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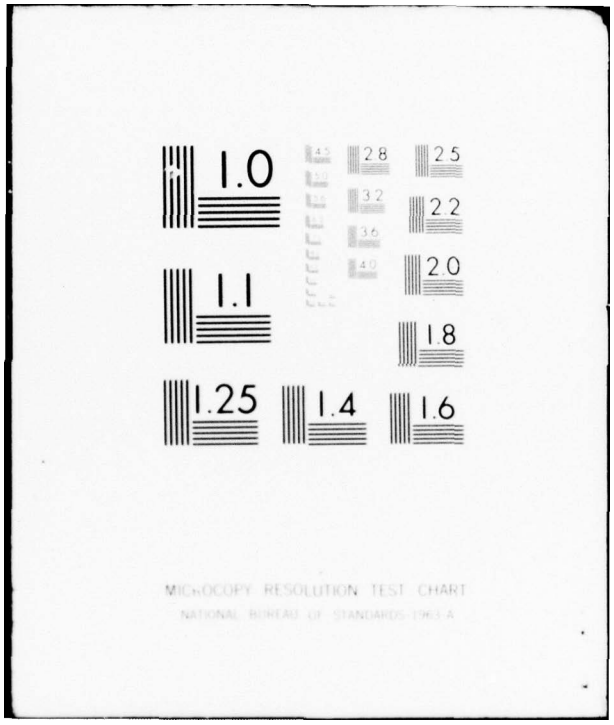
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October 1977

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THE SHOCK AND VIBRATION DIGEST

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DIRECTOR NOTES

National Defense*reports a budget request of $2.7 billion for test and evaluation of weapons systems during fiscal year 1978. Lt. Gen. Walter E. Lotz, Jr., USA, (Ret.), Deputy Director of Defense Research and Engineering, Test and Evaluation, describes this money as a good investment. This opinion was given in his report to Congress and in his keynote address at the 1977 Annual IES Meeting**. I agree with Gen. Lotz. Test and Evaluation is an insurance policy we cannot afford to drop.

Testing insures confidence provided we can have confidence in the information provided by the tests. It is mandatory, then, that we establish test requirements on a sound realistic basis and that our procedures for performing the test and controlling the input be standardized to insure repeatability from laboratory to laboratory. No one knows better than those of you who perform shock and vibration tests the difficulty in doing this. In spite of our difficulties, I am encouraged by the progress that has been made. We have come a long way toward consistency of tests.

I have previously referred to the excellent effort on the part of the IES and others in working with the government to establish an effective approach to testing. Recently I described the useful study of a Defense Science Board Task Force on specifications and standards. From both government and industry the problems are being attacked with a new vigor. Let's keep up the good work. By doing so we can make our test programs more realistic and cost-effective, and we can have more confidence in our decisions based on the results.

H.C.P.

*F.O. DuPre, "Missiles and Astronautics," National Defense - J. of the American Defense Preparedness Assoc. (July/Aug 1977).

**W.E. Lotz., Lt. Gen. USA (Ret.), "Dept. of Defense Test and Evaluation Policy," J. of Environmental Sciences (July/Aug 1977).

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EDITORS RATTLE SPACE

National Bureau of Standards: A Declining Resource

It is unfortunate that a resource such as the U.S. National Bureau of Standards (NBS) should decline due to lack of funds. According to a recent article in Science magazine*, a seemingly endless number of new responsibilities have been thrust upon the NBS while funding has not changed appreciably. In fact, the NBS has lost personnel because of inflationary demands on their budget. To quote Science: "In recent years, Congress has made increasing demands on the technical expertise at NBS. It has passed 15 laws since 1965 giving the bureau new assignments. But during that time NBS has had a constant budget despite inflation and has had to reduce the number of its employees from 3,163 permanent full-time workers to 3,055. The result, say NBS administrators, is that the bureau is no longer able to fulfill its functions". Although development and maintenance efforts aimed at measurement standards have not entirely collapsed, such efforts have been reduced on standards crucial to regulatory agencies, consumers, and industries.

NBS has had to withdraw from national and international standards activities involving shock and vibration, however: at one time the USA (NBS) held the Secretariat for ISO TC 108/SC3 -- Shock and Vibration Measurements. This Secretariat is now operated by Denmark. NBS personnel no longer particpate in committee work involving standardization of shock and vibration measurement techniques and equipment. It also appears that NBS efforts on calibration and instrument research have been seriously curtailed.

What does this mean to the American public? Regulatory agencies and commerce require technically sound, clearly defined standards, so that comparisons of goods and applications of regulations will be fair and consistent. Without a strong NBS we can expect chaos in trade and regulation. No amount of confining legislation can make up for a lack of basic standards.

R.L.E.

*"National Bureau of Standards: A Fall from Grace," Science, 197 (4307), pp 968-970 (Sept 2, 1977).

A COMPARISON OF TECHNIQUES AND EQUIPMENT FOR GENERATING VIBRATION

W. Tustin *

***Abstract** - This article reviews the following shaker types: mechanical, electrohydraulic, electromagnetic, and pneumatic. Vibroacoustic facilities are also mentioned.*

This review considers practical techniques for generating vibratory force and/or motion for determining the natural frequencies f_n and modal responses of structures and for assessing the ruggedness and reliability of equipment. Most equipment and techniques mentioned in this review were developed for the aerospace industry but are being successfully used in other industries. The types of shakers described in this article are mechanical, electrohydraulic, electromagnetic, and pneumatic. Acoustic test facilities are discussed in some detail. Current developments and practical limitations of each type are mentioned. Information about the complex controls needed for electrohydraulic and electromagnetic shakers and vibration analysis is not included.

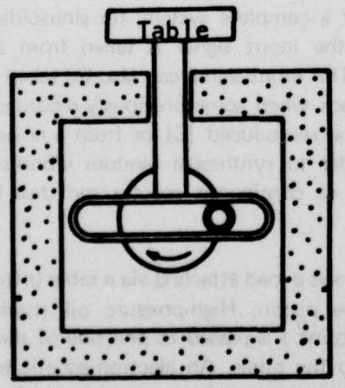

Figure 1. An Early Shaker

* Tustin Institute of Technology, Inc.
Santa Barbara, CA 93105

MECHANICAL SHAKERS

The earliest practical shakers were "brute force" or "direct drive" machines (see Fig. 1). Variable-ratio pulleys allowed variable shaft speed. Rotation of a shaft attached to a table is converted by a cam or yoke to variable forcing frequency, f_f, reciprocating motion. The test load is attached to the table. The variable forcing frequency can be adjusted during a test, but the test must be stopped to adjust the peak-to-peak displacement, or stroke, D. The generated force, F, is calculated by

$$F = MA$$

M is the total mass of vibrating parts (load + any attachment fixture + the table). A is the peak or vector acceleration in gravitational units. It is calculated by

$$A = 0.0511 f_f^2 D$$

if double amplitude or peak-to-peak displacement, D, is given in inches, or by

$$A = 0.00202 f_f^2 D$$

if D is given in millimetres.

Depending upon the total mass M, F may exceed the strength limitations of the shaker and cause damage. By contrast, with reaction mechanical shakers (see Fig. 2), electrohydraulic shakers, and electromagnetic shakers, F is limited; the available acceleration A varies inversely with the total mass, as

$$A = \frac{F}{M}$$

With the reaction shaker, contra-rotating masses, locked in phase, spin at the variable forcing frequency. The generated force F can be calculated by $F = Mr\omega^2$, where r is the fixed radius, ω is the angular velocity, and M is the unbalance mass. Most such shakers must be stopped in order to reset M.

Reaction shakers cost more than direct drive ones, but are generally capable of attaining higher frequencies and have a waveform with less harmonic distortion. Further, reaction shakers are easy to install because the vibrations transmitted to the base are small; by contrast, most direct drive shakers are attached to heavy reaction masses which in turn are supported by rubber or springs.

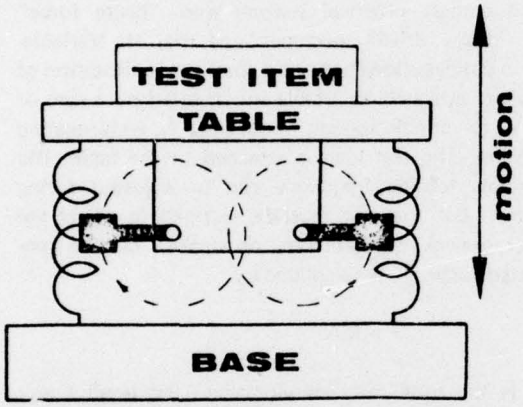

Figure 2. A Reaction Shaker

The principal advantages of mechanical shakers, as opposed to electrohydraulic and electromagnetic ones, are their low initial cost, ease of installation, and operating simplicity. They are also reliable -- hundreds of hours of continuous or intermittent vibration testing are possible -- and are available in a number of models that fit environmental chambers. Finally, because no feedback loops exist as with electrohydraulic and electromagnetic shaker systems. The load on a mechanical shaker affects its own vibration environment.

Mechanical shakers do have limitations, however: little vibratory force is developed at low frequencies, they are limited to about 100 Hz by inevitable looseness between parts which becomes troublesome as

$$D = \frac{A}{0.0511 f_f^2 D} \text{ or } \frac{A}{0.00202 f_f^2 D}$$

becomes small, particularly at small force settings. With the direct drive type, second harmonic distortion is particularly strong; gears, belts, and other moving parts generate considerable unwanted high frequency force and motion. And until recently, mechanical shakers generated only nominally-sinusoidal waveforms; manufacturers of mechanical shakers are currently striving to overcome this limitation. In the Rotocon shaker [1, 2], for example, a series of hammers is attached to a 3,000 RPM rotating element. The hammers strike an anvil, to which is attached the test item. The resulting force and motion have a line (as opposed to a continuous) spectrum extending from 50 to more than 10,000 Hz. Military avionics organizations have encountered premature in-service failures [3], and earlier reliability-demonstration tests, utilizing sinusoidal vibration, have not identified the weaknesses. It has been recognized [3, 4] that random vibration occurs, often in combination with temperature and stresses [5].

ELECTROHYDRAULIC SHAKERS

The tremendous available dynamic force

$$F = PA$$

(P represents oil pressure and A represents piston area) available from hydraulic actuators makes them attractive for generating vibration. Electrohydraulic shakers have been available since the mid 1950s, when actuators were combined with fast-acting electronic servo valves. Figure 3 shows the major elements of a complete system; for sinusoidal vibration tests the input signal is taken from a signal oscillator. The input signal can also be taken from a tape playback when some previously-recorded vibration is to be reproduced [6] or from a noise generator in order to synthesize random vibration [7]. Either line or continuous spectra can thus be generated.

Figure 4 shows a load attached via a table (often omitted) to the piston. High-pressure oil (typically a net 2,000 lb/in.^{2}) is passed to one side of the piston and then to the other. An electromagnetic (electrodynamic) driver unit and a power valve or hydraulic amplifier are used. Typical piston strokes are 4 to 6 in., although some -- usually those intended for higher-frequency testing, to perhaps 200 Hz -- are only 1 in. (the maximum known to the author is 20 ft [8]). The low-frequency limit of electrohydraulic shakers is usually zero.

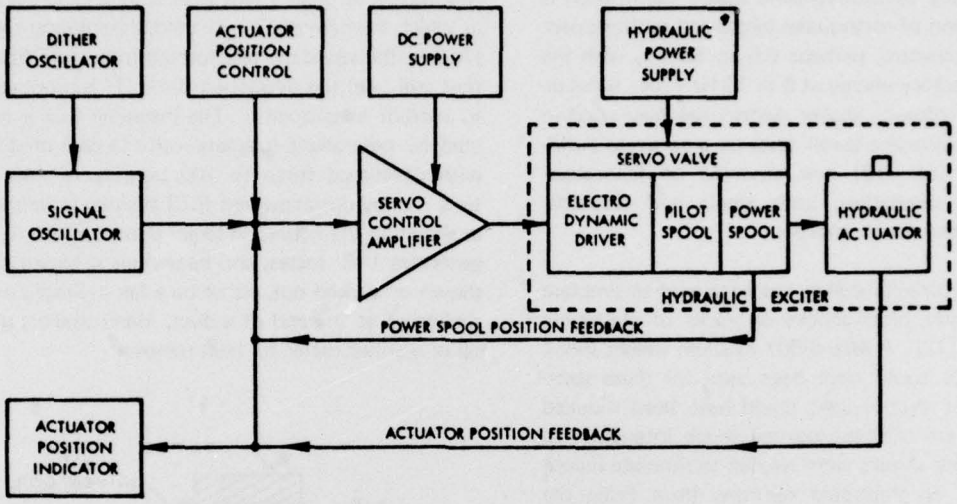

Figure 3. Elements of an Electrohydraulic Shaker

Force, and thus acceleration, are limited by pressure and piston area. Peak or vector velocity may be limited by insufficient hydraulic supply flow or by insufficient opening of the power valve.

Waveforms are generally considered to be better than those from mechanical shakers but are not as free of harmonic distortion as the electromagnetic shakers discussed below.

Because the generated force is usually many times greater than shaker mass, a heavy reaction mass is necessary if much vibratory force is to be introduced into a large structure. When the test load can be brought to the shaker, as in an environmental testing laboratory, a heavy reaction mass is no problem. When shakers are taken to a large, fixed structure, the mass is a complicating factor; others include high pressure oil hoses, which tend to be stiff and awkward, and cooling the oil.

Four or more laboratory electrohydraulic shakers are often connected to large loads; e.g., truck. Sometimes the shakers vibrate an intermediate platform (table) on which the load rests, as in transportation or earthquake simulation. The shakers usually vibrate horizontally or vertically, but they can be set at an intermediate angle so that the resulting motion has both vertical and horizontal components. Sometimes vertical and horizontal-acting shakers drive a common load via hydrostatic spherical couplings [9]. Multiple shakers may be driven by a common electronic signal source or by separate signal sources.

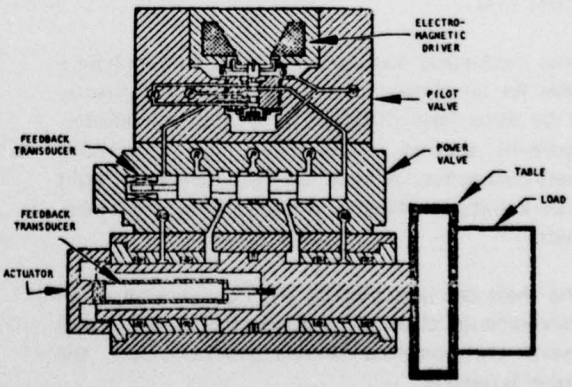

Figure 4. Electrohydraulic Shaker with Test Load

An interesting electrohydraulic shaker application is the simulation of earthquake forces and motions over continuous spectra, perhaps 0.5 to 50 Hz, with the greatest vibratory energy at 6 to 10 Hz [10]. A portable electrohydraulic shaker system has been used in destructive resonant dwell tests on a concrete building [11]. Kao [12] has reported on laboratory earthquake simulation, both single and two-axis, using electrohydraulic shakers.

An electrohydraulic shaker has been used to simulate shipboard gun blast shocks on racks of electronic equipment [13]. A ***MIL-S-901*** medium weight shock test machine could have been used for these tests. The hammer drop height could have been reduced because about 1/20 the normal shock intensity was desired. Many shocks were needed to simulate repetitive shocks on shipboard resulting from firing the ship's guns. An electrohydraulic shaker rated at 50,000 lb force, 1 in. stroke, and 17 in./sec velocity was used. The shock response spectrum was to cover 10-500 Hz. The load, consisting of electronic assemblies, was mounted via isolators into a rack. The rack in turn connected to a slip plate driven by the shaker. One advantage of the electrohydraulic shaker was that shock tests could immediately follow ***MIL-S-167*** 4-33 Hz sinusoidal vibration tests, with no delay for transferring to a shock test machine and no need for an additional test fixture. Electrohydraulic shakers have been used to simulate road inputs to heavy trucks [14].

Most mechanical and electromagnetic shakers have a table for attachment of the test load either directly or by some form of fixture [15]. However, electrohydraulic shakers usually have only a threaded shaft connection. A table can be purchased or built with a fixture, which is threaded onto the shaker shaft.

The shaft can pass through the floor or wall or an environmental chamber so that test loads can receive several environmental stresses simultaneously; the shaker is outside.

ELECTROMAGNETIC SHAKERS

Electromagnetic shakers (see Fig. 5) are also called electrodynamic shakers, probably because of their similarity to electrodynamic loudspeakers. Magnetic flux passes through a cast steel body and across a gap in which the driver coil is located. Alternating current (AC) at the vibration test forcing frequency flows in that coil, and the developed force F is proportional to current magnitude I. The magnetic flux is generated by permanent magnets -- in the case of shakers with developed force to 100 pounds, or 440 newtons -- or by direct current (DC) flowing in field coils, as shown in the figure, on larger shakers. Current flow generates I^2R losses, and heated air is blown out as shown or sucked out, either by a fan mounted on the shaker or at the end of a duct. Many shakers utilize oil or distilled water for heat removal.

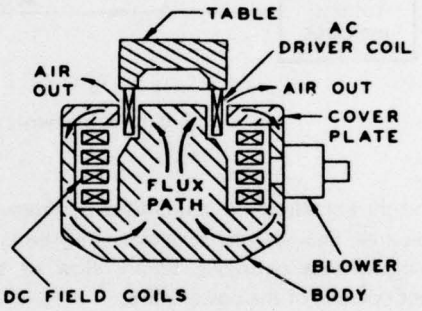

Figure 5. An Electromagnetic Shaker

Around 1960 combined environment tests utilized liquid-cooled electromagnetic shakers inside environmental test chambers, so that test loads could be close-coupled to shaker tables (necessary for testing to 2,000 Hz). However, in most laboratories today the shaker is outside the chamber, and the test load is connected through the chamber wall or floor by a table extender.

Not shown in Figure 5 are the AC electrical connections to the usual multi-turn driver coil. These leads are a hazard to operational reliability and have been eliminated in one current high-reliability design, in which high AC currents are induced by a transformer into an aluminum sheet single turn coil. Also missing from Figure 5 are provisions for shielding test loads against potentially harmful stray AC and DC magnetic fields. The flexures that constrain motion to a straight line are not shown.

The signal source may be a sinusoidal oscillator, tape playback, random noise generator, or any combination of the preceding, depending upon the type of force or motion desired. Considerable power amplification is required, up to 150 kilowatts for the larger shakers having force ratings above 30,000 pounds. Solid-state power amplifiers offer many advantages over earlier power-tube types.

Electromagnetic shakers respond to AC current of any frequency to zero, but not all power amplifiers will deliver extremely low frequencies. The high-frequency limit is usually somewhat below one of the table/coil assembly's natural frequencies. The natural frequencies should be avoided because table oil-canning or diaphragming, at which the motion at the center of the table is perhaps 50 times greater than that at the edges; and, axial resonance, in which the table/coil assembly alternately lengthens and shortens distort results.

The waveform of electromagnetic shakers has less distortion than does that of other types. This is an advantage for sinusoidal vibration tests, for determining the natural frequencies and modal responses of structures, and for calibrating such motion-sensing transducers as accelerometers.

Electromagnetic shakers range in size. Small ones that can be carried by a man are favored for exciting large, fixed structures. Sometimes several such shakers vibrate at the same forcing frequency. Single large units used to generate peak or vector sinusoidal forces to 30,000 pounds are used to vibrate large avionics packages and missile nose cones to 50 g or greater accelerations and to frequencies of 500 Hz and above. Because the generated force is usually less than shaker mass, elaborate installations are seldom needed. Shakers are usually suspended near and coupled to the structure being investigated. Sinusoidal vibratory force and frequency are remotely controlled, and the structure's responses are observed and analyzed.

The peak-to-peak displacement is limited by the length of the magnetic gap, the length of the AC coil, and flexures. Peak-to-peak displacements of 1 in. are most common, but can reach 6 in. Force limitations can be caused by insufficient power amplifier current or by heating the shaker; and that these will limit available acceleration according to

$$A = \frac{F}{M}$$

M is the total moving mass, including the coil, table, any adapting fixture needed, and the test load. Some manufacturers offer 150 g on light loads. Velocity limits may be caused when insufficient voltage is available to the AC driver coil from the power amplifier. Shaker velocity limits of 70 in./sec will meet most test specifications.

A relatively recent application for small, highly portable electromagnetic shakers has been to determine the natural frequencies and modal responses of a variety of loads -- from flight structures to nuclear power plant equipment and structures [16].

PNEUMATIC SHAKERS

Air-driven vibrators [4] are an inexpensive and reliable way to generate motions and forces if pure sinusoidal motion, flat random spectra, and reproduction of magnetic tapes are not necessary. The driving units can be adapted from the pneumatic vibrators often employed by industry to move bulk materials or to release entrapped gasses from castings. Pistons alternately strike cylinder ends, creating repetitive shock impulses having line spectra. Such motion and force spectra can simultaneously excite all the response modes of an electronic assembly, thereby causing failures of poorly-soldered connections and interference from bits of wire and loose screws.

Because more realistic reliability demonstration tests on avionics units and on airborne missiles during their captive flight stage have been sought, several laboratories are utilizing pneumatic shakers. One longitudinal and eight radial General Dynamics/Pomona shakers have been reported to deliver 6 to 14 RMS vibration (at different missile locations) at frequencies up to 5,000 Hz [17]. Varying the air pressure at about 7 Hz modulates the spectral lines; the internal response spectra are fairly continuous, with a shape approximating the responses noted during flight tests. The amplitude distribution is somewhat Gaussian. The repetition rate is 30 to 120 impacts/second.

ACOUSTIC SOURCES

All the shakers described in this review generate force mechanically and couple it mechanically to test loads. This approach is reasonable at low frequencies where service vibrations are generated and transmitted mechanically. However, the vibration path of high-performance aircraft and missiles is not exclusively mechanical. Rather, air is an important part of the transmission path. It would thus seem logical for high-frequency tests to utilize intense sound (airborne vibration), rather than shakers, in order to generate vibratory responses of avionic and missile internal parts.

Eldred [18] has written about large scale vibroacoustic facilities in the U.S. and the reasons for preferring acoustic tests. Murray [19] described the design, construction, instrumentation, and usage of the large Wyle chamber at Huntsville, Alabama. The NASA facility at Houston has also been described [20], as has the acoustic energy needed to conduct vibration tests at NASA Houston [21]. At the launch phase simulator at NASA-Goddard, temperature and altitude extremes and vibration and noise act on a specimen being spun on a centrifuge [22].

Most facilities employ high-velocity flow of vast quantities of nitrogen gas or air. Flow is modulated by fast-acting valves driven either electromagnetically (similar to Fig. 5) or electrohydraulically (similar to Fig. 4). Valves are generally activated by random noise generators and suitable power amplifiers in order to create a flow containing all desired test frequencies in a continuous spectrum. Equalizers permit the spectrum to be shaped as desired. Slusser [23] has described the JPL/Pasadena facility, particularly the digital controls.

After the gas passes through the valves, it expands through a horn that opens into the test chamber, in which the test load is supported. The chamber must be large in order to develop high intensity at low audio test frequencies. Unfortunately, large chambers require much acoustic power in order to develop high acoustic pressures as specified for many tests. A simpler, less expensive approach utilizes up to 35 complex sirens to modulate air flow and to produce as many as 35 pure or narrow band tones, fixed or sweeping. By sweeping the band tones at different rates, broadband sound is possible. The 156,000 cubic foot chamber at Wright-Patterson Air Force Base features 1×10^6 watts acoustic power and intensities to 170 db [24]; 40,000 HP is used for the air compressor. Tests in the noise chamber have also been described [25, 26].

One goal of acoustic tests is to excite high-frequency vibratory responses of exceedingly small components as, for example, burn in tests. Some workers feel these tests should be extended to lower frequencies, but the large test chambers necessary are expensive.

Most chambers are reverberant, with maximum reflections from internal surfaces; the design maximizes dispersion so as to minimize standing waves. Some chambers are progressive wave, rather than reverberant. Chamber design and external acoustic treatment minimize sound leaks outside the chamber. Chambers are costly and hard to relocate. All U.S. acoustic testing facilities as of 1975 have been surveyed [27].

Everett [28] described combining noise and temperature extremes for tests on Navy missile electronics sections.

CONCLUSION

The reason for this article was the imminent increase in random vibration testing. Electrohydraulic and electromagnetic shakers, with their hydraulic supplies or large amplifiers and complicated controls, are very expensive. Alternate methods are needed; and, the merits of the various methods should deal with techniques and results.

In general, only mechanical shakers and pneumatic shakers are sufficiently reliable for long-term tests. There are many weaknesses in electrohydraulic and electromagnetic shaker systems; on long-time tests, some laboratories have difficulty in predicting whether the shaker system or the test item will fail first. These weaknesses have been greatly improved between 1966 - 1976 by, for example, adopting solid-state electronic circuits in place of vacuum tube circuits. Further, electrohydraulic and electromagnetic shaker systems, with their highly complex controls and powerful amplifiers, require highly skilled and trained operators and maintenance personnel. Mechanical shakers are not only reliable, but they are also inexpensive to purchase and simple to set up, operate and maintain.

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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.

This issue of the DIGEST features review articles on plate vibrations by Dr. Leissa and flow-induced vibrations by Dr. Chen.

Dr. Leissa completed a monograph on plate vibrations in 1967. This article reviews the technology for the time period 1973-1976.

Dr. Chen reviews the state-of-the-art of flow-induced vibration of circular cylindrical structures. He indicates areas where further work is needed.

RECENT RESEARCH IN PLATE VIBRATIONS: CLASSICAL THEORY

A.W. Leissa*

Abstract - This paper is Part I of a two-part review of literature published over the period 1973-1976 that deals with free, undamped vibrations of plates. Part I is limited to problems governed by the classical theory of plates. Complicating effects is the subject of Part II.

The classical equation for the free, undamped vibration of plates is given by

$$D\nabla^4 w + \rho \frac{\partial^2 w}{\partial t^2} = 0 \qquad (1)$$

where w is the transverse displacement of a typical point on the plate, D is the flexural rigidity and is defined by

$$D = \frac{Eh^3}{12(1 - \nu^2)}$$

E is Young's modulus, h is the plate thickness, ν is Poisson's ratio, ρ is mass density per unit area of the plate, t is time, and $\nabla^4 = \nabla^2\nabla^2$, where ∇^2 is the Laplacian operator.

When free vibrations are assumed, the motion is expressed as

$$w = W \cos \omega t \qquad (2)$$

where ω is the circular frequency and W is a function of the position coordinates. Substitution of equation (2) into (1) yields

$$(\nabla^4 - k^4) W = 0 \qquad (3)$$

where $k^4 = \rho\omega^2/D$.

This review, like a similar review** published in 1967 [1], is divided into two parts: (a) problems governed by equation (1) and appropriate boundary conditions and (b) the effects of such complicating factors as anisotropy, inplane forces, variable thickness, surrounding media, large (nonlinear) deflections, shear deformation, rotary inertia, and material nonhomogeneity. Each factor complicates equation (1). This paper is a review of literature from 1973 to 1976 having to do with problems governed by classical theory. Part II will review the recent literature dealing with complicating factors.

The material of the various plates described in Part I, is assumed to be linearly elastic. Structures formed by connecting a plate to one or more additional structural elements -- i.e., beam, plate, ring, shell -- are not included. The second assumption creates difficulties: for example, should a circular plate having a step change in thickness be treated as a plate with variable thickness or the combination of solid and annular circular plates. Similarly, edge beams having mass are omitted, but the effects of elastic edge constraint are included. The review is not limited to theory; experimental results are included when they can be found. The literature search for this review was completed before the end of 1976, and foreign references, especially those of Eastern Europe, are incomplete.

CIRCULAR PLATES

When boundaries are circular, it is convenient to express equation (3) in terms of polar coordinates (r, θ). Exact solutions can then be found as (cf., [1])

$$W(r,\theta) = \sum_{n=0}^{\infty} W_n(r) \cos n\theta + \sum_{n=1}^{\infty} W_n^*(r) \sin n\theta \qquad (4)$$

where W_n and W_n^* are various types of Bessel functions. Satisfying the usual boundary conditions -- clamped, simply supported, or free -- yields second

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**In the year 1967 the author completed the writing of a monograph digesting the literature of the world dealing with free vibrations of plates. The primary purpose of that work was to summarize all known results for free vibration frequencies, mode shapes and nodal patterns. A thorough search of sources revealed approximately 500 references.

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order and fourth order determinants respectively for solid and annular plates, the roots of which are the desired eigenvalues (frequencies).

The solution of circular plate vibration problems by the classical procedure outlined above has been carried out for at least 150 years [2]. Although many numerical results are available [1], a thorough and accurate numerical study of all possible boundary conditions for solid and annular plates over the range of Poisson's ratio remains to be done.

Jones [3] devised a simple approximate formula for calculating fundamental (i.e., lowest) frequencies if the static deflected shape of a uniformly loaded plate is known. Johns [4] used a two-term solution for static deflection shapes to evaluate frequencies of clamped and simply supported circular plates and compared them with those of Jones [3].

Extensive experimental results for free circular plates have been obtained by Ravenhall and Som [5]. Frequencies for the first 29 modes of test specimens of aluminum, brass, and steel were determined, and the results were used to obtain empirical formulas for the problem.

The case of a solid plate having mixed boundary conditions on its edge has been investigated [6]. The finite element method was used to analyze plates having a portion of the edge clamped and the remaining portion either simply supported or free. Results were compared with experimental ones obtained using laser holography. The partially clamped, partially free case has also been used [7] to demonstrate the method of layer potentials. Numerical results obtained for the first four modes of plates with 3/8 and 1/2 of their boundaries clamped were compared with experimental results.

Various approximate methods have recently been used [8] for circular plates having clamped, simply supported or elastically supported (rotational springs) edges. Extensive results for fundamental frequencies of elastically supported plates obtained by means of Galerkin method have also been published [9]. The problem was subsequently generalized further [10] to include both rotational and translational springs on the outer boundary; clamped, simply supported, and free boundaries were special cases. The Galerkin method was again used; only axisymmetric modes were considered. Although some results are available [11], much work needs to be done for point supported circular plates.

Finite elements have been used [12] to analyze the free vibrations of annular plates. Numerical results were obtained for the lowest axisymmetric frequencies of CC, CF, and SS annuli for $0.1 \leq b/a \leq .5$ (.05). The first letter refers to the inner boundary, r=b, and the second to the outer, r=a; C, S, and F identify clamped, simply supported, and free boundaries, respectively. The results were in good agreement with exact results. The method was also demonstrated on the clamped and simply supported solid circular plates for the fundamental frequency. Experimental results for the FS annulus are available [13].

ELLIPTICAL PLATES

The ellipse is, of course, a generalization of the circle, and all parameters which can be present for a circular plate -- e.g., simple or mixed boundary conditions, point or intermediate supports, internal boundaries -- can also be present for an elliptical one as well as the parameter of aspect ratio, a/b (see Fig. 1). Analytically, however, the ellipse is much more formidable. Although it can be expressed in terms of elliptical coordinates and exact solutions of the resulting transformed equations can be found in terms of Mathieu functions [1], the expressions required are unwieldy, and the computation and behavior of Mathieu functions are not as well understood as those for Bessel functions. Evaluation of

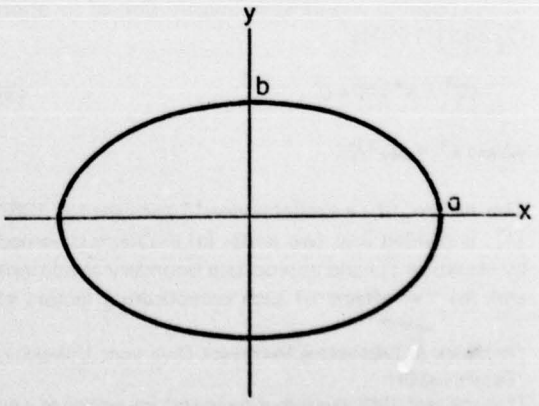

Figure 1. Elliptical Plate

necessary functions or integrals along an elliptical boundary using approximate methods is also relatively awkward. For these reasons, and because elliptical plates have far less practical significance than, say, circular or rectangular ones, very little published literature appeared prior to 1965 [1]. In fact, the number of publications between 1973 and 1976 equals all of those before 1965.

Four recent papers deal directly with the clamped ellipse. Nayfeh et al [14] treated the problem as a perturbation of the clamped circle in an analysis of plates having small ellipticity. Results are presented for the first six modes for b/a ratios of 0.9 and 0.8. Licari and Warner [15] used a parameter differentiation method, and Johns [4] used the two-term solution for static deflection shapes. Pneuli [16] applied a method that yielded lower bounds on the frequencies. Simple algebraic formulas expressed the frequency parameter as a function only of the area of the plate (no explicit dependence upon a/b). The simply supported case was also treated.

The case of the free boundary has also received recent attention. Beres [17] used the Ritz method; 25 terms of an algebraic polynomial were retained in a careful analysis of the problem. Frequenices and nodal patterns were presented for 21 modes, and direct comparison was made with the classical experimental results of Mary Waller [18]. The problem has also been addressed by Sato [19], who used an exact solution in terms of Mathieu functions. Numerical results of frequenices for the first five doubly symmetric (only) modes were computed for $1 \leq a/b \leq 7$ and compared with experimental results.

Sato [20] also used the exact solution in terms of Mathieu functions to investigate the vibrations of annular elliptical plates; i.e., the boundaries were the confocal ellipses. Two problems were treated: both boundaries free and clamped inner and free outer boundaries. Frequency variation was determined for various ratios of the inner semiminor axis to the outer semiminor axis (b_i/b_o) for the first six doubly symmetric modes of an ellipse having an outer boundary aspect ratio (a_o/b_o) of 1.2; the results were with those from experiments. A thorough exposition of nodal patterns was also given.

The case of the annular ellipse having both boundaries clamped was analyzed by Ozkul [21], who also used Mathieu functions. Numerical results were obtained by two methods for a special case: the inner boundary degenerates to a straight line joining the two focii. Physically, the problem then becomes the solid elliptical plate clamped along an interior line segment. A simple Ritz solution was also calculated for comparison when the ellipticity becomes zero; i.e., a circular plate clamped at the outside and point supported at the center.

RECTANGULAR PLATES

Twenty-one combinations of simple boundary conditions -- either clamped, simply supported, or free -- are possible for rectangular plates. Figure 2 shows a representative case, a rectangular plate having the edges x=o and x=a both simply supported, the edge y=o clamped and the edge y=b free. For purposes of concise and clear identification, each of the 21 cases will be denoted by four letters, abbreviating the conditions found on each edge, beginning with x=o and preceding clockwise around the plate. *Correspondingly*, the case shown in Figure 2 is a SCSF plate.

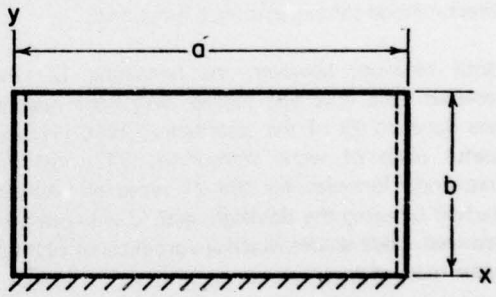

Figure 2. SCSF Rectangular Plate

Nondimensional frequency parameters, conveniently expressed as $\omega a^2\sqrt{\rho/D}$, do not depend upon Poisson's ratio unless at least one of the edges is free. However, because D contains Poisson's ratio, the frequencies themselves depend upon v for all cases.

For the six cases having two opposite sides simply

supported, exact solutions are available by choosing

$$W_m(x, y) = \left[A_m \sin\sqrt{k^2-\alpha^2}\, y + B_m \cos\sqrt{k^2-\alpha^2}\, y + C_m \sinh\sqrt{k^2+\alpha^2}\, y + D_m \cosh\sqrt{k^2+\alpha^2}\, y\right] \sin \alpha x \qquad (5)$$

where $\alpha = m\pi/a$, m=1, 2.... This satisfies the differential equation (3) as well as the boundary conditions on the edges x=o and a exactly. Substituting equation (5) into the boundary conditions along y=o and b yields a fourth order characteristic determinant, the roots of which are k^2 and, hence, the frequencies.

For the remaining 15 cases not having exact solutions, three problems have received a great deal of attention. The completely clamped case (CCCC) is frequently used as a test problem for analytical methods because of the simple boundary conditions. The cantilever plate (CFFF) has been extensively studied because of its practical engineering importance. The completely free plate received early attention, first as the vehicle by which Chladni [22] demonstrated the existence of nodal patterns on plates, and secondly as the problem Ritz [23] chose to demonstrate the application of his now-famous direct method for extremizing a functional.

Until recently, however, the remaining 12 cases received little coverage; indeed, very little research was done on six of the cases before 1966 [1]. In a useful piece of work Warburton [24] presented frequency formulas for the 21 types of problems derived by using the Rayleigh method with one-term assumed mode shapes which are products of vibrating beam mode shapes.

Comprehensive Studies for Rectangular Plates

To present in one place reasonably accurate results for the vibration frequencies of the 21 cases, the writer undertook the work leading to reference [25]; exact results for the six cases having the opposite sides simply supported were obtained with equation (5). Characteristic equations that are expansions of the fourth order determinants take two forms, depending upon whether $k^2-\alpha^2$ is positive or negative in equation (5). Proofs are presented for the existence or nonexistence of eigenvalues such that $k^2-\alpha^2$ is negative for the six cases and, where existence is possible, the range of existence is delineated. For the three cases having modes symmetric and antisymmetric with respect to the line y=b/2 (SSSS, SCSC, and SFSF) simplified characteristic equations are presented for the symmetric and antisymmetric modes for $k^2-\alpha^2$ both positive and negative.

Tables give the nondimensional frequency parameters $\omega a^2\sqrt{\rho/D}$ for each of the six cases over a range of aspect ratios and their reciprocals (a/b = 2.5, 1.5, 1, 2/3, 0.4) for a Poisson ratio of 0.3 [25]. Results for the nine lowest values of $\omega a^2\sqrt{\rho/D}$ to six significant figures for each a/b are given. In addition, a mode shape identification number for each frequency presented describes the number of approximate half waves in each direction. The effects of changing Poisson's ratio are studied in detail on the SFSF case. Of particular interest is the fact that increasing the Poisson ratio does not always yield an increase in frequency.

The 15 cases not having exact solutions have been analyzed [25] by the Ritz method using beam functions.

$$W(x, y) = \sum_{p,q} A_{pq} X_p(x) Y_q(y) \qquad (6)$$

X_p and Y_q are normalized eigenfunctions that satisfy exactly the equation of motion of a freely vibrating, uniform beam. Clamped and simply supported plate boundary conditions are exactly satisfied by use of beam functions; free edge conditions are approximate, however, so that the approach is less accurate when a free edge is involved. The 15 cases were analyzed using the first six beam functions in each direction; a 36th order determinant was found except in those cases having one or two axes of symmetry. In these cases the determinant reduced to two 18th order or four ninth order determinants, respectively; that is, one determinant for each symmetry class. The six lowest values of $\omega a^2\sqrt{\rho/D}$ are given for a/b = 2.5, 1.5, 1, 2/3, and 0.4 for each case. Poisson's ratio is taken as 0.3. Mode shape identification numbers are also given.

Accurate results permitted comparison with those of a simple, one-term solution form of equation (6), as carried out by Warburton [24]. For the first six modes of the 15 cases the difference between one-term and 36-term solutions was less than one percent, as often as not. The presence of free edges could cause considerable error in the one-term solutions, as

much as 24 percent for the cases studied. Graphical results for frequencies of the first several modes of the 21 cases are available for a Poisson ratio of 0.3 [26]. A summary of the results found in earlier literature has been published [27].

Two Opposite Sides Simply Supported

The rectangular plate simply supported on all four edges is useful in establishing the accuracy of approximate methods because a simple, exact, closed form statement of its frequencies exists.

$$W_{mn} = \sqrt{D/\rho}\left[(m\pi/a)^2 + (n\pi/b)^2\right] \qquad (7)$$

where m, n = 1, 2... are the integers representing the numbers of half waves in the mode shapes in the x and y directions, respectively. The problem has been used to demonstrate the finite element method [28]; a finite-strip difference method, as contrasted with the usual finite-point difference method [29, 30]; the use of Southwell stress functions with finite element models [31]; and solution of the problem in polar coordinates by using small sector angles and large radii [32]. Ochs and Snowdon [33] also published clear, experimentally-determined Chladni patterns. Frequency parameter versus a/b has also been plotted [34] for all six cases having two opposite sides simply supported.

Other Simple Edge Conditions

The rectangular plate clamped all around has the most simply stated boundary conditions, and many accurate, although not exact, frequency values are available in the literature. This problem is thus useful in testing approximate methods. Other techniques have also been demonstrated with this problem [8, 14]. In addition, the subdomain method [35], the Galerkin method [36], and an extension of the Kantorovich method [37] have been used. The work by Jones and Milne [37] is particularly noteworthy because it presents frequencies for the first nine modes for $0.10 \leq a/b \leq 1.00$ (0.02). Nair and Durvasula [38] also used the problem to demonstrate the "curve veering" phenomenon often found in the literature [1, 39] in plots of frequency parameter versus aspect ratio.

Bassily and Dickinson [40] discussed the shortcomings of the beam functions when used with the Ritz method in analyses of problems involving free edges. They suggested another set of functions as more accurate for such problems.

Elastic, Discontinuous, and Point Supports

Rectangular plates having elastically supported boundaries have been analyzed [41]. Noteworthy is the attention given to cases having unequal rotational constraint on the boundaries.

The finite element has been used [42] to analyze square plates having mixed boundary conditions. Three problems were studied:

- the simply supported plate having a portion of one edge clamped, beginning at a corner
- the simply supported plate having portions of two opposite edges clamped, symmetrically located
- the free plate having portions of all edges simply supported, with symmetrical edge supports beginning at the four corners.

A thorough variation of support length parameters was made for all problems.

A great deal of attention [43-49] has recently been given to a square plate that is free on its boundaries but is supported symmetrically at four points along its diagonals (see Fig. 3). The problem has been analyzed by finite elements, by finite differences, and by energy methods; frequencies have been obtained for the complete range of c/a (see Fig. 3) and compared with experimental results. A 10 x 10 finite element mesh has been used [43]. Extensive nodal patterns have been shown [48]. Results for the first seven modes are available [48]. Dowell [49] also determined fundamental frequencies for other rectangular plates (a/b - 0.5, 2) having point supports along the diagonals.

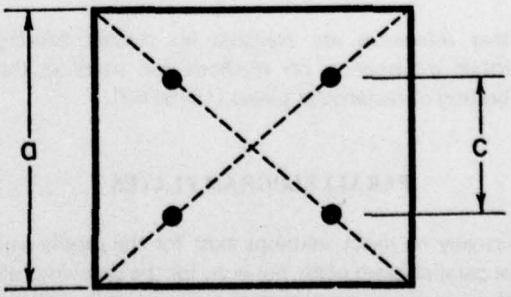

Figure 3. Square Plate Supported Symmetrically at Four Points Along its Diagonals

The finite element method has also been used [50] to study square plates supported at 3, 5, 7, and 9 points along each edge. Results were compared with the simply supported plate. Experimental results for this problem are also available [51]. A simply supported plate having one additional point support along a diagonal (x=a/2, y=b/2 and x=a/3, y=b/3) has been examined [52]. Experimental results are also available [11].

Added Mass and Internal Cutouts

Compared with earlier work [1], little has been done recently with regard to the problem of the vibrating rectangular plate having additional point masses. Laura et al [8] analyzed the simply-supported square plate having a central point mass.

Some attention has been given to rectangular plate having cutouts. Hegarty and Ariman [53-55] used the point matching method to analyze square plates having a central circular hole. They considered plates having the outer boundary either all clamped or all simply supported. Results showed variation of frequency with hole size for various values of Poisson's ratio.

Variational principles in conjunction with finite differences have been used to study rectangular plates having square cutouts [56-57]. Particular attention was given to the problem of representing a re-entrant corner. Theoretical and experimental frequencies are reported for SCSS plates having one and two internal square cutouts and for the SSSS plate having one square cutout. Paramasivian [58] also developed finite difference operators capable of representing a re-entrant corner. Frequencies of clamped and simply supported square plates having square cutouts of various sizes were determined. A clamped square having a circular opening was also analyzed.

Other references are available for readers desiring further information on methods for studying the vibration of rectangular plates [16, 59-63].

PARALLELOGRAM PLATES

Virtually no exact solutions exist for the problem of the parallelogram plate, not even for the case when all sides are simply supported. A typical case is depicted in Figure 4, where both rectangular (x, y) and skew coordinates (ξ, η) are used. The plate shown has its boundaries ξ=o, η=o, ξ=a, ξ=b simply supported, clamped, free, and simply supported, respectively, and is therefore designated as a SCFS parallelogram plate. The skew angle is show to be α. Most of the research prior to 1966 [1] dealt with one case - the cantilevered parallelogram (CFFF); however, recent research has been on other cases. The term "skew plate" although frequently used in the literature, is avoided here because trapezoidal and triangular plates can also be skewed.

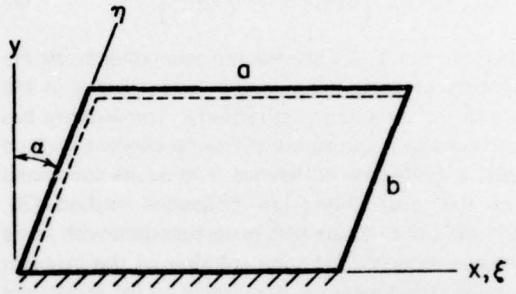

Figure 4. SCFS Parallelogram Plate

Nair and Durvasula [64] made an excellent analytical study of five cases involving clamped and simply supported boundaries (CCCC, CCSC, CSSC, CSCS, CSSS). The Ritz method was used in skew coordinates with beam functions, and 36 terms were retained in the solution. Extensive numerical results are presented for frequencies and nodal patterns for the first eight modes for a/b=1, 2/3, and 1/2 and for $0 \leqslant \alpha \leqslant 50^\circ$ (see Fig. 4). The same authors also used CCCS and SCSC rhombic (i.e., a=b) plates to demonstrate the curve veering phenomenon [38] and obtained results for the CCCC case for various a/b and α by the subdomain method. They compared their results with those in which the Galerkin method and finite elements were used [35]. Some results for the CCCC case are also available [65].

The SSSS parallelogram has also been analyzed by Tai and Nash by the edge function method [59] and by others [15, 66].

Srinivasan and Munaswamy [48] used an energy method -- with algebraic functions in one coordinate direction and beam functions in the other -- to solve the problem of the rhombic plate having free edges, but supported at four symmetrically located points

along the diagonals. Results are given for α = 15°, 30°, and 45°; nodal patterns are also shown.

TRAPEZOIDAL PLATES

Very little has been done recently for trapezoidal plates. In one excellent paper [67], however, the finite element method was used with two types of high precision, conforming, plate bending elements - a quadrilateral and a triangle. Extensive numerical results for the frequencies and nodal patterns of the first six (and additional) modes of symmetrical trapezoidal plates completely clamped or simply supported are presented for: (1) d/a=1.5 and b/a= 0.4; (2) d/a=6 and b/a=0.8, 0.2 (see Fig. 5).

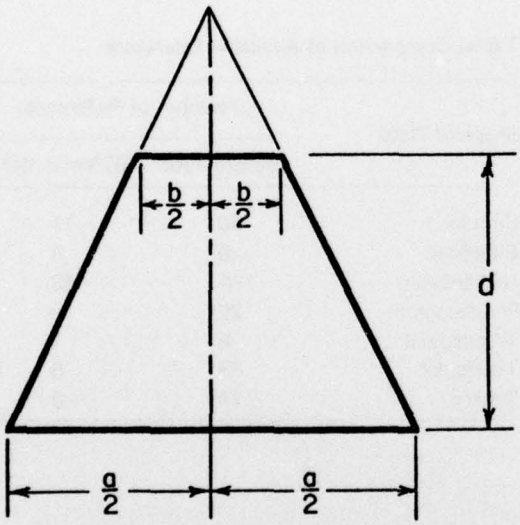

Figure 5. Symmetrical Trapezoidal Plate

TRIANGULAR PLATES

Attention has been given to CCC and SSS triangular plates [67]. Numerical results for the frequencies and nodal patterns of the first six (and additional) modes of isosceles triangular plates completely clamped or simply supported are presented for d/a=1.5 and 6(b/a=0 in Fig. 5).

The SSS plate, for the case of equilateral sides, was also analyzed by Williams et al [68, 69]. A solution was obtained in terms of trilinear coordinates. Trilinear coordinates are seldom used and not widely understood, but these references present an excellent and clear exposition of their use. Experimental results were also obtained and compared with the analytical ones.

A method yielding lower bounds applied to triangular plates has been presented [16]. Some results for plates having free boundaries and supported on three symmetrically placed supports are also available [11].

PLATES OF OTHER SHAPES

General (approximate) methods exist for the analysis of free vibrations of plates of arbitrary shape. The methods can be grouped into three categories, depending upon whether they satisfy the differential equation (3), the boundary conditions, or neither, exactly [70]. Two interesting methods for analyzing arbitrarily shaped plates have already been mentioned [3, 16]. Laura and Gutierrez [71] also demonstrated a previously developed method which is an interesting and powerful combination of two methods -- conformal mapping and the Galerkin method. They used this method to obtain frequencies of clamped and simply supported regular polygonal plates having 4, 5, 6, 7, and 8 sides.

Rubin has investigated problems of sectorial plates. He used a Kantorovich-like energy method to completely analyze clamped sectors [72]. Numerical results were presented for the radial and circular modes for sector angles varying from 30° to 180°. He also obtained an exact solution to equation (3) by assuming

$$W(r, \theta) = f(r) \cos m\theta \qquad (8)$$

and solving the resulting fourth order equation in f by the Frobenius method [73]. The function W then satisfies simply supported boundary conditions along the radial edges $\theta = \pm\pi/2m$. Numerical results are given for the first eight modes of an annular sector having the inner boundary clamped and the outer free, for a boundary radius ratio (a/b) of 20 (see Fig. 6).

Ramaiah and Vijayakumar [74] made a thorough study of annular sectorial plates having simply supported radial boundaries and all nine possible combinations of clamped, simply supported and free

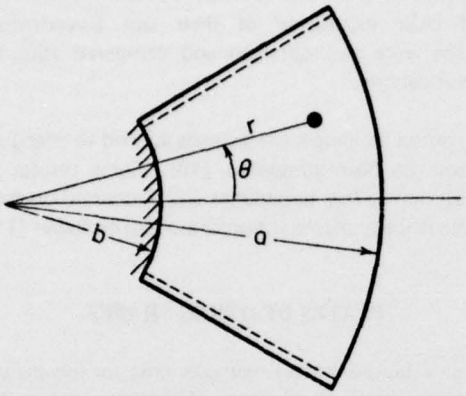

Figure 6. Annular Sectorial Plate

boundary conditions along the circular edges, r=a, b. The Ritz method was used.

Bhattacharya and Bhowmic [75] demonstrated the use of the Kantorovich method for analyzing sectorial plates clamped along the radial edges and having arbitrary conditions along the single circular boundary (r=a). They reported numerical results for the cases of semicircular plates having their circular boundary clamped, simply supported, and free (and their diameters clamped, of course).

Vivoli and Phillipi [7] also demonstrated their method using layer potentials to analyze the vibrations of a plate having the unusual shape shown in Figure 7, clamped all around its periphery.

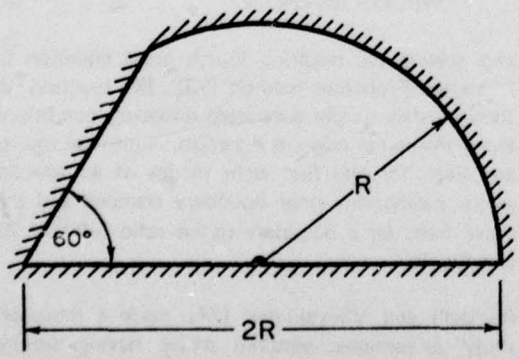

Figure 7. Shape Analyzed by Vivoli and Phillippi [7]

A collection of plates of various shapes having various different support arrangements has been considered by Steinberg [76].

SUMMARY

It is interesting to compare the extent of research into free vibrations of plates preceding 1966 [1] and between 1973 and 1976 (see the Table). There is no question that the extent of useful numerical results, their accuracy, and their comprehensiveness -- i.e., complete, rather than piecemeal, studies of the effects of varying a parameter such as a/b or Poisson's ratio, and careful comparison with previously known results for special cases -- has increased in the references between 1973 and 1976.

Table. Comparison of Available Literature

Shape of Plate	Number of References	
	Before 1966	*1973-mid 1976*
Circular	48	11
Elliptical	8	8
Rectangular	161	43
Parallelogram	22	8
Trapezoidal	8	1
Triangular	38	5
Others	14	9

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FLOW-INDUCED VIBRATIONS OF CIRCULAR CYLINDRICAL STRUCTURES PART I: STATIONARY FLUIDS AND PARALLEL FLOW

S.-S. Chen*

Abstract - The objective of this paper is to review the state-of-the-art of flow-induced vibration of circular cylindrical structures and to indicate areas that need further work. Both parallel and cross flow problems are considered. Part I of the review contains a general discussion of analytical methods, classification of structural responses, and characteristics of the vibration of cylinders in stationary fluid and parallel flow. Part II considers cross-flow-induced vibration, design, and research needs.

Flow-induced vibration of circular cylinders has been known to man since ancient times; the vibration of a wire at its natural frequency in response to vortex shedding was known in ancient Greece as aeolian tones. But systematic studies of the problem were not made until a century ago when Strouhal established the relationship between vortex shedding frequency and flow velocity for a given cylinder diameter [1]. The early research in this area has been summarized [2].

Since the collapse of the Tacoma Narrows Bridge in 1940, flow-induced vibration has attracted much attention. Flow-induced vibration problems have become significant as structures have become lighter and more slender due to the use of high-strength materials, and as advanced nuclear power reactors have been developed. The potential for detrimental vibration in such system components as suspension bridges, tall buildings, chimney stacks, heat-exchanger tubes, ocean piles, transmission lines, and reactor systems has added to the need for studies of flow-induced vibration. Several reviews deal with general features of flow-induced vibrations and contain material relevant to circular cylindrical structures [3-13].

GENERAL CONSIDERATIONS

An understanding of structural responses in a fluid environment involves identification of basic excitation mechanisms. The following is a list of potential excitations: vortex shedding [14, 15]; fluidelastic mechanisms [16, 17]; turbulent buffeting [18, 19]; jet switching [20]; acoustic noises [21-23]; flow pulsations [24, 25]; and turbulent boundary layer pressure fluctuations [26, 27]. Depending on conditions, any of several excitation sources can be the dominant excitation mechanism. It is sometimes difficult to identify the dominant excitation, however, because two or more mechanisms may interact.

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A cylindrical structural system departs from its equilibrium position when acted upon by fluid excitation; the new configuration of the system can be represented by the generalized coordinate $\{q\}$. In general, the equations of motion may be reduced to

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = \{Q\} \qquad (1)$$

M is a mass matrix and includes the added mass effect; C is a damping matrix and includes fluid dynamic damping; K is a stiffness matrix and includes fluidelastic effect. Q is a generalized force that includes fluid excitation forces [28, 29]. Note that the matrices M, C, K, and Q can be dependent of q and are not necessarily symmetric. The interdependences that govern fluidelastic behavior of a cylindrical structural system can be represented as shown in Figure 1.

A circular cylindrical structural system immersed in a fluid stream can vibrate for a variety of reasons; the behavior of the system can be either static or dynamic.

Static Behavior

- static deformation: static displacements can be induced by such steady fluid forces as drag forces [30], fluid centrifugal forces [31], and static fluid pressure [32].
- static instability: buckling of cylindrical tubes has been observed experimentally [33]. The same phenomenon occurs when an Euler column is subjected to an axial compression.

Dynamic Behavior

- forced vibration: in subcritical flow velocity ranges, the structure is subjected to flow excitations. If the excitation force is periodic, such as vortex

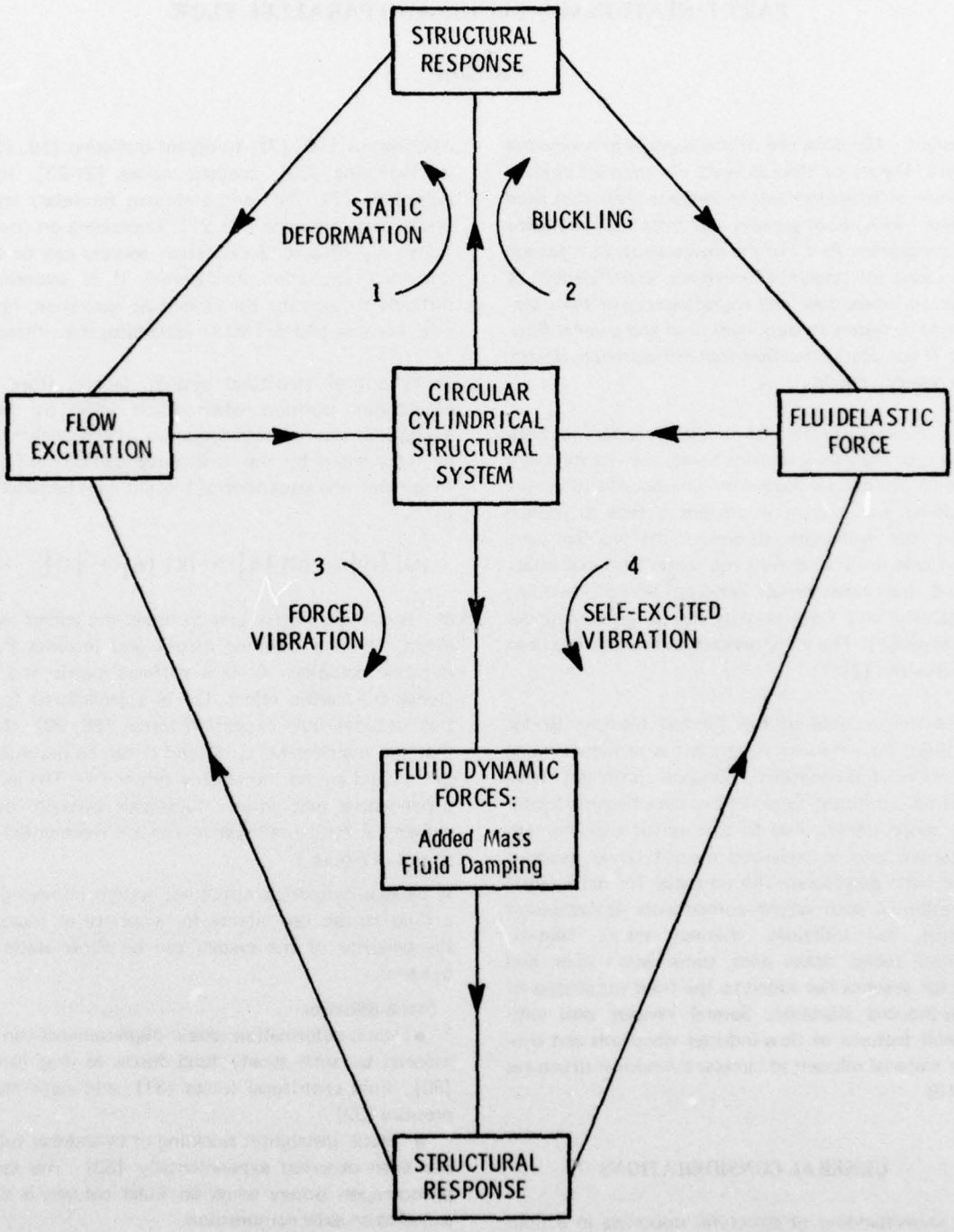

Figure 1. Fluidelastic Responses of Circular Cylindrical Structures

shedding, large oscillations associated with resonance can occur [34]. If the excitation is due to random pressure fluctuations, the oscillations are likely to have a small amplitude [8, 26].

- self-excited vibration: large amplitude vibrations are frequently observed in heat exchanger tube banks [16] and in pipes carrying fluid traveling at high velocity [8, 17].
- parametric resonance: pulsating or two-phase flows can induce parametric and combination resonances [24, 25].

Note that the first four phenomena -- static deformation, static instability, force vibration, and self-excited vibration -- follow only one of the four loops shown in Figure 1; parametric resonance involves both loops 3 and 4. Many practical problems do not follow a single loop. For example, in the lock-in region of vortex-induced vibration of a single cylinder, loops 3 and 4 are involved; at other flow velocity ranges only loop 3 is involved.

VIBRATIONS IN STATIONARY FLUID

When a structural element submerged in a fluid vibrates, the surrounding fluid must be displaced to accommodate the motions. This effect is usually accounted for with the added mass concept. Ideally, the added mass should be calculated from the three-dimensional Navier-Stokes equations, but such a calculation is difficult even in simple cases. When the oscillation has a small amplitude, added mass can usually be computed from the potential flow theory. A summary of potential flow results for circular cylindrical structures including formulas, graphs, and computer programs has recently been compiled [35]. The limitations to potential flow theory should be recognized. Experimental results for a single cylinder have demonstrated that, within certain parameter ranges, the potential flow solution may be in serious error [36-38]. In most vibration problems, however, the threshold of large oscillations, or steady-state, small-amplitude oscillations are sought; the potential flow theory is applicable in such cases.

With a viscous fluid, the fluid force can be separated into two components: one in phase with the acceleration (added mass effect) and the other opposing the movement (damping effect) [39-41]. In most practical situations, with the exception of a confined region, the effect of fluid viscosity on added mass is small. But fluid viscosity contributes significantly to system damping -- particularly in a confined region, where damping associated fluid viscosity can be very large. So long as the vibration amplitude is small, the linear viscous flow theory gives sufficiently accurate results [39]. As the vibration amplitude increases, the nonlinear effects of the flow field become important. In fact, it has been shown that the magnitude of added mass and damping depend upon vibration amplitude [41, 42].

The effect of fluid compressibility on structural motion is similar to that of viscosity: the added mass for a single cylinder in an infinite fluid depends on wavelength, and radiation damping can be significant [43]. Fluid compressibility affects structural modes due to fluid-structure coupling as well as certain acoustoelastic modes, in which structural motion and fluid motions are strongly coupled [44, 45]. If the vibration of a structure is a main concern, the fluid can be considered incompressible.

The importance of flow-induced vibrations in nuclear reactor vessels, thermal shields, and core barrels has created a need for detailed investigations of circular cylindrical shells containing fluid [44-51]. The added mass for shells can be very large in contrast to that for tubes or rods vibrating in a liquid. The added mass for a cylindrical shell containing fluid is equal to $\rho R C_M/h$ where ρ is fluid density, h is shell thickness, R is shell radius, and C_M is added mass factor. The value of the added mass factor depends on the axial and circumferential wave numbers and usually ranges from 0.1 to 1.0 [45]. The added mass for a cylindrical shell is a function of shell mode shape, unlike a slender tube vibrating in lower modes, where added mass is independent of vibrational modes.

Significant progress has been made with regard to coupled vibrations of multiple structural elements. Because of the fluid coupling effect, the motion of any cylinder in a group of cylinders will excite the others, and all cylinders will respond as a group rather than individually. Such behavior is not always recognized. Even though the dynamic response of a group of cylinders submerged in a liquid has been of interest to many engineers. The many studies include two parallel cylinders [52-54], two cylinders located concentrically and separated by a fluid [40, 47, 49, 51, 55-57], a row of cylinders [16, 20, 29, 58-60],

and a group of cylinders [28, 61-69]. When a group of cylinders vibrates -- called coupled vibration -- in a liquid, a definite phase relationship exists among the cylinders. If only one cylinder is oscillating while all others are stationary, the motion is called uncoupled vibration. The general dynamic characteristics of coupled vibration differ from those of a single cylinder. Consider, for example, a group of identical cylinders with a natural frequency in vacuo equal to Ω, and a mass per unit length of m. The natural frequencies for three cases are as follows:

- single cylinder in infinite fluid

$$\Omega_s = \frac{\Omega}{\left(1 + \frac{m_f}{m}\right)^{1/2}} \qquad (2)$$

- uncoupled vibration of multiple cylinders

$$\Omega_u = \frac{\Omega}{\left(1 + \frac{\gamma}{m}\right)^{1/2}} \qquad (3)$$

- coupled vibration of multiple cylinders

$$\Omega_c = \frac{\Omega}{\left(1 + \frac{\mu}{m}\right)^{1/2}} \qquad (4)$$

The displaced mass of fluid is m_f; γ is the added mass of the cylinders; and μ is the eigenvalue of the added mass matrix [28]. These relationships have been confirmed experimentally [69]. Studies show that a group of cylinders has an infinite number of frequency bands corresponding to the infinite number of natural frequencies for a solitary cylinder [67]. Each frequency band has 2k natural frequencies for a group of k cylinders. The frequencies are distributed close to the frequency of a corresponding single cylinder. Within each frequency band, the steady-state response of the group of cylinders differs significantly from that of a single cylinder. In the past, uncoupled modes were used to calculate cylinder response. It is now clear, however, that coupled modes should be used to calculate the response of a group of cylinders.

PARALLEL-FLOW-INDUCED VIBRATION

It is convenient to classify flow-induced-vibration problems as parallel and cross flows, depending on the orientation of fluid flow with respect to the structural axis. Parallel-flow problems can be internal or external, according to the position of the fluid with respect to structure. This section considers vibration and stability of cylinders conveying fluid [17, 24, 25, 27, 31-33, 70-129] and cylinders subjected to external parallel flow [26, 28, 130-184].

Early studies of parallel-flow problems dealt with internal flow, largely because it applied to such practical systems as oil pipelines and fuel lines. The following problems have been studied: cantilevered pipes [76, 77, 79, 83, 90], articulated pipes [17, 88, 115], pipes with pinned or fixed end conditions [33, 71, 81], elastically supported pipes [93, 104], and cylindrical shells [27, 122-129]. The fluid flows discussed include steady flow, pulsating flow [24, 112-118], and two-phase flow [119-121]. One of the most fascinating problems involves fluid-conveying pipes fixed at the upstream end and free at the downstream end -- a classic example of a nonconservative system. It has been shown that the pipe loses stability by flutter. At subcritical flow velocity, the flow-induced oscillation of a cantilevered pipe is usually small because of the large damping value associated with the Coriolis force. If the downstream end is fixed or pinned, the system is called a conservative system [103], a gyroscopic conservative system, or a nonconservative system [101]. As the flow velocity reaches a certain value, the pipe becomes unstable and buckles; in the subcritical flow velocity range, the Coriolis force does not contribute to damping. It has also been shown that flutter instability can occur in pipes with support at the downstream end; the flow velocities required for instability are higher than those that cause buckling. A complete analysis of a pipe clamped at the upstream end and elastically supported at the downstream end has recently been analyzed [104]. It was shown that the pipe can become unstable by buckling, flutter, or both, depending on the magnitudes of the displacement and the rotational springs at the end. It should be pointed out that these studies were based on the linear theory. After a pipe becomes unstable, however, the linear theory is no longer applicable, and the significance of the higher critical flow velocities is difficult to assess.

Relatively little attention has been directed to curved pipes. Hill and Davis [100] used the finite-element technique to examine the effect of initial forces on the vibration and stability of clamped pipes. They showed that neglecting initial forces results in out-of-plane buckling; including these forces prevents buckling within the elastic limit. Doll and Mote [111] also used the finite element method. Their results show that, for pipes with small curvature, analytical results based on the inextensional theory were in better agreement with experimental data than those based on the variable curvature theory.

Parametric and combination resonances in pipes conveying fluid are possible with periodic flow [24, 112-118] and two-phase flow [119-121]. Analytical investigations have been made for articulated pipes, simply-supported pipes, and cantilevered pipes. Paidoussis [24] has demonstrated the existence of both parametric and combination resonances with a harmonically perturbed flow velocity. Such velocities occur over specific ranges of pulsation amplitudes, frequencies, and flow rates. Two-phase-flow-induced instability also has been noted [119, 120]; a relatively large perturbation and a high flow velocity are generally required to induce instability. Such a combination is not likely to occur in practical systems.

When a pipe is relatively short compared with its diameter, the potential flow theory, rather than slug flow, has been used to study instability [122-129]. It has been shown that flutter is possible for all types of end conditions. With pinned or clamped end conditions, however, buckling always precedes the onset of flutter. This is similar to results using beam theory with slug flow. Flutter of shells has been observed experimentally, but buckling-type instability has not been verified [125].

No significant progress has been made in the area of vibration induced by external parallel flow, even though it is of concern in nuclear fuel rod wear in advanced reactor design. The main thrust of the analytical and experimental work has been toward developing a method for predicting fuel rod response under operating conditions. For a single cylinder vibration in an ideal flow condition, several semi-empirical corrections are available for predicting rod amplitude: Paidoussis' empirical correction [141], Chen's parametric model [150, 151], Reavis' correction [142], and the Chen-Wambsganss' method [26, 155]. These expressions are useful in predicting rod response within an order of magnitude, but the current state-of-the-art is such that an accurate prediction of vibration amplitude is difficult without experimental information.

One improvement on the mathematical modeling of fuel bundle vibration is the fluidelastic coupling [28]. All previous models used a single cylinder as the model for fuel bundles. This is not appropriate, especially when the cylinders are closely packed such as those in a nuclear fuel assembly. Analytical and experimental results show that the general characteristics of a fuel bundle differ significantly from those of a single rod. In the future, fluid-elastic coupling effect will have to be included in the development of mathematical models.

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BOOK REVIEWS

DYNAMICS OF STRUCTURES: Volume I (Bygningsdynamik: Bind I)

C. Dyrbye
Lyngby, Polyteknisk Forlag (1973)

The book is primarily designed as a textbook for a course on structural dynamics in the Technical University of Denmark, but the author hopes that it will also find use in practice. It is confined to linear undamped dynamic problems of structural components and systems.

In Chapter 1 the response of a single-degree-of-freedom system is considered for various conditions (free and forced vibrations, foundation excitation, impuslive loading, resonance, etc.). The necessary theoretical concepts are formulated in Chapter 2. Equations of motion are derived by making use of influence functions of linear systems. Basic properties of natural modes and frequencies are considered in some detail. For approximate determination of natural frequencies Rayleigh's principle and Dunkerley's formula are presented. Chapter 3 deals with multidegree-of-freedom systems. In Chapter 4, the vibrations of beams are treated, e.g., the Kolousek functions are derived and the solution of the Timoshenko beam is given. Chapter 5 deals briefly with vibrations of continuous beams and frames. In Chapter 6 the equations for longitudinal vibrations of a bar, transverse vibrations of a string, and torsional vibrations of a shaft are derived.

The presentation is clear and well organized. Acquaintance with basic structural analysis and calculus provides sufficient prerequisite. Regarding the size and level of the book, a fairly versatile treatment is given to the dynamic problems of structures. Reviewer believes that the book serves its purpose very well as an introductory text to structural dynamics.

M. J. Mikkola, Finland
Courtesy of Applied Mechanics Reviews

NONLINEAR STEADY VIBRATIONS (Nelineinye statsionarnye kolebaniya)

N. G. Bondar
Kiev, Izdatelstvo "Naukova Dumka" (1974)

The author's so-called method of variable scale is the underlying theme throughout this book. Its use has unified the approximate treatment of a broad class of nonlinear one-degree-of-freedom systems. The method of variable scale consists in transforming both the independent and the dependent variables so as to produce a linear differential equation with a forcing function that depends on the unknown solution. Approximations made at this stage then lead to corresponding approximate solutions. It is not clear how this technique is based solely on G. Polya's plausible inference, as claimed in the introduction. However, the book does present a large number of interesting solutions with emphasis on the amplitude versus frequency characteristic. Types of excitation include harmonic, biharmonic, periodic, and trains of impulses.

Being intended for engineers, the book concentrates on getting approximate solutions rather than on questions of existence, convergence, or error estimates.

Solutions from analog and digital computers are often compared with the author's approximate analytical solutions. Apparently the author regards the good agreement as a vindication of his method. However, in making these comparisons he does in fact raise the broader question of the respective roles of the computer simulation and the approximate analytical approach.

D. B. Macvean, United Kingdom
Courtesy of Applied Mechanics Reviews

NORMS FOR THE STRUCTURAL ANALYSIS OF ELEMENTS OF REACTORS, STEAM GENERATORS, VESSELS AND PIPINGS OF NUCLEAR POWER PLANTS, AND OF EXPERIMENTAL AND RESEARCH NUCLEAR REACTORS AND INSTALLATIONS

(Normy rascheta na prochnost elementov reaktorov parogeneratorov, sosudov i truboprovodov atomnykh elektrostantsii, optnykh i issledovatelskikh yadernykh reaktorov i ustanovok)

Moscow, "Metallurgiya" (1973)

The reviewed book represents a code for the design, construction, and operation of nuclear reactors and power stations in the USSR.

The types of failure considered are:

(a) fracture,
(b) large plastic deformation,
(c) instability,
(d) residual deformation large enough to impede proper function,
(e) fracture due to cyclic loading.

First part of the book contains tables of material parameters for temperature levels up to 600°C. Next, simple formulas are given for determination of minimal thicknesses of various components; listed are allowable stress levels, stress concentration factors, etc.

The main part of the text is divided into five appendices.

I - First appendix is devoted to thermoelastic analysis of cylindrical containers. A rather elaborate numerical example (pressure, thermal gradient, cyclic loading) illustrates listed formulas.

II - A two-page appendix contains several formulas to be used in creep analyses of subassembly ducts (made from zirconium) and piping systems (made of chrome-molybdenum alloys).

III - Next 35 pages contain an explanation of methods to be used for determination of various mechanical properties of materials (ranging from simple yield stress determination for steel at various temperature levels to determination of hysteresis loops for various materials in plastic range).

IV - Next 150 pages contain unified analytical and experimental methods for determination of stresses, strains, and deformations. A host of formulas for cylindrical, spherical, and elliptic shells, circular plates, rings, and bellows is listed for a variety of loading conditions and thermal fields. Also listed are formulas for multilayered shells, perforated plates, etc.

V - Final 90 pages contain description of design methods for various details, such as flanges, other connections, tees, branches, etc.

In conclusion, book represents a rather ambitious and certainly a worthwhile attempt to help a structural engineer engaged in design of nuclear reactors. Quite obviously it does not cover all possible circumstances and in many respects has a strong precomputer era flavor. However, there is very little doubt that practical engineers in USSR will find this text helpful. In fact, in many respects this code appears to be superior to ASME BPV Code.

D. Krajcinovic, USA
Courtesy of Applied Mechanics Reviews

REDUCTION OF MACHINERY NOISE
(Revised Edition)

Malcolm J. Crocker, Editor

The Purdue University series of short courses on the reduction of machinery noise was begun in 1972 by Dr. Malcolm Crocker at the Herrick Laboratories. The current revised edition of Reduction of Machinery Noise contains the proceedings of two short courses held at Purdue University in December 1975. Twelve papers comprise the first course, "Fundamentals of Noise Control," and 21 papers the second course, "Reduction of Machinery Noise."

Fundamentals of Noise Control covers the full range of topics usually included in noise control engineering. The basics of sound, effects of noise on people, simple acoustical instrumentation, and measurement methods are described, as well as vibration isolation and such techniques for noise control as the use of sound-absorbing materials, sound barriers, and mufflers. The final paper is a brief discussion of the noise regulations of OSHA and state and local governments.

The 12 papers are generally basic in nature and are written for the beginner in noise control, but they are also comprehensive and present information beyond the simple basics. For example, the paper on room acoustics includes a brief presentation of geometrical theory and wave theory, in addition to the more common statistical theory approach. The paper on outdoor sound propagation includes the effects of wind, humidity, and temperature gradients, as well as sound propagation over grass.

The other papers of the first course are standard presentations of typical noise control methods. The paper on absorption discusses the mechanisms by which sound is absorbed and points out the differences between normal and random incidence absorption coefficients. The papers on vibration isolation contain qualitative descriptions of some of the problems and techniques of isolation. These include equipment balance, low and high frequencies and wave effects, inertia blocks, short circuits, and shock isolation.

The 21 papers of the second course, "Reduction of Machinery Noise," are formally divided into 17 general papers and four case histories, but are actually nine general papers and 12 case histories. Six papers deal with engine noise or diesel truck noise. The other case histories, and some of the general papers, deal specifically with data measurements and noise control procedures and/or results for:

- petrochemical plants
- strip feed press
- punch press
- electrical equipment
- construction equipment
- metal cutting operations
- large steam turbine/generators
- valves and piping
- compressors
- fans and blowers
- lawn mowers

All the papers include at least a general description of the problem and some data, theory, and analysis. Most of the papers include some references that should be valuable to someone desiring further information. Overall the material is well prepared; even if specific questions are left unanswered, sufficient specifics of the problem are given to alert the reader to those aspects of his own situation that will make additional searching fruitful.

The main drawback of this revised edition is that, of the 33 papers, at least 15 are apparently reprints from the earlier edition, and some have even appeared in other publications. Therefore, although this book would be a useful addition to a noise control engineer's library, he should examine it, especially if he already has a copy of the first edition, which was published in 1974.

W. Ernie Purcell
Noise Control Program
Bechtel Corporation, San Francisco, California

SHORT COURSES

NOVEMBER

MACHINERY VIBRATION

Dates: November 8 - 10, 1977
Place: Cherry Hill, New Jersey
Objective: Lectures and demonstrations on rotor dynamics and torsional vibration have been scheduled for this seminar. General sessions on the opening day are intended to serve as a review of the technology; included are the concepts of critical speeds, resonances, and stability of machines; the finite element method; and rotor dynamic measurements. Double sessions on rotor dynamics and torsional vibrations will be held on the second and third days. The following topics are included in the rotor dynamics sessions: bearing (antifriction and fluid film) dynamics, rotor dynamic calculations, dynamics of foundations, application of large computer programs for structural vibration analysis, modern balancing techniques and applications and solutions to industrial balancing problems. The sessions on torsional vibration feature fundamentals, modeling measurement and data analysis, self-excited vibrations, isolation and damping, transient analysis, and design of machine systems. Participants will be able to attend lectures in the area commensurate with their interests.

Contact: Vibration Institute, 101 W. 55th St., Clarendon Hills, IL 60514 (312) 654-2254/654-2053

AN INTRODUCTION TO VIBRATION AND SHOCK SURVIVABILITY, MEASUREMENT, ANALYSIS, CALIBRATIONS, AND TESTING

Dates: November 7 - 11, 1977
Place: Washington, D.C.
Objective: This course is intended to provide a basic education in resonance and fragility (vulnerability) phenomena, in vibration and shock environmental measurement and analysis, also in vibration and shock testing to prove reliability. This seminar will benefit quality and reliability personnel, test laboratory managers, engineers and aides, plant engineers and maintenance supervisors, packaging and transportation engineers, men in Government and military activities and their contractors. There are no definite prerequisites for this course.

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

THE 15TH ANNUAL RELIABILITY ENGINEERING AND MANAGEMENT INSTITUTE

Dates: November 14 - 18, 1977
Place: Tucson, Arizona
Objective: This seminar, presented by the Univ. of Arizona, College of Engineering and Honeywell Information Systems, Arizona Computer Operations, Phoenix, is designed to cover the following subjects: reliability engineering theory and practice; component, equipment and system reliability prediction; reliability testing and demonstration; maintainability engineering theory and practice; safety; liability; and reliability maintainability management.

Contact: Dr. Dimitri Kececioglu, Aero. & Mech. Engrg. Dept., Univ. of Arizona, Bldg. 16, Tucson, AZ 85721 (602) 884-2495/884-3901/884-3054

ACOUSTICAL MODELING WORKSHOP IV

Dates: November 14 - 18, 1977
Place: MIT, Cambridge, Massachusetts
Objective: Participants will build their own models, take and interpret data to solve complex acoustic propagation problems. Sessions will consider applications of data to environmental noise prediction, evaluation of noise control measures, and site selection for buildings, roadways and guideways. Some subjects covered include sound speed, frequency and geometric scaling, air absorption, surface reflectivity, impulsive and continuous signals, spatial distribution of sources, interior and exterior noise situations and their characteristics, effect of barriers and absorbers in control of noise, control of reverberation, and the use of data in design.

Contact: Ms. M. Toscano, Rm. 3-366, Acoustical Modeling Workshop IV, Massachusetts Institute of Technology. Cambridge, MA 02139

DYNAMIC ANALYSIS WORKSHOP

Dates: November 14 - 18, 1977

Place: San Diego, California

Objective: A weeklong course will be presented on the latest techniques of analyzing noise and vibration in rotating machinery and power-driven structures. The workshop will cover both the theory and practical aspects of tracking down malfunctions and preventing failures caused by unbalance, misalignment, wear, oil whirl, etc. Included in the course will be demonstrations and practical, hands-on experience with the latest noise and vibration instrumentation: Real Time Analyzers, FFT Processors, Transfer Function Analyzers and Computer-Controlled Modal Analysis Systems. Actual case histories and specific machinery signatures will be discussed.

Contact: Bob Kiefer, Spectral Dynamics Training Manager, P.O. Box 671, San Diego, CA 92112 (714) 565-8211

DECEMBER

VIBRATION SURVIVABILITY

Dates: December 6 - 10, 1977

Place: Palo Alto, California

Objective: Increasing an equipment's ability to survive in the dynamic environments of vibration and shock will be the main subject of a 5-day short course near San Francisco. The course will meet at the facilities of Watkins-Johnson Co., 3333 Hillview Ave. in Palo Alto, California. Among the troublesome vibration and shock environments to be considered are missiles and aircraft, ships, automotive vehicles, modern buildings, and nuclear power plants. The course is designed to provide education in resonance and fragility phenomena, in environmental vibration and shock measurement and analysis, also in vibration and shock testing to prove survivability. This course will concentrate upon techniques and equipments rather than upon mathematics and theory.

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

NEWS BRIEFS

news on current and Future Shock and Vibration activities and events

ICNO - Prague 1978

The Institute of Thermomechanics of the Czechoslovak Academy of Sciences will organize the 8th International Conference on Non-Linear Oscillations in Prague, September 11 - 16, 1978. The Conference is sponsored by the Czechoslovak Academy of Sciences in co-operation with the Academy of Sciences of the GDR, the Polish Academy of Sciences, and the Academy of Sciences of the Ukrainian SSR.

The conference will be conducted in three topical sections:

I. The mathematical theory of non-linear oscillations;

II. Non-linear oscillations in mechanical systems;

III. Non-linear oscillations in electrical systems.

The scientific program will be supplemented with a social and ladies' program.

More detailed information will be contained in the invitations to be distributed by the organizers of the Conference at the end of 1977. It is expected that the full texts of the papers will be required for publishing in the Proceedings by February 1978.

All correspondence concerning the Conference should be addressed to:

The ICNO 78 Organizational Bureau
Institute of Thermomechanics
Czechoslovak Academy of Sciences
Puskinovo nam. 9
160 00 Prague 6.

DYNAMIC ANALYSIS and SPACE SHUTTLE DYNAMICS Sessions Planned

The SAE Technical Committee G-5, Aerospace Shock and Vibration, is organizing two sessions to be presented at the 1977 SAE Aerospace Engineering and Manufacturing Meeting, November 14 thru 17, 1977, Airport Sheraton Inn, Los Angeles, California. The title of the two sessions are:

Dynamic Analysis

Space Shuttle Dynamics

Information on the finalized program may be obtained from:

R. W. Mustain
Rockwell International, Space Division
Mail Code AB97, 12214 S. Lakewood Blvd.
Downey, CA 90241

CALL FOR PAPERS INTER-NOISE 78

"Designing for Noise Control" will be the theme of INTER-NOISE 78, the seventh International Conference on Noise Control Engineering which will be held at the Jack Tar Hotel, San Francisco, California, USA on 8 - 10 May 1978.

Contributed papers are welcome as are case histories of solutions to noise control problems. Abstracts of contributed papers and contributions to the noise clinics should be 400 words in length. Three copies of each abstract should be submitted as soon as possible to Daniel R. Flynn, Technical Program Chairman, National Bureau of Standards, Washington, DC 20234. The deadline for receipt of abstracts is 24 October 1977. For more information contact: INTER-NOISE 78, P.O. Box 3469, Arlington Branch, Poughkeepsie, NY 12603, USA.

ABSTRACT CATEGORIES

ANALYSIS AND DESIGN

- Analogs and Analog Computation
- Analytical Methods
- Dynamic Programming
- Impedance Methods
- Integral Transforms
- Nonlinear Analysis
- Numerical Analysis
- Optimization Techniques
- Perturbation Methods
- Stability Analysis
- Statistical Methods
- Variational Methods
- Finite Element Modeling
- Modeling
- Digital Simulation
- Parameter Identification
- Design Information
- Design Techniques
- Criteria, Standards, and Specifications
- Surveys and Bibliographies
- Tutorial
- Modal Analysis and Synthesis

COMPUTER PROGRAMS

- General
- Natural Frequency
- Random Response
- Stability
- Steady State Response
- Transient Response

ENVIRONMENTS

- Acoustic
- Periodic
- Random
- Seismic
- Shock
- General Weapon
- Transportation

PHENOMENOLOGY

- Composite
- Damping
- Elastic
- Fatigue
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- Thermoelastic
- Viscoelastic

EXPERIMENTATION

- Balancing
- Data Reduction
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- Procedures
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COMPONENTS

- Absorbers
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- Bearings
- Blades
- Columns
- Controls
- Cylinders
- Ducts
- Frames, Arches
- Gears
- Isolators
- Linkages
- Mechanical
- Membranes, Films, and Webs
- Panels
- Pipes and Tubes
- Plates and Shells
- Rings
- Springs
- Structural
- Tires

SYSTEMS

- Absorber
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- Active Isolation
- Aircraft
- Artillery
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- Building
- Cabinets
- Construction
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- Human
- Isolation
- Material Handling
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- Off-Road Vehicles
- Optical
- Package
- Pressure Vessels
- Pumps, Turbines, Fans, Compressors
- Rail
- Reactors
- Reciprocating Machine
- Road
- Rotors
- Satellite
- Self-Excited
- Ship
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- Structural
- Transmissions
- Turbomachinery
- Useful Application

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.

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ANALYSIS AND DESIGN

ANALYTICAL METHODS

(Also see No. 1829)

77-1725

System Properties of One-Dimensional Distributed Systems

L.S. Bonderson

Dept. of Mech. Engrg., Arya-Mehr Univ. of Tech., Tehran, Iran, J. Dyn Syst., Meas. and Control, Trans. ASME, 99 (2), pp 85-90 (June 1977) 6 figs, 4 refs

Key Words: Continuous parameter method

The system properties of passivity, losslessness, and reciprocity are defined and their necessary and sufficient conditions are derived for a class of linear one-dimensional multipower distributed systems. The utilization of power product pairs as state variables and the representation of the dynamics in first-order form allows results completely analogous to those for lumped-element systems.

77-1726

Performance Standards in Dynamics

N. Komaroff

Moorooka, Brisbane Q., Australia, J. Dyn. Syst., Meas. and Control, Trans. ASME, 92 (2), pp 118-122 (June 1977) 8 refs

Key Words: Dynamic structural analysis

A method to evaluate the performance of dynamical systems governed by ordinary differential equations is presented. It is based on averaging functions describing system behavior (e.g., velocities) over prescribed domains (e.g., surfaces) in phase space. Quantitative measures of motion are introduced to indicate e.g. how oscillatory or how monotone would be the response following a disturbance. Examples demonstrate how these measures serve as new design specifications whose role is to define, compare and control system performance in a more comprehensive manner. Another application of work is to qualitative studies in both the analysis and synthesis contexts.

77-1727

The Steady-State Response of Systems with Spatially Localized Non-Linearity

W.D. Iwan and R.K. Miller

California Inst. of Tech., Pasadena, CA 91125, Intl. J. Nonlinear Mech., 12 (3), pp 165-173 (Mar 1977) 5 figs, 5 refs

Key Words: Periodic response, Nonlinear systems

This paper presents an approximate analytical approach for determining the steady-state response of a class of systems with spatially localized non-linearity. Fundamental properties of the response are identified. An example illustrates the nature and accuracy of the results of the approximate analysis.

77-1728

Curve Fitting of Aeroelastic Transient Response Data with Exponential Functions

R.M. Bennett and R.N. Desmarais

Langley Res. Center, NASA, Langley Station, VA., In: NASA Langley Res. Center Flutter Testing Tech., pp 43-58 (1976) (N77-21022)
N77-21024

Key Words: Curve fitting, Transient response

The extraction of frequency, damping, amplitude, and phase information from unforced transient response data is considered. These quantities are obtained from the parameters determined by fitting the digitized time-history data in a least-squares sense with complex exponential functions. The highlights of the method are described, and the results of several test cases are presented. The effects of noise are considered both by using analytical examples with random noise and by estimating the standard deviation of the parameters from maximum-likelihood theory.

77-1729

Turbulence Excited Frequency Domain Damping Measurement and Truncation Effects

J. Soovere

Lockheed-California Co., Burbank, CA, In: NASA Langley Res. Center Flutter Testing Tech., pp 115-142 (1976) (N77-21022)
N77-21027

Key Words: Turbulence, Flutter, Frequency domain, Modal analysis, Modal damping, Laplace transformation, Fourier transform

Existing frequency domain modal frequency and damping analysis methods are discussed. The effects of truncation in the Laplace and Fourier transform data analysis methods are described. Methods for eliminating truncation errors from measured damping are presented. Implications of truncation effects in fast Fourier transform analysis are discussed. Limited comparison with test data is presented.

NUMERICAL ANALYSIS

77-1730

Efficient Numerical Treatment of Periodic Systems with Application to Stability Problems

P. Friedmann, C.E. Hammond, and T.-H. Woo

Mechanics and Structure Dept., Univ. of Calif., Los Angeles, CA, Intl. J. Numer. Methods Engr., 11 (7), pp 1117-1136 (1977) 10 figs, 1 table, 26 refs

Sponsored by the NASA Langley Res. Center and U.S. Army Air Mobility R&D Lab.

Key Words: Numerical analysis, Stability analysis, Rotor blades

Two efficient numerical methods for dealing with the stability of linear periodic systems are presented. Both methods combine the use of multivariable Floquet-Liapunov theory with an efficient numerical scheme for computing the transition matrix at the end of one period. The numerical properties of these methods are illustrated by applying them to the simple parametric excitation problem of a fixed end column. The practical value of these methods is shown by applying them to some helicopter rotor blade aeroelastic and structural dynamics problems.

STABILITY ANALYSIS

(See No. 1764)

PARAMETER IDENTIFICATION

77-1731

Nonlinear Parameter Identification from a Vibration Test (Nichtlineare Parameter-Ermittlung aus einem Schwingungsversuch)

H. Kohler

Vereinigte Flugtechnische Werke - Fokker GmbH, Abt. Ev 421-L, 2874 Lemwerder, Z. Flugwiss, 1 (1), pp 50-57 (1977) 6 figs, 3 tables, 7 refs

(In German)

Key Words: Parameter identification, Vibration tests

A theory for the determination of the nonlinear vibration behavior of a discrete, holonomic, elasto-mechanical system is described by means of a substitute system reduced, after a general survey, to two degrees of freedom. The method is applied to the nonlinearities in frequency/angle of rotation diagrams of the VFW 614 lateral control system measured during a static vibration test. A detailed discussion of the overall vibration behavior compared to the linear theory follows.

77-1732

Specification of Inputs and Instrumentation for Flutter Testing of Multivariable Systems

N.K. Gupta and W.E. Hall, Jr.

Systems Control, Inc., Cambridge, MA, In: NASA Langley Res. Center Flutter Testing Tech., pp 143-180 (1976) (N77-20122)

N77-21028

Key Words: Flutter, Testing techniques, System identification

The application of system identification methods in flutter testing of aeroelastic structure is discussed. The accuracy with which flutter parameters are estimated depends upon the test plan and on the algorithms used to reduce the data. The techniques for selecting the kinds and optimal positions of inputs and instrumentation, under typical test constraints, are presented. Identification results for both the input/output transfer function and the value of physical parameters are given. Numerical results on the optimal input spectrum and the accelerometer location for estimating flutter parameters of a two dimensional wing are obtained using these algorithms. Current work on applying system identification methods to high order three dimensional aeroelastic structures is reported.

CRITERIA, STANDARDS, AND SPECIFICATIONS

77-1733

Acoustical Testing of Building Components

M.W. Blanck

Kodaras Acoustical Laboratories, Div. ETL, Inc., Inst. Environ. Sci., Proc. 23rd Annual Mtg., Los Angeles, CA, pp 378-381 (Apr 25-27, 1977)

Key Words: Standards and codes, Acoustic tests, Mechanical-acoustical systems, Structural elements

The author reviews some standards, codes and specifications for the acoustic testing of several mechanical and architectural building components.

SURVEYS AND BIBLIOGRAPHIES

77-1734

Noise Measurement, Noise Rating (Annual Survey)

R. Martin

VDI Z., 119 (10), pp 525-533 (June 1977) 5 figs, 3 tables, 90 refs

Key Words: Reviews, Noise measurement

Books, standards, and guide lines are reported. Effects of *noise and their relation to measurement quantities are discussed.* Sound level meters and dosimeters are reported. *Noise measurements at machines, noise measurements at* vehicles and characterization of noise emmissions are listed.

77-1735

Bond Graph Bibliography for 1961 - 1976

V.D. Gebben

Lewis Research Center, Cleveland, OH, J. Dyn. Syst., Meas. and Control, Trans. ASME, 92 (2), pp 143-145 (June 1977)

Key Words: Bibliographies, Bond graph techniques

This bibliography updates the list published by D.C. Karnopp and R.C. Rosenberg in the "Special Issue on Bond Graph Modeling for Engineering Systems," Journal of Dynamic Systems, Measurements, and Control, Trans. ASME, Vol. 94, No. 3, 1972, pp 177-178. It lists 6 books and 114 reports and is divided into 11 sections. The last category, Related Subjects, gives some references to reports that are directly related to bond graph theory. Background material such as classical network theory and graph theory is not included.

COMPUTER PROGRAMS

GENERAL

(Also see Nos. 1778, 1788, 1796, 1792, 1866)

77-1736

Aircraft Hydraulic System Dynamic Analysis. Volume 1. - Transient Analysis (HYTRAN) Computer Program User Manual

G. Amies, R. Levek, and D. Struessel

Mcdonnell Aircraft Co., St. Louis, MO, Rept. No. AFAPL-TR-76-43-Vol-1, 200 pp (Feb 1977) AD-A038 690/4GA

Key Words: Computer programs, Aircraft equipment, Hydraulic equipment

The hydraulic transient analysis (HYTRAN) computer program has been developed to simulate the response of a hydraulic system to sudden changes in flow demand by the system loads. For a selected system temperature, pump RPM, and initial steady state conditions, the program will calculate the pressures and flow amplitudes resulting from changes in flow demand or some other controller input. It will predict transient pressures due to water-hammer and the onset of cavitation due to the opening and closing of valves.

77-1737

Aircraft Hydraulic System Dynamic Analysis. Volume II. - Transient Analysis (HYTRAN) Computer Program Technical Description

G. Amies, R. Levek, and D. Struessel

Mcdonnell Aircraft Co., St. Louis, MO, Rept. No. AFAPL-TR-76-43-Vol-2, 501 pp (Feb 1977) AD-A039 037/7GA

Key Words: Computer programs, Aircraft equipment, Hydraulic equipment, Transient response

The hydraulic transient analysis (HYTRAN) computer program has been developed to simulate the response of a hydraulic system to sudden changes in flow demand by the system loads. For selected component temperatures, pump RPM, and initial steady state conditions, the program will calculate the pressures and flow amplitudes resulting from changes in flow demand or some other controller input. It will predict transient pressures due to water-hammer and the onset of cavitation due to the opening and closing of valves.

77-1738

Aircraft Hydraulic System Dynamic Analysis. Volume III. - Frequency Response (HSFR) Computer Program User Manual

G. Amies and B. Greene

Mcdonnell Aircraft Co., St. Louis, MO, Rept. No. AFAPL-TR-76-43-Vol-3, 77 pp (Feb 1977) AD-A038 691 2/GA

Key Words: Computer programs, Aircraft equipment, Hydraulic equipment, Acoustic excitation, Pumps

The hydraulic system frequency response (HSFR) computer program was developed to simulate the dynamic response of a hydraulic system to the acoustic noise generated by the pump. Detailed instructions for modeling the system pump, lines, and components, and for using the program are presented. For a selected system pressure, temperature, flow, and pump speed range, the program calculates the pulsation pressure and energy levels generated by the pump. It predicts the amplitude and location of the resulting acoustical standing waves, and how these waves are transmitted and attenuated throughout the hydraulic system. The program may be used for acoustical analysis in the pressure side or both the pressure and return sides of the hydraulic system.

77-1739

Aircraft Hydraulic System Dynamic Analysis. Volume IV. Frequency Response (HSFR) Computer Program Technical Description

G. Amies and B. Greene

Mcdonnell Douglas Corp., St. Louis, MO, Rept. No. AFAPL-TR-76-43-Vol-4, 200 pp (Feb 1977) AD-A038 884/3GA

Key Words: Computer programs, Aircraft equipment, Hydraulic equipment, Acoustic excitation, Pumps

The hydraulic system frequency response (HSFR) computer program was developed to simulate the dynamic response of a hydraulic system to the acoustic noise generated by the pump. A detailed technical description of the program is presented. For a selected system pressure, temperature, flow, and pump speed range, the program calculates the pulsation pressure and energy levels generated by the pump. It predicts the amplitude and location of the resulting acoustical standing waves, and how these waves are transmitted and attenuated throughout the hydraulic system. The program may be used for acoustical analysis in the pressure side or both the pressure and return sides of the hydraulic system. Estimated line lengths and sizes from preliminary design work give a good estimate of hydraulic system natural frequencies and pressure amplitudes. The program outputs plots of the peak flow, pressure, and impedance amplitudes of any selected harmonic of the pulsation noise versus pump speed for selected locations in the system. In addition, the program outputs plots of total acoustic energy density and intensity (power) versus pump speed.

77-1740

Nonlinear Model Solution Process: Energy Approach

S.M. Holzer and A.E. Somers

Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, ASCE J. Engr., Mech. Div., 103 (EM4) pp 629-647 (Aug 1977) 9 figs, 33 refs

Sponsored by the AF Weapons Lab., Kirtland AFB

Key Words: Computer programs, Mathematical models, Structural elements, Reinforced concrete, Beam columns, Finite element technique

The paper provides a comprehensive treatment of the mathematical model and solution process of the computer code SINGER. The function of SINGER is to predict the geometrically and physically nonlinear response, including element failures and structural collapse, of skeletal reinforced concrete and steel structures to static and dynamic loads. The model of SINGER represents an assemblage of one-dimensional finite elements, which is expressed in the form of an energy function. The solution process is based on function minimization. A selection of test problems is presented to provide an indication of the capability of SINGER.

NATURAL FREQUENCY

77-1741

Applications of GIFTS III to Structural Engineering Problems

H.A. Kamel and M.W. McCabe

Aerospace & Mech. Engrg. Dept., Univ. of Arizona, Tucson, AZ 85721, Computers and Struc., 7 (3), pp 399-415 (June 1977) 23 figs, 1 table, 5 refs

Key Words: Computer program, Finite element technique, Graphic methods

This paper describes the latest version of the GIFTS system (Graphics Oriented Interactive Finite Element Package for Time-Sharing), due for release at the end of March 1976. This paper gives a description of the program modules available in the GIFTS library and the options available within its framework. Examples are given to demonstrate the use of GIFTS in design-oriented applications. Some performance measurements are included. GIFTS features include automatic model and load generation, generation and display of higher order elements, display of mode, loads, boundary conditions, deflections and stresses, suitability for use as a pre- and post- processor for large batch programs, static analysis capabilities for trusses, frames, membranes, plates and shells, vibrational mode computation for complex structures, transient response analysis using either direct integration or a modal analysis approach, substructuring and constrained substructuring, mixed boundary conditions, and thermal stresses. Three examples have been chosen for inclusion in this paper. They illustrate some of the more important aspects of the GIFTS III system. These examples include the analysis of a three-dimensional framework, vibrational mode computation of an aircraft wing and the analysis, using substructures, of a bulk-ore carrier.

ENVIRONMENTS

ACOUSTIC

(Also see Nos. 1759, 1843)

77-1742

Some Experimental Data for the Design of Acoustic Arrays

M. Pappalardo
Istituto O.M. Corbino, Via Cassia, 1216, Rome, Italy,
J. Sound Vib., 52 (4), pp 579-586 (June 22, 1977)
5 figs, 1 table, 7 refs

Key Words: Acoustic arrays

The frequency spectra of resonant vibration of a PZT4 piezoelectric plate was observed, for width-to-thickness ratios ranging from 0·3 to 4·0. The results give useful information for the design of line arrays applicable, for example, to medical diagnostic sonars. The effect of backing and impedance matching on PZT4 ceramic slabs was also studied experimentally.

77-1743

Investigation of the Trade-Off Effects of Aircraft Noise and Number

C.G. Rice
Inst. of Sound and Vibration Res., Univ. of Southampton, Southampton S09 5NH, UK, J. Sound Vib., 52 (3), pp 325-344 (June 8, 1977) 11 figs, 15 tables, 8 refs
Sponsored by the Science Res. Council

Key Words: Aircraft noise, Human response, Measurement techniques

This paper describes a laboratory study which investigated a trade-off between aircraft noise level and number of events. The method developed for making judgments over periods of time and the experimental design, were such that data could be interpreted in terms of Scandinavian, UK and USA social survey results.

77-1744

Development of Cumulative Noise Measure for the Prediction of General Annoyance in an Average Population

C. G. Rice
Inst. of Sound and Vibration Res., Univ. of Southampton, Southampton S09 5NH, UK, J. Sound Vib., 52 (3), pp 345-364 (June 8, 1977) 11 figs, 13 tables, 11 refs

Key Words: Aircraft noise, Traffic noise, Human response

This paper describes a laboratory investigation into the concept of using a unified index for the prediction of annoyance from aircraft and traffic noise heard over periods of time.

77-1745

Predicting Community Response to Road Traffic Noise

F.L. Hall and S.M. Taylor
Dept. of Geography, McMaster Univ., Hamilton, Ontario, Canada, J. Sound Vib., 52 (3), pp 387-399 (June 8, 1977) 2 figs, 5 tables, 19 refs

Key Words: Traffic noise, Human response

Several problems related to identifying the potential future impacts of road traffic noise on residential areas require for their solution the ability to predict subjective response to road traffic noise. There has been no reported test of whether or not the data used meet the assumptions of the regression model. This is the main difficulty in using existing regression equations relating subjective response and traffic noise for such predictions. If the assumptions are not met, the replicability of the results and hence the reliability of the predictions, as measured by confidence limits or standard errors, cannot be established, because such inference rests on the statistical assumptions.

77-1746

Laboratory Studies on Traffic Noise Annoyance

R. Rylander, E. Sjöstedt, and M. Björkman
Dept. of Environ. Hygiene, Univ. of Gothenburg, Gothenburg, Sweden, J. Sound Vib., 52 (3), pp 415-421 (June 8, 1977) 1 fig, 5 tables, 7 refs

Key Words: Traffic noise, Human response, Experimental data

A laboratory study was undertaken to investigate the relation between traffic noise and annoyance with special reference to the number of noisy events. Students were exposed to different noise conditions for 45 and 120 minutes whereafter their reactions were assessed using a questionnaire.

PERIODIC

77-1747

Impact of a Rigid Body on an Elastic Half Space

G.N. Bycroft
Seismic Engrg. Branch, U.S. Dept. of the Interior, Geological Survey, Menlo Park, CA, J. Appl. Mech., Trans. ASME, 44 (2), pp 227-230 (June 1977)

Key Words: Impact shock, Periodic response, Plates

A Fourier synthesis of the steady-state vibrations of a rigid plate on an elastic half space is used to determine the deceleration and penetration of a rigid body impacting an elastic half space over a flat circular area. In order to obtain a satisfactory solution, it is necessary to integrate to a large value of the frequency factor. The theoretical values are compared with some simple experiments on lead and Neoprene.

RANDOM

77-1748

Behaviour of Bistable Oscillatory System with Random External Force

K. Shirai, K. Akizuki, and T. Yamada
Waseda Univ., Tokyo, Japan, Bull. JSME, 20 (143) pp 548-553 (May 1977) 4 figs, 7 refs

Key Words: Oscillators, Vibrating structures, Random excitation

In this paper an oscillatory system which has two stable oscillatory modes and is disturbed by random external force is considered. In the deterministic case, the state settles to a stable point which is determined by the initial condition. If the random input is applied to this system, an interesting statistical phenomenon is seen that the state moves between both modes. For the oscillatory systems the averaging method is useful. The stochastic differential equations in regard to the amplitude and phase are obtained and the system is analyzed on the basis of them. First the behavior of the steady state is considered. Secondly the first passage time problem, namely the time which the state takes to make transition to another stable area leaving one stable area, is discussed. The analytic results are compared with those obtained by the digital simulation.

77-1749

Generalized Cumulants Representing a Transient Random Process in a Linear System

A. Mayer
Optical Technology Div., The Perkin-Elmer Corp., Danbury, CT, J. Dyn Syst., Meas. and Control, Trans. ASME, 99 (2), pp 103-108 (June 1977) 4 figs, 18 refs

Key Words: Random vibration, Linear systems

The state vector of a linear system responding to gaussian noise satisfies a Langevin equation, and the moment-generating function of the probability distribution of the state vector satisfies a partial differential equation. The logarithm of the moment-generating function is expanded in a power series, whose coefficients are organized into a sequence of symmetric tensors. These are the generalized cumulants of the time-dependent distribution of the state vector. They separately satisfy an infinite sequence of uncoupled ordinary differential tensor equations. The normal modes of each of the generalized cumulants are given by an easy formula. This specifies transient response and proves that all cumulants of a stable system are stable. Also, all cumulants of an unstable system are unstable. As an example, a particular non-gaussian initial distribution is assumed for the state vector of a second-order tracking system, and the transient fourth cumulant is calculates.

77-1750

Synthesis of Multivariate Random Vibration Systems: A Two-Stage Least Squares AR-MA Model Approach

W. Gersch and J. Yonemoto
Dept. of Information and Computer Sciences, Univ. of Hawaii, Honolulu, Hawaii 96822, J. Sound Vib., 52 (4), pp 553-565 (June 22, 1977) 3 figs, 3 tables, 29 refs

Key Words: Random vibration, Mathematical models, Least squares method

A parametric time series model procedure for the synthesis of multivariate stationary time series random vibrations is shown. The vibrations are assumed to be the outputs of a regularly sampled, random noise excited, differential equation model of a vibration system. The procedure is a two-stage least squares method for realizing a multivariate discrete time mixed autoregressive-moving average (AR-MA) model from a given stationary process matrix covariance function. The synthesis procedure and the problem of the minimal representation of multivariate output systems and the overparameterization of AR-MA models are discussed and illustrated.

77-1751

Stationary Random Vibration of Hysteretic Systems

H. Takemiya and L.D. Lutes

Okayama Univ., Okayama, Japan, ASCE J. Engr. Mech. Div., 103 (EM4), pp 673-687 (Aug 1977) 5 figs, 1 table 15 refs

Key Words: Random vibration, Hysteretic damping, Equivalent linearization technique

A rigorous derivation of the modified power balance method is given for general yielding systems. It is demonstrated that the physical meaning of the equivalent linearization criteria derived by the mean-square minimization (Krylov-Bogoliubov) method are the equivalency of the dissipative and potential energies of the linear and nonlinear systems. Thus, linearization by power balance can be the same as by mean-square minimization. Simple gradient-stiffness approximations for the amplitude-dependent average frequency of hysteresis cycles and the overall average frequency of random response are presented for systems of Masing's type. In addition to the previously studied bilinear hysteretic system, the method is applied to compute rms response levels of trilinear hysteretic and Ramberg-Osgood type systems.

77-1752

Oscillator Response to Modulated Random Excitation

R.B. Corotis and T.A. Marshall

Northwestern Univ., Evanston, IL, ASCE J. Engr. Mech. Div., 103 (EM4) pp 501-513 (Aug 1977) 5 figs, 20 refs

Key Words: Random vibration, Spectral energy distribution technique, Earthquake response

A closed-form expression for the response power spectral density function is derived for the case of exponentially modulated stationary excitation as an extension of the Heaviside case. A simply analytical expression is obtained for the mean-square response due to broad-band input when the excitation modulation can be expressed as the sum of exponential terms. Examples are presented to graphically compare the response for oscillator parameters typical of structures and two modulations approximating earthquake excitation. Numerical calculation of the first passage probabilities based on the two-state Markov approach permits a comparison of the stationary, Heaviside, and exponential excitation envelopes.

SEISMIC

(Also see Nos. 1752, 1766, 1790, 1834, 1850)

77-1753

Response of Partially Filled Liquid-Storage Circular Cylindrical Tank with or without an Interior Cylindrical Baffle under Seismic Actions Using Finite Element Technique

S.H. Shaaban

Ph.D. Thesis, Univ. of Massachusetts, 237 pp (1977) UM 77-15,121

Key Words: Tanks (containers), Fluid-filled containers, Seismic response, Finite element technique

The structure under consideration is an elastic cylindrical liquid storage tank attached to a rigid base slab. The tank is either empty or filled to an arbitrary depth with an inviscid, incompressible liquid. A finite element analysis is presented, for both tank and liquid, to investigate the free vibration of the coupled system permitting determination of natural frequencies and associated mode shapes. Sanders shell theory is employed to express the strain-displacements relationship in the derivation of the shell finite element. The response of the tank to artificial earthquake excitation is also determined. Similar investigations are performed with the addition of an elastic cylindrical perforated baffle to control the system natural frequencies.

SHOCK

(Also see Nos. 1781, 1789, 1827)

77-1754

Air Blast Measurement Technology

D.C. Sachs and E. Cole

Kaman Sciences Corp., Colorado Springs, CO, Rept. No. K-76-38U(R), DNA-4115F, 204 pp (Sept 1976) AD-A038 321/6GA

Key Words: Air blast, Transducers, Measuring instruments, Shock tube tests, Nuclear weapons effects

Primary objectives of the project are to establish a baseline regarding currently available transducers and measurement technology for the study of air blast phenomena. This project represents an effort toward improvements in existing sensors and measurement practices through understanding and dissemination of information as well as a search for techniques to measure parameters that are being measured with limited success or not at all. The study is focused on measurements of air blast parameters associated with peak overpressures above 140 N/sq. cm. (200 psi) that are related to HE tests and large-scale explosively-driven shock tubes designed to simulate the air blast effects and environment from a nuclear explosion.

77-1755

Structural Response to Simulated Nuclear Overpressure

R.P. Syring, T.G. Swaney, W.D. Pierson, G.M. Campbell, and D.W. Garrison

The Boeing Co., Inst. Environ. Sci., Proc. 23rd Annual Mtg., Los Angeles, CA, pp 324-333 (Apr 25-27, 1977) 7 figs, 4 tables, 4 refs

Sponsored by the Headquarters Defense Nuclear Agency and the Air Force Weapons Lab.

Key Words: Aircraft, Structural elements, Blast resistant design, Nuclear weapons effects

This paper presents a comparison of analytical and experimental results regarding the response of basic structural elements to a simulated nuclear overpressure environment and a uniform externally applied static pressure field. The test specimens, which are representative of elements found in aircraft structure, consist of flat and curved, stiffened and unstiffened panels, skin/frame cylinders, and columns. Included are a wide variety of boundary conditions, failure mechanisms, and construction types. The paper discusses enhancement of the free field shock environment due to interaction with the test specimens, magnification of structural response obtained from comparing response of structure to shock loads versus response to static loads, relationship between structural response characteristics and structural type, test facilities, test techniques, and analysis results obtained from an AFWL computer program that idealizes structure as two dimensional models.

77-1756

Model Study of Dynamic Response of Landing Mat

F.W. Kiefer, V.T. Christiansen, and P.T. Blotter

Utah State Univ., Logan, UT, ASCE J. Engr. Mech. Div., 103 (EM4), pp 659-672 (Aug 1977) 11 figs, 2 tables, 15 refs

Sponsored by the AF Weapons Lab., Kirtland AFB

Key Words: Landing pads, Dynamic response, Landing shock, Mathematical models

A 1/7 scale model is developed that simulates the dynamic response of AM2 landing mat subjected to C-5A aircraft landings. The fundamental variables include length, material stiffness, density, aircraft deceleration and velocity, coefficients of friction, tire pressure, and soil-mat interaction. The model is validated by simulating a buckling failure in prototype AM2 mat at Dyess Air Force Base. Five runway modifications are tested: Restraint by pretensioned bands riveted to the mat surface; diagonal laying pattern; increased friction at the mat-subgrade interface; cleats attached to the underside of the mat; and longitudinal stiffeners.

77-1757

Crashworthiness Engineering of Automobiles and Aircraft: Progress and Promise

R.J. Melosh

MARC Analysis Res. Corp., Palo Alto, CA, J. Aircraft, 14 (7), pp 693-698 (July 1977) 1 table, 102 refs

Key Words: Collision research (automotive), Crash research (aircraft), Crashworthiness

This paper reviews progress made in improving the technological resources of crashworthiness engineering: physical testing developments, analytical simulation techniques, and inventions and design tools. It defines some of the unresolved problems associated with development of design tools by discussing modeling of structures and exteriors. It concludes that physical test technology is well advanced for highway vehicles, and that available mathematical models, principally for structures and bioengineering, are of limited value because of inadequate work in assuring numerical modeling fidelity and strengthening test-analysis correlation, and that significant improvements in crashworthiness of in-use vehicles awaits more design tools.

GENERAL WEAPON

77-1758

Blast from Moving Guns

D.G. Mabey and D.S. Capps

Royal Aircraft Establishment, Bedford, UK, J. Aircraft, 14 (7), pp 687-692 (July 1977) 12 figs, 4 tables, 11 refs

Key Words: Gunfire effects, Weapons effects

To investigate the blast loads from the guns of military aircraft, a 7.62-mm caliber rifle was fired in the RAE 3-ft X 3-ft wind tunnel over the speed range from M=0 to 1.8, and over a wide range of static pressures. The blast wave arrival times and the local static pressure ratios were measured by transducers mounted on an adjacent plate, offset at spacings of 10, 20, and 30 calibers. These measurements generally were well correlated by Smith's theory, both with respect to the variation of speed and pressure. However, downstream of the muzzle, discrepancies between the measurements and the theory increased with speed, particularly when the plate was closest to the gun.

TRANSPORTATION

(Also see Nos. 1743, 1744, 1745, 1746, 1757)

77-1759

A Statistical Theory for Road Traffic Noise Based on the Composition of Component Response Waves and Its Experimental Confirmation

M. Ohta, S. Yamaguchi, and H. Iwashige
Dept. of Electrical Engrg., Hiroshima Univ., Hiroshima, Japan, J. Sound Vib., 52 (4), pp 587-601 (June 22, 1977) 5 figs, 9 refs

Key Words: Traffic noise, Statistical analysis

None of the existing standards, which express the needs of engineers, consider correlation properties of traffic noise. But the correlation properties of traffic noise often seem to have a fundamental importance in certain engineering fields of noise control, such as the design of barriers for sound insulation and the detection of voices in noisy out-of-doors situations. In this paper the correlation properties in the time domain and the frequency characteristics of the sound intensity at an observation point are discussed. The equivalence problem of replacing the several lanes of the road by a representative single lane is also discussed in detail, as an application of the statistical method. Finally, the values obtained from the theoretical expressions for several kinds of correlation functions of lower and higher orders are compared with experimental values, as obtained by use of the digital simulation technique.

PHENOMENOLOGY

COMPOSITE

(Also see No. 1852)

77-1760

The Measurement of Dynamic Young's Modulus in Composite Laminates

Y.F. Cheng
Watervliet Arsenal, NY. Rept. No. WVT-TR-77005, 16 pp (1977)
AD-A038 180/6GA

Key Words: Composite materials, Laminates, Vibration measurement, Measurement techniques, Modulus of elasticity

The suitability of the resonance-free vibration method and the impact method in the measuring of the dynamic Young's modulus in boron aluminium, fibreglass-epoxy and boron-epoxy laminates has been studied. It is concluded that, in the dynamic characterization of fibre-reinforced laminate materials, the resonance-free vibration method is preferable to the impact method.

77-1761

Asymptotic Analysis of the Possibilities of Making Use of Non-Linear Effects in Acoustic-Diagnostics of Layered Media

U. Nigul
Inst. of Cybernetics, Lenin Ave 10, 200104 Tallinn, Estonian S.S.R., USSR, Intl. J. Nonlinear Mech., 12 (3), pp 153-163 (Mar 1977) 4 figs, 1 table, 6 refs

Key Words: Laminates, Diagnostic techniques, Acoustic techniques, Nonlinear response

The asymptotic formulae derived by the author earlier for description of the small nonlinear distortion of the one-dimensional finite pulses in the layered media are used for obtaining the solution of the inverse problems of information extraction on the properties of the layered media from the non-linear distortion of the echo-pulses. It is shown that, when by processing of the echo-pulses on the basis of the linear theory it is possible to establish only the impedance ratios of the layers and the delay-time for each of them, then by processing of the echo-pulses on the basis of the non-linear theory it is, in principle, possible to obtain for each layer the following additional data: the thickness, the velocity of wave propagation, and the coefficient of nonlinearity of material.

DAMPING

(Also see No. 1818)

77-1762

Torsion Damper

J. Kirshenboim and Z. Rigbi
Engr. Matl. Des., 21 (5), pp 45-47 (May 1977) 5 figs

Key Words: Coulomb friction, Dampers

The Rubber and Plastics Research Association (RAPRA) developed and described a damper for linear motion based on the resistance encountered when a loaded rigid cylinder rolls on a rubber layer. Although the Association did foresee the use of a rotary damper in one of its patents, the idea was not developed. Permission of RAPRA was obtained for the developments described in this paper.

ELASTIC

(Also see No. 1760)

77-1763

The Influence of Support Characteristics on the Stability of an Elastic System Subjected to a Circulatory Force

G.L. Anderson
Watervliet Arsenal, NY, Rept. No. WVT-TR-77008, 34 pp (Mar 1977)
AD-A037 929/7GA

Key Words: Elastic foundations, Pendulum, Flutter

The stability of a vertical double pendulum with elastic joints, mounted on a platform whose horizontal motion is constrained by an elastic spring and subjected to circulatory force, is examined. Attention is focused on the determination of the critical loads of divergence and flutter as functions of the platform mass and spring stiffness parameters, which characterize the effects of the support on the stability of the double pendulum. The frequency equation is derived, and several typical eigencurves are plotted in the load-frequency plane. Stability maps in the load-tangency coefficient plane indicate the existence of regions of stability, divergence and flutter. Certain boundary curves of these regions are strongly dependent upon the values of the parameters that characterize the support.

FLUID

(Also see Nos. 1802, 1813, 1814, 1815, 1847, 1866)

77-1764

The Stability of an Isolated Rectangular Surface Embedded in Uniform Subsonic Flow

C.H. Ellen
Dept. of Math., Imperial College of Science and Tech., London, UK, J. Appl. Mech., Trans. ASME, 44 (2), pp 201-206 (June 1977) 3 figs, 11 refs

Key Words: Stability, Fluid-induced excitation

This paper examines the stability of a rectangular surface lying in isolation in an inviscid fluid in uniform subsonic motion when the surface, in its undeformed state, lies in a plane with its edges aligned parallel and perpendicular to the flow direction. The problem is formulated in the form of an integral equation which is solved approximately using the one-term Galerkin method so that expressions for the stability parameter are determined in the form of asymptotic series for the high and low aspect ratio limits. Surfaces supported on all edges as well as those whose edges are only partially supported are investigated. The results are compared with those for an infinite array of panels and an isolated panel replacing part of a rigid surface.

77-1765

Optimization of Active Control Systems to Suppress Flutter and Minimize Turbulence Response

C.S. Rudisill
Dept. of Mech. Engrg., Clemson Univ., Clemson, SC, AIAA J., 15 (6), pp 779-785 (June 1977) 3 figs, 3 tables, 12 refs

Key Words: Control equipment, Flutter, Turbulence

A method for optimizing an active control system which will suppress flutter and minimize the response of a lifting surface to atmospheric turbulence is presented. A mathematical search method is developed which will find a control law which will cause an active control system to flutter at a specified freestream velocity, air density, and Mach number. With the flutter velocity of the system held constant, the control law is then modified in such a way that the peak output power spectral density function of the angular response of a lifting surface (as a result of atmospheric turbulence) is minimized for a specified flight velocity which is less than the flutter velocity. The von Karman generalized power spectrum for the transverse components of turbulence is used to find the value of the output power spectral density function of the response. The optimization procedure is used in an example problem to increase the flutter velocity and minimize the turbulence response of a simplified delta-wing model which has leading and trailing edge control surfaces.

SOIL

77-1766

Site-Dependent Seismic Response Spectra for Soft Sites

J.S. Dalal, H.B. Seed, and D.-L. Wu
Struct. Analysis Group, United Engineers and Constructors, Inc., Philadelphia, PA, ASCE J. Power Div., 103 (PO1), pp 15-25 (July 1977) 12 figs, 1 table, 12 refs

Key Words: Seismic response, Soils

Different approaches are presented for developing site-dependent response spectra for soft sites where recorded historical motions are not available Seismic response analyses

were performed for a given site with an appropriate input motion to determine the site-frequency characteristics in terms of surface response spectra. These results were combined with statistically derived response spectra from historic motions recorded at sites with similar soil characteristics to determine site-dependent response spectra. In addition, site responses were computed in terms of surface response spectra for appropriately selected 12 historic earthquake motions. Response spectrum derived by statistical analysis of these results was compared with the site-dependent response spectrum. Pertinent results and conclusions from the study are presented herein along with the site-dependent spectra derived.

VISCOELASTIC

77-1767
Dynamic Mechanical Response of Some Polymers
S. Shih
Ph.D. Thesis, Brown Univ., 152 pp (1976)
UM 77-14,189

Key Words: Polymers, Elastomers, Pulse excitation

An experimental technique for the observation of mechanical pulses propagating along stretched filaments of rubber, polyethylene, and nylon is described. The pulses were produced either by suddenly volatilizing a piece of piano wire, which was used to maintain the additional stretch of the specimen, or by firing a gas gun against a small clamp on the pre-stretched specimen. The particle velocity of the specimen was measured by a magnetic transducer. This technique affords an extremely convenient method for studying the propagation of mechanical pulses and observing the formation and decay of shock waves. Changing the initial conditions of the experiments provides information which helps to elucidate the nature of the various observed phenomena.

77-1768
Vibration Analysis of Viscoelastic Bodies with Small Loss Tangents
Z. Hashin
Dept. of Solid Mech., Materials and Struc., School of Engrg., Tel-Aviv Univ., Tel-Aviv, Israel, Intl. J. Solids Struc., 13 (6), pp 549-559 (June 1977) 6 refs

Key Words: Viscoelastic media

The correspondence principle for vibrations of viscoelastic bodies is specialized to the case of small loss tangents, resulting in considerable simplification: Analytical evaluation of oscillatory fields is greatly simplified; peak frequencies and peak amplitudes under forced vibrations can be simply and directly determined; numerical solution of viscoelastic vibration problems becomes no more complicated than that of elastic problems. Similar simplifications result for computation of real and imaginary parts of effective complex moduli of composite materials.

EXPERIMENTATION

DIAGNOSTICS
(Also see No. 1761)

77-1769
Monitoring the Complex Vibration Characteristics of Bladed Machinery
J.S. Mitchell
Endevco, San Juan Capistrano, CA., Power, 121 (7), pp 38-42 (July 1977) 9 figs

Key Words: Diagnostic techniques, Blades, Compressor blades, Turbine blades

The details on systems that should be considered for monitoring the health of axial compressors, steam and gas turbines, gears, motors and generators are presented.

77-1770
Bearing Testing Method Checks Shock Energy
Power Trans. Des., 17 (7), pp 38-39 (July 1977)

Key Words: Bearings, Diagnostic techniques, Shock pulse method

In the article the Shock Pulse Method is described which measures the impact velocity of a mechanical shock pulse, initiated, for example, when a ball in a bearing passes an irregularity. A peizoelectric accelerometer transducer, along with a tuned circuit, measures the instantaneous compression wave, when first particles of both bodies come in contact. Instruments include portable bearing testers that provide operating condition directly; a more comprehensive visual indicating instrument; and a continuous monitoring system.

77-1771
Ball Bearing Machinery Diagnostics (Diagnose von Wälzlagern in Maschinen)
R. Ullmann

Ingenieurbüro für vorbeugende Instandhaltung Dresden, Maschinenbautechnik, 26 (3), pp 116-120 (Mar 1977) 8 figs, 3 tables, 18 refs
(In German)

Key Words: Diagnostic techniques, Ball bearings

A diagnostic technique for the determination of a ball bearing race failure is described. All experiments are based on the evaluation of the running quality of the bearing. It was determined that the simplest measurement is the measurement of structure-borne noise. The design of an electronic measuring instrument based on the structure-borne sound wave analysis is outlined.

77-1772

Development of Diagnostic Test Equipment for Inspecting Antifriction Bearings

F.N. Kusenberger and J.R. Barton
Southwest Research Inst., San Antonio, TX, Rept. No. AMMRC-CTR-77-13, 78 pp (Mar 1977)
AD-A038 980/9GA

Key Words: Diagnostic instrumentation, Nondestructive testing, Antifriction bearings, Computer-aided techniques

Historical background summarizing the need for improved nondestructive inspection of antifriction bearings is presented. A state-of-the-art computer supervised semi-automated bearing inspection system is described which incorporates the magnetic perturbation method for surface and subsurface flaw detection and the Barkhausen noise method for assessing the state of stress in the active regions of the raceway. The capabilities and features of the inspection system are presented along with verification test data comparing results from a preliminary prototype unit and a prototype system. Other inspection data from used and refurbished bearing races are summarized. Metallurgical sectioning and endurance test results are included which verify the flaw detection capability of the system and establish the capability of the system to detect subsurface flaws which cause failure. Highlights of system development are also briefly summarized.

77-1773

Computer Aided Failure Analysis

R.S. Smith
Bendix Corp., Kansas City, MO., Rept. No. BDX-613-1522-Rev, 16 pp (Sept 1976) refs
N77-21456

Key Words: Failure analysis, Diagnostic techniques, Electronic instrumentation, Computer-aided techniques

A computer aided failure analysis system (CAFA) is being developed to troubleshoot defects in electronic assemblies. Through a question and answer procedure, the system provides step by step directions to guide a troubleshooter to the fault location. A diagnostic logic routine has been established for one product, and the software necessary to store and implement the routine has been developed. The time share operation (TSO) terminal has been installed, and the completed system has been found to be functional. A visual aid catalog has been developed for the current CAFA routine.

77-1774

Computation of Changing Variances

S. Braun
Faculty of Mech. Engrg., Technion-Israel Inst. of Tech., Haifa, Israel, J. Sound Vib., 52 (3), pp 433-439 (June 8, 1977) 6 figs, 1 table, 6 refs

Key Words: Vibration signatures, Testing techniques, Diagnostic techniques

A method suitable for the processing of repetitive vibration signatures of unstable character has been found valuable in various applications. As it is based on a combination of time domain averaging of the signal and its variance, computational methods suitable for on-line or time-varying variances are of interest. Various schemes for such computations are suggested, differing mainly in the kind of averaging filter used.

EQUIPMENT

(Also see No. 1780)

77-1775

Electro-Hydraulic Shaking Machine (Report 3, Influences of Oscillatory Test Structure and Their Compensation)

H. Hirai and A. Matsuzaki
Mech. Engrg. Res. Lab., Hitachi Ltd., Japan, Bull. JSME, 20 (143), pp 561-567 (May 1977) 13 figs, 4 refs

Key Words: Vibrators (machinery), Shakers

In this paper, control characteristics of a shaking machine under the influences of an oscillatory test structure are discussed. In addition, it is shown that the influences of the oscillatory test structure can be compensated by feeding back the relative acceleration, velocity and displacement between the shaking table and the test structure with proper gain rate. The effect of this compensation method is confirmed experimentally with a shaking machine which has a one ton table.

77-1776

Low Cost Mechanical Random Shakers

D. Nolan and W. Cox

L.A.B. Mfg. Corp., Inst. Environ. Sci., Proc. 23rd Annual Mtg., Los Angeles, CA, pp 238-241 (Apr 25-27, 1977) 3 figs, 4 refs

Key Words: Shakers, Test equipment

Correlation of military equipment field failures with laboratory predictions and "Agree" production testing is unsatisfactory. Revision "C" of Mil Std 781 is pending, with likely callout of random vibration, rather than single frequency sine in the narrow range of 20 to 60 Hz. Cost impact of implementing this with electromagnetic shakers would be astronomical. Tradeoffs and performance of "BRN" shakers, at near identical costs to existing "Agree" shakers is included.

77-1777

Mechanical and Pneumatic Shakers for Military Standard 781C

W. Tustin

Tustin Inst. of Tech., Santa Barbara, CA., Inst. Environ. Sci., Proc. 23rd Annual Mtg., Los Angeles, CA., pp 242-248 (Apr 25-27, 1977) 13 figs, 1 table, 11 refs

Key Words: Shakers, Test equipment, Standards & codes

In this paper, environmental testing aspects of Mil Std 781 C are investigated. The author treats vibration tests that can be accomplished by means of relatively inexpensive but highly reliable mechanical and pneumatic shakers. Thus he mainly considers tests on fixed ground and shipboard equipment which many laboratories have long performed on mechanical shakers. He also investigates tests on avionic equipment for jet aircraft, which can possibly be met by mechanical and pneumatic shakers.

FACILITIES

77-1778

Time Series Analysis in Flight Flutter Testing at the Air Force Flight Test Center: Concepts and Results

R.W. Lenz and B. McKeever

Air Force Flight Test Center, Edwards AFB, CA, In: NASA Langley Res. Center Flutter Testing Tech., pp 287-318 (1976) refs (N77-21022)
N77-21033

Key Words: Test facilities, Flutter, Flight tests, Modal analysis, Computer programs

The Air Force Flight Test Center (AFFTC) flight flutter facility is described. Concepts of using a minicomputer-based time series analyzer and a modal analysis software package for flight flutter testing are examined. The results of several evaluations of the software package are given. The reasons for employing a minimum phase concept in analyzing response only signals are discussed. The use of a Laplace algorithm is shown to be effective for the modal analysis of time histories in flutter testing. Sample results from models and flight tests are provided. The limitations inherent in time series analysis methods are discussed, and the need for effective noise reduction techniques is noted. The use of digital time series analysis techniques in flutter testing is shown to be fast, accurate, and cost effective.

INSTRUMENTATION

77-1779

The Effect of an Air Flow on a Single Side Branch Helmholtz Resonator in a Circular Duct

J.S. Anderson

Dept. of Mech. Engrg., The City Univ., London EC1V 4PB, UK, J. Sound Vib., 52 (3), pp 423-431 (June 8, 1977) 7 figs, 13 refs

Key Words: Natural frequencies, Helmholtz resonators, Ducts

A single side branch Helmholtz resonator has been tested in a circular duct in which both sound and an air flow could be passed in the same direction. The sound input was broad band and the transfer function across the resonator was determined by using two microphones and a cross-correlation analysis technique in which the broad band sound input was cross-correlated with each microphone signal in turn. The fundamental resonant frequency, as obtained from the transfer function of the resonator, was found to increase with increasing flow velocities in the duct. It was possible for the entire mass end correction of the orifice of the resonator to be eliminated by the flow. The higher natural frequencies of the resonator were not affected as much by the air flow.

77-1780

A Torsion Pendulum for Measurement of Damping Capacity and Related Phenomena

D.W. James, J.D. Stott, and B. Emery

Scientific Services Dept., Central Electricity Generating Board, Portishead, Avon, UK, J. Test Eval., 5 (4), pp 270-277 (July 1977) 8 figs, 7 refs

Key Words: Internal damping, Material damping, Test instrumentation

Investigation of the damping mechanisms of metals and alloys requires that damping capacity measurements be made over wide stress, frequency, and temperature ranges. The torsion pendulum described herein fulfills these requirements in all respects except that it has a limited (low) frequency range. This versatile apparatus also allows creep, fatigue, stress relaxation, elastic after-effect, static and dynamic moduli and hysteresis curves to be made at temperature and in vacuo. It is possible to superimpose a magnetic field on the specimen during these measurements. The specimen may also be heat treated or plastically deformed in situ. An electronic data processing system has been designed to calculate and plot material damping characteristics during a free decay test. The damping characteristics are thus obtained more quickly and with greater accuracy than was previously possible.

77-1781

Recording System for Blast Noise Measurement

D.E. Siskind and V.J. Stachura

U.S. Dept. of the Interior, Twin Cities, MN., S/V, Sound Vib., 11 (6), pp 20-23 (June 1977) 7 figs

Key Words: Recording instruments, Vibration recording, Mines (excavations), Shock response

A multichannel recording system has been built by the Bureau of Mines for an investigation of impulsive noise and vibration produced by blasting in surface mines and quarries. Current application of the system includes the monitoring of both noise overpressures and vibrations inside and outside residential structures in order to assess damage and annoyance potential, structural response, and the comparative effects of ground and airborne blast vibrations.

77-1782

Safety Devices and Chassis Used in Multi and Single Exciter Vibration Testing

R. Lowenadler

Perkin-Elmer Corp., Norwalk, CT., Inst. Environ. Sci., Proc., 23rd Annual Mtg., Los Angeles, CA, pp 344-350 (Apr 25-27, 1977) 15 figs

Key Words: Vibration tests, Test instrumentation

With the advent of large specimen and multiexciter testing, normal vibration procedures and techniques cannot be used to maintain test item safety. Devices used to prevent test item over/under testing due to operator error and equipment malfunction are available. Among devices used for this purpose, the author describes the Closed Loop Chassis, a safety device permitting the set up of automatic vibration control off-line; the Auxiliary Level Control with a 40 db range for testing large specimens; Cross Dump System to prevent an amplifier from shutdown or "dump" during a test; a remote shutdown; a Sine/Random Signal Vibration Protector allowing the operator to set over and under test limits within a certain dynamic range; the Real Time Analyzer; and the Waterflow Monitor/Interlock.

77-1783

Description and Elaboration of a Dynamic Ellipsometer. Application to Dynamic Photo-Elastic Analysis (Description et Elaboration d'un Ellipsometre Dynamique. Application a la Photoelasticimetrie Dynamique)

M. Ferre

Ecole Nationale Superieure de Techniques Avancees, Paris, France, Rept. No. Rept-073, 84 pp (July 1976) refs

(In French)

N77-21478

Key Words: Test instrumentation, Photoelastic analysis, Shock tests, Vibration tests

A new type of dynamic ellipsometer based on representation forms of light and optical operator algebra is described. The application of the ellipsometer to dynamic photoelastic analysis is illustrated for shock and vibration tests.

PROCEDURES

77-1784

Investigation of Aeroelastic Stability Phenomena of a Helicopter by In-Flight Shake Test

W.-L. Miao, T. Edwards, and D.E. Brandt

Boeing Vertol Co., Philadelphia, PA., In: NASA Langley Res. Center Flutter Testing Tech., pp 473-500 (1976) refs (N77-21022)

N77-21040

Key Words: Helicopters, Stability, Testing techniques

The analytical capability of the helicopter stability program is discussed. The parameters which are found to be critical to the air resonance characteristics of the soft in-plane hingeless rotor systems are detailed. A summary of two model test programs, a 1/13.8 Froude-scaled BO-105 model and a 1.67 meter (5.5 foot) diameter Froude-scaled YUH-61A model, are presented with emphasis on the selection of the final parameters which were incorporated in the full-scale YUH-61A helicopter. Model test data for this configuration are shown. The actual test results of the YUH-61A air resonance

in-flight shake test stability are presented. Included are a concise description of the test setup, which employs the Grumman Automated Telemetry System (ATS), the test technqiue for recording in-flight stability, and the test procedure used to demonstrate favorable stability characteristics with no in-plane damping augmentation (lag damper removed). The data illustrating the stability trend of air resonance with forward speed and the stability trend of ground resonance for percent airborne are presented.

77-1785
Wind Tunnel Investigation of Supersonic Wing-Tail Flutter

L.J. Huttsell, T.E. Noll, and D.E. Holsapple
Air Force Flight Dynamics Lab, Wright-Patterson AFB, OH 45433, In: NASA Langley Res. Center Flutter Testing Tech., pp 193-212 (1976) refs (N77-21022)
N77-21030

Key Words: Wind tunnel tests, Flutter, Aircraft wings, Random Decrement technique, Spectral energy distribution technique

A flutter model, consisting of a wing, horizontal tail, and splitter plate/fuselage mechanism, was tested in a 4-foot transonic tunnel in the Mach number range 1.1 to 1.3. Two types of flutter were encountered during the testing: a wing-tail flutter bending-torsion flutter mode. Recorded model test data were digitized for a power spectral density (PSD) analysis and Random Decrement (Randomdec) analysis. Comparisons between the frequency and damping obtained from the PSD plots and the Randomdec signatures agreed very well. A limited flutter analysis was conducted using a Mach box unsteady aerodynamics method which accounted for interference and airfoil thickness. Analytical comparisons with experimental flutter speeds agreed well.

77-1786
F-15 Flight Flutter Test Program

H. Katz, G.F. Foppe, and D.T. Grossman
Lockheed Aircraft Corp., Burbank, CA., In: NASA Langley Res. Center Flutter Testing Tech., pp 413-432 (1976) refs (N77-21022)
N77-21037

Key Words: Flutter, Flight tests, Wind tunnel tests, Aircraft vibration

The modes to be observed during the F-15 flight flutter test program were selected on the basis of the results of analytical studies, wind tunnel tests, and ground vibration tests. The modes (both symmetrical and antisymmetrical) tracked on this basis were: fin first bending, fin torsion, fin tip roll, stabilator bending, stabilator pitch, boom lateral bending, boom torsion, boom vertical bending, wing first bending, wing second bending, wing first torsion, outer wing torsion, and aileron rotation. Data obtained for these various modes were evaluated in terms of damping versus airspeed at 1525 m (5000 ft), damping versus altitude at the cross-section Mach numbers (to extrapolate to the damping value to be expected at sea level), and flutter boundaries on the basis of flutter margin of various modal pairs representing potential flutter mechanisms. Results of these evaluations are summarized in terms of minimum predicted flutter margin for the various mechanisms.

77-1787
YF-16 Flight Flutter Test Procedures

W.J. Brignac, H.B. Ness, M.K. Johnson, and L.M. Smith
General Dynamics, Fort Worth, TX., In: NASA Langley Res. Center Flutter Testing Tech., pp 433-456 (1976) refs (N77-21022)
N77-21038

Key Words: Aircraft vibration, Flutter, Flight tests, Random Decrement technique

The Random Decrement technique (Randomdec) was incorporated in procedures for flight testing of the YF-16 lightweight fighter prototype. Damping values obtained substantiate the adequacy of the flutter margin of safety. To confirm the structural modes which were being excited, a spectral analysis of each channel was performed using the AFFTC time/data 1923/50 time series analyzer. Inflight test procedure included the careful monitoring of strip charts, three axis pulses, rolls, and pullups.

77-1788
The Application of Digital Computers to Near-Real-Time Processing of Flutter Test Data

S.R. Hurley
Lockheed-California Co., Burbank, CA., In: NASA Langley Res. Center Flutter Testing Tech., pp 377-394 (1976) refs (N77-21022)
N77-21035

Key Words: Flutter, Flight tests, Testing techniques, Computer programs

Procedures used in monitoring, analyzing, and displaying flight and ground flutter test data were presented. These procedures include three digital computer programs developed to process structural response data in near real time. Qualitative and quantitative modal stability data were derived

from time history response data resulting from rapid sinusoidal frequency sweep forcing functions, tuned-mode quick stops, and pilot induced control pulses. The techniques were applied to both fixed and rotary wing aircraft, during flight, whirl tower rotor systems tests, and wind tunnel flutter model tests. An hydraulically driven oscillatory aerodynamic vane excitation system utilized during the flight flutter test programs accomplished during Lockheed L-1011 and S-3A development is described.

SCALING AND MODELING

(See No. 1840)

TECHNIQUES

(Also see Nos. 1732, 1733, 1754, 1760, 1778, 1779, 1854, 1876)

77-1789

Ambient and Forced Vibration Analysis of Full-Scale Structures

C.A. Kircher

Ph.D. Thesis, Stanford Univ., 254 pp (1977)
UM 77-12,654

Key Words: Vibration measurement, Measurement techniques, Computer-aided techniques, Multistory buildings, Shock response

Vibration analysis techniques are used to examine the dynamic characteristics of full scale structures. Specifically, the results of a study of six similar high-rise apartment buildings and a study of two 230 KV air blast circuit breakers are presented. A portable mini-computer system has been used to perform on-site acceleration measurements and corresponding analyses (e.g., calculation of power spectra). This mini-computer system is programmed for data acquisition and discrete Fourier analysis. Forced vibration excitation of the breaker structures is accomplished by a portable electromagnetic shaker unit. The forced vibration input to the structures include white noise as well as sinusoidal excitations.

77-1790

Inertial Excitation Systems

G.K. Hobbs

MTS Systems Corp., Inst. Environ. Sci., Proc., 23rd Annual Mtg., Los Angeles, CA., pp 382-385 (Apr 25-27, 1977) 3 figs, 9 refs

Key Words: Vibration excitation, Testing techniques, Seismic response, Buildings, Bridges, Dams

This paper reviews some applications of inertial excitation of buildings, bridges and dams. Some small portable systems are discussed and then a two mass electrohydraulic system in which each mass of 272,400 kg (600,000 lbs.) moves 4.1m (162 in.) is described.

77-1791

Some Experience Using Subcritical Response Methods in Wind-Tunnel Flutter Model Studies

J.T. Foughner, Jr.
Langley Res. Center, NASA, Langley Station, VA.,
In: NASA Langley Res. Center Flutter Testing Tech., pp 181-192 (1976) (N77-21022)
N77-21029

Key Words: Wind tunnel tests, Flutter

Experiences obtained with four methods of predicting flutter of wind-tunnel models from subcritical response data are described. The four methods are: co/quad, randomdec, power spectra density, and the peak-hold spectrum. Model excitation techniques included both forced (sinusoidal sweep) and random (tunnel turbulence). These methods were successfully used to measure the frequency and damping (or an inverse response amplitude proportional to the damping) in the predominant flutter modes. Implementation and application of each method are discussed. Some results and comparisons between methods are presented.

77-1792

Flutter Testing Techniques

Langley Res. Center, NASA, Langley Station, VA., Rept. No. NASA-SP-415, 483 pp (1976)
N77-21022

Key Words: Flutter, Testing techniques

Developments in methodology and data analysis techniques for flutter testing in flight and on the ground are discussed.

77-1793

Determination of Subcritical Damping by Moving-Block/Randomdec Applications

C.E. Hammond and R.V. Doggett, Jr.
Army Air Mobility R&D Lab., Langley, VA., In: NASA Langley Res. Center Flutter Testing Tech., pp 59-76 (1976) (N77-21022)
N77-21025

Key Words: Flight vehicles, Testing techniques, Flutter, Helicopter rotors, Random Decrement technique, Moving block technique

Two techniques are described which allow the determination of subcritical dampings and frequencies during aeroelastic testing of flight vehicles. The moving-block technique is shown to have the advantage of being able to provide damping and frequency information for each mode which might be present in a signal trace, but it has the disadvantage of requiring that the structure be excited transiently. The randomdec technique requires only random turbulence for excitation, but the randomdec signature is difficult to analyze when more than one mode is present. It is shown that by using the moving-block technique to analyze the randomdec signatures, the best features of both methods are gained. Examples are presented illustrating the direct application of the moving-block method to model helicopter rotor testing and application of the combined moving-block/randomdec method to flutter studies of two fixed-wing models.

77-1794

Transient Excitation and Data Processing Techniques Employing the Fast Fourier Transform for Aeroelastic Testing

W.P. Jennings, N.L. Olsen, and M.J. Walter
Boeing Commercial Airplane Co., Seattle, WA., In: NASA Langley Res. Center Flutter Testing Tech., pp 77-114 (1976) (N77-21022)
N77-21026

Key Words: Data processing, Transient excitation, Aircraft vibration, Flutter, Fast Fourier Transform, Wind tunnel tests, Flight tests

The development of testing techniques useful in airplane ground resonance testing, wind tunnel aeroelastic model testing, and airplane flight flutter testing is presented. Included is the consideration of impulsive excitation, steady-state sinusoidal excitation, and random and pseudorandom excitation. Reasons for the selection of fast sine sweeps for transient excitation are given. The use of a fast fourier transform dynamic analyzer is presented, together with a curve fitting data process in the Laplace domain to experimentally evaluate values of generalized mass, model frequencies, dampings, and mode shapes. The effects of poor signal to noise ratios due to turbulence creating data variance are discussed. Data manipulation techniques used to overcome variance problems are also included. The experience is described that was gained by using these techniques since the early stages of the SST program. Data measured during 747 flight flutter tests, and SST, YC-14, and 727 empennage flutter model tests are included.

77-1795

On Identifying Frequencies and Damping in Subcritical Flutter Testing

J.C. Houbolt
Aeronautical Res. Associates of Princeton, Inc., NJ, In: NASA Langley Res. Center Flutter Testing Tech., pp 1-42 (1976) (N77-21022)
N77-21023

Key Words: Flutter, Aircraft, Wind tunnel tests

Various procedures that might be used in evaluating system response characteristics as involved in subcritical flight and wind-tunnel flutter testing of aircraft are reviewed with emphasis on the means for eliminating or minimizing the contamination effects produced by an unknown noise in the input. Results of a procedure developed for identifying modal frequency and damping values, and a possible way for making a detailed evaluation of system parameters, are also given.

77-1796

The Application of Recent Techniques in Flight Flutter Testing

M.A. Abla
Gates Learjet Corp., Denver, CO., In: NASA Langley Res. Center Flutter Testing Tech., pp 395-412 (1976) refs (N77-21022)
N77-21036

Key Words: Flutter, Aircraft vibration, Flight tests, Testing techniques, Computer programs, Data porcessing, Random Decrement technique, Autocorrelation method

The relative merits of sinusoidal excitation versus random atmospheric turbulence was investigated. The randomdec and autocorrelation methods were used to analyze data from a Learjet flight test. A parameter identification digital program, using least squares approach, was developed to determine the aeroelastic characteristics of a two mode system. The flight test program, computer program, and data reduction procedure is presented. Final results of the two modes of excitation obtained by Randomdec method are discussed.

77-1797

Flight Flutter Testing Technology at Grumman

H.J. Perangelo and F.W. Milordi
Grumman Data Systems Corp., Bethpage, NY, In: NASA Langley Res. Center Flutter Testing Tech., pp 319-376 (1976) refs (N77-21022)
N77-21034

Key Words: Flutter, Testing techniques, Computer programs

Analysis techniques used in the automated telemetry station (ATS) for on line data reduction are encompassed in a broad range of software programs. Concepts that form the basis

for the algorithms used are mathematically described. The control the user has in interfacing with various on line programs is discussed. The various programs are applied to an analysis of flight data which includes unimodal and bimodal response signals excited via a swept frequency shaker and/or random aerodynamic forces. A nonlinear response error modeling analysis approach is described. Preliminary results in the analysis of a hard spring nonlinear resonant system are also included.

77-1798

Correlation with Flight of Some Aeroelastic Model Studies in the NASA Langley Transonic Dynamics Tunnel

W.H. Reed, III

Langley Res. Center, NASA, Langley Station, VA., In: NASA Langley Res. Center Flutter Testing Tech., pp 243-262 (1976) refs (N77-21022)
N77-21032

Key Words: Wind tunnel tests, Test facilities, Testing techniques, Flutter

The NASA Langley transonic dynamics tunnel, which has a variable density Freon-12 (or air) test medium, was designed specifically for the study of dynamics and aeroelastic problems of aerospace vehicles. During the 15 years of operation of this facility, there have been various opportunities to compare wind tunnel and flight test results. Some of these opportunities arise from routine flight checks of the prototypes; others, from carefully designed comparative wind-tunnel and flight experiments. Such data obtained from various published and unpublished sources are presented. The topics covered are: gust and buffet response, control surface effectiveness, flutter, and active control of aeroelastic effects. Some benefits and shortcomings of Freon-12 as a test medium are also discussed.

HOLOGRAPHY

77-1799

Time-Averaged Holography for the Study of Three-Dimensional Vibrations

R. Tonin and D.A. Bies

Dept. of Mech. Engrg., Univ. of Adelaide, Adelaide, South Australia 5000, J. Sound Vib., 52 (3), pp 315-323 (June 8, 1977) 6 figs, 9 refs

Key Words: Holographic techniques, Interferometers, Cylinders, Three-dimensional problems, Loves shell theory

The general theory of time-averaged holographic interferometry has been analytically extended to take account of possible motion of the surface under investigation in three dimensions but in simple harmonic motion at a single frequency. The argument of the characteristic function is replaced with an expression which includes the effects of motion in orthogonal directions as well as the directions of illumination and observation. The amended characteristic function formula is used to calculate the radial and tangential components of a vibrating cylinder from several time-averaged holograms. The components thus calculated agree well with theoretical predictions for the cylinder Love mode. Thus the problem of the strange shift in amplitude plots previously reported when holograms from different angles were taken of vibrating curved surfaces is resolved.

COMPONENTS

BEAMS, STRINGS, RODS, BARS

(Also see Nos. 1740, 1822, 1873)

77-1800

Stress Measurement in a Bar Deformed Dynamically to Plastic Range

T. Hayashi, Y. Fujimura, and H. Yamamura

Faculty of Engrg. Science, Osaka Univ., Japan, Bull. JSME, 20 (143), pp 534-538 (May 1977) 9 figs, 4 refs

Key Words: Bars, Dynamic tests, Dynamic plasticity

A simple method is presented for measuring dynamic stresses in a bar under impact loading. This method is based on the fact that in a bar under one-dimensional axial stress, there is a singular direction along which plastic strain vanishes, and by measuring the strain in this direction, the axial stress can be obtained. According to the present method, the stress and strain of the plastic wave along a bar with uniform cross section were observed separately.

77-1801

In-Plane Vibration of Viscoelastic Circular Rod with Consideration of Shearing Deformation and Rotatory Inertia

K. Nagaya and Y. Hirano

Faculty of Engrg., Yamagata Univ., Yonezawa, Japan, Bull. JSME, 20 (143), pp 539-547 (May 1977) 11 figs, 13 refs

Key Words: Rods, Rotatory inertia effects, Transverse shear deformation effects, Viscoelastic media

This paper discusses the problem of in-plane vibrations of a viscoelastic circular rod under the consideration of rotatory inertia and shearing deformation. A three-element viscoelastic model is adopted in the analysis, and the solution for the viscoelastic rod is obtained from the correspondence principle by applying the Laplace transform to the constitutive equation for the viscoelastic materials and the equation of motion for the elastic rod developed from the improved theory. The results obtained are compared with those for the elementary theory which are obtained by neglecting the effects of the shear and the rotatory inertia in this study.

77-1802

Environmental Effects on the Natural Frequencies of Rod-Shaped Structural Elements (Beeinflussung der Eigenfrequenzen stabartiger Bauteile durch Umgebungsmedien)

D. Albrecht and G. Tschirner

Ingenieurhochschule Zittau, Sektion Kraftwerksanlagen und Energieumwandlung, Maschinenbautechnik, 26 (4), pp 158-160 (Apr 1977) 7 figs, 4 refs

Key Words: Rods, Structural elements, Fluid-induced excitation, Natural frequencies, Piping systems, Heat exchangers

In the paper the effect of a stationary, variable-viscosity medium on the natural frequencies of rod-shaped structural elements of circular or rectangular cross section is investigated.

77-1803

Equilibrium and Stability of a Circularly Towed Cable Subject to Aerodynamic Drag

J.J. Russell and W.J. Anderson

U.S. Air Force Academy, Colorado Springs, CO., J. Aircraft, 14 (7), pp 680-686 (July 1977) 6 figs, 12 refs

Key Words: Cables (strings), Towed bodies, Finite element technique, Stability

The finite-element method is used to study the equilibrium and stability of an elastic cable whose upper end is towed in a horizontal circular path at a constant angular velocity. Fluid drag is assumed to be composed of tangential and normal components, which are proportional to the tangential and normal velocity components squared, respectively. The problem includes strong geometric nonlinearities and is nonconservative, thereby admitting both static and dynamic instabilities. Equilibrium equations for a cable element including elastogeometric, centripetal, and aerodynamic stiffness matrices are developed in terms of problem parameters and a shape function. All geometric nonlinearities are retained, but small elongations are assumed. The resulting nonlinear algebraic equations are solved using a Newton-Raphson procedure. The stability of an equilibrium position is determined by perturbing the nonlinear equations of motion and calculating the eigenvalues of the resulting linearized dynamic equations. Results indicate multivalued solutions, the number depending on the rotational frequency and tow radius. Both static "jump"-type and dynamic instabilities are found.

77-1804

Finite Element Analysis of Nonlinear Elasto-Plastic-Slack Cable Networks

D.C.-C. Ma

Ph.D. Thesis, Illinois Inst. of Tech., 82 pp (1976) UM 77-13,751

Key Words: Cables (ropes), Geometric effects, Finite element technique

The purpose of this study is to present a numerical procedure for determining the dynamic response of cable system which includes both nonlinear goemetry and material effects. These effects include cases of elastic, plastic and slack. Finite element analogoues are used as the basis for numerical modeling for the spatial behavior. The Newmark β-method is used as the basis for the numerical integration for the temporal behavior. Numerical study of single cable, two-dimensional and three-dimensional cable systems are included.

BEARINGS

(Also see Nos. 1770, 1771, 1772)

77-1805

A Study of High Speed Hydrostatic Bearings (Part 1. Theoretical Analysis of Static and Dynamic Characteristics of Hybrid Plain Journal Bearings)

A. Ichikawa

Central Research Lab., Mitsubishi Electric Corp., Amagasaki, Hyogo, Japan, Bull. JSME, 20 (143), pp 652-660 (May 1977) 13 figs, 5 refs

Key Words: Journal bearings, Hydrostatic bearings, Dynamic properties

This paper presents a theoretical analysis of a hybrid plain journal bearing with many capillary-restrictors for high speed and heavy load.

77-1806

Experimental Determination of the Damping Coefficient of a Double-Row Cylindrical Roller Bearing (Experimentelle Ermittlung der Dämpfungskonstante eines doppelreihigen Zylinderrollenlagers)

W. Klepzig

Ingeneiurhochschule Zwickau, Sektion Technologie der mvl, z.Z. Hochschule Stankin, Moscow, USSR, Maschinenbautechnik, 26 (3), pp 112-115 (Mar 1977) 10 figs, 9 refs

(In German)

Key Words: Damping coefficients, Bearings, Machine tools

The fact that damping in spindle-bearing systems is caused mainly by radial bearings was tested experimentally by determining bearing damping coefficients of a double row cylindrical roller bearing. The coefficients obtained were compared with bearing damping coefficients, required to reach the usual degree of damping of main spindles, when only the bearings are acting as dampers.

BLADES

(Also see No. 1769)

77-1807

Linearized Blade Row Compression Component Model. Stability and Frequency Response Analysis of a J85-3 Compressor

W.A. Tesch, R.H. Moszee, and W.G. Steenken

Aircraft Engine Group, General Electric Co., Cincinnati, OH, Rept. No. NASA-CR-135162, 88 pp (Sept 1976) refs

N77-21089

Key Words: Blades, Compressor blades, Stability

Stability and frequency response analysis techniques developed on NASA programs were applied to a dynamic blade row compression component stability model to provide a more economic approach to surge line and frequency response determination than that provided by time-dependent methods.

77-1808

A 100-kW Wind Turbine Blade Dynamics Analysis, Weight-Balance, and Structural Test Results. Final Report

W.D. Anderson

Lockheed-California Co., Burbank, CA., Rept. No. NASA-CR-134957, 102 pp (June 1975) refs

N77-21468

Key Words: Turbine blades, Dynamic tests, Experimental results

The results of dynamic analyses, weight and balance tests, static stiffness tests, and structural vibration tests on the 60-foot-long metal blades for the ERDA-NASA 100-kW wind turbine are presented. The metal blades are shown to be free from structural or dynamic resonance at the wind turbine design speed. Aeroelastic instabilities are unlikely to occur within the normal operating range of the wind turbine.

77-1809

Dynamic Behavior of Laminated Polymeric Matrix Composites

R.W. Mortimer and P.C. Chou

Dept. of Mech. Engrg. and Mechanics, Drexel Univ., Philadelphia, PA., Rept. No. AFML-TR-76-127, 58 pp (July 1976)

AD-A038 067/5GA

Key Words: Turbine blades, Fans, Impact response, Blades, Plates, Computer programs

The primary goal of this two-year program is to study, numerically, and experimentally the dynamic response of idealized laminated graphite-epoxy fan blades subjected to impact loads. The blade is simulated by a flat plate. Two impact cases are studies: one is the in-plane impact, the other is the shear-bending impact. This report includes results of the theoretical and experimental predictions of wave velocities and strain histories for the cases of in-plane and shear-bending impact of aluminum, graphite-epoxy cross-ply, and graphite epoxy angle-ply plates. In addition, the status of the program to compute local responses (using the finite-difference code HEMP) and structural responses (using NASTRAN) of laminated structures is presented. Finally, preliminary results of an impact parametric study(utilizing NASTRAN) involving the impact of a laminated beam structure are presented.

77-1810

Vibration Characteristics of Composite Fan Blades and Comparison with Measured Data

C.C. Chamis

Materials, and Struc. Div., Lewis Res. Center, NASA, Cleveland, OH, J. Aircraft, 14 (7), pp 644-647 (July 1977) 6 figs, 4 tables, 4 refs

Key Words: Fan blades, Natural frequencies, Mode shapes, Computer programs, Experimental data

The vibration characteristics of a composite fan blade for high-tip-speed applications were determined theoretically, and the results compared with measured data. The theoretical results were obtained using a computerized capability consisting of NASTRAN coupled with composite mechanics by way of pre- and postprocessors. The predicted vibration frequencies and mode shapes were in very good agreement with the measured data.

77-1811

An Analysis of the Flutter and Damping Characteristics of Helicopter Rotors

S.P. Viswanathan

Ph.D. Thesis, Georgia Inst. of Tech., 161 pp (1977) UM 77-15,044

Key Words: Rotary wings, Helicopters, Flutter, Damping coefficients

Two relatively new methods of vibrational analysis of nonuniform rotor blades in combined flapwise bending and torsion are reviewed. The structural dynamic characteristics of an example blade are evaluated using the Transmission matrix method and are later used in flutter analyses.

CONTROLS

77-1812

Transient Response of Second Order Relay Servomechanism

S. Ogino

Faculty of Engrg., Yamagata Univ., Yonezawa, Japan, Bull. JSME, 20 (143), pp 568-574 (May 1977) 11 figs, 7 refs

Key Words: Transient response, Servomechanism

An exact solution in mathematical sense for the transient response of a second order relay servomechanism is obtained. By applying the succession function method, the condition for the system to have a cycle is given and the proof that this cycle is a limit cycle is established. Based on this proof an algorithm and a chart to calculate the period and the amplitude of the cycle are constructed. The approximate periodic solution obtained by the describing function method is also studied.

CYLINDERS

77-1813

Vibration of a Group of Circular Cylinders in a Confined Fluid

H. Chung and S.S. Chen

Components Tech. Div., Argonne Nationl Lab., Argonne, IL., J. Appl. Mech., Trans. ASME, 44 (2), pp 213-217 (June 1977) 6 figs, 16 refs

Sponsored by the U.S. Energy Res. and Dev. Admin.

Key Words: Cylinders, Fluid-induced excitation, Coupled response

This paper presents an analytical method for evaluating the hydrodynamic masses of a group of circular cylinders immersed in a fluid contained in a cylinder. The analysis is based on the two-dimensional potential flow theory. The fluid coupling effect among cylinders is taken into account; self and mutual-added masses for both inner and outer cylinders are evaluated. Based on the proposed method, the free vibration of two eccentric cylinders with a fluid-filled gap is analyzed as an example.

77-1814

A Study on the Fluctuating Force Acting on a Cylinder Placed in the Downstream of a Moving Cylinder

T. Adachi, S. Nakajima, and Y. Sawada

Inst. of Structural Tech., Univ. of Tsukuba, Sakura, Ibaraki 300-31, Japan, Bull. JSME, 20 (143), pp 584-592 (May 1977) 16 figs, 2 tables, 5 refs

Key Words: Cylinders, Fluid-induced excitation

Experiments of the fluctuating force acting on a cylinder placed in the downstream of a moving cylinder with constant velocity in a uniform airstream have been carried out. The case of both cylinders stationary is treated. Experimental results and knowledge of the flow pattern around the cylinders enable the formation of the idea that the separation point shifts downstream because of the turbulence arising from the upper cylindor. Owing to this interference, the lift and drag acting on the cylinder placed in the downstream are changed.

77-1815

On Wake-Induced Flutter of a Circular Cylinder in the Wake of Another

Y.T. Tsui

Hydro-Quebec Research Inst., Varennes, Quebec, Canada, J. Appl. Mech., Trans. ASME, 44 (2), pp 194-200 (June 1977) 3 figs, 3 tables, 34 refs

Key Words: Cylinders, Flutter, Fluid-induced excitation

Two-dimensional stability of leaward cylinder in the wake of fixed windward cylinder is studied within the framework of quasi-static aerodynamic theory at both subcritical and supercritical flow region. Routh-Hurwitz stability criterion is employed.

DUCTS

77-1816
The Generation of Sound by Vorticity Waves in Swirling Duct Flows

M.S. Howe and J.T.C. Liu
Dept. of Engrg., Univ. of Cambridge, UK, J. Fluid Mech., 81 (2), pp 369-383 (June 24, 1977) 4 figs, 26 refs

Key Words: Ducts, Sound generation

Swirling flow in an axisymmetric duct can support vorticity waves propagating parallel to the axis of the duct. When the cross-sectional area of the duct changes a portion of the wave energy is scattered into secondary vorticity and sound waves. Thus the swirling flow in the jet pipe of an aeroengine provides a mechanism whereby disturbances produced by unsteady combustion or turbine blading can be propagated along the pipe and subsequently scattered into aerodynamic sound. In this paper a linearized model of this process is examined for low Mach number swirling flow in a duct of infinite extent.

77-1817
Attenuation of Sound in Multi-Element Acoustically Lined Rectangular Ducts in the Absence of Mean Flow

W. Koch
Institut für Strömungsmechanik, DFVLR/AVA Göttingen, Bunsenstrasse 10, D-34 Göttingen, Federal Republic of Germany, J. Sound Vib., 52 (4), pp 459-496 (June 22, 1977)

Key Words: Ducts, Acoustic linings, Noise reduction

Extensions of the ordinary Wiener-Hopf technique are outlined and applied to the solution of sound attenuation in multi-element ducts with acoustically absorbing liners in series as well as in parallel combination. For demonstration purposes the simplest case of engineering interest is chosen: namely, a rectangular channel at zero convection velocity. Extensions to circular and annular geometries as well as to mean flow situations are possible. In the absence of a realistic source model acoustic power attenuation results are presented for an incoming fundamental mode only, to show the influence of major design parameters for point reacting liners. The broad band-width attenuation capacity of some liner configurations as well as the necessity to include wave reflections at liner discontinuities for multi-element liners is clearly demonstrated. For a given acoustic source a multimode solution can be found by summing the contribution of each incoming unattenuated mode.

LINKAGES

77-1818
Damping in Friction-Grip Bolted Joints

S. Vitelleschi and L.C. Schmidt
Dept. of Housing and Construction, Hawthorn, Victoria, Australia, ASCE J. Struc. Div., 103 (ST7), pp 1447-1460 (July 1977) 8 figs, 6 tables, 11 refs

Key Words: Joints, Coulomb friction

The object of the work reported in this paper is to obtain a measure and an understanding of the damping in high-strength friction-grip bolted joints. Static tests to determine the coefficient of friction and cyclic tests to determine the amount of damping in symmetrical double-coverplated butt joints are described. Four plate surfaces were examined, i.e., galvanized, inorganic zinc silicate, urethane chromate primer, and mill scale. An energy loss relationship was found for each surface type. At the working load levels, the damping factors ranged from 5% to 12%, and the energy losses, after early variations, tended to stable values with increasing numbers of cycles. Suggestions on improvements to increase joint damping are given.

PIPES AND TUBES

(See No. 1824)

PLATES AND SHELLS

(Also see Nos. 1753, 1809)

77-1819
Non Linear Dynamic Analysis of Flat Laminated Plates by the Finite-Element Method

A.R. Zak

Dept. of Aeronautical and Astronautical Engrg., Illinois Univ. at Urbana-Champaign, IL., Rept. No. BRL-CR-334, 74 pp (Mar 1977)
AD-A038 427/1GA

Key Words: Plates, Finite element technique, Mathematical models, Computer programs, Dynamic structural analysis

A finite-element structural model has been developed for the dynamic analysis of laminated, thick plates. The model uses constant thickness quadrilateral elements to represent the shape of the plate and these elements are stacked in the thickness direction to represent the desired material layers. The analysis allows for orthotropic material properties of each layer as well as for elastic-plastic material response. Nonlinear strain displacement relations are used in the formulation to represent large, transverse plate deflections. The finite-element model is used to prepare a computer program for the numerical calculations. Two versions of the program have been prepared, which correspond to two different time integration numerical methods. These methods include finite-difference and predictor-corrector techniques. The computer programs are designed for time and space dependent pressure loads to be applied to one surface of the plate. However, the programs could be used for other loading conditions by changing one subroutine.

77-1820

Non-Linear Flexural Vibrations of Orthotropic Rectangular Plates

M.K. Prabhakara and C.Y. Chia
Dept. of Civil Engrg., The Univ. of Calgary, Calgary, Alberta, Canada, J. Sound Vib., 52 (4), pp 511-518 (June 22, 1977) 5 figs, 2 tables, 8 refs
Sponsored by the National Res. Council of Canada

Key Words: Rectangular plates, Orthotropism, Flexural vibration, Large amplitudes

This study is an analytical investigation of free flexural large amplitude vibrations of orthotropic rectangular plates with all-clamped and all-simply supported stress-free edges. The dynamic von Karman-type equations of the plate are used in the analysis. A solution satisfying the prescribed boundary conditions is expressed in the form of double series with coefficients being functions of time. The model equations are solved by expanding the time-dependent deflection coefficients into Fourier cosine series. As obtained by taking the first sixteen terms in the double series and the first two terms in the time series, numerical results are presented for non-linear frequencies of various modes of glass-epoxy, boron-epoxy and graphite-epoxy plates.

77-1821

Free Vibrations of Randomly Inhomogeneous Plates

A.D. Wood and F.D. Zaman
Cranfield Inst. of Tech., Cranfield, Bedford MK43 0AL, UK, J. Sound Vib., 52 (4), pp 543-552 (June 22, 1977) 3 figs, 9 refs

Key Words: Rectangular plates, Natural frequencies

Consider a large collection of elastic rectangular plates with random inhomogeneities, but otherwise indistinguishable in any overall sense. An expression is obtained for the natural frequency, Ω, of such plates, vibrating freely under simply supported boundary conditions, in the form $\Omega = \Omega^{(0)} + \epsilon\Omega^{(1)} + \epsilon^2\Omega^{(2)} + \ldots$, where $\Omega^{(0)}$ is the natural frequency of a homogeneous comparison plate, ϵ is a small real parameter measuring the degree of inhomogeneity, and the coefficients $\Omega^{(1)}, \Omega^{(2)}, \ldots$, are given explicitly.

77-1822

Vibrations of Circular Cylindrical Shells with Cutouts

S. Toda and K. Komatsu
National Aerospace Lab., 1880 Jindaiji-machi, Chofu, Tokyo, Japan, J. Sound Vib., 52 (4), pp 497-510 (June 22, 1977) 14 figs, 2 tables, 11 refs

Key Words: Cylindrical shells, Hole-containing media, Natural frequencies, Beams

An experimental and analytical study was carried out to examine the effect of circular cutouts on the resonant frequencies of thin cylindrical shells. The experimental results were obtained from tests performed on clamped-free aluminum cylinders and clamped ring-stiffened tri-acetyl cellulose shells with a lap-joint seam. The analytical solution was a simplified Rayleigh-Ritz type approximation. For the beam type mode, the circular cutouts had a significant influence on the frequency.

77-1823

Dynamic Response of a Cylindrical Shell to a Concentrated Periodical Force (2nd Report, Stress Response)

K. Shirakawa and K. Mizoguchi
College of Engrg., Univ. of Osaka Prefecture, Sakai, Japan, Bull. JSME, 20 (143), pp 521-527 (May 1977) 4 figs, 4 refs

Key Words: Cylindrical shells, Periodic excitation

Following a previous paper on the forced vibration problem of a cylindrical shell, the stress response is discussed when a certain point on the cylinder surface is periodically excited by a concentrated force. The principal parts of the stress response may be represented by the closed terms, and the property of their singularities may be also examined briefly. The results of some computations are presented for the behavior of stress response between certain frequency regions, in which the effect of in-plane inertia on them and their correspondence with the deformation response may be examined.

77-1824

Distorted Cylindrical Shell Response to Internal Acoustic Excitation Below the Cut-Off Frequency

S.N. Yousri and F.J. Fahy

School of Engrg. and Applied Sciences, Univ. of Sussex, Brighton BN1 9QT, UK, J. Sound Vib., 52 (3), pp 441-452 (June 8, 1977) 10 figs, 1 table, 10 refs

Key Words: Cylindrical shells, Acoustic excitation, Tubes

The mechanism of coupling between a plane wave acoustic mode and a non-axisymmetric structural mode of a thin walled, circular, cylindrical shell, via the geometrical distortion of the shell, is considered. A theoretical model of response below the acoustic cut-off frequency is used to estimate the vibration level induced in a tube having small circumferential variations of wall thickness, radius and modulus of elasticity. The results have been confirmed experimentally.

77-1825

Distorted Cylindrical Shell Response to Internal Acoustic Excitation Below the Cut-Off Frequency

S.N. Yousri and F.J. Fahy

Inst. of Sound and Vib. Res., Southampton Univ., Southampton, UK, Rept. No. ISVR-TR-82, 34 pp (Jan 1976) refs

Sponsored by Babcock & Wilcox (Operations) Ltd. N77-21476

Key Words: Cylindrical shells, Acoustic excitation

The mechanism of coupling between a planewave acoustic mode and a non-axisymmetric structural mode of a thin wall, circular, cylindrical shell, via the geometrical distortion of the shell is considered. A theoretical model of response below the acoustic cut-off frequency is used to estimate the vibration level induced in a tube having small circumferential variations of wall thickness, radius and modulus of elasticity. The results have been confirmed experimentally.

77-1826

Static and Dynamic Behavior of Noncircular Cylindrical Shells

J. Kempner

Dept. of Mech. and Aerospace Engrg., Polytechnic Inst. of New York, Brooklyn, NY, Rept. No. POLY-M/AE-77-5, AFOSR TR-77-0212, 23 pp (Feb 1977) AD-A038 203/6GA

Key Words: Cylindrical shells, Rings, Dynamic structural analysis, Bibliographies

In this report, emphasis is placed upon problems concerned with the buckling, postbuckling, and vibrations of rings and cylindrical shells of variable curvature. Some work was performed on reinforced spherical and noncircular cylindrical shells. The list of references at the end of this report represents reports, publications, talks, and theses prepared.

77-1827

Elasto-Plastic Response of a Multi-Layered Spherical Vessel to Internal Blast Loading

W.L. Ko, H.G. Pennick, and W.E. Baker

Southwest Res. Inst., San Antonio, TX 78284, Intl. J. Solids Struc., 13 (6), pp 503-514 (June 1977) 10 figs, 8 refs

Key Words: Spherical shells, Shock response

Dynamic response of a multi-layered spherical vessel subjected to intermittent internal blast loading is analyzed. The vessel is composed of N concentric unsupported spherical shells of identical material and of the same thickness, separated by evacuated gaps of equal thickness. The wall material is assumed to be elasto-plastic obeying the bilinear stress-strain law. Taking into account of the wave interactions, induced by inter-laminar impacts, response of the vessel system was calculated up to five cycles of vibration and the results are presented for several gap sizes.

77-1828

Elastic Response of Submerged Shells with Internally Attached Structures to Shock Loading

D. Ranlet, F.L. DiMaggio, H.H. Bleich and M.L.Baron

Weidlinger Assoc., 110 E. 59th St., New York, NY 10022, Computers and Struc., 7 (3), pp 355-364 (June 1977) 17 figs, 17 refs

Key Words: Shells, Submerged structures, Interaction: structure-fluid, Shock response

A method is presented for obtaining the elastic response, to a shock wave, of a shell, with internal structure, submerged in an infinite acoustic fluid. Modal structural analysis is employed, and the structure-fluid interaction is accounted for by means of an approximate relation between the radiated fluid pressure and velocity.

77-1829

Direct Dynamic Analysis of Shells of Revolution Using High-Precision Finite Elements

H. Suryoutomo, P.L. Gould, and P.K. Basu
Earthquake Engrg. Systems, San Francisco, CA 94105, Computers and Struc., 7 (3), pp 425-433 (June 1977) 16 figs, 16 refs

Key Words: Shells of revolution, Dynamic analysis, Finite element technique

The purpose of this study is to develop and demonstrate a direct integration algorithm which is compatible with an existing high-precision rotational shell finite element. Excellent comparative efficiency for static problems was achieved with this element by the incorporation of the exact geometry, the utilization of high-order interpolation polynomials and, yet, the retention of only a minimum number of nodal variables in the global formulation. Likewise, accurate and efficient results for the free vibration analysis of rotational shells were facilitated by the inclusion of a consistent mass matrix and the utilization of a rationally justified kinematic condensation procedure. The approach to the direct integration stage is strongly tempered by the established characteristics of this element which enable a given shell to be modeled accurately in the spatial domain with a comparatively coarse discretization.

RINGS

77-1830

Transient Response of Three-Layered Rings

M.J. Sagartz
Simulation Res. Dept., Sandia Labs, Albuquerque, NM, J. Appl. Mech., Trans. ASME, 44 (2), pp 299-304 (June 1977) 9 figs, 1 table, 17 refs

Key Words: Equations of motion, Rings, Laminates, Transverse shear deformation effects, Rotatory inertia effects

Hamilton's principle is used to derive equations of motion for a linear elastic three-layered ring. The theory includes the effects of shear deformation and rotatory inertia in each layer and radial strain effects in the middle layer. A convenient computational technique is developed for transient response evaluation. A companion experimental study was conducted using two different rings. Both rings had aluminum inner and outer layers, but each had a different low-modulus middle layer. Radial impulse loads distributed as a cosine over half the ring circumference, were applied to the outer ring surface, and the transient respone was monitored with strain gages mounted on the aluminum layers. Measured strain-time histories were compared with theoretical calculations, and good agreement was obtained.

STRUCTURAL

(Also see Nos. 1733, 1740, 1755)

77-1831

Optimal Design of Plastic Structures Under Impulsive and Dynamic Pressure Loading

Ü. Lepik and Z. Mróz
Univ. of Tartu, Tartu, Estoniam S.S.R., USSR, Intl. J. Solids Struc., 13 (7), pp 657-674 (July 1977) 13 figs, 2 tables, 6 refs

Key Words: Optimization, Structural elements, Dynamic excitation

Optimal design of a rigid-plastic stepped beam and circular plate is considered in the first part of the paper assuming the mode form of motion. The form of optimal mode is sought for which a structure of constant volume attains a minimum of local or mean deflection. It is assumed that the constant kinetic energy Ko is attained by the structure through impulsive loading. Differences between optimal static and dynamic solutions are discussed. Non-uniqueness of modes is demonstrated and significance of stable mode motions is emphasized. In the second part of the paper, an optimal design of a rigid-plastic stepped beam loaded by a uniform pressure over a specified time interval is considered assuming constant beam volume and looking for a design corresponding to minimum of local deflection. The solution presented is valid for moderate dynamic pressures when mode motion occurs during consecutive time intervals and no travelling plastic hinges exist.

77-1832

Acoustoelasticity: General Theory, Acoustic Natural Modes and Forced Response to Sinusoidal Excitation, Including Comparisons with Experiment

E.H. Dowell, G.F. Gorman, III, and D.A. Smith
Princeton Univ., Princeton, NJ 08540, J. Sound Vib., 52 (4), pp 519-542 (June 22, 1977) 12 figs, 28 refs

Key Words: Cavities, Walls, Mathematical models, Acoustic response, Natural frequencies, Forced vibration

A comprehensive theoretical model has been developed for interior sound fields which are created by flexible wall motion resulting from exterior sound fields. Full coupling between the wall and interior acoustic cavity is permitted. An efficient computational method is used to determine acoustic natural frequencies of multiply connected cavities. Simplified formulae are developed for interior sound levels in terms of cavity, wall and external acoustic field parameters. Comparisons of theory and experiment show generally good agreement.

77-1833

Racking Tests of High-Rise Building Partitions

S.A. Freeman

URS/John A. Blume & Assoc. Engrs., San Francisco, CA, ASCE J. Struct. Div., 103 (ST8) pp 1673-1685 (Aug 1977) 5 figs, 9 tables, 11 refs

Key Words: Multistory buildings, Walls, Stiffness, Energy absorption

The results of a program of racking tests of wall panels can be incorporated into the analysis of high-rise structures influence by nonstructural partitions. Stiffness and energy-absorbing characteristics were obtained from racking tests of wall panels simulating lateral interstory displacements in high-rise buildings. These characteristics were combined with structural frame periods and damping to estimate overall building periods and damping. Illustrative examples are presented.

77-1834

Behavior of Ten-Story Reinforced Concrete Walls Subjected to Earthquake Motions

J.D. Aristizabal-Ochoa

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 398 pp (1977)

UM 77-14,924

Key Words: Walls, Reinforced concrete, Multistory buildings, Seismic excitation, Experimental results

The response of ten-story reinforced concrete walls coupled by beams to earthquake base motions was investigated through experimental and analytical models. The experimental work involved tests of small-scale ten-story reinforced concrete walls coupled by beams subjected to base motions, simulating one horizontal component of representative earthquake-motion records, on the University of Illinois Earthquake Simulator. The experimental results were compared with results of linear dynamic analyses based on spectral response.

SYSTEMS

ABSORBER

77-1835

The Dynamic Vibration Absorber Principle Applied to a High-Quality Phonograph Pickup

A.R. Groh

Shure Brothers Inc., Evanston, IL, J. of Audio Engrg., 25 (6), pp 385-390 (June 1977) 11 figs, 1 table, 6 refs

Key Words: Dynamic vibration absorption (equipment)

Recent developments in phonograph disc recording have placed increased demands on the playback transducer. Both dynamic range and bandwidth have been extended, particularly on discrete four-channel records. The dynamic vibration absorber principle is studied as a means of extending transducer bandwidth without compromising other parameters. An application of the vibration absorber is developed for use in a top quality magnetic phono pickup that provides high performance through almost five decades of frequency.

ACOUSTIC ISOLATION

77-1836

Effects of Outdoor Exposure on Sound Absorption Materials

M.M. Myles, I.L. Vér, and H.R. Henderson

Bolt Beranek and Newman, Inc., Cambridge, MA, S/V, Sound Vib., 11 (6), pp 24-27 (June 1977) 11 figs, 1 table, 4 refs

Key Words: Acoustic insulation, Absorbers (materials), Environmental effects

An experiment is described in which sample anechoic wedges, made from a variety of glass fiber and foam materials, were continuously exposed to the weather for about a year. The normal incidence absorption coefficients were measured for each wedge before and after exposure. These data, plus descriptions of the materials' physical condition after exposure are presented. The results indicated that many commonly used kinds of sound absorbing materials can withstand continued exposure outdoors.

NOISE REDUCTION

(Also see Nos. 1817, 1842, 1855, 1867, 1874)

77-1837

Noise Control Economics of Siting Gas Turbine Power Plants

G.F. Hessler

Gas Turbine Intl., 18 (3), pp 22-24 (May/June 1977) 2 figs

Key Words: Power plants (facilities), Noise reduction

Correct selection and specification of sound criteria for gas turbine installations is absolutely necessary to maintain good neighbor and employee relations. This paper is intended to illustrate that diligent acoustic site analysis and criterion selection can also result in substantial economic benefits to the gas turbine user.

ACTIVE ISOLATION

77-1838

A Pneumatic On-Off Vehicle Suspension System

V.L. Klinger and A.J. Calzado

Systems Control, Inc., Palo Alto, CA, J. Dyn. Syst., Meas. and Control, Trans. ASME, 92 (2), pp 130-136 June 1977) 7 figs 11 refs

Key Words: Suspension systems (vehicles), Active isolation, railroad cars

An active, nonlinear, pneumatic suspension applicable to passenger railcars is described. Standard on-off valves modulate pressure differences between dual opposing airbags to attenuate vibration and create guidance forces. Improved vibration isolation over that of conventional passive suspensions is achieved at low power levels. Guidance forces are provided with small suspension travel using short bursts of compressed air taken from vehicle supply reservoirs. Acceleration, relative displacement, and pressure transducers provide the control signals required for stabilization, feedforward guidance commands, and disturbance attenuation. Simulation results indicate that performance comparable to hydraulic servosystems can be attained with substantially reduced system complexity and power requirements.

77-1839

Design Concepts for a Fully Active Helicopter Vibration Isolation System by Means of Output Vector Feedback (Konzepte zur Auslegung eines vollaktiven Hubschrauber-Schwingungs Isolationssystems mittels Ausgangsvektorrueckfuehrung)

G. Schulz

Deutsche Forschungs- und Versuchsanstalt f. Luft- und Raumfahrt, Oberpfaffenhofen, W. Germany, Rept. No. DLR-IB-552-76/12, 63 pp (Sept 1976) refs

(In German)

N77-21085

Key Words: Helicopters, Active isolation

Concepts taken from the theory of output vector feedback (few parameters) were used to develop a controller for fully active vibration isolation of helicopters. These controller concepts were tested on several models of the BO-105 helicopter, and their efficiency is demonstrated. A compensation of the rotor-originated blade number harmonic vibration excitations and of the fast automatic trimming in the case of maneuvers was achieved.

77-1840

The Design, Analysis, and Testing of a Low-Budget Wind-Tunnel Flutter Model with Active Aerodynamic Controls

R. Bolding and R. Stearman

General Dynamics Corp., San Diego, CA., In: NASA Langley Res. Center Flutter Testing Tech., pp 213-242 (1976) refs (N77-21022)

N77-21031

Key Words: Flutter, Wind tunnel tests, Aircraft wings, Testing techniques, Vibration control

A low budget flutter model incorporating active aerodynamic controls for flutter suppression studies was designed as both an educational and research tool to study the interfering lifting surface flutter phenomenon in the form of a swept wing-tail configuration. A flutter suppression mechanism was demonstrated on a simple semirigid three-degree-of-freedom flutter model of this configuration employing an active stabilator control, and was then verified analytically using a doublet lattice lifting surface code and the model's measured mass, mode shapes, and frequencies in a flutter analysis. Preliminary studies were significantly encouraging to extend the analysis to the larger degree of freedom Air Force Flight Dynamics Laboratory (AFFDL) wing-tail flutter model where additional analytical flutter suppression studies indicated significant gains in flutter margins could be achieved. The analytical and experimental design of a flutter suppression system for the AFFDL model is presented along with the results of a preliminary passive flutter test.

AIRCRAFT

(Also see Nos. 1736, 1737, 1738, 1739, 1743, 1744, 1755, 1785, 1787, 1793, 1794, 1795, 1796)

77-1841

Analytical Studies of Some Acoustic Problems of Jet Engines

S.M. Candel

Guggenheim Jet Propulsion Ctr., California Inst. of Tech., Pasadena, CA., Rept. No. DOT/TST-76-104, 240 pp (May 1976)
PB-264 918/4GA

Key Words: Aircraft noise, Jet engines, Noise generation

The propagation and generation of acoustic waves in a choked nozzle is considered where pressure and entropy fluctuations caused by gas stream non-uniformities like 'hot spots,' are incident on the nozzle entrance. A novel noise-generation mechanism is found which produces acoustic waves of strength proportional to the entrance entropy fluctuation and local gradient of the mean flow velocity. A transformation is introduced which relates the solutions of problems involving the propagation of acoustic waves in a moving medium to the solutions of associated problems in a stationary medium.

77-1842

Core Noise Measurements on a YF-102 Turbofan Engine

M. Reshotko, A. Karchmer, P.F. Penko, and J.G. McArdle

Lewis Res. Center, NASA, Cleveland, OH., J. Aircraft, 14 (7), pp 611-612 (July 1977) 4 figs, 1 ref

Key Words: Jet aircraft, Aircraft noise, Engine noise, Noise reduction, Fans, Jet noise

In the past several years considerable progress has been made in reducing the noise generated by jet aircraft engines. The two largest sources of engine noise, the fan and the jet exhaust, have been reduced significantly. Further treatment of these sources may not reduce the overall engine noise because an acoustic threshold may have been reached. This threshold consists of noise generated by heretofore poorly understood sources within the engine core. One of the most likely sources of far-field noise originating from the engine core is the combustion process, during which large amounts of chemical energy are released.

77-1843

Combustion Noise Investigation

D.C. Mathews, N.F. Rekos, Jr., and R.T. Nagel

Institute of Labs, Jamaica Plain, MA., Rept. No. PWA-5478, FAA-RD-77-3, 202 pp (Feb 1977)
AD-A038 154/1GA

Key Words: Aircraft noise, Aircraft engines, Engine noise, Combustion noise, Noise prediction

Improved methods for predicting both direct and indirect combustion noise from aircraft engines are developed and experimentally evaluated by conducting rig experiments and by comparing with data from several full scale engines. Comparison of predictions with full scale engine data was made.

77-1844

An Engine Nozzle Vibration Phenomenon Encountered in B-1 Flight Tests

S.K. Dobbs, J.R. Stevenson, and C.L. Arulf

B-1 Div., Rockwell International, Inst. Environ. Sci., Proc., 23rd Annual Mtg., Los Angeles, CA., pp 318-323 (Apr 25-27, 1977) 6 figs, 1 ref

Key Words: Airframes, Aircraft engines, Geometric effects, Engine vibration, Vibration reduction

An engine nozzle vibratory instability encountered in B-1 flight tests is described. Measured engine and engine nozzle ground and flight vibration data were utilized to develop a theory that both explains the phenomenon and discloses a stable nozzle configuration. Flight and engine test cell data are presented demonstrating the validity of the theory.

BRIDGES

77-1845

Dynamic Analysis of Horizontally Curved I-Girder Bridges

S. K. Chaudhuri and S. Shore

Dept. of Civil and Urban Engrg., Univ. of Pennsylvania, Philadelphia, PA, ASCE J. Struc. Div., 103 (ST8), pp 1589-1604 (Aug 1977) 18 figs, 1 table, 20 refs

Sponsored by the Consortium of Univ. Res. Teams and Federal Highway Administration

Key Words: Bridges, Plates, Beams, Moving loads, Mathematical models

The finite element displacement method is used with annular plate, thin-walled curved beam, straight prismatic beam, and frame-type diaphragm elements for the dynamic analysis of horizontally curved I-girder highway bridges. The stiffness and inertia properties of the finite elements are obtained within the bounds of linear elasticity and small displacement theories. Warping of the girder cross section due to torsion is included in the analysis. The moving vehicle on the bridge is idealized as a sprung mass supported on two unsprung masses. The centrifugal forces arising due to the motion of the vehicle in a circular path are included in the analysis.

77-1846
Model Experiments for Span-Vehicle Dynamics

J.F. Wilson
Civ. Engrg. Dept., Duke Univ., Durham, NC, ASCE J. Engr. Mech. Div., 103 (EM4), pp 701-715 (Aug 1977) 11 figs, 14 refs
Sponsored by the U.S. Dept. of Transportation

Key Words: Bridges, Moving loads, Mathematical models

The transient dynamics of multiple-span beam -type bridges responding to constant speed, sprung and unsprung vehicle loads are investigated experimentally. Both instrumentation and the severe problems of dynamic modeling of realistic prototypes are considered. Scaling parameters such as vehicle mass to span mass ratio, passage frequency to bridge frequency ratio, vehicle suspension frequency ratios, and loading length to span length ratio are defined and applied to the design of a laboratory test facility. Considered are problems of data retrieval for the bridge dynamics and for the vehicle heave acceleration. The latter data, needed to design safe and comfortable vehicle suspension systems, are essential in future urban and interurban transportation systems. Span data are presented in nondimensional form, suitable for design purposes.

77-1847
Forced and Self-Excited Responses of a Bluff Structure in a Turbulent Wind

W.-H. Lin
Ph.D. Thesis, Princeton Univ., 349 pp (1977)
UM 77-14,249

Key Words: Suspension bridges, Fluid induced excitation, Wind-induced excitation

A general theoretical method is first set out to describe the phenomenon of the aerodynamic buffeting of bluff, elongated bodies -- in particular, the deck of a long, suspended-span bridge. The analytical model includes the equations of motion, the self-excited forces, and the time-dependent buffeting forces of the wind, these last being considered independent of the others.

BUILDING
(Also see No. 1789)

77-1848
Estimation of Alongwind Building Response

E. Simiu, R.D. Marshall, and S. Haber
Center for Building Tech., National Bureau of Standards, Washington, D.C., ASCE J. Struc. Div., 103 (ST7), pp 1325-1338 (July 1977) 1 fig, 3 tables, 27 refs

Key Words: Buildings, Wind-induced excitation

The differences between the values calculated for the dynamic alongwind response, the gust response factors, and the total alongwind response obtained using various current procedures may in certain cases be of the order of 100%. The purpose of this paper is to investigate the causes of such differences. A comparison is made between alongwind deflections of typical buildings selected as case studies, calculated by both new and traditional procedures, some of which are described in various building codes. The reasons for the differences between the respective results are pointed out. The procedures were evaluated on the basis of a recently developed method which utilized a logarithmic variation of wind speed with height above ground and a height-dependent expression for the spectrum of the longitudinal wind speed fluctuations. The method also allows for realistic cross-correlation between pressures on the windward and leeward building faces.

77-1849
Ambient and Forced Vibration Analysis of Full-Scale Structures

C.A. Kircher
Ph.D. Thesis, Stanford Univ., 254, pp (1977)
UM 77-12,654

Key Words: Forced vibration, Multistory buildings

Vibration analysis techniques are used to examine the dynamic characteristics of full scale structures. Specifically, the results of a study of six similar high-rise apartment buildings and a study of two 230 KV air blast circuit breakers are presented. A portable mini-computer system has been used to perform on-site acceleration measurements and corresponding analyses (e.g., calculation of power spectra). This mini-computer system is programmed for data acquisition and discrete Fourier analysis. Forced vibration excitation of the breaker structures is accomplished by a portable electromagnetic shaker unit. The forced vibration input to the structures include white noise as well as sinusoidal excitations. The study of six similar high-rise apartment buildings is performed by the examination of power spectra obtained from ambient vibration measurements. Two 230 KV air blast circuit breakers are studied by examining the power spectra from ambient and forced vibration measurements.

77-1850
Torsional Seismic Response of Symmetrical Structures
M. Valathur and H.H. Shah
Sargent & Lundy, Chicago, IL, ASCE J. Power Div., 103 (PO1), pp 65-75 (July 1977) 11 figs, 5 tables, 3 refs

Key Words: Buildings, Seismic response

An approach to evaluate the torsional effect has been presented, using the time-history method of analysis. This approach considers the effect of building size, wave propagation velocity, and the dynamic characteristics of the structure. Based on wave-propagation consideration, the ground motion is treated to produce translational and torsional input time-history motions for which a conventional seismic model can be analyzed.

CONSTRUCTION

(See No. 1851)

FOUNDATIONS AND EARTH

77-1851
Vibroreplacement and Reinforced Earth Unite to Strengthen a Weak Foundation
A. Muñoz, Jr. and R.M. Mattox
U.S. Dept. of Transportation, Fed. Highway Admin., 819 Taylor St., Ft. Worth, TX 76102, Civ. Engr., 47 (5), pp 58-62 (May 1977) 4 figs

Key Words: Construction equipment, Soils, Vibratory techniques

The Reinforced Earth technique is well known in the U.S.; the Vibroreplacement process is relatively new. It utilizes the same equipment as the Vibroflotation process, namely the Vibroflot, to place "stone columns" through the weak soil to support the fill above. On top of these columns a Reinforced Earth retaining wall is built. The stone columns are placed by using the Vibroflot to penetrate the subsurface soil to a pre-determined depth. The jetting medium can be water or compressed air. The resulting hole is backfilled in stages with coarse granular fill which is thoroughly compacted and displaced into the surrounding soil. The compaction process is carried out by withdrawing the vibrator slowly with alternating up and down movements.

77-1852
Semianalytic Hyperelement for Layered Strata
E. Kausel and J.M. Roesset
Stone and Webster Engrg. Corp., Boston, MA, ASCE J. Engr. Mech. Div., 103 (EM4) pp 569-588 (Aug 1977) 6 figs, 8 refs

Key Words: Wave propagation, Layered materials, Interaction: soil-structure, Foundations

The paper presents a new numerical technique to solve dynamic wave propagation problems in layered systems. The method is based on the closed-form analytical solution in the direction parallel to the layering, and arbitrary displacement expansions in the direction perpendicular to it. Detailed information is given for the use of the theory for the particular case of a linear expansion. The main advantage of the theory is that a great reduction in the number of degrees-of-freedom necessary to model a system, as compared to conventional finite element models, can be attained. The advantage is achieved at the expense of having to solve the system in the frequency domain, and having to compute the stiffness matrix for each individual frequency. The method is, therefore, limited to linear systems. The relatively modest size of the problem allows a solution in fast memory, without having to resort to peripheral storage allocation.

77-1853
Design of Machine Foundations on Piles
J.P. Singh, N.C. Donovan, and A.C. Jobsis
Dames & Moore, San Francisco, CA, ASCE J. Geotech. Engr. Div., 103 (GT8) pp 863-877 (Aug 1977) 8 figs, 2 tables, 18 refs

Key Words: Interaction: soil-structure, Machine foundations, Cantilevers

A practical method for the analysis of pile-supported foundations subjected to dynamic loadings is described. The method uses a single-degree-of-freedom mass-spring-dashpot model of a form similar to that used for shallow foundations to analyze the response of the actual system. The method of analysis uses the concept of an equivalent cantilever, which is a technique to simplify the soil-structure interaction problem, and allow the computation of equivalent spring constants in all modes of vibration. The method is demonstrated with an actual case history where computed and observed motions are compared.

77-1854
Method for Dynamic Testing of Dams
D.K. Ostrom and T.A. Kelly
Southern California Edison, Los Angeles, CA, ASCE J. Power Div., 103 (PO1), pp 27-36 (July 1977) 8 figs, 2 tables, 7 refs

Key Words: Dams, Dynamic tests, Testing techniques, Seismic response

The Popper Test is an effective test that is easy to conduct and can be used to help determine the dynamic response characteristics of small to moderately large concrete dams. The Popper Test method is particularly suited in single-arch and multiple-arch concrete strength dams. This test method combines the versatility, ease, and low cost of ambient testing with the data quality advantages of active testing. Fundamental mode data (mode, shape, frequency, and damping) can be extracted visually in the field with proper filtering of the transducer signal. Detailed higher mode information must be obtained by analytical techniques or more specialized field equipment.

HELICOPTERS

(Also see Nos. 1784, 1811, 1839)

77-1855

Helicopter Noise Reduction Design Trade-Off Study

M.A. Bowes

Kaman Aerospace Corp., Bloomfield, CT, Rept. No. R-1493, FAA-AEQ-77-4, 252 pp (Jan 1977) AD-A038 192/1GA

Key Words: Helicopter noise, Noise reduction

A study was performed to determine the noise reduction benefits and costs associated with applying state-of-the-art noise reduction methods to future design civil helicopters. As part of this study, a survey of the make-up of the civil fleet was performed, and this fleet make-up was projected to the 1980 time frame. Analytical methods were developed and/or adopted for calculating helicopter component noise, and these methods were incorporated into a unified total vehicle noise calculation model. Analytical methods were also developed for calculating the effects of noise reduction methodology on helicopter design, performance and cost. The analytical methods were used to calculate baseline noise and cost characteristics of several existing civil helicopters. These methods were also used to calculate changes in noise, design, performance and cost due to the incorporation of engine and main rotor noise reduction methods. All noise reduction techniques were evaluated in the context of an established mission performance criterion which included consideration of hover ceiling, forward flight range/speed/payload and rotor stall margin.

77-1856

Flight Flutter Testing of Rotary Wing Aircraft Using a Control System Oscillation Technique

J.G. Yen, S. Viswanathan, and C.G. Matthys

Bell Helicopter Co., Fort Worth, TX, In: NASA Langley Res. Ctr. Flutter Testing Tech., pp 501-512 (1976) refs (N77-21022)
N77-21041

Key Words: Flutter, Flight tests, Helicopters, Moving block technique

A flight flutter testing technique is described in which the rotor controls are oscillated by series actuators to excite the decay. The moving block technique is then used to determine the damped frequency and damping variation with rotor speed. The method proved useful for tracking the stability of relatively well damped modes. The results of recently completed flight tests of an experimental soft-in-plane rotor are used to illustrate the technique. Included is a discussion of the application of this technique to investigation of the propeller whirl flutter stability characteristics of the NASA/Army XV-15 VTOL tilt rotor research aircraft.

HUMAN

77-1857

A Survey of Longitudinal Acceleration Comfort Studies in Ground Transportation Vehicles

L.L. Hoberock

Mech. Engrg. Dept., The Univ. of Texas at Austin, TX, J. Dyn. Syst., Meas. and Control, Trans. ASME, 99 (2), pp 76-84 (June 1977) 4 figs, 15 tables, 20 refs
Sponsored by the U.S. Dept. of Transportation

Key Words: Passenger vehicles, Human tolerance, Longitudinal response

Experimental studies of objective and subjective passenger response to various fore-and-aft, or longitudinal, vehicle acceleration transients are reviewed. It is found that the wide variability in type of study and form of results does not allow conclusive statements to be made regarding passenger acceptability of any specific acceleration-jerk profile in a given transportation system.

77-1858

Drilling Tools for the Flydrilling. Measurements for the Analysis of Vibration and Noise

G. Vonnemann

VDI Z., 119 (9), pp 446-450 (May 1977) 8 figs, 12 refs

Key Words: Tools, Vibration measurement, Noise measurement

It will be necessary in the future to take care at an ever increasing measure that hand drill hammers work vibrationless and with little noise. In order to achieve a better understanding, the manner of functioning of electric drill hammers is explained in the first place followed by an insight into the method of the flydrilling. Subsequently it is shown that the tool generates an essential portion of the originating vibrations and of the emitting noise. Suggestions for the reduction of the environmental load result from the representation of the vibrations on account of the tool and of the noise formation by drilling tools. In order to increase the reproducibility of vibration measurements at drill hammers, a physical model of the human hand-arm system is required which in its behavior can be applied as a feeding system for electric drill hammers.

MATERIAL HANDLING

77-1859
Vibrating Conveyance of Granular Materials

K. Sakaguchi
Nagoya Industrial, Japan, Bull. JSME, 20 (143), pp 554-560 (May 1977) 12 figs, 10 refs

Key Words: Conveyors, Vibrating structures, Granular materials

The conveying mechanism is analyzed considering air flow resistance and re-arrangement of the granules that is explained by frictional model. Rice, gravel and Alundum are experimentally conveyed, and the acceleration, the loci, the landing phase and the conveying velocity are measured.

MECHANICAL
(Also see No. 1733)

77-1860
The Critical Excitation of Nonlinear Systems

R.F. Drenick
Dept. of Systems Engrg., Polytechnic Inst. of New York, Brooklyn, NY, J. Appl. Mech., Trans. ASME, 44 (2), pp 333-336 (June 1977) 8 refs
Sponsored by the National Science Foundation

Key Words: Failure analysis, Maximum response, Nonlinear systems, Mechanical systems

The critical excitation of a mechanical system, in the terminology of this paper, is one that drives the system to a larger response peak than any other in some class of allowed excitations. The critical excitation is of interest in questions related to the reliability and safety because the magnitude of the response peek is frequently an indicator of the survivability of the system. The problem of finding it has been solved for linear systems some time ago. This paper deals with the generalization of the problem to nonlinear systems. It is shown that its solution is in many ways analogous to its earlier counterpart.

METAL WORKING AND FORMING
(See No. 1806)

PUMPS, TURBINES, FANS, COMPRESSORS
(Also see 1738, 1739, 1807)

77-1861
Study on High Specific Speed Airfoil Fans (First Report, Effects on Tongue Clearance & Mouth Ring Clearance)

S. Suzuki and Y. Ugai
Noise Control Engrg. Ctr., Central Res. Institute, Ebara Mfg. Co., Ltd., Fujisawa-shi, Japan, Bull. JSME, 20 (143), pp 575-583 (May 1977) 25 figs, 1 table, 6 refs

Key Words: Fans, Noise generation

The work presented here is a study to determine the effects of such structural factors. For experimental purposes two types of tongues were developed: a skew type slanting in the direction parallel to the vane outlet width; and a modified type having a clearance changed in the same direction as above. A series of experiments was performed in single suction type airfoil fans in which these parameters were incorporated. As a result, their effects on the performance, noise level and noise spectrum of the fan were clarified, thus enabling us to obtain useful information for fan design optimization.

77-1862
Acoustic and Aerodynamic Performance of a 1.5-Pressure-Ratio, 1.83-Meter (6 ft) Diameter Fan Stage for Turbofan Engines (QF-2)

R.P. Woodward, J.G. Lucas, and J.R. Balombin
Lewis Res. Center, NASA, Cleveland, OH, Rept. No. NASA-TM-X-3521; E-8968, 57 pp (Apr 1977) refs
N77-21051

Key Words: Fans, Turbofan engines, Aerodynamic response, Acoustic response

The fan was externally driven by an electric motor. Design features for low-noise generation included the elimination of inlet guide vanes, long axial spacing between the rotor and stator blade rows, and the selection of blade-vane numbers to achieve duct-mode cutoff. The fan QF-2 results were compared with those of another full-scale fan having essentially identical aerodynamic design except for nozzle geometry and the direction of rotation. The fan QF-2 aerodynamic results were also compared with those obtained from a 50.8 cm rotor-tip-diameter model of the reverse rotation fan QF-2 design. Differences in nozzle geometry other than exit area significantly affected the comparison of the results of the full-scale fans.

77-1863
Effect of Inlet Disturbance on Fan Inlet Noise During a Static Test

K.L. Belofske, R.E. Sheer, Jr., and J.C.F. Wang
General Electric Co., Schenectady, NY, Rept. No. NASA-CR-135177, 89 pp (Apr 1977) refs
N77-21091

Key Words: Fans, Noise measurement

Measurements of fan rotor inlet noise taken during static test situations are at variance with aircraft engine flight data. In particular, static tests generally yield a significantly higher tone at blade passage frequency than that measured during flight. To explain this discrepancy, the extent of the influence of inlet ground vortices and large-scale inlet turbulence on the forward-radiated fan noise measured at a static test facility was investigated. While such inlet disturbances were generated intentionally in an anechoic test chamber, far-field acoustic measurements and inlet flow-field hot-film mappings of a fan rotor were obtained. Experimental results indicate that the acoustic effect of such disturbances appears to be less severe for supersonic than for subsonic tip speeds. Further, a reverse flow that occurs on the exterior cowl in static test facilities appears to be an additional prime candidate for creating inlet disturbance and causing variance between flight and static acoustic data.

77-1864
Computer Analysis of Turbine Vibration

Diesel and Gas Turbine Progress, 43 (7), pp 28-29 (July 1977) 5 figs

Key Words: Turbines, Vibration measurement, Computer aided techniques

A Data Memory System (DMS) for measuring the effects of transient phenomena on turbine gas generator rotor dynamics, such as blade loss, is described. It is a modular solid state recorder that captures information digitally from extremely short duration events, and plays back in digital or analog form to a variety of display and analysis devices.

77-1865
Turbocharger Radial Turbine with Improved Vibrational Characteristics

M. Naguib
Brown Boveri Rev., 64 (4), pp 221-225 (Apr 1977) 5 figs, 1 table, 7 refs

Key Words: Turbines, Design

Turbochargers are specified by the engine manufacturers for various charging systems which can deal with high pressure ratios and which are efficient enough to cope with severe conditions. These can be high exhaust-gas temperatures, frequent load changes and pulse charging. In order to take account of these requirements by widening the capabilities of the RR turbocharger, it was necessary to develop a new radial turbine. Modern experimental and analytical aids were employed in the development of a vibration-resistant radial turbine: the natural frequencies and natural modes of the blades were determined with the aid of holography; the dynamic stresses and frequencies were measured with telemetric equipment and the natural frequencies, the natural modes and the stress distribution were calculated with the aid of the finite element method. A comparison of the measured and calculated values shows that they correlate well. The turbine manufactured on the basis of the new design has been undergoing trials since the summer of 1976.

RAIL

(See No. 1838)

REACTORS

77-1866
Computer Modeling of Flow Induced in-Reactor Vibrations

P. Turula and T.M. Mulcahy
Components Tech. Div., Argonne National Lab., Argonne, IL, ASCE J. Power Div., 103 (PO1), pp 37-50 (July 1977) 6 figs, 1 table, 20 refs

Key Words: Nuclear reactors, Fluid-induced excitation, Computer programs

An assessment of the reliability of finite element method computer models, as applied to the computation of flow induced vibration response of components used in nuclear reactors, is presented. The prototype under consideration was the East Flux Test Facility reactor being constructed for US-ERDA. Data were available from an extensive test program which used a scale model simulating the hydraulic and structural characteristics of the prototype components,

subjected to scaled prototypic flow conditions as well as to laboratory shaker excitations. Corresponding analytical solutions of the component vibration problems were obtained using the NASTRAN computer code. Modal analyses and response analyses were performed. The effect of the surrounding fluid was accounted for. Several possible forcing function definitions were considered. Results indicate that modal computations agree well with experimental data. Response amplitude comparisons are good only under conditions favorable to a clear definition of the structural and hydraulic properties affecting the component motion.

RECIPROCATING MACHINE

77-1867

On the Frequency Content of the Surface Vibration of a Diesel Engine

V. Marples

Dept. of Engrg., Univ. of Warwick, Coventry, UK, J. Sound Vib., 52 (3), pp 365-386 (June 8, 1977) 12 figs, 17 refs

Key Words: Diesel engines, Vibration effects, Noise source identification, Noise reduction

The results of an experimental investigation into the narrow band frequency content of the surface vibration of a particular four cylinder, water-cooled, indirect injection diesel engine are described. The long term objective, of which the work reported here is a part, is the reduction of noise emission at source. Noise is radiated from the engine as a result of surface vibration. The characteristics of surface vibration are described and an explanation is given of why the discrete frequency response of the engine has hitherto appeared to be broad band in nature. The relationship of the pure tone response to the combustion pressure spectrum is also described.

ROAD

77-1868

An Experimental Investigation of Trunk Flutter of an Air Cushion Landing System

C.J. Forzono

Air Force Flight Dynamics Lab., Wright-Patterson AFB, OH, Rept. No. AFFDL-TR-75-107, 101 pp (Nov 76)
AD-A038 559/1GA

Key Words: Ground effect machines, Air cushion landing systems, Flutter

The objective of this work was to experimentally investigate the phenomenon of air cushion vehicle trunk flutter and attempt to eliminate it. The occurrence of trunk flutter was found to be eliminated with the use of tread strips (1/2 in.-wide pieces of rubber, cut to certain lengths and thicknesses) attached to the bottom of the trunk tread. These strips form channels when placed side-by-side that allow the flutter-producing cushion air to escape from beneath the vehicle without causing trunk flutter. This flutter elimination device can be employed without the loss of the required cushion pressure or an increase of the drive air flow into the air cushion system.

77-1869

Coupled Vertical-Lateral Dynamics of Pneumatic Tired Vehicles Subject to Roadway Roughness Inputs

N.S. Nathoo

Ph.D. Thesis, The Univ. of Texas at Austin, TX, 199 pp (1976)
UM 77-11,561

Key Words: Interaction: wheel-pavement, Mathematical models, Surface roughness, Automobiles, Coupled response, Pneumatic tires

A method is presented which permits the simulation of the coupled vertical and lateral response of an automobile to roadway roughness inputs. A general set of equations in matrix form is obtained for an assumed twelve degrees of freedom mathematical model of the vehicle-tire system using generalized linear and Euler angle coordinates. Kinematic relations for a rolling tire which treat it as an elastically supported string under tension are formulated to study its lateral behavior. A mathematical representation is obtained for the external forces that act on the vehicle through the tire-road contact interface as a function of vehicle response variables and parameters of the vehicle-tire system. The general set of equations is subsequently simplified in order to apply them to a vehicle moving along a straight rough roadway.

ROTORS

77-1870

A General Rotor Model System for Wind-Tunnel Investigations

J.C. Wilson

Langley Res. Center, NASA, Hampton, VA, J. Aircraft, 14 (7), pp 639-643 (July 1977) 11 figs, 1 table, 8 refs

Key Words: Rotors, Wind tunnel tests

A complex rotorcraft model system has been developed for the NASA Langley Research Center and the U.S. Army Air Mobility R&D Laboratory, Langley Directorate, for aerodynamic and acoustic experimental investigations in the NASA Langley V/STOL tunnel. This generalized rotor model system has a powered main rotor, tail rotor, and auxiliary engine capability. It may be configured to represent a variety of rotorcraft configurations. The first investigation was conducted to determine the performance, acoustic, stability, and control characteristics of the NASA/Army Rotor Systems Research Aircraft with an articulated rotor. In a second investigation, a 1/4-scale AH1G configuration with a teetering rotor is being represented to determine if a V-tail will improve the directional characteristics. Future programs are planned to investigate advanced rotor blade airfoils for improved performance and acoustic characteristics.

77-1871

Frequency Response Testing at High Frequency in a Noise Environment with Particular Reference to Condition Monitoring

M.F. White

Inst. of Sound and Vib. Res., Southampton Univ., Southampton, UK, Rept No. ISVR-TR-84, 112 pp (Apr 1976) refs

Sponsored by the Science Res. Council

N77-21477

Key Words: Rotating structures, Rotors, Natural frequency

Condition monitoring of rotating machinery demands a knowledge of the frequency response characteristics of machine structures over a wide frequency range. The problems of high frequency vibration testing are considered both theoretically and experimentally with particular reference to frequency response measurement in a noisy environment. The linear swept sinewave transient excitation method was applied to both simple and more typical test structures, and techniques for signal to noise ratio improvement were investigated. The improvement in accuracy of transient test data using ensemble averaging was found to be governed by the timebase stability of the excitation signal and frequency resolution. Finally, a method of inverse transformation was considered to enable signals from components within a machine to be related to the exciting force with the aid of transfer functions.

77-1872

Whirl Stability of the Pendulously Supported Flywheel System

W.T. Thomson, F.C. Younger, and H.S. Gordon Dept. of Engrg., Univ. of California, Santa Barbara, CA, J. Appl. Mech., Trans. ASME, 44 (2), pp 322-328 (June 1977) 12 figs, 2 tables, 7 refs

Key Words: Whirling, Flywheels, Rotor-bearing systems

The steady-state whirl-spin relationships for the pendulously supported flywheel with bearing flexibilities, stiff sections of shaft and gyroscopic action are derived and experimentally verified. Stable and unstable operations of the system are experimentally demonstrated, and damping necessary to stabilize an inherently unstable system is theoretically derived for two modes of bearing displacements.

77-1873

The Coupled Response of a Dynamic Element Riding on a Continuously Supported Beam

A.A. Alexandridis

Ph.D. Thesis, Princeton Univ., 170 pp (1977)

UM 77-14,232

Key Words: Mass-spring systems, Mass-beam systems, Coupled response, Moving loads

The dynamic interaction between a Linear Induction Motor primary, modelled as a spring-mass-damper dynamic element, and its secondary, modelled as a prestressed, continuously supported, infinitely long beam, is analyzed both theoretically and experimentally. The stability of the fully coupled dynamic system is determined analytically for all motor speeds by direct solution of the system characteristic equation. The existence of two transition speeds is established. At the lower transition speed, the frequency and damping ratio of the coupled system response attain their minimum and maximum values, respectively. The system is unstable at speeds higher than the second transition speed, which is designated as the "flutter" speed. Experimentally determined values of the frequency and damping ratio confirm the validity of the mathematical model.

SHIP

77-1874

Ship-Noise Control Case History

S/V, Sound Vib., 11 (6), pp 4-6 (June 1977)

Key Words: Boats, Noise reduction

Noise reduction on two U.S. Navy Weapon Retriever boats is described. It was accomplished by replacing the existing mufflers and exhaust pipe with eight wet type 4 inch high performance mufflers and new exhaust piping, lining the engine room bulkheads, hatch covers and interior hull surfaces with sound absorbing material, and insulating the exhaust piping from the engine manifold to the exhaust exit point through the hull just above water line.

SPACECRAFT

77-1875
Improvement in Flight Simulation of Space Vehicle Acoustic Tests

C.D. Knauer and A.J. Peterson
Hughes Aircraft Co., El Segundo, CA, Inst. Environ. Sci., Proc. 23rd Annual Mtg., Los Angelea, CA, pp 365-371 (Apr 25-27, 1977) 8 figs, 2 tables, 3 refs

Key Words: Spacecraft, Acoustic tests, Vibration response

Several Hughes-built communication satellites have been subjected to ground acoustic tests to demonstrate structural adequacy and to verify estimated component vibration environments under flight simulated conditions. Two different techniques were used in a recent acoustic test program. One technique utilizes a booster fairing around the space vehicle (shroud-on) while the other uses the space vehicle alone (shroud-off). In the shroud-on case, the space vehicle is subjected to a measured external shroud acoustic environment and responds to an attenuated chamber acoustic spectrum. In the shroud-off case, an analytically predicted transfer function which includes fairing attenuation, displaced cavity volume and other dynamic effects is used in conjunction with the shroud external environment to generate the applied space vehicle acoustic spectrum. The subject paper describes the differences between and effect of the two test techniques, notes the improvement in simulation with the shroud-on test data to acoustic testing of flight vehicles without shrouds.

77-1876
Alternatives to Notched Swept Sine Testing for Spacecraft and Other Large Systems

J.R. Fowler, R.J. Zuziak, D.T. DesForges, and P.R. Schrantz
Hughes Aircraft Co., El Segundo, CA, Inst. Environ. Sci., Proc. 23rd Annual Mtg., Los Angeles, CA, pp 351-361 (Apr 25-27, 1977) 10 figs, 2 tables

Key Words: Spacecraft, Testing techniques

The present test program evaluated four possible testing appoaches for qualifying both primary and secondary spacecraft structure, using a development model of the Intelsat IVA spacecraft. The primary structure test methods investigated were a variation to the current notched sine with a sweep rate of 8 oct/min rather than 4 oct/min, and a narrow band random dwell at primary structural resonances. Two transient test methods were employed for examining secondary structural response. The direct transient approach attempted to reproduce the analytically predicted response at a critical spacecraft location. The least favorable response transient test defined a time history whose Fourier spectrum amplitude and phase were most critical (least favorable) for a selected location. A detailed description of each of the above test methods is presented along with a comparison of each method to both the current notched sine approach and recent flight data.

77-1877
NASTRAN Structural Analysis of a Missile Fuze Electronic Assembly

D.W. Neily
Harry Diamond Labs., Adelphi, MD, Rept. No. HDL-TM-76-37, 24 pp (Dec 1976)
AD-A038 030/3GA

Key Words: Missile components, Natural frequencies, Mode shapes, Computer programs

The structure of the XM818 Fuze Electronic Assembly for application in the PATRIOT missile was analyzed by using the NASTRAN computer program. The levels and locations of maximum stress were found for a static loading. The shapes and frequencies of the lowest vibration modes were also computed. However, because of several limiting assumptions in the analysis, the stress levels for dynamic loads were not included. Experiments are recommended to obtain this information.

77-1878
Transient Excitation and Mechanical Admittance Test Techniques for Prediction of Payload Vibration Environments. Final Report

D.D. Kana and L.M. Vargas
Southwest Res. Inst., San Antonio, TX, Rept. No. NASA-CR-2787, 39 pp (Mar 1977) refs
N77-21473

Key Words: Transient excitation, Mechanical admittance, Launch vehicles, Mass-beam systems

Transient excitation forces were applied separately to simple beam-and-mass launch vehicle and payload models to develop complex admittance functions for the interface and other appropriate points on the structures. These measured admittances were then analytically combined by a matrix representation to obtain a description of the coupled system dynamic characteristics. Response of the payload model to excitation of the launch vehicle model was predicted and compared with results measured on the combined models. These results are also compared with results of earlier work in which a similar procedure was employed except that steady-state sinusoidal excitation techniques were included.

TRANSMISSIONS

77-1879

Prediction of Vibration and Noise of a Transmission Using a Dynamic Model Partially Derived from Test Data

M.A. Bowes and A. Berman
Kaman Aerospace Corp., Bloomfield, CT 06002,
Inst. Environ. Sci., Proc. 23rd Annual Mtg., Los Angeles, CA, pp 334-338 (Apr 25-27, 1977) 6 figs, 8 refs

Key Words: Power transmission systems, Helicopters, Component mode synthesis, Mathematical models, Vibration prediction, Noise prediction

A technique of component synthesis using discrete frequency impedance matrices has been applied to the prediction of the vibration and noise characteristics of a helicopter transmission. The separate mathematical models of the shaft and gears, the gear mesh induced forcing functions, and the housing radiated sound power were developed using purely analytic methods. The mathematical model of the complex transmission housing was developed using dynamic shake test data. The method includes the ability to predict the excitation forces, strains and displacements of the shafts, housing acceleration, and the radiated sound power. The method was validated by comparison of predictions with actual measurements taken on the complete system. The method is especially convenient and economical for the evaluation of the effects of design changes. Descriptions of the methods of analysis are presented, including the application to an actual transmission, the housing shake test and the correlation of housing accelerations and sound power measurements.

USEFUL APPLICATION

(See No. 1835)

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CALENDAR

NOVEMBER 1977

27 - Dec 2 **Winter Annual Meeting,** [ASME] Atlanta, GA *(ASME Hq.)*

DECEMBER 1977

6-8 **Sixth Turbomachinery Symposium,** Houston, TX *(Dr. M.P. Boyce, Gas Turbine Labs., ME Dept., Texas A&M, College Station, TX 77843)*

13-16 **Acoustical Society of America, Fall Meeting,** Miami Beach, FL *(ASA Hq.)*

MARCH 1978

25-27 **Applied Mechanics Western and J.S.M.E. Conference,** Honolulu, Hawaii *(ASME Hq.)*

APRIL 1978

3-5 **Design Engineering Conference & Show** [ASME] Chicago, IL *(R.C. Rosaler, Rice Assoc., 400 Madison Ave., N.Y., NY 10017)*

9-13 **Gas Turbine Conference & Products Show,** [ASME] London *(ASME Hq.)*

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)*

JUNE 1978

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

OCTOBER 1978

1-4 **Design Engineering Technical Conference,** Minneapolis, MN *(ASME Hq.)*

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

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

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

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

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

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

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

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

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

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

ARPA: Advanced Research Projects Agency

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

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

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

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

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

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

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

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

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

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

INCE: Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch,
Poughkeepsie, N.Y. 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, England

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

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

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, Mass. 02173