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13. ABSTRACT *(Maximum 200 words)*
This report describes the work performed to predict dynamic response and stress limites for quartz tubes for the NASP prototype facility. The specific objective was to evaluate the responses of several flat plate, curved plate, and tube configurations when subjected to a given level of overall sound pressure level. The RMS stress values were obtained at several locations and the maximum value for each case is reported in this report. The objective of this study was to identify concepts with the RMS stress response that does not exceed the recommended design tensile stress level. Three concepts were investigated: the flat plate, curved plate; and cylindrical tube. The flat plate concept results in a high level of response. Several curved plates met the design criteria.

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1. Introduction

This report describes the work performed to predict dynamic response and stress limits for quartz tubes and plates for the NASP prototype test facility (refer to Figure 1. The specific objective was to evaluate the responses of several flat plate, curved plate, and tube configurations when subjected to a stationary random 180 dB overall sound pressure level (equivalent to 2.9 psi pressure) over 50-1,000 Hz bandwidth. The PSD pressure input at this level is 8.85×10^{-3} psi^2/Hz. The assumed level of damping in all cases except for those that were used to evaluate the effects of damping was 1%. The RMS stress values were obtained at several locations and the maximum value for each case is reported in this report. The objective of this study was to identify concepts with the RMS stress response that does not exceed the recommended design tensile stress level of 1,000 psi[1]. (The design stress for compression, however, is 160,000 psi.) Three concepts were investigated: the flat plate, curved plate; and cylindrical tube. The flat plate concept results in a high level of response and to bring the stress level below the design stress, the plate thickness would have to be increased to 0.75". Several curved plates met the design criteria.

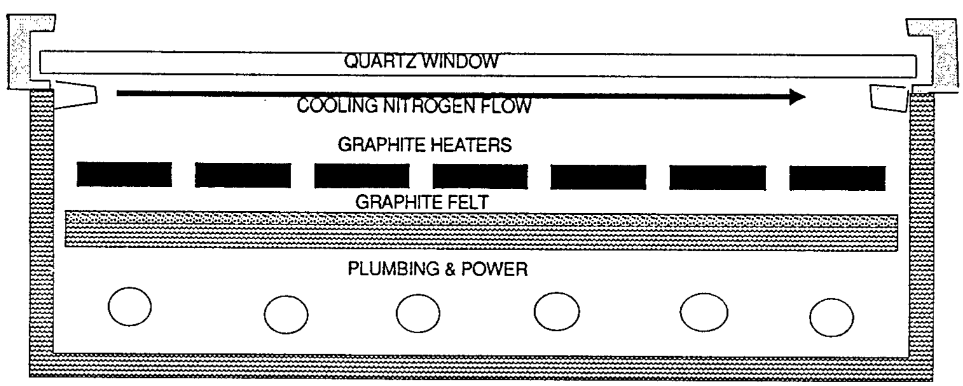

Figure 1: Prototype test fixture with flat plate

For all analyses, pressures were assumed to be perfectly correlated over the entire loaded surface. In fact, the flow of gas past the window will result in phase lags between any pair of points located at different streamwise stations. Omission of these phase lags from the analyses was thought to be conservative since phase-lagging pressures at various locations cancel each other out to some degree.

[1]The recommended design stress value for good surface quality fused quartz was obtained from GE Quartz Products brochure

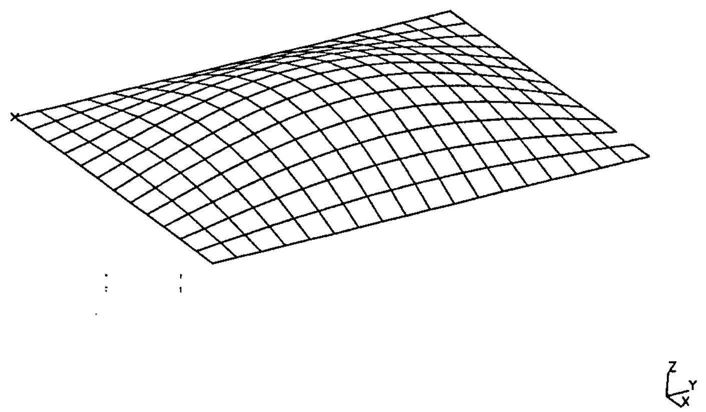

Figure 2: First bending mode of the simply supported flat plate

2. Flat Plate Concept

Several flat plate concepts were modeled, all with overall dimensions of 18" long and 12" width. The change in the stress response due to change in plate thickness and boundary conditions was investigated.

The first concept had 0.5" thickness with simply supported boundary at all four edges. The normal modes analysis was performed first to obtained natural frequencies below 3,000 Hz. There were four modes - all bending - within this range; Table 1 lists these modes. Figure 2 shows the eigenvector plot of the first bending mode. The maximum RMS stress, which occurs at the center of the plate, is 10,245 psi. Evidently, the level of response precludes this flat plate concept because the predicted stress were too high.

This concept was also used to investigate the effects of damping. Two cases were

Mode	Frequency (Hz)	No. of sine waves	
		Length	Width
1	769.4	1	1
2	1,474.7	2	1
3	2,368.6	1	2
4	2,653.3	3	1

Table 1: Normal modes of simply supported 18"x12" flat quartz plate (t=0.5")

Damping % critcal	RMS stresses (psi)
0.5	14,195
1.0	10,295
2.0	7,307

Table 2: Damping vs RMS Stresses of 18"x12" flat plate (t=0.5")

Mode	Frequency (Hz)	No. of sine waves	
		Length	Width
1	1,470.9	1	1
2	2,260.2	2	1

Table 3: Normal modes of fixed-fixed 18"x12" flat quartz plate (t=0.5")

run; one with structural damping of 0.5% and the other with 2%. Table 2 shows lists the change in RMS stresses due to three different level of damping. Even after increasing the damping to 2% level, the stress level is still relatively high (7,307 psi).

The second flat plate concept had fixed-fixed boundary at each of its four edges. The normal modes were obtained for all frequencies below 3,000 Hz. There were two modes within this range (Table 3). The maximum RMS stress, which occurs at the center of the plate, is 509 psi. Three and half times the RMS stress for 99% confidence level is 1,782 psi. This exceeds 1,000 psi of recommended design stress.

The third and fourth concepts involved change in the plate thickness to 0.75" and 1.0" respectively. Simply supported boundary condition was used for these analyses. Table 4 lists modes below 3,000 Hz and the maximum RMS stresses (the results for 0.5" thick plate are included for comparison.)

Table 5 provides the summary of results from the flat plate concepts. All concepts

	Plate thickness		
	0.5"	0.75"	1.0"
Mode 1 (Hz)	769.4	1,154.7	1,539.6
Mode 2 (Hz)	1,472.7	2,213,3	2,951.1
Max RMS Stress (psi)	10,249	629	254

Table 4: Comparision of simply supported 18"x12" flat plate (t=0.5", 0.75", and 1")

Boundary condition	Damping (%)	Thickness (in)	Max RMS (psi)
SS	0.5	0.50	14,195
SS	1.0	0.50	10,295
SS	2.0	0.50	7,307
FF	1.0	0.50	509
SS	1.0	0.75	649
SS	1.0	1.00	254

Table 5: Summary of results from five curved plate concepts

had overall dimension of 18"x12".

3. Curved Plate Concept

A number of curved plate concepts were considered, all had simply supported boundary along the edges. The finite element models were created using a mesh generation program *makecyl3,* specifically developed for this project.

The first concept had 18" length, 12" width, 18" radius, and 0.125" thickness. Normal modes were obtained for all frequencies below 3,000 Hz. There were fifteen modes within this range; Table 6 lists lowest five modes. The peak response due to uniformly applied load occurs near 1,234 Hz where 1 x 3 mode predominates (refer to Table 6 and Figure 4). The maximum RMS stress for this concept is 859 psi. Three and half times the RMS stress for 99% confidence level is 3,000 psi. This exceeds the recommended design stress.

The second concept was same as the first concept except for thickness which was increased to 0.25." Normal modes were obtained for all frequencies below 3,000 Hz. There were six modes within this range; Table 7 lists lowest five modes. The maximum

Mode	Frequency (Hz)	No. of sine waves	
		Length	Width
1	1,099.8	1	2
2	1,234.3	1	3
3	1,598.0	2	3
4	1,732.4	2	2
5	2,071.0	3	3

Table 6: Normal modes of simply supported cuved quartz plate (R=18", t=0.125")

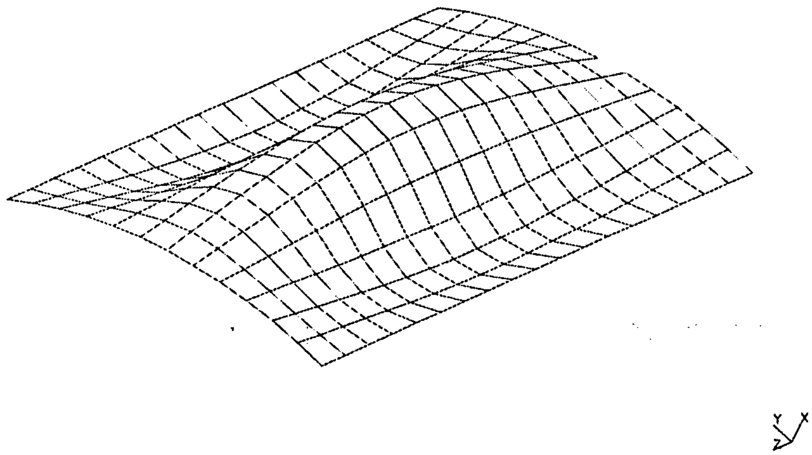

Figure 3: Bending mode of the simply supported curved plate (R=18", t=0.125")

Mode	Frequency (Hz)	No. of sine waves	
		Length	Width
1	1,475.6	1	2
2	2,197.2	2	2
3	2,203.8	1	3
4	2,541.6	2	3
5	2,878.7	3	2

Table 7: Normal modes of simply supported cuved quartz plate (R=18", t=0.25")

RMS stress for this concept is 341.5 psi. Three and half times the RMS stress for 99% confidence level is 1,195 psi. This exceeds the recommended design stress by about 20%.

The third concept had 60" length, 20" width, and 26" radius with 0.375" thickness. Normal modes were obtained for all frequencies below 2,000 Hz. There were thirteen modes within this range; Table 8 lists lowest five modes. The maximum RMS stress for this concept is 260.5 psi. Three and half times the RMS stress for 99% confidence level is 912 psi. This is within allowable design stress.

The fourth concept had 48" length, 10" width, and 7.25" radius with 0.25" thickness. There were nine normal modes below 3,500 Hz; Table 9 lists lowest five modes. The maximum RMS stress for this concept is 29.8 psi. Three and half times the RMS stress for 99% confidence level is 105 psi. This is well within allowable design stress.

The fifth concept had 60" length, 10" width, and 7" radius with 0.375" thickness.

Mode	Frequency (Hz)	No. of sine waves	
		Length	Width
1	634.3	1	2
2	873.6	2	2
3	1,125	3	2
4	1,148	1	3
5	1,212	2	3

Table 8: Normal modes of simply supported cuved quartz plate (R=26", t=0.375")

Mode	Frequency (Hz)	No. of sine waves	
		Length	Width
1	1,344	1	2
2	1,871	2	2
3	2,479	3	2
4	2,610	1	3
5	2,690	2	3

Table 9: Normal modes of simply supported cuved quartz plate (R=7.25", t=0.25")

Mode	Frequency (Hz)	No. of sine waves	
		Length	Width
1	1,733	1	2
2	2,059	2	2
3	2,502	3	2
4	2,992	4	2
5	3,484	5	2
6	3,758	1	3

Table 10: Normal modes of simply supported cuved quartz plate (R=7", t=0.375")

Radius (in)	Length (in)	Width (in)	Thickness (in)	Max RMS (psi)
18.0	18.0	12.0	0.125	859
18.0	18.0	12.0	0.250	341.5
26.0	60.0	20.0	0.375	260.5
7.25	48.0	10.0	0.250	29.8
7.0	60.0	10.0	0.375	28

Table 11: Summary of results from five curved plate concepts

Normal modes were obtained for all frequencies below 4,000 Hz. There were nine modes within this range; Table 10 lists lowest six modes. The maximum RMS stress for this concept is 28 psi. Three and half times the RMS stress for 99% confidence level is 98 psi. This is well within allowable design stress. As expected, the lower the radius of curvature, the lower the stress level. Table 11 provides the summary of the first five curved plate cases.

Additionally, a parametric study was performed to determine effects of the plate thicknesses and radii of curvature on the response. Specifically, three thicknesses (0.125", 0.15", 0.175", and 0.20") and four curvatures (6.0", 6.5", 7.0", 7.5") were chosen. The length and width of the plate was set at 24" and 5", respectively. Table 12 provides the summary of the six curved plate cases. Overall, smaller the radius of curvature of the plate, lower the level of RMS stress. Also, the increase in the plate thickness reduces the response. Howeve, responses from several concepts did not fit this trend. The variation from the expected response is estimated to about 15%. This may be due to instances where a mode with high participation factor may have been left out of the solution set in the modal response analysis.

4. Tube Concept

Two tube concepts were considered, all with simply supported boundary condition but with different configuration. Test fixture for this concept is as shown in (refer to Figure 4.) The finite element model was created using a mesh generation program *maketube*, specifically developed for this project. In analyzing the tube concept, a question arose as to how to apply the loads. Obviously, the pressure would act to some extent on the back side of as well as the front side. Application of a uniform load all around the tube would excite only the "breathing" mode of the tube, would be unrealistic and unconservative. It was decided conservatively, to apply the load only to the outer 180°.

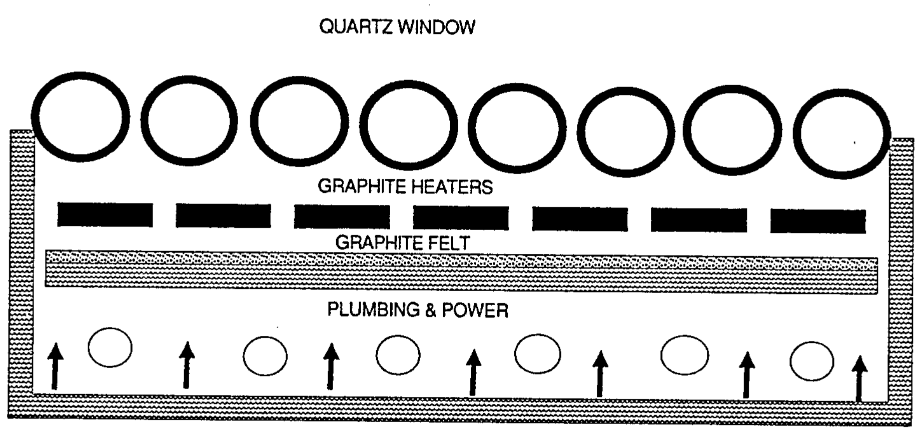

Figure 4: Prototype test fixture with tube

The possible problem of tubes touching each other was not investigated. No significant streamwise deformation would be predicted unless the load were applied with same sort of streamwise bias.

The first concept had 72" length, 3" radius with 0.125" thickness. Normal modes were obtained for all frequencies below 2,000 Hz. There were 23 modes within this range; Table 13 lists lowest six modes. Note that due to the symmetry in the model, there are two eigenvectors for each eigenvalue. The peak response due to uniformly applied load occurs near 450.9 Hz where first global bending mode predominates (refer to Table 13.) The maximum RMS stress for this concept is 9,985 psi. This exceeds the recommended design stress.

The second concept had 11" length, 3" radius with 0.125" thickness. Normal modes were obtained for all frequencies below 7,000 Hz. There were 16 modes within this range; Table 14 lists lowest six modes. Note that due to the symmetry in the

Mode	Frequency (Hz)	Mode type
1	450.9	First global bending (zx plane)
2	450.9	First global bending (yz plane)
3	607.0	First ring mode
4	607.0	First ring mode
5	715.8	Second ring mode
6	715.8	Second ring mode

Table 13: Normal modes of simply supported tube (L=72", R=3", t=0.125")

model, there are two eigenvectors for each eigenvalue. The first global bending is 6,475 Hz. The maximum RMS stress for this concept is 170 psi. This is well below the recommended design stress.

Table 15 summarizes the tube concepts investigated; thickness of both concepts was 0.125" and radius was 3".

Mode	Frequency (Hz)	Mode type
1	2,903.2	Third ring mode
2	2,903.2	Third ring mode
3	3,694.3	Second ring mode
4	3,694.3	Second ring mode
5	3,776.0	Third ring mode
6	3,776.0	Third ring mode

Table 14: Normal modes of simply supported cuved quartz plate (L=11", R=3", t=0.125")

Length (in)	First global bending (hz)	Max RMS (psi)
11.0	450.9	9,985
72.0	6,475	170

Table 15: Summary of results from two tube concepts

5. Conclusion

The curved plate concept seems most promising. In summary, the RMS response decreases substantially when the lowest mode of the plate is higher than the highest forcing frequency which is 1,000 Hz. This can be achieved by selecting a set of the plate thickness and radius of curvature so that the lowest mode is higher than 1,000 Hz. To keep the response below the recommended design stress (i.e. three and half times the RMS stress less than 1,000 psi), the 18"x 12" flat plate needs to be about 1" thick. On the other hand, the curved plate with 18" radius can be only 0.375" and still meet the design criteria.