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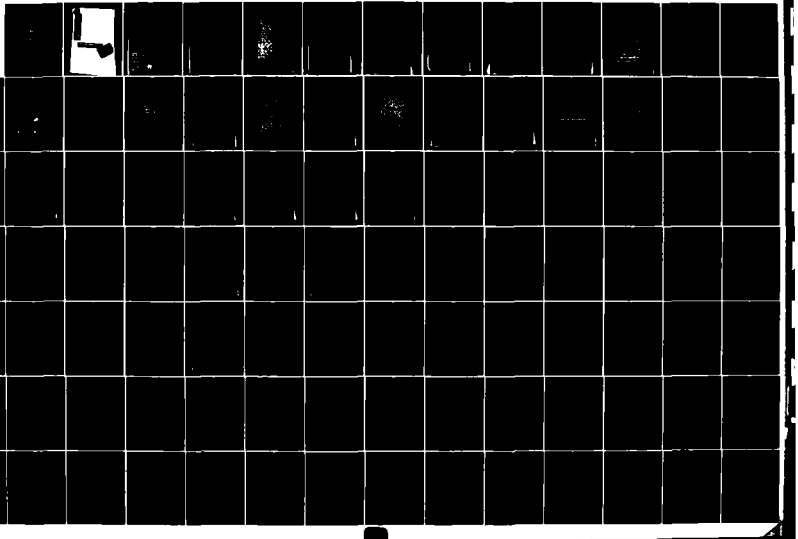

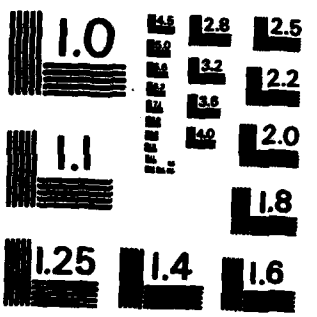

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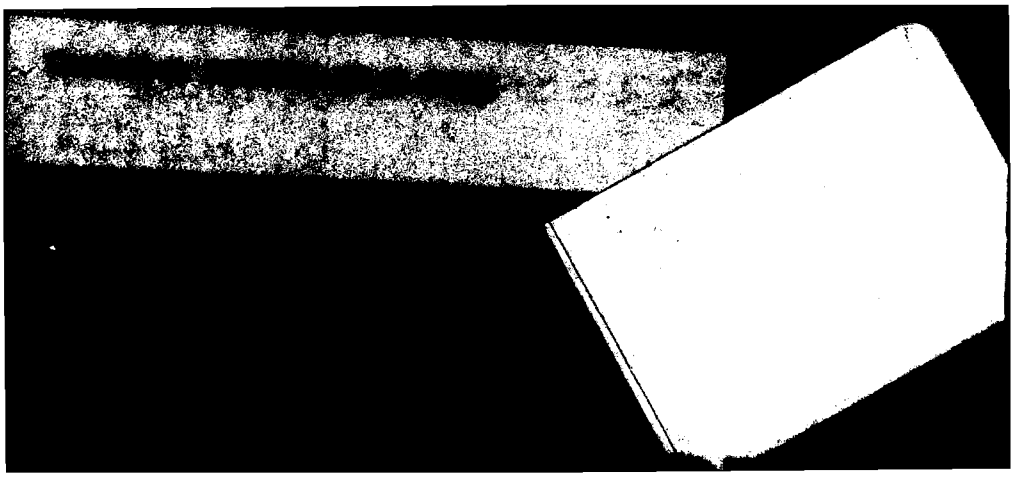


ABSTRACTS

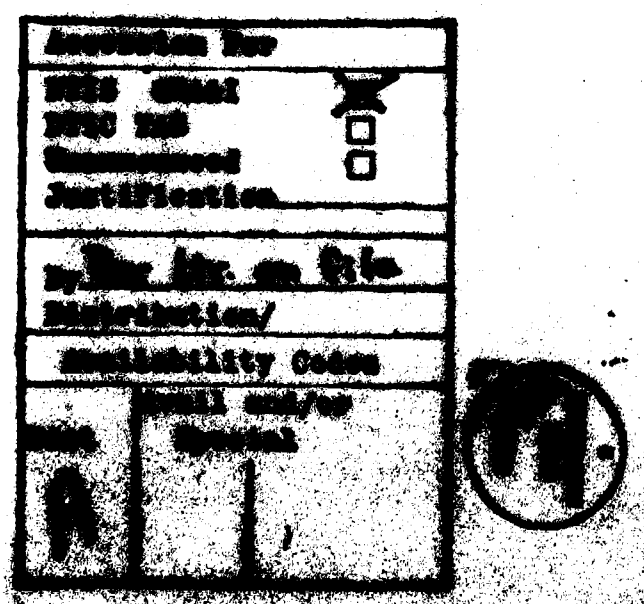
19th ANNUAL MEETING

SOCIETY OF ENGINEERING SCIENCE

OCTOBER 27, 28, 29, 1982

UNIVERSITY OF MISSOURI-ROLLA

ROLLA, MISSOURI



Preface

The focal point of the activities of the Society of Engineering Science is its annual technical meeting. The Department of Engineering Mechanics of the University of Missouri-Rolla is honored to be serving as host for this Nineteenth Annual Meeting of the Society.

The technical program of this meeting consists of 48 sessions in which 330 papers are scheduled for presentation. This book contains the abstracts of these papers. The program also includes three general lectures. On Wednesday, October 27, Professor J. L. Ericksen of the University of Minnesota will speak on "Some Phase Transitions in Solids". Thursday morning, Professor H. Grad of the Courant Institute of Mathematical Sciences, New York University will speak on "A Perspective On Magnetic Fusion Energy", and on Friday, Dr. Marvin E. Goldstein, Chief Scientist, NASA Lewis Research Center, will speak on "Aeroacoustics - The Interaction of Sound and Flows". Professor Grad is this year's SES medalist.

Most of the Program was developed by members of the Technical Program Committee. Their efforts in organizing interesting sessions are gratefully acknowledged. Papers marked with a * have been invited by the session organizers. Special thanks go to the three general lecturers, the authors and the session chairpersons and co-chairpersons for their contributions.

On behalf of the Local Organizing Committee we would like to thank the U.S. Army Research Office-Durham and the Office of Naval Research for financial support which defrayed part of the expenses of the meeting. We thank the U.S. National Science Foundation [illegible] providing travel support to a few participants from India. The views, opinions, and findings reported in this [illegible] are those of the author(s), and not those of any of the sponsors.

The Local Organizing Committee would also like to express its appreciation to Vicki Hudgins, Charlotte [illegible], and [illegible] for their invaluable assistance in every phase of the [illegible] arrangements.

Rolla, October 1982

R. C. [illegible]
R. L. [illegible]

ORGANIZATION OF THE 19th ANNUAL FIRE MEETING

[redacted]

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Session MM-1: ELASTICITY

Organizer and Chairperson: L. WHEELER, University of Houston
Co-Chairperson: R. ABEYARATNE, Michigan State University

* 9:30 - 10:00 C. O. HORGAN, Michigan State University:
"Further Results on Saint-Venant's Principle in Finite Elastostatics"

* 10:00 - 10:30 R. D. JAMES, Brown University:
"An Assessment of the Validity of the Clausius-Clapeyron Equation for Phase Transformations in Solids"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 L. E. PAYNE, Cornell University:
"Decay Estimates for a Class of Problems in Nonlinear Elasticity"

* 11:30 - 12:00 R. A. STERNBERG, Carnegie-Mellon University:
"On the Ellipticity of the Equations for Finite Elastostatic Plane Strain"

* 12:00 - 12:30 I. A. KUNIN, University of Houston:
"Elasticity as a Gauge Theory"

Further Results on Saint-Venant's Principle in Finite Elasticity*

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Abstract:

In a recent paper [1], a version of Saint-Venant's principle was formulated and established for [illegible] elasticity. In this context, it is no longer sufficient to consider self-equilibrated loads only (as in the linear theory) and the stress decay rate depends in general on the load level, as well as on geometric and material characteristics.

The setting considered in [1] is that of finite subregions (bands of homogeneous isotropic incompressible materials and the analysis used there is based on a subregion principle for second-order quasilinear elliptic partial differential equations. In this talk, we discuss two extensions of the work contained in [1]. On the basis of these, the joint work with R. Abeyaratne [2], concerning pointwise estimates for plane elasticity problems are used to obtain sharper estimates than those obtained in [1] for the case of self-equilibrated loads. Secondly, we report on an alternative approach (material due to collaboration with C. O. Horgan (to be published)) based on energy estimates.

References

[1] C. O. Horgan and J. K. Knowles, The effect of nonlinearity on a principle of Saint-Venant type, J. of Elasticity, 11 (1981), 271-281.

[2] C. O. Horgan and R. Abeyaratne, Finite anti-plane shear of a semi-infinite strip subject to a self-equilibrated end traction, Int. J. Solids Struct. (In press).

*This work was supported by the National Science Foundation under Grant [illegible].

An Assessment of the Validity of the Clausius-Clapeyron Equation for Phase Transformations in Solids

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The Clausius-Clapeyron equation is a relation between the heat absorbed in a slow phase transformation and derivative of the equilibrium pressure with respect to temperature. It can be generalized easily to thermoelastic solids, subject to nonhydrostatic stress, and as such it would appear to be a cornerstone of the thermodynamics of phase transformations in solids.

Unfortunately this is not the case. I shall give examples of some materials belonging to the class of shape-memory materials, which appear to be thermoelastic materials, for which the Clausius-Clapeyron equation fails. For other phase transformations, the α-β transition in quartz for example, and even for some of the shape-memory alloys at high temperatures, results based on the Clausius-Clapeyron equation agree quite well with observations.

To understand how the Clausius-Clapeyron equation may fail and to see what relations should replace it, I shall consider the assumptions from which it is derived. It is argued that the Gibbs stability criterion from which the Clausius-Clapeyron follows, while inappropriate for solids which change phase, can be modified to give reliable results.

Decay Estimates for a Class of Problems in Nonlinear Elasticity

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We consider a semi-infinite cylinder of homogeneous elastic material loaded on its base by a self-equilibrated distribution of forces. The lateral surface is assumed to be traction free. Under certain appropriate hypotheses it is then possible to show that either the displacements grow exponentially in L_2 with distance from the base or the mean value of the displacement over the cross section tends to a constant vector as this distance tends to infinity. In this latter case, it can be shown that the L_2 norm of the difference between the displacement and its mean value decays exponentially with distance from the base (work done jointly with R. J. Knops).

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Elasticity as a Gauge Theory

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It is well known that the development of the contemporary physics of elementary particles is closely connected with gauge theories. Recently, it was found [1,2] that the theory of dislocations and disclinations can be developed as a gauge theory starting from classical elasticity. This approach has led to interesting new results in the theory of defects.

In this paper, we show that linear and nonlinear elasticity are also gauge theories. This permits one to understand better the group-theoretical background of elasticity, as well as group invariance properties of solutions of the equations of elasticity.

1. A. A. Golebiewska-Lasota, Int. J. Engng. Sci., 17, 263 (1979).

2. A. Kadić and D. G. B. Edelen, Int. J. Engng. Sci., 20, 433 (1982).

Session WM-2: ACOUSTIC PROPAGATION

Organizer and Chairperson: A. CUMMINGS, University of Missouri-Rolla
Co-Chairperson: S. SAMI, Southern Illinois University

* 9:30 - 10:00 W. K. Van MOORHEM, University of Utah:
"A Review of Acoustic Propagation in the Atmosphere"

* 10:00 - 10:30 D. W. THOMSON, The Pennsylvania State University:
"Today's Micrometeorology Applied to the Interpretation of Outdoor Sound Propagation"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 R. J. ASTLEY, University of Missouri-Rolla:
"Finite and Infinite Elements for Acoustical Radiation"

* 11:30 - 12:00 K. J. BAUMEISTER, NASA Lewis Research Center:
"Numerical Techniques in Turbofan Inlet Acoustic Suppressor Design"

* 12:00 - 12:30 M. J. WALKINGTON and W. EVERSMAN, University of Missouri-Rolla:
"Finite Difference Solution to a One-Dimensional Nonlinear Problem in Acoustics"

A Review of Acoustic Propagation in the Atmosphere

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The propagation of acoustic signals in the atmosphere was one of the first areas investigated after the orgin of the science of acoustics. After several hundred years understanding of the major phenomena occuring in atmospheric propagation is not yet complete.

The propagation of acoustic signals in the atmosphere is dominated by six major effects, geometrical spreading, atmospheric absorption, reflection from the ground surface, refraction due to gradients in the speed of propagation, scattering from turbulence, and diffraction around obstacles. Present understanding of these phenomena ranges from essentially complete to very poor. Each of these areas is discussed in terms of the level of present understanding and in terms of its implications for long range acoustic propagation modeling.

Today's Micrometeorology Applied to the Interpretation of Outdoor Sound Propagation

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Contemporary field measurements and models of the atmosphere's surface and planetary boundary layers have been used to examine the spatial and temporal characteristics of sound propagating outdoors. From a micrometeorologist's point-of-view the characteristics of propagating sound are so sensitive to ambient velocity and temperature gradients that signal behavior can provide a viable "indirect" measure of atmospheric structure and processes. Specification of the atmospheric refractive index environment for acoustic propagation studies has been, generally, inadequate to facilitate examination of the mechanisms responsible for, in particular, observed signal fading. This paper reviews methods for evaluating signal amplitude and phase variations resulting from characteristic mean gradient and turbulent velocity and temperature fluctuations in the lower atmosphere. Particular attention is devoted to problems of sound propagation in complex terrain environments in which the refractive index field is not generally horizontally homogeneous. Recommendations for needed field experiments are also summarized.

FINITE AND INFINITE ELEMENTS FOR ACOUSTICAL RADIATION

R. J. Astley, Department of Mechanical and Aerospace Engineering
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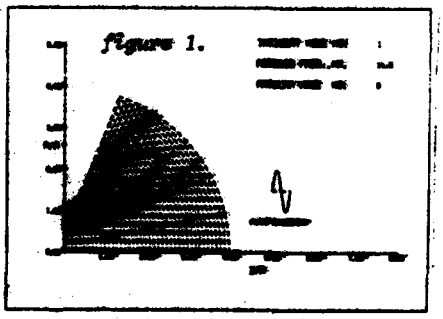
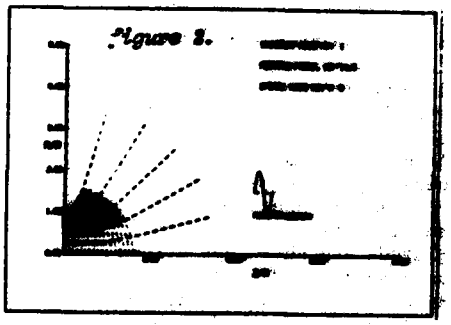
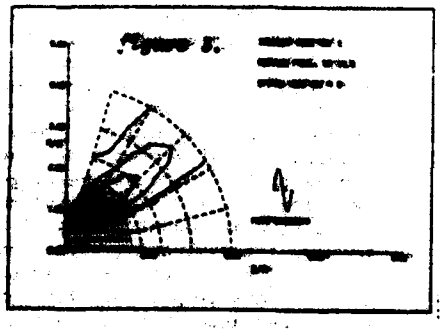
Radiation conditions at the open boundaries of wave propagation problems raise significant practical difficulties when purely numerical solutions are sought. The straightforward approach of selecting a suitably 'distant' boundary on which to impose a condition of locally normal plane wave propagation (a 'pu' admittance in acoustical terminology) frequently involves the use of an unacceptably large number of mesh points, especially for cases where the wavelength of the disturbance is small compared with the overall geometrical length scale of the problem.

An acoustical problem exhibiting these characteristics is that of fan noise radiation from the inlet of a turbofan aircraft engine and the results presented here form part of a continuing program to develop numerical techniques for this particular application. In an attempt to avoid the use of high resolution meshes, except in the near vicinity of the nacelle, finite element schemes are developed which utilize the infinite element and wave envelope element concept in an outer region but which match compatibly onto a conventional finite element scheme in the neighbourhood of the inlet itself. Typical computed absolute pressure contours for radiation from an 'hypothetical' bellmouth onto are shown in figures 1-3 for conventional, infinite element and wave envelope schemes respectively. The infinite element and wave envelope schemes are shown to be effective in representing the near field with an economy comparable to that of a more extensive conventional discretization. The wave envelope approach also yields reliable results in the far field.







NUMERICAL TECHNIQUES IN TURBOFAN INLET ACOUSTIC SUPPRESSOR DESIGN

Kenneth J. Baumeister
NASA Lewis Research Center
Cleveland, OH 44135

"Steady" state finite element theories and transient finite difference theories are currently being applied to the design of acoustically treated nacelles of turbojet engines. In this paper, numerical theories in conjunction with previously published analytical results are used to estimate the performance of an acoustic liner in a typical engine installation.

First, some background information on analytical and numerical techniques in duct acoustics is presented. In particular, a bibliography of numerical techniques in linear duct acoustics is included. Next, a procedure is presented for using previously published analytical results as the starting point of the numerical calculations. The importance of the cut-off ratio in the design is emphasized. Immediately following, a procedure for applying the numerical techniques is presented. The coupling between the duct and the far field in the numerical analysis is shown to significantly effect the predicted attenuation. Some design calculations are then presented which compare analytical, numerical, and experimental results for a commercial JT15D turbofan engine. Finally, the limitations of present numerical theories are discussed and future work is outlined.

FINITE DIFFERENCE SOLUTION TO A ONE-DIMENSIONAL NONLINEAR PROBLEM IN ACOUSTICS

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Linear acoustic theory is used extensively to solve problems in duct acoustics. In regions of high Mach number this theory fails as shown by the Fubini solution for plane waves in uniform ducts and more recently by the work of Myers and Callegari [1] for non-uniform ducts. There is also experimental evidence to suggest that subsonic choking may occur which has not been predicted by linear theory.

The finite difference method is employed widely to obtain approximate solutions to transonic flow problems. This method has been adapted here to solve a nonlinear acoustics problem. In order to limit the computational demands a one-dimensional model is considered. A method of modeling noise sources and anechoic terminations is developed by considering the characteristics of the gas dynamic equations.

Presently only continuous solutions have been sought, however, work is currently being undertaken to extend this technique to obtain shocked solutions. The results obtained to date are in good agreement with those obtained by Fubini and Myers and Callegari.

1. Myers and Callegari. Sound in Ducts Containing Nearly Choked Flows. AIAA-79-0623.

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Session III-A: [redacted]

Organizer and Chairperson: A. [redacted], Ohio University

Co-Chairperson: Th. S. Stevens, Kansas State University

- 9:30 – 10:00 [redacted]
- 10:00 – 10:30 [redacted]
- 10:30 – 11:00 [redacted]
- 11:00 – 11:30 [redacted]
- 11:30 – 12:00 [redacted]
- 12:00 – 12:15 [redacted]
- 12:15 – 12:30 [redacted]

OPTIMAL DESIGN OF VIBRATING ELASTIC-VISCOELASTIC SANDWICH BEAMS

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This topic features the application of an optimal control algorithm to a new class of continuous one-dimensional structural design problems. Both elastic and viscoelastic material distributions serve as control functions. Numerical results are presented.

PROBLEMS OF SHAPE OPTIMAL DESIGN

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Several examples of problems of shape optimal design of elastic bodies are presented, including constraints on stress, deflection, natural frequency, and admissible location of the boundary of the body. A material derivative technique is used, with variational formulation of the governing boundary-value problems of elasticity, to obtain derivatives of cost and constraint functionals with respect to domain variation. A discretization of the boundary design that is consistent with finite element numerical solution of the boundary-value problem is presented. Numerical solutions of examples, using gradient projection and augmented Lagrangian techniques are presented.

PARAMETER OPTIMIZATION IN THE DESIGN OF DYNAMIC SYSTEMS

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There are many interesting engineering design problems involving dynamical systems where the "control variables" are required to be parameters. Such a problem may be viewed from two perspectives. It is commonly viewed as a special case within optimal control theory. As shown here it may also be viewed as an extension of classical parameter optimization theory. Using each of these two viewpoints a different set of necessary conditions is obtained. This observation might appear to be of minor practical consequence since the two sets of conditions can be shown to be equivalent. However, this is not the case, since numerical implementation of the two sets of conditions differ greatly. The necessary conditions obtained from parameter optimization theory are generally easier to implement. This is demonstrated with the aid of some engineering design examples.

OPTIMIZATION PROBLEMS ASSOCIATED WITH CONTROLLABILITY AND ATTAINABILITY

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The problem of steering a system to a pre-specified target is termed the controllability problem. Two questions arise naturally in the study of this problem: (1) does there exist a control which steers the system to the target and (2) if a steering control exists, how can it be determined. Both of these questions can be answered by solving related optimization problems. These optimization problems are static dimensionally; hence, they are suitable for computer solution. The technique is applied to a two-point boundary problem and a time scaling problem.

The attainability problem is concerned with determining a system so that it reaches prescribed conditions (or, other problems in equivalent to this problem of bringing a system to a specified end). Finite dimensional optimization techniques are then applied to various engineering problems and illustrative numerical examples. The results are illustrated by applying them to a chemical reactor problem and a variation of the double integrator problem.

It is also shown that the results may be extended to systems where disturbances are present to obtain controls that guarantee the target is reached (or avoided) regardless of the disturbances.

Transformation Methods for Optimal Structural Design

Ashok D. Belegundu and Jasbir S. Arora
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The paper presents a general framework for the efficient use of transformation methods in optimal design of structural and mechanical systems. The term "transformation method" is used to describe any method that solves the constrained optimization problem by transforming it into one or more unconstrained problems. Transformation methods include multiplier methods, exterior and interior penalty function methods.

Many of the constraint functions in optimal structural design are implicit functions of design variables. This implicit nature of the constraint functions makes it very expensive to calculate their gradients. Transformation methods essentially collapse all constraints of the design problem into one equivalent functional constraint which serves as a penalty term for the transformation methods. It will be shown in this paper that the adjoint variable approach can be used to calculate the gradient of this functional without calculating the gradients of the individual constraint functions from which the functional is constructed. As a result, the gradient of the transformation functional is obtainable at a very cheap price and hence the minimization of this functional can be performed with little computational effort. Transformation methods are therefore able to exploit the implicit nature of the optimal design problem, unlike other methods, and are very attractive for optimal design of large systems. Moreover, transformation methods are also attractive because they have been proved to be globally convergent--that is, they converge from arbitrary starting designs.

Various algorithms for penalty function and multiplier methods are presented. The methods of computing the gradient of the transformation functional is described, and detailed operation counts are given to demonstrate significant savings in the suggested approach over the two other approaches used in the literature. The above idea has been used to optimize several small and large scale engineering design problems. Some of these results are presented. Finally, various other applications of the basic idea presented herein to compute the gradient of a functional are discussed.

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1. Arora, J. S., Huang, M. J., and Hsieh, C. C., "Efficient Constraint Treatment in Structural Optimization", Paper 80-DET, ASME National Convention, Hollywood, Fla., Oct. 1980.

Optimal Design of Minimum I-Columns

A. K. Agrawal and M. A. Ibrahim
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PO Box- 1616, Dhahran, Saudi Arabia

Optimal design of columns on the basis of minimum-weight has been the subject of extensive research. While some of the earlier works have been reviewed in Ref.(1), refs. (2-4) are cited to serve as a representative sample of some recent investigations into this area. Most of the work, which deals mainly with the shape optimization either over specified or assumed constraints, unfortunately does not lead to practical solutions. As I-sections are commonly used in engineering work, it is of interest to designers to find the optimum design of such shapes. An optimal design of homogeneous columns of built-up I-sections has been presented in Ref. 5. In this paper, the case of an I-section supported by a linear variation in depth is considered. The flange sheet are assumed to be constant for the column.

In seeking an optimal design of a tapered I-section, the general case of having different unsupported lengths about the principal axes is considered. While the buckling load in the plane of the web can be determined easily, that in the plane perpendicular to the web would require solution of an eigenvalue problem. The specified constraints are the minimum depth of web, the minimum plate thickness and the permissible width-thickness ratios of plate elements. Using an iterative search procedure on a computer, the minimum-weight proportioning is identified within the feasible design space.

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3. Taylor, J.E. and Liu, C.T., "Optimal Design of Columns", AIAA Journal, Vol.6, August, 1968.
4. Farshad, M., "Optimum Shape of Cantilevers Columns", Int. Journal Mech. Science, Vol.16, 1974.
5. Asad, A.K. "Rapid Design of Built-up I-shaped Compression Members", Canadian Journal of Civil Eng., Vol.9, 1982.

Session WM-4: PLASTICITY

Organizer and Chairperson: L.E.M. LEE, University of Notre Dame
Co-Chairperson: W.D. WEBSTER, General Motors Institute

* 9:30 - 10:00 M. J. FORRESTAL and D. B. LONGCOPE, Sandia National Laboratories:
"Analytical and Experimental Studies on Penetration into Geological Targets"

* 10:00 - 10:30 K. S. HAVNER, North Carolina State University:
"On the Existence of Plastic Potentials in Metal Crystals and Crystalline Aggregates at Finite Strain"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 E. KREMPL, Rensselaer Polytechnic Institute:
"Plasticity. Some Thoughts On Its Identification and Modeling"

* 11:30 - 12:00 P.S. SYMONDS and W. T. FLEMING, JR., Brown University:
"On Conditions for Validity of Simple Methods for Plastic Analysis of Pulse-Loaded Structures"

12:00 - 12:15 T. G. TRUCANO and D. E. GRADY, Sandia National Laboratories:
"Effect of Adiabatic Shear on High-Velocity Penetration"

12:15 - 12:30 M. DAVID and S. R. BODNER, Technion-Israel Institute of Technology:
"Dynamic Perforation of Viscoplastic Plates by Rigid Projectiles"

Analytical and Experimental Studies on Penetration into Geological Targets*

M. J. Forrestal and D. B. Longcope

Sandia National Laboratories
Albuquerque, N. M. 87185

Several elastic-plastic models which predict forces on rigid penetrators for normal impact into geological targets are developed and predictions from these models are compared with laboratory scale experiments and field tests. Constitutive description of the targets is guided by triaxial material test data for dry rock, concrete, and sea ice. These target materials are described by a linear hydrostat, a Mohr-Coulomb failure criteria with a tension cutoff and material density. The analyses are simplified by employing the cylindrical cavity expansion approximation which considers the target as thin independent layers normal to the penetration direction and allows only radial target motion. Governing partial differential equations are reduced, via a similarity transformation, to nonlinear ordinary differential equations and are solved both numerically and in closed-form for some special cases.

Laboratory scale experiments designed to verify the mathematical models were conducted. A light gas gun is used to accelerate simulated geological targets to steady velocities and impact the penetrators. Rigid body penetrator motion is measured for the time corresponding to two main lengths of penetration with laser interferometry and oscilloscopes. Resultant forces calculated from these data are in reasonably good agreement with predictions.

*This work was supported by the U. S. Department of Energy and the U. S. Army, Pershing II Project Manager's Office.

On the Existence of Plastic Potentials in Metal Crystals and Crystalline Aggregates at Finite Strain*

Kerry S. Havner

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Precise conditions for the existence of plastic potentials in single crystals are reassessed, following the analysis of Hill and Havner [1] (which amplifies and extends the seminal work of Hill and Rice [2]). Arbitrary, work-conjugate stress and strain measures are used throughout, with crystallographic slip the sole mechanism of inelastic deformation and the underlying lattice taken as Green-elastic. The proof of existence is extended to quasi-static (but not necessarily inviscid) deformation of crystalline aggregates through Hill's [3] averaging theorem and invariant bilinear form (recently reviewed in [4]). From [1], the principal results for single crystals are made explicit in terms of Green's measure of strain, supplemented by equations of transformation to other variables.

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*This work was supported in part by the U.S. National Science Foundation, Solid Mechanics Program, through Grant MEA-7908134.

PLASTICITY. SOME THOUGHTS ON ITS IDENTIFICATION AND MODELING

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Abstract

Recently new methods of defining "plasticity" were proposed which differ from the traditional plastic yield surface concept. Starting from the acknowledged fact that the plastic strains do not the only cause of "plasticity" fundamental hypotheses evolve. No necessary requirement with regard to definition of "plasticity" as distinguished from any viscoelasticity or other constitutive models. This distinction can then aid in selecting suitable constitutive equations for plasticity."

The proposed definition of plasticity goes with the commonly known observation that prior mechanical history changes the mechanical characteristics (strength) permanently. It rests on the comparison of the output histories of at least two specimens (volume elements), the first with the usually different prior mechanical history, to the same input history. If the two output histories are different, plasticity is said to have occurred for this combination of the applied mechanical effects on the specimens (volume elements). The proposed identification of plasticity holds in the presence of viscoelastic (hereditary) effects.

The changes in the output history to the same input history can be explained by acknowledging that the prior mechanical history permanently changed the internal constitution of the specimen (volume) element. Constitutive equations which are to represent plasticity must take into account suitable supplementary (or state) internal changes.

The above definitions will be illustrated by results of experiments performed with a servocontrolled 1100 aluminum specimen at room temperature and by the discussion of constitutive equations with various measures of internal change.

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On Conditions for Validity of Simple Methods for Plastic Analysis of Pulse-Loaded Structures

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In the analysis of dynamic plastic response of structures to pulse loading, certain idealizations form the basis of a body of theory and practical techniques. The idealizations include those of static limit analysis: rigid-perfectly plastic behavior and negligible geometry changes. The further idealizations of homogeneous stress-strain rate relations and of piecewise constant loading make possible an attractive "simple rigid-plastic" (SRP) theory for dynamic response. Within this theory upper and lower bounds are provided on response deflections and times; it is shown that the velocity pattern tends toward a mode form; efficient methods for determining these fundamental mode form solutions are derived; and they are the basis for approximate techniques. Analogous to the limit theorems of static analysis, the several estimation techniques provided by SRP theory are extraordinarily simple. The actual dynamic response, with mixed elastic/plastic/viscoplastic behaviors at large strains and deflections, is complex. Full details can be obtained only by numerical programs of considerable size and sophistication. The simple techniques meet a need. Unfortunately it is difficult to predict when they are valid, for load pulses of arbitrary magnitude and shape. There is a paucity of comparisons either with complete numerical solutions or with experiments.

The present paper makes use of a large finite element program[1] capable of treating material and geometrical nonlinearities to compare certain key features of the complete response with those predicted by an SRP analysis and by several estimation techniques based on it. These comparisons, particularly of energy dissipation rates and of the changing partition of plastic work over the structure, show the meaning of criteria for SRP analysis involving energy input and pulse duration parameters. They also clarify the significance of the mode approximation technique and of simplified elastic-plastic treatments based on separation of elastic and plastic response stages[2,3].

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EFFECT OF ADIABATIC SHEAR ON HIGH-VELOCITY PENETRATION

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Abstract

We report the results of an experimental and computational effort focused on identifying the effects and significance of adiabatic shear band formation in metal penetration phenomena. In the experiments that were performed, a hardened steel sphere impacted targets of 6061-T6 aluminum. The impact velocity varied from 0.6 to 1.2 km/sec. The targets were large enough to be treated as infinite half-spaces in the analysis and calculations. Depth of penetration and target microstructure were observed after each experiment, and compared with the results of quasistatic punch tests performed on identical targets. Shear bands were observed under the steel spheres in the dynamic experiments, but were absent in the quasistatic tests. Work-of-penetration differences were also noted between quasistatic and high-velocity tests. Computation and analysis performed indicated that thermal softening and/or thermal shear localization does strongly influence the dynamic penetration process. Calculations which did not explicitly account for thermal softening mechanisms fail to predict the observed depths of penetration. However, we have found that the importance of thermal softening and/or thermal shear localization is not as significant as previously reported by Stock and Thompson.[1]

*This work performed by Sandia National Laboratories supported by the U. S. Department of Energy under contract number DE-AC04-76-DP00789.

1. T. A. C. Stock and R. R. L. Thompson, Metallurgical Trans. Vol. 1, 219 (1970).

DYNAMIC PERFORATION OF VISCOPLASTIC PLATES BY RIGID PROJECTILES*

by

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Abstract

A model is formulated for the dynamic perforation of viscoplastic plates by rigid projectiles. The process is considered to occur in five continuously coupled but distinct stages which are amenable to analytical treatment. An essential feature of the analysis is the use of postulated, physically motivated deformation mechanisms in conjunction with the upper bound theorem of plasticity theory which is modified to include dynamic effects. Special attention is given to the bulging process and effects associated with the later stages. This model is self-contained and devoid of empirical factors. It predicts the exit velocities of the projectile and the plug and also the plug shape, provides the force-time history of the process, and describes a number of geometrical features of the transient and final deformation state of the target plate.

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*The research work reported in this paper has been sponsored in part by the U.S. Army (European Research Office, London) under Contract DAJA37-81-C-0047.

Session WM-5: BOUNDARY INTEGRAL METHODS

Organizer and Chairperson: M. STEIN, The University of Texas at Austin
Co-Chairperson: K. J. SENGH, General Electric Co.

* 9:30 - 10:00 G. F. CAREY and S. W. KIM, The University of Texas at Austin:
"Extension of Boundary Element Method to Lifting Subcritical Flows"

* 10:00 - 10:30 A. R. ROBINSON, University of Illinois-Urbana:
"Approximate Determination of Stresses and Displacements Near a Rounded Notch - A Boundary Integral Approach"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 G. FAIRWEATHER, The University of Kentucky and R. L. JOHNSTON, University of Toronto, Canada:
"The Method of Fundamental Solutions for Elliptic Boundary Value Problems"

* 11:30 - 12:00 M. MORJARIA, Cornell University:
"Inelastic Stress Analysis by the Boundary Element Method"

12:00 - 12:15 T. J. RUDOLPHI, Iowa State University:
"The Boundary Element Method for Zoned Media with Stress Discontinuities and Interior Cracks"

12:15 - 12:30 L. S. KANTHIS, Imperial College of Science and Technology, England:
"A General Direct BIE Formulation for Bounded- and Unbounded- Media with Cracks of Arbitrary Shape"

EXTENSION OF BOUNDARY ELEMENT METHOD

TO LIFTING SUBCRITICAL FLOWS

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The University of Texas at Austin

Abstract:

The boundary element method[1] is extended here to analysis of incompressible flows with circulation Γ. The Kutta condition is applied in two different approaches to show how the flow field and circulation can be efficiently determined. Numerical results have been computed for NACA 0012 airfoil at angle of attack α and computed life coefficient compared with experimental results. A detailed discussion is given in [2]. In a second part of the investigation we indicate how the method may be extended further to treat compressible flows using a Rayleigh-Jantzen type perturbation expansion and appropriate divergence manipulations to obtain the desired boundary integral form. The approach is currently being implemented in the boundary element program.

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1. Brebbia, A.C., Boundary Element Method for Engineers, Pentech Press, London, 1978.

2. Carey, G.F. and S.W. Kim, "Lifting Airfoil Calculations Using the Boundary Element Method", submitted to Int. J. Numer. Meth. Fluids, 1982.

3. Carey, G.F., "Extension of Boundary Element Method to Subcritical Flows", in Proc. Finite Elements and Fluids, Tokyo, August 1982 (to appear).

APPROXIMATE DETERMINATION OF STRESSES AND DISPLACEMENTS NEAR A ROUNDED NOTCH — A BOUNDARY INTEGRAL APPROACH

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University of Illinois at Urbana-Champaign

ABSTRACT

The plane elasticity solution for a loaded body having a notch with a continuously turning contour will clearly result in stresses and displacements near the notch that are strongly dependent on the details of the contour of the notch. Yet, at points in the body situated at a distance from the notch equal to a large multiple of its smallest radius of curvature, the stresses will be almost indistinguishable from what would be obtained were the notch sharp. A method is developed using a boundary integral equation technique that readily leads to solutions having this general character.

The procedure makes use of earlier work for a sharp notch that introduced new types of singularities in the boundary integral equation method. These are singularities that have long been known to describe the behavior near a sharp notch. In the present work, modifications of the earlier technique are made to arrive at a series of fundamental solutions all of which satisfy the boundary conditions on the contour of the notch. The coefficients of the series are generalized coordinates which are determined from boundary integral equations.

The method does not suffer from errors due to the crowding of points in the highly curved part of the boundary. It has been found to give accurate and numerically stable results with quite small computational effort.

THE METHOD OF FUNDAMENTAL SOLUTIONS FOR ELLIPTIC BOUNDARY VALUE PROBLEMS

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A useful technique for the numerical solution of certain elliptic boundary value problems is the boundary integral equation method (BIEM), which is applicable when a fundamental solution of the differential equation in question is known. In this method, such a solution is combined with the desired solution through a reciprocal theorem to reformulate the boundary value problem as an integral equation on the boundary of the domain of the problem. A boundary method of more recent vintage is the method of fundamental solutions (MFS), [1,2], which has some of the characteristics of the BIEM, and several advantages over this method. In the MFS, the desired solution u is approximated by a function u_N of the form

$$u_N(\underline{c},\underline{t};P) = \sum_{j=1}^{N} c_j K(P,Q_j) , \quad P \in \bar{\Omega} ,$$

where $\Omega \subset \mathbb{R}^n$ is the domain of the problem with boundary $\partial\Omega$, $\bar{\Omega} = \Omega \cup \partial\Omega$, $K(P,Q)$ is a fundamental solution of the differential equation, $\underline{c} = (c_1,c_2,\ldots,c_N)^T$, and $\underline{t}$ is an nN-vector giving the coordinates of the singularities, Q_j, $j=1,\ldots,N$, which lie outside $\bar{\Omega}$. If the boundary conditions are of the form $Bu=0$, one seeks the best approximation $u_N^* = u_N(\underline{c}^*,\underline{t}^*;P)$ satisfying

$$\|Bu_N^*\|_2^2 = \min_{\underline{c},\underline{t}} \|Bu_N\|_2^2 = \min_{\underline{c},\underline{t}} \sum_{i=1}^{m} |Bu_N(\underline{c},\underline{t};P_i)|^2 ,$$

where $\{P_i\}_{i=1}^m$ is a set of points lying on the boundary $\partial\Omega$. This is a non-linear least squares minimization problem, which can be solved using existing software. For the solution of Laplace's equation, an adaptive MFS algorithm has been developed [3], and many difficult problems, such as those with discontinuous boundary conditions or involving re-entrant corners, have been handled relatively easily.

The MFS has several advantages over the BIEM. For example, it does not require a discretization of the boundary $\partial\Omega$, nor does it involve any integrations over $\partial\Omega$. Also the determination of an approximation to u(P), $P \in \Omega$, requires only an evaluation of the approximate solution u_N whereas in the BIEM a quadrature is necessary. Until recently, a serious drawback of the MFS was that its formulation for problems other than those involving Laplace's equation or the Helmholtz equation was unknown. However, a newly established connection between the MFS and the indirect BIEM indicates how other problems may be tackled using the MFS. This connection will be discussed and the extension of the MFS to the biharmonic equation and problems in plane elasticity described.

1. R. Mathon & R.L. Johnston, SIAM J. Numer. Anal., 14(1977), 638-650.
2. R.L. Johnston & R. Mathon, Inter. J. Numer. Meth. Engn., 14(1979), 1739-1760.
3. S. Ho-Tai, R.L. Johnston & R. Mathon, Technical Report 136/79, Computer Science Department, University of Toronto.

Inelastic Stress Analysis by the Boundary Element Method

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ABSTRACT

The boundary element scheme for solution of various problems of time dependent inelastic deformation in bodies will be presented. The formulation utilizes more accurate combined creep and plasticity constitutive theories with state variables to model material behavior.

The general solution scheme consists of formulating the given problem in terms of real time rates. This leads to a linear inhomogeneous boundary value problem which is solved at each time step to find the rates of variables of interest. These rates are then used to integrate forward in time to obtain time-histories of variables of interest. An Euler type integration scheme with automatic time-step control will be presented.

Specific applications of the boundary element method have been made to the general inelastic plane strain/stress plate bending, axisymmetric and torsion problems. Some numerical results for all these problems will be presented.

A powerful and interesting application of the boundary element method to inelastic fracture mechanics will also be presented. This formulation involves modification of the integral kernels in order to satisfy the proper boundary conditions and singularity at the crack surface. Some numerical results for this application will also be presented.

THE BOUNDARY ELEMENT METHOD FOR ZONED MEDIA WITH STRESS DISCONTINUITIES AND INTERIOR CRACKS

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The boundary element method as it applies to two dimensional elastostatic problems is implemented with quadratic variation in boundary variables and geometry. Additional parameters are associated with nodes at segment intersections to allow for discontinuous tractions. Supplementary equations consistent with linear elasticity are used to augment the regular boundary integral equations for certain mixed and displacement boundary conditions. Zoning or subregionalization capabilities are included to provide solutions to piecewise nonhomogeneous problems or to problems on regions of irregular shape which can normally cause numerical instabilities.

With the usage of modified kernels, as developed from the point load in an infinite medium with a crack, the method may be used to solve problems involving multiple interior cracks. Stress intensity factors for mixed mode crack interaction are readily determined. Example problems are given to demonstrate the accuracy of the technique.

A General Direct BIE Formulation for Bounded - and Unbounded - Media with Cracks of Arbitrary Shape.

By L.S. Kassiotis

Mathematics Department, Imperial College of Science and Technology, London S.W.7, England.

ABSTRACT:
The direct application of the new classical BIE formulation to a cavity problem when the cavity 'shrinks' to a crack (i.e. a cavity with no interior) is nugatory, unless a 'sub-domain' modelling technique is used - at the cost, though, of introducing artificial boundaries. Other remedial methods have been proposed such as 'open cavity' or 'open notch' modelling, symmetric crack modelling, the use of fundamental crack solutions, etc., but these methods either do not model the exact crack or do not fit comfortably in the framework of the general procedure.

In the present paper a formulation is proposed which aims at avoiding the above difficulties and treats the arbitrary crack problem as a system of two Direct BIE's, a 'first-order' and a 'second-order' one [1]. The validity of this formulation is exhibited by treating an anti-plane crack problem in a finite medium using a quadratic isoparametric boundary element implementation.

[1] L.S. Kassiotis : 'Higher-order Direct Boundary Elements', 4th Intern. Conf. B.E.M. in Engng., University of Southampton, Southampton, England, (1982).

Session WM-6: FLOW IN COLLAPSIBLE TUBES AND PERISTALTIC FLOW

Organizer and Chairperson: H. J. RATH, University of Bremen, W. Germany
Co-Chairperson: P.N.O. MBAEYI, Universität Tubingen

* 9:30 - 10:00 R. COLLINS, A. HIFDI and E. COLLINS, Université Paul Sabatier, France:
"Airflow in the Human Respiratory System - A Computational Model"

* 10:00 - 10:30 D. C. WINTER, University of Houston:
"Elastic Properties of Collapsing and Expanding Airways In-Vivo"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 O. MAHRENHOLTZ, University of Hannover, W. Germany:
"Peristaltic Flow: Mathematical Description and Experimental Verification"

* 11:30 - 12:00 H. J. RATH, University of Bremen, W. Germany:
"Peristaltic Flow of Non-Newtonian Two-Phase Mixtures"

AIRFLOW IN THE HUMAN RESPIRATORY SYSTEM - A COMPUTATIONAL MODEL

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A complete branching model of the respiratory system is developed on the basis of detailed anatomical measurements of Horsfield et al. (1971) and Fredberg et al. (1978). A quasi one- dimensional formulation for the coupled fluid/wall interaction is resolved numerically using a modified two- step Lax-Wendroff finite- difference technique. This solution can subsequently be used to estimate the regional deposition of fine aerosol particles in the human lung.

ELASTIC PROPERTIES OF COLLAPSING AND EXPANDING AIRWAYS IN-VIVO

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The compliance of the airways is a determining factor in the collapse of the airways and also in the airway wave speed, which is important in expiratory flow limitation. We previously reported on in-vivo compliance measurements in the tracheas of anesthetized dogs and found them to be significantly different than for excised trachea (1). The previous work was for expanding tracheas, and we have modified our method to measure the compliance of collapsing tracheas.

Anesthetized, open chest dogs were intubated ~4cm above the carina and ventilated. The upper portion of the trachea was then sealed at both ends. Volumes of air could be injected into the sealed segment and pressures inside the segment measured. Initial volume was estimated with the trachea in place after the experiment by measuring the upper and lower diameters and length of the sealed segment.

Results for one sequence of pressure-volume measurements are shown in Figure 1. Beginning at resting volume (zero transmural pressure) an increasing volume of air was injected into the sealed segment in 1 ml increments. The pressure inside was allowed to stabilize before the next volume was injected. After a maximum pressure of $\sim 2.5 \times 10^3$ dynes/cm^2 was reached, 1 ml volumes were successively removed until the original volume was reached. Note the hysteresis exhibited by the curve and that the compliance (as measured by the inverse slope of the linear portions of the curves) is the same for increasing and decreasing volumes.

Figure 2 shows one pressure-volume curve for which the pressure was returned to zero between each volume injection and for which measurements were taken for both positive and negative transmural pressures. Average compliance values for collapsing trachea were higher (28.4×10^{-6} (dynes/cm^2)$^{-1}$) than for expanding trachea (15.0×10^{-6} (dynes/cm^2)$^{-1}$) for all dogs. The compliance values for expanding trachea agreed with those we previously reported (1).

References: 1. Winter, D.C. et al., Elastic properties of the dog trachea in-vivo, 1981 ASME Biomechanics Symposium, Boulder, CO.

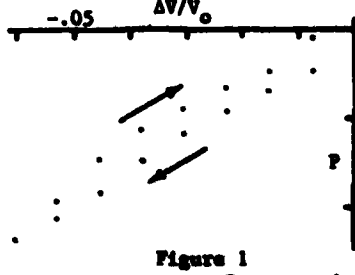

Figure 1

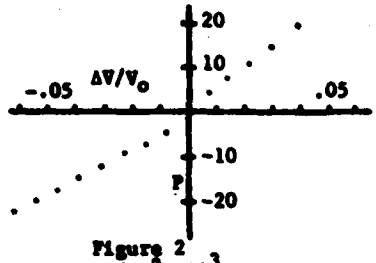

Figure 2

Pressure is shown in dynes/cm^2 x 10^3

PERISTALTIC FLOW: MATHEMATICAL DESCRIPTION AND EXPERIMENTAL VERIFICATION

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Peristaltic flow which belongs to inner biofluiddynamics is a most unique transporting mechanism. Over short distances alimentation of living cells and taking away metabolic products is carried out by diffusion and osmotic pressure. But with rising distances in higher developed animals a directed and controlled flow of the transporting solvent is needed. In contrast to technology, where a huge quantity of different pumpes is used, nature presents only a small variety of pumping processes, mainly pumping of the heart and in various hollow organs the use of peristalsis.

Although the peristaltic motion has been known for a long time, fluidmechanical behaviour was not investigated until about two decades ago.

Modern mathematical methods in combination with effective computer-systems followed the first restricted approaches. Pressure height, volume flow, velocity distribution, stream- and path-lines have been calculated for unsymmetrical waves, higher amplitude ratios and higher Reynolds numbers.

To verify these results, we used an experimental set-up, which models a plane-flow-condition with one moving wall. Beside the characteristic figures of the pumping process depending on the geometry, the motion of fluid-particles relative to each other is a most interesting detail. A hydrogen-bubble-technique was used for the visualization. The generated bubble profiles were filmed by a movie-camera and compared to the calculated profiles. On pictures of streamlines in the moving wave frame in which the flow is stationary the behaviour of the boundary layer is visible.

Under the effect of inertia and the presence of an adverse pressure gradient the boundary-layer separates in the diverging part of the channel. As backflow is obstructed by this the pressure height of peristalsis is enlarged.

PERISTALTIC FLOW OF NON-NEWTONIAN TWO-PHASE MIXTURES

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The dynamics of fluid transport by peristaltic motion of the confining walls has received careful study in the recent literature. Peristaltic pumping is the common mechanism for urine transport from kidney to bladder, food mixing and motility in the intestine, ejection of semen in male reproductive organs, and egg transport in female fallopian tubes. Technical roller and finger pumps using viscous fluids also operate on this principle.

We consider the two-dimensional plane peristaltic flow of an incompressible Non-Newtonian fluid containing solid spherical particles. The traveling waves are represented by the function $h(x,t) = a + b \sin(2\pi/\lambda\ (x - c\ t))$ where a is the mean half width of the channel, b is the amplitude of the peristaltic wave, c is the constant wave speed and λ is the wavelength. It is assumed that the wavelength is large compared with the channel width and the appropiate Reynolds number is small compared with unity. Furthermore we introduce the wave frame of reference (X,Y) which moves in the x- direction with the wave speed c relative to the laboratory frame (x,y,t). The variables measured in the wave frame are defined by

$$X = x - c\ t\ ;\ Y = y\ ;\ \hat{\alpha} = \alpha\ ;\ P = p\ ;\ U = u - c\ t\ ;\ U_p = u_p - c\ t\ ;\ V = v\ ;\ V_p = v_p.$$

where $(U,V),(U_p,V_p)$ are the components of the fluid velocity and particulate velocity in the X- and Y directions, respectively, P is the pressure and $\hat{\alpha}$ is the volume fraction of the particles, measured in the wave frame. The continuity equations and the inertia- free momenium equations for the fluid phase and particulate phase are given by

$$\frac{\partial((1-\hat{\alpha})U)}{\partial X} + \frac{\partial((1-\hat{\alpha})V)}{\partial Y} = 0\ ;\quad \frac{\partial(\hat{\alpha}U_p)}{\partial X} + \frac{\partial(\hat{\alpha}V_p)}{\partial Y} = 0$$

$$-(1-\hat{\alpha})\frac{\partial P}{\partial X} - \hat{\alpha}F\ (U - U_p) + \frac{\partial}{\partial Y}\left(K(\hat{\alpha})\ \frac{\partial U}{\partial Y}\ \left|\frac{\partial U}{\partial Y}\right|^{n-1}\right) = 0$$

$$-\frac{\partial P}{\partial X} + F\ (U - U_p) = 0\ ;\quad -\frac{\partial P}{\partial Y} + F\ (V - V_p) = 0$$

$$-(1-\hat{\alpha})\ \frac{\partial P}{\partial Y} - \hat{\alpha}F\ (V - V_p) = 0$$

where K and n are the parameters of the rheological model and F is the drag coefficient for the spherical particles. For $n = 1$ we have Newtonian behavior of the fluid ($K = \mu$). We see that by means of the wave frame of reference the fundamental equations become stationary. The partial differential equation system standing above has been solved analytically. Velocity distributions of the fluid phase and particular phase as well as relative concentration curves and pressure- flow relationships are given. The results are compared with the case of a single- phase fluid. It will be shown that the parameters K, n, $\hat{\alpha}$, F, the normalized pressure gradient and the dimensionless time- mean flow have an influence on the velocity distributions and pressure-flow relationship.

Session WM-7: FRACTURE OF COMPOSITE MATERIALS

Organizer and Chairperson: G. J. DVORAK, University of Utah

Co-Chairperson: R. SCHRENKER, Monsanto, St. Louis

* 9:30 - 10:00 S. GHAFFARI and J. AWERBUCH, Drexel University: "Monitoring Damage Accumulation in Graphite/Polyimide Laminates During Fatigue Loading Through Acoustic Emission"

* 10:00 - 10:30 W. L. BRADLEY and P. S. VANDEKKLEY, Texas A & M Univ.: "Mixed Mode Delamination Cracking of Graphite/Epoxy Composites"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 U. YUCEOGLU and D. P. UPDIKE, Lehigh University: "Delamination Fracture in Bonded Laminates and Joints"

11:30 - 11:45 T. R. TAUCHERT and S. ADIBHATLA, University of Kentucky: "Optimum Design of Composite Plates"

11:45 - 12:00 J. T. PINDERA and B. R. KRASNOWSKI, University of Waterloo, and M-J. PINDERA, Material Sciences Corporation, PA: "Fracture Mechanics of Homogeneous and Heterogeneous Structures Using Isodyne Photoelasticity"

12:00 - 12:15 V. K. KINRA and E. L. KER, University of Colorado: "On the Existence of Pass-Bands and Stop-Bands in Periodic Particulate Composites"

12:15 - 12:30 G. OMDIKE and C. VILMANN, Michigan Technological University: "Dislocations in Layered Media"

12:30 - 12:45 R. P. KHETAN and D. C. CHANG, General Motors Research Laboratories: "Surface Damage of Sheet Molding Compound Panels Subject to a Point Impact Loading"

"Monitoring Damage Accumulation in Graphite/Polyimide Laminates During Fatigue Loading Through Acoustic Emission"*

S. Ghaffari and J. Awerbuch**

This study concentrates on monitoring damage initiation and progression through acoustic emission in unnotched and center-notched graphite/polyimide $[0/+45/90-45]_{2s}$ laminate, subjected to low cycle fatigue loading. Specimens were cycled at a frequency of 0.1 Hz and 1.0 Hz up to 5000 and 10,000 cycles, respectively. The objective of this study is to investigate the potential of acoustic emission for locating existing damage, detecting and tracking damage initiation and progression, identifying potential fracture sites and possibly distinguishing between the major failure mechanisms. Special emphasis is placed on an attempt to distinguish those emissions caused by newly created damage from those caused by friction among existing fracture surfaces (delamination and matrix cracking). It has already been determined that a significant amount of emission is caused by such existing damage.

Data recorded include accumulative events, counts, count-rate, and number of counts per event as a function of applied load and number of cycles, and line location and amplitude distribution histograms of events. Acoustic emission results are compared qualitatively with visual microscope observations of the actual damage progression in real time and with the fracture behavior and deformation characteristics of the subject laminate.

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* Work supported in part by NASA Langley Research Center

**Graduate Student and Associate Professor, respectively, Department of Mechanical Engineering and Mechanics, Drexel University, Philadelphia, PA 19104

Mixed Mode Delamination Cracking of Graphite/Epoxy Composites

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A new test for studying the mixed mode I/mode II delamination fracture has been developed. An asymmetrically loaded double cantilevered beam (DCB), rigidly supported at the uncracked end, is tested with the results analyzed using simple beam theory. Superposition is utilized to separate the loads into a symmetric component $\frac{P_1 + P_2}{2}$ and an asymmetric component $\frac{P_1 - P_2}{2}$. The pure mode I energy release rate G_I is determined using standard DCB analysis for a load of $\frac{P_1 + P_2}{2}$ pulling the beams open. The mode II energy release rate G_{II} is calculated assuming the two beams are deflected in the same direction with a load of $\frac{P_1 - P_2}{2}$. Adjacent to the crack tip the inside elements of the two beams are in tension and compression respectively, giving a pure shear stress at the crack tip.

As the fraction of mode II energy release rate $(\frac{G_{II}}{G_I + G_{II}})$ increases from 0 to 0.35, the total critical energy release rate $G_{I,IIc}$ increased from 150 J/m^2 to 550 J/m^2. Fractographic examination of the specimens indicated increasing incidence of "scalloping" and fiber breakage with increasing component of G_{II}. The results have been interpreted to imply that the effect of increasing mode II shear is to continually redirect the crack into the fibers, the crack apparently trying to propagate on the principal normal stress plane. As the crack cannot typically break the fibers, microcracks must be repeated nucleated and coalesced with the macrocrack, giving a fracture surface with a morphology similar to that of a saw blade.

DELAMINATION FRACTURE IN BONDED LAMINATES AND JOINTS

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Fatigue and static failure behavior observed in anisotropic layered composites such as bonded multi-layer plates and shells are very complicated. Several failure modes interact and modify each other in many cases. It is obvious, then, that the task of including all the failure mechanisms in an analytical model would be intractable. Therefore, some simplications in the analytical model are necessary. In the case of bonded multi-layer plates and shells made up from metallic alloys the dominant failure modes are usually a mixture of transverse cracking and delamination within the adhesive layer. Experimental observations indicate that failure usually initiates from initial flaws and discontinuities where relatively high stress concentrations occur.

Therefore, the objective of this study is to consider approximate analytical formulation of the static delamination failure in multi-layer cylindrical shells starting from one (or two closely spaced) initial delamination flaw(s). The composite shell is assumed to be under internal pressure with pressure leaking into both flaws or cavities as in Fig. 1. The delamination fracture/failure criteria used for adhesive bonded laminates are mainly S - Criterion [1] and G - Criterion [2]. Since the stress concentration factors can be readily calculated as shown in [2], the G - Criterion is employed here. Then Griffith's Strain Energy Release Rate or G - Criterion yields the critical pressure at the onset of unstable delamination propagation as

$$P_{cr}\sqrt{t/B\gamma_a} = \{2/[(k_1+1)^2 + (B/G)(k_2^2+k_3^2)]\}^{\frac{1}{2}}; \quad P_o \longrightarrow P_{cr} \qquad (1)$$

where t is the adhesive thickness and B and G is adhesive elastic constants, and k_1 is the adhesive normal stress and k_2, k_3 are adhesive shear stress concentrations. Assuming that γ_a for the adhesive is known or obtained experimentally, the critical pressure P_{cr} is, then, calculated and plotted as a function of delamination flaw length $\ell(\ell_1 = \ell_2 = \ell)$. Further extension of the analysis to the dynamic delamation fracture cases is also discussed.

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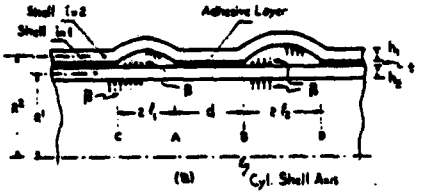

Fig. 1

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OPTIMUM DESIGN OF COMPOSITE PLATES

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Optimum design of laminated fiber-reinforced composite structures entails a determination of the number of plies and the corresponding ply orientations. In this paper an optimization procedure is proposed for the design of composite plates subject to flexure. The optimality criterion considered is that of minimum strain energy. This criterion, known also as the criterion of maximum stiffness [1], has been used successfully for the design of fiber-reinforced beams and pressure vessels [2]. In the case of plates obeying the Kirchhoff-Love hypothesis, deformation analysis is carried out using the Rayleigh-Ritz method. A quasi-Newton procedure is used for the optimization, with the initial point obtained via a random jump technique. Numerical results are presented for rectangular laminates possessing mid-plane symmetry. Various boundary conditions and loadings, including distributed and discrete forces and temperature variations, are considered. The effects of imposing orientation restrictions [3] on the laminate design are also examined.

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FRACTURE MECHANICS OF HOMOGENEOUS AND HETEROGENEOUS STRUCTURES USING ISODYNE PHOTOELASTICITY

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The actual stress states at tips of notches and cracks in plates, or lamination boundaries, are three-dimensional and are pronounceably spatially distributed. In homogeneous materials, the existence of such stress states is often overlooked in engineering practice and research, particularly when the geometry of body suggests the existence of a plane stress state. In heterogeneous materials (laminated or composite structures) this problem is much more complicated; however, the influence of the actual, three-dimensional stress state on the structural integrity for these materials is often stronger than for homogeneous materials.

The current experimental methods are insufficient to verify various simplified analytical solutions because of inherent limitations, particularly when employed for heterogeneous materials.

It is also well-known that the three-dimensional stress state influences the crack initiation and propagation in homogeneous materials; in composite structures, e.g. connections, the actual three-dimensional stress state can lead to delaminations, which are caused by the so-called peel stresses; in the plane stress field approach such stresses are neglected.

It has been shown that the non-destructive methods of isodyne photoelasticity can be easily applied to detect and to determine the actual components of the stress states in regions of contacts and cracks.

A problem of great importance in laminated composite structures is the stress redistribution in the vicinity of cracked layers. Such situations arise in configurations that include laminae oriented at 90° to the load axis. That problem is the main topic of this paper.

The actual stress fields determined by the method of isodynes is compared with various analytical results in order to determine the range of validity of the idealized mathematical models.

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On the Existence of Pass-Bands and Stop-Bands in Periodic Particulate Composites

by

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It has been shown previously that the dispersion curve for periodic layered (one-dimensional) and fibrous (two-dimensional) composites is characterized by pass-bands and stop-bands. In this work we demonstrate experimentally the existence of the same in two periodic particulate (three-dimensional) composites: 1) glass spheres (2 mm dia.) in an epoxy matrix with a $(2.54\ \text{mm})^3$ unit cell and a volume fraction of inclusions, $C = 13.5\%$; and 2) steel spheres (1.1 mm dia.) in PMMA with a 1.32 x 1.32 x 2.63 mm tetragonal cell, and $C = 25.6\%$. Two through-transmission ultrasonic apparatus were used: 1) water-immersion and 2) direct-contact. The phase velocity, $\langle C_1 \rangle$, and the attenuation, $\langle \alpha \rangle$, of longitudinal waves in the [100] crystal direction were measured in the frequency range $0.17 \leq n \leq 2.5$ MHz. Both the toneburst (steady state) and the ultrasonic spectroscopy (transient) methods were used.

RESULTS. Let $\Omega = k_1 d/\pi = (2d/C_1)n$ and $\xi = \langle k_1 \rangle d/\pi$, where d is the unit cell dimension and $\langle\ \rangle$ denotes a composite property. The figure shows three pass-bands and two stop-bands. In a layered composite the pass-bands do not overlap; here, along the ξ-axis, they do. The inset shows corresponding results for a fibrous composite [1]: the pass-bands overlap. The condition ξ = a positive integer for stop-bands (exact for a layered composite) is satisfied only approximately. The higher stop-bands, $\xi = 3$ and $\xi = 4$, are not observed. (For glass/epoxy case (larger spheres), $\xi = 1$ was observed, $\xi = 2$ and $\xi = 3$ were not). We conjecture that the absence of higher stop-bands is due to the excitation of particle resonances which dominates the lattice resonances. Steel/PMMA random composites with the same C were also tested. At very low and very high Ω, $\langle C_1 \rangle$ for the two cases becomes nearly identical; $\langle \alpha \rangle$ is generally higher for the random case.

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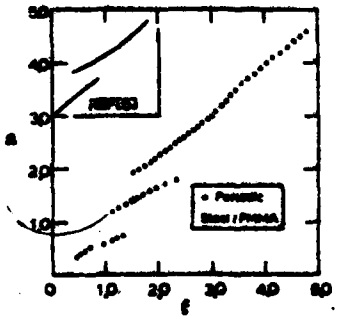

Dislocations in Layered Media

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The stress field due to an edge dislocation is useful in modelling deformation and fracture phenomena associated with composite materials [1,2,3]. In this work the stress and displacement field is developed for dislocations lying within and at the intersection of, infinite isotropic layers with differing elastic constants. These layers are assumed to have perfectly coherent interfaces where both traction and displacement remain continuous. Using the image theory of dislocations [4,5] and the stress functions obtained by Mura and Dundurs [6], the Airy stress function for each of the layers may be constructed. The resulting series solution may be truncated at any degree of accuracy desired. In general, since the stress term associated with dislocations are all of the order (1/r), relatively few reflections are needed to accurately represent the stress field.

With this stress field developed, it is used as a Green's function of an integral equation developed to model slip band development and fracture within a layer. With the Green's function in series form it is seen that the associated integral equation may be solved in a very straight forward manner. Both slip bands and cracks are studied as they approach interfaces.

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SURFACE DAMAGE OF SHEET MOLDING COMPOUND PANELS SUBJECT TO A POINT IMPACT LOADING

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ABSTRACT

Surface damage resulting from impact by foreign objects, such as flying stones, is an important design consideration for automotive body panels. Traditionally, the surface damage of metal body panels is characterized by the dent depth. However, parameters in addition to the dent depth are needed for evaluating composite panels because of the differences in observed damage modes. In this paper, our primary interest is to study the damage of panels made of chopped-fiber reinforced sheet molding compound (SMC) composites subject to a point impact loading. We selected glass-fiber reinforced SMC-35 (35% fiber by weight in a polyester resin and calcium carbonate filled matrix) since it is typical of the materials used for automotive applications.

Results were obtained for the energy absorbed, the dent depth, and the surface damage area at impact speeds ranging from 45 to 180 km/h. A steel ball, 22.2 mm in diameter with a mass of 48.4 g, was fired from an air gun to provide the point impact loading. High-speed photography was employed to obtain the impact and rebound speeds and hence the energy absorbed. The dent depth was measured by the shadow moire method. The apparent surface damage was evaluated by three different methods: radiographic, ultrasonic, and crack enhancement techniques.

In summary, we have studied qualitatively as well as quantitatively the damage characteristics of SMC panels subject to a point impact loading. Based on the results of this study, we conclude that, instead of the dent depth, the surface damage area should be used as the primary parameter to characterize the impact damage of SMC panels. The crack enhancement method is the most suitable technique among the three methods studied for measuring the surface damage area.

Session WM-8: EXPERIMENTAL AND ANALYTICAL STUDIES OF CONSTITUTIVE RELATIONSHIPS FOR ANISTROPIC SOLIDS

Organizer and Chairperson: C. E. TAYLOR, University of Florida
Co-Chairperson: J. der HOVANESIAN, Oakland University

* 9:30 - 10:00 G. A. COSTELLO, University of Illinois-Urbana:
"Axial and Rotational Response of Wire Rope"

* 10:00 - 10:30 R. E. ROWLANDS, University of Wisconsin-Madison:
"Photomechanical Analysis of Diverse Problems"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 J. L. TURNER, Auburn University, and J. L. FORD, Firestone Central Research Lab., Akron:
"Shear Coupling Effects in Cord-Rubber Composites"

* 11:30 - 12:00 S. K. CHATURVEDI, University of Florida-Gainesville:
"Photoelastic Constitutive Relations for Anisotropic Birefringent Composites"

12:00 - 12:15 R. LAKES, University of Iowa:
"Experimental Generalized Continuum Mechanics of a Porous Material"

12:15 - 12:30 T. B. SZWILSKI, University of Kentucky:
"Method of Determining the Anisotropic Elastic Moduli of Coal"

12:30 - 2:00 LUNCH BREAK

Axial and Rotational Response of Wire Rope

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ABSTRACT:

The equations governing the axial and rotational response of wire rope are presented. The previous nonlinear equations are linearized and expressions are presented for the axial force and the axial twisting twisting moment in terms of the axial strain and the axial rotational strain. The results are applied to a 6 x 19 Seale IWRC wire rope. A load deformation curve for the above mentioned rope is obtained experimentally and the results are compared with theory.

PHOTOMECHANICAL ANALYSIS OF DIVERSE PROBLEMS

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ABSTRACT:

Photomechanics (moiré, holography, speckle, Young's fringes and photoelasticity) is used to analysis several contemporary problems in engineering science. The experimental techniques are frequently synergized with numerical and strengths concepts. Situations involving anisotropy, heterogeneity, nonlinearity, cryogenics, fracture mechanics or dynamics are emphasized. Examples are selected from bolted joints, wood and paper physics, fibrous composites and energy storage.

SHEAR COUPLING EFFECTS IN CORD-RUBBER COMPOSITES

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&

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The shear coupling phenomenon is demonstrated to be significant and controlling the response of two ply cord-rubber composites. Interlaminar shear strain distributions are found to be strongly dependent on thickness-to-width ratio of the specimens. Two ply specimens become highly shear flexible as thickness-to-width ratios exceed 1/30. Linear elastic orthotropic material characterization of cord-rubber composites is found to be justifiable within limits. Numerical modelling of axisymmetric cord-rubber structures requires a three-dimensional displacement formulation. Such a model has been developed and experimentally validated.

PHOTOELASTIC CONSTITUTIVE RELATIONS FOR ANISOTROPIC BIREFRINGENT COMPOSITES

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The theories of photoelasticity for composite materials proposed in the literature may broadly be divided into two main streams, namely; the ad hoc and/or the approach involving stress-proportioning between composite constituents, and the phenomenological one. The ad hoc approaches appear inadequate in view of their failure in interpreting unquivocally the observed isochromatic and isoclinic fringe patterns. While the later based upon idealization of composites on a macroscopic scale as anisotropic and homogeneous (optically as well as elastically) appear to be very promising in providing a rational basis for the photoelastic interaction. The above concepts will be examined closely to interpret a proposed photomechanical constitutive relation with a view to uniquely determine the number of independent photoelastic constants for a composite and to interpret the effect of initial birefringence upon its response.

Results will be presented to show also that the composites exhibit a lower degree of anisotropy with respect to strain-optic behavior than with respect to stress-optic behavior and isoclinics, in general, represent neither the directions of principal stresses nor of principal strains. Finally, some important deviations from isotropic photoelasticity will be presented.

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EXPERIMENTAL GENERALIZED CONTINUUM MECHANICS OF A POROUS MATERIAL

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A porous polymeric foam material with cell size ~ 1 mm is examined experimentally with the aim of characterizing it as a generalized continuum. Cosserat (micropolar) and microstructure (micromorphic) elasticity theories are considered as possible generalized continuum models. The following experimental methods were used: (i) quasistatic tension, torsion, and bending of cylindrical rods of different sizes, and (ii) propagation of compressional waves. Dead weight loading was used to achieve tension and a microscope was used to measure displacements. For torsion and bending, the interaction between a Helmholtz coil and a permanent magnet generated the torque, and a laser was used to measure the angular displacement. The quasistatic experiments are sufficient to determine all six elastic constants of an isotropic micropolar material. The wave experiments reveal its micromorphic degrees of freedom, if any.

In quasistatic torsion, the experimental data are fitted well by choosing a shear modulus $G = 0.6$ MN/m^2, a polar ratio $\psi = 1.5$, a characteristic length in torsion $\ell_t = 3.8$ mm, and a coupling number $N^2 = 0.09$. In tension, the measured Young's modulus is $E = 1.3$ MN/m^2, and $\nu = 0.07$. Since $E = 2G(1 + \nu)$ as in the classical case, E based on G and ν should be 1.284 MN/m^2, a satisfactory agreement with E measured directly in tension. For bending, the data cannot be fitted accurately by a theoretical micropolar curve. For larger diameter specimens, the experimental points are consistent with $E = 1.1$ MN/m^2, $N^2 = 0.09$, and the characteristic length in bending $\ell_b = 5$ mm. The smaller diameter specimens are more compliant than what is predicted by micropolar theory. To explore the possibility that the material may have micromorphic degrees of freedom, wave experiments were also done. A sharp cutoff of waves was observed at 10 kHz. The cutoff is too abrupt to be relaxational in nature, but is consistent with a coupling of the acoustic wave with micro-vibrations.

In conclusion, the foam is describable as a classical continuum for specimen diameters greater than 60 mm. Cosserat elasticity is an appropriate continuum model for diameters 60 mm to 28 mm. Deviations from Cosserat elasticity are observed in bending of rods with diameter 20 mm or less. In wave propagation experiments, micromorphic effects are observed for wavelengths of the order 25 mm. Micromorphic degrees of freedom may be responsible for the quasistatic results in the bending of thin rods.

Method of Determining the Anisotropic Elastic Moduli of Coal
by Tony B. Szwilski, Department of Mining Engineering, University of Kentucky

ABSTRACT:

Under a project funded by the Department of Energy, a stiff multiaxial compression cell has been designed to allow 30.5cm (12 ins.) cube specimens to be loaded in compression, Figure 1. The principal objective of the research program is to determine the elastic constants of various coals by static methods. In addition, these elastic properties will be correlated with the structural properties of the various coals in search of valid connections between elastic moduli and other more readily determined material properties. The main research effort is establishing a theoretical relation between load and deformation in a molecular solid whose structure is intermediate between the rubbery entropy dominated, random chain configurations treated by Flory [1] and the elastically stiff, bond energy dominated, linear chain configurations treated by Treloar [2].

Figure 2 shows the test specimen, loading configuration and deformation gage schematically. The specimen is 30.5cm (12 ins.) cub and has a 3.81cm (1.5 ins.) cylindrical hole drilled through its center. The cube faces are loaded by principal stresses σ_1, σ_2,and σ_3 by means of flatjacks and the corresponding radial displacements are measured by a United States Bureau of Mines gage [3] which is emplaced and positioned in the cylindrical hole by means of a placement rod. An existing theory [4], relating the radial displacements in a cylindrical hole to the transverse principal stresses in an elastically othortropic material, gives an adequate account for material anisotropy. Based on this theory a solution has been developed to determine the elastic moduli perpendicular to the centrally drilled hole.

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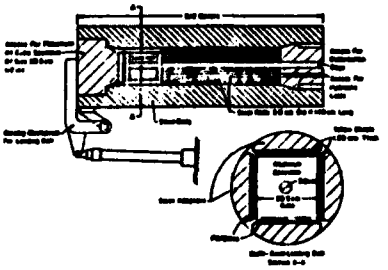

Fig. 1

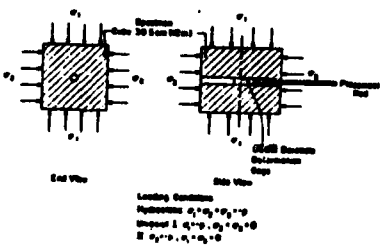

Fig. 2

Session WA-1: CONTINUUM THERMODYNAMICS

Organizer and Chairperson: D. E. CARLSON, University of Illinois-Urbana

* 2:00 - 2:30 B. D. COLEMAN, Carnegie-Mellon University:
"On the Thermodynamics and Statistical Mechanics of Second Sound in Dielectric Crystals"

* 2:30 - 3:00 J. E. DUNN, Virginia Polytechnic Institute and State University:
"Dynamic Implications of Gibbs' Stability Criterion"

* 3:00 - 3:30 R. L. FOSDICK, University of Minnesota:
"Equivalent Extremum Problems In Classical Thermostatics"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 D. R. OWEN, Carnegie-Mellon University:
"The Role of the Concepts of Accessibility and Restorability in the Foundations of Thermodynamics"

4:30 - 4:45 C-S. MAN, The University of Manitoba:
"Solid-Fluid Transitions in Uniaxial Creep Tests of Nonlinear Viscoelastic Materials"

4:45 - 5:00 S. J. SPECTOR, Southern Illinois University:
"On Gibbs Stability in the Classical Theory of Fluid Mixtures"

5:00 - 5:15 W. DREYER, I. MÜLLER, and P. STREHLOW, Technische Universität Berlin, W. Germany:
"A Study of Equilibria of Interconnected Balloons"

5:15 - 5:30 A. M. ANILE, Universita di Catania, Italy:
"Experiments and Extended Irreversible Thermodynamics"

5:30 - 5:45 Y. ERSOY, Middle East Technical University, Turkey:
"A Thermodynamic Development of Generalized Fourier and Ohm Conduction Laws for Anisotropic Materials"

On the Thermodynamics and Statistical Mechanics of Second Sound in Dielectric Crystals

Bernard D. Coleman, Department of Mathematics, Carnegie-Mellon University, Pittsburgh, Pa. 15213

In another talk at this meeting David R. Owen will describe work we have done with Mauro Fabrizio which yields the restrictions that the second law of thermodynamics places on the constitutive equations commonly employed to describe second sound in dielectric crystals. In that work we show that in the temperature range in which second sound occurs, the constitutive equation for the internal energy E must contain a quadratic form in the heat flux $\mathbf{q}$, and this quadratic form is determined by the temperature dependence of the tensor $\mathbf{\mathcal{L}}$, defined as $\mathbf{\mathcal{L}} = \mathbf{K}^{-1}\mathbf{T}$, with $\mathbf{K}$ the steady-state thermal conductivity tensor and $\mathbf{T}$ a tensor introduced by Pao and Banerjee, whose components are relaxation times for resistive processes that cause damping of second sound. (Under appropriate circumstances the velocity U of second sound propagating in a direction $\mathbf{n}$ obeys the formula $U^2 = \mathbf{n}\cdot\mathbf{\mathcal{L}}^{-1}\mathbf{n}/c$ with c the equilibrium heat capacity.) In this talk I shall show that an elementary statistical mechanical argument, based on the phonon picture of thermal excitations in dielectric crystals, yields an explicit formula for the dependence of E on $\mathbf{q}$, and this formula agrees perfectly with that obtained from continuum thermodynamics. Moreover, when the results from continuum physics and quantum statistical mechanics are combined, one obtains an easily evaluated formula for $\mathbf{\mathcal{L}}^{-1}$ (and hence a formula for U) as an appropriately weighted sum of tensor products of phonon velocities.

Dynamic Implications of Gibbs' Stability Criterion

by

J. E. Dunn

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The (thermostatical) idea of Gibbs that states which under isolation maximize the entropy (i.e., Gibbsian states) should, in some sense, be "stable" is examined within the context of modern thermodynamics. Precise conditions are given for the Lyapunov stability of (i) a broad class of uniform (one phase) Gibbsian states, and (ii) those non-uniform (multi-phase) Gibbsian states that satisfy a mathematically precise form of the Phase Rule. Our results depend in a crucial way on certain growth conditions for the energy-entropy-volume surface characterizing the equilibrium states of the material, but are relatively insensitive to its detailed dynamical response. We thus expect our results to be applicable to a very broad class of materials.

Our methods build on and extend certain results of J. Ericksen, B. Coleman and J. Greenberg.

Equivalent Extremum Problems in Classical Thermostatics

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In classical thermostatics there are several fundamental problems of minimization and maximization that generally are considered to be equivalent. These equivalences, however, are not without certain conditions, and it is the purpose of this talk to discuss such questions.

The Role of the Concepts of Accessibility and Restorability in the Foundations of Thermodynamics

by

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Recent developments in continuum physics support the idea that the concept of state in thermodynamics be broad enough to include scalar and tensor fields on a three dimensional body and time-histories of a material element. In order to implement this idea in the context of thermomechanics, one must examine various notions of system in terms of the collection of states and the class of processes which can connect pairs of states. In this talk I consider several definitions of system appropriate to both classical and modern applications, and I show how the concepts of accessibility and restorability play a key role in the formulation and analysis of these definitions.

Solid-Fluid Transitions in Uniaxial Creep Tests of Nonlinear Viscoelastic Materials

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Canada R3T 2N2

Abstract

Depending on the temperature θ and the stress level σ, some materials (e.g., frozen soils) manifest qualitatively different behaviour in uniaxial constant-temperature and constant-stress creep tests: for some (θ, σ)'s, the creep ultimately becomes damped; for other (θ, σ)'s, the creep eventually becomes stationary. We say that a material is in the solid phase at (θ, σ) if in creep tests at the given temperature and stress level the rate of strain $\dot{\varepsilon}(t) \to 0$ as the time $t \to \infty$; it is said to be in the fluid phase if $\dot{\varepsilon}(t) \to$ constant $\neq 0$ as $t \to \infty$. For each material capable of such change in behaviour, the θ-σ plane thus exhibits a phase diagram. We prove several "generic" results regarding the solid-fluid transition and such phase diagrams. These results are "generic" in the following sense: when the set X of all materials that are capable of such transitions is equipped with a suitable topology, our results hold for an open and dense subset in X.

ON GIBBS STABILITY IN THE CLASSICAL THEORY OF FLUID MIXTURES

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Consider an inviscid fluid mixture composed of $N + 1$ constituents. A homogeneous state $\overset{\circ}{g}$ of such a mixture is an $N + 2$-tuple $\overset{\circ}{g} = (\overset{\circ}{p},\overset{\circ}{\theta},\overset{\circ}{\mu}^1,\overset{\circ}{\mu}^2,\ldots,\overset{\circ}{\mu}^N)$ consisting of the pressure, temperature, and the reduced chemical potential of the first N constituents.

Gibbs analyzed such mixtures and concluded that the state $\overset{\circ}{g}$ is stable under isolation if

$$\varepsilon(g) - \overset{\circ}{\theta}\eta(g) + \overset{\circ}{p}\nu(g) - \overset{\circ}{\mu}^{\alpha}m^{\alpha}(g) \geq \varepsilon(\overset{\circ}{g}) - \overset{\circ}{\theta}\eta(\overset{\circ}{g}) + \overset{\circ}{p}\nu(\overset{\circ}{g}) - \overset{\circ}{\mu}^{\alpha}m^{\alpha}(\overset{\circ}{g})$$

for all homogeneous states g. (Here ε,η,ν, and m^{α} are the energy, entropy, specific volume, and mass flux respectively.) His argument was based upon static considerations and the precise relation of Gibbs' criterion to dynamic stability was unclear.

Recent works in thermodynamics have considered the dynamic implication of stability under isolation and proven that Gibbs' criterion is sufficient for dynamic stability. These works did not address the question of necessity. Our purpose is to give an elementary proof of the necessity of Gibbs' criterion.

We use the second law of thermodynamics as a basis to prove that

if Gibbs' criterion fails at a state $\overset{\circ}{g}$

then $\overset{\circ}{g}$ is not dynamically stable,

in the sense of Lyapunov in the $L^{\infty}(B)$ topology.

A STUDY OF EQUILIBRIA OF INTERCONNECTED BALLOONS

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The equilibria of two balloons connected by a pipe are systematically studied. This case provides a non-trivial occasion to illustrate that unstable thermodynamic states may be stabilized by a change of environment.

EXPERIMENTS AND EXTENDED IRREVERSIBLE THERMODYNAMICS

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It is well known that in gasdynamics the Navier-Stokes constitutive equations for the viscous stress and the Fourier law for the heat-flux vector fail in those cases where rapid macroscopic changes occur, such as for high-frequency sound waves and for strong shock waves [1]. In these situations it is customary to resort to kinetic theory. However it is of some interest to investigate whether modified constitutive fluid equations might provide an equally acceptable description as kinetic theory. Modified constitutive equations for fluiddynamics have been put forward by Müller [2] in the framework of extended irreversible thermodynamics. These equations of the Müller type have the pleasant feature of leading to finite wave speeds for thermal pulses and acceleration waves, at variance with the Navier-Stokes and Fourier laws.

The propagation of small acoustic disturbances in a monatomic gas in the framework of Müller's theory has been studied by Anile, Dixon and Pluchino [3] and the results have been compared with the experimental data [4].

The problem of the shock wave structure has been studied for a monoatomic gas in Müller's theory by Anile and Majorana [5] and the results have been compared with the available experimental data [6].

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A THERMODYNAMIC DEVELOPMENT OF GENERALIZED FOURIER AND OHM CONDUCTION LAWS FOR ANISOTROPIC MATERIALS

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This paper aims at investigating a systematic and rational approach to the formulation of generalized Fourier and Ohm Laws in the framework of classical continuum mechanics. With the use of the thermoelectrical equilibrium state and of the extremum value for dissipations of energy per unit volume and time, a set of rather general constitutive equations involving several magnetothermoelectric effects in rigid anisotropic solids are derived and certain restrictions on the material tensors (moduli) are explored. From these general equations, the Maxwell-Cattaneo equation for heat conduction and the Newtonian-Ohm law for electrical conduction come out in a natural way if the coupling terms are neglected while the material being isotropic. Thus the foresaid empirical equation characterizing certain relaxation phenomena in the conducting materials are now justified on thermodynamic grounds as well as they are generalized for magnetothermoelectrical anisotropic and inhomogeneous materials.

In the derivation of the generalized equations, it is shown that there need at most six independent material tensors to describe the thermoelectrical relaxation phenomena when a linear constitutive theory is taken into account. For the materials, which are rather simple not having certain effects, the number of the material tensors reduce either four or two depending upon the assumptions. In particular, it is emphasized that the governing equations of either thermally conducting or electrically conducting solids give rise to the propagation of heat and / or current pulses with finite speeds since the theory leads to a set of hyperbolic PDE's.

Furthermore, the set of temporal evolationary relationships is expressed in the form of integral equations. It is of interest to note that these integral equations are equivaleht to that of the constitutive theory based on the axiom of fading memory. It is also worthwhile to mention that the equation of electrical conduction is in agreement with the results obtained by means of the special theory of relativity. Finally, the theory developed for the general anisotropy is applied to special cases, materials with higher order symmetries and materials not having certain effects.

Session WA-2: ACOUSTIC/STRUCTURE INTERACTION

Organizer and Chairperson: J. F. UNRUH, Southwest Research Institute
Co-Chairperson: M. SATHYAMOORTHY, Clarkson College of Tech

* 2:00 - 2:30 D. B. BLISS and B. H. TONGUE, Princeton University:
"Impedance and Sound Absorption Characteristics of a Flexible Porous Medium"

* 2:30 - 3:00 L. R. KOVAL, University of Missouri-Rolla:
"Two Models for the Sound Transmission Through Laminated Composite Panels"

* 3:00 - 3:30 A. CRAGGS, University of Alberta:
"Sound Transmission Between Two Enclosures Which Are Bounded by a Flexible Structure"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 D. J. MEFSKE and S. H. SUNG, General Motors Research Laboratories:
"Automobile Interior Noise Prediction Using a Coupled Structural-Acoustic Finite Element Model"

* 4:30 - 5:00 R. VAICAITIS, Columbia University:
"Cabin Noise Control for Twin Engine General Aviation Aircraft"

* 5:00 - 5:30 R. D. BLEVINS, General Atomic Company:
"Acoustic Resonance in Heat Exchanger Tube Bundles"

5:30 - 5:45 J. LAMÉRIS, R. NAVANEETHAN and J. ROSKAM, University of Kansas:
"Noise Reduction Characteristics of Various Types of General Aviation Materials"

ABSTRACT

IMPEDANCE AND SOUND ABSORPTION CHARACTERISTICS OF A FLEXIBLE POROUS MEDIUM

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A fundamental study of the acoustic-structural interaction of an elastic layer of porous material backed by a rigid wall has been conducted. Interest in this problem started from experimentally observed irregularities in the low frequency impedance curves of some porous materials. Coupled wave equations describing the behavior of both the fluid and solid media have been derived and solved subject to the appropriate boundary conditions. The coupling occurs through viscous and virtual mass terms arising from the relative motion of the two media. The important effect of structural damping has also been included. Computed results for the impedance and sound absorption coefficient are presented in a general manner in terms of the sets of relevant nondimensional parameters of the system. A detailed physical interpretation of the results is given and it is fcund that many features can be explained in terms of the behavior of a simpler model problem. The interesting behavior of the system is related to the occurrence of resonant conditions in the fluid and/or solid media. For instance, it is found that the sound absorption coefficient exhibits a complicated behavior near the structural resonances, with minima occurring at the resonant frequencies.

TWO MODELS FOR THE SOUND TRANSMISSION THROUGH LAMINATED COMPOSITE PANELS

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Two models are presented for the sound transmission through a laminated composite panel. The first model considers an infinite composite panel subjected to a uniform distribution of oblique plane waves. The transmission of a single oblique wave is determined first, and from this, the field-incidence transmission loss of the panel computed. The panel consists of an arbitrary number of fiber-reinforced laminates, with each laminate having an arbitrary orientation of its fibers. The effect of different fiber orientations is numerically studied, as is the effect of noise insulation treatments, on the transmission loss of the panel.

The second model deals with the sound transmission through a finite composite panel into a finite receiving room with hard side walls and an absorbent rear wall. This model is an attempt to model the ANRD Noise Effects Branch noise transmission test facility at NASA Langley Research Center. The effects of fiber orientation and insulation treatments are examined for this model, also.

The two models are compared with each other, as well as with experimental data obtained by NASA.

Sound Transmission between two enclosures which are bounded by a flexible structure

By A. Craggs

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The paper is concerned with sound transmission between two small acoustic enclosures bounded by a flexible resonant structure. The problem is expressed first as a free vibration problem in which damping is neglected and then forced vibration under the influence of sound absorption will be considered.

Frequently the acoustics of enclosures is treated in terms of hard walled modes and it is assumed that the natural frequencies are not affected by the presence of the boundaries; this is true in many cases. However, when the boundary is flexible and has natural frequencies in the same range as the enclosure then several unusual phenomena can occur. Firstly, resonant modes exist which have nodal surfaces of pressure close to the boundary - implying that the boundary is soft rather than hard. Secondly, due to the coupling between the structure, twin modes exist in one enclosure. These have the same shape but different natural frequencies.

In the paper a finite element model is used to calculate the eigenvectors or transmission modes of the complete system and consequently explain the above phenomena. The model is then used to calculate the sound transmission from one enclosure to another when absorbent linings are present.

AUTOMOBILE INTERIOR NOISE PREDICTION USING A COUPLED STRUCTURAL-ACOUSTIC FINITE ELEMENT MODEL

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Interior noise in the automobile passenger compartment can result from road and powertrain excitations transmitted through the vehicle structure to the compartment cavity. To reduce this structure-borne noise at the design stage, it is helpful to employ analytical methods for modeling the vehicle and predicting its response. Among these analytical methods, the finite element method has been the most successful for modeling the complex geometry of the automotive structure [1] and the interior passenger compartment [2,3]. Previous applications of the finite element method to the passenger compartment have included the prediction of both the free and forced acoustic response of the compartment. However, in these studies, the vehicle structure model was not coupled with the acoustic compartment model, and dissipative effects were not considered in the acoustic analysis.

The present paper employs the finite element methodology to develop a coupled structural-acoustic model, including dissipation, for vehicle interior noise prediction. In this development, the finite element equations are first formulated for coupling an acoustic cavity with surrounding wall panels, where acoustic and structural damping are included in the formulation. Then, the reduction of this large system of coupled equations in terms of its modal parameters is described. The paper also describes the implementation of this coupled analysis within the framework of a commercially available finite element code (NASTRAN) and the solution procedure.

As an example, a coupled structural-acoustic model is presented for the automobile passenger compartment. In this model, three-dimensional acoustic elements are used to represent the passenger compartment cavity, which are then coupled according to the formulation with a structural finite element model of the vehicle body. This coupled model is used to predict the interior acoustic response for forced harmonic excitations applied to the vehicle structure. The structural modal participations contributing to the acoustic response are identified from the model. The accuracy and limitations of the model are discussed, as well as the importance of including damping in the model.

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CABIN NOISE CONTROL FOR TWIN ENGINE GENERAL AVIATION AIRCRAFT

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An analytical model has been developed to predict the noise transmission into the cabin of a twin-engine G/A aircraft [1]. This model is then used to optimize the interior A-weighted noise to an average level of 85 dBA. The basic concept of the analytical model is that of modal analysis wherein the acoustic modes in the cabin and the structural modes of the sidewalls are accounted for.

The noise input pressure due to propeller blade passage harmonics is expressed in the form of a propagating pressure field wherein noise spectral levels measured under static test conditions are used. The cabin interior is treated as a rectangular enclosure. The sidewalls of the aircraft are modeled by several discretely stiffened panel units. Transfer matrix techniques are used to calculate the natural frequencies and normal modes of the skin-stringer panels. The additional noise losses due to cabin sidewall treatments which do not have a direct effect on the structural dynamic characteristics of the skin-stringer panels are estimated by the impedance transfer method.

To reduce the average noise levels in the cabin from about 105 dBA (baseline) to 85 dBA (optimized), add-on treatments which do not involve changes in the fuselage primary structure are used. The add-on treatments considered in this optimization study include lightweight aluminum honeycomb panels, constrained layer damping tapes, porous acoustic blankets, septum barriers and limp trim panels. The added weight of the noise control treatment is about 1.1% of the total gross take-off weight of the aircraft.

References

1. Vaicaitis, R. and Slazak, M., "Cabin Noise Control For Twin Engine General Aviation Aircraft," NASA Contract Report 165833, 1982.

ACOUSTIC RESONANCE IN HEAT EXCHANGER TUBE BUNDLES

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Many gas-cooled tube-and-shell heat exchangers emit an intense acoustic tone when shell side flow is brought to a certain level. The tone then persists as flow is varied. Sound levels as high as 165 db have been measured inside heat exchangers ranging from small process units to nuclear reactors and utility power boilers (Refs. 1,2). The sound is thought to be the result of periodic vortex shedding from the tubes at a frequency which coincides with the natural frequency of an acoustic mode within the heat exchanger shell.

The sound within the heat exchanger shell is described by Lighthill's equation for aerodynamic sound:

$$\frac{\partial^2 p}{\partial t^2} - c^2\nabla^2 p = \rho c^2 \sum_{i=1}^{3}\sum_{j=1}^{3} \frac{\partial^2 u_i u_j}{\partial x_i \partial x_j}$$

Sound propagation through a tube array is analogous to propagation through an array of small scatters (Ref.3). The speed of sound is slowed by the presence of the tubes, damping is increased, and the effective density is increased. The nautral acoustic modes within the heat exchanger tube array are coupled with the modes of the entrances and exits, which are free of tubes. Thus, either numerical or matching solutions are required for the acoustic mode shapes.

The amplitude of the acoustic wave is sought by solution of the modal equation

$$(1-\sigma)V\ddot{P}_r + R_r\dot{P}_r + w_r^2 P_r = c^2 \int_{\text{tube}} \nabla\phi_r \cdot \vec{F}'_m dx_m$$

Here R_r is a damping factor and F'_m is the force exerted on the fluid by a tube. F_m may either retard the acoustic wave or impell it, depending on the phase of the force with respect to the acoustic mode ϕ_r.

Tests on a variety of tube bundles in a rectangular shell are planned to measure the acoustic modes and the onset of resonance. A criterion will be established to differentiate between array geometry and damping that lead to resonance and those that are free of resonance.

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Blevins, R.D., "Flow Induced Vibration in Nuclear Reactors: A Review," Prog. Nucl. Energy 4, 25-40 (1979).

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NOISE REDUCTION CHARACTERISTICS OF VARIOUS TYPES OF GENERAL AVIATION MATERIALS

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This paper describes results of recent tests at the KU-FRL* acoustic test facility to determine noise reduction characteristics of stiffened aluminum panels, fiber-reinforced laminated panels, and commercially used general aviation aircraft interior trim panels. The tests are part of a continuing effort at the KU-FRL to document noise reduction characteristics of panels and materials used in general aviation aircraft. Previous results are summarized in References 1-3.

Tests were carried out on 20"x20" panels in a frequency range of 20 to 5000 Hz. The noise sources used were a swept sine wave generator and a random noise generator. The angle of sound incidence was maintained at 90°. Typical parameters varied for the stiffened aluminum panels included curvature, constrained layer damping, percentage of area covered, pressurization and addition of sound absorption material. In the case of composite panels, effects of ply orientation and stiffeners were studied. Twenty-two different trim panel combinations were tested.

Results of varying each of these parameters on the noise reduction characteristics at selected frequencies are discussed. In general, pressure differentials across a panel will increase noise reduction at low frequencies. For curved panels, noise reduction at higher frequencies will decrease in value with increasing pressure differential. The effect of a damping layer was found to be small in the non-resonant region. At high frequencies, increase in noise reduction is of the same magnitude as the increase due to higher surface mass density.

Composite laminated panels exhibit greater low frequency noise reduction than conventional aluminum panels. However, at high frequencies they follow the mass law.

The efficiency of the trim panels is discussed as a function of surface mass density. Doubling the core thickness of sandwich panels is more beneficial than increasing the thickness of the skin layers.

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2. Grosveld, F.; Navaneethan, R.; Roskam, J., "Noise Reduction Characteristics of General Aviation Type Dual Pane Windows," AIAA Aircraft Systems Meeting, Anaheim, California, August 4-6, 1980.
3. Grosveld, F.; Navaneethan, R.; Roskam, J., "Summary of Typical Parameters That Affect Noise Transmission through Typical General Aviation Aircraft Panels," Business Aircraft Meeting, SAE, Wichita, Kansas, April 1981.

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Session WA-3: OPTIMIZATION

Organizer: V.B. VENKAYYA, AF Wright Aeronautical Laboratories
Chairperson: N.S. KHOT, AF Wright Aeronautical Lab.

Co-Chairperson: R. RIESS, Howard University

* 2:00 - 2:30 W. D. PILKEY and B. P. WANG, University of Virginia:
"Optimization of Dynamic Structural Systems"

* 2:30 - 3:00 P. K. BASU and D. VASILOPOULOS, Washington University in St. Louis:
"p- vs. h-Versions of FEM in Design Synthesis"

* 3:00 - 3:30 J. L. JUNKINS, Virginia Polytechnic Institute and State University:
"Continuation and Derivative Update Methods for Enhancement of Parameter Optimization Algorithms"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 M. P. KAMAT, V. B. VENKAYYA, N. S. KHOT, AF Wright Aeronautical Laboratories:
"Optimization with Frequency Constraints-Limitations"

4:30 - 4:45 O. IBIDAPO-OBE, University of Lagos, Nigeria:
"Optimal Actuators and Sensors Placements for the Active Control of Flexible Structures"

4:45 - 5:00 V. B. VENKAYYA , V.A. TISCHLER, and F. E. EASTEP, AF Wright Aeronautical Laboratories:
"Application of Optimization Methods to Composite Structures"

5:00 - 5:15 W. C. LEWIS, JR., Renaselaer Polytechnic Institute:
"Data Flow Control of Job Shops: Are Scheduling and Dynamic Allocation Comparably Effective?"

5:15 - 5:30 C. L. FRIESE, Auburn University and A. K. RIGLER, University of Missouri-Rolla:
"A Nonlinear Regression Algorithm Based On Predictions Generated by an Eigensystem"

5:30 - 5:45 A. R. CHOWDHURY and A. B. ROY, Jadavpur Univerasity, India:
"Multiple Criterion Decision Making in Shortest Route Problem"

OPTIMIZATION OF DYNAMIC STRUCTURAL SYSTEMS

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This paper presents several optimization formulations based on a scheme for the efficient reanalysis of large systems. The formulations can be used to solve a variety of dynamic response problems, including the modification of systems to reduce the response and the design of systems to achieve prescribed response characteristics. One problem treated in detail is the optimal vibration reduction over a frequency range. The reanalysis methodology provides the opportunity to handle large scale versions of the familiar single mass tuning problem. Another problem is the design of damping controllers for the modal vibration control of large structures. A two-stage optimization procedure is proposed in which the optimal controller locations are chosen independant of the optimum gains. An eigenvalue separation hypothesis is presented for the optimal location stage.

p- vs. h-Versions of FEM in Design Synthesis

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For a successful synthesis of the structural design process it is necessary to combine a reliable analysis tool with an efficient optimization scheme. The most popular analysis tool is based on the finite element method, which can be used in two modes, one is the h-version and the other p-version. The superiority of the p-version of the FEM in terms of convergence characteristics, reliability, and insensitivity to input parameters has been established both numerically and analytically. Also, this version is better suited to an adaptive scheme which is a desirable feature. The results of numerical experimentation to demonstrate the performance of the p-version of the FEM in design synthesis are presented and compared with those obtained by using the h-version of the FEM. The optimization tool used for this purpose was the NASA's program COMMIN.

Continuation and Derivative Update Methods for Enhancement of Parameter Optimization Algorithms

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A large family of iterative optimization methods (those based upon successive local linearizations of the performance index and constraint functions) suffer from two common drawbacks: (1) obtaining "sufficiently good" starting estimates to ensure convergence of the iterations and (2) the repetitive expense of calculating certain partial derivatives and solving certain linear systems of algebraic equations. The present paper details results which, for most problems and most optimization algorithms, significantly enhances both reliability and efficiency of convergence.

Continuation methods (also known as "homotopy methods", and "imbedding algorithms"), are used to imbed the original nonlinear problem into a one parameter family of problems. The family is constructed in such a fashion that it has at least one "simple" problem whose solution is available without iteration; the one-parameter family of problems is constructed such that $\alpha = 0$ causes the family to degenerate continuously into the simple problem, while $\alpha = 1$ causes the family to reduce to the nonlinear problem whose solution is sought. By setting α to a sequence of values, by solving each of the sequence of problems, one can insure that arbitrarily good starting iteratives are available for each problem in the sequence; the converged intermediate problems simply serve as "stepping stones" (a homotopy chain) to provide, ultimately, arbitrarily close starting iteratives for the problem of interest. Except for certain rare singular events (e.g., bifurcation points), this approach has been found to be rather versatile and reliable. It applies, in principle, to all parameter optimization algorithms.

We also consider methods for approximately updating available partial derivatives based upon the nonlinearly evaluated changes which occur in the objective and constraint functions on successive iterations, in lieu of formal re-evaluation using analytical or finite difference methods. The methods presented are multi-dimensional generalizations of the "secant" method; the partial derivative matrix is "updated" in a minimum norm sense to make the truncated Taylor's series predict exactly the nonlinear function changes on the just completed iteration. While this update approach is heuristic, it has been shown to be reasonably reliable and typically an order of magnitude less expensive to calculate than finite difference approximation of the partial derivative matrix. In the occasional event that the derivatives approximated by the update method are not sufficiently accurate, this will be evident by a divergent iteration; in which case one simply recycles to the previous best point and formally recalculates the derivative matrix via analytical or finite difference methods. Using several examples, we show that one can often iterate to convergence with a single initial derivative calculation and a sequence of iterations using the derivative update scheme.

The results presented represent a synthesis of several existing ideas which do not appear to be widely appreciated. The tutorial approach and examples provided in the present paper should make these useful methods accessible to a wide audience.

OPTIMIZATION WITH FREQUENCY CONSTRAINTS - LIMITATIONS

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V. B. Venkayya
N. S. Khot

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The authors stress the limitations of designing minimum weight structures for a specified frequency of vibration. Beginning with Turner's solution an optimum bar with a specified fundamental frequency, the authors show that the amount of material that would be necessary for an optimum bar of a fixed configuration (length and boundary conditions) to obtain an arbitrarily prescribed frequency, can be disproportionately high to yield a design that is completely impractical. Similar conclusions can be also shown to hold for optimum vibrating beams. The point is further emphasized by the consideration of the optimum design of a sled within the cross-sectional area and the moment of inertia are approximately linearly related.

OPTIMAL ACTUATORS AND SENSORS PLACEMENTS FOR THE ACTIVE CONTROL OF FLEXIBLE STRUCTURES

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A methodology for the active control of flexible structures is proposed; the paper is specifically concerned with the problem of optimal placement of limited number of sensors and actuators for the effective control of the structure under minimum energy requirements. The scheme relies on the interpretation of the functional relationship (transfer matrix/control gain) of the actuators and modes of the system.

The model considered in this paper is a slender structure subject to horizontal random wind forces whose equation of motion can be written as follows:

$$EI\frac{\partial^4}{\partial x^4}\left[w(x,t)+\xi w(x,t)\right]+m\frac{\partial^2}{\partial x^2}w(x,t)+C\frac{\partial}{\partial t}w(x,t)+Dw(x,t)$$

$$= P(x,t) + u(x,t)$$

where EI is the rigidity; w(x,t) is the horizontal deflection at point x after time t; ξ is the internal viscous damping; C and D are external viscous damping and measure of equivalent spring stiffness; P(x,t) is the horizontal random wind forces and u(x,t) is the generalised control forces including moments.

It is shown that the structure of the matrix essentially determines the optimal location of sensors and activators; the implementation of the algorithm is simple and circumvents the rigours of having to solve the classical equations (Hamilton-Jacobi-Bellman) of optimal control theory.

Several examples are given for differing actuators and sensors placements along the idealised prismatic beam.

Application of Optimization Methods to Composite Structures

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An aeroelastically tailored composite wing structure has been optimized for strength requirements. The wing was analyzed using the displacement method of finite element analysis and optimized using an optimality criteria. The wing was modeled with membrane elements and subjected to six static loading conditions. The weight of the wing was the merit function in optimization. The divergence characteristics of the optimized wing structure were then analyzed using the NASTRAN program.

Data flow control of job shops: Are scheduling and dynamic allocation comparably effective? William C. Lewis, Jr., Assistant Professor, Mechanical Engineering, Rensselaer Polytechnic Institute, Troy, NY 12181

Data flow optimization algorithms perform comparably to scheduling algorithms for some job shop applications. Specifically, data flow optimization produces machine tool utilization exceeding 90% and allows a parts introduction policy which ensures shorter flow times for more important batches.

A data flow algorithm concerns directed flow of messages (data) between nodes in a graph. An individual node fires (transforms the data) only when data are present on all its inputs. A machine in a job shop may be considered a node. It is possible to maximize the utilization and minimize the interactions of collections of such nodes by the following data flow protocol.

Work descriptions (NC programs) are partitioned into tasks, and transmitted as messages. These are saved in FIFO queues within those nodes capable of performing the work described. Typically, each message will be saved in several nodes. Any idled node is assigned to the first program in its queue. Once assigned, it deletes the program from the rest of the system, retaining only its own copy. It next obtains appropriate consumable resources (tools, workpiece), executes the current task, and returns the consumable resources. It then increments the program's task pointer to indicate the next task, and re-broadcasts the work description as a message. The message will be saved in FIFO queues by nodes capable of performing the work, as before. This completes the cycle. The last task of any work description is removal from the system, performed at a specialized unloading node. That the work description's task pointer must eventually indicate this last task is a consequence of the FIFO queues and of incrementing the task pointer at each task completion.

One can think of the consumables as tokens flowing through a data flow net, drawn to idle nodes by the work description. The idle nodes fire when all consumables have arrived.

Certain additional measures concerning timing and message redundancy are required to ensure system efficiency and stability. A series of simulation experiments suggested system insensitivity to machine tool failure, job stream composition, machine tool characteristics, and limited tool supply. Measurements recorded simulated utilization exceeding 90% given random machine tool failures below 16%, and good response of batch flow time to batch weight.

A Nonlinear Regression Algorithm Based on Predictions Generated by an Eigensystem

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This paper describes a new algorithm for the solution of unconstrained minimization problems where the objective function is in the form of a sum of squares. The new algorithm is a conjugate direction method that utilizes the eigenvectors of a certain matrix as the conjugate directions. A significant time saving feature of the algorithm is the generation of a sequence of points from predictions rather than searches, that converge to a solution. The results obtained by computing solutions of traditional test functions demonstrate that this algorithm is capable of following the narrow curved valleys, when the starting point is far from the solution. Such problems typically occur as the result of a SUMT transformation of a constrained optimization problem into a sequence of unconstrained problems. The usually preferred method is to add weighted penalty terms that represent the constraints to the objective function, and then increase the penalty term weights in formulating a sequence of problems. The solutions to the sequence of unconstrained problems will converge to the solution of the original constrained problem. As the penalty term weight is increased, the relative difficulty of obtaining a solution to the resulting unconstrained problem also increases due to the "narrowing" of the curved valleys in the contours of the objective function surface. Limited experience with the new algorithm has shown that the "narrowing" of the curved valleys has little, if any, effect on obtaining the solution. The new algorithm does require that the objective function be of the form of a sum of squares which is the form of many functions, while many other functions can be transformed to that form.

MULTIPLE CRITERION DECISION MAKING IN SHORTEST ROUTE PROBLEM

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There are many realistic situations in network flow problems demanding decision in the midst of multiple criterion which can be formally stated as

$$\text{Maximise } z = Cx$$

$$\text{subject to } Ax \leq b \quad \text{and } x \geq o$$

where C and A are matrices and each element of Z is to be maximised. The techniques and methods of solving multiple objective linear programming problems are less well developed.

We shall consider here the shortest route problem in a network under multiple criterion where the flow constraints are conserved but the weights attached to each edge is a r-dimensional ($r > 1$) vector.

The minimum formalism based on Benayoun, Montgolfier, Tergny and Laritchev [1] is adopted here to convert the problem into a modified LP problem. An algorithm based on the idea of Dijkstra [2] is developed to find the shortest path in the multiple objective linear programming problem

i) from a source to sink,
ii) between all the ordered pairs of vertices in G.

Lastly all the algorithms are explained with the help of an example.

References

[1] Benayoun, R. Montgolfier, J., and Laritchev, O., Math. Prof. 1971, 1, 366-375.
[2] E. W. Dijkstra., Numerische Math. Vol. 1 269-271 (1959).

Session WA-4: MAGNETIC FLUIDS/FERROMAGNETIC ELASTIC SOLIDS

Organizer and Chairperson: P.D.S. VERMA, Kurukshetra University, India
Co-Chairperson: H.M. CHANG, The University of Alabama in Huntsville

* 2:00 - 2:30 A. MARTINET, University of Paris:
"Ferrofluids"

* 2:30 - 3:00 P. PINCUS, University of California at Los Angeles:
"Stabilization of Magnetic Colloids"

* 3:00 - 3:30 J. T. JENKINS, Cornell University:
"Continuum Theories for Magnetic Fluids"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 R.K.T. HSIEH, Royal Institute of Technology, Stockholm, Sweden:
"Continuum Ferromagnetic Liquid Seals in Blood Flow"

* 4:30 - 5:00 P.S. DUBBELDAY, Naval Research Laboratory, Orlando, and M.S. PTAK, Florida Institute of Technology:
"Hydroacoustic Ferrofluid Projector in Toroidal Configuration"

5:00 - 5:15 M. SINGH, Simon Fraser University, Vancouver, Canada:
"Mathematical Theory of Nonlinear Waves on the Surface of a Magnetic Fluid"

5:15 - 5:30 O. O. AJAYI, University of Lagos, Nigeria:
"The Asymmetric Fluid Motions Induced by a Rotating Magnetic Field"

5:30 - 5:45 P.D.S. VERMA and O.H. RANA, Kurukshetra University, India:
"Soft Ferro-magnetic Microelastic Solids"

5:45 - 6:00 H. M. CHANG and S. T. WU, The University of Alabama in Huntsville:
"Compressible MHD in Long Circular Cylinder"

6:00 - 6:15 B. R. GULATI, Southern Connecticut State College:
"Transverse Heat Transport in Ferrofluid in Rotating Magnetic Field"

FERROFLUIDS

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After giving an overview of the magnetic colloids commonly referred to as Ferrofluids, we will discuss their structure, basic properties, and applications in industry, medicine and art. Also a schematic presentation of real experiments will be given.

Stabilization of Magnetic Colloids

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Ferrofluids are colloidal dispersions of magnetic grains which interact mainly via long range magnetic dipole forces. This force augmented by Van-der-Waals attraction tends toward flocculation. To maintain the dispersion, the grains are often coated with surfactant molecules which act as bumpers preventing segregation. We shall discuss the physics of colloid stabilization in both polar and non-polar solvents.

Continuum Theories for Magnetic Fluids

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We outline continuum theories that have been proposed for magnetic fluids. These materials are suspensions of single-domain ferromagnetic particles in Newtonian fluids. The suspensions are stabilized by the addition of a surfacant that coats the particles and prevents their agglomeration.

The continuum theories account for the additional degrees of freedom associated with the orientation of the particles in an applied magnetic field. Such theories have been proposed in order to explain the variation of the apparent viscosity with the orientation of the applied field in simple flows [1] and to provide a context for the interpretation of existing experiments on ultrasonic propagation and attenuation [2,3].

The theories differ in the internal variables introduced to describe the additional degrees of freedom, in the characterization of the inertia and dissipation associated with the internal variables, and in the treatment of the electrohydrodynamics. These differences will be highlighted and the theories evaluated with reference to the experiments.

[1] McTague, J. P., J. Chem. Phys. 51; 133 (1969).

[2] Chung, D. Y., Isler, W. E., J. Appl. Phys. 49, 1809 (1978).

[3] Isler, W. E., Chung, D. Y., J. Appl. Phys. 49, 1812 (1978).

CONTINUUM FERROMAGNETIC LIQUID SEALS IN BLOOD FLOW.

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Blood is a suspension of discrete cells, mostly red cells in a Newtonian liquid, plasma which flows through vessels.

It has been experimentally determined that when ferromagnetic fine particles are introduced into such system without an application of the magnetic field no considerable biological effects are reported i.e. ferromagnetic fine particles could pass through the capillaries in the body. This paper investigates ferromagnetic liquid seals with an applied magnetic field of arbitrary direction in blood.

It is found from principles of continuum mechanics that the corresponding Bernouilli equation predicts the sealing capacity of the hydrostatic plug. Such liquid seal can be used for producing blood flow stasis during surgery and has the advantage of causing less arterial wall damage.

HYDROACOUSTIC FERROFLUID PROJECTOR IN TOROIDAL CONFIGURATION

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The coupling between a magnetic field and fluid motion embodied in ferrofluids make this material a candidate for electroacoustic transduction. A design for an acoustic projector for underwater application that specifically uses the fluid property has been proposed before [1]. A description of the construction of a toroidal projector based on this design is presented here, and preliminary measurements of its acoustic properties are reported.

The force per unit volume on the ferrofluid in a toroidal configuration is proportional to $H(r)/r$, where $H(r)$ is the circumferential magnetic field, as a function of the distance r to the axis of the toroid (Fig. 1). The top and bottom of the toroid are rigid. The cylindrical walls are elastic, the outer wall is in direct contact with the ambient medium and the inner wall is in contact with a layer of air kept at ambient pressure for pressure release. The dc bias field is created by a current through thin plates arranged in a fan-like fashion. The ac current wires are arranged as shown in the sketch of Fig. 2. The dc bias field drives the magnetization to saturation to ensure linearity of operation. The device is especially suited for low frequencies in the range from about 100 to 500 Hz.

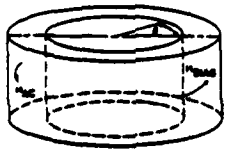

Fig. 1

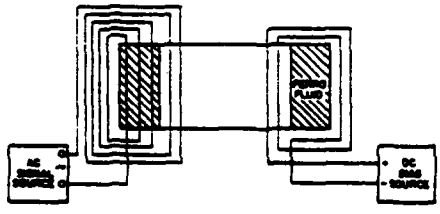

Fig. 2

1. "Application of ferrofluids as an acoustic transducer material," Pieter S. Dubbelday, IEEE Transactions on Magnetics, Vol MAG-16, pp 372-374, 1980.

Mathematical Theory of Nonlinear Waves on the Surface of a Magnetic Fluid

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Using bifurcation theory techniques, we study the stability of a ferro-fluid under a static magnetic field. In particular, we examine the situation when the half space $y_3 \leq 0$ is filled with a ferro-fluid. If a vertically directed magnetic field of sufficient strength is passed through this ferro-fluid, the horizontal surface will change. Analogous to Bernard cells in convection, both the rectangular and the hexagonal relief patterns are observed. Both structures are also observed in the electrical analog for a dielectric in the presence of an electrical field. Simplifying assumptions have been made to allow for a mathematical solution to the problem. We assume that the ferro-fluid is incompressible, magnetically linear, isotropic, and free of internal currents. We also consider the fluid to be static, of infinite depth and of constant magnetic permeability. After obtaining a trivial solution, the full problem is mapped onto a Banach space setting. Through the Frichet derivative, the critical magnetic field strength (and associated wave length) at which the non-planar surface appears can be found. With the help of an adjoint function, the existence of a bifurcating branch of solutions, and the onset of instability of the planar surface are demonstrated.

THE ASYMMETRIC FLUID MOTIONS INDUCED BY A ROTATING MAGNETIC FIELD

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The electrohydrodynamic and magnetohydrodynamic effects on rigid and deformable bodies have attraced the attention of various authors. These analyses have usually dealt with configurations in which there is axial symmetry, largely because when there is axial symmetry the use of a stream function is justifiable and its use invariably simplifies the analysis. In an asymmetric configuration this simplifying factor is lost altogether and solution of the problem is not easy.

Here we consider such an asymmetric configuration. We investigate the effect of a rotating magnetic field on a conducting incompressible viscous drop immersed in a non-conducting incompressible viscous fluid. We show that the drop is deformed and an unsteady flow field is induced both inside and outside the drop by the electric stress exerted on the drop surface. The problem is formulated generally but for clarity we discuss the extreme cases $R_m \ll 1$, $R \gg 1$, where R_m is the magnetic Reynolds number.

SOFT FERRO-MAGNETIC MICROELASTIC SOLIDS

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Using the variational principle, the field equations and the boundary conditions are derived for soft ferro-magnetic microelastic solids. The constitutive equations governing such bodies are determined by assuming an appropriate form of energy density function. Magnetisation gradient is included. The general theory so formulated is then applied to investigate the propagation of plane waves in the above type of solids. Four modes of propagation are shown to exist. The applied magnetic field and the magnetization produced spontaneously give rise to a considerable change in the magnitude of Alfven's velocity. Furthermore, the analysis of coupled waves indicates that eddies decay with time.

COMPRESSIBLE MHD IN LONG CIRCULAR CYLINDER

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The compressible MHD in circular infinite long cylinder has been discussed in this paper, in stationary and infinite conductive cases. Neglecting v^2-term in momentum equation but retaining the first order v-term in induction equation, we proved by the theory that, the radial magnetic field $B_r = 0$ always. As for radial mass flow velocity, v_r, we have proved that if $v_r = 0$, the magnetic field should be a force-free field; if $v_r \neq 0$ the magnetic field must be a constant pitch field, and v_r being determined by axial magnetic field B_z.

In $v_r \neq 0$ case, the constant pitch field with radial flow has been solved. All three components of magnetic field $\vec{B}$ and current density $\vec{j}$, thermodynamic quantities P, T, ρ and radial velocity v_r have been obtained. Ten curves of these ten quantities versus radius have been plotted for different parameters.

It has been found that in most cases, the convective magnetic field is being concentrated around its symmetrical axis as a magnetic flux tube, but its diameter increases with β_o. In some other cases the concentration is being violated, no magnetic flux tubes are formed. The convective magnetic flux tubes may have either a cool core or a hot core.

TRANSVERSE HEAT TRANSPORT IN FERROFLUID IN ROTATING MAGNETIC FIELD

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It is shown that transverse heat arises in rotating magnetic field. Heat current perpendicular to both the applied temperature gradient and angular velocity of magnetic field takes place. Coefficient of entrainment of the particles is found as a function of the temperature and the magnitude of magnetic field. The estimation of the transverse temperature difference is made and the possibility to measure the same is discussed.

Session WA-5: BOUNDARY INTEGRAL/ELEMENT METHODS IN MECHANICS

Organizer and Chairperson: D. J. SHIPPY, University of Kentucky
Co-Chairperson: L.W. Schmerr, Iowa State University

* 2:00 - 2:30 B. KHATIB-SHAHIDI and D. L. SIKARSKIE, Michigan State University:
"A Boundary Element Approach to Finite Elasticity: Neo-Hookean Model"

* 2:30 - 3:00 P.L-F. LIU and S. K. KIM, Cornell University:
"Numerical Solutions of Tsunami Run-Up Using the Boundary Integral Equation Method"

* 3:00 - 3:30 F. J. RIZZO, M. REZAYAT and D. J. SHIPPY, University of Kentucky:
"A Boundary Integral Equation Method for Heat Conduction in Moving Solids"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 R. P. SHAW and Y. K. SUN, State University of New York at Buffalo:
"Elastic Plate Vibrations by Boundary Integral Equations-Asymptotic Formulation"

4:30 - 4:45 G.D. MANOLIS, State University of New York at Buffalo:
"Reduced Dynamic Green's Functions for the Linear Elastic Halfplane"

4:45 - 5:00 F. BARADARI, D. R. EDWARDS and H. D. KEITH, University of Missouri-Rolla:
"Comparative Study of the Boundary Element Technique and the Finite Element Method in Two Dimensional Eigenvalue Problem"

A Boundary Element Approach to Finite Elasticity: Neo-Hookean Model

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David L. Sikarskie**

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In this paper a two dimensional finite elasticity solution procedure is formulated using a boundary element approach. The analysis and examples are specifically developed in Langrangian coordinates and for Neo-Hookean materials but can be straightforwardly generalized to other consitutive behavior. The problem is formulated in terms of stress functions $\phi(x_1,x_2)$, $\psi(x_1,x_2)$ resulting in field equations

$$\nabla^2 \phi = -P_{,1}\,(1+u_{1,1}) - P_{,2}\,u_{1,2} - P\,[P_{,1}\,(1+u_{2,2}) - P_{,2}\,u_{2,1}] = F_1$$

$$\nabla^2 \psi = -P_{,2}\,(1+u_{2,2}) - P_{,1}\,u_{2,1} - P\,[P_{,2}\,(1+u_{1,1}) - P_{,1}\,u_{1,2}] = F_2$$

where u_1, u_2, P are displacements and unknown pressure, respectively. For F_1 and F_2 known functions of x_1, and x_2 the boundary element solution is well known, and contains both contour and surface integrals. The contour integrals involve unknown distributions adjusted to satisfy the boundary conditions. For this problem the surface integrals contain F_1, F_2 which are functions of the unknown displacements and pressure. Thus, an iteration procedure must be introduced. An initial assumed form for F_1, F_2 (from the linear elastic solution) is substituted into the boundary element equations. The unknown distributions can now be found and then used to find a new stress and displacement state which updates F_1, F_2. This procedure continues until convergence is established.

Two examples are given, namely: the uniform extension of a strip in plane strain and the pressurisation of a cylindrical tube (Lame' problem). In the uniform extension problem the exact solution has constant pressure and thus results in $F_1 = F_2 = 0$. There is excellent agreement between the numerical and exact solutions but the problem does not provide a test of the iteration procedure. For the Lame' problem an exact analytical solution (in polar coordinates) has first been developed for comparative purposes. Although a general scheme for finding this solution exists in Green and Zerna, "Theoretical Elasticity," p. 87, specific analytic results for Neo-Hookean materials are cited here. The numerical solution for this problem is developed completely in cartesian coordinates, hence, it is general and it demonstrates convergence of the iterative scheme, solutions for curved boundaries, and solutions for multiply connected regions.

* Graduate Research Assistant
**Professor and Chairman

NUMERICAL SOLUTIONS OF TSUNAMI RUN-UP USING THE BOUNDARY INTEGRAL EQUATION METHOD

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Tsunamis are long waves generated by undersea earthquakes. As Tsunamis propagated across the ocean and approach coasts, wave amplitudes grow significantly due to refraction and shoaling effects. The final tsunami run-up could cause not only severe property damage but also loss of human life. It is, therefore, important to develop an efficient numerical scheme for predicting the maximum run-up location as a part of Tsunami warning systems.

In this paper, the boundary integral equation method (BIEM) is developed as a tool for studying two-dimensional run-up problems. The flow motions are described by the potential flow theory. Nonlinear free surface boundary conditions are incorporated in the BIEM formulation (Liu and Liggett, 1982). The Tsunami is modeled by either a solitary wave or two successive solitary waves. For simplicity, the beach topography is assumed to have a linear slope which intersects with a constant water depth region. For the case of a single solitary wave, numerical experiments are carried out for different solitary wave heights and different beach slopes. The accuracy of the present numerical scheme is verified by comparing with available experimental data and existing numerical solutions. Some typical comparisons are shown in Table 1. Agreement is considered to be fairly good in view of the fact that wave breaking could actually occur in some cases. The maximum run-up and run-down are presented as functions of beach slope and the incident wave height. The effects of the second solitary wave on the maximum run-up are also examined.

Initial Wave Height H_o/D	Slope S	Maximum run-up R/D	
		Present result	Previous result
0.48	1	1.591	1.27
0.10	0.1	0.411	0.40
0.10	0.3	0.318	0.234

Table 1. Comparison between present results and previous data

Reference

Liu, P.L-F. and J.A. Liggett, Applications of boundary element methods to problems of water waves, in Developments in Boundary Element Methods - 2 (ed. K.I. Banerjee and R.P. Shaw) Elsevier Science Publishers, England.

A BOUNDARY INTEGRAL EQUATION METHOD FOR HEAT CONDUCTION IN MOVING SOLIDS

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The solid-phase heat conduction problem applicable to flame spreading over a pyrolyzing fuel, including the heat conducted through the solid forward of the flame, is formulated for solution using the Boundary Integral Equation (BIE) Method. A specific problem of interest is that of a rectangular slab of fuel being consumed by a gas-phase flame, on both sides of the slab, that spreads at a steady speed into a wind which opposes the flame. Surface temperature results are obtained using the BIE and compared with some published experimental measurements. Upstream heat flux computations are compared with an approximate solution based on an asymptotic expansion. The steps in development of the BIE formulation and the adopted numerical approach are outlined. Because of the presence of an integrable singularity in the surface heat flux at a corner in the slab, an improved numerical approach which involves the use of singular shape functions, defined and derived here, is given and the validity of the improved approach is established.

The differential equations governing the title problem also describe a number of physically unrelated but mathematically similar problems, which are identified. One such problem is that of the variation of drawdown in a leaky aquifer. This problem and perhaps another involving steady state acoustic radiation from a sphere will be discussed as time permits

Elastic Plate Vibrations by Boundary Integral Equations - Asymptotic Formulation

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The development of a two dimensional theory of elastic plates from a general three dimensional theory of elastic solids depends on the concept of a small thickness to length ratio and on the appropriate assumptions to be made regarding the variation of the dependent variables through the thickness, e.g. (1). Boundary integral formulations perform this reduction from three to two dimensions automatically and exactly; they contain an explicit representation of the actual functional dependence of the dependent variables at interior points in terms of their behavior on the surfaces. While such boundary integral formulations may be difficult to solve analytically, they may be solved numerically or, as in the present case, be rewritten in terms of an asymptotic expansion in orders of the thickness to length ratio which may then be solved 'order by order'. This ratio, ε , appears in the kernels of the integral equation. The zeroth order solution, corresponding to an infinite plate, is already available, (2). The present discussion considers the general asymptotic expansion and in particular the influence of the edges. The development is based on displacement potentials, e.g. (3), rather than displacements and tractions directly, e.g. (4).

References

1. R.D. Mindlin, 'An Introduction to the Mathematical Theory of Vibrations of Elastic Plates', U.S. Army Signal Corps Engineering Laboratories, Fort Monmouth, N.J., 1955.

2. R.P. Shaw, 'Elastic Plate Vibrations by Boundary Integral Equations, Part 1: Infinite Plates', Res Mechanica, Vol. 4, 1982.

3. R.P. Shaw, 'Retarded Potential Approach to the Scattering of Elastic Waves by Rigid Obstacles of Arbitrary Shape', J.A.S.A., Vol. 44, 1968.

4. T.A. Cruse and F.A. Rizzo, 'A Direct Formulation and Numerical Solution of the General Transient Elastodynamic Problem, I', J. Math Anal. and App., Vol. 22, 1968.

REDUCED DYNAMIC GREEN'S FUNCTIONS FOR THE LINEAR ELASTIC HALFPLANE

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Fundamental singular solutions or Green's functions for the reduced (steady-state) equations of elastodynamics are of importance since they are key ingredients in a boundary integral equation (BIE) reformulation of the general problem of wave propagation and scattering. Engineering solutions to two-dimensional problems using Green's functions for the infinite plane have been obtained in the past [1,2]. However, problems involving the halfplane are inherently more interesting because of applications to geomechanics.

In this work, the fundamental singular solution for a point force impulse in an infinite elastic medium is used in conjunction with a superposition scheme originally devised by Mindlin [3] in order to arrive at a singular solution valid for the halfplane. In particular, solutions for a point force in the vertical and horizontal directions, a dipole without moment and a dipole with moment in the vertical directions at the image point are superimposed to the fundamental singular solution at the source point. The image point is the reflection of the source point about the horizontal (free) surface. The resulting singular solution reproduces a nearly traction-free boundary condition at the free face.

This new singular solution and its derivatives are subsequently used as kernels in a BIE formulation in the Laplace transformed domain. The particular example solved is the case of a circular cylindrical cavity embedded close to the free surface of the halfplane under a pressure wave pulse traveling parallel to the free surface. The dynamic stress field around the cavity, obtained from the BIE method in conjunction with a numerical inverse transformation, is found to be in good agreement with other analytic and numerical solutions.

References

1. Cruse, T. A., and F. J. Rizzo, J. Math. Anal. Appl., 22, 1968.

2. Manolis, G. D., and D. E. Beskos, Int. J. Num. Meth. Engrg., 17, 1981.

3. Mindlin, R. D., Physics, 7, 1936.

COMPARITIVE STUDY OF THE BOUNDARY ELEMENT TECHNIQUE AND THE FINITE ELEMENT METHOD IN TWO DIMENSIONAL EIGENVALUE PROBLEM

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and

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In this work we investigate the applicability of a "Boundary Element method" for the numerical solution of the Liouville and Helmholtz eigenvalue problem for different two dimensional geometries including a typical reactor configuration. The method is based on the discretization of the unknown along the boundary and Green's function representation of the governing equation.

To compare the capability of this method with the finite element method, a finite element code which uses quadratic quadrilateral isoparametric elements was developed. A boundary element code was also written. These codes were used to determine the fundamental eigenvalue for several two dimensional geometries -- square, "L" shaped, circular, and a quarter of a typical reactor core. The results of both codes were compared with each other and with analytical solutions where available. To optimize the computer time for the code based on the boundary element method, a powerful search technique called Fibonacci search was used to determine the fundamental eigenvalues.

During the course of this study, it was found that eliminating the imaginary part of the fundamental solution of the Helmholtz equation produced an instability in the result. The results show that, due to the use of the iteration procedure in the boundary element method to evaluate the determinant of the deduced matrix, more computer time is required for the boundary element solution than the finite element solution. However, the results obtained on the basis of the boundary element technique are more accurate than those from the finite element method.

Session WA-6: RECENT DEVELOPMENTS IN BIOMECHANICS

Organizer and Chairperson: R. P. VITO, Georgia Institute of Technology
Co-Chairperson: A. ENGIN, Ohio State University

* 2:00 - 2:30 G. C. LEE, State University of New York at Buffalo:
"Recent Studies on Finite Element Modeling of Lungs"

* 2:30 - 3:00 R. N. VAISHNAV, Catholic University:
"Nonlinear Mechanical Characterization of Orthotropic, Incompressible Arterial Tissue"

* 3:00 - 3:30 J. G. PINTO, San Diego State University:
"Continuum Models of the Mammalian Myocardium"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 D. L. WATER and J. HUMPHREY, Georgia Institute of Technology:
"Optimal Placement of Magnetometers for Studying Lung Function"

* 4:30 - 5:00 G. W. CHRISTIE, University of Auckland, New Zealand:
"The Biomechanics of Tissue Heart Valves"

5:00 - 5:15 M. SINGH and A. PERIASAMY, Indian Institute of Technology-Madras:
"Comparison of the Displacement Pattern of the Different Heart Regions as Observed on the Chest Wall by Laser Speckle"

5:15 - 5:30 P. N. TANDON and R. S. GUPTA, H. B. Technological Institute, Kanpur, India:
"Analysis of Elastohydrodynamic Lubrication in Reference to Human Joints"

5:30 5:45 B.K. DUTTA, S.V. College, D. SEN, Burdwan University and A.B. ROY, Jadavpur University:
"A Model Study of Diffusional Effects On A Simple Parmacodynamic Network"

Recent Studies on Finite Element Modeling of Lungs

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Structural properties and characteristics have always been regarded as important components in respiratory mechanics studies. However, very few advancements were made prior to 1970. In the last decade or so, solid mechanics principles and the finite element method have been introduced into the study of lung elasticity. This has opened up a variety of challenging research opportunities. This presentation will attempt to define the general problem area of finite element analysis of lungs and to describe some recent research results on the subject.

A recently-published book entitled Finite Elements in Biomechanics contains some relevant and updated information on this subject area. Those who are interested may refer to this book.*

*Finite Elements in Biomechanics, edited by
R.H. Gallagher, B.R. Simon, P.C. Johnson, and J.F. Gross,
John Wiley & Sons, 1982.

See Chapter 5, "Finite Element Analyses in Soft Tissue Mechanics"
G.C. Lee and N.T. Tseng

Chapter 6, "Deformation of the Lung: The Role of Interfacial Forces"
D.L. Vawter and W.H. Shields

Chapter 7, "Finite Element Analysis of the Lung Parenchyma"
A.D. Karakaplan, M.P. Bieniek and R. Skalak

NONLINEAR MECHANICAL CHARACTERIZATION OF ORTHOTROPIC, INCOMPRESSIBLE ARTERIAL TISSUE

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The large arteries serve as compliant conduits to carry oxygen-rich blood from the heart to the peripheral regions of the vascular bed. The mechanical properties of these arteries are important determinants of the hemodynamics of the cardiovascular system in health and disease. A study of these properties is therefore important in developing realistic models of the circulatory system. The tissue of the large arteries is capable of undergoing rather large deformations and its mechanical behavior is nonlinear in terms of the usual measures of stress and strain. In addition, the tissue is orthotropic, viscoelastic, and essentially incompressible (1). Outlined here are our attempts over the past decade to characterize realistically the nonlinear elastic and viscoelastic properties of the arterial tissue under a physiological loading consisting of an intravascular pressure and a longitudinal tethering force. The elastic (hyperelastic) characterization (2) is based on assuming that there exists for the arterial tissue a strain energy density function which is a function of the circumferential and longitudinal Green-St. Venant strains. On the basis of inflation-extension experiments on segments of canine middle descending thoracic aortas it is shown that a polynomial of the third degree in strains satisfactorily represents the elastic stress-strain response of the tissue. Similarly, it is shown (3) that the nonlinear viscoelastic response of the tissue can be characterized in terms of ten relaxation functions. Finally, a thermomechanical formulation (4) is presented to show how one can start with a general theory of continuum thermomechanics and systematically reduce it to a form applicable toward thermomechanical characterization of an incompressible, orthotropic vascular tissue.

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Acknowledgments: Support of NSF grant CME8006338 is gratefully acknowledged.

AD-A121 920 ABSTRACTS 19TH ANNUAL MEETING SOCIETY OF ENGINEERING SCIENCE INC OCTOBER 27 28 & 29 1982(U) MISSOURI UNIV-ROLLA OCT 82 N00014-82-0-0055 2/4

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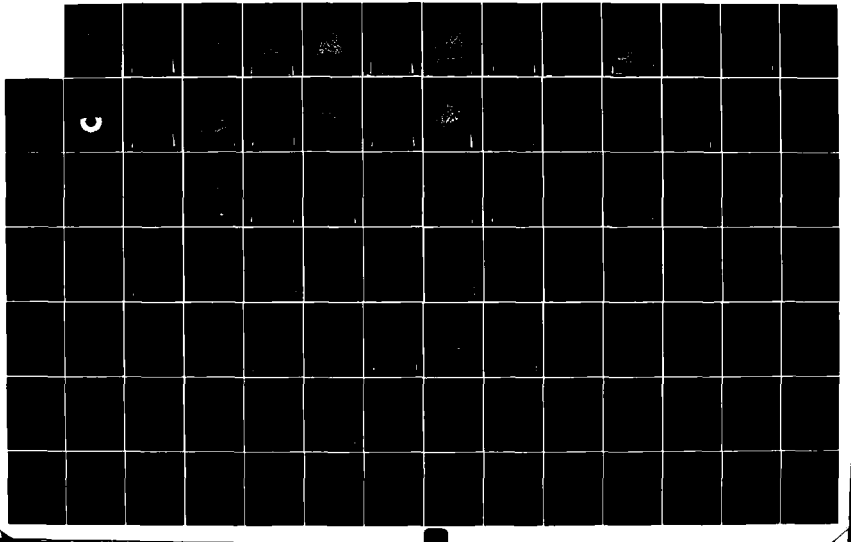

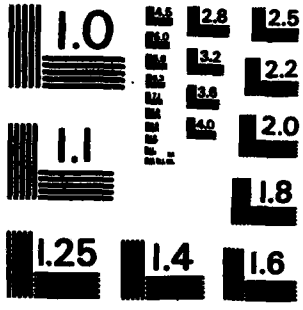

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

CONTINUUM MODELS OF THE MAMMALIAN MYOCARDIUM

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A primary motivation for research in cardiac mechanics is the desire to form reliable estimates of the cardiac function. Heart is an organ possessing complicated geometry, wall architecture and non-simple viscoelastic material constitution. During a normal beat, the size and shape of the heart undergo large finite changes. Thus for an accurate analysis of the stress distribution in the myocardium, it is necessary to include the finite deformation of the wall, its three-dimensional geometry, the complex wall-architecture, the nonuniform contractile pattern of its musculature and the interaction between its four chambers.

A mechanical analysis of the heart including all the major features mentioned above is not feasible at the present time because an understanding of (all) the necessary aspects is not adequate. However, recent technological advances have facilitated measurement of its time-changing size and shape. The wall-structural aspects are also relatively well known. On the "constitutive front" the complexities associated with the organ have precluded the development of a reasonable law for the muscle. Consequently, researchers have primarily focused their attention to an essentially one-dimensional segment of muscle.

Based on experimental results we propose the following models to characterize the cardiac muscle.

For passive muscle:

$$T(\lambda,\theta,t) = \int_0^t G(t-\tau)\,\frac{\partial T^e}{\partial \lambda}\,\frac{\partial \lambda}{\partial \tau}\,d\tau \quad \ldots\ldots\ldots \quad (1)$$

where $\frac{dT^e}{d\lambda} = \alpha(T^e+\beta)$ and $G(t) = 1+C\ln(t/\tau_2)/1+C\ln(\tau_2/\tau_1)$

Here T is stress, λ is stretch ratio, t is time T^e is "elastic" response, θ is temp. and α, β, C, τ_1, τ_2 are muscle parameters.

For active muscle:

$$T[T(t)] = \frac{1}{V_0}\frac{d\lambda}{dt} + \frac{1}{V_0}\int_0^t \phi(t-\tau)\frac{d\lambda}{d\tau}\,d\tau \quad \ldots\ldots \quad (2)$$

where $\phi(t) = \frac{d\psi}{dt}$, $\phi(t) = \sum_i A_i\, e^{-t/\eta_i}$ (sum over i), $T[T] = \frac{c(1-T/T_0)}{c + T/T_0}$

Here $c = a/T_0$, $V_0 = bT_0/a$, T(t) is active muscle force, t is time, T_0 is peak force of contraction and a, b, A_i, η_i are muscle parameters of the active muscle. Alternatively, an empirical expression of the form

$$P(\lambda,t) = A(\lambda)\, t^{\gamma} e^{-\delta t} \quad \ldots\ldots\ldots\ldots \quad (3)$$

(γ,δ muscle parameter) appears to adequately describe many features of the active muscle.

OPTIMAL PLACEMENT OF [illegible]
FOR STUDYING LUNG FUNCTION

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Magnetometers have been used for some time in attempts to estimate and infer lung volumes when spirometric techniques are inconvenient. Magnetometers are devices which measure and monitor magnetic fields. With appropriate instrumentation they can be calibrated to measure the distance between the transmitter and the receiver.

Previous studies have used three pairs of magnetometers. Two were placed anterior-posteriorly on the chest and abdomen and two were placed laterally on the chest and abdomen. If one is to use these for measurement of lung volume one must propose a model which predicts volumes from measurements of the dimensions of the chest and/or abdomen. A variety of these models are mathematical models only and do not attempt to model the geometry of the body.

We shall present the results of a study to determine the optimal placement of the magnetometers. An optimal position is one which has a high correlation with volume measurements and which is not redundant. By redundant we mean a measurement which is highly correlated with another magnetometer path.

Preliminary results indicate that measurements of lateral dimensions correlate poorly with volume and are much less sensitive. Both chest and abdomen are dimensions sensitive with which volumes. Elimination of [illegible] by locating pairs of magnetometers in [illegible] can be explained.

References

Hunter, B. L., "[illegible]
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THE BIOMECHANICS OF TISSUE HEART VALVES

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New Zealand

Porcine aortic valves, preserved in glutaraldehyde and mounted on a supporting frame are very commonly used as substitute cardiac valves. Such devices offer superior quality of life to the patient compared with the purely prosthetic disc and ball valves; however, they still exhibit uncertain durability.

One of the common causes of late failure of bioprosthetic valves is the tearing of the leaflets near points of high stress. The purpose of this study has been to calculate the stress using a nonlinear finite element program and to investigate which factors need to be controlled during valve fabrication.

The computer program places no limits on the magnitudes of either strains or displacements. The tissue leaflets are approximated as a thin hyperelastic membrane reinforced with two independent families of fibres to represent the distinct collagen and elastin layers. The valve closed by the three tissue leaflets forming a common seal along their adjacent boundaries so a contact boundary condition was introduced to properly represent this condition.

The numerical studies have shown that small particular distortions to the natural valve geometry introduced during fabrication can greatly augment stress concentrations in the tissue after the valve has been implanted. It has also been shown to demonstrate that the natural arrangement and waviness of the collagen and elastin components within the tissue is highly advantageous to the valve both in terms of load bearing capacity and closure efficiency.

A review will be given of the clinical motivation for this work, the numerical formulation and how the understanding of the mechanics and structure of bioprosthetic heart valves should lead to improvements in valvular longevity in vivo.

COMPARISON OF THE DISPLACEMENT PATTERN OF THE DIFFERENT HEART REGIONS AS OBSERVED ON THE CHEST WALL BY LASER SPECKLE

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The laser speckle interferometry has widely been used in engineering to determine the displacement and vibratory pattern of the various objects. In the present work the time average speckle interferometry has been applied to determine the displacement pattern, produced by the mechanical activities of the human, on the chest wall. Healthy male subjects with normal medical backgrounds were asked to sit in the upright position on the stool, and to hold the breathing in order to reduce the unwanted movement during the exposure of displacement fringes. The photographic plate with 5.0 mW He-Ne laser of wavelength 632.8 nm, which was kept at the frontal plane of the lense combination convex lens, and was exposed for three seconds. After processing the plate, the fringe pattern, thought to emerge, formed due to the interference of the scattered radiation, from the various points of the chest wall was analysed by point-wise method for determining the displacement, given by

$$d = (\quad)$$

[illegible] pattern, [illegible] the various points of the chest wall. These studies indicate that the various [illegible] and the various [illegible] the various [illegible] from the [illegible] the [illegible] the [illegible]

ANALYSIS OF ELASTOHYDRODYNAMIC LUBRICATION IN REFERENCE TO HUMAN JOINTS

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In the present analysis, elastohydrodynamic lubrication (EHL) of solids covered by soft layers, are applied to the heavy load bearing human joints. The basic equation governing the pressure in the fluid film has been derived by considering lubricant as a power law fluid which represents the non-Newtonian behaviour of the synovial fluid in joint cavity. Results concerning the pressure, load capacity and coefficient of friction of the joint are obtained using iteration process. It has been observed that the elastorheodynamic mode of lubrication plays an important role in the lubrication mechanism of human joints. This mode is beneficial in maintaining a fluid film for a longer lasting time and increases the contact area and load carrying capacity of the joint as a whole.

A NOTE ON [illegible]

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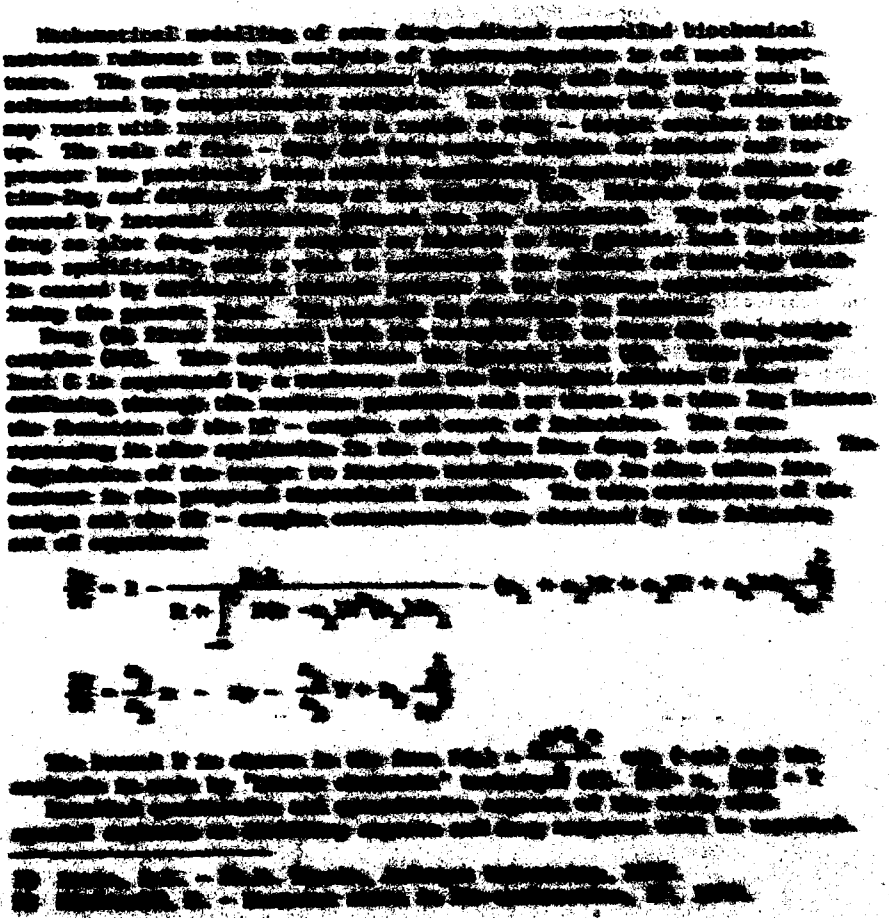

Session WA-7: FRACTURE/FATIGUE

Chairperson: F. W. SCHMIEDESHOFF, U.S. Army Research Office

Co-Chairperson: P.S. PAO, McDonnel-Douglas Corporation

2:00 - 2:30 C. W. SMITH and J. S. EPSTEIN, Virginia Polytechnic Institute and State University:
"Studies on an Optical Modeling Technique for Predicting Flaw Shapes and Stress Intensity Distributions in Cracked Bodies"

2:30 - 2:45 I. MISKIOGLU, A. S. VOLOSHIN and C. P. BURGER, Iowa State University:
"Evaluation of Stress Intensity Factors Using Half Fringe Photoelasticity"

2:45 - 3:00 Ph. DESTUYNDER, Electricite de France, Calmart:
"Recent Developments in Numerical Fracture Mechanics"

3:00 - 3:15 I. A. KUNIN and J. SELYAKOVSKY, University of Houston:
"Boundary Integral Equations for a Three-Dimensional Crack"

3:15 - 3:30 A. S. KRAUSZ and K. KRAUSZ, University of Ottawa, Canada:
"Thermal Activation in Subcritical Crack Growth"

3:30 - 4:00 REFRESHMENT BREAK

4:00 - 4:15 A. SHUKLA, University of Rhode Island and H. P. ROSENSMITH, Technical University, Vienna, Austria:
"Wave Induced Fracture in Pre-Cracked Thick-Walled Cylinders"

4:15 - 4:30 R. SOLECKI, University of Connecticut:
"New Method of Analyzing Vibration of a Rectangular Plate with a Crack Parallel to One Edge"

4:30 - 4:45 T. S. RAMAN and V. I. PAKRASHY, Concordia University:
"Exact Solution to Some Crack Problems in Transversely Isotropic Bodies"

4:45 - 5:00 H. CHEREPY, University of Rhode Island:
"Description of the Fatigue Crack Front Distribution"

5:00 - 5:15 E. J. LEE, C. E. LEE and P. C. CHEN, IBM Corporation, Endicott:
"Fatigue Element Analysis and Its Application to Print Hammer Design and Material Selection"

5:15 - 5:30 M. S. TROITSKY, Z. A. KIELBASKI and M. S. PERSHNAR, Concordia University:
"Stress Concentration in Steel Stack at Rectangular Opening and Pipe Connections Under Internal Pressure"

5:30 - 5:45 K. A. GUPTE and S. SANKARAN, Indian Institutes of Technology-Bombay:
"Study of Size Dependent Plasticity and Crack Growth in Thin HSI Loading - A New Tactic for the Determination of K_{IIIc}"

5:45 - 6:00 J. P. HUPPERT, Clarkson College of Technology:
"The Tunning of a Shift Plane"

6:00 - 6:15 T. C. HSU (Statement), University of New Mexico, M. H. [illegible], Bhopal University, India and V. SHIVAKUMAR, Lockheed-Georgia, Marietta:
"Interaction Between a Circular Hole and Two Symmetrically Placed Collinear Cracks"

Studies on an Optical Modelling Technique for Predicting Flaw Shapes and Stress Intensity Distributions in Cracked Bodies

by

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The most common type of service fracture results from the enlargement of small cracks by fatigue loading to critical size after which fracture occurs. Such problems often involve curved crack fronts, non-uniform stress intensity distributions and non-planar cracks. Moreover, since such cracks usually start at stress raisers, complex boundary conditions away from crack surfaces are also often involved.

For over a decade, the first author and his associates have been working to develop a cost effective modelling technique for estimating flaw shapes and SIF distributions where neither are known a-priori in order to assist efforts of analysts in formulating numerical models for such problems. First developed by combining frozen stress photoelasticity with linear elastic fracture mechanics for pure Mode I loads [1],[2], it was then extended to mixed mode analysis [3],[4] and recently augmented [5] with Moiré interferometry to provide added experimental information.

After briefly reviewing the current approach to the problem, this paper attempts to assess the extent of applicability and limitations of these optical methods when utilized to attack three dimensional cracked body problems of high priority technological importance. Examples are drawn from aerospace and nuclear power fields.

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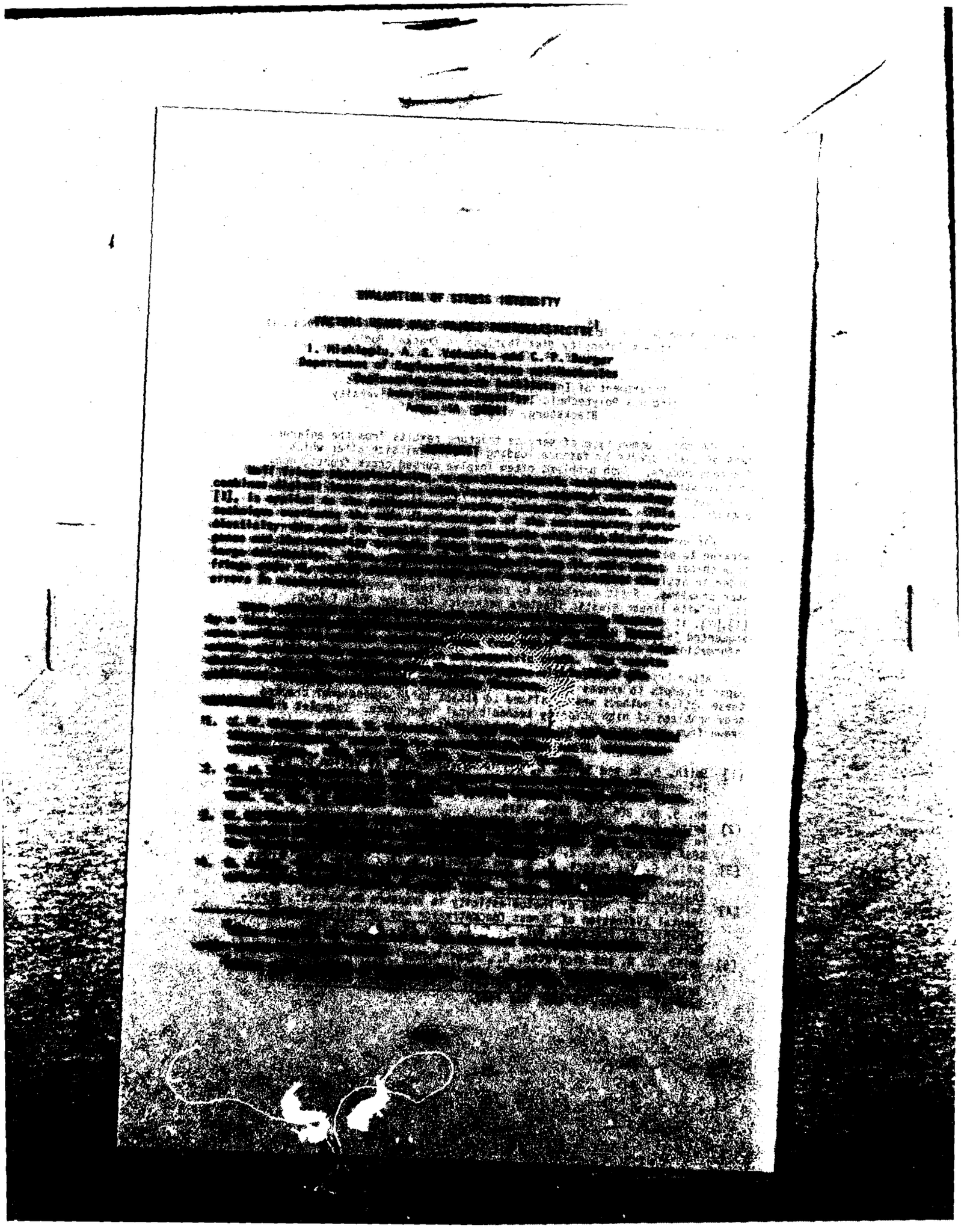

RECENT DEVELOPMENTS IN NUMERICAL FRACTURE MECHANICS

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The goal of this paper is to give a description of the last tools developed at Electricite de France for the analysis of a crack propagation in the framework of linear elasticity.

First of all, we recall how the use of thermodynamics and the choice of a dissipation potential leads to a propagation law. Then, we examine the case of a complex loading and give a new rule of additivity in case of simultaneous loading. Creeping and fatigue phenomena are analyzed on several examples.

All the obtained propagation laws make use of the energy release rate, which is also known as the crack propagation strength.

We suggest here a new computational approach of this quantity based on the notion of derivative with respect to a domain. Numerical results-compared with other methods such as the J-integral prove the validity of our suggestion.

The question of stability (with help of the second order derivative of the Potential Energy with respect to the crack length) is discussed. Bifurcation criteria are also discussed. Finally, we mention -as an example- the question of propagation of a crack in a bending plate and for a thermo-elastic media.

"BOUNDARY INTEGRAL EQUATIONS FOR A THREE-DIMENSIONAL CRACK"

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Boundary integral equations for arbitrary shaped nonplanar cracks in a three-dimensional linear anisotropic medium are obtained. The method of regularization of the corresponding singular integral operators (pseudo-differential operators) is based on a new technique developed in [1]. These equations are convenient for numerical as well as approximate analytical solutions. Expressions for stress intensity factors are investigated.

A comparison with other approaches to the problem [2-6] is given.

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6. J. Shlyapobersky, J. Appl. Math. Mech. - PMM, 42, 532, 1978.

ABSTRACT

THERMAL ACTIVATION IN SUBCRITICAL CRACK GROWTH

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Time dependent, subcritical, fracture processes are thermally activated. The fundamental mechanism is controlled by stochastic bond breaking events leading to a rigorous mathematical description in terms of statistical mechanics concepts. The relation between the rigorous transition state theory and the empirical Arrhenius equation will be discussed.

The kinetics of time dependent crack propagation processes and its application to environmentally assisted fracture was determined. It was also established that, because thermally activated mechanisms are stochastic, a probabilistic aspect is always associated with environmental effects. The consequent reliability analysis in design and test engineering will be presented.

Following the developments that took place in the 70's in the application of the Griffith theory to time dependent fracture, the process of subcritical, thermally activated, crack propagation was investigated. The transition from the go - no go continuum mechanics consideration of the Griffith theory was revised by considering the discrete atomic character of the materials. This has led to the description of slow crack propagation in terms of atomic interaction, crack driving force, and temperature.

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A. S. Krausz and K. Krausz, "The inherently probabilistic character of sub-critical fracture processes" Proc. of the Design Engineering Techn Conf. of the American Society for Mechanical Engineers, Hartford, Conn. pp. 23-28 (1981).

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Wave-Induced Fracture in Pre-Cracked Thick-Walled Cylinders

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and
H. P. Rossmanith
Technical University Vienna, Austria

Abstract

Slow stable crack extension as well as dynamic crack propagation in pre-cracked cylindrical vessels subjected to shock loading has received considerable attention in recent years because of its importance in several branches of applied engineering [1]. This paper attempts to experimentally study crack initiation and propagation in thick rings fabricated from a polyester material Homalite 100. Dynamic photoelasticity and high speed photography are utilized to obtain complete transient stress field during crack wave interaction process. A typical photograph showing the interaction at a particular time is given in Fig. 1 The data from such photographs is analyzed to obtain crack propagation behavior and the oscillation in the stress intensity factors during the interaction process.

References

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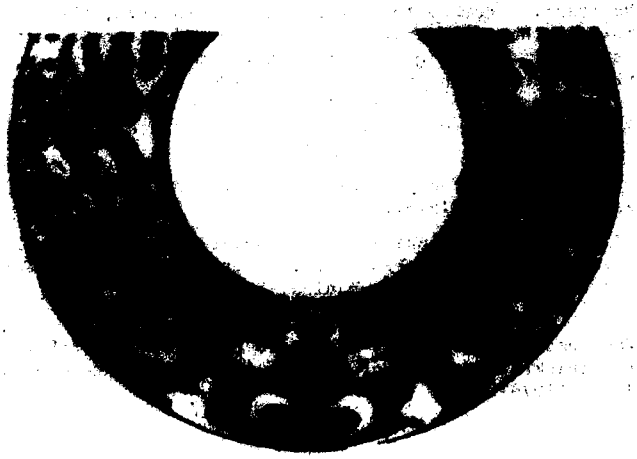

Fig. 1: Dynamic Isochromatic Fringes Showing Crack-Wave Interaction in a Thick Walled Cylinder.

New Method of Analyzing Vibration of a Rectangular Plate With a Crack Parallel to One Edge

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Scarcity of solutions for vibrating,cracked finite plates results mainly from lack of sufficiently general methods. It was shown in [1] that the case of doubly symmetric location of a crack can be reduced to the solution of a system of dual series. A more general configuration was investigated in [2] but the singularities at crack tips were disregarded.Lately the method based on representing a crack as continuous distribution of dislocations was shown to be quite general and efficient.However for finite plates the mechanical state due to the presence of a point dislocation is unknown and hence direct reduction of such problems to a system of singular integral equations is sofar not possible. The method proposed in [2] is perfected here.Its main features are:a)application of double finite Fourier transformation to a differential equation defining a discontinuous function.This step is simplified by application of generalized Green-Gauss theorem.Transformed equation obtained in this way depends on the unknown discontinuities across the crack and on the intensities of singularities at its tips;b)next the boundary conditions are applied.This step requires differentiation of not uniformly convergent double series.Extensive algebraic manipulations involved here are presently considerably simplified by a repeated application of Green-Gauss theorem.A coupled system of infinite,homogeneous algebraic equations is thus obtained.The characteristic determinant of this system is equated to zero providing the frequency equation.Numerical data are obtained and compared for the special case with results presented in [2] .

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EXACT SOLUTION TO SOME CRACK PROBLEMS IN TRANSVERSELY ISOTROPIC BODIES

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ABSTRACT:

Consider a transversely isotropic elastic half-space $z \geq 0$ with the plane of isotropy parallel to the boundary. The following boundary conditions are prescribed on $z = 0$:

$$\sigma_z = \sigma(\rho,\phi) \quad \text{with } 0 \leq \rho < \infty \quad 0 \leq \phi < 2\pi$$

$$\left.\begin{aligned} \tau_{zx} &= \tau_{zx}(\rho,\phi) \\ \tau_{yz} &= \tau_{yz}(\rho,\phi) \end{aligned}\right\} \text{with } 0 \leq \rho < a \quad 0 \leq \phi < 2\pi$$

$$\left.\begin{aligned} u_x &= u_x(\rho,\phi) \\ u_y &= u_y(\rho,\phi) \end{aligned}\right\} \text{with } a \leq \rho < \infty \quad 0 \leq \phi < 2\pi$$

All three components of the displacement vector are assumed to be zero outside the circle $\rho = a$. The problem is then reduced to the solution of three dual integral equations, which, in the general case, are coupled. The method of solution is based on the expansion of the unknown functions in series of Jacobi polynomials.

A mixed-type boundary-value problem for a half-space is considered. The exact solution to this problem is obtained under the assumption that the series expansibility of all the functions involved.

In particular, results for axisymmetric, as well as plane strain problems are obtained as well. The latter problem is solved for the case when the elastic constants of the material are such that the material is isotropic in the plane of the crack. The results for this case are compared with those obtained by Sneddon and Tait [1] for the corresponding problem in isotropic elasticity. It is shown that the above mentioned results are identical. Several numerical examples are also presented.

DESCRIPTION OF THE FATIGUE CRACK FRONT DISTRIBUTION

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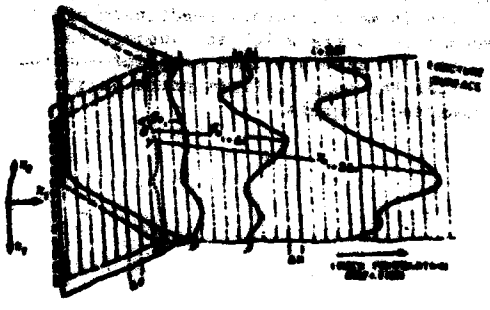
In this paper a mathematical model describing the fatigue crack front during the propagation process, as shown in the figure below, is developed. This mode is based on three assumptions: 1 - the propagation process is an irreversible process, 2 - the existence of the crack front at a particular position is not directly influenced by the mechanical and physical details of its other previous position, and 3 - the crack front attempts to maintain a particular curvature in order to keep the maximum principal stress constant along the front. Based on these assumptions and using concepts of discontinuous Markovian stochastic process, the crack front is mathematically described as:

$$(u_a; V_a) = (u_{a_o} e^{\lambda i}, \xi u_{a_o} e^{\lambda i} (e^{\lambda i} - 1))$$

where U_a and V_a are the mean variance of the crack front distribution at cycle i, u_{a_o} is the initial crack length, λ is a material constant and ξ is a parameter that accounts for the neighborn interaction and edge effects.



Schematic of proposed fatigue crack propagation model

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FATIGUE MOMENT ANALYSIS AND ITS APPLICATION TO PRINT HAMMER DESIGN AND MATERIAL SELECTION

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General Technology Division
Endicott Laboratory

During a study of fatigue strength of materials for high-speed printer applications, a new method of analysis for the limit of endurance for notch gages was established in terms of fatigue-groups. Print hammers made with different designs and materials were tested in conventional cyclic fatigue. With various values of the applied load, stress-cycle curves and moment-cycle curves were obtained.

As a result of [illegible] gun design for minimum hammer-to-anvil bounce were made. The [illegible] and the fillet radii of gage notch [illegible]. Also, the general configuration [illegible] was modified in accordance with a shooting pattern. The new design hammers definitely showed superiority to others including the old design injection-molded [illegible], and exceptional life gains. This change in application and shows 100% improvement in moment endurance limits. The [illegible] and the new design hammers showed [illegible] and the new design hammers showed [illegible] military feature of more than 40% in operation.

In conclusion, the use of [illegible] determines superior design and yields more economic [illegible] of hammers for the mechanical gages which are subject to repeated stress cycles. It also provides [illegible] for estimating a material for such [illegible] print hammers of high-speed printers.

STRESS CONCENTRATION IN STEEL STACK AT RECTANGULAR OPENING AND PIPE CONNECTIONS UNDER INTERNAL PRESSURE

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A rectangular opening provided near the base of the stacks, Fig. 1, facilitates access to high temperature flue gases. Some reference material gives certain design information concerning the stress condition at circular opening. However, the stress distribution in the vicinity of rectangular joints under internal flue gas pressure is not well known and became the subject of this study. The range of internal pressure for the present study was considered according to Ref.(1,2,3). Stresses are computed using finite element program ANSYS. A triangular isoparametric elastic flat shell element having six degrees of freedom per node; three orthogonal translations and three rotations was chosen. The results provide the deflections and in-plane membrane and bending stresses at joints. Although the corners intersecting edges of the opening sustain significantly high values of membrane and bending stresses, not necessarily the highest values are present at these points. However, their simultaneous presence and comparable intensities make these regions a critical location of stress concentration. The high bending stresses (shown in Fig. 1) are localized at point 'A' but at point 'B' large hoop stresses occur as a result of the removed material. Critical stresses at a given point have to be determined by superimposing stresses due to the governing load combination including own weight and wind.

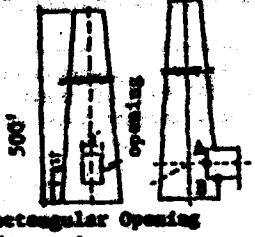

Fig. 1 - Steel Stack with Rectangular Opening and Pipe Connection

1. American National Standard Institute, "Pressure Design Power Piping Code B31.1-77", p.15.
2. American National Standard, "Chemical Plant and Petroleum Refinery Piping B31.3-76", pp.40-42.
3. American Society for Mechanical Engineers, "Guide for Gas Piping Systems-75",p. 20 and "Boiler Pressure Vessel Code"
4. Baldwin, C.J. and Swanson, J.A. "ANSYS Engr. Analysis System User's Manual, Swanson Analysis System,Inc. 1975.

[redacted]

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[redacted]

THE TEARING OF A HALF PLANE

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The surface of an elastic half space is subjected to sudden antiplane mechanical disturbances. Both prescribed shear tractions or prescribed displacement distributions sufficient to cause tearing are treated. The preferred direction of crack propagation is investigated; instantaneous skew crack propagation is considered, as well as instantaneous crack bifurcation. The analysis is, of course, directly applicable to geometries with weak planes, as in strike-slip faulting.

For constant crack-tip velocities the particle velocity is self-similar, a feature that allows the use of Chaplygin's transformation - which reduces each problem to the solution of Laplace's equation in a strip. The Schwartz-Christoffel transformation is subsequently employed to map the semi-infinite strip on a half-plane. The appropriate harmonic function in the half plane is obtained by using the theory of functions of complex variables. The question of completeness is important since the harmonic function may satisfy the boundary conditions but may not give the correct crack tip singularity. For various values of crack propagation velocity the dependence of the stress intensity factor on the angle of crack propagation is studied. Analytic solutions are obtained for two particular geometries, and these solutions provide checks on the numerical results. Some conclusions about the possible mode of tearing are drawn.

INTERACTION BETWEEN A CIRCULAR HOLE AND TWO SYMMETRICALLY PLACED COLLINEAR CRACKS

[redacted]

Cracks adjoining holes are a common type of flaw problem that occurs in aerospace structures, and for this which safe-life computations are frequently required. This paper consists of an investigation of the stresses in an infinite isotropic elastic plate containing a circular hole and two symmetrically placed collinear cracks. A uniform pressure is applied to the hole boundary in addition to uniform tensile stresses applied infinitely remotely from the hole.

The analysis is based on the two-dimensional theory of elasticity and derives the Kolosov stress functions using Laurent's series representations of the stress functions. The problem is reduced to a dual homogeneous Riemann problem, the solution to which leads to a finite set of algebraic equations involving the complex coefficients of the stress function series representations.

A study of the crack-tip stresses is presented, with the variation of stress-intensity factor ratios as functions of geometry, viz., length of the crack and proximity to the hole, and as a function of the applied loading conditions.

Session 3A-2: MATERIALS SCIENCE AND METALLURGY

Chairperson: C. T. LIU, Office of Naval Research

Co-Chairperson: R. SRIVAS, National Institute of Foundry and Forge Technology, India

2:00 - 2:15 M. T. HUNT and R. E. REP, University of Missouri-Rolla: "Mechanical Properties of Aluminum for Orthopedic Implant Use"

2:15 - 2:30 M. P. LEMENT, JR., University of Missouri-Rolla: "Fracture Annihilation - A Tool for Studying Defects in Metals"

2:30 - 2:45 A. H. [illegible] and M. [illegible], University of Petroleum & Minerals, Saudi Arabia: "A Reliability Model for a Non-Linear Damage Process"

2:45 - 3:15 R. E. [illegible], Lawrence Livermore National Laboratory: "Modeling Interactions and Thermodynamics of Gaseous Mixtures for a Reactive Material"

3:15 - 3:30 E. A. [illegible] and E. E. [illegible], University of Missouri-Rolla: "Ion Implantation of Steel for Enhanced Wear Resistance"

3:30 - 4:00 [illegible]

4:00 - 4:15 M. A. [illegible] and S. M. Ali, Al-Azhar University, Egypt: "On the Mechanical Properties of γ' - Hardened Ni-[illegible] Co Alloy"

4:15 - 4:30 E. E. [illegible], Centro de Ingeniería-IVIC, Venezuela: "High Temperature Mechanical Properties and Oxidation Behavior of [illegible] with Si and Co Additions"

4:30 - 4:45 S. E. [illegible], Brigham Young University, and T.E. [illegible], M. E. [illegible], Sandia National Laboratories: "A Numerical and Experimental Study of Ductile Failure in Metals"

4:45 - 5:00 S. M. [illegible], University of South Carolina, and R. [illegible], National Institute of Foundry and Forge Technology, India: "Experimental Determination of Machinability, Aging Characteristics and Mechanical Properties of Aluminum + 4.5% Copper Alloys Treated with Rare Earths"

5:00 - 5:15 M. L. [illegible] and A. A. [illegible], Bureau of Mines Rolla Research Center: "A Standard Test Suite Soldering of Aluminum Alloys"

5:15 - 5:30 J. M. [illegible], Rao Bikaneer Purba, India: "Bending in Low Carbon, Low Alloy Steels"

MECHANICAL PROPERTIES OF ALUMINA FOR ORTHOPAEDIC IMPLANT USE

by

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ABSTRACT

The time to failure, flexural strength and chemical corrosion were measured for three commercially produced, polycrystalline aluminas, two of orthopaedic implant grade, aged in demineralized water at 37° and 70°C. Experiments were performed to determine if the significant differences in the time to failure of these aluminas correlated with their impurity content, particularly Ca and Si. At 37°C, the Ca concentration of the demineralized water in contact with these aluminas initially increased with time up to ~30 hours and then remained constant. No detectable amounts of Al were found in the demineralized water and only trace amounts of Na and Si were detected. The amount of Ca dissolved from the aluminas by demineralized water was independent of the load (stress) applied to the alumina specimens. Auger analysis of the external surfaces of the aluminas also showed a decrease in the Ca and Si concentration after immersion in demineralized water.

The three aluminas showed reductions in flexural strength of 5 to 75% after aging for 7 days in demineralized water (at 37° or 70°C) or 1 to 8 wt. % HF solution. The high purity alumina, not of implant grade purity, showed the largest decrease in flexural strength, up to 75% in 8% HF solution. Microstructural examination of the fracture surface of this alumina showed that it had been completely penetrated by the 8% HF solution. The grain boundary phase(s) containing the Ca impurity had been dissolved and new Ca-containing crystals had formed. The depth of penetration was proportional to the HF concentration, but there was no observable penetration by demineralized water.

These results show that the mechanical properties of orthopaedic implant grade aluminas can be significantly different depending upon the impurities they contain. It is not totally certain whether all of these differences are due exclusively to the Ca impurity, but it is clear that Ca is dissolved from such aluminas under conditions similar to those for in vivo use. The presence of other impurities such as Si, which can affect the chemical composition and corrosion resistance of the phase containing the Ca impurity, may be expected to be important to the mechanical properties of such aluminas when in contact with aqueous liquids.

POSITRON ANNIHILATION - A TOOL FOR STUDYING DEFECTS IN METALS

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When a positron, the positively charged analog of an electron, interacts with an electron, an annihilation occurs. This produces two gamma rays. Ideally, each has an energy of 511 keV, and they are emitted at pi radians from each other. However, if the process occurs in a conducting solid, i.e., a metal or an alloy, either the positron will annihilate with a valence electron of some atom, which is loosely bound to the crystal lattice and has a relative low energy, or it will annihilate with a core electron, which is more strongly bound to the atom nucleus and has a relatively higher energy. The energy of the emitted gamma rays and the angle they make with one another are dependent upon the energy and the momentum of the annihilating positron-electron pair.

The vacancies in the metal crystal provide lattice sites in which the positron may act as a substitute for the missing positively charged metal ion. As a result, the positron is trapped. Other types of defects, such as grain boundaries, dislocations, and voids, act as traps as well. In the traps, there is a deficiency of valence electrons, even though distance between the positron and nearest core electron is large. When annihilation does occur between the trapped positron and valence electrons, the distribution of energy of the emitted gamma rays is different than the distribution of the gamma rays energy resulting from the positron-electron events in a perfect region of the crystal.

There are three experimental techniques that can be used to measure the annihilation effect of gamma rays. Angular correlation is used to measure the angle between the annihilating gamma rays. The defects narrow the angle between the rays. In lifetime measurements, the time between the emission of a positron by a radioactive isotope and its annihilation is measured for many events. From these measurements, a lifetime can be determined. The presence of traps increases the lifetime of the positron in a metal so that more than one lifetime can be determined. In Doppler broadening measurements, the energy of the gamma rays depends on the relative number of annihilation events that take place in perfect regions of the crystal compared with the number of events occurring between trapped positrons and valence electrons. Any increase in the number of traps increases the probability of trapping the positron before it can annihilate.

The three experimental methods may be used to determine the presence of defects in a metal or an alloy. A number of experiments have been performed from which the energy of formation for vacancies in various pure metals has been obtained. The presence of vacancies and their annealing characteristics has been determined in metals that have been severely quenched. Void diameters have been determined in metals that have been subjected to intense radiation damage by high energy neutrons. The number of dislocations resulting from cold working has been determined as a function of the amount of cold working. Recently, attempts have been made to determine the number of defects generated by fatigue as a tool for predicting failure long before enough fatigue cycles have taken place.

A RELIABILITY MODEL FOR A NON LINEAR DAMAGE PROCESS

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Several types of damage processes lead to the failure of mechanical devices. Some examples of these damage processes are: wear, fatigue, creep and corrosion. In this paper we consider a generalized damage process defined by the random function D(t);

$$D(t) = At^{B} \quad ; \quad t \in T \tag{1}$$

where A, B and T are random variables, and
D(t) = damage incurred at time t.

If the life of the device is terminated when the damage exceeds a limiting value D_ℓ (i.e., $D(t) \geq D_\ell$), then, it will be shown that, under certain assumptions regarding random variables A and B, the following reliability model of the device is obtained:

$$R(t) = \Phi\left[\frac{\ln \alpha_\ell - C_\ell}{\beta_\ell}\right] \tag{2}$$

where $\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} \exp\left[-\frac{1}{2}\xi^2\right] d\xi$,

and C_ℓ, α_ℓ, β_ℓ are the functions of D_ℓ and the mean and variance of the random variables A and B.

In this paper various statistical characteristics of the reliability model proposed in equation (2) are discussed. The generalized nature of the proposed model is emphasized, and it is shown that the lognormal model is a special case of the proposed model. The method of estimation of the parameters of the reliability model from a set of realizations (sample functions) of the damage process is also illustrated.

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Abstract submitted to the 19th Annual Meeting of SES, Oct. 1982

MODELLING DEFORMATIONS AND THERMODYNAMICS OF CRACK KINETICS FOR A BRITTLE MATERIAL*

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A physical, rather than a mathematical, description of a crack is modelled. The approach uses concepts from dislocation and microcrack models to define idealized attributes describing the tip region of a crack. The attributes characterize both geometry and deformation; and identify a material defect species called a crack dislocation. With the attributes as variables, and using some statistical mechanics concepts, a scalar density function for each crack dislocation species can be defined.

The crack dislocation is different from the common edge or screw species in that it creates a new surface area as well as a displacement discontinuity as it propagates through a crystalline lattice. To model the discontinuities, a relative deformation functional is developed which depends on the crack dislocation density function. The crack dislocations are assumed to be the only material defects that can contribute deformation discontinuities; therefore, the model is only for brittle materials.

The thermodynamic model uses primarily the methodology established by Gibbs. The existence of an internal energy functional is assumed. The methodology results in a definition for a thermodynamic potential for crack dislocation kinetics, a generalization of the Griffith crack propagation concept, and a local measure for the surface strain energy density changes on the crack dislocation line. The equilibrium thermodynamic potential for crack dislocation kinetics introduces a thermodynamic concept to demarcate crack dislocation density transitions from stationary to non-stationary; hence, it provides a fracture criterion that has a thermodynamic basis. For nonequilibrium thermodynamics, the Onsager formalism is used to model the rates and fluxes of the thermodynamic functions.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

ION IMPLANTATION OF STEEL FOR ENHANCED WEAR RESISTANCE

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Ion implantation is a surface modification technique in which a target material is bombarded by a beam of high energy, accelerated ions. These ions strike the surface of the target, become embedded, and can produce major modifications in surface properties. Significant development of the process occurred in the mid-to-late 1960's and early 1970's, with most applications relating to the semiconductor industry. Studies concerning the potential modification of engineering metals did not begin until the early 1970's but have continued to produce encouraging results. The process possesses a number of attractive features and some laboratory results are nothing short of phenomenal. Current limitations focus largely on the high capital equipment cost and lack of an established scientific data base.

Focusing attention to possible improvements in wear resistance, it was noted that order-of-magnitude reductions in wear rates were commonly reported. However, nearly all of this data was obtained from laboratory testing under extremely light loading (less than 2000 psi). Investigation at the University of Missouri-Rolla sought to further consider wear improvements, but with evaluation being conducted at much more realistic loads and pressures. Over the past two years, efforts have resulted in:

1. The development of an acceptable high pressure wear test procedure for ion implanted specimens. (Ref. 1)
2. Documentation of an order of magnitude reduction in the wear rate of steel by nitrogen implantation at pressures well into the realms encountered in wear-sensitive mechanical components. (Ref. 2)
3. Determination of the dose dependency of wear resistance for nitrogen implants. (Ref. 2)
4. Observation of a dose rate effect for high dose implants.
5. Consideration of alternate implant species, and
6. Concern for thermal history of the material prior to, during, and subsequent to implant.

Current work is focusing on enhancing the understanding of already observed phenomena and establishing guidelines and limitations regarding the applicatfons of the technique.

References

1. "Measurements of the Wear Properties of Metallic Solids with a Falex Lubricant Testing Machine", E.B. Hale, C.P. Ming, and R.A. Kohser, accepted for publication, Journal of Scientific Instruments.

2. "Improved Wear Resistance by Ion Implantation", R.A. Kohser, and E.B. Hale, Proceedings of the Tenth North American Manufacturing Research Conference, Society of Mfg. Engr., 1982.

ON THE MECHANICAL PROPERTIES OF γ' - HARDENED Ni-10% CO ALLOY

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The variation of the mechanical properties as a function of ageing at 873 K- 073 K for Ni-10% Co alloy precipitation strengthened by γ'-phase was investigated. Constant stress creep tests have been carried out over a range of stresses at 1073 K. The dependence of the true creep strain, over almost the entire creep curve, can be described by:

$$\varepsilon = \varepsilon_o + \varepsilon_t(1-e^{-mt}) + \dot{\varepsilon}_s t + \varepsilon_t e^{\dot{p}}(t-t_t)$$

where ε_o is the instantaneous strain on loading, ε_p the transient creep strain, m is a constant, $\dot{\varepsilon}_s$ the steady creep rate, ε_t and $\dot{p}$ are tertiary creep parameters and t_t is the time to the onset of tertiary creep. The dependence of the steady creep rate, $\dot{\varepsilon}_s$, on applied stress, σ, can be described accurately as:

$$\dot{\varepsilon}_s = A\ (\sigma - \sigma_o)^p$$

The exponent $p \simeq 4$, σ_o is the back stress and A is a material dependent constant. Previous methods of identifying σ_o for a particular system have involved creep testing and electron metallography. The work described in this paper proposes that σ_o can be measured at only a single stress. Consequently, the variation of the back stress as a function of the applied stress can well be predicted by the relation:

$$\sigma_o = \sigma - B\sigma^{n/4}$$

where n is the observed stress exponent of steady state creep.

The applicability of this relation has, also, been extended to Nimonic 90, a commercially developed alloy, creep tested over a wide temperature range. The practical gains of the present method arise from minimizing the amount of testing required for the evaluation of a new engineering material and in simplifying the task of identifying the operative creep mechanism.

High Temperature Mechanical Properties and Oxidation Behaviour of Ni_3Al with Hf and Co Additions.

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Ni-based alloys are finding increasing use in aircraft, marine, industrial gas turbines and other high temperature applications, due to their increasing strength and corrosion resistance over a wide temperature range. The ability of these alloys to maintain, or improve at elevated temperatures some of their room temperature mechanical properties is due to the presence of the intermetallic compound Ni_3Al (γ').

In the present work the high temperature, up to 1000°C, mechanical properties and cyclic oxidation behaviour between 45-1175°C of the intermetallic compound Ni_3Al (γ') with Hf and Co additions were studied. The flow stress for these alloys varied little with temperature up to about 700°C and then dropped rapidly with increasing temperature, Fig. 1. This behaviour was attributed to the presence of a fine γ' precipitate in the (Ni_3Al) matrix. Co additions had no effect on the cyclic oxidation behaviour of Ni_3Al, while Hf additions improved remarkably the resistance to spalling during thermal cycling, Fig. 2.

Fig.1

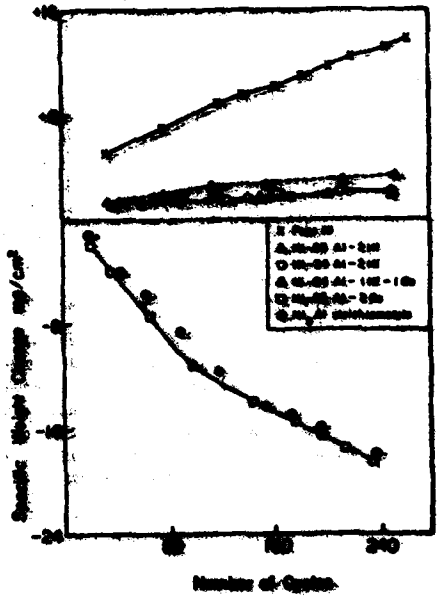

Fig.2

A NUMERICAL AND EXPERIMENTAL STUDY OF DUCTILE FAILURE IN METALS*

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ABSTRACT

A combined experimental/numerical analysis has been performed on the nonlinear response and ductile failure of beryllium, 7075-T651 aluminum, A533B steel and 304 stainless steel. The different specimen shapes which were tested and analyzed produced: (1) pure shear, (2) uniaxial, (3) biaxial, and (4) triaxial states of stress in an axisymmetric geometry. Experiments performed on these specimens were subsequently analyzed with large strain finite element calculations. The calculations closely modeled experimental behavior. The calculated stresses and strains were then used to study ductile multiaxial failure criteria for monotonic loading configurations. This study concludes that the strain at which the metals fail is dependent upon the existing triaxial stress field, the higher the triaxiality, the smaller the effective plastic strain at failure. The relationship between strain at failure and the degree of triaxiality is given by the failure criteria.

*This work was supported by the U.S. Department of Energy (DOE), under Contract DE-AC04-DP00789.

**A U.S. Department of Energy Facility

ABSTRACT

"Experimental Determination of Machinability, Aging Characteristics and Mechanical Properties of Aluminum + 4.5% Copper Alloys Treated With Rare Earths"

by

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The present paper deals with the influence of misch metal addition to aluminum + 4.5% copper on the aging characteristics and also on the machinability. The age-hardening process at 100°C occurs at two stages, while at 200°C and 300°C, it takes place in single stage and results are in agreement to previous workers. The beneficial effect on aging time on machinability was obtained. The addition of misch metal was found to accelerate the rate of aging, particularly at 100 and 200°C. The optimum addition being 3.0%. Further with 3.0% misch metal addition only single peak was obtained and the results of alloy treated with 3% misch metal at 100°C was found, similar to that of untreated alloy at 200 and 300°C. The machinability of alloy treated with 3% misch metal in solution treated condition, was better by about 50% than the basic alloy. As in the case of alloy 108, the beneficial effect of aging time was obtained on the alloy treated with misch metal.

A Method for Soft Soldering of Aluminum Alloys

by

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ABSTRACT

The Bureau of Mines, U.S. Department of the Interior, has developed a system that permits the ready "soft" soldering of aluminum and aluminum alloys with standard tin-lead solders. The method employs the application of a thin nickel-copper alloy coating to the substrate prior to soldering. The alloy preplating enables the tin-lead solders to wet and spread onto the areas to be joined. With conventional technology, it is virgually impossible to soft solder aluminum and its alloys. The reactive subst rates inherently have tenacious surface oxide films which prevent wetting and spreading of the solders.

With the developed method, the aluminum substrate is given a mechanical or chemical cleaning treatment sufficient to bond to a subsequent thin layer of zinc applied in an electroless zincate treatment on the area to be soldered. A nickel-copper (30 to 70 pct Ni) alloy coating is then applied electrolytically over the zincate using either a conventional electroplating cell or brush-coating. Specific acetate electrolyte formulations and conditions are employed to plate the appropriate nickel-copper coating, which can then be joined readily with standard tin-lead solders using conventional fluxes. The solder joints so formed on aluminum and aluminum alloys are corrosion-resistant, ductile, and exhibit strengths equivalent to or greater than those formed in joining copper and brass substrates with the same tin-lead solders and fluxes.

The brush-coating variation is particularly useful for restricting the nickel-copper alloy coating to specific areas to be soldered, such as for soft-solder repair of brazed fixtures, for which no viable alternative repair technique is available.

The soldering method may be applicable to other reactive or difficult-to-solder substrates upon which a thin, cohesive coating of nickel-copper alloy can be plated.

BANDING IN LOW CARBON, LOW ALLOY STEELS

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White ferritic bands, basically soft and gummy to the machine, often appear in the microstructures of "as received" case hardening steels. A study on influence of such banding on Machinability, Heat Treatment as well as on end properties, was undertaken and the important results are reported in this paper. Effects of banding on carburising, hardening and gear cutting operations in respect of tool life and surface finish are discussed. Use of intermediate heat treatments with an attempt for reducing the ineffectiveness of banding was experimented and no significant change was indicated in support of improvement of the microstructures. Effects of banding on improper finishing heat treatments like case tempering and on resulting structures and properties are also mentioned. Analysis of few typical failures are also described, for example, an interesting field failure of worm gears is highlighted, where the gear was found to fail due to the fatigue cracks which developed at the root of the teeth having deep tool marks acting as notch causing severe concentration beyond fatigue limits of the material during service. Detailed analysis revealed no significant metallurgical discrepancies other than the fact that the deep tool marks/notches on the unground flanks of the teeth could be attributed to the banded structure in "as received" case-hardening gear blank steel.

Session TM-1: NONLINEAR ELASTICITY

Organizer: M.F. BEATTY, University of Kentucky

Chairperson: S. J. SPECTOR, Southern Illinois University
Co-Chairperson: T. J. DELPH, Lehigh University

* 9:30 - 10:00 R. P. VITO, Georgia Institute of Technology:
"Some Applications of the Theory of Large Elastic Deformations in Soft Tissue Mechanics"

*10:00 - 10:30 M. F. BEATTY, University of Kentucky:
"On the Instability of a Fiber Reinforced, Compressible Hyperelastic Thick Plate Under Axial Loads"

10:30 - 11:00 COFFEE BREAK

11:00 - 11:15 R. L. FOSDICK, University of Minnesota and
G. P. MAC SITHIGH, University of Missouri-Rolla:
"Necessary Conditions for Minimizers in Inextensible, Finite Elasticity"

11:15 - 11:30 R. ROSTAMIAN, Pennsylvania State University:
"Internal Constraints in Linear Elasticity: Existence of Solutions"

11:30 - 11:45 S. DOST and P. G. GLOCKNER, The University of Calgary, Canada:
"On Beltrami-Mitchell Equations in Finite Elasticity"

SOME APPLICATIONS OF THE THEORY OF LARGE ELASTIC DEFORMATIONS IN SOFT TISSUE MECHANICS

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Biological soft tissues exhibit complex mechanical behavior. As materials, they are inhomogeneous, anisotropic and probably compressible. Deformations and strains are large. For example, an artery in-vivo may be strained by up to 70%.

There are a number of problems which are physiologically important where mechanics and mechanical modeling are relevent. Fung (1981) has suggested using the "pseudo-elastic" response as a starting point.

This paper will review several applications of known solutions to problems of large elastic deformations (Green and Adkins, 1970) to biomechanics problem (Vito and Dixon 1980, Vito 1979, Vito et al 1979).

Some recent results of modeling the arterial wall which account for dynamic effects and the layered nature of the wall will also be presented.

1. Fung, Y.C., Biomechanics: Mechanical Properties of Living Tissues. Springer, New York (1981).
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3. Vito, R.P., The role of the pericardium in cardiac mechanics. J. Biomech. 12 (8): 587-92 (1979).
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ON THE INSTABILITY OF A FIBER REINFORCED, COMPRESSIBLE HYPERELASTIC THICK PLATE UNDER AXIAL LOADS

by

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Euler's instability criterion based upon existence of an adjacent configuration of equilibrium for dead loads is applied to study the instability of a thick, compressible hyperelastic slab reinforced by high strength fibers through its thickness normal to the axis of tensile and compressive loadings. The solution contains results derived elsewhere for special rubberlike materials. In the present investigation, subject only to certain well known empirical restrictions on the strain energy function, the solution is obtained for every compressible and isotropic, hyperelastic material having inextensible reinforcement arranged as mentioned above. It is shown that due to the reinforcement instability in both tension and compression may occur.

NECESSARY CONDITIONS FOR MINIMIZERS IN INEXTENSIBLE, FINITE ELASTICITY

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and

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We study the mixed boundary-value problem of displacements and dead-load tractions for an inextensible, hyperelastic body. We formulate it as a variational problem; that of minimizing the potential energy of the body and loading device over a class of kinematically admissible deformations.

We obtain the following necessary conditions for a piecewise regular minimizer containing singular surfaces: first and second variation conditions, multiplier rule, jump conditions, Euler-Lagrange equation, natural boundary conditions and Legendre-Hadamard condition.

INTERNAL CONSTRAINTS IN LINEAR ELASTICITY; EXISTENCE OF SOLUTIONS

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Let S, E, and K denote stress, strain, and the compliance tensor fields for an elastic material. Thus $E = K(S)$. A material is internally constrained at a point if K has a non-trivial null space at that point, that is, certain stresses do not contribute to the strain. See Pipkin [1].

Consider an elastic body in a bounded domain Ω in $\mathbb{R}^N$, subjected to a body force field f in Ω, and prescribed displacements $\bar{u}$ and tractions $\bar{s}$ on complementary parts $\partial_1\Omega$ and $\partial_2\Omega$ of the boundary of Ω. Let n denote the unit outward normal to the boundary and suppose that K is symmetric. Then by the principle of the Minimum Complementary Energy (see Gurtin [2]) the equilibrium stress is a stationary point of the functional

$$I(S) = \frac{1}{2}\int_\Omega S \cdot K(S)\,dx - \int_{\partial_1\Omega} \bar{u} \cdot Sn\,da$$

in the set

$$C = \{S: \quad \operatorname{div} S = f \text{ in } \Omega, \quad Sn = \bar{s} \text{ on } \partial_2\Omega\}.$$

In the presence of internal constraints, K has a non-trivial null space, so I is not coercive and the usual proof of the existence of minimizers does not go through. Another unusual feature is an extra compatibility condition that must be satisfied by $\bar{u}$. To illustrate, let's consider a very special case when the material is incompressible and the displacement is prescribed on the entire boundary. Clearly only those $\bar{u}$ are admissible that leave the total volume invariant. With other types of internal constraints, inextensible fibres for example, classes of admissible data are not so intuitively obvious.

We examine this, and more general boundary value problems, formulate the admissibility criteria for the data and prove the existence of solutions in $W^{1,2}(\Omega)$.

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ON BELTRAMI-MITCHELL EQUATIONS IN FINITE ELASTICITY*

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ABSTRACT

In the linear theory of elasticity, substitution for the strain tensor in the compatability equations yields six equations in terms of stresses referred to as "Beltrami-Mitchell" equations which, together with the equilibrium equations and appropriate boundary conditions, define the stress boundary value problem. Application of this procedure in nonlinear elasticity theory is not as straight forward since the constitutive relations are not easily inverted. In addition, the compatibility equations in term of deformation (or strain) tensor are highly nonlinear and the equilibrium equations in terms of the second Piola-Kirchhoff stress tensor involve the displacement field explicity.

The aim of this paper is to derive Beltrami-Mitchell equations for nonlinear elasticity theory. To eliminate the difficulties mentioned above, the first Piola-Kirchhoff stress tensor, $\underline{S}$, and the deformation gradient, $\underline{F}$, are chosen as field variables in the derivation so as to yield linear equilibrium and compatibility equations in terms of $\underline{S}$ and $\underline{F}$, respectively. It is assumed that an energy density, $W(\underline{F})$, and correspondingly, a complementary energy density, $W_c(\underline{S})$, exist [1] such that the contact transformation $W(\underline{F}) + W_c(\underline{S}) = \mathrm{tr}\,(\underline{S}\,\underline{F})$ yields $\underline{S} = \partial W/\partial \underline{F}$ and $\underline{F} = \partial W_c/\partial \underline{S}$. It is required that $W(\underline{F})$ and $W_c(\underline{S})$ satisfy the axiom of objectivity. Provided the constitutive equations for $\underline{S}$ are invertable, or equivalently, $W_c(\underline{S})$ exists, substitution of the deformation gradient, $\underline{F}$, into the compatibility equations yields nonlinear differential equations in terms of $\underline{S}$ only which can be regarded as the Beltrami-Mitchell equations of nonlinear elasticity. Introduction of stress functions satisfying the equilibrium equations identically leads to a system of nine equations in terms of these stress functions, which, together with appropriate boundary conditions, represent a stress boundary value problem.

As an example, the equations are also derived for "semi-linear" elastic materials introduced in [2].

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* Professor and Head

** Associate Professor

* The results presented here were obtained in the course of research sponsored by the Natural Sciences and Engineering Research Council of Canada, Grant No. A-2736.

Session TM-2: NONLINEAR EQUATIONS

Organizer: M.K. MYERS, The George Washington University
Chairperson: W. EVERSMAN, University of Missouri-Rolla

* 9:30 - 10:00 A. D. PIERCE, Georgia Institute of Technology:
"Nonlinear Propagation of Sound: A Tutorial Review"

* 10:00 - 10:30 M. K. MYERS, The George Washington University:
"Nonlinear Propagation of Sound Through Nearly Sonic Duct Flows"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 J. H. GINSBURG, Georgia Institute of Technology:
"A Direct Method for Non-Linear Acoustics and Its Application to Underwater Sonar"

* 11:30 - 12:00 P. H. ROGERS, Office of Naval Research, Arlington and D. H. TRIVETT, Naval Research Laboratory, Washington, D.C.:
"Scattering of Sound by Acoustic Pulses and the Pulsed Parametric Array"

12:00 - 12:15 G. H. McDONALD and J. PEDDIESON, JR., Tennessee Technological University:
"An Approximation Method for Velocity-Sensitive Combination-Instability Problems"

NONLINEAR PROPAGATION OF SOUND:
A TUTORIAL REVIEW

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Acoustics is ordinarily concerned with small-amplitude disturbances, so nonlinear effects are typically of minor significance. Small nonlinear terms in the fluid-dynamic equations can have appreciable accumulative effects, however, over long distances of propagation or over long periods of time. Present paper reviews theories applicable to when the disturbance everywhere locally resembles a propagating plane wave.

The classical developments of Riemann and Earnshaw lead to a "first-cut" model for truly one dimensional disturbances in a homogeneous fluid without dissipation. A waveform distorts as it propagates because points of different amplitudes move with different velocities; the local speed of propagation varies because of the dependence of sound speed on pressure and because the disturbance itself induces a flow in the fluid, relative to which the sound propagates. To a first approximation, the acoustic pressure p satisfies

$$\partial p/\partial t + [c + \beta p/\rho c]\partial p/\partial x = 0$$

where β is a thermodynamic property of the fluid, density ρ and sound speed c are for undisturbed state. This equation does not apply at shocks; the Rankine-Hugoniot equations lead to prediction that these move with speed equal to average of $c + \beta p/\rho c$ before and after discontinuity. This in turn leads to the highly useful "equal area rule" first discovered by Landau for predicting locations of shocks.

The small discontinuity in entropy (third order in amplitude) at a shock accounts for an intrinsic loss in energy independent of whatever physical mechanism causes the attenuation. To explicitly take dissipation into account one can derive appropriate nonlinear propagation equations (such as Burgers' equation) by first finding the dispersion relation for constant frequency linear acoustic waves, $k = k(\omega)$, then replacing ik by $\partial/\partial x$, $-i\omega$ by $\partial/\partial t$, and c by $c + \beta p/\rho c$. The dominant mechanism is often relaxation, rather than viscosity or thermal conduction, but often the phenomena is adequately approximated by an equivalent bulk viscosity. Plane wave models of weak nonlinear propagation have been wedded to geometrical acoustic models by Whitham, Hayes, and others, with the assumption that ray paths are not altered by nonlinear effects. (Material discussed in paper is covered in greater detail in Chapter 11 of author's textbook, Acoustics.)

NONLINEAR PROPAGATION OF SOUND THROUGH NEARLY SONIC DUCT FLOWS

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The behavior of sound in a high subsonic variable-area duct flow is of practical interest in connection with the so-called sonic engine inlet, in which marked reductions of upstream traveling sound have been observed. A near-sonic steady flow near the throat of the duct causes a transonic trapping of upstream waves, and the resulting intensification of the field gives rise to nonlinear interactions between the sound and the flow.

A quasi-one dimensional theory which describes the inherently nonlinear acoustic propagation process in near-sonic flows has been developed in an attempt to understand some of the physical mechanisms responsible for reductions of noise ultimately transmitted out of the duct. The theory is derived using the method of matched asymptotic expansions and yields, in the near-sonic inner region of the flow, a set of nonlinear equations of motion which describe the interactions between the flow and the acoustic field. These equations can be solved analytically using the method of characteristics, and their solution is asymptotically matched to the linearized acoustic solution valid in the low Mach number regions of the flow.

It is shown that the nonlinear effects of the flow on sound are appreciable. For example, sound energy introduced by a simple harmonic source is partitioned into an infinite number of superharmonic components and a steady streaming component after passing through the near-sonic flow region. Even in the absence of dissipation, this partitioning can reduce significantly the energy transmitted in the fundamental compared to that imparted at the source. Of more physical consequence, however, is the fact that sufficiently high Mach numbers or frequencies cause the nonlinear acoustic waves to develop shocks in the near sonic region. The thermoviscous effects modeled by the shock jump conditions result in a major attenuation of the total acoustic energy transmitted out of the duct. This, in conjunction with the spreading of energy into harmonics, can lead to a power reduction of as much as 90% in the fundamental harmonic during passage of the sound through the duct.

A major result of the work is an analytical solution for the location and strength of the shocks in the periodic waveform, which is a generalization of the "equal area" rule of classical weak shock theory. This analysis will be described in some detail, and various computed results will be presented to illustrate the theory.

A DIRECT METHOD FOR NON-LINEAR ACOUSTICS AND ITS APPLICATION TO UNDERWATER SONAR*

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The distortional phenomenon of amplitude dispersion in the propagation of nonlinear, nondissipative sound waves in fluids has been thoroughly studied for the one-dimensional case. However, the methods used for such investigations are difficult to extend to multi-dimensional problems in which there is strong variation along the wavefronts. A perturbation method for solving such problems has evolved through a sequence of analyses of progressively more complicated systems. The result is a general "direct" method which can derive the wave motion without phenonenological assumptions in situations where the analogous linear system can be solved.

The basis for the method is the general nonlinear wave equation governing velocity potential. The method begins by expanding the potential in a regular perturbation series whose small parameter is the amplitude of the excitation scaled relative to ambient conditions. In the usual manner, the leading term in the expansion, which is the linearized solution, is used to form the nonhomogeneous source terms which drive the second order terms. Due to wave resonances (secularity) which are inherent to nondispersive waves, a portion of the second order potential grows cumulatively relative to the first order terms. The direct method focuses only on such growth terms when it forms the particle velocity and pressure. Cumulative growth means that the solution is not uniformly accurate. This condition is corrected by introducing a coordinate straining transformation which must regularize the pressure and particle velocity simultaneously. The transformation describes the distortion of the signal. The resulting analytical expressions are valid up to the location where a shock forms; extension beyond that location requires shock fitting.

The application of the direct method to sound beams which radiate from a transducer in an infinite baffle will be described. The analysis obtains the potential function by a Hankel transform and an integration using the method of stationary phase. The fluid medium in this case acts as an infinite wave guide whose individual modes occur in a continuous spectrum. In addition to the sawtooth type distortion observed in simpler systems, the waveform in a sound beam is found to display strong asymmetries between compression and rarefaction, in agreement with earlier experimental work.

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Scattering of Sound by Acoustic Pulses and the Pulsed Parametric Array

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An examination of the scattering of sound by sound indicates that the boundary of the interaction region is very important in determining not only the level of the scattered sound but also the frequency of the scattered sound. In the case of a pulse propagating through a cw plane-wave (where the boundary of the interaction region is propagating at the sound speed) the frequency of the far-field scattered sound at a fixed angle is the cw frequency, Doppler shifted i.e.,

$$f_s(\theta,\phi)=f_2\ (1-\cos\theta)/(1-\cos\phi)$$

where f_2 is the frequency of the plane-wave, θ is the angle between the cw wavevector and the pulse wavevector and ϕ is the observation angle with respect to the pulse wavevector in the interaction plane. The scattered signal has strong maximum at the Doppler angle ϕ_d, where the frequency of the scattered signal is equal to the sum frequency. The scattered signal at ϕ_d observed at a finite distance from the interaction region thus appears as a pulse whose frequency sweeps from a value somewhat above the sum frequency to a value somewhat below the sum frequency. In addition to the absence of the sum and difference frequency at most angles, the theory yields no off-axis, $\phi=0$, scattered signal when the pulse propagates in the same direction as the cw plane wave. Since this is the geometry of the pulsed parametric array, which has been experimentally demonstrated to scatter sum and difference frequency, the scattered signal must be generated at some time other than when the pulse (i.e., interaction region) is freely propagating. We find that while the interaction region has a stationary boundary (i.e., during the time the pulse exits the transducer) a sum and difference frequency signal is produced. However, once the pulse leaves the transducer (so that both boundaries move at the sound speed) no off-axis scattered signal is produced. The beam pattern is similar to that obtained by Westervelt (J. Acoust. Soc. Am. 35, 535-537 (1963) in his cw calculation. The received difference frequency pulse, however, appears as if radiated directly from the transducer.

AN APPROXIMATION METHOD FOR VELOCITY-SENSITIVE COMBINATION-INSTABILITY PROBLEMS

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ABSTRACT

The model differential equation

$$\partial_t^2\phi-\nabla^2\phi+\bar{w}(\partial_t\phi+2\partial_z\phi+\varepsilon N\vec{\nabla}\phi\cdot\vec{\nabla}\phi)+\varepsilon(2\vec{\nabla}\partial_t\phi-\kappa\nabla^2\partial_t^2\phi) = 0 \qquad (1)$$

arises in a simplified analysis of velocity-sensitive combustion instability in liquid-fuel rocket motors. In (1) all quantities are dimensionless with z denoting the mean flow direction, t the time, ϕ a velocity potential, $\bar{w}$ a measure of the mean burning rate, N a measure of the unsteady burning rate, ε a measure of the initial disturbance, and κ a measure of the influence of baffles. The presence of the term multipled by N in (1) distinguishes equations of this type from those normally encountered in nonlinear acoustics. There is a need to develop both exact and approximate methods for the solution of equations similar to (1). The present paper discusses one relatively simple approximate method. It consists of performing an approximate modal analysis of (1) using the Galerkin method and then solving the resulting system of ordinary nonlinear differential equations approximately by the two-variable perturbation method (method of multiple scales).

The method is illustrated through consideration of a combustor in the shape of an annulus of narrow gap width. In a polar coordinate system (r, θ, z) the combustor extends from an injector at z = 0 to a nozzle at z = L and has a mean radius r = 1. A variety of solutions are obtained for the case of transverse disturbances ($\phi = \phi(\theta, t)$).

One especially interesting closed-form solution can be obtained under the assumption that the last two terms in (1) can be neglected. It has the traveling-wave form

$$\phi = \exp(-\bar{w}t/2)\sec(\varepsilon N(1-\exp(-\bar{w}t/2))/2^{1/2})\sin(t-\theta)$$
$$+\exp(-\bar{w}t/2)\tan(\varepsilon N(1-\exp(-\bar{w}t/2))/2^{1/2})\sin(2(t-\theta))/2^{2/3}+\ldots \qquad (2)$$

It can be seen that this solution exhibits a violent instability (it becomes infinite in a finite time) for

$$N > \pi/(2^{1/2}\varepsilon) = 2.22/\varepsilon \qquad (3)$$

This behavior is quite different from the process of shock formation familiar from nonlinear acoustics.

Session TM-3: CONSTITUTIVE ASPECTS OF GEOLOGICAL/ GEOPHYSICAL MODELING

Organizer and Chairperson: J. B. RUNDLE, Sandia National Laboratories
Co-Chairperson: M. SHAHINPOOR, Clarkson College

* 9:30 - 10:00 J. B. RUNDLE, Sandia National Laboratories:
"Some Constitutive Aspects of Modeling Physical Processes in the Earth"

* 10:00 - 10:30 W. R. WAWERSIK and D. H. ZEUCH, Sandia National Laboratories:
"On the Description of Low Stress, Low Temperature Creep of Rock Salt"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 M. McNUTT, Massachusetts Institute of Technology:
"Estimates of Rheological Behavior of the Earth's Crust and Upper Mantle Over Million Year Time Scales"

* 11:30 - 12:00 D. A. YUEN, Arizona State University:
"The Viscosity of the Lower Mantle: Inferences from Polar Motion Data"

12:00 - 12:15 M. SHAHINPOOR and G. AHMADI, Clarkson College of Technology:
"Stable Granular Rings in Weak Gravitational Fields"

12:15 - 12:30 J. G. SINGH and P. C. UPADHYAY, Banaras Hindu University, India:
"Creep Bending of Rocks"

SOME CONSTITUTIVE ASPECTS OF MODELING PHYSICAL PROCESSES IN THE EARTH

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For the last one hundred years, it has been known that the earth is capable of transmitting vibrations due to earthquakes. This realization led in turn to elegant calculations by Lord Rayleigh, H. Lamb, A. E. H. Love, and others, in which the earth was modeled as an elastic body in and over which elastic waves might propagate. Even then, it was known that the earth could not be perfectly elastic, because the vibrational energy decayed to zero in a matter of hours, or at most, days. Detailed treatment of models in which these imperfections of elasticity are correctly included in wave propagation calculations has come only recently with the advent of modern high speed computing.

At the same time that applied mathematicians were sharpening their calculations of wave propagation, geologists began to realize that permanent deformations due to earthquakes could occur. Led by Henry Fielding Reed, the committee charged with the investigation of the 1906 San Francisco Earthquake concluded in their report of 1911 that the seismic event had been the product of an "elastic rebound". Precise earth surveying measurements, which began in the middle of the 19th century, revealed that sharp offsets of survey monuments occurred during the event. These offsets extended some ten kilometers away from the fault, and were modeled well by a physical model involving foam blocks in relative stick-slip motion. More important, post-1906 surveys extending up to the present time reveal a pattern of continuing displacements. These deformations are often associated with no known seismic event, and are clearly the product of a variety of inelastic physical processes. That such continuing deformations can occur was at first surprising. However, the new theory of plate tectonics predicted very large scale deformations extending over geologic time, and it was finally realized that these deformations are only a local manifestation of plate scale motions.

During the last few years, many of the phenomena associated with plate tectonics, including earthquakes, isostasy, fluid flow and fluvial processes, and rock deformation, have been modeled using a variety of techniques. These models require both a geometric representation of the process, as well as a constitutive law to relate stress to deformation. A few examples which will be considered here include inelastic geodetic crustal deformation due to earthquakes, volcanoes, well pumping and hydrofracture in a semisothermal, fluid infiltrated crust; plate flexure due to the imposition of large volcanic loads such as the Hawaiian-Emperor seamount chain; constitutive modeling of laboratory rock deformation; large scale flow processes in the earth's mantle and crust; and constitutive laws relating slip on faults to applied stresses.

*This work was supported by the U.S. Dept. of Energy Contract DE-AC04-76DP00789.

On the Description of Low Stress, Low Temperature Creep of Rock Salt*

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The thermomechanical behavior of rock salt is of interest to interpret the formation of salt structures and to evalute the design of mines, storage caverns and radioactive waste repositories. An important aspect of these problems is the nature of salt creep at low stresses and low homologous temperatures. As a result, several creep studies were carried out using single and multistage tests where either stress or temperature was increased between stages. Measurements appear to fit best a simple power law of stress to describe steady state creep. Transient creep was fitted to at least three functions. All of them suggest that transients are relatively unimportant because they are short-lived and limited to small strains.

This paper addresses three questions which are important for the application of the present creep models. (1) Are the models valid under arbitrary stress and temperature histories? (2) Are the mechanisms controlling salt creep sufficiently understood to justify extrapolations to lower stresses, lower temperatures and long times?, and (3) Are observations on laboratory specimens representative of the behavior of salt masses in situ?

Results will be described from creep experiments with complex stress and temperature histories where stress and temperature were increased and decreased. In addition, substructure observations will be reviewed which were made on "as received" laboratory and experimentally deformed specimens and on naturally deformed crystals which were collected from the walls of mine drifts.

Many creep measurements under decreasing stress and temperature resulted in anomalously low creep rates which are not predicted by the present models. These low creep rates may persist for times which are long compared with the time scale of engineering problems. The data available do not exclude the possibility that the anomalies following unloading affect the full recovery of secondary creep.

Comparisons of creep rates at different stresses and temperatures as well as substructural observations indicate that at low temperature creep of rock salt may not be controlled by dislocation climb even though the form of the power law fit for steady state creep data is consistent with that mechanism. This suggestion is based on the measurement of effective activation energies and transients following temperature changes. It is also based on abundant evidence of dislocation glide and on the absence of subgrains in many cases. Uncertainties about the rate controlling deformation mechanisms suggest caution in the extrapolation of the present models. However, substructure comparisons in "laboratory deformed" and "mine deformed" samples indicate that the processes in laboratory tests are representative of the processes which are active in situ.

*This work was supported by the U.S. Dept. of Energy Cont. ERDA-AC04-76-DP00789.

ESTIMATES OF RHEOLOGICAL BEHAVIOR OF THE EARTH'S CRUST AND UPPER MANTLE OVER MILLION YEAR TIME SCALES

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The answers to a number of important questions in geotectonics and geodynamics await adequate models for the rheological characteristics of earth materials over geologic time scales. Most of the insight into this problem has been derived from the results of laboratory experiments on rock samples. It is difficult, however, to apply these models with much confidence to geological and geophysical studies because of disparity in time scales and physical dimension as well as the presence of impurities in the real earth.

One way to circumvent these difficulties is to take advantage of nature's own experiments as seen in field observations of rock deformation. The real-earth laboratory is less than ideal in the sense that there are only a limited number of cases for which we have sufficient knowledge of the boundary conditions of the system and the prior history of the experiment. Nevertheless, a fairly consistent picture emerges for the rheological behavior of the oceanic crust and upper mantle when geophysical observations are interpreted within the context of laboratory models. Strength in the upper layers of the seafloor is limited by pressure-dependent brittle processes and may exceed 600 MPa at 15- to 20-km depths. At deeper levels ductile-flow processes dominate. The exponential dependence of yield strength on temperature causes a rapid transition at about 40-km depth from a high-strength "mechanical lithosphere" to a deeper zone where the mantle supports deviatoric stresses less than 50 MPa over million year time scales.

Determining the long-term rheological behavior of continental materials is a much more difficult problem. In contrast to the simple layer structure, fairly uniform rock chemistry, and short (200 m.y) geologic history of the ocean basins, the continents are heterogeneous in all dimensions and have experienced many deformation events over their billion-year history. Data from laboratory experiments on granite and quartzite suggests that the continental crust is much weaker than the basaltic seafloor, but the field evidence does not always support this claim. In many areas where continents do appear to be exceptionally weak, deformation may have been localized on a detachment surface at midcrustal depth where a combination of parameters such as pressure, temperature, pore pressure, and rock composition have produced a low-strength layer.

The Viscosity of the Lower Mantle: Inferences from Polar Motion Data

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Until recently most estimates of the deep mantle viscosity were based on analyses of post glacial uplifts and there were no estimates of the sensitivity of the derived viscosity solutions to variations of the input parameters, such as those associated with the surface loading. In this paper the viscosity of the lower mantle is arrived at by making comparisons of the observed secular motions of the earth's rotation axis with theoretical results from a layered viscoelastic, rotating earth, which has been subjected to glacial forcing. Our model, consisting of an elastic lithosphere, a two-layer viscoelastic mantle, and an inviscid core, is essentially analytical and this makes it economically feasible to use as an aid in conducting an extensive sensitivity analysis of the lower mantle viscosity from changes in the parameters connected with the deglaciation phenomenon. On the basis of this type of investigation, the viscosity of the deep mantle is shown to lie between 1 and $2X10^{22}$ P. Our results, which just rely on the second harmonic of the strain field, also lead to a determination of an upper bound to the thickness of the globally averaged lithosphere. This value, ranging between 150 and 170 km, suggests that strong lateral heterogeneities between oceanic and continental plates may extend at most around 260 km into the upper mantle.

Stable Granular Rings In Weak Gravitational Fields

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Abstract

A recently developed statistical kinetic theory for rapid flow of granular materials and evolution of field fluctuations [1], [2] has been applied to the problem of equilibrium granular ring configurations in weak central gravitational fields. The derived governing equations admit such solutions to exist and further reveal that in such stable granular ring systems particles possess a mean velocity plus a random fluctuating component. The velocity fluctuation field is created by continuous random collisions of particles with each other as they move through the gravitational field. The average mean square energy associated with such random fluctuations is denoted by e and is shown to be coupled through three nonlinear second order differential equations with the bulk density ρ and the mean tangential velocity V_θ of the grains. It appears that certain perturbations of central gravitational fields allow stable granular ring configurations to form. Two specific ring solutions are finally presented and discussed.

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1 - Ahmadi, G. and M. Shahinpoor, "A Kinetic Theory for Rapid Granular Flows and Evolution of Fluctuations," MIE-CCT, Granular Materials Research Laboratory, Res. Rep. No. 077, March (1982).

2 - Shahinpoor, M. and G. Ahmadi, "Fluctuation Equilibrium In Rapid Flow of Granular Materials," (in press), (1982).

CREEP BENDING OF ROCKS

by

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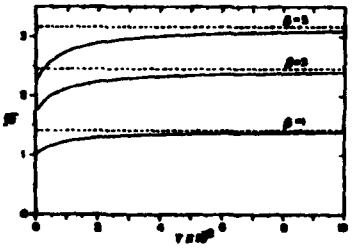
Various constitutive equations, empirical as well as those based on the mechanical models, have been proposed in the literature to define rock creep behavior. However, a fact that the creep rates of rock under tensile and compressive loadings differ significantly [1-2] has not received much attention as far as its possible effect on the bending of rock structures is concerned. For the elastic bending of rock beams [3] and plates [4-5] (without creep) it has been reported that the inclusion of the double elastic property (unequal Young's modulus in tension and compression) of rocks affects the bending results significantly. In this work we present the effect of double elastic and viscosity constants on the creep bending of rock beams and plates, based on the Burger's model. The influence has been found quite significant. The figure, for example, shows, for different β, the shifting of the neutral surface (NS) as the creep progresses. β and ϕ represent, respectively, the ratios of the Young's modulii and viscosity constants in tension and compression, and δ = ht/hc is the ratio of the thicknesses of tensile and compressive zones on the two sides of the neutral surface. The initial position of the NS is governed by the value of β, while its final (time $\to \infty$) position (shown dotted), corresponding to pure viscous state, is decided by the value of ϕ. During the intermediate times, NS position is governed by a factor θ, which is a function of β,ϕ and some other parameters related to the Burger's model. This shifting of the NS, consequently, brings changes in the other related quantities like deflections etc., which are discussed in the paper. Similar to β and ϕ, the influence of the other parameters have also been depicted and discussed in detail.



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Session TM-4: FINITE STRAIN PLASTICITY

Organizer: J. F. BELL, The Johns Hopkins University
Chairperson: A. S. KHAN, The University of Oklahoma-Norman

* 9:30 - 10:00 J. F. BELL, The Johns Hopkins University:
"Cyclical Loading at Finite Plastic Strain: A Comparison of Experiment and Theory"

* 10:00 - 10:30 T. W. WRIGHT, Ballistic Research Laboratory:
"Plastic Waves in a Circular Cylindrical Rod"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 M. PITTERI, Universita di Padova, Italy:
"On the Kinematics of Twinning"

* 11:30 - 12:00 K. S. HAVNER, North Carolina State University:
"Interrelations Among Hardening Rules, Minimum Work, and Uniqueness in Finite Multiple-Slip of F.C.C. Crystals"

CYCLICAL LOADING AT FINITE PLASTIC STRAIN: A COMPARISON OF EXPERIMENT AND THEORY - James F. Bell, Johns Hopkins University, Baltimore, Maryland.

The close correlation between experiment and a proposed incremental theory of finite plastic strain has been described previously.[1,2,3] Any general theory of plasticity whether for infinitesimal or finite strain must include unloading. For complete generality one should determine, too, the response for non-proportional stress paths in the domain of cyclical loading. The results given here are for such a study.

Six types of two-dimensional non-proportional stress paths are considered, including those of the experiments made famous by Taylor and Quinney in the 1930's. Sufficient repetitions and variations for each type of cyclical stress path made it possible to examine in detail a number of pertinent questions beyond the main result, which was the finding that the writer's incremental theory provides constitutive relations for the region of total plasticity at finite strain after a cyclical stress incursion. Each test included several unloading and reloading intervals. In some instances total unloading occurred; in others, there were different degrees of unloading. The history of cyclical stress paths ranged from slow or smooth unloading and reloading to incremental impact. In all instances, including sudden loads in the unloaded domain, subsequent reloading closely followed the writer's incremental theory for finite plastic strain. When the unloading cycle included rapidly applied loads there was a rise in stress at the generalized or effective stress where finite strain plasticity recommenced on reloading, the magnitude of the outer yield surface increased but the subsequent response was in as close a correlation with the rate independent incremental theory of finite plastic strain as in the initial loading for the same test.

The experimental aspects of this study also included the role of the strain increment vector at the outer yield surface and during subsequent loading; various types of time delay during the unloading cycle; the role of creep; and, unloading chosen to examine in detail the interesting properties of the outer yield surface itself.

Noting that the writer's incremental theory of finite strain defines all stress and strain components in terms of the original undeformed reference configuration, these cyclical loading experiments compare the plastic response for components thus defined with plastic response in which stress and strain components are referred to subsequent unloading configurations. For the latter, the observed response functions are disordered. In cyclical loading, theory and experiment correlate only when components are referred to the original undeformed state, as assumed in the incremental theory of finite strain. Even when the unloading and subsequent finite strain intervals occur as many as seven or eight times in an individual test, this correlation obtains.

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(3) James F. Bell and Akhtar S. Khan, "Finite Plastic Strain in Annealed Copper during Non-Proportional Loading." Internat'l Jnl. Solids & Structures, Vol. 16, pp. 573-583 (1980).

PLASTIC WAVES IN A CIRCULAR CYLINDRICAL ROD

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Rods are simple structures that are often regarded as one-dimensional continua, but because of finite transverse dimensions, propagating waves are subject to dispersion, which may mask other effects. A linear theory [1] and a nonlinear generalization [2] have been published to model the dispersive effect in elastic materials. Some of the principal features of those theories are as follows. There exist two characteristic wave speeds that may carry discontinuities in acceleration or stress gradients. Nevertheless, for problems of pulse propagation the main effect is a smooth wave and is carried by a third speed. The first two correspond to bulk speeds, and the third corresponds to the bar speed. Periodic steady waves in either the linear or nonlinear case can be found, and solitary steady waves can be found in the nonlinear case.

The rod model discussed above may be viewed as a one-dimensional continuum theory with one internal, scalar variable. The same structure may be used to model plastic waves in a rod. That is to say, the same kinematic and stress variables may be used to model plastic deformation as have been used for elastic deformation. The increment of mechanical work done on an element of the rod may be written as follows,

$$dW = Sdw' + Pdu + Qdu',$$

where w' is axial strain, u is radial strain, S is axial stress, P is average radial pressure, and Q is the radial moment of radial shear stress. The prime denotes the derivative with respect to the axial coordinate. In the nonlinear elastic case the stress variables are obtained from a potential, but in the plastic case a yield function and flow rule must be obtained after decomposing the strains into elastic and plastic parts. This can be done in a plausible, though not in a rigorous way.

In the plastic case, as in the elastic case, the bar speed is always less than the fast characteristic speed, but it turns out that there is a substantial range of parameters for which the calculated bar speed is less than the slow characteristic speed. Since the slow speed is the lower limit at which information can propagate in the rod, the very low calculated bar speed probably indicates a major change in the mode of deformation such as necking in a strong tensile pulse or mushrooming in a strong compression pulse.

Systematic scaling and expansion procedures are being developed for pulse propagation so that the structure of solutions may be examined more completely. Some special solutions will be discussed.

[1] R. D. Mindlin and G. Herrmann, A One-Dimensional Theory of Compressional Waves in an Elastic Rod, Proc. 1st U.S. Nat. Cong. Appl. Mech., pp. 187-191 (1950).

[2] T. W. Wright, Nonlinear Waves in Rods, Proc. IUTAM Symp. on Nonlinear Elasticity (Lehigh, Aug. 1980, to appear). See also Tech. Rept. ARBRL-TR-02324, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, May 1981.

ON THE KINEMATICS OF TWINNING

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Most theories of twinning are essentially kinematic and aim at explaining some features of the phenomenon, like twinning planes and twinning directions for various crystalline species. We outline a kinematic theory of twinning which is a continuum theory, that is, involving gross quantities like the gradient of deformation. On the other hand, the material symmetry of the constitutive equations is such as to retain some features of the description of a crystal in terms of a crystalline lattice. We show that the definition we propose is consistent with a number of twinning modes in the cubic, tetragonal and hexagonal classes and show that, in a simple case, we get results consistent with experience from the kinematics we propose and thermoelastic equilibrium theory.

Interrelations among Hardening Rules, Minimum Work, and Uniqueness in Finite Multiple-Slip of F.C.C. Crystals*

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As first argued in [1], one cannot expect hardening rules that represent qualitative features of finite distortion and latent hardening of single crystals under axial load to uniquely predict experimentally-observed response in multiple-slip orientations. For double-slip positions of f.c.c. crystals, the postulate of *minimum* rate of plastic work (for a given axial-load rate) introduced in [1] and further explored in [2] resolves the question of uniqueness for several plausible hardening rules (including classical Taylor hardening and the "simple theory" of rotation-dependent anisotropy first proposed in [3]) in favor of the highest symmetry deformation mode, which seems physically likely. In higher symmetry positions (4, 6 or 8-fold symmetry), minimum plastic working follows from loading axis stability and axisymmetric deformation, but the converse does not necessarily hold. For such cases an hypothesis of *minimum* plastic work to second-order in nominal stress increment is suggested and its consequences investigated as regards uniqueness for different hardening rules.

[1] Havner, K. S., A theoretical analysis of finitely deforming f.c.c. crystals in the sixfold symmetry position. Proc. R. Soc. Lond. A 378, 329-349 (1981).

[2] Havner, K. S., Minimum plastic work selects the highest symmetry deformation in axially-loaded f.c.c. crystals. Mech. Materials 1, 15 pp. (1982, in press).

[3] Havner, K. S. and Shalaby, A. H., A simple mathematical theory of finite distortional latent hardening in single crystals. Proc. R. Soc. Lond. A 385, 47-70 (1977).

*This work was supported in part by the U. S. National Science Foundation, Solid Mechanics Program, through Grant MEA-7808154.

Session TM-S: BOUNDARY METHODS

Organizer: I. HERRERA, Universidad Nacional Autonoma de Mexico
Chairperson: G. ALDUNCIN, Universidad Nacional Autonoma de Mexico
Co-Chairperson: M. M. TANG, University of Missouri-Rolla

* 9:30 - 10:00 I. HERRERA, Universidad Nacional Autonoma de Mexico: "Foundations of the Use of Complete Systems of Solutions"

* 10:00 - 10:30 U. HEISE, Technische Hochschule, Aachen, W. Germany: "Applications of the Extrapolation Method"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 G. ALDUNCIN, Universidad Nacional Autonoma de Mexico: "Boundary Methods in Contact Problems"

* 11:30 - 12:00 F. J. SANCHEZ-SESMA, Universidad Nacional Autonoma de Mexico, Mexico: "Boundary Methods in Scattering of Elastic Waves"

* 12:00 - 12:30 M. DRAVINSKI, University of Southern California, Los Angeles: "Diffraction of P, SV, and Rayleigh Waves by Two Alluvial Valleys of Arbitrary Shape"

FOUNDATIONS OF THE USE OF COMPLETE SYSTEMS OF SOLUTIONS

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IIMAS - D. F. Mexico

There are two main approaches for the formulation of boundary methods; one is based on boundary integral equations and the other one, on the use of complete systems of solutions. The author has given extensive descriptions of the latter methods [1-3]. Their theoretical foundations embrace the following aspects: a) Approximating procedures and conditions for their convergence; b) Formulation of variational principles; and c) Development of complete systems of solutions. Here, a general exposition of those foundations is given. Among the procedure included are the null field and the source methods.

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1. I. Herrera, "Boundary Methods for Fluids", in Finite Elements in Fluids Vol. IV, E.H. Gallagher, et al., eds., John Wiley & Sons, 1982.
2. I. Herrera, "An Algebraic Theory of Boundary Value Problems", KINAM, Vol. 3, No. 2, 1981, pp. 161-230.
3. I. Herrera, "Mathematical Foundations for the Use of Complete Systems of Solutions", in Fundamentals of Boundary Elements, Vol. 3, C.A. Brebbia, ed., Pentech Press, 1982. (In press)

APPLICATION OF THE EXTRAPOLATION METHOD

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Numerical results of the boundary integral equation method are extrapolated. However, this paper could be interesting also for users of other methods (e.g. for users of the finite element method) since in principle extrapolations are applicable whenever results depend on a step size.

For numerical treatment of integral equations the boundary is usually divided into elements and the sought function is approximated by a linear combination of given functions over each element. The coefficients of the combination are determined e.g. by collocation. To improve the accuracy of the results, either the number of elements or the degree of interpolation can be increased. The extrapolation method considered here is capable of yielding extremely accurate results with a relatively small number of elements and a low degree of interpolating functions. Its principle consists of solving the problem in question not only once but m times with differently fine divisions of the boundary into elements and of combining the m solutions in a suitable manner.

The knowledge of the functions $f_i(h)$ occurring in the asymptotic expansion of the error $\varepsilon(h)$ represents a presupposition for application of the extrapolation method:

$$\varepsilon(h_i) = \sigma(h_i) - \sigma^* = a_1 f_1(h_i) + a_2 f_2(h_i) + \ldots + a_{m-1} f_{m-1}(h_i) + R_m(h_i)$$

where σ is the numerical solution. It depends on the length h_i $(i=1,2..m)$ of the elements of the i-th discretization. σ^* is the corresponding exact solution.

Neglecting the error term $R_m(h_i)$ of higher order one obtains a system of m algebraic equations for calculation of an "extrapolated value" $\tilde{\sigma}^*$ and of approximations $\tilde{a}_i$ for the coefficients a_i:

$$\tilde{\sigma}^* + \sum_{r=1}^{m-1} \tilde{a}_r f_r(h_i) = \sigma(h_i)$$

Usually $\tilde{\sigma}^*$ is much more accurate than the best one of the values $\sigma(h_i)$ directly calculated with the aid of the boundary integral equation method.

For extrapolation of numerical values it is necessary that the unknown exact solution is unique. However, the operator of one important type of integral equations has isolated zero eigenvalues, i.e. arbitrary linear combinations of the corresponding eigenfunctions are superimposed on the solution. It is shown by an example how uniqueness can be enforced. Certain eigenfunctions of the adjoint operator are added to the kernel. These can be interpreted mechanically as layers of edge dislocations.

U. Heise, Removal of the zero eigenvalues of integral operators in elastostatic boundary value problems, Acta Mechanica 41 (1981), 41-61.

BOUNDARY METHODS IN CONTACT PROBLEMS

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ABSTRACT.

This talk is devoted to explain the application of boundary methods, formulated via approximations of complete systems of solutions, to contact problems or, in general, to problems with unilateral constraints on the boundary. Examples from elastostatics and heat conduction theory are presented.

BOUNDARY METHODS IN SCATTERING OF ELASTIC WAVES

by

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ABSTRACT

A brief review is presented of boundary methods in elastodynamics in connection with problems of scattering of elastic waves. A boundary method based on the use of complete systems of solutions is discussed, as an alternative to boundary integral equations. The method has been applied with success to problems of scattering of harmonic SH waves (1,2). Here an extension is made to treat the scattering of elastic P, SV and Rayleigh waves by irregularities on the surface of an elastic half-space. Such irregularities are of the types shown in figure 1. Some numerical results are given. They are compared with those obtained by Wong (3) who uses a boundary method which employs solutions for line sources. Some possible applications in earthquake engineering and engineering seismology are discussed.

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1. England, R., Sabina, F. J., and Herrera, I., "Scattering of SH waves by surface cavities of arbitrary shape using boundary methods", *Physics of the Earth and Planetary Interiors*, 21 (1980) 148-157.

2. Sánchez-Sesma, F.J., Herrera, I., and Avilés, J., "A boundary method for elastic wave diffraction. Application to scattering of SH waves by surface irregularities", *Bulletin of the Seismological Society of America*, 72 (1982) 473-490.

3. Wong, H. L. "Diffraction of P, SV, and Rayleigh waves by surface topographies", University of Southern California, Report No. CE79-05, (1979).

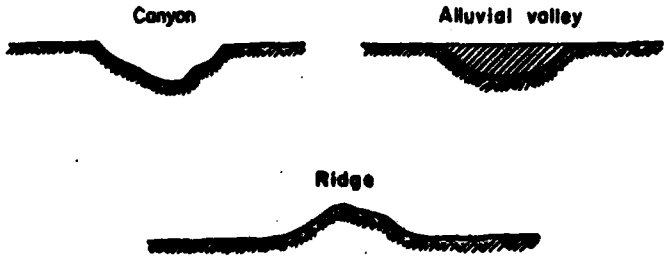

Fig 1. Types of surface irregularities in an elastic half-space

DIFFRACTION OF P,SV, AND RAYLEIGH WAVES BY TWO ALLUVIAL VALLEYS OF ARBITRARY SHAPE

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Plane strain model for diffraction of harmonic waves by two alluvial valleys of arbitrary shape is investigated by using a boundary integral method. Perfect bonding between the valleys and the half-space is assumed. Displacement field is evaluated through-out the media for linearly elastic, homogeneous and isotropic materials so that the continuity conditions between the valleys and the half-space are satisfied in mean square-sense.

Numerical results are presented for two semi-elliptical valleys for incident P,SV, and Rayleigh waves for different angles of incidence (P and SV-waves). It is shown that the surface motion depends very much upon the angle of incidence and the type of incoming wave. Maximum surface motion is observed atop the valley which is in "shade" of the other valley relative to direction of the incident wave. Comparison with the single valley models indicate that the presence of the additional valley changed significantly the surface response atop each of the valley. This is a different result when compared with the one for the anti-plane strain model, where "illuminated" valley detected very little the presence of additional valley.

Session TM-6: UNILATERAL ASPECTS OF FRACTURE

Organizer: M. COMNINOU, University of Michigan
Chairperson: J. R. BARBER, University of Michigan
Co-Chairperson: N. C. HUANG, University of Notre Dame

* 9:30 - 10:00 S. NEMAT-NASSER, and H. HORII, Northwestern University:
"Compression Induced Crack Kinking and Curving with Application to Splitting, Exfoliation, and Rockburst"

* 10:00 - 10:30 G.A.C. GRAHAM, Simon Fraser University, Burnaby, Canada:
"Crack Problems in Viscoelasticity Theory"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 M. COMNINOU and J. R. BARBER, University of Michigan:
"The Penny-Shaped Interface Crack with Heat Flow: Imperfect Contact Case"

* 11:30 - 12:00 N. KIKUCHI, University of Michigan:
"A Finite Element Analysis of Crack Problems Involving Closure"

12:00 - 12:15 K. P. MEADE and L. M. KEER, Northwestern University:
"A Semi-Infinite Plane Crack on a Bimaterial Interface"

COMPRESSION INDUCED CRACK KINKING AND CURVING WITH APPLICATION TO SPLITTING, EXFOLIATION, AND ROCKBURST*

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ABSTRACT

Kinked and curved extension of a pre-existing crack induced by compression in linearly elastic brittle solids is analyzed, and it is shown that, depending on the orientation of the pre-existing crack and on the friction factor, kinking occurs for a wide range of pre-existing crack orientations at an angle close to 70° from the direction of the pre-existing crack, and curves and grows parallel to the direction of the maximum compression. The growth process is stable initially, but the rate of increase of kink length with respect to the increasing axial compression dramatically increases after a certain kink length is attained, and, in fact, the kink length becomes unbounded, if a small lateral tension also exists. Various limiting cases are examined, and the corresponding analytical estimates are compared with the numerical results, arriving at good correlations. A series of qualitative experiments are performed on glass plates and thin plates of Columbia resin CR 39, arriving at excellent agreement with the analytical results. In light of the analysis, the phenomena of axial splitting, exfoliation (or sheet fracture), and rockburst are examined, and it is shown that they may all be the results of kinked curved tensile crack extension induced by great compression. This assertion is then supported by a series of experiments which show that compression induced tension cracks seem to have no tendency to move toward the free surface, but rather they extend more or less parallel to the free boundary, in the direction of maximum compression. Possible lateral buckling which may result, and which may cause further unstable crack extension, is illustrated experimentally and discussed in an effort to shed light on the phenomena of rockburst and surface spallation.

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Crack problems in viscoelasticity theory

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To a degree greater than their elastic counterparts, viscoelastic boundary value problems for cracked bodies are subject to difficulties arising from the unilateral nature of the boundary conditions that should be satisfied over the crack faces. For a crack of constant length in a body loaded in tension/compression perpendicular to the plane of the crack [1] or subject to an alternating field of pure bending [2] analyses of at least the initial phase of the motion have been made. In the former case a quite comprehensive treatment including a steady state solution has been given for a standard linear solid [3]. For a material whose relaxation functions vanish at infinity (e.g. a Maxwell body) steady state solutions to the problems described in [1] [2] may be obtained from a direct analysis [4]. All these solutions involve stress intensity factors that can change sign and crack opening when its elastic analogue would be closed. The problem described in [1] is in some ways simpler in the context of a crack that grows whenever it is entirely open [5]: in that case the crack is open or closed depending on whether the body is in tension or compression and the stress intensity factor does not become negative.

[1] G.A.C. Graham, Stresses and displacements in cracked linear viscoelastic bodies that are acted upon by alternating tensile and compressive loads, Int. J. Engng. Sci. 14 (1976), 1135-1142.
[2] G.A.C. Graham, Viscoelastic crack in a field of pure bending.
[3] G.A.C. Graham and G.C.W. Sabin, Steady state solutions for a cracked standard linear viscoelastic body, Mechanics Research Communications, 8 (1981), 361-368.
[4] G.A.C. Graham and M. Comninou, Periodic solutions of viscoelastic boundary value problems.
[5] G.A.C. Graham and G.C.W. Sabin, The opening and closing of a growing crack in a linear viscoelastic body that is subject to alternating tensile and compressive loads, Int. Journ. of Fracture 14 (1978), 639-649.

THE PENNY-SHAPED INTERFACE CRACK WITH HEAT FLOW:

IMPERFECT CONTACT CASE

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A solution is given for the thermal stresses due to a penny-shaped crack at the interface between dissimilar materials loaded in tension, for the case where the heat flux is into the material with the lower distortivity. Regions of separation, imperfect contact and perfect contact are developed at the crack plane. A harmonic potential function representation is used to reduce the problem to a four part boundary value problem which is formulated at a set of simultaneous Abel integral equations using the method of Green and Collins. These equations are further reduced to a single Fredholm equation which is solved numerically. Interface tractions and stress functions are presented for representative cases.

The effect of heat flow is profoundly influenced by the relative signs of Dundurs constant β and a constant γ describing the mismatch of distortivities. If the more distortive material is also the more rigid, the contact region of the crack face is increased by heat flow. Otherwise it is reduced.

A FINITE ELEMENT ANALYSIS OF CRACK PROBLEMS INVOLVING CLOSURE

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Although there are rather complete studies of crack problems involving unilateral contact, few attempts have been made to solve the problem using finite element methods. One of the difficulties in the process of finite element approximations is the well-known singular behavior of the stress around the crack tip. In this article, a mesh optimization approach is used to improve the quality of the finite element approximation instead of the introduction of a "singular element" around the tip. Another feature of the present study is the unilateral nature of cracks. For the opening case, the problem becomes a usual crack problem. However, if the closing case is included, a contact problem with friction must be solved. Two approaches are used in considering the unilateral contact. The first is essentially the penalization - regularization method combining incremental analysis and is popular in the area of finite element methods. The second approach is a method combining the classical and finite element analyses. The local nature of the contact is considered by the existing analytical solutions whereas the remaining part of the problem is taken care of by finite element methods. Comparison of the two approaches is discussed for several problems.

A SEMI-INFINITE PLANE CRACK ON A BIMATERIAL INTERFACE

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The problem of a pair of point loads applied to the faces of a semi-infinite plane crack on a bimaterial interface is considered. The vectorial representation of Trefftz for the displacement vector is used in the formulation.

The first step in the solution is to consider the elastic equilibrium of a half-space where part of the surface is fixed and on the remaining part a normal point force is applied. A straight line divides the two regions. This represents a limiting case for the title problem where one of the materials is rigid. The solution is obtained through the use of integral transforms which must be inverted numerically. Stress-intensity factors as well as level curves for the stresses on the fixed portion of the boundary are obtained.

This procedure is extended to the case where normal point forces are applied to the faces of a semi-infinite plane crack on a bimaterial interface and similar quantities are evaluated. The case of applied shear forces is also discussed.

Session TM-7: DYNAMICS OF COMPOSITE MATERIALS

Organizer: T.C.T. TING, University of Illinois at Chicago Circle
Chairperson: P.G. HANSEN, University of Missouri-Rolla
Co-Chairperson: T. MURA, Northwestern University

* 9:30 - 10:00 L. E. MALVERN, R. L. SIERAKOWSKI, C. A. ROSS, C. T. SUN, H. W. DODDINGTON and S. K. CHATURVEDI, University of Florida-Gainesville"
"Ballistic Impact Damage in Fiber-Reinforced Composite Laminates"

* 10:00 - 10:30 J. N. REDDY, Virginia Polytechnic Institute and State University:
"Forced Motions of Anisotropic Composite Plates"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 C.T. SUN, Purdue University - West Lafayette:
"On Modeling Impact Response and Damage in Composite Laminates"

* 11:30 - 12:00 T.C.T. TING, University of Illinois at Chicago Circle:
"Higher Order Asymptotic Solution for Wave Propagation in Elastic Layered Composites"

* 12:00 - 12:30 D. P. UPDIKE and A. KALNINS, Lehigh University:
"Application of Composite Shell Analysis to Mechanics of Tonometry of the Eye"

BALLISTIC IMPACT DAMAGE IN FIBER-REINFORCED COMPOSITE LAMINATES

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Abstract

Ballistic impact experiments on glass/epoxy laminates have revealed that a sequential delamination mechanism, initiated by a generator strip cut out of the first impacted lamina, is a significant factor in energy absorption at subperforation speeds. A linear relationship was found between impactor kinetic energy and total delamination area (above a threshold speed). Effects of variations in impactor length, mass and nose shape and of laminate stacking sequence have been investigated. Details of the transient deformation wave and of the generator strip and delamination crack propagation have been recorded by high-speed photography and by strain gages and other sensors.

Previous results are reviewed, and recent results obtained with an eight-channel transient recording system are presented. The residual or retained strength and stiffness of impact-damaged plates has also been studied in static three-point bend tests. The investigation has recently been extended to other materials (graphite/epoxy and Kevlar/epoxy). Qualitative differences were observed between the effects of laminate stacking sequence in the graphite/epoxy and glass/epoxy plates for the 0°/90° laminates prepared from unidirectional prepreg tapes and cured in an autoclave.

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FORCED MOTIONS OF ANISOTROPIC COMPOSITE PLATES†

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ABSTRACT

A shear-flexible finite element is employed to investigate the transient response of layered composite plates[1]. The element is based on the equations governing the heterogeneous laminated plate theory that accounts for the transverse shear strains and large rotations (in the von Karman sense). The closed-form solutions to the linear theory are shown to exist for two different lamination schemes under appropriate boundary conditions, and sinusoidal distribution of the transverse load. The closed-form solutions are presented in the form of ordinary differential equations in time, and the ordinary differential equation are integrated using the Newmark direct integration method. Numerical results for deflections and stresses are presented showing the effect of plate side-to-thickness ratio, aspect ratio, material orthotropy, and lamination scheme. The results presented herein should be of interest to composite-structure designers, and to experimentalists and numerical analysts in verifying their results.

Reference

1. Reddy, J. N., "On the solutions to forced motions of rectangular composite plates," Report No. VPI-E-81-24, Department of Engineering Science and Mechanics, VPI & SU, Blacksburg, Va.

†This investigation is supported by the Structural Mechanics Program of the Air Force Office of Scientific Research (AFOSR) through Grant AFOSR-81-0142.

ON MODELING IMPACT RESPONSE AND DAMAGE IN COMPOSITE LAMINATES

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Abstract

When a composite laminate is subjected to impact of a hard object, stress waves and damage are produced in the laminate. In general, the energy imparted from the object to the target laminate is absorbed in two forms, i.e., the vibration energy stored in the laminate and energy dissipated at the failure cites. The latter is responsible for the so-called impact damage which causes reduction in strength and fatigue life of impacted composite. The separation of the two forms of energy is an important step in quantifying impact damage.

In this paper, a complete procedure for modeling the impact phenomenon is presented. A static indentation test was used to establish the contact law for a spherical object and a graphite/epoxy laminated composite. The contact law consists of loading and unloading parts. For loading we have

$$F = k\alpha^{1.5}$$

where F is the contact force, k is a contact rigidity coefficient and α is the indentation. The unloading curve is given by

$$F = F_m\left(\frac{\alpha - \alpha_0}{\alpha_m - \alpha_0}\right)^{2.5}$$

where F_m is the contact force at which unloading begins. α_m is the indentation corresponding to F_m, and α_0 is the permanent indentation.

The measured contact law was then incorporated into a plate finite element program for computing the contact force history, the dynamic response of the laminate and the energy dissipated during impact. Experiments were conducted to measure the contact force and the dynamic strain responses at various locations on the laminate. The experimental results were found to agree with the finite element solutions.

Included in this paper are experimental results for residual strength and fatigue life of the laminate after impact. The reduction in strength and fatigue life was correlated with a plastic energy resulting from impact.

HIGHER ORDER ASYMPTOTIC SOLUTION FOR WAVE PROPAGATION IN ELASTIC LAYERED COMPOSITES

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Wave propagation normal to the layering of a semi-infinite elastic composite which occupies the space $x > 0$ is studies. Each unit cell of the composite consists of two layers of linear, not necessarily isotropic, elastic materials. The stress response at the N cells distance from $x = 0$ is obtained by an asymptotic analysis. By comparing the one-term, two-term and three-term asymptotic solutions, we obtain the values of N for which each asymptotic solution may be considered as a reasonable approximate solution. Finally, we apply the three-term asymptotic solution to $N = 5$ and compare the result with the exact solution obtained by the ray theory. Good agreement is obtained even for this small value of N.

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APPLICATION OF COMPOSITE SHELL ANALYSIS TO MECHANICS OF TONOMETRY OF THE EYE

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Tonometry of the eye is analyzed from an engineering point of view. By tonometry is meant here the measurement of the intraocular pressure using an instrument which does not puncture the eyeball. In tonometry, the determination of the intraocular pressure is based on force and deformation measurements of the eye. The relationship between the measured forces and deformations, when the tonometer is applied to the eye is explained on the basis of the theory of composite shells. Application of shell theory to most of the basic types of tonometers is discussed. Particular emphasis is placed on the mechanics of the problem of the flattening of an inflated spherical shell and its relationship to the operation of a Maggy-Ring tonometer.

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Session TM-8: EXPERIMENTAL ASPECTS OF CONSTITUTIVE MODELLING

Organizer: H. F. BRINSON, Virginia Polytechnic Institute and State University
Chairperson: T. A. SCHAPERY, Texas A & M University

Co-Chairperson: D. C. CHANG, General Motors Research Lab

* 9:30 - 10:00 D. H. ALLEN, W. E. HAISER and W. L. BRADLEY, Texas A & M University:
"Experimental and Analytical Correlation of Several Rate Dependent Thermomechanical Constitutive Equations at Elevated Temperature"

* 10:00 - 10:30 D. A. DILLARD, University of Missouri-Rolla and H. F. BRINSON, Virginia Polytechnic Institute and State University:
"Experimental Aspects of a Nonlinear Viscoelastic Model for Graphite/Epoxy Laminates"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 T. NICHOLAS, Wright-Patterson Air Force Base:
"Constitutive Modeling of Engine Materials"

* 11:30 - 12:00 E. KREMPL, Rensselaer Polytechnic Institute:
"Viscoplasticity. Theory and Experiment."

12:00 - 12:15 Z. REIGENG and W. MIANBA, Academia Sinica, China:
"The Relationship Between Loading Rate and the Compressive and Tensile Strength of Granite Specimens"

12:15 - 12:30 Y. E. HASSAN, Ontario Research Foundation, Canada and K. E. MACHIN, University of New Brunswick, Canada:
"Dynamic Stress Concentration in Plates Subjected to Biaxial Impact"

12:30 - 2:00 LUNCH BREAK

Experimental and Analytical Correlation of Several Rate Dependent Thermomechanical Constitutive Equations at Elevated Temperature

David N. Allen
Assistant Profesor
Aerospace Engineering

Walter E. Haisler
Professor
Aerospace Engineering

Walter L. Bradley
Professor
Mechanical Engineering

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During the past decade, considerable research has been initiated to quantify analytically the precise thermomechanical constitution of crystalline metals at high temperature. Models currently under investigation include the microphenomenologically based model proposed by Krieg, et al. [1], the nonlinear viscoelasticity theory proposed by Walker [2], and the classical plasticity theory by Allen and Haisler [3]. These models are similar in that each is formulated using two internal state variables representing the dislocation density and dislocation arrangement. They differ considerably in the growth law for each of these internal state variables. Therefore, a controlled experimental program is underway to determine the accuracy of these theories. In this research these three models will be compared analytically to experimental results obtained at Texas A & M University. Uniaxial bars of Hastelloy X will be subjected to the low cycle tensile-compressive loadings at constant temperatures of 600°F and 1000°F. The comparative results will lead to assessments for future improvements of the current models.

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3. Allen, D. N., and Haisler, W. E., "A Theory for Analysis of Thermoplastic Materials," Computers & Structures, Vol. 13, pp. 129-135, 1981.

Experimental Aspects of a Nonlinear Viscoelastic Model for Graphite/Epoxy Laminates

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A discussion indicating laminated fiber-reinforced composite materials are finding numerous applications in a variety of fields as designers strive for lightweight structural components is given. Associated with this increased usage, is a growing concern over the long term structural integrity of composite systems. Although the fiber reinforcement may exhibit minimal time dependent response, the currently used polymeric matrix systems do exhibit substantial viscoelastic behavior. These time dependent processes are greatly accelerated by elevated temperatures, absorbed moisture, and higher stress levels. To ensure long term structural integrity of these material systems, accelerated characterization procedures are needed to allow the designer to predict the long term behavior of a general laminate based on a minimal amount of short term tests [1, 2]. A numerical procedure is currently being developed to predict the response of a general laminate based on short term tests on the unidirectional material [3].

A nonlinear viscoelastic model based on the Findley procedure [4] has been used to accurately represent the creep of several graphite/epoxy composites. Applying this approach to unidirectional 0°, 90° and 10° off-axis tensile specimens, the viscoelastic response of a lamina can be characterized. The resulting lamina model has been useful for representing the behavior of a lamina in a numerical procedure to predict creep and delayed failures of general laminates. Also, independently, the Findley procedure has been used to characterize the nonlinear viscoelastic behavior of general laminates.

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Constitutive Modeling of Engine Materials

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Turbine engine structural components are subjected to extremes in temperature and stresses. In advanced military engines, disks can undergo inelastic and time-dependent deformation, especially in the region of stress concentrations. In order to accurately predict component life, the material behavior must be realistically described in a computationally efficient form. The model must be able to describe monotonic as well as cyclic loading, creep and relaxation, and strain rate effects. The constants in the model must be obtained from simple laboratory tests.

This paper describes the testing program used to generate experimental data on three nickel base superalloys used as turbine disk materials in Air Force engines. The types of tests and data are described along with the procedures for determining material constants in several constitutive models which are used to describe time-dependent inelastic material behavior. Included are the Bodner-Partom incremental strain rate model which includes load history effects through the use of a state variable. Variations of the Malvern overstress model combined with Norton's law for creep are also presented. Applications to problems involving cracked geometries are presented and discussed.

VISCOPLASTICITY. THEORY AND EXPERIMENT.

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Abstract

The theory of viscoplasticity based on total strain and overstress [1,2] and servocontrolled testing with strain measurements on the specimen gage length are used to illustrate the necessary interplay between experiment and theory in constitutive equation development. All tests are done at room temperature on AISI Type 304 Stainless Steel and on a Ti-alloy. Both materials exhibit significant rate dependence creep and relaxation in the plastic range.

The uniaxial version of the theory contains two material functions, the viscosity function which depends only on the overstress, and the equilibrium stress-strain curve. It is operationally defined as the stress-strain curve traced out as the loading rate approaches zero. In constant strain(stress)-rate loading the constitutive equation, linear in the stress and the infinitesimal strain rates but nonlinear in stress and the infinitesimal strain, admits an asymptotic solution which is rapidly attained.

For the determination of the equilibrium stress-strain curve relaxation tests with extrapolation to an inelastic strain rate of 10^{-12} s^{-1} are most suitable. Alternatively strain-rate change tests involving two orders of magnitude are used in conjunction with the asymptotic solution to determine the overstress and therefore the equilibrium stress [3,4].

The three-dimensional, infinitesimal, isotropic formulation requires the use of a generalized Poisson's ratio. Using strain gages and axial and transverse clip-on extensometers, Poisson's ratio is determined in uniaxial monotonic and cyclic loading. Results show deviations from the constant volume assumption of inelastic deformation. The viscoplasticity theory based on overstress permits the inclusion of these inelastic compressibility effects.

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THE RELATIONSHIP BETWEEN LOADING RATE AND THE COMPRESSIVE AND TENSILE STRENGTH OF GRANITE SPECIMENS

by Zhu Reigeng and Wu Mianba

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Rock mass is subjected to dynamic load at different loading rates during propagation of stress wave from the focus by the rock mass. It is of importance to seek after the relationship between the loading rate and the compressive and tensile strength of rock for studying blasting effects in rock mass, determining safty distance and evaluating stability of geotechnical projects, etc..

Some compression and double punch tests have been conducted to five groups of cylinder-shaped granite rock specimens sizes of ϕ90mm X 190mm and ϕ90mm X 105mm at different loading rates in the range from 10^0 kg/cm²/sec. to 10^5kg/cm²/sec., by a fast pneudraulic loading machine which the maximum load is 400 ton and the fastest rise time is 8ms.

Conclusions:

1. The granite rock specimens gain much in compressive and tensile strength with lifting the loading rate. The formulation of this problem is assumed by these tests as follows:

$$\sigma = \sigma_0 \left(1 + D_1 \lg\frac{\dot{\sigma}}{\dot{\sigma}_0} + D_2 \left(\lg\frac{\dot{\sigma}}{\dot{\sigma}_0}\right)^2\right)$$

where σ_0 and $\dot{\sigma}_0$ are the static value of strength and loading rate, σ and $\dot{\sigma}$ are the dynamic value of strength and loading rate. D_1 is 0.075 and D_2 is 0.030 in compression tests, D_1 is 0.050 and D_2 is 0.007 in tension tests.

2. Q, the rate of the compressive strength and the tensile strength of the granite specimens, increases with the loading rate going up. Some data are presented:

lg $\dot{\sigma}$	0	1	2	3	4	5
Q	13.0	13.6	14.5	15.5	17.0	20.5

Fair agreement between results and practical problems ha been obtained.

Dynamic Stress Concentration in Plates Subjected to Biaxial Impact

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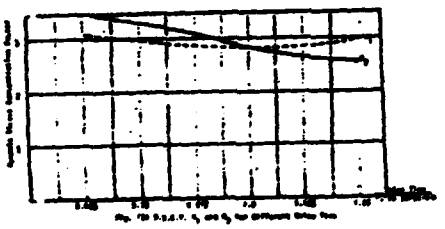
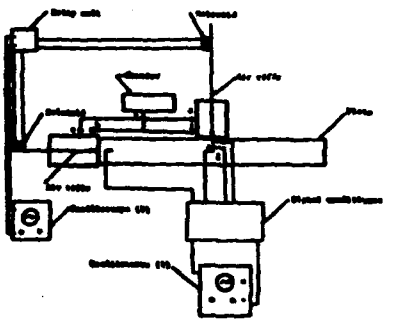
Response of structural discontinuities in plates subjected to biaxial impact is investigated experimentally using explosively induced stress pulses. Series of tests were performed on aluminum plates with and without discontinuities. Each plate is subjected to two independantly induced pulses. The apparatus used in this investigation consists of a long aluminum plate ballistically suspended using threads of low inertia and free to move in a horizontal plane. As shown in Figure (1), the plate is subjected to two biaxial impacts, perpendicular to each other but in the plane of the plate. Each impact is produced by lead pellets fired from an air rifle. An automatic firing mechanism is used to fire each rifle. The two firing mechanisms are connected together by a delay unit which is used to delay the operation of one firing mechanism with respect to the other by a certain specified amount of delay time which could be controlled from 0-200μ sec. Strain gages were used to measure strains at the discontinuity, a central circular hole of 3/4 inch diameter, and the results were displayed on an oscilloscope. The results are summarized in Figure (2) where the dynamic stress concentration factors, K_1 and K_2 in direction 1 and 2 of Figure (1), are plotted against the delay time between the two pulses. It is concluded that the dynamic stress concentration factor decreases at the point where two perpendicular compressive pulses meet. It is also concluded that this effect is greater for pulses with a wider wave front.





Session TA-1: CONTINUUM MECHANICS

Organizer and Chairperson: S. L. PASSMAN, Sandia National Laboratories
Co-Chairperson: W-L. YIN, Georgia Institute of Technology

* 2:00 - 2:30 D. R. OWEN, Carnegie-Mellon University:
"Consequences of the Second Law of Thermodynamics for the Cattaneo-Maxwell Model of Rigid Heat Conductors"

* 2:30 - 3:00 R. D. JAMES, Brown University:
"Coherent Phase Transformations in Metals and Rocks"

* 3:00 - 3:30 R. G. MUNCASTER, University of Illinois-Urbana:
"A Theory of Pseudo-Rigid Bodies: General Structure and Simple Exact Solutions"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 J. M. OTTINO, University of Massachusetts-Amherst:
"Description of Mixing of Diffusing and Reacting Fluids in Terms of the Concept of Material Surfaces"

4:30 - 4:45 M. E. GURTIN and K. A. SPEAR, Carnegie-Mellon University:
"On the Relationship Between the Logarithmic Strain Rate and the Stretching Tensor"

4:45 - 5:00 C. G. SPEZIALE, Stevens Institute of Technology:
"On Non-Newtonian Secondary Flows in Tubes of Non-Circular Cross-Section"

5:00 - 5:15 G. P. GALDI and S. RIONERO, Universita di Napoli:
"Non-Linear Asymptotic Stability Analysis for Solutions to Navier-Stokes Equations in a Half Space"

5:15 - 5:30 R. KIENZLER, Technische Hochschule, W. Germany and A. G. HERRMANN, Stanford University:
"On Conservation Laws in a Consistent Shell Theory"

5:30 - 5:45 T. J. DELPH, Lehigh University:
"Isovector Fields and Self-Similar Solutions for Power Law Creep"

Consequences of the Second Law of Thermodynamics for the Cattaneo-Maxwell Model of Rigid Heat Conductors

by

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The kinetic theory of gases and the quantum theory of heat conduction in crystalline solids provide a basis for modifying Fourier's law of heat conduction with a term linear in the time derivative of the heat flux vector. From the point of view of continuum thermodynamics, it is natural to give an interpretation of the modified Fourier law within a set of constitutive equations which is compatible with the Second Law and to study the resulting equation of energy balance. In this talk on rigid heat conductors I describe joint work (1) with Bernard D. Coleman and Mauro Fabrizio on compatibility with the Second Law and (2) with Bernard D. Coleman on preliminary studies of the energy equation. In the research (1) we take the Second Law to be the statement that the integral along a cyclic process of the heat gained divided by the absolute temperature not be positive and we show that there exists a unique entropy function which obeys the Clausuis-Duhem inequality. The smoothness of this function yields an explicit formula for the internal energy as a function of temperature and heat flux in which dependence on heat flux cannot be trivial. The research (2) shows that the energy equation is necessarily nonlinear in the heat flux - even though the modified Fourier law is itself linear - and yields non-trivial travelling wave solutions.

Coherent Phase Transformations in Metals and Rocks

by

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Coherent first-order phase transformations are identified by surfaces of discontinuity of the deformation gradient or composition produced by a continuous deformation. These transformations are responsible for twinning and martensitic transformations in metals and the coherent phases of some feldspars; as such they attract the attention of both metallurgists and geologists.

Some simple theorems of kinematics place strong restrictions on the way such phases arrange themselves. An analysis of all possible arrangements show that very few of them meet the conditions of continuity mentioned above. I shall present a brief description of the arrangements which are possible, and then I shall consider further restrictions which follow from the equations of equilibrium applied to the stress fields defined on these arrangements. A definite set of "phase rules" emerges which follow from kinematics, equilibrium, symmetry, and infinitesimal stability.

An application to the (225) habit plane in martensitic steels will be discussed.

A Theory of Pseudo-Rigid Bodies: General Structure and Simple Exact Solutions

by

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Shells may be viewed as two-dimensional bodies with one director. Rods may be considered one-dimensional bodies with two directors. Pseudo-rigid bodies are zero-dimensional bodies with three directors. The main descriptors of the motion of a pseudo-rigid body are a position vector locating the mass center and a director tensor for characterizing orientation as well as compression and shearing effects of deformation.

A theory of pseudo-rigid bodies represents the simplest step up from rigid body mechanics to a theory of deformable bodies. In this lecture a theory of pseudo-rigid bodies devised independently by Cohen and Muncaster will be outlined. It is novel in that the basic governing equations are ordinary differential equations.

The general structure of the theory, and its relationship to nonlinear elasticity will be described. Also some simple exact solutions will be presented which indicate the value such a theory may have in practical problem solving.

Description of Mixing of Diffusing and Reacting Fluids in Terms of the Concept of Material Surfaces

by

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The essence of fluid mechanical mixing of diffusing and reacting fluids can be traced back to kinematics, connectedness of material volumes, and transport processes occurring across deforming material surfaces. Descriptions based on kinematics of homeomorphic deforming material surfaces (tracers) are solely restricted to continuous motions and conveniently analyzed by transport equations in Lagrangian frames.

Connectedness of material volumes restricts the mixing topology and generates bicontinuous structures characterized by intermaterial area and striation thickness distributions. Upper bounds for area generation and material line elongation are related to mean values of viscous dissipation and govern the average reaction rate in diffusion controlled reactions. Two concepts are introduced: micromixing, related with local flows, rate of stretching, and local viscous dissipation, and macromixing, associated with connectedness of isoconcentration surfaces, vorticity, and average viscous dissipation.

Several small-scale flows can be used to typify the interplay between fluid mechanics, mass and energy transport, and chemical reactions: elliptically symmetrical stagnation flows, vortex decay, and swirling flow with uniform stretching. It is proposed that complex fluid motions might be interpreted in terms of integrated behavior of populations of small scale flows distributed in space and time to simulate mixing behavior.

The objective of this work is to present the foundations of a continuum mixing description making reference to earlier approaches to demonstrate computational applicability and practical significance.

ON THE RELATIONSHIP BETWEEN THE LOGARITHMIC STRAIN RATE AND THE STRETCHING TENSOR

by

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ABSTRACT

In this paper we investigate the relationship between the stretching tensor $\underline{D}$ and the logarithmic (Hencky) strain $\ln \underline{V}$, with $\underline{V}$ the left stretch tensor. We establish the simple formula

$$\underline{D} = (\ln \underline{V})^{\circ} - \operatorname{sym}(\underline{\Omega}\, \underline{F}^{-1}) ,$$

which holds for arbitrary three-dimensional motions. Here $\underline{F}$ is the deformation gradient, $(\ln \underline{V})^{\circ}$ is the time derivative of $\ln \underline{V}$ measured in a coordinate system which rotates with the left principal strain axes, and $\underline{\Omega}$ is the spin of the right principal strain axes. We use this formula to show that $\underline{D} = (\ln \underline{V})^{\circ}$, (or, equivalently, $\underline{D} = (\ln \underline{V})^{*}$, the Jaumann derivative of $\ln \underline{V}$), if and only if the characteristic spaces of the right stretch tensor $\underline{V}$ are constant on any time interval in which the number of distinct principal stretches is constant. Finally, we show that the asymptotic approximation

$$\underline{D} = (\ln \underline{V})^{*} + 0(\varepsilon^3)$$

holds whenever the displacement gradient $\underline{H}$ satisfies $\underline{H}, \dot{\underline{H}} = 0(\varepsilon)$.

ON NON-NEWTONIAN SECONDARY FLOWS IN TUBES OF NON-CIRCULAR CROSS-SECTION*

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ABSTRACT

It has long been recognized that the steady flow of an incompressible non-Newtonian fluid through a straight tube of non-circular cross-section will not, in general, be unidirectional like its Newtonian counterpart [1,2]. Secondary flows occur in the transverse planes of the tube independent of end effects. Here, the flow is initiated by a constant axial pressure gradient which is maintained by external means. The tube is infinitely long so that the velocity field and pressure gradient are independent of the axial coordinate.

In this paper, a simple sufficient condition will be derived for the onset of secondary flow. More specifically, it will be proven that secondary flow occurs when the axial velocity gives rise to any non-zero difference in the transverse normal stresses. The proof of this result will be obtained by an analysis of the vorticity transport equation subject to the assumption that the normal stresses possess two continuous partial derivatives with respect to each cross-sectional coordinate of the tube. It will be shown how this sufficient condition can be utilized in a direct manner to prove that for simple fluids such secondary flows constitute a nonlinear effect (a fact which has long been recognized). However, it will also be shown that, for non-simple fluids (i.e. fluids where nonlocal effects are important), these secondary flows can arise from linear terms. Applications of certain non-Newtonian models that have been utilized in turbulence will be considered along with the prospects for future research.

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[2] C. Truesdell and W. Noll, Handbuch der Physik Vol. III/3, Springer-Verlag (1965).

*Research sponsored by the Exxon Education Foundation.

NON LINEAR ASYMPTOTIC STABILITY ANALYSIS FOR SOLUTIONS TO NAVIER-STOKES EQUATIONS IN A HALF SPACE.

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We study uniqueness and non linear stability of steady solutions to Navier Stokes equations in a half space H, say, $z>0$.These solutions depend only on the z coordinate orthogonal to $z=0$. The main mathematical difficulties in treating this kind of problem are essentially

a) H is an unbounded domain with unbounded boundary;
b) The basic solutions do not have any summability property (in fact, they are constant in both x,y directions).

We prove uniqueness of the above solutions in a class I of solutions which are infinitesimal as $z\to\infty$ and may even "grow" as $(x^2+y^2)\to\infty$. Successively, assuming that the initial perturbation is square summable in H, we reduce the non-linear stability analysis to an eigenvalue problem (which is shown to be solvable) and prove that if a suitable "Reynolds number" associated to the unperturbed motion is not "too large" then all perturbations belonging to an I-type class necessarily belong to $L^2(H)$ and, moreover, become uniformly bounded in space for large time t and, finally, tend to zero as $t\to\infty$, in the supremum norm. The methods employed are essentially those developed in [1],[2].

The above theory can be applied to several physically interesting cases such as the buoyancy boundary layer [3] and the Ekman boundary layer [4].

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On Conservation Laws in a Consistent Shell Theory

by
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and
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Within the framework of linear or non-linear elasticity, conservation laws proved to be successful in calculating energy-release rates in fracture mechanics or forces acting on mobile energy sources such as defects. Invariance of the Lagrangian with respect to a group of material transformations leads to path-independent integrals in three-dimensional and plane two-dimensional elasticity.

Recently attempts have been made to establish path-independent integrals for shells. It seems that the assumptions of *first-order* shell theories complicate the criteria as to what kind of transformations on a curved surface are admissible. Application of a consequent quadratic approximation of the equations of three-dimensional elasticity theory results in a consistent shell theory. The Lagrangian takes all terms into account up to the order $h^2/12R^2$. (h is the thickness of the shell and R is a characteristic radius of curvature of the middle surface.) It turns out that the existence of path-independent contour integrals depends not only on the type of transformation, but also on the geometry of the shell middle surface as well.

In general, material translations lead to conservation laws only for developable surfaces (cylinders and cones). Circular cylindrical and conical shells allow material rotations if the state of loading and deformation is rotationally symmetrical. In addition, rotation of a closed ring of a shell of revolution in circumferential direction is independent of the width of the ring chosen in the meridional direction.

These transformations lead to conservation laws in a first-order shell theory, if terms of the same order of magnitude are neglected, which were omitted in the derivation of the first-order theory, i.e. if errors are admitted as acceptable in the sense of Koiter.

* - At present a visitor at the Division of Applied Mechanics, Stanford University.

ISOVECTOR FIELDS AND SELF-SIMILAR SOLUTIONS FOR POWER LAW CREEP

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Isovector methods represent a recent and promising mathematical technique for obtaining information concerning the behavior of solutions of systems of linear and nonlinear partial differential equations. Applications of the technique include the generation of self-similar solutions, conservation laws, and Backlund transformations, depending on the system of equations under consideration. The major disadvantage of isovector methods is the enormous amount of algebra involved in calculating the equations defining the isovector fields. This difficulty has now been largely overcome with the development by Edelen of computer programs written in a symbolic manipulation language which automatically carry out the necessary calculations.

Isovector techniques have recently been applied to the study of the governing equations for a power-law creeping body with elastic strains, considering both antiplane and plane strain deformation. The results yield a one-parameter family of self-similar solutions which generalize to some extent self-similar solutions recently obtained by Riedel. In addition, it is proved that these are the only extent set of self-similar solutions. Conservation laws for power law creep with elastic strains were found not to exist.

Session TA-2: STRUCTURAL MECHANICS/SOIL-STRUCTURE INTERACTION

Chairperson: S. NEMAT-NASSER, Northwestern University

Co-Chairperson: J. B. HEAGLER, University of Missouri-Rolla

2:00 - 2:15 C.T.T. HSU, New Jersey Institute of Technology; C.S.S. SEA, The R. M. Parsons Company, Pasadena; H. P. LEE, Ontario Hydro; and P. CHAN, New Jersey Institute of Technology: "Complete Moment-Curvature Relations for Structural Concrete Beams"

2:15 - 2:30 C.T.T. HSU, New Jersey Institute of Technology: "Analysis of Reinforced Concrete Members Under Combined Biaxial Bending and Axial Tension"

2:30 - 2:45 M. M. ALI, Skidmore, Owings and Merrill, IL: "Optimization of Concrete Structures Using Non-Linear Programming"

2:45 - 3:00 C.L.D. HUANG, Kansas State University: "Effects of Thickness of Cylinders on the Moisture and Heat Transfer in Concrete Tubes"

3:00 - 3:15 G. VALENTE, Universita di Roma, Italy: "Static and Dynamic Remarks for Hanging Roof with Stiffening Beams in the Second Order Theory"

3:15 - 3:30 A. FARAH, Laurentian University: "Response of Floors to Walking and Heel Impact"

3:30 - 4:00 REFRESHMENT BREAK

4:00 - 4:15 K. W. SCHULER, Sandia National Laboratories; S. E. BENZLEY, Brigham Young University; and H. J. SUTHERLAND, Sandia National Laboratories: "A Study of Subsidence Over Longwall Panels Using Numerical and Physical Modeling Techniques"

4:15 - 4:30 Z. A. ZIELINSKI, M. S. TROITSKY and M. S. PIMPRIKAR, Concordia University, Canada: "Bearing Pad Performance Under High Stress"

4:30 - 4:45 J. L. HILL, The University of Alabama: "Optimal Design of Pile Foundation Layouts"

4:45 - 5:00 I. HATHOUT, University of Waterloo, and A. MAHMOUD, Cairo University, Egypt: "Dynamic Sensitivity of Soil Structure Interaction"

5:00 - 5:15 T. BALENDRA, C. W. TAT and S.-L. LEE, National University of Singapore:
"Seismic Response of Torsionally Coupled Buildings on Elastic Foundations"

5:15 - 5:30 S. PRAKASH and S. SARAN, University of Roorkee, India:
"Deformation Dependent Earth Pressure in Rigid Retaining Walls"

5:30 - 5:45 S. PRAKASH, University of Roorkee, India:
"Solutions for Displacements in Soil Mechanics"

5:45 - 6:00 R. GHOSH, North Bengal University, India:
"Rayleigh Waves Due to a Nonuniformly Propagating Dip-Slip Fault"

COMPLETE MOMENT-CURVATURE RELATIONS FOR STRUCTURAL CONCRETE BEAMS

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Present design practice for statically indeterminate reinforced concrete structures is based on the inconsistent procedure of analysing the structure elastically and proportioning the section inelastically. As a consequence, the ultimate strength of the structure as a whole and, hence the factor of safety against failure remains undefined. In countries prone to earthquake, it is important that the structures behave in a ductile manner when subjected to the action of severe seismic disturbances. Strength and ductility of reinforced concrete structures are dependent upon the complete behavior of the moment-curvature and, therefore, the moment-rotation characteristics for the component members.

Two methods were used to evaluate a complete moment-curvature behavior for a reinforced concrete section : 1) The first method is based on control of applied concrete deformation and is able to obtain the ascending and descending branches of the moment-curvature curves. The computer program continues to evaluate the moment-curvature values until the differences in the compressive and tensile forces in section go beyond a suitable prescribed limit. In this case, the section is assumed to have attained the ultimate load stage. 2) Another method was developed by modifying the extended Newton-Raphson numerical analysis method; this computer program has the ability to use any section geometry and material properties. Again, the ascending and descending branches of the moment-curvature curves can be obtained; but the curves are terminated when the maximum strains in the concrete or the steel bars exceed certain pre-defined maximum strain values. In this case, the section is considered to have failed. Both methods have utilized the complete stress-strain curves for the concrete and the reinforcing steel.

The above moment-curvature values were incorporated in special purposed computer programs to analyse the behavior of simply supported and continuous beams for their complete response as the applied loads were increased from zero until failure. The analysis results were compared with the experimental values, and a reasonably good agreement was obtained from the present investigation.

ANALYSIS OF REINFORCED CONCRETE MEMBERS UNDER COMBINED BIAXIAL BENDING AND AXIAL TENSION

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The research reported herein is to study the ultimate strength behavior of reinforced concrete members subject to biaxial bending moments combined with axial tension. A numerical analysis and computer program based on a modification of the extended Newton-Raphson method was developed to study the three-dimensional strength interaction diagrams and failure surfaces for members under combined biaxial bending and axial load. The analysis can be used for the determination of strain and curvature distributions in structural concrete elements. The computer analysis developed has the ability to use any section geometry and material properties. The resulting strength interaction diagrams and failure surfaces can account for both axial compression and axial tension combined with uniaxial or biaxial bending moments.

Based on the above numerical analysis and resulting failure surfaces, two design formulas for reinforced concrete members subject to combined biaxial bending and axial tension were proposed for square or circular and rectangular sections respectively. For square or circular section, the design equation is given by:

$$\left(\frac{-P_n}{-P_o}\right) + \left(\frac{M_{nx}}{M_{ox}}\right)^{1.75} + \left(\frac{M_{ny}}{M_{oy}}\right)^{1.75} = 1.0 \qquad (1)$$

For a rectangular section, the equation can be expressed in the form:

$$\left(\frac{-P_n}{-P_o}\right) + \left(\frac{M_{nx}}{M_{ox}}\right)^{1.5} + \left(\frac{M_{ny}}{M_{oy}}\right)^{1.5} = 1.0 \qquad (2)$$

Where $M_{nx} = -P_n e_y$, $M_{ny} = -P_n e_x$, $M_{ox} = M_{nx}$ capacity at axial load $-P_n$ when M_{ny} and $-P_n$ are null, $M_{oy} = M_{ny}$ capacity at axial load $-P_n$ when M_{nx} and $-P_n$ are null, e_x = eccentricity along x-axis, e_y = eccentricity along y-axis, $-P_n$ = axial tension, $-P_o$ = pure tensile capacity.

Equations (1) and (2) represent two non-dimensional design formulas which are a further improvement of the load contour methods developed by Bresler and Parme, and can be found useful for the practical design uses.

OPTIMIZATION OF CONCRETE STRUCTURES USING NON-LINEAR PROGRAMMING

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In recent years, optimization techniques have been used extensively by researchers to solve structural analysis and design problems where cost, weight of materials or energy absorbed in the structure, etc. is the governing objective adopted for the design [1, 2, 3]. Considerable work has been done for steel structures where the material is homogeneous. For concrete structures, the application of optimization technique has been relatively slower since reinforced concrete is a composite material comprising concrete having brittle characteristics and reinforcing steel possessing ductile properties. Further, when service and ultimate constraints are to be included in the optimization process, the occurrence of inelastic phenomena at the various levels of material, sectional and structural response adds considerable complexity, even when the structure behaves primarily in flexure.

The present paper proposes a non-linear design method for concrete structures that includes the strength, ductility, deflection and crack control criteria as the active set of constraints to the optimum design. The design is performed within a mathematical programming context by minimizing the total cost of materials. The resulting non-linear programming (NLP) problem is solved using a computer program that specifies the Sequential Unconstrained Minimization Technique (SUMT) algorithm and uses a Feasible Conjugate Direction (FCD) technique to solve sub-problems having explicit linear constraints. For the NLP problem, an investigation into the existence and uniqueness of solution is carried out. For the frame example presented, it is concluded that a solution exists to the NLP problem and the solution is non-unique, i.e., only a local optimum is at best guaranteed, [4].

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EFFECTS OF THICKNESS OF CYLINDERS ON THE MOISTURE AND HEAT TRANSFER IN CONCRETE TUBES

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ABSTRACT

In recent years, there has been considerable interest in the physics of moisture movement in porous media under the influence of a thermal gradient and the size effects. The knowledge of interactions of heat and mass transfer in porous media is of great importance in areas such as those of heat and moisture transfer in building materials, thermal-insulation materials, and in concretes used for construction of nuclear reactors.

Attempts to apply the diffusion theory to the drying of concrete have not been successful, because the effect of a thermal gradient on the movement of moisture in concrete is excluded in using a diffusion theory. In the present study, the new mechanistic theory [1], developed by the writer in using the principles of irreversible flows of heat and mass, the linear phenomenological relations, and the laws of conservation in continua, is applied to study the effects of the thickness of concrete cylinder upon the moisture migration and heat transfer in the concrete cylinder. The set of basic equations for heat and mass transport in the concrete cylinder comprises three nonlinear partial differential equations and an empirical formula for sorption equilibrium curve which characterizes the topological properties of the porous concretes. The unsteady temperature, pressure, and moisture distributions in a concrete cylinder of various thickness are obtained by an implicit finite difference method. The effects of thickness of concrete cylinder upon the migration of moisture and heat transfer from the heated zone toward the unheated zone and the interactions of mass and heat transfer are discussed.

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AD A121 920 ABSTRACTS 19TH ANNUAL MEETING SOCIETY OF ENGINEERING SCIENCE INC OCTOBER 27 28 & 29 1982(U) MISSOURI UNIV-ROLLA OCT 82 N00014-82-G-0055 3/4

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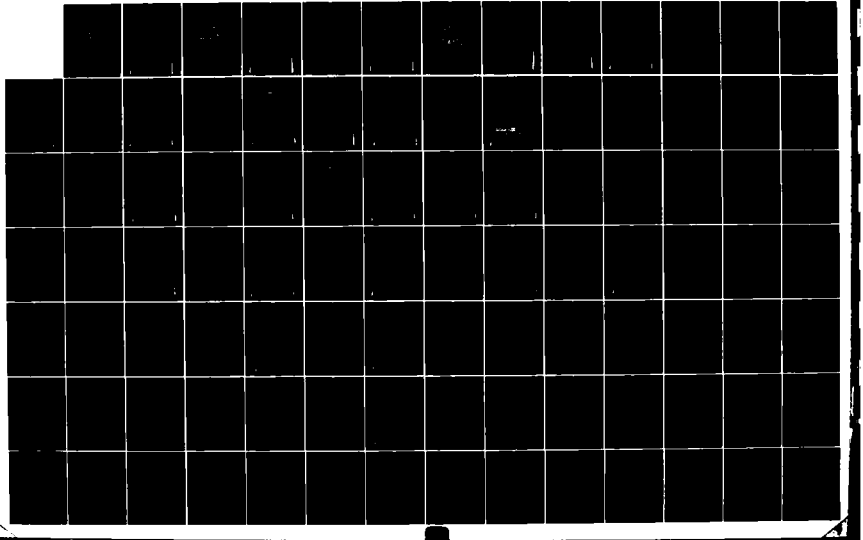

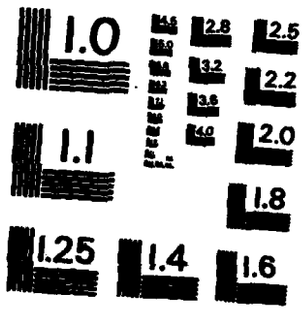

MICROCOPY RESOLUTION TEST CHART
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Static and Dynamic Remarks for Hanging Roof With Stiffening Beams in the Second Order Theory

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The roof structure of the new hangars by the international Fiumicino airport in Roma designed by Morandi is taken into account. It consists of 19 prestressed concrete cable-like members, directly supporting the roof plates and having catenary longitudinal shape. The cable-like members (40x15 cm) are spaced 4.45 m, each one is prestressed by means of 3 high tensile steel tendons consisting of 8 1/2" strands: moreover, owing to the different values of the forces to which they are subjected, both the cross-section and the number of prestressing cables are different from tendon to tendon. All transverse beams are horizontal, with span 82.00m, and develop themselves over the length of 55.70m. The two end cross beams are sited in correspondence of the joints between cables and ties; they are also of prestressed concrete of variable cross section. Ten cross beams are hanging from the roof. They are truss steel beams of triangular section with two upper and one lower chord; such beams are intended to distribute along the roof the heavy concentrated loads of the bridge cranes. The stability of the roof against the wind suction is due to the dead weight only, which is considerable because the plates of the actual roof are also made of concrete. Hereunder are given some values of the design loads: total dead load 230 kg/mq, overload 120 kg/mq, wind load 100 kg/mq, moving load at bridge cranes 10 tons. The large deformability of such structure makes necessary an investigation with second order theory on the static and dynamic behaviour in order to control any risk araising from resonance phenomena caused by the wind.

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Response of Floors to Walking and Heel Impact

by

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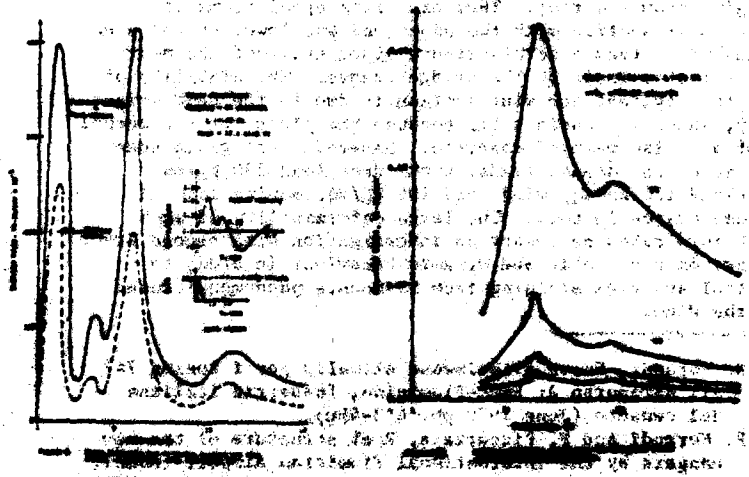
A study of the response of floors to steady-walking and heel impact is presented. The force of interaction between the human and the floor is represented by the force-time history of the resultant of the vertical forces at the foot. This resultant force exceeds the body weight during the double support phase and is less than it in the single support phase. However, the actual magnitude of the force-time curve vary depending on the subject and the walkway. Additionally, the point of application of the resultant force is described in terms of the displacement-time history. When the displacement-time curve is normalized, the variation among individuals is considerably reduced.

It is shown that resonance conditions occur when the floor frequency is equal to, or is a multiple of the step frequency. Shallow resonance occurs when a multiple of the step frequency, the floor frequency, and the natural frequency of whole body vibration coincide at about 2Hz (Fig.1).

Floors usually [illegible] under conditions as in the walking of a random number of [illegible]. In this case, floor response parameters are modelled as a [illegible] process. Typical results and plots will be [illegible].

The serviceability of floors is judged by the level of the vibrational power through a biodynamical model of man located on the floor whereupon. It is shown that the results of this study correlate well with human subjective assessments of problem floors.



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A Study of Subsidence Over Longwall Panels Using Numerical and Physical Modeling Techniques*

by

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ABSTRACT

The strata movement and resulting surface subsidence in a transverse section across the center of a longwall panel is modeled by a two-dimensional plane strain finite element analysis and by a scale model built up of rock slabs. The model is loaded by placing it on a large centrifuge. The finite element analysis employs an elastic-plastic material model which incorporates the usual shear strength dependence on pressure and a unique plastic volume change behavior which accounts for rubblization of the strata overlying the extracted coal. As an element of the overlying strata fails, it distends and falls, either to the mine floor or top of the rubble pile; subsequently it compacts as it is loaded by overlying elements which fail. This model has been incorporated into a commonly available finite element program called PLAST. Calculations have been concentrated on modeling the subsidence and strata motion observed over the Old Ben #24 mine of the Illinois coal basin. Preliminary calculations have shown good agreement with surface profiles, and comparisons with subsurface observations are also being made. To supplement the subsurface field measurements made at Old Ben #24, the physical models loaded in the centrifuge have provided valuable data on the extent and sequence in which failure occurs in overlying layers.

*This work was performed at Sandia National Laboratories and was supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789 for the U. S. Department of Energy.

[illegible]

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The use of elastomeric bearing has become common for supporting various bridge superstructures and connecting elements in North America. The elastomeric bearings are designed for 800 psi compressive stress (1,2) which is below the allowable values permitted in other countries (3,4,5). Also, in some instances where the necessity to strengthen existing structures or applying heavier loads than those adopted in original designs based on allowable stress in bearings pads of 800 psi. For example, the problem of overloading of bearing pads has been encountered at the tower structure of the Olympic Stadium in Montreal and thus the need for studying the capacity and the behavior of pads under heavy loads and subsequent failures. A research investigation on this area has been undertaken presently at Concordia University. The research includes tests on elastomeric pads under compressive stress levels, multi-cycle, and creep tests (upto 2500 psi) which are higher than those presently established current levels of 1000 psi and 800 psi, respectively (1). The results are compared with the available values and will be displayed and discussed in the paper.

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2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]

OPTIMAL DESIGN OF PILE FOUNDATION LAYOUTS

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A great many monolithic concrete structures designed require pile foundations. A typical structure may require hundreds of piles. The selection and placement of the piles in the foundation must be such that limitations on pile forces and structural displacements are not exceeded for a large number of load cases of the concrete structure.

The analysis methods of pile foundations due to Hrennikoff [1] and Saul [2] have been incorporated into a design strategy. The objective of the design is to produce a layout of piles that satisfies the limitations for all load cases that contains a minimum number of piles. The pile layout is organized as a collection of zones. The design method selects the spacing, batter slopes and layout of piles in the zones of the foundations. The first step in the optimal design is to select the batter slope in each zone so that the bending of the pile is minimized. The spacings are examined by deleting underloaded piles and reanalyzing the foundation until a minimum number of piles is determined. The devised method compares a great many designs and selects the best among those considered.

A computer program, PILEOPT, has been developed and used in this work to produce pile foundations for a set of realistic pile-foundation design problems. These include pile foundations for a dam sill monolith, a lock-gate monolith, an abutment monolith, and a pump station. In all four of these cases, the pile layouts from PILEOPT contained fewer piles than used in the actual design. It appears that PILEOPT is successful in obtaining satisfactory pile layouts for large structures. The foundation for the abutment monolith containing 76 piles, while the lock-gate monolith required 286 piles. The PILEOPT designs required an average of 16% fewer piles than were actually used in the structures.

This work was supported by the U.S. Army Engineer Corps - Lower Mississippi Valley Division.

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Dynamic Sensitivity of Soil Structure Interaction

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In the last few decades attempts have been made to represent the foundation soil interaction by a system of elastic springs and dashpots. This is based on the assumption that the amplitudes of dynamic foundation motions are small and it is therefore acceptable to consider that the soil behaves as an elastic body. The objectives in this study are to investigate the sensitivity of the damped frequencies, of a building on a rubber pad plate, to variations in the elastic characteristics of the soil foundation interaction, and to define the degree of reliability of using these elastic characteristics. The equations of the damped free vibration of a building with 6 degrees of freedom are developed using Hamilton's principle for non-conservative systems. The resulting equations can be written in a matrix form as follows:

$$\underline{A}\ddot{\underline{x}} + \underline{B}\dot{\underline{x}} + \underline{C}\underline{x} = \underline{0} \qquad (1)$$

where $\underline{A}$, $\underline{B}$, and $\underline{C}$ are the mass, damping, and stiffness matrices respectively. Using the method of Laplace-Carson integral transformation, Eq. (1) is transformed into the following generalized eigenvalue problem

$$\underline{S}(s, \underline{\lambda})\underline{\psi} = 0 \qquad (2)$$

where $\underline{S}$ is a matrix of complex terms, s are the generalized eigenvalues in the complex plane, $\underline{\lambda}$ is a vector of parameters and $\underline{\psi}$ is the displacement vector in the frequency domain. The roots of equation (2) are obtained using the complex integration on a unit circle and the generalized damping, frequencies and mode shapes. The sensitivity equations are developed to Ref. [1] and a computer program is written to perform the calculations required to compute the eigenvalues, their sensitivities, and the mode shapes of the buildings.

The principal conclusions of this study can be summarized as follows:

1. The damped frequencies are found to be insensitive to small variations in the elastic characteristics of the soil foundation interaction.
2. Large variations in the springs characteristics produced larger effects than those of the dashpots.
3. The complex integration on a unit circle is far superior over the traditional Laplace transformation method.

Further work in this area is underway and will be reported later.

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SEISMIC RESPONSE OF TORSIONALLY COUPLED BUILDINGS ON ELASTIC FOUNDATIONS

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A torsionally coupled shear building on a linear elastic foundation is considered. The interaction forces at the soil-structure interface corresponding to translational, rocking and torsional modes of vibrations are represented by frequency independent expressions given by Richart, et. al. (1). The maximum seismic response of the system is obtained by the response spectrum technique which requires the approximate normal modes and the associated damping ratios of the interaction system. A set of approximate normal modes which diagonalizes the inertia and stiffness matrices is found. However, as the transformed damping matrix is still nondiagonal, an equivalent diagonal matrix is constructed. An accurate estimate of the damping ratios is obtained by matching the approximate normal mode solution with the rigorous solution, at the natural frequencies of the interaction system. A systematic iterative procedure is presented to achieve the matching of the responses by solving a set of simultaneous non-linear algebraic equations with the damping ratios of significant normal modes as the unknowns. The degree of freedom that is chosen as the basis for the matching should be sensitive to damping, as otherwise the damping ratio obtained will be inaccurate. In view of this, the degrees of freedom of the top floor are chosen as they are the most sensitive to damping. There are three degrees of freedom per floor, namely translation of the center of mass in two orthogonal horizontal axes, viz. x- and y- directions, and rotation of the floor about a vertical axis. The particular degree of freedom that should be selected as the basis for the matching at a particular frequency may be established by an examination of the approximate normal eigenvector corresponding to that frequency. The eigenvector will have displacement components in the x- and y- directions and rotation components about a vertical axis. One of these components will be dominant and the degree of freedom at the top floor corresponding to this dominant component is selected for matching. Furthermore, when the dominant component corresponds to displacement in x- or y-direction, the assumed ground motion should be in the direction of the dominant component. If the dominant component corresponds to rotation about a vertical axis, the direction of the ground motion should be such that a greater torsional motion is created. Hence the degree of freedom chosen for matching the response varies from frequency to frequency and the directions of the assumed ground motion is dictated by the choice of the particular degree of freedom.

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DEFORMATION DEPENDENT EARTH PRESSURE ON RIGID RETAINING WALLS

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Retaining walls are one of the very important Civil Engineering Structures used to retain earth or any other material whose conditions do not permit the mass to assume its natural slope. These are usually designed for ultimate values of earth pressures obtained from classical theories (Rankine, 1857, Coulomb, 1776). These therefore give the value of total earth pressure when the deformation of wall is sufficient to bring the soil in plastic equilibrium state. The points of application of these pressures are additionally assumed.

In this paper an analytical solution has been developed to evaluate earth pressure and its distribution at any known deformation of the wall. The rotation of the wall about the base away from the backfill has been considered. The use of non-linear constitutive laws of backfill material has been made in developing the methodology. It has been observed that on deformation of the wall increases, the earth pressure increases in the beginning and after further increase in deformation, it remains decreasing.

Non-dimensional charts have been prepared for getting earth pressure distribution at various deformation values.

Analytical results have been compared with the existing experimental data.

SOLUTIONS FOR DISPLACEMENTS IN SOIL MECHANICS

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All soils undergo deformations when stressed. The stress deformation characteristics of soils are non-linear. This makes computation of displacements of structures supported on soils difficult.

The factors on which displacements of such structures depend are:

1. Nature of the soil and its engineering properties
2. Stress-strain characteristics
3. Geometry of the problem
4. Stress-distribution in soils

The structures in which displacements need to be computed are:

1. Footing foundation
2. Pile foundation
3. Earth dam
4. Laterally loaded piles
5. Retaining structures

A technique for computation of settlements of footing foundations has been developed by Prakash, Saran and Saran (1977). This is based on the (1) determination of stress-strain characteristics from triaxial tests and (2) stress computation from elastic theory. The stress distribution below the footing in sand and clay was assumed such that compatibility conditions of displacements below the rigid footing was satisfied.

A semi-empirical method for computing displacements of earth dams under earthquake conditions has been proposed by Newmark (1965) and Seed (1980).

In this paper, questions of simulating geometry by a simple mathematical model and limitations of simple but needed practical solutions have been discussed.

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The study of dynamic crack propagation has a very important role in geophysics and in earthquake engineering sciences. In geophysics it is desirable to formulate the earthquake source features of physical parameters and to study the long period waves over a large distances and for a long time. In structural engineering also it is important to analyse the nature of the surface waves covering a large distances. As a particular phase the ground motion produced by earthquake is a very complicated function of the nature of propagation of the crack and of the geological properties of the places as well. Most of the known solutions of the moving crack are restricted by the assumption of constant velocity of propagation, which is not in general expected.

Maruyama (1972) discussed Rayleigh wave propagation by a finite fault moving with constant velocity. Burridge (1969) discussed the wave motions in case of a unidirectionally expanding line load. Thomson and Haskell (1973) considered a model in which a plane source shear crack starts from rest at a certain time under the action of uniform loading. Similarly, Kostrov and Nikitin (1968) have also studied the motion of an edge dislocation emerging from rest and moving subsonically on its slip plane.

In the [redacted] of elastodynamic problems cannot be considered. [redacted] at a certain depth below the free surface [redacted] and the wave excitation [redacted] with [redacted] in displacement [redacted] the fault plane is prescribed. The [redacted] of displacement on the fault surface due to Rayleigh wave [redacted] determined for [redacted] of the crack.

The [redacted] Haskell and Ohtsuki (1955) with [redacted] the [redacted] of the problem. These particular cases of [redacted] speed of the crack are considered. Numerical and [redacted] of surface displacements due to Rayleigh waves [redacted] and complex have been plotted.

[redacted]

Session TA-3: STABILITY OF DYNAMICAL SYSTEMS

Organizer and Chairperson: W. F. AMES, Georgia Institute of Technology
Co-Chairperson: T. G. TRUCANO, Sandia National Laboratory

* 2:00 - 2:30 E. F. INFANTE, National Science Foundation and Brown University:
"Liapunov Functions of Some Dynamical Systems"

* 2:30 - 3:00 N. CHAFEE, Georgia Institute of Technology:
"The Electric Ballast Resistor"

* 3:00 - 3:30 H. A. LEVINE, Iowa State University:
"An Analysis of Surfactant Induced Surface Motion on the Interface of a Forming Droplet"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 W. F. AMES, Georgia Institute of Technology:
"On Wave Propagation in Viscoelastic and Viscoplastic Materials"

4:30 - 4:45 M. PODOWSKI, Rensselaer Polytechnic Institute:
"Stability of Integral-Differential Systems Arising from Nuclear Reactor Dynamics"

4:45 - 5:00 R. BOSTANIAN, The Pennsylvania State University:
"Nonlinear Diffusion, Monotonicity of Solutions, and the Effect of Convexity of the Domain"

5:00 - 5:15 M. MAIELLARO and A. KEDAELLI, Universita di Bari, Italy:
"Non-Linear Stability of the Circular Couette Flows In Anisotropic M.H.D."

Liapunov Functions of Some Dynamical Systems

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Liapunov functions are extremely useful tools for the determination of stability conditions for ordinary, functional and partial differential equations, be they linear or not. Conversely, theorems are known that insure the existence of such functions if the dynamical systems under consideration have certain stability properties. Unfortunately, the construction of such functions is not a straightforward task.

A series of examples centered on ordinary, functional, and integrodifferential equations are presented to illustrate the use of Liapunov functions in asymptotic stability arguments and to present an approach to the construction of these functions.

THE ELECTRIC BALLAST RESISTOR

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The electric ballast resistor consists essentially of a piece of wire through which there passes an electric current. It is reasonable to suppose that within this wire the electrical resistivity depends in a nonlinear way on the local temperature. Under these circumstances one can ask, what is the long term or asymptotic behavior of the temperature distribution within the wire? In this lecture we shall answer that question in two distinct cases: the first, in which one assumes that the current flowing through the wire is of constant strength or intensity; and the second, in which one assumes the difference in electric potential from one end of the wire to the other is held constant. In each of these two cases we shall exhibit interesting phenomena of stability and bifurcation. Also, with regard to these same phenomena, we shall see a remarkable distinction between the two cases at hand.

AN ANALYSIS OF SURFACTANT INDUCED SURFACE MOTION ON THE INTERFACE OF A FORMING DROPLET

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Burkhart and Poonawalla have observed regular surface flow patterns on the interface of forming droplets when the droplet phase is immiscible in the adjacent phase. In this talk we shall discuss their experimental results and indicate how one could have expected such results by analyzing (qualitatively) the equations of mass transport in the surface and the surface stress balance equations. The analysis, while relatively elementary, yields surprisingly good agreement with experiment.

ON WAVE PROPAGATION IN VISCOELASTIC AND VISCOPLASTIC MATERIALS

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One dimensional problems of the title are describable by the system equations $\rho v_t - \sigma_x = 0$, $\epsilon_t - v_x = 0$, $\sigma_t - f(\epsilon,\sigma,\epsilon_t) = 0$, with appropriate identification of the variables. Group analysis is employed to characterize all those functions which are left invariant under the dilatation and spiral groups. Three exact solutions are constructed and the paper closes with an algorithm for solving the general invariant problem.

STABILITY OF INTEGRAL-DIFFERENTIAL SYSTEMS ARISING FROM NUCLEAR REACTOR DYNAMICS

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Abstract

The subject of the paper concerns stability analysis for a class of integral-differential systems with infinite time lag. The method applied in the analysis constitutes an extension of the 2nd method of Liapunov, and is based on a new concept of stability. Namely, new definitions for stability have been introduced, referring not only to the magnitude of initial trajectories but to that of their derivatives as well. Consequently, the basic stability theorem formulated for the class of systems under consideration employs a Liapunov functional defined for all bounded and continuous functions having bounded and piecewise continuous first derivatives.

The approach discussed above has proven very useful in the analysis of stability in bounded domains of initial perturbations for systems arising from nuclear reactor dynamics. In particular, the following system has been investigated

$$\dot{x} = \varphi(1+x) - \int_{-\infty}^{t} f(t-\theta)[x(t) - x(\theta)]d\theta$$

where $\varphi = [\varphi(x)](t)$ is a causal time-invariant functional. New criteria for asymptotic stability of the solution $x(t)=0$ of the above equation have been established. These criteria can be effectively used to evaluate allowable domains of initial perturbations, ensuring convergence to the steady state for the perturbed trajectories.

To illustrate practical usefulness of the proposed method, selected examples have been discussed, dealing with some specific forms for the functional φ.

NONLINEAR DIFFUSION, MONOTONICITY OF SOLUTIONS, AND THE EFFECT OF CONVEXITY OF THE DOMAIN

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The equation $\partial u/\partial t = \operatorname{div}(|\nabla u|^{m-1}\nabla u)$, $m > 1$, describes diffusion in a medium where the diffusivity depends on the gradient of the concentration, see Serrin [4, §63] for a discussion in connection with heat conduction. The spreading of biological populations can also be related to this type of equation, see Gurtin and MacCamy [3] for a close variant. We have studied in [1,2] the large-time behavior of solutions of this equation under various conditions. In particular for the Neumann boundary value problem, with null data on the boundary of a bounded region Ω in $\mathbb{R}^N$, we obtain the following results. Let $\|\cdot\|_p$ denote the norm in $L^p(\Omega)$, $1 \le p \le +\infty$, and let $u_0(x) = u(x,0)$, and α = the average of $u_0(x)$ in Ω. Then as $t \to \infty$ the solution $u(x,t)$ converges to α and the gradient $\nabla u(x,t)$ approaches zero, uniformly in Ω. Moreover, the decay of $\|u(\cdot,t) - \alpha\|_p$ is <u>monotone</u> in time for all p, while $\|\nabla u(\cdot,t)\|_p$ is monotone in general domains <u>only when</u> $p = m + 1$. In fact by a judicious choice of Ω we can have $\|\nabla u_0\|_\infty = 1$, and $\|\nabla u(\cdot,t)\|_\infty$ arbitrarily large at some time $t = \bar{t}$. (Note however that ∇u eventually goes to zero anyway).

In contrast, we also show that if Ω is <u>convex</u>, then $\|\nabla u(\cdot,t)\|_p$ <u>is monotone</u> for all p, including $p = +\infty$.

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NON LINEAR STABILITY OF THE CIRCULAR COUETTE FLOWS IN ANISOTROPIC M.H.D.

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ABSTRACT-Taking into account the Hall and ion-slip currents [1] in the anisotropic M.H.D., for an incompressible isothermal flow, we prove that: a) the boundary problem for the class $\{\underline{v}=v_0(\rho)\underline{e}_\theta;\ \underline{H}=[H_0+h_z(\rho)]\underline{e}_z\}$ in cylindrical coordinates (ρ,θ,z):

$$(1)\quad \begin{cases} \partial_t \underline{v} = -\underline{v}\cdot\nabla\underline{v} - \nabla\pi + \nu\nabla^2\underline{v} + \frac{\beta_0}{\rho_0}(\nabla\times\underline{H})\times\underline{H} \\ \partial_t \underline{H} = \nabla\times(\underline{v}\times\underline{H}) + \eta_0\nabla^2\underline{H} + \beta_H\nabla\times(\underline{H}\times(\nabla\times\underline{H})) + \beta_1\nabla\times(\underline{H}\times(\underline{H}\times(\nabla\times\underline{H}))) \\ \nabla\cdot\underline{v} = 0, \quad \nabla\cdot\underline{H} = 0 \end{cases}$$

$$(2)\quad \begin{cases} v_0(r_1) = \Omega_1 r_1 \\ v_0(r_2) = \Omega_2 r_2, \end{cases} \qquad \begin{cases} h_z(r_1) = h_1 \\ h_z(r_2) = h_2, \end{cases}$$

for a cylindrical layer with rigid, uniformly rotating and conducting walls $\rho=r_1$ and $\rho=r_2(>r_1)$, has for unique solution the steady motion:

$$(3)\quad \begin{cases} v_0(\rho) = \frac{1}{r_2^2-r_1^2}\left[(\Omega_2 r_2^2-\Omega_1 r_1^2)\rho + r_1^2 r_2^2(\Omega_1-\Omega_2)\frac{1}{\rho}\right] \\ H_0 + h_z(\rho) = \left(\frac{1}{\beta_H+\beta_1}\right)^{\frac{1}{2}}\left[\rho+(r^2+\frac{4\eta_0^2\beta_1}{\beta_H+\beta_1})^{\frac{1}{2}}\right]^{\frac{1}{2}}\left[\rho-(r^2+\frac{4\eta_0^2\beta_1}{\beta_H+\beta_1})^{\frac{1}{2}}\right]^{\frac{1}{2}}\delta; \end{cases}$$

with $\delta = \sigma\cdot\mathrm{sign}\,\Phi + k_1\sigma\in[r_1,r_2]$ and σ,k suitable constants depending of the boundary conditions.

b) If we introduce the non dimensional ion-slip parameter $\Sigma = \beta_1 H_0^2/\eta_0$ and if we put, in a suitable non-dimensional variables, $r = r_2/r_1$, $\alpha_1 = \inf\{\Sigma\in\mathbb{R}^+;\ \alpha_1 = \sup\{\Sigma\in\mathbb{R}^+;\ \alpha_2 = \sup\{\Phi_0/\Phi\},$ with $\alpha\in[\alpha_1,\alpha_2]$, the following condition:

$$(4)\quad \begin{cases} r^2\alpha_2^2\Sigma + 2\Sigma\alpha_2\alpha_3 - r^2 < 0 \\ r^2\alpha_2^2\alpha_3^2\Sigma^2 + 4r^2\alpha_2\alpha_3\Sigma - 4 < 0, \end{cases}$$

ensure the non linear asymptotic exponential stability of the motion (3) with respect to the measure $\frac{1}{2}\int_\Omega \rho(\underline{u}^2+\frac{1}{\mu_0}\underline{h}^2)d\rho$ of the perturbations belonging to the class $\{u_\theta(\rho,t)\underline{e}_\theta + u_\rho(\rho,t)\underline{e}_\rho;\ h_\theta(\rho,t)\underline{e}_\theta + h_\rho(\rho,t)\underline{e}_\rho\}$. [2].

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(*)Work performed under the auspices of the G.N.F.M.-C.N.R. Italy .

Session TA-4: THERMODYNAMICS/FLUID MECHANICS/APPLIED MATHEMATICS

Chairperson: P. K. TENNAKOON, University of Missouri-Rolla

Co-Chairperson: C. MORRIS, University of Missouri-Rolla

2:00 - 2:15 J. L. SCHMITT, University of Missouri-Rolla:
"The Practical Thermodynamics of a Fast-Expansion Cloud Chamber"

2:15 - 2:30 J. L. KASSNER, JR. and D. R. WHITE, University of Missouri-Rolla:
"A Cooled Wall Expansion Cloud Chamber for Producing Slow Adiabatic Expansions in Atmospheric Studies"

2:30 - 2:45 Ph. ARQUES, Universite de Valenciennes, France:
"Thermodynamic Cycle of Reciprocating Internal Combustion Engines with Compressed Air Energy Storage"

2:45 - 3:00 C. RAYCHAUDHURY, S. C. BASAK, S. K. RAY, J. J. GHOSH, Calcutta University; A. B. ROY, Jadavpur University, India:
"Graph-Theoretical Invariant and Thermodynamic Property: A QSAR Study of Alcohols"

3:00 - 3:15 W. E. SCOTT, The University of Tennessee:
"Taylor Column Genesis in a Rapidly Rotating Right Circular Cylinder"

3:15 - 3:30 P. K. DAVIS and G. N. COLEMAN, Southern Illinois University:
"Flow and Design Characteristics of the Hydrocyclone"

3:30 - 4:00 REFRESHMENT BREAK

4:00 - 4:15 L. E. JONES, JR., University of Florida and X. B. REED, JR., University of Missouri-Rolla:
"On Stokes' and Oseen's Equations"

4:15 - 4:30 N. SARIGÜL, University of Arizona and M. C. DÖNMEZ, Istanbul Technical University:
"Quasi-Variational Principles for Viscous Incompressible Fluids"

4:30 - 4:45 M. BAKOU, BLIDA, Algeria:
"Study of a Fluid Saturated Porous Damper"

4:45 - 5:00 A. B. SOUGLINE, University of Lagos, Nigeria:
"The Drop Shaped Tank"

5:00 - 5:15 K. [redacted], Jadavpur University, India:
"[redacted]"

5:15 - 5:30 R.R.O. [redacted], University of Tuebingen, Germany:
"[redacted]"

5:30 - 5:45 M.M.[redacted], The University of Western Ontario:
"[redacted]"

5:45 - 6:00 M. [redacted], Egypt:
"[redacted]"

ABSTRACT

THE PRACTICAL THERMODYNAMICS OF A FAST-EXPANSION CLOUD CHAMBER

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This paper describes the achievement of an adiabatic expansion with a precision Wilson cloud chamber. The following topics will be discussed: the expansion of the cloud chamber, the measurement of the thermodynamic conditions in the chamber, the practical design and control of the device, and its application to the formation of droplets in the study of homogeneous nucleation.

A COOLED WALL EXPANSION CLOUD CHAMBER FOR PRODUCING SLOW ADIABATIC EXPANSIONS IN ATMOSPHERIC STUDIES

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*also Department of Engineering Mechanics

The Graduate Center for Cloud Physics Research at the University of Missouri-Rolla is in the process of constructing two cooled wall expansion cloud chambers for use in studies of numerous atmospheric processes associated with cloud formation and development. The chambers utilize a double wall construction in which the temperature of the thick outer heat sink is maintained by circulation of a thermostated fluid. Thermoelectric cooling modules located between the outer heat sink and the thin inner walls are used to maintain the inner wall surface at the same temperature as the sample within the chamber.

The control and data acquisition computer can control the gas pressure-temperature and wall temperature independently of each other. By independently maintaining the gas and wall temperatures at the same value the perturbing heat flow from the walls experienced by conventional fast expansion chambers is eliminated.

The chambers are designed to operate at temperatures between ± 40°C. Pressures are from slightly (50-100 torr) above ambient down to about 250 torr absolute. Cooling rates decrease as the temperature difference across the thermoelectric modules increase but the small (1.2 m) chamber can achieve rates of 10°C/min while the larger (2.84 m) chamber can achieve 15°C/min. Maximum expansion rates exceed the rates required for either wet or dry adiabatic expansions at the maximum cooling rates.

Four separate optical systems are available for remote sensing for the cloud droplets as they form and grow. The systems are independent and each has its own strong points and limitations.

The system is backed up by an extensive system for producing and characterizing aerosols for use in the expansion chambers.

The small chamber is scheduled to be operational by the end of 1982 and the large chamber approximately a year later.

Work is being supported by the Department of Defense through the Air Force Office of Scientific Research.

Thermodynamic cycle of reciprocating internal combustion engines with compressed air energy storage

Ph. ARQUES, Professor

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In 1860 LENOIR /1,2/ invented the gas engine with electrical ignition. Two years later, BEAU de ROCHAS /2,3/ set out the principle of the four stroke cycle with preliminary compression mixture, which was carried into effect in 1863 by OTTO; then in 1893 DIESEL /2,4/ conceived the engine with thermodynamic ignition of the mixture. Because of its poor qualities LENOIR's cycle is today ignored to the advantage of the two other cycles and the mixed cycle /2/ which is nearer to the real cycle of reciprocating internal combustion engines. We have examined the energetic data of LENOIR's two stroke cycle by letting the gas /5/ considered as perfect gas into the cylinder after isothermic compression and storage in a reservoir followed by a reheating from the exhaust gases (Fig. 1).
1st stroke : 1 to 2 : compressed gas intake (pressure P_2) previously reheated from exhaust gas ; 2 to 3' : heat added at constant volume ; 3' to 3 : heat added at constant pressure, the pressure being the maximum allowed by the engine ; 3 to 4 : reversible and adiabatic expansion of gas. 2nd stroke : 4 to 5 : opening of exhaust valve ; 5 to 6 : forcing back of gas.
The efficiency of such a cycle (η_c) is the ratio between on the one hand the work on the piston (W_c), and on the other, the sum of the heat release Q during the phases 2-3' and 3'-3 and of isothermal work (W_t) which is necessary to the gas compression $\eta_c = W_c/(Q+W_t)$.
The work (W_c) obtained with LENOIR's cycle for an intake pressure P_2 of 30 bars(435 Psi) and the efficiency of this cycle (η_c) (Fig.2) relative to the geometric ratio ε between the maximum volume of the cylinder and the combustion volume (V_3/V_2) are better than the work and efficiency of the BEAU de ROCHAS, DIESEL and mixed cycles (respective curves B, D,m) relative to the volumetric compression ratio, identified in this instance, with the geometric ratio ε. The isothermic compression of air in the reservoir is executed during the low electricity consumption hours by a compressor connected to an electric motor. At peak electricity consumption hours, the performance coefficient (C_{pc}) of LENOIR's engine represents the ratio between the work resulting from the expansion gas processes in the cylinder (W_c) and the energy provided in the form of fuel.

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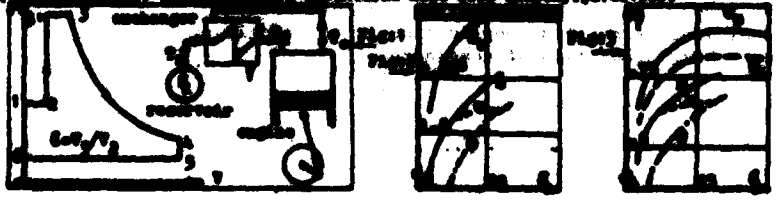

GRAPH-THEORETICAL INVARIANT AND THERMODYNAMIC PROPERTY: A [illegible] OF ALKANES

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Prediction of thermodynamic properties of molecules is important for chemical engineering, pharmacology and biochemistry. One of the current trend in this area is to correlate the thermodynamic properties of congeners with the topological indices of the corresponding chemical graphs realising the molecules. Such indices are usually defined on the hydrogen-depleted skeleton of the planar chemical graph.

In our formalism the usual (non-hydrogen suppressed, linear or multigraph) molecular graph is considered to define a topological index. Defining a first order topological neighborhood the vertex set V(G) of the graph G is partitioned into disjoint subsets. If $A_1, A_2, \ldots, A_k$ be the partition of X(G) the topological information content of X(G) is defined by Shannon's formula:

$$(IC)_G = -\sum_{i=1}^{k} p_i \log_2 p_i$$

where p_i $(i = 1,2,\ldots,k)$ represent the probabilities of the partitioned subsets. p_i is defined as n_i/n, n_i and n being the cardinalities of A_i and X(G) respectively.

Subsequently, another topological index, complementary information content (CIC), was defined as:

$$(CIC)_G = \log_2 n - (IC)_G = \sum_{i=1}^{k} \frac{n_i}{n} \log_2 n_i$$

In this paper it is shown that the CIC values of a series of alkanes are highly correlated with their thermodynamic properties viz. heat of vaporization (ΔH_v) and heat of formation (ΔH_f). It is speculated that CIC and related topological indices may find application in the modelling of thermodynamic properties of congeners.

Taylor Column Genesis in a Rapidly Rotating Right Circular Cylinder

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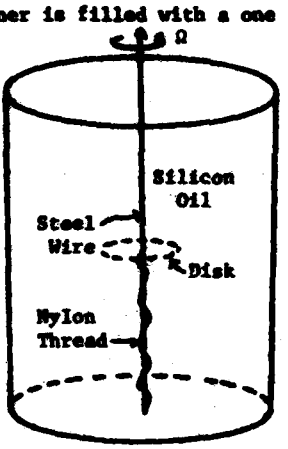
A taut, fine steel wire, coincident with the long axis of a right circular cylinder, passes through the center of a foam imbedded plastic disk as shown. If the container is filled with a one centistoke silicon oil, the disk (released from rest at the center of the cylindrical container by cutting a nylon thread attached to the disk) rises along the steel wire to the top of the container in about five seconds. If the container is allowed to rotate about its long axis, the rise time of the disk increases to about eight seconds. If, now, the height of the cylinder is changed infinitesimally to make it a resonant one (i.e., to enable it to support inertial waves[1]), the rise time increases to about fifteen seconds!



The analysis for the flow due to the disk, though following rather closely Greenspan's[2] unbounded (i.e., infinite) fluid analysis, is more difficult; for the boundary conditions lead to dual Fourier-Bessel[3] equations rather than the well studied dual integral equations Greenspan encountered. With some effort, a solution is obtained, and the analysis shows that the excited inertial waves propagate ahead of the rising disk, generating a Taylor column in about one revolution. Hence, the accompanying slower ascent of the disk is due to its having to push against this column, the "rigidity" of which impedes the motion of the disk.

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FLOW AND DESIGN CHARACTERISTICS OF THE HYDROCYCLONE

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ABSTRACT

The hydrocyclone is a device that utilizes the centripetal and centrifugal forces associated with circular motion to separate a desired material, such as coal, from more dense undesirable "impurities" which are all mixed in water as a carrier liquid. The rotational "cyclone" or "tornado" type motion is created by tangential injection of the slurry into the device as shown in Figure 1. Water containing the lighter particles goes out the overflow while water carrying the heavier particles passes through the underflow. Of particular interest in this research project sponsored by the Illinois Mining and Mineral Resources Research Institute and the U.S. Department of Energy is the discovery of how the various design and flow variables affect the operation of the hydrocyclone. These data are used to determine optimum design criteria for the separation of coal fines from more dense solid particles such as clay, shale, pyritic sulfur, and sandstone.

Experimental hydrocyclones have been constructed which allow the efficiency of separation to be determined while design parameters such as the length and diameter of the hydrocyclone, the cone angle, the diameter of the underflow, the flow rate, the specific gravity of the solid material, and the amount and size of solid material in the input are all controlled. Initially, spheres were used to model the coal and the heavier impurities. The spheres are colored according to specific gravity. Spheres of known size, specific gravity, and number are loaded into the system upstream from the hydrocyclone, then collected downstream from both the overflow and the underflow. Since the spheres are color coded, they are easily counted for the purpose of determining efficiency of separation. The data are presented in non-dimensional plots which may be used for selection of design purposes by users in industry.

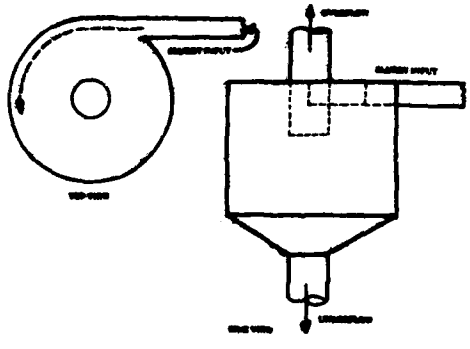

FIGURE 1. DIAGRAM OF A HYDROCYCLONE

On Stokes' and Oseen's Equations

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The Navier-Stokes equation is invariant under transformation of inertial frames but otherwise has the usual corrections from the Coriolis theorem. Linearizations of the Navier-Stokes equation in an inertial frame and in a rigid frame in relative motion lead to corresponding equations: in the former the Stokes equation results, in the latter the Stokes equation with Coriolis *corrections*. Conversely, if the Stokes equation is transformed from an inertial frame to a rigid one in relative motion, a generalized Oseen equation results.

QUASI-VARIATIONAL PRINCIPLES FOR VISCOUS INCOMPRESSIBLE FLUIDS *

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This paper presents certain quasi-variational principles which are desirable in obtaining approximate solutions to the initial-and boundary-value problems of incompressible fluids. To begin with, the principle of virtual power is stated and then it is used to deduce a one-field variational principle of viscous fluids. The principle generates the Euler equations of motion and the associated natural traction boundary conditions, and it contains the rest of the fundamental equations as constraints. These constraints conditions are relaxed by means of the dislocation potentials and Lagrange multipliers, and hence the unconstrained quasi-variational principles are formulated in a systematic manner for inviscid and viscous incompressible fluids. The first unconstrained variational principle is shown to generate, as the appropriate Euler equations, all the fundamental equations of viscous incompressible fluids, that is, the equation of continuity, the equations of motion, the kinematic and constitutive relations, the natural traction and velocity boundary conditions, and the natural initial conditions. Further, special cases of the unconstrained quasi-variational principle are studied and the quasi-variational principle operating on the velocities and its reciprocal principle, and the quasi-variational principle operating on the pressure of viscous fluids, and the quasi-variational principle of ideal fluids are given. Lastly, a brief discussion of the variational principles, their comparisons with certain earlier variational and quasi-variational principles, and a need of future research for the subject are presented.

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STUDY OF A FLUID SATURATED POROUS DAMPER

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This work presents a theoretical and experimental study of a fluid saturated porous damper. The squeleton of the damper is elastic, the liquid filling the pores is viscous and the system stiffness is pneumatic. The damping ratio depends mainly on the fluid viscosity and the medium porosity. The use of such a damper is to reduce the absolute transmissibility over the whole frequency range. Depending upon the operating conditions of the system, one can choose the appropriate parameters to obtain the desired values of transmissibility.

In this paper vibration isolation provided by such a damper is presented. The analysis has been limited to the case of an unidirectionally loaded damper. The fluid and the squeleton of the damper are assumed to have the same constant temperature. A simplified approach is presented using operational calculus for deriving the problem solution. Analytical results are compared with experimental data.

The Drop Shaped Tank

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The drop shaped tank is a shell of constant strength used on land for storing drinking water or liquified petroleum gas (LPG). In offshore oil exploration, it is sometimes necessary to store crude oil in containers due to bad weather that may prevent the transportation of the same by tankers onshore for refining. In this paper, the possible use of the drop shaped tank for storage in an underwater environment will be discussed. Some results obtained to date will be presented. Future developments will also be discussed.

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GRAVITY WAVES DUE TO A PERIODIC SURFACE PRESSURE ON A SLOPING BEACH

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India

In this paper, the linearised two-dimensional problem of water waves due to a surface pressure of the form $f(x) \exp(i\omega t) H(t)$, $H(t)$ = Heaviside Unit Function, has been explicitly solved for a beach of slope angle $\pi/2q$, $q = 1,2,3,\ldots$. This involves the solution of a Fredholm integral equation of the first kind by means of a generalized Fourier transformation. A method of finding the complete asymptotic expansion of the surface displacement over different possible ranges of large times and distances is illustrated for $q = 2$. For a certain class of pressure distributions, the gradual attainment of a steady state is shown to take place throughout the fluid. The average rate of transmission of energy by the pressure system is calculated in the steady state and it is shown that no energy is transmitted through the fluid in the steady state at certain frequencies. This phenomenon of zero energy radiation has also been noted by Sretenskii (1963), Morris (1974) and Stoker (1966).

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MOBILITIES, RELAXABILITIES AND NONLINEAR MODELS OF ATMOSPHERIC DYNAMICS

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This paper develops nonlinear models of atmospheric dynamics as an application of nonlinear field theory (see Mbaeyi 'Nonlinear Field Theory of Measurable Energy-Matter Aggregations' expected to appear in 1982).

The first step is to transform the four dimensional space-time of atmospheric dynamics into a three dimensional space-time. This transform has the following advantage: it facilitates the direct incorporation of land/sea - air masses' interactions into the consideration of atmospheric dynamics, or alternately of the (outer) space - air masses' interactions (e.g. high energy particle bombardments of the atmospheres). The last case will be defined by an inverse question. The next step is to introduce a hierarchy of density functionals representing a quantization of atmospheric variables and parameters, which leads eventually to systems of coupled nonlinear equations. Of particular interest in this second step are the aggregation patterns and the nonlinear boundary (layer) processes which define the associated gradient balances and their effects on atmospheric layerings. In addition, attention is paid to the distributed nonlinear terms (representing spatial inputs) which affect the atmospheres.

The concepts of mobilities and relaxabilities (arising out of the development of nonlinear field theory and defined as functions of 'measures of fluidity of aggregations') are briefly introduced, and used to derive the basic equations of atmospheric dynamics subject to internal gradient balances. These are then extended to other transient cases, including models for atmospheric turbulence etc. Brief (stability) analysis of each class of models is included.

ABSTRACT

LEAST SQUARE TRIANGLE METHOD FOR SURVEYING

By MIR M. ALI
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Suppose that the object of a survey is the determination of the co-ordinates (x, y) of a fixed point Q which is either inaccessible or unsuitable for placing instruments. If Q is observed from two points A and B, and the co-ordinates of A and B as well as the angles $\angle BAQ$ and $\angle ABQ$ are determined, then (x, y) can be easily determined. However, if Q is at a somewhat moderate distance from A and B, slight experimental errors in the measurement of the angles result in highly unreliable estimates of (x, y).

To overcome this difficulty, it is proposed that n pairs of points $(A_1, B_1), \ldots, (A_n, B_n)$, $n \geq 2$ be so chosen that A_iB_iQ for $i = 1, \ldots, n$ are collinear and the co-ordinates of the 2n points be determined. Let Δ_i^2 be the square of the area of the triangle A_iB_iQ. Ideally, Δ_i^2 should equal zero; however, the errors of measurements of the co-ordinates of A_i, B_i would result in A_iB_iQ to be a triangle. Δ_i^2 is easily seen to be a quadratic function of x and y. It is proposed that (x, y) should be determined by minimizing $\Delta_1^2 + \ldots + \Delta_n^2$ with respect to x and y.

STOCHASTICS DIFFERENTIAL GAMES AND THE APPLICATION FOR THE TRACKING AND CAPTURE GAME

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53, E l-Montaneastreet
Heliopolis, Cairo, Egypt

The Differential games were first studied in Isaacs' pioneering way in a series of Rand corporation memoranda that appeared in 1954, but the rules for his deterministic games for both players were when both of them know the present state of the game and how it proceeds.

Let $x=(x_1,x_2,x_3,\ldots,x_n)$ be a vector in the real Euclidean space (E^n), (t) denotes the time and $\Omega(c)$ be a fixed region in (t,x) space. The state of the game at (t) is given by x(t) and is determined by a system of differential equations which can be given in the vector form:

$dx/dt = f(t,x,u,v)$ and initial condition $x(t_o) = x_o$

$x \in G \subseteq E^n$, $u \in U \subseteq E^r$, and $v \in V \subseteq E^s$

At time (t) when player (J_1) chooses u(t) he does not know that (J_2) chooses v(t) and vice versa. The question what are the informations available for (J_1) and (J_2) and how do the informations flow?

To model the informations flow 'A. Friedmam', 'W. H. Flemming', 'R.J. Elliott', 'P. Varaiya' and 'E. Roxin' discussed approximating differential games by considering for any integer (n), a partition of the game's time.

The research for the game of tracking and capture was formulated when (P)-the pursuer-is searching for the evader(E) above or below his flight plane by a height(H) using a tracking system to capture (E)in (E's) plane. For all input data of (P) and (E) there are output answer which can be given by: - The probability of capture at each time of the game. - The probability of capture corresponding to the distance between (E) and the terminal surface of the game.

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2. EL-ARABATY, M., "Laser System and Their Optimal Control", Proceedings of the 26th Annual Meeting of the Society for General Systems Research with AAAS, pp. 1066-1071, Washington, D.C. Jan. 5-9, 1982.

Session TA-5: FINITE-ELEMENT AND FINITE-DIFFERENCE METHODS IN FLUIDS

Organizer: J. N. REDDY, Virginia Polytechnic Institute and State University
Chairperson: Th. HEINBERT, Virginia Polytechnic Institute and State University
Co-Chairperson: B. R. SHANKAR, Westinghouse Electric Corporation

* 2:00 - 2:30 R. K. AGARWAL, McDonnell Douglas Corporation, St.Louis:
"A Higher-Order-Accurate, Compact Differencing Scheme for Steady Navier-Stokes Equations in Orthogonal Curvilinear Coordinate Systems"

* 2:30 - 3:00 A. J. BAKER and M. O. SOLIMAN, University of Tennessee, Knoxville:
"On Accuracy and Efficiency Aspects of a Finite Element Algorithm for the Navier-Stokes Equations"

* 3:00 - 3:30 B. R. PERRELLI, Bell Laboratories, Murray Hill, NJ:
"Numerical Methods in Semiconductor Device Engineering"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 A. ABDELRAHIM and A. BERK, Purdue University at Indianapolis:
"Iterative Solution of Compressible Flows Using Finite Element Method"

* 4:30 - 5:00 K. N. GHIA and U. GHIA, University of Cincinnati:
"Review of Higher-Order Methods for Solution of Incompressible Viscous Flows"

* 5:00 - 5:30 B. S. MASSEY, Illinois Institute of Technology, Chicago:
"Numerical Methods for Steady Flows of Fluids with Memory"

A HIGHER-ORDER-ACCURATE, COMPACT DIFFERENCING SCHEME FOR STEADY NAVIER-STOKES EQUATIONS IN ORTHOGONAL CURVILINEAR COORDINATE SYSTEMS*

Ramesh K. Agarwal**
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ABSTRACT

A fourth-order-accurate, compact differencing scheme, based on the method of Allen and Southwell,[1] is proposed for the solution of three-dimensional steady Navier-Stokes equations in orthogonal curvilinear coordinate system (ξ,η,ζ). The scheme is compact in the sense that in *one* dimension, only three nodes are required to obtain the fourth-order accuracy, in contrast to the standard scheme which requires five nodes. The compact difference equations are derived by using the compact relations, first suggested by Kreiss, between the function f and its derivatives (f_ξ, f_η, f_ζ, $f_{\xi\xi}$, $f_{\eta\eta}$, $f_{\zeta\zeta}$). The solution of the compact difference equations is obtained by successive-over-relaxation. The scheme is applied to computing the laminar flow in a curved pipe and the flowfield of a rotating sphere at low Reynolds number. Higher accuracy is achieved on a coarser mesh than that required with second-order methods for achieving the same accuracy.

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*This work was supported by McDonnell Douglas Independent Research and Development program.

**Scientist, McDonnell Douglas Research Laboratories.

[1]Allen, D. N. DeG. and Southwell, R. V., "Relaxation Methods Applied to Determine the Motion in Two Dimensions of a Viscous Fluid Past a Fixed Cylinder," Quart. J. Mech. Appl. Math., Vol. 8, 1955, pp. 129-145.

ON ACCURACY AND EFFICIENCY ASPECTS OF A FINITE ELEMENT ALGORITHM FOR THE NAVIER-STOKES EQUATIONS

A. J. Baker, Professor
and
M. O. Soliman, Ass't Professor

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A multi-pole finite element algorithm for the Navier-Stokes equations for a viscous, compressible multi-dimensional flow is reviewed. Utilizing a generalized coordinates framework, and boundary-fitted coordinate transformations, a matrix tensor product decomposition of the Newton iteration algorithm is generated. Computational results for several mixed supersonic- subsonic flowfields are presented, assessing key aspects of accuracy, convergence and efficiency of the developed algorithm.

Numerical Methods in Semiconductor Device Engineering

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Murray Hill, New Jersey 07974

Computer aided design tools play an important role in the modern semiconductor device design and technology development, and will be even more important as the device dimensions are scaled down in VLSI (Very Large Scale Integration) technology. Numerical simulations of semiconductor devices in one and two spatial dimensions are routinely used in the advanced technology development. Attempts to develop computer programs in three spatial dimensions are under way as technology moves towards VLSI and submicron size devices.

Mathematical formulation of the problems pertinent to the fabrication and operation of the semiconductor devices along with the numerical methods used to solve the mathematical equations will be the subject of this paper. There are two broad interrelated areas of simulation in the semiconductor device engineering. The first, process simulation, calculates the impurity profiles that characterize the device. The second, device simulation, calculates the electrical operating characteristics of the devices and utilizes the impurity profiles generated by process simulation.

Process simulation involves the solution of a coupled set of nonlinear parabolic equations, possibly with moving boundaries. Device simulation requires the solution of nonlinear Poisson and current continuity equations. Numerical aspects related to the spatial discretization, time integration, linearization and solution of large linear systems will be briefly covered. Typical simulation results will be presented.

ITERATIVE SOLUTION OF COMPRESSIBLE FLOWS USING FINITE ELEMENT METHOD

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ABSTRACT

The study of three-dimensional compressible flows around a body with complex geometry needs a computational effort proportional to the the size of the employed computational grids. A detailed understanding of three-dimensional flows generally requires a large number of grid points, and computer systems of large capacity. The efficiency of the solution is closely related to the iterative scheme used in obtaining such solutions. The purpose of this study is to develop a fast solver which minimizes the storage requirements and the computation time. The solver is general in a sense that it can handle irregular grids. The method uses a Green function to distribute the residuals over an element, and the iterations are continued until the residuals vanish in all elements. Since the information needed for the iterations are only at the element level, this reduces the required storage considerably and avoids the decomposition of a global matrix.

Solutions are obtained for various values of the free stream Mach number. The numerical results obtained are being verified by comparing with the available data. Also, the history of the convergence of the numerical solution for both compressible and transonic flows is investigated.

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* Research Associate

** Professor

REVIEW OF HIGHER-ORDER METHODS FOR SOLUTION OF INCOMPRESSIBLE VISCOUS FLOWS

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ABSTRACT

For 2-D incompressible viscous flows, the discretization of the continuous flow problems has generally been achieved using conventional three-point finite difference schemes, leading to an algebraic system which is tri-diagonal. Careful implementation of these schemes in the numerical solution procedure can lead to uniform second-order accuracy for both temporal and spatial coordinates with uniform mesh. However, complex viscous flows of engineering interest often require the solution of problems with irregular boundaries, high Reynolds number, derivative boundary conditions, etc. Vigorous research for the last several years is attempting to address some of these difficulties and has provided an impetus to the development of higher-order numerical methods with the significant advantages of reducing the overall mesh size, i.e., storage, as well as the computing time, but still providing improved accuracy.

This paper will briefly summarize the existing intrinsic-higher-order numerical methods which may be conveniently divided into two groups. The first group consists of conventional techniques that lead to a matrix system which is pentadiagonal and, therefore, requires special consideration for implementing boundary conditions and developing efficient solution techniques. The second group of methods uses a collocation procedure and treats functional values as well as certain derivatives as unknowns, leading to a block-tridiagonal system of discretized equations. These methods can be derived by the use of Taylor Series (Hermite) or polynomial interpolation (spline). The paper will briefly review the second group of schemes for viscous-flow analysis. In particular, a new spline formulation, that also employs the integrated form of the governing differential equations, will be described. Application of these various schemes in the second group to the solution of viscous flows will be considered via model problems for external as well as internal flow configurations.

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NUMERICAL METHODS FOR STEADY FLOWS OF FLUIDS WITH MEMORY

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ABSTRACT

Finite Element methods for solving steady-flow problems involving fluids with single-integral constitutive equations have been developed [1,2]. Early work involved the simple (and not entirely satisfactory) "Maxwell model". This paper shows how the techniques proposed in refs. 1 and 2 can be employed to solve problems with stress-strain laws derived from chemical kinetic theories. Numerical results using the Doi-Edwards and Curtiss-Bird equations in a variety of flow geometries will be presented.

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2. M. Virayuthakorn and B. Caswell, J. Non-Newtonian Fluid Mechs., 7, pp. 245-267, 1980.

Session TA-6: BIOMECHANICS

Organizer: D. N. GHISTA, Chedoke-McMaster Hospital

Chairpersons: D. N. GHISTA, Chedoke-McMaster Hospital
P. D. STEIN, Henry Ford Hospital

* 2:00 - 2:30 H. N. VAYO, University of Toledo:
"Red Blood Cell Geometry"

* 2:30 - 3:00 P. D. STEIN, Henry Ford Hospital:
"Relation of Frequency and Amplitude of the Second Sound to Properties of the Aortic and Pulmonary Valves and Ventricular Hemodynamics"

* 3:00 - 3:30 J. MAZUMDAR, T. HEARN, and D. N. GHISTA, McMaster University:
"Vibration Analyses of Atrio-Ventricular Valve Leaflets Contributory to Cardiac Auscultation"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 S. N. REDDY and E. E. DANIEL, McMaster University:
"Electromechanical Coupling in the Gastrointestinal (GI) System"

* 4:30 - 5:00 L. T. COOK, A. A. DeSMET,
M.A. ASHER, M.A. TARLTON, and S.J. DWYER III,
University of Kansas Medical Center:
"A Computerized Spine Visualization System"

ABSTRACT

RED BLOOD CELL GEOMETRY

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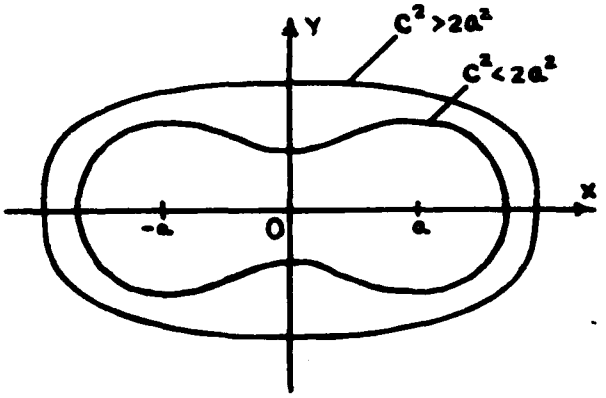
Expressions are presented for the volume, cross-sectional area, surface area, and circumference of the red blood cell based on a model geometry using the Oval of Cassini. Derivations are discussed and literature cited as these expressions are not readily accessible.



The case for the "sphering" cell is presented via examination of its volume relation. Various values of the geometric parameters are given for a range of normal red blood cell dimensions.

RELATION OF FREQUENCY AND AMPLITUDE OF THE SECOND SOUND TO PROPERTIES OF THE AORTIC AND PULMONARY VALVES AND VENTRICULAR HEMODYNAMICS

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The second heart sound is caused by vibration of the closed aortic and pulmonary valves. The intensity of the aortic and pulmonary components of the second sound depends upon (1) the distensibility of the respective valve, (2) characteristics of the valve materials that tend to dampen vibrations, (3) the mass of the valve, (4) hemodynamic factors that participate in causing the valve to distend and vibrate, (5) the viscosity of the blood and its ability to inhibit diastolic valve motion, (6) the size of the aorta and the ventricle, (7) the ability of the walls of the great vessels and ventricles to absorb or reflect sound energy, and (8) the transmissibility of sound to the chest wall. Numerous factors interact that modify these variables. Recognition of the interaction of these physical, physiological and anatomic factors contributes to a meaningful interpretation of auscultation of the intensity of the second heart sound.

The primary hemodynamic variable related to the driving force productive of valve vibration is the rate of change of the pressure gradient that develops across the closed valve. The pressure gradient across the valve at the moment of valve closure also may affect the amplitude of the second sound. Both depend largely upon ventricular negative dp/dt. Ventricular negative dp/dt is a measure of isovolumic relaxation. In a sense, therefore, the driving force for valve vibration depends on isovolumic relaxation.

Valve characteristics vary with age, size of the patient, and disease. Differences between size and distensibility of the aortic and pulmonary valves contribute to differences of the intensity of the aortic and pulmonary components of the second sound. In equations that describe valve vibration and sound due to valve vibration, it is important to emphasize that the equations describe effective mass. This includes the mass of the blood in the region of the valve. Failure to consider the effective mass misled some previous investigators into believing that the energy of vibration of the valve would be insufficient to produce audible sound.

The frequency of vibration of the aortic and pulmonary valves, and consequently the frequency of the second sound relates to the stiffness of the valve, the effective mass, and the damping force coefficient. Changes of stiffness to have greater effects than proportional changes of mass of the valve. The diameter of the aorta was shown to have no effect upon the frequency. Hemodynamic factors that affect the amplitude of the second sound also have no effect upon the frequency.

In conclusion, the intensity and frequency of the second sound can be interpreted on the basis of the various factors that affect valve vibration, keeping in mind that the transmission and absorption of sound in the body also play a role.

VIBRATION ANALYSES OF ATRIO-VENTRICULAR VALVE LEAFLETS CONTRIBUTORY TO CARDIAC AUSCULTATION

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Hear sounds result from vibrations of cardiac structures. However, improved interpretation and application of phonocardiograms requires understanding of the relative contributions to the heart sound content of the vibrating cardiac structures, in order that the characteristics of the relevant components of the heart sound be correlated to the properties of the vibration of cardiac structures.

The equation of motion of the valve membrane is of the type

$$\rho \iint_{\Omega} \frac{\partial^2 W}{\partial t^2}\, d\Omega + d \iint_{\Omega} \frac{\partial W}{\partial t}\, d\Omega - T \oint_{C_u} \frac{\partial W}{\partial n}\, ds = \iint_{\Omega} F\, d\Omega$$

wherein (i) the terms represent inertial, viscous damping, elastic and driving forces, (ii) F, arising from ventricular contraction, is $qh(\tau)$. The solution to this equation is found using the normal mode expansion in terms of the eigenfunctions of the associated free vibration problem.

Interpretations of the computed displacement and velocity responses provide explanations for phenomena, such as diminished sound production in a poor contracting ventricle and due to valve leaflet calcification, a louder first heart sound associated with higher membrane velocity response, and for the first heart sound being predominantly of left-sided origin. It will also be shown how the membrane property can be assessed from the response characteristics.

ELECTROMECHANICAL COUPLING IN THE GASTROINTESTINAL (GI) SYSTEM

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The normal GI motility involves mixing and propelling the ingested meal along the GI tract so as to facilitate the intestinal absorption of nutrients, electrolytes, water etc. This is achieved by various patterns of tonic and phasic or rhythmic contractions of the gut wall. Tonic contractions generate a steady local pressure on the gut lasting several minutes and appear to be unrelated to any electrical activity. However the phasic contractions are contemporaneous with spike bursts, the occurence of which is controlled in time and space by omnipresent rhythmic slow wave oscillations.

The slow wave of a smooth muscle cell is characterized by a resting membrane potential, a depolarizing phase, a plateau phase superimposed with or without spike bursts and repolarizing phase. The frequency of the slow waves in humans range from 3 c/m in the stomach to 12 c/m in the small intestine. Thus the maximum rate of phasic contractions is the same as the frequency of the slow waves. However, the one-to-one relationship between contractions and spike bursts is by no means universal in the GI system; the stomach may contract due to an increased plateau phase of the slow wave; the colon exhibits no definite relation between slow waves, spikes and contractions; and the sphincteric regions may spike continuously unrelated to the oscillatory activity.

The oscillatory slow waves of adjacent cells are coupled to each other with the distal one leading the proximal one so that the cells act in unison in generating mechanically effective contractions. The structural and functional basis for the electrical coupling appears to be the low resistance gap junctions among the smooth muscle cells. Even though the slow waves are myogenic in nature, these, and in turn the contractions, are also modulated by neural and humoral factors specific to a given stimulus, such as an ingested material.

In conclusion, the GI system per se is characterized by an electromechanical coupling. The rhythmic slow waves behave as a system of coupled relaxation oscillators. They are integrative in function in that they appear to propagate aborally and to control, in time and space, the occurence of spike bursts and, hence, contractions.

A COMPUTERIZED SPINE VISUALIZATION SYSTEM

L. T. Cook, A. A. DeSmet, M. A. Asher, M. A. Tarlton, S. J. Dwyer III
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We have originated a computerized radiographic method for observing and recording the three-dimensional coordinates of spinal landmarks. Posteroanterior and posterior oblique radiographs of the spine are obtained with the patient standing within a specially constructed framework which also holds the films. Points on each of the three films are digitized using a sonic digitizer tablet. Data entry is facilitated through the use of interactive color graphics data entry program which prompts the entry of each data item and records the data entered. This information is used to calculate the three-dimensional coordinates of spinal landmarks. The information is then displayed as a stylized spine using the color graphics system. Classical measures of scoliosis are calculated and displayed. A top view of the spine can also be selected and viewed with this system.

More than 100 patients have been examined using this system. Our aim is to examine patients over time for scoliosis progression and other changes. Eventually, we hope to identify factors which are expressed in the shape of a scoliotic curve and are indications of future progression.

We will discuss our results concerning spinal landmark location, and we will present some interesting clinical data.

Session TA-7: LAMINATED AND DISCONTINUOUS STRUCTURES

Organizer: C.E.S. UENG, Georgia Institute of Technology
Chairperson: A. MAEWAL, Yale University
Co-Chairperson: F.M. CUNNINGHAM, University of Missouri-Rolla

* 2:00 - 2:30 C. C. CHAMIS, NASA Lewis Research Center:
"A Theory to Predict Life/Durability in Fiber Composite Angleplied Laminates"

* 2:30 - 3:00 S. K. CHATURVEDI and C. T. SUN, University of Florida-Gainesville, and R. F. GIBSON, University of Idaho-Moscow:
"Storage and Loss Moduli in Aligned Discontinuous Polymer Composites"

* 3:00 - 3:30 T.P. YU and S.S. WANG, University of Illinois-Urbana:
"Energy Release Rates for Interlaminar Fracture in Composite Laminates"

3:30 - 4:00 COFFEE BREAK

* 4:00 - 4:30 J.T-S. WANG, Georgia Institute of Technology; S.B. HUGHES and L. W. LIU, Lockheed-Georgia Company:
"Skin/Stiffner Interface Stresses in Composite Stiffened Panels"

4:30 - 4:45 J. T. PINDERA and B. R. KRASNOWSKI, University of Waterloo, and M.-J. PINDERA, Material Science Corporation:
"Interface Stresses in Composite Structures: Analytical and Experimental Approaches"

4:45 - 5:00 J. W. LAMBERT, Consulting Engineer, CA:
"Intralaminar Stresses in Filament Reinforced Composites"

5:00 - 5:15 H. A. ABBOUR, University of Manitoba, Canada:
"Postbuckling Behavior and Secondary Buckling of Composite Plates Under Biaxial Loading"

A THEORY TO PREDICT LIFE/DURABILITY IN FIBER COMPOSITE ANGLEPLIED LAMINATES

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Cleveland, Ohio

ABSTRACT

The design driver for strength-controlled fiber composite structures is life/durability in general. The life/durability of fiber composite angleplied laminates is presently determined experimentally. Though the experimental approach is direct, it is not generic since measured data from one angleplied laminate is not transferable to any other. In addition, the experimental approach becomes time consuming and costly. It frequently ties up manpower and equipment for extended periods of time. Both of these are compounded when the life/durability of composite angleplied laminates is to be determined in hygrothermal (hot-wet) environmental conditions.

On the other hand, a theory to predict the life/durability of angleplied laminates, based on measured life/durability of unidirectional composites (plies) is general and applicable to any angleplied laminates from the same composite system. The theoretical approach has the additional advantage that it can be based on constituent materials using composite micromechanics. The objective of this paper is to describe a theory for predicting the life/durability of fiber composite angleplied laminates subjected to hygrothermomechanical loadings (cyclic loads in hot-wet environments).

The theory is based on recent developments at the Lewis Research Center for predicting the life/durability of unidirectional composites using static, room-temperature, dry data. The non-dimensional generic equation for predicting the life/desirability of unidirectional composites is simply given by the following equation:

$$\frac{S}{S_0} = \left[\frac{T_{gw} - T}{T_{gd} - T_0}\right]^{1/2} - B \log N \qquad (1)$$

where S is the desired life/durability; S_0 is the reference static stress determined at room temperature (T_0) dry conditions; T_{gw} is the glass transition temperature of the composite at the anticipated wet condition; T_{gd} is the glass transition temperature of the dry composite; T is the anticipated use temperature; B is the cyclic load degradation coefficient and N is the anticipated number of cycles. The degradiation coefficient has the following values for graphite-fiber/epoxy-matrix composites: 0.02 for longitudinal tension cyclic loading, 0.07 for longitudinal compression and 0.10 for transverse compression and intralimanar shear.

Equation (1) is used in a combined-stress failure criterion to predict the life/durability of unidirectional composites subjected to combined hygrothermomechanical loadings. The combined-stress strength-criterion is then used in conjunction with laminate theory and ply stress influence coefficients to predict the life/durability of angleplied laminates. Subsequently, the theory is extended, using Findly's Theory, to include possible viscoelastic behavior and its effect on life/durability. A.so, reference is made on how to base the theory at the constituents materials level using appropriate composite micromechanics.

STORAGE AND LOSS MODULI IN ALIGNED DISCONTINUOUS POLYMER COMPOSITES

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ABSTRACT:

It is fairly known that fiber reinforced polymer composites exhibit significantly greater internal damping [1,2] than the conventional structural metals. However, the potential for significant improvement and optimization of damping in these modern materials has not been fully realized. This paper describes recent analytical and experimental efforts to determine the effects of fiber aspect ratio, fiber spacing, and the viscoelastic properties of constituent materials on damping and stiffness of aligned discontinuous fiber reinforced polymer matrix composites. Two different analytical models show that there is an optimum fiber aspect ratio for maximum damping that changes with change in the ratio of fiber extensional loss factor to matrix shear loss factor. If this ratio is less than 1/3, the predicted optimum fiber aspect ratios lie in the range of actual aspect ratios for whiskers and microfibers, otherwise a continuous reinforcement will exhibit maximum damping. Experimental data for E-glass/epoxy and graphite/epoxy specimens are presented for comparison with predictions.

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ENERGY RELEASE RATES FOR INTERLAMINAR FRACTURE IN COMPOSITE LAMINATES

by

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Abstract

Interlaminar fracture, also called delamination, is one of the most unique and frequently encountered failure modes in advanced composites. It generally results from the inherently weak interlaminar strength along a ply interface, high stress concentrations at geometric boundaries, and imperfect bonding between dissimilar composite laminae. Recent studies on the interlaminar crack behavior have led to proposed fracture mechanics tests for evaluation of interlaminar fracture toughness of fiber-reinforced composites. The presence and growth of delamination may cause significant failure problems such as stiffness reduction and structural disintegration. Fracture characterization, reliable design, and analyses of advanced composites require better understanding of the fundamental nature of delamination and the establishment of suitable failure criteria for prediction of initiation and growth of interlaminar cracks.

The nature of delamination is well recognized to be very complex. It is basically a fracture problem involving crack or debond between two highly anisotropic, fiber-composite laminae under a complex state of stress. In this paper, a study is conducted on the evaluation of energy release rates of interlaminar fracture behavior in fiber-reinforced composite laminates. Based on different interlaminar fracture mechanics models recently developed, formulations and solution schemes of the problem are presented. Fracture mechanics parameters such as G_I, G_{II}, G_{III} and K_I, K_{II}, K_{III}, are determined. Effects of material nonlinearity, geometric and lamination variables on interlaminar fracture mechanics are reported. In the nonlinear part, the order of stress singularity near the crack tip is obtained by using an asymptotic expansion method. Nonlinear interlaminar stress intensity factors and associated strain energy release rates are evaluated and compared with those in a linear case. Numerical solutions by using a finite element method are also obtained for independent check. Important implications on the physical behavior and mathematical models of the composite fracture problem are discussed.

SKIN/STIFFENER INTERFACE STRESSES IN COMPOSITE STIFFENED PANELS

by

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Separation of stiffeners from the skin (web) is one of the major failure modes to be considered in the design of composite stiffened panels. This tendency to separate may result from surface loads on the skin or from stresses developed in post buckled skins. The purpose of this study is to propose an analytical model and a solution method which allow direct computation of stresses at the skin/stiffener interface as well as related deformation and stresses in the skin and stiffener plates.

The physical model consists of a stiffener flange and the portion of the skin directly attached to the stiffener. The two components are treated as separate orthotropic plates connected by an elastic isotropic layer. Stresses in the interface layer are treated as surface loadings on the plates. The skin plate is subjected to edge loading along the free edge of the stiffener plate, and the general analysis accounts for the effect of inplane preloading.

For experimental verification of the model, an exact solution for a one dimensional model with identical skin and stiffener plates has been obtained, and some results will be presented. Limited experimental results agree well with the analytical solutions. Analytical results indicate that the peak stresses and the boundary layer zones containing peak normal interface stress near the loading locations are not sensitive to the width of the model.

For the general two dimensional model, a weighted residual procedure is used in the analysis. Inplane and transverse displacements for each plate coupled through the interacting interface stresses represented by appropriate sets of orthogonal functions are first solved in terms of unknown coefficients for the stresses. These unknown coefficients, subsequently determined by requiring continuity in displacements of the two plates through the interface layer, allow direct computation of interface stresses. As the sets of coordinate functions used in both directions are complete, well behaved solutions are anticipated. Furthermore, the integration procedure for the weighted residuals with coordinate functions used as the weighting functions can be systematically performed, and the general expressions of the elements of the coefficient matrix of the resulting system of algebraic equations can be explicitly established. These desirable features allow the analysis to be easily and systematically automated.

INTERFACE STRESSES IN COMPOSITE STRUCTURES: ANALYTICAL AND EXPERIMENTAL APPROACHES

by

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Interlaminar stresses in laminated structures constructed of so-called advanced composite materials, which arise because of mismatch in material properties of differently oriented laminae, can be responsible for early delamination failures. Various authors have shown that under certain loading conditions these stresses are restricted to a small region in the vicinity of the free edge. This boundary layer region is characterized by high values of the out-of-plane stress components that in some cases suggest singular behaviour along laminae interface at the free edge.

So far, no satisfactory experimental methods have been developed to determine the interface stress states because of inherent experimental difficulties. - A comprehensive review of experimental investigations of composite materials has been presented by I.M. Daniel.

The method of isodynes recently developed by J.T. Pindera and co-workers allows to determine all the stress components acting on a given cross-section directly without recourse to any auxiliary elastic relations. This methodology therefore appears particularly well suited for determination of boundary layer characteristics in optically transparent layers of a laminated structure which are observable from a point outside the configuration.

The difference in values of Poisson ratios of laminated plies or layers is recognized major parameter influencing the interface stresses and particularly the peel stresses. Accordingly, the dependence of the interface stress components on the mismatch of Poisson ratios in the range from 0.02 to 0.36 (0.38) is analyzed.

Sample of References

[1] N. J. Salamon, "An Assessment of the Interlaminar Stress Problem in Laminated Composites", J. Composite Materials Supplement, 14(1980), 177-194.

[2] I. M. Daniel, "Photoelastic Investigation of Composites", In: Mechanics of Composite Materials, edited by G. P. Sendeckyj, Academic Press, New York, 1974.

[3] J. T. Pindera, "Analytical Foundations of the Isodyne Photoelasticity", Mechanics Research Communications, 8(1981), 391-397.

INTRALAMINAR STRESSES IN FILAMENT REINFORCED COMPOSITES

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ABSTRACT

A solution is found for the stresses between two equal thickness, finite, rectangular laminae whose filaments are oriented at plus and minus the same angle β to the x axis and the pair is subjected to a uniform normal stress in the x direction.

The solution satisfies 3 dimensional equilibrium equations and exact boundary conditions on all 6 faces of both laminae. Anisotropic stress strain relations appropriate to two transversally isotropic media rotated plus and minus β to each other are also satisfied.

There are no unbounded stresses on the edges, although high stress gradients occur over short distances on the order of the lamina thickness. Formulae are given for all maximum values of interlaminar stress as well as their locations.

POSTBUCKLING BEHAVIOR AND SECONDARY BUCKLING OF COMPOSITE PLATES UNDER BIAXIAL LOADING

by

HAMDY A. ASHOUR *

ABSTRACT

This work presents an analysis for the post-primary-buckling and secondary buckling problems of generally orthotropic laminated rectangular plates under biaxial compression with simple support boundary conditions. Based on the analysis, two computer programs called CBMCP (Classical Buckling Modes for Composite Plates) and SBCP (Secondary Buckling of Composite Plates) have been developed. HP-45 desk-top computers have been used to run CBMCP and SBCP, and to automatically produce required curves. Numerical results are presented for isotropic as well as composite laminated plates. For square isotropic plates under axial compression, the results of the present analysis compare favorably with previous solutions. The present results suggest that each of the aspect ratio, biaxial compressive load ratio, laminae material, and laminae orientation angles, has an apparent effect on the primary buckling, post-primary-buckling, and secondary buckling behaviors of simply supported rectangular plates. Such factors have to be taken into consideration whenever an optimum design for such plates is sought. Based on the present results, a simple design criterion has been proposed for simply supported isotropic or composite laminated rectangular plates under biaxial compression, when they are used in the post-primary-buckling range.

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Session TA-8: EXPERIMENTAL VERIFICATION OF SYSTEMS PARAMETERS

Organizer and Chairperson: M. E. FOURNEY, University of California, Los Angeles
Co-Chairperson: C. R. HASS, University of Missouri-Rolla

* 2:30 - 3:00 R. COPPOLINO and S. RUBIN, The Aerospace Corporation:
"Detectability of Structural Failures in Offshore Platforms by Vibration Monitoring"

* 3:00 - 3:30 M. W. DOBBS, Forensic Science Associates and P. IBÁÑEZ, ANCO Engineers, Inc.:
"Monitoring of Dam Integrity by Testing and Analysis"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 R. M. KOERNER, Drexel University and J. D. LEAIRD, Acoustic Emission Tech. Corporation:
"Acoustic Emission Monitoring of Subsurface Phenomena Involving Seepage, Grouting and Hydrofracturing"

4:30 - 4:45 C.E.H. SHG and W.P.T. NORTH, University of Windsor:
"A Digital Optical Transducer to Measure Displacement, Strain and for Inspection Purposes"

DETECTABILITY OF STRUCTURAL FAILURES IN OFFSHORE PLATFORMS BY VIBRATION MONITORING

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Historically, underwater visual examination by divers has been employed to monitor the structural integrity of fixed offshore platforms. Alternative approaches for inspection are being sought to lessen the cost and hazard of diver operations, especially in deep and hostile waters. During the past five years, government sponsored efforts have been conducted by the Aerospace Corporation on vibration monitoring as a potential inspection method. Analytical and experimental feasibility studies have led to a novel scheme, flexibility monitoring, which has the ability of locating individual structural member failures. Field tests are currently in progress to demonstrate and refine the flexibility monitoring technique.

MONITORING OF DAM INTEGRITY BY TESTING AND ANALYSIS

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Dam integrity and dam safety have always been a major concern of regulatory agencies and research agencies. However, a number of failures and near failures of major dams have prompted intensified measures for dam inspection and safety assessment. In response to these intensified needs, the National Science Foundation awarded two grants to ANCO Engineers, Inc. (ANCO) to dynamically test and acoustically analyze concrete dams. The purpose of this program was to complement traditional techniques for inspection and damage assessment.

The basic premise of this program was to monitor the dynamic and acoustic emission properties of the arch during periodic forced vibration tests and to relate changes in these properties to changes in the integrity of the arch and the foundation and abutment regions. Changes in the dynamic properties (decreases in resonant frequencies) would be a strong indicator of global damage (reduction in stiffness), while changes in the acoustic properties (increases in acoustic emissions) would be a strong indicator of local damage (regions of cracks and zones of high stress).

To investigate the application of the method, ANCO conducted research in forced vibration testing of concrete dams, in acoustic emission analyses of concrete, in finite element dynamic analysis, and in Bayesian estimation for parameter identification and damage assessment. The forced vibration tests were done using single-unit and dual-unit eccentric mass sinusoidal shakers. Force levels up to 0.556 MN (125,000 lbf) were used, and crest response levels of 0.01 g were attained. In all the tests the resonant frequencies were identified, the response shapes were mapped, the critical damping ratios were estimated, and the acoustic emissions were monitored. Three concrete dams in California were tested.

The results of the forced vibration tests, the dynamic analyses, and the Bayesian estimation anayses for parameter identification are discussed in the present paper. The major conclusions include (1) forced vibration tests and parameter identification are necessary for finite element model verification and accurate safety analyses, and (2) the proposed method has application to damage assessment after extreme loadings.

ACOUSTIC EMISSION MONITORING OF SUBSURFACE PHENOMENA INVOLVING SEEPAGE, GROUTING AND HYDROFRACTURING

by

Robert M. Koerner[1] and James D. Lenird[2]

Abstract

The acoustic emission method is a nondestructive testing technique whereby stress waves which are generated by material instabilities are sensed, recorded and analyzed in various ways. The emissions are generally sensed by a piezoelectric transducer which results in a wave form that can be treated by standard techniques. Furthermore, by using a multiple channel pickup system it is possible to source locate the cause of the instability within the structure itself. It is this aspect of source location which is the focus of this paper.

The material system of concern is soil which has an infamous history of failing when seepage occurs above certain levels. When this occurs, the usual remedy is by injection grouting of low viscosity chemical grouts. The danger, however, is that high grouting pressures can cause tensile splitting of the soil mass (called "hydrofracturing"), oftentimes causing more damage than good.

Each of these mechanisms (seepage, grouting and hydrofracturing) create nonequilibrium within the soil mass and results in acoustic emissions. The goal of the project is to locate in three-dimensional real time the locus of these events. Using this information, the seepage can be controlled, the grout direction monitored and the hydrofracturing located and/or avoided.

To date, both large scale laboratory monitoring of seepage and grouting and field monitoring of grouting have been performed. The multi-channel acoustic emission system is functioning and currently results in delay times between individual arrivals at the various sensors. Software programs are currently being developed to define the source location in three-dimensional space. The system will eventually be fitted with a CRT screen so that a real time graphic output will result.

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A DIGITAL OPTICAL TRANSDUCER TO MEASURE DISPLACEMENT, STRAIN AND FOR INSPECTION PURPOSES

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An optical detector utilizing integrated circuit technology to combine a planar light sensor with amplification and triggering, provides a device whose output frequency is a function of incident light. The detector in itself is an analog to digital converter which incorporates an integrated circuit for frequency conversion. The variable frequency output of the detector makes it ideal for numerous applications in the areas of stress analysis, aerospace and automotive industries, robotics and automation. Employing optical techniques, accurate measurement of displacement, strain and inspection for quality control was conceived.

When using the principle of quasi-diffraction and a He-Ne laser as the light source to measure small strains, resolution of 25 microstrain was achieved for a gage length of 40mm. The "optical digital strain gage" is shown to have high sensitivity, linearity and accuracy. It is unaffected by humidity, temperature, transverse strain, time effects and other variables affecting the output of electrical resistance gages. Furthermore it is simple to use, usable in hostile conditions, inexpensive and is a form of non-contact measurement in the sense that there need be no physical connection between specimen and readout. Also, digital readout provides easy interpretation of results.

A further application was tested using the detector for qualifying bolts for proper length, diameter and the presence of the correct thread.

Session FM-1: PERSPECTIVES IN THE THEORIES OF ORIENTED MEDIA

Organizer: C. DAVINI, Universita di Pisa, Italy
Chairperson: C. CAPRIZ, CNUCE/CNR, Pisa, Italy
Co-Chairperson: R. S. R. GORLA, Cleveland State University

* 9:30 - 10:00 S. C. COWIN, Tulane University:
"Some Remarks on the Development of Theories of Oriented Materials 1960-80"

* 10:00 - 10:30 P. PODIO-GUIDUGLI, Universita di Pisa, Italy:
"Structured Continua from a Lagrangian Point of View"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 C. DAVINI, Universita di Udine, Universita di Pisa, Italy:
"An Approach to the Kinetmatics of Defect in Crystalline Solids"

* 11:30 - 12:00 G. P. PARRY, The University of Bath, England:
"Phase Changes of the First Kind in Thermoelasticity"

12:00 - 12:15 M.N.L. NARASIMHAN, L. B. ILCEWICZ and J. B. WILSON, Oregon State University:
"Theory of Bilevel Anisotropic Elastic Solids with Nonlocal Polar Constitution"

12:15 - 12:30 S. DOST, The University of Calgary:
"Propagation of Acceleration Waves in Elastic Dielectrics"

12:30 - 12:45 L. B. ILCEWICZ, M.N.L. NARASIMHAN and J. B. WILSON, Oregon State University:
"Macro and Micro Material Symmetries in Generalised Continua"

SOME REMARKS ON THE DEVELOPMENT OF THEORIES OF ORIENTED MATERIALS 1960-1980

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A great deal of work has been published on the continuum theories of oriented materials in the twenty year period from 1960 to 1980. A wide but selective assessment of these contributions is undertaken here. Following a short historical introduction, and a presentation of the basic ideas and equations, certain aspects of the general theory are discussed. In particular the nature of the equation described as the "conservation of microinertia" is critiqued. Guidelines for the formulation of boundary conditions are discussed. The applicability of these theories to the flow of liquid crystals, blood, suspensions and to turbulent flows, stress concentrations in metals and bone, composite solid materials, granular materials and to solid materials with small distributed voids are discussed. An effort is made to extract from these two decades of literature some suggestions for good practice in the formulation of oriented continuum models for real materials.

(1) Goodman, M.A. and S.C. Cowin, A Continuum Theory for Granular Materials, Arch. Rational Mech. Anal., 44, 249-266, 1972.
(2) Cowin, S.C., The Theory of Polar Fluids, Advances in Applied Mechanics, (C.S. Yih, ed.) 17, 274-347, 1974.
(3) Atkin, R.J., S.C. Cowin and N. Fox, On Boundary Conditions for Polar Materials, Z. Angew Math. Phys., 28, 1017-1026, 1977.
(4) Cowin, S.C. and F.H. Laselle, On Kinetic Energy and Momenta in Cosserat Continua, Z. Angew. Math. Phys., 31, 247-260, 1980.
(5) Nunziato, J.W. and S.C. Cowin, A Non-Linear Theory of Elastic Materials with Voids, Arch. Rational Mech. Anal., 72, 175-201, 1979.

STRUCTURED CONTINUA FROM A LAGRANGIAN POINT OF VIEW

P. Podio-Guidugli
University of Pisa, Italy

As is known, the standard Lagrangian formalism for finite-dimensional dynamical systems can be adapted to give theories of structured continua a format which includes macro and micro strain and stress variables, and leads effortlessly to lay down an appropriate set of balance laws.

We give a succinct account of this approach, along lines detailed in [1] and [2], focusing on a feature which is absent in classical Lagrangian dynamics, namely, that the possible distributions of internal forces are restricted by a condition of vanishing power for every admissible rigid virtual velocity field.

The theory has sufficient generality to encourage as special cases all the theories proposed so far to cover an amazingly wide range of applications. Applications of the theory to liquid crystals and to elastic rods will be described in some detail.

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[1] G. Capriz and P. Podio-Guidugli, Materials with Finite-Dimensional Structure in Mechanics of Structured Media, Part A, pp. 255-268, A.P.S. Selvadurai Ed., Elsevier, 1981.

[2] G. Capriz and P. Podio-Guidugli, Structured Continua from a Lagrangian Point of View, forthcoming.

AN APPROACH TO THE KINEMATICS OF DEFECT IN CRYSTALLINE SOLIDS

Ceasare Davini
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We use the usual body of the director theories of continua to describe a crystalline body, but interpret the directors as delivering the average values, on the microscope scale, of the lattice vectors which define the material cell on the atomic scale. When the crystalline texture is not perfect, it is assumed that the lattice distortions induced by defects such as vacancies, intersticials or dislocations are adequately described by the local values of the directors and their curls.

Under the assumption that the defects do not change whenever the cells behave materially (elastic deformations), and only in this case, we study the line, surface and volume-integrals, involving the directors and their curls, that are invariant under such deformations. This provides a list of defect measures that characterize the elastic range of any given configuration of the body, and also a basis for their classification.

The paper elaborates on this and discusses some examples.

PHASE CHANGES OF THE FIRST KIND IN THERMOELASTICITY

G. P. Parry
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Abrupt changes in the geometry of crystals may be categorized according to the type of geometric parameter which is discontinuous. In nonlinear thermoelasticity, jumps in the macroscopic strain arise through the supposed noninvertibility of the free energy. In internal variable theories, a similar assumption gives jumps in the internal variable, and also interesting properties in the thermo-elasticity theory which derives from it. These changes are analysed and compared with a view to finding some macro-scopic feature which distinguishes the two types of transition.

THEORY OF BILEVEL ANISOTROPIC ELASTIC SOLIDS WITH NONLOCAL POLAR CONSTITUTION

by

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L.B. Ilcewicz
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J.B. Wilson
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Abstract

In analytical treatment of problems involving material behavior from a generalized continuum mechanical standpoint one is often faced with the problem of incorporating different forms of anisotropy at different levels of micro and macroscopic aggregates within the same material. In this paper, a continuum theory of anisotropic elastic solids incorporating nonlocal effects of its microstructures is so developed as to permit analytically the treatment of diverse anisotropic properties at micro and macroscopic levels. In order to illustrate the mathematical development in practical applications the theory is applied to the case of materials which possess orthotropy on the microscopic level and transverse isotropy on the macroscopic level as such situations are of special relevance, for instance, to wood and wood based products. The resulting field equations are solved for the propagation of plane waves in a bilevel anisotropic nonlocal micropolar elastic solid.

PROPAGATION OF ACCELERATION WAVES IN ELASTIC DIELECTRICS

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ABSTRACT

In the paper the propagation of acceleration waves of arbitrary form propagating into a deformed elastic dielectric with polarization effect is investigated. An acceleration wave is defined as a second order propagating surface of discontinuity on which the position vector, the polarization vector and Maxwell potential, and their first order derivatives with respect to time and space coordinates are continuous while the second derivatives of these quantities may suffer jumps but are continuous everywhere else. By computing the jumps of the balance equations on the singular surface, implicit equations for wave speeds corresponding to non-zero amplitudes of acceleration wave are obtained. It is noteworthy that the jumps of the second order derivatives of Maxwell potential are also continuous across the acceleration wave.

The same equations for wave speeds are also derived for isotropic elastic dielectrics. The wave speeds for longitudinal and transverse waves are obtained in explicit forms and the conditions of existence of real wave speeds are investigated.

The growth and decay of acceleration waves are also examined herein. Calculation of the jumps of the time derivatives of the balance equations leads to a general growth equation. The explicit expression of the growth equation is given in the case of isotropic materials. The growth equation for longitudinal and transverse waves is integrated by taking advantage of the fact that the wave speeds are constant. The decay conditions are examined for both cases, and the shock formation is presented. Furthermore, the results are applied to the plane, cylindrical and spherical waves.

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* Associate Professor

MACRO AND MICRO MATERIAL SYMMETRIES IN GENERALIZED CONTINUA

by

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Abstract

Nonlocal polar theory (NLP) utilizes a generalized continuum from which nonlocal (NL), micropolar (MP) and classical continuum theories can be derived as special cases. The NLP theory allows the study of material behavior arising from different levels of micro and macro-domains of the same body. In this paper, the balance laws and constitutive equations for NLP materials are developed for purposes of direct applications in the fields of solid mechanics. The resulting constitutive laws are expressed in Eulerian form and compared with those of NL, MP and classical theories. Independent nonvanishing constitutive moduli are obtained for a variety of classes of macro and micro material symmetries, including triclinic, monoclinic, rhombic (orthotropic), tetragonal, cubic, hexagonal and transverse isotropic. A suitable attenuation function is employed for purposes of incorporating the nonlocal interactions of neighboring material points at any material point of a body. The concept of such an attenuation function as it applies to solid mechanics is developed and illustrated by specific examples and forms that are useful in modeling materials with many different levels of internal sub-structures.

Session PM-2: MATHEMATICAL CHARACTERIZATION OF SOILS

Organizer and Chairperson: S. L. KOH, West Virginia University
Co-Chairperson: L. THIGPEN, Lawrence Livermore National Lab

* 9:30 - 10:00 K. C. VALANIS, University of Cincinnati:
"An Endochronic Geomechanical Model for Soils"

* 10:00 - 10:30 G. Y. BALADI, U.S. Army Engineer Waterways Experiment Station, Mississippi:
"Mathematical Characterization of Soil Using the Cap Model"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 W. F. CHEN, Purdue University and S. L. KOH, West Virginia University:
"Constitutive Modeling of Soils and Earthquake-Induced Landslides"

* 11:30 - 12:00 S. STURE, University of Colorado:
"Modelling of Stress-Induced Anisotropy in Soils"

12:00 - 12:15 L. ROTHENBURG, Golder Associates, Mississauga, Canada:
"Strength Components of Granular Assemblies"

12:15 - 12:30 G. AHMADI and M. SHAHINPOOR, Clarkson College of Technology:
"New Evolutionary Equations for Fluctuations in Rapid Granular Flows"

12:30 - 12:45 K.-F. V. WONG, D. DASGUPTA, S. SENGUPTA and N. HERRON, University of Miami:
"Mathematical Characterization of the Chemical Behavior of a South Floridian Soil"

AN ENDOCHRONIC GEOMECHANICAL MODEL FOR SOILS

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Soils exhibit a hydrostatic response, which is uniquely different from that of metals, in that they may dilate or densify under constant confining pressure and (cyclic) shearing motion depending on the prevailing stress and porosity conditions. A three dimensional unified theory that can predict this phenomenon quantitatively, is proposed and discussed. The theory is of the endochronic type, previously advanced by the author, where the measure of intrinsic time is a positive definite norm of the increment of the plastic strain tensor.

Specifically, it is shown that the analytical prediction of the stress and hydrostatic strain responses of Sacramento River sand in a triaxial test, is very close to the experimental data of Lee and Seed. More importantly the physical foundations of softening and the transition from dilatency to densification are laid bare and discussed in the context of the analytical setting.

MATHEMATICAL CHARACTERIZATION OF SOIL USING THE CAP MODEL

By George Y. Baladi,[1] Member, ASCE

The cap model is a mathematical description of the behavior of geological materials which is based on the classical theory of plasticity. The yield surface for this model consists of a failure envelope, which is usually fixed in stress space (ideally plastic) and a moveable cap whose position is a functional of the volumetric strain history of the material. The model uses an associated flow rule to satisfy theoretical continuity and uniqueness requirements. It controls dilatancy while it allows hysteresis and apparent Bauschinger effects, in a load-unload cycle. With a hardening failure envelope the model can represent cyclic hysteresis. Also, material anisotropy, rate-dependency, and the effects of pore fluid can all be included in the model.

The model is the natural development of earlier work, starting from the Drucker-Prager elastic-plastic models. The idea of adding a moveable cap is due to Drucker, Gibson, and Henkel and Jenike and Shield. Finally, Roscoe and his co-workers at Cambridge University formulated a cohesionless model which involves a strain-hardening yield function of volumetric compressive strain, but has doubtful uniqueness and continuity properties.

The cap model has been used to simulate the behavior of a wide range of geological and man-made materials such as soil, rock, concrete, etc. This paper describes the development and the numerical implementation of a three-dimensional elastic-viscoplastic work-hardening cap model for earth materials. The constitutive relationship is capable of reproducing the hysteretic behavior of the material under both hydrostatic and deviatoric states of stress; it also accounts for shear-induced volume change and the effect of superimposed hydrostatic stress on shearing response. The capability of the constitutive relationship for simulating the observed time-dependent response of earth materials is examined; an example fit for a dry sand is given based on static and dynamic laboratory triaxial shear and uniaxial strain test results.

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CONSTITUTIVE MODELING OF SOILS AND EARTHQUAKE-INDUCED LANDSLIDES

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ABSTRACT

The first part of the paper attempts to evaluate critically the existing soil constitutive relations and failure criteria based on the theories of elasticity and plasticity. Three basic criteria have been used for model evaluation:

(1) Theoretical evaluation of the models with respect to the basic principles of continuum mechanics to ascertain the consistency with the theoretical requirements of continuity, stability and uniqueness.

(2) Experimental evaluation of the models with respect to their suitability to fit experimental data from a variety of available tests, and the ease of the determination of the material parameters from standard test data.

(3) Numerical and computational evaluation of the models with respect to the facility with which they can be implemented in computer calculations. Particular emphasis here is placed on the implementation in nonlinear incremental finite element computer codes for obtaining solutions of landslide problems under general stress condition including monotonic as well as cyclic loadings.

The second part of the paper summarizes the applications of various constitutive models to earthquake-induced landslides. More specifically, the following thesis' work related to the NSF-Sponsored Research (PFR-7809326 to Purdue University) will be briefly reported:

1. "Perfect Plasticity Upper Bound Limit Analysis of the Stability of a Seismic-Infirmed Earthslope," by S.W. Chan, M.S. Thesis, School of Mechanical Engineering, August, 1980.

2. "Constitutive Models for Soils in Landslides," by A.F. Saleeb, Ph.D. Thesis, School of Civil Engineering, May, 1981.

3. "Plasticity Modeling of Soils and Finite Element Applications," by E. Mizuno, Ph.D. Thesis, School of Civil Engineering, December, 1981.

4. "Seismic Safety Analysis of Slopes," by C.J. Chang, Ph.D. Thesis, School of Civil Engineering, August, 1981.

"Modelling of Stress-Induced Anisotropy in Soils"

Stein Sture

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The presentation addresses experimental and analytical issues related to stress-induced anisotropy and rotating principal stress directions in a soil mass subjected to nonproportional, reversed, and cyclic loading. The influence of these factors on earth masses and structural response behavior is discussed.

Stress-induced stiffness anisotropy in soils is only revealed when the principal stress directions change with respect to the material fabric or structure. Conventional and most current experimental devices are unable to carry out such loading and allow measurements of response without resorting to simplified techniques that may disturb the stress-induced changes. However, recent advances in experimental techniques make it possible to improve our understanding of mechanical behavior of soils that are subjected to such complex forms of loading. It has been demonstrated that when soils are loaded by uniform and controlled stress states, which in turn are subjected to controlled rotations, as for example performed in directional shear cells, multiaxial cubical apparatuses that allow jump rotations, and hollow cylinder triaxial torsion apparatuses, significant changes in stiffness moduli occur. The principal moduli are often reduced many orders of magnitude during such loading. For these reasons stress-induced anisotropy and rotations of the principal stress directions have become important concerns in geotechnical constitutive modeling and analysis. Modern stress-strain-strength models based on isotropic elastic-plastic hardening merged with kinematic plastic concepts are in principle capable of simulating these behavioral features. Experimentally obtained information about stress-induced anisotropy is ideally suited for calibrating anisotropic constitutive models, and it can also be used to test or validate the performance of these models for load histories that are different from those used during model calibration. Although anisotropic models are expected to simulate response behavior under arbitrary loading events more realistically than isotropic models, neither model category requires explicit input information that characterizes the alterations taking place, when the principal stress directions rotate. The kinematic rule which reflects changes in the soil fabric due to induced anisotropy are utilized for simulating modifications in moduli. It is shown that conventional formulations may be insufficient means for achieving the significant changes observed in the laboratory.

The theory and implementation of an anisotropic elasto-plastic constitutive model of the Mroz-Iwan-Prevost type is discussed. Experimental test results for dry Leighton Buzzard sand in compression and extension are compared to analytical simulations.

STRENGTH COMPONENTS OF GRANULAR ASSEMBLIES

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Much work on physical strength components of cohesionless soils is related to attempts to correlate the macroscopic angle of internal friction ϕ'_{cv} with the angle of interparticle friction (ϕ_μ). A number of theories that relate these parameters and assert that no shearing resistance can exist without interparticle friction ($\phi_\mu = 0$) are reviewed in (ref. 1) in light of recent experimental evidence showing no $\phi_{cv} \sim \phi_\mu$ correlation.

According to the following micromechanical analysis of plane assemblies, non-vanishing shearing strength of a granular mass with $\phi_\mu = 0$ can be attributed to microstructural anisotropy induced during shearing deformation.

Consider a large assembly of equal size discs (diameter d_o) under a uniform state of stress σ'_{ij} (understood in the micromechanical sense, ref.2) and expressed in terms of microscopic characteristics as follows

$$\sigma'_{ij} = 2\frac{\rho\gamma}{\pi d_o}\int_0^{2\pi}[\bar{f}_n(\theta)n_i(\theta)n_j(\theta) + \bar{f}_t(\theta)t_i(\theta)n_j(\theta)]\,S(\theta)d\theta \quad , \qquad (1)$$

where $\bar{f}_n(\theta)$, $\bar{f}_t(\theta)$ are average normal and tangential force components over contacts with orientation θ; $S(\theta)$ is a contact orientation distribution equal to $1/2\pi$ for isotropic assemblies; ρ - packing fraction and γ - average co-ordination number.

Due to symmetry $\theta \to \theta+\pi$ functions in (1) can be decomposed into Fourier series with even components. Noting from the form of (1) that Fourier components of the order higher than the second will not contribute to σ'_{ij}, it is convenient to neglect $\bar{f}_t(\theta)$ ($\phi_\mu = 0$) and approximate the remaining as follows

$$S(\theta) = \frac{1}{2\pi}[1 + a\cos 2(\theta-\theta_o)] \quad , \quad f_n(\theta) = f_o[1 + a_f\cos 2(\theta-\theta_f)] \quad .$$

The first of the above defines anisotropic distribution of contact orientations with preferred direction θ_o and parameter of anisotropy a. Average normal forces are direction-dependent with the overall magnitude f_o.

For a system with specified microstructure (a, θ_o) and prescribed loads (σ'_{ij}) parameters defining average contact forces (f_o, a_f, θ_f) can be obtained from three equations (1). General expressions are somewhat involved but when the principal direction of σ'_{ij} coincides with the direction of anisotropy, the following relationship is recovered for small anisotropies

$$\sin\phi'_m = \sigma'_t/\sigma'_n = 0.5\,(a + a_f)$$

where σ'_n, σ'_t are hydrostatic and deviatoric invariants of σ'_{ij} and ϕ'_m is referred to as "mobilized angle of friction".

The above relationship shows that cohesionless assemblies can resist deviatoric loads by developing anisotropic structure and allowing directional variation of average contact forces .

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New Evolutionary Equations for Fluctuations In Rapid Granular Flows

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Abstract

Motivated by the molecular kinetic theory of dense fluids a rapid flow of a large number of equal hard spheres in a bounded domain of 3-D Euclidean space is modeled statistically. In doing this a special version of the Boltzmann equation with nonvanishing collision operator is considered. Having derived the statistical field equations the BGK or the Krook's approximation is applied to the collision operator to arrive at a desired probability distribution function. In particular an equation is derived for the production and diffusion of random fluctuation energy. Furthermore, two explicit expressions are given for the stress tensor as well as the flux vector of random fluctuation energy. The derived expressions not only involve the random fluctuation energy but also its time rate of change. These governing equations which form a complete set are applied to two problems involving rapid granular flows; one a plane couette flow and the other a simple gravity flow down an inclined plane. The solutions, thus obtained, agree with the known results and, further, enable one to derive expressions relating the root mean square of random velocity fluctuations, the bulk density, and the shear rate.

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1 - Ahmadi, G. and M. Shahinpoor, "A Kinetic Theory for Rapid Granular Flows and Evolution of Fluctuations," MRL-CGT Granular Materials Research Laboratory, Res. Rep. No. 077, March, (1982).

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MATHEMATICAL CHARACTERIZATION OF THE CHEMICAL BEHAVIOR OF A SOUTH FLORIDIAN SOIL

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Subrata Sengupta, Nelson Nemerow

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Various factors govern the transport of heavy metal pollutants in saturated soil. The key mechanisms which govern the interaction of saturated soil with the liquid pollutant include convection, diffusion, biological and chemical transformation, chemical adsorption or desorption, and precipitation. Chemical adsorption is modelled by an equation describing the dependency of the sorbed concentrated on the solution concentration. The adsorption equation used is the Langmuir equation.

$$\beta = \frac{K_1 K_2 \gamma}{1 + K_1 \gamma}$$

where β = pollutant concentration in the soil

γ = pollutant concentration is the liquid phase

K_1, K_2 = Langmuir equations

The present paper deals with batch experimental studies which model the chemical interaction between the soil and the liquid pollutant phase over a wide concentration range. The experimental results for the interaction of Hallandale fine sand (a soil found in South Florida) and three cations, copper, iron and zinc, are presented. From these experimental results, the Langmuir coefficients, K_1 and K_2 are evaluated for each of the cations.

These coefficient are then used for modelling purposes in the one dimensional Langmuir transport equation:

$$\phi \frac{\partial C}{\partial t} + w\phi \frac{\partial C}{\partial z} - D\phi \frac{\partial^2 C}{\partial z^2} + (1-\phi) \frac{K_1 K_2 \rho_s}{(1 + K_1 C)^2} \frac{\partial C}{\partial t} = 0$$

where ϕ = porosity; C = concentration of pollutant in the liquid phase

D = diffusion coefficient; t = time

w = convective velocity; z = space coordinate

Session FM-3: DIFFERENTIAL EQUATIONS/APPLIED MATHEMATICS

Chairperson: J. CHANDRA, U.S. Army Research Office

Co-Chairperson: D. BLACKMORE, New Jersey Institute of Technology

* 9:30 - 10:00 M. I. YOUNG, University of Delaware:
"The Non-Linear Mechanics of Stall Flutter Oscillations"

10:00 - 10:15 D. BLACKMORE, New Jersey Institute of Technology:
"Differential Equations With No Periodic Solutions"

10:15 - 10:30 W-L YIN, Georgia Institute of Technology:
"Two-Dimensional Interior Solutions of the Navier-Stokes Equation in Terms of Analytic Functions"

10:30 - 11:00 COFFEE BREAK

11:00 - 11:15 J. R. FOOTE, University of New Orleans and M.E. FETTIS Mountain View, CA:
"Eigenvalues of a Pseudo-Latzko Differential Equation and of Neighboring Boundary Value Problems"

11:15 - 11:30 B. J. LEHMAN, State University of New York at Buffalo:
"Normal Modes for Asymmetric Systems"

11:30 - 11:45 B. J. LEHMAN, State University of New York at Buffalo:
"An Oscillation Theorem for Damped Distributed Parameter Systems"

11:45 - 12:00 T. L. HICKS, University of Missouri-Rolla:
"Random Normed Spaces"

12:00 - 12:15 H. H. BOSHARDT, Newport Beach, CA:
"N-Space Formulation of the Scattering Problem in the Time Domain for Very Large Problems"

12:15 - 12:30 D. M. CLAUDIO, Curso de Pos-Graduacao em Ciencia da Computacao, Brazil:
"Remarks on Correct Significant Digits and Nonlinear Equations"

12:30 - 12:45 V. ALADYEV, All-Union Project-Technological Institute, USSR:
"Homogeneous Structures in Engineering Sciences"

THE NON-LINEAR MECHANICS OF STALL FLUTTER OSCILLATIONS

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Abstract

Stall flutter oscillations of propeller blades and similar structures are self-limiting, limit cycle torsional instabilities. Although boundary layer separations and the unsteady aerodynamics are clearly the dominant and controlling effects[1] a mechanical-mathematical model based on the concept of a switching servomechanism[2] is proposed. In this model the linear and non-linear domains of the aerodynamic pitch damping of the torsional oscillations are represented, together with their hysteresis, aerodynamic angle of attack and angle of attack rate of change sensitivities and the high incidence self-limiting features. The model is seen to have the analytical flexibility to correctly predict the occurence of damped linear type torsional oscillations below the needed threshold conditions, and onset of self-limiting torsional limit cycle oscillations when the threshold conditions are exceeded. It is also seen that the tendency of the limit cycle oscillations to occur at the blade fundamental torsional natural frequency[3] is also correctly modelled.

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[3] Maurice I. Young and Norman D. Ham, "Torsional Oscillations of Helicopter Blades Due to Stall, Journal of Aircraft, May-June, 1966.

Differential Equations with no Periodic Solutions

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Let $\frac{dx}{dt} = X(x)$ be a differential equation of class C^n ($n \geq 1$) on the 3-sphere S^3. The Seifert conjecture states that the differential equation must have a periodic solution in S^3. P. Schweitzer found a counter-example to this conjecture for the case $n=1$. By using a variant of a construction of Blackmore (an example of a local flow on a manifold, Proc. Amer. Math. Soc. 42, 1974) we obtain counterexamples for any finite $n \geq 1$. On the basis of the differential equations constructed we draw several conclusions of interest to control systems engineers regarding the existence and stability of oscillations, and ergodic and almost periodic behavior.

Two-Dimensional Interior Solutions of the Navier-Stokes Equation in Terms of Analytic Functions

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ABSTRACT

Considered as a function of $z = x + iy$, $\bar{z} = x - iy$ and t, the stream function U in an unsteady plane flow of an incompressible viscous fluid is governed by the equation

$$\mathrm{Im}\left[i\, U_{\bar{z}zt} - 4i\nu\, U_{zzz\bar{z}\bar{z}} - 4\, U_{z}\, U_{zz\bar{z}} \right] = 0 \qquad (1)$$

Those solutions of Eq. (1) which are representable in the form

$$U = \mathrm{Re}\left[\bar{z}\, \varphi_1(z,t) + \varphi_0(z,t) \right], \qquad (2)$$

where φ_0 and φ_1 are analytic functions of z, form a class that includes irrotational flows, constant vorticity flows and circulation-preserving flows ("universal solutions"). New exact solutions of the Navier-Stokes equation can be obtained by means of the more general representation

$$U = \mathrm{Re}\left[\sum_{i=0}^{N} \bar{z}^{i}\, \varphi_i(z,t) \right]. \qquad (3)$$

Substitution of (3) into (1) yields an equation of the form ($n > N$)

$$\mathrm{Im}\left[\sum_{j=1}^{n} \xi_j(z,t)\, \overline{\eta_j(z,t)} \right] = 0, \qquad (4)$$

where ξ_j and η_j are analytic functions formed from φ_i, φ_i', φ_i'' and $\partial \varphi_i'/\partial t$. We prove that (4) holds if and only if

$$\xi_j(z,t) = \sum_{k=1}^{n} C_{jk}(t)\, \eta_k(z,t), \qquad j = 1, \ldots n. \qquad (5)$$

where the coefficients C_{jk} form a Hermitian matrix ($C_{jk} = \bar{C}_{kj}$). The system (5) consists of n second order ordinary differential equations in the complex variable z for the N analytic functions $\varphi_1, \ldots \varphi_N$. With appropriate coefficients $C_{ij}(t)$ this over-determined system of equations admits solutions. Applying the method to the representation (2), we determine the complete class of plane universal solutions of Navier-Stokes fluids.

EIGENVALUES OF A PSEUDO-LATZKO DIFFERENTIAL EQUATION AND OF NEIGHBORING BOUNDARY VALUE PROBLEMS

J. R. Foote* and H. E. Fettis**

Latzko [1] derived and solved approximately a boundary value problem for heat transfer in a fully developed turbulent flow in a circular tube. Fettis [2] displayed a way to approximate the eigenvalues and eigenfunctions by treating the Latzko problem as neighboring to a hypergeometric differential equation satisfied by Jacobi polynomials. The Latzko problem is

$$\frac{d}{dx}[(1-x^7)\frac{dy}{dx}] + \omega x^7 y = 0, \quad y(0) = 0, \quad y(1) = \text{finite}.$$

The neighboring problem is

$$\frac{d}{dx}[(1-x^7)\frac{dy}{dx}] + \lambda x^5 y = 0, \quad y(0) = 0, \quad y(1) = \text{finite}.$$

It is found that the one-parameter class of neighboring problems

$$\frac{d}{dx}[(1-x^p)\frac{dy}{dx}] + \lambda x^{p-2} y = 0, \quad \lambda > 0, \quad p - 2 \geq 0,$$

also is solved by Jacobi polynomials, and the two-parameter pseudo-Latzko differential equation is

$$\frac{d}{dx}[(1-x^p)\frac{dy}{dx}] + \omega x^{p+m-2} y = 0, \quad p + m - 2 \geq 0, \quad |m| \leq 2.$$

Each initial condition $y(0) = 0$, $y'(0) = 0$, $\gamma y'(0) - \delta y(0) = 0$ can be associated with finiteness of $\sigma y'(1) - \tau y(1)$. Eigenvalues for λ and eigenfunctions are found as explicit formulas for the first two conditions; the distribution of eigenvalues is found for the third case and approximate methods for their calculation are given.

Five numerical examples were calculated for the first ten eigenvalues ω, using double precision arithmetic with the Fettis method:

(1) Nusselt problem: p=1, m=2, with $y(0) = 0$ (laminar).
(2) Latzko problem: p=7, m=2, with $y(0) = 0$.
(3) p=7, m=2, with $y'(0) = 0$ (insulated wall).
(4) p=4, m=2, $y(0) = 0$ (intermediate turbulence).
(5) p=4, m=2, $y'(0) = 0$.

The smaller eigenvalues agree very well with such published values as exist, and $\omega > \lambda$ in all cases. The case p=4 confirms that $\omega(p=7)$ are an order of magnitude greater than corresponding $\omega(p=1)$.

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2. H. E. Fettis, "On the Eigenvalues of Latzko's Differential Equation," ZAMM, 37, p. 308-309 (1957).

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NORMAL MODES FOR ASYMMETRIC SYSTEMS

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This work presents a necessary and sufficient condition for a general linear dynamic system to become uncoupled by a modal transformation. The systems considered here are those that can be modeled by

$$A\ddot{x} + B\dot{x} + Cx = 0 \tag{1}$$

where A,B and C are nxn square matrices and x is an n-vector of generalized coordinates. Caughey and O'Kelly [1] have shown that if A,B and C are symmetric and positive definite, then a necessary and sufficient condition for (1) to possess classical normal modes is that $BA^{-1}C = CA^{-1}B$. This condition insures that the modal matrix associated with the stiffness matrix C decouples the equation of motion (1). Rayleigh or proportional damping provides an example of a class of systems which decouples under the modal matrix transformation. The results of [1] are generalized here to systems which are not necessarily symmetric.

A result is presented for a subclass of systems described by (1) such that (i) A^{-1} exists and (ii) $A^{-1}B$ and $A^{-1}C$ have real eigenvalues and a complete set of eigenvectors. Taussky [2], has shown that condition (ii) holds if and only if $A^{-1}B$ and $A^{-1}C$ may be factored into the product of two symmetric matrices one of which is positive definite. It has been shown in [3] that under this assumption, equation (1) is similar to a symmetric system if and only if the factorization of $A^{-1}B$ and $A^{-1}C$ is of the form

$$A^{-1}B = S_1S_2$$
$$A^{-1}C = S_1T_2$$

where S_1, S_2 and T_2 are symmetric and S_1 is positive definite. Under this condition it is shown that (1) possesses classical normal modes if and only if $BA^{-1}C = CA^{-1}B$. Thus stating clearly the subclass of non conservative asymmetric systems which may be decoupled by a modal transformation. The result is illustrated by a numerical example.

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[2] Taussky, O., "Positive Definite Matrices and Their Role in the Study of the Characteristic Roots of General Matrices", Advances in Mathematics, 2, 175-186, 1968.

[3] Inman, D.J., "Lambda Matrices with Asymmetric Coefficients with Application to Vibration Problems", SIAM Conference on Applied Linear Algebra, Rayleigh, NC, April 1982.

An Oscillation Theorem for Damped Distributed Parameter Systems*

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This work presents a sufficient condition for each of the temporal solutions of a damped distributed parameter system to be damped oscillations. The systems considered are those that may be described by the following partial differential equation:

$$u_{tt}(x,t) + L_1 u_t(x,t) + L_2 u(x,t) = 0 \quad \text{in } \Omega$$
$$Bu(x,t) = 0 \quad \text{on } \partial\Omega \tag{1}$$

where (i) $(.)_t$ indicates partial differentiation with respect to the time t, (ii) Ω is a bounded, open region of R^n, n=1,2,3, with boundary $\partial\Omega$, (iii) L_1 and L_2 are real linear spatial differential operators, which are self adjoint and positive definite (with respect to Bu=0), and (iv) B is a linear operator which reflects the boundary conditions. With additional assumptions the system (1) can adequately describe vibration problems related to damped beams, plates, shells, etc. and the solution may be written in the form

$$u(x,t) = \sum_{n=1}^{\infty} a_n(t)\phi_n(x) \tag{2}$$

where $\phi_n(x)$ are a complete set of functions. It was shown in [1] that if in addition to the above assumptions, L_1 and L_2 have compact resolvents and commute on a certain domain, then the oscillatory nature of each of the temporal functions $a_n(t)$ is determined by the definiteness of the operator $4L_2-L_1^2$ defined on the same domain. The work presented here extends this result to systems which do not satisfy the commutivity condition.

This work is an extension of the work given in [1] to more general systems. The method of proof does not depend on finite approximations to (1), as is done in [2], but depends only on the form of the operators L_1 and L_2. The result is compared to the method used in [2] and to related problems in the current literature. Examples are provided indicating the utility of the result.

[1] Inman, D.J. and Andry, A.N., Jr. "The Nature of the Temporal Solutions of Damped Distributed Systems with Classical Normal Modes", to appear in Journal of Applied Mechanics.
[2] Rocha, Rui. and Bailey, Eds., "Critical Damping in Certain Linear Continuous Dynamic Systems", International Journal of Solids and Structures, Vol. 17, pp. 575-580, 1981.

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Random Normed Spaces

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ABSTRACT: For a random normed space, we have a linear space X and, for each x in X, we associate a distribution function F_x (instead of a real number $||x||$) with x. The collection of distribution functions $\{F_x\}$ are required to satisfy axioms modeled after the norm conditions for a normed linear space. We simplify the origin system of axioms given by Serstnev in 1963. Necessary and sufficient conditions for a random normed space to be a (metrizable) topological linear space will be given. A new structure, called a random H-space, will be introduced. It will be shown that they coincide with the metrizable topological linear spaces.

K-SPACE FORMULATION OF THE SCATTERING PROBLEM IN THE TIME DOMAIN FOR VERY LARGE PROBLEMS

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The arbitrary direct scattering problem is solved numerically in closed form in the time domain and spatial Fourier transform space. This solution consists of casting the general basic global laws (i.e., the second order partial differential wave equation or its integral representation) as a local algebraic equation in the spatial Fourier transform space, and leaving the specific local constitutive equations (i.e., the algebraic boundary condition, which specify a given structure, which are conventionally imposed on the differential or integral representation of the general basic global wave equation(as a local algebraic equation in real space, thereby reducing the scattering problem to a statement of two simultaneous local algebraic equations in two unknowns (the fields and the induced sources) in two spaces connected by the spatial Fourier transform. By virtue of causality, a numerically efficient closed form solution to this set of equations is obtained that utilizes the fast Fourier transform algorithm as the transformations between the two spaces. By virtue of the numerically efficient fast Fourier transform algorithm and the local algebraic representations, the number of required complex multiply-add operations and storage allocation is of the order of $N\log_2 N$ and N per temporal descretization respectively (where N is the number of spatial cells into which the scattering problem is descretized). It is shown that the solution is only of the order of $\log_2 N$ slower than an ideal solution. The solution is thus practical for very large one, two, and three dimensional scattering problems. Numerico-experimental results for very large two dimensional problems are presented cinematographically.

REMARKS ON CORRECT SIGNIFICANT DIGITS AND NONLINEAR EQUATIONS

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During the past two decades, several new algorithms based on the theory of interval mathematics have been developed, having in R.E. MOORE on of its precursors.

This work makes use of the same philisophy wich orients the interval methods, but does not make use its arithmetic.

The metod that will be developed, from now on called Hybrid Interval Method (HIM) consist of:

i) Let f be a function that is twice differentiable on some interval $X^{(-1)}$ containing a zero point x*. Let f be strictly increasing or decreasing and convex or concave on $X^{(-1)}$.
ii) Computer an initial approximation x_{-1} with exact significant Digits = DIGSE $(x_{-1}) = K \leq t-2$ from real methods, were t is the number of the computer digits.
iii) Convert the punctual interval $[x_{-1};x_{-1}]$ from ii) into the interval $[\nabla x_{-1};\Delta x_{-1}] = X^{(0)}$ with K = f(DIGSE) and $\nabla.\Delta$ the directed rounding.
iv) The interval process begins with $X^{(0)}$ to obtain two new points in $X^{(0)}$ from the utilization of two methods M_1 and M_2 (Modified Newton and Modified Regula Falsi).
v) The directed rounding is applicated to the obtained interval, now with K = t or K = t-1, and we have $X^{(1)} \subseteq X^{(0)}$
vi) Repeate iv) and v) until the exactness cannot be improved any more.

The HIM is compared with some existing methods in the literature. It presents the following advantages in the case of functions considered in this papers.

HIM x Fixed Point Methods

The HIM Methods presents the same advantages as the interval methods. We obtain a method that is always convergent and provides directly the error bounds.

HIM x Interval Methods

The times are compared, to obtain same given exactness, with the methods suggested by Alefeld, and Krawczyk, and we verity that HIM is always faster and as simple to apply as the others.

According to the research performed, the HIM show us enough promissing and it seems to us that in the future we will be able to extend this theory to new mathematical methods.

HOMOGENEOUS STRUCTURES IN ENGINEERING SCIENCES

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The homogeneous structure (HS) is a formalization of the concept of an infinite regular array of identical finite-state machines uniformly interconnected in the sense that each machine can directly receive information by means of interconnecting wires from a finite number of neighboring machines. Each machine can synchronously change its state at discrete time steps as a function of the states of the neighboring machines. This function can change from time step to time step, but will be identifical for each machine in the array at any given time step. The simultaneous action of these local functions will define global functions which will act on the entire array changing configurations of machine states in the array to other configurations.

Such models have been applied in such diverse areas as pattern recognition, parallel computing systems, development theories, adaptive systems, parallel processing and parallel algorithms, chemistry, physics, crystallography and so on [1,2]. HS can serve as the basis for modelling of many discrete processes, and the mathematical theory of HS has become each year more and more fruitful and popular [2,3]. Survey of the general directions of the theory of HS and their applications in connection with engineering sciences is presented in the present paper.

At the present there are enough reasons for the further development of the concept of HS. Indeed, many important phenomena such as reliability, probability and so on in the above-mentioned areas cannot obtain satisfactory description in terms of the classical concept of HS. Because the concept of HS must be very extensive [2]. It admits a number of essential deviations from classical concept. A number of generalizations of this concept are discussed.

A number of interesting properties of crystals can be studied with the aid of HS. Another application of a theory of HS is the study of numerical solutions of the partial differential and difference equations in the parallel manner. HS can serve as some mathematical model of the physical universe or, in particular, as some universe of modern theoretical physics. Models of parallel processing on the basic of HS allow to create data processing systems and control systems of high effectiveness up to systems with direct economical effect [3,4]. Much of work in HS has been motivated by the growing interest in modelling of discrete systems and parallel computing technique [2-4].

There are other areas in engineering where HS are applied. More detail discussion of these results is beyond the scope of the present paper. I hope that this work will help to clear up general aspects of the mathematical theory of HS and their applications in engineering sciences.

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2. Aladyev V.Z., Mathematical Theory of Homogeneous Structures and Their Applications, Valgus Press, Tallinn, 1980.
3. Parallel Processing and Parallel Algorithms, Vol.1 (ed.V.Z.Aladyev), Valgus Press, Tallinn, 1981.
4. Parallel Processing and Parallel Algorithms, Vol. 2 (ed.V.Z.Aladyev), Valgus Press, Tallinn, 1982.

Session FM-4: LUBRICATION IN METALWORKING/METAL FORMING

Chairperson: E. A. SAIBEL, U. S. Army Research Office

Co-Chairperson: T. R. CHANDRUPATLA, General Motors Institute

* 9:30 - 10:00 W.R.D. WILSON, Northwestern University:
"Mathematical Modeling of Lubrication in Metal Forming Processes"

* 10:00 - 10:30 T. R. CHANDRUPATLA, General Motors Institute:
"Strain Measurement in Sheet Metal Forming"

10:30 - 11:00 COFFEE BREAK

11:00 - 11:15 R. SOWERBY and P. C. CHAKRAVARTI, McMaster University:
"Grid Strain Analysis in Sheet Metal Forming"

11:15 - 11:30 P. R. DAWSON, Cornell University:
"Strain Distributions in Hot Rolling"

11:30 - 11:45 N. L. DUNG, Universität Hanover, W. Germany:
"Finite Element Analysis of Forging of Turbine Blades"

11:45 - 12:00 J. ETAY and M. GARNIER, CNRS-GIS Madylam, France:
"Electromagnetic Processes for Controlling Molten Metal Free Surfaces"

12:00 - 12:15 S. N. DWIVEDI, The University of North Carolina:
"Application of Industrial Robots in Metalforming"

12:15 - 12:30 Y. EL-KARAMANY, Machine Tool Developing Institute, Halasztelek, Hungary:
"Optimum Machining Variables in Turning Long Workpieces"

Mathematical Modeling of Lubrication in Metal Forming Processes

by

W. R. D. Wilson, Professor
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Northwestern University
Evanston, Illinois 60201

Abstract

In most metal forming processes extremely severe tribological conditions with high pressures, sliding, surface deformation and often high temperatures make effective lubrication of the workpiece tooling interface essential to economic viability. A wide variety of different liquid and solid lubricant compositions are used but they all have the primary functions of preventing direct metal-to-metal contact which can result in workpiece material adhering to the tooling with consequent damage to the product and the necessity of replacing or refurbishing the tooling. Lubricants also decrease friction between the workpiece and tooling, reducing force and energy requirements and avoiding residual stresses and defects in the product by promoting more homogeneous deformation. Tooling life is extended, not only by the reduction in stresses due to lowered forces but also by the lubricant film reducing wear and acting as a thermal insulating shield between the tooling and a hot workpiece.

A variety of different lubrication regimes can be associated with a given process. In each regime different physical and chemical factors control lubrication. Different regimes can occur as a result of changes in lubricant and workpiece properties, forming speed, temperature, process geometry or workpiece or tooling roughness. Furthermore, several different regimes can co-exist at different locations in the workpiece-tooling interface or succeed one another at different stages in the process.

Most of the mathematical modeling of lubrication has dealt with full film regimes in which the surfaces are separated by a continuous film of lubricant which has a mean thickness of at least three times the RMS roughness of the surfaces involved and is large compared with the lubricant molecular size. This allows the lubricant film to be treated using the methods of continuum mechanics. Such analyses are useful not only for detailed modeling of full film regimes but also in defining the range of conditions under which full films are possible and thus implying which regime is present in a particular situation.

The various mechanisms by which full films are formed and subsequently transported and break down will be discussed in detail for both liquid and solid lubricants. The influence of lubricant and workpiece properties and processing geometry on frictional conditions and the implications of these on choosing methods of characterizing frictions in metal forming models and screening tests for lubricant effectiveness will also be analysed.

STRAIN MEASUREMENT IN SHEET METAL FORMING

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ABSTRACT

Circle grids are widely used in measuring strain in sheet metal deformation processes. The use of circle grids in the development of forming limit diagrams is surveyed. Application of other grid geometries is explored.

GRID STRAIN ANALYSIS IN SHEET METAL FORMING

by
*R. Sowerby and †P. C. Chakravarti
*Faculty of Engineering and †Faculty of Science
McMaster University
Hamilton, Ontario, Canada

While the principles of grid strain analysis are well known, it is often not appreciated that the technique relies on the assumption of homogeneous deformation. This deformation mode converts straight lines to straight lines, squares to parallelograms, circles to ellipses, etc., but it is unlikely to exist over the entire surface of a deformed part. In many sheet metal stampings, both the plastic strains and the strain gradients are small over much of the surface and initially square or circular grids do appear to have been deformed into parallelograms or ellipses. If a deformed square has the appearance of a curvilinear quadrilateral, then homogeneous deformation has not taken place throughout that particular domain. Smaller initial grids could be employed in order to reduce the domain of inspection, but the measurement of very fine grids of lines, dots or circles is both tedious and subject to large errors.

The question arises as to the representative (or equivalent) strain accumulated following some homogeneous deformation path. It transpires that the minimum equivalent strain is accumulated when the deformation takes place by pure homogeneous deformation. In the latter mode, a pair of orthogonal lines can be identified, i.e. the principal axes, which remain orthogonal throughout the deformation and hence the principal strains, and their orientation, and the representative strain can be evaluated [1]. Note this is not the case for homogeneous deformation and total principal strains cannot be identified in such processes. The objective of the present work is to evaluate the representative strain for finite homogeneous deformation processes. A technique has been established whereby the representative strain can be computed from measurements made on the final deformed grid, assuming that the straining path is known and that the same mode persists from beginning to end.

Although circles have been the most widely applied grid pattern, an array of dots, squares or rectangles is more convenient for digitizing, the position of the dots or the vertices of a square can be monitored by means of an optical grid analyzer. If only the vertices of a square are being tracked, then without loss of generality, the starting grid could be an array of parallelograms or some other suitably shaped quadrilaterals.

If the initial and final shape of a grid is known, but not the deformation path, the only recourse is to assume pure homogeneous deformation in order to get some estimate of the strains.

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[1] R. Sowerby, E. Chu and J. L. Duncan, "The Determination of Large Strains in Metalforming", to appear J. Strain Analysis.

Strain Distributions in Hot Rolling

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Sibley School of Mechanical and Aerospace Engineering
Cornell University

Aluminum and steel alloys frequently are rolled in either the hot or warm working temperature regime in the early stages of processing. Deformations are large and the temperature changes result from dissipative heating as well as from heat losses to the surroundings. The thermomechanical histories of points throughout the workpiece, therefore, exhibit changing rates of deformation, strains, stresses and temperatures. Further, in some regimes of deformation rate and temperature, microstructural defects accumulate and contribute to hardening or softening of the flow properties. In this presentation, the essential features of a viscoplastic formulation for modeling the inelastic flow of metals during primary forming processes is summarized. The methodology for integrating the strains experienced by material particles as they traverse a computational mesh that is fixed in space is also reviewed. The central emphasis focuses on the application of the modeling to the rolling of flat slabs. The effect of various assumptions relative to the traction vectors and heat flux transmitted across the slab/roller interface are examined. In particular, the changes in the predicted free surface position, the internal strain field, and the temperature distribution are shown for sticking and slipping friction.

FINITE ELEMENT ANALYSIS OF FORGING OF TURBINE BLADES

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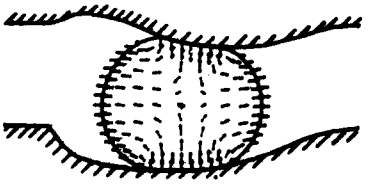
Energy conversion equipment such as steam and gas turbines require large number of forged blades. In order to manufacture these blades in large numbers and with a high degree of geometrical accuracy the forging process must be carefully controlled and well understood. Methods of analysis are required which will determine forging loads, details of material flow and the distribution of tooling or contact stresses throughout the process.

Various previous investigations have dealt with plane strain forging of circular rods; for example LEE and KOBAYASHI (1971) presented calculations for side pressing of circular rods between flat dies. AKSENOV et al (1975) studied the unsteady process of blade forging both experimentally and theoretically; slip-line field analysis and numerical integration techniques were used to determine contact stresses and forging loads during deformation. Computer programs based on elementary theory have been developed by AKGERMAN and ALTAN (1976) as a computer-aid in tool and process design. Most of these theories predicted load and contact stresses satisfactorily but did not reveal adequate information on the geometry of metal flow. Because of the complicated die shape and the constantly changing thickness of material in the deformation zone it is difficult to analyse the unsteady forging processes except by using finite element methods such as those developed for these problems by DUNG (1981).

In this present paper, a simplified finite element method is used to analyse forging a blade from a rigid-plastic material. The method is based on a modification of Markov's principle in which incompressibility and friction at the boundary are added; use of linear elements and a simplified integration technique for volume integrals lead to computational economy. The unsteady process is analysed in a step-by-step manner using a reuning procedure where necessary. The complete process from the initial circular billet to the final forged blade is analysed.

The finite element solutions agree well with the experimental results of AKSENOV and the method developed can be used to determine contact stresses and material flow during the whole process. This provides a valuable technique for the tool and process designer.



Forging of blade between curved asymmetrical dies

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AKGERMAN, N. and ALTAN, T., J. Engrg. Power 98(1976), pp. 290-296.
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ELECTROMAGNETIC PROCESSES FOR CONTROLLING MOLTEN METAL FREE SURFACES

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In industrial metallurgy, the contact between the molten metal and the walls used to contain or to shape the metal is at the origin of many problems because of chemical contamination of the melt from the walls. Moreover some rolling and reheating processes could be saved and the life of moulds could be extended if this undesirable contact could be suppressed. The possibility of inducing electromagnetic forces in an electrically conducting medium without any contact between this medium and any wall, by using alternating magnetic fields, brings solutions of these problems because the wall can be suppressed and replaced by magnetic field lines.

We present some examples of such electromagnetic devices which can be used for flowrate regulation, guiding and shaping of liquid metal columns without having resort to any wall. These devices are experimented with mercury in Grenoble.

In the electromagnetic device for molten metal confinement, a coil surrounding the molten metal column is provided with alternating currents whose frequency imposes the skin depth to be equal to the radius of the column. The effect of the magnetic field is to make the pressure in the liquid to decrease and to accelerate the flow whose cross section has to reduce. To a given intensity of the current in the coil corresponds a given cross section. Flowrate regulation is then achieved since it is possible to control and to impose the section of a liquid metal flow whose velocity is fixed by the height of metal above the constricted section.

If a high frequency magnetic field configuration is imposed by a suitable inductor in which the magnetic field intensity is very weak along a given line, a liquid metal column initially falling near this line will be flowing in such a way that its axis will be coincident with this particular line. Magnetic guiding of molten metal flows can be so achieved, as confirmed by experiments.

To obtain magnetic shaping horizontal high frequency (300 KHz) fields are imposed by suitably disposed conductors parallel to the axis of the metal column. A strong skin effect excludes these fields from the liquid and the equilibrium shape of the column results from the competition between the non-uniform magnetic pressure and the surface tension. Two examples are presented:

- in the first one the non-uniform electromagnetic force is induced by four parallel conductors generating a quadrupole field centered on the axis of the metal column. The resulting section of the column is cruciform.
- in the second one, two coils generate a high frequency quasi-unidirectional field, perpendicular to the axis of the initially circular molten metal column: the electromagnetic forces tend to give a very thin ribbon shape to the initially circular column. Ribbons of several centimeters wide, easily obtained, are very stable under the effect of the magnetic field and may be used to make amorphous metal ribbons.

APPLICATION OF INDUSTRIAL ROBOTS IN METAL FORMING

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Charlotte, North Carolina

This paper is a cumulation of study and research work done to answer the question of, "what contributions are robots making in the industrial world in relationship to increasing the current level of productivity" specifically in the field of metalforming processes. The various applications of industrial robots in forging, powder, metalforming, sus-forming, stamping, machining, plastic molding have been discussed. In most of metalforming processes loading, unloading, and lubricating close die presses is fatiguing, dirty and monotonous job. Robots are relieving men from this tedious, hazardous job in tough environments. Due to recent researches and the developments in the field of robotics, the capability of the robots are well matched to the loading and unloading task. The reliability of the robots are quite high. Robots are producing better quality products in metal-forming processes. Considering the great demand of unmanned factory in the future, the role of robots are very critical in manufacturing as a whole and particularly in metalforming processes. Also in this paper on the basis of the authors' research and personal insight, the sincere consideration has been given regarding the future potential application of the industrial robots in metalforming process.

OPTIMUM MACHINING VARIABLES IN TURNING LONG WORKPIECES

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The paper represents a method for computerized determination of optimum cutting variables on turning machines. The method takes into consideration the variation of static stiffness of the machine-workpiece system along the workpiece axis. The systems stiffness has great influence on machining accuracy when cutting long workpieces L/D > 6. Mathematical models have been derived and tested by numerical examples solved on computer by using the gradient method. The paper also discussed the application of this method through Adoptive Control System.

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Session FM-5: PENALTY METHODS IN FINITE ELEMENTS

Organizer and Chairperson: T. M. WICKS, University of Missouri-Rolla
Co-Chairperson: A. D. GUPTA, U.S. Army Ballistic Research Laboratory

* 9:30 - 10:00 G. F. CAREY and M. UTKU, The Texas Institute for Computational Mechanics:
"Penalty Methods for Inter-Element and Boundary Constraints"

* 10:00 - 10:30 M. WHEELER, Rice University:
"Interior Penalty Methods for Immiscible Displacements"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 N. KIKUCHI, University of Michigan:
"On An Exterior Penalty Method for Dual Variational Principles"

* 11:30 - 12:00 M. ENGELMAN, CIRES, University of Colorado:
"Consistent vs. Reduced Integration Penalty Methods for Incompressible Fluid Flows"

PENALTY METHODS FOR INTER-ELEMENT AND BOUNDARY CONSTRAINTS

G.F. Carey and M. Utku
Texas Institute for Computational Mechanics

We examine the use of penalty methods for enforcing constraints across interelement boundaries and for satisfying essential boundary conditions. In the former case, we are specifically interested in the Hermite cubic triangle (Zienkiewicz triangle) for plate bending problems. This element is known not to converge. By means of the penalty approach we show that this element can now produce convergent results. To achieve optimal results, the penalty parameter should depend on mesh size h and the penalty term should be underintegrated if a viable integral penalty form is to hold. Similar issues concerning the choice of penalty quadrature arise in connection with the use of penalty methods for treating essential boundary conditions. We also show how the boundary penalty procedure permits us to circumvent the Babuska paradox dealing with polygonal approximation of a simply supported plate.

References:

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INTERIOR PENALTY METHODS FOR INCOMPATIBLE DISPLACEMENTS

M. Wheeler
Rice University
Houston, TX

(Abstract not available)

On an Exterior Penalty Method for Dual Variational Principles

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Department of Mechanical Engineering
and Applied Mechanics
University of Michigan
Ann Arbor, MI 48109

Methods of exterior/interior penalty have been widely applied to solve constrained problems in mechanics, since they can be physically justified as Courant stated in his original paper on penalty methods in 1943.

In this article, we shall apply an exterior penalty method to resolve the equilibrium equations in the dual principle in linear elasticity. As shown in Taylor and Zienkiewicz, the exterior penalty method works under certain restricted choices of finite elements, but it is very sensitive. We shall discuss this in connection with the so-called LBB-condition that dominates the stability of the method and the finite element approximation.

CONSISTENT VS. REDUCED INTEGRATION PENALTY METHODS FOR INCOMPRESSIBLE FLUID FLOWS

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CIRES/NOAA
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Boulder, Colorado 80309

The penalty function approach to the fluid element simulation of incompressible fluid flows has achieved widespread use in recent years. The majority of practitioners employ "reduced integration" to evaluate the penalty matrix. A more general approach to the penalty method is to derive a "consistent" penalty matrix from the original discretised equations. It will be shown that the reduced integration approach is in fact a restricted subset of the consistent approach and is, in general, more accurate. The consistent penalty method also widens the set of elements that can be used with the penalty formulation. Two large scale simulations will be presented to demonstrate the effectiveness of the penalty method: a three-dimensional simulation of the air flow in an aerosol centrifuge and the transient simulation of an inpackage pasteurisation process. A motion picture of the transient simulation will be shown.

Session FM-6: BIOMECHANICS

Organizer and Chairperson: D. J. SCHNECK, Virginia Polytechnic Institute and State University
Co-Chairperson: I. KALEPS, Wright-Patterson Air Force Base

* 9:30 - 10:00 J. W. GRANT, Virginia Polytechnic Institute and State University:
"Platelet Distribution in Platelet Rich Plasma Following Separation from Red Cells by Sedimentation"

* 10:00 - 10:30 F. J. WALBURN, H. N. SABBAH and P. D. STEIN, Henry Ford Hospital, Detroit:
"Characteristics of Flow in Branching Tubes"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 R. B. DAVIS and D. J. SCHNECK, Virginia Polytechnic Institute and State University:
"An Exa[illegible]tion of the Hemodynamic Aspects of Coronary Spasm"

* 11:30 - 12:00 A. S. POPEL and M. LEVIN, University of Houston:
"Fluid Mechanics of Stochastic Microvascular Networks"

PLATELET DISTRIBUTION IN PLATELET RICH PLASMA FOLLOWING SEPARATION FROM RED CELLS BY SEDIMENTATION

J. Wallace Grant
Assistant Professor
Department of Engineering Science and Mechanics
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

In modern blood transfusion therapy a recipient is usually given a blood component instead of whole blood. The separation of blood into components is accomplished in a centrifuge by the process of differential sedimentation. An analytic model for predicting the concentration distribution of platelets and red cells in the sedimentation process can be developed from the continuity equation. When allowances are made for the concentration dependence of sedimentation, the resulting governing equations are a set of two quasilinear, hyperbolic, first order, partial differential equations. The solutions to this set of equations can be found by the method of characteristics. This method produces solutions, which involve discontinuities which propagate through the blood suspension. These discontinuities separate regions of constant concentration, and regions with concentration gradients.

A solution for the distribution of platelets in the platelet rich plasma layer above the red cell interface gives a constant platelet concentration region followed by a region of increasing concentration gradient. Measurements of the actual concentration profiles in platelet rich plasma agree with the form of this solution. In all cases the actual profiles do agree with the analytic solution. Rotor deceleration in the centrifuge seems to have a significant effect on the results.

Characteristics of Flow in Branching Tubes

Frederick J. Walburn, Hani N. Sabbah and Paul D. Stein

Departments of Medicine (Division of Cardiovascular Medicine) and Surgery, Henry Ford Hospital, Detroit, Michigan.

Clinical and pathologic observations reveal that atherosclerosis occurs preferentially at specific sites, such as bifurcations. Disturbances of flow are also present at these sites. With this realization, two fluid dynamic factors have been suggested to relate to atherogenesis - mechanical damage by high shear stresses and mass transfer in regions of low shear stresses. These apparently conflicting theories may be different aspects of a more comprehensive phenomenon - namely flow separation. The resulting wake region can contain high and low shear areas which actually coexist spontaneously. It becomes important, therefore, to examine the characteristics of flow in branching tubes in view of the possible role of hemodynamics in arterial disease.

Laser Doppler anemometer studies were performed in symmetrically branched glass tubes with branch-to-trunk area ratios and angles of branching comparable to the aortic bifurcation in humans. During equal branch flow, separation was not observed in any of the test sections at Reynolds numbers ranging up to 1500. In one of these branched tubes that had an area ratio of 0.8 and an angle of branching of 70^{o}, velocity profiles in the branch near the vertex were markedly skewed toward the inner wall. During the minimal phase of the flow cycle, transient flow reversals were found along the outer wall at mean Reynolds numbers below 1000. The wall shear rate during peak flow along the inner wall ranged between 500 sec^{-1} and 1600 sec^{-1} for Reynolds numbers of 500 - 1500. During unequal flow, separation occurred in the partially occluded branch when the branch flow was 8 to 14 percent of the total flow at Reynolds numbers of 1000 and 1500. Spiraling occurred in the branches whether flow in the branches was equal or unequal.

Further studies have been performed in molds of normal and atherosclerotic human aortic bifurcations. A laser Doppler anemometer was used to measure the wall shear stress along the lateral wall of a normal human aortic bifurcation. During peak flow, the aortic wall shear stress was 7.1 $dynes/cm^{2}$. Closer to the vertex, the aortic wall shear stress diminished and at the vertex, the shear stress along the lateral wall was 1.4 $dynes/cm^{2}$. Flow reversals also occurred at this site. The wall shear stress increased further downstream in the branch. Flow in a mold of an atherosclerotic human abdominal aorta and common iliac arteries was studied by flow visualization. Flow separation and transient flow reversals were found distal to atherosclerotic plaques. Spiraling of flow occurred in both branches downstream from the vertex.

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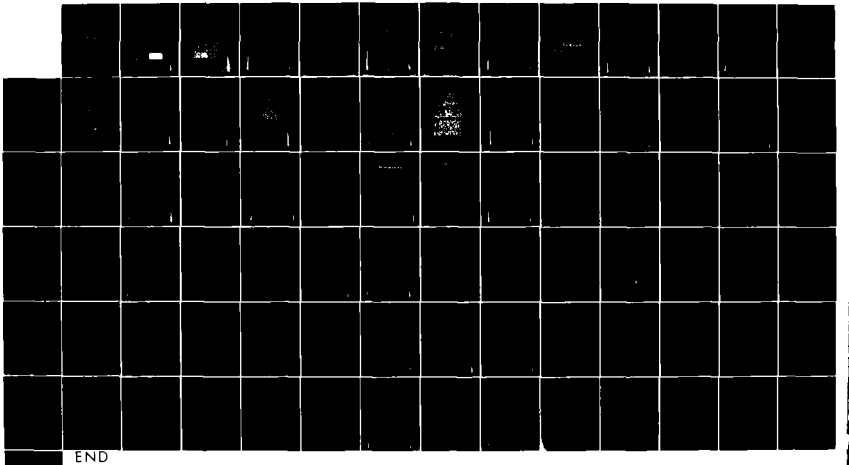

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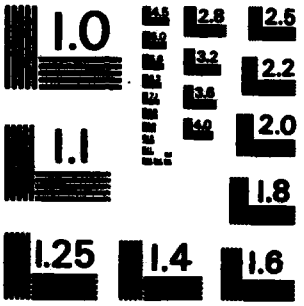

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AN EXAMINATION OF THE HEMODYNAMIC ASPECTS OF CORONARY SPASM

Davis, R.B., III, and Schneck, D.J.
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Although the death rate due to cardiovascular disease is declining, this decrease is due more to technological advances related to the early diagnosis and control of existing disease conditions, rather than to a broader understanding of the basic disease process itself. Thus, much work remains to be done in this area, particularly in the study of coronary artery hemodynamics and its relationship to a specific form of cardiovascular dysfunction, i.e., coronary spasm. This sudden rapid constriction of a coronary artery has been linked directly to the incidence of myocardial infarction. The recirculating flow configuration depicted in Figure 1 has been designed to simulate pulsatile flow through the left main coronary artery and its first two branches. The simulation was accomplished by matching experimental non-dimensional parameters (such as Reynolds number, unsteady Reynolds number, and tube properties and geometry) to corresponding physiologic variables. The elastic branching arterial model was fabricated in an acrylic mold using Dow Corning SYLGAR 184, a silicon-based elastomer. Fluid enters the test section from the left branch (the left main coronary artery), shown in Figure 1 as viewed from above, and either flows laterally into the left circumflex branch or continues straight into the anterior descending branch. The simulated spasm is accomplished by applying uniform pressure to the outer wall surface of the test section, thereby generating a pressure gradient across the wall so as to collapse the tube. Figure 2 shows a collapsed circumflex branch (as viewed axially from the branch side) with its "peanut-shaped" wall displacement (see arrow). Flow through the test section is quantified using a photochromic dye tracer technique. Local fluid velocity profiles at the branch site of the test section are obtained in three dimensions while specific spasm characteristics are varied. These include: the point in the flow cycle at which the spasm is initiated; the length (in time) of the spasm; the rate at which the tube collapses and/or returns to its uncollapsed state; the degree of occlusion of the vessel due to spasm; and, the amount of the vessel (in space) that is involved in the collapse. The experimental data allows one to assess the changes taking place as a result of coronary spasm, with the corresponding implications as they relate to subsequent vascular pathology.

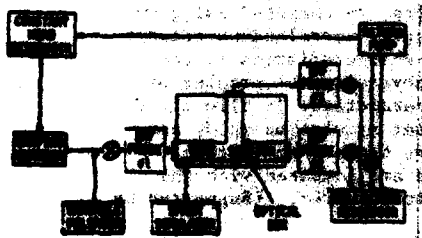

Figure 1: Flow Configuration

Figure 2: Collapsed Condition

FLUID MECHANICS OF STOCHASTIC MICROVASCULAR NETWORKS

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Morphological measurements indicate that vascular networks are characterized by wide distributions of such geometric parameters as diameters and lengths of vessels of the same order, and of topologic parameters such as the number of daughter vessels per parent vessel. These and other parameters of vascular networks are the statistical results, and their probability distributions can be measured from observations. On the other hand, the hemodynamic parameters, such as the capillary flow, pressure, and hematocrit (the volume concentration of red blood cells) are also random variables to be statistically determined by experiments. Recently, the concept of hemodynamic heterogeneity in the microcirculation (the vascular network, and more in the subdivision of blood flow regulation in our terms, [illegible] suitable of characterizing vascular beds by statistical geometric characteristics of vessels of the same order and, then, use the ordered hemodynamic models. The present work demonstrates a probabilistic approach to the problem, and its goals to be a further quantitative development of the hemodynamic heterogeneity in terms of probability distributions of the geometric parameters, and of various other characteristics of the system. The analysis starts with examples of some theoretically derived orders of the vessel classification with the statistical step in classification of the vessels into, [illegible] and [illegible] [illegible] [illegible]

Session FM-7: COMPOSITES

Organizer and Chairperson: H.T. HAHN, Washington University in St. Louis
Co-Chairperson: R. BADALIANCE, McDonnel-Douglas Corporation

* 9:30 - 10:00 L.-C LEE and C. K. LIM, TRW, Radicott:
"Finite Element Analysis of Multilayer Printed Circuit Board"

* 10:00 - 10:30 R. BADALIANCE, McDonnel-Douglas, St. Louis:
"Fatigue Damage Mechanism in Composites Due to Bearing Load"

10:30 - 11:00 COFFEE BREAK

* 11:00 - 11:30 R. J. NUISMER, University of Utah:
"The Effects of Load Path on Composite Damage"

* 11:30 - 12:00 D. H. MORRIS, Virginia Polytechnic Institute and State University:
"Fracture of Graphite/Polyimide Composites at Extreme Temperatures"

12:00 - 12:15 S. P. GUPTA, Lead Corporation:
"Elastic Constants of a Uniaxial Composite by Finite Element Energy Method"

12:15 - 12:30 S. RAMAKRISHNAN, Indian Institute of Technology-Bombay, INDIA:
"Determination of Fracture Toughness of Composite Materials"

FINITE ELEMENT ANALYSIS OF MULTILAYER PRINTED CIRCUIT BOARD

By

Li-chung Lee, C.K. Lin

Central Technology Division

ABSTRACT

A multilayer printed-circuit board is composed of a number of layers of power planes and signal planes. All of the adjacent copper planes are insulated from each other with sheets of electronic glass fiber with reinforced epoxy. In a recent design, a 20-layer composite of these layers was constructed. The internal signal planes are used in pairs. Communication between the X-Y planes of a signal pair is accomplished by the laser drilled and additive-plated perpendicular vias. The laminated composite is also drilled with plated-through holes which improve the internal signal and power connections.

With increasing electronic packaging density, the circuit lines are made thinner and plated-through holes are drilled with an aspect ratio of greater than 10. The structural integrity of the composite, which connect the proper electrical paths/lines, is of major concern. For this, the finite element analysis of the stresses and deformation in the composite is obviously necessary. ANSYS, which is a large scale, general purpose, finite element program, has been used throughout the analysis. In general, the model is generated interactively with a graphics terminal, the solution is run in batch mode, and the results are then interpreted and plotted in graphical form.

Due to the thermal expansion mismatch between the epoxy-glass and the copper in the direction normal to the board, thermal stresses occur when the board is subject to a temperature change. Two dimensional axisymmetric models were used for the component site and the plated-through holes. Linear elasticity was assumed to simplify the analysis. Both thermal and mechanical loadings were investigated to ensure the structural and electrical integrity of the circuit board.

In comparison with existing three dimensional programs, ANSYS is, in general, very effective in both problem definition and computer run time for the present case.

FATIGUE DAMAGE MECHANISM IN COMPOSITES DUE TO BEARING LOAD

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The objective of this study was to investigate influence of bearing loads on fatigue life of graphite-epoxy composite laminates. Constant amplitude fatigue tests of specimens with high bearing loads demonstrated two distinct modes of failure; hole wear, and laminate rupture. Specimens that failed in the laminate rupture mode showed hole wear prior to rupture. The enlarged epoxy photographs of these specimens show that the hole wear damage mechanism is a local one and it occurs in the compact pulverization of the material directly under the bearing load, and matrix cracks beside the fibers. Based on these observations, the strain energy density around the incremental volume element at the location of maximum bearing stress was used to measure fatigue damage. The energy density was calculated with respect to the bearing ultimate strain energy density, and used to correlate constant amplitude hole wear lives of several laminated coupons at various stress ratios and environments. This technique was then used to predict spectrum lives, indicating good correlations with test data.

THE EFFECTS OF LOAD PATH ON COMPOSITE DAMAGE

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The existence of micro-damage zones in fiber-reinforced composite materials is well known [1,2]. An attempt to include the effects of this damage in the constant-amplitude behavior of a composite ply has been made in [3]. The resulting relationships were basically phenomenological in nature although based on simple models of the physical damage modes known to occur in composites. This research has been directed at using this model to predict the stress-strain and fatigue behavior of multidirectional laminates subjected to spectrum loading [4]. The conclusions, which differed in some cases up to relatively insignificant to the damage modeling.

In the present study, an experimental investigation has been made of damage growth and its effects on fatigue properties in the case where the loading is not constant but varies. In the experimental work, damage growth was monitored [illegible] in various experiments of varying complexity. The [illegible] experiments in determining damage growth, its effects on the [illegible] fatigue life were carried out [illegible].

Analytical predictions have been made using the model developed in [3]. Experiments on this model are [illegible], thereby [illegible] explicit evaluation of the accumulation curves resulting from changes discussed in subsection [illegible]. The predictions of damage growth and effects on fatigue to be made were sensitive to the changing load path and results close to the constant cases reported in [3], providing a better indicator of damage modeling accuracy.

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FRACTURE OF GRAPHITE/POLYIMIDE COMPOSITES AT EXTREME TEMPERATURES

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Notched and unnotched laminates were tested at -250, 75, and 600°F. The laminates consisted of Celion 6000 fibers in a matrix of PMR-15 and NR-150B2 polyimide. Elastic moduli and fracture strengths were determined for $[\pm 45]_{2S}$, $[0/45/90/-45]_S$ and $[45/0/-45/0]_S$ laminates. The tensile modulus and tensile strength of the unnotched $[\pm 45]_{2S}$ laminate decreased with increasing temperature. The effect of matrix material on the modulus and strength of this matrix dominated laminate was negligible. In addition, the effect of temperature and matrix material on the tensile modulus and strength of the fiber dominated $[0/45/90/-45]_S$ laminate was negligible.

The fracture strength of the $[0/45/90/-45]_S$ notched laminate was determined using 2.5 or 4.0 in. wide plates. The notched strength of the laminate was modeled using the point stress and average stress criteria of Nuismer and Whitney [1]. The ratio of notched to unnotched strength was essentially independent of temperature and plate width, as well as matrix material. The characteristic length associated with the fracture criteria was linear with temperature. The same type of behavior was observed for the $[45/0/-45/0]_S$ laminate. This laminate was also tested with crack-like slits. The difference in fracture behavior between holes and slits was insignificant. The fracture behavior of the $[\pm 45]_{2S}$ notched laminate could not be modeled using the Nuismer-Whitney criteria.

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ELASTIC CONSTANTS OF A UNIAXIAL COMPOSITE BY FINITE ELEMENT ENERGY METHOD

by

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Several closed form and series solutions exist for the determination of effective elastic constants of a uniaxial composite layer. However, for certain composite materials, the properties obtained by using these methods differ greatly from each other. We have devised a new method based on finite element technique and strain energy that will overcome this shortcoming. A representative volume of an idealized array of a composite material is analyzed by using finite element method, by imposing nine sets of boundary conditions. The energy values obtained by these nine analyses are then used to solve a set of simultaneous equations for the determination of the material stiffness of the composite layer. We call this method the Finite Element Energy Method.

Following is an example that proves the validity of this method by comparing the computed properties by different methods of a glass/epoxy composite having a fiber volume fraction of 20 percent.

Method	E_L	E_T	ν_{TL}	G_{LT}	G_{TT}	ν_{TT}
Rule of Mixtures [1]	[illegible]	[illegible]	[illegible]	[illegible]	---	---
Halpin-Tsai[1]	[illegible]	[illegible]	[illegible]	[illegible]	---	---
Ekvall[2]	[illegible]	[illegible]	[illegible]	[illegible]	---	---
Greszczuk[3]	[illegible]	[illegible]	[illegible]	[illegible]	---	---
Hashin[4] (Lower Bound)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hashin (Upper Bound)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
F.E.E.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(L and T subscripts represent axes parallel and perpendicular to the fiber direction. Moduli are given in psi x [illegible].)

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DETERMINATION OF FRACTURE TOUGHNESS OF COMPOSITE MATERIALS

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One of the major problems of the determination of fracture toughness of a composite material, is the identification of the load level at which an instability, equivalent to the start of crack extension in metals, occurs in a composite material. Inherent to the concept of fracture toughness, however, is the axiom that the stress intensity factor at which the instability occurs in the material should be independent of size and geometry of the test specimen. In order to evolve a simple but suitable criterion for the identification of the instability which is consistent with this axiom, CT and CCT specimens with 5.5mm thickness out of different widths ranging from 25 to 250mm have been tested.

The material investigated is a chopped strand mat type glass fibre reinforced plastic composite where the crack propagates in a self-similiar manner and the fracture toughness in a macroscopic scale is isotropic. The composite has 20 percent glass fibre by volume and the matrix is araldite. The determination of the fracture roughness of such type of composites is important since such composites are currently being considered for critical load bearing applications.

Load vs. load-line displacement test records were obtained to enable simultaneous measurements of K_I and J_I. Three points were identified on the test record - the ASTM E399 5% secant value, termed as K_Q; the maximum value of K_I in the test record, termed as K_{max}; and the value of K_I at which a milky debonded zone forms at the crack tip, termed as K_{db}.

It is observed that K_Q as also the K_{max} values vary significantly with the width and the specimen geometry. On the other hand, K_{db} is almost independent of size and geometry. Thus, K_{db} could form a basis for K_{IC} measurements in such materials. The agreement between the measured K_I and J_I values at debonding is good indicating that a K-based toughness could be used in spite of the low thickness of the specimens.

[redacted]

Organizers and Chairpersons: W. Z. [redacted], Colorado State University

[redacted], NASA Lewis Research Center

* 9:30 – 10:00 J. E. [redacted], Cambridge University, England:

* 10:05 – 10:35 [redacted]

10:30 – 10:45 [redacted]

* 11:00 – 11:30 [redacted]

* 11:30 – 12:00 [redacted]

* 12:00 – 12:30 [redacted]

12:30 – 2:00 [redacted]

ACOUSTIC ANALOGIES AND TURBULENCE

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The mechanics by which sound evolves from unsteady boundaries and flow can be represented in acoustic analogies which provide a formal structure for analyzing the process of sound creation. The acoustic analogy of Lighthill has been the firmest foundation for modelling the jet noise problem. Studies of that problem have gradually increased in sophistication and scope to a point where the analogy itself has been developed to display characteristics that are novel and a little startling. The early models regarded turbulence as prescribed and concentrated purely on the acoustical consequences of that turbulence. But the more advanced analogies recognize definite constraints on acoustically important elements of turbulence and point to the susceptibility of the noise generating elements of turbulence to external stimulus. Other long waves induced by turbulence can be similarly analyzed and correspondingly interesting deductions made on vibrational fields induced by turbulent flow. This paper will describe some of the developments leading to notions that turbulence can be influenced by well chosen external stimuli and speculate a little on areas where these effects might have significant practical application.

BROAD-BAND ACTIVE SOUND ABSORPTION IN A PIPE IN THE PRESENCE OF FLOW

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Ecole Centrale de Lyon, France

A new active noise control system is proposed with a view to reducing the inlet noise of centrifugal fans. It consists of two or more stages of single monopole controllers, each of them reducing the noise in one octave of broad-band sound in the 63-500 hz frequency range.

This set up is an improvement of the monopole system recently described by Eghtesadi & Leventhall (J. Acoust. Soc. Am., 1982, 71, p. 608).

Our investigation is made in a short (1 m) square duct (0.1 x 0.1m^2) at flow velocities up to 30 m/s. It is demonstrated that in the case of plane waves, each stage, of only 0.4 m length including the detector, can achieve attenuation within 15 - 20 dB in third-octave random noise, regardless of variations in flow speed. From these experiments fundamental limitations in flow duct noise control are discussed. It is shown that if a suitable transfer function of the controll is required to maintain optimal performance, the difficulty of accurate acoustic detection in the turbulent pressure field is the main practical problem; the corrupting effect of turbulence on the acoustic propagation seems very small at the low frequencies and velocities used in the present investigation.

Shear Layer Momentum Thickness and Jet Development*

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McDonnell Douglas Research Labs

A systematic experimental data base is being developed to characterize flowfield instabilities, their role in affecting turbulent scale development in jet shear flows, and the potential for using the interacting instability mechanisms for control of flowfield and acoustic-field effects as the basis for optimal noise-suppressor development.

For jets with thin laminar initial shear layers, the early development of turbulent structure is governed by the shear-layer instability mechanism, I_s, consisting of the growth of instability waves at the most amplified frequency, f_s, which scales on the shear-layer momentum thickness, Θ. Axisymmetric vortices develop, subsequently amalgamate, and produce large-scale vorticity concentrations. The region at the end of the potential core is postulated to be governed by the jet-column instability mechanism, I_j, which generates a frequency f_j that scales on the jet diameter, D. Experimental data are presented for three subsonic axisymmetric air jets: 1) For a jet with an initially laminar shear layer with $f_s > 2^4 f_j$, the shear-layer instability mechanism I_s is decoupled from the rest of the flow and is limited in its effect to the initial region of the shear layer. The rest of the flow is governed by the jet-column instability mechanism, I_j, which is independent of velocity. 2) For a laminar shear layer with $f_s/f_j \leq 8$, the shear-layer instability frequency governs the coherent scale development throughout the entire flowfield. The mechanism I_j enters only indirectly by limiting the lowest nondimensional frequency in the flowfield to $St_j \pm 0.15$. 3) The onset of turbulence in the initial shear-layer eliminates the initial shear layer thickness as a factor in determining the rate at which coherent structures develop in the jet. For this case the only coherent motion is at the Strouhal number $St_j \approx 0.45$, and the flow is governed entirely by the jet-column instability mode. The influence of the initial shear layer momentum thickness is different in jets with thin and thick shear layers (cases 1 and 2). If the frequency data measured throughout the flowfield are normalized with the initial momentum thickness, Θ, and plotted against the normalized momentum thickness, R/Θ, rather than jet velocity, then data from several jets with different diameters can be consolidated on one curve.

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*This research was conducted under the McDonnell Douglas Independent Research and Development program.

The Phenomenon of Self-Excitation of Axisymmetric Jets*

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The self-sustained excitation of an axisymmetric jet via a 'whistler nozzle' appears highly promising for various applications involving turbulent transport, combustion and aerodynamic noise production. The device consists of a pipe, along with a movable outer collar, attached to a jet nozzle exit. The characteristics of the phenomenon and the response of the jet flow to self-excitation have been investigated for wide ranges of the controlling parameters, and the phenomenon at work is explained. It is shown that the phenomenon is the coupling of two independent resonance mechanisms: shear-layer tone [1] resulting from the impingement of the pipe-exit shear layer on the collar lip and organ-pipe resonance of the pipe. The crucial role of the shear-layer tone in driving the organ-pipe resonance is proven by reproducing the event in pipe-ring and pipe-hole configurations in the absence of the collar. Furthermore, resonable collapse of the data in nondimensional form is achieved only when the initial momentum thickness is used as the length scale. Unlike the jet tone, ring tone, hole tone [2-4] and the shear layer tone, where the successive stages occur with overlaps, there are intra-stage ranges for which the whistler tone is inoperative because conditions for both resonance mechanisms cannot be simultaneously met in these ranges. The self-excitation produces a large enhancement of the near-field jet turbulence and increases jet spread at all downstream distances. The self-excitation produces broadband turbulence amplification in the jet up to $x/D \cong 6$. This amplification is the maximum at $x/D \cong 4$ and is higher at higher jet Reynolds numbers. Further details of the self-excited jet characteristics and of the phenomenon are available in references [5] and [6], respectively.

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*Supported by NASA Lewis Research Center Grant NAG-3-198.

EFFECT OF INCIDENCE ANGLE ON NOISE GENERATED BY AN AIRFOIL ENCOUNTERING HIGH FREQUENCY CONVECTED DISTURBANCES

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An analysis is developed which accounts for the influence of airfoil incidence angle on the far field noise generation when an airfoil encounters vortical or entropic disturbances. The theory is based on the exact inviscid equations linearized about the nonuniform compressible mean flow (Goldstein, 1978). The airfoil is modelled as a flat plate at incidence angle, α, to a subsonic stream. Three-dimensional disturbances whose wavelengths are small compared to the airfoil chord ($k \gg 1$) are imposed on this steady, two-dimensional flow. In order to develop a closed form solution for the high frequency case, the additional assumption $\alpha^2 k \ll 1$ is introduced. Physically, this implies that, compared to the disturbance wavelength, the displacement of the mean flow stagnation streamline from the airfoil leading edge is small. For consistency with the high frequency assumption, α must then be small and the simplifications in Kerschen and Balsa (1980) are applicable. The solution to the linearized equations is developed using singular perturbation techniques. In the vicinity of the airfoil leading and trailing edges, local regions which scale on the disturbance wavelength are present. Away from the airfoil leading and trailing edges the mean flow variation is "slow" compared to the disturbance wavelength, and the solution has a multiple scales or geometric acoustics form. The perturbation terms representing incidence angle effects are $O(\alpha k^n)$, where $n = \frac{1}{2}, 0, -\frac{1}{2}$ etc. Thus, the effect of incidence angle is larger for higher frequencies.

The results of the analysis show that, for high frequency disturbances, the noise generation is concentrated at the airfoil leading and trailing edges. The mean flow nonuniformity away from the airfoil edges bends the acoustic rays and modifies the radiation pattern, but does not generate additional noise. This result can be explained physically by noting that over most of the flow field, the disturbance is "slow". Noise generation requires a "rapid" distortion, which occurs only at the airfoil edges. The results also indicate that for high frequencies the generated noise level is controlled by the "local" incidence angle of the leading edge rather than the total airfoil loading. In agreement with the empirical correlation of Binder and Hardy (1957). Comparing the present results with the acoustic analogy approach, it appears that at high frequencies the free quadrupoles representing airfoil loading effects are ineffective noise sources compared to the boundary terms on the airfoil surface.

Binder, R.B. and Hardy, B.E. (1957) J. Aircraft 14, 897-898.
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Session FA-1: POLYMERS/NON-NEWTONIAN FLUIDS

Organizer and Chairperson: K. R. RAJAGOPAL, The Catholic University of America
Co-Chairperson: D. S. MALKUS, Illinois Institute of Technology

* 2:00 - 2:30 B. D. COLEMAN, Carnegie-Mellon University and L. J. ZAPAS, National Bureau of Standards:
"A New Method of Representing the Memory Functionals of Non-Linear Viscoelastic Materials. Part I. Theory."

* 2:30 - 3:00 L. J. ZAPAS, National Bureau of Standards, and B. D. COLEMAN, Carnegie-Mellon University:
"A New Method of Representing the Memory Functionals of Non-Linear Viscoelastic Materials. Part II. Experiments."

* 3:00 - 3:30 A. PETERLIN, National Bureau of Standards:
"The Influence of the Polymer Morphology on the Transport Properties"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 A. S. WINEMAN, University of Michigan; K. R. RAJAGOPAL, The Catholic University of America; and J. J. SHI, Rocketdyne, Division of Rockwell International:
"Diffusion of a Fluid Through a Highly Elastic Spherical Membrane"

4:30 - 4:45 A. M. VINOGRADOV, The University of Calgary, Canada:
"Symmetrical and Nonsymmetrical Stability Problems of Axially Compressed Viscoelastic Cylindrical Shells"

4:45 - 5:00 A. ZIGNER, The University of Alabama:
"Some New Results in Rheological Fluid Mechanics Concerning Free Surface Viscometry"

5:00 - 5:15 J.-X. YUAN, Academia Sinica, China:
"A Method of Determining the Rheological Parameters and Relaxation Spectrum of Generalized Rheological Models"

5:15 - 5:30 S. I. HARIHARAN, NASA Langley Research Center:
"On the Normal Stress Effects of Incompressible Non-Newtonian Fluids"

A NEW METHOD OF REPRESENTING THE MEMORY FUNCTIONALS OF NON-LINEAR VISCOELASTIC MATERIALS. PART I. THEORY.

S.B. Coleman, Carnegie-Mellon University, Pittsburgh, PA 15213, and L.J. Zapas, National Bureau of Standards, Washington, DC 20234.

A new type of expansion will be proposed for non-linear functionals possessing the convolution integration approximation for the response of viscoelastic materials with gradually fading memory. The first term in the expansion is in general non-linear and has the form of the single integral functional in the relation proposed by Rabotnov, Pipkin, & Rivlin; the higher order terms are iterated integrals of convolution functions. The relation of the expansion to others presented in the literature will be explained, and theorems will be given which suggest that the stress in a non-linear viscoelastic material, far from the "most history", may be given to a good approximation by just the first two terms in the expansion.

It will be shown how the expansion may be applied to characterize the stress in motions of extension and general shearing motions. It also will be shown that, in principle, each successive term in the expansion can be determined by an elementary set of experiments.

A NEW METHOD OF REPRESENTING THE MEMORY FUNCTIONALS OF NON-LINEAR VISCOELASTIC MATERIALS. PART II. EXPERIMENTS.

L.J. Zapas, National Bureau of Standards, Washington, DC 20234, and S.B. Coleman, Carnegie-Mellon University, Pittsburgh, PA 15213.

In this part we examine some experimental results which were obtained for concentrated polyisobutylene solutions. The data were obtained from simple and multistep shearing deformations in the non-linear region. Both the shearing stress and the first normal stress differences were measured. Using a special case for the second term of the expansion (which we represent as a product of two functions) we show how to characterize various types of strain histories. In view of these results we can explain the behavior observed in some other materials for similar strain histories.

THE INFLUENCE OF THE POLYMER MORPHOLOGY ON THE TRANSPORT PROPERTIES

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The diffusive component in the contemporaneous polymer mixes plane almost exclusively through the amorphous component. The crystals are practically impermeable and act as obstacles to the transport. The modifications of the amorphous component by the crystals are geometrical and physical. The geometrical modifications are described by the tortuosity and the blocking factors. The crystals compel the diffusing molecules to travel a longer path than in a purely amorphous material. A great many processes are too complex for large molecules. The physical modifications are the consequence of the fact that practically all the intermolecular links in the amorphous component are on one (side) or on both (sides, the unbroken) chain found in the original location. Higher concentrations hence reduce the chain mobility and packing and by doing so enhance the orientation preparation of the amorphous component. A much longer effort is needed by the plastic deformation which alters the shape, thereby material remains impermeable or only so the original location. Another component is completely destroyed upon the thermal recrystallization. Very small fractions suffice this plane during stretching of the thermo-material which considerably increases the total chemical cohesion and strength. Annealing can so much relax the chains in the amorphous layers of the drawn polymer that the transport properties become comparable with those in the original isotropic material.

Diffusion of a Fluid Through a Highly Elastic Spherical Membrane

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There are several problems of practical interest like the problem of filtration where a membrane theory for the diffusion of a fluid through an elastic solid would be appropriate. A starting point for such a theory would be the work developed by Green and Adkins [1] for purely elastic solids. However, modifications have to be made to the above theory to make it appropriate in the case of interacting continua. For instance, in the case of interacting continua, the gradients of the stretch ratios in the thickness direction are found to be significant and, hence, cannot be ignored, as is done in the single constituent elastic theory. In this work, we study the diffusion of a fluid through a spherical membrane of highly deformable rubber-like non-linearly elastic solid within the framework of the theory of interacting continua. The problem of specifying the boundary conditions for such a problem is resolved by using a relation between surface tractions and the stretching when the mixture is in a saturated state (cf. Shi, Rajagopal, Wineman [2]). The specific boundary value problem of diffusion through a spherical membrane is studied in great detail.

[1] Green, A. E. and J. E. Adkins, Large Elastic Deformations, Clarendon Press, Oxford (1960).

[2] Shi, J. J., K. R. Rajagopal and A. S. Wineman, Intl. J. Eng. Sci., 19, 871-889 (1981).

SYMMETRICAL AND NONSYMMETRICAL STABILITY PROBLEMS OF AXIALLY COMPRESSED VISCOELASTIC CYLINDRICAL SHELLS*

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The paper presents a creep stability analysis of a viscoelastic cylindrical shell subjected to a uniform axial compressive load, p smaller than the classical buckling load for corresponding elastic shells, p_e. It is assumed that the load is applied to the shell instantaneously at the time t = 0 and kept constant at t > 0. The material properties of the shell are defined by the constitutive equations of the linear theory of viscoelasticity in terms of integral operators of hereditary type.

The governing equation to the nonsymmetrical stability problem of the viscoelastic shell is of integro-differential form

$$\frac{B^0}{h}(\nabla^4 w) + \frac{B^0}{R^2}\left(\frac{\partial^2 w}{\partial x^2}\right) + pV^4\left(\frac{\partial^2 w}{\partial x^2}\right) = 0 \qquad (1)$$

where the normal displacement w is a function of coordinates x,y and time t. B^0 and B^1 represent two linear integral operators of Volterra type. It is assumed that the boundary conditions to the problem are stationary in time. The governing equation to the symmetrical stability problem is derived as a special case of the equation (1).

In the presence of creep two destabilizing parameters are responsible for instability of the structure - the applied load and time. A particular moment in time when bifurcation of equilibrium of the structure becomes possible under static load $p < p_e$ is defined as the viscoelastic critical time. To derive the instability condition from the governing integro-differential equation (1) a combination of two solution methods is applied - the separation of variables method and the quasi-elastic solution technique. First the viscoelastic stability problem is reduced to the eigenvalue problem of a linear integral equation of Volterra type. Then from this equation the viscoelastic critical time is determined as a function of the magnitude of the applied compressive load and the creep properties of the material.

To illustrate the derived solution a particular case for a shell made of a simple viscoelastic model material is considered and the results are presented in graphical form.

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* The results presented here were obtained in the course of research sponsored by the Natural Sciences and Engineering Research Council of Canada in the form of a Grant No. A-4000.

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The University of [redacted]
[redacted], [redacted]

[redacted]

A METHOD FOR DETERMINING THE RHEOLOGICAL PARAMETERS AND RELAXATION SPECTRUM OF GENERALIZED RHEOLOGICAL MODELS

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Academia Sinica, Wuhan, China

Most of the engineering materials like metals, plastics, soft soils and rocks exhibit rheological behaviour to a certain degree. Although the creep and relaxation characteristics of those materials have been studied well either in the field or in the laboratory, the application of the rheological effect in practical engineering problems is not often found in the design offices. The main reason is that the determination of the parameters of rheological models is not easy except for simple models. In this paper, a method for determining the rheological parameters and relaxation spectrum for generalized Maxwell model is given.

For constant strain $\varepsilon = \varepsilon_0$, the generalized Maxwell model shown in Fig. 1 can be described by the equation

$$(\frac{D}{E_1}+\frac{1}{\eta_1})(\frac{D}{E_2}+\frac{1}{\eta_2})\ldots(\frac{D}{E_n}+\frac{1}{\eta_n})\sigma = 0 \qquad (1)$$

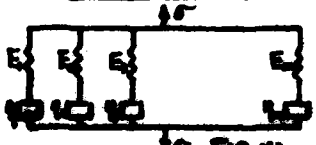

Fig.(1)

whose solution is

$$\sigma = \sum_{i=1}^{n} a_i e^{-t/\tau_i}, \quad \tau_i = \frac{\eta_i}{E_i} . \qquad (2)$$

Here $\tau_1, \tau_2, \ldots \tau_n$ are the relaxation spectra. The coefficients $a_1, a_2, \ldots a_n$ and $\tau_1, \tau_2, \ldots \tau_n$ can be determined by using the method given by Forberg.[1] For the ith element alone, we have

$$\sigma_i = a_i e^{-t/\tau_i}$$

where again $\varepsilon = \varepsilon_0$ = constant. For $t=0$, $\sigma_{io} = a_i$; since $\varepsilon_0 = \sigma_{io}/E_i$, therefore $E_i = a_i/\varepsilon_0$. Recalling that a_i had already been calculated, we can find E_i and hence $\eta_i = E_i \tau_i$. Thus the rheological parameters E_i and η_i of the generalized Maxwell model are now completely determined. Consequently, the relaxation function

$$\phi(t) = \sum_{i=1}^{n} E_i e^{-t/\tau_i}$$

and the integral form of the stress-strain relation

$$\sigma(t) = \int_{-\infty}^{t} (t-\tau) \frac{d\varepsilon(\tau)}{d\tau} d\tau$$

can be determined.

C.-E. Froberg, "Introduction to Numerical Analysis", 1965 Addison International Series, Addison-Wesley Pub. Co. Inc. London.

ON THE NORMAL STRESS EFFECTS OF INCOMPRESSIBLE NON-NEWTONIAN FLUIDS

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At present there are various viscometric flow models available to determine the rheological properties of incompressible non-Newtonian fluids. These models of fluids describe mechanical behaviour of an incompressible fluid completely by three material functions η, σ_1 and σ_2 which depend on the state of shear k. In the literature, η is known as the viscosity function and σ_1 and σ_2 are known as the first and second normal stresses of the fluid. In this note we introduce a new viscometric flow model and derive a theory for the measurement of the second normal stress function σ_2. We also indicate how such a measurement can be performed in practice.

Session FA-2: RAPID FLOWS OF GRANULAR MATERIALS

Organizer: J. T. JENKINS, Cornell University
Chairperson: O. RICHMOND, U. S. Steel Corporation

* 2:00 - 2:30 C. CAMPBELL and C. BRENNEN, California Institute of Technology:
"Computer Simulation of Granular Material Shear Flows"

* 2:30 - 3:000 H. H. SHEN and N. L. ACKERMANN, Clarkson College of Technology:
"Constitutive Relationships for Two-Dimensional Granular Flow with Anisotropic Collision Effects"

* 3:00 - 3:30 J. T. JENKINS, Cornell University:
"A Kinetic Theory for Rapid Deformations of Granular Materials"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 S. B. SAVAGE, McGill University, Canada:
"Vibrational Fluidisation and Mixing of Granular Materials"

* 4:30 - 5:00 M. M. MEHRABADI, Tulane University:
"Micromechanically Based Rate-Independent Constitutive Relations for Granular Flow"

5:00 - 5:15 S. C. CHENNENNU, University of Nigeria, Nsukka:
"Probabilistic Stresses in Granular Media"

COMPUTER SIMULATION OF GRANULAR MATERIAL SHEAR FLOWS

C. Cundall and O. Strack
California Institute of Technology

This paper presents results on shear flow of granular materials obtained using a two dimensional computer simulation. Inclined chute flows with gravity and boundary shear as the drivers of motion are modelled using assemblages of circular cylinders whose motions are followed individually. The collisions are inelastic; interstitial fluid effects are neglected. Velocity, solids fraction, and "granular temperature" profiles are presented for various choices of the governing parameters (such as chute inclination, ratio of particle size to flow depth, coefficient of restitution, etc.). In addition, the statistical properties of these flows such as the departure from Maxwellian velocity distribution, the collision angle distribution, and the parameter "Q" are examined and are shown to be functions of the solids fraction and the coefficient of restitution. This comparison is made with the recent theoretical studies of Savage and Jeffrey [1], Jenkins and Savage [2], and others.

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[1] Savage, S.B. and Jeffrey, D.J., "The Stress Tensor in a Granular Flow at High Shear Rates", J. Fluid Mech., Vol. 110, 1981, pp. 255-272.

[2] Jenkins, J.T., Cowin, S.C., "Theories for the Rapid Flow of Identical, Smooth, Nearly Elastic, Spherical Particles", in Mechanics of Granular Materials: New Models and Constitutive Relations, Elsevier Scientific Publishing Co., Amsterdam, 1983.

CONSTITUTIVE EQUATIONS FOR TWO-DIMENSIONAL GRANULAR FLOW AND COMPARISON WITH EXPERIMENTS

Haruo H. Ishida and Masaharu M. Nakagawa
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Oklahoma College of Technology

Constitutive relationships are developed which describe the rapid shearing motion of a two-dimensional granular mixture. A binary collision model is used to describe the collision dynamics of the particles, both the collisional interactions and wave motion are studied. Rheological terms developed during particle collisions are averaged to obtain the time dependent solutions for some previously derived constitutive relationships, e.g. Ogawa et al. [1] and Shen and Ackermann [2] do not appear. The theories are found to be in much better agreement with experiments than those derived with rectangular collision models.

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[1] Ogawa, S., Umemura, A., and Oshima, N., "On the Equations of Fully Fluidized Granular Materials", Z. angew. Math. Phys., Vol. 31, 1980, pp. 483-493.

[2] Shen, H., and Ackermann, N.L., "Constitutive Relationships for Fluid-Solid Mixtures", J. Eng. Mech. Div., ASCE, Vol. 108, 1982, pp. 748-768.

A Kinetic Theory for Rapid Deformations of Granular Materials

J.T. Jenkins
Department of Theoretical and Applied Mechanics
Cornell University

We present a theory for rapid deformations of granular materials that was recently proposed by Jenkins and Savage [1]. They focused attention on a material comprised of identical, smooth, nearly elastic, spherical particles and used arguments employed in the kinetic theory of gases to derive balance laws for the mean density, mean velocity, and mean kinetic energy of the velocity fluctuations. The introduction of a simple but natural form for the probability distribution governing the liklihood of collisions between pairs of particles permits the calculation of the stress tensor, the flux of fluctuation energy, and the rate of dissipation of fluctuation energy. We illustrate the predictions of this theory for some simple flows. We highlight the assumptions upon which the theory rests and emphasize the limitations of the formulation in an effort to indicate the directions for further research.

Reference

[1] Jenkins, J.T., and Savage, S.B., "A Theory for the Rapid Flow of of Identical, Smooth, Nearly Elastic, Spherical Particles," J. Fluid Mech. (pending publication).

VIBRATIONAL FLUIDIZATION AND MIXING OF GRANULAR MATERIALS

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This paper describes experimental and theoretical studies of vibration induced flow and mixing of dry granular materials. Tests were performed on spherical polystyrene beads contained in a rectangular box having transparent front and back walls and a flexible, nominally horizontal, bottom which could be driven at various frequencies and amplitudes. The amplitude of the bed vibrations was a maximum at the center and decreased toward the vertical side walls. Because of the nonuniform energy input through the bed, slow recirculating flow patterns develop and mix the granular material. Velocity fields were measured as a function of bed vibration frequency and amplitude. An approximate analysis of the recirculating flow patterns is developed by making use of the constitutive theory of Jenkins and Savage [1].

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[1] Jenkins, J.T., and Savage, S.B., "A Theory for the Rapid Flow of Identical, Smooth, Nearly Elastic, Spherical Particles," J. Fluid Mech. (pending publication).

MICROMECHANICALLY BASED RATE-INDEPENDENT CONSTITUTIVE RELATIONS FOR GRANULAR FLOW

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Tulane University

Our recent work [1] on the micromechanical description of the granular material behavior is summarized. The relationship between the overall stresses [2] and a measure of fabric of the material [3,4] is discussed. Evolution of fabric and the corresponding kinematics is also discussed. Based on the observation that the change in fabric induces change in contact forces, rate-independent constitutive equations are developed, and some special cases are considered.

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[1] Mehrabadi, M.M., and Nemat-Nasser, S., "A Micromechanically Based Rate Constitutive Description of Granular Materials," (pending publication).
[2] Christoffersen, J., Mehrabadi, M.M., and Nemat-Nasser, S., "A Micromechanical Description of Granular Material Behavior," J. Appl. Mech. 48, 339-344 (1981).
[3] Oda, M., Nemat-Nasser, S., and Mehrabadi, M.M., "A Statistical Study of Fabric in a Random Assembly of Spherical Granules," Int'l J. for Num. and Anal. Meth. in Geomech. 6, 77-94 (1982).
[4] Mehrabadi, M.M., Nemat-Nasser, S., and Oda, M., "On Statistical Description of Stress and Fabric in Granular Materials," Int'l J.for Num. and Anal. Meth. in Geomech. 6, 95-108 (1982).

PROBABILISTIC STRESSES IN GRANULAR MEDIA

by
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of Nigeria, Nsukka, Nigeria.

ABSTRACT: In recent years a probabilistic approach is being developed for the prediction of stresses in a half-space of soil that is subjected to loads on the surface.

In the diffusion model the applied influence (normal surface load) performs a random-walk from particle to particle and the spreading of the influence is analogous to a diffusion process. For the Boussinesq problem of a point force acting normally (z-direction) on the surface (x-y plane) of the half-space of granular material, the vertical-normal stress, σ_{zz}, is thus governed by the diffusion equation

$$\frac{\partial \sigma_{zz}}{\partial t} = C \left(\frac{\partial^2 \sigma_{zz}}{\partial x^2} + \frac{\partial^2 \sigma_{zz}}{\partial y^2} \right), \qquad (1)$$

where $t = z^2$ gives the analogy between the (unsteady) diffusion problem and the (steady) Boussinesq problem, and C is the diffusion analogy constant.

The solution of eqn.(1) for the Boussinesq problem is, with $r^2 = x^2 + y^2$,

$$\sigma_{zz} = (1/4\pi Cz^2)\exp(-r^2/4Cz^2). \qquad (2)$$

For a granular medium consisting of randomly-packed uniform spheres, it is shown that $C = 1/(N-2)$, where N is the average number of points of contact, per particle, with other particles. This formula is then used to relate C to the relative density of the medium. Over a wide range of relative densities this formula gives vertical-normal stresses that are in fairly good agreement (especially near the load axis) with experimental data for sands subjected to uniform circular normal surface pressure. This goes a long way towards (perhaps for the first time) explaining quantitatively the considerable scatter in the observed stress distributions in sands as reported in the various tests that have been conducted over the years.

References: (1) Harr, M.E., Mechanics of Particulate Media: A Probabilistic Approach, McGraw-Hill, New York, 1977.

(2) Chikwendu, S.C. and Alimba, M.U., Diffusion Analogy for Some Stress Computations, J. Geotech. Engrg. Div., ASCE, 105, 1337, 1979.

Session FA-3: DYNAMICAL SYSTEMS

Organizer and Chairperson: J.S. GIBSON, University of California, Los Angeles
Co-Chairperson: J. A. WALKER, Northwestern University

* 2:00 - 2:30 A. ANDRY, JR., Lockheed California Co. and D.J. INMAN, SUNY, Amherst, NY:
"Modal Control for a Class of Linear Discrete Vibrating Systems"

* 2:30 - 3:00 L. G. CLARK, University of Texas at Austin:
"Longitudinal Stability and Control of a Traffic String"

* 3:00 - 3:30 J. R. DICKERSON, University of South Carolina:
"Behavior of Dynamical Systems in Accelerating Frames"

3:30 - 3:45 C. D. BAILEY and R. D. WITCHEY, The Ohio State University:
"Harmonic Motion of Nonconservative, Forced, Damped Systems Subjected to Nonpotential Follower Forces"

3:45 - 4:00 REFRESHMENT BREAK

Modal Control for a Class of Linear Discrete Vibrating Systems

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Lockheed California Company
Burbank, California

D. J. Inman
Dept. of Mechanical Engineering
SUNY
Amherst, New York

The central topic of this paper is the establishment of an efficient synthesis procedure for modifying the modal structure of a vibrating system. This procedure is direct in the sense that it is non-iterative. The setting of the paper will be in state space, but the actual design is performed relative to classical specifications, i.e., modes and mode distribution, by placing eigenvalues in the complex plane and eigenvectors at some desired locations (regions) within the state space. The method can handle configurations subject to structural controller constraints. The theoretical background and a numerical example are provided.

LONGITUDINAL STABILITY AND CONTROL OF A TRAFFIC STRING

L. G. Clark
University of Texas at Austin, Texas

The logic for the individual control of a vehicle in a moving string is based on the absolute velocity of the vehicle and its displacement and velocity relative to the preceding vehicle. The stability properties are considered from a systems viewpoint involving the entire traffic string rather than one or two vehicles. The equations of motion of the system can be expressed in the form:

$$\ddot{z}_1 = -F[\sigma_1]_\tau + \ddot{y}_0$$

$$\ddot{z}_2 = -F[\sigma_2]_\tau + F[\sigma_1]_\tau$$

$$\vdots$$

$$\ddot{z}_n = -F[\sigma_n]_\tau + F[\sigma_{n-1}]_\tau \quad ,$$

where $\sigma_n = -\dot{y}_n + z_n + v_s + B\dot{z}_n$, $\dot{y}_n$ is the absolute velocity of vehicle n, z_n is the deviation from the proper spacing between vehicles n and $n-1$. The function $F[\cdot]$ is piecewise linear representing the signal input which determines the accelerating and braking of the vehicle. The subscript τ on F indicates a τ second delay between the measurement of displacement and velocity signals and the mechanical actuation of braking or accelerating. It has been shown that several arbitrary parameters that would ordinarily appear in the above equations can be chosen as unity without disturbing the generality or practicality of the problem. v_s is the steady state string velocity.

The Liapunov approach is used to obtain certain bounds on the parameter B which determines sequential stability. For the linear forms the Liapunov Direct Method gives a strong stability criterion than is obtained by the usual Fourier Transform which does not allow for non-zero initial perturbations in the traffic string. The non-linear forms can only be treated by the Liapunov Method.

Behavior of Dynamical Systems in Accelerating Frames

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Given a conservative mechanical system in an inertial reference frame with generalized coordinates $q_1, q_2, \ldots q_n$, the dynamical behavior is determined by specification of the kinetic energy $T(q_i, \dot{q}_i, t)$ and the potential energy $V(q_i)$. The paper considers the effect on the behavior of such systems when the reference system is accelerating and/or rotating.

An example of a stable elastic system attached to a uniformly rotating (constant angular acceleration) frame is discussed in detail. This problem arose in an attempt to design and build a high speed grinding machine for medical surgical knives which required a very stable grinding surface.

Harmonic Motion of Nonconservative, Forced, Damped Systems Subjected to Nonpotential Follower Forces

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Solutions to the harmonically forced motion of a nonconservative, viscously damped, continuous system with nonpotential follower forces is demonstrated. The solution is obtained by direct application of the method of Ritz through the equation which Hamilton called the Law of Varying Action. The resulting motion constitutes a "traveling wave phenomena for which the "phase angle" is a function of the independent space variable. No complex variables and no differential equation nor the theory thereof enter the problem.

Session FA-4: ELASTICITY/INELASTICITY

Chairperson: J. BURDURS, Northwestern University

Co-Chairperson: J. PADOVAN, University of Akron

2:00 - 2:15 G. P. GALDI and S. RIONERO, Universita di Napoli, Italy:
"Continuous Dependence Theorems in Linear Elastodynamics in Unbounded Domains Without Definiteness Assumptions on the Elasticities"

2:15 - 2:30 D. HUI and A. W. LEISSA, The Ohio State University:
"Effects of Uni-Directional Geometric Imperfections on Vibrations of Pressurized Shallow Spherical Shells"

2:30 - 2:45 M. TRIANTAFYLLIDIS, The University of Michigan:
"On a Non-Linear Theory for Large Deformations of Inelastic Shells"

2:45 - 3:00 E. N. KUZNETSOV, University of Illinois:
"Statics of Axisymmetric Chebyshev Nets"

3:00 - 3:15 E. C. TING and S. PAYDARFAR, Purdue University:
"Thermomechanical Coupling in Biaxial Thermally Induced Waves"

3:15 - 3:30 M. M. SAED, University of Rhode Island and C. Y. CHA, Pennsylvania State University:
"Dynamic Non-Fourier Thermoelastic Solutions in Cylindrically Bounded Domains"

3:30 - 4:00 [illegible]

4:00 - 4:15 M. [illegible] and H. D. KUMOMENI, University of Delaware:
"On the Response of Poroelastic Layers to Moving Loads"

4:15 - 4:30 D.S. CHEMIL and M. BASED, Tech. University of Nova Scotia:
"On the Bending of Shear Elastic Plates"

4:30 - 4:45 K. A. ANSARI, University of Petroleum and Minerals, Saudi Arabia:
"A Modal Approach to the Solution of Nonlinear Vibration Problems"

4:45 - 5:00 B.P. WOLFSON, John Deere Product Engineering Center, Iowa:
"Tire Slip Phenomena"

5:00 - 5:15 M. GHOSH, North Bengal University, India:
"Torsional Response of an Elastic Half Space to a Rotationally Expanding Ring Source"

[illegible] UNIQUENESS THEOREMS IN LINEAR ELASTODYNAMICS IN UNBOUNDED DOMAINS WITHOUT RESTRICTIVE ASSUMPTIONS ON THE ELASTICITIES.

Giovanni P.Galdi & Salvatore Rionero

Istituto di Matematica "R.Caccioppoli", Mergellina 5, 80134 Napoli, Italy

By suitably coupling the weight function [1] and logarithmic convexity methods(cf.,e.g.,[2]) we prove a "weighted convexity inequality" (WCI) in unbounded domains for classical solutions of linear elastodynamics. These solutions are allowed to "grow" at large spatial distances and the density is allowed to be infinitesimal as well. Moreover, the elasticities are not requested to be sign-definite. The WCI is the steering point to show uniqueness and continuous dependence theorems on initial data, body forces and elasticities in a pointwise metric. To give an idea of our results, we quote the following uniqueness theorem. Let $\mathcal{D}$ be an unbounded domain, $v(x,t)$ a solution to the equations of linear elastodynamics subject to zero data, $\rho(x)$ the density and $a_{ijhk}(x)$ the elasticities. Setting $g = \exp(-\alpha r^2)$, $\alpha>0$, $r = |x-x_0|$, $x_0 \in \mathcal{D}$, we have

THEOREM- Assume $(T>0)$

$$(\rho g)^{1/2} v \in L^2(\mathcal{D}\times(0,T)), \quad (\rho g)^{1/2} \frac{\partial v}{\partial t} \in L^2(\mathcal{D}\times(0,T)), \quad (g/\rho)a_{ijhk}\frac{\partial v_h}{\partial x_j} \in L^2(\mathcal{D}\times(0,T)).$$

Then

$$\int_0^T\int_{\mathcal{D}} \rho v^2 \, dx\,dt < \infty, \quad \lim_{\alpha\to 0} \alpha \int_0^T\int_{\mathcal{D}} (g/\rho)(a_{ijhk}\frac{\partial v_h}{\partial x_j})^2 \, dx\,dt = 0 \Rightarrow v \equiv 0.$$

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1. S.Rionero & G.P.Galdi, Arch. Rational Mech Anal 69 (1979) 37-52.
2. L.H.Payne, Improperly posed problems in PDE, CBMS Reg Conf Series in Appl Math, SIAM (1975).

EFFECTS OF UNI-DIRECTIONAL GEOMETRIC IMPERFECTIONS ON VIBRATIONS OF PRESSURIZED SHALLOW SPHERICAL SHELLS*

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It is now well established that the discrepancies between the experimental and theoretical buckling loads of cylindrical or spherical shells are largely attributed to the presence of unavoidable initial geometric imperfections. The influence of imperfections on the vibrations of cylindrical shells has also been analyzed, but by relatively few researchers [1,2]. The present investigation is the first known one demonstrating the effects of geometric imperfections on vibrations of pressurized spherical shells.

The title problem is based on a solution of the non-linear Donnell shell equations in terms of a normal displacement and a stress function. The pre-vibration state of static equilibrium is determined exactly since the non-linear terms automatically drop out due to the uni-directional character of the initial geometric imperfections. A two-term sinusoidal solution form is assumed for the vibration mode, and the compatibility equation is solved exactly in terms of a three-term stress function. The dynamic equilibrium equation is then solved approximately using a Galerkin procedure. The minimum frequency is sought for all possible wave numbers. Frequency versus applied pressure interaction curves are plotted for a fixed value of Poisson's ratio (ν=0.3) and various values of the imperfection amplitude (μ) and wave number (n) (see example figure for n=1.0), showing considerable reduction in vibration frequency for imperfection amplitudes on the order of the shell thickness.

(1) Watanala, L., "Influence of Initial Geometric Imperfections on Vibrations of Thin Circular Cylindrical Shells", Ph.D. Dissertation, Univ. of Mass., Sept. 1981.

(2) Singer, J. and Prucz, "Influence of Initial Geometrical Imperfections on Vibrations of Axially Compressed Stiffened Cylindrical Shells", J. of Sound and Vibration, Vol. 80, No. 1, 1982, pp. 117-143.

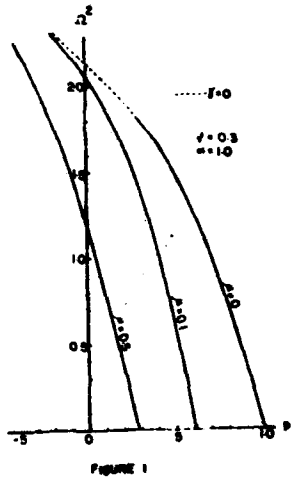

FIGURE 1

* 19th Annual Meeting, Society of Engrg. Sci., Inc. Oct 27-29, 1982, University of Missouri - Rolla.

* Assistant Professor
**Professor

ON A NON-LINEAR THEORY FOR LARGE DEFORMATIONS OF INELASTIC SHELLS

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Numerous attempts have been made up-to-date to construct non-linear shell theories. Motivated by applications in metal plasticity, where, especially in low hardening materials a small strain formulation is inaccurate even at relatively low strain levels and by the desire of making only one assumption, we construct a non-linear shell theory suitable for large deformations and strains valid for a wide class of anelastic materials. Two examples have been worked out in order to give us some preliminary information on the behavior of this theory: one involving a thin elastic plate and the other finite strain bending of a thick plate and results are compared with exact solutions.

Statics of Axisymmetric Chebyshev Nets

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A net represents an underconstrained structural system with intricately interrelated statics and geometry: its equilibrium configuration is a function of the applied load, and, on the other hand, equilibrium in a given configuration is possible only under certain types of loads. A Chebyshev net is one of the most common nets: all of its elementary cells are rhombi. It was proved by Chebyshev that due to and at the expense of the varying net angle the net is applicable to any smooth surface.

The subject of this study is the statical-geometric interrelation for an axisymmetric Chebyshev net. A net segment similar to a basketball net is attached to two parallel and coaxial circular rings of which one is supported in the axial direction while the other is subjected to a given axial tension force. In this case the problem is homogeneous and has as its solution [1] one of the three existing types of pseudospherical surfaces [2]. This configuration and the corresponding stress state are taken as initial conditions for a subsequent surface loading.

Three types of surface loading are considered: 1) uniformly distributed (pneumatic) internal or external pressure; 2) centrifugal load resulting from rotation of the net about its axis of revolution (either the actual mass of the net or a uniformly distributed surface mass are considered); 3) normal pressure resulting from a steady internal axial gas flow. For each of the above loads, the first integral of the solution was evaluated analytically yielding closed-form expressions for the meridian slope and internal forces in the net. These were found in terms of the load parameters, the net angle and radius of revolution. The latter, however, can only be determined numerically, using some kind of forward integration procedure.

The obtained analytical solutions led to several interesting qualitative results. For example, for a net segment under axial tension and uniform internal pressure, a cylindrical form is a possible equilibrium configuration, whereas a conical one is not. As a result, when a net segment stretched between two equal edge disks is subjected to gradually increasing pressure, it changes its shape from a pseudosphere (Gaussian curvature $K<0$), through a cylinder ($K=0$) to a barrel-shaped surface ($K>0$). In the case of unequal edge disks, the initially negative Gaussian curvature first reaches the zero value at the smaller edge and then gives rise to a zone of $K=0$ propagating toward the larger edge and forming a sequence of bell-shaped surfaces.

References

1. E. N. Kuznetsov. Axisymmetric Static Nets, Intern. Journal of Solids and Structures, Vol. 18, 1982.
2. D. E. Struik. Lectures on Classic Differential Geometry. Addison-Wesley, 1957.

Thermomechanical Coupling in Biaxial Thermally Induced Waves

by

E. C. Ting* and S. Paydarfar**

Solutions of the transient thermoelastic analysis induced by rapid heatings or thermal shocks have drawn considerable interest, particularly in the ordnance development and in the design of aerospace vehicles and nuclear reactor components. In general, the analysis can be classified as uncoupled or coupled, depending on whether the study includes the thermomechanical coupling effect. The uncoupled solutions are analytically simpler and a majority of the reported studies in dynamic thermoelasticity falls into this category. Applications of fully coupled theory were also considered recently. The analysis is usually much more complicated and thus solutions are often limited to asymptotic forms or for special cases.

Because of the complexity in handling inertia and coupling effects, existing analyses are often limited to physical problems which involve uniaxial stress conditions only. Usually, an infinite or semi-infinite medium is assumed to eliminate reflections. Based on these studies, it has been concluded that the coupling effect is not a dominant factor. Hence, it is generally believed that the coupling can either be neglected or included through a weak coupling procedure such as explicit iterations.

Recently, we have developed a variational principle for the finite element analysis which has the capability of treating strong coupling between the deformation and heat conduction, without recourse to any iterations. In this paper, the numerical scheme is extended to study biaxial stress waves in a finite plane induced by a rapid boundary heating or a concentrated heat source. The heat source can either be stationary or moving rapidly. One of our results is that the thermomechanical coupling effect in biaxial condition can be significant. Temperature distribution and the location of the wave front at a specific time can be changed due to coupling. We also show that for longer times the coupling induces a dissipation effect in the finite domain.

References:

1. G. A. Keramidas and E. C. Ting, "Variational Formulation for Heat Conduction Problems," J. Appl. Phys., 50, p. 673 (1979).

2. G. A. Keramidas and E. C. Ting, "A Finite Element Formulation for Thermal Stress Analysis - I. Variational Formulation," Nucl. Engng. Design, 39, p. 267 (1976).

3. E. C. Ting and M. C. Chen, "A Unified Numerical Approach for Thermal Stress Waves," Computers & Structures, 15, p. 105 (1982).

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Dynamic Non-Fourier Thermoelastic Solutions in Cylindrically Bounded Domains

by

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Uncoupled dynamic thermoelasticity solutions are presented for the case where the material obeys a non-Fourier conduction law. In contrast to the classical Fourier law which predicts an infinite speed of heat propagation, the non-Fourier theory used herein implies that the speed of thermal signals are finite. The particular conduction constitutive equation used accounts for thermal inertia by generating a hyperbolic heat conduction equation.

Previous work in this area, e.g. Lord and Shulman [1], Norwood and Warren [2], Kao [3] and Nayfeh [4] have presented only Cartesian thermoelastic solutions. The present work includes curvature effects by developing solutions for axisymmetric problems for regions interior and exterior to a circular cylinder. All problems deal with thermally induced stress waves generated with step function temperature boundary conditions.

Solutions are generated through the use of Laplace transforms and asymptotic analysis. Comparisons of the temperature, displacement and stress fields with the corresponding classical Fourier results are presented. Results indicate that non-Fourier temperatures and stresses are initially larger than Fourier results, but that these differences quickly disappear as time progresses.

References

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[2] Norwood, F.R. and W.E. Warren, "Wave Propagation in the Generalized Dynamical Theory of Thermoelasticity," Quart.J.Mech.Math, 22, 283, (1968).

[3] Kao, T.T., "On Thermally Induced Non-Fourier Stress Waves in a Semi-Infinite Medium," AIAA Jour., 14, 818, (1976).

[4] Nayfeh, A.H., "Propagation of Thermoelastic Disturbances in Non-Fourier Solids," AIAA Jour., 15, 967, (1977).

On The Response of Poroelastic Layers to Moving Loads

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ABSTRACT

This paper presents a study of the response of layers of fluid-filled porous, elastic (poroelastic) materials to various types of moving surface loads; a problem which finds application in such disparate fields as biomechanics, ocean engineering, geotechnics and paper manufacture.

The study begins with a critical review of Biot's formulation of the field equations of poroelastic media. These equations are used to formulate the two dimensional boundary value problem of a load or displacement distribution moving at a constant speed across the surface of poroelastic layer which is bonded to a rigid, impermeable surface. The problem is solved by a Fourier Transform method which employs the Fast Fourier Transform for numerical inversion.

The general solution form is used to examine the effect of the imposed surface load or displacement distribution, load speed, allowed flow conditions through the surface, and layer thickness on internal stress, fluid pressure, fluid flow, and distribution of flow through the layer surface. Materials systems considered include water in sand, articular cartilage and wool felt.

ON THE BENDING OF SKEW ELASTIC PLATES

by

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Halifax, N. S.

M. Basso, Graduate Student
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Halifax, N. S.

This report is concerned with the bending of a parallelogram plate subjected to a transverse load. The analysis of this problem is more challenging than the analogous problem of a rectangular plate and in general closed form solutions cannot be derived. In most of the investigations dealing with the bending, buckling and vibrations of skew plates, various special and approximate methods have been used to find a reasonably accurate solution. In this submission, the given differential equation is perturbed to give rise to a sequence of differential equations. The leading equation of this sequence is the well known bi-harmonic equation solution of which for a particular problem are either known or can be easily constructed. Thus, starting with a known solution, the solution to the given differential equation can be found by a sequence of successive approximations. The procedure is illustrated for a special case where the edges of the plate are simply supported and the load distribution is uniform.

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A MODAL APPROACH TO THE SOLUTION OF NONLINEAR VIBRATION PROBLEMS

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University of Petroleum & Minerals
Dhahran, Saudi Arabia

An approximate method of arriving at a solution to nonlinear vibration problems is discussed. The technique presented involves derivation of solutions for free as well as forced vibrations by an application of the stationary functional method using normal modes. As an example, the nonlinear problem of a three-degree-of-freedom spring-mass system with nonlinear restoring springs is analyzed and numerical results are presented and discussed. It is seen that a definite advantage of applying this technique to a lumped-parameter system is that nonlinear modes higher than the fundamental can also be easily generated.

TIRE SLIP PHENOMENA

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A new approach is given to explain vehicle tire slip phenomena. It is shown that the term "wheel slip", as used by engineers in connection with off-road machines, covers four different physical phenomena which we call respectively slip of the first, second, third and fourth type. Three of these phenomena are not a slipping of a tire on a surface and, what is more, two of them are not essentially slipping. The main attention is focused on components of slip which can explain the experimental deviation of a flexible tire behavior from zero slip without any sliding at the tire-surface contact zone. On the basis of this interpretation of the slip phenomena, an explanation of the well known experimental relationships between pull (thrust) and slip is given.

* * *

In spite of rather intensive investigations a slip phenomenon (see, for example, [1-5]) during many years there is the following text in monograph [2]:

> "For the classical rigid wheel rolling on a flat plane any slip whatsoever is complete sliding. However, the flexible tire structure can deviate from straight line free rolling without complete sliding at the tire-load interface. Although the **exact mechanics have not been worked out**, the results are well known."(Words in bold type are by B.P.V.)

In this paper an attempt is made to study the physical nature of what is known as a tire slip phenomenon and to explain unknown mechanics on a basis of the four different physical phenomena. Each of these phenomena manifests itself in an experiment as the obvious difference between a distance $L = 2 \pi R_L$, which the tire should travel in each revolution, and a distance L_R, which the tire travels in fact. If in the process of an experiment the above mentioned difference is not equal to zero, it would be agreed by most observers that the wheel was slipping. But as it is demonstrated in the paper, it is not always true.

It is shown that a more accurate understanding of the slip phenomenon is important both for dynamic analysis of a vehicle behavior and for correct choice of an experimental technique for a slip measurement in the process of lab and field tests. It is possible, that depending on experimental conditions, the different parameters should be measured.

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TORSIONAL RESPONSE OF AN ELASTIC HALF SPACE TO A NONUNIFORMLY EXPANDING RING SOURCE

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The dynamic behaviour of an elastic solid under various form of moving loads and torsional pressure has an important role in seismology, structural design and under ground exploration.

Gakenheimer (1971) presented in detail the problem of a load emanating from a point on the surface and then expanding radially at a constant rate. Ghosh (1971) considered a problem of propagation of a stress discontinuity over an expanding circular region with a constant velocity. Strong (1970) discussed the problem of accelerating line load in an acoustic half space. Roy (1979) and Brock (1980) discussed the wave motions as expected in case of a uniform pressure distribution over a circular zone expanding with nonuniform velocity on the surface of an elastic half space.

In this paper the displacement at any point (r,z,t) in the semi-infinite medium is determined by prescribing a time dependent torsional force over the rim of a circular region by Cagniard De-Hoop technique. The ring source is assumed to expand in any arbitrary manner. It is found that sometimes displacement field contains besides the usual SH-waves, contribution from conical waves which arise due to the motion of the source. The region of conical waves which dependon the nature of motion of the source and the intial speed of expansion of the source are investigated in detail. Different wave front surfaces are located and first motion responses near different wave arivals have been obtained.

Numerical evaluation of the displacement on the free surface has been made for a decelerating source whose radius at time t is of the form $h(t) = A\sqrt{t}$. Displacements at points on the free surface for different positions of the source have been plotted.

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Session FA-5: COMPUTATIONAL METHODS IN FLUID FLOW

Organizer and Chairperson: T. J. CHUNG, The University of Alabama in Huntsville
Co-Chairperson: A. K. RAO, Monsanto, St. Louis, MO

2:00 - 2:15 W. W. BOWER, McDonnell Douglas Research Laboratories, St. Louis:
"Solution of the Parabolized Navier-Stokes Equations Using the Agarwal Algorithm"

2:15 - 2:30 Y. ISHIDA and M. SHOJI, Kajima Corporation, Tokyo, Japan:
"A New F.E.M. Formulation for Navier-Stokes Equations"

2:30 - 2:45 J. K. LEE and S. H. ADVANI, Ohio State University:
"Modelling and Finite Element Simulation of Hydraulic Fracturing"

2:45 - 3:00 J. R. O'LEARY, Illinois Institute of Technology:
"An Error Analysis for Singular Finite Elements"

* 3:00 - 3:30 J. N. REDDY and R. TAM, Virginia Polytechnic Institute and State University:
"On an Isoparametric Finite Difference Energy Method and a Five-Node Finite Element for the Solution of Fluid Flow Problems"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 T. J. CHUNG and J. Y. KIM, University of Alabama in Huntsville:
"Two-Dimensional Combined Mode Convection-Radiation Heat Transfer by Finite Elements"

4:30 - 4:45 R.S.R. GORLA, Cleveland State University:
"Heat Transfer in Micropolar Boundary Layer Flows"

4:45 - 5:00 H. M. BADR, University of Petroleum and Minerals, Saudi Arabia:
"Study of Natural Convection in Eccentric Cylindrical Annuli Using the Variational Approach"

Solution of the Parabolized Navier-Stokes Equations Using the Agarwal Algorithm*

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In a variety of fluid mechanics problems, the computation of three-dimensional, steady, turbulent flowfields does not require solution of the fully elliptic time-averaged Navier-Stokes equations. Rather, in these problems there is a predominant direction of flow with no flow reversal in that direction such that the upstream conditions alone determine what happens downstream. These flows are termed "parabolic" and are described by the parabolized three-dimensional Navier-Stokes equations, which are more general than the boundary layer equations since they account for pressure gradients normal to the primary flow direction.

By taking advantage of the parabolic character of the equations, it is possible to formulate solution techniques which permit marching from the upstream boundary to the downstream boundary and thereby eliminate the need to simultaneously solve the entire flowfield. This approach offers savings in both computer time and storage, since at each cross-stream plane in the marching direction, it is necessary to solve the governing equations only on that plane. Consequently, only a two-dimensional array storage of the flow variables is required, which permits finer grids and higher Reynolds numbers than are possible with the finite-difference solution of the fully elliptic equations.

The proposed paper describes application of the Agarwal algorithm[1,2] to the parabolized time-averaged Navier-Stokes and k-ε turbulence model equations in three dimensions. This technique, which in previous work[1,2] has been applied to the fully elliptic Navier-Stokes equations, is based on a third-order-accurate upwind scheme for discretising the convective derivatives. Details of the solution procedure will be described, and computations will be presented for two (one internal and one external) three-dimensional parabolic-flow configurations. The first is developing turbulent flow in a duct of square cross section, and the second is an axisymmetric jet discharging from a blocking plate into a stationary fluid. Comparisons will be made between the computed flow properties and data.

1. Agarwal, R. K., "A Third-Order-Accurate Upwind Scheme for Navier-Stokes Solutions at High Reynolds Numbers", AIAA Paper No. 81-0112, presented at the AIAA 19th Aerospace Sciences Meeting, St. Louis, MO, 12-15 January 1981.
2. Agarwal, R. K., "A Third-Order-Accurate Upwind Scheme for Navier-Stokes Solutions in Three-Dimensions", Proceedings of the Winter Annual Meeting of the American Society of Mechanical Engineers, November 1981.

*Research conducted under the McDonnell Douglas Independent Research and Development program.

A NEW F.E.M FORMULATION FOR NAVIER-STOKES EQUATIONS

by

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ABSTRACT

The most convenient numerical methods that are used by physical scientists and engineers to analyse the Navier-Stokes equations would be the Marker-And-Cell Method, a sort of finite differences, and finite elements. In the present paper a new formulation is proposed to further promote the merits of these two techniques.

By applying the new formulation to the Navier-Stokes equations, simultaneous equations which have a symmetrical coefficient matrix can be introduced with the pressure at nodal points unknown. The time split procedure to advance the pressure and velocity fields through the time dimension is applied and is used until the fields become stationary. The advantage in using the present formulation comes from the fact that (1) only one linear shape function is needed for both pressure and velocity and (2) the continuity equation can be monotonously satisfied as an employed time step is shrinked.

The present formulation will be applied to three rather practical problems : (1) circulatory motion of a body of fluid in the square cavity, (2) ventilating motion of a body of fluid in the closed square region and (3) wake formation around two obstacles. In all examples, an appropriate time step was determined experimentally to satisfy the continuity equation rigorously. The maximum size of problem (900 elements and 906 nodal points) was solved with 45 minutes cpu times by a 'HITAC M-200H' computer system. It can be seen that the present method can give practically meaningful results in a relatively simple manner.

Modelling and Finite Element Simulation of Hydraulic Fracturing

by

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Abstract: Hydraulic fracturing is an important stimulation technique widely used by oil and gas industries in extracting energy resources. This study deals with finite element formulations and numerical predictions of hydraulic fracture geometry. Under a set of suitable assumptions, governing equations for the width w(x,t) and length L(t) of a vertical fracture can be written as

$$c_1 \frac{\partial^2 w^3}{\partial x^2} - \frac{\partial w}{\partial t} - \frac{c_2}{\sqrt{t-\tau(x)}} = 0 \quad \text{if } o \leq x < L(t)$$

and

$$c_3 \frac{d}{dt} \int_o^L w\,dx + c_4 \int_o^t \frac{dL}{d\tau} \frac{d\tau}{\sqrt{t-\tau}} = Q \text{ for } o < t \leq T$$

in which $c_1 \sim c_4$ and Q are some constants (cf. [1] for a detail). This combined model is an improvement over models proposed earlier (see [2] for a review). Physical accounts of the model coupled with the fracture mechanics aspects and some numerical results have been reported by the current authors in Ref. [1]. Current studies have concerned with a further improvement of the model by introducing effects of non-Newtonian fluids and variable fracture height and searching for an efficient solution algorithm. Some of recent developments will be presented along with numerical results.

References

1. S.H. Advani and J.K. Lee, "Finite Element Model Simulations Associated with Hydraulic Fracturing," Soc. of Pet. Eng. J., April, 1982.

2. J. Geertsma and R. Haafkens, "A Comparison of the Theories for Predicting Width and Extent of Vertical Hydraulically Induced Fractures," J. of Energy Res. Tech., ASME, 101, 8, 1979.

AN ERROR ANALYSIS FOR SINGULAR FINITE ELEMENTS

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Ill. Inst. of Tech.

This paper addresses the question of convergence for the finite element method when singular (crack tip) elements are employed in the construction of the approximation subspace. A-priori and a-posteriori error estimates are developed for a model boundary valve problem defined over a plane domain with a reentrant corner. The a-priori estimates are given in terms of either the global energy norm or the maximum norm over an interior subdomain. This latter measure allows for the development of error estimates on approximations for the strength intensity factor when obtained as an internal degree of freedom for the singular element. Verification of these results is obtained by extensive numerical experiments on a suitably constructed singular ordinary differential equation. The a-posteriori estimate is obtained in terms of a computationally convenient measure suitable for employment in a self-adaptive mesh refinement scheme.

ON AN ISOPARAMETRIC FINITE DIFFERENCE ENERGY METHOD AND A FIVE-NODE FINITE ELEMENT FOR THE SOLUTION OF FLUID FLOW PROBLEMS

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The paper presents results of two separate investigations: (1) an isoparametric finite difference energy method, and (2) an isoparametric five-node rectangular element for the solution of Navier-Stokes equations for two-dimensional incompressible flows. The concept of isoparametry, borrowed from the finite element method, in finite difference energy method makes the finite difference method more flexible in the analysis of flow problems with curved boundaries. The five-node rectangular element is investigated for its accuracy compared with that of the four-node rectangular element in the penalty-finite element formulation of the Navier-Stokes equations. Results are presented showing the relative accuracy and computational efforts involved in using the isoparametric finite difference energy method, the five-node isoparametric element, and the four-node isoparametric element.

TWO-DIMENSIONAL COMBINED MODE CONVECTION-RADIATION HEAT TRANSFER BY FINITE ELEMENTS

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The University of Alabama in Huntsville

The two-dimensional heat flux is derived and finite element analysis is performed on combined mode convection-radiation problems in the divergent and convergent channel flow. It is shown that, if the optical thickness increases and radiation dominates over convection, the mean temperature of the flow domain becomes high in the divergent channel whereas this trend diminishes in the convergent channel. If optically thin, the effect of radiation on the temperature profiles is very weak. It is believed that calculations of temperature distribution for two-dimensional radiative flux have been made available for the first time to the best knowledge of the authors.

HEAT TRANSFER IN MICROPOLAR BOUNDARY LAYER FLOWS

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ABSTRACT

The study of microcontinuum fluid mechanics has received the attention of many research workers. Eringen (1) has formulated the theory of micropolar fluids. This theory includes the effects of local rotary inertia and couple stresses and is expected to provide a mathematical model for the non-Newtonian behavior observed in certain man-made liquids such as polymeric fluids. The theory of thermomicropolar fluids has been developed by Eringen (2). Gorla (3) has recently studied the thermal boundary layer of a micropolar fluid flow in the vicinity of a stagnation point.

In the present paper, we have analyzed the flow and heat transfer characteristics of the micropolar boundary layers. The specific geometries of the flow are the flat plate flow, cross flow on a circular cylinder and longitudinal flow along a circular cylinder including traverse curvature effects. The governing boundary layer equations for each case are formulated and are solved numerically. The numerical results presented cover a wide range of values of the dimensionless material parameters and Prandtl numbers of the fluid. Similarity solutions are obtained for the boundary conditions of constant surface temperature, constant surface heat flux and viscous dissipation effects are included. The effects of nonisothermal boundary conditions leading to nonsimilarities in velocity and temperature fields are discussed.

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2. A.C. Eringen, J. Math. Anal. Appl., 38, 480 (1972)

3. R.S.R. Gorla, Int. J. Engng Sci., 18, 611 (1980)

STUDY OF NATURAL CONVECTION IN ECCENTRIC CYLINDRICAL ANNULI USING THE VARIATIONAL APPROACH

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The problem of natural convection heat transfer in the annulus between two eccentric horizontal tubes has been solved numerically by using a variational finite element method similar to that used in reference [1]. Isothermal conditions were considered at the surfaces of the inner (hot) and outer (cold) tubes. The governing equations of motion, namely the mass, momentum, and energy conservation equations, were solved for a range of Rayleigh numbers, Ra, from 10^2 to 10^6 [based on the average gap width $b = 1/2(D_o - D_i)$] while keeping the Prandtl number, Pr, at a constant value of 0.7. The eccentricity of the inner tube was varied from 0.6 to -0.6 times the average gap width.

The method of solution was tested by solving the problem of natural convection in a concentric cylindrical annulus at different values of Rayleigh numbers and comparing the results with the numerical and experimental results obtained by Kuehn and Goldstein [2]. The comparison showed an excellent agreement.

It was found from the present study that increasing the eccentricity tends to change the velocity and temperature distributions significantly from those prevailing in the case of concentric tubes. Accordingly, the distribution of the temperature gradient at the surfaces of the inner and outer tubes and the local heat tranafer coefficient were found to vary considerably. Figure (1) shows a typical streamline and isotherm patterns for the case of Rayleigh number, $Ra = 10^5$, Prandtl number, Pr = .7, and eccentricity ratio $e/b = -0.6$. These lines were plotted only in one half of the field because of symmetry with respect to a vertical plane passing through the axes of the inner and outer tubes. The overall convective heat transfer coefficient increased by as much as 38% at Rayleigh number $Ra = 10^5$, diameter ratio $\frac{D_o}{D_i} = 2.6$ and eccentricity ratio of -0.6. However, at high Rayleigh numbers, the effect of increasing the eccentricity on the overall heat transfer coefficient becomes less. The general criteria agrees with the experimental results obtained by Kuehn and Goldstein [3] at high Rayleigh numbers. The numerical solution gave an insight to the flow and temperature fields which enabled accurate determination of the local and overall heat transfer rates.

ACKNOWLEDGEMENTS

This study was supported by the University of Petroleum and Minerals, Dhahran, Saudi Arabia.

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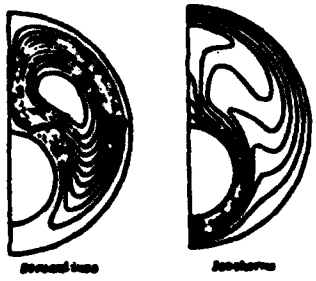

Figure (1): Streamlines and Isotherms for the case of $Ra=10^5$, Pr=.7, $\frac{D_o}{D_i}=2.6$, and $\frac{e}{b}=-0.6$.

Session FA-6: APPLICATIONS OF THE FINITE ELEMENT METHOD/ STRUCTURAL MECHANICS

Chairperson: S. N. DWIVEDI, University of North Carolina

Co-Chairperson: D. D. ARDAYFIO, University of Missouri-Rolla

2:00 - 2:15 S. NAKAMURA, R. L. BENEDICT and R. S. LAKES, University of Iowa:
"Finite Element Analysis of Anisotropic Micropolar Elastic Materials"

2:15 - 2:30 M. EPSTEIN and H. P. HUTTELMAIER, The University of Calgary:
"Finite Element Formulation of Multilayered and Thick Shells"

2:30 - 2:45 J. N. CRADDOCK, Southern Illinois University:
"Approximate Analysis of Non-Axisymmetric Configurations"

2:45 - 3:00 J. L. HILL, The University of Alabama and S. CHAIVIRAT, Chulalongkorn University, Thailand:
"Stress Analysis of Frictional Contact of Threaded Joints"

3:00 - 3:15 F. A. BATLA, North Dakota State University:
"Idealization of Prestressing Forces for Finite Element Analysis"

3:15 - 3:30 S. NAKAMURA and R. L. BENEDICT, University of Iowa:
"Temporal Finite Elements Based on a True Minimum Principle for Initial Value Problems"

3:30 - 4:00 REFRESHMENT BREAK

4:00 - 4:15 M. SATHYAMOORTHY and R. MULLADY, Clarkson College of Technology:
"Nonlinear Behavior of Beams by Finite Element Method"

4:15 - 4:30 S. R. IDELSOHN and A. CARDONA, National Council for Scientific and Technological Research, Argentina:
"Two-Stage Discretization Techniques in Nonlinear Structural Dynamics"

4:30 - 4:45 D. KARAMANLIDIS, Georgia Institute of Technology; LE THE HUNG and R. HASSLICH, Technical University of Berlin:
"A New Doubly Curved Mixed Hybrid Finite Element for Thin Plate Analysis"

4:45 - 5:00 D. D. ARDAYFIO, University of Missouri-Rolla:
"Cantilever Dynamic Vibration Absorbers with Increased Effectiveness"

5:00 - 5:15 A. NASSIRHARAND and B. KAFTANOGLU, Oklahoma State University:
"Computer-Aided Design and Optimization of a Four-Bar Mechanism to Trace a Given Path"

Finite Element Analysis of Anisotropic Micropolar Elastic Materials

by

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R.L. Benedict
R.S. Lakes

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The total potential energy for a body composed of an anisotropic micropolar linear elastic material is developed and used to formulate a displacement type finite element method of analysis. As an example of this formulation triangular plane stress (and plane couple stress) elements are used to analyze several problems. The program is verified by computing the stress concentration around a hole in an isotropic micropolar material for which an exact solution exists. Several anisotropic material cases are presented which demonstrate the dependence of the stress concentration factor on the micropolar material parameters.

Finite Element Formulation of Multilayered and Thick Shells

by Marcelo Epstein and H. Peter Huttelmaier

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T2N 1N4

Based on the general nonlinear theory of multilayered shells presented in [1], a finite element analysis is developed which can be applied not only to true multilayered shells, but also to very thick shells, by subdividing the thickness into an arbitrary number of layers. Such shells are beyond the range of applicability of so-called thick shell theory in which transverse shear strains are included by allowing the normal to the shell to remain straight but not necessarily normal to the reference surface. In the theory used herein a generalized version of this hypothesis is used independently for each layer and as a result any transverse shear or normal strain variation can be accommodated by a sufficiently large number of layers. As shown in [2] for the case of beams and plates very accurate transverse strain and stress distributions are obtained even in extreme situations.

A bilinear isoparametric concept is adopted, which has been shown [3] to yield reliable results in thin shell theory and to be economically competitive. This is coupled with a direct formulation of the stiffness from the principle of virtual work which results in a considerable saving in computer implementation. A number of examples, including laminated shells and thick structures, are presented to illustrate the accuracy and versatility of the formulation.

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[3] Kanok-Nukulchai, W., Taylor, R.L. and Hughes, T.J.R., "A Large Deformation Formulation for Shell Analysis by the Finite Element Method", Computers and Structures, 13, 19-27, 1981.

Approximate Analysis of Non-Axisymmetric Configurations

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A finite element method of analysis is developed for structural configurations which are derived from axisymmetric geometries but contain definite nonaxisymmetric features in the circumferential direction. The purpose of the present analysis is to develop a method which will take into consideration the fact that the stress and strain conditions in these geometries will be related to the corresponding axisymmetric solution. The analysis is devleoped in terms of a cylindrical coordinate system r, θ and z. As the first step of the analysis, the geometry is divided into several segments in the r-θ plane. Each segment is divided into a set of quadrilateral elements in the r-z plane. The axisymmetric displacements are obtained for each segment by solving a related axisymmetric configuration. A perturbation analysis is then performed to match the solutions at certain points between the segments, and obtain the perturbation displacements for the total structure. The total displacement is then the axisymmetric displacement plus the perturbation displacement. The stresses and strains are then calculated at any desired point once the total displacements are known. The method is applied to a number of examples to illustrate the accuracy of the method. The results for these examples are presented and discussed. A detailed discussion of this problem is presented in Reference [1]

A. R. Zak, J. N. Craddock, W. H. Drysdale, "Approximate Finite Element Method of Stress Analysis of Non-Asixymmetric Configurations". Introduction J of Computers and Structures, Vol. 9 (1978), pp. 201-206.

STRESS ANALYSIS OF FRICTIONAL CONTACT OF THREADED JOINTS

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Surawat Chaivirat, Assistant Professor
Chulalongkorn University
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The analysis of a threaded joint is considered an axisymmetric contact stress problem. The threaded joint includes multiple contact surfaces on which dry friction governs the slippage. The stresses and displacements in frictional contact problems are loading-history dependent and are calculated incrementally.

A numerical solution technique is developed to analyze frictional contact of threaded joints. The axisymmetric finite element method is used. Bodies in contact are decomposed into smaller parts, some of which are identical. A simple static condensation is performed on each part of the bodies to reduce the number of unknown displacements.

Multiple contact surfaces are possible. Contact forces are calculated by using the local flexibility equations of each pair of contact surfaces. Loads are applied incrementally, and the solution is sought by means of an interation procedure for each load level.

The method is checked with the well-known classical Hertz problem involving contact between a sphere and an elastic space. Results are in good agreement with the analytical solution. History of load-dependence of frictional contact problems is established in the second example using a hollow cylinder pressed on an elastic base. Stress analyses of a threaded joint with and without friction are presented in the last example.

This work was supported by the U.S. Army Missile Command under Contract KAAK40-76-C-1084.

IDEALIZATION OF PRESTRESSING FORCES FOR FINITE ELEMENT ANALYSIS

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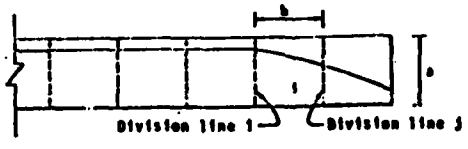
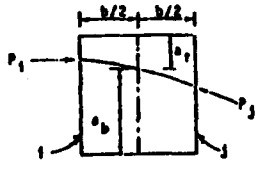
The exact representation of the geometry of tendon profile and the variation of the prestressing force along the tendon length for the analysis of a prestressed concrete structure by the finite element method is a complex and time consuming effort.

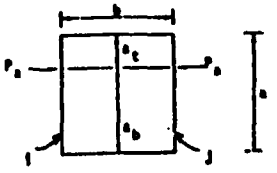
In the finite element method a continuum is considered to be an assemblage of discrete elements. This paper presents a similar approach in which a prestressing tendon is represented by piecewise straight segments. The tendon is divided in as many segments as the number of elements it passes through, and the prestressing force is assumed to be constant within each segment. The prestressing force in each element is then represented by concentrated loads on the edges of the element. The effective prestressing force in each segment of the tendon is evaluated by the conventional methods of the prestressed concrete design.

The overall effort of representing the tendon profile and the prestressing force is, therefore, substantially reduced. The approximation of the tendon profile and the prestressing force in the tendon converges rapidly to the exact representation as the number of divisions of the structure for the finite element analysis is increased. The analysis using this approach indicate a very good comparison with the results obtained by using the more rigorous methods of analysis in which the prestressing forces are more accurately represented.





Actual tendon profile and forces in element 'i'



Idealized tendon profile and forces in element 'i'

$$P_a = \frac{P_i + P_j}{2}$$

Idealization of Prestressing Force

Temporal Finite Elements Based On a True Minimum Principle for Initial Value Problems

by

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A symmetric, convex, functional is presented whose necessary conditions for minimization are the dynamic equations of motion and their appropriate initial boundary conditions. A temporal finite element method is developed by discretizing this functional using shape functions in a manner analagous to the development of spatial finite elements. The equations of motion for a linear dynamic system are thus reduced to a set of linear algebraic equations. The resulting coefficient matrix is large but very sparse and well structured. A computational technique has been developed which takes advantage of the special structure of this matrix to collapse its nonzero elements into a narrow band to increase solution efficiency.

The resulting dynamic analysis technique is stable for arbitrary time discretizations and works well for stiff systems. Convergence is uniform and "even" in a global sence. That is, we observe that the error at the final time point is no greater than the error anywhere else in the global time interval.

Computational examples are presented which compare this technique to various integration techniques. Examples include multiple degree of freedom particle problems and a spatial finite element discretized beam.

NONLINEAR BEHAVIOR OF BEAMS BY FINITE ELEMENT METHOD

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Abstract

Nonlinear static and dynamic behaviors of beams with various boundary conditions have been studied by several investigators in the past [1]. A recent survey paper by Reddy [2] summarizes the contributed efforts in the area of nonlinear analysis of beams during the last ten-year period using the finite element method. Most of the investigations reported so far, however, are concerned with geometric-type nonlinearity where the nonlinearity is either due to nonlinear moment-curvature relationship or due to nonlinear strain-displacement relationship caused by the extension of the neutral axis of the beam. These two types of nonlinearities are the result of a beam undergoing large deformation. In contrast material type nonlinearities have received far less attention in the literature. Iyengar and Murthy [3] used programming techniques to study the free vibration behavior of simply supported beams with nonlinear material properties while Prathap and Varadan [4] investigated the nonlinear load deflection behavior. This paper is concerned with the study of nonlinear static and dynamic behavior of beams with Ramberg-Osgood type of stress-strain formula, that is characterized by a continuous slope change typical of metals at elevated temperatures. The finite element technique is used to obtain solutions for beams with various boundary conditions made of non-Hookean materials. Nonlinear load-deflection curves are presented for static problems. Linear and nonlinear fundamental frequencies are tabulated for dynamic cases. Effects of both material nonlinearity and boundary conditions on the nonlinear behavior are discussed. Present results are compared with some existing solutions wherever possible [3,4].

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2. J.N. Reddy, "Finite Element Modeling of Structural Vibrations: A Review of Recent Advances," Shock and Vibration Digest, Vol. 11, pp. 25-39, 1979.

3. N.G.R. Iyengar and P.N. Murthy, "Nonlinear Free Vibration of a Simply Supported Beam by Programming Techniques," Journal of Sound and Vibration, Vol. 20, pp. 277-286, 1972.

4. G. Prathap and T.K. Varadan, "The Inelastic Large Deformation of Beams," ASME Journal of Applied Mechanics, Vol. 43, pp. 689-690, 1976.

TWO-STAGE DISCRETIZATION TECHNIQUES IN NONLINEAR STRUCTURAL DYNAMICS

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Cuenes 3450 - 3000 Santa Fe - República Argentina

ABSTRACT

In the last years, the finite element method has successfully been used as a tool for the approximate solution of large number of physical problems. The major advantage of this method is that the same basis functions set used in a discretization may be employed in a variety of load cases. Therefore, it is not necessary to have a good knowledge of the solution to obtain proper results. Unfortunately, most large-scale problems and specially nonlinear problems require an excessive amount of computer time. In order to avoid this difficulty, it is possible to achieve the discretization of a structure by means of a few well chosen basis functions, leading to small systems of equations that represent the behavior of the structure as well as the large systems[1,2]. Two stage-discretization techniques or reduction methods are all methods to discretize automatically a geometrically complex structure with a few well chosen modes. These methods will be tested here in nonlinear structural dynamics.

After a presentation of the two-stage discretization technique, a discussion on the selection of the basis vectors and error estimation is introduced. The last is very important in non-linear problems because it points out when the basis vectors must be updated. Several examples of different structures submitted to a sudden load and seismic load are tested and compared with a one-stage finite element discretization and other reduction methods[2,3]. It is shown that the proposed error estimation guarantees the most suitable selection of the basis vectors and it increases quickly when they must be updated. In some examples, they must never be changed but in all cases a considerable gain of computer time was obtained.

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2 - IDELSOHN, S. and CARDONA, A., "Reduction Methods and Explicit Time Integration Techniques in Structural Dynamics". Int. J. of Computer Method in Applied Mech. and Engineering. (In the press).

3 - NICKELL, R.E., "Nonlinear Dynamics by Mode Superposition". Comp. Meth. in Applied Mech. and Engineering. Vol. 7, pp. 107-129 (1976).

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A New Doubly Curved Mixed Hybrid Finite Element for Thin Plate Analysis*

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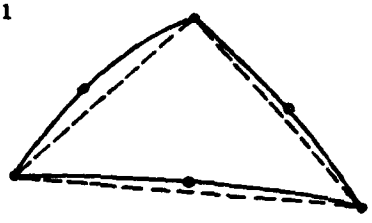
The purpose of the present investigation is the development of a doubly curved shallow shell element based on a modification of the Hellinger/Prange/Reissner variational principle, wherein the primal variables $\underline{q}$ and $\underline{u}$ (vector of the shell stress resultants and boundary displacement vector respectively) are assumed so as to satisfy a priori conditions listed below:

a) membrane equilibrium equations
b) shallow shell bending equilibrium equation and
c) displacement boundary conditions on C_u (part of the boundary on which displacements are prescribed).

Comparing the new mixed hybrid triangular shell element (see Fig. 1) with assumed displacement finite elements the following major advantages of the new element can be pointed out:

Fig. 1



● master nodal points
○ auxiliary nodal points

a) the exact representation of the rigid body as well as the constant strain modes,
b) the a priori enforcement of C^1 interelement displacement continuity (the interelement traction reciprocity continuity being satisfied a posteriori as natural boundary condition).

Furthermore, it is worth noting that in comparison with similar recently developed mixed hybrid shell elements [1], [2] the following improvements have been made within the new element:

a) a priori satisfaction of the complete shallow shell bending equilibrium equation instead of only the homogenous part of the plate bending equation, and
b) C^0 continuous shell geometry approximation (upon use of auxiliary nodes, Fig. 1) in contrast to the discontinuous ones used in [1], [2].

In order to demonstrate the applicability and efficiency of the new element, extensive numerical studies on relevant problems have been carried out.

*Research sponsored by the German Science Foundation (DFG) under Grant Ka 487/3.

1. Boland, P.L., Ph.D Thesis, M.I.T. 1975.
2. Norrigruse, A., Ph.D. Thesis, Trondheim University, 1977.

CANTILEVER DYNAMIC VIBRATION ABSORBERS WITH INCREASED EFFECTIVENESS

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This paper is directed to the analysis of two novel configurations of cantilever dynamic vibration absorbers. The first is multiple cantilever absorbers mounted radially from the same support on the vibrating body. The second arrangement is where a dual cantilever system is attached at two points on the vibrating body. The cantilever beams are treated as distributed parameter Bernoulli-Euler beams, while the vibrating body is represented by a single-degree-of-freedom elastic system in the presence of sinusoidal forces. Characteristic curves for each system are plotted to show the effect of varying the absorber parameters on its performance.

COMPUTER-AIDED DESIGN AND OPTIMIZATION OF A FOUR-BAR MECHANISM TO TRACE A GIVEN PATH

By

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Oklahoma State University, Stillwater, Oklahoma 74078

ABSTRACT

The present study introduces a numerical procedure and an algorithm to synthesize a four-bar mechanism so that its coupler point generates a given path e.g. a straight line with the least possible error. In industrial applications such mechanisms are used to generated specific motions in cutting, welding, hoisting, and in a multitude of other operations where robotics are being used for automated production.

In the present study, the general equations of motion are developed for any four-bar linkage giving the coordinates of the coupler point as a function of the crank angle. The required path to be followed is expressed by an equation and in this paper a linear path is given as an example. The normal distance between the coupler curve and the required path is computed for an arbitrary number of points, and squared and summed to find the error function. Using a constrained modified Rosenbrock optimization algorithm, this error is minimized by altering the design variables such as, the dimensions of the four-bar mechanism, starting angle and etc. For the example given in the paper, an accuracy of less than 3 percent has been obtained for the approximations of the required path by the coupler curve.

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* Graduate Teaching Assistant

** Visiting Professor

Session FA-7: COMPOSITE MATERIALS: ANALYSIS AND EXPERIMENT

Organizer: C. W. BERT, The University of Oklahoma
Chairperson: U. YUCEOGLU, Lehigh University
Co-Chairperson: C.R. SAFF, McDonnell Douglas Corporation

* 2:00 - 2:30 W. C. CHAO and J. N. REDDY, Virginia Polytechnic Institute and State University:
"Large Deflection Bending of Laminated Shells"

* 2:30 - 3:00 E. D. REEDY, JR., Sandia National Laboratories:
"Notched Boron/Aluminum: Effect of Matrix Properties"

* 3:00 - 3:30 W. W. PREDEBON and W. E. THOMPSON, Michigan Technological University:
"The Effect of Interlamellar Spacing on Incipient Fracture in Shock-Loaded Lamellar Metal-Alloy Composites"

3:30 - 4:00 REFRESHMENT BREAK

* 4:00 - 4:30 C. W. BERT and C. J. REBELLO, The University of Oklahoma:
"Bending of Thick Beams Laminated of Bimodular Material"

* 4:30 - 5:00 A.P.S. SELVADURAI, Carleton University, Canada:
"The Flexure of a Flat Elastic Fibre Embedded in an Isotropic Elastic Medium"

LARGE DEFLECTION BENDING OF LAMINATED SHELLS*

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Abstract

A finite-element analysis of laminated anisotropic shells is investigated using the so-called three-dimensional degenerate element. The element is based on the incremental variational formulation (i.e., virtual work statement) of the total Lagrangian description of the equations of shells. The element has five degrees of freedom: three translational degrees of freedom along the global coordinate axes, and two rotations with respect to the (element) local axes. The element is used to obtain load-deflection results for shells of various geometries under different boundary conditions. The present results are compared with the results of a two-dimensional shear-deformable shell theory that accounts for the von Kármán strains, and with the results of other finite-element analyses. The present results are found to be in good agreement with the other results.

*The results reported here were obtained during an investigation supported in part by the Structural Mechanics Program of the Air Force Office of Scientific Research and the Mechanics Division of the Office of Naval Research.

NOTCHED BORON/ALUMINUM: EFFECT OF MATRIX PROPERTIES*

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Abstract

The manner in which matrix shear properties affect the notched behavior of unidirectional boron/aluminum is assessed. Center-notched tensile specimens of as-fabricated boron reinforced 1100 and 6061 aluminum were tested. The B/6061 was also tested in a heat-treated condition. Previous rail shear tests of these materials revealed significant differences in their shear response. The load-notch opening displacement records of the notched specimens also exhibit significant differences. The maximum notch-opening displacement attained by the heat-treated B/6061 is just 28% of that of the B/1100 even though their failure loads are within 8%.

A previously developed method of analysis is used to calculate stresses within a specimen and also its overall response to load. This analysis is based upon the familiar shear-lag assumptions and is formulated for finite-dimensioned monolayers made from work-hardening constituents [1]. Predicted response is a function of measured constituent properties and specimen geometry. The specimens tested contained a 0.5 in. notch and were 1.0 in. wide with a 3.0 in. gage length. Calculations were performed with both uniform traction and uniform edge displacement boundary conditions. Calculated matrix yield zones for materials with a relatively high yield strength are sufficiently localized that both boundary conditions produce nearly identical results. The predicted load-notch opening displacement records are in excellent agreement to those actually measured. Materials with rather soft matrices, such as found in the B/1100, exhibit different behavior; yielding is predicted throughout the gage section. The predicted maximum load carried by a B/1100 specimen subject to tractions is only 53% of that predicted for a displacement condition. The predicted load-notch opening displacement relations serve as bounds to the experimental records. This suggests that the actual load condition applied by the wedge-action grips lies between these extremes. Also briefly discussed are calculations which illustrate how nonuniform fiber spacing, flaw geometry, and growth of shear cracks modify notched response.

[1] E. D. Reedy, Jr., "Analysis of Center-Notched Monolayers with Application to Boron/Aluminum Composites," J. Mech. Phys. Solids, Vol. 28 (1980), p. 265.

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*This work performed at Sandia National Laboratories supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789.

THE EFFECT OF INTERLAMELLAR SPACING ON INCIPIENT FRACTURE IN SHOCK-LOADED LAMELLAR METAL-ALLOY COMPOSITES*

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Abstract

Incipient fracture in a bi-phase lamellar eutectic metal is investigated using a finite-difference computer code simulation. Through the simulation, the mode and location of incipient fracture are predicted and compared to results from dynamic fracture experiments for the case of constant interlamellar spacing.[1] The case considered is an initially planar shock pulse traveling parallel to the direction of the lamellae. Incipient fracture is predicted through the use of the cumulative damage spall model, based on a maximum principle stress criterion for the damage threshold.

In the formation of a lamellar eutectic metal composite one finds that the interlamellar spacing varies, and it is of interest to determine its effect on incipient fracture. In a similar way in manufactured composites, where the spacing can be prescribed, it would be important to determine spacings which best resist fracture. In the CoAl eutectic system considered in this study the 30 μm spacing was found to be a critical spacing. For interlamellar spacings greater and less than 30 μm, fracture was enhanced.

[1] G. H. Brawley and W. W. Predebon, An Investigation of Shock-Induced Fracture in a Lamellar Eutectic Two-Phase Metal Alloy, Engineering Fracture Mechanics J. 16, 613-624(1982).

*Supported by the NATIONAL SCIENCE FOUNDATION under grant DM 78-05741.

BENDING OF THICK BEAMS LAMINATED OF BIMODULAR MATERIAL*

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Abstract

It has been known as early as 1864 that certain actual materials have quite different elastic behavior when they are subjected to tension rather than compression. However, the concept of a bimodular material, i.e., a bilinear material having different moduli in tension and in compression, was not originated until 1941 by Timoshenko [1], who considered a beam of such a material undergoing pure bending. Examples of composites exhibiting bimodular behavior include cord-reinforced rubber, fiber-reinforced plastics, paperboard, reinforced concrete, and soft biological tissues.

Apparently Kamiya [2] was the first to include transverse shear strain effects in the analysis of bimodular beams. Ref. [3] presented an extensive survey of the literature for such beams. Very few papers were concerned with laminated beams: none included transverse-shear deformation effects and no extensive investigation of the effects of stacking sequence has been undertaken heretofore. Both of these effects are considered in the present work. Closed-form solutions for two different loading/boundary condition cases are presented and the significance of the numerical results are discussed in detail.

[1] S. Timoshenko, Strength of Materials, Pt. II, 2nd. Ed., Van Nostrand, Princeton, NJ, 1941, pp. 362-389.

[2] N. Kamiya, "Transverse Shear Effect in a Bimodulus Plate," Nuc. Eng. Design, Vol. 32 (1974), pp. 351-357.

[3] A.D. Tran and C.W. Bert, "Bending of Thick Beams of Bimodulus Materials," Computers and Structures, to appear.

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*This work was sponsored by the Office of Naval Research, Mechanics Division.
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THE FLEXURE OF A FLAT ELASTIC FIBRE EMBEDDED IN AN ISOTROPIC ELASTIC MEDIUM

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ABSTRACT

The problem of flexure of a flat ribbon like inclusion embedded in an elastic medium is of some interest to the stress analysis of fibre reinforced materials. We consider the type of ribbon shaped fibre in which flexure takes place only in the fibre direction. The flat beam shaped fibre is embedded in bonded contact with the surrounding isotropic elastic medium. The flexural interaction is induced by a concentrated load which acts normal to the plane of the fibre. Similar interactions can be caused by micro-buckling of a fibre induced by edge loading of the composite. The analysis of the problem is developed by assuming that the condition related to rigid behaviour of the fibre cross section is satisfied in an approximate fashion. Three particular estimates for the flexural interaction problem are presented. In the first case the normal stresses at the fibre-elastic medium interface are approximated by distributions which give nearly uniform displacement across the width of the ribbon shaped fibre. The remaining estimates are derived by developing approximate solutions for the integral equation governing the flexural interaction problem. The solutions are based on Mathieu function and asymptotic series expansion solutions, in which the interface normal stresses exhibit singular behaviour at the edges of the fibre cross section. Numerical results are presented for the flexural moment induced in the embedded fibre due to the applied concnetrated lateral force.

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* Professor and Chairman

Session FA-8 TURBULENCE-2

Organizers and Chairpersons: W. Z. SADEH, Colorado State University and M. GOLDSTEIN, NASA Lewis Research Center

* 2:00 - 2:30 D. JUVE, P. ROLAND and G. COMTE-BELLOT, Ecole Centrale de Lyon, France:
"Instantaneous Two-Dimensional Acoustic Intensity Measurements"

* 2:30 - 3:00 H. ATASSI, University of Notre Dame:
"Regularization of Goldstein's Splitting of Unsteady Vortical and Entropic Distortions of Potential Flows"

* 3:00 - 3:30 T. F. BALSA, General Electric Research and Development Center, Schnectady, New York:
"A Review of Recent Developments in the Theory of Jet Noise"

3:30 - 4:00 COFFEE BREAK

* 4:00 - 4:30 C. E. FEILER, NASA Lewis Research Center:
"Recent Results in Fan Noise - Its Generation, Radiation and Suppression"

4:30 - 4:45 L. V. K. V. SARMA and S. KISHORE KUMAR, Indian Institute of Technology, Madras, India:
"Drag on an Elliptic Cylinder Oscillating in a Dusty Viscous Fluid"

4:45 - 5:00 M. VASUDEVAIAH, Pazarignar Anna University of Technology, India:
"Slow Viscous Flow Past a Rough Sphere"

INSTANTANEOUS TWO-DIMENSIONAL ACOUSTIC INTENSITY MEASUREMENTS

D. Juve, P. Roland & G. Comte-Bellot
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A 3 microphone probe has been developed to measure 2 components of the mean and instantaneous acoustic intensity vector.

For the mean flux the cross spectrum method (1) is used twice between microphones 1 and 2, and 1 and 3:

$$I_{1-2}(w) = \frac{1}{2\rho\Delta r_{1-2}} \quad \frac{\mathrm{Im}\,[S_{p1p2}]}{w}$$

(Δr_{1-2} distance between the two transducers, $\mathrm{Im}\,[S_{p1p2}]$ imaginary part of the cross spectrum). Suitable corrections are introduced to take into account the phase and amplitude differences between the microphones and the gradient approximation.

The instantaneous measurements are made according to the sum and difference approach in an all-digital fashion

$$I_{1-2}(t) = \frac{-1}{\rho} \quad \frac{P_1 + P_2}{2} \quad \int_0^t \frac{P_1 - P_2}{\Delta r_{1-2}} \, dt$$

The temporal evolution of the intensity vector is then obtained as well as some of its statistical properties (probability density of the modulus and of the direction). In the frequency range 1 - 6 kHz (which is fixed mainly by the spacing between the microphones Δr_{1-2} = 10mm) the response of the probe is very satisfactory: the angular and amplitude deviations are within 2^o and $\pm$ 5% for incidence angles in the range $\pm$ 80^o relative to the probe axis.

The technique is applied to the acoustic near field of a subsonic jet which can be excited along the column mode. Results concerning the source distribution along the jet axis and the intermittency of the sound emission are compared with previous studies using the causality technique (2) and the polar correlation technique (3).

(1) FAHY F. J., JASA, 62, 1977.
(2) JUVE D. & SUNYACH M., IUTAM Symp. Springer, 1979.
(3) FISCHER M. J., HARPER-BOURNE M. & CLEGG S.A.L., JSV, 51, 1977.

REGULARIZATION OF GOLDSTEIN'S SPLITTING OF UNSTEADY VORTICAL AND ENTROPIC DISTORTIONS OF POTENTIAL FLOWS

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For small amplitude vortical and entropic unsteady disturbances of potential flows, Goldstein* proposed a partial splitting of the velocity field into a vortical part $\vec{u}^{(I)}$ that is a known function of the imposed upstream distortion field and the mean potential flow, and a potential part $\nabla\phi$ satisfying a linear inhomogeneous wave equation with a dipole-type source term. This splitting provides a unified approach to aerodynamic studies of airfoils response to gust loading and to the rapid distortion theory of turbulence for three-dimensional compressible flows.

However for the most common case where the mean flow has a stagnation point, $\vec{u}^{(I)}$ becomes singular along the entire body boundary and its wake, and as a result $\nabla\phi$ will also be singular along the entire body surface. Practically, this singular behavior will make solutions very difficult to obtain particularly when numerical computations are involved.

Recognizing that the physical solution is regular at the body surface except may be at the stagnation point, the present paper proposes to modify Goldstein's splitting by introducing a part $\nabla\tilde{\phi}$ that is a known function of the imposed upstream disturbance field and the mean potential flow, and such that $\vec{u}^{(I)} + \nabla\tilde{\phi}$ is <u>regular</u> and furthermore has a zero normal component along the body surface. The present method is applied to flows that exist for all time by considering an incident harmonic disturbance field. Explicit and particularly simple expressions are obtained for two-dimensional mean flows but three-dimensional unsteady disturbances for single bodies and cascades. The general behavior of the unsteady solution near the stagnation point is also investigated.

*J. Fluid Mech., 89, 3, pp. 433-468, (1978).

A Review of Recent Developments in the Theory of Jet Noise

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A study of the theory of jet noise was initiated by Lighthill about thirty years ago. He showed that the unsteadiness that is embodied in turbulence shows up as noise in the far field; the general characteristics of this noise are very similar to those of convecting acoustic quadrupoles. Lighthill's most famous contribution is his 8th - power law which states that the noise is proportional to $(U_j)^8$ where U_j is the jet velocity.

An extremely careful set of experimental studies in the mid-seventies revealed that the dependence of jet noise on jet temperature is far more intricate than anticipated by Lighthill. This finding, together with the emergence of supersonic transports such as the Concorde, has triggered a major new research effort in jet noise.

The purpose of this talk is to highlight some of the recent and significant developments in the theoretical study of jet noise. The topics discussed will include the derivation and relevance of the Lilley equation, the frequency dependence of convective amplification, the effects of jet flow on jet noise and a new theory of shock associated noise.

RECENT RESULTS IN FAN NOISE - ITS GENERATION, RADIATION AND SUPPRESSION

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A review of recent developments at NASA Lewis in fan noise including its generation, radiation characteristics, and suppression by acoustic treatment is presented.

In fan noise generation, results from engine and fan experiments using inflow control measures to suppress noise sources related to inflow distortion and turbulence will be described. The suppression of sources related to inflow allows the experiments to focus on the fan or engine internal sources. Some of the experiments incorporated pressure sensors on the fan blades to sample the flow disturbances encountered by the blades. From these data some information can be drawn about the origins of the disturbances. Also, hot wire measurements of a fan rotor wake field will be presented and related to the fan's noise signature.

The radiation and the suppression of fan noise are dependent on the acoustic modes generated by the fan. It is unfortunate that these are usually not known in any detail and is there a really simple way to measure them. Some progress has been made in describing fan noise suppression and radiation through the relating of these phenomena to the mode cutoff ratio parameter. In addition to its utility in acoustic treatment design and performance prediction, cutoff ratio has been useful in developing a simple description of the radiation patterns for broadband fan noise. Some of the newer findings using the cutoff ratio parameter will be presented.

DRAG ON AN ELLIPTIC CYLINDER OSCILLATING IN A DUSTY VISCOUS FLUID

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In this paper we investigate the flow of a dusty viscous fluid due to the oscillatory motion of an elliptic cylinder $r = a\,[1 + \varepsilon P_2(\cos\theta)]$. The expression for the drag experienced by the cylinder is obtained in the form $D = M^1 U_o \omega\,(K \sin \omega t - K^1 \cos \omega t)$ by using asymptotic expansions expansions of modified Bessel functions. The two parameters K and K^1 involve ν, f, r characterizing the two phase system together with ε and ω. Graphs are drawn to represent the variation in the parameters K and K^1. It is observed that over a period of oscillation considered, the drag is more in the case of dusty fluid compared to the case of clean fluid. The second term in the expression for the drag involving K^1 shows the force opposing the movement of the cylinder and is thus a damping force out of phase with the acceleration. This is the force which produces the decay of oscillations of the cylinder.

The case of circular cylinder can be obtained by taking 'ε' to be zero and the expressions for K and K^1 agree with those obtained in an earlier paper [1]. Further, as the mass of the dust particles tends to zero, the expressions for K and K^1 reduce to those in the case of clean fluid [2].

[1] L.V.K.V. Sarma and S. Kishore Kumar: Drag on a Circular Cylinder Oscillating in a Dusty Viscous Fluid, to appear in I.I.Sc. Journal.

[2] Stuart, J.T.: Laminar Boundary Layers: Ed. Rosenhead, L., Ch. VII, pp. 1392 (1963).

SLOW VISCOUS FLOW PAST A ROUGH SPHERE

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The paper deals with axisymmetric slow viscous flow past an axially rough sphere $r = 1+\eta F(\theta)$, $\alpha \le \theta \le \pi$, where the flow Reynolds number $R_e = Ua/\nu$ ($<<1$) and $\eta/R_e = \sigma = O(1)$. The body is a realistic model whose applications in physiology and chemical engineering is well known. The corresponding equation for the stream function ψ, is to be solved subject to the boundary conditions

$$\psi = \partial\psi/\partial r = 0 \quad \text{on } r = 1+\eta F(\theta), \; 0 \le \theta \le \pi, \tag{1a}$$

$$\text{where } F(\theta) = \sum_{n=0}^{\infty} A_n P_n(\mu), \quad \psi \sim (-1/2)\, R_e \sin^2\theta \quad \text{as } r \to \infty \tag{1b}$$

The matching technique of Proudman and Pearson is adopted to overcome Whitehead's paradox and locally valid expansions for the velocity field in Stokes's and Oseen's region are obtained up to $O(R_e)$. The total drag coefficient is calculated as $C_D = C_{DS} + C_{DV}$ (2a)

$$\text{where } C_{DS} = \frac{6\pi}{R_e}\left[\frac{1}{3} + R_e\left\{\frac{1}{6} + \frac{\sigma}{15}(5A_0 - 7A_2)\right\}\right], \tag{2b}$$

$$C_{DV} = -\frac{6\pi}{R_e}\left[\frac{2}{3} + R_e\left\{\frac{1}{6} + \frac{2\sigma}{15}(5A_0 + 2A_2)\right\}\right] \tag{2c}$$

The following observations are made:

1. The contribution to the Proudman and Pearson's drag formula, due to roughness is $\sigma R_e(A_0 - A_2/5)$, which either increases or decreases the Oseen's limit, depending on its sign, while there is no contribution if $A_0 = A_2/5$. For bodies with $A_0 = 0$, $C_{DS} : C_{DV} = 1:2$ as in the case of Stokes flow. Choosing $\sigma = -15/[8(5A_0 - A_2)]$ the total contribution of $O(R_e)$ to (2a) can be made zero.
2. If $\eta = O(R_e^{1/m})$ with $m < 1$, the contribution of roughness is accounted in higher order terms (higher than R_e) of the expansion procedure, while if $m > 1$, Stokes equation should be considered as

   $\psi = \psi_0 + \sum_{n=1}^{m-1} R_e^{n/m}\psi_n + O(R_e)$, where ψ_n's are completely determined from Stokes equation only, with vanishing conditions both on the body surface and at infinity. However matching is to be resorted to obtain the terms of $O(R_e)$.

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