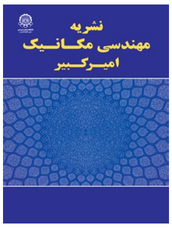

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Determination of the Flutter Instability Boundary of a Composite Wing Using Support Vector Machine

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ABSTRACT: The main goal of this article is to train a support vector machine in order to determine the boundary of the composite wing aeroelastic instability. Aircraft wing is modeled as a cantilever beam with two degrees of freedom with thrust as a follower force and mass of the engine. For structural modeling of composite wing the layer theory has been used and in the aerodynamic model, the flow has been assumed to be unsteady, subsonic and incompressible. Using the assumed mode method, the wing dynamic equations of the motion have been derived by Lagrange equations. Linear flutter speed according to the eigenvalues of the motion equations has been calculated. The process of flutter speed calculation has been converted to a computer code in which the number of layers, angle of fibers in each layer, the mass of the engine, and the thrust are input variables and the flutter speed is its output. Determination of the instability boundary using this conventional method is time consuming. In this article, a support vector machine has been adopted to reduce the calculation cost. The results indicate that support vector machine can be used in determining the boundary of the wings flutter instability as an accurate and fast tool.

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1- Introduction

To model the behavior of a system, we can use different methods such as Markov chains, graphs and graph theory, clustering methods and classification methods. In this research, classification method has been used by Support Vector Machines (SVMs). In recent years the use of support vector machines, is highly regarded [1].

In this article, training and review of the support vector machine are used to determine the boundary of the dynamic instability of a composite wing.

2- Support Vector Machines

The support vector machine is an efficient classifier originated from pattern recognition in machine learning. The SVM training algorithm aims at building a hyperplane that separates all training data of one category from those of the other category. The optimal hyperplane is the one that has the largest distance to the nearest training samples of any class [2].

In many applications for analyzing a system, we first model the behavior of the system based on the information we have from the system, and then use that model to detect the future behaviors of that system. This process is actually the same as in the reverse engineering process.

3- Equation of Motion

Aircraft wing is modeled as a cantilever beam with two degrees of freedom with thrust as a follower force and mass of the engine. For structural modeling of composite wing the layer theory has been used and in the aerodynamic model, the flow has been assumed to be unsteady, subsonic and incompressible.

Using the assumed mode method, the wing dynamic equations of the motion have been derived by Lagrange equations. Linear flutter speed according to the eigenvalues of the motion equations has been calculated [3].

To calculate the flutter speed of a wing, the equations of motion of the system, which are Eqs. (1) and (2), must be transformed into matrix form using assume modes.

$$\begin{aligned}&C_0\xi_1''+C_1\alpha_1''+C_2\xi_1'+C_3\alpha_1'+C_4\xi_1+C_5\alpha_1\\&+C_6w_1+C_7w_2+C_8w_3+C_9w_4\\&+A_1\left(\frac{1}{1.8751^4}\right)\left(\frac{\bar{\omega}}{U^*}\right)^2G(\xi)\\&+A_{12}Kb^*\left(\frac{r_a}{U^*}\right)^2\left(\frac{2}{\pi}\right)^2M(\alpha)=f(\tau)\end{aligned}\tag{1}$$

$$\begin{aligned}&D_0\xi_1''+D_1\alpha_1''+D_2\xi_1'+D_3\alpha_1'+D_4\xi_1+D_5\alpha_1\\&+D_6w_1+D_7w_2+D_8w_3+D_9w_4\\&+A_2\left(\frac{2}{\pi}\right)^2\left(\frac{1}{U^*}\right)^2M(\alpha)\\&+A_{12}^Tb^*\left(\frac{1}{U^*}\right)^2\left(\frac{2}{\pi}\right)^2G(\xi)=g(\tau)\end{aligned}\tag{2}$$

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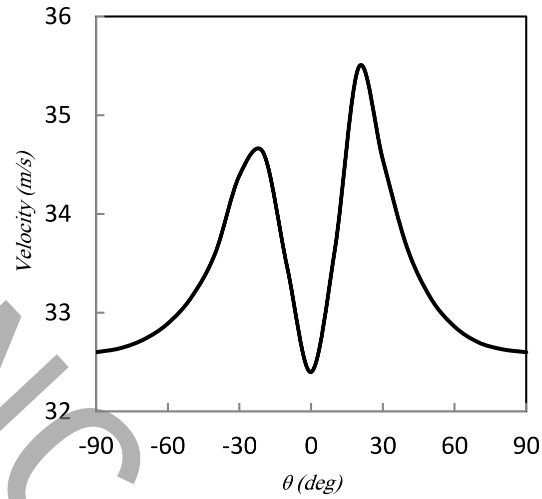

Fig. 1. Flutter speed of composite wing against fiber orientation

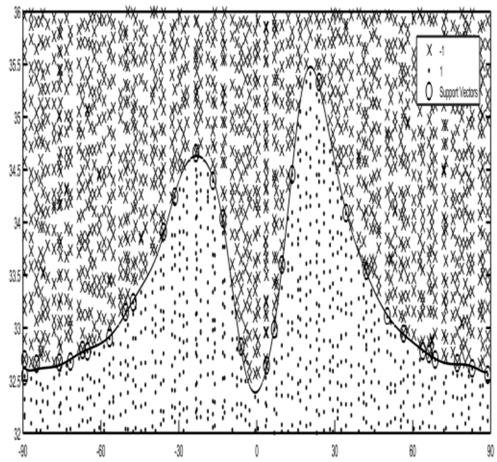

Fig. 2. Training support vector machine with 2100 samples

Table. 1. Wing validation

HALE wing	Flutter speed
Reference [6]	32.2 m/s
Present study	32.4 m/s

Table. 2. Comparing results

	samples	Calculation time (second)	Error
Main equations	1800000	72630	-
1st Machine	200	10	2.1 %
2nd Machine	550	25	2.2 %
3rd Machine	1200	55	1 %
4th Machine	2100	108	0.3 %

The process of calculating the flutter speed in this paper is shown in reference [4].

4- Wing Modeling

The wing is a rectangular sheet that geometrical and material properties listed in reference [5].

5- Solution Procedure

For the training of the support vector machine, the flutter speed changes for the wing are considered without any impact of follower force and mass.

The speed of the flutter calculated with the obtained equations and the velocity obtained from reference [6] for HALE wing is compared in Table 1.

As seen in Fig. 1, by changing the angle of fiber, the speed of instability has also changed and represents that the top of the graph is failure or unsafe area and under the graph is a safe area.

In this research, it has been shown that a support vector machine easily identifies this pattern at very high speed and low error with a few training samples. There is also a time-based comparison with the main equations. Four support vector machines have been trained on different sets of training data.

The fourth support vector machine in Fig. 2 finally trained with 2100 samples which was in good agreement with the original samples in Fig. 1.

6- Results and Discussion

At first, a support vector machine was trained with 200 samples. As it was seen, almost the support vector machine was able to detect the boundary between safe and unsafe area. Then it was trained again with different number of samples.

Finally, a general comparison in Table 2 is made with the main equations based on the number of samples, the time of calculation and the accuracy of the support vector machine.

The support vector machine error was reduced by increasing the number of sample, and even a support vector machine with 200 training data could have a very good convergence with the main equations.

7- Conclusions

Determining the boundary of flutter instability of a wing has relatively high computational cost by using conventional methods. Learning machines are used today as an appropriate tool for data classification. In this paper, we have attempted to determine the flutter instability of a wing using a support vector machine. The results of this paper show that not only the support vector machine is a proper and accurate tool for determining the boundary of instability, but it can also greatly reduce the computational cost.

The method presented in this paper can be used in sensitivity analyzes, which are usually used to optimize and calculate the reliability of flutter instability of a wing, and not only to reduce computational cost, but also, in some cases, enable problem solving.

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