

PIEZOELECTRIC ACTUATOR OPTIMIZATION FOR SIMULTANEOUS AIRCRAFT CABIN NOISE AND VIBRATION CONTROL

Daniel Tse and Anant Grewal

Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, Canada

1. INTRODUCTION

In turboprop aircraft such as the de Havilland Dash 8, the unsteady pressure field generated by the propellers introduces high levels of fuselage vibration and cabin noise. The use of piezoelectric (PZT) elements as control actuators has been demonstrated to be effective in reducing both noise and vibration. The present study aims at exploring a strategy in which the PZT elements are divided into different control groups as a means to simplify the control system while increasing the control authority. The optimal grouping, placement and actuation of the piezoelectric elements constitute a large-scale combinatorial optimization problem that can be solved by applying computational intelligence methodologies such as genetic algorithms (GAs). A genetic algorithm, with a novel coding scheme for the design parameters, was developed¹ to address the optimization of noise and vibration separately and independently. By applying a Pareto cooperative optimization approach, the present work extends that application to consider the simultaneous maximization of both noise and vibration reduction performance.

2. PARETO GA OPTIMIZATION

Both the noise and vibration suppression problems can be cast into the same general form:

$$e_i = G_i u + d_i \quad i = n \text{ (noise)} \text{ or } i = v \text{ (vibration)}$$

The quantities in the above equation are complex-valued: u is the control force vector, d_i the primary forcing vector, G_i the matrix of transfer function coefficients, and e_i is the overall response at the sensors. The elements of d_i and G_i are determined experimentally as discussed in Grewal and Tse.¹ Altogether 6 microphones and 8 accelerometers are used to monitor the noise and vibration response. Their positions, together with those for the 31 pairs of PZT elements used in the experiment, are illustrated in Figures 1 and 2.

Given an actuator configuration, the optimal control force vector \hat{u} is determined by applying a complex least squares procedure to minimize the Hermitian inner product $e_i^H e_i$, where e_i^H denotes the complex conjugate of e_i . A non-dimensional fitness function F_i is then defined for GA operation as follows:

$$F_i = 10 \cdot \log \left[d_i^H d_i / e_i^H e_i \right] \quad i = n \text{ (noise)} \text{ or } i = v \text{ (vibration)}$$

F_i represents the dB reduction due to an actuator set-up.

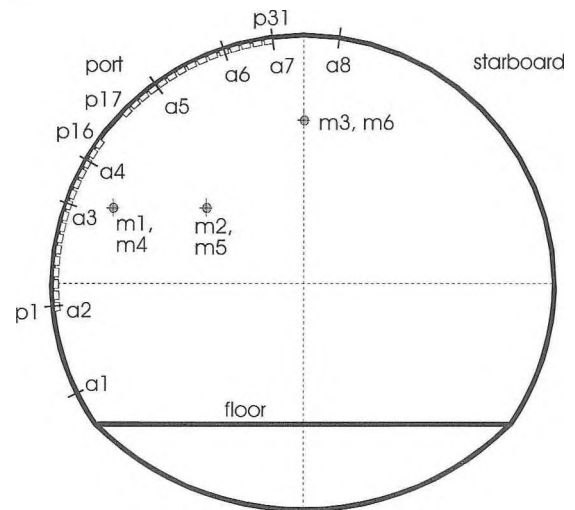


Figure 1: Sectional view of fuselage showing locations of piezoelectric pairs (p1 to p31), accelerometers (a1 to a8) and microphones (m1 to m6).

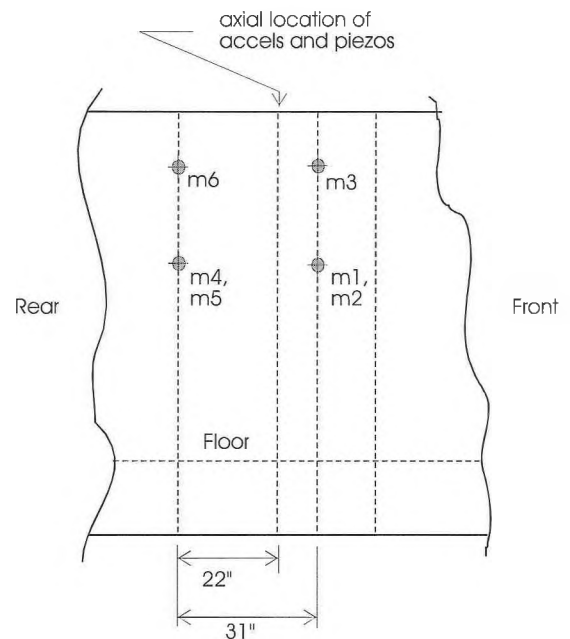


Figure 2: Side view of fuselage showing locations of microphones.

Pareto GA is a technique for the simultaneous optimization of problems with multiple objectives. For the present problem of maximizing the reduction in both noise and vibration, the ordered pair (F_n, F_v) are ranked according to a domina-

tion principle explained in Goldberg.² The goal is to generate a Pareto front which is a set of non-dominated solutions. The construction of such a front allows for an evaluation of solutions that represent the best compromises between the objectives.

With a particular actuator configuration, the optimal control force \hat{u} for maximizing the noise reduction will in general be different from that for maximizing the vibration reduction. The simultaneous optimization of the two objectives thus requires a sequential approach. Three possibilities are examined – Method I: optimization is done with respect to the noise objective only with the vibration reduction obtained solely as a direct result of the former. Method II: optimization is done with respect to the vibration objective only with the resulting noise reduction being a direct result of the former. Method III: an alternating procedure is proposed – in one generation of GA operation, \hat{u} is determined by maximizing the noise reduction objective, and in the next generation \hat{u} is determined by maximizing the vibration reduction objective.

3. RESULTS AND DISCUSSIONS

The results to be discussed all use the same GA parameters: 100 population members, 100 generations, probability of crossover = 1.0, and probability of mutation = 0.1. Details of the GA procedure are given in Grewal and Tse.¹

Figures 3 and 4 show the evolution of Pareto fronts for Methods I and II, respectively. The results of using 1 group of control actuators are contrasted to those of using 4 groups. When more control groups are used, there is a significant improvement in the simultaneous maximization of the noise and vibration reduction. As a consequence of the solution procedures, the Pareto fronts in Figure 3 are biased towards the noise objective while those in Figure 4 are biased towards the vibration objective.

Figure 5 shows the evolution of Pareto fronts for Method III. In contrast to the previous results, the fronts span evenly between the two objectives. While the approaches used in Methods I and II can give better performance for a particular objective, Method III produces more solutions that represent the best compromises in the medium range in either objective.

4. REFERENCES

- ¹Grewal, A. and Tse, D., "Optimization of Piezoelectric Actuator Grouping for Aircraft Cabin Noise Control," AIAA Paper 2000-1558.
- ²Goldberg, D.E., *Genetic Algorithms in Search, Optimization, and Machine Learning*, Addison-Wesley, 1989, pp.197-201.

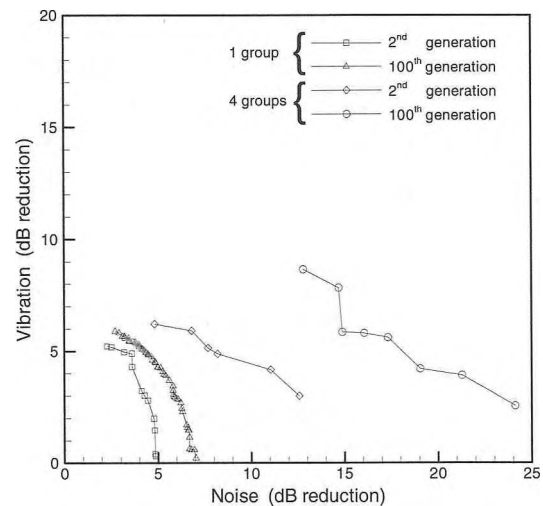


Figure 3: Pareto fronts obtained by Method I.

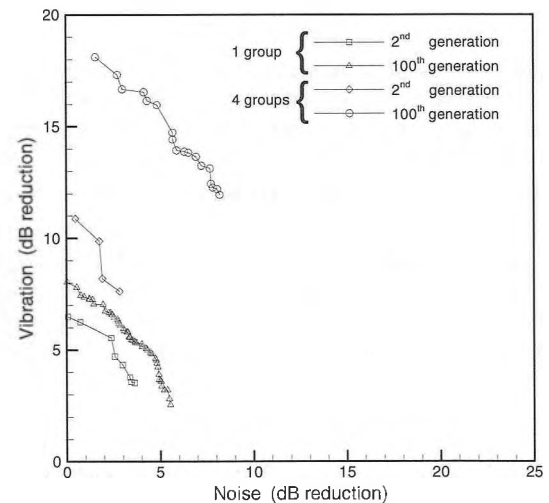


Figure 4: Pareto fronts obtained by Method II.

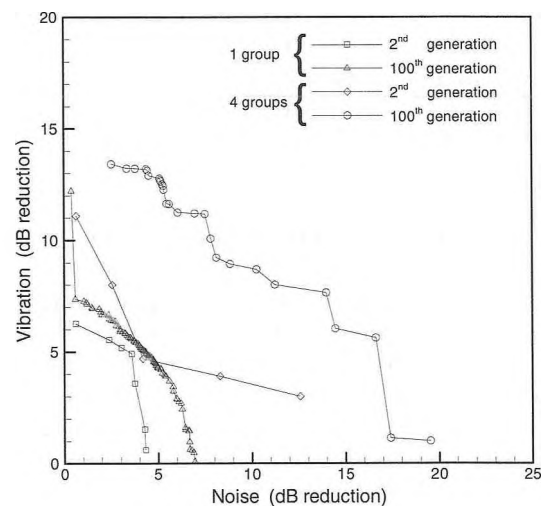


Figure 5: Pareto fronts obtained by Method III.