Experimental investigation on dynamic response of aircraft panels excited by high-intensity acoustic loads in thermal environment

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Abstract. Metallic and composite panels are the major components for thermal protection system of aircraft vehicles， which are exposed to a severe combination of aerodynamic, thermal and acoustic environments during hypersonic flights. A thermal-acoustic testing apparatus which simulates thermal and acoustic loads was used to validate the integrity and the reliability of these panels. Metallic and ceramic matrix composite flat panels were designed. Dynamic response tests of these panels were carried out using the thermal acoustic apparatus. The temperature of the metallic specimen was up to 400℃, and the temperature of the composite specimen was up to 600℃. Moreover, the acoustic load was over 160 dB. Acceleration responses of these testing panels were measured using high temperature instruments during the testing process. Results show that the acceleration root mean square values are dominated by sound pressure level of acoustic loads. Compared with testing data in room environment, the peaks of the acceleration dynamic response shifts obviously to the high frequency in thermal environment.

1. Introduction

Aircraft vehicle structures are exposed to a severe combination of aerodynamic, thermal and acoustic environments during hypersonic flights. The temperature of acreage thermal protection systems is in the range from 750℃ to 1450℃ and the temperature of nose or control surface leading edge is up to 2000℃. The sound pressure level (SPL) of acoustic load induced by boundary layer at airframe is over 160dB. Especially, acoustic load at local location induced by power system or shocks are up to 170dB [1]. It presents a significant challenge for the integrity and the durability of thermal protection systems, since these panels are easily damaged by high-intensity acoustic loads. The structure design, thermal insulation mechanism and thermal stress analysis for thermal protection systems have been extensively studied in the past 20 years. However, few studies have focused on the dynamic response analysis and tests of panel structures exited by acoustic load in thermal environment.

Finite element analysis and thermal acoustic tests were conducted for improving the anti-acoustic performance of thermal protection systems. It is shown that the natural vibration frequencies and natural vibration shapes of thin panels altered with the maximal temperature and its distribution [2]. The response of thin-walled structure excited by thermal and acoustic loads is nonlinear [3]. For a single panel or assemble panel array about metallic TPS of HOPPER vehicle, a series of tests, such as vibration test, thermal test and acoustic test, were accomplished [4]. A scaled thermal acoustic

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apparatus has been established. Metallic and composite flat panels were fabricated, and thermal acoustic tests were performed in the thermal acoustic apparatus.

2. Test apparatus and procedure

2.1. Thermal acoustic apparatus

A diagram of thermal acoustic apparatus for metallic panels is shown in Fig. 1. Testing articles are heated by quartz lamps and the high-intensity acoustic load is generated by a progressive wave tube (PWB). The sizes of the cross section of PWB testing zone are about 300mm×300mm. The testing articles were mounted at one side wall of PWB and the quartz lamp heater was placed near the PWB at another side wall of PWB.

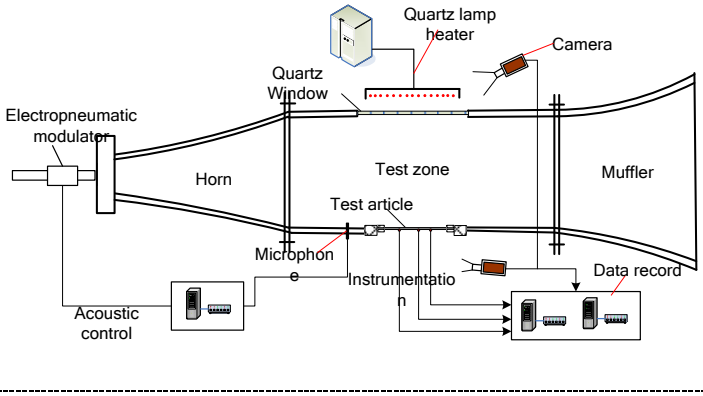


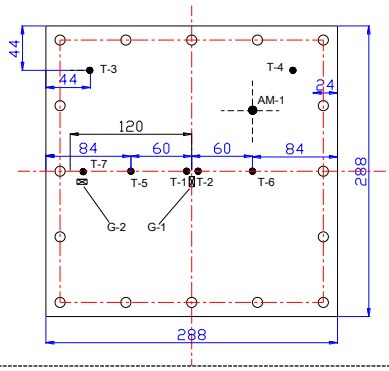
Fig. 1 Diagram of thermal acoustic apparatus

2.2. Testing conditions

The required acoustic load applied on testing articles is white noise and its frequency is in the range of 50 to 500Hz. Control errors are less than 3dB. The sound pressure levels of acoustic load are 156dB, 159dB, 162dB, and 162dB, respectively. Thermal conditions of the central temperature values of the titanium panels are 200℃ and 400℃.Thermal conditions of the central temperature values of the C/SiC panels are 200℃, 400℃, 500℃ and 600℃.The sizes of these panels are 288mm×288mm and their thickness is 2mm. For mounting the panels, a steel fixture was used and some soft blankets were placed between the fixture and testing panel for thermal insulation.

2.3. Instrumentation

A room-temperature microphone was used for measuring the acoustic load in testing zone of PWB. Its location is far away from the quartz lamp heater. The titanium panel was attached with some K thermocouples and one high-temperature accelerometer. The number and locations of instrumentation for the titanium panel are show in Fig. 2(a). The photo of the titanium panel installed at the PWB side wall is shown in Fig. 2(b).



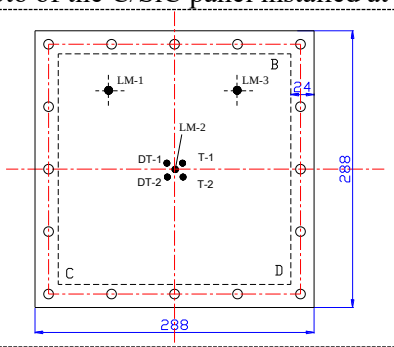
(a) Testing locations



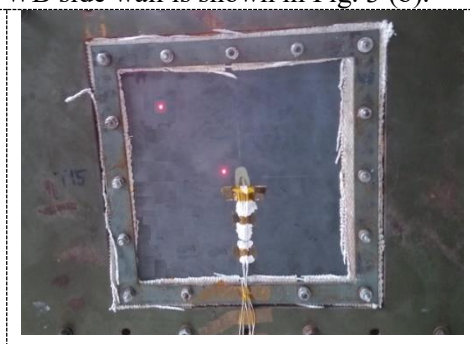
(b) the titanium panel

Fig. 2 Testing locations of high instrumentation at the titanium panel

The temperature of the C/SiC panel was measured by the K thermocouples (T1, T2) and the infrared thermometer(DT-1, DT-2). The acceleration responses of the C/SiC panel were measured using laser vibration instrument. The number and locations of instrumentation for the C/SiC panel are show in Fig. 3(a). The photo of the C/SiC panel installed at the PWB side wall is shown in Fig. 3 (b).



(a) Testing locations



(b) the C/SiC flat panel

Fig. 3Test locations of high instrumentation at the C/SiC flat panel

2.4. Testing cases and procedure

The two testing cases in the thermal acoustic test of the titanium flat panel are as follows:

- Case(1) thermal acoustic test of the titanium flat panel with temperature of 200℃;
- Case (2) thermal acoustic test of the titanium flat panel with temperature of 400℃.

The four testing cases in this thermal acoustic test of the C/SiC flat panel are as follows:

- Case (1) thermal acoustic test of the C/SiC flat panel with temperature of 200℃;
- Case (2) thermal acoustic test of the C/SiC flat panel with temperature of 400℃;
- Case (3) thermal acoustic test of the C/SiC flat panel with temperature of 500℃;
- Case (4) thermal acoustic test of the C/SiC flat panel with temperature of 600℃.

The control method of the quartz heater is manual. The testing procedure is that the testing article is heated firstly to the required temperature, then the acoustic load is applied, and the article's temperature is adjusted correctly with the increasing of acoustic load.

3. Results and discussion

3.1. Titanium flat panel

Acoustic loads in PWB test zone measured during thermal acoustic tests are shown in Fig. 4. The sound pressure levels of acoustic load are about 156.5dB, 160.0dB and 162.6dB, respectively.

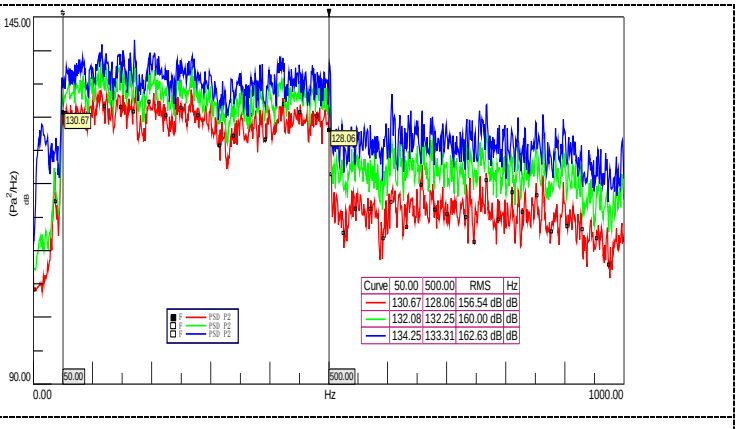


Fig. 4 Testing acoustic loads

Temperature variation of the titanium panel in testing case (1) is illustrated in Fig. 5(a). The temperature is controlled according to testing points T1 or T2. When the temperature of this test panel is close to 200℃, the acoustic load with the SPL 156dB begins to be applied. It is clear that the temperature values decrease obviously because of the effects of acoustic gas flow. Then the acoustic loads with the SPL 159dB and 162dB are applied sequentially. The duration time of each acoustic load level is about 60s. It was observed that some thermocouples, such as T1, are damaged by vibration induced by acoustic load or acoustic gas flow. The temperature variation in testing case (2) is illustrated in Fig. 5(b). The temperature at test location T5 maintains about 400℃, and the temperature at the different location is also affected by acoustic load.

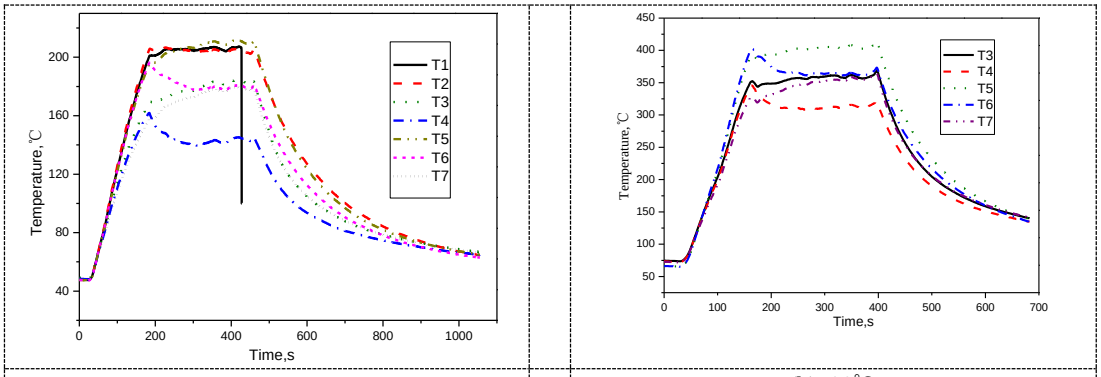
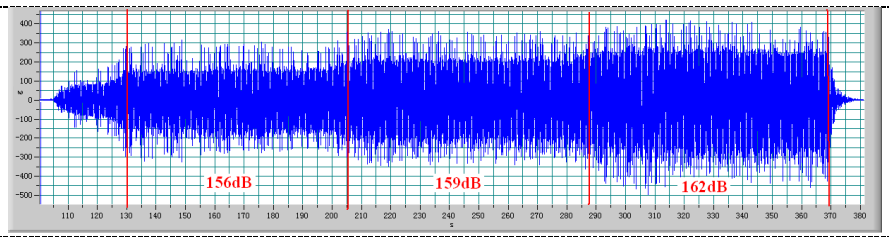
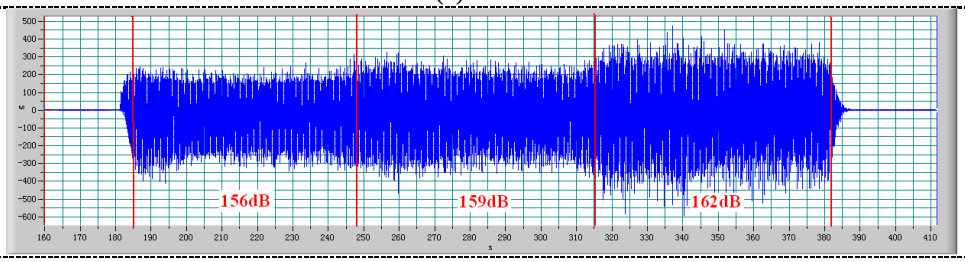


Fig. 5 Temperature variation of the titanium panel

The acceleration testing point (AM-1) locates at the top-right side of the titanium flat panel. Acceleration data in time domain of this panel are shown in Fig. 6. It is apparent that the maximal value of dynamic response increases with the increasing of acoustic load SPL. The root mean square (RMS) values of the flat panel response are given in Table 1. It is shown that the maximal value of dynamic response is about 250g and the RMS value is about 90.1g at the temperature conditions of 200℃ and SPL 162dB. Moreover, the maximal value of dynamic response is about 300g and the RMS value is about 94.5g at the conditions of 400℃ and SPL 162dB.



(a)200℃



(b)400℃

Fig. 6 Acceleration data in time domain of the flat panel

Table 1. Root mean square (RMS) values of acceleration responses of the titanium panel

Temperature	Acceleration RMS（g）		
	156dB	159dB	162dB
200℃	63.0	76.5	90.1
400℃	76.8	78.5	94.5

Comparison of acceleration PSD of the titanium panels for different temperature is shown in Fig. 7 and the acoustic load is about 156dB. With the increasing of the temperature from 200℃ to 400℃, the location of the first response peak shifts towards high frequency and some response peaks towards low frequency.

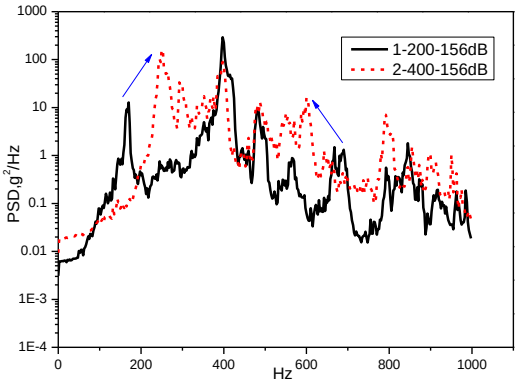


Fig. 7 Comparison of acceleration PSD at different temperature values

3.2. C/SiC flat panel

Acoustic loads in PWB test zone measured during thermal acoustic tests of the C/SiC panel are shown in Fig. 8. The sound pressure levels of acoustic load are about 155.9dB, 159.1dB, 161.9dB and 164.4dB, respectively.

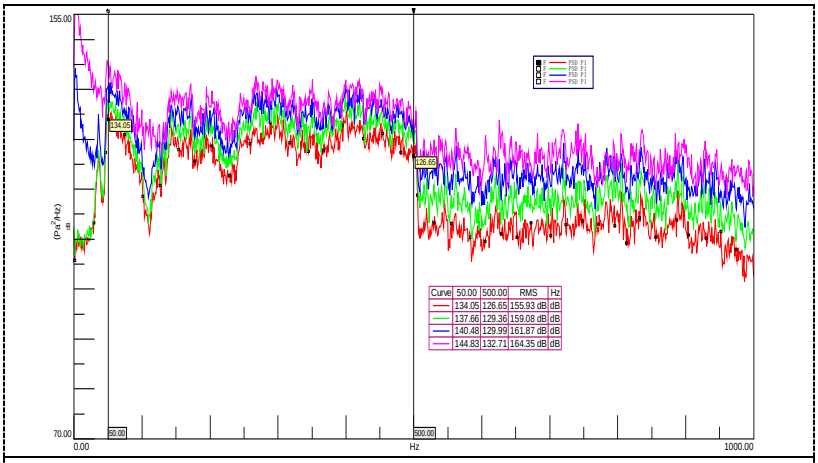
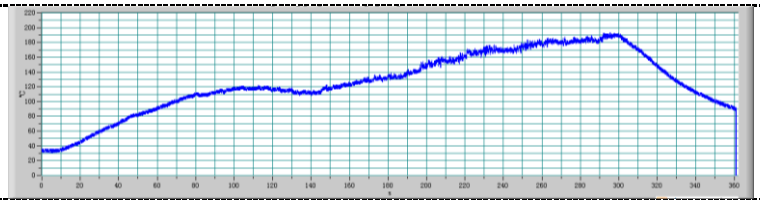
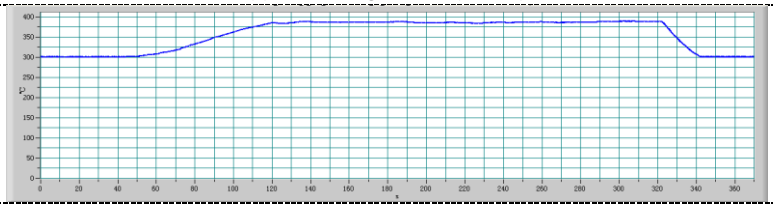


Fig. 8 Test acoustic loads

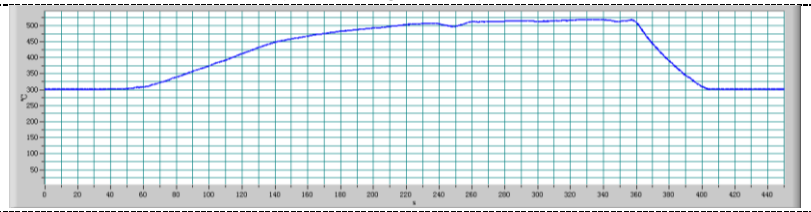
Temperature variations of the C/SiC panel in testing case (1) ~ case (3) are illustrated in Fig. 9.



(a) the testing cases 1(200℃)



(b) the testing cases 2(400℃)



(c) the testing cases 3(500℃)

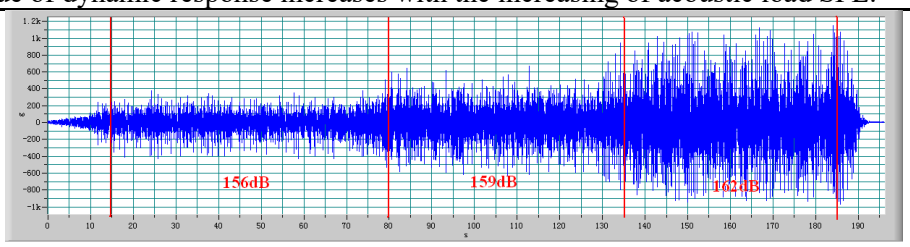
Fig. 9 Temperature variation & time of the C/SiC flat panel

The root mean square (RMS) values of the flat panel are given in Table 2. It is known that the maximal RMS value at testing location LM1 is about 178.3g. The maximal RMS value at testing location LM2 is about 269.8g. The maximal RMS value at testing location LM3 is about 158.7g。

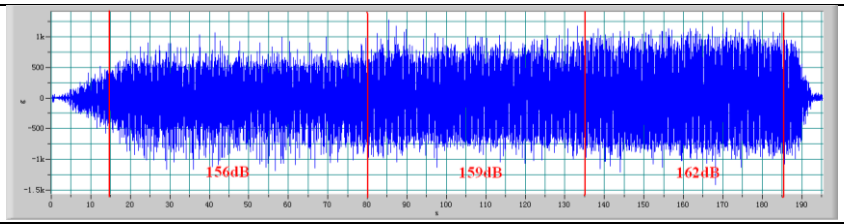
Table 2. Root mean square (RMS) values of acceleration responses of the C/SiC flat panel

Temperature	Testing Location	Acceleration RMS（g） 156dB	159dB	162dB	165dB
200℃	LM1	40.9	66.8	117.6	—
	LM2	185.1	234.4	269.8	—
400℃	LM1	61.2	103.7	178.3	—
	LM3	73.6	78.6	99.1	—
500℃	LM3	—	—	—	124.2
600℃	LM3	—	—	—	158.7

Acceleration data in time domain of this C/SiC flat panel are shown in Fig. 10. It is apparent that the maximal value of dynamic response increases with the increasing of acoustic load SPL.



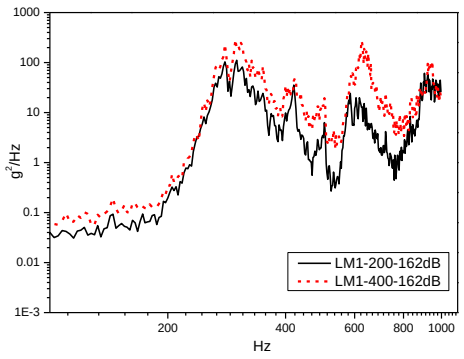
(a) testing location LM1



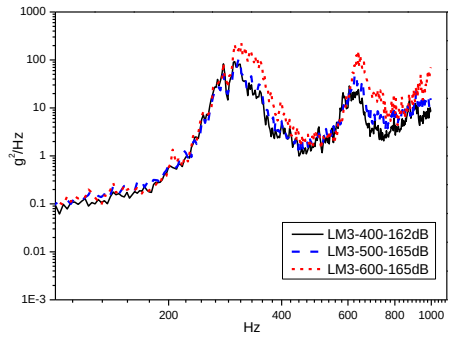
(b) testing location LM2

Fig. 10 Acceleration response data in time domain of the C/SiC flat panel

Effects of temperature on acceleration PSD distribution of the C/SiC flat panel are shown in Fig. 11. The change of acceleration PSD distribution of C/SiC flat panel is not clear in different thermal conditions. It is not also clear the location of response peaks shifts towards high frequency.



(a) Testing position LM1



(b) Testing position LM3

Fig. 11 Effects of temperature on acceleration PSD distribution of the C/SiC flat panel

4. Conclusions

The dynamic response of the panel at high-temperature and high-intensity acoustic conditions is very large. These dynamic response RMS values of these panels are determined by the acoustic load. Thermal environment has a little effect on the dynamic response RMS values. However, acceleration PSD distribution of the titanium panels is changed by thermal environment greatly. With the increasing temperature of the titanium panel, the location of some response peaks shifts towards high frequency or low frequency. With the increasing temperature of the C/SiC panel, it is not obvious that the location of response peaks shifts towards high frequency.

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