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SPACECRAFT STRUCTURAL ACOUSTICS

D.C.G. EATON

EUROPEAN SPACE AGENCY

INTRODUCTION

High frequency mechanical vibrations are induced in the spacecraft and its equipment during launch due to the effects of rocket and aerodynamic noise transmitted into the payload bay of the launch vehicle. The payload bay noise level is $<$150 dB and of short duration, and the random vibration levels arising at the spacecraft interface are quite low. As a result acoustic fatigue of primary structure is unlikely. However, the vibrations induced in the structure can create problems for service and payload equipment together with their supports. Similarly, the acoustic energy accepted by equipment with large surfaces can augment these vibration levels.

The means for predicting such vibration levels at an early stage of the spacecraft design and in defining sub-system vibration test levels and test requirements have yet to be fully developed into a readily available design aid. The ESA-sponsored research work is attempting to achieve such aims. A general description of these on-going activities is presented here.

Zoning the spacecraft into regions where vibration levels are likely to be similar has been considered in past aerospace investigations, including those at NASA and ESA. Additionally, past acoustic fatigue investigations, have demonstrated that it is possible to confine oneself to structural segments rather than the complete structure when conducting investigations. These concepts are being further investigated in current ESA research activity. The ultimate goals are to provide a better understanding of response behaviour, reduce the complexity of both theoretical and experimental modelling, and to evolve improved structural configurations for housing payloads and equipment from high frequency vibration aspects. It should also lead to more realistic test levels where mechanical test simulation of acoustic environmental effects is used in the qualification of equipment.

SPACECRAFT ZONING

In order to obtain experimental observations to explore the zoning of the spacecraft, a simplified satellite configuration was evolved which could be readily broken down into its constituent parts. Thus the complete assembly or sub-assemblies could be examined under acoustic excitation to demonstrate the relevant importance of individual components and their structural/acoustic couplings. The dynamic properties of such components are also investigated. Corresponding theoretical estimations are being made in order that the scope and accuracy of such prediction methods can be understood.

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A reverberant sound field is assumed in acoustic testing and theoretical predictions. However, the near field sound characteristics within a launch vehicle payload shroud can modify the local structural response and this aspect is the subject of additional studies using a simulated shroud enclosure containing the satellite structures. This combination is also subjected to reverberant excitation in the acoustic chamber. The testing is mainly carried out in the acoustic facility at IABG, Munich.

In order to provide more complex configurations, a similar programme of work is being undertaken using a MAROTS prototype flight model and sub-assembly components for separate dynamic tests. Investigations will shortly take place using a development version of the Spacelab pallet.

APPLICATION OF STATISTICAL ENERGY ANALYSIS

Because of the possible frequency range of interest (25 to 10,000 Hz) and the large number of modes that can be present, Statistical Energy Analysis (SEA) is extensively used to obtain average response predictions. Appropriate sub-systems are selected, such as the noise field inside a rocket payload shroud, and different components of the structure (for example, central core, platforms, sidewalls, etc.). SEA considers the vibratory power flow between these coupled sub-systems and establishes the power balance between them.

British Aerospace (Aircraft Group) Bristol have developed a suite of programs for ESA called GENSTEP. This allows the SEA technique to be applied to a wide range of spacecraft components including such items as plain and stiffened thin-walled cylinders, beams, frames, together with appropriate representation of acoustic cavities.

The suite has been developed on a modular basis which facilitates ease of application, trouble shooting and the introduction of new features.

In the first step the basic properties of the noise field and the structure are introduced. This information is then checked and some basic sub-system SEA parameter properties are calculated. In subsequent steps matrices of modal density, loss factor and coupling loss factor for the sub-systems are constructed. Further steps permit the assessment of the power distribution and calculation of the energies in the sub-systems. Finally, average response or sound transmission characteristics for the appropriate sub-systems are established. The program is capable of handling twenty linked sub-systems.

Much of the current effort is producing a data bank of information for use with this program, such as damping values, and modal density characteristics where such information is not fully available. During the related initial experimental work carried out at ESTEC difficulties were experienced in establishing such parameters.

Means of establishing both the loss factor and modal density indirectly have been developed as a result of theoretical and experimental studies conducted at the Institute of Sound and Vibration Research, Southampton University. Using SEA power flow concepts, it is possible to demonstrate that the modal density and loss factor can be established by measuring the input force generated by point excitation and considering the spatial average response velocity characteristics. In most of the work, a fast sine sweep (transient excitation) has been used. Similar results can be obtained using stationary random point excitation, though more sophisticated data reduction is required in this case.

INTERIM FINDINGS

It has been found that over most of the important high-frequency range it may well be possible to test platform-mounted equipment using a representation of the platform alone. This could simplify development testing and provide more representative conditions than realised in mechanical vibration tests. On-going investigations will provide more information on this concept.

- The presence of a large central mass, which could be an apogee boost motor or fuel tank, had little effect on the response levels of the satellite structure.
- Struts only noticeably modify the responses of adjacent structures in the frequency bands where fundamental flexural strut resonances occur.
- Cable harness has some effect on local frequency response characteristics, but little impact on spatial average behaviour.
- The method of mounting the simplified satellite specimen in the acoustic chamber, such as with a low frequency sling or by a support at its base, had little effect on its high frequency response characteristics.
- Comparison of the effects of the shroud enclosure configuration with the results of basic reverberant room tests indicate that platform responses may be enhanced at frequencies greater than one kilohertz, but the central cylinder levels are reduced in the lower frequency regime. The response of appendages relatively close to the shroud wall are likely to be significantly increased.
- More quantitative assessments are expected after completion of the MAROTS specimen studies.
- The findings for the modal densities of plates and cylinders compare closely with theoretical values except at the cylinder ring frequency. In general good correlation has been observed when comparing predictions and test findings for a number of configurations. However, errors are evident at the ring and critical frequencies.

Some difficulties were incurred with response predictions for honeycomb structures, but a better understanding of the important structural parameters in the response behaviour has recently led to improved assessments.

Other work being undertaken using the test structures and simulated experiments, appendages and equipment, considers the effects of mechanically induced high frequency vibrations at the base of the structure. This will provide guidelines on the likely vibration levels induced in different regions of the structure by this means.

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The work also serves to illustrate that, as a result of the directional nature of such vibrations and their localised input, substantial differences in the relative response behaviours of different structural zönes are observed when compared with those set up by the loadings induced by a diffuse sound-field. This demonstrates that it is often impractical to simulate acoustic excitation by mechanical testing, at least for complex configurations. Mechanical testing is suitable for many classes of equipment when it can be demonstrated that the vibratory energy is mainly transmitted by the local structure. This will not be the case if the equipment in question has large flexible surfaces likely to accept acoustic energy.Current activities will culminate in the first issue of a Structural Acoustics Design Guide, later this year. Topics will include:

- Guide to modelling techniques and how they should be used
- Where appropriate, guidance on choice of SEA parameters
- Glossary of loss factors
- Recommended test methods, including guidance on simulation of structural vibrations in testing of equipment
- Recommendations on means of scaling past test data for use in confirming vibration levels
- General observations from surveys of various acoustic and high frequency mechanical vibration testing
- Examples of application of prediction and scaling methods.

FUTURE WORK

Future work will consider the application of SEA to mechanically induced vibration and explore the practical boundaries of such techniques. In this context the low frequency, low modal density requirements are receiving attention with a view to establishing simple theoretical models, of sufficient engineering accuracy.

With the establishment of greater understanding of the response behaviours, improved scaling laws can be expected. These will permit the extrapolation of test data to cover a wide range of launch configurations.

Additional work is required in order to design against high frequency vibration problems. The use of artificial damping treatments to reduce vibration levels is one aspect of this work.

Further studies of coupling loss factor have to be undertaken, and the modal densities of advanced structural configurations such as carbon fibre honeycomb have yet to be properly investigated. Behaviours in cylinder ring frequency and critical frequency regimes require further study.

More detailed accounts of aspects of this work will be contained in an article to be published in the May issue of the ESA Bulletin and the June issue of the ESA Journal (1981). A description of the indirect method for establishing modal density and loss factor characteristics is to be published shortly in the Journal of Sound and Vibration (co-authors, B. L. Clarkson and R. J. Pope, Institute of Sound and Vibration Research).