$19^{th}$ INTERNATIONAL CONGRESS ON ACOUSTICS
MADRID, 2-7 SEPTEMBER 2007

# From MPA to Strategically Designed Absorbers Using Solid Freeform Fabrication Techniques

PACS: 43.55.Ev

Godbold, Oliver[1]; Kang, Jian[2]; Soar, Rupert[1]; Buswell, Richard[3]
[1]Wolfson School Of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, United Kingdom; o.b.godbold@lboro.ac.uk, r.c.soar@lboro.ac.uk
[2]School of Architecture, Arts Tower, University of Sheffield, Western Bank, Sheffield, S10 2TN, United Kingdom; j.kang@sheffield.ac.uk
[3]Department of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, United Kingdom; r.a.buswell@lboro.ac.uk

## ABSTRACT

This paper reports on current work investigating the development of an alternative single material, broad frequency acoustic resonator by applying geometric changes to the cavity, without using sub-millimetre features. The inclusion of internal features such as fins and perforated layers are considered. The manufacture of these complex components is possible directly from CAD data via relatively new manufacturing techniques collectively know as Rapid Manufacturing. The technology has limitations for this application which are explored in the paper. Significant resistance however, has been achieved without the use of resistive materials or sub-millimeter features and significant improvements in peak absorption and increases in bandwidth over ¾ of an octave have been attained. These findings are currently being utilised in the development of a broad frequency absorber.

## INTRODUCTION

### Micro perforated panels

The Micro Perforated Absorber (MPA) is a development of the Helmholtz type resonant absorber. Its structure addresses the problem of limited energy dissipation associated with traditional resonator constructions, to achieve broadband acoustic absorption. This has only previously been possible thorough the use of additional resistive or porous materials. The exclusion of these separate material types is becoming more desirable as they are hard to clean; presenting hygiene issues and can also release fibres into the air. Their inherent fragility affects durability, particularly in physically harsh surroundings. They can also introduce environmental issues, principally their recyclability [1].

The MPA achieves significant energy losses through viscous effects within the resonator neck. This is due to the neck dimensions being comparable to the thickness of the viscous boundary layer of air. However accurate fabrication of sub millimetre features, which are often used in a MPA can present manufacturing difficulties [2,3], restricting the material types that can be used [4]. The high viscous resistance of the sub-millimetre holes is sufficient to enable broadband absorption of up to 3 or 4 octaves. Alternative constructions incorporating lateral elongation of the resonator neck [5,6] have demonstrated similar absorption properties but also possess complexity in construction.

### Potential of cavity modifications

One successful method of adding acoustic resistance to traditional resonators involves the incorporation of porous resistive materials within the cavity. This method has been well studied both analytically and experimentally e.g. [7,8]. There has been limited work reporting on alternative methods of adding cavity resistance. The influence of the cavity shape has been explored, comparing the energy dissipation in simple horn and bulb shaped cavities [9]. Theoretical analysis of fractal cavities has related losses to the perimeter area within the cavity

[10]. Most cavity shape analysis, however, has been concerned with the effects on the resonant frequency [11,12].

The losses that are commonly associated with an empty resonator are predominately neck related. These effects of radiation and viscous resistance could be exploited within the resonator cavity, to add resistance through modifications to the shape of the cavity or the incorporation internal features. If significant resistance could be achieved, an alternative broadband fibreless absorber could be conceived, without a dependency on the production of accurate sub-millimetre holes. Increasing the surface area the oscillating air within the cavity has to travel over by adding internal surfaces within the cavity, and impeding the motion of air by incorporating restrictions, are investigated in this paper.

**Selective laser sintering**

The addition of intricate internal cavity modifications does not necessarily require the fabrication of sub millimetre features, however the relative complexity of the intended geometries would require an unfeasible level of manufacturing effort using traditional techniques. This issue has be addressed through the use of a relatively new manufacturing technique know as Selective Laser Sintering (SLS). This process is one of many additive manufacturing technologies often referred to as Solid Freeform Fabrication or Rapid Prototyping. These processes allow the additive fabrication of solid three dimensional parts by growing slices of material from the bottom to the top of the part, directly from computer-driven data [13]. The computer-driven nature of SFF technologies allows parts to be produced directly, with minimal human interaction and offers new levels of design freedom.

SLS is a powder based process that requires no separate support structures to be fabricated, allowing parts with complex ‘floating’ internal features to be produced. It uses a scanning laser beam to selectively solidify a single layer of material. The build material is a polymer coated powder, held just below the polymer’s melt temperature and melted using additional energy supplied by the laser. Once a layer has been solidified the build platform is lowered by the depth of one layer and recoated with powder using a counter rotating roller, as illustrated in Figure 1. All the test parts were produced using a nylon based material. The availability and ease of sample production offered by this process invites an empirical approach to this research.

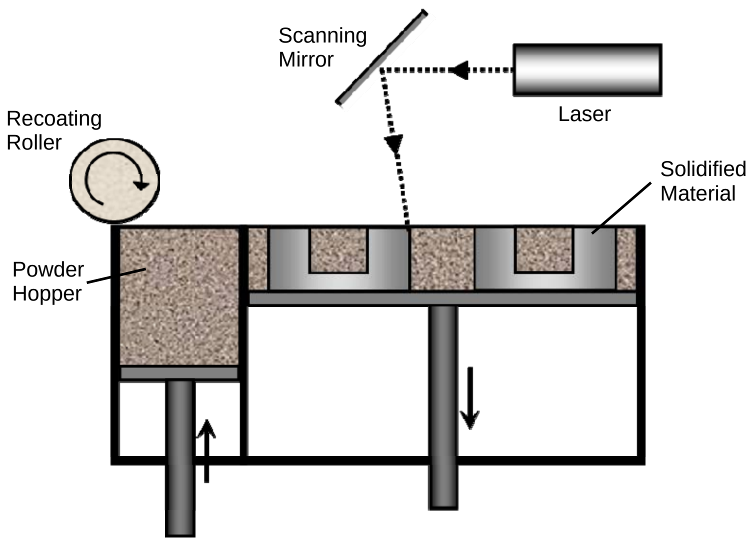


Figure 1. – Selective Laser Sintering process schematic.

**METHODOLOGY**

A standard resonator geometry design was chosen to base all tests samples on, allowing direct comparison between the different cavity modifications. A design tuned to 300Hz using a 15mm diameter neck, 15mm neck length and a cavity volume of 219772 $mm^3$ was chosen to allow easy powder removal and to achieve a sample size suitable for the available standing wave test equipment. The measurement of the acoustic absorption properties of each test sample was carried out in accordance with BS EN ISO 10534-2 [14], using a two microphone transfer function method and a computer data acquisition unit.

The effect of increased cavity surface area was explored through the addition of thin, concentric fins within the cavity, as illustrated in Figure 2a and 2b. The spacing between the fins was varied, increasing the area over which the oscillating air has to travel. Standard equations for steady state specific flow resistance for a single channel indicate that viscous effects may be further increased as the spacing between adjacent fins decreases [15]. The fins were orientated in the vertical direction to reflect the major axis of air travel and do not occupy the upper section of the cavity where two dimensional flow occurs as it leaves the neck, ensuring they interact with the planar air propagation as expected within a cavity with a length to diameter ratio greater than 0.1 [11]. To maintain constant volume between test samples, the cavity diameter was increased to reflect the added volume of the internal fins.

The effect of adding features to restrict the motion of air within the cavity was explored through the addition of a perforated layer within cavity as illustrated in Figure 2c and 2d. The effects of varying the hole parameters, and the location of the layer were investigated. Hole size was varied, with the lower hole diameter limit set within the machine capabilities at 1mm. Perforation percentage was also varied with an upper limit of 10% set to ensure the discs not be considered acoustically transparent. These sample discs were placed 15mm (one neck diameter) down from the orifice to avoid the area of two dimensional air flow [2], however the position of one disc was varied to ascertain the effects of perforation position.

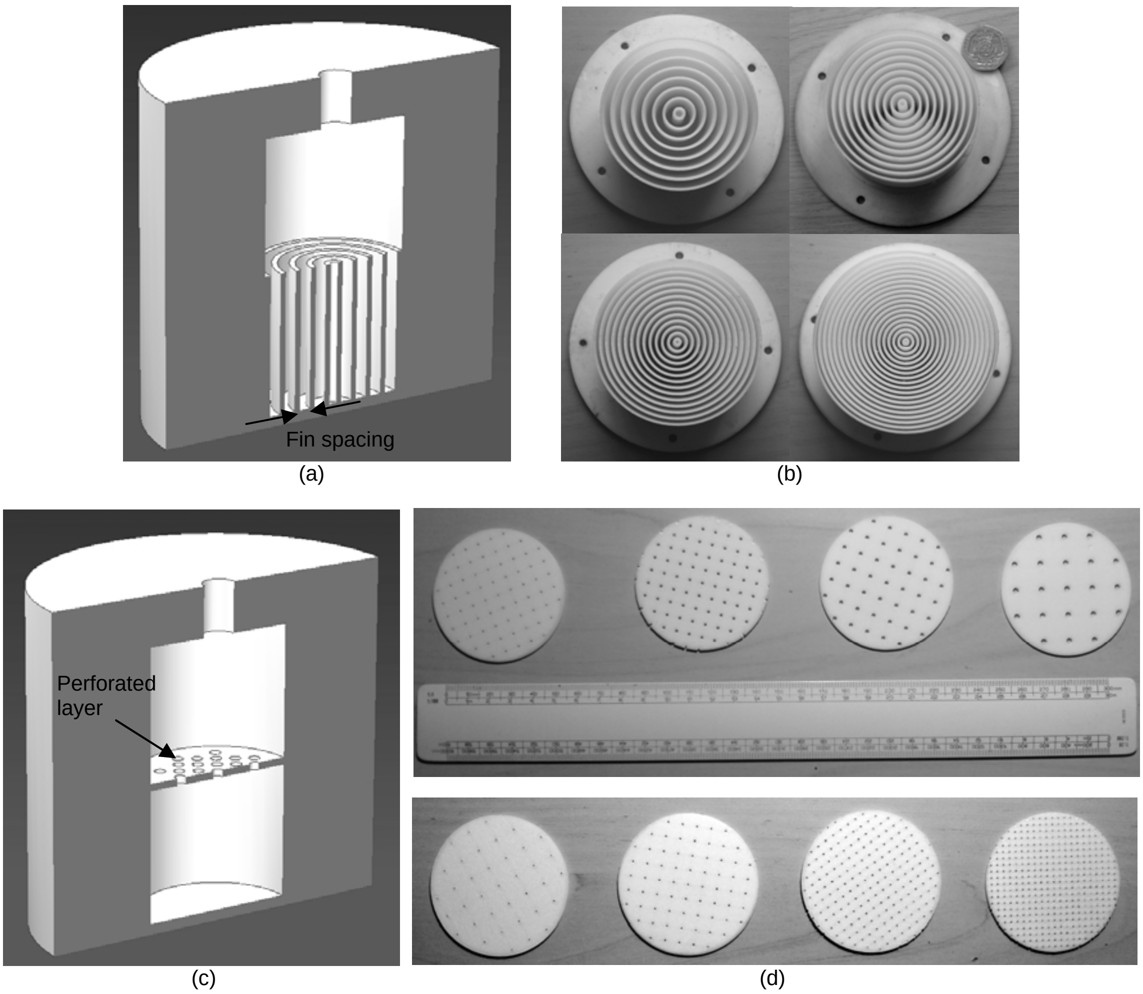


Figure 2. – Internal cavity geometries: (a) Internal fins CAD view, (b) fabricated fins, (c) perforated layer CAD view, (d) fabricated perforations.

## RESULTS AND DISCUSSIONS

The absorption readings were acquired at a resolution of 3.125 Hz and in each case were plotted on graphs with a low to mid frequency range up to 1000Hz, and logarithmic 1/3 octave scale increments. The absorption results for the internal fins are shown below in Figure 3. The results depicting the hole size, perforation percentage and perforation position for the internal perforations are shown below in Figures 4, 5 and 6 respectively.

The inclusion of internal fins shows increased peak absorption over a broader range than an empty cavity. The different spacings show small improvements as the spacing decreases, with the most significant increase in absorption characteristics coming from the fins with the minimum spacing that could feasibly be fabricated (1mm). This particular result showed a 0.3 improvement in the maximum absorption coefficient, and a 1/3 octave increase in bandwidth at an absorption coefficient value of 0.4. These results can be attributed to an increase in resistance, with a noticeable trend towards higher resistance values as the spacing between fins is reduced.

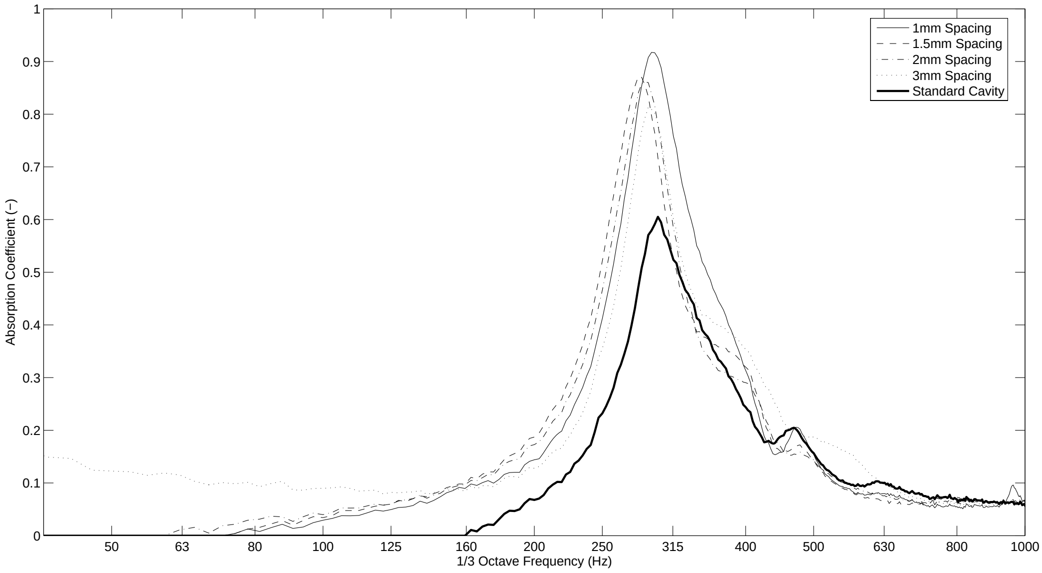


Figure 3. – Absorption coefficient with internal fins.

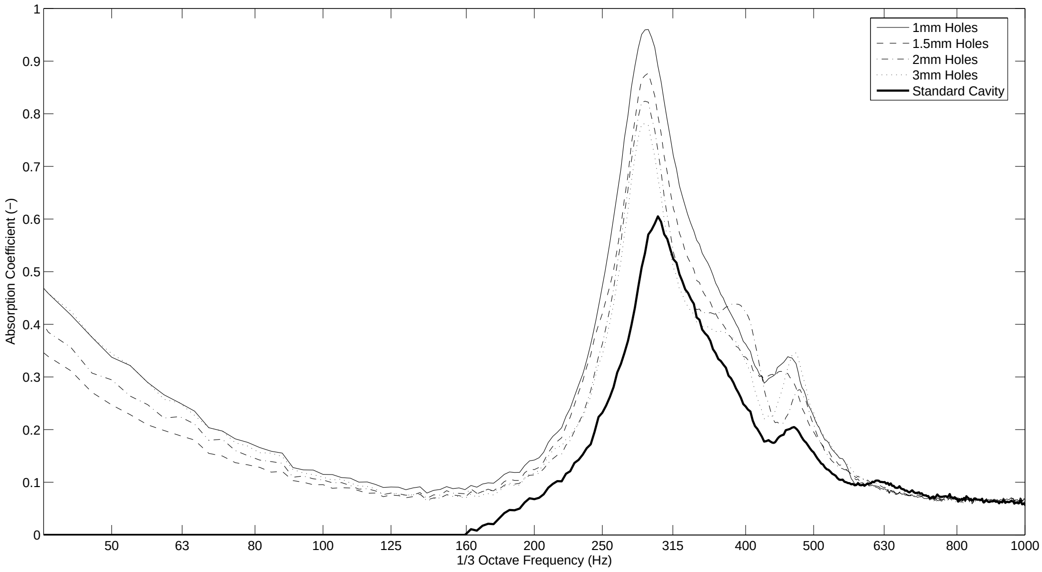


Figure 4. – Absorption coefficient with internal perforations (5% perforation); variable hole size.

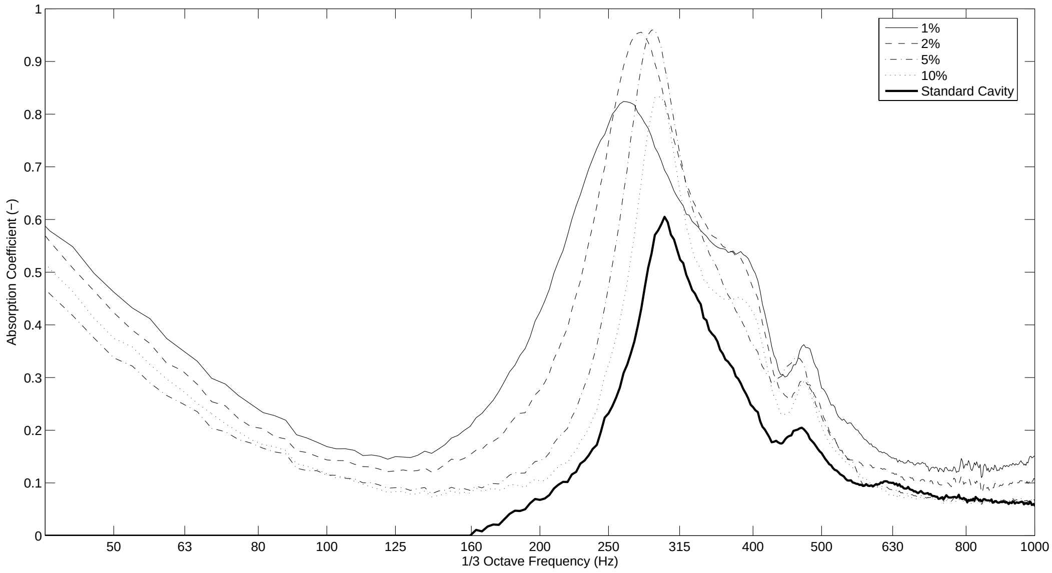

Figure 5. – Absorption coefficient with internal perforations (1mm holes); variable perforation percentage.

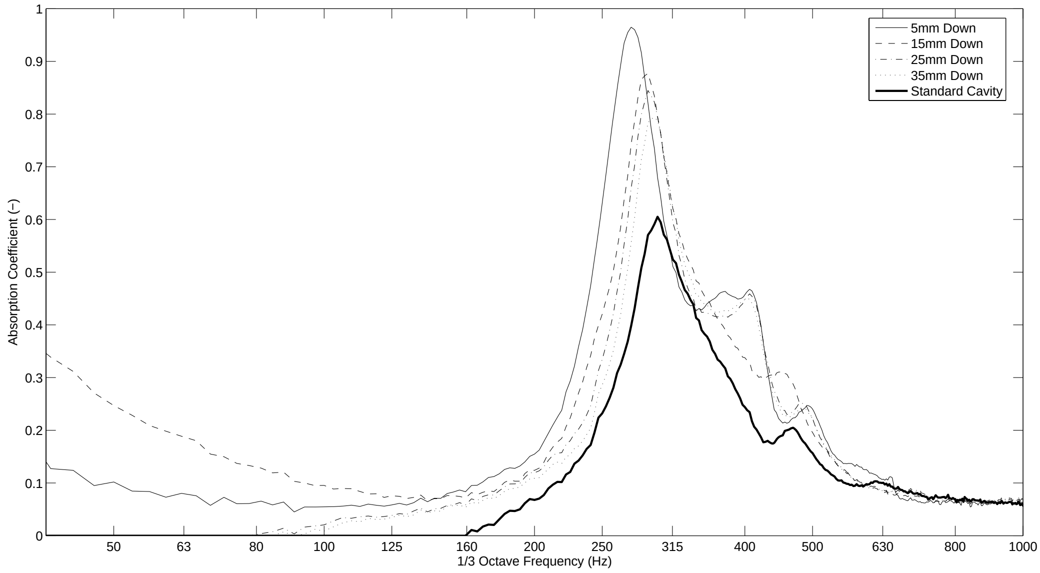

Figure 6. – Absorption coefficient with internal perforations (1.5mm holes, 5% perforation); variable perforation position.

The inclusion of internal perforations also showed significant improvements in absorption. Smaller hole sizes and lower perforation percentages demonstrate the most significant effect. A combination of the two produce a broad absorption curve over ¾ of an octave wider than an empty cavity, at an absorption coefficient of 0.4. The position of the perforations within the cavity shows to affect the absorption with a layer situated higher in the cavity producing greater absorption characteristics. This is particularly noticeable when the layer is situated in the region of two dimensional air flow at the top of the cavity, where a peak absorption coefficient of 0.97 is reached. In each case the improvements in absorption were accompanied with increases in resistance, with significant increases noticeable at low perforation percentages and with perforations situated in the upper region on the cavity.

Changes in resonant frequency were noticeable with varying perforation percentage, but not with hole size; trends towards lower frequencies are noticeable as perforation percentage decreases. This echoes trends associated with standard perforated plate theory [16], as the total neck area only changes with perforation percentage. A reduction in resonant frequency was also noticeable with perforated layers situated higher in the cavity.

The effect of the position of the internal features has been further investigated through the fabrication of a small fin section only occupying the upper 20% of the cavity, with channels conforming to estimated two dimensional air flow paths. It has shown superior absorption improvements over a cavity incorporating the same spaced fins occupying the lower 80%.

The fabrication of the internal fins presented minor problems in the removal of un-sintered powder from in between the thinner spaced fins (1 and 1.5mm). Also the accuracy of perforation sizes was unacceptable, requiring separate reaming by hand to ensure accurate hole size. These issues could be resolved through redesign: Not terminating the fins to aid powder removal, and implementing alternative methods of segregating the cavity volume to impede the movement of air. Alternatively a more accurate SLS, or an alternate liquid based process could be used.

## CONCLUSIONS

The addition of internal perforated and fin features to the cavity of a Helmholtz type acoustic resonator, have been shown to add significant resistance, improving the absorption characteristics. The fabrication of features capable of providing this resistance has been enabled through the use of Solid Freeform Fabrication techniques. Filling the cavity with many finely spaced fins and the inclusion of small perforations at a low perforation percentage (both incorporating feature dimensions around 1mm in size), has shown the most significant results. The results also suggest that the application of these features to the upper cavity area, just behind the neck, can maximise their effect.

The Selective Laser Sintering process used for the fabrication of the test geometries demonstrated limitations, particularly with the accurate production of small perforations and the removal of powder from tight spaces. However these limitations could be circumnavigated through design changes or the use of alternative SFF processes. These areas are currently under investigation.

The performance of the geometrical solutions are not comparable in performance to the broadband absorption offered by micro perforated absorbers, especially multiple layers; however the results of this pilot study are promising. Further work will consider the design of multiple frequency resonant structures, with the application of internal resistive features enabling the conception of a broadband solution.

**References**: [1] H.V. Fuchs: Alternative Fibreless Absorbers – New Tools and Materials for Noise Control and Acoustic Comfort. Acta Acustica **87, No.3** (2001) 414-422
[2] T.J. Cox, P. D'Antonio: Acoustic Absorbers and Diffusers. Spon Press (2004)
[3] D.Y. Maa: Potential of Microperforated Panel Absorber. Journal of the Acoustical Society of America **104, No.5** (1998) 2861-2865
[4] H.V. Fuchs: Helmholtz Resonators Revisited. Acta Acustica **86** (2000) 581-583
[5] R.T. Randeberg: A Helmholtz Resonator With a Lateral Elongated Orifice. Acustica **86** (2000) 77-82
[6] F.P. Mechel: Helmholtz Resonators with Slotted Neck Plates. Acustica **80** (1994) 321-331
[7] A. Selamet, M.B. Xu, I.J. Lee, N.T. Huff: Helmholtz Resonator Lined With Absorbing Material. Journal of the Acoustical Society of America **117, No.2** (2005) 725-733
[8] U. Ingard: On the Theory and Design of Acoustic Resonators. The Journal of the Acoustical Society of America **25, No.6** (1953) 1037-1061
[9] Y.A. Ilinskii, B. Lipkens, E.A. Zabolotskaya: Energy Losses in an Acoustical Resonator. Journal of the Acoustical Society of America **109, No.5, Pt 1** (2001) 1859-1870
[10] B. Sapoval, O. Haeberlé, S. Russ: Acoustical Properties of Irregular and Fractal Cavities. Journal of the Acoustical Society of America **102, No.4** (1997) 2014-2019
[11] A. Selamet, P.M. Radavich, N.S. Dickey, J.M. Novak: Circular Concentric Helmholtz resonators. Journal of the Acoustical Society of America **101, No.1** (1997) 41-51
[12] M. Alster: Improved Calculation of Resonant Frequencies of Helmholtz Resonators. Journal of Sound and Vibration **63, No.1** (1972) 63-85
[13] K.G. Cooper: Rapid Prototyping Technology - Selection and Application. Marcel Dekker, Inc (2001)
[14] British Standards Institute: Acoustics - Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes. BS EN ISO 10534-2:2001 (2001)
[15] U. Ingard: Notes on Sound Absorbing Technology. Noise Control Foundation (1994)
[16] L.E. Kinsler, A.R. Frey, A.B. Coppens, J.V. Sanders: Fundamentals of Acoustics, 4th Edition. John Wiley & Son (2000)