Computer Aided Liner Optimization for Broadband Noise

This article may be found at
http://www.soton.ac.uk/~cedc/posters.html

Lorenzo Lafronza, A.J. Keane
CEDC
School of Engineering Sciences
University of Southampton
Southampton SO17 1BJ UK

Tel: +44 (0) 2380 592944,
Fax +44(0)2380 593230
E-mail: L.Lafronza@soton.ac.uk

UTP for design

C
E
D
C

Introduction

Like all rotating machines, a fan or compressor system will exhibit sound that has both tonal and broadband characteristics. Aircraft turbofan engine intake and bypass ducts are commonly lined with a sound absorbent acoustic lining to reduce such noise emission.
Broadband acoustic attenuation in the intake is investigated here with the aim of developing an automated method for predicting the performance of acoustic treatments. A parallel implementation of the problem and a parallel optimization search engine make the possibility of aeroacoustic optimization more realistic than before. In this work the Perceived Noise Level (PNL) is used as the objective function when optimizing the liner characteristic.

Acoustic Problem

Modeling sound propagation in a real turbofan intake duct is a challenging problem because the duct geometry and mean flow are three-dimensional.
However for some problems it is sufficient to consider a simpler model of the intake duct. In this case the intake is modelled as a uniform duct lined for a fixed axial region as shown in figure (1).

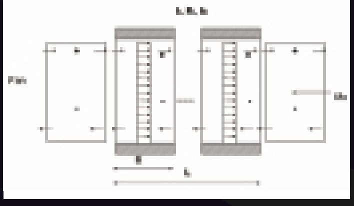

Figure 1 Intake model

The BroadBand noise propagation model is defined by
– A multi-mode analysis, with all the cut-on modes in the frequency spectrum used (up to 2BPF) taken into consideration.
– Equal energy per mode
– Uncorrelated mode propagation
– A mode-matching procedure across sections with different impedances to match the scattering effect due to the impedance changes
– approximate Perceived Noise Level (PNL) calculation

The type of liner determines the specific acoustics impedance Z at the duct wall, which affects the attenuation of the sound. In this study a SDOF (Single-degree-of-freedom) liner model has been used. The design variables are l, R, h, respectively the length, resistance and depth of the liner.

Optimization Procedure

The main problem in this optimization search is to avoid a large number of simulations since the objective function evaluation is expensive in time, but at the same time a reasonable conceptual design condition is desired.
A relative new optimization approach is to build a surrogate model and search this model instead of the full function, i.e., by building a Response Surface Model (RSM). The basic RSM process involves selecting a limited number of points at which the expensive code will be run, normally using formal DoE (Design of Experiments) methods. Then, when these designs have been analyzed, usually in parallel, a response surface (curve fit) is constructed through or near the data. Design optimization is then carried out on this surface to locate new and interesting combinations of the design variables, which may then be fed back into the full code. Those data can then be used to update the model and the whole process repeated until the user either runs out of effort, some form of convergence is achieved, or sufficiently improved designs are reached. There are a number of variations and refinements that may be made to this basic RSM approach.
The approach used here is shown in figure (2). It takes an LPτ DOE sequence of initial sample points generated in parallel and then a kriging model is applied to build the RSM. Here a two stage search (genetic algorithm GA – dynamic hill climbing DHC) of the likelihood function has been carried out to tune the hyper-parameters that define the kriging RSM. Then a further GA, DHC search has been carried out on the tuned RSM to find a new set of optimum locations. In the first stage of the RSM search at each update of the database 10 new points are analyzed simultaneously (i.e., in parallel). When a sufficient number of evaluations are reached, a single point update is conducted until a steady optimum solution is achieved.

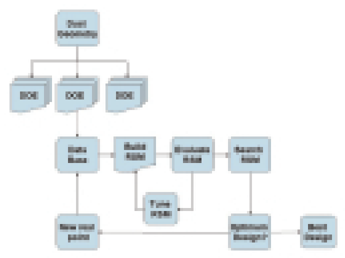

Figure 2 Optimization procedure

Results

The task of this investigation was to determine a liner optimization approach for broadband noise. Assuming that at every frequency of the BroadBand spectrum the incident sound field is formed by an uncorrelated ensemble of modes each of which carries equal sound power per unit of frequency, then at each frequency all the cut-on modes (the propagating mode) are calculated.
The optimization variables resistance and liner depth have been taken in the range R = 1:5 and h = 6:60 mm (rig scale). The flight condition is at Mach number M = 0.57 and the blade passing frequency BPF is = 4198 Hz. The frequency spectrum used goes up to 2 BPF. Then an approximate evaluation of the Perceive Noise Level gives the objective function for this optimization.
For a five variable problem, with two axial liners, an initial set of 150 points generated with the LPτ DOE distribution was used. Then 100 new points were added until an optimum is found. Finally some data applicable to the uniform liner case are also added and a final RSM search conducted.
In figure (3) the contour map of a single liner configuration is presented. The plot shows the optimum values that maximize the difference between the PNL for a non lined duct and the PNL of a lined duct. The optimum conditions for the full scale engine lies at h = 4 cm and R = 4 with a maximum attenuation, ΔPNL = 1.5 dB.

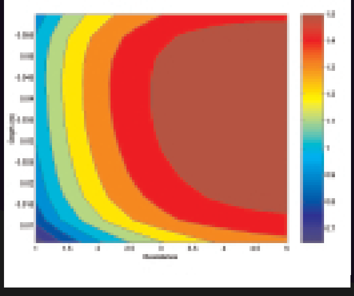

Figure 3 PNL_{hw}-PNL for uniform liner

C
E
D
C

In figure (4) a 5D HAT plot is shown. Each plot is associated with a different liner length, and in each plot the variation of the PNL with the liner depth and resistance is shown.

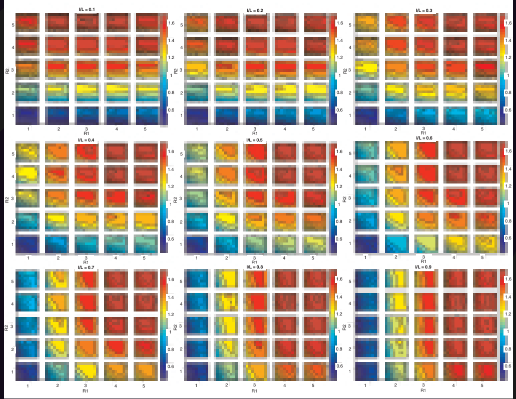

Figure 4 PNL_{hw}-PNL for axial liner at different values of l/L, and all the R,d combination for the axial liner case.

The problem does not present an absolute optimum, but different optima can been located in the design space.
Nevertheless a combination for which the object function assume an absolute minimum can be interpolated from figures (5) (6) and (7). The optimum liner for the full scale engine configuration is given here by R1 = 3.5, R2 = 4.5, d1 = 1.5 cm, d2 = 4.3 cm, and l / L = 13 %.

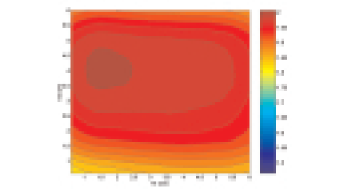

Figure 5 Depth optimum for axial varying liner at the optimum R_1,R_2,l/L

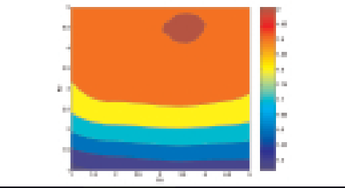

Figure 6 Resistance for axial varying liner at the optimum d_1,d_2,l/L

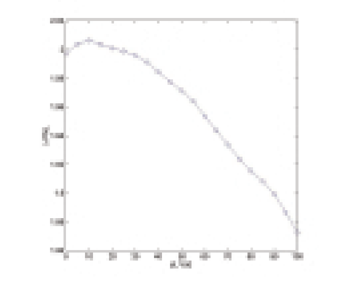

Figure 7 Optimum l/L for axial varying liner at the optimum R_1,R_2,d_1,d_2

It is clear that there is benefit in using an axial varying liner since the maximum attenuation achieved is now 2 dB against the 1.5 dB of a uniform liner.
This result is strongly encouraging and suggests a more detailed investigation to understand how far the benefits of using varying liner configurations can be taken.

University of Southampton