES
1
989
RAYTRACING
LEGACY
    -2000.0  100000.0  -1500.0
    1.0 3.000
    0.25   250.0   0.1
    1
    0.
MODE
THOMAS
FILE
FocusRay_StartingSignature.txt
110.0   110.0
TRAJECTORY
FILE
FocusRay_Trajectory.trj
END
```

Figure B-63 Modified FOBoom input file to reflect the Burgers-LNTE interface altitude.

10. Modify the FOBoom trajectory file

a. Open FocusRay_Trajectory.trj in a text editor

b. Modify TADVNCE in line 4 (for this example, try any number less than 10 with up to two decimal places of precision) as shown in Figure B-64. Save the changes to overwrite the existing FocusRay_Trajectory.trj in the active directory.

Iterating the modeled trajectory point will help approximate the Burgers-LNTE intersection point in order to properly model the curvature of the focus delta ray.

```
1  keyword   tstart     xplane     yplane     fltalt      mach      dmdt       d2mdt      head
2  longlat              -117.000   35.000
3                0.00       0.00       0.00   45000.0    1.4121   0.015681   0.000359   90.00000
4  TADVNCE   4.5
5  END
```

Figure B-64 FOBoom trajectory file with TADVNCE keyword and adjusted Advance time.

11. Run FOBoom

a. Double click Run_FocusRay.bat to begin raytracing at the new trajectory points. Ensure that the command prompt indicates computation at the new TADVNCE time. Note that the original .age, .mco, .org, .out, .ssg, .u28, and .un6 files have been overwritten with new data.

b. When FOBoom finishes running, open FocusRay.out in a text editor.

c. Search for “GROUND INTERCEPT” and click on the second instance of that phrase, which is within the TADVNCE data block. (This will not always occur on the same line number.) Look at the first entry, as shown in Figure B-65. Compare this to $X_{TADVNCE}$ calculated in step 8.

d. Close the command prompt by clicking the “X” button. This will halt the batch script from moving on to the next step.

```
TADVNCE
  0.25    0.100    250.0    0.0   1.00
    6321.          0.      45000.       4.50       0.00       0.00     1     1
  1.4863    0.0000   90.0000          48.22
   0.1729650000D-01     0.0000000000D+00     0.0000000000D+00
   0.3590000000D-03     0.0000000000D+00     0.0000000000D+00
     0.00       1  phi
GROUND INTERCEPT =
  51482.2        ).0       989.0      65.863    0.77330    0.00000   -0.63404
```

Figure B-65 Ground intercept at TADVNCE from FOBoom output file.

12. Repeat steps 10.a through 11.c until the value from step 11.c closely approximates $X_{TADVNCE}$ from step 8.

a. Note that $X_{TADVNCE}$ in Figure B-65 is less than $X_{TADVNCE}$ calculated in step **8**, which indicates a greater TADVNCE value is warranted.

b. See Figure B-66 for the final TADVNCE value and Figure B-67 for the corresponding ground intercept that most closely approximates the Burgers-LNTE interface point for this example. This close approximation indicates the focus delta ray has been modeled at the correct location.

```
1   keyword    tstart       xplane      yplane      fltalt        mach        dmdt       d2mdt        head
2   longlat                 -117.000    35.000
3                   0.00        0.00        0.00     45000.0      1.4121    0.015681    0.000359    90.00000
4   TADVNCE    6.46
5   END
```

Figure B-66 FOBoom trajectory file with TADVNCE keyword at final adjusted Advance time.

```
TADVNCE
  0.25    0.100    250.0    0.0   1.00
    9178.          0.      45000.       6.46       0.00       0.00     1     1
  1.5209    0.0000   90.0000          49.14
   0.1800014000D-01     0.0000000000D+00     0.0000000000D+00
   0.3590000000D-03     0.0000000000D+00     0.0000000000D+00
     0.00       1  phi
GROUND INTERCEPT =
  52276.8        0.0       989.0      66.408    0.75570    0.00000   -0.65491
```

Figure B-67 Final ground intercept at TADVNCE from FOBoom output file.

13. Run RayCau

a. When FOBoom processing is complete, press any key while in the command prompt to continue.
b. The RayCau interface will open to allow for visualization of the focus delta ray with respect to the ground and prompt PCBurg to execute molecular relaxation on the focus delta ray at the correct time along the trajectory.
c. Press the “right” arrow key to adjust the trajectory time such that *Tangent ray at Tac* is equal to TADVNCE from the final iteration of step 12, as shown in Figure B-68.
d. Press the “F7” key to write the focus (.foc) file and save it in the active directory. Note that this will overwrite the .foc file from step 6.c.
e. Press the “Esc” key to close RayCau.

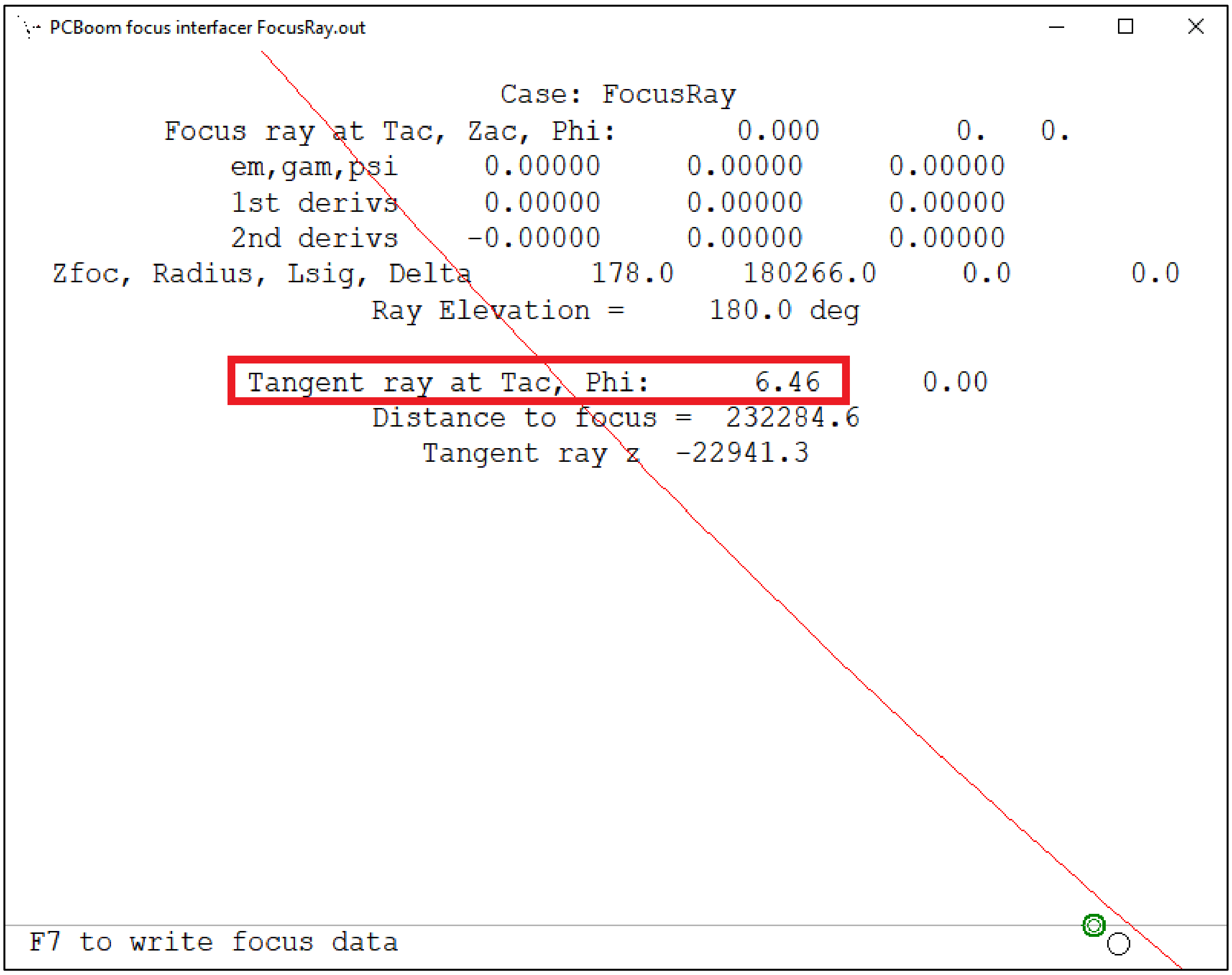


Figure B-68 RayCau interface tangent ray at Tac = TADVNCE.

14. Run PCBurg

a. When RayCau closes, press any key while in the command prompt to continue.
b. The PCBurg interface will open to allow for manual propagation of the signature to the Burgers-LNTE interface point, including molecular relaxation.
c. Press the “b” key *to begin Burgers evolution from this point*, as prompted in the interface.

d. Press the "Enter" key until the display stops changing.
    i. Pressing enter will propagate the signature in 1000 ft increments. The displayed metrics and plot will change with each keystroke. A red *Calculating…* will appear over the plot between computed altitudes before the display changes. Propagation terminates when the waveform has reached what FOBoom interprets to be the ground. In this example, propagation will terminate when *Z = 989*, as specified in the FOBoom input file.
e. Confirm that *Tac* is equal to the final TADVNCE from step 12. See the final PCBurg display in Figure B-69.
f. Press the "F7" key to write the signature file at the Burgers-LNTE interface altitude. Save it in the active directory with the altitude in the file name for clarity (sig-989.txt). This file will be used in the next step.

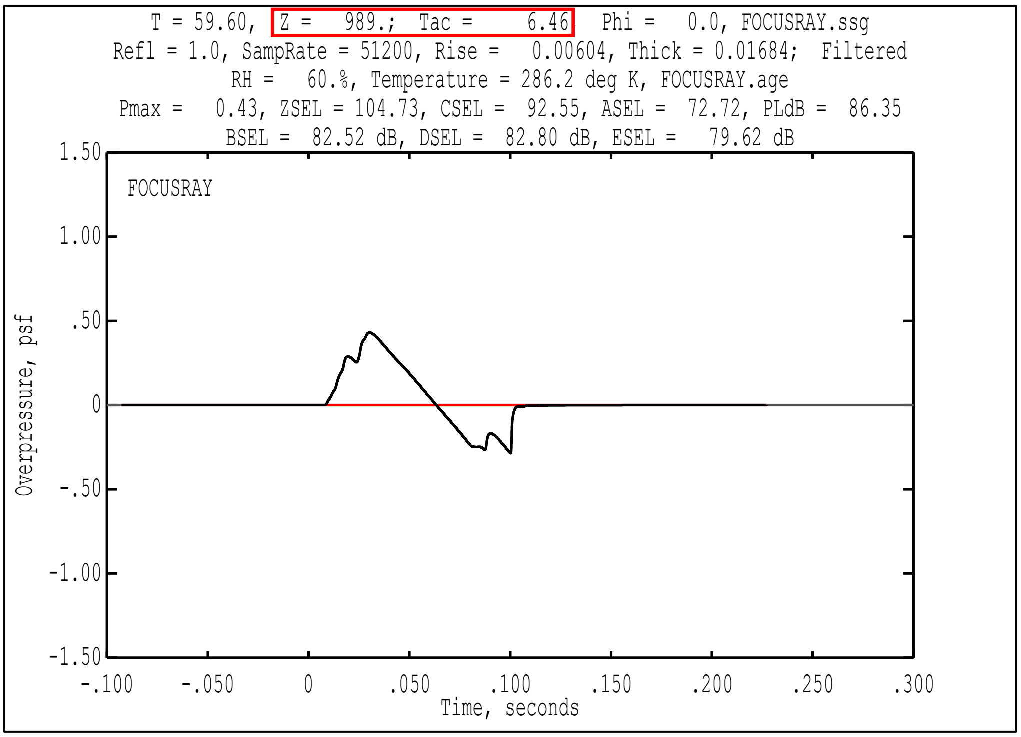


Figure B-69 PCBurg focus delta ray propagation termination at Burgers-LNTE interface altitude and T_{ac}= TADVNCE.

15. Concatenate PCBurg Files

a. Open both PCBurg signature .txt files (sig-190.txt and sig-989.txt) in a text editor.
b. Copy lines 7-10 from sig-190.txt and paste to replace lines 7-10 in sig-989.txt.
    i. This provides the LNTE module with both the copied caustic information calculated at the true ground height in step 7 and the signature information at the Burgers-LNTE interface location calculated in step 14. The resulting file is shown in Figure B-70.
c. Save this file as "sig-989.txt" to match the LNTE module input file name in line 7 of the batch script (Figure B-58).

Close PCBurg by clicking the "X" button. This will allow the batch script to move on to the next step.

```
T = 59.60,  Z =   989.;  Tac =      6.46,  Phi =    0.0, FOCUSRAY.ssg
Refl = 1.0, SampRate = 51200, Rise =   0.00604, Thick = 0.01684;  Filtered
RH =   60.%, Temperature = 286.2 deg K, FOCUSRAY.age
Pmax =   0.43, ZSEL = 104.73, CSEL =  92.55, ASEL =  72.72, PLdB =  86.35, BSEL =  82.52 dB, DSEL =  82.80 dB, ESEL =   79.62
dB
NPTS =   16384

Rcau  =   180266.
Tsig  =     101.6
Delta =     976.3
p0 =   2024.05
wind x,y,z =      8.00      0.00      0.00
zbar = 0
x,y,z,tg =  50592.6       0.0      989.0    65.233
long,lat =     0.138775    0.000000       989.0
zbar = 1
x,y,z,tg =  52276.8       0.0      989.0    66.408
long,lat =     0.143394    0.000000       989.0

     Time, sec        P, psf         pimag

      -0.092790       0.000000      -0.000000
      -0.092771      -0.000003      -0.000000
```

Figure B-70 Concatenated LNTE starting signature file from PCBurg output.

16. Run the LNTE module

a. When PCBurg closes, press any key while in the command prompt to continue. This will prompt the LNTE module to generate the Tricomi input file "sig-987_tricomi.inp" in the active directory and subsequently compute the focused signatures. The command prompt will display each step of computation. Running LNTE can take a significant amount of time, on the order of hours, depending on the computer specifications.

b. LNTE must be used at this point to predict the focused signatures because geometrics ray acoustic theory is no longer valid.

c. Note that the file FocusedSignatures.out has been written to the folder with the input files and executables.

17. Read LNTE module output

LNTE output file is written in a binary format with little-endian ordering and contains the data described in Table B-1. Note that the atmospheric output data do not correspond to those in the FOBoom input file.

Table B-1 LNTE output data sequence and description.

Data Description	Data Type
Total number of iterations	Integer
Total pseudotime	Double
Sample rate, Hz	Double
Total points in the time axis	Integer
$\bar{z}$spacing	Double
Number of $\bar{z}$ layers	Integer
Characteristic acoustic frequency, Hz	Double
Total radius of curvature, meters	Double
Temperature, Kelvin	Double
Atmospheric pressure, kPa	Double
Relative humidity, %	Double
x-wind, m/s	Double
z-wind, m/s	Double
$\bar{z}$ min	Double
$\bar{z}$ max	Double
Input waveform that has been zero-padded to the same number of points in the time axis, Pa	Double
Pressure data matrix, Pa – starts at $\bar{z}$ min and moves up to $\bar{z}$ max in blocks of time axis slices at each $\bar{z}$ layer	Double

18. Optional. Follow these steps if signatures at a specific $\bar{z}$ distance from the caustic are desired

a. Copy and rename the Tricomi input file created in step 16.a.

b. Edit second and third to last entries in line 2 with the minimum and maximum $\bar{z}$ distances, respectively. Save those changes. Figure B-71 displays an example, which will compute signatures from -7 to 1 $\bar{z}$ locations.

  i. Note that these inputs only define the minimum and maximum $\bar{z}$ output limits. Data at $\bar{z}$ locations between the limits can be extracted from the pressure data matrix based on the number of z-axis layers and dz spacing selected. For instance, data for $\bar{z}$ = 0 can be extracted in the 3500th row of the pressure data matrix, which contains 4000 evenly spaced entries between -7 and 1.

c. Rerun the LNTE module by creating and running a batch script with the new LNTE module input and output file names.

```
1  Tricomi format input file created from PCBoom Burgers output file:  sig-989.txt
2  12.778      54946.  286.2   96.9   60.0   2.0   1.4  -7.00  1.00   4000
3    16384     51200.0
4    0.0000000000000000
5    0.0000000000000000
6   -0.0000030000000000
```

Figure B-71 Modified LNTE input file to include $\bar{z}$ min = -7.

Appendix B.10 Over-the-Top (OTT)/Secondary Sonic Booms

As shown in Figure B-72, there are two carpet regions that can be observed: the primary and secondary boom carpets. The primary carpet consists of rays that travel from the aircraft directly down to the ground. Primary sonic booms have much higher maximum overpressure and loudness metric values and a relatively short propagation time compared to secondary, or "Over-the-Top," sonic booms. The secondary carpet consists of rays from two longer propagation paths. Rays that initiate at azimuth angles above the flight path originate with upward propagation before refracting down toward Earth, resulting in a secondary sonic boom. Rays that reflect upward after hitting the primary carpet and subsequently curve back down to Earth also result in a secondary sonic boom. This example will examine the rays that comprise the secondary sonic boom carpet.

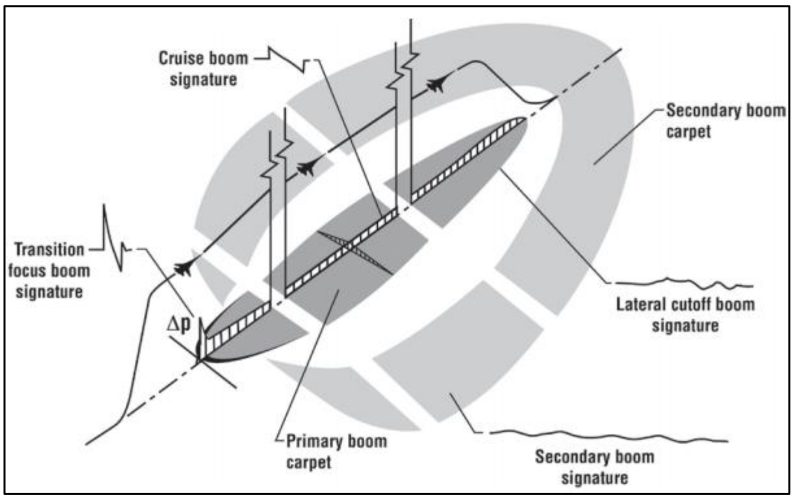


Figure B-72 Sonic boom carpet regions.[22]

Computation of secondary boom carpets and signatures requires the set of "Over the Top" computational modules, as shown in Figure B-73. POTRAY accounts for the curvature of the Earth when computing ray paths and ground intercept data for rays originating at all azimuth angles. POTTI visualizes the secondary sonic boom ray paths, including ground intercepts and ray bounces computed in POTRAY, in order to select individual rays for further examination of the sonic boom signature. Using the OTT keyword, FOBoom traces individual complex 3D ray paths and detailed ray tube parameters needed for computation of secondary sonic boom signature evolution. OTTER is used to visualize the signature propagation of a selected OTT ray tube output from FOBoom.

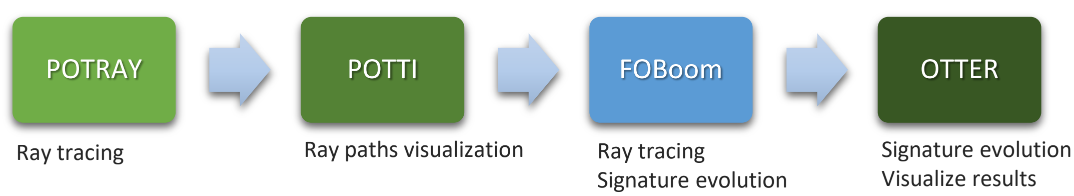


Figure B-73 Over-the-Top/Secondary sonic boom workflow.

[22] Maglieri, D., P. Bobbitt, K. Plotkin, K. Shepherd, P. Coen, D. Richwine, "Sonic Boom Six Decades of Research" NASA/SP-2014-622, June 2014.

1. **Create a directory that contains executables for POTRAY, POTTI, FOBoom, and OTTER modules.**
2. **Extract the contents of Examples.zip\10_OTT\Inputs to the same directory as the executables.**
3. **Review the batch script file Run_OTT.bat shown in Figure B-74. This file can be opened in any text editor.**
   a. Line 1 runs POTRAY with inputs specified in the *OTT.nml* file.
   b. Line 3 runs POTTI, which uses the outputs from POTRAY (*OTT000XX*) as inputs to visualize each ray individually.
   c. Line 5 runs FOBoom (*pcboom730win.exe)* with inputs specified in the *OTT1.dat* file. The ioutputs option *32* prompts the output of the .ott and .ots files.
   d. Line 7 runs OTTER, which uses the outputs from FOBoom as inputs to visualize the selected ray path.

Note that the keyword pause is not required to run the modules. It serves to pause processing between lines, which allows the user to observe the outputs from each module individually, and to manually initiate the next step, when ready.

```
potray730.exe OTT.nml
pause
potti730.exe OTT
pause
pcboom730win.exe OTT1 32
pause
otter730.exe OTT1
pause
exit
```

Figure B-74 OTT case batch script file.

4. **Review the POTRAY input file OTT.nml shown in Figure B-75. This file can be opened in any text editor.**
   a. Note that the *&allinputs* keyword is used indicate the start of the POTRAY input definitions.
   b. Note that the *trjfile =* keyword specifies that the external file OTT_*Trajectory.trj* contains the trajectory data.
      i. Review the trajectory input file OTT_Trajectory.trj. This file can be opened in any text editor. Note that the file contains data for 3 trajectory points. Output file names will be grouped with “0001” - “0003” to specify analysis of individual trajectory points. Also note that OTT_Trajectory.trj is formatted according to the FOBoom TRAJECTORY FILE option input requirements. For more information on the TRAJECTORY data format options, see Section 3.1.15.
   c. Note that the *atmfile =* keyword specifies that the external file *OTT_Atmosphere.att* contains the atmosphere data.
      i. Review the atmosphere file OTT_Atmosphere.att. This file can be opened in any text editor. Note that the file is formatted according to the FOBoom ATMOS ATT option input requirements. For more information on the ATT file format, see Section 3.1.9.1.
   d. Note that the *outfile =* keyword specifies the name of the POTRAY output file to be *OTT.out.*
   e. Note that the *zg =* keyword is used to specify the ground height in ft MSL.
   f. Note that the *iphi1 =* keyword is used to specify the minimum azimuth angles in degrees.
   g. Note that the *iphi2 =* keyword is used to specify the maximum azimuth angles in degrees.
   h. Note that the *idelphi =* keyword is used to specify the azimuth angle increment in degrees.
   i. Note that the *nbmax =* keyword is used to specify the maximum number of bounces to compute.

j. Note that the / keyword is used to indicate the end of the POTRAY input definitions.

```
&allinputs
trjfile  =  'OTT_Trajectory.trj'
atmfile  =  'OTT_Atmosphere.att'
outfile  =  'OTT.out'
zg       =  0.
iphi1    =  -180
iphi2    =   180
idelphi  =   2
nbmax    =   2
/
```

Figure B-75 OTT case POTRAY input file.

5. Run POTRAY

a. Double click *Run_OTT.bat* for POTRAY to begin computing the ray paths at specified trajectory points.
b. A command prompt will be displayed with times along the trajectory.
c. Note that the .hit, .out, and .ray files for each trajectory point have been written to the folder with the input files and executables.

6. Run POTTI

a. When POTRAY processing is complete, press any key while in the command prompt to continue.
b. The POTTI interface will open to allow for visualization of the resulting footprint from each trajectory point, including primary and secondary sonic booms at all azimuth angles.
    i. Note that POTTI will display data from the first trajectory point by default, but footprint plots for all trajectory points can be viewed using the ">" key to change the view.
c. Move the mouse until the circular cursor is in the location shown in Figure B-76.
    i. The red box annotation indicates the current display reflects the first trajectory point, which will be the point analyzed in the rest of the workflow.
    ii. The yellow box annotations indicate the visual cues used to confirm that a secondary sonic boom occurs at this trajectory point at an azimuth angle greater than 90 degrees. The cursor is highlighting a dashed red line, which indicates that the over-the top ray originally propagated up, and was refracted back down to Earth as part of the secondary sonic boom carpet. This is confirmed in the vertical section view of the ray path, shown in Figure B-77. If the dashed line in Figure B-76 was black, it would indicate that the over-the-top ray originated as part of the primary boom carpet, which reflected off the ground before returning to Earth.
    iii. The green box annotation confirms the secondary sonic boom classification.
    iv. The blue box annotation indicates that the secondary sonic boom occurs at an azimuth angle of 148 degrees. The rest of the analysis will focus on this azimuth angle.
d. Press the "Enter" key to open the ray path visualizer for this point. The result is shown in Figure B-77, in which two bounces are evident.
e. Press the "Esc" key to close POTTI.

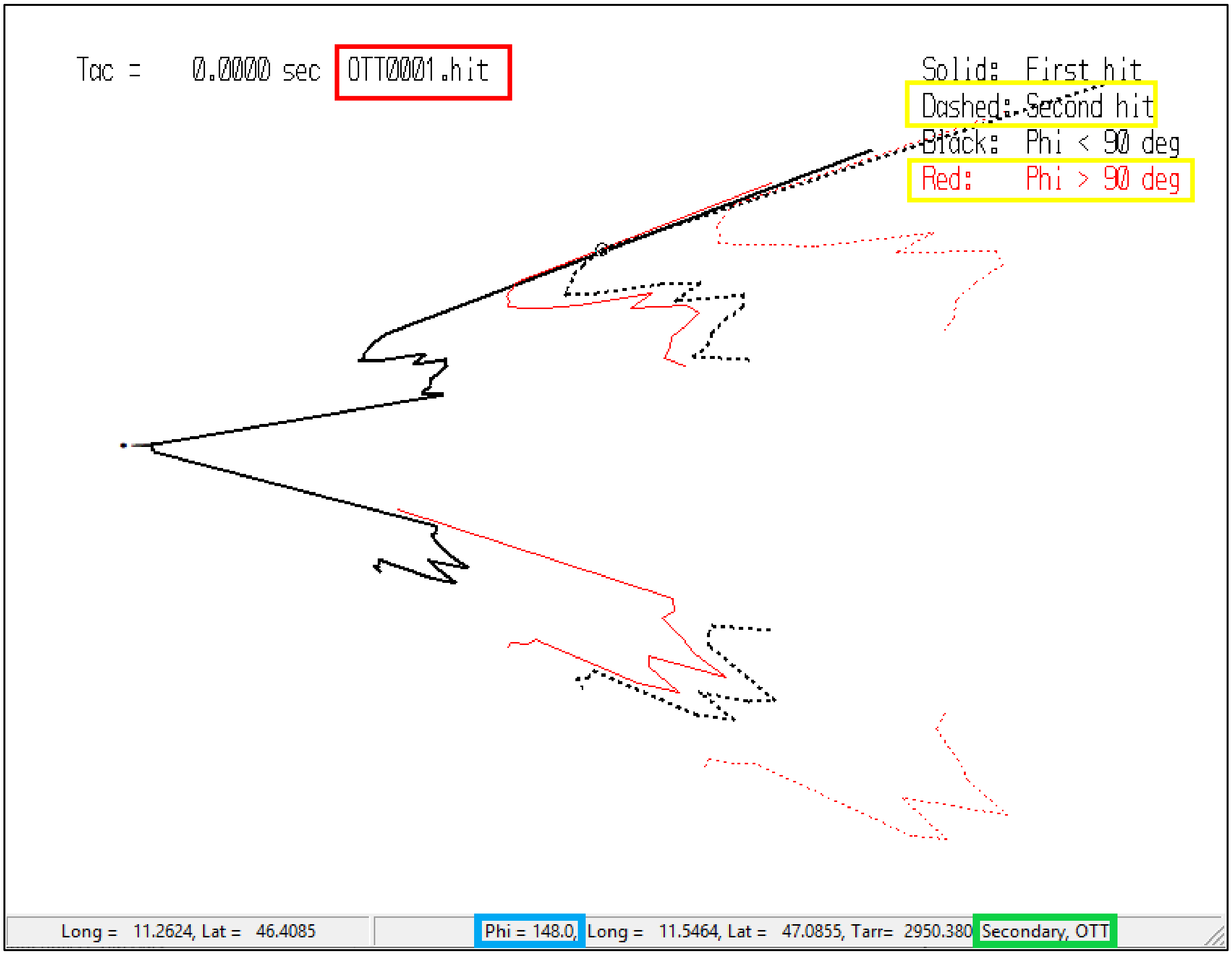


Figure B-76 OTT case POTTI visualization of the primary and secondary sonic boom footprint from the first trajectory point.

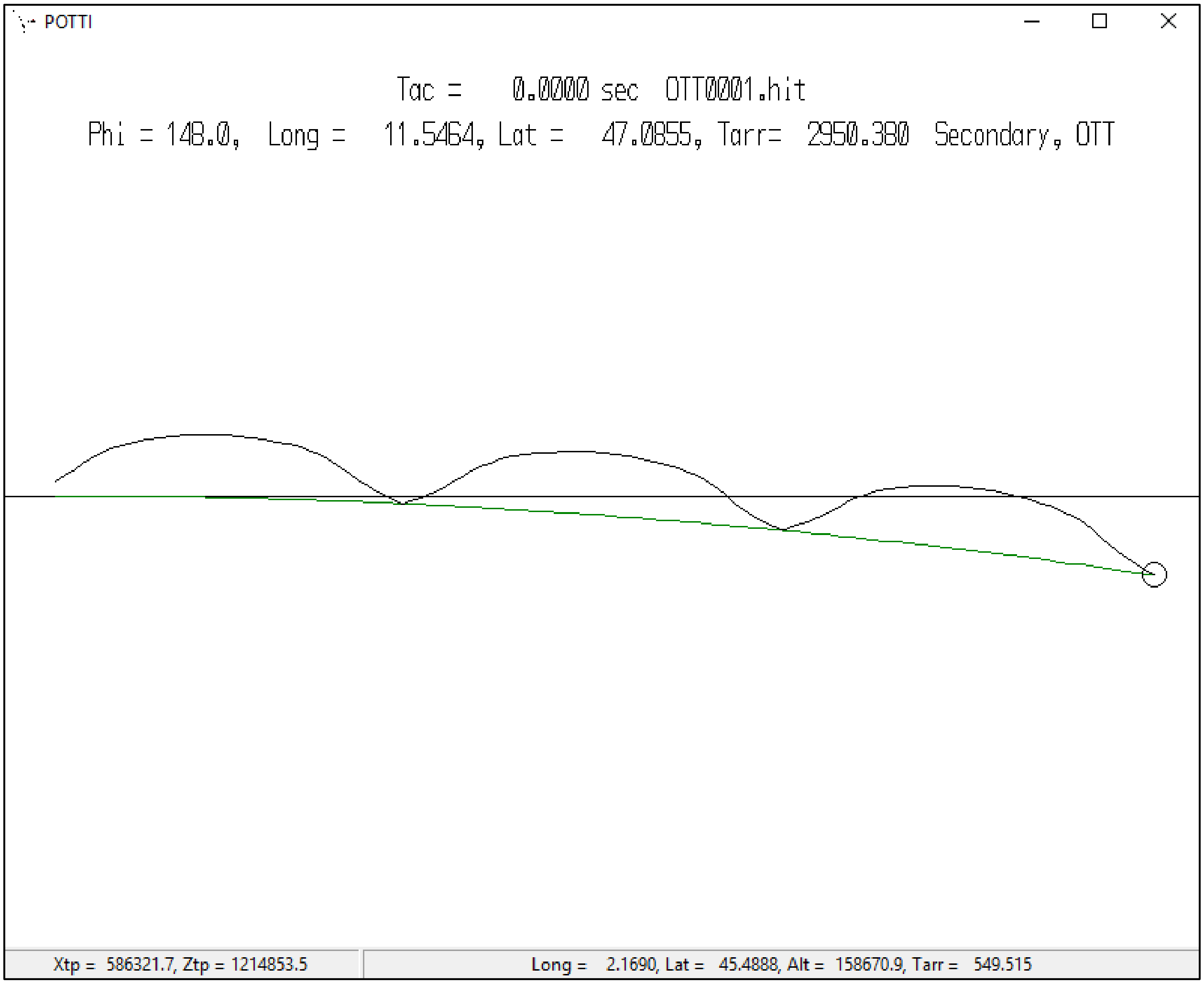


Figure B-77 OTT case POTTI visualization of secondary sonic boom ray bounces from the first trajectory point.

7. **Review the FOBoom input file OTT1.dat shown in Figure B-78. This file can be opened in any text editor.**
    a. Note that the *CASENAME* keyword is used to specify the name of the case as *OverTheTop*.
    b. Note that the *OUTPUTS* keyword section indicates 3 output types, including display of the command prompt screen and two types of output files. For more information on outputs, see Section 3.1.5.
    d. Note that the *OTT* keyword is to prompt the output of the .ott and .ots files, which will be used as inputs for the OTTER module.
    c. Note that the *ATMOS* keyword with the *ATT* option specifies that the external file *OTT_Atmosphere.att* contains the atmosphere data and the latitude of *0.0* degrees on the following line ties the atmosphere data to a location.
        i. Review the atmosphere file OTT_Atmosphere.att. This file can be opened in any text editor. For more information on the ATT file format, see Section 3.1.9.1.
    d. Note that the *ALTITUDES* keyword and following two lines in the file specify the number of altitudes of interest (3) and the altitudes (25000.0, 15000.0, and 0.0 ft MSL) for which data will

be extracted. Note that the latter corresponds to the ground height *zg = 0* specification in the OTT.nml input file for POTRAY.

e. Note that the *RAYTRACING* keyword with the *SCHULELLIPSE* option is used and the designation of the modeling parameters follow on the next 5 lines. This mode is chosen to account for the curvature of the Earth. Note the input parameter *148* on line 23 designates the azimuth angle of interest (in degrees) for which FOBoom will complete ray tracing and OTTER will visualize. Recall that the secondary sonic boom located in POTTI occurred at phi = 148 degrees. For more information on the modeling parameters, see Section 3.1.12.

f. Note that the *MODE* keyword is used with the *CARLSON* and *ACNAME* options, which specify that the known source characteristics for the selected *F-18* aircraft will be used for the starting signature. For more information on the CARLSON mode, see Section 3.1.13.1.

g. Note that the *TRAJECTORY* keyword with the *FILE* option specifies that the external file *OTT1_Trajectory.trj* contains the trajectory data.

    i. Review the trajectory input file OTT1_Trajectory.trj. This file can be opened in any text editor. Note that this file contains data for only one trajectory point, corresponding to the first trajectory point input to POTRAY. Recall that this trajectory point was used to locate the secondary sonic boom at phi = 148 degrees in POTTI. For more information on the TRAJECTORY data format options, see Section 3.1.15.

```
CASENAME
OverTheTop
OUTPUTS
3
SCREEN
UN6
U28
OTT
ATMOS
ATT
OTT_Atmosphere.att
0.0
ALTITUDES
   3
25000.  15000.   0.
RAYTRACING
SCHULELLIPSE
 0. 0. 0.
 1.9   1.
 .5  500.  .5
 1
 148.
MODE
CARLSON
ACNAME
F-18
TRAJECTORY
FILE
OTT1_Trajectory.trj
```

Figure B-78 OTT case input file.

8. Run FOBoom for the identified ray

a. When POTTI closes, press any key while in the command prompt to continue.
b. The command prompt will display progress for the trajectory point of interest.
c. Note that the .delt, .mco, .org, .ots, .ott, .u28, and .un6 files have been written to the folder with the input files and executables.

9. Run OTTER to visualize the Over-the-Top signature

a. When FOBoom processing is complete, press any key while in the command prompt to continue.
b. The OTTER interface will open, as shown in Figure B-79. The cursor is used to select the location of the signature to visualize along the ray.
c. Open the signature view
    i. Press the "f" key to move the cursor to the first focus point.
    ii. Press the "Enter" key to view the signature at this location, as shown in Figure B-80.
    iii. Press the "F6" key to save this graphic. A window will pop up with printing options. Click *WMF Output* to save this graphic.
    iv. Press the "F7" key to save the pressure signature data in a tabular format.
d. View the Over-the-Top ground signature
    i. Use the right arrow key to move the cursor to the second ray bounce, as part of the secondary sonic boom carpet, as shown in Figure B-81.
    ii. Press the "Enter" key to view the signature at this location, as shown in Figure B-82.
    iii. Press the "F6" key to save this graphic. A window will pop up with printing options. Click *WMF Output* to save this graphic.
    iv. Press the "F7" key to save the pressure signature data in a tabular format.

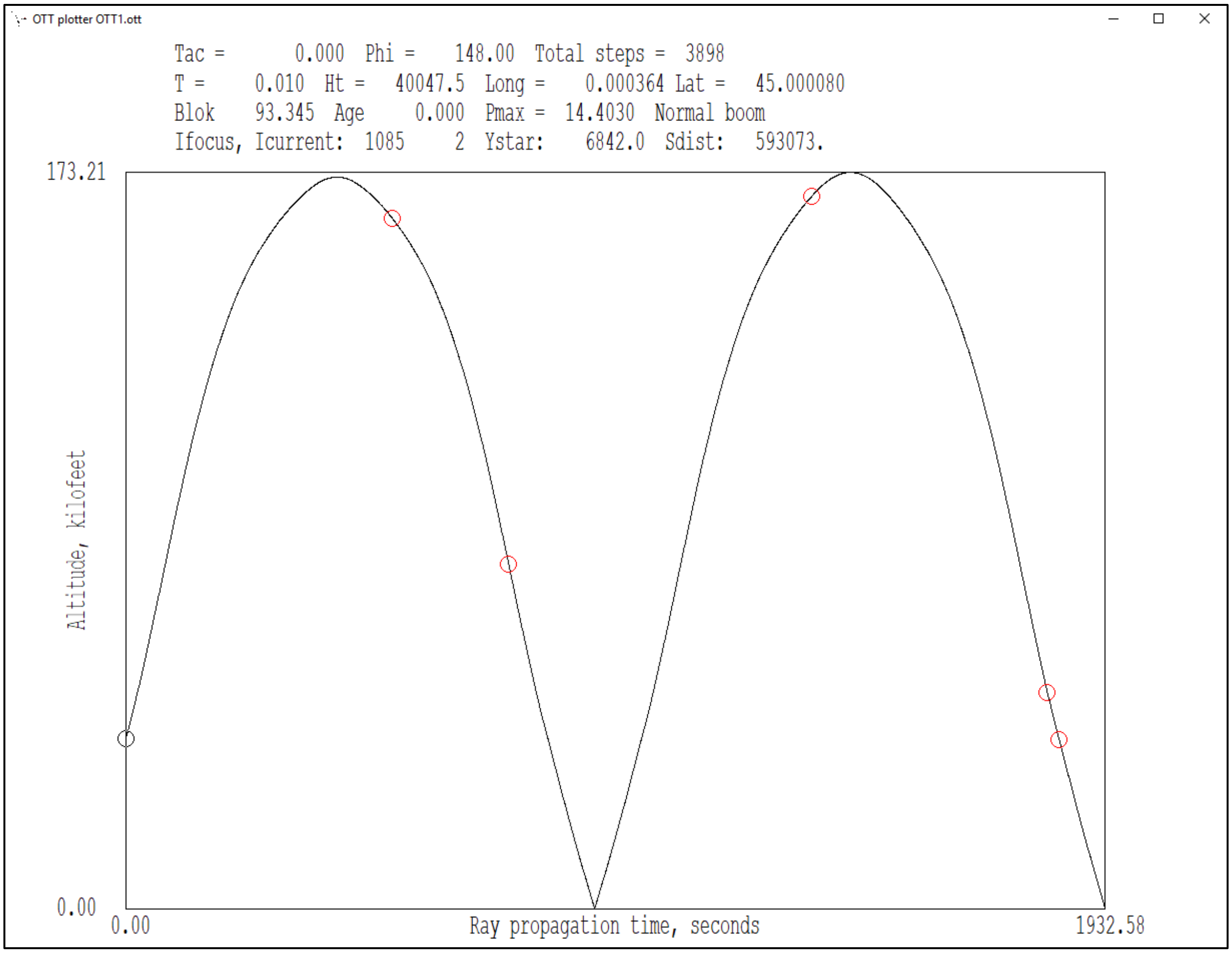


Figure B-79 OTT case OTTER ray path plot.

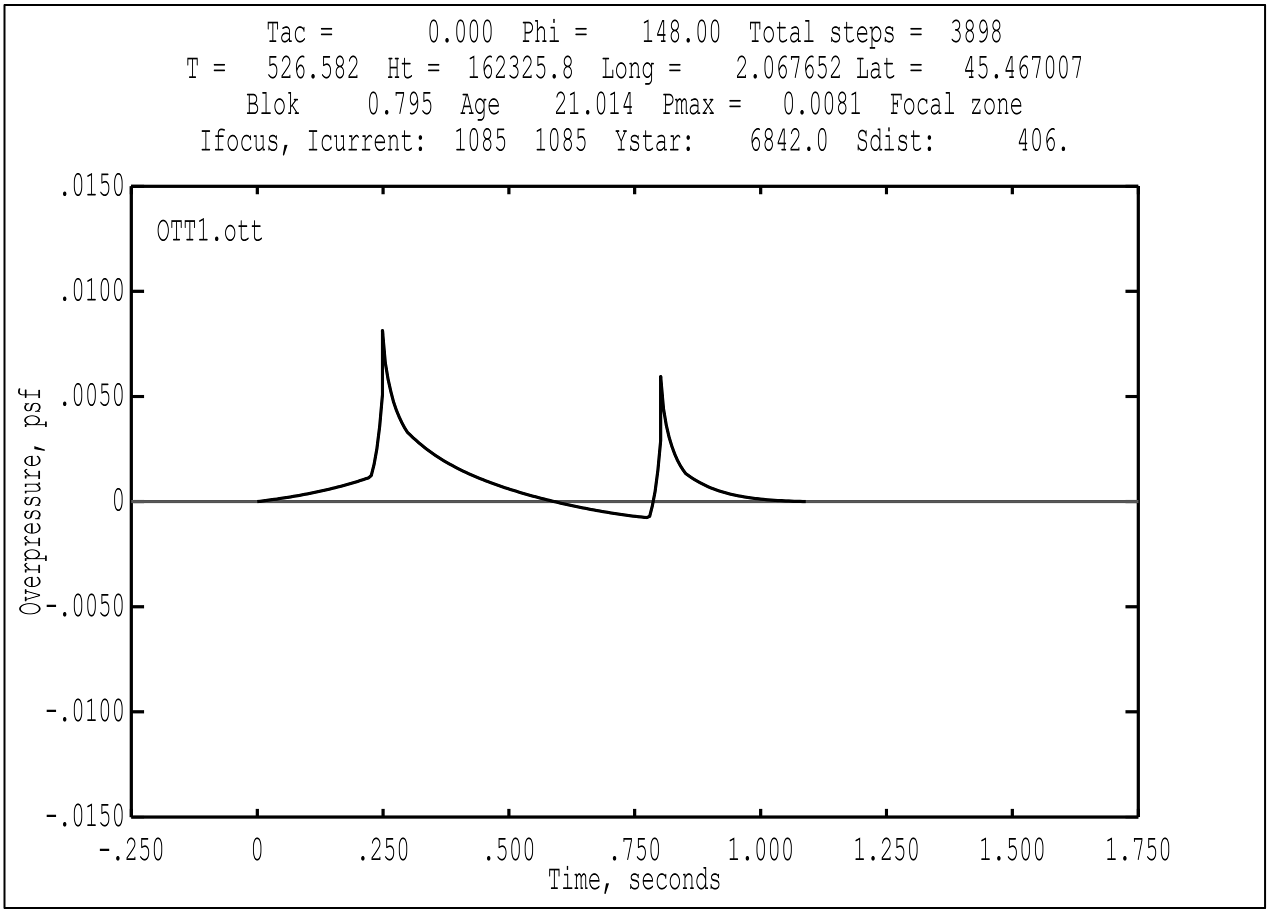


Figure B-80 OTT case OTTER signature view at first focus point.

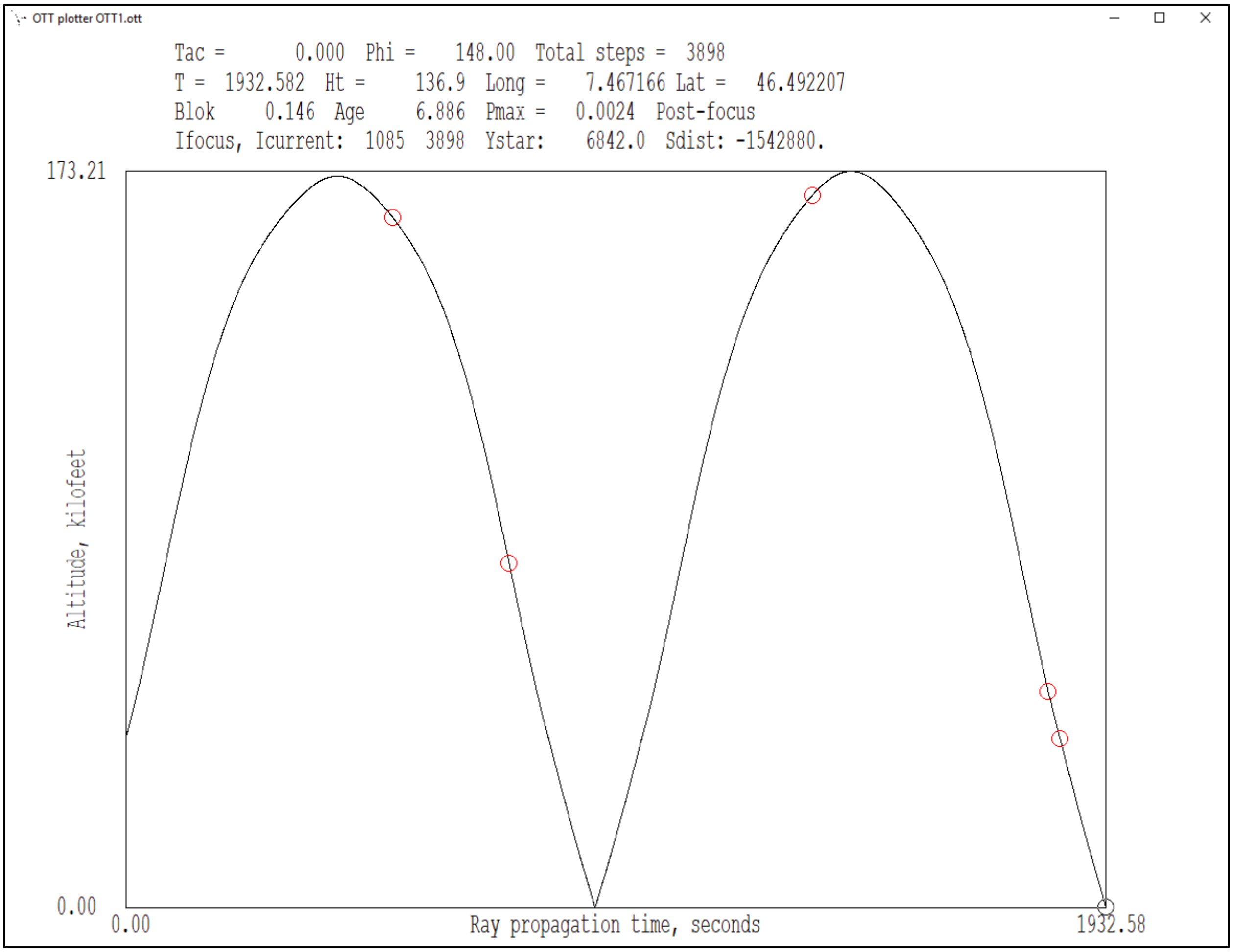


Figure B-81 OTT case OTTER ray path plot with cursor on second bounce (secondary sonic boom).

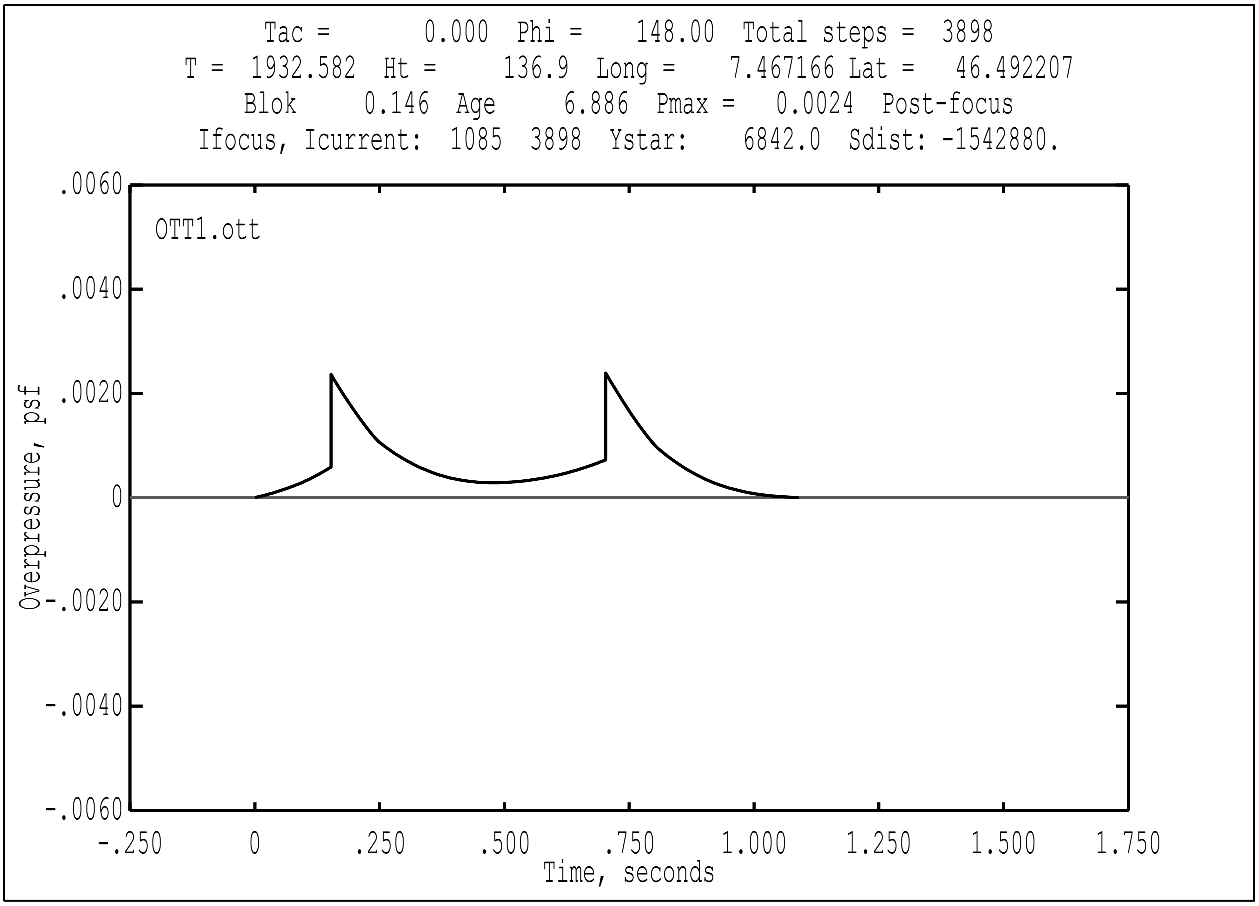


Figure B-82 OTT case OTTER signature view at second bounce point (Over-The-Top Ground Signature).