

DEDICATION

This thesis is dedicated to my family: my parents, James Allan and Mary Janet Stafne, my brother, Mark Willms Stafne, and my surviving grandmother and grandfather, Elvina Everetts and Paul Willms, respectively. It also dedicated to the memory of my late grandparents: my grandmother, Clara Argo Willms, who passed away just before my thesis defense, and my grandfather, Alvin Stafne

ACKNOWLEDGEMENTS

Theses are not works of a single individual; several persons and organizations usually provide valuable advice, help, equipment and support. My thesis is no exception and the following persons and organizations are recognized for their contributions.

First, special thanks is reserved for my advisor, Professor Larry D. Mitchell. Professor Mitchell constantly provided encouragement and technical advice and support. Additionally, he was always available for consultation no matter how trivial the concern. Stated simply, his direction ensured the successful completion of this thesis.

Second, special thanks is also reserved for my committee member, Professor Robert L. West. Professor West acted essentially as a "co-advisor" throughout my research. Since he and a former doctoral student developed and originally implemented ESDM, he provided valuable technical advice and support, particularly computer programming support. Like Professor Mitchell, his efforts ensured the successful completion of this thesis.

Third, the advice and help provided by my Modal Laboratory colleague, David Coe, proved invaluable. David, like Professor West, is very familiar with ESDM and I constantly sought his advice and insight. Thanks, David.

Fourth, I must thank my other committee member, Professor Charles E. Knight. Professor Knight provided finite element modeling advice during the test structure design phase. He also provided advice about the particular software package used to design the test structure.

Fifth, I must recognize several organizations that provided material, equipment and fabrication support: Welded Tube Corporation of America provided free construction material for the test structure; the departmental Computer-Aided Design Laboratory provided computer facilities for the test structure design effort; the departmental machine shop fabricated the test structure; The Modal Shop provided a free and timely replacement part for the acoustic digitizer during LDV scanner calibration; and PCB Piezotronics calibrated needed accelerometers at no cost.

Last, I must thank all my colleagues and friends within and outside the Modal Laboratory. They constantly provided both encouragement and support and enlivened my graduate school experience. Thank you all.

TABLE OF CONTENTS

Abstract	i
Dedication	ii
Acknowledgements	iii
Table of Contents	v
List of Figures	ix
List of Tables.....	xiii
Chapter One	
Introduction	1
Chapter Two	
Literature Review	5
Chapter Three	
ESDM Technique.....	7
ESDM Capabilities.....	7
General ESDM Procedure.....	10
LDV Registration	13
Time-Domain Velocity Signal Reconstruction	20
ESDM Finite Element Formulation	25
Velocity Field Solution Processing	36
ESDM Software	38
Chapter Four	
LDV Scanner Calibration.....	39
Nomenclature	39
Scanner Description	40

Scanner Control System	43
Scanner Calibration Method: Analytical Approach	44
Scanner Calibration Method: Experimental Procedure.....	49
Scanner Calibration Results	53
Chapter Five	
Test Structure Development.....	63
Nomenclature	63
Test Structure Design Criteria.....	65
Test Structure Design Process.....	66
Test Structure Finite Element Model Development.....	69
Final Test Structure Design.....	82
Test Structure Fabrication	83
Actual Test Structure Modal Characteristics	86
Chapter Six	
ESDM Evaluation: Experimental Method	100
Preliminary Considerations	100
Experimental Approach.....	108
Experimental Procedure	111
Chapter Seven	
ESDM Evaluation: Experimental Results	122
Nomenclature	122
ESDM Results	123
Accelerometer Results.....	128

Comparison and Discussion	129
Chapter Eight	
Conclusions and Recommendations.....	139
Conclusions	139
Recommendations	140
References	145
Appendix	
LDV Scanner Calibration: Additional Material.....	151
Nomenclature	151
Transformation Equation Development.....	152
Calibration Data	159
Vita.....	160

LIST OF FIGURES

Figure 1. Typical scanner mounting configuration	14
Figure 2. Horizontal and vertical scan angles defined	16
Figure 3. Position vectors which define the location of an arbitrary scan point illuminated by the laser beam in the LDV coordinate system.....	17
Figure 4. Relationship between LDV and structure coordinate systems	18
Figure 5. Ometron LDV	40
Figure 6. Scanner components	41
Figure 7. Scanner mounting configuration.....	42
Figure 8. Scanner control system schematic	44
Figure 9. Scan angles calculated via right-triangle approach.....	46
Figure 10. Scan angles calculated via cosine-law approach.....	48
Figure 11. Experimental arrangement for improved LDV scanner calibration procedure.....	50
Figure 12. Aluminum plate with three pins.....	51
Figure 13. Horizontal scan angle residuals between horizontal scan angle data and regressed scan angle values at each DAC step increment.....	54
Figure 14. Horizontal scan angle residuals between horizontal scan angle data and regressed scan angle values at each recorded analog voltage	56
Figure 15. Vertical scan angle residuals between vertical scan angle data and regressed scan angle values at each DAC step increment.....	58
Figure 16. Vertical scan angle residuals between vertical scan angle data and regressed scan angle values at each recorded analog voltage	59
Figure 17. Estimated average horizontal and vertical scan angle uncertainty associated with LDV scanner calibration procedure based upon cosine-law approach at various distances from laser beam home position.....	62

Figure 18. Portal arch and Vierendeel truss.....	66
Figure 19. First and second mode motions exhibited by portal arches and Vierendeel trusses	67
Figure 20. Welded RHS joint	70
Figure 21. Stiffness model for welded RHS joint.....	70
Figure 22. Test structure coordinate system	73
Figure 23. Base plate attachment method and coordinate system	74
Figure 24. y-direction translational stiffness model for test stand attachment scheme	75
Figure 25. θ_x - and θ_z -direction rotational stiffness model for test stand attachment scheme.....	78
Figure 26. Plan view of test stand attachment scheme showing coordinate system and distances from bolt to column center	79
Figure 27. Model used to derive rotational stiffness associated with test stand attachment scheme.....	79
Figure 28. Final test structure design	83
Figure 29. Test structure bolted to test stand	86
Figure 30. Plan view of test structure showing accelerometer placement and impact hammer strike locations	87
Figure 31. Mobility magnitude: out-of-plane excitation and response.....	88
Figure 32. Mobility phase: out-of-plane excitation and response	88
Figure 33. Coherence: out-of-plane excitation and response	89
Figure 34. Mobility magnitude: in-plane excitation and out-of-plane response	89
Figure 35. Mobility phase: in-plane excitation and out-of-plane response	90
Figure 36. Coherence: in-plane excitation and out-of-plane response	90

Figure 37. Mobility magnitude: in-plane excitation and response	91
Figure 38. Mobility phase: in-plane excitation and response	92
Figure 39. Coherence results: in-plane excitation and response	92
Figure 40. Mobility magnitude: out-of-plane excitation and in-plane response	93
Figure 41. Mobility phase: out-of-plane excitation and in-plane response.....	93
Figure 42. Coherence: in-plane excitation and out-of-plane response.....	94
Figure 43. Plan view of test structure showing accelerometer placement and impact hammer strike locations	95
Figure 44. Mobility magnitude: out-of-plane excitation and response recorded along direction oriented about 5° from test structure <i>z</i> -axis	96
Figure 45. Mobility magnitude: in-plane excitation and out-of-plane response recorded along direction oriented about 5° from test structure <i>z</i> -axis	96
Figure 46. Mobility magnitude: in-plane excitation and response recorded along direction oriented about 5° from test structure <i>x</i> -axis	97
Figure 47. Mobility magnitude: out-of-plane excitation and response recorded along direction oriented about 5° from test structure <i>x</i> -axis	98
Figure 48. Plan view of specified test structure motion	101
Figure 49. Test structure excitation location and direction	102
Figure 50. Scan surface selected.....	103
Figure 51. Scanner control and data acquisition systems	107
Figure 52. Tri-axial accelerometer configuration placement	109
Figure 53. Tri-axial accelerometer configuration placement at multiple front surface locations	110
Figure 54. Test structure excitation arrangement	112
Figure 55. Tri-axial accelerometer configuration location.....	113

Figure 56. LDV position for first front surface scan	114
Figure 57. LDV position for second front surface scan.....	119
Figure 58. LDV position for third front surface scan	119
Figure 59. LDV position for fourth front surface scan.....	120
Figure 60. Finite element mesh created by ESDM which modeled the column front surface geometry	124
Figure 61. Tri-axial accelerometer configuration locations	126
Figure 62. Velocity magnitude in x -direction obtained from ESDM and accelerometer data at each accelerometer location.....	130
Figure 63. Relative phase in x -direction between velocity and excitation force obtained from ESDM and accelerometer data at each accelerometer location.....	130
Figure 64. Velocity magnitude in y -direction obtained from ESDM and accelerometer data at each accelerometer location.....	131
Figure 65. Relative phase in y -direction between velocity and excitation force obtained from ESDM and accelerometer data at each accelerometer location.....	131
Figure 66. Velocity magnitude in z -direction obtained from ESDM and accelerometer data at each accelerometer location.....	132
Figure 67. Relative phase in z -direction between velocity and excitation force obtained from ESDM and accelerometer data at each accelerometer location.....	132
Figure 68. Horizontal in-plane ESDM velocity magnitude in x -direction	136
Figure 69. Out-of-plane ESDM velocity magnitude in x -direction.....	137
Figure A1. Plate dimensions and pin locations	152

LIST OF TABLES

Table 1.	Statistical properties associated with residuals between horizontal scan angle data and regressed horizontal scan angle values obtained from Eqs. (95) and (96) at each DAC step increment.....	54
Table 2.	Statistical properties associated with residuals between horizontal scan angle data and regressed horizontal scan angle values obtained from Eqs. (99) and (100) at each recorded analog voltage	55
Table 3.	Statistical properties associated with residuals between horizontal scan angle data and regressed horizontal scan angle values obtained from Eqs. (102) and (103) at each DAC step increment.....	57
Table 4.	Statistical properties associated with residuals between horizontal scan angle data and regressed horizontal scan angle values obtained from Eqs. (106) and (107) at each recorded analog voltage	60
Table 5.	Predicted test structure modal characteristics.....	84
Table 6.	Stiffness values assigned to translational spring elements in finite element model for final test structure design	85
Table 7.	Stiffness values assigned to rotational spring elements in finite element model for final test structure design	85
Table 8.	Signal analyzer data acquisition parameters.....	118
Table 9.	Velocity results obtained via ESDM at indicated accelerometer locations	126
Table 10.	Velocity results obtained from accelerometer data collected at the indicated locations.....	129
Table 11.	Magnitude and phase comparisons between velocity components obtained from ESDM and the accelerometer data at the six accelerometer locations ..	133
Table A1.	Scan angle/DAC step and scan angle/analog voltage data	159