NASA Technical Memorandum 104093

EXPERIMENTS FOR LOCATING DAMAGED TRUSS MEMBERS IN A TRUSS STRUCTURE

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May 1991

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

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ABSTRACT

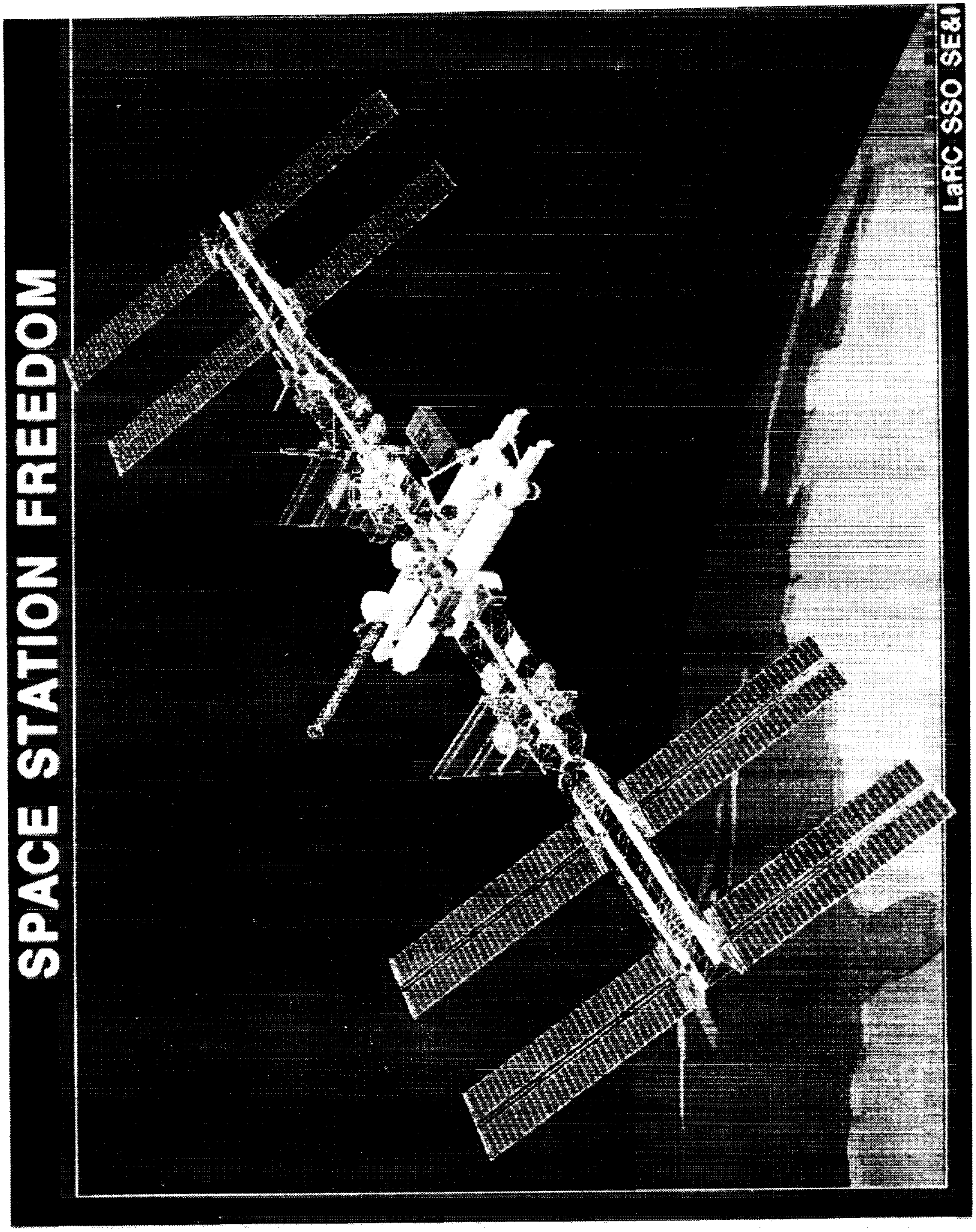
Locating damaged truss members in large space structures will involve a combination of sensing and diagnostic techniques. Methods developed for damage location require experimental verification prior to on-orbit applications. To this end, a series of experiments for locating damaged members using a generic, ten-bay truss structure have been conducted. In this paper, a "damaged" member is a member which has been removed entirely. Previously developed identification methods are used in conjunction with the experimental data to locate damage. Preliminary results to date are included, and indicate that mode selection and sensor location are important issues for location performance.

A number of experimental data sets representing various damage configurations were compiled using the ten-bay truss. The experimental data and the corresponding finite element analysis models are available to researchers for verification of various methods of structure identification and damage location.

SPACE STATION FREEDOM

Locating damaged members of a large space truss structure, such as Space Station Freedom shown in the adjoining figure, will inevitably involve a combination of sensing and diagnostic techniques. Structure identification methods which use dynamic response measurements can make a valuable contribution to this effort. In particular, optimal-update identification methods are well-suited for this application because they require data for only a few modes to produce an adjusted stiffness matrix. Areas of reduced stiffness indicate damage to a member or members of the truss.

Laboratory experiments to provide data to demonstrate an approach for locating damaged truss members have been designed and conducted. "Damaged" members as used herein are members which have been removed entirely, although the damage location approach presented is capable of locating members with significantly reduced stiffness, as well.


SPACE STATION FREEDOM
LaRC SSO SE&I

EXPERIMENT OBJECTIVES AND APPROACH

A review of on-orbit identification of large space structures was prepared by a task committee whose stated goal was to "develop a state-of-the-art report on methods for identification of large structures in space" (ref. 1). Their recommendations included a call for experimental evaluations and comparison studies of identification methods. Consequently, there are two related objectives for this experimental program, which define two related approaches.

Experimental data from several damage situations of a laboratory truss structure will provide researchers with a set of measurements to use to evaluate the performance of new and previously developed identification techniques. Ground tests and analyses of the truss structure are conducted to provide these "benchmark" cases.

Demonstration of a previously developed approach for damage location involves application of, and comparison of performance for, various identification and processing techniques. The approach is applied with data from the laboratory truss structure to determine and locate the removed member of the truss for each case.

OBJECTIVES:

TO PROVIDE EXPERIMENTAL DATA TO RESEARCHERS IN STRUCTURAL IDENTIFICATION AND HEALTH MONITORING.

TO DEMONSTRATE A PREVIOUSLY DEVELOPED APPROACH FOR LOCATING DAMAGED MEMBERS IN LARGE SPACE TRUSS STRUCTURES.

APPROACH:

CONDUCT GROUND TESTS AND ANALYSES OF A LABORATORY TRUSS STRUCTURE.

APPLY DAMAGE LOCATION APPROACH TO "LOCATE" REMOVED MEMBERS OF THE LABORATORY TRUSS.

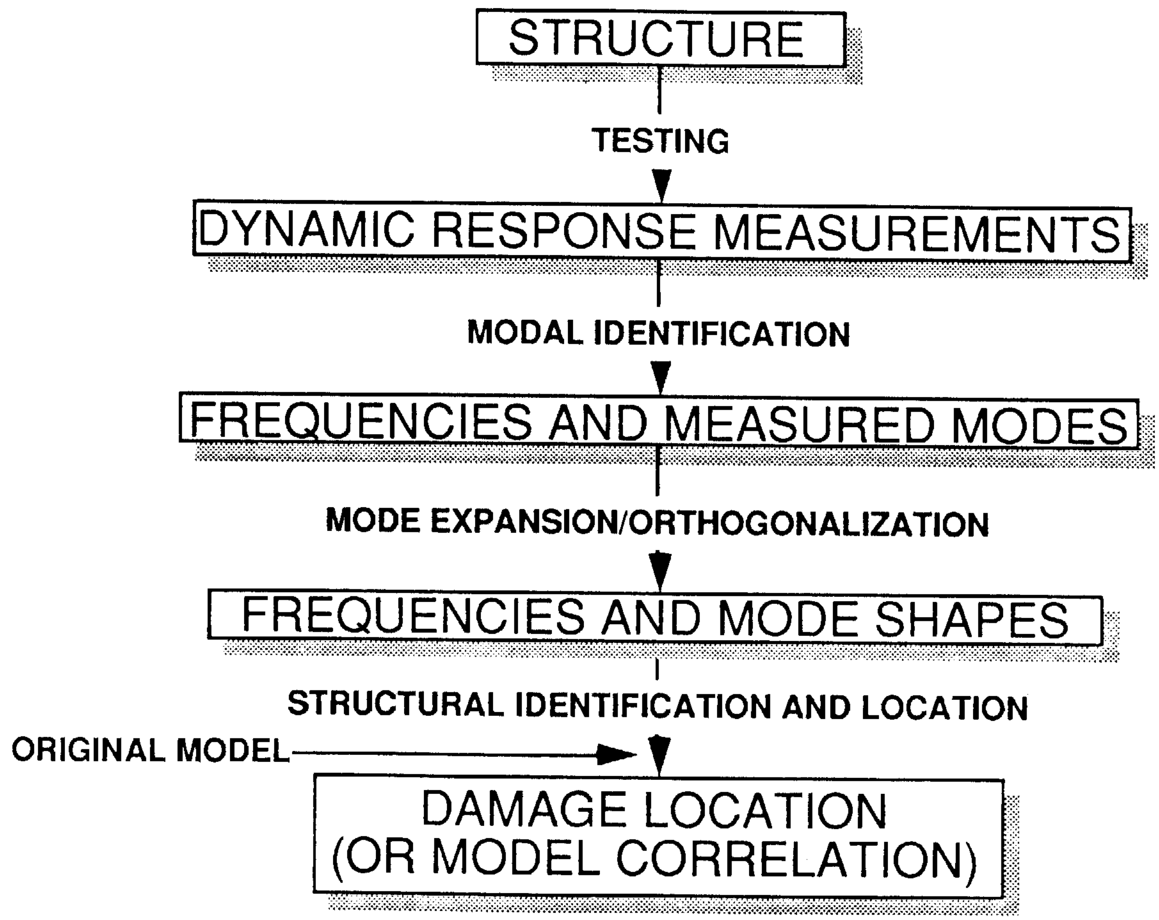
DAMAGE LOCATION APPROACH

A flow chart illustrating the approach envisioned for damage location (ref. 2, 12) is presented in the accompanying figure. Each vertical arrow represents a process that produces the result in the subsequent block. Several algorithms exist as possible candidates for each process. Ongoing research is, in part, evaluating performance of specific algorithms.

Tests of the structure produce dynamic response measurements--time histories of acceleration, for example. Modal identification procedures produce frequencies and mode shapes which include only the measured degrees-of-freedom (dofs). Techniques for mode shape expansion and orthogonalization estimate the full mode shape of the structure to compare with analytical model modes and for subsequent use in stiffness matrix adjustment. The next process involves optimal-update identification of the stiffness matrix, where the original model is a correlated model of the undamaged structure. A subsequent damage location technique is used to determine an area of reduced stiffness, which locates the damaged member of the truss.

This entire approach is analogous to test/analysis correlation for mathematical model improvement, where the original model is the analysis model of the structure.

DAMAGE LOCATION APPROACH



STIFFNESS MATRIX ADJUSTMENT

Several optimal stiffness matrix adjustment algorithms are options for the structural identification process in the damage location approach. Baruch and Bar Itzhack (ref. 3) introduced a stiffness update method which optimally adjusts the stiffness matrix to be consistent with the measured modal data. This update was also used by Berman and Nagy (ref. 4). Kabe (ref. 5) presented a technique which preserves the zero-nonzero pattern of the original stiffness matrix in the updated result, precluding unrealistic load paths in the updated model. The Projector Matrix (PM) method presented by Kammer (ref. 6) is another option which preserves the connectivity of the original model in the optimally adjusted stiffness matrix. Finally, secant-method adjustment techniques of Smith and Beattie (ref. 7) are possibilities for the identification process. One secant method, MSMT-EC, allows for inaccuracies in the modal data.

STIFFNESS MATRIX ADJUSTMENT

- o AN ADJUSTED STIFFNESS MATRIX IS DETERMINED WHICH IS AS "CLOSE" AS POSSIBLE TO THE ORIGINAL MATRIX, BUT IS ALSO CONSISTENT WITH THE MEASURED DATA.

- o IDENTIFICATION OPTIONS:

  - OPTIMAL CORRECTION OF THE STIFFNESS MATRIX:
    Baruch and Bar Itzhack (1978)
    ANALYTICAL MODEL IMPROVEMENT (AMI) METHOD
    Berman and Nagy (1983)

  - STIFFNESS MATRIX ADJUSTMENT (KMA)
    Kabe (1985)

  - PROJECTOR MATRIX (PM) METHOD
    Kammer (1988)

  - SECANT-METHOD ADJUSTMENT (MSMT)
    Smith and Beattie (1989)

MODE SHAPE EXPANSION

Several mode shape expansion algorithms are options for preparing the results of the modal identification process to be inputs for the stiffness matrix adjustment process. Stiffness matrix adjustment algorithms assume that for each of the m observed modes all n modeled degrees of freedom are accessible to measurement. The mode shape vectors, as a set, are also presumed to be orthogonal with respect to the structure mass matrix. Due to instrumentation costs and data handling capabilities, on-orbit measurements may be limited to a relatively few structure points, r. Values for the unmeasured dofs are extrapolated based on the modeled dynamic information and the r available measured dofs.

Berman and Nagy (ref. 4) used an expansion technique from the reordered, partitioned eigenvalue problem. Baruch and Bar Itzhack's (ref. 3) optimal orthogonalization technique can be used to subsequently adjust the expanded modes. Another expansion option was presented by O'Callahan (ref. 8). Kammer (ref. 9) presented a model reduction technique which also leads to the same expansion process. For the expansion method of both references 8 and 9, subsequent orthogonalization is needed. Finally, Smith and Beattie (ref. 10) developed a simultaneous expansion/orthogonalization technique based on the Orthogonal Procrustes problem for comparing subspaces.

MODE SHAPE EXPANSION

- o MODE SHAPE EXPANSION IS USED TO COMPARE A SET OF MEASURED MODES, $[\Phi_m]_{rxm}$ TO THE CORRESPONDING SET OF ANALYSIS MODES, $[\Phi_a]_{nxm}$ where,

  r = Number of Measured Degrees-of-Freedom
  n = Number of Analysis Degrees-of-Freedom, $r << n$
  m = Number of Measured Modes

- o MODE SHAPE EXPANSION/ORTHOGONALIZATION PROVIDES COMPLETE ORTHOGONAL MODES, $[\Phi_e]_{nxm}$ FOR STRUCTURAL IDENTIFICATION.

- o EXPANSION OPTIONS:

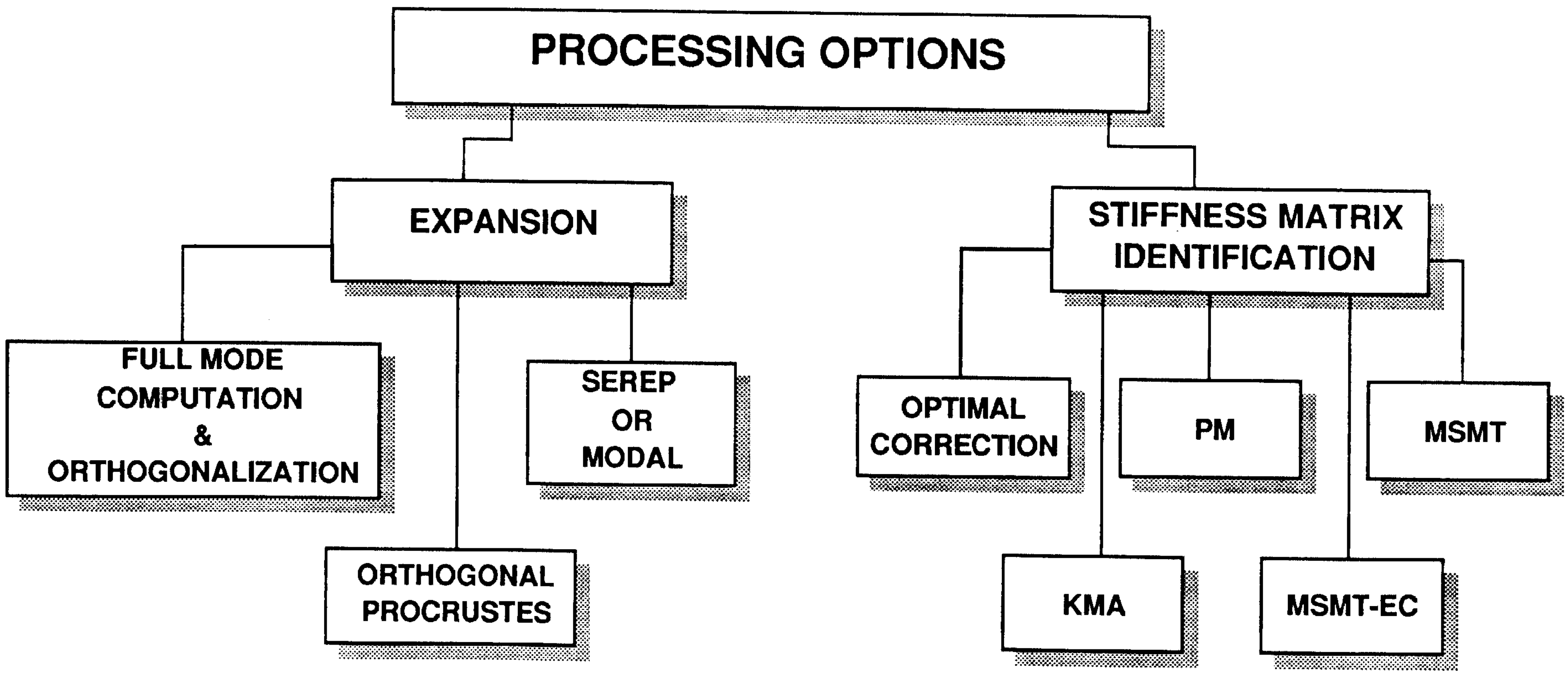
  - FULL MODEL COMPUTATION WITH SUBSEQUENT ORTHOGONALIZATION
    - Berman and Nagy (1983)
    - Baruch and Bar Itzhack (1978)
  - SYSTEM EQUIVALENT REDUCTION EXPANSION PROCESS (SEREP)
    - O'Callahan, et. al. (1989)
  - MODAL REDUCTION TECHNIQUE
    - Kammer (1987)
  - ORTHOGONAL PROCRUSTES EXPANSION
    - Smith and Beattie (1990)

DAMAGE PROCESSING OPTIONS

Ultimately, the performance of several expansion techniques and stiffness matrix adjustment techniques will be evaluated to establish efficient processes for the damage location approach. As a summary for these two focus processes, the adjoining figure presents the options listed on the previous charts.

Currently, full mode computation with subsequent orthogonalization, as presented by Berman and Nagy and Baruch and Bar Itzhack respectively, is selected for use with the experiment results presented in this paper. Also, Kabe's stiffness matrix adjustment (KMA) methods used.

DAMAGE PROCESSING OPTIONS



DSMT HYBRID-SCALE MODEL

An example of a complex structure in which damage location may be important is shown in the accompanying figure. This structure is a hybrid-scale structural model of an early Space Station Freedom assembly configuration (MB-2). Hybrid-scaling refers to the 1/5:1/10 scale factor applied to the model design. All truss planform dimensions have been scaled to l/10-size of the full-scale station design. The truss modal joints, mass and frequencies are 1/5-scale. This design provides a model which can be tested in existing facilities, yet has the low frequency dynamics characteristic of the station structure. The model was developed by the Lockheed Missiles and Space Company (ref. 11) under the Dynamic Scale Model Technology (DSMT) research program for NASA Langley Research Center (LaRC). The MB-2 configuration consists of ten truss bays which are connected by an articulating rotary joint and on which a number of solar arrays, radiators and pallets are mounted. Ground tests of this model will be performed at LaRC to develop techniques for predicting the on-orbit dynamic response of such structures. Simulated damage cases of this complex structure will provide insight into the expected behavior of other structures, including other configurations of Space Station Freedom.

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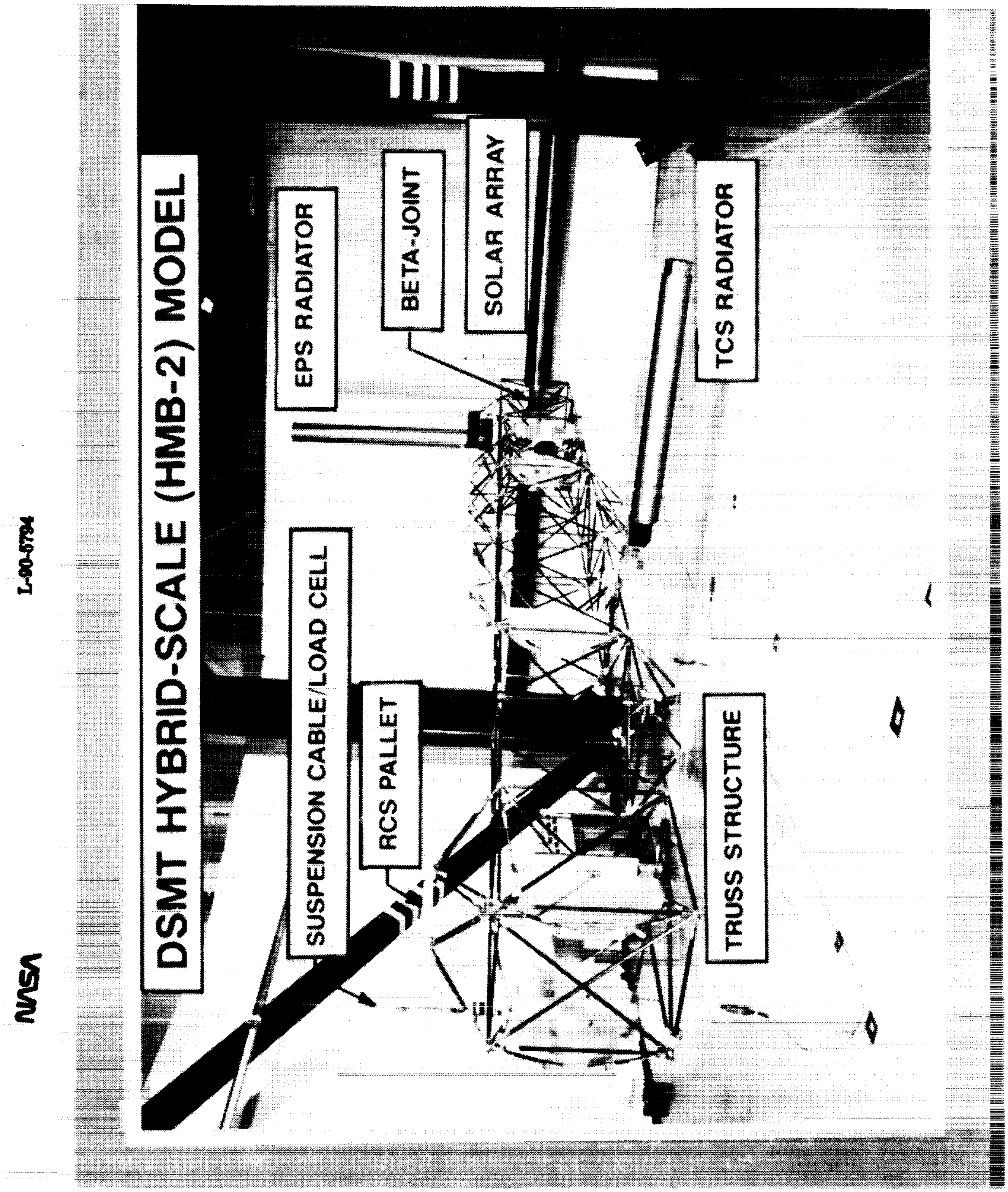
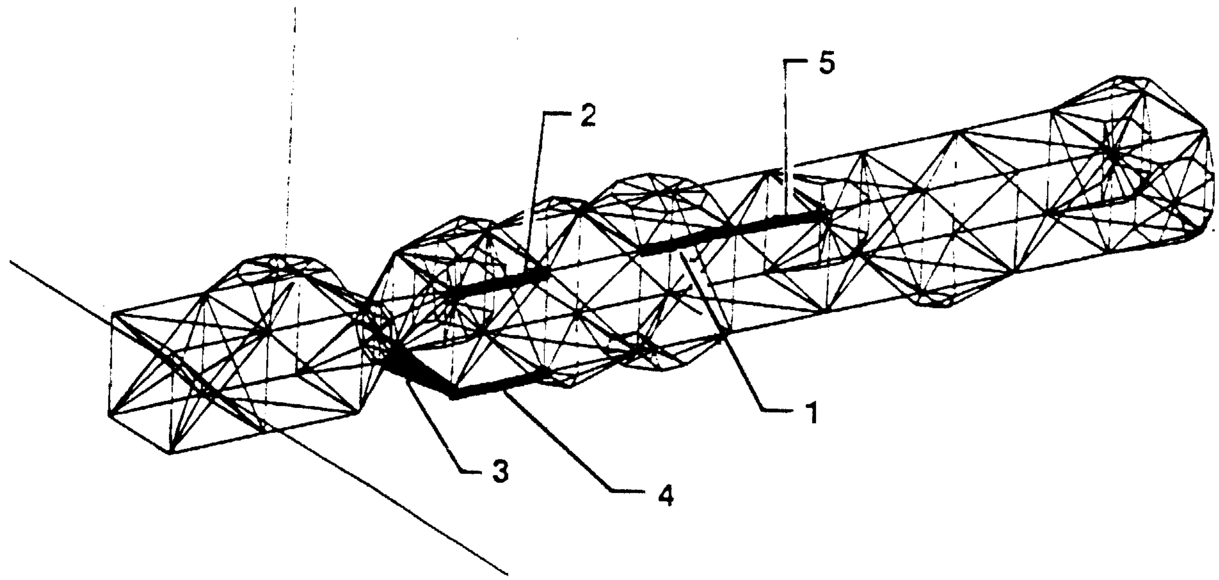


HYBRID-SCALE MODEL SELECTED DAMAGE STUDY CASES

In this study the effects of various damaged members on the global vibration frequencies of the hybrid-scale model were examined. The figure depicts a finite element analysis model of the structure, with each damage case denoted by number. Selection of members for damage was arbitrary and was intended only to examine trends. Cases 1, 2, 4 and 5 each consist of removing a longeron truss member from a single bay of the truss structure, whereas case 3 consists of removing 3 members from a connecting leg of the rotary joint.

HYBRID-SCALE MODEL SELECTED DAMAGE STUDY CASES



CASE 1 : LONGERON "1" IN 6th BAY

CASE 2 : LONGERON "2" IN 8th BAY

CASE 3 : CONNECTING STRUTS IN ALPHA-JOINT

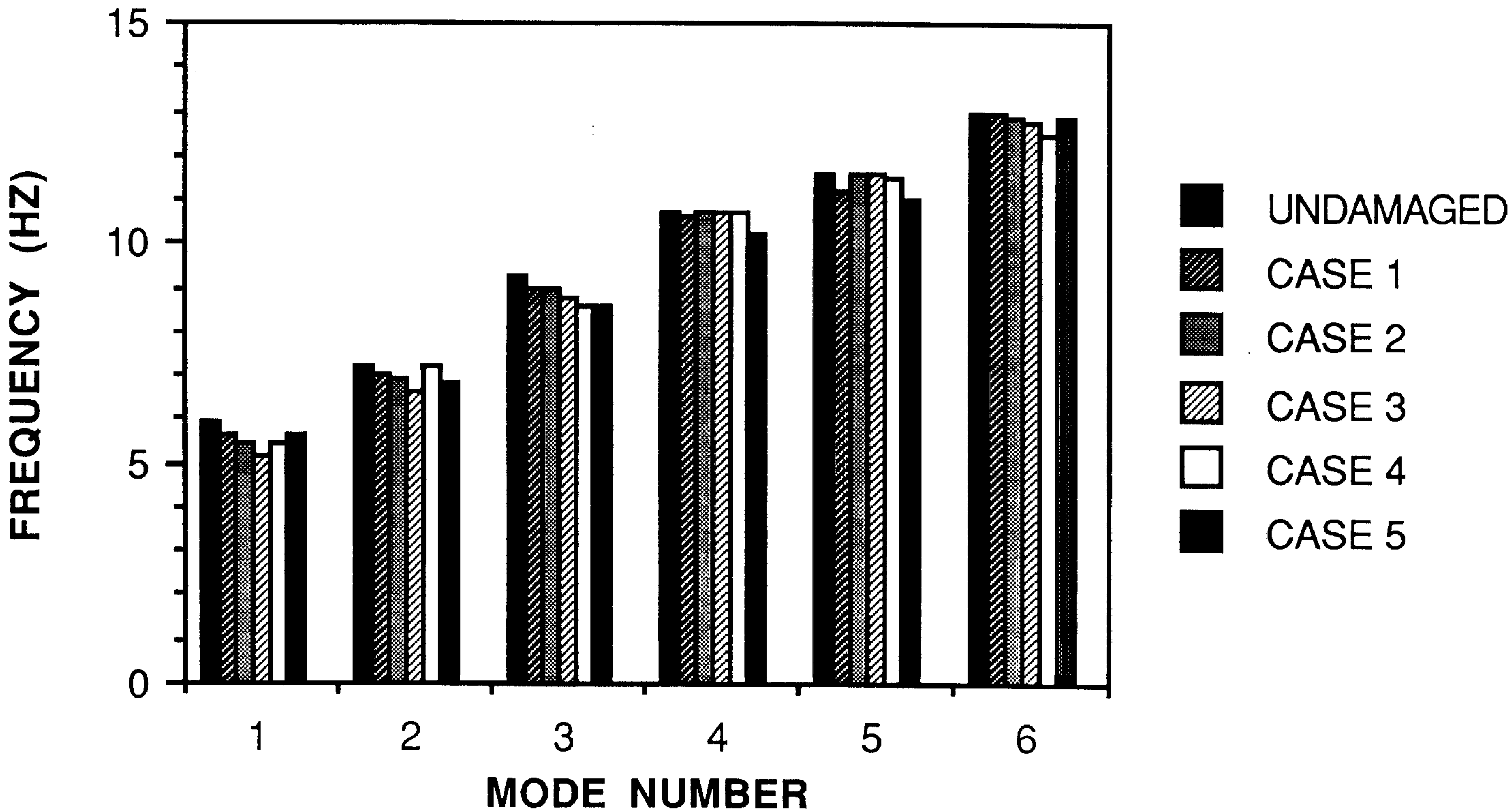
CASE 4 : LONGERON "4" IN 9th BAY

CASE 5 : LONGERON "5" IN 5th BAY

HYBRID-SCALE MODEL DAMAGE RESULTS

Results for the global frequencies as predicted by finite element analysis for the hybrid-scale model are shown in the adjoining graph. Each damage case as defined in the previous figure is shown along with the undamaged model results for the first six structural modes. Of interest is the reduction in frequency for each mode due to the damaged truss member. Case 3 is shown to have the single largest effect on the first structural mode, with a frequency reduction of 13 percent in that mode. Other cases have less effect overall, but still cause a sizeable change in the frequency of the modes. Therefore, identification techniques which use frequency change information, as data will have significant inputs. These results also indicate that without a procedure for detecting structural damage, erroneous predictions of dynamic response of such a structure could occur.

HYBRID-SCALE MODEL DAMAGE RESULTS



TEN-BAY GENERIC TRUSS STRUCTURE

The test article for this study was a ten-bay truss constructed of aluminium joints and truss members. This truss is one of a series of structures being used in the DSMT research program to study dynamic scale model ground testing (ref. 12,13). Each bay of the truss is a cube with the side dimension of 1.64 feet. This length is 1/10 that proposed for the space station structure. The truss was cantilevered as shown in the figure. Plates were attached to the free end of the truss. These plates weighed 86.25 lbs. and accounted for approximately 60 percent of the total test article weight of 147.4 lbs.

Modal tests of this structure were performed to determine vibration frequencies and mode shapes. Accelerometers were placed at each of the 44 truss nodal joints in two directions perpendicular to the truss longitudinal axis. Axial acceleration measurements were also acquired at the two driving points, at the four truss nodes of the free end, and at the four nodes of the truss mid-frame. Two shakers in the transverse directions were located at the eighth truss bay. The structure was excited by a burst random signal which was on for 50 percent of the data acquisition block. Frequency response functions were measured in a 0-128 Hz bandwidth, such that the first nine structural modes were excited and measured. All test data was acquired with a GenRad 2515 MTS and analyzed by the TDAS module of the SDRC I-DEAS package.

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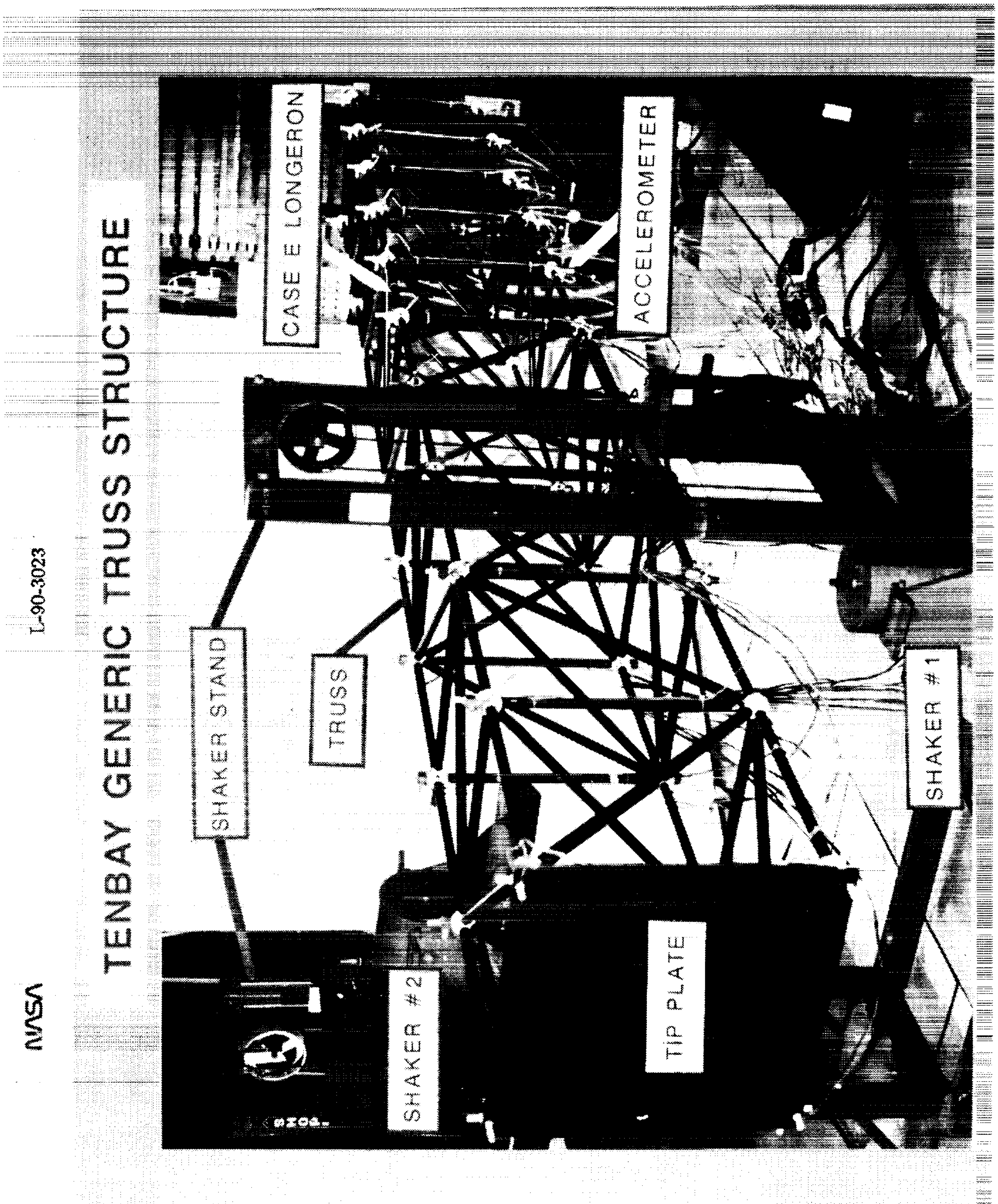


TEST/ANALYSIS COMPARISON FOR UNDAMAGED TRUSS

Listed in the table are the test/analysis comparisons for the undamaged truss structure. The first nine structural modes are listed and the mode descriptions are those corresponding to the next figure of the paper. Excellent agreement between the measured test and predicted analysis frequencies is evident. The maximum percent difference between test and analysis frequencies is only 3.9 percent. Also listed is the Modal Assurance Criterion (MAC) parameter (ref. 14), which is used to indicate correspondence between test and analysis mode shapes. A MAC value of 1.0 indicates perfect correlation of two shapes within a scale factor. Orthogonal modes produce a MAC value of 0. These results provide confidence in the undamaged truss analysis model, which is subsequently used as the original model in the damage location approach.

TEST/ANALYSIS COMPARISON FOR UNDAMAGED TRUSS

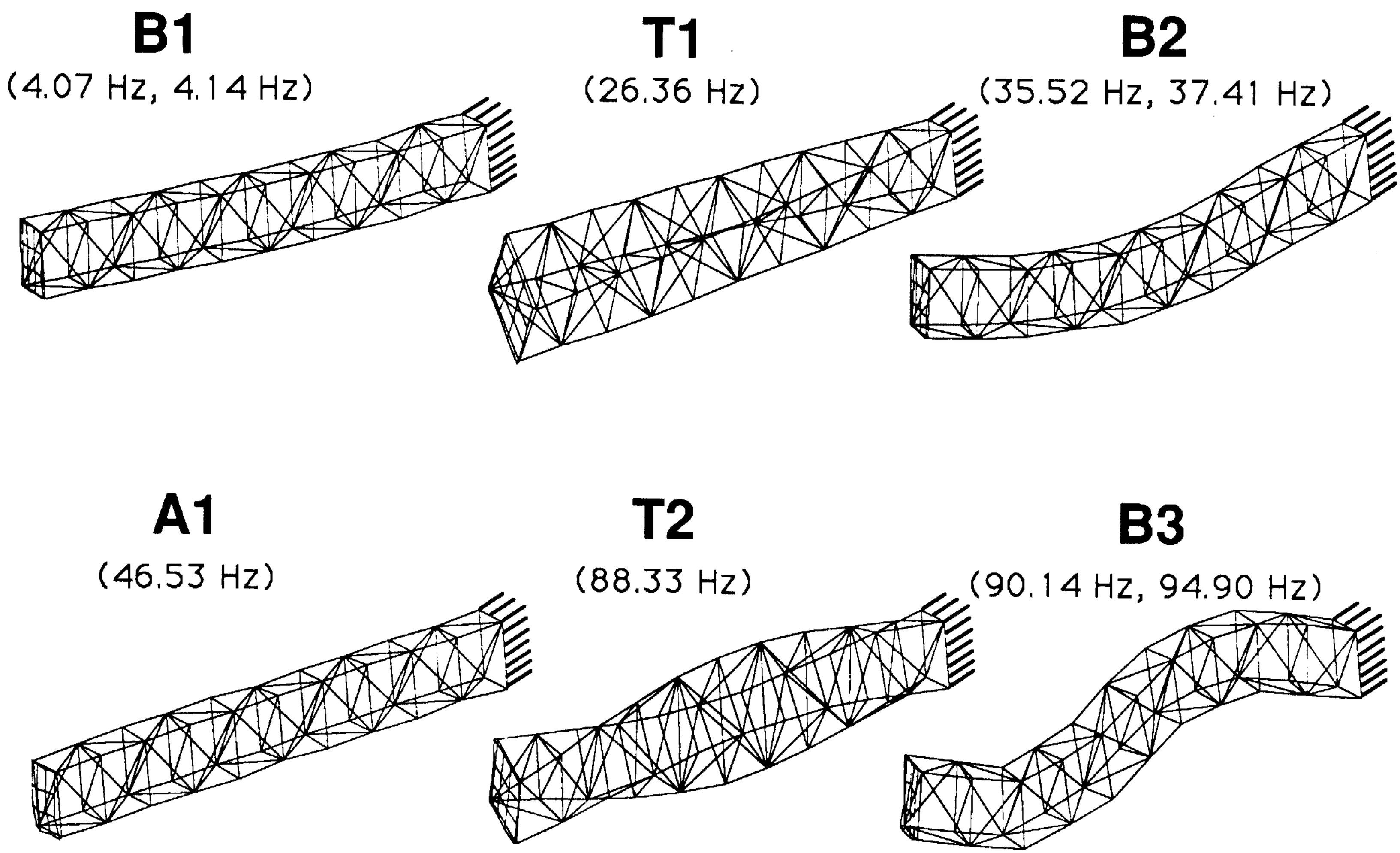
MODE NUMBER	MODE DESCRIPTION	FREQUENCY (HZ)		PERCENT DIFF.	MAC*
		ANALYSIS	TEST		
1	B1	4.07	3.91	3.9	1.00
2	B1	4.14	3.98	3.9	1.00
3	T1	26.36	25.78	2.2	1.00
4	B2	35.52	35.37	0.4	1.00
5	B2	37.41	37.00	1.1	1.00
6	A1	46.53	45.72	1.7	0.99
7	T2	88.33	88.92	0.7	0.99
8	B3	90.14	88.50	1.8	0.99
9	B3	94.90	92.55	2.5	1.00

*MAC = MODAL ASSURANCE CRITERION

TEN-BAY TRUSS ANALYSIS MODE SHAPES (UNDAMAGED)

Analytical mode shapes for the undamaged truss structure are depicted in the figure. Three bending mode parts (Bl, B2 and B3), two torsional modes (Tl and T2) and one axial mode (Al) are included. For simplicity, only one mode of each bending mode pair is shown in the figure. Due to the lacing of the truss member diagonals, each of the bending mode pairs actually involve vibration about axes which are rotated 45 degrees from the truss transverse axes. In this way it can be seen that removal of a truss member on one side of the truss will affect only a single mode from any given bending mode pair.

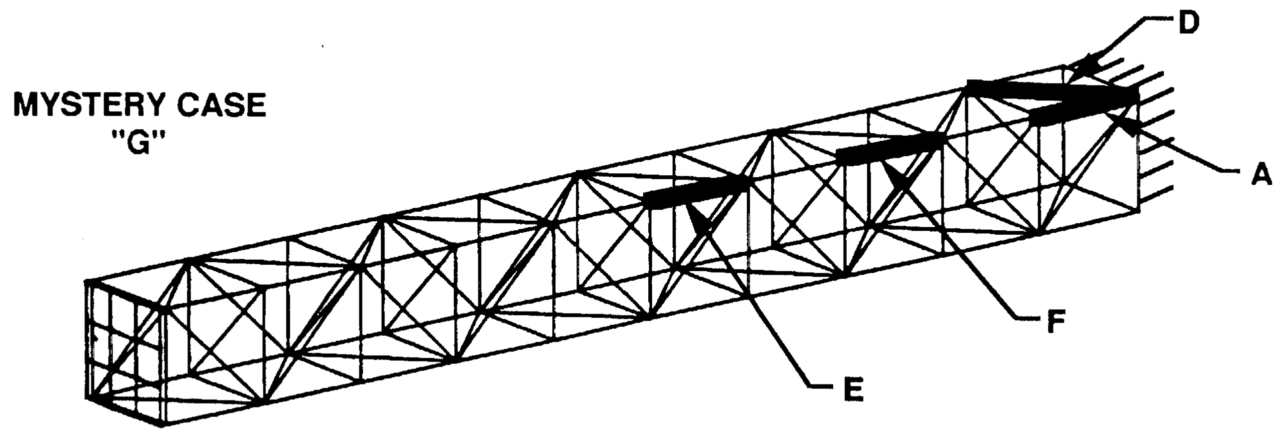
TEN-BAY TRUSS ANALYSIS MODE SHAPES (UNDAMAGED)



SELECTED DAMAGE STUDY CASES

Damage cases selected for the present study are shown in the adjoining figure. For completeness, case numbers and member labels shown are consistent with those used in reference 12. Not all damage case studies from reference 12 are considered, however. Cases A, E and F each involve a removed longeron truss member. Case D involves 2 removed diagonal member from the truss root. Finally, Case "G" is denoted the mystery case since test and analysis results are included in this paper, but the location of the removed member is not revealed. Case "G" will serve as a final validation of any approach for locating damage since the member location is not known a priori.

SELECTED DAMAGE STUDY CASES



CASE 1 : LONGERON "A" IN 1st BAY

CASE 4 : DIAGONAL "D" IN 1st BAY

CASE 5 : LONGERON "E" IN 5th BAY

CASE 6 : LONGERON "F" IN 3rd BAY

CASE 7 : MYSTERY CASE "G"

EFFECT OF REMOVED MEMBERS ON TRUSS STRUCTURE

The table is a presentation of those modes most affected in frequency by the damaged member for each damage case. The case numbers and member labels correspond to the previous figure. Comparison of percent maximum frequency change as predicted by analysis and as measured by test are listed. Again excellent agreement is found between the test and analysis values. It can be seen that removal of a longeron truss member primarily affects the truss bending modes (e.g., case E). Likewise, truss torsion modes are most affected by removal of 2 diagonal member (e.g., case D). Also shown in the final two columns of the chart are MAC comparisons of the damaged truss mode shapes with those found for the undamaged truss. MAC values for the analysis and test cases are again in agreement.

These results indicate that although the modes most affected in frequency by the removed member can be clearly distinguished, effects of damage on the mode shape are less obvious. For example, in case F the second bending mode was reduced in frequency by approximately 23 percent, but the damaged mode still retains the same shape as the undamaged mode. On the other hand, the seventh mode from case D was reduced by approximately 21 percent in frequency, and also showed poor correlation with the undamaged mode shape. It appears that an additional criterion for comparing spatial information from the damage cases is necessary.

EFFECT OF REMOVED MEMBERS ON TRUSS STRUCTURE

CASE NUMBER	REMOVED MEMBER	MODE AFFECTED	PERCENT MAXIMUM FREQUENCY CHANGE		MAC* COMPARISON WITH UNDAMAGED	
			ANALYSIS	TEST	ANALYSIS	TEST
1	A	2 (B1)	30.0	29.4	1.00	0.99
4	D	7,3 (T2, T1)	21.1, 15.6	20.6, 14.4	0.61, 0.93	0.63, 0.93
5	E	5,2 (B2, B1)	18.2, 14.0	17.3, 13.6	0.97, 1.00	0.99, 0.99
6	F	2,9 (B1, B3)	23.9, 9.6	23.1, 8.6	1.00, 0.98	0.99, 0.99
7	G	4,1 (B2, B1)	20.2, 8.1	19.8, 7.9	0.98, 1.00	0.99, 1.00

*MAC = MODAL ASSURANCE CRITERION

TEST/ANALYSIS RESULTS FOR DAMAGED TRUSS

Results for test and analysis of damage case E are presented in the adjoining table and are compared to those obtained from the undamaged truss. Once again, test and analysis frequency comparisons are excellent. MAC values for the damaged truss are also presented to correlate the test and analysis mode shapes for this damage case. In the last column of the table MAC comparisons of the damage case mode shapes with the corresponding undamaged mode shapes is shown. For brevity only the measured test modes are compared. As discussed in the previous chart, effects of the damage on the mode shapes are much less apparent than are effects on frequency.

The four tables following the results for damage case E list the corresponding results for the remaining damage cases A, D, F and G. Similar trends to those described for damage case E are observed in these cases.

TEST/ANALYSIS RESULTS FOR DAMAGED TRUSS

(DAMAGE CASE E)

MODE NUMBER	MODE DESCR.	FREQUENCY (Hz) UNDAMAGED		FREQUENCY (Hz) DAMAGED		MAC* DAMAGED ANALYSIS - TEST	MAC* UNDAMAGED/DAMAGED TEST - TEST
		ANALYSIS	TEST	ANALYSIS	TEST		
1	B1	4.07	3.91	4.07	3.91	1.00	1.00
2	B1	4.14	3.98	3.56	3.44	1.00	0.99
3	T1	26.36	25.78	26.37	25.79	1.00	1.00
4	B2	35.52	35.37	35.58	35.51	1.00	1.00
5	B2	37.41	37.00	30.62	30.60	1.00	0.99
6	A1	46.53	45.72	45.06	44.18	1.00	0.71
7	T2	88.33	88.92	88.51	89.56	0.87	0.92
8	B3	90.14	88.50	90.21	88.59	0.94	0.93
9	B3	94.90	92.55	93.97	91.99	0.99	1.00

*MAC = MODAL ASSURANCE CRITERION

TEST/ANALYSIS RESULTS FOR DAMAGED TRUSS

(DAMAGE CASE A)

MODE NUMBER	MODE DESCR.	FREQUENCY (Hz) UNDAMAGED		FREQUENCY (Hz) DAMAGED		MAC* DAMAGED ANALYSIS - TEST	MAC* UNDAMAGED/DAMAGED TEST - TEST
		ANALYSIS	TEST	ANALYSIS	TEST		
1	B1	4.07	3.91	4.07	3.88	1.00	1.00
2	B1	4.14	3.98	2.90	2.81	1.00	0.99
3	T1	26.36	25.78	26.36	25.75	1.00	1.00
4	B2	35.52	35.37	35.52	35.11	0.99	0.98
5	B2	37.41	37.00	33.72	33.54	0.99	0.99
6	A1	46.53	45.72	45.22	44.34	0.99	0.83
7	T2	88.33	88.92	88.33	88.97	0.99	1.00
8	B3	90.14	88.50	90.16	88.42	0.99	1.00
9	B3	94.90	92.55	93.90	92.09	0.99	1.00

*MAC = MODAL ASSURANCE CRITERION

TEST/ANALYSIS RESULTS FOR DAMAGED TRUSS

(DAMAGE CASE D)

MODE NUMBER	MODE DESCR.	FREQUENCY (Hz) UNDAMAGED		FREQUENCY (Hz) DAMAGED		MAC* DAMAGED ANALYSIS - TEST	MAC* UNDAMAGED/DAMAGED TEST - TEST
		ANALYSIS	TEST	ANALYSIS	TEST		
1	B1	4.07	3.91	4.05	3.89	1.00	0.99
2	B1	4.14	3.98	4.12	3.95	1.00	0.97
3	T1	26.36	25.78	22.25	22.07	1.00	0.93
4	B2	35.52	35.37	33.39	33.31	1.00	0.83
5	B2	37.41	37.00	36.68	36.23	1.00	0.82
6	A1	46.53	45.72	46.33	45.50	0.99	0.98
7	T2	88.33	88.92	69.72	70.58	1.00	0.63
8	B3	90.14	88.50	89.35	88.72	0.97	0.69
9	B3	94.90	92.55	93.29	91.56	0.96	0.86

*MAC = MODAL ASSURANCE CRITERION

TEST/ANALYSIS RESULTS FOR DAMAGED TRUSS

(DAMAGE CASE F)

MODE NUMBER	MODE DESCR.	FREQUENCY (Hz) UNDAMAGED		FREQUENCY (Hz) DAMAGED		MAC* DAMAGED ANALYSIS - TEST	MAC* UNDAMAGED/DAMAGED TEST - TEST
		ANALYSIS	TEST	ANALYSIS	TEST		
1	B1	4.07	3.91	4.07	3.91	1.00	1.00
2	B1	4.14	3.98	3.15	3.06	1.00	0.99
3	T1	26.36	25.78	26.36	25.74	1.00	1.00
4	B2	35.52	35.37	35.54	35.43	1.00	1.00
5	B2	37.41	37.00	36.88	36.43	0.99	0.99
6	A1	46.53	45.72	43.72	42.92	0.98	0.84
7	T2	88.33	88.92	88.43	89.47	0.87	0.92
8	B3	90.14	88.50	90.35	88.82	0.80	0.79
9	B3	94.90	92.55	85.83	84.62	0.99	0.99

*MAC = MODAL ASSURANCE CRITERION

TEST/ANALYSIS RESULTS FOR DAMAGED TRUSS

(DAMAGE CASE G)

MODE NUMBER	MODE DESCR.	FREQUENCY (Hz) UNDAMAGED		FREQUENCY (Hz) DAMAGED		MAC* DAMAGED ANALYSIS - TEST	MAC* UNDAMAGED/DAMAGED TEST - TEST
		ANALYSIS	TEST	ANALYSIS	TEST		
1	B1	4.07	3.91	3.74	3.60	1.00	1.00
2	B1	4.14	3.98	4.14	3.98	1.00	1.00
3	T1	26.36	25.78	26.38	25.68	0.99	1.00
4	B2	35.52	35.37	28.34	28.35	1.00	0.99
5	B2	37.41	37.00	37.48	37.03	1.00	1.00
6	A1	46.53	45.72	45.18	44.29	0.99	0.80
7	T2	88.33	88.92	88.42	88.60	0.98	0.96
8	B3	90.14	88.50	86.97	85.22	0.96	0.99
9	B3	94.90	92.55	94.97	92.49	0.97	0.98

*MAC = MODAL ASSURANCE CRITERION

DAMAGE LOCATION RESULTS (CASE E ANALYTICAL DATA)

Damage location results are presented in the next two tables for Case E damage of the truss, first using simulated data from the analytical model (adjoining table) and then using data measured in the experiments. Several sets of mode shapes are used for the input data as noted across the top of the table. Several sets of selected sensors are examined as well. These mode sets and sensor sets were chosen arbitrarily to examine trends in the results. Using 120 sensors represents measurement of every dof at every unconstrained modal joint. The remaining subsets selected correspond to all dofs measured in the experiment at specific truss frame locations. For example, the 24-sensors set includes 12 each at the mid-frame and at the tip.

For each mode-set/sensor-set combination shown, "located" means that the removed longeron was unambiguously determined by the damage location approach. "Indicated" means that the longeron was one of a few (less than 5) members indicated as having reduced stiffness. "Unresolved" means that the damage location process did not indicate a localized reduction in stiffness. These results show that for mode-set and sensor-set options, even with analytical model data, damage location may be unresolved.

DAMAGE LOCATION RESULTS
(CASE E ANALYTICAL DATA)

MODE SELECTION / SENSOR SELECTION	MODES 1, 2, 3	MODES 1, 2, 4	MODES 1, 2, 5	MODES 4, 5, 7
120 SENSORS	LOCATED	UNRESOLVED	INDICATED	INDICATED
90 SENSORS	UNRESOLVED			
58 SENSORS				
42 SENSORS				
24 SENSORS	INDICATED			

DAMAGE LOCATION RESULTS (CASE E MEASURED DATA)

The adjoining table presents the current damage location results for Case E damage using data measured from the truss. For the sensor-set and mode-set options shown, expansion and subsequent orthogonalization of modes was performed. Kabe's stiffness matrix adjustment method was used for the structural identification process in the damage location approach.

Again, mode selection and sensor selection are important aspects of damage location performance. Even when the location of the damaged member is unresolved for a particular data combination, performance of the individual processes can be evaluated to understand performance of the overall approach.

DAMAGE LOCATION RESULTS
(CASE E MEASURED DATA)

MODE SELECTION / SENSOR SELECTION	MODES 1, 2, 3	MODES 1, 2, 4	MODES 1, 2, 5	MODES 4, 5, 7
90 SENSORS	UNRESOLVED	UNRESOLVED	UNRESOLVED	
58 SENSORS				
42 SENSORS				
24 SENSORS				
14 SENSORS				

SUMMARY

Experiments have been designed and conducted with a 10-bay, cantilevered laboratory truss structure to give researchers in the identification and health monitoring fields data sets for evaluating methods and algorithms.

With the results of these experiments, an approach for damage location is under evaluation. Preliminary results indicate mode selection and sensor locations are important issues for location performance.

The available experimental data allows the study of mode selection and sensor location to enhance the development of damage location approaches.

SUMMARY

EXPERIMENTAL DATA IS AVAILABLE FOR RESEARCHERS IN STRUCTURAL IDENTIFICATION AND HEALTH MONITORING.

A PREVIOUSLY DEVELOPED APPROACH FOR LOCATING DAMAGED MEMBERS IN LARGE SPACE TRUSS STRUCTURES IS UNDER EVALUATION WITH THE TEST DATA.

PRELIMINARY RESULTS INDICATE SENSOR LOCATION AND MODE SELECTION ISSUES NEED MORE STUDY.

AVAILABLE DATA ALLOWS STUDY OF MODE AND SENSOR SELECTION.

AVAILABILITY OF TEST/ANALYSIS RESULTS

All finite element analysis results and modal test results reported in this paper are available to researchers in system identification and health monitoring. The analysis model is available in both COSMIC and MSC/NASTRAN formats. Any damaged case can be analyzed by removing the appropriate member from the truss. Also, all test data is available in SDRC universal file format. This data consists of frequency response functions, mode shapes and modal parameters.

AVAILABILITY OF TEST/ANALYSIS RESULTS

- ALL FINITE ELEMENT ANALYSIS (FEA) AND MODAL TEST RESULTS ARE AVAILABLE TO RESEARCHERS IN SYSTEM IDENTIFICATION AND HEALTH MONITORING.
  - FEA MODELS AVAILABLE IN COSMIC AND MSC/NASTRAN FORMATS
  - TEST DATA AVAILABLE IN SDRC UNIVERSAL FILE FORMAT
    - FREQUENCY RESPONSE FUNCTIONS
    - MODE SHAPES
    - MODAL PARAMETERS

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NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM 104093		

4. Title and Subtitle	5. Report Date
Experiments for Locating Damaged Truss Members in a Truss Structure	May 1991
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Paul E. McGowan, Suzanne W. Smith, and Mehzad Javeed	
	10. Work Unit No. 590-14-31-01
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-5225	11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20456-0001	13. Type of Report and Period Covered Technical Memorandum
	14. Sponsoring Agency Code

15. Supplementary Notes

Presented at the 2nd USAF/NASA Workshop on System Identification and Health Monitoring of Precision Space Structures, March 27-29, 1990, Pasadena, California.
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16. Abstract

Locating damaged truss members in large space structures will involve a combination of sensing and diagnostic techniques. Methods developed for damage location require experimental verification prior to on-orbit applications. To this end, a series of experiments for locating damaged members using a generic, ten-bay truss structure have been conducted. In this paper, a "damaged" member is a member which has been removed entirely. Previously developed identification methods are used in conjunction with the experimental data to locate damage. Preliminary results to date are included, and indicate that mode selection and sensor location are important issues for location performance.

A number of experimental data sets representing various damage configurations were compiled using the ten-bay truss. The experimental data and the corresponding finite element analysis models are available to researchers for verification of various methods of structure identification and damage location.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Damage Location, Ground Tests, Truss Structures, Identification, Test/Analysis Correlation	Unclassified--Unlimited Subject Category 39

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	45	A03

NASA FORM 1626 OCT 86