Acoustic Testing and Response Prediction of the CASSIOPE Spacecraft

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Acoustic Testing and Response Prediction of the CASSIOPE Spacecraft

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ABSTRACT

A high intensity acoustic test in a reverberant chamber was conducted on the CASSIOPE spacecraft in the final stages of integration and test campaign to ensure that it would survive the acoustic loads during launch. This paper describes the acoustic test methodology, the details of the model used for analytical prediction of the structural response for acoustic excitation and discussion of the predicted response comparison with test results that provided confidence in the spacecraft structural design for acoustic loads.

The objective of the spacecraft acoustic test was to demonstrate the ability of the structure and avionics to withstand the broadband random acoustic environment experienced within the launch vehicle payload fairing. The CASSIOPE spacecraft was tested in the reverberant chamber at overall sound pressure level up to 142.1 dB. The automatic spectral control system of the acoustic test facility, which used six control microphones, was able to achieve and the maintain target spectrum levels around the spacecraft within tolerances without manual adjustments to the noise generators' controls. The dynamic response of the CASSIOPE spacecraft during the test was measured using a large number of accelerometers installed on critical locations of the structure. Low level pre-test and post-test structural response signatures as well as electrical integrity checks performed after the exposure to the proto-flight acoustic environment demonstrated the ability of the spacecraft to survive the launch. The acoustic response of the spacecraft was also predicted based on a finite element model analysis to identify the critical components, evaluate structural margins and assess the risks in proceeding with a proto-flight acoustic test based on the specified launch vehicle spectrum. The analysis method used to predict the responses combines the NX/NASTRAN solver and RAYON, a vibro-acoustic simulation software. The RAYON software functionality is based on a boundary element model that enables the creation of an accurate fluid loading on the structure, with consideration of fluid mass and damping effects. The study used a finite element model of the structure that was correlated through an experimental modal survey test and actual spectrum levels achieved during the acoustic test. Responses of most locations compared favourably with the predictions in critical locations such as the solar arrays. Due to the limited availability of the satellite as well as time and cost constraints in a spacecraft development program, it is important to perform both qualification tests as well as analytical predictions in an efficient and timely manner to validate structural designs of spacecraft.

1.0 INTRODUCTION

CASSIOPE is a Canadian small satellite mission combining multiple payloads [1]. The prime contractor for the mission is MacDonald Dettwiler and Associates (MDA). The mission is enabled by contributions from the Canadian Space Agency (CSA) and Technology Partnerships Canada (TPC). The mission objectives are to demonstrate the advanced communications technologies of the Cascade (CX) payload, to investigate the topside ionosphere using the ePOP science payload, and to develop a Canadian small satellite bus for future CSA missions. Bristol Aerospace Ltd. developed the bus as part of the CSA SmallSAT Bus initiative. The Cascade payload contributed by MDA provides a high speed Ka-Band store and forward capability [2]. The ePOP payload known as Enhanced Polar Outflow Probe is a suite of eight science instruments provided by the University of Calgary.

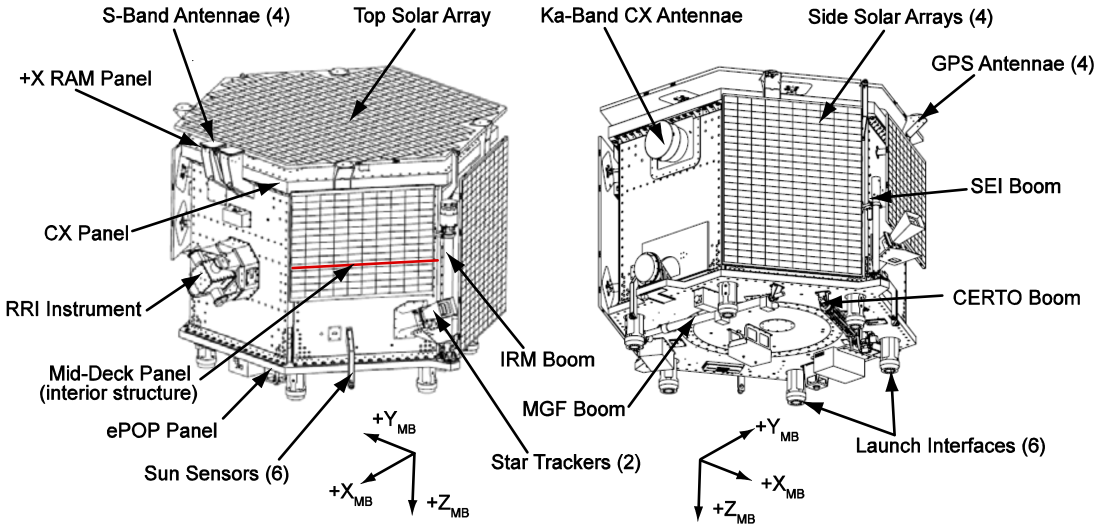

Figure 1 CASSIOPE spacecraft in the stowed launch configuration

As part of the spacecraft environmental test campaign, a high intensity acoustic test was conducted on the proto-flight model of the CASSIOPE spacecraft, which included all of the payload, solar panels, bus instruments and electronics boxes. The proto-flight model (PFM) level acoustic testing was performed using the large reverberant chamber at the Institute for Aerospace Research of the National Research Council Canada (NRCC) in Ottawa, Ontario, Canada in June 2009. This test exposed the integrated spacecraft to reverberant acoustic loading to ensure that it would survive the acoustic loads during launch. MDA held overall responsibility for the test planning and execution, with facility and instrumentation support from NRCC and CSA, respectively.

The reverberant acoustic test chamber facilities used for qualification of spacecraft are required to generate high levels of random noise and maintain high spectral accuracy for short durations, typically 30 to 90 seconds, which preclude manual adjustments of the noise generators' controls within this very limited test durations [3]. The generation of target acoustic fields that represent launch vehicle loads is challenging due to the highly non-linear noise generation process and the effect of the spacecraft within the acoustic filed [4]. Interaction between the structural and the fluid medium is particularly important for the design of satellites such as CASSIOPE integrated with components that are susceptible to acoustic loads. Unaccounted dynamic behaviour for acoustic loading of the satellite structure may lead to catastrophic failure in structural components or damage to the payload during launch. Therefore, successful design and deployment of precision systems such as satellites require highly accurate analytical models that need to be validated using experimental data. Prior to the test campaign, analytical predictions of the acoustic response were performed by MDA Space Missions to verify structural margins of safety and to ensure predicted equipment interface responses were within qualification limits. The response of the spacecraft under acoustic excitation was predicted using an analysis method that combines the NX/NASTRAN finite element method (FEM) solver and the RAYON vibro-acoustic simulation software. The structural model developed using FEM was updated through a full-scale modal test of the spacecraft, which experimentally extracted the modal parameters up to 120 Hz for correlation. Details of this ground vibration modal survey test and FEM model correlation process have been published previously [5]. In addition, these structural response predictions uses the actual 1/3-octave acoustic spectrum levels achieved during the test as input. This finite element methodology was selected due to its capability to predict the responses of major structural panels, where peak responses are expected to be below 250 Hz. Other prediction methods, such as the statistical energy analysis, have also been studied for acoustic response prediction applications for spacecraft [6, 7].

The objective of this paper is to describe the details of the acoustic testing methodology and analytical prediction technique used to achieve successful qualification of the CASSIOPE spacecraft under launch acoustic loads. This paper provides details of the acoustic test procedure including the spacecraft configuration, test setup, instrumentation, data acquisition and spectrum analysis techniques to characterise the diffused acoustic environment to compare the achieved noise levels to the target spectrum. More importantly, this paper includes the details of the analysis that was used to predict the response of the spacecraft structure under acoustic loading using an experimentally correlated finite element model and the actual 1/3-octave spectrum levels achieved during the acoustic test. Experimentally observed responses at critical locations of the structure are compared with the analytical predictions in order to assess the fidelity of the tool for spacecraft response prediction for acoustic excitation. Evaluating the responses of the major elements of the spacecraft was particularly important to validate their structural designs for launch acoustic loads.

Figure 2 CASSIOPE spacecraft in the test chamber

2.0 SPACECRAFT DESCRIPTION

The CASSIOPE spacecraft in the stowed launch configuration is shown Figure 1. The 490 kg spacecraft is a hexagonal structure of nominal side dimension of 1.6 m with 1.4 m in height. The interface to the launch vehicle consists of six discrete mounts which mate with non-explosive actuators on the launch vehicle. The spacecraft core structure consists of a hexagonal vertical frame constructed of aluminum honeycomb sandwich panels and machined corner posts. There are three horizontal aluminum honeycomb sandwich panels: the ePOP payload panel, the internal Mid-Deck panel, and the CX payload panel. All panels of the structure support spacecraft avionics and harnessing. Five solar arrays, constructed of composite facesheet and aluminum core sandwich, are mounted to the external panels via titanium flexures to thermally decouple the arrays from the spacecraft. The solar arrays are especially susceptible to launch acoustic excitation due to their low mass to area ratio.

3.0 ACOUSTIC TEST SETUP

The objectives of the spacecraft proto-flight acoustic test were; (i) to demonstrate that the spacecraft secondary structure could survive the proto-flight level acoustic environment, (ii) to demonstrate that the spacecraft structural responses do not exceed the unit interface specifications, and (iii) to expose the spacecraft avionics to the proto-flight level acoustic environment such that subsequent electrical integrity checks provide confidence in the overall quality of the component integration and their ability to survive the launch loads. In order to perform the test, the fully integrated CASSIOPE spacecraft was placed in the center of the reverberant acoustic test chamber as shown in Figure 2. The spacecraft was installed on a fixture stand using launch vehicle interfaces. The fixture was isolated from the chamber floor using pneumatic isolators. The isolation mounts were inflated such that the resonance of the spacecraft and fixture assembly was below the minimum frequency of acoustic excitation.

3.1 Reverberant Chamber

The reverberant acoustic chamber at NRCC is a specialized high-intensity noise testing facility designed to test full-size aerospace components at high levels of sound pressure field. This reverberant chamber has dimensions of 6.9m x 9.75m x 8.0m and encloses a test volume of ~540 m^3. This test facility is capable of generating overall sound pressure levels greater than 157 dB with accurate acoustic spectrum shaping between 25 Hz and 10,000 Hz. Four horns with lower cut off frequencies of 25 Hz, 32 Hz, 100 Hz and 200 Hz are installed through the walls in order to generate the shaped noise spectrum. Test chamber walls were constructed with reinforced concrete to withstand high intensity noise generated within the chamber.

3.2 Measurement Microphones

The acoustic environment around the spacecraft was measured by seven high intensity condenser microphones placed around the spacecraft as shown in Figure 3. The microphones were located approximately 0.6 m from the spacecraft external surfaces. These precision microphones feature a wide frequency range as well as a high dynamic range in order to accurately measure the far field noise. The signals from these microphones were amplified and conditioned and the amplified output of microphones labelled Mic1 through Mic6 were multiplexed in the time domain at a rate of 0.2 Hz and used as the control input to the automatic spectral control system of the test facility. However, microphone labelled Mic7 located underneath the ePOP deck was only used for monitoring purposes because the cavity between the spacecraft and support structure did not represent the diffused acoustic environment.

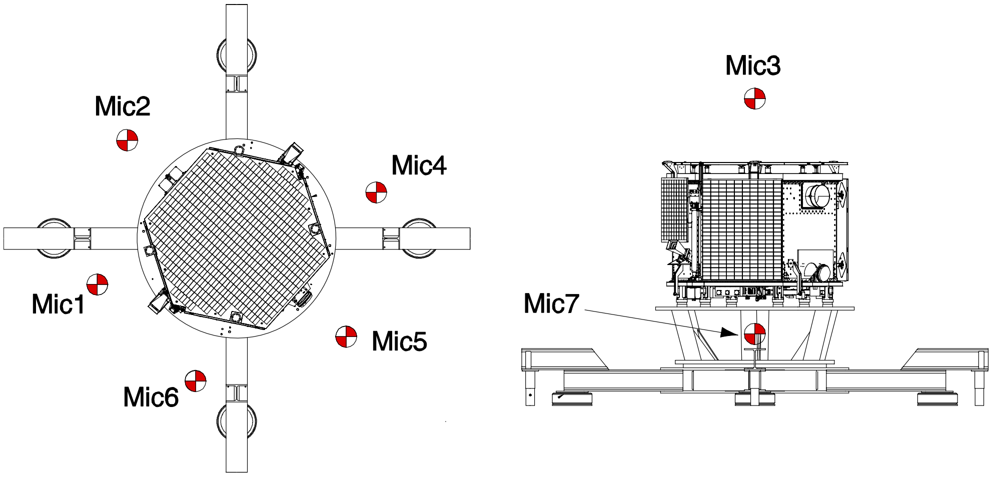

Figure 3 Tope view (left) and side view (right) of microphone positions

3.3 Noise Generation

The reverberant noise field during for this acoustic test was generated by two Wyle Laboratories WAS-3000 airstream modulators, one mounted on the 25 Hz horn and the other on the 100 Hz horn located in the chamber wall. A supply of dry compressed air at a pressure of 25 psig was used to drive the generators. The WAS-3000 is an electro-pneumatic noise source rated at 30 kW acoustic power, with either sine or random wave input, over a frequency range of 25 to 10,000 Hz. The specifications for WAS-3000 show that the nominal controllable frequency range extending up to 1250 Hz and it can generate very high overall sound pressure levels. The actual controllable amplitude and frequency of these airstream modulators can be varied depending on the air pressure, drive current and spectral shape. It should be noted that the effective control of the noise spectrum is possible only between the lower cut-off frequency of the drive horn and the upper cut-off frequency of the noise generators, whereas the required test spectrum generally covers a much wider frequency range. Therefore, spectral content above the 1250 Hz is controlled only indirectly through non-linear distortion from lower frequency noise. During this acoustic test, two impingement corner jets were also used to supplement the high frequency content of the spectrum with controllable input. These impingement jets were operated at 19 psig and 13 psig in order to generate the required high frequency noise spectrum for this acoustic test.

3.4 Automatic Spectral Control System

A customized automatic spectral control system (ASCS) developed at NRCC automatically analyzes and controls the random noise spectrum within the chamber during acoustic tests, ensuring the accuracy of the simulated environment is maintained throughout the duration of the test. The ASCS is able to match the acoustic specifications of the space shuttle, rocket launches, aircraft structural excitation, engine nacelle noise, unsteady turbulent airflows and other acoustic test specifications. The acoustic control system analyzes the multiplexed output from the measurement microphones using a spectrum analyzer to generate real-time 1/3-octave band levels. The control software compares the spectrum of the measured microphone signals with the target spectrum and updates the band levels of a bank of 1/3-octave filters within a noise shaper via an array of closed loop controllers. This results in an accurate and robust shaping of the drive current of the noise generators to maintain the noise environment within the specified tolerances without manual adjustments during the test. Prior to placing the test article in the chamber, room empty trials were carried out in order to ensure that the target acoustic spectrum could be achieved and maintained during the specified test duration. The controller parameters, including the steady state values of the 1/3-octave band shaper, from the room empty trials were used as the initial estimate values for the ASCS during the acoustic test with the spacecraft. Using these initial values, the ASCS is able to rapidly produce accurate acoustic levels in this reverberant chamber by overcoming challenges due to highly non-linear acoustic generation process and acoustic absorption or insertion effects of large spacecraft placed within the acoustic environment.

3.5 Response Accelerometers

The response of the critical locations of the CASSIOPE spacecraft were measured using 99 high sensitivity miniature accelerometers provided by the David Florida Laboratory of the Canadian Space Agency, which were bonded to the structure. Use of low weight miniature accelerometers mitigated the effect of mass loading on the test article. The high sensitivity of the accelerometers was ideal to obtain good signal-to-noise ratio measurements even when the response amplitudes were relatively low. The finite element model was used to determine the placement and quantity of the accelerometers required to clearly identify the important dynamic response of the spacecraft. These include locations to extract fundamental modal frequencies of major panels and vibration response of critical equipment installed in the satellite. Response data from the accelerometers were subsequently used to compare to predicted responses for acoustic loads.

3.6 Data Acquisition System

Two LMS SCADAS III digital data acquisition systems were used for simultaneous data recording of the accelerometers and microphone channels during the acoustic test [8]. The sampling frequency of the data acquisition system was set at about 10 times above the maximum frequency of interest in order to capture high quality data at high frequencies. The frequency resolution was set to 4 Hz for the test and the maximum number of linear averages was taken during the length of the test in order to mitigate the noise in the measured data.

4.0 ACOUSTIC TEST RESULTS

The proto-flight model (PFM) acoustic test levels for the CASSIOPE spacecraft were based on the acoustic spectrum analysis for the launch vehicle. The test sequence included pre-test low level at –10 dB for 30 seconds duration, acceptance level test at –3 dB for 30 seconds duration, PFM level test for 60 seconds duration and post-test low level at –10 dB for 30 seconds duration. Since the lower level tests were performed specifically to ensure safety of the spacecraft and/or validate the subsequent structural condition of the spacecraft, data pertaining only to the PFM level test is discussed in this paper.

4.1 Comparison of Achieved Spectrum to the Target

The achieved acoustic level measured using the multiplexed signal of the six control microphones is compared with the target test levels and tolerances using OASPL and 1/3-octave bands as shown in Figure 4. The reverberant acoustic test facility was able to generate the required acoustic environment within tolerances to meet the OASPL and all of the 1/3 octave narrow bands except for two bands. The 40 Hz and 80 Hz 1/3-octave band were out of tolerance by 0.4 dB and 0.2 dB, respectively. However, both these bands, including all other bands, were within tolerance during room empty trials that were conducted to identify the control parameters for the ASCS setup. The accuracy of the acoustic spectrum achieved with the spacecraft in the chamber was very good and the small exceedance of tolerances in the two low frequency bands were considered minor.

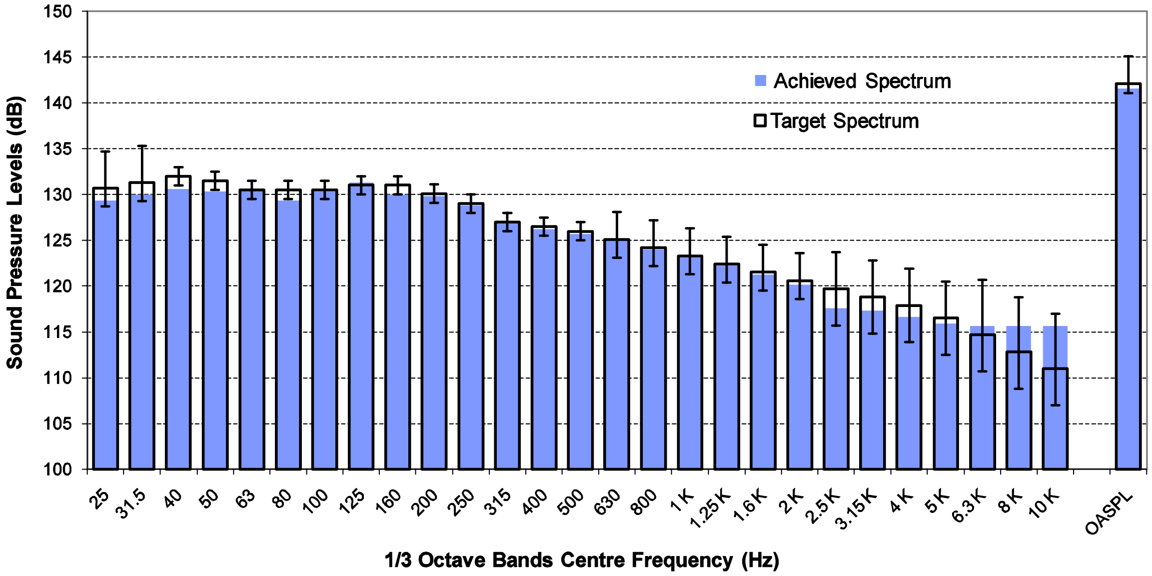

Figure 4 Target and Achieved spectrum

4.2 Characterization of Acoustic Environment

Comparison of the 1/3 octave bands measured by the six control microphones placed around the spacecraft shown in Figure 5 recognizes the variation in the surrounding acoustic environment in the presence of the CASSIOPE spacecraft. The data show larger variation in the lower frequencies. This variation in low frequencies may be attributed to two primary reasons; (i) presence of a large spacecraft within the acoustic filed with absorption or insertion effects (ii) presence of a relatively small number of acoustic modes due to the physical size of the chamber. The ability of a reverberant acoustic facility to produce a diffused environment at lower frequencies directly depends on the volume of the test chamber [9]. Multiplexing the signals from the six control microphones spatially distributed around the spacecraft as well as the time domain averaging of the multiplexed signal during the test is used to account for the variation in the input spectrum during this challenging broadband random noise generation process.

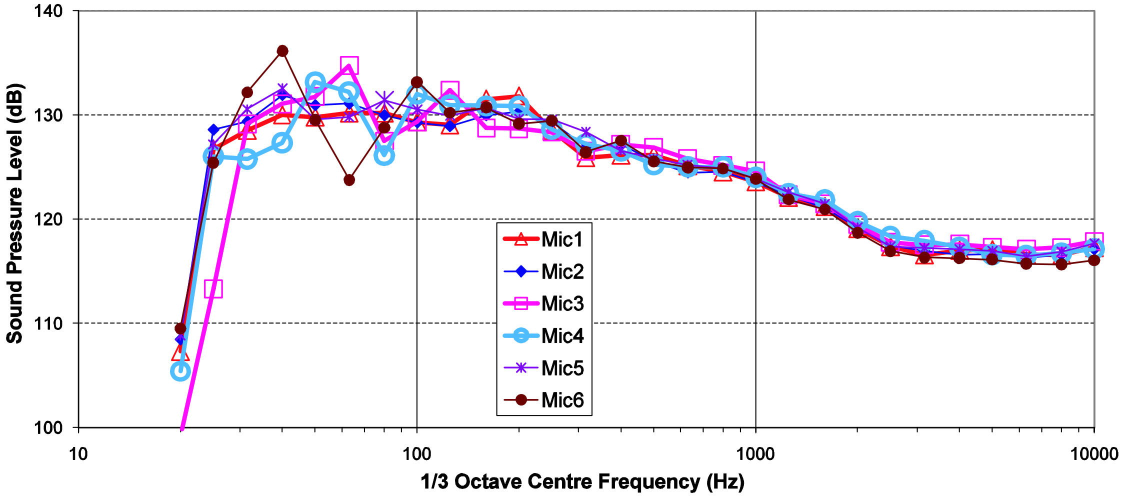

Figure 5 Spatial variation acoustic environment around the spacecraft

4.3 Structural Responses

The structural responses of the spacecraft measured using accelerometers were analyzed in the form of Power Spectral Density (PSD) plots and overall acceleration was measured in root-mean-square (RMS) values in units of g(rms). With the exception of a few locations that showed minor peak response exceedance, most of the responses measured during the PFM level acoustic test were well within unit qualification levels. Typical structural responses of five different panels during the PFM level acoustic test are shown Figure 6. These particular locations were selected for this present study because these panels exhibited a variety of dynamic behaviour due to acoustic excitation. Characteristics of these curves will be discussed in detailed in Section 6.0 by comparing with the response predictions performed using the analytical method introduced in Section 5.0. It is important to note that low level pre-test and post-test structural response signatures as well as electrical integrity checks performed after the exposure to the proto-flight test level confirmed the structural integrity of the spacecraft to survive the launch acoustic loads.

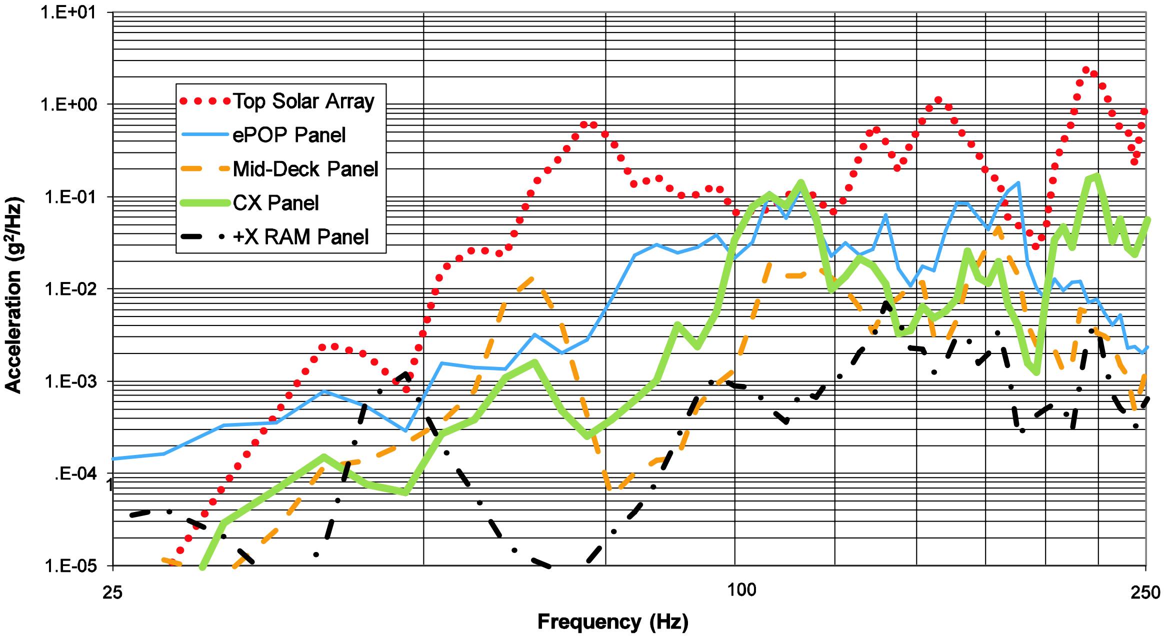

Figure 6 Responses of different panels during the PFM level acoustic test

5.0 RESPONSE PREDICTION METHODOLOGY

Successful design and deployment of precision systems such as satellites require very accurate analytical tools that must be validated using experiments to be used for prediction. Unaccounted dynamic behaviour in the satellite structure may lead to failures during the test campaign or prone for catastrophic damage during the launch. Therefore it was important to perform analytical predictions of the acoustic response of the CASSIOPE spacecraft prior the test in order to verify structural margins of safety and to ensure responses of critical components were within qualification limits. This current study enhanced the confidence of these prediction methodologies to be used in an efficient and timely manner to validate spacecraft designs.

5.1 Analysis Objectives

This response prediction analysis focused on the areas of the spacecraft which were most susceptible to the acoustic excitation. These areas of concern are; (i) external items with low mass to area ratio such as the body mounted solar arrays, (ii) external payload panel responses, and (ii) the spacecraft electronics equipment interfaces. The objectives of the analysis was to predict the acoustic responses at these locations, in terms of power spectral density (PSD) and root-mean-square (RMS) values, and to compare the levels obtained to structural allowables and equipment qualification levels. In the current study the frequency range as been limited to 250 Hz. This low frequency analysis enveloped most of the primary modes of critical spacecraft components while reducing complexity of the FEM and improving computational time.

5.2 Analytical Method

The CASSIOPE spacecraft features lightweight solar panels mounted adjacent to the primary structure honeycomb panels. In this configuration, the fluid acoustic loads need to be adequately modeled. Thus a vibro-acoustic simulation software, RAYON, was selected for this application. This simulation software uses the boundary element method (BEM) model that creates the fluid sound pressure loading on the structure. The RAYON software is a fluid-structure analysis software dedicated to linear acoustic and vibration analysis in the frequency domain.

Although there are several options available for application of mechanical and acoustic loads to the FEM model, planar waves are the most suitable to represent acoustic excitation of the CASSIOPE spacecraft. A diffuse acoustic field that exists in the test chamber was simulated by means of uncorrelated planar waves uniformly distributed around a sphere. The diffuse acoustic field was then modeled using 26 planar waves with 45° separation between each wave. The boundary of the fluid model was defined using a 2D surface model. The appropriate side of the BEM surface was exposed to acoustic sound pressure excitation to represent the current application.

The test correlated CASSIOPE spacecraft FEM model was generated by Bristol Aerospace Ltd. and MAYA Heat Transfer Technologies, while the fluid BEM surfaces were generated by MDA. These models are presented in the Figure 7. The FEM model correlation was performed for modes up to 120 Hz based on a full-scale modal test of the flight model spacecraft performed by NRCC. The spacecraft modal survey was conducted in a flight-like configuration with a high level of equipment integration to experimentally obtain the most realistic modal information to update the FE model. The multi-input multi-output modal test which used two independently driven shakers simultaneously, generated multi-referenced Frequency Response Functions (FRFs) to resolve closely spaced modes [10]. Furthermore, the advanced curve fitting algorithm used for the modal analysis generated clear stability diagrams using FRFs so that the modal parameters could be extracted without much difficulty. The details of the modal survey ground vibration test have been published previously [5]. The purpose of the present study is to evaluate the accuracy of the acoustic analytic method within the frequency range of 25 Hz to 120 Hz for which the FEM model was correlated based on the modal test, and also for a higher frequency range, up to 250 Hz, that becomes critical for bus mounted units. The RAYON software was used in conjunction with the NX/NASTRAN software to obtain the acceleration responses in PSD and RMS as well as loads and stresses of the spacecraft under acoustic excitation.

5.3 Modal Damping

Modal damping is an important parameter that needs to be properly quantified in order to accurately predict the response of structures subjected to excitation loads. Within the present study, the structural modal damping was defined using the standard amplification parameter known as Q. The parameter $Q = 1/2\zeta$, where ζ is the critical damping ratio. For the present predictions of acoustic responses, the Q values were defined as follows for two distinct frequency ranges; a Q of 10 was set for the frequency range from 25 Hz to 150 Hz while a Q of 25 was set for the frequency range from 150 Hz to 250 Hz. These Q values were applied for the entire spacecraft FEM model. The correlation between the response predicted through this analysis and the experimental test results are shown to have reasonable agreement using these amplification factors.

However, the experimental Q values extracted from the base input vibration test performed on the CASSIOPE spacecraft were different than the above mentioned nominal values assumed for the FEM predictions. The Q values derived for the frequency range of 25 Hz to 120 Hz from the low level sine sweeps vibration test for several response locations, namely, Top

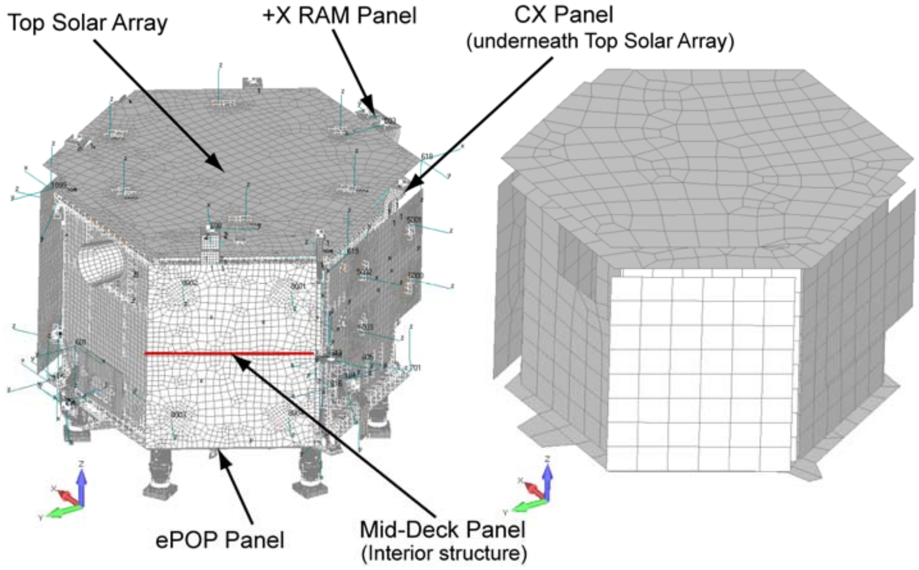

Figure 7 CASSIOPE spacecraft FEM (left) and BEM (right) representation

Solar Array, ePOP Panel, and the CX Panel were 33, 10 and 18, respectively. These Q value amplification factors are all higher than those values used to predict the acoustic responses of the structure. Typically the Q values obtained from a low magnitude test are higher than Q obtained from a high magnitude test because the level of damping increases for higher magnitude responses. Therefore, using Q values derived from low level vibration test provides more conservatism if used for the analytic prediction of acoustic responses.

6.0 COMPARISON OF TEST DATA WITH PREDICTIONS

In this section, the predicted structural responses from the analysis are compared to the acceleration obtained during the CASSIOPE spacecraft PFM level acoustic test. The power spectrum density (PSD) and the root mean square (RMS) acceleration are presented for the frequency range of 25 Hz to 250 Hz. All responses presented are the panel out-of-plane responses, which are significantly higher than the in-plane responses. The input excitation level used for the analysis was the averaged 1/3-octave acoustic sound pressure levels measured by the multiplexed signal of the six control microphones. The frequency range for the analysis has been limited to 250 Hz, which is the frequency range of interest for the major structural panel responses. The frequency uncertainty needs to be considered for the test data because the frequency resolution was set at 4 Hz. Results are presented for five response locations in order to cover the dynamic behaviour of different panel configurations. These include a lightweight-large area of the Top Solar Array, a heavy and populated payload panels known as CX and ePOP panels, an internal panel known as the Mid-Deck panel, and an external avionics support panel known as the +X RAM panel shown in Figure 7.

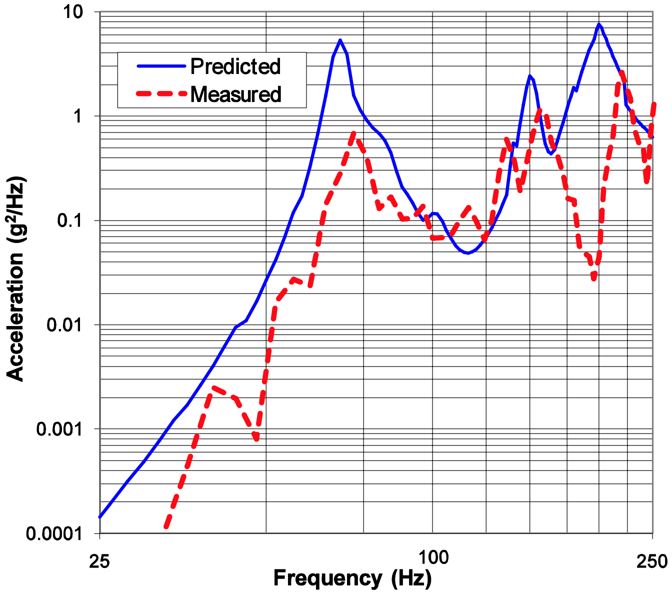

Figure 8 PSD responses for Top Solar Array

6.1 Top Solar Array

The PSD of the predicted and test responses at the center of the large hexagonal top solar array, which is mounted to the CX panel via flexures, is shown in Figure 8. The dominant natural frequencies of the panel are predicted well and the PSD response curve closely matches the test data observed during the acoustic excitation. The predicted RMS acceleration was 17 g(rms) while the measured response was 9.2 g(rms). The predicted response was 5 dB higher than that measured during the test, however this is considered acceptable given the uncertainty in modal damping of the lightweight-large structure during acoustic test. The natural frequencies and PSD peak values are summarized in Table 1.

Table 1: Peak Frequency and PSD Level comparison for Top Solar Array

FEM Predictions		Test measurements	
Peak Frequency (Hz)	PSD Level (g^2/Hz)	Peak Frequency (Hz)	PSD Level (g^2/Hz)
68	5.3	72	0.7
150	2.4	156	1.2
200	7.5	220	2.6

Table 2: Peak Frequency and PSD Level comparison for CX payload panel

FEM Predictions		Test measurements	
Peak Frequency (Hz)	PSD Level (g^2/Hz)	Peak Frequency (Hz)	PSD Level (g^2/Hz)
98	0.37	116	0.14
200	0.044	224	0.17

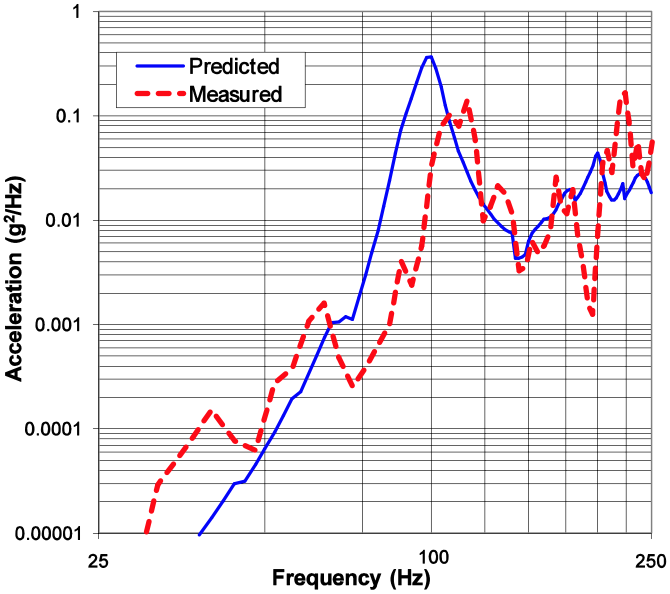

Figure 9 PSD responses for CX panel

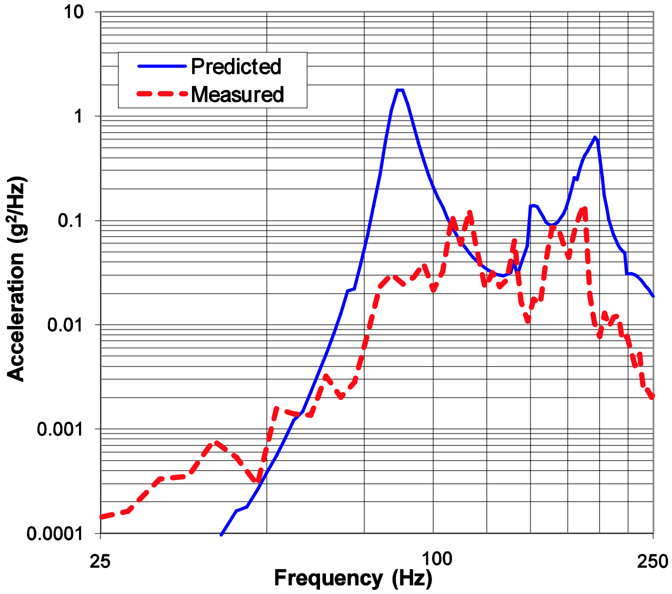

Figure 10 PSD responses for ePOP panel

6.2 CX Payload Panel

The honeycomb CX payload panel located directly under the top solar array is populated with heavy electronic units. The PSD of the predicted and test responses for this panel are shown in Figure 9. The natural frequencies and PSD amplitude levels for the prediction and test are compared in Table 2. The FEM predicted RMS acceleration response was 2.5 g(rms) while the measured response was 2.4 g(rms) and this difference is considered negligible. The primary panel natural frequency at 116 Hz is predicted well, while the second peak is not captured by the FEM analysis. The poor prediction of the main peak around 224 Hz may be attributed to the level of fidelity of the FEM model at higher frequency for the CX panel, since the correlation of the FEM model with spacecraft experimental modal test data was limited to 120 Hz. One possibility is that this main peak occurs above 250 Hz in the FEM predicted responses, thus invisible since it is beyond the frequency range of 25 Hz to 250 Hz considered in this study.

6.3 ePOP Payload Panel

The ePOP panel is a honeycomb deck which closes out the spacecraft and supports a number of payload units. The predicted and test PSD responses for the ePOP panel are shown in Figure 10. The FEM predicted RMS acceleration response was 5.8 g(rms) while the measured response was 2.5 g(rms). The predicted acceleration response was 7 dB higher than the test. As shown in Figure 10, the first main peak predicted at 88 Hz was not measured during the acoustic test, nevertheless this mode was correlated with the FEM model following the spacecraft ground vibration modal test. Further investigation showed that the acoustic field in the proximity of this spacecraft panel, recorded by a microphone labelled Mic7 in Figure 3 for monitoring only, shows relatively higher variation amplitudes at frequencies near the ePOP panel resonance frequency range of 70 Hz to 100 Hz. This is likely due to the presence of cavities between the mounting fixture and the ePOP panel as well as its close proximity to the top floor of the support stand. These interface stand boundaries were not modeled in the

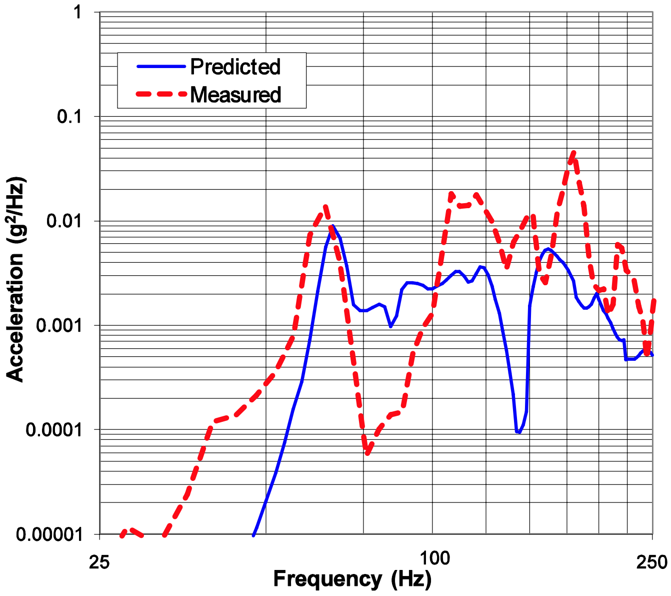

Figure 11 PSD responses Mid-Deck panel

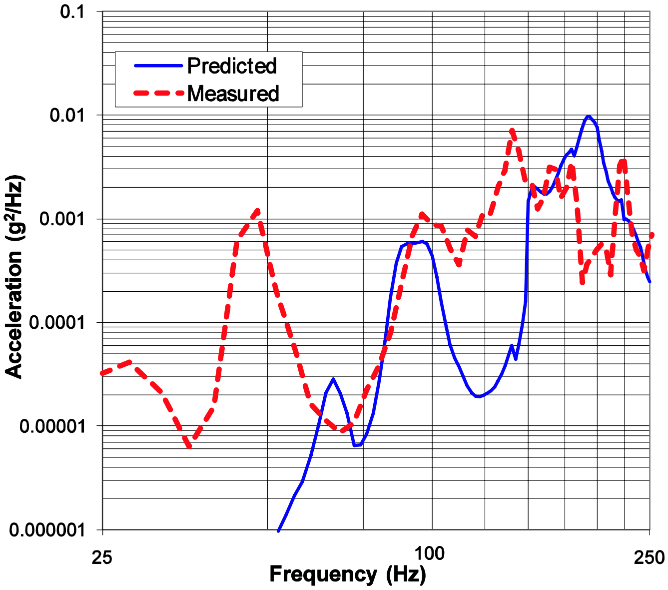

Figure 12 PSD responses +X RAM panel

acoustic prediction FEM analysis. At higher frequencies, from 150 Hz to 250 Hz, the predicted PSD has a reasonable match with the test measurement. The predicted response PSD peak at 196 Hz was 0.6 g^2/Hz while the measured PSD peak at 188 Hz was 0.14 g^2/Hz. In this frequency range the Mic7 microphone showed stable noise measurement which correlated well with the far field noise environment measured by control microphones.

6.4 Internal Mid-Deck Panel

The Mid-Deck panel is positioned inside the bus and is therefore not directly exposed to the external acoustic sound pressure field. The response of this interior panel to the acoustic field is of interest as lightweight sensitive equipment, with low frequency vibration modes, are mounted onto it. The PSD amplitude level predicted by analysis and measured during test, in the out-of-plane direction, are presented in Figure 11. In the present study the Mid-Deck panel was not part of the BEM model and the spacecraft internal cavity was not defined in the RAYON model. The responses predicted for this panel are then only the indirect consequence of the other panel responses excited by the external acoustic pressure. However, in reality the encapsulated air inside the spacecraft bus may interact with the dynamic motion of the external bus panels and result in a small acoustic excitation of the Mid-Deck panel. This effect is not taken into account in the present study and could explain the difference shown in the comparison plot. The frequencies of the predicted PSD peaks show a good match with the test peaks, but the overall magnitude of the predicted PSD is lower than measured data.

6.5 +X RAM Panel

The +X RAM panel is located on the front external face of the CASSIOPE spacecraft. This response location is adjacent to the spacecraft computer equipment interface. Although the response at this location was very low, the predicted PSD response showed a relative good match with the test data. The FEM predicted overall RMS acceleration response was 0.49 g(rms) while the measured response was 0.50 g(rms). The difference between the predicted RMS response and the measured response is negligible. As shown in the Figure 12, the acoustic test PSD response reveals a spacecraft first mode of 48 Hz while the FEM modal analysis and acoustic prediction revels a first mode at 64 Hz. This phenomenon is attributed to the presence of the pneumatic isolators between the fixture and the chamber floor. The isolator flexibility was not modeled for the analytical predictions based on FEM.

7.0 CONCLUSIONS

The high intensity acoustic test was performed on the proto-flight model of the CASSIOPE spacecraft and the acoustic response of the spacecraft was predicted using a derived analytical model. The CASSIOPE spacecraft was tested in a reverberant acoustic chamber at overall sound pressure levels up to 142.1 dB and the automatic spectral control system of the test facility was able to achieve and the maintain target spectrum levels around the spacecraft within tolerances without manual adjustments during the test. The acoustic test setup in the chamber provided a stable acoustic environment to simulate the acoustic excitation expected during launch although the generation of a diffused random noise filed is challenging due to the highly non-linear noise generation process and the effect of the spacecraft within the acoustic filed.

Low level pre-test and post-test structural response signatures as well as electrical integrity checks performed after the exposure to the proto-flight acoustic environment demonstrated the ability of the spacecraft to survive the launch.

The acoustic responses of the spacecraft were predicted using an analytic method based on the RAYON software in conjunction with the NX/NASTRAN software. This simulation software used a BEM model to that creates the fluid sound pressure loading on the structure to perform linear acoustic and vibration analysis in the frequency domain. This analysis tool predicted the response of the spacecraft structure under acoustic loading condition using an experimentally correlated structural FEM model and the actual spectrum achieved during the PFM level acoustic test. The responses in most critical locations of the major structural elements such as the Top Solar Array, CX panel and +X RAM panel compared favourably with the predictions from the FEM analysis. This analytical tool is useful for spacecraft response prediction for acoustic excitation experienced during qualification test as well as launch. The approach presented here provided an efficient and timely means to validate structural integrity of spacecraft design.

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