Relative Characteristic Analysis on Reverberation Acoustic Facility

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Abstract: - The structure of reverberation acoustic chamber stands as a critical development parameter for the account of guaranty on the full frequency response coverage. That is because the chamber itself is a subset of the test system which is too stimulating the greater number of mode. Considering the launching environment is generating extreme acoustic pressure intensity process in the launch vehicle's nosecone. Defining the control channel or mode for the system is significant. Each reverberation space has its specific boundary form due to the size, shape, and volume of the chamber. Understanding the ability, performance, limitation and acoustic response stay crucial to gather all information on the chamber characteristic. Assessment characteristic deliberates functionality of the chamber in ANGKASA compared to other facilities in space acoustic testing. The relative results shall give more information on whether ANGKASA's facility is capable of delivering the same scale of testing with the existing acoustic chamber on the small and medium space object. Future enhance assessment shall be carried on to prove the performance of ANGKASA's facility it fit for purposes and knowing the chamber is a compliment to each other.

Key-Words: - Characterization, Acoustic, Frequency, Noise, Density, Spacing

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1 Introduction

The function of Reverberation Acoustic Test Facility (RATF) is used to test articles subject, inclusive of the flight module system. The facility is to test spacecraft such as satellite, space module, equipment, or subsystems under the simulated acoustic field with the high-intensity pressure of a launcher vehicle. The volume of these chambers typically falls in the range of $1000m^3$ to $2200m^3$ although there are chambers out of this range [1]. Most of the RATF able to produce overall sound pressure level from range 130 dB to 160 dB based on the design need and purpose. Most commercial launch vehicles produce over 140dB sound pressure level in the fairings and the sound ranges frequency is up to 10 kHz [2]. For the large RATFs, a varied range of satellites able to assess because of the ability to produce a wide range of acoustic spectra for the acoustic test.

The sound wave generating in a chamber is through horns system that is capable of produce multiple frequencies types up to 10 kHz [3]. The development of reverberation acoustic chamber is the critical process stage where it is subject to the full frequency response as the product. That is because the chamber itself is a part of the test system. Each reverberation chamber has its specific boundary condition due to the dimensions and shape of the chamber. By understanding the ability, performance, limitation and the response, the assessment characteristic of the chamber be able to discover. For each facility, the chamber characteristics need to shape the acoustic test conditions and the aim volume size.

Theoretically, the chamber volume determines the lowest frequency outcome where it provides an acceptable reverberation acoustic test field since lower frequencies need larger chamber dimension [4]. An outsized chamber facility is expensive; nevertheless, create advantages on lower cut-off frequency. Small chambers require less power and are less expensive, but have a higher low-frequency cut-off. Still, the cost may be exponential due to the volume size and more details construction to carry out.

The RATF system is consist of noise generation system, control system, the interlocking system for safety measure, support system and the main item reverberation chamber. High-intensity noise is generated using electro-pneumatic noise sources, such as the Wyle Acoustic Source (WAS) electro-pneumatic gas stream modulators like the WAS 3000 and WAS 5000 [6]. In common practise, the noise generation system utilizes nitrogen (N2) gas from the vaporizer system from the liquid nitrogen. The transformation is necessary in order to create a uniform environment and minimize the environmental effect caused by the water vapour, oxygen and mixture gases to the generated noise [19]. The nitrogen surrounding also is creating a simulation of the launch phase scenario.

Since most of the RATF has similar system setup, yet the chambers have a different dimension that contributes to the advantages and limitations for the sound wave propagation and direction. The prerequisites to investigate and determine the chamber characteristic shall provide more findings and indicates the functionality of the facilities. The research objective is to characterize the current chamber and perform a relative analysis between the selected acoustic facilities. This shall provide an important statement on ANGKASA's facility whether it fit for purposes and knowing the chamber is a compliment to each other.

2 Chambers Selection

On this research, there are several established RATFs has been identified to evaluate the calculated performance comparing with ANGKASA's RATF. These RATFs has different sizes build up and volume between each chamber, nevertheless deliver the performance and heritage in performing space grade acoustic test for satellites, space capsule/module, launch vehicle nosecone, equipment, and subsystems. The selected established RATFs are Thales (Alenia Space), Japan Aerospace Exploration Agency (JAXA), Indian Space Research Organisation (ISRO), and Intespace (AIRBUS).

The significance of this selection is subject to the volume size of the chamber and the experiences of performing acoustic tests. ANGKASA's RATF is a new facility in this test field. It is the first facility in Southeast Asia and capable of supporting the demands on performing the acoustic test at a different level. On top of that, Malaysia's industry can continue to grow with this facility's support. The non-space acoustic test also can be accomplished in the reverberation chamber.

The other chambers selection is to pinpoint how the chamber dimension play a significant role in the frequency of sound wave creation. Table 1 is tabling the dimension and chamber ratio based on the height dimension of each RATF.

Table 1 Reverberation Time and Minimum Distance of Measurement Configuration

Name	**Dimension W, L, H (m)**	**Ratio**
ANGKASA	7.54: 9.79: 13.54	1: 1.30: 1.80
Alenia Space	7.99: 10.0: 12.59	1: 1.25: 1.58
Intespace	8.2: 10.3: 13.0	1: 1.26: 1.59
ISRO	8.2: 10.33: 13.0	1: 1.26: 1.59
JAXA	7.7: 9.7: 12.2	1: 1.26: 1.58

The relative ratio of dimension (length, width, and height) of a chamber are furthermost important. Based on Bolt and Walker researches, the range of chamber ratio that shall be producing the smoothest chamber characteristics at low frequencies has been represented by criterion in Figure 1 [17]. The chamber dimension ratio for all reverberation chambers has been plotted in Figure 1.

The Blue mark is representing ANGKASA whereas Yellow and Orange marks are representing other agencies. From Figure 1, the result of the ration for all RATF is in the Bolt and Walker plot area. Although Bolt and Walker's studies are based on small rectangular chambers, the significance of the ratio value and the criterion indicating chamber dimension yielding the smoothest response and uniform distribution at low-frequency mode.

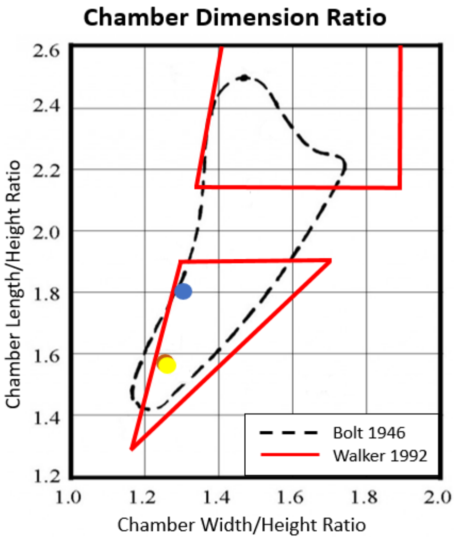

Fig. 1 Bolt and Walker Criterion

3 Frequency of Sound Wave

The chamber parameters have it is own boundary condition due to the size of the chamber. The number of modes will reflect the acoustic response of the chamber. As the wave number, k is defined by integer axis (nx, ny, nz) over the chamber dimension (Lx, Ly, Lz), the modal resonance frequencies can be produced [14, 15]. The integer for each axis (nx, ny, nz) can be valued start from 0 up to the significant number that able to represent the frequency mode (number) and the frequency which been generated [15]. The modal resonance frequencies can be defined as Equation 1 has been used by Krzysztofik, 2009 [5].

$$f_k = \frac{c}{2}\sqrt{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_y}{L_y}\right)^2 + \left(\frac{n_z}{L_z}\right)^2} \qquad (1)$$

where L is the length (x), width (y) and height (z) of the chamber and c is the wave velocity in the chamber, c=3.108 m/s as in free space. The number of acoustic modes, N has been calculated based on the extension of Equation 1 with the limits frequencies in the 1/3 octave band. Equation 2 which been used by Morse and Bolt, 1944 [9] where the number of modes is represented as

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

where f is the selected frequency limit (1/3 octave), V is the room volume, S is the total room surface and L are the total perimeter of the room. Table 2 is indicating for each chamber parameters. Different volume size of the chamber plays a significant role in producing different type number of mode and the acoustic resonance [13]. The most important objective is to provide the chamber's performance in creating the launch profile during the testing.

Table 2 Facilities parameters for mode calculation

Name	Room Volume	Room Surface	Room Perimeter
ANGKASA	999.48	503.96	123.48
Alenia Space	1,005.94	488.97	122.32
Intespace	1,097.98	518.00	126.00
ISRO	1,101.18	518.84	126.12
JAXA	911.22	459.36	118.40

The calculated chambers frequencies response below 100 Hz is shown in Figure 2. Below 31.5 Hz, there were limited numbers of resonance due to the response of the sound wave in the chamber. The calculated frequencies were increased subject to the increasing of the integer numbers and the interference of the incident waves and the stationary wave in the chamber. The result can be used as the chamber's performance graph in profiling the chamber. The result of the mode calculation is shown in Figure 3 for each of the chambers.

Volume size of the chamber above 1000m^3 is showing that the number of modes is slightly higher compared to others. However, below 1000m^3 volume size is a bit lower in value. These same situations occur with the chamber's performance graph in Figure 2 where the frequencies response for Intespace and ISRO indicate of generating more resonance compared to others.

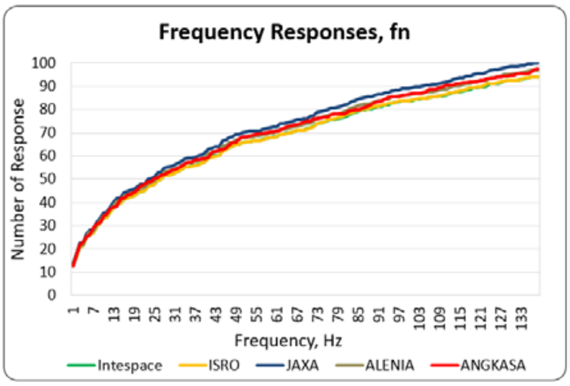

Fig. 2 Chambers Response below 100Hz

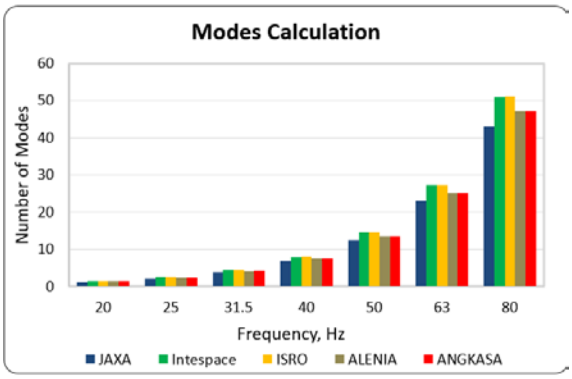

Fig. 3 Comparison chamber's calculated modes

4 Chamber Performance

Essentially, the number of modes involve the length of the edge which is axial modes, areas of walls which is tangential modes and volume of a cavity which is oblique modes [11]. These can derive the modal density of the chamber as regards to the indicated frequencies range of 1 Hz of the total frequency spectrum spread. The modal density, MD is defined by Equation 3 where it represents the chamber capability and performance [7].

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

MD is the differential value of a rectangular reverberation chamber that been retrieve from the frequencies. Figure 4 is the Modal Density assessment for each chamber against the frequencies response.

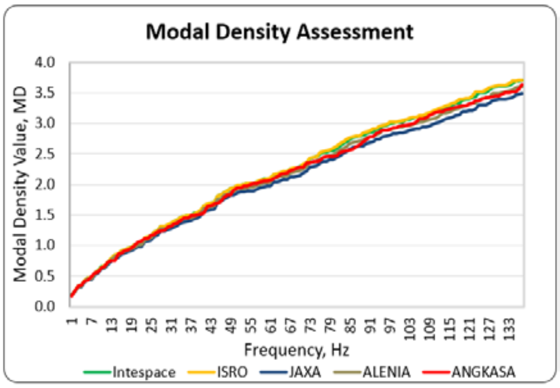

Fig. 4 Modal Density for each chamber

Based on the simulation, it is defined that each chamber has low modal density value at below 50 Hz range but quadratic increasing as the increasing frequency at higher frequencies. This show that it is impossible to have a 1000m^3 chamber that has five modes in the 20 Hz 1/3 octave band. The result also shows that each chamber has its own pattern of performance due to volume size.

Nonetheless, for Intespace and ISRO which is having almost the same dimension and volume size, the performance graph is still different. ANGKASA and Alenia has very nearly similar performance graph. This similarity provides benefit to ANGKASA's RATF by adopting Alenia's chamber as a benchmark on profiling test acoustic test.

Spatial analysis between the frequencies response, the modal spacing, MS calculation has been implemented as per Equation 4 which been used by Im [16]. This value is indicating the stretch gap between the frequencies based on the chamber size.

$$\mathrm{MS} = \frac{1}{\mathrm{MD}} \qquad (4)$$

Based on the modal spacing result in Figure 5, it shows that each chamber modal spacing decrease with increasing frequency. This occurrence is predictable for a small chamber where there are big gaps between the frequencies mode below 50 Hz compared to the bigger chamber.

The result indicates that ANGKASA's mode spacing is better than JAXA. Meanwhile, Intespace and ISRO mode spacing is much smoother than the rest. This relationship occurs with the larger volume size where it provides more area for the sound to propagate and offer smaller gap on among the frequencies [8].

The modal spacing or modal density analysis is essential to ensure that the chamber performance and capability in acoustic testing are denser than the test object. Comparing the evaluation result from Figure 5, ANGKASA's chamber is fit for purpose in acoustic testing.

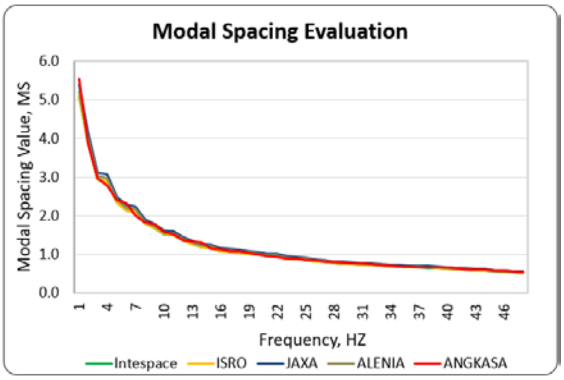

Fig. 5 Modal Spacing vs Frequencies response

Chamber resonance can cover at least a single mode of half bandwidth power from the test object [18]. The individual test item resonance mode is based on two characteristics. First is the mode of the natural resonance frequency, fTI and second is the magnification factor, QTI [16].

According to Monastero, 2013 [10], when the mode of vibration is excited by force at the same frequency between the chamber, fCh and natural resonance frequency, fTI, the maximum response of the test mode will be generated.

However, the maximum response value is small and can be assumed by the half-power or "-3 dB" [11]. The half-power bandwidth of the test item resonance, ΔfTI is defined by the natural resonance frequency, fTI over the magnification factor, QTI [1].

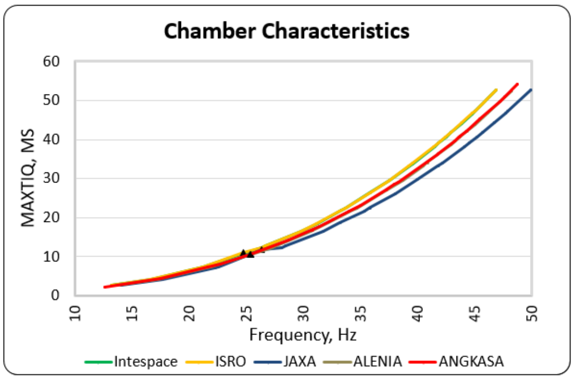

Fig. 6 Characteristic of chamber's MAXTIQ

The maximum value of QTI can be justified by the chamber's frequencies response. This is through the natural resonance frequency, fTI and the modal density, MD. MAXTIQ is a basic characteristic of a reverberation chamber and can be calculated using an analytical model which been defined as Equation 5 [16].

$$\mathrm{MAXTIQ}\left(\mathrm{Q}_{\mathrm{TI}}\right)=\mathrm{f}_{\mathrm{TI}}\ MD$$

The MAXTIQ of the RATF's chamber is shown in Figure 6 where the black triangle is representing the f >25 Hz and the value of Q<10 criteria. Intespace and ISRO achieve the criteria with both chambers MAXTIQ is at 10.54 and 10.56 at 24.74 Hz. For MAXTIQ of ANGKASA and Alenia is 10.52 at 25.35 Hz and 10.50 at 25.44 Hz. JAXA's MAXTIQ is 10.58 at 26.35 Hz above the f >25Hz criteria. The result indicates the boundary condition based on the chamber size affecting the Q values due to the higher resonance and fine-scale data generation. The result also points out that ANGKASA facility has the capability and significant role in providing acoustic testing.

5 Discussion

Understanding the capability, performance, limitation and the response of the reverberation acoustic chamber is essential to gather all the information on the characteristic. The relative analysis was accomplished and been analyzed to characterize all the selected acoustic chamber. The plotted relative ratio of length, width, and height of all chambers shown that all chambers have the capability in yielding the smoothest frequency response and uniform distribution at the low-frequency mode. These result helps to identify the uniform distribution of the modes of the chamber in low-frequency bands.

Different volume size of the chamber plays a significant role in producing frequencies response. The frequencies response analysis showed that there were limited numbers of resonance at below 31.5 Hz. The calculated frequencies were increasing with cumulative of the integer numbers and the interference of sound wave. This result can be concluded as the chamber profile performance graph. Above 1000m^3 volume size, modes of calculation analysis have shown that the number of modes is slightly higher compared to others. These same conditions appear with the chamber profile performance graph which the frequencies response generating more resonance compared to others.

Modal density, MD results shown each chamber has a low modal density value at below 50 Hz range yet quadratically increasing as the frequency increases at higher frequencies. The analysis results show each chamber has its pattern of performance subject to the volume size. Nonetheless, for Intespace and ISRO or Alenia and ANGKASA which is having almost the same dimension and volume size, the performance graph is different.

On the Modal Spacing, MS show that each chamber mode spacing decrease with increasing frequency. A larger chamber was producing much smoother MS than the rest. For the MAXTIQ, the graph assessment indicates that all chambers have met the target criteria. However, the larger chamber has achieved it early compared to other chambers. The spread of the number of modes has shown a smooth pattern in each estimation graph results. These allow more frequency to be generated and provide maximum response outcome to be delivered.

6 Conclusion

ANGKASA's facility is capable of delivering the same scale of testing compared to the existing facility. From the research, ANGKASA and Alenia have nearly similar performance graph. This condition showed the benefit of ANGKASA's facility, by adopting Alenia's facility as a benchmark for profiling test acoustic test. This condition has shown that ANGKASA's facility can benefit from all the acoustic tests set up and make a benchmark with the Alenia's facility. More complex acoustic test analysis in the future shall prove the performance of ANGKASA's facility it fit for purposes and knowing the chamber is a compliment to each other.

Comparing to the other facilities, ANGKASA has the capability to join the major space player in providing a new spectrum of research and development in the South East Asia Region. This opportunity shall open new windows for the aerospace activities and support the harsh environment testing in preparing the nation for more economic value. The only critical aspect that needs to consider is to reach the international standard by applying all the rules and regulations. Further investigation and assessment for future space and non-space product shall provide a more confident level for the potential end user.

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