CHAPTER ONE
INTRODUCTION

Traditionally, the dynamic response of a structure has been measured with accelerometers. Experimental modal analysis has then been employed to model and characterize structural dynamic response in the frequency domain [1]. Unfortunately, because of mass and stiffness alteration concerns and cost, it is usually impractical to place accelerometers at many locations or create models with many degrees of freedom. Consequently, such an approach yields extensive frequency-domain information at only a few structure locations and the spatial nature of structural dynamic response is typically neglected. However, relatively new transducers and methods allow the measurement of dynamic response at many structure locations. Therefore, new opportunities exist for the modeling and characterization of dynamic response in the spatial-domain as well as the temporal- and frequency-domains.

One such transducer which allows the measurement of dynamic response at many structure locations is the scanning laser Doppler vibrometer (LDV). A scanning LDV incorporates scanners which direct a laser beam to several structure locations called scan points. The scanners are controlled by user-specified voltage signals. At each scan point, surface velocity magnitude and phase in the direction of the laser beam is measured by the LDV. Velocity measurement is based upon the Doppler effect and is described in detail by Drain [2].

The availability of spatially dense velocity response data provided by a scanning LDV encouraged Montgomery and West [3] to develop a new technique which models continuous, three-dimensional velocity-response fields using LDV velocity data. The technique is called Experimental Spatial Dynamics Modeling (ESDM). As presently developed, ESDM reconstructs translational velocity fields associated with structures harmonically excited at a single frequency only; future ESDM versions will consider multi-frequency excitations as well. Reconstruction is performed both temporally and spatially in three dimensions and is based upon a finite element approach.

The ability of ESDM to reconstruct such fields is extremely useful. Once the translational velocity field is obtained, other dynamic response fields are easily determined by mathematical manipulation of the translational velocity field: 1) the curl of the translational velocity field divided by two yields the rotational velocity field; 2) differentiation and integration of the translational velocity field in time yields the translational acceleration and displacement fields, respectively; and likewise, 3) differentiation and integration of the rotational velocity field yields the rotational acceleration and displacement fields, respectively. Additionally, for specific structure types which have a neutral axis very close to the surface at which velocity is reconstructed, namely thin-walled structures, appropriate spatial differentiation of the translational displacement field yields the dynamic strain field. Furthermore, the subsequent application of an appropriate stress-strain relationship yields the dynamic stress field. The ability to reconstruct dynamic strain and stress fields is especially noteworthy. Up to now, average strain and stress has typically been measured by strain gages over the gage area at only a few discrete locations on a structure. With ESDM, the capability to measure dynamic strain and stress at any point on a structure now exists and common problems associated with strain gage use, most notably bonding problems, fatigue failures and temperature sensitivity [4], are eliminated.

Heretofore, the ability of ESDM to accurately reconstruct translational velocity fields has not been thoroughly evaluated experimentally. Montgomery simulated the three-dimensional velocity response field of a long beam using Euler-Bernoulli beam theory and Lamé modes, and subsequently demonstrated analytically that ESDM can accurately reconstruct such velocity fields [5]. He also added artificial noise to the simulated velocity response field and showed that ESDM can accurately reconstruct velocity fields contaminated with noise [6]. However, no experimental evaluation of the ability of ESDM to accurately reconstruct velocity response fields was conducted. Consequently, the need for an independent, controlled and comprehensive experimental evaluation of ESDM exists. The results contained in this thesis partially satisfy this need.

Usually, a scanning LDV is positioned relative to a structure such that its laser beam is predominantly transverse to the surface of a structure. This ensures that adequate light is reflected back to the LDV. Hence, a scanning LDV accurately measures velocity components which are transverse to a surface; however, velocity components parallel to the surface are greatly diminished and not as accurately measured. Such measurement inaccuracy reduces the ability of ESDM to accurately reconstruct velocity field components parallel to the surface of a structure. Therefore, the objective of this research was to experimentally evaluate the ability of ESDM to reconstruct velocity response fields with large in-plane components parallel to a structure surface in the presence of small out-of-plane components transverse to the surface. Secondary research objectives included 1) the development of a new LDV scanner calibration procedure and 2) the development and fabrication of a test structure suitable for this evaluation and future ESDM evaluations.

The remainder of this thesis is arranged as follows. Chapter Two briefly describes techniques other than ESDM which reconstruct three-dimensional dynamic response fields using experimental data. Chapter Three subsequently explains ESDM and presents its theoretical underpinnings. Chapter Four then describes the new LDV scanner calibration procedure which yields mathematical relationships between LDV scanner voltage signals and resulting laser beam deflections. The specific mathematical relationships which apply to the scanners installed in the particular scanning LDV used for this work are also presented. Chapter Five describes development of the aforementioned test structure. Chapter Six provides a complete explanation of the experimental method employed and Chapter Seven presents evaluation results. Last, Chapter Eight presents conclusions and recommendations.