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THE SHOCK AND VIBRATION DIGEST

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WASHINGTON, D.C.

OFFICE
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DIRECTOR NOTES

This month we are including the Call for Papers for our 49th Shock and Vibration Symposium. As always, we expect this to be an interesting, productive meeting. We hope that many of our readers plan to attend. I would call your particular attention to the potential program, which is expected to be formed based upon our greatest needs coupled with the most significant contributions. I ask each of you to consider your own work and accomplishments. Can you contribute to the advancement of our technology? The forms at the back of this issue are for that purpose. We would be pleased to receive your proposed contribution.

In connection with this publication, we are once again seeking input from our readers on ways of improving its usefulness. Over the past ten years we have, whenever possible, formulated the contents of this DIGEST based upon the needs of the technical community. Your opinions on how well we have done our job, as well as suggestions as to how we can do it better are earnestly solicited. Please take a few minutes to fill out and mail the form at the back of this issue. I will be most grateful.

As we go beyond the survey mentioned above and as future issues are delivered, I ask that you not be hesitant in corresponding with me. As readers, your input is invaluable. Tell us when we have committed sins of omission. Give us your opinion on a regular basis on good and bad features. On controversial issues we will be happy to publish discussions and rebuttals. In general, I think a continuing dialogue between reader and publisher can only serve the common good.

H.C.P.

EDITORS RATTLE SPACE

TECHNICAL PAPERS: QUANTITY OR QUALITY

At a recent major meeting of the ASME, one of the major issues being discussed involved the right of each member to receive twenty free technical papers. This issue came to be controversial because, as a budgeting matter, a small handling charge was assessed for each paper. The Society had to assess this charge or find other means of deferring the cost of its publication program. This action is a sign of the times. The cost of issuing technical publications has risen along with the quantity of them. What it all means is that eventually the prohibitive cost of publication is going to stop the proliferation of technical material. Whether good or bad material will suffer from lack of publication remains to be seen. A review of past efforts on cost cutting and selection of material for publication is interesting.

At one time every author thought it was his or her right to publish research results, good or bad, without cost. They did not expect to get paid for writing the paper; however, they surely did not expect the publication to cost them anything. This was the way it was before the advent of the page charge. About ten years ago some major societies noted that subscriptions to technical journals did not cover the costs of processing and printing. Rather than raise the price of the journals, they decided to levy a page charge for publication. I suspect it was the first attempt to induce people to be more selective about what they would submit for publication. It didn't work very well because the page charge was paid by the author's company, if, in fact, it was paid at all. In the end, payment of the page charge was not mandatory for publication. While it did generate some revenue, it was not enough to significantly affect publication costs.

The next cost cutting procedure involved the quality of editing, layout, and printing. Some journals reduced editorial staff thus degrading accuracy. Others sought means of reducing printing costs by using typewriters or cold type rather than hot type. After all these compromises we are still faced with the basic problem that we cannot afford to publish trivial or reworked technology.

The cost of good papers to users has never been an issue. If the work is good and will help to solve a problem, the user will pay the real cost of publication. After all this does not include the cost of research and engineering involved in generating the technology. The right of the ASME members to receive twenty papers free is a separate issue; however, it does have a bearing on publication costs. These costs are small compared to those incurred by indiscriminate paper publication.

To what conclusion does all this discussion lead us? Two facts of life are evident. First, we can no longer afford to publish trivial, reworked, repeated technology. Second, we need to stop rewarding people for quantity of publication and find some reward mechanism for quality. If we don't get the publication process in order, it is likely that some good work will suffer from lack of publication while the trivial material continues to be published.

R.L.E.

COMPUTER PROGRAMS FOR THE DIRECTIONAL RESPONSE OF HIGHWAY VEHICLES

J.E. Bernard*

Abstract - This review delineates the state of the art in the simulation of the directional response of highway vehicles. Modeling of tires, brakes, and suspensions is stressed. Two peripheral matters -- path-following techniques and the choice of computer hardware -- are also considered.

A systematic investigation of the problems of vehicle handling appeared in the literature during the 1930s and 1940s with the pioneering work of Olley [1]. Subsequent investigators developed linearized equations whose solution would yield the trajectory of a vehicle subject to steering [2] and the ride motions of a vehicle subject to rough road input [3]. Further advances in linear analysis have included transfer functions for the driver [4] and a detailed consideration of the roll degree of freedom [5].

Efforts have also been directed at analyzing various nonlinear aspects of vehicle systems. Perhaps the best overview of this subject is that of Ellis [6]. The equations of vehicle motion can become difficult in the general case; it is not surprising, therefore, that computer simulation has been frequently used by vehicle dynamicists.

Perhaps the best known early computer simulation was that of Ellis [7], who developed in 1961 a three-degree-of-freedom analog computer model for studying the lateral motion of an articulated vehicle. Since that time, the advent of ever more sophisticated equipment has allowed simulations of increasing complexity. Many research facilities now use highly nonlinear passenger car simulations with at least 14 degrees of freedom, including six degrees of freedom for the vehicle body, a vertical or wheel hop degree of freedom for each wheel, and a spin degree of freedom for each wheel. In addition, investigators have developed simulations that include impacts with curbs, other vehicles, and massive barriers.

These multi-degree-of-freedom nonlinear simulations are reviewed below. However, this is not to suggest that less complex models or linear analysis are less worthy tools. The trade-offs inherent in the complexity of vehicle simulations have been discussed [8].

A very large number of vehicle simulations are in use throughout the world. No attempt is made to rank these programs in this review. (Several simulations in the public domain in the United States have already been reviewed [9], and a brief critical review of several simulations of international stature has been published [10].) The following discussion is an attempt to delineate the state of the art with particular attention to three key areas: tires, brakes, and suspensions. Two short sections are concerned with simulation methodology; the first has to do with path-following and inverse techniques, the second the choice of computer hardware.

Vehicle ride is not explicitly treated in this review, but the models under discussion have sufficient degrees of freedom to allow consideration of rigid body ride motion in depth. However, ride quality is now understood to depend as much on beaming motion as on rigid body motion. Thus, an additional body of related literature has appeared, much of it concerned with analysis in the frequency domain [11, 12].

THE FORCES AND MOMENTS AT THE TIRE-ROAD INTERFACE

Because the trajectory of the vehicle is almost entirely dependent on forces and moments applied to the vehicle from the road, the representation of the tire-road interface is of primary interest in vehicle simulation. A schematic diagram of a tire showing these forces and moments at the tire-road interface is presented in the Figure.

The two purposes for modeling these forces and moments are to aid in understanding tire mechanics and to facilitate the simulation of selected tire-vehicle combinations. Although these two purposes are not entirely exclusive, the former is usually

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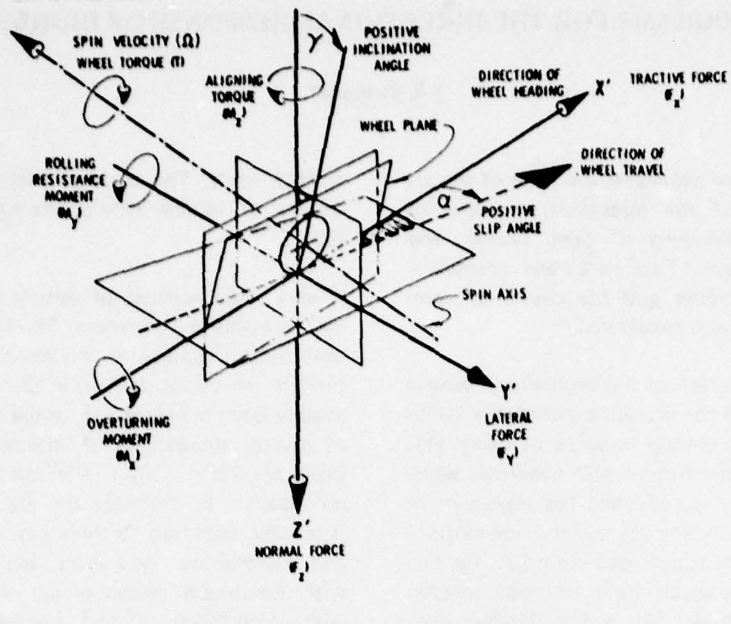

Kinematics of the Tire-Road Interface

considered to involve a detailed understanding of the role of various tire properties: toroidal geometry of the tire, cord, angles, plies, and belt compounding. The second purpose is to relate, as expeditiously as possible, the forces and moments at the tire-road interface to tire-road kinematics. This second purpose is of concern in this review.

Consider first the calculation of the forces at the tire-road interface. The forces are traditionally represented by a simple model for the normal force and a more complex model for the shear force.

Normal Forces

The choice of a simple model for the normal force reflects the fact that the simple model works very well for smooth road simulations, which are usually used. (Attempts to model the normal force in the presence of more demanding terrain have been described [13].) The present discussion is restricted to situations in which normal forces can be expected to be a straightforward function of the position of the tire. Methods for predicting and computing shear forces are briefly outlined below. A historical overview of this subject, as well as the development of associated experimental techniques, has been published [8].

Shear Forces

The variety of models that have been proposed for the shear forces at the tire-road interface are denoted in this review as semi-empirical, in contrast to empirical models, for which all needed data are obtained and directly entered into a vehicle simulation [10]. Empirical models range from extremely simple ones, in which lateral forces are computed from a measured slope at zero slip angle and a measure of the maximum force [7] to relatively complex algorithms, in which the input includes data measured at several loads and slip angles [10].

The character of the input tire data needed for effective computer simulation varies with the purpose of the calculations. But some measured data are needed so that the calculations can be compared favorably with field tests. Further, if maneuvers that push the tire into its nonlinear range are to be considered (nominally above 0.3 g on a dry surface), it is desirable to use input data from tests of the tire-surface combination of interest.

Of course, neither extreme care in modeling the tire nor large quantities of input data are warranted in every instance. In fact, a simple tire model with a correspondingly small empirical burden for input data may well suffice for low intensity turning maneuvers or for braking maneuvers that are either of low enough intensity so as to be well below the limits of the adhesion, or of such high intensity as to clearly preclude any rolling of the tire. More care is required for the following: when the level of turning pushes the tire into its nonlinear range, when braking near the limits of adhesion occurs, or when simultaneous braking and turning occur.

In the case of braking and turning, which is the most *difficult smooth road simulation*, either of two options may be used -- a classical or a modern approach. The classical approach entails a three-step procedure:

1. calculation of longitudinal force, F_x, on the basis of longitudinal slip and normal load.
2. calculation of free-rolling lateral force, $\bar{F}_y$, on the basis of lateral slip and normal load.
3. calculation of the lateral force, F_y, on the basis of F_x and $\bar{F}_y$.

The strength of this approach lies in its conceptual simplicity -- virtually any formulation can be used to compute F_x in Step 1 and $\bar{F}_y$ in Step 2. Step 3 *can then be a friction ellipse* [13], or a tabular function modifying $\bar{F}_y$ as a function of longitudinal slip [10, 14].

The success of this methodology has derived in large part from the fidelity of the calculations of F_x and $\bar{F}_y$. The F_x calculations have been based upon tabular μ-slip curves that can be made as accurate as is deemed reasonable, and the $\bar{F}_y$ calculations have been based on the Fiala formulation [15], which invariably provides a reasonable fit to measured free-rolling tire data for bias and bias-belted tires. An additional positive factor in favor of this approach derives from the tendency of a braked wheel to go to full lock in a severe braking maneuver. *In this instance the tire model need only predict* the lateral and longitudinal forces associated with a sliding, locked wheel.

Newer and so-called modern approaches to the modeling of shear force generation contrast with the above-defined classical approach in that the shear stresses in the contact patch are calculated as a function of longitudinal and lateral slip, normal load, and normal pressure distribution. The longitudinal and lateral forces are obtained by integrating the shear stresses over the contact area.

This procedure, which was first presented in 1970 [16], has been used in a number of vehicle dynamics studies [17]. A negative feature has been that the predictions of free-rolling lateral force were often not representative of real tires because so many simplifying assumptions had to be made. The assumption that the *normal pressure* at the tire-road interface is uniform leads to reasonable results for radial tires and inferior results for most bias and bias belted tires. Improvements to remedy this situation have been presented [8]. Thus the state of the art now includes the capability to accurately model measured braking and/or turning shear forces using either modern or classical models.

The advantage of modern techniques is that calculation of the interaction between F_x and F_y is based on a carefully conceived model of the tire-road interface rather than on the modification of F_x and F_y based on a preordained rule that might be inadequate. A carefully conceived model is particularly important in maneuvers involving turning while braking under action of anti-skid brake systems.

Moments

The moment about the z axis in the Figure, the so-called aligning torque, is important to vehicle directional response as a result of two separate effects, namely, the modification of steer angles due to the action of aligning torque on a compliant steering system, and the overall stabilizing effect on linear range turning maneuvers. The overturning moment (about the x axis) and the rolling resistance (about the y axis) are of lesser importance and are often neglected in computer simulations of vehicle directional response.

Aligning torque has not thus far been modeled with any success for use in computer simulation. Rather, the procedure has been to directly load in measured data [10] or to fit the measured data to a curve and load the curve-fit parameters into the simulation [18]. An appropriate reference for modeling efforts in this area was published in 1974 [19].

BRAKE SYSTEMS

In brakes, as in tires, there are two distinct purposes for mathematical modeling. Brakes are modeled to aid in the understanding of brake systems and to facilitate the simulation of selected vehicle-brake systems. To aid in the understanding of brake systems, several models have been proposed that allow the calculation of brake torque using submodels of such components as linings, drum, and cylinders. A few of these efforts have led to models simple enough to use in vehicle-brake system simulation [20].

Calculations aimed at vehicle-brake system analysis are more often performed using tables of brake dynamometer data as input to a simulation. Either of two types of a dynamometer data are commonly procured -- an inertial dynamometer can be loaded with the desired rotational inertia for spin down tests, or an instrumented vehicle may be used as a dynamometer in carefully controlled braking tests. (A third method, using constant velocity tests, has been presented [21].)

Whatever the particulars of the test methodology, however, variations in brake torque at a constant pressure will be obvious. But even though the variations are obvious, the functional dependence of variations on computable variables is not accurate. Calculation of brake torque for use in simulation of vehicle maneuvers thus remains beyond the state of the art. Further information has been published [22, 23, 24].

It should be emphasized that, despite the fact that accurate calculations are beyond the state of the art, useful simulations of braking vehicles are often performed. They range from extremely simple calculations to aid in sizing the brakes of particular vehicles [25] to extremely complex commercial vehicle anti-skid braking simulation [26].

SUSPENSION SYSTEMS

Historically, models have ranged from a fixed inclined roll axis, as suggested by Segel [2] in his pioneering work on linear analysis, to those with extremely general capabilities [10]. The limits presently imposed on the accuracy of the simulation involve the expense necessary to measure the parameters needed as input data rather than the mathematical models themselves. An explanation of a measurement facility designed to procure all the needed parameters has been given [27].

It is mainly in commercial vehicle suspensions that new approaches have been indicated in recent publications. The facets of this area that have received special attention are tandem axle dynamics [28, 29] and the handling of large amounts of coulomb friction [30].

SOME NOTES ON PATH FOLLOWING

In traditional nonlinear vehicle simulations, the input variables include the actions of the driver via steering motions (steering wheel angle or road wheel angle) and braking levels (line pressure). The output is then the vehicle's motion, as indicated by the calculated state variables. Thus, validation work has involved calculating vehicle motions based on a given input, applying this same input to a test vehicle, and then comparing measurements and calculations. The advantage of the relatively clean validation methodology is offset by the disadvantage that time-varying steering and braking must be determined a priori, thus making impossible the use of calculations to study the demands placed on a vehicle or driver-vehicle system attempting to follow a given path.

One useful modification of traditional techniques has been wagon-tongue steering [13], in which steer angle calculations are based on the error between the vehicle's path and some desired path. Such calculations can be cumbersome, however, because the loop must be very carefully closed to avoid unwanted oscillations. (The ultimate loop closure, a model of the driver, is briefly discussed below.)

A more frequently used mechanism for path-following is the inverse technique, in which the path replaces steering and braking as an input function of time, and the steering and braking levels become state variables to be computed. Two well-known examples of the inverse technique have been published [31, 32].

The advantage of the inverse technique is that a particular path of interest can be used as input. Disadvantages include the increased difficulty of validation and the fact that highly complex models do not lend themselves to the required variable inversion. Further, such timely topics as antilock brake analysis are incompatible with inverse techniques.

The obvious extension of this work would be to model the performance of driver-vehicle as a system, a task now beyond the state of the art. However, promising related work in this area has been performed using linear models [4].

THE METHODOLOGY OF THE CALCULATIONS -- AN OVERVIEW

It is obvious that mathematical tools and computer hardware are available to perform several tasks of interest in vehicle simulations. A related question that merits attention is a mechanistic one: should analog, hybrid, or digital calculations be used? The answer to this question has been changing as computer hardware has evolved. A reasonable position at the present time includes the following:

1. Analog hardware is valuable for its potential for real time use. However, significant digital capability is required to handle the kinematics of the most complex models and to compute the shear forces at the tire-road interface. Purely analog operations are thus limited to relatively simple models.

2. Hybrid simulation is clearly appropriate in many instances, particularly those in which several (hundreds, at least) similar calculations are frequently performed in open loop sequence or in which real time capability is required [10, 14]. (Not all hybrid vehicle simulations run real time, as the digital side may not be able to keep up.)

3. Digital calculations have two advantages over hybrid calculations: the programs can easily be modified, and continuing maintenance is not necessary. The major drawbacks, compared to hybrid computation, are the inability to perform real time calculations and the expense associated with a large number of runs. (The expense of digital calculations is approximately linear with the number of runs; hybrid costs drop as setup time is amortized over more runs.) However, costs of digital calculations continue to drop due to hardware improvements and software modifications [33].

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LITERATURE REVIEW

survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four review articles each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the DIGEST reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

In this issue of the DIGEST a series of four articles on seismic waves by Dr. S. De are initiated. An introduction to seismic waves is provided in this issue.

The last article on parametric vibrations involving stochastic problems written by Drs. R.A. Ibrahim and J.W. Roberts is included in the literature review.

ON SEISMIC WAVES
PART I: INTRODUCTION

S. De*

Abstract - This review of Seismic Waves is divided into four parts:

I. Introduction
II. Surface Waves and Guided Waves
III. Mathematical Methods (1)
IV. Mathematical Methods (2)

The articles review principal developments and recent literature in the area.

Any event that causes sudden motion of a part of the earth -- from a falling boulder to an earthquake -- causes a seismic disturbance. Earthquakes caused by the release of elastic strain energy are called tectonic earthquakes. Small ground movements that last one or two seconds and are due to such local disturbances as traffic or wind are called micro-seisms. Seismology involves the study of the propagation of elastic waves.

Seismic properties of earth. The earth consists of three zones -- crust, mantle, and core. The outermost 30 to 40 km (18 to 24 mi), often referred to as the crustal layer, is much more heterogeneous than the region below, at least in continental regions. A study of seismograms during an earthquake in 1910 showed that the velocities of waves known as primary (P) and secondary (S) increased abruptly below a depth of about 50 km [1, 2]. This abrupt change, known as the Mohorovičič discontinuity (Moho) after the man who discovered it, was attributed to a change in the character of the crustal layers (Figure 1). The Moho marks the bottom of the earth's crust and separates it from the mantle. There is a world wide discontinuity in the mantle at a depth of about 500 km.

The density of the mantle increases from about 3.3 g/cm^3 just below the Mohorovičič discontinuity to about 5.7 g/cm^3 at the lower boundary of the mantle. It then increases from 9.4 g/cm^3 to 11.5 g/cm^3 at the bottom of the outer core. The density is much greater in the inner core. Rigidity (resistance to shearing stress) increases in the mantle, the lower limits being almost four times more rigid than steel. The outer core is not very rigid; indeed, it is said to be fluid.

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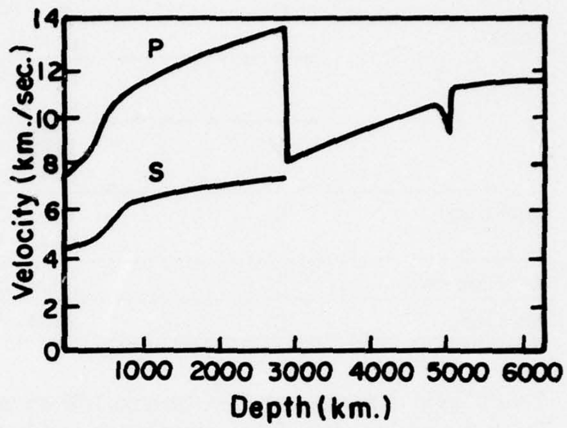

Figure 1. Velocity as a Function of Depth According to H. Jeffreys

Incompressibility (resistance to pressure) does not change substantially at the core boundary. The pressure is about 1.3 x 10^6 atmospheres at the bottom of the mantle and about 4 x 10^6 atm. at the center of the earth. Bullen [3] concluded that the inner core is most likely solid.

Granite, one of the main constituents of the continental crust, is absent under the deep oceans, where the crust is appreciably thinner than that underlying the continents. The upper mantle is thought to consist of ultrabasaltic rock rich in olivine. The character of olivine is believed to change in regions where velocities of seismic waves increase strongly. At one time it was thought that the core consisted of iron and nickel, but recent investigations suggest that the outer core consists of material similar to that of the mantle but transformed by the prevailing high pressure. The inner core is still believed to consist chiefly of iron and nickel.

Jeffreys - Bullen Seismic Travel Time

Name	Region	Range of Depth (miles)	P Velocity (miles/sec)	S Velocity (miles/sec)
crustal layers	A	0 - 25 (density just below the crust, $\varphi = 3.3 g/cm^3$)	widely variable	widely variable
mantle	B	25 - 250 ($\varphi = 3.3 - 3.6 g/cm^3$)	5.0 - 5.6	2.7 - 3.1
	C	250 - 600 ($\varphi = 3.6 - 4.7 g/cm^3$)	5.6 - 7.1	3.1 - 4.0
	D'	600 - 1700 ($\varphi = 4.7 - 5.7 g/cm^3$)	7.1 - 8.5	4.0 - 4.6
	D''	1700 - 1800 ($\varphi = 4.7 - 5.7 g/cm^3$)	8.5	4.6
outer core	E	1800 - 3100 ($9.4 - 11.5 g/cm^3$)	5.0 - 6.8	assumed zero
transition region	F	3100 - 3200	6.8 - 7.0	not observed
inner core	G	3200 - 3960	7.0 - 7.1	not observed

A sharp jump in density occurs in the ratio 1.65 across the boundary between the mantle and the central core. The density at the center of the earth is between 14.5 and 18.

Waves travel more slowly in the crust than in the mantle beneath; waves passing through the crust are therefore refracted and bent upward when they meet the mantle. Both refracted and direct waves will reach the surface within a certain distance from their origin (Figure 2). The refracted wave will overtake the direct wave because the former travels faster in the lower layer. But, because its path is longer, more energy is lost and the phase recorded on a seismogram will be smaller than that due to the direct wave. Therefore a small P phase appears succeeded by another much larger P phase.

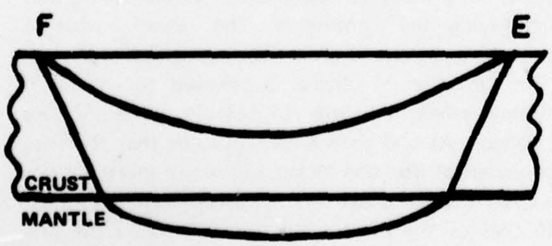

Figure 2. Direct and Refracted Rays from Focus (F) to Epicenter (E) *(see text)*

General features of waves. The waves that constitute an earthquake are of two types: body waves which travel through the interior of the mass in which they are generated; and surface waves which travel only along the surface. Surface waves contribute mostly to the disturbance in the far-field and consequently are responsible for most of an earthquake's disastrous effects. Although surface waves travel near the earth's surface, their energy is distributed to considerable depths. The energy of a long wave thus penetrates to a greater depth than that of a short wave. Because wave velocity increases with depth due to the character of the earth, the energy of a wave travels faster than that of a shorter wave and arrives first at a distant station. The rate of dispersion of surface waves is used to study changes in wave velocity with distance from the earth's surface [4, 5].

The study of body waves provides information about the nature of the forces acting at the point at which an earthquake originates and about the character of the earth's interior. The earth can be considered an unbounded isotropic solid. Two types of elastic wave can be propagated in such a solid: dilatational (irrotational) and distortional (equivoluminal). The earth transmits seismic waves because it contains deformable material, but the earth is not perfectly elastic near the surface. The manner of transmission of seismic waves through such inelastic substances is not well known, but in general the same types of pulses are to be expected. The main effects are distortion of pulse shape, increased energy absorption, and the spread of the pulse in time [6]. Dilatational waves travel at a velocity of $[(\lambda + 2\mu)/\rho]^{1/2}$. The velocity of distortional waves is equal to $(\mu/\rho)^{1/2}$. In these expressions λ and μ are Lame's constants and ρ is the density of the medium.

The first type of elastic wave that radiates into the earth during an earthquake is known as a sound wave or push-pull wave. Such waves can travel through any material -- solid, liquid, or gas. The particle motions are parallel to the direction of energy transmission.

When an earthquake occurs, the point, or limited region, from which energy first radiates is called the focus or hypocenter. No focus has been recorded at a depth greater than 700 km. The distance from the focus to the surface is so much larger than the dimensions of the focal region that the curvature of wave fronts can be neglected. The epicenter -- the point of the earth's surface directly above the focus -- can be estimated from the time interval between two responses, one caused by a transverse wave and the other by a longitudinal wave.

Three wave patterns are recorded on seismographs: primary (P), secondary (S), and long (L). S waves are usually larger in amplitude than P waves, but P waves move faster. P and S waves travel from the focus through the interior of the earth to a recording station.

In general, L waves lack a distinct beginning and gradually increase in amplitude. The earliest L waves generally have the longest periods. They travel from the epicenter along the earth's surface to the recording station, arriving after P and S waves (Figure 3).

A series of L waves that arrives at a station particularly early and has an exceedingly long period is generated by a pulse called a G pulse. The largest L wave is labeled M; the part of the earthquake following this maximum wave is called the coda [6].

P pulses produce dilatational waves, and S pulses produce shear waves. In seismology, an S wave so polarized that all particles move horizontally during its passage is known as an SH wave. When the particles move in vertical planes, one of which is the direction of propagation, the wave is known as a

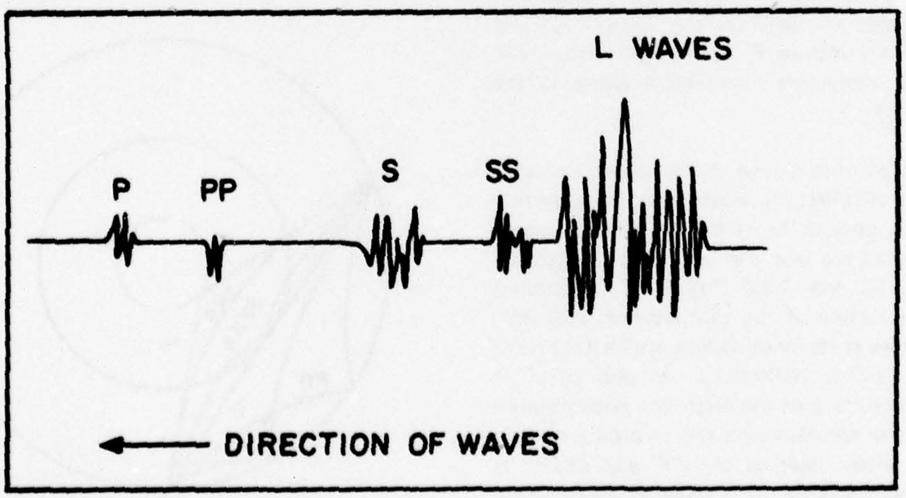

Figure 3. Typical Recorded Wave Patterns. Primary (P) Waves, Reflected P (PP) Waves, Secondary (S) Waves, Reflected S (SS) Waves, and Surface (L) Waves

SV wave. Travel-time tables are used to determine velocity distributions of P and S waves in the earth.

Not all of the strain energy accumulated in the earth is released during a single earthquake. The total energy of the aftershocks can equal, and even exceed, that of the original shock. Sometimes many hundred of aftershocks occur over a period of months.

The degree of violence of an earthquake is assessed according to the degree of shaking perceptible to humans, the degree to which man-made structures are damaged, and the nature of visible deformations of the earth itself. The energy released during an earthquake can be estimated by measuring the amplitudes of ground motions recorded by seismographs.

If the frequency of vibrations caused by an earthquake corresponds to the natural frequency of oscillation of any body of water -- a bay, pond, or lake -- a resonance phenomenon can occur: the amplitude of water gradually increases until the seismic waves pass, then decreases for a considerable time. Such oscillations, called seiches, are often observed at distances far from where an earthquake is felt [6].

Classification of waves. Waves can be classified by the number of reflections they undergo along their path. Reflected waves can be large, but those that are not reflected are generally the largest and most important. They include P, S, PKP (P'), PKS, SKP, and SKS; K represents longitudinal waves in the core (Figure 4).

Waves reflected once can be characterized according to the point of reflection. Waves in which reflection occurs at an obvious point on the earth's surface between the source and the station are designated PP, PS, SP, SS and SKSP (Figure 5). Reflections at the outer surface of the core are PcP, PcS, ScP, and ScS. Those at its inner surface are PKKP, PKKS, SKKP, and SKKS. Reflections can also occur at points on the surface of the earth at a great distance from both the epicenter and the recording station; those most often observed are P'P' and SKPP'. It is usually not possible to distinguish SKPP' from PKSP', P', SKP, or P'PKS. They arrive at the station about the same time unless the hypocenter is very deep. Another group that sometimes occurs almost

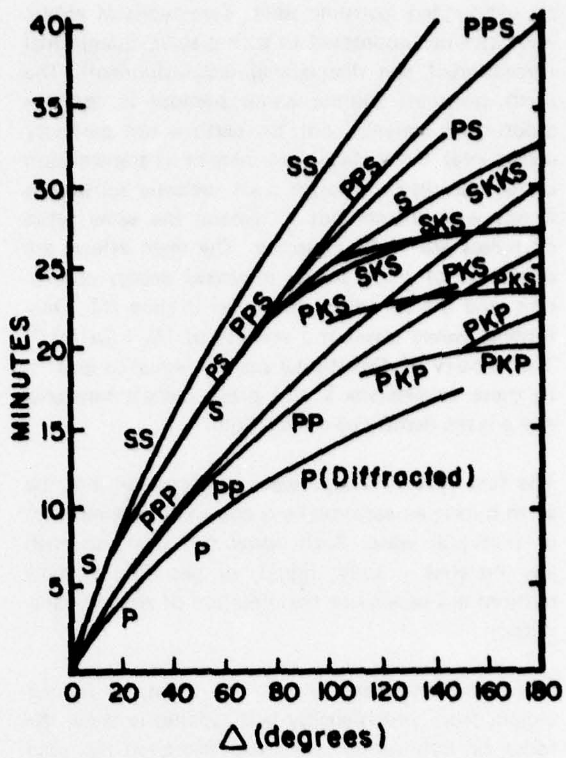

Figure 4. Travel-Times for a Surface Focus (Jeffreys-Bullen)

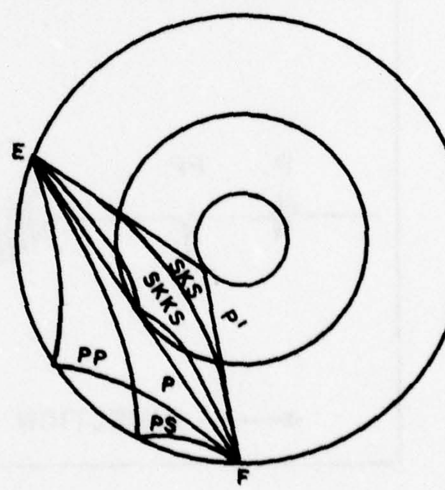

Figure 5. Rays from Focus (F) to Epicenter (E) at a Distance of 108° (see text)

simultaneously is PK, SPKS, PKSSKP, SKPPKS, and SKPSKP. Some SKSSKS have been observed. Reflected waves comparatively near the epicenter are observed for the most part during deep-focus earthquakes. The notation used for such waves and for repeated reflections has been published [7].

*Nonhomogeneities in the earth's surface cause reflec*tion and refraction of the elastic waves caused by an earthquake. When a dilatational wave of velocity C_1 is incident on a free surface, two reflected waves are generated. One, a dilatational wave, is reflected at an angle equal to the angle of incidence α; the other, a distortional wave of velocity C_2, is reflected at a smaller angle β, where $\sin\beta/\sin\alpha = C_2/C_1$. Similarly, if a distortional wave is incident on a free boundary at an angle β, both a distortional and a dilatational wave are generally reflected. The distortional wave is reflected at an angle β and the dilatational wave at an angle α.

The shadow zone for the P phase extends from about 105° to 143° epicentral distance. The P phase is usually weak in strong earthquakes. The appearance of P waves in the shadow zone can be due either to diffraction around the boundary of the earth's core or to a spreading of rays caused by a gradual decrease in wave velocity just outside the core. In addition to this weak P phase, later weak P phase occurs in the shadow zone.

Study of seismic waves. The theoretical study of wave propagation involves solving a partial differential equation or a system of such equations under certain initial and boundary conditions and interpreting the results. The frequency equation for surface waves in various models of the earth having vertical and/or lateral nonhomogeneity and/or anisotropy have been derived using the normal mode theory and the ray theory.

The electrical state of the earth and the electrical properties of rocks and minerals under different geological environments, are used in seismology. Geoelectric exploration uses the principles of geoelectricity to map concealed structures, to explore for ores, minerals, and oil, and to solve hydrogeological and engineering problems. Both stationary and variable currents are used; they are produced either artificially or by natural processes.

Problems involving body waves have been solved by suitably representing their sources -- including arbitrary shear dislocation, jumps in displacement and stress across the surface passing through a focus, arbitrary spherical sources, and finite line sources.

Quantities associated with linear seismic waves include wavelength and wave number, period or frequency, and velocity -- i.e., phase velocity and group velocity with which the energy propagates. Special techniques are required to define these quantities for nonlinear waves. Because no general methods exist for solving nonlinear partial differential equations, specific methods are used for individual problems. Analytic and approximate methods are used, as are computers.

Existence and uniqueness theorems applied to nonlinear partial differential equations (and the nonlinear seismic waves represented by them) are important; the next step will be the development of a constructive theory, in which the solution for a given boundary value and eigenvalue problem can be put to practical use.

The object of these articles is to review principal developments and recent literature in the hope of providing research direction. The mathematical methods used to study seismic waves are outlined. Information about theoretical developments associated with body waves, surface waves, and free oscillations of the earth has been published [8].

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PARAMETRIC VIBRATION
PART V: STOCHASTIC PROBLEMS

R.A. Ibrahim* and J.W. Roberts**

***Abstract** - This survey of the theory of parametric vibration and its related current problems consists of five review articles. The titles are:*

I. Mechanics of Linear Problems
II. Mechanics of Nonlinear Problems
III. Current Problems (1)
IV. Current Problems (2)
V. Stochastic Problems

Because it is inconvenient to refer to all published materials, the authors have tried to review the most important literature and to emphasize recent results. Parts IV and V contain lists of unreferenced literature.

The preceding articles in this series reviewed the deterministic approach to the analysis of parametric vibration problems. In many problems of engineering interest, however, either the excitation or the time variation of the system parameters is not periodic. That the deterministic approach is an idealization and simplification of the actual behavior of such systems during parametric vibration is known to the many authors who have investigated such behavior. In attempting to overcome this problem, they have modeled complex forms of excitation as random processes. The analysis of such processes involves probability theory and the theory of stochastic differential equations. System response and stability properties are characterized by probability measures and problems of statistical estimation arise when attempts are made to relate the results of such procedures to experimental observations. In addition, the level of mathematical difficulty associated with such analyses has restricted development of the theory of random parametric vibration.

This final article of the series is a review of published work on the stability and response of linear and nonlinear vibratory systems under random parametric excitation. A substantial body of literature exists on the stability theory of stochastic differential equations. The theory has been applied to such fields as optimal control, filtering, and prediction theory, as well as structural dynamics. A useful survey of the various modes of stochastic stability has been published [1].

The present review is concerned principally with work that is directly relevant to actual problems in engineering dynamics and structural vibration. The three methods most widely used to analyze random vibration problems are: the Fokker-Planck method, the averaging method, and the Liapunov direct method. The results obtained with these approaches are reviewed, and additional methods that have been applied to specific problems are considered. Published experimental work and analog computer studies are described.

THE FOKKER-PLANCK METHOD

The Fokker-Planck method is valid for a wide range of random excitation problems the system equations of which can be written in the form of a so-called Langevin stochastic differential equation with additive white noise [2].

$$\frac{dx_i}{dt} = f_i(x_j,t) + G(x_j,t)\, W_i(t) \qquad (1)$$

In equation (1), x_i is the n dimensional state vector; $f_i(\ )$ is a vector function of the state variables, possibly nonlinear; G is a matrix; and $W_i(t)$ is a vector of white noise or shot processes. For such systems the response is a vector Markov process; that is, the conditional probability density function is independent of all but the most recent realization.

$$p(\underset{\sim}{x}(t_k) \mid \underset{\sim}{x}(t_1), \underset{\sim}{x}(t_2) \ldots\ldots \underset{\sim}{x}(t_{k-1})) = p(\underset{\sim}{x}(t_k) \mid \underset{\sim}{x}(t_{k-1})) \qquad (2)$$

$$t_k > t_{k-1} > \ldots\ldots t_1$$

The evolution of the transition probability density of the process $p(\underset{\sim}{x}(t) \mid \underset{\sim}{x}(t_0))$ is described by the Fokker-Planck equation [3-7], also known as the forward Kolmogorov equation.

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$$\frac{\partial p}{\partial t} = -\sum_{i=1}^{n} \frac{\partial}{\partial x_i} [a_i(\underline{x}, t)p] + \tfrac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\partial}{\partial x_i \partial x_j} [b_{ij}(\underline{x}, t)p] \quad (3)$$

In equation (2) $a_i(\underline{x}, t)$ and $b_{ij}(\underline{x}, t)$ are the first and second incremental moments of the Markov process $\underline{x}(t)$. These are determined from equation (1) as

$$a_i(\underline{x}, t) = \lim_{\delta t \to 0} \frac{1}{\delta t} E\left\{x_i(t+\delta t) - x_i(t)\right\}$$

$$b_{ij}(\underline{x}, t) = \lim_{\delta t \to 0} \frac{1}{\delta t} E\left\{[x_i(t+\delta t) - x_i(t)][x_j(t+\delta t) - x_j(t)]\right\} \quad (4)$$

$E\{\ \}$ denotes expectation.

It is generally not possible to obtain an analytical solution for equation (3) in terms of the process *transition probability* function. The existence and uniqueness of the solutions of equation (3) have been discussed [3, 4, 8]. Caughey [3, 4] determined a number of conditions for the governing equations of the system by which solutions can be obtained:

- no inertial or damping coupling exists between the generalized coordinates of the system.
- the correlation function matrix of the excitation is proportional to the damping matrix of the system.
- the system restoring forces are conservative.

For the majority of dynamical systems, it is unlikely that all of these conditions will apply. Fundamental solutions of the Fokker-Planck equation have been derived for only a limited number of special cases of systems with stochastic coefficients [9-14].

White Noise Controversy

The Fokker-Planck approach has stimulated considerable discussion. In the case of random parametric excitation controversial results have been obtained for the incremental moment coefficients "a_i" of apparently identical systems of the type expressed in equation (1) by Caughey and Dienes [11] on the one hand and by Kozin and Bogdanoff [15] and Astrom [9] on the other. The difficulty is the nature of the white noise processes $W_i(t)$. From the engineering point of view, white noise has a flat spectral density up to some high frequency limit such that its correlation time is very short compared with any characteristic system response time. In this case the sample functions of the process are integrable with the probability function.

However, for strict application of the Markov vector approach, $W_i(t)$ must be regarded as mathematical white noise having a constant spectral density up to infinite frequency, in which case it is physically unrealizable, having an infinite mean square and a correlation function of Dirac delta form. It is customary to regard such a process as the formal derivative of the Brownian or Wiener-Levy process $(B_i(t),\ t > t_o)$; i.e., $W_i(t) \equiv \frac{dB_i}{dt}$, where $B_i(t)$ is a zero mean Gaussian process with independent increment. But such a process presents considerable mathematical difficulties. It is known [2, 16] that the Wiener process has sample function continuity but is not differential in any sense, the sample functions being of unbounded variation. Similarly, the white noise process is not integrable in a mean-square Riemann sense, and in a strict sense equation (1) has no mathematical meaning. This is a property of the ideal white noise process [2, 16, 17].

The mathematical difficulty has been resolved by using an alternative form of equation (1) in terms of the increments of the Wiener process:

$$dx_i(t) = f_i(x_j, t)\, dt + G(x_j, t)\, dB_i \quad (5)$$

Although equations (1) and (5) might appear identical, they are essentially different. Equation (5) must be interpreted as a relationship between integrals as follows:

$$x_i(t) - x_i(t_o) = \int_{t_o}^{t} f_i(x_j, \tau)\, d\tau + \int_{t_o}^{t} G(x_j, \tau)\, dB_i(\tau) \quad (6)$$

The final integral in equation (6) does not exist with probability one as a mean-square Riemann integral and is a specifically defined Ito stochastic integral. The form of equation (5) is referred to as an Ito stochastic equation [18, 19]. Definitions, properties, and the calculus of operations involving stochastic integrals can be found in books by Doob [16] and Kushner [20, 21].

Gray and Caughey [17] examined the apparent paradox of the different forms of the Fokker-Planck equation as expressed in equation (1) and equation (5). Gray and Caughey compared the mathematical derivation of the Fokker-Planck equations -- using the properties of the stochastic integral -- with the physical derivation, in which the white noise parametric excitation is considered a limit of a realizable wideband Gaussian process, such that integrability of the sample functions is preserved. They showed that the two approaches led to different forms for the first incremental moment coefficients a_i, the difference arising as a result of the defined properties of the stochastic integral.

Similarly, Ariaratnam and Graefe [22] examined the Fokker-Planck equation for a system of n first order state equations with a combination of random forcing and parametric terms. They found that the form of the first incremental moments depended on whether the random functions were Gaussian white processes or increments of Brownian processes. Their results confirmed those of Gray and Caughey [17].

System Moment Equations

Although it is generally not possible to obtain a solution for the transition probability of most systems, it is usually possible to derive from the Fokker-Planck equation a set of differential equations for the moments of any order of the system response. This important development was apparently first used by Caughey and Dienes [11] who indicated that the moments of $p(x, t \mid x_0, t_0)$ of any order N

$$m_{k1,k2,k3\ldots k_n} = E\{x_1^{k1}, x_2^{k2}, \ldots x_n^{kn}\} \qquad (7)$$

$$N(=k1 + k2 + \ldots kn) = 1, 2, 3 \ldots\ldots$$

can be obtained by multiplying the system Fokker-Planck equation by $(x_1^{k1}, x_2^{k2}, \ldots x_n^{kn})$ and integrating by parts over the entire state space $-\infty < x_i < \infty$. This approach has been widely used to obtain practical results concerning the stability of random parametric systems [22-25].

Ariaratnam and Graefe [23] and Bogdanoff and Kozin [25] obtained general stability criteria for linear systems and clarified the question of whether or not an inherently unstable linear system could be stabilized by random variation of its parameters. Their results supported the argument of Caughey [26] against Samuels [27] and showed that the addition of a random parametric variation would not stabilize such systems. (see also the work of Rabotnikov [28]). Leibowitz [29] obtained similar results for systems with Gaussian shot noise coefficients.

Gray [30], Ariaratnam and Graefe [24], and others [31, 32] extended the application of the Fokker-Planck method to the linear nth order differential equation

$$\frac{d^n}{dt^n} x(t) + \sum_{k=0}^{n-1} [b_k + W_k(t) \frac{d^k}{dt^k} x(t)] = W(t) \qquad (8)$$

and obtained expressions for the moments, correlation functions, and spectral densities of the system responses. Gray [30] showed that the spectral density of a linear parametric system is identical to that of an equivalent linear system in which the parametric excitation has been replaced by an equivalent nonhomogeneous random forcing term. The Fokker-Planck approach has also been used to develop necessary and sufficient conditions for mean square stability [32]. The so-called frozen system -- obtained by setting the stochastic coefficients to zero -- was introduced in this approach; the stability criteria are based upon the assumption that the frozen system is asymptotically stable. Nakamizo and Sawaraji [33] generalized the results to the nth order linear equation of the type shown in equation (8).

The stochastic stability of such real systems as the free surface of a liquid inside a cylindrical tank subjected to a random vertical acceleration [34], a pin-ended column [35, 36], and elastic structures [37] subjected to random axial loading have been investigated for the case of Gaussian white noise excitation.

These studies indicated that, for systems satisfying equations of motion of the form

$$\ddot{y} + 2\zeta\omega_0\dot{y} + [\omega_0^2 - \alpha(t)]y = 0 \qquad (9)$$

where ω_0 is the natural frequency, ζ the damping ratio, and $\alpha(t)$ a Gaussian white noise process with spectral density S_0 such that

$$E[\alpha(t_1)\,\alpha(t_2)] = 2\,S_0\,\delta(t_1 - t_2) \qquad (10)$$

The system response y(t) is stable in the mean square if the excitation spectral density S_0 satisfies a simple inequality

$$S_0 < 2\zeta\omega_0^3 \qquad (11)$$

Non-White Parametric Excitation

Non-white parametric excitation has considerable practical significance. The Markov vector approach can be applied if the non-white processes are considered to be derived by linear filtering from white noise sources. The state equations of the system are then augmented by a set of first order filter equations. However, the moment equations of any order derived from the Fokker-Planck equation are coupled with moments of higher order. The moment equations of the system form a set of so-called infinite hierarchy equations [25, 38-41]. A similar situation results if the system equations contain nonlinear terms. Such coupling causes serious difficulties in determinations of system responses or of stability criteria in terms of mean squares [25].

Bogdanoff and Kozin [25] and Bolotin [42] obtained an infinite set of moment equations for second order systems excited parametrically by filtered Gaussian white noise. Bolotin [42] assumed that higher order moments were related to lower order moments by multi-dimensional Gaussian process relations, with the cumulants of the corresponding order equated to zero. He used a truncated linearized form of the moment equations and obtained approximate conditions for the second moment stability. He plotted the stability boundaries for various values of the damping parameter on a chart (Figure 1) similar to the Strutt diagram of Mathieu's equation. Figure 1 has two regions of instability: one when the center frequency of the excitation is in the neighborhood of twice the system natural frequency, and another when the center frequency is close to the system natural frequency.

Wedig [43-45] followed another approach for similar systems: parametric excitation was obtained by passing Gaussian white noise either through a low-bass filter or a band-bass filter. The resulting moment equations were weakly coupled with higher order

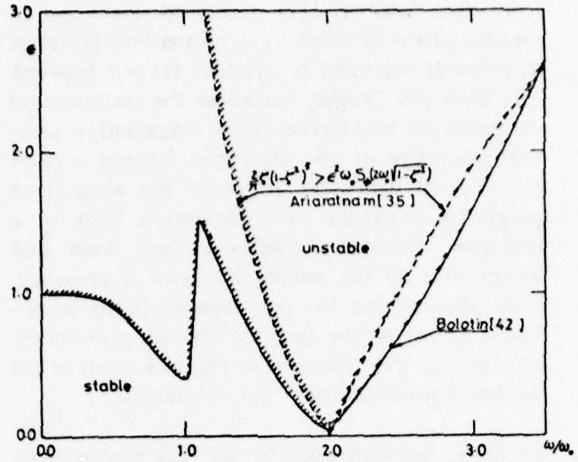


Figure 1. Stochastic Stability Boundaries of a Linear System
$\ddot{x} + 2\omega_0\zeta\dot{x} + \omega_0^2\,[1 - \epsilon\Phi(t)]\,x = 0,$
filter equation $\ddot{\Phi} + 2\omega\eta\dot{\Phi} + \omega^2\Phi = W(t)$

moments. Wedig used a perturbation technique in which the eigen-frequency and eigenvector were expanded in power series of a small parameter ϵ. He obtained approximate expressions for the critical variance ϕ of the parametric excitation, which defines the limit of the instability regions. The boundaries of these regions, shown in Figure 2, have features similar to those obtained by Bolotin. Wedig showed that the destabilizing effect decreased as the bandwidth of the band-bass process was *increased.* He extended his method for a two-degree-of-freedom system excited parametrically by a random narrow-band process [46] and obtained three regions of instability in the mean square sense in the neighborhood of $2\omega_1$, $2\omega_2$, and $\omega_1 + \omega_2$ (where ω_1 and ω_2 are the natural frequencies of the two modes).

The problem of the infinite hierarchy of moment equations has been discussed [38-41]. A number of truncation schemes have been examined for elementary cases with attention to the need to preserve essential moment properties such as non-negativity mean squares and variances. Thus far these schemes have no rigorous mathematical basis.

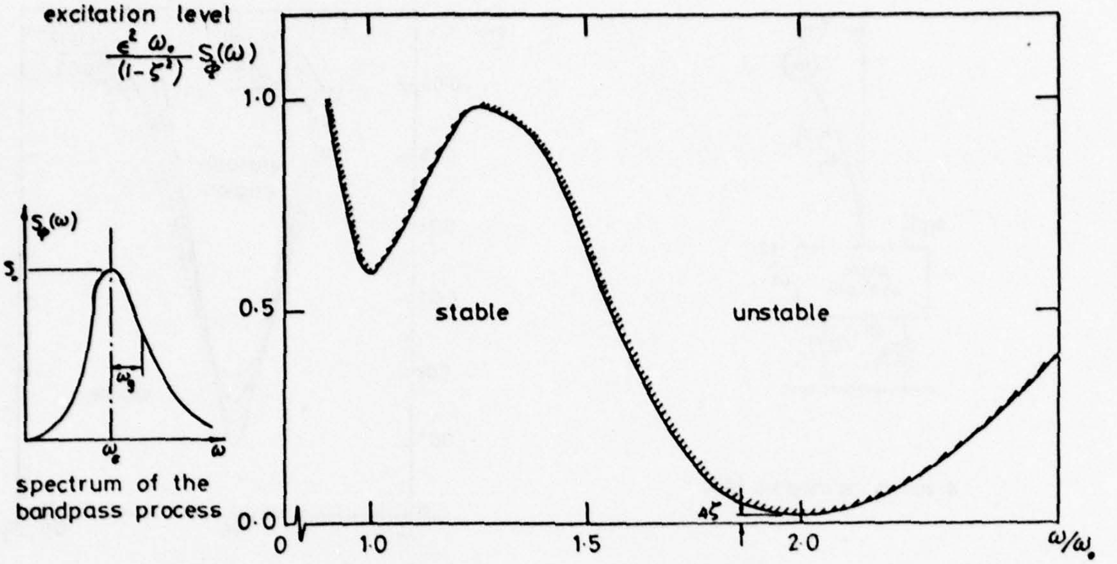


Figure 2. Stability Boundary of a Parametric Bandpass Process [45]

Systems with Autoparametric Coupling

The Fokker-Planck approach has also been applied to systems in which nonlinear coupling known as autoparametric coupling occurs. Ibrahim and Roberts [47, 48] considered a two-degree-of-freedom system with autoparametric coupling in which the primary system was excited by stationary white noise. It was assumed that for small nonlinearity the joint density function of the responses did not depart significantly from Gaussian form; third and higher order moments were expressed in terms of first and second moments.

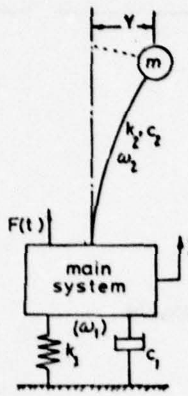
Results for the system response moments were obtained by numerical integration of a set of 14 moment equations. The results indicated that, when the system was close to the internal resonance condition, large random motions of the coupled system occurred and gave rise to a suppression effect on the primary system. In the vicinity of the internal resonance condition the random motions of the system were quasi-stationary, and steady oscillatory terms appeared in the response moments (Figure 3).

The stability of the linear solution was examined for the same system [48]. Stability boundaries were expressed in terms of excitation and system parameters, beyond which coupled random motions would occur. It was demonstrated that the damping coefficient of the primary system could have a destabilizing effect (Figure 4). Similar results have been obtained for some systems excited by random parametric excitation [49, 50]. The Gaussian approximation for high order moments had been used previously by Bolotin [42] and Newland [51] in a study of energy transfer between modes with some nonlinear coupling. A perturbation technique was used in the latter study to demonstrate the significance of internal resonance in determining mean square modal response.

Although the Fokker-Planck method has contributed to the analysis of systems with random parametric excitation, further work is needed to develop rational truncation schemes for moment equations and to extend the treatment of nonlinear coupling in multi-degree-of-freedom systems by numerical integration techniques.

THE AVERAGING METHOD

The averaging method has been used in deterministic problems with periodic coefficients. One such class of problems involves non-stationary vibrations caused by time variation in the frequency of a parametric excitation [52]. The transition from purely



a. schematic diagram [47]

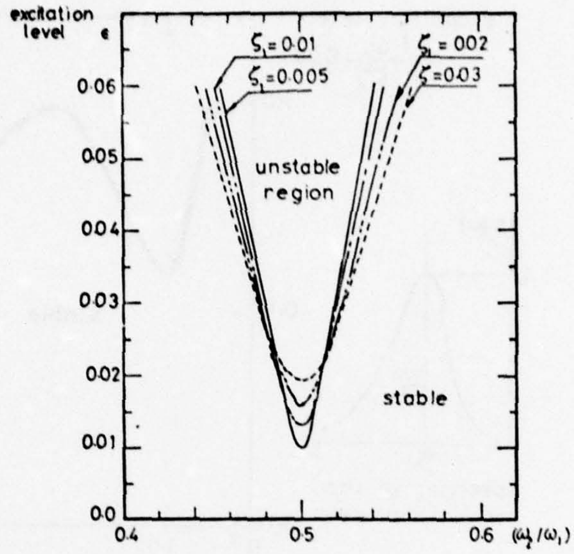
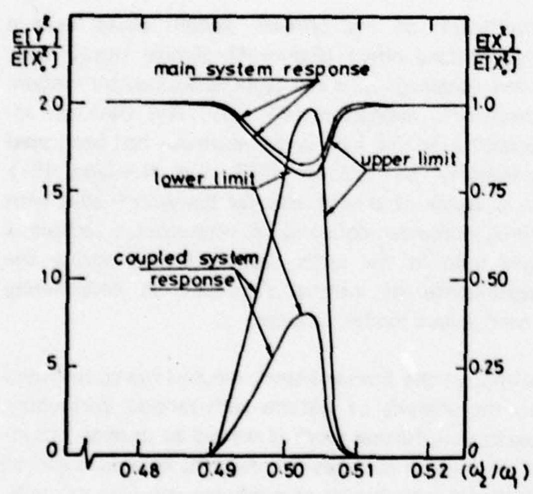


Figure 4. Stability Boundaries of the Stationary Solution of the Autoparametric System of Figure 3 [48]



b. limits of quasi-stationary second moments $E[X_0^2]$ is the second moment of the system without coupling

Figure 3. An Autoparametric System

harmonic parametric excitation to strong fluctuation scatter has been studied [7]. During the transition the spectral density of the oscillations, initially in the shape of a delta function, becomes progressively broader.

The effects of high frequency quasi-periodic parametric excitation on the stability of dynamical systems have been examined [53-61] by using the inverted pendulum as a model and applying the averaging method [62]. Stability analysis of the inverted pendulum involves the derivation of equations governing the evolution of certain smoothed coordinates of the system [53-56, 59]. The equations are averaged over a time interval that is short compared with the time scale of variation of the smoothed coordinates, yet large compared with a typical period of parametric excitation. Thus it is assumed that the smoothed coordinates remain fixed during averaging.

Bogdanoff [53] established the validity of this procedure for stochastic support motions under certain conditions. He assumed that the power spectrum of the high frequency imposed motions is discrete, and that frequency differences are large compared to the imaginary parts of the characteristic roots of the averaged equations.

Bogdanoff and Citron [54, 55] pointed out that a pendulum stabilized in the upward position with a discrete high frequency support oscillation could be destabilized by adding a continuous spectrum of Gaussian random noise. Hemp and Sethna [58] showed that the effect of support motion at two frequencies close to each other can destabilize the pendulum. Sethna [63] mentioned that it is not possible to stabilize an inverted pendulum unless the power spectrum of the parametric fluctuations is zero in the neighborhood of the origin. He extended the method of averaging and obtained a criterion for the stability of the pendulum subjected to arbitrary rapid support motion [61]. Mitchell [60] added that the pendulum exhibits instability when one excitation frequency is about twice the other. He also demonstrated that additional regions of instability appear when the difference between two frequencies of an almost periodic support motion is small. Analog computer simulation [60] has indicated that the pendulum can be stabilized when the damping in the system is sufficiently large and the support motion is a stochastic process with a high-pass power spectral density function.

Howe [59] confirmed the results obtained by Bogdanoff [53-55] and derived another condition involving the power spectrum of the effective support excitations at twice the frequency of the induced stabilized oscillations of the pendulum about the upward vertical. This latter result has also been derived by others [64-66]. Howe's analysis is a combination of the averaging method and an extension of the energy distribution concept used to study wave propagation in random media [67]. Howe obtained an integro-differential equation that governed the development with time of the energy content of each frequency component of the smoothed variable pendulum motion. The equation indicates that an interchange of energy occurs among the various frequency components of the oscillation and is caused by interactions (scattering) with the support motions. Another important feature of the equation is that it accounts for resonant interactions between the various frequency components of the pendulum motion and the Fourier components of the support motion. The Fourier components have twice the frequency of the oscillation of the inverted pendulum.

Zaslavskii [68] examined the stochastic stability of a nonlinear system with randomly varying coefficients. He derived the conditions under which the time dependence of phase can be regarded as an approximate sequence of random numbers. Valeev [69] investigated the stability of various dynamical systems with periodic, quasi-periodic, and random coefficients by formalizing a new asymptotic method.

Various forms of the method of averaging have been used by Stratonovich and Romanovski [70], Weidenhammer [66], and others [14, 60, 71-74]. One form developed by Stratonovich [7] requires that averaging be carried out for terms free from the random excitation. Terms containing the excitation function are replaced by the sum of the mean value and the fluctuation about the mean.

Chelpanov [71] examined the statistical properties of the solution of a second order system and found that the correlation between the orthogonal components of the characteristic solution decreased with time. The averaging method has also been applied to components of twice the system natural frequency in the spectrum of the parametric excitation function [64-66].

Weidenhammer [66] used a form of the averaging method to study the stability of a parametrically excited system in which the random excitation function was small and had a particular spectral density. Graefe [65] extended Weidenhammer's analysis for the case of arbitrary random excitation with small intensity. Ariaratnam [35] followed the Weidenhammer approach to determine the stability of a lightly damped column. The stability of dynamical systems, including gyroscopic forces and nonconservative loads, has been studied by Ariaratnam [75] and Nemat-Nasser [76] respectively. They showed that such systems are described by the set of equations

$$\ddot{x}_i + \epsilon \sum_{j=1}^{n} \zeta_{ij}\dot{x}_j + \omega_i^2 x_i + \epsilon f(t) \sum_{j=1}^{n} P_{ij}x_j = 0 \qquad (12)$$

$$i = 1, 2, \ldots, n$$

where ϵ is a small parameter $<<1$, and ζ a matrix, possibly nonsymmetric, arising from damping and gyroscopic forces. P defines the components of the applied load. When f(t) is a stationary narrow-band Gaussian process with spectral density $S(\omega)$, having center frequency ω_c, and a significant width $\Delta\omega$, the following results are obtained [76]:

- If $\omega_c - \frac{\Delta\omega}{2} \leq \omega_i + \omega_j \leq \omega_c + \frac{\Delta\omega}{2}$ (13)

  the condition under which the system is stable for

  $P_{ij}P_{ji} > 0$ is

$$\zeta_{ii} + \zeta_{jj} > \frac{\epsilon P_{ij}P_{ji}}{\omega_i\omega_j} S(\omega_i + \omega_j) \tag{14}$$

  If $P_{ij}P_{ji} < 0$ the system remains stable.

- If $\omega_c - \frac{\Delta\omega}{2} \leq |\omega_i - \omega_j| \leq \omega_c + \frac{\Delta\omega}{2} \quad i \neq j$ (15)

  the condition under which the system is stable for

  $P_{ij}P_{ji} < 0$ is

$$\zeta_{ii} + \zeta_{jj} > -\frac{\epsilon P_{ij}P_{ji}}{\omega_i\omega_j} S(\omega_i - \omega_j) \tag{16}$$

- If $\omega_c - \frac{\Delta\omega}{2} \leq 2\omega_i \leq \omega_c + \frac{\Delta\omega}{2}$ (17)

  stability is defined by

$$\zeta_{ii} > \frac{\epsilon}{2\omega_i^2} P_{ii}^2 \; S(2\omega_i) \tag{18}$$

Equation (18) has been obtained independently [65, 66, 70].

Ariaratnam [75] obtained slightly different expressions for the stability of a rotating shaft and indicated that stability conditions obtained by the Stratonovich method differ from those obtained by the Liapunov direct method [20]. Ariaratnam and Tam [77, 78] extended the application of the method of stochastic averaging to derive stability conditions for single- and multi-degree-of-freedom linear systems parametrically excited by a combined harmonic process and stationary stochastic process.

Kolomietz [14] combined the standard averaging method and the Fokker-Planck equations approach to study quasi-linear systems containing a small random parameter. A similar approach was used by Dimentberg and Gorbinov [79, 80] to obtain an analytical solution for a nonlinearly damped oscillator subjected to combined periodic parametric and random external excitation.

THE LIAPUNOV DIRECT METHOD

The Liapunov second, or direct, method attempts to derive stability statements about equilibrium states of physical systems by constructing suitable functions, known a Liapunov functions, defined in the phase space. Liapunov functions are essentially extensions of the energy principle: that an equilibrium state is stable if the energy of the system is always decreasing as the equilibrium state is approached. The sign of the Liapunov function and the sign of its time derivative thus determine whether or not the system is stable. The method of constructing Liapunov functions has been explained [81, 82].

Bertram and Sarachik [83] were apparently the first to use the Liapunov second method to investigate the stability of the first order differential equations with stochastic coefficients of the form:

$$\frac{dx}{dt} = X(\underline{x}, \underline{F}(t), t) \tag{19}$$

where $\underline{x}$ is an n-vector, $\underline{F}(t)$ are random functions, and X is a continuous vector function satisfying Lipschitz conditions. Bertram and Sarachik established the basic theorems, which are similar to their counterparts for deterministic systems, for stability in the mean. The equilibrium solution of equation (19) is stable in the mean if a Liapunov function $V(\underline{x}, t)$ of the system satisfies the following conditions:

- $V(0, t) = 0$
- $V(\underline{x}, t)$ is continuous in both $\underline{x}$ and t, and its first partial derivatives with respect to x and

t exist.

- $V(\underline{x}, t) \geq \beta \, \| \underline{x} \|$ for some $\beta > 0$, where $\| \underline{x} \|$ is the norm of the solution $\underline{x}$.
- $E \left\{ \frac{d}{dt} V(\underline{x}, t) \right\} \leq 0$.

Additional conditions by which equation (19) can be asymptotically and globally stable in the mean have also been established [83]. Although these theorems have been developed for a general nonlinear system, Bertram and Sarachik indicated that Liapunov functions can be constructed only in special cases. The technique was independently developed by Kats and Krasovskii [84], who considered the stability in the probability mode of the systems with parameters that are finite sets of Markov processes.

Nevelson [85] showed that, if a deterministic system is unstable in the Liapunov sense, it remains almost surely unstable upon the addition of sufficiently small random terms. Dickerson and Caughey [86] later obtained similar results and showed that parametrically excited systems would be stable if the system were stable in the absence of the excitation and if the average value of the modulus of the excitation were sufficiently small.

Kozin [87] used Gronwell-Bellman's inequality to derive sufficient conditions for almost sure asymptotic stability of linear dynamical systems defined by the system of equations:

$$\frac{d\underline{x}(t)}{dt} = [\underline{A} + \underline{F}(t)]\, \underline{x}(t) \quad , \quad \underline{x}(t_0) = \underline{I} \qquad (20)$$

$\underline{A}$ is a constant n x n matrix, and $\underline{F}(t)$ is an n x n matrix the nonzero elements of which are stochastic processes. Kozin's results require that equation (20), with constant coefficients -- i.e., F = 0 -- be asymptotically stable in the large and that the stochastic processes $\underline{F}(t)$ are as follows: measurable and continuous with a probability of one; strictly stationary; and able to satisfy ergodicity. Kozin [88] later established another theory for sufficient conditions of almost sure asymptotic Liapunov stability in the large. The stationary solution of equation (20) $x_1 = x_2 = \ldots x_n = 0$ is almost surely asymptotically stable in the Liapunov sense if:

$$\int_{t_0}^{\infty} E \left\{ \| x(t, x_0, t_0) \| \right\} dt < \infty \qquad (21)$$

Caughey and Gray [89] extended the Liapunov approach and derived almost sure asymptotic stability criteria for the linear systems described by equation (20). They also examined certain classes of nonlinear systems. Kozin subsequently questioned their results. Mehr and Wang [90] established additional theories relevant to the results of Caughey and Gray [89] and also compared Kozin's results [87] with those of Caughey and Gray [89].

It had been indicated [89] that the limits required to guarantee almost sure stability on the mean square can approach infinity as damping goes to infinity. This result has been discussed further by Gray [91]. Lepore and Stoltz [92] also indicated that for the case of uncorrelated excitation and response the excitation variance can increase without bound as damping is increased.

Wang [93, 94] generalized the most important results of Kozin [87] and Caughey and Gray [89] to particular classes of linear distributed-parameter and time-lag dynamical systems described by a set of linear partial differential-integral equations with stochastic parameters.

Infante [95] obtained sufficient conditions for the almost sure stability of equation (20) by using the properties of pencils of quadratic forms. That is, if $\underline{G}$ and $\underline{H}$ and n x n real symmetric matrices and $\underline{H}$ is positive definite, the form $\underline{x}'\underline{G}\underline{x} - \underline{x}'\underline{H}\underline{x}$ is called a regular pencil of quadratic forms. The equation det $[\underline{G} - \lambda \underline{H}] = 0$ is called the characteristic equation of the pencil, and the λ are the eigenvalues of the pencil. Infante found that the stability conditions of the two systems

$$\ddot{x} + 2\zeta\dot{x} + [\omega^2 + f(t)]\, x = 0 \qquad (a)$$
$$\ddot{x} + [2\zeta + f(t)]\, \dot{x} + \omega^2 x = 0 \qquad (b) \qquad (22)$$

are expressed respectively as

$$E[f^2(t)] < 2\zeta^2\omega^2 \qquad (a)$$
$$E[f^2(t)] < 4\zeta^2/(\zeta^2 + \omega^2) \qquad (b) \qquad (23)$$

Man [96] extended Infante's [95] work and obtained results for the stability regions of second order systems. However, his maximum eigenvalues λ_{max} were found to be incorrect by Kozin and Wu [97]. They correlated Infante's results [95] with their almost sure stability for both Gaussian noise coefficients and periodic coefficients and found a significantly greater increase in the stability region than that given by Infante.

The Liapunov approach has been successfully used for systems with narrow-band parametric excitation [91, 98-101]. Caughey and Dickerson [98] derived sufficient conditions that guarantee the asymptotic stability of a class of linear systems. They illustrated their method for two cases of multi-degree-of-freedom systems having classical modes. Gray [91] utilized the method for that portion of the spectral density of the excitation close to twice the natural frequency of the system. For equation (22a) he found that the almost sure stability conditions are:

$$E[f^2(t)] < 4\zeta^2(1 - \frac{\zeta}{\omega})^2/\omega^2 \quad \text{for } \zeta^2/\omega^2 < 1/2$$
$$E[f^2(t)] < 1 \quad \text{for } \zeta^2/\omega^2 > 1/2 \qquad (24)$$

Gray admitted that these results were less conservative than those obtained previously [89]. Figure 5 is a comparison for stability boundaries obtained by a number of authors [35, 87, 89, 95]. It seems that the results of Infante and Plaut [102] are the best of those available for almost-sure stability. In addition, they show unbounded excitation variance growth with increasing damping.

Kozin [103, 104] discussed the question of the true stability of second order systems with such a stationary ergodic Gaussian coefficient in the sense of Liapunov. He extended the Ito equation approach of Khasminiskii [72, 73] and obtained numerically the stability boundary of second order systems. Kozin correlated the results obtained in terms of Ito differential equations with those obtained by Infante [95] for real noise coefficient systems. As the real noise coefficient approached white noise, the system of equations required the addition of correction terms. He found [104] that the correction terms of the system considered by Infante were identically zero, so that the results were close to the true stability boundary.

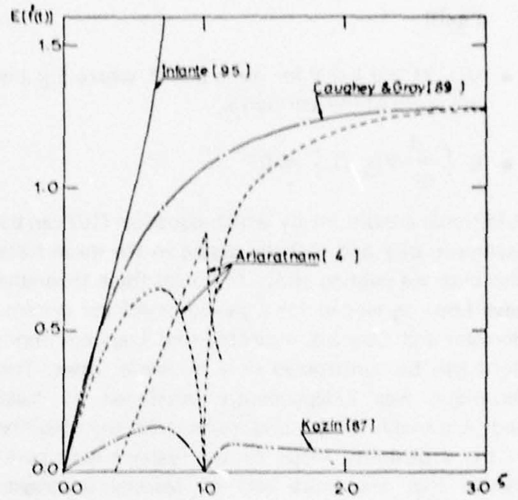


Figure 5. Comparison of the Almost Sure Stability for Gaussian Processes Obtained by Various Theories [4, 87, 89, 95]

Sunahara et al [105] combined the stochastic averaging method developed by Khasminiskii and the Liapunov direct method into a new approach. They derived several theorems to provide sufficient conditions for asymptotic stability of nonlinear dynamical systems described by the equation

$$\ddot{x} + \omega^2 x + \epsilon g(x, \dot{x}) = \delta h(x, \dot{x}) W(t) \qquad (25)$$

where g(x, x) and h(x, x) are nonlinear functions, W(t) is a white Gaussian noise, and ϵ and δ are small parameters.

The Liapunov approach has been used to define the stability regions of such structural elements as columns subjected to random axial loads [102, 106, 107], cylindrical shells subjected to simultaneous axial and radial stochastic excitations [108, 109], cylindrical shells with nonlinear strain-displacements acted upon by stochastic radial loading [110], circular plates subjected to radial stochastic excitations [111], and a rectangular flat plate with simultaneous stochastic inplane loading along its length and width [92].

OTHER METHODS AND RESULTS

Among the various techniques that have been developed to treat complex dynamical systems during stochastic excitation are the equivalent linearization method [112], the spectral density approach [113], the perturbation method [114], and others [115-118]. These methods have been applied to nonlinear systems by are not widely used for random parametric systems.

Two methods have been developed [113, 119-121] for studying nonstationary systems that are based on the spectral density approach originally used in control theory [122]. One method has been used to determine the response of helicopter rotor blades in forward flight. The problem involves a time-dependent system with periodic stiffness, damping, and input modulation functions as described by the equation of flapping motion [113, 119]

$$\ddot{x} + (\gamma/2)C(t)\dot{x} + [\omega^2 + (\gamma/2)K(t)]x = (\gamma/2)B(t)N(t) \tag{26}$$

where γ is known as the lock blade inertia number, $C(t)$ and $K(t)$ are periodic functions, $B(t)$ is a well defined envelope function, and $N(t)$ is a random function. Gaonkar and Hohenemser [119, 120] showed that the flapping response to typical atmospheric turbulence is a quasi-coherent narrow-band random process. Wan indicated that the peak mean square deflection of the blade in forward flight was substantially larger than that in hovering.

The effects of torsion-flapping coupling during high-advance ratio flight on the peak statistics of turbulence-excited rotor blade vibration have been investigated [123-125]. Although such coupling can influence certain narrow band features of flapping and have a detrimental effect on the probability of high-level torsional excursions, these effects were negligible in most practical cases.

For linear systems with weakly periodic nonstationary excitation, Prelewicz [126] pointed out that any steady-state response, if it exists, is also a weakly periodic nonstationary process. The spectral density method has also been used in conjunction with Volterra functional analysis [118] for a number of nonlinear systems with periodic coefficients and stochastic forcing.

Rosenbloom [127, 128] used a power spectral density approach to determine the stability of the response moments of a randomly time-dependent first order linear system. The stability in the mean square of second order systems with random stiffness coefficients has been evaluated following a similar approach [129, 130].

Many general definitions of stochastic stability for vibrating systems exist [1, 21, 31, 72, 131-139]. Kozin [1] classified the common modes of convergence into three groups; namely, convergence in probability, convergence in the mean, and almost-sure convergence. Additional results and theorems for the stability of stochastic systems have been published [140-147].

The classical perturbation method has been adapted for random vibration problems involving small nonlinearities and has been used successfully for single- and multi-degree-of-freedom systems with nonlinear stiffness [114, 115]. In systems with parametric random coefficients or autoparametric coupling, however, the method fails to predict the stability of the response unless initial conditions for the first approximation are imposed.

Kolovskii and Troitskaia [148] and Dimentberg [149] determined the stability of linear systems with randomly varying parameters. The initial conditions of the first approximation were assumed to be random variables [148]. Examples used to illustrate the method included automatic control models. Dimentberg [149, 150] discussed a number of cases in which the amplitude of vibration at resonance could be reduced by introducing random components in the coefficients of the system. Chang and Soong [151] combined the method of equivalent linearization of Kryloff and Bogoliuboff and a perturbation scheme to determine the average angular displacement of a vertical pendulum.

The method of integro-differential equations, which has been applied by Schmidt in deterministic parametric vibration problems [152], has recently been utilized to study the influence of such parameters as excitation, linear and nonlinear damping, and other nonlinearities on the response of vibrating systems [153]. Schmidt indicated that the influence of damping is markedly different for periodic and for random parametric excitations. A similar approach has recently been used by Iyengar and Dash [116] to derive the autocorrelation of the response of equation (26). They also applied two other methods: (1) a series technique in which response is expressed as a series in the powers of the random coefficient K(T), so that the method can be regarded as a generalization of the Galerkin method; (2) a numerical solution on a digital computer of the system for various simulations of K(T) and N(t).

EXPERIMENTAL WORK AND ANALOG SIMULATION RESULTS

Little experimental work has been done for dynamical systems with stochastic excitation, particularly the parametric case. Some experimental studies on an RLC circuit with randomly varying capacitance showed that any value of the spectral density of the capacity variation would carry the circuit into unstable regions if the damping were zero [129]. This instability was controlled by the circuit nonlinearities when the response exceeded a critical level. These properties were verified in an analog computer simulation [49, 129].

Bogdanoff and Citron [54, 55], and Ness [57] conducted a series of experiments to investigate the stability of an inverted pendulum subjected to random support motion. The excitation $\xi(t)$ was obtained by summing the outputs of several harmonic oscillators of the form

$$\xi(t) = \sum_{i=1}^{n} a_i \cos(\omega_i t + \phi_i) \qquad (27)$$

The results supported the theoretical conclusion [53] that only variation of the base velocity influences the stability of the inverted pendulum provided that a_i are small. For six input frequencies the results suggested that it might not be possible to stabilize the pendulum if $\xi(t)$ has a continuous spectrum. Mitchell [60] simulated the motion of the inverted pendulum on an analog computer using a Gaussian white noise generator with a high pass filter. The simulation showed that the pendulum could be stabilized if damping were sufficiently large.

An exploratory experimental study of the behavior of the free surface of a liquid in a tank during random excitation in the longitudinal direction was conducted by Dalzell [154]. This study, which included narrow- and wide-band excitations, indicated that large amplitude free surface response to random excitation was qualitatively similar to the half-subharmonic response observed under harmonic excitation. Estimation of the probability distribution of the free surface indicated that for excitation levels, the response was nearly Gaussian. When a large amplitude subharmonic response was excited, however, the probability structure approached a doubly exponential distribution. No correlations with theoretical studies were reported [34, 130].

Baxter and Evan-Iwanowski [155] conducted a series of experiments to measure the response amplitude of a column excited by random axial forces. Their observations supported theoretical results [64-66] that the column vibrates near its natural frequency when the spectral density of the excitation is sufficiently high within the parametric resonance zone of the column. They also found that the variance of the response amplitude decreases with increasing excitation band-width. Bolotin [42] simulated the equations of motion of a column excited by a filtered Gaussian white noise on the analog computer. The stability boundaries obtained confirmed his theoretical results.

Frolov [156] obtained the amplitude-frequency response of a system excited simultaneously by a stationary parametric excitation and a periodic forced excitation in the form

$$\ddot{x} + 2\omega\zeta^2\dot{x} + \omega^2[1 + \epsilon w(t)]\,x = a.\cos\Omega t \qquad (28)$$

where w(t) is a stationary, zero-mean function and ϵ is the mean square value of variation of the natural frequency of the oscillator. For small ϵ Frolov showed that the maximum amplitude response can be reduced by random variation of the parameters.

Kropac and Drexler [157-162] conducted a series of experimental and analog simulation investigations for a special class of parametrically excited vibratory electromechanical systems in which the damping term is controlled by a binary random signal that switches the system between damping and exciting states. These systems are described by equation (29)

$$\ddot{x} + 2\omega_0\left\{\zeta + C\psi(f,p;t) + KA[x]\right\}\dot{x} + \omega_0^2\,x = 0 \qquad (29)$$

where $\psi(f,p;t)$ is a symmetric pseudo-random binary signal having a binomial distribution of pulse length; f is the sampling frequency of the random generator; p is the +1 probability of the occurrence of a pulse; A[x] is the envelope of x(t); and K and C are constants. The analog studies indicated that the mean value for the envelope process of the response changed significantly as a function of the damping coefficient, and the mean square remained approximately constant. The nonlinear feedback in the damping term, which is dependent on the instantaneous value of the envelope, ensured the stability of the motion in the prescribed range and very effectively kept the envelope random process quasi-stationary with respect to its first probability density.

CONCLUSION

The papers and reports referred to in this article represent a substantial extension of the theory of stochastic differential equations and the application of that topic to interesting and demanding engineering problems in the field of random parametric excitation of dynamical systems. The Fokker-Planck approach shows promise in the investigation of *truncation schemes* for the infinite hierarchy of moment equations generated by linear and nonlinear parametrically excited systems. It is hoped that some difficult problems of stability and response will be resolved by this technique. Contributions to the development of random parametric vibration with the averaging method and the Liapunov direct approach are equally important, and an impressive range of stability criteria for a wide variety of systems has been obtained with them.

The survey pointed out the lack of supporting experimental results for much of the theoretical work. Reasons include the general difficulty of accurately imposing the conditions of mathematical models -- such as the spectral density of parametric loading -- and of evaluating stability boundaries for experimental random parametric systems. However, a continuing and extending program of experimental work is desirable for three reasons. First, a balanced judgement of the real value of such research can be obtained only by constant observation of the behavior of real engineering systems under parametric excitation. Second, such observations can be expected to generate further investigations into relevant areas. Finally, only with experimental work can theoretical results be evaluated and justified, especially results based upon approximations and derived by methods rigorous mathematical proof.

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BOOK REVIEWS

STRESS WAVE PROPAGATION IN SOLIDS. AN INTRODUCTION

R. J. Wasley
Marcel Dekker, Inc.
New York, 1973

The field of stress wave propagation in solids has immense technological application:

- in impacts or explosions used in fabrication; i.e., in explosive high-energy rate forming, hardening, welding, cutting, and piercing
- in explosive or percussive rock breakage, mining, drilling and earth removal
- in such accident analysis and mitigation involving impact or explosion as automobiles, aircraft, and nuclear reactors
- in the analysis of ballistic impact and penetration, for instance, turbine blade breakage, tornado-blown debris damage, and ordnance design

Practitioners in the field of stress wave propagation fall into two groups: those interested in elastic waves and those concerned with nonlinear phenomena. The latter group is small, its members as often as not employed by, or alumni of, defense-related research laboratories in which the field was first developed. With a number of notable exceptions, the academic community has been relatively uninformed about the major advances in nonlinear stress waves in the last two decades, and the transfer of technology to industry as a whole has been slow.

Perhaps because of the general lack of interest on the part of the academic community and the lack of necessity to publish textbooks in defense-related laboratories, few good texts have appeared. It is therefore of interest to encounter a book on stress wave propagation in solids, particularly since the author has for many years been actively engaged in both theoretical and experimental work in one of the largest groups at the Lawrence Livermore Laboratory.

The book is divided into two parts. In the first and largest part, on dynamic elasticity, the author states that linear elasticity provides a good foundation for understanding dynamic nonelastic phenomena. Part 2 attempts such an extension in two special cases, uniaxial stress and uniaxial strain.

Part 1 is a conventional elementary exposition of dynamic elasticity in the style of and at a level compatible with an introductory course. Remarks on elementary tensor notation are given. Concepts of stress and strain and Hooke's law, topics of harmonic waves in extended media, reflection and refraction of waves at plane boundaries, and some aspects of the Pochhammer-Chree solution in rods are developed in an easy style. The author connects these concepts to some problems but does not develop them.

Part 2 focuses on two topics: the split Hopkinson pressure bar apparatus, which has been extensively used to study dynamic plasticity under conditions approximating uniaxial stress; and the plane wave experiment involving high explosive or gun-driven flat plate impacts, in which uniaxial strain conditions are approached. These two techniques are the principal ways of investigating nonelastic stress wave propagation in the laboratory.

The second part of the book is more qualitative than the first; it contains few equations, relying instead on experimental observations to introduce a few rudimentary concepts of dynamic plasticity and the high pressure thermodynamic equation of state.

The subtitle of the book is appropriate; it does indeed provide a good introduction to the subject. The book should be useful to graduate engineers and those with little or no prior exposure to dynamic stress wave propagation. The book will also be useful to university students requiring an introduction to stress wave effects. Specialists in dynamic elasticity or practitioners in nonlinear stress wave propagation research will find little that is not part of standard elasticity texts and older research literature.

No hint is given of the exciting developments that have taken place over the last 15 years or so as a result of the application of modern continuum mechanics, constitutive theory, singular surface analysis, and micromechanical theories of deformation. Nor is the employment of the principles of stress wave propagation in the many technological applications given more than cursory mention. These topics remain buried in the research literature, with only a few review articles in symposia proceeding or anthologies to serve as guides.

Dr. W. Herrmann
Sandia Laboratories
Albuquerque, NM 87115

ELASTOKINETICS

H. Reismann and P.S. Pawlik
West Publishing Company, St. Paul, Minnesota

This book caters to students and practicing engineers in the fields of civil, mechanical, and electrical engineering. It explains various facets of dynamics and vibration and is divided into two parts -- discrete and continuous systems.

Chapters 1 and 2 of Part I consider the linear oscillator, as well as responses and harmonic functions derived by Laplace transforms. Hamilton's Principle is also explained and examples given. Lagrange Equations are also presented.

In chapters 3, 4, and 5 small oscillations are explained in normal coordinates and applied to free vibrations, Rayleigh's principle, and a unique Mohr circle construction for dynamic systems. The continuous system is introduced and advanced applications to torsional vibrations and constraints in a system are described. The reviewer would have liked to have seen Hamilton's principle extended to Euler-Lagrange equations of motion.

Chapters 6 and 7 consider damping and the relationship of damping to a damped structure in a forced system. A short explanation of Rayleigh-type damping is given, but hysteretic damping is not considered. Wave propagation is discussed. Examples of a mechanical filter and transient wave motion serve as an introduction to the more advanced aspects given is Part II.

Part II on continuous systems is the heart of the book. Chapter 8 describes the convenience of using cartesian tensors to express the deformation and stresses in continua. Chapter 9 deals with the mechanics of continua. Employing cartesian tensors, more in-depth explanations of Hamilton's Principle, as well as the expression of results in Lagrange and Euler coordinates of the elastic body, are presented.

Chapter 10 describes the dynamics of elastic bodies using cartesian tensors. Neumann's uniqueness theorem concerning boundary conditions and velocity fields is also given. The free vibration of bounded elastic bodies is considered, as is forced motion. A specific example is the spherical shell.

Chapter 11 considers the more advanced aspects of wave motions in elastic media -- irrotational plane waves, dilatational waves, Rayleigh surface waves, reflected waves, and progressive waves in elastic plates and cylinders. The chapter concludes with a discussion of longitudinal, torsional, and flexural waves.

Chapter 12 describes longitudinal waves in rods and torsional motion of rods of finite and unbounded lengths. Detailed explanations of the latter are not included in most texts.

Chapter 13 introduces dynamics of elastic beams and contains descriptions of the equations of motion involved and explanations of shear deformation and shear coefficients. Differences between the Euler-Bernoulli beam and the Timoshenko beam are emphasized. Examples include forced motion, wave motion, and impulsive loads on beams.

Chapter 14 is concerned with the dynamics of elastic plates. The equations of motion are derived in cartesian tensors. Detailed explanations of the equations of forced motion are given and applied to circular plates, simply supported plates, and wave motion in plates. The Timoshenko equations are applied to plates; a number of Reismann's papers on plates have been incorporated into this chapter.

The book is a good one but the reviewer believes that it should have contained sections on Galerkin's Method and Rayleigh-Ritz method, an introduction to random vibration, and a chapter on finite elements -- which are assuming an ever greater role in design and analysis. A chapter on shells would also have been worthwhile because many structures are now designed using shell theory.

In summary, the book fulfills the purpose of the authors to provide useful linear models and to show their relationships to nonlinear models. Several important methods are also presented. The reviewer recommends that students and interested readers study the book before undertaking the more advanced aspects of dynamics.

Herb Saunders
General Electric Company
Schenectady, New York 12345

NEWS BRIEFS

news on current and Future Shock and Vibration activities and events

INTERNATIONAL CONFERENCE ON MINING MACHINERY - 1979

An international conference on mining machinery is being organized by The Institution of Engineers, Australia and the Australasian Institute of Mining and Metallurgy. Emphasis of the technical program will be on the design and maintenance of heavy machinery used in the mining industry. Papers are invited on current technology review; future developments and requirements; equipment selection; design of mechanical, electrical, or hydraulics systems; construction, maintenance and repair techniques; instrumentation, automatic control and data logging; and case histories of specific operational problems and their solutions. The conference will be held at the University of Queensland, Brisbane, Australia on 2 - 6 July 1979.

For further information contact: The Conference Manager, International Conference on Mining Machinery - 1979, The Institution of Engineers, Australia, 11 National Circuit, Barton, A.C.T. 2600, Tele. (062) 733633/Telegrams: ENJOAUST, Canberra.

10th SYMPOSIUM ON EXPLOSIVES AND PYROTECHNICS - CALL FOR PAPERS

You are invited to submit papers for presentation at the 10th Symposium. All papers must be unclassified. Please send titles and abstracts to Mr. R. H. Thompson, Franklin Institute Research Laboratories, Philadelphia, PA 19103 by the deadline: July 14, 1978.

CALL FOR PAPERS 15th ANNUAL MEETING OF THE SOCIETY OF ENGINEERING SCIENCE

This meeting will be highlighted by five special lectures. One will be given by the Eringen Medalist for 1978, and four other lectures will be presented by internationally known researchers in polymers, applied mathematics, hydrodynamics of coastal waters and geotechnical engineering.

A balanced program of topics representing a wide spectrum of fields of engineering is planned. Abstracts submitted should relate to the topics listed below. Among the topics to be emphasized are:

Acoustics
Atmospheric fluid mechanics
Biomechanics and biomaterials
Composite materials and methodology
Computational methods
Earthquake related problems
Elasticity
Energy generation and storage
Engineering approach to societal problems
Engineering cybernetics
Environmental effects
Experiemental stress analysis
Fracture mechanics
Gas dynamics
Geotechnical engineering
Heat transfer
High pressure and temperature technology
Kinetic theory of gases
Machine and structure design
Materials evaluation and testing
Mechanics of fracture
Micromechanics of imperfections in solids
Modeling, control and structural analysis of transportation systems
Molecular dynamics
Non-destructure testing
Nuclear component design and analysis
Numerical methods
Optimization and control
Particle transport theory
Plasma physics
Plasticity
Plates and shells
Reliability, engineering statistics, & manufacturing
Solar and wind energy
Space dynamics
Statistical mechanics
Viscoelasticity

Papers to be presented at the conference will be selected on the basis of a formal review procedure from submitted extended abstracts. For further information regarding abstract format contact: Professor R. L. Sierakowski, Div. of Continuing Education, Univ. of Florida, 2012 W. University Ave., Gainesville, FL 32603.

CALL FOR PAPERS

49th SHOCK AND VIBRATION SYMPOSIUM*

The 49th Shock and Vibration Symposium will be held at the International Inn, Washington, D.C. on 17, 18, and 19 October 1978. The NASA Goddard Space Flight Center, Greenbelt, Maryland is the host for this meeting.

SUBMISSION OF PAPERS

Those wishing to offer formal full-length papers for the symposium should carefully follow the instructions on the reverse side of the SUMMARY COVER SHEET. Papers may be offered either for presentation at the Symposium, or publication in the Bulletin, or both. Summaries of papers accepted for presentation will be published and distributed prior to the Symposium. Six copies of the two page (approximately 600 words) summary should be submitted. No figures should be included in the summary. Prospective authors are encouraged to submit supplemental figures and additional information which the program committee can use to evaluate the paper, but this material should not be referenced in the summary which will be published if accepted. Authors are required to furnish such a summary even if the complete paper is submitted. In general, unclassified-unlimited distribution summaries of classified papers are requested. If this is impossible, a classified summary may be submitted, but this will not be published. Deadline for receipt of summaries is 19 June 1978.

CLASSIFIED SESSIONS

The Shock and Vibration Symposium provides a special platform and publication medium for authors of classified papers up to SECRET. To simplify problems of paper release, SVIC policy for the 49th Sumposium is that attendance at classified sessions will be limited to U.S. citizens & others having the required clearance and need-to-know. Limited distribution papers which are accepted will likely be programmed in the classified sessions.

SHORT DISCUSSION TOPICS

Because of continued interest, a session will once again be programmed covering progress reports on current research efforts and unique ideas, hints and kinks on instrumentation, fixtures, testing, analytical short cuts and so forth. It is intended to provide a means for up-to-the-minute coverage of research programs and a forum for the discussion of useful ideas and techniques considered too short for a full-blown paper. These discussions will not be published. Presentation of a short discussion at this meeting will not prevent later publication of the final results in SVIC publications or other journals. Accepted speakers will have 5 minutes for presentation and 5 minutes for discussion. Only unclassified-unlimited distribution discussions will be programmed for this session. Those interested only need to submit a short summary on the enclosed form due at SVIC on 11 September 1978.

SUGGESTED TOPIC AREAS

Papers from all areas of shock and vibration technology will be considered. The following are possible topics for discussion based upon suggestions from the shock and vibration community.

- Ground Motion
- Ship Shock and Vibration Problems
- Reliability Testing and Field Failures
- Dynamic Testing and Environments
- Software/Pocket Calculator Analysis
- Impedance Methods
- Response of Special Materials
- Transportation & Packaging
- Instrumentation & Data Analysis
- Biomechanics
- Structural Analysis
- Rotor Dynamics & Balancing
- Mechanical Signature Analysis

CRITERIA FOR ACCEPTANCE

Papers will be evaluated on technical merit. They should describe work that advances the technology and which has not been published previously. Papers with a commercial flavor will not be accepted, however technical submissions from vendor employees will be judged without bias and on the same basis as those of other prospective authors.

PUBLICATIONS

For your scheduling, if your paper is offered for publication, three review copies of the complete paper, neatly typed in your own format, must be in this office by 11 September 1978. If the paper is accepted for publication, an author kit will be provided for final copy preparation. Acceptance for publication in the 49th Bulletin depends upon favorable referee review.

PROGRAM

The advance program for the Symposium will be distributed in September, together with hotel, security clearance, and registration information.

*Forms enclosed in this issue of the DIGEST

SHORT COURSES

MAY

ANTICIPATING FAILURES OF ROTATING MACHINERY WITH VIBRATION ANALYSIS

Rochester	May 2 - 4, 1978
Schenectady	May 9 - 11, 1978
Cleveland	May 23 - 25, 1978
Chicago	May 30 - June 1, 1978
Houston	June 13 - 15, 1978

Objective: This seminar is a basic course in the analysis of rotating machinery vibration. Emphasis will be on why certain machine abnormalities produce specific vibration signatures. Topics to be covered in the seminar are: the distinctions between different types of transducers and vibration monitoring equipment, causes of common machine vibratory phenmena, diagnosing machine failure modes by signature analysis, and suggestions for possible corrective action.

Contact: John Sramek, Nicolet Scientific Corp., 245 Livingston St., Northvale, NJ 07647 - (201) 767-7100, ext. 505.

FINITE ELEMENT METHOD AND NASTRAN USAGE

Dates: May 8 - June 15, 1978
Place: Troy, Michigan
Objective: A sequence of four professional development courses will be presented to provide an understanding of the technological content in general purpose finite element programs; and to provide training in the use of NASTRAN. The courses and dates are:

- Matrix Structural Analysis and Finite Elements - May 8 - 12, 1978
- Static and Normal Modes Analysis using NASTRAN - May 15 - 18, 1978
- DMAP and Substructural Analysis using NASTRAN - June 6 - 9, 1978
- Dynamic and Nonlinear Analysis using NASTRAN - June 12 - 15, 1978

Contact: Schaeffer Analysis, Kendall Hill Road, Mont Vernon, NH 03057 - (603) 673-3070.

JUNE

EXPLOSION HAZARDS EVALUATION

Dates: June 12 - 16, 1978
Place: San Antonio, Texas
Objective: This course covers the full spectrum of problems encountered in assessing the hazards of accidental explosions involving handling or storage of particularly hazardous chemicals. Design for proper containment and development of techniques to reduce incidence of accidents during normal plant and transport operations will be covered. Specifically the following topics will be covered: fundamentals of combustion and transition to explosion; free-field explosions and their characteristics; loading from blast waves; structural response to blast and non-penetrating impact; fragmentation and missile effects; thermal effects; damage criteria; and design for blast and impact resistance.

Contact: Wilfred E. Baker, Southwest Research Institute, P.O. Box 28510, San Antonio, TX 78284 (512) 684-5111, ext. 2303.

ANALYSIS AND PREVENTION OF MECHANICAL FAILURES

Dates: June 15 - 16, 1978
Place: University of Michigan, Ann Arbor
Objective: To present methods for analyzing, preventing, and correcting failures of mechanical components and assemblies. Failures treated may arise from a faulty design, material, fabrication or assembly, or from operator's abuse. Interpretation of failure data will be included.

Contact: Engineering Summer Conferences, 200 Chrysler Ctr., North Campus, The University of Michigan, Ann Arbor, MI 48109.

VIBRATION SURVIVABILITY
Dates: June 5 - 9, 1978
Place: Santa Barbara, CA
Objective: Testing an equipment's ability to survive in the dynamic environments of vibration and shock and a basic education in resonance and fragility phenomena, in environmental vibration and shock measurement and analysis, also in vibration and shock environmental testing to prove survivability are the objects of this course.

Contact: Wayne Tustin, Tustin Institute of Technology, 22 East Los Olivos St., Santa Barbara, CA 93105 - (805) 963-1124.

JULY

9TH ANNUAL INDUSTRIAL PRODUCT NOISE CONTROL INSTITUTE
Dates: July 10 - 14, 1978
Place: Union College, Schenectady, NY
Objective: For engineers, designers, environmental health specialists and managers concerned with noise and vibration control. This course will provide information on the theory measurement and economics of noise reduction. The course will cover the latest information on the nature of sound and noise control, including noise criteria, airborne sound distribution, vibration control, and noise signature analysis. Other topics include how noise is produced by different types of engineering equipment such as compressors, electric motors, fans, valves, and transformers.

Contact: Graduate Studies & Continuing Education, Union College, Wells House - 1 Union Avenue, Schenectady, NY 12308 - (518) 370-6288.

INSTRUMENTATION, MEASUREMENTS ENGINEERING AND APPLICATION
Dates: July 17 - 21, 1978
Place: Union College, Schenectady, NY
Objective: This course is designed for technicians and engineers involved in the field of instrumentation and measurements who wish to be informed on the latest "State-of-the-Art". The data reduction techniques that can be used coinciding with the instrumentation to resolve a particular problem will be included. Major topics will include: transducer design, applications and limitations, engineering the test probram, recording techniques, data reduction and interpretation, and case histories. These will be applied to both static and dynamic measurement.

Contact: Graduate Studies & Continuing Education, Union College, Wells House - 1 Union Avenue, Schenectady, NY 12308 - (518) 370-6288

COMPUTER WORKSHOP IN FINITE ELEMENT METHODS OF ANALYSIS FOR STRESS AND OTHER FIELD PROBLEMS
Dates: July 24 - 28, 1978
Place: Union College, Schenectady, NY
Objective: To develop the basic formulations of the finite element structural analysis, to examine practical applications and to present Fortran IV computer programs for both 2D and 3D problems. The programs will be applied to tutorial and student generated problems.

Contact: Graduate Studies and Continuing Education, Union College, Wells House - 1 Union Avenue, Schenectady, NY 12308 - (518) 370-6288.

COMPUTER WORKSHOP IN EARTHQUAKE AND STRUCTURAL DYNAMICS
Dates: July 24 - 28, 1978
Place: Union College, Schenectady, NY
Objective: To develop the basic formulations of structural dynamic analysis for linear and nonlinear systems, to examine practical applications to earthquake and structural dynamics and to present Fortran computer programs for multi-degree-of-freedom systems. The programs will be applied to tutorial and student generated problems.

Contact: Graduate Studies and Continuing Education, Union College, Wells House - 1 Union Avenue, Schenectady, NY 12308 - (518) 370-6288.

NOISE CONTROL ENGINEERING
Dates: July 31 - August 4, 1978
Place: University of Michigan, Ann Arbor

Objective: This course provides engineers and managers with comprehensive knowledge of noise-control engineering and criteria for application to practical problems.

Contact: Engineering Summer Conferences, 200 Chrysler Ctr., North Campus, The University of Michigan, Ann Arbor, MI 48109.

AUGUST

PYROTECHNICS AND EXPLOSIVES

Dates: August 14 - 18, 1978
Place: Philadelphia, PA
Objective: This seminar combines the subjects of pyrotechnics and solid state chemistry along with explosives and explosive devices. It will be practical so as to serve the men working in the field. Presentation of theory is restricted to that necessary for an understanding of basic principles and successful application. Coverage emphasizes recent effort, student problems, new techniques, and applications. The prerequisite for this seminar is a bachelor of science degree in engineering or equivalent.

Contact: Registrar, The Franklin Institute Research Labs., Philadelphia, PA 19103 - (215) 448-1236.

SEPTEMBER

7TH ADVANCED NOISE AND VIBRATION COURSE

Dates: September 11 - 15, 1978
Place: Institute of Sound and Vibration Research, University of Southampton, England
Objective: The course is aimed at researchers and development engineers in industry and research establishments, and people in other spheres who are associated with noise and vibration problems. The course, which is designed to refresh and cover the latest theories and techniques, initially deals with fundamentals and common ground and then offers a choice of specialist topics. The course comprises over thirty lectures including the basic subjects of acoustics, random processes, vibration theory, subjective response and aerodynamic noise which form the central core of the course. In addition, several specialist applied topics are offered, including aircraft noise, road traffic noise, industrial machinery noise, diesel engine noise, process plant noise and environmental noise and planning.

Contact: Dr. J. G. Walker or Mrs. O. G. Hyde, Institute of Sound and Vibration Research, The University, Southampton, S09 5NH, England.

MACHINERY VIBRATION

Dates: September 20 - 22, 1978
Place: Cherry Hill, New Jersey
Objective: Lectures and demonstrations on rotor-bearing dynamics, turbomachinery blading, and balancing have been scheduled for this Vibration Institute-sponsored seminar. The keynote address on the development of balancing techniques will be given on the first day along with sessions on modal analysis, oil whirl, and computer programs. Simultaneous sessions on rotor-bearing dynamics and turbomachinery blading will be held on the second and third days. The following topics are included in the rotor-bearing dynamics sessions: critical speeds, stability, fluid film bearing design and analysis, balancing sensitivity, generator rotor balancing, gas turbine balancing, and industrial balancing. The sessions on turbomachinery blading feature excitation and forced vibration of turbine stages, structural dynamic aspects of bladed disk assemblies, finite element analysis of turbomachinery blading, steam turbine availability, metallurgical aspects of blading, torsional-blading interaction, and field tests of turbogenerator sets. Each participant will receive a proceedings covering all seminar sessions and can attend any combination of sessions.

Contact: Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

REVIEWS OF MEETINGS

CONFERENCE ON AEROSPACE POLYMERIC VISCOELASTIC DAMPING TECHNOLOGY FOR THE 1980'S

7-8 February 1978
Dayton, Ohio

This conference was sponsored by the Air Force Flight Dynamics Laboratory. The principal organizer was Dr. Lynn C. Rogers of the Structural Mechanics Division. The purpose of the conference was to explore damping technology as a mechanism for improving structural reliability of aircraft structures, avionics and accessories which are subject to severe dynamic environments. The conference was also to provide increased definition and support for a proposed AFFDL program titled "Dynamics Abatement and Major Payoff thru Integrated Technology (DAMP IT)." This program is an organized approach to the integration of damping technology into the design and manufacturing process. In the opinion of the reviewer, the program has considerable merit.

The conference was well orgainzed. There were a number of excellent presentations on basic damping technology including additive and constrained layer damping, tuned dampers, material properties and environmental effects. Drs. D.I.G. Jones and Jack Henderson of the Air Force Materials Laboratory contributed significantly in these presentations. Professor F.C. Nelson of Tufts University gave an interesting and useful talk on "Damped Vibration Theory: A State of the Art Assessment." Professor R. Plunkett of the University of Minnesota offered a similarly fine contribution on "Measurement of Material and System Damping."

A number of presentations were given covering case-history applications of damping to solve dynamic problems for structures, avionics, and other equipment. Valuable lessons can be learned by looking at the experiences of others as they approach complex problems. Presentations by the principal manufacturers of damping materials on the capabilities of their products added to the overall usefulness of the conference.

Hopefully the proceedings of this conference will be made available in fairly complete form. If so, it should provide a useful reference to those concerned with damping and its applications.

Henry C. Pusey

ABSTRACTS FROM THE CURRENT LITERATURE

Copies of articles abstracted in the DIGEST are not available from the SVIC or the Vibration Institute (except those generated by either organization). Inquiries should be directed to library resources. Government reports can be obtained from the National Technical Information Service, Springfield, VA 22151, by citing the AD-, PB-, or N- number. Doctoral dissertations are available from University Microfilms (UM), 313 N. Fir St., Ann Arbor, MI; U.S. Patents from the Commissioner of Patents, Washington, D.C. 20231. Addresses following the authors' names in the citation refer only to the first author. The list of periodicals scanned by this journal is printed in issues 1, 6, and 12.

ABSTRACT CONTENTS

ANALYSIS AND DESIGN

ANALYTICAL METHODS

78-631
Periodic Solutions of Hamiltonian Systems
P.H. Rabinowitz
Mathematics Res. Center, Wisconsin Univ., Madison, WI, Rept. No. MRC-TSR-1783, 52 pp (Aug 1977)
AD-A046 393/5GA

Key Words: Forced vibration, Free vibration, Hamiltonian principle

The existence of periodic solutions of Hamiltonian systems of ordinary differential equations is proved in various settings. A case in which energy is prescribed is treated. Both free and forced vibration problems, where the period is fixed, are studied.

78-632
Forced Oscillations of a Piecewise-Linear Nonlinear Dynamic System with Several Degrees of Freedom
T.K. Caughey and A. Vijayaraghavan
California Inst. of Tech., Pasadena, CA 91125, Intl. J. Nonlinear Mech., 12 (6), pp 339-353 (1977) 1 fig, 7 refs

Key Words: Forced vibration, Dynamic systems, Harmonic excitation, Reid springs

Exact periodic solutions are derived for a dynamic system with several degrees of freedom consisting of a series of 'Reid springs' with piecewise-linear, non-linear characteristics; however, the solutions are restricted to a class of harmonic excitation in the 'modal form' described subsequently in the paper. Conditions are derived for the asymptotic stability of the periodic solution and an example has been worked out in detail on the response of a dynamic system with two degrees of freedom.

NONLINEAR ANALYSIS

78-633
Identification of Non-Linearity of Vibrations in Structures Defined by a Dynamic System with a Finite Number of Degrees of Freedom
M. Kulisiewicz
Bull. Acad. Polon. Sci., Ser. Sci. Tech., 25 (5), pp 167-172 (1977) 4 figs, 5 refs

Key Words: Mathematical models, Dynamic properties, Nonlinear theories

A method is presented of defining elasticity and damping characteristics of binding elements in a discrete dynamic system with a series structure. The system models structural vibrations. It is a simple empirical method and it does not require specially controlled forcing. The method is based on a "passive" measurement of proper vibrations of a structure, the most convenient state being a non-determined state. In the method under question characteristic points of phase of trajectory solutions are used. The method makes a mathematical model for identification of dynamic properties of a structure.

STATISTICAL METHODS

(See No. 757)

FINITE ELEMENT MODELING

(See No. 731)

MODELING

78-634
Application of Perturbation Methods to Improve Analytical Model Correlation with Test Data
J.A. Garba and B.K. Wada
Structures and Materials Section, Jet Propulsion Lab., Pasadena, CA., SAE Paper No. 770959, 2 figs, 11 tables, 16 refs

Key Words: Mathematical models, Experimental data, Correlation techniques, Perturbation theory

This activity describes the positive and negative experiences in using a method published by C.W. White to update a mathematical model of a structure. An extension of the method is shown. The results are based upon our understanding of the method as published.

78-635
Reduction of Models of Large Scale Lumped Structures Using Normal Modes and Bond Graphs
D.L. Margolis and G.E. Young
Dept. of Mech. Engrg., Univ. of California, Davis, CA 95616, J. Franklin Inst., 304 (1), pp 65-79 (July 1977) 9 figs, 6 refs

Key Words: Mathematical models, Bond graph technique, Normal modes

Bond graphs are an extremely useful modeling procedure for representing the actual energy exchange mechanisms of interacting dynamic systems. A procedure is developed whereby the original equations are reduced to a form suitable for modal decomposition. The resulting modes are reinterpreted in bond graph form with the resulting model being an extremely accurate system representation while requiring only a fraction of the original number of equations. The procedure is demonstrated through example.

PARAMETER IDENTIFICATION

(Also see Nos. 642, 644)

78-636
Identification of Structural Component Failures Under Dynamic Loading
S. Simonian and G.C. Hart
Univ. of California, Los Angeles, CA., SAE Paper No. 770958, 8 refs

Key Words: Parameter identification technique

For purposes of parameter identification, a class of N-degree of freedom dynamical systems are decoupled, to a single degree of freedom subsystem. This is achieved by utilizing all measured accelerations, and a coordinate transformation. In cases where additional data of strains or displacements are available, the decoupled equations are further simplified. The merits of this decoupling are clearly indicated.

DESIGN TECHNIQUES

78-637
Automated Design of Earthquake Resistant Multistory Steel Building Frames
N.D. Walker
Ph.D. Thesis, Univ. of California, Berkeley, 195 pp (1977)
UM 77-31,575

Key Words: Buildings, Earthquake resistant structures, Computer-aided techniques

This report presents a methodology for automating the design process for earthquake-resistant multistory steel building frames. The design process is viewed as a complex collection of interrelated decision processes, the conduct of which requires specification of the motivation for making the decisions and identification of the decision constraints. Total cost, including both construction-related expenses as well as cost of expected future damage, is adopted as the basic decision motivator. Decision constraints are composed essentially of standard and projected building code restrictions.

CRITERIA, STANDARDS, AND SPECIFICATIONS

78-638
Ride Quality Criteria
D.G. Stephens
Langley Res. Center, NASA, Hampton, VA 23665, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA, pp 463-482 (Oct 17-19, 1977) 15 figs, 1 table, 21 refs

Key Words: Ride dynamics, Aircraft, Ground vehicles, Vibration excitation, Noise generation, Standards

The ride environment of air and surface vehicles as well as the subjective response to environmental stimuli, as determined from laboratory and field studies, are presented. In addition, criteria/standards for vibration, noise, and combined stimuli are discussed.

78-639
Sound Measurement Standards for Surface Transportation Vehicles
R.K. Hillquist
P.O. Box 113, Milford, MI 48042, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 425-430 (Oct 17-19, 1977) 4 tables, 3 refs

Key Words: Standards, Noise measurement, Interior noise, Ground vehicles, Railroad cars

National and international standards used for exterior and interior sound levels of highway and rail vehicles are discussed. A trend toward testing conditions more representative of actual in-service operations and toward greater international compatibility is seen. The presence of governmental regulatory activity is also seen to be a factor in development of future standards.

78-640

Acoustical Standards and Their Application to Aircraft Noise

W.J. Galloway

Bolt Beranek and Newman, Inc., P.O. Box 633, Canoga Park, CA 91305, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 415-424 (Oct 17-19, 1977) 3 tables, 3 refs

Key Words: Standards, Aircraft noise

The activities of national and international standards groups for aircraft noise are summarized.

78-641

For Turbomachinery...New Acceptance Criteria Proposed

P.E. Simmons

ICI Petrochemicals Div., Wilton, Middlesbrough, UK, Hydrocarbon Processing, 57 (1), pp 169-171 (Jan 1978) 4 figs

Key Words: Turbomachinery, Critical speed, Unbalanced mass response

A generation of large turbomachines for the process industries is emerging. It is difficult and may be undesirable to achieve the degree of separation between the operating speed range and lateral critical speeds commonly specified. Alternative criteria are suggested which are based on rotor response to deliberate unbalance.

SURVEYS AND BIBLIOGRAPHIES

78-642

System Identification in Structural Dynamics

G.C. Hart and J.T.P. Yao

Mech. and Structures Dept., Univ. of California, Los Angeles, CA., ASCE J. Engr. Mech. Div., 103 (EM6), pp 1089-1104 (Dec 1977) 2 figs, 3 tables, 68 refs

Key Words: System identification technique, Reviews

This paper summarizes past work in system identification in the structural dynamics area.

MODAL ANALYSIS AND SYNTHESIS

(See Nos. 681, 758)

COMPUTER PROGRAMS

GENERAL

(Also see Nos. 693, 708, 747)

78-643

Alternate Approaches to Vibration and Shock Analysis Using NASTRAN

R.E. Denver and J.M. Menichello

IBM Federal Systems Div., Owego, NY, In: NASA, Washington Sixth NASTRAN Users' Colloq., pp 199-212 (1977) refs

N78-12458

Key Words: Shock response, Vibration response, NASTRAN (computer program), Computer programs

A method that derives an approximate equivalent static load to a base excitation shock analysis is described. The transient analysis in the current level of NASTRAN, level 16, does not directly provide for either input acceleration forcing functions or enforced boundary displacement. In the suggested alternate analysis format, equivalent force input functions are applied to the constrained locations by using the artifice of placing a large mass, with respect to the total system mass, at the desired acceleration input points. This shortcut static analysis approach is presented to approximate the expensive and time consuming dynamics analysis approach to the base excitation shock analysis.

78-644

Modal Identification of Structures from the Responses and Random Decrement Signatures

S.R. Ibrahim and G.L. Goglia

Old Dominion Univ., Norfolk, VA., Rept. No. NASA-CR-155321, 52 pp (Oct 1977) refs

N78-12442

Key Words: NASTRAN (computer program), Computer programs, Parameter identification technique, Signature analysis, Vibration signatures

The theory and application of a method which utilizes the free response of a structure to determine its vibration parameters are described. The technique is applied to a complex generalized payload model previously tested using sine sweep method and analyzed by NASTRAN. Ten modes of the payload model are identified. Where free decay response is not readily available, an algorithm is developed to obtain the free responses of a structure from its random responses. The algorithm is tested using random responses from a generalized payload model and from the space shuttle model.

78-645

A NASTRAN DMAP Alter for the Coupling of Modal and Physical Coordinate Substructures

T.L. Wilson

Fairchild Space and Electronics Co., Germantown, MD, In: NASA, Washington Sixth NASTRAN Users' Colloq., pp 119-130 (1977) refs

N78-12452

Key Words: NASTRAN (computer program), Computer programs, Mathematical models, Modal synthesis

A method is described to derive a generalized coordinate model consisting of flexible cantilever modes and rigid body modes from a physical coordinate model using a direct matrix abstraction procedure. This model can readily be coupled to other substructures using modal synthesis techniques. It allows the use of a reduced size model for structural analyses while maintaining the capability of recovering the accelerations, forces, stresses, etc., from the original, large, complex model. This output recovery is accomplished with the use of a loads transformation matrix which relates the output parameters to the modal coordinate accelerations. In addition, a method is described to synthesize structural models consisting of hybrid coordinates for use in dynamic response analyses where one structure is described using physical coordinates and the other using generalized modal coordinates.

78-646

Development of an Automated Multi-Stage Modal Synthesis System for NASTRAN

D.N. Herting and R.L. Hoesly

Universal Analytics, Inc., Playa Del Rey, CA., In: NASA, Washington Sixth NASTRAN Users' Colloq., pp 435-448 (1977) refs

N78-12471

Key Words: NASTRAN (computer program), Computer programs, Modal synthesis

A mode synthesis development to be scheduled in the NASTRAN multi-level substructuring system for general dynamics applications is described. The method combines the better features of several state of the art mode synthesis techniques, yet is general enough to provide for any arbitrary combination of boundary degrees of freedom and normal mode boundary conditions. Normal modes or complex eigenvectors may be used in the definition of a structure component which may be combined with other components of any type. Combination structures fabricated from component modes may be processed as normal substructures, including further multi-stage mode synthesis reductions. Included are discussions of the user control of the system and advantages in actual application.

78-647

NASTRAN Use for Cyclic Response and Fatigue Analysis of Wind Turbine Towers

C.C. Chamis, P. Manos, J.H. Sinclair, and J.R. Winemiller

Lewis Res. Center, NASA, Cleveland, OH, In: NASA, Sixth NASTRAN Users' Colloq., pp 213-233 (1977) refs

N78-12459

Key Words: Towers, Windmills, Fatigue life, Wind-induced excitation, NASTRAN (computer program), Computer programs

A procedure is described which uses NASTRAN coupled with fatigue criteria via a postprocessor to determine the cyclic response and to assess the fatigue resistance (fatigue life) of wind turbine generator towers. The cyclic loads to which the tower may be subjected are entered either in a quasi-static approach through static load subcases or through the direct dynamic response features of NASTRAN. The fatigue criteria are applied to NASTRAN output data from either rigid format through an externally written user program embedded in a postprocessor.

78-648

A Computer Program to Calculate Normal Mode Propagation in a Medium in Which Stratification is a Function of Position

W.G. Kanabis

New London Lab., Naval Underwater Systems Ctr., New London, CT, Rept. No. NUSC/NL-TM-2211-11-71, 26 pp (Jan 1971)

AD-A046 680/5GA

Key Words: Computer programs, Normal modes, Elastic waves

This program, written in FORTRAN, uses normal mode theory to predict acoustic propagation, in a medium whose velocity profile varies slowly with distance from the acoustic source, over an ocean bottom whose depth and acoustic impedance change slowly with range. It produces CAL-COMP plots for given modes at any frequency in the medium described above of the following: Amplitude as a function of depth and the ray equivalent of any mode at given distances from a source; and Propagation loss as a function of range.

78-649

A Three Dimensional Finite Difference Code for Seismic Analysis on the ILLIAC IV Parallel Processor

A.S. Hopkin
Inst. of Advanced Computation, Univ. of Illinois, Champaign-Urbana, IL, SAE Paper No. 770956, 4 figs, 3 refs

Key Words: Computer programs, Seismic response

The speed and data storage limitations of most current computer systems make the cost of realistic three dimensional seismic simulations prohibitive. One exception is the implementation of the earthquake simulation code TRES on the ILLIAC IV. The TRES program simulates the propagation of elastic waves emanating from an earthquake using a centered, finite difference scheme over a large three dimensional grid. The algorithms of the program have been modified for the unique computational environment of the ILLIAC IV parallel processor.

ENVIRONMENTS

ACOUSTIC

(Also see Nos. 649, 719, 728, 751)

78-650

Basic Aspects of the Application of Frequency Analysis

H.A. Crostack
Inst. of Physical Production Engrg., Univ. of Dortmund, Germany, Ultrasonics, 15 (6), pp 253-262 (Nov 1977) 26 figs, 13 refs

Key Words: Frequency analysis, Acoustic excitation

This paper is intended to provide a brief introduction to the application of frequency analysis in evaluating acoustic emission pulses. Where background interference noise is high it is necessary to characterize the pulses and correlate them with their sources. Frequency analysis can be used to do this, and its advantages and disadvantages are discussed.

78-651

A Normal Mode Analysis of the Sound Power Injection in Reverberation Chambers at Low Frequencies and the Effects of Some Response Averaging Methods

K. Bodlund
Div. of Bldg. Tech., Dept. of Bldg. Acoustics, Lund Inst. of Tech., S-220 07, Lund, Sweden, J. Sound Vib., 55 (4), pp 563-590 (Dec 22, 1977) 14 figs, 3 tables, 22 refs

Key Words: Modal analysis, Normal modes, Reverberation chambers

A normal mode analysis of the sound power injection in rectangular reverberation rooms has been carried out. It has been restricted to a pure tone, high impedance point source, typical laboratory chambers and the 125 Hz 1/3-octave band frequency interval. The main goal has been to identify results and guidelines that can be theoretically deduced and that should be of significance in actual sound power measurement situations. Some fundamental implications of the normal-mode theory are pointed out. The problematical power dependency on the chamber dimensions, the source position and the source frequency has been numerically analyzed to obtain a quantitative description of the various sources of error associated with the reverberation room method.

78-652

Interior Acoustic Environment of STOL Vehicles and Helicopters

J.F. Wilby and J.I. Smullin
Bolt Beranek and Newman, Inc., Box 633, Canoga Park, CA 91305, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 165-178 (Oct 17-19, 1977) 12 figs, 24 refs

Key Words: Aircraft noise, Helicopter noise, Interior noise, Noise source identification, Noise reduction

This paper reviews existing information regarding the interior noise levels of short take-off and landing (STOL) airplanes and helicopters. Noise levels measured or predicted for STOL aircraft and helicopters are compared with levels in other vehicles. The main noise sources and propagation

paths are identified. Methods of reducing the interior noise levels are discussed, with emphasis being placed on modification to the propagation paths.

78-653
Sound Level Measurements

Army Test and Evaluation Command, Aberdeen Proving Ground, MD, Rept. No. TOP-1-2-608, 33 pp (June 3, 1977)
AD-A046 109/5GA

Key Words: *Sound measurement, Machinery noise, Weapons systems*

The report concerns methods of measuring noise levels of material as a means of evaluating personnel safety, speech intelligibility, and security from acoustic detection. It covers steady-state and impulse noise from military vehicles, weapon systems, and noise-generating machinery. It includes impulse noise tests of explosive ordnance material. It is not applicable to explosive ordnance blast effects such as lethality.

RANDOM

78-654
Soil-Structure Interaction in a Random Seismic Environment

M.P. Romo-Organista
Ph.D. Thesis, Univ. of California, Berkeley, 161 pp (1977)
UM 77-31,520

Key Words: Interaction: soil-structure, Seismic excitation, Random excitation

An analytical method for the study of soil-structure interaction problems is described. It takes into account the randomness of earthquake motion both in the definition of the design motion and the computed response. In this procedure seismic environment is defined in terms of the given response spectrum and using the extreme value theory, converted into a design power spectrum. This procedure is reversible and can also be used to compute response spectra from power spectra.

SEISMIC

(Also see Nos. 637, 654, 679, 693, 697, 700, 709, 710, 735, 737)

78-655
Nonstationary Seismic Response of Light Equipment

M.P. Singh and Y. Wen
Dept. of Engrg. Sci. and Mech., Virginia Polytechnic Inst. and State Univ., Blacksburg, VA., ASCE J. Engr. Mech. Div., 103 (EM6), pp 1035-1048 (Dec 1977) 10 figs, 1 table, 15 refs

Key Words: Seismic excitation, Seismic design, Equipment response, Piping systems

A method is developed to obtain floor spectra curves that include the effect of nonstationarity of seismic motions. The response of a simple structure-equipment system is examined for excitations modeled by Gaussian shot-noise and filtered shot-noise. The nonstationarity due to time-varying intensity of the excitation and also due to the zero-starting condition is considered. The effects of various seismic intensity modulation functions and structural parameters on the response are evaluated. Useful results of practical importance are obtained in terms of response ratios of nonstationary-to-stationary responses, and their application in the generation of floor spectra curves for a structure is illustrated.

78-656
Mitigating Earthquake Effects on Power Systems

A.J. Schiff and D.E. Newsom
School of Mech. Engrg., Purdue Univ., West Lafayette, IN, J. Tech. Councils of ASCE, 103 (TC1), pp 39-51 (Dec 1977) 1 fig, 1 table, 4 refs

Key Words: Electric power plants, Earthquake response

A study was conducted using the Delphi method with a series of four questionnaires to identify and evaluate methods for mitigating the effects of earthquakes on electric power systems. The emphasis was on transmission and distribution facilities rather than generation.

78-657
Earthquake Simulation Testing of a Stepping Frame with Energy-Absorbing Devices

J.M. Kelley and D.F. Tsztoo
Earthquake Engrg. Res. Center, California Univ., Berkeley, CA., Rept. No. UCB/EERC-77/17, 55 pp (Aug 1977)
PB-273 506/6GA

Key Words: Earthquakes, Simulation, Framed structures, Testing techniques, Energy absorbers

Results are reported of earthquake simulation tests on a model frame with a partial base isolation system that includes energy-absorbing devices. Two series of tests using scaled accelerations from the El Centro N-S 1940 and Pacoima Dam 1971 earthquake ground motion records were used as input to the shaking table on which the tests were performed. Results from these tests are compared to those from earlier tests on an identical frame with the foundation anchored as in conventional design, and permitted to uplift freely.

78-658
Shear Transfer in Thick Walled Reinforced Concrete Structures Under Seismic Loading
R.N. White and P. Gergely
Dept. of Structural Engrg., Cornell Univ., Ithaca, NY, Rept. No. 75-10, NSF/RA/E-75/133, 92 pp (Dec 1975)
PB-273 808/6GA

Key Words: Reinforced concrete, Seismic excitation, Experimental results, Mathematical models, Containment structures

The mechanism of membrane shear transfer under cyclic loading in thick-walled cracked reinforced concrete structures is studied. The specimens incorporate interface shear transfer and dowel action acting both alone and in concert. The results are used in a dynamic analysis program to predict nonlinear response of containment vessels. The work reported here includes experiments on specimens with 1/2 to 3/4 inch diameter reinforcing bars crossing a crack; development of a mathematical model to predict stiffness characteristics of dowel action in thick concrete sections; dowel action experiments (under cyclic loading) to correlate with the mathematical model predictions; a dynamic analysis program that accounts for the non-linear load-slip behavior at a crack carrying reversing shear stresses; and results of experiments on specimens with large bars (no. 14 maximum size) where shear is carried by combined dowel action and interface shear transfer.

78-659
Earthquake Engineering Research at Berkeley - 1976
Earthquake Engrg. Res. Center, California Univ., Berkeley, CA., Rept. No. UCB/EERC-77/11, 198 pp (May 1977)
PB-273 507/4GA

Key Words: Earthquake-resistant structures, Seismic design

At the Sixth World Conference on Earthquake Engineering held in New Delhi, India, January 10-14, 1977, twenty-five papers were presented by faculty participants and research personnel associated with the Earthquake Engineering Research Center, University of California, Berkeley. The papers have been compiled in this report to illustrate some of the research work in earthquake engineering being conducted at the University of California, Berkeley.

78-660
Effective Seismic Input Through Rigid Foundation Filtering
D. Ray and D.P. Jhaveri
Nuclear and Innovative Div., John A. Blume & Associates, San Francisco, CA 94105, Nucl. Engr. Des., 45 (1), pp 185-195 (1978) 5 figs, 2 tables, 13 refs

Key Words: Interaction: soil-structure, Wave diffraction, Seismic excitation

In this paper a simple yet realistic approach to account for a class of important soil-structure interaction phenomenon, namely wave scattering is reported. These effects are evaluated for arbitrarily incident, horizontally polarized shear waves. The results are expressed in terms of filtering functions for various foundation geometries and embedment conditions and compared with 'exact' and other approximate solutions. Numerical results for a time history are presented in the form of translational and torsional acceleration response spectra.

SHOCK

(Also see No. 643)

78-661
Theoretical Study of Aircraft Impact on Reactor Containment Structures
D. Carlton and A. Bedi
Taylor Woodrow Construction Ltd., Southall, Middlesex UBI 2QX, UK, Nucl. Engr. Des., 45 (1), pp 197-206 (1978) 9 figs, 9 refs

Key Words: Containment structures, Nuclear reactors, Impact response, Aircraft

In containment design there is a requirement to protect the reactor system from the effects of external hazards and hence it is necessary to provide suitable wall thicknesses. This paper describes some theoretical studies for the particular case of an aircraft impact. Concrete is assumed to have a limited tensile stress capacity. The paper briefly describes the theory and makes comparisons for different concrete thicknesses.

GENERAL WEAPON

(See No. 683)

PHENOMENOLOGY

COMPOSITE

78-662

Wave Propagation in Viscoelastic Composites Reinforced by Orthogonal Fibers

H. Demiray and A.C. Eringen
Div. of Appl. Math., Marmara Research Inst., 141, Kadikoy-Istanbul, Turkey, J. Sound Vib., 55 (4), pp 509-519 (Dec 22, 1977) 5 figs, 8 refs

Key Words: Composite structures, Viscoelasticity theory, Wave propagation

A two-dimensional lattice dynamics model for a viscoelastic composite reinforced with two sets of orthogonally interlocking fibers is given, and the propagation of plane harmonic waves in such a medium is investigated. The composite considered consists of two sets of orthogonal equivalent elastic fibers and a viscoelastic matrix. The dispersion relations of waves propagating in the medium are studied and various special cases are investigated.

DAMPING

78-663

Steady Impact Vibration of a Body Having Hysteresis Collision Characteristics (3rd Report. Stability Analysis)

S. Maezawa and T. Watanabe
Faculty of Engrg., Yamanashi Univ., Kofu, Japan, Bull. JSME, 20 (150), pp 1580-1585 (Dec 1977) 12 figs, 6 refs

Key Words: Vibration response, Hysteretic damping

The stability problem for steady impact vibrations in a vibrating system with a stop having triangular hysteresis loop characteristics for force of restitution is investigated. Stability charts are constructed by performing stability analysis of solutions for variational equation of the original equation of motion. The stable and unstable branches of resonance curves given in the foregoing report are identified by referring to these stability charts. Several points on the stable branches are confirmed by analog computer solutions.

78-664

Internal Damping of Two- and Three Dimensional Continua (Ein Ansatz f. die Werkstoffdämpfung zwei- und dreidimensionaler Kontinua)

H. Grundmann
Institut f. Bauingenieurwesen I, Technische Universität München, D-8 München 2, Z. angew. Math. Mech., 57 (10), pp 565-569 (Oct 1977)
(In German)

Key Words: Internal damping

For the phenomenological description of the internal damping some equations are developed connecting the hydrostatic pressure and dilatation of volume and the components of the stress- and the strain-deviator. The given equations allow a simple linearization.

78-665

Models for RC Frames with Degrading Stiffness

J.C. Anderson and W.H. Townsend
Univ. of Southern California, Los Angeles, CA., ASCE J. Struc. Div., 103 (ST12), pp 2361-2376 (Dec 1977) 14 figs, 1 table, 16 refs

Key Words: Reinforced concrete, Structural members, Hysteretic damping, Mathematical models

Analytical models for representing the hysteretic behavior of reinforced concrete members are reviewed. Two degrading trilinear models are suggested, one of which considers the effect of the connection. The inelastic dynamic response of a 10-story single-bay frame to earthquake excitation is evaluated using the two proposed models. For purposes of comparison, the response using a bilinear model and degrading bilinear model is also considered.

FLUID

(See No. 689)

SOIL

(Also see Nos. 654, 660, 737, 738)

78-666
Soil-Structure Interaction for Transient Loads Due to Safety Relief Valve Discharges
W.S. Tseng and N.C. Tsai
Bechtel Power Corp., San Francisco, CA 94119,
Nucl. Engr. Des., 45 (1), pp 251-259 (1978) 8 figs, 2 refs

Key Words: Interaction: soil-structure, Foundations, Transient response

Dynamic responses of BWR Mark II containment structures subjected to axisymmetric transient pressure loadings due to simultaneous safety relief valve discharges were investigated using finite element analysis. To properly consider the soil-structure interaction effect, a simplified lumped parameter foundation model and an axisymmetric finite element foundation model with viscous boundary impedance are used. Analytical results are presented to demonstrate the effectiveness of the simplified foundation model and to exhibit the dynamic response behavior of the structure as the transient loading frequency and the foundation rigidity vary. The impact of the dynamic structural response due to this type of loading on the equipment design is also discussed.

EXPERIMENTATION

BALANCING

78-667
An Analysis of a New Type of Automatic Balancer
M.T. Hedaya and R.S. Sharp
Dept. of Mech. Engrg., The University of Leeds, UK,
J. Mech. Engr. Sci., 19 (5), pp 221-226 (Oct 1977) 4 figs, 1 table, 5 refs

Key Words: Dynamic balancing, Rotors

A new type of automatic balancer which consists of a pair of two-ball balancers to compensate for unbalanced inertia forces and moments is presented. A stability analysis of the balanced condition achievable by such a balancer and the results of a parametric study of its stability are included. Conclusions are drawn regarding the satisfactory operation of the balancer.

DATA REDUCTION

(See No. 634)

DIAGNOSTICS

78-668
Structural Calibration Technique for Quantitative Application of Acoustic Emission
A. Pollock
Dunegan/Endevco, San Juan Capistrano, CA.,
Acustica, 38 (5), pp 281-284 (Nov 1977) 2 figs, 10 refs

Key Words: Diagnostic techniques

Acoustic emission simulators can be used to provide information for system design, to verify system performance, and to provide a basis for quantitative data interpretation. The problem of transferring a diagnostic approach from the laboratory to the field is the major subject of this paper. Transfer methods for both events data and counts data are presented, and the significance of emission amplitude distribution in this context is demonstrated.

78-669
Acoustic Incipient-Failure Detection
H.P. Bloch
Exxon Chemical Co., Baytown, TX 77520,
Oil and Gas J., 76 (6), pp 62-72 (Feb 6, 1978) 3 tables, 8 refs

Key Words: Diagnostic techniques, High frequency resonance technique, Computer-aided techniques

Defects in machinery and mechancial structures are characterized by corresponding abnormalities and changes in the high-frequency emission pattern. These acoustic high frequencies can be measured with electronic instruments which, for reasons of cost effectiveness and continuous on-line surveillance, can be incorporated in a computerized monitoring system. Application of acoustic incipient failure detection (IFD) technology at Exxon Chemical Co., Baytown, Texas, is described.

78-670
Computer Assisted Vibration Monitoring Successful
M.H. Price
ARCO Chemical Co., Channelview, TX 77530,
Hydrocarbon Processing, 56 (12), pp 85-90 (Dec 1977) 11 figs, 4 tables, 2 refs

Key Words: Computer aided techniques, Diagnostic techniques

A computer assisted vibration monitoring system is described, which provides a practical method of closely monitoring large critical rotating equipment. It continuously monitors vibrations levels of critical rotating equipment, automatically analyzes, stores, and updates vibration information for troubleshooting purposes and generates alarms that indicate the source of trouble if problems develop.

EQUIPMENT

78-671

A Systematic Study of Vibration Standards - Mounting Effects

R.S. Koyanagi, J.D. Pollard, and J.D. Ramboz

Vibration Section, National Bureau of Standards, Washington, D.C., Rept. No. NBSIR-73-291, 44 pp (Sept 1973)

Sponsored by the Dept. of Defense Calibration Coordination Group, Redstone Arsenal, AL

PB-272 376/5GA

Key Words: Standards and codes, Accelerometers, Equipment mounts

The purpose of the study was to determine the extent of the sensitivity change of laboratory quality piezoelectric accelerometers for various mounting conditions. The mounting variables included the material upon which the accelerometer was mounted, geometry, the use of commercial insulated studs, and the use of mounting stud thread size adaptors.

FACILITIES

78-672

Automating Truck Noise Data Acquisition and Reduction

N.A. Miller

International Harvester, 2911 Meyer Rd., Fort Wayne, IN 46803, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA, pp 483-498 (Oct 17-19, 1977) 11 figs

Key Words: Test facilities, Noise measurement, Data reduction, Trucks

The truck noise data acquisition and reduction system at International Harvester is a totally automated drive-by test facility. The system was designed specifically to perform development and compliance tests associated with the SAE J366b drive-by procedure and the requirements of the U.S. EPA Noise Standard for Medium and Heavy Duty Trucks. The rationale upon which that system was based and the description of the components elected are presented.

78-673

A Research Program to Reduce Interior Noise in General Aviation Airplanes. Design of an Acoustic Panel Test Facility

J. Roskam, V.U. Muirhead, H.W. Smith, and T.D. Henderson

Center for Research, Inc., Kansas Univ., Lawrence, KS 66044, Rept. No. NASA-CR-155152; KU-FRL-317-3, 102 pp (Aug 1977)

N77-33957

Key Words: Test facilities, Sound transmission loss, Acoustic insulation, Panels, Aircraft

The design, construction, and costs of a test facility for determining the sound transmission loss characteristics of various panels and panel treatments are described. The pressurization system and electronic equipment used in experimental testing are discussed as well as the reliability of the facility and the data gathered. Test results are compared to pertinent acoustical theories for panel behavior and minor anomalies in the data are examined. A method for predicting panel behavior in the stiffness region is presented.

78-674

A Research to Reduce Interior Noise in General Aviation Airplanes. General Aviation Interior Noise Study

J. Roskam, V.U. Muirhead, H.W. Smith, and T.D. Peschier

Center for Research, Inc., Kansas Univ., Lawrence, KS 66044, Rept. No. NASA-CR-155153; KU-FRL-317-4, 159 pp (Aug 1977)

N77-33958

Key Words: Test facilities, Sound transmission loss, Acoustic insulation, Panels, Aircraft noise, Noise reduction

The construction, calibration, and properties of a facility for measuring sound transmission through aircraft type panels are described along with the theoretical and empirical methods used. Topics discussed include typical noise source, sound transmission path, and acoustic cabin properties and their effect on interior noise.

78-675

Laboratory Model Testing for Earthquake Loading

R.W. Clough and V.V. Bertero

Univ. of California, Berkeley, CA., ASCE J. Engr. Mech., Div., 103 (EM6), pp 1105-1124 (Dec 1977) 23 figs, 20 refs

Key Words: Test facilities, Earthquake response, Structural members

Two types of facilities used at the University of California, Berkeley, for laboratory study of earthquake response characteristics of typical structures are described: A 20-ft square shaking table; and a variety of controlled loading devices.

78-676

Wind-Tunnel Testing of Structures

J.E. Cermak

Dept. of Civil Engrg., Colorado State Univ., Fort Collins, CO, ASCE J. Engr. Mech. Div., 103 (EM6), pp 1125-1140 (Dec 1977) 12 figs, 42 refs

Key Words: Test facilities, Wind tunnel tests, Scaling, Buildings, Wind-induced excitation

Special meteorological wind tunnels that simulate essential characteristics of natural boundary-layer-type wind are available as shown in this paper. Modeling criteria, measurement techniques, and data processing to determine mean and fluctuating wind pressures, dynamic response, and induced street level winds from measurements on small-scale models of structures have been established.

INSTRUMENTATION

78-677

A Broadband Probe for Studies of Acoustic Surface Waves

E. Harnik

Dept. of Physics, The City Univ., St. John Street, London EC1V 4PB, UK, J. Phys. E. (Sci, Instr.), 10 (12), pp 1217-1218 (Dec 1977) 3 figs, 6 refs

Key Words: Measuring instruments, Rayleigh waves

An acoustic surface wave probe has been developed for use in broadband non-destructive testing and in seismological modeling. It takes a negligible amount of energy from the ultrasonic beam and appears to reproduce accurately the shape of an ultrasonic pulse. The probe is characterized by simplicity of construction and operation.

78-678

Wind-Tunnel Measurement of Dynamic Cross-Coupling Derivatives

E.S. Hanff and K.J. Orlik-Ruckemann

National Aeronautical Establishment, National Res. Council of Canada, Ottawa, Ontario, Canada, J. Aircraft, 15 (1), pp 40-46 (Jan 1978) 10 figs, 7 refs

Key Words: Instrumentation, Dynamic testing, Aircraft, Wind tunnel tests

An oscillatory apparatus and the associated data-reduction procedure for routine measurement of the 12 static and dynamic moment derivatives due to pitching and yawing have been developed. The list of derivatives includes some dynamic cross-coupling derivatives, which have never been systematically measured before. It was therefore considered desirable to develop an independent calibration system to verify the basic principles of the method and to confirm the validity of the data-reduction procedure used. A three-degrees-of-freedom dynamic calibratory was constructed, with which the aerodynamic moments in pitch, yaw, and roll could be simultaneously simulated.

78-679

Earthquake Response and Instrumentation of Buildings

C. Rojahn and R.B. Matthiesen

U.S. Geological Survey, Menlo Park, CA, J. Tech. Councils of ASCE, 103 (TC1), pp 1-12 (Dec 1977) 10 figs, 23 refs

Key Words: Measuring instruments, Building response, Earthquake response

An optimal instrumentation system for interpreting building response, designed so that motion in the horizontal plane of each instrumented floor is defined, is described. Strong-motion recording systems utilizing single and multiaxial remote accelerometers connected via data cable to a central recorder(s) are used for buildings rather than self-contained triaxial accelerographs.

SCALING AND MODELING

(See No. 759)

TECHNIQUES

78-680

A New Technique for Noise Source Identification on a Multi-Cylinder Automotive Engine

R.J. Alfredson

Dept. of Mech. Engrg., Monash Univ., Clayton, Victoria 3168, Australia, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 307-318 (Oct 17-19, 1977) 10 figs, 2 tables, 15 refs

Key Words: Engine noise, Noise measurement, Measurement techniques

An approach for identifying and ranking noise sources in a multisource situation for noise control purposes is described. It consists of measuring the acoustic intensity at a large number of positions close to the surface of the engine. The intensity is determined from simultaneous measurement of the fluctuating pressure and pressure gradient. Digital techniques are used for all data processing.

78-681

Modal Test Methods and Applications

C.V. Stahle

Space Div., General Electric Co., J. Environ. Sci., 21 (1), pp 24, 33-35 (Jan/Feb 1978)

Key Words: Modal tests, Testing techniques

In this article modal test objectives are reviewed -- data applications and usage are discussed. Some problem areas and current test methods are described. The base excitation method, a method with many advantages and that is not too commonly used, is emphasized. Some alternate test methods, approaches and developments that might be possibilities in the future are suggested. The most cost effective modal test method is view of recent fast fourier transform/minicomputer advances is discussed.

78-682

Dynamic Tests of Full-Scale Structures

D.E. Hudson

California Inst. of Tech., Pasadena, CA., ASCE J. Engr. Mech. Div., 103 (EM6), pp 1141-1157 (Dec 1977) 12 figs, 59 refs

Key Words: Dynamic tests, Earthquake response, Wind-induced excitation, Underground explosions

Basic objectives of dynamic testing are outlined, and major test types are summarized. Force generation equipment suitable for tests of full-scale structures is described. Results of low-level ambient vibration tests are compared with higher-level vibration generator tests, and with excitations caused by strong earthquake ground motion. Some instrumentation systems suitable for such testing are described. Information is given on the ground motions caused by large underground explosions, and the use of such explosions to simulate damaging earthquake excitations is considered.

78-683

Performance Evaluation of Shipping Containers for the GBU-15 Guided Bomb System and the AIM 9J-1 Canards

J.J. Berardino

Air Force Packaging Evaluation Agency, Wright-Patterson AFB, OH, Rept. No. PTPT-77-40, 17 pp (Sept 1977)

AD-A046 643/3GA

Key Words: Shipping containers, Ammunition, Transportation effects, Drop tests (impact tests), Vibration tests

Each of the four containers used for the GBU-15 TV guided bomb system were subjected to vibration and superimposed load tests to simulate conditions experienced during transport and storage respectively. In addition, the dynamic performance of the containers was evaluated using one or more mechanical or rough handling tests, including free-fall drop, edgewise rotational drop, and pendulum impact. The containers were checked for pressure retention before and after completion of the tests. All tests were conducted in conformance with Federal Test Method Standard 101B. Subsequent functional tests conducted on each GBU-15 item indicated they were fully operational. Evaluation of the M548 ammunition can for the AIM 9J-1 canards was limited to vibration and free-fall drop tests.

COMPONENTS

SHAFTS

78-684

Quasi-Stationary Vibrations of a Rotating Shaft

Which Rubs Against an Interference. Spiral Vibration (Quasi-Stationare Schwingungen einer rotierenden Welle, die an einem Hindernis streift -- Spiral Vibration)

W. Kellenberger and A.G. Brown
Boveri & Cie, CH-5401 Baden, Switzerland, Ing. Arch., 46 (6), pp 349-364 (1977) 12 figs, 3 refs

Key Words: Shafts, Rotating structures, Vibration response

The rubbing of a rotating shaft on a stationary interference is represented, subject to some simplifying assumptions, by a system of nonlinear vector differential equations. Sliprings, collectors and scaling rings are typical interference elements in electrical machines, as are stators and housings in turbines. The vibration vector of the rotating shaft varies with time in the rotating coordinate system. The locus of the vibration vector point is approximately circular and its magnitude can quickly rise to an unacceptable value after a sufficiently long time and heat dissipation. The process can therefore become unstable. To a good approximation the slow rotation of the vibration vector can be derived from an ordinary vector equation. The theoretical results cast light on both former and recent observations on machines in operation.

78-685

Stability Analysis of a Rotating Shaft System with Many Bearings and Disks

K. Kikuchi and S. Kobayashi
Mech. Engrg. Research Lab., Hitachi Ltd., Tsuchiura, Japan, Bull. JSME, 20 (150), pp 1592-1600 (Dec 1977) 10 figs, 6 tables, 7 refs

Key Words: Shafts, Rotors, Self-excited vibrations

A calculation method incorporating the transfer matrix method and the characteristic-vector locus method (Cremer-Leonhard-Muxsulob's criterion) has been developed for stability analysis of the self-excited vibration of a rotating shaft system with many bearings and disks. As the result of calculations and experiments on some model rotors supported by cylindrical journal bearings, it was concluded that calculation results agreed well with almost all experimental ones, and that a comparatively large gyroscopic moment of disk affected the stability of a rotor system even when the bearing eccentricity was more than about 0.8.

BEAMS, STRINGS, RODS, BARS

(Also see No. 711)

78-686

Natural Vibrations of a Uni-Tapered Beam with Two Intermediate Supporting Points

M. Kuroda, S. Hatano, and N. Sonoda
Faculty of Engrg., Seikei Univ., Musashino-shi, Tokyo, Japan, Bull. JSME, 20 (150), pp 1586-1591 (Dec 1977) 5 figs, 2 tables, 7 refs

Key Words: Beams, Variable cross section, Rotational inertia effects, Transverse shear deformation effects, Natural frequencies, Flexural vibrations

Two types of frequency equations for bending vibrations of a uni-tapered beam with two intermediate supporting points are introduced. One is for the case where the effects of shear deformation and rotational inertia are taken into consideration and the other is for the case where these effects are neglected. Qualitative and quantitative differences of the two frequency equations are made clear with the help of experimental data and numerical computations, demonstrating the usefulness of the study.

78-687

Vibrational Characteristics of Cracked Cantilever Plates

J.S. Ogg
Aeronautical Systems Div., Wright-Patterson AFB, OH, Rept. No. ASD-TR-77-65, 50 pp (Oct 1977) AD-A046 636/7GA

Key Words: Cantilever beams, Cantilever plates, Cracked media, Vibration response

An analytical solution to the vibrational characteristics of a rectangular cantilever plate with a discontinuous boundary condition (crack) at the root is presented. Mechanical damping which may exist as a result of the contact between the crack's free surfaces during vibration has been eliminated by assuming the crack surface to be a free boundary. The approach to solution involves the use of the method of Ritz applied to Hamilton's Law of Varying Action. A comparison is made to the solution as obtained from conventional finite element theory (NASTRAN). No exact solution is available for comparison. The assumptions which underlie both theories are outlined. A comparison is made to the experimental results for a cantilever plate with a narrow slot of varying lengths at the root. Indications are that significant frequency deterioration and nodal pattern variations occur with increasing crack length. Further work on the effect of cracks/flaws on plate response is warranted.

78-688

Continuum Models for the Dynamic Analysis of Beams and Beam-Like Structures

O.I. Abdulkarim

Ph.D. Thesis, Univ. of California, Berkeley, 164 pp (1977)
UM 77-31,264

Key Words: Beams, Eigenvalue problems, Continuum mechanics, Mathematical models

A new method for obtaining approximate solutions for eigenvalue problems associated with continuum modeling of beams and beam-like structures is introduced here. The method features an efficient, iterative, numerical shooting technique for simultaneous generation of the eigenvectors and estimation of the eigenvalues. It is suited for obtaining the first dozen or so frequencies and mode shapes. Continuum modeling of this class of structures is becoming practical by the development of this numerical technique.

BLADES

78-689

Noise Due to Interaction of Boundary-Layer Turbulence with a Compressor Rotor

N. Moiseev, B. Lakshminarayana, and D.E. Thompson
Applied Res. Lab., Pennsylvania State Univ., State College, PA, J. Aircraft, 15 (1), pp 53-61 (Jan 1978) 21 figs, 3 tables, 7 refs
Sponsored by the David W. Taylor Naval Ship Res. & Dev. Center

Key Words: Compressor blades, Noise generation, Flow-induced excitation, Turbulence

The radiated sound due to a compressor or propulsor rotating blade row was investigated under various operating conditions and inflows. The propulsor was operated in air with different blade space-to-chord ratios, different flow coefficients and differing turbulence (nonisotropic) inflows. A parametric investigation of the effect of inflow characteristics on the radiated sound was made.

78-690

Nonlinear Aeroelastic Equations for Combined Flapwise Bending, Chordwise Bending, Torsion, and Extension of Twisted Nonuniform Rotor Blades in Forward Flight

K.R.V. Kaza and R.G. Kvaternik
Lewis Res. Center, NASA, Cleveland, OH, Rept. No. NASA-TM-74059, 111 pp (Aug 1977)
N77-33107

Key Words: Rotor blades, Beams, Equations of motion

Second-degree nonlinear aeroelastic equations were developed using Hamilton's principle. The implications of the slender beam approximation as applied to the derivation of the second-degree nonlinear equations of motion are discussed and a mathematical ordering scheme which is compatible with the assumption of a slender beam is introduced. The blade aerodynamic loading was obtained. The equations were compared with several of those existing in the literature and the results are discussed.

78-691

An Experimental and Analytical Investigation of Proprotor Whirl Flutter

R.G. Kvaternik and J.S. Kohn
Langley Res. Center, NASA, Langley Station, VA, Rept. No. NASA-TP-1047; L-11656, 76 pp (Dec 1977) refs
N78-12039

Key Words: Rotors, Propeller blades, Flutter

The results of an experimental parametric investigation of whirl flutter are presented. The model consists of a windmilling propeller-rotor, or proprotor, having blades with offset flapping hinges mounted on a rigid pylon with flexibility in pitch and yaw. Cases of forward whirl flutter and of backward whirl flutter are documented.

DUCTS

(Also see No. 746)

78-692

Analytical and Experimental Studies of Acoustic Performance of Segmented Liners in a Compressor Inlet

R.E. Motsinger, R.E. Kraft, J.E. Paas, and B.M. Gahn
Aircraft Engine Group, General Electric Co., Evendale, OH, Rept. No. NASA-CR-2822; R77AEG377, 147 pp (Sept 1977)
N77-33960

Key Words: Acoustic liners, Ducts, Compressors

The performance of axially segmented (phased) acoustic treatment liners in the inlet of a compressor was investigated. Topics discussed include: the validation of a theoretical procedure to predict propagation and suppression characteristics of duct liners; the in-duct measurement of spinning modes; investigation of phased treatment designs; high

Mach inlet acoustic tests; and an experimental investigation of inlet turbulence.

FRAMES, ARCHES

78-693
Space Frame Simulated for Structural Design
J.F. McDonough, T.M. Baseheart, and B.C. Ringo
Univ. of Cincinnati, Cincinnati, OH 45221, Computers and Struc., 7 (6), pp 747-750 (Dec 1977) 5 figs, 3 refs

Key Words: Framed structures, Buildings, Reinforced concrete, Earthquake resistant structures, Computer programs

This paper presents a unique, cost-saving analysis procedure for a complex space frame structure subjected to earthquake and wind loadings. Simplification is made by simulation of the structural model for a multi-story, unsymmetrical, reinforced concrete building subject to substantial lateral loads. The concept combined two computer analysis procedures and reduced the time and cost incurred in the overall analysis.

GEARS

78-694
Dynamic Behavior of Planetary Gear (3rd Report. Displacement of Ring Gear in Direction of Line of Action)
T. Hidaka, Y. Terauchi, M. Nohara, and J. Oshita
Faculty of Engrg., Yamaguchi Univ., Tokiwadai, Ube, Bull. JSME, 20 (150), pp 1663-1672 (Dec 1977) 20 figs, 2 tables, 11 refs

Key Words: Gears, Dynamic response, Finite element technique

The calculation for the deformation of a ring gear was made using a finite element model.

MECHANICAL

78-695
Dynamics of Disconnectable Microdrives of Mine Hoisting Units
D.P. Pampura and A.K. Maslix
NASA, Washington, D.C., Rept. No. NASA-TM-75186, 14 pp (Nov 1977) refs (Transl. into Engl. from Izu. Uyssh. Ucheb. Zaved., Elektromekh. (USSR), no. 9, pp 1002-1007, Sept 1969)
N78-12416

Key Words: Clutches, Dynamic response

A model study is presented on drives for the electromagnetic clutches used in hoists. Equations were set up and solved, describing the principles of the slip variation during the transient period of the plate engagement.

PANELS

78-696
Finite-Element Panel Flutter in Three-Dimensional Supersonic Unsteady Potential Flow
T.Y. Yang and S.H. Sung
Purdue Univ., West Lafayette, IN, AIAA J., 15 (12), pp 1677-1683 (Dec 1977) 9 figs, 19 refs
Sponsored by the Air Force Flight Dynamics Lab

Key Words: Panels, Flutter, Fluid-induced excitation, Finite element technique

A finite-element formulation and solution procedure were developed for flutter prediction of rectangular panels with one surface exposed to three-dimensional supersonic unsteady potential flow. Each element was divided into several Mach boxes. The aerodynamic influence coefficients between each pair of sending and receiving boxes were computed by the method of Gaussian quadrature.

PIPES AND TUBES

(Also see No. 655)

78-697
Locating Pipe Supports for Combined Thermal and Seismic Loading
C.A. Miller, C.J. Costantino, and H.I. Fink
The City College of New York, New York, NY, ASME Paper No. 77-PVP-63

Key Words: Pipes (tubes), Supports, Seismic response

A method was developed for evaluating the optimum number and location of the pipe supports for a system subjected to

both thermal and seismic loading. A single run of pipe was isolated with moment springs simulating the stiffness of the remainder of the system. Thermal shear deformations were placed at the end of the pipe run simultaneously with seismic disturbance defined in spectral form. The number and location of supports which minimize the maximum moment were determined.

78-698

Transient Cavitation Effects in Fluid Piping Systems

C.A. Kot and C.K. Youngdahl

Argonne National Lab., Argonne, IL 60439, Nucl. Engr. Des., 45 (1), pp 93-100 (1978) 8 figs, 9 refs

Key Words: *Piping systems, Nuclear power plants, Cavitation, Fluid hammer*

An accurate prediction of pressure transients and associated loadings in nuclear power plant piping systems requires a treatment of cavitation. A technique for calculating this effect in a general fluid-hammer analysis by the method of characteristics was developed. While the model is a simplification of the actual phenomena it reproduces the essential features of transient cavitation. Computational results obtained for a variety of piping arrangements demonstrate the versatility of the approach, and clearly illustrate the fact that neglecting cavitation leads to erroneous pressure - time loadings in the piping systems. Comparisons of calculated results with available experimental data, for a simple piping arrangement are provided.

PLATES AND SHELLS

(Also see Nos. 687, 711)

78-699

Dynamic Buckling of Shells: Evaluation of Various Methods

V. Svalbonas and A. Kalnins

Engrg. Dept., The Franklin Inst. Research Labs., Philadelphia, PA 19103, Nucl. Engr. Des., 44 (3), pp 331-356 (Dec 1977) 16 figs, 1 table, 33 refs

Key Words: Shells, Dynamic buckling, Computer programs

The purpose of this paper is to compare and evaluate some methods of analysis for dynamic buckling of shells by applying them to a specific problem. A shallow spherical cap, subjected to an axisymmetric, uniform-pressure, step loading, is used as the structural example. The approximate methods used by Akkas are compared to the more rigorous and general solutions of the KSHEL, STARS, DYNASOR, and SATANS computer programs, and the various simplifying assumptions utilized are evaluated.

78-700

Experimental Evaluation of Seismic Design Methods for Broad Cylindrical Tanks

D.P. Clough

Ph.D. Thesis, Univ. of California, Berkeley, 259 pp (1977)

UM 77-31,322

Key Words: Cylindrical bodies, Storage tanks, Fluid-filled containers, Seismic excitation

The current seismic design approach for cylindrical tanks is presented in detail, and its application in a typical design situation is illustrated. Records of tanks damaged in four earthquakes are examined, and a relatively high earthquake vulnerability is found in tanks with height greater than radius. It is concluded that present seismic design methods neglect the most important aspects of seismic response in "broad" tanks. Considerations in the development of more refined analytical models which account for uplift from the foundation and coupled liquid-structure vibration in cross-section distortion modes are discussed.

78-701

Vibration Characteristics of Imperfect Cylindrical Shells with Rigidly Fixed Ends

C.A. Yoerkie

Ph.D. Thesis, The Univ. of Connecticut, 109 pp (1977)

UM 77-31,239

Key Words: Cylindrical shells, Geometric imperfection effects, Vibration response

The effects of a particular geometric imperfection in the form of a wall thickness eccentricity in a thin cylindrical shell are evaluated with respect to vibrations. The thickness of the cylinder is a function of circumferential position. The study also includes experimental work with cylinders having eccentricities of 19% and 55%.

78-702

Dynamics and Failure of Cylindrical Shells Subjected to Axial Impact

G. Maymon and A. Libai

Technion-Israel Inst. of Tech., Haifa, Israel, AIAA J., 15 (11), pp 1624-1630 (Nov 1977) 10 figs, 4 tables, 11 refs

Key Words: Cylindrical shells, Axial excitation, Failure analysis

Time histories of the expected values of stresses and radial displacements in imperfect, closely spaced, stiffened cylindrical shells subjected to axial impact were analyzed. The analyses were based on Donnell-type equations for the dynamics of stiffened (and unstiffened) cylindrical shells with assumed statistical distributions of the initial imperfections, leading to a statistical description of the response. An engineering-oriented failure criterion was utilized for practical purposes. A specially constructed computer program was utilized for presenting several numerical parametric studies of axially stiffened shells. Of interest is the apparent existence of an optimal size of stiffening.

78-703

Response of Circular Plates to Central Pulse Loading

A.L. Florence

SRI International, Menlo Park, CA 94025, Intl. J. Solids Struc., 13 (11), pp 1091-1102 (1977) 7 figs, 7 refs

Key Words: Plates, Circular plates, Pulse excitation

An analysis is presented for the response of a clamped circular plate subjected to a rectangular pulse uniformly distributed over a central circular area. The plate is rigid-perfectly plastic with yielding according to the Johansen criterion and the associated flow rule. Bending is assumed to be the predominant response. Simple formulas were obtained for the permanent central deflection for all pressures and loaded areas.

78-704

Increase of the First Natural Frequency and Buckling Load of Plates by Optimal Fields of Initial Stresses

F.G. Rammerstorfer

Inst. f. Allgemeine Mechanik, Tech. Univ. Wien, Karlsplatz 13, A-1040 Wien, Austria, Acta Mech., 27 (1-4), pp 217-238 (1977) 7 figs, 17 refs

Key Words: Plates, Circular plates, Natural frequency, Fundamental frequency

This paper deals with the problem of maximizing the fundamental frequency of structures by optimizing fields of initial stresses without varying the given appropriate shape of the structure. Thin elastic circular and rectangular plates are considered. They may be loaded by external inplane forces. Optimal initial membrane stress fields are calculated which produce values of the first natural frequency of the free bending vibrations as high as possible. The optimal fields of initial stresses of the buckling plates are calculated as extreme cases in the same manner.

78-705

Vibrations of Highly Prestressed Anisotropic Plates Via a Numerical-Perturbation Technique

R.L. Ramkumar, M.P. Kamat, and A.H. Nayfeh

Dept. of Engrg. Science and Mech., Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, Intl. J. Solids Struc., 13 (11), pp 1037-1044 (1977) 1 table, 10 refs

Key Words: Membranes, Circular plates, Anisotropy, Flexural vibration, Perturbation theory, Finite element technique

The method of matched asymptotic expansions was used to reduce the problem of the transverse vibrations of a highly prestressed anisotropic plate into the simpler problem of the vibration of an anisotropic membrane with modified boundary conditions that account for the bending effects. In the absence of an exact solution the membrane problem can be solved by any well-known numerical technique. The numerical-perturbation results for a clamped circular plate with rectangular orthotropy and a uniform tensile stress applied on its boundary show an excellent correlation with finite-element solutions for the original problem. Furthermore, the solutions obtained for annular plates form the basis for solutions to problems involving near-annular plates.

78-706

Vibration Analysis of Heated Plates

B.O. Almroth, J.A. Bailie, and G.M. Stanley

Lockheed Missiles and Space Co., Inc., Sunnyvale, CA., AIAA J., 15 (12), pp 1691-1695 (Dec 1977) 8 figs, 12 refs

Key Words: Plates, Aircraft wings, Natural frequencies, Mode shapes

A study has been carried out of the free vibrations of a solid-wing structure with a diamond-shaped profile. Vibration frequencies and modes are obtained at different levels of the temperature, which is distributed in a way that is typical for such wings at high speed.

78-707

Analytical and Experimental Investigation of the Free Vibrations of Clamped Plates of Regular Polygonal Shape Carrying Concentrated Masses

J.L. Pombo, P.A.A. Laura, R.H. Gutierrez, and D.S. Steinberg

Inst. of Appl. Mechanics, Base Naval Puerto Belgrano, 8111 Argentina, J. Sound Vib., 55 (4), pp 521-532 (Dec 22, 1977) 9 figs, 1 table, 12 refs

Key Words: Plates, Natural frequencies, Mode shapes

This paper presents a comparison of frequency results obtained by means of analytical, numerical and experimental methods in the case of the fundamental mode of transverse vibration of a clamped, regular polygonal plate carrying concentrated masses. It is shown that it is also possible to obtain an approximate value of the frequency corresponding to a higher mode by using an analytical approach (with no concentrated mass acting on the plate).

78-708

Application of the TRPLT1 Element to Large Amplitude Free Vibrations of Plates

C. Mei and J.L. Rogers, Jr.

Vought Corp., Hampton, VA., In: NASA Sixth NASTRAN Users' Colloq., pp 275-298 (1977) refs N78-12462

Key Words: Plates, NASTRAN (computer program), Flexural vibration, Finite element technique

A finite element formulation is developed for analyzing large amplitude free flexural vibrations of thin plates in NASTRAN. Stress distributions in the plate, in addition to deflection shapes and nonlinear frequencies are determined. Linearized equations of motion governing large amplitude oscillations of plates and a linearized geometrical stiffness matrix are presented. The solution procedure and convergence characteristics are discussed.

STRUCTURAL

(Also see No. 675)

78-709

Effect of Beam Strength and Stiffness on Dynamic Behavior of Reinforced Concrete Coupled Walls. Volume 1: Text

J.M. Lybas and M.A. Sozen

Dept. of Civil Engrg., Illinois Univ. at Urbana-Champaign, IL, Rept. No. STRUCTURAL RESEARCH SER-44-Vol-1, UILU-ENG-77-2016-Vol-1, 256 pp (July 1977)

PB-273 876/3GA

Key Words: Walls, Reinforced concrete, Seismic excitation, Earthquake resistant structures

This project attempted to develop an understanding of the response of reinforced concrete coupled wall systems to seismic loading. Five test structures (approximately one-twelfth scale) were subjected to one component of the earthquake base motion measured at El Centro, California (1940). The base motions were strong enough to cause yielding of the test structures. A sixth test structure was subjected to slowly applied cyclic lateral loading. An analytical study of the static hysteretic response of the test structures was undertaken. Equivalent viscous damping factors, consistent with the calculated overall structure hysteresis relation, were determined. The variation of damping factor with response mode and response amplitude was studied. The feasibility of simulating the observed dynamic responses with a linear viscously damped analytical model was investigated. Both response-spectrum analyses and response-history analyses were performed. Finally, the experimental results were compared with the results of the analytical studies.

78-710

Effect of Beam Strength and Stiffness on Dynamic Behavior of Reinforced Concrete Coupled Walls. Volume 2: Tables and Figures

J.M. Lybas and M.A. Sozen

Dept. of Civil Engrg., Illinois Univ. at Urbana-Champaign, IL, Rept. No. STRUCTURAL RESEARCH SER-444-Vol-2, UILU-ENG-77-2016-Vol-2, 340 pp (July 1977)

PB-273 877/1GA

Key Words: Walls, Reinforced concrete, Seismic excitation, Earthquake resistant structures, Experimental results

This volume contains tables and figures relevant to the text of the report presented in Volume 1 (see abstract number 78-709).

78-711

The Application of Dynamic Plastic Analysis to Problems of Structural Impact

O.M. Shawa

Ph.D. Thesis, Univ. of California, Berkeley, 190 pp (1977)

UM 77-31,535

Key Words: Structural, Beams, Plates, Impact response (mechanical), Dynamic plasticity

A rapid and approximate method for determining the probable performance of structures and structural systems subject to impact or impulsive loadings is described. Problems treated include simple models of beams and plates, both with and without backing materials. The method can be applied to a wide variety of structural elements and systems in design and analysis as well as to experimental setups for response to impact by projectiles with velocities in the ballistic range (100-400 ft./sec.).

78-712
Elastodynamic Response of a Wedge to Surface Pressures
J.D. Achenbach and R.P. Khetan
Dept. of Civil Engrg., Northwestern Univ., Evanston, IL 60201, Intl. J. Solids Struc., 13 (11), pp 1157-1171 (1977) 5 figs, 14 refs

Key Words: Wedges, Elastodynamic response

An elastic wedge of interior angle $\kappa\pi$, where $1 < \kappa \leqslant 2$, is subjected to the impact of spatially uniform pressures on its faces. The application of the pressures produces a system of longitudinal waves, transverse waves and head waves. In this paper the elastodynamic stress singularity in the circumferential stress at the vortex of the wedge is analyzed.

SYSTEMS

ABSORBER
(Also see No. 657)

78-713
One-Shot Shock Absorbers
J.A. Kirk and N. Overway
Univ. of Maryland, College Park, MD, Mach. Des., 49 (24), pp 152-157 (Oct 20, 1977)

Key Words: Energy absorption, Shock absorbers

The types and design of nonrecoverable energy absorbers is described. Such absorbers convert kinetic energy into heat, eliminating spring back.

78-714
A Non-Linear Free-Piston Dynamic Vibration Absorber
H.M. Miller
Ph.D. Thesis, The Univ. of Connecticut, 174 pp (1977)
UM 77-31,201

Key Words: Dynamic vibration absorption (equipment)

Past history of linear and nonlinear dynamic vibration absorber investigations are reviewed in this dissertation. It describes an unique design of a dynamically tunable vibration absorber which suspends the absorber mass on two opposing air springs. This absorber also incorporates means for maintaining approximately equal volumes in each of the two air springs suspending the absorber mass. Design parameters are discussed, and a prototype absorber, which successfully attenuated 87% of the acceleration of the main mass at resonance, is described.

78-715
Breakaway Link Assembly for Maintaining a Structural Alignment of Shock-Sensitive Equipment
R.H. Duchild
Dept. of the Navy, Washington, D.C., PAT-APPL-833 121/GA, 19 pp (Sept 1977)
AD-D004 381/0

Key Words: Equipment mounts

Resilient shock absorbers cushion the force. The absorbers also function to subsequently return the block to its locked position and realign the structure. The detent profile includes a shallow-angle peripheral ramp to facilitate realignment.

78-716
Energy Absorbing Highway Barrier Material Investigations
R.L. Stoughton, D.M. Parks, J.R. Stoker, and E.F. Nordlin
Transportation Lab., California State Dept. of Transportation, Sacramento, CA., Rept. No. 636405, 141 pp (June 1977)
PB-273 827/6GA

Key Words: Guardrails, Concrete, Energy absorption

This project concentrated on developing a vermiculite concrete crash cushion for use in gore areas on elevated bridge structures to replace hazardous concrete wedge shaped blocks which served as terminals at the intersection of converging bridge rails.

NOISE REDUCTION

(Also see Nos. 652, 673, 674, 692, 727, 745, 749, 750, 752, 753)

78-717

A Model of Close Fitting Acoustical Enclosures

L.W. Tweed and D.R. Tree

Ray W. Herrick Laboratories, Purdue Univ., West Lafayette, IN 47907, Proc. NOISE-CON 77, NASA, Langley Res. Ctr., Hampton, VA, pp 319-330 (Oct 17-19, 1977) 8 figs, 8 refs

Key Words: Mathematical models, Enclosures, Noise reduction

This paper describes several mathematical models used in the design of partially or totally fitting acoustical enclosures, a derivation of a new model used in this study, and a comparison of the results from this model with measured data.

78-718

Internal Combustion Engine Exhaust Muffling

M.J. Crocker

School of Mech. Engrg., Ray W. Herrick Laboratories, Purdue Univ., West Lafayette, IN 47907, Proc. NOISE-CON 77, NASA, Langley Res. Ctr., Hampton, VA., pp 331-358 (Oct 17-19, 1977) 18 figs, 68 refs

Key Words: Engine noise, Mufflers, Noise reduction

This paper reviews the existing theories used in muffler design and also discusses recent advances and problems still to be solved.

78-719

Rail Transit System Noise Control

G.P. Wilson

Wilson, Ihrig & Associates, Inc., 5605 Ocean View Dr., Oakland, CA 94618, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 247-256 (Oct 17-19, 1977) 5 figs, 4 tables

Key Words: Rail transportation, Noise control

The purpose of this paper is to present a progress report and review of the noise performance characteristics which have been achieved by the new rail transit system facilities and vehicles incorporating the noise control provisions. Data from other older transit facilities and equipment are also presented to provide comparison of the noise levels and an indication of the level of achievement produced by the modern design features and noise control provisions.

78-720

Active Liquid Silencers in Oil Hydraulics

J. Rebel

VDI Z., 119 (19), pp 937-943 (1977) 11 figs, 10 refs

Key Words: Hydraulic systems, Noise reduction

Pressure oscillations in hydraulic systems (oil hydraulical drives and controls) can propagate to all elements of the circuit and excite these and also the attached working machine to vibrations. These vibrations may result directly in reducing the working quality and the functional ability of the machine. If the vibrations or their harmonics are radiated as air sound, this leads to an increased noise emmission of the plant. This contribution is devoted to experimental results which were obtained by using active liquid sound silencers. Thereby very considerable noise reductions could be achieved.

78-721

A Research Program to Reduce Interior Noise in General Aviation Airplanes

J. Roskam, V.U. Muirhead, H.W. Smith, T.D. Peschier, D. Durenberger, K. Vandam, and T. Shu

Center for Research, Inc., Kansas Univ., Lawrence, KS 66044, Rept. No. NASA-CR-155154; KU-FRL-317-5, 76 pp (Oct 1977)

N77-33959

Key Words: Sound transmission loss, Acoustic insulation, Aircraft

Analytical and semi-empirical methods for determining the transmission of sound through isolated panels and predicting panel transmission loss are described. Test results presented include the influence of plate stiffness and mass and the effects of pressurization and vibration damping materials on sound transmission characteristics. Measured and predicted results are presented in tables and graphs.

ACTIVE ISOLATION

(Also see No. 742)

78-722

Structural Aspects of Active Controls

AGARD, Paris, France, Rept. No. AGARD-CP-

228; ISBN-92-835-0200-00, 102 pp (Aug 1977)
Proc. of 44th Mtg. of AGARD Struct. and Mater. Panel, Lisbon, Apr 21, 1977
(In English and French)
N77-33208

Key Words: Aircraft vibration, Flutter, Active flutter control

Design and implementation factors regarding flight control systems are reviewed. Flutter suppression system testing is discussed, including wind tunnel tests, as well as actual flight tests. The impact flight command stability system on aircraft dynamic response is considered.

78-723
Airplane Math Modeling Methods for Active Control Design
K.L. Roger
Boeing Co., Wichita, KS, In: AGARD Structural Aspects of Active Controls, 11 pp (Aug 1977)
N77-33212

Key Words: Aircraft vibration, Active flutter control

Selected analytical methods are described which are useful and practical in math modeling for airplane active control system design. A technique for writing state equations is presented which is suitable for incorporating lifting surface aerodynamic solutions. An economical method of computing unsteady aerodynamic influence matrices is presented for line doublets and plate doublets, the latter usable at any Mach number. An economical way to analyze three-dimensional turbulence and a convenient way of using design criteria in n-dimensions are presented to aid in designing for statistical performance.

78-724
Wind Tunnel Study of an Active Flutter Suppression System
R. Destuynder
Div. de Recherche, Office National d'Etudes et de Recherches Aerospatiales, Paris, France, In: AGARD Structural Aspects of Active Controls, 9 pp (Aug 1977)
N77-33215

Key Words: Active flutter control, Wing stores, Aircraft, Wind tunnel tests

Active flutter control was tested in a wind tunnel on a model of wing carrying an external tank. The aerodynamic forces of the control system were generated by a classical aileron, piloted by a miniaturized servo-control from a signal issued by an accelerometer detecting the wing movement. A single control law was used in the whole velocity range.

78-725
Active Flutter Suppression of an Airplane with Wing Mounted External Stores
H. Hoenlinger
Unternehmensbereich Flugzeuge, British Aircraft Corp., Filton, UK, In: AGARD Structural Aspects of Active Controls, 15 pp (Aug 1977)
N77-33211

Key Words: Aircraft vibration, Flutter, Wing stores, Active flutter control

A wing store flutter suppression system with store mounted vanes was designed. The system was proved effective when implemented and flight-tested on a Fiat G 91/T3 aircraft. The relatively small vanes used were very effective in controlling flutter and their use did not alter aircraft flight mechanical characteristics.

78-726
A Practical Optimum Selection Procedure for a Motivator in Active Flutter Suppression System Design on an Aircraft with Underwing Stores
M.R. Turner and C.G. Lodge
Commercial Aircraft Div., British Aircraft Corp., Filton, UK, In: AGARD Structural Aspects of Active Controls, 19 pp (Aug 1977)
N77-33209

Key Words: Aircraft vibration, Flutter, Wing stores, Active flutter control

Theoretical active flutter control of a variable sweep wing with external stores with four combinations of store configuration/wing sweep/Mach number was studied. Electrically modified outputs of a structure-mounted transducer were used to drive an auxiliary control surface on the wing or store. The best transducer/force positions on the wing and stores were found using Nyquist plots, representing the control surface loads by point forces. The object was to see if a common active flutter control system using a control surface on the wing could be found for a range of stores, Mach numbers and wing sweep angles.

AIRCRAFT
(Also see Nos. 638, 640, 673, 674, 678, 706, 721, 722, 723, 724, 725, 726, 758)

78-727
Noise Component Method for Airframe Noise
M.R. Fink
United Technologies Res. Center, Silver Lane, East Hartford, CT 06108, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 397-412 (Oct 17-19, 1977) 10 figs, 20 refs

Key Words: Aircraft noise, Noise reduction

Current advances in the reduction of the noise from fans and propeller installations are reviewed.

78-728
Results of Concorde Monitoring
J.E. Densmore
Federal Aviation Administration, 800 Independence Ave., S.W., Washington, D.C. 20591, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 155-164 (Oct 17-19, 1977) 2 figs, 4 tables

Key Words: Aircraft noise, Supersonic frequencies, Noise generation, Acoustic excitation

Air France and British Airways were given permission to conduct limtied scheduled commercial flights of the Concorde supersonic transport into the United States for a trial period not to exceed 16 months. Results of noise measurements and the opinions of residents are given.

78-729
Normal Modes Vibration Analysis of the JT9D/747 Propulsion System
J.L. White and E.S. Todd
Boeing Commercial Airplane Co., Seattle, WA, J. Aircraft, 15 (1), pp 28-32 (Jan 1978) 9 figs, 6 refs

Key Words: Propulsion systems, Aircraft engines, Mathematical models, Natural frequencies, Mode shapes

The results of an exploratory research program on structural integration of aircraft propulsion systems are reported. The need for cooperative analysis by the engine and airframe manufacturers is discussed. The procedures for executing a multicompany, integrated vibration analysis are described. The model was evaluated by correlation with available test data.

78-730
Analysis of Lateral Dynamic Stability of an Airplane with Deformable Control Systems. Part II. Numerical Analysis
Z. Dzygadlo and E. Piotrowski
Polish Academy of Sciences, Inst. of Fundamental Technological Research, Warszawa, Poland, J. Technical Physics, 18 (3), pp 347-358 (1977) 7 figs, 10 refs

Key Words: Aircraft, Dynamic stability, Numerical analysis

The results of numerical calculations of the lateral dynamic stability of an airplane with moving control units are presented. Elasticity and damping in control systems, and the effect of the unbalance on the control systems are considered.

78-731
Dynamic Model of a Deformable Aircraft for Natural Vibration Analysis by the Finite Element Method
Z. Dzygadlo and J. Blaszczyk
Polish Academy of Sciences, Inst. of Fundamental Technological Research, Warszawa, Poland, J. Technical Physics, 18 (2), pp 219-229 (1977) 3 figs, 6 refs

Key Words: Aircraft, Mathematical models, Natural frequencies, Finite element technique

A dynamic model of a deformable aircraft is presented for studying natural frequencies and modes of vibration. A one-dimensional discretization of deformable structural units by means of finite elements is used.

78-732
An Exposition on Aircraft Response to Atmospheric Turbulence Using Power Spectral Density Analysis Techniques
E.W. Turner
Air Force Flight Dynamics Lab., Wright-Patterson AFB, OH, Rept. No. AFFDL-TR-76-162, 73 pp (May 1977)
AD-A046 108/7GA

Key Words: Aircraft, Power spectra, Mathematical models, Turbulence

The traditional power spectral density design procedure is reviewed. The evolution of modeling atmospheric turbulence is traced from the discrete gust to the present continuous representation. The modeling of an aircraft structure as a lumped parameter linear system excited by oscillatory air forces is outlined, and solutions to the resulting equations of motion are indicated.

78-733

Impact of a Command and Stability Augmentation System on Gust Response of a Combat Aircraft

K.D. Collmann and O. Sensburg

Vereinigte Flugtechnische Werke-Fokker G.m.b.H., Bremen, West Germany, In: AGARD Structural Aspects of Active Controls, 17 pp (Aug 1977)

N77-33210

Key Words: Aircraft, Wind-induced excitation

To get reasonable results for gust response calculations it is necessary to introduce the elastic aircraft behavior as well as the Command and Stability Augmentation System (CSAS) into the mathematical model. It is demonstrated how calculation results are influenced by using aerodynamic interference air forces; the influence of the CSAS is then presented.

78-734

Flutter Analysis of a Glider Made of Synthetic Materials

P.C. Hensing

NASA, Washington, D.C., Rept. No. NASA-TM-75160, 38 pp (Oct 1977) refs (Transl. into English from Flutteranalyse van een Kunststof Zweefuliegtuig (Delft), UTH-187, 35 pp, Sept 1974)

N78-12012

Key Words: Gliders, Flutter

A description of the flutter behavior of the Standard Cirrus is given. Steady vibration tests were conducted, and vibration and flutter calculations were made.

BUILDING

(Also see No. 679)

78-735

Dynamic Behavior of a Multistory Triangular-Shaped Building

J. Petrovski, R.M. Stephen, E. Gartenbaum, and J.G. Bouwkamp

Earthquake Engrg. Res. Center, California Univ., Richmond, CA., Rept. No. EERC-76-3, 138 pp (Oct 1976)

PB-273 279/0GA

Key Words: Buildings, Earthquake resistant structures, Vibration tests, Mathematical models

As a part of a continuing program to evaluate the dynamic response of actual structures and to accumulate a body of information on the dynamic properties of structures, especially when these structures have novel design features, a dynamic test program was conducted on the forty-story Century City Theme Tower building. The dynamic tests of the building included both a forced vibration study and an ambient vibration study.

FOUNDATIONS AND EARTH

(Also see No. 666)

78-736

Better Ways to Repair Machinery Foundations

E.M. Renfro

Adhesive Services Co., Houston, TX, Hydrocarbon Processing, 57 (1), pp 95-98 (Jan 1978) 9 figs, 5 refs

Key Words: Machine foundations, Turbomachinery, Vibration control

Most turbomachinery is mounted on structural steel platforms sometimes referred to as base plates or skids. Vibration problems caused by improper installation and insufficient mass and/or rigidity of these platforms are discussed in the article.

78-737

Dynamic Response of Rectangular Foundations to Obliquely Incident Seismic Waves

H.L. Wong and J.E. Luco

Dept. of Civil Engrg., School of Engrg., Univ. of Southern California, Los Angeles, CA, Intl. J. Earthquake Engrg. and Struc. Dynam., 6 (1), pp 3-16 (Jan-Feb 1978) 9 figs, 2 tables, 24 refs

Key Words: Foundations, Seismic excitation, Interaction: soil-structure

A study is made of the harmonic response of a rigid massless rectangular foundation bonded to an elastic half-space and subjected to the action of both external forces and obliquely incident plane seismic waves. The associated mixed boundary value problem is discretized and solved numerically.

78-738

Dynamic Interaction of a Foundation and an Elastic Halfspace (Dynamische Wechselwirkung eines Fundamentes mit dem Viskoelastischen Halbraum)

L. Gaul

Lehrstuhl B f. Mechanik, Technische Universität Hannover, West Germany, Ing. Arch., 46 (6), pp 401-422 (1977) 21 figs, 28 refs

Key Words: Interaction: soil-foundation

The dynamics of soil-foundation interactions has to be included in calculating the response of dynamically loaded footing-supported structures. Vertical and rocking vibrations of an arbitrarily shaped rigid base resting on the surface of a viscoelastic halfspace are considered. A three-dimensional dynamic stress boundary value problem is solved using a continuum approach. Based on this solution one can calculate by means of linear superposition spring and damping coefficients of a lumped-parameter model for the halfspace, the actual pressure distribution at the interface between base and soil as well as the wave-propagation in the vicinity of the excitation.

78-739

Development of Seismic Design Criteria for Category 1 Cofferdams

S. Chakrabarti, A.D. Husak, P.P. Christiano, and D.E. Troxell

E. D'Appolonia Consulting Engrg., Inc., 10 Duff Rd., Pittsburgh, PA 15235, Nucl. Engr. Des., 45 (1), pp 277-283 (1978) 1 fig, 10 refs

Key Words: Dams, Seismic design

Design/analysis parameters are suggested for evaluating extreme condition seismic loading, i.e., the Safe Shutdown Earthquake (SSE). Included among the parameters are: active and passive dynamic earth pressure coefficients; location of groundwater and free water surfaces to be used in conjunction with the SSE; the coefficient of friction acting at the interface between the fill material within the cell and the material on which the cell is founded; dynamic pressure distributions due to groundwater and free-standing water adjacent to the structure; vertical and horizontal coefficients of seismic acceleration. In addition, the consequences of postulated liquefaction of adjacent materials are investigated, and measures are suggested to adjust the analysis to accomodate such an occurrence. Among the postulated failure conditions which are considered under seismic loading are the following: sliding, overturning, slippage between the sheeting and the cell fill, shear failure along the centerline of the cell, Cummings method of horizontal shear, and interlock strength.

HUMAN

78-740

Guideline for Ride-Quality Specifications Based on TRANSPO '72 Test Data

W.C. Caywood, H.L. Donnelly, and N. Rubinstein

Applied Physics Lab., Johns Hopkins Univ., Laurel, MD, Rept. No. UMTA-MD-06-0022-77-3, 46 pp (Oct 1977)

PB-273 272/5GA

Key Words: Ride dynamics, Human response

Ride-quality acceleration measurements and the ride-jury comfort ratings that were recorded during the Post-TRANSPO '72 test program are examined for possible use in establishing standards for the ride-quality of Automated Guideway Transit systems. The four TRANSPO systems, the techniques used for making the ride-comfort tests, and data processing and analysis methods are described. Results are presented for the vibratory motions associated with travel at a constant speed over a straight guideway and for transient events associated with starting and stopping, traversing switch areas, and entering and exiting curves.

METAL WORKING AND FORMING

78-741

Mechanics of Cutting and Boring. Part 6. Dynamics and Energetics of Transverse Rotation Machines

M. Mellor

Cold Regions Res. and Engrg. Lab., Hanover, NH, Rept. No. CRREL-77-19, 45 pp (Aug 1977)

AD-A045 127/8GA

Key Words: Machine tools, Dynamic response

The report deals with forces and power levels in cutting machines having a disc or drum that rotates about an axis perpendicular to the direction of advance. The forces on individual cutting tools are related to position on the rotor and to characteristics such as tool layout, rotor speed, rotor size, machine advance speed, and rotor torque. Integration leads to expressions for force components acting on the rotor axis, taking into account tool characteristics, cutting depth of the rotor, and rotor torque. These provide estimates of tractive thrust and thrust normal to the primary free surface.

78-742

Development of a Quasi-Moment Damper

M. Mochizuki, N. Tominari, and H. Takahashi

On-Life Research Co., Ltd., 3-8-6, Ginza, Chuo-ku, Tokyo, Japan, Bull. JSME, 20 (148), pp 1261-1268 (Oct 1977) 22 figs, 1 table, 2 refs

Key Words: Machine tools, Chatter, Quasi-moment dampers, Active damping

One of the major obstacles to raising the work efficiency of the machining process using a machine tool in the past was the phenomenon of chattering. Several factors, conceivable as the causes of chatter are discussed. This paper includes the experimental results and theoretical analysis of a ram provided with a quasi-moment damper.

78-743

Regenerative Chatter in Cylindrical Plunge Grinding

I. Inasaki, K. Tonou, and S. Yonetsu

Faculty of Engrg., Keio Univ., Yokohama, Japan, Bull. JSME, 20 (150), pp 1648-1654 (Dec 1977) 11 figs, 7 refs

Key Words: Chatter, Grinding (material removal), Self excited vibration

Self-excited vibrations in grinding caused by the regenerative effect of workpiece surface and grinding wheel surface are theoretically investigated. The limit of stability and the rate of chatter increase are analyzed by calculating the root of characteristic equation of the system. From the results, some useful data are drawn for selecting the adequate grinding condition.

PUMPS, TURBINES, FANS, COMPRESSORS

(Also see No. 689)

78-744

Some Advances in Design Techniques for Low Noise Operation of Propellers and Fans

R.E. Hayden

Bolt Beranek and Newman, Inc., 50 Moulton St., Cambridge, MA 02138, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA, pp 381-396 (Oct 17-19, 1977) 10 figs, 2 tables, 15 refs

Key Words: Fans, Propellers, Noise reduction

Several new approaches to reducing the sources of "self-noise" of propellers and fans operating in proper aerodynamic environments are discussed.

78-745

Effects of Simulated Flight on Fan Noise Suppression

M.F. Heidmann and D.A. Dietrich

Lewis Res. Center, NASA, Cleveland, OH, Rept. No. NASA-TM-73708; E-9247, 34 pp (Oct 1977)

Sponsored by AIAA

N77-32157

Key Words: Fans, Noise reduction

Attenuation properties of three treated fan inlets were evaluated. Tunnel flow simulated the inflow clean-up effect on source noise observed in flight and allowed observation of the blade passage frequency tone cut-off phenomenon.

78-746

Duct Effects on the Dynamic Fan Characteristics of Air Cushion Systems

M.J. Hinchey and P.A. Sullivan

Inst. for Aerospace Studies, Toronto Univ., Ontario, Canada, Rept. No. UTIAS-TN-211; CN-ISSN-0082-5263, 49 pp (June 1977) refs

N78-12030

Key Words: Fans, Ducts, Vibration response, Mathematical models, Finite difference theory, Method of characteristics

During dynamic operation of an air cushion system, the fan operating point as seen at the cushion is described. It is shown that loop type behavior can be predicted theoretically. The theory models the fan-duct-plenum system as a one dimensional acoustic vibration system. Methods of solution are reviewed.

78-747

Improved Dynamic Modeling of a Space-Shuttle Turbo-Pump

D.A. Evensen and J.D. Chrostowski

J.H. Wiggins Co., SAE Paper No. 770960, 5 figs, 4 tables, 6 refs

Key Words: Pumps, Mathematical models, Computer programs

The dynamic response of turbo-pumps has traditionally been modeled mathematically using electrical networks. A recently developed computer program is used herein to adjust the model parameters of the electrical network in an attempt to bring the analytical response of the network into closer agreement with newly-available experimental results. Results are presented for a fully-wetted (non-cavitating) test of a Space-Shuttle Turbo-Pump and a significant improvement in the dynamic model is achieved.

RAIL

(Also see Nos. 639, 719)

78-748

A Comparative Study of the Ride Quality of TRACV Suspension Alternatives

R.A. Luhrs

Air Force Inst. of Tech., Wright-Patterson AFB, OH, Rept. No. AFIT-CI-78-2, 125 pp (Sept 1977)

AD-A046 565/8GA

Key Words: Ground effect machines, Mass transportation, Suspension systems (vehicles), Mathematical models

A linear, unconstrained perturbation model for the Tracked Ram Air Cushion Vehicle (TRACV) is developed. This model is the result of theoretical expressions for the TRACV which have been verified by wind tunnel and towed model tests. The basic, passively suspended, and actively suspended vehicles are analyzed to determine root mean squared values for vertical acceleration in the foremost and rearmost seats in the passenger cabin, gap variation at the front and rear winglet areas, and control deflection. The acceleration spectral density of each of the vehicle types is compared to the Urban Tracked Ram Cushion Vehicle standard. The active control system is analyzed to see if a reduced set of sensors may achieve acceptable ride quality based on the above measures.

78-749

Wheel/Rail Noise: The State-of-the-Art

P.J. Remington

Bolt Beranek and Newman, Inc., 50 Moulton St., Cambridge, MA 02138, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 257-284 (Oct 17-19, 1977) 19 figs, 1 table, 60 refs

Key Words: Interaction: rail-wheel, Noise reduction, Rail transportation

State-of-the-art review of wheel-rail noise is presented. The general categories of squeal noise, rolling noise and impact noise are surveyed. Gaps in understanding of the generation and control of wheel/rail noise are discussed. Noise from squeal, impact, and rolling is discussed. Information on the effectiveness of various techniques for noise control is reviewed.

78-750

Field Evaluation of Wheel/Rail Noise Control

H.J. Saurenman

Wilson Ihrig & Associates, Inc., P.O. Box 2900, Oakland, CA 94618, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 285-292 (Oct 17-19, 1977) 3 figs, 2 tables

Sponsored by the Urban Mass Transportation Admin.

Key Words: Rail transportation, Noise reduction, Interaction: rail-wheel

Interim results from a field evaluation of three methods of controlling wheel/rail noise are presented in this paper. The three methods are: use of resilient wheels, truing wheel running surfaces, and grinding the rail running surface.

RECIPROCATING MACHINE

(Also see No. 729)

78-751

The Partial Coherence Technique for Source Identification on a Diesel Engine

R.J. Alfredson

Dept. of Mech. Engrg., Monash Univ., Clayton, Victoria, Australia 3168, J. Sound Vib., 55 (4), pp 487-494 (Dec 22, 1977) 5 figs, 10 refs

Key Words: Diesel engines, Noise source identification, Engine noise

The partial coherence technique was applied to a diesel engine in an attempt to identify the significant radiating surfaces. The technique gave insight to which areas were not important radiating surfaces rather than those which were. Further experience and development is needed for the partly coherent multi-source situation.

78-752

State-of-the-Art of Turbofan Engine Noise Control

W.L. Jones and J.F. Groeneweg

Lewis Res. Center, NASA, Cleveland, OH, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA., pp 361-380 (Oct 17-19, 1977) 25 figs, 22 refs

Key Words: Turbofan engines, Engine noise, Noise reduction

This paper reviews the state of the art of turbofan noise control. The fan stage of the high bypass engines is identified as the dominant noise source. Existing and new methods of reducing fan source noise as well as suppression by acoustical treatment are discussed. Some experimental results of suppressors, designed by new spinning mode theory methods, and a bulk absorber design were compared. Noise sources other than fan noise are also identified and discussed.

ROAD

(Also see Nos. 638, 639, 672)

78-753

Highway Noise Control - A State of the Art Review

S.E. Dunn

Florida Atlantic Univ., Boca Raton, FL 33431, Proc. NOISE-CON 77, NASA Langley Res. Ctr., Hampton, VA, pp 293-306 (Oct 17-19, 1977) 32 refs

Key Words: Highway transportation, Traffic noise, Noise reduction

The following aspects of highway noise control are discussed in the paper: criteria for the description of highway noise impact, development and use of highway noise environmental impact assessment methodologies, and identification and use of feasible abatement or mitigation measures.

ROTORS

(Also see Nos. 667, 685)

78-754

Steady-State Unbalance Response of a Three-Disk Flexible Rotor on Flexible, Damped Supports

R.E. Cunningham

Lewis Res. Center, NASA, Cleveland, OH, Rept. No. NASA-TM-X-73666; E-9091-1, 42 pp (Sept 29, 1977)

N77-33160

Key Words: Rotors, Flexible supports, Ball bearings, Critical speeds, Unbalanced mass response, Squeeze film dampers

Experimental data are presented for the unbalance response of a flexible, ball bearing supported rotor to speeds above the third lateral bending critical. Values of squeeze film damping coefficients obtained from measured data are compared to theoretical values obtained from short bearing approximation over a frequency range from 5000 to 31000 cycles/min. Experimental response for an undamped rotor is compared to that of one having oil squeeze film dampers at the bearings. Unbalance applied varied from 0.62 to 15.1 gm-cm.

SELF-EXCITED

78-755

An Analysis of Self-Excited Vibrations Where the Effects of Machine Characteristics are Considered

J. Zahradka

Research Inst. of CKD Praha, Ceskomoravska 205, 190 02 Praha 9, Czechoslovakia, Mech. and Mach. Theory, 13 (1), pp 57-73 (1978) 17 figs, 6 refs

Key Words: Self-excited vibrations, Machinery

This paper deals with the analysis of self-excited vibrations in a nonlinear system with two-degrees-of-freedom where machine characteristics are taken into account. Most attention is given to determining the stability boundaries of the system, given by a limiting value of damping coefficient, which will ensure system stability for a given ratio of moments inertia. The theoretical results are applied to the practical problem of the dynamics of the axle-driving system for diesel-electric locomotives under conditions where the adhesion limit is exceeded.

78-756

Existence and Stability of Self-Excited Vibrations with Impacts

F. Peterka

Inst. of Thermomechanics, Czechoslovak Academy of Sciences, Puskinovo nam. 9, 160 00 Praha 6, CSSR, Mech. and Mach. Theory, 13 (1), pp 75-83 (1978) 8 figs, 2 refs

Key Words: Self-excited vibrations

The different types of the conditions of existence of the motion of two-mass nonlinear system are investigated. The nature of the various boundaries of existence is explained with the aid of the amplitude characteristics of the relative motion of the bodies. A study is also made of the dependence of the impact velocity on the system's parameters.

SHIP

78-757
Stochastic Analysis of Ship-Dynamic Responses
Y. Chen
Ph.D. Thesis, Univ. of California, Berkeley, 152 pp (1977)
UM 77-31,316

Key Words: *Ships, Water waves, Stochastic processes*

A general theory of ship dynamics in random seas is developed. The analysis covers the steady-state wave-induced response and the transient-state slamming response. Wave-induced response includes both the low-frequency rigid-body modes (seakeeping) and the high-frequency hull flexural modes (springing). The strip theory of Salvesen, Tuck, and Faltinsen is used to determine the hydrodynamic forces.

78-758
On the Nature of Resonance in Non-Conservative Systems
I. Fawzy and R.E.D. Bishop
Dept. of Mech. Engrg., Univ. of Cairo, Cairo, Egypt, J. Sound Vib., 55 (4), pp 475-485 (Dec 22, 1977) 4 figs, 1 table, 10 refs

Key Words: Ships, Aircraft, Modal analysis, Resonant frequency

Resonant vibration is commonly excited in ships and aircraft as a means of investigating the variation of effective damping – e.g., with changes of speed. Such systems as ships and aircraft are "non-conservative" and the only existing linear theory governing their behavior under near-resonant conditions is semi-empirical. This theory is examined in the terms of modal analysis and various aspects of its nature are pointed out. A slight revision of previous theory as to the form of polar plots appears to be in order.

SPACECRAFT

78-759
Experimental Studies of the Space Shuttle Payload Acoustic Environment
A.G. Piersol and P.E. Rentz
Bolt Beranek and Newman, Inc., SAE Paper No. 770973, 19 figs, 2 tables, 6 refs

Key Words: Space shuttles, Noise reduction, Scaling

Two series of experiments were conducted to reduce the uncertainties concerning the Space Shuttle payload bay acoustic environment. Tests using a one-fifth scale model showed large changes in level below 125 Hz with the introduction of typical payloads. The changes were associated with particular acoustic modal behavior and were sensitive to the type of acoustic excitation. Another series of experiments evaluated the noise reduction of the first orbiter vehicle.

78-760
Response of Space Shuttle Surface Insulation Panels to Acoustic Pressure
R. Vaicaitis and E.H. Dowell
Columbia Univ., New York, NY, J. Spacecraft and Rockets, 14 (12), pp 739-746 (Dec 1977) 4 figs, 7 tables, 17 refs

Key Words: Panels, Heat shields, Acoustic excitation, Free vibration, Shuttles (spacecraft)

The free vibration characteristics and dynamic response of reusable space shuttle surface insulation panels to acoustic random pressure fields are studied. A Rayleigh-Ritz technique is used as the basic analytical approach in formulating the governing equations of motion.

78-761
747 Shuttle Carrier Aircraft/Space Shuttle Orbiter Mated Ground Vibration Test: Data Via Transient Excitation and Fast Fourier Transform Analysis
N.L. Olsen and M.J. Walter
The Boeing Company, SAE Paper No. 770970, 9 figs, 2 tables, 6 refs

Key Words: Space shuttles, Vibration tests, Fast Fourier transform

The experimental procedure employed to define the natural modes of vibration of the 747 Shuttle Carrier Aircraft and Space Shuttle Orbiter mated configuration is described. A discussion of test results and comparison to structural analysis results is also included. Random transient signals were used as inputs to electromagnetic shakers to provide excitation to the mated vehicle test configuration.

78-762
Flutter Tests of the Mated 747 Shuttle Carrier Aircraft-Orbiter
L.V. Andrew
Space Div., Rockwell International, SAE Paper No. 770971, 21 figs, 3 tables, 6 refs

Key Words: Space shuttles, Flutter

Flutter tests of the mated 747 shuttle carrier aricraft-orbiter are discussed. The monitored telemetered data on real-time displays are described. The safety criteria is applied during buffet tests. The instrumentation and telemetering of orbiter data are treated for both the unpowered (inert) and the powered up (active) orbiter.

78-763

Effects of Flow Separation on Shuttle Longitudinal Dynamics and Aeroelastic Stability

J.P. Reding and L.E. Ericsson

Lockheed Missiles & Space Co., Sunnyvale, CA., J. Spacecraft and Rockets, 14 (12), pp 711-718 (Dec 1977) 15 figs, 37 refs

Key Words: Shuttles (spacecraft), Fluid-induced excitation, Aerodynamic stability

The longitudinal dynamic and aeroelastic stability characteristics of various shuttle configurations, investigated at transonic speeds, are reported.

STRUCTURAL

(Also see No. 647)

78-764

Response Analysis of Floating Structures

M.K. Kaul

Nuclear Services Corp., Campbell, CA 95008, ASCE J. Engr. Mech. Div., 103 (EM6), pp 1023-1034 (Dec 1977) 11 figs, 2 tables, 4 refs

Key Words: Off-shore structures, Floating structures, Water waves, Interaction: fluid-structure

The dynamic response of a floating structure may be obtained either by analyzing the complete fluid-structure system or by a simpler method, in which the hydrodynamic effects are accounted for by the inclusion of added mass. Since the added mass of a floating structure is dependent on the frequency of its oscillation, the traditional use of a constant added mass is large over the frequency range of interest. A method to construct an equivalent model for the fluid-structure system in such cases, for the time domain response analysis of the floating structure, is presented in this paper.

TRANSMISSIONS

78-765

Belt Deformation in V-Belt Drives Under Dynamic Loading

D.L. Cronin and D.W. Mertz

Dept. of Mech. and Aerospace Engrg., Univ. of Missouri-Rolla, Rolla, MO 65401, Exptl. Mech., 17 (12), pp 463-467 (Dec 1977) 7 figs, 11 refs

Key Words: V-belts, Dynamic response

Recent theoretical work permits a characterization of loads in the cord layer of operating V-belts. Experimental evidence corroborating theory has been limited. Such evidence has been collected and is presented in this paper. Empirical relationships describing how peak strains across and along the belt occurring during an operating cycle vary with preload, transmitted torque, pulley diameter and speed are given.

TURBOMACHINERY

(Also see No. 641)

78-766

Turbomachinery Problems: Causes and Cures

J.S. Sohre

Turbomachinery Consultant, Ware, MA 01082, Hydrocarbon Processing, 56 (12), pp 77-84 (Dec 1977) 11 figs, 9 refs

Key Words: Turbomachinery, Unbalanced mass response, Alignment, Resonant response, Critical speed, Torsional response

This article uses the case history approach to illustrate the most common types of turbomachinery problems found in field operation. The problems investigated are unbalance, distortion, misalignment, resonance, critical speed and torsionals.

AUTHOR INDEX

CALENDAR

MAY 1978

4 - 5 **IX Southeastern Conference on Theoretical and Applied Mechanics** [SECTAM], Nashville, TN *(Dr. R. J. Bell, SECTAM, Dept. of Engrg. Sci. & Mech., Virginia Polytechnic Inst. & State Univ., Blacksburg, VA 24061)*

8 - 10 **Inter-NOISE 78,** San Francisco, CA *(INCE, W. W. Lang)*

8 - 11 **Offshore Technology Conference,** Houston, TX *(SPE, Mrs. K. Lee, Mtgs. Section, 6200 N. Central Expressway, Dallas, TX 75206)*

14-19 **Society for Experimental Stress Analysis,** Wichita, KS *(SESA, B. E. Rossi)*

16-19 **Acoustical Society of America, Spring Meeting,** [ASA] Miami Beach, FL *(ASA Hq.)*

JUNE 1978

19-23 **International Conference on Fundamentals of Tribology,** [U.S. Army Research Office] MIT, Cambridge, MA *(Prof. Nam P. Suh, Dept. of Mech. Engrg., MIT, Cambridge, MA 02139 - Tele. (617) 253-2225)*

30 **Eighth U. S. Congress of Applied Mechanics,** [ASME] Los Angeles, CA *(ASME Hq.)*

SEPTEMBER 1978

11-13 **IUTAM Symposium on Variational Methods in the Mechanics of Solids,** [U.S. Army Research Office & National Science Foundation & Northwestern University] Evanston, IL *(Prof. S. Nemat-Nasser, Dept. of Civil Engrg., Northwestern Univ., Evanston, IL 60201 - Tel. (312) 492-5513.)*

24-27 **Design Engineering Technical Conference,** [ASME] Minneapolis, MN *(ASME Hq.)*

OCTOBER 1978

8 -11 **Diesel and Gas Engine Power Conference and Exhibit,** [ASME] Houston, TX *(ASME Hq.)*

8 -11 **Petroleum Mechanical Engineering Conference,** [ASME] Houston, TX *(ASME Hq.)*

17-19 **49th Shock and Vibration Symposium,** [U.S. Naval Research Lab.] Washington, D.C. *(H. C. Pusey, Director, The Shock and Vibration Info. Ctr., Code 8404, Naval Res. Lab., Washington, D.C. 20375 - Tel. (202) 767-3306)*

17-19 **Joint Lubrication Conference,** [ASME] Minneapolis, MN *(ASME Hq.)*

NOVEMBER 1978

26 - Dec 1 **Acoustical Society of America, Fall Meeting,** [ASA] Honolulu, Hawaii *(ASA Hq.)*

DECEMBER 1978

4 - 6 **15th Annual Meeting of the Society of Engineering Science, Inc.,** [SES] Gainesville, FL *(Prof. R. L. Sierakowski, Div. of Continuing Education, Univ. of Florida, 2012 W. University Ave., Gainesville, FL 32603)*

10-15 **Winter Annual Meeting,** [ASME] San Francisco, CA *(ASME Hq.)*

JUNE 1979

11-15 **Acoustical Society of America, Spring Meeting,** [ASA] Cambridge, MA *(ASA Hq.)*

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AFIPS: American Federation of Information Processing Societies
210 Summit Ave., Montvale, NJ 07645

AGMA: American Gear Manufacturers Association
1330 Mass. Ave., N.W.
Washington, D.C.

AHS: American Helicopter Society
1325 18 St. N.W.
Washington, D.C. 20036

AIAA: American Institute of Aeronautics and Astronautics, 1290 Sixth Ave.
New York, NY 10019

AIChE: American Institute of Chemical Engineers
345 E. 47th St.
New York, NY 10017

AREA: American Railway Engineering Association
59 E. Van Buren St.
Chicago, IL 60605

AHS: American Helicopter Society
30 E. 42nd St.
New York, NY 10017

ARPA: Advanced Research Projects Agency

ASA: Acoustical Society of America
335 E. 45th St.
New York, NY 10017

ASCE: American Society of Civil Engineers
345 E. 45th St.
New York, NY 10017

ASME: American Society of Mechanical Engineers
345 E. 47th St.
New York, NY 10017

ASNT: American Society for Nondestructive Testing
914 Chicago Ave.
Evanston, IL 60202

ASQC: American Society for Quality Control
161 W. Wisconsin Ave.
Milwaukee, WI 53203

ASTM: American Society for Testing and Materials
1916 Race St.
Philadelphia, PA 19103

CCCAM: Chairman, c/o Dept. ME, Univ. Toronto, Toronto 5, Ontario, Canada

ICF: International Congress on Fracture
Tohoku Univ.
Sendai, Japan

IEEE: Institute of Electrical and Electronics Engineers
345 E. 47th St.
New York, NY 10017

IES: Institute of Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, IL 60056

IFToMM: International Federation for Theory of Machines and Mechanisms, US Council for TMM, c/o Univ. Mass., Dept. ME
Amherst, MA 01002

INCE: Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch
Poughkeepsie, NY 12603

ISA: Instrument Society of America
400 Stanwix St.
Pittsburgh, PA 15222

ONR: Office of Naval Research
Code 40084, Dept. Navy
Arlington, VA 22217

SAE: Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, PA 15096

SEE: Society of Environmental Engineers
6 Conduit St.
London W1R 9TG, UK

SESA: Society for Experimental Stress Analysis
21 Bridge Sq.
Westport, CT 06880

SNAME: Society of Naval Architects and Marine Engineers, 74 Trinity Pl.
New York, NY 10006

SPE: Society of Petroleum Engineers
6200 N. Central Expressway
Dallas, TX 75206

SVIC: Shock and Vibration Information Center
Naval Research Lab., Code 8404
Washington, D.C. 20375

URSI-USNC: International Union of Radio Science - US National Committee c/o MIT Lincoln Lab.,
Lexington, MA 02173

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SUMMARY COVER SHEET
49TH SHOCK AND VIBRATION SYMPOSIUM
Washington, D.C., 17-19 October 1978

(SEE OTHER SIDE FOR INSTRUCTIONS)

Author(s) ____________
(Underscore name of author who will present the paper, if accepted.)

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The Shock and Vibration Bulletin is a refereed journal which contains the proceedings of the symposium and an additional number of papers not presented at the symposium.

THOSE WHO DO NOT WISH TO PREPARE A FORMAL PAPER, may choose the PRESENT ONLY category. No written paper will be required.

THOSE WHO WISH TO PUBLISH BUT NOT PRESENT a paper at the symposium, may choose the PUBLISH ONLY category. This will enable them to submit their paper for the refereeing procedure and publication if accepted.

ALL PAPERS offered for presentation or publication or both, must have:

1. Title
2. Summary (600 words) (no figures) – Summaries will be published.
3. Any additional information, including figures or a complete paper which may help the program committee.

NOTE:
1. Six copies of each summary with title, author, and affiliation are to be attached.
2. Submission deadline is 19 June 1978. Earlier submissions will be appreciated.
3. Mail to: Shock and Vibration Information Center, Code 8404, Naval Research Laboratory, Washington, D.C. 20375.
4. Receipt of summary will not normally be acknowledged. Notification of Program Committee action will be given promptly.

It is the author's responsibility to obtain all necessary clearances and releases regarding the material he intends to present. Non-government organizations wishing to present classified papers must process the clearance through the cognizant contracting activity. Unclassified papers must also be cleared for public release by appropriate authority. This must be accomplished before the date on which the program becomes firm (Aug. 7,1978). A written release for oral presentation and publication must accompany the complete paper. This is due in the office of the Shock and Vibration Information Center on September 11, 1978.

SUMMARY OF SHORT DISCUSSION TOPIC

49TH SHOCK AND VIBRATION SYMPOSIUM

Washington, D.C., 17-19 October 1978

SUBMISSION DEADLINE, 11 SEPTEMBER 1978
Mail to: Shock and Vibration Information Center Naval Research Laboratory Code 8404 Washington, D.C. 20375

Discussions offered should cover a short progress report on a current effort, or a useful idea or other information too short for a full-length paper. These are for oral presentation only and will not be published so that publication at a later date is not precluded.

Speaker's Name: ______________________________

Affiliation: ______________________________

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