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Engineering Notes

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Modified Genetic Algorithm for the Identification of Aircraft Structures

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Introduction

STRUCTURAL dynamic analyses for aircraft structures typically employ mathematical models that are considerable idealizations of the actual aircraft structure. Often these models are developed by taking experimentally determined modal frequencies and mode shapes from a ground vibration test (GVT) and adjusting the model to give better correlation. These processes are often based on deterministic methods with the explicit or implicit constraint that the changes to the model from the initial conditions are kept to a minimum.[1] No such constraints will be required in the method presented in this Note.

It is proposed that a more efficient means of obtaining such models is to start the process with GVT results and then, by use of an optimization tool such as a genetic algorithm (GA), create the model directly from these data with as few as possible a priori assumptions.

The inverse structural problem of determining the single unknown of the impact location on a beam has been tackled using a GA as described in Doyle.[2] GAs have been used for finite element model refinement with simulated data for a truss structure and solving for three unknowns by Larson and Zimmerman[3] and for three unknowns for a beam using experimental data in Dunn.[4] The results of applying a modified GA, which is shown to be more efficient for this problem than a standard GA, will be presented here for the identification of a model for a simple tailplane with eight unknowns.

Aerospace Airtrainer CT4 Tailplane

The test article used here was the tailplane of a CT4, a propeller-driven military trainer. The structure is of a traditional aluminium construction involving two spars, ribs, and a riveted skin. The tailplane was mounted on springs and loaded at its tip as shown in Fig. 1. The loading consisted of band-limited white-noise (0–100 Hz) and accelerations were measured at the six locations shown in Fig. 1 with a roving accelerometer. The transfer function between the accelerometer readings and the measured load input was determined. It was these transfer functions that were then used in the model identification process.

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Three configurations consisting of the tailplane arrangement with different added masses (Table 1) were tested. The mounting, loading, and added masses were such that no torsional modes were excited.

Objective Function

Given the frf measurements at the ith freedom and the jth frequency $\chi'_{i,j}$, and the predictions $\chi_{i,j}$ based on the estimated model properties p, we can write the objective function as

$$\min[\varepsilon(p)] = \sum_{j=1}^{N} \sum_{i=1}^{n} |\chi_{i,j}(p) - \chi'_{i,j}| \tag{1}$$

Table 1 Added masses for the three configurations

Configuration	Added mass
1	2.0 kg at 1 and 11
2	0.2 kg at 1 and 11, 0.9 kg at 4 and 8
3	1.2 kg at 1 and 11, 0.575 kg at 2 and 10

Table 2 Comparison of the modified GA with more standard single-run GAs[a]

			Objective function		
Population	Generations	Functional evaluations	Best	Mean	Standard deviation
Modified GA		15,300	1.67	1.94	0.35
100	153	15,300	1.96	5.06	1.96
153	100	15,300	2.58	3.36	0.89
300	51	15,300	2.34	3.82	0.88
51	300	15,300	2.15	3.02	0.71
30	500	15,000	2.73	3.47	0.42
500	30	15,000	3.34	3.81	0.33

[a]Each form of GA was run eight independent times.

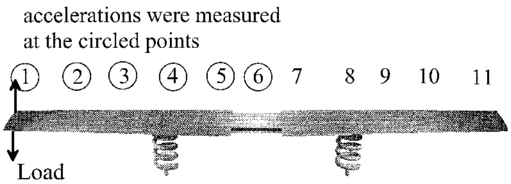

Fig. 1 Tailplane arrangement showing the point of load application, the spring mountings, and the positions where measurements were taken and masses could be added.

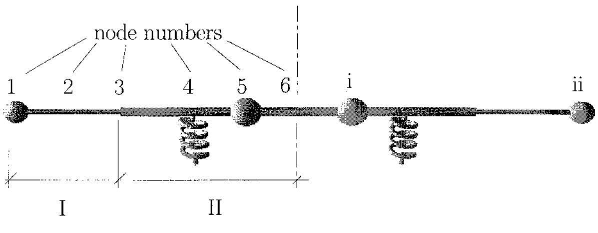

Fig. 2 Diagram showing layout of finite element model and the node positions where the masses, i and ii, and the beams, I and II, can be placed.

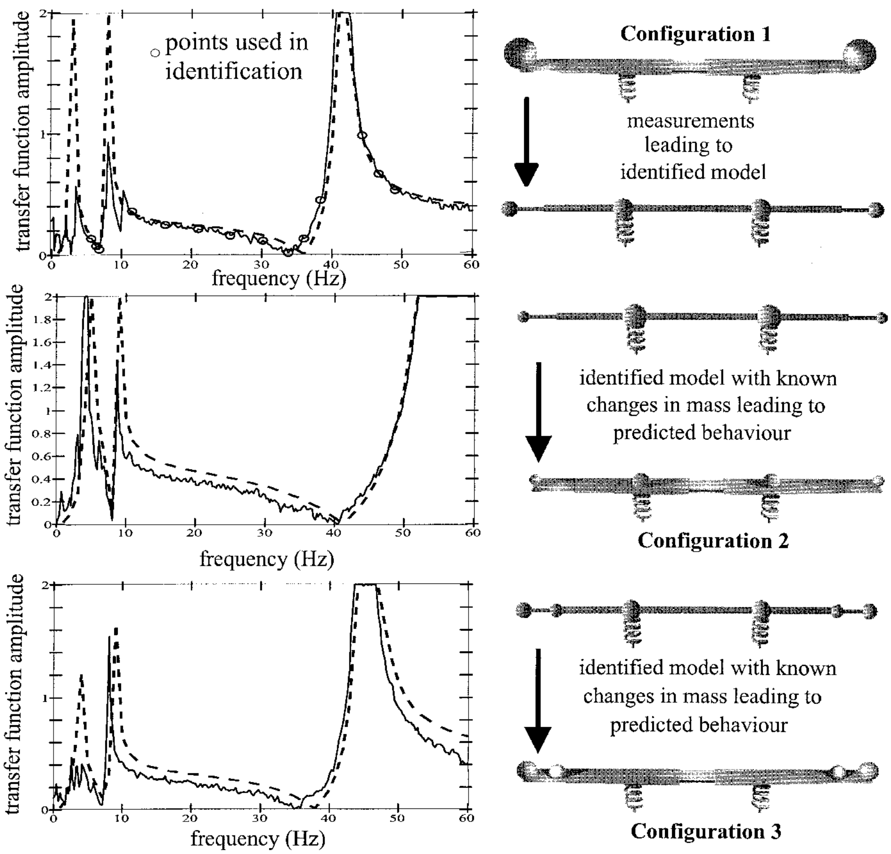

Fig. 3 Identified and predicted dynamic behavior of the tailplane loaded as shown in Fig. 1. The dashed line represents the identified and predicted response of the finite element model and the solid line shows the measurements.

where N and n represent the number of measured frequencies and freedoms used in the optimization process, respectively.

The model to be determined is as shown in Fig. 2. The unknown parameters are 1) the stiffnesses of beams I and II, 2) the magnitudes of the masses i and ii, 3) the node location of the change in stiffness, 4) optimal node location of the masses, and 5) the stiffness of the mounting springs. These unknowns lead to a search in eight-dimensional space with the continuous variables of the stiffnesses and masses being defined with eight-bit resolution within the GA.

Model Identification Using Genetic Algorithms

For the identification process as used here it is assumed that the structure geometry is known, as is the location of the acceleration measurements and load input. The aim of the identification is to determine the structural properties so that the difference between the measured transfer functions and those predicted by the model are minimized. The reasons for using transfer function data in the identification process are discussed in Ref. 4.

The basic form of the GA used here is described in detail by Dunn[4]; a modification that has been found to be of use in this problem and is analogous to a technique described in Ref. 5 is described as follows. Carry out a GA n times, and then for the $(n + 1)$st time, the previous n solutions are added to the initial population. The aim of such a technique is that the initial solutions will have some attractive features that, in the subsequent runs, will be shared between these solutions via the mechanism of crossover.

This was implemented for the problem described here as follows:

1) Run the standard GA 10 independent times with a population of 30 for 30 generations; the initial population of 30 is randomly created.

2) Take the 10 solutions from the previous step and a randomly selected population of 30 and run the GA now with a population of 40 for 30 generations and so on.

3) Take the 14 solutions from the 14 previous GAs, now with a population of 44 for 30 generations.

After all of this, 15,300 cost function evaluations had been carried out. The standard GA as described by Dunn[4] was run for various populations and numbers of generations using approximately the same number of function evaluations as the modified GA. Each solution technique was carried out eight independent times for configuration 1 (as shown in Table 1) and the results for the final solutions of each run are shown in Table 2. The results presented in Table 2 show that the additional complexity of the modified technique is worthwhile.

Predictions Based on the Identified Model

The identification was carried out on the tailplane in configuration 1 as shown in Table 1. The frequencies used in the cost function determination and the frf predicted by the identified model are shown in Fig. 3 (note, results for the nodes not shown exhibited similar agreement).

The aim of the identification is to determine a model that will predict the structure's dynamic behavior under different conditions. Adjusting the identified model to account for the known changes in mass distribution, the predicted frf, and the measured response for the tailplane in configurations 2 and 3 are shown in Fig. 3.

Conclusions

This Note has demonstrated how a modified genetic algorithm can be a powerful tool in estimating the structural properties that best represent an aircraft component in a finite element model. The efficacy of the modified approach, which is based on running quick GAs and then allowing these solutions to crossbreed in subsequent runs, has been shown in comparison with more standard GAs. The suitability of the identified model was demonstrated by showing its predictive capabilities against tests with significantly different mass distributions.

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Induced Drag Computations on Wings with Accurately Modeled Wakes

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Introduction

THE trailing wake model employed by classical finite wing theory is a thin vorticity sheet that leaves the trailing edge in the freestream direction. Although this straight wake differs from the physical, force-free wake shape, it is drag free, since the wake vorticity is parallel to the freestream. This fact enables accurate induced drag computation with straight wakes by integration of the wake properties in the Trefftz plane. The use of straight wakes in linear potential methods is well established, providing sufficient accuracy for most engineering analyses.

Although the potential for reducing drag may be small, the influence of the force-free wake on induced drag has become the subject of active research. A study of the nonlinear effects of wake shape on induced drag requires Trefftz-plane integration on the force-free wake. However, any error in the computed wake shape will produce an error in the integrated drag, since the wake is no longer force-free. This Note presents a novel wake relaxation scheme that was developed to enable accurate Trefftz-plane integration of induced drag with force-free wakes.

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Background

References 1–3 have demonstrated that surface-pressure integration is an unreliable method of computing induced drag. Errors arising from inadequate resolution of the pressure distribution may be planform dependent, leading to incorrect conclusions about the influence of planform shape on induced drag.[1,2] When panel methods are used, the induced drag may be determined by surveying the trailing wake properties and numerically evaluating the well-known Trefftz plane integral. Reference 1 described the application and accuracy of this technique using the Boeing A502 high-order panel code.[4] All induced drag values presented in this Note were computed by this technique.

Linear panel methods require that the wake geometry be prescribed, and so either a straight wake model or a model of the force-free wake shape must be obtained. A variety of techniques exist for computing the force-free wake shape downstream of the wing. The most widely used methods use a discrete vortex–lattice model of the wing and wake.[5–7] The velocities induced on the wake are computed and an iterative procedure is used to displace the wake to align it with the local flow. A viscous core model is required to prevent erratic behavior of the vortex filaments when they pass near each other. Reference 8 describes an alternative method of relaxing a distributed-vorticity wake sheet, using a smoothing algorithm to prevent erratic behavior along the outboard edge. Once the force-free wake shape is created, it can then be converted to a panel geometry for Trefftz plane drag analysis by the high-order panel code.

Errors Associated with Vortex–Lattice Wake Relaxation Schemes

A time-marching vortex–lattice wake relaxation program[5] was used to create a force-free wake model for an elliptical wing [aspect ratio, (AR) = 7, with straight trailing edge] at 4.0-deg angle of attack. This wing was chosen based on a hypothesis described in Refs. 9 and 10, indicating that a straight wake model and an accurate force-free wake model should produce the same Trefftz-plane drag for this planform. A panel model of the same wing was created with NACA 0012 airfoils and a panel representation of the force-free wake geometry from the vortex–lattice method. The 50-vortex model of the wake was edited to match the 18 spanwise panels on the wing. Convergence studies in Ref. 1 indicate that the expected error in numerical evaluation of the Trefftz-plane integral with 18 panels is about 0.5%. Since the wing lift (circulation) rather than angle of attack determines the wake shape, the angle of attack of the panel model was adjusted to match the lift coefficient of the vortex–lattice model.

The computed span efficiency, $e = C_L^2/\pi \mathrm{AR} C_{D_i}$, of this model was 1.035, almost 5% higher than the expected value based on the straight wake result, $e = 0.99$. To improve the resolution of the wake shape, the 50-vortex wake model was re-edited to create a model with 19 spanwise panels. This produced a computed $e = 1.058$. A second vortex–lattice wake model was then generated with half the time-step size, again to improve the resolution of the wake shape. A 19-panel representation of this wake produced a computed $e = 1.082$, 9% higher than the expected value. The small change in wake shape that produced this large change in computed span efficiency is shown in Fig. 1. Evidently, the drag computed in the Trefftz plane is highly sensitive to details of the wake shape.

One possible source of error in wake shape is the approximation of the wing flowfield inherent to the vortex–lattice method. The wake shape is determined from velocities induced by the bound and trailing vortex systems, but vortex–lattice methods have velocity singularities at the panel edges, and the velocities are correct only at the control points. Significant velocity errors exist at other points in the field, particularly at