EnclosureShop™

Advanced Transducer & Enclosure Modeling

EnclosureShop provides advanced simulation and modeling of transducers and their enclosures. While other modeling programs offer only simple low order idealized approximations, EnclosureShop provides a vast array of outstanding capabilities including: true acoustical network analysis, high order diffraction shell analysis, advanced transducer models, support of multiple transducers/chambers/ports, and arbitrary enclosure structure modeling.

Perhaps one of the most important enhancements in EnclosureShop is the revolutionary new diffraction analysis engine. The effects of enclosure shape and driver/port locations can be examined in detail. Nearly any enclosure shape and transducer layout can be modeled into a variety of radiation domains. EnclosureShop provides a full-featured 3D editor allowing visualization of the enclosure shape and providing precise positioning of the transducers, ports, and enclosure.

The open architecture and broad spectrum of features will dramatically reduce development time, while greatly improving the quality of the final result, and demonstrates why LEAP has become the #1 choice of professional loudspeaker designers worldwide for nearly two decades.

Features

- Revolutionary Diffraction Analysis
- Nonlinear Acoustic Network Simulator
- Arbitrary Structural Enclosure Analysis
- Far Field, Near Field, Pressure Analysis
- Chamber, Port, Pressure Analysis
- Excursion, Velocity, Acceleration Analysis
- 360 Degree Horiz/Vert Polar Field Simulation
- Advanced 53 Parameter Transducer Model
- Infinite or Finite Volume Domains
- Transducer Parameter Derivation
- Quick Design & Reverse Speaker Tools
- Full, Half, Quarter, and Eighth Space Domains
- OpenGL 3D Graphics & 3D Object Support
- Scalable Enclosure & Transducer 3D Objects
- Reference Manual - 576 Pages
- Application Manual - 178 Pages
**Introduction**

The advanced capabilities offered by EnclosureShop will require many users to view enclosure modeling from a new perspective and with much greater detail than they had in the past. This places more demands on the part of the user. For example, it is no longer possible to simulate an enclosure simply by entering a single \( \text{Vab} \) value. The entire shape and dimensions of the enclosure must now be defined, along with the 3D spatial locations of all transducers and ports on the enclosure.

EnclosureShop features an ultra high performance diffraction engine. This revolutionary diffraction analyzer provides detailed and accurate simulation of external enclosure behavior. Considerable advancements were made in the methods of numerical diffraction computation resulting in several orders magnitude speed increase and practical high order analysis. All analysis is performed in true 3D space with full 360° field simulation around any arbitrary enclosure shell.

The realistic and highly detailed analysis provided by EnclosureShop demands 3D realization of all objects in the simulation. Therefore a proprietary 3D Layout Editor is provided to permit easy manipulation of the enclosure elements. Pre-built 3D objects are provided for the various types of elements, along with many specialized editing features ideally suited to enclosure simulation.

This brochure will define and explain some of the more significant modeling techniques used by EnclosureShop to simulate transducers and their enclosures. A detailed treatment of the many subjects discussed here would be far beyond the scope of this brochure. Rather, the information provided in the following pages merely serves to introduce some of the advanced capabilities.

**Application Software**

The main program screen is shown below. EnclosureShop is a large Win32 program and contains over 200 dialogs, extensive 2D & 3D graphics, a wide assortment of post processing utilities, and intensive numerical mathematics. Over 80 specialized Windows custom controls were created for the program. All simulations are performed utilizing both frequency and time domain analysis. Many of the numerical floating point routines are written in 80x87 assembly language and were highly optimized using the Intel VTune Performance Analyzer to maximize FPU performance and minimize analysis time. All computations are performed with either Double (64bit) or Extended (80bit) floating point precision.
EnclosureShop provides extensive graphs each containing many curves for the simulation results. The analysis of a design can produce 20-200 curves. Additional curves can also be imported for display and printing on the graphs.
**Transducer Modeling**

Conventional transducer modeling has been around for over 50 years. This type of modeling describes the transducer using a simplified set of fixed constants. In many cases complex parameters were assumed to be negligible, or have fixed constant values, to allow for a simplified approximate solution. While this approach was very appropriate decades earlier, and actually demanded due to the limitations of hand calculation, modern computer computational abilities allow for much more detailed and advanced analysis to be performed.

All of the acoustic pressure diffracting around an enclosure has its origin in the 90 degree off-axis response of the transducer. Errors in the simulated off-axis behavior can produce errors in the entire simulated field around an enclosure. This is especially significant for the response at the sides and rear of an enclosure, where all sound arrives solely from diffraction. Therefore, realistic diffraction analysis demands that realistic models be utilized for the directional behavior of the transducers.

Two parameters *Shape* and *Profile* are used by the transducer models of EnclosureShop to determine the essential high frequency characteristics for the transducer. They directly control radiation impedance, directivity, and off-axis response for the transducer. These parameters greatly affect the diffraction modeling of enclosures.

**Diaphragm Profile**

There are three possible profiles available for use as shown here. Flat profile is sometimes needed for ribbon tweeters and possibly other special devices, but the Cone and Dome profiles are common.

**Diaphragm Shape**

In order to simulate the behavior of all possible structural variations in a generalized fashion, a methodology of small source arrays was developed. The small sources embody their own directional characteristics. Additional transfer functions are applied to the array elements which enable a wide variety of directional characteristics to be emulated.

Each transducer is modeled by a group of sources arranged in the required geometry as shown in the drawings here. Between two and three dozen array elements are used in each shape model. These sources are driven by a suitable group of transfer functions as dictated by the shape and profile parameters.

**Transducer Parameters**

The transducer modeling capabilities contained in EnclosureShop are considerably more detailed then past conventional methods. In fact EnclosureShop supports three different transducer models: STD, TSL, LTD. The standard model STD uses a minimal set of legacy parameters. The TSL model is a continuation from LEAP-4, and the new LTD model in LEAP-5 adds numerous parameters for highly accurate simulation across a large dynamic range.
Transducer Model Performance Comparison

The LTD model was developed through actual measurements on dozens of various electrodynamic transducers. Over 1,000 curves were taken to develop this model under a wide array of environmental and operating conditions. Each was measured in free air clamped in a rigid fixture. An accelerometer was also attached to the cone to provide direct measurement of excursion, velocity, and acceleration. After the dynamic measurements were completed, the voice coil was fixed to obtain the blocked impedance data.

The impedance function of a driver is very important. It represents both the electrical and mechanical system. The current flowing through the driver is a direct function of the driver’s impedance since it is driven by a constant voltage source power amp. The resulting acoustic response is fundamentally linked to the voice coil current, with the additional anomalies of diaphragm parasitics.

To illustrate the differences between the STD, TSL, and LTD models with actual transducers, a large number of real transducers were measured and parameterized ranging from 18 Inch woofers to 1 Inch dome tweeters. The complete results of these tests span 300 graphs and are available on the web site for download. One set of comparison examples will be given here for a 10 Inch woofer.

The graphs below show the results from each of the three models, as compared to the actual driver behavior. The excellent correlation between the LTD model and the real measurements demonstrate the remarkable capabilities of the LTD model. These six graphs represent power levels ranging from 22mW to 225W. Even at the highest drive level of 30 Vrms the model displays an excellent representation of the actual nonlinear behavior. At this power level the temperature rise is not static but changing throughout the entire sweep, causing variable voice coil heating. It should be noted that the model reproduces the changes in resonance frequency and losses throughout this large power range with excellent accuracy.
Enclosure Modeling

Traditional enclosure modeling has relied on representation of the enclosure elements as simple lumped constants. Many elements were approximated in this way to produce simplified analysis and facilitate easy computation. However, real acoustic elements are invariably frequency dependent, and in many cases pressure or volume velocity dependent as well.

EnclosureShop contains sophisticated models for many of these enclosure elements and performs true acoustical circuit analysis. A proprietary circuit simulator is employed to specifically handle the unique requirements of electroacoustic system analysis.

Analysis of both standard and arbitrary enclosure structures is supported. Multiple chambers, ports, and transducers can be arranged in nearly any configuration. The enclosure can be simulated in a variety of domains, both free field and closed space, and may also include boundary reflections.

■ Standard Structure Models
The structure of an enclosure refers to the number of elements and how they are arranged. There are four types of elements which can comprise an enclosure: Shell, Chambers, Transducers, and Ports. There is always a single shell definition for any enclosure but possibly multiple chambers, transducers, and ports. EnclosureShop provides ten predefined enclosure models and also provides the ability to create custom structures. The standard models are shown here.

■ Custom Structure Models
Custom enclosures are designed using the Custom Multipass Enclosure dialog. This dialog allows chambers to be placed in any arrangement, and connected with any transducers and/or ports between them.

The enclosure structure is displayed in a generalized format numbering all chambers, transducers, and ports as shown in the pictorial below. The polarity of each transducer can be controlled by flipping it from one side to the other across a partition. The chamber to be tuned with a particular port is defined in a similar fashion.

■ Chambers
An enclosure may contain no chambers (in the case of reference and flat enclosures), may contain a single chamber, or may contain multiple chambers. Each model dialog has a section which defines the chamber properties.

Chambers can be represented using either a non-reflective lumped parameter model or a transmission line model which includes reflections. The primary parameter of importance here is Vab. A shape is always involved to facilitate the computation of the chamber volume.

A chamber can also include a portion of its volume occupied by a fibrous filling material. Parameters are provided for the type of media, density of media, and the percentage of volume filled. The material is used to absorb internal reflections.
EnclosureShop provides a catalog of predefined chamber shapes with automatic volume calculation. The dimensional variables can be assigned values by the user. The program will then compute the internal net volume, including compensation for finite wall thickness.

Analysis of an enclosure produces several curves for each chamber in the enclosure, including the pressure response. Each curve may be enabled/disabled for display depending on the interests of the user. Examples of chamber pressure curves are shown here.

Two pair of typical on-axis and chamber response curves are shown in the graphs, with 50% fill of fiberglass and 0% respectively. Chamber response curves are always much higher than free field curves, since the radiation into the chamber is confined.

These graphs show the internal chamber reflections coming through the external on-axis response and clearly illustrate the benefits of the damping material used inside.

### Ports

An enclosure may contain one or more ports, and each may represent either an air vent or drone passive radiator. Each model dialog has a section which defines the port properties for a particular location.

When the Fp field is clicked another dialog will open to define the detailed parameters of the port as shown left. Different fields appear depending on vent or drone.

Vents can also include a fibrous filling material for extra damping control, and to absorb reflections. These are similar to the chamber filling parameters. Ports can be represented with either a lumped parameter or transmission line model.

Analysis of an enclosure produces five curves for each port location in the enclosure. The near field port pressure SPL curve is shown here.

The analysis of port behavior can also include the effects of standing wave reflections inside the port. This is shown by the two near field port curves in the graph.

These reflections may or may not show up in the external enclosure response on-axis, depending on the chamber and port design.
**Shell Modeling**

The concept of an external enclosure definition will probably be new to most readers. The *shell* of an enclosure specifies the external shape and dimensions. This specification is necessary for diffraction analysis.

The shell of an enclosure may or may not be the same as a chamber. For example, consider the two enclosure models shown here. The Sealed Highpass model has a single chamber. The shell for this enclosure is simply defined from the single chamber. However, the Sealed Bandpass model has two chambers. Enclosures with multiple chambers require separate choices for the shell.

<table>
<thead>
<tr>
<th>Sealed Highpass</th>
<th>Sealed Bandpass</th>
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EnclosureShop provides a catalog of 18 predefined shell shapes, as shown here on the right. The dimensional variables for these shapes can be assigned values by the user. Thus the standard shells can be scaled or aspect ratios changed to provide virtually unlimited numbers of different shells.

**Imported Custom Shells**

It is also possible to import 3D definitions for the shell of any enclosure. Three file formats are supported: OBJ, DXF, and 3DS. The OBJ and DXF formats are text while the 3DS format is binary. The OBJ format was created by Alias/Wavefront (now Silicon Graphics Inc SGI) and is commonly used in the Maya program. Maya is one of the few graphics programs designed for true polygon editing and representation.

While it is possible to use many 3D CAD or graphics programs to work out the design of your enclosure shell, you will probably find that very few are capable of exporting the object properly with the required clean polygon structure. Most graphics programs do not allow polygon editing with the precision required. Even when you can create the proper polygons, many do not provide a means to export the objects whole and will force tessellation.

However, a proper OBJ file can also be created relatively easily by manual means by using any text editor. In many cases this method may be the only or best choice. An example of generating a proper OBJ file is shown below. The OBJ file used for this shell required only 37 lines of text. When generating the enclosure shell model for a physical enclosure, some simplification is often appropriate and necessary. It is not important to model each and every detail. This would only complicate and lengthen the diffraction analysis. The contribution of any edge or face is roughly proportional to its size on the enclosure. Therefore, small shell details are relatively insignificant.

Curved surfaces must be represented as one or more faceted flat planes. The example here shows the curved sides as a sequence of five flat vertical strips. The vertex nodes around the top and bottom of the shell are assigned numbers as shown below. The axis and origins are shown for each of the three views.
**Layout Editor**

This special 3D editor was created solely for the purpose of enclosure design and contains a large number of unique and sophisticated features. One of the most important aspects of the editor is to enforce the specific rules of alignment and positioning necessary for diffraction analysis. It also satisfies the need for an easy method to accurately position objects in a meaningful way. This approach is further facilitated by the use of pre-built objects for all of the required 3D entities.

The Layout Editor provides the ability to move sources around on the faces of the enclosure. Sources can be positioned on any face. Several examples of various source locations are shown here in the Eggoid shell example.

Transducers and ports are sources of radiation. Sources may be internal or external. The position of internal sources is not important for external field analysis, but the position of external sources is critically important. External sources must be positioned on the external faces of the shell for diffraction analysis.

The elements of the editor screen are shown below. In addition to the large viewing window, the editor has its own menu, toolbar, and status bar. The editor is virtually a large program itself. The main window shows the scene of the enclosure and domain. Different domains will appear depending on the selection in the enclosure model dialog. The scene view is based on a camera position and includes a perspective. The menu contains many different functions for display and editing of the scene. The toolbar contains many of the same menu items, but also additional functionality not available from the menu. The status bar at the bottom provides many readouts and editing fields for zoom, position, rotation angles, and messages.
Diffraction Analysis

When a wave strikes the surface of a hard object a reflection occurs. When a wave strikes the edge of an object a diffraction occurs. Therefore, reflection is associated with the area of a surface while diffraction is associated with the edge of a surface. These two types of phenomenon are shown here.

Here we see a point source radiating towards an object with a receiver located at another point in space. The acoustic pressure received at this location is the sum of three different types of radiation: direct, reflected, and diffracted.

The contribution of the reflection wave generated by the surface of the object is relatively easy to compute. However, the diffraction wave is highly complex. It is dependent on the angle of the source, the angle of the receiver, and the solid angle of the wedge. The pictorial above shows only a two dimensional representation. The true physical process requires complex three dimensional geometry.

In the case of a loudspeaker enclosure the transducer is generally mounted on the surface of a wall as is represented here in the pictorial. In this special case the object is an enclosure, and both the direct and reflected waves are identical. The wave striking the edge arrives from the 90 degree off-axis radiation of the source. For this reason, the off-axis response of the transducer must be represented with reasonable accuracy. All of the enclosure diffraction originates from the 90 degree off-axis transducer response.

The diffraction which occurs from the source to the first edge is known as 1st order diffraction. However, real enclosures have multiple edges. The diffracted wave leaving the first edge strikes other edges producing higher orders of diffraction. The process is shown here in the pictorial for a single path. In reality there are many paths.

The source radiates outward towards all of the edges around the baffle board. These edges then diffract and re-radiate towards any adjacent edges. This process continues forever with decreasing amplitude through each order of diffraction.

You may now be wondering what the on-axis detailed response looks like for different orders of diffraction on a simple box. Note the graph below. As one would expect the 0th order diffraction shows major errors in the response. Actually, this is the exact infinite baffle response. With 1st order diffraction the response begins to take shape but is still in error by several dB at low frequencies. With 2nd order diffraction the response becomes much more accurate. Further increases of diffraction order produce only small improvements. However, different shell designs can require much higher order diffraction analysis.

The polar graph below show the response using 4th order diffraction and a resolution of 6kHz. Using polar plots to evaluate diffraction analysis is invaluable. The response at all angles around the enclosure is obtained at once. Remarkable effects of shell design and transducer/port location can be examined in detail.
**Simulation Accuracy**

The graphs here demonstrate an assortment of simulation vs. measurement comparisons. A variety of different graphs and data illustrate the detail of the simulations.

Note difference in 100W curve pair below 20Hz. This is due to the highly distorted waveforms in the actual measurement, and the assumption of sinusoidal waveforms in the simulation. The large harmonic content cannot be represented accurately by equivalent RMS sine wave analysis at this very high level of nonlinearity.

Four curves are shown: the pair of simulations, and the pair of measurements. While they are similar the response at high frequencies is entirely different. The woofer model was not tuned to replicate the actual transducer used in the test. However dividing the curves removes the common driver response differences and leaves the Diffraction as shown in Ratio curves above.
**EnclosureShop Highlights**

- Revolutionary Diffraction Engine
- Nonlinear Acoustic Network Simulator
- Arbitrary Structural Enclosure Analysis
- Standard or Custom Enclosure Structures
- Far Field, Near Field, Pressure Analysis
- Infinite or Finite Volume Domains
- Full, Half, Quarter, Eighth Space Domains
- 360 Degree Horiz/Vert Polar Field Simulation
- New Advanced LTD Transducer Model
- Multiple Transducer Models: STD, TSL, LTD
- Chamber Transmission Line Simulation Model
- Port Transmission Line Simulation Model
- Accurate Fill Media Characterizations
- Diaphragm Shape & Profile Characterization
- Diaphragm Directivity Off-Axis Simulation
- Transducer Acoustic Mount: Para/Ser/ParaSer
- Transducer Electrical Wire: Para/Ser/ParaSer
- Nonlinear Port Simulation & Analysis
- Nonlinear Transducer Simulation & Analysis
- Multiple Transducers/Ports per Chamber
- Multiple Chambers per Enclosure
- Chambers/Ports with Media Fill & Density
- Passive & Active Drone Ports/Speakers
- Volume Object Parameter Calculators
- Area Object Parameter Calculators
- Built-in Unit Conversions on All Parameters
- Specialized 3D Graphical Object Editor
- Automatic Enclosure Shell Generator
- Prebuilt Scalable 3D Enclosure Objects
- Enclosure Shell 3D Import/Export
- Transducer/Port 3D Location Editing
- Quick Design & Reverse Speaker Utilities
- Multi Curve Transducer Parameter Derivation
- Comprehensive 2-Volume Manual Set

**System Requirements**

EnclosureShop is an extremely intensive numerical application. The program contains literally hundreds of numerical mathematics algorithms, some of which are extremely large and place very high demands on the CPU's floating point performance.

EnclosureShop will use all of the speed your processor has to offer, and probably want much more. The complexity of your design will largely determine the amount of CPU power and memory required. For high order enclosures the program can consume the entire Win32 2GB address space. For more typical simple enclosures, memory usage runs anywhere from 50-250MB.

EnclosureShop also uses extensive graphics including OpenGL® 3D display modes. For best results a 1024 x 768 video resolution is suggested with 16 bit to 32 bit color depth. High quality modern 3D video cards with hardware acceleration are strongly recommended.

**Minimum System Requirements**

- Mouse and Keyboard
- USB port for license key
- Windows® 95, 98, SE, ME, NT4, 2000, XP
- 250MB free Hard Drive space
- 64MB RAM Memory
- Pentium® II / 350 or equivalent
- Video 800 x 600 Resolution / 24 or 32 bit Color
- TrueType® or Adobe® Fonts

**Recommended System Requirements**

- Windows® 2000 or Windows® XP
- 300MB free Hard Drive space
- 256MB RAM Memory or more
- Pentium® III / 1GHz or equivalent
- Video 1024 x 768 Res / 24 or 32 bit Color
- Nvidia® OpenGL® version 1.2 drivers
- Adobe® Fonts with Adobe Type Manager®

*Note: Due to the limitations of Win9X, not all of the program's features and/or capabilities will be available in those operating systems.*