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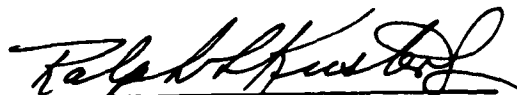Wright-Patterson Air Force Base, Ohio 45433

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Research was conducted to develop an improved method for ground vibration testing of airplanes. The resulting method, a single point excitation-frequency response analysis method, utilizes the computer, modern electronic equipment, developments in vibration testing theory and improvements in mechanical system design to accomplish ground vibration tests at greatly reduced cost while significantly improving accuracy. A demonstration ground vibration test was conducted using the improved method on an A-10 Airplane.

PREFACE

The research reported in this document was conducted by The Boeing Company for the Air Force Wright Aeronautical Laboratories under Air Force Contract F33615-77-C-3059, "Optimum Ground Vibration Test Method." Otto F. Maurer was the Air Force Technical Monitor for the contract. Bennie F. Dotson was the Program Manager, Roman F. Michalak was the Principal Investigator for Phase I and David W. Gimmestad was the Principal Investigator for Phases II and III at Boeing Military Airplane Company. Carl S. Doherty was the Lead Engineer, and significant contributions were made by Rita M. Nadreau, at the Vibration Laboratory of Boeing Commercial Airplane Company. At the University of Cincinnati, subcontractor to Boeing in this research, Dr. David L. Brown was Principal Investigator with significant contributions from Randall J. Allemang and Ray Zimmerman.

The body of this report was written by Roman F. Michalak, David L. Brown, Randall J. Allemang and David W. Gimmestad. Appendix A, the "Guide for Ground Vibration Testing of Airplanes" was written by Carl S. Doherty and Rita M. Nadreau. Appendix B, the "Aircraft Soft Support System" was written by David W. Gimmestad.

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LIST OF SYMBOLS

SYMBOL

ζ Damping Coefficient

δ Decay Rate

ω Frequency

x_p Displacement at Location p

F_q Applied Force at Location q

i $\sqrt{-1}$

U   Real Part of Modal Amplitude

V   Imaginary Part of Modal Amplitude

ϕ Phase Angle

A   Residue

s   Laplace Variable

h   Impulse Response Function

t   Time

H   Frequency Response Function

SUMMARY

The development of an improved aircraft ground vibration testing method is dis-
cussed. This method, a single point excitation-frequency response analysis
method, greatly reduces the cost of ground vibration testing while offering
significant improvements in accuracy. The development of this improved method
begins with a description of the testing philosophy and objectives of ground
vibration testing at airframe manufacturers in the United States, followed by a
description of the ground vibration test. The state of the art review includes a
broadly based literature survey. The industry interviews reveal areas where the
airframe industry, with exceptions, is behind the state of the art, and shows
opportunities for rapid improvement.

The single point excitation-frequency analysis method separates the ground
vibration test into a measurement phase and an analysis phase. The measurement
phase is conducted on the test site, and results in measurements of excitation
and response. The analysis phase is conducted in the laboratory computer room,
and results in frequency response functions and modal characteristics. Recom-
mendations include methods for ground vibration testing and specific equipment
items to improve the test.

Recommendations are also made for future research and development and for
approaches by which ground vibration testing improvements may be applied to USAF
programs. A demonstration ground vibration test was conducted using the recom-
mended method. This test on an A-10 airplane is reported in Volume II of this
report. A "Guide for Ground Vibration Testing of Airplanes," which incorporates
the recommended method is also included in an appendix.

1.0 INTRODUCTION

Ground vibration testing is an important element in the development of airplane structures. Knowledge of the dynamic characteristics of an aircraft is needed to analyze gust loads, flutter, shimmy, stability and control, maneuver loads, buffet loads, environmental vibration, ride comfort, acoustics, taxi loads, landing loads, etc. Calculating the dynamic characteristics is a complicated process which is done during preliminary design and final design of an airplane. The Ground Vibration Test is necessary to insure that the dynamic characteristics used in all the dynamic analyses are correct.

The opportunity for a significant improvement in ground vibration testing occurred when advances in a number of the vibration testing detail techniques had improved. These advances were the result of incorporating the computer into the test equipment, developments in integrated electronic circuitry, developments in vibration testing theory and improvements in mechanical system design. Selection of the methodology for this improved ground vibration testing method, integration of advances in detailed techniques into this method, some further advances and a demonstration of this improved method constituted the reported research.

The discussion in this report begins with testing philosophy and objectives. The testing philosophy and objectives of vibration testing as practiced in the United States, and by the airframe industry in particular, is defined. The description of a ground vibration test follows, in which its differentiation into measurement and analysis phases, and its goals and assumptions are discussed.

The state of the art review draws from a literature review, industry interviews and in-house experience. The review first discusses the general methods used in vibration testing, then reviews specific techniques used in ground vibration testing and the characteristics of modal parameter estimation. The process for selection of a recommended ground vibration testing (GVT) method follows. The candidate methods are rated by several criteria and analytical studies of the modal estimation process are discussed.

The recommended ground vibration testing method, the single point excitation-frequency response analysis method, is described in detail. The measurement phase and the interpretation phase of a test conducted by this method are outlined.

Conclusions are drawn on the current state of the art and on the recommended GVT method. Recommendations on ground vibration test method are made. Also the use of certain items of equipment is recommended for use in a GVT. Research and development recommendations which would further improve the GVT are made. Finally recommendations are made on applying the GVT improvements.

The appendices include a "Guide for Ground Vibration Testing of Airplanes" which incorporates the recommended method and Volume II contains the "A-10 Demonstration GVT Test Report." The latter report documents a demonstration GVT that was conducted using the recommended method. An appendix discusses design and development of an aircraft soft support system that was fabricated for use in the demonstration GVT.

2.0 DISCUSSION

2.1 TESTING PHILOSOPHY AND OBJECTIVES

An airplane ground vibration test is a test performed on an airplane to measure its structural dynamic characteristics. The principal reason for conducting a GVT is usually to support the flutter clearance program, a critical safety of flight item. Other important problem areas supported by the GVT include gust loads, shimmy, stability and control, maneuver loads, buffet loads, environmental vibration, ride comfort, acoustics, taxi loads and landing loads.

In the flutter clearance program a mathematical model of the airplane is usually developed. This model is the flutter engineer's abstraction of the mass and stiffness characteristics of the airplane. The objective of the ground vibration test is to provide data to validate, improve or replace the mathematical model.

The quality of the finished test data must be adequate for the engineering task it is needed for. Concurrent with this, the resources expended must be minimized and all cost and time estimates must be reliable. This implies that:

a. The length of time the test airplane is commited to the test must be minimized.

b. The number of skilled engineers and technicians necessary to run the test must be minimized.

c. The test usually runs 24 hours/day, until it is complete.

d. Total cost of running the test must be minimized. This cost includes the opportunity cost associated with occupancy time on the test airplane, man

power, equipment and the costs associated with delays in feedback of test results into the airplane development cycle.

2.2 DESCRIPTION OF GROUND VIBRATION TESTING

2.2.1. Definition of Experimental Modal Analysis

Experimental modal analysis is a test procedure for experimentally determining the motion of a structure in response to forces that excite the structure. This description includes a mathematical model for abstracting the behavior of the structure and the values of the parameters in that model. The model chosen is based upon assumptions about the structure's behavior. The values of the parameters are determined by a parameter estimation process applied to measurements of the structure's input (excitation force) and output (motion or response) signals. In this respect the structure is treated as a "black box" problem, in which the behavior is inferred from the input-output measurements. The process of experimental modal analysis generally consists of a measurement phase and an interpretation (or analysis) phase.

2.2.1.1 Measurement

In the measurement phase of a ground vibration test excitation is applied to the airplane and its response is measured. During most ground vibration tests a controlled force input is applied to the airplane and acceleration, velocity or displacement are measured at a number of points on the airplane.

2.2.1.2 Interpretation

Interpretation of the measurements is in terms of the mathematical model assumed for the airplane.

Linear Mathematical Model

A linear mathematical model is usually assumed for the airplane whenever possible. The unknown model parameters interpreted from the test measurements are invariably the modal characteristics of this model; frequency, damping and modeshape. Occasionally additional characteristics are reduced from the measurements. These include generalized mass and point mass, stiffness and damping coefficients.

Non-Linear Mathematical Model

When a linear model is not a sufficient approximation to the airplane's structural dynamic characteristics, a non-linear model must be used. This is done as infrequently as possible, and the models are kept as simple as possible, because this interpretation process is substantially more difficult than in the case of the linear mathematical model. There is no generally applicable nonlinear mathematical model. A model appropriate to the problem at hand must be selected for each application. Considerable research remains to be done on the subject of measurement interpretation for nonlinear mathematical models.

2.2.2 Goals

The identification of the goals of an experimental modal analysis test is an essential part of the choice of best test procedure. At the present time there are three primary uses of modal parameters:

1. Trouble Shooting
2. Modeling
3. Synthesis

Vibration testing is concerned with all three uses of the results at varying points in the life of an airplane. As the use of modal parameters change the test requirements are changed.

In the specific case of the airplane ground vibration test, verification and, if necessary, modification of the mass and stiffness matrices, used in the flutter analysis, is often the primary goal of the test. The construction of a mathematical model for flutter analysis is occasionally the goal, wherein generalized mass, stiffness, damping, and (via the modeshape) aerodynamic force matrices are developed. Modal parameters is a convenient mathematical model which can be applied to both the experimental test and the theoretical analysis.

2.2.3 Assumptions

Three basic assumptions about a structure are made in order to perform an experimental modal analysis which includes a linear mathematical model. First, the structure is assumed to be linear. This means that the response of the structure

to a combination of forces, simultaneously applied, is the sum of the individual responses to each of the forces acting alone (i.e., the superposition principle holds). For a wide variety of structures this is a very good assumption. When a structure is linear, its behavior can be characterized by a controlled-excitation experiment in which the forces applied to the structure have a form convenient for measurement and parameter estimation, rather than being similar to the forces that are actually applied to the structure in its normal environment. For many important kinds of structures, however, the assumption of linearity is not valid. In these cases the linear model that is identified often provides a reasonable approximation of the structure's behavior.

The second basic assumption is that the structure is time-invariant. This means that the parameters that are to be determined are constants. In general, a system which is not time-invariant will have components whose mass, stiffness, or damping depend on factors that are not measured or are not included in the model. If the structure that we are testing is changing with time, then measurements made at the end of the test period would determine a different set of modal parameters than measurements made at the beginning of the test period.

The third basic assumption is that the structure is observable. This means that the input-output measurements that we make contain enough information to generate an adequate behavioral model of the structure. Structures and machines which have loose components, or more generally, which have degrees of freedom of motion that are not measured are not completely observable. Consider describing the motion of a partially-filled tank of liquid when complicated sloshing of the fluid occurs. Sometimes we can make enough measurements so that our system is observable under the form chosen for the mathematical model, and sometimes no amount of measurements will suffice until we change the model.

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2.3 STATE OF THE ART REVIEW

2.3.1 Survey

2.3.1.1 Literature Review

The literature reviewed was identified by both manual and automated search proce-
dures. Known articles of value, as well as literature referenced within these
articles, were identified first. This material dates back to approximately 1945.
Then, independent computer searches were conducted by the University of Cincin-
nati and The Boeing Company involving the following data sets:

1. NTIS

2. COMPENDEX

3. ISMEC

4. SAE ABSTRACTS

5. NASA

6. DDC

    Classified

    Unclassified

The results of the computer searches consisted of about 2,000 listings of title,
author, source, and abstract. This computer search process included material no
earlier than 1965. Candidate literature items were selected by review of the
contents of their abstracts. Finally, the manual and computer searches were
combined to eliminate duplication which resulted in approximately 400 pieces of
literature being identified. Ninety percent of this literature was acquired.

(See reference lists following this volume.) The most significant literature of the reference material was selected and is summarized in Appendix D by subject matter. A chart summarizing the content of the reviewed literature is shown in Appendix E.

2.3.1.2 Industry Interviews

A series of interviews were held to ascertain the state of the art as practiced in the airframe industry. The groups selected for interview were identified by the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories as experienced in ground vibration testing. Additional individuals selected as having expertise in vibration testing were also interviewed.

Most of the personal interviews were performed on the site of the organization interviewed. The interviews were conducted by a combined team from the University of Cincinnati and The Boeing Company. Typically, two to three hours were spent in the interview combined with a tour of test facilities and equipment. A standard interview reporting form was used and frankness was encouraged by keeping the details of the interview confidential.

2.3.2 Current State of the Art

2.3.2.1 Airframe Industry Practice

Aircraft industry practice varied widely. All large airframe companies have an in-house ground vibration test group. Their experience levels vary dramatically; some conduct several GVT's a year; others run one test per decade. The

most difficult problem the airframe industry has in conducting vibration testing is in finding, training, and retaining adequately skilled people. A summary of the industry interviews can be found in Appendix C.

The survey disclosed four major reasons why airplane companies conduct GVT:

1. Comparison with a mathematical model developed for flutter analysis
2. Troubleshooting of existing aircraft
3. Research
4. Development of modal parameters to use in analysis

In most airplane GVT's, frequencies, dampings and mode shapes are the desired test result. Where fast Fourier transform equipment is in use, frequency response functions and coherence plots are produced as matter of course. The *more advanced developments, complex mode shapes,* generalized mass, stiffness and damping, transfer functions and orthogonality checks, are less frequently required, although there are organizations where some of these are routine.

Shakers are used for excitation for most airplane ground vibration tests, although occasionally impact and operating inputs are used. Impact testing has been utilized for testing flight control surfaces. Autopilot inputs to a large flight control surface have provided sufficient inertia excitation to shake out critical wing modes on a very large airplane. Single shaker inputs are used to excite both one degree of freedom at a time or multiple degrees of freedom. Of the multiple shaker systems in common use, most are groups of shakers operated in or out of phase to drive symmetric and antisymmetric airplane modes. They are used less frequently in apportioned force approaches. With rare exceptions the

multiple shaker arrangements are used to excite one degree of freedom at a time. Several organizations had research activities addressing the measurement of multiple degrees of freedom using multiple exciters.

The excitation signal used in GVT systems which do not incorporate a fast Fourier transform computer is invariably sinusoidal. The excitation signals generally used with FFT systems are random, although others are used such as sinusoidal, periodic random, random transient, impact, chirp, etc.

The data acquisition techniques used were found to be a function of the GVT development work done. Where little development had been done, a roving acceler-ometer was used with a strip chart recorder. In the developed systems, over 100 fixed response transducers were used with digitized data being recorded directly on disk under computer control. The norm is a large number of accelerometers with their response recorded directly on analog tape.

Parameter estimation under swept sine and dwell is a single degree of freedom (i.e. a single mode) at a time process. The parameter estimation techniques used with the modal analyzer computers usually used the software provided by the manufacturer. User written parameter estimation algorithms are rarely used on GVT outside research organizations. The algorithms used in GVT are single degree of freedom, single degree of freedom with residuals, multiple degree of freedom, and multiple degree of freedom with residuals.

A free-free support for the airplane in test is universally desired, although there is some disagreement over the frequency separation necessary. Require-ments specified varied from 10 to 1 to 2 to 1. At the 10 to 1 end of the spectrum

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special aircraft support systems are necessary such as airsprings (XB-70 support system), bungee or mechanical springs. At the 2 to 1 end of the spectrum a bottomed landing gear oleo and soft tires are satisfactory.

It was difficult to always obtain a frank discussion of chronic problem areas. Many of the difficulties expressed seemed to be due to inadequate preparation or lack of skill. As a result, problems were quite often attributed to nonlinearities. The most pressing problem is that the test airplane is available for the GVT for a very short period of time. One of the essential requirements of GVT procedure in the United States is speed. A second problem is that the interface between the test and analysis group is often poor. This is reflected not only in test planning, but in the post-test feedback of data into the analysis group. A third problem is that when introducing new technology, a large pool of acquired knowledge concerning the old techniques is obsoleted, and is only slowly replaced by the familiarity with the new techniques.

Nonlinearities are a chronic problem. Known nonlinearities, e.g., control surface actuator free play, are routinely shimmed or preloaded out, and the airplane is tested as linear. Often a separate test is run to document specific non-linearities. Unknown nonlinearities often appear during a test. The source of a strong nonlinearity must be determined and fixed before the test may proceed.

Although a pretest analysis is widely regarded as necessary, it usually consists of the free-free modes and frequencies of the airplane mathematical model used in the flutter analysis. On rare occasions it is a forced response calculation predicting the test response of the airplane in GVT configuration, including special modifications of the airplane for test and the airplane support system. The data resulting from the test is used for three purposes:

1. To validate the mathematical model

2. To revise a mathematical model

3. To construct a structural dynamic analysis

In some instances, little or no use was made of the data.

2.3.2.2 Ground Vibration Testing Methods

To compare various methods applicable to experimental modal analysis, a categorization will be used to identify major differences. This section of the report will describe the general characteristics of each method. When discussing criteria for method selection in Section 2.4.1, specific techniques and/or references will be used to evaluate each method.

Ground vibration testing methods are divided into three groups for this evaluation. The first grouping includes all methods pertinent to the forced response analysis technique documented by Lewis and Wrisley. This general testing procedure will be described as a Multiple Point Excitation--Sine Dwell (MPE-SD) approach. The second category that has found widespread application cannot be attributed to any one person or group. It involves measuring frequency response functions and determining modal parameters through comparison to a linear mathematical model. This general testing procedure will be described as a Single Point Excitation--Frequency Response Analysis (SPE-FRA) approach. The final category can best be described as all of the techniques not fitting in the first two general concepts. The reasoning behind this last grouping is that many of these techniques, while showing great promise, do not have adequate

documentation of pertinent details to receive serious consideration as a viable approach at this time. This is not to say that theoretical development is questioned but that little general knowledge of the practical application and results is available at this time. For this reason, most of the discussion under Criteria for Method Selection is limited to the two categories: MPE-SD and SPE-FRA.

Multiple Point Excitation--Sine Dwell Method

Modern MPE-SD techniques are based upon a forced response analysis approach first implemented by Lewis and Wrisley (112) and theoretically developed by Fraejis de Veubeke (45). The basic approach is to apply forces to a structure to compensate for energy loss through damping. If the forces are distributed in proportion to the damping and exactly balance the damping forces, the structure vibrates with the same motion as in the free undamped case.

The primary consideration of any MPE-SD approach is force appropriation. This involves three distinct problems. First, the number of exciters must be sufficient to address the effective number of degrees of freedom. Secondly, the number of exciters should be optimally located to excite a given mode. Finally, the vector forcing function must be determined. Although all three problems are difficult, the first and last can be automated with some success using various methods. The optimum location of the exciters can be evaluated by way of finite element pre-test analysis although no straight forward closed loop approach has been identified.

The use of digital computers has been of great value in the MPE-SD approach. Many of the force appropriation processes have been automated by the use of a

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computer controlled system. Data acquisition, storage, and display is more easily handled in a computer based system. Unfortunately, there is no uniform system available commercially that has found widespread use for the MPE-SD techniques. Much of the existing hardware in use has been custom built and ranges up to 15 years in age.

Most MPE-SD techniques involve many similar considerations. All have elaborate excitation control systems (often up to 16 shakers). All depend upon the concept of a phase resonance criteria for identifying the mode. Often Lissajous patterns are used to confirm this. Free decay is normally used to calculate damping factors and to verify the purity of the mode excited. Finally, the diagonalization of the reduced finite element mass matrix is used to verify the orthogonality of the measured modes.

Single Point Excitation--Frequency Response Analysis Method

Present day SPE-FRA techniques are based upon system identification procedures related to a causal black-box concept of structural dynamics. Frequency response functions are analyzed with modal parameter estimation algorithms to determine estimates of modal parameters. Such a process was utilized nearly 20 years ago with equipment known as Transfer Function Analyzers. This process was strictly a swept sinusoidal excitation with tracking filters to determine the output versus input. With the advent of fast Fourier analysis equipment nearly 10 years ago, other forms of excitation, notably broadband frequency signals, allowed complete frequency response functions to be measured in reduced time. The basic approach presently is to excite a structure with an appropriately chosen force signal at one location at a time. The frequency response function between the input force

and output response points of interest are measured and stored. Averaging of a number of inputs and responses is common practice in the development of the frequency response function. Modal parameters are estimated using any of a number of single degree of freedom (SDOF) or multiple degree of freedom (MDOF) algorithms. Often the modal parameter estimation routines take advantage of redundancy in a data set to improve the accuracy of the algorithm.

The primary consideration of any SPE-FRA approach is to obtain the best possible measurement data in the form of a frequency response function. This involves identification of measurement errors, proper location(s) of the single excitation to assure that no modes are missed, and determination of sufficient frequency resolution to identify closely-spaced modes. The use of the coherence function is vital in evaluation of measurement error and averaging requirements.

A secondary consideration of any SPE-FRA approach is to utilize proper modal parameter estimation algorithms. SDOF algorithms are often unacceptable if the modes are closely spaced in frequency. MDOF algorithms often use weighting schemes which provide varying results with the amount of damping present. The current trend is toward a flexible system with a number of SDOF and MDOF algorithms available.

Most SPE-FRA systems are very similar. The hardware is produced by a limited number of manufacturers and is made up of nearly identical components. Certainly the basic measurement capabilities are equal. Software to analyze the data is often available from the manufacturers but no new software systems have been available from this source for three to four years. Often, the individual users program particular algorithms for use on typical structures of a given industry

and much of this software is available from consulting firms, universities, and others. Since all systems are computer based, matrix operations such as orthogonality checks or modal vector manipulations are usually trivial computations to implement.

Other Methods

Two or three approaches are under development which show some degree of promise but for which there is little comprehensive documentation at present. A technique involving broadband multiple point excitation with frequency response analysis is under investigation at the University of Cincinnati. This concept would be very similar to a SPE-FRA approach but without the problems of energy distribution or multiple configurations to assure no modes are missed. A technique based upon free decay and global eigenvalue/eigenvector concepts is under investigation by Ibrahim (87, 88, 89). This system eliminates exciter problems and completely automates the data reduction process. Another new technique under evaluation by Link and Vollan (113) involves direct estimation of reduced mass, stiffness, and damping matrices. This obviously would be of great value in the interaction with finite element models.

For some further details in these areas, the background literature can provide additional information. Little further discussion will be made regarding these methods due to the lack of proven capability. It is of some interest to note, though, that the hardware and general development of the SPE-FRA approach could easily encompass many aspects of these other techniques should any one of them prove to be superior in the future.

2.3.2.3 Specific Techniques Used in Ground Vibration Testing

The state of the art of each of the principal facets of experimental model analysis is described in this section. The various methods of experimental modal analysis use different combinations of these components. These modal analysis methods are discussed in Section 3.1.2.

Excitation Configuration

Excitation configuration refers to the number of simultaneous forces used to excite the structure. Typically, the designation Single Input (SI) or multiple input (MI) is a sufficient description of the situations used for the Multipoint Excitation Sine Dwell (MPE-SD) or Single Point Excitation Frequency Response Analysis (SPE-FRA) techniques. With respect to the two general cases (SI and MI), SI is simple in terms of set-up time and cost of equipment. The inability to distribute energy throughout the structure can cause problems because not all modes can be excited from one point. Because of this, for most airplanes the SI test must be repeated with the excitation at several different locations.

Narrowband (sinusoidal) and broadband frequency excitation with SI can efficiently utilize the fast Fourier transform to develop frequency response information.

MI requires duplication of exciter systems which increases both the set-up time and costs. Additionally, the only practical technique using MI is a sinusoidal, forced response analysis approach. This requires additional control equipment

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to achieve force appropriation for a particular eigenvector. If this tuning process is automated (Asher (6, 7) Feix (57), Hallauer (70), Morosow (126, 127), Su (199), Traill-Nash (206)), more sophisticated control equipment is required. No current techniques use broadband frequency excitation with MI. Problems with estimating the number of exciters to use (based upon effective degrees of freedom) and with determining exciter location are difficult. The analysis of eigenvalue and eigenvector is very simple when tuning is successful.

Response Measurement Configuration

Response measurement configuration refers to the transducers used to record the structural motion. The designations of roving set or fixed set describe the configurations commonly used. For the case of a roving set of transducers, equipment is kept to a minimum but time can be a problem if multiple sets of data must be taken. Therefore, this approach is generally unattractive with the MI technique or with SI techniques when multiple configurations of the test structure are required. Calibration and set-up are minimized with a roving set of transducers and the quality of data should be equal to the fixed set of transducers at frequencies below 500 Hertz. As higher frequencies are required, the roving set of transducers must be rigidly attached to the structure. This is normally too time consuming to use.

More equipment is generally required using fixed transducers than roving. Additional time is spent in pre-test calibration and set-up. However, the total occupancy time on the test airplane can be reduced by using more channels of data

acquisition. The amount depends upon the number of points and test configurations. In the case of impact testing, one fixed transducer may be used while the location of the impact excitation is moved. Both multipoint excitation and single point excitation concept can utilize either a roving or fixed set of transducers.

Excitation Signal Format

Excitation signal format refers to the frequency content of the force input(s). The designation of sinusoidal is used to describe signals of only one frequency, while broadband encompasses fast sinusoidal sweeps, transients, and all forms of random signals. Sinusoidal signals have the advantage of minimum information and, thus, an easily recognizable form. This permits time domain analysis in terms of magnitude and phase and is psychologically reassuring during the test phase. Both MPE-SD and SPE-FRA can use sinusoidal excitation although implementation is somewhat different. Normally, with sinusoidal excitation, the input-output relationship is calculated one frequency at a time and modal interaction, particularly in the MPD-SD, is desired to be minimal. This is sometimes not possible to achieve.

Broadband excitation has the advantage of increased frequency content and, therefore, maximum information. The analysis of such data requires digital signal processing techniques such as fast Fourier transforms, digital filtering, and averaging to obtain frequency response information. Thorough understanding of the mathematics and peculiar physical phenomena (aliasing, leakage, etc.) of digital signal processing are required. Modal interaction is not suppressed by the excitation.

Confidence Factors

There are several confidence factors applicable to measurement. The first is repeatability. This involves duplicate measurements using the same procedures or measurements taken via different procedures. A second measure is to compute the coherence function. Holes in the coherence function immediately flag deficiencies in the measurement, local modes, or extraneous inputs to the system such as noise or non-linearities. The third measure is decay trace frequency and amplitude stability and logarithmic amplitude linearity. Deviations will indicate inadequate tuning, poor signal-to-noise ratios, nonlinearity and other problems.

Data Acquisition

The measurement process may involve testing many configuration variations. In a sinusoidal technique, data acquisition requirements dictate single word storage for the input and output measurements at each identified frequency. In wideband techniques, much more computer memory is required since many frequencies are processed simultaneously. Both situations can achieve an improvement in accuracy through averaging.

Filtering equipment is normally involved in most techniques whether for purposes of elimination of aliasing, narrow-band tracking, or reduction of noise. Care must be taken in applying filtering techniques to avoid any compromise or degradation of the data due to the unique problems associated with filters, e.g., rolloff, truncation.

Transducer sensitivity and amplifier characteristics need to match the other test equipment so that maximum accuracy can be maintained.

Sufficient time must be spent during the measurement phase to ascertain both the validity and quality of the data. This involves averaging where necessary as well as the use of coherence function. Even small errors or compensations made during this phase increase the potential difficulty in estimating the modal parameters.

Interpretation of Measurement

The current techniques of modal parameter estimation may be categorized as modal parameter estimation via direct measurement and modal parameter estimation via frequency response analysis. In the direct measurement technique the test apparatus is adjusted so that, in the judgement of the operator, the test item is vibrating in a normal mode. The frequency of vibration is recorded as the natural frequency and the displacement amplitudes are recorded as modeshapes. In the frequency response analysis technique, frequency response functions are developed from the measurement. A frequency response function can be developed by a slow sine sweep at constant input force amplitude, in which case the frequency response function is the displacement as a function of frequency. More commonly the frequency response function is developed by Fourier transforming time histories of the input force and the resulting displacement. Note that a frequency response function refers to the response of the structure at one point to excitation at another, and that a set of frequency response functions is necessary to describe the dynamic characteristics of the entire test item.

In addition to modal parameter estimation by direct measurement and by frequency response function analysis, there are several hybrid techniques that combine features of both approaches.

Characteristics of Modal Parameter Estimation

Single Degree of Freedom - Modal parameter estimation techniques which involve only one eigenvalue and eigenvector at a time are classed as single degree of freedom (SDOF) techniques. The oldest method is attributed to Kennedy and Pancu (96) and is often referred to as the "circle-fit" method. Using the amplitude and phase at the damped natural frequency or the quadrature part of the frequency response at the damped natural frequency are common techniques (Broadbent (23), Brown, (222), Klosterman(99)). More sophistication is gained by using a single partial fraction expansion, in the area of the damped natural frequency, based upon the Laplace domain formulation for a SDOF with damping (Stahle (194, 195), Richardson (169, 170), Sloane (187)).

SDOF techniques are simple to implement and analysis time is kept to a minimum. The amplitude and quadrature techniques are essentially those used in MPE-SD techniques. Little operator skill or interaction is required, however, closely spaced eigenvectors and coupled eigenvectors can be very difficult to separate with SDOF techniques.

Multiple Degree of Freedom - Multiple degree of freedom (MDOF) techniques are more complicated in terms of time operator skill, and operator interaction. Such techniques are usually based upon non-linear solution procedures of a partial

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fraction expansion of the Laplace domain formulation of the mathematical model. Often matrix procedures are used to take advantage of special forms of the data. These processes can be very slow since one frequency response function is analyzed at a time. In addition, the current techniques do not take advantage of redundant information (global eigenvalues or eigenvectors). This is the subject of much current research and considerable improvement may be anticipated in the future.

The operator skill is imperative in current MDOF techniques. The evaluation of "goodness of fit" is not always obvious nor is the specific choice of the number of degrees of freedom. These two considerations alone can mean the difference between satisfactory and meaningless results. Additionally, the time required by the operator to manually manipulate these factors causes the total time for analysis to increase. Therefore, those MDOF techniques which can give better results through automatic procedures are very attractive.

Complex Eigenvectors - Complex eigenvectors is the general characteristic found in real structures, with real eigenvectors being a special case which occurs with proportional damping. The MPE-SD techniques do not permit the formulation of complex eigenvectors and, thus, the results are always real eigenvectors. The SPE-FRA techniques allow complex or real eigenvectors depending upon the mathematical model chosen. Currently, the mathematical model methods commonly used to approximate the test configuration, due to time constraint, cost and experience, are real eigenvector solutions. In the aerospace industry, the structures are

often satisfactorily evaluated based upon real eigenvectors alone. When problems are encountered in force appropriation with MPE-SD techniques, the complication is attributed to poor exciter locations, insufficient number of exciters, or inadequate iteration in the tuning. The existence of complex eigenvectors may often be an additional significant source of difficulty.

Residuals - Both SDOF and MDOF techniques may or may not involve the use of residuals. Residuals are variables which are used to approximate the effects of eigenvectors below and above the frequency range of the modal parameter estimation technique. The constant associated with the lower eigenvectors is often referred to as inertia restraint and the constant associated with the higher eigenvalues is called residual flexibility. Some techniques do not allow the use of residuals (for example quadrature) but most of the sophisticated SDOF and MDOF techniques permit them. Residuals are necessary in the separation of modal interaction to accurately credit the proper influence to each mode.

Global Eigenvalue - Global eigenvalue refers to the concept that the eigenvalues are constants with respect to the test structure. If this contraint is imposed in the MDOF estimation techniques, the solution process can now be linearized. This has the benefit of reduced operator interaction, simplification of analysis, and overall improvement of eigenvalue estimate. Obviously, a side benefit is a great reduction in analysis time (Brown (222), Ibrahim (87, 88)). Some difficulty can be encountered if measurement errors or non-linearities are present, since the eigenvalues will then appear to change between measurements.

Global Eigenvector - Global eigenvector refers to the concept that the major structural modes of vibration should be observed to be unchanged regardless of where the test excitation is applied to the structure. Therefore, if multiple applications of a single point excitation can be separately analyzed and combined or collectively analyzed, the result should be a single eigenvector for each eigenvalue. Manipulation of estimates of eigenvectors from different test points can give improved definition of a global eigenvector as well as statistical input as to the variance in the measurements. Work relating to this concept has been formulated by Ibrahim (87, 88) and Richardson (172).

Local Eigenvectors - In addition to global eigenvectors, the ability to allow local eigenvalues and eigenvectors is very important. Measurements in a certain area of the test structure may contain modal parameters which are not found over the rest of the structure. If the modal parameter estimation techniques cannot permit additional degrees of freedom when this situation exists, the estimated values for the global eigenvectors will be very poor.

The capability to handle local modal parameters as well as global modal parameters requires increased refinement in the software. This will permit more automation and less operator interaction. Current applications of such techniques have been very time consuming because they are based upon non-linear solution methods. The application of linearizing techniques to the solution as well as increased automation may provide a great reduction in analysis time.

Confidence Factors - The confidence factors for use in modal parameter estimation are less well developed than those for use in measurement. They detect poor quality but do not ensure high quality.

A first check is to compute the generalized mass matrix from the estimated mode shape and a "given" point mass model of the test item. A general rule of thumb requires the off diagonal terms be no more than 10 percent of the diagonal for an acceptable mode. A second check is to compare modal parameters predicted in a pretest analysis to those estimated from test. Since error metrics have not been developed for use in this area, the basis for comparison is intuitive. A third commonly used check is to predict the system response using the estimated parameters. This is done most effectively in the time domain by predicting the system response to a known arbitrary forcing function and comparing the measured response to this forcing function. One may also predict frequency domain response, although this is less useful.

2.4 SELECTION OF RECOMMENDED GVT METHOD

2.4.1 Criteria For Method Selection

This section contains the key points in the evaluation process. The criteria for evaluation were developed from the contract Statement of Work, industry inter-views, and personal experience. The weighting of the criteria is based upon identifying the optimum GVT technique within the restriction of well-documented, state of the art practice. Those criteria which rate purely mechanical consider-ations and apply to most or all techniques equally have been given very little weight. The evaluation of the general methods with respect to the criteria is based upon a review involving literature, industry interviews, and personal experience. This evaluation did not seriously consider many pieces of literature which lacked a sufficient documentation of detail, a sufficient demonstration of proficiency, and/or an adequate evaluation of real world examples.

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2.4.1.1 Primary Considerations

The following criteria are basic concerns in the evaluation of any GVT approach. The subtopics are in order of decreasing importance in method selection.

Quality of Results

The MPE-SD approach and the SPE-FRA approach appear to be nearly equal in the ability to obtain modal parameters for a given structure. Of the other techniques, insufficient documentation is presently available, although the Link and Vollan (113) and Ibrahim (88) approaches show future potential. For aircraft structures, the MPE-SD approach may be slightly superior but the continuing availability of improved modal parameter estimation algorithms for the SPE-FRA method indicates that any small advantage is temporary.

Time Constraint

The amount of time needed to complete a GVT is in direct conflict with the need for quality of modal parameter estimates. Any reduction in available test time due to impending flight schedules or previous delays contributes directly to the degradation of the final result. None the less, the high cost of hardware, test fixturing, and personnel dictates that total test time be kept to a minimum.

The MPE-SD approach appears to give superior results for a reduced number of modes if the time constraint is severe. Since each mode is tuned independently, not all modes will be documented and potentially important modes will be missed.

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This is a direct result of the variability of the amount of time needed to tune a given mode. The requirement of individual tuning of modes does not permit any separation of tasks (which would permit some of the analysis to be performed at a later time).

When the time constraint is severe, the SPE-FRA approach will yield some data on all or nearly all modes of interest. Also, based upon an exact time constraint, a reliable estimate of the maximum amount of data to be acquired can be made. This assures, assuming confidence factors are utilized, that some information about all modes can be obtained. This ability to spend the total test time window in the measurement process, if needed, while deferring the time consuming analysis phase represents a unique and powerful attribute of the SPE-FRA approach.

When time constraints are completely removed, both approaches yield similar results. There is a tendency for the MPE-SD technique to obtain fewer modes even though the global modes are found. An example of this can be seen in a recent paper by Hanks, et all., (75).

Operator Expertise

Both the MPE-SD and SPE-FRA approaches, with respect to the present state of the art, require a very high level of operator expertise. Through industry interviews and literature discussions, it is obvious that this requirement is often overlooked. The aircraft design that requires experienced finite element engineers for the analytical solution often is left to completely inexperienced

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technicians and engineers for the experimental solution. This is a management problem that needs to be corrected.

The MPE-SD approach is at a slight disadvantage since the operator expertise is involved in tuning each mode. The primary involvement of operator expertise in the SPE-FRA approach is in the modal parameter estimation phase.   In both approaches a knowledgeable test engineer is required to continuously evaluate the measurement process.

A very popular misconception of the SPE-FRA approach relates to the concept of operator expertise. An expert operator who is estimating modal parameters using various SDOF and MDOF algorithms cannot compensate for poor data (noise, aliasing, leakage, distortion, frequency resolution, etc.). These software routines cannot efficiently extract reasonable modal parameter estimates if the data was taken carelessly. This accounts for far more of the failures of the SPE-FRA approach than is generally recognized.

Within the limitations summarized, both the MPE-SD and the SPE-FRA approaches involve a similar degree of operator expertise and experience. Again, with future developments, the availability of better, faster, and more automatic modal parameter estimation algorithms will give the SPE-FRA approach an advantage.

Closely Spaced Modes

Closely spaced modes create equal problems in all techniques. The MPE-SD approach requires more tuning in force appropriation. The SPE-FRA approach requires more interaction in the modal parameter estimation process. These factors in terms of difficulty are judged to be essentially equal. The more significant result of closely spaced modes is an increase in time to achieve equivalent estimates of modal parameters.

Increased Accuracy

Since both the MPE-SD and SPE-FRA approaches currently result in similar quality of results, the question of increased accuracy is dependent upon identification and solution of the problem areas within each technique. To improve the MPE-SD technique, the number of forces, the force location, and the force appropriation must each be automated. Limited success has been achieved in determining the number of forces and the force appropriation with automated procedures. No documented effort has been made to determine optimum force location. An unfortunate problem with the development of the MPE-SD approach is that only those individuals interested in improving GVT techniques are contributing to the improved procedures; there is no cross-furtilization of MPE-SD improvements from other areas of technology. To improve the SPE-FRA technique, measurement technique and modal parameter estimation algorithms must be improved. Great success in both areas has taken place over the last ten years and is continuing. The distinct advantage in the development of the SPE-FRA approach is that these areas are of great interest to researchers in other areas such as controls and electronics. A reasonable amount of technology transfer can be expected.

Many of the theoretical studies performed to analyze the accuracy of either method have proven to be less useful than anticipated. Most examples have utilized an MDOF model with random noise to use in a comparative study. In the real test environment, the noise due to extraneous inputs and measurement error is rarely white random and almost always biased. Studies based upon white random noise are not necessarily appropriate measures of the ability to accurately estimate modal parameters.

Complex Modal Coefficients

The question of real versus complex modes must be considered in terms of the quality of the experimental modal analysis approach. The MPE-SD approach does not lend itself to the concept of complex modes. All other approaches, including SPE-FRA, can utilize real and complex mode concepts.

There is no doubt that much GVT work can be satisfactorily accomplished without the complex mode concept. The real world though does have complex modes and in order to accurately describe the phenomena measured, this capability is required both analytically and experimentally. Some flexibility in the definition of phase resonance and in the definition of orthogonality of modes is often taken with the MPE-SD approach. This flexibility may be necessary to compensate for the inability of the MPE-SD approach to deal with slightly complex modes. The MPE-SD approach does not contain the flexibility to document this realistic possibility.

Complicating Factors

Most complicating factors in the GVT process are related to some nonlinear characteristic in the test item. Neither MPE-SD nor SPE-FRA approaches are ideally designed to address this kind of difficulty. Both approaches can handle such a complicating factor as a nonlinearity with equal effort and success. If the mathematical form of the nonlinearity is known a priori, the SPE-FRA would have a distinct advantage.

Confidence Factors

Recognition of good or poor estimates of modal parameters during the test window is vital to the resulting quality of the GVT. The two basic approaches each contain methods for on-line determination of confidence prior to completion of the total test protocol. Using the MPE-SD approach, the ability to approach the phase resonance criterion at all shakers for a given mode can be very useful. Unfortunately, if too few inputs are utilized this result may be misleading. The decay of the mode of vibration when the inputs are removed is another potential measure of the purity of the single mode excited by the MPE-SD approach. This is very useful in concept, but when a small amount of distortion is present, the question of 'how much is too much' is not always easy to answer. Additionally, the MPE-SD approach can involve mode orthogonalization as a measure of confidence after each mode has been tuned.

The SPE-FRA approaches have useful confidence factors as well. The coherence function calculation associated with each frequency response function gives a

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good indication of the amounts of noise, sensitivity problems, and measurement error such as leakage. Unfortunately, since this function is a frequency dependent quantity between zero and one, the question of 'how bad is too bad' must be answered. Additionally, any lack of experience and knowledge in using the coherence function in this manner provides some difficulty. The ability to estimate modal parameters quickly using SDOF techniques allows partial mode shapes to be processed during the test to check consistency of data or problems with closely spaced or coupled modes. The use of many separate input locations and increased frequency resolution during an initialization stage also results in on-line alteration of test protocol to assure that no modal information is missed. Other techniques, such as mode orthogonalization, can be involved in the on-line confidence factor process but realistically lend themselves to post-processing confidence considerations.

In summary, both the MPE-SD and the SPE-FRA approaches have adequate confidence factors available. The confidence factors available presently are of approximately equal merit but the SPE-FRA approaches require proper background education. The ability to involve averaging in the measurement and analysis phases of the SPE-FRA approach allow for application of statistics in the confidence building process.

2.4.1.2 Secondary Considerations

Some of the criteria involved in method selection need to be considered but are not primary considerations. Four subtopics have been identified within this weighting category. The first two subtopics are important but should be sacrificed to maintain the integrity of the primary considerations. The final two subtopics are also important but apply somewhat equally to the MPE-SD and SPE-FRA approaches. Once again each succeeding subtopic is in order of decreasing importance in method selection.

Cost Reduction

The total cost of a GVT is an important concern. With both the MPE-SD and the SPE-FRA approaches, the test hardware represents a trivial cost compared to the total test cost. It is remarkable, though, that despite this fact, there is some reluctance to provide more hardware to facilitate parallel processing and computer controlled data handling. The significant cost is normally the involvement of the test airplane, fixturing, and personnel during the total test time window. The ability to process more data faster significantly reduces total test cost for very little expenditure. Therefore, the time constraint directly determines the cost factor. Both the MPE-SD and the SPE-FRA approaches can be optimized in terms of parallel data processing and handling in similar ways.

One significant advantage of the SPE-FRA approach with respect to cost reduction is the ability to defer some or all of the analysis to a later time. In this way the test configuration need only be maintained during the measurement phase.

Only the equipment and personnel involved in the estimation of modal parameters need to be budgeted for the total time period.

Personnel Reduction

At the present state of the art, neither the MPE-SD approach nor the SPE-FRA approach can account for significant personnel reduction. Both testing concepts can be run with minimum personnel involvement if time is not critical. Likewise, both testing concepts benefit during test set-up and data measurement by parallel tasking of technician level support. Since exciter and transducer set-up is labor intensive, the SPE-FRA approach maintains a small advantage due to a reduction in the number of exciters utilized.

Application to Sub-Assemblies

Any experimental modal analysis technique used for GVT purposes is capable of testing subassemblies of the complete aircraft structure. Typical examples of such components would be the landing gear, nacelle mounted engines, control surfaces, stores or a scaled flutter model. The MPE-SD and SPE-FRA approaches can both be used for such purposes. Since the SPE-FRA only requires a single excitation and can be used with techniques such as impact testing, the flexibility of this technique is a distinct advantage when cost, time, personnel and/or test fixturing problems would mitigate against the use of the MPE-SD approach.

Post-Test Analysis

The ability of a GVT method to provide input to computational schemes for comparing and checking experimental results with analytical prediction is another valuable criterion. The calculation of generalized mass or the use of a reduced finite element mass matrix to check mode orthogonality are common examples of this need. Since the MPE-SD and the SPE-FRA approaches both normally involve a direct interface to at least a mini-computer, such calculations can be attempted with either approach quite easily. The frequency response functions utilized in the SPE-FRA approach result in a larger available data base. The concepts of modal synthesis, time domain simulation, frequency response and loads prediction are all currently under development and may require a large data base to obtain accurate results. As these methods are developed to the point of routine application, the SPE-FRA approach appears to be more capable of providing the data base that will be required.

2.4.1.3 Minor Considerations

The remaining criteria to be considered are of equal merit in both techniques and cannot be heavily weighted for purposes of the selection of an optimum GVT method.

Input/Output Format

The ability to present modal data in a variety of formats is extremely useful. The data may need to be on punched cards or magnetic tape for further analysis. Modal shapes should be animated for visual perception as well as CRT and hard

copy plots with appropriate annotation for report purposes. There is no difference in capability of such presentation of the modal data in any of the experimental modal analysis techniques.

Hardware Portability

Both the MPE-SD approach and the SPE-FRA approach are portable enough to provide GVT capability. Any such system required can be placed in a large trailer and moved to a remote site if necessary.

Safety

The safety of personnel involved with the test as well as the test airplane is of vital concern always. No significant difference exists in the application of any method discussed.

2.4.1.4 Summary

The comparison of the MPE-SD and SPE-FRA methods is summarized in Figure 1. Based on this evaluation, the SPE-FRA method is recommended as the better method. The elements of the method are discussed in detail in Section 3.0.

The SPE-FRA method is selected as the method for further development when considering both the primary and secondary weighted criteria. Consideration of minor criteria shows neither method at advantage. Although the MPE-SD and the SPE-FRA approach appear to be nearly equal in ability to obtain modal parameters

Criteria	MPE-SD	SPE-FRA
Primary		
Quality of results		
Complex modal coefficients	−	+
Closely spaced modes	+	+
Complicating factors	+	+
Confidence factors	+	−
Increased accuracy	−	+
Time constraint	−	+
Operator expertise	+	+
	−	**+**
Secondary		
Cost reduction	−	+
Personnel reduction	+	+
Subassemblies	−	+
Post-test analysis	−	+
	−	**+**
Minor		
I/O format	+	+
Portability	+	+
Safety	+	+
	+	**+**
·Summary	**—**	**+**

Figure 1. Method Selection Summary

of a structure, the continuing availability of improved modal parameter estimation algorithms for the SPE-FRA method is a decided advantage. The consideration of complex modal coefficients, closely spaced modes, complicating factors, confidence factors and increased accuracy lead to a decision in favor of SPE-FRA. The other primary criteria, the time constraint and operator expertise both favor SPE-FRA. Consideration of secondary criteria, cost reduction, personnel reduction, treatment of sub-assemblies and post test analysis also support a decision in favor of the SPE-FRA method.

2.4.2 Analytical Studies of the Modal Estimation Process

Part of the work for the method selection process was to conduct simple computer evaluations of the potential methods. In the evaluation of the literature, there were a number of computer studies of both the multi-point excitation and the single point excitation methods: Craig and Su (34), Feix (57), Asher (6), Berman and Flannelly (14), Sloane and McKeever (187) and Gold and Hallauer (223). Instead of duplicating these studies in a similar fashion, the literature was reviewed.

The computer simulations conducted were limited to evaluation of the parameter estimation schemes that will be used during the contract. Studies were made upon the sources of errors in making frequency response measurements and the sources of errors in the evaluation of curve fitting algorithms which are used for the parameter estimation phase of the GVT (see Section 3.1). It should be noted that one of the problems noted in the literature and in our own computer studies is that an ideal system is normally simulated and then its characteristics are

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computed using the algorithm to be evaluated. Most of the algorithms that are evaluated in this fashion work well since in most cases noise added to the process to simulate the noise involved in the measurement processes is Gaussian distributed. Most of the curve fitting process work well on this type of data. Unfortunately, the type of noise that is common to an actual measurement process has large bias errors due to nonlinearities or other excitation sources which may exist in the testing environment. As a result, these techniques which often appear to work well in the computer studies do not work well in practice.

In the literature there were a number of studies where the multiple point method was evaluated against single point random or some other method. It was clearly evident from these studies that in most cases the testing group was expert with one technique but lacked experience with the other techniques. As a result, the evaluation was clearly biased towards the method they were expert in. Another problem was that a piece of hardware was tested whose exact characteristics were unknown. The test structure was normally complicated. There were questions concerning the validity of the existing finite element model. As a result, it was difficult to determine just how well each technique performed.

3.0 RESULTS

3.1 RECOMMENDED GROUND VIBRATION TESTING METHOD

The method which is recommended for ground vibration testing of aircraft is the single point excitation/frequency response analysis method. The reasons for the selection of this method are given in the previous section.

In this section the method that has been selected will be described in detail. The implementation of the method is described in Appendix A, "Guide for Ground Vibration Testing of Airplanes". Note that one of the main reasons for choosing this technique is because it will be expanded by future research to include much better parameter estimation schemes. When these are developed they will replace some of the techniques which will be described in this section.

In this section the excitation procedures, measurement procedures and data analysis method will be described. Also, measurement equipment and data analysis equipment will be discussed.

3.1.1 Measurement Phase

In using this method it is necessary to measure the frequency response between a number of exciter positions (force input points) and a number of output points (displacements). The frequency response measurements can then be used to estimate the modal parameters of the aircraft and/or aircraft system. Different exciter locations are used to estimate different sets of modal parameters. The

number of exciter positions depends upon the nature of the GVT and the complexity
and modal density of the aircraft system. The frequency response measurements
can be made several different ways. The preferred technique is determined by a
number of factors:

1. The type of measuring equipment and the number of simultaneous input
   channels,

2. The characteristics of the structure (linear or nonlinear),

3. The testing environment,

4. The test time window, and

5. The purpose and type of GVT (total aircraft, control surface, etc.).

The type of equipment used, analog or digital, is important. It is recommended
that a digital system be employed because it has the greatest flexibility in the
measurement phase and can also be used to reduce the data. The analog method is
very slow since it is limited to swept sine testing unless a large number of
multiple channels of data are processed simultaneously.

With the digital equipment, periodic, random, transient and operating inputs can
be used to measure the frequency response. Also, the digital system can be
updated periodically by simply updating the measurement and data analysis soft-
ware. As mentioned in the previous section, there is a great amount of research

being conducted by a number of researchers in the area of structural system identification and these improved techniques can be incorporated into a digital system.

If the system is linear then any excitation technique can be used to measure the frequency response of the aircraft. However, for nonlinear structures it is important to use a measurement technique which will generate a frequency response measurement which is compatible with the selected parameter estimation scheme. In the following sections, the frequency response measurement and parameter estimation schemes will be described in detail.

3.1.1.1 Excitation Techniques

The excitation techniques can be classified into four general categories; periodic, random, transient and operating.

A periodic signal is one which repeats itself with a given time interval or varies in a manner which is slow enough that in terms of signal processing it can be considered periodic. Examples of this type of input are swept sine, pseudo random and periodic chirps.

A random input signal is a non-deterministic signal which can be characterized by a probability density function and a power spectral density function. This kind of input can be pure random or periodic random, where periodic random is a cross between pure random and pseudo-random.

A transient signal is one where the excitation force changes drastically as a function of time but changes in a deterministic fashion. In most cases the input force decays to a steady state value after a short period of time. Examples of transient inputs are impulses, unit steps and chirps (fast sine sweeps).

The operating input corresponds to input forces generated by the actual device being tested.

Periodic Signals

Swept Sine Testing - Since swept sine testing has been in use since the early 1960's it is the most popular and best understood of the excitation methods. The procedure used is a simple one. A sweep oscillator is used both as an input to an electro-mechanical or hydraulic exciter and as the tuning signal to a narrow band tracking filter. The frequency sweep rate is sufficiently low that the excitation and response are very nearly sinusoidal. The force input to the system is measured with a load cell and the response of the system is measured with a suitable transducer such as an accelerometer or velocity pickup. The signals from the transducers are passed through the tracking filters to log converters where signals proportional to the logarithm of the force and response are produced.

The logarithm of the force signal is subtracted from the logarithm of the response signal yielding a signal proportional to the log of response divided by force. The two signals are also passed through a phase meter to get the relative

phase between the force and response. The output of this type of system typically goes to an X,Y,Z plotter where it is plotted as amplitude and phase versus frequency. The output could also be digitized and fed into a digital computer for further analysis. By sweeping the oscillator through the entire frequency range of interest, the frequency response can be generated.

The principal advantage of swept sine testing is that the input force can be precisely controlled. This is particularly useful in the study of nonlinear systems. By measuring the frequency response of the system with several different force levels, much can be learned about the cause and behavior of the nonlinearity. Because all signals at frequencies other than the input frequency are filtered out, swept sine testing gives the best signal to noise ratio at the measurement frequency of any of the excitation techniques. Swept sine testing also has the advantage that it can be performed with relatively inexpensive analog or digital equipment.

The major disadvantage of swept sine testing is that it is slow. A test of the frequency range from 1 Hz to 100 Hz with a two Hz bandwidth filter takes approximately 20 minutes. Another disadvantage of swept sine testing is that it gives a very poor linear approximation of a nonlinear system. This is a serious problem if the data is to be curve fitted to estimate modal parameters since digital parameter estimation schemes are all based on linear models and the premise that the structure behaves in a linear manner.

The advantages of swept sine testing are:

1. It has the best peak to rms energy ratio;

2. It has, by far, one of the best signal to noise characteristics;

3. It is good for documenting the nonlinear characteristics of the test system;

4. It has the longest history of use and as a result it is the most widely accepted input.

Its disadvantages are:

1. For nonlinear systems the measurement doesn't have the form that satisfies the curve fitting models used to obtain the modal coefficients.

2. It is slow. It will take at least 20 minutes for a measurement in the 0-100 Hz range. For a typical modal survey conducted on an aircraft a total of more than a thousand frequency response measurement may be taken. This would correspond to several months of work. With the other techniques the test could be done in several days.

Pseudo-Random - Because of the development of the digital Fourier analyzer, pseudo-random input testing has become a practical method of frequency response measurement. Using Fourier transforms it is not necessary for periodic inputs to be sinusoidal; they can have almost any spectrum content. In fact it would be

possible, though not practical, to tune a large number of oscillators to different frequencies, mix the signals together and use the resulting signal to excite a system. In one sample of data it would be possible to determine the frequency response of the system at all the excitation frequencies.

In practice the procedure for implementing a pseudo-random signal is to use a digital to analog converter (DAC) connected to the computer of the Fourier analyzer to generate the excitation signal. The signal is created in the frequency domain, normally with uniform amplitude and random phase angle throughout the desired frequency range. If necessary, the amplitude versus frequency characteristics of the signal can be modified to compensate for impedance mismatch between the exciter and the structure thereby producing a flat shaker output spectrum. Once the desired frequency domain signal is produced, it is Fourier transformed into the time domain and output to the exciter system through the DAC. This process leads to one of the important advantages of pseudo-random excitation. Because the excitation signal is created in the frequency domain and transformed into the time domain, it is always periodic within the sample window and therefore does not suffer from the leakage errors of the pure random signal. Because the signal contains energy at all frequencies of interest, it is possible, in a low noise environment, to make a reasonably good frequency response measurement with only one sample of data. In normal testing environments, a few samples may be required. One of the principle disadvantages of pseudo-random excitation is that nonlinearities or loose components will generate periodic noise which cannot be averaged out of the data. Due to this condition, the overall quality of a pseudo-random measurement is generally lower than that made by any of the other techniques. However, in mode shape surveys, where several

hundred measurements may be made with no intention of curve fitting for frequency and damping, the speed of pseudo-random is a fair tradeoff for lower quality data.

For linear systems in low noise environments, pseudo-random is a good choice for modal surveys. A structure for which it would work well would be a frame type structure. A structure for which it would not work as well would be an aileron system because of the nonlinearities in the flight control system.

The advantages of pseudo-random are:

1. It is fast. For a frequency range of 0 to 100 Hz it takes one sample period of the Fourier analyzer to produce the frequency response. This is about 6 seconds for 1024 time domain points. This compares to about 20 minutes for a similar test using swept sine excitation.

2. It is controlled. Both the amplitude and frequency content of the excitation signal can be precisely controlled.

3. It has a low ratio of peak to rms energy.

4. Noncoherent noise can be conveniently averaged out.

5. Leakage errors are eliminated by using an input that is periodic within the sample window of the Fourier analyzer.

Its disadvantages are:

1. It is very sensitive to rattles. Loose components generate periodic coherent noise which cannot be averaged out. The noise appears as spikes on the frequency response measurement which can cause difficulty in curve fitting the data to extract modal parameters.

2. The energy input at any given frequency is small compared to swept sine. The reason, of course, is that all frequencies are being excited simultaneously.

Periodic Fast Sine Sweep - Another choice of a periodic time domain signal is the periodic fast sine sweep. Good test results are obtained using the periodic log swept sine forcing function by actually making the function a true transient signal. The log swept sine forcing function is formed by means of software in a Fourier data block and output through the DAC to the exciter. Since timing is critical in making a truly periodic forcing function in the Fourier analyzer's sample time (T), a transient signal is sometimes used that allows time for the response to die out before the end of the time sample T. This is accomplished by stopping the sweep typically at 85% of the total time sample taken. The modal damping values of the system under test will dictate this length. Lightly damped systems may require stopping the sweep at 70%. In any event, the sweep is stopped, allowing enough time for the systems to decay out to 10% or less of its peak resonnance. To soften startup and shutdown transients, the amplitude of the sweep time history are also linearly ramped using a 5% ramp time at the beginning and the end of the sweep.

In the measurement phase of the test, the swept sine has an appealing nature compared to random in that as each resonance is traversed the response blossoms, giving a quick intuative feel as to signal-to-noise ratios and system dampings. Data dropouts and other anomalies are much easier to recognize using sine versus random. The periodic sine sweep gives good signal-to-noise ratios and good peak to RMS energy ratios. Leakage errors are eliminated by virtue of its periodicity. Its main disadvantage is that any nonlinearities are not averaged out. In a ground vibration test of a complete aircraft, the small nonlinearities within the structure can present a serious problem when attempting to curve fit the data to obtain modal parameters.(93)

Random Signals

Pure Random - Pure random excitation typically has a Gaussian distribution and is characterized by the fact that it is in no way periodic, i.e., it does not repeat. The output of a random signal generator may be passed through a bandpass filter to concentrate energy in the band of interest. Generally the filter spectrum will be flat except for the filter rolloff and, hence, only the overall level is easily controlled.

One disadvantage of this approach is that, although the shaker is being driven by a flat spectrum, the structure is being excited by a force with a different spectrum due to the impedance mismatch between the structure and the exciter. This means that the force spectrum is not easily controlled and the structure is not being excited in the optimum manner. Since it is difficult to shape the spectrum because it is not generally controlled by the computer, some form of closed loop force control system would ideally be used.

A more serious problem of pure random excitation is that the measured input and response signals are not periodic in the measurement time window of the Fourier analyzer. A key assumption of digital Fourier analysis is that the time waveforms be exactly periodic in the observation window. If this condition is not met, the corresponding frequency spectrum will contain "leakage" due to the nature of the discrete Fourier transform; that is energy from the nonperiodic parts of the spectrum will "leak" into the periodic parts of the spectrum, thus giving less accurate results (161).

In digital signal analyzers, nonperiodic time domain data is typically multiplied by a weighting function, such as a Hanning window, to help reduce the leakage caused by nonperiodic data and a rectangular window. When a nonperiodic time waveform is multiplied by this window, the values of the signal in the measurement window more closely satisfy the requirements of a periodic signal. The result is that the leakage in the spectrum of a signal that has been multiplied by a Hanning window is reduced.

However, multiplication of two time waveforms, i.e., the nonperiodic signal and the Hanning window, is equivalent to the convolution of their respective Fourier transforms (recall that multiplication in one domain is exactly equivalent to convolution in the other domain). Hence, although multiplication of a nonperiodic signal by a Hanning function reduces leakage, the spectrum of the signal is still distorted due to the convolution with the Fourier transform of the Hanning window.

With a pure random signal, each sampled record of data T seconds long is different from every other sample. This gives rise to the single most important advantage of pure random excitation. Successive records of frequency domain data can be ensemble averaged together to remove nonlinear effect, noise, and distortion from the measurement. As more and more averages are taken, all of these components of a structure's motion will average toward an expected value of zero in the frequency domain data. Thus, a much better measure of the least squares estimate of the structural response can be obtained. This is especially important because digital parameter estimation schemes are all based on linear models and measurements that contain distortion are more difficult to fit.

The advantages of pure random are:

1. It gives the best linear approximation of a nonlinear system.

2. It is relatively fast. It is slower than impact or pseudo-random but is significantly faster than swept sine.

3. It is well controlled. The force levels can be easily and accurately controlled.

4. It has good peak to rms values.

The disadvantages of pure random are:

1. For lightly damped systems, the frequency resolution of the discrete Fourier transform can be a serious problem. However, this problem can be reduced or eliminated by using a zoom transform.

2. It is difficult to control the frequency spectrum without using special computer software and hardware.

3. Serious leakage errors exist because pure random excitation is not periodic in the Fourier Analyzer time window.

Periodic Random - Periodic random input combines the best features of pure random and pseudo-random, but without the disadvantages, that is, it satisfies the conditions for a periodic signal, yet changes with time so that it excites the structure in a purely random manner.

The process begins by outputting a pseudo-random signal from the DAC to the exciter. After the transient part of the response has died out and the structure is vibrating in a steady state condition, a measurement is taken, i.e., the auto and cross spectrums are formed. Then, instead of continuing to output the same signal again as in pseudo-random excitation, a different uncorrelated pseudo-random signal is synthesized and output. This new signal excites the structure in a new steady manner and a new measurement is made.

When the power spectrum of many measurements are averaged together, nonlinearities and d stortion components are removed from the frequency response measurement. Thus, the ability to use a periodic random signal eliminates leakage problems and ensemble averaging is now useful for removing distortion because the structure is subjected to a different excitation before each measurement.

The only drawback to this method is that it is not as fast as pseudo-random or pure random, since the transient part of the structure's response must be allowed to die out before each new ensemble average can be made. The time required for a comparable number of averages may be from two to three times as long. Still, in many practical measurement situations, periodic random provides the best solution in spite of the extra time required.

The advantages of periodic random are:

1. It is the best signal for exciting a system to determine its modal characteristics by curve fitting.

2. It, like pure random, gives the best linear approximation for a nonlinear system.

3. Both the input level and spectrum can be carefully controlled.

The disadvantages are:

1. It requires additional hardware over standard pure random measurements (DAC output from the computer).

2. It is slightly slower than standard random measurements, however, it is up to 10 times faster than swept sine testing methods.

Random Transient - The random transient excitation function is basically the previous "periodic random" modified so that it is totally observed transient. This is simply accomplished by requiring a dead band at the end (typically the last 20%) of each sample period of T seconds. The actual duration of the dead band must be adjusted for each test specimen so that the sampled data satisfy the criterion of a totally observed transient, i.e., no truncation of the measured response data in the sample period, T. This is fairly easy to accomplish if the test setup parameters establishing the duration of the T-second sample length allow sufficient frequency resolution to adequately define all modes in the excitation frequency range. This usually requires that Fourier transforms be obtained with block sizes of 4K time domain data points for typical aircraft structures. With the availability of new Fourier Analyzer systems with increased computer data space, block sizes of 8K time domain data points are becoming realizable.

The random transient excitation function exhibits all the advantages of periodic random. It has random amplitude and phase in the frequency domain. Each ensemble of the random transient is uncorrelated with previous ensembles.

Response nonlinearities are thus randomized from one ensemble to another such that the ensemble average should obtain the best linear estimate of the structural transfer function. Since each ensemble, when properly executed, is a "totally observed transient"; there are no leakage errors. The input level and frequency spectrum can be controlled. It does not have the severe time handicap of the periodic random requirement that one or several ensembles be wasted while establishing periodicity of the vibrating structure.(90)

Transient Signals

Impact - When the Fourier analyzer was first introduced it seemed as though impact testing was the answer to every frequency response tester's dreams. In theory it was possible to determine the frequency response of any structure simply by hitting it with a hammer. This was felt to be possible since an impact is an approximation to a unit impulse function which contains energy at all frequencies. However, when impact testing was first tried, it produced a variety of results. It seemed to work quite well in some cases and not at all in others.

A great deal of research has been conducted at the University of Cincinnati into the use of impact testing (225). This research has shown that impact testing can be one of the most useful testing techniques available if the proper restrictions are applied as to the type of structure, selection of impactors and the signal processing techniques used.

There are two very important structural characteristics to be considered in impacting: linearity and damping. Since impact has a very high ratio of peak to

rms energy content, it tends to excite nonlinearities in a system. For this reason, impacting does not work well on a nonlinear system. The amount of damping in the system is also important. If there is too little damping, the response signal will not decay to zero within the sampling time and severe leakage errors will result. If there is too much damping in the system, noise becomes a more significant problem. This is because the response signal decays to zero shortly after the start of sampling but any noise will be present throughout the total time. Both of these conditions can be improved by the use of the proper signal processing techniques.

The problems with impact testing are caused by the pulse-like nature of the impact signal. It has a very high peak value with very short duration. This causes the force to overdrive (i.e., excite the nonlinearities) the system while putting very little total energy into it. As a result, nonlinear response is greatly exaggerated while the signal to noise ratio for the entire measurement is very low.

Impact Testing Technique - Unlike the exciter techniques, impact testing requires much more care in setup and procedure to obtain good results. One serious problem, caused by the high force levels involved, is that of overdriving amplifiers, filters, digitizers, and the system itself. The possibility of this occurring and going unnoticed is compounded by the anti-aliasing filters used with digital processing systems. These filters can make even overloaded signals look good. Extreme care must be used to be sure overloads do not occur.

Mounting of transducers is also very important. Because of the high force levels involved, high local accelerations can occur. For this reason, methods of accelerometer attachment which may work well for other excitation methods do not work with impacting. Magnets, for example, are very bad because of their tendency to bounce.

The proper choice of an impact hammer is also important. The prime consideration is what frequency range is to be excited. The frequency content of an impulse is inversely proportional to the width of the pulse. Factors which affect the pulse width are the weight of the hammer, the hardness of the hammer tip, the technique of the person swinging the hammer and the mass and stiffness of the structure under test. Figures 2 and 3 show the effect of different hammers, tips and masses on the excitation force spectrum.

If proper care is exercised in the test setup and procedure and with the proper signal processing techniques, impact testing can be a very useful testing technique.

The advantages of impact testing are:

1. Setup and fixturing time are a minimum of all the excitation techniques.

2. Equipment requirements are the least of all the testing methods.
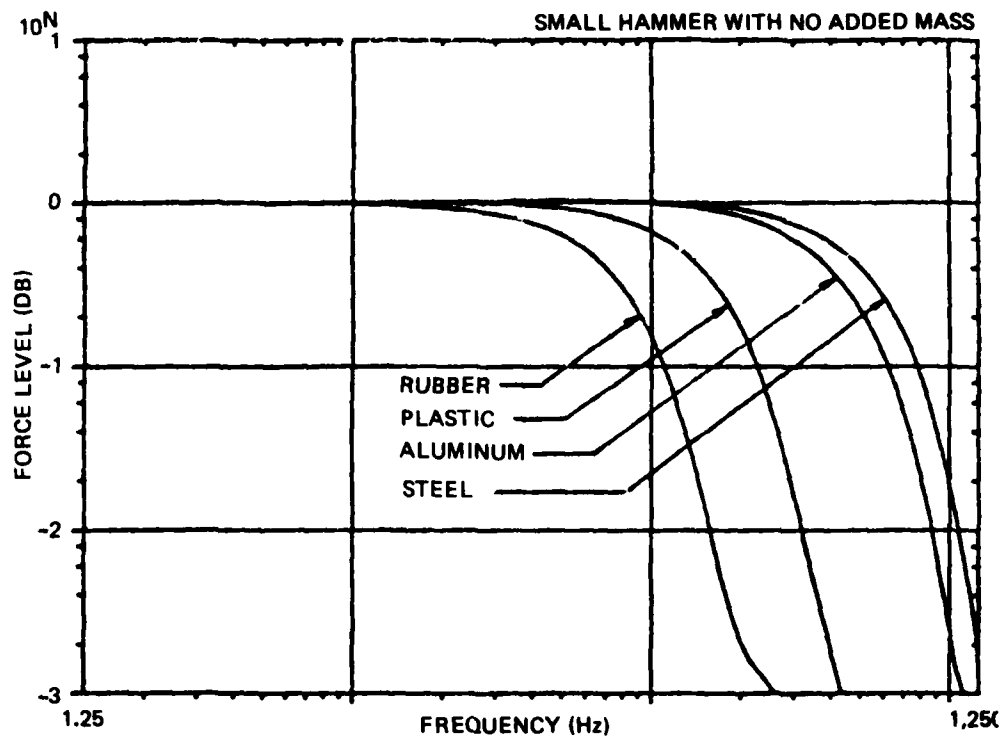
Figure 2. Effect of Tip Hardness on Force Spectrum
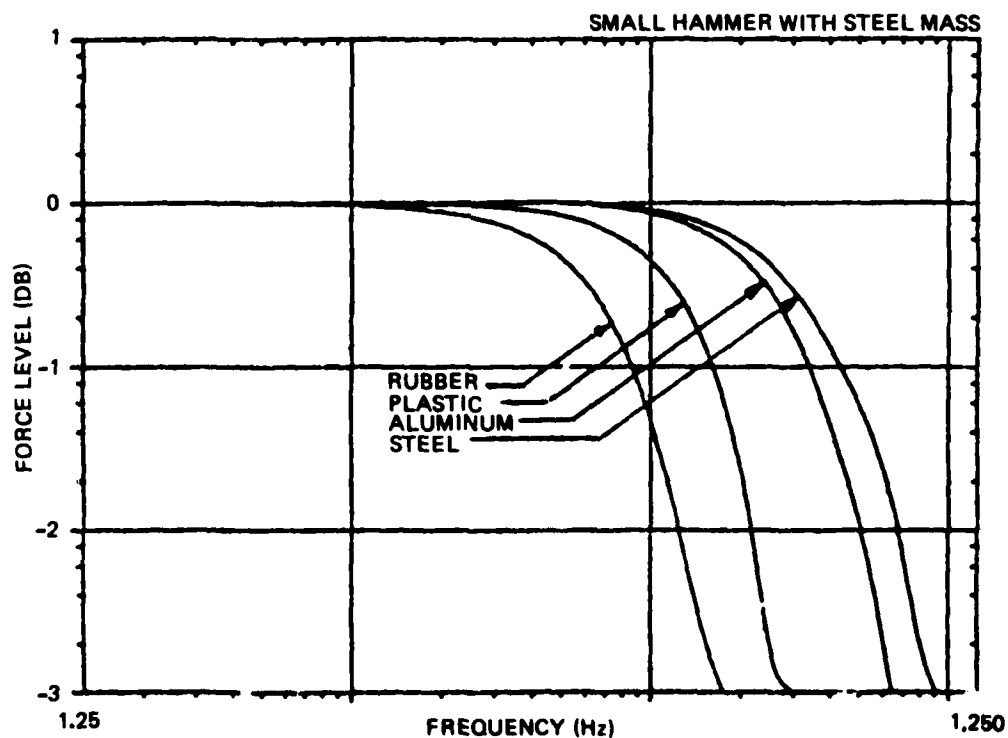
Figure 3. Effect of Mass on Force Spectrum

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3. It is the fastest test method for low noise environments.

4. It is ideal for use in tight quarters where an exciter will not fit.

Its disadvantages are:

1. It has a very high peak to rms energy ratio and is therefore not suitable for nonlinear systems.

2. Since little energy is input into the system, it has poor signal to noise characteristics.

3. Special care must be taken to eliminate overloads to system, signal processing equipment and/or the data analysis equipment.

Unit Step Function Testing (Step Relaxation) - A second type of transient input frequently used for measuring the frequency response of a system consists of a unit step function input. A unit step function is normally generated by preloading the structure with a measured force through a cable and then releasing the cable.

For aircraft testing this technique is of limited usefulness. Therefore, only a very brief list of its advantages and disadvantages are given below:

Its advantages are:

1. It can be used on very small or large structures.

2. The direction and magnitude of the force vector can easily be controlled.

3. It has superior low frequency energy content.

Its major disadvantage is that it is difficult to implement on normal structures.

A more detailed complete evaluation of this type of excitation can be found in Reference 225.

Chirps (Fast Sine Sweeps) - A chirp is a nonperiodic fast sine sweep where the sweep rate exceeds the quasi-steady state condition necessary for swept sine testing. It has limited use for aircraft testing where the excitation signal is supplied by an exciter system. However, it is used when operating inputs excite the system. This will be briefly discussed in the following section.

Operating Inputs

Operating inputs would appear to be an ideal excitation source for measuring the frequency response of a system where the actual force input due to operation is used to excite the system. Unfortunately, except for simple cases the input forces are very difficult to measure.

Successful operating inputs have been unbalances in rotating machinery and aircraft control surfaces shaking an airplane via inertia forces. In the latter case the operating command was derived from the stability augmentation system computer and was actuated through the normal operating flight control system. Signal processing for operating inputs is identical to that for random inputs.

A Comment On Linearity

In the preceeding paragraphs the importance of exciting the structure to minimize nonlinear effects has been noted. This importance is a direct consequence of the way the data will be used. In general, the goal of the engineer involved in a structural dynamics test is to extract the best estimates of the modal parameters of the structure, i.e., each mode's natural frequency, damping factor, and characteristic shape. It is this information which is used to study, alter, and improve the dynamic behavior of the structure.

Nearly all techniques in use today to extract modal parameters are based on linear structural models. In general, a linear model is fitted to the measured data by some form of curve fitting method. Any nonlinear distortion in the measured data will impair the ability of the analytical curve fitting algorithm to accurately extract modal parameters.

It is noted that evaluation of nonlinearities is not trivial. The study of a structure's nonlinear characteristics by exciting it with a sinusoidal source where the frequency and amplitude can be accurately controlled is occasionally required. However, if one wishes to extract modal parameters, the structure must be excited such that it's linear characteristics may be measured.

3.1.1.2 Test Setup

The test setup should be supported by a pretest analysis that identifies the dynamic characteristics of the test article relative to various excitation inputs, exciter locations and transducer positions. This procedure maximizes the success of the test. In the absence of a pretest analysis, experience, good test practice and procedures, and additional test data must suffice. The important aspects of the test setup include aircraft suspension, excitation equipment and technique, and transducers.

Aircraft Suspension

The suspension of the aircraft falls into three categories: (1) frequency separation techniques to achieve nearly free-free modes, (2) known or measured boundary conditions, and (3) a clamped condition. In any event the boundary condition must be well understood so that interaction between the structure and the constraint can be accounted for in the test results. Considerations of the aircraft suspension is simplified when included as a part of a pre-test analysis. Without pre-test analysis, a suspension system that introduces little contamination of the deformation modes of the test article or whose characteristics are well understood is essential.

Frequency Separation Techniques - The frequency separation techniques in common usage attempt to obtain free-free modes of the structure by achieving a separation between the fundamental mode of the aircraft and the rigid modes of the aircraft on the suspension. This implies that the constraints are very lightly

damped and well separated in frequency from the airplane modes. Various techniques include testing on under-inflated tires with the landing ge··· effectively bottomed, suspending the aircraft on bungee cord, suspension on commercially available air springs and the use of specially designed support systems such as mechanical springs. The choice of technique here is dependent on the overall size and weight of the aircraft as well as its fundamental mode. Care must be taken so that the total suspension system does not introduce modes in the frequency range of the test article.

Known or Measured Boundary Conditions - The free-free techniques such as under-inflated tires, air springs, bungee cord and mechanical springs can also represent known or measured boundary conditions. In these cases the effects of the known or measured boundary conditions can be used in a pretest or post-test analysis to compute the mathematical model of the test aircraft.

The "Clamped Condition" - In this case one attempts to achieve a cantilevered or near-cantilevered boundary condition. A free-free airplane model is obtained from the measured modal parameters by including rigid body degrees of freedom in a post test analysis. The clamped condition is the most difficult boundary condition to achieve and may or may not be successful. This technique is not recommended for aircraft suspension, but may be suitable for testing airplane components.

Excitation Equipment

Excitation equipment falls into two main categories: shakers and impulsive exciters. Both categories are recommended and their use is dictated by the test article and personal preference.

Shakers - Shakers are categorized mainly as electromagnetic, hydraulic, air and inertia. Electromagnetic and hydraulic are used for most applications. Air shakers are generally quite limited and only used in applications where the structure is so light that no single attachment to the structure can be made. Inertia shakers are not usually used in ground vibration testing of aircraft but quite often have application in flight flutter testing. The power requirements for the shakers can best be determined by pre-test analysis, however, when a pre-test analysis is not available experience must suffice.

Impulsive Exciters - Typical impulsive exciters are instrumented hammers, bonkers and step relaxation equipment. The use of these techniques all require measurement of the force imparted to the structure. The use of bonkers, which are explosive devices such as shot shells, is somewhat limited in aircraft testing where they have been mainly used as flight flutter exciters. The use has probably been supplanted by the use of aerodynamic vanes for that purpose (90).

Instrumented hammer techniques are in wide usage in industry for impact testing. Their use can be restricted by local structure loading requirements but they have been used on very large structures such as transmission towers and small and lightweight structures such as flutter models. One selects an appropriate hammer for each application.

Step relaxation techniques can be used in some applications where hammer techniques are inappropriate. With this method a measured impulse is imparted to the structure under test by pulling on it with a known force and then impulsively releasing, such as with a cut string.

Sensors

The selection of transducers may cover a wide range. Accelerometers, velocity sensors, strain-gages, displacement sensors and force transducers are all appropriate. Generally, accelerometers are recommended for most aircraft testing. Accelerometer selection is dependent on the frequency resolution required for the aircraft under test. When aircraft with low frequencies are being tested, servo type accelerometers or similar equipment with flat response down to DC are required. If resolution to only 5 Hz is necessary, less expensive accelerometers are used. The use of many fixed accelerometers are recommended for large aircraft applications rather than the use of roving pickups because of the cost of time on test. Another advantage is in being able to format the test data display of vibration modes during the test.

3.1.1.3 Data Handling

Two data collection techniques are in use; a standard analogue technique and a more automated state-of-the-art method using an analog to digital converter and a multiplexer. The latter technique requires more specialized equipment. This includes off-the-shelf 32-channel equipment that greatly improves the efficiencies of data collection and processing.

The standard analogue technique acquires time domain data of all transducers including the excitation signal, a data ready pulse and time code. The data is stored to an analog tape recorder. Any one accelerometer is monitored on line and provides a check of the quality of the measurement in the frequency domain. The coherence function is also calculated and examined for each measurement.

The data acquisition is handled using a computer which is also used to provide the excitation signals and a synchronous data ready pulse signaling the start of each separate test ensemble.

The data is collected over a time period, T, chosen for each sample of data such that the structural response has died out within the time period and that the frequency resolution, 1/T, is sufficiently small to adequately define the resonant peaks. Generally, the frequency resolution should be about one-fourth the half power point bandwidth of the resonant peaks.

Considerable improvements can be implemented in data acquisition systems via the new generation of off-the-shelf hardware. Autoranging amplifiers, analog-to-digital converters, digital link recording and computer-driven CRT's can be integrated into a computer controlled system with little or no development work. Data management is greatly simplified by using a computer system with a real time executive.

3.1.1.4 Data Processing

Computer Hardware

The computer equipment must be able to perform Fast Fourier Transforms, digital signal processing, curve fitting and test control. Although these functions are available in signal analyzer equipment, the minicomputer based modal analysis computer system is preferred because of its greater capability and versatility.

Computer Software

Data processing to be performed consists of calculation of the frequency response function from the measured data, curve fitting the frequency response function, calculation of the modal parameters (frequency, damping, modeshape amplitude and phase, mass) and data display. Commercial software systems are available for measurement and data processing.

The data generated will be output in printed arrays and/or animated mode shapes in a CRT display. Display coordinates for each transducer will be defined. The graphical displays will show the entire deformed structure relative to its undeformed shape or vector displays at each transducer coordinate. Hard copies of the CRT display will be made.

3.1.1.5 System Checks

System checks are controlled by a series of handbook procedures. These checks
cover all aspects of the GVT, in addition to procedures for checking the computer
based systems.

3.1.1.6 Signal Processing Techniques

Several signal processing techniques can be used to improve signal to noise ratio
problems. One common source of noise on both the force and response signals is
electrical noise occurring at harmonics of the power line frequency. This noise
can be minimized by choosing a sample period such that the power line harmonics
are exactly periodic within the sample window, i.e., the total measurement time
is an integer multiple of 1/60 second. This will cause them to fall exactly on a
single spectral line of the analyzer where they can be modified without affecting
other data. One modification would be to set the power line harmonics to the
average value of the two adjacent spectral lines. Of course this technique is
only useful if the data of interest do not fall at the power line frequencies.

Another source of noise is digitizer or "bit" noise. This is characterized by
random one or two bit excursions of the signal about zero volts. Figure 4
illustrates this with a greatly magnified force pulse. Intuitively it would seem
that this noise is insignificant when compared with the amplitude of the force
pulse. However, when the energy associated with the noise is compared with the
energy of the force pulse the noise becomes very significant.

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A technique which can be used to minimize the digitizer noise on the force signal involves multiplying the time domain signal by a window or weighting function as shown in Figure 5. The characteristics of this window are that it has unity amplitude for the duration of the force and a smooth transition to zero after the force pulse is ended. Since the force signal is known to be zero after the impactor has left the surface, no measurement errors are introduced by using this technique. The effect of using this window is shown in Figures 6 and 7.

For severe noise problems such as might be encountered in analyzing tape recorded data, curve fitting techniques can be used to clean up the force signal. Figure 8 shows a force spectrum from an impact with a signal to noise ratio of one (i.e., the rms noise level is equal to the rms signal level). Figure 9 shows the same force spectrum after it has been fitted using a complex exponential algorithm using five degrees of freedom (225, 226). Figure 10 shows a spectrum from the same force signal with no added noise. It can be seen that this method can recover a reasonable force signal even from a force pulse with very high noise.

Noise on the response signal is handled much like the digitizer noise on the force signal except that a different weighting function is used. With a transient input, the signal level at the beginning of the sample is much higher than at the end of the sample. Assuming a uniform noise level, the signal to noise ratio decreases as the signal level decreases. Thus the data at the beginning of the sample is much more reliable than that at the end. For this reason the weighting function shown in Figure 11 is used. Unlike the force window, this window does have an effect on the measured frequency response. However, the effects are known and correctable. The window has the form of $Ae^{-\alpha t}$ and its

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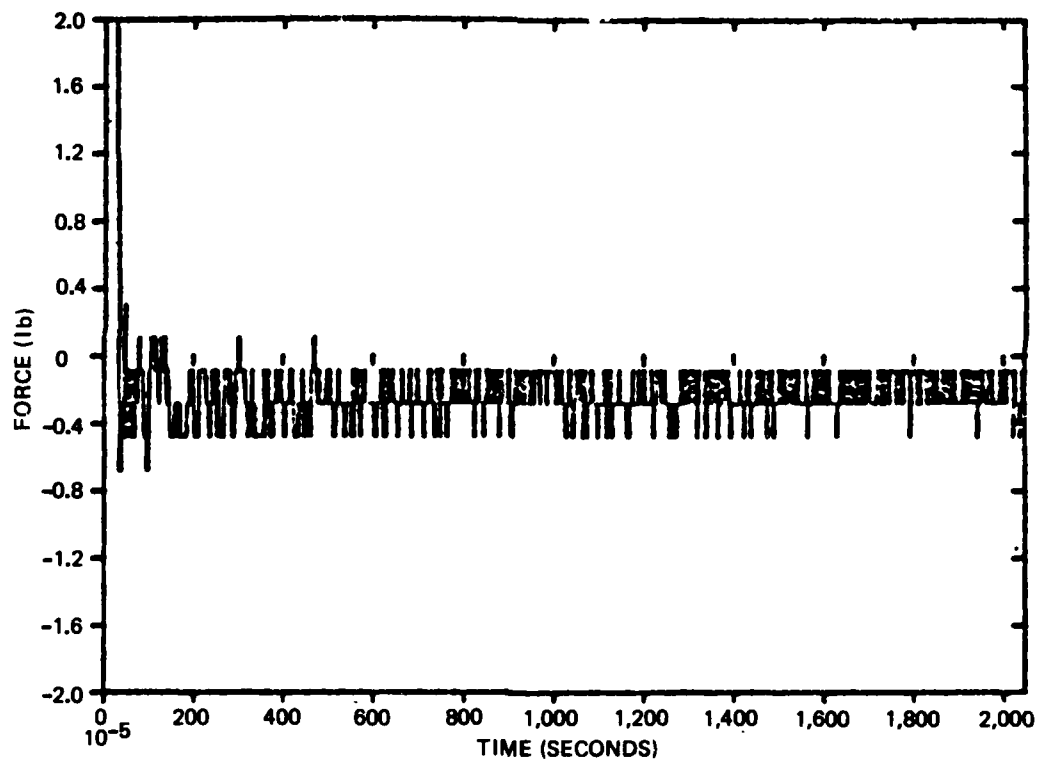
Figure 4. Force Signal Showing Digitizer Noise
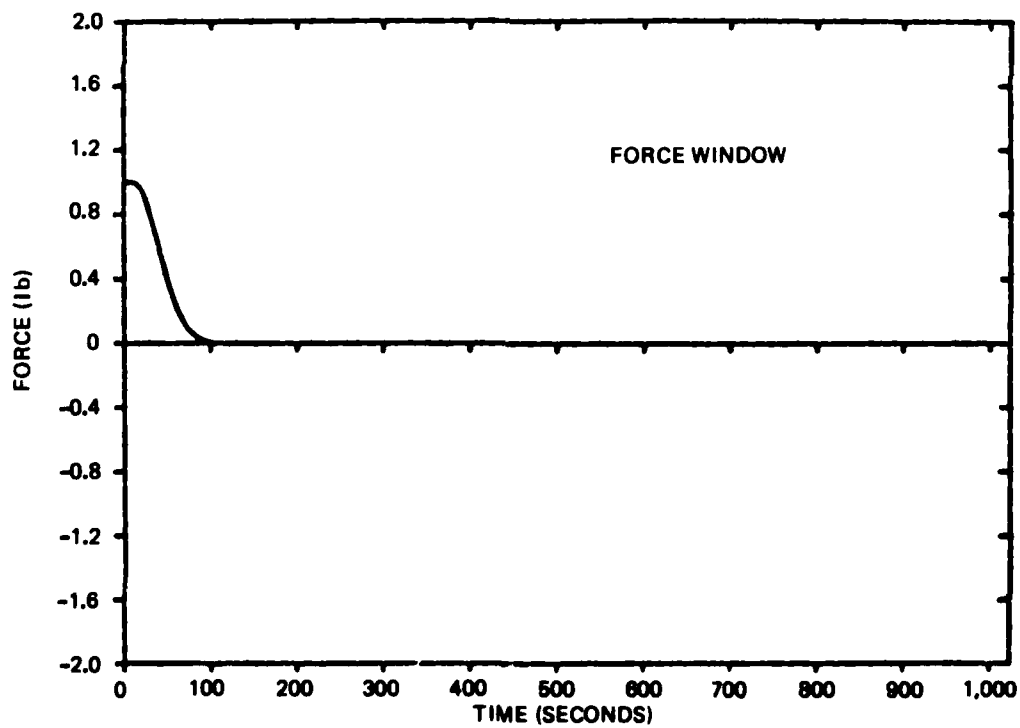
Figure 5. Force Window

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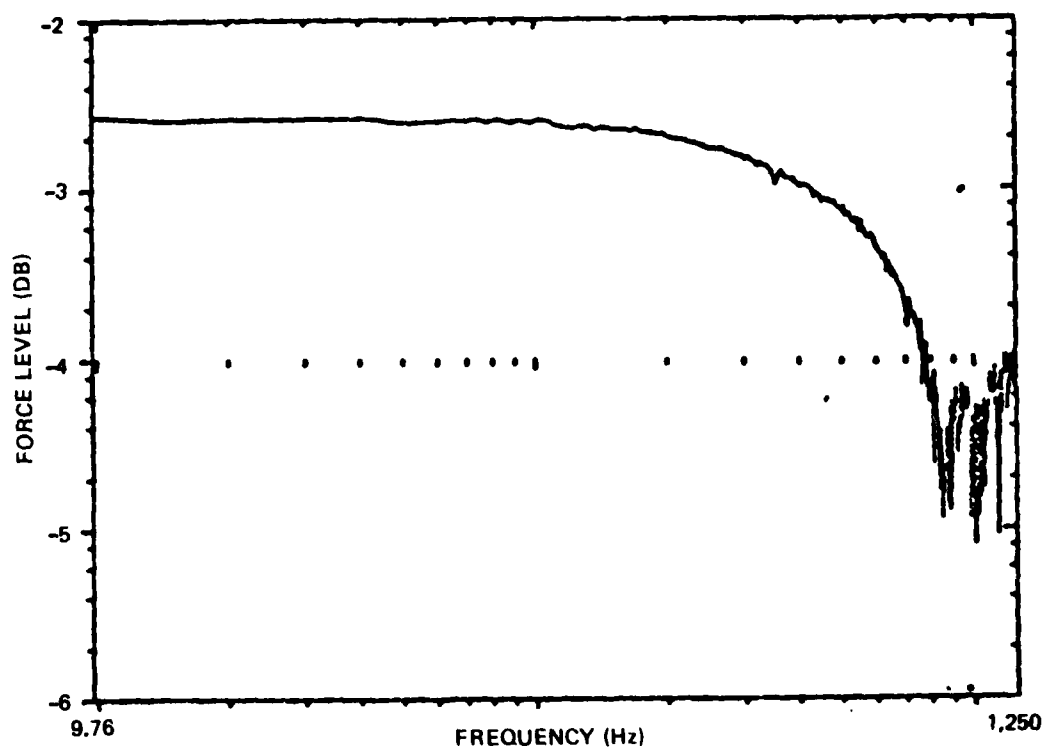
Figure 6. Force Spectrum With No Window Used
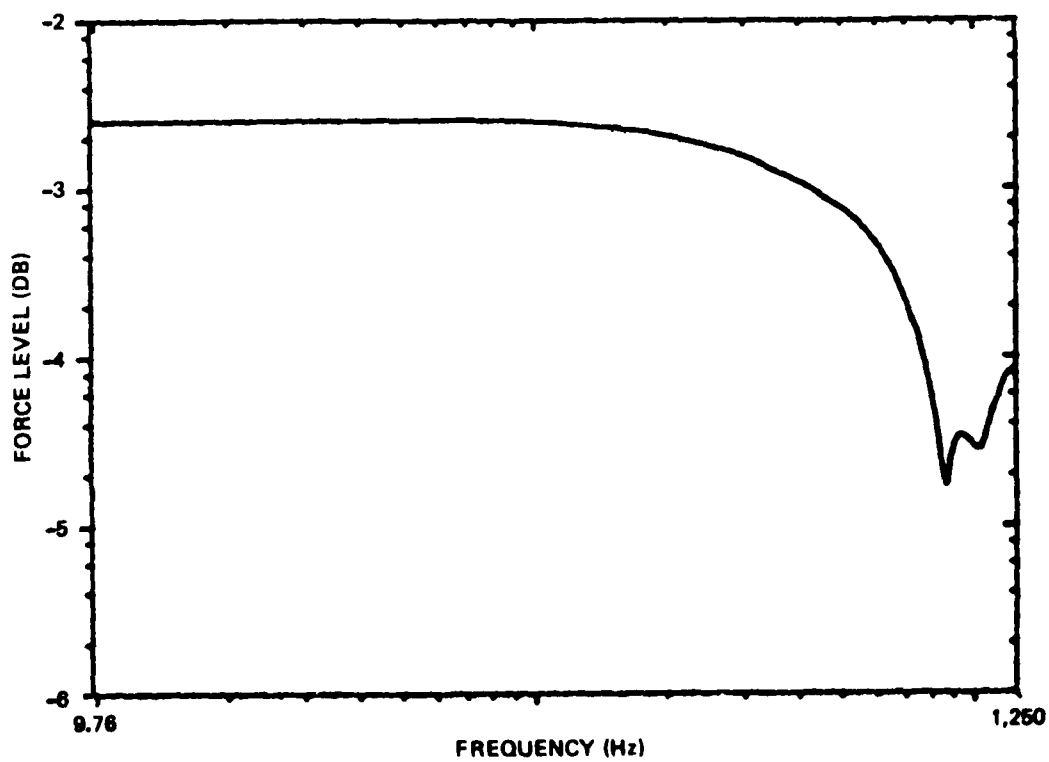
Figure 7. Force Spectrum Smoothed With Force Window

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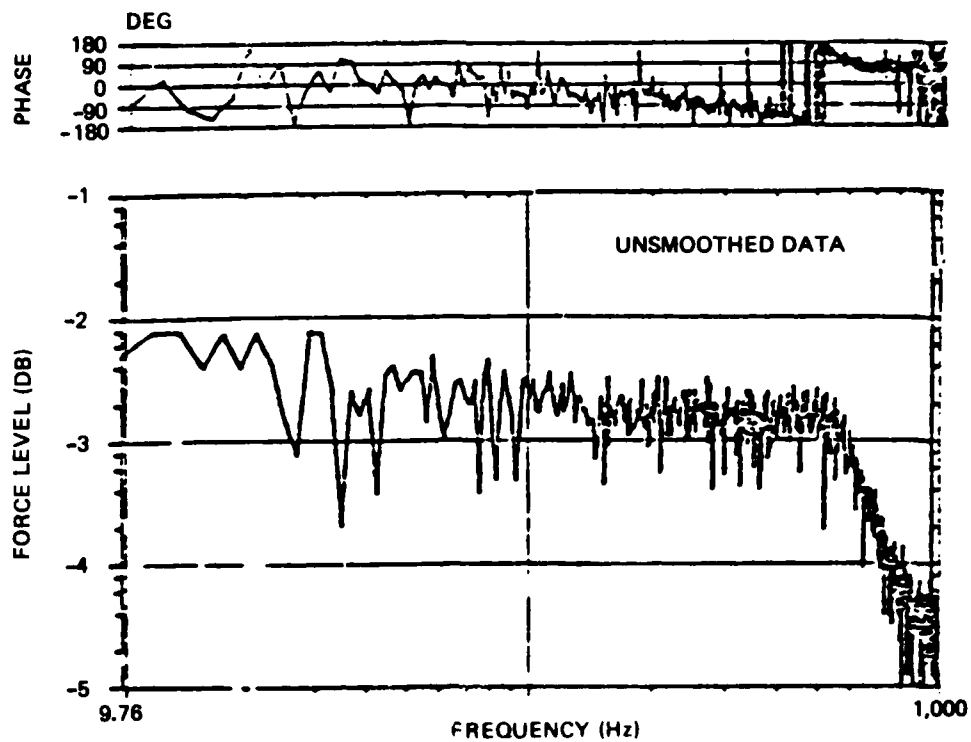
Figure 8. Force Spectrum Versus Frequency - Unsmoothed Data
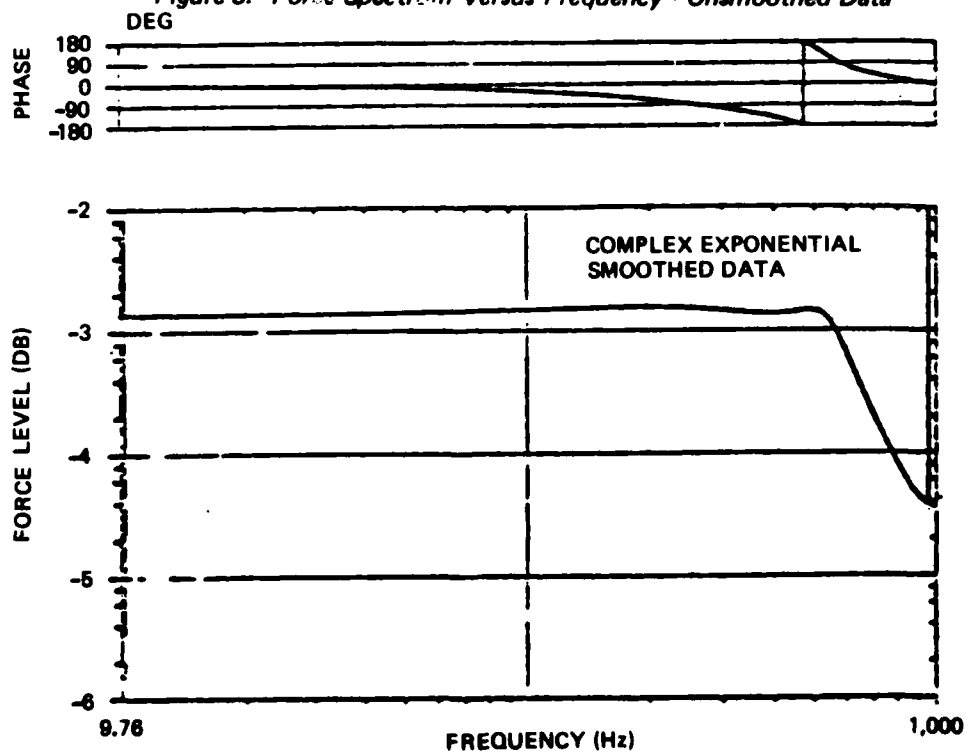
Figure 9. Force Spectrum Versus Frequency - Complex Exponential Smoothed Data
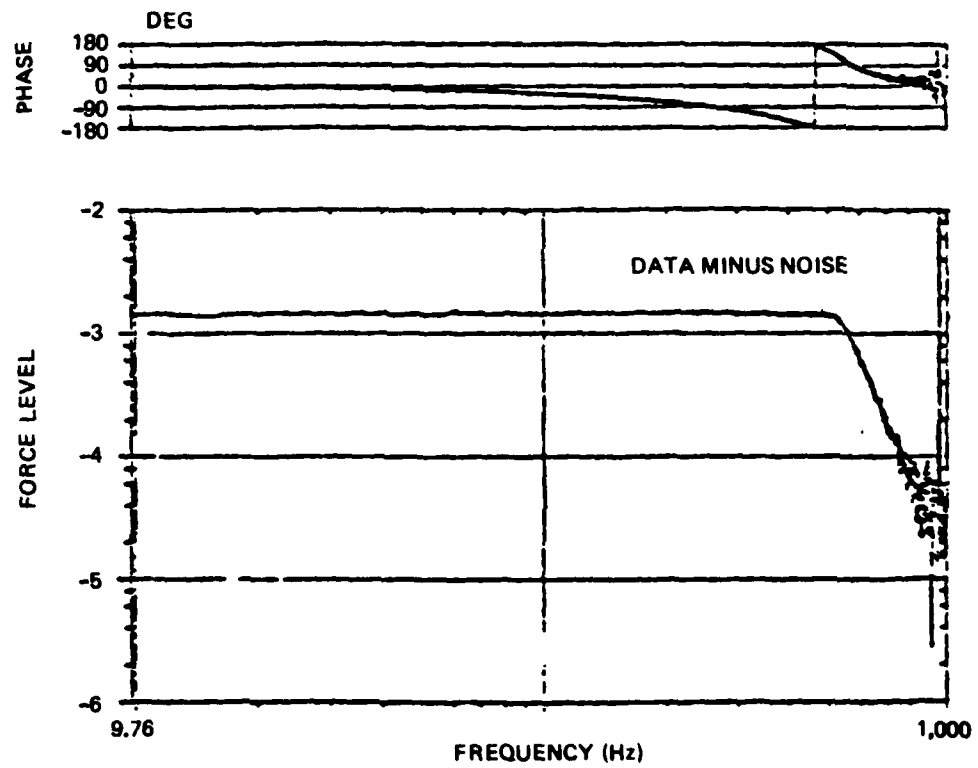
Figure 10. Force Spectrum Versus Frequency - Data Minus Noise

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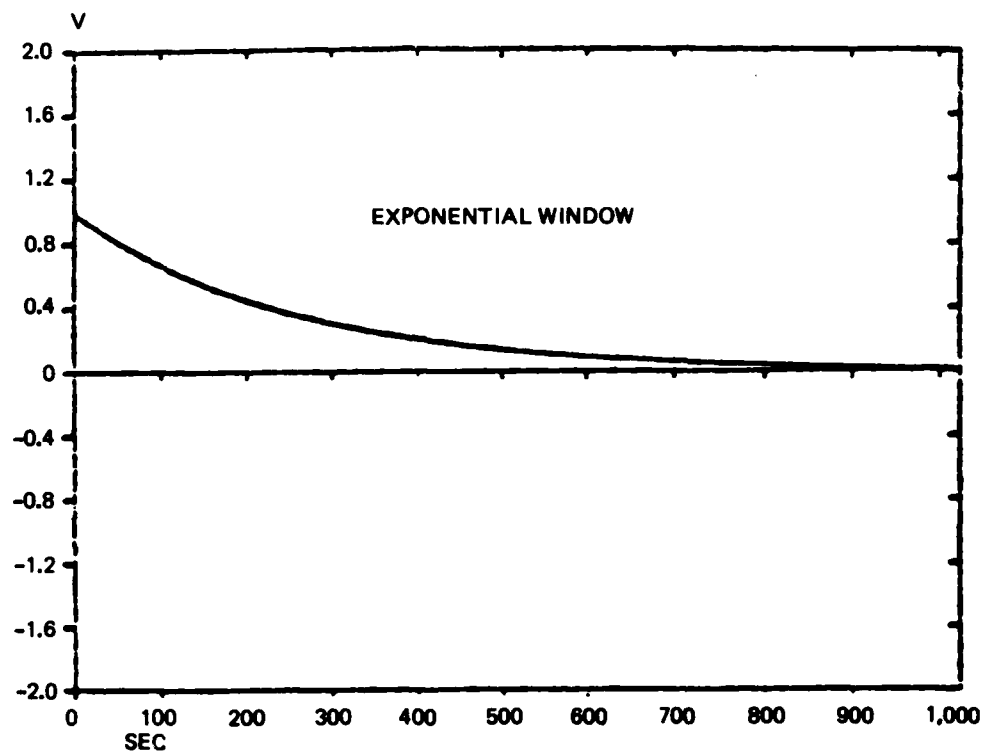
Figure 11. Exponential Window

effect is equivalent to adding damping to the system. If the actual damping in the system is required, the damping added by the window can be easily subtracted off.

3.1.2   Interpretation Phase

3.1.2.1   Introduction to Modal Analysis*

Review of Modal Analysis Using Transfer Functions

Modes of vibration have already been defined in terms of the eigenvalues and eigenvectors of the time domain equations of motion. Since the transfer function method of modal testing is based upon the measurement of frequency domain functions, it is next shown that modes of vibration can be defined by parameters of a transfer function matrix model of the structure, which is equivalent to the time domain model.

It should become clear from this analysis that during a typical modal test, one row or column of the transfer matrix model is being measured, and that this is sufficient information to identify all the parameters which define the modes of vibration. It should also become clear that a complete dynamic model can be constructed from the modal parameters.

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*This section is excerpted, with permission, from "Measurement and Analysis of the Dynamics of Mechanical Structures", a lecture by Mark H. Richardson.

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Time Domain Model - In a measurement situation the actual input forces and responses for a finite number of degrees-of-freedom of the structure are measured. So if a model were constructed from the measurements involving these specific degrees-of-freedom, the model would give an accurate description of the structural dynamics involving those points. This is a different situation than with a finite element model where the degrees-of-freedom and the size and shape of the elements are chosen so as to approximate the dynamics of the structure as closely as possible.

The time domain structural dynamic model, as shown in Figure 12, exhibits the same form as the finite element model but, at least in principle, is an exact model of the structural dynamics if obtained from measurements.

Laplace Domain Model - We do not directly measure the time domain model of Figure 12, but rather its Laplace domain equivalent, shown in Figure 13.

In this model the inputs and responses of the structure are represented by their Laplace transforms. Time domain derivatives (i.e. velocity and acceleration) do not appear explicity in the Laplace domain model but are accounted for in the transfer functions. The transfer matrix contains transfer functions which describe the effect of an input at each degree-of-freedom (D.O.F.) upon the response at each D.O.F. Because the model is linear, the transformed total motion for any D.O.F. is the sum of each transformed input force multiplied by the transfer function between the input D.O.F. and the response D.O.F.

$$M \ddot{x}(t) + C \dot{x}(t) + K x(t) = f(t)$$

MASS MATRIX — DAMPING MATRIX — STIFFNESS MATRIX — APPLIED FORCE VECTOR

ACCELERATION VECTOR — VELOCITY VECTOR — DISPLACEMENT VECTOR

IF n-DEGREES-OF-FREEDOM ARE MEASURED ON THE STRUCTURE THEN THE VECTORS HAVE n-COMPONENTS AND THE MATRICES ARE (n×n).
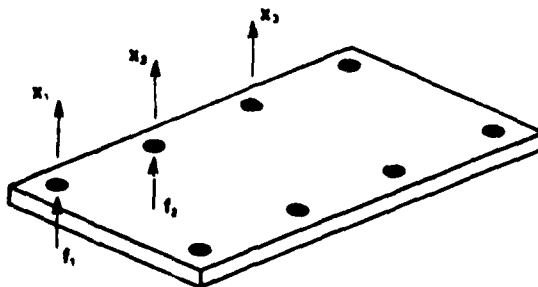
Figure 12. The Structure Dynamic Model (Time Domain)

$$\begin{bmatrix} X_1(s) \\ X_2(s) \\ \cdot \\ \cdot \\ \cdot \end{bmatrix} = \begin{bmatrix} h_{11}(s) \; h_{12}(s) \; \cdots \\ h_{21}(s) \; \cdot \\ \cdot \\ h_{n1}(s) \end{bmatrix} \begin{bmatrix} F_1(s) \\ F_2(s) \\ \cdot \\ \cdot \end{bmatrix}$$

LAPLACE TRANSFORMS OF RESPONSES — TRANSFER FUNCTION MATRIX — LAPLACE TRANSFORMS OF APPLIED FORCES

$$h_{nr}(s) = \frac{a_0 s^m + a_1 s^{m-1} + \cdots + a_m}{b_0 s^m + b_1 s^m + \cdots + b_m} \qquad \text{TRANSFER FUNCTION}$$

$x_r(t) \rightarrow X_r(s)$

$x_1(t) \rightarrow X_1(s)$

h_{27}

h_{17}

$f_7(t) \rightarrow F_7(s)$
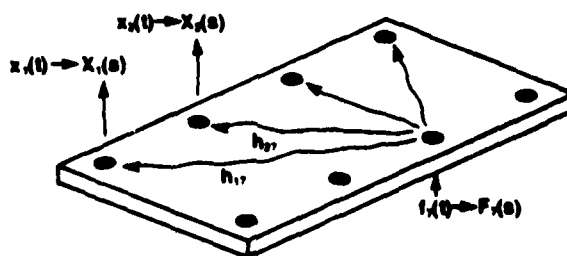
Figure 13. The Structure Dynamic Model (Laplace Domain)

For example,

$$X_1(S) = h_{11}(S)F_1(S) + h_{12}(S)F_2(S) + \ldots + h_{1n}(S)F_n(S)$$

Transfer Function of a Single Degree-of-Freedom - The Laplace variable is a complex number, normally denoted by $S = \sigma + j\omega$. Since the transfer function is a function of the S-variable, it too is complex valued. Plots of a typical transfer function on the S-plane are shown in Figure 14. Because it is complex, the transfer function is represented by its REAL and IMAGINARY parts or equivalently by its MAGNITUDE and PHASE. Note that in this case, the transfer function is only plotted over half of the S-plane, i.e., it is not plotted for any positive values of σ. This was done to give a clear picture of the transfer function values along the $j\omega$-axis. These values will become important later in this development.

Note also that the magnitude of the transfer function goes to infinity at two points in the S-plane. These discontinuities are called the POLES of the transfer function. These poles define resonant conditions on the structure which will "amplify" an input force. The location of these poles in the S-plane is defined by a FREQUENCY and DAMPING value as shown in Figure 15. Hence, the σ-axis and $j\omega$-axis of the S-plane have become known as the damping axis and the frequency axis respectively. The frequency and damping which define a pole in the S-plane are the frequency and damping of a mode of vibration of the structure.

Transfer Matrix in Partial Fraction Form - The elements of the transfer matrix can be written as ratios of polynomials as shown in Figure 13. With some minor assumptions, (explained later) the transfer matrix can be re-written in partial
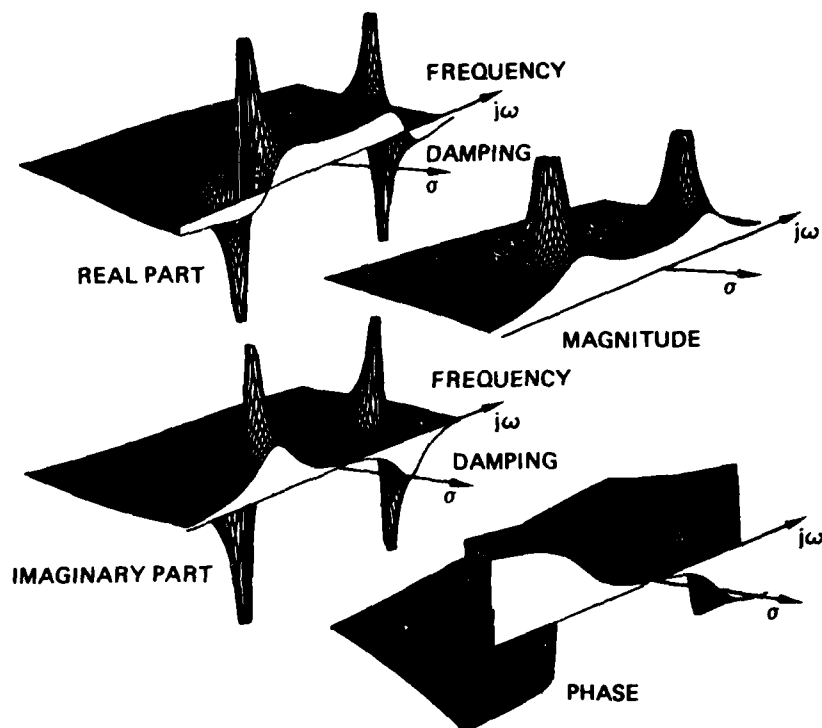
Figure 14. Transfer Function of a Single Degree-of-Freedom
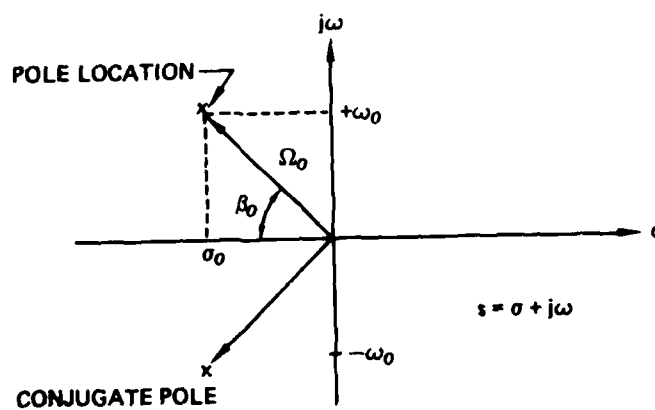
σ_0 — Damping coefficient
ω_0 — Damped natural frequency
Ω_0 — Resonant (undamped) natural frequency
$\zeta_0 = \cos \beta_0$ — Damping factor (or percent of critical damping)

Figure 15. S-Plane Nomenclature

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fraction form as shown in Figure 16. This form clearly shows the transfer function in terms of the parameters which describe its pole locations, namely $p_k = \sigma_k + j\omega_k$. For a model with n-degrees-of-freedom, it is clear that the transfer functions contain n-pole pairs (p_k, p_k^*).

Two unique features of the partial fraction form are that <u>all</u> transfer functions contain the same denominator terms involving the S-variable, and that the numerators simply become constants (numbers) which are assembled into the RESIDUE matrix, and its conjugate matrix.

Transfer Matrix in Terms of Modal Parameters - After writing it in partial fraction form, the transfer function can be further simplified by writing the residue matrix in terms of a MODAL VECTOR (u_k) as shown in Figure 17.

The derivation of this form is given in References (156) or (170). This is a crucial step, for now we have reduced the transfer matrix (i.e. the entire dynamic model) to a parametric form involving only modal parameters. As stated in Figure 17, a mode of vibration is characterized by a <u>pair</u> of conjugate poles and a <u>pair</u> of conjugate mode vectors.

---

* - denotes complex conjugate

$$H(s) = \sum_{k=1}^{n} \left[\frac{r_k}{s - p_k} + \frac{r_k^*}{s - p_k^*} \right]$$

$p_k = \sigma_k + j\omega_k = k^{th}$ POLE

r_k — MATRIX OF RESIDUES FOR k^{th} POLE

$$r_k = \begin{bmatrix} r_{11}(k) & r_{12}(k) & \cdots \\ r_{21}(k) & \cdot & \\ \vdots & & \ddots \\ \vdots & & \end{bmatrix} \quad (n \times n)$$

Figure 16. Transfer Function Matrix in Partial Fraction Form

$$H(s) = \sum_{k=1}^{n} \left[\frac{u_k u_k^{'}}{s - p_k} + \frac{u_k^* u_k^{*'}}{s - p_k^*} \right]$$

u_k — k^{th} MODAL VECTOR (n — DIMENSIONAL)

MODE OF VIBRATION: A MODE (k) IS CHARACTERIZED BY A
PAIR OF CONJUGATE POLES (p_k, p_k^*) AND A PAIR OF
CONJUGATE MODAL VECTORS (u_k, u_k^*).

Figure 17. Transfer Matrix in Terms of Modal Parameters

Note that the unique form of the residue matrix allows the entire (n x n) matrix to be defined once the n-dimensional mode vector is known. Furthermore, since every row and column contains the mode vector multiplied by a different component of itself, ONLY ONE ROW OR COLUMN of the residue matrix (and hence the transfer matrix) needs to be measured in order to identify the mode vector. A 2-dimensional case is written out in Figure 18 to illustrate this point.

The numerators of the first column of the transfer matrix are made up of the mode vector (u_{11}, u_{21}) multiplied by its first component (u_{11}), plus the conjugate mode vector $(u_{11}, *u_{21}*)$ multiplied by its first component $(u_{11}*)$, for mode #1. Similiarly, two more terms are added for mode #2. The denominators, which contain the pole locations (p_1, p_1*) and (p_2, p_2*), are the same for every transfer function in the matrix.

Modal Testing Implications - The modal testing implications of this final parametric form of the transfer function model are stated in Figure 19.

Normally only one row or column of the transfer matrix is measured in a modal test, although multiple row and column elements could be measured to obtain better estimates of the modal parameters. Reference (172) covers this subject.

The assumptions made in order to derive the parametric form of the model are explained in more detail in Reference (170). These assumptions can be satisfied in a large number of test situations but they must be kept in mind during a modal test since they can be easily violated when testing complex structures.

$$H(s) = \frac{1}{s - p_1}\left[\begin{bmatrix} u_{11} \\ u_{21} \end{bmatrix} \begin{bmatrix} u_{11} & u_{21} \end{bmatrix} \right] + \frac{1}{s - p_1^*}\left[\begin{bmatrix} u_{11}^* \\ u_{21}^* \end{bmatrix} \begin{bmatrix} u_{11}^* & u_{21}^* \end{bmatrix} \right]$$

<div align="center">MODE #1</div>

<div align="center">+</div>

$$\frac{1}{s - p_2}\left[\begin{bmatrix} u_{12} \\ u_{22} \end{bmatrix} \begin{bmatrix} u_{12} & u_{22} \end{bmatrix} \right] - \frac{1}{s - p_2^*}\left[\begin{bmatrix} u_{12}^* \\ u_{22}^* \end{bmatrix} \begin{bmatrix} u_{12}^* & u_{22}^* \end{bmatrix} \right]$$

<div align="center">MODE #2</div>

Figure 18. Two Degree-of-Freedom Case

Modal parameters can be identified from one row or column of the transfer function matrix

Assumptions

1. Structural motion can be described by linear second order equations
2. The structure exhibits symmetry (or reciprocity)
3. Only one mode exists at each pole location
4. Modes are defined in a global sense

Figure 19. Modal Testing Implications

Transfer Function Measurement

In a test situation we do not actually measure the transfer function over the entire S-plane, but rather its values along the $j\omega$-axis.

These values are known as the FREQUENCY RESPONSE FUNCTION, as shown in Figure 20. Since the transfer function is an "analytic" function, its values throughout the S-plane can be inferred from its values along the $j\omega$-axis. More specifically, if we can identify the unknown modal parameters of a transfer function by "curve fitting" the analytical form in Figure 16 to measured values of the function along the $j\omega$-axis, then we can synthesize the function throughout the S-plane.

Alternative Forms of the Frequency Response - The frequency response function, being complex values, is represented by two numbers at each frequency. The so called CO-QUAD pilot, or real and imaginary parts, derives its origin from the days of swept sine testing when the real part was referred to as the COincident waveform and the imaginary part as the QUADrature waveform. The Bode plot, or log magnitude and phase vs. frequency, is named after H. W. Bode who made many contributions to the analysis of frequency response functions. (Many of Bode's techniques involved plotting these functions along a log-frequency axis.)

The Nyquist plot, or real vs. imaginary part, is named after the gentleman who popularized its use for determining the stability of linear systems. The Nichols plot, or log magnitude vs. phase angle, is named after N. B. Nichols who used such plots to analyze servo-mechanisms.

FREQUENCY RESPONSE FUNCTION

REAL PART

MAGNITUDE

IMAGINARY PART

PHASE
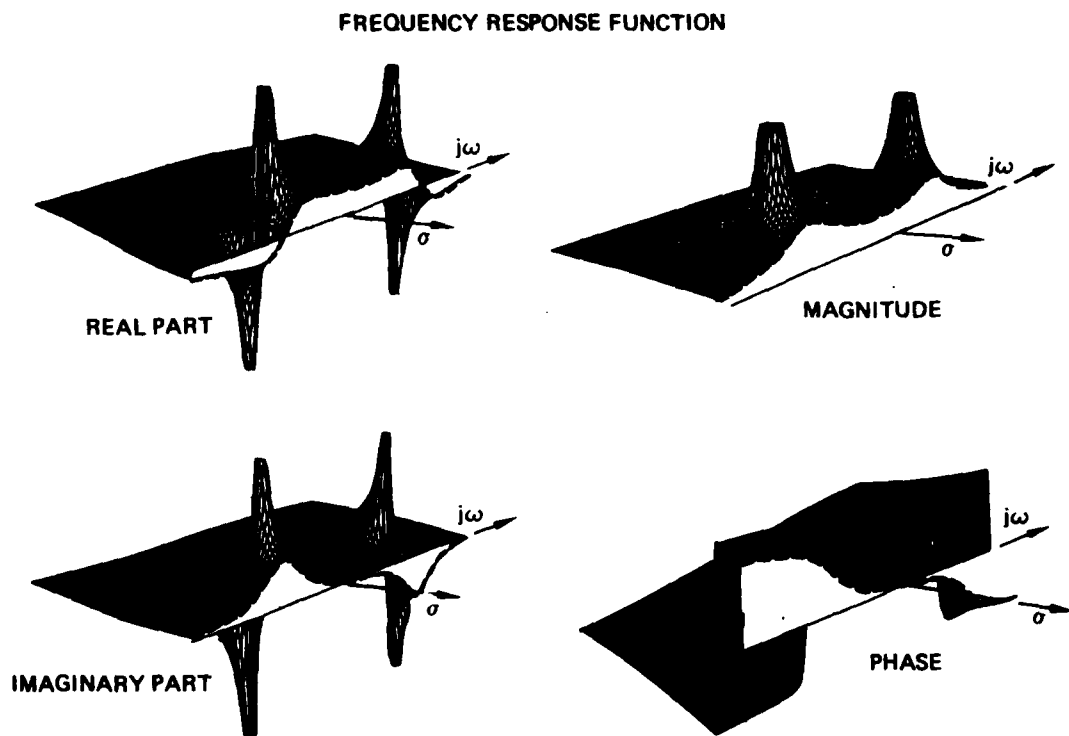
Figure 20. Transfer Function of a Single Degree-of-Freedom

Measuring Elements of the Transfer Matrix - The simplest way of measuring elements of the transfer matrix (i.e. frequency response functions) is to measure them one at a time, as shown in Figure 21. In this simple 2-dimensional case the frequency response function ($h_{11}(\omega)$) is measured by exciting the sdtructure at pt. #1 and measuring response at pt. #1. Then the function is formed by dividing the Fourier transform of the measured response motion ($X_1(\omega)$) by the Fourier transform of the measured input force ($F_1(\omega)$). Likewise the second element in the first row ($h_{12}(\omega)$) is measured by exciting the structure at pt. #2 and then dividing the Fourier transform of the response motion ($X_1(\omega)$) by the Fourier transform of the input force ($F_2(\omega)$). The second row of elements can be measured in a similar manner.

More sophisticated measurement methods involving multiple inputs and responses could be implemented, but this simplified single input-single output approach is most commonly used.

If time savings is a significant test objective, as it often is in larger modal tests, than test time can be significantly reduced by measuring a single input force and several response motions simultaneously. From this data, several transfer functions in a single column of the transfer matrix can be computed.

Modal Parameter Identification

Once a set of transfer functions has been measured from a structure, modal parameters are identified by "curve fitting" an ideal form for the transfer function to the measurement data.

$$\begin{bmatrix} X_1(\omega) \\ \\ X_2(\omega) \end{bmatrix} = \begin{bmatrix} h_{11}(\omega) & h_{12}(\omega) \\ \\ h_{21}(\omega) & h_{22}(\omega) \end{bmatrix} \begin{bmatrix} F_1(\omega) \\ \\ F_2(\omega) \end{bmatrix}$$
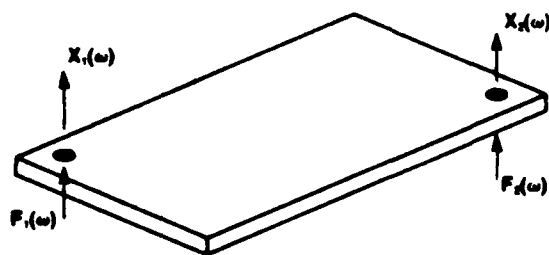
FIRST ROW

$X_1(\omega) = h_{11}(\omega) F_1(\omega) + h_{12}(\omega) F_2(\omega)$ $\qquad h_{11}(\omega) = X_1(\omega)/F_1(\omega)$

$X_1(\omega) = h_{11}(\omega) F_1(\omega) + h_{12}(\omega) F_2(\omega)$ $\qquad h_{12}(\omega) = X_1(\omega)/F_2(\omega)$

SECOND ROW

$X_2(\omega) = h_{21}(\omega) F_1(\omega) + h_{22}(\omega) F_2(\omega)$ $\qquad h_{21}(\omega) = X_2(\omega)/F_1(\omega)$

$X_2(\omega) = h_{21}(\omega) F_1(\omega) + h_{22}(\omega) F_2(\omega)$ $\qquad h_{22}(\omega) = X_2(\omega)/F_2(\omega)$

Figure 21. Measuring Elements of the Transfer Matrix

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As shown in Figure 22, at least one row or column of transfer functions from the transfer matrix must be measured in order to identify the mode shapes. The mode shapes, or mode vectors, are then assembled from the identified residues from each measurement at the same modal frequency.

Figure 23 shows a breakdown of a measurement into a summation of the contributions due to each of the modes of vibration. That is, the magnitude of the transfer function shown by the solid line in the figure, is really the summation of a number of magnitude functions shown by the dashed lines in the figure, each one due to a different mode of vibration.

The modal parameters (frequency, damping and residue), of a single mode can be identified by curve fitting the dashed line function corresponding to that mode. However, since only the solid line function was measured, it is clear that to identify modal parameters accurately, all the parameters of all the modes must be identified siultaneously by some method which fits a multiple mode form of the transfer function to the data. This method is called a "multiple mode" curve fitting method.

Many times, the accuracy of a multiple mode method is not required, so simple, easier-to-use methods known as "single mode" methods are used to identify the unknown parameters. A single mode method treats the data in the vicinity of a modal resonance peak as if it is due solely to a single mode of vibration. In other words the "tails" of the resonance curves from other modes are considered to have negligible contribution to the data in the vicinity of the resonance peak in question.

MEASURE AT LEAST
ONE ROW OR COLUMN
OF TRANSFER MATRIX

IDENTIFY MODAL
- FREQUENCY
- DAMPING
- RESIDUES
BY CURVE FITTING MEASUREMENTS

ASSEMBLE MODAL VECTORS
FROM RESIDUES AT SAME
FREQUENCY
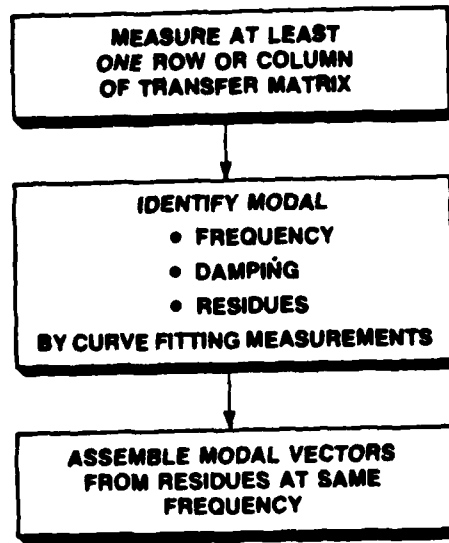
Figure 22. Modal Parameter Identification

MAGNITUDE OF A MULTI DEGREE-OF-FREEDOM SYSTEM
TRANSFER FUNCTION
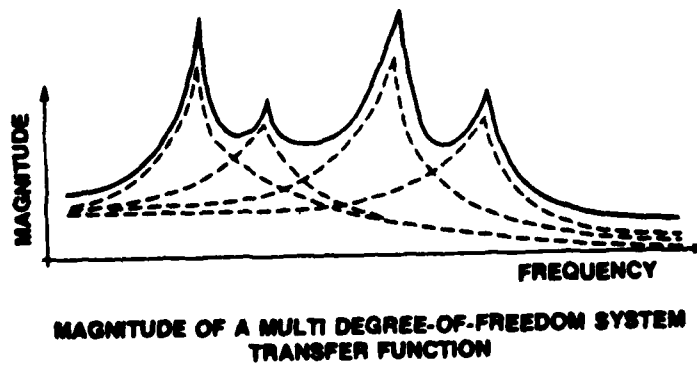
Figure 23. Multiple Degree-of-Freedom Transfer Function

The amount of error incurred with the use of single mode methods is dictated by the amount of "modal coupling" in the measurements.

In a light modal coupling case the measurement data in the vicinity of a modal resonance peak is predominantly due to that mode, and the influence of the other modes is minimal. In this case a single mode curve fitting method can give accurate results.

In a heavy modal coupling case the influence of the tails of other modes is not negligible, so a single mode method will incorrectly identify modal parameters.

3.1.2.2 Modal Parameter Determination

Once the frequency response information on the aircraft has been measured, the frequency response information is curve fit to identify the modal parameters. In the following sections, the modal parameter identification algorithms are described in detail. An algorithm is defined as a mathematical solution procedure. These procedures can, in general, be implemented on any computer. Care must be taken in discussing algorithms because the resulting computer program implementation is often also called (mistakenly) an algorithm. The curve fitting computer programs are applied to selected portions of the frequency response functions. The analysis of one frequency response function could conceivably involve the use of all available curve fitting routines, each applied to a different frequency band. A typical frequency response function is shown on Figure 24.
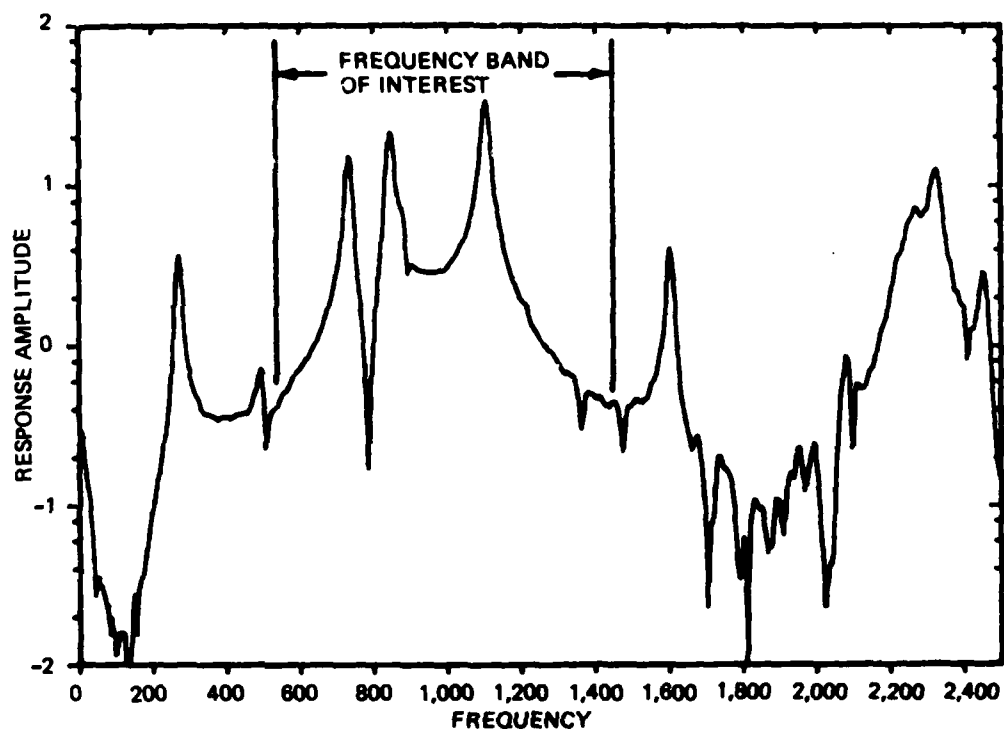
Figure 24. Typical Frequency Response Measurement

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Single Degree of Freedom Approximations

In most modal parameter estimation schemes, the usual procedure is to first estimate the eigenvalues (natural frequencies and damping factors) and then to estimate the eigenvectors (modal coefficient). Note that the solution for the eigenvalues from measured frequency response information is mathematically a nonlinear process which, in general, greatly complicates the parameter estimation schemes, particularly the multiple degree of freedom cases.

The methods that are discussed in this section are all single degree of freedom approximation procedures. Many of the techniques are those which were used historically with swept sine testing techniques utilizing analog data analysis equipment. As a result of this type of equipment, the initial modal coefficients were output directly from the analog equipment (CO-QUAD Analyzers) or graphically determined from plotted frequency response information. With the advent of small, dedicated mini-computer systems it is possible to measure frequency response information and computationally determine the modal parameters. As a result of this improved computational capability, a large number of computational algorithms have been developed in recent years for computing modal information. In the next several sections each technique will be described as to its implementation, advantages, and disadvantages.

Amplitude Response - Perhaps the simplest modal estimation procedure is to measure the magnitude of the frequency response at one of the natural frequencies. The natural frequencies for this simple case can be determined by choosing the frequencies where the magnitude of the frequency response reaches a maximum. If

the damping coefficient is known, the modal coefficient is given by the following relationship:

$$B_{pq} = 2\zeta_r \left(\frac{X_p}{F_q}\right)_{peak}$$ (1)

The damping can be estimated by a number of different techniques, the most common being the half power points or by measuring the rate of change of the phase angle through the resonance peak (99).

If the damping coefficient is unknown, the terms on the right hand side of Equation 1 can be lumped together and used as the modal coefficient. In other words, the total response can be used as the modal coefficient. In fact, this is frequently done since the resulting mode differs only by a scale factor. This assumption depends upon the damping coefficient being a fixed global property of the system.

The only advantage of this technique is that a minimum amount of equipment can be used. If the structure is excited with a sine wave at the frequency of the resonance being investigated and the resulting response is filtered to eliminate the harmonic distortion, then a simple voltmeter can be used to measure the modal coefficient. An oscilloscope can be used to determine the phase. The main disadvantage of this technique is that it does a very poor job of separating modes.

Quadrature Response - In order to better separate the modes, the quadrature response can be measured. The quadrature response is the ninety degree out-of-phase response of the structure displacement or acceleration with respect to the input force.

The quadrature, or imaginary component of the frequency response of the system for a single degree of freedom reaches a maximum at the undamped natural frequency of the system and approaches zero away from the resonance frequency. It is this characteristic which helps to separate adjacent modes.

Again if the damping is known, the modal coefficient can be computed from the quadrature frequency response by the following relation:

$$B_{pq} = j2\zeta_r \left\{ quad \left(\frac{X_p}{F_q} \right)_{peak} \right\} \qquad (2)$$

When the damping is unknown, by the same argument as before, the quadrature part of the response is used as the modal coefficient.

For cases where the system is lightly damped or the modes are well separated, the quadrature response is a very good technique.

The quadrature response technique has been. and still is, one of the more popular techniques for determining modal coefficients and is used extensively with the multiple shaker excitation approach. For troubleshooting cases, where it is not necessary to generate a modal model, the quadrature response technique will almost always give acceptable results. Typically, the frequency of the peak

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quadrature response is chosen from a typical measurement or by constructing a summation of power spectrums of the quadrature responses from a number of measurements (Figure 25 and 26). Once the frequency is known, the value of the quadrature response at that frequency can be determined from the measured frequency response data at all points of interest on the structure.

The damping can be estimated by one of the multiple degree of freedom techniques described later or can be estimated using the rate of change of the phase angle, half power points, or magnification factor (Q) method.

Circle Fit - The original approach for this method was developed by Kennedy and Pancu (96) for systems with hysteretic damping characteristics. As will be shown, the method can be extended to the viscous damping cases and also can be extended to include complex modes by using Equation 13 with the following assumptions:

1. The modes are only weakly coupled in the range where one mode is predominant. The contribution of lower and higher modes can be approximated by a complex constant $(R + jI)$.

2. The system is relatively lightly damped.

The frequency response of the structure in the frequency range where the r-th mode is predominant can be written as:

$$\frac{X_p}{F_q} = \frac{U_{pqr} + jV_{pqr}}{-\delta_r + j(\omega - \omega_{pr})} + R + jI \tag{3}$$

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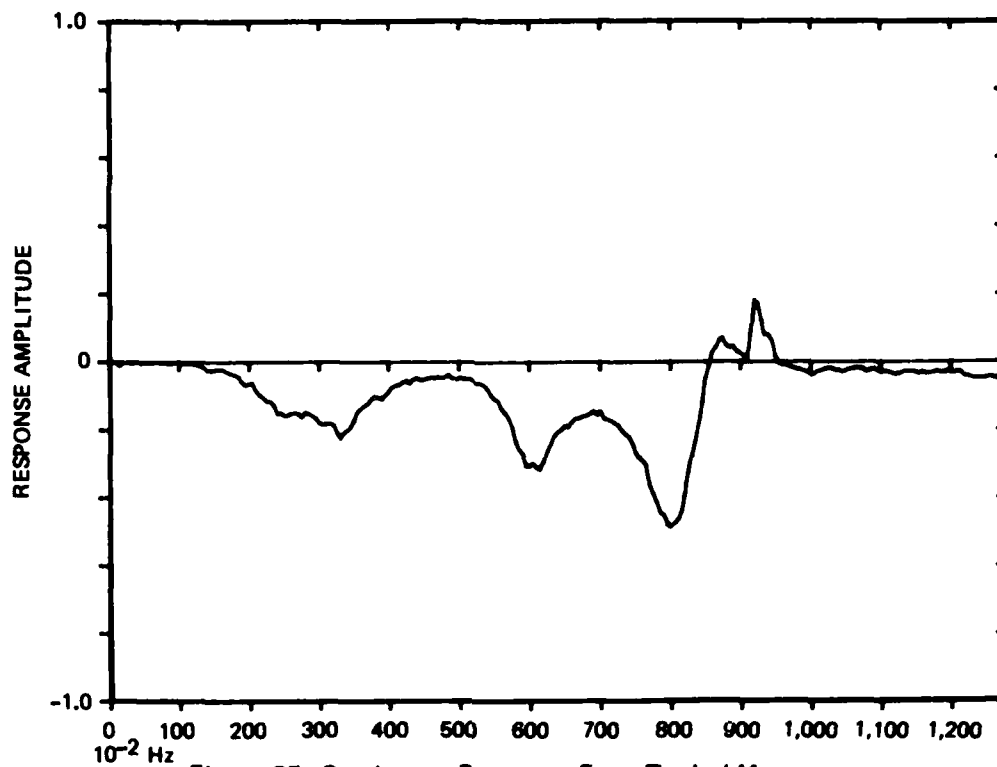
Figure 25. Quadrature Response For a Typical Measurement
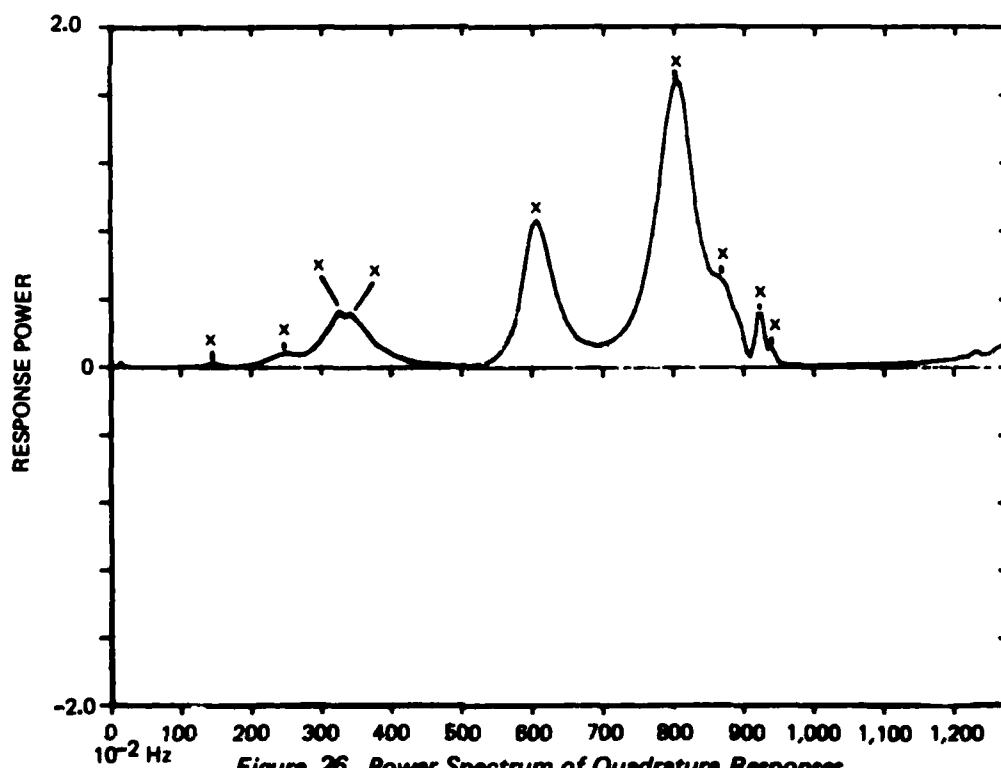
Figure 26. Power Spectrum of Quadrature Responses

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where R+jI includes the contribution of the term associated with the conjugate eigenvalue. If the complex constant is neglected and the magnitude of the mode is set to unity, ($U = 0$ and $V = -1$ for a single degree of freedom, $\omega > 0$) the following relations can be obtained:

$$Re\left\{\frac{X_p}{F_q}\right\} = -\frac{(\omega - \omega_{pr})}{(\omega - \omega_{pr})^2 + \delta_r^2} \tag{4}$$

$$Im\left\{\frac{X_p}{F_q}\right\} = \frac{\delta_r}{(\omega - \omega_{pr})^2 + \delta_r^2} \tag{5}$$

and thus,

$$\left[Re\left\{\frac{X_p}{F_q}\right\}\right]^2 + \left[Im\left\{\frac{X_p}{F_q}\right\} - \frac{1}{2\delta_r}\right]^2 = \left[\frac{1}{2\delta_r}\right]^2 \tag{6}$$

In other words, the contribution of one mode to the general response can be represented in the Argand plane as a circle (Figure 27). Taking into account the complex constant and the complex modal coefficients, the coordinates of the center can be calculated as:

$$\left(R - \frac{U_{pqr}}{2\delta_r}, I - \frac{V_{pqr}}{2\delta_r}\right) \tag{7}$$

and the diameter as:

$$d = \frac{\sqrt{U_{pqr}^2 + V_{pqr}^2}}{\delta_r} \tag{8}$$
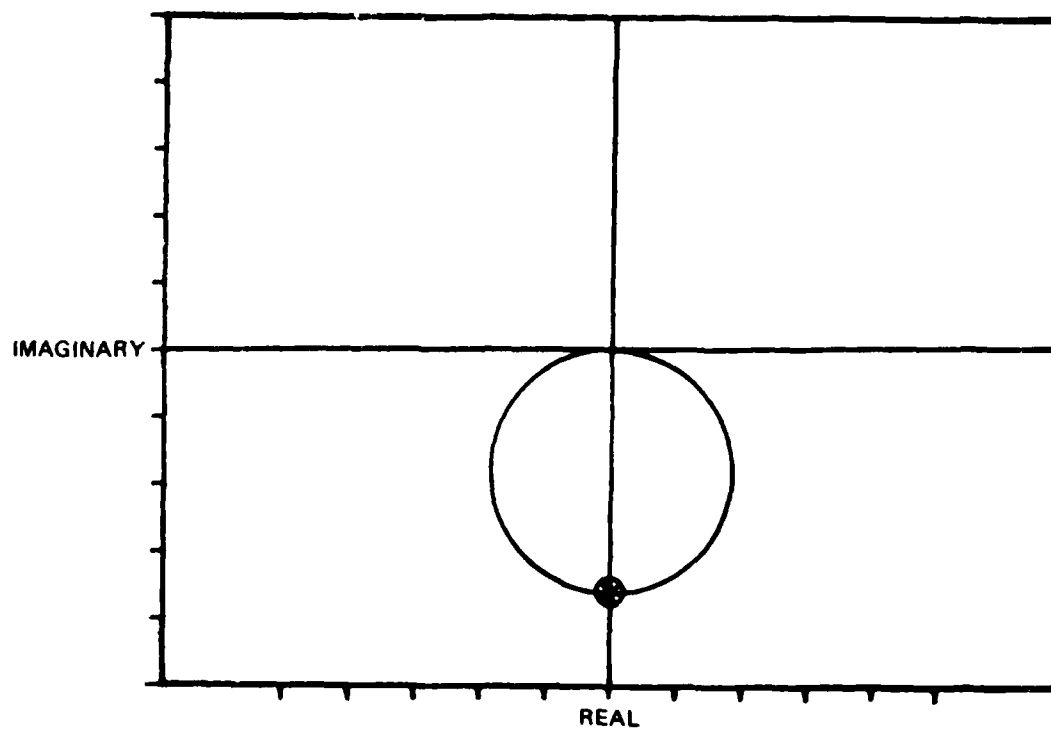
Figure 27. Argand Plane—Single Degree of Freedom
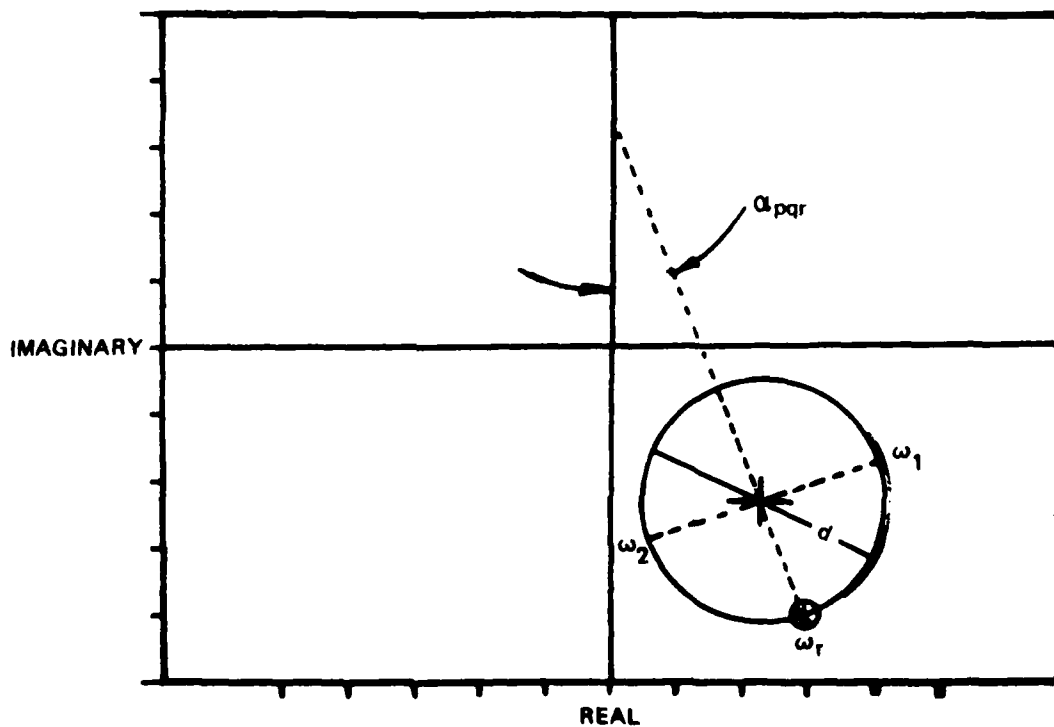
Figure 28. Characteristics of Kennedy-Pamcu Circle Fit

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The complex modal displacement vector expands or reduces the diameter and rotates the circle in the Argand plane. On the other hand, the complex constant (R+jI) will translate the center of the circle in the Argand plane (Figure 28).

A measure of the accuracy of this method is given by the shape of the frequency response in the region of the resonance: the more circular the curve, the more accurate the result.

It was shown in Reference 99 that the resonance frequency could be found where the variation of the phase angle as a function of frequency is a maximum:

$$\frac{\partial^2 \phi}{\partial \omega^2} = 0 \qquad (9)$$

The damping ratio, ζ_r , can also be determined from the fitted circle. By locating the two frequencies $\omega 1$ and $\omega 2$ at ± 90 degrees with respect to the damped natural frequency (Figure 28), the damping can be calculated by the following relation:

$$\zeta_r = \left| \frac{\omega_1 - \omega_2}{2\omega_r} \right| \qquad (10)$$

The diameter of the circle is proportional to the modulus of the residue:

$$d = \frac{1}{\delta_r} \left\| A_{pqr} \right\|^2 \qquad (11)$$

The phase angle, α_{pqr}, of the complex modal coefficient can be calculated by passing a straight line through the point of the resonance frequency, ω_r , and

the center of the circle. The angle this line makes with the imaginary axis is equal to the phase angle of the complex modal coefficient:

$$\alpha_{pqr} = \arctan \left(\frac{U_{pqr}}{V_{pqr}} \right) = \frac{\pi}{2} + \arg \left(A_{pqr} \right) \qquad (12)$$

Circle fitting typically is the next level of parameter estimation above quadrature response. It does a better job of separating coupled modes than the quadrature technique, but it, like most of the more complicated methods, can diverge and give very poor answers. In general, the method is fast and can be used to obtain complex modes, but in order to get the best possible results it should be used interactively. The center frequency and bandwidth used in the circle fit can be varied depending upon the amount of noise, the coupling of modes, and the damping of the mode. This choice of data points utilized in the circle fit gives different answer and the best answer becomes a judgement. As a result, the best answers are obtained by a skillful operator.

The normal procedure for using the circle fit is to first determine the natural frequency of the system using any one of a number of different procedures. The peaks in the quadrature response or the peaks in a summation of power spectrums (constructed from the quadrature response of all of the measurements) are very good indicators.

Using the least squares Circle Fit algorithm, a circle can be interactively fit to the measured frequency response data at the designated natural frequency. The damping ratio (ζ_r) as well as the modal coefficient (amplitude and phase) are defined by the location, diameter, and orientation of the circle.

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In order to illustrate one of the more serious problems with circle fitting, the following example will be used. The first two modes of a cantilever beam will be determined using circle fitting. The mode shapes for the beam are shown in Figure 29. If an excitation force is applied at point one on the beam, the measured frequency response plots between point one and all other points are shown in Figure 30. In this figure the resonance frequencies are marked with a symbol and the bandwidth used in the circle fit are shown by the double line. The problem which is being illustrated shows in the measurement at point 2. At point 2 the modal contribution of mode 2 is nearly zero. The circle fit in this case is really a fit of the skirt of the first mode. Instead of getting a value near zero, a very large value is obtained. Due to this type of problem and due to bad estimates caused by noise, it is necessary to interactively fit the data with the Circle Fit algorithm.

Multiple Degree of Freedom Approximations

In studies carried out by Klosterman (99), Van Loon (208), and Richardson (170, 171, 227) a derivation is given for the general formula of the frequency response of a multiple degree of freedom system with viscous or hysteretic damping.

For general viscous damping, the frequency response for a multiple degree of freedom mechanical system can be written as:

$$\frac{X_p}{F_q} = \sum_{r=1}^{\infty} \left[\frac{A_{pqr}}{j\omega - \delta_r} + \frac{A^{\bullet}_{pqr}}{j\omega - \delta_r^{\bullet}} \right] \tag{13}$$

where
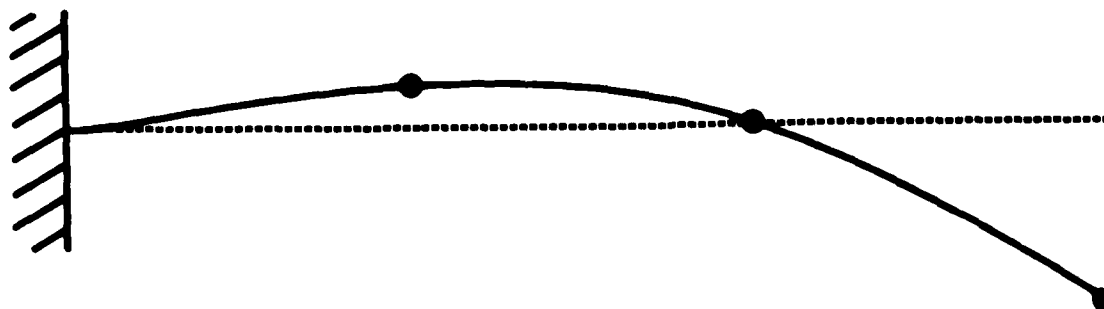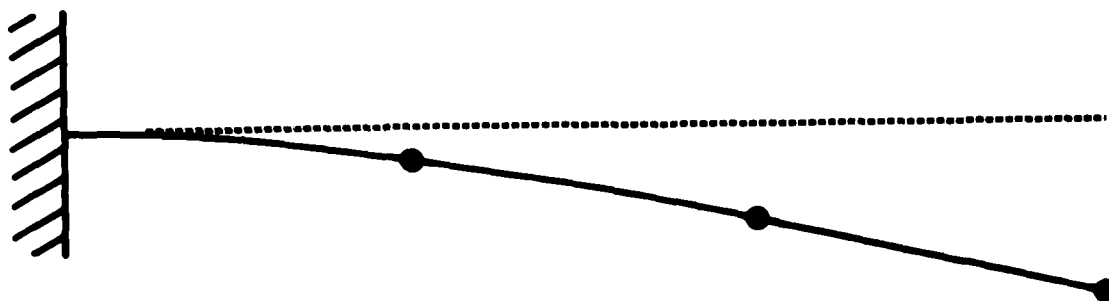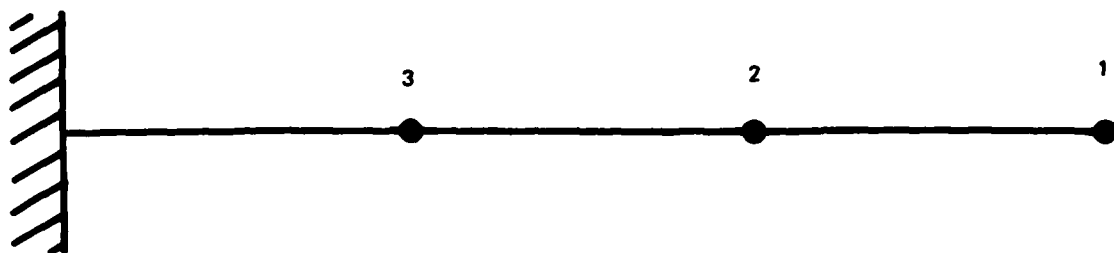
Figure 29. Cantilever Beam—Two Degrees of Freedom
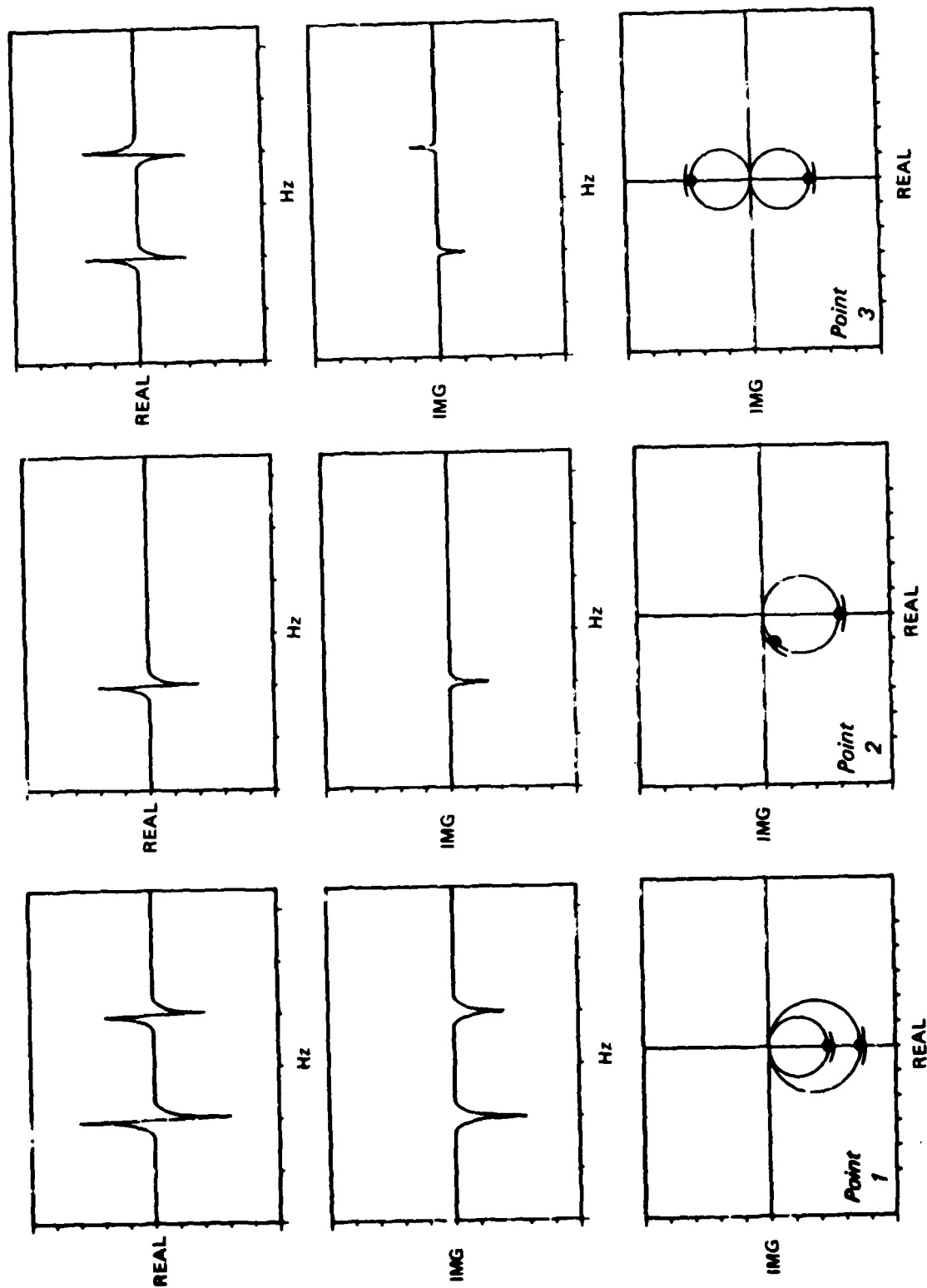
Figure 30. Cantilever Beam Frequency Response

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x_p = response at point p,

F_q = input at point q,

$j = \sqrt{-1}$,

s_r = eigenvalue of r-th mode = $\delta_r + j\omega_{dr}$.

ω_{dr} = damped natural frequency of the r-th mode,

δ_r = decay rate of r-th mode (damping),

A_{pqr} = complex residue of r-th mode = $U_{pqr} + jV_{pqr}$.

Continuous systems have an infinite number of degrees of freedom, but, in general, only a finite number of modes can be used to describe the dynamic behavior of a system. The theoretical number of degrees of freedom can be reduced by using a finite frequency range (f_a, f_b). The frequency response could be separated into three partial sums, each covering the modal contribution corresponding to modes located in the frequency ranges $(0, f_a)$, (f_a, f_b) and (f_b, ∞) (Figure 13). In the frequency range of interest, the modal parameters can be estimated to be consistent with Equation 13. In the lower and higher frequency ranges, residual terms can be included to handle modes in these ranges. In this case, Equation 13 can be rewritten as:

$$\frac{X_p}{F_q} = L_{pq} + \sum_{r=r_a}^{r_b} \left[\frac{A_{pqr}}{j\omega - s_r} + \frac{A_{pqr}^*}{j\omega - s_r^*} \right] + Z_{pq} \tag{14}$$

where

r_a = lower mode index of the frequency range of interest,

r_b = upper mode index of the frequency range of interest,

L_{pq} = lower residual term, and

Z_{pq} = upper residual term.

Frequently, the lower residual term is called the inertia restraint, and the upper residual term is called the residual flexibility. These can be written as:

$$L_{pq} = - \frac{Y_{pq}}{\omega^2} = Re \left\{ \sum_{r=1}^{r_a-1} \left[\frac{A_{pqr}}{j\omega - s_r} + \frac{A^*_{pqr}}{j\omega - s_r^*} \right] \right\} \tag{15}$$

$$Z_{pq} = Re \left\{ \sum_{r=r_b+1}^{\infty} \left[\frac{A_{pqr}}{j\omega - s_r} + \frac{A^*_{pqr}}{j\omega - s_r^*} \right] \right\} \tag{16}$$

where

Re z = real part of a complex number z,

Y_{pq} = inertia restraint, and

Z_{pq} = residual flexibility.

Therefore, Equation 13 can be rewritten as:

$$\frac{X_p}{F_q} = - \frac{Y_{pq}}{\omega^2} + \sum_{r=r_a}^{r_b} \left[\frac{A_{pqr}}{j\omega - S_r} + \frac{A^*_{pqr}}{j\omega - S_r^*} \right] + Z_{pq} \tag{17}$$

An alternate way to write the frequency response in terms of its undamped natural frequency and damping coefficient is:

$$\frac{X_p}{F_q} = - \frac{Y_{pz}}{\omega^2} + \sum_{r=r_a}^{r_b} \frac{B_{pqr} + j\left(\frac{\omega}{\omega_r}\right) B'_{pqr}}{1 - \left(\frac{\omega}{\omega_r}\right)^2 + j2\zeta_r\left(\frac{\omega}{\omega_r}\right)} + Z_{pq} \tag{18}$$

where by definition,

$$\omega_r = \sqrt{\delta_r^2 + \omega_{dr}^2} \qquad B'_{pqr} = \frac{2U_{pqr}}{\omega_r} \tag{19}$$

$$\zeta_r = - \delta_r/\omega_r$$

$$B_{pqr} = -\frac{2\left(\delta_r U_{pqr} + \omega_{pr} V_{pqr}\right)}{\omega_r^2} \tag{20}$$

The above terms have the units of compliance and as a result the numerator of Equation 18 is the "complex compliance". For the case of proportional damping, the equation for the frequency response has the more classical form:

$$\frac{X_p}{F_q} = -\frac{Y_{pq}}{\omega^2} + \sum_{r=r_a}^{r_b} \frac{B_{pqr}}{1-\left(\frac{\omega}{\omega_r}\right)2 + J2\zeta\left(\frac{\omega}{\omega_r}\right)} + Z_{pq} \tag{21}$$

where

$$B_{pqr} = \text{modal compliance} = \frac{\text{displacement output}}{\text{force input}}$$

Many of the parameter estimation techniques that are used will assume that only one mode exists in the range of interest and all of the other modes appear as residual terms. For this case Equation 14 can be rewritten as:

$$\frac{X_p}{F_q} = -\frac{Y'_{pq}}{\omega^2} + \frac{A_{pq}}{j\omega - s} + \frac{A^*_{pq}}{j\omega - s^*} + Z'_{pq} \tag{22}$$

or for the case of proportional damping as:

$$\frac{X_p}{F_q} = -\frac{Y'_{pq}}{\omega^2} + \frac{B_{pq}}{1-\left(\frac{\omega}{\omega_r}\right)^2 + j2\zeta_r\left(\frac{\omega}{\omega_r}\right)} + Z'_{pq} \tag{23}$$

Several of the curve fitting cases which will be discussed utilize the unit impulse response of the system. The unit impulse response is the Fourier transform of the frequency response. Therefore, a mathematical expression for the unit impulse response can be obtained by a Fourier transform of Equation 13:

$$h_{pq}(t) = \sum_{r=1}^{\infty} \left[A_{pqr} e^{s_r t} + A^{*}_{pqr} e^{s^{*}_r t} \right] \tag{24}$$

The remainder of this discussion in this report will involve experimentally determining the modal parameters by using a parameter estimation technique based on one of the expressions presented in this section.

For cases where single degree of freedom approximations do not give satisfactory answers, the modal parameters can be determined directly by curve fitting either Equation 17 to frequency response information or Equation 24 to unit impulse information. Due to the nonlinear nature of these two equations, the parameter estimation schemes are difficult to implement. In this section several different multiple degree of freedom algorithms will be presented.

Frequency Domain Algorithms - The multiple degree of freedom frequency domain algorithms presented are some of the techniques that are currently being developed. The most promising algorithms solve Equation 17 in a least squares sense.

Restating Equation 17:

$$\frac{X_p}{F_q} = -\frac{Y_{pq}}{\omega^2} + Z_{pq}$$

$$+ \sum_{r=r_a}^{r_b} \left[\frac{U_{pqr} + jV_{pqr}}{-\delta_r + j(\omega - \omega_{pr})} + \frac{U_{pqr} - jV_{pqr}}{-\delta_r + j(\omega + \omega_{pr})} \right] \tag{25}$$

This equation contains 4n+2 unknown parameters: δr, ω_{dr}, U_{pqr}, V_{pqr} for each of n modes in the frequency range of interest, and two parameters Y_{pq} and Z_{pq} to handle the residual contribution of lower and higher modes. It is obvious

that the equation could be solved given 4n+2 pieces of information, but it would not be wise to do so, because measurement errors would usually cause the solution to be useless. In fact, the equations are nonlinear in δ_r and ω_{dr}, which means that an iterative solution is necessary. Getting a solution of this form to converge to a unique answer in the presence of noise would be very difficult. In order to handle the noise problem, a least squares solution can be used.

Let G represent the experimentally determined frequency response, and H represent the mathematical model Equation 5. The data varies only with frequency, and is known at M frequencies:

$$\left(\frac{Xp}{Fq}\right)_{experimental} = G(f) \qquad f=f_1, f_2, \ldots f_m$$

The model depends not only on frequency, but also on the modal parameters, which will be represented by the 4n+2 components, γ_i, of a vector γ :

$$\left(\frac{\frac{Xp}{Xp}}{Fq}\right)_{model} = H(f, \gamma) = H(f, \gamma 1, \ldots, \gamma 4n+2)$$

The error in the fit at frequency f_k is

$$E_k(\gamma) = G(f_k) - H(f_k, \gamma) \tag{26}$$

and the functional to be minimized for the least squares process is

$$E_t = \sum_{k=1}^{M} E_k(\gamma) E_k^*(\gamma) = \sum_{k=1}^{M} \|E_k(\gamma)\|^2 \tag{27}$$

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If the derivatives of this error functional with respect to the unkown variables γ_i are set to zero, then there are 4n+2 equations available to determine the unknowns:

$$\sum_{k=1}^{M}\left[E_k^* \frac{\partial H}{\partial \gamma_i}(f_k, \gamma) + E_k \frac{\partial H^*}{\partial \gamma_i}(f_k, \gamma)\right] = 0 \qquad (28)$$

These equations are nonlinear in δ_r and ω_{dr}, and so a solution must be found by an iterative aproximation, starting from initial values for δ_r and ω_{dr}. This means calculating a $\Delta\delta_r$ and $\Delta\omega_{dr}$ for each interaction step. The iteration can be stopped when the process has converged.

Equations 28 can be used in two different ways:

1. A linear least squares method calculating 2n+2 parameters (U_{pqr}, V_{pqr}, Y_{pq}, Z_{pq}), starting with fixed values of δ_r and ω_{dr} that are determined by some other method, and which are constant throughout the solution, or

2. An iterative least squares for all of the modal parameters.

Some details of an algorithm with both solution possibilities are given in Reference 208. This program has been implemented in minicomputer based Fourier analyzers, so that the parameter estimation process can be controlled interactively. If the eigenvalues are not fixed, the solution is best done interactively since the solution will frequently diverge if the starting estimates for the eigenvalues are poorly chosen. The program has a built-in algorithm to recognize a divergent condition and will eliminate the diverging mode and try to continue the solution to convergence using the remaining modes.

Linear Least Squares Algorithm for Residues - If the eigenvalues are known or can be chosen, then the eigenvectors (modal coefficients) can be determined directly, because Equations 28 reduces to a set of linear simultaneous equations. Since the solution is based on a least squares development, the data can be weighted to optimize the results. The type of weighting that should be used depends on the characteristics of the measurement. For example, for very lightly damped data, it is desirable to weight the off-resonance data. The reason for this is that the amplitude is sharply peaked at the resonance, and hence the most significant errors due to "leakage" and nonlinearity will occur at or near the resonances. Data near weak resonances may be more heavily weighted to help extract those modes. Areas of low coherence between input forces and output response should be weighted very lightly.

It is important to include local modes in those measurements where they are active. A local mode is a mode for which the modal displacement is nearly zero at all points on the structure except in a very small region. (The first bending mode of a flagpole on a battleship, for example.)

The least squares modal coefficient calculation is very straightforward and will normally give a solution if a good set of eigenvalues have been determined. The eigenvalues are usually considered to be global properties of the structure, and should therefore be independent of the choice of the measurement point. Variation of the eigenvalues from point to point can be caused by measurement problems or nonlinearities in the structure. On linear structures, the assumption that the eigenvalues are global properties is valid, and this condition can be enforced in the parameter estimation scheme. If the curve fitting process allows

the eigenvalues to change with measurement location, they may vary due to noise, measurement errors, and nonlinearities, and will give confusing results.

It is important, therefore, to be able to obtain a set of global eigenvalues for the structure being analyzed if good modal coefficients are to be estimated using this approach. This normally requires that a good estimate of the number of degrees of freedom be obtained. Also good measurement techniques must be used in order to prevent the eigenvalues from changing as a function of measurement process.

Linearized Least Squares Algorithm for all Modal Parameters - For cases where it is not possible to test the structure so that the eigenvalues remain constant, it is necessary to allow the eigenvalues to change as a function of the measurement position. For example, when a very light structure is tested using transducers with significant mass, the eigenvalues change as the transducers are moved around on the structure, because of mass-loading of the structure. If the eigenvalues are allowed to change, there are 4n+2 unknown parameters in the curve fitting process. From statistical considerations, as the degrees of freedom increase the amount of data that is necessary to obtain the same confidence levels on the estimated parameters likewise increases.

The Gauss-Newton procedure is used to linearize the estimation process. Equation 17 is expanded in terms of a Taylor series, and then the higher-order terms are neglected, using the assumption that the changes in the parameters from their initial (or "starting") values will be small. The result is:

$$H(f,\gamma) = H(f, \gamma_{sv}) + \sum_{i=1}^{4n+2} \frac{\partial H}{\partial \gamma_i}(f, \gamma_{sv})\Delta\gamma_i \qquad (29)$$

where γ_{sv} = vector of starting values of the modal parameters, and $\Delta\gamma_i = \gamma_i - (\gamma_i)_{sv}$ = the change in the i-th parameter.

The error at frequency f_k is now

$$E_k(\gamma) = G(f_k) - H(f_k,\gamma_{sv}) - \sum_{i=1}^{4n+2} \frac{\partial H}{\partial \gamma_i}(f, \gamma_{sv}) \Delta\gamma_i \qquad (30)$$

which is linear in all of the parameters γ_i, because γ_{sv} is a constant vector. The derivatives of H with respect to γ_i are created by a formal differentiation of Equation 17, and are evaluated at γ_{sv}. The results are functions of only frequency:

$$\beta_i(f) = \frac{\partial H}{\partial \gamma_i}(f, \gamma_{sv})$$

so the functional to be minimized is

$$E_t = \sum_{k=1}^{M} \| G(f_k) - H(f_{kr}\,\gamma_{sv}) - \sum_{i=1}^{4n+2} \beta_i(f_k)\,\Delta\gamma_i \|^2 \qquad (31)$$

By equating to zero the derivatives of E_t with respect to γ_i, the results are linear equations for the values of $\Delta\gamma_i$. These are solved at each iteration step, and the "starting" values vector is updated,

$$(\gamma_{sv})_{new} = (\gamma_{sv})_{old} + \Delta\gamma \qquad (32)$$

in preparation for the next iteration. The iteration is stopped if the least squares error, σ, satisfies the criteria:

$$0.99\sigma_{old} < \sigma_{new} < 1.01\sigma \text{ old} \qquad (33)$$

The iteration procedure is constructed so that any of the eigenvalues can be fixed and the remaining parameters iterated. If any one mode starts to diverge, it can be fixed at the starting value or dropped from the list of eigenvalues. The most common form of divergence is for one mode (which typically has a very small modal coefficient) to start to diverge. If this is allowed to continue, the complete process will diverge.

It is important for the nonlinear solution to have a very good set of starting values and for the data to have minimum distortion due to measurement errors (such as "leakage" errors associated with the Fourier transform (12, 13)).

Time Domain Multiple Degree of Freedom Algorithm - In the time domain the unit impulse response of the viscous-damped linear system is given by Equation 34. Experimentally, the unit impulse can be determined by measuring the frequency response and computing the inverse Fourier transform.

$$h_{pq}(t) = 2\,Re\left\{\sum_{r=1}^{n} (U_{pqr} + jV_{pqr})e^{(\delta_r + j\omega_{dr})t}\right\} \qquad (34)$$

In this equation, the unit impulse is described in terms of 4n unknown parameters. The equation is nonlinear in terms of δ_r and ω_{dr}. The Complex Exponential algorithm and the least squares Complex Exponential algorithm can be used to solve for the four parameters of each mode.

Complex Exponential Algorithm - A collocation solution to the parameter estimation problem is developed in Reference 228. The solution technique is referred to as the Complex Exponential algorithm and uses the Prony method of solution. It should be noted that 4n pieces of information are used to determine the 4n unknowns. The equations are nonlinear and an iteration process is used to obtain a solution.

The Complex Exponential algorithm will compute the A_{pqr} and S_r to fit the unit impulse response h_{pq} as given in Equation 34. Since the equation is nonlinear in S_r, the values of S_r are determined by an iterative procedure. The equations are linear in the parameter A_{pqr}, so these coefficients are determined by solving a standard system of linear simultaneous equations.

This algorithm is a collocation parameter estimation technique; there are 4n degrees of freedom, and it uses 4n samples of h_{pq}. In other words, there is no smoothing involved in the estimation process, as there is in a least squares algorithm. Most collocation estimation routines will diverge if the form of the data does not satisfy the assumed model. Due to numerical limitations, the Complex Exponential algorithm tends to compensate for this deviation and will

give a reasonable fit even if it cannot match the underlying form of the actual data. In other words, numerical errors in the calculation prevent the solution from passing exactly through the data points, with the result that the solution process is relatively robust.

When the impulse response function is sampled at equally-spaced instants in time, Equation 34 can be rewritten as:

$$h_{pq}(t_k) = \sum_{r=1}^{N} \left[A_{pqr} \, e^{s_r kT} + A_{pqr}^* \, e^{s_r^* kT} \right] \tag{35}$$

or

$$h_{pq}(t_k) = \sum_{r=1}^{N} \left[A_{pqr} \, X_r^k + A_{pqr}^* \, (X_r^*)^k \right] \tag{36}$$

where

    N = *number of nodes in the frequency range* (0, 1/2T),

    T = sampling interval,

$$X_r = e^{s_r T} \tag{37}$$

Now, h_{pq} is a real valued function; that is:

$$h_{pq}(t_k) = 2Re \left\{ \sum_{r=1}^{N} A_{pqr} \, X_r^k \right\} \tag{38}$$

A collocation solution to the set of equations obtained from Equation 38 for different values of t_k can be found using Prony's method. A new set of real-valued unknowns a_i $i = {2N \atop 0}$ are introduced which are the coefficients of the terms in the polynomial equation

$$\prod_{r=1}^{N} (X - X_r)(X - X_r^*) = \sum_{k=0}^{2N} a_k X^k = 0 \tag{39}$$

The 2N roots of Equation 39 are the complex exponentials $e^{S_r T}$ and the coefficients a_k are called the autoregression coefficients of the assumed model in Equation 35.

Multiplying Equation 38 by the coefficients a_k and adding the equations (we suppress the subscripts p and q on h and A):

$$a_0 h (t_{m+0}) = 2a_0 \operatorname{Re}\left(\Sigma A_r X_r^{m+0}\right)$$
$$a_1 h (t_{m+1}) = 2a_1 \operatorname{Re}\left(\Sigma A_r X_r^{m+1}\right)$$
$$a_2 h (t_{m+2}) = 2a_2 \operatorname{Re}\left(\Sigma A_r X_r^{m+2}\right)$$
$$\vdots \qquad \vdots$$
$$a_k h (t_{m+k}) = 2a_k \operatorname{Re}\left(\Sigma A_r X_r^{m+k}\right)$$
$$\vdots \qquad \vdots$$
$$a_{2N} h (t_{m+2N}) = 2a_{2N} \operatorname{Re}\left(\Sigma A_r X_r^{m+2N}\right)$$

$$\overline{\sum_{k=0}^{2N} a_k h (t_{m+k}) = 2 \sum_{k=0}^{2N} a_k \operatorname{Re}\left(\sum_{r=1}^{N} A_r X_r^{m+k}\right)}$$

$$= \operatorname{Re}\left(\sum_{r=1}^{N} A_r X_r^{m} \left(2 \sum_{k=0}^{2N} a_k X_r^{k}\right)\right)$$

According to equation 39, this last term must be zero, so:

$$\sum_{k=0}^{2N} a_k h\,(t_{m+k}) = 0 \quad \text{for } m = 0,1,2,\ldots \tag{40}$$

This equation indicates that there are only 2N linearly independent amplitudes in the sampled impulse response. If the autoregression coefficients are normalized by choosing $a_{2N} = 1$, then

$$\sum_{k=0}^{2N-1} a_k h\,(t_{m+k}) = -h(t_{m+2N}) \tag{41}$$

Therefore there are 2N linear equations which can be written for the variables a_k, and these are computed directly from the measured unit impulse response. In practice, the values of m that are used are typically $0 \leqslant m < 2N$, but any set of 2N can be used. Having solved for the a_k, the roots of Equation 39 can be found using an iterative polynomial solver, and the eigenvalues can be determined from Equation 37.

Once the eigenvalues are determined, the resulting modal coefficients (residue terms) can be calculated from the following relation:

$$\sum_{r=0}^{N} \left[A_{pqr} X_r^k + A^*_{pqr} \left(X_r^* \right)^k \right] = h\left(t_k \right) \tag{42}$$

These equations are linear in the values of A_{pqr}, as in the case of the previous frequency domain solution.

Equations 41 and 42 involve Toeplitz and Van der Monde matrix forms, which can be solved in a much more convenient manner than standard simultaneous linear equation techniques, such as Gauss elimination. Expanding Equation 41 in matrix form (here the typical selections for m are used):

$$
\begin{bmatrix}
h(t_{2N-1}) & h(t_{2N}) & h(t_{2N+1}) & \ldots & h(t_{4N-2}) \\
h(t_{2N-2}) & h(t_{2N-1}) & h(t_{2N}) & \ldots & h(t_{4N-3}) \\
h(t_{2N-3}) & h(t_{2N-2}) & h(t_{2N-1}) & \cdots & h(t_{4N-4}) \\
\vdots & \vdots & \vdots & & \vdots \\
h(t_0) & h(t_1) & h(t_2) & \ldots & h(t_{2N-1})
\end{bmatrix}
\begin{bmatrix}
a_0 \\
a_1 \\
a_2 \\
\vdots \\
a_{2N-1}
\end{bmatrix}
=
\begin{bmatrix}
h(t_{4N-1}) \\
h(t_{4N-2}) \\
h(t_{4N-3}) \\
\vdots \\
h(t_{2N})
\end{bmatrix}
\tag{43}
$$

Both the Toeplitz coefficient matrix and the constant vector are composed of the unit impulse response. The last row of the coefficient matrix is the initial portion of the unit impulse response. The next to last row is the unit impulse shifted one sampling interval later in time, and so on. As a result of the shifting, the elements of the matrix are identical along any descending-to-the-right diagonal. The Toeplitz matrix solution can be accomplished in computer memory space on the order of N locations versus N squared, and a computation time on the order of N squared versus N cubed, compared to a standard matrix solution.

The Van der Monde matrix equation is derived from Equation 42. In expanded form
it is

$$
\begin{bmatrix}
1 & 1 & 1 & \cdots & 1 \\
X_1 & X_2 & X_3 & \cdots & X_N \\
X_1^2 & X_2^2 & X_3^2 & \cdots & X_N^2 \\
\vdots & \vdots & \vdots & & \vdots \\
X_1^{N-1} & X_2^{N-1} & X_3^{N-1} & \cdots & X_N^{N-1}
\end{bmatrix}
\begin{bmatrix}
A_{pqi} \\
A_{pq2} \\
A_{pq3} \\
\vdots \\
A_{pqN}
\end{bmatrix}
\begin{bmatrix}
h(t_0) \\
h(t_1) \\
h(t_2) \\
\vdots \\
h(t_{N-1})
\end{bmatrix}
$$

In this case each row in the matrix is a higher power of the same components as in
the previous row. It also can be solved in much less time, with less computer
memory, than the general case. The details of the Complex Exponential algorithm
can be found in Reference 228.

The Complex Exponential algorithm has the advantage that the nonlinear solution
for the eigenvalues is computationally straightforward. Once the eigenvalues
have been estimated, the modal coefficients can be directly determined, as was
the case with the frequency domain solution. Since it requires no starting
values, it is easy to use and is a completely "blind" technique. In order to
obtain a solution, it is only necessary to supply the algorithm with the impulse
response function and the expected number of modes to be found in the data.

One of the major problems with this technique is that of determining the number
of modes in the data. For systems with light damping and widely spaced modes,
the most convenient method for estimating the number of modes from the measured
frequency response data is by a visual inspection. Of course, data of this type

can be very conveniently analyzed using one of the simpler single degree of freedom techniques. For closely coupled systems with high modal density, it is difficult to estimate the number of degrees of freedom visually. Another complicating factor is that the algorithm needs extra degrees of freedom ("computational" modes) to compensate for noise or distortion in the data. A good rule, based upon experience, is to input one and one-half times the number of modes that are expected.

A second characteristic of the algorithm is that a nonuniform distribution of modes across the frequency range causes the program to miss modes in the areas of high modal density. For this case, it will calculate "computational" modes in areas of low modal density, and not enough modes in the areas of high modal density. If a larger number of modes is specified, the algorithm will eventually find the desired number of modes in the areas of high density, but will compute a large number of "computational" modes. Sometimes it is difficult to separate the real modes from the "computational" modes. The best way to minimize this problem is to use a zoom Fourier transform to measure the frequency response in the regions of high modal density, and then use the Complex Exponential algorithm on the banded frequency response data.

Zoom Fourier transform data can be handled very conveniently with the Complex Exponential algorithm by Fourier-transforming the banded frequency response data into the time domain. The resulting filtered impulse response can be fitted with the Complex Exponential algorithm. In this case the frequencies computed by the algorithm are shifted by the frequency at the beginning of the zoom range (Figure 31). The zoom Fourier transform also helps to reduce distortion errors in the

frequency response measurement due to "leakage", which is a rather significant source of error with the Complex Exponential algorithm.

Mathematically, there is a rather straightforward way to determine the number of modes in a measurement when using the Complex Exponential algorithm. It consists of determining the rank of the coefficient matrix used in calculating the eigenvalues. This can be done by varying the number of potential modes and computing the value of the determinant of the coefficient matrix. Theoretically, when the specified number of modes exceeds the actual number of modes the matrix is singular. If the determinant is evaluated repeatedly for increasing choices of the number of modes, the determinant rapidly falls to zero after the actual number of modes is exceeded. With practical data, noise causes the value of the determinant to decrease gradually, and it typically will never reach exactly zero. Figure 32 shows a schematic diagram of this behavior. It becomes a matter of judgement as to how close the determinant should be to zero. Despite this limitation, the procedure is very useful.

A second method for determining the number of modes involves using different segments of the impulse response to compute the modal coefficients. The variance in the computed modal coefficients can be used to separate the true modes from the "computational" modes.

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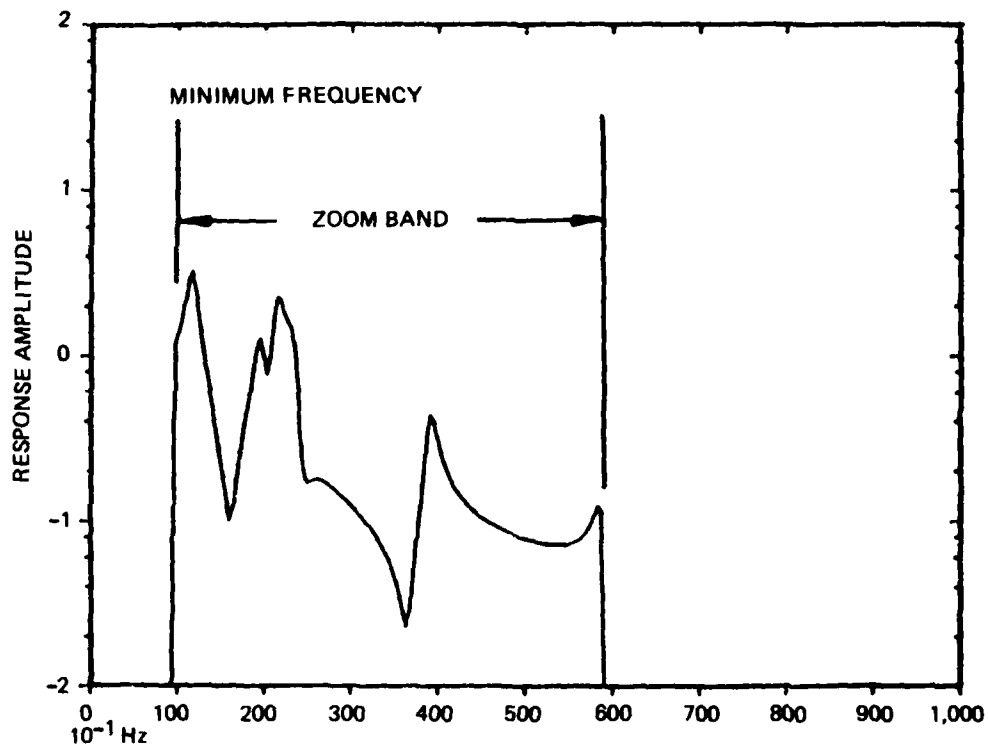
Figure 31. Typical Zoom Frequency Response Measurement
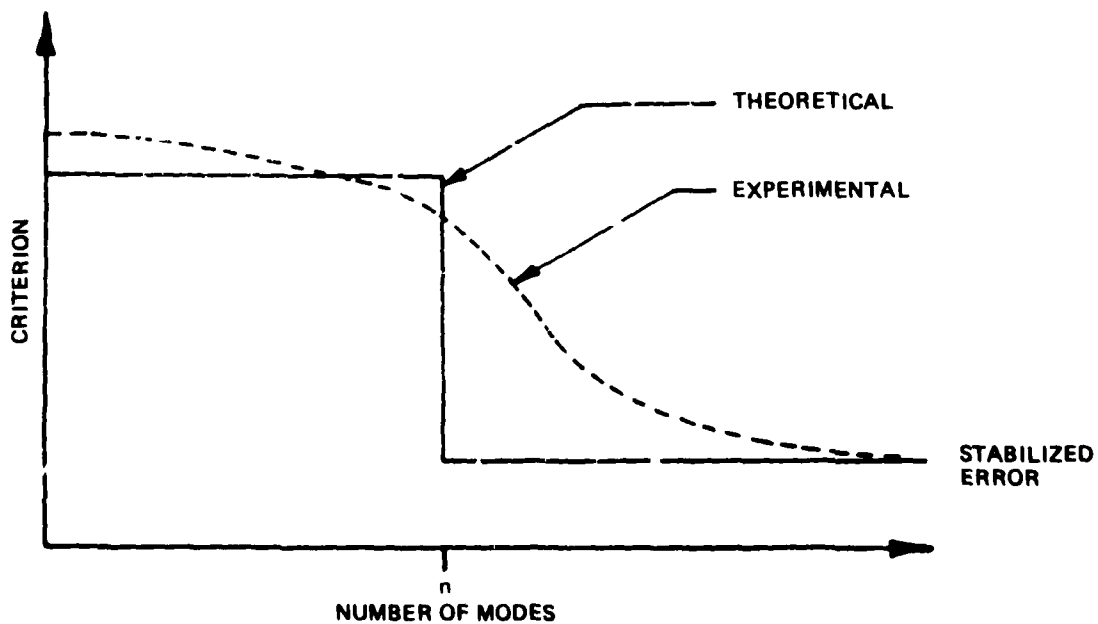
Figure 32. Least Squares Multiple Degree of Freedom Criterion

A significant source of error concerning the use of the Complex Exponential algorithm is the truncation of the frequency response in the frequency domain. A sin(x)/x type of distortion error is induced in the corresponding impulse response. This results in distorted estimates for damping and frequency (Figure 33).

The greatest problem with using the Complex Exponential algorithm for modal parameter estimation is that a new set of eigenvalues is computed for every measurement, when in theory, the eigenvalues are global properties of the structure. It should be noted that for any given measurement there are a number of sets of eigenvalues which can be computed by the Complex Exponential algorithm, depending on the number of degrees of freedom allowed. Any one of these sets will fit the data to within very close limits. From a plot of the curve fit data, it may not be possible to distinguish any difference. The resultant set of data that will be computed depends on small differences in the measured data due to noise or distortion. The variation between the computed modal coefficients can easily exceed 30%, while the fit to the frequency response may be within 1%. An example of this is shown in Figure 34.

In summary, the Complex Exponential algorithm is a very simple technique to use. It does an exceptional job of fitting any individual measurement, but because it can compute different eignevalues for each measurement, it has limited applicability for modal measurements. It is also rather sensitive to noise since it has no inherent smoothing. For single measurements it works very well, so it appears to be generally useful for single-input and single-output systems.

a) FREQUENCY RESPONSE

b) UNIT IMPULSE RESPONSE

c) FREQUENCY DOMAIN WEIGHTING

d) IMPULSE RESPONSE OF WEIGHTING WINDOW

e) TRUNCATED FREQUENCY RESPONSE

f) MODIFIED UNIT IMPULSE RESPONSE
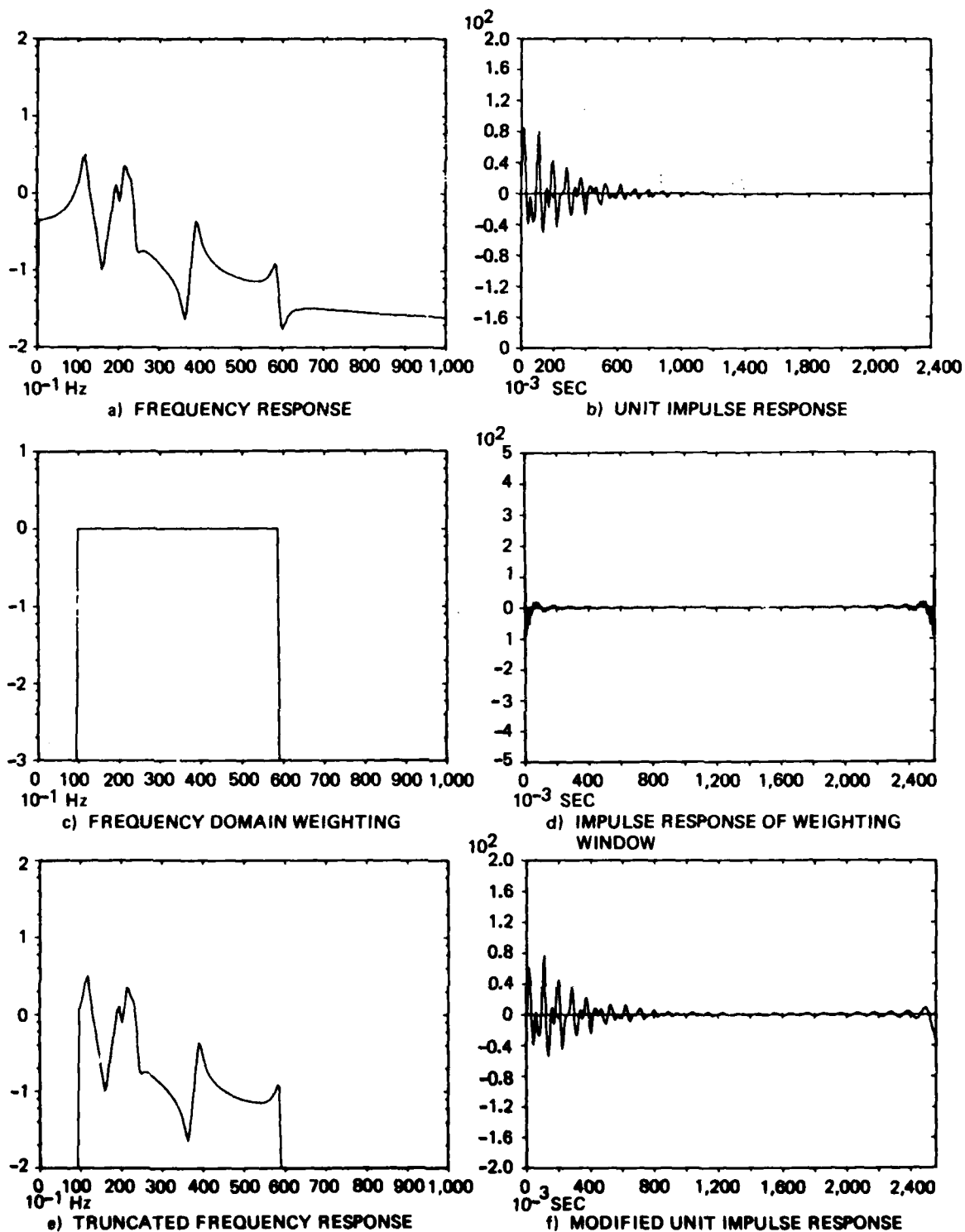
Figure 33. Use of the Complex Exponential Algorithm

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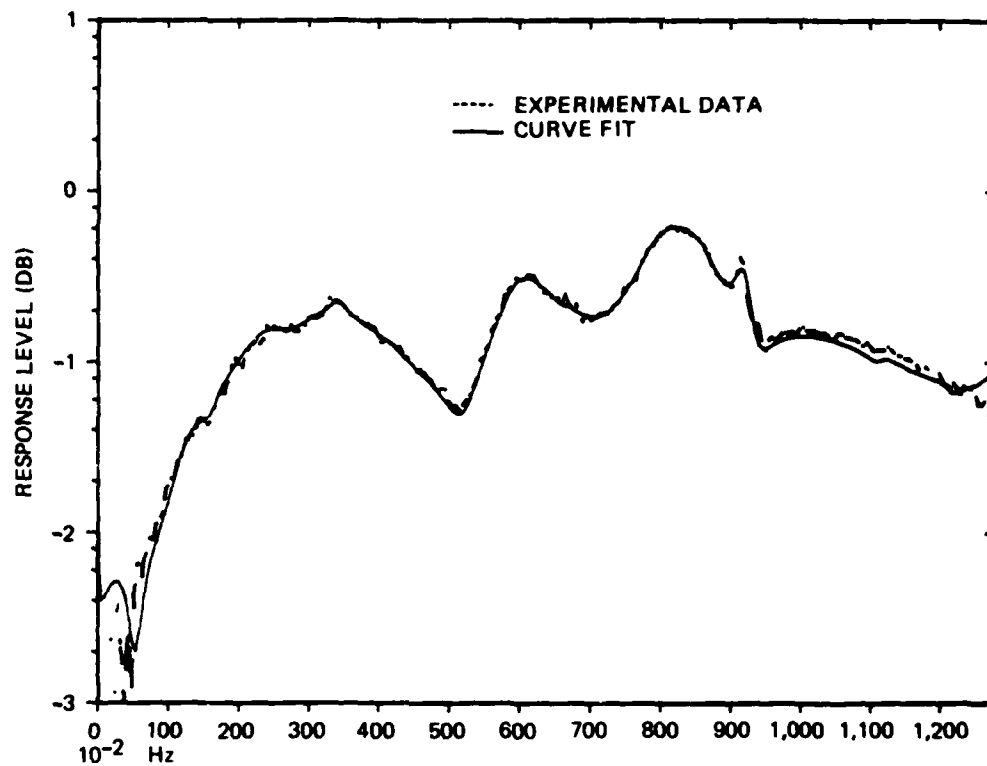
a) COMPARISON OF EXPERIMENTAL DATA AND CURVE FIT DATA
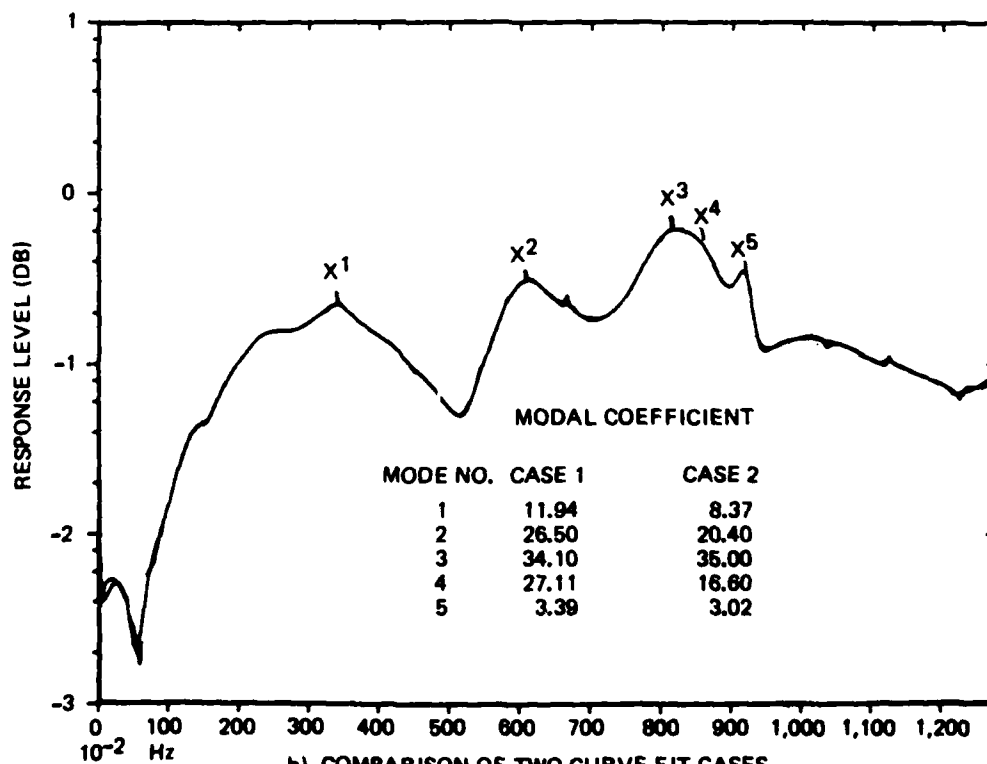
b) COMPARISON OF TWO CURVE FIT CASES

MODE NO.	CASE 1	CASE 2
1	11.94	8.37
2	26.50	20.40
3	34.10	35.00
4	27.11	16.60
5	3.39	3.02

MODAL COEFFICIENT

Figure 34. Curve Fitting Comparison Using the Complex Exponential Algorithm

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Least Squares Complex Exponential Algorithm - The Prony algorithm used in the Complex Exponential Algorithm can be replaced by a least squares method. As usual, we write the sum of the squares of the errors, differentiate with respect to the parameters, and set the result to zero, in order to find the values of the parameters which minimize the sum. From Equation 41, the error in the fit for the m-th equation is:

$$E_m^2 = [\sum_{K=0}^{2N-1} a_k h\,(t_{m+k}) + h\,(t_{m+2N})]^2 \tag{44}$$

and thus the total error is

$$E = \sum_{m=1}^{M} E_m^2 \tag{45}$$

where M is the number of equations that are used in the fit. The derivatives are given by

$$\frac{\partial E}{\partial a_i} = 0 = \sum_{m=1}^{M} h\,(t_{mti})\,[\sum_{k=0}^{2N-1} a_k h\,(t_{m+k}) + h\,(t_{m+2N})] \tag{46}$$

or

$$\sum_{k=0}^{2N-1} a_k\,[\sum_{m=1}^{M} h\,(t_{m+i})\,h\,(t_{m+k})] + \sum_{m=1}^{M} h\,(t_{m+i})\,h\,(t_{m+2N}) = 0 \tag{47}$$

Making the substitution

$$R_{i,k} = \sum_{m=1}^{M} h\,(t_{m+i})\,h\,(t_{m+k}) \tag{48}$$

the resulting equations are

$$\sum_{k=0}^{2N-1} R_{i,k} a_k = -R_{i,2N} \tag{49}$$

or in matrix form,

$$
\begin{bmatrix}
R_{0,0} & R_{0,1} & R_{0,2} & \cdots & R_{0,2N-1} \\
R_{1,0} & R_{1,1} & R_{1,2} & \cdots & R_{1,2N-1} \\
R_{2,0} & R_{2,1} & R_{2,2} & \cdots & R_{2,2N-1} \\
\vdots & \vdots & \vdots & & \vdots \\
R_{2N-1,0} & R_{2N-1,1} & R_{2N-1,2} & \cdots & R_{2N-1,2N-1}
\end{bmatrix}
\begin{bmatrix}
a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_{2N-1}
\end{bmatrix}
= -
\begin{bmatrix}
R_{0,2N} \\ R_{1,2N} \\ R_{2,2N} \\ \vdots \\ R_{2N-1,2N}
\end{bmatrix}
\tag{50}
$$

When M becomes very large, the values of $R_{i,k}$ are approximately equal to the values of the autocorrelation function R_{hh} (i-k). Here the lag value (i-k) is the true lag value divided by the sampling interval, T. Because the auto-correlation function is even, that is,

$$R_{hh}\,(i\text{-}k) = R_{hh}\,(k\text{-}i) \tag{51}$$

the equations can be expressed in terms of the autocorrelation function as

$$
\begin{bmatrix}
R_{hh}(0) & R_{hh}(1) & R_{hh}(2) & \cdots & R_{hh}(2N-1) \\
R_{hh}(1) & R_{hh}(0) & R_{hh}(1) & \cdots & R_{hh}(2N-2) \\
R_{hh}(2) & R_{hh}(1) & R_{hh}(0) & \cdots & R_{hh}(2N-3) \\
\vdots & \vdots & \vdots & & \vdots \\
R(2N-1) & R(2N-2) & R(2N-3) & \cdots & R_{hh}(0)
\end{bmatrix}
\begin{bmatrix}
a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_{2N-1}
\end{bmatrix}
= -
\begin{bmatrix}
R_{hh}(2N) \\ R_{hh}(2N-1) \\ R_{hh}(2N-2) \\ \vdots \\ R_{hh}(1)
\end{bmatrix}
\tag{52}
$$

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The least squares residues (modal coefficients) can be computed from the unit impulse response as follows. From Equation 42, the unit impulse response can be written in terms of sine and cosine functions. Assuming that the mean value of h_{pq} is zero.

$$h_{pq}(t_k) = 2 \sum_{r=1}^{N} e^{\delta_r t_k} [U_{pqr} \cos(\omega_{pr} t_k) + V_{pqr} \sin(\omega_{pr} t_k)] \tag{53}$$

The error in the fit to the k-th point of the impulse response is chosen as the discrepancy between this model and the data, g_k, for $k = 0,1,2,\ldots,M$:

$$E_k = g_k - h_{pq}(t_k) \tag{54}$$

and the total error functional associated with the fit of M samples is

$$E = \sum_{k=1}^{M} [g_k - \sum_{r=1}^{N} (C_{rk} U_{pqr} - S_{rk} V_{pqr})]^2 \tag{55}$$

where the notation $\quad C_{ik} = e^{\delta_i t_k} \cos(\omega_{di} t_k) \quad S_{ik} = e^{\delta_i t_k} \sin(\omega_{di} t_k)$
was used

$$\frac{\partial E}{\partial U_{pqi}} = \sum_{k=1}^{M} C_{ik} [g_k - 2 \sum_{r=1}^{N} (C_{rk} U_{pqr} - S_{rk} V_{pqr})] \tag{56a}$$

$$\frac{\partial E}{\partial V_{pqi}} = \sum_{k=1}^{M} S_{ik} [g_k - 2 \sum_{r=1}^{N} (C_{rk} U_{pqr} - S_{rk} V_{pqr})] \tag{56b}$$

Let

$$A_{ir} = \sum_{k=1}^{M} C_{ik} C_{rk} \qquad B_{ir} = \sum_{k=1}^{M} S_{ik} S_{rk}$$

$$D_{ir} = -\sum_{k=1}^{M} C_{ik} S_{rk} \qquad X_i = \sum_{k=1}^{M} C_{ik} g_k$$

$$Y_i = -\sum_{k=1}^{M} S_{ik} g_k \qquad U_i = U_{pqi} \quad V_i = V_{pqi}$$

Then the matrix form of the equations for the residues is

$$\begin{bmatrix} A & D \\ D^T & B \end{bmatrix} \begin{bmatrix} U \\ V \end{bmatrix} = \begin{bmatrix} X \\ Y \end{bmatrix}$$

(57)

where A, B, and D are N x N submatrices, U_{pq} , V_{pq} , X, and Y are N x 1 column vectors, and D^T is the transpose of D. The formal solution for the real and imaginary components of the modal coefficients is

(58)

$$\begin{bmatrix} U \\ V \end{bmatrix} = \begin{bmatrix} A & D \\ D^T & B \end{bmatrix}^{-1} \begin{bmatrix} X \\ Y \end{bmatrix}$$

There is an approximate solution

$$U_{pqr} = X_r / A_{rr} \qquad V_{pqr} = Y_r / B_{rr}$$

(59 a,b)

which is valid when the diagonal terms, compared to the off-diagonal terms, are very large in the coefficient matrices A and B, and the elements of D are small.

The major advantage of the least squares version of the Complex Exponential algorithm is that it has least squares elimination of noise. Like all least squares techniques the data can be weighted so that the parameter estimation will favor the strongly weighted data. For cases where the testing procedures generate eigenvalues which can be considered global properties of the structure, this algorithm can be used to determine a weighted least squares estimate of the eigenvalues. All of the measurements can be used, or any selected combination of measurements. It can be used to determine overall system modes, or it can be used on any subset of the measurements to estimate local modes.

The least squares version of the Complex Exponential algorithm has the same problems as the ordinary Complex Exponential algorithm. It is difficult to estimate the number of modes to input into the algorithm. Again the rank of the matrix given in Equation 50 can be used to estimate the number of independent modes in the data, as can the least squares error function. The least squares error is large when too few modes are assumed in the solution, and reduces to some small value determined by the numerical noise when too many modes are assumed. A schematic plot of the error as a function of the number of assumed modes is shown in Figure 32. As can be seen from this figure, for actual data the curve gradually approaches the noise floor, and it is a judgement to specify the optimum number of modes. In Figure 35 the least squares error is shown as a function of the number of assumed modes for a typical structure.

```
DOF  2   ERROR =   .131646E+00  @**********************************    @
DOF  3   ERROR =   .849838E-01  @*********************************     @
DOF  4   ERROR =   .637487E-01  @********************************      @
DOF  5   ERROR =   .381210E-01  @*******************************       @
DOF  6   ERROR =   .333203E-01  @******************************        @
DOF  7   ERROR =   .206978E-01  @*****************************         @
DOF  8   ERROR =   .136885E-01  @****************************          @
DOF  9   ERROR =   .586078E-02  @***************************           @
DOF 10   ERROR =   .457281E-02  @**************************            @
DOF 11   ERROR =   .264529E-02  @*************************             @
DOF 12   ERROR =   .203324E-02  @************************              @
DOF 13   ERROR =   .629060E-03  @***********************               @
DOF 14   ERROR =   .345465E-03  @**********************                @
DOF 15   ERROR =   .318746E-03  @**********************                @
DOF 16   ERROR =   .291623E-03  @**********************                @
DOF 17   ERROR =   .246767E-03  @**********************                @
DOF 18   ERROR =   .184763E-03  @********************                  @
DOF 19   ERROR =   .134928E-03  @********************                  @
DOF 20   ERROR =   .157361E-03  @*********************                 @
DOF 21   ERROR =   .146148E-03  @*********************                 @
DOF 22   ERROR =   .144245E-03  @*********************                 @
DOF 23   ERROR =   .132823E-03  @*********************                 @
DOF 24   ERROR =   .991931E-04  @********************                  @
DOF 25   ERROR =   .716190E-04  @*******************                   @
DOF 26   ERROR =   .642475E-04  @*******************                   @
DOF 27   ERROR =   .555702E-04  @*******************                   @
DOF 28   ERROR =   .512450E-04  @*******************                   @
DOF 29   ERROR =   .425030E-04  @*******************                   @
DOF 30   ERROR =   .427652E-04  @*******************                   @
DOF 31   ERROR =   .485362E-04  @*******************                   @
DOF 32   ERROR =   .434270E-04  @*******************                   @
DOF 33   ERROR =   .411622E-04  @******************                    @
DOF 34   ERROR =   .274866E-04  @*****************                     @
DOF 35   ERROR =   .258191E-04  @*****************                     @
```

Figure 35. Error Output From Algorithm

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In general, the least squares version of the Complex Exponential algorithm does a very good job of generating a set of eigenvalues for a structure. For a given choice of input location (exciter position) a set of eigenvalues will be generated which will do an excellent job of fitting all of the measurements taken with the exciter position. A different exciter position may generate a different set of eigenvalues and eigenvectors. At the present time an engineers judgement is required to edit the sets of eigenvectors generated from different exciter positions into a consistent set which can be used to describe the structural characteristics of the system being analyzed.

Mode Enhancement

Enhancement of one mode in a frequency range may be accomplished by a technique that is based on the same principle as the generation of normal modes for the multiple-exciter sine test. A forced-response function is created by computing a linear combination of a set of frequency response functions that have either a common response location or a common exciter location. The coefficients of this linear combination correspond to a forcing vector applied to the structure at the varying locations associated with the set of frequency response functions used. If the variation is in the exciter location, this correspondence is direct; if the variation is in the response locations, then the correspondence depends on the validity of assuming that the structure has a symmetric frequency response function matrix (that is, that Maxwell-Betti reciprocity is true for the structure).

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When the vector composed of the coefficients of the linear combination (the pseudo-forcing vector) is approximately equal to the components of the mode shape for the mode to be enhanced, the mode of interest is "excited" more strongly than the other modes, and the forced-response function appears much more like a frequency response function of a structure having a single degree of freedom.

Figure 36 shows a typical measurement from a test executed under adverse conditions for measurement of frequency response. Figure 37 shows a forced-response function derived from a set of measurements from that test that enhances one of the modes seen in Figure 36.

For a proper choice of the pseudo-forcing vector, the forced-response function can be used with a curve fitting program to obtain a better determination of a mode's eigenvalue than would be calculated from any of the frequency response functions used in the linear combination. If there are frequency response measurements available for several exciter locations as well as several response locations, then a set of forced-response functions can be computed, using the same pseudo-forcing vector, to calculate mode shape components with greater accuracy.

This enhancement technique requires that the frequency response functions in the linear combination be consistent, in the sense that they all have the same eigenvalue for the mode to be enhanced, and that the pseudo-forcing vector correspond rather closely to the mode shape. If this is not the case, the forced-response function will include distortions that prevent the curve fitting programs from computing a proper eigenvalue. In fact, executing the enhancement

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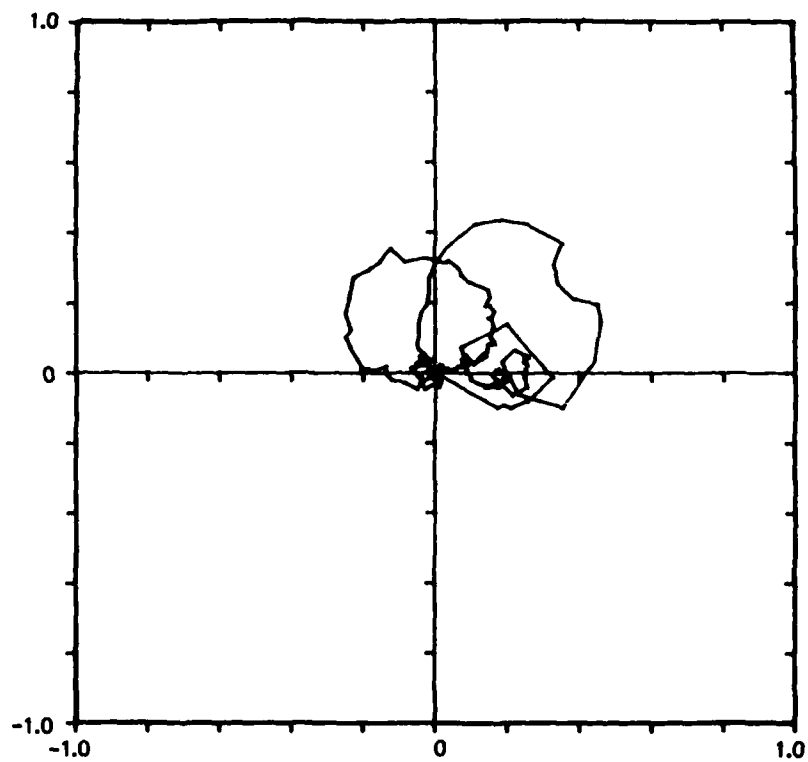
Figure 36. Argand Plane—Typical Measurement
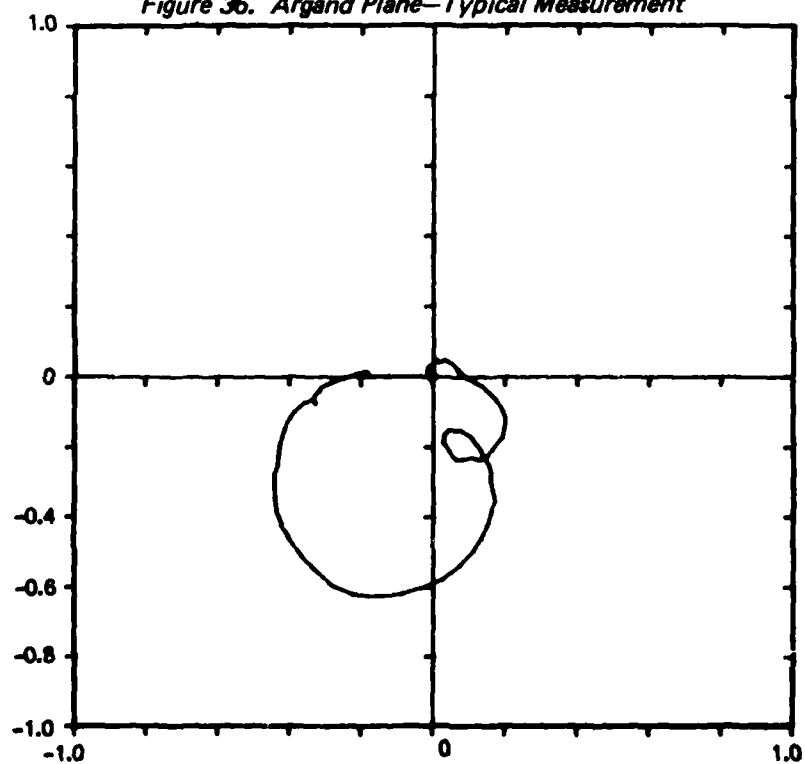
Figure 37. Argand Plane—Enhanced Measurement

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and curve fitting the result provides a check on the validity of the eigenvalue and eigenvector that were obtained directly from the frequency response functions.

For the example shown in Figure 34, the quadrature response was used to generate the pseudo-forcing vector.

3.1.2.3 Mathematical Model Correlation

Correlation between ground vibration test results and mathematical models is meaningful only in the areas of significance of the mathematical model. This applies not only to bandwidth, but also to the area of the airplane under consideration. For example, in a mathematical model for flutter analysis the frequency range of interest on the wing may be 5-15 Hz, that on the vertical tail 10-30 Hz, that on a control surface 40-100Hz and that on a control surface tab 100-200 Hz.

Mathematical Model Comparisons

Mode Shape and Frequency - The most common comparison is on modeshape and frequency. The modeshapes and natural frequencies of the mathematical model are computed. Usually the mathematical model is the free-free airplane; occasionally the free-free model is modified to include the GVT boundary conditions. Generally, unless both frequency and modeshape are quite close the correlation is deemed poor. Poor correlation could be due to errors in mathematical modeling, measurement or modal interpretation of the measurement.

Frequency Response Function - Occasionally frequency response functions of the mathematical model with the GVT boundary conditions are computed. In the comparison of measured with calculated frequency response functions, no modal analysis of the measurement, involving the judgment of the test engineer, is involved. It has the disadvantage that the analysis engineer must make assumptions about damping in his analysis. In this comparison the frequency of significant response peaks and their relative amplitudes must agree well or the comparison is poor. In this case poor correlation is due to errors in mathematical modeling or measurement.

Mathematical Model Revisions

Intuitively Based - Revisions of mathematical models to match test results is nearly always intuitively based. This is an art all of its own, and discussion of it is beyond this report.

Systems Identification - Although considerable research has been expended in identifying point mass, stiffness and damping from GVT data, little of this research has reached application. The principle difficulties seem to be involved with reliability and with handling noise contaminated test data. Work remains to be done in developing rugged, useful systems identification algorithms.

4.0 CONCLUSIONS

4.1 STATE OF THE ART

Recent advances in vibration testing have made it possible to use substantially fewer resources to conduct tests of the same or higher quality than previously. Typically, the application of these advances can reduce cost, reduce time on test, and reduce the number of people involved. The improvements include using computers, improved test equipment, digital systems and developments in vibration testing theory.

Application of the minicomputer to the vibration test has provided the most stunning advance. The minicomputer has made possible automating excitation and data acquisition, data management and on-site or off-line frequency response analysis.

Test equipment has benefited from the recent advances in electronic circuitry design as well as routine design improvements. LSI chips and microprocessors have found application throughout the test systems giving inexpensive, high sensitivity, rugged transducers, and modest cost autoranging amplifiers, analogue to digital and digital to analogue converters, multiplexers and other items. Mechanical design improvements have included readily available off the shelf suspension system components.

Converting the signal format to digital throughout much of the test equipment system has substantially improved dynamic range, improved signal to noise levels and has often reduced equipment cost.

Vibration testing theory advanced when the application of the digital computer and frequency response analysis to vibration testing made practical many concepts heretofore only of academic interest. Vibration testing theory has developed by adapting and expanding upon Fourier Analysis, digital signal processing theory and the theory of random processes.

4.2 RECOMMENDED GVT METHOD

Single Point Excitation/Frequency Response Analysis Method

The recommended method for ground vibration testing is the single point excitation/frequency response analysis methods. Its primary advantages over other methods are that it is more efficient and has the prospect for substantial improvement. In particular, the multipoint excitation/sine dwell method has had many years development and should be considered mature, yet both it and the recommended method give equivalent results. Also, the test time and cost estimates for the recommended method are reliable whereas good estimating of test time and cost for the multipoint excitation/sine dwell method is often quite difficult because of the unpredictability of the effort required in tuning each mode.

5.0 RECOMMENDATIONS

5.1 GROUND VIBRATION TEST METHOD

The recommended ground vibration test method is the single point excitation/ frequency response analysis method. The recommended method is directly applicable as described to whole airplane ground vibration tests. For testing models and components the recommended method, with appropriate adaptations for test article support and size, is applicable. Although the recommended method is currently in use for flight flutter testing, and gives results equally satisfactory to those from other methods, improvement on current practice is needed. Specifically, signal to noise ratios are often poor, particularly when flying in turbulence, and rapid reliable techniques for estimating damping are lacking.

5.2 EQUIPMENT

5.2.1 Digital

The entire signal handling system used in the test should be based on digital equipment to as near to the data capturing sensors as possible. The advantages of going digital are many. Signal quality deterioration downstream of the analogue to digital converter is virtually eliminated, digitally based equipment has become very reasonably priced and computer compatibility of the system is enhanced.

5.2.2 Multiplexer

The multiplexer converts a number of parallel data streams from the transducers into one time division multiplexed signal. It makes possible recording the digital output from a large number of transducers serially on tape or disk. Using a multiplexer is desirable because it substantially increases the efficiency of the data recording system.

5.2.3 Autoranging Amplifier

An autoranging amplifier should be used. A variable gain amplifier is necessary on each signal circuit. Using a piece of hardware which sets its own gains makes the process much more reliable by eliminating a possibility for human error, reduces test time by speeding up the gain setting process and reduces the size of the test crew.

Although autoranging type amplifiers have been available for a long time, recent advances in electronics have resulted in price reductions that have made their use in a GVT practical.

5.2.4 Soft Support System

The use of a soft support system is recommended. In the past soft support systems tended to be costly, difficult to keep functioning well and generally not too successful. The advent of commercial airsprings has changed this. The commercially available airsprings with a servo controlled level and integral damping satisfy the isolation requirements at modest cost.

5.2.5 FFT Computer

The minicomputer incorporating fast Fourier transform capability is an essential item of equipment for testing via the single point excitation/frequency response analysis method. The use of the FFT computer has become practical with the reductions in price for the computer and with the development of software for use on the GVT.

5.3 FURTHER RESEARCH AND DEVELOPMENT

5.3.1 Measures of Confidence

5.3.1.1 Measurement

Currently the quality of the measurements is observed by monitoring the raw signals for all channels on oscilloscopes and by computing frequency response and coherence functions for the reference accelerometer. Although the frequency response and coherence functions are fine measures of measurement quality, they are usually available for only one channel of data. It would be impractical to compute and monitor these functions for all channels. A better approach is needed.

5.3.1.2 Analysis

The modal confidence factor and the modal assurance criteria are fine aids in estimating the quality of curve fit modes. Further work is needed in developing

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methods which can compare a set of curve fit modes with all the frequency response functions from all the excitation points of a test. These methods will probably have to be statistical in nature.

5.3.2 Mathematical Model Correlation Criteria

Current techniques for comparing the test results with a mathematical model are clearly unsatisfactory.

The usual approaches are to compare curve fit modeshapes and frequencies with modeshapes and frequencies computed from the mathematical model. The difficulty comes in accessing the significance of differences between the test and analysis results. E.g., is a 5% difference in second torsion mode natural frequency acceptable? Is 10%? Is 20%?

Two approaches to improve mathematical model correlation seem evident. The first is to base the correlation on frequency response function, not on modeshapes and frequencies. This avoids the most subjective part of the test. The second is that a specific correlation exercise has significance only in terms of the application area intended for the mathematical model. This probably implies a weighting function applied to an error function. An end product of an approach like this could be a rating of the correlation error in terms of the performance criteria involved. An expected result of a correlation exercise like this might be:

Application Area	Correlation Error
Low Altitude Flutter	20 Knots Flutter Speed
High Altitude Flutter	-40 Knots Flutter Speed
Low Speed, Low Altitude Gust	10% Wing Root Bending Moment
Bomb Damage Repair Induced Taxi Loads	-15% Pylon Loads

5.3.3 Curve Fitting Algorithms

5.3.3.1 Algorithm Development

Current curve fitting algorithms require substantial operator intervention and expend much operator time on routine tasks. In addition to automating the routine curve fitting tasks, algorithms are needed which are more noise tolerant, which utilize simultaneously data from several single point excitation runs and which are more efficient. Work is also needed in systems integration of algorithms so that on one computer system, without reformatting the stored data, the engineer could call up any algorithm for use. There are a number of approaches which, although referred to as independent methods, are really only alternative curve fitting algorithms. One such algorithm is Ibrahims Time Domain Method. These algorithms should be incorporated into an integrated system.

5.3.3.2 Computer Systems

Most algorithm development has been done on minicomputers. Some of the new algorithm developments are near the capacity of these machines. New algorithm development should follow two paths. In the future all algorithms that need

large computer capacity should be developed for use on big mainframe computers. All algorithms, large or small, should be installed on the big mainframe computer. The large and small systems should be as compatible as possible so that a set of test results may be processed on both systems as necessary.

5.3.4 System Identification

Development of the point mass, stiffness and damping of a structure from test modeshape, frequency and damping has been pursued for many years. These approaches involve nonlinear systems of equations, and are difficult. The success of these approaches has been limited. An alternative approach is suggested for development work. Beginning with the measured frequency response function, algorithms should be developed which best fit unknown values for point mass, stiffness and damping in a mathematical model. This has the advantages that:

1. This approach is linear, insuring a much greater chance of success than nonlinear approaches and

2. The engineer may specify portions of his mathematical model as known and other parts as variables to be best fit. This has the advantage of minimizing the size of the problem and of reflecting the reality that the engineer usually has portions of the mathematical model he is quite confident are correct and parts where he doubts the correctness of the model. The engineer usually knows where the problem areas are.

5.3.5 Instrumented Test Boundary Condition

In principle, no special boundary condition is necessary for a ground vibration test. If the forces and accelerations are measured across the boundaries, the frequency response function for the free-free test article may be computed from the measured frequency response functions. There would be much advantage in eliminating the requirements for a special boundary condition. A three part investigation is suggested.

1. Computer studies. Exercise the equations with noise contaminated signals and with various kinds of boundary conditions.
2. Laboratory model studies. Repeat the exercises of 1. on laboratory models.
3. Airframe GVT. Get an old airframe out of the boneyard and experiment with various excitation signals, boundary conditions, etc.

5.3.6 Data Basing Systems

Large volumes of data are created in a ground vibration test. Data basing systems should be applied to the storage and retrieval of this data.

5.3.7 Utility Computer Programs

The family of utility computer programs for use on minicomputer based modal analyzers is inadequate. Engineers using these computers waste considerable time executing the steps in utility tasks manually. The utility computer programs to automate these tasks should be written.

5.4 APPLYING GVT IMPROVEMENTS

5.4.1 Documentation

Improvements are needed in the cost and quality of contractor ground vibration tests without increasing total program cost. It is suggested that this could be accomplished by requiring that the usual intermediate steps of the process be formally documented (rather than informal internal documentation as is usual). Quality is invariably enhanced when data is prepared for Company management review prior to release. However, since this data is normally prepared anyway, the total program cost increase should be minimal.

5.4.2 Pretest Analysis

The pretest analysis predicts the frequency response functions that will be measured in the test. The mathematical model of the airplane plus the mathematical model of the support system is used in this computation. This pretest analysis is an important aid in test planning. The pretest analysis should be completed before proceeding with the ground vibration test.

5.4.3 Frequency Response Function

The frequency response function is the direct result of the test measurement, normalized to unit force levels. The development of the frequency response function is direct and straight-forward, following very routine procedures.

The frequency response functions should be part of the GVT test report. This should include the coherence functions associated with the frequency response functions.

5.4.4 Correlation With Mathematical Model

Correlation with the mathematical model should be a required part of the test report. At present this correlation would be limited to comparing modeshapes and frequency. As the correlation criteria of section 5.3.2 are developed they should be applied to give a more definative measure of the differences between the mathematical model and the test.

5.4.5 Soft Support Measurement

If a soft support is used, the bandwidth on selected frequency response functions must include the soft support frequencies. A sufficient number of excitation locations and response points must be included so that all the rigid body airplane on soft support modes are measured.

5.4.6 Modal Characteristics

The modeshapes, natural frequencies and dampings deduced from the test should be included in the GVT test report, just as is done at the present.

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APPENDICES

APPENDIX A

GUIDE FOR GROUND VIBRATION

TESTING OF AIRPLANES

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GUIDE FOR GROUND VIBRATION

TESTING OF AIRPLANES

1.0 INTRODUCTION

This "Guide for Ground Vibration Testing of Airplanes" contains guidelines for ground vibration testing via the single point excitation/frequency response analysis method. It is intended that these guidelines not be dogmatic; the state of the art is changing rapidly, the engineering philosophy in various organizations will dictate many different approaches to problems and the equipment and skilled manpower available will circumscribe one's capabilities.

The approach taken here is that of an aircraft manufacturer. It is assumed that costs involved in the test are weighed on a return on investment basis. The consequences of this are that testing time must be minimized, cost and manpower expenditures controlled and computerized equipment agressively utilized.

This guide discusses test planning, test equipment, test operations, and general guidelines, both as they apply to ground vibration testing in general, and to the single point excitation/frequency response analysis method in particular.

2.0 TEST PLANNING

2.1 Test Planning Document

The principal written coordination vehicle between the customer for the test and the testing group is the test planning document. It must encompass all aspects of the test and documentation of the test. The document is written jointly by the customer engineer responsible for the test and the test group engineer responsible for the test. This document is revised many times, as often as necessary, to keep it up to date with current plans as the test date approaches. Since all people involved with conducting the test receive copies of the test plan document, the regular revisions help keep everyone current.

2.2 Test Schedule

Pre-test planning should include a carefully layed out test schedule for both equipment and manpower allotments. The airplane preparation should be planned and sufficient time allotted for each item. Instrumentation that is required must be planned for and made ready for the test.

2.2.1 Boilerplate Tests

Frequently test equipment is to be used or test procedures used which are new. The risk of problems with untried equipment or new procedures during the ground vibration test is minimized by conducting boilerplate tests with them before the GVT. The boilerplate tests are conducted in the laboratory some time before the GVT. They are conducted on an ad hoc basis with minimum crew and expenditure.

2.2.2 Length of Test

Since most airplanes are essentially ready for flight at the time of a GVT, the time available for the test is usually at a premium. The new techniques used for GVT have vastly reduced the length of tests and have resulted in efficient automation of data. Since several vibrator locations are usually used with different airplane configuration, the time for test will vary.

For a new airplane configuration where a complete GVT is required, a carefully planned test will require from eight to twelve, eight-hour shifts.

2.2.3 Test Crew

The required test crew for a GVT will vary according to the complexity and amount of data points that are required. Normally, for a large airplane, the crew will consist of:

Set-up crew to move equipment into place

Instrumentation crew to place transducers, string cable, hook-up all electronic equipment, perform calibration and operate equipment.

Test planners, director, and supervision.

The total manpower requirement varies from 3 to 20 persons, depending on the complexity of the test, the latter being an all up test on a large airplane running three shifts a day until completion.

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2.3 Test Planning for Measurement Phase

2.3.1 Equipment List

A complete and comprehensive equipment list must be prepared at the earliest possible date. It should contain a list of the equipment that will be required for the test, including transducers, cables for transducers and vibrator, amplifiers, filters, tape recorders, oscillographs, VTVM, oscilloscope, function generator, computer equipment, etc.

2.3.2 Airplane Configuration

A detailed description of the configuration(s) that are to be tested should be drawn up. Control surface support, weight of equipment, and landing gear configuration must be spelled out in detail. The testing sequence must be planned so that reconfiguration of the airplane for successive test conditions is performed as efficiently as possible.

2.3.3 Airplane Suspension

Since the method of suspension may affect the test data, detailed planning must be done for exact configuration of suspension system. Plans should be made to check support frequencies and damping of the airplane suspension system.

2.3.4 Accelerometer Locations

A drawing should be prepared of complete airplane calling out exact body station and water line of each accelerometer. Lists should then be made and tabulated for the test document describing the location of the measured structural response locations.

2.3.5 Exciter Locations

A pretest analysis can be used to determine the best location(s) to excite the modes. Usually several locations will be used. Each location should be clearly indicated on pre-test plan drawings or sketches with WL and BS called out.

2.3.6 Pre-Test Analysis

A pre-test analysis of the airplane to be tested is desirable. A pre-test anslysis uses a mathematical model of the airplane structure. This mathematical model may be a finite element model, a beam model or some other abstraction of the airplane structure. The most desirable math model is the airplane in GVT configuration, including the test boundary conditions at the airplane support. Less desirable are models of the free-free airplane or the airplane in configurations similar to the test configuration. Models of the airplane in other configurations are of lesser value.

There are two kinds of pre-test analysis. The first is computation of frequency response functions. This calculation of the response at various points in the

structure due to excitation at a point, as a function of excitation frequency, is usually accomplished by solution of a set of linear algebraic equations. When this computation is repeated for all the candidate exciter and transducer locations, these predicted response amplitudes due to a unit amplitude oscillating force input provides strong guidance in selecting exciter and transducer locations. A second use of these frequency response functions is to select exciter size and transducer sensitivity. Third, the frequency response function is an easy, quick comparison between GVT measurements and the structural mathematical model since a measurement may be converted into frequency response function form with no operator judgment or intervention and little computation. Fourth, the predicted frequency response function may be used (usually with appropriate noise degradation) as a data set to exercise curve fitting routines, both as a data set to practice on and to screen candidate algorithms for use on the test data.

An alternative pre-test analysis that is often performed is computation of mode-shapes and natural frequencies. The predicted data is more difficult to use in this form than in the form of frequency response function. The modal amplitudes may be used as a guide in selecting exciter and transducer locations. However, no information to specify required exciter size and transducer sensitivity is available. Comparison between test measurements and the structural mathematical model requires development of natural modes and frequencies from the test data. This presents no difficulty if the test technique of sine sweeps and dwells is used because modes and frequencies is the data recorded from the test. When more sophisticated testing techniques are used, the modal parameters must be extracted from the frequency response functions by modal analysis. In a further

complication, this comparison is sometimes very difficult when it is not entirely clear how to pair experimental and analytical modes for evaluation.

2.3.7 Instrumentation Calibration

Plans should be made for all transducers to be calibrated over the frequency ranges of interest and at several representative amplitudes. Calibration sheets should be made out that can be used during actual calibration that are suitable for test report. In a computerized laboratory the calibrations will be recorded and used within the computer systems, and the paperwork minimized. For most major tests the calibration is required to be NBS traceable.

2.3.8 Photographic Documentation

Photographic documentation of the test must be planned. For engineering documentation photographs are usually needed of instrumentation layouts, shaker installations, control surface blocking and airplane configuration. In addition, still and motion pictures are often taken for use by the test customer groups.

2.4 Test Planning for Analysis Phase

2.4.1 Data Reduction Plan

A data reduction plan is necessary for both scheduling purposes and for budgeting. This plan includes an estimate of the number of frequency response functions to be analyzed, the bandwidth of interest for each major component of the

airplane, an estimate of the number of modes to be processed and anticipated problem areas. The data reduction plan is written as part of the overall test plan, and is revised as necessary after the measurements are complete.

2.4.2 Documentation Plan

A documentation plan is included in the test plan document. A written agreed on plan for documentation developed before the test is important in getting satisfactory test reports. The documentation plan should define the contents of the document and the documentation specifications.

3.0 TEST EQUIPMENT

3.1 Test Equipment for Measurement Phase

3.1.1 Test Supervision Equipment

A minicomputer is often used for test supervision. This computer, with a keyboard and paper (or cassette) tape reader, executes control programs to initiate excitation and data acquisition, terminate excitation, terminate data acquisition and automatically perform the online data processing. This computer need not have much capacity. A standard desktop computer will suffice, or this control function may be done as a shared function in the larger minicomputer of a modal analyzer. This computer must have a standard digital data bus interface.

3.1.2 Excitation Equipment

3.1.2.1 Excitation Signal Generator

In the usual equipment arrangement incorporating electrodynamic shakers, an analogue electrical signal is input to a power amplifier. The output from the power amplifier drives the shaker. A force transducer between the shaker and the airplane is used to provide force feedback to the shaker control equipment.

Modal Analyzer

One common excitation signal source is an FFT type modal analyzer. The engineer constructs his desired force spectrum in the analyzer. The analyzer is then

operated in the inverse Fourier transform mode. The resulting time history signal output from the FFT computer is processed through a digital to analogue converter and transmitted to the shaker control equipment.

Sine Wave Oscillator

Pure sinusoidal signals are not usually used with the single point excitation/ frequency response analysis method except in documenting nonlinearities. When a sinusoidal signal is required a sine wave oscillator is an excellent source. The oscillator output is patched into the shaker control panel input instead of the digital to analogue converter output.

Random Noise Generator

Bandwidth limited random noise may be created by a random noise generator in conjunction with a high pass and a low pass filter as well as by the modal analyzer. It may be advantageous to use the random noise generator for long continuous (or pure) random excitation runs (durations typically approaching one hour). This frees the modal analyzer, which may now be used during the continuous random excitation periods to perform preliminary curve fitting or other appropriate computations.

Magnetic Tape

It is often advantageous to create complex or unusual excitation signals in the laboratory prior to the test and record them on magnetic tape. The output from the tape recorder is patched directly into the shaker control panel.

3.1.2.2 Shaker Control Equipment

The shaker control panel receives the excitation signal and routes it to the power amplifiers. Output level for the power amplifiers are controlled from the shaker control panel. Some installations utilize feedback from the force transducer between the shaker and the airplane, while other systems function open loop. The shaker control panel instrumentation monitors excitation signal and output force signal.

3.1.2.3 Shaker and Shaker Attachments

The exciters usually used are electro-mechanical vibrators with several hundred pounds force capability. Vibrators used for control surfaces and tabs are smaller, in the range of 1-25 pounds force. These vibrators usually have the voice coil suspended on flextures with the voice coil attached to the airplane. Flextures are usually placed on the end of the attachment rod to reduce moment transmitted and reduce alignment difficulty. A vacuum cup has been found to be a convenient way to attach to the aircraft surface although double back tape may also be employed.

3.1.2.4 Impact Hammer

Impact hammers contain a force transducer so that the force time history of the impact may be recorded. Impact hammers are available in several sizes with various kinds of material on the impact surface. Vibration testing on airplanes with the impact hammer is not well developed and little definitive experience

exists. The work that has been done indicates that the impact hammer is potentially useful on control surfaces and other small components. The technique has proven useful on panels, wind tunnel force models and, to a limited extent, on wind tunnel flutter models.

3.1.2.5 Other Excitation Methods

Operating Inputs

Operating inputs are rarely used in ground vibration testing of airplanes. This is probably because the available operating inputs almost never excite all of the modes of interest.

In one instance where operating inputs were used, a transport airplane required a ground vibration test after a design modification. The test was conducted to measure only certain of the antisymmetric wing modes. These modes were excited by providing swept sine input to the rudder channel of the automatic flight control system. The inertia forces of the oscillating rudder provided sufficient excitation to the modes of interest.

Bonkers

On occasion an airplane fitted with bonkers for flight flutter testing has required a ground vibration test, and the bonkers have been used as an excitation source. This technique is most certainly expedient, although it appears that only the first few modes have been extracted where this approach has been used.

Unit Step Response

The unit step response has been attempted with limited success on wind tunnel flutter models. No applications of this technique to airplanes are known.

3.1.3 Aircraft Support System

3.1.3.1 Soft Support System

On many occasions the test airplane is supported on a special purpose soft support system. This system must offer low enough natural frequencies so that the support system is well separated from the elastic modes of the airplane. The system must also be stable and reliable.

3.1.3.2 Soft Tires

Frequently transport airplanes are shaken on soft tires. The landing gear oleo struts are either bottomed or overfilled with oil to eliminate any motion in the strut. Air pressure in the tires is reduced to make the tires function as soft springs. This method requires no special equipment and little preparation. It has the disadvantages that the frequency separation is not as good as a soft support system and usually the set of tires used is damaged so severely they must be discarded.

3.1.3.3 Hard Mount

Attempts have been made to rigidly constrain the test airplane at its suspension points. With care this can be successful on small airplanes. However, on large

airplanes it has proven extremely difficult to provide a stiff enough support and backup structure (which often must include the building floor and foundation).

3.1.4 Data Acquisition Equipment

3.1.4.1 Transducers

Accelerometers

Accelerometers are used for sensing response of the structure. These accelerometers are attached in a temporary manner with tape or a removable cement. Since low frequencies are usually measured at low acceleration levels, an accelerometer with good output and phase characteristics is required. The large servo-type, strain gage, accelerometer is recommended for most GVT work. Where smaller transducers are required, other more compact type transducers may be used of the crystal or strain gage type.

Force Gages

Since the accurate measurement of the force vector input to the airplane is required, a reliable force measuring transducer is used between the vibrator and the airplane. This force transducer is usually attached to the push rod from the vibrator and may be a crystal or strain gage sensing element. The gage should have a minimum of cross-talk output resulting from moment forces that are applied during the excitation.

Strain Gages

Strain gages are rarely placed on an airplane for use in ground vibration testing because the low strain levels produced during a GVT result in poor signal to noise ratios. However, strain gages placed for other purposes are used. No special preparations are necessary on the strain gage, it has ample bandwidth and phase stability, but care must be taken that the signal conditioning equipment used with the strain gages is appropriate to vibration testing rather than static load testing where most strain gages are used.

Others

Among other transducers used are displacement and velocity sensors.

3.1.4.2 Signal Conditioning Equipment

Filters

Usually the system is calibrated for amplitude and phase using a high-pass filter set at a low value of 1 or 2 Hz to eliminate zero shift arising from balance differences of each circuit.

Cathode following or charge amplifiers serve as impedance matching signal conditioning instruments for crystal transducers with high impedance. Locating the charge amplifier close to the transducers is desirable to reduce the line loss for long lead lengths.

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Amplifiers

Amplifiers are required to raise the low level signals from the transducers to levels that can be tape recorded. Specifications for an amplifier include the following items:

Linearity

Sensitivity

Signal to Noise

Gain Settings

Phase

3.1.4.3 Signal Conversion and Storage

There are two general approaches to signal conversion and storage. Although the digital system is superior and very much preferred, a discussion of the older analogue system approach is included because many organizations have the analogue systems and no opportunity to upgrade.

Digital System Approach

Anti-Alias Filters—Low pass filters are included upstream of the analogue to digital converter on each signal circuit to serve as anti-alias filters. The filters must be set to function with the sampling rate on each circuit.

Auto Ranging Amplifier—The autoranging amplifier functions in two modes. First, while autoranging it samples the incoming signal continuously to find the maximum

signal. The autoranging function is carried out on command. This is done in a GVT during typical excitation. The autoranging results in an amplifier gain factor that will produce a specified peak amplitude output. In the second mode, the amplifier function of the autoranging amplifier outputs the gain and the input signal scaled by the gain.

Analogue to Digital Converter—The analogue to digital converter creates a digital signal from its input analogue signal. The conversion takes palce either on an internal trigger (clock) or an external trigger. For a GVT all the trigger commands are usually taken from one central clock which is usually located in the modal analyzer.

Multiplexer—A digital time division multiplexer is used to amalgamate the signals from many sensors for recording serially on one device. Equipment is available which combines the functions of autoranging amplifier, analogue to digital converter and multiplexer into one unit.

Minicomputer—A minicomputer is needed to format the multiplexer output data for recording and to function as a disk or tape controller.

Disk or Tape Recorder—Disk recording is preferred over tape because it is much faster, allowing increased bandwidth (or equivalently additional channels of multiplexing). However, many disk units do not have enough capacity to record all the data for one run, and in that case one must record directly on tape and accept its limitations.

Analogue System Approach

Variable Gain Amplifiers—A separate variable gain amplifier is used for each transducer circuit. During typical excitation the test technician adjusts the gain setting on each amplifier to give a desired output signal amplitude (as monitored on an oscilloscope). The technician records the gain settings on his clipboard.

Analogue Tape Recorder—The output from the variable gain amplifiers is the input to the analogue tape recorders. Since analogue tape recorders tend to be capacity limited, several are required, running in parallel, for the usual GVT.

3.1.5 Data Verification Equipment

The onsite modal analyzer is used for data verification. In addition, monitor oscilloscopes displaying all transducers during data acquisition provide the engineer with a qualitative check on signal quality.

3.2 Test Equipment for Analysis Phase

A computer system is used for frequency response analysis. The system most commonly used is the minicomputer based modal analyzer, with an appropriate set of peripheral equipment (often including a hardware band selectable Fourier transform processor). Some organizations have chosen to perform their frequency response function analysis on the big mainframe computer. There is a trade off here - the big mainframe has more capacity and is more versatile but more modal analysis software exists for minicomputers.

4.0 TEST OPERATIONS

4.1 Calibration

The transducers should be checked over the range of frequencies of interest with several levels of known input. A calibration table should be used with a secondary standard pickup. The remainder of the electronic equipment must be checked with traceable standards to insure amplifier and tape recorders are operating within standard tolerances. Each item of equipment must have an up-to-date calibration sticker indicating the instrument is current.

4.2 Aircraft Preparation

4.2.1 Configuration

The airplane configuration tested may include modifications not typical of flight. For example, the airplane of the A-10 demonstration ground vibration test was tested with the flaps removed because they were known to be the source of a strong nonlinearity.

4.2.2 Fuel System

The ideal fuel state to shake an airplane is empty. Then there is no question of the effect of fluid interactions on the test data. Shaking the airplane empty of fuel is frequently adequate in organizations where the effect of fuel can be added to the airplane mathematical model analytically.

The next ideal fuel state is with every fuel tank either empty or completely full. In this case the fluid interaction effect is between the fluid bulk and the surrounding tank walls. Fortunately the frequencies at which this effect is significant are usually well above those important in whole airplane structural dynamics - flutter, gust, etc. Note, however, that this effect is significant at panel flutter frequencies.

The most difficult fuel state is a partially filled tank. In this case there is a fluid surface, in addition to the fluid bulk, interacting with the structure. The fluid surface in general exhibits non-linear behavior which is not only a function of vibration amplitude, but also a function of the boundaries of the fluid surface, i.e. an airplane fuel tank tested with the same volume of fuel in two different attitudes can give different dynamic characteristics.

Fuel Safety—The primary danger is not from fire but from explosion of a fuel vapor-air mixture in the ullage area of the fuel tank. This problem is more severe for airplanes fueled with JP-4 (JET-B) than with JET-A. Nitrogen inerting has usually been sufficient to eliminate the danger of explosion, although occasionally the fire safety organization will require a full purge on some systems.

4.2.3 Ejection Seat

If the airplane contains an ejection seat it must be removed unless it can be satisfactorily safetyed. Access to the cockpit must then be strictly limited to qualified personnel.

4.2.4 Oxygen Systems

The oxygen systems on the airplane must be configured to satisfy the health and safety organizations requirements.

4.2.5 Flight Control System

The flight control system of the airplane usually contains nonlinearities and often couples closely with the elastic modes of the airplane. Because of this the flight control system is modified to minimize these effects for the airplane ground vibration test. If the dynamic characteristics of the control system must be measured this is best done as a separate test. Typical modifications to the flight control system include blocking or pining the control stick (or wheel) or to block the control stick (or wheel) output quadrant so that vibratory motion of the cockpit will not induce oscillatory inputs into the flight control system. A second modification is to block (usually with shims and wedges) the control surface PCU input quadrant (powered surfaces) or the control surface actuator quadrant (manually controlled surfaces). A third measure is to test the airplane with all automatic flight control systems off or disconnected. This is so that vibration of the AFCS sensors do not cause commands for oscillatory motion at the PCU actuators.

4.2.6 Dummy Engines

There has been concern that during a GVT the vibrations induced in the jet engines on the test airplane could damage the engines. The engine manufacturers access this potential for damage for each engine design and write

recommendations. In the worst case the engines are removed from the airplane and replaced with mass-properties-equivalent dummy engines. For less severe situations the requirement may be 1) to motor the engines at all times the airplane is being shaken, 2) rotate the engine periodically during the test (typically every four hours) or, 3) no special requirement. In recent years the trend has been toward less stringent restrictions because of 1) improvements in bearing design and 2) testing with predominantly random excitation rather than sinusoidal provides a more benign environment to the engines.

4.2.7 Other Vibration Sensitive Equipment

Ground vibration testing is not an adverse environment for most equipment other than the engines because the equipment is qualified to stringent specifications. The possibility for damage to unqualified nonspecification equipment must be considered.

4.2.8 Test Equipment Installation

The test equipment installation should be rapid because the length of time the test airplane is occupied for the GVT must be minimized. This is accomplished by assembling and checking the equipment in the laboratory prior to the test, by rack mounting equipment, by making up accelerometer installation kits and by preplanning the test equipment installation for maximum effciency.

4.3 Test Operations For Measurement Phase

4.3.1 System Checks

4.3.1.1 Electronic Equipment

The usual checks of installed electronic equipment are satisfactory; exercising systems with reference and calibration signals, etc.

4.3.1.2 Aircraft Support System

The aircraft support system must first be checked for function and stability. Then the rigid body modes of the airplane must be measured; obtaining natural frequencies, damping and modeshape. This is most expediently done by setting the lower bandpass limits well below the expected rigid body natural frequencies for the initial random excitation of the airplane. Energy considerations may dictate separate runs to measure the rigid body modes, using bandwidth limited noise encompassing only the expected rigid body frequencies.

4.3.1.3 Rattles

Walk around inspections of the airplane while it is being excited at a fairly high force level is important. Any rattles present are indicative of non-linearities. This may be due to loose equipment or due to free play. Particular attention should be paid to the shims and wedges in flight control systems. Invariably some of them won't be sufficiently tight, and will need tightening or rework, possibly more than once.

4.3.2 Force Level Selection

Although excitation force level is predicted by the pretest analysis, excitation force levels to be used are selected by trial and error in the vicinity of the predicted force level. Low force levels are desired because most nonlinear systems behave in a more linear fashion at low force levels, but at low force levels the signal to noise ratios are poor. A best compromise force level is sought.

4.3.3 Data Acquisition

4.3.3.1 Excitation

The excitation signal of T seconds duration is generated in a Fourier analyzer data block in the time domain and output to the shaker through the digital-to-analog converter. The excitation signal may be of the following types:

1. Periodic random transient

2. Periodic log swept sine transient

3. Pure random

The exiciter locations and directions of excitation may typically include vertical excitation on one of the wing tips, lateral excitation on the aft body, lateral excitation on the vertical fin, vertical excitation on the horizontal stabilizer, and chordwise excitation on the horizontal stabilizer.

Force levels are determined by a combination of visual verification of actual airplane vibration amplitudes and accelerometer response signal levels as observed in the monitor scopes. The frequency range may encompass frequencies up to 50.0 Hz and may be subdivided into smaller ranges such as 0 to 10.0 Hz, 5.0 Hz to 20.0 Hz, and/or 20 Hz to 50 Hz with varying frequency resolution or time duration. Frequency resolution, f, or time duration, $T = 1/f$, are sampling parameters that are functions of the structure's damping characteristics, frequency range and the sample size (or block size) of the Fourier analyzer.

4.3.3.2 Signal Conditioning and Recording

Digital Recording System

If an analogue to digital converter and a multiplexer are used, then all the analog tape recorders would be replaced by one digital magnetic tape unit as the storage device for the digitized multiplexed time histories. A multiplexer affords a significant improvement in signal-to-noise ratio over an analog system. A multiplexer with an automatic gain range amplifier affords the added benefit to improved S/N ratio by operating with an optimum gain level on each word of the incoming data stream. The force input signal measured at the shaker and the accelerometer response signals are the only required signals to be digitized and recorded on the digital magnetic tape unit. Data qualifiers such as block size, scale factor, data calibrators and frequency resolution are also stored on the digital tape with each block of data. The sampling rate of the multiplexer analog-to-digital converter is clocked by the control computer ADC. The multiplexer ADC is triggered by the data-ready pulse of the control computer so that all response time histories are periodic and synchronous with the excitation signal.

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Analog Recording System

If an analog recording system is used, then on each analog wideband FM tape
recorder are recorded the time domain data from:

1. The force input signal as measured from a force transducer on the shaker at
   the point of excitation.

2. The response signals from the accelerometers mounted at preselected coordi-
   nate points and directions on the airplane.

3. The data-ready pulse which signals the start of each sweep at T=0 of each
   Fourier time window. For post-test data analysis, this pulse is used to
   trigger the analog-to-digital converter (ADC) of the Fourier analyzer.

4. Time-code signal.

5. Voice identification.

For each test condition, there are several analog tape recorders running simul-
taneously depending on the number of accelerometer signals being recorded for
that particular test condition.

4.3.3.3 Data for Zoom Transforms

The zoom transform is a measurement technique in which Fourier-transform based
digital spectrum analysis is performed over a frequency band whose upper and
lower frequencies are independently selectable. Zoom can provide an improvement

in frequency resolution and dynamic range over a baseband measurement which extends from dc to some maximum frequency, Fmax. The zoom transform operates an incoming time domain data to the analyzer's analog-to-digital converter (ADC) or on time domain data that has previously been recorded on a digital mass storage device (in real time, i.e., no samples lost). The time domain data is digitally filtered and only the filtered data stored and then Fourier transformed.

The zoom transform lends itself ideally to testing situations wherein successive ensembles of data are random in nature. If frequency resolution is improved by a factor of n over the original base-band measurement, then it follows that the time record of the input signals for a zoom measurement must be n times as long (Ref. 5).

In testing situations wherein successive ensembles of data are totally observed transients such as with periodic random transient excitation, the zoom transform is not readily adaptable. In these instances, frequency resolution is improved by increasing the number of samples or block size, N. An 8192 point transform is now available which increases the sample size capacity of the newer version of minicomputer-based Fourier analyzers.

4.3.4 Verification

The incoming data stream of both the force input signal and the monitor accelerometer response signal as seen in the display scope of the Fourier analyzer can provide a visual check of the data in the time domain. This visual verification of the signal requires some prior experience on the part of a knowledgeable test operator.

In the frequency domain, the quality of the frequency response function is checked by means of the coherence function. After the frequency response function has been calculated, the coherence function is then calculated as the next step in the Fourier keyboard program. It is defined as follows (Ref. 2):

$$\text{Coherence function} \qquad \gamma^2 = |H|^2 \frac{G_{xx}}{G_{yy}} = \frac{|G_{xy}|^2}{G_{xx}G_{yy}}$$

where

G_{xy} = cross power spectrum

G_{xx} = input auto power spectrum

G_{yy} = response auto power spectrum

If the coherence is equal to 1 at any specific frequency, the system is said to have perfect causality at that frequency. In other words, the measured output is totally caused by the measured input, or by sources coherent with the measured input. A coherence value less than 1 at a given frequency indicates some degree of noise contamination and/or non-linear distortion.

Modal analysis for selected modes and a suitable subset of all accelerometers is often performed to gain additional confidence. The goals of modal analysis to be accomplished during the test must be modest because there is limited time available to perform the analysis.

4.3.5 Nonlinearities

Nonlinearities are handled in three ways; by eliminating, by averaging or by documenting. Free play may be eliminated by shimming, blocking or preloading. Nonlinear components may be removed from the test article or may be replaced with a linear "dummy" component. The technique of averaging the measured data from random excitation produces frequency response functions that are the linear equivalent average of the nonlinear system. Nonlinearities are documented by special testing techniques appropriate to the type of nonlinearity at hand.

4.4 Analysis Phase Test Operations

4.4.1 Preparation of Frequency Response Functions

4.4.1.1 Disk File Digital Time Histories

A series of actions, none of them very automated at present, is necessary to produce digital time histories on the disk file computer storage of the modal analyzer.

If digital magnetic tape is the data storage media the problem is that the data on the tape is in time division multiplexed form. The demultiplexing operation, called unweaving, involves either selective reading of a few channels at a time from the tape using the minicomputer or exporting the tape to a big mainframe computer where the tape is rewritten into demultiplexed form, and then reading this tape into the modal analyzer.

If analogue magnetic tape is the storage media then the analogue signal is read into an analogue to digital converter and then to the modal analyzer disk, mimicing a realtime analysis of the test data.

4.4.1.2 Signal Processing

The engineer must judge the extent of modifications to the time history signals necessary to produce analyzable frequency response functions. Generally this signal processing accentuates one facet of the signal to the detriment of others. Some of the processes carried out are windowing, decimation and averaging. From these processes computation of the frequency response function via fast Fourier transforms follows directly. An alternative process which produces a frequency response function having fine frequency resolution over a limited bandwidth is called a band selectable Fourier transform (a zoom transform).

4.4.2 Curve Fitting

The Laplace modal parameters of frequency and damping, magnitude and phase can be estimated for each mode of vibration by curve-fitting a Laplace math model to the frequency response functions on the modal disc. The choice of curve-fitting algorithms is dependent upon the particular modal analysis software system being used.

4.4.2.1 Parameter Estimation Techniques

Amplitude Response

The simplest parameter estimation technique is to measure the magnitude of the frequency response at each of the frequencies where the magnitude reaches a maximum. The total response can be used as the modal coefficient. This method assumes a single degree of freedom system. Frequencies are determined visually by noting where the peaks occur in the frequency response function. No attempt is made to curve-fit a Laplace model to the data. Damping may be estimated using any of several popular techniques. Recommendation: This method does a poor job of separating modes. It is not recommended for use on complex structures.

Quadrature Response

Another parameter estimation technique is to measure the quadrature or imaginary, component of the frequency response at each frequency where the imaginary component reaches a maximum, these being the undamped natural frequencies of the system. The quadrature response is used as the modal coefficient. This method assumes a single degree of freedom system. Frequencies can be determined visually or from a power spectrum composite of the quadrature responses of all the measurements. No attempt is made to curve-fit a Laplace model to the data. Damping may be estimated using any of several popular techniques. Recommendation: This method can be used on systems that are lightly damped and that have modes that are well separated.

Circle Fit

A third parameter estimation technique is accomplished by presenting each mode of the frequency response function as a circle in the complex plane. Resonant frequency is found where the rate of change of phase angle as a function of frequency is a maximum. The amplitude and phase angle of the complex modal coefficient is defined by the location, diameter and orientation of the circle. This method assumes a single degree of freedom. No attempt is made to curve fit a Laplace model to the data. Damping may be estimated by the circle fit technique originally developed by Kennedy and Pancu. (Ref. 6). Recommendations: This method may be used on systems that are relatively lightly damped and that have modes that are only weakly coupled in the range where one mode is predominant. The actual curve fitting procedure must be an interactive process.

Least Squares

Eigenvalue solution using least squares complex exponential algorithm in time domain—Another parameter estimation technique is the least squares complex exponential algorithm which solves the impulse response form of the multiple-degree of freedom equations. The equations are non-linear in 4 unknowns and an iteration process is used to obtain a solution. The algorithm searches all measurements in the declared frequency range and constructs a composite power spectrum from the frequency response functions. The least squares error as a function of number of degrees of freedom is then printed out. From this, an estimate is made of the number of modes to input into the algorithm. Additional or "computational" modes are carried to compensate for noise or distortion in the data. A set of eigenvalues is then generated for each mode being carried in the frequency band.

Eigenvector solution using least squares in the frequency domain-With these fixed sets of eigenvalues, the partial fraction form of the equations in the frequency domain are then solved for the other two unknowns, the complex eigenvectors, for each measurement. The whole process is an automatic one, with the modal analyst having the option of accepting or rejecting the fit for any measurement.

Recommendations: This method does a good job of fitting closely-spaced modes. It has the difficulty fitting other modes in the same frequency band. It is recommended for use on multiple degree of freedom systems in conjunction with the curve-fitting technique described in the following section.

Eigenvalue and eigenvector solution using least squares algorithm in the frequency domain—Another parameter estimation technique is to obtain the eigenvalues and eigenvectors *by solving the* partial fraction form of the non-linear equations in the frequency domain by least squares method. The process is iterative and all four modal parameters are updated with each iteration. Starting estimates of all four parameters for each mode may be automatically generated by the system or entered by the modal analyst at the terminal. The process is interactive allowing the analyst to add or drop modes, select the number of interations, and select the type of residual function to fit the tails of modes lying just outside the frequency band.

Recommendations: This method does an accurate, dependable job of curve-fitting frequency response functions. It is recommended for use on multiple degree of freedom systems in conjunction with the curve-fitting technique described earlier in this section.

4.4.2.2 Integration of Results

The current curve fitting computer programs operate on the data from a single
test run. During the entire ground vibration test runs with several different
shaker locations, force levels and accelerometer layouts are usually made. Inte-
gration of the curve fitting results into a whole airplane linear mathematical
model of modeshapes, frequency and damping is done intuitively. The most
important aids to the engieer in doing this job are the pretest analysis and the
frequency response function plots.

4.4.3 Data Display

4.4.3.1 Modal Data

The modal data can be presented graphically and in printouts of the residues
along with the associated frequency and damping values of each mode of vibration.
The graphics display can be in the form of animated mode shape displays of each
mode as seen in the display scope of the Fourier Analyzer system. This display
can be plotted showing undeformed and deformed positions for a permanent record.
Mode shapes can also be graphically displayed as delta functions or vectors
representing amplitude and phase at each measurement point on the airplane.
These vectors can be shown in animation on the display scope and can also be
plotted along with the complete outline of the airplane. Again permanent records
of these vector plots can be made.

The printouts of the mode shapes are in matrix form with each row representing a
measurement point on the airplane and each column representing a mode.   The

residues are expressed as a magnitude vector and a phase angle in engineering units.

4.4.3.2 Frequency Response Functions

Each frequency response function can be plotted in terms of its magnitude versus frequency and also its phase versus frequency. Permanent records of these plots can be made.

4.4.4 Measures of Confidence

Five measures of confidence in curve fitting are plausibility, wild points, measured vs fit frequency response functions, modal confidence factor and generalized mass.

Plausibility is the experienced engineer's intuitive review of the modeshapes, frequencies and dampings. The data is reviewed for reasonableness in terms of prior airplane designs, development experience on the airplane under test and the experiences during the measurement phase of the test.

Wild points are readily apparent in animated modeshape plots, provided the accelerometer layout is not too sparse. The rigid body modes of the airplane are particularly good for spotting improperly installed or malfunctioning accelerometers.

Comparison of the measured frequency response function plots with the frequency response functions computed from the curve fit results is a good check on the quality of the curve fitting.

The modal confidence factor is a comparison of the curve fit modeshapes from different shaker locations. It is a measure of the repeatibility of the data. Note that a low modal confidence factor is to be expected where a shaker was located near a node point; the mode was simply very poorly excited from that point.

Generalized mass, although often referred to by investigators in the field, is not really a very good measure of confidence. In this case we are talking of a generalized mass matrix which is computed from a theoretically derived reduced mass matrix at the test measurement points, m, and from the matrix of curve fit modeshapes, ϕ. The generalized mass is computed as:

$$M = \phi^T m \phi.$$

The judgment usually made is to compare the size of the off diagonal terms with the diagonal. The ambiguity is in the lack of a metric to judge the quality of the generalized masses. If the off diagonal terms are several orders of magnitude below the diagonal then obviously the modes are mass orthogonal. If the off diagonal terms are of the same order of magnitude the modes are definitely not mass orthogonal, and the process is in error somewhere. However frequently the generalized mass falls between these two cases and no clear guidance is given.

4.4.5 Modal Analysis Software Systems

The state of the art in modal analysis software systems is developing rapidly. The manufacturers of modal analysis hardware systems offer modal analysis software packages with their equipment. Since the equipment is based on general

purpose minicomputers, the user and the researcher may augment this ensemble with more advanced software of his own. One such package is that developed at the University of Cincinnati and the University of Luven. A copy of this package is delivered to the Air Force under this contact.

4.5 Follow-On Activities

Feedback into the airplane design loop is the end product of a ground vibration test. The most frequent feedback mechanism is verification and modification of the mathematical model of the airplane. Less frequently (in the United States) the mechanism is the creation of a mathematical model of the airplane directly from test data.

5.0 GENERAL GUIDELINES

5.1 Common Problems

5.1.1 Friction

The friction between structural components/fixtures is present for most GVT tests. For riveted structures, this situation is accepted and is similar in structures of similar design.

Friction in nacelle engine mounted systems has been of considerable interest with engines mounted on wing pylons and must be tested with variable force amplitude.

Control surfaces often have variable friction and break-away forces that must be dealt with carefully. Power actuated controls must be tested with power-on to determine working frequencies and transfer functions.

5.1.2 Free-play

Free-play in control surfaces must be carefully treated. First, measurements must be made with and without power to determine static free-play and bring within tolerance. Then vibration tests must be conducted with frequency-amplitude studies to determine the effect of free-play on the dynamics of the surface.

5.1.3 Damping

Structural damping values are usually determined for each resonant condition of the airplane in the GVT. These measurements may be made at several amplitudes of excitation to determine the amount of non-linear effects on damping values.

5.1.4 Airplane Asymmetries

Considerations must be made to configurations where asymmetric loading takes place. This could be from internal equipment placement or for combinations of external stores.

5.1.5 \Closely Spaced Modes

Closely spaced modes are those which are sufficiently close in frequency and overlapping in off resonant response that separation of these modes into frequency, damping and modeshape is not readily accomplished. Two measures may be taken when the online frequency response functions or the pretest analysis indicate closely spaced modes are a problem: 1) take an additional data set with a long pure random record so that fine frequency resolution may be achieved in the neighborhood of the closely spaced modes via zoom transforms. A reference accelerometer frequency response function may be checked in real time using a hardware zoom unit, which will assure that sufficient frequency resolution has been acquired so that the closely spaced modes may be resolved during curve fitting. 2) a second measure that aids in separating modes is to repeat the single point excitation at several locations. This aids because modes which appear to be closely spaced on frequency response functions from one excitation

often will be much less coupled on frequency response functions from another exciter location.

Given a comprehensive set of measurements (i.e. frequency response functions for all accelerometer locations and shaker locations with adequate frequency resolution and signal to noise ratio) most closely spaced modes may be separated during the analysis phase of the test. This analysis will involve using data from several different accelerometers and different exciter locations, possibly in linear combinations, and attempting curve fitting by several multiple degree of freedom approaches, perhaps with many different signal conditioning processes. Zoom transforms will be used as necessary to achieve frequency resolution. Although this iterative process may be just as time consuming as modal tuning, it is substantially less costly because it is performed off-line by one person on a computer whereas the modal tuning is done during the test time, occupying the test airplane, all the test equipment and the full test crew.

5.1.6 Strut Mounted Wing Engines and External Stores

Nearly identical repeated subassemblies on the wing give rise to closely spaced modes, for which approaches are suggested in sections 5.1.5. A second problem arises with nonlinearities in engine and external stores. Usually the nonlinearities are mild enough that they may be averaged out, and documented in separate testing as necessary. A third problem is in repeatibility of bomb installations. Special care must be taken to insure that the bombs are hung the same every time, and that free play and friction are absolutely minimized.

5.1.7 Hydraulic Pressure Source

A hydraulic mule is usually used to provide hydraulic pressure to the airplane
during a ground vibration test. The mule interferes with the test in two ways:
1) pressure pulses are transmitted from the pump in the mule into the airplane
through the hydraulic tubing, and 2) acoustic noise from the mule exciting the
airplane. Two approaches to this problem are suggested. The first approach
eliminates the problems due to the hydraulic mule. This approach is applicable
if the airplane hydraulic system requires only low flow rates while data is being
taken. This approach is to charge a large accumulator, perhaps 50 gal., before
the data run, then isolate the mule out of the system with an appropriate set of
valves, turn the mule off and utilize the accumulator as the pressure source
during the data run.

A second approach must be used if flow volume beyond the accumulator capacity are
required. The mule will have to be used as the pressure source. The pressure
pulses are attenuated by placing an accumulator in the output line from the mule,
as close to the mule as possible. The accumulator should be tuned to remove the
major component of the pressure pulse. The acoustic transmission is minimized by
placing the mule outside the hangar. If this is not possible, completely
surround the mule with acoustic isolation material.

5.1.8 Local Mode Response

The accelerometers located near the shaker in a single point excitation will
sense the local modes as well as the global modes of the airplane. If the primary
objective of the test is measurement of global modes, as opposed to local, the

best signals for this purpose will come from the accelerometers on the symmetric other side of the airplane from the shaker. Their signals will contain very little local mode motion. For global modes heavily instrument the opposite side of the airplane from the shaker. For local modes heavily instrument on the same side of the airplane as the shaker.

5.1.9 Landing Gear

Occasionally it is necessary to shake the landing gear. These tests are run with the gear down and locked and the airplane jacked so that the wheels do not touch the ground. The dynamic characteristics of the gear, as installed on the airplane, are desired. This test is difficult because the landing gear contains a number of nonlinearities, some of which are not very reproducible.

The large number of joints in the landing gear are the source of free play and friction. When the gear is cycled the free play and friction do not reproduce. The free play must be preloaded out as much as possible. The friction effects may be mapped by testng at several different force levels. This should include the lowest possible force level, which will minimize the effects of free play and friction. To control the effect of the oleo strut it should be either preloaded with a suitably high strut extend pressure or overfilled with oil.

5.2 NOTES

5.2.1 Safety - People

Since some of the accelerometer locations are well above the floor, crew stands must be used for access. These stands must meet standard aircraft safety codes with railings around all platforms and mechanical locks for hydraulic jacks. Personnel must use harnesses whenever they are working on the wing, fuselage or tail surfaces that are securely tethered to prevent falling.

5.2.2 Safety - Airplane

All testing is accomplished with a defueled and purged fuel system. The aircraft must be securely mounted, if normal landing gear is not used for support, with adequate safety precautions. Stands that are to be used for vibrators must be sturdily built and secured adequately to preclude damage to aircraft. Powered control surfaces must be locked adequately before attachment of vibrators to prevent inadvertent control motion.

5.2.3 Force Level Selection: A-10 Test Experience

Several excitation force levels were used during the demonstration A-10 ground vibration test. The best signals in the A-10 test were achieved at 5 pounds RMS (3-40 Hz bandwidth) on most main surfaces and at levels as low as .2 pounds RMS on control surfaces. At these levels there is very little visible motion on the airplane, and the test crew must be very watchful that a test observer does not touch the airplane and inadvertently degrade the data set being taken. Part of

the rationale that the lowest force level that gives good signals is desirable for determining linear mathematical model characteristics is:

1. The blocking and shimming used to restrain control surface and other free play is more effective at lower vibration levels.

2. Free play in many control surfaces, landing gear uplocks and other components remains preloaded out via gravity resting the component against a stop, provided the vibration level is low enough.

3. Non-linear springs usually exhibit more nearly linear characteristics at low vibration amplitudes.

4. Hydraulic actuator feedback mechanisms often have a dead band; therefore the chance of undesired feedback is minimized at low vibration amplitudes.

5.3 Equipment Portability And Van Installation

For portability the test equipment should:

1. Be modular with components small enough to be handled by one man

2. All equipment interfaces must be via standard specification interconnects (e.g., IEEE 488-1975 specification for digital data bus)

3. Pieces of equipment that perform identical functions must be interchangeable

4. Reliable high quality connectors must be used

For a van installation the following additional requirements are suggested:

1. All equipment be rack mountable

2. All racks installed in the van be shock mounted

3. Equipment racks be located in the van to give adequate rear access

4. Adequate space provisions be made in the van for cable runs

5. Air conditioning in the van be sufficient to remove the maximum design electric power coming into the van plus $100^{\circ}F$ exterior temperature. Heating should be sufficient for $0^{\circ}F$ exterior temperature and no electronic equipment operating.

6. All equipment should be adequately durable to withstand both the operating and the van transport environments, especially with regard to

    -vibration

    -dust

    -temperature

    -humidity

    Note that many items of equipment which are suitable for use in a laboratory or computer room are not suitable for field use in a van.

7. A voltage isolator should be installed in the van input electrical power line.

6.0 GVT SOFTWARE

This section contains a users manual and software listing for the ground vibration test computer programs *furnished to the Air Force by* the University of Cincinnati under this contract. This software is operational on the Hewlett-Packard 5451B.

6.1 Users Manual

UCME/KUL

MODAL ANALYSIS

SYSTEM

5451C WITH HPIB

VERSION
4/21/80

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This Modal Analysis System software is a HP 5451C
contributed program which allows one to perform a complete
modal analysis of a mechanical structure with the use of the
5451C hardware and the University of Cincinnatti / University
of Lueven software. This system takes advantage of the 5451C
hardware (with a few exceptions) to make the necessary
measurements to define a structure's modal parameters; in
addition, special software has been included in the form of
5451C User Programs which enable one to extract the modal
parameters from measured data, output these results in printed
form, and obtain animated displays of the structure's modes of
vibration.

This document gives a detailed decsription of the Modal
System and its operation. For best results, it is recommended
that the user read and understand this entire document before
attempting to operate the system. If this is done, one will be
able in a short time to take advantage of the full range of
system capabilities and to overcome any operational
difficulties which may arise. In chapter 8 there is a "canned"
step by step example of processing a given set of measured
transfer functions to extract the modal parameters.

1

2.1   HARDWARE REQUIREMENTS

        5451C Base System which includes:
            2648 terminal
            7900 disc
            64K memory

2.2   HARDWARE OPTIONS

            2631A Line Printer (HPIB)
            2631G Line Printer (HPIB)
            2748B Photoreader
            2895B Paper Tape Punch
            7210 Digital Plotter
            9872B Digital Plotter
            7245B Digital Plotter
            7970 Magnetic Tape
            Option 600 5440A Mainframe
            Option 620 54420A Digital to Analog
                               converter
            Option 640 54440A Low Pass Filter
            Option 670 54470A PreProcessor

2

2.3 USER PROGRAMS

User Program 0088 --- Data Annotation

User Program 0090 --- Test ID & Setup

User Program 0009 --- Modal Program

User Program 0040 --- Hardware Zoom Setup (option 670)

User Program 0045 --- Zoom Measurement Program

User Program 0100 --- Filters (option 640)

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2.4 DATA SPACE REQUIREMENTS

There are two coreloads located on the modal disc. The
first coreload contains the modal software (Y90,Y9) for
extracting the modal parameters from the test data. The second
coreload contains a modified 5451C operating system.

The first coreload (coreload 0) is used in conjunction
with overlays stored in file 8 on the disc. The amount of data
space available in the Modal System is determined when the
Fourier system together with the largest overlay (overlay 10)
is first excuted. The maximum block size that can be stored to
the disc is 1024.

During the operation of the system, some or all of the
total data space available will be allocated by the Modal
System (in the K 0 command of the Data Setup section which is
usually performed first) for storing system parameters, modal
coefficients, and data for the animated mode shape displays.
The Modal System allocates space for these items in terms of
time domain, (block size 1024) data blocks required to perform
the most important Modal functions. Storage may take from one
to four BS 1024 data blocks, depending on the number of
structure test points entered when the K 0 Data Setup function
is performed. The number of blocks required to store modal
coefficients may be computed as follows:

$$\text{Number of Blocks} = \frac{3 \times \text{No. of Modes} \times \text{No. of Points}}{1024}$$

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Therefore, if storage for 10 modes and 150 points was
desired, the system would require

$$\frac{3 \times 10 \times 150}{1024} = 5$$

data blocks for storing modal coefficients.

Based upon the maximum number of test points, the data
space for modal coefficients will be allocated and the maximum
number of "modes per session" calculated. If mode shape
information for more modes is required, the process of
parameter estimation of the test data will need to be repeated.

The system always considers block 0 and 1 to be
"available" since the data arrays they contain can be recreated
if the other system blocks are intact. These "available"
blocks may be used in normal 5451 operations without affecting
the parameters stored by the Modal System in upper data space.

2.5   DISC SPACE CONSIDERATIONS

The Modal System uses a data arrangement for the HP 7900
Disc which allows disc data records 0 through 819. Of these
records 0 through 750 are typically used for data (transfer
functions), and 751 through 799 are used for storing modal
parameters and setup information from User Program Y 9. Test
setup information from Y 90 is stored in disc file 7 records 1
through 19, file 7 records 20 to 39 can be used to store
variable parameters for use by the 5451C measurement coreload
(coreload   1).

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2.6 FOURIER KEYBOARD FUNCTIONS

With minor exceptions, all Fourier System keyboard functions contained in the Modal System coreload (coreload 0), perform in exactly in the same manner as the standard 5451 enviroment (see the 5451C Operating Manual). The basic differences are that there are no "Gold Key" functions, i.e. no variable parameters and the graphics commands must be implemented using the Y 5800 series user programs.

The second coreload contains a standard 5451C operating system with some modifications so that it is compatiable with the modal software. The differences include: 1.) there is no overlay swaping capability 2.) the data headers have been rearranged 3.) the maximum block size that can be stored to the disc is 1024. The 5451C coreload has built in, User Programs 5,6,88,100, the digital to analog converter (DAC) and the hardware Zoom (option 670).

2.7 MODE SHAPE PROGRAMS

User Program 0009 is the software which contains the operational logic of the Modal System. This program is entered from the Fourier System in the same way as a standard User Program -- that is, by entering " Y 9 " on the keyboard or terminal. Once the program has been entered, there are a variety of mnemonic commands available which direct the system to perform various functions. Most of the rest of this manual discusses this structure and the uses of each of the commands.

Within Y 9 there are three monitors, and each monitor has associated with it a set of available commands. The monitors in the Modal System are as follows:

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DATA SETUP AND DISPLAY MONITOR -- " * " MONITOR

CONNECTIVITY MONITOR ------------ " C " MONITOR

CIRCLE FIT MONITOR ------------- " D " MONITOR

The characters (if any) associated with each monitor are
the characters printed on the terminal after a user-entered
command has been executed. They signify that the system is now
waiting for a new user command to be entered.

Once the program has been entered, you interact with the
system through the system terminal or Fourier Keyboard. You
communicate to the system by entering commands, parameters, and
data in turn. The system communicates with you by printing out
messages, warnings, parameters, and data as requested or
needed.

Functionally, the Modal System can be broken into four
sections, each of which is described in detail in a seperate
section of this manual.

2.7.1   Data Setup Section

Using the appropriate commands, the details of the test
setup, a spatial description of the structure being tested, and
the order in which the structure's points are to be displayed
(display sequence) are entered into the system.

2.7.2   Parameter Estimation Section

This section allows the user to identify the modal
parameters (frequency, damping and complex coefficient) of up

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to 10 modes from the frequency response data, print the list of parameters for inspection, and save the results of this process to the disc. This process may be performed on measurements taken in any of three directions at as many as 250 structure points.

2.7.3   Data Display Section

Using the data accumulated in the Data Setup and Acquisition Sections, you may construct an animated display of the test structure's modes of vibration. In addition, the animated modes of individual structural "components" (see section 3) may be displayed separately for closer examination. You also have a wide variety of commands available which control such items as the size and position of the display and the amplitude and speed of the animation.

2.7.4   Data Presentation Section

Once a display has been calculated and displayed on the 5460 display unit, a plot can be initiated to the 2648A terminal, 7210 plotter, 9872 plotter, 7245 plotter, or a raster dump from the 2648 terminal to a 2631G line printer. Display of ASCII text to the 5460 display unit is also available for use in movie or video tape. After the necessary frequency response measurements have been made on the test structure, the above four sections of the Modal System enable you to perform a complete modal analysis of that structure.

The above four sections of the Modal System are set up to run in a dynamic overlaying environment. In other words, if an operation is requested that is available in only one of the programs, that program (in overlay form) will be loaded and executed. To accommodate this feature, the 13 required overlays (out of a total of 14) must be loaded into the disc in order, and the largest overlay (10) must be executed first allowing the data space to reallocate. Thereafter, any other

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overlay could be loaded but data space must not be reallocated.

2.8 SYSTEM INITIALIZATION

When the Modal System is entered for the first time, it will automatically perform some initialization (further initialization is performed during a K 0 command). Once the initialization has been performed, it is never performed again (in normal operation) unless the original software is reloaded into memory, the initialization is then performed when the first " Y 9 " call is made after each such reloading.

2.9 SYSTEM BLOCKSIZES

When the Modal System is entered by the call " Y 9 " the system records the current blocksize (denoted "external blocksize) and then operates from an "internal blocksize" which is dependent upon the section of the program being used. These blocksizes are determined as follows:

    DATA SETUP SECTION ---------- "INTERNAL" BS = 1024

    DATA AQUISITION SECTION ----- "INTERNAL" BS = "EXTERNAL" BS

    DATA DISPLAY SECTION -------- "INTERNAL" BS = 1024

The "internal" blocksize of the Modal System may not be changed.

When the program is exited normally (that is, by using

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commands) the external blocksize is always restored. If the
program is aborted by pressing "RESTART" on the keyboard, the
blocksize resulting will be the "internal" blocksize.

        In general, before entering the Modal System, it is
advisable to set the blocksize (using the Fourier "BLOCKSIZE"
command) to the value desired for the test. With this version,
the measurements will be made using the 5451C software in
coreload 1, rather than the Modal System software in coreload
0. Consequently the block size normally used in the Modal
System software will be 1024.

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3.1   Overview

     There are two phases of the Modal System setup. A test
setup using User Program Y 90 and a data setup using Y 9.

3.2   User Program Y 90

     This program is a utility program written to handle
operations connected with the modal package that due to space
or convenience could not be programmed elsewhere.

     Three primary functions are handled within Y 90. The
first function is that of inputting test set-up information
that will be stored in the header with each data record stored
to the disc by User Program Y 88. The second function provides
three forms of run logs for a disc with data stored in the
format generated by Y 88. The third function is that of
correcting information stored in the header area of each disc
data record.

     The program operates in a monitor mode as does the mode
shape program. The prompt character generated by Y 90 is "@ ".
This character is written on the terminal and indicates that
the program is ready for the next command. Commands can be
entered from the Fourier keyboard or from the terminal.

     To enter the program, overlay 0 must be in memory. At
bootup, overlay 0 is automatically brought into memory. If

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some other overlay is currently in memory a "Mass Store" 38 0
ENTER, followed by a Mass store 18 1 Enter, will bring in the
correct overlay. With the correct overlay in memory a Y 90
command is entered from the Fourier keyboard or the terminal.
After the prompt character is printed, any of the commands
which follow can be entered.

3.2.1   CLEAR - CL

CL N1 N2   *** CLEAR BUTTON***

        N1 = First record of disc file 1 data space to be
             cleared (default value = 1)

        N2 = Last record of disc file 1 data space to be
             cleared.

                    (If N1 is given, then N2 default value = N1)

                    (If N1 is not given, then N2 default = 819)

     When data is stored to the disc a header with test
information is also stored. This command resets one word of
the header so that the Y 88 program will know that the data
record is available for storing new data.

     This command does not alter the data or the test setup
stored with the data. In case a record is accidentally
cleared, it can be "uncleared" with the /R (REPLACE) command
described later.

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3.2.2   KEYBOARD - K

K   N1 N2   *** KEYBOARD BUTTON ***

This command is used to input the test setup information

N1 = 0 (default value)
    Enter test I.D. and date

N1 = 1
    Enter model number, serial number and calibration
    of load cell and transducer(s)

N1 = 2
    Enter zoom information if zoom processing is used,
    and test type (random or impact)

N2 ≠ 0 (default value)
    Allows input of information required by part N1 of
    this test setup.

N2 = 0
    Initializes all information associated with that
    part of the test setup that is specified by N1.
    Only parts 2 and 3 can be initialized by specifying
    N2 = 0.

The calibration numbers for the transducers are stored as
real numbers. If the calibration numbers is positive it
represents a constant by which all data in the block can be
scaled. If the calibration is negative it represents the disc
data record where the appropriate calibration curve is stored.
If the calibration is zero then no calibration is specified.
User Y 90 does not perform the calibration of the data.

The test I.D. is comprised of 10 ASCII characters. The
I.D. should be left justified, i.e., do not enter spaces
before the first letter of the I.D.

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3.2.3   LIST   /L

```
/L N1 N2 N3                       *** LIST BUTTON ***
------------
```

N1 = 1

> Run log type 1, listing is in order of disc data
> records between N2 and N3 that contain the test I.D.
> and zoom range specified. After the /L 1 command is
> entered, the user is prompted for the test I.D. and
> zoom range. If "ZA" is specified for the zoom range,
> then all zoom ranges are listed. The Analog In (RA)
> button is equivalent to entering ZA at the terminal.

N1 = 2

> Run log type 2, listing is in order of point numbers.
> Shows data records between N2 and N3 that contain data
> stored with test I.D. and zoom range entered by the
> user. A specific zoom range between Z0 and Z5 must be
> entered. A negative disc record number indicates a
> negative transducer orientation.

N1 = 3 (default value)

> Run log of all test I.D.'s and zoom ranges stored on
> the disc between records N2 and N3.

N1 =4

> Searches disc between records N2 and N3 for records
> stored with the specified test I.D. Each record is
> checked for zoom range. The minimum frequency and
> delta frequency for each zoom range is stored. After
> all zoom ranges in records checked, are found, they are
> printed out with minimum, center, maximum and delta
> frequency for each range. If multiple frequency
> information is found for any zoom range a warning is
> printed for each record with the different frequency
> information. Switch register bit 15 can be used to
> supress the warning.

N2 = first record of search (default value = 1)

N3 = last record of search

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(If N2 is given, N3 default = N2)

if N2 is not given, N3 default = 819)

The output device is selected by the switch register (bit 6 =
line printer (HPIB device), default = terminal). If the output
is a line printer, then the number of lines per page is
adjusted for an 11 inch page. If the output device is the
terminal then a RESET PAGE command is sent to the terminal
before the first page is listed. The number of lines per page
is adjusted to just fill the terminal screen. If switch
register bit 0 is on then the paging feature is defeated and
the output consists of continuous lines with a single header at
the beginning of the list. Paging resumes when bit 0 is turned
off.

3.2.4   STORE - X>

X> N1   *** STORE BUTTON ***

    N1 = Disc data record where test setup information will
         be stored (default value = 19)

    When setup information is entered using the K (KEYBOARD)
command the information is in computer memory only. The
STORE command stores this information in record N1 of the
disc data space.

3.2.5   LOAD X<

X<   *** LOAD BUTTON ***

    N1 = Disc data where test setup information has been
         stored (default value = 19).

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This command recovers the test setup information from disc data record N1 and places it in computer memory. Before returning to the monitor mode the test I.D. and the date are printed on the output device.

3.2.6   PRINT - W

W   N1 N2 N3   *** PRINT BUTTON ***

  N1 = 0

        Prints test I.D. and date to the output device
        specified by the computer switch register (bit 1) or
        default = terminal, bit 6 = line printer).

  N1 = 1

        Print out information entered through the KEYBOARD 1 (K
        1) command.

  N1 = 2

        Prints out information entered through the KEYBOARD 2
        (K 2) command.

  N1 = (defaulted)

        Prints put all test setup information entered through
        The KEYBOARD command. Any section initialized and
        containing no setup information will not be printed.

  N1 = 4 N2 N3

        This command prints out all test setup information
        stored in the header area of record N2 if N3 is not
        entered. If N3 is entered then just the information in
        header word number N3 of record N2 is printed out.

    As mentioned above, the switch register determines the output device. If bit 4 is turned on, then the setup is dumped to the paper tape punch. No output is made to any other device. After punching out the tape, the prompt character will be printed on the system terminal.

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3.2.7 SUBROUTINE - <

```
<                          *** SUBROUTINE BUTTON ***
------
```

This command causes control to be returned to the Fourier system.

3.2.8 POINT - /.

```
/.                         *** POINT BUTTON ***
-------
```

N1 = Point number to be searched for.

N2 = First disc data record to be checked
     (N2 default value = 1)

N3 = Last disc data record to be checked
     (If N2 is given, N3 default value = N2)
     (If N2 is not given, N3 default value = 819)

This command searches data records N2 to N3 for data with response point number N1. When a record is found that has point N1, then the point number, response transducer orientation and the disc data record are printed out.

3.2.9 INTEGRATE - $

```
$  N1 N2                    *** INTEGRATE BUTTON ***
---------
```

N1 = first disc data record to be checked
     (N1 default value = 1)

N2 = last disc record to be checked
     (If N1 is given, N2 default value = N1)
     (If N1 is not given, N2 default value = 819)

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The program formerly used to store data to the disc used channels in the data space near the end of the data block to store the test I.D., date, point number and transducer orientation. This format is not compatible with the new mode shape program. The INTEGRATE command allows the user to change the format by searching from record N1 to N2 for the data stored with the old test I.D. (The user will be prompted for this information). These records are restored on the disc with the new format using the new test I.D. entered through the KEYBOARD 1 (K 1) command, and pertinent information entered through K 2 and K 3 commands. The date, point number and transducer orientation are read from the old format and added to the new format. Information concerning minimum and delta frequencies will not be stored with the data. These may be added using the REPLACE command. Test type, load cell information and exciter position and direction will be stored, if entered. When a record is changed, the point number and orientation are outputted to the terminal unless bit 15 of the switch register is on, in which case, the program continues but no output is printed.

3.2.10   PHOTOREADER - R

R   *** PHOTOREADER BUTTON ***

This command is used to read a punched paper tape of a test setup. The tape must have been punched out using the PUNCH (P) command or the WRITE command with bit 4 turned on. When this command is given, a pause is executed which halts the computer giving the user time to load the paper tape reader. When the reader is ready the user simply pushes the RUN button on the computer.

The same action will result if a KEYBOARD (K) command is given with bit 5 of the switch register turned on.

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3.2.11   PUNCH - P

P   *** PUNCH BUTTON ***

     This command punches out a paper tape of the test setup.
The same action results if a WRITE (W) command is given with
bit 4 of the switch register turned on.

3.2.12   REPLACE - /R

 /R N1 N2   *** REPLACE BUTTON ***

        N1 = first disc data record where test setup information
             is to be corrected. (N1 default value = 1)

        N2 = last disc record to be corrected.
             (If N1 is given, N2 default value = N1)
             (If N1 is not given, N2 default value = 819)

     This command is used to correct header information. All
records between N1 and N2 will be changed regardless of test
I.D. or zoom range. The information that can be corrected by
using this command is that which is independent of the
transducer. This would be, for example, test I.D., zoom range,
load cell information or frequency information. After giving
this command, the user may request a list of header word
numbers where changes may be made.

     If this command is being used to "unclear" disc data
records accidently cleared using the CLEAR (CL) command, the
user should specify header word number 6. No further input is
required in this case.

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3.2.13   CONVOLUTION - CV

```
CV  N1 N2            *** CONVOLUTION BUTTON ***
----------
```

> N1 = first disc data record of search
>   (N1 default value = 1)
>
> N2 = last disc data record of search
>   (If N1 is given, N2 default value = N1)
>   (If N1 is not given, N2 default value = 819)

This command is used to correct header information associated with the response transducer. Disc data records N1 to N2 are searched for either a transducer number (1,2 or 3) or a transducer serial number. The only valid transducer numbers are 1,2, or 3. If an invalid transducer number is entered, then it is assumed that the search will be on a transducer serial number which the user is then asked for. Each time the correct transducer number or a transducer serial number id found, the corrected information is placed in the specified header word.

3.2.14   INTERCHANGE - X

```
X  N1 N2             *** INTERCHANGE BUTTON ***
-----------
```

> N1 = first disc data record of search
>   (N1 default value = 1)
>
> N2 = last disc data record of search
>   (If N1 is given, N2 default value = N1)
>   (If N1 is not given, N2 default value = 819)

This command is used to interchange transducer information. Disc data records N1 to N2 are searched for point number and transducer number. The user must enter a list of where and how the transducer information is to be reorganized. For example, if the number of response directions is three then three lines should be entered when asked for new and old

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transducer numbers.   If the following were entered:

        1, 3
        2, 1
        3, 2

        Then the information that was stored where transducer
number 3 was, will be stored where transducer number 1 was.
Since the transducer number can also be interchanged, the above
numbers refer to the transducer numbers before the interchange
is performed.

        The user must also enter a list of header word numbers
corresponding to the information that is to be interchanged.
Word numbers 19, 47, 48, 51 and 79 can be interchanged,
however, word 51 (transducer number) specifies which data block
that data came from when user program Y 88 stored it, and
should probably not be changed.

        Finally, the user must enter a list of point numbers that
are stored between disc data records N1 and N2.   The method of
entering these point numbers is the same as for entering the
connectivity file in the mode shape program.   Two numbers may
be entered per line (N3, N4).   If N3 is not equal to N4 then
points N3 through N4 are added to the list begining with N3 and
ending with N4.   If N4 is not entered, then only N3 is added to
the list.   If N3 is less than or equal to zero then the list is
terminated.   No editing of the list is allowed.   The user may
then request a list of the point numbers.   The point numbers
should be in the same order as they are stored on the disc.
This minimizes the amount of search time required to find the
needed data records.

        The program starts with disc data record N1 and begins
searching for the first point number in the list.   Each time
the correct point number is found, the data is checked to be
sure that the transducer number has not already been found.   If
at any point in the search, an error is found involving a
particular point number, an error message is printed out giving
some information as to the type of error and the point number
is skipped, i.e.   the headers are not altered.   These points
can be looked at later to determine why the error occured.

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Errors that can occur are:

1) A point at either end of the search range may not
   be entirely within the range which means that fewer
   directions than the number of directions specified
   will be found.

2) The point may have been repeated within the search
   range resulting perhaps in the same transducer number
   being found twice.

3) The transducer number may not be a valid number
   (1, 2 or 3).

If a point is repeated within the search range, either
enter that point in the point number list each time it is
repeated or omit it and go back later using a search range that
covers only one of the sets of data at a time. Otherwise, only
the first occurance of that point number will be interchanged.
When the search reaches later occurances of the point number,
it will be searching for other point numbers and nothing will
be done to these.

3.2.15   SWITCH REGISTER OPTIONS

OUTPUT CONTROL

Bit 0 - continuous run log output, no paging

Bits 3-8 are checked, lowest numbered bit that is on
    sets logical unit number of output device. Default
    (no bits on) sets logical unit number to 1
    (terminal).

Bit 4 - punch

Bit 6 - line printer

INPUT CONTROL

All information is inputted through the Fourier System
keyboard or the terminal except for when reading a
punched paper tape of a test setup.

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Bit 5 - photoreader input.

PROGRAM CONTROL

Bit 14 - exits from certain portions of the program:
(/R, X , CL, /L, W , CV, /.)

Bit 15 - supresses print out during run logs and integrate
command. Print out resumes when bit 15
is turned off.

Before entering the monitor mode bits 4, 5, 14, and 15 are
turned off if found to be on. Bit 0 is turned off after any
run logs.

3.2.16   HEADER WORD NUMBER INFORMATION

The following may be corrected using the REPLACE (/R) command.

WORD #   USAGE

ASCII STORAGE AREA

10   TEST ID
24   EXCITER ORIENTATION
26   DATE
30   TIME
34   DATA TYPE CODE
36   ZOOM RANGE

INTERGER STORAGE AREA

45   RESPONSE POINT NUMBER
46   EXCITATION POINT NUMBER
49   LOAD CELL MODEL #
50   LOAD CELL SERIAL #

REAL STORAGE AREA

75   MINIMUM FREQUENCY
77   DELTA FREQUENCY

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The following may be corrected using the CONVOLUTION (CV) or INTERCHANGE (X) command.

WORD #   USAGE

ASCII STORAGE AREA

19   TRANSDUCER ORIENTATION

INTEGER STORAGE AREA

47   RESPONSE TRANSDUCER MODEL #
48   RESPONSE TRANSDUCER SERIAL #
51   RESPONSE TRANSDUCER NUMBER

REAL STORAGE AREA

79   DATA CALIBRATION OR RECORD #

3.3   USER PROGRAM Y 9

The Data Setup Section of the Modal System is entered by typing " Y 9 " on the system terminal. The program will then respond by printing a " * " on the terminal, signifying that you are currently operating from the " * " monitor.

3.3.1   STRUCTURE DESCRIPTION

Knowing how to describe the test structure to the system in the Display Setup Section is of the utmost importance in obtaining meaningful displays of the analysis results.

The Modal System allows you to describe a test structure in terms of up to 10 component coordinate systems, each component system having its own origin and orthogonal orientation with respect to one global coordinate system. Once these component systems have been defined, all structure measurement points may be described relative to these systems. Furthermore, points may be described within the component

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coordinate systems in either rectangular or cylindrical coordinates, following certain guidelines discussed later.

To enter the data setup mode, a command is entered from the Fourier System or the terminal. The Modal System is entered and a program will respond with an " * " prompt being typed on the terminal. This indicates that it is in the monitor. The Data Setup mode is then called by the following commands:

3.3.2   KEYBOARD - K   Commands

K   N1   *** KEYBOARD ***

The basic procedure is as follows. Using the "KEYBOARD" button, the sequence required for setup is:

        K 0 Test Setup Information

        K 1 Structure Components

        K 2 Structure Coordinates

        K 3 Structure Connectivity

        K 4 Modal Coefficients

After each of the commands, questions or input will be required as explaned in the following sections.

N1 = 0

        The test ID, date and number of test points are
        requested. The maximum number of modes to be analyzed
        per session will be calculated. A request to clear
        data from a previous setup (components, geometry,
        connectivity, and modal coefficients) or only the
        current modal coefficients is made.

Test ID   = ten characters

Max. test points   = 250

Max. modes   = 10

Max. # of components   = 10

N1 = 1

The X/Y/Z coordinates of each component origin with
respect to the global system must be inputted (X,Y,Z).
The orientation of the component coordinate system axis
with respect to the global system axis (IX,IY,IZ) and
the code for rectangular or cylindrical coordinate
system (IC) is also inputted.

The code for inputting the orientation of the component
coordinate system axis is used to determine the
direction of the x, y, z axis in the component system
with respect to the global system axis. A plus or
minus one, two, or three is inputted for the x, y, z,
axis respectively. For example, if the y axis of the
component runs in the +x direction of the global
system, then a +1 is entered for IY. If the z axis of
the component runs in the negative y- direction of the
global system, the IZ = -2 etc. The use of direction
cosines in not allowed.

The code for the type of coordinate system is one (1)
for rectangular and zero (0) for cylindrical.

N1 = 2

The point number, x, y, z, coordinate of the point, and
the component number is inputted for each point. A
zero or negative entry of the point number will
terminate the entry. To change a point or to edit,
simply reenter the data for the desired point.

N1 = 3

This is the input for the connectivity of the

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structure.   Due to the complexity of this input, the
next section describes this input.

N1 = 4

This is the modal coefficient input and output command.
The mode number, point number, and x, y, z, deformation
and phase angle values can be inputted.

The data inputted during the keyboard entry can be
printed out with the print command from the display
monitor.

As an example of how the points on a structure may be
spatially described to the system, let us consider the
structure of figure III-1 and assume that we wish to
describe this structure in terms of two components
systems, one for the "box" and one for the "cylinder".
Let us also assume that we wish to describe to the
system the spatial locations of the points marked "PT
1" and "PT 2" in terms of the two component coordinate
systems.

We must first tell the system the component origins in
rectangular coordinates (X,Y,Z) With respect to the
global origin and the global axes.   The origin of
component system 1 is thus determined to be (3,0,2),
while that for system 2 is (4,1,1).

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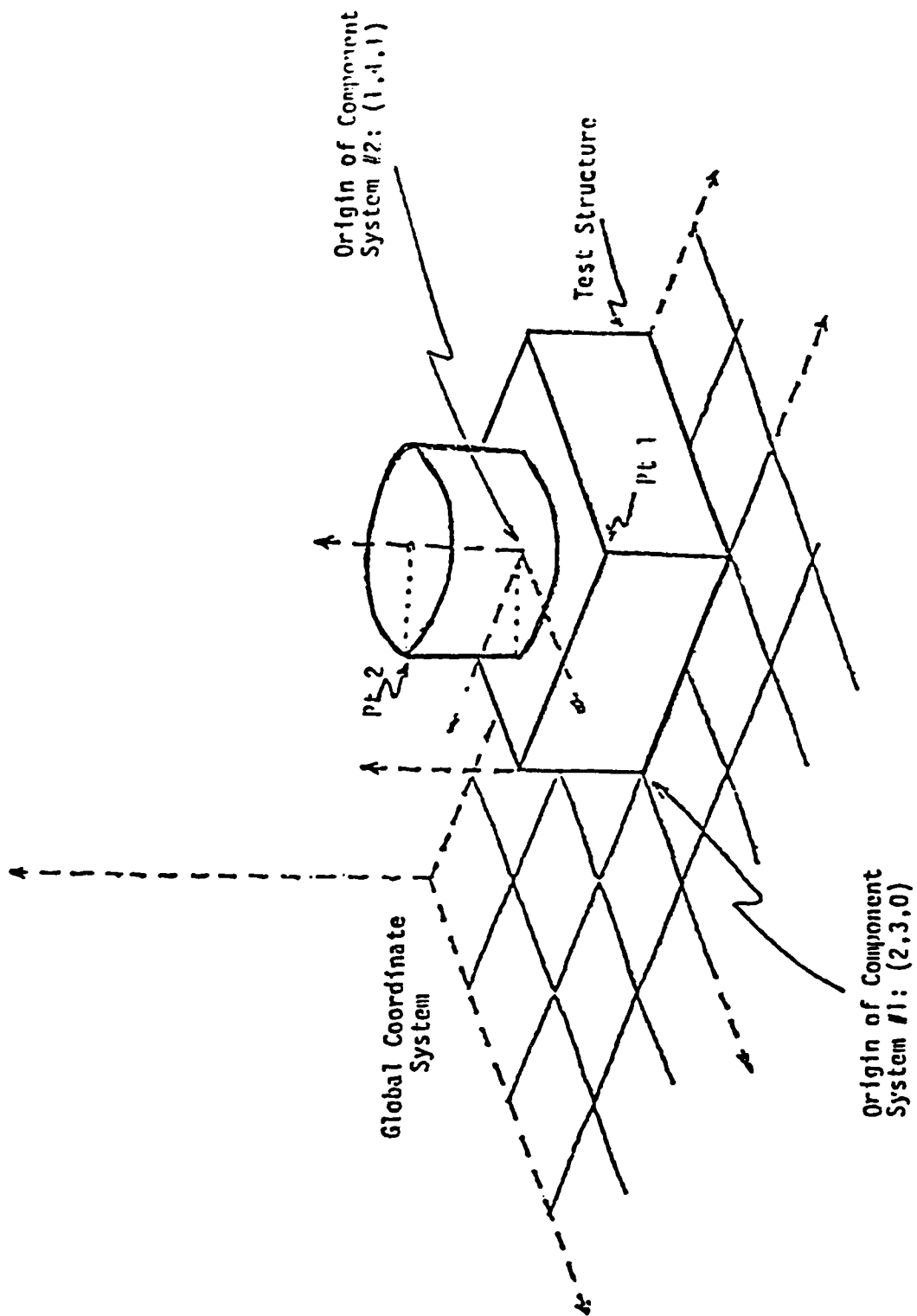
Figure III-1. Example of Component System Definition

Next it is necessary to describe the component system
axis orientation with respect to the global system
axis. All component axes must be co-linear with any
one of the global axes so that only three variables are
needed to describe the orientation for each component
system these variables are denoted IX, IY, and IZ.
Each of these variables is either +1, +2, or +3
depending upon which global axis direction coincides
with a particular X, Y, or Z component positive axis
direction. The convention for determining IX, IY, IZ
is easily established by considering the two sample
components. For component system 1, the component
positive X axis is in the global positive Y (+2)
direction (IX = +2), the component positive Y axis is
in the global positive Z (+3) direction (IY = +3), and
the component positive Z axis is in the global positive
X (+1) direction (IZ = +1). For component system 2,
the component positive X axis is in the global negative
X (-1) direction (IX = -1), the component positive Y
axis is in the global positive Z (+3) direction (IY = +
3), and the component positive Z axis is in the global
positive Y (+2) direction (IZ = +2).

Now that the component information for this structure
has been completely specified, it necessary to enter
the coordinates of each point on the structure relative
to the components. Any combination of points may be
defined to be on any component -- it is most useful,
however, to define points lying on a complete physical
"substructure" to be on the same component. In our
example, therefore, it would probably be most useful to
consider points on the "box" in component :, and points
on the "cylinder" in component 2.

The coordinates of each point within a component system
may be described in either cylindrical or rectangular
coordinates, depending upon which description is most
natural. (The "coordinate type" is a variable that
must be given along with the coorinates for each
point). Considering our example, we see that the "box"
part of the structure is most naturally described in
rectangular coordinates, while the "cylindrical" part
of the structure is most naturally described in
cylindrical coordinates. Therefore, when describing
points on these structure components, we would probably
use the corresponding coordinate types for our

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description. When cylindrical coordinates are to be used, the following two rules apply:

1)

The Z axis of the cylindrical (r, theta, Z) system should coincide with with the Z axis of the system.

2)

Angle Convention:

Component X axis: theta = 0 degrees

Component Y axis: theta = 90 degrees

Therefore, positive theta is determined by use of the "right hand rule".

Using the above conventions, the coordinate data for two points of interest may be easily described. Point 1, on structure component 1, is described in terms of component coordinate system 1 and rectangular coordinates, so that (X_1, Y_1, Z_1, IC_1) = (1, 0, 2, 1) ... (IC, the coordinate type variable, is (0) for cylindrical and (1) for rectangular Coordinates). Similary, point 2 on component 2 is described in cylindrical coordinates as (r_2, theta 2, Z_2, IC_2) = (0.5, 45, 1, 0).

For display purposes, it may at times be useful to define the component origin such that the structure is " broken apart". For example, if the origin of component system 2 in Figure III -1 had been defined to be at (4, 1, 3) rather than (4, 1, 1), the cylindrical portion of the structure would be seperated in the Z direction from the rest of the structure on the display, and the "hidden" corner of the "box" would now be visible. This is simply done since the structure of the Data Setup Section allows the component origins and all other structure information to be altered at any time.

3.3.3   FLOATING POINT DATA

In the Data Setup Section, floating point values entered for
the test point coordinates are stored in a data "block floating
point" form in a system data block.   In the Data Acquisition
Section, floating point modal coefficients are also stored in
"block floating point" format in system data blocks.   This
floating point representation increases the system capability
compared to a simple integer representation, but has
limitations of which you should be aware when operating the
system.

     Figure III-2 demonstrates the inherent limitation of the
system's data block floating point number storage.   Test point
coordinates ranging from 1 to 10000 were entered into the
system (as an extreme case), and were in turn stored by the
system in one of the system data blocks.   Due to the fact the
scaling of this data block is determined by the largest number
it contains, it can be seen that the smaller numbers suffer
greatly in accuracy compared to the larger numbers.   For
example, the number 10, three orders of magnitude smaller than
the largest number in the block, has incured a 1% error in this
representation and becomes 9.91.   Smaller number fare even more
poorly.

     A reasonable rule of thumb is that the coordinate file and
the modal coefficient file should differ within the file from
the largest to the smallest by no more 2 or at most 3 orders of
magnitude to retain full calculational accuracy.

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PT		CORRDINATED		COMP	ENTRY	ERROR/ENTRY
1	.58	.58	.58	1	1	4.2E-1
2	1.75	1.75	1.75	1	2	1.2E-1
3	4.67	4.67	4.67	1	5	6.6E-2
4	9.91	9.91	9.91	1	10	9.0E-3
5	19.83	19.83	19.83	1	20	8.5E-3
6	49.57	49.57	49.57	1	50	8.6E-3
7	99.73	99.73	99.73	1	100	2.7E-3
8	199.45	199.45	199.45	1	200	2.7E-3
9	499.80	499.80	499.80	1	500	4.0E-4
10	999.59	999.59	999.59	1	1000	4.1E-4
11	1999.77	1999.77	1999.77	1	2000	1.2E-4
12	4999.14	4999.14	4999.14	1	5000	1.7E-4
13	9999.45	9999.45	9999.45	1	10000	5.5E-5

Fig. III-2 Example of Floating Point Number Storage

3.3.4   DATA SETUP SECTION -- Command Summary

There are five "files" which may be edited and listed using the commands in the Data Setup Section:

File 0 : Test Setup Information

File 1 : Structure Components

File 2 : Structure Coordinates

File 3 : Structure Display Sequence
          (connectivity)

File 4 : Modal Coefficients

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3.3.5   Data Setup Section -- Display Sequence File

The Display Sequence file is a sequence of numbers, each of which represents a point on the structure. The sequence specifies the order in which the structure points are to be displayed and how they are to be connected together (blanking on or off).

Let us consider the simple plate structure of Figure III-3a. After describing to the system the locations of the four points, we now need to decsribe to the system how to display the points. We therefore wish to start at point 1 (arbitrary) and draw a solid line through points 2, 3 and 4, and finally a solid line from point 4 back to point 1. The simplest display sequence which will accomplish this is:

Sequence	Point	
1	1	start at point 1
2	2	solid line to point 2
3	3	solid line to point 3
4	4	solid line to point 4
5	5	solid line to point 1

The display will cycle through this display sequence in the manner shown to produce a display like that of Figure III-3b (identical to that of Figure III-3a).

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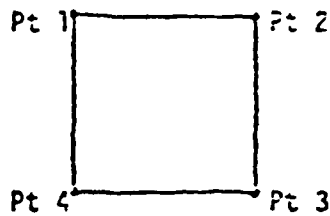
Fig. III-3a. Test Plate
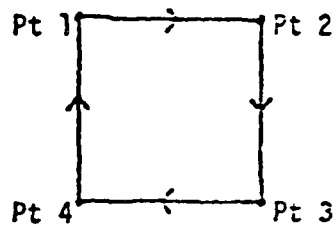
→ denotes direction of beam motion

Fig. III-3b. Test Plate Display
with Display Sequence File of

#	PT
1	1
2	2
3	3
4	4
5	1
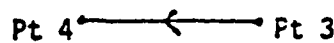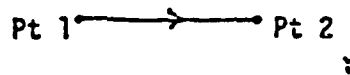
Fig. III-3c. Test Plate Display
with Display Sequence File of

#	PT
1	1
2	2
3	-3
4	4
5	-1

If it is desired to "blank" the beam from, say, point 2 to point 3, and from point 4 to point 1 (leaving horizontal lines only) the display sequence file would be:

Sequence	Point	
1	1	start at point 1
2	2	solid line to point 2
3	-3	blank to point 3
4	4	solid line to point 4
5	-1	blank to point 1

Note that, to blank the beam, the end point of the blanking is negative. The display for the above display sequence file would be that of Figure III-3c.

When constructing a display sequence, it is suggested that the following three rules be followed:

1)

If possible, close all possible sequence loops explicitly within the display sequence. If this is not done, confusing displays may result (the deformed and undeformed structure displays may be

2)

Points on the same component should be "grouped together" in the display sequence file, if possible.

3)

The first point of a component should always be blanked to give correct partial displays by component.

The fact that structure components can be displayed individually (see Chapter 5) must be taken into account when constructing a display sequence file, and adding "dummy" points may be necessary to obtain correct displays in all cases. For

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example, consider the "T – Plate" of Figure III-4a, defined by 8 test points. Let us assume the display sequence for the T-Plate is as follows:

Sequence	Point	(Component)
1	-6	1
2	1	1
3	2	1
4	3	1
5	4	1
6	5	1
7	6	1
8	7	2
9	8	2
10	3	1
11	6	1
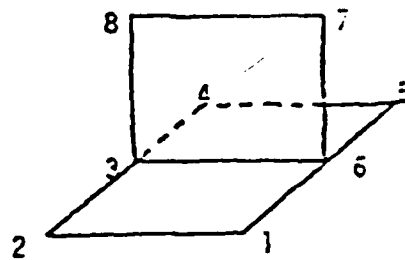
Pts 1-6: Component 1
(Horizontal Plate)

Pts 7-8: Component 2
(Vertical Plate)

Fig. III-4a. T - Plate
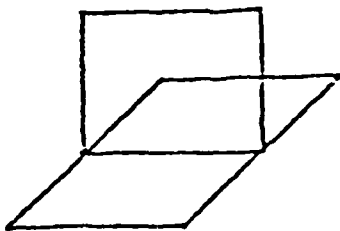
Fig. III-4b. Both Components
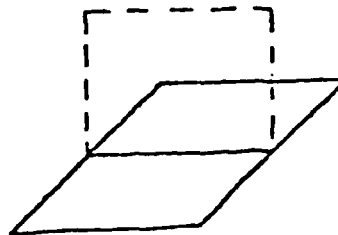
Fig. III-4c. Component 1
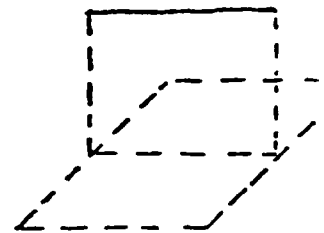
Fig. III-4d. Component 2
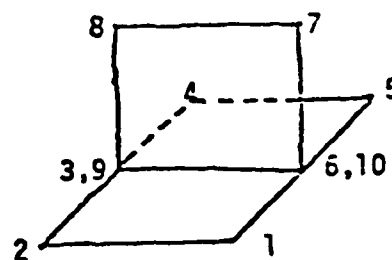
Pts 1-6: Component 1
(Horizontal Plate)

Pts 7-10: Component 2
(Vertical Plate)

Fig. III-4e. T - Plate with "Dummy" Points
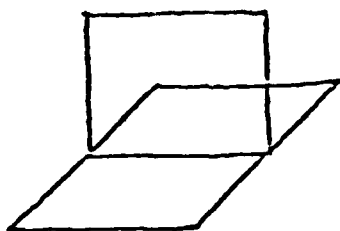
Fig. III-4f. Both Components
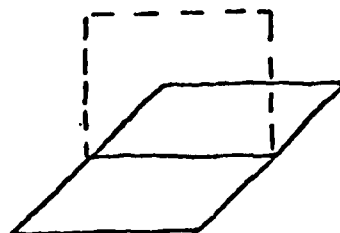
Fig. III-4g. Component 1
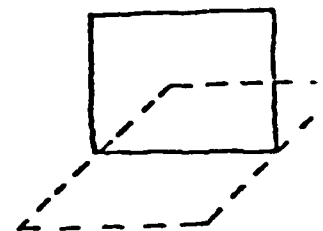
Fig. III-4h. Component 2

Let us also assume we would like to consider the T-Plate comprised of two components, one for the horizontal plate and one for the vertical plate. We therefore define points 1 - 6 to lie on component 1, and points 7 and 8 to be on component 2.

When both components 1 and 2 are displayed, the desired display of Figure III-4b results. However, when only one of the two components is displayed, the display sequence entries for points on other components are effectively non-existent. When component 1 alone is displayed, this is of no consequence as Figure III-4c shows however, the display of component 2 alone is incomplete due to the missing lines formerly provided by the simultaneous display of component 1 (Figure III-4d).

Figure III-4e shows the T-Plate redefined with dummy points 9 and 10, defined to be in the same locations as points 3 and 6 except on component 2 rather than component 1, included.

The correct display sequence would now be:

Sequence	Point	(Component)
1	-6	1
2	1	1
3	2	1
4	3	1
5	4	1
6	5	1
7	6	1
8	-10	2
9	7	2
10	8	2
11	9	2
12	10	2
13	-3	1
14	6	1

The new displays are shown in Figures III-4f, III-4g, and III-4h which display the structure and its components as desired.

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The above display sequence file happens to be a good
example of a display sequence following the rules given above
that is, all sequence loops (there are three -- one for each
component seperately and one for the two components combined)
are explicitly closed, and the points defining components 1 and
2 are "grouped together" in the file. To illustrate what
happens if these rules are not followed, you should consider
the the following display sequence file for the T-Plate of
Figure III-4e:

Sequence	Point
1	6
2	1
3	2
4	3
5	8
6	7
7	6
8	5
9	4
10	9
11	10
12	6

and why it would be unsatisfactory for displaying only one
T-Plate component at a time.

3.3.6   Data Setup Section -- Monitor Commands

Note: () denotes optional parameters

3.3.7   KEYBOARD - K 3

K 3   *** KEYBOARD BUTTON ***

This command is used to enter the Display Sequence Monitor.

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This is a very inportant input and great effort has been spent
on trying to automate the connectivity file. The maximum
number of connections cannot be greater than 500.

In this mode, a secondary monitor is used to input the
connectivity. This monitor is denoted "C" and uses the
following commands for input:

3.3.8   COUNT -

N1   *** COUNT BUTTON ***

    This command can be used to reset the counter to
the value N1. The counter is the number of the last
display vector (connectivity) entered. If a new
display sequence is ever required, the old connectivity
file can be eliminated by setting the counter to zero
(N1 = 0). The connectivity file is stored using line
numbers with one line number per vector (the vector is
the ending point number of the beam trace).

3.3.9   KEYBOARD - K

K   *** KEYBOARD BUTTON ***
-------   /

    The Keyboard command is used for entering the connectivity
file.

    After the K command is issued, the computer waits for
input N1 and N2 can be entered. If N2 is greater than N1 in
the connectivity file, the counter is incremented and the
connectivity from N1 to N2 is sequentially stepped. If N2 is
defaulted, the N1 value is added to the connectivity file and
the counter is incremented. If N2 is less than N1 the

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connectivity is incremented from N2 to N1. This input is
terminated by inputting zero (0) for N1.

    If it is desired to move from point A to another point
without drawing a line, N1 should be equal to a negative of
point B.

    Line numbers are automatically calculated and updated by
way of the counter. Termination returns the user to the
Display Sequence monitor.

3.3.10   DELETE - /D

 /D N1 (N2)   *** DELETE BUTTON ***

    This command will delete the connectivity file from
counter N1 to N2.   If N2 is defaulted then N1 will be deleted.

3.3.11   INSERT - /I

 /I N1   *** INSERT BUTTON ***

    This command will insert after counter value N1. After
the /I N1 command is input, then the computer will wait for an
input where N2 in entered. The value N2 will be entered into
the connectivity file. Additional values can be entered until
a zero value is inputted and control is returned to the
connectivity file monitor. Terminate with a 0.

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3.3.12   PHOTOREADER - R

```
R                            *** PHOTOREADER ***
-----
```

This command will read a paper tape that has been punched as a result of the print command.

3.3.13   REPLACE - /R

```
/R N1                        *** REPLACE BUTTON ***
---------
```

This command is used just like the insert command but eliminates line N1 with the first entry.

3.3.14   PRINT - W

```
W  (N1) (N2)                 *** PRINT BUTTON ***
--------------
```

This command will write the connectivity file for line number N1 to N2. If N1 is equal to 0, then the complete connectivity file will br listed. If switch register bit 14 is pressed, the output will be aborted. If switch register bit 4 is pressed prior to issuing this command, the output will be to the punch.

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3.3.15   RETURN - <

<   *** SUBROUTINE RETURN BUTTON ***

This command will return control to the display monitor.

3.4   DATA SETUP SECTION - I/O DEVICES

The I/O device selection in the Data Setup Section is
controlled by Switch Register bits 4, 5, 6, and 8.

Input: On input, the input device for the data entered
is determined by bit 5 or bit 8 as follows:

Bit 5	Bit 8	INPUT DEVICE
OFF	OFF	TERMINAL
OFF	ON	MAG TAPE, if available
ON	OFF	PHOTOREADER, if avail.
ON	ON	PHOTOREADER, if avail.

Output: On output, the output device is determined from
bit 4 and bit 6 as follows:

Bit 5	Bit 6	OUTPUT DEVICE
OFF	OFF	TERMINAL
OFF	ON	LINEPRINTER, if avail.
ON	OFF	PUNCH, if avail.
ON	ON	PUNCH, if avail.

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```
+-------------------------------------------------+--------------------+
|                                                 |                    |
|    PARAMETER ESTIMATION                         |    CHAPTER   4     |
|                                                 |                    |
+-------------------------------------------------+--------------------+
```

4.1   OVERVIEW

The Parameter Estimation Section of the modal system is
designed to obtain, automatically, data from file one of the
mass storage area of the disc, check to determine if the data
belongs to the current data set, and use one of four parameter
estimation techniques to determine the real or complex modal
coefficients. The four estimation techniques available are as
follows:

1) Amplitude (single degree of freedom)

2) Quadrature (single degree of freedom)

3) Kennedy-Pancu circle fit (single degree
   of freedom with constant residual)

4) Linear least squares (multiple degree of
   freedom with residual mass and stiffness)

A linear least square time domain program to calculate
global frequency and damping values is available to all four
techniques but is required for only the last technique. This
eigenvalue algorithm involves multiple measurements in the
calculation of frequency and damping to be used for residue
estimation.

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4.2   MEASUREMENT NOTES

In order to identify the modes of vibration of a structure, it is necessary that frequency response data be measured on the structure in such a way that the resulting data is sufficient to identify all modes of interest at all points of interest.   The Modal System requires that these measurements be made between a fixed "input" point (the point at which the force is applied) and multiple "response" points (the point at which the response to the input force is measured), or a fixed "response" point and multiple "input" points.

The frequency response measurements may be made using transient or random inputs and baseband or Band Selectable Fourier Analysis (ZOOM).The type of structure, testing convenience, and desired quality of the results being the prime consideration in making the choice between them.   Any of the "standard" frequency response programs documented in the 5451 Operating Manual may be used, or modified to measure the required data, in addition, these programs may be supplemented by the use of Y 5, and Y 6 (ADC overload, and number of channels check).   Coreload number 1 contains the 5451C software that allows measurements to be made using the 54420 DAC, and the 54470 Preprocessor (Zoom).   Y 88 is also part of this coreload and is used to store the measured data to the disc with the proper information so the data can be used by the Modal System (coreload 0).   Y 90 is also used in conjunction with Y 88 and both of these are described elsewhere in this manual.

4.3   EIGENVALUE ESTIMATION

The task of determining damped natural frequencies can be performed one of three ways:

1) Manually (channel Number)

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2) Cursor (channel Number)

3) Least Squares Eigenvalue (frequency and damping)

With the first two methods, only one piece of data can be used at a time. Therefore, it is wise to scan at least one frequency response function from all major structure components so that no important modes are inadvertantly missed. Operation of the cursor automatically stores the channel number and frequency with the designated mode.

With the third method, a linear least squares time domain method based upon complex exponentials is used to determine the exact damped natural frequency and damping rate. This process can involve any and/or all of the measurements taken. The nearest channel number and a calculation of bandwidth (number of channels on each side of the center frequency) is also performed to allow for any method of residue estimation.

4.3.1   EIGENVALUE - MANUAL

With this method, a data record of representative data will be requested followed by a request for mode and bandwidth. After this, the channel number can be entered from the terminal. (some valid data must be in block zero in order for the frequency calculation to be correct). No information concerning damping is utilized.

Once the information is stored, the mode number and bandwidth question will be repeated. To exit, a mode number of zero is entered.

4.3.2   EIGENVALUES - CURSOR

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In this method, a request for a representative data record is the first question asked, followed by the mode number and bandwidth. Again, damping information is not calculated or utilized.

After this data is inputted, block zero is displayed with the cursor superimposed. The switch register is used to control the cursor:

Switch 7 is fast right

Switch 8 is step right

Switch 13 is fast left

Switch 12 is step left

Switch 11 is expand around cursor position

Switch 9 returns data to computer

Switch 6 resets cursor to zero channel

Switch 5 aborts the cursor and returns a
        zero channel number for the
        currently requested mode

Once data has been returned to the program a new mode number is requested. When finished, a mode number of zero is entered.

4.3.3   EIGENVALUES - Linear Least Squares Time Domain

This method allows the calculation of eigenvalues for the system in certain frequency ranges of interest. So, a first request will be for a representative data record, followed by some questions of starting channel (manual or cursor entry) and number of channels in calculation. The range of interest is defined by starting channel and number of points to be used

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(64, 128, 256).

Because the method uses a great number of measurements, one must enter the first and last record of data to be taken into account, as well as the approximate number of measurements in the range.

4.4 RESIDUE - ESTIMATION

At the present time, the Modal System is capable of estimating complex modal coefficients with the limitation of magnitude resolution of 1 in 2000 and phase resolution of 1 in 10. The ability to animate a display is limited, though, to real modes. With this in mind, the parameter estimation techniques are as follows:

1) Amplitude - The magnitude and phase of a given frequency is recorded. The frequency can be chosen manually, with the cursor, or with the "starting value algorithm".

2) Quadrature - The value of the quadrature, or imaginary, part of the data at a specified frequency is recorded as the magnitude and the angle is assumed to be 90 degrees. The frequency can be chosen manually, with the cursor, or with the "starting value algorithm".

3) Kennedy-Pancu Circle Fit - The Modal System identifies modal coefficients from measured frequency response data by fitting circles in the complex-frequency (or argand plane) through the points centered at a mode's natural frequency and a number of data points on either side of the center channel.

    The magnitude is determined from the diameter of the fitted circle while the phase is determined in a similiar manner as in method one but a "displaced origin" is utilized to eliminate effects of other modes. The frequency can again be chosen manually,

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with the cursor, or with the "starting value algorithm".

4) Linear Least Squares Frequency Domain The Modal System executes a least squares error estimation of the data within a 64-128-256 data channel range based upon a frequency domain model of a multiple degree-of-freedom system. The process is linear since the starting values of frequency and damping are not allowed to change from measurement to measurement. The results are the complex residues for the measurement. The model is based upon the following equation:

$$ H(ij) = [SUM]_{r=1}^{N} \frac{A(rij)}{S - P(r)} + \frac{A(rij)*}{S - P(r)} $$

Where   A(r) = Complex residue
        A(r)* = Complex conjugate
        P(r) = a(r) + j w(r) = Eigenvalue
        w(r) = Damped natural freq.
        a(r) = Damping coefficient

4.5   COMPARISON OF TECHNIQUES

The choice of parameter estimation technique depends upon the system being tested. Each technique assumes certain characteristics and will not work well when these conditions are not met.

The amplitude and quadrature methods are limited since they use frequency response values at only one frequency for each mode. This is a rapid and straight forward process which is the basic attraction of these methods. In cases of close modes or high damping, the effects of nearby modes are not eliminated,

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thereby giving non-unique modes. Additionally, the finite
resolution gives rise to potentially large errors if the damped
natural frequency is not described correctly.

To provide more sophistication, the circle fit method can
be used to improve points in the neighborhood of the damped
natural frequency. This gives better results as long as a mode
is present in the argand diagram (that is, not at a node).

Again, resolution can be a problem (as well as noisy
data), but better accuracy can be obtained compared to the
first two methods. Even so, if the mode coefficient becomes
zero or if modes are highly biased or coupled, this method will
give confusing results and require manual control of the fit.
When run automatically, the speed is not objectional but when
run manually, the lack of speed becomes a problem.

In the situation where the first three methods fail, the
linear least squares frequency domain fit will provide some
success. This technique involves a multiple degree of freedom
frequency domain model to generate estimates of residues based
upon fixed values of frequency and damping in modes present
within a frequency range. To account for effects of modes
below the minimum frequency, a residual mass term (function of
the inverse of frequency squared) is included. Likewise, to
account for modes above the maximum frequency a residual
stiffness term (complex constant) is included. Using this
approach, closely spaced modes of vibration may often be
seperated.

4.6   CIRCLE FIT PRESENTATION

After a circle fit is computed for a mode, the system
displays the following waveforms on the 5460 display screen:

1) The circle fit for the present mode (this is only

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displayed with the 5460 switch in the COMPLEX position

2) The data center channel and (BW + 15) data points on
   either side of the center channel (if they exist).

3) (intensified). The data center channel and (BW) data
   points on either side of the center channel (if they
   exist).

    The data points may not exist for display, for example, if
the center channel of a mode was channel 5 and the bandwidth
was 2. In this case, the display of (2) above would extent
from data channel 0 to channel 22.

    If the mode center channel is near either end of a data
block, the system will use as many points as possible up to the
normal limit to calculate the circle fit and display the
results.

    The circle fit display is used to judge the acceptability
of the circle fit and, hence, the accuracy of the modal
coefficient determined from it. In general, the data points
should lie near or on the circle. Due to the finite
resolution, the points may not be evenly spaced on the circle,
especially for very lightly damped modes. A "typical" circle
fit display (for BW = 2) is shown in Figure IV -1.

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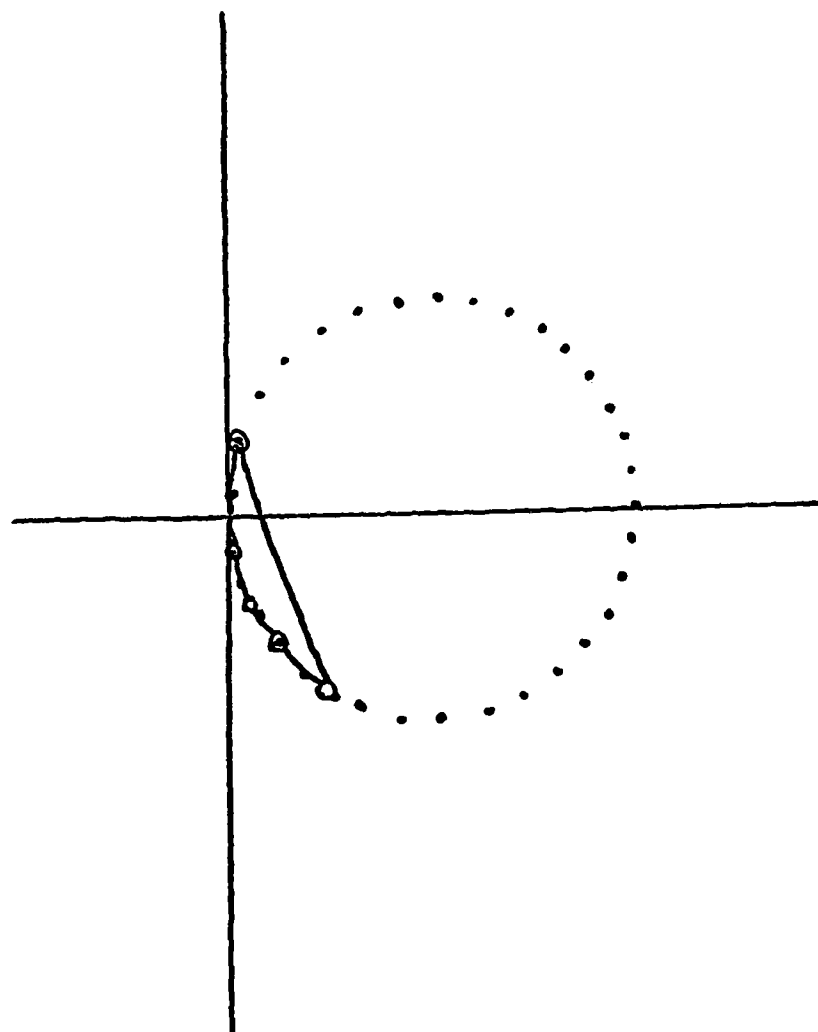
. denotes circle fit point

O denotes data point

Fig. IV-1. "Typical" Circle Fit Display (for BW=2)

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4.7 PARAMETER ESTIMATION - Command Summary

Note: ( ) Denotes optional parameters

4.7.1 ADD - A+

A+   *** ADD BUTTON ***

This mode of operation is primarily conservational. Seperate sub-monitors are available for circle fit, starting value algorithm, and linear least squares frequency domain parameter estimation.

The system prompts with a request to enter the option to be used to determine the frequencies and damping as follows:

                1) MANUAL
                2) CURSOR
                3) LEAST SQUARES ESTIMATE
                4) CURRENTLY SELECTED VALUES
                5) RETURN TO MONITOR

The most common entry is Least Squares Estimate, and it can be used with any method to determine the modal coefficients.

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4.8   LEAST SQUARES EIGENVALUE - COMMAND SUMMARY

This monitor is conversational, and it will prompt the operator as to the disc record number of typical test data and whether the choice for the starting channel is a manual or cursor entry.

It will also ask the number of points to be used in the parameter estimation (typically 128), and it will ask the range of disc records to be used to determine the frequencies and dampings.

After answering the above question, the system will search all disc records with the 5460 nixie display indicating which measurement it is currently working with. It will then print out a list of the Least Squared Error as a function of the number of degrees of freedom. At this point, the " SP " command is used to specify the number of degrees of freedom to be used. Typically one looks for the number of degrees of freedom where the Least Squared Error has reached a "minimum" where more degrees of freedom does not significantly further reduce the error.

One then uses the " D " and " CL " commands to view where the modes are relative to a typical measurement display. Modes can be deleted using the " /D " command, and the revised list of modes can be printed with the " W " command.

When the number of modes preserved are what is desired the Eigenvalue program is exited using the " (" command. At this point the system prompts the operator to pick the method to be used to determine the modal coefficients. The options are as follows:

      1)   MAGNITUDE
      2)   IMAGINARY PART
      3)   REAL PART
      4)   KENNEDY-PANCU CIRCLE FIT
      5)   LEAST-SQUARES FREQUENCY DOMAIN
      6)   RETURN TO MONITOR

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4.8.1 POWER SPECTRUM - SP

SP N1   *** POWER SPECTRUM ***

This command calculates the relative least squares error
for degrees of freedom N1. In the automatic mode, N1 = 32. If
N1 = 0, an interactive mode requests the range of degrees of
freedom N1 to N2.

If N1 is a value in the range of 2 to 40, the error as
well as the realistic modal parameters are printed out.

The value of N1 cannot be defaulted.

4.8.2 DELETE - /D

/D N1   *** DELETE BUTTON ***

This command deletes the modal parameters for mode N1 from
the list of modes created by a " SP N1 " command. The modal
parameter list is immediately renumbered.

4.8.3 CLEAR - CL

CL N1   *** CLEAR BUTTON ***

This command clears the channel(s) nearest to the

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calculated damped natural frequency(s) and then performs a Log
Magnitude calculation of the frequency response function. The
command give visual identification as to the location of the
damped natural frequencies with respect to the peaks in the
composite power spectrum display.

If the clear command is given a second time the cleared
channels go to the top of the screen instead of the bottom of
the screen.

4.8.4   DISPLAY - D

D (No Parameters)   *** DISPLAY COMMAND ***

Calculates a magnitude display of the composite power
spectrum data to be used for visual identification of the
location of the damped natural frequencies.

4.8.5   PRINT - W

W (No Parameters)   *** PRINT BUTTON ***

This command prints the current values of the modal
parameters to the output device as selected by the switch
register.

4.8.6   RETURN - <

< (No Parameters)   *** SUBROUTINE RETURN BUTTON ***

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This command returns to the parameter estimation logic to
allow the residues to be estimated based upon the current list
of starting values. If too many starting values have been
identified, the values must be reordered according to
importance or some must be deleted.

4.9   LEAST SQUARES RESIDUES - COMMAND SUMMARY

The system will prompt the operator to clear the current
modal coefficients (enter a 0 to clear or a space not to
clear). It will then ask which option is to be used for the
residual terms. It then asks whether an interactive or
automatic mode is desired (typical response is automatic). The
next question asked is the range of disc records to be used for
the current test. There are some switch register options
listed at this point, the most common one is bit 2 which is
useful for a printout of the modal parameters. The system will
then begin fitting each measurement and displaying in a
front-back mode the data versus the fit. To continue on to the
next measurement a " D -1 " or a " -1 " is entered on the
terminal.

4.10   LEAST SQUARES RESIDUES - AUTOMATIC MODE

4.10.1   DISPLAY - D

D N1 N2   *** DISPLAY BUTTON ***

This command is used to display channels N1 through N2 of
the raw and theoretical data in a front to back format. To

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exit the display, an integer number N1 is entered. If N1 = 0, this measurement is skipped and the next measurement in the range is read from the disc. If N1 < 0, the data is saved and the next measurement is is processed.

4.11   LEAST SQUARES RESIDUES - INTERACTIVE MODE

In this mode a double asterisk (**) is displayed as the monitor prompt character.

4.11.1   MASS STORE - MS

MS   N1 N2   *** MASS STORE BUTTON ***

This command operates the same way as the Fourier system command. It is used to store the modal data to the disc.

4.11.2   PRINT - W

W (no parameters)   *** PRINT COMMAND ***

This command prints out the modal parameters of mode number, frequency, damping (zeta), and the magnitude and phase along with the real and imaginary parts of the residue.

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4.11.3   CURVE FITTING - CR

CR   (no parameters)   *** CORELATION BUTTON ***

    This command calculates a set of residues for the starting
values for a measurement. The range of measurement locations
on the disc is input interactively so that, after each
calculation is accepted, the next measurement in the range will
be processed.

4.11.4   RECONSTRUCTION - CV

CV   (no parameters)   *** CONVOLUTION BUTTON ***

    This command takes the results of the residue calculation
and forms the mathematical frequency response function for
display verification. It is usually called right after the CR
command.

4.11.5   RESIDUE CONSTRUCTION - SP

SP N1   *** POWER SPECTRUM ***

    If N1 is less than or equal to 0, a set of starting values
can be entered.

    If N1 is greater than 0, the residue calculation begins as
in the CR command but no data is read from the disc. The data
is assumed to be in block 0.

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4.11.6   DISPLAY - D

D   N1 N2   ***** DISPLAY BUTTON *****

This command is the same as that found under automatic option.

4.12   CIRCLE FIT MONITOR

The Circle Fit Monitor allows you to interactively change the circle fit or the coefficient (the monitor character " D " is printed).

The values of center channel and bandwidth are considered "permanent" values. When you first fit a mode using the command, these permanent values are assigned to "temporary" or "working" values from which the circle fit is calculated. The circle fit is always calculated from these "temporary" values of center channel and bandwidth.

The Circle Fit commands allow the "temporary" center channel and bandwidth to be varied in order that the circle fit for a mode may be improved. Whenever new circle fits are calculated, a new modal coefficient is found. When you judge the fit or the coefficient to be acceptable, the coefficient may be saved. In addition, the new "temporary" center channel and bandwidth may be saved as the "permanent" values in the table, so that they will be used as the "temporary" values for this mode in later measurements.

Additional Circle Fit commands allow a "temporary" estimate of damping for the current mode to be made if desired, this "temporary" estimate may be stored into the table, or the table value may be recalled to become the "temporary" value.

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4.13   CIRCLE FIT COMMAND SUMMARY

Note: ( ) denotes optional parameters

4.13.1   N1   TEMPORARY BANDWIDTH

N1 Assign New ("temporary") bandwidth

Assign the value of N1 (1<N1<30) to the "temporary"
bandwidth for the current mode, and recalculate the circle fit
using this new bandwidth value. N1 = 0 uses the quadrature
response and proceeds. N1<0 accepts the current circle fit.

The bandwidth refers to the number of data points to be
included in the circle fit. A bandwidth of "1" uses the center
channel plus and minus one channel.

4.13.2   ROTATE -

Assign New Center Channel   *** ROTATE BUTTON ***

Increment the current "temporary" center channel value by
value N1 (+ or -) and recalculate the circle fit.

4.13.3   SUBSTRACT -   A-

A-   Recall Old Center Channel   *** SUBSTRACT BUTTON ***

Assign the center channel value from the table to the
"temporary" center channel, print the value, and recalculate
the circle fit.

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4.13.4   CLEAR - CL

CL   Clear Coefficient   *** CLEAR BUTTON ***

Sets the modal coefficients to zero and proceeds.

4.13.5   REPLACE - /R

/R   Save "temporary" values   *** REPLACE BUTTON ***

Save the "temporary" values of center channel, bandwidth,
and damping into the table, thereby making them the "permanent"
values for the current mode.

4.13.6   MISC. INFORMATION

Automatic Circle Fit (Bit 1)

If switch register bit 1 is on when the algorithm is
entered, the coefficeints from the modal circle fits will
automatically accepted with no circle fit displays or user
interaction.

Suppress Printout (Bit 15)

If switch register bit 15 is on, the printout of point
number and orientation will be suppressed.

At the completion of processing the range of measurements
requested, the system returns from the circle fit monitor (D)
to the Y 9 monitor (*) where one could then ask for the
animated displays, etc.

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```
+----------------------------------------------+----------------------+
|                                              |                      |
|   DATA DISPLAY                               |   CHAPTER   5        |
|                                              |                      |
+----------------------------------------------+----------------------+
```

5.1   OVERVIEW

The Data Display Section of the Modal System is entered by
typing 'Y 9' on the system TTY. The program will then respond
by printing a "*" on the TTY signifying that the "*" monitor is
now in operation.

This section outlines the Data Display commands available.
Once the necessary steps of the Data Setup and Data Acquisition
sections have been performed, these commands allow you to
obtain animated mode shape displays for the test structure.

5.2   CONSTRUCTING THE DISPLAY

Note that, as the display is being constructed, data
blocks 0 and 1 are being used to store various 'working' arrays
of display points. As long as the contents of these blocks
remain intact, the program will display the animated mode shape
whenever the "*" monitor is active. If the "*" monitor is
exited via a command and then later re-entered by calling 'Y
9', the animated display will appear provided blocks 0 and 1
are intact. When blocks 0 and 1 are filled, a flag is written.
When the "*" monitor is exited and then re-entered the system
checks to see if this flag is there. If block 0 has been
destroyed or altered, the flag will probably have been altered
also - if this is the case, the system will not display on the
screen when the "*" monitor is active until another command is

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given which constructs a display. Of course, it is possible to
alter the contents of blocks 0 and 1 without altering the flag
- in this case, the display that you see when the "*" monitor
is re-entered will be erroneous and system errors may occur.

5.3   AXIS ORIENTATION

The global coordinate system for display purposes is assumed to
be:

```
                        Y

                        +
                        +
                        +
                        +
                        +
                        +
                        +
                        +
                    +       +
                  +           +
                +               +
              +                   +
            +                       +
          +                           +
        Z                               X
```
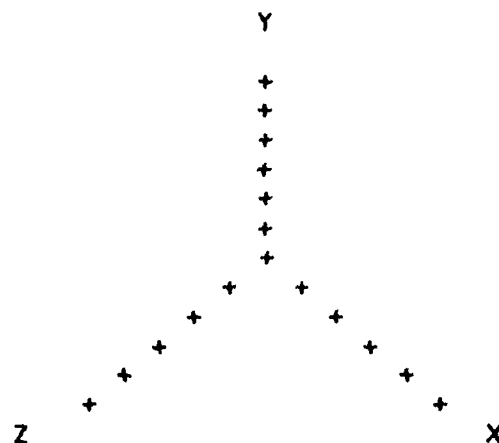
        The system resolves coordinates and deformations in the
three global directions shown above into the display
two-dimensional system.

```
                  Y

                  +
                  +
                  +
                  +
                  +
                  +
                  +
                  + + + + + + + +   X
```

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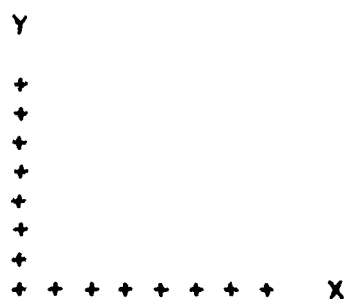
5.4   SCALING CONSIDERATIONS

The working arrays of points stored in block 0 and 1 are defined relative to the display X-Y coordinate system.

Ultimately, all structure coordinates and motion are broken down into coordinates and motion within this X-Y system.

The display calculation will automatically scale to 80% of the 5400 display unit, with the display switch in the Complex Mode. In this position only the left portion (8 x 8) of the total display (10 x 8) is utilized.

5.5   When to use the Data Display Commands

Although some care has been taken to make the Data Display Commands usable at any time, it is recommended that these commands be used only after performing the Data Setup for the structure acquiring modal coefficients through the Data Acquisition process. Using the Data Display commands at times when valid data does not exist will produce neaningless results or possible system errors.

5.6   Initialization of Display Parameters

Whenever the "*" monitor is entered by typing 'Y 9', display parameters controlling the following functions are initialized to

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```
Deformation Amplitude
Display Expansion      (80% of maximum)
Display Rotation       (no rotation)
Horizontal Position    (to center of display)
Vertical Position      (to center of display)
View Position          (to (1,1,1) )
"Still" Function       (display undeformed shape)
                            plus animation)
```

The various Data Display commands are capable of changing
all of the above parameters for the purpose of modifying the
display. The system "remembers" the values of parameters
controlling the display functions even though the modes or
components being displayed may change. These parameters may be
"reset" to default values either by exiting and re-entering the
"*" monitor (which resets all except animation speed) or by
entering the appropriate Data Display command with no
parameters (this resets only the parameter for that command).
In this matter, the position (for example) of the animated
display display will never be changed once it has been set
unless a specific command is given to restore the default
display position.

5.7   Command Summary

Note: ( ) denotes optional parameters

5.7.1   PRINT - W

```
W  N1 (N2) (N3) (N4)              *** PRINT BUTTON ***
--------------------
```

    N1 = 0 The test set-up is printed.

    N1 = 1 The component data from N2 to N3 is printed.

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N1 = 2   The geometry data from point N2 to N3
         is printed.

N1 = 3   The connectivity file from N2 to N3 is printed.

N1 = 4   Mode frequencies and damping is printed.

N1 = 5   The modal coefficients from mode N1 from point
         N3 to N4 is printed. Note N2 cannot be
         defaulted if N1 = 5.

    If N1 = 2, 3, 4, or 5 and switch 14 is pressed the output
will be aborted.

5.7.2   STORE X<

X> (N1)   *** STORE BUTTON ***

    This command will store the set-up and modal coefficient
which then can be loaded later. N1 specifies the record number
where the information is written. The next available record
will be reported. (0 < N1 < 800)

5.7.3   LOAD X<

X< (N1)   *** LOAD BUTTON ***

    This command will read the store command. N1 specifies
the record number.

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5.7.4 CONVOLVE – CV

```
CV N1                            *** CONVOLUTION BUTTON ***
-------
```

This command controls the display rate of the display The larger the value of N1 the slower the display. Typical values are in the range of 1 to 10. For displays with a very few number of points little control of the display rate will be possible.

5.7.5 DIVIDE – : (or EX)

```
:  (or EX) N1              *** DIVIDE BUTTON ***
-------
```

This command will expand the view by the percentage N1.

5.7.6 TRANSFER FUNCTION – CH (or AM)

```
CH  (or AM)  N1            *** TRANSFER FUNCTION BUTTON ***
------
```

This command will expand the amplitude of vibration by the percentage N1.

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5.7.7   SUBSTRACTION   A-   (or R)

A- (or R)   N1   *** SUBTRACTION BUTTON ***

      This command will rotate the view by an angle equal to N1
degrees. Default of N1 is approximately 81 degrees.

5.7.8   DIFFERENTATION - %   (or V)

% (or V) (N1) (N) (N3) (N4)   *** DIFFERENTIATE BUTTON***

      This command changes the viewing position where N1, N2,
and N3 are the X, Y, Z coordinates of the viewing position with
respect to the global coordinate system. If N4 is input, only
the transformation matrix is recalculated. A new display will
not be calculated. (Default N1 = N2 = N3 = 1)

5.7.9   POWER SPECTRUM - SP

SP N1   *** POWER SPECTRUM BUTTON ***

      This rescales the initial display upon entering a new mode
so that the display fills the CRT screen. A typical value for
N1 is 3400.

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5.7.10 DISPLAY - D

D (N1) (N2) (N3) (N4) (N5) (N6)   *** DISPLAY BUTTON ***

    This command is used for displaying the mode shape data.
N1=0 or positive, mode N1 will be displayed, where N1 = 0 is
the undeformed mode shape. All components will be displayed as
long as N2 is defaulted. If N1 is positive, mode N1 will be
displayed for N2 number of components with components N3, N4,
N5, and N6 being displayed. A display command with all
parameters defaulted, stops the display or removes the
undeformed geometry. It works in a cyclic fashon, with the
first entry stopping animation, second entry removing
undeformed geometry with animation, third stopping animation
and the fourth entry replacing undeformed geometry, which was
the initial condition. If N1<0, the mode will be completely
recalculated even if the requested mode is currently being
displayed.

5.7.11 ROTATE (or M)

M N1 N2 (or rotate key) *** ROTATE BUTTON ***

    The move command will move the display so that the point
N1 is centered in the display screen If N2 is given then the
display will shift N1 percent to the right and N2 percent up.
Negative is left and down.

5.7.12 INTERROGATE - ?

? (N1)   *** INTEROGATE BUTTON ***

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This command is used to intensify a point being currently displayed. N1 is the point number to be displayed. If N1=0, (default) the intensify function is turned off.

5.7.13   SUBROUTINE - <

<   *** SUB-RETURN BUTTON ***

This command returns control to the Fourier monitor.

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6.1   OVERVIEW

This section of the Modal System is intended to facilitate the process of making a formal report or graphic record of modal data either in plotted or animated form. Most features are designed to work with an HP - 7210 plotter, HP - 9872 plotter or a Tektronix 4012 terminal interchangeably. Software has been implemented which can locate the proper I/O slot so that a particular configuration is unnecessary. In the plotting mode, any deformed or undeformed position can be presented (with the undeformed shape, the data points can be annotated and the lines can be dotted). Labeling is available at any time. Of particular interest to videotape or movie presentations is the capability of displaying alphanumeric titles to the HP 5460 Display CRT.

6.2   DATA PRESENTATION COMMANDS - USE

Data Presentation Commands can be executed at any time although, if sufficient data is not available, an error message will result. In general, if a request has been made to plot a Mode Shape or annotate a plotted mode shape, an animated display must be available. Displaying titles on the HP 5460 Display unit can be done at any time.

6.3   DATA PLOTTING - COMMAND SUMMARY

NOTE: ( ) denotes optional parameter

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6.3.1   ANALOG OUT - B

B (N1) (N2)   *** ANALOG OUT BUTTON ***

   This command is used to plot the mode shape currently
being displayed. For N2 = 0 (default), the undeformed shape is
plotted. For N2 = 1 - 20 the deformation position (1 - 20) is
plotted. If N1 = 10 plot will be to the HP 7210. If N1 = 6
plot will be to the HP 2648 terminal. If N1 = 37 (default),
plot will be to the HP 9872 or the 7245 digital plotter. The
undeformed shape is normally in dotted format. If solid lines
are required, switch 12 on will give solid lines. The points
can be labeled if a point command has been issued prior to the
solid line undeformed shape plot. When using the 2648 Terminal
or the Tektronic 4012, switch 15 on will abort the auto erase
between plots.

   If N2 is negative, a plot of 10 positions of the deformed
shape will be generated to device N1.

6.3.2   LABEL - L

L (N1) (N2) (N3) (N4)   *** LABEL BUTTON ***

   This command is used to label the plot. The label size
and position is controlled as follows:

          N1 = device
             = 10 for HP 7210
             = 37 for HP 9872

          N2 = (default = 50) = X starting position

          N3 = (default = 700) = Y starting position

setup will then be restored to the disc.
(N4 default value = none

Upon issuing the Y 88 N1 (N2) (N3) (N4) command the
program will respond with a prompt character " D " on the
terminal. The user must then enter the point number and
transducer orientation as such:

N (IX) (IY) (IZ), where:

N = Point number associated with current
    measurement.

IX = Transducer orientation associated with data
     in block 1.

IY = Transducer orientation associated with data
     in block 2.

IZ = Transducer orientation associated with data
     in block 3.

Transducer orientations are expressed as integers of -3,
-2, -1, 1, 2, or 3 corresponding to local coordinate directions
-z, -y, -x, x, y, z respectively. The correct orientation
entry is that which describes the local direction in which the
transducer is pointing.

The direction of the transducer can be imagined by drawing
a vector from the base of the transducer through the top of it.
As an example, if the transducer associated with the data in
block 1 is pointing in the positive local Y direction then IX =
2.

If successive measurements have the same transducer
orientation then switch register bit 1 may be turned on to have
automatic incrementing of the point number. If switch register

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/

N4 = (default = 200) = width and height of
characters (HP 7210)

N4 = (default = 1) = Pen Number (HP 9872)

After the command is entered, the label is entered on the
terminal. Further lines may be entered below the first line
after the first line has been output to the device. This mode
is exited by the Terminate Button (/).

6.3.3   POINT - /.

```
/. (N1) (N2) (N3) (N4) (N5)          *** POINT BUTTON ***
-----------------------------
```

This command is used to enable the plotting of point
numbers on the undeformed, solid line plot (switch 12 on). N1
is the X offset, N2 is the Y offset, and N3 is the character
size. Default values for all three parameters are 100. This
feature has been implemented only on the HP 7210 plotter and
the HP 9872 plotter. Switch 13 will abort only the labeling.
If N4 and N5 are entered, only those point numbers between N4
and N5 will be printed.

6.3.4   LIST - /L

```
/L (N1) (N2) (N3)          *** LIST BUTTON ***
-------------------
```

This program executes a call to subroutine similiar to
User Program 7074 (Reference Chapter 9) which displays ASCII
text to the HP 5460 Display Unit for use as titles in
video-taping or movie-making.

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N1 = 0   Title will be entered manually

N1 > 0   Automatic display of the frequency
         for mode number N1

N1 < 0   Disc record (-N1) where previously
         constructed titles have been stored.

N2 =   Character size (N2 x N2)
         a value of 1000 yeilds a character size
         of 1 cm by 1 cm.

N3 =   Y position of starting line of text
         (-32000 to 32000).

    The X position of each line of text is automatically
centered.

Default values: N1 = 0

                  N2 = 500

                  N3 = 5000

    This feature is aborted when any character is entered.

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This program is called within the data acquisition keyboard program (using the 5451 C software coreload 1) in order to put the proper test ID information into the data block header area when the data is stored to the disc.

The following command formats may be used:

Y 88 5 N1

> Reads test setup from record N1 on the disc (N1 default value is = 19).

Y 88 6 N1

> Writes current core resident setup to the disc record N1 (default value = 19).

Y 88 N1 (N2) (N3) (N4)

> N1 = 1, 2 or 3
>
> > Stores data block 1 through N1 to the disc
>
> N2 = Point number increment value
> (N2 default value = 1)
>
> N3 = Zoom range parameter (N3 = 0 -5)
> (N3 default value = 0 ie, baseband)
>
> N4 = Disc data record number where setup is
> stored. Setup will be read before
> storing current data blocks, an updated

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bit 0 is off then point number is increased by N2. If bit 0 is
on then point number is decreased by N2.

        If the parameter N2 is less than or equal to zero the
point number is not incremented and the data is stored with the
current point number and transducer orientation.

        The third parameter, N3, specifies the two character zoom
range parameter that will be stored in the header. N3 is an
integer from 0 to 5 which specifies a parameter of Z0 to Z5
respectively. The zoom range parameter provides an easy key on
which other programs can search when looking for a specific
frequency range.

        The fourth parameter, N4, specifies the disc data record
where the test setup has been stored using Y 90. If N4 is
specified then the test setup is read from the disc data record
N4 (file 7) before the current data is stored to the disc.
After the data has been stored, the test setup is restored to
disc data record N4. In this way the test setup always
contains the last point number and transducer orientation used.
Before the setup is read, the mass store file 1 pointer is kept
so that after reading or writing the test setup, the data file
pointer is returned to its original location

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This chapter lists in order, a typical listing of the terminal printout during the operation of the modal software. Indented wordage within brackets are comments not printed by the terminal.

MAX BLOCKS #/SIZE/SPACE
        2   2048   4992

Y 90

  UCMIE   TEST SET-UP PROGRAM :   Y 90

e

K

ENTER TEST I.D. :
A/P

ENTER DATE :
040980

ENTER DISC STORAGE START RECORD :
1

e

K 1

ENTER EXCITER POSITION AND DIRECTION : [INTEGERS]
1,3
        1 Z

ENTER LOAD CELL MODEL # AND SERIAL # :
101,11

ENTER NUMBER OF RESPONSE DIRECTIONS :

79

3

ENTER 3 RESPONSE TRANSDUCER'S
 MODEL NUMBER , SERIAL NUMBER , CALIBRATION NUMBER :
102,1,1
103,2,1
104,3,1

@

K 2

ENTER DATA TYPE CODE (2 CHARACTER) :
AC

ENTER ZERO FOR IMPACT OR ONE FOR RANDOM :
1

INPUT NUMBER OF ZOOM RANGES :
0

@

X>2

@

<

MS38 10

MS18 1
MAX BLOCKS #/SIZE/SPACE
        4/   2048/   8512

Y 9

UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS SYSTEM
              VERSION: NOVEMBER   1979
*
X<708

      (Here previous data, consisting of components,
       coordinates, display sequence, etc. are loaded)

TEST ID IS   A/P
*
W

TEST ID IS   A/P

80

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```
DATE IS                                04 09 80

NUMBER OF POINTS IS                          39
NUMBER OF MODES IS                           10
*
A+

ENTER OPTION TO BE USED FOR FREQUENCIES AND DAMPING
            1) MANUAL
            2) CURSOR
            3) LEAST SQUARES ESTIMATE
            4) CURRENTLY SELECTED VALUES
            5) RETURN TO MONITOR

3

INPUT DISC DATA RECORD OF TYPICAL TEST DATA:
1

E .TER OPTION FOR CHOICE OF STARTING CHANNEL:
        1) MANUAL
        2) CURSOR

2

SET CURSOR ON STARTING CHANNEL:

        (USE SWITCH 9 ONCE CURSOR IS ON DESIRED
         STARTING CHANNEL)

ENTER NUMBER OF POINTS TO BE USED IN THE PARAMETER ESTIMATION:
        (64,128,256)

128

STARTING FREQUENCY       .18000E+01
CHANNEL    180 TO    308

ENTER 0 TO ACCEPT:

0

ENTER RANGE OF DISC RECORDS FOR CURRENT TEST:(N1,N2,N3)
            N1 = STARTING RECORD
            N2 = ENDING RECORD
            N3 = NUMBER OF SAMPLES/MEASUREMENT (OPTIONAL)
1 46
```

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```
DOF   2   ERROR =   .188360E+00  @****************************  @
DOF   3   ERROR =   .645750E-01  @***************************  @
DOF   4   ERROR =   .539607E-01  @**************************  @
DOF   5   ERROR =   .312228E-01  @*************************  @
DOF   6   ERROR =   .153011E-01  @***********************  @
DOF   7   ERROR =   .371186E-02  @*********************  @
DOF   8   ERROR =   .159108E-02  @*******************  @
DOF   9   ERROR =   .973241E-03  @******************  @
DOF  10   ERROR =   .605324E-03  @****************  @
DOF  11   ERROR =   .232289E-03  @***************  @
DOF  12   ERROR =   .167100E-03  @**************  @
DOF  13   ERROR =   .817006E-04  @*************  @
DOF  14   ERROR =   .392982E-04  @************  @
DOF  15   ERROR =   .399587E-04  @************  @
DOF  16   ERROR =   .299855E-04  @************  @
DOF  17   ERROR =   .262208E-04  @************  @
DOF  18   ERROR =   .191537E-04  @***********  @
DOF  19   ERROR =   .118225E-04  @**********  @
DOF  20   ERROR =   .634055E-05  @*********  @
DOF  21   ERROR =   .402889E-05  @*********  @
DOF  22   ERROR =   .445822E-05  @**********  @
DOF  23   ERROR =   .508565E-05  @**********  @
DOF  24   ERROR =   .406191E-05  @*********  @
DOF  25   ERROR =   .422703E-05  @**********  @
DOF  26   ERROR =   .198142E-05  @********  @
DOF  27   ERROR =   .241073E-05  @*********  @
DOF  28   ERROR =   .255934E-05  @*********  @
DOF  29   ERROR =   .244375E-05  @*********  @
DOF  30   ERROR =   .213828E-05  @*********  @
DOF  31   ERROR =   .203096E-05  @********  @
DOF  32   ERROR =   .190712E-05  @********  @
**
SP20

DOF 20   ERROR =   .634055E-05  @**********                      @
MODE    FREQUENCY   DAMPING RATIO           ZETA (%)

   1        1.800           .055          3.0654502
   2        1.916           .265         13.7217903
   3        1.918           .017           .8817592
   4        2.107           .040          1.8927138
   5        2.181           .074          3.4007921
   6        2.491           .078          3.1388712
   7        2.597           .095          3.6707439
   8        2.676           .034          1.2614412
   9        2.896           .077          2.6539407
  10        3.080           .206          6.6735630

  11        3.080           .790         24.8577423
**
D
```

```
**
CL
**
 /D11
**
 /D10
**
 /D2
**
W
MODE     FREQUENCY    DAMPING RATIO      ZETA (%)

  1        1.800           .055        3.0654502
  2        1.918           .017         .8817592
  3        2.107           .040        1.8927138
  4        2.181           .074        3.4007921
  5        2.491           .078        3.1388712
  6        2.597           .095        3.6707439
  7        2.676           .034        1.2614412
  8        2.896           .077        2.6539407
**
<
```

ENTER OPTION TO BE USED TO DETERMINE MODAL COEFFICIENTS:
    1) MAGNITUDE
    2) IMAGINARY PART
    3) REAL PART
    4) KENNEDY-PANCU CIRCLE FIT
    5) LEAST SQUARES FREQUENCY DOMAIN
    6) RETURN TO MONITOR

5

ENTER 0 TO CLEAR CURRENT MODAL COEFFICIENTS
0

ENTER OPTION FOR RESIDUAL TERMS TO BE INCLUDED:
    1) NO RESIDUALS
    2) RESIDUAL MASS ONLY
    3) RESIDUAL FLEXIBILITY ONLY
    4) RESIDUAL MASS AND FLEXIBILITY
4

INTERACTIVE(0) OR AUTOMATIC(1)
1

SWITCH 15   ABORT POINT PRINT
SWITCH 14   ABORT PARAMETER ESTIMATION
SWITCH 13   ABORT AUTOMATIC CALIBRATION
SWITCH 11   ABORT NIXIE TUBE DISPLAY
SWITCH 10   SUPRESS SCALING QUESTION

83

```
SWITCH  2  PRINT RESIDUE RESULTS
SWITCH  0  ABORT DATA RECONSTRUCTION

ENTER RANGE OF RECORDS FOR CURRENT TEST:
1 46
Z    1
 LEAST SQUARED ERROR =      .10024E-01
-1
Z    2
 LEAST SQUARED ERROR =      .10405E-01
-1
           (TURN ON SWITCH 0)
Z    3
Z    4
           (THIS CONTINUES FOR ALL MEAS.)


*
D 1


     1.8000 HERTZ
*
```

At this point one could ask for various printouts, display
other modes or plot the results. Typically one would also
store this analysis to the disc in a typical location like
record 720.

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Y 7074 - ALPHANUMERIC DISPLAY ON CRT

This program allows the user to generate ASCII characters in a data block for display purposes. It was written with the intention of generating titles, sub-titles and labels for video tapes of mode shapes.

There are 60 characters available, plus the space. The characters are:

                    A through Z
                    0 through 9

        ! " # $ % ' ( ) * - : = _ T @ : < > , . / ?

The command call is: Y 7074 - LY ISIZE

                    where: LY is the location
                           of the first character Y-axis

                           ISIZE is the character size

The screen is divided as shown here:

85

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```
 +32000  +-----------+-----------+****
         +-----------+-----------+****
         +-----------+-----------+****
         +-----------+-----------+****
         +-----------+-----------+****
Y-axis  0  +-----------+-----------+****
         +-----------+-----------+****
         +-----------+-----------+****
         +-----------+-----------+****
         +-----------+-----------+****
 -32000  +-----------+-----------+****

       -32000           0          +32000

                    X-axis
```

Note: Characters must be viewed in the COMPLEX
      plane. Therefore, only an eight division portion of
      the display is used.

The parameter ISIZE defaults to 400, LY defaults to 0.

ISIZE can range from 32000, but becomes unreasonable past
2000.

Following the command call, the system responds on the
terminal with the number of characters available per line
without overflow to the next line. This permits the user to
calculate positioning of the characters before entry. The
system then waits for an input from the terminal of up to 70
characters and spaces. The program will "line feed"
automatically when the number of characters exceeds the
available per line. A "line feed" may be forced by placing a
blackslash at the location desired in the character string.
The blackslash is not counted as a character. If the number of
characters is greater than the block can hold, the system will
respond with a CL WHAT?

After calculation of the character string, the system prints on
the terminal a message indicating the block, and starting and
ending channels of the string.

86

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EXAMPLE:

Y 7074 U.C.   MECHANICAL ENGINEERING BLOCK 0, CHANNELS 1 THROUGH
407

This information can be used to give a display at maximum
display size as in the following keyboard program.

```
L 0
Y 3220 0 1 569 12
J 0
```

For an acceptable display for video taping, the storage
scope must be used in the POINT DISPLAY mode.

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10..1   INTERCHANGE - X

X N1   *** INTERCHANGE BUTTON ***

   N1 = default - Modal Assurance Criteria

   N1 = 1 Mode Scaling

   N1 = 2 Mode Substraction

   This section is interactive and relatively straight
forward in nature. Remember a space terminates further entry.

10..2   LOAD - X<

X< N1   *** LOAD BUTTON ***

   N1 = record where data is stored

10..3   STORE X>

X> N1   *** STORE BUTTON ***

   N1 = record where data is to be stored.

88

A-152

FLOW CHART - DATA ACQUISITION

```
        *********
        * START  *
        *********
            +
            +
            +
            +
            +
****************************
* LOAD Y90 OVERLAY        *
****************************
* Y 90                    *
****************************
* CL IREC1   IREC2        *
****************************
* K  0                    *
****************************
* K  1                    *
****************************
* K  2                    *
****************************
* X)  IREC3               *
****************************
            +
            +
            +
            +
            +
            +
```

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```
*************************
*                       *
* LOAD Y88 PROGRAM      *
*                       *
* (coreload 1)          *
*                       *
*************************
*                       *
* ENTER KEYBOARD        *
*                       *
* PROGRAM TO CALCULATE  *
*                       *
* FREQUENCY RESPONSE    *
*                       *
* MEASUREMENTS IN       *
*                       *
* BLOCKS 1,2,3          *
*                       *
*************************
*                       *
* Y 88 N1 N2 N3 IREC3   *
*                       *
*************************
*                       *
* TAKE MEASUREMENTS     *
*                       *
* FOR EACH POINT OF     *
*                       *
* INTEREST              *
*                       *
*************************
```

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FLOW CHART - MODE SHAPE ANALYSIS

```
    *************
    * START     *
    *************
         +
         +
         +
         +
         +
         +
*************************************
* LOAD LARGEST OVERLAY (10)         *
*************************************
* Y 9                               *
*************************************
* K 0   GENERAL SETUP               *
*************************************
* K 1   COMPONENT SETUP             *
*************************************
* K 2   GEOMETRY SETUP              *
*************************************
* K 3   CONNECTIVITY SETUP          *
*************************************
         +
         +
         +
         +             * * * *
         + + + +       *  A  *
         +             * * * *
         +
         +
         +
***************************************
*                                     *
*   A+    PARAMETER ESTIMATION        *
*         FREQUENCY                   *
*         DAMPING                     *
*         MODAL COEFFICIENTS          *
*                                     *
***************************************
         +
         +
         +             * * * *
         + + + +       *  A  *
         +             * * * *
         +
         +
         +
```

```
********************************
*                              *
*  D N1    DISPLAY MODES        *
*                              *
********************************
            +
            +
            +
            +
     *  *  *  *
     *        *
     *     B  *
     *        *
     *  *  *  *
```

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```
          * * * *
          *     *
          *  A  *
          *     *
          * * * *
             +
             +
             +
             +
             +
    ***************************************
    *                                     *
    *   X> N1    STORE PRESENT             *
    *                                      *
    *           INFORMATION TO             *
    *                                      *
    *           DISC                       *
    *                                      *
    ***************************************
    *                                      *
    *   X< N1    READ PREVIOUSLY           *
    *                                      *
    *           ENTERED INFORMATION        *
    *                                      *
    *           FROM DISC                  *
    *                                      *
    ***************************************
```

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```
                * * * *
                *     *
                *  B  *
                *     *
                * * * *
                   +
                   +
                   +
                   +
                   +
                   +
    ******************************************
    *                                        *
    *   B N1 N2  PLOT PRESENTLY              *
    *                                        *
    *           DISPLAYED MODE               *
    *                                        *
    *           SHAPE                        *
    *                                        *
    ******************************************
    *                                        *
    *  L N1 N2   LABEL CURRENT               *
    *                                        *
    *           PLOT                         *
    *                                        *
    ******************************************
    *                                        *
    *  /L N1 N2  WRITE ASCII                 *
    *                                        *
    *           TEXT TO                      *
    *                                        *
    *           CRT SCREEN                   *
    *                                        *
    ******************************************
```

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HEADER INFORMATION - MODAL DATA

WORD 6   52525B

ASCII STORAGE (SEARCH KEY)

WORD 9	70
WORD 10	TEST ID(1)
WORD 11	TEST ID(2)
WORD 12	TEST ID(3)
WORD 13	TEST ID(4)
WORD 14	TEST ID(5)
WORD 15	DELIMITER (.)
WORD 16	POINT NUMBER (1)
WORD 17	POINT NUMBER (2)
WORD 18	DELIMITER (.)
WORD 19	TRANSDUCER ORIENTATION
WORD 20	DELIMITER (.)
WORD 21	EXCITER LOCATION (1)
WORD 22	EXCITER LOCATION (2)
WORD 23	DELIMITER (.)
WORD 24	EXCITER ORIENTATION
WORD 25	DELIMITER (.)
WORD 26	DATE (1)
WORD 27	DATE (2)
WORD 28	DATE (3)
WORD 29	DELIMITER (.)
WORD 30	TIME (1)
WORD 31	TIME (2)
WORD 32	TIME (3)
WORD 33	DELIMITER (.)
WORD 34	DATA TYPE CODE
WORD 35	DELIMITER

INTEGER STORAGE

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```
WORD 45                         RESPONSE POINT NUMBER
WORD 46                         EXCITATION POINT NUMBER
WORD 47                         RESPONSE TRANSDUCER MODEL NUMBER
WORD 48                         RESPONSE TRANSDUCER SERIAL NUMBER
WORD 49                         LOAD CELL MODEL NUMBER
WORD 50                         LOAD CELL SERIAL NUMBER
WORD 51                         DATA BLOCK NUMBER
```

FLOATING POINT STORAGE

```
WORD 75                         MINIMUM FREQUENCY
WORD 76
WORD 77                         DELTA FREQUENCY
WORD 78
WORD 79                         DATA CALIBRATION VALUE
WORD 80                         OR - RECORD NUMBER
```

DATA TYPE CODES (WORD 34)

```
10                              TIME
11                              CORRELATION
20                              FREQUENCY
21                              FREQUENCY RESPONSE (D/F)
22                              FREQUENCY RESPONSE (V/F)
23                              FREQUENCY RESPONSE (A/F)
25                              POWER SPECTRUM
29                              COHERENCE
40                              CURVE FIT DATA
59
60                              SYNTHESIZED DATA
70                              SETUP
71                              MODAL SETUP (Y 90)
72                              MODAL COEFFICIENTS
75                              TEST SETUP (Y 88)
```

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6.2 Software Listing

```
0001   FTN4,L
0002   C
0003   C                  VERSION   1-JUN-78  PM   MRH    COMMON: REV D
0004   C
0005          SUBROUTINE Y0090(INT,IPAR)
0006          DIMENSION LINE(36),LINE1(35),IPAR(6),IH(1),IM(3),
0007         1 RH(3),NIH(5),CRH(3),ICMMD(14),IOID(2),IPT(2),
0008         2 IZR(10),IXX(1),IYY(1),IZZ(1),NX(3),NY(3),NZ(3),
0009         3 FN(10),FC(10),FM(10),FD(10)
0010          COMMON ICOMM,IT(5),ID(3),IX(3),IS(3),ID1,LMN,LSN,MN(3),
0011         1 ISN(3),IXP(3),IXDIR,ICF(5),IBW(5),IR(5),IAVG(5),IOVL(5),
0012         2 NAVG,NZR,NRS,KTEST,KTYPE,IREC,TCAL(3),IZOOM,FMIN,DF,KZ,KAVG
0013          EQUIVALENCE (LINE(2),LINE1)
0014          EXTERNAL  HDR8 , DTAD0 , SIZE
0015          DATA ICMMD/2H/R,2HCV,2HX ,2H$ ,2HCL,2HX<,2HX),2H/.,
0016         1 2H/L,2H< ,2HP ,2HR ,2HW ,2HK /
0017          DATA IDUM1/-1/,IZR/2HZ0,2HZ1,2HZ2,2HZ3,2HZ4,2HZ5,
0018         12HZ6,2HZ7,2HZ8,2HZ9/
0019   C
0020   C    ****************************************************************
0021   C                                                                  *
0022   C    THIS VERSION OF Y0090 HAS THE FOLLOWING FEATURES :            *
0023   C                                                                  *
0024   C         1)   CORRECT HEADER INFORMATION                          *
0025   C         2)   CORRECT TRANSDUCER INFO. IN HEADER                  *
0026   C         3)   INTERCHANGE TRANSDUCER INFO. FOR A POINT            *
0027   C         4)   CHANGE OLD Y8 FORMAT TO CURRENT Y90 FORMAT          *
0028   C         5)   CLEAR DISK RECORDS READY FOR Y88                    *
0029   C         6)   LOAD OR STORE TEST SET-UP TO DISK                   *
0030   C         7)   SEARCH DISK RECORDS FOR A POINT NUMBER              *
0031   C         8)   THREE TYPES OF RUN LOGS                            *
0032   C         9)   PUNCH TEST SET-UP TO PAPER TAPE                    *
0033   C        10)   READ TEST SET-UP FROM PAPER TAPE                   *
0034   C        11)   ENTER TEST SET-UP FROM KEYBOARD                    *
0035   C        12)   WRITE CURRENT TEST SET-UP                          *
0036   C        13)   WRITE HEADER INFO. FROM DISK RECORD                *
0037   C                                                                  *
0038   C    ****************************************************************
0039   C
0040          CALL SETAD(HDR8,IH,-8,0)
0041          CALL SETAD(HDR8,RH(1),67,0)
0042   C
0043   C
0044   C     IPNTMX IS USED IN RUN LOG 2 .   IT IS USED TO SET
0045   C    SYSTEM BLOCK SIZE SO IT MUST BE A POWER OF 2.
0046   C
0047   C
0048          IRECMX=819
0049          JRECMX=39
0050          IPNTMX=512
0051   C
0052          CALL SETAD(DTAD0,IXX,IPNTMX,-1)
0053          I=IPNTMX*2
0054          CALL SETAD(DTAD0,IYY,I,-1)
0055          I=IPNTMX*3
0056          CALL SETAD(DTAD0,IZZ,I,-1)
```

```
0057           CALL GETI(SIZE,IBS)
0058           IBSIZE=IBS
0059           CALL IOSW(LU,0)
0060           WRITE(1,100)
0061       100 FORMAT(//," UCMIE   TEST SET-UP PROGRAM :   Y 90",/)
0062           IF(IDUM1.NE.-1) GOTO 200
0063           IPAR1= 1
0064           IPAR2= 0
0065           GO TO 8000
0066        50 IDUM1=0
0067       200 I=ISWR(140061B,0,0)
0068           WRITE(1,210)
0069       210 FORMAT(/,1H@ ,/)
0070           IPAR1=-9999
0071           IPAR2=-9999
0072           IPAR3=-9999
0073           IPAR4=-9999
0074           DO 230 I=1,36
0075       230 LINE(I) = 2H,,
0076           CALL TTYIN(LINE)
0077       242 CALL TEST(1,IST,LOG)
0078           IF(IST.LT.0) GOTO 242
0079           CALL CODE
0080           READ (LINE,320) IL
0081       320 FORMAT(A2)
0082           CALL CODE
0083           READ(LINE1,*) IPAR1,IPAR2,IPAR3,IPAR4
0084       330 IF(IL.EQ.2H##) GOTO 200
0085           NCMMD = 14
0086           DO 338 IMRH=1,NCMMD
0087           IF(IL.EQ.ICMMD(IMRH)) GOTO 344
0088       338 CONTINUE
0089           CALL IOSW(LU,0)
0090           WRITE(1,340)
0091       340 FORMAT(/,"INVALID COMMAND")
0092           GO TO 200
0093       344 IF(IMRH.GT.5) GOTO 350
0094           IF(IPAR1.EQ.-9999) GOTO 348
0095           IF(IPAR2.EQ.-9999) IPAR2=IPAR1
0096           GO TO 350
0097       348 IPAR1 = 1
0098           IPAR2 = IRECMX
0099       350 IF(IMRH.LT.8.OR.IMRH.GT.9) GOTO 360
0100           IF(IPAR2.EQ.-9999) GOTO 358
0101           IF(IPAR3.EQ.-9999) IPAR3=IPAR2
0102           GO TO 360
0103       358 IPAR2=1
0104           IPAR3=IRECMX
0105       360 GOTO(1000,9000,9500,2000,3000,4000,4500,4900,5000,
0106         1 9995,6400,6500,7000,8000) IMRH
0107   C
0108   C     ***********************************************************
0109   C         CORRECT INFORMATION STORED IN HEADER AREA  ( /R )
0110   C     ***********************************************************
0111   C
0112      1000 CALL IOSW(LU,0)
```

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```
0113        WRITE(1,1015)
0114   1015 FORMAT(/,"LIST HEADER WORDS ?",/,
0115      1 "(YES OR NO) :")
0116        READ(1,1017) IANS
0117   1017 FORMAT(A1)
0118        IF(IANS.EQ.1HY ) GOTO 1800
0119   1025 IF(ISSW(14).LT.0) GOTO 200
0120        WRITE(1,1030)
0121   1030 FORMAT(/,"ENTER HEADER WORD NUMBER:")
0122        READ(1,*) IK
0123        IF(ISSW(14).LT.0) GOTO 200
0124        IF(IK.EQ.6) GOTO 1601
0125        CALL HDRWD(IK,I)
0126        IF(I.EQ.1) GOTO 1035
0127        IF(I.EQ.0) GOTO 1043
0128        WRITE(1,1040) IK
0129   1040 FORMAT(/,"ERROR : TO CHANGE WORD NUMBER ",I3,/,
0130      1 "USE INTERCHANGE(X ) OR CONVOLUTION(CV) COMMANDS")
0131        GO TO 200
0132   1043 WRITE(1,1044) IK
0133   1044 FORMAT(/,I4," :   INVALID WORD NUMBER")
0134        GO TO 1025
0135   1035 WRITE(1,1041) IK
0136   1041 FORMAT(//,"ENTER NEW INFORMATION FOR",
0137      1 /,"WORD NUMBER :",I5)
0138 C
0139 C      READ NEW HEADER INFORMATION    ***************************
0140 C
0141        IF(IK.EQ.24) GOTO 1200
0142        IF(IK.EQ.34.OR.IK.EQ.36) GOTO 1250
0143        IF(IK.EQ.26) GOTO 1300
0144        IF(IK.GE.45.AND.IK.LT.75) GOTO 1400
0145        IF(IK.GE.75) GOTO 1500
0146        DO 1100 I=1,5
0147   1100 NIH(I)=2H
0148        READ(1,1101) (NIH(K),K=1,5)
0149   1101 FORMAT(5A2)
0150        GO TO 1601
0151   1200 READ(1,1210) NIH(1)
0152   1210 FORMAT(A2)
0153        IF(NIH(1).EQ.2H-X) NIH(1)=2HX-
0154        IF(NIH(1).EQ.2H-Y) NIH(1)=2HY-
0155        IF(NIH(1).EQ.2H-Z) NIH(1)=2HZ-
0156        GO TO 1601
0157   1250 READ(1,1210) NIH(1)
0158        GO TO 1601
0159   1300 READ(1,1301) NIH(1),NIH(2),NIH(3)
0160   1301 FORMAT(3A2)
0161        GO TO 1601
0162   1400 READ(1,*) NIH(1)
0163        GO TO 1601
0164   1500 I = (IK-73)/2
0165        READ(1,*) CRH(1)
0166   1601 IF(ISSW(14).LT.0) GOTO 200
0167        IF(IK.EQ.6) NIH(1)=52525B
0168        IF(IK.EQ.36) GOTO 1602
```

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```
0169           IF(IK.EQ.75.OR.IK.EQ.77) GOTO 1602
0170           GO TO   1604
0171      1602 WRITE(1,1603)
0172      1603 FORMAT(/,"ENTER ZOOM RANGE TO BE SEARCHED FOR:")
0173           READ(1,1210) K
0174      1604 DO  1600   II=IPAR1,IPAR2
0175           CALL KYBD(2HMS,31,II)
0176           CALL KYBD(2HMS,11)
0177           IF(IH(6).EQ.12345.AND.IK.NE.6) GOTO 1600
0178           CALL BCHK(IBS,IH(5))
0179           IF(IK.EQ.6) GOTO 1700
0180           IF(IK.EQ.36) GOTO 1610
0181           IF(IK.EQ.75.OR.IK.EQ.77) GOTO 1610
0182           GO TO 1620
0183      1610 IF(IH(36).NE.K) GOTO 1600
0184    C
0185    C      STORE NEW INFORMATION IN HEADER   *********************
0186    C
0187      1620 IF(IK.GT.50) GOTO 1710
0188      1700 IH(IK) = NIH(1)
0189           IF((IK.NE.10).AND.(IK.NE.26)) GOTO 1725
0190           IF(IK.EQ.10) NLPS=4
0191           IF(IK.EQ.26) NLPS=2
0192           J=IK
0193           DO 1705 N=1,NLPS
0194           L=N+1
0195           J=J+1
0196           IH(J) = NIH(L)
0197      1705 CONTINUE
0198           GO TO 1725
0199      1710 RH(I) = CRH(1)
0200      1725 IF(IK.NE.45.AND.IK.NE.46) GOTO 1730
0201           J=16
0202           DO 1726 N=45,46
0203           IPT(1)=IH(N)
0204           CALL ASCPT(IPT(1))
0205           IF(N.EQ.46) J=21
0206           IH(J)=IPT(1)
0207           IH(J+1)=IPT(2)
0208      1726 CONTINUE
0209    C
0210    C      STORE DATA WITH CORRECTED HEADER   ********************
0211    C
0212      1730 CALL KYBD(2HMS,31,-1,1)
0213           CALL KYBD(2HMS,21)
0214      1600 CONTINUE
0215           GOTO 200
0216    C
0217    C      LIST HEADER WORD INFORMATION   ************************
0218    C
0219      1800 CALL IOSW(NU,0)
0220           IF(NU.EQ.1) WRITE(NU,5028)
0221           WRITE(NU,1810)
0222      1810 FORMAT(/,10X," WORD #",10X,"USAGE",/)
0223           WRITE(NU,1819)
0224      1819 FORMAT(/,10X," ASCII STORAGE AREA",/)
```

```
0225        WRITE(NU,1811)
0226   1811 FORMAT(11X,"10",12X,"TEST ID")
0227        WRITE(NU,1812)
0228   1812 FORMAT(11X,"24",12X,"EXCITER ORIENTATION")
0229        WRITE(NU,1813)
0230   1813 FORMAT(11X,"26",12X,"DATE",/,11X,"30",12X,"TIME")
0231        WRITE(NU,1814)
0232   1814 FORMAT(11X,"34",12X,"DATA TYPE CODE",/,11X,"36",12X,"ZOOM RANGE")
0233        WRITE(NU,1817)
0234   1817 FORMAT(/,10X," INTEGER STORAGE AREA",/)
0235        WRITE(NU,1815)
0236   1815 FORMAT(11X,"45",12X,"RESPONSE POINT NUMBER",/,
0237      1 11X,"46",12X,"EXCITATION POINT NUMBER",/,
0238      2 11X,"49",12X,"LOAD CELL MODEL #",/,
0239      3 11X,"50",12X,"LOAD CELL SERIAL #")
0240        WRITE(NU,1818)
0241   1818 FORMAT(/,10X," REAL STORAGE AREA",/)
0242        WRITE(NU,1816)
0243   1816 FORMAT(11X,"75",12X,"MINIMUM FREQUENCY",/,
0244      1 11X,"77",12X,"DELTA FREQUENCY",/)
0245        GO TO 1025
0246 C
0247 C    ***********************************************************
0248 C       CHANGE OLD Y8 FORMAT TO NEW FORMAT USING HEADER AREA ( $  )
0249 C    ***********************************************************
0250 C
0251   2000 CALL IOSW(LU,0)
0252        WRITE(1,2010)
0253   2010 FORMAT(/,"ENTER OLD TEST I.D. :")
0254        READ(1,2015) IOID(1),IOID(2)
0255   2015 FORMAT(2A2)
0256        WRITE(1,5004)
0257        READ(1,1210) IZOOM
0258        DO 2020 I=1,3
0259   2020 IM(I)=ID(I)
0260        DO 2040 IJ=IPAR1,IPAR2
0261        IF(ISSW(14).LT.0) GOTO 200
0262        CALL KYBD(2HMS,31,IJ)
0263        CALL KYBD(2HMS,11)
0264        CALL BCHK(IBS,IH(5))
0265 C
0266 C       GET OLD TEST ID
0267 C
0268        II=IH(5)/2 - 20
0269        CALL GETW(0,II,IZ1,IZ3)
0270        II=II+1
0271        CALL GETW(0,II,IZ2,IZ3)
0272        IF((IZ1.NE.IOID(1)).OR.(IZ2.NE.IOID(2))) GOTO 2040
0273 C
0274 C       GET POINT , ORIENTATION AND DATE
0275 C
0276        DO 2041 K=1,3
0277        II=II+1
0278        CALL GETW(0,II,IPT(1),0)
0279        CALL ASCPT(IPT(1))
0280        ID(K)=IPT(2)
```

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```
0281    2041 CONTINUE
0282         II = II + 1
0283         CALL GETW(0,II,ID1,0)
0284         II = II + 1
0285         CALL GETW(0,II,IS(1),0)
0286         CALL KYBD(2HMS,31,-1,1)
0287         DO 2042 K=9,44
0288    2042 IH(K) = 2H .
0289         IF(ISSW(15).LT.0) GOTO 2043
0290         IF(ID1.EQ.2HX ) ID1 = 1
0291         IF(ID1.EQ.2H-X) ID1 = -1
0292         IF(ID1.EQ.2HY ) ID1 = 2
0293         IF(ID1.EQ.2H-Y) ID1 = -2
0294         IF(ID1.EQ.2HZ ) ID1 = 3
0295         IF(ID1.EQ.2H-Z) ID1 = -3
0296         CALL CODIT(IS(1),ID1)
0297         GO TO 2045
0298    2043 IF(ID1.EQ.2H-X) ID1=2HX-
0299         IF(ID1.EQ.2H-Y) ID1=2HY-
0300         IF(ID1.EQ.2H-Z) ID1=2HZ-
0301         IPT(1)=IS(1)
0302         CALL ASCPT(IPT(1))
0303         IS(2)=IPT(1)
0304         IS(3)=IPT(2)
0305    C
0306    C      PUT INFO INTO HEADER
0307    C
0308    2045 CALL STORH(0)
0309         IH(36)=IZOOM
0310         IH(34)=2H23
0311         CALL KYBD(2HMS,21)
0312    2040 CONTINUE
0313         DO 2050 I=1,3
0314    2050 ID(I)=IM(I)
0315         GOTO 200
0316    C
0317    C    ***********************************************************
0318    C       CLEAR DATA RECORDS FOR USE BY Y88   ( CL )
0319    C    ***********************************************************
0320    C
0321    3000 CALL IOSW(LU,0)
0322         DO 3040 II=IPAR1,IPAR2
0323         IF(ISSW(14).LT.0) GOTO 200
0324         CALL KYBD(2HMS,31,II)
0325         CALL KYBD(2HMS,11)
0326         CALL BCHK(IBS,IH(5))
0327         IH(6) = 12345
0328         CALL KYBD(2HMS,31,-1,1)
0329         CALL KYBD(2HMS,21)
0330    3040 CONTINUE
0331         GOTO 200
0332    C
0333    C    ***********************************************************
0334    C       READ TEST SET-UP   ( X( )
0335    C    ***********************************************************
0336    C
```

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```
0337   4000 IF(IPAR1.LT.0) IPAR1 = JRECMX
0338        CALL COM2(0,IPAR1)
0339   C
0340   C    CHECK HEADER FOR TYPE CODE OF "75"
0341   C    IF NOT "75" , PRINT WARNING BUT PROCEED
0342   C
0343        IF(IH(34).NE.2H75) WRITE(1,4002)
0344   4002 FORMAT(/,"NON-STANDARD SET-UP BLOCK")
0345        IPAR1 = 0
0346        NDIR=0
0347        DO 4010 I=1,3
0348        IF(MN(I).EQ.0) GOTO 4010
0349        NDIR=I
0350   4010 CONTINUE
0351        IFLAG2=0
0352        IF(LMN.NE.0) IFLAG2=1
0353        IF(NDIR.NE.0) IFLAG2=1
0354        IF(IXP(1).NE.0) IFLAG2=1
0355        IFLAG3=0
0356        IF(KTEST.NE.-1) IFLAG3=1
0357        KZOOM=1
0358        IF(NZR.EQ.0) GOTO 7000
0359        DO 4020 I=1,NZR
0360        IF(IR(I).NE.0.OR.IOVL(I).NE.0) KZOOM=0
0361   4020 CONTINUE
0362        GO TO 7000
0363   C
0364   C    ************************************************************
0365   C        STORE TEST SET-UP   ( X) )
0366   C    ************************************************************
0367   C
0368   4500 IF(IPAR1.LT.0) IPAR1 = JRECMX
0369        CALL STORH(0)
0370        CALL COM2(1,IPAR1)
0371        GO TO 200
0372   C
0373   C    ************************************************************
0374   C
0375   C    SEARCH FOR POINT NUMBER   ( /. )
0376   C
0377   C    ************************************************************
0378   C
0379   4900 CALL IOSW(LU,0)
0380        DO 4910 I=IPAR2,IPAR3
0381        IF(ISSW(14).LT.0) GOTO 200
0382        CALL KYBD(2HMS,31,I)
0383        CALL KYBD(2HMS,11)
0384        IF(IH(45).NE.IPAR1) GOTO 4910
0385        WRITE(LU,4905) IPAR1,IH(19),I
0386   4905 FORMAT(I4,1X,A2," IS IN RECORD ",I4)
0387   4910 CONTINUE
0388        GO TO 200
0389   C
0390   C    ************************************************************
0391   C    PRINT RUN-LOG   ( /L )
0392   C    ************************************************************
```

```
0393    C
0394      5000 CALL IOSW(LU,0)
0395           IF(IPAR1.GT.4) GOTO 338
0396           IF(IPAR1.LE.0.OR.IPAR1.EQ.3) GOTO 5500
0397           WRITE(1,8120)
0398           READ(1,8125) (IT(II),II=1,5)
0399           IF(IPAR1.EQ.4) GOTO 5600
0400      5023 WRITE(1,5004)
0401      5004 FORMAT(/,"ENTER ZOOM RANGE :")
0402           READ(1,1210) IZOOM
0403    C
0404    C      ANALOG IN (RA) OR "ZA" WILL INDICATE ALL ZOOM RANGES
0405    C
0406           IF(IZOOM.EQ.2HRA) IZOOM=2HZA
0407           IF(IPAR1.NE.2.AND.IZOOM.EQ.2HZA) GOTO 5025
0408           DO 5024 II=1,10
0409           IF(IZOOM.EQ.IZR(II)) GOTO 5025
0410      5024 CONTINUE
0411           WRITE(1,5008)
0412      5008 FORMAT(/,"INVALID RANGE")
0413           GO TO 5023
0414      5025 IF(IPAR1.EQ.2) GOTO 5100
0415    C
0416    C          RUN LOG   TYPE 1
0417    C
0418    C          GIVES RUN LOG BY RECORD NUMBER
0419    C          FOR GIVEN TEST I.D.
0420    C
0421           CALL IOSW(LU,0)
0422           NLIN=54
0423           IF(LU.NE.1) WRITE(LU,5080)
0424           IF(LU.NE.1) GO TO 5029
0425           NLIN=25
0426           WRITE(LU,5028)
0427      5028 FORMAT("")
0428      5029 WRITE(LU,5030)IT(1),IT(2),IT(3),IT(4),IT(5)
0429      5030 FORMAT(/,10X,"RUN LOG FOR TEST:   ",5A2)
0430           WRITE(LU,5035)IZOOM
0431      5035 FORMAT(/,10X,"ZOOM PARAMETER:      ",A2,//)
0432           WRITE(LU,5040)
0433      5040 FORMAT(59X,"FREQUENCY",/,10X,"RECORD",3X,"POINT",3X,
0434         $ "ORIENT",4X,"DATE",5X,"ZOOM",4X,"MINIMUM",4X,"MAXIMUM",/)
0435           III=0
0436           IFLAG=0
0437           DO 5090 IJ=IPAR2,IPAR3
0438           IF(ISSW(14).LT.0) GOTO 200
0439           CALL KYBD(2HMS,31,IJ)
0440           CALL KYBD(2HMS,11)
0441           CALL CHKID(IT,IC)
0442           IF(IC.EQ.0) GO TO 5090
0443           IF(ISSW(15).LT.0) GOTO 5090
0444    C
0445    C      CHECK DATA TYPE CODE FOR FREQ. DATA
0446    C
0447           IC=IOR(IAND(IH(34),77400B),60B)
0448           IF(IC.EQ.2H70) GOTO 5062
```

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```
0449          IF(IZOOM.EQ.2HZA) GO TO 5045
0450          IF(IH(36).NE.IZOOM) GO TO 5090
0451    5045 FM(1)=RH(1)+RH(2)*FLOAT(IH(5)/2)
0452          WRITE(LU,5060)IJ,IH(45),IH(19),IH(26),IH(27),IH(28),
0453        $ IH(36),RH(1),FM(1)
0454    5060 FORMAT(10X,I5,5X,I3,6X,A2,3X,3(1X,A2),4X,A2,1X,2F11.4)
0455          GO TO 5068
0456   C
0457   C      CHECK DATA TYPE CODE FOR TEST OR MODAL SET-UP
0458   C
0459    5062 IC=IH(34)
0460          IF(IC.EQ.2H75) WRITE(LU,5063) IJ
0461          IF(IC.EQ.2H75) GOTO 5068
0462          IF(IC.NE.2H71) GOTO 5090
0463          IF(IJ.LE.(IFLAG+1)) GOTO 5090
0464          IFLAG=IJ
0465          WRITE(LU,5064) IJ
0466    5063 FORMAT(10X,I5,5X,".....  Y90: TEST SET-UP  .....")
0467    5064 FORMAT(10X,I5,5X,".....  Y 9: MODAL SET-UP  .....")
0468    5068 III=III+1
0469          IF(ISSW(0).LT.0) GOTO 5090
0470          IF(III.GE.NLIN)GO TO 5070
0471          GO TO 5090
0472    5070 IF(LU.EQ.1) GOTO 5081
0473          WRITE(LU,5080)
0474    5080 FORMAT(//////)
0475    5081 WRITE(LU,5030)IT(1),IT(2),IT(3),IT(4),IT(5)
0476          WRITE(LU,5035)IZOOM
0477          WRITE(LU,5040)
0478          IF(LU.EQ.1) NLIN=26
0479          III=0
0480    5090 CONTINUE
0481          GO TO 200
0482   C
0483   C         RUN LOG    TYPE 2
0484   C
0485   C         GIVES RUN LOG BY POINT NUMBER AND ORIENTATION
0486   C         UNDER A GIVEN TEST I.D. AND ZOOM PARAMETER
0487   C
0488    5100 IPTMAX=0
0489          IPTMIN=IPNTMX
0490          CALL KYBD(2HBS,IPNTMX)
0491          IBS=IPNTMX
0492          CALL KYBD(2HCL,1)
0493          CALL KYBD(2HCL,2)
0494          CALL KYBD(2HCL,3)
0495          DO 5200 I=IPAR2,IPAR3
0496          IF(ISSW(14).LT.0)GO TO 200
0497          CALL KYBD(2HMS,31,I)
0498          CALL KYBD(2HMS,11)
0499          CALL CHKID(IT,IC)
0500          IF(IC.EQ.0) GOTO 5200
0501          IF(IH(36).NE.IZOOM) GO TO 5200
0502   C
0503   C      CHECK DATA TYPE CODE FOR FREQ. DATA
0504   C
```

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```
0505          IC=IOR(60B,(IAND(IH(34),77400B)))
0506          IF(IC.EQ.2H70) GOTO 5200
0507    C
0508          IS1=IH(45)
0509          IF(IS1.LE.0) GOTO 5200
0510          IF(IS1.GT.IPNTMX) GOTO 5200
0511          IF(IS1.GT.IPTMAX)IPTMAX=IS1
0512          IF(IS1.LT.IPTMIN)IPTMIN=IS1
0513          ID1=IH(19)
0514          IF(ID1.EQ.2HX ) IXX(IS1)= I
0515          IF(ID1.EQ.2HX-) IXX(IS1)=-I
0516          IF(ID1.EQ.2HY ) IYY(IS1)= I
0517          IF(ID1.EQ.2HY-) IYY(IS1)=-I
0518          IF(ID1.EQ.2HZ ) IZZ(IS1)= I
0519          IF(ID1.EQ.2HZ-) IZZ(IS1)=-I
0520     5200 CONTINUE
0521    C
0522    C     FIND LAST RECORD FOUND TO GET FREQ. INFO
0523    C
0524          IF(IXX(IPTMAX).NE.0) I=IXX(IPTMAX)
0525          IF(IYY(IPTMAX).NE.0) I=IYY(IPTMAX)
0526          IF(IZZ(IPTMAX).NE.0) I=IZZ(IPTMAX)
0527          I=IABS(I)
0528          CALL KYBD(2HMS,31,I)
0529          CALL KYBD(2HMS,11)
0530          FM(1)=RH(1)+RH(2)*FLOAT(IH(5)/2)
0531          CALL IOSW(LU,0)
0532          NLIN=53
0533          IF(LU.NE.1) WRITE(LU,5080)
0534          IF(LU.NE.1) GOTO 5210
0535          NLIN=24
8536          WRITE(LU,5028)
0537     5210 WRITE(LU,5030)(IT(I),I=1,5)
0538          WRITE(LU,5215)IZOOM
0539     5215 FORMAT(/,10X,"ZOOM PARAMETER:      ",A2,/)
0540          WRITE(LU,5220) RH(1),FM(1)
0541     5220 FORMAT(10X,"MINIMUM FREQUENCY :",F15.7,/,10X,
0542        $ "MAXIMUM FREQUENCY :",F15.7,//)
0543          WRITE(LU,5270)
0544     5270 FORMAT(10X,"POINT NO.",5X,"X-DIR",8X,"Y-DIR"8X,"Z-DIR")
0545          III=0
0546          DO 5400 I=IPTMIN,IPTMAX
0547          IF(ISSW(14).LT.0) GO TO 200
0548    C
0549    C     IF NO DATA STORED FOR A POINT NUMBER HIGHER
0550    C     THAN 250 , THEN SKIP PRINT OF THAT POINT.
0551    C
0552          J=IXX(I)+IYY(I)+IZZ(I)
0553          IF(I.GT.250.AND.J.LE.0)GOTO 5400
0554          NX(1)=IXX(I)
0555          NY(1)=IYY(I)
0556          NZ(1)=IZZ(I)
0557          CALL ASCPT(NX(1))
0558          CALL ASCPT(NY(1))
0559          CALL ASCPT(NZ(1))
0560          IF(IXX(I).EQ.0) NX(1)=2H
```

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```
0561          IF(IXX(I).EQ.0) NX(2)=2H-
0562          IF(IYY(I).EQ.0) NY(1)=2H
0563          IF(IYY(I).EQ.0) NY(2)=2H-
0564          IF(IZZ(I).EQ.0) NZ(1)=2H
0565          IF(IZZ(I).EQ.0) NZ(2)=2H-
0566          IF(ISSW(15).LT.0) GOTO 5400
0567          WRITE(LU,5350)I,NX(1),NX(2),NY(1),NY(2),NZ(1),NZ(2)
0568     5350 FORMAT(11X,I5,3(9X,2A2))
0569          III=III+1
0570          IF(ISSW(0).LT.0) GOTO 5400
0571          IF(III.GE.NLIN)GO TO 5360
0572          GO TO 5400
0573     5360 IF(LU.EQ.1) GOTO 5370
0574          WRITE(LU,5080)
0575     5370 WRITE(LU,5030)(IT(IJ),IJ=1,5)
0576          WRITE(LU,5215)IZOOM
0577          WRITE(LU,5220) RH(1),FM(1)
0578          WRITE(LU,5270)
0579          IF(LU.EQ.1) NLIN=25
0580          III=0
0581     5400 CONTINUE
0582          GO TO   200
0583   C
0584   C         RUN LOG    TYPE 3
0585   C
0586   C         GIVES SEQUENTIAL RUN LOG OF DISK
0587   C
0588     5500 NLIN=59
0589          IF(LU.NE.1) WRITE(LU,5080)
0590          IF(LU.NE.1) GOTO 5501
0591          NLIN=30
0592          WRITE(LU,5028)
0593     5501 WRITE(LU,5502)
0594     5502 FORMAT(/,10X,"RECORD",3X,"TEST ID",5X,"ZOOM",3X,"TYPE",
0595        $ 3X,"POINT",2X,"ORIENT",4X,"DATE",//)
0596          III=0
0597          IFLAG=0
0598          DO 5510 I=IPAR2,IPAR3
0599          IF(ISSW(14).LT.0) GOTO 200
0600          CALL KYBD(2HMS,31,I)
0601          CALL KYBD(2HMS,11)
0602          IF(IH(6).NE.52525B)GO TO 5510
0603          IF(ISSW(15).LT.0) GOTO 5510
0604          IC=IOR(IAND(IH(34),77400B),60B)
0605          IF(IC.EQ.2H70) GOTO 5520
0606          WRITE(LU,5505)I,IH(10),IH(11),IH(12),IH(13),IH(14),IH(36),
0607        1 IH(34),IH(45),IH(19),IH(26),IH(27),IH(28)
0608     5505 FORMAT(11X,I4,4X,5A2,3X,A2,5X,A2,I8,6X,A2,3X,3(A2,1X))
0609          GO TO 5515
0610     5520 IC=IH(34)
0611          IF(IC.EQ.2H75) WRITE(LU,5522) I,(IH(J),J=10,14)
0612          IF(IC.EQ.2H75) GOTO 5515
0613          IF(IC.NE.2H71) GOTO 5510
0614          IF(I.LE.IFLAG+1) GOTO 5510
0615          IFLAG=I
0616          WRITE(LU,5524) I,(IH(J),J=10,14)
```

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```
0617    5522 FORMAT(' ,I4,4X,5A2,3X,"..... Y90: TEST SET-UP  .....")
0618    5524 FORMAT(11X,I4,4X,5A2,3X,"..... Y 9: MODAL SET-UP  .....")
0619    5515 III=III+1
0620         IF(ISSW(0).LT.0) GOTO 5510
0621         IF(III.GE.NLIN)GO TO 5507
0622         GO TO 5510
0623    5507 IF(LU.EQ.1) GOTO 5508
0624         WRITE(LU,50B0)
0625    5508 WRITE(LU,5502)
0626         IF(LU.EQ.1) NLIN=31
0627         III=0
0628    5510 CONTINUE
0629         GO TO 200
0630   C
0631   C                          "RUN-LOG" TYPE 4
0632   C
0633   C       LIST FMIN , FCNTR , FMAX , FDELT FOR ZOOM RANGES
0634   C       UNDER GIVEN TEST I.D. BETWEEN RECORDS IPAR2 & IPAR3
0635   C
0636    5600 IF(LU.EQ.1) WRITE(LU,5028)
0637         WRITE(LU,5602) (IT(I),I=1,5)
0638    5602 FORMAT(/,10X,"TEST I.D. : ",5A2)
0639         WRITE(LU,5604)
0640    5604 FORMAT(/,7X,"ZOOM",27X,"FREQUENCIES",/,6X,"RANGE",6X,
0641       $ "MINIMUM",9X,"CENTER",8X,"MAXIMUM",10X,"DELTA",/)
0642         DO 5606 I=1,6
0643         FN(I)=0.
0644         FC(I)=0.
0645         FM(I)=0.
0646         FD(I)=0.
0647    5606 CONTINUE
0648         DO 5620 I=IPAR2,IPAR3
0649         IF(ISSW(14).LT.0) GOTO 200
0650         CALL KYBD(2HMS,31,I)
0651         CALL KYBD(2HMS,11)
0652         CALL CHKID(IT,IC)
0653         IF(IC.EQ.0) GOTO 5620
0654         IC=IOR(IAND(IH(34),77400B),60B)
0655         IF(IC.EQ.2H70) GOTO 5620
0656         III=0
0657         DO 5608 II=1,10
0658         IF(IZR(II).NE.IH(36)) GOTO 5608
0659         III=II
0660    5608 CONTINUE
0661         IF(III.EQ.0) GOTO 5620
0662         IF(FC(III).EQ.0) GOTO 5610
0663         FTEST=RH(1)+RH(2)*FLOAT(IH(5)/2)
0664         FTEST=ABS(1.0 - FTEST/FM(III))
0665   C
0666   C    ******** FTEST & FM WITHIN 1%  ?       ********
0667   C
0668         IF(FTEST.LT.0.001) GOTO 5620
0669         IF(ISSW(15).LT.0) GOTO 5620
0670         WRITE(LU,5611) IH(36),I
0671    5611 FORMAT("    DISCREPENCY IN FREQUENCIES FOUND FOR",
0672       $ 1X,"ZOOM RANGE ",A2," AT RECORD",I4)
```

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0673          GO TO 5620
0674    5610 FN(III)=RH(1)
0675          FD(III)=RH(2)
0676          FTEST=RH(2)*FLOAT(IH(5)/4)
0677          FC(III)=RH(1)+FTEST
0678          FM(III)=FC(III)+FTEST
0679    5620 CONTINUE
0680          DO 5630 I=1,10
0681          IF(FC(I).EQ.0) GOTO 5630
0682          WRITE(LU,5635) IZR(I),FN(I),FC(I),FM(I),FD(I)
0683    5635 FORMAT(8X,A2,4F15.7)
0684    5630 CONTINUE
0685          GO TO 200
0686   C
0687   C     **************************************************************
0688   C      PUNCH TEST SET-UP
0689   C     **************************************************************
0690   C
0691    6400 LU=4
0692   C
0693   C      PUNCHED PAPER TAPE MUST BEGIN WITH AN ASTERISK
0694   C
0695          WRITE(LU,6401)
0696    6401 FORMAT("*")
0697   C
0698          WRITE(LU,8125) (IT(I),I=1,5)
0699          WRITE(LU,8135) (ID(I),I=1,3)
0700          WRITE(LU,6403) IREC,IXP(1),KTYPE,IXP(2),IXP(3),IXDIR,
0701         $ LMN,LSN,NDIR,IFLAG2,IFLAG3
0702    6403 FORMAT(2I4,4A2,2I10,3I2)
0703          DO 6404 I=1,3
0704    6404 WRITE(LU,6405) I,MN(I),ISN(I),TCAL(I)
0705    6405 FORMAT(I3,2I10,E15.7)
0706          WRITE(LU,6406) KZOOM,KTEST,NZR
0707    6406 FORMAT(3I2)
0708          DO 6407 I=1,5
0709    6407 WRITE(LU,7441) ICF(I),IBW(I),IR(I),IAVG(I),IOVL(I)
0710          GO TO 200
0711   C
0712   C     **************************************************************
0713   C      PHOTOREAD OPTION FOR INPUTTING TEST SET-UP
0714   C     **************************************************************
0715   C
0716    6500 PAUSE 1
0717          LU=5
0718   C
0719   C      SEARCH LEADER FOR AN ASTERISK
0720   C
0721          CALL POSIT(5)
0722   C
0723          READ(LU,8125) (IT(I),I=1,5)
0724          READ(LU,8135) (ID(I),I=1,3)
0725          READ(LU,6403) IREC,IXP(1),KTYPE,IXP(2),IXP(3),IXDIR,
0726         $ LMN,LSN,NDIR,IFLAG2,IFLAG3
0727          DO 6503 I=1,3
0728    6503 READ(LU,6405) I,MN(I),ISN(I),TCAL(I)
```

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```
0729          READ(LU,6406) KZOOM,KTEST,NZR
0730          DO 6505 I=1,5
0731     6505 READ(LU,7441) ICF(I),IBW(I),IR(I),IAVG(I),IOVL(I)
0732          I=ISWR(40B,0,0)
0733          IPAR1=0
0734          GOTO 7000
0735   C
0736   C    ****************************************************************
0737   C       WRITE TEST SET-UP INFORMATION    ( W )
0738   C    ****************************************************************
0739   C
0740     7000 CALL IOSW(LU,0)
0741          IF(LU.EQ.4) GOTO 6400
0742          IF(IPAR1.GT.3) IPAR1=0
0743          IF(LU.EQ.1.AND.IPAR1.LT.0) WRITE(LU,5028)
0744          IF(IPAR1.EQ.1) GOTO 7300
0745          IF(IPAR1.EQ.2) GOTO 7400
0746          IF(IPAR1.EQ.3) GOTO 7500
0747   C
0748   C       WRITE TEST ID & DATE    ***************************
0749   C
0750          WRITE(LU,7201) (IT(II),II=1,5)
0751     7201 FORMAT(///,10X," TEST ID :    ",5A2)
0752          WRITE(LU,7202) (ID(II),II=1,3)
0753     7202 FORMAT(/,10X," DATE :   ",3(A2,1X))
0754          WRITE(LU,7203) IREC
0755     7203 FORMAT(/,10X," DATA START RECORD : ",I5)
0756          IF(IPAR1.EQ.0) GOTO 200
0757          IF(ISSW(14).LT.0) GOTO 200
0758   C
0759   C       WRITE EXCITER AND TRANSDUCER INFORMATION  ******
0760   C
0761     7300 IF(IFLAG2.NE.0) GOTO 7310
0762          WRITE(LU,7309)
0763     7309 FORMAT(/,10X," NO LOAD CELL OR TRANSDUCER INFORMATION")
0764          IF(IPAR1.EQ.2) GOTO 200
0765          GO TO 7400
0766     7310 WRITE(LU,7301) IXP(1),IXDIR
0767     7301 FORMAT(////,10X," EXCITER POSITION :   ",I4,/,10X,
0768        1 " EXCITER ORIENTATION :   ",A2)
0769          WRITE(LU,7302) LMN,LSN
0770     7302 FORMAT(/,10X," LOAD CELL MODEL #   ",I11,/,10X,
0771        1 " LOAD CELL SERIAL #   ",I10)
0772          IF(NDIR.EQ.0) GOTO 7306
0773          WRITE(LU,7303)
0774     7303 FORMAT(////,10X," RESPONSE TRANSDUCER(S)",//,11X,"NUMBER",
0775        1 9X,"MODEL #",10X,"SERIAL #",6X,"CALIBRATION",/)
0776          DO 7304 II=1,NDIR
0777          WRITE(LU,7305) II,MN(II),ISN(II),TCAL(II)
0778     7305 FORMAT(10X,I4,7X,I10,8X,I10,5X,F12.3)
0779     7304 CONTINUE
0780     7306 IF(IPAR1.EQ.1) GOTO 200
0781          IF(ISSW(14).LT.0) GOTO 200
0782   C
0783   C       WRITE  ZOOM INFORMATION    **********************
0784   C
```

```
0785   7400 IF(IFLAG3.NE.0) GOTO 7401
0786        WRITE(LU,7405)
0787   7405 FORMAT(/,10X," NO ZOOM TEST INFORMATION")
0788        GO TO 200
0789   7401 WRITE(LU,7408) KTYPE
0790   7408 FORMAT(//,10X," DATA TYPE CODE:",2X,A2)
0791        IF(KTEST.EQ.0) WRITE(LU,7411)
0792        IF(KTEST.EQ.1) WRITE(LU,7421)
0793   7411 FORMAT(/,10X," TEST TYPE :   IMPACT")
0794   7421 FORMAT(/,10X," TEST TYPE :   RANDOM")
0795        IF(NZR.EQ.0) GOTO 200
0796        IF(KZOOM.EQ.0) WRITE(LU,7431)
0797        IF(KZOOM.EQ.1) WRITE(LU,7432)
0798   7431 FORMAT(/,10X," CNTRFRQ",3X,"BNDWDTH",4X,"BGNREC",3X,
0799      $ "NUMAVGS",3X,"OVLPFAC")
0800   7432 FORMAT(/,10X," CENTER FREQ",6X,"BANDWIDTH",5X,"NO. AVERAGES")
0801        DO 7440 II=1,NZR
0802        IF(KZOOM.EQ.1) GOTO 7443
0803        WRITE(LU,7441) ICF(II),IBW(II),IR(II),IAVG(II),IOVL(II)
0804        GO TO 7440
0805   7443 WRITE(LU,7442) ICF(II),IBW(II),IAVG(II)
0806   7441 FORMAT(6X,5I10)
0807   7442 FORMAT(4X,3I15)
0808   7440 CONTINUE
0809        GO TO 200
0810  C
0811  C      WRITE HEADER INFO STORED WITH DATA RECORD IPAR2
0812  C
0813   7500 IF(IPAR2.LT.0.OR.IPAR2.GT.IRECMX) GOTO 338
0814        CALL KYBD(2HMS,31,IPAR2)
0815        CALL KYBD(2HMS,11)
0816        IF(IH(6).EQ.12345) GOTO 7598
0817        IF(IPAR3.GE.0) GOTO 7600
0818        IF(LU.EQ.1) WRITE(LU,5028)
0819        WRITE(LU,7502) IPAR2
0820   7502 FORMAT(10X,"HEADER INFORMATION FOR RECORD",I5,/)
0821        WRITE(LU,7504) (IH(I),I=10,14)
0822   7504 FORMAT(/,10X,"TEST I.D..................",5A2)
0823        WRITE(LU,7506) (IH(I),I=26,28)
0824   7506 FORMAT(10X,"DATE......................",3A2,/)
0825        WRITE(LU,7508) IH(16),IH(17)
0826   7508 FORMAT(10X,"POINT NUMBER..............",2A2)
0827        WRITE(LU,7510) IH(19)
0828   7510 FORMAT(10X,"TRANSDUCER ORIENTATION....",2X,A2,/)
0829        WRITE(LU,7516) IH(36),IH(34)
0830   7516 FORMAT(10X,"ZOOM RANGE................",2X,A2,/,
0831      1 10X,"DATA TYPE.................",2X,A2)
0832        WRITE(LU,7511) IH(51)
0833   7511 FORMAT(10X,"TRANSDUCER NUMBER.........",I3,/)
0834        WRITE(LU,7512) IH(21),IH(22)
0835   7512 FORMAT(10X,"EXCITER LOCATION..........",2A2)
0836        WRITE(LU,7514) IH(24)
0837   7514 FORMAT(10X,"EXCITER ORIENTATION.......",2X,A2,/)
0838        WRITE(LU,7518) (IH(I),I=47,50)
0839   7518 FORMAT(10X,"TRANSDUCER MODEL NUMBER...",I6,/,
0840      1 10X,"TRANSDUCER SERIAL NUMBER..",I6,//,
```

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```
0841          2 10X,"LOAD CELL MODEL NUMBER....",I6,/,
0842          3 10X,"LOAD CELL SERIAL NUMBER...",I6,/)
0843            WRITE(LU,7520) (RH(I),I=1,3)
0844     7520 FORMAT(10X,"MINIMUM FREQUENCY.........",F15.7,/,
0845          2 10X,"DELTA FREQUENCY...........",F15.7,//,
0846          3 10X,"DATA CALIBRATION NUMBER...",F15.7,/)
0847            GO TO 200
0848     7598 WRITE(LU,7599) IPAR2
0849     7599 FORMAT(/,"RECORD",I4," IS CLEARED")
0850            GO TO 200
0851   C
0852   C        WRITE HEADER WORD NUMBER IPAR3 FOR RECORD IPAR2
0853   C
0854     7600 WRITE(LU,7502) IPAR2
0855            WRITE(LU,7610) IPAR3
0856     7610 FORMAT(10X,"WORD",I4," CONTAINS :",/)
0857            IF(IPAR3.LT.10) WRITE(LU,7615) IH(IPAR3)
0858            IF(IPAR3.GE.10.AND.IPAR3.LT.45) WRITE(LU,7620) IH(IPAR3)
0859            IF(IPAR3.GE.45.AND.IPAR3.LT.75) WRITE(LU,7630) IH(IPAR3)
0860            IF(IPAR3.LT.75) GOTO 200
0861            IPAR3=(IPAR3-73)/2
0862            WRITE(LU,7640) RH(IPAR3)
0863     7615 FORMAT(10X,@7,"B")
0864     7620 FORMAT(10X,A2)
0865     7630 FORMAT(10X,I10)
0866     7640 FORMAT(10X,E15.7)
0867            GOTO 200
0868   C
0869   C   *****************************************************************
0870   C        ENTER TEST SET-UP THRU KEYBOARD   ( K )
0871   C   *****************************************************************
0872   C
0873     8000 CALL IOSW(LU,1)
0874            IF(LU.EQ.5) GOTO 6500
0875            IF(IPAR1.LE.0) IPAR1=0
0876            IF(IPAR1.EQ.0) GOTO 8100
0877            IF(IPAR1.EQ.1) GOTO 8200
0878            IF(IPAR1.EQ.2) GOTO 8300
0879            GO TO 338
0880   C
0881   C        KEYBOARD  0  **********   TEST ID & DATE  ***********
0882   C
0883     8100 DO 8111 II = 1,5
0884     8111 IT(II) = 2H
0885            WRITE(1,8120)
0886     8120 FORMAT(/,"ENTER TEST I.D. :")
0887            READ(1,8125) (IT(II),II=1,5)
0888     8125 FORMAT(5A2)
0889            WRITE(1,8130)
0890     8130 FORMAT(/,"ENTER DATE :")
0891            READ(1,8135) ID(1),ID(2),ID(3)
0892     8135 FORMAT(3A2)
0893            WRITE(1,8140)
0894     8140 FORMAT(/,"ENTER DISK STORAGE START RECORD :")
0895            READ(1,*) IREC
0896            IF(IREC.LE.0.OR.IREC.GT.IRECMX) IREC=1
```

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```
0897           GO TO 200
0898   C
0899   C       KEYBOARD  1  ***********   LOAD CELL & TRANSDUCER  *****
0900   C
0901   C                                  K 1 0 : INITIALIZES SET-UP
0902   C
0903   8200 IF(IPAR2.NE.0) GOTO 8205
0904           IFLAG2=0
0905           IS(1)=0
0906           NDIR=1
0907           LMN=0
0908           LSN=0
0909           IXDIR=2H
0910           DO 8202 II=1,3
0911           IX(II)=II
0912           MN(II)=0
0913           ISN(II)=0
0914           TCAL(II)=1.0
0915           IXP(II)=2H
0916   8202 CONTINUE
0917           IXP(1)=0
0918           IF(IDUM1.EQ.-1) GOTO 8300
0919           GO TO 200
0920   8205 IFLAG2=1
0921           WRITE(1,8210)
0922   8210 FORMAT(/,"ENTER EXCITER POSITION AND DIRECTION: [ INTEGERS ]")
0923           READ(1,*) IXP(1),IXDIR
0924           CALL CODIT(IXP(1),IXDIR)
0925           WRITE(1,8220)
0926   8220 FORMAT(/,"ENTER LOAD CELL  MODEL #  AND  SERIAL # :")
0927           READ(1,*) LMN,LSN
0928           WRITE(1,8230)
0929   8230 FORMAT(/,"ENTER NUMBER OF RESPONSE DIRECTIONS :")
0930           READ(1,*) NDIR
0931           IF(NDIR.EQ.0) GOTO 200
0932           WRITE(1,8240) NDIR
0933   8240 FORMAT(/,"ENTER",I3," RESPONSE TRANSDUCER'S",/,
0934        1 " MODEL NUMBER , SERIAL NUMBER , CALIBRATION NUMBER :")
0935           DO 8245 II=1,NDIR
0936   8245 READ(1,*) MN(II),ISN(II),TCAL(II)
0937           GO TO 200
0938   C
0939   C       KEYBOARD  2  ***********   ZOOM  INFORMATION  **********
0940   C
0941   C                                  K 2 0 : INITIALIZES SET-UP
0942   C
0943   8300 IF(IPAR2.NE.0) GOTO 8305
0944           IFLAG3=0
0945           NZR=0
0946           KZOOM=1
0947           KTEST=-1
0948           KTYPE=2H20
0949           DO 8302 II=1,5
0950           ICF(II)=0
0951           IBW(II)=0
0952           IR(II) =0
```

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```
0953            IAVG(II)=0
0954            IOVL(II)=0
0955      8302 CONTINUE
0956            IF(IDUM1.EQ.-1) GOTO 50
0957            GO TO 200
0958      8305 IFLAG3=1
0959            WRITE(1,8306)
0960      8306 FORMAT(/,"ENTER DATA TYPE CODE (2 CHARACTER):")
0961            READ(1,8307) KTYPE
0962      8307 FORMAT(A2)
0963            WRITE(1,8330)
0964      8330 FORMAT(/,"ENTER ZERO FOR IMPACT OR ONE FOR RANDOM :")
0965            READ(1,*) KTEST
0966      8301 WRITE(1,8310)
0967      8310 FORMAT(/,"INPUT NUMBER OF ZOOM RANGES :")
0968            READ(1,*) NZR
0969            IF(NZR.LE.0) GOTO 200
0970            IF(NZR.GT.5) GOTO 8301
0971            WRITE(1,8315)
0972      8315 FORMAT(/,"ENTER  1  FOR ON-LINE ZOOM OR",/,
0973           $ 7X,"0  FOR OFF-LINE ZOOM :")
0974            READ(1,*) KZOOM
0975            IF(KZOOM.EQ.1) WRITE(1,8319)
0976            IF(KZOOM.EQ.0) WRITE(1,8320)
0977      8319 FORMAT(//,"FOR EACH ZOOM RANGE INPUT :",/,"CENTER FREQUENCY ,",
0978           $ 1X,"BANDWIDTH , NUMBER OF AVERAGES")
0979      8320 FORMAT(//,"FOR EACH ZOOM RANGE INPUT :",/," CNTR FREQ , BNDWDTH",
0980           1 " , BEGNG REC , NO. AVGS , OVRLP FAC")
0981            DO 8325 II=1,NZR
0982            IF(KZOOM.EQ.1) GOTO 8322
0983            IF(KZOOM.EQ.0) GOTO 8324
0984      8322 READ(1,*) ICF(II),IBW(II),IAVG(II)
0985            GO TO 8325
0986      8324 READ(1,*) ICF(II),IBW(II),IR(II),IAVG(II),IOVL(II)
0987      8325 CONTINUE
0988            GO TO 200
0989    C
0990    C    ***************************************************************
0991    C
0992    C       REPLACE DATA ASSOCIATED WITH A PARTICULAR TRANSDUCER
0993    C                SUCH AS MODEL# , SERIAL# OR CALIBRATION#      ( CV )
0994    C
0995    C    ***************************************************************
0996    C
0997      9000 WRITE(1,1015)
0998            READ(1,1017) IANS
0999            IF(IANS.EQ.1HY ) GOTO 9400
1000      9001 IF(ISSW(14).LT.0) GOTO 200
1001      9009 ISER=0
1002            WRITE(1,9007)
1003      9007 FORMAT(/,"ENTER TRANSDUCER NUMBER",/,
1004           $ "OF DATA TO BE CORRECTED :")
1005    C
1006    C       VALID NUMBERS ARE 0,1,2,3
1007    C
1008            READ(1,*) N
```

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```
1009          IF(ISSW(14).LT.0) GOTO 200
1010          IF(N.GE.0.AND.N.LE.3) GOTO 9002
1011   C
1012   C      IF TRANSDUCER NUMBER IS NOT VALID THEN USE
1013   C      SERIAL NUMBER FOR SEARCH.
1014   C
1015          ISER=1
1016          WRITE(1,9008)
1017   9008 FORMAT(/,"ENTER SERIAL NUMBER INSTEAD:")
1018          READ(1,*) N
1019          IF(ISSW(14).LT.0) GOTO 200
1020          IF(N.GT.0) GOTO 9002
1021          WRITE(1,9010) N
1022   9010 FORMAT(/,I15," :   INVALID NUMBER")
1023          GO TO 9009
1024   9002 WRITE(1,1030)
1025          READ(1,*) IK
1026          IF(ISSW(14).LT.0) GOTO 200
1027          CALL HDRWD(IK,I)
1028          IF(I.NE.0) GOTO 9003
1029          WRITE(1,1044) IK
1030          GO TO 9002
1031   9003 IF(I.NE.1) GOTO 9005
1032          WRITE(1,9004) IK
1033   9004 FORMAT(/,"TO CHANGE WORD NUMBER",I3," USE THE",/,
1034       $ "REPLACE COMMAND (/R)")
1035          GO TO 200
1036   9005 WRITE(1,1041) IK
1037          IF(ISSW(14).LT.0) GOTO 200
1038          IF(IK.GE.75) READ(1,*) CRH(1)
1039          IF(IK.GE.45.AND.IK.LT.75) READ(1,*) NIH(1)
1040          IF(IK.NE.19) GOTO 9020
1041          READ(1,1210) NIH(1)
1042          IF(NIH(1).EQ.2H-X) NIH(1)=2HX-
1043          IF(NIH(1).EQ.2H-Y) NIH(1)=2HY-
1044          IF(NIH(1).EQ.2H-Z) NIH(1)=2HZ-
1045   9020 DO 9100 I=IPAR1,IPAR2
1046          IF(ISSW(14).LT.0) GOTO 9200
1047          CALL KYBD(2HMS,31,I)
1048          CALL KYBD(2HMS,11)
1049          IF(IH(6).NE.52525B) GOTO 9100
1050          CALL BCHK(IBS,IH(5))
1051   C
1052   C      IF TRANSDUCER NUMBER IS ZERO THEN REPLACE WITHOUT CHECK
1053   C
1054          IF(N.EQ.0) GOTO 9025
1055          IF(ISER.EQ.0.AND.IH(51).NE.N) GOTO 9100
1056          IF(ISER.EQ.1.AND.IH(48).NE.N) GOTO 9100
1057   9025 IF(IK.GE.75) GOTO 9030
1058          IH(IK)=NIH(1)
1059          GO TO 9040
1060   9030 IJ=(IK-73)/2
1061          RH(IJ)=CRH(1)
1062   9040 CALL KYBD(2HMS,31,-1,1)
1063          CALL KYBD(2HMS,21)
1064   9100 CONTINUE
```

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```
1065          GO TO 200
1066    C
1067    C        EXIT BEFORE COMPLETING ALL RECORDS
1068    C
1069    9200 IF(I.EQ.IPAR1) GOTO 200
1070          IJ=I-1
1071          WRITE(1,9210) IJ,I
1072    9210 FORMAT(/,"RECORDS THROUGH",I4," HAVE BEEN SEARCHED",/,
1073         $ "RECORDS FROM",I4," ON HAVE NOT BEEN ALTERED")
1074          GO TO 200
1075    C
1076    C        LIST HEADER WORD INFORMATION
1077    C
1078    9400 I=9001
1079          GO TO 9410
1080    9401 I=9501
1081    9410 CALL IOSW(NU,0)
1082          IF(NU.EQ.1) WRITE(NU,5028)
1083          WRITE(NU,1810)
1084          WRITE(NU,1819)
1085          WRITE(NU,9420)
1086    9420 FORMAT(12X,"19",11X,"TRANSDUCER ORIENTATION")
1087          WRITE(NU,1817)
1088          WRITE(NU,9430)
1089    9430 FORMAT(12X,"47",11X,"RESPONSE TRANSDUCER MODEL #",/,
1090         1 12X,"48",11X,"RESPONSE TRANSDUCER SERIAL #",/,
1091         2 12X,"51",11X,"RESPONSE TRANSDUCER NUMBER")
1092          WRITE(NU,1818)
1093          WRITE(NU,9440)
1094    9440 FORMAT(12X,"79",11X,"DATA CALIBRATION OR RECORD #",/)
1095          IF(I.EQ.9501) GOTO 9501
1096          GOTO 9001
1097    C
1098    C    ******************************************************************
1099    C
1100    C        INTERCHANGE TRANSDUCER INFORMATION    ( X  )
1101    C
1102    C    ******************************************************************
1103    C
1104    9500 WRITE(1,3030)IPAR1,IPAR2
1105    3030 FORMAT(/,"YOU ARE ABOUT TO ALTER RECORDS",I5,"  THROUGH",
1106         1 I5,/,"IS THIS CORRECT ?  (YES OR NO)")
1107          READ(1,1017) IANS
1108          IF(IANS.NE.1HY ) GOTO 200
1109          WRITE(1,1015)
1110          READ(1,1017) IANS
1111          IF(IANS.EQ.2HY ) GOTO 9401
1112    9501 WRITE(1,8120)
1113          READ(1,8125) (IT(I),I=1,5)
1114          IF(ISSW(14).LT.0) GOTO 200
1115    9505 WRITE(1,8230)
1116          READ(1,*) ND
1117          IF(ND.LT.1.OR.ND.GT.3) GOTO 9505
1118          WRITE(1,9506)
1119    9506 FORMAT(/,"ENTER NEW AND CORRESPONDING OLD TRANSDUCER NUMBERS")
1120    C
```

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```
1121  C       THIS TABLE WILL INDICATE WHICH DATA WILL BE STORED WHERE
1122  C       IE: THE RECORD WITH THE FIRST NUMBER (NEW) WILL RECEIVE
1123  C       THE DATA NOW STORED IN THE RECORD WITH THE SECOND (OLD)
1124  C       NUMBER.
1125  C
1126          DO 9508 I=1,ND
1127     9508 READ(1,*) NX(I),NY(I)
1128     9518 DO 9513 I=1,5
1129     9513 IYY(I)=-9999
1130          WRITE(1,9514)
1131     9514 FORMAT(/,"ENTER HEADER WORD NUMBERS",1X,
1132          1 "TO BE INTERCHANGED",/,"(19,47,48 AND/OR 79) ",3X,
1133          2 "(TERMINATE LIST WITH A ZERO)")
1134  C
1135  C  THE ABOVE STATEMENT DOES NOT INCLUDE WORD 51 , HOWEVER THE
1136  C  PROGRAM ALLOWS IT TO BE INTERCHANGED ALSO.
1137  C  IT IS NOT INCLUDED BECAUSE THE USER MAY SIMPLY COPY THE
1138  C  NUMBERS AND 51 IS ONE THAT SHOULD NOT BE CHANGED INDISCRIMANTLY
1139  C
1140          DO 9515 I=1,5
1141          READ(1,*) IK
1142          IF(IK.LE.0) GOTO 9510
1143          CALL HDRWD(IK,J)
1144          IF(ISSW(14).LT.0) GOTO 200
1145          IF(J.EQ.2) GOTO 9517
1146          WRITE(1,1044) IK
1147          GO TO 9518
1148     9517 IYY(I)=IK
1149     9515 CONTINUE
1150     9510 WRITE(1,9507)
1151     9507 FORMAT(/,"ENTER POINT NUMBERS WHERE TRANSDUCER ",1X,
1152          1 "INFORMATION",/,"IS TO BE INTERCHANGED (TERMINATE LIST",1X,
1153          2 "WITH A ZERO)")
1154          I=0
1155     9509 J=-9999
1156          K=-9999
1157          READ(1,*) J,K
1158          IF(K.GT.0) GOTO 9511
1159          IF(J.LE.0) GOTO 9520
1160          I=I+1
1161          IXX(I)=J
1162          GOTO 9509
1163     9511 M=1
1164          IF(J.GT.K) M=-1
1165     9512 I=I+1
1166          IXX(I)=J
1167          IF(J.EQ.K) GOTO 9509
1168          J=J+M
1169          GO TO 9512
1170     9520 IF(I.LE.0) GOTO 200
1171          WRITE(1,9525)
1172     9525 FORMAT(/,"LIST POINT NUMBERS ?   (YES OR NO)")
1173          READ(1,1017) IANS
1174          IF(IANS.NE.1HY ) GOTO 9528
1175          CALL IOSW(LU,0)
1176          WRITE(LU,9526)
```

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```
1177    9526 FORMAT(/,"POINT NUMBERS",/)
1178         DO 9529 J=1,I
1179         WRITE(LU,9527) IXX(J)
1180    9527 FORMAT(I5)
1181    9529 CONTINUE
1182         WRITE(1,9521)
1183    9521 FORMAT(/,"ARE POINTS CORRECT? (YES OR NO)")
1184         READ(1,1017) IANS
1185         IF(IANS.NE.1HY ) GOTO 9510
1186   C
1187   C      NO EDIT OF POINT NUMBERS ALLOWED
1188   C
1189    9528 M=IPAR1
1190         DO 9590 KJ=1,I
1191    9530 NP=0
1192   C
1193   C      FOR EACH POINT SEARCH FOR A NUMBER OF RECORDS
1194   C      EQUAL TO THE NUMBER OF DIRECTIONS.
1195   C
1196         DO 9550 J=M,IPAR2
1197         IF(ISSW(14).LT.0) GOTO 9600
1198         CALL KYBD(2HMS,31,J)
1199         CALL KYBD(2HMS,11)
1200         CALL CHKID(IT,IC)
1201         IF(IC.EQ.0) GOTO 9550
1202         IF(IH(45).NE.IXX(KJ)) GOTO 9550
1203         NP=NP+1
1204   C
1205   C      TEST FOR TOO MANY RECORDS FOUND FOR THIS POINT
1206   C
1207         IF(NP.GT.ND) GOTO 9552
1208         IM(NP)=J
1209         IF(NP.EQ.1) GOTO 9540
1210         NP1=NP-1
1211   C
1212   C      TEST TO SEE IF THIS DIRECTION HAS ALREADY BEEN FOUND
1213   C
1214         DO 9535 MJ=1,NP1
1215         IF(IM(MJ).NE.J) GOTO 9535
1216         NP=NP1
1217         GO TO 9557
1218    9535 CONTINUE
1219   C
1220   C      TEST TO SEE IF ALL DIRECTIONS HAVE BEEN FOUND
1221   C
1222    9540 IF(NP.LT.ND) GOTO 9550
1223         GO TO 9560
1224    9550 CONTINUE
1225         IF(NP.LT.ND.AND.M.EQ.IPAR1) GOTO 9557
1226         M=IPAR1
1227         GO TO 9530
1228    9552 WRITE(1,9553) IXX(KJ)
1229    9553 FORMAT(/,"POINT NUMBER",I4," HAS MORE DIRECTIONS THAN",1X,
1230       $ "SPECIFIED",/,"THIS POINT WILL BE SKIPPED")
1231         GO TO 9590
1232    9557 WRITE(1,9558) IXX(KJ),NP,ND
```

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```
1233   9558 FORMAT(/,"POINT NUMBER",I4,/,
1234        1 "ONLY",I3," OF THE",I3," DIRECTIONS FOUND",/,
1235        2 "THIS POINT WILL BE SKIPPED")
1236          GO TO 9590
1237   9560 M=J
1238          DO 9561 J=1,ND
1239   9561 NZ(J)=IM(J)
1240          DO 9562 J=1,ND
1241          CALL KYBD(2HMS,31,NZ(J))
1242          CALL KYBD(2HMS,11)
1243          K=IH(51)
1244          DO 9563 KK=1,ND
1245          IF(NX(KK).EQ.K) GOTO 9564
1246   9563 CONTINUE
1247          WRITE(1,9567) IXX(KJ)
1248   9567 FORMAT(/,"ERROR IN TRANSDUCER NUMBER FOR POINT",I4,/,
1249        $ "THIS POINT WILL BE SKIPPED")
1250          GO TO 9590
1251   9564 IM(KK)=NZ(J)
1252   9562 CONTINUE
1253          CALL KYBD(2HMS,31,IM(1))
1254          CALL KYBD(2HMS,11)
1255          CALL SORT(IYY(1),NIH(1),IH(1),CRH(1),RH(1))
1256          IF(ISSW(14).LT.0) GOTO 9600
1257          DO 9570 J=1,ND
1258          DO 9566 K=1,ND
1259          IF(NY(K).EQ.NIH(5)) GOTO 9568
1260   9566 CONTINUE
1261   9568 CALL KYBD(2HMS,31,IM(K))
1262          CALL KYBD(2HMS,11)
1263          CALL BCHK(IBS,IH(5))
1264   C
1265   C     INTERCHANGE WHAT IS IN CORE WITH WHAT IS IN HEADER
1266   C
1267          CALL SORT(IYY(1),NIH(1),IH(1),CRH(1),RH(1))
1268          CALL KYBD(2HMS,31,-1,1)
1269          CALL KYBD(2HMS,21)
1270   9570 CONTINUE
1271   9590 CONTINUE
1272          GOTO 200
1273   9600 IF(KJ.EQ.1) GOTO 200
1274          K=KJ-1
1275   C
1276   C     IF EXIT BEFORE ALL POINTS ARE DONE THEN PRINT
1277   C     WHICH HAVE BEEN DONE AND WHICH HAVE NOT.
1278   C
1279          WRITE(1,9602) IXX(K),IXX(KJ)
1280   9602 FORMAT(/,"POINTS THROUGH NUMBER",I4," HAVE HAD THE",/,
1281        1 "TRANSDUCER INFORMATION INTERCHANGED.  POINTS FROM",/,
1282        2 "NUMBER",I4," ON HAVE NOT BEEN ALTERED")
1283          GO TO 200
1284   C
1285   C     ************************************************************
1286   C
1287   C                               EXIT  FROM  Y90
1288   C
```

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```
1289   C  ************************************************************
1290   C
1291     9995 CONTINUE
1292          CALL KYBD(2HBS,IBSIZE)
1293          END
```

** NO ERRORS**   PROGRAM = 09865   COMMON = 00072

```
1294   C
1295   C
1296   C
1297         SUBROUTINE HDRWD(IK,I)
1298         I=0
1299         IF(IK.EQ.10.OR.IK.EQ.24) GOTO 10
1300         IF(IK.EQ.26.OR.IK.EQ.34) GOTO 10
1301         IF(IK.EQ.36.OR.IK.EQ.45) GOTO 10
1302         IF(IK.EQ.46.OR.IK.EQ.49) GOTO 10
1303         IF(IK.EQ.50.OR.IK.EQ.75) GOTO 10
1304         IF(IK.EQ.77) GOTO 10
1305         IF(IK.EQ.19) GOTO 20
1306         IF(IK.EQ.47.OR.IK.EQ.48) GOTO 20
1307         IF(IK.EQ.51.OR.IK.EQ.79) GOTO 20
1308         RETURN
1309      10 I=1
1310         RETURN
1311      20 I=2
1312         RETURN
1313         END
```

** NO ERRORS**   PROGRAM = 00143   COMMON = 00000

```
1314  C
1315  C
1316  C
1317        SUBROUTINE SORT(IYY,NIH,IH,CRH,RH)
1318        DIMENSION IYY(1),NIH(1),IH(1),CRH(1),RH(1)
1319        DIMENSION IJ(4)
1320        DATA IJ/19,47,48,51/
1321  C
1322  C     THIS SUBROUTINE TAKES SPECIFIED HEADER INFO CURRENTLY
1323  C     IN MEMORY AND EXCHANGES IT WITH TEMPORARY ARRAYS NIH & CRH
1324  C
1325        DO 10 I=1,5
1326        J=IYY(I)
1327        IF(J.LE.0) GOTO 20
1328        IF(J.GE.75) GOTO 5
1329        DO 2 K=1,4
1330        IF(J.EQ.IJ(K)) GOTO 3
1331      2 CONTINUE
1332      3 IT=IH(J)
1333        IH(J)=NIH(K)
1334        NIH(K)=IT
1335        GO TO 10
1336      5 J=(J-73)/2
1337        T=RH(J)
1338        RH(J)=CRH(1)
1339        CRH(1)=T
1340     10 CONTINUE
1341     20 NIH(5)=IH(51)
1342        RETURN
1343        END
```

** NO ERRORS**   PROGRAM = 00151   COMMON = 00000

```
1344   C
1345   C
1346   C
1347         SUBROUTINE BCHK(ISYSB,IDATB)
1348         IF(ISYSB.EQ.IDATB) RETURN
1349         CALL KYBD(2HBS,IDATB)
1350         ISYSB=IDATB
1351         CALL KYBD(2HMS,31,-1,1)
1352         CALL KYBD(2HMS,11)
1353         RETURN
1354         END
```

**   NO ERRORS**   PROGRAM = 00039   COMMON = 00000

1355   END$

```
0001   FTN4
0002         SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C        THIS  PROGRAM IS STORED UNDER $Y907
0005   C
0006   C**********************************************************************
0007   C
0008   C        PROGRAMMER:   R.J.ALLEMANG
0009   C                      MAIL LOCATION # 72
0010   C                      UNIVERSITY OF CINCINNATI
0011   C                      CINCINNATI, OHIO  45221
0012   C                      513-475-6670
0013   C
0014   C        REVISION DATE:  DEC 17,1979
0015   C
0016   C**********************************************************************
0017         DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018        1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019        2,IC1(1),IPTCM(1),LABEL(20),IPOINT(1)
0020         EQUIVALENCE (LINE(2),LINE1)
0021         COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022        1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023        2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024        3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025        4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026         EXTERNAL HDR8,DTAD0,NMAX
0027         DATA ICMMD/2HD ,2HV ,2HX ,2HEX,2H: ,
0028        12HM ,2H_ ,2HRO,2HA-,2HAM,
0029        22HCH,2HSP,2HX<,
0030        32HX),2HCV,2H< ,2HB ,2HL ,
0031        42HW ,2HI ,2HK ,2HA+,2H/L,
0032        52H/./
0033   C**********************************************************************
0034   C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0035   C
0036   C        PLOTTING PROGRAM    TEK  4012
0037   C**********************************************************************
0038         IBELL=7B
0039         IPAGE=15414B
0040         CALL SETAD(HDR8,IH,-8,0)
0041         ICOMM=0
0042         IBS=1024
0043         CALL KYBD(2HBS,IBS,0)
0044         CALL GETI(NMAX,IBLM)
0045         ION=IBLM-1
0046         ICM=ION-1
0047         IBM=2
0048         I=ION*IBS+270
0049         CALL SETAD(DTAD0,IPTCM,I,-1)
0050         CALL RWCOM(0)
0051   C
0052   C        IF INITIALIZATION IS REQUIRED, LOAD Y 91
0053   C
0054         IF(ICOMM.EQ.12345)GO TO 900
0055         CALL KYBD(2HMS,38,-7,1)
0056         CALL OVLD(9)
0057   900   CONTINUE
0058         CALL SETAD(DTAD0,IX1,0,-1)
```

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```
0059        CALL SETAD(DTAD0,IY1,256,-1)
0060        CALL SETAD(DTAD0,IDX,512,-1)
0061        CALL SETAD(DTAD0,IDY,768,-1)
0062        CALL SETAD(DTAD0,IC1,1024,-1)
0063        CALL SETAD(DTAD0,IDIV,1536,-1)
0064        CALL SETAD(DTAD0,IPOINT,1600,-1)
0065        NPD=IDIV(21)
0066        IFLG7=0
0067        MXOFF=IDIV(22)
0068        MYOFF=IDIV(23)
0069        MCSIZE=IDIV(24)
0070        MP1=IDIV(25)
0071        MP2=IDIV(26)
0072        IFLG7=IDIV(27)
0073        IF(IFLAG.EQ.1)GO TO 1130
0074  C**********************************************************************
0075  C         START OF MONITOR
0076  C**********************************************************************
0077   1000 WRITE(1,1010)IBELL
0078   1010 FORMAT("*",A2)
0079        I=ISWR(177677B,0,0)
0080        IPAR1=-9999
0081        IPAR2=-9999
0082        IPAR3=-9999
0083        IPAR4=-9999
0084        IPAR5=-9999
0085        IPAR6=-9999
0086   1020 DO 1030 I=1,36
0087   1030 LINE(I)=2H,,
0088   1040 CALL TTYIN(LINE)
0089   1042 CALL TEST(1,IST,LOG)
0090        IF(IST.LT.0)GO TO 1042
0091        CALL CODE
0092        READ(LINE,1120)IL
0093        IF(ICOMM.EQ.12345)GO TO 1115
0094  C
0095  C         PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
0096  C              EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
0097  C
0098   1115 CONTINUE
0099   1120 FORMAT(A2)
0100        CALL CODE
0101        READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0102  C**********************************************************************
0103  C         MONITOR COMMAND TABLE
0104  C**********************************************************************
0105   1130 IFLAG=0
0106        CALL RWCOM(1)
0107        IF(IL.EQ.2H**)GO TO 1000
0108        NCMMD=24
0109        DO 1138  I=1,NCMMD
0110        IF(IL.EQ.ICMMD(I))GO TO 1144
0111   1138 CONTINUE
0112   1139 WRITE(1,1140)
0113   1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0114        GO TO 1000
0115   1144 IF(I.GT.10)GO TO 1146
0116        GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0117   1146 I=I-10
0118        IF(I.GT.10)GO TO 1148
```

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```
0119          GO TO (9004,9004,9004,9004,9004,9995,8000,2000,9002,9001),I
0120     1148 I=I-10
0121          GO TO (9001,9003,9008,7000),I
0122     C
0123     C        ENTER DATA TO SET UP POINT LABELING OF PLOT
0124     C
0125     7000 CONTINUE
0126          IF(IPAR1.EQ.-9999)IPAR1=100
0127          IF(IPAR2.EQ.-9999)IPAR2=100
0128          IF(IPAR3.EQ.-9999)IPAR3=100
0129          IF(IPAR4.EQ.-9999)IPAR4=1
0130          IF(IPAR5.EQ.-9999)IPAR5=250
0131          IFLG7=1
0132          MXOFF=IPAR1
0133          MYOFF=IPAR2
0134          MCSIZE=IPAR3
0135          MP1=IPAR4
0136          MP2=IPAR5
0137          GO TO 1000
0138     2000 CONTINUE
0139          IF(IPAR.EQ.37)GO TO 9005
0140          IF(IPAR.EQ.10)GO TO 9006
0141     C************************************************************************
0142     C                  PLOTS MODE SHAPES ON THE TEK 4012
0143     C************************************************************************
0144     8000 CONTINUE
0145          IF(IPAR1.EQ.37)GO TO 9005
0146          IF(IPAR1.EQ.10)GO TO 9006
0147          IJJ=IPAR2
0148          IF(IPAR2.EQ.-9999)IPAR2=0
0149          ITEK=6B
0150          DSHTEK=9.
0151          XTEK=390.
0152          YTEK=390.
0153          TEKSCL=84.0
0154          IF(ISSW(15).LT.0)GO TO 8008
0155          WRITE(1,8009)IPAGE
0156     8009 FORMAT(A2)
0157     8008 CONTINUE
0158          XCENT=XTEK
0159          YCENT=YTEK
0160          PSCAL=TEKSCL
0161          DASH=DSHTEK
0162          IDEV=ITEK
0163          CALL FNDLU(IDEV,LU)
0164          IF(LU.EQ.0)WRITE(1,8236)IBELL
0165     8236 FORMAT(/,"ERROR-INVALID LOGICAL UNIT",A2)
0166          IF(LU.EQ.0)GO TO 1000
0167          IF(NPD.LE.2)GO TO 8110
0168          IF(NPD.GT.500)GO TO 8110
0169     C
0170     C        INITIALIZE
0171     C
0172          IF(IPAR2.LE.0)IJJ=1
0173          IF(IPAR2.GT.20)IJJ=1
0174     8045 CONTINUE
0175     C
0176     C        PLOT LOOP
0177     C
0178     C            SWITCH 12   SOLID UNDEFORMED LINES
```

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/

```
0179  C              SWITCH 13    ABORT POINT LABELING
0180  C              SWITCH 14    ABORT PLOT
0181  C
0182         DO 8100 I=1,NPD
0183  C
0184  C        SWITCH 14 TO ABORT PLOT
0185  C
0186         IF(ISSW(14).LT.0)GO TO 1000
0187         J=IABS(IC1(I))
0188         JGARY=1
0189         IF(IC1(I).LT.0)JGARY=-1
0190         IJX=FLOAT(IX1(J))/PSCAL+XCENT
0191         IJY=FLOAT(IY1(J))/PSCAL+YCENT
0192         IF(I.EQ.1)IXOLD=IJX
0193         IF(I.EQ.1)IYOLD=IJY
0194         JX=IJX+IDX(J)/(IDIV(IJJ)*PSCAL)
0195         JY=IJY+IDY(J)/(IDIV(IJJ)*PSCAL)
0196         IF(IPAR2.NE.0)GO TO 8050
0197  C
0198  C        PLOT UNDEFORMED SHAPE
0199  C
0200         IF(ISSW(12).LT.0)GO TO 8060
0201  C
0202  C        SET SWITCH 12 FOR UNDEFORMED SOLID LINES
0203  C
0204         IF(JGARY.EQ.-1)GO TO 8060
0205         CALL DOT(IXOLD,IYOLD,IJX,IJY,DASH,LU)
0206         GO TO 8062
0207    8060 WRITE(LU)JGARY,1,IJX,IJY
0208    8062 CONTINUE
0209         IXOLD=IJX
0210         IYOLD=IJY
0211         GO TO 8100
0212  C
0213  C              PLOT MAXIMUM DEFORMED SHAPE
0214  C
0215    8050 WRITE(LU)JGARY ,1,JX,JY
0216    8100 CONTINUE
0217         IF(IPAR2.LT.0)IJJ=IJJ+2
0218         IF((IPAR2.LT.0).AND.(IJJ.LT.12))GO TO 8045
0219         IFLG7=0
0220    8108 CONTINUE
0221         JGARY=-1
0222         WRITE(LU)JGARY,1,0,30
0223         WRITE(1,8109)IT,FRQ(NMP)
0224    8109 FORMAT(2X,5A2,4X,F10.3)
0225         GO TO 1000
0226    8110 CONTINUE
0227         WRITE(1,8111)
0228    8111 FORMAT(/,"ERROR-DISPLAY NOT PREVIOUSLY CALCULATED",/)
0229         GO TO 1000
0230  C*********************************************************************
0231  C        EXIT TO OTHER OVERLAYS
0232  C*********************************************************************
0233    9001 I=1
0234         GO TO 9900
0235    9002 I=2
0236         GO TO 9900
0237    9003 I=3
0238         GO TO 9900
```

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```
0239    9004 I=4
0240         GO TO 9900
0241    9005 I=5
0242         GO TO 9900
0243    9006 I=6
0244         GO TO 9900
0245    9008 I=8
0246         GO TO 9900
0247    9900 CONTINUE
0248         IFLAG=1
0249         CALL RWCOM(1)
0250         CALL KYBD(2HMS,38,I)
0251         CALL OVLD(9)
0252    9995 CONTINUE
0253         1L=2H##
0254         IF(ICOMM.EQ.12345)CALL RWCOM(1)
0255         CALL KYBD(2HBS,IBS,0)
0256         RETURN
0257         END
0258         END$
```

```
0001   FTN4
0002          SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C          THIS PROGRAM IS STORED UNDER $Y906
0005   C
0006   C*********************************************************************
0007   C
0008   C          PROGRAMMER:   R.J.ALLEMANG
0009   C                        MAIL LOCATION # 72
0010   C                        UNIVERSITY OF CINCINNATI
0011   C                        CINCINNATI, OHIO  45221
0012   C                        513-475-6670
0013   C
0014   C          REVISION DATE:   DEC 17, 1979
0015   C
0016   C*********************************************************************
0017          DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018         1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019         2,IC1(1),IPTCM(1),LABEL(20),IPOINT(1)
0020          EQUIVALENCE (LINE(2),LINE1)
0021          COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022         1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023         2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024         3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025         4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026          EXTERNAL HDR8,DTADO,NMAX
0027          DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
0028         12HM ,2H_ ,2HRO,2HA-,2HAM,
0029         22HCH,2HSP,2HX<,
0030         32HX>,2HCV,2H( ,2HB ,2HL ,
0031         42HW ,2HI ,2HK ,2HA+,2H/L,
0032         52H./
0033   C*********************************************************************
0034   C          UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0035   C
0036   C              PLOTTING PROGRAM   HP 7210
0037   C*********************************************************************
0038          IBELL=7B
0039          IPAGE=15414B
0040          CALL SETAD(HDR8,IH,-8,0)
0041          ICOMM=0
0042          IBS=1024
0043          CALL KYBD(2HBS,IBS,0)
0044          CALL GETI(NMAX,IBLM)
0045          ION=IBLM-1
0046          ICM=ION-1
0047          IBM=2
0048          I=ION*IBS+270
0049          CALL SETAD(DTADO,IPTCM,I,-1)
0050          CALL RWCOM(0)
0051   C
0052   C          IF INITIALIZATION IS REQUIRED, LOAD Y 91
0053   C
0054          IF(ICOMM.EQ.12345)GO TO 900
0055          CALL KYBD(2HMS,38,-6,1)
0056          CALL OVLD(9)
0057      900 CONTINUE
0058          CALL SETAD(DTADO,IX1,0,-1)
```

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```
0059        CALL SETAD(DTAD0,IY1,256,-1)
0060        CALL SETAD(DTAD0,IDX,512,-1)
0061        CALL SETAD(DTAD0,IDY,768,-1)
0062        CALL SETAD(DTAD0,IC1,1024,-1)
0063        CALL SETAD(DTAD0,IDIV,1536,-1)
0064        CALL SETAD(DTAD0,IPOINT,1600,-1)
0065        NPD=IDIV(21)
0066        IFLG7=0
0067        MXOFF=IDIV(22)
0068        MYOFF=IDIV(23)
0069        MCSIZE=IDIV(24)
0070        MP1=IDIV(25)
0071        MP2=IDIV(26)
0072        IFLG7=IDIV(27)
0073        IF(IFLAG.EQ.1)GO TO 1130
0074 C*******************************************************************
0075 C        START OF MONITOR
0076 C*******************************************************************
0077 1000 WRITE(1,1010)IBELL
0078 1010 FORMAT("*",A2)
0079        I=ISWR(177677B,0,0)
0080        IPAR1=-9999
0081        IPAR2=-9999
0082        IPAR3=-9999
0083        IPAR4=-9999
0084        IPAR5=-9999
0085        IPAR6=-9999
0086 1020 DO 1030 I=1,36
0087 1030 LINE(I)=2H,,
0088 1040 CALL TTYIN(LINE)
0089 1042 CALL TEST(1,IST,LOG)
0090        IF(IST.LT.0)GO TO 1042
0091        CALL CODE
0092        READ(LINE,1120)IL
0093        IF(ICOMM.EQ.12345)GO TO 1115
0094 C
0095 C       PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
0096 C           EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
0097 C
0098 1115 CONTINUE
0099 1120 FORMAT(A2)
0100        CALL CODE
0101        READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0102 C*******************************************************************
0103 C        MONITOR COMMAND TABLE
0104 C*******************************************************************
0105 1130 IFLAG=0
0106        CALL RWCOM(1)
0107        IF(IL.EQ.2H##)GO TO 1000
0108        NCMMD=24
0109        DO 1138  I=1,NCMMD
0110        IF(IL.EQ.ICMMD(I))GO TO 1144
0111 1138 CONTINUE
0112 1139 WRITE(1,1140)
0113 1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0114        GO TO 1000
0115 1144 IF(I.GT.10)GO TO 1146
0116        GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0117 1146 I=I-10
0118        IF(I.GT.10)GO TO 1148
```

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```
0119          GO TO (9004,9004,9004,9004,9004,9995,8000,8200,9002,9001),I
0120     1148 I=I-10
0121          GO TO (9001,9003,9008,7000),I
0122   C
0123   C        ENTER DATA TO SET UP POINT LABELING OF PLOT
0124   C
0125     7000 CONTINUE
0126          IF(IPAR1.EQ.-9999)IPAR1=100
0127          IF(IPAR2.EQ.-9999)IPAR2=100
0128          IF(IPAR3.EQ.-9999)IPAR3=100
0129          IF(IPAR4.EQ.-9999)IPAR4=1
0130          IF(IPAR5.EQ.-9999)IPAR5=250
0131          IFLG7=1
0132          MXOFF=IPAR1
0133          MYOFF=IPAR2
0134          MCSIZE=IPAR3
0135          MP1=IPAR4
0136          MP2=IPAR5
0137          GO TO 1000
0138   C********************************************************************
0139   C                    PLOTS MODE SHAPES ON THE HP   7210
0140   C********************************************************************
0141     8000 CONTINUE
0142          IF(IPAR1.EQ.37)GO TO 9005
0143          IF(IPAR1.EQ.6)GO TO 9007
0144          IJJ=IPAR2
0145          IF(IPAR2.EQ.-9999)IPAR2=0
0146          IPLOT=10B
0147          XPLOT=5000.
0148          YPLOT=5000.
0149          DSHPLT=100.
0150          PLTSCL=6.56
0151     8010 CONTINUE
0152          XCENT=XPLOT
0153          YCENT=YPLOT
0154          PSCAL=PLTSCL
0155          DASH=DSHPLT
0156          IDEV=IPLOT
0157          CALL FNDLU(IDEV,LU)
0158          IF(LU.EQ.0)WRITE(1,8236)
0159          IF(LU.EQ.0)GO TO 1000
0160          IF(NPD.LE.2)GO TO 8110
0161          IF(NPD.GT.500)GO TO 8110
0162   C
0163   C        INITIALIZE
0164   C
0165          IF(IPAR2.LE.0)IJJ=1
0166          IF(IPAR2.GT.20)IJJ=1
0167   C
0168   C        ARRAY TO FLAG POINTS ALREADY LABELED
0169   C
0170          DO 8038  I=1,250
0171     8038 IPOINT(I)=1
0172          DO 8040 I=MP1,MP2
0173     8040 IPOINT(I)=0
0174     8045 CONTINUE
0175   C
0176   C        PLOT LOOP
0177   C
0178   C             SWITCH 12    SOLID UNDEFORMED LINES
```
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```
0179  C              SWITCH 13    ABORT POINT LABELING
0180  C              SWITCH 14    ABORT PLOT
0181  C
0182         DO 8100 I=1,NPD
0183  C
0184  C          SWITCH 14 TO ABORT PLOT
0185  C
0186         IF(ISSW(14).LT.0)GO TO 1000
0187         J=IABS(IC1(I))
0188         JGARY=1
0189         IF(IC1(I).LT.0)JGARY=-1
0190         IJX=FLOAT(IX1(J))/PSCAL+XCENT
0191         IJY=FLOAT(IY1(J))/PSCAL+YCENT
0192         IF(I.EQ.1)IXOLD=IJX
0193         IF(I.EQ.1)IYOLD=IJY
0194         JX=IJX+IDX(J)/(IDIV(IJJ)*PSCAL)
0195         JY=IJY+IDY(J)/(IDIV(IJJ)*PSCAL)
0196         IF(IPAR2.NE.0)GO TO 8050
0197  C
0198  C          PLOT UNDEFORMED SHAPE
0199  C
0200         IF(ISSW(12).LT.0)GO TO 8060
0201  C
0202  C      SET SWITCH 12 FOR UNDEFORMED SOLID LINES
0203  C
0204         IF(JGARY.EQ.-1)GO TO 8060
0205         CALL DOT(IXOLD,IYOLD,IJX,IJY,DASH,LU)
0206         GO TO 8062
0207   8060  WRITE(LU)JGARY ,1,IJX,IJY
0208  C
0209  C      POINT LABELING
0210  C
0211         IF(IFLG7.EQ.0)GO TO 8062
0212  C
0213  C        ABORT POINT LABELING    SWITCH 13
0214  C
0215         IF(ISSW(13).LT.0)GO TO 8062
0216         IF(IPOINT(J).EQ.1)GO TO 8062
0217         THETA=0.0
0218         IRAD=20
0219         DO 8055 KK=1,10
0220         JXXX=IJX+IRAD*SIN(THETA)
0221         JYYY=IJY+IRAD*COS(THETA)
0222         THETA=THETA+0.628312
0223         WRITE(LU)1,1,JXXX,JYYY
0224   8055  CONTINUE
0225         WRITE(LU)-1,-1,MXOFF,MYOFF
0226         WRITE(LU,8065)MCSIZE,0,0,MCSIZE,J
0227   8068  CONTINUE
0228         WRITE(LU)-1,1,IJX,IJY
0229   8065  FORMAT(4I5,I3)
0230         IPOINT(J)=1
0231   8062  CONTINUE
0232         IXOLD=IJX
0233         IYOLD=IJY
0234         GO TO 8100
0235  C
0236  C          PLOT MAXIMUM DEFORMED SHAPE
0237  C
0238   8050  WRITE(LU)JGARY ,1,JX,JY
```

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```
0239          GO TO 8100
0240    8100 CONTINUE
0241          IF(IPAR2.LT.0)IJJ=IJJ+2
0242          IF((IPAR2.LT.0).AND.(IJJ.LT.12))GO TO 8045
0243          IFLG7=0
0244    8108 CONTINUE
0245   C
0246   C           PRINT TEST I.D. AND MODE FREQUENCY
0247   C
0248          IF(NMP.EQ.0)GO TO 1000
0249    8155 CONTINUE
0250          WRITE(LU)-1,1,100,7000
0251          WRITE(LU,8156)200,0,0,200,IT
0252    8156 FORMAT(4I5,5A2)
0253          WRITE(LU)-1,1,100,6500
0254          WRITE(LU,8157)200,0,0,200,FRQ(NMP)
0255    8157 FORMAT(4I5,F10.3)
0256          GO TO 1000
0257    8110 CONTINUE
0258          WRITE(1,8111)
0259    8111 FORMAT(/,"ERROR-DISPLAY NOT PREVIOUSLY CALCULATED",/)
0260          GO TO 1000
0261   C*******************************************************************
0262   C           CODE LABELS MODE SHAPE PLOTS
0263   C*******************************************************************
0264    8200 CONTINUE
0265          IF(IPAR1.EQ.37)GO TO 9005
0266          IDEV=10B
0267          CALL FNDLU(IDEV,LU)
0268          IF(LU.EQ.0)WRITE(1,8236)
0269          IF(LU.EQ.0)GO TO 1000
0270          IF(IPAR4.NE.-9999)GO TO 8210
0271          IPAR4=200
0272          IF(IPAR3.NE.-9999)GO TO 8210
0273          IPAR3=700.0
0274          IF(IPAR2.NE.-9999)GO TO 8210
0275          IPAR2=350.0
0276   C
0277   C               IPAR1 = DEVICE  THAT THE LABEL IS TO BE PRINTED ON
0278   C               IPAR2 = STARTING X POSITION OF LABEL
0279   C               IPAR3 = STARTING Y POSITION OF LABEL
0280   C               IPAR4 = SIZE OF CHARACTERS(IPAR4 X IPAR4)
0281   C
0282    8210 CONTINUE
0283          IPAR2=IPAR2*10
0284          IPAR3=IPAR3*10
0285          WRITE(LU)-1,1,IPAR2,IPAR3
0286          DO 8226 I=1,20
0287    8226 LABEL(I)=2H
0288          WRITE(1,8230)IBELL
0289    8230 FORMAT(/,"ENTER LABEL:",A2,/)
0290          READ(1,8235)(LABEL(I),I=1,20)
0291          CALL TEST(1,ISTAT,LOGX)
0292          LOGX=(LOGX+1)/2
0293    8235 FORMAT(20A2)
0294          IF(LABEL(1).EQ.2H/ )GO TO 1000
0295    8236 FORMAT(/,"ERROR-INVALID LOGICAL UNIT ")
0296          WRITE(LU)-1,1,IPAR2,IPAR3
0297          WRITE(LU,8240)IPAR4,0,0,IPAR4,(LABEL(I),I=1,LOGX)
0298    8240 FORMAT(4I5,20A2)
```

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```
0299        IPAR3=IPAR3-IPAR4*12/10
0300        GO TO 8210
0301 C*********************************************************************
0302 C          EXIT TO OTHER OVERLAYS
0303 C*********************************************************************
0304   9001 I=1
0305        GO TO 9900
0306   9002 I=2
0307        GO TO 9900
0308   9003 I=3
0309        GO TO 9900
0310   9004 I=4
0311        GO TO 9900
0312   9005 I=5
0313        GO TO 9900
0314   9007 I=7
0315        GO TO 9900
0316   9008 I=8
0317        GO TO 9900
0318   9900 CONTINUE
0319        IFLAG=1
0320        CALL RWCOM(1)
0321        CALL KYBD(2HMS,38,I)
0322        CALL OVLD(9)
0323   9995 CONTINUE
0324        IL=2H**
0325        IF(ICOMM.EQ.12345)CALL RWCOM(1)
0326        CALL KYBD(2HBS,IBS,0)
0327        RETURN
0328        END
0329        END$
```

```
0001   FTN4
0002           SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C          THIS PROGRAM IS STORED UNDER $Y905
0005   C
0006   C*****************************************************************************
0007   C
0008   C          PROGRAMMER:   R.J.ALLEMANG
0009   C                        MAIL LOCATION # 72
0010   C                        UNIVERSITY OF CINCINNATI
0011   C                        CINCINNATI, OHIO  45221
0012   C                        513-475-6670
0013   C
0014   C          REVISION DATE:   DEC 17, 1979
0015   C
0016   C*****************************************************************************
0017           DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018          1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019          2,IC1(1),IPTCM(1),LABEL(20),IPOINT(1)
0020           EQUIVALENCE (LINE(2),LINE1)
0021           COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022          1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023          2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024          3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025          4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026           EXTERNAL HDR8,DTAD0,NMAX
0027           DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
0028          12HM ,2H_ ,2HRO,2HA-,2HAM,
0029          22HCH,2HSP,2HX<,
0030          32HX>,2HCV,2H< ,2HB ,2HL ,
0031          42HW ,2HI ,2HK ,2HA+,2H/L,
0032          52H/./
0033   C*****************************************************************************
0034   C          UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0035   C
0036   C             PLOTTING PROGRAM   HP   9872
0037   C*****************************************************************************
0038           IPAGE=15414B
0039           IBELL=7B
0040           CALL SETAD(HDR8,IH,-8,0)
0041           ICOMM=0
0042           IBS=1024
0043           CALL KYBD(2HBS,IBS,0)
0044           CALL GETI(NMAX,IBLM)
0045           ION=IBLM-1
0046           ICM=ION-1
0047           IBM=2
0048           I=ION*IBS+270
0049           CALL SETAD(DTAD0,IPTCM,I,-1)
0050           CALL RWCOM(0)
0051   C
0052   C          IF INITIALIZATION IS REQUIRED, LOAD Y 91
0053   C
0054           IF(ICOMM.EQ.12345)GO TO 900
0055           CALL KYBD(2HMS,38,-5,1)
0056           CALL OVLD(9)
0057       900 CONTINUE
0058           CALL SETAD(DTAD0,IX1,0,-1)
```

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```
0059          CALL SETAD(DTAD0,IY1,256,-1)
0060          CALL SETAD(DTAD0,IDX,512,-1)
0061          CALL SETAD(DTAD0,IDY,768,-1)
0062          CALL SETAD(DTAD0,IC1,1024,-1)
0063          CALL SETAD(DTAD0,IDIV,1536,-1)
0064          CALL SETAD(DTAD0,IPOINT,1600,-1)
0065          NPD=IDIV(21)
0066          IFLG7=0
0067          MXOFF=IDIV(22)
0068          MYOFF=IDIV(23)
0069          MCSIZE=IDIV(24)
0070          MP1=IDIV(25)
0071          MP2=IDIV(26)
0072          IFLG7=IDIV(27)
0073          IF(IFLAG.EQ.1)GO TO 1130
0074   C*********************************************************************
0075   C          START OF MONITOR
0076   C*********************************************************************
0077   1000 WRITE(1,1010)IBELL
0078   1010 FORMAT("*",A2)
0079          I=ISWR(177677B,0,0)
0080          IPAR1=-9999
0081          IPAR2=-9999
0082          IPAR3=-9999
0083          IPAR4=-9999
0084          IPAR5=-9999
0085          IPAR6=-9999
0086   1020 DO 1030 I=1,36
0087   1030 LINE(I)=2H,,
0088   1040 CALL TTYIN(LINE)
0089   1042 CALL TEST(1,IST,LOG)
0090          IF(IST.LT.0)GO TO 1042
0091          CALL CODE
0092          READ(LINE,1120)IL
0093          IF(ICOMM.EQ.12345)GO TO 1115
0094   C
0095   C          PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
0096   C               EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
0097   C
0098   1115 CONTINUE
0099   1120 FORMAT(A2)
0100          CALL CODE
0101          READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0102   C*********************************************************************
0103   C          MONITOR COMMAND TABLE
0104   C*********************************************************************
0105   1130 IFLAG=0
0106          CALL RWCOM(1)
0107          IF(IL.EQ.2H**)GO TO 1000
0108          NCMMD=24
0109          DO 1138  I=1,NCMMD
0110          IF(IL.EQ.ICMMD(I))GO TO 1144
0111   1138 CONTINUE
0112   1139 WRITE(1,1140)
0113   1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0114          GO TO 1000
0115   1144 IF(I.GT.10)GO TO 1146
0116          GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0117   1146 I=I-10
0118          IF(I.GT.10)GO TO 1148
```

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```
0119        GO TO (9004,9004,9004,9004,9004,9995,8000,8200,9002,9001),I
0120   1148 I=I-10
0121        GO TO (9001,9003,9008,7000),I
0122 C
0123 C      ENTER DATA TO SET UP POINT LABELING OF PLOT
0124 C
0125  7000 CONTINUE
0126        IF(IPAR1.EQ.-9999)IPAR1=100
0127        IF(IPAR2.EQ.-9999)IPAR2=100
0128        IF(IPAR3.EQ.-9999)IPAR3=100
0129        IF(IPAR4.EQ.-9999)IPAR4=1
0130        IF(IPAR5.EQ.-9999)IPAR5=250
0131        IFLG7=1
0132        MXOFF=IPAR1
0133        MYOFF=IPAR2
0134        MCSIZE=IPAR3
0135        MP1=IPAR4
0136        MP2=IPAR5
0137        GO TO 1000
0138 C********************************************************************
0139 C                PLOTS MODE SHAPES ON THE HP  9872
0140 C********************************************************************
0141  8000 CONTINUE
0142        IF(IPAR1.EQ.10)GO TO 9006
0143        IF(IPAR1.EQ.6)GO TO 9007
0144        IJJ=IPAR2
0145        IF(IPAR2.EQ.-9999)IPAR2=0
0146        IPLT=37B
0147        XPLT=5500.0
0148        YPLT=3500.0
0149        PLTSKL=9.28
0150  8020 CONTINUE
0151        XCENT=XPLT
0152        YCENT=YPLT
0153        PSCAL=PLTSKL
0154        ICOLOR=1
0155        IF(IPAR3.NE.-9999)ICOLOR=IPAR3
0156        IDEV=IPLT
0157 C
0158 C      CHECK TO FIND LOGICAL UNIT
0159 C
0160        CALL FNDLU(IDEV,LU)
0161        IF(LU.EQ.0)WRITE(1,8236)
0162        IF(LU.EQ.0)GO TO 1000
0163        IF(NPD.LE.2)GO TO 8110
0164        IF(NPD.GT.500)GO TO 8110
0165 C
0166 C          INITIALIZE AND SELECT PEN COLOR
0167 C
0168        WRITE(LU,8035)ICOLOR
0169  8035 FORMAT("IP0,0,11000,8000"/"PU"/"IW0,0,11000,8000"/"SP"I6/
0170       1"LT")
0171        IF(IPAR2.LE.0)IJJ=1
0172        IF(IPAR2.GT.20)IJJ=1
0173 C
0174 C          ARRAY TO FLAG POINTS ALREADY LABELED
0175 C
0176        DO 8038  I=1,250
0177  8038 IPOINT(I)=1
0178        DO 8040 I=MP1,MP2
```

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```
0179    8040 IPOINT(I)=0
0180    8045 CONTINUE
0181  C
0182  C          PLOT LOOP
0183  C
0184  C             SWITCH 12    SOLID UNDEFORMED LINES
0185  C             SWITCH 13    ABORT POINT LABELING
0186  C             SWITCH 14    ABORT PLOT
0187  C
0188         DO 8100 I=1,NPD
0189  C
0190  C          SWITCH 14 TO ABORT PLOT
0191  C
0192         IF(ISSW(14).LT.0)GO TO 1000
0193         J=IABS(IC1(I))
0194         JGARY=1
0195         IF(IC1(I).LT.0)JGARY=-1
0196         IJX=FLOAT(IX1(J))/PSCAL+XCENT
0197         IJY=FLOAT(IY1(J))/PSCAL+YCENT
0198         IF(I.EQ.1)IXOLD=IJX
0199         IF(I.EQ.1)IYOLD=IJY
0200         JX=IJX+IDX(J)/(IDIV(IJJ)*PSCAL)
0201         JY=IJY+IDY(J)/(IDIV(IJJ)*PSCAL)
0202         IF(JGARY.EQ.-1)WRITE(LU,8075)
0203    8075 FORMAT("PU")
0204         IF(IPAR2.NE.0)GO TO 8080
0205  C
0206  C       SWITCH 12 ON: SOLID LINES
0207  C
0208         IF(ISSW(12).GE.0)WRITE(LU,8072)
0209    8072 FORMAT("LT2,1.0")
0210  C
0211  C          UNDEFORMED SHAPE
0212  C
0213         WRITE(LU,8078)IJX,IJY
0214    8078 FORMAT("SM."/"PA",I6,",",I6/"PD"/"SM")
0215         IF(IPOINT(J).EQ.1)GO TO 8100
0216         IF(IFLG7.EQ.0)GO TO 8100
0217  C
0218  C       SWITCH 13 ON: ABORT POINT NUMBER
0219  C
0220         IF(ISSW(13).LT.0)GO TO 8100
0221         WRITE(LU,8013)MXOFF,MYOFF
0222    8013 FORMAT("PU"/"PR",I6,",",I6/)
0223         IF(J.LT.10)WRITE(LU,8015)J
0224         IF((J.GE.10).AND.(J.LT.100))WRITE(LU,8016)J
0225         IF(J.GE.100)WRITE(LU,8017)J
0226    8015 FORMAT("LB",I1)
0227    8016 FORMAT("LB",I2)
0228    8017 FORMAT("LB",I3)
0229         WRITE(LU,8430)
0230         WRITE(LU,8014)IJX,IJY
0231    8014 FORMAT("PU"/"PA",I6,",",I6/"PD")
0232         IPOINT(J)=1
0233         GO TO 8100
0234    8080 CONTINUE
0235  C
0236  C          DEFORMED SHAPE
0237  C
0238         WRITE(LU,8078)JX,JY
```

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```
0239    8100 CONTINUE
0240         IF(IPAR2.LT.0)IJJ=IJJ+2
0241         IF((IPAR2.LT.0).AND.(IJJ.LT.12))GO TO 8045
0242         IFLG7=0
0243    8108 CONTINUE
0244    C
0245    C         PRINT TEST I.D. AND MODE FREQUENCY
0246    C
0247         IF(NMP.EQ.0)GO TO 1000
0248         WRITE(LU,8109)IT,FRQ(NMP)
0249    8109 FORMAT("PU"/"PA1000,7300"/
0250        1"LBTEST   ",5A2/" "/F10.3," HERTZ")
0251         WRITE(LU,8430)
0252          GO TO 1000
0253    8110 CONTINUE
0254         WRITE(1,8111)
0255    8111 FORMAT(/,"ERROR-DISPLAY NOT PREVIOUSLY CALCULATED",/)
0256          GO TO 1000
0257    C*****************************************************************************
0258    C         CODE LABELS MODE SHAPE PLOTS
0259    C*****************************************************************************
0260    8200 CONTINUE
0261         IF(IPAR1.EQ.10)GO TO 9006
0262         IDEV=37B
0263         CALL FNDLU(IDEV,LU)
0264         IF(LU.EQ.0)WRITE(1,8236)
0265         IF(LU.EQ.0)GO TO 1000
0266    C
0267    C              IPAR1 = DEVICE  THAT THE LABEL IS TO BE PRINTED ON
0268    C              IPAR2 = STARTING X POSITION OF LABEL
0269    C              IPAR3 = STARTING Y POSITION OF LABEL
0270    C              IPAR4 = SIZE OF CHARACTERS(IPAR4 X IPAR4)
0271    C
0272    8230 FORMAT(/,"ENTER LABEL",A2,/)
0273    8235 FORMAT(20A2)
0274    8236 FORMAT(/,"ERROR-INVALID LOGICAL UNIT ")
0275    8400 CONTINUE
0276         ICOLOR=IPAR4
0277         IF(IPAR4.NE.-9999)GO TO 8410
0278         ICOLOR=1
0279         IF(IPAR3.NE.-9999)GO TO 8410
0280         IPAR3=7300
0281         IF(IPAR2.NE.-9999)GO TO 8410
0282         IPAR2=5000
0283    8410 CONTINUE
0284         WRITE(LU,8420)ICOLOR,IPAR2,IPAR3
0285    8420 FORMAT("IP0,0,11000,8000"/"PU"/"IW0,0,11000,8000"/"LT"/
0286        1"SP"I6/"PA",I6,",",I6)
0287    8422 DO 8425 I=1,20
0288    8425 LABEL(I)=2H
0289         WRITE(1,8230)IBELL
0290         READ(1,8235)(LABEL(I),I=1,20)
0291         CALL TEST(1,ISTAT,LOGX)
0292         LOGX=(LOGX+1)/2
0293         IF(LABEL(1).EQ.2H/ )WRITE(LU,8430)
0294         IF(LABEL(1).EQ.2H/ )GO TO 1000
0295    C
0296    C         CONTROL C TO TERMINATE  HP  9872
0297    C
0298    8430 FORMAT("")
```

```
0299        WRITE(LU,8440)(LABEL(I),I=1,LOGX)
0300   8440 FORMAT("LB",20A2)
0301        WRITE(LU,8430)
0302        GO TO 8422
0303 C*********************************************************************
0304 C         EXIT TO OTHER OVERLAYS
0305 C*********************************************************************
0306   9001 I=1
0307        GO TO 9900
0308   9002 I=2
0309        GO TO 9900
0310   9003 I=3
0311        GO TO 9900
0312   9004 I=4
0313        GO TO 9900
0314   9005 I=5
0315        GO TO 9900
0316   9006 I=6
0317        GO TO 9900
0318   9007 I=7
0319        GO TO 9900
0320   9008 I=8
0321        GO TO 9900
0322   9900 CONTINUE
0323        IFLAG=1
0324        CALL RWCOM(1)
0325        CALL KYBD(2HMS,38,I)
0326        CALL OVLD(9)
0327   9995 CONTINUE
0328        IL=2H**
0329        IF(ICOMM.EQ.12345)CALL RWCOM(1)
0330        CALL KYBD(2HBS,IBS,0)
0331        RETURN
0332        END
0333        END$
```

```
0001   FTN4
0002          SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C         THIS PROGRAM IS STORED UNDER $Y901
0005   C
0006   C**************************************************************************
0007   C
0008   C         PROGRAMMER:   R.J.ALLEMANG
0009   C                       MAIL LOCATION # 72
0010   C                       UNIVERSITY OF CINCINNATI
0011   C                       CINCINNATI, OHIO  45221
0012   C                       513-475-6670
0013   C
0014   C         REVISION DATE:  DEC 17,1979
0015   C
0016   C**************************************************************************
0017          DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018         1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019         2,IC1(1),IPTCM(1),RH(1)
0020          EQUIVALENCE (LINE(2),LINE1)
0021          COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022         1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023         2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024         3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025         4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026          EXTERNAL HDR8,DTAD0,NMAX
0027          DATA ICMMD/2HD ,2HV ,2HZ ,2HEX,2H: ,
0028         12HM ,2H_ ,2HRO,2HA-,2HAM,
0029         22HCH,2HSP,2HX<,
0030         32HX>,2HCV,2HK ,2HB ,2HL ,
0031         42HW ,2HI ,2HK ,2HA+,2H/L,
0032         52HX /
0033   C**************************************************************************
0034   C         UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0035   C
0036   C         SET-UP OR INITIALIZATION PROGRAM (KEYBOARD ENTRIES)
0037   C**************************************************************************
0038          IBELL=7B
0039          IPAGE=15414B
0040          CALL SETAD(HDR8,IH,-8,0)
0041          CALL SETAD(HDR8,RH(1),67,0)
0042          ICOMM=0
0043          IBS=1024
0044          CALL KYBD(2HBS,IBS,0)
0045          CALL GETI(NMAX,IBLM)
0046          ION=IBLM-1
0047          ICM=ION-1
0048          IBM=2
0049          I=ION*IBS+270
0050          CALL SETAD(DTAD0,IPTCM,I,-1)
0051          CALL RWCOM(0)
0052          IF(IFLAG.EQ.1)GO TO 1130
0053          IF(ICOMM.EQ.12345)GO TO 1000
0054   C
0055   C         THE FOLLOWING VARIABLES ARE INITIALIZED ONLY THE FIRST TIME
0056   C
0057          DO 600 I=1,IBLM
0058          J=I-1
```

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```
0059          CALL KYBD(2HCL,J)
0060    600   CONTINUE
0061          ICON=1
0062          NM=0
0063          NUMPT=1
0064          FSHFT=0.0
0065          NPD=2
0066          NMP=0
0067          NCOM=0
0068          IIBS=1024
0069          IP=1
0070          MDVA=0
0071          MANRE=0
0072          BETA=0.0
0073          MCF=0
0074          IBLS=1
0075          DO 800 I=1,3
0076          DO 800 J=1,10
0077          XXX(I,J)=0.0
0078          IX(1,J)=1
0079          IX(2,J)=2
0080          IX(3,J)=3
0081          IC(J)=1
0082          XR(I)=0.0
0083          IB(J)=0
0084          NCN(J)=0
0085          FRQ(J)=0.0
0086          ZETA(J)=0.0
0087          DO 800 K=1,2
0088          XXA(K,I)=0.0
0089          YYA(K,I)=0.0
0090    800   CONTINUE
0091    C
0092    C         SET UP DISPLAY VIEWING DEFAULT POSITION AS 1 1 1
0093    C
0094          A(1,1)=0.70711
0095          A(1,2)=0.0
0096          A(1,3)=-0.70711
0097          A(2,1)=-0.408248
0098          A(2,2)=0.816497
0099          A(2,3)=-0.408248
0100          O(1)=0.
0101          O(2)=0.
0102          O(3)=0.
0103          DO 801 I=1,5
0104    801   IT(I)=2H
0105          DO 802  I=1,3
0106    802   ID(I)=2H
0107    C*****************************************************************
0108    C       START OF MONITOR
0109    C*****************************************************************
0110    998   CONTINUE
0111          WRITE(1,997)IPAGE
0112    997   FORMAT(A2)
0113          WRITE(1,999)
0114    999   FORMAT(/,"UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS SYSTEM",/,
0115         115X,"VERSION:  NOVEMBER      1979")
0116    1000  WRITE(1,1010)IBELL
0117    1010  FORMAT("*",A2)
0118          I=ISWR(177677B,0,0)
```

```
0119        IPAR1=-9999
0120        IPAR2=-9999
0121        IPAR3=-9999
0122        IPAR4=-9999
0123        IPAR5=-9999
0124        IPAR6=-9999
0125   1020 DO 1030 I=1,36
0126   1030 LINE(I)=2H,,
0127   1040 CALL TTYIN(LINE)
0128   1042 CALL TEST(1,IST,LOG)
0129        IF(IST.LT.0)GO TO 1042
0130        CALL CODE
0131        READ(LINE,1120)IL
0132   1120 FORMAT(A2)
0133        CALL CODE
0134        READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0135   C*********************************************************************
0136   C       MONITOR COMMAND TABLE
0137   C*********************************************************************
0138   1130 IFLAG=0
0139        CALL RWCOM(1)
0140        IF(IL.EQ.2H##)GO TO 1000
0141        NCMMD=24
0142        DO 1138  I=1,NCMMD
0143        IF(IL.EQ.ICMMD(I))GO TO 1144
0144   1138 CONTINUE
0145   1139 WRITE(1,1140)IBELL
0146   1140 FORMAT(/,"ERROR-ILLEGAL COMMAND",A2)
0147        GO TO 1000
0148   1144 IF(I.GT.10)GO TO 1146
0149        GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0150   1146 I=I-10
0151        IF(I.GT.10)GO TO 1148
0152        GO TO (9004,9004,6000,6500,9004,9995,1100,1100,9002,1145),I
0153   1148 I=I-10
0154        GO TO (1145,9003,9008,9011),I
0155   1100 CONTINUE
0156        IF(IPAR1.EQ.37)GO TO 9005
0157        IF(IPAR1.EQ.10)GO TO 9006
0158        IF(IPAR1.EQ.6)GO TO 9007
0159        GO TO 1139
0160   1145 IF(IPAR1.EQ.-9999)IPAR1=0
0161        IF(IPAR1.EQ.0) GO TO 1152
0162        IF(IPAR1.EQ.1) GO TO 1260
0163        IF(IPAR1.EQ.2) GO TO 1400
0164        IF(IPAR1.EQ.3) GO TO 1460
0165        IF(IPAR1.EQ.4) GO TO 3000
0166        IF(IPAR1.EQ.5) GO TO 1660
0167        WRITE(1,1140)
0168        GO TO 1000
0169   C*********************************************************************
0170   C       COMMAND KYBD 0    TEST ID AND SET-UP
0171   C*********************************************************************
0172   1152 DO 1153  I=1,5
0173   1153 IT(I)=2H
0174        WRITE(1,1154)IPAGE,IBELL
0175   1154 FORMAT(A2,/,"ENTER TEST ID-10 CHARACTERS",A2)
0176        READ(1,1156)(IT(JJJ),JJJ=1,5)
0177   1156 FORMAT(5A2)
0178        WRITE(1,1235)(IT(JJJ),JJJ=1,5)
```

```
0179          CALL RWCOM(1)
0180          WRITE(1,1158)IBELL
0181     1158 FORMAT(/,"ENTER DATE - 6 DIGITS(XXXXXX)",A2)
0182          READ(1,1157)ID(1),ID(2),ID(3)
0183     1157 FORMAT(3A2)
0184          WRITE(1,1159)IBELL
0185     1159 FORMAT(/,"ENTER NUMBER OF TEST POINTS",A2)
0186     1161 READ(1,*)IP
0187          IF(IP.GT.250) WRITE(1,1180)
0188          IF(IP.GT.250)GO TO 1161
0189          IF(NUMPT.GT.IP)NUMPT=IP
0190   C
0191   C          ALLOW TWO BLOCKS FOR COMMON AND DATA POINTS
0192   C              AND TWO BLOCKS FOR DISPLAY
0193   C
0194          XP=3.0*(FLOAT(IP))
0195          IBLS=IBLM-4
0196          Z1=FLOAT(IBLS*IBS)/XP
0197          NM=IFIX(Z1)
0198          IF(NM.GT.10)NM=10
0199          MANRE=NM
0200          WRITE(1,1160)NM
0201     1160 FORMAT(/,"ALLOWABLE NUMBER OF MODES STORED PER SESSION: ",I3)
0202     1180 FORMAT(/,"ERROR-NUMBER OF POINTS EXCEEDS 250")
0203     1190 CONTINUE
0204     1197 WRITE(1,1200)IBELL
0205     1200 FORMAT(/,"ENTER OPTION TO INITIALIZE THE DATA SPACE",
0206          1/,5X,"0)    CLEAR ONLY THE EXISTING MODAL COEFFICIENTS",
0207          2/,5X,"1)    CLEAR ALL EXISTING SET-UP FROM PREVIOUS TESTS",
0208          3/,5X,"         (GEOMETRY,CONNECTIVITY,MODAL COEFFICIENTS,ETC.)",
0209          4/,5X,"2)    RETURN TO MONITOR",A2,/)
0210          ICOMM=12345
0211          READ(1,*)IZ1
0212          IF(IZ1.EQ.0)GO TO 1210
0213          IF(IZ1.EQ.1)GO TO 1201
0214          IF(IZ1.EQ.2)GO TO 1000
0215          GO TO 1197
0216     1201 DO 1188 J=1,3
0217          DO 1188 I=1,10
0218          XXX(J,I)=0.0
0219          IX(J,I)=0
0220     1188 IC(I)=1
0221          NUMPT=1
0222          ICON=0
0223          NCOM=1
0224     1210 CALL GETQ(0,INQ)
0225          INQ(2)=176500B
0226          INQ(3)=77777B
0227          RMAX=0.
0228          IF(IZ1.EQ.0) IZ2=ION-2
0229          IF(IZ1.EQ.1) IZ2=ION
0230          DO 1220 I=IBM,IZ2
0231          CALL KYBD(2HCL,I)
0232     1220 CALL PUTQ(I,INQ)
0233          DO 1225 I=1,10
0234     1225 RMM(I)=0.0
0235          CALL RWCOM(1)
0236          GO TO 1000
0237     1235 FORMAT(/,"TEST ID IS",23X,5A2)
0238   C*******************************************************************
```

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```
0239  C        COMMAND KYBD 1      COMPONENT DESCRIPTION
0240  C***********************************************************************
0241  1260 WRITE(1,1270)IPAGE,IBELL
0242  1270 FORMAT(A2,/,"ENTER: COMPONENT NUMBER, X, Y, Z, IX, IY, IZ, IC",
0243       1//,5X,"IX,IY,IZ ARE THE NUMBERS OF THE TRANSDUCERS(1,2,3)",
0244       2/,5X,"IN THE GLOBAL X,Y,Z DIRECTIONS",A2,//)
0245  1275 DO 1277 I=1,36
0246  1277 LINE(I)=2H,,
0247  1280 CALL TTYIN(LINE)
0248  1290 CALL TEST(1,IST,LOG)
0249       IF(IST.LT.0)GO TO 1290
0250       CALL CODE
0251  1300 READ(LINE,*) I
0252       IF((I.LT.0).OR.(I.GT.10))GO TO 1305
0253       IF(I.EQ.0)ICOMM=12345
0254       IF(I.EQ.0) GO TO 1000
0255       IF(I.GT.NCOM)NCOM=I
0256       GO TO 1307
0257  1305 WRITE(1,1306)
0258  1306 FORMAT(/,"ERROR-INVALID COMPONENT NUMBER")
0259       GO TO 1275
0260  1307 CONTINUE
0261       CALL CODE
0262       READ(LINE1,*)XXX(1,I),XXX(2,I),XXX(3,I),
0263       1IX(1,I),IX(2,I),IX(3,I),IC(I)
0264       CALL RWCOM(1)
0265       GO TO 1275
0266  C***********************************************************************
0267  C        COMMAND KYBD 2      POINT NUMBER SET-UP
0268  C***********************************************************************
0269  1400 WRITE(1,1410)IPAGE,IBELL
0270  1410 FORMAT(A2,/,"ENTER: POINT NUMBER, X,Y,Z COORDINATES, "
0271       1"COMPONENT NUMBER",A2)
0272  C
0273  C        PHOTOREAD OPTION - COORDINATES
0274  C
0275       CALL IOSW(NU,1)
0276       IF(NU.EQ.5) PAUSE 1
0277  1420 READ(NU,*)I,Z1,Z2,Z3,IZ5
0278       IF(I.GT.IP) GO TO 1425
0279       IF(I.EQ.0)ICOMM=12345
0280       IF(I.EQ.0) GO TO 1000
0281       IF(I.LT.0)GO TO 1425
0282       IF(I.GT.NUMPT)NUMPT=I
0283       CALL RWCOR(I,Z1,Z2,Z3,ICM,0)
0284       IPTCM(I)=IZ5
0285       CALL RWCOM(1)
0286       GO TO 1420
0287  1425 WRITE(1,1427)
0288  1427 FORMAT(/,"ERROR-INVALID POINT NUMBER")
0289       GO TO 1420
0290  C***********************************************************************
0291  C        COMMAND KYBD 3      CONNECTIVITY SET-UP
0292  C***********************************************************************
0293  1460 WRITE(1,1470)
0294  1470 FORMAT(/,"CONNECTIVITY MONITOR")
0295  1480 WRITE(1,1485)IBELL
0296  1485 FORMAT("*C",A2)
0297       IPAR1=-9999
0298       IPAR2=-9999
```

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```
0299          CALL IPUT(IL,IPAR1,IPAR2,IPAR3,IPAR4)
0300     1490 IF(IL.EQ.2HK ) GO TO 1510
0301          IF(IL.EQ.2HW ) GO TO 1530
0302          IF(IL.EQ.2H/I) GO TO 1570
0303          IF(IL.EQ.2H/D) GO TO 1610
0304          IF(IL.EQ.2HR ) GO TO 1640
0305          IF(IL.EQ.2H# ) GO TO 1500
0306          IF(IL.EQ.2H< ) GO TO 1655
0307          IF(IL.EQ.2H/R) GO TO 1656
0308          WRITE(1,1140)
0309          GO TO 1480
0310   C
0311   C          COUNTER COMMAND - CONNECTIVITY
0312   C
0313     1500 ICON=IPAR1
0314          GO TO 1480
0315   C
0316   C          KEYBOARD COMMAND - CONNECTIVITY
0317   C
0318     1510 IZ2=-9999
0319          READ(1,*)IZ1,IZ2
0320          IF(IZ1.EQ.0)ICOMM=12345
0321          IF(IZ1.EQ.0) GO TO 1480
0322          IF((IZ2.LE.0).AND.(IZ2.GT.-9998)) GO TO 1480
0323          IF((IZ1.LT.0).AND.(IZ2.NE.-9999)) GO TO 1515
0324          GO TO 1516
0325     1515 IZ4=IABS(IZ1)
0326          IF(ICON.GT.500)WRITE(1,1535)
0327          IF(ICON.GT.500)GO TO 1480
0328     1535 FORMAT(/,"ERROR-MAXIMUM NUMBER OF DISPLAY VECTORS EXCEEDED")
0329          ICON=ICON+1
0330          CALL RWCON(ICON,IZ1,ION,0)
0331          INC=1
0332          IF(IZ4.GT.IZ2)INC=-1
0333          IZ1=IZ4+INC
0334     1516 IF(IZ2.EQ.-9999)IZ2=IZ1
0335          IF(IZ2.LT.IZ1) GO TO 1521
0336   C
0337   C          INCREMENT POINT NUMBERS
0338   C
0339          DO 1520 I=IZ1,IZ2
0340          IF(ICON.GT.500)WRITE(1,1535)
0341          IF(ICON.GT.500)GO TO 1480
0342          ICON=ICON+1
0343     1520 CALL RWCON(ICON,I,ION,0)
0344          CALL RWCOM(1)
0345          GO TO 1510
0346   C
0347   C          DECREMENT POINT NUMBERS
0348   C
0349     1521 IZ4=IZ1+1
0350          IZ5=IZ1-IZ2+1
0351          DO 1522 I=1,IZ5
0352          IZ4=IZ4-1
0353          IF(ICON.GT.500)WRITE(1,1535)
0354          IF(ICON.GT.500)GO TO 1480
0355          ICON=ICON+1
0356     1522 CALL RWCON(ICON,IZ4,ION,0)
0357          CALL RWCOM(1)
0358          GO TO 1510
```

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```
0359    C
0360    C           PRINT COMMAND - CONNECTIVITY
0361    C
0362    1530 IF(IPAR1.NE.-9999) GO TO 1540
0363         IPAR1=1
0364         IPAR2=ICON
0365    1540 NU=1
0366         IF(IPAR1.LT.1)GO TO 1000
0367         IF(IPAR2.EQ.-9999)IPAR2=IPAR1
0368         IF(IPAR2.LT.1)GO TO 1000
0369         DO 1550 I=IPAR1,IPAR2
0370         IF(ISSW(14).LT.0)GO TO 1562
0371         CALL RWCON(I,IZ1,ION,1)
0372    1550 WRITE(NU,1560)I,IZ1
0373    1560 FORMAT(2I6)
0374    1562 CONTINUE
0375         GO TO 1480
0376    C
0377    C           INSERT 'AFTER' COMMAND  CONNECTIVITY
0378    C
0379    1570 IZ1=IPAR1+1
0380    1580 READ(1,*)IZ2
0381         IF(IZ2.EQ.0) GO TO 1480
0382         IF(ICON.GT.500)WRITE(1,1535)
0383         IF(ICON.GT.500)GO TO 1480
0384         ICON=ICON+1
0385         DO 1590 I=1,ICON
0386         IZ4=ICON-I
0387         IZ5=IZ4+1
0388         IF(IZ4.LT.IZ1) GO TO 1600
0389         CALL RWCON(IZ4,IZ3,ION,1)
0390    1590 CALL RWCON(IZ5,IZ3,ION,0)
0391    1600 CALL RWCON(IZ1,IZ2,ION,0)
0392         IZ1=IZ1+1
0393         GO TO 1580
0394    C
0395    C           DELETE COMMAND - CONNECTIVITY
0396    C
0397    1610 IF(IPAR1.EQ.-9999)GO TO 1485
0398         IF(IPAR2.EQ.-9999)IPAR2=IPAR1
0399         IZ1=IPAR2-IPAR1+1
0400         DO 1620 I=1,ICON
0401         IZ2=IPAR1+I-1
0402         IZ3=IPAR2+I
0403         IF(IZ3.GT.ICON) GO TO 1630
0404         CALL RWCON(IZ3,IZ4,ION,1)
0405    1620 CALL RWCON(IZ2,IZ4,ION,0)
0406    1630 ICON=ICON-IZ1
0407         GO TO 1480
0408    C
0409    C           PHOTOREAD OPTION - CONNECTIVITY
0410    C
0411    1640 CONTINUE
0412         ICON=0
0413         CALL IOSW(NU,1)
0414         IF(NU.NE.8)NU=5
0415         READ (NU,*) IZ1,IZ2
0416         DO 1650 I=IZ1,IZ2
0417         READ(NU,*)IZ3,IZ4
0418         IF(IZ4.EQ.0)GO TO 1480
```
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```
0419          IF(ICON.GT.500)WRITE(1,1535)
0420          IF(ICON.GT.500)GO TO 1480
0421          ICON=ICON+1
0422     1650 CALL RWCON(IZ3,IZ4,ION,0)
0423          GO TO 1480
0424     1655 CONTINUE
0425          ICOMM=12345
0426          CALL RWCOM(1)
0427          GO TO 1000
0428   C
0429   C          REPLACE COMMAND - CONNECTIVITY
0430   C
0431     1656 CONTINUE
0432          IZ1=IPAR1
0433          IF(IZ1.GT.ICON)WRITE(1,1658)
0434     1658 FORMAT(/,"ERROR-CONNECTIVITY LINE NUMBER TOO LARGE",//)
0435          IF(IZ1.GT.ICON)GO TO 1480
0436     1657 READ(1,*)IZ2
0437          IF(IZ2.EQ.0)GO TO 1480
0438          CALL RWCON(IZ1,IZ2,ION,0)
0439          IZ1=IZ1+1
0440          GO TO 1657
0441   C*********************************************************************
0442   C       COMMAND KYBD 4      FREQUENCIES AND DAMPING
0443   C*********************************************************************
0444     3000 CONTINUE
0445          WRITE(1,3002)IPAGE,IBELL
0446     3002 FORMAT(A2,/,"ENTER RECORD NUMBER OF TYPICAL DATA",A2)
0447          READ(1,*)IREC
0448          CALL KYBD(2HMS,31,IREC)
0449          CALL KYBD(2HMS,11)
0450          FSHFT=RH(1)
0451          DF=RH(2)
0452   C
0453   C          MCF = 6 MEANS THAT FREQ/DAMP DATA HAS BEEN MANUALLY ENTERED
0454   C
0455          MCF=6
0456          WRITE(1,3005)IBELL
0457     3005 FORMAT(/,"ENTER: MODE NUMBER,FREQUENCY,ZETA(%)",/
0458         1,"TERMINATE WITH MAXIMUM MODE,ZERO",A2,//)
0459     3010 CONTINUE
0460          READ(1,*)IMODE,F,Z
0461          IF(IMODE.EQ.0)GO TO 1000
0462          IF(F.EQ.0.0)MANRE=IMODE
0463          IF(F.EQ.0.0)GO TO 1000
0464          IF((IMODE.LT.1).OR.(IMODE.GT.10))GO TO 3400
0465          FRQ(IMODE)=F
0466          ZETA(IMODE)=Z
0467          IB(IMODE)=F*Z/(DF*SQRT(10000.0-Z**2))
0468          NCN(IMODE)=F/DF-FSHFT/DF+1
0469          GO TO 3010
0470     3400 CONTINUE
0471          WRITE(1,3405)IBELL
0472     3405 FORMAT(/,"ERROR-INVALID MODE NUMBER",A2,/)
0473          GO TO 3010
0474   C*********************************************************************
0475   C       COMMAND KYBD 5      MODAL COEFFICIENTS
0476   C*********************************************************************
0477     1660 WRITE(1,1670)IPAGE,IBELL
0478     1670 FORMAT(A2   ,"ENTER: MODE NUMBER, POINT NUMBER, X,Y,Z "
```

```
0479          1"DEFORMATIONS, X,Y,Z PHASE ANGLES",
0480          2/,5X,"(DEFORMATIONS = + OR - MAGNITUDE)",
0481          3/,5X,"(PHASE ANGLES = 0 TO 180 DEGREES)",/,A2)
0482    C
0483    C          PHOTOREAD OPTION - MODAL COEFFICIENTS
0484    C
0485          CALL IOSW(NU,1)
0486          IF(NU.EQ.5) PAUSE 2
0487    1680 READ(NU,*)M,I,Z1,Z2,Z3,LO1,LO2,LO3
0488          IF(M.LE.0)GO TO 1000
0489          RMAX=RMM(M)
0490          CALL RWCMC(1,Z1,LO1,M,I,IP,IBM,RMAX,0)
0491          CALL RWCMC(2,Z2,LO2,M,I,IP,IBM,RMAX,0)
0492          CALL RWCMC(3,Z3,LO3,M,I,IP,IBM,RMAX,0)
0493          RMM(M)=RMAX
0494          GO TO 1680
0495    C
0496    C       STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
0497    C
0498    C          READ
0499    C
0500    6000 CALL KYBD(2HMS,35,1)
0501          CALL KYBD(2HMS,25)
0502          IF(IPAR1.EQ.-9999)GO TO 9011
0503          IF((IPAR1.GE.0).AND.(IPAR1.LE.800)) CALL KYBD(2HMS,31,IPAR1)
0504          IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0505          CALL KYBD(2HMS,11,0)
0506          CALL KYBD(2HMS,31,-1,1)
0507          CALL RWCOM(-1)
0508          IF(ICOMM.NE.12345)GO TO 6800
0509          CALL KYBD(2HMS,11,ION)
0510          CALL RWCOM(0)
0511          IF(ICOMM.NE.12345)GO TO 6800
0512          NMP=0
0513          IRJ=ICM
0514          CALL KYBD(2HMS,11,IRJ)
0515          IRJ=IRJ-1
0516    6100 DO 6200 I=IBM,IRJ
0517    6200 CALL KYBD(2HMS,11,I)
0518          CALL KYBD(2HMS,35,1)
0519          CALL KYBD(2HMS,15)
0520          ICOMM=12345
0521          WRITE(1,1235)(IT(I),I=1,5)
0522          GO TO 1000
0523    C
0524    C          STORE
0525    C
0526    6500 CALL KYBD(2HMS,35,1)
0527          CALL KYBD(2HMS,25)
0528          IF(IPAR1.EQ.-9999)GO TO 9011
0529          IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
0530          IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0531          IL=2H##
0532          CALL RWCOM(1)
0533          IH(6)=52525B
0534          IH(9)=10
0535          IH(10)=IT(1)
0536          IH(11)=IT(2)
0537          IH(12)=IT(3)
0538          IH(13)=IT(4)
```

```
0539        IH(14)=IT(5)
0540        IH(34)=2H71
0541        CALL KYBD(2HMS,21,ION)
0542        CALL KYBD(2HMS,21,ICM)
0543        IH(34)=2H72
0544        IRJ=ICM-1
0545        IPAR1=IPAR1+2
0546        DO 6700 I=IBM,IRJ
0547        IPAR1=IPAR1+1
0548   6700 CALL KYBD(2HMS,21,I)
0549        WRITE(1,6701)IPAR1
0550   6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
0551        CALL KYBD(2HMS,35,1)
0552        CALL KYBD(2HMS,15)
0553        GO TO 1000
0554   6800 WRITE(1,6801)
0555   6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
0556        NMP=0
0557        ICOMM=12345
0558        GO TO 1000
0559 C********************************************************************
0560 C          EXIT TO OTHER OVERLAYS
0561 C********************************************************************
0562   9002 I=2
0563        GO TO 9900
0564   9003 I=3
0565        GO TO 9900
0566   9004 I=4
0567        GO TO 9900
0568   9005 I=5
0569        GO TO 9900
0570   9006 I=6
0571        GO TO 9900
0572   9007 I=7
0573        GO TO 9900
0574   9008 I=8
0575        GO TO 9900
0576   9011 I=11
0577        GO TO 9900
0578   9900 CONTINUE
0579        IFLAG=1
0580        CALL RWCOM(1)
0581        CALL KYBD(2HMS,38,I)
0582        CALL OVLD(9)
0583   9995 CONTINUE
0584        IL=2H**
0585        IF(ICOMM.EQ.12345)CALL RWCOM(1)
0586        CALL KYBD(2HBS,IBS,0)
0587        RETURN
0588        END
0589        END$
```

```
$Y902   T=00004 IS ON CR00103 USING 00082 BLKS R=0702

0001   FTN4
0002         SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C        THIS PROGRAM IS STORED UNDER $Y902
0005   C
0006   C******************************************************************
0007   C
0008   C        PROGRAMMER:   R.J.ALLEMANG
0009   C                      MAIL LOCATION # 72
0010   C                      UNIVERSITY OF CINCINNATI
0011   C                      CINCINNATI, OHIO  45221
0012   C                      513-475-6670
0013   C
0014   C        REVISION DATE:  DEC 17,1979
0015   C
0016   C******************************************************************
0017         DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018        1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019        2,IC1(1),IPTCM(1)
0020         EQUIVALENCE (LINE(2),LINE1)
0021         COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022        1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023        2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024        3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025        4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026         EXTERNAL HDR8,DTAD0,NMAX
0027         DATA ICMMD/2HD ,2HV ,2HZ ,2HEX,2H: ,
0028        12HM ,2H_ ,2HRO,2HA-,2HAM,
0029        22HCH,2HSP,2HX<,
0030        32HX>,2HCV,2H< ,2HB ,2HL ,
0031        42HW ,2HI ,2HK ,2HA+,2H/L,
0032        52HX /
0033   C******************************************************************
0034   C       UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0035   C
0036   C       OUTPUT PROGRAM (PRINT COMMAND)
0037   C******************************************************************
0038         IBELL=7B
0039         IPAGE=15414B
0040         CALL SETAD(HDR8,IH,-8,0)
0041         ICOMM=0
0042         IBS=1024
0043         CALL KYBD(2HBS,IBS,0)
0044         CALL GETI(NMAX,IBLM)
0045         ION=IBLM-1
0046         ICM=ION-1
0047         IBM=2
0048         I=ION*IBS+270
0049         CALL SETAD(DTAD0,IPTCM,I,-1)
0050         CALL RWCOM(0)
0051         IF(ICOMM.EQ.12345)GO TO 900
0052         CALL KYBD(2HMS,38,-2,1)
0053         CALL OVLD(9)
0054   900   CONTINUE
0055         IF(IFLAG.EQ.1)GO TO 1130
0056   C******************************************************************
0057   C       START OF MONITOR
0058   C******************************************************************
```

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```
0059    1000 WRITE(1,1010)IBELL
0060    1010 FORMAT("*",A2)
0061         I=ISWR(177677B,0,0)
0062         IPAR1=-9999
0063         IPAR2=-9999
0064         IPAR3=-9999
0065         IPAR4=-9999
0066         IPAR5=-9999
0067         IPAR6=-9999
0068    1020 DO 1030 I=1,36
0069    1030 LINE(I)=2H,,
0070    1040 CALL TTYIN(LINE)
0071    1042 CALL TEST(1,IST,LOG)
0072         IF(IST.LT.0)GO TO 1042
0073         CALL CODE
0074         READ(LINE,1120)IL
0075    1120 FORMAT(A2)
0076         CALL CODE
0077         READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0078    C********************************************************************
0079    C       MONITOR COMMAND TABLE
0080    C********************************************************************
0081    1130 IFLAG=0
0082         CALL RWCOM(1)
0083         IF(IL.EQ.2H**)GO TO 1000
0084         NCMMD=24
0085         DO 1138  I=1,NCMMD
0086         IF(IL.EQ.ICMMD(I))GO TO 1144
0087    1138 CONTINUE
0088    1139 WRITE(1,1140)
0089    1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0090         GO TO 1000
0091    1144 IF(I.GT.10)GO TO 1146
0092         GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0093    1146 I=I-10
0094         IF(I.GT.10)GO TO 1148
0095         GO TO (9004,9004,6000,6500,9004,9995,1100,1100,1142,9001),I
0096    1148 I=I-10
0097         GO TO (9001,9003,9008,9011),I
0098    1100 CONTINUE
0099         IF(IPAR1.EQ.37)GO TO 9005
0100         IF(IPAR1.EQ.10)GO TO 9006
0101         IF(IPAR1.EQ.6)GO TO 9007
0102         GO TO 1139
0103    C
0104    C       PRINTER COMMAND TABLE
0105    C
0106    C       PRINT COMMAND DEFAULTS TO SET-UP FILE
0107    C
0108    1142 IF(IPAR1.EQ.-9999)IPAR1=0
0109         IF(IPAR1.EQ.0)GO TO 1250
0110         IF(IPAR1.EQ.1) GO TO 1310
0111         IF(IPAR1.EQ.2) GO TO 1430
0112         IF(IPAR1.EQ.3) GO TO 1525
0113         IF(IPAR1.EQ.4) GO TO 1690
0114         IF(IPAR1.EQ.5) GO TO 1695
0115         WRITE(1,1140)
0116         GO TO 1000
0117    C********************************************************************
0118    C       COMMAND PRINT 0    TEST ID AND SET-UP
```
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```
0119  C**********************************************************************
0120  C
0121  C          PRINT-OUT FOR KYBD 0
0122  C
0123    1250 CONTINUE
0124         CALL IOSW(NU,0)
0125         WRITE(NU,1235)(IT(JJJ),JJJ=1,5)
0126    1235 FORMAT(/,"TEST ID IS",23X,5A2)
0127         WRITE(NU,1251)ID(1),ID(2),ID(3)
0128    1251 FORMAT("DATE IS",26X,3( A2,1X),/)
0129         WRITE(NU,1252)IP,NM
0130    1252 FORMAT("NUMBER OF POINTS IS",20X,I3,/,
0131        1"NUMBER OF MODES IS",22X,I2)
0132         GO TO 1000
0133  C**********************************************************************
0134  C       COMMAND PRINT 1     COMPONENT DESCRIPTION
0135  C**********************************************************************
0136  C
0137  C          PRINT COMMAND - COMPONENTS
0138  C
0139    1310 IZ1=IPAR2
0140         IZ2=IPAR3
0141         IF(IPAR2.EQ.-9999) IZ1=1
0142         IF(IPAR2.EQ.-9999) IZ2=NCOM
0143         IF((IPAR2.NE.-9999).AND.(IPAR3.EQ.-9999))IZ2=IZ1
0144         IF((IZ1.LE.0).OR.(IZ1.GT.NCOM))IZ1=1
0145         IF((IZ2.LE.0).OR.(IZ2.GT.NCOM))IZ2=NCOM
0146         CALL IOSW(NU,0)
0147         DO 1320 I=IZ1,IZ2
0148    1320 WRITE(NU,1330)I,XXX(1,I),XXX(2,I),XXX(3,I),IX(1,I),IX(2,I)
0149        1,IX(3,I),IC(I)
0150    1330 FORMAT(2X,I2,2X,3F11.4,4I6)
0151         GO TO 1000
0152  C**********************************************************************
0153  C       COMMAND PRINT 2     POINT NUMBER SET-UP
0154  C**********************************************************************
0155  C
0156  C          PUNCH/PRINT   OPTION - COORDINATES
0157  C
0158    1430 CONTINUE
0159         CALL IOSW(NU,0)
0160         IR=0
0161         IZ1=IPAR2
0162         IZ2=IPAR3
0163         IF(IPAR2.EQ.-9999)IZ2=NUMPT
0164         IF(IPAR2.EQ.-9999)IZ1=1
0165         IF((IPAR2.NE.-9999).AND.(IPAR3.EQ.-9999))IZ2=IPAR2
0166         IF((IZ1.LE.0).OR.(IZ1.GT.IP))IZ1=1
0167         IF((IZ2.LE.0).OR.(IZ2.GT.IP))IZ2=NUMPT
0168         IF((NU.EQ.1).OR.(NU.EQ.6))WRITE(NU,1432)(IT(I),I=1,5)
0169    1432 FORMAT("",/,"TEST I.D.     ",5A2,
0170        $2/,"POINT",10X,"X",11X,"Y",11X,"Z",5X,"COMPONENT",/)
0171         DO 1440 I=IZ1,IZ2
0172         IF(ISSW(14).LT.0)GO TO 1000
0173         CALL RWCOR(I,Z1,Z2,Z3,ICM,1)
0174         IZ5=IPTCM(I)
0175         IF(NU.EQ.8)GO TO 1434
0176         IF(NU.EQ.4)GO TO 1434
0177         IR=IR+1
0178         IF(IR.GT.54)WRITE(NU,1432)(IT(IJ),IJ=1,5)
```

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```
0179        IF(IR.GT.54)IR=0
0180   1434 CONTINUE
0181   1440 WRITE(NU,1450)I,Z1,Z2,Z3,IZ5
0182        I=0
0183        IF((NU.NE.4).OR.(NU.NE.8))GO TO 1000
0184        WRITE(NU,1450)I,IZ1,Z2,Z3,IZ5
0185   1450 FORMAT(I5,1X,3(2X,F10.2),1X,I5)
0186        IF(NU.NE.8)GO TO 1000
0187        END FILE NU
0188        GO TO 1000
0189 C*******************************************************************
0190 C       COMMAND PRINT 3    CONNECTIVITY SET-UP
0191 C*******************************************************************
0192 C
0193 C         PRINT COMMAND - CONNECTIVITY
0194 C
0195   1525 IPAR1=IPAR2
0196        IPAR2=IPAR3
0197   1530 IF(IPAR1.NE.-9999) GO TO 1540
0198        IPAR1=1
0199        IPAR2=ICON
0200   1540 CALL IOSW(NU,0)
0201 C
0202 C         PUNCH OPTION   CONNECTIVITY
0203 C
0204        IF(IPAR1.LT.1)GO TO 1139
0205        IF(IPAR2.EQ.-9999)IPAR2=IPAR1
0206        IF(IPAR2.LT.1)GO TO 1139
0207        IF((NU.EQ.1).OR.(NU.EQ.6))GO TO 1545
0208        WRITE(NU,1560)IPAR1,IPAR2
0209   1545 CONTINUE
0210        DO 1550 I=IPAR1,IPAR2
0211        IF(ISSW(14).LT.0)GO TO 1562
0212        CALL RWCON(I,IZ1,ION,1)
0213   1550 WRITE(NU,1560)I,IZ1
0214   1560 FORMAT(2I6)
0215        IF(NU.NE.8)GO TO 1562
0216        END FILE NU
0217   1562 CONTINUE
0218        GO TO 1000
0219 C*******************************************************************
0220 C       COMMAND PRINT 4    FREQUENCIES AND DAMPING
0221 C*******************************************************************
0222   1690 CONTINUE
0223        CALL IOSW(NU,0)
0224        IF((NU.EQ.1).OR.(NU.EQ.6))WRITE(NU,2000)
0225   2000 FORMAT(/,"MODE   CHANNEL   BANDWIDTH   FREQUENCY   ZETA(%)"
0226       1," METHOD    MODE",/)
0227        DO 1692 I=1,MANRE
0228        J=MCF
0229        IF(I.GT.NM)J=0
0230        WRITE(NU,1693)I,NCN(I),IB(I),FRQ(I),ZETA(I),J,I
0231        IF(I.EQ.NM)WRITE(NU,1696)
0232   1696 FORMAT(" ")
0233   1692 CONTINUE
0234   1693 FORMAT(I3,3X,I5,6X,I3,4X,F10.3,2X,F10.7,4X,I3,4X,I3)
0235        IF(NU.NE.8)GO TO 1000
0236        END FILE NU
0237        GO TO 1000
0238 C*******************************************************************
```

```
0239  C          COMMAND PRINT 5    PRINT OF MODAL COEFFICIENTS
0240  C***************************************************************************
0241  1695 CONTINUE
0242       IZ1=IPAR2
0243       IF(IZ1.GT.NM)IZ1=1
0244       I=IPAR3
0245       IZ2=IPAR4
0246       IF(I.LE.0)I=1
0247       IF(I.GT.IP)I=1
0248       IF(IZ2.LE.0)IZ2=NUMPT
0249       IF(IZ2.GT.IP)IZ2=NUMPT
0250  C
0251  C          PUNCH OPTION  MODAL COEFFICIENTS
0252  C
0253       CALL IOSW(NU,0)
0254       IF((NU.EQ.1).OR.(NU.EQ.6))WRITE(NU,2002)
0255  2002 FORMAT(/,"MODE POINT          X,Y,Z DEFORMATIONS"
0256      1,"               X,Y,Z PHASE ANGLES",/)
0257       RMAX=RMM(IZ1)
0258       DO 1700 II=I,IZ2
0259       IF(ISSW(14).LT.0)GO TO 1000
0260       CALL RWCMC(1,Z1,LO1,IZ1,II,IP,IBM,RMAX,1)
0261       CALL RWCMC(2,Z2,LO2,IZ1,II,IP,IBM,RMAX,1)
0262       CALL RWCMC(3,Z3,LO3,IZ1,II,IP,IBM,RMAX,1)
0263  C
0264  C          THIS WRITE MUST BE THE SAME AS 1680
0265  C
0266  1700 WRITE(NU,1710)IZ1,II,Z1,Z2,Z3,LO1,LO2,LO3
0267  1710 FORMAT(I2,I5,1X,3(2X,G12.3),3(2X,I4))
0268       IZ1=0
0269       II=0
0270       Z1=0.0
0271       Z2=0.0
0272       Z3=0.0
0273       LO1=0
0274       LO2=0
0275       LO3=0
0276       WRITE(NU,1710)IZ1,II,Z1,Z2,Z3,LO1,LO2,LO3
0277       IF(NU.NE.8)GO TO 1000
0278       END FILE NU
0279       GO TO 1000
0280  C
0281  C     STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
0282  C
0283  C       READ
0284  C
0285  6000 CALL KYBD(2HMS,35,1)
0286       CALL KYBD(2HMS,25)
0287       IF(IPAR1.EQ.-9999)GO TO 9011
0288       IF((IPAR1.GE.0).AND.(IPAR1.LE.800)) CALL KYBD(2HMS,31,IPAR1)
0289       IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0290       CALL KYBD(2HMS,11,0)
0291       CALL KYBD(2HMS,31,-1,1)
0292       CALL RWCOM(-1)
0293       IF(ICOMM.NE.12345)GO TO 6800
0294       CALL KYBD(2HMS,11,ION)
0295       CALL RWCOM(0)
0296       IF(ICOMM.NE.12345)GO TO 6800
0297       NMP=0
0298       IRJ=ICM
```

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```
0299          CALL KYBD(2HMS,11,IRJ)
0300          IRJ=IRJ-1
0301     6100 DO 6200 I=IBM,IRJ
0302     6200 CALL KYBD(2HMS,11,I)
0303          CALL KYBD(2HMS,35,1)
0304          CALL KYBD(2HMS,15)
0305          ICOMM=12345
0306          WRITE(1,1235)(IT(I),I=1,5)
0307          GO TO 1000
0308   C
0309   C        STORE
0310   C
0311     6500 CALL KYBD(2HMS,35,1)
0312          CALL KYBD(2HMS,25)
0313          IF(IPAR1.EQ.-9999)GO TO 9011
0314          IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
0315          IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0316          IL=2H##
0317          CALL RWCOM(1)
0318          IH(6)=52525B
0319          IH(9)=10
0320          IH(10)=IT(1)
0321          IH(11)=IT(2)
0322          IH(12)=IT(3)
0323          IH(13)=IT(4)
0324          IH(14)=IT(5)
0325          IH(34)=2H71
0326          CALL KYBD(2HMS,21,ION)
0327          CALL KYBD(2HMS,21,ICM)
0328          IH(34)=2H72
0329          IRJ=ICM-1
0330          IPAR1=IPAR1+2
0331          DO 6700 I=IBM,IRJ
0332          IPAR1=IPAR1+1
0333     6700 CALL KYBD(2HMS,21,I)
0334          WRITE(1,6701)IPAR1
0335     6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
0336          CALL KYBD(2HMS,35,1)
0337          CALL KYBD(2HMS,15)
0338          GO TO 1000
0339     6800 WRITE(1,6801)
0340     6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
0341          NMP=0
0342          ICOMM=12345
0343          GO TO 1000
0344   C*********************************************************************
0345   C        EXIT TO OTHER OVERLAYS
0346   C*********************************************************************
0347     9001 I=1
0348          GO TO 9900
0349     9003 I=3
0350          CO TO 9900
0351     9004 I=4
0352          GO TO 9900
0353     9005 I=5
0354          GO TO 9900
0355     9006 I=6
0356          GO TO 9900
0357     9007 I=7
0358          GO TO 9900
```

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```
0359    9008 I=8
0360         GO TO 9900
0361    9011 I=11
0362         GO TO 9900
0363    9900 CONTINUE
0364         IFLAG=1
0365         CALL RWCOM(1)
0366         CALL KYBD(2HMS,38,I)
0367         CALL OVLD(9)
0368    9995 CONTINUE
0369         IL=2H##
0370         IF(ICOMM.EQ.12345)CALL RWCOM(1)
0371         CALL KYBD(2HBS,IBS,0)
0372         RETURN
0373         END
0374         END$
```

```
0001   FTN4
0002         SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C          THIS PROGRAM IS STORED UNDER $Y903
0005   C
0006   C********************************************************************
0007   C
0008   C          PROGRAMMER:  R.J.ALLEMANG
0009   C                       MAIL LOCATION # 72
0010   C                       UNIVERSITY OF CINCINNATI
0011   C                       CINCINNATI, OHIO  45221
0012   C                       513-475-6670
0013   C
0014   C          REVISION DATE:  DEC 17,1979
0015   C
0016   C********************************************************************
0017         DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018        1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019        2,IC1(1),IPTCM(1),RH(1)
0020         EQUIVALENCE (LINE(2),LINE1)
0021         COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022        1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023        2,0(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024        3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025        4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026         EXTERNAL HDR8,DTAD0,NMAX
0027         DATA YMAX/0./
0028         DATA ICMMD/2HD ,2HV ,2HZ ,2HEX,2H: ,
0029        12HM ,2H_ ,2HRO,2HA-,2HAM,
0030        22HCH,2HSP,2HX<,
0031        32HX>,2HCV,2H< ,2HB ,2HL ,
0032        42HW ,2HI ,2HK ,2HA+,2H/L,
0033        52HX /
0034   C********************************************************************
0035   C          UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0036   C
0037   C          PARAMETER ESTIMATION SET-UP PROGRAM
0038   C********************************************************************
0039         IBELL=7B
0040         IPAGE=15414B
0041         ICOMM=12345
0042         IFLG2=7777
0043         IBS=1024
0044         CALL SETAD(HDR8,IH,-8,0)
0045         CALL SETAD(HDR8,RH(1),67,0)
0046         CALL KYBD(2HBS,IBS,0)
0047         CALL GETI(NMAX,IBLM)
0048         ION=IBLM-1
0049         ICM=ION-1
0050         IBM=2
0051         CALL RWCOM(0)
0052   C
0053   C          IF PROGRAM REQUIRES INITIALIZATION, LOAD Y 91
0054   C
0055         IF(ICOMM.EQ.12345)GO TO 900
0056         CALL KYBD(2HMS,38,-3,1)
0057         CALL OVLD(9)
0058     900 CONTINUE
```

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```
0059          IFLG4=0
0060          IF(IFLAG.EQ.1)GO TO 1130
0061          IF(IFLAG.EQ.96)GO TO 1900
0062          IF(IFLAG.EQ.97)GO TO 1000
0063          IF(ICOMM.NE.12345)GO TO 1000
0064    C**********************************************************************
0065    C         START OF MONITOR
0066    C**********************************************************************
0067     1000 WRITE(1,1010)IBELL
0068     1010 FORMAT("*",A2)
0069          I=ISWR(177677B,0,0)
0070          IPAR1=-9999
0071          IPAR2=-9999
0072          IPAR3=-9999
0073          IPAR4=-9999
0074          IPAR5=-9999
0075          IPAR6=-9999
0076     1020 DO 1030 I=1,36
0077     1030 LINE(I)=2H,
0078     1040 CALL TTYIN(LINE)
0079     1042 CALL TEST(1,IST,LOG)
0080          IF(IST.LT.0)GO TO 1042
0081          CALL CODE
0082          READ(LINE,1120)IL
0083          IF(ICOMM.EQ.12345)GO TO 1115
0084     1115 CONTINUE
0085     1120 FORMAT(A2)
0086          CALL CODE
0087          READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0088    C**********************************************************************
0089    C         MONITOR COMMAND TABLE
0090    C**********************************************************************
0091     1130 IFLAG=0
0092          CALL RWCOM(1)
0093          IF(IL.EQ.2H**)GO TO 1000
0094          NCMMD=24
0095          DO 1138 I=1,NCMMD
0096          IF(IL.EQ.ICMMD(I))GO TO 1144
0097     1138 CONTINUE
0098     1139 WRITE(1,1140)
0099     1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0100          GO TO 1000
0101     1144 IF(I.GT.10)GO TO 1146
0102          GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0103     1146 I=I-10
0104          IF(I.GT.10)GO TO 1148
0105          GO TO (9004,9004,6000,6500,9004,9995,1100,1100,9002,9001),I
0106     1148 I=I-10
0107          GO TO (9001,1400,9008,9011),I
0108     1100 CONTINUE
0109          IF(IPAR1.EQ.37)GO TO 9005
0110          IF(IPAR1.EQ.10)GO TO 9006
0111          IF(IPAR1.EQ.6)GO TO 9007
0112          GO TO 1139
0113    C**********************************************************************
0114    C         MODAL SET-UP    STARTING VALUES
0115    C**********************************************************************
0116     1400 CONTINUE
0117          WRITE(1,1450)IPAGE,IBELL
0118          READ(1,*)IANS
```

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```
0119    1450 FORMAT(A2,/,"ENTER OPTION TO BE USED",
0120         1" FOR FREQUENCIES AND DAMPING",
0121         2 /," 1) MANUAL",
0122         3 /," 2) CURSOR",
0123         4 /," 3) LEAST SQUARES ESTIMATE",
0124         5 /," 4) CURRENTLY SELECTED VALUES",
0125         6 /," 5) RETURN TO MONITOR",A2,/)
0126         IF((IANS.LT.1).OR.(IANS.GT.5))GO TO 1400
0127         IF(IANS.EQ.5)GO TO 1000
0128         IF(IANS.EQ.4)GO TO 1900
0129         MCF=0
0130         DO 1460 I=1,10
0131         FRQ(I)=0.0
0132         ZETA(I)=0.0
0133         NCN(I)=0
0134         IB(I)=0
0135    1460 CONTINUE
0136         IFLG4=1
0137    C
0138    C      IFLG4=0      CURSER HAS ALREADY BEEN INITIALIZED
0139    C      IFLG4=1      THIS IS THE FIRST TIME INTO CURSER
0140    C
0141    1500 WRITE(1,1600)IBELL
0142    1600 FORMAT(A2,/,"INPUT DISC DATA RECORD OF TYPICAL TEST DATA:")
0143         READ(1,*)I
0144         IF((I.LT.0).OR.(I.GT.810))GO TO 1500
0145         CALL KYBD(2HMS,31,I)
0146         CALL KYBD(2HMS,11,0)
0147         IIBS=IH(5)
0148    C
0149    C      MAKING SURE ALL OF THE BLOCK WAS LOADED
0150    C
0151         IF((IIBS.LE.2048).AND.(IIBS.GE.128))GO TO 1650
0152         WRITE(1,1651)
0153    1651 FORMAT(/,"ERROR-ILLEGAL BLOCK SIZE")
0154    1650 CONTINUE
0155         CALL KYBD(2HBS,IIBS,0)
0156         CALL KYBD(2HMS,31,I)
0157         CALL KYBD(2HMS,11,0)
0158         IZR=IH(36)
0159         IF(IH(4).NE.99)GO TO 1680
0160         WRITE(1,1670)IZR
0161    1670 FORMAT(/,"ZOOM RANGE OF THE DATA IS",2X,A2)
0162    1680 CONTINUE
0163         FSHFT=RH(1)
0164         DF=RH(2)
0165         IF(IANS.LT.3)GO TO 1700
0166    C
0167    C      LEAST SQUARES STARTING VALUE SET-UP
0168    C
0169         WRITE(1,1665)IBELL
0170    1665 FORMAT(/,"ENTER OPTION FOR CHOICE OF STARTING CHANNEL:",A2
0171         1/,5X,"1) MANUAL",
0172         2/,5X,"2) CURSOR",/)
0173         READ(1,*)MMMM
0174         IF(MMMM.EQ.2)GO TO 1668
0175         WRITE(1,1669)IBELL
0176    1669 FORMAT(/,"ENTER CHANNEL NUMBER:",A2,/)
0177         READ(1,*)NS
0178         GO TO 1772
```

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```
0179    1668 CONTINUE
0180         WRITE(1,1660)IBELL
0181    1660 FORMAT(/,"SET CURSOR ON STARTING CHANNEL:",A2,/)
0182         ITEMP=0
0183         CALL CURSE(0,ITEMP)
0184         IF(ITEMP.EQ.-9999)NS=0
0185         NS=IABS(ITEMP)
0186    1772 CONTINUE
0187         IF(NS.EQ.0)NS=1
0188         F=FLOAT(NS)*DF+FSHFT
0189    1688 WRITE(1,1691)IBELL
0190    1691 FORMAT(/,"ENTER NUMBER OF POINTS TO BE USED IN THE",
0191        1," PARAMETER ESTIMATION:",/,5X,"(64,128,256)",A2,/)
0192         READ(1,*)NE
0193         IF((NE.EQ.64).OR.(NE.EQ.128).OR.(NE.EQ.256))GO TO 1696
0194         GO TO 1688
0195    1696 CONTINUE
0196         M3=400
0197         IF(NE.EQ.64)M3=700
0198         IF(M3.EQ.256)M3=300
0199         NE=NS+NE
0200         DO 1695 MMMM=1,M3
0201    1695 CALL KDIS(0,NS,NE,4)
0202         WRITE(1,1692)F,NS,NE,IBELL
0203    1692 FORMAT(/"STARTING FREQUENCY",E14.5,
0204        1/,"CHANNEL ",I5," TO ",I5,
0205        2//,"ENTER 0 TO ACCEPT:",A2,/)
0206         READ(1,*)MMMM
0207         IF(MMMM.NE.0)GO TO 1400
0208         CALL KYBD(2HBS,IBS,0)
0209         GO TO 9009
0210  C
0211  C          MANUAL AND CURSOR STARTING VALUE SET-UP
0212  C
0213    1700 CONTINUE
0214         WRITE(1,1730)IBELL
0215    1730 FORMAT(/,"ENTER MODE NUMBER AND BANDWIDTH:",A2)
0216    1740 READ(1,*)M,IBW
0217         IF(M.LT.0)GO TO 1500
0218         IF(M.EQ.0) GO TO 1800
0219         IF(M.GT.NM) WRITE(1,1760)
0220         IF(M.GT.NM) GO TO 1700
0221         IF(IANS.EQ.2)GO TO 1743
0222         WRITE(1,1742)IBELL
0223    1742 FORMAT(/,"ENTER CHANNEL NUMBER:",A2)
0224         READ(1,*)ITEMP
0225         GO TO 1746
0226    1743 CONTINUE
0227         IF(IFLG4.EQ.1)ITEMP=0
0228         IF(IFLG4.EQ.1)IFLG4=0
0229         CALL CURSE(0,ITEMP)
0230         IF(ITEMP.EQ.-9999)NCN(M)=0
0231         IF(ITEMP.EQ.-9999)GO TO 1000
0232    1746 NCN(M)=IABS(ITEMP)
0233         ITEMP=IABS(ITEMP)
0234         FRQ(M)=FLOAT(NCN(M))*DF+FSHFT
0235         WRITE(1,1750)NCN(M),FRQ(M)
0236    1750 FORMAT(I4,2X,F12.4)
0237    1760 FORMAT(/,"ERROR-VALUE GREATER THAN NUMBER OF MODES")
0238         IB(M)=IBW
```

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```
0239         GO TO 1700
0240   1800 CONTINUE
0241         CALL KYBD(2HBS,IBS,0)
0242         CALL RWCOM(1)
0243   C***************************************************************************
0244   C         MODAL COEFFICIENT ACQUISITION          PARAMETER ESTIMATION
0245   C***************************************************************************
0246   1900 CONTINUE
0247         WRITE(1,1905)IPAGE,IBELL
0248   1905 FORMAT(A2,/,"ENTER OPTION TO BE USED TO",
0249        1" DETERMINE MODAL COEFFICIENTS:"
0250        1,/,"          1) MAGNITUDE"
0251        2,/,"          2) IMAGINARY PART"
0252        3,/,"          3) REAL PART"
0253        4,/,"          4) KENNEDY-PANCU CIRCLE FIT"
0254        5,/,"          5) LEAST-SQUARES FREQUENCY DOMAIN"
0255        6,/,"          6) RETURN TO MONITOR",A2,/)
0256         READ(1,*)IANS
0257         IF((IANS.LT.1).OR.(IANS.GT.6))GO TO 1900
0258         IF(IANS.EQ.6)GO TO 1000
0259         WRITE(1,1906)IBELL
0260   1906 FORMAT(/,"ENTER 0 TO CLEAR CURRENT MODAL COEFFICIENTS",A2)
0261         READ(1,*)I
0262         IF(I.NE.0)GO TO 1909
0263         CALL KYBD(2HCL,0)
0264         CALL GETQ(0,INQ)
0265         INQ(2)=176500B
0266         INQ(3)=77777B
0267         DO 1907 I=IBM,ION-2
0268         CALL KYBD(2HCL,I)
0269   1907 CALL PUTQ(I,INQ)
0270         DO 1908 I=1,10
0271   1908 RMM(I)=0.0
0272         CALL RWCOM(1)
0273   1909 CONTINUE
0274         MCF=IANS
0275         IF(IANS.EQ.5)GO TO 9010
0276         ICUR=-9999
0277         WRITE(1,1910)IBELL
0278   1910 FORMAT(" SWITCH 15  ABORT POINT PRINT",
0279        1/," SWITCH 14  ABORT PARAMETER ESTIMATION",
0280        2/," SWITCH 13  ABORT AUTOMATIC CALIBRATION",
0281        3/," SWITCH 12  SKIP DIRECTIONAL COSINE CHECK",
0282        4/," SWITCH 11  ABORT NIXIE TUBE DISPLAY",
0283        5/," SWITCH 10  SUPPRESS SCALING QUESTION",
0284        5/," SWITCH  0  AUTOMATIC CIRCLE FIT",
0285        6//," ENTER RANGE OF DISC RECORDS FOR CURRENT TEST:",A2)
0286         READ(1,*)IREC1,IREC2
0287         IF((IREC1.LT.0).OR.(IREC1.GT.819))IREC1=0
0288         IF((IREC2.LT.0).OR.(IREC2.GT.819))IREC2=819
0289   C
0290   C         SWITCH 15  SUPPRESS PRINTOUT TO TERMINAL
0291   C         SWITCH 14  ABORT MODAL COEFFICIENT ACQUISITION
0292   C         SWITCH 13  SKIP DATA CALIBRATION
0293   C         SWITCH 12  SKIP DIRECTIONAL COSINE CHECK
0294   C         SWITCH 11  SKIP NIXIE TUBE DISPLAY
0295   C         SWITCH  0  AUTOMATIC CIRCLE FIT ACQUISITION
0296   C
0297         CALL KYBD(2HMS,31,IREC1)
0298         IIBS=1024
```

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```
0299    2000 CONTINUE
0300         IF(IREC1.GT.IREC2)GO TO 1000
0301         IF(ISSW(14).LT.0)GO TO 1000
0302         IF(ISSW(11).LT.0)GO TO 2001
0303         CALL NIXIT(IREC1)
0304    2001 IREC1=IREC1+1
0305         CALL KYBD(2HMS,11,0)
0306   C
0307   C          GET DATA FROM HEADERS
0308   C
0309         IIBS=IH(5)
0310         CALL CHKID(IT,ICIC)
0311         IF(ICIC.EQ.0)GO TO 2000
0312         CALL KYBD(2HBS,IIBS,0)
0313         IF(IH(36).NE.IZR)GO TO 2000
0314    2004 ID1=IH(19)
0315         IS=IH(45)
0316         IF(IS.GT.IP)GO TO 2000
0317   C
0318   C          CORRECT DATA WITH STORED CALIBRATION CONSTANT
0319   C          OR CALIBRATION CURVE
0320   C
0321         IF(ISSW(13))2030,2010
0322    2010 CONTINUE
0323         IF(RH(3).GT.0.0)GO TO 2030
0324         IRCAL=IFIX(ABS(RH(3)))
0325         WRITE(1,2012)IRCAL
0326    2012 FORMAT(/,"CALIBRATION RECORD IS ",I4)
0327         IF(ICUR.EQ.IRCAL)GO TO 2020
0328         CALL FNDFP(1,IPTR)
0329         CALL KYBD(2HMS,31,IRCAL)
0330         CALL KYBD(2HMS,11,1)
0331         CALL KYBD(2HMS,31,IPTR)
0332         ICUR=IRCAL
0333    2020 CONTINUE
0334         CALL KYBD(2H: ,1)
0335   C
0336   C          SWITCH 15 ON  SUPRESS OUTPUT TO TERMINAL DURING AUTO SEARCH
0337   C
0338    2030 IF(ISSW(15))2060,2040
0339    2040 CALL IOSW(NU,0)
0340         WRITE(NU,2050)ID1,IS
0341    2050 FORMAT(A2,I5)
0342    2060 DO 2220 I=1,NM
0343         IBW=IB(I)
0344         NC=NCN(I)
0345         CALL GET(0,NC,X,Y)
0346   C
0347   C          MAGNITUDE
0348   C
0349         R=ABS(SQRT(X*X+Y*Y))
0350         ANG=ATAN2(Y,X)
0351         IF(IANS.EQ.1)GO TO 2140
0352   C
0353   C      REAL PART
0354   C
0355         R=X
0356         ANG=1.5707963
0357         IF(IANS.EQ.3)GO TO 2140
0358   C
```

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```
0359   C          IMAGINARY PART
0360   C
0361          R=Y
0362          ANG=1.5707963
0363          IF(IANS.EQ.2)GO TO 2140
0364          IF(IBW.EQ.0)GO TO 2140
0365   C
0366   C          CIRCLE FIT AND INTERACTIVE EDITING
0367   C
0368    2070 CALL CIR(NC,IBW,X1,Y1,R)
0369          R=ABS(R)
0370          X=X-X1
0371          Y=Y-Y1
0372          ANG=ATAN2(Y,X)
0373   C
0374   C          SWITCH 0 ON     NO DISPLAY     AUTOMATIC CIRCLE FIT
0375   C
0376          IF(ISSW(0))2110,2080
0377    2080 CALL KYBD(2HX),1)
0378          IZ1=33
0379          IZ2=NC-IBW
0380          IZ3=NC+IBW
0381          IZ4=IZ2-15
0382          IZ5=IZ3+15
0383          Z1=0.0
0384          DO 2090 J=1,IZ1
0385          Z1=Z1+.2
0386          Z2=R*SIN(Z1)+X1
0387          Z3=R*COS(Z1)+Y1
0388    2090 CALL PUT(1,J,Z2,Z3)
0389          WRITE(1,2091)IBELL
0390   C
0391   C          CIRCLE FIT MONITOR "D"
0392   C
0393    2091 FORMAT("*D",A2)
0394          CALL TTYIN(LINE)
0395    2100 CALL TEST(1,IST,LOG)
0396   C
0397   C          CIRCLE FIT DISPLAY
0398   C
0399          CALL KDIS(0,IZ2,IZ3,4)
0400          CALL KDIS(1,1,IZ1,4)
0401          CALL KDIS(0,IZ4,IZ5,4)
0402          CALL KDIS(0,IZ2,IZ3,4)
0403          IF(IST)2100,2110,2110
0404    2110 CALL CODE
0405          READ(LINE,1120)IL
0406          IF(IL.EQ.2HCL)GO TO 2130
0407          IF(IL.EQ.2H_ )GO TO 2125
0408          IF(IL.EQ.2HA-)GO TO 2112
0409          IF(IL.EQ.2H/R)GO TO 2114
0410          CALL CODE
0411          READ(LINE,*)IPAR1,IPAR2,IPAR3,IPAR4
0412          IBW=IPAR1
0413          IF(IPAR1)2135,2120,2070
0414    2112 NC=NCN(I)
0415          GO TO 2070
0416    2114 NCN(I)=NC
0417          IB(I)=IBW
0418          GO TO 2070
```

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```
0419    2120 R=Y
0420         GO TO 2140
0421    2125 CALL CODE
0422         READ(LINE1,*)IPAR2
0423         NC=NC+IPAR2
0424         GO TO 2070
0425    2130 R=0
0426    2135 R=R*2.0
0427    2140 CALL KYBD(2HBS,IBS,0)
0428    C
0429    C         MODAL COEFFICIENT IS PROPORTIONAL TO DIAMETER
0430    C
0431         RMAX=RMM(I)
0432         IF(RH(3).GT.0.0)R=R*RH(3)
0433         IF(ANG.GE.0)GO TO 2143
0434         R=(-1.0)*R
0435         ANG=ANG+3.14159265
0436    2143 L1=IFIX(ANG*57.295774)
0437    C
0438    C         CORRECT FOR TRANSDUCER ORIENTATION
0439    C
0440         IF((ID1.EQ.2HX-).OR.(ID1.EQ.2H-1)) GO TO 2160
0441         IF((ID1.EQ.2HX ).OR.(ID1.EQ.2H1 ))GO TO 2170
0442         IF((ID1.EQ.2HY-).OR.(ID1.EQ.2H-2))GO TO 2180
0443         IF((ID1.EQ.2HY ).OR.(ID1.EQ.2H2 ))GO TO 2190
0444         IF((ID1.EQ.2HZ-).OR.(ID1.EQ.2H-3))GO TO 2200
0445         IF((ID1.EQ.2HZ ).OR.(ID1.EQ.2H3 ))GO TO 2210
0446    C
0447    C         DIRECTIONAL COSINE CHECK
0448    C
0449         IF(ISSW(12))2144,2149
0450    2144 CONTINUE
0451         IF(ID1.NE.2HD )GO TO 2149
0452         PI=3.14159265
0453         DO 2145 IM=1,3
0454         IM3=IM+3
0455         R1=R*COS(RH(IM3)*PI/180.0)
0456         CALL RWCMC(IM,R1,L1,I,IS,IP,IBM,RMAX,0)
0457    2145 CONTINUE
0458         GO TO 2215
0459    2149 CONTINUE
0460         WRITE(1,2150)
0461    2150 FORMAT(/,"ERROR-WRONG COORDINATE CODE")
0462         CALL KYBD(2HMS,1)
0463         GO TO 2000
0464    2160 R=-R
0465    2170 CALL RWCMC(1,R,L1,I,IS,IP,IBM,RMAX,0)
0466         GO TO 2215
0467    2180 R=-R
0468    2190 CALL RWCMC(2,R,L1,I,IS,IP,IBM,RMAX,0)
0469         GO TO 2215
0470    2200 R=-R
0471    2210 CALL RWCMC(3,R,L1,I,IS,IP,IBM,RMAX,0)
0472    2215 CONTINUE
0473    C
0474    C         RMM ARRAY HAS THE SCALE FACTOR FOR
0475    C         EACH MODE---VALUES ARE STORED AS
0476    C         NUMBERS FROM 1 TO 2000
0477    C
0478         RMM(I)=RMAX
```

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```
0479    2220 CONTINUE
0480         GO TO 2000
0481    C
0482    C         STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
0483    C
0484    C         READ
0485    C
0486    6000 CALL KYBD(2HMS,35,1)
0487         CALL KYBD(2HMS,25)
0488         IF(IPAR1.EQ.-9999)GO TO 9011
0489         IF((IPAR1.GE.0).AND.(IPAR1.LE.800)) CALL KYBD(2HMS,31,IPAR1)
0490         IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0491         CALL KYBD(2HMS,11,0)
0492         CALL KYBD(2HMS,31,-1,1)
0493         CALL RWCOM(-1)
0494         IF(ICOMM.NE.12345)GO TO 6800
0495         CALL KYBD(2HMS,11,ION)
0496         CALL RWCOM(0)
0497         IF(ICOMM.NE.12345)GO TO 6800
0498         NMP=0
0499         IRJ=ICM
0500         CALL KYBD(2HMS,11,IRJ)
0501         IRJ=IRJ-1
0502    6100 DO 6200 I=IBM,IRJ
0503    6200 CALL KYBD(2HMS,11,I)
0504         CALL KYBD(2HMS,35,1)
0505         CALL KYBD(2HMS,15)
0506         WRITE(1,1235)(IT(I),I=1,5)
0507    1235 FORMAT(/,"TEST ID IS",23X,5A2)
0508         GO TO 1000
0509    C
0510    C         STORE
0511    C
0512    6500 CALL KYBD(2HMS,35,1)
0513         CALL KYBD(2HMS,25)
0514         IF(IPAR1.EQ.-9999)GO TO 9011
0515         IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
0516         IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0517         IL=2H##
0518         CALL RWCOM(1)
0519         IH(6)=52525B
0520         IH(9)=10
0521         IH(10)=IT(1)
0522         IH(11)=IT(2)
0523         IH(12)=IT(3)
0524         IH(13)=IT(4)
0525         IH(14)=IT(5)
0526         IH(34)=2H71
0527         CALL KYBD(2HMS,21,ION)
0528         CALL KYBD(2HMS,21,ICM)
0529         IH(34)=2H72
0530         IRJ=ICM-1
0531         IPAR1=IPAR1+2
0532         DO 6700 I=IBM,IRJ
0533         IPAR1=IPAR1+1
0534    6700 CALL KYBD(2HMS,21,I)
0535         WRITE(1,6701)IPAR1
0536    6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
0537         CALL KYBD(2HMS,35,1)
0538         CALL KYBD(2HMS,15)
```

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```
0539          GO TO 1000
0540    6800  WRITE(1,6801)
0541    6801  FORMAT(/,"ERROR-INVALID DATA RECORD")
0542          NMP=0
0543          ICOMM=12345
0544          GO TO 1000
0545   C****************************************************************
0546   C           EXIT TO OTHER OVERLAYS
0547   C****************************************************************
0548    9001  I=1
0549          IFLAG=1
0550          GO TO 9900
0551    9002  I=2
0552          IFLAG=1
0553          GO TO 9900
0554    9003  I=3
0555          IFLAG=1
0556          GO TO 9900
0557    9004  I=4
0558          IFLAG=1
0559          GO TO 9900
0560    9005  I=5
0561          IFLAG=1
0562          GO TO 9900
0563    9006  I=6
0564          IFLAG=1
0565          GO TO 9900
0566    9007  I=7
0567          IFLAG=1
0568          GO TO 9900
0569    9008  I=8
0570          IFLAG=1
0571          GO TO 9900
0572    9009  I=9
0573          IFLAG=92
0574          GO TO 9900
0575    9010  I=10
0576          IFLAG=92
0577          GO TO 9900
0578    9011  I=11
0579          IFLGA=1
0580          GO TO 9900
0581    9900  CONTINUE
0582          CALL RWCOM(1)
0583          CALL KYBD(2HMS,38,I)
0584          CALL OVLD(9)
0585    9995  CONTINUE
0586          IL=2H**
0587          IF(ICOMM.EQ.12345)CALL RWCOM(1)
0588          CALL KYBD(2HBS,IBS,0)
0589          RETURN
0590          END
0591          END$
```

```
0001   FTN4
0002         SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C         THIS PROGRAM IS STORED UNDER $Y904
0005   C
0006   C*******************************************************************
0007   C
0008   C         PROGRAMMER:   R.J.ALLEMANG
0009   C                       MAIL LOCATION # 72
0010   C                       UNIVERSITY OF CINCINNATI
0011   C                       CINCINNATI, OHIO  45221
0012   C                       513-475-6670
0013   C
0014   C         REVISION DATE:  NOV 20,1979
0015   C
0016   C*******************************************************************
0017         DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018        1,IDIV(1),ICMMD(26),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019        2,IC1(1),IPTCM(1),LO(3),LABEL(20)
0020         EQUIVALENCE (LINE(2),LINE1)
0021         COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022        1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023        2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024        3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025        4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026         EXTERNAL HDR8,DTAD0,NMAX
0027         DATA IDZ/00/,INZ1/0/,SCALE/32760./
0028         DATA ICMMD/2HD ,2HV ,2HZ ,2HEX,2H: ,
0029        12HM ,2H_ ,2HRO,2HA-,2HAM,
0030        22HCH,2HSP,2HX<,
0031        32HX>,2HCV,2H< ,2HB ,2HL ,
0032        42HW ,2HI ,2HK ,2HA+,2H/L,
0033        52H? ,2H/.,2HX /
0034   C*******************************************************************
0035   C         UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0036   C
0037   C         DISPLAY PROGRAM
0038   C*******************************************************************
0039         IBELL=7B
0040         IPAGE=15414B
0041         CALL SETAD(HDR8,IH,-8,0)
0042         ICOMM=0
0043         IBS=1024
0044         CALL KYBD(2HBS,IBS,0)
0045         CALL GETI(NMAX,IBLM)
0046         ION=IBLM-1
0047         ICM=ION-1
0048         IBM=2
0049         I=ION*IBS+270
0050         CALL SETAD(DTAD0,IPTCM,I,-1)
0051         INTPT=0
0052         CALL RWCOM(0)
0053   C
0054   C         IF PROGRAM REQUIRES INITIALIZATION, LOAD Y 91
0055   C
0056         IF(ICOMM.EQ.12345)GO TO 900
0057         CALL KYBD(2HMS,38,-4,1)
0058         CALL OVLD(9)
```

```
0059      900 CONTINUE
0060          CALL SETAD(DTAD0,IX1,0,-1)
0061          CALL SETAD(DTAD0,IY1,256,-1)
0062          CALL SETAD(DTAD0,IDX,512,-1)
0063          CALL SETAD(DTAD0,IDY,768,-1)
0064          CALL SETAD(DTAD0,IC1,1024,-1)
0065          CALL SETAD(DTAD0,IDIV,1536,-1)
0066          IDZ=0
0067          IDIV(22)=0
0068          IDIV(23)=0
0069          IDIV(24)=0
0070          IDIV(25)=0
0071          SF1=.1
0072          IANSPD=4
0073          NMP=0
0074          NMP1=0
0075          NPD=2
0076          IKZ=1
0077          IFLG3=0
0078          IF(IFLAG.EQ.1)GO TO 1130
0079   C****************************************************************************
0080   C          DISPLAY PROGRAM INFO
0081   C
0082   C          LIST OF VARIABLES:
0083   C
0084   C          NMP1=                LAST MODE WHICH DISPLAY WAS CALCULATED FOR
0085   C
0086   C          NMP=                 CURRENT REQUESTED DISPLAY MODE
0087   C
0088   C          NS1=                 THE NUMBER OF FRAMES DISPLAYED OF EACH
0089   C                               DEFORMATION
0090   C
0091   C          INZ1=0               ANIMATED DEFORMATIONS WITH UNDEFORMED
0092   C          INZ1=1               STILL DEFORMATION WITH UNDEFORMED
0093   C          INZ1=2               ANIMATED DEFORMATIONS ONLY
0094   C          INZ1=3               STILL DEFORMATION ONLY
0095   C
0096   C          IDZ=0                UNDEFORMED SHAPE ONLY
0097   C          IDZ=1                DISPLAY ACCORDING TO INZ1 PARAMETER
0098   C
0099   C          IFLG3=0              A DISPLAY HAS NOT BEEN PREVIOUSLY CALCULATED
0100   C          IFLG3=1              A DISPLAY HAS BEEN PREVIOUSLY CALCULATED
0101   C
0102   C          IFLG4=0              A FULL DISPLAY HAS BEEN REQUESTED
0103   C          IFLG4=1              A PARTIAL DISPLAY HAS BEEN REQUESTED
0104   C
0105   C          IKZ=0                THE REQUESTED MODE IS THE SAME AS PREVIOUS
0106   C          IKZ=1                THE REQUESTED MODE IS DIFFERENT
0107   C
0108   C          IX1                  X COORDINATES OF THE DISPLAY (UNDEFORMED)
0109   C          IY1                  Y COORDINATES OF THE DISPLAY (UNDEFORMED)
0110   C          IDX                  X COORDINATES OF THE DISPLAY (DEFORMED)
0111   C          IDY                  X COORDINATES OF THE DISPLAY (DEFORMED)
0112   C          IC1                  CONNECTIVITY FILE FOR CURRENT DISPLAY
0113   C          IPTCM                POINT LOCATION BY COMPONENT NUMBER FILE
0114   C
0115   C          IFLG5=0              AUTOMATIC EXPANSION
0116   C          IFLG5=1              INHIBIT AUTOMATIC EXPANSION
0117   C
0118   C          IFLG6=0              AUTOMATIC DISPLAY CENTERING
```

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```
0119  C        IFLG6=1              INHIBIT AUTOMATIC DISPLAY CENTERING
0120  C
0121  C        INTPT                POINT NUMBER OF POINT TO BE INTENSIFIED
0122  C
0123  C        IFLG8=0              NO DISPLAY OVERFLOW
0124  C        IFLG8=1              OVERFLOW OF DISPLAY CALCULATION
0125  C
0126  C*****************************************************************************
0127  C
0128  C        START OF MONITOR
0129  C
0130  C*****************************************************************************
0131  1000 WRITE(1,1010)IBELL
0132  1010 FORMAT("*",A2)
0133       I=ISWR(177677B,0,0)
0134       IF((NPD.GT.510).OR.(NPD.LT.2)) NPD=2
0135       NS1=IANSPD*300/NPD
0136       IF(NS1.LE.0)NS1=1
0137       IF(NS1.GT.100)NS1=100
0138       L=0
0139       IPAR1=-9999
0140       IPAR2=-9999
0141       IPAR3=-9999
0142       IPAR4=-9999
0143       IPAR5=-9999
0144       IPAR6=-9999
0145  1020 DO 1030 I=1,36
0146  1030 LINE(I)=2H,,
0147  1040 CALL TTYIN(LINE)
0148  1042 CONTINUE
0149       IF(IFLG3.EQ.1)GO TO 1044
0150  1043 CALL TEST(1,IST,LOG)
0151       IF(IST.LT.0)GO TO 1043
0152       GO TO 1111
0153  1044 CONTINUE
0154       CALL SDISP(IX1(1),IY1(1),IDX(1),IDY(1),IC1(1),NPD,NMP,INTPT)
0155  1045 IF(L.GT.19)L=0
0156       L=L+1
0157       DO 1100 II=1,NS1
0158  1050 CALL TEST(1,IST,LOG)
0159  1060 IF((INZ1.EQ.2).OR.(INZ1.EQ.3)) GO TO 1070
0160  C
0161  C        DISPLAY UNDEFORMED SHAPE
0162  C
0163  1065 CALL XDISP(32767,NPD)
0164  1070 IF(IDZ.EQ.0) GO TO 1090
0165  C
0166  C        DISPLAY ONE POSITION OF DEFORMED SHAPE
0167  C
0168  1080 CALL XDISP(IDIV(L),NPD)
0169  1090 IF(IST.GE.0)GO TO 1110
0170       IF((INZ1.EQ.1).OR.(INZ1.EQ.3)) GO TO 1050
0171  1100 CONTINUE
0172       GO TO 1045
0173  1110 CALL TDISP
0174  C
0175  C        PROCESS NEW COMMAND
0176  C
0177  1111 CONTINUE
0178       CALL CODE
```

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```
0179          READ(LINE,1120)IL
0180          IF(ICOMM.EQ.12345)GO TO 1115
0181  C
0182  C         PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
0183  C             EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
0184          DO 1112 I=1,12
0185          IF(IL.EQ.ICMMD(I))GO TO 1139
0186    1112 CONTINUE
0187          IF(IL.EQ.ICMMD(17))GO TO 1139
0188  C
0189    1115 CONTINUE
0190    1120 FORMAT(A2)
0191          CALL CODE
0192          READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0193  C***********************************************************************
0194  C         MONITOR COMMAND TABLE
0195  C***********************************************************************
0196    1130 IFLAG=0
0197          CALL RWCOM(1)
0198          IF(IL.EQ.2H**)GO TO 1000
0199          NCMMD=26
0200          DO 1138  I=1,NCMMD
0201          IF(IL.EQ.ICMMD(I))GO TO 1144
0202    1138 CONTINUE
0203    1139 WRITE(1,1140)
0204    1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0205          GO TO 1000
0206    1144 IF(I.GT.10)GO TO 1146
0207          GO TO (2280,2250,2250,2500,2500,3000,3000,4500,4500,4000),I
0208    1146 I=I-10
0209          IF(I.GT.10)GO TO 1148
0210          GO TO (4000,7000,6000,6500,5000,9995,1200,1200,9002,9001),I
0211    1148 I=I-10
0212          GO TO (9001,9003,9008,8000,7500,9011),I
0213    1200 CONTINUE
0214          IF(IPAR1.EQ.37)GO TO 9005
0215          IF(IPAR1.EQ.10)GO TO 9006
0216          IF(IPAR1.EQ.6)GO TO 9007
0217          GO TO 1139
0218  C
0219  C         JUMP HERE FOR DISPLAY COMMAND ERROR
0220  C
0221    1900 CONTINUE
0222          WRITE(1,1902)IBELL
0223    1902 FORMAT(/,"ERROR-DISPLAY REQUIRES FURTHER INPUT",A2,/)
0224          GO TO 1000
0225    1910 CONTINUE
0226          WRITE(1,1912)IBELL
0227    1912 FORMAT(/,"ERROR-NO CURRENT DISPLAY",A2,/)
0228          GO TO 1000
0229  C***********************************************************************
0230  C         VIEW COMMAND
0231  C
0232  C         CALCULATE THE MATRIX TO CONVERT GLOBAL X,Y,Z TO
0233  C             SCREEN X,Y OF THE 5460 DISPLAY UNIT
0234  C***********************************************************************
0235    2250 CONTINUE
0236          IF(IFLG3.EQ.0)GO TO 1910
0237          IF(IPAR1.EQ.-9999)IPAR1=1
0238          IF(IPAR2.EQ.-9999)IPAR2=1
```

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```
0239          IF(IPAR3.EQ.-9999)IPAR3=1
0240          Z1=IPAR1
0241          Z2=IPAR2
0242          Z3=IPAR3
0243          XL=SQRT(Z1*Z1+Z2*Z2+Z3*Z3)
0244          ST=Z2/XL
0245          CT=SQRT(Z1*Z1+Z3*Z3)/XL
0246          CP=0.
0247          SP=1.
0248          XL=Z1*Z1+Z3*Z3
0249          IF(XL.LT.0.0001)GO TO 2270
0250          XL=SQRT(XL)
0251          SP=Z3/XL
0252          CP=Z1/XL
0253   C
0254   C          THE FOLLOWING CODE ORIENTS THE Y DIRECTION
0255   C          OF THE GLOBAL COORDINATES TO THE Y DIRECTION
0256   C          OF THE 5460 SCOPE UNIT
0257   C
0258    2270 A(1,1)=+SP
0259          A(1,2)=0.0
0260          A(1,3)=-CP
0261          A(2,1)=-ST*CP
0262          A(2,2)=CT
0263          A(2,3)=-ST*SP
0264          IF(IPAR4.EQ.-9999)GO TO 2364
0265          GO TO 1000
0266   C*******************************************************************
0267   C          DISPLAY COMMAND
0268   C*******************************************************************
0269    2280 CONTINUE
0270   C
0271   C      CHECK TO SEE IF DATA SET HAS BEEN ENTERED
0272   C
0273          IF(ICOMM.NE.12345)GO TO 1900
0274          IF(NUMPT.EQ.1)GO TO 1900
0275          IF(ICON.EQ.0)GO TO 1900
0276          IF(NCOM.EQ.0)GO TO 1900
0277          IF(IPAR1+9999) 2300,2290,2300
0278    2290 INZ1=INZ1+1
0279          IF(INZ1.GE.4) INZ1=0
0280          IF(NMP.EQ.0)INZ1=0
0281          GO TO 1000
0282   C*******************************************************************
0283    2300 CONTINUE
0284          IF(IABS(IPAR1).GT.NM)GO TO 1138
0285          IF(IPAR1.LT.0)IFLG3=0
0286          IF(IPAR1.LT.0)NMP1=0
0287          IF(IPAR1.LT.0)IPAR1=-IPAR1
0288          NMP=IPAR1
0289          INZ1=2
0290          IF(NMP.EQ.0)INZ1=0
0291   C
0292   C          CHECK FOR PARTIAL DISPLAY
0293   C
0294          IF(IPAR2.EQ.-9999)IFLG4=0
0295          IF(IPAR2.EQ.-9999)GO TO 2306
0296          IF((IPAR2.LT.1).OR.(IPAR2.GT.4))GO TO 1900
0297          IFLG4=1
0298   C
```

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```
0299   C          SET UP IZ ARRAY ACCORDINGLY
0300   C
0301          IZ(1)=IPAR3
0302          IZ(2)=IPAR4
0303          IZ(3)=IPAR5
0304          IZ(4)=IPAR6
0305          IZ1=IPAR2+1
0306          DO 2302 I=IZ1,10
0307     2302 IZ(I)=0
0308          IFL=0
0309          DO 2304 I=1,10
0310     2304 IF((IZ(I).LT.0).OR.(IZ(I).GT.NCOM))IFL=1
0311          IF(IFL.EQ.1)GO TO 1900
0312          IFL=0
0313          GO TO 2310
0314     2306 CONTINUE
0315          DO 2308   I=1,10
0316     2308 IZ(I)=I
0317     2310 CONTINUE
0318   C
0319          IKZ=1
0320          IF(NMP.EQ.0)IDZ=0
0321          IF(NMP.GT.0)IDZ=1
0322   C
0323          IF(NMP1.EQ.NMP)IKZ=0
0324          IF(NMP.EQ.0)IKZ=0
0325          NMP1=NMP
0326          IF(IFLG4.EQ.1)IKZ=1
0327          IF(IFLG3.EQ.0)IKZ=1
0328   C
0329          IF(IKZ.EQ.0)GO TO 1000
0330          IF(IFLG3.EQ.1)GO TO 2364
0331   C*****************************************************************
0332   C          CALCULATE THE LONGEST VECTOR IN X,Y,Z SPACE
0333   C             IN ORDER TO INITIALLY SCALE THE DISPLAY
0334   C*****************************************************************
0335     2360 CONTINUE
0336          SCALU=0.0
0337          SCALD=0.0
0338          XMAX=-1E30
0339          YMAX=-1E30
0340          ZMAX=-1E30
0341          XMIN=1E30
0342          YMIN=1E30
0343          ZMIN=1E30
0344          RMAX=1.0
0345          DO 2363 I=1,NUMPT
0346          CALL RWCMC(1,XXA(2,1),LO(1),NMP,I,IP,IBM,RMAX,1)
0347          CALL RWCMC(2,XXA(2,2),LO(2),NMP,I,IP,IBM,RMAX,1)
0348          CALL RWCMC(3,XXA(2,3),LO(3),NMP,I,IP,IBM,RMAX,1)
0349          CALL RWCOR(I,XXA(1,1),XXA(1,2),XXA(1,3),ICM,1)
0350          IZ5=IPTCM(I)
0351          IF((IZ5.LT.1).OR.(IZ5.GT.NCOM))GO TO 2363
0352   C
0353   C          ONLY CONSIDER POINTS WITH REQUESTED COMPONENTS
0354   C
0355          DO 2371 IIR=1,NCOM
0356          IF(IZ(IIR).EQ.IZ5)GO TO 2372
0357     2371 CONTINUE
0358          GO TO 2363
```

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```
0359    2372 CONTINUE
0360          IF(IC(IZ5).NE.0) GO TO 2361
0361    C***********************************************************************
0362    C            CONVERT CYLINDER COORDINATES TO RECTANGULAR
0363    C
0364    C***********************************************************************
0365    C
0366    C           XXX( , )=          LOCAL ORIGINS WITH RESPECT TO GLOBAL
0367    C                             ORIGIN AS INPUTTED IN Y0091
0368    C                             NEEDED TO CREATE ABSOLUTE GEOMETRY
0369    C
0370    C           XXA(1, )=          LOCAL POINT COORDINATES
0371    C           XXA(2, )=          LOCAL MODAL COEFFICIENTS
0372    C
0373    C           YYA(1, )=          GLOBAL POINT COORDINATES
0374    C           YYA(2, )=          GLOBAL MODAL COEFFICIENTS
0375    C
0376    C***********************************************************************
0377          Z1=XXA(2,1)
0378          Z2=XXA(1,2)/57.29577951
0379          Z3=COS(Z2)
0380          Z4=SIN(Z2)
0381          Z5=XXA(1,1)
0382          XXA(2,1)=Z1*Z3-XXA(2,2)*Z4
0383          XXA(2,2)=Z1*Z4+XXA(2,2)*Z3
0384          XXA(1,1)=Z5*COS(Z2)
0385          XXA(1,2)=Z5*SIN(Z2)
0386    C
0387    C          CONVERT FROM LOCAL TO GLOBAL COORDINATES USING
0388    C             COMPONENT ORIGINS AND ORIENTATIONS
0389    C
0390    2361 DO 2362 K=1,2
0391          DO  2362 II=1,3
0392          IZ1=IABS(IX(II,IZ5))
0393          Z1=IX(II,IZ5)/IZ1
0394          Z3=XXX(II,IZ5)
0395          IF(K.EQ.2)Z3=0
0396    2362 YYA(K,II)=XXA(K,IZ1)*Z1+Z3
0397    C
0398    C          FIND MAX AND MIN POINTS TO COMPUTE DISPLAY CENTER
0399    C
0400          XMIN=AMIN1(XMIN,YYA(1,1))
0401          XMAX=AMAX1(XMAX,YYA(1,1))
0402          YMIN=AMIN1(YMIN,YYA(1,2))
0403          YMAX=AMAX1(YMAX,YYA(1,2))
0404          ZMIN=AMIN1(ZMIN,YYA(1,3))
0405          ZMAX=AMAX1(ZMAX,YYA(1,3))
0406    C***********************************************************************
0407    C           SF(1)=MAXIMUM UNDEFORMED VECTOR FROM GLOBAL ORIGIN
0408    C           SF(2)=MAXIMUM DEFORMED VECTOR FROM GLOBAL ORIGIN
0409    C***********************************************************************
0410    C
0411    C           CALCULATIONS ARE FROM (0,0,0) NOT THE DISPLAY ORIGIN
0412    C
0413    C***********************************************************************
0414          Z3=SQRT(YYA(2,1)**2+YYA(2,2)**2+YYA(2,3)**2)
0415          SCALD=AMAX1(SCALD,Z3)
0416          Z3=SQRT(YYA(1,1)**2+YYA(1,2)**2+YYA(1,3)**2)
0417          SCALU=AMAX1(SCALU,Z3)
0418    2363 CONTINUE
```

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```
0419   C
0420   C          COMPUTE "O" VECTOR     ACTUAL 3-D DISPLAY ORIGIN
0421   C
0422          O(1)=(XMAX+XMIN)/2.
0423          O(2)=(YMAX+YMIN)/2.
0424          O(3)=(ZMAX+ZMIN)/2.
0425   C
0426   C          USE SCALE FACTORS TO MAKE DEFORMED AND UNDEFORMED
0427   C             VECTORS AS LARGE AS POSSIBLE
0428   C
0429          IF(SCALU.EQ.0.0)SCALU=1.0
0430          IF(SCALD.EQ.0.0)SCALD=1.0
0431          SCALU=SCALE/SCALU
0432          SCALD=SCALE/SCALD
0433   C****************************************************************************
0434   C          START OF ACTUAL DISPLAY CALCULATION
0435   C****************************************************************************
0436    2364 NPD=0
0437          SF(1)=SCALU
0438          SF(2)=SCALD
0439          CALL KYBD(2HCL,0)
0440          CALL KYBD(2HCL,1)
0441    2365 DO 2366 I=1,NUMPT
0442          IX1(I)=32760
0443    2366 IY1(I)=32760
0444          XMAX=-1E30
0445          YMAX=-1E30
0446          XMIN=1E30
0447          YMIN=1E30
0448          XAVG=0.0
0449          YAVG=0.0
0450   C****************************************************************************
0451   C          DISPLAY LOOP
0452   C****************************************************************************
0453          RMAX=1.0
0454          DO 2380 J=1,ICON
0455          CALL RWCON(J,IZ3,ION,1)
0456          IZ6=IZ3
0457          IZ3=IABS(IZ3)
0458          IF((IZ3.EQ.0).OR.(IZ3.GT.NUMPT))WRITE(NU,2374)
0459    2374 FORMAT(/,"ERROR-CONNECTIVITY FILE")
0460          IF((IZ3.EQ.0).OR.(IZ3.GT.NUMPT))IFLG3=0
0461          IF((IZ3.EQ.0).OR.(IZ3.GT.NUMPT))GO TO 1000
0462          CALL RWCOR(IZ3,XXA(1,1),XXA(1,2),XXA(1,3),ICM,1)
0463          IZ5=IPTCM(IZ3)
0464          IF((IZ5 LT.1).OR.(IZ5.GT.NCOM))GO TO 2380
0465          DO 2367 II=1,NCOM
0466          IF(IZ(II).EQ.IZ5) GO TO 2369
0467    2367 CONTINUE
0468          GO TO 2380
0469   C
0470   C          THE COMPONENT NUMBER (IZ5) IS TO BE INCLUDED IN THE
0471   C          NEW DISPLAY
0472   C
0473    2369 NPD=NPD+1
0474          IC1(NPD)=IZ6
0475          IF((IX1(IZ3).NE.32760).AND.(IY1(IZ3).NE.32760)) GO TO 2380
0476          CALL RWCMC(1,XXA(2,1),LO(1),NMP,IZ3,IP,IBM,RMAX,1)
0477          CALL RWCMC(2,XXA(2,2),LO(2),NMP,IZ3,IP,IBM,RMAX,1)
0478          CALL RWCMC(3,XXA(2,3),LO(3),NMP,IZ3,IP,IBM,RMAX,1)
```

```
0479          IF(IC(IZ5).NE.0) GO TO 2370
0480     C
0481     C          CONVERTS CYLINDRICAL COORDINATES TO RECTANGULAR
0482     C
0483          Z1=XXA(2,1)
0484          Z2=XXA(1,2)/57.29577951
0485          Z3=COS(Z2)
0486          Z4=SIN(Z2)
0487          Z5=XXA(1,1)
0488          XXA(2,1)=Z1*Z3-XXA(2,2)*Z4
0489          XXA(2,2)=Z1*Z4+XXA(2,2)*Z3
0490          XXA(1,1)=Z5*COS(Z2)
0491          XXA(1,2)=Z5*SIN(Z2)
0492     C
0493     C          CONVERTS LOCAL COORDINATES TO GLOBAL
0494     C              ADJUSTMENT TO DISPLAY ORIGIN
0495     C
0496     2370 DO 2375 I=1,2
0497          DO 2375 II=1,3
0498          IZ1=IABS(IX(II,IZ5))
0499          Z1=IX(II,IZ5)/IZ1
0500          Z2=O(II)
0501          Z3=XXX(II,IZ5)
0502          IF(I.EQ.2)Z3=0
0503          IF(I.EQ.2) Z2=0
0504     2375 YYA(I,II)=XXA(I,IZ1)*Z1+Z3-Z2
0505     C
0506     C          CONVERTS GLOBAL X,Y,Z COORDINATES TO X,Y SCREEN
0507     C              COORDINATES OF THE 5460 DISPLAY UNIT
0508     C              WITH THE PROPER VIEWING POSITION
0509     C
0510          DO 2380 I=1,2
0511          X=(A(1,1)*YYA(I,1)+A(1,2)*YYA(I,2)+A(1,3)*YYA(I,3))*SF(I)
0512          Y=(A(2,1)*YYA(I,1)+A(2,2)*YYA(I,2)+A(2,3)*YYA(I,3))*SF(I)
0513          X=AMAX1(X,-32765.)
0514          Y=AMAX1(Y,-32765.)
0515          X=AMIN1(X,32765.)
0516          Y=AMIN1(Y,32765.)
0517          IF(I.EQ.2)GO TO 2376
0518          XMAX=AMAX1(XMAX,X)
0519          XMIN=AMIN1(XMIN,X)
0520          YMAX=AMAX1(YMAX,Y)
0521          YMIN=AMIN1(YMIN,Y)
0522     2376 CONTINUE
0523          IF(I.EQ.1)IX1(IZ3)=X
0524          IF(I.EQ.1)IY1(IZ3)=Y
0525          IF(I.EQ.2)IDX(IZ3)=X
0526          IF(I.EQ.2)IDY(IZ3)=Y
0527     2380 CONTINUE
0528     C
0529     C          CENTER DISPLAY
0530     C
0531          IF(IFLG6.EQ.1)GO TO 2382
0532          XAVG=(XMAX+XMIN)/2.
0533          YAVG=(YMAX+YMIN)/2.
0534          DO 2378  I=1,NUMPT
0535          IX1(I)=FLOAT(IX1(I))-XAVG
0536          IY1(I)=FLOAT(IY1(I))-YAVG
0537     2378 CONTINUE
0538     2382 CONTINUE
```

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```
0539          IFLG6=0
0540   C
0541   C         MAXIMIZE DISPLAY TO 80 %
0542   C
0543          XMAX=ABS(XMAX-XAVG)
0544          XMIN=ABS(XMIN-XAVG)
0545          YMAX=ABS(YMAX-YAVG)
0546          YMIN=ABS(YMIN-YAVG)
0547          XMAX=AMAX1(XMAX,XMIN,YMAX,YMIN)
0548   C
0549          Z1=26000./XMAX
0550   C
0551   C         CALCULATE DIVISORS USED FOR DISPLAY POSITIONS
0552   C            OF EACH FRAME
0553   C
0554   2390 DR=-.314159265
0555          R=-DR
0556          DO 2400 I=1,20
0557          R=R+DR
0558          IDIV(I)=IFIX(1./(SF1*COS(R)))
0559   2400 CONTINUE
0560   C
0561   C         IDIV(21)=NPD ONLY SO THAT THE VARIABLE
0562   C            NPD WILL BE AVAILABLE IN Y 94
0563   C
0564          IDIV(21)=NPD
0565   C
0566          IFLG3=1
0567          IKZ=1
0568          IF(IFLG5.EQ.1)GO TO 2602
0569   C
0570          IF(NMP.EQ.0)GO TO 2452
0571          IF(ISSW(14).LT.0)GO TO 2452
0572          CALL IDSW(NU,0)
0573          WRITE(NU,2450)FRQ(NMP)
0574   2450 FORMAT(/,F12.4," HERTZ",/)
0575   2452 CONTINUE
0576          GO TO 2510
0577   C
0578   C         EXPAND COMMAND
0579   C
0580   2500 Z1=IPAR1
0581          Z1=Z1/100.
0582   2510 SF(1)=Z1*SF(1)
0583          SF(2)=SF(2)*Z1
0584          IFLG8=0
0585          DO 2600 I=1,NUMPT
0586          X1=FLOAT(IX1(I))*Z1
0587          Y1=FLOAT(IY1(I))*Z1
0588          DX=FLOAT(IDX(I))
0589          DY=FLOAT(IDY(I))
0590          X1=AMIN1(X1,32765.)
0591          Y1=AMIN1(Y1,32765.)
0592          DX=AMIN1(DX,32765.)
0593          DY=AMIN1(DY,32765.)
0594          X1=AMAX1(X1,-32765.)
0595          Y1=AMAX1(Y1,-32765.)
0596          DX=AMAX1(DX,-32765.)
0597          DY=AMAX1(DY,-32765.)
0598          IX1(I)=X1
```

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0599        IY1(I)=Y1
0600        IDX(I)=DX
0601        IDY(I)=DY
0602        IF((DX.EQ.32765.).OR.(DX.EQ.-32765.))IFLG8=1
0603        IF((DY.EQ.32765.).OR.(DY.EQ.-32765.))IFLG8=1
0604   2600 CONTINUE
0605        IF(IFLG8.EQ.1)WRITE(NU,2698)IBELL
0606   2698 FORMAT(/,"ERROR-DISPLAY OVERFLOW",A2)
0607   2602 CONTINUE
0608        IFLG5=0
0609        GO TO 1000
0610   C
0611   C       MOVE COMMAND
0612   C
0613   3000 IF(IPAR2.EQ.-9999) GO TO 3070
0614        IZ1=FLOAT(IPAR1)*320.
0615        IZ2=FLOAT(IPAR2)*320.
0616        DO 3050 I=1,NUMPT
0617        IX1(I)=IX1(I)+IZ1
0618        IY1(I)=IY1(I)+IZ2
0619   3050 CONTINUE
0620   C
0621   C       MOVE THE DISPLAY IPAR1 % UP AND IPAR2 % RIGHT
0622   C       IF THE PARAMETERS ARE NEGATIVE , GO THE
0623   C       OPPOSITE DIRECTION
0624   C
0625        GO TO 1000
0626   3070 CALL RWCOR(IPAR1,XXA(1,1),XXA(1,2),XXA(1,3),ICM,1)
0627        IZ5=IPTCM(IPAR1)
0628        IF(IC(IZ5).NE.0) GO TO 3100
0629        Z5=XXA(1,1)
0630        Z2=XXA(1,2)
0631        Z2=Z2/57.2957791
0632        XXA(1,1)=Z1*COS(Z2)
0633        XXA(1,2)=Z1*SIN(Z2)
0634   3100 DO 3200 I=1,3
0635        IZ1=IABS(IX(I,IZ5))
0636        Z4=IX(I, IZ5)/IZ1
0637   3200 O(I)=XXA(1,IZ1)*Z4+XXX(I,IZ5)
0638   C
0639   C       IFLG6 = 1   INHIBITS AUTO CENTERING
0640   C
0641        IFLG6=1
0642        GO TO 2364
0643   C
0644   C       AMPLITUDE COMMAND
0645   C
0646   4000 IF(IPAR1.LE.0)IPAR1=100
0647        Z1=IABS(IPAR1)
0648        SF1=SF1*Z1/100.
0649   C
0650   C       IFLG5 = 1   INHIBITS AUTO EXPANSION
0651   C
0652        IFLG5=1
0653        GO TO 2390
0654   C
0655   C       ROTATE COMMAND
0656   C
0657   4500 Z1=IPAR1
0658        Z1=Z1/57.29577951
```

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```
0659          Z2=COS(Z1)
0660          Z3=SIN(Z1)
0661          DO 4600 I=1,NUMPT
0662          Z4=IX1(I)
0663          Z5=IDX(I)
0664          IX1(I)=Z2*Z4-Z3*FLOAT(IY1(I))
0665          IDX(I)=Z2*Z5-Z3*FLOAT(IDY(I))
0666          IY1(I)=Z2*FLOAT(IY1(I))+Z3*Z4
0667    4600  IDY(I)=Z2*FLOAT(IDY(I))+Z3*Z5
0668          GO TO 1000
0669    C
0670    C         CONVOLUTION COMMAND
0671    C
0672    5000  IANSPD=IPAR1
0673          GO TO 1000
0674    C
0675    C         STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
0676    C
0677    C         READ
0678    C
0679    6000  CALL KYBD(2HMS,35,1)
0680          CALL KYBD(2HMS,25)
0681          IF(IPAR1.EQ.-9999)GO TO 9011
0682          IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
0683          IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0684          CALL KYBD(2HMS,11,0)
0685          CALL KYBD(2HMS,31,-1,1)
0686          CALL RWCOM(-1)
0687          IF(ICOMM.NE.12345)GO TO 6800
0688          CALL KYBD(2HMS,11,ION)
0689          CALL RWCOM(0)
0690          IF(ICOMM.NE.12345)GO TO 6800
0691          NMP1=0
0692          NMP=0
0693          IFLG3=0
0694          IRJ=ICM
0695          CALL KYBD(2HMS,11,IRJ)
0696          IRJ=IRJ-1
0697    6100  DO 6200 I=IBM,IRJ
0698    6200  CALL KYBD(2HMS,11,I)
0699          CALL KYBD(2HMS,35,1)
0700          CALL KYBD(2HMS,15)
0701          WRITE(1,1235)(IT(I),I=1,5)
0702    1235  FORMAT(/,"TEST ID IS",23X,5A2)
0703          GO TO 1000
0704    C
0705    C         STORE
0706    C
0707    6500  CALL KYBD(2HMS,35,1)
0708          CALL KYBD(2HMS,25)
0709          IF(IPAR1.EQ.-9999)GO TO 9011
0710          IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
0711          IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0712          IL=2H**
0713          CALL RWCOM(1)
0714          IH(6)=52525B
0715          IH(9)=10
0716          IH(10)=IT(1)
0717          IH(11)=IT(2)
0718          IH(12)=IT(3)
```

```
0719          IH(13)=IT(4)
0720          IH(14)=IT(5)
0721          IH(34)=2H71
0722          CALL KYBD(2HMS,21,ION)
0723          CALL KYBD(2HMS,21,ICM)
0724          IH(34)=2H72
0725          IRJ=ICM-1
0726          IPAR1=IPAR1+2
0727          DO 6700 I=IBM,IRJ
0728          IPAR1=IPAR1+1
0729    6700 CALL KYBD(2HMS,21,I)
0730          WRITE(1,6701)IPAR1
0731    6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
0732          CALL KYBD(2HMS,35,1)
0733          CALL KYBD(2HMS,15)
0734          GO TO 1000
0735    6800 WRITE(1,6801)
0736    6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
0737          NMP1=0
0738          NMP=0
0739          IFLG3=0
0740          ICOMM=12345
0741          GO TO 1000
0742   C
0743   C          AUTO SCALE OF DISPLAY
0744   C
0745    7000 Z1=IPAR1
0746          IF(Z1.LT.2000)GO TO 7100
0747          IF(Z1.GT.5000)GO TO 7100
0748          SCALE=Z1*10.
0749    7100 CONTINUE
0750          GO TO 1000
0751   C
0752   C          ENABLE POINT LABELING FOR PLOT
0753   C
0754    7500 CONTINUE
0755          IF(IPAR1.EQ.-9999)IPAR1=100
0756          IF(IPAR2.EQ.-9999)IPAR2=100
0757          IF(IPAR3.EQ.-9999)IPAR3=100
0758          IF(IPAR4.EQ.-9999)IPAR4=1
0759          IF(IPAR5.EQ.-9999)IPAR5=250
0760          IDIV(22)=IPAR1
0761          IDIV(23)=IPAR2
0762          IDIV(24)=IPAR3
0763          IDIV(25)=IPAR4
0764          IDIV(26)=IPAR5
0765          IDIV(27)=1
0766          GO TO 1000
0767   C
0768   C          INPUT POINT TO BE INTENSIFIED
0769   C
0770    8000 CONTINUE
0771          INTPT=IPAR1
0772          GO TO 1000
0773   C*************************************************************************
0774   C          EXIT TO OTHER OVERLAYS
0775   C*************************************************************************
0776    9001 I=1
0777          GO TO 9900
0778    9002 I=2
```

```
0779            GO TO 9900
0780      9003  I=3
0781            GO TO 9900
0782      9004  I=4
0783            GO TO 9900
0784      9005  I=5
0785            GO TO 9900
0786      9006  I=6
0787            GO TO 9900
0788      9007  I=7
0789            GO TO 9900
0790      9008  I=8
0791            GO TO 9900
0792      9011  I=11
0793            GO TO 9900
0794      9900  CONTINUE
0795            IFLAG=1
0796            CALL RWCOM(1)
0797            CALL KYBD(2HMS,38,I)
0798            CALL OVLD(9)
0799      9995  CONTINUE
0800            IL=2H##
0801            IF(ICOMM.EQ.12345)CALL RWCOM(1)
0802            CALL KYBD(2HBS,IBS,0)
0803            RETURN
0804            END
0805            END$
```

```
0001   FTN4
0002         SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C        THIS PROGRAM IS STORED UNDER $Y908
0005   C
0006   C********************************************************************
0007   C
0008   C        PROGRAMMER:   R.J.ALLEMANG
0009   C                      MAIL LOCATION # 72
0010   C                      UNIVERSITY OF CINCINNATI
0011   C                      CINCINNATI, OHIO   45221
0012   C                      513-475-6670
0013   C
0014   C        REVISION DATE:   DEC 17, 1979
0015   C
0016   C********************************************************************
0017         DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018        1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019        2,IC1(1),IPTCM(1),LABEL(20),IPOINT(1)
0020         EQUIVALENCE (LINE(2),LINE1)
0021         COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022        1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023        2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024        3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025        4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026         EXTERNAL HDR8,DTAD0,NMAX
0027         DATA ICMMD/2HD ,2HV ,2HZ ,2HEX,2H: ,
0028        12HM ,2H_ ,2HRO,2HA-,2HAM,
0029        22HCH,2HSP,2HX<,
0030        32HX>,2HCV,2H< ,2HB ,2HL ,
0031        42HW ,2HI ,2HK ,2HA+,2H/L,
0032        52H/./
0033   C********************************************************************
0034   C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0035   C
0036   C        MOVIE PROGRAM
0037   C********************************************************************
0038         IBELL=7B
0039         IPAGE=15414B
0040         CALL SETAD(HDR8,IH,-8,0)
0041         ICOMM=0
0042         IBS=1024
0043         CALL KYBD(2HBS,IBS,0)
0044         CALL GETI(NMAX,IBLM)
0045         ION=IBLM-1
0046         ICM=ION-1
0047         IBM=2
0048         CALL RWCOM(0)
0049   C
0050   C        IF INITIALIZATION IS REQUIRED, LOAD Y 91
0051   C
0052         IF(ICOMM.EQ.12345)GO TO 900
0053         CALL KYBD(2HMS,38,-8,1)
0054         CALL OVLD(9)
0055    900 CONTINUE
0056         IF(IFLAG.EQ.1)GO TO 1130
0057   C********************************************************************
0058   C        START OF MONITOR
```

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```
0059   C***********************************************************************
0060     1000 WRITE(1,1010)IBELL
0061     1010 FORMAT("*",A2)
0062          I=ISWR(177677B,0,0)
0063          IPAR1=-9999
0064          IPAR2=-9999
0065          IPAR3=-9999
0066          IPAR4=-9999
0067          IPAR5=-9999
0068          IPAR6=-9999
0069     1020 DO 1030 I=1,36
0070     1030 LINE(I)=2H,,
0071     1040 CALL TTYIN(LINE)
0072     1042 CALL TEST(1,IST,LOG)
0073          IF(IST.LT.0)GO TO 1042
0074          CALL CODE
0075          READ(LINE,1120)IL
0076          IF(ICOMM.EQ.12345)GO TO 1115
0077   C
0078   C         PUT A CHECK FOR ANY COMMANDS THAT ARE NOT TO BE
0079   C              EXECUTED UNLESS ENOUGH SET-UP IS PRESENT
0080   C
0081     1115 CONTINUE
0082     1120 FORMAT(A2)
0083          CALL CODE
0084          READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0085   C***********************************************************************
0086   C         MONITOR COMMAND TABLE
0087   C***********************************************************************
0088     1130 IFLAG=0
0089          CALL RWCOM(1)
0090          IF(IL.EQ.2H**)GO TO 1000
0091          NCMMD=24
0092          DO 1138   I=1,NCMMD
0093          IF(IL.EQ.ICMMD(I))GO TO 1144
0094     1138 CONTINUE
0095     1139 WRITE(1,1140)
0096     1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0097          GO TO 1000
0098     1144 IF(I.GT.10)GO TO 1146
0099          GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0100     1146 I=I-10
0101          IF(I.GT.10)GO TO 1148
0102          GO TO (9004,9004,6000,6500,9004,9995,1100,1100,9002,9001),I
0103     1148 I=I-10
0104          GO TO (9001,9003,3000,9004),I
0105     1100 CONTINUE
0106          IF(IPAR1.EQ.37)GO TO 9005
0107          IF(IPAR1.EQ.10)GO TO 9006
0108          IF(IPAR1.EQ.6)GO TO 9007
0109          GO TO 1139
0110   C
0111   C         ASCII TEXT TO 5460 CRT SCREEN
0112   C
0113     3000 CONTINUE
0114          IF(IPAR3.EQ.-9999)IPAR3=5000
0115          IF(IPAR2.EQ.-9999)IPAR2=500
0116          ICC=0
0117          IF(IPAR1.EQ.-9999)IPAR1=0
0118          IF(IPAR1.GT.NM)IPAR1=0
```

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```
0119          IF(IPAR1.LT.0)GO TO 3100
0120          IF(IPAR1.GT.0)A1=FRQ(IPAR1)
0121          IF((IPAR1.GT.0).AND.(IPAR1.LE.NM))ICC=1
0122          CALL CRT(IPAR2,IPAR3,ICC,A1)
0123          GO TO 1000
0124   3100 CONTINUE
0125          IPAR1=IABS(IPAR1)
0126          IF(IPAR1.GT.820)GO TO 1000
0127          CALL KYBD(2HMS,31,IPAR1)
0128          CALL KYBD(2HMS,11)
0129          IPNT=IH(13)
0130          IF(IH(10).NE.2HCH)GO TO 1000
0131          CALL TTYIN(LINE)
0132   3110 CALL TEST(1,IST,LOG)
0133          CALL KDIS(0,1,IPNT,12)
0134          IF(IST.LT.0)GO TO 3110
0135          GO TO 1000
0136   C
0137   C        STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
0138   C
0139   C        READ
0140   C
0141   6000 CALL KYBD(2HMS,35,1)
0142          CALL KYBD(2HMS,25)
0143          IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
0144          IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0145          CALL KYBD(2HMS,11,0)
0146          CALL KYBD(2HMS,31,-1,1)
0147          CALL RWCOM(-1)
0148          IF(ICOMM.NE.12345)GO TO 6800
0149          CALL KYBD(2HMS,11,ION)
0150          CALL RWCOM(0)
0151          IF(ICOMM.NE.12345)GO TO 6800
0152          NMP=0
0153          IRJ=ICM
0154          CALL KYBD(2HMS,11,IRJ)
0155          IRJ=IRJ-1
0156   6100 DO 6200 I=IBM,IRJ
0157   6200 CALL KYBD(2HMS,11,I)
0158          CALL KYBD(2HMS,35,1)
0159          CALL KYBD(2HMS,15)
0160          WRITE(1,1235)(IT(I),I=1,5)
0161   1235 FORMAT(/,"TEST ID IS",23X,5A2)
0162          GO TO 1000
0163   C
0164   C        STORE
0165   C
0166   6500 CALL KYBD(2HMS,35,1)
0167          CALL KYBD(2HMS,25)
0168          IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
0169          IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0170          IL=2H**
0171          CALL RWCOM(1)
0172          IH(6)=52525B
0173          IH(9)=10
0174          IH(10)=IT(1)
0175          IH(11)=IT(2)
0176          IH(12)=IT(3)
0177          IH(13)=IT(4)
0178          IH(14)=IT(5)
```

```
0179          IH(34)=2H71
0180          CALL KYBD(2HMS,21,ION)
0181          CALL KYBD(2HMS,21,ICM)
0182          IH(34)=2H72
0183          IRJ=ICM-1
0184          IPAR1=IPAR1+2
0185          DO 6700 I=IBM,IRJ
0186          IPAR1=IPAR1+1
0187   6700 CALL KYBD(2HMS,21,I)
0188          WRITE(1,6701)IPAR1
0189   6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
0190          CALL KYBD(2HMS,35,1)
0191          CALL KYBD(2HMS,15)
0192          GO TO 1000
0193   6800 WRITE(1,6801)
0194   6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
0195          NMP=0
0196          ICOMM=12345
0197          GO TO 1000
0198  C*****************************************************************
0199  C          EXIT TO OTHER OVERLAYS
0200  C*****************************************************************
0201   9001 I=1
0202          GO TO 9900
0203   9002 I=2
0204          GO TO 9900
0205   9003 I=3
0206          GO TO 9900
0207   9004 I=4
0208          GO TO 9900
0209   9005 I=5
0210          GO TO 9900
0211   9006 I=6
0212          GO TO 9900
0213   9007 I=7
0214          GO TO 9900
0215   9900 CONTINUE
0216          IFLAG=1
0217          CALL RWCOM(1)
0218          CALL KYBD(2HMS,38,I)
0219          CALL OVLD(9)
0220   9995 CONTINUE
0221          IL=2H##
0222          IF(ICOMM.EQ.12345)CALL RWCOM(1)
0223          CALL KYBD(2HBS,IBS,0)
0224          RETURN
0225          END
0226          END$
```

```
0001  FTN4
0002        SUBROUTINE Y0009(INTOT,IPAR)
0003  C****************************************************************************
0004  C          THIS PROGRAM IS STORED UNDER $Y909
0005  C
0006  C****************************************************************************
0007  C
0008  C          PROGRAMMER:   R.J.ALLEMANG
0009  C                        MAIL LOCATION # 72
0010  C                        UNIVERSITY OF CINCINNATI
0011  C                        CINCINNATI, OHIO  45221
0012  C                        513-475-6670
0013  C
0014  C          REVISION DATE:  JAN 19,1980
0015  C
0016  C****************************************************************************
0017        INTEGER BLANC,STER
0018        DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0019       1,IDIV(1),ICMMD(9),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0020       2,IC1(1),IPTCM(1)
0021       3,A1(1),M1(1),NDD1(20),BMU(10),BNU(10),IY(1)
0022       4,AM(1),X1(1),IPL(41),AMU(1),ANU(1),AD(1),BD(1),Q(1)
0023        EQUIVALENCE (LINE(2),LINE1)
0024        COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0025       1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0026       2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0027       3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0028       4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0029        EXTERNAL HDR8,DTAD0,NMAX
0030        DATA ICMMD/2HK ,2HMS,2HW ,2HSP,2H/D,
0031       12H< ,2HD ,2HCL,2HCR/
0032        DATA BLANC,STER,KROL/1H ,1H*,1H@/
0033  C****************************************************************************
0034  C          UNIVERSITY OF CINCINATI/LEUVEN MODAL ANALYSIS PROGRAM
0035  C
0036  C          LEAST SQUARES STARTING VALUE PROGRAM
0037  C****************************************************************************
0038        IBELL=7B
0039        IPAGE=15414B
0040        CALL SETAD(HDR8,IH,-8,0)
0041        ICOMM=0
0042        IRTN=1000
0043        IBS=1024
0044        CALL KYBD(2HBS,IBS,0)
0045        CALL GETI(NMAX,IBLM)
0046        ION=IBLM-1
0047        ICM=ION-1
0048        IBM=2
0049        CALL RWCOM(0)
0050  C
0051  C          IF INITIALIZATION IS REQUIRED, LOAD Y 91
0052  C
0053        IF(ICOMM.EQ.12345)GO TO 900
0054    850 CALL KYBD(2HMS,38,-9,1)
0055        CALL OVLD(9)
0056    900 CONTINUE
0057        IF(IFLAG.NE.92)GO TO 850
0058  C
```

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```
0059   C           NOTE!!!!!!   DATA DISC RECORDS ABOVE 810 ARE USED BY THIS PROGRAM
0060   C
0061   C
0062   C         STORE MODAL INFORMATION TO DISC
0063   C
0064           CALL KYBD(2HMS,35,1)
0065           CALL KYBD(2HMS,25)
0066           CALL KYBD(2HMS,31,811)
0067           IL=2H##
0068           CALL RWCOM(1)
0069           CALL KYBD(2HMS,21,ION)
0070           CALL KYBD(2HMS,21,ICM)
0071           IRJ=ICM-1
0072           DO 950 I=IBM,IRJ
0073     950 CALL KYBD(2HMS,21,I)
0074           CALL KYBD(2HMS,35,1)
0075           CALL KYBD(2HMS,15)
0076   C
0077   C         SET-UP DATA SPACE FOR STARTING VALUE PROGRAM
0078   C
0079           CALL SETAD(DTAD0,Q,1024,-1)
0080           CALL SETAD(DTAD0,AM,2048,-1)
0081           CALL SETAD(DTAD0,AD,3770,-1)
0082           CALL SETAD(DTAD0,BD,5410,-1)
0083           CALL SETAD(DTAD0,X1,5492,-1)
0084           CALL SETAD(DTAD0,AMU,5574,-1)
0085           CALL SETAD(DTAD0,ANU,5654,-1)
0086           CALL SETAD(DTAD0,A1,0,-1)
0087           CALL SETAD(DTAD0,M1,256,-1)
0088           GO TO 1501
0089   C****************************************************************************
0090   C         START OF MONITOR
0091   C****************************************************************************
0092    1000 WRITE(1,1010)IBELL
0093           MFLAG=0
0094    1010 FORMAT("**",A2)
0095           I=ISWR(177677B,0,0)
0096           IPAR1=-9999
0097           IPAR2=-9999
0098           IPAR3=-9999
0099           IPAR4=-9999
0100    1020 DO 1030 I=1,36
0101    1030 LINE(I)=2H,,
0102    1040 CALL TTYIN(LINE)
0103    1042 CALL TEST(1,IST,LOG)
0104           CALL KDIS(0,NS,NE,4)
0105           IF(IST.LT.0)GO TO 1042
0106           CALL CODE
0107           READ(LINE,1120)IL
0108    1120 FORMAT(A2)
0109           CALL CODE
0110           READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0111   C****************************************************************************
0112   C         MONITOR COMMAND TABLE
0113   C****************************************************************************
0114           NCMMD=9
0115           DO 1138   I=1,NCMMD
0116           IF(IL.EQ.ICMMD(I))GO TO 1144
0117    1138 CONTINUE
0118    1139 WRITE(1,1140)
```

```
0119    1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0120         GO TO 1000
0121    1144 CONTINUE
0122         GO TO (1500,3000,1700,1400,1630,1610,5990,2000,5000),I
0123    C***********************************************************************
0124    C          STARTING VALUE PROGRAM BEGINS
0125    C***********************************************************************
0126    C          KEYBOARD ENTRY
0127    C***********************************************************************
0128    1501 MFLAG=1
0129    1500 CONTINUE
0130         PI2=6.283185
0131    C***********************************************************************
0132    C
0133    C          IN Y909 AND Y910, THE FOLLOWING VARIABLES ARE USED AS FOLLOWS:
0134    C
0135    C          MFLAG  =  FLAG FOR AUTOMATIC OR INTERACTIVE
0136    C          ITYP   =  1   NO RESIDUAL TERMS
0137    C          ITYP   =  2   INFLUENCE OF RESIDUAL MASS ONLY
0138    C          ITYP   =  3   INFLUENCE OF RESIDUAL FLEXIBILITY ONLY
0139    C          ITYP   =  4   INFLUENCE OF RESIDUAL MASS AND FLEXIBILITY
0140    C          BETA   =  EXP. DECAY RATE OF EXP. WINDOW USED ON IMPACT DATA
0141    C                        EXP**(-BETA*TIME)
0142    C          SCA    =  SCALE FACTOR OF MEASUREMENTS
0143    C          NDD    =  NUMBER OF SETS OF DATA POINTS TO BE DELETED
0144    C                        BETWEEN NS AND NE
0145    C          NDD1(X)=  START AND END CHANNELS OF SETS OF DATA
0146    C                        DESCRIBED BY NDD
0147    C          MDVA   =  0,1,2  DATA IS DISPLACEMENT, VELOCITY, ACCELERATION
0148    C          NES    =
0149    C          MAMU   =  MAXIMUM POSSIBLE NUMBER OF MODES IN CALCULATION
0150    C          MAN2   =  REQUESTED NUMBER OF DEGREES OF FREEDOM
0151    C          TOL    =
0152    C          MAN1   =  MAXIMUM POSSIBLE NUMBER OF MODES IN CALCULATION
0153    C          MSAMP  =
0154    C          NN     =
0155    C          BMU(X) =  FINAL ARRAY OF DAMPING FACTORS
0156    C          BNU(X) =  FINAL ARRAY OF DAMPED NATURAL FREQUENCIES
0157    C          MANRE  =  NUMBER OF MODES USED IN PARAMETER ESTIMATION
0158    C          NMZ    =  DIMENSION OF GREATEST POSSIBLE MATRIX
0159    C                        REQUESTED PLUS ONE
0160    C          MAN3   =  ACTUAL NUMBER OF ELEMENTS IN THE LARGEST MATRIX
0161    C          MZ     =  POSSIBLE NUMBER OF ELEMENTS IN THE LARGEST MATRIX
0162    C          AMU(X) =  WORKING ARRAY FOR DAMPING FACTORS
0163    C          ANU(X) =  WORKING ARRAY FOR DAMPED NATURAL FREQUENCIES
0164    C          MAN4   =
0165    C
0166    C***********************************************************************
0167         NES=0
0168         TOL=1.E-6
0169         MAMU=20
0170         MSAMP=15
0171         NN=40
0172         DO 1561 II=1,10
0173         BMU(II)=0.
0174    1561 BNU(II)=0.
0175         MANRE=0
0176         MAN1=MAMU
0177         MAN2=NN
0178         NMZ=41
```

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```
0179        MZ=861
0180        MAN3=MZ
0181        MANU=NN
0182        DO 1590 II=1,MANU
0183        AMU(II)=0.
0184   1590 ANU(II)=0.
0185        MAN4=NMZ
0186        IF(MFLAG.EQ.1)GO TO 5000
0187        GOTO 1000
0188 C***********************************************************************
0189 C          CORRELATE COMMAND
0190 C***********************************************************************
0191   5000 CONTINUE
0192        MDVA=0
0193        BETA=0.0
0194        MSHIF=NS
0195        MIBS=(NE-NS)*2
0196        DO 5002 I=1,512
0197   5002 Q(I)=0.
0198        DO 5003 I=1,MZ
0199   5003 AM(I)=0.
0200        XNO=0.
0201        WRITE(1,9510)IBELL
0202   9510 FORMAT(/,"ENTER RANGE OF DISC RECORDS FOR CURRENT TEST:"
0203       1,"(N1,N2,N3)"
0204       2,/,10X,"N1 = STARTING RECORD"
0205       3,/,10X,"N2 = ENDING RECORD"
0206       4,/,10X,"N3 = NUMBER OF SAMPLES/MEASUREMENT (OPTIONAL)",A2)
0207        I=0
0208        READ(1,*)MBL1,MBL2,I
0209        I1=MBL2-MBL1
0210        MSAMP=180/I1+2
0211        IF(I.GT.MSAMP)MSAMP=I
0212        IF(MSAMP.GT.60)MSAMP=60
0213        NOSAMP=0
0214   5005 CALL KYBD(2HMS,31,MBL1)
0215        CALL KYBD(2HMS,11,0)
0216        IF(ISSW(11).LT.0)GO TO 5006
0217        CALL NIXIT(MBL1)
0218   5006 IF(ISSW(2).LT.0)GO TO 5120
0219        CALL CHKID(IT,ICIC)
0220        IF(IH(36).NE.IZR)GO TO 5900
0221        IF(ICIC.EQ.0)GO TO 5900
0222   5120 CALL KYBD(2H_ ,0,MSHIF)
0223        CALL KYBD(2HBS,MIBS,0)
0224        CALL KYBD(2HX),1)
0225        CALL KYBD(2H: ,0,30000)
0226        CALL KYBD(2H: ,0,30000)
0227        CALL KYBD(2H: ,0,30000)
0228        MMM=MIBS/2
0229   5190 CONTINUE
0230        CALL KYBD(2HF ,0)
0231   5200 CALL GETQ(0,INQ)
0232        DT=1. /(DF*FLOAT(INQ(1)))
0233        XNO=XNO+1.
0234        INQ(2)=IAND(INQ(2),-64)/64
0235        CAL=(10.**INQ(2))*FLOAT(INQ(3))/FLOAT(32767)**2
0236        CAL1=CAL*CAL
0237        DO 5250 I=1,MSAMP
0238        NOSAMP=NOSAMP+1
```

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```
0239          IK=I-1
0240          CALL SETAD(DTAD0,IY,IK,-1)
0241          J=0
0242          DO 5150 II=1,NMZ
0243          DO 5150 K=1,II
0244          J=J+1
0245    5150 AM(J)=AM(J)+CAL1*(FLOAT(IY(II))*FLOAT(IY(K)))
0246    5250 CONTINUE
0247          CALL KYBD(2HF ,0)
0248          CALL KYBD(2H*-,0)
0249          CALL KYBD(2HF ,0)
0250          CALL SETAD(DTAD0,IY,0,-1)
0251          DO 5600 I=1,MIBS
0252    5600 Q(I)=Q(I)+FLOAT(IY(I))*CAL
0253    5900 CALL KYBD(2HBS,IBS,0)
0254          IF(MBL1.GE.MBL2)GO TO 5990
0255          MBL1=MBL1+1
0256          GO TO 5005
0257  C*************************************************************************
0258  C         DISPLAY COMMAND
0259  C*************************************************************************
0260    5990 CALL KYBD(2HCL,0)
0261          CALL KYBD(2HBS,MIBS,0)
0262          DO 5905 I=1,MIBS
0263          XVAL=Q(I)
0264          J=I-1
0265    5905 CALL PUT(0,J,XVAL,YVAL)
0266          CALL KYBD(2HF ,0)
0267          CALL KYBD(2HBS,IBS,0)
0268          I=IBS/2-MSHIF-1
0269          CALL KYBD(2H_ ,0,I)
0270          IF(NOSAMP.LT.60)GO TO 5995
0271          IF(MFLAG.EQ.1)GO TO 1404
0272          GO TO 1000
0273    5995 WRITE(1,9599)
0274    9599 FORMAT("ERROR-NUMBER OF MEASUREMENTS INSUFFICIENT", )
0275          GO TO 1000
0276  C*************************************************************************
0277  C         PARAMETER ESTIMATION BASED ON PREVIOUSLY
0278  C             CALCULATED MATRIX
0279  C*************************************************************************
0280  C         SP 0     GO TO 1402  OUTPUT ERROR FOR
0281  C                              ALL DEGREES OF FREEDOM
0282  C                              OR DEGREES OF FREEDOM N1 TO N2
0283  C*************************************************************************
0284    1400 CONTINUE
0285          IF(IPAR1.EQ.-9999)IPAR1=0
0286          IF(IPAR1.EQ.0)GO TO 1402
0287          L1=IPAR1
0288          L2=IPAR1
0289          GO TO 1403
0290    1402 WRITE(1,9401)
0291    9401 FORMAT(" ENTER RANGE OF DEGREES OF FREEDOM TO BE ",
0292         1"USED IN PARAMETER",/,"      ESTIMATION:",/)
0293          READ(1,*)L1,L2
0294          GO TO 1403
0295    1404 L1=2
0296          L2=32
0297          IPAR1=0
0298    1403 WRITE(1,9404)IPAGE
```

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```
0299    9404 FORMAT(A2)
0300   C
0301   C          DO LOOP FOR ERROR CALCULATION
0302   C
0303   C          SETTING MATRIX DATA (AM) INTO WORKING ARRAY (AD)
0304   C
0305         DO 1480 MAN2=L1,L2
0306    1406 DO 1417 I=1,MZ
0307    1417 AD(I)=AM(I)
0308         GO TO 1407
0309    1407 MAN3=(MAN2*MAN2+MAN2)/2
0310         MANU=MAN2
0311         IF(ISSW(15).LT.0)WRITE(1,9415)AD
0312    9415 FORMAT(5E14.5)
0313         MAN4=MAN2+1
0314         DO 1409 I=1,MAN2
0315         L=MAN3+I
0316    1409 BD(I)=-AD(L)
0317   C****************************************************************
0318   C          STEL PERFORMS GAUSSIAN REDUCTION OF MATRIX
0319   C****************************************************************
0320         CALL STEL(MAN2,IER,AD(1),BD(1),X1(1))
0321         IF(IER.LT.0) GO TO 1498
0322         DO 1408 I=1,MAN2
0323    1408 X1(I)=BD(1)
0324         X1(MAN4)=1.
0325         ERROR=0.
0326         DO 1435 I=1,MAN4
0327         L=MAN3+I
0328    1435 ERROR=ERROR-X1(I)*AM(L)
0329         ERROR=ABS(ERROR)
0330         SR=ERROR/AM(1)
0331   C
0332   C          PLOT ERROR IN * FORMAT
0333   C
0334         DO 1436 I=2,41
0335    1436 IPL(I)=BLANC
0336         IPL(1)=KROL
0337         IPL(41)=KROL
0338         SI=ALOGT(SR)*4.
0339         IK=IFIX(39.5+SI )
0340         IF(IK.GT.40)IK=40
0341         IF(IK.LE.2)IK=2
0342         DO 1437 I=2,IK
0343    1437 IPL(I)=STER
0344         CALL IOSW(NU,0)
0345    1480 WRITE(NU,9430)MAN2,SR,(IPL(I),I=1,41)
0346    9430 FORMAT("DOF",I3," ERROR = ",E14.6," ",41A1)
0347         IF(IPAR1.EQ.0)GO TO 1000
0348   C****************************************************************
0349   C          SP N1    COMMAND
0350   C
0351   C          CALCULATE FREQUENCY, DAMPING, AND ERROR
0352   C               FOR N1 DEGREES OF FREEDOM
0353   C
0354   C****************************************************************
0355         MAN2=L1
0356         CALL NRRT(X1(1),BD(1),MAN2,AMU(1),ANU(1),IER)
0357         IF(IER.NE.0) GO TO 1499
0358         DO 1430 I=1,MAN2
```

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```
0419        SM=SC/SG
0420        DRL=DRL-(SJ+SK)*AU(J)-(SL-SM)*AV(J)
0421        DAM=DAM-(SM+SL)*AU(J)-(SK-SJ)*AV(J)
0422   8230 CONTINUE
0423        IF(IFL1.EQ.1)GO TO 8099
0424        IF(ITYP.EQ.1)GO TO 8100
0425        IF((ITYP.NE.2).AND.(ITYP.NE.4))GO TO 8200
0426        SA = -OM*OM + BETA*BETA
0427        SB = 2.*BETA*OM
0428        SC = SA*SA + SB*SB
0429        DRL = DRL + AMASS*SA/SC
0430        DAM = DAM + AMASS*SB/SC
0431   8200 IF((ITYP.NE.3).AND.(ITYP.NE.4))GO TO 8100
0432        DRL = DRL + AFLEX
0433   8099 SA=SCA*(OM**MDVA)
0434        IF(MDVA.EQ.2)SA=-SA
0435        DRL=DRL*SA
0436        DAM=DAM*SA
0437   8100 CONTINUE
0438        IF(JZZ.NE.INC1)GO TO 8101
0439        CALL GET(2,I,ARX,AIX)
0440        XSX=ARX-DRL
0441        YSY=AIX-DAM
0442   8101 CALL PUT(3,I,DRL,DAM)
0443        CALL GET(2,I,AR,AI)
0444   8060 SOM = SOM+(AR-DRL)**2 + (AI-DAM)**2
0445        IF(IFL1.NE.1)GO TO 8065
0446        DO 8063 I=1,NPOIN
0447        CALL GET(3,I,DRL,DAM)
0448        DRL=DRL+XSX
0449        DAM=DAM+YSY
0450        CALL PUT(3,I,DRL,DAM)
0451   8063 CONTINUE
0452   8065 CONTINUE
0453        WRITE(1,8999)IBELL,SOM
0454   8999 FORMAT(" LEAST SQUARED ERROR = ",A2,E14.5)
0455   C*************************************************************************
0456   C           END OF BENA3 SUBROUTINE
0457   C*************************************************************************
0458        IPAR1=1
0459        IPAR2=NPOIN
0460        IF(IFL1.EQ.1)IPAR1=INC2-20
0461        IF(IFL1.EQ.1)IPAR2=INC2+20
0462        M=2
0463        N=3
0464        GO TO 8322
0465   C*************************************************************************
0466   C           DISPLAY
0467   C*************************************************************************
0468   2000 IF(IPAR2.LT.4)M=IPAR1
0469        IF(IPAR2.LT.4)N=IPAR2
0470        IFL1=1
0471   8322 CALL KYBD(2HY ,117)
0472        CALL KYBD(2HY ,117,M,0)
0473        CALL KYBD(2HY ,117,N,M)
0474        CALL KYBD(2HY ,117,M,N)
0475        CALL KYBD(2HY ,117,0,M)
0476   8321 DO 6773 I=1,36
0477   6773 LINE(I)=2H,,
0478   6759 CALL TTYIN(LINE)
```

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```
0479        IF((INC2.LT.1).OR.(INC2.GT.255))INC2=1
0480   6757 CALL KDIS(M,IPAR1,IPAR2,4)
0481        CALL KDIS(N,IPAR1,IPAR2,4)
0482        DO 6745 I=1,5
0483   6745 CALL KDIS(N,INC2,INC2,4)
0484        CALL TEST(1,ISTST,LOGX1)
0485        IF(ISTST)6757,6758,6758
0486   6758 IPAR2=9999
0487        CALL CODE
0488        READ(LINE,*)IPAR1,IPAR2
0489 C
0490 C          IPAR1 = 0    NO MODAL COEFFICIENTS ARE STORED
0491 C          IPAR1 < 0    STORE MODAL COEFFICIENTS
0492 C          IPAR1 > 0    DISPLAY POINTS IPAR1 TO IPAR2
0493 C                       IF IPAR2 IS DEFAULTED, ADD MODE
0494 C                       IPAR1 TO RECONSTRUCTION
0495 C
0496        IFL1=0
0497        IF(IPAR1)5060,6780,6790
0498   6780 IPARR=0
0499        CALL KYBD(2HBS,IBS,0)
0500        GO TO 5999
0501   6790 CONTINUE
0502        IF(IPAR2.NE.9999)GO TO 8321
0503        IFL1=1
0504        IDMODE=IPAR1
0505        IF(IPAR1.GT.(MANRE+1))IPAR2=NPOIN
0506        IF(IPAR1.GT.(MANRE+1))GO TO 8321
0507        IF(IPAR1.EQ.(MANRE+1))IFL1=0
0508        GO TO 1500
0509 C***************************************************************************
0510 C        STORE MODAL COEFFICIENTS
0511 C***************************************************************************
0512   5060 CONTINUE
0513        IFL1=0
0514        CALL IOSW(NU,0)
0515        DO 5250 I=1,MANRE
0516        ANG=ATAN2(AV(I),AU(I))
0517        R=ABS(SQRT(AU(I)**2+AV(I)**2)/BMU(I))
0518        IF(RH(3).GT.0.0)R=R*RH(3)
0519        IF(RH(3).GT.0.0)AMASS=AMASS*RH(3)
0520        IF(RH(3).GT.0.0)AFLEX=AFLEX*RH(3)
0521   5140 CALL KYBD(2HBS,IBS,0)
0522        IF(ANG.GE.0)GO TO 5143
0523        R=-1.*R
0524        ANG=ANG+PI2/2.0
0525   5143 L1=IFIX(ANG*57.295779)
0526        IF(I.GT.NM)GO TO 5250
0527        RMAX=RMM(I)
0528        IF((ID1.EQ.2HX-).OR.(ID1.EQ.2H-1)) GO TO 5160
0529        IF((ID1.EQ.2HX ).OR.(ID1.EQ.2H1 ))GO TO 5170
0530        IF((ID1.EQ.2HY-).OR.(ID1.EQ.2H-2))GO TO 5180
0531        IF((ID1.EQ.2HY ).OR.(ID1.EQ.2H2 ))GO TO 5111
0532        IF((ID1.EQ.2HZ-).OR.(ID1.EQ.2H-3))GO TO 5500
0533        IF((ID1.EQ.2HZ ).OR.(ID1.EQ.2H3 ))GO TO 5210
0534 C
0535 C          DIRECTIONAL COSINE CHECK
0536 C
0537        IF(ISSW(12))5144,5149
0538   5144 CONTINUE
```

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```
0539          IF(ID1.NE.2HD )GO TO 5149
0540          DO 5145  IM=1,3
0541          IM3=IM+3
0542          R1=R*COS(RH(IM3)*PI2/360.0)
0543          CALL RWCMC(IM,R1,L1,I,IS,IP,IBM,RMAX,0)
0544     5145 CONTINUE
0545          GO TO 5515
0546     5149 CONTINUE
0547          WRITE(1,5150)
0548     5150 FORMAT(/,"ERROR-WRONG COORDINATE CODE")
0549          GO TO 5999
0550     5160 R=-R
0551     5170 CALL RWCMC(1,R,L1,I,IS,IP,IBM,RMAX,0)
0552          GO TO 5515
0553     5180 R=-R
0554     5111 CALL RWCMC(2,R,L1,I,IS,IP,IBM,RMAX,0)
0555          GO TO 5515
0556     5500 R=-R
0557     5210 CALL RWCMC(3,R,L1,I,IS,IP,IBM,RMAX,0)
0558     5515 CALL KYBD(2HBS,IBS,0)
0559          RMM(I)=RMAX
0560          IF(ISSW(2))7100,7200
0561     7100 CONTINUE
0562          CALL IOSW(NU,0)
0563          IF(I.EQ.1)WRITE(NU,7300)IS,ID1
0564     7300 FORMAT(/,"POINT NUMBER             = ",I4
0565        1,/,"DIRECTION                = ",A2,/)
0566          IF(I.EQ.1)WRITE(NU,9173)AMASS,AFLEX
0567          IF(I.EQ.1)WRITE(NU,7005)
0568     7005 FORMAT(/,"MODE",8X,"FREQUENCY",4X,"ZETA(%)",4X,"MAGNITUDE"
0569        1,6X,"PHASE"/)
0570          WRITE(NU,7105)I,FRQ(I),ZETA(I),R,L1
0571     7105 FORMAT(1X,I4,4X,F10.3,4X,F9.6,3X,G12.6,4X,I5)
0572     7200 CONTINUE
0573     5250 CONTINUE
0574     5999 IF(MBL1.EQ.MBL2.AND.MFLAG.EQ.0)GO TO 1000
0575          IF(MBL1.EQ.MBL2.AND.MFLAG.EQ.1)GO TO 9003
0576          MBL1=MBL1+1
0577          GO TO 5005
0578 C******************************************************************
0579 C             MASS STORE COMMAND
0580 C******************************************************************
0581     3000 CALL KYBD(2HMS,IPAR1,IPAR2)
0582          GO TO 1000
0583 C******************************************************************
0584 C         REPLACE COMMAND
0585 C******************************************************************
0586     3500 CONTINUE
0587          DO 3600 I=1,MANRE
0588          FRQ(I)=BNU(I)/PI2
0589          NCN(I)=BNU(I)/(DF*PI2)-FSHFT/DF+1.0
0590          IB(I)=-1.0*BMU(I)/(DF*PI2)
0591          ZETA(I)=(-1.0)*BMU(I)*100.0/(SQRT(BMU(I)**2+BNU(I)**2))
0592     3600 CONTINUE
0593          GO TO 1000
0594 C
0595 C         RETURN TO MONITOR
0596 C
0597     9001 CONTINUE
0598 C
```

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```
0599   C          EXIT TO $Y901
0600   C
0601          IFLAG=1
0602          CALL RWCOM(1)
0603          CALL KYBD(2HMS,38,-10,1)
0604          CALL OVLD(9)
0605     9003 CONTINUE
0606   C
0607   C          EXIT TO $Y903
0608   C
0609          IFLAG=97
0610          CALL RWCOM(1)
0611          CALL KYBD(2HMS,38,-8,1)
0612          CALL OVLD(9)
0613     9995 CONTINUE
0614          IL=2H##
0615          IF(ICOMM.EQ.12345)CALL RWCOM(1)
0616          CALL KYBD(2HBS,IBS,0)
0617          RETURN
0618          END
0619          END$
```

```
0001   FTN4
0002          SUBROUTINE Y0009(INTOT,IPAR)
0003   C********************************************************************
0004   C          THIS PROGRAM IS STORED UNDER $Y911
0005   C********************************************************************
0006   C
0007   C        PROGRAMMER:   R.J.ALLEMANG
0008   C                      MAIL LOCATION # 72
0009   C                      UNIVERSITY OF CINCINNATI
0010   C                      CINCINNATI, OHIO  45221
0011   C                      513-475-6670
0012   C
0013   C        REVISION DATE:  JAN 03, 1980
0014   C
0015   C********************************************************************
0016          DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0017         1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0018         2,IC1(1),IPTCM(1),JDIR(3),JCOMP(10),JPT(250)
0019          EQUIVALENCE (LINE(2),LINE1)
0020          COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0021         1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0022         2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0023         3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0024         4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0025          EXTERNAL HDR8,DTAD0,NMAX
0026          DATA ICMMD/2HD ,2HV ,2H% ,2HEX,2H: ,
0027         12HM ,2H_ ,2HRO,2HA-,2HAM,
0028         22HCH,2HSP,2HX<,
0029         32HX),2HCV,2H< ,2HB ,2HL ,
0030         42HW ,2HI ,2HK ,2HA+,2H/L,
0031         52HX /
0032   C********************************************************************
0033   C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0034   C
0035   C        MODE MANIPULATION PROGRAM
0036   C********************************************************************
0037          IBELL=7B
0038          IPAGE=15414B
0039          CALL SETAD(HDR8,IH,-8,0)
0040          ICOMM=0
0041          IBS=1024
0042          CALL KYBD(2HBS,IBS,0)
0043          CALL GETI(NMAX,IBLM)
0044          ION=IBLM-1
0045          ICM=ION-1
0046          IBM=2
0047          DTR=6.283185/360.0
0048          I=ION*IBS+270
0049          CALL SETAD(DTAD0,IPTCM,I,-1)
0050          CALL RWCOM(0)
0051          IF(ICOMM.EQ.12345)GO TO 900
0052          CALL KYBD(2HMS,38,-2,1)
0053          CALL OVLD(9)
0054   900    CONTINUE
0055          IF(IFLAG.EQ.1)GO TO 1130
0056   C********************************************************************
0057   C      START OF MONITOR
0058   C********************************************************************
```

```
0059    1000 WRITE(1,1010)IBELL
0060    1010 FORMAT("*",A2)
0061         I=ISWR(177677B,0,0)
0062         IPAR1=-9999
0063         IPAR2=-9999
0064         IPAR3=-9999
0065         IPAR4=-9999
0066         IPAR5=-9999
0067         IPAR6=-9999
0068    1020 DO 1030 I=1,36
0069    1030 LINE(I)=2H,,
0070    1040 CALL TTYIN(LINE)
0071    1042 CALL TEST(1,IST,LOG)
0072         IF(IST.LT.0)GO TO 1042
0073         CALL CODE
0074         READ(LINE,1120)IL
0075    1120 FORMAT(A2)
0076         CALL CODE
0077         READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0078    C*********************************************************************
0079    C        MONITOR COMMAND TABLE
0080    C*********************************************************************
0081    1130 IFLAG=0
0082         CALL RWCOM(1)
0083         IF(IL.EQ.2H**)GO TO 1000
0084         NCMMD=24
0085         DO 1138  I=1,NCMMD
0086         IF(IL.EQ.ICMMD(I))GO TO 1144
0087    1138 CONTINUE
0088    1139 WRITE(1,1140)
0089    1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0090         GO TO 1000
0091    1144 IF(I.GT.10)GO TO 1146
0092         GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0093    1146 I=I-10
0094         IF(I.GT.10)GO TO 1148
0095         GO TO (9004,9004,6000,6500,9004,9995,1100,1100,9002,9001),I
0096    1148 I=I-10
0097         GO TO (9001,9003,9008,2000),1
0098    1100 CONTINUE
0099         IF(IPAR1.EQ.37)GO TO 9005
0100         IF(IPAR1.EQ.10)GD TO 9006
0101         IF(IPAR1.EQ.6)GO TO 9007
0102         GO TO 1139
0103    C*********************************************************************
0104    C        CALCULATE MODAL ASSURANCE CRITERION BETWEEN SHAPEVECTORS
0105    C*********************************************************************
0106    2000 CONTINUE
0107         IF(IPAR1.EQ.1)GO TO 4000
0108         IF(IPAR1.EQ.2)GO TO 8000
0109         DO 2010 I=1,3
0110    2010 JDIR(I)=I
0111         DO 2020 I=1,10
0112    2020 JCOMP(I)=I
0113         DO 2030 I=1,250
0114    2030 JPT(I)=I
0115    2040 CONTINUE
0116         WRITE(1,2050)IPAGE,IBELL
0117    2050 FORMAT(A2,/,"ENTER OPTION FOR MODAL ASSURANCE CRITERIA: "
0118         1,/,10X,"1) MEASUREMENT DIRECTION"
```

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```
0119          2,/,10X,"2) COMPONENTS"
0120          3,/,10X,"3) POINT NUMBERS"
0121          4,/,10X,"4) CONTINUE"
0122          5,/,10X,"5) RETURN TO MONITOR",A2)
0123          READ(1,*)IANS
0124          GO TO (2100,2200,2300,2400,1000)IANS
0125     2100 CONTINUE
0126          DO 2110 I=1,3
0127     2110 JDIR(I)=0
0128     2120 CONTINUE
0129          N1=-9999
0130          N2=-9999
0131          WRITE(1,2140)IBELL
0132     2140 FORMAT(A2,/,"DIRECTION(S)?")
0133          READ(1,*)N1,N2
0134          IF(N1.LE.0)GO TO 2040
0135          IF(N1.GT.3)GO TO 2120
0136          IF((N2.LE.0).OR.(N2.GT.3))N2=N1
0137          DO 2150 I=N1,N2
0138     2150 JDIR(I)=I
0139          GO TO 2120
0140     2200 CONTINUE
0141          DO 2210 I=1,10
0142     2210 JCOMP(I)=0
0143     2220 CONTINUE
0144          N1=-9999
0145          N2=-9999
0146          WRITE(1,2240)IBELL
0147     2240 FORMAT(A2,/,"COMPONENT(S)?")
0148          READ(1,*)N1,N2
0149          IF(N1.LE.0)GO TO 2040
0150          IF(N1.GT.10)GO TO 2220
0151          IF((N2.LE.0).OR.(N2.GT.10))N2=N1
0152          DO 2250 I=N1,N2
0153     2250 JCOMP(I)=I
0154          GO TO 2220
0155     2300 CONTINUE
0156          DO 2310 I=1,250
0157     2310 JPT(I)=0
0158     2320 CONTINUE
0159          N1=-9999
0160          N2=-9999
0161          WRITE(1,2340)IBELL
0162     2340 FORMAT(A2,/,"POINT NUMBER(S)?")
0163          READ(1,*)N1,N2
0164          IF(N1.LE.0)GO TO 2040
0165          IF(N1.GT.250)GO TO 2320
0166          IF((N2.LE.0).OR.(N2.GT.250))N2=N1
0167          DO 2350 I=N1,N2
0168     2350 JPT(I)=I
0169          GO TO 2320
0170     2400 CONTINUE
0171          WRITE(1,2410)IBELL
0172     2410 FORMAT(A2,/,"ENTER REFERENCE MODE NUMBER:")
0173          READ(1,*)IMODE
0174          WRITE(1,2420)IBELL
0175     2420 FORMAT(A2,/,"ENTER ANALYSIS MODE NUMBER:")
0176          READ(1,*)JMODE
0177          WRITE(1,2430)IBELL
0178     2430 FORMAT(A2,/,"ENTER METHOD TO BE USED TO CALCULATE 'MAC':"
```

```
0179         1,/,10X,"1) COMPLEX SHAPEVECTOR"
0180         2,/,10X,"2) REAL SHAPEVECTOR",/)
0181          READ(1,*)MAC
0182          IF((MAC.NE.1).AND.(MAC.NE.2))MAC=1
0183          AM1=0.0
0184          AM2=0.0
0185          CMR=0.0
0186          CMI=0.0
0187          DO 3000 I=1,IP
0188          IF(JPT(I).EQ.0)GO TO 3000
0189          K=IPTCM(I)
0190          IF(JCOMP(K).EQ.0)GO TO 3000
0191          DO 2900 J=1,3
0192          IF(JDIR(J).EQ.0)GO TO 2900
0193          IF(ISSW(14).LT.0)GO TO 1000
0194          RMAX1=RMM(IMODE)
0195          RMAX2=RMM(JMODE)
0196          CALL RWCMC(J,R1,L1,IMODE,I,IP,IBM,RMAX1,1)
0197          CALL RWCMC(J,R2,L2,JMODE,I,IP,IBM,RMAX2,1)
0198          IF(MAC.EQ.2)L1=90
0199          IF(MAC.EQ.2)L2=90
0200          AR1=R1*COS(FLOAT(L1)*DTR)
0201          AR2=R2*COS(FLOAT(L2)*DTR)
0202          AI1=R1*SIN(FLOAT(L1)*DTR)
0203          AI2=R2*SIN(FLOAT(L2)*DTR)
0204          AM1=AR1*AR1+AI1*AI1+AM1
0205          AM2=AR2*AR2+AI2*AI2+AM2
0206          CMR=AR2*AR1+AI2*AI1+CMR
0207          CMI=AR1*AI2-AR2*AI1+CMI
0208     2900 CONTINUE
0209     3000 CONTINUE
0210          AMAC=(CMR*CMR+CMI*CMI)/(AM1*AM2)
0211          SFR=CMR/AM1
0212          SFI=CMI/AM1
0213          CALL IOSW(NU,0)
0214          WRITE(NU,3100)AMAC,SFR,SFI
0215     3100 FORMAT(/,"MODAL ASSURANCE CRITERION.....",10X,F10.7
0216         1,/,"MODAL SCALE FACTOR(REAL)......",4X,F16.7
0217         2,/,"MODAL SCALE FACTOR(IMAG)......",4X,F16.7)
0218          GO TO 1000
0219     C************************************************************************
0220     C         MODE SCALE
0221     C************************************************************************
0222     4000 CONTINUE
0223          WRITE(1,4020)IBELL
0224     4020 FORMAT(A2,/,"ENTER ANALYSIS MODE NUMBER?")
0225          READ(1,*)IMODE
0226          WRITE(1,4030)IBELL
0227     4030 FORMAT(A2,/,"ENTER DESTINATION MODE NUMBER?")
0228          READ(1,*)KMODE
0229          IF(IMODE.EQ.KMODE)GO TO 4000
0230          IF(IPAR2.NE.-9999)GO TO 4050
0231          WRITE(1,4040)IBELL
0232     4040 FORMAT(A2,/,"ENTER MODAL SCALE FACTOR")
0233          SFR=0.0
0234          SFI=0.0
0235          READ(1,*)SFR,SFI
0236     4050 CONTINUE
0237          RMAX3=0.0
0238          DO 5000 I=1,IP
```

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```
0239          DO 4900 J=1,3
0240          IF(ISSW(14).LT.0)GO TO 1000
0241          RMAX1=RMM(IMODE)
0242          CALL RWCMC(J,R1,L1,IMODE,I,IP,IBM,RMAX1,1)
0243          AR1=R1*COS(FLOAT(L1)*DTR)
0244          AI1=R1*SIN(FLOAT(L1)*DTR)
0245          AR3=(AR1*SFR+AI1*SFI)
0246          AI3=(AI1*SFR-AR1*SFI)
0247          SFF=SFR*SFR+SFI*SFI
0248          AR3=AR3/SFF
0249          AI3=AI3/SFF
0250          R3=SQRT(AR3*AR3+AI3*AI3)
0251          ANG=ATAN2(AI3,AR3)
0252          L3=ANG/DTR
0253          IF(L3.GE.0)GO TO 4500
0254          R3=(-1.0)*R3
0255          L3=L3+180
0256     4500 CONTINUE
0257          CALL RWCMC(J,R3,L3,KMODE,I,IP,IBM,RMAX3,0)
0258     4900 CONTINUE
0259     5000 CONTINUE
0260          RMM(KMODE)=RMAX3
0261          FRQ(KMODE)=FRQ(IMODE)
0262          ZETA(KMODE)=ZETA(IMODE)
0263          NCN(KMODE)=NCN(IMODE)
0264          IB(KMODE)=IB(IMODE)
0265          GO TO 1000
0266     C****************************************************************
0267     C          MODE SUBTRACTION
0268     C****************************************************************
0269     8000 CONTINUE
0270          WRITE(1,8010)IBELL
0271     8010 FORMAT(A2,/,"ENTER REFERENCE MODE NUMBER?")
0272          READ(1,*)IMODE
0273          WRITE(1,8020)IBELL
0274     8020 FORMAT(A2,/,"ENTER ANALYSIS MODE NUMBER?")
0275          READ(1,*)JMODE
0276          WRITE(1,8030)IBELL
0277     8030 FORMAT(A2,/,"DESTINATION MODE NUMBER?")
0278          READ(1,*)KMODE
0279          IF(IMODE.EQ.KMODE)GO TO 8000
0280          IF(JMODE.EQ.KMODE)GO TO 8000
0281          RMAX3=0.0
0282          DO 8990 I=1,IP
0283          DO 8900 J=1,3
0284          IF(ISSW(14).LT.0)GO TO 1000
0285          RMAX1=RMM(IMODE)
0286          RMAX2=RMM(JMODE)
0287          CALL RWCMC(J,R1,L1,IMODE,I,IP,IBM,RMAX1,1)
0288          CALL RWCMC(J,R2,L2,JMODE,I,IP,IBM,RMAX2,1)
0289          AR1=R1*COS(FLOAT(L1)*DTR)
0290          AR2=R2*COS(FLOAT(L2)*DTR)
0291          AI1=R1*SIN(FLOAT(L1)*DTR)
0292          AI2=R2*SIN(FLOAT(L2)*DTR)
0293          AR3=AR2-AR1
0294          AI3=AI2-AI1
0295          R3=SQRT(AR3*AR3+AI3*AI3)
0296          ANG=ATAN2(AI3,AR3)
0297          L3=ANG/DTR
0298          IF(L3.GE.0)GO TO 8500
```

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```
0299        R3=(-1.0)*R3
0300        L3=L3+180
0301   8500 CONTINUE
0302        CALL RWCMC(J,R3,L3,KMODE,I,IP,IBM,RMAX3,0)
0303   8900 CONTINUE
0304   8990 CONTINUE
0305        RMM(KMODE)=RMAX3
0306        FRQ(KMODE)=FRQ(JMODE)
0307        ZETA(KMODE)=ZETA(JMODE)
0308        NCN(KMODE)=NCN(JMODE)
0309        IB(KMODE)=IB(JMODE)
0310        GO TO 1000
0311 C
0312 C        STORE AND READ SET-UP AND MODAL DATA TO AND FROM DISC
0313 C
0314 C        READ
0315 C
0316   6000 CALL KYBD(2HMS,35,1)
0317        CALL KYBD(2HMS,25)
0318        IF(IPAR1.EQ.-9999)GO TO 7000
0319        IF((IPAR1.GE.0).AND.(IPAR1.LE.800)) CALL KYBD(2HMS,31,IPAR1)
0320        IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0321        CALL KYBD(2HMS,11,0)
0322        CALL KYBD(2HMS,31,-1,1)
0323        CALL RWCOM(-1)
0324        IF(ICOMM.NE.12345)GO TO 6800
0325        CALL KYBD(2HMS,11,ION)
0326        CALL RWCOM(0)
0327        IF(ICOMM.NE.12345)GO TO 6800
0328        NMP=0
0329        IRJ=ICM
0330        CALL KYBD(2HMS,11,IRJ)
0331        IRJ=IRJ-1
0332   6100 DO 6200 I=IBM,IRJ
0333   6200 CALL KYBD(2HMS,11,I)
0334        CALL KYBD(2HMS,35,1)
0335        CALL KYBD(2HMS,15)
0336        ICOMM=12345
0337        WRITE(1,1235)(IT(I),I=1,5)
0338   1235 FORMAT(/,"TEST ID IS",23X,5A2)
0339        GO TO 1000
0340 C
0341 C        STORE
0342 C
0343   6500 CALL KYBD(2HMS,35,1)
0344        CALL KYBD(2HMS,25)
0345        IF(IPAR1.EQ.-9999)GO TO 7500
0346        IF((IPAR1.GE.0).AND.(IPAR1.LE.800))CALL KYBD(2HMS,31,IPAR1)
0347        IF((IPAR1.LT.0).OR.(IPAR1.GT.800))GO TO 6800
0348        IL=2H**
0349        CALL RWCOM(1)
0350        IH(6)=52525B
0351        IH(9)=10
0352        IH(10)=IT(1)
0353        IH(11)=IT(2)
0354        IH(12)=IT(3)
0355        IH(13)=IT(4)
0356        IH(14)=IT(5)
0357        IH(34)=2H71
0358        CALL KYBD(2HMS,21,ION)
```

```
0359          CALL KYBD(2HMS,21,ICM)
0360          IH(34)=2H72
0361          IRJ=ICM-1
0362          IPAR1=IPAR1+2
0363          DO 6700 I=IBM,IRJ
0364          IPAR1=IPAR1+1
0365    6700 CALL KYBD(2HMS,21,I)
0366          WRITE(1,6701)IPAR1
0367    6701 FORMAT(/,"NEXT DATA RECORD IS ",I4)
0368          CALL KYBD(2HMS,35,1)
0369          CALL KYBD(2HMS,15)
0370          GO TO 1000
0371    6800 WRITE(1,6801)
0372    6801 FORMAT(/,"ERROR-INVALID DATA RECORD")
0373          NMP=0
0374          ICOMM=12345
0375          GO TO 1000
0376  C
0377  C          LOAD MODE SHAPEVECTOR
0378  C
0379    7000 CONTINUE
0380          WRITE(1,7001)IBELL
0381    7001 FORMAT(A2,/,"SOURCE MODE NUMBER?")
0382          READ(1,*)IMODE
0383          RMAX=RMM(IMODE)
0384          DO 7100 I=1,IP
0385          CALL RWCMC(1,R,L1,IMODE,I,IP,IBM,RMAX,1)
0386          CALL RWCMC(1,R,L1,1,I,IP,1,RMAX,0)
0387          CALL RWCMC(2,R,L1,IMODE,I,IP,IBM,RMAX,1)
0388          CALL RWCMC(2,R,L1,1,I,IP,1,RMAX,0)
0389          CALL RWCMC(3,R,L1,IMODE,I,IP,IBM,RMAX,1)
0390          CALL RWCMC(3,R,L1,1,I,IP,1,RMAX,0)
0391    7100 CONTINUE
0392          IBW=IB(IMODE)
0393          ICHAN=NCN(IMODE)
0394          FREQ=FRQ(IMODE)
0395          DAMP=ZETA(IMODE)
0396          MAXPT=IP
0397          GO TO 1000
0398  C
0399  C          STORE MODE SHAPEVECTOR
0400  C
0401    7500 CONTINUE
0402          WRITE(1,7501)IBELL
0403    7501 FORMAT(A2,/,"TARGET MODE NUMBER?")
0404          READ(1,*)IMODE
0405          IF(IMODE.GT.NM)GO TO 7500
0406          IF(IP.GT.MAXPT)GO TO 7900
0407          RMM(IMODE)=RMAX
0408          IB(IMODE)=IBW
0409          NCN(IMODE)=ICHAN
0410          FRQ(IMODE)=FREQ
0411          ZETA(IMODE)=DAMP
0412          DO 7600 I=1,IP
0413          CALL RWCMC(1,R,L1,1,I,IP,1,RMAX,1)
0414          CALL RWCMC(1,R,L1,IMODE,I,IP,IBM,RMAX,0)
0415          CALL RWCMC(2,R,L1,1,I,IP,1,RMAX,1)
0416          CALL RWCMC(2,R,L1,IMODE,I,IP,IBM,RMAX,0)
0417          CALL RWCMC(3,R,L1,1,I,IP,1,RMAX,1)
0418          CALL RWCMC(3,R,L1,IMODE,I,IP,IBM,RMAX,0)
```

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```
0419    7600 CONTINUE
0420         GO TO 1000
0421    7900 CONTINUE
0422         WRITE(1,7901)IBELL
0423    7901 FORMAT(A2,/,"ERROR-ILLEGAL VECTOR LENGTH")
0424         GO TO 1000
0425    ***************************************************************************
0426    C        EXIT TO OTHER OVERLAYS
0427    C***************************************************************************
0428    9001 I=1
0429         GO TO 9900
0430    9002 I=2
0431         GO TO 9900
0432    9003 I=3
0433         GO TO 9900
0434    9004 I=4
0435         GO TO 9900
0436    9005 I=5
0437         GO TO 9900
0438    9006 I=6
0439         GO TO 9900
0440    9007 I=7
0441         GO TO 9900
0442    9008 I=8
0443         GO TO 9900
0444    9900 CONTINUE
0445         IFLAG=1
0446         CALL RWCOM(1)
0447         CALL KYBD(2HMS,38,I)
0448         CALL DVLD(9)
0449    9995 CONTINUE
0450         IL=2H**
0451         IF(ICOMM.EQ.12345)CALL RWCOM(1)
0452         CALL KYBD(2HBS,IBS,0)
0453         RETURN
0454         END
0455         END$
```

```
0001   FTN4,L
0002         SUBROUTINE Y0009(INTOT,IPAR)
0003   C
0004   C          THIS PROGRAM IS STORED UNDER $Y900
0005   C
0006   C*********************************************************************
0007   C
0008   C          PROGRAMMER:   R.J.ALLEMANG
0009   C                        MAIL LOCATION # 72
0010   C                        UNIVERSITY OF CINCINNATI
0011   C                        CINCINNATI, OHIO  45221
0012   C                        513-475-6670
0013   C
0014   C          REVISION DATE:  JAN,19,1980
0015   C
0016   C*********************************************************************
0017         DIMENSION IPAR(6),LINE(36),LINE1(35),IZ(10),INQ(6)
0018        1,IDIV(1),ICMMD(24),IH(1),IX1(1),IY1(1),IDX(1),IDY(1)
0019        2,IC1(1),IPTCM(1)
0020         EQUIVALENCE (LINE(2),LINE1)
0021         COMMON ICOMM,MANRE,MDVA,BETA,IBLS,IT(5),ID(3),IP,NUMPT
0022        1,NM,ICON,NCOM,XXX(3,10),IX(3,10),IC(10),NMP,XR(3),A(2,3)
0023        2,O(3),IB(10),NCN(10),SF(2),XXA(2,3),YYA(2,3)
0024        3,FSHFT,DF,MCF,IZR,IL,IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0025        4,IFLAG,NS,NE,RMM(10),FRQ(10),ZETA(10)
0026         EXTERNAL HDR8,DTAD0,NMAX
0027         DATA ICMMD/2HD ,2HV ,2HX ,2HEX,2H: ,
0028        12HM ,2H_ ,2HRO,2HA-,2HAM,
0029        22HCH,2HSP,2HX<,
0030        32HX>,2HCV,2H< ,2HB ,2HL ,
0031        42HW ,2HI ,2HK ,2HA+,2H/L,
0032        52HX /
0033   C*********************************************************************
0034   C        UNIVERSITY OF CINCINNATI/LEUVEN MODAL ANALYSIS PROGRAM
0035   C
0036   C        DUMMY OVERLAY PROGRAM
0037   C*********************************************************************
0038         IBELL=7B
0039         IPAGE=15414B
0040         CALL SETAD(HDR8,IH,-8,0)
0041         ICOMM=0
0042         IBS=1024
0043         CALL KYBD(2HBS,IBS,0)
0044         CALL GETI(NMAX,IBLM)
0045         ION=IBLM-1
0046         ICM=ION-1
0047         IBM=2
0048         I=ION*IBS+270
0049         CALL SETAD(DTAD0,IPTCM,I,-1)
0050         CALL RWCOM(0)
0051         WRITE(1,900)IBELL
0052     900 FORMAT(A2,/,"ERROR-COMMAND NOT AVAILABLE IN CONFIGURATION"
0053        1,/,"         OF SOFTWARE AND HARDWARE")
0054   C*********************************************************************
0055   C        START OF MONITOR
0056   C*********************************************************************
0057    1000 WRITE(1,1010)IBELL
0058    1010 FORMAT("*",A2)
```

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```
0059          I=ISWR(177677B,0,0)
0060          IPAR1=-9999
0061          IPAR2=-9999
0062          IPAR3=-9999
0063          IPAR4=-9999
0064          IPAR5=-9999
0065          IPAR6=-9999
0066     1020 DO 1030 I=1,36
0067     1030 LINE(I)=2H,,
0068     1040 CALL TTYIN(LINE)
0069     1042 CALL TEST(1,IST,LOG)
0070          IF(IST.LT.0)GO TO 1042
0071          CALL CODE
0072          READ(LINE,1120)IL
0073     1120 FORMAT(A2)
0074          CALL CODE
0075          READ(LINE1,*)IPAR1,IPAR2,IPAR3,IPAR4,IPAR5,IPAR6
0076     C*******************************************************************************
0077     C        MONITOR COMMAND TABLE
0078     C*******************************************************************************
0079     1130 IFLAG=0
0080          CALL RWCOM(1)
0081          IF(IL.EQ.2H##)GO TO 1000
0082          NCMMD=24
0083          DO 1138  I=1,NCMMD
0084          IF(IL.EQ.ICMMD(I))GO TO 1144
0085     1138 CONTINUE
0086     1139 WRITE(1,1140)
0087     1140 FORMAT(/,"ERROR-ILLEGAL COMMAND")
0088          GO TO 1000
0089     1144 IF(I.GT.10)GO TO 1146
0090          GO TO (9004,9004,9004,9004,9004,9004,9004,9004,9004,9004),I
0091     1146 I=I-10
0092          IF(I.GT.10)GO TO 1148
0093          GO TO (9004,9004,9004,9004,9004,9995,1100,1100,9002,9001),I
0094     1148 I=I-10
0095          GO TO (9001,9003,9008,9011),I
0096     1100 CONTINUE
0097          IF(IPAR1.EQ.37)GO TO 9005
0098          IF(IPAR1.EQ.10)GO TO 9006
0099          IF(IPAR1.EQ.6)GO TO 9007
0100          GO TO 1139
0101     C*******************************************************************************
0102     C         EXIT TO OTHER OVERLAYS
0103     C*******************************************************************************
0104     9001 I=1
0105          GO TO 9900
0106     9002 I=2
0107          GO TO 9900
0108     9003 I=3
0109          GO TO 9900
0110     9004 I=4
0111          GO TO 9900
0112     9005 I=5
0113          GO TO 9900
0114     9006 I=6
0115          GO TO 9900
0116     9007 I=7
0117          GO TO 9900
0118     9008 I=8
```

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```
0119          GO TO 9900
0120    9011  I=11
0121          GO TO 9900
0122    9900  CONTINUE
0123          IFLAG=1
0124          CALL RWCOM(1)
0125          CALL KYBD(2HMS,38,I)
0126          CALL OVLD(9)
0127    9995  CONTINUE
0128          IL=2H##
0129          IF(ICOMM.EQ.12345)CALL RWCOM(1)
0130          CALL KYBD(2HBS,IBS,0)
0131          RETURN
0132          END
0133          END$
```

APPENDIX B

AIRCRAFT SOFT SUPPORT SYSTEM

1.0 SYSTEM REQUIREMENTS

An aircraft soft support system for use in ground vibration testing is a system which supports the airplane in such a manner that its elastic modes of vibration are little modified by the presence of the support. This is accomplished by supporting the airplane so that 1) its rigid body natural frequencies are sufficiently lower than the first elastic mode and the damping in these rigid body modes sufficiently low so that there is little coupling between these rigid body and elastic modes, 2) the support pickup points on the airplane are selected to minimize their effect on the significant elastic modes of the airplane, 3) the internal resonances of the support system (including the test airplane mass) are well separated from the elastic modes of interest on the test airplane and, 4) the airplane resting on the support system is sufficiently stable. In addition the support system should be sufficiently rugged and reliable to require little attention during use.

2.0 CANDIDATE APPROACHES

2.1 Low Spring Rate Component

Soft support systems usually contain a discrete low spring rate component to provide the low frequency support and avoid internal resonances. This section discusses several ways this has been accomplished.

Soft Tires - Partially deflating the tires is an expedient way to obtain a soft support. In addition there is no doubt about airplane stability, as the airplane rests on the landing gear just as it was designed to do. Soft tires have the disadvantage that the frequency separation between the rigid body and elastic modes is margional, typically 1:2 in frequency, and frequently the tires are damaged.

Air Bags - Supporting the test airplane on air bags can offer excellent frequency separation. Air bags have the disadvantage of having such low damping and low lateral stiffness that stability of the airplane becomes a problem. Often auxiliary devices must be used to compensate for this shortcoming of air bags.

Mechanical Springs - Mechanical springs can be selected which offer excellent frequency separation. Friction in the springs and the large static deflection that accompanies the low natural frequencies cause difficulties with mechanical springs.

Bungee - Bungee cord supports have been constructed that had very good frequency separation. Difficulties involved large static deflections and load distribution among the multiple bungee cords.

Airsprings - Airsprings have been used with success on a number of tests. The airsprings consist of an air chamber with a sealed platform floating on the air contained in the chamber. Self leveling feedback control devices and dampers are common components. Potential disadvantages of airsprings are limited travel and a requirement for a compressed air source. Custom fabricated airsprings were developed for use in the XB-70 GVT and are in routine use at DFVLR. The airsprings used in the A-10 test were commercially available off the shelf models.

2.2 Support Configuration

Overhead - Suspending the test airplane from an overhead support is a very attractive way to satisfy airplane stabillity requirements. Regardless of the inherent stability of the low spring rate component, pendulum stability will assure a stable system. The difficulty with this approach is that the overhead support invariably has a long load path to ground. This load path must be quite stiff to avoid internal support resonances that couple with the test airplane. Hangar walls and roofs rarely provide the required stiffness and a special overhead frame is usually required for the GVT.

Underneath - Suspending the test airplane from below rather than with an overhead suspension permits designing to avoid internal support resonances much more easily. The load paths to ground are usually very short, although care must be

taken to verifying that the hangar floor the supports rest on is reasonably rigid. On a number of unfortunate occasions the fill under the floor was found to have settled, and the floor was really hollow. Special attention must also be paid to airplane stability with an underneath suspension. The low spring rate components tend to be unstable in compression and special attention must be paid to this in designing the support system. Although easier access to the airplane has been cited as an advantage to an overhead support system, accessibility is much more affected by design details of the system than by overhead or under configuration.

3.0 A-10 TEST SOFT SUPPORT SYSTEM

3.1 System Description

The system selected for the A-10 demonstration ground vibration test of this contract included airsprings and an underneath support configuration. Three airsprings and supports were used. The airplane was supported at the aft body jacking point and at the auxiliary jacking points at either side of the fore body. This provides minimum constraint to the wing and to aft body torsion, so the coupling between the soft support system and most of the significant modes of the airplane should be low. This support configuration also provided stability. Both roll and pitch stability were insured because the fore body jacking fittings are located vertically near the c.g. and because the forebody and aft body jacking fittings are far apart.

3.1.1 Airsprings

Commercially available airsprings were used in the A-10 system. These airsprings had a mechanical servo system that kept the floating platform at a constant level. When the load on the airspring increased and the level dropped the input air valve opened and the air pressure in the airspring increased until the platform was returned to the desired level. When the load decreased and the platform level raised air was valved from the airspring by the servo to regain the desired level. The time constant in this servo system was about 10 seconds. Because this airspring is a nearly constant air volume device, the natural frequency is nearly independent of the mass it is supporting. For the airsprings

selected, the manufacturer specified a vertical natural frequency of 1.5 ± .1 Hz. The manufacturer also specified a lateral natural frequency of 2.5 Hz. The airsprings incorporated a damper.

3.1.2 Support

The supports under the airsprings were concrete blocks. The concrete blocks rested on the hangar floor. Their height was selected to facilitate installation of the airplane on the soft support system. The hangar floor at the test site had been constructed quite some time ago of very massive heavily reinforced concrete especially for test work.

3.2 Fabrication

The commercially available airsprings were delivered in less than four weeks after ordering. The concrete blocks were poured in-house in wooden forms. Note the fork lift fittings cast into the concrete blocks and the steel bed plate on top of the concrete blocks (see the photographs). New concrete blocks should probably be poured for each new airplane design tested since a different support height will usually be required and the blocks are easy to fabricate. The blocks for this test were fabricated in three days at very modest cost.

A fitting was fabricated to mate the top of the airspring to the airplane jacking fitting. Although this fitting was originally designed as a ball and socket fitting, it later had to be redesigned as a clamped fitting. This is needed because the floating plate of the airspring can transmit no moments, and in order

that the plate float level either a point load must be applied at its exact center, or a clamped fitting must be used forcing the plate to float level.

3.3 Installation

The concrete blocks were sized to permit easy installation of the airplane on the soft support system. To install the support system first the airplane's oleo struts were blown to full extension. The concrete blocks were positioned under the jack fittings and the airsprings were placed in position. The airsprings are unpressurized and bottomed. The wing jacks were set in place and the airplane was jacked from the wing jacks. The main landing gear oleo strut was depressurized and the main landing gear was retracted. The wing jacks were slowly lowered, placing the weight of the airplane on the airsprings. The nose gear oleo strut was depressurized and the nose gear was retracted.

3.4 Operating Procedure

The system worked fine with little attention required. At the end of the test day the wing jacks were set in place and the air was released from the airsprings. To start the test day the airsprings were pressurized and the wing jacks removed. About every three days the nitrogen bottle used to pressurize the system was replaced. The rate of nitrogen consumption was increased because of valving when someone would be walking on one wing (e.g. to check a troublesome accelerometer) with the suspension system active.

4.0 BOILERPLATE TEST

A boilerplate test was conducted on the airsprings to verify their operation before the GVT and to confirm the manufacturers natural frequency specifications.

Two different test rigs were used. The test rigs were assembled from standard structures laboratory "tinker toy" I beams, 2500 lb. dead weights and the airsprings. The first test rig attempted to simulate the airplane mass, inertia and jacking point locations. As first built up this rig had its center of gravity about two feet higher than the airplane's. This system was unstable in roll because the natural frequency in roll coincided with the natural frequency of the servo-leveling feedback control system. (Note that gravity acts as a negative spring in roll for this case. The effective roll spring is the airsprings minus the gravity effect. The higher the c.g. the larger is the gravity effect.) After the rig was rebuilt to get the c.g. correct there were no more stability problems. The rig was shaken to determine its modes and frequencies.

The results of this test are tabulated in Figure B-1. A sketch of this rig is included in Figure B-2. Because this rig proved undesirably flexible a second test rig was built. This rig had the long flexible elements shortened up as much as possible. The mass of the airplane was matched by the rig and the jacking point locations approximately preserved, but inertia was not matched. The rig was only shaken for the vertical translation mode, which was recorded as 1.41 Hz.

Photographs of the test rig are shown on Figures B-3 through B-8.

Frequency	Description
.5 Hz	Body roll - More rocking motion on aft pillow
1.17 Hz	Roll about logitudinal Not a clean mode
1.5 Hz	Pitching of body (frequency could be from 1.5 to 1.7 Hz.)
2.6 Hz	Forward - Aft pitching forward end with small amplitude - not in or out of phase
2.9 Hz	Body torsional - Aft shimmy lateral (frequency could be from 2.8 to 3.0 Hz.)
3.7 Hz	Forward body vertical
4.5 Hz	Right front vertical some rolling of structure with FWD-AFT movement
6.9 to 9.0 Hz	Beam bending and 2640# mass motion (rocking)

Note: The response of this structure is complex - all modes contain motion in practically every possible direction. Damping appears low - for the structure and high for the pillow supports. The supports do bottom out at low frequencies and lateral motion of only about 1/4" can exist before exceeding the units side travel.

Figure B-1. Boilerplate Test Rig No. 1 Results

REF POINT

IV — 3

EXCITER DRIVING POINT

2,640-lb BLOCKS (8)

V

30

60

VI

CL

VII

RIGHT

FORWARD ← → AFT

LEFT

12

24

30

III

24

II

36

120

I

30

VIII

36 9

▲ = Accelerometer pickup location

240

66

53

20½

43 37 24

SUPPORTS

REF POINT ON FLOOR

• All dimensions in inches
• Not to scale

• Beams—65 lb/running ft
• Bed plates under weights—1-in steel
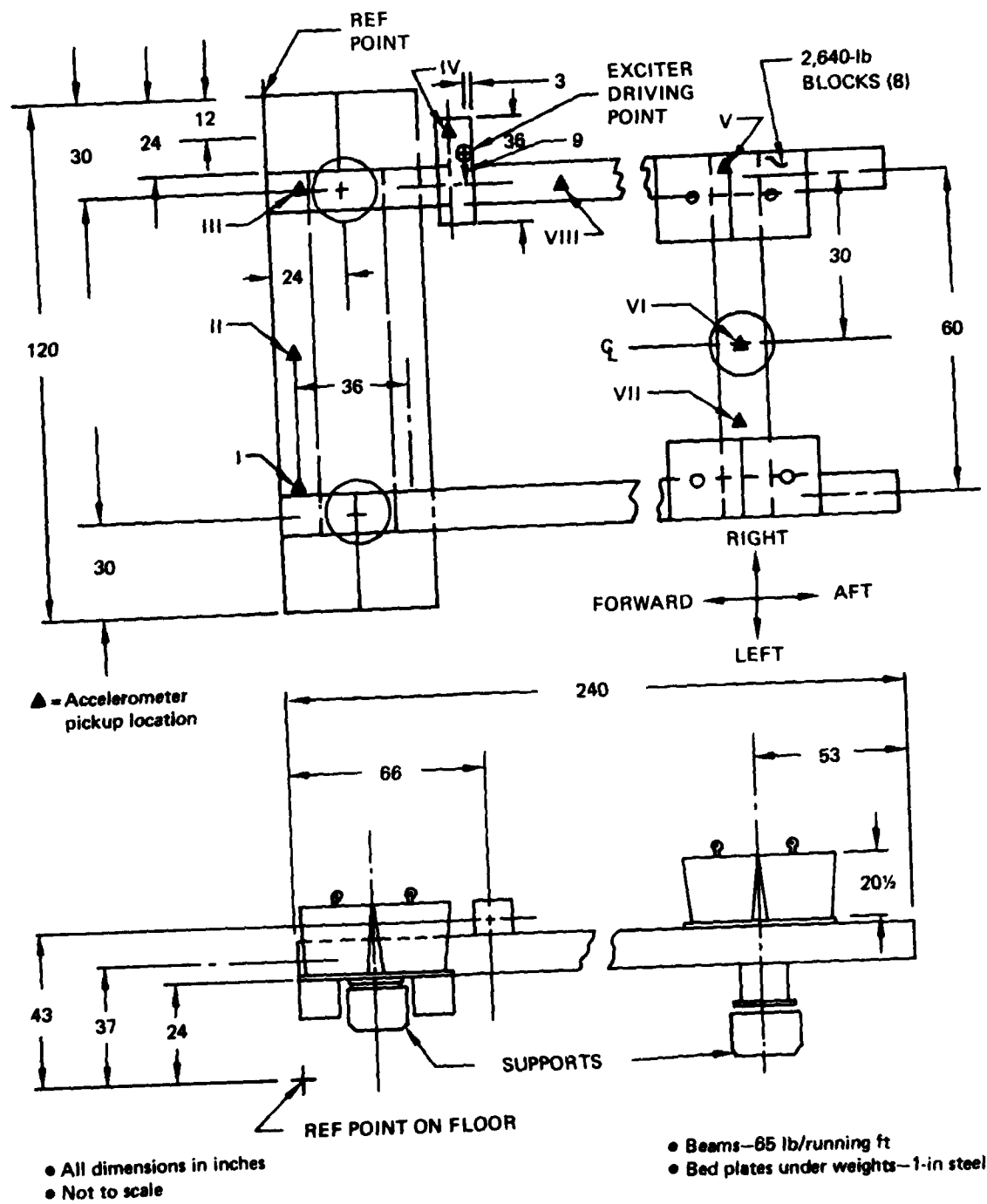
Figure B-2. A-10 Air-Spring Suspension

Figure B-3. Boilerplate Test Rig

B-14
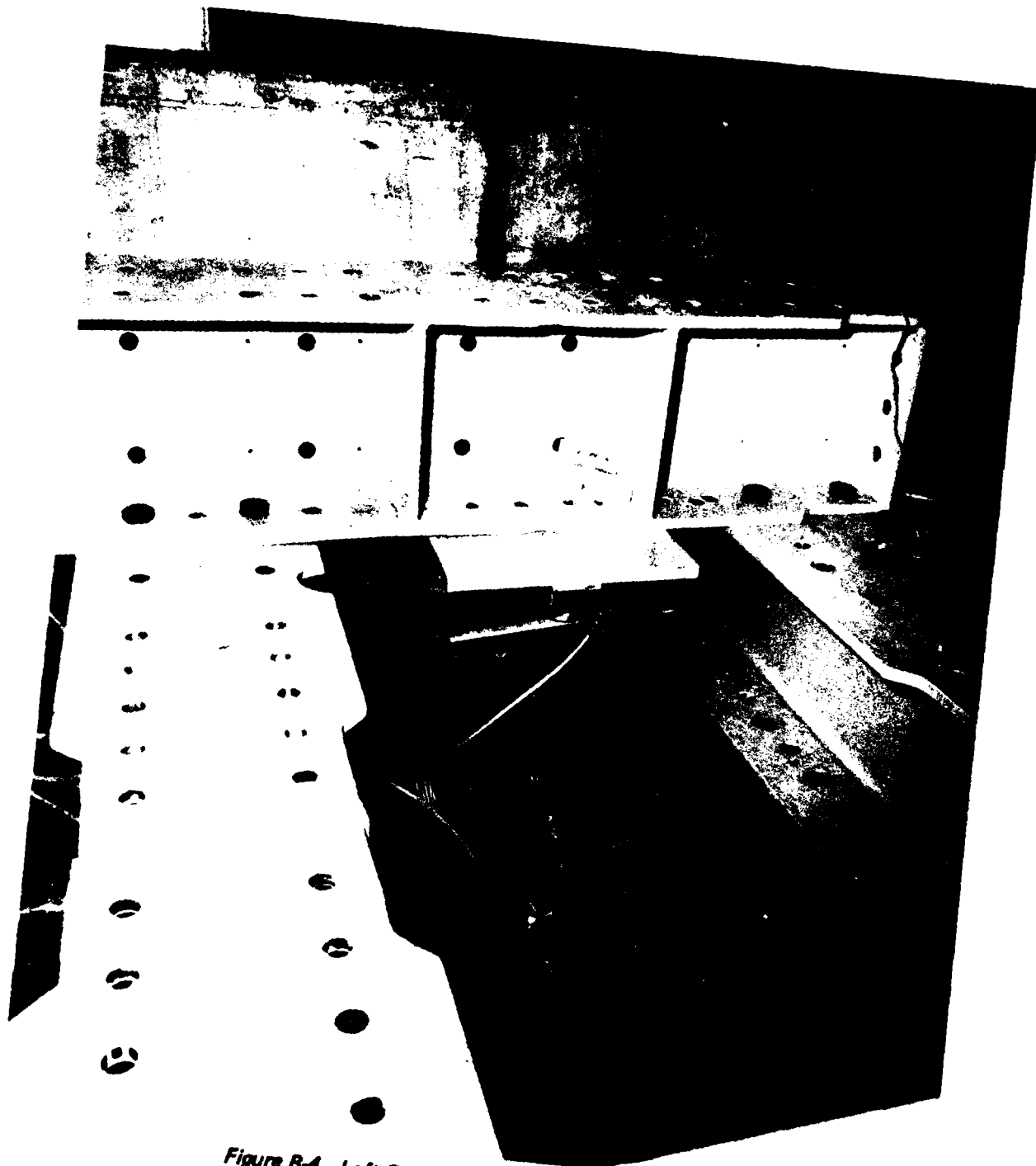
Figure B-4. Left Front Airspring—Boilerplate Test
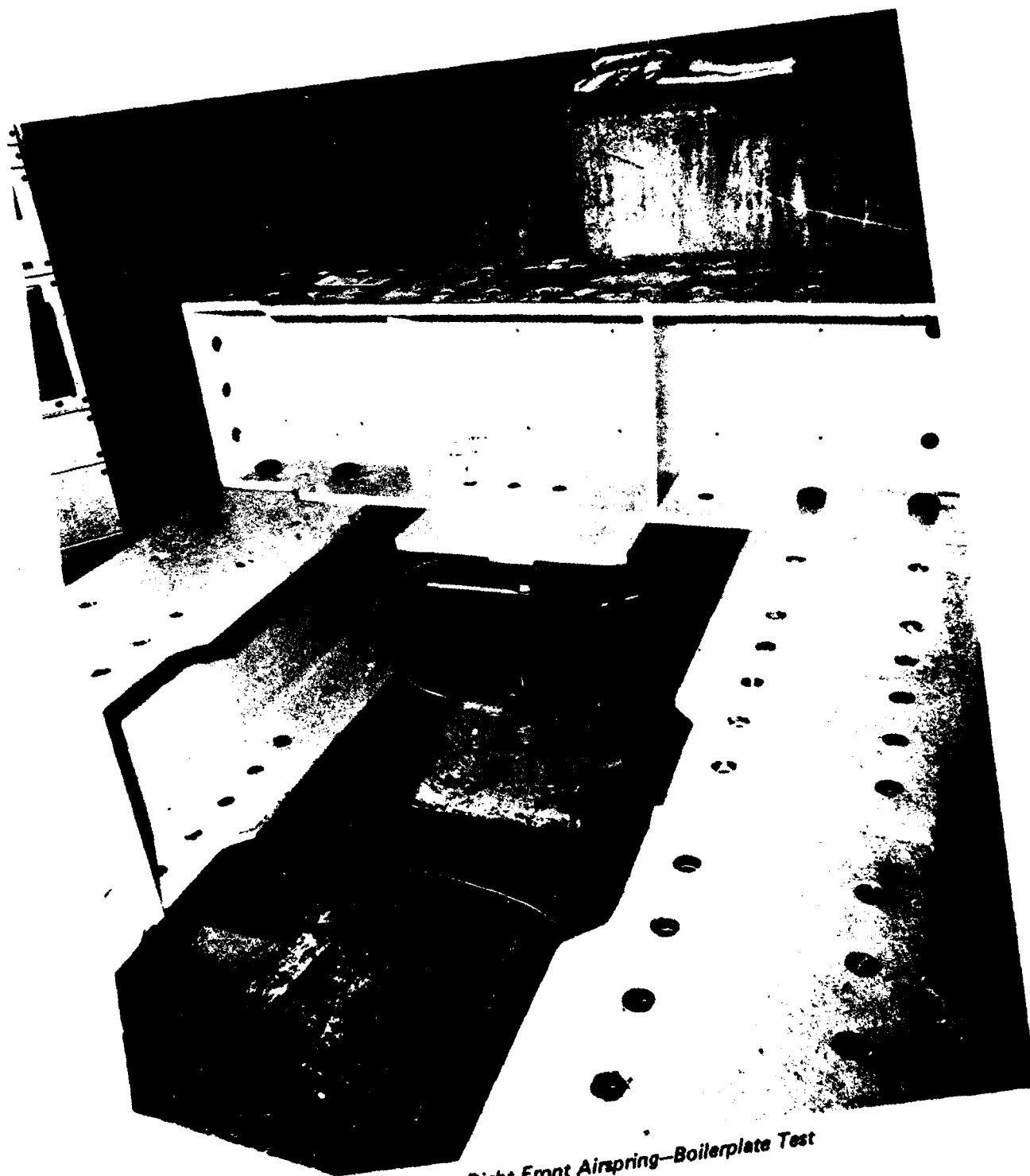
Figure B-5. Right Front Airspring—Boilerplate Test
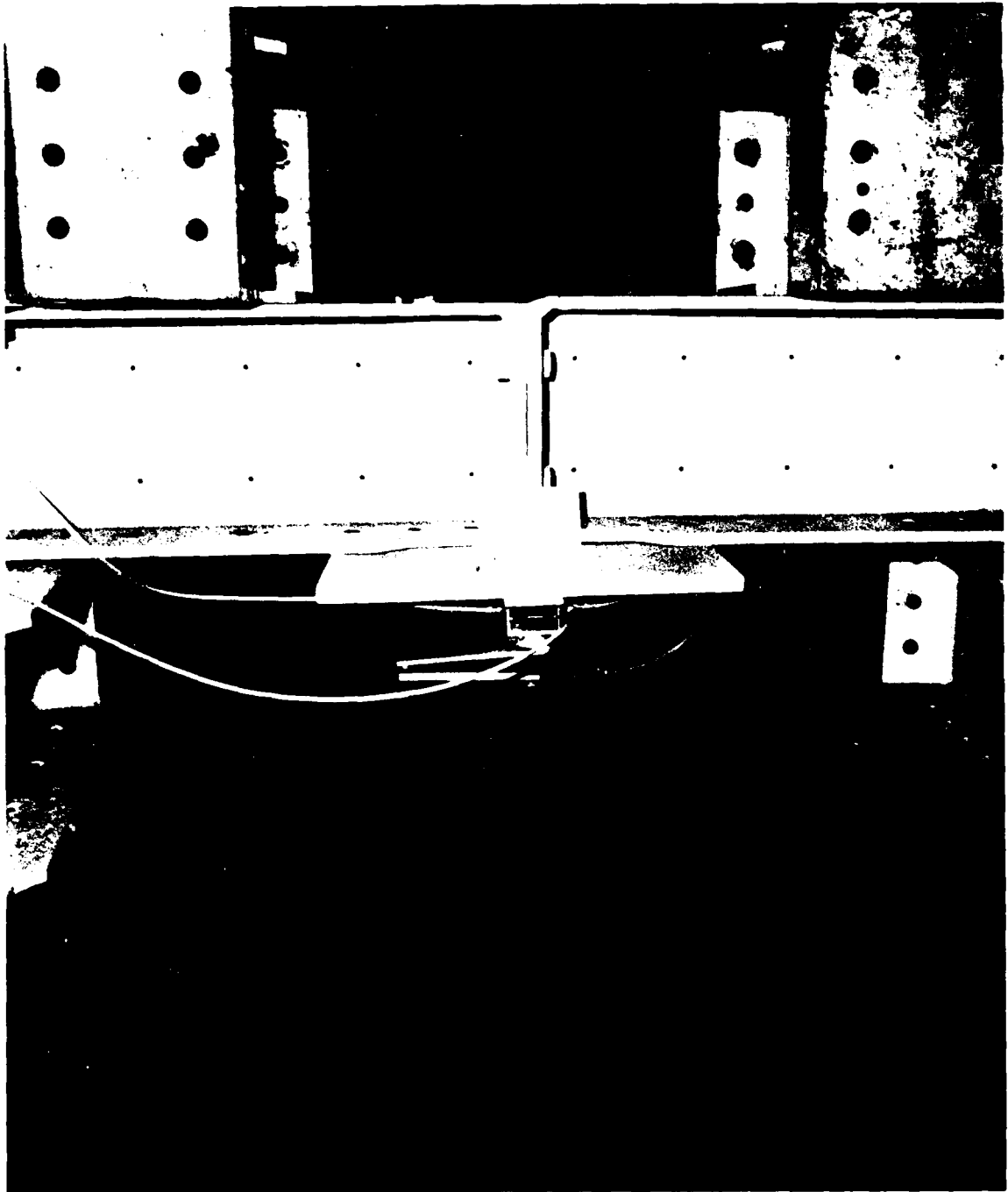
Figure B-6. Aft Airspring—Boilerplate Test
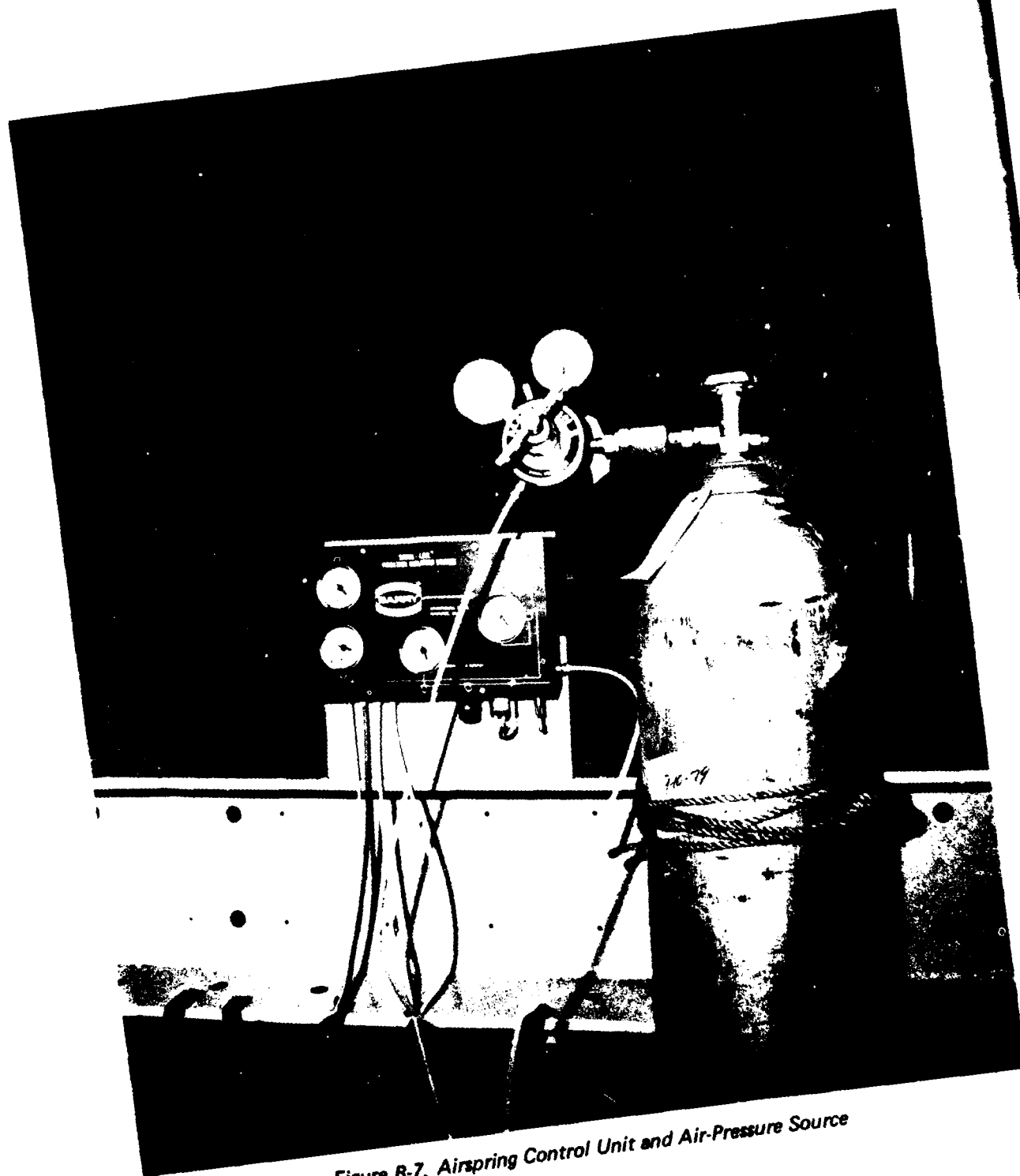
Figure B-7. Airspring Control Unit and Air-Pressure Source
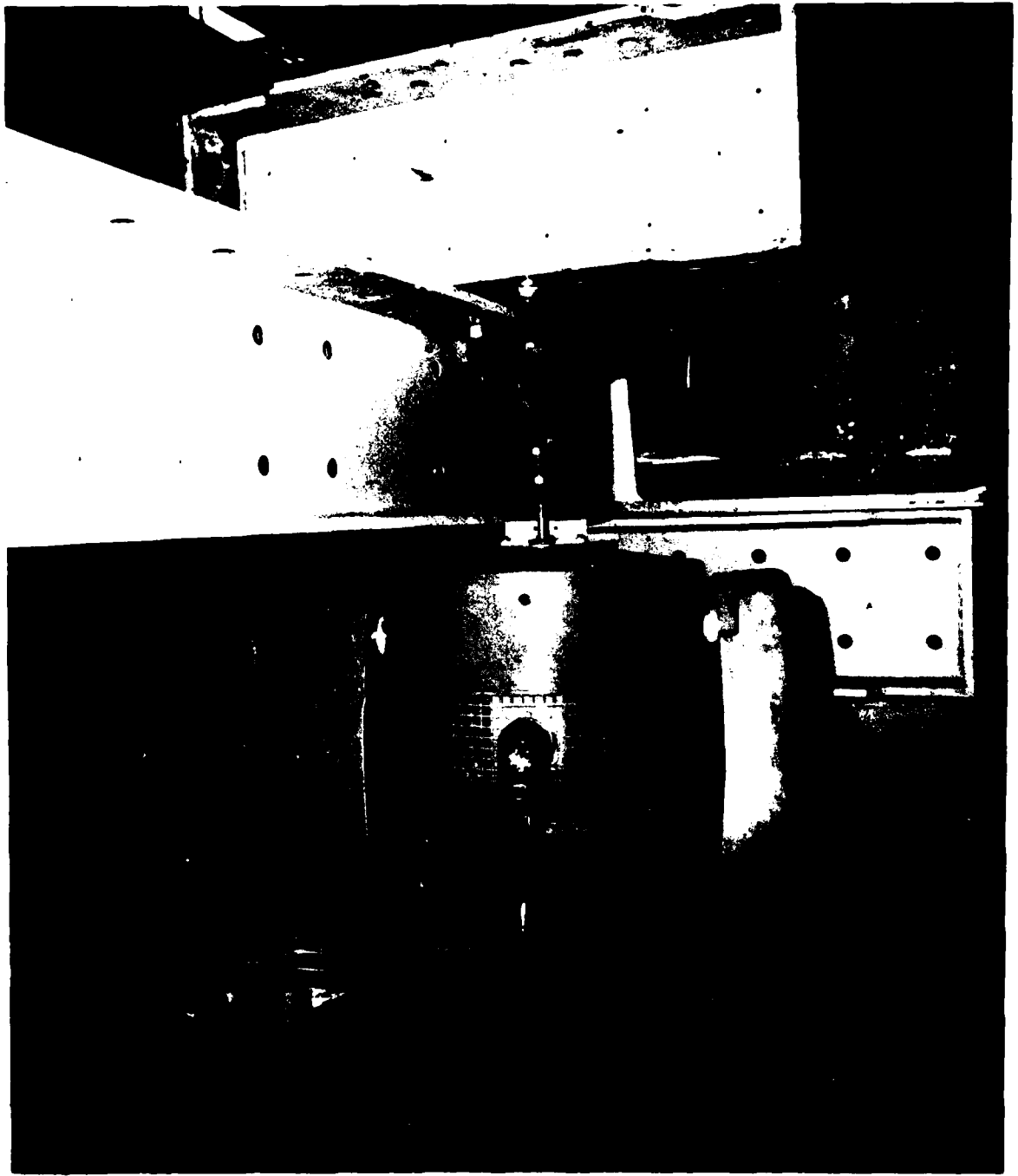
Figure B-8. Shaker Installation—Boilerplate Test

APPENDIX C

SUMMARY CHART - INDUSTRY INTERVIEWS

	Company	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Reason for GVT	Comparison with flutter model		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
	Development of mass, stiffness, damping		✓		✓					✓	✓	✓			✓			✓				✓		
	Substructure modeling			✓	✓													✓						
	Troubleshooting		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓			✓	✓	✓		✓	✓	✓
	Research		✓						✓			✓	✓	✓	✓			✓	✓				✓	
	Other	✓	✓		✓										✓				✓	✓				
Test requirements	Frequencies	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Normal mode shapes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Complex mode shapes			✓						✓	✓		✓		✓			✓				✓		
	Damping	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓
	Generalized mass, stiffness, damping		✓		✓				✓					✓					✓					
	Transfer functions	✓	✓				✓			✓			✓		✓	✓		✓						
	Frequency response functions				✓	✓	✓		✓	✓	✓	✓	✓		✓	✓			✓	✓		✓		
	Coherence plots				✓		✓				✓		✓		✓	✓		✓		✓		✓		
	Orthogonality check		✓		✓			✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓
	Other		✓		✓																			
Excitation techniques	Single shaker, single D.O.F.		✓						✓	✓	✓	✓	✓	✓	✓	✓				✓		✓		
	Single shaker, multiple D.O.F.		✓				✓			✓	✓	✓	✓		✓			✓				✓	✓	
	Multiple shaker, single D.O.F.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Multiple shaker, multiple D.O.F.											✓												
	Other		✓								✓													

Summary Chart - Industry Interviews

C-2

		Company																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Excitation signal	Sinusoidal	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Periodic		√					√				√	√		√			√	√	√	√	√	√	√
	Random		√	√			√		√	√		√	√		√			√	√		√	√	√	
	Random transient		√		√										√			√						
	Transient		√								√	√						√	√	√	√			
	Other		√				√				√	√							√	√		√		
Data acquisition techniques	Roving response transducers	√	√	√		√	√	√		√		√		√	√			√	√	√	√	√		√
	L.T. 100 fixed response tranducers	√	√	√		√	√	√		√	√			√	√	√	√	√	√	√	√		√	
	G.T. 100 fixed response transducers	√	√		√				√	√		√			√		√	√	√	√	√	√	√	√
	Other								√															
Parameter estimation techniques	Single D.O.F.	√	√		√		√		√				√		√			√	√	√	√	√	√	
	Single D.O.F. with residuals		√							√	√	√	√	√	√		√		√	√	√	√	√	
	Multiple D.O.F.		√	√					√	√	√	√	√					√	√	√	√	√	√	
	Multiple D.O.F. with residuals		√							√	√	√			√			√		√	√	√	√	
	Other					√	√		√		√					√								
Test item support	Fixed	√	√						√			√			√			√	√	√	√	√	√	√
	Free-free	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	On landing gear	√	√	√					√		√				√			√			√	√	√	
	other		√																					

Summary Chart - Industry Interviews (Continued)

C-3

Company

Chronic problems		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Closely coupled modes	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓
	Local modes		✓											✓		✓					✓		✓	
	Determination of normal mode		✓	✓			✓							✓	✓	✓								
	Orthogonality check							✓							✓	✓				✓				
	Non-linearities	✓	✓						✓	✓			✓			✓		✓			✓			✓
	Test time window	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓			✓	✓					✓
	Test expense		✓			✓				✓											✓	✓	✓	✓
	Other		✓					✓				✓								✓	✓			

Non-linearities		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Free-play	✓	✓	✓		✓			✓		✓	✓	✓			✓	✓	✓	✓			✓	✓	
	Buckling	✓	✓	✓							✓	✓				✓	✓						✓	
	Friction	✓	✓			✓			✓		✓	✓				✓	✓	✓	✓	✓			✓	
	Hardening spring	✓	✓							✓	✓	✓							✓		✓			✓
	Softening spring		✓								✓	✓												
	Other		✓												✓									

Treatment of non-linearities		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Linearize	✓	✓			✓			✓	✓	✓	✓					✓	✓	✓		✓	✓		
	Document force relationships	✓	✓			✓		✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓
	Other		✓				•																	

Summary Chart - Industry Interviews (Concluded)

C-4

APPENDIX D

PRINCIPAL TOPICS - MOST SIGNIFICANT LITERATURE

Author	Date	Ref. No.	Test theory	Parameter estimation theory	Equipment description	Simplified test results	Actual test results	Survey of techniques
Asher	1968	6	X			X		
Asher	1967	7	X			X		X
Beatrix	1973	11						X
Berman	1971	14	X	X	X		X	
Bishop	1963	16		X		X	X	
Brown	1977	25	X					
Craig	1974	34	X					
Cromer	1978	36	X	X		X		X
Dat	1975	37	X					
DeVeubeke	1956	45	X					
DeVries	1967	47					X	
Flannelly	1972	59	X	X		X		
Halbauer	1978	70	X			X		
Halvorsen	1977	71	X			X		
Hamma	1976	73						
Hanks	1979	75						
Hawkins	1967	79						
Ibanez	1976	86	X					X
Ibrahim	1978	87						
Ibrahim	1977A	88	X	X			X	
Johnston	1978	94		X	X	X	X	X
Kennedy	1947	96		X				
Klosterman	1971	99		X				
Klosterman	1975A	104	X		X	X		
Leppert	1976	111	X	X	X	X	X	X
Link	1960	112				X		
Link	1978	113						
Morosow	1978	127						
Mustain	1976	129						
Natke	1976	136	X					X
Nguyen	1976	138						
Niebel	1976	140						
Olsen	1977	144						
Pendered	1963A	147		X	X	X	X	X
Pendered	1963C	149		X	X	X	X	X
Potter	1975	157		X	X			
Ramsey	1975A	161						
Ramsey	1976	162	X	X		X		X
Richardson	1974	170	X	X		X		
Richardson	1976	172	X	X		X		
Sillard		183		X				X
Sloane	1975	187						
Smith	1975	188					X	
Smith	1972B	190	X	X		X		
Stahle	1968	194	X	X		X		
Traill-Nash	1968	206	X					
Van Loon	1974	208					X	
Wada	1975	210		X			X	X
Woodcock	1963	218		X			X	
Brown	1979	222						X

Principal Topics - Most Significant Literature

APPENDIX E

SUMMARY CHART - FULL BIBLIOGRAPHY

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPE-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Noncon-ventional Modal	Equipment description
Abrahamson	1977	1					X					
Allemang	1978	2					X					
Anderson	1971	3										
Angelini	1976	4	X									
Archer	1966	5						X		X		X
Asher	1968	6						X		X		
Asher	1967	7										
Bailey	1971	8						X				
Beliveau	1969	9										
Barton	1975	10										
Beatrix	1973	11								X		X
Bendat	1976	12									X	X
Bendat	1976	13				X			X			
Bennett	1971	14									X	
Berman	1973	15								X		
Bishop	1963	16	X		X	X				X		
Blanchard	1977	17						X				
Bouche	1975	18										X
Bowie	1966	19				X						X
Bowles	1972	20	X									
Breitbach	1973	21			X	X				X		X
Breitbach	1976	22										
Broadband	1968	23			X							
Brown	1978	24								X		
Brown	1977	25					X		X			X
Budd	1971	26					X		X			
Budd	1969	27	X									
Caughey	1960	28							X			
Cheng	1980	29						X				
Clarkson	1965	30				X				X		
Collins	1974	31				X						
Collins	1972	32				X				X		
Coupry	1977	33				X				X		
Craig	1974	34						X				
Cromer	1976	35				X			X			
Curtis	1976	36		X								
Det	1975	37										
Det	1973A	38										
Det	1974A	39								X		
Det	1973B	40				X		X				
Det	1973C	41				X						
Det	1974B	42										
Det	1974C	43					X		X			
Degener	1977	44										
DeVeubeke	1966	45								X		
DeVeubeke	1976	46								X		

Summary Chart - Full Bibliography

Summary Chart — Full Bibliography (Continued)

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPE-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Nonconventional Modal	Equipment description
DeVries	1967	47								X		X
Dixon	1967	48									X	
Dodds	1975	49										X
Durrani	1972	50										
Elenewskii	1976	51							X			
Enochson	1968	52							X			
Enochson	1976	53							X			
Ewing	1972	54							X	X		
Ewins	1975	55							X	X		
Favour	1972	56										
Felx	1975	57	X	X				X				
Filod	1978	58										
Flannelly	1972	59				X	X					
Flannigan	1973	60							X			
Fourney	1968	61					X	X				
Fowler	1978	62										
Freeland	1969	63										
Geukroger	1974	64				X	X					
Gordon	1977A	65					X					
Gordon	1977B	66										
Goyder	1976	67				X						
Gravitz	1958	68										
Held	1976	69								X		
Heller	1978	70										
Helvorsen	1977	71							X			
Hemma	1978	72	X									
Hesina	1978	73		X								
Hammond	1976	74		X		X						
Hinks	1979	75										
Herting	1972	76								X		
Hamilman	1976	77				X						
Hawkins	1976	78				X			X			
Hawkins	1967	79				X						
Holzmann	1972	80										
Hewlett-Packard	1976	81										
Hewlett-Packard	1972	82										
Hoberock	1969	83										
Horner	1968	84				X						
Hunter	1976	85								X		X
Ibanez	1978	86								X		X
Ibrahim	1977A	87									X	X
Ibrahim	1977B	88									X	
Ibrahim	1978	89									X	
Imes		90					X					
Ip		91										
Ismail	1974	92							X			

E-3

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPE-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Nonconventional Modal	Equipment description
Jennings	1976	93		X			X	X	X			
Johnston	1978	94					X				X	
Kana	1977	95			X							
Kennedy	1947	96										
Kiesling	1978	97							X			
Kiesling	1975	98										
Kiesling	1971	100										
Klosterman	1973	101					X					
Klosterman	1972A	102					X					
Klosterman	1972B	103					X					
Klosterman	1975	104					X				X	X
Klosterman	1975A	105					X				X	
Klosterman	1975B	106					X				X	
Knaus	1975	107									X	
Laidlaw	1968	108				X		X				
Langenworthy	1972	110						X				
Lint	1975	111		X						X		
Loonds	1974	112					X				X	
Loport	1976	113										
Link	1960	114					X					
Linxart	1978	115					X					
Ludwig	1972	116										
MacKenzie	1974	117			X	X			X	X		
Mahalingam	1967	118										
Mahalingam	1975	119										
Mahalingam	1976	120										
Mahalingam	1973	121							X	X		
Marchand	1974	122					X					
Marples	1974	123										
Merritt	1973	124				X			X			
Mehmend	1977	126										
Moronov	1976	127							X	X		
Moronov	1977	128										
Moronov ""128""	1978	129	X									
Muenin	1972	130										
Muser	1976	131										
McConnell	1973	132										
McGraw	1969	133										
Netta	1969	134										
Netta	1972	135										
Netta	1975	136	X				X			X		
Netta	1973	137										
Neuman	1974	138										

Summary Chart - Full Bibliography (Continued)

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Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPE-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Nonconventional Modal	Equipment description
Nichols	1973	139						X				
Niedbal	1976	140	X								X	
Nieim	1967	141									X	
Nooman	1968	142										
North	1967	143										
Olen	1977	144										
Ottens	1975	145					X	X				
Paramenter	1973	146						X				
Pendered	1963A	147			X				X	X		
Pendered	1963B	148			X				X	X		
Pendered	1963C	149							X	X		
Peterson	1977	150										
Piazzoli	1967	151										
Piazzoli	1976	152										
Piazzoli	1977	153					X					
Potter	1976	154										X
Potter	1977	155									X	X
Potter	1974	156				X						X
Potter	1975	157							X			
Ranny	1972	158							X			
Ranny	1969	159										
Rades	1975	160			X						X	
Ramsey	1975A	161										
Ramsey	1976	162							X			
Ramsey	1975B	163							X			
Rapin	1976	164							X			
Renz	1975A	165										
Renz	1975B	166										
Reber	1975	167										
Reverman	1970	168										
Richardson	1975A	169							X			
Richardson	1974	170							X			
Richardson	1975B	171							X			
Richardson	1976	172							X			
Roberts	1971	173					X		X			
Roberts	1975	174							X			
Rodden	1967	175										
Roe	1971	176				X						
Rucker	1976	177					X				X	
Rynneld	1974	178										
Sawyer	1973	179						X		X		
Schenton	1969	180										
Schiff	1972	181				X						
Schmitz	1974	182								X		
Sillard		183										
Sisson	1973	184					X		X			

Summary Chart - Full Bibliography (Continued)

Author	Date	Ref. No.	Survey of Modal techniques	Comparison of Modal techniques SPE-FRA VS MPF-SD	Modal parameter estimation	Modal parameter estimation MDOF	Test results SPE-FRA	Test results MPE-SD	Test theory SPE-FRA	Test theory MPE-SD	Nonconventional Modal	Equipment description
Skingle	1973	185			X							
Skopowski	1969	186										
Sloane	1975	187										X
Smith	1975	188						X	X	X		
Smith	1972A	189								X		
Smith	1972B	190								X		
Smylov	1972	191						^				
Soovere	1976	192										X
Spectral Dynamcs	1976	193										
Stahle	1968	194			X	X						
Stahle	1962	195			X	X						
Stahle	1978	196		X								
Stroud	1976	197										
Strutz	1978	198					X					
Su	1972	199								X		
Sugiura	1975	200										
Suzuki	1975	201										X
Targoff	1976	202				X				X	X	X
Taylor	1967	203				X						
Thoren	1972	204										
Tilov	1973	205								X		
Traill-Nash	1968	206					X					
Van Brussel	1975	207						X	X			
Van Loon	1974	208						X	X			
Viswanathan	1974	209						X	X			
Wada	1976	210							X			
Wada	1974	211										
Weleman	1974	212						X				
White	1975	213			X			X				
White	1976	214						X				
White	1969	215										
White	1971	216										
White	1972	217			X							
White	1976	218										
Woockcock	1963	219										
Yeh	1973	220										
Young	1969	221				X						
Zimmerman	1977	222			X	X						
Brown	1979	223									X	
Gold	1979	224										
Wiley	1979											

Summary Chart - Full Bibliography (Concluded)