Fatigue Life Prediction in Frequency Domain Using Thermal-Acoustic Loading Test Results of Titanium Specimen

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1. Introduction

The skin of fuselage and wing of the supersonic/hypersonic aircraft is designed thermal protection structures to prevent thermal load from being transferred into the interior of the aircraft [1]. The thermal protection structure is consist of double panel, and the outer skin panels in contact with the outside are designed to thin plate which thickness of 0.5 to 3.8 mm. Because of an acoustic loading by the aerodynamic flow and engine noise, the thin skin panels are exposed to the acoustic loading more than 180 dB OASPL(Overall Sound Pressure Level) in the range of 0 to 10 kHz [1]. Therefore, it is necessary to predict the fatigue life of the skin panels subjected to thermal-acoustic loading.

The acoustic loading during flight of a supersonic/hypersonic aircraft is generally expressed a SPL(Sound Pressure Level) in a frequency band without phase information.

The fatigue life of the skin panels subjected to thermal-acoustic loading can be predicted by the time domain fatigue life prediction method and the frequency domain fatigue life prediction method. A response stress history should be generated to calculate the fatigue life in the time domain. However, in order to verify the accuracy of the fatigue life prediction results calculated from the frequency domain fatigue life prediction results and the generated response stress history, it is necessary to compare with the time domain fatigue life prediction results of the actual signals [2].

In this paper, thermal-acoustic testing of the titanium specimen under thermal-acoustic load was performed. The response stress history of the specimen was obtained, and the fatigue life was predicted by the time and frequency domain fatigue life prediction method, as shown in Fig. 1. Stress history was generated by a sine series of random phase from stress PSD without phase information. The fatigue life of generated stress history was predicted by time and frequency domain fatigue life prediction method.

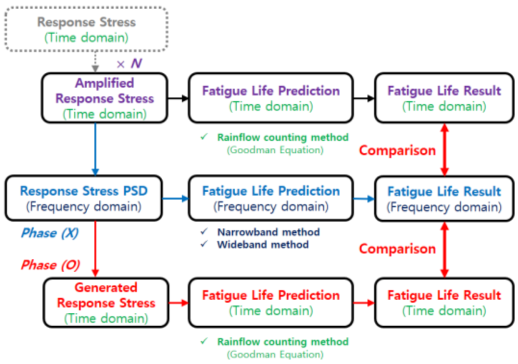

Fig.1 Schematic of time and frequency domain fatigue life prediction

2. Thermal-acoustic loading test

The thermal-acoustic loading test was performed on the titanium specimen of beam shape using the thermal-acoustic test facility, as shown in Fig. 2. The thermal-acoustic test facility is composed of a speakers to generate an acoustic load, a near-infrared lamp to generate a thermal load, horn, test section, and absorber. The thermal-acoustic loading tests were performed OASPL 150 dB at room temperature and 150 °C, as shown in Fig. 3 and Fig. 4. Mean stress was measured 2.4 MPa at 25 °C and -6.9 MPa at 150 °C, respectively. It was confirmed that the natural frequency increases with

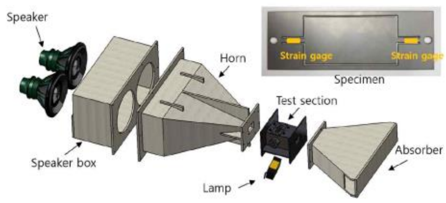

Fig.2 Thermal-acoustic test set-up

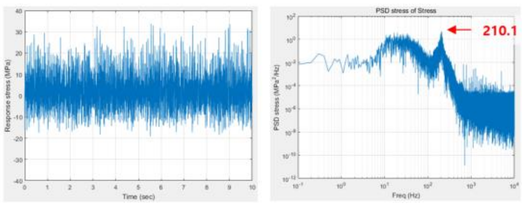

Fig.3 Response stress history and PSD (25 °C)

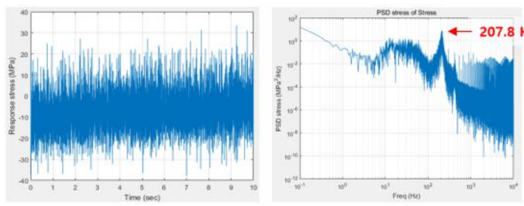

Fig.4 Response stress history and PSD (150 °C)

increasing temperature. Although the maximum acoustic load of the speakers were generated, fatigue failure did not occur due to response stress below the fatigue limit of the specimen. In this paper, the strain of the structure and the acoustic load were assumed to be linear relationship, and the amplified response stress of the specimen by the amplified acoustic load (Fig. 5) was calculated.

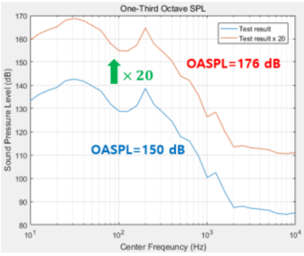

Fig.5 Amplified acoustic load

3. Generated response stress history

The response stress history of the sine series is generated from the response stress PSD using random phase, as in Eq (1) [3].

$$f(t) = \sum_{k=1}^{\infty} \sqrt{2S_{XX}(f_k)\Delta f}\,\sin(f_k t + \theta_k) \qquad (1)$$

The generated response stress history for the amplified acoustic load OASPL 176 dB and 25 °C condition test is shown in Fig. 6.

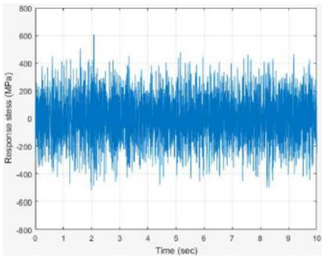

Fig.6 Generated response stress history (25 °C)

4. Fatigue analysis results

The fatigue life in the time domain and frequency domain was predicted using the amplified response stress history at each temperature condition, as shown in Fig. 7. It was confirmed that the time domain and frequency domain fatigue life result were similar in the 25 °C condition. In the 150 °C condition, the error of the time domain and frequency domain fatigue life results increased due to the mean stress.

The time and frequency domain fatigue life results of the generated stress history were compared, as shown in Fig. 8. The results of the fatigue life prediction in time and frequency domain are similar. The results of time domain fatigue life prediction of the measured stress and the generated stress were compared. Fatigue life predicted by the generated stress history was more conservatively predicted than measured stress.

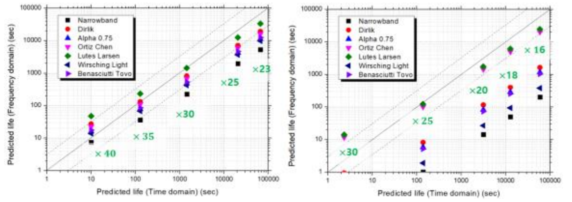

Fig.7 Fatigue analysis results for test results (25 °C and 150 °C)

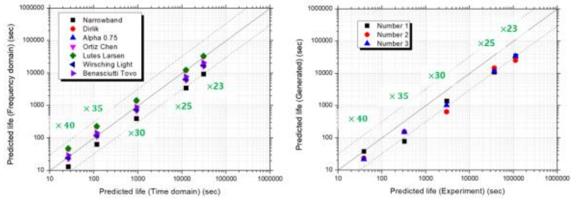

Fig.8 Comparison of fatigue analysis results for generated stress history

5. Conclusion

In this paper, thermal-acoustic tests of the titanium specimen under thermal-acoustic load were performed. The response stress history of the specimen was obtained, and the fatigue life was predicted by the time and frequency domain fatigue life prediction method. Stress history without phase information is generated by a sine series with random phase, and fatigue life is predicted by time domain fatigue life prediction method and compared with fatigue life prediction result of actual stress history. It was confirmed that the results of the fatigue life prediction in the time and frequency domain of the stress history without the mean stress were similar. In addition, fatigue life predicted by the generated stress history was more conservatively predicted than measured stress.

Acknowledgment

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