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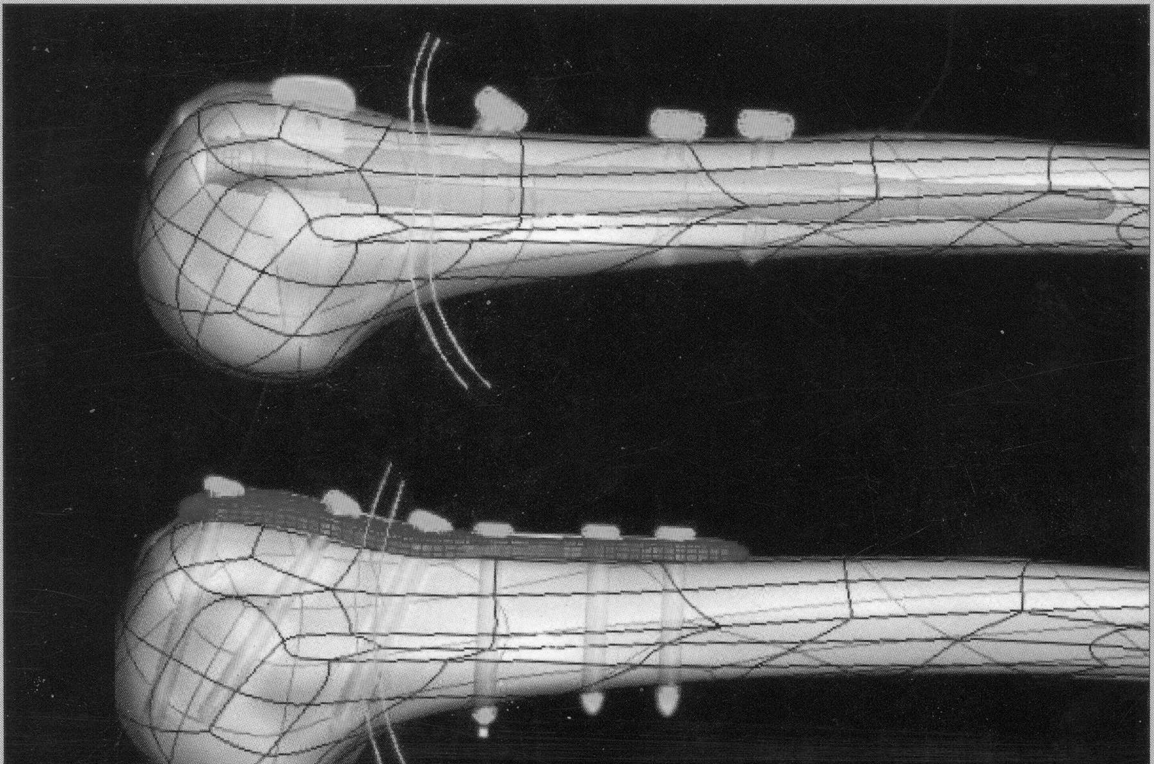
Edited by
B.H.V. Topping, G. Montero and R. Montenegro



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Cover Image: Three-dimensional CAD models of plates and nails used in the treatment of a proximal humeral fracture. This image is used with the permission of C. Pereira. For more details, see Paper 189.

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Contents

Proceedings of the Fifth International Conference
on Engineering Computational Technology,
B.H.V. Topping, G. Montero and
R. Montenegro, (Editors),
Civil-Comp Press, Stirlingshire, Scotland, 97-98.

Paper 43

Shape Design of Noise Barriers Using Evolutionary Optimization and Boundary Elements

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Keywords: noise barriers, shape optimization, genetic algorithms, boundary element method, outdoor noise propagation, noise attenuation.

Noise Barriers are a useful tool for abating road traffic noise near residential buildings. They are widely used for environmental protection on the boundaries of high traffic roads near a population nucleus in order to reduce the noise impact. A large body of research has been carried out in the last two decades focussed to the study of the diffraction of sound around barriers, predicting their performance and developing more efficient designs [1]. Different theoretical methods have been proposed. Among these, the use of the boundary element method (BEM) has been investigated to evaluate complex barrier configurations. The main advantages of the BEM over other methods based on a geometrical theory of diffraction approach are its flexibility, arbitrary shapes and surface acoustic properties can be accurately represented, and accuracy. A correct solution of the governing equations of acoustics to any required accuracy can be produced providing a boundary element size with small enough fraction of a wavelength.

Evolutionary algorithms have been widely used for shape design optimization in different engineering fields. The following can be cited: aeronautics, or solid mechanics [2]. The applications of evolutionary algorithms to the shape design in outdoor acoustics are scarce in literature. In this work the authors propose the application of a methodology based in evolutionary algorithms combined with a BE analysis technique to the optimum shape design of complex noise barriers.

The model assumes an infinite, coherent line source of sound, parallel to an infinite noise barrier of uniform cross section and surface covering along its length. In these conditions the model is two-dimensional. The study is carried out in the frequency domain. This problem is constituted by an emitting the source of fixed position, which pulses in a frequency range, and a receptor. Between the source and the receptor a generic shape obstacle (noise barrier) is situated. The shape of this barrier is modified to minimize the measured sound level in the receptor. The sound level is calculated, being known: the source and receptor position, the barrier shape, and the sound frequency. The fitness function (FF) to maximize is the difference between the sound level in the receptor with and without a barrier, respectively (insertion loss IL). In the performed analysis, a maximum limit on the effective height (h) of the barrier is imposed. Because of the critical performance of sound barriers associated to the h, shape optimization is desired for a maximum constant h. This maximum h value originates a trapezoidal search space and a transformed domain is achieved from cartesian barrier domain in order to make the shape design optimization easier. Performing the shape optimum design considering various frequencies is more accurate with respect to the real sound propagation problem. It also avoids possible problems associated with one single frequency optimization, that could guide the solutiona to false IL values resulting from frequencies nearer to eigenfrequencies associated with the BEM evaluation.

Three armed-shape barriers are taken into account to validate this methodology. The BEM elements used are parabolic and only the barrier surface is discretized with these elements, since the used fundamental solution satisfies the boundary conditions on the ground surface. A maximum element length not greater than $\lambda/4$ (λ being the wavelength) is necessary to obtain an appropriately accurate solution. A total of five frequencies corresponding to the octave centre band (63, 125, 250, 500 and 1000 Hz.) are taken into account in the fitness function.

First, an inverse problem has been handled; being the reference IL values those belonging to a previously defined barrier. The presented methodology allows the accurate fit of both IL curves (fitness function value of 8e-4), even in terms of one-third octaves spectra (63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800 and 1000 Hz.) and to locate the original barrier shape. Then, shape optimization is accomplished by forcing the IL reference curve to increase its performance, both in 15% and 30%, respectively, and to obtain their corresponding shape design barriers. The greater the search improvement, the worst the FF obtained (harder optimization work). However, the results obtained succeed in accomplishing the imposed requirements with acceptable FF values (0.09 and 1.95 respectively). Results are detailed in terms of IL values and barrier shape designs, numerically and graphically.

A successful methodology based on coupling evolutionary optimization and the boundary element method has been presented for sound attenuation barriers. Concretely, shape optimum design has been carried out for three armed barriers. An inverse problem is solved and successive improved shape barriers are obtained, both for 15% and 30% better performance in terms of IL reference points.

References

[1] T. Ishizuka, K. Fujiwara, "Performance of noise barriers with various edge shapes and acoustical conditions", Applied Acoustics 65, pp. 125-141, 2004.

[2] T. Burczynski, A. Osyczka (Eds.), "IUTAM Symposium on Evolutionary Methods in Mechanics", Solid Mechanics and its Applications, 117, Kluwer Academic Publishers, 2004.

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Shape Design of Noise Barriers Using Evolutionary Optimization and Boundary Elements

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Abstract

Evolutionary algorithms have been widely used for Shape Design Optimization. It is a problem handled in many fields of science and engineering, e.g., aeronautics or solid mechanics. In this work we propose the application of this methodology based on evolutionary algorithms, to the shape design of a noise barrier. Noise Barriers are widely used for environmental protection in the boundaries of high traffic roads near population nucleus in order to reduce the noise impact. A bidimensional problem of sound propagation in the frequency domain is handled. This problem is constituted by an emitting source of fixed position, which pulses in a frequency range, and a receptor. Between the source and the receptor a generic shape obstacle (noise barrier) is situated. The shape of this barrier is modified to minimize the measured sound level in the receptor. The sound level is calculated using the Boundary Element Method (BEM), being known: the source and receptor position, the barrier shape, and the sound frequency. The objective function to maximize is the difference between the sound level in the receptor with and without barrier, respectively (insertion loss IL). In the performed analysis, a maximum limit to the effective height of the barrier is imposed. First, an inverse problem using the IL barrier curve as reference is successfully performed. Finally, improved performance barriers are obtained, showing the potential of the exposed technique.

Keywords: noise barriers, shape optimization, genetic algorithms, boundary element method, outdoor noise propagation, noise attenuation.

1 Introduction

Barriers are a useful tool for abating road traffic noise near to residential states. A large body of research has been carried out in the last two decades focussed to the study of the diffraction of sound around barriers, predicting their performance and developing more efficient designs. Different theoretical methods have been proposed. Among these, the use of the Boundary Element Method (BEM) has been investigated by several authors (see e.g. [1-4]) to evaluate complex barrier configurations. Two of the authors of the present work have developed a Boundary Element model for the study of the efficiency of single or multiple edge noise barriers [5,6]. The main advantages of BEM over other methods based on a geometrical theory of diffraction approach are its flexibility -arbitrary shapes and surface acoustic properties can be accurately represented- and accuracy – a correct solution of the governing equations of acoustics to any required accuracy can be produced providing a boundary element size with small enough fraction of a wavelength-.

Evolutionary algorithms have been widely used for Shape Design Optimization in different engineering fields. The following can be cited: aeronautics (e.g. by means of approximation curves as Bezier splines, for the airfoil design) [7-10], or solid mechanics (e.g. using Finite Element Method or Boundary Element Method, by means of discrete elements or Beta-Spline approximations) [11,12]. To the author's knowledge, the applications of Genetic Algorithms (GA) to the shape design in outdoor acoustics are scarce in literature, and some of these studies have considered active control to perform the optimization [13,14] instead of shape modification [15].

In this work the authors propose the application of a methodology based in evolutionary algorithms combined with a BE analysis technique to the optimum shape design of complex noise barriers. The model assumes an infinite, coherent line source of sound, parallel to an infinite noise barrier of uniform cross section and surface covering along its length. In these conditions the model is two-dimensional. The study is carried out in frequency domain. Once a maximum limit to the barrier effective height is fixed, the objective function to maximize is the insertion loss (IL), that is the difference between the sound level in the receptor with and without barrier, respectively.

The structure of the paper is as follows: In section 2 the handled acoustic problem of sound attenuation with barriers is described. Section 3 exposes the methodology considering evolutionary optimization and numerical issues. Later, section 4 shows the results and discussion. Finally, the paper ends with the conclusions section.

2 Problem Definition: Acoustic Attenuation with Barriers

The configuration considered along this paper is shown in Figure 1. It is a two-dimensional model which assumes an infinite, coherent mono-frequency source of sound, situated parallel to an infinite noise barrier of uniform cross section. This barrier is situated on a flat plane (ground) of uniform admittance. In this paper, the ground and all the surfaces of the barrier are perfectly reflecting (zero admittance).

The effective height (h) of a barrier is the most important factor affecting its acoustic efficiency. Therefore, in the present investigation, all the barrier profiles have been assumed with the same effective maximum height (h = 3 m). They were formed with three arms, different slope and t = 0.1 m. thickness. The barrier projection to the ground is constant in all cases (b = 1 m). In this general configuration, common T-, Y- and arrow-profile barriers are included. Finally, the source and receiver are placed in the ground surface at d = 10 and r = 50 m from the center line of the barrier, respectively (receiver on the opposite side of the source).

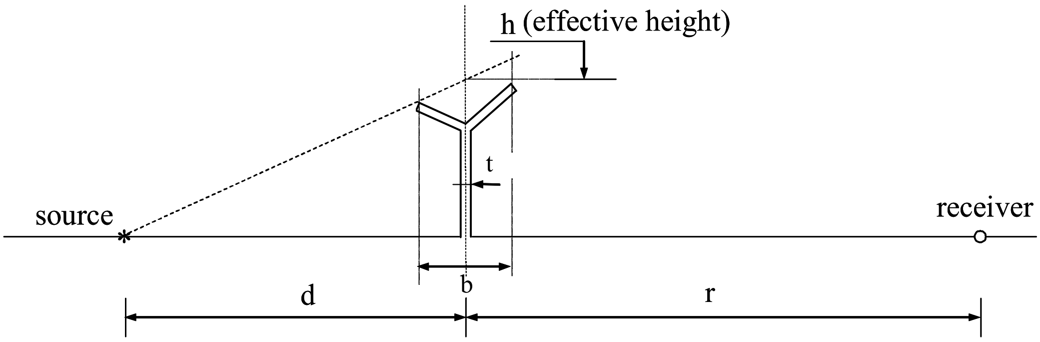

Figure 1. Two-dimensional configuration studied. Generic geometry of a three-arm barrier. All boundaries are perfectly reflecting.

Results are given in terms of *insertion loss* (*IL*), defined as:

$$IL = -20\log\left(\frac{P_S}{P_B}\right) dBA \tag{1}$$

and calculated at one-third octave band spectra, where P_B and P_S is the acoustic pressure at the receiver for the given source position with and without the presence of the barrier respectively. This parameter is an accepted estimation of the acoustic efficiency of the analyzed profile.

3 Methodology

Shape optimization is carried out using genetic algorithms coupled to a boundary element program for exterior acoustic problems. The objective is to minimize the fitness function (*FF*) which can be defined for each analyzed barrier profile as:

$$FF = \sum_{i}^{NFrecs} \left(IL_i - IL_i^R\right)^2 \tag{5}$$

that takes into account the differences among the reference *IL* values (IL^R) and the *IL* values of the candidate solution to the power of two for each octave band frequency. Performing the shape optimum design considering various frequencies is more accurate with respect to the real sound propagation problem, and also allows surpassing the possible problems associated with one single frequency optimization, that could guide to false IL values due to frequencies nearer to eigenfrequencies associated to the BEM evaluation [16].

The barrier profile is modelled from η_1, ξ_2, η_2, and η_3, which are the design variables. Because of the critical performance of sound barriers associated to the effective height (h), shape optimization is desired for a constant h. This h value originates a trapezoidal search space (right part of Figure 2) and a transformed domain is achieved (left part of Figure 2) from cartesian barrier domain in order to make the shape design optimization easier.

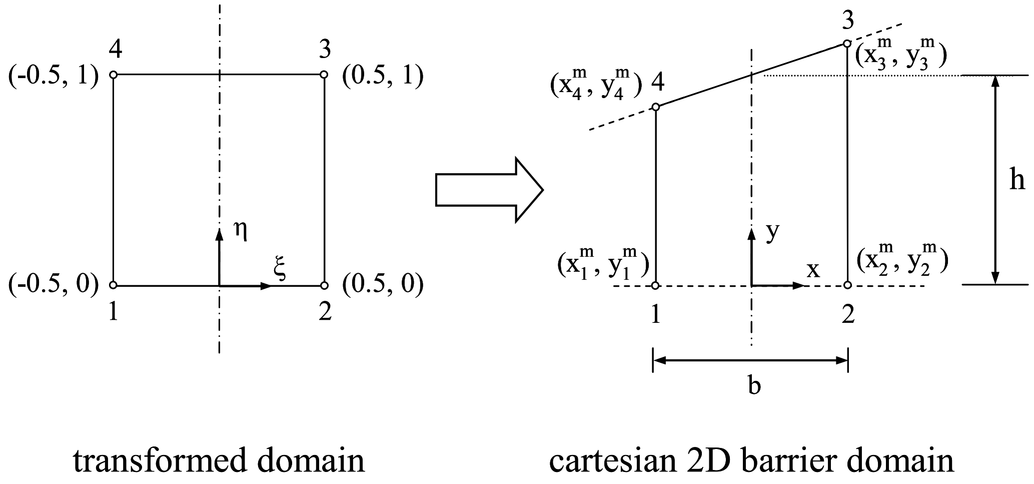

Figure 2. Two-dimensional coordinate systems

The transformation is shown in Figure 2, where is easy to see that:

$$\begin{aligned} x_1^m &= -\tfrac{b}{2} \quad & y_1^m &= 0 \\ x_2^m &= \tfrac{b}{2} \quad & y_2^m &= 0 \\ x_3^m &= \tfrac{b}{2} \quad & y_3^m &= h\,(1+\tfrac{1}{2}\tfrac{b}{d}) \\ x_4^m &= -\tfrac{b}{2} \quad & y_4^m &= h\,(1-\tfrac{1}{2}\tfrac{b}{d}) \end{aligned} \tag{2}$$

To each point (ξ_i , η_i) in the transformed domain corresponds one point (x_i, y_i) in cartesian domain. The most convenient form of establishing this relation is shown in Equation (3).

$$\begin{Bmatrix} x_i \\ y_i \end{Bmatrix} = \phi_1(\xi_i,\eta_i)\begin{Bmatrix} x_1^m \\ y_1^m \end{Bmatrix} + \phi_2(\xi_i,\eta_i)\begin{Bmatrix} x_2^m \\ y_2^m \end{Bmatrix} + \phi_3(\xi_i,\eta_i)\begin{Bmatrix} x_3^m \\ y_3^m \end{Bmatrix} + \phi_4(\xi_i,\eta_i)\begin{Bmatrix} x_4^m \\ y_4^m \end{Bmatrix} \tag{3}$$

where

$$\begin{aligned} \phi_1 &= (\tfrac{1}{2}-\xi)(1-\eta) \\ \phi_2 &= (\tfrac{1}{2}+\xi)(1-\eta) \\ \phi_3 &= \eta\,(\tfrac{1}{2}+\xi) \\ \phi_4 &= \eta\,(\tfrac{1}{2}-\xi) \end{aligned} \tag{4}$$

are the shape functions in terms of coordinates in the transformed domain:

$$-0.5 \leq \xi \leq 0.5, -1 \leq \eta \leq 1.$$

The analyzed barrier profile is determined from 3 points defined in transformed domain (Figure 3), where the coordinates ξ_1 and ξ_3 were established 'a priori' (-0.5 and 0.5, respectively).

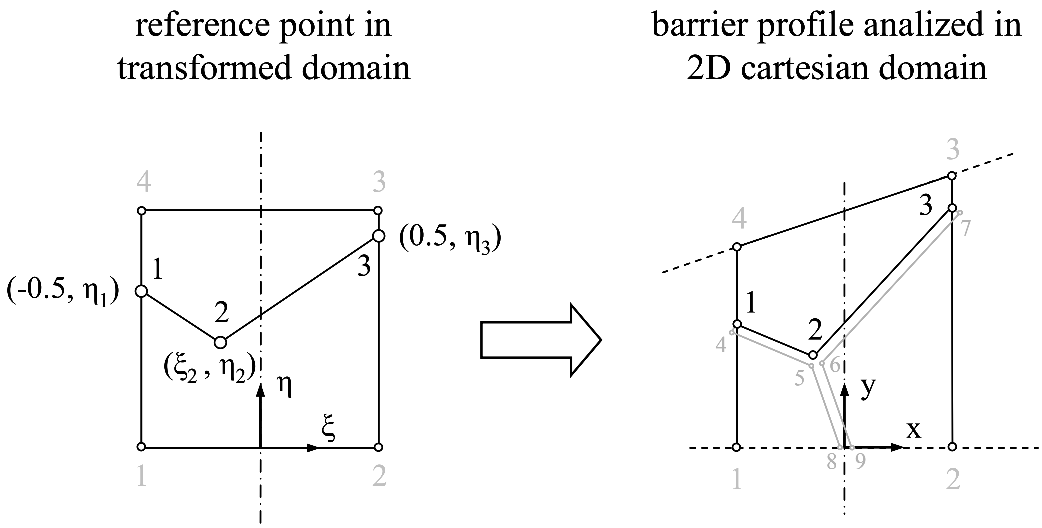

Figure 3. Process to obtain the 3 arms-profile barrier.

The coordinates x, y of points 1,2 and 3 are obtained using Equation (3). The cartesian coordinates of the rest of corners of the barrier (4,5,6,7,8,9) represented in Figure 3, can be calculated using simple geometric operations, considering that each arm thickness is perpendicular to its length.

With this geometry and for a given source position, the boundary element program calculates the acoustic pressure at the receiver position. The used boundary elements are parabolic and only the barrier surface is discretized with these elements, since the used fundamental solution satisfies the boundary conditions on the ground surface. A maximum element length not bigger than λ / 4 (being λ the wavelength) is necessary to obtain an appropriate accurate solution.

4 Results

A steady-state genetic algorithm, replacing the two worst individuals, has been used with 3% uniform mutation rate, uniform crossover and a population size of 100 individuals. Codification of the four design variables has been carried out with eight precision bits with the Standard Binary Reflected Gray Code [17], which has shown good performance over the standard binary code in structural optimum design, both in single [18] and multiobjective optimization [19]. Four independent executions have been considered in each problem with a total number of fitness function evaluations of forty thousand as stop criterion. A total of five frequencies corresponding to the octave center band (63, 125, 250, 500 and 1000 Hz.) are taken into account in the fitness function.

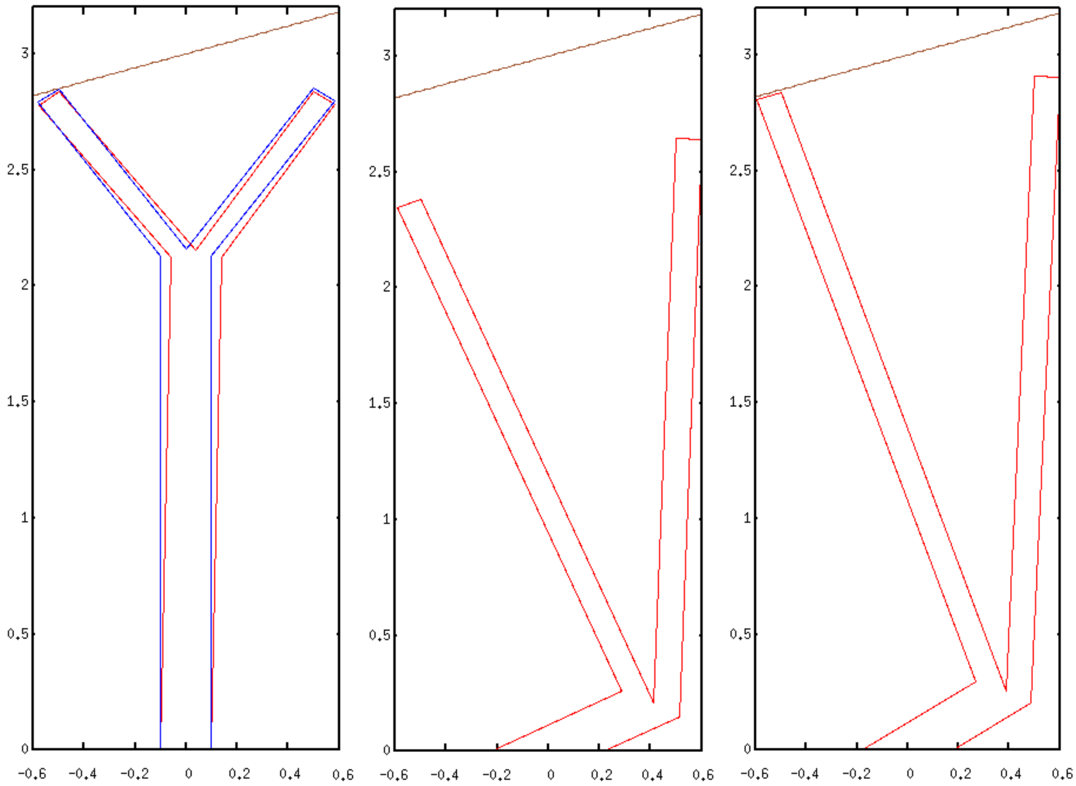

Figure 4: Sound Barriers Shapes corresponding to the solutions: inverse (left), 15% improved (middle) and 30% improved (right), in red; and initial reference, in blue.

Frequ. (Hz)	Original Reference IL	Inverse Solution IL	Reference Improved 15% IL	Best Solution 15% IL	Reference Improved 30% IL	Best Solution 30% IL
63.0	**-3.97288**	**-3.97391**	**-4.56881**	**-4.42546**	**-5.16474**	**-5.45912**
80.0	-3.18012	-3.17403		-4.69769		-2.55566
100.0	-6.29461	-6.49776		-2.00095		-5.89571
125.0	**-6.98294**	**-7.00249**	**-8.03038**	**-8.21023**	**-9.07782**	**-8.90730**
160.0	-10.26678	-10.2227		-7.41861		-7.58246
200.0	-8.91329	-8.81003		-7.91441		-8.78388
250.0	**-8.93007**	**-8.94653**	**-10.26958**	**-10.1438**	**-11.60909**	**-11.5118**
315.0	-8.73366	-8.80478		-9.24486		-9.79365
400.0	-12.75769	-12.5218		-9.11673		-10.3124
500.0	**-11.04924**	**-11.0404**	**-12.70663**	**-12.5759**	**-14.36401**	**-13.1092**
630.0	-13.59727	-13.5609		-14.35398		-16.2488
800.0	-15.49830	-15.7207		-16.0716		-15.4453
1000.0	**-16.14999**	**-16.1590**	**-18.57249**	**-18.5122**	**-20.99499**	**-20.4901**
FF.Value		*0.00081*		*0.08946*		*1.95478*

Table 1: Detailed Numeric Solutions, with IL at different frequencies and Fitness Function (FF) values.

Nodal Coordinates	$\eta 1$	$\xi 2$	$\eta 2$	$\eta 3$
Reference Solution	1.00000	0.00000	0.70000	0.90000
Inverse Solution	0.99609	0.03906	0.69531	0.89453
Improved Solution 15%	0.82422	0.41406	0.00391	0.82812
Improved Solution 30%	0.99609	0.38672	0.01953	0.91797

Table 2: Detailed Points Coordinates in Transformed Domain corresponding to Reference, Inverse and Improved Solutions.

First, an inverse problem has been handled; being the reference IL values those belonging to a previously defined barrier (second column of Table 1). Their design coordinates are exposed in Table 2 (reference solution) and the barrier shape is represented graphically in blue in the left part of Figure 4.

The best obtained solution has a fitness function value of 8e-4, being their IL values, coordinates and shape represented in third column of Table 1, third row of Table 2 and red figure of left part of Figure 4, respectively. The comparison between the IL curves of both reference and best inverse solution with a precision of one-third octave band spectra (63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800 and 1000 Hz) is also shown in Figure 5. The presented methodology allows to fit accurately both curves and to locate the original barrier shape.

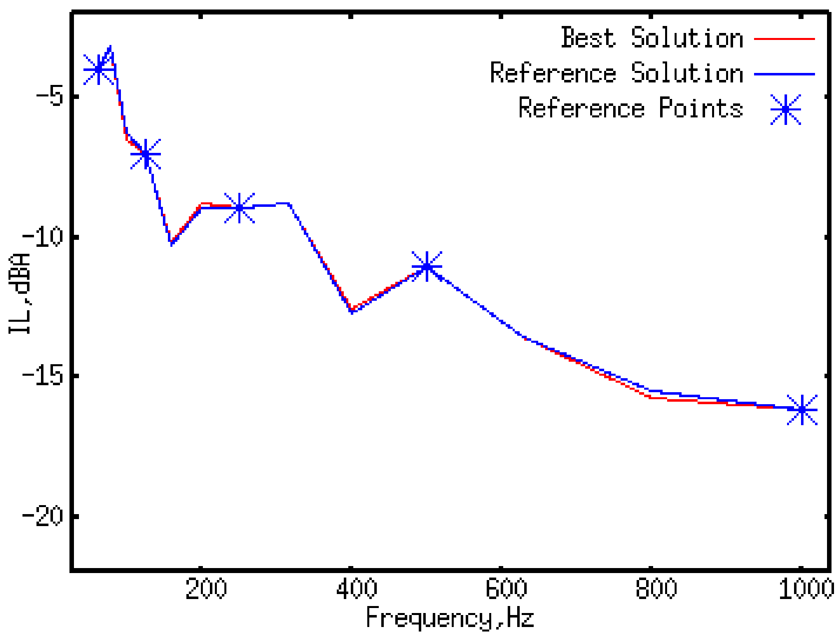

Figure 5: Comparison of IL curves of Reference Solution and Best optimized Solution (one-third octave band in graphic representation).

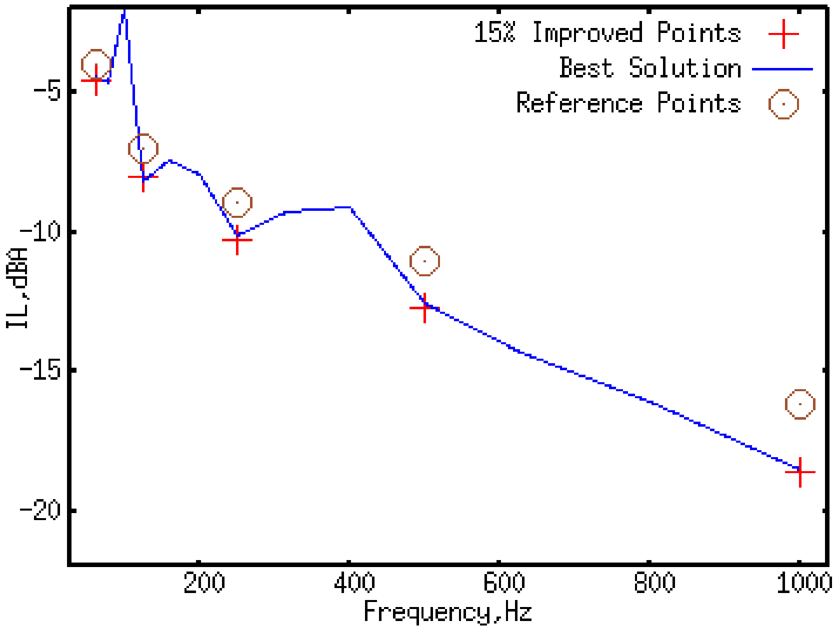

Figure 6: Comparison of IL curves of Reference Points, 15% improved Points and 15% Improved Best Solution (one-third octave band in graphic representation).

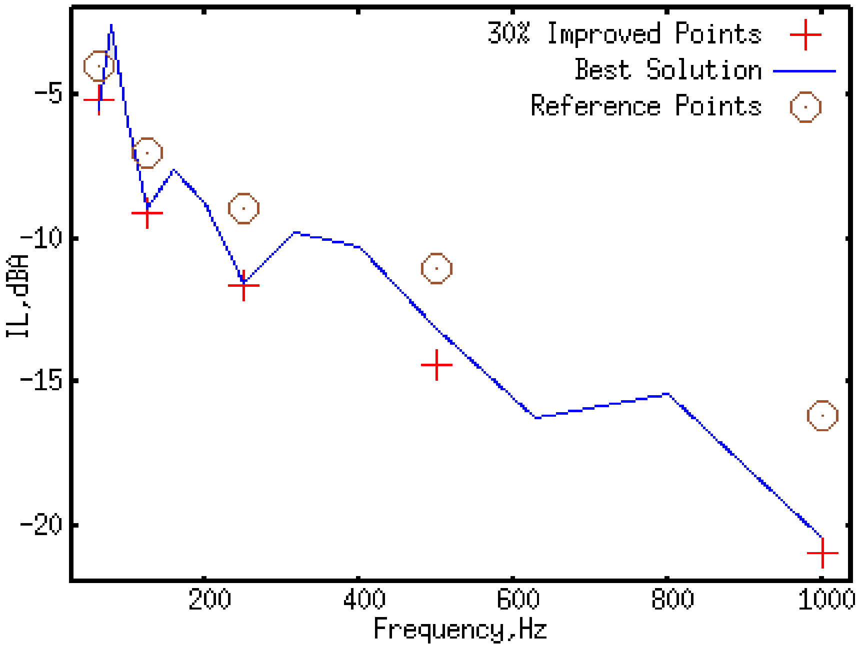

Figure 7: Comparison of IL curves of Reference Points, 30% improved Points and 30% Improved Best Solution (one-third octave band in graphic representation).

Shape optimization is accomplished by forcing the IL reference curve to increase its performance, both in 15 and 30%, respectively, and to obtain their corresponding shape design barriers. The best solution shape design barriers obtained are represented graphically in Figure 4, where its middle part corresponds to the 15% improved shape and the right part to the 30% improved shape. The upper inclined brown line limits the effective height constraint in the three parts of Figure 4. The IL numerical values of each solution are detailed in Table 1, where the bold type is associated to the reference values taken into account in the fitness function (FF). The last row shows also the FF value of the best solution in each case.

The best FF value corresponds to the inverse problem (8e-4), and the worst to the 30% improved solution (1.95). Therefore, the greater the searched improvement, the worst the FF obtained (harder optimization work). In Table 2 all the design coordinate values in transformed domain are shown. Figures 6 and 7 represent the Reference Points (corresponding to the first real barrier with circles), the Improved Reference points (with crosses) and the IL curve of the obtained barrier with one-third octave spectra (continuous line).

5 Conclusions

A successful methodology based on coupling evolutionary optimization and boundary element method has been presented for sound attenuation barriers. Concretely, shape optimum design has been carried out for three armed barriers. An inverse problem is solved and successive improved shape barriers are obtained, both for 15 and 30% better performance in terms of IL reference points.

Further research will involve greater number of IL points included in the fitness function evaluation and their influence in the accuracy of the obtained solution and the associated increased calculation time.

References

[1] R. Seznec. “Diffraction of sound around barriers: use of the boundary element technique”, Journal of Sound and Vibration, 73, 195-209, 1980.

[2] D.C. Hothersall, S.N. Chandler-Wilde, M.N. Hajmirzae. “Efficiency of single noise barriers”, Journal of Sound and Vibration, 146(2), 303-322, 1991.

[3] D.C. Hothersall, D.H. Crombie, S.N. Chandler-Wilde. “The performance of T-profile and associated noise barriers”, Applied Acoustics, 32, 269-287, 1991.

[4] D.H. Crombie, D.C. Hothersall. “The performance of multiple noise barriers”, Journal of Sound and Vibration, 176(4), 459-473, 1993.

[5] F. Perdomo, J.J. Aznárez, O. Maeso. “Application of BEM for evaluating strategies to abate noise near highways”, Revista de Acústica, 23(1,2), 13-19, 2002 (in spanish).

[6] O. Maeso, J.J. Aznárez. “Strategies for reduction of acoustic impact near highways. An application of BEM”. University of Las Palmas of GC. ISBN: 84-689-0340-X, 2005 (in spanish).

[7] G. Winter, R. Berriel, P. Cuesta, B. Galván, D. Greiner, I. Sánchez, “Improving performance of genetic algorithms in shape optimization”, ECCOMAS Computational Fluid Dynamics, John Wiley & Sons, 209-214, 1998.

[8] J.F. Wang, J. Periaux, M. Sefrioui, “Parallel evolutionary algorithms for optimization problems in aerospace engineering”, Journal of Computational and Applied Mathematics, 149 (1): 155-169 Dec 2002.
[9] A. Oyama, M.S. Liou, S. Obayashi, “Transonic axial-flow blade optimization: Evolutionary algorithms / three-dimensional Navier-Stokes solver”, Journal of Propulsion and Power 20 (4): 612-619 Jul-Aug 2004.
[10] S. Nagarathinam, L. Gonzalez, E. Whitney, S. Karkenahalli, J. Periaux, “Aerodynamic Optimisation using a Robust Evolutionary Algorithm and Grid-Free Flowsolver”, 44th AIAA Aerospace Sciences Meeting and Exhibit (2006), AIAA Paper 2006-0052.
[11] W. Annichiarico, M. Cerrolaza, “Structural shape optimisation 3D finite-element models based on genetic algorithms and geometric modelling”, Finite Elements in Analysis and Design, Vol. 37 No.5, 403-15, 2001.
[12] T. Burczynski, A. Osyczka (Eds.), “IUTAM Symposium on Evolutionary Methods in Mechanics”, Solid Mechanics and its Applications nº 117, Kluwer Academic Publishers, 2004.
[13] S.J. Elliott and P.A. Nelson, “Active Noise Control,” IEEE Signal Processing Magazine, Vol 10-4, 12-35, 1993.
[14] K.S. Tang, K.F. Man, S. Kwong, P.J. Fleming, “GA Approach to Multiple Objective Optimization for Active Noise Control”, Algorithms and Architectures for Real-Time Control 95, 13-19, Belgium, 31 May-2 Jun 1995.
[15] E.A. Divo, A.J. Kassab, M.S. Ingber, “Shape optimization of acoustic scattering bodies”, Engineering Analysis with Boundary Elements, 27, 695-703, 2003.
[16] T. Ishizuka, K. Fujiwara, “Performance of noise barriers with various edge shapes and acoustical conditions”, Applied Acoustics 65, 125-141, 2004.
[17] D. Whitley, S. Rana, R. Heckendorn, “Representation Issues in Neighborhood Search and Evolutionary Algorithms”, in Eds: D. Quagliarella, J. Périaux, C. Poloni, G. Winter, Genetic Algorithms and Evolution Strategies in Engineering and Computer Science, John Wiley & Sons, 39-57, 1997.
[18] D. Greiner, G. Winter, JM. Emperador. “Optimising Frame Structures by different strategies of genetic algorithms”, Finite Elements in Analysis and Design, Elsevier, 37(5), 381-402, 2001.
[19] D. Greiner, G. Winter, JM. Emperador, B. Galván. “Gray Coding in Evolutionary Multicriteria Optimization: Application in frame structural optimum design”, Eds: C. Coello, A. Hernández-Aguirre, E. Zitzler, Evolutionary Multicriterion Optimization 2005, Lecture Notes in Computer Science 3410, 576-591, 2005.