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Vibro-acoustic analysis of the acoustic-structure interaction of flexible structure due to acoustic excitation ☆

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ABSTRACT

The application of BE–FE acoustic-structure interaction on a structure subject to acoustic load is elaborated using the boundary element–finite element acoustic structural coupling and the utilization of the computational scheme developed earlier. The plausibility of the numerical treatment is investigated and validated through application to generic cases. The analysis carried out in the work is intended to serve as a baseline in the analysis of acoustic structure interaction for lightweight structures. Results obtained thus far exhibit the robustness of the method developed.

1. Introduction

During flight missions, space vehicles, such as illustrated in Fig. 1 [1], are subjected to a severe dynamic pressure loading and broadband, aeroacoustic and structure-borne excitations of various circumstances, which can endanger the survivability of the payload and the vehicles electronic equipment, and consequently the success of the mission. Aerospace structures are generally characterized by the use of exotic composite materials of various configurations and thicknesses, as well as by their extensively complex geometries and connections between different subsystems. It is therefore of crucial importance for the modern aerospace industry, the development of analytical and numerical tools that can accurately predict the vibroacoustic response of large, composite structures of various geometries and subject to a combination of aeroacoustic excitations.

Assisted with computing capability and user-friendly computer-aided analysis software, the analyst is challenged to ensure that the analysis includes all the relevant physical phenomena. Simple fundamental principles are mandatory, in order not to lose insight into the interrelationships between relevant elements, and to devise simple methods that are robust to address various problems. Space borne structure must be able to resist the loads induced by the launch environment, and meet all the functional performances required on orbit such as dimensional stability and structural integrity. Noise and vibration should also be taken as critical consideration in the design of aerospace vehicles for fatigue of components arising from interior structural and acoustic pressure fluctuations due to external structural or acoustic loading [2–9]. Other related works are reported in references [10–13]. Pappa et al. [10–12] summarize modal testing activities at the NASA Langley Research Center for generic aircraft fuselage structures. Citarella et al. [13] set up an integrated approach for an automobile vibro-acoustic analysis to assess, visualize and compare vibro-acoustic performance to pre-determined design targets and identify and quantify the forces and sound sources responsible for their prevailing behavior.

The great number of design variables allows us to synergistically fulfill high stiffness and acoustic standards. Hence the objective of the present paper is to describe the application of BE–FE fluid structure interaction on a structure subject

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Fig. 1. An illustration of a spacecraft being inspected at APL's Kerschner Space Building [1].

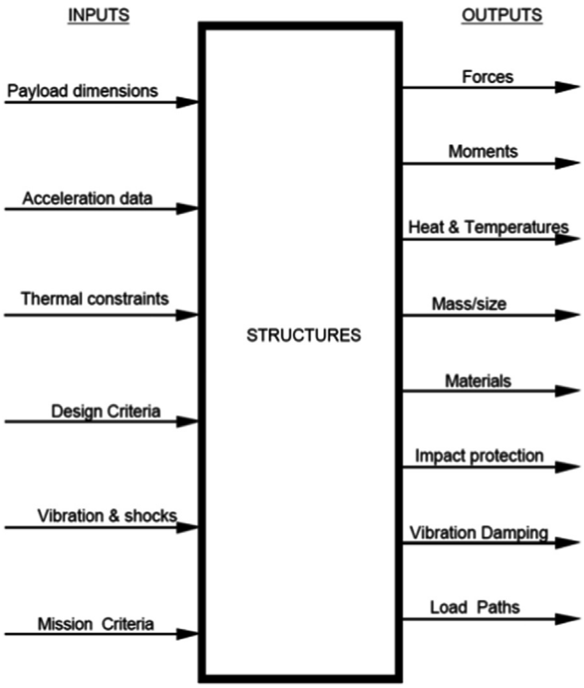

Fig. 2. Structures subsystem interface [21].

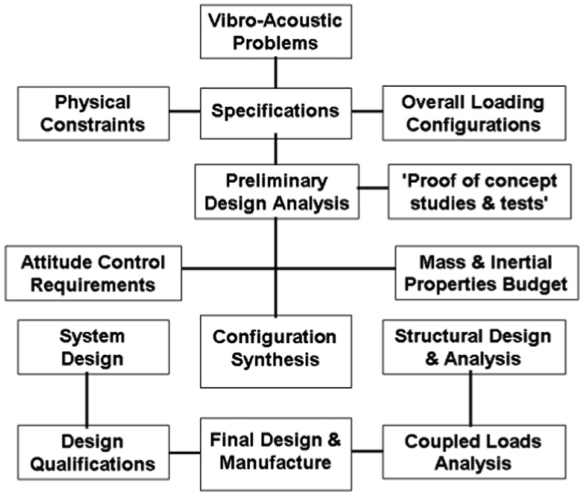

Fig. 3. A technique to estimate driving force spectra of equipment packages subjected to broadband random acoustic excitations [21].

to acoustic load and to elaborate FE formulation of the computational scheme for unified approach on acoustic–aeroelastic interaction as developed earlier [15–20]. Fig. 2, adapted from [21], shows schematically the structures subsystem interface. This is divided into two separate categories, inputs and outputs, to allow for easy referencing. A technique to estimate driving force spectra of equipment packages attached to cylindrical structures subjected to broadband random acoustic excitations is summarized in Fig. 3, adapted from [21]. This procedure is considered indicative of the present state-of-the-art and will provide satisfactory predictions of the vibratory environment.

2. Problem formulation

To address the problem associated with fluid structure interaction, in particular the vibration of structures due to sound waves, aerodynamics and their combined effects, a generic approach to the solution of the elasto-acousto-fluid-dynamic interaction will be followed in order to develop the foundation for the computational scheme for the calculation of the influence of the acoustic disturbance to the aeroelastic stability of the structure, starting from a rather simple and instructive model to a more elaborate FE–BE fluid-structure one. The generic approach consists of two parts, as schematically summarized in Fig. 4 which exhibits the computational strategy to treat the acoustic-structure interaction.

The first is the formulation of the acoustic wave propagation governed by the Helmholtz equation by using a boundary element approach, which then allows the calculation of the acoustic pressure on the acoustic-structure boundaries. The influence of the acoustic excitation field has been given rigorous consideration by taking into account both the incident and scattering acoustic pressure, following the governing equations described by Dowling and Ffowcs-Williams [22] and Norton [23]. The second part addresses the structural dynamic problem using a finite element approach. In the formulation of BE–FE coupling to treat the fluid-structure interaction,