The Acoustic Limit of Control of Structural Dynamics

A. H. von Flotow
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
Cambridge, MA, 02139, USA

ABSTRACT
This paper investigates the acoustic limit of active control of structural dynamics; the limit as the control bandwidth includes a very large number of natural modes of the structure. The point is made that in this limit modal analysis cannot provide reasonably accurate models of the structural dynamics, and that control design with respect to modal models is then of questionable value. Alternative modeling approaches are reviewed. A particular wave propagation formalism, applicable to modeling the acoustic response of networks of slender structural members, is described in some detail. Control options designed with reference to this formalism are reviewed, and speculations as to future developments of such control are offered.

1. INTRODUCTION
Modal analysis is a powerful analysis technique, central to the discipline of structural dynamics since the publication of Rayleigh’s[1] book. Nevertheless, practical limitations to the applicability of modal analysis do exist. This paper attempts a definition of one such limitation, the high-frequency acoustic limit, and points out the relevance of this limitation to the technology of active control of structural dynamics.

It is difficult to define the boundary between structural dynamics and structural acoustics, indeed, one might even insist that the former includes the latter. The boundary between analysis techniques is somewhat more clear; modal analysis relies upon a global description of an entire structure, while structural acoustic response is typically described in terms of the scattering properties of local components. Exceptions exist. It may be convenient to describe some portions of a structure in terms of acoustic parameters and other portions via modal analysis. Structures which are coupled to a fluid or elastic body[2] of infinite extent are examples of such exceptions, since it is then convenient to employ modal analysis for the structural response, and acoustic techniques to define the effect of the infinite medium.
The discussion of this paper will be confined to structures of finite extent. Even in such situations techniques of structural acoustics may be preferable to modal analysis. A structural component, though finite, may be *effectively infinite*. This limit is approached if the component is much larger than disturbance wavelengths or if damping levels are high enough to attenuate a disturbance before many reflections can occur. Both situations tend to occur when excitation frequencies include many of the structure's natural modes. The frequency boundary between structural acoustics and structural dynamics thus depends upon the structure under consideration. A reasonable division for aircraft might be a few tens of Hz. Ultrasonic devices are well described by modal analysis at frequencies of several hundred kHz. Large flexible spacecraft, with fundamental frequencies below one Hz, would enter the acoustic response regime at frequencies as low as a few Hz. Figure 1 attempts to provide a graphical version of these arguments.

**FIGURE 1** Approximate boundaries between the regions of applicability of modal analysis and local acoustic analysis are sketched in the *S-plane*. The high-frequency limit of modal analysis is due to sensitivity to parameter uncertainty. The low frequency limit of acoustic modeling is less well defined, and depends on geometrical complexity of the structure.