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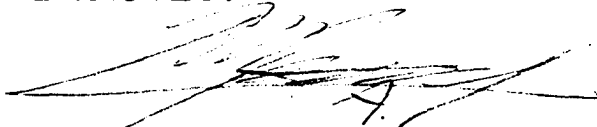
PREVIEW

**PROBABILISTIC EVALUATION OF A VIBRATIONAL NDE DAMAGE
DETECTION AND RELIABILITY ASSESSMENT METHOD
FOR AEROSPACE STRUCTURES**

THOMAS W. STEPHENSON

Department of Civil Engineering

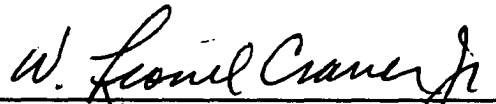
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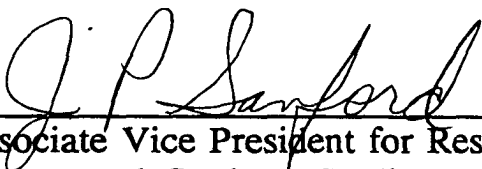
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by

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THESIS

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PREVIEW

Dedicated to
Delia, Jessica, and Jeanette

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ABSTRACT

The topic of detecting damage on space structures using changes in measurements of the vibrational characteristics is considered. A general theory of damage detection from changes in resonant frequencies is presented. The solution algorithm is modified to account for uncertainties in the frequency measurements. The effects of experimental uncertainties on the damage predictions are examined by simulating a number of NDE inspections on a hypothetical cantilever beam subjected to a single damage at several locations using Monte Carlo techniques. The statistics of the final damage predictions are obtained through the simulation results. The probability of detecting various levels of damage along the beam is examined by defining successful detection based on a combination of several damage detection events.

An entire space structure is modeled as a free-free beam. The free-free end conditions are simulated in the laboratory by suspending a beam vertically. The nature of the uncertainties on the experimental measurements is determined by repetition of the impact testing on an undamaged beam. Monte Carlo techniques are used to determine the probability of detecting damage on the model structure using the statistical parameters for each frequency measurement. Damage experiments are conducted for separate damage cases by taking several sets of frequency measurements before and after inflicting damage to the beam.

A method of estimating the reliability of the structure directly from the damage

predictions is formulated. A limit state function is derived in which the statistics of the damage predictions from the experimental NDE inspections are substituted for the damage variable. The reliability method is tested by using the experimental damage predictions, and these results are verified utilizing Monte Carlo simulation techniques.

PREVIEW

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iv

ABSTRACT v

TABLE OF CONTENTSvii

LIST OF TABLES xi

LIST OF FIGURES xiii

CHAPTER

1 INTRODUCTION 1

 1.1 Background of Damage and Damage Detection 1

 1.2 Vibrational Methods 3

 1.3 Structural Reliability Methods 4

 1.4 Problem Statement 6

 1.5 Objectives of the Study 7

 1.6 Scope of the Study 8

2 EXACT THEORY OF DAMAGE DETECTION 9

 2.1 Structural Dynamics 9

 2.2 Dynamic Differences Between Undamaged and Damaged Systems 11

 2.3 Relationship to Location of Damage 13

 2.4 Proportionally Damped Systems 16

 2.5 Damage Detection Algorithm 17

3	ANALYTICAL INVESTIGATION OF DAMAGE PREDICTION STATISTICS FOR HYPOTHETICAL CANTILEVER BEAM	21
3.1	Description of Cantilever Beam	22
3.2	Uncertainty Modeling of Experimental Measurements	24
3.3	Monte Carlo Simulation	25
3.4	Damage Detection Events	27
3.5	Investigation of Damage Prediction Algorithm	29
4	RESULTS OF ANALYTICAL STUDY ON CANTILEVER BEAM	31
4.1	Probability Distributions of Final Damage Predictions	31
4.2	Damage Detection Probabilities	39
4.3	Conclusions from Analytical Study on Cantilever Beam	50
5	EXPERIMENTAL PROCEDURES	52
5.1	Description of Experimental Beam	52
5.2	Material Properties of Experimental Beam	54
5.3	Description of Impact Testing Procedure	55
5.3.1	Equipment and Experimental Set-up	55
5.3.2	Measurement of Resonant Frequencies	56
5.3.3	Experimental Determination of Modes of Vibration	59
5.4	Finite Element Model of Experimental Beam	60
5.5	Damage Cases for Experimental Beam	69

6	ANALYTICAL INVESTIGATION OF DAMAGE PREDICTION STATISTICS FOR EXPERIMENTAL FREE-FREE BEAM	72
6.1	Description of Simulated NDE Inspections on Experimental Beam	72
6.2	Damage Detection Probabilities	74
6.3	Statistics of Damage Predictions on Free-Free Beam	85
7	DAMAGE DETECTION RESULTS FOR EXPERIMENTAL FREE-FREE BEAM	93
7.1	Damage Predictions on Experimental Beam	93
7.1.1	Beam 1, Damage at Location 10	93
7.1.2	Beam 2, Damage at Location 8	97
7.1.3	Beam 3, Damage at Location 6	100
7.1.4	Beam 4, Damage at Location 4	105
7.1.5	Beam 5, Damage at Location 2	109
7.2	Analysis of Non-Convergence of NDE Method	110
7.3	Comparison of Experimental Results to Simulation Results	115
8	STRUCTURAL RELIABILITY THEORY	125
8.1	Basic Structural Reliability Theory	125
8.2	Hasofer - Lind Reliability Index	127
8.3	Determination of Design Point	130
8.4	Limit State Function for Experimental Free-Free Beams	133
8.5	Determination of Bending Stress by Mode Superposition	136

8.6	Reliability Analysis of Experimental Beams	139
9	RESULTS OF RELIABILITY ANALYSIS ON EXPERIMENTAL BEAMS	145
9.1	Probability of Failure for Experimental Beams	146
9.1.1	Beam 1, Damage at Location 10	146
9.1.2	Beam 2, Damage at Location 8	152
9.1.3	Beam 3, Damage at Location 6	157
9.1.4	Beam 4, Damage at Location 4	159
9.2	Verification of Reliability Results Using Monte Carlo Simulation	164
10	SUMMARY AND CONCLUSIONS	174
10.1	Summary	174
10.2	Conclusions	176
	REFERENCES	179
	APPENDIX - A	
	List of Symbols	182
	APPENDIX - B	
	Gaussian and Lognormal Probability Paper Plots for the CDF's of the Observed Distributions of the Final Damage Predictions at Each Damaged Location for the Cantilever Beam	188
	CURRICULUM VITAE	196

LIST OF TABLES

Table	Page
3.1 Damaged and Undamaged Frequencies (Hz)	24
4.1 Statistics of Damage Predictions at Damaged Location	38
5.1 Statistical Parameters of Measured Frequencies	59
5.2 Comparison of Numerical and Experimental Frequencies (Hz)	68
5.3 Experimental Damage Cases	70
6.1 Probability of Detecting Damage on Free-Free Beam	76
6.2 Statistics of Damage Predictions at Damaged Locations, Free-Free Beam . .	86
7.1 Mean Values of Measured Frequencies for Beam 1	94
7.2 Damage Predictions for Beam 1 Using Mean Values	94
7.3 Mean Values of Measured Frequencies for Beam 2	98
7.4 Damage Predictions for Beam 2 Using Mean Values	98
7.5 Mean Values of Measured Frequencies for Beam 3	103
7.6 Damage Predictions for Beam 3 Using Mean Values	103
7.7 Mean Values of Measured Frequencies for Beam 4	106
7.8 Damage Predictions for Beam 4 Using Mean Values	106
7.9 Mean Values of Measured Frequencies for Beam 5	110
7.10 Comparison of Numerical and Experimental Values of $\delta\omega/\omega$, Beam 1	112
7.11 Comparison of Numerical and Experimental Values of $\delta\omega/\omega$, Beam 2	113
7.12 Comparison of Numerical and Experimental Values of $\delta\omega/\omega$, Beam 3	114

Table	Page
7.13 Comparison of Numerical and Experimental Values of $\delta\omega/\omega$, Beam 4	115
7.14 Comparison of Numerical and Experimental Values of $\delta\omega/\omega$, Beam 5	116
8.1 Maximum Bending Moment at Each Location	141
8.2 Assumed Distribution Types and Parameters of Random Variables for Reliability Analysis of Experimental Beam	143
9.1 Mean and Standard Deviation of α for Beam 1	147
9.2 Probability of Failure at Each Location - Beam 1	148
9.3 Mean and Standard Deviation of α for Beam 2	153
9.4 Probability of Failure at Each Location - Beam 2	154
9.5 Mean and Standard Deviation of α for Beam 3	157
9.6 Probability of Failure at Each Location - Beam 3	158
9.7 Mean and Standard Deviation of α for Beam 4	160
9.8 Probability of Failure at Each Location - Beam 4	161
9.9 Probability of Failure at Location 1 and Each Damaged Location	167

LIST OF FIGURES

Figure	Page
2.1 Flowchart for Vibrational NDE Damage Detection Algorithm	20
3.1 Analytical Cantilever Beam	23
4.1 Distribution of α at Location 3, 5% Actual Damage	32
4.2 Distribution of α at Location 3, 10% Actual Damage	32
4.3 Distribution of α at Location 3, 15% Actual Damage	32
4.4 Distribution of α at Location 3, 20% Actual Damage	32
4.5 Distribution of α at Location 7, 5% Actual Damage	32
4.6 Distribution of α at Location 7, 10% Actual Damage	32
4.7 Distribution of α at Location 7, 15% Actual Damage	33
4.8 Distribution of α at Location 7, 20% Actual Damage	33
4.9 Distribution of α at Location 11, 5% Actual Damage	33
4.10 Distribution of α at Location 11, 10% Actual Damage	33
4.11 Distribution of α at Location 11, 15% Actual Damage	33
4.12 Distribution of α at Location 11, 20% Actual Damage	33
4.13 Distribution of α at Location 15, 5% Actual Damage	34
4.14 Distribution of α at Location 15, 10% Actual Damage	34
4.15 Distribution of α at Location 15, 15% Actual Damage	34
4.16 Distribution of α at Location 15, 20% Actual Damage	34
4.17 Distribution of α at Location 19, 5% Actual Damage	34

Figure	Page
4.18 Distribution of α at Location 19, 10% Actual Damage	34
4.19 Distribution of α at Location 19, 15% Actual Damage	35
4.20 Distribution of α at Location 19, 20% Actual Damage	35
4.21 Gaussian Probability Paper Plot for Cumulative of α at Location 19, 5% Level of Damage	36
4.22 Lognormal Probability Paper Plot for Cumulative of α at Location 19, 5% Level of Damage	36
4.23 Probability of Detecting Damage at Location 3	40
4.24 Probability of Detecting Damage at Location 7	40
4.25 Probability of Detecting Damage at Location 11	41
4.26 Probability of Detecting Damage at Location 15	41
4.27 Probability of Detecting Damage at Location 19	42
4.28 Number of Maximum Damage Predictions at Each Location Given Damage at Location 3	46
4.29 Number of Maximum Damage Predictions at Each Location Given Damage at Location 7	46
4.30 Number of Maximum Damage Predictions at Each Location Given Damage at Location 11	47
4.31 Number of Maximum Damage Predictions at Each Location Given Damage at Location 15	47
4.32 Number of Maximum Damage Predictions at Each Location Given Damage at Location 19	48
5.1 Experimental Free-Free Beam	53

Figure	Page
5.2 Schematic of Experimental Set-up	56
5.3 Distribution of Measured Resonant Frequencies, First Mode	58
5.4 Distribution of Measured Resonant Frequencies, Fourth Mode	58
5.5 Distribution of Measured Resonant Frequencies, Seventh Mode	58
5.6 Distribution of Measured Resonant Frequencies, Tenth Mode	58
5.7 Comparison of 1st Experimental and 1st Analytical Mode Shapes	62
5.8 Comparison of 2nd Experimental and 2nd Analytical Mode Shapes	62
5.9 Comparison of 3rd Experimental and 3rd Analytical Mode Shapes	63
5.10 Comparison of 4th Experimental and 4th Analytical Mode Shapes	63
5.11 Comparison of 5th Experimental and 5th Analytical Mode Shapes	64
5.12 Comparison of 6th Experimental and 6th Analytical Mode Shapes	64
5.13 Comparison of 7th Experimental and 7th Analytical Mode Shapes	65
5.14 Comparison of 8th Experimental and 8th Analytical Mode Shapes	65
5.15 Comparison of 9th Experimental and 9th Analytical Mode Shapes	66
5.16 Comparison of 10th Experimental and 10th Analytical Mode Shapes	66
5.17 Comparison of 11th Experimental and 10th Analytical Mode Shapes	67
6.1 Probability of Detecting Damage at Each Damage Location Using Event 1	75
6.2 Probability of Detecting Damage at Each Damage Location Using Events 1 and 2	75

Figure	Page
6.3 Probability of Detecting Damage at Each Damage Location Using Events 1 and 3	76
6.4 Number of Maximum Damage Predictions per Location Given Damage at Location 1	79
6.5 Number of Maximum Damage Predictions per Location Given Damage at Location 2	79
6.6 Number of Maximum Damage Predictions per Location Given Damage at Location 3	80
6.7 Number of Maximum Damage Predictions per Location Given Damage at Location 4	80
6.8 Number of Maximum Damage Predictions per Location Given Damage at Location 5	81
6.9 Number of Maximum Damage Predictions per Location Given Damage at Location 6	81
6.10 Number of Maximum Damage Predictions per Location Given Damage at Location 7	82
6.11 Number of Maximum Damage Predictions per Location Given Damage at Location 8	82
6.12 Number of Maximum Damage Predictions per Location Given Damage at Location 9	83
6.13 Number of Maximum Damage Predictions per Location Given Damage at Location 10	83
6.14 Mean Values of α Given Damage at Location 1	87
6.15 Mean Values of α Given Damage at Location 2	87
6.16 Mean Values of α Given Damage at Location 3	88

Figure	Page
6.17 Mean Values of α Given Damage at Location 4	88
6.18 Mean Values of α Given Damage at Location 5	89
6.19 Mean Values of α Given Damage at Location 6	89
6.20 Mean Values of α Given Damage at Location 7	90
6.21 Mean Values of α Given Damage at Location 8	90
6.22 Mean Values of α Given Damage at Location 9	91
6.23 Mean Values of α Given Damage at Location 10	91
7.1 Damage Predictions Using Actual Measured Frequencies of Beam 1 - 5% Damage at Location 10	96
7.2 Damage Predictions Using Actual Measured Frequencies of Beam 1 - 10% Damage at Location 10	96
7.3 Damage Predictions Using Actual Measured Frequencies of Beam 2 - 5% Damage at Location 8	101
7.4 Damage Predictions Using Actual Measured Frequencies of Beam 2 - 10% Damage at Location 8	101
7.5 Damage Predictions Using Actual Measured Frequencies of Beam 3 - 10% Damage at Location 6	104
7.6 Damage Predictions Using Actual Measured Frequencies of Beam 4 - 5% Damage at Location 4	108
7.7 Damage Predictions Using Actual Measured Frequencies of Beam 4 - 10% Damage at Location 4	108
7.8 Comparison of Experimental α to Expected Range From Simulations Given 5% Damage at Location 10	118

Figure	Page
7.9 Comparison of Experimental α to Expected Range From Simulations Given 10% Damage at Location 10	118
7.10 Comparison of Experimental α to Expected Range From Simulations Given 5% Damage at Location 8	119
7.11 Comparison of Experimental α to Expected Range From Simulations Given 10% Damage at Location 8	119
7.12 Comparison of Experimental α to Expected Range From Simulations Given 10% Damage at Location 6	120
7.13 Comparison of Experimental α to Expected Range From Simulations Given 5% Damage at Location 4	120
7.14 Comparison of Experimental α to Expected Range From Simulations Given 10% Damage at Location 4	121
8.1 Transformation of Random Variables from Original Space to Reduced Space	128
9.1 Probability of Failure at Each Location for Undamaged and Damaged Beam - 5% Damage at Location 10	168
9.2 Probability of Failure at Each Location for Undamaged and Damaged Beam - 10% Damage at Location 10	168
9.3 Probability of Failure at Each Location for Undamaged and Damaged Beam - 5% Damage at Location 8	169
9.4 Probability of Failure at Each Location for Undamaged and Damaged Beam - 10% Damage at Location 8	169
9.5 Probability of Failure at Each Location for Undamaged and Damaged Beam - 10% Damage at Location 6	170
9.6 Probability of Failure at Each Location for Undamaged and Damaged Beam - 5% Damage at Location 4	170

Figure	Page
9.7 Probability of Failure at Each Location for Undamaged and Damaged Beam - 10% Damage at Location 4	171

PREVIEW

CHAPTER 1

INTRODUCTION

1.1 Background of Damage and Damage Detection

Structural systems which are subjected to large and uncertain loading conditions must be routinely inspected for any possible damage. Damage may be defined as any deviation in the structure's geometric or material properties which cause undesirable displacements or vibrations in the structure. These deviations may be due to cracks, loose bolts, broken welds, corrosion, fatigue, and so on. If a structure has sustained a damage, and the damage remains undetected, the damage could progressively increase until the structure ultimately fails. Therefore, early detection, analysis, and repair of a damaged structure, if necessary, is vital for the safe performance of the structure.

There are currently a number of non-destructive techniques available for damage detection and assessment, such as X-ray radiography, infrared thermography, ultrasonic spectroscopy, acoustic holography, etc. These methods have been well developed, can be used on a variety of structures and materials, and give very accurate information on the type and extent of any damage. The major drawback with these methods is that they are all local in nature; that is, a defect is detected by placing the respective measurement equipment relatively close to the location of the damage. The time required to inspect a large structure completely using any of these methods is quite lengthy, and the costs

associated with such an inspection make them impractical as a global detection technique.

Recently a global damage detection scheme has been suggested which includes the possibility of utilizing the vibrational characteristics of a structure in order to determine the location and magnitude of damage [1]. This technique is based on the fact that damage of any structure is characterized by a decrease in the stiffness of the structure. These stiffness changes are then reflected in the dynamic response of the structure as changes in the natural resonant frequencies (eigenvalues) and the corresponding modes of vibration (eigenvectors). The vibrational properties are obtained by taking transducer measurements at various locations of the structure. Changes in the vibrational signatures, extracted before and after the infliction of damage, may be used to estimate the location and extent of damage. Then, any local inspection method can be employed to ascertain the exact nature and scope of the damage, and structural reliability concepts can be used to determine the safety of the structure given that damage. From these results, a decision can be made as to whether immediate repair of the structure is warranted.

Orbiting aerospace structures are subject to potentially damaging events, such as impacts from micrometeoroids, collisions with space debris, booster engine firings, docking, thermal cycles, and so on. It is important to identify and analyze damage to these types of structures early, since the expense of replacing a failed space structure can be enormous. In the case of manned space systems, this need is critical. Since an emergency evacuation of a space structure which is on the verge of failure is almost impossible, such a failure would result in loss of life as well as loss of the structure.

Any of the inspection techniques currently available for inspection of ground based structures could, theoretically, be used on aerospace structures. However, due to the large costs associated with planning and implementing a mission to inspect a space structure by one of the local methods, and the inherent danger to the crew involved in executing the mission, it is not feasible to use these methods, even to verify a known damage. Therefore, it is highly desirable to develop a global inspection system which not only can correctly locate damage, but also accurately estimate the overall safety of the structure given this damage.

1.2 Vibrational Methods

Various researchers [2-11] have demonstrated that different types of damage result in measurable changes in the vibrational characteristics of a structure, which can then be used to locate the damage. Cole [4] developed the Random Decrement method, which consists of averaging time history measurements of the dynamic response due to random excitations. This technique was applied to offshore structures by Yang, Dagalakis, and co-workers [5,6]. Adams and co-workers [9] showed that damage could be detected by a reduction in stiffness whether the damage was localized as in a single crack, or distributed throughout the structure as many micro-cracks. Cawley and Adams [11] determined that measurement of dynamic characteristics, natural frequencies, and damping ratios is potentially a very attractive technique for non-destructive evaluation, since these properties can be measured at a single point on the structure, and are