ANGKASA Reverberation Acoustic Chamber Characterization

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Abstract: - Reverberation acoustic chamber has been designed to stimulate as many mode as possible over the frequency spectrum in line to simulate the launching stage and define strength and stress on the test object. Launching stage is producing highly intensity of acoustic pressure by the propulsion system to the launcher's payload and causing numerous of stress and constraints. Knowing the capabilities of the chamber be able to stretch its characteristic thru analysis and calculation. Reverberation time, T_r has been completed by integrated impulse response method. Additional analysis for repeatability measurement can be performed in order to know the exact value for each central frequency T_r. For the chamber diffusivity, number of acoustic mode, frequency response, and natural resonance frequency (MAXTIQ) has been defined. In succession to have sufficient analysis on total spread of frequency spectrum, the modal density, *MD* and modal analysis, *MS* has been included. Results shown that chamber can fulfilled in providing the reverberation acoustic test. Most of the chamber resonance cater at least one mode in the half power band width of the test object. Lower frequencies is well covered eventhough it is limited characteristic. Based on the analysis the absorption coefficient are in reasonable arrangement and the calculated equivalent sound absorption area are none exceeds the maximum limit for a chamber volume of 999.5m^3. There is lessen absorption factor when the environment are totally dry air. ANGKASA's RATF OASPL has the capability to meet the maximum 155dB requirement. Further analysis is suggested with different arrangement of OASPL in the chamber for pattern evaluation.

Key-Words: - Characterization, Acoustic, Frequency Response, Noise, Diffusivity, Absorption

1 Introduction

The Reverberation Acoustic Test Facility at National Space Agency of Malaysia (ANGKASA) consists of reverberation chamber, which bounce the sound wave in all directions, noise generation system, noise control system and safety interlocking system. The reverberation chamber has multiple usages, including source power level measurements of sound sources, experimental of random incidence absorption coefficients of materials by using the noise source as transmission loss testing, and for high intensity noise testing to establish the vibration response and fatigue tolerance of aerospace structures[1].

Reverberation chamber are precisely designed in order to stimulate as many mode as possible over the frequency spectrum. Most of the acoustic test except the source power level measurement, nitrogen gas will be fill up i n the chamber as medium to homogenize the sound wave scattering and reduce the absorption factor that could appear from the ground support equipment and the chamber's environment. A totally dry air environment be able to build least absorption factor.[9] Typically, the chamber wall, floor and ceiling is heavy duty concrete build up and the surface is epoxy coated which will help to propagate the sound wave as per at the launching pad or in the launcher's nosecone.

Launching stage is producing highly intensity of acoustic pressure by the propulsion system to the launcher's payload and causing numerous of stress and constraints. The high intensity acoustic pressure causes a vibration excitation inside and outside of the launcher. The produced stress is capable to damage most of the spacecraft's structure and components. Most of the common failures is such as failure of the joint structures, crack on the circuit board, interior misalignment optical elements, failure of electronics and chafing of wires.[6] Sound pressure level in the fairings of most commercial launch vehicles is over 140dB and the frequency of the sound ranges is up to 10 kHz[8].

In the reverberation chamber, the sound wave will be generating through the horns that capable to produce multiple type of frequency from 25 Hz to 10 kHz.[6] The stress take place for a short time and typically for one or two minutes. Exposure in the simulated acoustic reverberation test will provide improvement and determination the reliability of the spacecraft components in order to survive the actual launch's acoustic sound pressure. With this testing, all the calculated risks such as the premature malfunctions and the failures can be eliminated or minimized.

2 Facility Arrangement

The acoustic chamber in ANGKASA is a rectangular parallelepiped chamber build up. The 999.5 m^3 reverberation chamber is about 9.79 m by 7.54 m by 13.54 m with surrounding 0.45 m thick reinforced concrete building walls. Chamber Dimension Ratio's based on the ISO 354 requires that the longest straight line (diagonal) in the chamber is such that the following condition is fulfilled.[1]

$$I_{max} < 1.9V^{1/3} \quad (1)$$

where I_{max} for the RATF was calculated is 16.68m. The ratios of the chamber dimensions relative to its height are 1:1.31:1.80 which as a whole can achieving a more uniform distribution of the modes in the low frequency bands. This method been developed by Richard Bolt and Walker in yielding the smoothest frequency response at low frequencies.[1] It is structurally isolated from the rest of the building by rubber seal and cemboard in turn to avoid any vibration coupling issue. The chamber condition will not only provides homogeneous mean energy density and pressure, but reduce the effects of standing waves between opposite surfaces and boost the diffusivity of the chamber at lower frequencies.

The noise generation and noise control is a close-loop acoustic system which generate, stabilize and measures sound field in chamber. All the measurements data will be recorded and processed after the test. Acoustic source is provided by four electro-pneumatic airstream modulators with either a sine wave or random noise input over a frequency range 25 Hz to 10 kHz. Each modulator will supply the sound energy to the chamber through the fiberglass exponential horns. Two large horns, with a 25 Hz and 50 Hz cut-off frequency will be used for requiring a very high intensity noise source at low frequencies. Two small horns, with both cut-off frequency of 200 Hz is intended to enhance the low frequencies. All horns assemblies are mounted on the upper side of the wall.

3 Measurement Configuration

For the measurement configuration in the acoustic testing, 8 units of microphones were being used. The microphones function is to measure the level of noise in the chamber. Measurement locations selected with different height positions from 1 m to 2 m and 1 m from any chamber surface. To avoid the effects from the direct emitted sound, the distance between chamber surface and microphone should exceed a minimum distance, d_{min} which can be estimated by the Equation 2[1]

$$d_{min} = 2 * \sqrt{\frac{V}{cT_r}} \quad (2)$$

where V is the volume of the chamber, c is the speed of sound in nitrogen at ~22°C, and T_r is the reverberation time. Acoustic pressers are higher at reflecting surface like walls, floors, and ceilings.[6] Another 1 unit of microphone being used to monitor the outside chamber noise level just in case of sound leakage. Fig. 1 is representing the layout of the measurement configuration.

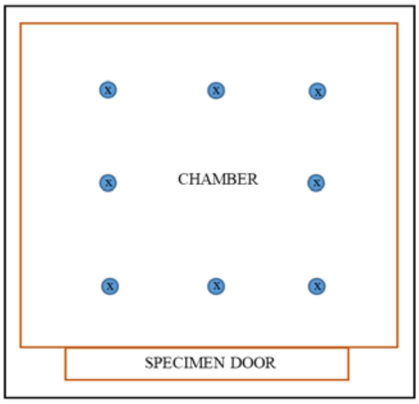

Fig. 1 Configuration of 8 Microphones

Reverberation time, T_r is the decay time for sound in a chamber after excitation stops. It is the time for a 60 dB drop in level but decay is usually evaluated over a 10, 20 or 30 dB drop. T_r is usually measured by the 1/3 octave band centre frequency (generally between 100 Hz and 2000 Hz).[5] Although, the sound field in a reverberation chamber is not a perfect diffuse field, the T_r been measured repeatedly with different sound sources and measurement locations within the chamber.[5]

The spatial average value is calculated as the T_r accordance to ISO 3382. Based on the T_r measurement, the average value for the T_r is 15 seconds and the highest T_r is 33 seconds at 100 Hz. Table 1 is showing the T_r values for the each selected frequency and d_{min}. The sufficient for a minimum distance between surface and a microphone is 0.89 meter. Therefore the current configuration for the measurement is comply with this equation.

Table 1 Reverberation Time and Minimum Distance of Measurement Configuration

1/3 Octave Band Central Frequency, f (Hz)	Reverberation Time, T_r (s)	Minimum Distance, d_{min} (m)
100	33	0.60
125	27	0.66
160	20	0.76
250	14	0.92
500	13	0.95
1,000	10	1.08
2,000	9	1.14

4 Room Diffusivity

In the reverberation chamber, the sound wave will be generate from the noise source and propogate forward and backward at the room surface and becoming resonances. These create stationary waves that are producing nodes and high pressure zones in the chamber. The diffusivity of the sound field in the chamber is dependent on the frequency from the lowest range to higher frequencies. A diffuse sound field is defined as an acoustic environment in which the acoustic energy density is equal at all locations.[1] The importance of a diffuse sound field is to establish the sound power level from the sound pressure levels in the chamber.

Chamber condition and boundary provide equal acoustic energy of sound wave flows in all directions. The rectangular parallelepiped chamber can be represented by axis x, y and z. Each axis will response respectively to the wave number. From these the normal mode frequencies of the chamber can be calculated. It is not only provide the geometry of the chamber but also the acoustic modal response. The mode frequencies can be defined by Equation 3,

$$f_k = \frac{c}{2}\sqrt{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_y}{L_y}\right)^2 + \left(\frac{n_z}{L_z}\right)^2} \quad (3)$$

where n are the respective mode in those axis and L_x, L_y, L_z are the length, width and height. On the number of acoustic mode, N, in a rectangular room between lower and upper limit can be calculated based on Equation 4 (Morse and Blot, 1944)[17] where the number of modes is represent as,

$$N = \frac{4\pi f^3 V}{3c^3} + \frac{\pi f^2 S}{4c^2} + \frac{fL}{8c} \quad (4)$$

where f are the frequency limit (one-third octave), S are the room total surface and L is the total perimeter of the room. Fifty modal frequencies were computed in the reverberation chamber for the 80 Hz and lower one third octave bands. Table 2 is showing the number of modes at low frequency up to 100 Hz. These are representing the number of modes at central frequency that will resonate in the chamber. While for the frequency responses for RATF chamber up to 100 Hz are shown in Fig. 2. The modal density, MD is defined by Equation 5[1]. The number of modal density is indicate the frequencies range of 1 Hz in the total spread of frequency spectrum.

$$MD = \frac{4\pi f^2 V}{c^3} + \frac{\pi f S}{2c^2} + \frac{L}{8c} \quad (5)$$

Table 2 Number of Modes of RATF

Central Frequency, f (Hz)	20	25	31.5	40	50	63	80	100
RATF	*1*	*3*	*5*	*8*	*14*	*28*	*50*	*86*

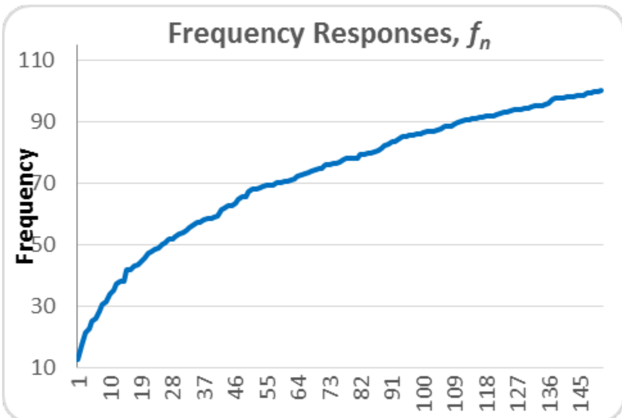

Fig. 2 Chamber Frequencies Responses up to 100Hz

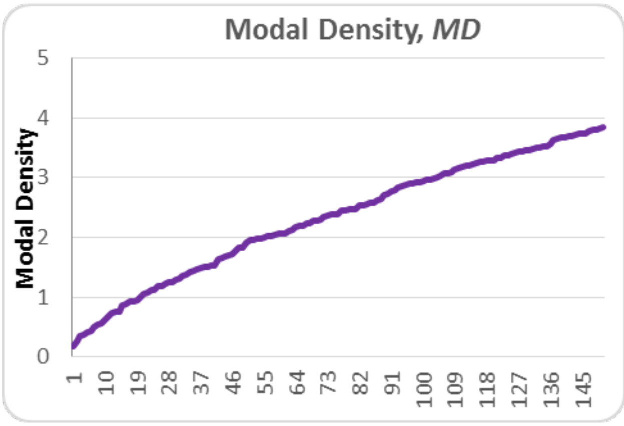

Fig. 3 Modal Density for ANGKASA's RATF

From the Fig. 3, the result shown the calculated modal density that representing the chamber's performance. The primary parameter of a chamber is the minimum acceptable volume of the chamber. Overall size, volume and design help derive the acceptable reverberant acoustic test field due to lower frequencies require large scale of dimension. On this matter, with the 1000m^3 volume chamber; the chamber can fulfill the criteria on providing the reveberantion acoustic test. As per result, lower frequencies is well covered and the graph is relatively smooth increased. The larger chamber has the capability to analysis the low frequencies level more better and provide more resonance and precise data measurement in that area.

Analyzing the gaps between each frequency in the chamber is also significant in order to evaluate the gap value that occurs between the generated frequencies. The modal density or modal spacing of the chamber should be denser than the test object. This is to ensure the conducted test are able to classify the shape and the parameter to be observed. Modal Spacing, *MS* are as defined in Equation 6. Fig. 4 is representing the calculated MS. Chamber mode spacing is increases with the decreasing frequencies. This characteristic shows the capability of the sound pressure to excite the resonance modes of the test object. The ideal case is at least one mode should be located in the half power band width of the test object. Usually, in the small chamber, the *MS* tendencies to be very large and irregular at low frequencies. Based on the Fig. 4, the shape of the RATF's *MS* is identical with the theoretical. The large gap between frequencies at the lower range is normal due to the size of the chamber. Whereas the gap at higher range is much smaller due to the number of modes in the range is higher .

$$MS = \frac{1}{MD} \qquad (6)$$

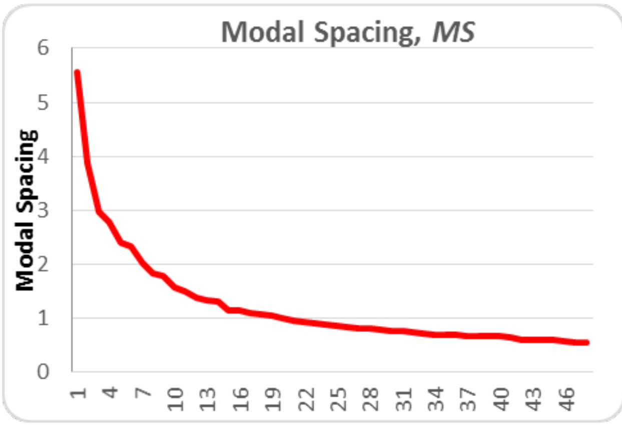

Fig. 4 Result of the Modal Spacing

There are two characteristics of an individual resonance mode of a test object. One is the mode's natural resonance frequency, f_{TI} and second, its magnification factor, Q_{TI}. The capability of a reverberation chamber to excite the test object resonance modes may be developed by adopting the criterion that there be at least one chamber mode frequency lying within the half power bandwidth of the test object resonance. For a given f_{TI}, there is a maximum value of Q_{TI} that will justify the criterion. MAXTIQ is a basic characteristic of a reverberation chamber, and it is a function of frequency. MAXTIQ been defined as Equation 7. The MAXTIQ of the RATF are shown in Fig. 5 where the red dot is representing the 25Hz frequency and the *Q* value is 10. This is minimal requirement for a 1000m^3 volume size reverberation acoustic chamber. While for larger chamber has higher *Q* value due to bigger volume size that provide more resonances and fine scale data.

$$MAXTIQ = Q_{TI} = \frac{f_{TI}}{MS} \qquad (7)$$

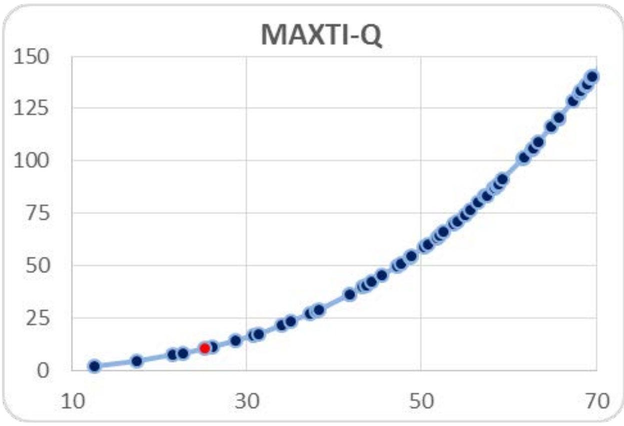

Fig. 5 RATF MAXTIQ Result

5 Room Absorption

The equivalent sound absorption area, A in a reverberation chamber can be derived from the reverberation time, T_r and the atmospheric absorption correction term, m in Equation 8. The value of m is dependent on the environment in the chamber such as temperature, relative humidity and atmospheric pressure during the test.

$$A = \frac{55.3V}{cT_r} - 4Vm \qquad (8)$$

The power attenuation coefficient, α_c can be calculated through the average Sabine absorption coefficient, $\bar{\alpha}$ by diving the equivalent sound absorption area by the total surface area of the chamber in Equation 9. Table 3 list the calculated power attenuation coefficient, the atmospheric absorption correction and equivalent sound absorption area for 1/3 octave band central frequency. The result show that the average Sabine absorption coefficient are in reasonable arrangement. While for the equivalent sound absorption area showing that none of the computed equivalent sound absorption area over the frequency range of interest exceeds the maximum limit for a chamber volume of 999.5m^3 when performing sound absorption measurements.

$$\bar{\alpha} = \frac{A}{S} \qquad (9)$$

Table 3 Calculated power attenuation coefficient, the atmospheric absorption correction, equivalent sound absorption area and average Sabine Absorption Coefficient.

1/3 Octave Band Central Freq., *f* (Hz)	α_c **(dB/m)**	**4Vm (m^2)**	**A (m^2)**	$\bar{\alpha}$
100	0.0001	0.03	4.85	0.01
125	0.0002	0.08	5.92	0.01
160	0.0004	0.13	8.00	0.02
250	0.0006	0.21	11.42	0.02
500	0.0008	0.30	12.30	0.02
1,000	0.0012	0.41	15.99	0.03
2,000	0.0015	0.54	17.77	0.04

6 Sound Pressure Level (OASPL)

The design of RATF chamber is to cater 155dB frequency spectrum profiling. With the noise generation and noise control system embedded with dedicated modulators pressure, the capability to achieve the target design is sufficient. The modulators be about to set up to within the range 24 psi to 28 psi for both WAS3000 and 30 psi to 38 psi for both WAS5000. The temperature setup is at 24°C ±1°C for an identical pressure and be able to be controlled.

The data collection setup arrangement through the microphone is still at the same configurations. After all modulators pressure are stable, noise generation will start producing noise pending to all the parameters reached the predetermined graph where which is 155dB graph profile. For the controlled parameters, the tolerance has been set on ±1dB or ± 3dB in the initial system design specifications. Fig. 6 is showing the OASPL 155dB where the blue line is the achieved graph between the red line (maximum tolerance) and the orange line (minimum tolerance). Further test, analysis and discussion need to be go through on the 25Hz as a result of below minimum limit. Different OASPL need to be arrange in order to materialize the pattern of the OASPL in the chamber.

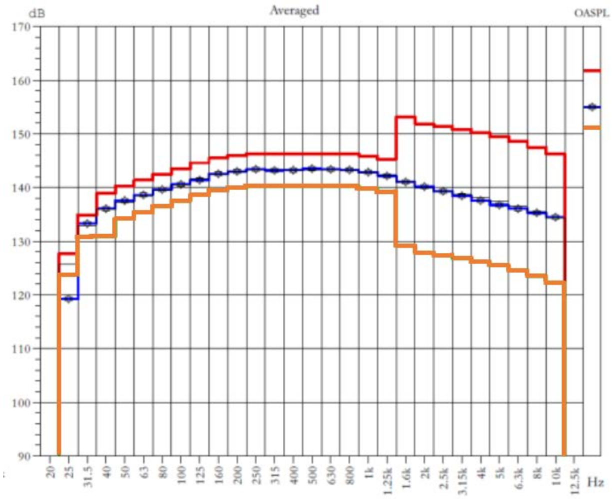

Fig. 6 OASPL 155dB with tolerance

7 Conclusion

Measurement were accomplished and results were analysed to characterize Reverberation Acoustic Test Facility at ANGKASA. The ratios of the chamber dimension is a good condition where the results is 1:1.31:1.80. These has identified the uniform distribution of the modes of the chamber in low frequency bands. Reverberation time, T_r has been done by using interrupted noise method or integrated impulse response method. It was performed by the arrangement of loudspeakers as the sound source. From the results, it show that the T_r decay as the frequency increased. The average value for the T_r is 15 seconds and the highest T_r is 33 seconds at 100Hz. Additional analysis can be performed in order to know the exact value for each central frequency T_r. Repeatability measurement is recommended therefore more reliable data can be analysis. The measurement configuration were compliant with the International Standards over the frequency range of interest.

For the chamber diffusivity, number of acoustic mode, N and the (mode) response frequency, f_k against the volume size of the chamber has been tested. The results show that fifthy modal frequencies were computed in the reverberation chamber for the 80 Hz and lower frequencies and it is adequate cover in the lower frequencies. On total spread of frequency spectrum, modal density, *MD* results shown that the chamber can fulfilled in providing the reverberation acoustic test. Based on the modal spacing analysis, the gaps between each frequency in the chamber is increasing with the decreasing frequecies. What is important for the resonanse is to cater at least one mode should be located in the half power band width of the test object. The basic characteristic of a chamber is define by the mode's natural resonance frequency, f_{TI} and second, its magnification factor, Q_{TI}. The MAXTIQ's result shown that Q value equal to 10 at 25Hz frequency. This is significant condition for a small volume size reverberation acoustic chamber.

Analysis on t he chamber absorption, it was conclude that the absorption coefficient are in reasonable arrangement. Whereas the computed equivalent sound absorption area are none exceeds the maximum limit for a chamber volume of 999.5m^3. It is recommended with Schroder frequency and other extended central frequency in order to verify the broadband measurement results. ANGKASA's RATF OASPL has the capability to meet the maximum 155dB requirement even though there is slight mischief on the 25Hz output. Further analysis is suggested with different arrangement of OASPL in the chamber for pattern evaluation.

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